PGM2016: A new geoid model for the Philippines

United Nations/Nepal Workshop on the Applications of Global Navigation Satellite Systems

Kathmandu, Nepal December 12-16, 2016

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Presentation Outline

- Introduction
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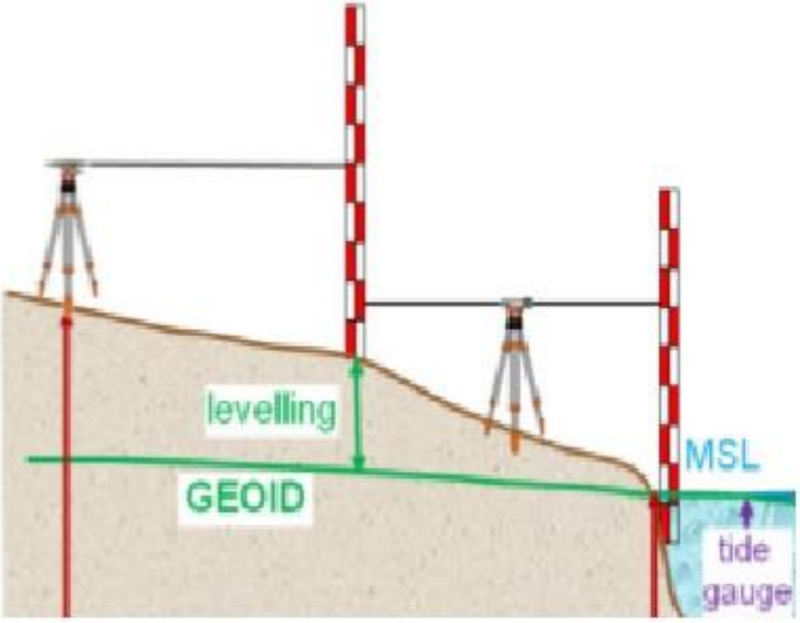
  - Gravimetric Geoid Computation
  - Geoid processing results
  - GNSS data comparison and final geoid
- Part II (PGM2016)
- Re-computation of the Philippine Geoid

Introduction

- Vertical coordinates (Heights) of points are referred to a coordinate surface called Vertical datum
- The geoid is the universal choice of a vertical datum; it is an equipotential level surface of the oceans at equilibrium

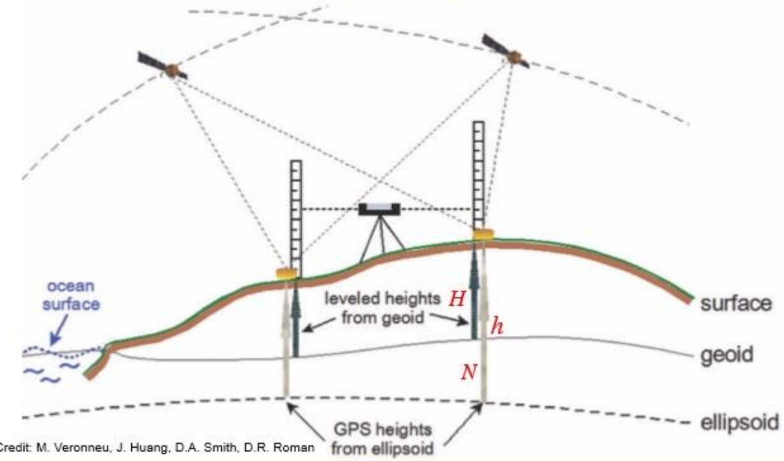


Introduction

- With the advent of GNSS, it has become much easier to estimate MSL elevation H using a geoid model
- A geoid model is a surface (N) which describes the theoretical height of the ocean and the zero-level surface on land

◆ **Connecting geometric to physical heights**

- Possible through the *geoid undulation* or *geoid height N*
  - ◆ N is **the separation between the physical and geometric reference surfaces**
- $h = H + N$ or $\Delta h_{12} = \Delta H_{12} + \Delta N_{12}$



Credit: M. Veronneu, J. Huang, D.A. Smith, D.R. Roman

Introduction

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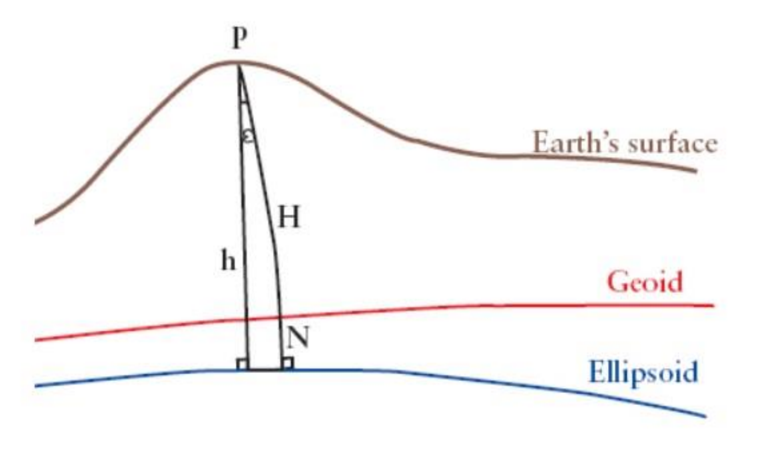
The geoid is required to obtain Orthometric height H from GNSS by

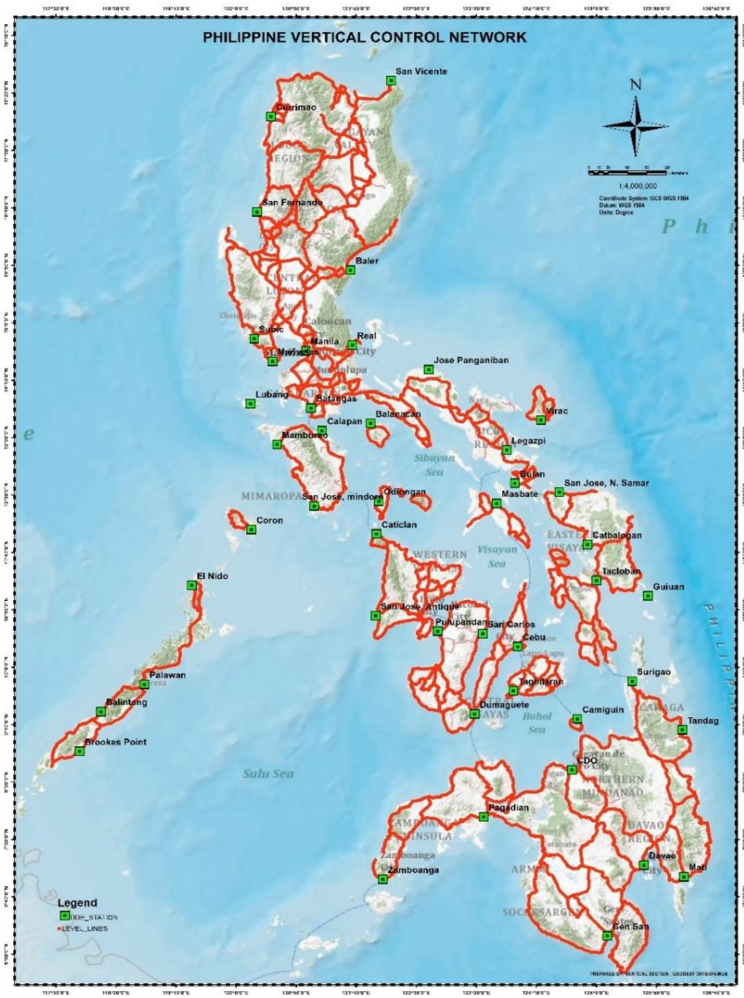
$$H = h^{GNSS} - N$$

Where h^{GNSS} is the GNSS ellipsoidal height and H the levelled height



Introduction

- In the Philippines, determination of H was normally conducted thru geodetic leveling
- From 2007 to 2012, 22,851 Benchmarks were established nationwide
- Applying a geoid model in GNSS surveys will eliminate the establishment of Benchmarks



