Benha University
Faculty of Engineering at Shoubra
Surveying Engineering Department

TOWARDS A UNIFIED VERTICAL DATUM FOR THE ARAB REGION

A Thesis Submitted in Partial Fulfillment of the Requirements for the M.Sc. Degree in Surveying and Geodesy

Submitted By
Eng. Shimaa Farouk Abd-El Ftah
B.Sc. in Surveying Engineering

Supervised By

Dr. Abdallah Ahmed Saad
Prof. of Surveying and Geodesy
Faculty of Engineering at Shoubra
Benha University

Dr. Mona Saad Elsayed
Assoc. Prof. of Surveying and Geodesy
Faculty of Engineering at Shoubra
Benha University

Cairo – Egypt

2018

Acknowledgement

Firstly, All Praise and thank Allah who guided me to complete this study, with the help of my distinguished professors, each of them deserves deep respect and recognition.

It is my gladness to gratefully acknowledge and express sincere gratitude to my professor, **Prof. Dr. Abdallah Ahmed Saad;** for his permanent encouragement, continuous guidance, helping, and supporting me from beginning of my study.

Deep gratefully to **Assoc. Prof. Mona Saad;** for her continued helping and psychological and moral support for me.

Special thanks from my heart to **my father** and **mother** since I could not complete any steps without their good supplications and prayers. I wish that this science will be in their good credit in their life and after long age for them, God willing.

Special thanks to my beloved husband **Essam El-Dein** for his continuous supporting and pushing forward, and bearing all pressures of life for me in order to be in continuous progress.

Finally, I would like to dedicate this study to my **sons** and my beloved brother **Abdallah**. I Supplicate Allah to be motiving for them.

Abstract

There are more than twenty-two separate vertical datum surfaces in the Arab world, all of them depend on the average readings of MSL measurements used to establish the vertical datums that were observed with an effect of the 18.6-year lunar tide gauges at a specific time. The mean sea level is used as a reference for height and still used until now although the average of this observed value does not exactly represent the geoid. In addition, the mean sea level at some sites differ in its value when it is compared with other sites because of the difference of equipotential surfaces. This is why the use of mean sea level as a reference causes a lot of problems that are associated with the application of vertical datum. The differences in Sea Surface Topography (SST) at tide gauge sites and differences in measuring techniques lead to delays in the implementation of regional projects in areas such as transportation, communication, and electricity reticulation grids and other projects that require heights. Therefore, the determination of a unified precise geoid represents a significant step in eliminating these differences as it forms the basis for the determination of regional geoid model.

This study focuses on presenting two proposals for unification the vertical datum in Arab region and the proposed implementation strategy, also it provides the best techniques to tie and unify the data (tide gauge stations, levelling, GNSS, and gravity points) in all Arab countries, commensurate with the modern technological development. After reviewing the available data from previous studies, and the researches in this field.

Some results can be concluded after implementing this proposed massive national project; Replacing the official levelling-based vertical datum all over the Arab region by unified precise geoid and GNSS

compatible vertical datum, because it will be very easy to compute the orthometric height from unified precise geoid and precise ellipsoidal height. Easy to follow up the changes of mean sea level in different times to geodetic works and oceanographic surface and protection of coastline. All Arab countries together with desert, remote and extremist areas will contain unified vertical control system. Easy to determine the effect of SST in all Arab region. Consistently with space-based positioning (e.g., GNSS, altimetry) is going to be guaranteed. The maintenance of the unified vertical datum is going to be less expensive. The vertical datum is going to be fairly stable due the actual fact that the geoid surface changes at a rate of 1 mm annually compared to 1 cm annually for the physical benchmarks related to the regional geodynamics.

Finally, by documenting and depending on the Unified Arab Vertical Datum, the Arab nation will face the challenges of the globalization and will keep abreast with the continuous scientific progress. Because it will have an effective role in global agencies which interested in surveying, maps, and geodesy, like the International Association of Geodesy (IAG), International Center for Global Gravity Model (ICGEM), International Gravity Field Services (IGFS).

Table of Contents

Chapter **Page**

Acknowledgements…………..…………………………….. i
Abstract………………………………………………… ii
Table of contents………………..………………………... iv
List of figure…………………………………………..….. x
List of tables……………..……………………………. xiii
Abbreviations…………………………………………... xiv

CHAPTER (1) 1
INTRODUCTION 1
1.1. The Variations of Mean Sea Level…………..………… 2
1.1.1. Earth Tides………………………………………… 4
1.1.2. Tidal Datum………………………………………. 5
1.1.3. Bench Mark………………………………..……… 6
1.1.4. Types of Tide Gauges…………………...…………… 7
1.1.4.1. Floating Gauges…………………..……………… 7
1.1.4.2. Pressure Gauge…………………………………… 7
1.1.4.3. Acoustic Gauges……………………….………… 8
1.1.4.4. Radar Gauges…………………..………………… 8
1.2. Height Systems……………………………………….. 8
1.2.1. Geo-potential Numbers……………….……………… 8
1.2.2. Dynamic Heights…………………………………….. 10
1.2.3. Ortho-metric Heights………………………………… 10
1.2.4. Normal Height………………………….…………….. 11
1.2.5. Ellipsoidal Heights. ……………………...……… 12
1.3. Vertical Datum Definition……………………..……. 13
1.3.1. Determination of Mean Sea-Level (MSL) ……..……. 14
1.3.2. Sea Surface Topography (SST)……………….……. 15
1.4. Vertical Datum Unification by Global Geodetic Observing System……..………………………….……..… 16
1.4.1. Regional Vertical Datum……………..…………… 17
1.4.2. Global Vertical Datum……………………………. 18
1.4.3. Global Vertical Datum Realization…………………… 18
1.4.4. The Role of Satellite Altimetry……………….……… 19
1.4.4.1. Satellite Altimetry Tasks…………………………. 20
1.4.4.2. The Advantages of Satellite Altimetry in Both the Definition and Realization phases..………………….….. 20
1.5. The Motive and Purpose of the Thesis…………………… 21
1.6. The Thesis Objectives……………………………..…. 22
1.7. Scope of Thesis………………………………….….. 22

CHAPTER (2)………………………………………………. 24
PREVIOUS CASES OF UNIFYING DIFFIRENT VERTICAL DATUMS
2.1. Unification of Vertical Datum in Australia (2005)……… 25
2.1.1. Data Sets Collection……………………………............ 25
2.1.2. Mathematical Methodology…………………………... 25
2.1.3. The Results……………………………………………. 26
2.2. Unification of Vertical Datum in Africa (2011)……….. 27
2.2.1. Data Sets Collection…………………………………... 28
2.2.2. Computation Methodology…………………….......... 28
2.2.3. Results…………………………………………………... 29
2.2.4. Improving the African Geoid Model………………… 30
2.3. Unification of Vertical Datum in New Zealand (2011).. 31
2.3.1. Data sets Collection…………………………………... 31
2.3.2. Mathematical Methodology…………………………... 33
2.4. Unification of Vertical Datum in Europe (2013)……..... 36
2.4.1. Data Sets Collection..………………..……………….. 37
2.4.2. Mathematical methodology…………………………… 37
2.4.3. The Results…………………………….……………… 38
2.5. Unification of Vertical Datum in North America (2014)……………………………………………………… 39
2.5.1. The Characteristics of the North American Official Vertical Reference Frame………... 41
2.5.2. Computations of the North American Datum offsets… 41
2.5.2.1. Basic Relationships……………………………..… 41
2.5.2.2. Computation of the NAVD88 Offset……………… 42
2.5.3. The Results……………………..……………………... 42
2.6. Unification of Vertical Datum in Poland (2015)……… 43
2.6.1. Data Sets in Poland………………………...………… 44
2.6.2. Mathematical Methodology…………………...……… 44
2.6.3. The Results……………………………………………. 46

CHAPTER (3)……..…………………………………………… 47
The CURRENT STATUS OF VERTICAL DATUMS IN ARAB REGION
3.1. The Vertical Datum in Egypt……………………………. 47
3.1.1. Historical Background and Status of the Egyptian Control Network…………………………………………….. 48
3.1.1.1. Gravity Measurements in Egypt………………….. 52
3.1.1.2. The Egyptian Survey Authority (ESA) Gravity Measurements…………………………………………………… 54
3.1.1.3. Other Gravity Measurements in Egypt………....... 55
3.1.2. GPS Network in Egypt……………………………...... 58

3.1.3. The Global Geo-potential Model in Egypt………….... 59
3.2. The Vertical Datum in Sudan………………………….... 60
3.2.1. GPS and Levelling Network in Sudan……………….. 60
3.2.2. The Global Geo-potential Model in Sudan………….. 60
3.3. The Vertical Datum in Djibouti………………………..… 62
3.3.1. GPS Network in Djibouti…………………………..… 62
3.4. The Vertical Datum in Somalia…………………….….… 63
3.5. The Vertical Datum in Emirates…………….………….... 64
3.5.1. History of Dubai Vertical Datum……..……………….. 64
3.5.2.The GPS and Levelling Network in United Arab Emirates……………………………………………….…..... 67
3.5.3. Dubai Virtual Reference Network (DVRS) and gravity data in UAE……………………………………..… 68
3.6. The Vertical Datum in Kuwait…………………………… 70
3.7. The Vertical Datum in Oman……………………..……... 71
3.8. The Vertical Datum in Iraq……………………………… 71
3.8.1. The Global Geo-potential Model in Iraq……………... 71
3.9. The Vertical Datum in Qatar…………………………...… 72
3.9.1. The Geoidal Model in Qatar…………………......... 72
3.9.2. Vertical Control Surveys Using GNSS………............ 72
3.9.3. The Base Stations in Qatar……………………….…... 72
3.10. The Vertical Datum in Morocco……………………..…… 73
3.10.1. The Geo-potential Model in Morocco……………… 73
3.11. The Vertical Datum in Saudi Arabia…………………… 73
3.11.1. Gravity Network in Saudi Arabia…………………… 74
3.11.2. GPS network in Saudi Arabia. ………………….….. 75
3.12. The Vertical Datum in Bahrain…………………………. 76
3.12.1. The Permanent Reference Network in Bahrain…..… 76
3.13. The Vertical Datum in Yemen……….……………….…. 77
3.14. The Vertical Datum in Mauritania……………………… 77
3.15. The Vertical Datum in Tunis…………………….…..… 78
3.16. The Vertical Datum in Algeria……………………….…. 78
3.16.1. Triangulation Network in Algeria…………..……… 78
3.16.2. Levelling Network in Algeria……….……………..... 78
3.16.3. Gravimetric Network in Algeria……………......... 79
3.16.4. The GPS Network in Algeria…………………......... 80
3.17. The Vertical Datum in Libya…………………………… 82
3.17.1. Levelling network in Libya……………………….… 82
3.17.2. The Gravity Network in Libya…………………...….. 83
3.17.3. GPS Network in Libya………………………..….... 83
3.17.4. The Geoid Model in Libya……………………..…… 84
3.17.5. The Global Geo-potential Model in Libya…………… 86
3.18. The Vertical Datum in Occupied Palestine…...………… 87

3.18.1. GPS and Levelling Network in Gaza……..……..….. 88
3.18.2. The GPS Network in Palestine…..……………….…. 88
3.19. The Vertical Datum in Syria……………………….…. 88
3.19. 1.The Global Geo-potential Model in Syria………..…. 89
3.20. The Vertical Datum in Lebanon……………………… 89
3.20.1. The Gravity Network in Lebanon………...…………. 89
3.20.2. Geoid Determination in Lebanon……………………. 90
3.20.3. Exiting GPS and Levelling points in Lebanon..……... 90
3.21. The Vertical Datum in Jordan………………………... 91
3.21.1. Geoid Determination in Jordan……………………… 91
3.21.2. GPS/Levelling Network in Jordan…...……………… 92
3.21.3. The Global Geo-potential Model in Jordan…………. 93
3.22. Summary of The Available Data in The Arab Region…. 94

CHAPTER (4)…………………………………………….... 101
ClASSICAL AND MODERN GEOID DETERMINATION METHODS
4.1. Geoid Description………………...……………..…..…. 102
4.2. Geoid Determination Methods……………………........ 103
4.2.1. The Classical Geoid Determination Methods……….... 103
4.2.1.1. The Astro-geodetic Method………...……...………. 103
4.2.1.2. The Gravimetric Method…………...……....…….. 105
4.2.1.3. The Astro-gravimetric Method………..……..….. 106
4.2.2. Gravity Field Determination by Using Satellites..…….. 107
4.2.2.1. Radar altimetry (RA) ……….............................. 108
4.2.2.2. Laser Altimetry (LA)………................................ 108
4.2.2.3. Gravity gradiometry………………………………. 108
4.2.2.4. High-Low Satellite-to-Satellite Tracking (hl-SST).. 109
4.2.2.5. Low-Low Satellite-to-Satellite Tracking (ll-SST)… 109
4.3. Examples of the Most Common Satellites Mission……… 109
4.3.1. Challenging Mini-satellite Payload (CHAMP)………. 109
4.3.2. The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE)……………………………………...… 110
4.3.3. The Gravity Recovery And Climate Experiment (GRACE)……………………………………………..….. 112
4.4. Global Geo-potential Model (GGM)….………………… 113
4.4.1. Satellite-only GGMs………………………………… 113
4.4.2. Combined GGMs……………………………………. 114
4.4.3. Tailored GGMs……………………………………… 114
4.4.4. Common Global Geopotential Models in a Simple Explanation……………………………………………...…. 117
4.4.4.1. Earth Gravitational Model 1996 (EGM96)……….. 117
4.4.4.2. Earth Gravitational Model 2008 (EGM2008)…….. 118

4.4.4.3. EIGEN-GL04C………………………………………… 119
4.5. Tailoring Global Geo-potential Models……………..… 119
4.5.1. Validity of Tailoring Global Geo-potential Models (GGMs) in Different Cases.…………………………………... 120
4.5.2. The Methodology for Tailoring the Geoid…….......... 124
4.5.3. Best Fitting the Global Geo-potential Model over a local Area……………………………………………...... 127

CHAPTER (5)……..……………………………………… 129
UNIFICATION OF VERTICAL DATUM IN THE ARAB WORLD
5.1. The First Proposal; part one……..…………………….… 129
5.1.1. Tide Gauge Stations in Arab World……….………….. 130
5.1.1.1. The Proposed First Device………………….............. 131
5.1.1.2. The Proposed Second Device…………….…...… 133
5.1.1.3. Dipper Reading With the Radar Gauge………..… 134
5.1.1.4. Changing the Old Gauge by New Accurate One…… 134
5.1.1.5. Sources of Error and Differences Among Two Tide Gauges…………………………………………………... 135
5.1.1.6. Using GNSS at the Tide Gauge Station…………..… 136
5.1.1.7. Connection between Tide Gauge and GNSS……..… 138
5.1.1.8. Utilizing satellite altimetry data at tide gauge stations. 139
5.1.2. Levelling Works……………………………………... 140
5.1.3. Positioning Works………………………………… 145
5.1.3.1. Existed GPS points distribution in Arab world……. 145
5.1.3.2. The Proposed GNSS Points Number and its Distribution in all Arab Countries…………………………….. 146
5.1.3.3. GPS Static Observations Specifications. ………….. 149
5.1.3.4 GPS data processing……………………………... 150
5.1.3.5. Satellite Visibility………………………………… 150
5.1.4. Gravity Works………………………...…………... 151
5.1.4.1. The available Gravity Data in Arab World…..…….. 151
5.1.4.2. Connection of Gravity Values in Arab Region….… 152
5.2. Part Two…………………...………………………. 153
5.2.1 The Proposed Work Plan…………………………..… 153
5.2.1.1.Concerning the Establishment of the Arab Geodetic Services…………………………………………….. 153
5.2.1.2.Concerning Tide Gauges Works…………..…….. 157
5.2.1.3. Concerning the Satellite Positioning Works..….. 157
5.2.1.4.Concerning the Gravity Works………………….. 160
5.2.1.5. Concerning the Arabian Geoid Determination...... 160
5.3. The Second Proposal…………………………………… 166
5.3.1. Precise Point Positioning (PPP)…………………....… 166

5.3.1.1.The Benefits of PPP Technique 167
5.3.2. Satellite-only Precise Geoid Models……..………...…. 168

CHPTER (6)……………………………………………….. 177
SUMMARY, CONCULUSIONS, AND RECOMMENDATIONS
6.1. Summery……….…………………….……..……………. 177
6.2. Conclusion………….………………………..…………… 180
6.3. Recommendations………………………………………… 183

REFERENCES………...…………………………………….. 186

APPENDIX (A)…..……….…..…………………………… 202
A.1. Factors Affecting Sea Surface Height (SSH) Change….... 202
A.2. Sea Surface Topography Determination……..………….. 203
A.3. Sea Surface Topography Component………………… 204
A.4. Methodology for Determination SST Models Based on the Combination of Satellite Altimetry and GGMs. (The Geodetic Approach)…………………………………… 205
A.5. The Role of SST Model in Detecting Error Propagation in Coastal Geodetic Levelling………………... 207
A.5.1. The East Coast of Australia as a Case Study. (The Ocean Approach)……………………………………………. 208
A.5.1.1 The Methodology in That Study….…………………… 209
A.5.1.2 Data used for that study ……………………………. 210
A.5.1.3 The problem……………………….……………….. 211
A.5.1.4 The Accuracy of Data Used……………………….. 213
A.5.1.5 The Results…………………………………………. 214

LIST OF FIGURES

Figure (1.1): Sea Level Temporal Variations………………… 3
Figure (1.2): A representation of tidal datums and their geodetic relationships…………………………... 6
Figure (1.3): The ortho-metric height (H^{ortho}) of P……….…... 9
Figure (1.4): The normal heights……………….................... 12
Figure (1.5): The normal-ortho-metric (H^{N-O}), quasi-geoid (ξ), ellipsoid (h), ortho-metric (H), and geoid (N) heights……….. 13
Figure (2.1): Vertical datum offset………………………… 29
Figure (2. 2): Schematic of LVD offsets and their effect on the initial quasigeoid……………………………….. 33
Figure (2.3): Iterative quasi-geoid datum unification scheme… 34
Figure (3.1): Alexandria Western Harbor and location of tide gauge use in Egypt…………..……………..… 48
Figure (3.2): The first order Levelling Network of Egypt…..... 50
Figure (3.3): The levelling network in the Delta 1936……….. 51
Figure (3.4): The International Gravity Standardization Net (IGSN) points………………………………….. 54
Figure (3.5): The Egyptian National Gravity Standardization Network (ENGSN97)…………………………... 56
Figure (3.6): Available local gravity stations in 2009…...….... 57
Figure (3.7): Available stations with known geoid undulation. 57
Figure (3.8): Distribution of the 394 available points with observed geoid undulation in Egypt…………….. 58
Figure (3.9): The HARN and NACN networks……..……… 59
Figure (3.10): The gravity points in Soudan in GETECH……. 61
Figure (3.11):Triple junction and Afar depression. Dots show locations of GPS stations……..………………… 63
Figure (3.12): Djibouti and Gulf of Tadjoura. Dots show locations of GPS stations……………………..... 63
Figure (3.13): Available GPS-levelling geoid data in Dubai…. 69
Figure (3.14): DVRS Stations Distribution………….…......... 69
Figure (3.15): Distribution of gravity data over land and marine area of UAE…………………………… 70
Figure (3.16): The location of tide gauge used in Saudi Arabia……………………………………….. 74
Figure (3.17): Absolute gravity stations of Saudi Arabia…….. 75
Figure (3.18): National vertical network of Saudi Arabia……. 76
Figure (3.19): Bahrain PRN Station Locations……………….. 77
Figure (3.20): Classical levelling networks in Algeria……….. 79
Figure (3.21): GPS network in Algeria……………………….. 80

Figure (3.22): Permanent GPS Network in Algria……………. 81
Figure (3.23): Levelling network by Pol-Service …………... 83
Figure (3. 24): CORS- Libya stations and coverage at 40 and 60 km interstation distances…...……………… 84
Figure (3.25): Geoidal undulation map with 1m interval for Libya…………………………………………… 86
Figure (3.26): The distribution of benchmark points in the area…………………………………………….. 87
Figure (3.27): The terrestrial gravity points in Lebanon……..... 89
Figure (3.28): GPS and Levelling points in Lebanon……….... 90
Figure (3.29): Gravity data distribution over Jordan territory... 92
Figure (3.30): GPS Static reference points and rapid static points (latitude and longitude in WGS84)…….. 93
Figure (3.31): The countries with defined dtaum origin……... 95
Figure (3.32): Shows the distribution of GPS points in Arab countries……………………………………….. 96
Figure (3.33): Gravity data which available in GETECH….… 97
Figure (3.34): Gravity data which available in BGI………..… 98
Figure (4.1): Illustrate the shape of ε, dN and ds……….….… 104
Figure (4.2): Simple shape of CHAMP…………..……….… 110
Figure (4.3): Simple shape of GOCE……...……….……….… 111
Figure (4.4): Simple shape of GRACE…………..……….….. 112
Figure (5.1): Shows the shape of acoustic tide gauge……..… 131
Figure (5.2): Another shape of acoustic gauge without protective enclosure………………………….. 132
Figure (5.3): Shows the proposed radar gauge station photo… 133
Figure (5.4): Antenna placed on the roof of the tide gauge hut. 137
Figure (5.5): The antenna closed to the tide gauge hut………. 137
Figure (5.6): The Tide gauge location, the proposed new Tide gauge location, and The core GNSS/levelling/absolute gravity points………… 147
Figure (5.7): The Tide gauge location, the proposed new tide gauge location, the core GNSS/levelling/ relative gravity points and permanent GNSS stations….. 149
Figure (5.8): Shows the proposed network chart for AGS…... 156
Figure (5.9): Shows the PPP system…………………………. 168
Figure (A.1): Shows the definition of collocated heights for SST determination…………………………….. 205
Figure (A.2): Shows the difference between SST at two tide gauges…………………………………..…….. 208
Figure (A.3): Shows the relation of the ellipsoidal height of MSL at a tide gauge and SST……………………. 208

Figure (A.4): Northeast coastline of Australia showing the location of 22 tide gauges (black circles) used in this study……………………………………… 211

LIST OF TABLES

Table (2.1): Comparison GPS/Levelling-AGP2003………… 30
Table (3.1): Location of tide gauge in all Arab world……..... 94
Table (3.2): The Available GPS/Levelling and Gravity Data in the Arab Region……………………………….. 99
Table (4.1): Examples of global geopotential models type…... 117
Table (5.1): The values of 'c' according to each CLASS of survey……..…………………………………….. 141
Table (5.2): Highest ORDER (R) that may be set to a height from a given CLASS surveying…………………. 142
Table(5.3):Shows the proposed device and its specifications……………………………………. 143
Table (5.4): Shows the proposed GNSS points distributions all over the Arab countries………………………… 148
Table (5.5): Techniques and basic components that will be associated with AGS. Where E means the observation at certain time and C is continuous observations……………………….................... 154
Table (5.6): Shows the closest IGS stations to Arab region….. 159
Table (5.7): Shows time table for executing the proposed work.. 164
Table (A.1): List of the 22 tide gauges along the first order re-levelling of the northeastern Australian coast in 1975-76. …... 212
Table (A.2): Shows some of CARS variables.......................... 214
Table (A.3): LS and LG loops... 216

Abbreviations

AAC: AGS Analysis Center…………………………………..
ABC: Arabian Backup Centers…………………….………….
ADC: Arabian Data Centers…………………………..…….
AGN: Algerian General Levelling Network…………….……….
AGS: Arabian Geodetic Services…………………………..….
AOS: Arabian Observing Stations…………………….……….
APN: Active Permanent Station……………………………….
ARABREF: ARAB Reference Frame..................................
ARP: Antenna Reference Point……………………………….
ASC: Aero - Service Corporation………..…………….……...
ATGSN: Arabian Tide Gauge Stations Network……….…….
AVDS: Arabic vertical datum service……………….…….….
BGI: Bureau Gravimetric International……………..……..
BVP: Boundary Value Problem..
CGG2005: Canadian Geoid model 2005……………………..
CGVD28: Canadian Geodetic Vertical Datum of 1928………
CHAMP: Challenging Mini satellite Payload………………..
CORS: Continuously Operating Reference Stations…………
DCP: Data Collection Platform……………………………….
DEM: Digital Elevation Model…….…………………..….
DHQ: Mean Diurnal High Water Inequality…………………
DIBM: Doha International Airport…………………………..
DLQ: Mean Diurnal Low Water Inequality……………..…...
DOT: Dynamic Ocean Topography……………………….…
DSW: Dead Sea Work………………………………………..
DVRS: The Dubai Virtual GPS Reference System. …………
EGMS: Earth Geo-potential Models…………………………
ENGSN97: Egyptian National Gravity Standardization Network……………………………..…………………...
ERS: European Remote Sensing Satellite………………….…...
EUVN-DA: European Vertical Network- Densification…......
EVRS: European Vertical Reference System….…….……...
ESA: Egyptian Survey Authority…………………………..…...
FBM: Fundamental Bench Mark……………...……….....…
FFT: Fast Fourier Transformation…………………..……….
FP: Fundamental Point……………………...…..…………
GBVP: Geodetic Boundary-Value Problem………….………
GETECH: Gravity Data from Geophysical Exploration Technology………………………………………….……..…..
GFZ: Deutsches GeoForschungs Zentrum…………...………
GGM: Global Geo-potential Model. ……………..……......

GGOS: Global Geodetic Observing System……………........
GLOSS: Global Sea Level Observing System…………….….…
GNS: Geodetic Navigation satellite science…………………..
GOES: Geostationary Operational Environmental Satellite…………………………………..……………….
GOCE: Gravity Field and Steady-State Ocean Circulation Explorer……………………………………………….….…
GPU: Geop-otential Units……………………………………..
GPS: Global Positioning System. …………………….….……
GPC: General Petroleum Company…………………..….......
GRACE: Gravity Recovery and Climate Experiment……..…
GSFC: Goddard Space Flight Center……………..……..….
GT: Great Diurnal Range……………………………...…
HARN: High Accuracy Reference NetworkNational Agricultural……………………………………….……..
HSU: Height System Unification…………………….….….
IAGBN: International Absolute Gravity Base station Network……………………………………………………..
IAG: International Association of Geodesy………………..…
ICGEM: International Center for Global Gravity Model….…
IGS71: International Gravity Standardization Net 1971………
ICSM: Intergovernmental Committee on Surveying and Mapping……………………………………………………
IGLD85: International Great Lakes Datum of 1985…….……
IGSN-71: International Gravity Standardization Net…………
IGFS: International Gravity Field Services……………………
INCT: National Institute of Cartography and Remote Sensing
InSAR: Interferometric Synthetic Aperture Radar……...……
ITRF: International Terrestrial Reference Frames ……………
JPL: Jet Propulsion Laboratory……………………...…..
KOC: Kuwait Oil Company, Construction Datum………..…
LVDs: Local Vertical Datums……………………………..…
LSC: Least-Squares Collocation…………………….........
LVD: local vertical datums …………………………….…
MDT: Mean Dynamic Topography…………………………..
MHHW: Mean Higher High Water…………….………….…
MHW: Mean High Water………………………….…………
MLW: Mean Low Water………………………….……..……
MLLW: Mean Lower Low Water………………….........
MN: Mean Range of Tide……………………….……………
MOWR: Ministry of Water Resources ………………………
MSS: Mean See Surface………………………...……..……
MSSH: mean sea surface height. ……………….……….……

MSL: Mean Sea Level……………………...…..……….…
NASA: National Aeronautics and Space Administration…..…
NAVD88: North American Vertical Datum of 1988……….....
NACN: Cadastral Network……………………………………
NEDECO: Netherlands Engineering Consultants……...……
NGI: National Geographic Institute…………………….……
NGA: National Geospatial-Intelligence Agency…………..…
NGS: National Geodetic Survey. …………………….………
NIMA: The US National Imagery and Mapping
Agency………………………………………………….......
NOAA: National Oceanic and Atmospheric Administration…
NOC: Normal Ortho-metric Correction…...…………………
NRIAG: National Research Institute of Astronomy and
Geophysics…………………………………….……….…..…
NRAJ: Natural Resources Authority of Jordan………………
NTDE: Metonic Cycle……………………………………..…
OSU: Ohio State University……………………………..……
PDO93: Petroleum Development Oman……………………..
PERSGA: Regional Organization for the Conservation of the
Environment of the Red Sea and Gulf of Aden……………..…
PGR: Post Glacial Rebound……………………….................
POLREF: Poland Reference Frame…………………….............
PORS: Permenente Operating Reference Stations……………
PPP: Precise Point Positioning……………………………......
PRARE: Precision Range and Range-Rate Equipment………
PRN: Permanent Reference Network…………………………
PSMSL: Permanent Service for Mean Sea Level…………..…
QND: Qatar National Datum……………….…………………
QVD: Qatar Vertical Datum……………………………..………
RTK: Real Time Kinematics……………………………..……..
SCC: Suez Canal Company…………………………………..…
SD: standard deviation…………………………………….....…
SGG: satellite gravity gradiometry……………………………
SLR: Satellite Laser Ranging………………………………….
SRI: Survey Research Institute……………….………………
SST: Sea Surface Topography……………………………..……
TGBM: Tide Gauge Bench mark…………….…………….…
TG: tide gauge……………………………………………........
TGZP: Tide Gauge Zero point………………………………..…
TGZ: Tide Gauge Zero. ………………………………………
TGBMs: Tide Gauge Bench Marks……………..……………
THG-09: Turkish Hybrid Geoid Model-2009……..…………
TQG-09: Quasi-Geoid Model…………………..…..…………

UNB model: University of New Brunswick model…….……
UNC: United Nations Committee…………………………..……
URL: Uniform Resource Locator……………………………..
VCN: Vertical Control Network………………………………
VCM: Variance-Covariance Matrix…………………………..…
VLBI: very long baseline interferometry………………..……....
WG: Working Group……………………..………..........................
WHS: World Height System…………………………………
ZP: Zero point……………………….....………………….

CHAPTER (1)

INTRODUCTION

The surveying maps and data represent one of the most important elements of perfect planning and decision making, the horizontal and vertical datum are the most important reasons of the success of work unification in national projects on the same level between the regional countries.

A vertical datum conceptually enables a meaning of the height of a basic benchmark in a vertical network with respect to some adopted reference surface. For most height systems, the geoid is adopted as the reference datum; i.e. the zero height reference. The geoid may be defined as the gravity equipotential surface which best estimates the Mean Sea Level (MSL) over the whole earth. Conventionally, MSL is defined as the mean level of the sea water as observed at tide gauge station at hourly intervals over some period of time. Vertical control network is established for vertical positioning in order to provide the third dimension of a complete three dimensional positioning on the earth's surface. This network basically consists of a series of levelling lines that have been interconnected in such a way that closed loops have been formed. Consequently, these levelling measurements provide heights of individual marked points (benchmarks), relative to the chosen vertical datum, as well as their accuracy estimates.

A vertical datum, along with the ellipsoid as a horizontal datum, is needed to provide three-dimensional positioning information of geodetic control network for surveying and mapping applications. A practical realization of the geoid is brought by registering the sea's water level at selected tide gauge stations over longer interval at least one year. The effect of tide and other periodic variations on these measurement could be filtered

out using appropriate numerical filters. Having the zero height being defined at tide gauges levelling combined with gravity can proceed to determine orthometric height of all benchmarks in the vertical control network [Mohamed, 2005].

The vertical control networks are needed for various geodetic and geoscientific applications, such as [Saad, 1993]:

- The reduction of the surveying observations and measurements from the surface of the earth to the computational reference ellipsoid.
- Providing precise height data for 3D adjustment of geodetic networks.
- The vertical crustal movement’s studies.
- Monitoring MSL variations with time and space.
- Determination of sea level rise due to the earth’s atmosphere warming up.
- Monitoring deformation of engineering structures.
- Relating the 3D satellite coordinates with the corresponding two dimension terrestrial coordinates.

1.1. The Variations of Mean Sea Level

The global seawater distribution displays global inhomogeneity due to the shape of coastlines and other factors, such as the ice melt, the permanently higher temperature of waters in the equatorial belt and lower temperature in the Polar Regions, the prevailing pattern of geostrophic winds, etc. A general spectrum of the frequencies amplitude, and regional extent of the diverse kinds of sea level variations shows in (Figure 1.1). This figure, shows that some of these variations have long, medium, and short periodic duration. They may occur over minutes, hours, days, years,

or even centuries and their influences extend over distances of meters, kilometers, and thousands of kilometers.

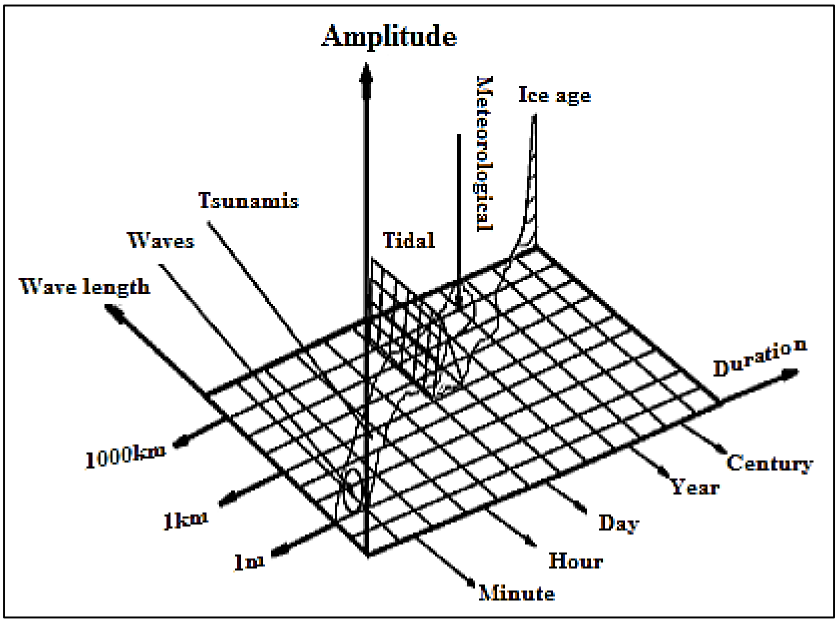


Figure (1.1): Sea level temporal variations [Mohamed, 2005].

Globally, sea level variations are more probably due to the melting of Antarctica's, as well as other, permanent ice sheets on the surface of the earth. The annual variations, which may be amount to several decimeters, originate primary from annual variations in temperature, pressure, wind direction, and wind magnitude. Semi-annual variations occur in some places located close to river estuaries due to the precipitation cycle. Short-periodic variations in sea level are because of tsunamis, waves, semi-diurnal and diurnal tides. The most important fact, herein, is that the global changes in sea level directly affect the definition of the geoid. That is because this class of variations affects the monthly and annual means normally used for the determination of the local mean sea level. Several investigations have been carried out worldwide to study the issue of the sea water rise and slope. The global mean sea surface appears to be rising at a rate of approximately 0.5 cm per year. Moreover estimation values for the

twentieth century trend in global sea level approximately 15-25 cm/century [Mohamed, 2005].

Analysis of long-period sea level trends at 27 primary tide stations shows that MSL along the coast of the United States rose at an average rate of 1.5 ± 0.3mm per year during the period 1940-1973. In the western coast of the United States, an apparent northward slope of 26 cm was reported. Similar studies in the United Kingdom, based on an analysis of monthly MSL between 1960 and 1975, show that there exists a latitudinal slope of MSL of 5.3±0.4 cm per degree of latitude. Corresponding local investigations about observations from 1906 to 1980 showed that the MSL in Egypt has approximately increased with a rate of 1.5 mm per year [Mohamed, 2005].

1.1.1. Earth Tides

The definition of the vertical datum zero level is also affected by the permanent deformation of the Earth caused by the Sun and the Moon (and other planets to a lesser extent). There are three models for dealing with these permanent tidal effects:

-The mean-tide includes both the permanent and elastic effects and so retains masses external to the Earth.

-The tide-free or non-tidal eliminates both the permanent and elastic effects.

-The zero-tide eliminates only the permanent effect but retains elastic effect.

The choice of tidal model used in geoid computation, height system definition and the reduction of gravity observations. The mean-tide model approximates the shape of sea level in its long term equilibrium state, so it is physically meaningful. That is because it includes the external masses

caused by the tidal deformation, it is not consistent with the requirements of Stokes's formula. Moreover it uses an integral mean gravity for height determination and so will introduce a bias due to the inclusion of the external masses. The tide-free model is compliant with Stokes formula because the permanent and time-independent external masses are removed. The zero-tide model is also compliant with Stokes formula (because all of the external masses are removed). Its advantage over the tide-free model is that it does not require the use of an assumption regarding elasticity (in the removal of the indirect effect) and so the reduction can be done completely by potential theory.

The International Association of Geodesy (IAG) endorsed the use of the zero-tide as the preferred tidal model. Equations to transform height differences, gravity observations and geoid heights between tidal systems were presented in [Mohamed, 2005].

1.1.2. Tidal Datum

For marine applications, a base elevation used as a reference from which to reckon heights or depths. It is called a tidal datum when defined in terms of a certain phase of the tide. Tidal datums are local datums and should not be extended into areas which have differing hydrographic characteristics. In order that they may be recovered when needed, such datums are referenced to fixed points known as bench marks. Tidal datums and their geodetic relationships show in (Figure 1.2), where Mean Higher High Water (MHHW) is defined as the arithmetic mean of the higher high water heights of the tide, Mean High Water (MHW) is defined as the arithmetic mean of the high water, Mean Low Water (MLW) is defined as the arithmetic mean of the low water, and Mean Lower Low Water

(MLLW) is defined as the arithmetic mean of the lower low water heights all observed over aspecific 18.6 year.

Only the higher high water of each pair of high water of a tidal day is included in the mean and only the lower low water of each pair of low waters of a tidal day is included in the mean. For stations with shorter series, simultaneous observational comparisons should be made with a control tide station in order to derive the equivalent of 18.6 year value. http://beta.tidesandcurrents.noaa.gov/datum_options.html.

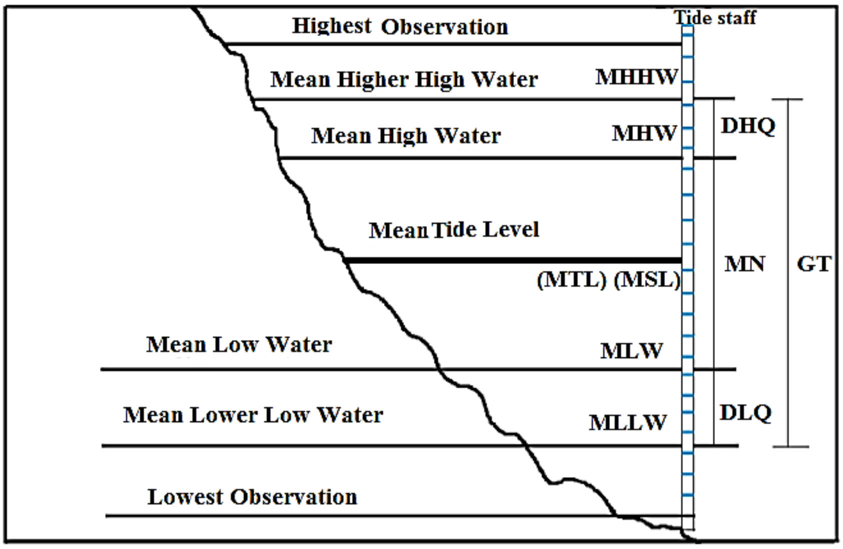


Figure (1.2): A representation of tidal datums and their geodetic relationships [http://beta.tidesandcurrents.noaa.gov/datum_options.html].

1.1.3. Bench Mark

A fixed physical object or mark used as reference for a horizontal or vertical datum. A tidal bench mark is one near a tide station to which the tidal datums are referenced. A primary bench mark is the principal mark of a group of tidal bench marks to which the tidal datums are referenced. The overall quality of datums is dependent on both the quality of the bench mark and the quality of the levelling between the bench marks and the tidal gauges.

1.1.4. Types of Tide Gauges

Mainly**,** there are four categories of tide gauge equipment available in work market, which are of significant differences in terms of accuracy and costs. These groups are floating, pressure, acoustic, and radar systems. Each category is summarized in the following sub-sections [Mohamed, 2005].

1.1.4.1. Floating Gauges

The traditional type of tide gauge is the analogue floating type. The main reasons to use a float gauge is its low technology and hence, low price. Recently, other types of tide gauge are available that are more precise and convenient to use. For example, there are floating tide gauges that use punched tape recorders instead of the paper sheet for data recording. This type of gauges does not give a continuous record of the tidal level but records spot heights at pre-determined time interval. These instruments contain a coding unit driven from the float mechanism. That is designed to transfer a height reading into a recording tape at each recording period. The height is punched out in a binary code form. An automatic reader is usually used to translate the information on the tape into a more usable form. Most types of floating tide gauges suffer from several problems [Mohamed, 2005].

1.1.4.2. Pressure Gauge

The more convenient, cost-effective, and practical recent tide gauge are those instruments depend on measuring the hydrostatic pressure of the water column above affixed pressure point and converting this pressure to a sea level equivalent.

1.1.4.3. Acoustic Gauges

Another category of tide gauge is known as acoustic gauges. These instruments depend on measuring the travel time of acoustic pulses reflected vertically from air-sea interface. To ensure continuous and reliable operation, the acoustic pulses are generally contained within a vertical tube or well which can provide some degree of surface stilling averaging a number of measurements will also have a stilling effect and give improved accuracy.

1.1.4.4. Radar Gauges

One of the most recent technologies of tide gauge is the system that uses the time of flight of a pulse of radar, rather than sound, to measure water level. A radar gauge produces radar source down onto the water from the sensor in the open air. The sensor transmits the pulses and receives the return pulse. Hence determining the time of flight and range. Other radar sensors use pairs of cables or rods, between which the radar pulse is transmitted as a wave guide, and there for could be deployed in a stilling well.

1.2. Height Systems

There are several different types of height systems that can be broadly classified according to the way that the Earth's gravity field is modeled. The following section shows some types of height systems.

1.2.1. Geo-potential Numbers

Strictly, all natural or physical height systems must be based on geo-potential numbers, **C**, a geo-potential number is the difference in potential from a reference equipotential surface, $\mathbf{W_0}$, (usually the geoid) to the

potential at the point of interest, **W_P** (Figure 1.3). This definition is shown algebraically in (Equation 1.1) where: **P** is the point of interest; **P_0** is the corresponding intersection of P with the geoid along the plumb line; and **g** is the gravity vector along the plumb line, dz [Heiskanen and Moritz, 1967].

$$C = W_0 - W_p = \int_{p_o}^{p} g dz \qquad (1.1)$$

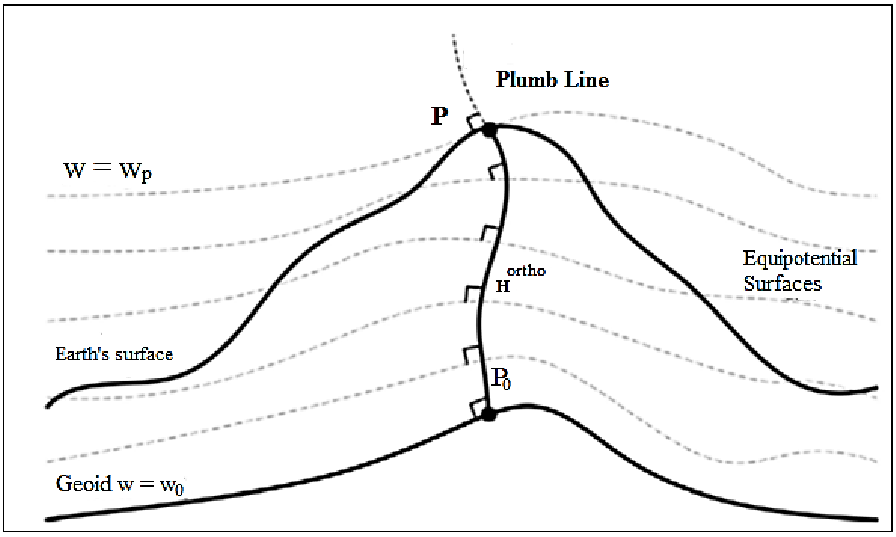


Figure (1.3): The orthometric height (H^{ortho}) of P [Amos, 2007].

Geo-potential number is measured in geo-potential units (GPU), where 1 GPU = 10 m^2s^{-2}. They accurately predict the flow of water (water will flow from a higher geo-potential number to a lower one based on laws of physics and potential theory) and provide a theoretical zero misclosure at any levelling route taken. Geo-potential numbers cannot be directly observed because there is no instrument that can actually measure gravity potential. Instead, they are practically determined using geo-potential differences ΔC that are derived from precise levelling and gravity observations [Heiskanen and Moritz, 1967].

$$\Delta C = g_{mean}\, dn \qquad (1.2)$$

where $\mathbf{g_{mean}}$ is the average surface gravity value and **dn** is the difference in height (both along the precise levelling route). The requirement for surface gravity observations is common to the most types of height.

1.2.2. Dynamic Heights.

The dynamic height $\mathbf{H^{dyn}}$ was proposed to overcome the intuitive problem with geo-potential numbers not being expressed in units of length. That height is obtained by dividing the geo-potential number by a constant gravity value, $\mathbf{g_o}$, often chosen to be the value of normal gravity, Υ, at $\varphi_{45°}$. The dynamic height is defined by [Saad, 1993]:

$$H^{dyn} = \frac{C}{g_o} \qquad (1.3)$$

1.2.3. Orthometric Heights

The orthometric height, $\mathbf{H^{ortho}}$, is defined as the length of the curved plumb line from a point, P, on the earth's surface to its intersection with the geoid, P_0, as shown in (Figure 1.3) and is given by [Saad, 1993]:

$$H^{ortho} = \frac{C}{g^-} \qquad (1.4)$$

where $\mathbf{g^-}$ is the integral mean value of gravity along the plumb line and is given by:

$$g^- = \frac{1}{H^{ortho}} \int_0^H g(z)dz \qquad (1.5)$$

To determine g, the exact path of the plumb line through the Earth and also the gravitational acceleration at all points, that plumb line need to be known. This requires knowledge of gravity variations or mass-density distribution through the topography. Because this information is not available, it is not possible to observe or compute a true orthometric height, despite what many people seem to believe. Several approaches have been developed to approximate g to overcome this limitation. Each

approximation results in a different kind of orthometric height, which is normally named after its proponent.

1.2.4. Normal Heights

The normal gravity field is defined as the gravity field defined by an Earth-fitting ellipsoid that contains the total mass of the Earth (including its atmosphere) and rotates with at a constant angular velocity more or less equivalent to that of the Earth. The normal gravity field can be used to define a height that avoids the density hypothesis for the crust. The normal height H^N was proposed in 1954 by Molodensky. It replaces g in (Equation 1.4) with normal gravity computed along the curved ellipsoidal normal (of the reference ellipsoid), Υ^{-}, hence [Saad, 1993]:

$$\mathrm{H}^{\mathrm{N}} = \frac{\mathrm{C}}{\gamma^{-}} \tag{1.6}$$

where $$\Upsilon^{-} = \frac{1}{H^N} \int_o^{H^N} \Upsilon\,(h)dh \tag{1.7}$$

It is defined geometrically as the distance along the ellipsoidal surface normal from the reference ellipsoid to the telluroid (Figure 1.4). The telluroid was defined by Molodensky as the surface which normal potential, U, at every point, Q, is equal to the actual potential, W, at the corresponding surface point, P, or $U_Q = W_P$. The distance between P and the telluroid, Q, is called the height anomaly, ζ. This is related to the ellipsoidal height, h [Saad, 1993]:

$$\xi = \mathrm{h} - H^N \tag{1.8}$$

Normal heights are simple to compute because they do not require knowledge of the internal mass-density structure of the Earth; this is a virtue of Molodensky's theory. The height anomaly is also defined as the distance between the ellipsoid and the quasigeoid as in (Figure 1.4), hence the normal heights can be compatible with GPS heights when they are

derived from the quasigeoid. Since normal heights do not have any physical meaning (being defined by a gravity model), they are not as applicable to the real Earth as the orthometric height, additionally they cannot universally predict fluid flows.

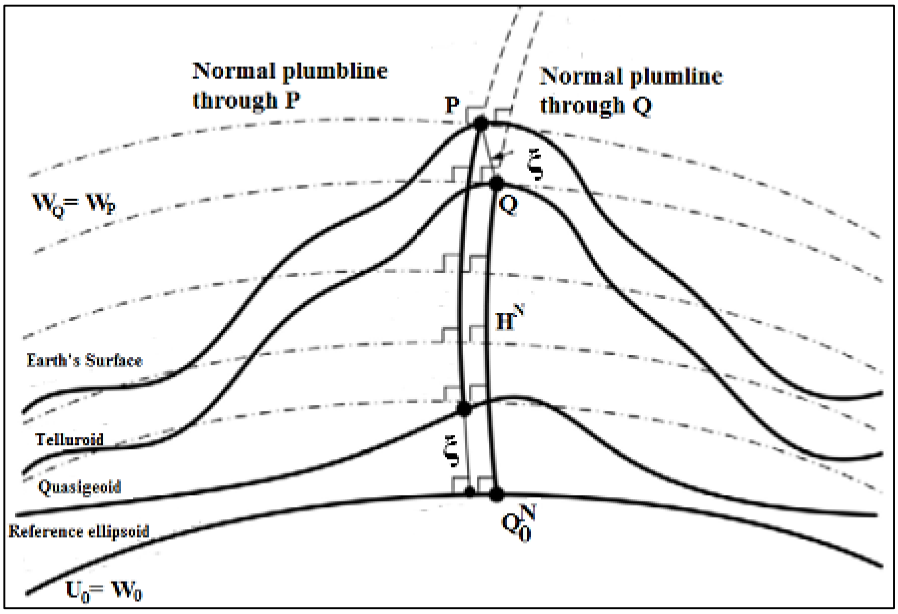


Figure (1.4): The normal height H^N [Amos, 2007].

The difference between normal and orthometric-type heights increases with elevation. The differences between normal and orthometric heights in the Swiss Alps are typically less than 2 cm but they can exceed 10 cm on the mountain tops (< 3000 m) [Amos, 2007].

1.2.5. Ellipsoidal Heights

The ellipsoidal height (h) is the distance from the reference ellipsoid to the earth's surface along the ellipsoidal surface normal as shown in (Figure 1.5). It is defined independently of the earth's gravity field, i.e., it is a purely geometric quantity. Consequently, ellipsoidal heights cannot reliably predict the flow of fluids. They are however relatively easy to define mathematically and as such are the type of height obtained from GNSS receivers (such as GPS).

Ellipsoidal heights are related to orthometric heights by H=h-N and the normal heights by H^N = h- ξ [Amos, 2007].

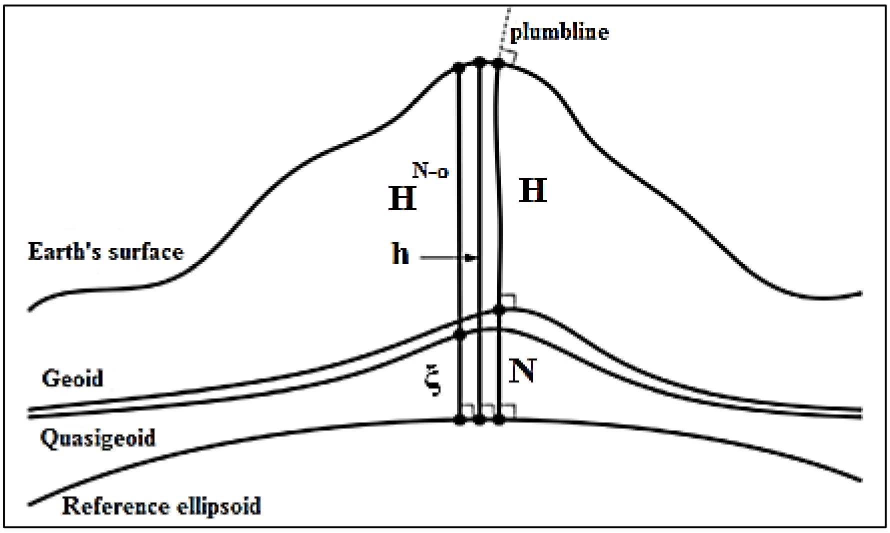


Figure (1.5): The normal-orthometric (H^{N-O}), quasigeoid (ξ), ellipsoid (h), orthometric (H), and geoid (N) heights [Amos, 2007].

1.3. Vertical Datum Definition

In order to identify a vertical datum, it is necessary to select a type of height system and a compatible reference surface. Once these choices are made, and the observed height differences have been corrected for systematic errors affecting their observation, a vertical datum can be identified point-wise by performing a least-squares adjustment of the corrected height differences to minimize the impact of random errors and levelling loops misclousure.

Ideally this adjustment should be performed on either geo-potential numbers or on height differences in a height system that it is suitable. However, this is not always possible. Furthermore, if the heights of multiple points are constrained in the adjustment, then they should all be on

the same equipotential surface. If they are not, then the vertical datum will be distorted and will not represent an equipotential surface over its extents.

The type of height system chosen normally depends on the data that was available to the agency responsible at the time of datum definition (or the system can be chosen and the necessary data then acquired). For example, if gravity observations are unavailable, then only the normal-orthometric or ellipsoidal height systems can be used. The choice of reference surface is guided by the choice of height system, i.e. orthometric heights use the geoid; normal heights the telluroid; normal-orthometric heights the quasigeoid and ellipsoidal heights the ellipsoid. While it is possible to obtain ellipsoidal heights from GNSS technology, it is not currently possible to directly observe the vertical datum surface in natural/physical height systems. Using the assumption that the geoid/quasigeoid and mean sea-level (MSL) in the open oceans are coincident it is possible to relate a vertical datum to the geoid/quasigeoid using local MSL observations.

A vertical datum can also be defined by computing the geo-potential number of the origin point using its ellipsoidal height (from GNSS observations) and absolute gravity value. This approach is well-suited to for the connection of continental height datums (i.e. across large water bodies) and is analogous to the geo-potential number method of datum unification. Because it is defined using a discrete number of points it also suffers from the adjustment weaknesses [Mohamed, 2005].

1.3.1 Determination of Mean Sea-Level (MSL)

In the ideal situation, the datum surface (i.e. zero height) of a height system will coincide with the geoid (true orthometric height system) or quasigeoid (normal-orthometric height system). It is not possible to

physically observe the geoid because there is no instrument that can directly measure the absolute value of the Earth's geo-potential. Recall that over the oceans the geoid and quasigeoid are coincident and that they represent an equipotential surface that generally approximates MSL in the open oceans. Thus, the acquisition of sea-level observations at tide-gauges is the most common method of MSL determination and thence vertical datum definition.

MSL observations are affected by three major problems, sea-level is affected by the presence of tides and other temporal phenomena, the presence of Sea Surface Topography (SST), storm surges, non-linear tides etc. and global changes in sea level due to climate effects [Amos, 2007].

It is necessary to make sea-level observations over a sufficiently long period to take into account the full tidal signature to determine MSL at a coastal tide-gauge. The major tidal effects (caused by the precession and nutation of the Moon and Sun over an 18.6 year metonic cycle) result in the diurnal (daily) and semi-diurnal (twice-daily) tides that are the most noticeable at the coast. Other celestial objects (e.g., planets) also have effects on the observed tides, but these are much smaller in magnitude than those of the sun and moon. Therefore, to determine MSL independent of these tidal effects, it is necessary to make regular (e.g., hourly) sea-level observations over at least an 18.6 year period [Amos, 2007].

1.3.2. Sea Surface Topography (SST)

In addition to accounting for the 18.6 year tidal cycle, the observed MSL will depart from the geoid due a phenomenon called SST. It is also called Dynamic Ocean Topography (DOT), it includes the effects of changes in sea water temperature, salinity, atmospheric pressure, prevailing winds, water currents, etc. SST is dynamic in that it is constantly changing

(e.g., due to seasonal weather variations). The magnitude of SST in the open oceans can be estimated by differencing a global geo-potential model with satellite altimetry derived sea-surface heights.

