

Modernization of PGRS

towards the Development and Sustainability
of the Global Geodetic Reference Frame



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FOREWORD

The National Mapping and Resource Information Authority (NAMRIA) is pleased to present this issue of Infomapper, NAMRIA's annual and semi-technical banner publication.

This year's issue focuses on the Modernization of the Philippine Geodetic Reference System (PGRS), pursuant to NAMRIA's mandate to establish and maintain the primary geodetic reference frame for all surveying and mapping activities in the country.

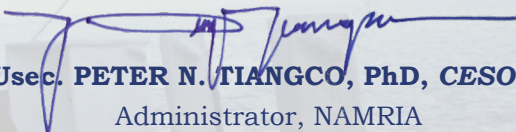
The first geodetic control network in the Philippines was put up from 1901 to 1946 by the Americans through the United States Coast and Geodetic Survey, the forerunner of the Bureau of Coast and Geodetic Survey (BCGS). The BCGS was one of the agencies merged into NAMRIA in 1987 under Executive Order number 192. NAMRIA upgraded the old national geodetic network into the Philippine Reference System of 1992 (PRS92). This was under the Geodetic Survey Component of the Philippines-Australia Natural Resources Management and Development Project implemented by DENR from 1989 to 1992. The year "1992" was the date when the initial upgrading of the network was finished. In 1993, by virtue of Executive Order number 45, PRS92 was made the standard reference for all mapping and surveying activities in the Philippines.

At present, NAMRIA is undertaking the modernization of PRS92, as part of its vision of building a geospatially empowered Philippines. The endeavor is aligned with Resolution 266 of the United Nations General Assembly during its 69th Session, dated 26 February 2015, that recommends the adoption and active participation of Member States in the definition of a global geodetic reference frame (GGRF) for sustainable development. The program will upgrade the existing PRS92, from a static and local system, to a datum consistent with GGRF that is in sync with real world ground deformations, to be managed and utilized by competent PGRS stakeholders. This 2021 edition of Infomapper deals with the developments made with the PGRS.

It is our hope that this issue will be a useful information, education, and communications tool for all stakeholders of the PGRS about the datum change, and how this will impact on their surveying and mapping activities.

It is time to change, from old to new, from local to global reference system. In order for us to be at par with other countries, international standards compel us to have a geodetic reference system that is interoperable and allows exchange of data.

Thank you and always stay safe. •


Usec. PETER N. TIANGCO, PhD, CESO I
Administrator, NAMRIA

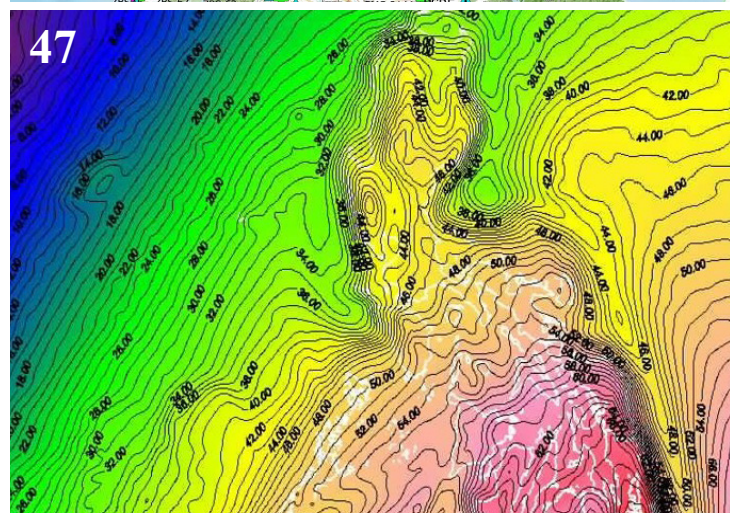
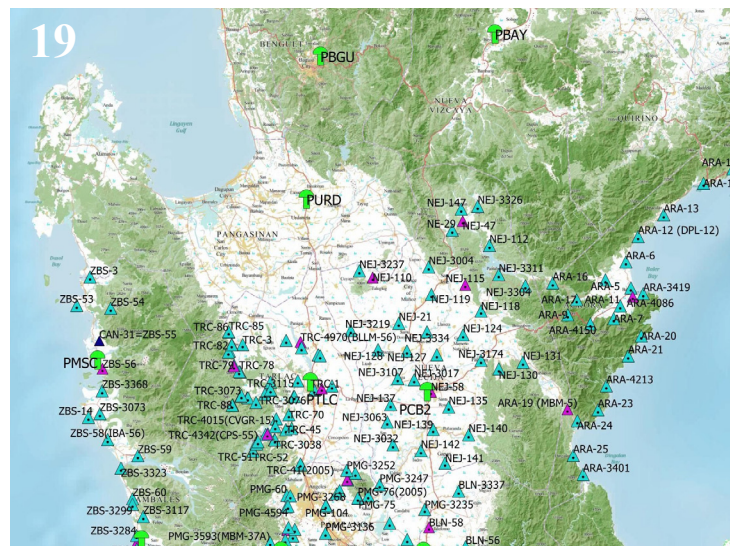
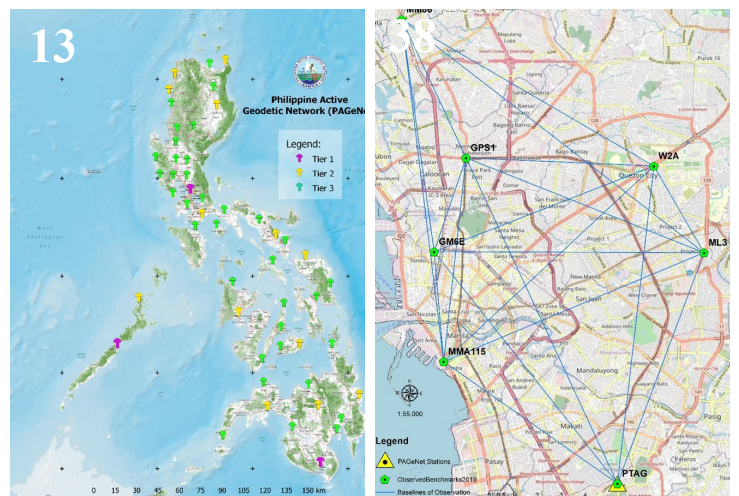




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Developing the Modern Philippine Geodetic Reference System



by: Engr. Charisma Victoria D. Cayapan and Engr. Abner A. Belmonte

The past two decades witnessed the upsurge of geospatial information and location-based services, with people becoming increasingly dependent on knowing the "where" of the "what" to go about their daily lives. For inclusive and sustainable development of the country's natural and built resources, an evidence-based decision making anchored on accurate, up-to-date, and reliable geospatial information is essential.

As in all types of measurements, defining one's location (or position) depends on the frame of reference from which the measurement is reckoned. Similarly, the quality of the position varies depending on the method used to arrive at that measurement. When position measurements carry with it legal rights, geodetic techniques are normally employed to achieve a high level of precision and accuracy, and to ensure that results are authoritative, i.e., consistent with other measurements, accurate according to published standards, and repeatable regardless of who made the measurement.

Defining Positions with Geodesy

Geodesy plays a crucial role in accurately determining the locations of objects, people, and events. Formally defined, Geodesy is the science of measuring and mapping the geometry, rotation, and gravity field of the Earth including their variations with time (Plag, et. al., 2010). From the time of Erathosthenes when he attempted to measure the

About the Photo: Shown are the velocities of the Asia Pacific Reference Frame (APREF) from its network of participating continuously operating GNSS reference stations (One of the distinguishing characteristics of modern reference frames is modelling geodynamism and studying its impact on positioning. NAMRIA contributes PAGENet data to the APREF, which is also closely aligned with the International Terrestrial Reference Frame [ITRF]).



circumference of the Earth by looking down a well, the work of geodesists continues to be relevant as the Earth is constantly changing.

What makes position measurements more accurate using geodetic techniques is that, unlike plane surveying, it takes into consideration the curvature of the Earth, including other factors, i.e., gravity, that may affect position determination. This is particularly important when surveying or mapping large areas, such as an entire continent or the whole world.

In defining positions with geodesy, one needs to understand reference systems, reference frames, and geodetic datums. Drewes (2009) differentiates the three terms as follows:

- **Reference systems** – define the constants, conventions, models, and parameters, which serve as the necessary basis for the mathematical representation of geometric and physical quantities.
- **Reference frame** – the realization of the reference system either physically, i.e., by a solid materialization of points, and mathematically, i.e., by the determination of parameters, e.g., geometric coordinates.
- **Geodetic datum** – fixes unequivocally the relation between a reference frame and a reference system by allocating a set of given parameters, e.g., the coordinates of the origin of the system (X₀, Y₀, Z₀), the directions of the coordinate axes X, Y, Z, and the scale as a unit of length, e.g., meter.

Generally, the terms *reference frame* and *geodetic datum* are used interchangeably. For clarity, the Philippine Geodetic Reference System (PGRS) referred to in this document pertains to both the reference system and the reference frame.

A geodetic datum is typically comprised of a horizontal control network (to define geometric positions) and a vertical control network (to define the elevations). Gravity observations are also conducted as variations in gravity impact elevation measurements. Traditionally, horizontal control networks were established using astronomical observations and triangulation methods to compute the positions of control points. The datum origin is normally set at a specific location, i.e., an outcrop of a bedrock, on the surface of the Earth, and the orientation of the coordinate axes are fixed using a reference azimuth between two control points.

Classical geodesy treats geodetic datums as static, with its parameters, i.e., origin, the direction of coordinate axes, and scale, fixed over time. Advances in space geodetic techniques, that brought about the increase in the temporal and spatial resolution of geodetic measurements and products, paved the way for modern reference systems. Modern reference systems are characterized as geocentric, i.e., origin is at the center of the Earth, global (transnational), and dynamic (time tagged 3D positioning) that make accurate and reliable geospatial information more easily accessible to the public.

For the Philippines, the geodetic reference primarily in use today is the Philippine Reference System of 1992 (PRS92) and the World Geodetic System 1984 (WGS84,

1987 version) for geometric positioning, and the mean sea level (MSL) for terrestrial elevation measurements. The legacy Luzon Datum of 1911 remains in use up to this day for land datasets that have yet to be integrated into PRS92.

Transitioning to a Modern PGRS

Discussions on modernizing the PGRS started as early as the mid-2000s (*Abad, 2003*). However, the country's geodetic infrastructure, human resource capability, and available resources at that time were limited to realize and sustain a fully functional modern PGRS.

The nationwide implementation of the PRS92 Project from 2007-2010 helped address some of these inadequacies. Through the project, the geodetic infrastructure was strengthened with the densification of passive geodetic control points (GCPs), benchmarks, and gravity stations, as well as the establishment of the Philippine Active Geodetic Network (PAGeNet) - the country's network of continuously operating geodetic reference stations. Also included in the project is the conduct of research and development studies, which include, among others, the recommendations for upgrading of PRS92 (*Paringit et. al., 2009*).

Working on these gains and recognizing the need to upgrade PRS92, NAMRIA convened a Stakeholders' Forum on the Modernization of the Philippine Geodetic Reference System in 2012. The event led to the establishment of an interagency technical working group comprising of representatives from government agencies engaged in surveying and mapping, private practitioners in the geomatics industry, as well as academic institutions providing courses in geodesy and geodetic engineering. Through a series of consultative meetings, the following key issues and developments were identified and have necessitated the modernization of the geodetic datum:

- *Degrading integrity of the geodetic control network because of geodynamics*

PRS92 was established almost 30 years ago. Since then, the country has been subjected to regular, and in some cases, significant ground movement that adversely impacted the geodetic control network. An analysis of repeated geodetic measurements reveals that the different parts of the archipelago have varying velocity rates (*Hsu et. al., 2016*), while

the earthquake monitoring by PHIVOLCS showed four big earthquakes (>Mw 7.0) in the past three decades alone. These geodynamics render the PRS92 coordinates obsolete in areas experiencing significant deformation, with positions becoming increasingly disparate from their actual locations on the ground. Lopez (2011) surmises that if the estimated 2-3 cm/year slip rate of the Philippine Fault Zone is considered, baselines, particularly those that cross active faults, would no longer meet the published accuracy standards for geodetic control networks after a certain period has elapsed. Galgana, et. al. (2019) also alludes to the likely effect of geodynamics on the vertical controls due to local gravitational anomalies, and recommends periodic resurveys of controls particularly in highly deforming areas and regions with significant accumulation of strain.

- *Non-homogeneity of datum*

Jones (1991) identified regional distortions that are inherent in the old triangulation network, which prevented the close alignment of the original Luzon 1911 coordinates to PRS92. The common stations used in deriving the PRS92-WGS84 (1987) transformation parameters likewise did not include the Mindanao area so the integration of cadastral datasets into PRS92 had to be done locally, i.e., per cadastral project/municipality. These hampered the seamless integration and interoperability with other geospatial information.

The differing mean sea levels also resulted in a disjointed vertical datum with benchmarks that are not interconnected among the major island groups. This issue is becoming increasingly significant with the massive infrastructure program currently being implemented by the government. Bridge and railway constructions that span across islands or regions require homogenous elevation measurements to ensure proper alignment of infrastructure projects.

- *Insufficiency of an existing datum to support transnational applications, such as climate change research and monitoring, aviation, navigation, and crustal deformation studies.*

The Philippines is ranked fourth in countries that are most susceptible to extreme weather

events in the period 2000-2019, based on Germanwatch's Global Climate Risk Index. The adverse impacts of these extreme weather events on the economy, and more importantly on the people, make climate change adaptation a priority thrust, not just for the government.

A global challenge requires a global approach in dealing with climate change. Geodetic observation techniques are organically operating in a global and geocentric reference frame. These techniques, which are considered vital tools for studying and monitoring climate variables, include global navigation satellite systems and satellite missions monitoring Earth's gravity field, such as NASA's Gravity Recovery and Climate Experiment (GRACE) and Challenging Mini-satellite Payload (CHAMP). The dynamic nature of the changing Earth also requires a geodetic reference that can keep track of these changes. A local and static datum such as PRS92 hampers monitoring and responding to these global events.

In addition to climate studies, international standards on civil aviation and navigation also call for the use of a Global Geodetic Reference Frame (GGRF) to ensure the safe passage of people and goods from one territory to another. Continuing to adopt a local datum would mean having to deal with discontinuities between aeronautical and navigational data, and land datasets such as topographic maps and land thematic data.

- ***Emerging trends in global geodetic reference frames***

As early as 1990, the *Fédération Internationale des Géomètres* (International Federation of Surveyors) recommended the adoption of a global geodetic reference, instead of a local datum like PRS92. The importance of global geodetic reference frames (GGRFs) is further highlighted with the passage of the United

Nations General Assembly Resolution 69/266, which calls for Member States to adopt and contribute to the development of a GGRF to underpin sustainable development.

Most, if not all countries have already aligned, or are in the process of transitioning from their local and static geodetic reference to a GGRF. The International Terrestrial Reference Frame (the realization of the International Terrestrial Reference System) is the most accurate GGRF available today, being realized by a combination of four space geodetic techniques namely GNSS, VLBI, SLR, and DORIS. Throughout the years, different ITRF realizations have been published, the latest being ITRF2014. The differences in the coordinates between realizations are attributed mainly to geophysical effects and more data availability. To date, the ITRF is used as the basis for other global and regional reference frames such as WGS84 and the Asia Pacific Reference Frame (APREF). It is also used as the foundation for a wide array of applications such as navigation, timing, surveying, and crustal deformation studies, to name a few.

- ***Increasing utilization of global navigation satellite systems and other global geospatial information and services***

The 2019 GNSS Market Report from the European GNSS Agency (GSA) forecasts that by the end of this decade, GNSS receiver shipments will have grown to 2.8 billion units from 1.8 billion in 2019, with 90% of these being used for smartphones and wearables to access location-based services.

In addition, the emergence of web GIS and the proliferation of freely available geospatial products and services like Google Earth have reiterated the need to upgrade PRS92. Position measurements in the local datum are generally off from a geocentric frame by 150 to 250 meters. With the increasing utilization of GNSS

and its derived products, it is but logical to adopt a geodetic datum that is compatible with the system so that end users can readily access geospatial information and services, without having to go through complex transformation procedures.

The PGRS Modernization Plan, Progress, and Way Forward

With the drivers in mind, NAMRIA pushed forth the proposal to develop a modern PGRS that will provide access to an authoritative and globally consistent geodetic reference that will be the foundation for attaining the country's sustainable development goals. The strategies drafted primarily aim to:

- Strengthen and upgrade the geodetic infrastructure through full utilization of modern positioning technologies such as GNSS,
- Establish the ICT mechanism to support FAIR (findable, accessible, interoperable, reusable) geodetic reference data, and
- Develop competent and informed PGRS stakeholders.

In a nutshell, the modern PGRS is envisioned to be:

- A semi-dynamic geocentric datum (Philippine Geocentric Datum of 2020, PGD2020) with a reference epoch of 16 January 2020 for geometric positioning that is aligned with a global geodetic reference frame and realized by a nationwide network of active geodetic stations and unified control points. PGD2020 comes with a national deformation model to account for geodynamics, as well as a distortion grid relating the existing datums in use to PGD2020.
- A unified vertical datum (Philippine Geodetic Vertical Datum of 2020, PGVD2020) that is consistent throughout the archipelago and connected to the World Height System. It also comes with a national geoid model (Philippine Geoid Model) relating GNSS-derived ellipsoidal heights to orthometric (mean sea level) heights.

This modern PGRS is programmed to be realized, maintained, and utilized by competent stakeholders with a good understanding of 4D geodetic reference frames.

Since the formal launching of the PGRS Modernization in 2017, a significant progress has been made in all its components:

- Philippine Geocentric Datum 2020
 - Densified the PAGeNet to 55 active geodetic stations nationwide
 - Is aligned with the ITRF/Computed PGD2020 reference coordinates
 - Completed 1st cycle of passive GCP re-observation to update the coordinates
 - Developed a national deformation model
 - Pilot tested the generation of a distortion grid in NCR and Region III
- Philippine Geodetic Vertical Datum 2020
 - Ongoing refinement and validation of the Philippine Geoid Model
 - Interisland benchmarks connected
 - Ongoing troubleshooting of the level network
 - Densified land gravity observations

The modernization of the PGRS is an arduous task, fraught with not only technical but also legal issues. To help address some of these issues, NAMRIA partnered with the University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) to explore the most suitable transformation strategy for migrating to the new datum and study its impact on the cadaster. It also tapped a post-graduate student from the University of New South Wales (Australia) to work on the methodology for connecting the country's vertical datum to the World Height System.

The agency continues to invest in capacity-building measures to equip its technical personnel with the needed skills in geodetic reference frame development. It commissioned the services of ThinkSpatial in Australia for training on the use of the scientific

software Bernese GNSS Software, and partnered with Ordnance Survey International for the optimization of the PAgNet. A series of trainings on deformation modeling were likewise conducted with experts from Newcastle University (United Kingdom) and Otago University (New Zealand).

Through its active participation in various international fora on geodesy, NAMRIA was able to build up its network among the global geodetic community, which contributed significantly to its modernization initiative. Its participation in the Reference Frame in Practice technical seminar series organized by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) led to the cooperation with Denmark Technical University and the US National Geospatial Intelligence Agency for the conduct of the nationwide aerial gravity survey and the development of the Philippine Geoid Model.

Much remains to be done. With the transition to the modern PGRS, there is a need to update land survey regulations, especially on geodetic control networks, to make them compliant with international standards. The development of a web portal where the end-user community may access these modern PGRS products and services should also be in the pipeline to promote user acceptance. The capacity building in geodesy and modern reference frames, be it within the halls of academic institutions or through localized IEC campaigns, is a must to encourage advocacy among stakeholders. Working with other government agencies to promote GNSS use and data sharing is also recommended to streamline government resources and improve productivity.

The country's transition to a modern PGRS is inevitable and it is the next logical step for it to take if it wants to effectively respond to the needs of changing times. As a new decade is ushered in, NAMRIA remains committed to providing the government and the public with accurate, reliable, and up-to-date geodetic products and services to help achieve the country's sustainable development goals. •

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The Philippine Geocentric Datum of 2020 (PGD2020): A Dynamic Reference Frame for a Modern Philippines

by: Engr. Charisma Victoria D. Cayapan and Engr. Ma. Almalyn A. Balladares

When the Philippine Reference System of 1992 (PRS92) was developed in the 1990s, the experts behind its realization recommended the adoption of a geocentric datum and considered the effect of geodynamics in the geodetic reference frame. The emerging global issues in the following decades such as climate change, advancing geodetic technologies, and increasing vulnerabilities to natural and man-made hazards, to name a few, further highlighted the need for a datum, accurate and dynamic enough, to meet the requirements of these developments.

Historically, geometric positioning in the country has been referred to the legacy Luzon 1911 datum or to PRS92 and its corresponding 1987 version of the World Geodetic Reference System 1984 (WGS84). PRS92, established based on surveys conducted in 1989-1991 using Global Positioning System (GPS) technology, is commonly referred to as the modified Luzon datum since it retained most of the old datum parameters (except for the geoid-spheroid separation) to minimize changes in coordinates (see Table 1.)

About the Photo: Using GNSS in establishing geodetic controls to help in the rehabilitation efforts in Marawi City (Data from the GNSS survey was used to control the unmanned aerial vehicle [UAV] mapping of the Most Affected Area [MAA] of the city.)

Parameter	Value
Reference Ellipsoid	Clarke Spheroid of 1866
Origin	Station Balanacan (Mogpog, Marinduque)
Latitude	13° 33' 41.000" N
Longitude	121° 52' 03.000" E
Reference azimuth (from south)	9° 12' 37.000" (Sta. Balanacan to Sta. Baltasar)
Geoid-spheroid separation	0.34 m (originally set to 0 m)

Table 1. PRS92 datum parameters

A local definition of WGS84 (1987) was used to facilitate the processing of the GPS baselines and adjustment of the network. The local definition of the WGS84 is estimated to approximate WGS84 (1987) to within six meters in latitude, longitude, and height (Jones, 1991). To relate the WGS84 to the modified Luzon Datum (PRS92), a set of transformation parameters was developed using 29 common stations.

The Modernization of the Philippine Geodetic Reference System (PGRS) Strategic Plan 2016–2020 identified the migration to a geocentric and (semi) dynamic datum as vital towards achieving the country's sustainable development goals. Named the Philippine Geocentric Datum of 2020 (PGD2020), this datum is envisioned to replace PRS92 as the standard reference for geometric positioning in the country, and will also be aligned with a global geodetic reference frame (GGRF) being recommended by the United Nations General Assembly through Resolution A/Res 69/266 "A Global Geodetic Reference Frame for Sustainable Development." PGD2020 is aligned with the International Terrestrial Reference Frame at reference epoch 16 January 2020 (2020.044). It comes with

a national deformation model that can be used to incorporate the effects of geodynamics to position measurements, and a distortion grid to facilitate the integration of various adjustments of existing datums to the new system.

ITRF: The Most Accurate GGRF

The PGD2020 is designed to be constrained to the International Terrestrial Reference Frame (ITRF). The ITRF is the most accurate realization of the International Terrestrial Reference System (ITRS), and it is maintained by the International Earth Rotation Service (IERS) through a global network of ground stations. It uses a combination of four space geodetic techniques namely, VLBI, SLR, DORIS, and GNSS in order to provide terrestrial coordinates to the highest possible accuracy. Figure 1 shows ground networks of the four space geodetic techniques contributing to the ITRF2014 realizations. The ITRF has gone through different realizations throughout the years, with each newer version providing better accuracies owing to a better modeling of geophysical processes and increasing number of stations contributing to its realization.

