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2017 Survey of Guam and Commonwealth of Northern Mariana Islands (CNMI)

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NATIONAL OCEAN SERVICE

National Geodetic Survey
Juliana P. Blackwell, Director

Survey Report

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I. Introduction

In the summer of 2017, the National Geodetic Survey (NGS) conducted a geodetic survey in Guam and the Commonwealth of the Northern Mariana Islands (CNMI). The primary purpose of the survey was to collect Global Navigation Satellite System (GNSS) data on geodetic control marks that had been surveyed in the past by NGS. Such data collection was intended to determine the rotational behavior of the Mariana tectonic plate. As travel to such a remote location is expensive, additional components were added, including the collection of terrestrial gravity and the reconnaissance of each island to determine a variety of future survey needs.

The survey was challenging and unique in a number of ways. It was planned and completed in an extremely short amount of time due to funding constraints and, even without that limitation, was logistically difficult. Due to this, the reporting of this project is also different in that the project team felt it was important to not only document why NGS had completed the project, but also how the project was completed. This report is in essence three reports: It comprises a report on the logistics, the horizontal and vertical data adjustment (internal NGS project number “GPS3209” and Attachment A herein), and the data necessary to complete rotation computations. The last two items are standalone products archived in other appropriate places within NGS records, but included as attachments here to provide an easy singular resource for the reader.

A. Authority

This project was planned and approved by the NGS Project Review Board, and the Project Plan was signed on August 16, 2017. The survey was conducted in accordance with the document titled “INSTRUCTIONS: 2017 Survey of Guam and CNMI,” approved by Juliana P. Blackwell, Director on August 23, 2017. Attached to the Project Instructions was a document prepared by Dru Smith titled “Island by Island Recommendations” (Attachment B), which outlined the priority of the marks to be collected on each island and detailed which historic surveys those marks represented. The field crew attempted to follow each list, but had a fallback plan if a mark was not observable or recovered. These recommendations, titled “2017 Guam/CNMI Survey In-situ Recommendations” (Attachment C), were edited based on incoming knowledge, with an attempt made to transmit an updated priority to the crew while on the charter boat after a mark on West Maug was not recovered.

B. Purpose

The primary purpose of this survey was to collect GNSS data and use that to compute IGS08 coordinates at select marks in Guam and CNMI. The marks were specifically selected because they had also been surveyed by NGS in the past with enough historic GPS data (2 or more hours, sometime after 1994) capable of computing historic IGS08 coordinates. These new and old coordinates are to be used to compute vectors of mark motion over time, which will, in turn, be used to estimate the Euler Pole Parameters (EPP) of the Mariana plate.

Secondary purposes of this project included:

1. The collection of terrestrial relative gravity data throughout Guam and CNMI (especially the northern islands)
2. Describing and photographing geodetic control points used in previous (1994 and forward) surveys of the northern islands
3. Performing reconnaissance of the northern islands for potential geodetic site installations (CORS, passive control marks and/or SAR reflectors)
4. Outreach to Rota and Tinian Islands for potential CORS installation

It should be noted that only minimal effort was able to be dedicated to items 3 and 4 above due to the intense nature of the field conditions and changes to the project schedule. Overall, the primary purpose and secondary purposes (items 1 and 2) were a resounding success. Attachment D lists all of the marks surveyed during this project, along with previous occupations.

C. Time Period

Considering travel days of the earliest team member assigned and the last returned, this project was underway from August 25 to September 26, 2017. Observations taken ranged from Day 239 to 265 although some days did not include observations and instead consisted of chartering from island to island.

II. Location

A. Locality

The project successfully completed observations on the islands of Guam, Rota, Tinian, Saipan, Sarigan, Alamagan, Pagan, Agrihan, Asuncion, and Maug.

B. Limits

Survey operations were roughly within the limits of:

20° 02’	North Latitude
13° 14’	North Latitude
214° 09’	West Longitude
215° 22’	West Longitude

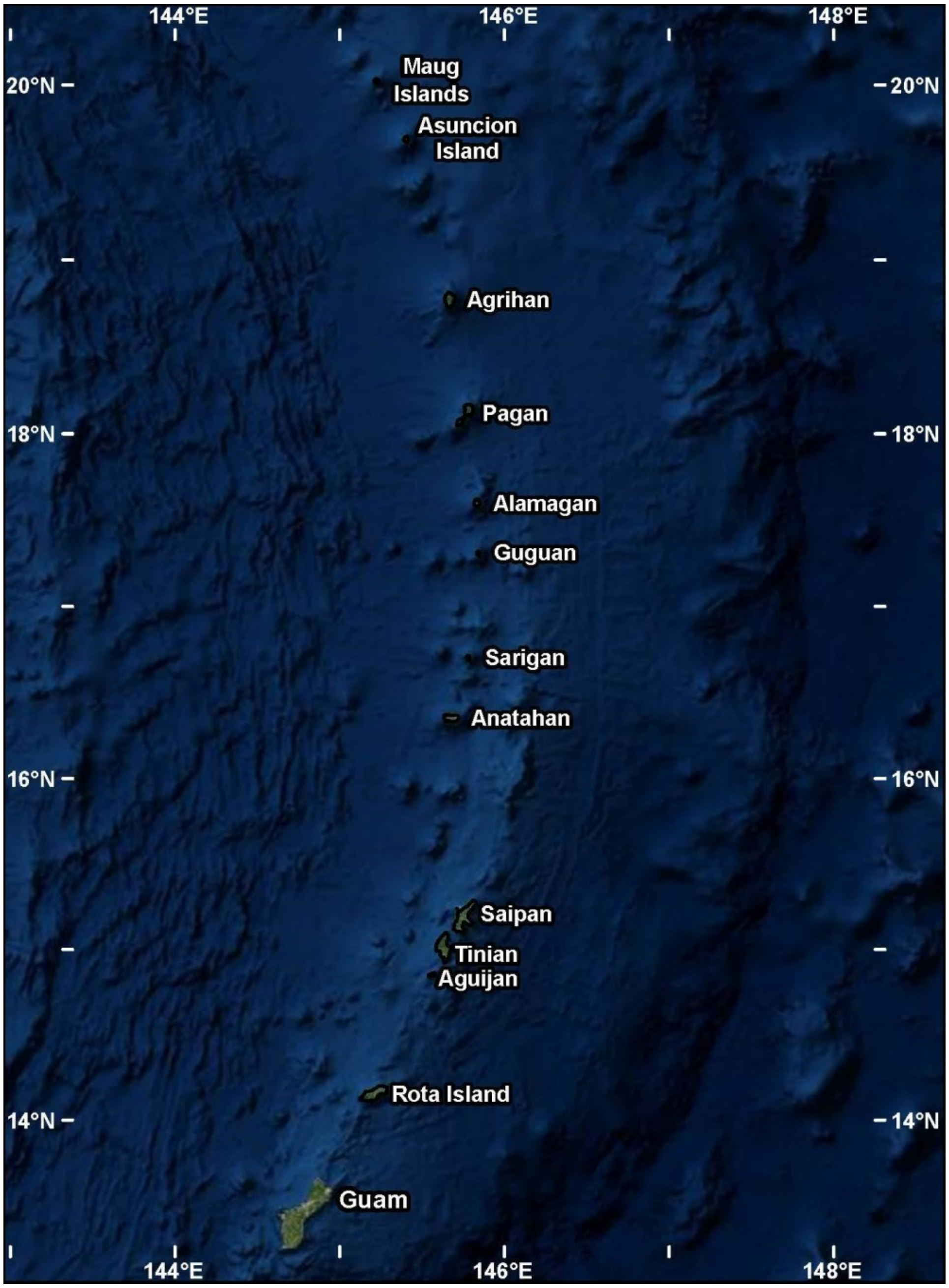


Figure 1. Map of Islands included in the project.

III. Organization of Party

A. Personnel

The following personnel were involved in the projects operations:

National Geodetic Survey

Ryan Hippenstiel	Project Manager / Field Operations Branch Chief
Dru Smith	Science Advisor / NSRS Modernization Manager
Kendall Fancher	Field Manager / Instrumentation & Methodologies Branch Chief
Ed Carlson	Field Observer / Pacific Regional Geodetic Advisor
Jim Harrington	Field Observer / Cartographer
Dan Gillins	Data Analyst / Geodesist

Office of Marine and Aviation Operations

Capt. Joe Bishop	NGS Director of Operations (Assigned at time)
Lt. Jared Halonen	(NOAA Corps) Field Observer / Marine Support

Figure 2. Team members hiking to a mark.

B. Team Composition

1. The field team that traveled to the islands was comprised of Fancher, Harrington, and Halonen. In addition, Carlson, assisted with observations on Guam, Rota, Tinian, and

Saipan. The NOAA Corps Officer (Halonen) was extremely valuable in operating the small vessel, allowing rest for the captain, and keeping sea conditions and safety in mind at all times.

2. The office team consisted of the Branch Chief and Regional Advisor from above, the Project Manager (Ryan Hippenstiel, FOB Chief), the NGS Director of Operations (Capt. Joe Bishop), and the NSRS Modernization Manager (Dru Smith). Fancher was the leader on costs estimates, project instructions, and the project plan. Carlson handled local contacts, the science license application, and charter acquisition. Bishop managed charter inspection and contracting. Smith dealt with the observation recommendations, the project charter, and the project plan.

3. Other NGS resources (Budget, Admin, Environmental Compliance Coordinator, HQ support, etc.) were critical to the successful creation and completion of this project.

4. In addition, we would like to acknowledge the aid given by the Guam Department of Land Management (DLM), who provided field surveyors to complete the GNSS observations conducted on Guam. NGS is grateful for their participation as it allowed the occupation of more marks during those survey days.

IV. Planning and Logistics

The planning of this project was difficult and the schedule was very tight. NGS was granted $73,000 from the National Ocean Service to help fulfill funds necessary for this project. With a charter boat necessary for reaching such a remote location and the time constraints of the federal government's fiscal year, team members were required to complete large tasks quickly. Within one week of the notification of stimulus funding, a draft project charter had been written, and research on past missions in the region had begun. Within one month, the charter was approved, observations plans were being improved, a statement of work for the charter vessel was drafted, and the application to work on the unpopulated islands was approved by the CNMI government. The vessel was contracted and cleared with OMAO support, final field instructions were issued, and the survey crew was on the ground within two months. This project was successful, but it is important to note that this short of a timeline is not recommended for future projects in this area.

A. Charter Boat

1. **Cost** — Current (2017) lowest pricing was roughly ~$8,000 per day, and the estimates ranged all the way up to ~$18,000 per day. The charter vessel was contracted, receipted, etc., through the normal NOAA Acquisition process. The charter company did require an additional letter to them requesting that someone who was certified in CPR and first aid be on the charter (even though it had been included in the Statement of Work). At the end of the survey, Acquisition personnel required a signed receipt and statement that the vessel provided services acceptable to NOAA and that it fulfilled the project mission.

2. **Compliance/Safety** — NOAA Form 57-11-02 needed to be completed and sent to OMAO Compliance Division in order to research the charter vessel and ensure it was seaworthy. The stated turnaround would normally be about a month but they did expedite the process for us in order to meet Contracting deadlines. NGS completed this form and pulled the Certificate of Documentation, Notices of Inspection, etc., for submission. The form was approved and returned with a SECD Reviewer's Report with concerns and/or recommendations for the vessel. In our case, the concerns were minimal and correctable. For example, the vessel was due for an inspection by the United States Coast Guard, but this inspection was arranged before departing to the northern chain of islands.

3. **Description** — The main charter vessel was sufficient for this survey although the accommodations were minimal due to the remote location. A formal kitchen/refrigerator was not available (only a freezer) so this should be accounted for when contracting and/or provisioning for future missions. The charter boat also had a smaller vessel for transport from the main vessel to the shore. It was a 19' aluminum vessel and sufficient for this purpose, but could only be used safely in appropriate sea conditions to facilitate landing.

Figure 3. Charter vessel on left with GNSS and gravity observations on-going to right.

B. Environmental Clearance

In order to ensure the survey and our presence on the islands was not harmful to the environment and met all local standards, we conducted both internal and external environmental clearance processes.

1. **Scientific Permit needed from CNMI** — The Commonwealth has a process in which NGS provided project details and submitted an application for a Scientific Research License. It was approved by the Division of Fish and Wildlife (DFW). NGS submitted the scope, location, and duration of the work to be performed and the DFW reviewed and, in this case, approved our survey project with a list of Special Conditions field personnel were required to follow (no fires, commercial fishing, etc.), and a term for which the license was valid. Our project did not cause any large concerns with DFW/CNMI, but they asked that we be aware of and not affect two species of snail, in the unlikely chance we would encounter it. At the time of survey, this application required a $10 fee and the form can be currently found on their site: http://www.dfw.gov.mp/Enforcement/SciencePermitForm.html

a) **Application** — Completed form is archived within NGS project files as “CNMI Scientific Research License Application-NGS-A-signed.pdf”
b) CNMI approved and then provided NGS with Conditions (document name in archive: Sci research license 2017.pdf)

c) **Email from CNMI**: “The Scientific Research Review Committee reviews applications on a monthly basis. Applications received by the 15th of the month are reviewed at our monthly meeting on the 4th Thursday of the month. The outcome of a committee review may be a recommendation to the DFW Director for approval and suggested license conditions, a request for more information, or a recommendation for denial of the application. I recommend you also contact the Northern Islands’ Mayor’s Office regarding this project.”

2. NGS received the information from DFW and also conducted internal scoping of any environmental or cultural concerns for the areas field personnel would be working. This information was documented by the Project Manager and submitted to the NGS Safety & Environmental Compliance Officer. A memo was drafted and then signed by the Director of NGS with all information, including the Science License, as attachments. This signed memo summarized all concerns and instructed the team to complete all project work in accordance with all environmental standards and laws pertinent to the project. These files can be found in internal project records.

C. Transportation of Equipment

Parcel shipments to Guam and the CNMI are considered as “international shipping”. This requires packages pass through a US Customs clearance process, potentially creating delays in the delivery process. To ensure availability of surveying equipment, project participants transported all surveying equipment as “excess baggage” on commercial airline flights. If this approach is used in the future, the extra baggage costs should be taken into account.

V. Field Work

Twenty-three days of campaign style GNSS observations were performed on Guam, Rota, Tinian, and Saipan in which as many as up to 8 receivers were deployed simultaneously by multiple team members. After those days, the charter crew readied for roughly two weeks of sailing north along the Mariana Islands chain. Once they departed, they were quickly out of cellular range and the only communications were satellite phone communications in case of emergency, and small text messages via a tracking beacon carried by one of the crew members.

A. Survey Instrumentation

1. **GNSS** — NGS used Trimble R8 and OPUS X90 GNSS receivers to collect GNSS data. The Trimble R8 and OPUS X90 receivers incorporate an integrated GNSS antenna. The Trimble R8 (antenna calibration TRM8_GNSS) and OPUS X90 (antenna calibration CHCX90D-OPUS) have been calibrated by NGS with calibration information available at the NGS GNSS Antenna Calibration webpage. In addition, the Guam Department of Land Management (DLM) used Leica GS15 receivers and Trimble 5700 receivers paired with Zephyr Geodetic antennas.

Figure 4. Typical equipment set-up and conditions of observations.

2. **Gravity** — The Scintrex CG-6 relative gravimeter was used to collect all relative gravity data associated with this project. This piece of equipment was transported as "carry-on" luggage with the Field Manager.

B. Observed Conditions

The following notes are conditions experienced during the surveys and related concerns about conditions or recommendations for future missions to the locations. These notes were compiled by the Field Manager, Kendall Fancher, and edited for the purposes of formatting. In addition, recommended locations for landing vessels can be found in Attachment E.

1. **Conditions of Islands**

a) Pagan has multiple well-protected anchorage locations and small watercraft landing areas near the primary control mark PAGAN 1 (AA5095), with landing areas consisting of sandy beaches. Traveling ship-to-shore at Pagan should be possible in all but the worst of weather conditions (when the winds are blowing from west to east). Pagan has a large population of feral pigs and cattle, and the foraging habits of these animals serves to keep vegetation under control. This makes it possible to hike around most of the island without the need for machetes. There are well established trails leading: from the landing areas east to the eastern shore, and to the north through a pine forest. At the time of this survey there were three individuals camping near PAGAN 1.

b) The three islands of Maug form a large, protected lagoon which offers several options for anchorage. Small watercraft landing areas for the islands consist of either lava flow areas or large, flat boulders located at the shoreline. Travel from ship-to-shore at Maug should be possible in all but the worst of weather conditions. In general, the terrain on all three islands is steep and rocky in nature. Without the use of mountain climbing gear, there are very few areas away from the shoreline which can be safely explored on these islands. The route from the landing area to control mark MAUG RM 2 (DQ9503) is a treacherous hike across boulders along the shoreline, finishing with a steep ascent up a grade consisting mostly of sandy loose soil and small boulders. Control mark MAUG LDGO (DQ9502) is located near the landing area. At the time of the survey there were no individuals living on the islands of Maug.

c) Asuncion has an anchorage location and small watercraft landing area located near primary control mark ASUNCION AZIMUTH MARK (DK2820). The landing area consists of a large, relatively flat lava flow extending out from the shoreline. Great care must be taken when exiting the small watercraft at the landing area as the rock surfaces can be very slick when wet. The route to ASUNCION AZIMUTH MARK, from the landing area, is a very slick hike across a lava flow area, then across boulders along the shoreline, finishing with a steep ascent up a grade consisting mostly of sandy loose soil and small boulders. The landing area for control mark MACAW (AA5096) is an approximate 40-foot tall cliff at the shoreline. There is a protruding rock feature of the cliff at the waterline, allowing for stepping off of the small watercraft when mild sea conditions permit. The cliff itself has sufficient hand holds such that it can be scaled with relative ease. Once on top of the cliff, the remaining hike to MACAW is a relatively easy trek across the mostly flat top surface of the cliff. In general, the terrain on Asuncion is very steep with dense jungle stretching from the shoreline to near the summit of the island. The jungle is too dense to allow for GNSS data collection without extensive clearing of underbrush and native trees. At the time of this survey there were no individuals living on the island of Asuncion.

d) Agrihan has anchorage and a landing area located nearby primary control mark AGRIHAN LDGO (DK2827). During our visit to this island the winds were not favorable for using the anchorage near the mark, so the ship anchored about 3 kilometers north of AGRIHAN LDGO in a small, protected bay area. The landing area is a sandy beach, which under prevailing weather conditions allows for a relatively easy and safe landing of a small watercraft. During our visit the winds were blowing from the northeast creating rather dangerous landing conditions with waves, approximately 8 feet in height, breaking at the beach line. The landing and departure of the small watercraft had to be timed very carefully, in between the waves breaking onto the beach. The hike from the landing area to AGRIHAN LDGO is an easy hike along a large and relatively flat lava flow area, interspersed with sandy areas, extending out into the ocean. In general the terrain on Agrihan is very steep with dense jungle stretching from the shoreline to near the summit of the island. The jungle is too dense to allow for GNSS data collection without extensive clearing of underbrush and native trees. At the time of this survey there were three individuals camping near AGRIHAN LDGO.

e) Alamagan has anchorage and a landing area located near primary control mark ALAMAGAN RM 3 (DK2819). There are two landing areas near the mark, one is a small cobblestone beach and the other is a relatively flat portion at the base of a large lava bluff in which ALAMAGAN RM 3 is set. During our visit the winds were blowing from the northeast, creating rather dangerous landing conditions with waves approximately 8 feet in height and breaking at the beach line. This sea state made the bluff landing site the safer option. The hike from the landing area at the base of the bluff to the control mark is a fairly easy climb up the bluff and across the top of the bluff to the mark. Great care must be taken when exiting the small watercraft at this landing area as the rock surfaces can be very slick when wet. In general, the terrain on Alamagan is very steep with dense jungle stretching from the shoreline to near the summit of the island. To the north of ALAMAGAN RM 3 is a large area of lava flow with vegetation mostly less than eye level. While steep and covered with loose boulders, this area is suitable for hiking and for GNSS data collection. To the south of ALAMAGAN RM 3 the jungle is too dense to allow for GNSS data collection without extensive clearing of underbrush and native trees. At the time of this survey there were no individuals living on the island of Alamagan.

f) Sarigan has anchorage and a landing area located nearby primary control mark SARIGAN AZIMUTH MARK (DK2824). The landing is along the north side and near the middle of a relatively flat lava flow extending out from the shoreline. Great care must be taken when exiting the small watercraft at the landing area as the rock surfaces can be very slick when wet. The route to the control mark from the landing area is easterly across the lava flow area to the jungle at the shoreline, then north through the jungle to the mark ahead, near a bluff line. Field personnel encountered several monitor lizards, which did not seem aggressive. The western side of Sarigan is very steep with dense jungle stretching from the shoreline to near the summit of the island. The jungle is too dense to allow for GNSS data collection without extensive clearing of underbrush and native trees. At the time of this survey there were no individuals living on the island of Sarigan.