The magnitude of SST in the open oceans can cause MSL to depart from the geoid by up to two meters. In coastal areas (where most tide-gauges are located), the determination of SST becomes even more difficult. This is because satellite altimetry does not work well close to the coast and also many tide-gauges are located in estuaries where they are also used for monitoring shipping-lanes. These areas are influenced by the freshwater outflows that can significantly alter the observed MSL at different times. Other non-SST effects, such as storm surges, also cause irregular short-term rises in sea-level. The presence of SST causes the MSL measured at tide gauges to depart from a single equipotential surface, thus offsets can occur between vertical datums [Amos, 2007].

1.4.Vertical Datum Unification by Global Geodetic Observing Systems (GGOS)

Over the past several decades, many different methods for defining a vertical reference system to be implemented all over the globe have been presented. The definition of such a global vertical reference system is complicated by accuracy and spatial coverage limitations of the traditional techniques, and the sea level variations affecting tide gauge and satellite altimetry measurements.

The following part highlights the role of mean sea level and altimetry satellite measurements to the vertical datum definition issue. Since one of the major problems with the definition and adoption of a globally defined datum is dealing with existing regional datums. Modeling global change requires geodetic reference frames with order of accuracy higher than the

magnitude of the effects that are introduced; consistency and reliability worldwide. Long-term stability definition, realization, maintenance and use of the ITRS/ITRF guarantees a worldwide unified geometric reference frame with reliability in the mm-level [Sánchez, 2012].

1.4.1. Regional Vertical Datum

There are five main approaches for defining the regional vertical datum [Sideris and Fotopoulos 2006];

- Define the vertical datum by performing a free-network adjustment where only one point is held fixed. A correction factor is applied to the adjusted heights so that the mean height of all tide gauges equals zero. Relies on measurements from a single tide gauge.
- Define the geoid by MSL as measured by a network of reference tide gauges situated along the coastlines and fixing the datum to zero at these stations. Results in distorted heights; ignores movements of tide gauges; MSL is not an equipotential surface and geoid varies from it by a few meters due to SST.
- Use the best model for the SST at the tide gauge stations and then adjust the network by holding MSL to zero for all tide gauges.
- Same as the third option, but allow the reference tide gauges to ‘float’ in the adjustment by assigning them realistic a-priori weights. It will improve greatly with better models for SST and MSL, and their errors from satellite altimetry.
- As in the fourth option, but use estimates of orthometric heights derived from ellipsoidal heights and precise gravimetric geoidal heights. Relates the regional vertical datum to a global vertical reference surface; aids in the realization of a World Height System (WHS).

1.4.2. Global Vertical Datum

There are four main Approaches for defining the global vertical datum [Sánchez, 2012];

- Pure oceanographic approach. Main problem with connecting regional vertical datums between continents separated by the ocean is the SST; models developed using geostrophic and steric levelling techniques; they are least reliable near coastal areas (where the 'datum connection' is).
- Satellite altimetry combined with geostrophic levelling, Global Geo-potential Model (GGM), where MSL, and SST can be computed using altimetry data and Marine geoid; Geostrophic levelling used for extrapolation of SST at tide gauges.
- The altimetry-gravimetric Geodetic Boundary-Value Problem (GBVP). Impractical due to data (GM, gravity, topography and altimetry) limitations.
- Satellite positioning combined with gravimetry. Connection between GPS heights and levelled heights referred to a certain local vertical datum is utilized; combined. Also the adjustment of GPS/geoid/levelling data must be performed, limited by the achievable accuracy of ellipsoidal heights and the internal precision of the geoid model.

1.4.3. Global Vertical Datum Realization

Selecting a vertical datum based on a geoid model implies the acceptance of this geoid's (constant) gravity potential W_0 as a fundamental parameter of the vertical datum. Also, $W_0 = U_0$, where U_0 is the gravity potential of the mean Earth ellipsoid. Then the height of any point P on the Earth's surface is defined by the geo-potential number $C_P = W_0 - W_P$. W_P is

obtained by either $W_P = U_P + T_P$ (from the solution of the GBVP) or $W_P = W_0 - C_P$ (from levelling and gravity).

Datum realization is done by selecting a Fundamental Point (FP), usually at a tide gauge station, where $C_{FP} = 0$, i.e., by selecting $W_{FP} = W_0 = U_0 = const.$, with U_0 referring to, e.g., WGS84. W_{FP} can refer to either a single point or, preferably, be the average potential at many points. For example, a value that is averaged over the seas can be adopted. This value can be obtained from precise satellite altimetry measurements, such as, e.g., from TOPEX /POSEIDON observations, by satisfying (Equation 1.9) [Sideris and Fotopoulos 2006] [Sánchez et al., 2013].

$$\Sigma (W - W_0)^2 = \text{minimum} \qquad (1.9)$$

Frame realization is done through the adjustment of all benchmark heights or geo-potential numbers, reduced to a common epoch and zero-tide system. Result: normal heights H^N. From the GBVP solution (or simply from a GRACE/CHAMP model) height anomalies ζ could be obtained at the same points. Then $h = H^N + \zeta$ and any discrepancies must be adjusted and distributed across the network. The procedure is the same if orthometric heights and geoid undulations N are used instead of normal heights and height anomalies, respectively. For Sea Surface Heights (SSH), the relationship becomes SSH = SST + N. Note: Over the oceans, and because the global SST average is not zero, $W_0 \neq U_0$ and (SSH - SST) will not be identical to N obtained from the solution of the GBVP; the difference is approximately $SST = (U_0 - W_0)/\gamma$ where γ is the normal gravity and must be taken into account [Sánchez et al., 2013].

1.4.4. The Role of Satellite Altimetry

For a global vertical datum, or WHS, the zero-level equipotential

surface is the MSL. For the realization of such a WHS, we obviously need to combine [Sideris and Fotopoulos, 2006];

• Best estimates of the MSL and other oceanographic models.

• PSMSL tide gauge time series.

• GPS/GNSS heights at tide gauges.

• Best gravimetric geoid models (from dedicated gravity satellite missions and other data).

1.4.4.1. Satellite Altimetry Tasks

• Determination of MSL for the last two decades.

• SSH/SST determination and removal from tide gauge and sea level data.

• Development of precise global geo-potential models.

• Determination of marine geoid and gravity models for the solution of the GBVP and improved GMs.

• Improvement of bathymetry determination, which in turn leads to better models of the marine geoid and gravity [Sideris and Fotopoulos, 2006].

1.4.4.2. The Advantages of Satellite Altimetry in Both the Definition and Realization phases

• Unprecedented near global coverage.

• High spatial resolution.

• Consistent accuracy.

• Temporal continuity.

• Independent alternative to surface techniques.

• Measurements with respect to a geocentric reference frame.

• Indispensable for the ocean surface, sea level, ocean circulation and tides [Sideris and Fotopoulos, 2006].

1.5. The Motive and Purpose of the Thesis

The mean sea level used as local vertical datum where the vertical and horizontal datums are used together to define the heights and the geodetic coordinates. The mean sea level is used as reference for height and still used until now although the average of this observed value does not represent the geoid. The mean sea level at some sites may be different in its value when it is compared with other sites because of the difference in equi-potential surfaces. That's why the use of mean sea level as reference surface causes a lot of problems that is associated with the application of vertical datum;

-The distortion that is composed from constraints in adjustment.

-The deviation in local vertical datum and its effect on terrestrial gravity anomalies.

-The change of the mean sea level in different times affects the geodetic works and oceanographic surface and protection of beaches.

According to the previous mentioned points, this thesis aims to present a proposal plan to unify the vertical datum in the Arab region to help in completing the investments and the national contribution projects among Arab countries. After implementation the suggested proposal which presented from this thesis, the advantages of replacing the official levelling-based vertical datum by common geoid and GNSS compatible vertical datum will be;

- Unified vertical control will exist for all Arab countries including desert, remote and extremist areas.

-Compatibility with space-based positioning (e.g., GNSS, altimetry) will be ensured.

-The datum maintenance will be less expensive.

-The vertical datum will be fairly stable due the fact that the geoid surface

changes at a rate of about 1 mm per year compared to 1 cm per year for the physical benchmarks due to the regional geodynamics [Fischer, 2009].

1.6. The Thesis Objectives

- Studying the scientific background for associated topics.
- Investigating and verifying the current situation of the vertical datums in the study area.
- Studying some previous similar cases such as the unified European vertical datum.
- Suggesting possible proposals to verify the aim of this research within the available and proposed data in the area.

1.7. Scope of Thesis

To fulfill the objectives of the thesis that were previously mentioned, this thesis contains six chapters and a list of used references are also included.

-The first chapter; contains introduction; the scientific topics and theoretical background, objectives, and scope of thesis.

-The second chapter; contains some unifications of the vertical datums in different regions around the world Such as Australia in 2005, Africa and New Zealand in 2011, Europe in 2013, America in 2014, and Poland 2015.

-Third chapter; contains description and discussion of the current state for vertical datums in Arab region and displays the available data.

-The forth chapter; contains description of geoid and classifications of geoid determination methods, explanation of satellite gravity missions, in addition to tailoring the global geo-potential models.

-The fifth chapter; displays, analyses and discusses the methods and steps which be suggested to unify the geodetic data (tide gauge stations, GPS,

levelling, and gravity points) for unifying the vertical datums in Arab countries and the strategy of implementation.

-The sixth chapter; summarizes the basic work performed in this thesis. Then, the important conclusions. Also, some recommendations based upon the extracted conclusions for both the preformed work herein and for future researches connected with the subject matter will be stipulated.

-Appendix (A) contains an information about SST value and its effect on tide gauge stations in Australia coast.

CHAPTER (2)

PREVIOUS CASES OF UNIFYING DIFFERENT VERTICAL DATUMS

Introduction

This chapter contains some unifications of the vertical datums in different regions around the world. Such as Australia in 2005, Africa in 2011, New Zealand in 2011, Europe in 2013, America in 2014, and Poland 2015.

The global unification of local vertical datums is by no means complete, though numerous studies have addressed the problem. The proper unification of vertical datums remains problematic because of the many theoretical and practical issues involved. These issues include the realization of vertical datums using tide-gauges and spirit levelling, the appropriate formulation and solution of geodetic boundary value problems, and the spatially varying accuracy of computed gravimetric geoid and Sea-Surface Topography (SST) models. Accordingly, the unification of vertical datums remains one major focus of current geodetic research, and is likely to be so for some time.

Some countries use separate Local Vertical Datums (LVDs) based on geodetic levelling from different tide-gauges. So these countries attempted to unify the local vertical datum, using some methods in order to inference a mediator surface to compare the user local surface by height reference frame offsets inference from the difference between the unified vertical datum and the local vertical datum which used. The key issue of height datum unification is to determine the potential differences among different height datums. Different approaches have been studied for this purpose. The geodetic levelling and gravity field approach and the ocean levelling approach.

The ocean levelling is a method to establish the potential difference between two points across ocean, and generally includes steric, dynamic, and altimetric levelling and observations across water expanses are difficult and limited to short distances. This makes the ocean levelling approach inappropriate for a global approach. The geodetic levelling approach combines observed height differences by spirit levelling and gravity in order to obtain geo-potential differences.

These approaches were used in some countries, and the methods of implementation and the results will be stated [Rülke et al., 2012 and Zhang et al., 2008].

2.1. Unification of Vertical Datum in Australia 2005

Australia has been fixed multiple tide-gauges to MSL which has caused the Australian Height Datum (AHD) to depart from a single equipotential surface.

2.1.1. Data Sets Collection

Data sets were collected from Australian Geoid 98 (AUS Geoid98) which used with GPS and Australian Height Datum (AHD), the heights at 1013 points, and subsets of them, these were divided between 50 points in Tasmania and 963 points on the Australian mainland to estimate the offset between the AHD (Mainland) and AHD (Tasmania) [Featherstone, 2005].

2.1.2. Mathematical Methodology

GPS derived ellipsoidal heights and a gravimetric geoid model is used to provide a 'reference surface' to which the heights on the local vertical datum are compared. The vertical offset (O) between the local vertical datum and this GPS-geoid reference surface is:

$$O = h - N - H \qquad (2.1)$$

where h is the GPS-derived ellipsoidal height, N is the geoidal undulation, H is the (ideally) orthometric height referred to the local vertical datum. For the approach to be valid, the GPS and geoid heights must refer to the same ellipsoid. A positive value for O in (Equation 2.1) implies that the vertical datum is situated vertically above the reference surface, and vice versa. However, the GPS-geoid reference surface is not well defined in its absolute position, primarily due to a poor knowledge of the zero-degree term in the gravimetric geoid. Therefore, (Equation 2.1) is applied in a relative sense such that the zero-degree deficiency is eliminated, as will be any other common features. This relative approach yields the vertical offset (V) between the two vertical datums as:

$$V = O^M - O^T \qquad (2.2)$$

where, from (Equation 2.2), O^M is the offset of the AHD (Mainland) from the reference surface and O^T is the offset of the AHD (Tas) from the reference surface. (Equation 2.2) also applies to the unification of other vertical datums.

2.1.3. The Results

Two attempts have been made to unify the AHD (Mainland) and AHD (Tas). The first attempt suggests a ~10cm offset between the AHD (Mainland) and AHD (Tas), with the AHD (Tas) being situated below the AHD (Mainland). This value has since been revised to ~40cm. The second attempt suggests a ~30cm offset between the AHD (Mainland) and AHD (Tas), also with the AHD (Tas) situated below the AHD(Mainland).

The largely north-south SST causes measurements of MSL to depart from a single equipotential surface, where the differing effect of SST among Australian tide-gauges, in conjunction with geodetic levelling errors, has introduced distortions into the AHD. Therefore, any vertical offset between the AHD (Mainland) and AHD (Tas) can also be expected to vary as a

function of position, with different offsets being calculated for different stations. The statistics of the differences between the AHD (Mainland) and AHD (Tas) and the reference surface, and the [assumed] vertical datum offset are made. It appears that the AHD (Tas) is offset below the AHD (Mainland) between (26±33) cm and (12±12) cm, which matches the previous estimates and sea-surface topography models [Featherstone, 2005].

2.2. The Vertical Datum in Africa 2011

In African countries, heights are generally considered to refer to Mean Sea Level (MSL) and most vertical reference frames attempt to approximate MSL as the datum for heights. In principle, the geoid is the ideal vertical datum, the current provisional geoid model for Africa, AGP2003 (is an attempt to produce a uniform precise geoid model for Africa) does not meet the stated requirements. Due to lack of data in some regions, it is of uneven quality and there are potential biases and tilts due to errors in the low frequency components.

In practice, both the geoid and MSL are approximated by taking tide gauge measurements at one or more sites over a limited period. Different methods, differing tide gauge sites and variable departures of MSL from a single level surface will lead to adjacent countries effectively establishing different vertical reference frames. For some landlocked countries the vertical datum may be defined by using the height of a benchmark on or near the border with a neighboring maritime state - this may also cause a departure from other established datums in the region.

Nowadays most control surveys are established using satellite positioning systems such as GPS. The reference frame for GPS is the WGS84, where heights are referred to the WGS84 ellipsoid, not to MSL. Consequently, in order to reference GPS-derived heights to the appropriate surface (geoid) the geoidal undulation must be known [Nairobi et al., 2011].

2.2.1. Data Sets Collection

Data sets from Continuous coverage over the oceans are available from satellite altimetry data, and from a data set compiled by the Danish National Survey and Cadaster. On land, the data set is based upon compilations produced by the Universities of Leeds and Cape Town. There are large blank areas (e.g. in the interior of Angola) and other areas where the coverage is sparse. In this case, the gaps in the 5' terrestrial data set were filled using the EGM96 geo-potential model [Merry, 2005].

2.2.2. Computation Methodology

The geoid was computed in several steps:

- The long wavelength component of the height anomalies (quasi-geoid) was computed using the EGM96 geo-potential model.
- The short wavelength component was computed using reduced gravity anomalies in a two-dimensional convolution representation of the Stokes' integration.
- The height anomalies were converted to geoidal heights using spherical harmonic representation of the separation between the two surfaces.

Key task of Africa Reference Frame (AFREF) should to place in each country some GPS control points at critical points of the national vertical network. Such critical points which include Tide Gauge Benchmarks (TGBM's) and nodal points of the first order levelling networks. Having precise International Terrestrial Reference Frame (ITRF), coordinates at these points, together with a precise geoid model, will enable the offset **(O)** of the vertical datum (with reference to the geoid) to be determined using the simple model (Figure 2.1) [Merry, 2005].

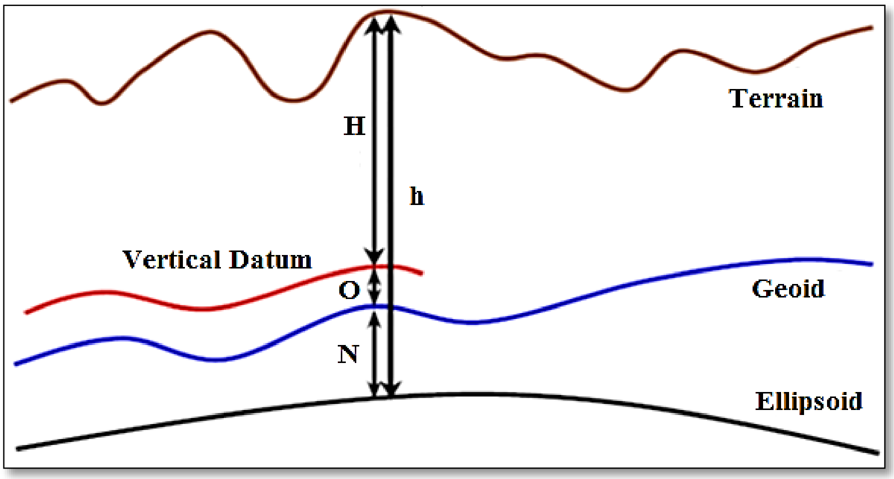


Figure (2.1) Vertical datum offset [Merry, 2005].

In (Figure 2.1), h is the ellipsoidal height of the point (determined from its ITRF co-ordinates) N is the geoidal undulation at that point (from the geoid model); and H is the orthometric height of the point in the local vertical datum (determined from precise levelling). The same model can be used if the quasi-geoid is the reference surface, replacing the geoidal undulation with the height anomaly and the orthometric height with the normal height. If more than one such critical point is available, the redundant data could be used to estimate any potential tilt of the vertical datum. In order to obtain a precise and reliable estimate of the offset, it is necessary that all components in (Equation 2.1) are both precise and free of bias.

2.2.3. Results

Data were obtained for parts of Algeria, Egypt and South Africa. It was immediately apparent that significant biases existed between the three regions shown in (Table 2.1). There is a multiplicity of potential sources for these biases;

- Errors in the long wavelength components of the EGM96 geo-potential model.
- Differences in the GPS reference frame used.

- Biases in the vertical datums used in the different countries.
- Cumulative systematic errors in the levelling networks.

Table (2.1) Comparison GPS/Levelling-AGP2003 [Merry, 2005].

Region	No. of Points	Bias(cm)	Std. Dev.(cm)
Algeria	13	-17	48
Egypt	8	+124	80
South Africa	42	-63	9

The South African vertical datum is known to be some 15-20 cm below current MSL. A similar magnitude exists for the Algerian and Egyptian vertical datums. Systematic errors in the levelling network (due to neglecting of gravity effects, refraction, etc) must not be ignored [Merry, 2005].

2.2.4. Improving the African Geoid Model

There is a need to ensure that sufficient precise GPS measurements are made at critical points of the national vertical networks, including the zero points and other Tide Gauge Bench Marks (TGBM's);

- Filling in gaps in the terrestrial gravity data coverage, will improve the accuracy in areas where data are sparse, however it will take many years to carry out the necessary surveys, even if airborne gravimetry is used.
- Replacing the EGM96 model with a more modern model, such as GGM01, will reduce zero and low frequency errors and biases.

The usage of such data is not enough to obtain a vertical datum for Africa.

2.3. Unification of Vertical Datum in New Zealand 2011

New Zealand uses 13 separate Local Vertical Datums (LVDs) based on geodetic levelling from 12 different tide-gauges. However the combination of tectonic motion, Sea Surface Topography (SST), and sea-level change in NZ means that MSL at each tide-gauge does not lie on the same equipotential surface. Volcanic activity, geothermal energy extraction, and earthquakes also cause localized height changes. Thus, the prospect of forming a single vertical datum based solely on the readjustment of the levelling networks based on MSL is becoming more remote with time.

In New Zealand, presenting an iterative technique for determining a gravimetric quasigeoid model based on the GPS-levelling fit (offsets) among the existing LVDs. It is necessary to consider these offsets in the reduction of gravity anomalies to a common LVD for subsequent quasigeoid determination through a series of iterations.

2.3.1. Data sets Collection

Data collected from:

-Tide-gauges and precise levelling networks. NZ LVDs are based on a determination of MSL at different tide-gauges over varying time intervals (normally 3 years).The Stewart Island/Rakiura1977 LVD is not defined by a tide-gauge. Instead, its zero level is based on the MSL value determined from three temporary tide-gauges by averaging the high and low levels of three to five successive (but not simultaneous) tides. It also uses trigonometric heights that could be in error by 0.2–0.3m, and the MSL could be in error by 0.5m from the long-term trend. This is a weakly defined LVD [Amos, 2007].

-Where two or more LVDs Separate or overlap, it is possible to directly estimate the offsets. However, this is affected by the distance and route of the levelling traverse to get to the junction point. Any deformation that has occurred while the levelling was being carried out (although this

deformation will be "spread-out" by the least-squares adjustment), along with observation and reduction errors. Accordingly, when LVDs join at multiple places, the observed offsets will differ.

-GPS-levelling data, a total of 1,422 points in NZ have both NZGD2000/ GRS80 ellipsoidal and LVD normal-orthometric heights (first- and second-order levelling).

The spatial distribution of the GPS levelling points is scattered, and there are significant gaps in the South Island. This is where the topography is particularly rugged so that the precise levelling traverses are restricted to roads. The levelled normal-orthometric heights were then divided among the 13 LVDs. No GPS-levelling points exist on the Chatham Islands and five points on Stewart Island have less accurate heights. The absolute accuracy of the ellipsoidal heights and the normal-orthometric heights is estimated to be on average 10 cm and the combined accuracy 14 cm. This error estimate assumes independence and does not account for the offsets among the LVDs.

-Land gravity, terrestrial gravity data in NZ is held by Global Navigation Satellite Science (GNS Science). The database (2007) consists of 40,737 observations covering the NZ and Chatham Islands were primarily collected for the production of gravity anomaly maps the accuracy of the gravity observations was 0.1– 0.5 mgal [Amos, 2007].

- Ship-track gravity observations in the vicinity of NZ have been collected over the past 45 years by various agencies at different times for different purposes. The databases (2007) comprise 1,300,266 gravity anomalies bounded by 160° E $\leq \lambda \leq 190^{\circ}$ E and 25° S $\leq \varphi \leq 60^{\circ}$ S. Estimated the overall accuracy of the marine data within 1 mgal [Amos, 2007].

-Satellite altimeter-derived gravity. The ship-track observations were combined with gravity anomalies derived from satellite altimetry to achieve better gravity data coverage over the NZ computation area. However

altimetry-derived gravity anomalies are known less accurate close to the coast.

The 1422 GPS-levelling points were then used to estimate the initial offsets for each LVD from this initial model, where the GPS-levelling points were divided into their respective LVDs. These points are not evenly distributed among the 13 LVDs because the levelling routes are located along highways.

2.3.2. Mathematical Methodology

The normal-orthometric H^{N-o}, quasigeoid (ζ) and GPS ellipsoidal (h) heights of a point in (Figure 2.2) are related by $h = \zeta + H^{N-o}$. Therefore, assuming the absence of other systematic error sources, the offsets (on LVD "*a*") were computed according to [Amos, 2011]:

$$H_a^{N-o} - h + \zeta = o_a \qquad (2.3)$$

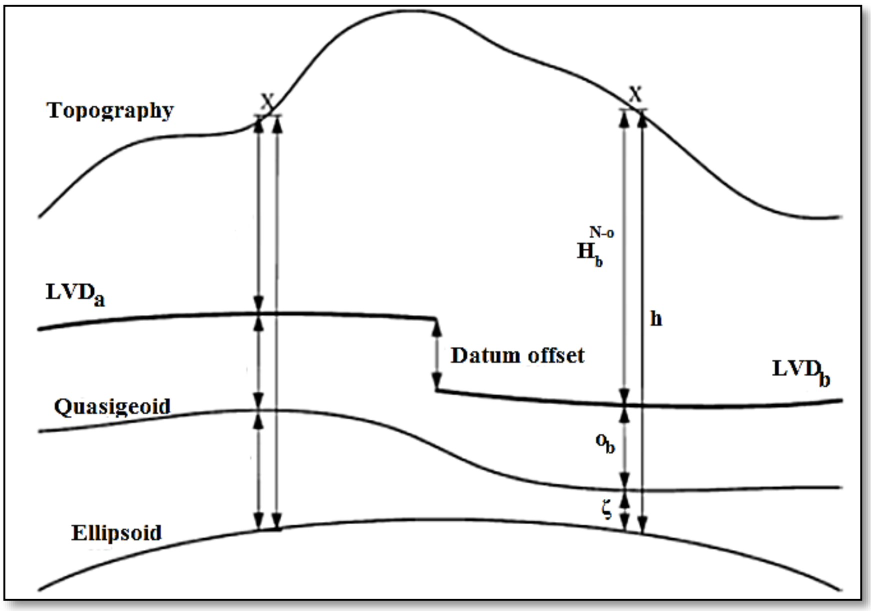


Figure (2. 2): Schematic of LVD offsets and their effect on the initial Quasigeoid [Amos, 2007].

A datum offset correction (δΔg) was proposed to correct gravity observations for the effect of offset LVDs and thus convert them to a

consistent reference system prior to computation. Where $\delta\Delta g$ has the form of the (first –order) free air gravity correction and units of mgal applied over LVD offset (o) [Amos, 2011].

$$\delta\Delta g = \Delta g^* - \Delta g = \frac{\partial \gamma}{\partial h} o \cong 0.30860 \quad (2.4)$$

where

$$\Delta g^* = g_{obs} - \frac{\partial \gamma}{\partial h} + (h_D + o) - \gamma \quad (2.5)$$

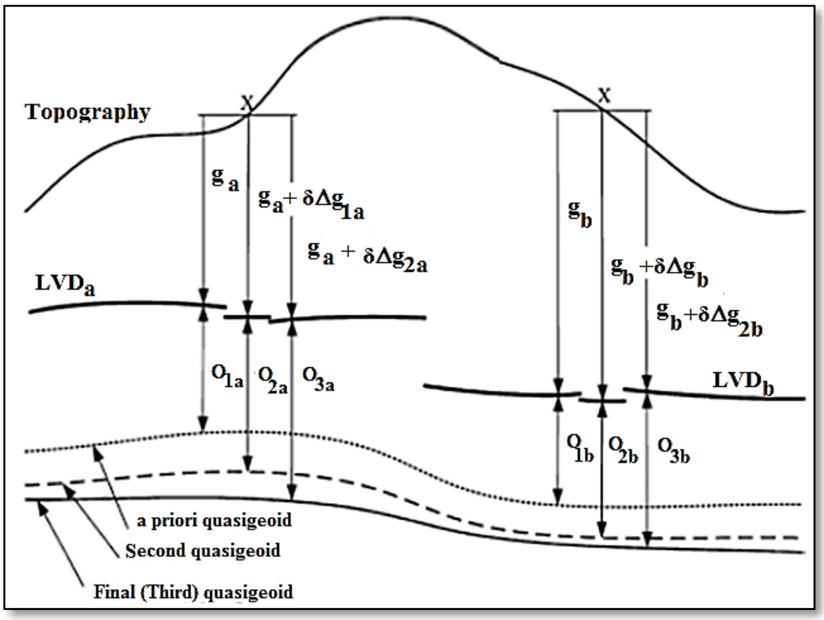


Figure (2.3): Iterative quasigeoid datum unification scheme [Amos, 2007].

$$\Delta g = g_{obs} - \frac{\partial \gamma}{\partial h} h_D - \gamma \quad (2.6)$$

The first step is to compute a preliminary/initial model using gravity anomalies reduced to their respective LVDs. This model and GPS-levelling observations are used to make a first estimate of the offsets (i.e. mean of the GPS/ levelling-quasigeoid differences) for each LVD (Equation 2.3). These offsets were then used in (Equation 2.4) to determine $\delta\Delta g$ for each LVD. The

original gravity anomalies were then "corrected" by adding the applicable $\delta\Delta g$ for each LVD.

The effect of using $\delta\Delta g$ to unify two datums with the iterative scheme is shown in (Figure 2.3), where the two LVDs meet, a step (smoothed by the Stokes filtering) occurs in the computed quasigeoid as a result of the offset. These "corrected" gravity anomalies were then used to evaluate a second model **(ζ_2)** shown as a dashed line in (Figure 2.3). The step in the second model at the datum boundary has been smoothed further in comparison to the preliminary model. This is because the offset bias is being better modeled by the LVD offset "correction" applied above. The original GPS-levelling data is then used again with the second model to re-evaluate the datum offsets.

The "again-corrected" gravity anomalies (g_{2a}, g_{2b}) were then used to compute a third model (ζ_3), shown as a solid line in (Figure 2.3). This model is even smoother than the second model across the LVD boundary. Again, the GPS/levelling data were used to evaluate the LVD offsets, o_{3a} and $\mathbf{o_{3b}}$. This process was repeated until the offsets computed in successive iterations are constant.

Final results after removing the mean offset for each LVD, the standard deviation (STD) for all 1,422 points is reduced from 0.124 m to 0.078m. General the NZ gravity observations were assumed to have been reduced to the LVD in which are located. By comparing the statistical results, the iterative procedure converged after only three iterations in NZ. The final LVD offsets and their standard deviations were compared with the levelled differences at junction points.

Ten of the 13 levelled offsets agree statistically with the so-computed offsets. When taking into account the crudely estimated precision of the GPS-levelling data of ~14 cm, all results were consistent and converged to final NZ gravimetric quasigeoid model represents a surface that has been

“corrected” for the biases otherwise introduced as a result of the gravity anomalies being computed in terms of offset LVDs [Amos, 2007].

2.4. Unification of Vertical Datum in Europe 2013

The weaknesses of European height system unification by levelling can be identified as different epochs of levelling observations in different countries, very long observation periods, very limited information about height changes with time, quality differences of levelling lines between neighboring countries, differences in national standards for levelling, accuracy differences of national levelling networks, low redundancy of levelling networks and the lack of independent information.

The European Vertical Reference System (EVRS) is related to the earth gravity field on and outside the solid Earth. It is a geo-potential reference system. The EVRS is defined as a kinematic height reference system and considers the following conventions [Rummel, 2014];

- The vertical datum is defined as the equipotential surface with a constant Earth gravity field potential on the Normal Amsterdam Peil (NAP) level: $Wo = Wo_E = const$
- The unit of length is meter (SI). The unit of time is second (SI). The scale is consistent.
- The height components are given by differences ΔW_p between the Earth gravity field potential in a point P (W_P) and the potential at EVRS conventional zero level (W_{OE}). The potential difference $-\Delta Wp$ is also termed as geo-potential number C_P ($-\Delta Wp = C_P = W_{OE} - Wp$) Normal heights are equivalent to geo-potential numbers, provided that the reference gravity field is specified.
- The EVRS is a zero tidal system, this in agreement with the IAG resolutions.

2.4.1. Data Sets Collection

The previous studies showed that the gravity field approach has been used in Europe where data sets were collected from, gravity field models, ellipsoidal and physical heights, and the height anomalies can be computed from a gravity field model. They are independent of the cross-border-observations necessary for the geodetic levelling approach. Height anomalies have been synthesized from three GGMs models in the zero tide system: TIM R3, GOCO03S and EGM2008, and combines observation data from GRACE and satellite altimetry as well as terrestrial gravity data. The GOCE TIM R3 model, The GOCO03S model was computed by using data sets from the missions GOCE, GRACE, and CHAMP. EGM2008 is a high resolution model up to degree/order (d/o 2190), a spatial resolution of 9 km [Rülke, 2012].

A widely used technique for the combination of GGMs is the catenation of sets of spherical harmonic coefficients of low resolution satellite-only models with higher degree and order coefficients from high resolution models. For example, spherical harmonic coefficients of a GOCE model up to d/o 190 are extended by EGM2008 spherical harmonic coefficients from d/o 191 to d/o 2190.

2.4.2. Mathematical Methodology

The obtained height anomaly $\zeta^{z}_{\mathrm{iObs}}$ in zero-tide system computed from an observed ellipsoidal height $\mathrm{h}^{\mathrm{a}}_{\mathrm{i}}$ and an observed physical height $\mathrm{H}^{\mathrm{a}}_{\mathrm{i}}$ given in their tidal systems a and b with [Rülke, 2012]:

$$\zeta^{z}_{\mathrm{iObs}} = h^{a}_{i} + \delta^{h}_{a\to z} - (H^{a}_{i} + \delta^{h}_{b\to z}) \tag{2.7}$$

If a and b are not zero-tide, corrections δ according to (Equation 2.7) to (Equation 2.10) need to be considered. This observed height anomaly is

now compared to the modeled height anomaly ζ^{z}_{iMods} from a gravity field model.

$$\Delta\zeta^{z}_{i} = \zeta^{z}_{iObs} - \zeta^{z}_{imod} \quad (2.8)$$

Since ζ^{z}_{imod} is related to $W_0 = U_0$ of the GRS80 reference system, $\Delta\zeta^{z}_{i}$ is the height of the national height reference system above U_0 of GRS80 in the zero tide system. Assuming that the gravity field model and the heights are error free $\Delta\zeta^{z}_{i}$ = const is true for all points i with in a specific national height reference frame. In reality, significant systematic effects may remain of the pure offset estimation. Here, a first order polynomial model is applied in a least squares adjustment. The observation equations for $\Delta\zeta^{z}_{i}$ of a point $P_i(\phi_i, \lambda_i)$ read :

$$\Delta\zeta^{z}_{i} + \hat{e} = m_1 + m_2 M_o(\phi_i - \phi_o) + m_3 N_o(\lambda_i - \lambda_o)\cos\phi \quad (2.9)$$

The three unknowns m_1, m_2 and m_3 represent the offset, a North-South and a West-East tilt, respectively. All observation points Pi (ϕ_i, λ_i) are related to a reference point. $P_o(\phi_o, \lambda_o)$. M_o and N_o describe the radius of curvature in the meridian and perpendicular to the meridian of the GRS80 ellipsoid in P_o, respectively. The residuals $\hat{e}$ are computed from the modeled height anomalies $\hat{\Delta}\zeta$ and the observed values $\Delta\zeta$:

$$\hat{e} = \hat{\Delta}\zeta - \Delta\zeta \quad (2.10)$$

The standard deviations of $\hat{e}$ and the quantities of m_2 and m_3 are a measure of the overall error budget of the observation data.

2.4.3. The Results

By comparing the results, the agreement between the method based on spirit levelling and the gravimetric based method is on the level of a few

centimeters. The height offset estimates based on different combined models vary by a few centimeters only; with a maximum of about 5 cm in some countries. High resolution gravity fields provide an independent validation method of national levelling data sets. The GOCE mission has significantly improved the capabilities of unifying height reference frames. Due to its global applicability, the gravimetric approach is the preferred method for the realization of a World Height System.

The performance of the filter combined model is better than the pure European Gravity Geoid (EGG2008) and significantly better than combinations based on the extension of sets of spherical harmonic coefficients. Thus, filter-combined models represent a good base for the unification of height systems in Europe.

2.5. Unification of Vertical Datum in North America 2014

The North American Vertical Datum of 1988 (NAVD88) and the International Great Lakes Datum of 1985 (IGLD85) are international vertical reference frames for North America. The levelling networks of Canada, USA and Mexico were adjusted together with the height of one primary tidal benchmark held fixed, i.e., NAVD88 and IGLD85 are constrained to the mean water level at Father Point/Rimouski, Quebec, and Canada. Few other datum definitions were studied and evaluated, among them fixing MSL at four tide gauges located at the corners of the network or fixing the old NGVD29 heights at 18 benchmarks well distributed across the network. Additionally, two options for establishing the new vertical datum were under consideration [Smith, 2013]:

- The tidal epoch option which required that the MSL was held fixed at all primary tidal benchmarks and adopt the latest tidal epoch.
- The minimally constraint adjustment option where the MSL at one tidal station is held fixed and all levelling data are adjusted to that level

surface in order to maintain the integrity and avoid distortions of the vertical control network. In addition, the datum was shifted vertically to ensure minimum recompilation of the existing mapping products.

IGLD85 is part of NAVD88. And the only difference is that the heights of the benchmarks in NAVD88 are Helmert orthometric heights computed by scaling the geo-potential numbers with the Helmert approximation of the mean gravity along the plumb line while the IGLD85 heights are dynamic computed by scaling the same geo-potential numbers with the normal gravity value at 45 degrees latitude.

The general adjustment of NAVD88 was completed in June 1991. It included improved existing levelling data and 81,500 km re-levelled first order levelling lines in order to reinforce the primary vertical control network. Rod scale and temperature, level collimation, astronomic (tidal), refraction and magnetic corrections were applied to the levelling data. It was determined that the systematic errors have large local effects on the re-adjusted heights but a minimal continental effect (except for the magnetic correction).

The use of true geo-potential numbers instead of normal-orthometric geo-potential numbers (as in the old reference frame NGVD29) had a small effect of 5-6 cm from coast to coast in USA but in the mountains, this effect reached 50 cm. The levelling network was connected to 57 USA primary tidal stations and 55 international water level stations along the Great Lakes shores. Connections between the USA and Canadian networks were established at 28 benchmarks, and the USA and Mexican vertical control networks were connected at 13 benchmarks. Geographical locations of BMs were scaled coordinates determined from digitized map products. Gravity values were interpolated from actual measured gravity data [Smith, 2013].

2.5.1. The Characteristics of the North American Official Vertical Reference Frames

Approximately half of the first order BMs in Canada have NAVD88 orthometric heights. Canada's official vertical datum is the Canadian Geodetic Vertical Datum of 1928 (CGVD28) constrained to the mean sea level of five tide gauges on the Pacific and Atlantic coasts and the water gauge at Father Point/Rimouski on St. Lawrence River used to constrain NAVD88. The heights are normal-orthometric, i.e., an approximation to the true orthometric heights, where the geo-potential numbers were computed with mean normal gravity instead of the actual gravity. As a result, the CGVD28 heights are systematically lower than the true orthometric heights. In the Rocky Mountains, the deviations are up to several decimetres. No corrections for glacial isostatic adjustment and MSL rise were applied.

2.5.2. Computations of the North American Datum Offsets

2.5.2.1. Basic Relationships

Given a set of GNSS BMs points, the geo-potential at the fundamental BM of the local height datum j, W_o^j, and the separation $\boldsymbol{\delta} N^j$ with respect to the global geo-potential surface defined by W_o. For apoint P with orthometric Height H_p^j, GNSS ellipsoidal height h_p geo-potential component from a GGM at the point P^- on the geoid, i.e Tp^-, the offset of the local datum j is computed as [Smith, 2013]:

$$\boldsymbol{\delta} N^j = -\boldsymbol{\delta} W_o^j/\gamma \tag{2.11}$$

Where the geo-potential diferrence is:

$$\boldsymbol{\delta} W_o^j = W_o^j - W_o = -W_o + U_o - \gamma_{Q_o}\left[h_p - H_P^j - \frac{T_{p-}}{\gamma_{Qj}}\right] \tag{2.12}$$

Where Q^j is the point at which $U_{Q_j} = W_{P^-}$, and Q_o is the point on the ellipsoid along the normal at the point P on the physical surface. The targeted 1cm

accuracy of Height System Unification (HSU) allows (Equation 2.12) to be simplified to:

$$\boldsymbol{\delta} W_o^j = W_o^j - W_o = -W_o + U_o - \gamma_{Q_o} \left[h_p - H_P^j - N_p \right] \quad (2.13)$$

The offset of the height datums in North America is computed relative to the global equipotential surface defined by the adopted by IAG; $W_o = 62636856.00\ m^2/s^2$.

2.5.2.2. Computation of the NAVD88 Offset

Lastly, $\boldsymbol{\delta} N^{\mathbf{NAVD88}}$ is computed using the USA GNSS BMs data and the combined USA and Canada GNSS BMs data. Results from statistical data show that the Canadian data have a little effect on the computed value. Note that the estimated errors are overly optimistic because no VCMs were available for the USA data. Furthermore, the addition of the higher frequencies (using EGM2008) improves the $N^{\mathbf{NAVD88}}$ value by only 2.5-2.6 cm. Compare this to the Canadian case where the difference is 8.5 cm.

2.5.3. The Results

- Release 3 GOCE-based direct and time-wise solutions are the best GGM_S medium frequencies in Canada and USA at present. These two models are recommended to be used for the North American height datum unification.
- The omission error of the GOCE-based GGMs is significant in Canada should be taken into account when using the GNSS BMs and TGs data for HSU. Though small, the omission error should also be taken into account when USA GNSS BMs are used if 1cm accuracy for HSU is aimed.

- Given the distribution of the Canadian data points, wavelengths smaller than 12 km have a negligible effect on the computed vertical datum offset.
- The higher frequencies of the local geoid should always be accounted for when tide gauge are used for HSU.
- NAVD88 (USA) and Nov07 (Canada) vertical reference frames have similar definitions and consequently the two fundamental level surfaces differ by only 2 cm. CGVD28 (Canada) will be replaced by 2013 by a new geoid-based vertical reference frame. Therefore, it is recommended that the Nov07 height information is used [Smith et al., 2013].

2.6. Unification of Vertical Datum in Poland 2015

In Poland, the Kronsztadt86 vertical reference frame is the result of adjustment of the third precise levelling campaign carried out in 1974 – 1988. The normal height are in non-tidal system and referred to the epoch 1978.0 [Lyszkowicz et al., 2015].

As mentioned previously, Vertical shifts between national vertical datums have been determined by various approaches in terms of height or geo-potential differences of their corresponding zero-height reference surfaces. The determination of the zero-height geo-potential level of an existing vertical datum is important for the connection of traditional height reference systems with a global height system or even a modern geoid-based vertical datum. Various methods have been used in practice for estimating the fundamental parameter **Δ**W which can be broadly classified into two basic categories. The first one is based on the combined adjustment of GGM and GPS/levelling data while the second one employs the formulation of a geodetic boundary value problem with the use of gravity anomaly data over

different local vertical zones. Both approaches have been extensively utilized by the scientific community [Lyszkowicz et al., 2015].

2.6.1. Data Sets in Poland

EGM2008 is a high resolution model up to degree and order 2190, with a spatial resolution of 9 km. This global model has been used in Poland with combines observation data from GRACE, satellite altimetry, and terrestrial gravity data. Height anomalies $\xi^{\mathbf{EGM2008}}$ have been synthesized from these model in the zero tide system.

The ellipsoidal heights used in Poland for this study are the results of adjustment of satellites networks POLREF, UEVN-DA, and ASG-EUPOS. The ellipsoidal heights in satellite networks are computed from the GRS80 ellipsoid to the non-tidal crust.

The POLREF network was observed in 1995, while EUVN-DA in 1999 and ASG-EUPOS in 2000. In order to compare the ellipsoidal heights with normal heights the normal heights have to be corrected due to land uplift.

2.6.2. Mathematical Methodology

The ellipsoidal height h^z of a point P with latitude φ were computed from its non-tidal ellipsoidal height h^n from (Equation 2.14) [Lyszkowicz et al., 2015].

$$h^Z = h^n + h\,(0.099 - 0.296^2\phi) \qquad (2.14)$$

where h is a const ≈ 0.61 describes the elastic response of Earth to tides. A zero-tidal physical height H^z at P computes from H^n in the non tidal system from (Equation 2.19):

$$H^Z = H^n + (K-h)(0.099 - 0.296\sin^2\phi) \qquad (2.15)$$

In addition to h the constant number k ≈ 0.30, is needed for this transformation. Height anomalies ζ were computed from the EGM2008 non tidal model at the points of the POLREF, EUVN-DA, and ASG-EUPOS networks.

The normal heights were corrected due to land uplift. Next the ellipsoidal heights and normal heights at satellite networks points were reduced to the zero tidal system. From corrected data the differences were computed, where h_i and H_i are corrected ellipsoidal and normal heights.

$$\boldsymbol{\Delta}\zeta_i = (h_i - H_i) - \zeta^{EGM2008} \tag{2.16}$$

$$\boldsymbol{\Delta}\zeta = \zeta^{GPS} - \zeta^{EGM2008} \tag{2.17}$$

The unknown parameter ΔW was computed from the set of n observation equations as:

$$\frac{1}{\gamma_i}\boldsymbol{\Delta}\mathrm{w} = \boldsymbol{\Delta}\zeta_i + v_i \tag{2.18}$$

For each satellite network separately. This solution was called solution#1. Due to several systematic errors affected the estimated parameter ΔW (Equation 2.18) was extended with additional (nuisance) parameters **x** and the vector of coefficients $\mathbf{a_i}$ dependent on the spatial points position.

$$\frac{1}{\gamma_i}\boldsymbol{\Delta}\mathrm{w} + a_i^T\,\mathrm{x} = \boldsymbol{\Delta}\zeta_i + v_i \tag{2.19}$$

This study in Poland uses only a simple model where the trend is modeled by a plane, i.e.

$$a_i^T\,x = x_1(\phi_i - \phi_0) + x_2(\lambda_i - \lambda_0)\cos\phi_i \tag{2.20}$$

where the plane inclination in the N–S direction is represented by the parameter x_1 and in the W–E direction by the parameter x_2. The coordinates ϕ_0 and λ_0 are the coordinates of the center of the area. This solution was called solution#2.

2.6.3. The Results

In this study, to compare normal and ellipsoidal heights, the normal heights have to be corrected by reason of land uplift where the model of land uplift used for this reason, as well as the deformations caused by the permanent tide should be removed in levelling and satellite networks.

- The value of parameter **Δ**W calculated for three networks based on ellipsoidal heights from satellite observations, quasigeoid separations computed from the EGM2008 model and normal heights obtained from the adjustment third levelling campaign are significantly different and change from 0.16 to 0.61 m^2s^{-2}. There is significant discrepancies still exist between the values **Δ**W estimated from three different satellite networks. It means that the described method strongly depends on the used data [Lyszkowicz et al., 2015].

- The average correction of such transformation between the non tidal system and zero tidal system was in order of -2.5 cm, while the largest correction is -4.4 cm and the smallest is -1.2 cm.
- Levelling heights of POLREF points were corrected due to land uplift in average about -4.1 cm, heights of EUVN-DA points about -5.0 cm and heights of ASG-EUPOS point about -5.3 cm. The statistical results depend on 328 points in POLREF, 57 points in EUVN-DA and 93 points in ASG- EUPOS known for them height anomaly from GPS and EGM2008, and the mean linear displacement between surfaces varies from 6 cm to 1.5 cm [Lyszkowicz et al., 2015].

CHAPTER (3)

THE CURRENT STATUS OF VERTICAL DATUMS IN ARAB REGION

Introduction

This chapter presents the current status of vertical datums in the Arab region, and the available data for each one.

The uses of various datums cause inconsistent heights across the border between the countries and the topographic height data from them. Using more than one vertical reference is yielding not only misalignment of the datums to the best known global geoid about 1–2 m accuracy, but also local uplift and subsidence issues which may significantly exceed 1–2 m in extreme cases. At the present time, the GNSS provides the ellipsoidal height about 1–2 cm accuracy globally [Smith et al., 2013].

The current uses of inaccurate vertical datums are no longer serve the purpose they once did. It is possible to have inconsistent heights along the borders due to the changes in the realization of the different systems. To avoid discrepancy, it is in the interest of both countries to have a united, seamless, and highly accurate vertical datum. So it was assembled all the data available in each of the Arab country until we can show an idea to unify the vertical datums in all the Arab countries. The currently available data for vertical datums in the Arab world can be displayed as follows.

3.1. The Vertical Datum in Egypt

In the Arab Republic of Egypt there are approximatly six tide gauge stations (Port Said, Alexandria, Suez Canal, Marsa Matroh, Ras El-Bar and Burullus) distributed in some parts of Red Sea and Mediterranean Sea for many purposes such as navigation, ships, hydrographic survey and weather

conditions, but the vertical datum has been set as the Mean Sea Level (MSL) at harbor of Alexandria (Figure 3.1) shows the tide gauge location [Shaker et al., 2005].

It was taken as the daily mean readings between the high and low water level during 1898 to 1906. These were the only available recorded data when the survey department undertook the levelling in 1906 and Tides are recorded by the Hughes mechanical tide gauge located within the Harbor (31° 11’ N, 29° 52’ E) [El-Geziry and Radwan, 2012].

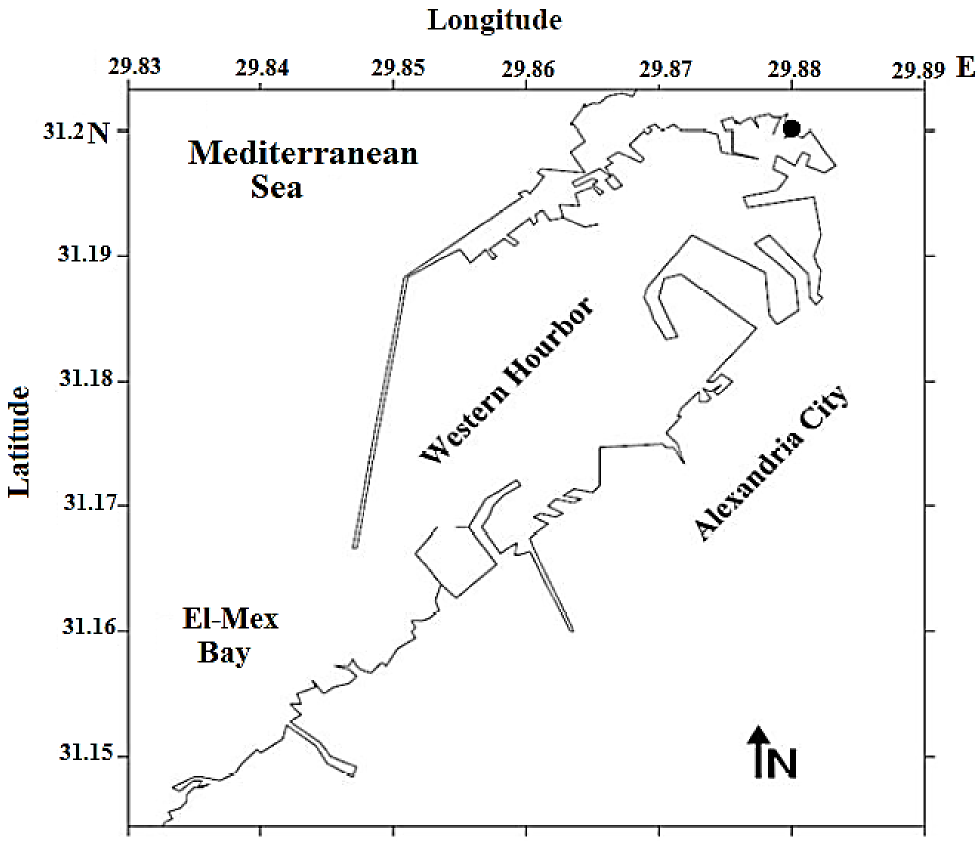


Figure (3.1): Alexandria Western Harbour and location of tide gauge use ●

[El-Geziry and Radwan, 2012].

3.1.1. Historical Background and Status of the Egyptian Control Network

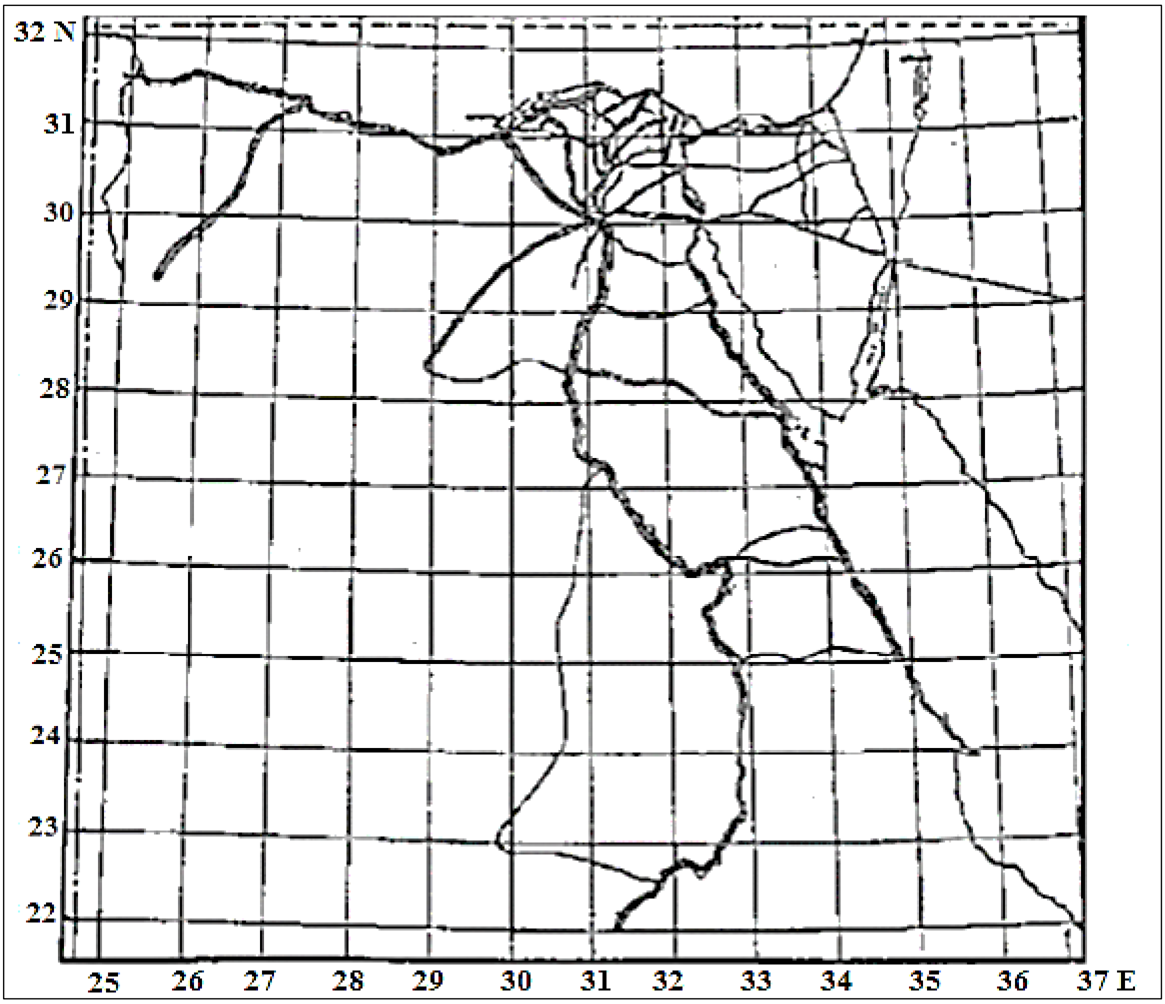
The first order levelling net in Egypt was built on successive sections

through several years since 1906. The levelling loops and lines, which were firstly measured, computed and corrected were considered and finally adjusted. Thus, when some benchmarks were used for any extension of subsequent loops or lines, no corrections were applied to the previously established points. So the closing error of the new loop affected only the new measured heights. In case of closure error, it was linearly distributed to the points forming the new loop proportional to the distance from the first benchmark to the benchmark to be computed.

In the years 1906 to 1912 the first network of precise levelling was established in Egypt by the survey of Egypt, to establish fundamental benchmarks over the whole country. As in (Figure 3.2), there are 11 closed loops from network covering the whole area of the delta, and two single lines joining this network to Alexandria and Suez [Saad, 1993].