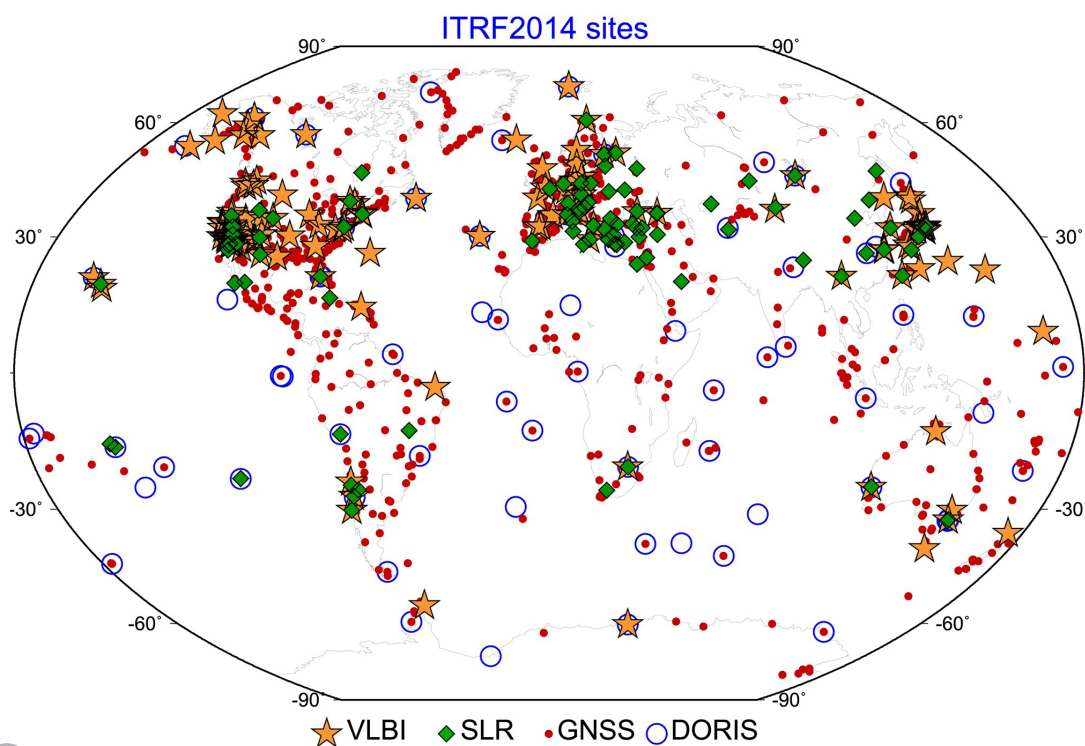


Figure 1. Ground networks of the four space geodetic techniques contributing to the ITRF2014 realizations

The latest version, ITRF2014, for example, includes enhanced modeling of nonlinear station motions and a post-seismic deformation model for stations that have experienced large earthquakes.

ITRF solutions are provided in Cartesian ECEF (Earth-Centered, Earth-Fixed) equatorial coordinates X, Y, and Z. To transform to geographic coordinates, the XVII General Assembly of the International Union of Geodesy and Geophysics (IUGG) recommends the use of the Geodetic Reference System 1980 (GRS80) ellipsoid with the following parameters: semi-major axis $a=6378137.0$ m, flattening= $1/298.257222101$.

Connections to the ITRF may be done through the use of the International GNSS Service (IGS) products which are typically referred to the ITRF. Reference station data, coordinates and velocities, as well as precise orbits and clock synchronization products are all downloadable from the IGS website and its associated data centers.

Aligning with the ITRF

PAGeNet: The Link to the World

The alignment of the country's geodetic reference frame to the ITRF is anchored on the Philippine Active Geodetic Network (PAGeNet), the network of continuously operating reference stations established by NAMRIA in 2008. To date, PAGeNet is comprised of 55 active geodetic stations (AGS) installed in strategic locations nationwide (see Figure 2). Three sites (site IDs PTAG, PPPC, and PGEN) are part of the IGS global network of tracking stations to improve precise orbit determination and clock synchronization. Each station is equipped with high-end geodetic reference station equipment gathering multiconstellation GNSS data.

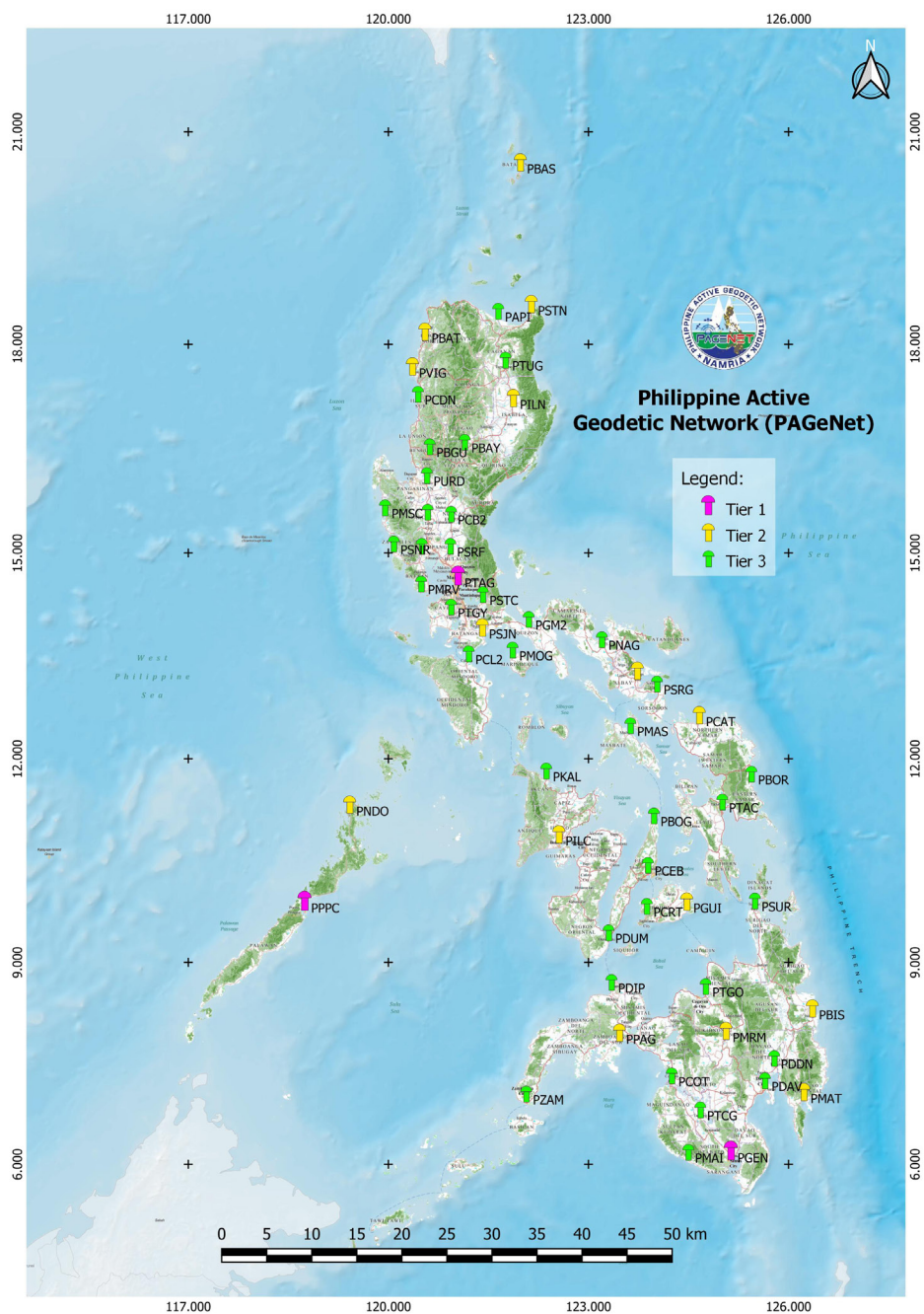


Figure 2. Locations of PAGeNet stations

The establishment of the network was envisioned to usher in the modernization of surveying and mapping in the country. With the PAGeNet, surveyors get access to highly precise, post-processed, and real-time correction services via the internet. The availability of geodetic reference station data ramps up productivity of surveying operations, thus paving the way for streamlined and smarter organizations. With over 11 years of GNSS data available, the PAGeNet provides the most stable and accurate means to connect to the ITRF.

Computing the PGD2020 Reference Coordinates

The PGD2020 reference coordinates are based on the monthly solution of the PAGeNet for January 2020. The daily solutions for that month were combined to get the final Cartesian and geodetic coordinates in ITRF2014 at the mean epoch 2020.044. To constrain the solution to ITRF2014, 17 IGS sites located around the archipelago were identified (see Figure 3).

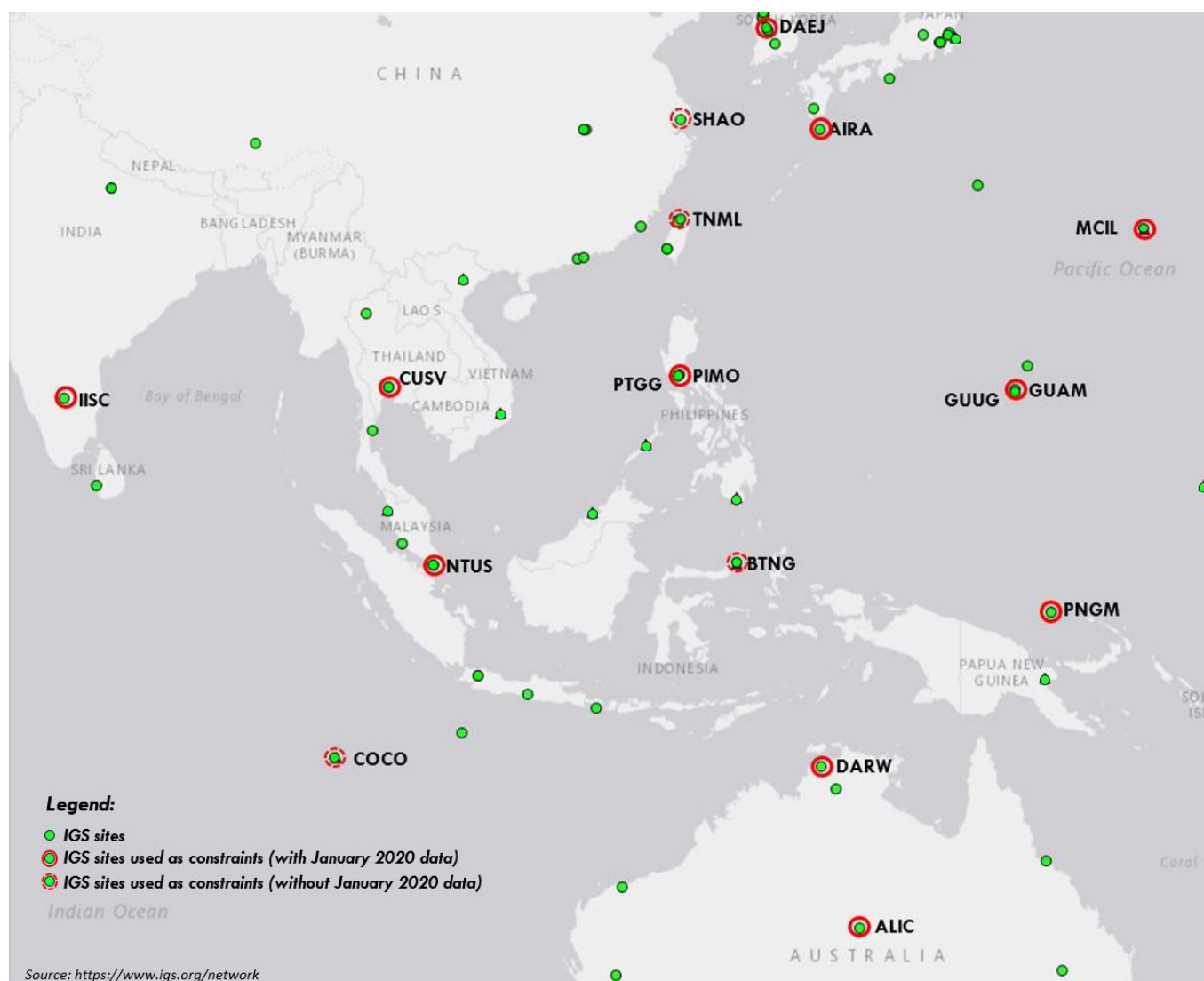


Figure 3. IGS stations around the Philippines

Of the 55 AGS, only 40 stations have data completeness above 50% for the month of January 2020. For the 10 stations with below 50% data completeness, their PGD2020 coordinates were based on the next best available 2019 monthly data and projected to the reference epoch using the station's estimated velocities. Two stations (PAPI and PILN) were not included in the computation as they had no data for January and their coordinate time series is not enough to provide a reliable velocity estimate. For PTGY (Tagaytay City) and PSJN (San Juan, Batangas), only the data after 12 January 2020 were used in the computation as the pre- and post-Taal eruption daily solutions were not consistent (PTGY displacement = 0.445 m from 11 to 13 January 2020).

The processing strategy adopted as depicted in Figure 4 followed the standards set forth in the IERS Conventions (2010). Bernese GNSS Software V5.2, a scientific, high-precision, multi-GNSS data processing software developed by Astronomical Institute of the University of Bern (AIUB), was used in processing. Table 2 shows the processing parameters for Bernese GNSS software V5.2.

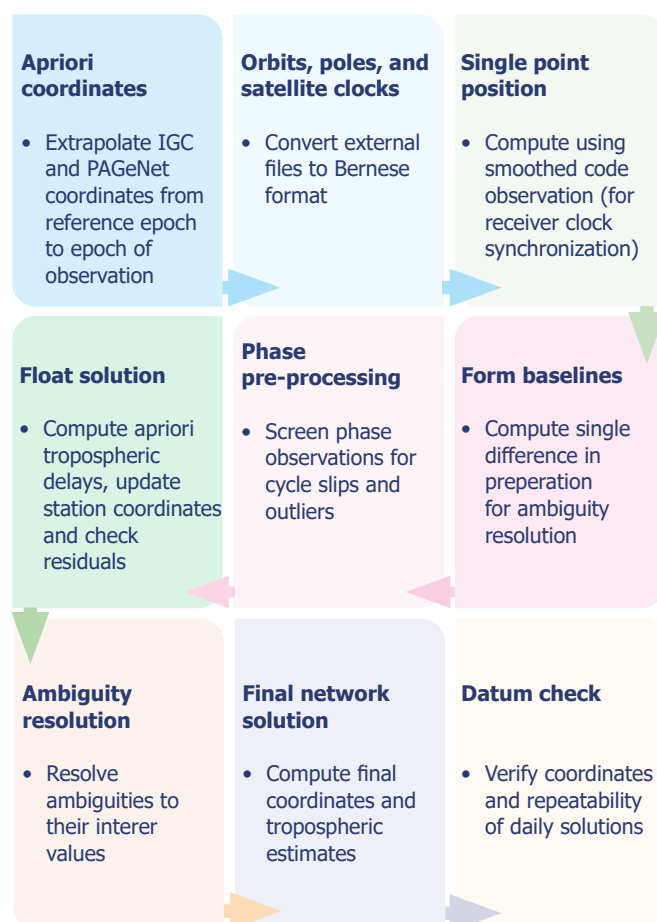


Figure 4. Bernese processing workflow

Processing Parameters	
Observables	GPS only (30s logging interval at 3° elevation mask)
Reference Frame	ITRF2014 at mean epoch of observations (2020.044)
Pre-processing	Phase-preprocessing to screen out cycle slips, outliers, and short observation data
Adjustment	Weighted least squares
Antenna phase center calibration	IGS14 absolute antenna phase center variation model
Satellite orbits, Earth orientation parameters, and clock	IGS final products
Ocean tide loading model	FES2004
Atmospheric tidal loading	Ray and Ponte (2003)
Plate motion model	NUVEL-1A no-net-rotation (NNR)
Troposphere	A priori troposphere model using Dry Global Mapping Function; for wet component, zenith path delays estimated using wet GMF estimated at 2-hr intervals and horizontal gradient with CHENHER at 24-hr interval
Ionosphere	Iono-free linear combination for 1st order effects, and ionosphere model for higher-order
Ambiguity resolution	Multi-step ambiguity resolution based on baseline length: Melbourne-Wubena (<6,000 km), widelane and narrow lane AR (<200 km), Quasi Iono-spheric-Free AR (<2,000 km), and Direct L1, L2 AR (<20 km)

Table 2. Processing parameters for Bernese

	PRS92 to PGD2020	WGS84(1987) to PGD2020
Translation (X)	-124.47672 ± 0.21247 m	3.14301 ± 0.21282 m
Translation (Y)	-69.44938 ± 0.17345 m	-2.20823 ± 0.17373 m
Adjustment	-40.46850 ± 0.13473 m	6.57907 ± 0.13496 m
Rotation (X)	3.137706 ± 0.004687 "	0.069745 ± 0.004695 "
Rotation (Y)	-4.869823 ± 0.003039 "	0.033146 ± 0.003044 "
Rotation (Z)	-1.600408 ± 0.008176 "	-0.022323 ± 0.008189 "
Scale	-1.01029 ± 0.01438 ppm	0.04465 ± 0.01440 ppm
RMS	0.03985 m	0.03991 m

Table 3. Preliminary transformation parameters

For comparing individual daily solutions, a maximum RMSE of 10 mm (for North and East components) and 20 mm (for Up component) was applied. A 3-parameter Helmert transformation is also computed to check the fit of the daily solution with the surrounding IGS reference stations.

The PGD2020 reference coordinates are collectively a combination of adjusted and projected coordinates using the best available data from the PAGeNet. Results show that the final station coordinates have repeatability root mean square of 2.51 mm, 2.94 mm, and 6.65 mm for N, E, U components, respectively. To relate the PGD2020 to the existing datums in use, preliminary sets of transformation parameters, as shown in Table 3 were derived to facilitate the moving to and from the new datum. The validation of the initial set of parameters shows that the transformation has a 2D accuracy of 6.15 cm.

Dealing with Geodynamics in the Reference Frame

A distinguishing characteristic of modern reference systems is their capability to handle geodynamics in the reference frame. The Philippines is located in a complex boundary zone with the converging movement of the northwest-bound Philippine Sea Plate on the east and the Sundaland Plate on the west creating an active tectonic deformation zone. These motions invariably affect the integrity of the reference frame, and one way to account for these is to develop a deformation model that can be used to move backward and forward in time and still arrive at an accurate position.

Using the following site trajectory model determines how dynamic reference frames deal with transient site motions, as shown in Equation 1.

$$x(t) = x_0 + v(t - t_0) + \sum_i \delta_i + \sum_n a_n \cos\{\omega_n(t - t_n)\} + b_n \sin\{\omega_n(t - t_n)\} + \sum_j A_j \log\left(1 + \frac{t - t_j}{\tau_j}\right) + \sum_k B_k (1 - e^{-\frac{t - t_k}{\tau_k}})$$

Equation 1. The site trajectory equation

where x_0 and v are the station's initial position and velocity, respectively, δ_i are offsets due to equipment changes, earthquakes, etc., while the fourth and fifth terms are the annual and semi-annual harmonic

motions, and the last two terms are the logarithmic and/or exponential post-seismic motions.

To generate the national deformation model, velocity measurements were sourced from NAMRIA's PAGeNet and geodetic control points re-observation data, published velocity vectors from Hsu, et. al. (2016) and Kreemer, et. al. (2014), and from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) which also maintains continuous stations and campaign sites nationwide for crustal deformation monitoring.

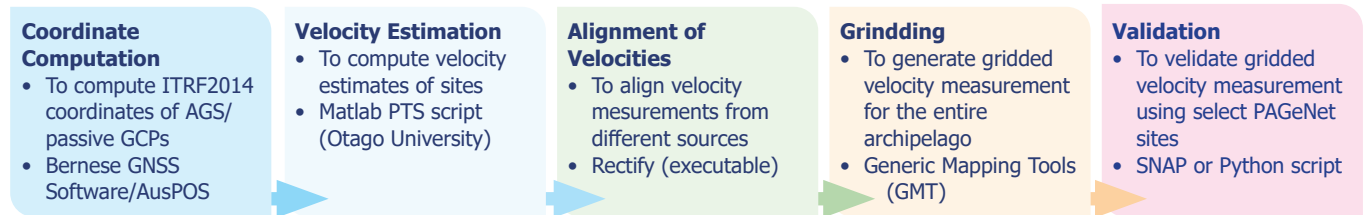


Figure 5. Deformation modeling workflow

Figure 5 provides a summary of the deformation modeling workflow. For the latest version of the deformation model, all available data from PAGeNet stations were used, from when they were first established up to 31 December 2019. The site velocities of the stations were estimated using the daily coordinate solutions from the Bernese processing as input to the site trajectory equation above. Major earthquake events, such as the 2017 M6.7 Surigao and the 2019

M6.1 Central Luzon earthquakes, were marked on the station's coordinate time series (see Figure 6), including other sources of offsets like equipment changes, so that only the site's secular velocity remains (see Figure 7).

