Using GNSS to Validate the Philippine Geoid Model

Donnie Mancera, Ronaldo C. Gatchalian, and Aila Leana Sampana
National Mapping and Resource Information Authority (NAMRIA)
PHILIPPINES

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Outline

- The Geoid
- Modernization Initiatives of NAMRIA
- Gravity Control Network and Geoid Model Development
- Philippine Geoid Model
- Validation of the Philippine Geoid Model Using GNSS Observation
- Conclusion and Recommendations

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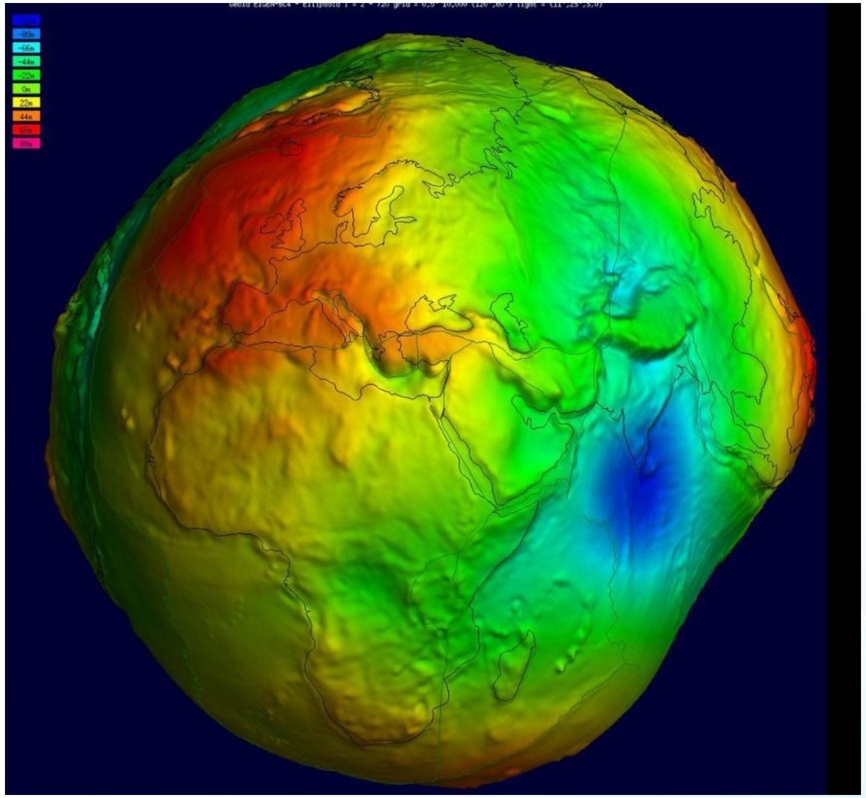
The Geoid



Geoid undulation in pseudocolor, shaded relief and vertical exaggeration (10000 vertical scaling factor) - Wikipedia

- It is an **equipotential surface** (surface of equal gravitational potential) best approximates the *global mean sea level.* Its shape is due to the uneven mass distribution within and on the Earth's surface.

- The Geoid is used as a **Vertical Datum**, where precise surface elevations can be measured

- Geoids are developed using gravity measurements
  - Satellite Gravity Measurements (GOCE, DTU10, DTU15)
  - Airborne Gravity Measurements
  - Terrestrial Gravity Measurements
  - Satellite Altimetry

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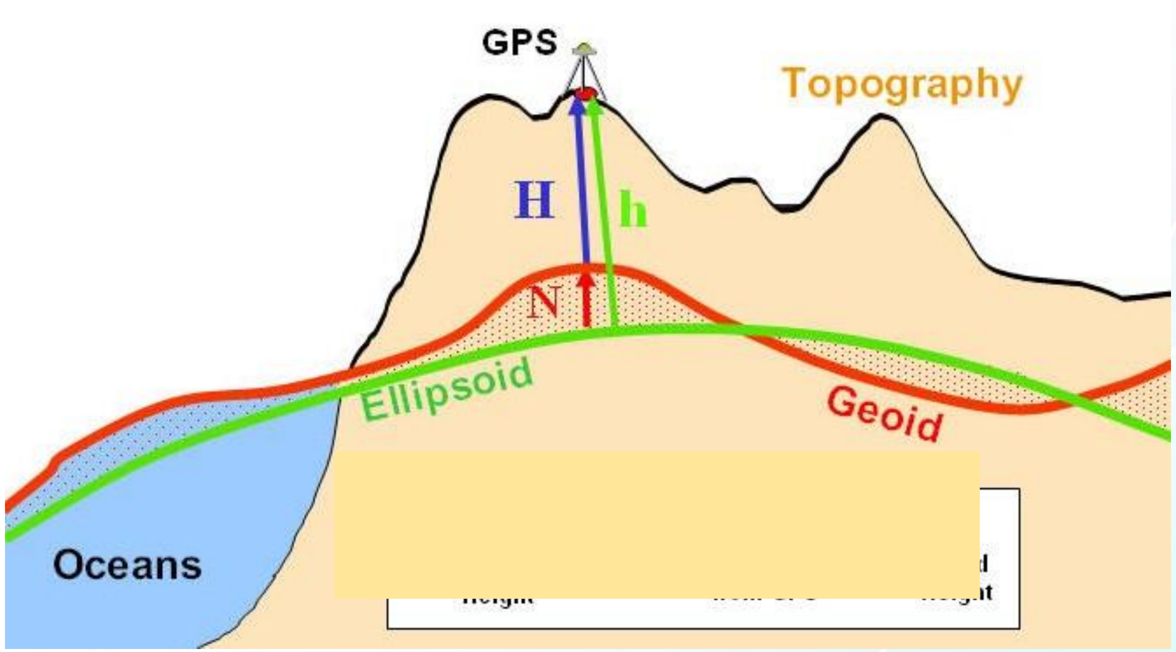
The Geoid