The Suez Canal Company (SCC) have established two Mareographs at both Suez and Port Said, the recorded observations gave values of MSL as 18.274m and 18.045m at Suez and Port Said respectivly relative to the SCC's own levelling datum in the period 1923-1937. Therefore, according to the Surveying vertical datum, it was established that the MSL at Suez, Port Said and Alexandria are 0.226m, 0.011m and 0.050m respectively.

In 1925, the original line which joined Alexandria with the network was recomputed. It was existed that a blunder error of 50 mm had been made between two benchmarks by that time. In 1936 it had been formed a network from 32 closed loops covered the whole Delta. The levelling routes had also arrived to Wadi Halfa, the southern boundary of Egypt over 1000 kilometers south of Cairo as (Figure 3.3) [Mohamed, 2005].



——— Levelling lines

▬▬ Levelling lines with gravity measurement

Figure (3.2): The first order Levelling Network of Egypt [Saad, 1993].

From 1962 to 1966, the variation on MSL have been studied in Alexandria to investigate the effect of pressure and wind speed, the result was that the new MSL is 45 cm above the gauge zero.

In 1969, the Egyptian Survey Authority (ESA) began an experiment to establish the vertical datum at Marsa Matroh and El-Saloom. Determination of MSL has been carried out using the mean of two-hour readings of sea level for 1969 and 1971[Mohamed, 2005].

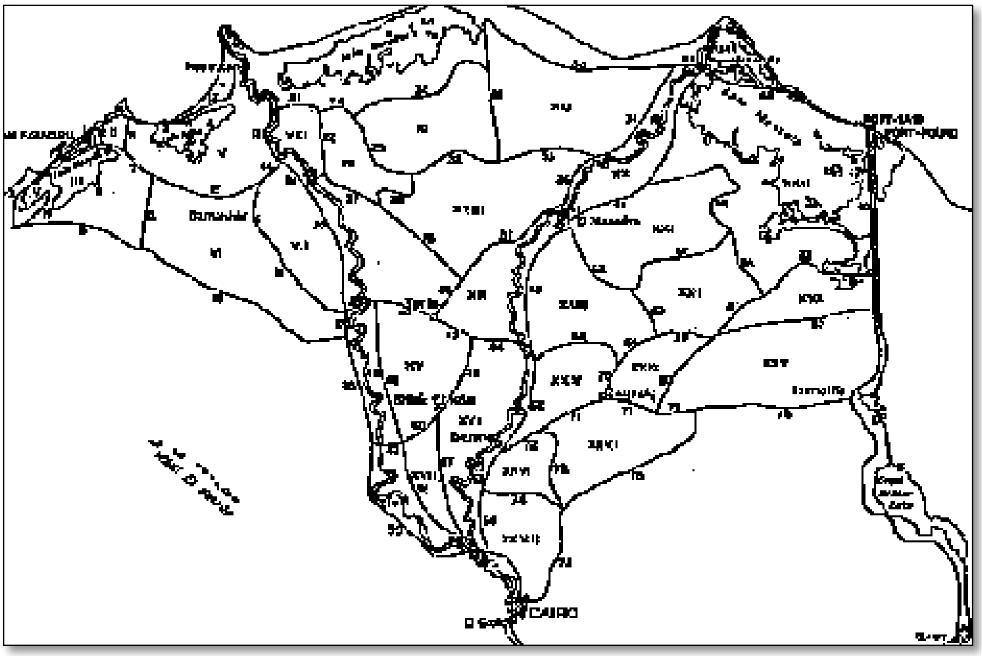


Figure (3.3): The levelling network in the Delta 1936 [Mohamed, 2005].

The ERS-1 satellite altimetry data has been utilized in an attempt to model the variations of the Sea Surface Topography (SST) in both Mediterranean Sea and the Red Sea area. SST values enable the study of sea water variation between the instantaneous water level and an adopted geoid model. The results of that investigation show that the values of SST in Mediterranean Sea range between –1.0m and 1.0m, with a zero value at an average latitude 32.5^0 while the corresponding values in the Red Sea range from-1.0m and 2.0m, with a zero value at Port Said is 25 cm relative to the Alexandria tide datum.

Another study for modeling SST based on a technique called zero-frequency response has been carried out using real data of recorded MSL readings of three tide gauge stations. The span of the data used are (1950-1989), (1925-1946), (1923-1937) for Alexandria, Port Said, and Suez tide station respectively. The study shows that SST values at Port Said and Suez are -8.4cm and 24.6 respectively relative to the Alexandria tide datum. A

comparison between results of both mentioned studies reveals that there is a difference of 16 cm between SST values at Port Said [Mohamed, 2005].

The results show that the use of more than one tide gauge with appropriate weights, distributed along the Red Sea and Mediterranean Sea coasts, caused a significant improvement overall accuracy of the Egyptian levelling network, as opposed to the considering only one tide gauge fixed or weighted.

3.1.1.1. Gravity Measurements in Egypt

In 1913, Helwan observatory observed four absolute gravity stations were located in Helwan, El-minia, Luxore and Aswan, the value of these stations were connected with the values of Kew (London). In 1914, the network was extended to southwards into Upper Egypt as a single line that reaches Aswan. In 1937, more absolute measurements were made at Port Said, port Tewfik and at the southern end of the Suez Canal. In 1951, other 21 gravity measurements were made at various parts of Egypt as a part of the world wide gravity base network, which has been linked to Potsdam international base net [Saad, 1993].

In 1971, the international Gravity Standardization Net (IGSN) had replaced the postdam system. There are 11 stations of the IGSN-71 which have been measured in Egypt. In August 1971, the International Gravity Standardization Net (IGSN-71) was introduced as the new global gravity reference system. The network contains 473 primary stations eight of them are absolute stations. The eighty six instruments utilized in the net are divided into three main categories: three absolute devices; six Pendulum instruments; and five gravimeters' types. The absolute data provided the datum and contributed to scale, the pendulum data contributed to scale and the gravimeter data gave the basic structure of the net. Approximately 25,000 observations are included in processing the IGSN-71. The standard errors for

the net’s gravity values are less than 0.1 mgal. As a part of the IGSN-71 activities, eleven gravity stations have been measured in Egypt (Figure 3.4) with standard deviations range from 0.024 to 0.035 mgal [Dawood, 1998].

In 1978, the general petroleum company established 60 gravity base stations through the country. The Egyptian vertical datum and the existing problems regarding the vertical control networks has attained a great attention in the geodetic community. Several investigations have been performed to study some items concerning these circumstances in Egypt. Using real or simulated data.

The NGSBN-77 consists of 66 stations and has tied to IGSN-71 stations located at Cairo International airport, Helwan observatory, Luxor, Aswan, and Port Said. The network’s 624 gravity observations have been carried out using two Worden gravimeters which have a sensitivity of 0.01 scale units. Most of the network’s stations have been tied to the triangulation networks to determine their horizontal coordinates (latitude and longitude) and their vertical position (elevations above MSL) by means of tachometry. The coordinates of about twenty stations located at inaccessible areas, in the western desert and Sinai, were interpolated from topographic maps. Stations located in remote areas in the western desert were conducted using aircrafts. The mean square errors for the observations range between 0.04 - 0.47 mgal. A final adjustment of the data has standard deviations of the gravity values ranging between 0.02 - 0.13 mgal [Dawood, 1998].

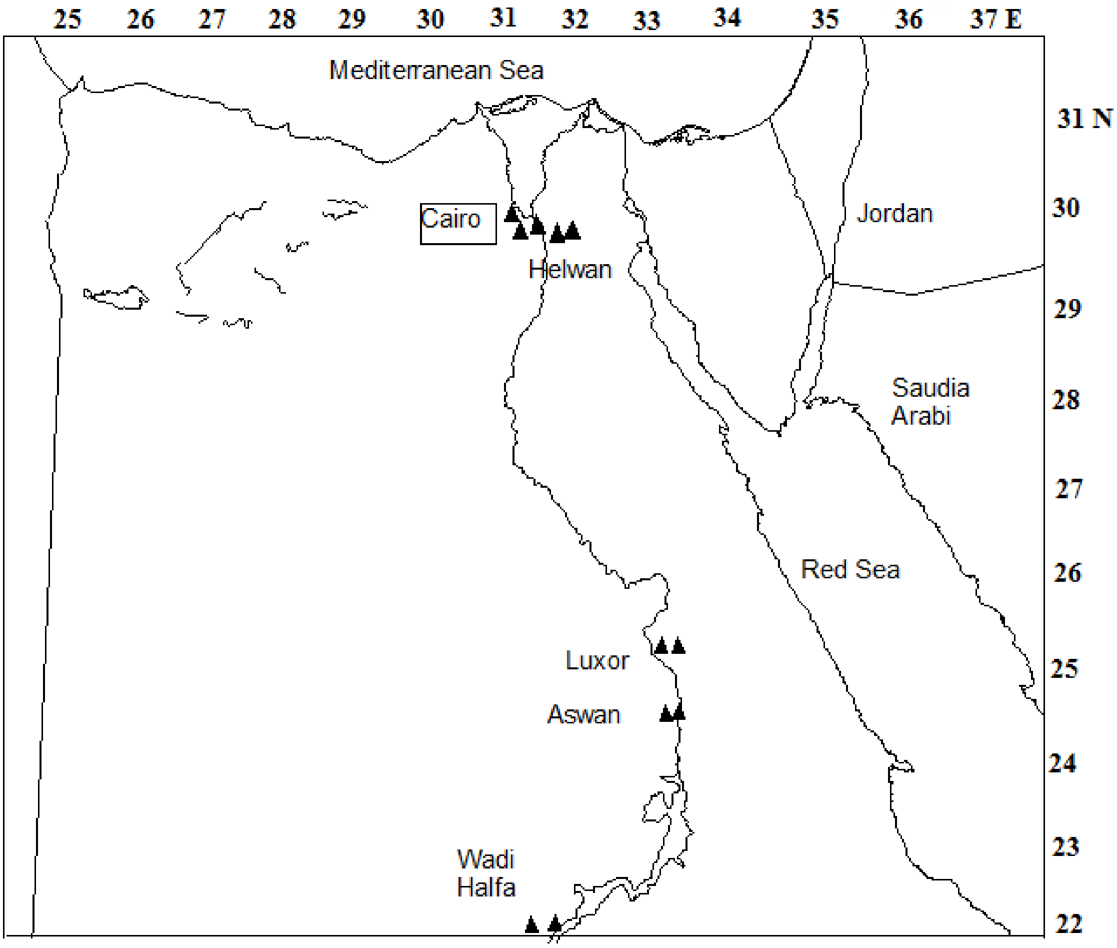


Figure (3.4): The International Gravity Standardization Net (IGSN-71) points [Dawood, 1998].

3.1.1.2. The Egyptian Survey Authority (ESA) Gravity Measurements

The Egyptian Survey Authority (ESA) has carried out some gravimetric surveys along the first order levelling lines concentrated in the Northern part of Egypt using Worden gravimeters. The main gravity loops observed by ESA (during the 70's) are;

- A loop from Giza to the mid of the Cairo-Alexandria desert road consists of 15 gravity observations at bench marks.
- A loop from Giza - Korimate - Ras Gharib - Shikh Fadl - Giza extending about 760 km and contains 72 gravity stations.

- A loop from Shikh Fadl - Ras Ghareb - Qena - Shikh Fadl contains 112 gravity points over 1046 km total distances. ESA is usually conducting several gravity missions needed to compute the required corrections for the first-order levelling routes.

3.1.1. 3. Other Gravity Measurements in Egypt

Several other organizations in Egypt conducted gravity missions for special purposes. The National Research Institute of Astronomy and Geophysics (NRIAG), for example, has observed several small gravity networks as a part of complex geodetic networks serve for the detection of crustal deformation. Most of these loops are concentrated in the active crustal movement Zone of Aswan Lake. The Egyptian National Gravity Standardization Network (ENGSN97) has been established by the Survey Research Institute (SRI). The ENGSN97 consists of 5 absolute gravity stations and 145 high-precision relative gravity stations. The locations of these sites have been selected to cover the largest portion of the Egyptian territory at Giza, Helwan, Marsa Matrouh, Aswan, and El-Kharga (Figure 3.5). The measurements have been carried out using the absolute gravimeter of 0.0011 mgal. And the other points by relative gravimeters. There are 52 stations with observed GPS Undulations (ENGSN-97) after [Dawood, 1998].

The distribution of the available free-air gravity anomaly stations on land for Egypt is very poor, concentrated mainly along the Nile valley. Many areas are empty. The values of the free-air gravity anomalies range between -190.51mgal and 294.74 mgal with an average of -3.28 mgal and a standard deviation of about 60.36 mgal. Highest values are in sea area [Salah, 2008].

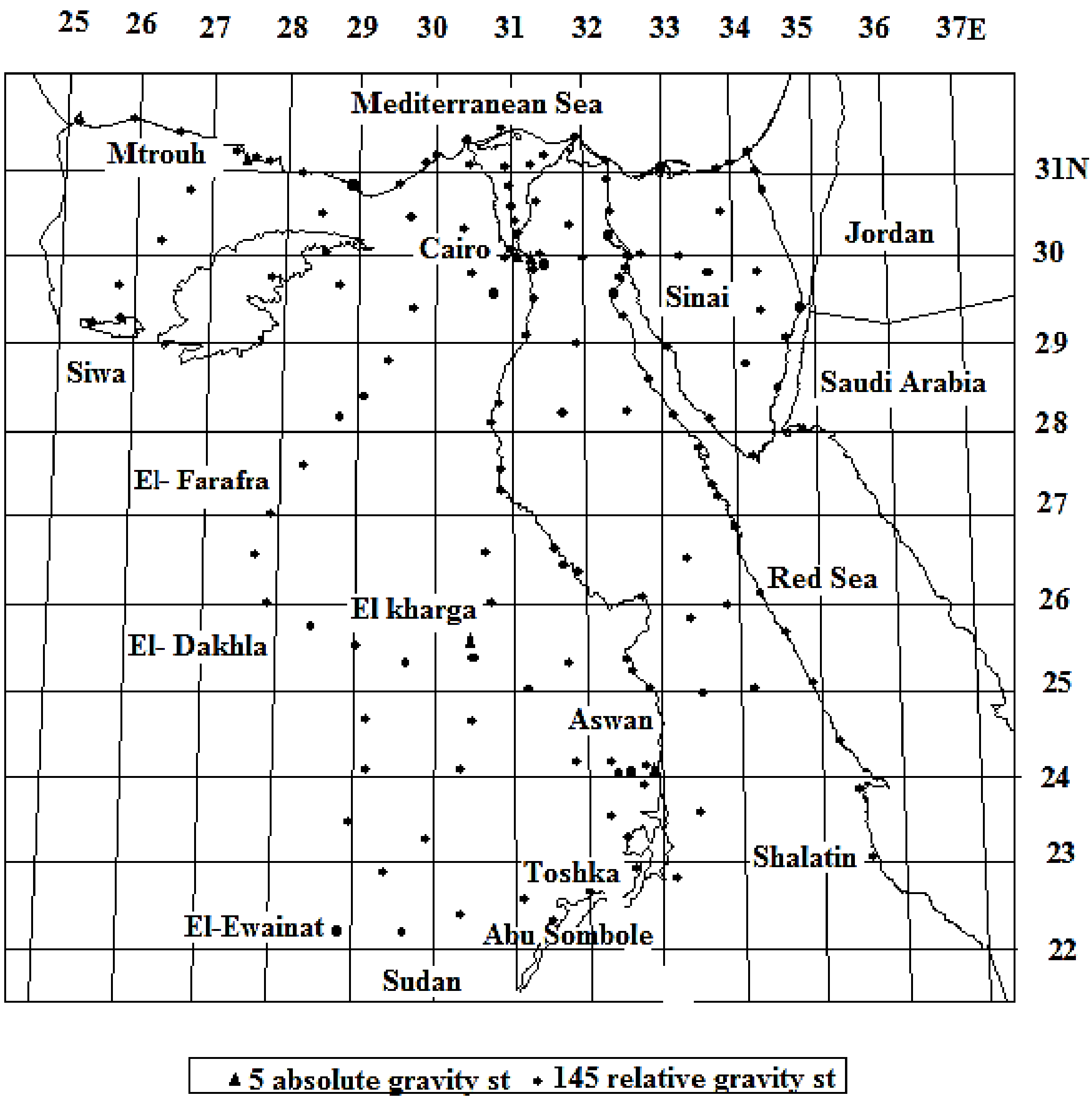


Figure (3.5): The Egyptian National Gravity Standardization Network (ENGSN97)[Dawood, 1998].

In 2009 the gravimetric data distribution in Egypt as in (Figure 3.6) 150 points from ENGSN97 Network and 988 older gravity points.

The HARN network consists of 30 stations, only 15 points have observed real orthometric heights, and consequently true geoid undulations as in (Figure 3.7) [Dawod and Mohamed, 2009]

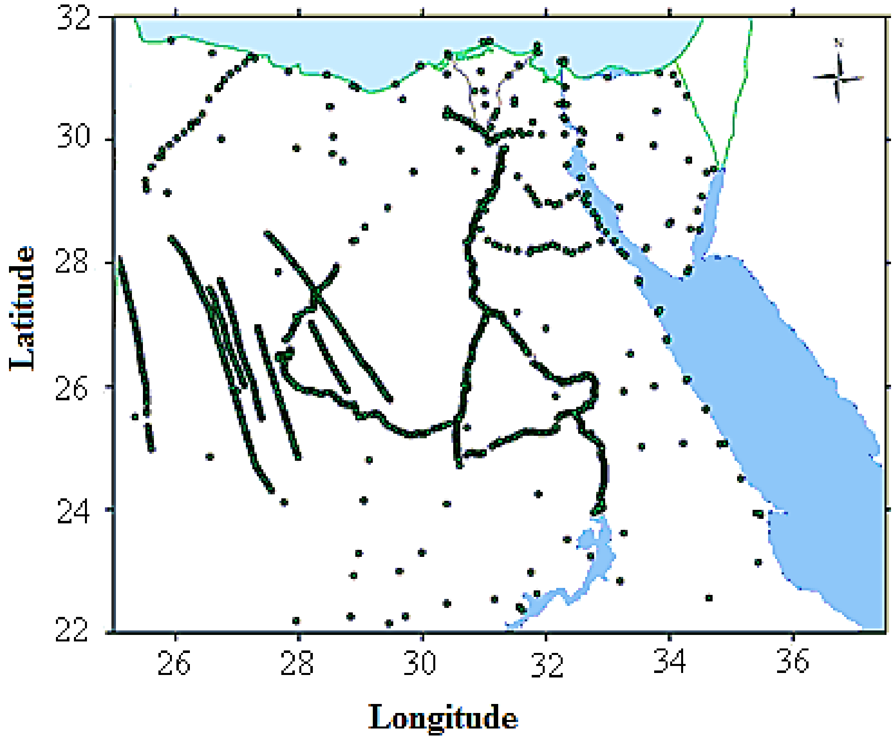


Figure (3.6): Available local gravity stations in 2009 [Dawod and Mohamed, 2009].

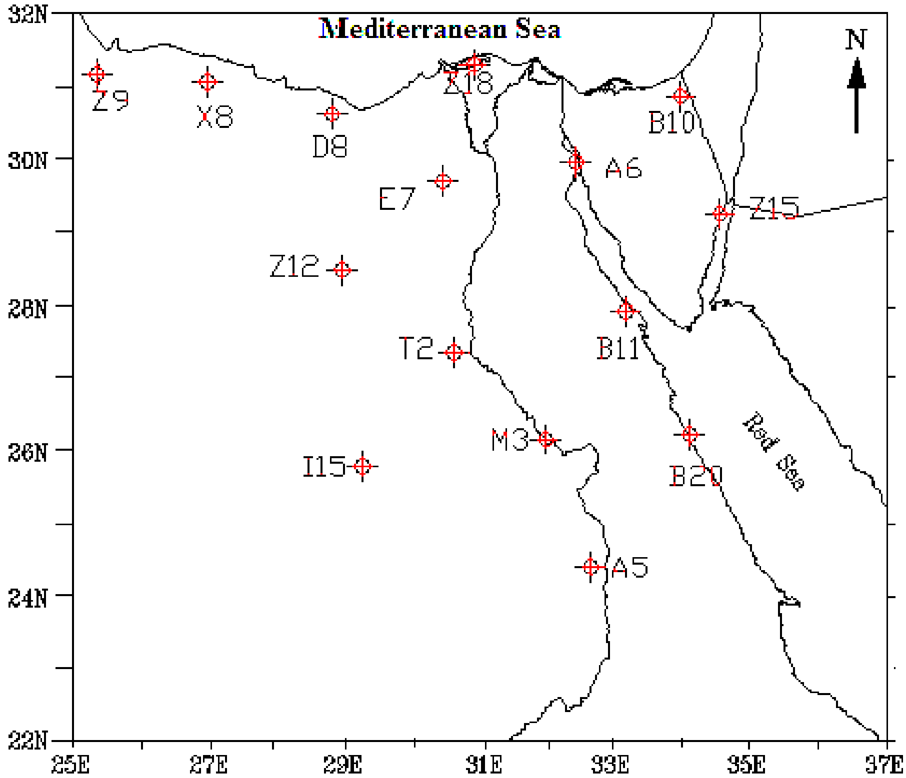


Figure (3.7): Available stations with known geoid undulations [Dawood and Mohamed, 2009].

In 2012 there are 394 available points with observed geoid undulation in Egypt as in (Figure 3.8).

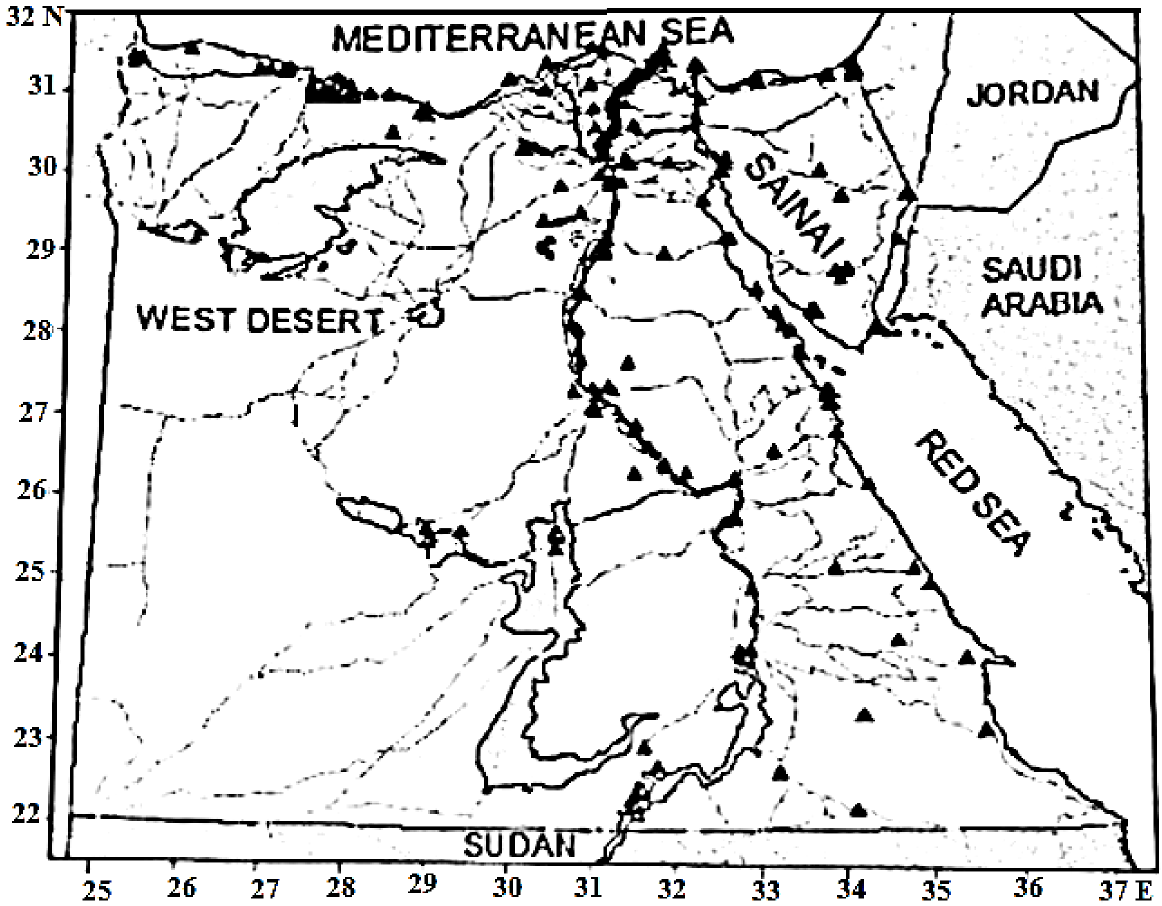


Figure (3.8): Distribution of the ▲ 394 available points with observed geoid undulation in Egypt [Salah, 2008].

3.1.2. GPS Network in Egypt

In 1995, two national GPS geodetic control networks have been established, by the Egyptian Survey Authority to furnish a nationwide GPS skeleton for surveying and mapping applications. The first network is the High Accuracy Reference Network (HARN) that covers the entire Egyptian territories and consists of 30 stations with approximate separation of 200 km. The relative precision level of HARN is 1:10,000,000. The second network is the National Agricultural Cadastral Network (NACN) that mainly covers the Nile valley and the Delta. NACN consists of 112 stations, with a station

separation of 50 km approximately, whose relative precision is 1:1,000,000. Both networks are depicted in (Figure 3.9) [Rabah and Kaloop, 2011].

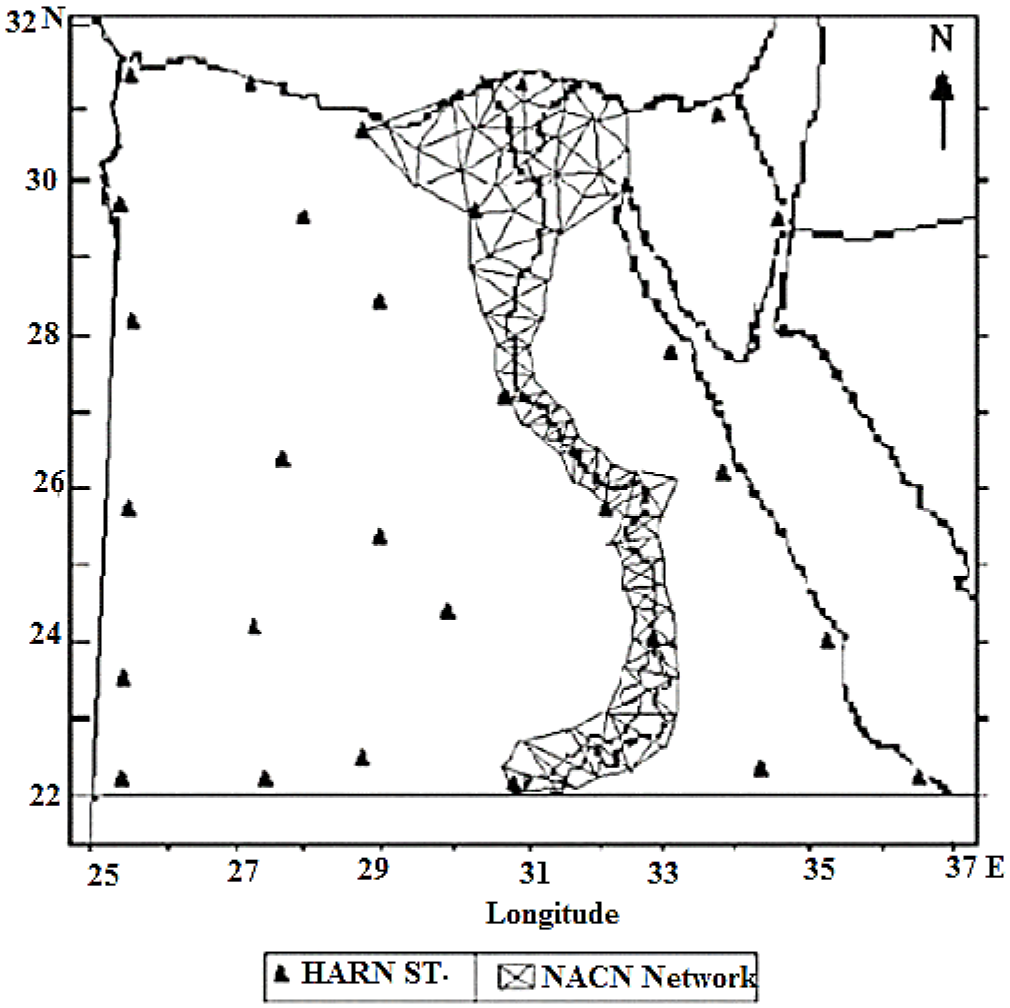


Figure (3.9): The HARN and NACN networks

[Rabah and Kaloop, 2011].

3.1.3. The Global Geo-potential Model in Egypt

The recent development of a space gravimetry carried out by the satellite missions Challenging Mini satellite Payload (CHAMP 2002), Gravity Recovery and Climate Experiment (GRACE 2002), and Global Ocean Circulation Experiment (GOCE 2009), provide accurate data that are routinely inverted into spherical harmonic coefficients of the Geo-potential forming a Global Geo potential Model (GGM), which describe the Earth

shape. Several Earth Geo-potential Models (EGMS) are released and covering the whole world.

Twenty-five of recent and old Global Geo-potential models released between 1996 and 2008 are tested. EGM2008 is the best one to fit Egypt among them with degree and order 2160 and from the old generation of GGM's models ELGEN-05C has degree and order 360 [Salah, 2012].

3.2. The Vertical Datum in Sudan

In Sudan, according to the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (ROCERSGA), the float tide gauge was deployed in 1961 in the Port Sudan station latitude 19°37 '27‟N and longitude 37°13'25‟E [Bakry, 2010].

3.2.1. GPS and Levelling Network in Sudan

In a project, GNSS/levelling data at 19 stations distributed over the area of Sudan (Figure 3.10). The heights of those stations have been determined by spirit levelling referred to 1st order, 2nd order, and 3rd order vertical control which is defined in the normal orthometric height system based on normal gravity. They are referred in this study as orthometric heights. Ellipsoidal heights of those stations were obtained from GNSS survey conducted in 12 h observing sessions in the framework of several geodetic projects between 2005 and 2008. The estimated accuracy of the GNSS/levelling was 0.1 to 0.5 m [Godaha and Krynski, 2013].

3.2.2. The Global Geo-potential Model in Sudan

Since 2010, a series of Global Geo-potential Models (GGMs) based on Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) satellite gravimetry mission have been released. In special study, the GGMs based on approximately 12 months of GOCE satellite gravity gradiometry

(SGG) data have been compared over the area of Sudan with the EGM2008 and terrestrial data.

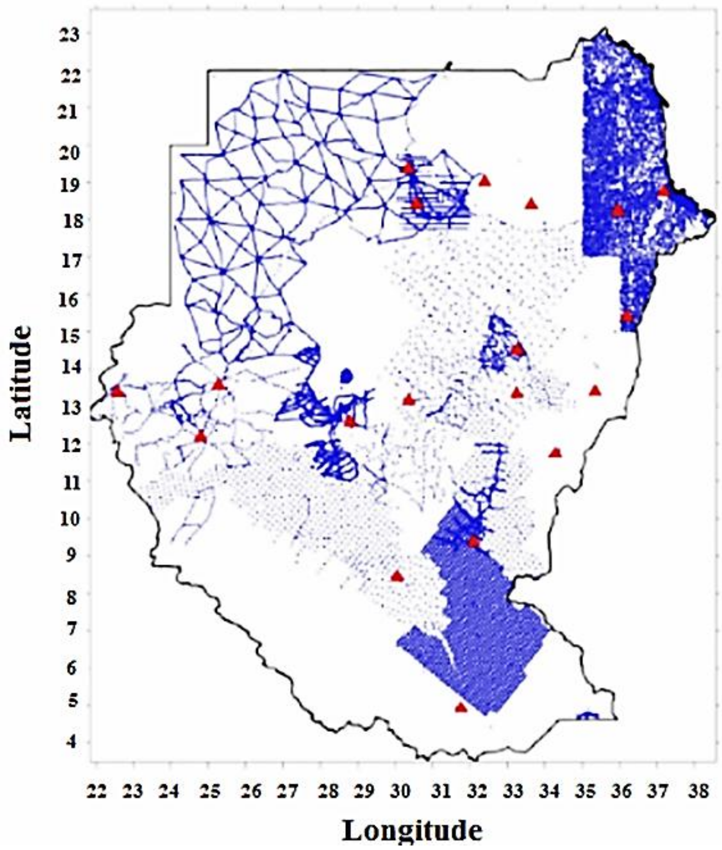


Figure (3.10): Distribution of original GETECH point gravity data (dots), and GNSS/levelling stations (triangles) [Godaha and Krynski, 2013].

Geoid heights and free-air gravity anomalies from four GOCE/GRACE satellite-only GGMs, and one GOCE/GRACE GGM combined with terrestrial/altimetric gravity data were compared with the corresponding ones obtained from the EGM2008, terrestrial free-air gravity anomalies and GNSS/levelling data. The results reveal that geoid heights and free-air gravity anomalies obtained from the GOCE-based GGMs agree with the corresponding ones from the EGM2008 truncated to d/o 200 with standard deviation of 18–20 cm, and 3.4–4.2 mgal, respectively. Their agreement with the terrestrial free air gravity anomalies and the GNSS/levelling geoid heights, in terms of standard deviation is about 5.5

mgal, and about 50 cm, respectively. The distribution of original GETECH gravity data, and GNSS/levelling stations in Sudan shows in (Figure 3.10) [Abdalla, 2009].

3.3. The Vertical Datum in Djibouti

In Djibouti there is one tide gauge station, vertical datum is the mean sea level at Djibouti harbour with latitude11°36 '48‶ E and longitude 43°08'28‵ N. Three Bench Marks are located around the harbour basin. The tide pole has been changed by a new one fixed in the south-east corner of the harbour basin.

For studying rifting processes along Tadjoura-Asal rift system sits on dry land in the Afar depression near the triple junction between the Arabia, Somalia, and Nubia plates, geodetic measurements were made during the period from 1978 to 2003. The surveys used triangulation, trilateration, levelling, and the Global Positioning System (GPS) [Sammari, 2004].

3.3.1. GPS Network in Djibouti

A network of about 30 GPS sites covers the Republic of Djibouti and additional points were also measured in Yemen and Ethiopia as in (Figure 3.11 and 3.12) shows some of these points [Sammari 2004 and Simon, 2007].

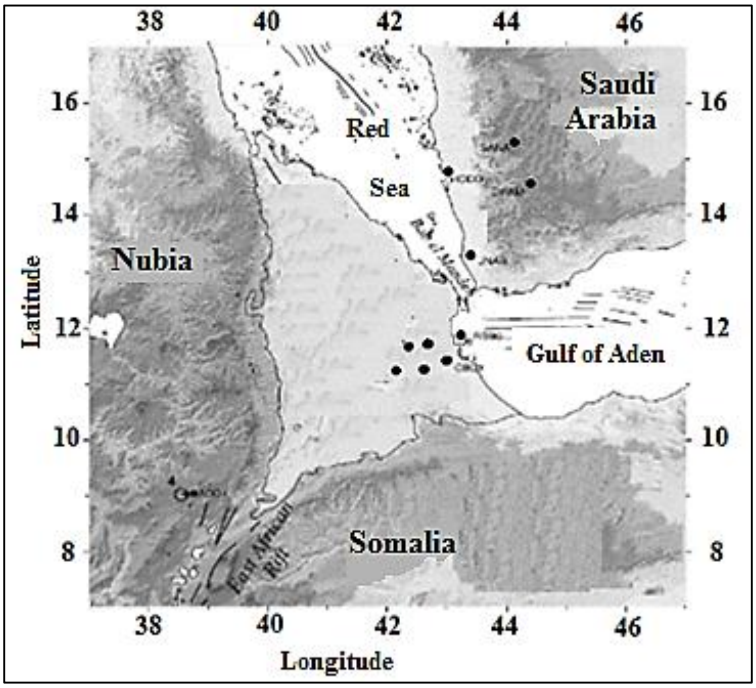


Figure (3.11) Triple junction and Afar depression. Dots show locations of GPS stations [Vigny et al., 2007].

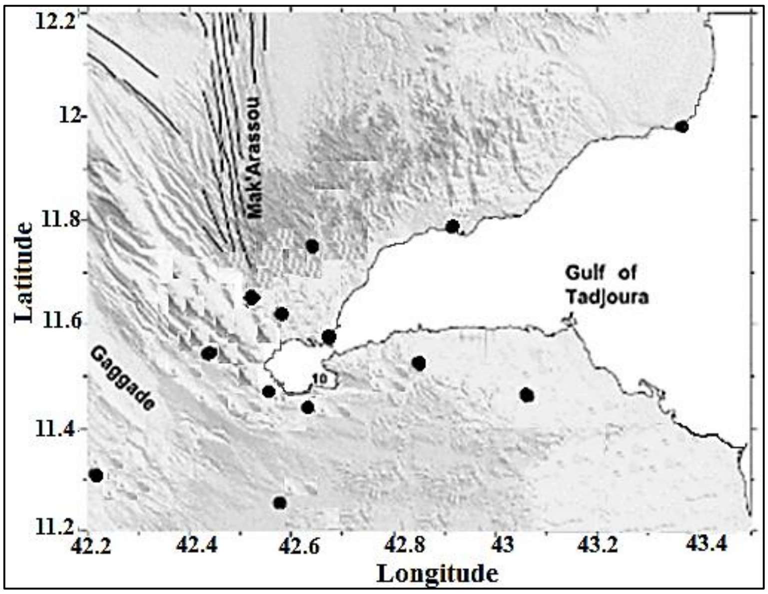


Figure (3.12) Djibouti and Gulf of Tadjoura. Dots shows locations of GPS stations [Vigny et al., 2007].

3.4. The Vertical Datum in Somalia

In Somalia, there are two tide gauge stations at Mogadishu and Hafyn harbor but the vertical datum is the mean sea level at tide gauge station in Mogadishu at 2°1 'N and 45°20 'E [Vigny et al., 2007].

3.5. The Vertical Datum in Emirates

The geodetic vertical datum in Emirates has been set as the Mean Sea Level (MSL) at Dubai harbor with latitude 13° 47′ 27″N, and longitude 50° 40′ 44″ E [Mohammed et al., 2011].

3.5.1. History of Dubai Vertical Datum

In 1954, first vertical datum was established in Dubai in the creek area for development works. Which was defined at a point 4.44 m. below a benchmark cut in the eastern door pillar of the petroleum development in coast house of Dubai. That Datum was established by the British Royal Navy with respect to a point 1.65 m. below a brass plate embedded in a concrete block situated in the northeast corner of the Imperial Airways enclosure at Sharjah State [Mohammed et al., 2011].

The estimated Lowest Astronomical Tide for the open sea at Dubai was computed with the help of Admiralty Tide Tables of the creek and with respect zero datum (chart datum) established 2.83 m below the specified benchmark. In 1959, an automatic Tide Recorder was setup with respect to the reference level from the benchmark previously mentioned for creek development works. Tidal readings were observed by this recorder between 1959 -1961. This tidal information was forwarded to the Admiralty in January 1960 for the calculation of Harmonic Constants. The Admiralty informed that the Halcrow's datum was approximately 30 cm below the Admiralty Chart Datum for Creek [Mohammed et al., 2011].

In 1967, with the commencement of construction of Port Rashid an automatic tide recorder was set on the Sheikh Ahmad Jetty in Jumeirah. The reference level for this Tide Gauge was also derived from the Creek benchmark by direct levelling. This automatic tide recorder was changed in 1968 to a rotary type level and set to read on a 32 hourly basis. The tidal information obtained from this gauge during the period 4th May 1968 to 17th

June 1968 was sent to the Admiralty. In August 1968, the Admiralty approved this datum as an Admiralty Datum for the open sea in Dubai.

In 1974, it became necessary to adopt a new metric system instead of the old feet system for Admiralty Charting, and hence the value of the benchmark was changed to +3.05 Meters. Subsequent tidal analysis during the period from 1972 to 1977 indicated that the difference between the Halcrow datum and predicted Lowest Astronomical Tide is less than 10 centimeters.

In 1978, submitted the details of Bench Mark No.001 (Federal Bench Mark, which was established at Port Rashid) to Dubai Municipality. The Survey Section of Dubai Municipality decided to accept that value and a loop of precise levelling was done from Port Rashid in Bur Dubai along the whole creek to Ras Al Khor and back to Deira and closing on the same Bench Mark (001) at Port Rashid within an accuracy of 4mm $\sqrt{\mathrm{K}}$, where K is in Kilometers. Every time loops were observed as double tertiary levelling (12mm$\sqrt{K}$), assuming the Bench Mark No. (001) has the same known level. The Benchmark (No.001) was destroyed in 1979 due to the construction and development activities at Port Rashid [Baqer et al., 2011].

During 1978 to 1982 The Survey Department of Dubai Municipality had transferred the level from Bench Mark No.001 at Port Rashid to Mina Jabel Ali by direct levelling and established a Tidal Bench Mark called A100 at Mina Jabel Ali. About 6000 Bench Marks in whole Emirate of Dubai were interconnected, and water levels from an established tide recorder at Maktoum Bridge (on the Creek) were observed.

During 1986 to 1992 water levels at Mina Jabel Ali were measured by the Local Port Authority. But in 1991, tide data of Mina Jabel Ali was analyzed by WIMPEY Environmental Company based on one-month tidal observations.

In 1993, Netherlands Engineering Consultants (NEDECO) carried out Tidal analysis based on the tidal observation taken during June 1988 to October 1989 at Mina Jabel Ali [Mohammed et al., 2011].

During 1994 to 1995, Again water levels observed at Mina Jabel Ali, by the Local Port Authority were analyzed by the Admiralty. In 1997, Martin Mid-East LLC (a private company engaged in Marine and offshore surveys), was contracted by Mouchel International to undertake a tide monitoring survey for four years along the coast of Dubai. In 2001, Jabel Ali Tide Pole was calibrated by the Port Authority and Cowi Almoayed Company.

In 2004, Dubai Municipality had established five tidal-meteorological stations along the coastal area finalize the discrepancies existed between different datums. The Survey Section of Dubai Municipality established a network of five fully automated Tide/Meteorological Stations along the coastal side of Dubai Emirate and started monitoring continuous Tide Meteorological data collected from all these stations for establishing a precise vertical datum for Dubai Emirate. Tidal Datums are based on water level observations related to a land reference mark (Benchmark) from a water level measurement system (Tide gauge). The tide data from the five fully automated tide stations made possible for the determination and maintenance of a well defined marine Vertical Datum for Dubai Emirate.

The data collected from the Tide/Meteorological stations. Which includes Mean Sea Level, Lowest Astronomical Tide, Highest Astronomical Tide, Tidal Constituents, Tidal and Tidal Stream Predictions and Meteorological data such as Wind Speed, Wind Direction, Humidity, Visibility, Air temperature and Water Temperature.

Five sites along the costal sides of Dubai are selected for establishing the fully automated Tide/Meteorological stations. The sites are so selected by the Dubai Municipality, that they cover evenly the coastal area as well the creek area of Dubai Emirate. The five long term and real time tide and

weather monitoring stations along Dubai coast and creek are established at the following locations [Al marzooqi et al., 2006] .

-Jabel Ali.

-Umm suqim II fishing harbor.

-Hamriya Port.

-Dhow Wharfage inside the Creek area.

-Jadaf (innermost portion of Dubai Creek Area).

3.5.2. The GPS and Levelling Network in United Arab Emirates

The Geodesy and Hydrographic Section of the Survey Department of Dubai Municipality had defined an offshore geoid model and land geoid model for Dubai Emirate in the year 2005 in view of updating the vertical datum of Dubai. A set of approx. 3750 leveled benchmarks with GPS ellipsoidal heights were made available by Dubai Municipality. The GPS data were tied into the ITRF base network of Dubai, and the levelling referred to a fundamental tide gauge at Port Rashid, Dubai. Most of levelling is third order, with some points leveled by trigonometric methods. Many GPS points were repeated RTK measurements (with a 5 cm acceptance limit); while other points in build-up areas were actually determined using classical techniques from nearby GPS points.

The Dubai Geoid model was developed integrating a comprehensive set of gravity measurements with GPS, levelling and digital elevation data. Gravity data used in determination of the Dubai precise geoid consisted of gravity measurements collected at a network of 1 Km x 1 Km covering the whole Dubai Emirate, referenced to three absolute gravity stations. Other available gravity data were also included from marine gravity surveys in the Arabian Gulf (provided by BGI, Toulouse) and KMS-01 gravity anomalies

derived from satellite altimetry. The heights of the gravity points were measured with fast static GPS.

In connection with the gravity observations, a levelling line was observed around the perimeter of the Dubai main area, and GPS observations (for gravity station heights) were done in connection with this. The eastern and southern part of the perimeter levelling line GPS was done using rapid static techniques. However, baselines were relatively short, and it appears that the accuracy was good enough also for geoid use (3-5 cm for most points). The perimeter GPS geoid data have therefore also been used for constraining the final geoid. Dubai Municipality GPS levelling geoid data, and the GPS geoid data from the gravity survey show in (Figure 3.13) [Al marzooqi, 2006].

3.5.3. Dubai Virtual Reference Network (DVRS) and gravity data in UAE

The Dubai Virtual GPS Reference System (DVRS) consists of five permanent GPS stations (Figure 3.14) and a Processing Centre for the processing and distribution of GPS data. The Survey Section of the Dubai Municipality carried out this project. The five permanent GPS stations within DVRS are continuously tracking all visible satellites. They were designed and constructed over the 2001 fiscal year. This network of permanent GPS stations will form the Zero-order geodetic network for the Dubai Emirate and connected to the ITRF epoch 2000. Distribution of gravity data over land and marine area of United Arab Emirates (UAE) (Figure 3.15) [Mohammed et al., 2011].

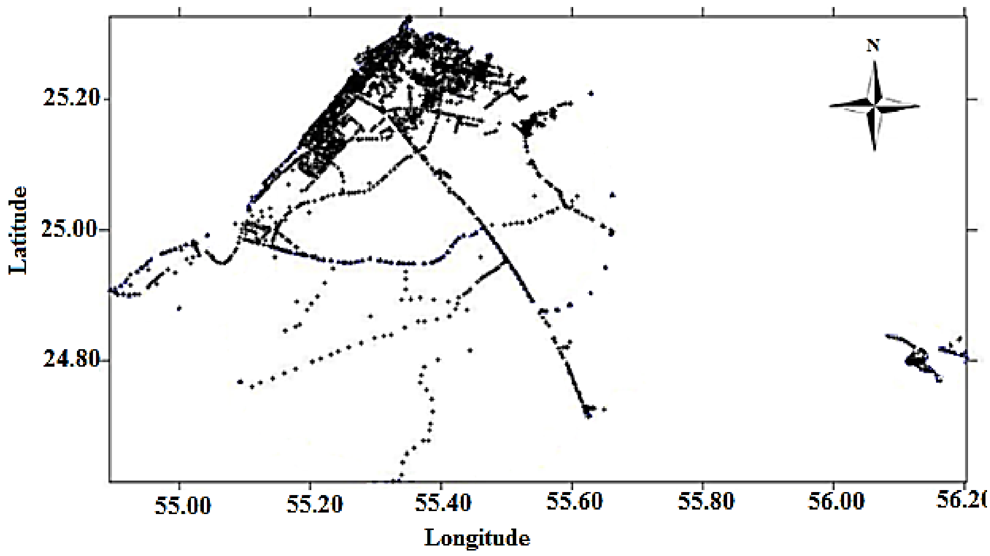


Figure (3.13): Available GPS-levelling geoid data [Mohammed et al., 2011].

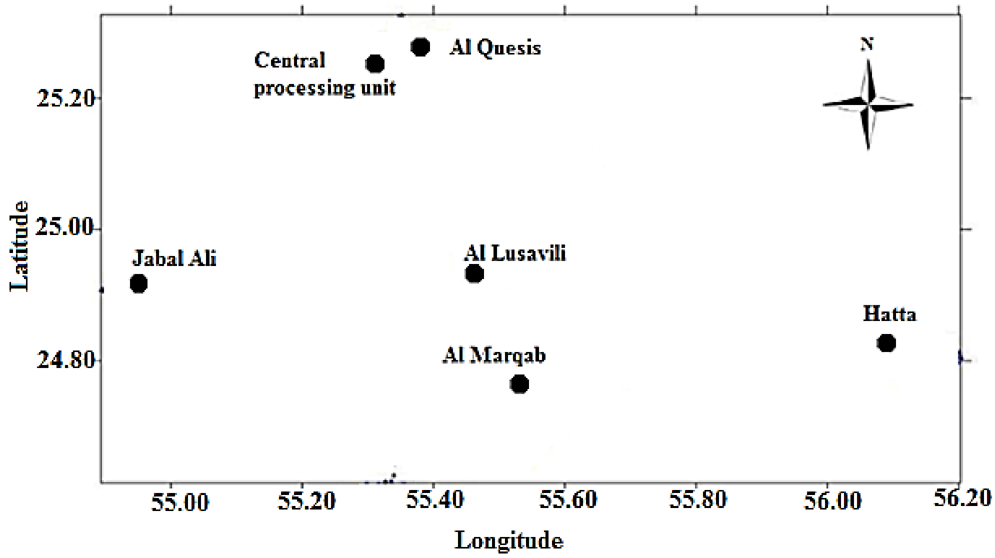


Figure (3.14): DVRS Stations Distribution [Al marzooqi et al., 2006].

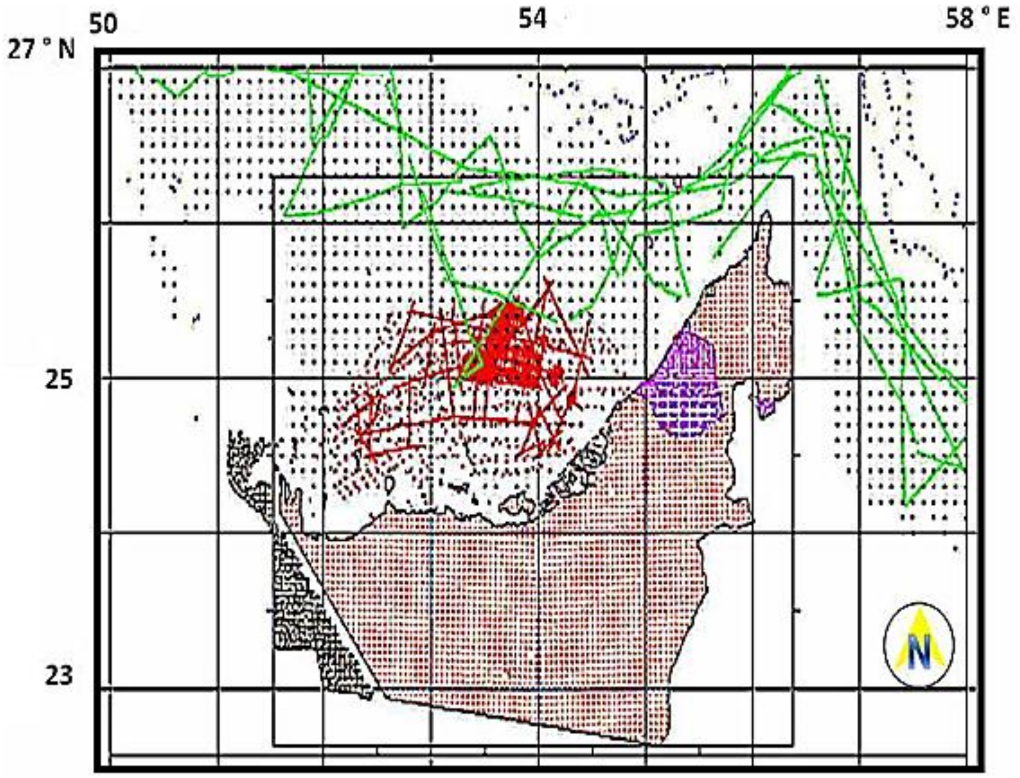


Figure (3.15): Distribution of gravity data over land and marine area of UAE [Mohammed et al., 2011].

3.6.The Vertical Datum in Kuwait

Vertical Datum used in Kuwait is KOC Construction Datum. Where KOC Construction Datum is a vertical datum first defined in 1952 and is suitable for use in Kuwait - onshore. KOC Construction Datum is a vertical datum for KOC survey control and facilities engineering. It was defined by information from Kuwait Oil Company. Approximately 1.52m below MSL. Created for the construction of the Mina al Ahmadi refinery,

Kuwait PWD is suitable for use in Kuwait - onshore. Kuwait PWD origin is Mean Low Low Water (MLLW) at Kuwait City. Kuwait PWD is a vertical datum for Municipality and military purposes. It was defined by information from Kuwait Oil Company. Approximately 1.03m below MSL [http://georepository.com/datum_5186/Kuwait-PWD.html].

3.7. The Vertical Datum in Oman

In Oman, the vertical datum which used is Fahud Height Datum 1993. Fahud Height Datum is suitable for use in Oman - onshore. Fahud Height Datum origin is Single MSL determination at Mina Al Fahal. Fahud Height Datum is a vertical datum for Oil industry mapping. It was defined by information from Petroleum Development Oman Based on reciprocal trigonometric height. Replaced by PDO93 Datum in 1993 is a vertical datum first defined in 1993 and it is suitable for use in Oman - onshore. PDO Height Datum 1993 is a vertical datum for Oil industry mapping.

It was defined by information from Petroleum Development Oman Misclosure between Muscat and Salalah less than 0.5 meters with differences up to 5 meters from old Fahud Datum.

[http://www.georepsository.com/datum_5124/Fahud-HeightDatum.Html]

[http://www.georepsository.com/search/by-name/?query=+Height+Datum +1993.

3.8. The Vertical Datum in Iraq

In Iraq, the vertical datum which used is Faw 1979 Height Datum. Faw 1979 Height Datum is a vertical datum which first defined in 1979 and is suitable for use in Iraq - onshore. Faw 1979 origin is Average sea level at Faw during two-year period in mid-late 1970s. Faw 1979 is a vertical datum for Topographic mapping, geodetic survey. It was defined by information from Survey Division, Ministry of Water Resources (MOWR). Levelling network established by Polservice consortium.

[http://georepository.com/datum_1028/Fao-1979.html].

3.8.1. The Global Geo-potential Model in Iraq

The chosen EGM96 global geoid presented good approximations for the geoid undulation and orthometric height of a small interested area inside

Mosul University. Based on the available data from the GPS receiver and EGM96 global geoid, the obtained average value of the geoid separation of the study area is 15.660m. This value can be used as a correction factor between GPS ellipsoidal height and the orthometric height [Ali, 2007].

3.9. The Vertical Datum in Qatar

The Qatar Vertical Datum is defined as the Mean Sea Level 1970-1972 being 8.004 meters below the Fundamental Bench Mark B (FBMB, Private Mark) located at the north end of the runway at Doha International Airport Station. ID 1962 with Latitude: 25° 17′ 12″ N, and Longitude: 51° 32′ 0″ E (permanent service for mean sea level) [Anaxandrida, 2012].

3.9.1. The Geoidal Model in Qatar

The State of Qatar has defined its own geoid model, Qatar95. It was derived by using the OSU91a geoid model and supplementing it with “known” geoid ellipsoid separations at 71 primary geodetic stations [https://www.scribd.com/doc/99097983/Qatar-Survey-Manual].

3.9.2. Vertical Control Surveys Using GNSS.

GNSS surveys in Qater achieve orthometric height network accuracies of 5 cm and orthometric height local accuracies from 2 to 5 cm, both at the 95 percent [Anaxandrida, 2012].

3.9.3. The Base Stations in Qatar

There are three national spatial reference points, distance between each point and the other is 75km.Three primary base stations, distance between each point and the other is 40km, 20 secondary base stations, distance between each point and the other is 15km and 30 local network stations, distance between each point and each other from 7 km to 10 km [Anaxandrida, 2012].

3.10. The Vertical Datum in Morocco

In Morocco the vertical datum is the mean sea level at Casablanca 1922 at 33° 32′ 0″ N, 7° 35′ 0″ W tide gauge station [Cartographic Materials Codes (1994): http://www.ifla.org/VI/3/p1996-1/appx-f.htm.].