Given that velocity measurements came from different sources, each with its own reference frame and estimation methodologies, the vectors were first aligned to ensure that the velocities were all consistently

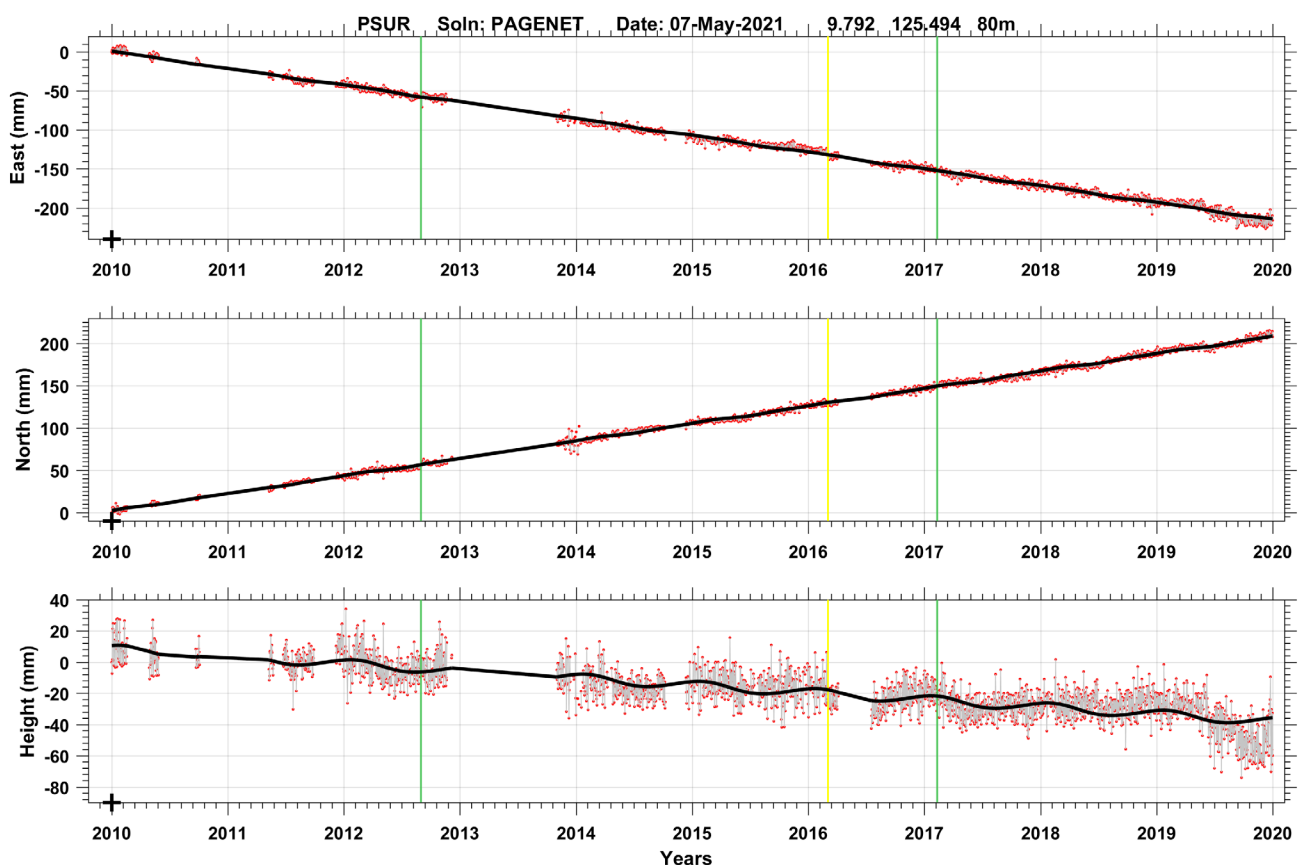
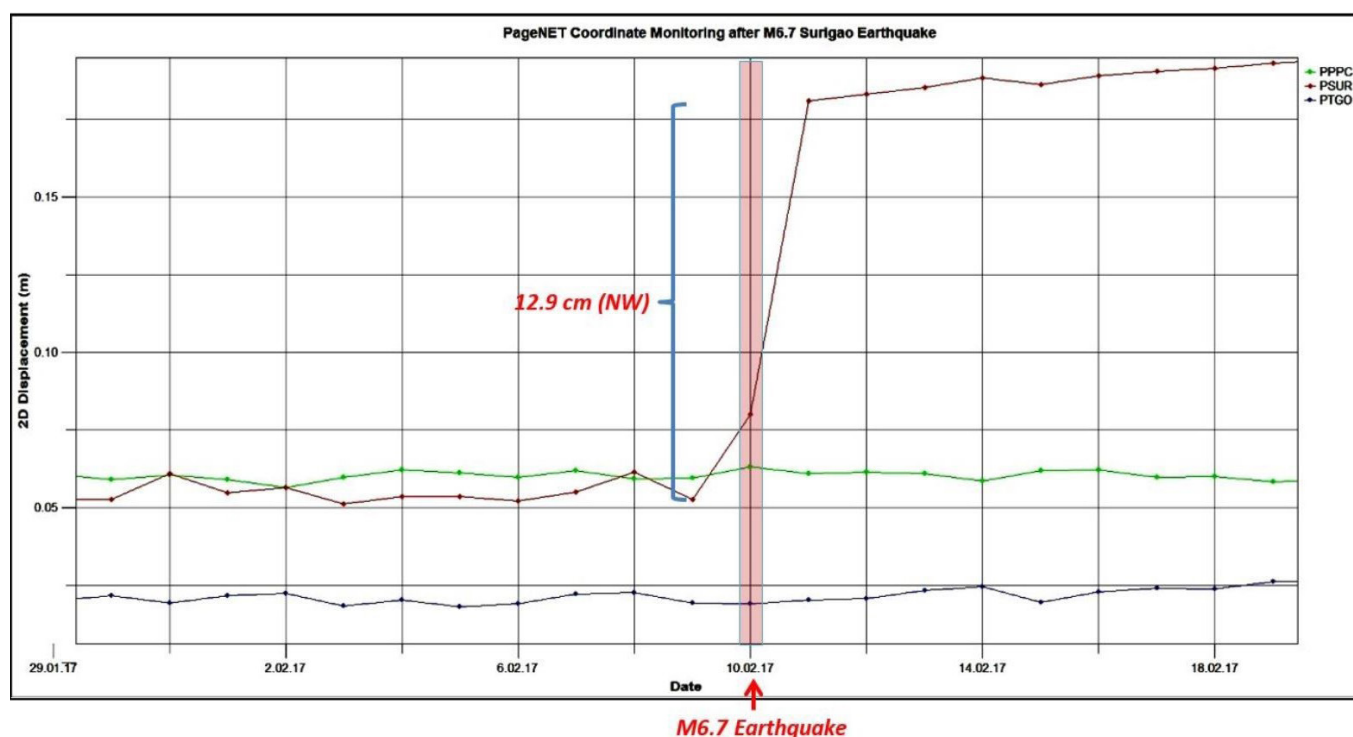


Figure 6. Coordinate time series showing the secular velocities



in one frame prior to interpolation and gridding. External constraints from Kreemer et. al. (for the east and west bounds of the archipelago) and Yong (Sulu Sea region) were also applied to improve gridding of velocities along the boundaries where measurements were sparse.

The secular velocity field generated, as shown in Figure 8, covered 115° E to 127° E in longitude and 4° N to 21° N in latitude at 3" interval. Validation of the 2020 grid is currently ongoing, but it is expected to be an improvement over the 2019 version whose RMS are at 4.65 mm/yr and 3.58 mm/yr for the E and N components, respectively, because of longer time series used as input to the velocity estimation of PAgNet stations.

The deformation model still does not include patches for large earthquake events that happened in the past decade. To incorporate this in the model, one needs to have published dislocation models of the earthquakes, or conduct post-earthquake re-observation of controls with sufficient density to generate the deformation grids. Without these patches, one cannot use the pre-earthquake measurements for the national re-adjustment.

Accounting for Distortions in the Existing Datums

With the introduction of PGD2020, there is a need to transform coordinates to and from existing datums (i.e., PRS92 or Luzon 1911), to ensure the successful transition and integration of datasets into the new system. A similarity or conformal transformation is typically employed as this preserves the size and shape of objects. Complicating this process, however, is the presence of distortions in the existing control network which can degrade the accuracy of the transformation.

Whereas deformation deals more with positional displacement brought on by secular motion of crustal blocks, distortion is affected by the effects of geophysical processes on positions. It is also affected by the subsequent changes introduced to the control network. This is in the case of distortion, as the new stations are added to the network, as the network is propagated into the lower order control networks, or as new adjustment strategies are adopted. In the case of PRS92, from the 332 first-order, 17 second-order and 11 third-order passive geodetic control points (GCPs) originally comprising PRS92, the geodetic control network has been sporadically densified over the succeeding two decades by NAMRIA and the

DENR regional offices. The network now consists of 64,375 GCPs as of March 2021. There are two PRS92 coordinate sets available to date:

- the original National Resource Management and Development Project (NRMDP) coordinates, and
- the 2010 adjustment when the zero-order control network was established.

A third set of coordinates computed from the first cycle of GCP re-observation campaigns from 2015-2019 is also available, but this is primarily intended for the development and refinement of the deformation model and distortion grids.

To deal with these distortions, a localized transformation is sometimes done in addition to the datum transformation, since a 7-parameter similarity transformation is, at times, not sufficient particularly if regional distortions are inherent in the network. Such was the strategy implemented when Luzon 1911 cadastral datasets were integrated into PRS92. In some cases, a national grid of distortions is developed, which is a more consistent and easier alternative compared to localized transformation.

The process for generating the PGD2020 distortion grids generally follows the workflow provided in Figure 9.

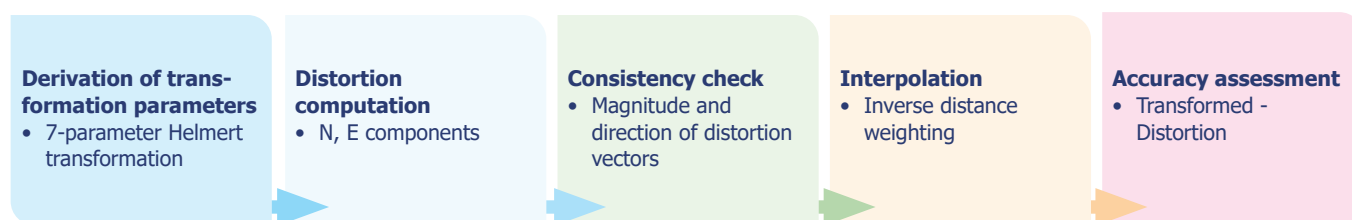


Figure 9. Distortion modeling workflow

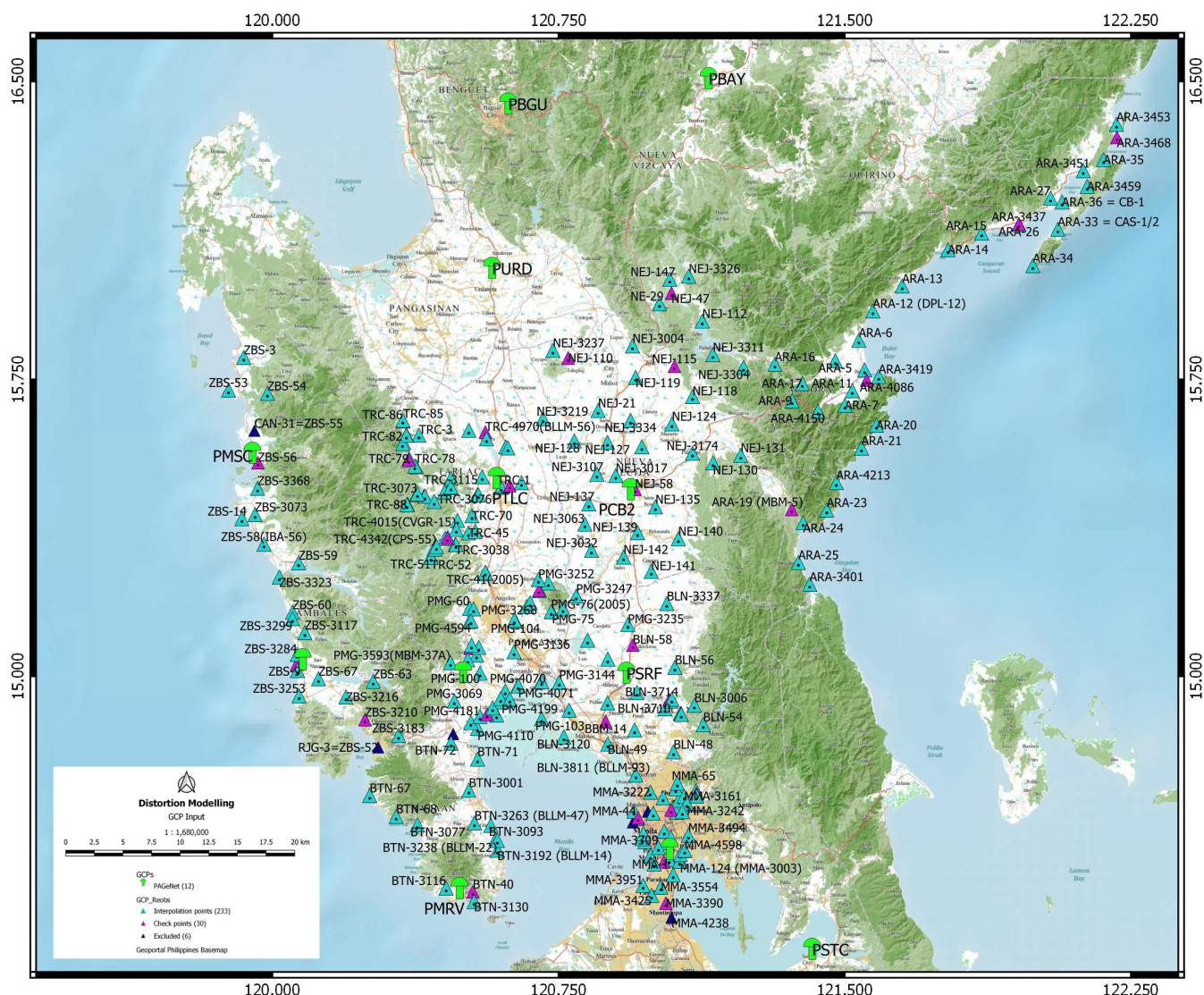
For the PRS92-PGD2020 distortion grids, three sets of coordinates are needed to compute the distortions:

- **PRS92 official** – published coordinates from the geodetic database
- **PGD2020 official** – based on the PGD2020 reference coordinates (January 2020 monthly solution of PAGeNet)
- **PGD2020 transformed** – transformed coordinates from a 7-parameter Helmert transformation (PRS92-PGD2020)

The distortion in the northing and easting components is the difference in meters between the PGD2020 official and transformed coordinates. A consistency check is done on the computed distortions

to filter out non-conforming vectors. The gridded distortions are generated using an inverse distance weighting interpolation, since it is assumed that the distortions are spatially auto correlated, meaning the distortion of a point will be affected by the distortions of its nearest neighbors, and that the influence reduces as the distance between the two points increases.

The same methodology was adopted in creating a prototype distortion model for the National Capital Region and Central Luzon, as shown in Figure 10. For this pilot test, a total of 281 points comprising PAGeNet AGS and re-observed GCPs, were used in the distortion computation. PRS92 and PGD2020 coordinates of 39 PAGeNet stations nationwide were used to derive the 7 transformation parameters. The PRS92 coordinates of the 281 points were then transformed to PGD2020 using the derived parameters.



As presented in Table 4, on the average, NCR had minimal 2D distortion at 6.9 cm (NE, NW direction). Non-conforming distortion vectors (both in magnitude and direction) were noticeably present in the province of Pampanga, which also posted the highest average distortions in Central Luzon. The distortions computed per province and their corresponding directions are shown below:

Figure 10. Inputs to the distortion modeling in NCR and Central Luzon

Province	Min	Max	Ave	StDev	Dir
NCR	0.006 m	0.132 m	0.069 m	0.031 m	NE, NW
Aurora	0.270 m	0.445 m	0.390 m	0.044 m	NW
Bataan	0.067 m	0.401 m	0.273 m	0.118 m	NE, NW
Bulacan	0.212 m	0.424 m	0.335 m	0.046 m	NW
N. Ecija	0.158 m	0.791 m	0.403 m	0.158 m	NE
Pampanga	0.345 m	1.160 m	0.611 m	0.284 m	NE
Tarlac	0.030 m	0.747 m	0.411 m	0.150 m	NE
Zambales	0.239 m	0.680 m	0.330 m	0.113 m	NE

Table 4. 2D distortions computed per province

Investigation into the non-conforming vectors eliminates geophysical causes, and points more to poor data quality and inconsistent reference coordinates used in the processing as the primary reasons for the inconsistent distortions.

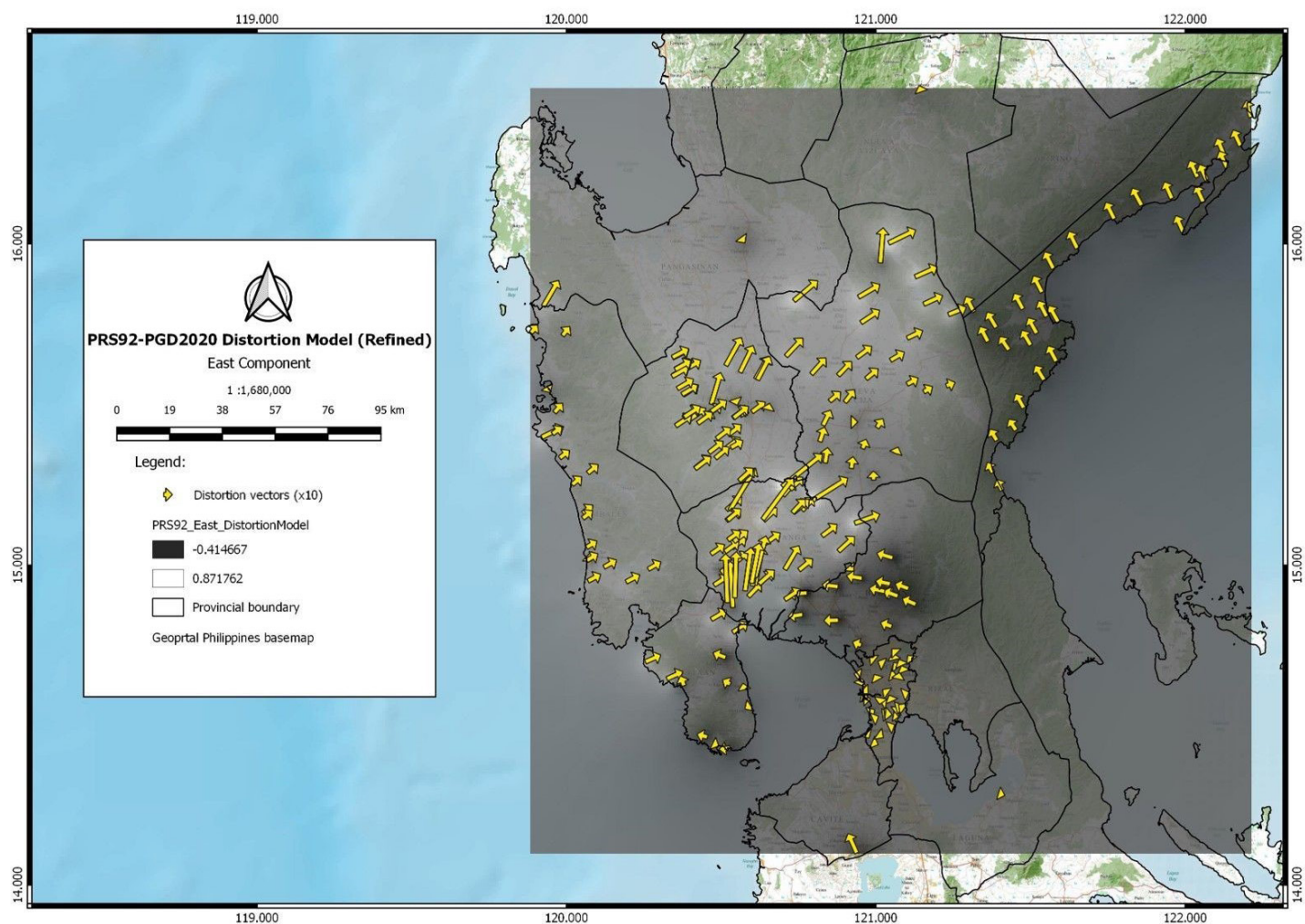
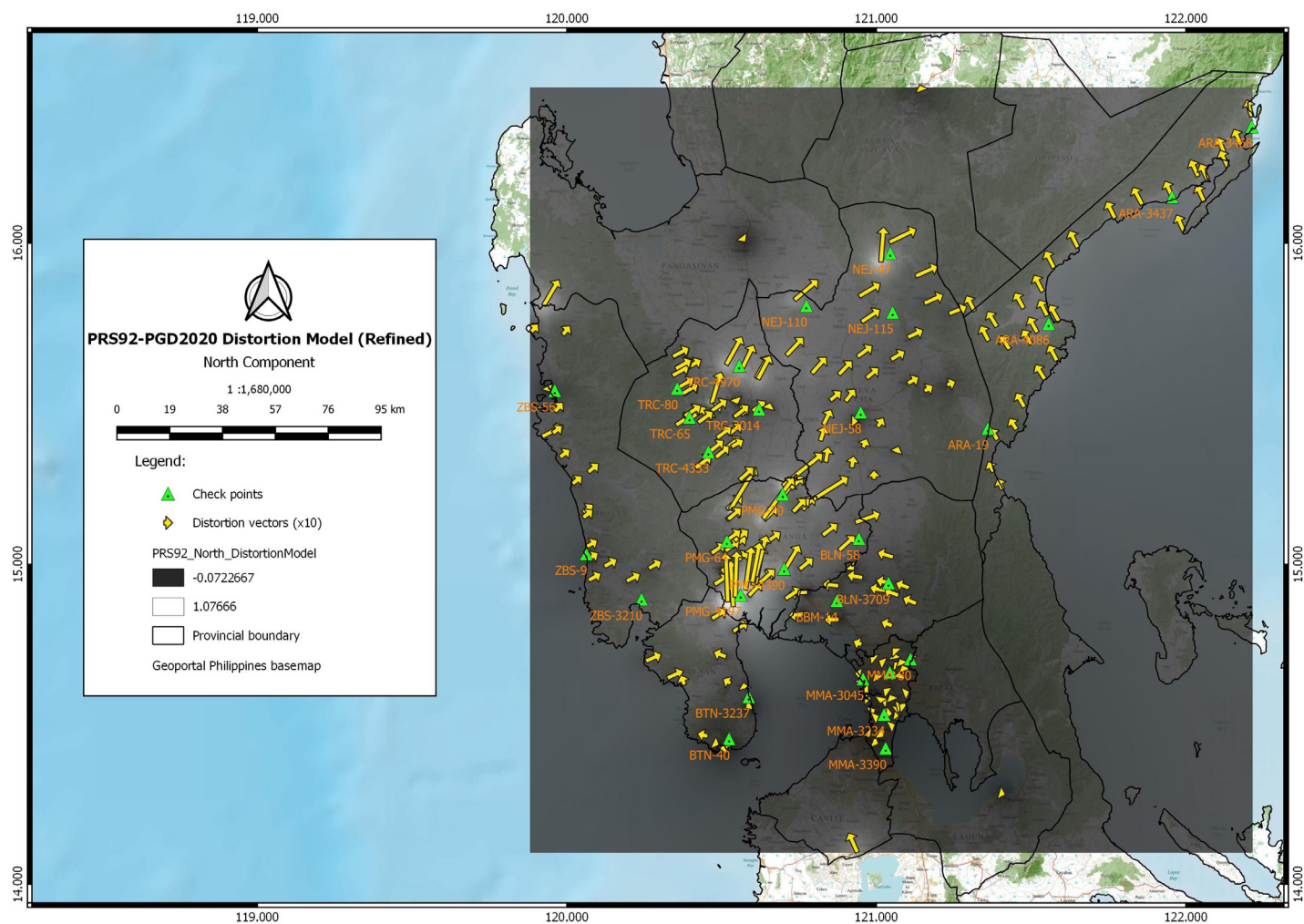


Figure 11. Distortions in the northing (top) and easting (bottom) components

The performance of the distortion model was assessed using preselected check points scattered over the pilot area. As shown in Figure 11, on the average, the model was within 0.03 m (in both northing and easting components) from the actual distortions computed on the check points. The distortions derived from the model were used to correct the PGD2020 transformed coordinates of the check points. Results show that the residuals improved after the distortions were removed from the data from 0.25 m and 0.06 m to 0.03 m in the north and east components, respectively.

Refining the Models: Passive GCP Re-observation

A key to the accuracy of the deformation model and distortion grid is the availability of control points evenly distributed throughout the archipelago, with a series of coordinate measurements to extract the site displacements and velocities. Continuously operating reference stations, like the PAgNet's AGS, are ideal for such monitoring. However, the current distribution of these stations is not dense enough for this purpose.