The Relationship of Geoid and Ellipsoid

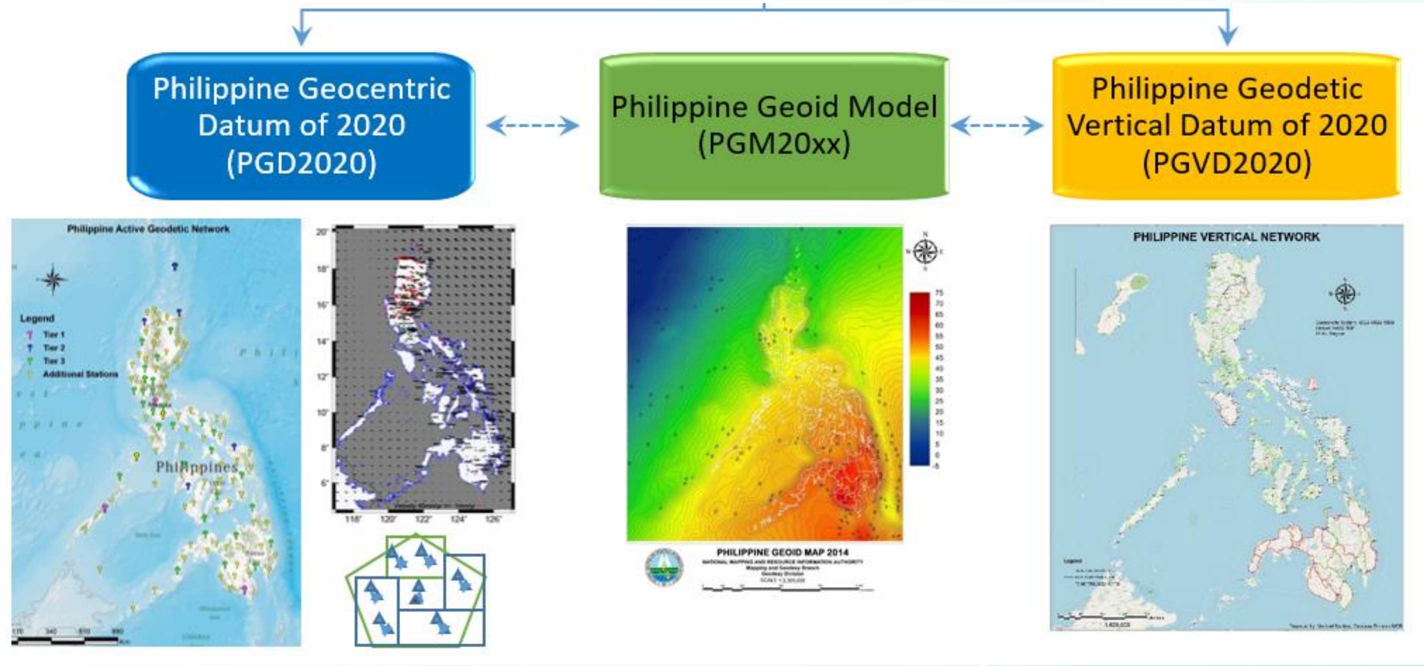


Using GNSS, we can determine the Orthometric Height of any point if we know the Geoid Height from our Geoid Model using the formula

$$H = h - N$$

Where
H = Orthometric Height (MSL)
h = Ellipsoidal Height (GNSS observation)
N = Geoidal Height

Modernization of the PGRS



Geometric RF:

Name: *PGD2020*

Type: *Semi-dynamic and Geocentric*

Realized in *ITRF2014 (reference epoch 16 January 2020)*

Vertical RF:

Name: *PGVD 2020*

Type: *MSL-fitted geoid*

Will be connected *to the IVRF (WHS)*

Comes with a *National Geoid, Deformation Model and Distortion Grid*

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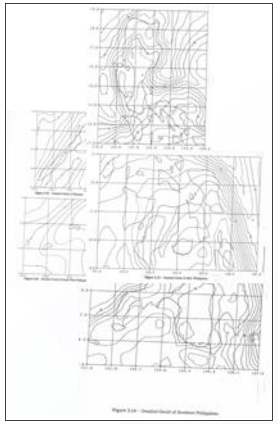
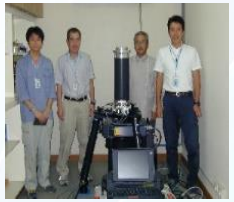
Gravity Control Network and Geoid Model Development