Introduction

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- The first attempt of computing a preliminary gravimetric geoid for the Philippines is through the Natural Resources Management Development Project (NRMDP) in 1991
- Land gravity data and altimetrically-derived anomalies at sea and OSU89A to degree and order 360 (reference global model) were used. Biases between the gravimetric N and GNSS/Leveling were found ranging from 2-6 m nationwide

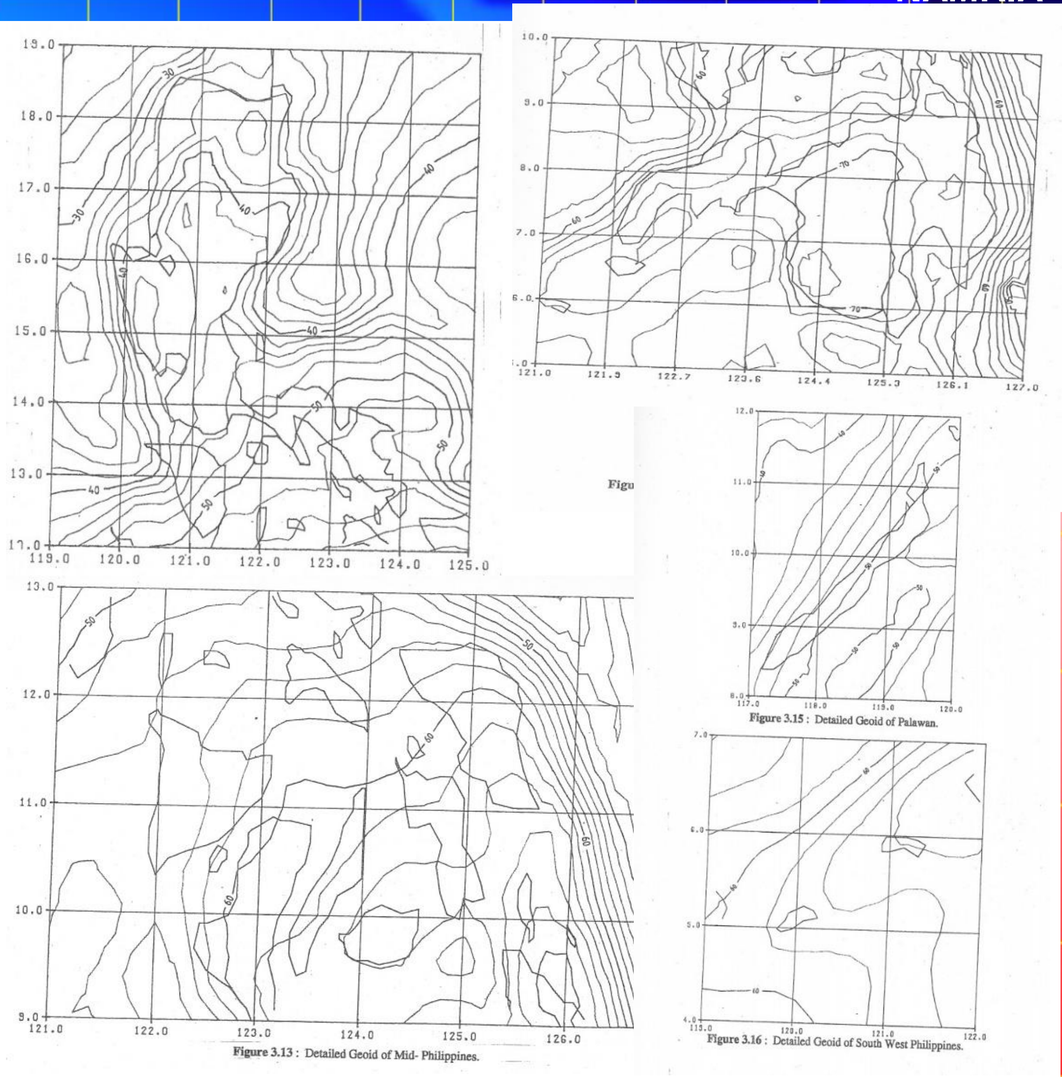

Figure 3.13 : Detailed Geoid of Mid- Philippines.

Figure 3.15 : Detailed Geoid of Palawan.

Figure 3.16 : Detailed Geoid of South West Philippines.

Introduction

- On October 28, 2014 with the assistance of Denmark Technical University (DTU-Space) and National Geospatial Intelligence Agency (NGIA), a preliminary geoid model i.e., Philippine Geoid Model 2014 (PGM2014) has been computed for the country to update the EGM2008 using the data from:
  - land gravity
  - airborne gravity
  - marine satellite altimetry
  - gravity data from the GOCE release 5

with an accuracy of 0.30meters

Airborne Gravity Survey Part I

- Cessna Grand Caravan aircraft was used in the airborne operations from March 6 to May 23, 2014

Airborne Gravity Survey

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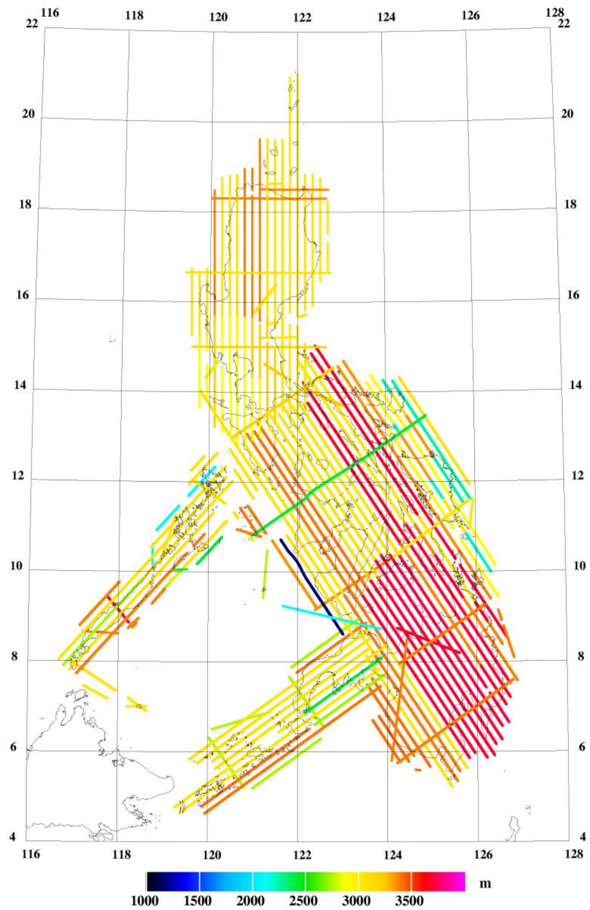
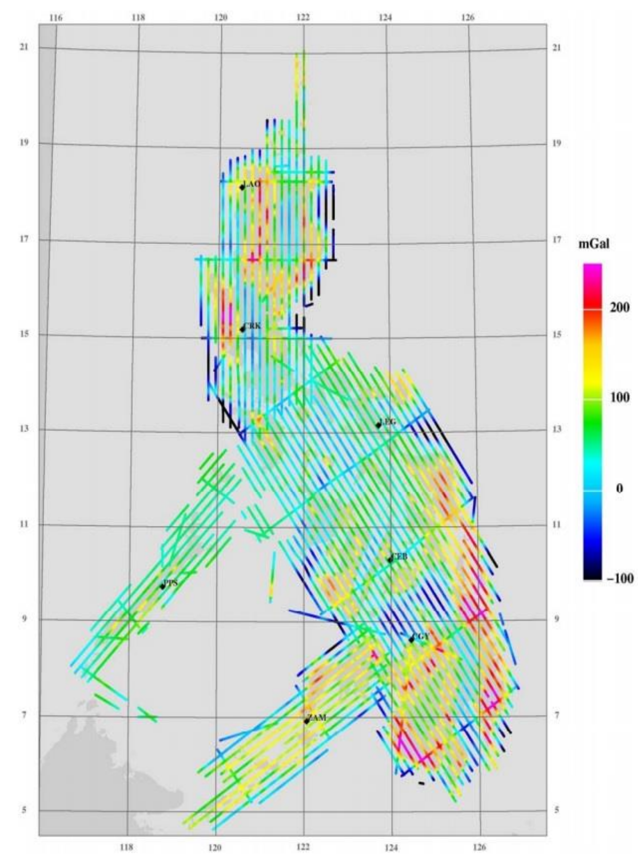
- Flight track elevations of the airborne gravity survey on the left and the free-air anomalies at altitude, right
- Mean altitude for all flights was 3185m