2. Conditions of Marks

Most of the control marks recovered during this project were recovered in relatively good condition. There were a few exceptions as noted in this section.

a) MAUG (DK2822) — A thorough search for this mark in the described location revealed no evidence of the monument. The mark was a disk set in a concrete post on a sandy saddle of a very steep ridge line. Severe erosion has occurred in this area over the years. Nearby reference mark MAUG RM1 is in danger of being completely undercut from wind erosion and in danger of tumbling into the ocean below. It was not safe to walk out to MAUG RM1 at this point as the surrounding area is very unstable. Based upon the conditions encountered, it is likely the soil around the monument for MAUG was eroded away due to wind and rain until the monument itself rolled off of the steep grade and into the ocean below. (DK2822 has since been archived in the NGS IDB.

b) SARIGAN AZIMUTH MARK — The mark is a survey disk set into a concrete monument projecting above the surrounding ground surface. The monument is in very poor condition. The concrete is failing and is severely cracked, with the top portion likely no longer affixed to the bottom of the monument. Severe erosion has occurred around the base of the monument. The land area that the monument was set in is also being eroded away, with the monument itself now being located about 2 meters from a steep cliff that falls off to the ocean. Based on the conditions encountered at the time of the survey, it is likely that this mark will eventually sluff off into the ocean below.

Figure 5. Condition of SARIGAN AZIMUTH mark.

C. Survey Observations

During the course of this survey, the primary data products collected were long static GNSS observations. Where possible, terrestrial gravity measurements were taken, often simultaneously with the GNSS observations when the benchmarks were available. There were a very small number of fast-static GNSS observations taken to support additional gravity measurements.

1. **GNSS observations** — The attached GPS Adjustment Report provides great detail about the observations collected and their adjustment. In general, the deliverables consisted of a data file, photos of the marks and equipment during data collections, and field logs that recorded pertinent information (condition of mark, equipment, instrument height, etc.). This metadata serves to inform the data

adjuster of the quality of the observations and assists troubleshooting potential anomalies in the data. The GNSS observations led to updates to coordinates in the NGSIDB and will be used to derive Euler Pole parameters in a new upcoming terrestrial reference frame for the Mariana plate region. This update will represent a thirty (30) percent difference from previous values. This work is detailed below as Attachment A.

2. **Gravity Data** — While the collection of gravity was a secondary goal, this project did provide a repository of terrestrial gravity data on the islands along with pushing our normal timeline of a relative survey. Gravity data were collected using a Scintrex CG-6 portable relative gravimeter in daily control "loops" (sometimes multiple) on each island. Often these loops shared stations, forming a small network of sites. The instrument acquired 1 Hz data for about 10–15 minutes at each site. At the end of the project, all of the data were analyzed as one large network, tying all the stations together and removing a single, linear instrument drift from the raw data. Absolute gravity station GUAM_AA served as the fundamental base station (all gravity values were differenced from this site). In total, 21 gravity values were determined with a typical total uncertainty of 10–15 microGals. The quality of the data was unexpectedly good (six weeks is much longer than a typical relative survey), and led to an AGU poster (van Westrum and Kanney) describing the possibility for new, efficient relative gravity survey methods. The figure below shows the marks or points in the control loops where gravity data was collected as the survey progressed.

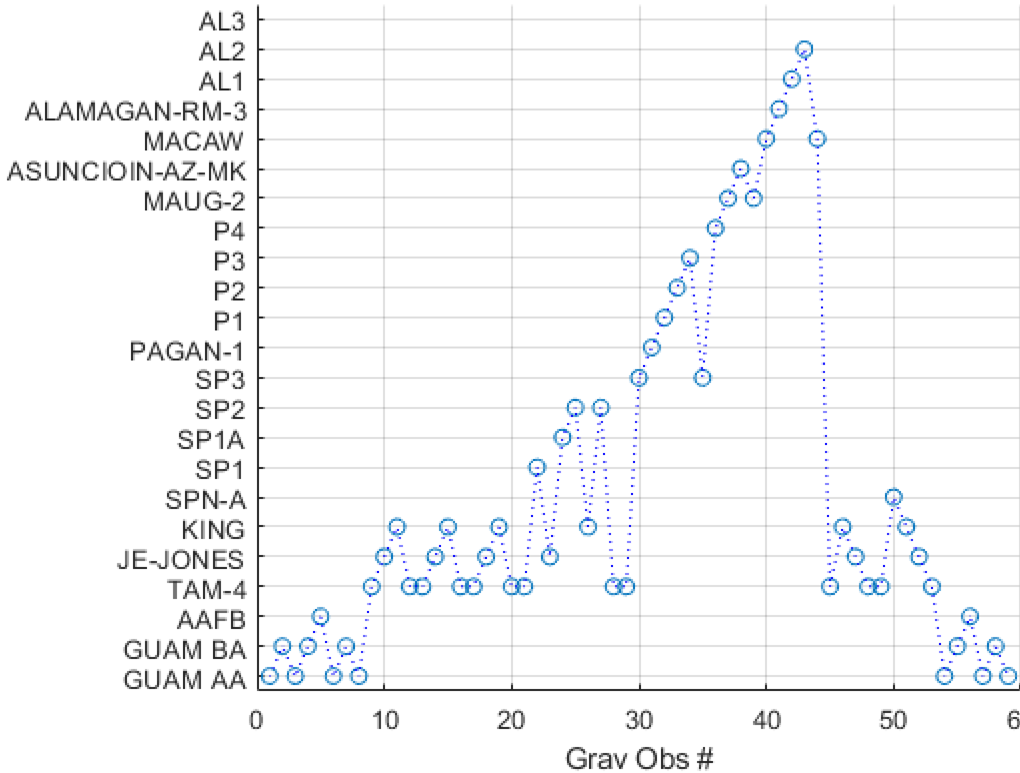


Figure 6. Locations of Gravity Observations over the Course of the Survey

VI. Deviation from Instructions

The project instructions and island-by-island recommendations were generally followed when conditions allowed, but the field crew was limited by terrain, vegetation, sea conditions, and the absence of benchmarks. In the case of vegetation, this meant multiple gravity marks (and an RTK observation of each) were not able to be observed so the field crew shifted its concentration to long gravity observations on the primary marks. The terrain and sea conditions also made it impossible to observe a certain group of marks because landing would prove too dangerous. For marks that were not safely accessible, or if they were found to be destroyed by natural conditions, substitutions were chosen and observed. In addition, the office team was receiving small communications from the field crew via the tracking beacon. Data about an island being skipped due to sea conditions or a mark not being observed were transmitted, and the Science Advisor produced on-the-fly suggestions on how to best adapt the survey (see Attachment C). These were communicated and taken into advisement by the field crew leader. In all cases it was agreed upon prior to the charter that the Field Manager would have final authority to make the best decision in concert with the charter captain to ensure the safety of the crew.

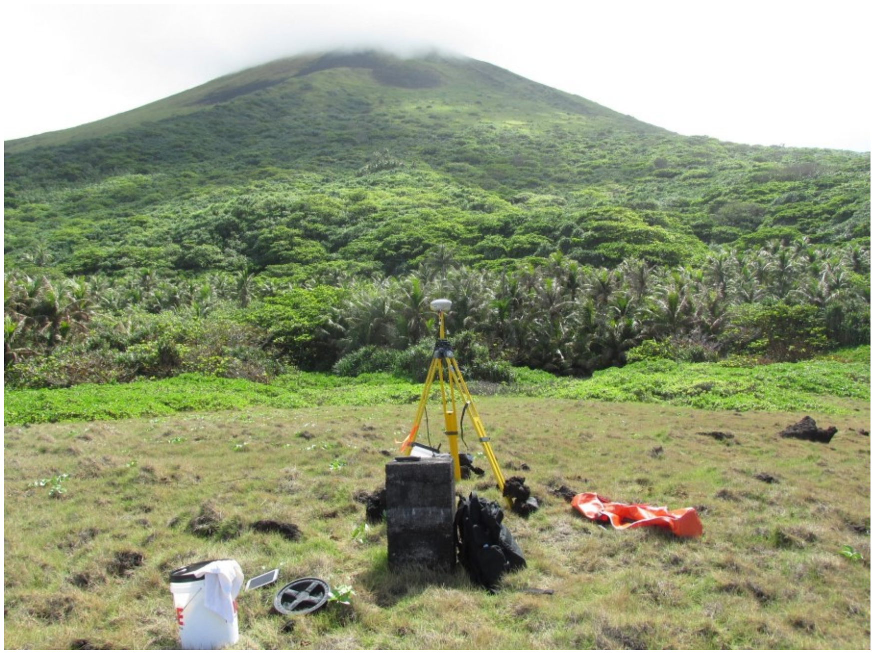


Figure 7. Thick vegetation restricting access to higher elevations was typical.

VII. Information/Recommendations for Future Missions

Each survey project is unique and requires a particular scope of work, but should another team be conducting a similar project or one in this geographic area, below is a list of items NGS suggests being taken into consideration.

A. Mission Timing

The most difficult and dangerous aspect of this project was transporting equipment and personnel from ship to shore. The optimal time of year to conduct this type of survey would be during the month of May, according to the captain of the vessel chartered for this survey. The captain stated that during the month of May the sea state is typically calm. Scheduling a similar survey during the month of May would provide the greatest assurance of being able to maintain a schedule and transit from ship to shore safely and efficiently.

B. GNSS Observations

The next survey should focus on GNSS observations. Relative gravity observations were not possible beyond the coastline on Maug, Asuncion, Alamagan and Sarigan due to the dense jungle foliage, prohibiting the use of GNSS to position gravity points. The intent of this survey was to collect RTK-GNSS observations on each gravity mark. This approach led to the selection of an integrated style of GNSS equipment with one module containing the antenna, receiver, and radio to deploy on this project. Because traveling around the island was not possible, the RTK capabilities were of no advantage to this project, thus it would have been more advantageous to utilize modular GNSS receivers and antennas, capable of higher accuracy on single points. The project team recommends focusing on collecting high-quality data with long-duration, static observations. This should include an antenna with a ground plane or choke ring which has a published calibration, and the solution may also be improved by deploying a receiver capable of tracking multiple GNSS constellations.

C. Duration of Data Collection Periods

Considering the above, and if sea conditions allowed, the next survey should consider an approach where the GNSS equipment is setup and left to run on each island during the cruise to the northern extent of the project (Maug). The equipment should be setup up to run for long durations of at least 72 hours. The equipment then could be retrieved on the return trip.

D. Limit Surveying Activities to Coastline

Figure 8. Steepness of terrain, thick vegetation, and sharp rocks were encountered at many marks.

With the exception of Pagan, the terrain on all of the unpopulated islands is very challenging to traverse. Hiking very far away from the coastline requires scaling large boulders, climbing steep inclines, and passing through dense jungle foliage. Surveying activities should be limited to the coastline.

E. Replace Deteriorating Marks

If observations on Sarigan are desired, a replacement mark should be set to replace SARIGAN AZIMUTH MARK which is in very poor condition and in danger of being destroyed through erosion in the near future.

VIII. Conclusion

Based on the results achieved from the data collection, this project was considered successful. The data observed led to over 24 control marks being assigned updated coordinates, an improved understanding of the rotation of the Mariana plate, the first terrestrial gravity data collected in the region, and an up-to-date understanding of the condition of the islands and control marks situated on them. All of this data is valuable now and will continue to be long into the future.

Figure 9. Field Manager conducting a GNSS observation.

IX. Attachments

A. Adjustment Report for 9097 (GPS3209) Project Name: Survey of Guam and CNMI Adjustment Report

NGS Project Tracking ID: 9097
Location: Guam and CNMI
Report Date: September 2018

Adjustment Report for 9097 (GPS3209) Project Name: Survey of Guam and CNMI Adjustment Report

1. Introduction

The primary purpose of this project was to collect GPS data to derive high-accuracy geodetic coordinates at select marks located in Guam and CNMI. These marks have coordinates determined from previous GNSS surveys executed by NGS or submitted to NGS. The intent was to estimate IGS08 coordinates from this survey as well as eventually use historic surveys in order to compute vectors of point motion over time, which could then be used to estimate Euler Pole Parameters (EPP) of the Mariana plate. The purpose of this report is to document the survey and necessary least squares adjustments in order to Blue Book the GPS project in the NGS IDB.

Table 1. Project participants (from NGS).

Name	Project duties
Ryan Hippenstiel	Project manager
Dan Gillins	Lead post-processor, runner of adjustments, adjustment report author
Ed Carlson	Regional geodetic advisor, field surveyor
Kendall Fancher	Field surveyor
Jim Harrington	Field surveyor

2. Project Attributes

Horizontal Datum: North American Datum of 1983 (NAD 83) (MA) epoch 2010.00
Vertical Datum: GUVD04 or NMVD03
Geoid Model: GEOID12B
Total number of stations in network: 37

- Number of new stations: 5-- (3 passive marks and 2 active IGS stations)
- Number of existing passive marks: 29
- Number of CORS: 3

a) Details of Passive Marks in Project

A total of thirty passive marks with published coordinates in the NGS IDB were recovered for this project. However, very noisy GNSS data were collected at one of the marks (designation "TOGUAN" with PID "TW0537") next to a tree, and this mark was ultimately removed from the final survey network. The two sessions on this mark were not precise, and there was no way of knowing for certainty which (if any) of its session solutions were correct. Thus, the final network consisted of only 29 existing passive marks.

Of the 29 existing passive marks, 26 have adjusted NAD 83(MA11) epoch 2010.00 coordinates (latitude, longitude, ellipsoid height) in the IDB (Tables 2 and 3). The other three have estimated coordinates that were scaled or derived from a hand-held GNSS receiver (Table 4).

Of the 29 existing passive marks, 28 have a published orthometric height in either GUVD04 or NMVD03 (Table 5). Twenty of these marks have an adjusted orthometric height from first-order, class 2 leveling;

three have a GNSS-derived orthometric height from a height modernization survey (i.e., “K”-heights); and five have an estimated GNSS-derived orthometric height from a GNSS survey that did not meet height modernization survey guidelines (i.e., “G”-heights).
Three additional passive marks that do not exist in the IDB were also observed as part of the survey (Table 6).

Table 2. Published geodetic coordinates (in NAD 83(MA11) epoch 2010.00) in the NGS IDB for the existing passive marks in project (26 marks).

SSN	PID	Designation	Latitude	Longitude	Ellipsoid_Height
102	DH3102	AAFB	13342003135N	215051097256W	227.873
505	DK2827	AGRIHAN LDGO	18440780060N	214205373770W	48.974
506	DK2819	ALAMAGAN RM 3	17365002326N	214104727484W	55.574
201	DG3974	AMP 1	15130368597N	214161631708W	56.569
303	DG4117	ANT	15032563648N	214230946734W	99.561
502	DK2820	ASUNCION AZIMUTH MARK	19412719968N	214363715775W	64.476
100	TW0372	BEACH	13215239952N	215205917407W	55.862
301	DG4122	CARMEN	15010807260N	214244126532W	108.702
403	DG4024	DUGI	14111772676N	214432262640W	168.956
2205	DH3017	GGN 2205	13183592128N	215141213098W	158.207
202	DG3961	GRPN 9	15074816952N	214171559852W	88.051
105	AA4393	GUM ARP	13285919890N	215121579030W	134.496
200	DG3982	JE JONES	15151852367N	214112313778W	119.518
405	DG4009	JP SN BUDBAS	14111500921N	214461622210W	141.563
205	DG3940	KING	15132815728N	214131751688W	126.732
300	DG4108	LOOP	15031878591N	214213783495W	127.205
501	AA5095	PAGAN 1	18073338689N	214143389205W	64.179
204	DE7041	SAIPAN AZ MK	15123874850N	214144316417W	259.283
103	TW0017	SALISBURY	13335458514N	215060153761W	242.178
503	DK2824	SARIGAN AZIMUTH MARK	16423464214N	214134968335W	79.753
106	TW0398	SOLEDAD	13174230974N	215202394530W	97.738
206	AA4415	SPN A	15065652397N	214170036074W	117.361
203	DG3969	TAM 4	15105317020N	214171034347W	58.069
402	AA4404	TATGUA 2	14103889619N	214472719064W	114.112
409	DG4014	TIDAL 3	14082224743N	214512115125W	56.274
302	AA4411	TIQ C	14594744842N	214231680071W	126.545

Table 3. Published standard deviations (σ, 68% confidence) in the NGS IDB for the geodetic coordinates of the existing passive marks in the project (26 marks).

SSN	PID	Designation	σ_n (cm)	σ_e (cm)	σ_u (cm)
102	DH3102	AAFB	1.66	1.88	2.88
505	DK2827	AGRIHAN LDGO	4.71	2.86	2.71
506	DK2819	ALAMAGAN RM 3	4.7	3.36	3.31
201	DG3974	AMP 1	0.44	0.44	1.14
303	DG4117	ANT	0.67	0.62	1.95
502	DK2820	ASUNCION AZIMUTH MARK	4.89	3.35	3.6
100	TW0372	BEACH	0.43	0.51	0.73
301	DG4122	CARMEN	0.66	0.62	1.82
403	DG4024	DUGI	0.42	0.45	1.24
2205	DH3017	GGN 2205	0.5	0.58	0.98
202	DG3961	GRPN 9	0.49	0.47	1.44
105	AA4393	GUM ARP	0.33	0.39	1.29
200	DG3982	JE JONES	0.5	0.48	1.43
405	DG4009	JP SN BUDBAS	0.39	0.35	1.05
205	DG3940	KING	0.49	0.48	1.51
300	DG4108	LOOP	0.67	0.62	1.94
501	AA5095	PAGAN 1	0.52	0.59	1.53
204	DE7041	SAIPAN AZ MK	0.43	0.42	1.13
103	TW0017	SALISBURY	0.54	0.61	2.18
503	DK2824	SARIGAN AZIMUTH MARK	6.5	3.58	3.64
106	TW0398	SOLEDAD	0.97	1.01	2.47
206	AA4415	SPN A	0.48	0.46	1.35
203	DG3969	TAM 4	0.49	0.49	1.49
402	AA4404	TATGUA 2	0.37	0.41	1.06
409	DG4014	TIDAL 3	0.38	0.39	1.08
302	AA4411	TIQ C	0.57	0.51	1.41

Table 4. Existing passive marks in the project without adjusted geodetic coordinates in the IDB (i.e., the three marks with only SCALED or HND_HELD1 coordinates).

SSN	PID	Designation	Latitude/Longitude
1215	DH2989	GGN 1215	SCALED
1952	DQ3228	GGN 1952	HD_HELD1
2456	DH3029	GGN 2456	SCALED

Table 5. Published orthometric heights in the IDB for the existing passive marks in the project.

SSN	PID	Designation	Orth.Hgt (m)	Order,Class or Vertical source	GPSOBS Code

102	DH3102	AAFB	173.647	1,2	
505	DK2827	AGRIHAN LDGO	2.4	GPS OBS	G
506	DK2819	ALAMAGAN RM 3	7.0	GPS OBS	G
201	DG3974	AMP 1	2.073	1,2	
303	DG4117	ANT	44.748	1,2	
502	DK2820	ASUNCION AZIMUTH MARK	17.6	GPS OBS	G
100	TW0372	BEACH	1.858	1,2	
301	DG4122	CARMEN	53.876	1,2	
403	DG4024	DUGI	115.023	1,2	
2205	DH3017	GGN 2205	104.971	1,2	
202	DG3961	GRPN 9	33.610	1,2	
105	AA4393	GUM ARP	80.19	GPS OBS	K
200	DG3982	JE JONES	65.65	GPS OBS	K
405	DG4009	JP SN BUDBAS	86.72	GPS OBS	K
205	DG3940	KING	72.605	1,2	
300	DG4108	LOOP	72.492	1,2	
501	AA5095	PAGAN 1	16.7	GPS OBS	G
204	DE7041	SAIPAN AZ MK	204.920	1,2	
103	TW0017	SALISBURY	187.872	1,2	
503	DK2824	SARIGAN AZIMUTH MARK	21.0	GPS OBS	G
106	TW0398	SOLEDAD	44.194	1,2	
206	AA4415	SPN A	62.989	1,2	
203	DG3969	TAM 4	3.516	1,2	
402	AA4404	TATGUA 2	59.503	1,2	
409	DG4014	TIDAL 3	1.482	1,2	
302	AA4411	TIQ C	71.847	1,2	
1215	DH2989	GGN 1215	35.551	1,2	
1952	*DQ3228*	*GGN 1952*	*Not Published*	*N/A*	
2456	DH3029	GGN 2456	5.327	1,2	

Table 6. Newly observed passive marks.

SSN	PID	Designation	Latitude/Longitude
1002	New	163 0000 V	New Station
507	New	MAUG LDGO	New Station
508	New	MAUG RM 2	New Station

b) Details of Selected CORS for Project

Three active GNSS stations that are part of the NGS CORS Network were included in the survey for use as control (hereinafter referred to as "CORS"), and two active stations in only the IGS Network were also added to the network for stabilizing tropospheric parameters in the baseline processing. Neither of these two IGS stations are part of the CORS Network, nor do they have datasheets or a PID. Using the NGS utility, Horizontal Time-Dependent Positioning (HTDP), the published IGS08 epoch 2005.00 coordinates of these two IGS stations were transformed to NAD 83(MA11) epoch 2010.00. The coordinates for all five of the active GNSS stations in the network are shown in Table 7.

