THE NEXT DECADE OF THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

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ABSTRACT

The International GPS Service for Geodynamics is facing new challenges and opportunities. The past seven years of development and the international collaboration for optimizing the use of the GPS Global Network have been more successful than anyone imagined, and so the question becomes -- Where do we go from here? In this paper we will discuss the potential expansion of the IGS to meet the GPS support requirements from other scientific applications. Also, we will touch on the probable commercial activities that could use IGS services and products, and the policy issues for IGS operations that might arise.

INTRODUCTION

There are a number of forces at work that are changing the utilization of GPS by many different sectors of society. The reduction of Cold War tensions is resulting in shifting priorities and increased focus on societal and economic priorities. Governments are becoming smaller, decentralized in many cases, and in many developed countries there is less government funding available for science and technology. With increasing population pressures worldwide, the interest in the environmental impact becomes a priority as we look to the future world of our children.

In Space a revolution is underway, fueled by technological and programmatic innovations that are resulting in much smaller space missions than advocated in the past. Small, automated, lower cost satellites that are launched in large numbers within a couple years instead of a decade or two, are providing a wealth of scientific information about our planet, as well as global communications and navigation services. In addition to its conventional roles in navigation, surveying and Space Geodesy, GPS will play a prominent role in ground and space applications in remote sensing of atmospheric and ionospheric processes.

Possible new directions for the IGS have been presented over the last year. We look at the possibility of new participants and sponsors for this activity, evaluate the IGS structure and try to determine how the IGS should interface with other government agencies and institutions, both private and public. The IGS has a very flexible, yet strong and robust infrastructure in place and receives a great deal of support from the scientific community.

As we become more involved in responding to the multi-disciplinary applications of GPS, the question arises -- are the auspices of the International Association of Geodesy (IAG) sufficiently broad? If IGS services and products are used increasingly for atmospheric and ionospheric applications, should the IGS consider expanding its sponsorship to include the International Association of Geomagnetism and Aeronomy (IAGA) and the International Association of Meteorology and Atmospheric Physics (IAMAP)? If sea level applications become prominent, should the International Association for the Physical Sciences of the Ocean (IAPSO) not also become a sponsor? Another direction to consider is the way in which the IGS relates to the commercial sector, which has been discussed since 1993. We are just beginning to assess the use and value of the GPS data and products for commercial companies.

The key areas for the use of GPS are: i.e., seismic hazard monitoring and detection, tide gauge benchmark monitoring, ground based meteorology, space-based atmospheric sounding and ionospheric tomography applications. Other areas of primary civilian use are Differential GPS (DGPS) for real-time navigation, Wide Area Augmentation System (WAAS) for real-time control of aviation, and GPS positioning as the registration points for all types of geographic information systems, mapping and charting.

BACKGROUND AND CURRENT STATUS

The development of the IGS is documented in a variety of publications (Zumberge, Liu, & Neilan, editors, 1995). A key to the success of the IGS through the last seven years has been the broad support from the international geodynamics and geodetic communities and their sponsoring organizations

IGS currently provides its users with GPS tracking data, precise IGS orbits, clocks, high resolution Earth rotation parameters (ERP's), and precise station coordinates and velocities. The IGS has a solid structure that provides support for science and engineering. The infrastructure for maintenance and control of the GPS global reference frame is nearing completion. The map in Figure 1 shows the operational stations of the IGS Network in July 1995; a number of future stations are still being planned to optimize the global distribution, particularly in the areas of Africa, Asia and the oceanic areas.

The direction that many scientists and agencies are heading is the implementation of dense or regional GPS arrays, often coupled with other instrumentation. The link between these arrays and the IGS is primarily in the hierarchy of reference frame and global data products. A pilot project for the Regional Densification of the IGS is underway and will provide a mechanism to extend the Terrestrial Reference Frame of the International Earth Rotation Service (the ITRF) to all GPS stations included in the project. (Zumberge & Liu, ed., 1995).

