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International GPS Service for Geodynamics (IGS)

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Chapter 1

Development, Present Structure, and Future of IGS

THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS: AN INTRODUCTION

Ivan I Mueller
Department of Geodetic Science and Surveying
The Ohio State University
Columbus,OH 43210-1247, USA

At the request of the organizers of this Workshop it is my pleasure to give some introductory remarks on the evolution of the International GPS Service for Geodynamics (IGS), although its history probably is well known to most participants.

At the 20th General Assembly of the IUGG in Vienna, Austria in August 1991 Resolution No.5 recommended that the concept of the IGS be explored over the next several years, that campaigns be conducted to test the practicality of the concept.

The primary goals of the IGS are to provide the scientific community with high quality GPS orbits on a rapid basis, to provide earth rotation parameters of high resolution as a byproduct, to expand geographically the current international Terrestrial Reference Frame (ITRF) maintained by the International Earth Rotation Service (IERS), and to monitor the global deformations of the earth's crust.

The emphasis being on the word **service,** the above products are to be available on a regular and timely basis through the Central Bureau (currently the Jet Propulsion Laboratory) and through the Network Data Centers (currently NASA's Crustal Dynamics Data Information System, the Institut Geographique National in France, and the Scripps Institution of Oceanography).

The "Call for Participation" in the 1992 test campaign (June 21-September 23) was responded to by more than 100 organizations around the world and resulted in the design of the first IGS structure consisting of the above Bureau and Network Data Centers, seven data Processing Centers and a Core network of some 30 GPS observatories equipped with precise so called P-code receivers and the important efficient data communication links to assure rapid data flow to the various data centers. More information on the early phase of IGS may be found in (Mueller, 1992; Mueller and Beutler, 1992).

The purpose of the 1992 test campaign was to **verify the proposing organizations' ability and willingness** to perform. The Campaign is being followed by the "IGS Pilot Service" phase until IGS becomes fully operational.

Scientific results of the campaign will be presented at this Workshop and the publication of the Proceedings will mark the end of the IGS Campaign. These Proceedings will form a part of the proposal to be submitted to the International Association of Geodesy for the establishment of the Service proper, Although the lGS is not approved yet as an international service it appears to be certain that continuous GPS observations will greatly contribute to geodynamics of the future. In fact since October 1992 GPS products have been introduced in the computations of the IERS and thus will have a beneficial effect on the future ITRF as well. Preliminary results indicate uncertainties in the daily coordinates of the pole ranging between 0.5 - 1.5 mas. Agreements in the orbits produced by the various Processing Centers are on the submeter level after the removal of biases due to inconsistencies in the reference frames inherent in the calculations.

It is hoped that eventually the lGS networks will include well over hundred stations which will then significantly improve our knowledge of the deformation of the globe and expand the geographic coverage of the present ITRF.

This introduction would not be complete without emphasizing the role of the IAG in these activities. In the past as well in the present the IAG managed to accomplish similar tasks despite of many setbacks due to international politics. As J.J. Levallois former Secretary General of the IAG noted in the 1980 Geodesist's Handbook: "History of the International Association of Geodesy", the IAG

> *"has overcome them all, despite international struggles, despite differences in nationality and scientific training, because geodesists feel at home in it. The mutual respect that arises out of continued direct contact and shared scientific concerns creates enduring ties of, friendship that transcend political jealousies and ideologies . . . . . These relationships, and the fruitful exchanges of ideas born of them, are extremely powerful forces for* scientific *progress, and one of the main reasons the* association *can be so influential. "*

In other words, the IAG has this unique unifying role because it has authority to influence, expertise based on free exchange of 'ideas, trust based on mutual respect of friends and it 'serves as a protective shelter because scientists feel home in it.

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The 1992 IGS Test Campaign, Epoch'92, and the IGS PILOT Service: An Overview

Gerhard Beutler *

Abstract

This report covers the time period between April 1992 and March 1993. The readers interested in the development and the structure of IGS are referred to (Mueller, 1992, 1993; Mueller and Beutler, 1992).
The 1992 **IGS** Test Campaign (21 June-23 September 1992) and the intensive observation campaign called Epoch'92 were organized by the IGS Campaign Oversight Committee. The declared goal of the three-month 1992 IGS Test Campaign was the routine production of accurate GPS orbits and of earth orientation parameters using the observations of about 30 globally distributed **IGS** Core Sites. The **IGS** Core Network is a relatively sparse global network. **IGS** fiducial sites (in future there should be about 200 of them) should serve as a first densification of this core network, which could then serve as a readily available terrestrial reference frame for geodynamics. Results of the Epoch'92 campaign may be found in these proceedings. The processing of Epoch'92 should be finished by mid-1993.
At the 3rd IGS Oversight Committee meeting in October 1992 at the Goddard Space Flight Center it was decided to establish **the IGS** Pilot Service to bridge the gap between the 1992 IGS Campaign and the routine IGS service, which should start on 1 January 1994. This means that beginning with 21 **June 1992 there is an uninterrupted series of high accuracy** GPS orbits and earth rotation parameters available for regional and local crustal dynamics investigations using the GPS.

The 1992 IGS Test Campaign and Epoch'92

The essential events are summarized in Table 1. The communications test in May 1992 showed that the capacity of the international scientific data network was sufficient to handle 30 sec data from the entire core network; this fact was the basis for the success of the 1992 IGS operations.
The communication between the IGS participants was made through the IGS (e-)mailbox at the University of Berne. This mailbox proved to be the essential tool to have the 1992 IGS experiments under control. Such a mailbox will be absolutely mandatory for the routine IGS service to be established.