Airborne Gravity Survey

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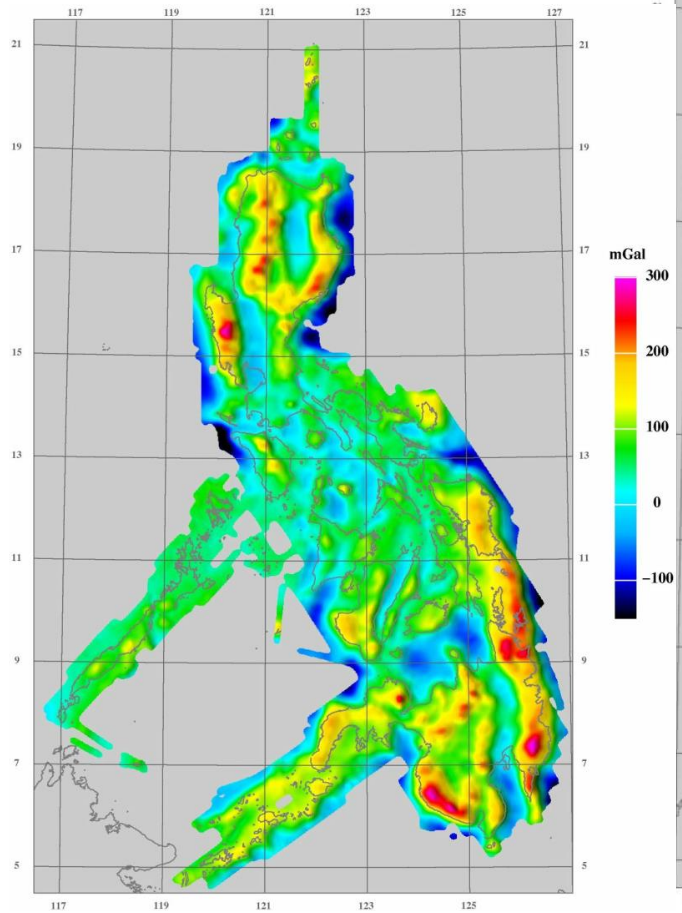
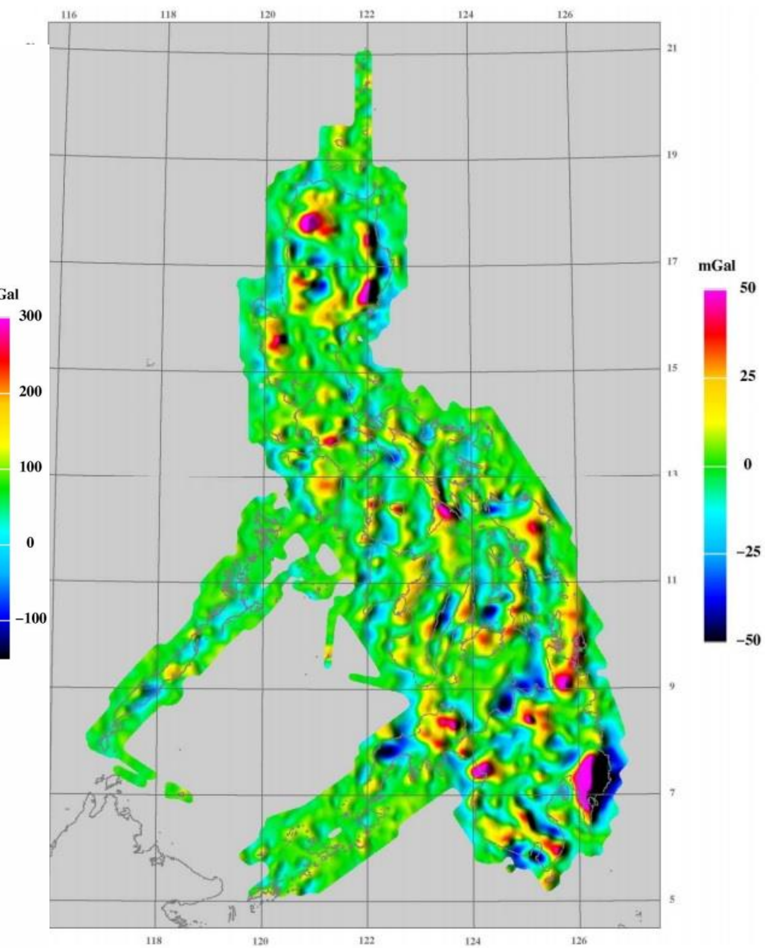
- Gridded free-air anomalies (left)
- Differences between airborne data and EGM08 amounting to more than 130mGal over SE Mindanao (right)





Gravimetric Geoid Computation

- The PGM2014 is computed by the *GRAVSOFT* system, a set of Fortran routines developed by DTU-Space and Niels Bohr Institute, University of Copenhagen

- The remove- restore technique was used in computing the geoid where a spherical harmonic earth geopotential model (EGM/GOCE combination) is used as a base

Gravimetric Geoid Computation

- The geoid is computed from the global contribution N_{egm}, a local gravity derived component N_2, and a terrain part N_3

$$N_{grav} = N_{egm} + N_2 + N_3$$

Gravimetric Geoid Computation

- The geoid is computed on a grid of $0.025° \, x \, 0.025°$ resolution (corresponding to roughly 2.7 x 2.5 km grid). The area of computation is $04° - 22°N \; and \; 112° - 128°E$, covering the Kalayaan Islands of West Philippine Sea

- Computations was based on least squares collocation and Fast Fourier Transformation methods which involve 1440 x 1280 grid points corresponding to 100% zero padding

- The data are gridded and downward continued by least squares collocation using the planar logarithmic model. GRAVSOFT programs such as *gpcol1, spfour, gcomb, geoip* are involved in the process