1961 - 1963

- *460 gravity stations was established by the U.S. Army Map Service, Far East*

- *358 gravity stations, including 70 base stations were established by BCGS*

1991

The first attempt of computing a preliminary gravimetric geoid through the Natural Resources Management Development Project (NRMDP)

2005

Establishment of Absolute Gravity Station in NAMRIA Fort Bonifacio, conducted relative gravity measurements in Manila through the assistance of Tokyo University

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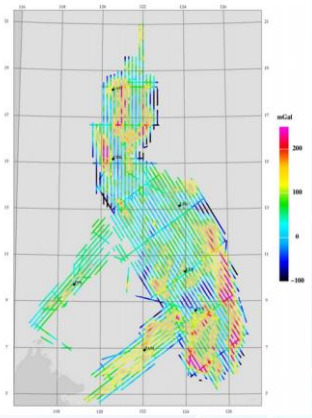
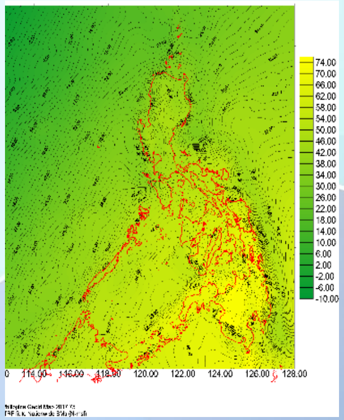
Gravity Control Network and Geoid Model Development









2008 - 2011

- Acquired CG-5 Gravimeters
- Established First and Second Order Gravity Stations

2014

- *Completed the establishment of 2nd Order Gravity Stations*
- *Completed the Airborne Gravity Survey*
- *Created a Preliminary Geoid Model (PGM2014)*

2015

Started the densification of 2nd Order Gravity Stations (2km distance)

2016 - onwards

- *Continuation of the densification of 2nd order gravity stations*
- *Refinement of Philppine Geoid Model (PGM)*
- *Validation of PGM using GNSS*

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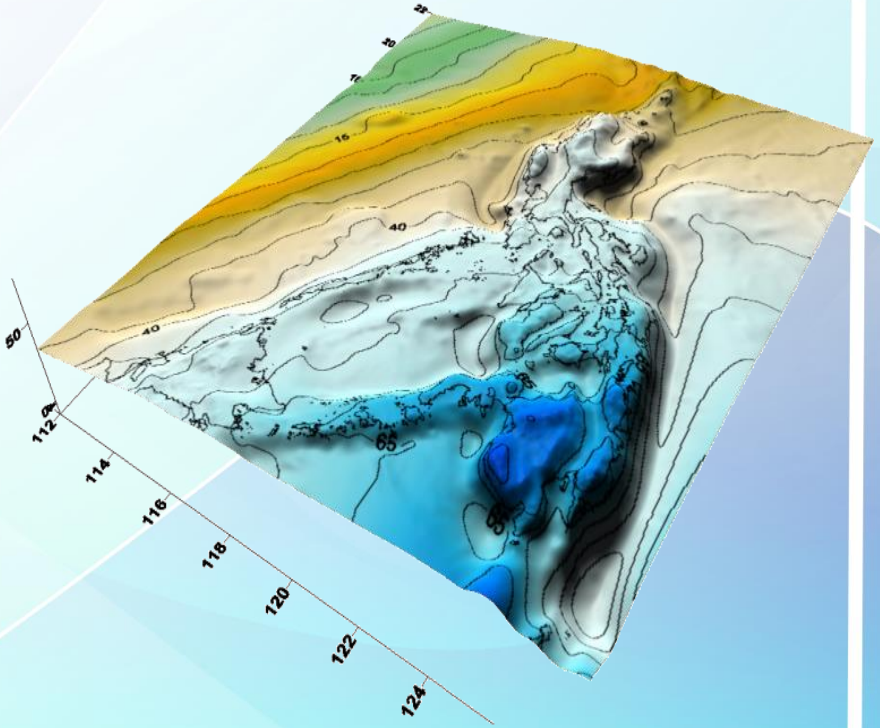
Philippine Geoid Model (PGM)

- Developed in 2014, through the assistance of the National Space Institute of Denmark Technical University (DTU-Space)
- Hybrid Geoid (MSL Based Geoid)
- Input data are:
  - Nationwide airborne gravity survey
  - 1,261 Land Gravity Stations
  - Marine Satellite Altimetry (DTU-10)
  - Satellite Gravity Data from Gravity Field and Steady State Ocean Circulation Explorer (GOCE)
  - A set of 190 GNSS/Leveling data (BMs) in ITRF 2014 was used to fit the Geoid
- RMS fit of GNSS/Leveling is 0.5 m with max offset value of 1.49 m