"Astronomical Institute University of Berne, Sidlerstrasse 5, CH-3012 Bern, Switzerland

Table 1: Chronicle of events

Starting date	Event
17-Mar-92	2nd IGS OSC Meeting at OSU
04-May-92	One-week Communication Tests
21-May-92	IGS e-mailbox installed
15-Jun-92	Start of Data Transmission
23-Jun-92	Start of IGS Test Campaign
5-Jul-92	First results from processing centers
27-Jul-92	Start of Epoch'92 (2 weeks)
1-Aug-92	First weekend with AS on
23-Sep-92	end of official campaign
15-Oct-92	3rd IGS OSC meeting at Goddard
1-Nov-92	Start of IGS Pilot Service
10-Dec-92	IGS OSC Business Meeting at AGU Meeting
24-Mar-93	4th IGS OSC Meeting in Bern
25-Mar-93	IGS Workshop in Bern

NASA's Crustal Dynamics Data Information System (CDDIS) and Scripps Institution of Oceanography (SIO) were available as network centers right from the beginning of the campaign, the French Institut Géographique National (IGN) started operating end of July (Table 2). The observations, but also the results (orbits and earth rotation parameters) were and are readily available at these centers. There were no serious complaints concerning the availability of data and results by the processing centers or by the steadily growing IGS user community.

At the beginning of July 1992 the processing centers gradually started delivering their products to CDDIS, S10, IGN , and to several regional data centers. in addition the earth orientation information was sent to the IERS Rapid Service and to the IERS Central Bureau. Seven processing centers became operational before the end of the campaign (Table 2).

Epoch'92 was taking place as scheduled (27 July - 9 August) the results are becomming available now. Epoch'92 was severely handicapped by AS, the so-called "Anti-Spoofing", which was turned on for 7 satellites over the weekend of August 1. (AS was on during most of the weekends thereafter for the rest of the IGS Test Campaign, the number of affected satellites was variable). Unfortunately the principal receiver of the core network did not handle the L2 phase observations properly under AS. The problem was not a trivial one, a receiver firmware upgrade which should handle AS data in a better way was sent out and installed at the beginning of February 1993.

The Transition Phase to the Routine IGS

On 23 September 1992 the 1992 IGS Campaign officially ended. Data collection, transmission, and analysis however went on afterwards on a best effort basis. At the third IGS Campaign Oversight Committee Meeting at Goddard Space Flight Center in October 1992

Table 2: Network and Processing Centers of the 1992 IGS Campaign

Abbreviation	Institution	Center Type
CDDIS	Crustal Dynamics Data Information System	Network
IGN	Intitut Géographique National	Network
SIO	Scripps Institution of Oceanography	Network
UTX	University of Texas at Austin	Processing
CODE	Center for Orbit Det. in Europe	Processing
GFZ	German Geod. Research institute	Processing
ESOC	European Space Operations Center	Processing
JPL	Jet Propulsion Laboratory, USA	Processing
S10	Scripps Inst. of Oceanography, USA	Processing
EMR	Energy, Mines, Resources, Canada	Processing

it was decidied to establish the IGS PILOT SERVICE starting November 1 to bridge the gap between the 1992 IGS Campaign and the start of the routine IGS. It was stated that
In the new undertaking the emphasis is on the SERVICE, meaning that (a) a better adherence to standards on all levels has to be reached and that (b) the core *and the fiducial network have to be completed. In these coordination tasks the Central Bureau (JPL) and the Analysis Center Coordinator (Prof. Clyde Goad) have to play important roles, the former concentrating on observational aspects, the latter on processing aspects. In particular it is expected that a routine quality control for the orbits is set up by the analysis center coordinator for the period of the IGS PILOT SER VICE.*
The routine orbit control was set up by the Analysis Center Coordinator. Since 1 November 1993 orbit comparisons (through 7-parameter Helmert transformations) between all the analysis centers are performed for each day and made available on a weekly basis by the Analysis Center Coordinator through the IGS report series (e-mail distributed through the Astronomical Institute, Bern).

Results of the 1992 Test Campaign and the IGS PILOT Service

The main purpose of the 1992 IGS Campaign was to check the ability of participating institutions to produce orbits regularly. This goal was reached : all seven centers were able to process one day of observational data in one calendar day over long time intervals (months, eventually years). The campaign was a challenge for all participants.
In a first analysis (Beutler, 1992) the orbit files from all centers available in October 1992 at CDDIS were taken and 7-parameter Helmert transformations were performed between the common satellite positions found in each pair of files. The rms of one satellite coordinate may be considered to be a measure of consistency of the orbit sets involved. The other measures consist of the transformation parameters themselves : Ideally they should be all zero because all centers are supposed to use the same reference frame. Table 3 contains the number of common orbit files found (in October 1992) in the time interval 21 June - 17 October (a total of 119 days). From two centers orbits are available for all days. Columns (a) show the total number of files available, columns (b) those of "good quality", i.e. files

Table 3: Number of common 1-day orbits (21 June-17 October 1992) (a) All days used(b) Bad quality days removed

	COD		SIO		JPL		UTX		EMR		GFZ		ESA	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
COD	-	-	105	88	100	85	75	69	48	46	95	87	119	113
S10	105	88	-	-	88	74	64	55	47	44	90	82	105	99
JPL	100	85	88	74	-	-	72	66	48	46	88	82	100	92
UTX	75	69	64	55	72	66	-	-	28	28	68	62	75	73
EMR	48	46	47	44	48	46	28	28	-	-	48	47	48	48
GFZ	95	87	90	82	88	82	68	62	48	47	-	-	95	91
ESA	119	113	105	99	100	92	75	73	48	48	95	91	-	-

Table 4: Mean ofRMS errors in meters of 7-parameter Helmert transformations between pairs of processing centers (21 June- 17 October 1992) (a) All days used (b) Bad quality days removed