To supplement the data from the continuous sites, a re-observation of around 3,000 passive GCPs

throughout the country was conducted. By the end of 2020, the first of the three cycles of re-observation campaigns targeted for the refinement of the models were completed.

Of the 50 zero-order GCPs established in 2008-2010, only 35 GCPs were re-observed during the 2015 campaign. Comparing the results of the zero-order GCP re-observation campaign with the estimated velocities of the PAgNet stations, it can be seen that the estimated velocities from the re-observation are generally consistent with the velocities of the AGS nearest to the GCP, with most estimates falling within 1 cm.

The apparent velocity trends can also be observed when the GCPs are clustered based on the major tectonic boundaries and active mobile microblocks as defined by Rangin, et. al. GCPs in the Luzon Block, particularly its northern part, and the East Philippine Sliver, largely trend northwest and move at a faster rate compared to the rest of the archipelago (see Figure 12). Based on Table 5, the GCPs in the Visayas Block showed the slowest velocities, which is to be expected as they are caught between the northwest moving EPS and the southeast trending Sunda Plate, which the island of Palawan is a part of.

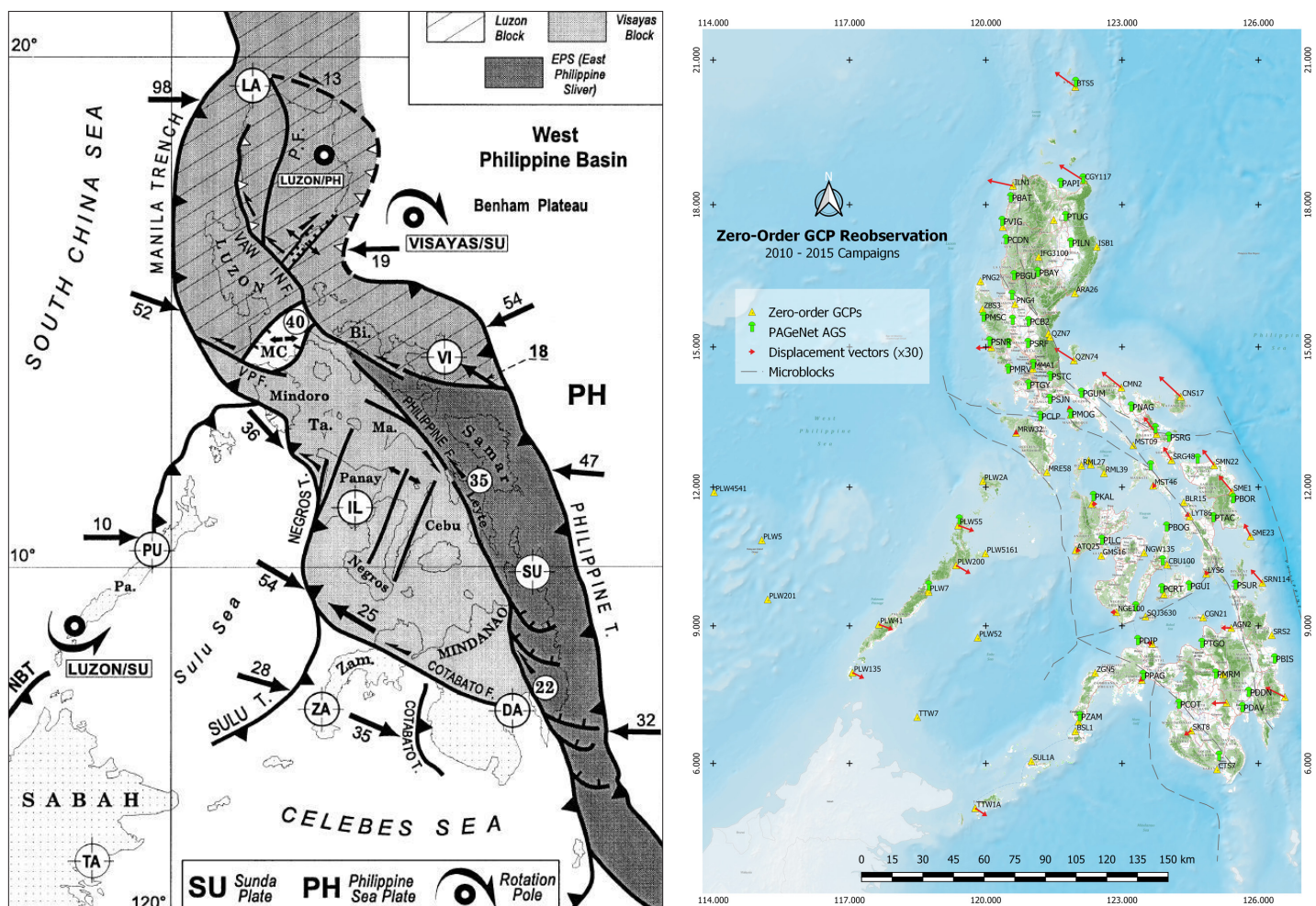


Figure 12. Active microblocks in the Philippines (left) and ITRF2014 displacement vectors of zero-order GCPs (right)

Microblocks	Average Veloceties (ITRF14)					Difference	
	Passive GCPs		Nearest PAGeNet AGS				
	Rate (mm/yr)	Dir	Distance (km)	Rate (mm/yr)	Dir	Rate (mm/yr)	Dir
Luzon Block							
Northeast Luzon	51	NW	1-7	57	NW	6	✓
Northwest Luzon	49	NW	40	51	NW	2	✓
Central Luzon	27	SW	5	28	SW	1	✓
Bicol	43	NW	62-125	41	NW	-2	✓
Visayas Block							
Southern Luzon	11	NW/SE	8-66	10	NW	-1	✗
Western Visayas	8	NE/SE/SW	8-66	5	NW	NE/SE/SW	✗
Central Mindanao	17	NW/SW	35-86	18	NW/SW	1	✓
East Philippine Sliver							
Bicol	30	NW	4-48	39	NW	9	✓
Eastern Visayas	30	NW	27-99	35	NW	5	✓
Eastern Mindanao	33	NW	68-87	34	NW	1	✓
Southern Mindanao Block							
	16	SW	62	18	SW	2	✓
Western Mindanao Block							
	16	SE	3-330	17	SE/SW	1	✗
Palawan/Sundaland							
	28	SE	3-330	28	SE	0	✓

Table 5. Computed ITRF2014 velocities of re-observed zero-order GCPs clustered per microblock

A re-observation of lower-order control GCPs, as reflected in Table 6, showed that the two PRS92 coordinate sets, i.e., original NRMDP and the 2010 adjustment, had different displacement trends (see Figure 13). For the 2010 adjustment (see Figure 14), the displacements tend to increase the farther the GCPs are from MMA-1 (or PTAG) in Taguig City. This is because MMA-1 was the basis for the PRS92 coordinates of PTAG, which was then held fixed in the succeeding adjustments of other AGS and the zero-order control network. This coordinate set became the basis for the 2010 adjustment of PRS92.

For the original NRMDP coordinate set, the displacements showed the distortion introduced by succeeding network adjustments as more control points are added to the network. For the GCPs in Central Visayas, for example, control points established after 2010 had the highest displacements (see yellow vectors in Figure 14). Investigation must be conducted to verify the quality of the controls used and confirm the results of the processing.

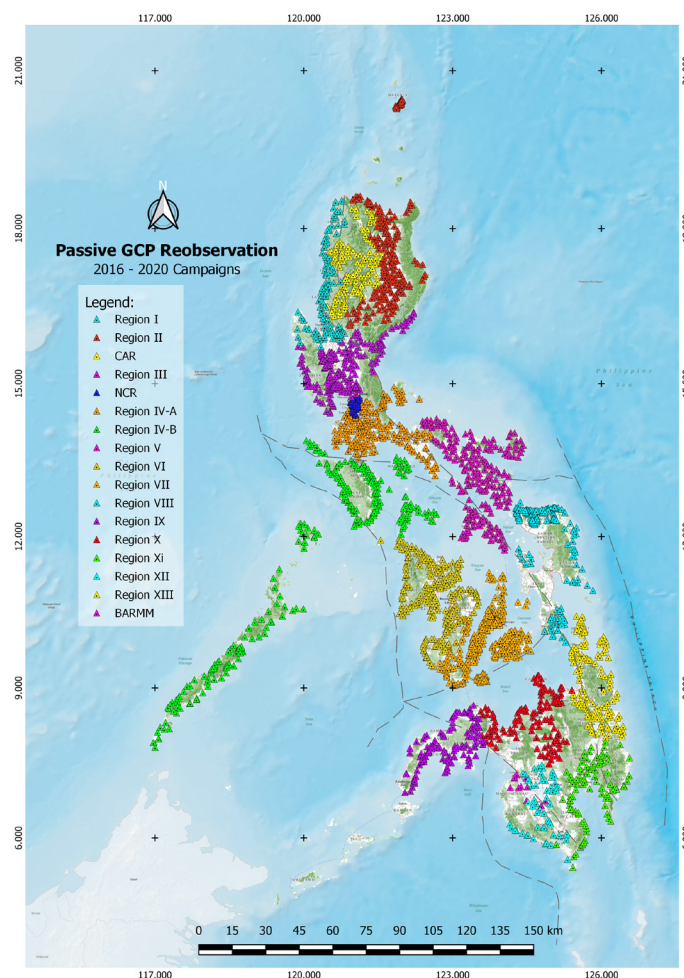


Figure 13. Re-observed lower-order GCPs

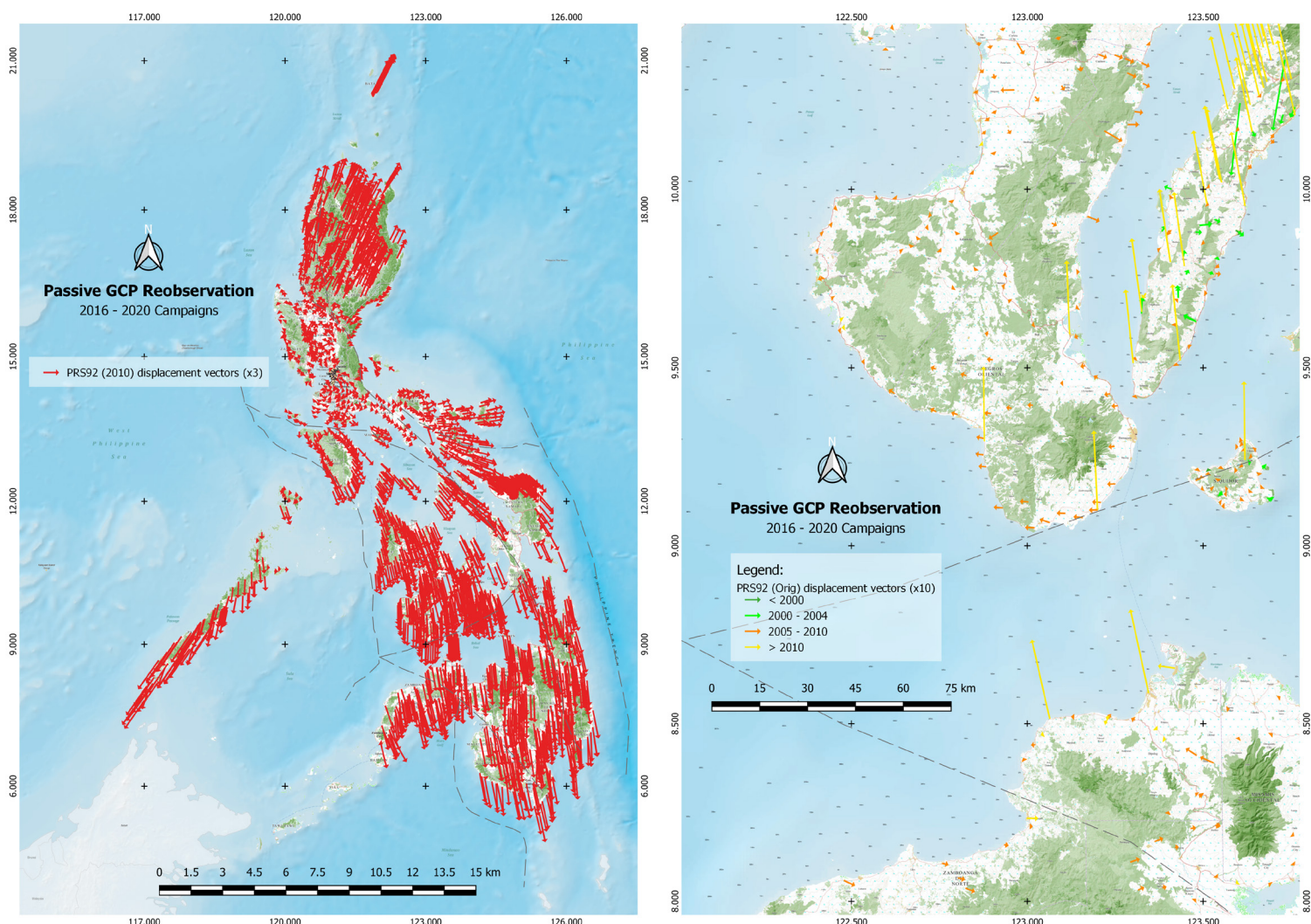


Figure 14. Re-observed lower-order GCPs and displacement vectors for PRS92 (2010) and PRS92 (original) coordinate sets (left and right, respectively)

Average 2D Displacement (m)					
Region	PRS92 (2010 adjustment)	PRS92 (original)			
		<2000	2000-2005	2005-2010	>2010
I	1.063	0.014	0.440	0.181	0.177
II	2.322	0.092	-	0.017	0.021
CAR	1.607	0.204	-	0.260	0.203
III	0.437	0.175	0.210	0.258	0.257
NCR	0.084	0.000	0.139	0.067	0.061
IV-A	0.350	0.091	0.099	0.109	0.126
IV-B	1.484	0.029	0.187	0.411	0.849
V	1.406	0.000	0.000	0.157	0.201
VI	2.078	0.018	0.275	0.110	0.105
VII	2.137	0.273	0.650	0.222	2.239
VIII	1.722	0.325	-	0.333	0.0677
IX	2.446	0.189	-	0.181	0.508
X	2.717	0.031	0.107	0.066	0.398
XI	2.863	0.000	0.000	0.248	0.997
XII	2.976	0.078	-	0.183	1.104
XIII	2.593	0.012	0.226	0.128	0.792
BARMM	3.190	-	-	0.000	0.074

Table 6. Computed displacements from re-observation of lower-order GCPs

The foundations for realizing a modern reference frame for geometric positioning in the country is now in place: a network of active geodetic stations providing real-time and precise positioning data to users, a deformation model with secular velocity fields to account for geodynamics in positioning, and the beginnings of a distortion grid to facilitate the integration of existing datasets to PGD2020.

Strengthening the geodetic infrastructure remains critical to maintain the accurate realization of PGD2020, especially given the geodynamic conditions in the country. The current density of active geodetic stations is still well below the 70-km spacing (~200 stations nationwide) targeted for the PAGeNet. NAMRIA needs to step up the rate at which it installs these stations, or explore other options such as partnerships with other government agencies to fill in the gaps in the network.

The re-observation campaigns of passive GCPs must be continued to complete at least two more cycles. Developing earthquake patches for large earthquake events must also be prioritized. These, together with data from the PAGeNet and the re-observation campaigns, will help ensure that the deformation model is accurate and up-to-date. Likewise, continuing the work on distortion modeling to cover the rest of the country is also vital to ensuring the seamless transition from existing datums to PGD2020.

Focus must also be given towards bringing these modern PGRS products to within reach of stakeholders. Having the deformation model and distortion grids incorporated into network adjustment software, or putting up a web portal for online positioning, will facilitate connecting to the PGD2020.

Computing the PGD2020 reference coordinates and developing the deformation model and distortion grids are just the beginning. But with the realization of the PGD2020, the country is one step closer towards an authoritative reference to underpin the country's sustainable development goals. •

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Philippine Geodetic Vertical Datum 2020 (PGVD2020)

by: Engr. Ronaldo C. Gatchalian

Vertical datum is a coordinate surface to which heights are referred (Vanicek, 1991). A vertical datum is defined by the selection of a height system and a reference surface. The most common type of height system is Orthometric Height H (with the geoid as its reference surface). It is defined as the length of the curved plumb line from a point P on the ground to its intersection with the geoid surface P_o (Amos, 2010). Physical height systems such as the orthometric system are based on geopotential numbers C with units of m^2/s^2 . Orthometric heights are computed using the formula:

$$H = \frac{C}{g}$$

with the \bar{g} as the mean value of gravity along the plumb line and C as the difference in potential from a reference equipotential surface W_o at the geoid to the potential at the point of interest W_p on the ground surface as illustrated in Figure 1.

About the Photo: The tide station in the City of San Fernando is collocated with a continuously operating GNSS reference station. Tide gauges (TG) measure the variations in sea levels relative to land, while the GNSS measures the movement of the land mass to which the tide gauge is attached to. Providing the tie between ellipsoidal height (GNSS) and orthometric heights (TG) is an integral component of modern height systems.

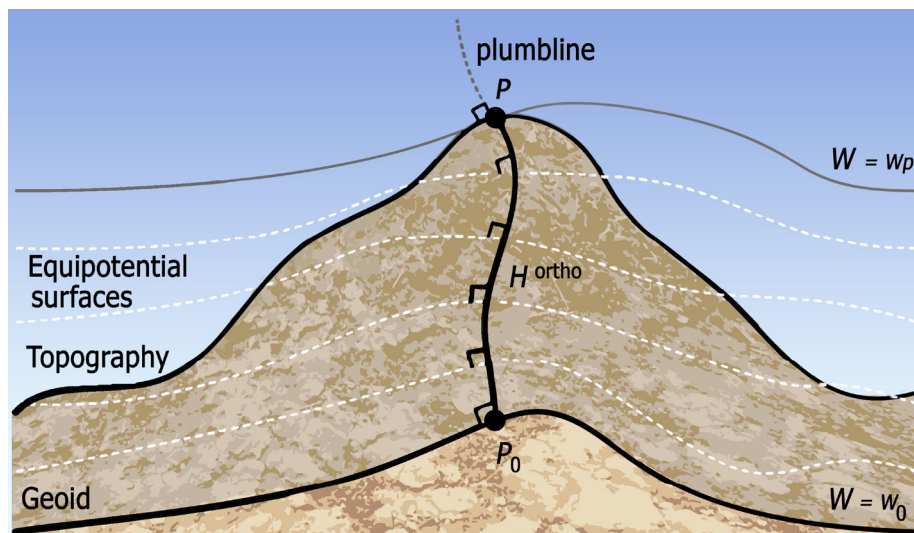


Figure 1. The curved plumb line of H and equipotential surfaces W_0 and W_p

Three values need to be determined to accurately compute the H : the mean gravity \bar{g} , the potential at the reference surface W_0 and the potential at the point of interest W_p . With these requirements, it is not feasible to compute the true H because:

- The exact path of the plumb line through the Earth and the gravitational acceleration at all points along the plumb line need to be known to compute the mean gravity (i.e., mass-density distribution through the topography), and
- Geopotentials W_0 and W_p cannot be directly observed.

An alternative to this is the use of Helmert-Orthometric Heights wherein the orthometric correction is applied to precise leveling but requires surface gravity observations at the points of interest. This height system is the most common type of approximate orthometric height in actual use.

The Philippines is currently using a height system of uncorrected spirit-leveled heights from different tide gauges of each main Island of the country. At present, there are 50 tide gauge stations that determine local mean sea level (LMSL) which ultimately becomes the reference surface of the Local Vertical Datum (LVD) of the area.

Therefore, the country's vertical datum can be defined as an uncorrected Helmert-Orthometric height system with the LMSL as the reference geopotential surface.

With the computation of the Philippine Geoid Model, the present height system can be replaced with an orthometric (H) one. The LMSLs would have to be

retained as the reference equipotential surface W_0 to preserve the existing vertical datum of the topographic maps. This vertical datum will be called Philippine Geodetic Vertical Datum 2020 (PGVD2020). The geopotential value of the reference surface W_0 will be computed (Jekeli, 2000) in the future to complete the PGVD2020 definition using the formula:

$$W_0 = U_{\bar{Q}} - \gamma_{\bar{Q}} (h_p - H_p - \frac{T_{\bar{P}}}{\gamma_{\bar{Q}}})$$

Consequently, the alignment of the PGVD2020 to the GGRF through its International Height Reference System (IHRF) will be done by computing the relationship of their potential values, i.e., $W_0 - W_{(pgvd)}$. The standard potential value W_0 of the IHRF vertical reference surface is 62,636,853.4 m^2/s^2 (JWG0.1.1, 2011-2015).

The topics in the next pages discuss the components of the PGVD2020. Geodetic leveling propagates the vertical control network that is referred to the LMSLs, while land gravity survey supplements the computation of the PGM. There is also a discussion on the making and validation of the PGM. •

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Geodetic Level Network of the Philippines

by Engr. Donnie T. Mancera

As horizontal networks were first developed, the vertical or level network usually gets secondary importance when it comes to geodesy. In Mathematics, to create three-dimensional models, the two dimensions (x and y) have to be established first before the third dimension (z), which is the vertical component. With this, having a reliable vertical network is as essential as having a well-developed horizontal network. A geodetic level network, which is the product of geodetic leveling is integral to many aspects of geodesy.

This article will adopt the following terminology definitions for *Leveling*, *Geodetic Leveling*, and the *Geodetic Level Network*. Leveling is the process of determining the differences in elevation or height between points on the Earth's surface. The measurements are usually referred to as the mean sea level (MSL). There are three leveling techniques namely, differential, trigonometric, and barometric.

Among the three, differential leveling is the most accurate. It is performed using two calibrated staff held in an upright position, in front, and behind the leveling instrument (see Figure 1). The difference in the reading equates to the difference in elevation between those points. Differential leveling uses a precise optical instrument called a *level*. The level has a compensator that automatically renders the line of sight horizontally.

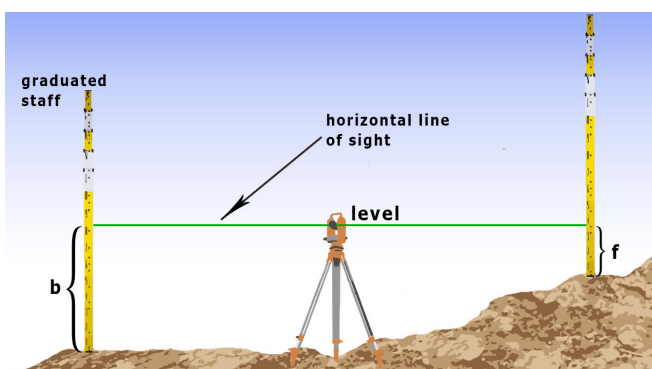


Figure 1. Differential leveling

Trigonometric leveling, as shown in Figure 2, uses vertical angles to measure the differences in elevation. It is usually done using a theodolite or a total station that can measure vertical angles between points. Trigonometric leveling is faster and more economical

when measuring elevations in small areas. However, this method is less accurate than differential leveling.