PHILIPPINE GEOID MODEL 2014

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Philippine Geoid Model (PGM)

- ❖ Prof. Rene Forsberg of DTU recommended the following to improve the geoid model:
    - ❖ Carefully analyze the leveling network for adjustment errors
    - ❖ Revisit connections and antenna height errors of GNSS data
    - ❖ Erroneous points (geoid outliers) must be resurveyed (gravity and GNSS)
    - ❖ Additional gravity surveys in major cities
    - ❖ New GNSS-fitted version of the geoid must be computed as new batches of GNSS-Leveling data come in

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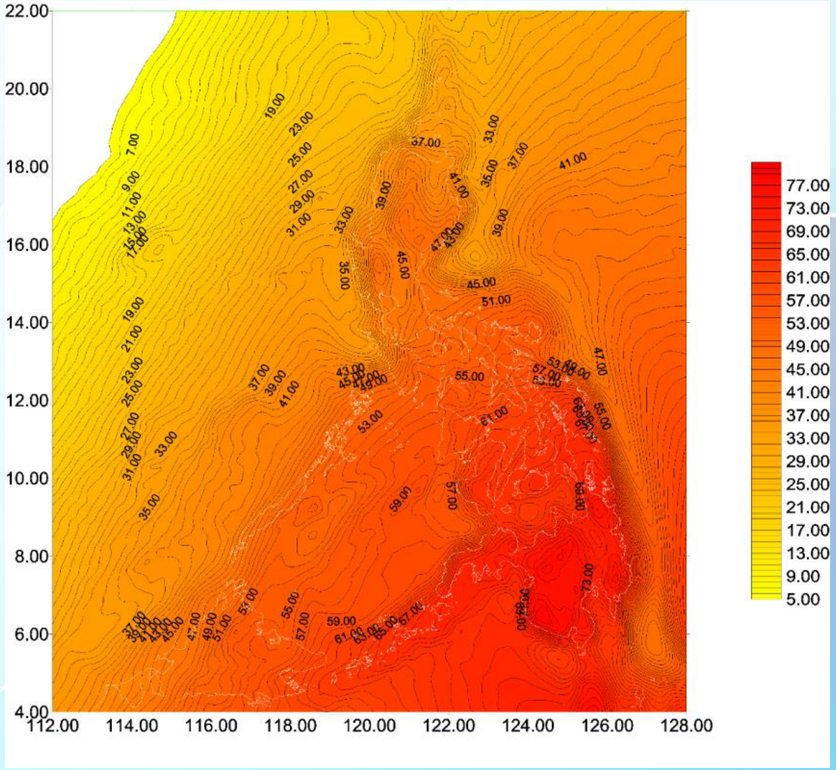
PGM 2014 to PGM 2016

- GNSS-levelling data were re-analysed, corrected, and outliers were deleted
- Old land gravity data were reprocessed and additional land gravity stations were established (2,214 in total)
- Only 101 of the original 190 GNSS/Leveling points remained and used in fitting the recomputed Geoid Model
- 2014 Airborne and satellite data processing results were used
- With the help of Prof. Forsberg, NAMRIA started the recomputation of the geoid model
- RMS fit is now 0.054 m with an SD of 0.022m



PHILIPPINE GEOID MODEL 2016

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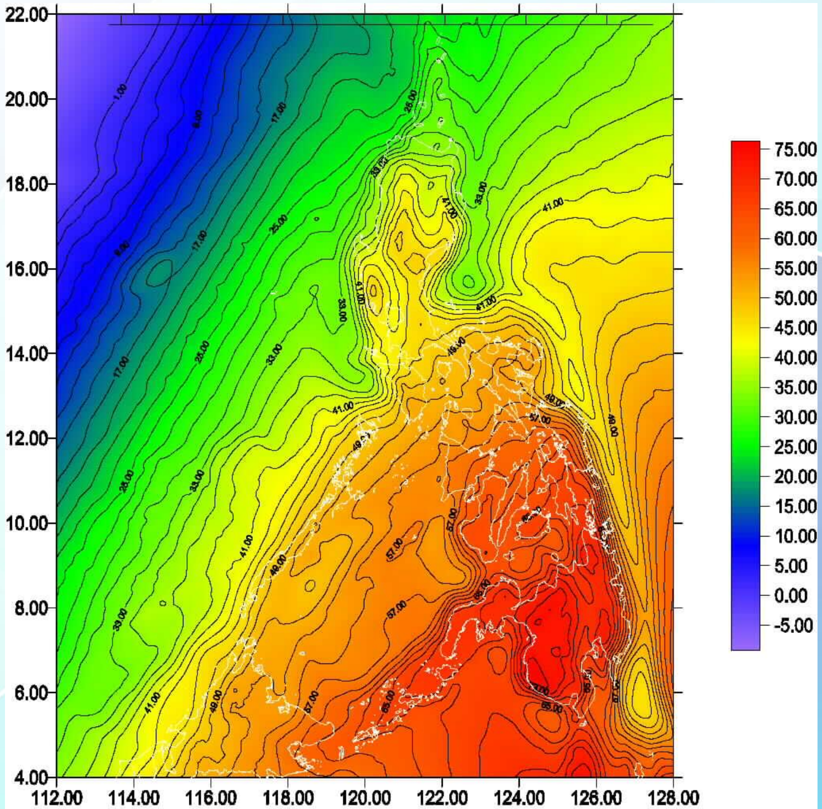
PGM 2016 to PGM 2018