	COD		SIO		JPL		UTX		EMR		GFZ		ESA	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
COD	-	-	.99	.62	.70	.50	.76	.64	.49	.43	.80	.68	1.09	1.00
SIO	.99	.62	-	-	.74	.47	.74	.53	.68	.50	.87	.70	1.24	1.06
JPL	.70	.50	.74	.47	-	-	.56	.45	.45	.35	.62	.54	.98	.86
UTX	.76	.64	.74	.53	.56	.45	-	-	.41	.41	.68	.62	.91	.87
EMR	.49	.43	.68	.50	.45	.35	.41	.41	-	-	.58	.56	.76	.76
GFZ	.80	.68	.87	.70	.62	.54	.68	.62	.58	.56	-	-	1.08	1.01
ESA	1.09	1.00	1.24	1.06	.98	.86	.91	.87	.76	.76	1.08	1.01	-	-

for which the actual rms error of one satellite coordinate was within the confidence interval. Table 4 shows the mean of the rms errors of transformation for the two populations. It can be concluded that all the centers were working in the sub-meter level, some even below the 50 cm level. The comparison of the transformation parameters (scale factors and rotations) revealed reference system differences. This technical issue was addressed during the IGS Pilot Service phase (see below).

The IG S earth rotation parameters were analyzed regularly by the IERS Rapid Service (McCarthy, 1992) and by the IERS Central Bureau (Feissel,1992). The message is clear : The uncertainty of the daily polar position was estimated to range between 0.5 and 1.5 mas . Also encouraging are the LoI) or UT1-UTC-drift estimates delivered by some of the processing centers (Feissel, 1992), (Gambis et al, 1993).

Based on this first analysis of the orbit quality a routine orbit comparison was set up by the IGS analysis center coordinator (Goad, 1993). Table 5 gives the number of common orbit files routinely processed between 1 November 1992 and 15 February 1993, Table 6 shows the mean rms (per coordinate and satellite) for each pair of processing centers. The comparison

Table 5: Number of common l-day orbits (1 November 1992-15 February 1993)

	COD	S10	JPL	EMR	ESA
COD	-	47	88	94	107
S10	47	-	38	47	47
JPL	88	38	-	85	88
EMR	94	47	85	-	94
ESA	107	47	88	94	-

Table 6: Mean of RMS errors of 7-parameter Helmert transformations between pairs of processing centers 1 November 1992-15 November 1993

	COD	S10	JPL	EMR	ESA
COD	-	.43	.46	.38	.87
SIO	.43	-	.48	.39	.81
JPL	.46	.48	-	.33	.75
EMR	.38	.39	.33	-	.70
ESA	.87	.81	.75	.70	.-

of Table 6 with Table 4 (columns (a)) clearly indicates that there is a steady improvement of results since the start of the IGS experiment in June 1992.

It should be mentioned that only the routine orbit comparisons appearing regularly as IGS reports were used to generate Tables 5 and 6. This is why some centers, from which today orbits are available for, the entire time period, do not show up at all (e.g. GFZ) and some (e.g. S10) have only relatively few days of data in Tables 5 and 6.

It seemed worthwile to compare the day-to-day rotations of the orbit systems delivered by two processing centers (in the earth fixed reference frame) with the differences of their day-to-day pole estimates. Figure 1 shows that the rotation of the orbit systems around the y-axis is very strongly correlated with the differences of the x-component estimates of the pole; the CODE and EMR processing centers (Table 2) were used as examples. Figure 2 shows that a similar statement holds for the rotation of the orbit systems about the x-axis and the difference of the y-estimates of the pole. Similar Figures can be produced for any pair of processing centers, usually a very high degree of correlation between the two curves as in Figures 1 and 2 is the result. The two figures also tell us that there are usually no significant rotations between the orbit systems of two IGS processing centers, if we compare them in the inertial reference frame (remember that the estimated pole positions have to be used for the transformation between the inertial and the earth fixed system).

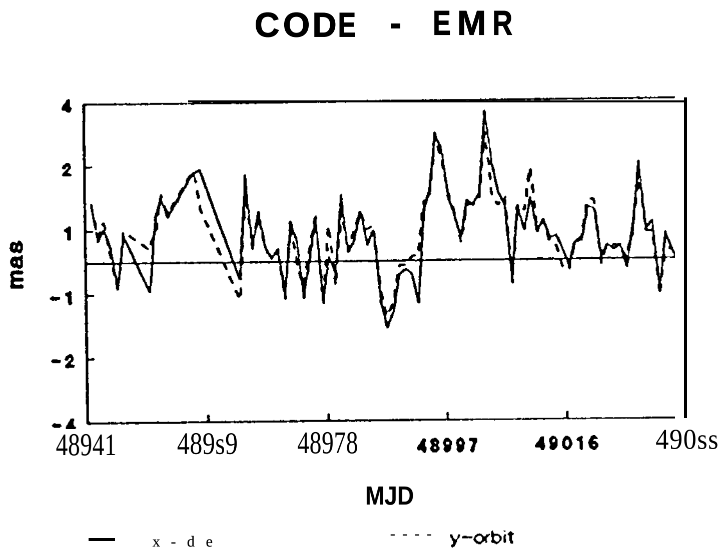

Figure 1: Differences (in mas) of x-Pole Estimates and of Rotations about y-Axis between Orbit Systems of the CODE and EMR Processing Centers