3.10.1. The Geo-potential Model in Morocco

Over Morocco area, there are two gravimetric geoid models. The first one is MGG97**.** It is based on data set consisting of 60448 free air gravity anomalies and OSU91A as global Geo-potential model. The second one is MORGEO05. Improvement is due to the use of EIGEN CG01C as global Geo-potential model for the estimation of long and medium wavelength. SRTM 90M as global digital terrain model is also used to take into account terrain correction in the determination of MORGEO05.

In Morocco, Special study to Comparing Global Geoids over Morocco area for GNSS altimetry determination shows EGM96 is corrected by a term of - 0.53m to fit better WGS84 ellipsoid, EGM2008 is better than GOCE and the corrected EGM 96 but in mountainous regions the terrain effects should be taken into account [EL Brirchie and EL Azzab, 2011].

3.11. The Vertical Datum in Saudi Arabia

In Saudi Arabia, there are 12 Tide Gauge Stations across the Kingdom seven sites along the Red Sea and five sites along the Arabian Gulf (Figure 3.16). The vertical datum in Suadi Aribia is Jeddah 1969 at tide gauge station with latittude 21^{o} 19' 12'N and longitude 39^{o} 6'E [Cartographic Materials Codes (1994): http://www.ifla.org/VI/3/p1996-1/appx-f.htm.] [El-Kherayef et al., 2015] [http://www.gcs.gov.sa/ar/ProductsAndServices/Products/PublicMaps/Pages/Official-Map-Of-The-Kingdom-Of-Saudi-Arabia.aspx].

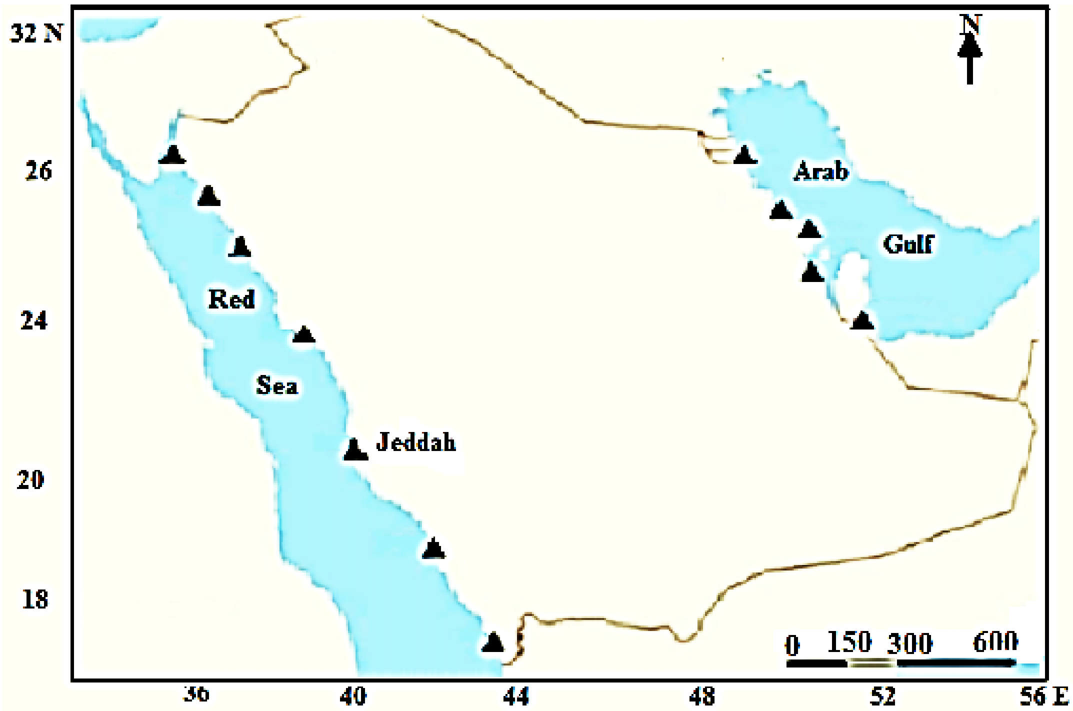


Figure (3.16): The location tide gauge station used in Saudi Arabia ▲

[El-Kherayef et al., 2015].

3.11.1. Gravity Network in Saudi Arabia

The National Absolute Gravity Network consists of 25 sites are shown in (Figure 3.17). Distributed within the kingdom (Ariyad - Al Khar j - Al Hufuf- Ad Dammam - An Nu'ayriyah- Hafar al Batin- Rafha - Ar'ar- Sakaka - Al Qurayyat- Tabuk - Tayma – AL Madinah- Badr - Zalm- Bishah - Najran - Sharurah- Wadi Ad Dawaser - Ar Ruwaydah- Buraydah- Ha'il- Jiddah - At Ta'if – Abha), in order to define gravity datum and scale by absolute gravity. All the sites are having two marks one inside and one outside. The accuracy of absolute gravity measurements is better than 10 m gal which provides first class second order accuracy classification. The relative gravity network consists of 266 stations spread to Saudi Arabia areas to observe the relative gravity points distributed on the GPS points, the new height points and on the old height points. Stations spread over the vertical network and between the absolute gravity stations [Mogren, 2010].

[http://www.gcs.gov.sa/Ar/ProductsAndServices/Products/Geodesy/N.ation al-Network-of-gravity/Pages/Absolute-stations.aspx.].

National vertical network in Saudi Arabia has 3279 height points where the length of base lines are 18487 km where the network of first order and first class.as in (Figure 3.18). [http://www.gcs.gov.sa/En/ProductsAndServices/Products/Geodesy/Nation al-Grid-Home/Pages/modern-network.aspx.]

3.11.2. GPS Network in Saudi Arabia

Continuously Operating Reference Stations (CORS) network covering the whole area of the Kingdom. The number of stations 105, base lines 281, the average distance 147km and the average density is 0.5 points each10000km^2.
[http://www.gcs.gov.sa/Ar/ProductsAndServices/Products/Geodesy/pages/c ors.aspx.].

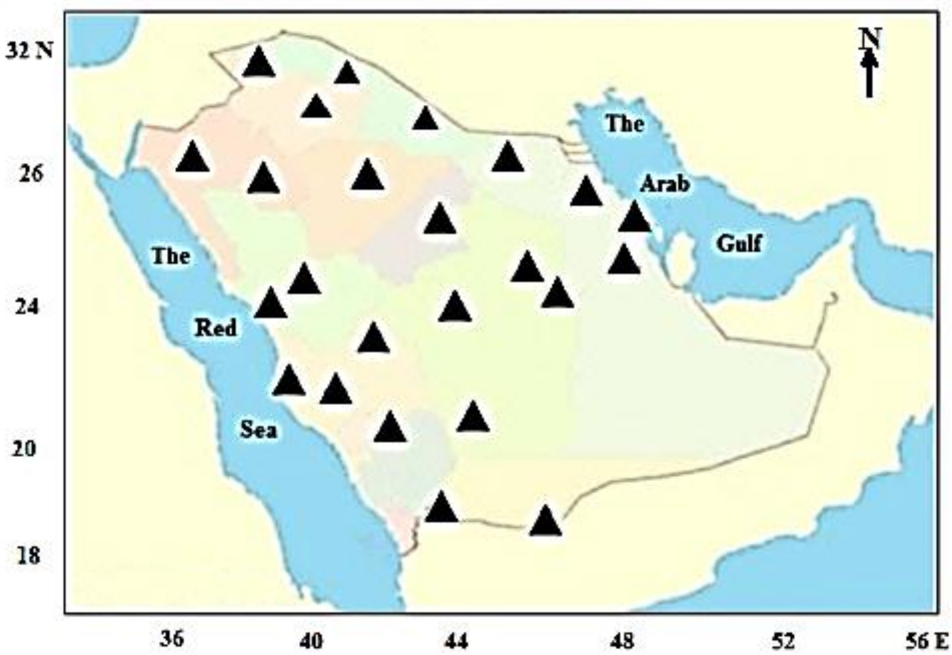


Figure (3.17): Absolut gravity stations in Saudi Arabia ▲
[http://www.gcs.gov.sa/Ar/ProductsAndServices/Products/GeodesyandLan dSurvey/NationalGravityNetwork/Pages/Absolute-stations.aspx].

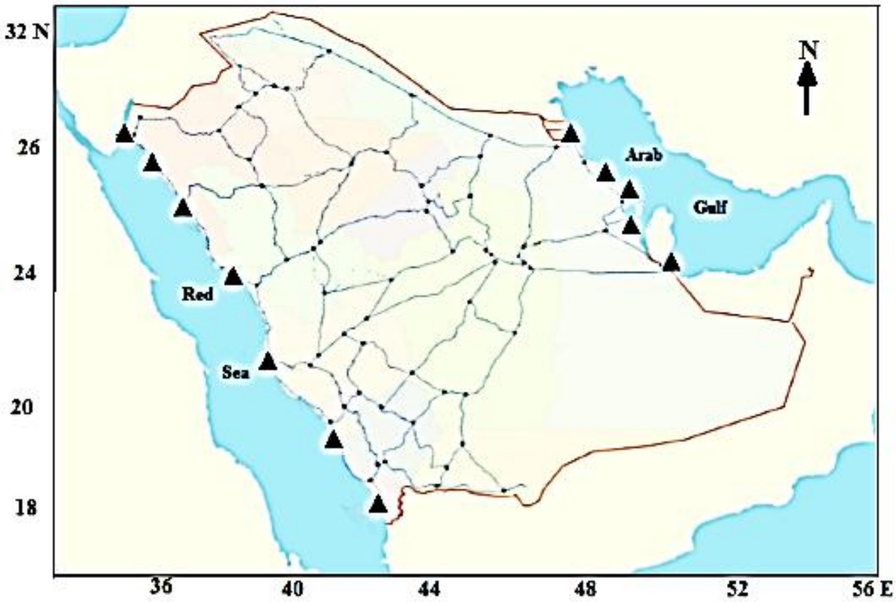


Figure (3.18): National vertical network of Saudi Arabia [http://www.gcs.gov.sa/Ar/ProductsAndServices/Products/GeodesyandLandSurvey/National-Grid-Home/Pages/default.aspx].

3.12. The Vertical Datum in Bahrain

The vertical datum in Bahrain is the mean sea level at Mina Salman with Latitude and Longitude 26º14' 00" and 50º 36' 00" [Hadi et al., 2007].

3.12.1. The Permanent Reference Network in Bahrain (PRN)

The Permanent Reference Network in Bahrain at King of Fahd Causcway, Amwaj, Awali ,Scout, Durrat Al Bahrain, Elawar and TSD as (Figure 3.19) [Hadi et al., 2007].

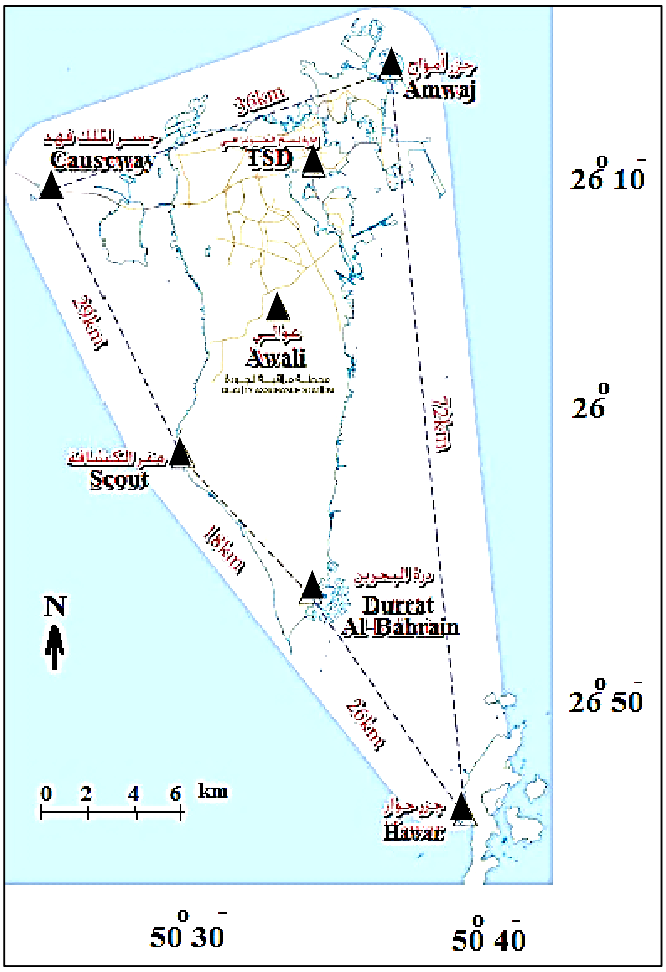


Figure (3.19): Bahrain PRN Station Locations ▲ [Hadi et al., 2007].

3.13. The Vertical Datum in Yemen

The vertical Datum in Yemen is the mean sea level at Aden Harbor at 12° 48′ 0″ N, 45° 2′ 0″ E. [Sammari, 2004] [https://tools.wmflabs.org/geohack GEOHACK –Aden]

3.14. The Vertical Datum in Mauritania

In Mauritania, the vertical datum is mean sea level at tide gauge station in Nouakchott harbour. It's not really a harbour but just a jetty of 1 km long about. It's coordinate 016° 02' 13,05'' W 17° 59'22,4" N. the location of tide gauge station [Odido, 2012].

The sensors are located at the edge of the main pier of the new jetty build by the Chinese in the 1990s. Tide gauge cabinet is placed in the last

top room of a meteorological observatory build by the Chinese also. The tower is also used as a radar station by the Mauritania Navy.

3.15. The vertical datum in Tunis

In Tunis the vertical datum is the mean sea level at tide gauge station at la Goulette with coordinate 36° 49' 21" N, 10° 18' 39" E [Naouali, 2011 and Naouali, 2012].

3.16. The Vertical Datum in Algeria

There are three tide gauge stations in Algeria for different purpose but the vertical datum in Algeria is defined as mean sea level from tide gauges data at Jijel 36º 49' N, 5º 44' 56"E. This reference will be used as a reference (zero origin) for the Algerian General Levelling Network (AGN) network, and improving the accuracy and the quality of the AGN network by applying the necessary corrections, including the orthometric correction [Touam, 2013].

3.16.1. Triangulation Network in Algeria

Triangulation network of Algeria began in 1854 and lasted until 1994, it was composed of 3740 points [Touam, 2013].

3.16.2. Levelling Network in Algeria

The Algerian General Levelling Network (AGN) (Figure 3.20), composed of two sub-networks, contain presently 40255 Kilometers, covering the whole national territory. The mean relative accuracy is at centimeter order. The actual works concern the maintenance and the densification of this network. Few thousand benchmarks, where it was Laborious, expensive Limited coverage of the country, Benchmarks are unstable, local networks, high maintenance costs [Kesraoui, 2012].

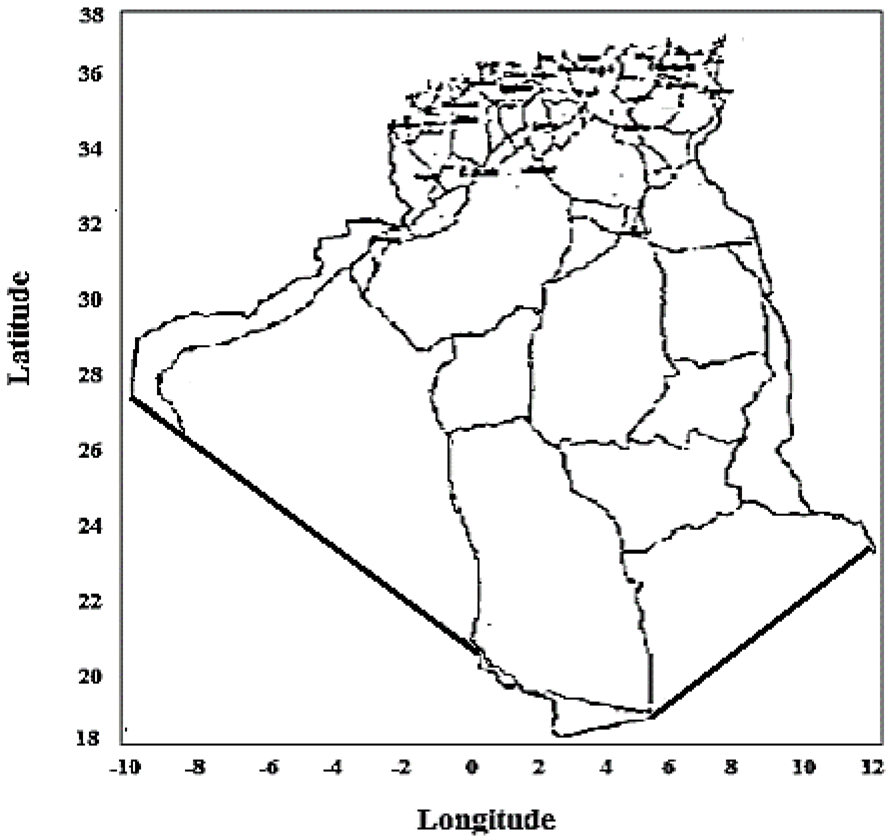


Figure (3.20): Classical levelling networks [Kesraoui, 2012].

3.16.3. Gravimetric Network in Algeria

The national gravimetric network is composed of two sub-networks, namely the fundamental network composed of 12 absolute points observed in 2011 using GF5-111 gravimeter of the National Science Foundation of the United States of America. The observations have been processed using spacial software, following exactly the international conventions in use in this domain. The mean accuracy of this network is about 1.5 μgal.

The secondary network composed of 1985 points obtained by relative gravity measures using Lacoste and Romberg gravimeter, distant from each other of about 30 Kilometers, and connected to the precise levelling network. The accuracy of this network is about 0.02 mgal. The maintenance and densification works are undertaken particularly along the roads during regular periods [Daho and Fairhead, 2001].

3.16.4. The GPS Network in Algeria

In the framework of the Tyrenean Geodetic network project, the National Institute of Cartography and Remote Sensing has observed in 1998 its zero order GPS network simultaneously with the observation TyrGeoNet campaign. Twelve points have been observed during 72 hours and processed using Bernese software. The accuracy was centimeter level. Another eight points have been also observed in June 2000 during one week and processed using WinPrism software. The accuracy of these points is decimeter level.

During June 2005, 15 points from the zero order GPS network have been observed during one week and processed with precise IGS products using the Bernese 5.0 software. The distribution of these points was shown in (Figure 3.21).

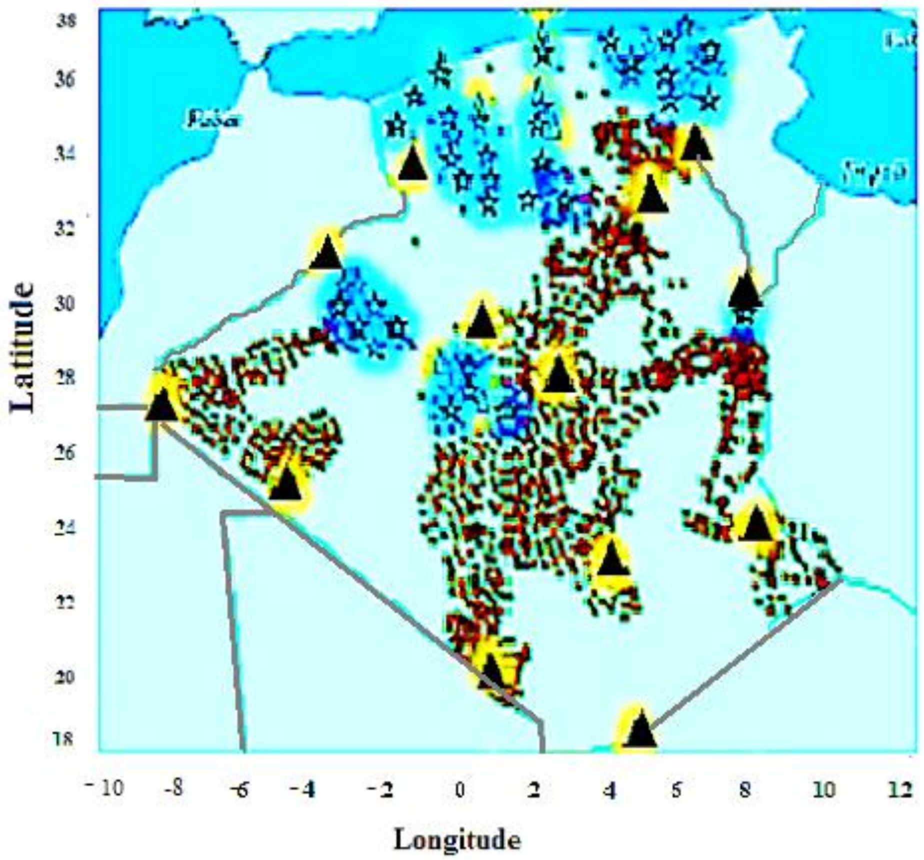


Figure (3.21): Δ Zero order GPS points ☆ GPS points (50-150km) ● first order GPS points (25-50km) [Daho and Fairhead, 2001].

The first order GPS network complements the North classical geodetic network and enabled the equipment of the national territory. The 1st order GPS network is composed of 1290 points distant from 25 to 50 km. The observations are done using dual-frequency receivers during two hours. The relative accuracy of this network is about 3 cm. In the other hand; INCT is undertaking great effort to deploy the Algerian GNSS network through the whole country. Nowadays, 07 permanent GNSS stations are already installed and operational to cover the country, as shown in (Figure 3.22).

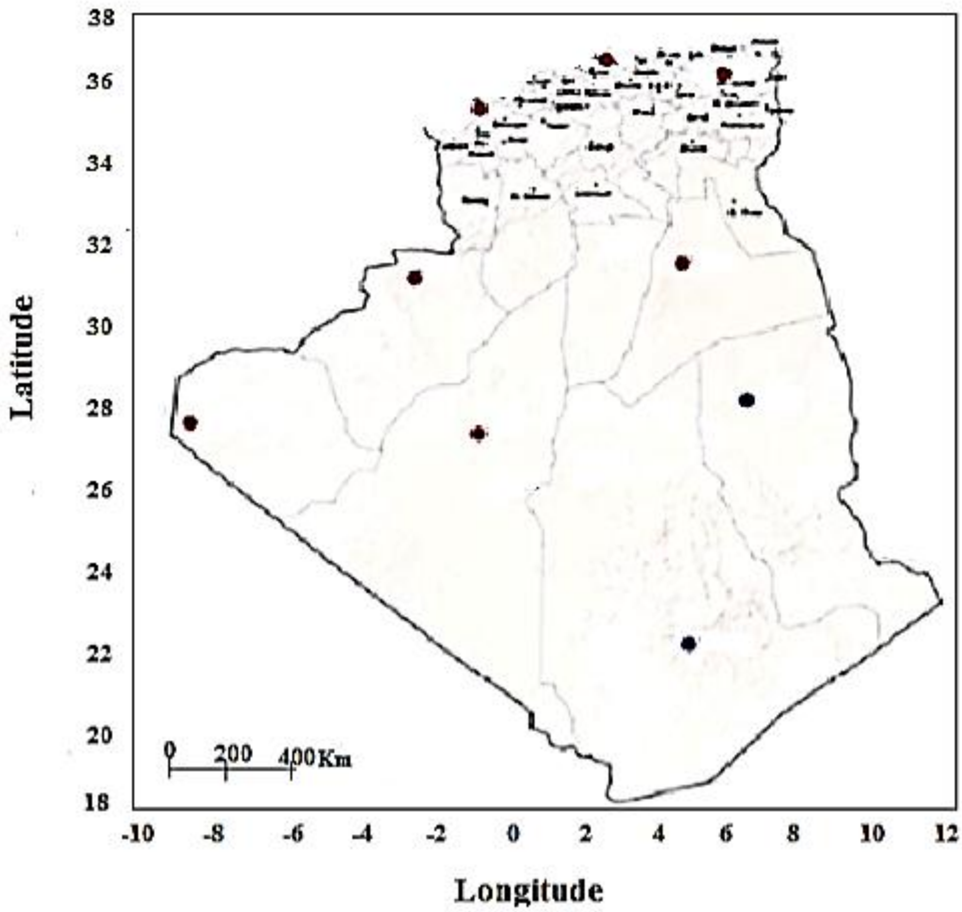


Figure (3.22) Permanent GPS Network [Daho and Fairhead, 2001].

The number of GPS stations used in this investigation was 258, which 16 are benchmarks of the first order levelling network, and the others belong to the second levelling network. All of these points are located in the north of Algeria. So, in order to make possible the estimation of geoid undulation

(N) in these points, all these GPS stations are connected to the national height system through spirit levelling. The GPS observations were performed with dual frequency receivers with baseline length ranging from about 1 to 1000 km, and the BERNESE software with precise ephemerides was used to process the GPS data. Among 258 GPS levelling points only 16 well distributed GPS levelling points are used as benchmarks points, and the others were excluded in order to estimate the real accuracy given by the comparison between the adjusted values and the known ones.

These values have been compared also to the Bureau Gravimétrique International (BGI) solution which is based on a set of 12183 validated points free air gravity anomalies supplied by the BGI, two elevation grids; 1 km x 1 km digital terrain model for the north of Algeria, the ETOPO5 for the rest of the area, and the OSU91A Geo-potential model, which were combined using the remove-restore technique in connection with the Fast collocation. The final result was a gravimetric geoid on a 5' x 5' grid in the area bounded by limits $20° \leq \phi \leq 37°$ and $-7° \leq \lambda \leq 10°$ [Daho and Fairhead, 2001].

3.17. The Vertical Datum in Libya

In Libya, the vertical datum is the mean sea level, and the vertical datum in Tripoli at 32° 54′ 8″ N, 13° 11′ 9″ E [http://www. Maradah Libya scale 1:2500 series 1501 sheet NH 34-9 Edition 5] [Cartographic Materials Codes (1994): Unimarc Manual, Bibliographic Format appendix F Cartographic Materials Codes, http://www.ifla.org/VI/3/p1996-1/appx-f.htm].

3.17.1. Levelling Network in Lybia

Aero - Service Corporation (ASC) in Lybia established 942 first order traverse stations and Pol-Service Geokart conducted 7468 levelling bench

marks and 63 first order gravimetric stations, and established 4 tide gauges along Mediterranean coast as in (Figure 3.23) [Odalovic et al., 2013].

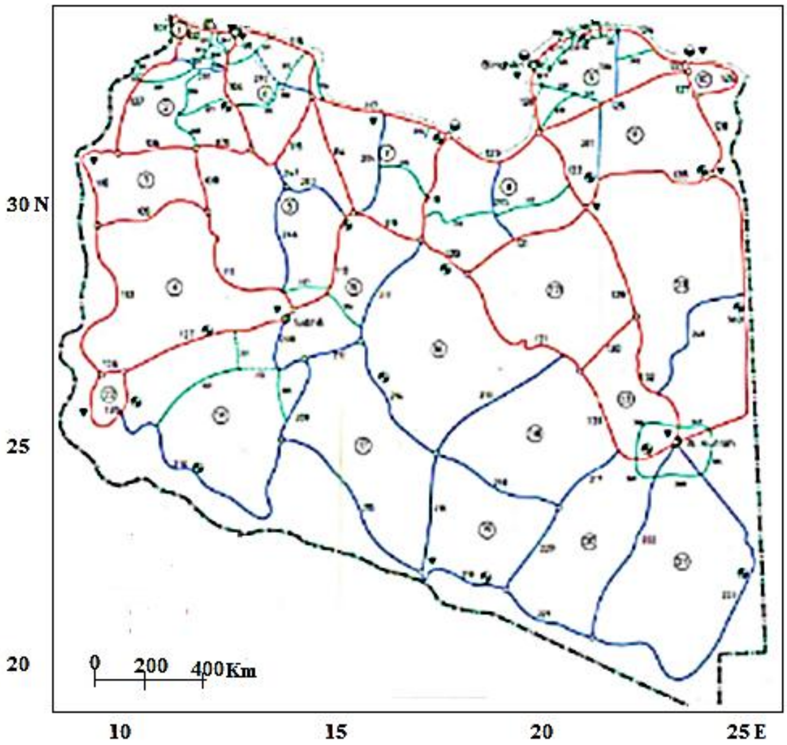


Figure (3.23): Levelling network by Pol-Service [Odalovic et al., 2013].

3.17.2. The Gravity Network in Libya

The total gravity station coverage represents about 35% to 40% of the total area of Libya . The overall gravity stations coverage is scattered. All the gravity points (25821 points) are relatively irregularly positioned throughout the territory of Libya, which surface is 1.76 million sq. km, the terrain of Libya is mostly flat and up the sea level. Libya's lowest point is at 47m below sea level and the highest point is at 2267m. The accuracy of gravimetric survey is not bigger than 0.1 mgal.

3.17.3. GPS Network in Libya

Continuously Operating Reference Stations (CORS), consists of a network of multi-functional RTK and DGNSS reference stations providing

signals that could be used for geodetic point positioning, land, marine and air navigation. CORS-LIBYA network consists of 45 reference stations with one control centers and the spacing between CORS stations is 60-100 km for all Northern Libya as illustrated in (Figure 3.24)[Al Arabi et al., 2010].

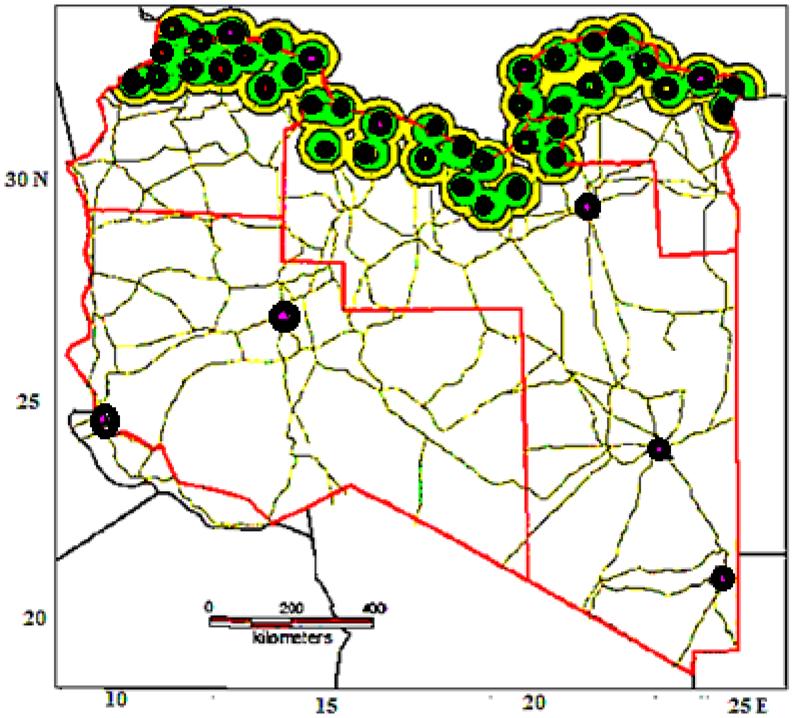


Figure (3.24): CORS- Libya stations and coverage at 40 and 60 km interstation distances [Al Arabi et al., 2010].

From CORS- Libya stations can be collecting all kinds of geographic data. Thus, speeding up the activities of national mapping, cadaster, assuring organized urbanization, constituting the spatial infrastructure for relevant works of e-government, and monitoring plate tectonics.

3.17.4. The Geoid Model in Libya

Up to now, there were four attempts to compute the Libyan geoid and all of them were before 2000. The first attempt, a geoid map based on 19 levelled Doppler were computed by National Geographic Institute (NGI). In its computations NGI is used as the only source of data, the deflections of

the vertical obtained from the comparison of the astronomical coordinates and their respective WGS72 to the levelled Doppler points above the same ellipsoid [Odalovic et al., 2012].

A second geoidal map was computed by Aero - Service Corporation (ASC). Two geoidal maps with relation to two different datums were computed, one with relation to the local datum, European Libyan Datum 1979 (ELD79) and the other one with relation to WGS72 datum.

The third computation of the gravimetric geoid for Libya depend on data from

• 5′ x 5′ gridded value of Bouguer anomalies based on African Gravity Project.

• Global 5′ x 5′ digital terrain

• The OSU91A and EGM96 Geo-potential models. Two geoid/quasi geoid models were computed, first model is referred to OSU91A and second one to EGM96 global model.

The fourth geoid determination for Libya was conducted in 2000. The technique which used based on the remove-restore technique with respect to 360 x 360 spherical harmonic reference model OSU91A with the terrain effect consideration, as in (Figure 3.25).

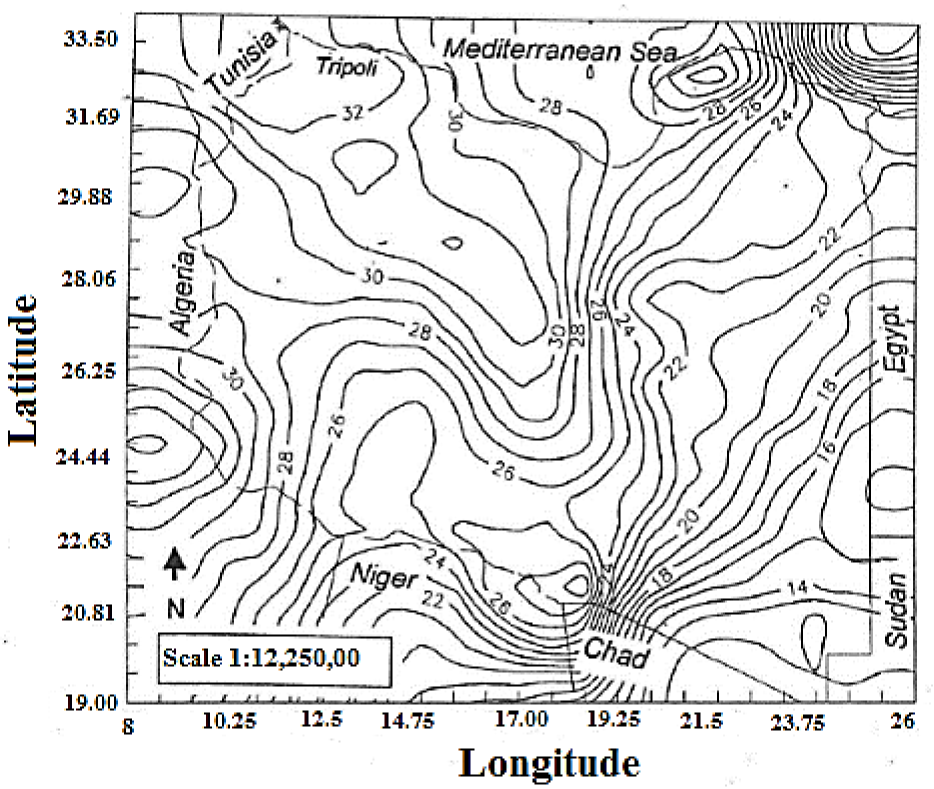


Figure (3.25): Geoidal undulation map with 1m interval for Libya [Odalovic et al., 2013].

3.17.5. The Global Geo-potential Model in Libya

In special project to compare between Global Geoptential Models (GGMs) with terrestrial gravity data in Libya, the EGM96, EGM2008, and EIGEN-6C2 global Geo-potential model for the territory of Libya were tested. The greatest agreement with the terrestrial data of the free air anomalies is achieved by using the EIGEN-6C2 model. The set of the terrestrial differences anomalies of free air and the anomalies that follow out of applying EIGEN-6C2 model has an average value of 0.22 mgal, with the standard deviation of 1.96 mgal. The results pointed to a great accordance between the EIGEN-6C2 and EGM2008 models as well as that by using all of these tested models far better approximations of gravity field in the territory of Libya than the one that follows after using the global EGM96 model are obtained [Odalovic et al., 2012].

3.18. The Vertical Datum in Occupied Palestine

There are two tide gauge stations in Occupied Palestine, the first tide gauge station is established at Haifa port in 1928-1931, where a reference benchmark was set-up, and then moved to a new TGBM established in Jaffa harbor in 1930 -1940. Where the vertical datum is mean sea level at Jaffa Harbor at 32° 49′ 12.43″ N, 35° 0′ 16.13″ E [Cartographic Materials Codes (1994): http://www.ifla.org/VI/3/p1996-1/appx-f.htm] [Rosen, 2005].

Figure (3.26): The distribution of benchmark points Gaza strip

[El-Hallaq., 2012].

3.18.1. GPS and Levelling Network in Gaza

In Gaza for the geoid development, field survey including levelling and GPS measuring in addition to data validation checks, 403 GPS/Levelling points were collected. The number of points is adequate to model such small area. 353 points were selected as modeling benchmarks and the rest 50 points are used to evaluate the performance of the developed model. The distance between any two modeling points do not exceed 3 km. These points show in (Figure 3.26) [El-Hallaq, 2012].

3.18.2. The GPS Network in Palestine

The permanent stations network, Active Permanent Station Network (APN) includes 19 stations spread throughout the country. The density of the station in the northern region is high due to the fact that most of the surveying activity as performed there; whereas the southern region consists of a number of stations at a lower density [Salmon, 2009].

3.19. The Vertical Datum in Syria

The vertical datum in Syria is the mean sea level at the tide gauge station in Al Beida Port-Latakia, at coordinate 35° 36′ 34.32 ″ N and 35° 46′ 19.471″ E at Mediterranean sea.

Special project in Syria by General Petroleum Company (GPC), only 800 gravity points were used in that project, include information about terrestrial gravity values for each point, GPS measurements with collaboration of the ministry of local Administrative and environment in Syria, data of gravity measurements and parameters of EGM96 Geoid model [Salmon 2009 and Al-Masri, 2010].

In addition to the gravimetric measurements, GPS was used in number of points (few points in different places in Syria) where the orthometric heights are known and the values of geoidal heights are computed from the difference between the ellipsoidal height and orthometric height.

3.19.1. The Global Geo-potential Model in Syria

The EGM96 behaves in Syrian better than OSU91 Geoid model and it is more accurate than the OSU91A due to the lack of gravity data of the Middle East area within the OSU91A model and the long wavelength error propagation in the GGM [Al-Masri, 2010].

3.20. The Vertical Datum in Lebanon

In Lebanon, the vertical Datum is the mean sea level at Beirut at 33° 53′ 13″ N, 35° 30′ 47″ E, [Cartographic Materials Codes (1994) http://www.ifla.org/VI/3/p1996-1/appx-f.htm.]

3.20.1. The Gravity Network in Lebanon

In Lebanon, the terrestrial gravity data are measured relatively, as differences of gravity from reference points to other points. The relative gravimeters are used for this task. The absolute gravimeter is used to measure the gravity value itself. The (Figure 3.27) shows the terrestrial gravity points [Bayound, 2008].

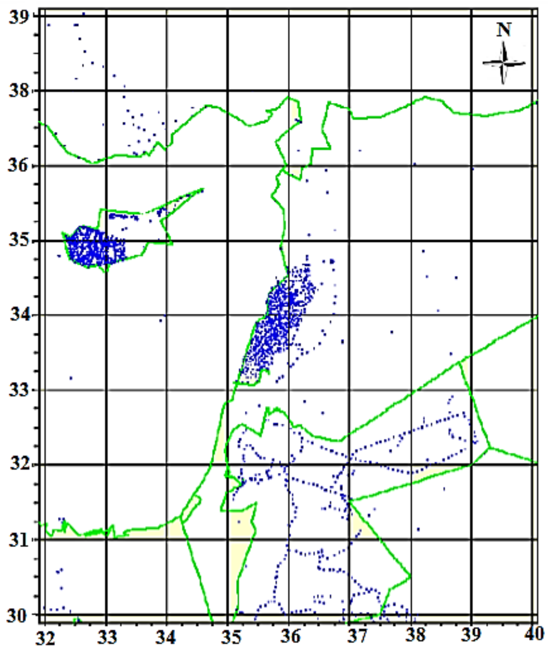


Figure (3.27): The terrestrial gravity points in Lebanon [Bayound, 2008].

3.20.2. Geoid Determination in Lebanon

GPS/Levelling is the only possible way to compute the geoid in Lebanon because an integrating the global geoid model with GPS/levelling is not possible due to the lack of the short wavelengths in the global geoid model. The suitable Geo-potential model in Lebanon is ELGEN-CG03C [Bayound, 2008].

3.20.3. Exiting GPS and Levelling points in Lebanon

GPS and levelling points are distributed in Lebanon as in (Figure 3.28).

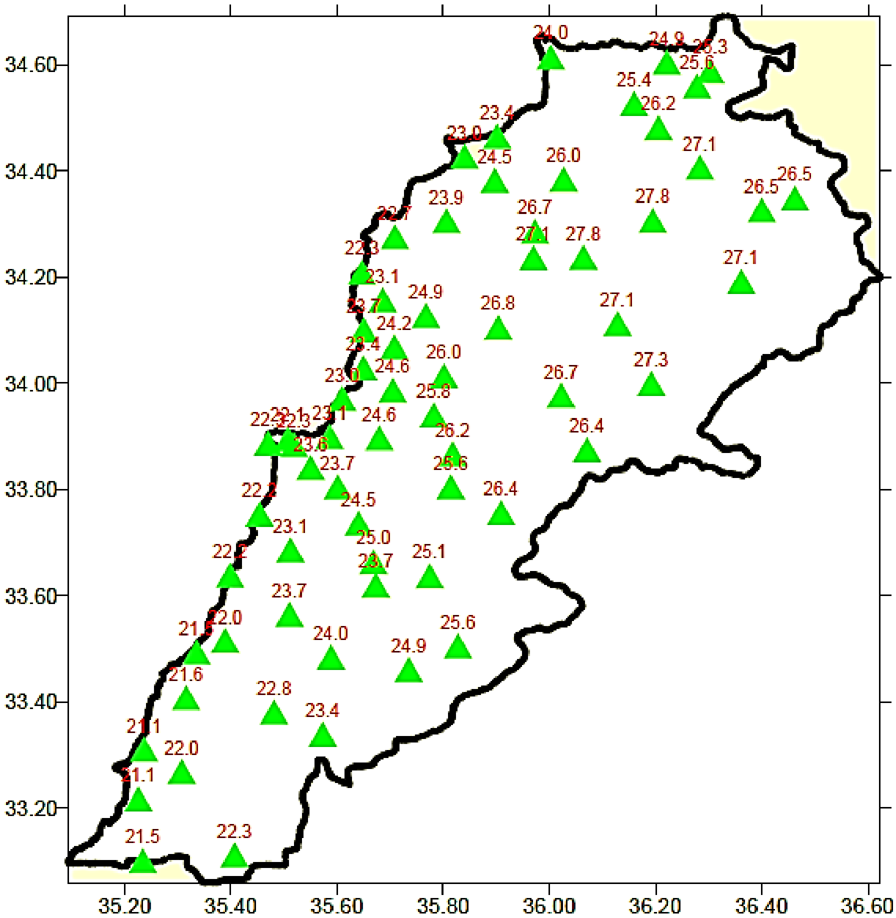


Figure (3.28): GPS and Levelling points in Lebanon [Bayound, 2008].

3.21. The Vertical Datum in Jordan

There are two tide gauge stations in Jordan in Aqaba Gulf and Dead Sea. The vertical datum in Jordan is the mean sea level at Aqaba Gulf 29° 31′ 0.12″ N, 35° 0′ 0″ E. The local vertical datum for the Dead Sea Work (DSW) is based on the single stable point alone called 43F this datum was named "Vertical Datum for the DSW 2008" with coordinates 31° 2′ 4.91″ N, 35° 22′ 16.02″ E. Dead sea is closed and not connected to the open water so it cannot be used as a reference for a global vertical control. [Sharni, 2008].

3.21.1. Geoid Determination in Jordan

The determination of the Geoid Model for Jordan never was easy due to the high costs of the process, difficulty accessing the gravimetric data that covers the country, difficulty to have GPS and precise levelling for the country, the lack of access to the gravimetric data in the neighboring countries. On the other hand, using available gravimetric data collected by the Natural Resources Authority of Jordan (NRAJ) for geophysical purposes. The number of gravimetric points measured offered a possibility to creating a Geoid Model for Jordan.

The GeoJordan model is determined by the remove-restore and Least-Squares Collocation (LSC) procedure. The Gravimetric Jordanian Geoid Model uses a combination of three input data sources,

- Gravity data are collected by the Natural Resources Authority of Jordan (NRAJ) mainly for geophysical purposes; distributed over the whole country (about 3000 free-air gravity anomalies), they allow to determine the effect of the intermediate geoid wave length, around 5 to 10 km. These data are part of the database covering the Jordan territory and are referenced to IGSN71. There are about 100 gravity point were available during preprocessing, the distribution of the gravity data used is shown in (Figure

3.29), the distance between points is approximately 5 km, and the standard error declared by NRAJ is 2 mgal.

-Global Geo-potential Model (GGM) to determine the long wave length of geoid undulations with more than 100 km spacing.

-Digital Elevation Model (DEM) which supplies most of the short wavelengths (~100 m) and is also required to satisfy theoretical demands of geoid computation from the geodetic boundary- value problem [Al-Bayari and Al-Zoubi, 2007].

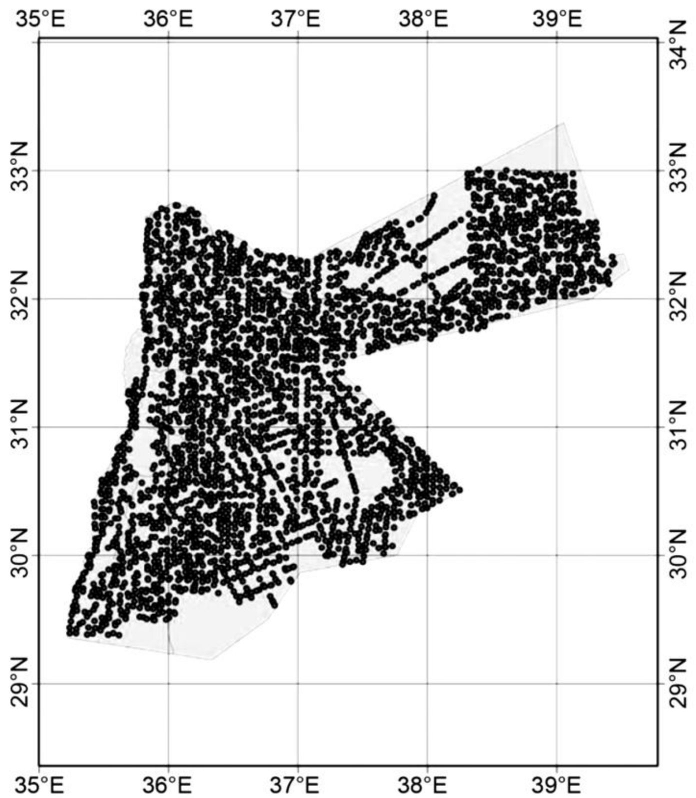


Figure (3.29): Gravity data distribution over Jordan territory

[Al-Bayari and Al-Zoubi, 2007].

3.21.2. GPS/Levelling Network in Jordan

The GPS/levelling measurements were carried out to study the accuracy of the Gravimetric Geoid Model (GeoJordan). Two GPS observation techniques were used; the static and the rapid static techniques.

The GPS static measurements were used to establish the reference network. While the rapid static and levelling measurements were used for the determination of geoidal undulation in the vicinity of Spirit levelling network. Spirit levelling network in Jordan is determined with respect to the mean sea-level defined at Aqaba Gulf as in (Figure 3.30).

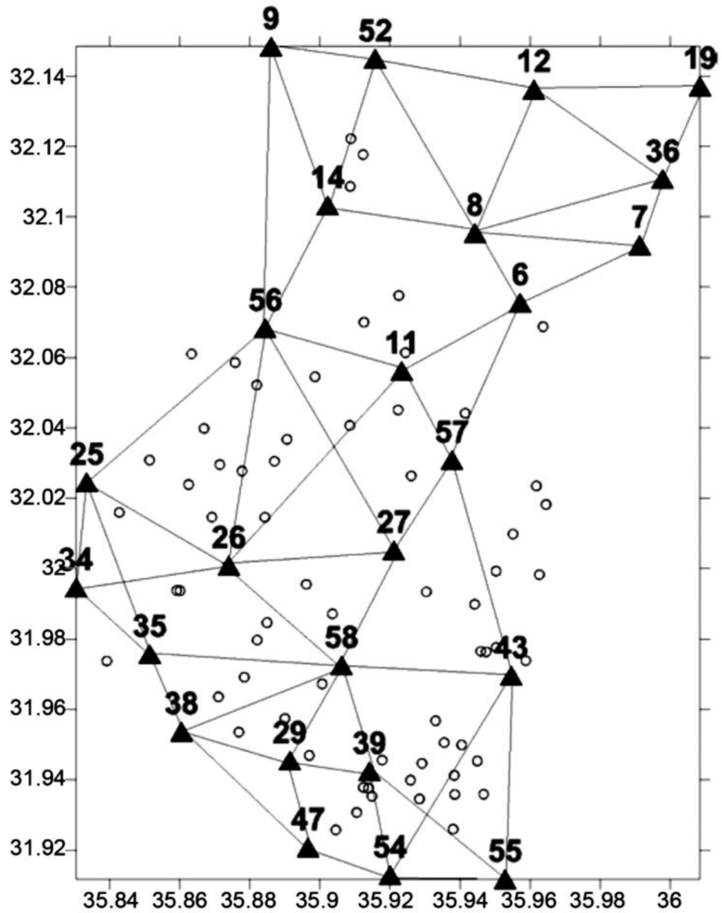


Figure (3.30): GPS Static reference points and rapid static points (latitude and longitude in WGS84) [Al-Bayari and Al-Zoubi, 2007].

3.21.3. The Global Geo-potential Model in Jordan

In Jordan, statistical parameters for the gravity residual (Δg_r) computed using EGM96 with 2994 points, standard deviation 28.44mgal and using OSU91A with 2994 points, standard deviation 31.82mgal. The statistical analysis shows better behavior for EGM96 than those computed

using OSU91A, the EGM96 is more accurate than the OSU91A due to the lack of gravity data of Jordan area within the OSU91A model and to the long wave length error propagation in the GGM [Al-Bayari and Al-Zoubi, 2007].

3.22. Summary of The Available Data in The Arab Region

-From the data which previously displayed, the location of tide gauges stations can be summarized in Arab world in (Table 3.1) and (Figure 3.31);

Table (3.1): Location of tide gauge in all Arab world.

Region	Country	Vertical Datum origin	Latitude	Longitude	T.G Location
Nile River Countries	**Egypt**	Alexandria Harbor	30°5l' N	29°53'E	Mediterranean sea
	Sudan	Port Sudan	19°37 '27‶N	37°13'25‶ E	Red sea
	Djibouti	Djibouti	43°08'28‶ N	11°36 '48‶E	Tadjoura Bay
	Somalia	Mogadishu	2°1 'N	45°20′ E	Indian Ocean
Arab Gulf Countries	**Yemen**	Aden MSL	12° 48′ 0″ N	45° 2′ 0″ E	Aden Gulf
	Oman	Mina Fahud	23° 37'57"N	58°29′57"E	The Arabian Sea
	Emirate	Dubi	13° 47′ 27″ N	50° 40′ 44″ E	Arabian Gulf
	Qatar	Doha	25° 17′ 12″ N	51° 32′ 0″ E	Arabian Gulf
	Bahrain	Mina Salman	26°14′ N	50°36′ E	Arabian Gulf
	Kuwait	Mina El Ahmedi	29°4′25″N	48°4′22″E	Arabian Gulf
	Iraq	Faw Harbor	29°58′52″N	48° 28′3″E	Arabian Gulf
	Saudi Arabia	Jeddah	21°19′12′ N	39°06′ E	Red Sea

Region	Country	Vertical Datum origin	Latitude	Longitude	T.G Location
Maghreb Countries Region	**Libya**	Tripoli	32° 54′ 8″ N	13° 11′ 9″ E	Mediterranean Sea
	Morocco	Casablanca	33° 32′ 0″ N	7° 35′ 0″ W	North Atlantic Ocean
	Mauritania	Nouakchott	17° 59’22,4” N	16° 02’ 13,05’’ W	North Atlantic Ocean
	Algeria	Jijel	36° 49' N	5° 44' 56"E	Mediterranean sea
	Tunisia	La Goulette	36° 49’ 21,05’’ N	10° 18’39,1” E	Mediterranean sea
El- Sham States	**Palestine**	Jaffa	32° 49′ 12.43 ″ N	35° 0′ 16.13″ E	Mediterranean sea
	Jordan	Aqaba Gulf	29° 31′ 0.12″ N	35° 0′ 0″ E	Aqaba Gulf
	Lebanon	Beirut	33° 53′ 13″ N	35° 30′ 47″ E	Mediterranean sea
	Syria	Al Beida Port-Latakia	35° 36′ 34.32 ″ N	35° 46′ 19″ E	Mediterranean sea

The location of tide gauges stations can be summarized in Arab world in (Figure 3.31):

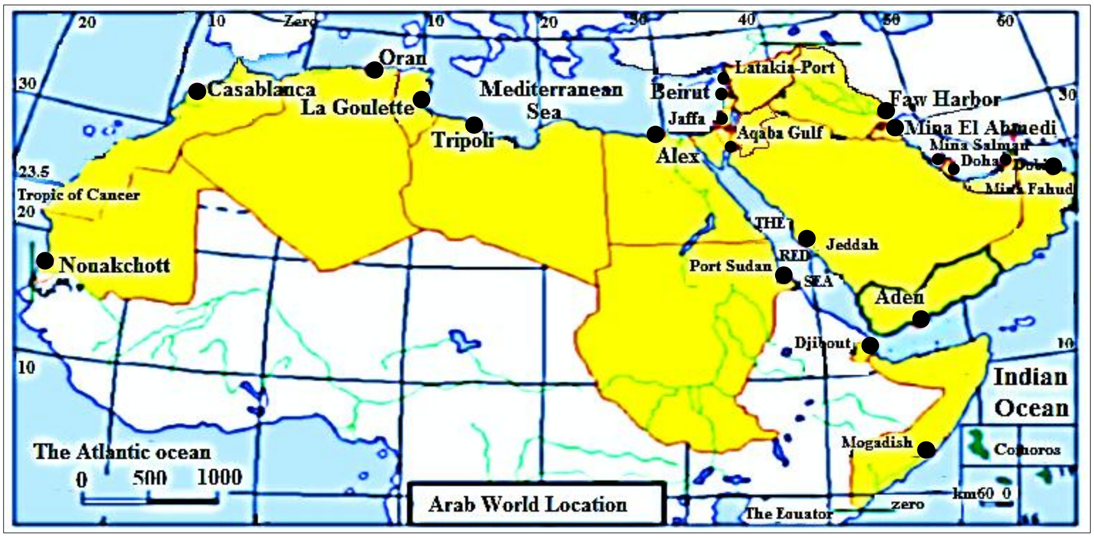


Figure (3.31): ▭ The country with defined datum origin ● The tide gauge stations.

