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NEW TRENDS IN TECHNOLOGY, AND THEIR APPLICATIONS:
GEODESY

Precise satellite survey results in revised position for the Northern Mariana Islands

Paper submitted by the United States of America**

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** Prepared by Lewis A. Lapine, Chief, National Geodetic Survey Division, National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, Maryland.

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INTRODUCTION

In 1993 the Photogrammetry Branch of the National Oceanic and Atmospheric Administration's (NOAA's) Coast and Geodetic Survey (C&GS) completed a large-scale Global Positioning System (GPS) survey of approximately 20 islands in the central and western Pacific Ocean. This survey established a very accurate geodetic network throughout the Hawaiian Islands, American Samoa, Republic of the Marshall Islands, Federated States of Micronesia, Northern Marianas, and Republic of Palau, at the same time upgrading the existing survey control networks of these islands. The accuracy of this network will improve GPS-aided air and ship navigation in the Pacific Basin, provide modern shoreline information for nautical charts, redefine two international maritime boundaries, and more precisely position 25 island airports.

The survey covered an area of several hundred thousand square miles and included measured baselines of nearly 4000 miles. The remote nature of many of the islands and the scarcity of the survey control on these islands increased the difficulty of the project. A survey of this magnitude, especially considering the distances involved and the remote location of many of the islands, requires a great deal of careful planning. Logistics were complex--personnel and equipment had to be transported over great distances on fixed time tables to areas with inadequate airline schedules. Adding to the complexity was the occurrence of several natural disasters during the survey.

Actual GPS survey operations were divided into three distinct phases: (1) a survey of the Hawaiian Islands, (2) extending this survey to 13 other Pacific islands and establishing a precise geodetic network based on the World Geodetic System Datum of 1984 (WGS 84) throughout the Pacific Basin, and (3) tying this network to existing surveys, based on local astronomic datums, in the Northern Mariana Islands. The project was sponsored by C&GS, the Federal Aviation Administration, the Defense Mapping Agency (DMA) and the U.S. Department of State. GPS observations supporting the survey were made by NOAA, DMA, the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), Stanford University, Lamont Doherty Earth Observatory of Columbia University, and the University NAVSTAR Consortium (UNAVCO).

PROJECT PREPARATION

Work began in January 1993 with preliminary survey and logistics planning to test the feasibility of a project spanning seven time zones, the International Dateline (IDL), and nearly 4,000 miles of the Pacific Ocean. Geodetic databases of the National Geodetic Survey (NGS), U.S. Geological Survey (USGS), and DMA were researched exhaustively to identify existing survey control. An important consideration of this investigation was to locate existing survey control data to allow correlation of earlier astronomically-based local surveys to the new GPS survey (and WGS 84), thereby ensuring that existing mapping data could be used to prepare new charts. This was difficult since some of the islands had not been surveyed since 1936.

Government and University geodesists were consulted to develop optimum techniques to establish geodetic control, make GPS observations, and process those observations precisely enough to determine accurate coordinates for baselines expected to exceed 6,000,000 meters (nearly 4000 miles) in length. While these technical issues were resolved, logistic arrangements were coordinated among four government agencies, three foreign governments, and two U.S. protectorates.

Developing a GPS observation schedule was a joint effort of logistics and survey control working groups. With survey crews working thousands of miles apart, on both sides of the IDL, observation schedules had to be carefully coordinated by time and date and for visibility of common satellites. Complicating the undertaking were inconvenient airline schedules. Commercial flights between the remote islands are on a three-day schedule (including crossing of the IDL). Flights are west-bound on one day and east-bound on the next. Shipment of equipment, supplies, camping gear, and emergency stores had to be carefully planned to correlate with transportation schedules, taking into account the custom's regulations of several different countries.

THE SURVEY

The operational phase of the survey began in late July 1993 when 4,500 pounds of equipment were shipped from Norfolk, Virginia; Washington, D.C.; and Seattle, Washington, to Honolulu, Hawaii, the logistical center for the project. In Honolulu two persons provided around-the-clock project coordination. They were responsible for keeping the survey on schedule by locating and shipping replacement equipment, ensuring that the project personnel were in place at the designated times, and coordinating any required changes. Their work was complicated by the remote locations of the observing sites, the three-day flight schedule to the remote sites, the requirement for simultaneous satellite observations over five time zones (including the IDL), lost equipment, flight delays, and missed connections. On some of the islands a problem with a plane or airline crew might delay a scheduled flight until the problem was resolved--no replacement planes or crews were available.

None of these problems compared to those created by nature. During reconnaissance of Guam, only a week before survey crews were to make GPS observations and to transit the Guam Airport on connecting flights to other islands, a magnitude 8.2 earthquake shook the island. Typhoons and volcanoes were active in the survey area and one observer had to be evacuated as a typhoon approached the island of Hawaii. Even with these obstacles, all phases of the survey, including additional requirements added during the course of the survey, were completed with great success.