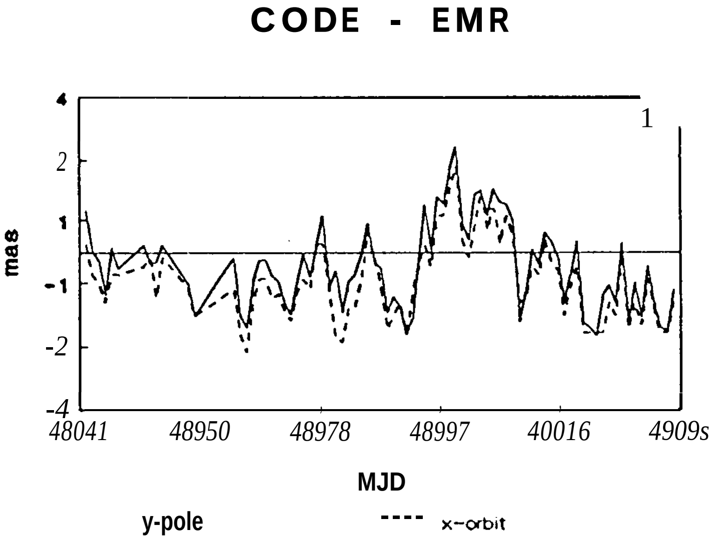

Figure 2: Differences (in mas) of y-Pole Estimates and of Rotations about x-Axis between Orbit Systems of the CODE and EMR Processing Centers

Conclusions

The proof of the concept for IGS was achieved through the 1992 IGS Campaign and the IGS Pilot Service. The solutions delivered by the seven processing centers are of good quality: 1 mas was achieved for the position of the pole, 50 cm for the orbits. It is the goal of the

IGS Pilot Service to reach the level of consistency between processing agencies necessary for science. First results indicate that we are actually moving into this direction.
The 1992 IGS Campaign was a great experiment. It was successful to an extent nobody had expected. This was due to an excellent international cooperation. There can be no doubt that, if we continue working into the same direction, IGS will be a fine tool for geodesy and geodynamics.

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INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

TERMS OF REFERENCE

A proof of concept for the international Global Positioning System Service for Geodynamics (IGS) was conducted with a three-month campaign during JuneSeptember 1992, and was continued through a Pilot-service until the formal establishment of the IGS in 1993 by the International Association of Geodesy (IAG). The routine IGS started on 1 January, 1994. IGS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and it operates in close cooperation with the International Earth Rotation Service (IERS).

The primary objective of the IGS is to provide a service to support, through GPS data products, geodetic and geophysical research activities. Cognizant of the immense growth in GPS applications the secondary objective of the IGS is to support a broad spectrum of operational activities performed by governmental or selected commercial organizations. The Service also develops the necessary standards/specifications and encourages international adherence to its conventions.

IGS collects, archives and distributes GPS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentation. These data sets are used by the IGS to generate the following-data products:

- high accuracy GPS satellite ephemerides
- earth rotation parameters
- coordinates and velocities of the IGS tracking stations
- GPS satellite and tracking station clock information
- ionospheric information.

The accuracies of these products are sufficient to support current scientific objectives including

realization of global accessibility to and the improvement of the international Terrestrial Reference Frame (ITRF)
- monitoring deformations of the solid earth
- monitoring earth rotation
- monitoring variations in the liquid earth (sea level, ice-sheets, etc.)
- scientific satellite orbit determinations
- ionosphere monitoring.

The IGS accomplishes its mission through the following components:

- networks of tracking stations
- data centers
- Analysis and Associate Analysis Centers
- Analysis Coordinator
- Central Bureau
- Governing Board.

NETWORKS OF TRACKING STATIONS

The networks consists of 30 - 40 Core Stations and 150-200 Fiducial Stations. The Core Stations provide continuous tracking for the primary purposes of computing satellite ephemerides, monitoring the terrestrial reference frame and determining earth rotation parameters. The Fiducial Stations may be occupied intermittently and repeatedly at certain epochs for the purposes of extending the terrestrial reference frame to all parts of the globe and to monitor the deformation of a polyhedron (designated as the IGS Polyhedron) defined by the Core and Fiducial Stations located at the vertices.

DATA CENTERS

The data centers required fall into three categories: Operational, Regional, and Global Data Centers.

The Operational Data Centers are in direct contact with the tracking sites. Their tasks include suitable data reformatting into a uniform format, compression of data files, maintenance of a local archive of the tracking data in its original receiver and in its reformatted format, and the electronic transmission of data to a Regional or Global Data Center. The Operational Data Center must down load data from the receivers located at the Core sites on a timely (e.g., daily) basis, without interruption.

The Regional Data Centers reduce traffic on electronic networks. They collect reformatted tracking data from several Operational Data Centers, maintain a local archive of the data received and transmit these data to the Global Data Centers. Regional Data Centers may also meet the operational requirements (as defined in the above paragraph) of strictly regional network operations.

The Global Data Centers are the main interfaces to the Analysis Centers and the outside user community. Their primary tasks include the following:

- receive/retrieve, archive and provide on line access to tracking data received from the Operational/Regional Data Centers
- provide on-line access to ancillary information, such as site information, occupation histories, etc.,
- receive/retrieve, archive and provide online access to IGS products received from the Analysis Centers
- backup and secure IGS data and products.

ANALYSIS CENTERS

The analysis centers fall into two categories: Analysis Centers and Associate Analysis Centers.

The Analysis Centers receive and process tracking data from one or more data centers for the purpose of producing IGS products. The Analysis Centers are committed to produce daily products, without interruption, and at a specified time lag to meet IGS requirements, The products are delivered to the Global Data Centers and to the IERS (as per bilateral agreements), and to other bodies, using designated standards.

The Analysis Centers provide as a minimum, ephemeris information and earth rotation parameters on a weekly basis, as well as other products, such as coordinates, on a quarterly basis. The Analysis Centers forward their products to the Global Data Centers.