-From the data which previously displayed in this chapter, the distribution of GPS points can be summarized in Arab world in (Figure 3.32);

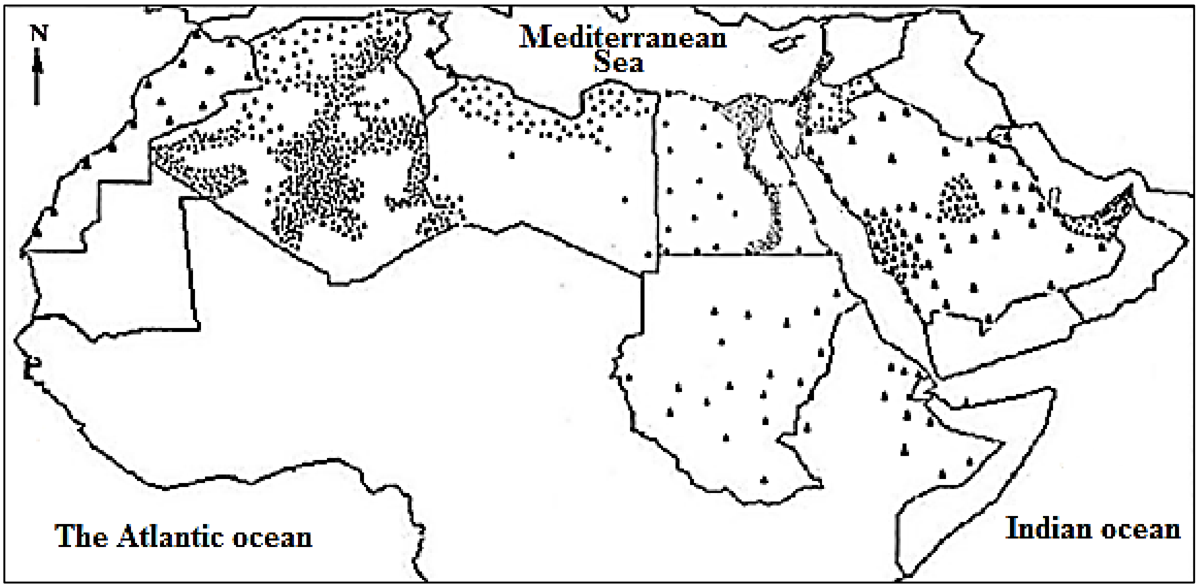


Figure (3.32): Shows the available distribution of GPS points in Arab countries**.**

-Information about gravity values of the Arab countries is available at the international organizations responsible for collecting gravity data such as the Geophysical Exploration Technology (GETECH) and The Bureau Gravimétrique International (BGI).

GETECH continues to grow what is already the world's most extensive commercial library of gravity and magnetic data. It has data covering almost every country in the world at a variety of scales and resolutions. Their global databases, the largest and most extensive in the world, are based on thousands of magnetic surveys and data from millions of gravity stations covering all the continents and continental margins of the world. Their global databases incorporate all of GETECH's continental-scale compilations of terrestrial data, with satellite and public domain data where appropriate.
[https://edx.netl.doe.gov/dataset/getech-gravity-and-magnetic-global coverage/revision_resource/63e1e0c4-03cd-7784-0ad3-17b93af236a1].

Gravity data in GETECH, which covers Arab world and their general distributions appeared in (Figure 3.33).

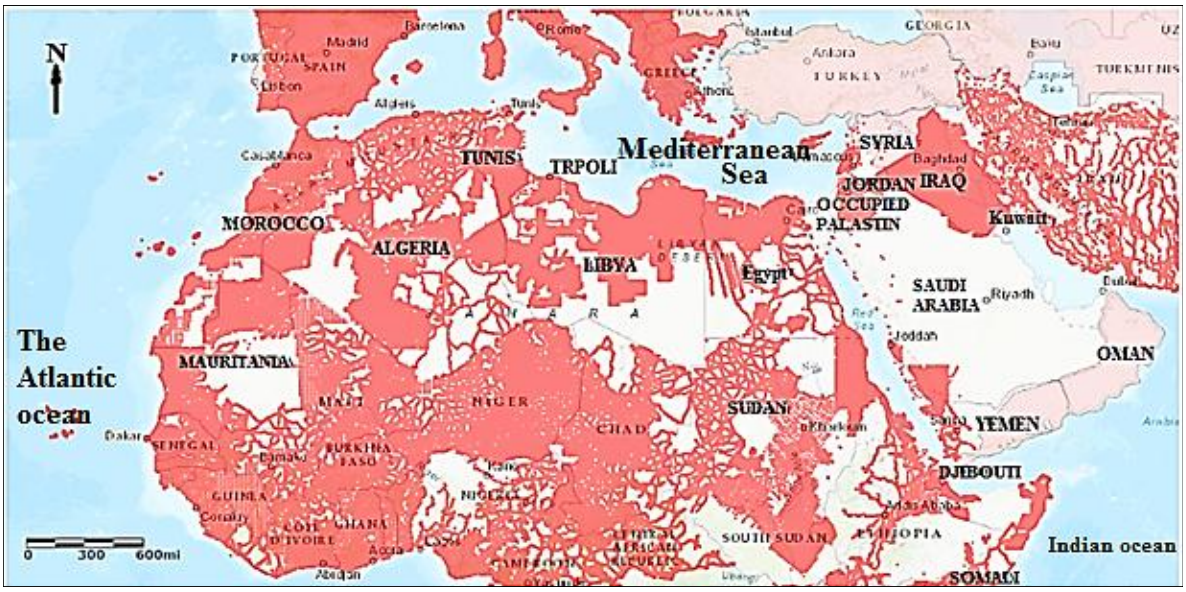


Figure (3.33): The gravity points [available at https://getech.com/map]**.**

The Bureau Gravimetrique International (BGI) has been created in 1951 as a service of IAG during the IUGG (International Union in Geophysics and Geodesy) General Assembly. The initial task of BGI was to collect, on a world-wide basis, all gravity measurements to generate a global digital database of gravity data for any public or private user. The technological and scientific evolutions which occurred over the last 50 years in the area of gravimetry (improvements in field, airborne and seaborne gravity meters, development of absolute gravity meters, space gravity missions, etc.) provided significant increases of the number, diversity and accuracy of the gravity field observables. Following these evolutions, the BGI has contributed to provide original databases and services for a wide international community concerned by the studies of the Earth gravity field. The BGI is an official service of the International Association of Geodesy (IAG) and is coordinated since 2003, with others IAG services by the International Gravity Field Service (IGFS).

BGI has the responsibility of 4 global scientific gravity databases; relative gravity measurements (land surveys), relative gravity measurements (marine surveys), absolute gravity measurements (free fall techniques), Reference gravity stations (International gravity network).

Gravity data in BGI, which cover Arab world and their general distributions can be illustrated in (Figure 3.34) [Bonvalot 2016].

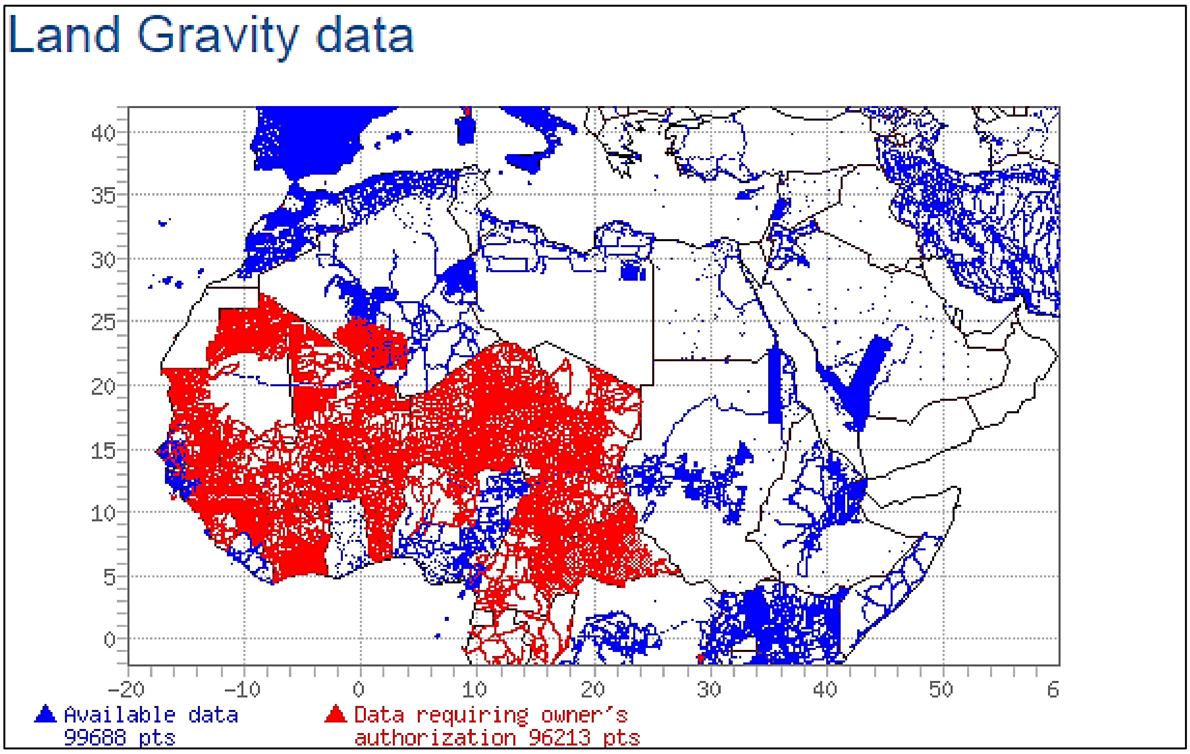


Figure (3.34): Gravity data which available in BGI. [http://bgi.omp.obs-mip.fr/data-products/Gravity-Databases/Land-Gravity-data].

Table (3:2): The Available GPS/Levelling and Gravity Data in the Arab Region

Country	GPS/Levelling data	Gravity Data and Available Data in GETECH
Egypt	- 32 closed levelling loops cover the whole area, - 2 single cover in Alex and delta. - 30 High Accuracy Reference Network (HARN) - 112 National Agricultural Cadastral Network (NACN)	- 150 relative point from Egypt National Gravity Standardization net. - 988 older gravity point. - 394 available points with observed geoid undulation. -Totally 6403 on land and 67651 marine data
Sudan	-19 GNSS/levelling points.	-Onshore 4 km / 10 km grid, -Offshore 2 km grid.
Djibouti	-30 GNSS/levelling points.	-Onshore 4 km / 10 km grid, -Offshore 2 km grid
Somalia	-	-Onshore 4 km / 10 km grid, -Offshore 2 km grid
Yemen	-30 GNSS/levelling points.	-Onshore 2 km / 10 km grid, -Offshore 2 km grid
Oman	-	-Onshore: 5 km grid, -Offshore: 2 km grid.
Emirates	-3750 leveled benchmarks with GPS ellipsoidal heights	-Offshore 2km grid.
Qatar	-3 primary base station. -20 secondary base station. -30 local network stations.	-71 points have geoidal undulation. -Offshore: 2 km grid.
Bahrain	-7 CORS Stations.	-Offshore, 2 km grid.
Kuwait	-	-Offshore 2 km grid
Iraq	-	-Onshore 1 km grid, -Offshore 2 km grid
Saudi Arabia	-3279 vertical network, height points. -105 CORS.	-25 Absolute Gravity points. -266 relative gravity network Offshore 2 km grid.

Countries	GPS/Levelling data	Gravity Data and Available Data in GETECH
Libya	942 first order traverse stations. -7468 levelling bench marks. -45 (CORS) stations.	-63 first order gravimetric stations. -25821 gravity points.
Morocco	-	-60448 free air gravity anomalies from GGM96 -On shore 4 km/10 km grid, -Offshore 2 km grid.
Mauritania	-	-Onshore 4 km / 10 km grid, -Offshore 2 km grid.
Algeria	-3740 Triangulation points. -258 GPS levelling points. -1290 1st order GPS points.	-636 Astronomical points. -12 absolute gravity points. -12183 points free air gravity anomalies.
Tunis		-On shore 4 km/10 km grid, -Offshore 2 km grid.
Palestine	-403 GPS/Leveling points. -19Active permanent points.	-Onshore 8 km grid, -Offshore 2 km grid.
Jordan	-26 GPS/levelling points	-3000 free-air gravity anomalies from NRAJ -100 gravity points
Lebanon	-69 GPS/levelling points	-Onshore 8 km grid, -Offshore 2 km grid.
Syria	-	-800 gravity points. On shore 8 km grid, Offshore 2km grid.

CHAPTER (4)

CLASSICAL AND MODERN GEOID DETERMINATION METHODS

Introduction

This chapter contains the description of geoid and classifications of geoid determination methods, explanation of satellite missions, in addition to geo-potential models and their types, and tailoring the GGM with some cases which applied this technique.

The geoid is the shape which is produced from the surface of the oceans would take under the effect of Earth's gravitation and rotation alone, without the other affections as winds and tides. This surface is expanded over the continents. Where all the points on the geoid have the same gravitational potential energy. The gravity force effects at any point perpendicular to the geoid. That means, plumb lines are orthogonal and level surfaces are parallel to the geoid. Furthermore, the geoid is the equipotential surface which coincides with the mean sea surface of the Earth if the seas and atmosphere were in balance at rest relative to the rotating Earth. Gauss is the first person described it, and defined it as the "mathematical shape of the Earth", it is a smooth but not regular surface due to uneven distribution of mass on the surface of the Earth and inside it.

It does not represent the actual surface of the Earth's crust, but it is a surface that cannot be known without measurements and calculations of gravity. In recent decades only, it has been defined to high precision. It is considered the true physical shape of the Earth, in contrast with the idealized reference ellipsoid which represents the geometrical figure of the earth. When there is a positive gravity anomaly (mass excess) the surface of the geoid is above the reference ellipsoid at any place and when there is a

negative gravity anomaly, the geoid becomes under the reference ellipsoid wherever [Xiong and Hans, 2006].

4.1. Geoid Description

There is a common variation between the geoid and ellipsoid, in spite of the geoid represents the true physical shape of earth, in presence of the highest peak of Everest reaches to +8,848 m and the lowest earth of dead sea reaches to -429m this makes the variation between the geoid and idealized ellipsoid ranges from -106 m to +85 m, totally 200m less than the ellipsoid [https://en.wikipedia.org/wiki/Geoid 2015].

The ocean surface is closely approximated from the geoid if it was has constant density and not disturbed by weather, currents, and tides. The ocean surface topography is defined as the deviation between the geoid and the mean sea level. If there are a series of tunnels or canals cross the continental land, in this case, the sea level at these canals is very close to the geoid. In fact, the geoid have not physical meaning under the continental, but the heights of points on that imaginary surface can be derived by spirit levelling.

Because the geoid is an equipotential surface, where the gravity force is everywhere upright. This makes nobody feels undulations of the geoid; the plump line is defined as local vertical is orthogonal to the geoid in time the local horizon is tangent to it and spirit levels are permanently parallel to the geoid. But GPS receiver on the ships through longer voyage indicates to height variations, even if there aren't tide effect because GPS receiver observes related to a geocentric ellipsoid. So the GPS readings must be adjusted to obtain a geoidal height. Contrarily, the orthometric height which directly obtained from spirit levelling depends on a tidal measurement station, like traditional land surveying, nowadays the geoid height (e.g. EGM-2008) over the global Geodetic System (WGS84) ellipsoid from the

current position can be obtained from modern GPS receivers which have a grid executed inside. This kind of receivers able to correct the height above WGS84 ellipsoid for obtaining the height above WGS84 geoid. This case when the height on the ship is not zero this because the effects of metrological effects as tides, atmospheric pressure, and local sea surface topography [Li and Gutze, 2009].

4.2. Geoid Determination Methods

Determining the linear separation between the geoid and the ellipsoid surfaces, which known by geoidal undulation N, can be classified into two categories related to the kind of data which used. The Classical methods for Geoid determination and using satellites in gravity field determination [Li and Gutze, 2009].

4.2.1. The Classical Geoid Determination Methods

Classical Geoid determination methods can be classified into three methods according to used geodetic measurements. When only one kind of geodetic measurements used is considered such as the astrogeodetic method and gravimetric method. However when a combination of two kinds of geodetic measurements are used is considered as in the astrogravimetric method [Seeber, 2003]

4.2.1.1. The Astrogeodetic Method

The geoid calculation using the astrogeodetic deflection components which determined based on the astronomic observations were taken at the point which known by its latitude and longitude. Thus when the deflection of the vertical is given, the shape of geoid can be determined. The basic equation is as follow [Arsov 2000, Featherstone, 2008].

$$dN = -\varepsilon \, ds \quad (4.1)$$

where

ε: is the deflection of the vertical,

ds: is the horizontal distance

dN: is the increment in geoid height [Saad, 1993].

If we integrate (4.1) we obtain

$$N_B = N_A - \int_A^B \varepsilon \, dS \tag{4.2}$$

where A, B are two points on the geoid as (Figure 4.1).

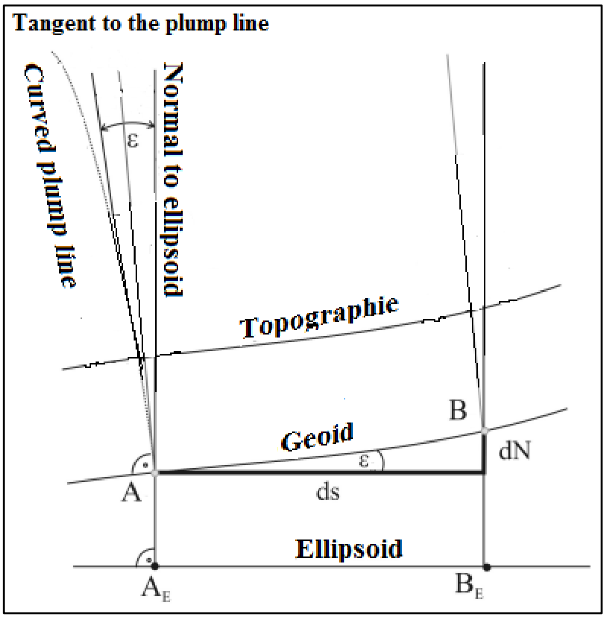


Figure (4.1): Illustrates the shape of **ε**, **dN** and **ds**

http://e-collection.library.ethz.ch/eserv/eth:31025/eth-31025-02.pdf

$$\varepsilon = \xi \cos \boldsymbol{\alpha} + \eta \sin \boldsymbol{\alpha} \tag{4.3}$$

where ξ and η are the components of the defection of the vertical along the profile AB with azimuth $\boldsymbol{\alpha}$. The possibility of producing a geoid map of a coveted area, depending on selecting an appropriate profile and the accurate value of a geoid height at the origin of the profile. Evaluating the integral in (Equation 4.2) by the numerical integration, the components of the deflection must be known at sufficient stations over the profile, so, the points between these stations can be reliably interpolated. In the flat area, the distance between the close astrogeodetic points is 20km and reach to 5-10km

in the mountain areas. For high precision geoid determinations and marine geoid studies, this method is not suitable because it is very expensive and take a lot of time [Arsov, 2000].

4.2.1.2. The Gravimetric Method

The geoid height be determined from a solution of the free Geodetic Boundary Value Problem (GBVP) when using the surface gravity data by Stokes' integral which relative to the geoidal undulation at appointing P to the gravity anomaly**Δ**g [Saad, 1993]:

$$N=\frac{R}{4\pi G}\iint_{\sigma} S(\psi)\,\Delta g d\,\sigma$$

(4.4)

Where R is Radius of the spherical model of the earth

G is the Mean normal gravity on the earth

Δg is free air gravity anomaly at the earth's surface

ψ is spherical distance from the computation point p to d σ

d σ is Element of surface area over which the integration is performed

S(ψ) is Stokes' function and defined by;

$$S(\psi) = \sin^{-1}\frac{\psi}{2} - 6\,sin\,\frac{\psi}{2} + 1 - 5\cos\psi - 3\,cos\psi\,ln\,(sin\,\frac{\psi}{2} + sin^2\frac{\psi}{2}) \quad (4.5)$$

And $$\Delta g = g_p - \gamma_Q \quad (4.6)$$

where: g_p is the observed gravity at point p on the geoid.

γ_Q is the normal gravity computed at the corresponding point on reference ellipsoid.

The Stokes' integration is extended on the whole earth, so Δg values are needed to be known at every point on the geoid. This formula neglecting the

flattening of the reference ellipsoid thus it supposes there is not mass outer the geoid. The Molodensky avoids gravity anomalies on the geoid and obtains height anomalies ξ by using surface gravity anomalies instead of the geoid undulation N. The N value based on some assumptions [Saad, 1993].

$$N = \xi + \frac{g^{-} \; + \gamma^{-}}{\gamma^{-}} H \tag{4.7}$$

g^{-} is the mean gravity along the plumb line between the geoid and the ground.

γ^{-} is the mean normal gravity along the normal plumb line between the ellipsoid and the telluroid.

H is the orthometric height.

ξ is the height anomaly, it is the distance between earth and telluride.

4.2.1.3. The Astrogravimetric Method

In this method, the geoid determination combines the astrogeodetic and gravimetric methods. The Vening Meinesz formula finds the deflections of the vertical by interpolation depending on the incorporation of the gravimetric data.

$$\begin{Bmatrix} \xi \\ \eta \end{Bmatrix} = \frac{1}{4\pi\gamma} \iint_{\sigma} \frac{ds(\psi)}{d\psi} \Delta g \begin{Bmatrix} cos\alpha \\ sin\alpha \end{Bmatrix} d\,\sigma \tag{4.8}$$

If the integration is not extended over the whole earth, there is an error due to neglecting the distant zones. But this error is the same for points that are not too far apart. Therefore, the interpolation between astrogeodetic deflections can be implemented by the computation of the gravimetric deflections in this way. **δ**ε is the difference between the computed gravimetric deflection components ε^{-} and the correct astrogeodetic deflection ε components is [Arsov, 2000]:

$\boldsymbol{\delta}\varepsilon = \varepsilon - \varepsilon^{-}$ (4.9)

The differences $\boldsymbol{\delta}\varepsilon$ can be computed by a linear interpolation because the above equation showed that the variation is only slowly and assumed to change linearly with distance, $\boldsymbol{\delta}\varepsilon$ commuted by;

$$\boldsymbol{\delta}\varepsilon = \boldsymbol{\delta}\varepsilon_A + \frac{\delta_{\varepsilon_B} - \delta_{\varepsilon_A}}{S_{AB}} S_{Ap} \quad (4.10)$$

where P is any point on the profile between A and B and S is the distance between the points corresponding to the subscript. After determining the interpolated deflections at close points along the profile, the geoid undulation differences can be determined using (Equation 4.2).

In the astrogravimetric technique, the astrogeodetic stations might reach to 100-200 kilometer in a leveled state, however, an enough dense gravity net should be extended to a minimum of double the distance between the two stations. For this reason, the number of needed astronomic stations are much less than the case of astrogeodetic technique. In This technique, the gravity anomalies are needed in a small area around the computation point. So this method is considered less expensive than other [Arsov, 2000].

4.2.2. Gravity Field Determination by Using Satellites

Satellite geodesy (SG) is the science branch which observe the size, shape of the Earth and the site of features on/in the surface of the Earth. It is considered a branch of the space geodesy field, which concludes a lot of other techniques as Very Long Baseline Interferometry (VLBI) and Lunar Laser Ranging (LLR). The most important objectives of SG are: The figure of the Earth determination, positioning, and navigation, earth's gravity field and its temporary variations and determination of geoid, dynamical SG and observe geodynamical phenomena and its measurements as crustal dynamics and polar motion. Categorization of SG techniques related to mechanism platform; the satellite observed with a ground-based device,

called earth-to-space-methods, the satellite contains a device or sensor to observe the Earth, called Space-to-Earth methods and the satellite tracks or be tracked from another one, it is named as Satellite to Satellite tracking. This technique called Space-to-space methods. The following is some satellite missions used in gravity field determination of the earth [https://en.wikipedia.satellite missions 2015].

4.2.2.1. Radar altimetry (RA)

Determining the distance between the spacecraft and sea surface by calculating the round-trip flight time of a microwave pulse among the satellite and the surface of the Earth. This distance aids to eliminate the effect of the local surface as tides, winds, and others for determining the height of the satellite above the geoid. At any time by using the precise ephemeris of the satellite, the ellipsoidal height and geocentric position of it can be easily determined. By subtracting the measured altitude from the ellipsoidal height, the geoid height can be calculated. This technique helps direct measurement of the geoid. The difference between the actual geoid and the ocean surface gives ocean surface topography. As TOPEX/Poseidon and Seasat [Ries et al., 2011].

4.2.2.2. Laser Altimetry (LA)

As Radar altimetry (RA) but it finds the spacecraft's height by utilizing the round-trip travel time of a light's beam at optical or infrared wavelengths, as ICES [Ries et al., 2011].

4.2.2.3. Gravity Gradiometry

It measures the components of the gravity vector at real-time. Gradiometry measures the difference in acceleration of test masses over small distances with two accelerometers for each direction. In this way,

components of the gravity tensor can be measured, which will mainly provide information on the high-degree spherical harmonics of the Earth's gravity field as GOCE [Ries et al., 2011].

4.2.2.4. High-Low Satellite-to-Satellite Tracking (hl-SST)

An alternative method to measure the position of a satellite is to use high-low satellite-to-satellite tracking (hl-SST) by means of GPS measurements for example CHAMP satellite [Weigelt et al., 2013].

4.2.2.5. Low-Low Satellite-to-Satellite Tracking (ll-SST)

A constellation of multiple satellites measuring their mutual distances (ll -SST), combined with an absolute positioning technique (hl-SST / SLR) can improve the estimation of the Earth's gravity field, especially its temporal variations, for example GRACE satellite [Weigelt et al., 2013].

4.3. Examples of the Most Common Satellites Mission

4.3.1. Challenging Minisatellite Payload (CHAMP)

It is a high-low satellite to- satellite tracking (hl-SST) and accelerometry data. The CHAMP dedicated gravimetry satellite was launched on 15 July 2000. CHAMP was a cooperative project between Germany and NASA, with NASA providing a GPS Blackjack Flight receiver. CHAMP mapping of the Earth's global long to medium wavelength gravity field, and CHAMP's multifunctional and complementary instrumentation provides for the first time in space geodesy's history an almost continuous tracking of the spacecraft motion at a low altitude with a high precision in-situ measurement of the forces acting on the satellite surface and simultaneously a global mapping of the magnetic field with a high precision and spatial resolution. The Champ orbits are a near-circular orbit at an initial altitude of 454 km and an inclination of 87.3° to the

equatorial plane. The hl-SST allows a near-global coverage of gravity field data, which was previously unavailable with ground-tracked satellite data. The CHAMP satellite also houses a three-axis accelerometer to help reduce the effect of non-gravitational perturbations [Salah, 2012].

The CHAMP concept of high-low satellite-to-satellite tracking, where the ~20200 km altitude GPS satellites continuously track the position of the ~454 km altitude CHAMP satellite shows in (Figure 4.2).

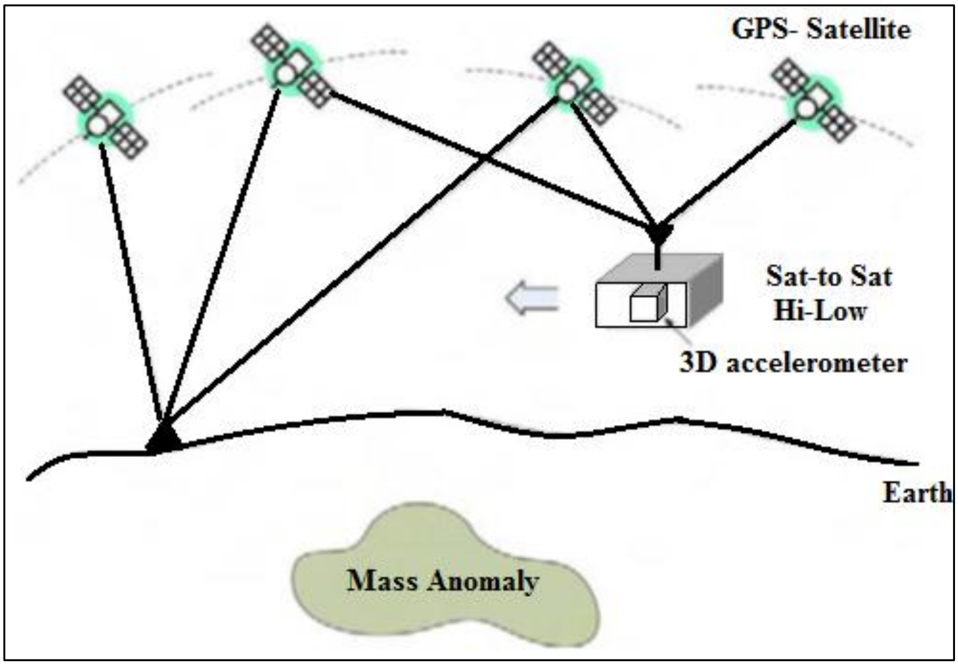


Figure (4.2): Simple shape of CHAMP [Salah, 2012].

4.3.2. The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE)

It is a European Space Agency-led mission primarily to determine the global gravity field. The GOCE mission use a low-Earth (~260-km altitude) orbiting satellite in a nearly Sun-synchronous orbit at 96.5 degrees inclination, together with high-satellite to low satellite GPS/GLONASS-based tracking. The GOCE satellite measures the earth's gravity field in two combined techniques, by satellite-to - satellite tracking (SST) plus accelerometer, and by gradiometry. First technique are using the onboard

accelerometers to determine the acceleration due to body forces, the GPS tracking of the satellite then constrains the estimation of gravitational accelerations, permitting the earth's gravitational field to be determined. This technique is particularly suited to longer wavelength parts of the gravity field [Visser, 2009].

The GOCE concept of a low-Earth orbiting (~250 km) satellite gravity gradiometer combined with high-low satellite-to-satellite tracking by GPS satellites shows in (Figure 4.3) [Salah, 2012].

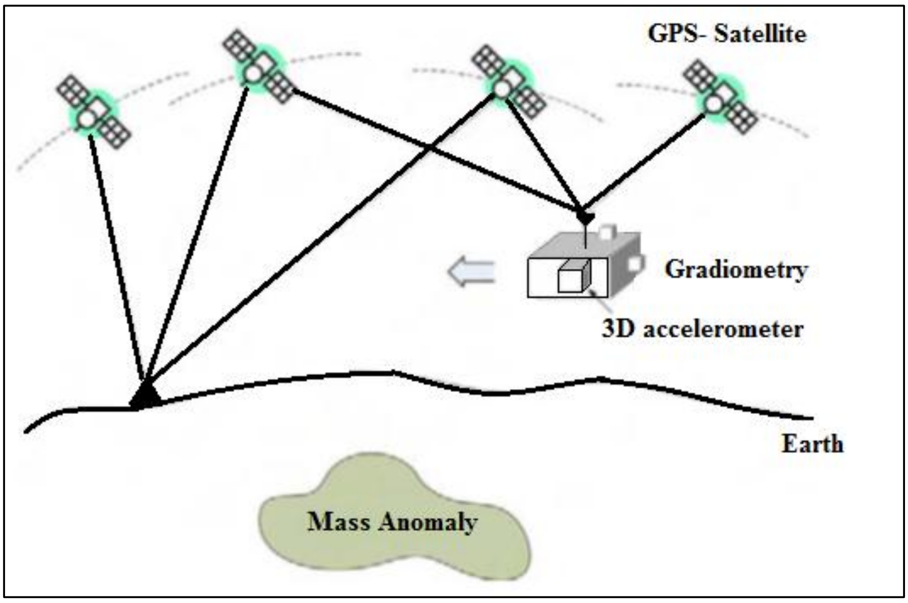


Figure (4.3): Simple shape of GOCE [Salah, 2012].

The second technique used in GOCE is gradiometry, and it is this method which permits the recovery of short wavelength features in the gravity field. Gradiometry uses a pair of accelerometers to measure the difference in gravitational acceleration between two nearby points (separated by 0.5m for GOCE). There are three such pairs in GOCE, arranged along mutually orthogonal axes, resulting in a full measurement of the three-dimensional gradient of gravity [Visser, 2009].

4.3.3. The Gravity Recovery and Climate Experiment (GRACE)

It is a joint project of the American space agency NASA with the German Aerospace Center (DLR). GRACE mission that follows on from CHAMP. The GRACE experiment consists of two identical spacecrafts flying in the same orbit about 220 kilometers apart. The mission consists of two identical CHAMP-type satellites following one other in nearly the same orbit separated by a distance of ~170- 270-km, Both satellites weight 485 kg each, fly at an initial altitude of 500 km and orbit the Earth in about 95 minutes, the so-called tandem formation.

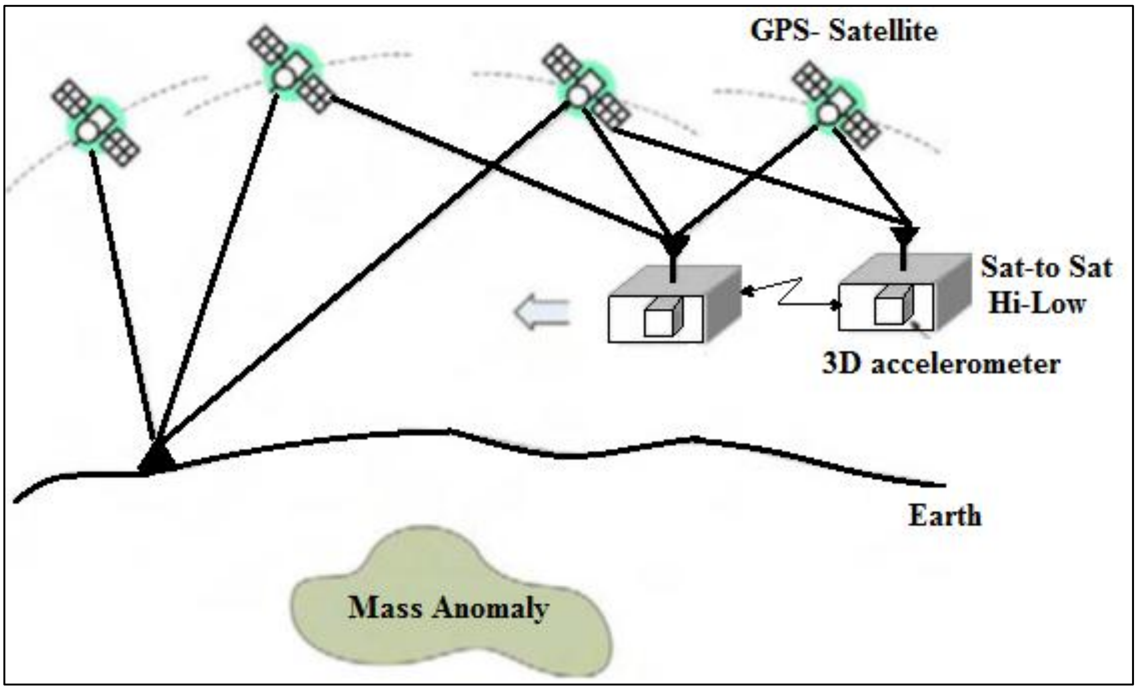


Figure (4.4): simple shape of GRACE. The GRACE concept of combined high-low and low-low satellite-to-satellite tracking; the coupling of hl-SST and ll-SST improves upon CHAMP in the low frequencies, and improves the spatial resolution [Salah, 2012].

The low-satellite to low-satellite inter-tracking is measured using microwave links, coupled with high-satellite to low-satellite GPS-based SST tracking of both satellites, in (Figure 4.4), simple shape of GRACE. The five-year GRACE mission was launched on 17 March 2002 supposedly

as follow-on to CHAMP, though there will be an overlap period of approximately two years. The GRACE mission will improve upon the CHAMP determination of the global gravity field at low frequencies and will also increase the spatial resolution. The improvement in the low frequencies is because of the redundancy offered by the use of two low-Earth orbiting satellites, coupled with high-low SST. It will also allow time variations in the Earth's gravity field to be mapped approximately every 30 days [Visser et al., 2002].

4.4. Global Geo-potential Models (GGM)

GGMs play a key role for the unification of national height systems and the support of vertical datum modernization efforts based on precise GPS positioning. In view of the recent progress and upcoming improvements in gravity field mapping (e.g. GOCE mission), it is not actually unreasonable to claim that a cm-level world vertical datum may be eventually realizable through a global geoid model obtained from a high-resolution and high accuracy GGM. There are essentially three classes of GGM [Amos and Featherstone, 2003].

4.4.1. Satellite-only GGMs

Derived solely from the analysis of the orbits of artificial Earth satellites. Historically, these models were limited in precision due to a combination of: the power-decay of the gravitational field with altitude; the inability to track complete satellite orbits using ground-based stations; imprecise modelling of atmospheric drag, non-gravitational and third-body perturbations; and incomplete sampling of the global gravity field due to the limited number of satellite orbital inclinations available. Therefore, while some satellite-only GGMs are available above degree 70, the higher degree coefficients, say greater than 20, are heavily contaminated by noise,

however, several of the above limitations have now been redressed by the use of the dedicated satellite gravimetry missions [Abdalla, 2009].

4.4.2. Combined GGMs

Combined GGMs are derived from the combination of satellite data, land and ship track gravity observations, and marine gravity anomalies derived from satellite radar altimetry, and more recently airborne gravity data. This generally allows an increase in the maximum spherical harmonic degree of the GGM. However, these models are also limited in precision due to the above-mentioned restrictions on [older] satellite-only GGMs, as well as the spatial coverage and quality of the additional data used. For instance, distortions in and offsets among different vertical geodetic datums cause long-wavelength errors in terrestrial gravity anomalies, among with many other causes. These will generate low-frequency errors in the combined GGMs if not properly high-pass filtered from the combined geo-potential solution [Abdalla, 2009].

4.4.3. Tailored GGMs

Tailored GGMs adjust (and often extended to higher degrees) a satellite-only or combined GGM using gravity data that may not necessarily have been used before. This is normally achieved from using integral formulas to derive ‘corrections’ to the existing geo-potential coefficients, as opposed to the combination at the normal equation level that is used to construct combined GGMs. Importantly, tailored GGMs only apply over the area in which the tailoring was applied, because spurious effects can occur in areas where no data are available. GGMs are used to determine the Earth’s external gravitational field and its functional (e.g. disturbing potential, geoid heights, gravity anomalies, etc.). The accuracy level of the quantities derived the models vary from region to region. Therefore, the performance of any

GGM needs to be validated in a regional scale by comparisons with other external data depending on the same gravity field. The accuracy of the models, commonly, has been assessed by using GNSS/levelling data. Also, the comparisons may be based on the other data sets including terrestrial gravity data and altimeter data over sea, etc.

Several studies have demonstrated various comparisons of the geoid heights obtained from the GGMs and the GNSS/levelling data in both absolute (at individual points) and relative (for baseline of varying lengths) sense. Moreover, there are many studies about the accuracy of the GGMs tested with the terrestrial gravity data and the altimeter data have used the vertical deflections to evaluate EGM2008. It has been stated that although the results from such evaluation studies depend on several factors (e.g. quality of the external data, consistency of their datums, applied testing methodology, etc.), they can mostly enable a reliable assessment of the accuracy level of GGMs over different areas. Nowadays, GNSS/levelling can be considered as an alternative for practical height determination. In the GNSS/levelling, the orthometric heights H are determined by converting the ellipsoidal heights h regards a reference ellipsoid by applying the fundamental equation where orthometric height equal ellipsoidal height minus geoidal height [Amos and Featherstone, 2003];

Hence, determining the geoid heights through an accurate geoid model (or GGM) enables to obtain the orthometric heights with sufficient accuracy using the GNSS positioning. In relation to this case, a requirement for a high precision geoid model preferably referring to a global geocentric datum. Accordingly, many countries have continued to make efforts to develop their own high precision geoid model. GGMs have important meanings as reference surface for calculating a local geoid. Also, the GNSS/levelling data are very important factor to fit gravimetric geoid

models to local vertical datum. Considering all of these, a precise geoid model is an important component for GNSS/levelling.

During the last 30 years, a variety of GGMs, which express the Earth's gravity field and thus geoid heights in terms of harmonic basis functions, have been computed by various groups, for an extensive description of existing models refer to the web pages of International Centre for Global Earth Models (ICGEM) (URL1). In the compilation of a GGM the long wavelength contribution of the Earth's gravity field is recovered from the satellite tracking data. Recall that the motion of a satellite is perturbed by various forces. By studying the satellite orbit perturbations the broad characteristics of the gravity field can be recovered.

Improvements to the Earth gravity models at medium and short wavelengths should come from the use of satellite altimetry, terrestrial, marine or airborne gravity surveys of varying epoch, quality and geographic coverage. The accuracy of such models, at higher degrees is quite dependent on the geographic coverage of gravity data that goes into the solution. Needless to mention that the weighting of the various data types in the GGM development is a delicate task. Prior to the year of 2000 the harmonic degree errors of the GGMs were roughly divided into three frequency bands [Amos and Featherstone, 2003]

-Spherical harmonic degrees $2 \leq n \leq 20$ offer a superior information source of the low frequency component of the geoid. The estimation of the coefficients of these degrees is exclusively based on the satellite derived contribution.

-Spherical harmonic degrees $20 \leq n \leq 120$, for which the GGM gives a reasonable accuracy almost everywhere on Earth and where the terrestrial data may offer an improvement in certain parts of the world, only if these data are of good quality.

-Spherical harmonic degrees $120 < n \leq 360$, for which the geo-potential

model may not be the best source of gravity field information and an improvement from terrestrial data should thus be sought [Rummel, 2014].

Some examples of Satellite only, tailored, and combined global geo-potential models types are shown in (Table 4.1).

Table (4.1): Examples of global geo-potential models types [Amos and Featherstone, 2003].

Model	Degree	Class
EGM96	360	Combined
EGM2008	2160	Combined
EGM96S	70	Satellite-only
GPM98C	1800	Tailored

4.4.4. Common Global Geo-potential Models in a Simple Explanation

4.4.4.1. Earth Gravitational Model 1996 (EGM96)

The EGM96 is a combined geo-potential model consisting of the spherical harmonic coefficients complete to degree and order 360. The US National Imagery and Mapping Agency (NIMA), now National Geospatial Agency (NGA), the US National Aeronautics and Space Administration (NASA), Goddard Space Flight Center (GSFC), and the Ohio State University (OSU), collaborated in the determination of EGM96. The geoid accuracy of the EGM96 is better than one meter with the exception of areas void of dense and accurate surface gravity data. It offers level of spatial resolution of ~55 km (or ~30 arc minutes) for the recovery of any gravity field functional over the entire globe [Amin et al., 2003].

New higher resolution models have been developed. For example, many of the authors of EGM96 worked on an updated model that should

incorporated much of the new satellite gravity data, and supported up to degree and order 2160. National Geospatial-Intelligence Agency (NGA) has announced the availability of EGM2008, complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159 [Pavlis, 2013]. [http://cddisa.gsfc.nasa.gov/emg96/egm96.html.

4.4.4.2. Earth Gravitational Model 2008 (EGM2008)

Developed by the NGA, EGM2008 is the first-ever global model that is capable of resolving the Earth's gravity field beyond spherical harmonic degree 2000). The EGM2008 set of spherical harmonic coefficients is complete to degree 2190 and order 2159. With the release of the EGM2008, a considerable improvement has been in high-resolution global gravity field modeling. The model allows determination of the Earth's gravity field globally with a spatial resolution of ~9 km (or ~5 arc minutes) in the latitudinal direction, which is 6 times higher than that of EGM96. As previously pointed out the discrepancies between the EGM2008 geoid heights and independent GNSS/levelling values are on the order of ±5 to ±10 cm over areas covered with high quality gravity data. Also, they have claimed that the accuracy of EGM2008, as gauged from comparisons with independent data, is 3 to 6 times higher than that of EGM96, depending on the gravitational functional.

Especially, unlike previous GGMs, the EGM2008 contains gravity data of 15' resolution for Asian regions. Furthermore, the gravity data provided by GRACE satellite system has greatly contributed to the development of EGM2008. The detailed overview of the model can be found from EGM2008 [Hirt, and et al., 2011].
[http://cddisa.gsfc.nasa.gov/emg2008/egm2008.html].

4.4.4.3. EIGEN-GL04C

The combined gravitational model EIGEN-GL04C was released on March 31, 2006 as an upgrade of EIGEN-CG03C. It is a combination GRACE and LAGEOS mission with high resolution 0.5° x 0.5° gravimetry and altimetry surface data. The satellite data have been analyzed by GFZ Potsdam and GRGS Toulouse. All surface gravity data are alike those of EIGEN-CG03C excluding the geoid undulations over the oceans derived from a new GFZ mean sea surface height (MSSH) model minus the ECCO sea surface topography (EIGENCG03C: CLS01 MSSH minus ECCO). EIGEN-GL04C is complete to degree and order 360 in terms of spherical harmonic coefficients and thus resolves geoid and gravity anomaly wavelengths of 110 km. High-resolution combination gravity models are important for all applications that require precise knowledge of the static gravity potential and its gradients are needed in the medium and short wavelength spectrum [Abdalla, 2009].

4.4. Tailoring Global Geo-potential Models

As mentioned before, the methods for geoid determination are depending on diversity of existing data as gravimetric method which using surface gravity data, satellite missions, and geometric method, where several factors affect the accuracy of geoid model determination such as the number and distribution of reference stations points (GPS/levelling stations). These points must be distributed homogeneously to the coverage area of the model and ellipsoidal heights (h) derived from GPS and the heights derived from levelling measurements (H) must have high Accuracy.

Global Geo-potential Models (GGMs) have a great effect in local and regional geoid determination. However, the modeled part of the gravity may contain long wavelength errors which affected the geoid heights derived

from it. So the best model which is able to generate accurate geoid heights N and geoid height differences ΔN [Abd-Elmotaal et al., 2015].

Tailoring is a process of enhancing the GGMs to improve and fit their spherical harmonic coefficient to the gravity data of the region with a view to improving it as a reference model for a local geoid determination. Combining GGMs and groups of local geodetic data has been achieved on a large scale in order to find the residuals of the global geo-potential models to increase their performance and accuracy in local area by minimizing the long wavelength geoid and datum inconsistencies depending on improving the model coefficients by adding the correction terms (harmonic analysis of the residuals) to the coefficient of the adopted GGMs to find the enhanced coefficients [Al-Krargy et al., 2014 and Amin et al., 2017].

There are several studies have shown that the GGMs tailored to gravity data are best suited for high precision regional and local geoid. (Equation 4.11) shows the process of improving the model's coefficients [Bašić et al., 1990 and Amin et al., 2003]:

$$\begin{Bmatrix} \Delta\bar{C}_{nm} \\ \Delta\bar{S}_{nm} \end{Bmatrix}_{Tailored\ GGM} = \begin{Bmatrix} \Delta\bar{C}_{nm} \\ \Delta\bar{S}_{nm} \end{Bmatrix}_{Original\ GGM} + \begin{Bmatrix} \delta\Delta\bar{C}_{nm} \\ \delta\Delta\bar{S}_{nm} \end{Bmatrix}_{Corrections} \quad (4.11)$$

There are several methods (different methods of harmonic analysis techniques) have been used to estimate the potential coefficients of the tailored geo-potential model as integral formulas through the iterative algorithm [Weber and Zommorrodian, 1988].

4.4.1. Validity of Tailoring Global Geo-potential Models (GGMs) in Different Cases

Several studies for tailoring the global GGMs are carried out in different regions over the world to be more suitable for these regions.

(globally, continental and regionally over a particular region). Globally tailoring the GPM98 models, tailoring OSU86F for Europe, tailoring EGM2008 in Africa, tailoring EGM96 and OSU91A for China, GPM2 for Iran, and others. Some of these studies briefly appear in the following section [Weber and Zomorrodian 1988, Basic et al., 2000, Abd-Elmotaal et al., 2015, Motao et al., 1996 and Weber et al., 1988];

- The GPM98A, GPM98B and GPM98C globally tailored geo-potential models have been computed to spherical harmonic degree 1800. The GPM98 models are based on the degree-20 expansion of EGM96 and global $5' \times 5'$ mean gravity anomalies collected from surface gravity and altimetry for about 75% of the earth's surface (the remaining areas being filled by larger block size values), where integral formulas in an iterative algorithm were applied for the calculation of the higher degree spherical harmonic coefficients. In areas well covered by high-resolution data, this solution provides a relative geoid accuracy of a few cm and gravity anomalies accurate to several 10 μms^{-2} [Weber and Zomorrodian, 1988].

- High-degree tailored reference geo-potential model EGM2008 have been created for Africa, to be used to fill the gravity data gaps, which are present in the database of the African Geoid Project, before the geoid computation process. This tailored model will also be updated iteratively.

  The gravity anomalies (topographically-isostatically) for Africa have been compiled and interpolated to a local data-grid of $0.5^o \times 0.5^o$ resolution. This grid has been merged with a global grid of EGM2008-based topographically- isostatically reduced gravity anomalies and used to estimate the potential coefficients of the tailored reference models for

Africa by three different techniques. They are the FFT, the least-squares and the Gauss numerical integration techniques. The tailored geo-potential models created in this investigation give smaller residual gravity anomalies for Africa. The variance and the range decreased by about 50% compared to the original free air anomalies. The FFT and the Gauss harmonic analysis techniques give quite similar results, which are very close to the least-squares, derived potential coefficients. The tailored geo-potential models created within this investigation are more suitable than EGM2008 or recent GRACE/GOCE derived geo-potential models for gravity interpolation considering the large data gaps appearing in the African gravity data base [Abd-Elmotaal, 2015].

- The IFE88E2 regionally tailored geo-potential model is based on the OSU86F global geo-potential model, and has been tailored using only European gravity data through integral formulas in an iterative algorithm. The model OSU86F has been tailored to Europe using as input data $0.5^{o} \times 0.5^{o}$ mean free-air gravity anomalies from the Institut für Erdmessung, University of Hannover, Germany, and Kort-og Matrikelstyrelsen, Denmark. The magnitude of residual point free-air anomalies relative to OSU86F and IFE88E2 were evaluated in 1495 points in Scandinavia. The RMS values of the differences were ±23.4 mGal and ±18.5 mGal respectively. Especially comparisons of the two models with GPS /levelling data in Europe show an improved accuracy of the IFE88E2 model. The RMS value of the differences relative to OSU86F is 0.774 m and decreases to 0.322 m for IFE88E2 [Kearsley and Forsberg 1990 and Basic et al., 2000].

- An ultra-high-degree tailored reference geo-potential model for Egypt called EGTGM2014, complete to degree and order 2160, has been based

on the EGM2008 reference geo-potential model. The local gravity anomalies for the Egyptian data window are gridded, after removing the effect of the topographic-isostatic masses for the data window as well as the effect of EGM2008 from n = 361 to n = 2160, in $0.5^{o} \times 0.5^{o}$ grid using kriging interpolation technique. The local gridded data are merged with the global $0.5^{o} \times 0.5^{o}$ gravity anomalies, computed using EGM2008 till N = 360 after removing the effect of the global topographic-isostatic masses using SRTM $0.5^{o} \times 0.5^{o}$ DHM, to establish the data set for computing the tailored geo-potential models. The merged $0.5^{o} \times 0.5^{o}$ global field has been then used to estimate the harmonic coefficients of the tailored reference model by an FFT technique, till degree and order 360, using an iterative process to enhance the accuracy of the obtained harmonic coefficients and to minimize the residual field. The higher coefficients (from n = 361 to n = 2160) of EGM2008 has then been restored generating the EGTGM2014 ultra-high-degree tailored geo-potential model complete to degree and order 2160. The tailored geo-potential model created in this investigation gives better residual gravity anomalies. The variance has dropped by about 35 %. Gravimetric geoids for Egypt have been computed using both the EGM2008 and the EGTGM2014 tailored geo-potential models. Using the EGTGM2014 tailored geo-potential model improves the external geoid accuracy by about 20%, and the range of the remaining differences has dropped by about 22 % [Abd-Elmotaal, 2014].

- Three different tailored geopotential models for Egypt have been created by maintaining the lower harmonics till degree 20, 36, and 72 to their values as of EGM96 model denoted as EGGM06A, EGGM0B, and EGGM06C, respectively. The tailored models EGGM06 computed to spherical harmonic degree 360. The local gravity anomalies for the

Egyptian data window are gridded in 0.5^o x 0.5^o grid using the remove/restore window technique. The local gridded data are merged with the global 0.5^o x 0.5^o gravity anomalies, computed using EGM96 till N = 360, to establish the data for computing the tailored geopotential models EGGM06.

The merged 0.5^o x 0.5^o global Field has been used to estimate the harmonic coefficients of the tailored reference models by FFT technique. The tailored geopotential models EGGM06A, EGGM06B, and EGGM06C created in this investigation give better residual gravity anomalies. All three tailored geopotential models developed within the current investigation give practically the same results [Abd- Elmetaal, 2014].

- Satellite-only and high degree reference geo-potential models denoted as GOCO05s and EGM2008, respectively, have been tailored (refined) to fit the gravity data in Egypt using integral formulas in order to select the optimal model that can be used for the reference gravity field model for the Egyptian territory. The results show that the tailored model of EGM2008 denoted as EGTM0817 is the one that gives better results in Egypt than the other tailored model of GOCO05s denoted as EGTGOC5s, where the mean value, the standard deviation and the range of the reduced gravity anomalies to EGTM0817 compared with EGTGOC5s have lesser values by about 80%, 30%, and 21%, respectively [Amin et al., 2017].

4.4.2. The Methodology for Tailoring the Global Geo-potential Model

The computation of the tailored model (Equation 4.11) is carried out by different methods of harmonic analysis techniques such as; integral

formulas through the iterative algorithm [Motao et al., 1996, Basic 2000, and Weber et al., 1988].

The standard representation of the earth's disturbing potential is equal to differences between the actual potential (W) and the normal potential (U). The disturbing potential (T) is a harmonic function taken as follows;

$$T(r,\theta,\lambda) = \frac{GM}{r} \sum_{n=2}^{\infty} \left(\frac{a}{r}\right)^n \sum_{m=0}^{n} (\Delta\overline{C}_{nm} \cos m\lambda + \Delta\overline{S}_{nm} \sin m\lambda)\, \overline{P_{nm}}\,(\cos\theta) \quad (4.12)$$

where r, θ, λ are the polar coordinates of the point at which T is to be determined

G is the geocentric gravitational constant,

M is the Earth mass-Gravitational constant product consistent

a is the semi-major axis of the reference ellipsoid,

$\bar{p}_{nm}$ denotes the associated fully normalized Legendre functions.

$\Delta\bar{c}_{nm}, \Delta\bar{s}_{nm}$ are differences between the fully normalized spherical coefficients of actual and normal gravity potential

The gravity anomaly (Δg) can be expressed in terms of spherical harmonics as;

$$\Delta g\,(r, \theta, \lambda) = -\frac{\sigma T}{\sigma T} - \frac{2}{r}\, T\,(r, \theta, \lambda) \quad (4.13)$$

Inserting (4.12) into (4.13), the expression for the gravity anomaly (Δg) becomes in spherical approximation.

$$\Delta g(r,\theta,\lambda) = \frac{GM}{r^2} \sum_{n=2}^{\infty} (n-1) \left(\frac{a}{r}\right)^n \sum_{m=0}^{n} (\Delta\overline{C}_{nm} \cos m\lambda + \Delta\overline{S}_{nm} \sin m\lambda)\, \overline{P_{nm}}\,(\cos\theta) \quad (4.14)$$

The quadrature procedure for estimating spherical harmonic coefficients may be computed from gravity anomalies by employing the orthogonality relationships for fully normalized spherical harmonic functions as [Torge, 1989].

$$\begin{Bmatrix} \Delta\bar{C}_{nm} \\ \Delta\bar{S}_{nm} \end{Bmatrix} = \frac{1}{4\pi} \iint_{\sigma} \frac{r^2}{GM} \left(\frac{r}{a}\right)^n \frac{1}{n-1} \Delta g(r,\theta,\lambda) \begin{Bmatrix} \cos m\lambda \\ \sin m\lambda \end{Bmatrix} \overline{P}_{nm}(\cos\theta)\, d\sigma \qquad (4.15)$$

Where σ is unit sphere and dσ is surface area element. The method of actual evaluation of (Equation 4.15) is carried out using a set of mean gravity anomalies ($\overline{\Delta g}$).

A mean gravity anomaly ($\overline{\Delta g}_{GGM}$) can be compute from global geo-potential models (GGMs) from (Equation 4.14) as follows;

$$\overline{\Delta g}_{GGM} = \frac{GM}{r^2} \sum_{n=2}^{n_{max}} (n-1) \left(\frac{a}{r}\right)^n \beta_n \sum_{m=0}^{n} (\Delta\bar{C}_{nm} \cos m\lambda + \Delta\bar{S}_{nm} \sin m\lambda)\, \overline{P}_{nm}(\cos\theta) \qquad (4.16)$$

Where n_{max} is maximum degree of GGM and β_n are the Pellinen smoothing functions.