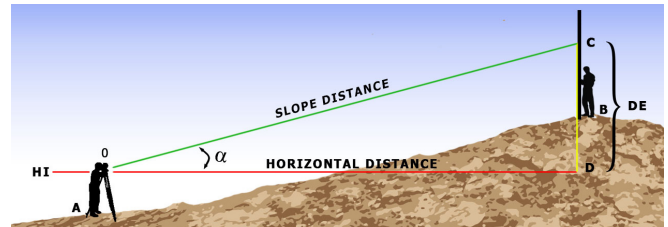


Figure 2. Trigonometric leveling

Barometric leveling determines the height differences in atmospheric pressure at various elevations (see Figure 3). It is a rapid and economical method of determining relative differences in height between a set of field stations. Aneroid or mercurial barometers are used to measure atmospheric pressures. Although cost-efficient, barometric leveling is the least precise leveling technique.

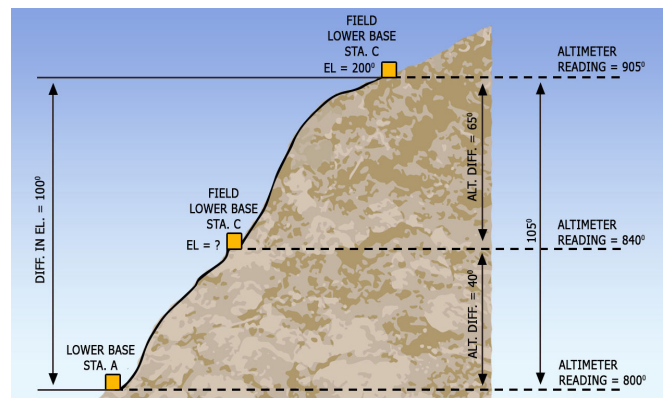


Figure 3. Barometric leveling

Geodetic leveling employs differential leveling. It is done with a high degree of accuracy extending over large areas. Geodetic leveling is performed to establish vertical controls for surveying and mapping operations. The Geodetic Level Network is the by-product of geodetic leveling. It is the level network that usually runs into hundreds or thousands of kilometers, and can found next to major thoroughfares such as highways or national roads (Berry, 1976). Figure 4 shows the geographic extent of geodetic leveling activities.

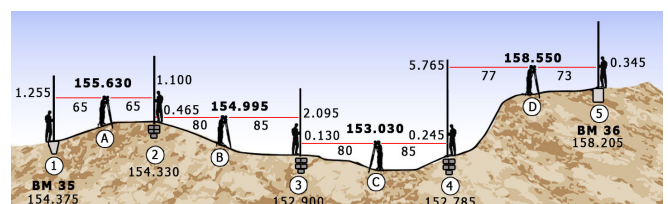


Figure 4. Geodetic leveling

1901-1911 1911 1946 1992 2007-2010 2012 2017 2020

From Luzon 1911 to PRS92 to PGRS: The History of the Philippine Datum



• Several triangulation networks with different origins were established in the Philippines by the United States Coast and Geodetic Survey (USCGS).

• These different networks on different datums and with different origins were consolidated into the Luzon Datum of 1911.

• The Luzon Datum of 1911 is defined by its origin at Station Balanacan near San Andres Point on Marinduque Island.

• The continuous triangulation led to the development of the Philippine Geodetic Network (PGN).

• PGN is a network of Second-Order triangulation stations concentrated along coastal areas and are used for topographic and hydrographic surveys.

• Following the merging of the Bureau of Coast and Geodetic Survey (BCGS) into NAMRIA, the Global Positioning System (GPS) was utilized to establish a First-Order Network.

• The series of new observations was adjusted and published as the Philippine Reference System of 1992 (PRS92).

1901-1911

1911

1946

1992

2007-2010

- The nationwide implementation of the PRS92 Program resulted in the densification of passive GCPs, benchmarks, and gravity stations.
- The Philippine Active Geodetic Network (PAGeNet), the country's network of continuously operating geodetic reference stations, was also established.

2012

- Stakeholders' Forum on the Modernization of the Philippine Geodetic Reference System (PGRS) was conducted.
- An interagency Technical Working Group was established during the event to discuss key issues and next steps for the modernization of the geodetic datum.

2017

- The PGRS Modernization was formally launched.

2020

- The Philippine Geocentric Datum 2020 and the Philippine Geodetic Vertical Datum 2020 were developed to realize a modern reference frame in the country.



Brief History of Leveling in the Philippines

Since ancient times, leveling has been employed by great civilizations, e.g., Egyptians during the construction of the Great Pyramids and Romans during the construction of aqueducts. Crude leveling instruments were used.

In 1608, Lippershey, a Dutch glass maker invented the telescope. This, together with the invention of the reticle and the level vial, gave way to the advances in optical leveling instruments. Henceforth, leveling instruments and techniques were continuously developed until they were able to achieve a millimeter level of accuracy.

In the Philippines, only a few leveling survey records exist during the Spanish colonization. Before World War II, when the Philippines was under American rule, several geodetic leveling surveys were performed but they were mostly limited to Metro Manila. Most of these leveling surveys were accomplished by the Bureau of Coast and Geodetic Survey (BCGS) of the United States Coast and Geodetic Survey (USCGS). During the Japanese occupation, a vertical network system was planned and executed. Unfortunately, the records and several benchmarks (BMs) were damaged by the war. The remaining pre-war BMs that survived are still included in the present level networks after being releveled.

After the liberation of the Philippines in 1945, the BCGS personnel were recalled and mandated to recover previous survey works. All recoverable data, including those of the Manila levels, were compiled. Through financial and technical assistance from the USCGS, that ended upon the expiration of the Rehabilitation Act in June 1950, a network of level lines covering the Manila area and its nearby municipalities was established. The network was made up of short level lines in various areas and was expressed in the second-order accuracy.

When the Philippine Reference System of 1992 (PRS92) was implemented, NAMRIA conducted the first-order geodetic leveling of Metro Manila in 2009. New BMs were also established in the region to expand the existing first-order level network. The survey was conducted by the Geodesy Division of the Mapping and Geodesy Branch in collaboration with the Hydrography Branch of NAMRIA. The agency then decided to develop its national vertical network consisting of interconnected first-order geodetic level lines all over the country. Since leveling of this magnitude is beyond

the capacity of NAMRIA, most of the first-order geodetic leveling surveys were outsourced to private surveying companies. Only a few level networks were done by the agency.

How Leveling Surveys are Conducted

Before the leveling survey, a map of the planned route of the survey is prepared. A reconnaissance team shall establish the BMs with their specific markings along the route and on feasible locations for them. The BMs are usually set up along major roads about one kilometer apart.

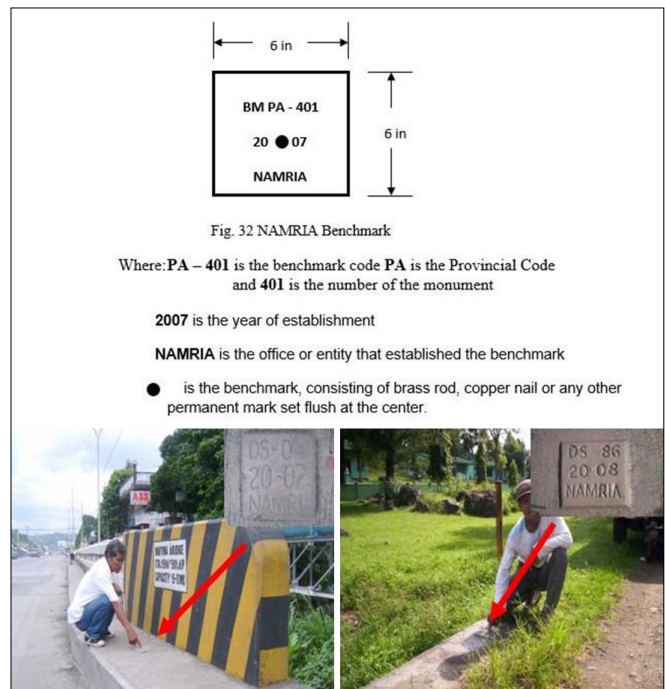


Figure 5. BM specifications and usual locations

In the Philippines, BMs are named according to the province where they are located, e.g., CS for Camarines Sur, LU for La Union, and BL for Bulacan. The code for each province can be found in the Manual of Geodetic Leveling created by the Geodesy Division of NAMRIA.

The Leveling Team

The leveling team consists of the following:

- Instrument Man who plans and executes the survey and makes sure that the measurements are well within the allowable error or limits of the survey;
- Observer who regularly checks the values recorded by the recorder, makes sure that the planned route is followed correctly, and must have a thorough understanding of the instrument;

- Recorder who records the measurements in a prescribed notebook or a portable computer;
- Rodman who ensures that the rods are perfectly vertical for precise leveling measurements and makes sure that the turning plates are not disturbed or moved during the observation. At least two rodmen are required in a leveling team to expedite the leveling survey;
- Pacer who measures and marks the location of the turning points by pacing and is in charge of the leveling team's safety by putting up markings and warning signs for dangerous locations; and
- Umbrella Holder who holds the umbrella to make sure that the level is not exposed to the heat of the sun or the rain as this could affect the accuracy of the leveling survey.

The Leveling Equipment and Tools

1. Level

The level is a piece of optical surveying equipment dedicated to leveling. It has a device inside known as the compensator that automatically sets the line of sight formed by a horizontal line when properly leveled, i.e., when the leveling bubble is at the center of the vial. Most modern levels have a digital interface. All measurements are stored in the instrument's memory which can then be downloaded for processing. Digital levels such as Leica DNA03™ and Trimble DiNi™ are used by NAMRIA's leveling team.



Figure 6. Leica DNA03 (top) and Trimble Dini (bottom)

2. Leveling rod or staff

The leveling rod or staff is usually made of wood or materials which have a low coefficient of thermal expansion to minimize measurement errors when the rods are exposed to the sun. Modern leveling rods are made of telescoping aluminum bars with barcodes instead of graduations. This barcode is matched with the barcode from the instrument's memory when making measurements. The rods must be held vertically by centering the level bubble found inside the rods during observations. To expedite the leveling survey, two rodmen are employed: one in front and the other one at the back of the instrument.



Figure 7. Modern leveling rods

3. Turning Plates

Turning plates are temporary supports where the rods are placed during observations. These plates must be placed on stable surfaces to prevent them from moving or sinking which can cause erroneous readings. Rodmen must be careful not to disturb these plates during observations. A minute disturbance could result in data inaccuracies which will require the team to level the section again.



Figure 8. Example of a turning plate

Geodetic Level Network



Figure 9. The locations of the first-order geodetic network of the Philippines and the tide stations (in red)

The Geodetic Level Network of the Philippines

The national first-order geodetic level network of the Philippines comprises 19,326 km of level lines with approximately 32,000 BMs. All major islands have at least one geodetic level line. Luzon has the most extensive first-order level network with 9,782 km, followed by Visayas with 4,774 km of level lines and Mindanao with 4,770 km. These level lines are tied to a specific tide station on each major island. Thus, all BM elevations are above or below a local mean sea level (MSL). Figure 9 shows the locations of the first-order geodetic network of the Philippines and the tide stations. The Metonic cycle is adopted to compute for the MSL, where tide stations record tidal data for a period of 18.6 years. This length of tidal observation is enough to consider major tidal variations and the precession and nutation due to lunar and solar motions in space. Tide stations with one or more complete Metonic cycles are called *primary tide stations* and those with less than one Metonic cycle are called *secondary tide stations*.

Adjusting the Level Network

Level lines are connected to form a closed loop. These loops are also connected to form a level network and then referenced to a tide station to compute the elevations of the benchmarks. Each loop is adjusted to make sure that the values fall within the allowable error of closure for the loop. For first-order level lines, the equation used is $4 \text{ mm } \sqrt{k}$, where k is equal to the distance in km. There should be no more than 4 mm of a discrepancy between the forward and backward runs of leveling in one km distance.

The Vertical Section of the Geodesy Division in NAMRIA is in charge of the adjustment and maintenance of the First-Order Geodetic Level Network of the Philippines. The Section checks if the level lines fall within the parameters of the first-order allowed values. The error of closure for each loop and the respective elevations of each BM are computed using Star*Net™ Adjustment Software. Once erroneous lines are found, they are flagged and then releveled by the Geodesy Leveling team to correct the erroneous observations. These BMs provide height references for the construction of buildings as well as irrigation lines.

The Philippine Geodetic Vertical Datum

The Philippine Geodetic Vertical Datum (PGVD) is an integral component of the modern reference system being developed by NAMRIA—the Philippine Geodetic Reference System (PGRS). With the aim of adopting a unified height system and a reference surface for the Philippines, the PGVD will be the first-ever vertical datum of the country.

The geoid model derived from land and aerial gravity measurements and the vertical or geodetic level network are necessary to the development of the Philippine Geodetic Vertical Datum. •

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Land Gravity Survey in the Philippines

by: Engr. Cesar B. Buenaobra and Engr. Hennesey R. Marohom

Gravity is the universal force of attraction acting between two bodies. It is by far the weakest known force in nature and plays no role in determining the internal properties of matter (Faller, J. E., et. Al., 2020). It controls, however, the trajectories of bodies in the solar system. All bodies on Earth have a weight, and a downward force of gravity pulls all objects toward the center of the planet. According to Sir Isaac Newton's Universal Law of Gravitation, the gravitational attraction between two bodies is stronger when the masses of the objects are greater and closer together. This rule applies to the Earth's gravitational field as well. Gravity varies at different locations on the planet because it is affected by the Earth's rotation as well as the variation of its mass and density in different areas. The acceleration g varies from about 9.78 m/s^2 at the Equator to approximately 9.83 m/s^2 at the poles.

The Earth's gravity plays a major role in determining the mean sea level (MSL). Geodetic Engineers calculate the elevation of locations on the Earth's surface based on the MSL. Therefore, knowing how gravity changes sea level helps in making more accurate measurements. In general, the areas of the planet where gravitational forces are stronger have higher MSL, and the areas with weaker gravitational forces have lower MSL.

The Earth's gravity field is measured in space and on land. Satellites gather data on gravitational changes as they pass over points on the Earth's surface, while gravimeters are used on land to measure the Earth's gravitational pull on a suspended mass. Detailed maps of gravitational fields are produced using these data and elevations on existing maps. Gravity measurements accurately reflect elevation changes on the surface of the Earth.

Gravity variations are far less than 1 m/s^2 . Because of this, the unit gal (named after Galileo) has been adopted to have a smaller unit for relative measurements. A gal is $1/100 \text{ m/s}^2$ and the most used unit is milligal, measured at 10^{-5} m/s^2 .

History of Ground-based Gravimetry in the Philippines

From 1906 to 1952, all gravity measurements in

the Philippines were conducted by visiting scientists. The first acceptable one was made by Alessio at the old site of the Manila Observatory, with the adopted value of 978.36 gals. Another determination on the same site was conducted by M. Selga and J. Carmellas in 1922 and they obtained the value of 978.371 gals. There was a discrepancy in the values obtained by Alessio and this can probably be attributed to the difference in the pre-season determinations in Washington, which was 44 in the seventh decimal place in the period of the pendulum.

The first extensive gravity survey was conducted by Father Lejay in 1933 and 1934 using a pendulum apparatus. He occupied 205 gravity stations distributed all over the country. Most of these gravity stations can no longer be recovered because they were destroyed either by the impacts of World War II or by natural causes. Father Lejay cited the results of his survey in his *Rapport Provisoire*.

Several gravity surveys were conducted thereafter to establish a network of gravity bases on a common datum throughout the world. In 1948, Dr. George Prior Woollard of Woods Hole Oceanographic Institution occupied the station at the Old Manila Weather Observatory (see Figure 1) and measured the value of gravity at 978.3614 gals using Worden Gravity Meter No. 10b. In 1951, William E. Bonini occupied



Figure 1. Old Site, Manila Observatory

several gravity stations established previously and his measurements were in substantial agreement with the measurements of those scientists that came before him.

In 1961, the U.S. Army Map Service–Far East (USAMSFE) executed a contract with the Philippine Bureau of Coast and Geodetic Survey (BCGS) and a private survey company, F.F. Cruz & Co., Inc., to establish a total of 460 gravity stations throughout the Philippines. It was also during that time that BCGS procured their first gravity meter, a La Coste Romberg gravimeter. Gravity observations were conducted at reference stations established by the U.S. Air Force in airports all over the Philippines. These base stations were also used to calibrate the gravimeter employed in the survey. The project was completed in January 1963.

Before the completion of the contract with USAMSFE, the BCGS realized that the established gravity stations and the survey conducted were not sufficient to cover the requirement for a nationwide gravity network. To address this concern, a nationwide gravity survey project was started in December 1962, with financial assistance from the National Science Development Board of the Philippines. A total of 358 gravity stations, including 70 base reference stations, were established under this project to supplement the existing stations. The stations were established in all existing airports, capital, and principal towns in each province. The sites were selected to ensure that the stations were made accessible for connecting local

gravity surveys conducted by private geophysical companies, and for testing and calibrating gravimeters.

Establishment of Absolute Gravity Station

In 2005, the Tokyo University of Japan, in collaboration with NAMRIA, established the first permanent absolute gravity station in the country. The Absolute Gravimeter FG5 #23 (Micro-g La Coste Inc.) of Tokyo University was used for the 2-day (18–19 November 2005) continuous gravity measurement at the main office of NAMRIA in Fort Bonifacio, Taguig City. A total of 5,750 pendulum drops, with a standard deviation of 0.0240 milligal per drop, were completed and the absolute gravity value gathered on top of the plate was 978,370.5562 + 0.0003 mGal.

While waiting for the completion of the absolute gravity measurement in NAMRIA, a simultaneous relative measurement was conducted in five locations in Metro Manila. These were: one station each in the University of the Philippines (UP), Manila Observatory in Quezon City, NAMRIA Magnetic Observatory in Muntinlupa City, and two stations in NAMRIA’s Hydrography Branch (HB) in the City of Manila. The observation was conducted on 18-22 November 2005 using Tokyo University’s G-583 and G-683 La Coste and Romberg Relative Gravity Meter. The resulting gravity values (in mGal) from the five stations are presented in Table 1.

Station	Latitude	Longitude	Height	Gravity Value
UP	14.6564° N	121.0697° E	50 m	978382.056
Manila Observatory	14.6367° N	121.0767° E	58 m	978390.787
HB 1	14.5981° N	121.9731° E	2 m	978345.833
HB 2	14.5981° N	121.9731° E	1.688 m	978346.077
Magnetic Observatory	14.3731° N	120.0189° E	64.9 m	978347.744

Table 1. Resulting gravity value (mGal)

Establishment of First- and Second-Order Gravity Stations

In 2008, NAMRIA realized that there was a need to further develop and augment the country’s gravity base network. With the newly acquired Scintrex CG-5 Gravimeter, the agency set out to establish at least one first-order gravity station per province and at least one second-order gravity station per city/municipality. The measurements began in 2009, and additional two

gravimeters were acquired in 2009 and 2010. The survey ended in 2014, with a total of 84 first-order and 1,568 second-order gravity stations established.

Development of a Philippine Geoid Model and Densification of Second-Order Gravity Stations

In 2014, through the funding of the National Geospatial Intelligence Agency (NGA), the National



Space Institute–Technical University of Denmark (DTU-Space) collaborated with NAMRIA to create a preliminary geoid model for the Philippines. The geoid, a complex mathematical model of the Earth, is used to approximate the mean sea level. The model was developed and computed using data from land gravity, airborne gravity, marine satellite altimetry, and satellite gravity data from the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) mission (Release 5).

DTU-Space conducted further analysis on the preliminary Philippine Geoid Model (PGM 2014) and it suggested that additional land gravity measurements should be made to further improve the accuracy and address the inconsistencies of the geoid model, especially along the areas near the bodies of water. Because of this, NAMRIA commenced the establishment of a denser gravity station network in 2015. The plan was to conduct gravity measurements at points two to three kilometers apart, using the existing NAMRIA horizontal and vertical control points. The gravity survey started in Region I (Ilocos Region) and progressed to the succeeding regions. The project is still ongoing and 6,222 points have already been completed. Through

this, NAMRIA was able to release a refined and more accurate Philippine Geoid Model (PGM2018). This model is available for download from the NAMRIA website, together with the geoid interpolation program that can be used to compute the geoid value (N) of any point in the country. •

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Validation of the Philippine Geoid Model

by: Engr. Ronaldo C. Gatchalian and Engr. Aila Leana T. Sampana

The preliminary Philippine Geoid Model was computed with the help of Professor Rene Forsberg of the Denmark Technical University in 2014 from satellite, airborne, and land gravity data. The geoid was computed in a global vertical reference system and then fitted into the Local World Geodetic System 1984 (WGS84) reference system using the Global Navigation Satellite System (GNSS)/Leveling data nationwide to preserve the existing vertical datum, i.e., mean sea level. It was named the Philippine Geoid Model 2014 (PGM2014).

Due to a large error in the preliminary model, with a standard deviation (SD) of ± 0.30 m and a 0.54 m root mean square (RMS) fit to GNSS/Leveling, PGM2014 was recomputed in 2016 (SD=0.022 m; RMS=0.054 m) and then in 2018 using reprocessed additional land gravity and new satellite gravity data. The SD of the latest model (PGM2018) was 0.010 m with an RMS fit of 0.020 m.

To validate and confirm the PGM2018 fit to the leveling network, benchmarks (BM) were observed through GNSS. The GNSS data were then post-processed using Trimble Business Center (TBC) Software with the PGM2018 file incorporated into it. With the PGM, TBC generate the MSL elevation of the BMs. These BM elevations (using GNSS+PGM) were compared to its geodetic leveling adjusted elevations.

The resulting elevation differences between the two methods indicated the accuracy of the PGM in determining absolute elevations above MSL. Large differences may indicate geodynamic effects, GNSS observation error, and in most cases, errors in leveling.

Data Acquisition

Survey Planning

Benchmarks were pre-selected from the adjusted level network based on their distribution. Reconnaissance was done in the field to recover and assess the condition of the marks and to check whether they were still intact and suitable (at least 50% clear view of the sky) for GNSS observation. Figure 1 shows

where the project workflow from reconnaissance to data analysis.

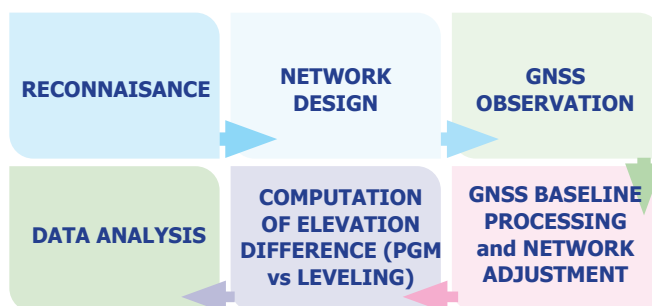


Figure 1. Project Workflow. The PGM validation survey starts from reconnaissance and recovery of the pre-selected BMs to determine its suitability for GNSS observation. After which, the network design was developed according to the number of receivers and was followed by the GNSS static observation. The GNSS data were downloaded for baseline processing and network adjustment. Output BM elevations from the TBC and their corresponding elevations in STARNet were entered into the PGM Validation Evaluation Checklist. Differences in elevations between the two sources were computed and analyzed to identify the erroneous dataset.

Network Design

The approximate locations of the recovered BMs were plotted on a map to design and plan the survey. The network design considered the distribution of the points, i.e., BMs while the survey design and schedule were governed by the number of points to be observed and the number of GNSS receivers to be used. The existing 10 GNSS receivers of NAMRIA and the Philippine Active Geodetic Network (PAGeNet) were considered in the design of the network loops.