Associate Analysis Centers are organizations that produce unique products, e.g., ionospheric information or Fiducial Station coordinates and velocities within a certain geographic region. Organizations with the desire of becoming Analysis Centers may also be designated as Associate Analysis Centers by the Governing Board until they are ready for full scale operation.

ANALYSIS COORDINATOR

The Analysis Centers are assisted by the Analysis Coordinator.

The responsibility of the Analysis Coordinator is to monitor the Analysis Centers' activities to ensure that the IGS objectives are carried out. Specific expectations include quality control, performance evaluation, and continued development of appropriate analysis standards. The Analysis Coordinator is also responsible for the appropriate combination of the Analysis Centers' products into a single set of products. As a minimum a single IGS ephemeris for each GPS satellite is to be produced. In addition, IERS will produce ITRF station coordinates/velocities and earth rotation parameters to be used with the IGS orbits.

The Analysis Coordinator is to fully interact with the Central Bureau and the IERS. Generally the responsibilities for the Analysis Coordinator shall rotate between the Analysis Centers with appointments and terms specified by the Governing Board.

CENTRAL BUREAU

The Central Bureau (CB) is responsible for the general management of the IGS consistent with the directives and policies set by the Governing Board. The primary functions of the CB are to facilitate communications, coordinate IGS activities, establish and promote compliance to IGS network standards, monitor network operations and quality assurance of data, maintain documentation, and organize reports. meetings and workshops, and insure the compability of IGS and IERS by continuous interfacing with the IERS. To accomplish these tasks the CB fully interacts with the independent Analysis Coordinator described above.

Although the Chairperson of the Governing Board is the official representative of the IGS at external organizations, the CB, consonant with the directives established by the Governing Board, is responsible for the day-to-day liaison with such organizations.

Through the existing reciprocity agreement between IGS and IERS the CB serves as the GPS Coordinating Center for IERS, and as such its designated representative is a member of the IERS Directing Board. in turn, the IERS Directing Board designates a representative to the IGS Governing Board (see below). This arrangement is to assure full cooperation between the two services.

The CB coordinates and publishes all documents required for the satisfactory planning and operation of the Service, including standards/specifications regarding the performance, functionality and configuration requirements of all elements of the Service including user interface functions.

The CB operates the communication center for the IGS. It maintains a hierarchy of documents and reports, both hard copy and electronic, including network information, standards, newsletters, electronic bulletin board, directories, summaries of IGS performance and products, and an Annual Report.

In summary, the Central Bureau performs primarily a long term coordination and communication role to ensure that IGS participants contribute to the Service in a consistent and continuous manner and adhere to IGS standards.

GOVERNING BOARD

The Governing Board (GB) consists of nine voting members distributed as follows:

Analysis Centers' representatives	3
data centers' representative	1
networks' representatives	2
director of the CB	1
IERS representative	1
IAG representative	1

The last three members are considered ex officio and are not subject to institutional restrictions. The other six persons must be members of different organizations and are nominated for each position by the IGS components they represent as listed above for a staggered four year term renewable once. (Initially one representative of each component is elected for a full term, the other three for half a term.)

The election for each position is by the number of nominations received from the relevant IGS component, i.e., from the networks (for this purpose organizations operating two or more Core Stations are considered a network), from the Analysis Centers and from the data centers. in case of a tie, the election is by the members of the Governing Board and the IGS Associate Members (see below) by a simple majority of votes received.

The Chairperson is one of the members of the GB elected by the Board for a term of four years with the possibility of reelection for one additional term. The Chairperson does not vote, except in case of a tie. He/she is the official representative of IGS to external organizations.

The IAG representative is appointed by the President of the IAG for a maximum of two four-year terms. The IAG representative is responsible to initiate and conduct the elections for the Governing Board membership at the appropriate times. Members of the GB are considered IAG Fellows with the appropriate rights and privileges (to be negotiated with the IAG by August, 1993)

The GB exercises general control over the activities of the Service including modifications to the organization that would be appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and theory.

Most GB decisions are to be made by consensus or by a simple majority vote of those present, provided that there is a quorum consisting of at least six members of the GB. In case of lack of a quorum the voting is by mail. Changes in the structure, membership and Chairperson of the GB can be made by a 2/3 majority of the full GB, i.e., by six or more votes.

The secretariat of the GB is provided by the Central Bureau.

The Board shall meet at least annually and at such other times as shall be considered appropriate by the Chairperson or at the request of three members.

IGS ASSOCIATE MEMBERS

Persons representing organizations which participate in any of the IGS components and who are not members of the Governing Board are considered IGS Associate Members. They are generally invited to attend non executive sessions of the GB meetings with voice but without vote.

IGS Associate Members together with the GB vote for the incoming members of the GB every two years, unless the membership has already been determined on the basis of the number of nominations received for each vacant position as described above.

IGS Associate Members are considered IAG Affiliates with the appropriate rights and privileges (to be negotiated with the IAG by August, 1993).

IGS CORRESPONDENTS

IGS Correspondents are persons on a mailing list maintained by the Central Bureau, who do not actively participate in the IGS but express interest in receiving IGS publications, wish to participate in workshops or scientific meetings organized by the IGS, or generally are interested in IGS activities. Ex officio IGS Correspondents are the following persons:

- IAG General Secretary
- President of IAG Section 11
- President of IAG Section V
- President of IAG Commission VIII
- Representative of FAGS

1 June 1993 (IIM)

THE FUTURE ROLE OF THE IGS CENTRAL BUREAU: PROPOSED FUNCTIONS, ORGANIZATION AND RESPONSIBILITIES

Ruth E. Neilan† , William G. Melbourne†, and Thomas P. Yunck*

This paper proposes the functions and responsibiiities of the Central Bureau of the International GPS Service for Geodynamics (IGS) and describes how the Central Bureau is to be organized to support the permanent and routine activities of the iGS beginning in January 1994.