SEISMIC HAZARD MONITORING AND DETECTION

The use of GPS for monitoring strain accumulation and seismic displacements is increasing. The Japanese are implementing a system that involves a network of nearly 1000 receivers for seismic hazard detection in the Tokyo/Kanto region, with a larger array throughout Japan as a national reference network. These groups are using the data and products of the IGS for orbit and reference frame control.

The Southern California Integrated GPS Network (SCIGN) in Southern California is an initiative established by a group of U.S. agencies (NASA, USGS, UCLA, USC, SIO, etc.) to monitor the metropolitan area of Los Angeles in the aftermath of the Northridge 6.7 earthquake on January 17, 1994. To enhance real-time strain monitoring, rapid predicted orbits from the IGS for near to real-time analysis are essential. To accomplish this, the timely availability of IGS tracking data is required. Improvements for these real-time applications will demand rapid real-time communication links and real-time processing of the data. More of these arrays will unquestionably be implemented in the next decade.

LOCAL MONITORING OF TIDE BENCHMARKS FOR SEA LEVEL CHANGE

The IGS is in the process of a joint initiative with the Permanent Service for Mean Sea Level (PSMSL) to assess the current state of, and develop a technique for, precise monitoring of tide gauge benchmarks. This will help to understand long term sea level change and coastal processes (where altimeter missions are limited) when coupled with the long record tide gauges of the Global Sea Level Observing System (GLOSS) Network of the Intergovernmental Oceanographic Commission (IOC). This is a joint IAG-IAPSO activity.

GROUND-BASED MONITORING FOR WEATHER AND CLIMATE

Research results over the last two years promise that GPS can be used to greatly enhance our understanding of weather processes and in particular storm hazard warnings (Bevis et al., 1993). GPS signal sensitivity to atmospheric delays has generally been a nuisance for GPS analysis that can be nearly eliminated for high precision applications (orbits, etc.). However, by equipping stations with meteorological packages for determining the dry air component of atmospheric delay, the delay due to total precipitable water vapor may be obtained. By determining the vertical precipitable water vapor at the millimeter level from an array of GPS receivers, one can study the dynamics of local or regional weather systems. These water vapor distributions, used as additional input to the numerical weather models, could improve weather forecasting and early storm warning. Such data at the global level could even be useful over the long term for climate studies worldwide. An additional thrust of the IGS is to support these