Comparing mean gravity anomalies ($\overline{\Delta g}_{GGM}$) derived by global geo-potential models (GGMs) with mean gravity anomalies ($\overline{\Delta g}_{data}$) derived from local gravity data, yields residual gravity anomalies.

$$\delta\overline{\Delta g} = \overline{\Delta g}_{data} - \overline{\Delta g}_{GGM} \qquad (4.17)$$

These residual anomalies ($\delta\overline{\Delta g}$) can then be expanded in spherical harmonic to yield correction $\delta\overline{\Delta C}_{nm}$, $\delta\overline{\Delta C}_{nm}$ to spherical harmonic coefficients of GGMs using the following expression as [Kearsley and Forsberg, 1990].

$$\begin{Bmatrix} \delta\Delta\bar{C}_{nm} \\ \delta\Delta\bar{S}_{nm} \end{Bmatrix} = \frac{1}{4\pi} \sum_{i=1}^{k} \frac{r_i^2}{GM} \left(\frac{r_i}{a}\right)^n \frac{1}{n-1} \frac{1}{\beta_n} \delta(\overline{\Delta g_i}) \iint_{\Delta\sigma_i} \begin{Bmatrix} \cos m\lambda \\ \sin m\lambda \end{Bmatrix} \overline{P}_{nm}(\cos\theta)\, d\sigma \qquad (4.18)$$

Where k is the number of differences occurring between GGMs and local gravity anomalies. Finally, the coefficients of tailored (modified) model are now obtained by adding the correction $\delta\overline{\Delta C}_{nm}$, $\delta\overline{\Delta C}_{nm}$ to start GGMs as (Equation 4.11)

Tailored model can now be used in (Equation 4.16) to produce mean gravity anomaly ($\overline{\Delta g}$), point gravity anomaly(Δg) and geiod height (N). Also, residual gravity anomalies (Equation 4.18) may once again be formed iteratively as follows;

$$\delta\,(\overline{\Delta g}_i) = \overline{\Delta g}_{data} - (\overline{\Delta g}_i)_{GGM} \qquad i = 1, 2, ...k \qquad (4.19)$$

where the index i signals the i^{th} tailoring step. Formula (4.11) to (4.19) can be iterated until $(\delta\overline{\Delta g})_i$ no longer show a significant decrease in the root mean square (RMS) variation.

Since the early 1980s different methods of harmonic analysis techniques can be used to estimate the potential coefficients of the geo-potential models such as; has introduced an effective and fast technique for the harmonic analysis of complete grids of a single data type using Fast Fourier Transform (FFT) [Colombo, 1981].

Finally, presented a modified technique which used Colombo's (1981) technique with iterative and scaling process for the harmonic analysis of data on the surface of both the sphere and on the ellipsoid [Abd-Elmotaal, 2004].

4.4.3. Best Fitting the Global Geo-potential Model over a Local Area

To best fit and check the global geoid model with the study area, the observed geoid undulations should be compared against the adopted best GGM for that area, several techniques are used for modeling the geoid heights (N) for a local area [Al-Krargy et al., 2014].

For a check the tailoring model, firstly the geoidal undulations at all GPS/levelling points have been obtained (N_{obs}) and at the same points the geoidal undulations have been obtained from GGMs (N_{GGMs}) then a comparison between geoidal undulations at all points have been done to determine the best model on the tested area by the following equations [Mohamed, 2003]:

$N_{obs} = h - H$ (4.20)

$dN = N_{obs} - N_{GGMs}$ (4.21)

where N_{ObS} is the difference between ellipsoidal heights "h" and orthometric heights "H" and N_{GGMs} is geoid undulations of the Global Geoid Model which adopted for the study area. Values of dN from the previous equations show the accuracy of both tailored and original model [Dawood et al., 2010].

CHAPTER (5)
UNIFICATION OF VERTICAL DATUMS IN THE ARAB WORLD

This chapter contains the suggested proposals for the vertical datum unification of the Arab region. The first proposal consists of two main parts;

- The first part demonstrates the information about the existing geodetic observations concerning the vertical datums;

  Tide gauge stations, GNSS stations, levelling BMs, and gravity stations in the study area. This part also includes the technical specifications for establishing the required observations, such as the number of stations, their distribution, and accuracy.
- While, the second part suggested a plan for unifying the vertical datum in the study area and contained the steps of establishing a main center to receive and deal with the observations (old and new) mentioned in part one, collecting them, filtering, processing, adjusting, and applying the suitable mathematical models to finally, guarantee a unified vertical datum for the users in the whole area.

5.1. The First Proposal; Part One

In Arab countries, the strategy of utilizing mean sea level as the reference for heights have been widely accepted up to now. It is known, that the mean observations of the local sea level at the tide gauge locations cannot be considered to correspond the geoid. That means, the mean sea level at one site has not the same geo-potential surface as that at another site and using the mean sea level as a height reference causes some problems in the applications of the vertical datum [Ihde, 2007].

In Arab region, there are several local vertical datums(LVD) that differ from one country to another. Most of these datums are based on averaging

sea level measurements of a single tide gauge (TG) (e.g. Egypt) or from multiple TGs (e.g. Saudi Arabia).

One of the obstacles against the huge regional projects between Arab countries as transportation lines, Petroleum Pipelines, electricity, and other projects which require heights, is the difference in SST at tide gauge sites and differences in measuring techniques. Therefore the Precise geoid determination is considered an important step in eliminating these differences as it represents the base for determination the regional geoid model.

5.1.1. Tide Gauge Stations in Arab World

Through the data presented in chapter three, in Arab countries there are at least twenty-two tide gauge stations were fixed to mean sea level. These stations are considered the origin of the vertical datum where they are scattered and distributed in the Arab world as a whole, as one tide gauge station in each country. Recall (Figure 3.31) from chapter three which shows the tide gauge's locations in all countries.

Sensors continually record the height of the water level according to a height reference surface very near to the geoid. By the bottom of pipe, water enters the device and water height is measured by electronic sensors and send the data to a computer. In general tide gauges are used for measuring tides and quantify the size of tsunamis. The taken measurements are used to derive the MSL and sea level slope.

Historical data have to be available for the twenty two stations all over Arab world, and also the continuous updates to those data should be available. Therefore all these tide gauge stations need a lot of continuo maintenance to guarantee the specified accuracy. So the Arabian tide gauge stations network should be formed, it'll be a continuous observation network and it'll introduce a continuous enhancements for all stations. Beside the historic data at every tide gauge station, the most accurate tide gauge unit will be fixed in every

tide gauge stations. The new units will be the same kind to guaranty the same accuracy at all the stations. The specified headquarter will receive the observations from the new units for one year beside the historic data. The analysis center will deal with all the received data and process them and get the final result along with the other collected data as will be mentioned.

Technological advances helped in solving several of the troubles associated with the old tidal recording systems. Microprocessor-based technology enable customized data collecting and will enhance measurement accuracy. Whereas older tidal measuring stations used mechanical floats.

5.1.1.1.The Proposed First Device

The first proposal is to use a new generation of follow up stations in installation the same advanced electronics acoustics gauges at all stations. Today acoustic gauges send an audio signal under a half-inch-wide sounding tube and measure the time for reflecting signal to travel back from the water's surface. The sounding tube is mounted within a 15cm diameter protecting well, that it is like to the old stilling well. The shape of acoustic gauge shows in (Figure 5.1).

[http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide11c.html]

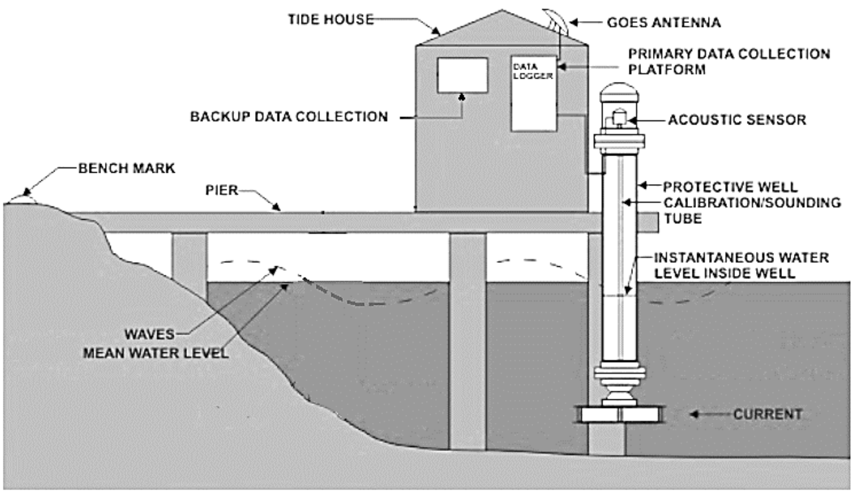


Figure (5.1): Shows the shape of acoustic tide gauge

https://www.google.com.eg/Acustic tide gauge.

Similar to the old recorders, the new measuring stations collecting data every six minutes. However, while the old recording stations used mechanical timers to give us a reading, timing is controlled on the new stations by a Geostationary Operational Environmental Satellite (GOES). Else the stations will use these satellites to move their data hourly to Arabian Geodetic Service (AGS) headquarters, it is mentioned with details in part two of this chapter. In case of a storm, the stations can be programmed to move their data every five minutes (as an example). Field teams will quickly check and maintain the systems by helping laptop computers. Additionally, all the processed and raw data will be available through the internet. Not all monitoring stations are housed in protecting enclosures. This water level recorder is attached directly to a pier. Another shape of acoustic tide gauge in (Figure 5.2) wherever on the left is that the acoustic sounding tube and sensor. Appears in the top a solar cell and above that, a satellite transmitter. The rest of the recording electronics are housed in a small weatherproof box. http://oceanservice.noaa.gov/education/kits/tides/tides11_newmeasure.htm.

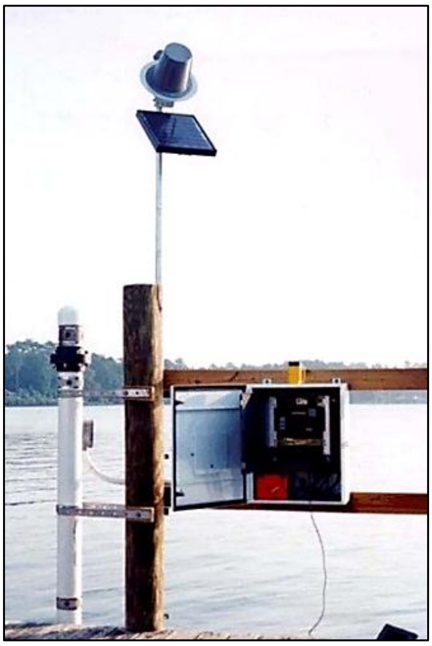


Figure (5.2): Another shape of acoustic gauge without protective enclosure

http://oceanservice.noaa.gov/education/kits/tides/tides11_newmeasure.html

5.1.1.2.The Proposed Second Device

In the second proposal, the radar tide gauge is used to measure water depth by radar waves has become used since the late 1980s and is currently a common technique with a several number of sensors available on work market. For coastal tide stations, the advantage of those ultra-frequency radars is that they have a fixed speed (the speed of light) giving height measurements over short distances that are not affected by environmental conditions. These gauges meet all the accuracy requirements. Nowadays, radar level sensors are widespread in hydrometry and are becoming the standard for tide stations all over the world because of the increased require for accurate measurements. The shape of radar tide gauge station appears in (Figure 5.3) [Illigner et al., 2015].

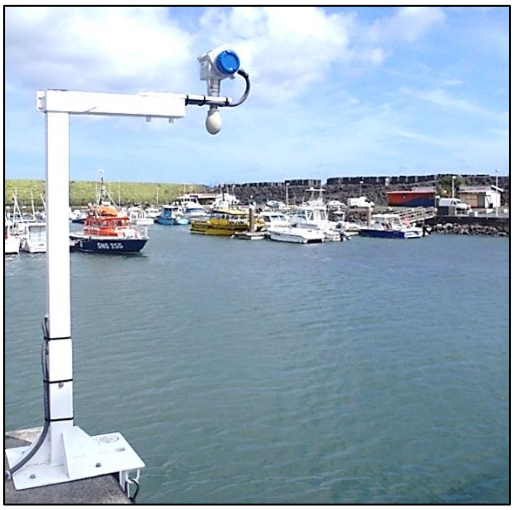


Figure (5.3): Shows the proposed radar gauge station shape http://refmar.shom.fr/en/documentation/instrumentation/maregraphes-radar)

The radar sensor calculates the distance by converting it into a digital signal reduced by the data recorder to a water depth referenced to the port datum. The tide gauge is permanently connected to the port tide station by levelling, its reference point in relation to the tide bench mark close to the station. Some of the radar sensors have a “reference” for levelling (antenna phase center, zero point (ZP) or provide calibrated offsets for their ZP. This permits a direct

connection of the radar readings to the Tide Gauge Zero point (TGZ) [http://refmar.shom.fr/en/documentation/instrumentation/maregraphes-radar]

5.1.1.3. Dipper Reading With the Radar Gauge

This thesis proposes using the automatic radar tide gauge at tide gauge stations, it is not monitored and unsupported by local operators as old tide gauge technique. To confirm the correct maintenance of the Tide Gauge Zero (TGZ) the dipper readings with the radar gauge whereas dipper measurements shall be used to monitor and determine the Zero Point (ZP) offset of the radar gauge by obtaining several readings during a high-to-low tide cycle then comparing it with the radar gauge measurements. It has been recommended weekly repetitions for dipper measurements to achieve the precision and accuracy of dipper measurements in general.

Dipper measurements by weekly taking 15 readings for, Aden (Yemen), Karachi (Pakistan), Chabahar (Iran) and Takoradi (Ghana) had been analyzed. Therefore the median and standard deviation (SD) for these readings were calculated. The varying of the dipper medians permits an evaluation of the constancy of the radar ZP estimation. To conclude the four analyzed data sets, it is confirmed that this approach is suitable for establishing a height reference to better than ±2.5cm repeatability with an SD of ±2 cm. The SD of the median every week is ±1.9 cm (Chabahar), ±1.5 cm (Aden), ±2.2 cm (Karachi), and ±3.1 cm (Takoradi) respectively [Illigner et al., 2015].

5.1.1.4. Changing the Old Gauge by New Accurate One

Up to twenty-two old tide gauge stations in the Arab world must be replaced by radar tide gauges around the red sea, Mediterranean Sea, and the Arabian Gulf, in order to fulfill the requirements for unifying the vertical datum all over the Arab region.

Overlapping periods among old and new stations must have suitable periods for recording the observations in different frequency ranges. These will be performed in different time series, in one year, monthly, daily, hourly, and five minutes, in order to records will able to determine the effect of instruments on the long-term on sea level products such as tides and mean sea levels [Pérez et al., 2014].

For the precise relation between the sea level time series from the old and the new tide gauges, the data will be combined from tide gauge stations and altimetry near to each station for comparison and accurately determine the sources of error.

If the new tide gauges will be installed at precisely the same position as the old tide gauge, this makes the expected differences at all frequencies will be small and the datum connection will be easier. In the other hand, if the new tide gauge will be installed at another position in the harbor with various frequency, just the lower frequencies of sea level will be expected to be coherent with the old station, and a high precision levelling is required to unify both tide gauges to the same datum [Albertella1, 2012].

5.1.1.5. Sources of Error and Differences Among Two Tide Gauges

A few problems may show up when the old gauges are supplanted by new tide gauges. There are two main sources of error, those according to instrumental/ installation problems, and the other source according to physical and environmental effects**.** It related to the geophysics factors which effect on tide gauge location as harbour resonances, wind, bio-fouling in the tubes, different reactions to sea level oscillations within a tube or well, effect of currents, density variations that affect particularly the pressure sensors, and other problems related to instrument as in the following steps [Mihanovi, et al., 2008]

-Time Shifts

Another common source of error is time shifting related to clock malfunction. This was in old tide gauges but not in the newest gauges as the radar gauge, which contains a GNSS receiver for time mission, one of the main needs of the new stations [Albertella1, 2012].

-Delamination Issue in Radar Antennas

Failure in the glue which connect the two circuit boards that form the antenna, the delamination problem appears. It permits to air to enter inside the joint and thus beginning a delamination operation. The result for this problem is a slowness rise of mean sea level during several hours in the radar data due to the other tide gauges, to remove this problem, the antenna must be replaced [Albertella1, 2012].

-Air Temperature Effects in Acoustic Sensors

Acoustic sensors is set up a few meters up to the water surface, for measuring the travel time of acoustic signals which reflected vertically from the air/sea interface to find the distance to the water surface. The travel time which determine by determination the speed of sound, which affects with air conditions as temperature gradients, to solve this problem, the sensors must be put inside protective tubes has a white colure to avoid temperature gradients. Errors in this operation appear as an increase the scale error and lower precision of the sensor through low waters and high waters level [Pérez et al., 2014].

5.1.1.6. Using GNSS at the Tide Gauge Station

GNSS antenna receives the satellites signals to be processed, and analyzed them, thus the sea level and its variation may be measured up to twenty times per second. The new GNSS tide gauge can measure, both land

and sea variations at the same time and location. Which means both long-term and short-term land movements (post-glacial rebound and earthquakes) shall be taken into consideration.

The sea level could be measured related to both the coast and the center of the Earth, which shows the difference between variations in the water level and variations in the land. For this GNSS antenna may be placed on the roof of the tide gauge hut as shown in (Figure 5.4) for monitoring the height and vertical motion of the tide gauge [Watson et al., 2012].

Figure (5.4): Antenna placed on the roof of the tide gauge hut.
[Illigner et al., 2015].

Moreover GNSS antenna may be placed close to the tide gauge station as shown in (Figure 5.5) for monitoring the height and vertical motion of the land and its effect on the tide gauge.

Figure (5.5): The antenna closed to the tide gauge hut [Watson, 2011]
http://gpsworld.com/new-tide-gauge-uses-gps-to-measure-sea-level-change)

The observations from GNSS controlled tide gauge locations and consequent analysis by IGS global analysis centers gives a time series of both vertical and horizontal movement of the land at those sites [Manning, 2001].

Continuous GNSS observations near to the Tide Gauge Benchmark (TGBM) will be needed for all AGS. This change in observation technique shall support satellite altimetry calibration and will determine the regional changes in sea level. Most vertical land movements can altogether modify the rates of sea-level rise which expecting from the sole climatic contributions of ocean thermal extension and land-based ice melting. The precise impacts of sea-level rise on the coast can be determined by focusing on advantage of existing GNSS receivers at this stations.

Thus GNSS receiver is to be fixed at every tide gauge stations and their observations will be transmitted and collected at the main center to be processed continuously with precise ephemeris using IGS base stations to obtain time series of precise coordinates of the tide gauge stations. So the vertical movements of the crust at the tide gauge stations can be followed. The proposed GNSS units will be the same kind, to guarantee the same accuracy. The closest IGS stations are showed in (Table 5.6).

5.1.1.7. Connection Between Tide Gauge and GNSS

To achieve connection between tide gauge and GNSS, coastal Tide Gauge Bench Marks (TGBMs) situated as near as possible to the tide gauges are utilized. These are connected to the real tide gauge readings by water level calibration. Usually establishing these network of bench marks to examine the relative height history of the marks, this indicates to any local subsidence or any stability problems with the marks.

Generally the work concerned with using the orthometric levelling to complete the connection, and using GNSS to derive, monitoring ellipsoidal heights on TGBMs. As needed by the Global Sea Level Observing System

(GLOSS), the accurate monitoring of sea level as the ellipsoidal heights will be related to global reference frame, where the orthometric levelling can just define local change in benchmark heights to other monuments [Watson et al., 2012].

Height connections are to the TGBM from the GNSS mark at tide gauge Stations by both of orthometric height from levelling and differential GPS. The targets of these connections were to determine the relative height differences between the Permanent GNSS and the Tide Gauge Benchmarks, and to derive an ellipsoidal height at the tide gauge benchmarks. As mentioned before, this connection gives important data for monitoring long term sea level change. Else this connection is required to help to better determine the separation between MSL and derived ellipsoidal heights from GNSS. Thus a levelling control network should be at each tide gauge station to confirm long-term stability and for establishing the connection between the Vertical Control Network (VCN) and the tide gauge reference height [Mihanovi et al., 2008].

Therefore precise geodetic tying to the Arabian Tide Gauge Stations Network (ATGSN) can be implemented using precise levelling, after re-adjust the benchmark related to the high accuracy tide gauge stations.

5.1.1.8. Utilizing Satellite Altimetry Data at Tide Gauge Stations

Many problems appear from neglecting (SST) and then the difference between the MSL and the Geoid. There are many permanent effects depending on tide gauge location in spite of considering long periods of sea level observation, strong winds, and even the type of device that still effect on the resulting of MSL. In some countries the vertical crustal movements known as it is Post Glacial Rebound (PGR), are responsible for strong rising sea level. Finally, bias in the vertical datum definition with sea level observations can be introduced by local disturbances of the Earth's gravity

field [Amos, 2007].

Satellite altimetry is considered one of the most important tools for unification the vertical systems between countries, as it provides valuable information for a precision realization of "Global Geoid". In the last years it gives good results but in coastal areas these results are still need to be improved. Nowadays the connection of the reference levels from satellite altimetry and tide gauge data which will permit finding and applying corrections for SST at tide gauges, thus the utilizing of satellite altimetry to homogenize the tide gauge reference levels will be a tool in a new promising thinking [Luz et al., 2007].

5.1.2. Levelling Works

In the proposal, precise spirit levelling will be done for the whole gravity stations which in its turn include the GNSS stations. Levelling will be done with unified standards to insure the same accuracy. The levelling works will be based on the tide gauge station in every country. The whole old and new levelling works will be collected in the main center. Precise spirit levelling is the foremost precise method of finding elevations and therefore the one most ordinarily utilized by engineers.
[http://www.civileblog.com/levelling].

Vertical control surveys are to be classified related to the planned and achieved accuracy. This goes to be a function of

• The design of networks.
• The different surveying practices.
• The instruments and equipment which used.
• The employing different reduction techniques.

The misclose or the difference between the start and end point in a levelling route, is ≤ to the value (e) using (Equation 5.1). The class and order of

levelling route appears in (Table 5.1 and 5.2) where L2A, LA, LB, LC, LD, and LE represent the degree of levelling route first order, second order, third order, forth order, fifth, and sixth order respectively [ICSM publication No.1, 2007]:

$$e = c\sqrt{S} \tag{5.1}$$

Where: e = the allowable max error, in mm.

c = constant factor related to each levelling class.

S = distance in km.

Table (5.1): The values of 'c' according to each class of survey [ICSM publication No.1, 2007].

Differential levelling $\mathbf{e = c}\sqrt{S}$	
Class	C (for 1 σ)
L2A	2
LA	4
LB	8
LC	12
LD	18
LE	36

Such to the case with class, set for an order is a dependent technique. Order set to the height of a mark, following adjustment will be proportional to:

• The new differential levelling class or trigonometric levelling class or GPS height.

• The constraining heights order.

• The transformation from one height datum to another one and its precision.

• The magnitude of the inconsistency between the recently observed height and ready existing height variations of the survey benchmarks at the project of the new and existing levelling routes/vertical networks.

• For the ellipsoidal height and the accuracy of the geoidal undulation.

Table (5.2): Highest Order (R) that may be set to a height from a given Class surveying [ICSM publication No.1, 2007].

Differential levelling	
CLASS	**ORDER**
L2A	R1
LA	R2
LB	R3
LC	R4
LD	R5
LE	R6

From the previous context, the decision makers should take in their account that Arabian Tide Gauge Stations Network (ATGSN) must have high accuracy devices with the same specifications at all stations in all Arabian countries to observe and monitor mean sea level changes for providing high-quality and homogeneous estimation of the vertical movement. All stations must give observations in the same time with the same accuracy to provide and report data in near real time, which will be tracked at Sea-level stations for monitoring easiness. ATGSN will include, data acquisition systems, and communication packages; however these improvements are cost-effective in expressing of the benefits that a real-time system will supply for mean sea level observing and monitoring and will enhance station performance related to early discovery of stations malfunctions. The Specifications of proposed devices suitable for the desired purpose that may be taken into account when establishing ATGSN are shown in the (Table 5.3).

Table (5.3): Shows the proposed device and its specifications

Device	Specifications
Radar	-It has non-contact Technology and removes the installation, erosion and problems of fouling with of flooded sensors, where it simplifies datum control. -The variations in water intensity and atmospheric conditions unaffected on the performance and accuracy of the sensor. -Minimum Range: 0.8 m, Maximum Range: 20 m, Beam Angle: ±6° -Frequency: 25 GHz, Accuracy: ±10 mm. Raw Sampling Rate: 8 Hz, Averaging period: Selectable (10 to 360 seconds). -Output Parameters: Mean Range, Mean Height, Std. Deviation [http://www.valeport.co.uk/Products/Tide Gauges/Tide-Gauge-Product Details/ProductID/40.].
Level	-The power level SDL30 with invar RAB-Code Staves, it is a digital level has a large internal memory. Users will measure heights and distances after adjustment the focus and press a single key. The results will appear on LCD screen and will be immediately digitally recorded in the internal memory – this makes the SDL30 the ideal device for quick and easy levelling. -The accuracy of height: Electronic Measurement 0.6mm with Standard deviation for 1.0mm, one kilometer double-run with visual measurement 1.0mm, The accuracy of distance: Electronic Measurement, up 10m to 50m: 0.1×D and over 50m: 0.2×D (D=measuring distance, unit: m).

Device	Specifications
	-This device can Measure the Range Electronic Measurement from 1.6 to 100m. The Capacity of data storage: 2000 points (64KB) [https://us.sokkia.com/products/levels-accessories/automatic-levels/sdl30-digital level]
GNSS Antenna	-This antenna can use Frequency range from: GLONASS L1/L2, GPS L1/L2/L5, Galileo E1\E2\E5, and BDS B1/B2/B3 ab. -Error of Phase Center: ±2 millimeters. -Board with multi-path rejection inside the antenna can remove the multi-path effect to measure error. It has high stabilization and high repeatability at phase center, low noise figure, independent ground plane. -The horizontal accuracy……3 millimeters + 0.5 part per million -The vertical accuracy………5 millimeters + 0.5 part per million -The time of Initialization ……… typically < 10 seconds. -The rate of reliability……….…..typically > 99.9% [Ashtech, 2011] [http//www.trimble.com/trimbler8gnss.shtml,"trimble R8 German]

5.1.3. Positioning Works

5.1.3.1. Existed GPS Points Distribution in Arab World

Recall (Figure 3.32) from chapter three, the available GPS points which cover the Arab countries. These information which the Author could get from the internet along with previous studies, but the proposed supervision side- the Arab league- can communicate the involved countries to obtain the real situation and the data itself. From that figure we notice that there are many gaps in all states with a concentration of points in certain regions that serve specific projects and studies. GPS points in all Arabian countries is not homogenous and there is not any existed scenario to tie these point. The point's distribution in this way does not serve the current study to unify the vertical datum. Therefore, the integrity and reliability characteristics of control networks in Arab regions vary seriously from one network to another. Moreover, many of these networks have not tied to a high-precision GPS datum that can be used to unify them.

Therefore a precise GNSS network is proposed to the Arab region. The points of the proposed network will be homogeneously distributed in the Arab countries. A number of points will be related to the area of the country. Existed points will be used with the proposed points. Core points will be observed simultaneously and their data will be processed with the data of the IGS stations using the more accurate precise ephemeris to obtain the more accurate absolute position.

Those points (core points) will be used as base station to the rest of the points in every country. One of these points in every country will be beside the tide gauge station in that country. The core points along with the other points (the whole proposed network) can be prepared to serve the users as permanent stations (CORS). The user in Arab area will has his position in

unified accurate absolute homogeneous system of coordinates wherever he is.

5.1.3.2. The Proposed GNSS Points Number and Its Distribution in All Arab Countries

The area of Egypt is about 1000,000 km^2 and it has a high accurate reference network (HARN) established in 1995. This HARN consists of 30 GPS stations, well distributed with point spacing about 200km. The accuracy of this network is 1:10,000,000. Five among the thirty stations were chosen to be core points whom are firstly observed, processed, and adjusted with the IGS stations using the best precise ephemeris at that time. Those five core stations are then used as base stations to the other 25 stations. The same pattern is proposed here for all the study area.

Every country will have its core points and among the stations of its own network. The number of the stations in each country will depend on its area, see (Table 5.4). The core points will be observed in one session in the whole Arab area, processed, and adjusted with highest GNSS standards. After that and in every country, the other stations will be observed as rovers with respect to the core (base) stations. Those GNSS observations will be processed and adjusted using the same adopted standards. Finally an accurate coordinates for the whole Arab GNSS stations will be defined in one accurate unified coordinate system. Again these stations can be prepared to serve as permanent stations to serve the users with the suitable corrections in the whole study area in real time service through the main center.

The Proposed Shape for Permanent GNSS/ Distribution in Arab countries shows in (Figure 5.6).

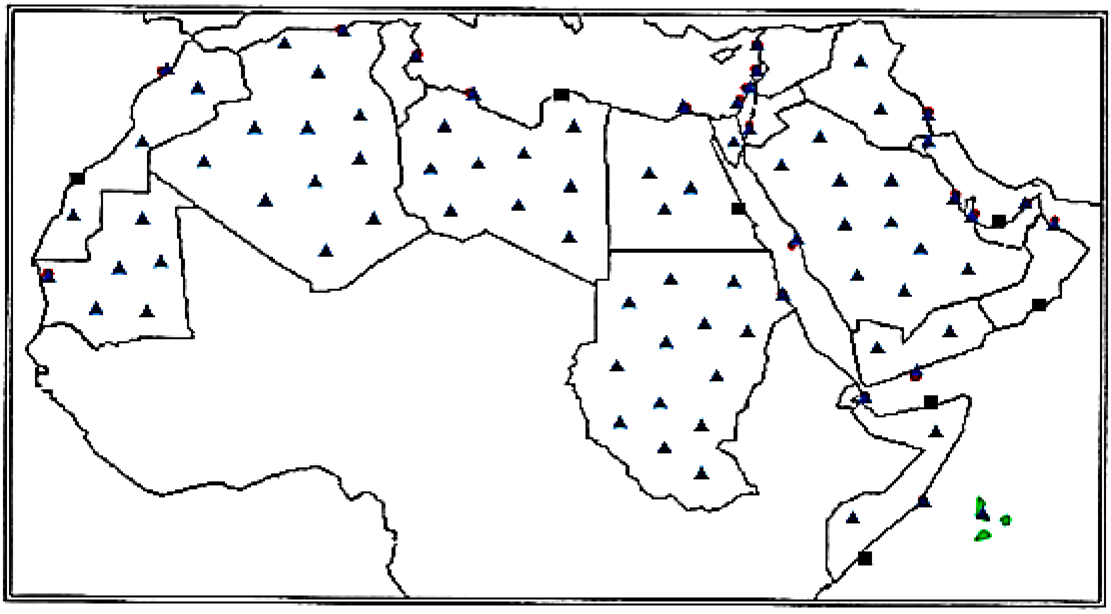


Figure (5.6): ● The Tide gauge location (the vertical datum origin).

■ The proposed new tide gauge location.

▲ The core GNSS// absolute gravity points.

Table (5.4): Shows the proposed GNSS points distributions all over the Arab countries

No.	The Arab Countries	Area $(km)^2$ [El Raey, 2012]	Coast line (km) [El Raey, 2012]	The proposed no. of Core GNSS Stations	The proposed no. of GNSS St. in the precise GNSS networks	The minimum no. of tide gauge stations related to the coast length
1	Bahrain	740	590	1	1	1
2	Iraq	435,052	58	2	14	1
3	Kuwait	17,818	499	1	1	1
4	Oman	309,500	2092	1	10	2
5	Qatar	11,427	563	1	1	1
6	United Arab Emirates	83,600	1318	1	3	2
7	Saudi Arabia	2,250,000	2640	12	72	2
8	Djibouti	23,200	370	1	1	1
9	Jordan	92,300	26	1	3	1
10	Somalia	637,657	3025	3	20	3
11	Sudan	2.505,000	853	13	78	1
12	Comoro	2,236	340	1	1	1
13	Yemen	555,000	1906	3	18	2
14	Egypt	1,002,000	2450	5	30	2
15	Palestine (Gaza Strip)	27,000	40	1	1	1
16	Lebanon	10,452	225	1	1	1
17	Syria	185,180	193	1	6	1
18	Algeria	2,381,741	998	12	75	1
19	Libya	1,775,000	1770	10	57	2
20	Mauritania	1,030700	754	6	33	1
21	Morocco	710,850	1835	4	22	2
22	Tunisia	165,150	1148	1	5	1
23	Total	14211.603	22.105	82	455	31

The Proposed shape of core GNSS stations and high precision GNSS points in all Arab countries are Shown in (Figure 5.7).

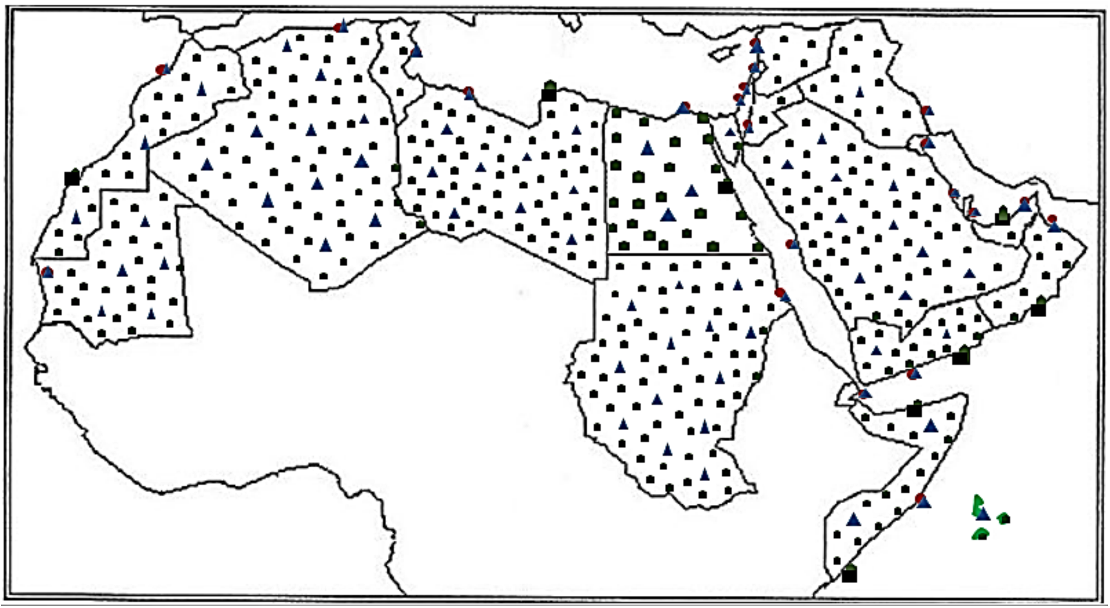


Figure (5.7): ● The tide gauge location (the vertical datum origin). ■ The proposed new tide gauge location. ▲The core GNSS/absolute gravity points tying on IGS stations. ☗ GNSS/levelling /relative gravity points tying on core GNSS stations.

5.1.3.3. GPS Static Observations Specifications

GPS survey (high accuracy static) will be to verify geodetic quality. It utilizes dual frequency, and GNSS receivers of full wave length with several channels to track GNSS satellites. It is preferred a choke ring antenna, while any geodetic ground plane antenna has high quality may be used. Any antenna type must be calibrated before and during the work [User's Guide, 2013].

The observation epoch will be 15-seconds, which ought to agree with the recording time interval of the reference stations (PORS) utilized to post-process the data. The elevation mask angle goes to be typically set for 10 degrees; low angle satellites can reduce the efficiency of the final solution.

The greatest possible amount of GNSS data must be collected if time and schedule permit, therefore the errors or invalid data, can be removed through the processing operation. The minimum requirement is 4 hours or 7200 observations of GPS data will be collected on a water level (tidal or geodetic) bench mark for one GNSS session [User's guide, 2013].

5.1.3.4. GPS Data Processing

Similar to the globally GPS specifications for high-precision networks, the following procedures are designed [User's guide, 2013].

- For Arabian network, the iono-free L1/L2 fixed solution must be obtained.
- Ionospheric and tropospheric models ought to execute.
- The tolerance of base line processing must be better than 1 cm for horizontal distance and 2 cm for vertical distance.
- Precise ephemerides should be utilized because they are preferable rather than the broadcasted values.

5.1.3.5. Satellite Visibility and Site Safety

The utmost desired GNSSBM must have 360 degrees allowance around the mark at 10 degrees and greater above the horizon. The new mark must be tied to the station bench mark network during conventional geodetic levelling, and GNSS observations shall be made.

The GNSSBM must be sited on public property not on private property, to avoid taking permissions from private property owners may be needed in the future to reach to the bench mark and to collect GNSS data. The distance should be no greater than one mile to the GNSS mark from the station to Data Collection Platform (DCP) [NOAA Technical Report NOS 139, 2015].

5.1.4. Gravity Works

5.1.4.1. The Available Gravity Data in Arab World

The Gravity points cover the whole area of Arab countries, but some countries suffered from weakness in gravity points. There are some visible gaps in south of Mauritania, west of Algeria, south of Libya, north - east of Soudan, middle of Somalia, and south west of Egypt, recall (Figure 3.33). That distribution of gravity points will affect the proposed vertical datum for the Arab world.

These are the information about the gravity points in the study area as appeared to the author. The supervision side (Arab League) can communicate each country to collect the whole required data they have. So, the discussion and the proposals in this thesis will be limited to the collected information.

The proposed gravity network in the study area consists of two sets of gravity stations. The first set will be observed using absolute gravimeters. The supervision side (Arab League) will communicate the world wide agencies whom have absolute gravimeters and arrange time table with them. The first set stations will be the same core GNSS stations mentioned above. After that every country with its relative gravimeters will define the gravity values at its stations of second set of the gravity stations. The same kind of relative gravimeters will be used in the whole study area, as long as the same style of observations will be followed. The whole observations will be sent to the main center for processing and getting the final values. The second set of gravity stations consists of 50km spacing stations including the already existing stations. In Egypt, for example, 400 stations will be required. At least 150 stations already exists since the last gravity network has been made in 1997.

Every country will establish the rest of its required stations. The FG5 absolute gravimeter is suggested to be used; it can determine the gravity

acceleration value with precision of 2-4 μGal [Okubo et al., 1997 and Guimarães, 2015].

5.1.4.2. Connection of Gravity Values in Arab Region

Determining the gravity value in all Arab region based on some points whose guarantee the gravity value's precision in all countries in harmonized uniform system.

- The first point is using the same method for determining the gravity value in each local reference network. It is proposed to use Forward Looping Method, this method is called step method where the base stations are tied together in a regular arrangement is called A-B-AB sequence. The measurements will be taken at the base station (A) and the instrument is then transmitted as quickly as possible to the other base station (B), then the measurements will be repeated at both stations. Taking reading should be fast, this makes the user able to assume the linearity of zero drift. From the four reading at A-B-AB the gravity differences can be estimated. If the divisions between the two differences are larger than the precision of the device, the readings will be repeated. The final measurement at the base station (B) will serve as a basis for the next connections for example if the next base point is (C) the similar sequence will be used as B-C-BC.

-The Second point, using the same type of the instrument which used in observation.

-The third point, using the same adjustment methods of the local survey network [Ellmann et al., 2009].

5.2. Part Two

5.2.1 The Proposed Work Plan

The proposed work plan will be explained in this part as follows;

5.2.1.1. Concerning the Establishment of the Arab Geodetic Services

Main center for the geodetic services in the Arab region will be established, in Egypt, where it occupies a distinctive geographical position as an intermediate place and it can be named Arabian Geodetic Service (AGS) it will be under the supervision of the Arab League. Members of this center could be the surveying authorities in Arab countries, universities, research centers, and any other concerned institutions. AGS will introduce all the geodetic services; data and consultations, and it will be in continuous cooperation with the similar worldwide services. AGS will have subservices among them the Arabic Vertical Datum Service (AVDS). Techniques and basic components that will be associated with AGS appears in (Table 5.5)

Table (5.5): Techniques and basic components that will be associated with AGS. Where E means the observation at certain time and C is continuous observations [NOAA Technical Report NOS 139, 2015].

Technique	The objective	The expected Accuracy	Results and Contributions
Tide gauges	The point's height related to sea level, and sea level changes	E: 10 cm C: 1 cm	The displacement of Surface, vertical reference frame, and physical height
GNSS	The position of point related to a satellite system/geocentric	E: 1-2 cm C: 1-2 mm	The displacement of Surface , 3-D reference frame, and geometrical height
	The height differences of points related to the geoid,	$< 2mm/km^{1/2}$	The displacement of surface, vertical reference frame, and orthometric height
Absolute gravimeers	Absolute gravity	2-4 μGal	The displacement of surface, gravity systems, mass changes, physical height
Altimetry		2cm	It directly measure the height of the ocean surface.

- **The Tasks and Objectives of AGS are Going to be as Follows:**

- To establish a network of stations with several collocated techniques shown in (Table 5.5).

- To access to the needed data. This suggests maintenance of databases, a lot of them via existing elements, similar to a metadata base as a section of the AGS portal.

-To contribute and support the continuous maintenance and the enhancement of precise geoid models in Arab world.

- To collect the geometric positioning with orthometric height and renewed gravity observations by high accuracy, and to supply connection to the sea level and sea level changes by tide gauges in the area.

- To contribute and realize the World Height System (WHS).

-To serve and supply different scientific agencies by data as; geodetic surveying, bathymetric surveying, cadastral surveying, aerial surveying, construction and engineering surveying and town planning….etc.

- AVDS will be organized by selected team work members from the experts, geodesists from different Arab countries.
- AVDS will communicate the surveying authorities, universities, research centers, and other concerned Institutions (its members) to collect the geodetic data; GNSS, TG, gravity, and levelling. The old already existed and the proposed data as in part one, will be sent from every AVDS member to the main center of AVDS via the internet without needing to go to the field. This saves both time and money. The following chart (Figure 5.8) shows the proposed shape for Arabian network.
- The main components of AGS are the Arabian Observing Stations (AOS) which form the national station networks, a second component is the Arabian Data Centers (ADC), its operation is storing the tide gauge data and GPS, gravity, and metadata for long-term.

  The third component is the AGS Analysis Centers (AAC) responsible to daily analysis of AGS data and must be extended to all Arab countries. It will process GPS data on a uniform basis with a very short latency giving orbit and clock products of different quality and the coordinate time series of station, therefore it completely supplies time series of vertical movement for a network of tide gauge stations.

The fourth component is the Arabian Backup Center (ABC) which will keep data from mislaying (Figure 5.8) shows the proposed network chart for AGS.

- Arabian Geodetic Services, (AGS), will integrate precise absolute and relative gravity, tide gauges, and local processing of GNSS data. The network positioning error will be reduced with passing time especially in the vertical component. It will serve as a regional network and it will provide necessary data and infrastructure for the initiative of (WHS).

- The coming steps mentioned in this proposal will be done either on the old (existed) data only or on the old and the new proposed data together. The steps can be done using the old collected data until the new data are available, so the work can be repeated.

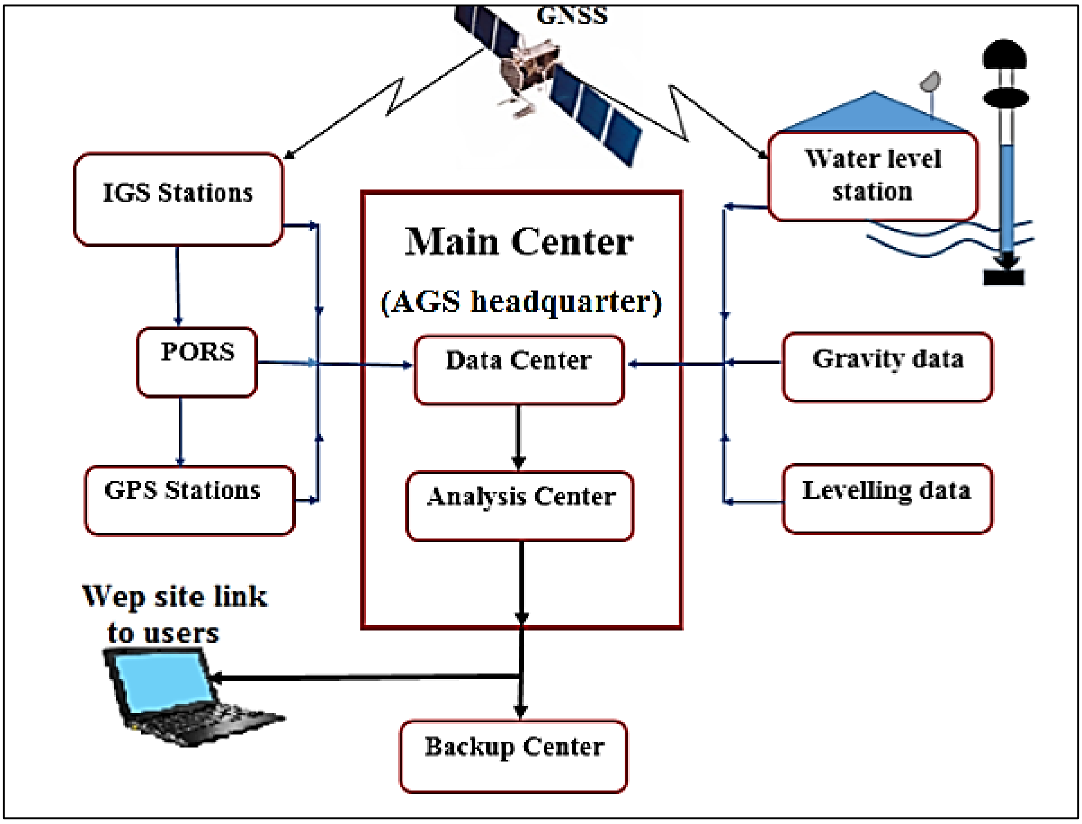


Figure (5.8): Shows the proposed network chart for AGS

5.2.1.2. Concerning Tide Gauges Works

Generally the implementation of AGS services will be started with the tide gauge observations: the new observations at every tide gauge station will be collected for one year and then added to the old observations and sent together to AVDS.

- The data will be reviewed, filtered, and processed to obtain the current mean sea level at every country.
- New observations can be compared with the old observations to define the change of the mean sea level w.r.t. time.
- Mean sea level for every country will be obtained during the same time period using the same instruments and methodology to assure homogeneity and same precision.
- Difference between the old and new value of Mean see level at every country will be obtained.
- All the old and new B.Ms in every country will be shifted to the new mean see level value in that country.

5.2.1.3. Concerning the Satellite Positioning Works

- AVDS will define certain time for the whole countries, start and end time, for GNSS observations at the core GNSS stations.
- Those observations will be collected at AVDS to be filtered, processed, and adjusted in addition to the observations of the nearest IGS stations. IGS stations will be chosen at the main four directions' w.r.t. the study area. The most accurate precise ephemeris will be used while processing. The (Table 5.6) shows the closest IGS stations to Arab region from the four directions.
- AVDS will define a certain period of time for the countries individually to observe the rest of its GNSS stations.

- The GNSS observations will be collected, filtered, processed, and adjusted using the core stations as base stations.
- At that moment, all GNSS stations in the study area will have their homogenous, accurate coordinates defined on WGS84 and the current ITRF.

Table (5.6): Shows the closest IGS stations to Arab region [http://www.igs.org/network].

N.	Site ID	Kind	city	country	Latitude	longitude
1	HALY	IGS	Halat Ammar	Saudi Arabia	29.1386111	36.0997222
2	YIBL	IGS	Yibal	Oman	22.1863889	56.1122222
3	BSHM	IGS	Haifa	Occupied Palestine	32.7788889	35.0200000
4	BHR4	IGS	Manama	Bahrain	26.2088889	50.6080556
5	ISBA	IGS	Palestine Street	Iraq	33.3413889	44.4383333
6	DJIG	IGS	Djibouti	Djibouti	11.5261111	42.8469444
7	ADIS	IGS	Addis Ababa	Ethiopia	9.0350000	38.7661111
8	CGGN	IGS	TORO	Nigeria	10.1230556	9.1180556
9	DAKR	IGS	Dakar	Senegal	14.7211111	-17.4394444
10	RABT	IGS	Rabat	Morocco	33.9980556	-6.8541667
11	MELI	IGS	Melilla	Spain	35.2811111	-2.9513889
12	NOT1	IGS	Noto	Italy	36.8758333	14.9897222
13	MFKG	IGS	Mahikeng	South Africa	25.855978	25.64031
14	DYNG	IGS	Dionysos,	Greece	38.098744	23.879018
15	TEHN	IGS	Tehran	Islamic Republic of Iran	35.6972222	51.3338889

5.2.1.4. Concerning the Gravity Works

- The old and the new absolute gravity observations will be collected at AVDS to be filtered, processed, and adjusted. The final absolute values of the gravity acceleration will be obtained. They will be homogeneous and having the same accuracy and datum.
- The old and the new relative gravity observations will be collected at AVDS to be filtered, processed, and adjusted. The absolute stations will be used as reference stations.
- The whole gravity stations in the study area will have homogeneous, accurate gravity values referred to one reference.

5.2.1.5. Concerning the Arabian Geoid Determination

- Finally, the study area will have a dense, well distributed, homogenous, accurate data of:

- A tide gauge station at every country.
- GNSS stations, and the considered value here is (h).
- BMs with orthometric height (H) related to the new value of their TG.
- Gravity network

- AVDS could adopt the last global DTM (SRTM) and the global geoid model (EGM2008) for the computation of the geoid in the area.
- A precise geoid model for the study area will be computed in AVDS using the above mentioned results and data.
- The adopted EGM will be tailored, modified to fit the study area using the resulted:

- Ellipsoid heights at GNSS Stations (h) and the corresponding orthometric heights (H) from;
- Gravity anomalies at the gravity network stations.
- Fixing the new values of MSL to zero in the solution (at T.G stations).
- Altimetry data and ocean model will be used.

- Tailoring GGM using terrestrial observations to fit some area is previously explained in chapter four.
- When using (EGM2008) to be tailored by:
  - T.Gs using Radar Level Sensor by accuracy: ±10 mm.
  - The approximate precision of observed undulations will come from the basic relationship between the ellipsoidal height and orthometric height;
  - Where the height difference between the orthometric height (H) and a specific ellipsoidal height (h) is known as the geoidal height (N).

$$N = h - H \quad (5.2)$$

To calculate the standard deviation of the value N, applying the error propagation law, it yields;

$$\sigma_N^2 = \sigma_h^2 + \sigma_H^2 \quad (5.3)$$

Using the precise first order levelling closed loop according to the standard formulation $2\sqrt{S}$ where S is the length by kilometer [ICSM publication No.1, 2007].

The distance in HARN network equal 200 km (equal 400 km in case of closed loop) so the precision of the orthometric height calculates by (Equation 5.4);

$$(H) = 2\sqrt{400} = 2\times 20 = 40\text{mm} \quad (5.4)$$

The HARN network scale is 1:10,000,000 and the spacing distance is 200 km, so the precision of ellipsoidal height equals 20mm, by substituting in (Equation 5.5); the expected precision of the geoidal undulation will be as:

$$\sigma_N^2 = (2\text{cm})^2 + (4\text{cm})^2 = 4\text{cm}^2 + 16\text{cm}^2 = 20\text{cm}^2 \quad (5.5)$$

$$\sigma_N = \pm\sqrt{(20cm^2)} \approx \pm 4.5\text{cm} \quad (5.6)$$

The approximate precision of gravity anomalies will be computed from the following basic relationship;

$$g^{-} = g_{obs} + 0.3086\ H \quad (5.7)$$

where, H is the height of gravity station in meters above the geoid and g^{-} is the gravity on the geoid, and g_{obs} is the gravity on the earth's surface,

$$\Delta g = g^{-} - \gamma_o \quad (5.8)$$

where γ_o is constant, the precision of g^{-} equals the precision of observed gravity add to 0.3086H, in order to compute the st. dv. of the computed value (g^{-}), by differentiating (Equation 5.7):

$$dg^{-} = dg_{obs} + 0.3086\ dH \quad (5.9)$$

By squaring (Equation 5.11);

$$\sigma^2_{g^-} = \sigma^2_{g_{obs}} + (0.3086)^2\ \sigma^2_{H} \quad (5.10)$$

By substituting in the (Equation 5.12) with the expected value of observed gravity and orthometric height as mentioned in the first part from this chapter and (Equation 5.6) ; 3μgal and 4cm respectively, the precision of gravity anomaly will equal;

$$\sigma g^{-} = \pm \sqrt{(\ (0.003)^2\ +\ [\ (0.3086)^2\ \times\ (0.04)^2])} \quad (5.11)$$

$$= \pm \sqrt{0.00016} \approx \pm\ 0.012\text{mgal} \approx \pm\ 12.7\mu\text{gal}$$

Improving the gravity anomalies and GPS/ data in Arab world can be predicted after tailoring the EGM2008 model (which be recommended in most Arab countries) by using the recommended data with its recommend specifications which previously discussed.

After studying the previously discussed cases (especially the European case) for tailoring the GGM by using terrestrial data. The Arab gravity anomaly will improve of more than 90% and GPS/ value will improve of more than 50% after tailoring the EGM2008 by the proposed high accurate data which previously discussed in the first proposal.

- Expected that after the implementation of the former steps, users anywhere in the Arab region can use any of the GNSS stations as a base station and obtain ellipsoidal height. Then subtract the undulation value obtained from the Arab geoid to obtain a precise value of the orthometric height. This will happen in one homogenous, accurate vertical control.

- Processing service can be introduced via AGS, besides the other geodetic services.
- Continuous observations will be used for updating and for following the change of MSL, and for crustal movement detection.

Nowadays the technological development and the information exchange speed through the internet, permit establishing backup centers in all Arab countries to protect the data from missing. At least two backup centers must be constructed, in east and west of the Arab region to involve all Arab countries. Algeria and United Arab of Emirates may be specified in addition to the main center in Egypt. A time table for executing the above-mentioned works is suggested in (Table 5.7).

Table (5.7): Shows time table for executing the proposed works.

No	Items in all Arab countries	First year in months												Second year in months												Third year in months												Forth year			
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
1	Presenting this proposal to decision makers.	■																																							
2	Communication with the surveying authorities, universities, research center and all interested in surveying and geodesy in each Arab country.		■																																						
3	A number of sessions must be held to discuss the implementation of this huge project in presence of the delegates from each Arab country;			■																																					
	A-The signing of the Convention on the implementation of this huge project.				■																																				
	B-Establishment protocol to exchange the available data between all Arab countries.					■																																			
4	Preparing and establishment the main center (Arab Geodetic Services).						■	■	■																																
5	Preparing and establishment the backup centers.						■	■	■																																
6	Selection the experts and geodesists team work members from different Arab countries.									■																															
7	Collection the old geodetic data by every AVDS member and sending them via internet, and using it until be establishment the new data.									■																															
8	**<u>Concerning tide Gauges works</u>.** A-renewal the tide gauge stations in all Arab countries										■																														
	B- Construction of new Tide gauge stations on long harbor										■																														
	C- Collection the observations at every Arab T.G stations for one year instead of 18.6 year and sending them by internet.										■	■	■	■	■	■	■	■	■	■	■	■																			
	D- Reviewing, filtering and processing the data to obtain the current mean sea level at every country.																						■	■	■	■															
	E- Defining the change of M.S.L. with respect to time by comparing the new observations and old observations.																										■	■													
	F-Obtaining the difference between the old and new value of M.S.L. at any Arab country.																												■	■											
	G-All the old and new B.Ms in every country will be shifted to the new mean see level value in that country.																														■	■									
9	**<u>Concerning the satellite positioning work</u>.** A- Choosing and Construction of permanent GNSS stations (core stations), AVDS will define certain time for the whole countries, start and end time, for GNSS observations at this core GNSS stations.											■	■	■	■																										

No	Items in all Arab countries	First year in months												Second year in months												Third year in months												Forth year			
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
	B-Those observations will be collected at AVDS to be filtered, processed, and adjusted in addition to the observations of the nearest IGS station. The most accurate precise ephemeris will be used while processing.																																								
	C-Choosing and Construction precise GNSS stations and tying them on core stations (base stations)																																								
	D-AVDS will define certain period of time for the countries individually to observe the rest of its GNSS stations.																																								
	E-The GNSS observations will be collected, filtered, processed, and adjusted using the core stations as base stations																																								
10	**<u>Concerning the gravity work</u>.** A-Choosing the absolute stations in all Arab countries																																								
	B-The old and the new absolute gravity observations will be collected at AVDS to be filtered, processed, and adjusted																																								
	C-The old and the new relative gravity observations will be collected at AVDS to be filtered, processed, and adjusted. The absolute stations will be used as reference stations.																																								
11	AVDS could adopt the last global DTM (STRM) and the global geoid model (EGM 2008) to compute the precise geoid in the area. By using the above mentioned results.																																								
12	The adopted EGM will be tailored and modified to fit the study area using the new results, h, H, gravity anomaly at the gravity network stations, and altimetry data will be used																																								

5.3. The Second Proposal

Similar to the procedures and sequences of the first proposal. The second proposal is suggested, it will be based on Precise Point Positioning (PPP) technique for positioning and satellite-only gravity model for determining the geoid undulation. In this proposal, the PORS stations and precise GNSS stations in every country will be replaced by PPP and the regional geoid model will be replaced by satellite-only model being not affected by terrestrial non-homogenous observations.