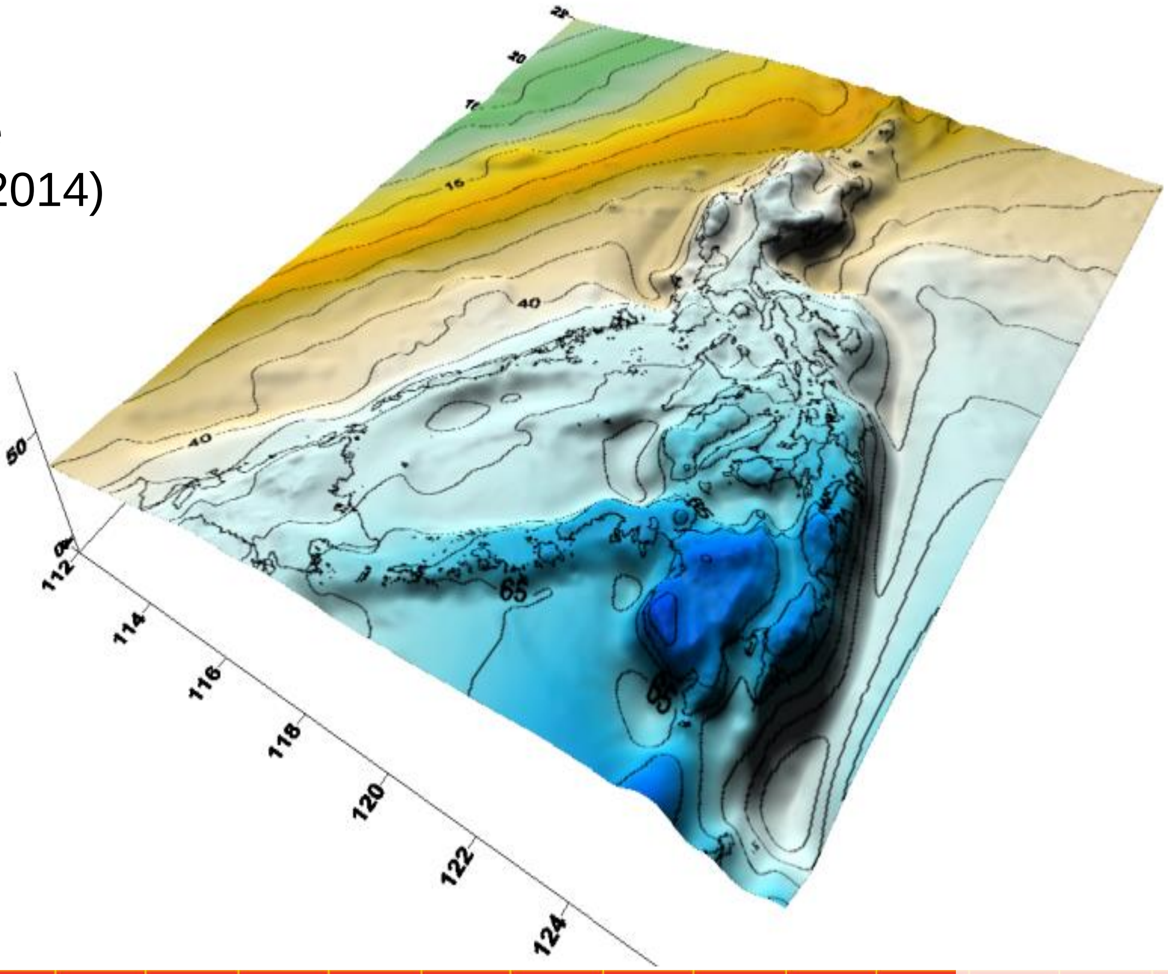
Gravimetric Geoid Computation

The final gravimetric geoid solution was computed by the following steps:

- *Subtraction of EGM08GOCE spatial reference field (in a 3-D "sandwich mode")*
- *RTM terrain reduction of surface gravimetry, after editing for outliers*
- *RTM terrain reduction of airborne gravimetry*
- *Reduction of DTU-10 satellite altimetry in ocean areas away from airborne data*
- *Downward continuation to the terrain level and gridding of all data by least-squares collocation using a 1° x 1° moving-block scheme with 0.6° overlap borders*
- *Spherical Fourier Transformation from gravity to geoid*
- *Restore of RTM and EGM08GOCE effects on the geoid*
- *Correction for the difference between quasigeoid and geoid (using a Bouguer anomaly grid)*
- *Shifting of the computed geoid by +80cm to approximately fit to Manila tide gauge datum*

Gravimetric Geoid Computation

- The preliminary Philippine Geoid Model 2014 (PGM2014)
- Contour interval 5m



Gravimetric Geoid Computation

Plots of the used and processed data

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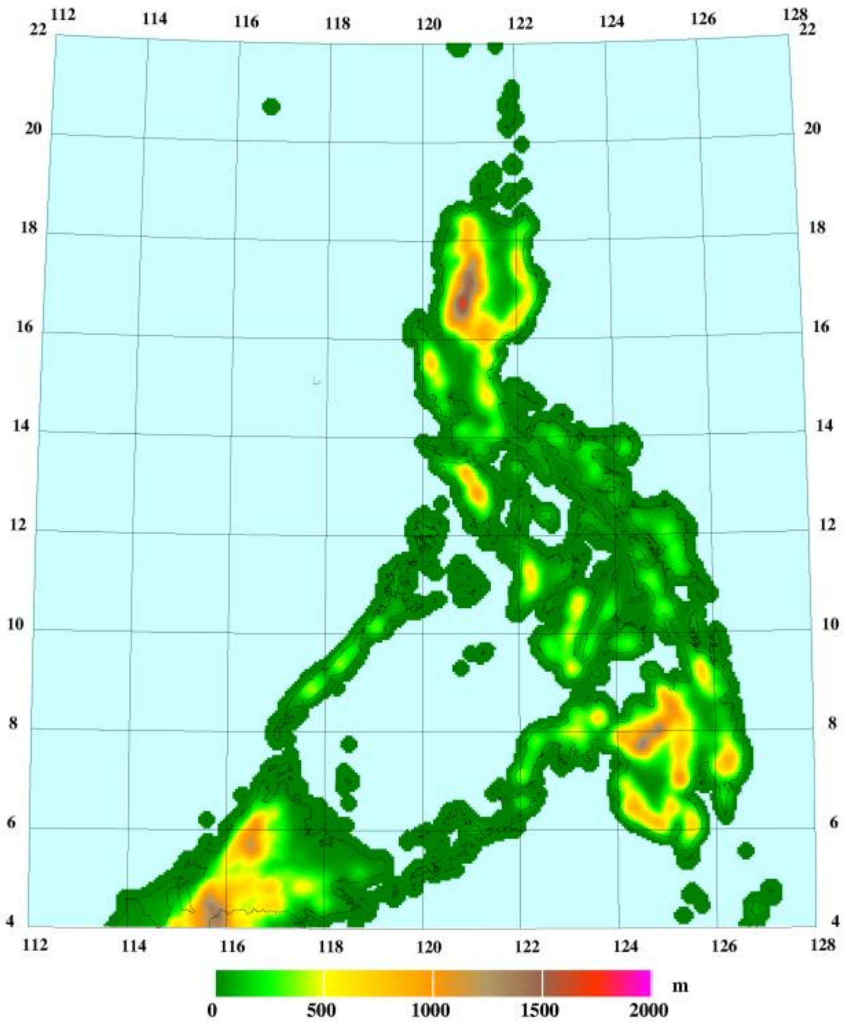
- Low-pass filtered mean elevation surface; used as reference in RTM terrain reductions (Elevation in meters)