The published formal standard deviations for the coordinates of two of the CORS (GUUG and GUAM) are sub-millimeter. Such small values are unrealistic and would warp the network if used for weighting control. Instead of using the formal standard deviations of the coordinates of the CORS, an internal tool developed at NGS was used to estimate the root-mean-square (RMS) error in northing, easting, and up between approximately 90 days of daily solutions centered about the middle of the time of this project and the predicted coordinates of the CORS. These RMS values were used as sigmas in ADJUST for weighting control (Table 8).

As explained later in this report, the two IGS stations were not held as constraints in the final network adjustments. Thus, standard deviations for their coordinates were not needed.

Table 7. Geodetic coordinates (in NAD 83(MA11) epoch 2010.00) for the active GNSS stations in the network. (Note the first three rows of coordinates are taken from NGS datasheets, the latter two rows of coordinates were derived from HTDP, v. 3.2.5).

SSN	PID	CORSID	Designation	Latitude	Longitude	Ellipsoid Height
9	AA4397	GUAM	GUMO	13352155606N	215075387275W	199.94
8	DF7980	CNMR	MARIANA ISLAND CORS ARP	15134688244N	214152484070W	62.414
10	DF7984	GUUG	U OF GUAM CORS ARP	13255951965N	215115020617W	132.756
11	*New*	*MCIL*	*MCIL 21789S001*	*24172432496N*	*206011679766W*	*33.873*
12	*New*	*POHN*	*POHN 51601M001*	*06573576839N*	*201472355387W*	*89.037*

Table 8. Root-mean-square error (RMS) in 90 days of daily solutions for the CORS (from an internal tool at NGS for generating short-term time-series plots). These values were used for weighting constraints in ADJUST.

CORSID	PID	Designation	RMS_n (cm)	RMS_e (cm)	RMS_u (cm)
GUAM	AA4397	GUMO	1.74	1.43	2.47
CNMR	DF7980	MARIANA ISLAND CORS ARP	0.35	0.77	1.08
GUUG	DF7984	U OF GUAM CORS ARP	0.89	1.89	3.09

It is important to note that GUUG also has a published orthometric height that meets height modernization standards ("K-height") of 78.82 m.

3. Fieldwork

The majority of the marks were occupied with GNSS receivers for two sessions of approximately 6 to 10 hours, making their total occupation time roughly 12 to 20 hours. However, as the crew worked northward into the remote islands of CNMI, receivers were left on a mark on the island for only a single, long session generally greater than 20 hours. A charter boat was required to access these islands, and such expense limited the ability to collect repeat sessions on these marks. Marks observed for a single, long session include:

- AGRIHAN LDGO
- ALAMAGAN RM 3
- ASUNCION AZIMUTH MARK
- MAUG LDGO
- MAUG RM 2
- SPN A

Field logs documenting the work were maintained throughout the project. These logs have been submitted separately with this report.

a) Equipment

The following GPS antennas were used during the campaign:

- LEIGS15 NONE
- CHCX90D-OPUS NONE
- TRMR8_GNSS NONE
- TRM41249.00 NONE
- TRM39105.00 NONE

b) GPS Session Schedule

A total of 23 GPS sessions were completed in 2017, as shown below. Each session is named to be identical with its 2017 calendar day of year (i.e., days of year 241, etc.). Sessions on the same day are split into "A" and "B" sessions. ARP heights in meters for the occupied stations in each session are also given in Table 9.

Table 9. ARP heights (in meters) for the occupied passive marks in each of the completed GPS sessions for the listed calendar days of year in 2017.

MarkID	Designation	239	240	241	243	244	247	249A	249B	250	251	252	254A	254B	255	256	257	259	261	263A	263B	264A	264B	265
1215	GGN 1215	2.000	2.000																					
1952	GGN 1952																				2.000		2.000	
2205	GGN 2205	2.000	2.000																					
2456	GGN 2456																				2.000		2.000	
aafb	AAFB	1.737	1.751	1.767																				
agri	AGRIHAN LDGO																	1.432						
ala3	ALAMAGAN RM 3																		1.359					
amp1	AMP 1				2.000	2.000																		
antx	ANT										2.000	2.000												
asaz	ASUNCION AZIMUTH MARK																1.587							
beac	BEACH	1.718	1.919																					
budb	JP SN BUDBAS															1.500	1.500							
crmm	CARMEN								2.000	2.000														
dugi	DUGI													2.000	2.000									
gpn9	GRPN 9				2.000	2.000																		
guma	GUM ARP	2.000	2.000																					
jone	JE JONES				1.823	1.789																		
kinn	KING						2.000	1.713																
loop	LOOP								1.500	1.500														
mg92	MAUG LDGO															1.686								
mrm2	MAUG RM 2															1.296								
pgn1	PAGAN 1												1.779	1.779										
salb	SALISBURY	2.000	2.000	R																				
sole	SOLEDAD	2.000	2.000																					
spaz	SAIPAN AZ MK						1.861	1.836			1.854													
spna	SPN A																							1.699
sraz	SARIGAN AZIMUTH MARK																			2.043		2.043		
tam4	TAM 4				1.929	1.917																		
tatg	TATGUA 2													2.000	2.000									
tid3	TIDAL 3															2.000	2.000							
tidv	163 0000 V	2.000	2.000																					
tiqc	TIQ C										2.000	2.000												
togu	TOGUAN																				R		R	

* Note that R = a rejected occupation

c) Other Data

In addition to the collection of the static GPS data as per the schedule above, digital photographs were taken of each setup as a quality control measure. Observation logs were also filled out after each setup, and these logs were scanned and submitted with this report.

4. Post-Processing and Adjustments

All session baseline processing was completed in Beta OPUS-Projects (v. 1.14).

In addition to uploading the data summarized in Table 8 for the passive marks, GPS data from the 5 active stations in Table 7 were also added to the project for all 23 sessions.

A preliminary network adjustment using the NGS utility GPSCOM within Beta OPUS-Projects was also completed. Unfortunately, subsequent horizontal and vertical adjustments could not be completed due to limitations in the development of Beta OPUS-Projects. Due to the remote location of this survey, Beta OPUS-Projects was unable to run adjustments in the ADJUST utility. Therefore, the B-file and G-file were extracted from Beta OPUS-Projects, and the horizontal and vertical adjustments were done in a PC version of ADJUST (i.e., outside of Beta OPUS-Projects).

a) Session Baseline Processing

Following guidance in the OPUS-Projects User Manual, the GPS data at the selected CORS and passive marks from all 23 sessions were processed in Beta OPUS-Projects following a “hub-and-spoke” network design. Either GUUG or CNMR were selected as the hub, depending on the shortest proximity to the passive marks in the session. The two IGS stations (MCIL and POHN) were only added to each session for decorrelating the wet component of the tropo error models. Only the geodetic coordinates for the session hub were constrained during session baseline processing with NORMAL constraint weights. All other stations were unconstrained.

Other data processing default settings in Beta OPUS-Projects were employed during session baseline processing.

- Tropo Model: Piecewise Linear
- Tropo Interval: 7200 s
- Elevation Cutoff: 15 degrees
- GNSS: GPS-only
- Reference Frame: IGS08
- Geoid Model: GEOID12B
- Ephemeris: final (precise)

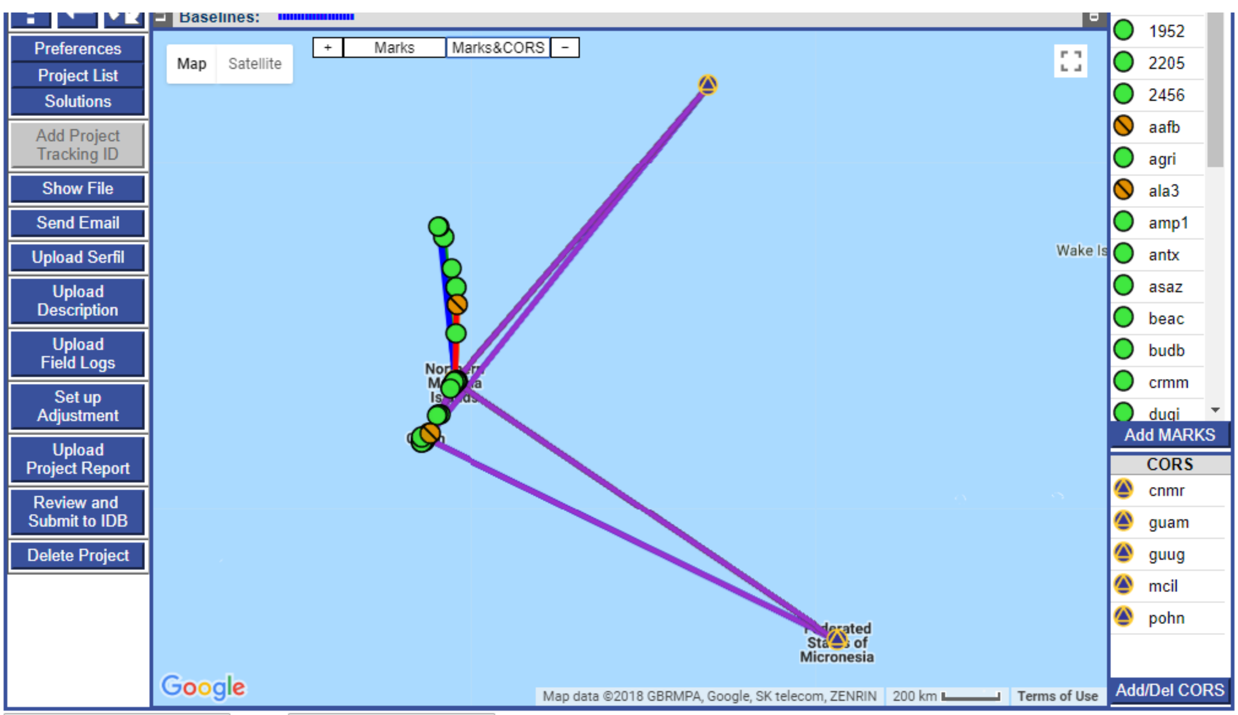


Figure 1. Screen capture of survey network in Beta OPUS-Projects

As per Table 9, due to poor repeatability in the session solutions, both sessions on station TOGUAN (mark identifier TOGU) were rejected. It was unclear if one or both of the sessions were in error, and this mark is under a large tree. Another session on mark SALISBURY was also rejected because its session solution differed significantly from its other two session solutions. No other occupations were rejected.

Tables 10 – 12 provide screen captures from Beta OPUS-Projects of the RMS of the baseline processing (cm), the percent observations used (%), and the percent of fixed integers (%), respectively. Generally, the RMS is less than 3 cm, the percent observations used is greater than 80%, and the percent ambiguities fixed is greater than 70% for all occupations. Only one concern is worth noting: a poor percentage of integer fixing was derived at ALA3 (i.e., ALAMAGAN RM 3), shown as 56.2%. Unfortunately, this station was only occupied once; therefore, the accuracy of this single solution is unclear.

Table 13 is a screen capture from Beta OPUS-Projects which shows that more than 77% of the observables were used and more than 74% of the ambiguities were fixed for the combined session solutions at each station (except at ALA3 as noted above). The peak-to-peak (P2P) differences in up for the session solutions at every passive mark and active station were all less than 6 cm. These values are decent considering the challenging environment and remoteness of the project. Unfortunately, somewhat large peak-to-peak errors in easting and northing (i.e., from 2.5 to 7.6 cm) were found at five stations: three at passive marks and two for the distant IGS stations. For some projects, it may make sense to reject occupations due to such large horizontal imprecision. However, it was decided to keep all of these occupations in the project as the intent was to derive vertical control, and the vertical precision, especially at the three passive marks, was quite small. Moreover, since only two sessions were completed on these three passive marks, it is unclear which session to reject and rejecting a session would cause the mark to become a “no check” station.

Table 10. RMS of baseline processing (cm) from Beta OPUS-Projects.

MARKS	Sessions																							MARKS
	2017-239-A	2017-240-A	2017-241-A	2017-243-A	2017-244-A	2017-247-A	2017-249-A	2017-249-B	2017-250-A	2017-251-A	2017-252-A	2017-254-A	2017-254-B	2017-255-A	2017-256-A	2017-257-A	2017-259-A	2017-261-A	2017-263-A	2017-263-B	2017-264-A	2017-264-B	2017-265-A	
1215	0.80	1.00																						1215
1952																				1.10		1.80		1952
2205	1.70	2.60																						2205
2456																				1.30		1.70		2456
aafb	1.60	3.10	3.20																					aafb
agri																	2.60							agri
ala3																		2.20						ala3
amp1				0.90	1.00																			amp1
antx										2.30	1.70													antx
asaz																2.60								asaz
beac	2.50	2.70																						beac
budb															1.70	2.20								budb
crmm								2.00	2.80															crmm
dugi													2.60	2.50										dugi
gpn9				1.60	1.60																			gpn9
guma	1.30	2.00																						guma
jone				1.40	1.30																			jone
kinn						1.10	1.30																	kinn
loop								2.10	2.50															loop
mg92															1.90									mg92
mrm2															2.70									mrm2
pgn1												2.50	2.60											pgn1
salb	2.10	2.80	–																					salb
sole	1.70	2.60																						sole
spaz						1.00	1.10			1.70														spaz
spna																							2.50	spna
sraz																			2.40		2.30			sraz
tam4				1.20	1.30																			tam4
tatg													2.70	2.60										tatg
tid3															1.90	2.40								tid3
tidv	1.60	2.30																						tidv
tiqc										2.20	1.80													tiqc
togu																				–		–		togu

Table 11. Percent observations used (%) from Beta OPUS-Projects.

MARKS	Sessions																							MARKS
	2017-239-A	2017-240-A	2017-241-A	2017-243-A	2017-244-A	2017-247-A	2017-249-A	2017-249-B	2017-250-A	2017-251-A	2017-252-A	2017-254-A	2017-254-B	2017-255-A	2017-256-A	2017-257-A	2017-259-A	2017-261-A	2017-263-A	2017-263-B	2017-264-A	2017-264-B	2017-265-A	
1215	96.9	96.4																						1215
1952																				99.8		96.7		1952
2205	96.8	91.2																						2205
2456																				99.1		97.7		2456
aafb	99.1	96.1	95.3																					aafb
agri																	95.3							agri
ala3																		95.1						ala3
amp1				93.1	94.6																			amp1
antx										93.1	97.3													antx
asaz																97.0								asaz
beac	86.5	77.7																						beac
budb															96.0	96.6								budb
crmm								95.6	94.2															crmm
dugi													94.7	96.1										dugi
gpn9				92.6	95.1																			gpn9
guma	98.9	95.1																						guma
jone				93.6	96.3																			jone
kinn						94.6	93.6																	kinn
loop								96.3	94.0															loop
mg92															99.1									mg92
mrm2															93.5									mrm2
pgn1												92.9	93.1											pgn1
salb	86.7	73.2	–																					salb
sole	97.7	94.5																						sole
spaz						91.5	93.2			92.8														spaz
spna																							91.7	spna
sraz																			93.6		94.2			sraz
tam4				85.8	85.8																			tam4
tatg													82.0	84.5										tatg
tid3															94.5	95.1								tid3
tidv	98.4	96.2																						tidv
tiqc										92.8	98.6													tiqc
togu																				–		–		togu

Table 12. Percent ambiguities fixed (%) from Beta OPUS-Projects.

MARKS	Sessions																							MARKS
	2017-239-A	2017-240-A	2017-241-A	2017-243-A	2017-244-A	2017-247-A	2017-249-A	2017-249-B	2017-250-A	2017-251-A	2017-252-A	2017-254-A	2017-254-B	2017-255-A	2017-256-A	2017-257-A	2017-259-A	2017-261-A	2017-263-A	2017-263-B	2017-264-A	2017-264-B	2017-265-A	
1215	100.0	100.0																						1215
1952																				100.0		96.7		1952
2205	100.0	97.2																						2205
2456																				94.9		100.0		2456
aafb	95.3	92.7	88.2																					aafb
agri																	82.3							agri
ala3																		56.2						ala3
amp1				98.3	96.7																			amp1
antx										95.3	97.9													antx
asaz																74.0								asaz
beac	98.4	86.4																						beac
budb															85.5	72.6								budb
crmm								96.4	93.9															crmm
dugi													91.5	94.7										dugi
gpn9				96.7	95.8																			gpn9
guma	100.0	90.7																						guma
jone				98.3	98.1																			jone
kinn						98.8	95.5																	kinn
loop								93.8	93.4															loop
mg92															87.5									mg92
mrm2															80.8									mrm2
pgn1												76.5	75.3											pgn1
salb	94.6	94.2	–																					salb
sole	100.0	91.9																						sole
spaz						98.3	100.0			95.0														spaz
spna																							97.4	spna
sraz																			85.5		89.3			sraz
tam4				97.3	98.8																			tam4
tatg													94.0	92.6										tatg
tid3															87.3	78.3								tid3
tidv	100.0	95.9																						tidv
tiqc										98.1	97.7													tiqc
togu																				–		–		togu

Table 13. Solution statistics from Beta OPUS-Projects.

MARKS	Solution & Statistics									MARKS
	occupations count	occupations used	solutions count	Obs Used	Obs Used(%)	AMB Fixed(%)	North P2P(cm)	East P2P(cm)	Up P2P(cm)	
1215	2	2	2	11966	96.7	100.0	6.81	3.44	0.69	1215
1952	2	2	2	11686	98.2	98.0	1.35	0.17	0.16	1952
2205	2	2	2	11284	94.0	98.4	0.12	0.33	1.78	2205
2456	2	2	2	11927	98.4	97.5	0.35	0.53	0.72	2456
aafb	3	3	3	17627	96.8	91.5	0.65	0.77	1.33	aafb
agri	1	1	1	8097	95.3	82.3	–	–	–	agri
ala3	1	1	1	16726	95.1	56.3	–	–	–	ala3
amp1	2	2	2	11207	93.8	97.5	0.95	0.52	0.23	amp1
antx	2	2	2	13264	95.1	96.2	0.65	0.66	1.12	antx
asaz	1	1	1	15467	97.0	74.0	–	–	–	asaz
beac	2	2	2	8825	82.1	92.5	0.57	2.39	4.58	beac
budb	2	2	2	12377	96.3	78.6	0.55	0.21	3.58	budb
crmm	2	2	2	13104	94.9	95.0	0.18	0.5	0.88	crmm
dugi	2	2	2	11400	95.4	93.2	0.27	0.68	1.33	dugi
gpn9	2	2	2	11008	94.0	96.2	0.91	1	2.25	gpn9
guma	2	2	2	11578	97.0	94.6	7.58	4.48	0.46	guma
jone	2	2	2	10555	94.9	98.2	0.71	0.49	1.86	jone
kinn	2	2	2	10621	94.1	97.3	0.16	0.42	1.22	kinn
loop	2	2	2	13439	95.2	93.7	1.64	0.58	3.65	loop
mg92	1	1	1	3161	99.1	87.5	–	–	–	mg92
mrm2	1	1	1	12325	93.5	80.8	–	–	–	mrm2
pgn1	2	2	2	19615	92.9	76.1	0.61	2.16	4.44	pgn1
salb	3	2	2	7210	77.8	94.3	0.58	0.49	0.09	salb
sole	2	2	2	10361	95.9	94.9	1.21	3.23	2.52	sole
spaz	3	3	3	16317	92.5	97.4	0.72	0.68	2.02	spaz
spna	1	1	1	3213	91.7	97.4	–	–	–	spna
sraz	2	2	2	7779	93.9	87.4	1.48	0.93	0.35	sraz
tam4	2	2	2	9081	85.8	98.0	0.89	0.38	1.7	tam4
tatg	2	2	2	9707	83.1	93.5	0.61	0.52	3.04	tatg
tid3	2	2	2	11702	94.8	82.9	1.96	2.31	5.6	tid3
tidv	2	2	2	11923	97.3	97.5	1.97	1.29	1.18	tidv
tiqc	2	2	2	15493	95.5	98.0	1.16	0.37	1.72	tiqc
togu	2	0	0	0	0	0				togu
cnmr	23	19	23	1790859	95.6	95.4	1.56	2.08	4.4	cnmr
guam	23	19	23	466904	95.2	95.5	1.68	1.93	5.57	guam
guug	23	19	23	895875	96.1	96.0	1.4	1.52	5.88	guug
mcil	23	19	23	430499	98.6	98.1	1.78	3.17	6.18	mcil
pohn	19	19	23	413274	93.8	96.0	2	3.74	6.1	pohn

b) Horizontal Free Adjustment

All horizontal and vertical adjustments were completed using a PC version of ADJUST. For the horizontal free adjustment, only station GUUG was held fixed.
Noteworthy statistics for this adjustment are given below.

- Degrees of Freedom: 348
- Variance of Unit Weight: 1.00
- RMS of residuals in northing: 0.7 cm
- RMS of residuals in easting: 0.6 cm
- RMS of residuals in up: 1.2 cm
- Minimum vector residual in up component: -3.6 cm
- Maximum vector residual in up component: +3.3 cm
- Maximum vector residual in horizontal component: 5.0 cm

It's important to note that Beta OPUS-Projects automatically scales the estimated standard deviations for the vectors in the G-file from GPSCOM by a factor of 10. Since the standard deviations are often small and overly optimistic from baseline processing, this initial scaling is meant to prevent ADJUST from dividing by a very small, near-zero number which can cause the program to crash. The vectors in the G-file had also been transformed to NAD 83(MA11)2010.00 using HTDP, v 3.2.5.