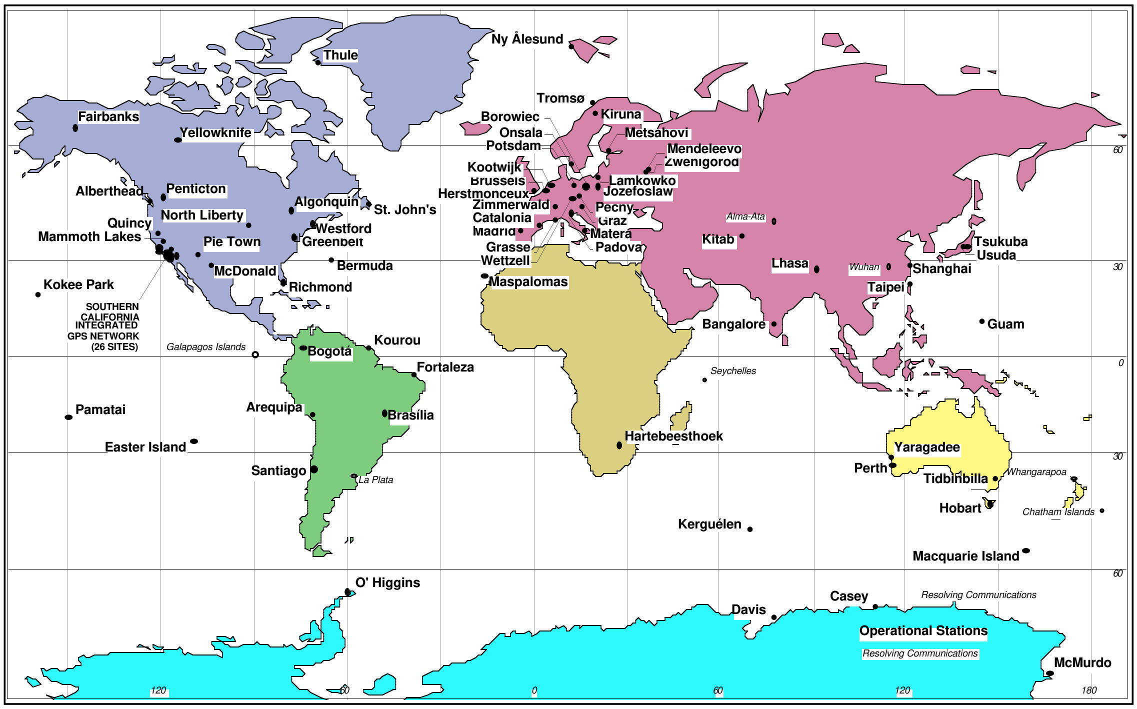

Fig. 1. Network of IGS Operational Tracking Stations as of July, 1995.

applications, by instrumenting GPS stations with precise meteorological packages and providing for rapid but accurate orbits and data processing for continuous monitoring techniques, and performing detailed analysis of the consistency between various software packages for determining these values (Gendt, 1995).

These same networks of receivers can be used for monitoring the ionosphere by tracking the change in total electron content (TEC) between each receiver and each observed GPS satellite. Maps of global electron distributions can be formed from these observations combined with certain ionosphere models. Although limited in vertical resolution, the horizontal resolution of these maps appears to be limited only by the density of the receiver deployment within the networks. The technique can be used to determine ionospheric current densities, which are noise sources for geomagnetic measurements. The maps may also be used to calibrate the group delay observations from single-frequency space-based radar altimetry.

SPACEBORNE APPLICATIONS OF SCIENTIFIC SATELLITES

Spaceborne applications of GPS will burgeon in the next few years; upward to a dozen Earth orbiters carrying GPS flight receivers for scientific applications will have flown by the end of the millennium, and for purely navigation functions, the number may well exceed 100. Missions such as TOPEX/Poseidon and Geosat have demonstrated the potential for precise positioning with GPS (a few centimeters orbital accuracy) in support of satellite atimetry and interferometric SAR. GPS/MET, launched in April 1995, was the first experiment to use the radio occultation technique with GPS to recover atmospheric temperature and pressure profiles, and TEC measurements of the ionosphere (Melbourne et al, 1994). Future missions such as Ørsted, Sunsat, CHAMP, SAC–C and Hummingbird will provide further demonstrations of atmospheric sounding using the radio occultation technique. Spaceborne GPS receivers will also be used to recover gravity information with unprecedented resolution down to the mesoscale level.

Within the next few years an operational constellation of small, dedicated and automated low Earth orbiters (LEO) probably will be deployed to continuously sound the atmosphere and ionosphere using the GPS radio occultation technique. A constellation of twenty LEOs would provide 5,000–10,000 occultations per day, with a mean geographical spacing of about 300 km. These data streams, when combined with atmospheric models and ground observation programs involving GPS, radiosondes and other instrumentation, promise significant improvements in medium-term weather forecasting; they would also contribute to global climate change studies. If future technological enhancements enable the GPS radio occultation technique to reliably recover refractivity profiles in the lower troposphere (which has been a difficult medium because of sharp vertical refractivity gradients), accurate (~5% in tropical oceanic regions) monitoring of global water vapor distributions could be achieved by combining the recovered refractivity profile with atmospheric models to account for the contribution of dry air. Water vapor is the principal medium for transport of thermal energy and its uncertainty is a major error source in state–of–the–art atmospheric models.