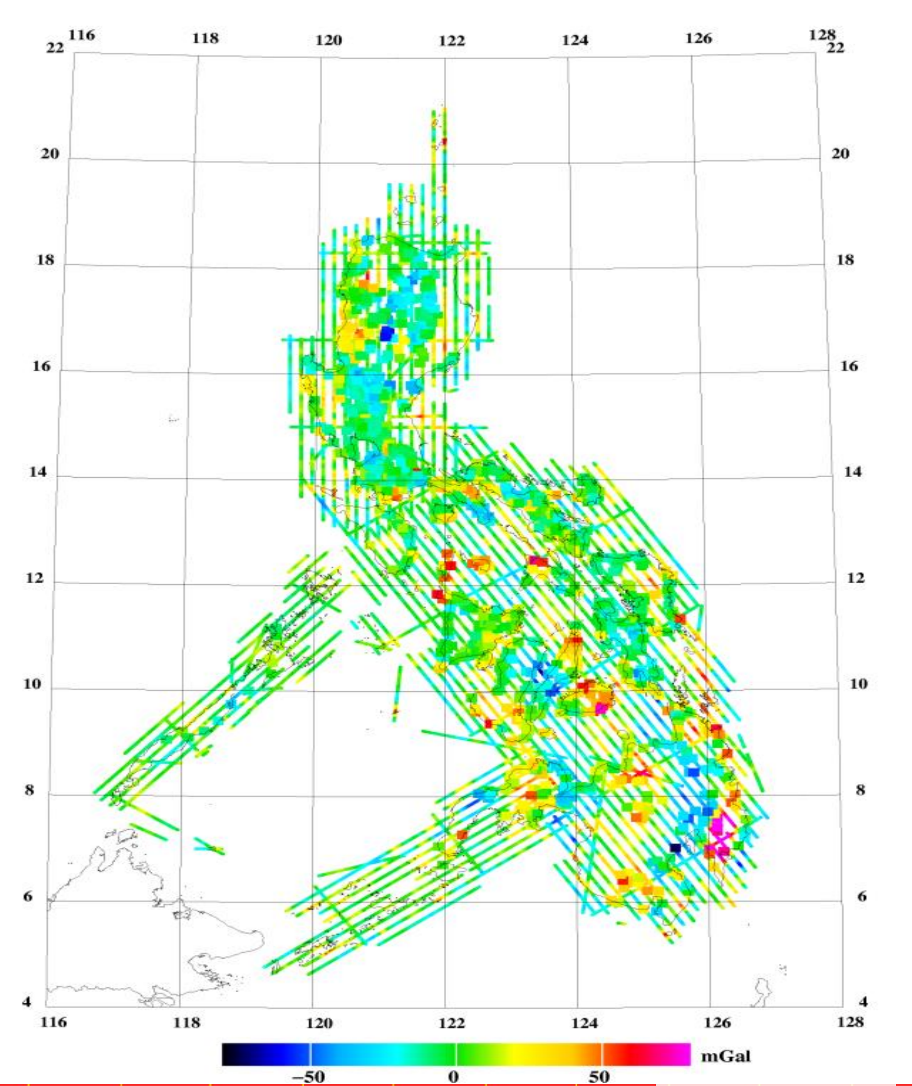


Gravimetric Geoid Computation

Plots of the used and processed data

- NAMRIA land gravity data (1261 points) and the airborne gravity data after terrain and EGM-reduction
- Some outliers (>50mgal) were deleted in the geoid processing

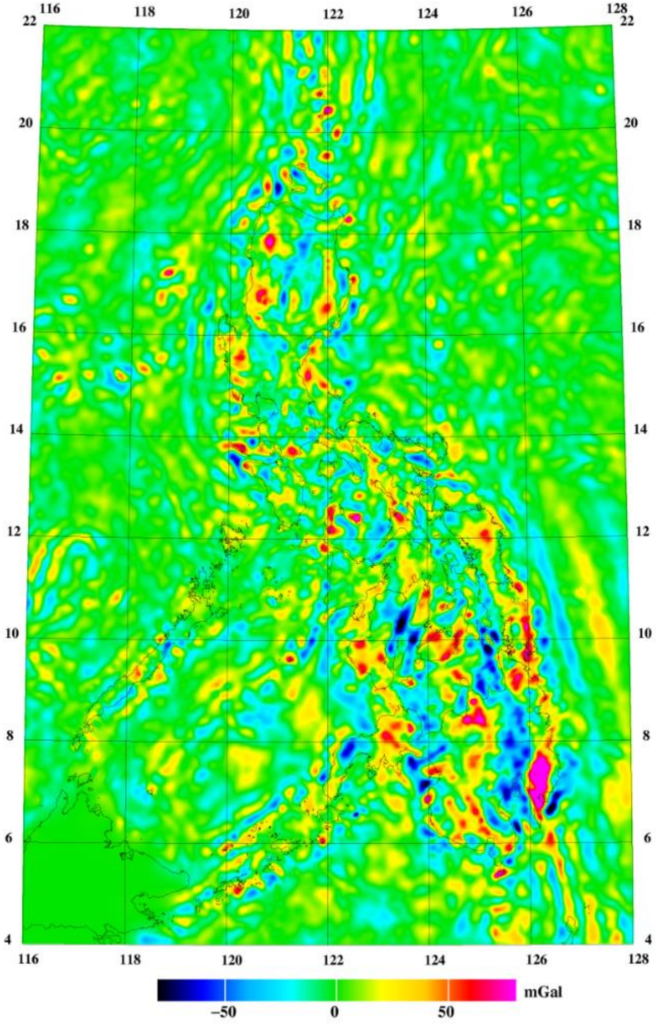
1mgal = 0.10mm



Gravimetric Geoid Computation

Plots of the used and processed data

- The LS -Collocation downward continued merged grid



Geoid Processing Results

Intermediate results

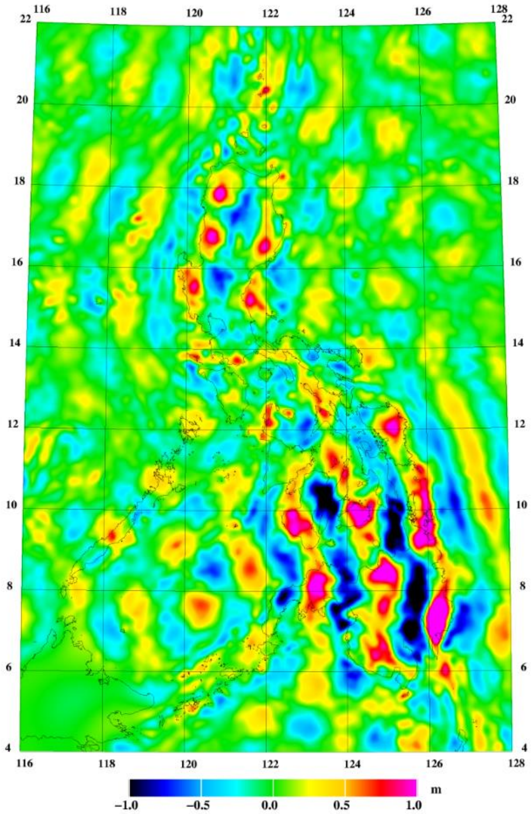
- The final geoid covers the region 4-22°N, 112-128°E, and has a resolution of 0.025° x 0.025° (1.5' x 1.5')
- The airborne and surface gravity data were gridded by spatial least squares collocation (*gpcol1, using covariance parameters* $\sqrt{C_0}$ *= 18 mgal, D= 6km, T=30km)*
- A priori errors assumed were 2 mGal for both the airborne data and the surface data (averaged in 0.025° blocks), and 5 mGal for DTU-10. The collocation downward continuation was done in 1° x 1° blocks, with 0.6° overlaps
- For the spherical FFT transformation of gravity to geoid, 3 reference bands were used

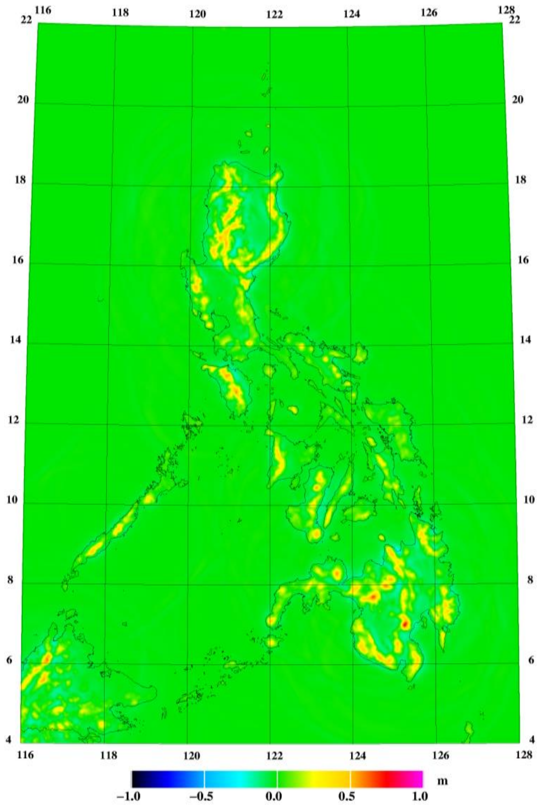
Final geoid restore statistics

Unit: meters	Mean	Std.dev.	Min.	Max.
Reduced geoid (after spherical FFT)	0.00	0.25	-1.61	2.88
RTM restore effects (computed by FFT)	0.00	0.04	-0.23	0.74
Final gravimetric geoid statistics	39.06	18.36	-9.02	76.43