When running a horizontal free adjustment, Beta OPUS-Projects inputs the "VVHU" flag in ADJUST to employ variance component estimation. The following factors were derived from the VVHU routine in the horizontal free adjustment. These factors are multiplied by the standard deviations of the vectors given in the scaled G-file, and this results in a variance of unit weight for the least squares adjustment to equal 1.00. (Note that had the aforementioned scaling by a factor of 10 not been applied, then these scale factors would have been 10 times bigger.)

- VVHU horizontal scale factor: 2.290
- VVHU vertical scale factor: 0.614

Given that the residuals were less than 3.6 cm in the up component for all vectors in the network, it was decided to not reject any of the GPS vectors in the survey. Although horizontal residuals are somewhat high, further rejection would result in "no check" solutions at some of the remote marks.

c) **Horizontal Constrained Adjustment**

The next step was to perform constrained horizontal adjustments in ADJUST. A total of five iterative adjustments were performed in order to evaluate control and ultimately pick a set of control that yielded the most-appropriate constrained adjustment. Unfortunately, published coordinates on many of the passive marks appear to be in error, so this iterative process required rejecting published coordinates at numerous marks.

Initially, the geodetic coordinates for all 26 passive marks and the three CORS in Tables 2 and 7, respectively, were constrained. Sigmas for these coordinates were estimated using data in Tables 3 and 8 for these coordinates.

The statistics for this initial adjustment were very poor. The variance of unit weight jumped to 10.98 and this value greatly exceeds the critical F-statistic value at 99% confidence. This failure of the F-statistic hypothesis test indicates that some of the constraints may need to be removed. Shifts in excess of 6 cm were noted at 5 stations. These five stations are listed below. The coordinates of these stations were thus unconstrained or rejected for the second iterative adjustment.

Table 14. Shifts and constraint ratios (CR) at stations to be unconstrained after the first iterative constrained horizontal adjustment.

Designation	shiftN_cm	shiftE_cm	shiftU_cm	crN	crE	crU
AGRIHAN LDGO	-3.7	-21.98	2.51	0.79	7.69	0.93
ALAMAGAN RM 3	0.28	-13.7	7.02	0.06	4.08	2.12
ASUNCION AZIMUTH MARK	5.24	-24.76	-3.88	1.07	7.39	1.08
PAGAN 1	5.98	-14.15	-4.25	11.50	23.98	2.78
SARIGAN AZIMUTH MARK	-17.06	-6.76	-98.9	2.62	1.89	27.17

After unconstraining the five stations in Table 14, another constrained horizontal adjustment was performed. The F-statistic dropped to 5.44, but this value is still much too high and the network fails the F-test. Due to the very poor performance of the published coordinates and the fear of continuing to warp the network, the next iteration was to only hold the published coordinates of the three CORS. After this adjustment, the resulting adjusted coordinates were differenced with the published coordinates for the 26 passive marks in Table 2 and the three constrained CORS. The residual differences in northing (dn), easting (de), and up (du) are shown below in Table 15.

As noted in Table 15, only eight stations appear to be potentially suitable for use as control as the shifts are less than 5 cm in northing, easting, and up. These eight stations were then constrained and a fourth iterative constrained adjustment was performed.

Table 15. Differences in adjusted coordinates with published coordinates after horizontal constrained adjustment where only the coordinates of the three CORS were held as control—third iterative constrained horizontal adjustment.

SSN	dn	de	du	Constrain?
102	-0.0578	0.0502	-0.118	
505	-0.0058	-0.2639	-0.04	
506	0.0332	-0.1728	0.01	
201	0.075	-0.0507	-0.063	
303	0.0676	-0.0436	-0.046	
502	0.0812	-0.2825	-0.11	
100	-0.0455	0.0466	-0.131	
301	0.0688	-0.0421	-0.031	
403	-0.0052	0.027	-0.029	C
2205	-0.0572	0.065	-0.073	
202	0.0673	-0.0439	-0.037	
105	-0.075	0.0767	-0.123	
200	0.0778	-0.0558	-0.062	
405	-0.0065	0.0417	-0.027	C
205	0.0765	-0.0567	-0.056	
300	0.0765	-0.0481	-0.024	
501	0.1543	-0.2893	-0.106	
204	0.0756	-0.0582	-0.068	
103	-0.0501	0.0355	-0.063	
503	-0.1614	-0.1081	-1.225	
106	-0.0833	0.0647	-0.097	
206	0.0898	-0.043	-0.09	
203	0.0904	-0.0519	-0.081	
402	-0.0061	0.0282	-0.002	C
409	-0.0212	0.021	-0.035	C
302	0.0569	-0.0427	-0.011	C
10-GUUG	-0.0556	0.0572	-0.029	C
9-GUAM	-0.0532	0.0469	0.011	C
8-CNMR	0.0108	-0.023	0.004	C

The eight constrained stations, shifts, and constraint ratios are shown in Table 16 after the fourth iterative adjustment. Unfortunately, the network still failed the F-test, with a variance of unit weight equal to 1.64.

Table 16. Shifts and constraint ratios (CR) at constrained stations in the fourth iterative constrained horizontal network adjustment.

Designation	shiftN_cm	shiftE_cm	shiftU_cm	crN	crE	crU
DUGI	-0.21	0.53	-0.78	0.50	1.18	0.63
JP SN BUDBAS	-0.3	0.7	-0.8	0.77	2.00	0.76
TATGUA 2	-0.2	0.4	0.34	0.54	0.98	0.32
TIDAL 3	-0.65	0.3	-0.74	1.71	0.77	0.69
TIQ C	3.59	-2.83	0.08	6.30	5.55	0.06
U OF GUAM CORS ARP	-5.73	5.04	-1.48	6.44	2.67	0.48
GUMO	-5.5	4.01	2.56	3.16	2.80	1.04
MARIANA ISLAND CORS ARP	0.88	-3	1.78	2.51	3.90	1.65

The constraint ratios for station TIQ C in northing and easting exceeded 5.5. This station was freed up and a fifth and final constrained horizontal adjustment was performed. Table 17 lists the final shifts and constraint ratios for the seven constrained stations.

Table 17. Shifts and constraint ratios at constrained stations in the final constrained horizontal network adjustment.

SSN	MARK ID	DESIG	DN (cm)	DE (cm)	DU (cm)	crN	crE	crU
403	DUGI	DUGI	0.0	0.2	-0.8	0.0	0.4	0.6
405	BUDB	JP SN BUDBAS	-0.1	0.4	-0.8	0.2	1.2	0.8
402	TATG	TATGUA 2	-0.1	0.1	0.4	0.2	0.3	0.4
409	TID3	TIDAL 3	-0.5	0.0	-0.6	1.2	0.0	0.6
10	GUUG	U OF GUAM CORS ARP	-5.1	3.6	-1.6	5.7	1.9	0.5
9	GUAM	GUMO	-4.9	2.6	2.5	2.8	1.8	1.0
8	CNMR	MARIANA ISLAND CORS ARP	1.5	-4.4	1.7	4.3	5.7	1.6

Note the shifts in northing and easting at the three CORS are somewhat larger than typical, but since these are the only three CORS in the vicinity of this remote project, it was decided to maintain all of them as constraints in the constrained horizontal adjustment.

This fifth adjustment passed the F-test at the 99% confidence level. Details are shown below.

The *F* statistical hypothesis test

	σ_o^2	DOF
Minimally Constrained Adjustment	**1.00**	**348**
Fully Constrained Adjustment	**1.28**	**366**
Confidence Level (1 - α)	**0.99**	
F-statistic	*1.28*	
Critical Value, $F_{\alpha/2}$	*1.31*	
Result	*PASS*	

Additional statistics are given below for the final constrained horizontal adjustment:

- Degrees of Freedom: 366
- Variance of Unit Weight: 1.28
- RMS of residuals in northing: 0.7 cm
- RMS of residuals in easting: 0.6 cm
- RMS of residuals in up: 1.2 cm
- Minimum vector residual in up component: -4.0 cm
- Maximum vector residual in up component: +3.2 cm
- Maximum vector residual in horizontal component: 4.9 cm

Shifts and constraint ratios at those *unconstrained* stations with published geodetic coordinates are listed in Table 18. As shown, the shifts are often larger than 4 cm horizontally and 4 cm in up. Some shifts are extremely large (e.g., ASUNCON AZIMUTH MARK, AGRIHAN LDGO, ALAMAGAN RM3, PAGAN 1, and SARAIGAN AZIMUTH MARK). Since these shifts are so large, it is recommended to publish the newly adjusted geodetic coordinates at all marks in Table 18 and supersede their currently published values.

Table 18. Shifts and constraint ratios at unconstrained stations in the final constrained horizontal network adjustment.

SSN	MARK ID	DESIG	DN (cm)	DE (cm)	DU (cm)	crN	crE	crU	Super-sede?
102	AAFB	AAFB	-5.3	2.9	-10.4	3.2	1.6	3.6	Y
505	AGRI	AGRIHAN LDGO	-0.2	-28.5	-2.7	0.1	10.0	1.0	Y
506	ALA3	ALAMAGAN RM 3	3.7	-19.4	2.3	0.8	5.8	0.7	Y
201	AMP1	AMP 1	7.9	-7.2	-4.9	18.0	16.3	4.3	Y
303	ANTX	ANT	7.2	-6.5	-3.3	10.7	10.4	1.7	Y
502	ASAZ	ASUNCION AZIMUTH MARK	8.5	-30.4	-9.5	1.7	9.1	2.6	Y
100	BEAC	BEACH	-4.1	2.6	-11.8	9.5	5.1	16.2	Y
301	CRMM	CARMEN	7.3	-6.3	-1.8	11.1	10.2	1.0	Y
2205	2205	GGN 2205	-5.3	4.4	-5.9	10.5	7.6	6.0	Y
202	GPN9	GRPN 9	7.2	-6.5	-2.4	14.6	13.8	1.7	Y
105	GUMA	GUM ARP	-7.0	5.6	-11	21.2	14.3	8.5	Y
200	JONE	JE JONES	8.2	-7.7	-4.9	16.5	16.0	3.4	Y
205	KINN	KING	8.1	-7.8	-4.3	16.5	16.2	2.8	Y
300	LOOP	LOOP	8.1	-6.9	-1.1	12.1	11.2	0.6	Y
501	PGN1	PAGAN 1	15.8	-31.1	-9.2	30.4	52.7	6.0	Y
204	SPAZ	SAIPAN AZ MK	8.0	-7.9	-5.5	18.6	18.8	4.9	Y
103	SALB	SALISBURY	-4.5	1.5	-4.9	8.4	2.4	2.2	Y
503	SRAZ	SARIGAN AZIMUTH MARK	-15.7	-12.9	-121.2	2.4	3.6	33.3	Y
106	SOLE	SOLEDAD	-7.9	4.4	-8.4	8.1	4.4	3.4	Y
206	SPNA	SPN A	9.4	-6.4	-7.7	19.6	13.9	5.7	Y
203	TAM4	TAM 4	9.5	-7.3	-6.8	19.3	14.9	4.6	Y
302	TIQC	TIQ C	6.1	-6.4	0.2	10.8	12.5	0.1	Y

d) Vertical Free Adjustment

The published orthometric height at mark DUGI was held fixed as well as the latitude and longitude of CNMR for this adjustment. The height was held due to its central location to the project area.

The table below presents the differences in the adjusted orthometric heights from the vertical free adjustment and all published orthometric heights that were either derived from first-order, class 2 leveling (i.e., 1,2) or from a GPS height modernization survey (i.e., K-heights). Table 5 and the text beneath Table 8 present these published heights. Note that very large differences are at stations GUM ARP and JP SN BUDBAS. Interestingly, the K-heights for these two stations involved the use of an EGM geoid model.

Table 19. Shifts in orthometric height from the vertical free adjustment and the published orthometric heights in the survey (for those existing stations in the network that were leveled or have a published K-height).

SSN	Designation	Published Orthometric Height (m)	Datum	Type	Adjusted Orthometric Height (m)	Vertical Shift (m)
102	AAFB	173.647	GUVD04	1,2	173.577	-0.07
201	AMP 1	2.073	NMVD03	1,2	2.088	0.015
303	ANT	44.748	NMVD03	1,2	44.745	-0.003
100	BEACH	1.858	GUVD04	1,2	1.77	-0.088
301	CARMEN	53.876	NMVD03	1,2	53.872	-0.004
403	DUGI	115.023	NMVD03	1,2	115.023	C
1215	GGN 1215	35.551	GUVD04	1,2	35.477	-0.074
2205	GGN 2205	104.971	GUVD04	1,2	104.958	-0.013
2456	GGN 2456	5.327	GUVD04	1,2	5.292	-0.035
202	GRPN 9	33.610	NMVD03	1,2	33.622	0.012
105	GUM ARP	80.19	GUVD04	K	80.08	-0.11
200	JE JONES	65.677	NMVD03	1,2	65.653	-0.024
405	JP SN BUDBAS	86.72	NMVD03	K	87.103	0.383
205	KING	72.605	NMVD03	1,2	72.575	-0.03
300	LOOP	72.492	NMVD03	1,2	72.518	0.026
204	SAIPAN AZ MK	204.920	NMVD03	1,2	204.915	-0.005
103	SALISBURY	187.872	GUVD04	1,2	187.865	-0.007
106	SOLEDAD	44.194	GUVD04	1,2	44.196	0.002
206	SPN A	62.989	NMVD03	1,2	62.966	-0.023
203	TAM 4	3.516	NMVD03	1,2	3.489	-0.027
402	TATGUA 2	59.503	NMVD03	1,2	59.572	0.069
409	TIDAL 3	1.482	NMVD03	1,2	1.509	0.027
302	TIQ C	71.847	NMVD03	1,2	71.865	0.018
10	U OF GUAM CORS ARP	78.82	GUVD04	K	78.813	-0.007

* C = constrained height

e) Vertical Constrained Adjustment

According to Table 19, the majority of the stations have vertical shifts less than 3 cm after running a free adjustment and holding mark DUGI fixed. However, five stations have very large vertical shifts ranging from 6.9 to 38.3 cm. Additionally, the vertical shift at one other station (GGN 2456) was 3.5 cm. Based on these results, two iterative, constrained vertical adjustments were performed. First, the six stations with shifts in Table 19 greater than 6.9 cm were unconstrained. Afterwards, a second iterative, constrained vertical adjustment was performed where the same six stations as well as GGN 2456 were unconstrained. Since the second adjustment hardly changed results, it was decided to keep GGN 2456 as a constraint and use the first iterative, constrained vertical adjustment where the six stations highlighted in red in Table 19 were unconstrained.

Statistics for this constrained vertical adjustment are given below:

- Degrees of Freedom: 365
- Variance of Unit Weight: 1.07
- RMS of residuals in northing: 0.7 cm
- RMS of residuals in easting: 0.6 cm
- RMS of residuals in up: 1.5 cm
- Minimum vector residual in up component: -4.6 cm
- Maximum vector residual in up component: +6.2 cm
- Maximum vector residual in horizontal component: 5.0 cm

The vertical adjustment passed the F-test at the 99% confidence level. Details are shown below.

The *F* statistical hypothesis test

	σ_o^2	DOF
Minimally Constrained Adjustment	**1.00**	**348**
Fully Constrained Adjustment	**1.07**	**365**
Confidence Level (1 - α)	**0.99**	
F-statistic	*1.07*	
Critical Value, $F_{\alpha/2}$	*1.32*	
Result	*PASS*	

The differences or shifts between the adjusted orthometric heights and the published orthometric heights at the six unconstrained stations are given in the table below:

Table 20. Shifts in orthometric height from the vertical constrained adjustment and the published orthometric heights at the six unconstrained stations in the network.

SSN	Designation	Published Orthometric Height (m)	Datum	Type	Adjusted Orthometric Height (m)	Vertical Shift (m)	Super-sede Height?
102	AAFB	173.647	GUVD04	1,2	173.583	-0.064	N
100	BEACH	1.858	GUVD04	1,2	1.776	-0.082	N
1215	GGN 1215	35.551	GUVD04	1,2	35.483	-0.068	N
105	GUM ARP	80.19	GUVD04	K	80.086	**-0.104**	**Y**
405	JP SN BUDBAS	86.72	NMVD03	K	87.104	**0.384**	**Y**
402	TATGUA 2	59.503	NMVD03	1,2	59.576	0.073	N

The shifts in Table 20 are larger than 6 cm at the six unconstrained stations, and it appears to be a good decision to unconstrain the orthometric heights at these stations. Due to the very large vertical shifts for the two stations with K-heights in Table 20 (GUM ARP and JP SN BUDBAS), we recommend publishing the newly adjusted orthometric height (i.e., superseding the published orthometric height).

It is difficult to say whether or not to supersede the orthometric heights from first order class 2 leveling at the four bench marks listed in Table 20. The vertical shifts are greater than 6 cm, but this could be due to errors in GEOID12B rather than in the leveling.

It is also interesting to examine the accuracy of those five marks in the survey with a GNSS-derived orthometric height that does not meet height modernization standards (i.e., so-called “G”-heights per Table 5). However, three of these marks are north of the boundary of GEOID12B. Thus, new GNSS-derived orthometric heights could not be derived at these three marks (AGRIHAN LDGO, ASUNCION AZIMUTH MARK, and PAGAN1). Very large, m-level vertical shifts are found at the other two marks (ALAMAGAN RM 3 and SARIGAN AZIMUTH MARK). Since these shifts are so large, we recommend superseding the GNSS-derived orthometric heights at the two noted stations in Table 21 and redacting or not publishing orthometric heights at any station outside of the boundaries of GEOID12B.

Table 21. Shifts in orthometric height from the vertical constrained adjustment and the published orthometric heights at the five marks in the network with “G”-heights.

SSN	PID	Designation	MarkID	Adjusted Ortometric Height (m)	Published Orthometric Height (m)	Vertical Shift (m)
506	DK2819	ALAMAGAN RM 3	ALA3	8.690	7.0	1.690
503	DK2824	SARIGAN AZIMUTH MARK	SRAZ	27.923	21.0	6.923
505	DK2827	AGRIHAN LDGO	AGRI	N/A	2.4	N/A
502	DK2820	ASUNCION AZIMUTH MARK	ASAZ	N/A	17.6	N/A
501	AA5095	PAGAN 1	PGN1	N/A	16.7	N/A

5. Comments and Recommendations for Loading Survey into IDB

This project report provided a summary of the passive marks and CORS selected for the GPS survey. It discussed the equipment, observation schedule, and some problems encountered in the field. It also summarized the decisions that were made to decide which stations to hold as control to complete the constrained horizontal and vertical adjustments.

Several iterative, constrained horizontal and constrained vertical adjustments were performed in order to evaluate the accuracy of the published coordinates for the existing passive marks. Unfortunately, it seems that the published geometric coordinates (latitude, longitude, or ellipsoid height) need to be superseded for numerous existing passive marks. We recommend superseding the geometric coordinates for those noted stations in Table 18 with the newly adjusted geometric coordinates from this survey. Table 22 lists the recommended geometric coordinates that should be published at each station, and if this is a new set of coordinates for the IDB or if the coordinates supersede a currently published values.

In addition, the published orthometric heights at some existing passive marks also appear to be in error, particularly at two previous GNSS height modernization stations that involved the use of an EGM geoid model. We recommend superseding the published orthometric heights (i.e., K-heights) at those two stations noted in Table 20 with the newly adjusted, GNSS-derived orthometric heights from this survey. Although not held in the constrained vertical adjustment, we do not recommend superseding the orthometric heights for those bench marks listed in Table 20 that were derived from leveling because the source of the vertical shifting error may be due to errors in the hybrid geoid model, GEOID12B.

We also recommend superseding the GNSS-derived orthometric heights (G-heights) for the two noted stations in Table 21. Orthometric heights at the other three stations in this table could not be estimated using GEOID12B, as they are outside of the footprint of the geoid model. We do not recommend publishing orthometric heights at any mark (including the three marks in Table 21) that is outside of the footprint of GEOID12B. Orthometric heights published at AGRIHAN LDGO, ASUNCION AZIMUTH MARK, and PAGAN1 should be redacted from the datasheets or not published. There are a total of seven marks in the network that are outside of the boundaries of GEOID12B.

The B-files from the constrained horizontal and constrained vertical adjustments were combined using the ELEVUP.exe utility in order to produce a final B-file. Afterwards, the codes in the B-file were updated for the orthometric heights.

Table 23 notes the recommended orthometric height that should be published at each station, the applicable code for the B-file, and if this is a new orthometric height for the IDB or an orthometric height that supersedes a currently published value.

Table 22. Final geometric coordinates in NAD 83(MA11)2010.00 to publish at all stations in the network and if the coordinates are new or supersede values currently published on NGS datasheets.