Then the user everywhere in the study area can obtain his orthometric height as a difference between the ellipsoidal height and geoidal undulation at the same point.

5.3.1. Precise Point Positioning (PPP)

PPP is a worldwide exact location serving, where it needs the accessibility and gathering the precise reference satellite orbit and clock product in real-time utilizing a system of GNSS reference stations disseminated around the world, to erase the first order impact of the ionosphere.

PPP can give position solutions at centimeter to decimeter level, even less than 1 cm-level situating in static mode. The difference between PPP and Real Time Kinematics (RTK) positioning, that it does not need access to observations from one or more accurate reference stations as RTK does. PPP technique based on precise orbit and clock data which are computed by processing center receives observations from reference stations from a comparatively distributed station network all over the world, and it is available for thousands of kilometers. These reasons make PPP is better than RTK. Whereas RTK coverage is not obtainable. But the PPP technique requires a lot of time for observation to reach to the max results (about ten

minutes). Nowadays, there are many consolidated post-processing PPP services.

The various unknowns as the phase ambiguities, the precise receiver coordinates, the receiver clock, and the zenith tropospheric delay are obtained by processing the observations which incoming from all satellites [Zhang 2011 and Ge, 2008].

There are some important and relevant factors affect the quality and efficiency of PPP technique, as the accuracy of orbit and satellite clock, the numbers and quality of the observations. Similar to all GNSS techniques, if there are any obstacles affect the satellite line of sight, the users cannot track the satellite. In this case the using GPS, GLONASS systems, or, in the future, Galileo (to provide by full range satellite) to guarantee the best service. . [https://en.wikipedia.org/wiki/Precise_Point_Positioning].

5.3.1.1. The Benefits of PPP Technique

Using PPP Technique is suggested because it has a lot of benefits which be demonstrated in the following points.

- It depends on one receiver, and does not require reference station behind the observers.
- PPP determines the positions related to a global reference frame. PPP gives most positioning consistency than the differential techniques, where it provides position solutions without local base station or stations.
- PPP saves the time and effort because it reduces the number of used receivers and the number of observers facilitates and handles field work where it deletes the dependency on base station(s).
- PPP provides a lot of applications besides determining the position coordinates, as estimating receiver clock and effect parameters of

troposphere. It uses a single GPS receiver to give another way for precise time transfer.

[http://www.navipedia.net/index.php/Precise_Point_Positioning].

The PPP service and the ground reference stations used in gathering correction data for the various signals broadcasted by each satellite shows in (Figure 5.9). The calculation of corrections from this data are broadcasted from geostationary satellites to the users receivers.

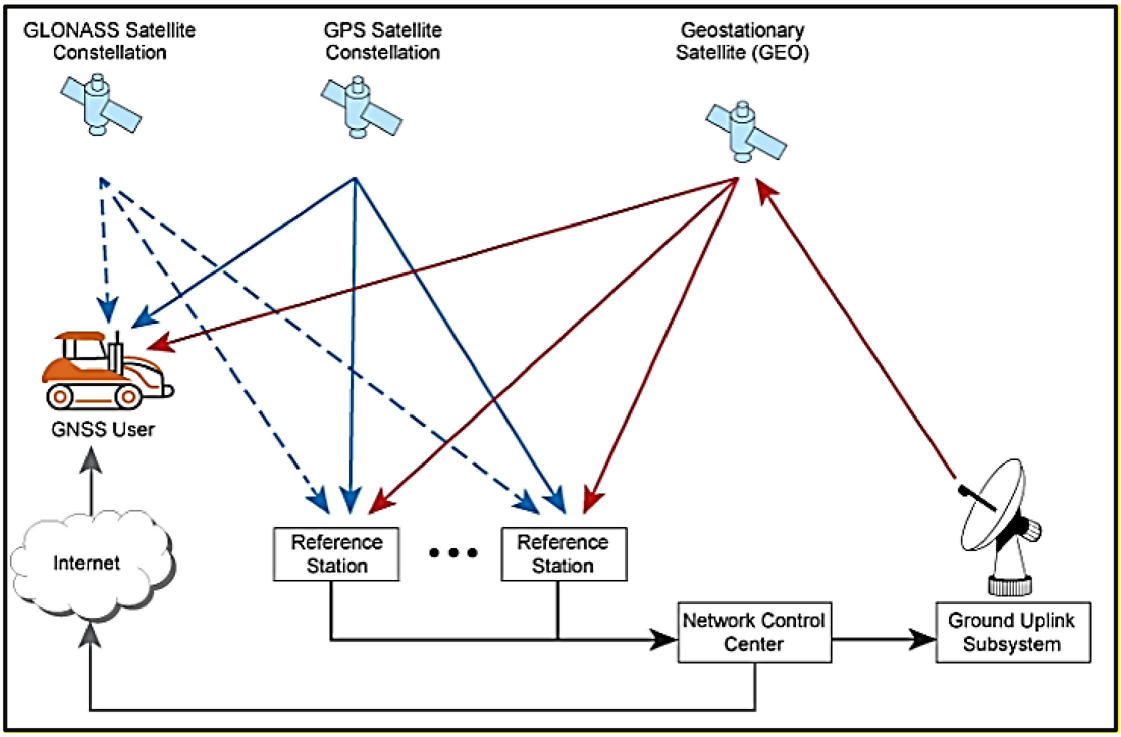


Figure (5.9): Shows PPP system

[http://www.novatel.com/technology-in-action/velocity/

5.3.2. Satellite-only Precise Geoid Models

The discrepancy between the GPS/levelling geoid undulations (h_{GNSS} – H) and gravimetric geoid undulations (N_{grav}) should be zero. However, gross, random, and systematic errors and datum differences involved in the three heights (h_{GNSS}, H and N_{grav}) cause discrepancies between the

gravimetric geoid undulations and the ones obtained from these two independent sources, GNSS and levelling measurements [Véronneau and Huang, 2011]

The long wavelength components of the gravity field can be obtained from satellite-only solutions, but they do not provide any local details. On the other hand, the terrestrial data can provide local details, but they generally contain systematic errors (e.g., datum inaccuracy) which propagate biases in the long-wavelength components. An optimum regional geoid solution can be obtained by the combination of the satellite-only solutions with terrestrial data. The method which use for the combination of satellite and terrestrial gravity data, remove-compute- restore technique [Ince et al., 2015].

The contribution of the satellite-based gravity technology is one critical component to the geoid-based vertical reference frame. Satellite-based gravity and terrestrial datasets are the sources that need to be investigated in the following experiment to develop a cm-accurate geoid model as a vertical datum in Canada.

- In an accurate study in 2015, GOCE-only solutions determined from the first two, eight, and eighteen-month observations, i.e. first, second and third generation models, were assessed in Canada and two sub-regions (the Great Lakes and Rocky Mountains). The global geo-potential model EGM2008, Canadian Gravimetric Geoid model CGG2005 and Canadian GPS/levelling-derived geoid undulations were used in the evaluation of the GOCE-determined gravimetric geoid models.

In Canada, the GPS measurements benchmarks were collected over three decades, their precisions range from millimeters to a few decimeters at the 95% confidence level. The GOCE-only solutions expanded up to different spherical harmonic degrees 90 to 180 are compared with the GPS/levelling-derived geoid heights on 2579 benchmarks in Canada, 652

and 659 benchmarks points in Great Lakes and Rocky Mountains respectively.

-In case of using satellite-only model; overall, the results show the precision of EGM2008 is 3.1 to 14.3 cm with an average of 9.5 cm relative agreement. GOCE-only has precision of 8 to 30 cm in Canada. The GOCE models show stable performance until degree 180, equivalent to a baseline of about 117 km. This inconsistency is likely related to uneven and sparse spatial distribution of the GPS and levelling data. (The pest distribution of the proposed Arab data will overcome this problem).

For the Great Lakes area, EGM2008 has a precision of 3 to 8.5 cm, and GOCE-only has similar behavior as Canada. For the Rockies, due to the rough topography, the relative agreement is relatively worse than those for the Great Lakes and Canada. EGM2008 indicates results between 3.1 to 14.6 cm relative agreement. The GOCE-only model DS03 indicates results from 7.9 to 40.2 cm relative agreement. Evidently, for the Great Lakes area, the general relative agreement of the geoid models is better than it is for Canada and the Rockies due to the flat land features. Similar to the absolute accuracy case, factors such as rough topography, distribution of stations, noisy GPS and levelling data and long wavelength errors contribute to the large deviations and worse precision in the Rockies [Ince et al., 2015].

- In case of using satellite-only model combined with the regional terrestrial data; the second and third generation GOCE-only satellite models DS03 and TW03 are combined with the regional terrestrial data to analyze the possible improvement from the recent GOCE models. This process was done to determine the optimum combination for the satellite model and the terrestrial data. Where the Canadian Gravimetric Geoid Model (CGG2005) includes 2.2 million gravity measurements obtained from different sources, used in the evaluation with combined GRACE model.

-The GPS/levelling comparison results for EGM2008, CGG2005, and the 8 GOCE-combined models are obtained. The results indicate that the standard deviations of the combined models range from 12.2 to 12.7 cm for Canada, 4.7 to 5.3 cm for the Great Lakes and 6.0 to 7.1 cm for the Rockies. These results suggest that the recent GOCE models are spectrally consistent with the gravity field in Canada up to degree 180 [Ince et al., 2015].

In general, it is known that GOCE models do not provide accurate information for the lower degree components of the gravity field. The possible satellite model to be used in the combined regional geoid model can be a product of combination of GRACE, GOCE and other geodetic techniques, rather than GOCE-only model [Huang and Véronneau, 2010].

- In another study, different combinations of GOCE-based models and terrestrial gravity data are tested in Yukon Territory, British Columbia and Nunavut regions on 291 benchmark points. The results show that GOCE can contribute to the geoid model in the region close to cm level compared to EGM2008. Also, new Canadian geoid model CGG2010 shows an improvement as large as centimeter or few centimeters over some regions such as the provinces of British Columbia and Alberta, Rocky Mountains, Yukon area compared to CGG2005 and EGM2008 due to the contribution of GOCE [Véronneau and Huang, 2011].
- In a special study in year 2015 carried out in Finland to compare altogether 16 GOCE models, 12 GRACE models and 6 combined GOCE+GRACE models with GPS-levelling data and gravity observations in Finland. The satellite-only models were compared against high resolution global geoid models EGM96 and EGM2008.

-The coverage of the gravity dataset (altogether 39318 points) is presented with the GPS-levelling. For the comparison of the height anomalies, two GPS-levelling datasets were used: The European Vertical Reference Network - Densification Action (EUVN-DA) dataset and a dataset of the

National Land Survey (NLS) of Finland. For the comparison of the free-air gravity anomalies the gravity database of the Finnish Geospatial Research Institute (FGI) was used. The database contains gravity observations from early 20th century to present where the observations include terrestrial gravity measurements.

-The models were evaluated up to four different degrees and order: 150 (the common maximum for the GRACE models), 200, 240 (the common maximum for the GOCE models) and maximum.

-Generally, all of the GOCE and GOCE+GRACE models give standard deviations of the height anomaly differences of around 15 cm and of gravity anomaly differences of around 10 mgal over Finland, when coefficients up to 240 or maximum are used. The results are comparable with the results of the high resolution models. The best performance of the satellite-only models is not usually achieved with the maximum coefficients, since the highest coefficients (above 240) are less accurately determined. Even at the lower degrees and orders, the high resolution EGM96 and EGM2008 models performed very well over Finland when compared to the satellite-only models.

-The GOCE-based models perform better than EGM96 and quite equally with EGM2008 when developed up to degree and order 200. This proves that GOCE has improved the knowledge of the long wavelengths of the Earth's gravitational field. When developed up to degree and order 240 the best satellite-only models are at the same level as the high resolutions models in Finland. This point is very important when using GOCE-only models in the unification of height systems.

-This study prove that, there is a small tilt may be present in the EGM96 over Finland due to long wavelength errors in the model, EGM96 and EGM2008 models do not perform equally well everywhere due to the inhomogeneous distribution of the terrestrial gravity data, and the excellent performance of

these models are due to the good high resolution terrestrial data that was already available in the study area (recommended in proposal one). But the satellite-only models do not show any tilt over Finland, as well as, they will perform homogeneously everywhere on the globe [Timo and Koivula, 2015].

- In a study has been carried out between Norway and most of Fennoscandia in 2011, GOCE derived satellite-only GGMs have been compared with EGM2008, the OCTAS (The OCTAS geoid represents a high resolution gravimetric geoid model covering the north Atlantic, the Arctic Sea and Fennoscandia) geoid and terrestrial gravity anomalies.

-In the first numerical experiment in the study area, it was compared geoidal surfaces computed from four satellite-only global gravity models based on GOCE observations. Three of them have been determined by using pure GOCE satellite-to-satellite tracking and satellite gravity gradiometry observations. The fourth model has been computed from a combination of GRACE and GOCE observations (GOCO01S) as well as the OCTAS geoid to EGM2008.

Spherical harmonic expansions have been truncated at maximum degree and order 200 corresponding to a spatial resolution of 100km. Higher frequencies of the OCTAS geoid and of the terrestrial gravity anomalies have been removed by either subtracting the signals computed from EGM2008 above degree 200.

Standard deviation of OCTAS geoid reaches only 0.139 m. All geoid models are only slightly biased within few millimeters as the corresponding mean values indicate. Where the standard deviation was 0.057m, 0.073m, 0.080m, and 0.072m to all the four satellite-only global gravity models based on GOCE observations.

-In the second numerical experiment, they compare gravity anomalies from all the four GOCE satellite-only global gravity models, EGM2008 and with

terrestrial mean free-air gravity anomalies. The standard deviation of differences between gravity anomalies with respect to EGM2008 were 1.694mgal, 2.572mgal, 2.778mgal, and 2.570 mgal to all satellite. But in the case of EGM2008 reaches to 7.977mgal [Šprlák et al., 2011].

An important issue investigated in several studies is the omission error of the satellite only model equipotential surface, which is due to the limited sensitivity of the satellite to the high frequency gravity field signals. Its impact has to be quantified e.g. by estimating the high frequency signals separately from other sources as EGM2008. High resolution models, such as EGM2008 or regional models, such as EGG2008 in Europe, can be used to further improve the results. A widely used strategy extends the spherical harmonic coefficients of the satellite-only model by EGM2008 values. In special study in Germany 2014, the performance of EGM2008 and EGG2008 is almost on the same level in Germany. The standard deviations are 2.80 cm and 2.63 cm for the EGG2008 and the EGM2008, respectively.

EGG2008 was selected for the extension of GOCO03S and GOCE TIM R3 models. In a simple approach, the global and the regional models were combined. The resulting combined models performed better when compared to the pure EGM2008 or EGG2008. The estimated standard deviation is 2.1 cm for the GOCE TIM R3 and 2.4 cm for the GOCO03S model. A further improvement could be expected, if space borne and terrestrial observations are combined.

The GOCE mission has significantly improved the capabilities of unifying height reference frames. Due to its global applicability.

Generally, it could be shown, that height systems can be unified based on a gravity field model. This requires physical heights obtained by spirit levelling in the height systems and ellipsoidal heights at specific points. But connecting levelling lines across borders are often limited, however, the accuracy of the estimated height offsets depends on the

accuracy and spatial resolution of the gravity field model (omission error). Especially, the omission error is the essential factor for small countries or networks with a less dense point distribution. In summary, three procedures of dealing with the omission error must be taken into account:

- A satellite-only gravity field model is used and the omission error is ignored. According to the previous studies, this procedure is sufficient for requirements in accuracy of about 10 cm. For large areas, such as continents, and well distributed point networks the accuracy may increase (as recommended in the first proposal).
- The satellite-only gravity field model is will enhance by a high resolution gravity field model, such as EGM2008. This procedure is sufficient for requirements in accuracy of about 2 to 3 cm.
- The omission error of the satellite-only gravity field model will improve from terrestrial observation data. In this case it can be expected that the accuracy can be increased up to 1 cm, depending on the quality and density of terrestrial gravity observations (these data recommended in first proposal) [Gruber et al., 2014].

Form the previous context, the second proposal which depends on the PPP technique and gravitational geoid model which determined from satellite-only data, by using GOCE-only or a combination of GRACE and GOCE at their maximum degree and order. This gravity only model should be enhanced by one method of tailoring the global geoid model which previously mentioned. The proposed accurate data with its higher specifications which mentioned in the first proposal will be used for this purpose in order to improve and raise the resolution for the Arab region. Therefore, the second proposal will reduce the large numerical effort and costs required when using the traditional methods. So this method suggested to be used.

In twenty-three from November at 2016, a conference was held by United Nations Committee of Experts on Global Geospatial Information Management for Arab State. Where it's headquarter in Saudi Arabia. It has already started to implement the first steps to establish ARABREF. It presents a strategy for states cooperation to establish a unified geodetic reference and called it WG3 provided that to be the main purpose of its objective is establishing a unified vertical reference in the next step [http://www. Un-ggim-as.org. Email, unggimas@gcs.gov.sa].

CHAPTER (6)

SUMMARY, CONCULUSIONS, AND RECOMMENDATIONS

6.1. Summery

There are more than twenty-two separate vertical datum surfaces in the Arab world, all of them depend on the average readings of MSL measurements used to establish the vertical datums were observed with an effect of the 18.6-year lunar tide gauges at a specific time. The mean sea level is used as local vertical datum where the vertical and horizontal datum are used together to define the heights and the geodetic coordinates. The mean sea level is used as a reference for height and still used until now although the average of this observed value does not exactly represent the geoid [Mohamed, 2005].

So the mean sea level at some sites may be different in its value when it is compared with other sites because of the difference of equipotential surfaces. That's why the use of mean sea level as reference surface causes a lot of problems that are associated with the application of vertical datum. The differences in SST at tide gauge sites and differences in measuring techniques lead to delays in the implementation of regional projects in areas such as transportation, communication, and electricity reticulation grids and other projects that require heights. Determination of a unified precise geoid represents a significant step in eliminating these differences as it forms the basis for the determination of regional geoid model.

This Thesis Consists of Three Main Parts;

-The first part Studies the scientific background for associated topics and illustrates the similar experiments as unification the vertical datum in Europe, Australia, Africa, America, and Poland. This part discussed in first and second chapter.

-The second part illustrates the information about the existing geodetic observations concerning the vertical datums, in the study area; Tide gauge stations, GNSS stations, levelling BMs, and gravity stations in the study area. The second part also includes the suggested plan for completing those observations by showing the proposed station numbers, their distribution, and quality. To be in a suitable case for verifying the thesis purpose. This part has been addressed and discussed in chapter three and first part of chapter five.

-The third part suggests plan for unifying the vertical datum in the study area, it will contain the steps of establishing a main center to receive the observations (old and new) which mentioned in second part at chapter five, collecting them, filtering, processing, adjusting, and applying the suitable mathematical models to finally, guarantee a unified vertical datum for the users in the whole area. This part has been discussed in details in chapter four and second part of chapter five.

-Part three also include;

-Modernizing and establishing tide gauge stations in every Arab country where they will have modern accurate devices, and all of them operate by the same technique to give results at the same time to guarantee high precision in all observations at all stations.

-Establishing GNSS station at every Tide gauge station for defining the position and studying the movements of the Earth's crust.

-Establishing Core and Permanent Operating Reference Station network (PORS) in every Arab country. It will be processed and adjusted related to the nearest IGS stations. Then establishing the high accuracy GPS network related to these permanent stations.

-Establishing precise gravity networks distributed in optimum distances in every country related to its area.

Thus, the proposal was presented with a time table for achievement the observations tasks. Provided that all Arab countries must cooperate to implement this proposal to assist in completing the investments and the national contribution projects among Arab countries.

This thesis suggested, the second proposal which based on Precise Point Positioning (PPP) technique for positioning and satellite-only gravity model for determining the geoid undulation. In this proposal, the permanent stations and precise GNSS stations in every country will be replaced by PPP and the regional geoid model will be replaced by satellite-only model being not affected by terrestrial non-homogenous observations. Then the user everywhere in the study area can obtain his orthometric height by the difference between the ellipsoidal height and geoidal undulation.

Several studies have been investigated around the world to evaluate the performance of satellite only model and its results.

Generally, it could be shown, that height systems can be unified based on a gravity field model. This requires physical heights obtained by spirit levelling in the height systems and ellipsoidal heights at specific points. But connecting levelling lines across borders are often limited, however, the accuracy of the estimated height offsets depends on the accuracy and spatial resolution of the gravity field model (omission error). Especially, the omission error is the essential factor for small countries or networks with a less dense point distribution. In summary, three procedures of dealing with the omission error will be taken into account:

1. A satellite-only gravity field model is used and the omission error is ignored. According to the previous studies, this procedure is sufficient for requirements in accuracy of about 10 cm. For large areas, such as

continents, and well distributed point networks the accuracy may increase (as recommended in the first proposal).

2. The satellite-only gravity field model is will enhance by a high resolution gravity field model, such as EGM2008. This procedure is sufficient for requirements in accuracy of about 2 to 3 cm.

3. The omission error of the satellite-only gravity field model will improve from terrestrial observation data. In this case it can be expected that the accuracy can be increased up to 1 cm, depending on the quality and density of terrestrial gravity observations (these data recommended in first proposal)[Gruber et al., 2014].

6.2. Conclusions

After studying the main three parts of this research subject, there is a possibility to present a comprehensive study for presenting suitable proposals contains a plan of complete elements for unification the vertical datum in the Arab world. This study clarified the following points;

1. Most Arab countries using old tide gauge stations and they still use by ancient techniques. For example, old tide gauge in Alexandria in Egypt has been operated since 1986.

2. There are old benchmarks networks depend on observations from old tide gauge. If the observations have been updated, the tide gauge would still effect on the observations.

3- A lot of benchmarks are damaged, and a levelling network still depends on that existing old benchmarks in their observations.

4- A precise GPS network such as HARN in Egypt has not been updated a long time ago despite some of its points have been exposed for damage.

5- The gravity networks in all Arab countries are likewise the other networks are suffering from its lack data and existing a lot of gaps without any gravity data in some areas. Besides that, these networks have not updated their stations.

- **This Thesis Proposed;**

-Using Radar Level Sensor, with accuracy and performance are unaffected by changes in water density and atmospheric conditions. Minimum Range: 0.8 m, Maximum Range: 20 m, Beam Angle: ±6° and its accuracy equal ±10 mm.

-Using the power level SDL30, a digital level with a large internal memory. With Electronic Measurement, up 10m to 50m; 0.1×D and over 50m: 0.2×D where D is the measuring distance in meter. Measuring Range Electronic Measurement equal 1.6 to 100m and data storage Capacity equal 2000 points with in 64KB.

-Using GNSS Antenna with Frequency Range GPS L1/L2/L5, GLONASS L1/L2 BDS B1/B2/B3, and Galileo E1\E2\E5ab. Its phase center error ±2mm where horizontal accuracy equal 3 mm + 0.5 ppm and the Vertical accuracy is 5 mm + 0.5 ppm.

-The FG5 absolute gravimeter is suggested to be used; it can determine the gravity acceleration value with precision of 2-4 μgal.

These proposed specifications and using the Arab proposed gravity anomaly data grid and GPS/levelling grid, these make the proposed Arab geoid will provide orthometric height with precision within ±4.5cm, and gravity anomaly with precision ± 12.7 μgal.

. After presenting and implementing this proposed massive national project, some results can be concluded as;

- Replacing the official levelling-based vertical datum all over the Arab region by unified precise geoid and GNSS compatible vertical datum.

- Combining the precise geoid with GNSS receivers, it will be very easy to compute the orthometric height from precise geoid and precise ellipsoidal height.

-Easy to follow up the changes of mean sea level in different times to geodetic works and oceanographic surface and protection of coastline.

- Easy to determine the effect of sea surface topography in Arab territory which has coast line.

-All Arab countries together with desert, remote and extremist areas will contain unified vertical control system.

-Consistently with space-based positioning (e.g., GNSS, altimetry) is going to be guaranteed.

-The maintenance of the unified vertical datum is going to be less expensive.

-The vertical datum is going to be fairly stable due the actual fact that the geoid surface changes at a rate of 1 mm annually compared to 1 cm annually for the physical benchmarks related to the regional geodynamics [Amjadiparvar et al., 2016].

-The Arab nation will have a great science to face the challenges of the globalization. Because it will have an effective role in global Agencies which interested in surveying, maps, and geodesy, as International Association of Geodesy (IAG), International Center for Global Gravity Model (ICGEM), International Gravity Field Services (IGFS).

- In a special study in Europe as presented in chapter four and five, uses a grid of gravity anomalies 0.5^o X 0.5^o. It noticed that Europe has difficult topography differs from the Arab world topography so gravity anomaly data

grid in Arab world proposed to be the same as Europe 0.5^o X 0.5^o, or 1^o X 1^o for saving the efforts, time, and costs [Kearsley et al., 1990].

-In the numerical investigation at 2015 using the GNSS-levelling and tide gauge stations in Canada, the USA, Alaska, and Mexico showed Canadian Atlantic and Pacific regions, the datum offsets can be estimated with 2.3 and 3.5 cm standard deviation, using GNSS-levelling stations. However, due to the low number of tide gauge stations, the standard deviation of the CGVD28 and NAVD88 datum offsets can reach one decimeter in the Pacific regions [Amjadiparvar et al., 2016].

So after study the numbers of the tide gauges in the Arab world, there is one tide gauge in every country, all observations depend on it as an origin for the vertical datum. But some countries have long coast line greater than 1000km. So this thesis proposes that one tide gauge at least for every 1000km. Hence, Oman, United Arab Emirates, Saudi Arabia, Djibouti, Somalia, Yemen, Egypt, Libya, and Morocco must have two tide gauge at least, and for the countries which have two coastlines should have one tide gauge station at least on every coast.

6.3. Recommendations

After studying and analyzing the previous experiments in most states for unification the vertical datum and, after studying the current status of data in all Arab countries and presenting a suitable proposal to unify the Arab vertical datum, some points should be taken into consideration as recommendations;

- The proposed Arab Geodetic Service should contact all global scientific agencies which interested in surveying, maps, and geodesy such as GETECH to modify the Arab world gravity maps, after filling in the gaps by the new precise data, to achieve maximum benefit from the new data.

- AGS should be realized in context with a globally integrated network, which combines at terrestrial reference stations geodetic space techniques, high precise absolute and relative gravity, levelling, and tide gauges with permanent or episodically observations, for guarantee achievement a precise World Height System.

- Must be using Arab tide gauge observations in monitoring absolute global sea level variations by Coordination with Permanent Service for Mean Sea Level (PSMSL).

- After unifying the Arab vertical datum, It is strongly recommended to supply ICGEM by all the new precise data of our Arab world to be used in the future for producing Global Geopotential Models, it is will be more appropriate for the Arab world.

- The satellite altimeter and ocean model data should be used in any future geoid solution for any Arab State where all Arab countries have a coast line.

- Sending this proposal to United Nations Committee of Experts on Global Geospatial Information Management for the Arab State, to be the initial point towards a unified vertical datum in the Arab world, and help them for planning for this project.

- After implementation the unified Arab vertical datum, gravity satellite models should be utilized in gravimetric geoid modelling, for applications such as the implementation of a regional geoid-based vertical datum, in order to see if there is improvement with respect to past gravimetric geoid models that have not utilized recently released GOCE models for long to medium wavelength contributions of the gravity field.

-It is important that the future studies should involve a complementary validation of geoid and ocean models within the 'geodetic' and 'ocean' approaches to determine SST profiles along coastlines. To be able to settle

up a 'best' ocean model then it's resulting SST profile could be used to provide a SST correction to MSL measurements made at tide gauges along the coast. Therefore, MSL can be expressed relative to a national datum, then datums in different countries along a coastline can be unified and consistence of a datum within each country can be verified. In other words, the MSL can be used as a 'level' surface once a suitable correction derived from a model can be determined upon.

The above remain open points that should be addressed by Arab countries if they are to seek proper benefit from the Arab vertical datum unification at the highest level.

REFERENCES

Abdalla, A., (2009): Determination of a Gravimetric Geoid Model of Sudan Using the KTH Method, M.SC., Thesis in Geodesy No. 3109 Division of Geodesy. Royal Institute of Technology, Sweden.

Abd-Elmotaal, H., (2004): An Efficient Technique for Harmonic Analysis on a Spheroid (ellipsoid and sphere), Surveying, vol., 3(4), pp.126-135.

Abd-Elmotaal, H., (2014): Egyptian Geoid Using Ultra High-Degree Tailored Geopotential Model. In Proceedings of the 25th international federation of surveyors FIG congress, Kuala Lumpur pp. 16-21.

Abd-Elmotaal, H., Seitz, K., Abd-Elbaky, M., and Heck, B., (2015): Tailored Reference Geopotential Model for Africa. Springer International Publishing Switzerland, DOI 10.1007/1345-2015-84.

Al Arabi, B., and Gledan, J., (2010): Establishment of Cors-Libya, FIG Congress 2010, Facing the Challenges Building the Capacity, Sydney, Australia, 11-16 April.

Al marzooqi, Y., Alzarouni, A., Gopi, S., (2006): Progress Towards Establishment of a Unique Vertical Datum for Hydrography and Land Surveying in the Emirate of Dubai-Case Study, TS, No. 19, PP. 1-12.

Al-Bayari, O., and Al-Zoubi, A., (2007): Preliminary Study of the Gravimetric Local Geoid Model in Jordan: Case Study GeoJordan Model, Annals of Geophysics, VOL. 50, N. 3, June.

Albertella1, A., Savcenko, R., Janjic, T., Rummel1, R., Bosch.W., and Schroeter, J., (2012): Mean Dynamic Ocean Topography from GOCE, DFG SPP1257 Final Colloquium 17-19, GFZ Potsdam.

Al-Krargy, E., Domaa, M., and Dawood, G., :(2014) Towards an Accurate Definition of the Local Geoid Model in Egypt using GPS/Leveling

Data: A Case Study at Rosetta Zone. International Journal of Innovative Science and Modern Engineering (IJISME), Volume-2 Issue-11.

Al-Masri, R., (2010): Improved Geoid Model for Syria Using the Local Gravimetric and GPS Measurements, Damascus University Journal Vol., 26,(1).

Amin, m., El-Fatairy, M., Hassouna, R., (2003): A Better Match Of The EGM96 Harmonic Model For The Egyptian Territory Using Collocation Shoubra Faculty of Engineering, Zagazig University.

Amin, m., El-Fatairy, M., Hassouna, R., (2003): The “EGM96EGIT” Geopotential Model Tailored to Egypt by the Stokes’ Integral Technique. Shoubra Faculty of Engineering, Zagazig University.

Amin, M., El-Fatairy, S., Hassouna, R., (2003): Two Techniques Of Tailoring A Global Harmonic Model: Operational Versus Model Approach Applied To The Egyptian Territory. Journal of Port Said Engineering - Suez Canal University.

Amin, M., Refaat, M. and Ruby, A., (2017): Satellite-only Versus Combined High Degree Global Geopotential Model Tailored to Gravity Field in Egypt, Using Integral Formulas. IJRDO- Journal of Applied Science 3 (8), 35-47

Amjadiparvar, B., Rangelova, E.,and Sideris, M., (2016): The GBVP Approach for Vertical Datum Unification, Recent Result in North America J Geod no 90, pp 45–63, , DOI 10.1007/s00190-015-0855-8.

Amos, M. J., (2011): Land Information New Zealand. J Geod., No. 83, pp.57–68. DOI 10.1007/s00190-008-0232-y, published on line.

Amos, M.,(2007): Quasigeoid Modelling in New Zealand to Unify Multiple Local Vertical Datums, Department of Spatial Sciences, Department

of Spatial Sciences, Ph.D., dissertation, Curtin University of Technology.

Anaxandrida, L., (2012): Qatar Survey Manual. Official Manual, Published by the State of Qatar, https://www.scribd.com/doc/99097983/Qatar-Survey-Manual.

Andersen, O., and Knudsen. P., (2009): DNSC08 Mean Sea Surface and Mean Dynamic Topography Models. Journal of Geophysical Research 114:C11001, doi: 10.1029/2008JC005179.

Arsov, D., (2000): A High Power Geoid Based on a Sensor Fusion Approach, Ph.D., dissertation, Technical Sciences at the Technical-University-Graz.

Ashtech, J., (2011): GNSS Accuracy Specification Versus Reality, J Geod no 80, pp 30–33. DOI 10.1008/s00190-015-0845-8.

Bakry, E., (2010): Tides Analysis in the Red Sea in Port Sudan and Gizan. M.Sc., thesis, Physical Oceanography, Sudan.

Baqer, M., Al falasi, E., Neelakandan, S., and Renati, K., (2011): Establishing and Updating Vertical Datum for Land and Hydrographic Surveying in Dubai Emirate, TS08J Marine/Coastal Modelling and Technology, no. 5058, pp. 22-32.

Basic, T., Denker, H., Knudsen, P., Solheim, D. and Torge, W., (2000): A New Geopotential Model Tailored to Gravity Data in Europe, Springer, No.50, PP. 109-118.

Bayound, F., (2008): Geoid Determination, Case Study Lebanon., Geo-consulting Middle East (CCME), Fabayound@gcmematics.com.

Bonvalot, S., (2016): International Gravimetric Bureau (BGI) IAG Scientific Services, J Geod, VOL (90).

Cartographic Materials Codes (1994): Manual, Bibliographic Format appendix F Cartographic Materials Codes, http://www.ifla.org/VI/3/p1996-1/appx-f.htm.

Colombo, O. L. (1981): Numerical Methods for Harmonic Analysis on the sphere (No. DGS-310). Ohio state university Columbus department of geodetic science.

Daho, B., and Fairhead, J., (2001): A New Quasi-Geoid Computation from Gravity and GPS Data in Algeria, National Centre of Space Techniques, Geodetic Laboratory, BP 13 Arzew, 31200, Algeria.

Dawood, G., (1998): The Egyptian National Gravity Standardization Network of 1997, Ph.D., dissertation, Shoubra Faculty of Engineering, Zagazig University, Egypt.

Dawood, G., and Abdel-Aziz, M. (2003): Establishment of a Precise Geodetic Control Network for Updating the River Nile Maps, Proceedings of Al-Azhar Engineering 7th International Conference, Cairo, April 7-10.

Dawood, G., Mohamed, H., and Ismail, S., :(2010) Evaluation and Adaptation of the EGM2008 Geopotential Model along the Northern Nile Valley, Egypt: Case Study, Journal of Surveying Engineering, DOI: 10.1061/ASCESU.1943-5428.0000002, published on line.

EL Brirchie, E., and EL Azzab, D., (2011): Comparing Global Geoids over Morocco Area for GNSS Altimetry Determination. Marrakech, Morocco, Bridging the Gap between Cultures, Marrakech, Morocco, 18-22 May.

El Raey., M. (2012): Impact of Sea Level Rise on the Arab Region, Ph.D. dissertation, University of Alexandria and Regional Center for Disaster Risk Reduction.

El-Geziry, T., and Radwan, A., (2012): A Decadal Sea Level Analysis off Alexandria, Egypt, The Egyptian Journal of Aquatic Research Volume 38, Issue 1, PP. 1–5.

El-Hallaq, M., (2012): Development of a Local GPS Leveling Geoid Model for the Gaza Strip Area, International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 3, March.

El-Kherayef, O., Salawu, A., Al- Qahtani, A., and Al- Rubaia, U., (2015): Re-establishment of Geodetic Network at General Commission for Surveying Saudi Arabia. From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17-21 May.

Ellmann, A., All, T., and Oja, T., (2009): Towards Unification of Terrestrial Gravity Data Sets in Estonia. Estonian journal of Earth Sciences, Volume 58, Issue 4, Pages 229–245

Kearsley, A., and Forsberg, R., (1990): Tailored Geopotential Models-Applications and Shortcomings, Springer, 15, PP.151-158.

Featherstone W., and FiLSer. M., (2012): The North-South Tilt in the Australian Height Datum is Explained by Mean Sea-Surface Topography. Journal of Geophysical Research- Oceans 117:C08035, doi:10.1029/2012JC007974.

Featherstone, E., (2008): Absolute and Relative Testing of Gravimetric Geoid Models Using Global Positioning System and Orthometric Height Data, Journal of Computer and Geosciences, VOL (27), PP. 807–814.

Featherstone, E., (2005): Attempts to Unify the Australian Height Datum Between the Mainland and Tasmania. Department of Spatial Sciences, Australia, Ph.D., dissertation, Curtin University of Technology.

Filmer, M. (2014): Using Models of the Ocean's Mean Dynamic Topography to Identify Errors in Coastal Geodetic Levelling. Marine Geodesy 37: 47-64.

Ge, M., Gendt, M., Rothacher, C., Shi, C., and Liu, J., (2008): Resolution of GPS Carrier Phase Ambiguities in Precise Point Positioning (PPP) with daily observations, Journal of Geodesy, Vol. 82, No. 7. pp 65-78

Ali, H., (2007): Technical Report: Determination of the Orthometric Height Inside Mosul University Campus by Using GPS Data and the EGM96 Gravity Field Model, Journal of Applied Geodesy ,PP. 241–247, DOI 10.1515/JAG.2007.026.

Godaha, W., and Krynski, J., (2013): Comparison of GGMs Based on one year GOCE Observations with the EGM08 and Terrestrial Data Over the Area of Sudan. JAG., No. 797, PP. 1- 8

Gommenginger, C., Cipollini., P, Snaith, H., West, L., and Passaro, M.,(2013): SAR Altimetry Over the Open and Coastal Ocean: Status and Open Issues. In Proc. SAR Altimetry Expert Group Meeting National Oceanography Centre, Southampton, UK, 26–27 June

Griffies, S., and Greatbatch, R., (2012): Physical processes that Impact the Evolution of Global Mean Sea Level in Ocean Climate Models. Ocean Model. 51, 37–72. doi:10.1016/j.ocemod.2012.04.003.

Gruber, T., Johannes, I., Liebsch, G., Rülke, A., Schäfer, U., Sideris, B., Rangelova, E., Woodworth, P., and Chris, H., (2014): Height System Unification with GOCE, Ph.D., dissertation, Institute of Astronomical and Physical Geodesy (IAPG).

Guimarães, G., and Blitzkow, D., (2015): New Geoid Model in the State of São Paulo, Springer International Publishing on line DOI 10.1007/1345_2015_131.

Hadi, W., and Tuckerman, P., (2007): Development and Operation of the Bahrain Permanent RTK Network, Journal of Geospatial Engineering, Vol. 4, No. 1, pp.31-40.

Hayden, T., Rangelova, E., Sideris, G., and Véronneau, M., (2013): Contribution of Tide Gauges for the Determination of W_0 in Canada, IAG Symp., 141, Springer-Verlag.

Heiskanen,W., and Moritz, H., (1967): Physical Geodesy, W.H. Freeman and Company, San Francisco and London.

Hirt, C., Gruber, T., and Featherstone, E., (2011): Evaluation of the First GOCE Static Gravity Field Models Using Terrestrial Gravity, Vertical Deflections and EGM2008 Quasigeoid Heights. Journal of Geodesy, 85(10), 723-740.

Hofmann B., and Moritz, H., (2005): Physical Geodesy, Second Edition, Springer, Wien, NewYork, ISBN-10 3-211-33544-7

Huang, J., and M., Véronneau. (2010): Methods of Using the Satellite-Based Global Gravity Field Models to Model the Geoid in Western Canada and Alaska, presented in the Second International Symposium of the International Gravity Field Service, 20-22 September 2010, Fairbanks, Alaska

Hughes, W., and Williams SDP., (2010): The Color of Sea Level: Importance of Spatial Variations in Spectral Shape for Assessing the Significance of Trends. J. Geophys. Res. 115, C10048, doi:10.1029/2010JC006102

ICSM publication No.1. (2007): Inter-Governmental Committee on Surveying and Mapping-Standaras and Practices for Control Surveys- Version 1.7, 2007, ICSM publication No.1.

Ihde, J., (2007): Realization of a Global Vertical Reference System, Richard-Strauss-Allee 11, D-60598, johannes.ihde@bkg.bund.de

Illigner, J., Sofian, I., Abidin, H., Syafi, M., and Schöne, T., (2015): Coastal Sea Level Monitoring in Indonesia: Connecting the Tide Gauge Zero to Leveling Benchmarks. DOI 10.1007/1345_2015_23, published on line.

Ince, E., Sideris, M., Huang, J., and Véronneau, M., Assessment of the GOCE-Based Global Gravity Models in Canada (2015): Geomatica DOI: 10.5623/cig2012-025.

Kearsley, A., and Forsberg, R., (1990): Tailored Geopotential Models-Applications and Shortcomings, Springer, No. 15, PP.151-158.

Kesraoui, A., (2012). High level Forum on Global Geospatial Management Information. Department of Geodesy, Report No.2, Doha, Qatar, Country Report: Algeria.

Li, X. and Gutze, H. J., (2009): Tutorial: Ellipsoid, Geoid, Gravity, Geodesy, and Geophysics, Journal of Geophysics, vol., 66 , PP.1660–1668.

Luz, R., Correia, S., Brasileiro, A., (2007): Improvement of Coastal Satellite Altimetry Data for Evaluating the Brazilian Geodetic Height System. Brasil, 21-26 abril 2007, INPE, p. 4623-4625.

Lyszkowicz, A., Birylo, M., Siehien, J., (2015): Unification of Polish Local Vertical Datum with Global Vertical Datum, Informatics, Research Gate. DOI: 10.13140/RG.2.1.1909.3843, No. 10, PP. 11-26.

Manning, J., Johnston, G., and Digney, P., (2001): GPS Connections at Antarctic Tide Gauge Bench Marks in 2000/2001 summer, published on line.

Merry, C., (2005): The African Geoid Project and Its Relevance to the Unification of African Vertical Reference Frames. 2nd FIG Regional Conference, Marrakech, Morocco, 18-22 May.

Meyssignac, B., and A. Cazenave, (2012): Sea level: A Review of Present-Day and Recent-past Changes and Variability. Journal of Geodynamics 58:96-109, doi: 10.1016/j.jog.2012.03.005.

Mihanovi, H., Domijan, N., Leder, N., Cupic, S., Strinic, G., and Gržeti, Z., (2008): CGPS Station Collocated at Split Tide Gauge. Hydrographic

Institute of the Republic of Croatia, Zrinsko-Frankopanska 161, 21000 Split, Croatia e-mail: hrvoje.mihanovic@hhi.hr;

Mogren, S., (2010): A Preliminary Attempt of a Quasi-geoid for Saudi Arabia, FIG Congress 2013, Facing the Challenges, Building the Capacity, Sydney, Australia, 11-16 April.

Mohamed, H. F., (2005): Realization and Redefinition of the Egyptian Vertical Datum Based on Recent Heterogeneous Observations, Surveying Department, Egypt, Ph.D. dissertation, Shoubra Faculty of Engineering, Zagazig University.

Mohamed, R., (2003): Modeling of Outer Gravity Filed in Egypt Using Recent Available Data. Ph.D. dissertation, Faculty of Engineering in Shebin El-Kom, Egypt.

Mohammed, M., Al falasi, E., Neelakandan, S., and Renati, K., (2011): Establishing and Updating Vertical Datum for Land and Hydrographic Surveying in Dubai Emirate, Bridging the Gap between Cultures conference Marrakech, Morocco, 18-22 May.

Motao, H., Zheng, G., and Ongzhong, Y., (1996): On the Improvement of Geopotential Model Using Gravity Data in CHINA, Springer, No.40, PP. 186-197.

Naouali, K., (2011): The GNSS Network of Tunisia**,** FIG Working Week 2011, Bridging the Gap between Cultures Marrakech, Morocco, 18-22 May 2011.

Naouali, K., (2012): The GNSS network of Republic of Tunisia**,** EUREF Symposium, Reference Frame sub-commission for Europe Paris 6-8 June 2012.

NOAA Technical Report NOS 139, (2015): NOAA Guidance Document for Determination of Vertical Land Motion at Water Level Stations Using GPS Technology.

Odalovic, O., Al-gharabli, H., Naod, V., (2013): Comparisons of Global Geopotential Models with Terrestrial Gravity Data in Libya. European journal of scientific research, vol.43 no.4, pp.290-310.

Odido, M., (2012): Regional Sea Level Observations Intergovernmental Oceanographic Commission (IOC) Sub Commission for Africa and the Adjacent Island States, The First Session of the Sub Commission, United Nations Offices, Nairobi 2 – 3 May.

Okubo, S., Yoshida, S., Sato, T., Tamura, Y., Imanishi, Y.,(1997) Verifying the Precision of a New Generation Absolute Gravimeter FG5 Comparison with Superconducting Gravimeters and Detection of Oceanic Loading Tide, an Agu journal, vol.,24, Issue 4, Pages 489–492.

Pavlis, N. K. (2013). Global Gravitational Models. In Geoid Determination pp. 261-310. Springer, Berlin, Heidelberg.

Pérez, B., Payo, A., López, D., Woodworth, L., and Fanjul, E., (2014): Overlapping Sea Level Time Series Measured Using Different Technologies: an example from the REDMAR Spanish network, doi:10.5194/nhess-14-589, Published On line.

Rabah, M., and Kaloop, M., (2011): The Use of Minimum Curvature Surface Technique in Geoid Computation Processing of Egypt. Arabian Journal of Geosciences No. 30, PP. 44-65.

Ries, J., Bettadpur, S., Poole, S., and Richter, T. (2011): Mean Background Gravity Fields for GRACE Processing, GRACE Science Team Meeting, Austin, TX, August 8-10. Published On line.

Rosen, D., (2005): National Report on Present Status of Sea Level Monitoring in Israel, 9th Session of the IOC/UNESCO Group of Experts on the Global Sea Level Observing System (GLOSS) Paris, France, 24-25 February.

Rummel, R., Gruber, T., Johannes, I., Liebsch, G., Rülke, A., Schäfer, U., Sideris, B., Rangelova, E., Woodworth, P., and Chris, H., (2014): Height System Unification with GOCE, Ph.D., dissertation, Institute of Astronomical and Physical Geodesy (IAPG).

Rülke, A., Liebsch, G., Sacher, M., Schäfer, U., Schirmer U., and Ihde, J., (2012): Unification of European Height System Realizations. Journal of Geodetic Science. DOI: 10.2478/v10156-011-0048-1, No.4, pp. 343-354

Saad, A., (1993): Towards the Redefinition of the Egyptian Vertical Control Network, Ph.D., dissertation, Shoubra Faculty of Engineering, Zagazig University, Egypt.

Sadatipour, S., Kiamehr, R., Abrehdary, M., and Sharifi, A., (2012): The Evaluation of Sea Surface Topography Models based on the Combination of the Satellite Altimetry and the Global Geoid Models in the Persian Gulf., Int. J. Environ. Res., vol., 6(3):645-652.

Salah, M., (2008): Tailored High-Degree Geopotential Model for Egyptian M.Sc., thesis, El-Minia University, Engineering Collage.

Salah, S., (2012): Assessment of the Gravitational Global Models in Egypt M.Sc. thesis, Faculty of Engineering, Al Azhar University, Egypt.

Salmon, E., (2009): The Permanent GNSS Network and its RTK Application in Israel. Surveyors Key Role in Accelerated Development, Eilat, Israel, 3-8 May.

Sammari, C., (2004): Tide Gauge Network on the Red Sea, Institute National of Sciences and Technologies, J Geoid., No.80, PP. 44-76, E-mail: cherif.sammari@instm.rnrt.tn

Sánchez, L., (2012): Towards a Vertical Datum Standardisation Under the Umbrella of Global Geodetic Observing System Research Article, Journal of Geodetic Science. DOI: 10.2478/v10156-012-0002-x, pp, 325-342.

Sánchez, L., (2012): Towards a Vertical Datum Standardization- SIRGAS annual meeting, pp.50-74.Published on line, October 31.

Sánchez, L., Dayoub, N., Čunderlík, R., Mikula, K., Minarechová Z., Šíma, Z., Vatrt,V., and Vojtíšková, M., (2013): Conventional Reference Level for a Global Unified Height System, J Geod., No. 89, pp, 22-36. See http://www.satoc.eu/projects/CP4O/meetings.html

Seeber, G. (2003). Satellite Geodesy: Foundations, Methods, and Applications. Walter de Gruyter.

Shaker, A., Alnaggar, D., Faisal, H., (2005): Sea Surface Slope and Variation Along the Egyptian Delta Coast. Published on line.

Sharni, D., (2008): New Vertical Datum for the Dead Sea Works, Surveyors Key Role in Accelerated Development Eilat, Israel, 3-8 May.

Sideris, M., and Fotopoulos, G., (2006): Mean Sea Level, Satellite Altimetry and Global Vertical Datum Realization, World Climate Research Program (WCRP), Paris, France, pp, 22-36.

Simon, F., (2007): Ott Hydro Sensor Installation Report Djibouti Ville. Republic of Djibouti, Intergovernmental Oceanographic Commission, report, 11-18 February.

Smith, A., Ve´ronneau, M., Roman, D. Huang, J., Wang, Y.,and Sideris, M.,(2013): Towards the Unification of the Vertical Datum Over the North American Continent. Silver Spring, DOI 10.1007/978-3-642-32998-2_36.

Šprlák, M., Gerlach, C., Omang, O., and Pettersen B., (2011): Comparison of GOCE derived satellite global gravity models with EGM2008, OCTAS geoid and terrestrial gravity data: case study for Nerway. General Assembly of the European Geosciences Union, 13–18 April, Vienna, Austria.

Tasnuva., H., (2013): Geopotential of the Geoid-Based North American Vertical Datum., Msc., university of Calgary Alberta.

thesis El-minia University, Egypt.
Timo, T., and Koivula, M.,(2015): Evaluation of GOCE-based Global Geoid Models in Finnish Territory, Finnish Geospatial Research Institute (FGI), EGU General Assembly 2015, held 12-17 April, 2015 in Vienna, Austria. id.4165, Published On line.
Torge W., (1989): Gravimetry. W. de Gruyter, Berlin.
Touam, S., (2013): Refection of National Geodetic Infrastructure Using GNSS Technique, United Nations, Croatia Workshop on the Applications of GNSS, Baška, 21 – 25 April.
User’s Guide, (2013): For GPS Observations at Tide and Water level station bench marcks. Engineering Division Center for Operational Oceanographic Products and Services, National Ocean Service, National Oceanic and Atmospheric Administration.
User's guide (2013): user's guide for GPS observations at tide and water level station bench marks, National Oceanic and Atmospheric Administration.
Vergos, G., and Teziavos, I.,(2010): On the Combined Adjustment of Tide Gauge, Marine Geoid and Sea Surface Topography Towards the Unification of the Greek Vertical Datum. General Assembly of the EGU –EGU2010, Session G14–Recent Developments in Geodetic Theory. Vienna, Austria May 02 –07, 2010. puplished on line.
Véronneau, M., and Huang, J., (2011): A New Gravimetric Geoid Model for Canada CGG2010, presented at CGU Annual Scientific Meeting, May 15-18, 2011, Banff, Alberta, Canada.
Vigny, C., de Chabalier, J. B., Ruegg, J. C., Huchon, P., Feigl, K. L., Cattin, R., and Kanbari, K. (2007): Twenty-Five Years of Geodetic Measurements Along the Tadjoura-Asal Rift System, Djibouti, East Africa. Journal of Geophysical Research: Solid Earth, 112(B6)

Visser, P., Rummel, R., Balmino, G., Sünkel, H., Johannessen, J., Aguirre, M., Woodworth, P.L., Le Provost, C., Tscherning, C.C. and Sabadini, R., (2002): The European, Earth Explorer Mission GOCE: Impact for the Geosciences, in: Mitrovica, J.X. and Vermeersen, B.L.A., Ice Sheets, Sea Level and the Dynamic Earth, Geophysical Monograph, 29, American Geophysical Union, Washington, USA.

Visser, M., and IJssel, J., (2009): GPS-Based Precise Orbit Determination of the Very Low Earth Orbiting Gravity Mission GOCE, Journal of Geodesy, 74: 590-602.

Watson P.J. (2011): Is There Evidence Yet of Acceleration in Mean Sea Level Rise Around Mainland Australia?, Journal of Coastal Research, vol.,27 (2), 368-377.

Watson, P., Commins, R., Jansse, V., McElroy, S., Batman, G., and Connors, D., (2012): Augmenting the Utility of NSW Longest Tide Gauge Records with Continuous GNSS Technology, published in the online at http://www.coastalconference.com/2012/.

Weber, G., Allee, R., and Zomorrodian, H., (1988): Regional Geopotential Model Improvement for the Iranian Geoid Determination. Bulletin Geodetic, vol., (52), pp. 177-190, Paris.177-190, Paris, 1978.

Weber, G., and Zomorrodian, H. (1988): Regional Geopotential Model Improvement for the Iranian Geoid Determination. Journal of Geodesy, vol., 62(2), pp.125-141.

Weigelt, M., Dam, T., Jäggi, A., Prange, L., Tourian, M. J., Keller, W., & Sneeuw, N. (2013). Time-Variable Gravity Signal in Greenland Revealed by High-Low Satellite-to-Satellite Tracking. Journal of Geophysical Research: Solid Earth, vol., 118(7), 3848-3859.

Woodworth, L., Hughes,W., Bingham.J., and Gruber,T., (2012): Towards Worldwide Height System Unification Using Ocean Information, Journal of Geodetic Science, vol.,2(4), pp. 302-318

Xiong, L., and Hans-Jurgen, G., (2006): “Tutorial: Ellipsoid, Geoid, Gravity, Geodesy, and geophysics”, Geophysics, vol.,6(66) , pp.1660-1668

Zhang, B., Teunissen, and Dennis, O., (2011): A Novel Un-differenced PPP-RTK Concept, The Journal of Navigation, vol. (64) pp. 180-191

Zhang, C., (2008): Height Datum Unification Between Shenzhen and Hong Kong Using the Solution of the Linearized Fixed Gravimetric Boundary Value Problem. Department of Land Surveying and Geo-informatics, J Geod DOI 10.1007/s00190-008-0234-9, published on line.