Another dramatic contribution of the LEO constellation operating in conjunction with globally distributed ground networks will be the mapping of the ionosphere using tomography. High tomographic resolution is achieved by probing the ionosphere with densely spaced sounding paths whose directions adequately span three-dimensional space. Ground-based TEC measurements of a common zone of the ionosphere tend to transect the medium along nearly parallel paths, resulting in large correlations between TEC measurements from neighboring ground stations and poor "vertical" resolution. On the other hand, TEC measurements from LEOs transect the ionosphere over widely varying directions and altitudes, which can result on average in much sharper 3-D tomographic resolution, particularly when combined with concurrent ground observations. Future monitoring of ionospheric variability may be revolutionized using flight/ground GPS observation programs such as that just described.

CIVILIAN SECTOR APPLICATIONS

Civilian applications are expanding rapidly from smart vehicle tracking with geographic information systems (GIS) to precision farming and autonomous route construction. One of the aspects most likely to mesh with the IGS is the need in many regions for control of GIS and mapping. Many GPS companies are now beginning to integrate GPS systems with the real-time collection and designation of assets for database development and mapping.

IGS has received requests for assistance for establishing national GPS reference networks in developing nations, and the question becomes how far to provide such advice or assistance. Perhaps the various national geodetic agencies participating in the IGS would be most suitable for such activities, such as IfAG, NGS etc. However, it is evident that the IGS is recognized as an organization with the expertise to advise and work with these groups for control networks. It is in this area that the IGS also has a long term goal of bringing all national networks into a common, precise reference frame.

The IGS may also have some input to the field of aviation by providing air traffic with the precise international Reference Frame and GPS orbits for precision navigation, approach and landing. Conceivably, a number of the IGS stations could be used in real-time mode for integrity monitoring and assurance and as an international augmentation to the Federal Aviation Administrations WAAS.

In selecting such active stations, we will have to carefully assess the reliability and liability issues. It could be that various contributing agencies of the IGS make these arrangements while continuing to support the primary charter of the IGS.

IGS: TO CHANGE OR NOT TO CHANGE

There are alternative views regarding appropriate IGS roles and functions in the next decade and consensus is needed to determine these directions and maintain the spirit of international cooperation that we have enjoyed for the last seven years. While there are other GPS service organizations, the IGS is the only one with such global scope and participation, and the most demanding scientific users in mind.

There is clearly a need for scientific and engineering services building on the current IGS charter as noted in the applications described above and discussed throughout these proceedings. The impacts on the IGS are mostly questions of organization. Should we co-opt additional Analysis Centers for specific application(s)? Should we add Coordinators for specific applications? Should we introduce Data Information Systems (DIS) Centers for specific applications? Should we introduce marketing functions within the IGS organization? Should we implement a financial management organization? Should we modify representation on IGS Governing Board to reflect expansion in these functions? Should we modify the IGS Central Bureau to cover expanded communications, management, and service requirements? All of these questions will come up over the next few years and will take careful thought and consideration.

Another thorny issue is the question of cost recovery and establishing a policy with regard to the commercial use of the services and products of the IGS. A number of national and international institutions providing scientific products and services have or are adopting a tiered policy with respect to users, depending on their classification. Scientific users or users from agencies providing significant support tend to have free access to the services and products, but commercial users and non-supporting agencies are charged a fee based on cost recovery considerations. The IGS during its development phase has been blessed by beneficent sponsors, but will this continue into the future? There are storm clouds on the horizon today that warn of changing spending priorities in several key nations. Our view is that the IGS Governing Board should promptly review these questions of scope and cost recovery and take appropriate action.

GENERAL RECOMMENDATIONS

In conclusion, it seems as though the IGS should build on our foundation to support these multi-disciplinary activities. A key point is to continue to establish the IGS as *the* network and reference system for GPS applications of the future. Where it makes sense, we should expand to meet user requirements. Of course, we must evaluate the need for IGS involvement in the different disciplines remaining thoughtful about the activities in which we become involved over the next decade.

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