SSN	MarkID	Designation	Latitude	Longitude	Ellipsoid Height(m)	Supersede Or New?
102	AAFB	AAFB	13342002963N	215051097158W	227.769	Supersede
1215	1215	GGN 1215	13254411708N	215115544323W	89.379	New
2205	2205	GGN 2205	13183591957N	215141212951W	158.148	Supersede
201	AMP1	AMP 1	15130368855N	214161631949W	56.520	Supersede
303	ANTX	ANT	15032563882N	214230946950W	99.528	Supersede
100	BEAC	BEACH	13215239819N	215205917321W	55.744	Supersede
301	CRMM	CARMEN	15010807498N	214244126744W	108.684	Supersede
403	DUGI	DUGI	14111772676N	214432262640W	168.956	
202	GPN9	GRPN 9	15074817185N	214171560069W	88.027	Supersede
105	GUMA	GUM ARP	13285919662N	215121578844W	134.386	Supersede
200	JONE	JE JONES	15151852635N	214112314035W	119.469	Supersede
205	KINN	KING	15132815991N	214131751948W	126.689	Supersede
300	LOOP	LOOP	15031878855N	214213783727W	127.194	Supersede
103	SALB	SALISBURY	13335458366N	215060153712W	242.129	Supersede
106	SOLE	SOLEDAD	13174230718N	215202394384W	97.654	Supersede
203	TAM4	TAM 4	15105317328N	214171034592W	58.001	Supersede
402	TATG	TATGUA 2	14103889619N	214472719064W	114.112	
1002	TIDV	163 0000 V	13263737290N	215203613618W	55.927	New
302	TIQC	TIQ C	14594745042N	214231680285W	126.547	Supersede
1952	1952	GGN 1952	13234915008N	215133377585W	78.553	New
405	BUDB	JP SN BUDBAS	14111500921N	214461622210W	141.563	
409	TID3	TIDAL 3	14082224743N	214512115125W	56.274	
2456	2456	GGN 2456	13215884028N	215135429547W	58.940	New
505	AGRI	AGRIHAN LDGO	18440780052N	214205374743W	48.947	Supersede
506	ALA3	ALAMAGAN RM 3	17365002446N	214104728141W	55.597	Supersede
502	ASAZ	ASUNCION AZIMUTH MARK	19412720245N	214363716818W	64.381	Supersede
507	MG92	MAUG LDGO	20013688211N	214460302409W	48.365	New
508	MRM2	MAUG RM 2	20014970984N	214471708042W	66.040	New
501	PGN1	PAGAN 1	18073339203N	214143390262W	64.087	Supersede
204	SPAZ	SAIPAN AZ MK	15123875110N	214144316682W	259.228	Supersede
206	SPNA	SPN A	15065652703N	214170036288W	117.284	Supersede
503	SRAZ	SARIGAN AZIMUTH MARK	16423463702N	214134968771W	78.541	Supersede
8	CNMR	MARIANA ISLAND CORS ARP	15134688244N	214152484070W	62.414	
9	GUAM	GUMO	13352155606N	215075387275W	199.940	
10	GUUG	U OF GUAM CORS ARP	13255951965N	215115020617W	132.756	
11	MCIL	MCIL 21789S001	24172432360N	206011679773W	33.895	New
12	POHN	POHN 51601M001	06573576708N	201472355387W	89.053	New

Table 23. Final orthometric heights to publish at all stations in the network, applicable codes, and if the orthometric height is new or supersedes a currently published height on NGS datasheets.

SSN	PID	Designation	MarkID	Code	Orthometric Height (m)	Supersede? Or New?
102	DH3102	AAFB	AAFB	A12	173.647	
1215	DH2989	GGN 1215	1215	A12	35.551	
2205	DH3017	GGN 2205	2205	A12	104.971	
201	DG3974	AMP 1	AMP1	A12	2.073	
303	DG4117	ANT	ANTX	A12	44.748	
100	TW0372	BEACH	BEAC	A12	1.858	
301	DG4122	CARMEN	CRMM	A12	53.876	
403	DG4024	DUGI	DUGI	A12	115.023	
202	DG3961	GRPN 9	GPN9	A12	33.610	
105	AA4393	GUM ARP	GUMA	K	80.09	Supersede
200	DG3982	JE JONES	JONE	K	65.65	
205	DG3940	KING	KINN	A12	72.605	
300	DG4108	LOOP	LOOP	A12	72.492	
103	TW0017	SALISBURY	SALB	A12	187.872	
106	TW0398	SOLEDAD	SOLE	A12	44.194	
203	DG3969	TAM 4	TAM4	A12	3.516	
402	AA4404	TATGUA 2	TATG	A12	59.503	
1002	New	163 0000 V	TIDV	K	1.74	New
302	AA4411	TIQ C	TIQC	A12	71.847	
1952	DQ3228	GGN 1952	1952	K	24.71	New
405	DG4009	JP SN BUDBAS	BUDB	K	87.10	Supersede
409	DG4014	TIDAL 3	TID3	A12	1.482	
2456	DH3029	GGN 2456	2456	A12	5.327	
505	DK2827	AGRIHAN LDGO	AGRI	N/A	*N/A	Supersede
506	DK2819	ALAMAGAN RM 3	ALA3	G	8.7	Supersede
502	DK2820	ASUNCION AZIMUTH MARK	ASAZ	N/A	*N/A	Supersede
507	New	MAUG LDGO	MG92	N/A	*N/A	
508	New	MAUG RM 2	MRM2	N/A	*N/A	
501	AA5095	PAGAN 1	PGN1	N/A	*N/A	Supersede
204	DE7041	SAIPAN AZ MK	SPAZ	A12	204.92	
206	AA4415	SPN A	SPNA	A12	62.989	
503	DK2824	SARIGAN AZIMUTH MARK	SRAZ	G	27.9	Supersede
8	DF7980	MARIANA ISLAND CORS ARP	CNMR	K	8.08	New
9	AA4397	GUMO	GUAM	K	145.38	New
10	DF7984	U OF GUAM CORS ARP	GUUG	K	78.82	
11	New	MCIL 21789S001	MCIL	N/A	*N/A	
12	New	POHN 51601M001	POHN	N/A	*N/A	

*N/A = Not applicable. Do not publish an orthometric height at this station as it is outside of the boundaries of GEOID12B.

B. 2017 Guam/CNMI Survey Island-by-Island Recommendations

Version 03, D. Smith, 2017/07/27

The islands below are listed in geographic order, progressing South to North, from Guam to Uracas (Farallon de Pajaros).

For Guam, the recommendation is to perform GPS on 4-6 points simultaneously for the 2-3 days that all four crew members are there. If overnight, great. If not, long sessions lasting all day (6- 12 hours or so).

For islands Rota, Tinian and Saipan, the recommendation is to perform a GPS survey on at least 2 passive control marks, preferably at the same time, for as long as possible.

In addition, the relative gravimeter should be "zeroed" at a mark which will be re-visited in 1-2 years time by the GRAV-D team and their A-10 absolute gravimeter.

No other special instructions are included for those four islands. The points to select for the GPS survey should be drawn from the prioritized list. If, however, CO-OPS has very specific points they wish to see surveyed, then such points should be considered "medium-high" priority.

For the northern islands, an island-by-island set of instructions is included.

A note on "Priorities" for Guam and Saipan: On these two islands, both GPS and gravity can be performed on a variety of marks. An attempt has been made to align the priority lists of both GPS and gravity, but in-the-field modifications may be necessary. Every attempt should be made to GPS the gravity marks (if they are outdoors), but this rule of thumb should not prevent the gravity work from going if GPS cannot be performed on the gravity marks chosen.

CRITICAL, for every geodetic control mark visited in this survey: Take photographs (close-up, eye level, horizon from many angles with and without equipment on it) and write new descriptions! Many marks in this area have out of date descriptions (old road names, etc) and almost NONE have actual photographs of the marks themselves.

Special instructions about gravity and GPS on the same point

2. On some islands (particularly those north of Saipan), gravity and GPS will be measured on the same survey mark. In order to accommodate both pieces of equipment, and to ensure (a) closed loops of relative gravity and (b) continuous GPS data collection, the following should always be followed, assuming that each island is visited one time only:

Arrival (take RTK, CG6 and long-session GPS equipment to island)

1) If the mark ***can be*** occupied by a CG6:
    a. Set up CG6 over the mark and measure gravity. Remove CG6 from mark when done.
    b. Set up the long-session GPS tripod and equipment over the mark and begin collection
2) If the mark ***cannot be*** occupied by a CG6:
    a. Set up the CG6 over an "eccentric point": some identifiable, stable, non-monumented location horizontally displaced from the mark by less than 5 meters
        i. If absolutely necessary, use a spot that is also vertically displaced from the mark
    b. Measure (to the nearest millimeter, using a tape measure) the distance and approximate the azimuth to the eccentric point.
        i. If necessary also measure (to the nearest millimeter, using a level and/or tape measure) the vertical displacement from the mark to the eccentric point
    c. Set up the long-session GPS tripod and equipment over the mark (not the eccentric point) and begin collection
    d. Occupy the eccentric point with the RTK rover, twice (for redundancy)

Throughout the day (take RTK and CG6 with you)

3) Leave the area with the CG6 and the RTK rover to begin measuring at other "spot" locations around the island (measuring gravity and location with RTK)

Departure:

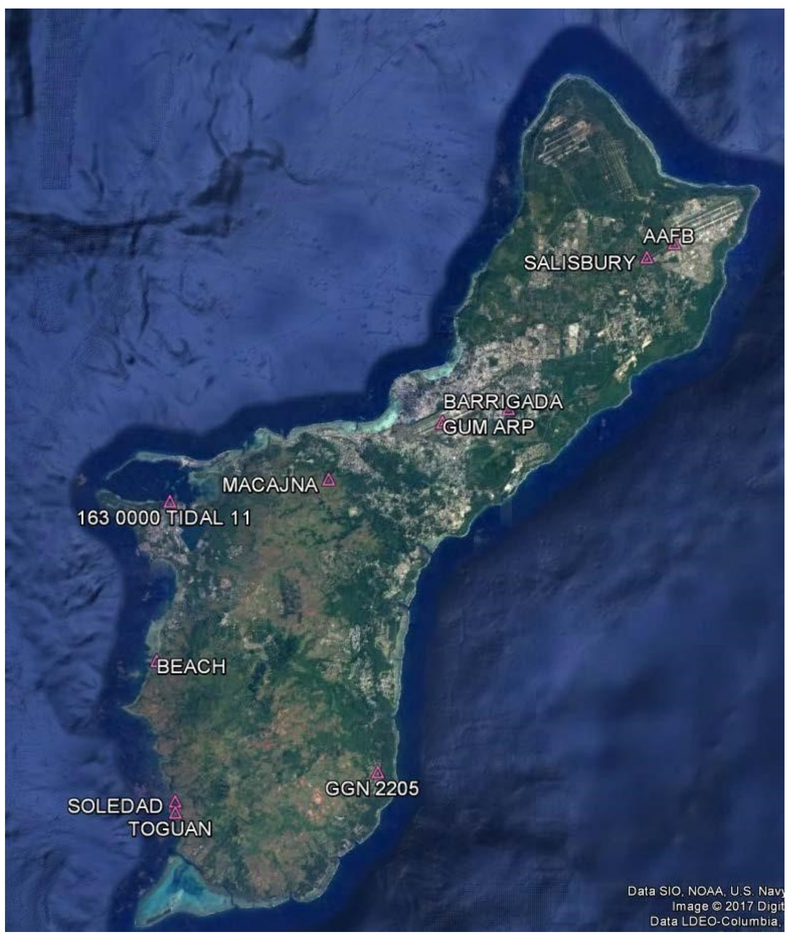
4) If the mark ***can be*** occupied by a CG6:
    a. Tear down the long-session GPS equipment from the mark
    b. Set up CG6 over the mark and measure gravity. Remove CG6 from mark when done.
5) If the mark ***cannot be*** occupied by a CG6:
    c. Set up the CG6 over the same "eccentric point" used earlier and measure gravity
    d. Occupy the eccentric point with the RTK rover, twice (for redundancy)
    e. Tear down the long-session GPS equipment from the mark
6) Pack up and take all equipment to the boat

1. Guam

1.1 GPS

Guam is the most surveyed of all the islands in this chain, yet surprisingly, very few of the passive control marks have been surveyed with GPS more than once. Of those, only two have seen a receiver twice after 1997 (when CORS and orbits will allow re-processing of files through OPUS). GPS should be performed on 4-6 points, preferably simultaneously, preferably for 6+ hours per setup. The following points are therefore recommended for a GPS survey:

Priority	**PID**	**Designation**	**Note**	**σ mm xyz**
High	TW0372	BEACH	4 surveys, 2 post 1997	2,1,1
High	DH3017	GGN2205	2 surveys post 1997	2,1,1
High	DH3102	AAFB	5 obs for GPS1987; Gravity	2,1,1
Medium-High	AA4394	163 0000 TIDAL 11	3 obs for GPS1987; TIDAL	2,1,1
Medium-High	TW0041	163 0000 TIDAL 4	**VDO**; Not in GPS1987; TIDAL	**unknown**
Medium	TW0504	MACAJNA	3 obs for GPS1987	2,1,1
Medium	TW0017	SALISBURY	3 obs for GPS1987	2,1,1
Medium	TW0398	SOLEDAD	3 obs for GPS1987	2,1,1
Medium-Low	TW0465	BARRIGADA	2 obs for GPS1987	2,2,1
Medium-Low	TW0537	TOGUAN	3 obs for GPS1194	2,2,1



1.2 Relative Gravity

Guam is well covered with relative gravity, so no densification is necessary. However, a minimum of two marks should be surveyed on Guam with the relative gravimeter to ensure that, in 2019, an absolute gravimeter can visit at least 1 of the 2 and tie your relative gravity survey to an absolute value.

The candidate points for your relative gravity survey on Guam may need to be modified on the fly, as some candidates listed below may or may not be deemed "usable" once the team actually visits them. No pictures exist of any of these points, making their determination of "usable" before actually visiting Guam somewhat difficult.

A "usable" mark should fulfill the criteria in the following table:

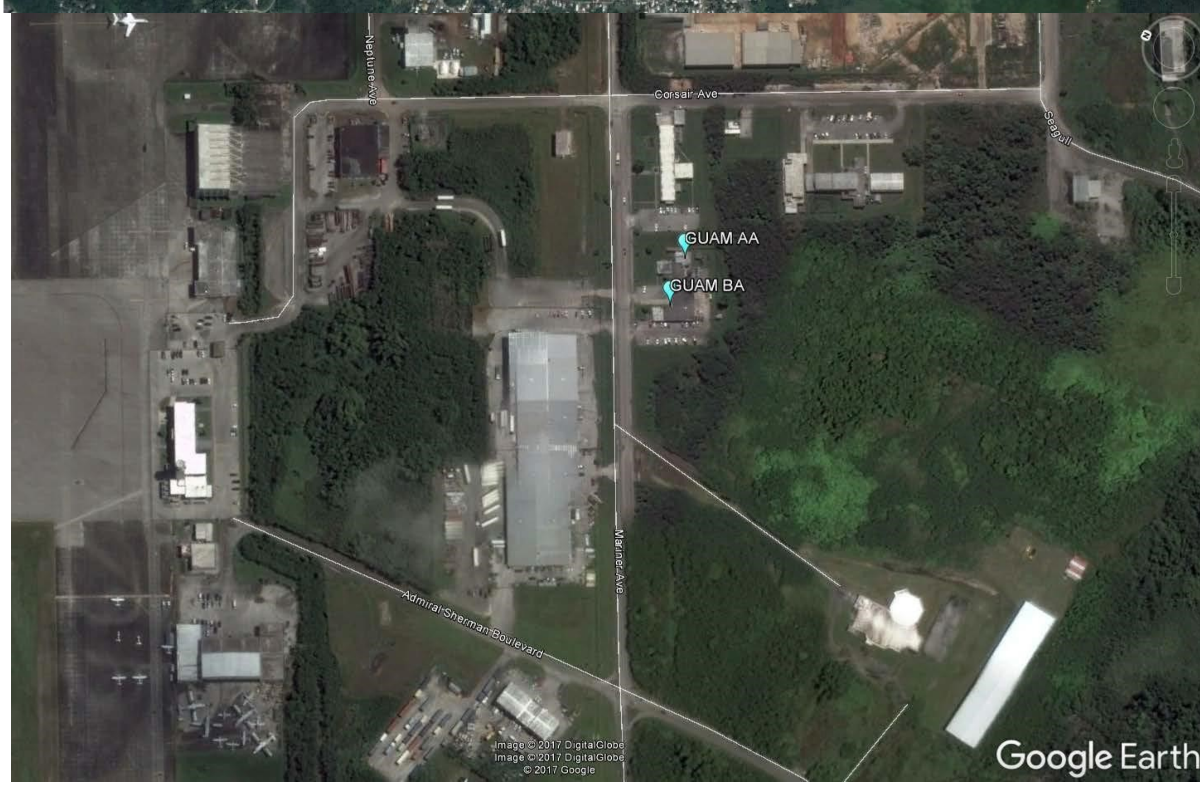
Criteria	Importance
An A-10 should "fit" over it. That is, the three legs of an A-10 should be able to straddle and solidly sit on firm ground at a radius of about 18 inches. Points set in the ground without a "collar" are not likely to fulfill this criteria.	Required
Should be accessible by vehicle. That is, the A-10 should be able to get to the point easily with a truck. Points in the middle of fields, for example, are not likely to fulfill this criteria.	Required
Should not be on the coast Wave noise will degrade the measurement.	Required
GPS-able It would be best to have a good GPS coordinate on the point. If not, a determination of the point's "survey-able" nature should be made. That is, can the point be easily surveyed using optical means?	Nice, but not required.
Indoors Obviously in direct conflict with being "GPS-able", being indoors provides a more stable meteorological environment for the A-10	Nice, but not required.
Have an existing historic gravity measurement For comparison purposes, it would be good to find a point that has had gravity measured before.	Nice, but not required.
Should be near both of the Guam airports (GUM and AAFB) The A-10 will be housed at one of these airports, so less travel is nice.	Nice, but not required.

Fulfilling the above criteria, the following priority list is recommended. Two of the points should be occupied. The "zeroing" should be done on GUAM AA if possible. That point should be also the final point visited when the meter returns to Guam.

Priority	PID	Designation
High	(no PID)	GUAM AA
Medium	DH3102	AAFB
Medium	(no PID)	GUAM BA

Should additional marks need to be considered, use the priority list form section 1.1.

See the next few figures for information on GUAM AA and GUAM BA.



Full descriptions of GUAM AA and GUAM BB are found in Appendix B.

1.3 Leveling

Perform whatever leveling work is agreed to in coordination with CO-OPS.

2. Rota

No gravity work on Rota. Only two points have ever been surveyed with GPS twice. None have been surveyed twice after 1997.

Priority	PID	Designation	Note	σ mm (xyz)
High (see below)	AA4401	ROP B	3 obs in GPS1837; GPS0667	2,2,1
High	AA4404	TATGUA 2	3 obs in GPS1837; GPS0667	2,2,1
Medium-High	DG4024	DUGI	3 obs in GPS1837	2,2,1
Medium-High	DG4017	ICM JR	3 obs in GPS1837	2,2,1
Medium-High	DG4009	JP SN BUDBAS	3 obs in GPS1837	2,2,1
Medium-High	DE7086	VIL	3 obs in GPS1837	2,2,1
Medium	DG4023	TAM 5	3 obs in GPS1837	3,2,1
Medium	AE4364	GRO C	2 obs in GPS1837	3,2,1
Medium	DG4014	TIDAL 3	2 obs in GPS1837	3,2,1
Medium-Low	DG4003	TAM 1	2 shorts obs* in GPS1837	8,5,3

According to Ed: "*I might have a hard time occupying 'ROP B' on the airport*". As such, TATGUA 2 should be prioritized, and then any of the "medium-high" priority marks picked next.

* Only 1 was usable

Aside from GPS on two marks on Rota, the airport authority should be approached about the possibility of installing a CORS on the island in 2018 or later.

3. Tinian

No gravity work on Tinian. Only one point has ever been surveyed twice with GPS (AA4407). None have been surveyed twice after 1997. Many have only had very short sessions and are not included.

Priority	PID	Designation	Note	σ mm xyz
High (see below)	AA4407	TIDAL 1	3 obs + 1 short* in GPS1837; GPS0667	3,2,1
Medium-High	DG4108	LOOP	3 obs in GPS1837	2,2,1
Medium-High	DG4136	TAM 10	3 obs in GPS1837	2,2,1
Medium-High	AA4411	TIQ C	3 obs in GPS1837	2,2,1
Medium	DG4117	ANT	3 obs in GPS1837	3,2,1
Medium	DG4122	CARMEN	3 obs in GPS1837	3,2,1
Medium	DG4133	DAGU	3 obs in GPS1837	3,2,1
Medium-Low	DE6136	TIDAL 3	2 short obs in GPS1837	8,5,3

According to Ed, regarding mark AA4407: "***the mark is on a pier and ferry ran into the pier and the mark has really been disturbed***". As such, any of the other marks listed as "medium-high" priority should be picked.