- Input data:
  - PGM 2016 re-computation
  - New Satellite Gravity Data (DTU15)
  - Additional Land Gravity Stations (5,779 Total)
  - 286 GNSS/Leveling stations (BMs)
- Gravimetric geoid has an accuracy of around 10 cm across the country
- RMS fit is now 0.022 m



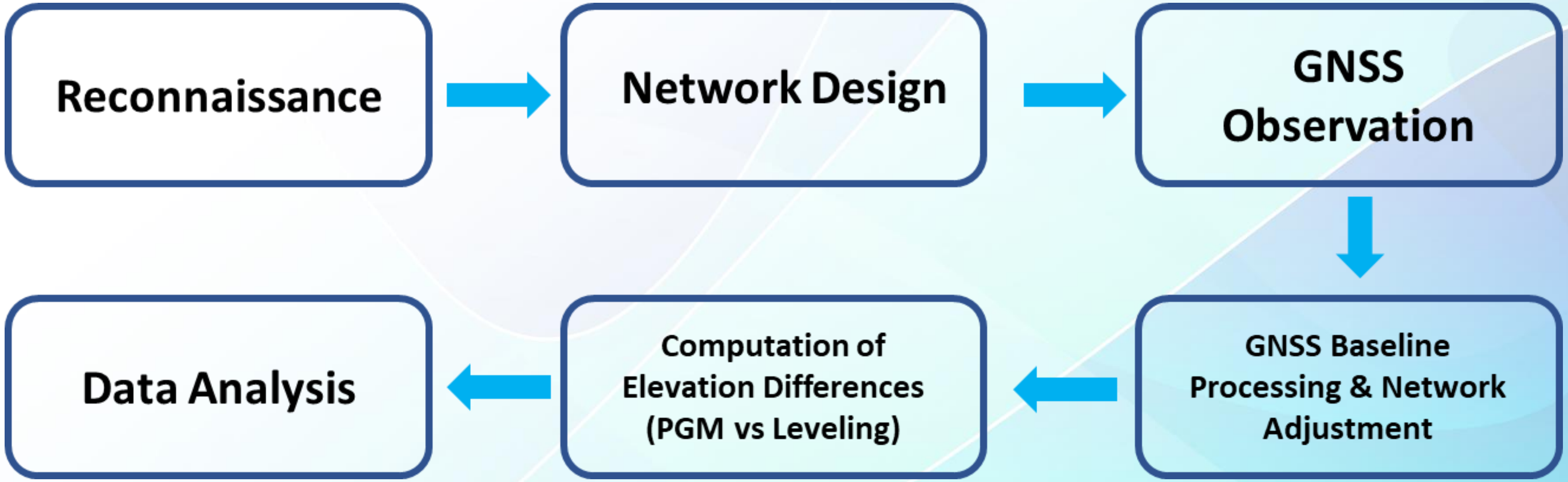
PHILIPPINE GEOID MODEL 2018

Validation of PGM2018 Using GNSS

- To validate and confirm the PGM2018 fit to the leveling network, benchmarks (BMs) were observed through GNSS surveys (to get the ellipsoidal height).
- GNSS Data were post-processed using Trimble Business Center (TBC), with the PGM2018 file integrated into the software.
- The TBC generates the MSL elevation of the BMs (based on the PGM2018).
- These TBC generated MSL elevations were then compared to the Geodetic Leveling adjusted elevations.
- The resulting elevation differences between the two methods indicated the accuracy of the PGM.

Validation of PGM2018 Using GNSS

Workflow of the PGM Validation



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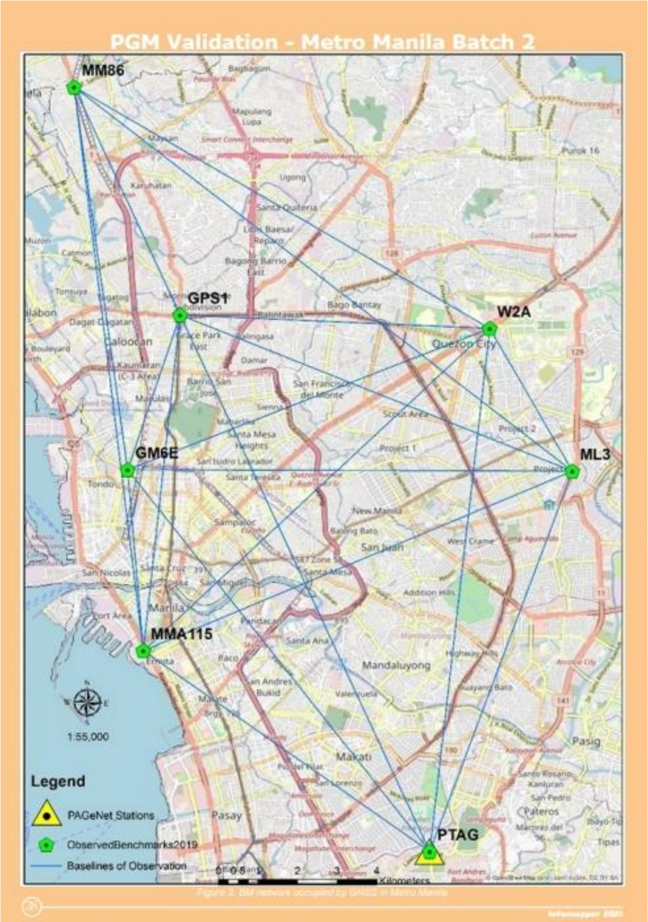
Validation of PGM2018 Using GNSS