Geoid Processing Results

Primary data grids



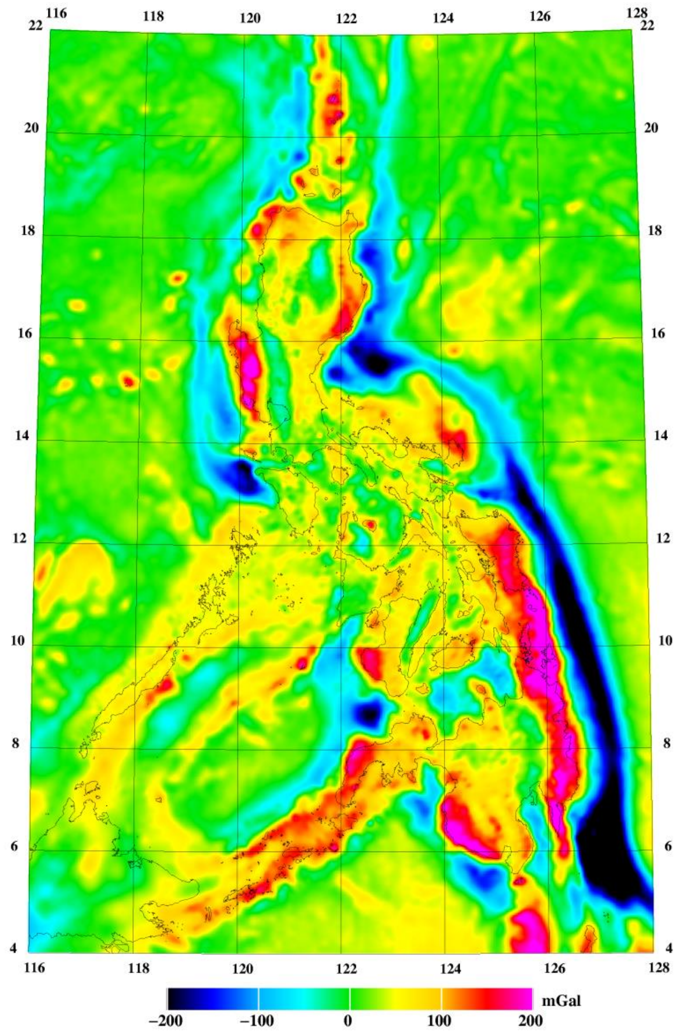


- Left: Reduced geoid (after spherical FFT transformation); right: RTM terrain effect on the geoid

Geoid Processing Results

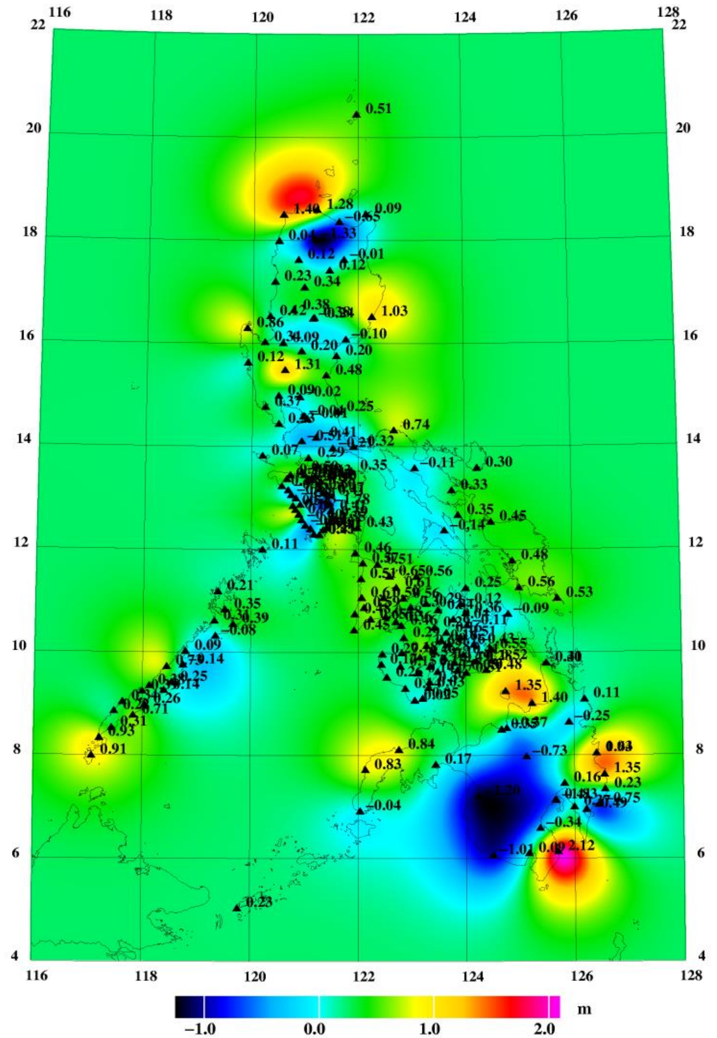
Primary data grids

- ❑ Bouguer anomaly grid, derived from the reduced data
- ❑ Used for the geoid-quasigeoid estimation



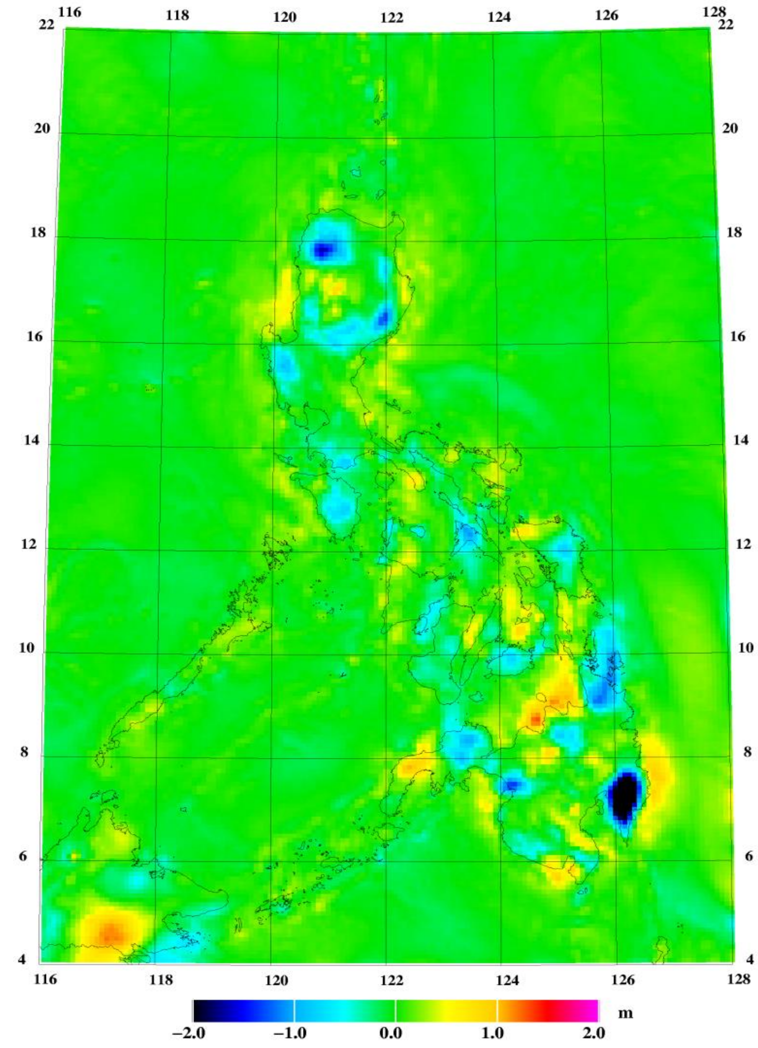
GNSS data Comparison and Final geoid

- A set of 190 GNSS data in ITRF2005 levelling benchmarks was used to compare with the final geoid (Fitted to GNSS-Leveling to preserve the existing vertical datum)
- These GNSS data showed large errors relative to the geoid (up to 2m), with large outliers in some regions likely due to levelling and GNSS errors
- The rms fit is 0.5 m; it is therefore not possible to use these data for validation of the geoid
- At right are the offset values and the geoid correction surface for a fitted geoid, gridded with 80 km correlation length, and GNSS-levelling apriori error of 10 cm



GNSS data Comparison and Final geoid

- Differences between the PGM2014 and EGM2008
- Large improvements are seen, especially in the south