Survey Schedule

The survey was scheduled into loops of points of simultaneous observations. The first set of loops occupied 10 BMs and then seven to eight of the receivers were transferred to the next loop, leaving two to three common points as connections to the first loop. Each loop was occupied for two observation sessions for an average of one to four hours per session using static technique (the receiver stayed on one point and logs GNSS data for at least 30 minutes) depending on the baseline length. Figure 2 shows a sample GNSS observation network in Metro Manila. Only six receivers were used in this loop (PTAG is a permanent GNSS station).

PGM Validation - Metro Manila Batch 2

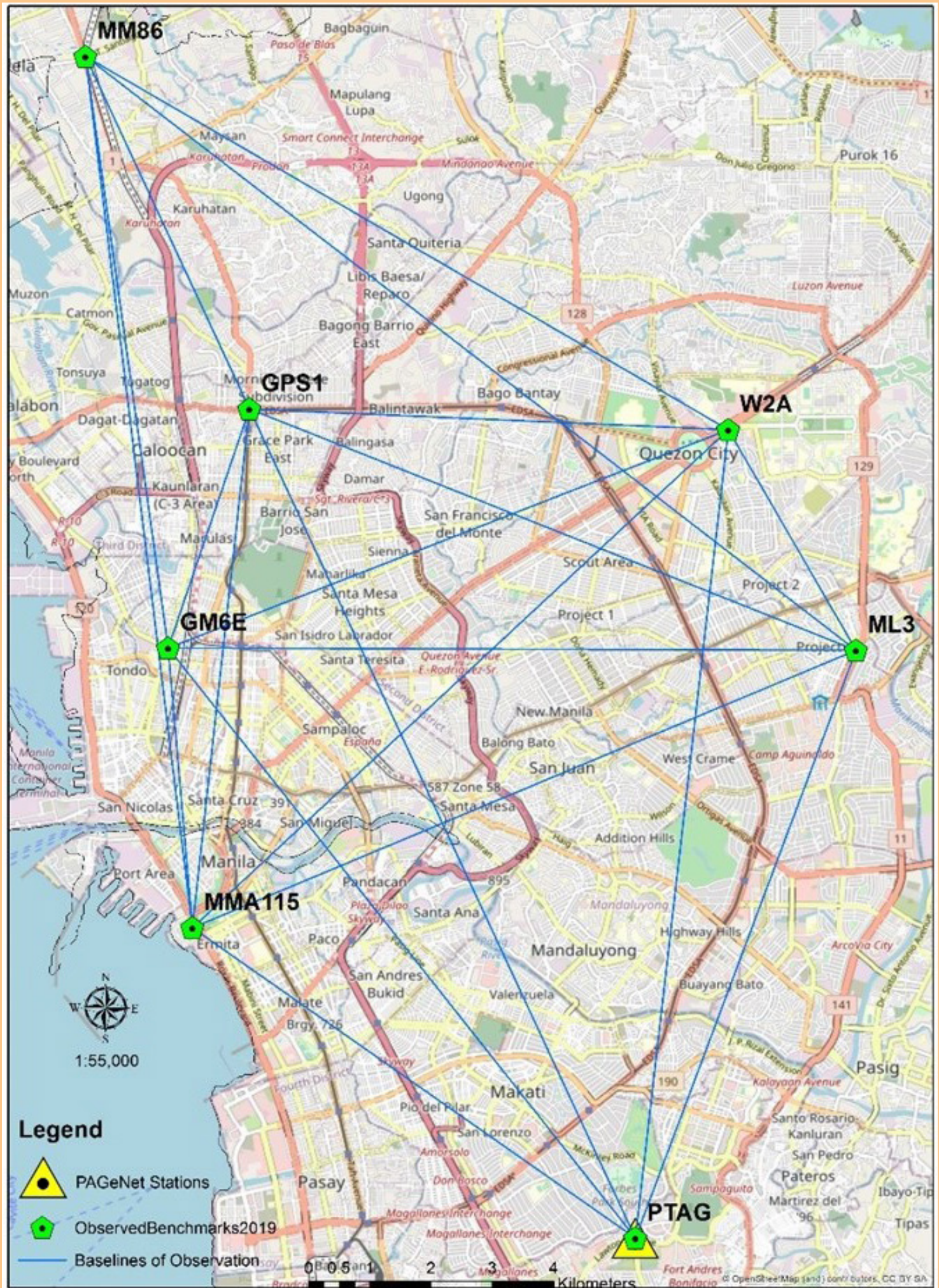


Figure 2. BM network occupied by GNSS in Metro Manila

GNSS Observation

In GNSS observations, the instrument was carefully centered on the mark within 2 mm and antenna heights were measured within 3 mm (see Figure 3). The elevation mask of the receivers was set to 3 degrees to get the ellipsoidal heights as accurately as possible.

Ten GNSS survey teams comprising of team leaders who oversaw the instrument, and assistants were formed for the project. The instruments used include Trimble R10 GNSS receivers (see Figure 4) and aluminum tripods. NAMRIA GNSS field sheets were used to record observation information.

Data Processing

GNSS Data Processing

The GNSS data were processed and adjusted one province or region at a time using the TBC Software. The Geoid Grid Format (ggf) of the PGM2018 was used and incorporated into the TBC to generate the MSL elevation of the BMs using the equation $H=h-N$, where, H is the MSL elevation, h is ellipsoidal height and N is the geoid height (extracted from the geoid model by the program). The datum used is the epoch 1987 of WGS84 (Local WGS84) and the geoid model used is *pgmwgs2018.98* (from the NAMRIA Website). Only Active Geodetic Stations (AGS) were used as reference in processing the GNSS data since their epoch of observations was consistent with that of the GNSS/Leveling.

GNSS Data Network Adjustment

After processing, the network of BMs (see Figure 5) was adjusted, with allowable setup errors of 3 mm and 2 mm in antenna heights and centering, respectively. The first adjustment was unconstrained, allowing for outlier detection and disabling baselines that exceeded the critical Tau error estimates (95% upper and 5% lower limits). In the final adjustment, the active station was constrained, and most residual error values were near zero (none beyond 1.96 sigma or 95% Confidence Level). The list of adjusted geodetic coordinates of points included the



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



Figure 4. TRIMBLE R10 GNSS receivers tested before the fieldwork

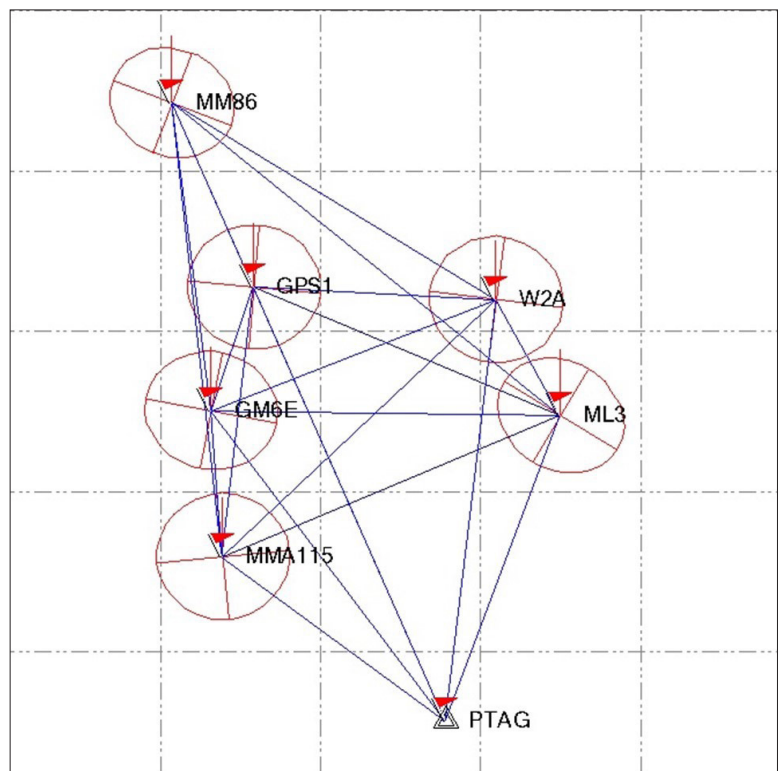


Figure 5. Network of points with their corresponding error ellipses

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
GM6E	N14° 37' 19.78596"	E120° 58' 19.71607"	46.9616	0.013	
GPS1	N14° 39' 26.31635"	E120° 59' 02.57359"	61.55764	0.012	
ML3	N14° 37' 18.63727"	E121° 04' 23.57747"	103.68939	0.024	
MM86	N14° 42' 32.86143"	E120° 57' 35.86834"	45.53595	0.018	
MMA115	N14° 34' 51.70557"	E120° 58' 32.40288"	48.96314	0.011	
PTAG	N14° 32' 07.43281"	E121° 02' 26.78149"	88.05700	?	LLh
W2A	N14° 39' 15.22590"	E121° 03' 15.91183"	93.65926	0.011	

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

height errors ranging from 0.011 m to 0.024 m as shown on the samples listed in Table 1. Horizontal accuracies were reported in the Network Adjustment Report as error ellipse components defined by their semi-major and semi-minor axis. A list of points (in WGS84 grid coordinates) with elevation was also reported as one output of the TBC Software.

Computation of Elevation Difference

The corresponding list of BMs with elevation from the leveling surveys was gathered from the output of the StarNet Adjustment Software. These data came from the densification of PRS92 vertical controls in 2007 and the various releveing and readjustment of the national vertical network from 2018-2020.

The BM points, together with their corresponding elevations by GNSS+PGM and Leveling were tabulated


with their difference in elevations using the PGM Validation Evaluation Checklist.

The result of the final network adjustment, with Metro Manila as a case example, was encoded into the PGM Validation Evaluation Checklist (see Table 2). The elevations from the adjusted geodetic leveling data were compared with that of the elevations estimated using the PGM.

Discussion and Analysis

Accuracy of GNSS Surveys

The computed elevations using the PGM depend on the accuracy of the GNSS surveys and the geoid model. The error ellipses and height errors from the final adjustment results indicate the precision of the GNSS data. These errors were also included in the

 PGM VALIDATION EVALUATION CHECKLIST											
NAMRIA-PGRSDM-Form29 Rev00											
STATION NAME	DESCRIPTION		GNSS DATA		VERTICAL DATA						Encoded in GNIS
	Updated Description	Submitted to GNIS for Archiving (Hard and Digital Copies)	Sessions = Two (2)	Error Ellipse (m)	ELLIPSOIDAL HEIGHT (m)	Height Error (m)	ELEVATION (m)				
							PGM (2018a)	Leveling	Difference	<input checked="" type="checkbox"/> if < 10-cm <input type="checkbox"/> if >	
GM6E	V. ALMUETE	TIM BALUYOT	<input checked="" type="checkbox"/>	0.002	46.969	0.013	1.776	1.964	-0.188	<input checked="" type="checkbox"/>	TIM BALUYOT
GPS1	V. ALMUETE	TIM BALUYOT	<input checked="" type="checkbox"/>	0.002	61.558	0.012	16.273	16.376	-0.102	<input checked="" type="checkbox"/>	TIM BALUYOT
ML3	V. ALMUETE	TIM BALUYOT	<input checked="" type="checkbox"/>	0.004	103.689	0.024	57.368	57.458	-0.090	<input checked="" type="checkbox"/>	TIM BALUYOT
MM86	V. ALMUETE	TIM BALUYOT	<input checked="" type="checkbox"/>	0.003	45.536	0.018	0.491	0.871	-0.380	<input checked="" type="checkbox"/>	TIM BALUYOT
MMA115	OK	OK	<input checked="" type="checkbox"/>	0.002	48.963	0.011	3.689	3.778	-0.089	<input checked="" type="checkbox"/>	TIM BALUYOT
W2A	OK	OK	<input checked="" type="checkbox"/>	0.002	93.659	0.011	47.618	47.692	-0.074	<input checked="" type="checkbox"/>	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

PGM validation evaluation checklists to ensure that the results of the GNSS survey are within a centimeter-level of accuracy. Table 3 provides a summary of the accuracy of the GNSS survey per province/region.

The millimeter error ellipses of the GNSS surveys met the accuracy standards for 1-centimeter control, which is the required accuracy classification control positioning prescribed in the Federal Geographic Data Committee (FGDC) for Geodetic Networks (*Committee, 1998*).

Particular attention was given to the accuracy of ellipsoidal heights because an accurate ellipsoidal height provided accurate elevation. A one to three-centimeters error in height in the final adjustment was deemed acceptable for a target 10 cm geoid. Table 3 shows the summary of height errors of the GNSS survey ranging from 0.003 m to 0.059 m.

	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

Accuracy of Geodetic Leveling Data

The precision of the geodetic leveling survey depends on the distance between two benchmarks, e.g., $4\text{ mm}\sqrt{k}$ where k is the separation of the two BMs. This precision is relative to two BMs only and not on the elevation itself. This means that the accuracy of the elevation is only as good as its reference BMs, e.g., the Tide Gauge BMs (TGBMs). The elevation error of the TGBM/s will propagate to the leveling network/s and will only be checked when the leveling survey reaches another TGBM of a different province.

Also, there is a problem with the integrity of the level data which may be altered by the survey crew. This alteration of data may cause the forward and backward runs to close. Additionally, the absence of orthometric corrections (applying gravity measurements) may add

to the uncertainty of the adjustment results. Table 4 shows the variation of the BM's standard deviation (0.003 m to 0.163 m) of the adjusted elevations using the StarNet software.

	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

Accuracy of the Philippine Geoid Model

The PGM2018 is computed in a global vertical reference system using new satellite gravity data and then fitted to the local WGS84 GNSS/Leveling. The satellite data, together with the densified gravity (7,533 points) and additional GNSS/Leveling points (286 BMs) were used in the PGM2018 computation. The geoid has a standard deviation of 1 cm and the RMS fit to GNSS/Leveling is 2 cm. From these results, we can infer that the accuracy is the combination of 1 cm and 2 cm, or to be a little conservative, the nominal accuracy of the PGM could be less than 10 centimeters.

Result of PGM Validation

The preceding paragraphs discussed the accuracies of the GNSS, leveling, and the PGM. From the table of data accuracies (Tables 3 and 4) in this campaign, GNSS has incurred a maximum height error of 5.9 cm; leveling error accounted for 16.3 cm in the Cordillera Administrative Region (CAR) and 12.2 cm in Calabarzon (Region IVA), while the PGM has a combined error of about 3 cm.

From the formula $H=h-N$, we can say that the highest accuracy attainable by GNSS+PGM for H is only about 8.9 cm with the ellipsoidal heights contributing about 5.9 cm and the PGM 3 cm. Depending on the GNSS survey data, these combined errors can be as good as 3.3 cm with the GNSS error being only 3 mm.

The estimated elevations from the GNSS+PGM from each of the provinces surveyed were compared

with the adjusted elevations from leveling. Bearing in mind that the GNSS+PGM elevation errors can only range from 3.3 cm to 8.9 cm, the acceptable differences should only result in this range for an assumed errorless leveling, which means that the leveling has high accuracy. The 286 validation points showed a wide range of differences relative to the GNSS+PGM extending from ± 0.000 m to ± 0.946 m (see Table 5), with large outliers in Batangas province.

While the CAR leveling has the highest SD in Table 4, Batangas province having the highest PGM-leveling difference, is rather unexpected. With the combined 8.9 cm error of the PGM and 12.2 cm leveling error in Batangas province, the difference should only be 21.1 cm and not 94.6 cm. With this result, alterations on the level data of Batangas province can be inferred, from which made the forward and backward run to pass the first-order criteria.

Province	Δ Elevation (m)	Province	Δ Elevation (m)	Province	Δ Elevation (m)
RI. Ilocos Norte	0.000 - 0.139	CAR. Mountain Province	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

Conclusions and Recommendations

Benchmark networks in 30 provinces have been observed by GNSS to validate and confirm the accuracy of the Philippine Geoid Model. The uncertainty of the GNSS survey in this campaign was found to be from 0.003 meters to 0.059 meters, while the standard deviations of the adjusted leveling data range from 0.003 meters to 0.163 meters and the uncertainty of the PGM was found to be 3 cm nationwide. Based on the analysis, the result of the leveling network adjustment is not guaranteed due to survey malpractices that compromise the adjustment results. With this discovery, we can conclude that the GNSS and PGM are more reliable than the leveling surveys.

PGM-Leveling differences in Northern Luzon give an average of ± 7 cm, while BMs from Southern Luzon, Cebu Province, and Mindanao have an average of ± 14 cm, ± 12 cm, and ± 50 cm, respectively. Small PGM-Leveling differences suggest that the adjusted BM Network in these areas conforms to the geoid model. Large differences are mainly attributed to geodynamic effects, and/or leveling survey errors or survey malpractices. The 286 PGM-leveling differences show that there exist some large leveling errors in parts of Southern Luzon. The rest of the country with good

leveling data resulted in an accuracy of approximately 10 cm for the PGM.

NAMRIA recommended that the validation of the PGM be continued, i.e., verifying its output elevation, to cover the remaining provinces nationwide, as well as to continue the densification of land gravity nationwide. To address the large PGM-leveling differences, an investigation of survey malpractices by contractors and releveling followed by re-adjustment of the national level network applying orthometric corrections are suggested to reduce the errors in leveling. •

Reference:

Committee, F. G. D. (1998). *Geospatial Positioning Accuracy Standards (Part 2: Standards for Geodetic Networks)*.



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Estimating Elevations using the PGM2018

by: Engr. Ronaldo C. Gatchalian

Vertical datum is a coordinate surface to which heights are referred. The universal choice of a vertical datum is the geoid, which is the reference surface for orthometric (elevation) and dynamic heights (Vanicek, 1991). The geoid is an equipotential level surface of the oceans at equilibrium; introduced by C.F. Gauss as the “mathematical figure of the earth” (Dr. Bernhard Hofmann-Wellenhof, 2005).

Since the ocean is not actually at equilibrium, the geoid differs from mean sea level (MSL) to about 0.70 m to 2.20 m globally, because of wind, salinity changes, temperature, and pressure (Sadatipour, Kiamehr, Abrehdary, and Sharifi, 2012). In the Philippines, the geoid-MSL differs from about -0.18 m to -1.40 m in the International Terrestrial Reference Frame system, where the MSL is above the geoid surface as illustrated in Figure 1.

The topographic maps of NAMRIA and most of the maps of the world use the MSL as a reference datum for all heights.

The conventional way of determining elevation H (height above sea level) of points and benchmarks

(BMs) is through the conduct of geodetic leveling, which refers to a high-accuracy determination of the difference in elevation (DE) of points. It is considered a tedious process that hinders the densification of BMs in the country (Mancera, 2014).

With the advent of Global Navigation Satellite Systems (GNSS), it has become much easier to estimate MSL elevations using a geoid model. The application of a geoid model in GNSS surveys can compute the H and will eliminate the conduct of leveling in inaccessible areas. This could be an alternative method when millimeter accuracy of H is not a strict requirement.

A geoid model is a surface (N) that describes the theoretical height of the ocean and the zero-level surface on land. In a modern vertical reference system, the geoid is required to obtain H from GNSS by $H = h^{GNSS} - N$, where h^{GNSS} is the GNSS ellipsoidal height, and H is the leveled elevation.

Elevation of points can be estimated using the Grid Interpolation Program provided by the Denmark Technical University (DTU) or using the geoid model that is incorporated into the Trimble Business Center (TBC) Software.

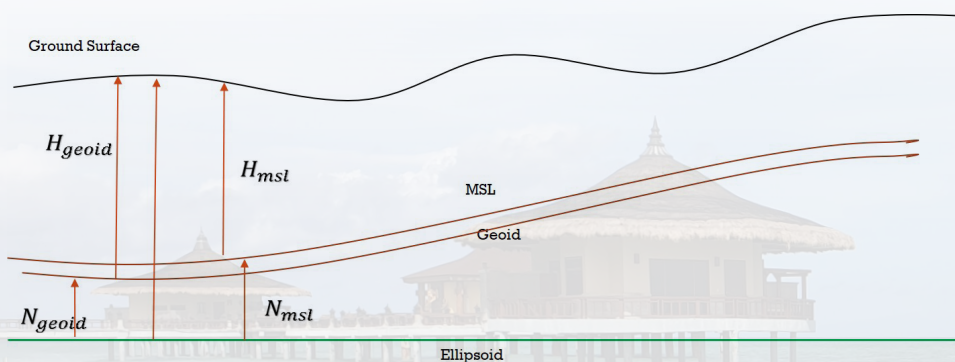


Figure 1. Relationships between ground, MSL, geoid, and ellipsoid surfaces



The First Philippine Geoid

The first attempt at computing a gravimetric geoid for the Philippines was through the Natural Resources Management Development Project (NRMDP) in 1991. A gravimetric geoid (or simply geoid) as used by “classical geodesists,” is a specific equipotential surface that can be computed from gravity measurements (land, air, and satellites) via Stokes’s integral (*Featherstone, 1998*). Land gravity data and altimetrically-derived anomalies at sea and the OSU89A Global Geoid Model to degree and order 360 were used. Large biases between the gravimetric geoid N and GNSS/leveling were found, ranging from two to six meters nationwide (*Kearsley, 1991*). This geoid model was never used.

Modeling the Geoid: The Making of PGM2018

On 28 October 2014, with technical assistance from the National Space Institute of the Denmark Technical University (DTU-Space) and funding from the National Geospatial Intelligence Agency (NGA), a preliminary geoid model, Philippine Geoid Model 2014 (PGM2014), was computed for the country. PGM 2014 used datasets from 1,261 land gravity surveys, nationwide airborne gravity surveys, marine satellite altimetry (DTU-10), and the newest satellite gravity data from the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) mission release 5.

Land gravity surveys in the Philippines started in 2007 with 8,180 stations in 2021. The airborne gravity survey was conducted from March to May 2014 (*Gatchalian, 2016*) using a Cessna Caravan aircraft. This is part of the project to improve the global gravity field model - Earth Gravitational Model EGM2008, based on the Basic Exchange and Cooperation Agreement (BECA) between NGA and the Danish Geodata Agency.

The mean altitude for all flights was 3,185 m with a terrain clearance of 545 m above mountains and 3,760 m in lowlands. Figure 2 shows the color-coded flight track elevations.

The PGM2014 (see Figure 3) was computed using the GRAVSOF system, a set of Fortran routines developed by DTU-Space and Niels Bohr Institute, University of Copenhagen (*Forsberg R, 2008*).