* The short obs on AA4407 is missing its field log so is unusable as is

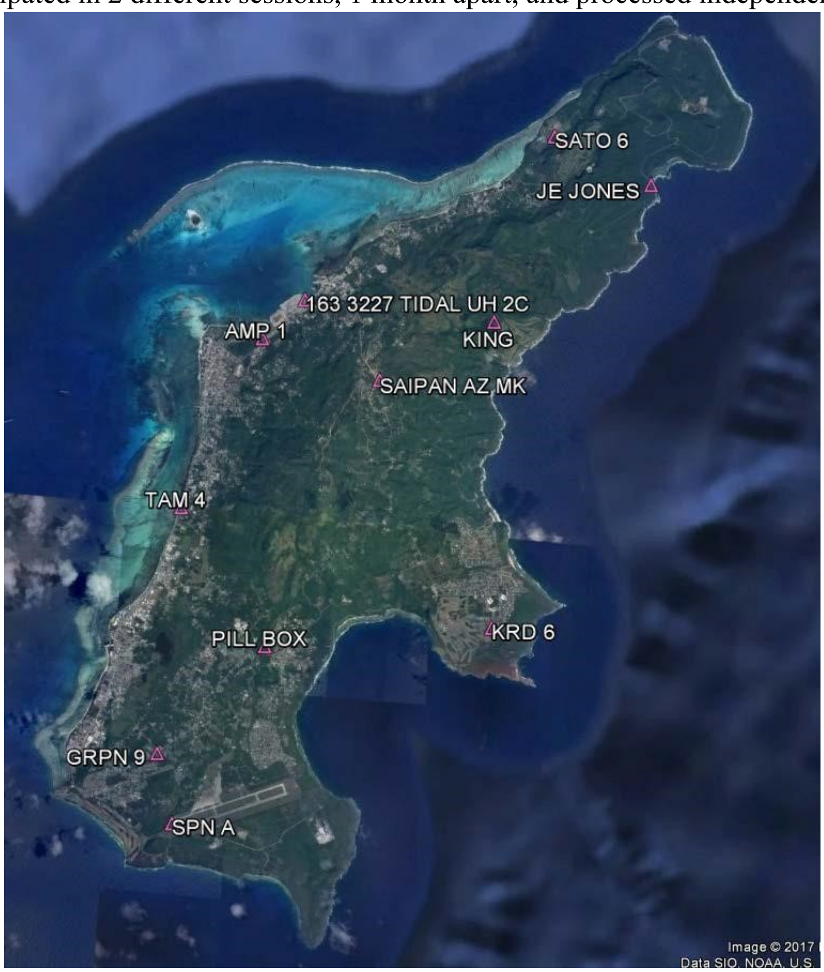
4. Saipan

4.1 GPS

No Saipan points have seen a GPS receiver twice, but some have stronger data than others as well as other reasons of importance.

Priority	PID	Designation	Note	σ mm xyz
High	DG3988	163 3227 UH 2C	**VDO**; 9 obs* in GPS1837; TIDAL	2,1,1 & 3,2,1***
Medium-High	DG3974	AMP 1	3 obs in GPS1837	2,1,1
Medium-High	DG3961	GRPN 9	3 obs in GPS1837	2,1,1
Medium-High	DG3982	JE JONES	3 obs in GPS1837	2,1,1
Medium-High	DG3940	KING	3 obs in GPS1837	2,1,1
Medium-High	DG3949	KRD 6	3 obs in GPS1837	2,1,1
Medium-High	AA4415	SPN A	3 obs in GPS1837	2,1,1
Medium-High	DG3969	TAM 4	3 obs in GPS1837	2,1,1
Medium	DG3926	SATO 6	3 obs** in GPS1837	2,1,1
Medium	DE7924	PILL BOX	2 obs + 1 short obs in GPS1837	2,1,1
Medium	DE7041	SAIPAN AZ MK	2 obs + 1 short obs in GPS1837	2,1,1

* Of 9 obs, only 6 field logs exist.
** Of 3 obs, only 2 field logs exist
*** This point participated in 2 different sessions, 1 month apart, and processed independently



4.2 Relative Gravity

As Saipan is the "stepping off" point for the cruise to the northern islands, it will be useful for the relative meter to occupy at least two points on the island. Saipan is well covered with terrestrial gravity otherwise (see Appendix C) so no additional relative gravity work is needed. The same criteria from section 1.2 should be used to pick marks. However, as no absolute gravity marks appear to have been established on Saipan, there are no obvious top contenders (and thus no likely "indoor" marks). Further, lack of pictures and other metadata may mean that, in the field, marks chosen may need to be different than those recommended below. The criteria used below are based solely on adopting the same priority level as used above in the GPS section.

Fulfilling the criteria from section 1.2, the following priority list is recommended

Priority	PID	Designation
High	DG3961	GRPN 9
High	AA4415	SPN A
Medium-High	DE7041	SAIPAN AZ MK

Should additional marks need to be considered, use the prioritized list from section 4.1.

5. Farallon de Medinilla (Do not stop)

This island is not a planned stop. However, should plans change in the field, the following recommendations are made:

1) As there are NO geodetic control marks on the island, do not attempt to find any
2) Perform a relative gravity survey, hitting at least a low point on the island, the highest point on the island and other geographically well-distributed points. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
3) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
4) Reconnoiter for a site suitable for installing a passive geodetic control mark
5) Reconnoiter for a site suitable for installing an InSAR reflector

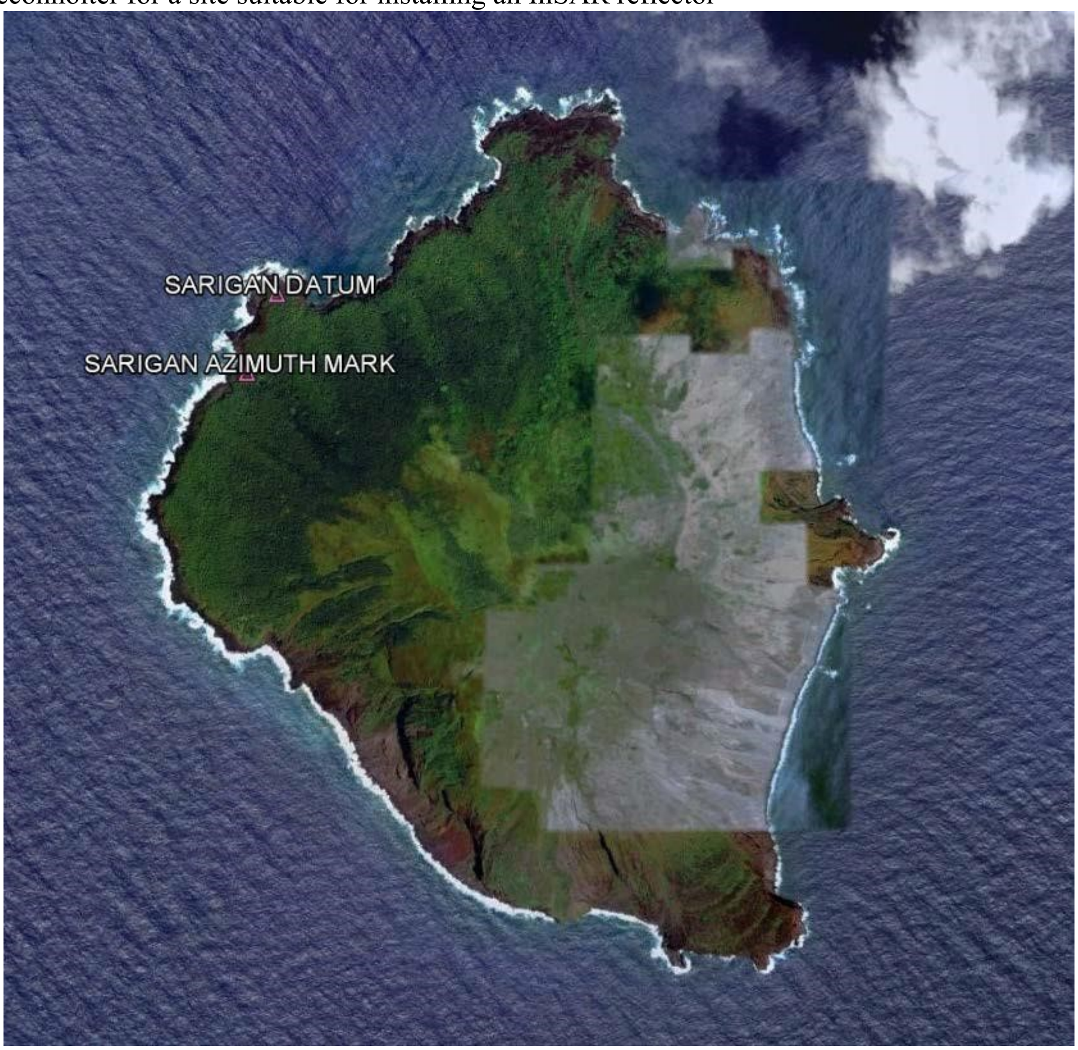
6. Anatahan (Do not stop)

This island is not a planned stop. However, should plans change in the field, the following recommendations are made:

1) As there are NO geodetic control marks on the island, do not attempt to find any
2) Perform a relative gravity survey, hitting at least a low point on the island, the highest point on the island and other geographically well-distributed points. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
3) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
4) Reconnoiter for a site suitable for installing a passive geodetic control mark
5) Reconnoiter for a site suitable for installing an InSAR reflector

7. Sarigan

1) Perform long-session GPS on point DK2824 (“SARIGAN AZIMUTH MARK”)
    a. **<u>Do NOT attempt to find, photograph or describe point AA5101 (“SARIGAN DATUM”).</u>** It was GPS’d in 1993, and while it has no descriptive data in the NGS IDB a hand-written note from field logs during GPS0667 (1993) says “***No mark set** – point selected can be photo identified*”. The GPS position was adjusted to NAD 83(MA11). It is about 20 meters above sea level at 16 42 43.43493(N) and 214 13 46.19712(W) or 145 46 13.80288(E). It seems unlikely the exact “photo identifiable” point will be found. If, by chance, you are near this area feel free to make a best guess, but don’t waste too much time.
2) Perform a relative gravity survey, looping through point DK2824 and AA5101 (if found) as well as hitting the highest point of the island. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
3) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
4) Reconnoiter for a site suitable for installing additional passive geodetic control marks
5) Reconnoiter for a site suitable for installing an InSAR reflector




SARIGAN DATUM
Image © 2017 DigitalGlobe

8. Guguan (Do not stop)

This island is not a planned stop. However, should plans change in the field, the following recommendations are made:

1) As there are NO geodetic control marks on the island, do not attempt to find any
2) Perform a relative gravity survey, hitting at least a low point on the island, the highest point on the island and other geographically well-distributed points. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
3) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
4) Reconnoiter for a site suitable for installing a passive geodetic control mark
5) Reconnoiter for a site suitable for installing an InSAR reflector

9. Alamagan

1) Perform long-session GPS on point "DK2819" ("ALAMAGAN RM 3")
2) Perform a relative gravity survey, looping through point DK2819 as well as hitting the highest point of the island. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
3) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
4) Reconnoiter for a site suitable for installing additional passive geodetic control marks
5) Reconnoiter for a site suitable for installing an InSAR reflector

10. Pagan

1) Perform long-session GPS on point "AA5095" ("PAGAN 1")
2) Attempt to find, photograph and describe point AA5100 ("RON SANFORD"). It was GPS'd in 1993, and while it has no descriptive data in the NGS IDB a hand-written note on a field log from GPS0667 (1993) says: "*Station set over a small shell in concrete base of NOAA automated weather station on Pagan Is. "Ron Sanford 6-22-90" scratched into cement.*" The GPS position was adjusted to NAD 83(MA11). It is about 10 meters above sea level at 18 07 28.67687(N) and 214 14 21.33271(W) or 145 45 38.66729 (E).
3) Perform a relative gravity survey, looping through point AA5095 and AA5100 (if found) as well as hitting the highest point of the island. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
4) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
5) Reconnoiter for a site suitable for installing additional passive geodetic control marks
6) Reconnoiter for a site suitable for installing an InSAR reflector


PAGAN 1
RON SANFORD


PAGAN 1
RON SANFORD
Image © 2017 DigitalGlobe

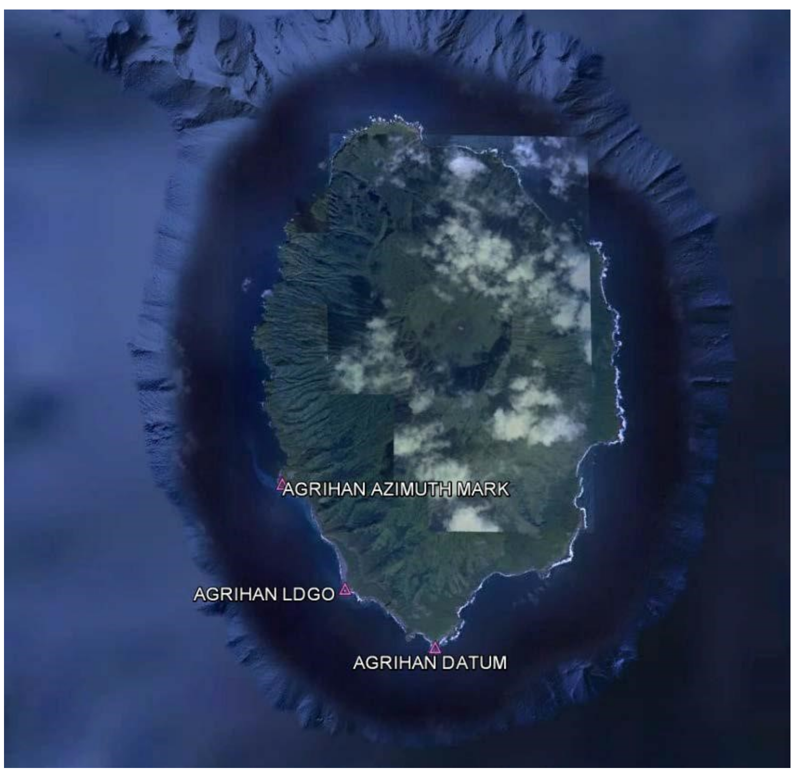
11. Agrihan

On this island (alone of all the northern islands) you have a choice of two passive control marks to perform the long-session GPS survey. However, they definitely have a priority order:

Priority	PID	Designation
High	DK2827	AGRIHAN LDGO
Medium	DK2818	AGRIHAN AZIMUTH MARK

Unless point "DK2827" is not a feasible option, it should definitely be the point over which the GPS survey is performed.

1) Perform long-session GPS on point DK2827 ("AGRIHAN LDGO") if possible, otherwise over DK2818 ("AGRIHAN AZIMUTH MARK")
2) Attempt to find, photograph and describe point AA5097 ("AGRIHAN DATUM"). It was GPS'd in 1993, but has no descriptive data. The GPS position was adjusted to NAD 83(MA11). It is about 11 meters above sea level at 18 43 33.06162(N) 214 19 57.52302(W) or 145 40 02.47698(E).
3) Perform a relative gravity survey, looping through point DK2827, DK2818 and AA5097 (if found) as well as hitting the highest point of the island. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
4) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
5) Reconnoiter for a site suitable for installing additional passive geodetic control marks
6) Reconnoiter for a site suitable for installing an InSAR reflector




AGRIHAN DATUM

12. Asuncion

1) Perform long-session GPS on point DK2820 ("ASUNCION AZIMUTH MARK")
2) Attempt to find, photograph and write a recovery note for point AA5096 ("MACAW"). It was GPS'd in 1993 and *does* have descriptive data. The GPS position was adjusted to NAD 83(MA11). It is about 13 meters above sea level at 19 40 56.56172(N) 214 36 35.53630(W) or 145 23 24.46370(E).
3) Perform a relative gravity survey, looping through point DK2820 and AA5096 (if found) as well as hitting the highest point of the island. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
4) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
5) Reconnoiter for a site suitable for installing additional passive geodetic control marks
6) Reconnoiter for a site suitable for installing an InSAR reflector


MACAW

13. Maug (West, North, East) – Only stop on Maug West

1) Perform long-session GPS on point DK2822 ("MAUG")
2) Perform a relative gravity survey, looping through point DK2822 as well as hitting the highest point of the island. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
3) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
4) Maug North and Maug East are not planned stops. However, should plans change in the field, the following recommendations are made:
   A) As there are NO geodetic control marks on these two islands, do not attempt to find any
   B) Perform a relative gravity survey, hitting at least a low point on the island, the highest point on the island and other geographically well-distributed points. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
   C) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
5) Reconnoiter for a site suitable for installing additional passive geodetic control marks
6) Reconnoiter for a site suitable for installing an InSAR reflector

14. Uracas (aka Farallon de Pajaros) (Do not stop)

This island is not a planned stop. However, should plans change in the field, the following recommendations are made:

1) Attempt to find, photograph and write a recovery note for point AA5098 ("NO 1"). It was GPS'd in 1993 but has no descriptive data. The GPS position was adjusted to NAD 83(MA11). It is about 13 meters above sea level at 20 32 56.46933(N) 215 05 55.75166(W) or 144 54 04.24834(E).
2) Attempt to find, photograph and write a recovery note for point AA5099 ("NORTH POINT OF ISLAND"). It was GPS'd in 1993 but has no descriptive data. The GPS position was adjusted to NAD 83(MA11). It is about 11 meters above sea level at 20 33 11.37153(N) 215 06 24.70880(W) or 144 53 35.29120(E).
3) Attempt to find, photograph and write a recovery note for point AA5094 ("NPT"). It was GPS'd in 1993 and *does* have descriptive data. The GPS position was adjusted to NAD 83(MA11). It is about 11 meters above sea level at 20 33 11.14051(N) 215 06 26.88368(W) or 144 53 33.11632(E).
4) Attempt to find, photograph and write a recovery note for point AA5093 ("JUDY YEAGER"). It was GPS'd in 1993 and *does* have descriptive data. The GPS position was adjusted to NAD 83(MA11). It is about 18 meters above sea level at 20 32 46.53777(N) 215 05 51.11684(W) or 144 65 08.88316(E).
5) Perform a long-session GPS survey on any one of the four above marks
6) Perform a relative gravity survey, hitting all four of the above marks, plus the high point of the island and other geographically well-distributed points. Collect RTK GPS positions on all occupations that do not have an actual geodetic control marker.
7) Take pictures and use hand-held GPS to record the locations of potential targets which might serve as reflectors for satellite based InSAR (natural or man-made)
8) Reconnoiter for a site suitable for installing additional passive geodetic control marks
9) Reconnoiter for a site suitable for installing an InSAR reflector


NPT
NORTH POINT OF ISLAND
NO 1
JUDY YEAGER

15. Appendix A: Metadata about the Northern CNMI islands

Below are some relevant metadata to help with planning. Yellow highlighting identifies those islands that are *not planned* to be visited during this survey.

Site Visit Status	**Island**	**Square Miles**	**HighestElevation AMSL**	**All PIDS with an *actual* mark (Listings in RED have good GPS coordinates but no descriptions and need to be found & described)**
Not Planned	Farallon de Medinilla	0.3	270’	None
Not Planned	Anatahan	13.1	2600’	None
Planned	**Sarigan**	**1.7**	**1800’**	**DK2824 (SARIGAN AZIMUTH MARK)**
Not Planned	Guguan	1.5	990’	None
Planned	**Alamagan**	**4.3**	**3200’**	**DK2819 (ALAMAGAN RM 3)**
Planned	**Pagan**	**18.2**	**1800’**	**AA5095 (PAGAN 1)** **AA5100 (RON SANFORD)**
Planned	**Agrihan**	**16.8**	**3200’**	**DK2818 (AGRIHAN AZIMUTH MARK)** **DK2827 (AGRIHAN LDGO)** **AA5097 (AGRIHAN DATUM)**
Planned	**Asuncion**	**3.1**	**2800’**	**DK2820 (ASUNCION AZIMUTH MARK)** **AA5096 (MACAW)**
	Maug (west)	**0.3**	**500’**	**DK2822 (MAUG)**
Not Planned	Maug (north)	0.2	700’	None
Not Planned	Maug (east)	0.4	600’	None
Not Planned	Uracas (Farallon de Pajaros)	0.9	1200’	AA5094 (NPT) AA5093(JUDYYEAGE) AA5098 (NO 1) AA5099 (NORTH POINT OF ISLAND)

The following marks were listed in red in the previous table. Meaning they have a good GPS coordinate with no descriptions and need to be found and described.

- AA5100 (RON SANFORD)
- AA5097 (AGRIHAN DATUM)
- AA5098 (NO 1)
- AA5099 (NORTH POINT OF ISLAND)

16. Appendix B: Descriptive Information about GUAM AA and GUAM BA

GG STATION DATA/DESCRIPTION

CONVENTIONAL STATION NAME	DOPPLER/GPS	GRAVITY STATION NAME	
		GUAM AA	
LOCATION GQ	DESCRIBED/RECOV. BY	AGENCY	DATE
NAVAL AIR STATION, GUAM	A. JOLL	DMAHTC/GSG	JUNE 1989

DESCRIPTION

655058 A01
NHO 0042.36
NN 727
DoD 0061-U

LAT 13 ~~12~~ 28 34.6 N
LONG 144 47 58.9 E
ELEV 250 FT.; 76.2 M.