Due to the distances involved, baselines between major control stations (one station per island) were observed for 8 hours a day for 6 continuous days in the Hawaiian Islands and for 8 continuous days on the remaining islands. Existing horizontal control networks and tidal bench marks were connected to the GPS network by baselines observed over single or double 8-hour sessions. Major stations were surveyed to Order-A accuracy specifications ($5mm \pm 1:1x10^7$), while most connections to existing local control were surveyed to Order-B accuracies ($8mm \pm 1:1x10^6$). A total of 181 geodetic positions (69 in the Hawaiian Islands) were determined from the GPS observations. Of these, 79 were ties to the existing local networks and 11 were collocated on tidal bench marks.

TECHNICAL CONSIDERATIONS

One of the longest baselines, measured between major stations in American Samoa and Republic of Palau, was 6,223,000 meters (3,868 miles) long or approximately 98% of the Earth's radius. To illustrate the magnitude of this baseline, the ends were separated by 21.7 degrees of latitude and 47.1 degrees of longitude (Figure 1). A total of 3,379 observations were used in the computation of this baseline. Accurate computation of baselines this long requires a precise knowledge of variations in the Earth's rotation and of GPS satellite orbits. As GPS satellites orbit the Earth, the terrestrial coordinate system, upon which geographic coordinates are based, is constantly shifting due to rotational irregularities of the Earth. These variations in the Earth's orientation translate into significant coordinate errors for long baselines. To provide corrections for these variations, Very Long Baseline Interferometry (VLBI) radio telescopes are used to monitor signals from extragalactic radio sources. The arrival times of these signals are sensitive to Earth orientation changes, and are used to determine orientation information at the centimeter-level of accuracy. Precise GPS orbits are made available by NGS from data contributed by the world-wide array of GPS receivers operated by the Cooperative International GPS Network (CIGNET). Certain CIGNET GPS receivers, collocated with VLBI telescopes in Japan, Australia, New Zealand, Hawaii, North America, Europe, and Africa, provide information allowing GPS orbits to be rectified for shifts in the Earth's orientation. The combination of Earth orientation information and precise GPS satellite orbits from VLBI and CIGNET GPS receivers provide the information required to determine accurately this project's extremely long baselines.

RESULTS

The GPS observations from this survey project, along with the precise GPS orbits and orientation information, will be processed by the NGS. Preliminary results indicate that the actual position of several islands in the Northern Marianas will shift by as much as 1.5 nautical miles to the north. One of these islands, Farallon de Pajaros, marks the northern limit of the U.S. maritime boundary. The resulting northerly shift, when confirmed, could increase the exclusive economic zone territorial and fisheries rights of the United States in this region. See Figure 2 for an example of the shift at the island of Sarigan. Final results are expected by early summer of 1995.