PILOT AREA (Metro Manila)

Reconnaissance

- BMs were selected from the adjusted level networks based on their distribution
- Field reconnaissance was done to ensure the BMs are still existing and asses the conditions and suitability for GNSS observation

Network Design

- Locations of the BMs are plotted on a map to design and create the survey plan
- The Network Design considered the distribution of the points and also the number of GNSS receivers that will be used for efficacy.

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Validation of PGM2018 Using GNSS

GNSS Observation

- ❖ Survey was scheduled into loops of points of simultaneous observations
- ❖ Each loop was occupied for two observation sessions for an average of two to four hours per session using static technique
- ❖ CORS were also used in the study (PTAG) to maximize the equipment available
- ❖ During the observation, instruments are carefully centered on the BMs and antenna heights were meticulously measured multiple times.

Figure 3. NAMRIA Geodesy Division personnel measuring the antenna height of the GNSS setup in Isabela

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Validation of PGM2018 Using GNSS

GNSS Data Processing

- Data were processed and adjusted using Trimble Business Center (TBC)
- The Geoid Grid Format (ggf) of thePGM2018 was used and incorporated into the TBC to generate the MSL elevations of the BMs using the equation H = h –N
- Datum used is the epoch 1987 of WGS84 and only CORS were used as reference in processing the GNSS data since their epoch of observations is consistent with that of the GNSS/Leveling

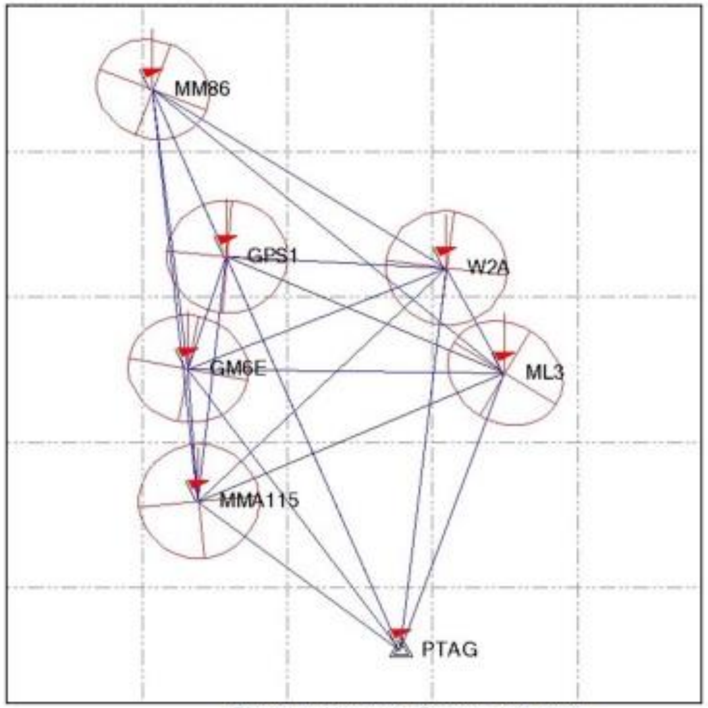

Figure 5. Network of points with their corresponding error ellipses

Validation of PGM2018 Using GNSS

GNSS Data Network Adjustment

- After processing, the network of BMs was adjusted with allowable setup errors of 3mm and 2 mm in antenna heights and centering respectively
- In the final adjustment, the CORS was constrained and most residual error values were near zero
- The list of adjusted geodetic coordinates of points included the height errors ranging from 0.011 m to 0.024 m as shown in the table

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
GM6E	N14º 37' 19.78596"	E120º 58' 19.71607"	46.9616	0.013	
GPS1	N14º 39' 26.31635"	E120º 59' 02.57359"	61.55764	0.012	
ML3	N14º 37' 18.63727"	E121º 04' 23.57747"	103.68939	0.024	
MM86	N14º 42' 32.86143"	E120º 57' 35.86834"	45.53595	0.018	
MMA115	N14º 34' 51.70557"	E120º 58' 32.40288"	48.96314	0.011	
PTAG	N14º 32' 07.43281"	E121º 02' 26.78149"	88.05700	?	LLh
W2A	N14º 39' 15.22590"	E121º 03' 15.91183"	93.65926	0.011	