INTRODUCTION

Since 1991 the Central Bureau (CB) of the proposed International GPS Service for Geodynamics (IGS) has been at the Jet Propulsion Laboratory, which is administered by the California Institute of Technology and functions as a NASA research center. The role of the CB has been limited to communications and coordination as necessary for the successful planning and execution of the demonstration IGS Campaign '92 [1]. In reviewing this role within the IGS, particularly over the last year, we have come to believe that IGS would benefit from a more active Central Bureau Office to assist in maintaining, supporting and coordinating the ongoing efforts of the many participating agencies and institutions committed to the IGS. We propose that the Central Bureau functions described here be in place for the IGS beginning in January 1994.

CENTRAL BUREAU FUNCTIONS

'I'he Central Bureau is responsible for the general management of the International GPS Geodynamics Service. These responsibilities will be consistent with the directives and policies set by the IGS Governing Board. The primary functions of the CB are to facilitate communications, coordinate day-to-day IGS activities, coordinate the establishment of IGS standards, promote compliance with the standards, monitor quality assurance of the data and products, maintain documentation, and organize reports, meetings and workshops. We propose that these functions become formally operative at the commencement of the routine service, currently slated for January 1994. To date the contributions to the IGS by all participants have been purely voluntary; no-one has been funded specifically to support the IGS. The extent of the expanded and proactive role of the CB proposed here will depend on successfully obtaining the required resources from NASA. The proposed CB functions are described in further detail below.

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† Telecommunications Science and Engineering Division, Jet Propulsion Laboratory, California Institute of Technology, Maii Stop 238-540,4800 Oak Grove Drive, Pasadena, CA 91109. Fax: 818-393-6686, Tel: 818-354-8330, Internet: ren@logos.jpl.nasa.gov

* Tracking Systems and Applications Section, Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 238-638,4800 Oak Grove Drive, Pasadena, CA 91109.

Facilitate Communications

The CB will operate the communications center for the IGS. It will maintain a library of documents and reports, both hard copy and electronic, to include network station information, network status reports, standards, quarterly newsletters, electronic mailing and bulletin board services, directories of GPS contacts, monthly summaries of IGS performance and data products, and an annual report to the IGS Governing Board. It will also organize workshops, annually or as needed, to promote enhanced performance of the service.

Coordinate Day-to-Day Activities

The CB will provide coordination of the IGS internal affairs, which is essential to the successful implementation and operation of the Service. Although the chairperson of the Governing Board is the official representative of the IGS, the Central Bureau, consonant with the directives established by the Governing Board, will act as the day-to-day liaison with the external organizations.

Coordination of IGS Standards

The Central Bureau will coordinate the development and modification of the IGS standards, which are a body of specifications regarding the performance, functionality and configuration requirements of all elements of the Service, including user interface functions.

The original Call for Participation in the IGS included two attachments which addressed the preliminary IGS standards: 1) Standards for Sites and Data Acquisition and 2) Standards for Data Analysis. These standards were intended to shape the initial campaign, and, in the light of our experience during the campaign, are now being revised and expanded. These standards will also support the utilization of the GPS technique within the International Earth Rotation Service (IERS). The CB is not responsible for generating all of these standards, but will coordinate the appropriate working groups to compile complete documents with the following divisions:

1) *Sites & Surveys:* physical and environmental characteristics of the GPS stations, including monumentation specifications, collocations and survey ties.

2) *Stations:* instrumental standards for the stations, including hardware, software, frequency standards, and on-site data storage capacities.

3) *Data* Systems: specifications and procedures for communications and transfers of data from operational centers to regional or network centers; detailed user documentation for access to and utilization of IGS data.

4) *Data Formats:* format specifications for RINEX (Receiver Independent Exchange), the agreed to GPS data exchange protocol, definitions and validity time periods for all previous versions of RINEX, and information on available translators.

5) *Analysis:* standards for data analysis such as models, constants and appendices from each center describing processing technique and philosophy.

6) *Product Formats:* specifications for products format, such as the National Geodetic Survey's SP2 or SP3, formats for clock information, etc., with inclusion of standards from the IERS for generating and reporting earth orientation parameters.

7) *Network Configuration:* procedures for maintaining network and station configuration, procedures for changes or variance from the standards, as well as a standard reporting format for network/station health and analysis status.

8) *Interface with the IERS:* specification of standards and procedures to be followed by IGS Analysis Centers in transmitting Earth rotation and terrestrial reference frame products to the IERS Central Bureau.

Monitor Quality Assurance of Data and Data Products

The CB (and/or its surrogates) will monitor all elements of the Service-Network, Data and Analysis Centers—to ensure compliance with the IGS standards; it will also effect remedial action within available IGS resources to mitigate or correct problem areas in a timely manner. The CB will conduct and coordinate quality assurance exercises for the principal IGS user products and procedures, and will monitor all IGS user interfaces to facilitate effective communication.

Maintain Documentation

The CB will coordinate and publish all documents required for the satisfactory planning and operation of the Service, including newsletters, catalogs, standards and any documents necessary to provide information to users. It will collect and deposit all pertinent IGS information at a central location and either make such information readily available to IGS users, or direct users to the location of requested information.

Organize Meetings and Workshops

The CB will organize annual meetings and workshops as required or as directed by the IGS Governing Board.