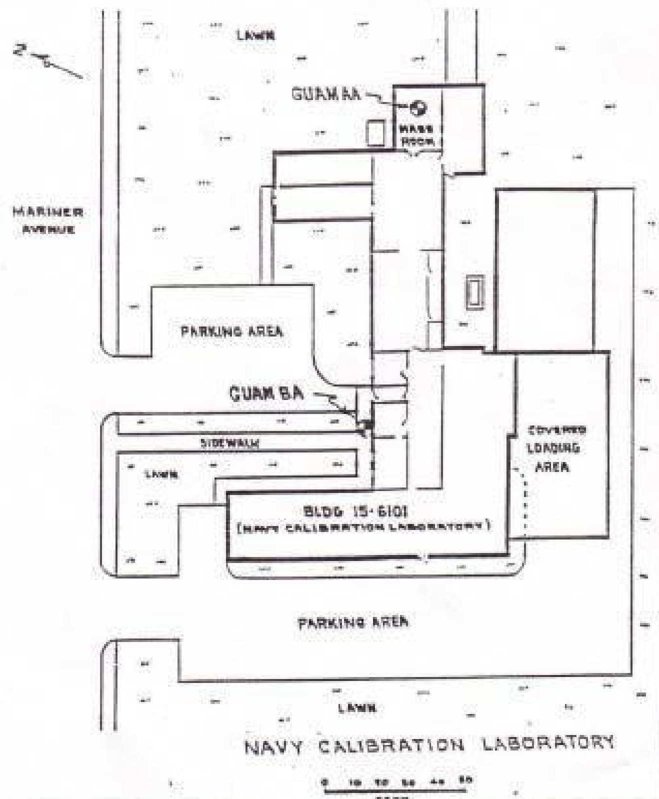
GRAVITY 978,506.~~185~~ .171 mGals

13.4763
144.7997

The station is located in the Mass and Balance Room at the Navy Calibration Laboratory on the Naval Air Station, Guam.

To reach the station from the Navy Control Tower (Building 17-75) on the southside of the runways go south on Admiral Sherman Boulevard for 0.2 mile to a slanting intersection with Mariner Avenue. Turn Left, east northeast, onto Mariner Avenue and go 0.2 mile to the Navy Calibration Laboratory (Building 15-6101) and the station on the right, south.

The station is in the Mass and Balance Room at the extreme eastern end of the laboratory. It is 2.555 meters north northwest of the southeastern wall of the room and 2.124 meters west southwest of the northeastern wall of the room. It is monumented with a 0.016 meter diameter aluminum plug, stamped GAUM AA (sic), set 0.003 meter below floor tile level and capped with clear epoxy to the tile level.



DMAHTC FORM 8240-2 (GG) Feb 1986

GUAM BA

GRAVITY STATION DESCRIPTION

LAT. 13° 28' 34.6" N 13.4763

LONG. 144° 47' 58.2" E 144.7995

POSIT. REF DMA GSG

ELEV. 76.2 m

ELEV. REF DMA GSG

TYPE EXCENTER

CROSS REF.

STATION NO. 0042.37

COUNTRY GUAM GQ

STATE

CITY AGANA

STATION NAME GUAM BA, NAVY CAL. LAB.

1971 DATUM g 978,506.~~28~~ 216 Mgals

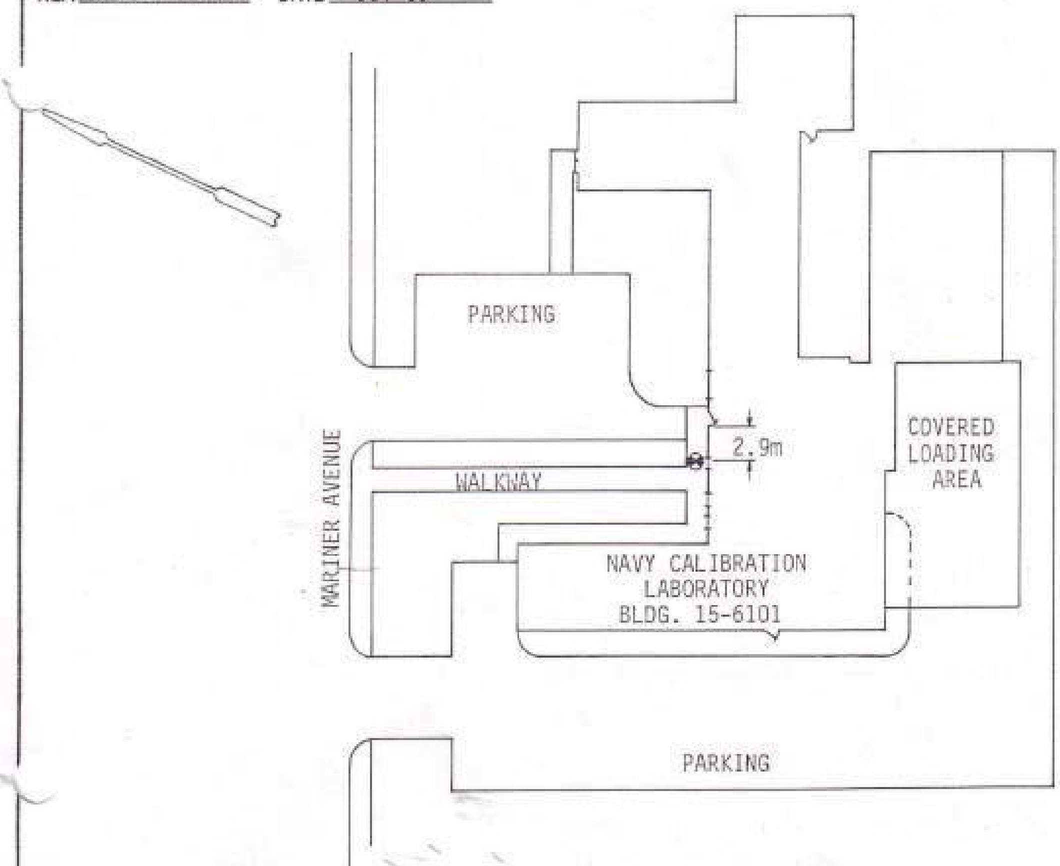
REF. GSG PUB 1201 DATE OCT 89

GSS 058A02 NN 728

THE STATION IS LOCATED ON THE WALKWAY IN FRONT OF THE NAVY CALIBRATION LABORATORY, NAVAL AIR STATION, GUAM. IT IS 2.9 meters (9.5') WEST OF THE WESTERN EDGE OF THE DOOR TO THE LABORATORY AND 0.26 meters (10.2") OUT FROM THE BUILDING. THE SITE IS MONUMENTER WITH A 5/8" DIAMETER ALUMINUM DISK, STAMPED GUAM BA.

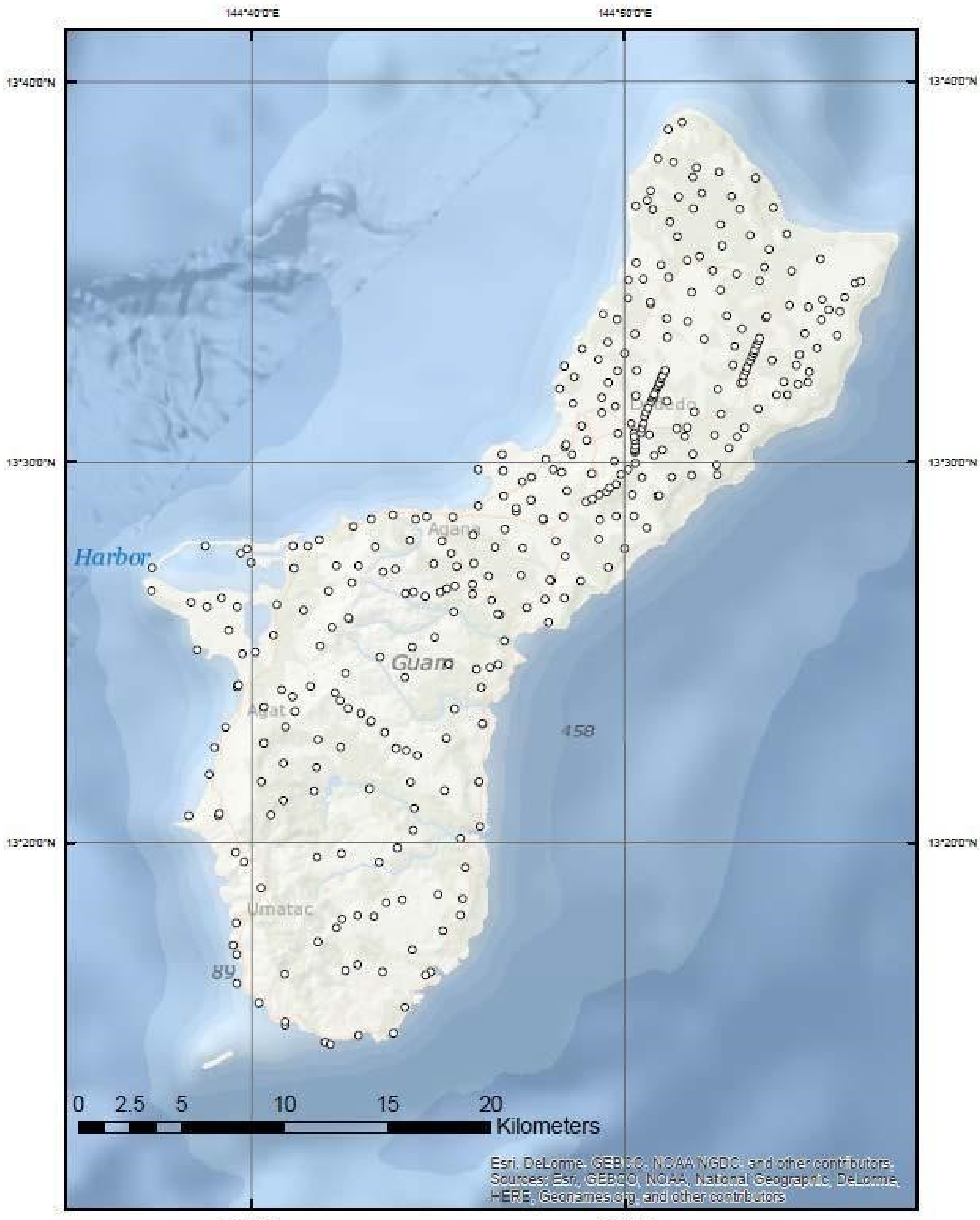
DoD #0061 - Q

REF. SGS PUB 1201 DATE OCT 89



17. Appendix C: Relative Gravity Maps for Guam and CNMI

Guam:



Rota:

Tinian and Saipan:

Northern Islands:

No terrestrial gravity data appears to exist for any of these islands. We will be the first.

18. Appendix D: Pictures of Select Marks

The NGS IDB does not, in general, have pictures of any of the marks mentioned in this document. However, photos do exist from various sources. Digital locations of key photos are listed below, and the very best photos themselves are actually included in the following pages.

18.1 Guam

No photos of any marks are currently available.

18.2 Rota

No photos of any marks are currently available.

18.3 Tinian

No photos of any marks are currently available.

18.4 Saipan

No photos of any marks are currently available.

18.5 Farallon de Medinilla

No marks are known to exist.

18.6 Anatahan

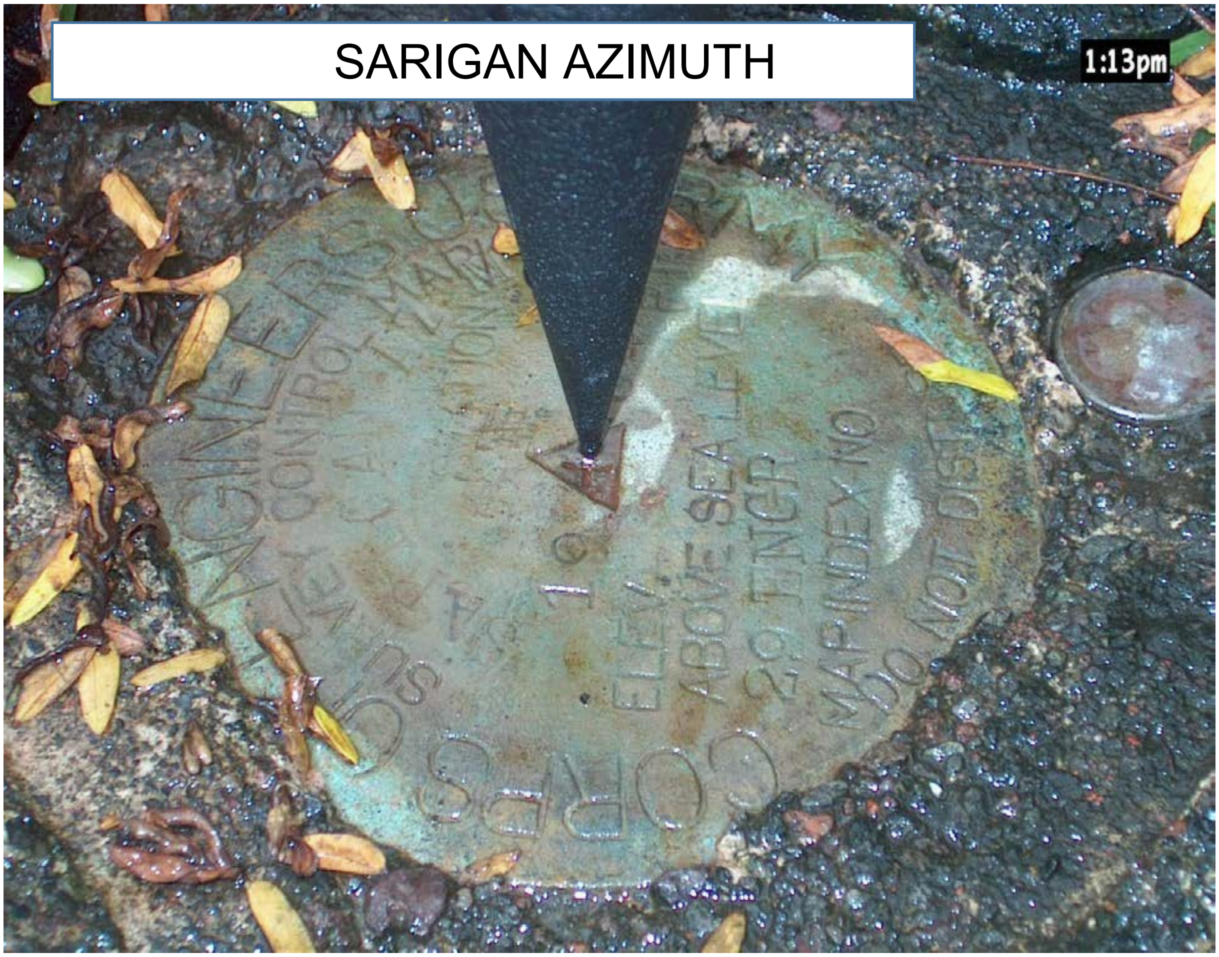
No marks are known to exist.

18.7 Sarigan

- SARIGAN AZIMUTH MARK (DK2824)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Sarigan\Photos
Best photo files:

- Sarigan 13.JPG
- Sarigan 24.JPG
- Sarigan 26.JPG
- Sarigan AZ Mark 02.JPG
- Sarigan AZ Mark 03.JPG
- Sarigan AZ Mark 04.JPG


SARIGAN AZIMUTH
1:13pm
CORPS
ELEV.
ABOVE SEA
MAP INDEX NO

SARIGAN AZIMUTH MARK

18.8 Guguan

No marks are known to exist.

18.9 Alamagan

- ALAMAGAN RM 3(DK2819)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Alamagan\Photos

Best photo files:

- Alamagan 024.JPG
- Alamagan 026.JPG
- Alamagan 049.JPG
- Alamagan 050.JPG
- Alamagan 051.JPG
- Alamagan 052.JPG

ALAMAGAN RM 3

ALAMAGAN RM 3

18.10 Pagan

a) 18.10. 1 PAGAN 1 (AA5095)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Pagan\Photos

Best photo files:

- Pagan 041.JPG
- Pagan 042.JPG
- Pagan 043.JPG
- Pagan 047.JPG
- Pagan 053.JPG
- Pagan 085.JPG
- Pagan 132.JPG
- Pagan 147.JPG
- Pagan 155.JPG
- Pagan panorama 2.jpg

PAGAN 1

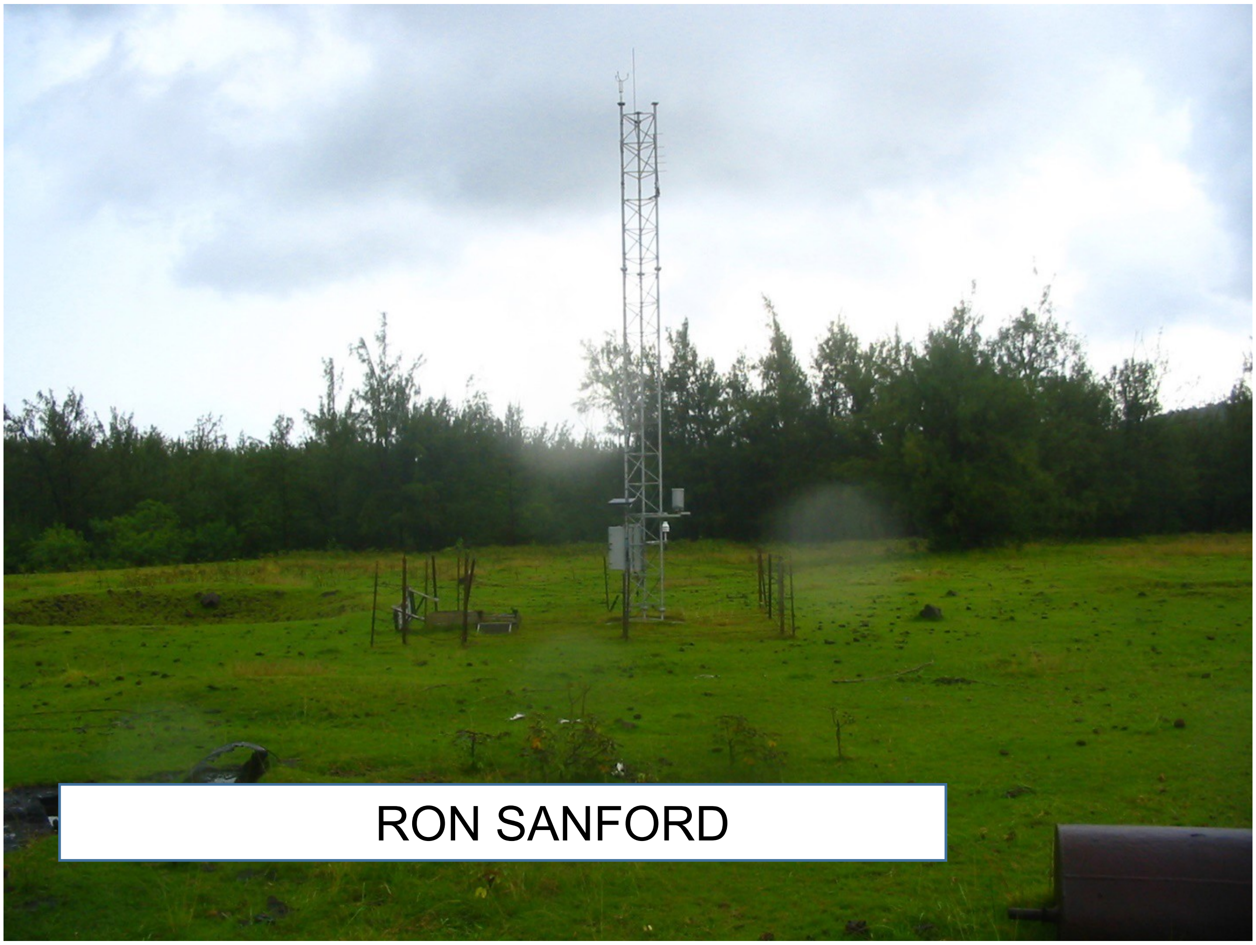
18.10.2RON SANFORD (AA5100)

From a hand-written 1993 description:

> *Station set over a small shell in concrete base of NOAA automated weather station on Pagan Is. "Ron Sanford 6-22-90" scratched into cement.*

As such, it is possible that this photo shows that station:

> Pagan 058.JPG (?)



18.11 Agrihan

18.11.1AGRIHAN LDGO (DK2827)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Agrihan\Photos

Best photo files:

- Agrihan028.JPG
- Agrihan 029.JPG
- Agrihan 031.JPG
- Agrihan 035.JPG
- Agrihan 036.JPG
- Agrihan 038.JPG
- Agrihan 039.JPG
- Agrihan 040.JPG
- Agrihan 041.JPG
- Agrihan 107.JPG
- Agrihan 109.JPG
- Agrihan 111.JPG
- Agrihan 112.JPG


AGRIHAN LDGO
LAMONT-DOHERTY GEOLOGICAL
OBSERVATORY
EARTHQUAKE RESEARCH
AGRIHAN
1992
DO NOT DISTURB

18.11.2AGRIHAN AZIMUTH MARK (DK2818)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Agrihan\Photos

Best photo files:

- Agrihan 128.JPG
- Agrihan 129.JPG
- Agrihan 130.JPG
- Agrihan 131.JPG
- Agrihan 132.JPG
- Agrihan 133.JPG

AGRIHAN AZIMUTH MARK

18.11.3 AGRIHAN DATUM (AA5097)

No photos of this mark are currently available.