Table 1. Adjusted Geodetic Coordinates with PTAG fixed in Lat/Long/Ht (LLh)

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Validation of PGM2018 Using GNSS

Computation of Elevation Difference

- Corresponding list of BMs with elevation from the leveling surveys was gathered (this was computed and adjusted using StarNet Adjustment Software)
- The BMs, together with their corresponding elevations by GNSS leveling were tabulated with their difference in elevations using the PGM Validation Evaluation Checklist (see table)
- The elevations from the adjusted geodetic leveling data were compared with that of the elevations estimated using the PGM

PGM VALIDATION EVALUATION CHECKLIST

NAMRIA-PGRSDM-Form29 Rev00

STATION NAME	DESCRIPTION		GNSS DATA		VERTICAL DATA						Encoded in GNIS
							ELEVATION (m)				
	Updated Description	Submitted to GNIS for Archiving (Hard and Digital Copies)	Sessions = Two (2)	Error Ellipse (m)	**ELLIPSOIDAL HEIGHT (m)**	Height Error (m)	PGM (2018a)	Leveling	Difference	☑ if < 10-cm ☒ if >	
GM6E	V. ALMUETE	TIM BALUYOT	☒	0.002	46.969	0.013	**1.776**	1.964	-0.188	☒	TIM BALUYOT
GPS1	V. ALMUETE	TIM BALUYOT	☒	0.002	61.558	0.012	**16.273**	16.376	-0.102	☒	TIM BALUYOT
ML3	V. ALMUETE	TIM BALUYOT	☒	0.004	103.689	0.024	**57.368**	57.458	-0.090	☑	TIM BALUYOT
MM86	V. ALMUETE	TIM BALUYOT	☒	0.003	45.536	0.018	**0.491**	0.871	-0.380	☒	TIM BALUYOT
MMA115	OK	OK	☒	0.002	48.963	0.011	**3.689**	3.778	-0.089	☑	TIM BALUYOT
W2A	OK	OK	☒	0.002	93.659	0.011	**47.618**	47.692	-0.074	☑	TIM BALUYOT
			Processed by:				Processed by:				
			Name/Position/Signature				Name/Position/Signature				

NOTED BY: ____________________ Horizontal Section Chief

APPROVED BY: ____________________ Geodesy Division Chief

Table 2. Comparison of elevations from geodetic leveling and the geoid model

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Validation of PGM2018 Using GNSS

Discussion and Analysis

- Accuracy of the result of this study depended largely on the ff:
  - Accuracy of GNSS/Leveling surveys
    - The millimetre error ellipses of the GNSS survey met the accuracy standard for 1 cm control positioning
    - Particular attention was given to the accuracy of ellipsoidal heights. A 1-3 cm error in height in the final adjustment was deemed acceptable for a target of 10 cm geoid accuracy.
  - Accuracy of Geodetic Levelling Data
    - Only First Order geodetic levelling was used in the study
  - Accuracy of the PGM
    - The accuracy of the PGM2018 is more or less 10 cm

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Validation of PGM2018 Using GNSS

Nationwide Result of PGM Validation

- ❖ GNSS survey error has incurred a maximum height error of 5.9 cm in Region II (refer to Table 3)
- ❖ Leveling error accounted for 16.3 cm in the Cordillera Autonomous Region (CAR) and 12.2 cm in Region IV-A

	Error Ellipse (m)	Height Error (m)
Region I	0.002 - 0.006	0.008 - 0.026
Region II	0.001 - 0.007	0.006 - 0.059
CAR	0.002 - 0.005	0.006 - 0.034
NCR	0.001 - 0.005	0.006 - 0.026
Region IVA	0.001 - 0.005	0.005 - 0.020
Region V	0.002 - 0.006	0.003 - 0.020
Cebu Province	0.003 - 0.006	0.012 - 0.035
Region IX	0.003 - 0.006	0.014 - 0.023
Region X	0.003 - 0.006	0.010 - 0.020

Table 3. GNSS Survey Accuracy, where error ellipse is for horizontal and height error is for vertical

	SD (m)
Region I	0.020 - 0.083
Region II	0.033 - 0.083
CAR	0.024 - 0.163
NCR	0.003 - 0.039
Region IVA	0.030 - 0.122
Region V	0.012 - 0.068
Cebu Province	0.021 - 0.058
Region IX	0.040 - 0.087
Region X	0.013 - 0.075

Table 4. Leveling Data Accuracy

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Validation of PGM2018 Using GNSS

Result of Nationwide PGM Validation

- Elevations from the GNSS+PGM from each province surveyed were compared with the adjusted elevations form levelling

- The 286 validation points showed a wide range of difference relative to the GNSS+PGM extending from +0.00 m to +0.946 m with large outliers in encircled areas

- Errors can be attributed to erroneous levelling data and have to be checked or releveled