Re-computation of the geoid Part II

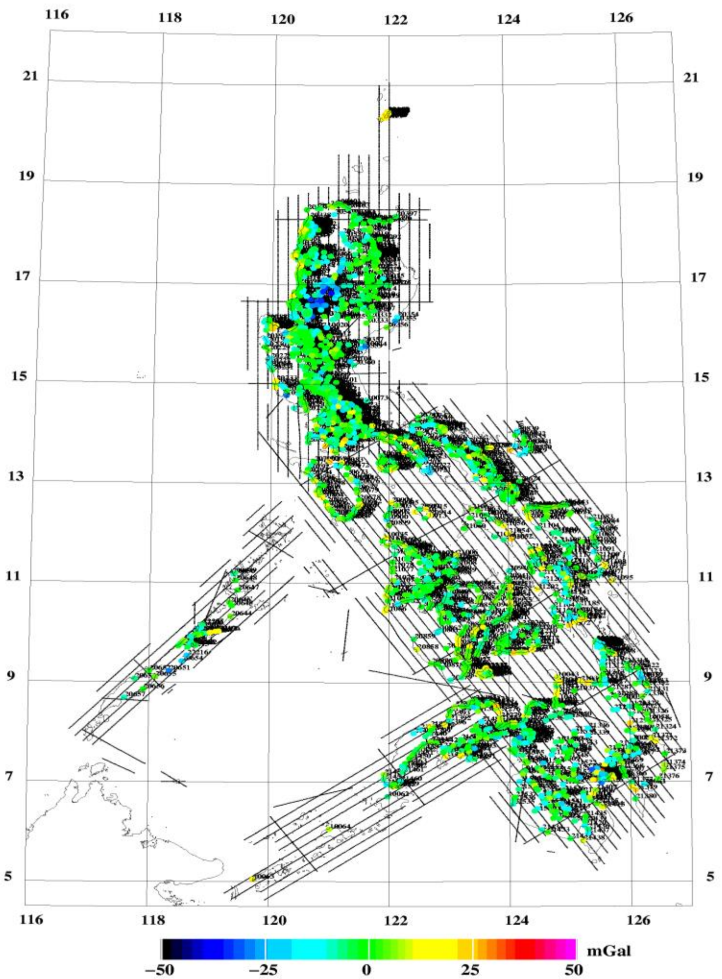
- To improve a geoid model, Professor Forsberg recommended to:
  - Carefully analyse the levelling network for adjustment errors
  - Revisit connections and antenna height errors of GNSS data
  - Erroneous points (geoid outliers) must be resurveyed by gravity, levelling and GNSS
  - New GNSS-fitted version of the geoid must be computed as new batches of GNSS-Levelling data, additional gravity surveys in major cities and GNSS users height problem reports comes in

Re-computation of the geoid

- In 2015, the GNSS-levelling data was re-analysed, corrected, and outliers deleted
- Reprocessing of gravity data and Densification of land gravity stations was conducted in some major cities of the country (2214 points to date)
- With the help of Professor Forsberg, NAMRIA started the re-computation of the Philippine Geoid

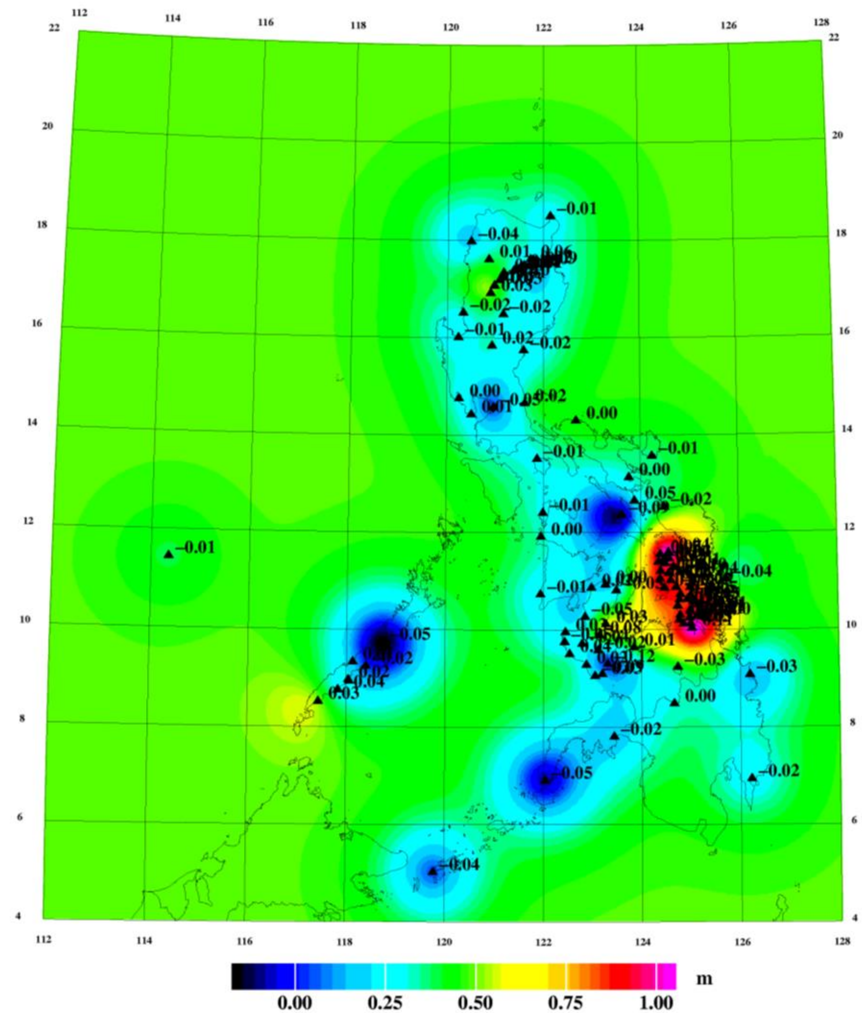
Re-computation of the geoid

- In this re-computation, the airborne and satellite data processing results were left as it is. Only the densified land gravity data were reprocessed and quality controlled
- Figure shows the new plots of the land and airborne gravity data. Significant improvements can be seen in the land data (thicker dots). Most dots are in green (near zero), some yellows and light blue (i.e., >25mGals difference in mountainous regions)