18.12 Asuncion

18.12.1 ASUNCION AZIMUTH MARK (DK2820)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Ascuncion\Photos

Best photo files:

- Asuncion 13.JPG
- Asuncion 14.JPG
- Asuncion 16.JPG
- Asuncion 17.JPG
- Asuncion 18.JPG
- Asuncion 19.JPG
- Asuncion 20.JPG
- Asuncion 21.JPG
- Asuncion 22.JPG
- Asuncion 27.JPG
- Asuncion 28.JPG
- Asuncion 29.JPG
- Asuncion 30.JPG
- Asuncion 73.JPG
- Asuncion 74.JPG

ASUNCION AZIMUTH MARK


ASUNCION AZIMUTH MARK

18.12.2 MACAW (AA5096)

No photos of this mark are currently available.

3. 18.13 Maug (West)

a) 18.13.1 MAUG (DK2822)

Photos in Google Drive at : GPS2394\CNMI_Northern Islands\Maug\Photos

Best photo files:

- Maug 019.JPG
- Maug 020.JPG
- Maug 021.JPG
- Maug 022.JPG
- Maug 023.JPG
- Maug 025.JPG
- Maug 040.JPG
- Maug 062.JPG
- Maug 063.JPG
- Maug 064.JPG
- Maug 065.JPG
- Maug 068.JPG
- Maug 071.JPG


MAUG

18.14 Uracas (aka Farallon de Pajaros)

a) 18.14.1 NO 1 (AA5098)

No photos are currently available of this mark

b) 18.14.2 NORTH POINT OF ISLAND (AA5099)

No photos are currently available of this mark

c) 18.14.3 NPT (AA5094)

No photos are currently available of this mark

d) 18.14.4 JUDY YEAGER (AA5093)

No photos are currently available of this mark

C. 2017 Guam/CNMI Survey In-situ Recommendations

Version 03, D. Smith, 2017/09/14

As the 2017 Guam/CNMI Survey is underway, two issues have come to light which require a modification to the initial survey instructions. These two issues are:

A) Questions about initial velocities
B) Missing marks on the unpopulated northern CNMI islands

Each will be addressed below.

1. Questions about initial velocities

Initial computations show that the GPS data collected on Guam yields velocities which are fairly consistent with each other if tied to the same historic surveys, but inconsistent across historic surveys and also inconsistent with the two CORS on the island of Guam.

It is hypothesized that one cause of this might be that most of the velocities are coming from differencing new GPS data (2017) on Guam from historic GPS data based almost entirely on one historic survey. Specifically, historic GPS data on Guam come from GPS1987 (2004) except for one point which is tied to GPS1194 (1997). See below. Velocities in mm/year.

Point	**Old Project**	**Old Year**	**vN**	**vE**	**vU**
BEACH (TW0372)	GPS1987	2004	1.0	9.2	-4.0
GGN 2205 (DH3017)	GPS1987	2004	2.2	1.7	-4.4
AAFB (DH3302)	GPS1987	2004	2.6	1.5	-2.5
SALISBURY (TW0017)	GPS1987	2004	5.3	9.8	-6.4
SOLEDAD (TW0398)	GPS1987	2004	0.4	3.2	-2.2
GUM ARP (AA4393)	GPS1194	1997	2.9	15.2	-4.4
GUUG CORS			4.3	8.9	-0.3
GUAM CORS			5.6	9.2	-1.3

Focus explicitly on the East velocity (which was a-priori known to be the larger of the two horizontal components of the Mariana plate rotation). Note that velocities in the East direction are mutually consistent for points tied to GPS1987, but that the one point tied to GPS1194 is an outlier. Furthermore, note that both CORS are outliers relative to all passive control.

In order to provide greater information, and explicitly eliminate bias in either GPS1987 or GPS1194 as a source of error, it is proposed that additional passive control points be surveyed on Guam which were not originally listed in the document "Island by Island recommendations", issued at the beginning of the project. The newly recommended points were not part of GPS1987.

An initial list of points, in priority order, were provided to Ed Carlson on 9/13/2017, and feedback on those points was received on 9/14/2017, indicating that some of the points were not optimal, or even impossible, to survey. The points with trouble are:

Priority	**PID**	**Designation**	**Note**	**σ mm xyz**	**Reason to skip**
~~High~~	~~TW0537~~	~~TOGUAN~~	~~3 obs for GPS1194~~	~~2,2,1~~	Under Tree
~~High~~	~~DK7596~~	~~DSC 1~~	~~2 obs in GPS2493~~	~~3,2,1~~	Destroyed
~~Medium High~~	~~DQ3229~~	~~GGN 2623~~	~~1 obs in GPS3070~~	~~7,5,3~~	Damaged

Before compiling a new priority list, the second issue needs to be addressed.

2. Missing marks on the unpopulated northern CNMI islands

When the field crew arrived in Maug, they found that the one and only point they needed to occupy was missing. Recalling that points needed to be (a) surveyed after 1997 and (b) have reliable data from that previous survey at NGS, the only point in Maug to serve in this capacity (point “MAUG”, PID DK2822) was missing. Two additional marks were found though, labeled “MAUG RM 2” and “MAUG 1992” from LDGO. While the MAUG 1992 point was part of a LDGO survey in 1992, it failed both criteria (it was surveyed before 1997, and the data was not at NGS).

The crew, with limited communications to HQ made the command decision to survey MAUG RM 2. But the possibility of surveying MAUG 1992 was raised at HQ, and this led to the question of whether NGS could, in any capacity, make use of pre-1997 surveys in the area. That is addressed in the next section.

At the moment, with the field crew needing to make immediate decisions, and so, guidance is provided on an island by island bases in the recommendations section, below. The basic rule is this: If the target mark is missing, but a nearby mark is available, then occupy the nearby mark *only* if it is on the list of marks for which NGS already has old (pre-1997) data in hand.

3. Making use of pre-1997 data

No fully fleshed-out plan exists to use pre-1997 surveys in this science experiment. However, such data is being looked at for its potential to inform certain aspects of this experiment. As such, it may be useful for this survey to overlap with a few of the NGS 1993 points. However it does not seem likely that the LDGO 1992 survey data will be as readily available as NGS’s 1993 survey, so no specific attempts to occupy LDGO 1992 points are included.

Furthermore, to make the best use of NGS’s 1993 survey, it would behoove us to have overlap between the 2017 and 1993 surveys. Such overlap on Saipan is currently missing, and some on Guam can be improved. Therefore, in the recommendations section, additional GPS surveys are requested on Saipan and Guam.

4. Recommendations

I recommend that the survey plan be modified as follows:

a) Recommendation #1 (Guidance to northern islands crew):

I recommend the PM provide the following guidance to the team, as needed, via the text capabilities of the Garmin they area carrying, as they attempt to visit all of the northern islands on the original list:

General recommendation: RTK, photograph, and describe ALL marks you come across

Island	**Target Mark for long session GPS**	**If Target is unavailable, then:**
Maug	MAUG (DK2822)	Set up GPS on any site (or no site at all, if none can be found), use it as RTK base station, perform gravity and other reconnaissance survey.
Asuncion	ASUNCION AZIMUTH MARK (DK2820)	Set up on site **MACAW (AA5096)** (NGS, 1993) If MACAW unavailable: Set up GPS on any site (or no site at all, if none can be found), use it as RTK base station, perform gravity and other reconnaissance survey.
Agrihan	AGRIHAN LDGO (DK2827)	*Agrihan is a special case.* ***See below*** *for specific instructions.*
Pagan	PAGAN 1	(As of the writing of this document, PAGAN 1 was already surveyed)
Alamagan	ALAMAGAN RM 3 (DK2819)	Set up GPS on any site (or no site at all, if none can be found), use it as RTK base station, perform gravity and other reconnaissance survey.
Sarigan	SARIGAN AZIMUTH MARK (DK2824)	Set up GPS on any site (or no site at all, if none can be found), use it as RTK base station, perform gravity and other reconnaissance survey.

Special recommendations for AGRIHAN

Because Agrihan, alone of all the northern islands, has ***two*** marks which were both visited by NGS post-1997 (with good data available), and because we failed to find our target mark on Maug, it is recommended that Agrihan receive special instructions in an attempt to try and get ***two*** independent velocity vectors on Agrihan. As such, here are the specific cases, and recommendations for each:

Situation when they arrive	Recommendations
AGRIHAN LDGO is available AGRIHAN AZIMUTH MARK is available	Day 1: GPS on AGRIHAN LDGO Day 2: GPS on AGRIHAN AZIMUTH MARK
AGRIHAN LDGO is available AGRIHAN AZIMUTH MARK is not available	Day 1: GPS on AGRIHAN LDGO Day 2: GPS on AGRIHAN LDGO
AGRIHAN LDGO is not available AGRIHAN AZIMUTH MARK is available	Day 1: GPS on AGRIHAN AZIMUTH MARK Day 2: GPS on AGRIHAN AZIMUTH MARK
AGRIHAN LDGO is not available AGRIHAN AZIMUTH MARK is not available AGRIHAN DATUM is available	Day 1: GPS on AGRIHAN DATUM Day 2: Leave
AGRIHAN LDGO is not available AGRIHAN AZIMUTH MARK is not available AGRIHAN DATUM is not available	Day 1: GPS on any mark found, or no mark at all, just to have an RTK base station for gravity Day 2: Leave

b) Recommendation #2 (Survey additional points on Saipan):

I recommend that point "SPN A" on Saipan be surveyed with GPS at least 1 time by Kendall Fancher, for 4-8 hours before he heads to Guam. If additional time exists, I recommend, at his choice, occupying any other points (including re-occupying SPN A) in priority order, below.

Priority	PID	Designation	Note	σ mm xyz
High	AA4415	SPN A	3 obs in GPS1837 & 6 obs in GPS0667 (1993)	4,3,2
Medium	AA4412	10854 DOPPLER	1 obs in GPS0667 (1993)	
Medium	AA4413	GARAPAN	1 obs in GPS0667 (1993)	
Medium	AA4414	PEAK 2	1 obs in GPS0667 (1993)	
Medium	AA4418	SUMMIT 2	1 obs in GPS0667 (1993)	
Medium	AA4419	TAM 10	1 obs in GPS0667 (1993)	
Low	AA4570	PP01	2 obs of 20 min each in GPS0667	
Low	AA4571	PP02	2 obs of 20 min each in GPS0667	
Low	AA4416	SPN B	1 obs under 2 hours in GPS0667	
Low	AA4417	SPN C	1 obs under 2 hours in GPS0667	
Lowest	AA4568	1007 DOPPLER	Was in GPS0667, but no data	

c) Recommendation #3 (Survey additional points on Guam):

I recommend that points “GGN 2456”, “GGN 1952” and “163 0000 TIDAL 11” on Guam be surveyed with GPS at least twice by Ed Carlson and/or with help from local surveyors.

Priority	**PID**	**Designation**	**Note**	**o mm xyz**
High	DH3029	GGN 2456	2 obs in GPS3070	4,3,2
High	DQ3228	GGN 1952	1 obs in GPS3070	6,5,2
High	AA4394	163 0000 TIDAL 11	3 obs for GPS1987; TIDAL & 5 obs in GPS0667 (1993)	2,1,1

D. Relevant Information about the History of Surveys and Marks in Guam and CNMI

NGS has in its archives GPS campaign data in the Mariana plate region from a variety of surveys, stretching back to 1993. In 2017, an inventory of such data was made, with the intent of identifying permanent geodetic control points which (a) were occupied by at least 2 hours of GPS data sometime during or after 1994, (b) were well distributed through the entire Mariana island chain and (c) were likely to still be intact. Once this inventory was made, a target set of 39 points in the Guam/Rota/Tinian/Saipan cluster, and another 10 in the unpopulated northern islands (Farallon de Medinilla to Uracas) were identified as potential candidates for a repeat GPS occupation so that a velocity might be computed between the historic occupation and a 2017 occupation. This list of 49 target points was prioritized and became the cornerstone of the survey plan for the 2017 NGS survey of the Mariana plate. The relevant details of the final points surveyed with GPS are listed below. Both time limits and mark destruction meant that only 29 of the 49 target points were found and occupied, with four additional marks (which had no historic NGS occupations) added as occupations of opportunity.

Table 2: All geodetic control points occupied with at least 2 hours of GPS during the 2017 survey, as well as all CORS used in this paper

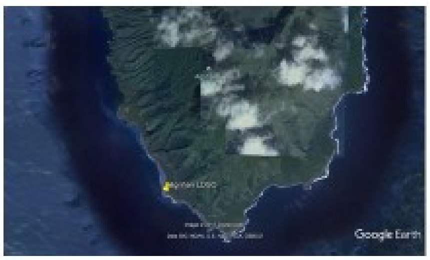
Island	Name	PID	Last Surveyed / Name of Project	Span of Years	# occ in 2017
Agrihan	AGRIHAN LDGO	DK2827	2003 / GPS2394	14	1
Alamagan	ALAMAGAN RM 3	DK2819	2003 / GPS2394	14	1
Asuncion	ASUNCION AZIMUTH MARK	DK2820	2003 / GPS2394	14	1
Guam	163 0000 TIDAL 5	TW0042	N/A	N/A	2
Guam	AAFB	DH3102	2004 / GPS1987	13	3
Guam	BEACH	TW0372	2004 / GPS1987	13	2
Guam	GGN 1215	DH2989	N/A	N/A	2
Guam	GGN 1952	DQ3228	2013 / GPS3070	4	2
Guam	GGN 2205	DH3017	2004 / GPS1987	13	2
Guam	GGN 2456	DH3029	2013 / GPS3070	4	2
Guam	GUM ARP	AA4393	1997 / GPS1194	20	2
Guam	SALISBURY	TW0017	2004 / GPS1987	13	3
Guam	SOLEDAD	TW0398	2004 / GPS1987	13	2
Guam	TOGUAN	TW0537	1997 / GPS1194	20	2
Guam	***CORS "GUUG"***	DF7984	2003-	14	N/A
Guam	***CORS "GUAM"***	AF9627	1992-	25	N/A
Maug	MAUG 92	N/A	N/A	N/A	1
Maug	MAUG RM2	N/A	N/A	N/A	1
Pagan	PAGAN 1	AA5095	2003 / GPS2394	14	2
Rota	DUGI	DG4024	2003 / GPS1837	14	2
Rota	JP SN BUDBAS	DG4009	2003 / GPS1837	14	2
Rota	TATGUA 2	AA4404	2003 / GPS1837	14	2
Rota	TIDAL 3	DG4014	2003 / GPS1837	14	2
Saipan	AMP 1	DG3974	2003 / GPS1837	14	2
Saipan	GRPN 9	DG3961	2003 / GPS1837	14	2

Saipan	JE JONES	DG3982	2003 / GPS1837	14	2
Saipan	KING	DG3940	2003 / GPS1837	14	2
Saipan	SAIPAN AZ MK	DE7041	2003 / GPS1837	14	3
Saipan	SPN A	AA4415	2003 / GPS1837	14	1
Saipan	TAM 4	DG3969	2003 / GPS1837	14	2
Saipan	***CORS "CNMI" (inactive)***	AJ6944	2001-2003	2	N/A
Saipan	***CORS "CNMR"***	DF9780	2003-	14	N/A
Sarigan	SARIGAN AZIMUTH MARK	DK2824	2003 / GPS2394	14	2
Tinian	ANT	DG4117	2003 / GPS1837	14	2
Tinian	CARMEN	DG4122	2003 / GPS1837	14	2
Tinian	LOOP	DG4108	2003 / GPS1837	14	2
Tinian	TIQ C	AA4411	2003 / GPS1837	14	2

The above table is not a definitive list of all geodetic quality GPS survey work in this region. However, at the time when the 2017 NGS survey was being planned, time and budget limitations required that the most critical points to visit were those points where the data was already in the hands of NGS, and which occurred after 1994 when IGS08 precise orbits were available.

E. Portage Locations and Recommendations

AGRIHAN LDGO– Located on island of Agrihan.



AGRIHAN LDGO– Located near the southern and west side of the island of Agrihan.

Boat anchorage area.

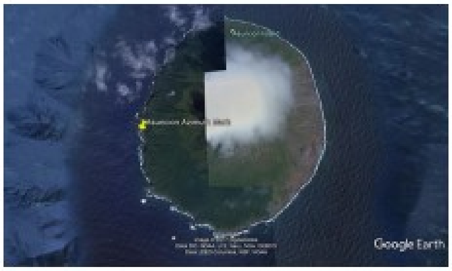
Tender boat landing area – The landing area is the southern end of a black sand beach. Trek from landing area to the mark is southerly across a large expanse of lava flow mixed with sandy areas to the mark on the right set in top a portion of lava rock projecting about 5-feet above the surrounding ground surface. Pack time from landing area is about 5 minutes.

ALAMAGAN RM 3– Located on the island of Alamagan.

ALAMAGAN RM 3– Located near the northern and west side of the island of Alamagan.

Boat anchorage area.

Tender boat landing area – The landing area is a flat portion of lava rock protruding out from and at the west end of a lava flow peninsula. From the landing area climb up to the top of the lava flow and then easterly to the mark set into the lava rock, Pack time to the mark a is about 1 minutes.



ASUNCION AZ MK– Located on island of Asuncion.

ASUNCION AZ MK– Located near the center and west side of the island of Asuncion.

Boat anchorage area.

Tender boat landing area – The landing area is a large area of outcropping lava rock. Careful, the landing area and all nearby rocks are very slick if wet. Trek from landing area to the mark is east across the lava outcrop area, then northerly along a boulder strewn beach, then up a grade with loose soil and exposed bedrock to a flat grassy area. Pack time from landing area is about 15 minutes.

MACAW– Located on island of Asuncion.

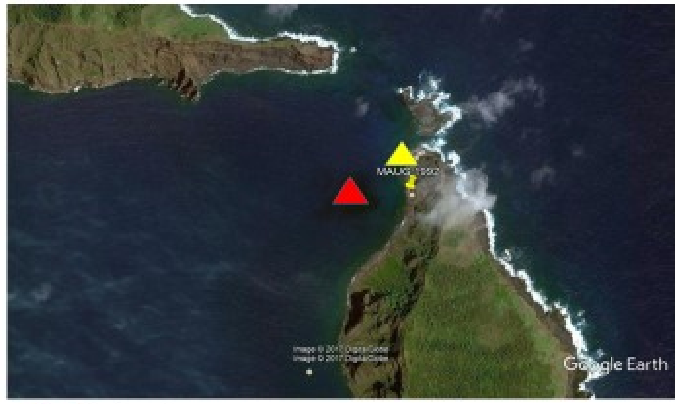
MACAW– Located on the southwest side of the island of Asuncion.

Boat anchorage area.

Tender boat landing area – The landing area is a rock ledge, of a bluff, located just to the north of MACAW. The bluff is perhaps 20 foot tall and the ledge is at water level. The bluff can be scaled using great caution. After climbing to the top of the bluff, trek to the south to the mark located in top of the bluff . Pack time from landing area is about 5 minutes.

MAUG 92 – Located on east island of Maug.

MAUG 92 – Located at north end and west side of the east island of Maug.

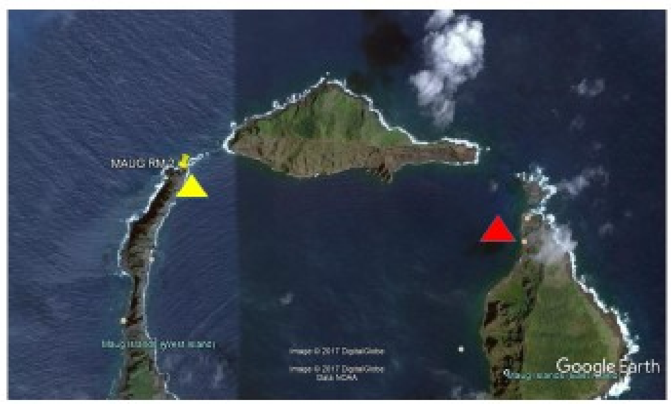


Boat anchorage area.

Tender boat landing area – The safest landing area is at a manmade rock shelf, built into the side of a large area of outcropping lava rock located just north of the mark. Careful, this rock shelf area and all nearby rocks are very slick if wet. Trek from landing area to the mark is across a relatively flat surface. Pack time from landing area is less than 1- minute.

MAUG RM 2 – Located on west island of Maug.

MAUG RM 2 – Located at north end of the island on west side of the ridgeline.



Boat anchorage area.

Tender boat landing area – Large flat boulder projecting out into the water. Careful, this boulder and all nearby rocks that are wet are very slick. Trek from the boulder to land requires wading thru knee high water. Trek from landing point to mark is north along a boulder strewn beach to the north end of the island, then southerly along the west side of the ridge line up a very steep grade with loose rock and soil. Pack time from landing area is about 20- minutes.

PAGAN 1 – Located on west side of Pagan

PAGAN 1 – Located at south end of a peninsula separating two bays.

Boat anchorage area.

Tender boat landing area - black sand beach. Trek from the beach to the mark is across flat easy terrain then up a steep incline to the mark on top of an outcropping area of lava rock. Pack time from the beach is about 10 minutes.

SARIGAN AZIMUTH MARK– Located on the island of Sarigan.

SARIGAN AZIMUTH MARK– Located near the northern and west side of the island of Sarigan.

Boat anchorage area.

Tender boat landing area – The landing area is a flat portion of lava rock protruding out from, along the north side and near the base of a lava flow peninsula. From the landing area trek easterly to the jungle ahead, then northerly through the jungle to the mark located near the edge of a cliff and at the north end of an old clearing that has become overgrown. Pack time to the mark is about 5 minutes.