The “remove-restore” technique was used in computing the geoid, where a spherical harmonic earth

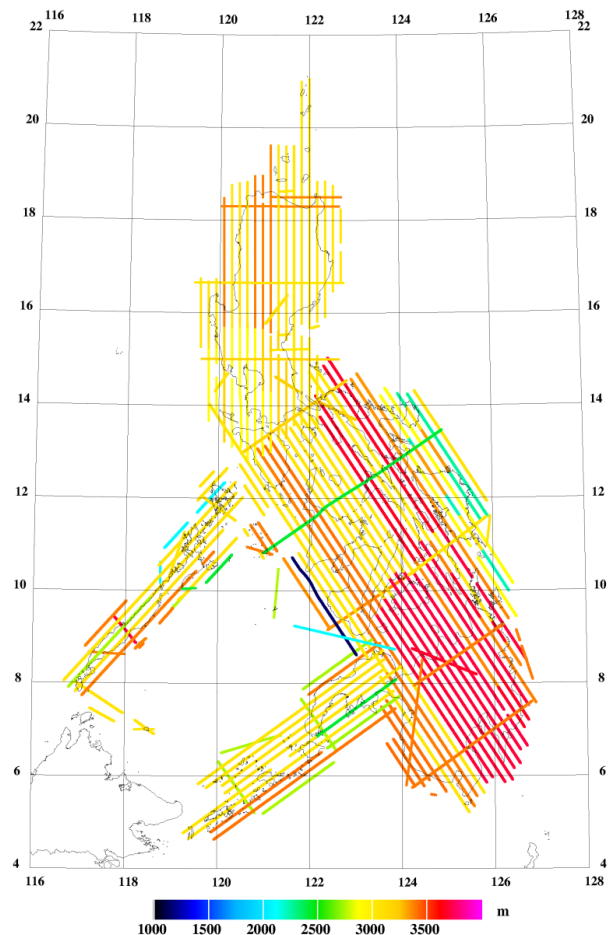


Figure 2. Flight track elevations of the airborne gravity survey

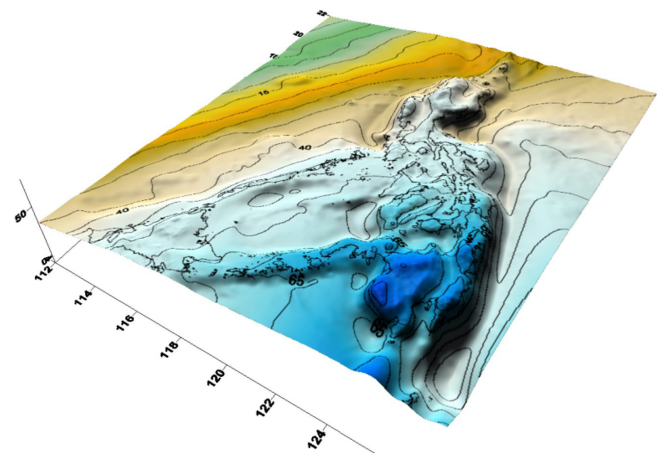


Figure 3. The Preliminary Philippine Geoid Model 2014 (PGM2014). The contour interval is set at 5 m

geopotential model (EGM/GOCE combination) was used as a base (*Pahlevi, Pangastuti, Sofia, Kasenda, and Prijatna, 2015*). The geoid is divided into three parts, namely: the global contribution N_{egm} , a local gravity-derived component N_2 , and a terrain part N_3 , and is expressed using the formula $N_{grav} = N_{egm} + N_2 + N_3$.

The geoid is computed on a grid of $0.025^\circ \times 0.025^\circ$ resolution (corresponding to roughly 2.7×2.5 km grid). The area of computation is 04° to 22° N and 112° to 128° E, covering the Kalayaan Island Group in West

Unit: meters	Mean	Std.dev.	Std.dev.	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

Table 1. Computed geoid statistics and standard deviation

Philippine Sea. Computations were based on least-squares collocation and Fast Fourier Transformation methods, which involved 1440 x 1280 grid points corresponding to 100% zero paddings. The data were gridded and downward continued by least-squares collocation using the planar logarithmic model with the computed geoid statistics and standard deviation shown in Table 1.

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

1. Subtract the EGM08GOCE spatial reference field (in a 3-D “sandwich model”)
2. Reduce the RTM terrain of surface gravimetry
3. Reduce the RTM terrain of airborne gravimetry
4. Reduct the DTU-10 satellite altimetry in ocean areas away from airborne data
5. Proceed to 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
6. Conduct Spherical Fourier Transformation from gravity to geoid
7. Restore RTM and EGM08GOCE effects on the geoid
8. Correct the difference between quasigeoid and geoid (using a Bouguer anomaly grid)
9. Shift the computed geoid by +80 cm to approximately fit to Manila tide gauge datum

The PGM2014 has an accuracy of 0.30 m with minimum and maximum errors of -1.61 m and 2.88 m, respectively. This is due to the errors in gravity data (position and gravity value), as depicted in Figure 4.

Recomputation of PGM2014

To improve a geoid model, Professor Forsberg in his paper “Towards a cm-geoid in Malaysia” (Forsberg, 2003) recommends:

- Leveling networks must be carefully analyzed for adjustment errors.
- Connections and antenna height errors of GNSS data on benchmarks must be revisited and re-analyzed.

- Erroneous points (geoid outliers) must be resurveyed by leveling (elevation) and GNSS (position).
- New GNSS-fitted version of the geoid must be computed as new batches of GNSS-leveling data, additional gravity surveys in major cities, and GNSS user’s height problem reports come in.

In 2016, NAMRIA started the recomputation of the PGM2014. The gravity data were reviewed and reprocessed. The densification of land gravity stations was also conducted in some major cities of the country. The leveling data were reanalyzed, readjusted, and corrected, while the outliers were deleted. The GNSS data were reprocessed and readjusted. The points with large error ellipses were deleted.

Land Gravity Data 2014, 2016, and 2018

In the 2016 recomputation, the original airborne and satellite data processing results were used. Only the land gravity data were reprocessed, densified to 2,214 points, and quality controlled.

In the 2018 recomputation, new satellite data, i.e., Primary Geopotential Model 2017 (PGM17) (Dawod, Mohamed, and Al-Krargy, 2019), the original airborne and additional land gravity data up to 5,779 points were used in the computation.

One quality check for the land gravity data is the comparison of its anomalies with that of the airborne. Figure 4 shows the plots of 2014 land gravity against airborne data and presents outliers as high as 60 milli gals (mGals) (depicted by red and blue dots). Figure 5 shows the new plots of the 2016 land and airborne gravity data. Significant improvements are observed in the land data (depicted by thicker dots). Most dots are in green, and some in yellow and light blue (25-50 mGals difference in mountainous areas only). Figures 6 and 7 show the 2018 land and airborne Bouguer differences in Luzon and Visayas-Mindanao regions. Most land gravity data (depicted by colored dots) conform with that of the airborne data (depicted by colored track lines).

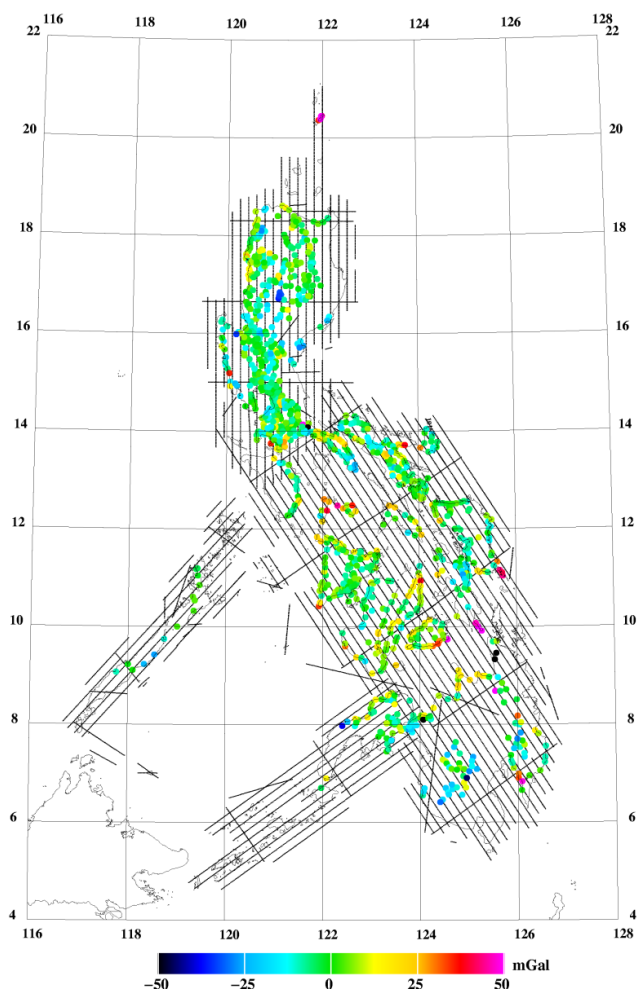


Figure 4. Plot of the comparison between 1,261 land and airborne gravity points in PGM 2014 (with visible outliers)

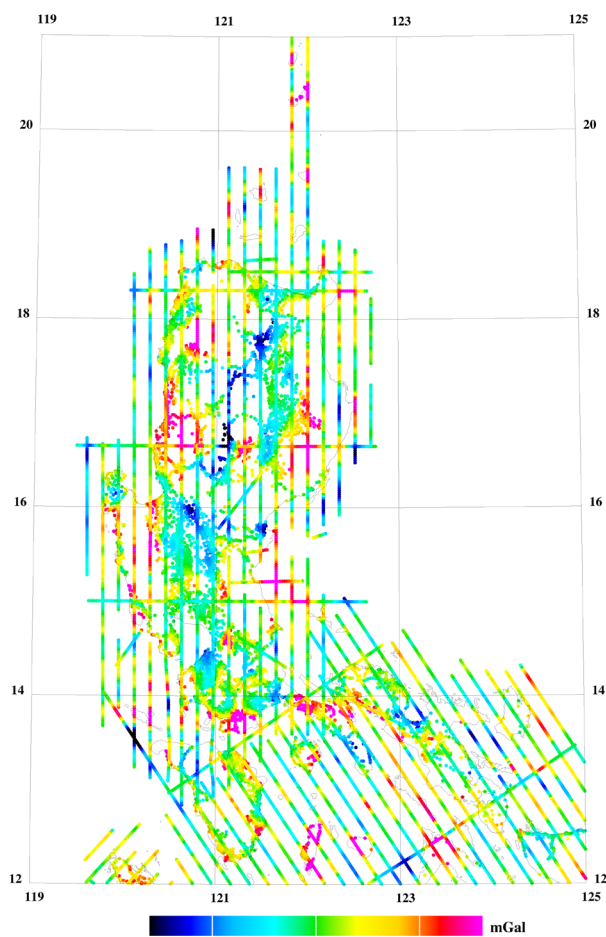


Figure 6. PGM2018 Air-Land (5,779 points) Bouguer differences in Luzon

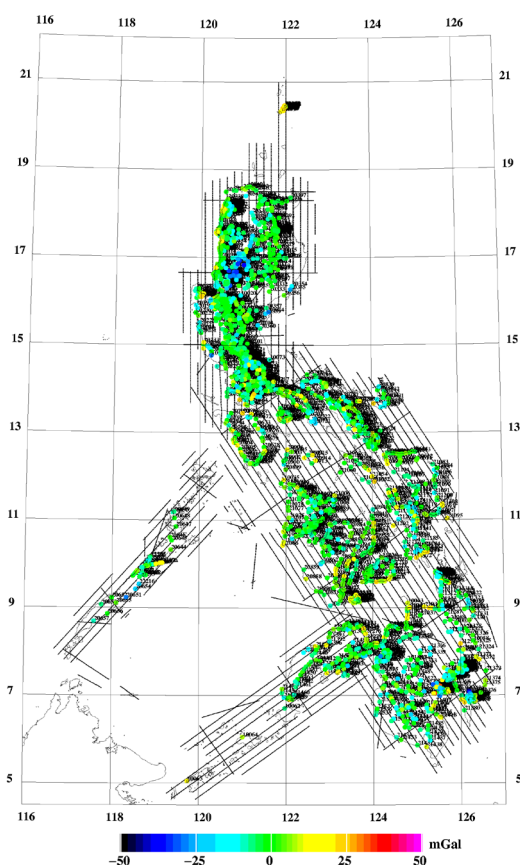


Figure 5. PGM2016 land gravity data after reprocessing and densification (2,214 points), and plotted with the airborne data (Most differences are below 25 mGals, although some points exceed 35 mGals in mountainous regions.)

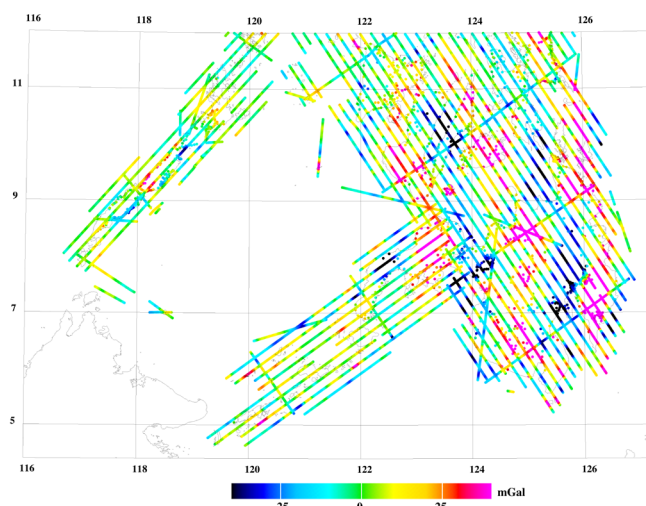


Figure 7. PGM2018 Air-Land (5,779 points) Bouguer differences in Visayas-Mindanao region

The recomputed Philippine Geoid Model 2016 and 2018

The PGM2014 was recomputed to PGM2016 with an accuracy of 0.022 m using additional land gravity stations combined with the same airborne and satellite gravity data.

Unit: meters	Mean	Std.dev.	Std.dev.	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

Table 2. The table summarizes the statistics of PGM2018 and its standard deviation. The range of N is from 38.95 m in Batanes up to 76.32 m in Davao.

In 2018, the most recent PGM was recomputed using new satellite data (PGM17), original airborne, and additional land gravity data with an accuracy of 0.01 m as shown in Table 2.

More land gravity data (up to 41,000 points) will be added until 2030 to recompute a new version and further refine the Philippine geoid. Figure 8 shows the new PGM2018. This geoid model is available for download at the NAMRIA website (www.namria.gov.ph).

GNSS/Leveling Data for 2014, 2016, and 2018

The computed geoid was reduced to the ML-3 reference level surface to roughly fit the geoid in the Metro Manila area. To close the gap between the MSL and the geoid and fit the latter to the different MSL reference level surfaces of the islands in the country (which in effect unifies them into an equipotential surface), tide gauge benchmarks (TGBMs) and BMs nationwide were surveyed by GNSS in 2010.

For PGM2014, a set of 190 GNSS/leveling data in local WGS84 was used in fitting the geoid. These data showed large errors relative to the geoid, with large outliers in some regions, likely from a combination of leveling and GNSS errors. The RMS fit is 0.50 m. Figure 8 shows the offset values of up to 1.35 m.

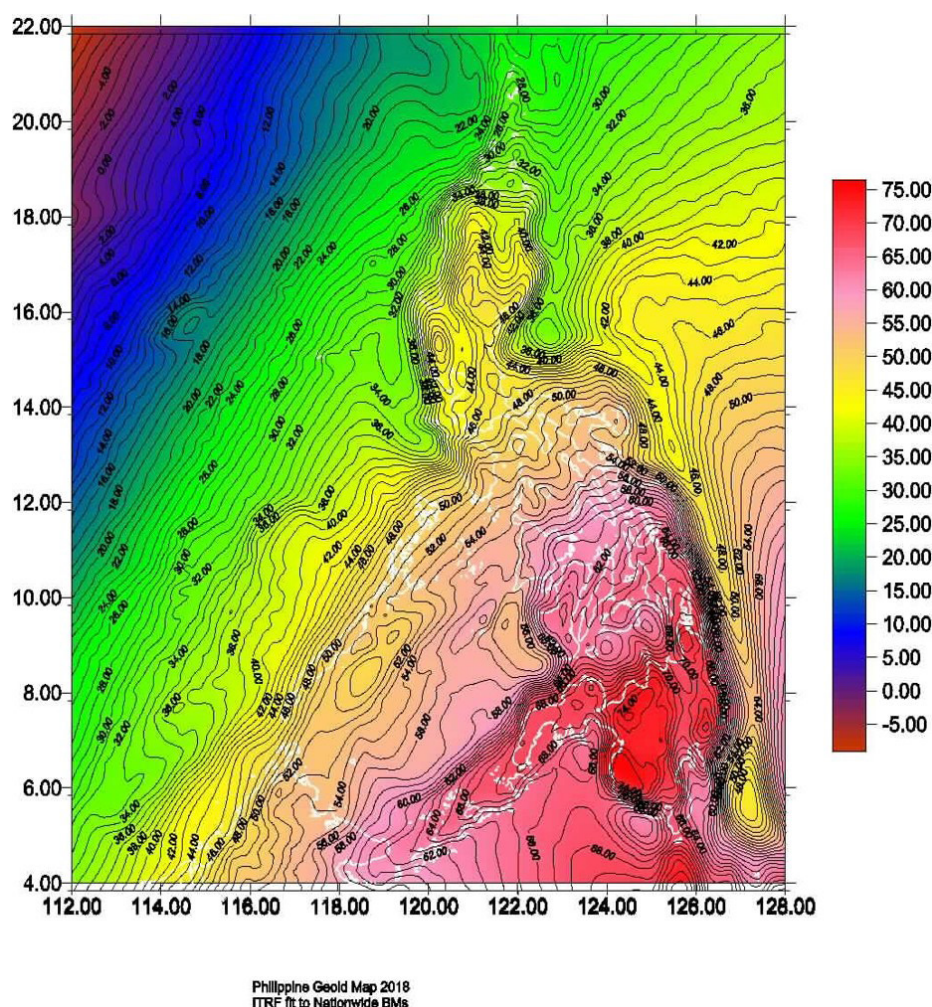


Figure 8. The new PGM2018 with contour interval set at 1 m (a surveyor can use this map to estimate elevation on a specified location by subtracting the contour value N from ellipsoidal height h)

For PGM2016, the GNSS/leveling data were readjusted while the outliers were removed. A total of 101 out of 190 BMs were used for the computations. After fitting the new GNSS/leveling, the RMS fit is 0.054 m, with minimum and maximum offset values of -0.124 m and 0.169 m, respectively. This improvement is attributed to the removal of erroneous leveling and GNSS points. Figures 9-11 show the offset values and the new geoid correction surface of PGM2016.

For PGM2018, 286 sets of GNSS/leveling data were used in fitting the geoid. The RMS fit is 0.020 m with minimum and maximum offset values of -0.061 m and 0.066 m, respectively.

More points will be added to the GNSS/leveling data as the PGM Validation Survey progresses.

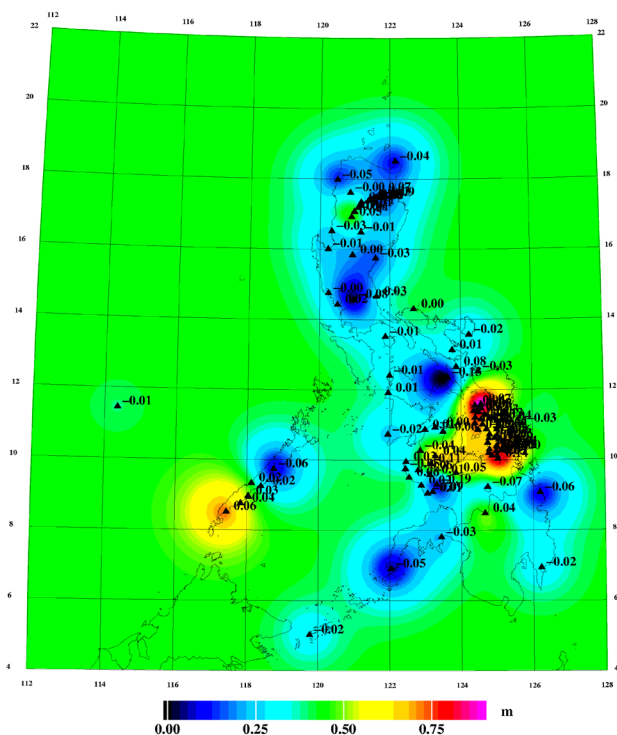


Figure 9. Location of GNSS/leveling data in PGM2014 (Colors show the offset values for the fitted geoid.)

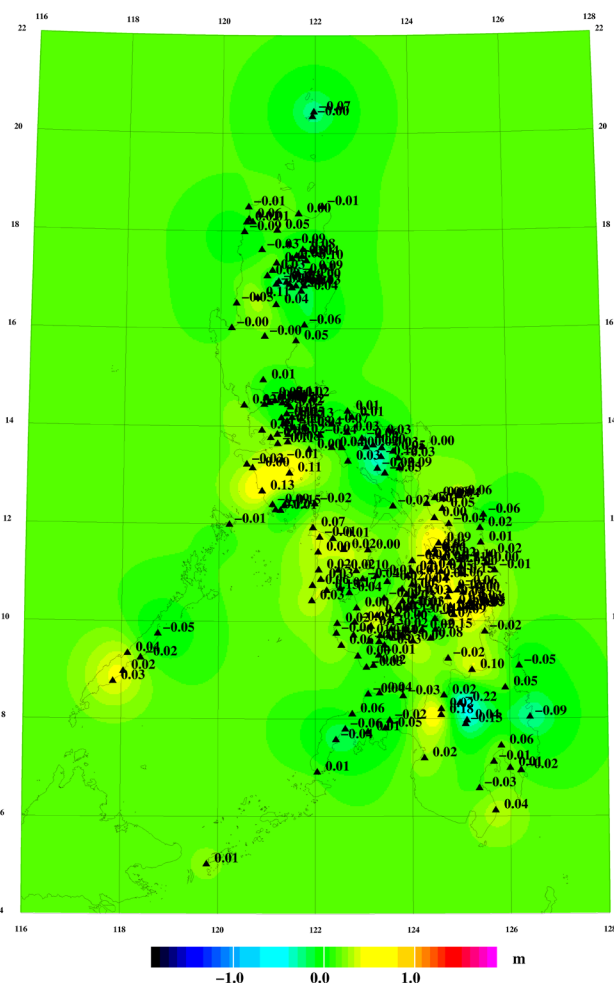


Figure 11. This shows the PGM2018 GNSS/leveling offset values. Majority of the points are in green and yellow, indicating a better fit of the geoid to the BMs

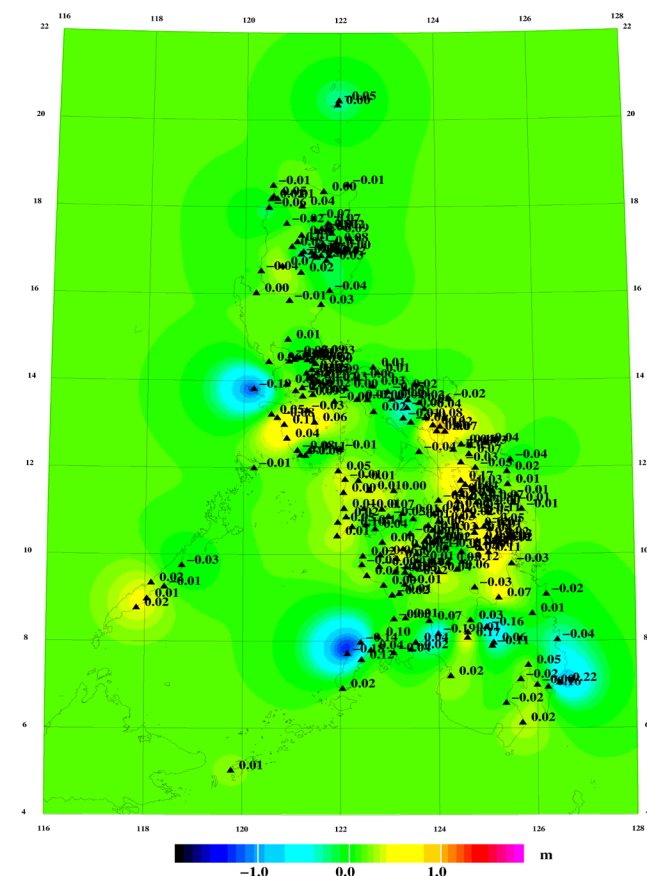


Figure 10. New offset values of the fitted geoid of PGM2016

Using the PGM

The PGM2018 can be used in two ways. The first method is by using the Grid Interpolation Program (see Figure 12) developed by Denmark Technical University (DTU). The steps are:

1. Select the grid format (.gri) of the PGM in local WGS84 or ITRF.
2. Enter the post-processed local WGS84 or ITRF latitude and longitude (input from keyboard) of the point desired. The geoid height will automatically pop up in the geoid value box.
3. Take the ellipsoidal height of the point and subtract it from the geoid value (use the formula $H = h^{GNSS} - N$) to get MSL elevation.
4. You can also compute the geoid heights in batch (listed in MS Excel file). The file format should be ID, latitude, and longitude.
5. Save the MS Excel file as .csv, open in Notepad, replace the comma with spaces then save the csv as .dat file.
6. Select the xxxxx.dat file (select point file) and name the output as xxxxx.out (output to file). The output file will have the geoid height (N)

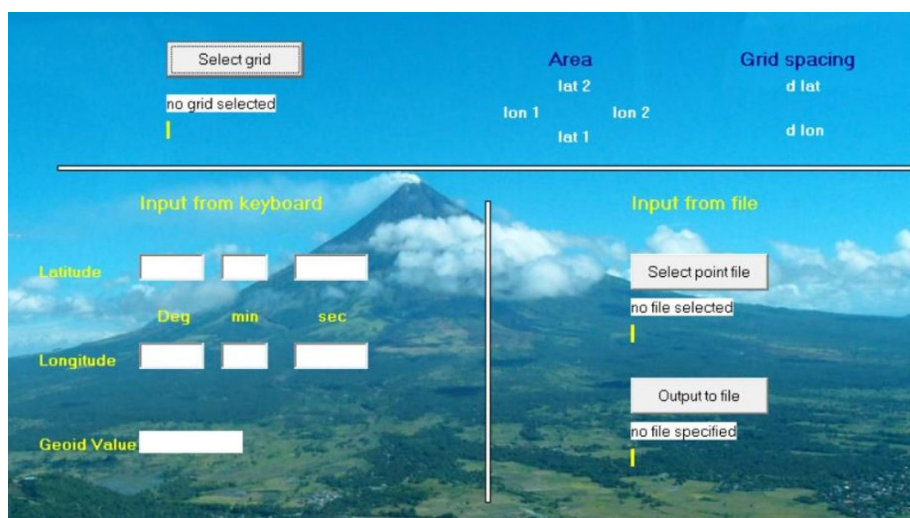


Figure 12. Geoid Grid Interpolation Program

at the fourth column (i.e., *ID, lat, long, N*). Use the formula $H = h^{GNSS} - N$ again to compute for the elevations. This program can be downloaded from the NAMRIA website.