Re-computation of the geoid

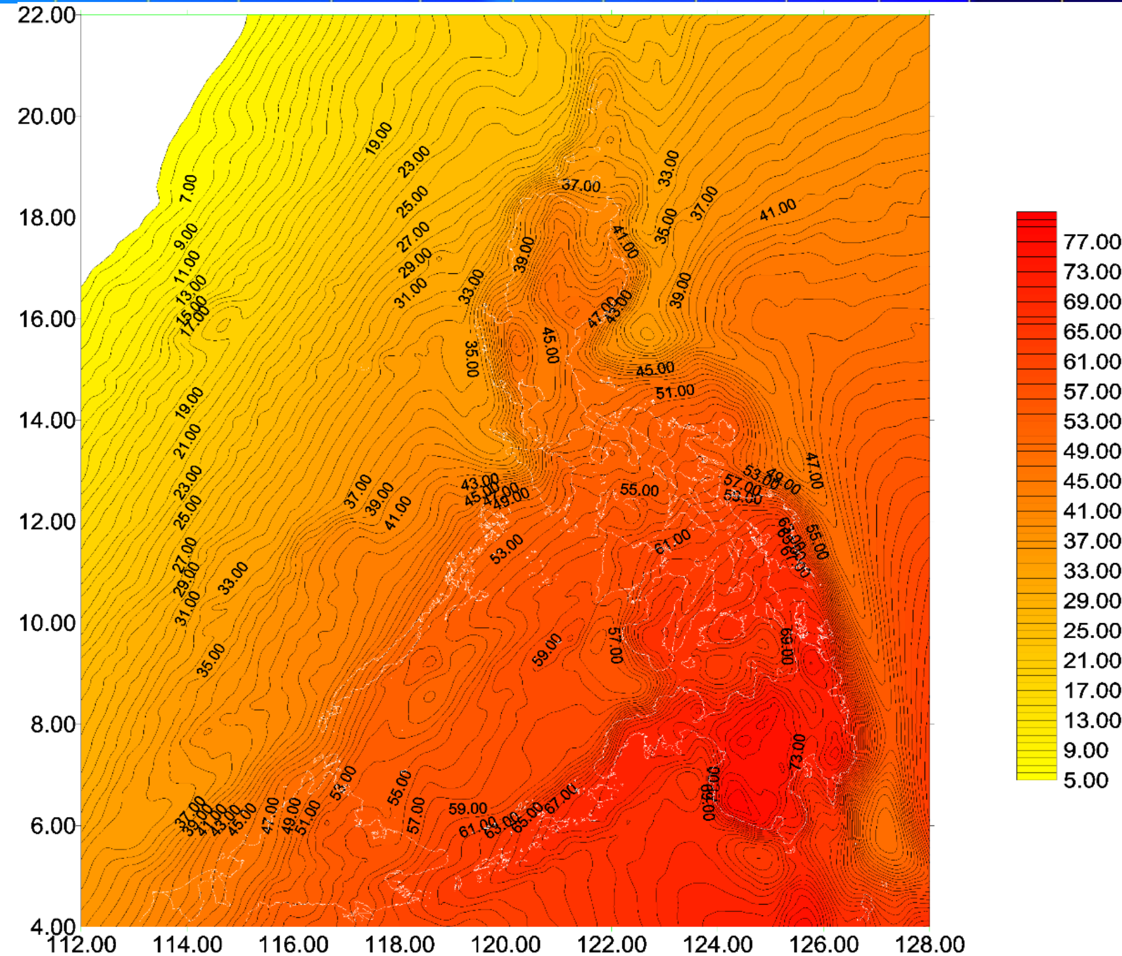
- 101 out of the 190 GNSS/Levelling data on BMs were left after cleaning up for outliers and use as validation points. After fitting the new GNSS/Levelling, the standard deviation now is 0.054m with a minimum and maximum offset value of -0.124m and 0.169m respectively
- Figure shows the offset values and the new geoid correction surface for the ITRF-fitted PGM2016
- More points will be added to the GNSS/Levelling data as the re-adjustment of the levelling network progresses



Re-computation of the geoid

- The PGM2014 was re-computed to the new PGM2016 (Figure at right) using additional land gravity stations combined with the same airborne and satellite gravity data

- More land gravity data (up to 41,000) will be added from 2017 until 2020 in order to refine the Philippine geoid



Philippine Geoid Map 2016.93
Local WGS84 fit to Nationwide BMs (N-msl)

Re-computation of the geoid

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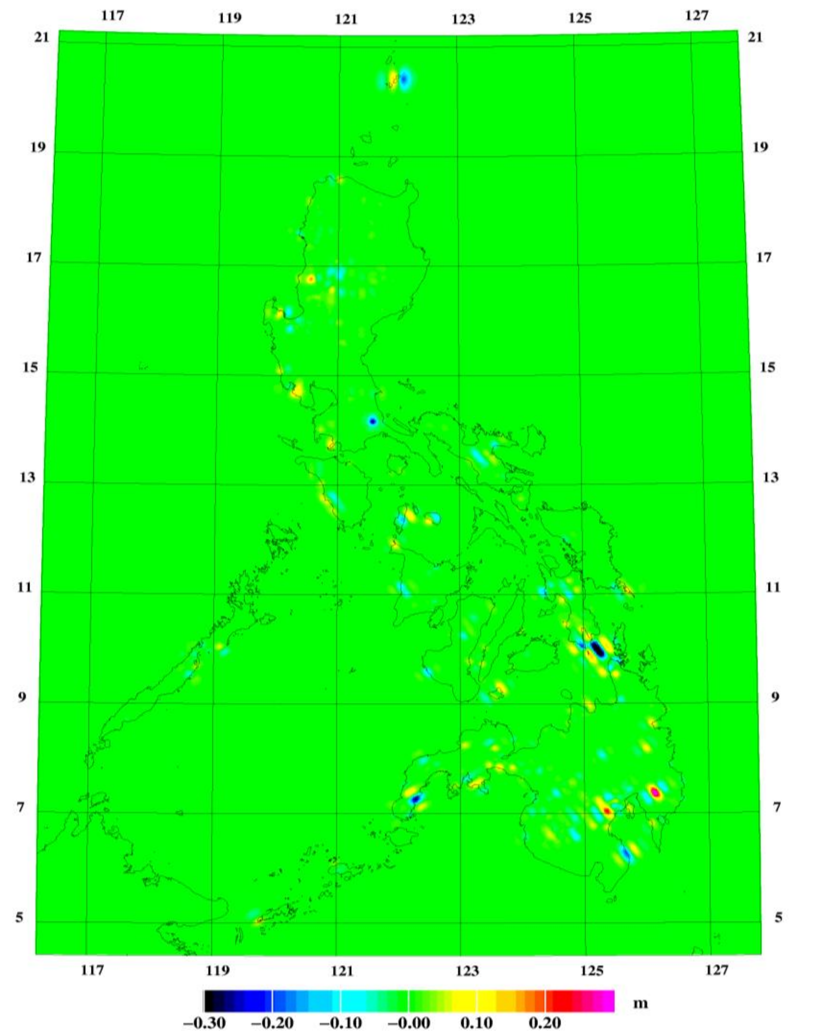
- Figure shows the differences between the new PGM2016 and PGM2014
- There are N value differences in some parts of the country as big as 0.30m



THANK YOU
Salamat Po

Gravimetric Geoid Computation

Global Contribution (N_{egm})

- The latest GOCE spherical harmonic model ("Direct" Release 5 model), complete to degree and order 280 was used to update EGM08 field in the following way:
  - *EGM08 used unchanged in spherical harmonic orders 2-80, and from 200 up*
  - *GOCE R5 direct model used in band 90-180*
  - *A linear blending of the two models done in bands 80-90 and 180-200*
- The mixed spherical harmonic model (EGM08/GOCE) has been used to spherical harmonic degree N = 720, corresponding to a resolution of 15' or approximately 28km (only 15' mean gravity data are assumed to be underlying EGM08)

Gravimetric Geoid Computation

Terrain Part (N_3)

- The terrain part of the computations were based on the RTM method, where topography is referred to a mean elevation level, and only residuals relative to this level is taken into account
- The mean elevation surface were derived from the SRTM 15" detailed model through a moving average filter with a resolution of approximately 20' (37 km)
- This is slightly longer than the 15' data resolution implied by spherical harmonic degree 720, in order to have a more smooth residual gravity signal Δg_2

Gravimetric Geoid Computation

Local Gravity (N_2)

- The method for the gravimetric geoid determination is *spherical FFT* with *optimized kernels*.
- This is a variant of the classical geoid integral ("Stokes integral"), in which there is a proper weighting of the long wavelengths from EGM08 and the shorter wavelengths from the local gravity data
- Mathematically it involves evaluating convolution expressions of form:

$$N_2 = S_{ref}\Delta(\varphi,\Delta\lambda) * (\Delta g_2(,\lambda) sin\varphi) = F^{-1}\Big(F\big(S_{ref}\big)F(\Delta g sin\varphi)\Big)$$

where S_{ref} is a modified "Stokes" kernel, $\Delta g_2 = \Delta g - \Delta g_{egm}$ is the EGM08/GOCE-reduced free-air gravity anomalies, and *F* is the 2-dimensional Fourier transform operator. For details see references (R. Forsberg, D. Solheim & J. Kaminskis, 1996), (R. Forsberg et al., 2002) and (R. Forsberg & Olesen, 2010)

GNSS data Comparison and Final geoid

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- The PGM2014 files are given as *GRAVSOFT* grids, and can be interpolated by the GUI program *grid_int*
- These are provided to NAMRIA as part of the computations, along with the general software and geoid job setups