CENTRAL BUREAU ORGANIZATION

The CB Office will be internally organized at JPL to assume and execute these functions described above. This office is still being developed, but the proposed plans include maintaining dedicated personnel with primary tasks related to the IGS and to the smooth implementation and operation of a robust, end-to-end global GPS tracking system. We also propose to solicit and support, as appropriate and within available resources, the sharing of certain responsibilities with other centers, designated as sub-Bureaus or sub-Groups, to assist in achieving and maintaining satisfactory performance of the IGS. To date sub-Bureaus or groups for Network Data System, IGS Analysis Products, and Epoch Cataloging have been proposed.

CONCLUSION

In summary, the Central Bureau performs what is primarily a long term coordination and communications role to ensure that IGS participants voluntarily contribute to the Service in a consistent and continuous manner, adhere to IGS standards, and to ensure that these participants and other users have ready access to the wealth of information provided by the Service.

ACKNOWLEDGMENT

The authors wish to acknowledge the efforts of Professor Gerhard Beutler, Chair of the Oversight Committee and his supporting staff at the Astronomical Institute of the University of Bern, Switzerland. His efforts as Chair during the past year and the responsibilities that he assumed went beyond the call of duty. The IGS community and especially the Central Bureau are indebted to him for his contribution. We also wish to acknowledge the efforts of Professor Ivan I. Mueller, the IAG Representative to the IGS, whose vision, dedication and organizational talent brought the IGS into being.

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The 4th IGS Oversight Committee Meeting and the Joint IERS and IGS Meeting in Bern, 24-27 March 1993

Gerhard Beutler *

Abstract

The 1993 Bern IGS Workshop took place from 25 to 26 March, 1993. It was surrounded by the 4th IGS Oversight Committee Meeting, consisting of an opening session, several working group meetings (24 March), of a summary meeting, and, last but not least, of a business meeting, where the future IGS structure was discussed (27 March). Very fruitful were the discussions between the IERS Directing Board and the IGS Oversight Committee. In these discussions a close collaboration (avoiding any duplication of efforts) between the future IGS and the IERS was agreed upon.
The most important results and the progress made since the Berne workshop are summarized below.

The 4th Oversight Committee Meeting

About 90 participants attended the 1993 IGS Workshop in Bern. The workshop was interesting and stimulating. Many participants of the workshop also attended the sessions and the discussions in the working groups of the 4th Oversight Committee Meeting. This demonstrated on the one hand the great interest of the campaign participants in the development, of IGS, it created on the other hand a very lively and fruitful atmosphere in the meetings.

The Opening Session (24 March)

Carey NoII, whose personal initiative in making NASA's Crustal Dynamics Data Information System (CDDIS) available for IGS was a key to the success of the 1992 IGS campaign, was elected as a new member of the IGS Oversight Committee.
Then the time period between the 3rd and the 4th IGS Oversight Committee Meetings, essentially the time period since the start. of the newly established IGS PILOT Service, was reviewed (Beutler, 1993).
It was stated that the number of users of IGS products was (and is) steadily increasing. Most users stem from scientific organizations or government agencies already collaborating with IGS, but there are also commercial users of IGS products. Later on during the Bern

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"Astronomical Institute University of Berne, Sidlerstrasse 5, CH-3012 Bern, Switzerland

IGS Meetings the rules for commercial requests during the IGS PILOT Phase were specified by the IGS Oversight Committee. They are available on request from the IGS chairman.
It was then stated that the writing of the proposal to IAG (International Association of Geodesy) to establish the routine IGS service would be the most urgent action item in the months following the Bern IGS Meetings. The proposal should be ready for the IAG Meeting in Beijing (August 1993).
Table 1 shows the working groups formed at the end of the plenary session. In a business meeting of the Oversight Committee later in the evening the working group leaders gave a short overview over the work accomplished.

Table 1: Working Groups at the 4th IGS Oversight Committee

Working Group	Headed by
Formats and Data Transfer	Werner Gurtner
Epoch Events	Peter Morgan
Networks and Standards	Ruth Neilan
Analysis Center Coordination	Clyde Goad
Proposal to IAG (Guidelines)	Ivan Mueller

The Summary Session and the Business Meeting (27 March)

The working group reports were presented by the working group leaders (see Table 1) on Saturday morning in an open plenary session, which, in view of the fine weather in Bern, was again very well attended. The concrete action items were then fixed in the business meeting, where only the oversight committee members were present.

Formats and Data Transfer

Residual problems with the Rinex Format (operation under AS) could be resolved (Gurtner, 1993). Today the IGS uses for its data transfer a considerable part of capacity of the international scientific data links. It is our interest to reduce our data transfer to the volume actually necessary. Several measures were proposed :

- Observation of the hierarchical structure of the network (station ⇒ operational center ⇒ regional center ⇒ network center). Avoid multiple downloads of receivers within IGS.
- Processing centers should get their observations from the nearest network center (e.g. European centers from IGN, Paris).
- Only the data of the core network (about 40 stations) are available at the three network centers. A complete catalogue of regional permanent tracking data is available at the

three network centers. Data from permanently operated regional sites (we might call them *regional* Core *Sites*) are available at regional centers.

- Reduce the volume of the IGS e-mail series (IGS mail, IGS Reports): Only the IGS Mail should be distributed (now by the AIUB, later on by the Central Bureau) to the full distribution list; the Reports are made available through anonymous FTP and sent by e-mail to the data- and analysis- centers only.

The last item is already operational now. IGS Reports (and IGS Mail messages, if required) may be retrieved from the anonymous FTP account:

130.92.4.10, directories [.astronomy.igsreport] and [.astronomy.igsmail]

The messages and the indices (files igsmess.index and igsreport.index) are available in the respective directories.