The Websites Used in Thesis

http://www.gcs.gov.sa/ar/ProductsAndServices/Products/PublicMaps/Pages/Official-Map-Of-The-Kingdom-Of-Saudi-Arabia.aspx.

http://www.gcs.gov.sa/En/ProductsAndServices/Products/Geodesy/National-Grid-Home/Pages/modern-network.aspx.

http://www.gcs.gov.sa/Ar/ProductsAndServices/Products/Geodesy/pages/cors.aspx.

http://www.gcs.gov.sa/Ar/ProductsAndServices/Products/Geodesy/N.ational-Network-of-gravity/Pages/Absolute-stations.aspx

https://en.wikipedia.org/wiki/Geoid. 2015.

https://en.wikipedia.satellite missions 2015.

http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide11c.html

http://oceanservice.noaa.gov/education/kits/tides/tides11_newmeasure.html

http://refmar.shom.fr/en/documentation/instrumentation/maregraphes-radar)

http://gpsworld.com/new-tide-gauge-uses-gps-to-measure-sea-level-change)

https://www.google.com.eg/Acustic tide gauge.

http://www.nationalgeographic.org/encyclopedia/altimeter/

https://science.nasa.gov/earth-science/oceanography/physical-ocean/ocean-surface-topography

http://www.valeport.co.uk/Products/Tide-Gauges/Tide-Gauge-Product Details/ProductID/40.

https://us.sokkia.com/products/levels-accessories/automatic-levels/sdl30-digital level.

http://www.civileblog.com/levelling.

https://en.wikipedia.org/wiki/Precise_Point_Positioning

http://www.novatel.com/technology-in-action/velocity/

http://www.navipedia.net/index.php/Precise_Point_Positioning

http://www.igs.org/network

http//www.trimble.com/trimbler8gnss.shtml,"trimble R8 German

http://www.geod.nrcan.gc.ca/hm/pdf/igfs2010_e.pdf).

http://www. Un-ggim-as.org. Email, unggimas@gcs.gov.sa

http://www.ancfcc.gov.ma/GeoideAr.

http://cddisa.gsfc.nasa.gov/emg96/egm96.html.

https://getech.com.

http://cddisa.gsfc.nasa.gov/emg2008/egm2008.html

http://www.marine.csiro.au/~dunn/cars2009/

http://beta.tidesandcurrents.noaa.gov/datum_options.html.

http://georepository.com/datum_1028/Fao-1979.html.

http://www. Maradah Libya scale 1:2500 series 1501 sheet NH 34-9 Edition5.

http://e-collection.library.ethz.ch/eserv/eth:31025/eth-31025-02.pdf

http://georepository.com/datum_5186/Kuwait-PWD.html

APPENDIX (A)

THE RELATION OF SST TO GEODESY

The ocean surface has highs and lows, similar to the hills and valleys of Earth's land surface depicted on a topographic map. These variations, called ocean surface topography or sea surface topography. Sea Surface Topography (SST) has many applications; it is used to map ocean currents, which move around the ocean's hills and valleys. And used also to understand how the ocean moves heat around the globe, a critical component of Earth's climate, and for monitoring changes in global sea level. Furthermore, it plays an important role in geodesy where the existence of the SST leads to the separation between the geoid and the MSL. Generally, SST, MSST, and MDT are used synonymously and refer to the height of the mean sea surface above the geoid [Tasnuva, 2013].

A.1. Factors Affecting Sea Surface Height (SSH) Change

Since the Earth's gravitational field is relatively stable on decadal to centennial timescales, ocean circulation plays a more significant role in the observed variation of SSH. Across the seasonal cycle changes in patterns of warming, cooling and surface wind forcing affect circulation and influence SSH.

SSHs are changeable due to changes in dynamic topography is that neither the geoid nor the ocean's crust is stationary, and SSH changes can be driven by their motion. Tide gauges directly measure sea-level change, whereas an independent measure of the crustal motion is needed to convert a measurement from a satellite to sea-level measurement. Therefore, to understand observed long-term sea-level changes, it becomes essential to account for both the crustal motion and geoid changes [Griffies and Greatbatch, 2012].

Both globally and regionally, a change in the sea surface can result

from a change in mass of the water column or a change in density caused by temperature and salinity changes. Using the change in density is an effective way to estimate the overall SSH change by helping the altimetry observations [Hughes and Williams, 2010].

SST can be derived from ship-going measurements of temperature and salinity. However, since 1992, a series of satellite altimetry missions, beginning with TOPEX/Poseidon and continued with Jason-1 and, Jason-2 and others for calculating the SST Where required altimetry observations time span should be more than 2 years, to 12 years being long enough for a long-term trend with a 1 mm per year precision [Gommenginger et al., 2013].

A.2. Sea Surface Topography Determination

The determination of the SST plays an important role. One is that the best ocean model can be used to connect datums between neighboring countries with coastlines. The second is that the validation of geoid models at the coast provides confidence in their use across continents, thereby providing datum connections between countries without coastlines [Hayden et al., 2013].

Generally, there are two basic approaches for determination SST at the coast.

The first approach is the geodetic approach, this approach adopts two options for determination the SST at the coast. The first option depends on a combination of tide gauge records and a geoid model where the ellipsoidal heights of mean sea level at tide gauge stations obtained with the use of GNSS receivers geodetically connected to the tide gauge zeros of the stations by means of conventional levelling. The second option depends on a combination of satellite altimetry sea surface heights and a geoid model, where ellipsoidal heights of sea level obtained from satellite radar altimetry, are compared to ellipsoidal heights from a geoid model. When gauge data

are used, this operation is conducted exactly at the coast, whereas altimetry data are employed, then the comparison has necessarily performed some tens of km offshore.

The second approach is the ocean approach depends on oceanic sea surface topography models. In some early versions to determine SST, sets of oceanographic and meteorological measurements were made (coastal sea level, ocean currents, temperatures, salinities, air pressures and winds) and analysed in the context of the known equations of motion in the ocean, so as to provide sets of sea surface gradient. Nowadays, it is more convenient to use the ocean numerical models in which the oceanographic data sets may have been assimilated. The result is a two- dimensional field of the SST which may be compared to those from the geodetic method [Woodworth, 2012].

As stated, the extent to which the sets of SST information at (or near) the coast are consistent between the two mentioned approaches provides assessments of the performance of the ocean and geoid models. The importance of ocean models refers to determine SST of the ocean along a coastline in different ways.

The values of coastal SST derived from an ocean model may be affected in several ways. One is that, although the model will have contained forcing from winds air pressures, and storm surge. Similarly, wave setup in bays, estuaries, and harbours can result in a SST measured at the coast differing from that implied by an ocean model. Other factors include freshwater runoff from large rivers. These effects can be estimated by merging global and regional models to reduce the occurrence of short wavelength [Woodworth et al., 2012].

A.3. Sea Surface Topography Component

The SST consists of two parts (ζ_c & ζ_t): the pseudo-static part

(unchangeable in time) and the changeable in time part. The pseudo-static topography is stable as the SSH on time period and the changeable topography changes with the slight changes in time scale and seasonal phenomena. (Figure A.1) shows SST and the definition of collocated heights for its determination [Sadatipour et al., 2012].

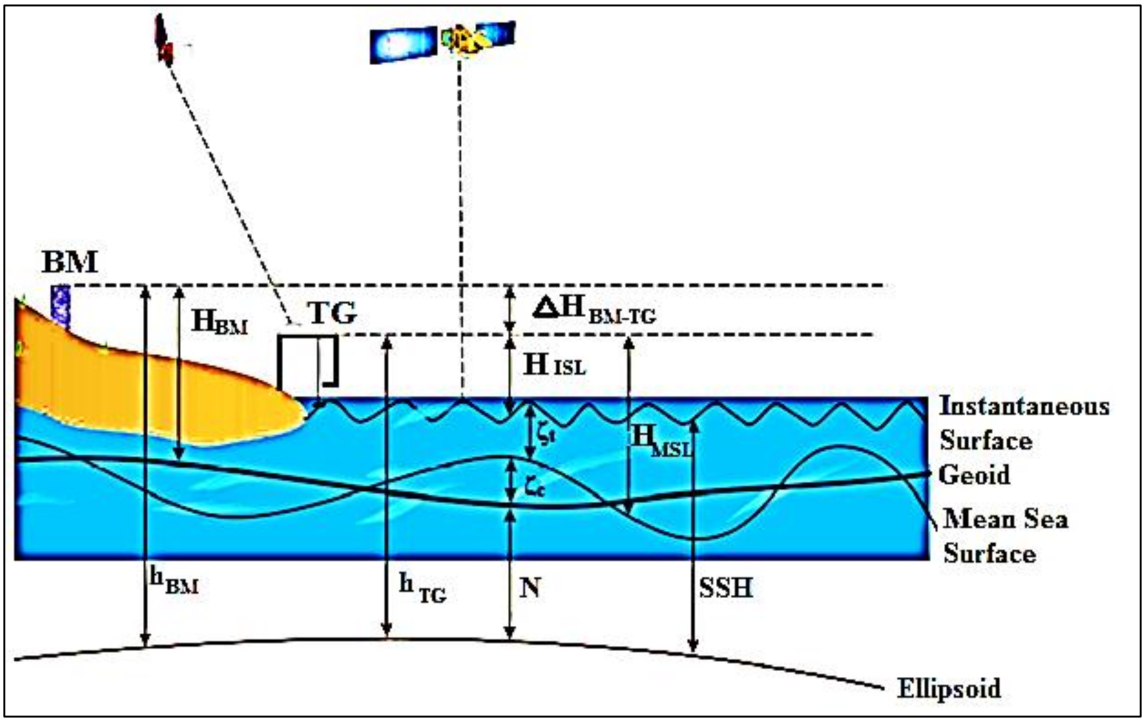


Figure (A.1): Shows the definition of collocated heights for SST determination [Vergos and Teziavos, 2010].

A.4. Methodology for Determination SST Models Based on the Combination of Satellite Altimetry and GGMs. (The Geodetic Approach)

-The systematic errors relating to satellite distance from the sea level which is measured by altimeter satellites (e.g. Topex/Poseidon, Jason -1 or GFO) should be corrected.

-Determination the correction value for each point from MGDR-B files (available on the internet) [Sadatipour et al., 2012].

-After correction the distance between the satellite and instantaneous sea surface (corrected Range), SSH will be obtained at the same point in regard to reference ellipsoid by having determined satellite altitude (H_{sat}) from the ellipsoid.

$$SSH(\lambda ,\phi ,t) = H_{sat} (\lambda ,\phi,t) - \text{Corrected Range} \qquad (A.1)$$

-Determine MSL and its time changes and then the periodic constituents be estimated. Therefore, the time series are assumed $h\{(ti)\} i = 1,2,\ldots, n$ the observations relating to the instantaneous SSH of the sea surface in a known point, so the appropriate model for tidal modeling is shown below;

$$H (\lambda ,\phi, t) = a_0 (\lambda ,\phi) + b_0 (\lambda ,\phi) t +\sum_{i=n}^{n}[a_i(\lambda ,\phi) \cos (2\pi f_i t)+$$

$$b_i (\lambda , \phi) \sin (2\pi f_i t)] \qquad (A.2)$$

In the above-mentioned formula, a_o denotes the MSL and a_i ,b_i denotes the tidal waves amplitude which should be determined as Fourier coefficients b_o denotes permanent increase in the seas water level which is considered constant in all of the sea levels due to the pole ices melting and f_i denotes the used frequencies**.**

Determination of the Fourier coefficients in the above-mentioned extension, in fact, led to the determination of a model for a phenomenon behavior. These coefficients are determined by using a sample and providing a parametric equations system. The least squares method is used to solve this parametric equation system.

-Determination the geoidal undulation from a precise global geoid model which is the most appropriate for the study area.

-The precise determination of the SST depends on the precise determination of the MSL and geoid.

$$SST|_{(\lambda ,\phi)} = MSL |_{(\lambda ,\phi)} - N_{Geoid} |_{(\lambda ,\phi)} \qquad (A.3)$$

-Calculation SST from N and SSH.

The relation between geoidal height and the sea surface topography is shown in (Figure A.1) in which ζ_t is the changeable part and ζ_c is the pseudo-static topography part;

$$SST_{(\zeta c + \zeta t)} = SSH - N \quad (A.4)$$

-Eliminate the SST value from MSL in order to obtain geoid compile to MSL.

-The same previous steps should be repeated at each T.G station to grantee a unified datum.

A.5. The Role of SST Model in Detecting Error Propagation in Coastal Geodetic Levelling

The errors in Costal Geodetic Levelling networks at Tide Gauge should be identified, these errors; blunders (field observation or booking mistakes) and systematic errors, many of which are difficult to identify and quantify, e.g., refraction, magnetic errors in automatic levels, staff settlement, staff expansion, Earth tides, and staff calibration. Rather than other error which effect on MSL observations; temporal variability in MSL, changes in Tide Gauge Zero (TGZ), tide gauge malfunction and/or equipment changes and vertical land motion at the tide gauge. Poor record keeping, or the records not being updated, inconsistent tide gauge observation periods and tide systems in the different data sets.

Using SST models to identify these errors in coastal levelling is possible because of significant improvements in SST models in recent years. When used in a relative sense (i.e. the difference between SST at two tide gauges). (Figure A.2) shows the difference between SST at two tide gauges [Meyssignac and Cazenave, 2012].

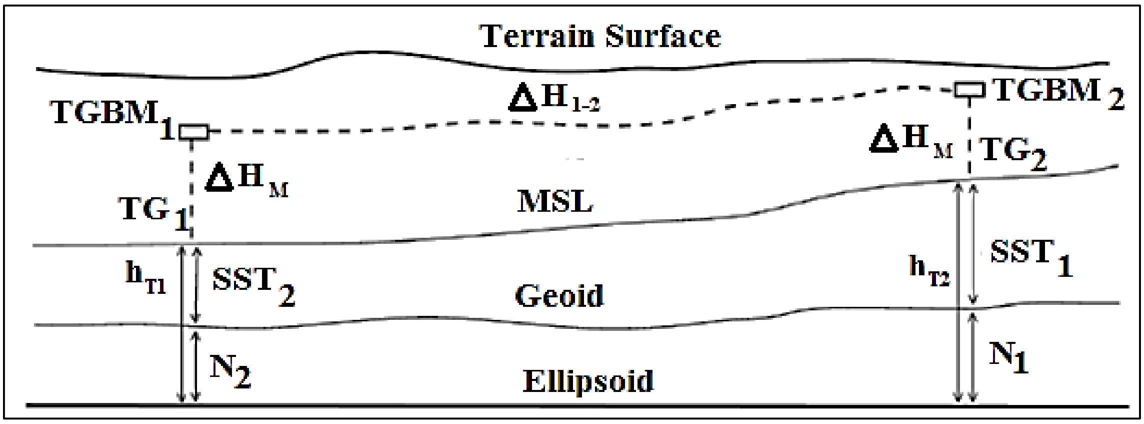


Figure (A.2): Shows the difference between SST at two tide gauges [Filmer, 2014].

A.5.1. The East Coast of Australia as a Case Study (The Ocean Approach)

In this study SST depends on the period over which the observations are taken. This is due largely to the time-variation of MSL, which comprise non-linear tides and long- and medium-term sea level variability that are collectively denoted υ, also SST should be corrected for the inverse barometer response (IBR) (Equation A.5), where h_t is the ellipsoidal height of MSL at a tide gauge, and N is the geoidal undulation, (Figure A.3) shows the relation of the ellipsoidal height of MSL at a tide gauge and SST [Filmer, 2014].

$$h_{TG} = N + (SST + IBR) + \upsilon \qquad (A.5)$$

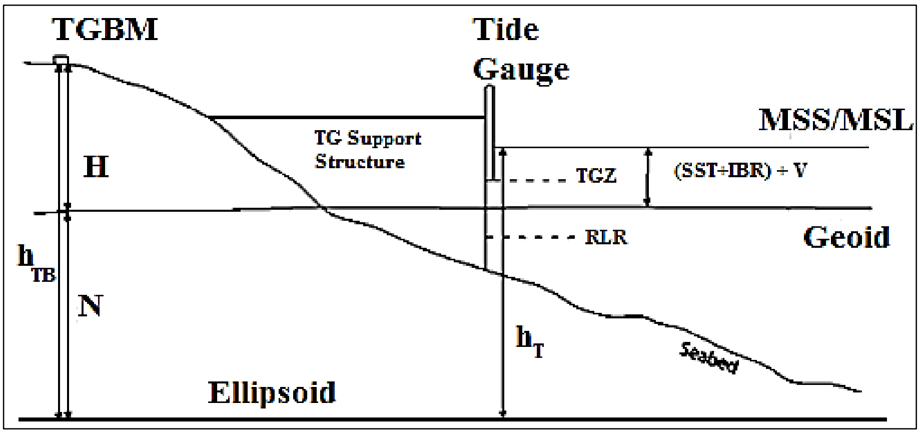


Figure (A.3): Shows the relation of the ellipsoidal height of MSL at a tide gauge and SST [Filmer, 2014]

A.5.1.1 The Methodology in That Study

A levelling-SST model loop (LS) with misclose (ε_{LS}) can be formed as

$$\Delta\ H_{1\text{-}2} + \Delta\ SST_{2\text{-}1} = \varepsilon_{LS} \qquad \text{(A.6)}$$

where $\Delta\ H_{1\text{-}2}$ is the levelled height difference correction applied from MSL at tide gauge 1 to MSL at tide gauge 2. $\Delta\ SST_{2\text{-}1}$ is the difference from SST_2 to SST_1, which are the modelled SST values at tide gauge 2 and tide gauge 1 respectively. Modelled SST converts MSL to the geoid, thus cancelling spatially variable SST between tide gauges, and eliminating the systematic misclose that exists when levelling between MSL at different tide gauges. This is comparable with the use of a geoid model to reduce GNSS h to the geoid (Equation A.8).

SST values at each tide gauge (Figure A.2) needed in (Equation A.6) are extrapolated from a SST model grid to the location of the tide gauge. While acknowledging that SST in coastal regions may differ significantly to SST further offshore [Featherstone and Filmer, 2012].

$\Delta H_{1\text{-}2}$ in (Equation A.6) comprises (1) the levelled height difference between the TGBM near tide gauge 1 to the TGBM near tide gauge 2 and (2) the levelled connection from each TGBM to MSL (ΔH_M) as (Figure A.2).

(1) is routine, but (2) can be problematic, because ΔH_M can be variable due to changes in sea level over different time-scales. This is particularly so for short time-period tide gauge records. The treatment of the IBR prior to computing (Equation A.6) also needs to be considered and is dependent on the SST model used. Where oceanographic-only SST models generally contain the IBR component within the modelled SST value, while geodetic-only SST models usually do not. This may necessitate the computation of

IBR and its application to the SST at tide gauges to be compatible with MSL observations that contain the IBR [Andersen and Knudsen, 2009].

$$\Delta H_M = \Delta H_Z + MSL_Z \tag{A.7}$$

ΔH_Z is the levelled height difference between the TGBM and the TGZ (tide gauge zero) and MSL_Z is the observed height of MSL above the TGZ from tide gauge records (Figure A.3). Levelling-GNSS-geoid (LG) can also be used to detect certain levelling errors, and in this study will be used to cross-validate the LS loops. LG loops are defined as (Figure A.2).

$$\Delta H_{1\text{-}2} + (\Delta h_{2\text{-}1} - \Delta N_{2\text{-}1}) = \boldsymbol{\varepsilon}_{LS} \tag{A.8}$$

The levelled height difference component of the LG loop is the same as that for the LS loop, $\Delta h_{2\text{-}1}$ is the difference between h_T at tide gauge 2 to tide gauge 1, and $\Delta N_{2\text{-}1}$ is the N difference from tide gauge 2 to tide gauge 1. (Equation A.8) relies on the relative accuracy of the geoid, which is generally low in coastal regions due to the lack of gravity data over the coast. To compute $\Delta h_{2\text{-}1}$ in (Equation A.8), h_T is;

$$h_T = h_{TB} - \Delta H_M \tag{A.9}$$

where h_{TB} is h at the TGBM (Figure A.3). This assumes that the TGBM is near the tide gauge (ideally on the tide gauge) so that the ellipsoid and geoid are parallel over this short distance. Thus N at the TGBM (N_{TB}) is equal to N at the tide gauge (N_T) and ΔH_M is equivalent to Δh_M (Δh from TGBM to MSL). This principle is vice versa if the distance between the TGBM and tide gauge become larger.

A.5.1.2 Data Used for That Study

That study limits itself to the coastal levelling between COFF tide gauge station (30° 18’S, 153° 08’E) and COOK tide gauge station (15° 28’S, 145° 15’E) (Figure A.4). Three data types are required for this method;

-The levelling network is contained in the Australian national levelling network (ANLN).

-MSL records at the tide gauges (Figure A.4 and Table A.1) were downloaded from the Permanent Service for Mean Sea Level (PSMSL) website (accessed 31 August 2012; http://www.psmsl.org/data/obtaining/)

-Modelled SST. The levelling network must be connected to MSL at the tide gauges. The addition of GNSS and geoid data adds efficiency to the results.

A.5.1.3 The problem

-1971 levelling (Australian third-order; maximum allowable misclosure (MAM) = $12\sqrt{d}$) used in the Australian Height Datum indicated an increase in MSL of +1.45 m (relative to the geoid) from COFF to COOK, with +0.989 m of this increase from COFF to CAIR. While offshore oceanographic levelling agreed that MSL increased from COFF to COOK.

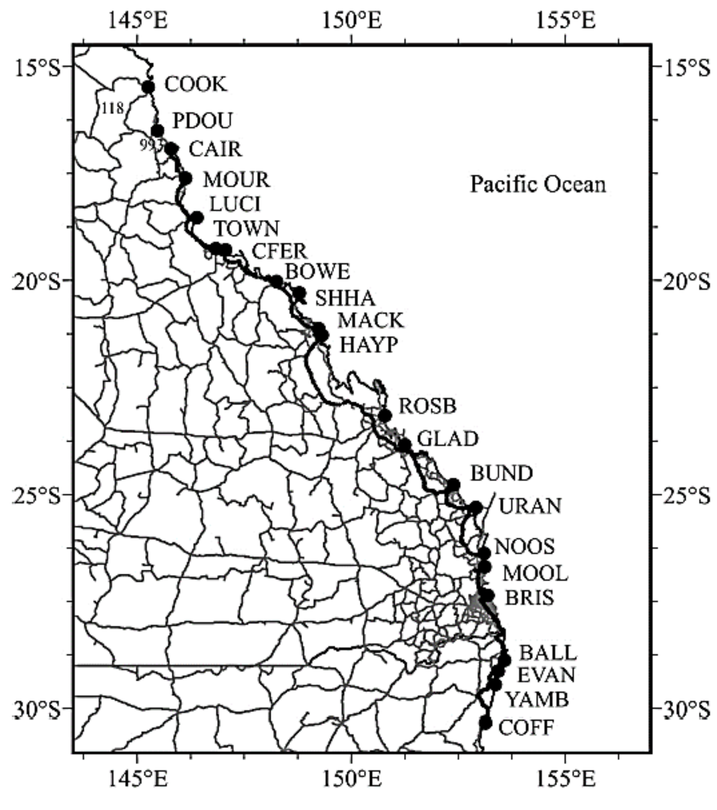


Figure (A.4): Northeast coastline of Australia showing the location of 22 tide gauges (black circles) used in this study [Filmer, 2014].

The 1975-1976 levelling summing the height differences from MSL at COFF to MSL at all 19 other tide gauges along the coast to CAIR, indicated a negative MSL (northward) slope of -0.505 m (with respect to the geoid) from COFF to CAIR compared to the previous positive MSL (northward) slope of +0.989 m from the original third order levelling.

These levelling error cannot be detected by levelling check. Should be provided additional information by SST models, with validation from GNSS-Geoid.

Table (A.1): List of the 22 tide gauges along the first order re-levelling of the northeastern Australian coast in 1975-76. Tide gauges marked with * indicate that a GNSS observation is available for that location [Filmer, 2014].

Tide gauge name	Abbreviation	MSL epoch	Levelled distance from COFF (km)
Coffs Harbour*	COFF	1956-1970	0
Yamba	YAMB	1989-2010	167
Evans Head*	EVAN	1968-1970	212
Ballina*	BALL	1959-1964	242
Brisbane*	BRIS	1966-2010	489
Mooloolaba	MOOL	1979-2009	598
Urangan	URAN	1958-1962	852
Bundaberg*	BUND	1966-2010	959
Gladstone	GLAD	1978-2010	1180
Rosslyn Bay*	ROSB	1993-2011	1341
Hay Point	HAYP	1985-2010	1657
Mackay*	MACK	1966-2010	1672
Shute Harbour	SHHA	1983-2010	1834
Bowen	BOWE	1986-2010	1863
Cape Ferguson	CFER	1992-2011	2049
Townsville*	TOWN	1959-2010	2073
Lucinda	LUCI	1985-2010	2217
Mourilyan	MOUR	1985-2009	2349
Cairns*	CAIR	1966-2010	2441
Port Douglas	PDOU	1987-2009	
Cooktown*	COOK	1966-1968	

A.5.1.4 The Accuracy of Data Used

In that study was used all the available records so that maximum length records and maximum number of tide gauges can be used given an accurate MSL. MSL was computed as the mean of available mean monthly sea level records which eliminates most aliasing due to monthly tidal changes.

-The TGBMs were mostly < 1 km from the tide gauge. Error estimates for h are ~±5 mm for TGBM, but increasing to ±29 mm and ±43 mm at BALL and EVAN respectively.

-AGQG09 Australian geoid 2009 be suggested to have relative uncertainties at tide gauges in the ~±50-100 mm range, which uses the zero-tide version of EGM2008.

-The SST model used in this study is CARS2009. CARS (0.5^o X 0.5^o grid covering the region) is a digital climatology or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state. The result is an excellent definition of oceanic structures and accuracy of point values. Some of CARS variables appears in (Table A.2) [Filmer, 2014].

CARS2009 is the best performing SST model in the Australian region. It is an oceanographic-only model which describes the ocean's physical surface, it contains the IBR, so it compatible with MSL observed at tide gauges without corrections for the IBR. Comparison with independent height data from levelling and/or GNSS- geoid provide empirical estimates of tide gauge

SST values. CARS2009 has been tested in a previous study using GNSS-geoid data along the northern east coast of Australia, it has been confirmed that SST error estimates to be generally <100 mm, but typically ~50 mm.

Table (A.2): Shows some of CARS variables [http://www.marine.csiro.au/~dunn/cars2009/

Name	Description
Latitude and longitude	grid point locations
depth	depths of the 79 mapping levels (in meters)
depth_ ann.	depths of the levels for which annual cycles are estimated
depth_ semi ann.	depths of the levels for which semiannual cycles are estimated
mean	estimate of mean value
cosine	cosine of annual cycle
sinine	sine of annual cycle
others	………………………

A.5.1.5 The Results

-ΔSST is convenient to use levelling MAM as the allowable limit of difference compared to levelling. Except for the COFF–YAMB ε_{LS} because the differences in MSL period between YAMB (1981-2010) and its neighboring tide gauges (mostly 1960-1970; Table A.1), or ΔHZ.

- ε_{LS} systematically increases in magnitude (northward) because the levelling technique changes from two-way 'rapid' first-order to 'rapid' one-way.

The 'rapid' one-way levelling technique has caused a systematic levelling error after BUND to incorrectly indicate MSL decreased relative to the geoid.

- The mean of the differences between the levelling for the COFFS to BUND section and CARS2009 SST is 5mm, the SD is ±35 mm, maximum +64 mm and minimum -59 mm. These differences include error components from the MSL observation (and any temporal bias by the length and epoch of observation) and the levelling.

- To cross-validate the LS loops, GNSS h- AGQG09 N at nine tide gauges were formed into the LG loops (all relative to COFF) using (Equation A.8). The almost constant offset between ε_{LS} and ε_{LG} indicates to an error in ΔHM at COFF, which is the common origin for the comparison and to an error in either h, N, or ΔH_Z based on the large deviation from the smoother CARS2009 ε_{LS}, and that geoid models tend to be less reliable over coastal boundaries.

- Apply the LS loop method to the suspected third-order levelling error causing the levelling-MSL difference to jump 0.46 m between COOK and CAIR tide gauges. But the location of any levelling error cannot be easily determined, because this is an example of a levelling loop with no adjoining loop on the coastal side loop 118 in (Figure A.4), which would otherwise provide a misclose covering the common section. Loop 118 levelling ε is -0.241 m, which is a lesser magnitude than the third-order levelling MAM, initially suggesting loop 118 does not contain a blunder. Six CARS2009 LS loops were formed. LS loops between CAIR and COOK are supplemented by LG loops as a GNSS h is available at COOK and CAIR TGBMs.

The statistics between LS and LG loops for CAIR-COOK indicate that the error to be between 0.44 and 0.48 m (Table A.3). Allowing some uncertainty in the SST and GNSS h-N component of these loops, it is likely that the apparent 0.46 m levelling-MSL jump between CAIR and COOK. This error has been previously undetected because the third-order levelling-only loop 118 ε was < third-order MAM. Redundant information from SST and h-N has made it possible to detect this error confirming the ability of

this method to find errors that were undetectable using standard levelling loop closures.

By recalling (Equation A.6) then compensation with Δ SST value in (Table A.3):

$$\Delta H_{1-2} + \Delta SST_{2-1} = \varepsilon_{LS} \quad (A.6)$$

$$0.989 + 0.444 = 1.433m \cong 1.45m \quad (A.10)$$

Table (A.3): LS and LG loops, E indicate east section of the levelling loop, W indicate western section of the loop. Units for *ε* and MAM in metres; for distance in km [Filmer, 2014].

Loop #	**TGs used**	**CARS2009** ε_{LS}	***h*-AGQG09 N** ε_{LG}	**Third-order**	**Levelled distance**
993-118E	CAIR-COOK	0.444	0.483	±0.222	343
993-118W	CAIR-COOK	0.204	0.243	±0.314	683

The MSL at CAIR tide gauge station was 0.989m and become 1.45m at CAIR tide gauge station as explained in (Equation A.10). It jumps to 0.46 m between COOK and CAIR tide gauges due to the presence of ΔSST value at COOK and CAIR, that value was not taken into account before. In case of isolating the ΔSST value from COFF, the MSL at COFF becomes convenient to MSL at CAIR.

نحو انشاء سطح اسناد رأسي موحد للمنطقة العربية

ملخص الرسالة:

يوجد في الوطن العربي العديد من أسطح الإسناد الرأسية التي تختلف من دولة الي أخري، التي تعتمد علي أخذ متوسط القياسات من سطح البحر عند محطة قياس المد والجزر لمدة تصل الي 18.6 سنة قمرية، فإستخدام منسوب سطح البحر علي إنه السطح المرجعى، يتسبب في بعض المشاكل في التطبيقات المرتبطة بمرجع الإسناد الرأسى منها:

- وجود التشوه distortion الذي ينشأ بسبب القيود في الضبط حيث وصلت قيمتة الي واحد متر في بعض الدول مثل كندا في عام 2013.
- وجود التضارب فى التقدير الخاص بسطح الأسناد الرأسى المحلى ويحدث تأثيرا علي الأرصاد مثل شذوذ الجاذبية الارضية حيث وصل قيمة هذا التضارب الي ±0.16mgal في بعض الدول مثل امريكا في عام 2010.
- تغير منسوب سطح البحر في اوقات مختلفه للأعمال الجيوديسيه وحماية الشواطئ.
- إنحدار سطح البحر في المساحات الكبيره والتى تتطلب سطح الإسناد الرأسى المتسق.

فإن إختلاف طبوغرافية سطح البحر عند مواقع مقاييس المد والجزر وايضا الإختلاف في أساليب القياس يعتبرإحدي الأسباب الرئيسية التي تؤدي الي إختلاف سطح الإسناد الرأسي من دولة الي أخري.

ومن ثم كان تحديد جيود دقيق وموحد للدول العربية يعتبر خطوة أساسية لإزالة هذه الإختلافات، ومن ثم انشاء شبكات رأسية دقيقية تغطي المنطقة التي ترجع اهميتها القصوي الي عدة نقاط علي سبيل المثال وليس الحصر :

– إسقاط الأرصاد والقياسات المساحية من سطح الأرض الي سطح الاسناد المرجعي الافقي.

- ربط الإحداثيات ثلاثية الابعاد للأقمار الصناعية بناظيراتها ثنائية الابعاد علي الارض.

- توفير معلومات دقيقة عن الارتفاعات في الاحداثيات ثلاثية الأبعاد في الشبكات الجيوديسية.

- دراسة تحركات القشرة الأرضية.

- دراسة إرتفاع وانخفاض سطح البحر.

- دراسة التشوهات التي تحدث للمنشآت الهندسية.

لذا فإن وجود جيود دقيق وموحد للدول العربية يمثل الأساس في تحديد Regional Geoid Model.

<u>وقد أوضحت هذه الدراسة النقاط التالية:</u>

1- معظم الدول العربية تستخدم محطات قياس مد وجزر ذات تقنيات قديمة. وتعتمد علي البيانات من هذة المقاييس وتستخدمها في الحسابات، على سبيل المثال، مقياس المد والجزر في مصر ما زال يعمل في ميناء محافظة الأسكندرية منذ عام 1896.

2- هناك شبكات ثوابت ارضية (روبيرات) تعتمد على الأرصاد من مقياس المد والجزر القديم. فإذا تم تحديث الأرصاد، فإن مقياس المد والجزر القديم لا يزال يؤثر على هذه الارصاد.

3- تضررت الكثير من الروبيرات، ولا تزال شبكة الميزانية تعتمد على هذة الروبيرات القديمة الموجودة لأخذ الأرصاد.

4- لم يتم تحديث شبكات ال GPS الدقيقة مثل ال HARN في مصر منذ فترة طويلة على الرغم من أن بعض نقاطها قد تعرضت للتلف.

5- شبكات الجاذبية في جميع الدول العربية هي أيضا مثل الشبكات الأخرى التي تعاني من افتقارها إلى البيانات وتوجد الكثير من الفجوات دون أي بيانات. وبالإضافة إلى ذلك، لم يتم تحديث هذه الشبكات منذ فترة طويلة.

بشكل عام تتمتع المنطقة العربية بموقع متميز بين كل دول العالم وتتميز بطبيعة سهلة الي حد ما حيث تتراوح الإرتفاعات بين أعلي قمة بالمنطقة العربية الي 4165 متر في جبل توبقال بدولة المغرب، و أقل قمة الي 103متر بدولة قطر. وتطل كل دولة من دول الوطن العربي علي واجهة ساحلية بداية من المحيط الأطلسي غرباً إلى بحر العرب والخليج العربي شرقاً، البحرالابيض المتوسط شمالا واخيرا البحر الاحمر. هذه الطبيعة تساعد كثيرا في وضع خطة إستراتيجية لتوحيد كل الدول علي سطح إسناد رأسي موحد. الذي يضمن إستمرار المشاريع الإستثمارية الكبري مثل إنشاء خطوط أنابيب البترول وخطوط النقل والمواصلات وشبكات الكهرباء وكل المشاريع التي تحتاج الي مناسيب دقيقة.

لذا في ضوء دراسة وتحليل الدراسات الأجنبية السابقة التي تمت في دول العالم المختلفة مثال استراليا 2005، نيوزلاندا 2011، اوربا 2013 .....وغيرهم من الدراسات، تم تقديم إقتراحين لتوحيد أسطح الإسناد الرأسية وتقديم الخطه الاستراتيجيه لتنفيذ هذه الإقتراحات. وذلك من أجل المساهمة في دعم إتخاذ القرار السليم والذي يتم بناءاً علي بيانات دقيقة وموحدة بأساليب علمية حديثة تتواكب مع التقدم التكنولوجي لهذا العصر. وذلك بعد عملية إعداد وربط وتوحيد كل البيانات المعنية بسطح الإسناد الرأسي: (tide gauge stations, levelling BMs, GNSS stations, and gravity points).

أولا: تم إقتراح توحيد الجهازالمستخدم لقياس المد والجزر وتم عمل مفاضلة بين أنواع الأجهزه المستخدمة لذلك الغرض من حيث السرعة والدقة، وقد تبين ان معظم الدول العربية تعتمد علي أجهزة قديمة لقياس المد والجزر والتي تكون عرضة لمصادر الأخطاء، علي سبيل المثال: التغير المفاجئ في سطح المياه نتيجة حركة السفن، تأثير حركة الرياح، موقع محطات المد والجزر، إنسداد الأنبوبة الحاوية لمقياس المد والجزر بقذائف السفن، إرتفاع درجة الحرارة وتغير الكثافات،......

لذلك تم إقتراح استبدال المقاييس القديمة بمقياس جديد ومتطور مثل radar gauge لقياس منسوب المياه لما يتميز به من سرعة ودقة تصل الي 10ملي وعدم إحتياجه الي متابعة من ال local operators مثلما يحدث لأساليب قياس المد والجزر القديمة، كما انه مستخدم في كل الدول الأجنبية المتقدمة. مع مراعاة النقاط التالية:

- يجب ان يكون التداخل بين الأرصاد من أجهزة قياس المد والجزر القديمة والحديثة في فترة لا تقل عن سنه وتأخذ فترات مختلفة من الرصد سنة، شهر، يوم وساعة حتي يتم التأكد من أداء الأجهزه وأنها تعمل بدقة علي المدي الطويل ولا تؤثر علي أرصاد Tide Gauge و MSL.
- يجب إدراج القياسات الألتيمترية للمنطقة التي بها محطات مد وجزر لحساب طبوغرافية سطح البحر.
- يجب ان يوضع مقياس المد والجزر الجديد (radar gauge) في نفس المكان للمقياس القديم حتي يسهل ربط سطحي الاسناد الرأسي ويقل الخطأ ويصل الي اقل مايمكن.
- يجب وضع GNSS receiver علي مقياس المد والجزر ويفضل ألا يوضع مباشرة عند المقياس لأنه في هذه الحالة يشعر بتغير المياه فقط ولايشعر بحدوث هبوط في الارض لذلك يفضل ان يوضع بالقرب منه حتي يشعر بتغيرات سطح الأرض فيمكن حسابها والغاء تأثيرها علي قياس سطح البحر.
- لكي يتم ربط مقاييس المد والجزر مع GNSS station يجب وضع روبيرات قريبة قدر الإمكان من مقياس المد والجزر حتي تتصل هذه النقاط مباشرة بالقراءات الحقيقية بواسطة معايرة سطح المياه. وبذلك يتم تحديد الفرق بين متوسط سطح البحر وبين ارتفاع الالبسويد

ثانيا: إنشاء شبكة من الروبيرات لإختبار إرتفاعات النقاط مع تغير الوقت، لمعرفة حدوث أي هبوط أو أي مشكلة في الإتزان، كما أن هذة النقاط تكون الأساس لكل خطوط الميزانيات التي سوف تغطي الدولة بكاملها التي يقترح رصدها بإستخدام ميزانية دقيقة درجة أولي في حلقة مغلقة spirit (levelling–first order). واقترح لذلك جهاز Power level SDL30 بدقة 0.6 ملي.

ثالثا: في كل دولة من دول الوطن العربي توجد الكثير من نقاط ال GPS ولكنها لا تغطي الدولة بكاملها، تم انشاؤها لكي تخدم مشروع معين وبالتالي هذة النقاط تختلف في توزيعها ودقتها ومواصفاتها من مشروع الي آخر (not homogenous)، كما ان نقاط الرصد المستمر CORS stations يختلف توزيعها المكاني من دولة الي اخري. إلي جانب وجود الفجوات التي لا تحتوي علي اي نقاط GPS والتي توجد في مناطق متفرقة ومناطق أخري تفتقر إلي وجود أي بيانات مثال الصحاري والمناطق المتطرفة من الدول. كما أنه لا يوجود تخطيط واضح لتوحيد هذة النقاط بين الدول. فتوزيع هذه النقاط علي هذه الشاكلة لايخدم الغرض من هذة الأطروحة.

فعلي غرار شبكة الـ HARN (30 نقطة) في مصر، تم اقتراح شبكات مماثلة في كل دولة عربية تتناسب مع مساحتها، حيث أُقترح إنشاء شبكة مماثلة في دولة الجزائر مثلا تكون عدد نقاطها 75 نقطة، منهم 12 نقطة يِكونوا الاساس (Core stations) لباقي النقاط (63 نقطة) التي تمثل (permanent stations.) حيث يتم الرصد علي أفضل مواصفات GPS static, dual frequency ولمدة 24 ساعة ويتم ربط هذة النقاط علي شبكات الرصد المستمر IGS stations (International GNSS Service) الاقرب من الأربع اتجاهات التي تحيط بالمنطقة، ومن ثم ال 75 نقطة تمثل الأساس base stations لكل النقاط التي يتم رصدها داخل الدولة، بالمثل لكل الدول حتي تتكون شبكة متجانسة تحمل نفس المواصفات وبنفس اسلوب الرصد وبنفس الدقة

فهي شبكة متجانسة من حيث التوزع والدقة وعدد النقاط ومنسوبة الي نفس سطح الاسناد وتغطي جميع أنحاء الدول.

رابعا: اقترح رصد نقاط جاذبية مطلقة بإستخدام FG5 absolute gravimeter بدقة تصل الي 2-4 µgal عند نقاط ال core stations بحيث تكون هذه النقاط بمثابة base stations لرصد باقي نقاط الشبكة التي تغطي الدولة. في الدول الاجنية التي تتسم بطبيعة وعرة وطبوغرافية مختلفة عن الدول العربية، تتم الحسابات الخاصة بسطح الإسناد وقياسات الجاذبية علي شبكة (grid) 0.5^ox0.5^o ، لذلك تم اقتراح شبكة جاذبية مماثلة في الدول العربية او 1^ox1^o وذلك لتوفير الوقت والجهد.

خطوات العمل المقترحة تهتم بعدة نقاط اساسية أولها انشاء المركز الرئيسي (main center)

هذا المركز الرئيسي المقترح إنشائه و المسمي بـ Arab Geodetic Service (AGS) سوف يكون تحت إشراف جامعة الدول العربية وسوف يقدم الخدمات الجيوديسية المختلفة، حيث يكون للـ AGS خدمات فرعية من بينها خدمات المرجع الرأسي Arabian Vertical Datum (AVDS) Service. AGS سيكون هو المسؤل عن التعامل مع مختلف انواع البيانات:

(tide gauge stations, levelling BMs, GNSS stations, and gravity point).

حيث يتم تجميع كل البيانات من خلال شبكة الإنترنت وترسل الي المركز الرئيسي من أجل المعالجه والتحليل والضبط، ومن ثم تصل الي المستخدم في اي مكان في المنطقة العربية.

علي أن يكون أعضاء هذا المركز من هيئات المساحة بكل الدول العربية، أساتذة الجامعات، مراكز الأبحاث، وأي هيئة أو جهة أخري مهتمة بأعمال المساحة والجيوديسيا. وسوف يكون هذا المركز في تعاون مستمر مع الهيئات العالمية التي تقدم خدمات مشابهة مثل الرابطة الدولية للجيوديسيا (IAG).

– يتكون هذا المركز من اربع مراكز فرعية: المركز العربي للارصاد Arabian Observing Stations(AOS) وهو المسؤل عن تكوين شبكات الارصاد في كل دولة من دول الوطن العربي ، المركز العربي للبيانات Arabian Data Center (ADC) ، وهو المسؤل عن تخزين البيانات. المركز العربي لتحليل البيانات Arabian Analysis Center (AAC) ، وهو المسؤل عن المعاجة اليومية للبيانات، المركز العربي لحفظ البيانات Arabian Backup Center (ABC)، وهو المسؤل عن حفظ البيانات من الفقد.

– تم اقتراح مقر المركز الرئيسي في جمهورية مصر العربية لوجود جامعة الدول العربية بها كما انها تتميز بموقع متوسط بين الدول علي ان يكون في كل دولة عربية مقر لمركز حفظ البيانات من الفقد.

– كل البيانات والأرصاد من محطات المد والجزر وتحديد الموقع وأعمال الجاذبية سيتم التعامل معها من خلال المركز الرئيسي (reviewing–filtering–processing–adjusting) بذلك تكون المنطقة العربية بها كثافة من البيانات السابق الاشارة اليها التي سوف تكون موزعة توزيع جيد، متجانسة ودقيقة ومنسوبة الي نفس المرجع datum.

<u>الإقتراح الأول يعتمد علي:</u>

استخدام تلك البيانات الحديثة المشار اليها بالمواصفات المقترحة في حساب جيود دقيق بـ

– تحديد قيمة ellipsoidal height عند كل نقاط GNSS stations.

– تحديد قيمة الـ gravity anomaly (Δg) في شبكة الجاذبية.

– تثبيت متوسط منسوب سطح البحر الي قيمة صفر في الحل عند كل محطات المد والجزر.

– استخدام البيانات الالتيمترية عندمحطات المد والجزر التي توجد في منطقة الدراسة.

بالإضافة الي استخدام النموذج الرقمي المناسب الممثل لطبوغرافية المنطقة مثل DTM (SRTM)

، وبمعرفة مواصفات كل عنصر من العناصر المستخدمة في حساب الجيويد (طريقة القياس –

الجهاز المستخدم – الدقة – طريقة الحساب) كما ذكر سابقا تم استنتاج دقة geoidal undulation (N) بمقدار ± 4.5 cm ودقة gravity anomaly (Δg) بمقدار $\pm$ 12.7μgal وايضا يمكن تحسين الدقة بعد عمل تحسين للموديل العالمي المناسب للحسابات في الدول العربية وليكن EGM2008 بإستخدام البيانات المقترحة بالموصافات المذكورة سابقا، فيمكن استنتاج تحسن الدقة لأكثر من 50% في قيمة GPS/levelling وأكثر من 90% في قيمة Δg كما هو الحال في الدول الاروبية وربما يكون أفضل بسبب توقع تحسين البيانات التي سوف تستخدم في الحل.

الأقتراح التاني يعتمد علي:

– تحديد الموقع عن طريق اسلوب تحديد الموقع بدقة عالية Precise Point Positioning (PPP) حيث يتم الاستغناء عن كلا من Core GNSS Stations و Permanent GNSS stations واستبدالها بـ PPP فهو إسلوب يوفر الوقت والجهد حيث ان اسلوب الـ PPP يعتمد علي مستقبل واحد فقط ولا يحتاج الي اي نقاط مرجعية بالقرب من الراصد، وهذا اسلوب يحدد الموقع بالنسبة الي مرجع عالمي كما انه يزودنا بدقة تصل الي سنتيميتر ويمكن ان تصل الي اقل من واحد سنتيميتر في حالة ال static mode.

– إيجاد إرتفاع الجيويد عن الإلبسويد بإستخدام نماذج الاقمار الصناعية (Satellite –only model) حيث انه لا يتأثر بالبيانات الأرضية وما بها من مشاكل، حيث تم عمل مقارنات عديدة للنتائج من pure sat–only model مع النتائج من الـ GGMs أو المحسنة ببيانات أرضيه فكانت النتائج جميعها تشير الي ان النماذج من الاقمار الصناعية تكون متجانسة في اي مكان علي سطح الكرة الارضيه علي عكس استخدام نماذج الجهد العالمية (global geopotential models) مثل EGM2008 أو EGM96 فأدائها جيد ومتجانس فقط في الاماكن التي بها بيانات دقيقة وموزعة توزيع جيد.

– فإن إستخدام تحليل Satellite – only model لإيجاد مجال الجاذبية الأرضية يوفر دقة تصل الي 10 سنتيميتر.

– يمكن تحسين مجال الجاذبية المستخلص من تحليل satellite only model باستخدام نموذج الجهد العالمي EGM2008 علي سبيل المثال في هذه الحالة يمكن ان تصل الدقة الي 2–3 سنتيمتر

– خطأ الاختزال (omission error) في تحليل الـ satellite only model يمكن ان يحسن بإستخدام البيانات الأرضية المحسنة بالمواصفات المذكوره في هذة الحالة يتوقع تحسين الدقة الي أكثر من 1سنتيميتر.

واشارت هذه الدراسة أيضا الي ان إستخدام حلول الأقمار الصناعية فقط يمكن الحصول علي مركبات الطول الموجي الطويل long wave length في مجال الجاذبية ولا يمكن الحصول علي اي تفاصيل محلية (local details) علي الجانب الآخر، البيانات الارضية terrestrial data بتوفر local details ولكن عموما بها systematic error لذلك فإن أفضل حل للجيويد يكون بالجمع بين استخدام حلول الاقمار الصناعية مع بيانات ارضية (بالمواصفات المقترحة والمشار اليها في إعداد البيانات).

ومن ثم يمكن تحسين (tailoring) نماذج الجهد العالمية مثال EGM2008 بإستخدام البيانات المقترحة لكي يتم تحسين الـ Resolution للمنطقة العربية كلها.

<u>النتائج المتوقعة بعد تنفيذ هذا المشروع الوطني المقترح:</u>

– استبدال أعمال الميزانيات التي تعتمد علي سطح الاسناد الرأسي بجيود دقيق وموحد بالإضافة الي تحديد الموقع من مستقبلات الشبكات العالمية للملاحة بإستخدام الاقمار الصناعية (GNSS) سيكون

من السهل جدا حساب orthometric height من جيود دقيق وارتفاع إهليلجي دقيق Ellipsoidal height.

– سهولة متابعة تغيرات متوسط مستوى سطح البحر MSL في أوقات مختلفة من أجل الأعمال الجيوديسية وحماية الشواطئ.

– سهولة تحديد تأثير تضاريس سطح البحر SST في الأراضي العربية التي لها خط ساحلي على البحر الأحمر،البحر الأبيض المتوسط، الخليج العربي، المحيط الهندي والمحيط الاطلسي.

– جميع الدول العربية جنبا إلى جنب مع الصحراء والمناطق النائية والمتطرفة سوف تحتوي على نقاط رأسية دقيقة precise vertical control.

– متابعة المرجع الرأسي الموحد سيكون أقل تكلفة.

– المرجع الرأسي سيكون مستقرا إلى حد ما نظرا للحقيقة الفعلية بأن سطح الجيود يتغير بمعدل 1 ملم سنويا مقارنة مع 1 سم سنويا لتغير B.Ms المتعلقة بالديناميكا الجيولوجية الإقليمية.

– ستتمكن الأمة العربية من مواجهة تحديات العولمة، فسيكون لها دور فعال جنبا الي جنب مع الوكالات العالمية التي تهتم بالمسح والخرائط والجيوديسيا مثل الرابطة الدولية للجيوديسيا (IAG)، والمركزالدولي لنموذج الجاذبية العالمية (ICGEM)، والخدمات الميدانية الدولية للجاذبية (IGFS).

<u>محتويات الرسالة:</u>

تشمل الرسالة علي ستة أبواب يمكن تلخيص محتواياتها فيما يلي:

<u>الباب الأول: مقدمة</u>

يشتمل علي مقدمة وتمهيد لموضوع الرسالة والدافع من وراءه وطريقة العمل فيه وتجميع الموضوعات العلمية المتعلقة بالموضوع وتلخيص لمحتويات الرسالة.

الباب الثاني: الحالات السابقة لتوحيد اسطح الاسناد الرأسية

يحتوى هذا الباب على تجميع و دراسة الدراسات الأجنبية السابقة المماثلة لموضوع الرسالة، من حيث الأرصاد والبيانات المستخدمة و طريقة العمل والنتائج التي توصلت إليها كل حالة. مثل الدراسة التي تمت في واستراليا عام 2005، افريقيا 2011، نيوزلاندا 2011، اوربا 2013، أمريكا 2014 ، بالإضافة الي بولاندا 2015.

الباب الثالث: الحالة الراهنة لأسطح الإسناد الرأسية في الوطن العربي

يتضمن هذا الباب وصف وعرض الحالة الراهنه التى عليها أسطح الإسناد الرأسية فى المنطقة العربية ، ووصف للبيانات المتاحة والمتوفرة من خلال الدراسات السابقه والأبحاث العلمية المعتمدة والمنشورة في المجلات العلمية من خلال شبكة الإنترنت. إجمالا في نهاية هذا الفصل تم حصر وتجميع موقع محطات رصد المد والجزر التي تستخدم في كل دولة عربية وتحديد موقعها بخط الطول ودائرة العرض، حتي يمكن تحديد العدد الأنسب منها والذي يتوافق مع طول الساحل لكل دولة عربية.

الباب الرابع: الطرق التقليدية والحديثة لتحديد الجيود

يحتوي هذا الباب على وصف و تصنيف طرق تحديد الجيود بالطرق التقليدية والطرق الحديثة، دراسة موجزة عن satellite missions و Global Geo-potential Models وأنواعها. ويحتوي ايضا علي بعض المحاولات لعمل تحسين Tailoring لهذه النماذج . إجمالا في نهاية هذا الباب يتم عرض لبعض الحالات حول العالم لدراسة تأثير عملية تحسين أنظمة الجهد العالمية (Tailoring Global Geo-potential Model) بإستخدام بيانات ارضية، والفرق بين قيم ال gravity anomaly و GPS/levelling للنقاط المستخدمه في كل دراسة قبل وبعد عملية ال tailoring.

الباب الخامس: توحيد اسطح الاسناد الرأسية لدول الوطن العربي

هذا الباب يستعرض ويحلل ويناقش الأساليب المختلفة لتوحيد البيانات بين الدول العربية، وتقديم الإقتراحات المناسبة لتوحيد أسطح الإسناد الرأسية بين الدول العربية وتقديم الجدول الزمني المناسب لتنفيذ خطوات الإقتراح. ويتكون هذا الباب من جزئين رئيسين، حيث يحتوي الجزء الأول علي مقترح لتوحيد البيانات الجيوديسية بما يتوافق مع الدقة التي تتطلبها الأعمال الجيوديسية وتتواكب مع تكنولوجيا هذا العصر الحديث. حيث تم إقتراح الأجهزه التي تستخدم لتوحيد الدقة لكل من مقاييس المد والجزر، وأحهزة أعمال الميزانيات، الهوائي المستخدم مع نظام الملاحة العالمي GNSS) (Antenna، بالأضافة الي أجهزة رصد الجاذبية.

بينما يركز الجزء الثاني علي تقديم خطة ممنهجة لتوحيد أسطح الإسناد الرأسية في الوطن العربي من خلال تقديم مقترحين أساسين لهذا الغرض مع توضيح شامل لكل النقاط التي سوف تقدم لأصحاب القرار بالإضافة الي الجدول الزمني لتنفيذ كل مرحلة الذي سوف يساعد في إتمام العمل.

الباب السادس: ملخص الدراسه والتوصيات

يشتمل هذا الباب ملخص لهذه الدراسة و كذلك التوصيات المقترحة بناءا على ما تم الوصول اليه. وتحتوي الرسالة أيضا علي قائمة بالمراجع العلمية التى تم الإستعانة بها.

الملحقات

تحتوي هذه الرسالة علي ملحق واحد يشرح أهمية دراسة طبوغرافية سطح البحر (SST) وتأثيرها في بعد متوسط سطح البحر (MSL) عن سطح الجيويد (Geoid) بما يصل الي 2.2 متر كما تم شرح طرق تحديد هذه القيمة وتطبيق هذه الطرق في دراسة علي شاطئ استراليا.

جامـــــعة بنـــــها
كلية الهندسة بشبرا
قسم هندسة المساحة

نحو إنشاء سطح إسناد رأسي موحد للمنطقة العربية

رسالة مقدمة كجزء من متطلبات الحصول علي درجة الماجستير في
هندسة المساحة و الجيوديسيا

مقدمه من

المهندسة/ شيماء فاروق عبد الفتاح ابراهيم

بكالوريوس هندسة المساحة

كلية الهندسة بشبرا

جامعة بنها

إشـــــراف

أ.د/ عبدالله أحمد سعد

أستاذ المساحة والجيوديسبا

كلية الهندسة بشبرا

جامعة بنها

أ.م.د/ مني سعد السيد

أستاذ مساعد المساحة والجيوديسبا

كلية الهندسة بشبرا

جامعة بنها

القاهرة – جمهورية مصر العربية

2018

جامــــعة بنـــها
كلية الهندسة بشبرا
قسم هندسة المساحة

نحو إنشاء سطح إسناد رأسي موحد للمنطقة العربية

رسالة مقدمة كجزء من متطلبات الحصول علي درجة الماجستير في
هندسة المساحة و الجيوديسيا

مقدمه من
المهندسة/ شيماء فاروق عبد الفتاح ابراهيم
بكالوريوس هندسة المساحة
كلية الهندسة بشبرا
جامعة بنها

إشـــــراف

أ.د/ عبدالله أحمد سعد
أستاذ المساحة والجيوديسيا
كلية الهندسة بشبرا
جامعة بنها

أ.م.د/ مني سعد السيد
أستاذ مساعد المساحة والجيوديسيا
كلية الهندسة بشبرا
جامعة بنها

القاهرة – جمهورية مصر العربية
2018