Province	△Elevation (m)	Province	△Elevation (m)	Province	△Elevation (m)
RI. Ilocos Norte	0.000 - 0.139	CAR. Mountain Prov-ince	0.038 - 0.123	RV. Camarines Sur	0.005 - 0.106
RI. Ilocos Sur	0.011 - 0.221	NCR. Metro Manila	0.017 - 0.380	RV. Sorsogon	0.042 - 0.086
RI. La Union	0.001 - 0.042	RIII. Bulacan	0.027 - 0.742	Cebu Province	0.044 - 0.381
RI. Pangasinan	0.004 - 0.527	RIVA. Batangas	0.054 - 0.946	RIX. Zamboanga del Norte	0.074 - 0.151
RII. Cagayan	0.003 - 0.119	RIVA. Cavite	0.041 - 0.406	RIX. Zamboanga del Sur	0.130 - 208
RIII. Isabela	0.007 0.345	RIVA. Laguna	0.030 - 0.373	RIX. Zamboanga Sibugay	0.064 - 0.165
CAR. Abra	0.052 - 0.184	RIVA. Quezon	0.001 - 0.818	RX. Bukidnon	0.017 - 0.145
CAR. Apayao	0.002 - 0.088	RIVA. Rizal	0.002 - 0.099	RX. Lanao del Norte	0.051 - 0.496
CAR. Ifugao	0.095 - 0.179	RV. Albay	0.027 - 0.130	RX. Misamis Occidental	0.148 - 0.168
CAR. Kalinga	0.059 - 0.291	RV. Camarines Norte	0.015 - 0.435	RX. Misamis Oriental	0.078 - 0.809

Table 5. Differences in Elevation between PGM-derived elevation and Leveling

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Conclusion

- PGM-Leveling differences tend to increase form North to South of the Philippines with ±7cm in Northern Luzon, ±14 cm in South Luzon, ±12 cm in Cebu Province and ±50 cm in Mindanao

- Large differences can be attributed to geodynamic effects or levelling errors

- Discounting the large errors which needs further investigation, the rest of the country with good levelling data results in an accuracy of approximately 10 cm for the PGM2018.

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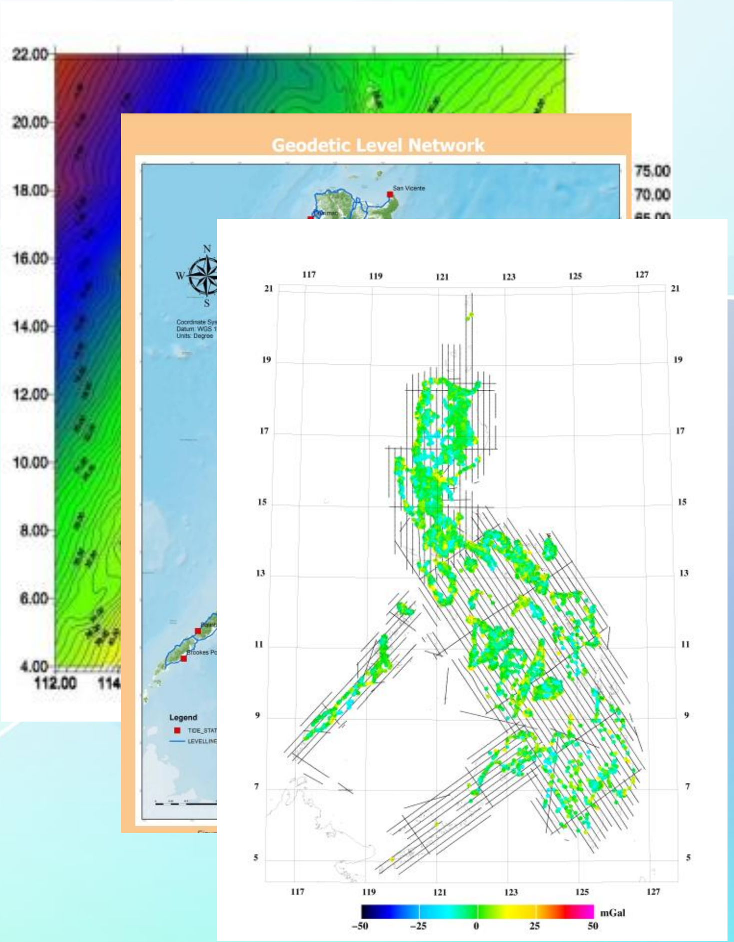
Recommendations

- NAMRIA recommends the continuation of the validation process of the Philippine Geoid Model

- Re-leveling and re-adjustment of the National First Order Geodetic Level Network (applying orthometric correction)

- Densification of Land Gravity points (40K+ points until 2030) nationwide is also needed for the refinement of the PGM.



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Maraming salamat po!

National Mapping and Resource
Information Authority (NAMRIA)
Lawton Ave., Fort Bonifacio, Taguig City

https://www.namria.gov.ph

geodesy@namria.gov.ph

(+63) 2 8884 2849

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