The second method is through Trimble Business Center (TBC) Software. The steps are:

1. Select the *.ggf* format of the PGM in local WGS84.
2. Copy the *geoid2018.98_wgsfit.ggf* to program data > trimble > geodata.
3. Open TBC > coordinate system manager > geoid model > add + > type name of PGM (for instance, *pgmwgs2018.98*) > filename > select the *.ggf* file you copied to geodata > ok > save > save.
4. Click change coordinate system > coordinate system and zone > worldwide/UTM > Zone 51North > next > WGS84 none > next > at predefined geoid model, select your recently added geoid model > survey quality > type MSL at the vertical datum name > finish. After adjustment, the WGS84 grid point list will include the MSL elevation of the points.

Conclusions and Recommendations

The computation and recomputation of the Philippine Geoid Model were discussed in this article. The nominal accuracy of the geoid (PGM2018) is about 1 cm. To preserve the existing vertical reference datum of the topographic maps, the geoid was made to fit the network of BMs in the country, thereby unifying the different vertical datum of the islands and regions. The standard deviation of the fit is about 2 cm. For GNSS survey projects requiring elevation accuracies of about 3 to 30 cm, the geoid model is a good alternative to geodetic leveling.

The resulting *H* can only be as accurate as the geoid model and the GNSS surveys, thus, the following observations should be noted:

- 3D coordinates of GCPs change with time because of advancement in GNSS technology and crustal deformation.
- Ellipsoidal heights must be accurate and computed in about the same epoch as the GNSS/leveling (2010

or later); if not, vertical deformation model is applied.

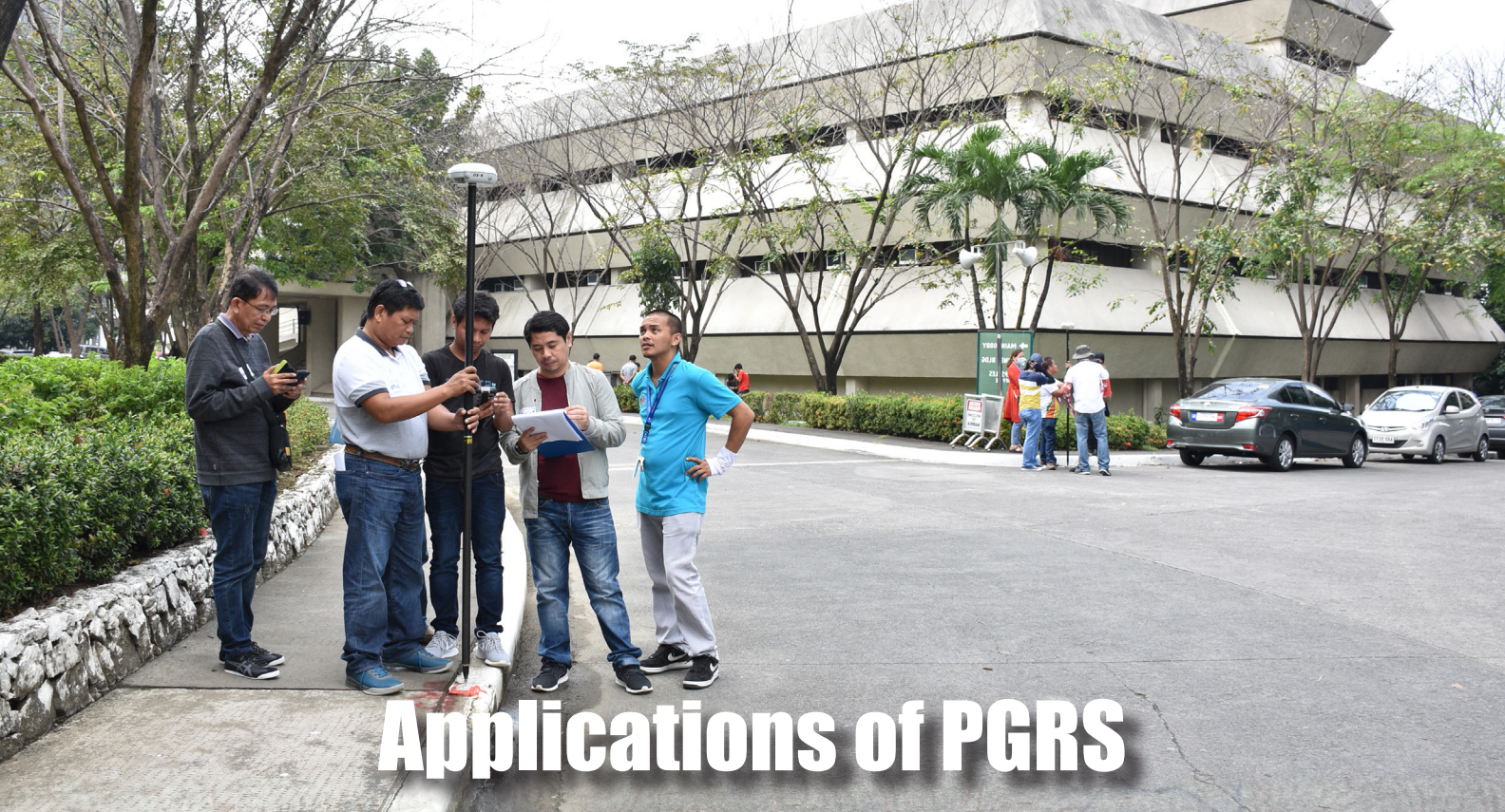
- If there is no deformation model, obtain the updated coordinates by connecting to an updated (reobserved) geodetic control. •

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Applications of PGRS

by: Engr. Charisma Victoria D. Cayapan

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egardless of one's awareness, everyone is affected by a change in the geodetic reference, either directly or indirectly. All position measurements emanate from the reference frame, so altering this foundation would naturally impact all geospatial information tied to it.

The modernization of the Philippine Geodetic Reference System (PGRS) is intended to address the limitations of an outdated datum and at the same time, take full advantage of the latest geodetic technologies to propel the attainment of the country's sustainable development goals. The work is by no means an easy task, fraught with technical, legal, and other issues that need to be carefully studied and sufficiently addressed. But the end goal of the modernization, that of accurate, up-to-date, and globally consistent geodetic reference data and services within reach of every Filipino, remains to be the driving force behind NAMRIA's geodetic reference system development activities.

A modern PGRS is expected to improve on how position measurements are collected and pave the way for the development and adoption of new applications utilizing geospatial information. The gains to be derived from the modernization cut across all sectors, from surveying and mapping, intelligent transport systems and unmanned navigation, climate adaptation and disaster mitigation, infrastructure development, and precision agriculture, to name a few.

The topics in the next pages discuss the benefits and ways forward of the PGRS Modernization Program in NAMRIA. The application of a modern PGRS for positioning in hydrographic survey are also in the succeeding articles. •

About the Photo: The modern PGRS supports the mainstreaming of GNSS in surveying and mapping operations. By transitioning to a modern PGRS, data from GNSS may be directly used without having to go through the complex transformation procedure that is needed when using a local geodetic datum.

Modern PGRS: What Is in It for You?

by: Engr. Ronaldo C. Gatchalian and Engr. Charisma Victoria D. Cayapan

As the frontliners to development tasked to define the “where” of the “what”, the surveying and mapping community is one of, if not the foremost stakeholder in the PGRS modernization. Transitioning to a geodetic reference frame that is in sync with the constantly changing world has both its upsides and challenges that geodetic engineers and geomatics practitioners need to be aware of.

Here is a rundown of the benefits:

Accurate (and up-to-date) positions. Coordinated monitoring of geodetic controls, both passive and active stations, means that end users have access to updated positions that are consistent with what is happening on the ground. The periodic refinement of the national deformation model provides a way to move backward and forward in time and still arrive at position measurements with geodynamic effects already accounted for.

Available 4D geodetic reference data. The geodetic infrastructure that has been established to support a geocentric and dynamic datum provides time-tagged geodetic reference data as in the case of the PAGeNet where precise GNSS data are gathered round-the-clock and in all-weather conditions. Once completed, users will also have access to unified control points that have all the geodetic reference data (geometric position, elevation, and gravity) in one monument.

Easier (and streamlined) survey operations. The availability of permanent and continuously operating reference stations result in faster and more cost-effective ground surveys with users no longer having to set up their reference or base stations to achieve more accurate results. Multiconstellation GNSS data from the active geodetic stations are available for download at different logging intervals and file lengths from the PAGeNet website (<http://pagenet.namria.gov.ph/AGN/Home.aspx>). Real-time correction services from a single base (real-time kinematic) or an array of reference stations (network-based real-time kinematic) are also available using industry-standard formats and transmitted using the Networked Transport of

Radio Technical Commission for Maritime Services via Internet Protocol (NTRIP).

With the development of the Philippine Geoid Model (PGM), GNSS heighting has also become feasible so users have an easier alternative for deriving elevation measurements compared to the conventional geodetic leveling. Users need only to input the geographic coordinates of the point of interest, and the geoid value will automatically be released which can then be used to compute the elevation above mean sea level (AMSL). Alternatively, users may upload the PGM grid file directly into their GNSS devices so that elevations AMSL will be automatically computed as they conduct their survey. The current version of the PGM app (2018.98) is available for download from the NAMRIA website (<https://www.namria.gov.ph/projects.aspx>).

Globally consistent data (and professionals). By connecting to a GGRF, position measurements have now become interoperable with other geospatial information from across the globe. Users can now take advantage of freely available global datasets and web-based platforms like Google Earth, without having to carry out (and understand) datum transformations.

It is not just the datum that has become interoperable with the rest of the world. Geomatics practitioners in the country are also capacitated to practice surveying and mapping on a global and dynamic stage. This is particularly important since the Philippines has taken part in mutual recognition agreements/treaties with its neighboring countries for the practice of geodetic engineering and geomatics.

The road to a modern PGRS is not an easy task. Changing the geodetic datum means having to deal with the change in positions. Users should expect the shift to be larger with the move to a geocentric datum, compared to when Luzon 1911 datum was upgraded to PRS92. In a research conducted by the University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) for NAMRIA on the implications of migrating to a geocentric datum on lot parcels, it was found that in the study area, positions were shifted by around 160 m southeast when cadastral



data were transformed from PRS92 (or Luzon1911) to PGD2020 (or ITRF2014). Other notable findings include:

- No significant change (>1 minute) was observed for bearings (or directions).
- Significant changes in distances (>1cm) and areas (>1 sqm) were detected. The changes depend on either theoretical (based on records) and actual (based on observed coordinates), Luzon 1911 (PTM) transformation, or PRS92 coordinates to PGD2020.
- Theoretical coordinates are not always consistent with observed coordinates. Effects of parameters on parcellary data are also significantly different depending on whether the parameters were derived using theoretical or observed PTM coordinates.
- PRS92 tends to have no significant change in technical descriptions because it is more homogeneous compared to the old Luzon 1911 (PTM).

The research team recommended the conduct of an actual ground survey of reference monuments/control points to verify the theoretical coordinates before using them to transform parcellary data to PGD2020. The actual ground survey will also allow for the establishment of a common point and cross-validation analyses to ensure the best combination of control points in deriving the transformation parameters.

Moreover, existing land survey regulations such as DENR Memorandum Circular 2010-13, on “Adopting the Manual on Land Survey Procedures,” still have no mention on the use of modern PGRS data and products in land surveying workflows. The current standards of accuracy of geodetic control networks also need to be updated to include the zero-order controls and to include other metrics in assessing positional uncertainty.

Transitioning to a modern PGRS requires a major shift on how the geodetic reference frame is realized and how users can connect to it. Communicating this change to stakeholders is paramount to ensure the successful transition into the new system. Academic institutions offering surveying and mapping courses play an important role in capacitating future geomatics practitioners on dynamic GRFs. Professional organizations also need to step up and upgrade the skills set within their ranks.

Understanding the hows and the whys of the PGRS modernization is one thing, ensuring that stakeholders can readily access modern PGRS data and products is another. NAMRIA is working on developing geodetic toolkits and putting up the platform to facilitate user access to modern PGRS data and products.

NAMRIA continues to work towards strengthening the geodetic infrastructure and bringing these modern PGRS products and services closer to the surveying and mapping stakeholders. •

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Positioning in Hydrographic Surveys and the Modernization of PGRS

by: LCdr. Gilbert A. Alviola

Hydrographic surveying is one of the core functions of NAMRIA. This task involves the mapping of seas and oceans to produce nautical charts which are used by mariners primarily for the safety of navigation. Hydrographic surveying is typically concerned with the measurement of depths, as well as the description of the physical features of bodies of water (IHO, 2005).

The application of this field of science is not only limited to maritime safety. The survey data can be used in support of other marine activities, especially in economic development and scientific research.

With the rapid advancement of technology in the past decades, hydrographic surveying has also evolved in the digital age, especially with the utilization of the Global Navigation Satellite System (GNSS) in positioning.

Most hydrographic surveys are conducted using two kinds of sonar equipment. Sonar (sound navigation and ranging) is a technology that uses sound waves or acoustic signals to detect objects and their location in the ocean. The single-beam echosounder system

primarily uses a single ping of a sound wave to measure the depth of water at a particular position, whereas the more sophisticated multibeam echosounder system uses a swath or a fan of sound waves, sending multiple signals to the seafloor so that a larger extent of the seabed is surveyed at one passing.

What is a sounding?

The fundamental element of a hydrographic survey is sounding. A sounding is a point on the surface of the water, much like a point on the ground described by its position in three dimensions. Whereas a point on the Earth is defined by latitude, longitude, and elevation, a sounding is typically defined by latitude, longitude, and depth. The depth here is the vertical distance from the seafloor to the chart datum being used.

What is a chart datum? One cannot just say that the depth of water is from the seafloor to the surface. Why? This is because the sea surface is rising and falling owing to the effect of the tide. Tide is the rising and falling of the surface of a body of water caused primarily by the gravitational forces of the moon and the sun.



Figure 1. Single-beam and multibeam survey boats of NAMRIA in Abra de Ilog, Occidental Mindoro

Horizontal and Vertical Positioning of Soundings in Hydrographic Survey

Importance of positioning in hydrographic survey

Positioning is an important aspect of hydrographic surveying. The first two elements of a sounding are the *X* and *Y* position and are referred to as the horizontal aspect of positioning. It is important for the positions of soundings to be acquired accurately for safety of navigation.

As an example, the US minesweeper ship USS Guardian ran aground on the country's Tubbataha Reef in 2013 causing colossal damage to the coral reefs. The ship had to be dismantled to be removed from the area and the United States had to pay 87 million pesos to the Philippine government. Upon investigation, the leading cause of the accident was an erroneous chart produced by the US National Geospatial-Intelligence Agency, where it was found that the position of soundings was highly inaccurate (*Philippine Daily Inquirer*, 2014).

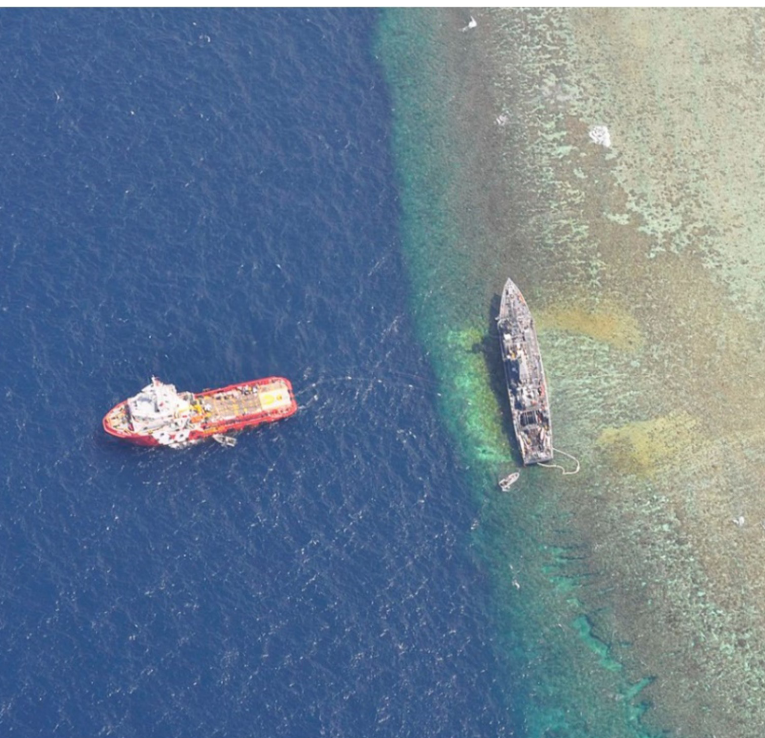


Figure 2. USS Guardian shown aground on Tubbataha Reef with an assisting Malaysian tugboat

Horizontal positioning in hydrographic surveys is now mainly achieved through the technology of GNSS, or more commonly known as Global Positioning System (GPS). The term GNSS is more appropriate to use because GPS is the satellite system of the United States. The GNSS devices in NAMRIA's survey equipment not only utilize the satellites from GPS, but also those from GLONASS (Russia), and sometimes GALILEO (European Union) and Beidou (China).

Standards of positioning in hydrographic survey

The current standards of positioning in NAMRIA's hydrographic surveys are set by the NAMRIA Standards for Hydrographic Surveys (NSHS), which is mostly based on the IHO (International Hydrographic Organization) S-44 publication (IHO Standards for Hydrographic Surveys). This NSHS also contains the manual or guidelines in conducting hydrographic surveys.

Essentially, the standards of positioning are determined by Total Propagated Uncertainty (TPU). TPU has two components in hydrographic surveys: Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU).

THU and TVU are not determined by just one factor such as the accuracy of the GNSS equipment; rather, these are the collective propagated uncertainties caused by variable factors in the sonar system (multibeam or single-beam echosounder system). Some of the parameters that need to be factored in are instrument error, sound speed error, tide measurement error, vessel motion, and time synchronization, among others.

Use of GCPs in RTK Positioning of Soundings

Horizontal positioning using RTK

Real-Time Kinematic (RTK) positioning is one of the primary positioning methods used by NAMRIA in the conduct of hydrographic surveys. In this GNSS technique, a base station is set up in a known location on land while the survey vessel is equipped with a GNSS rover receiver as part of its echosounder system. The GNSS base station will broadcast satellite corrections that will be received by the rover receivers in real time, which will dramatically increase the accuracy of the measured position of soundings. Figure 3 shows a diagram of hydrographic surveying using RTK positioning.

Vertical Positioning of Soundings in Hydrographic Surveys

The vertical positioning of soundings in traditional NAMRIA hydrographic surveys is highly dependent on the tidal data as processed by its Hydrography Branch. The vertical distance from the seafloor to the water surface is subjected to the application of tidal



corrections, or the corrective vertical distance from the surface to the chart datum. In hydrographic surveys, NAMRIA's chart datum is referred to the Mean Lower Low Water (MLLW). The MLLW is the average of the lower low water levels in a particular area in a given epoch, which is usually over 19 years.

The role of the modernization of PGRS

The modernization of the Philippine Geodetic Reference System (PGRS) is critical to the improvement of sounding positioning in hydrographic surveys. The updating of the base stations to the current realization of the World Geographic System (WGS84) datum would imply that the resulting soundings from the surveys will also be referenced to the current realization of WGS84. With this, the nautical charts that will be produced with these surveys will now be consistent with the widely used Google Maps and Google Earth interface, providing increased convenience for the mariners and the general public.

The modernization of the PGRS will improve the accuracy and integrity of the base stations used in hydrographic surveys. This will aid the hydrographic and bathymetric products of NAMRIA to be at par with global standards. •

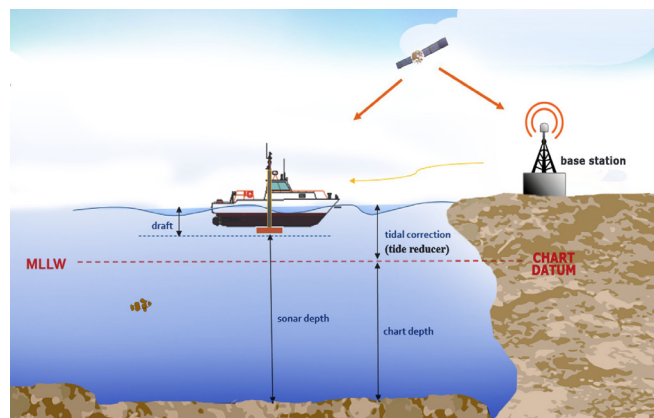


Figure 3. Diagram of hydrographic surveying using RTK positioning

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