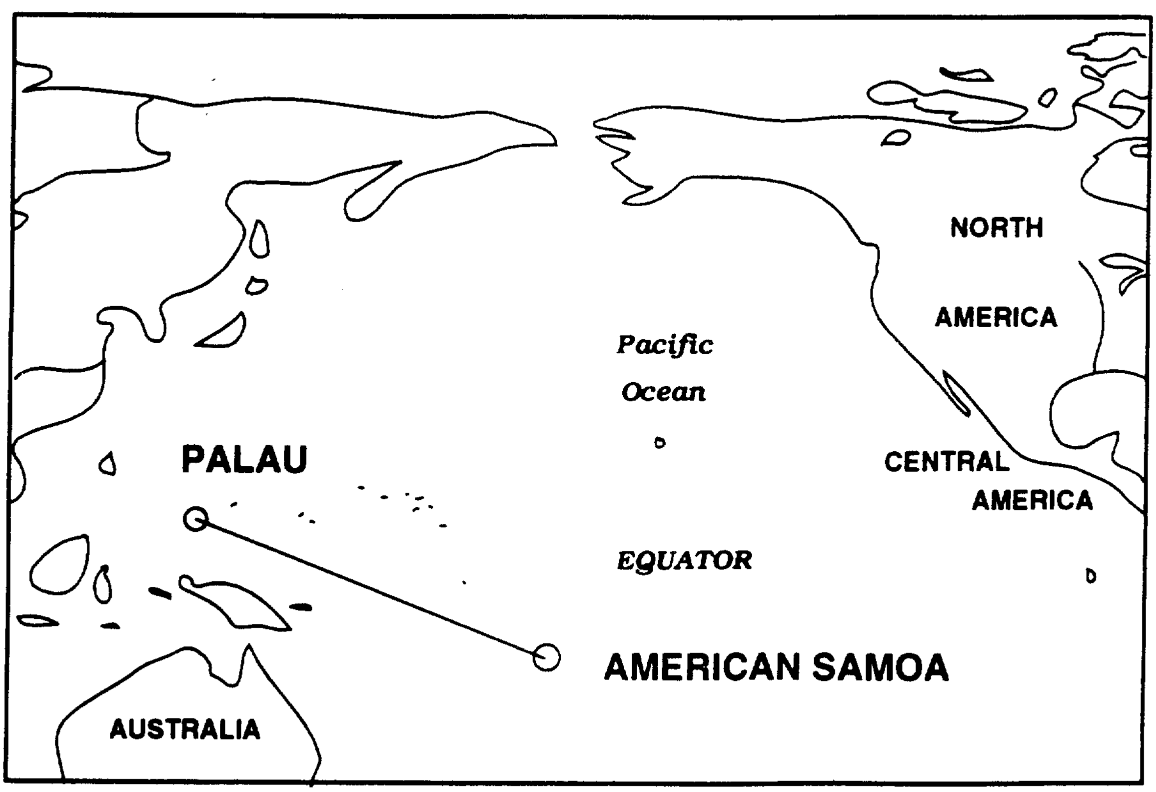

Figure 1
American Samoa to Palau Baseline

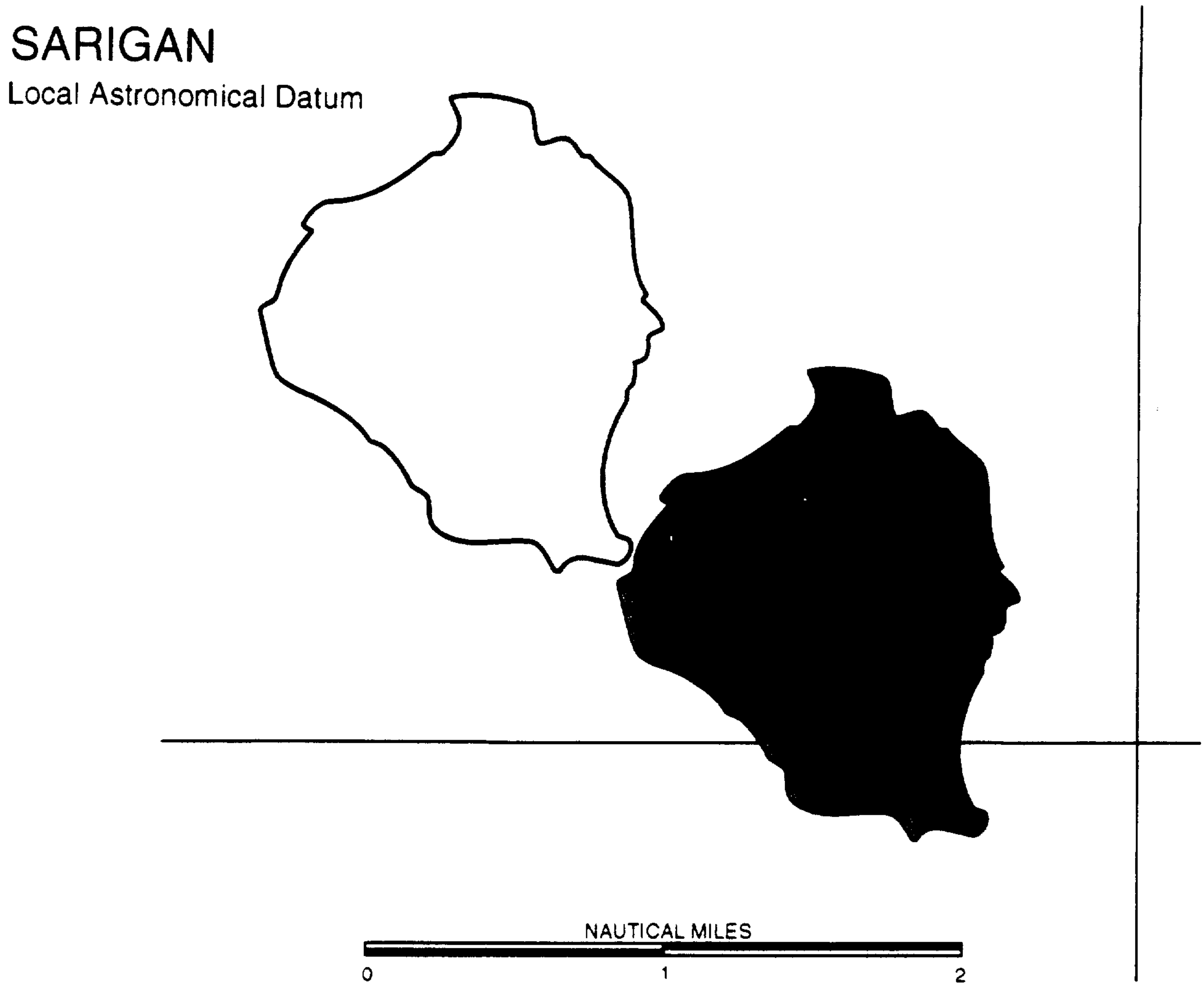

Figure 2
Shift at Island of Sarigan, Northern Mariana Islands

CONCLUSION

Today's technology allows the survey and precise positioning of remote areas of the world in a timely, accurate, and cost-ffective manner not previously possible. Access to this positioning information may result in signficant changes to maps and charts and the territorial and economic rights of nations.