Epoch Campaigns

It was first clearly stated that Epoch events have to be an integrated part of the future IGS. On the other hand it is also clear that, *if the IGS orbits are used, and if the observations of some nearby IGS sites (core or fiducial sites within a radius of 2000 km) are included in a regional GPS analysis, and if the coordinates of these IGS sites are kept fixed*, it would not be necessary to organize world-wide coordinated Epoch campaigns in future. It is absolutely necessary however *to define the set of IGS fiducial sites.* These sites together with the IGS core network may be called the *IAG Polyhedron.* Ivan Mueller (Mueller, 1993a) strongly advocates that such an IAG polyhedron should be defined and maintained by the IGS. Peter Morgan, in collaboration with Ivan Mueller and with Claude Boucher, was declared responsible for the definition of this polyhedron. The decision whether or not to organize an Epoch campaign in the year 1993 was postponed to the IGS business meeting.

Networks and Standards

The IGS community and the users of its products (in particular orbits, coordinates, site information) badly need an official IGS Site Cat slog. Also needed is a cat slog where the requirements for IGS Core and Fiducial Sites are listed. The editing and maintenance of these catalogues were confirmed to be responsibilities of the Central Bureau. The responsibilities of the IGS Central Bureau, at present at JPL, were discussed at length. The discussions were controversial, but in the end fruitful: two documents included in this Volume (Neilan, 1993), (Mueller, 1993b) demonstrate the convergence on this issue.

Analysis Center Coordination

The usefulness of the regular orbit comparisons was generally acknowledged. These comparisons show that the consistency of the daily orbit systems from different centers soon

approaches the 20 cm level, after a 7-parameter Helmert transformation. A comparison of the rotations between the orbit systems and the pole parameters of these centers reveals, that in general there are *no significant rotations between the orbit systems in the inertial reference frame, but that there arc such rotations (up to I-5’ mas) in the terrestrial reference frame.* Larger transformation errors occasionally occur, but usually these maybe attributed to single satellites, where for one reason or another different centers used different criteria to reject observations. In view of these results it seems not only feasible but it was recommended to combine these different solutions into one combined IGS solution. These *official IGS orbits* would meet the needs of the largest part of the IGS user community. An example for the combination of IGS orbits may be found in (Springer et al, 1993).
In order to detect the reason for the systematic differences between the results of different IGS processing centers the Analysis Center Coordinator in collaboration with the processing centers selected the two weeks

17-30 January 1993 (GPS weeks 680, 681)

to be reprocessed by all IGS processing centers, using exactly the same coordinates (and local ties, antenna heights) for the coordinates held fixed. The list of coordinates (including the related information) was to be defined by Zuheir Altamimi and Claude Boucher, Peter Morgan was responsible for the site information. It will be interesting to see whether or not the systematic rotations between the orbit systems of the different centers will disappear or not. If the results will be satisfactory, this coordinate set (plus the related information) will be used by all IGS processing centers in future.
The opportunity will be taken by the processing centers to process these data using many different processing options. A variety of questions may be addressed. Jan Kouba was asked to coordinate such activities directly between the processing centers, and to stimulate discussions and the exchange of ideas and results.

IGS Proposal to the IAG

In view of the success of the 1992 IGS Campaign and of the IGS PILOT Service, everybody agreed that the official IGS Service should start as soon as possible, but not later than *1 January 1994*. Ivan Mueller was declared responsible to set up the guidelines, then to write the first draft of the proposal to IAG (international Association of Geodesy). Due to the circumstance that nobody became hungry during the business meeting (it started around 11 a.m. on Saturday and ended around 4 p.m., without lunch or coffee break (!)) an agreement could be reached for most of the critical items. A draft for the Terms of Reference for the future Service (the second iteration) is included in these proceedings (Mueller, 1993b). Ivan Mueller was assisted by the members of the Oversight Committee when writing this draft. Let me summarize here the tentative *schedule for the establishment of the International GPS Geodynamics Service (IGS):*

- First draft of the Proposal available end of April (done, see (Mueller, 1993b))
- Letters asking the participants of the 1992 IGS Campaigns to confirm their participation in the future IGS (duty of the chairman, letter sent out 31 March 1993, responses

due 15 May 1993).

- Letters asking the participants of the 1992 IGS Campaigns for nominations of the first IGS Governing Board (duty of the chairman, letter sent out 1 April 1993, answers to I.I. Mueller by 19 May 1993).
- Finalize the interface between IERS and IGS (after the meeting of the IERS Directing Board in Paris)
- Business meeting of the IGS Oversight Committee end of May in Baltimore: Prepare the documents to be sent to IAG with the goal to start the IGS on 1 January 1994, possibly election of the first Governing Board of the IGS.
- Proposal (including these proceedings as a documentation of the 1992 IGS events, and the letters of confirmation) to be sent to IAG in June.

Joint Meeting of the IERS and the IGS (26 March)

A joint meeting of the IERS directing board (led by Martine Feissel replacing the Chairman of the IERS Directing hoard) and selected "members of the IGS Oversight Committee took place Friday, March 26.

The IGS chairman first pointed out that the collaboration between the IGS and the IERS was excellent right from the beginning of the 1992 IGS campaign. The regular analyses of all sets of IGS earth rotation parameters by the IERS Rapid Service Subbureau (Mc-Carthy, 1992), and the analyses by the IERS Central Bureau were particularly helpful and stimulating for the IGS.

Martine Feissel then presented the IERS Directing Board's ideas of the interface between the future IGS and IERS: The IERS wishes the IGS to be responsible for the GPS observations and their organization in future, the IERS on the other hand will establish direct contacts with the IGS processing centers in order to continue the fruitful collaboration that already exists. The IERS wishes that the IGS rules include provision for the interfacing with the IERS. The IGS will adopt (as a matter of fact already has adopted) the IERS standards and will help developing them if necessary. The IERS will also be responsible for the maintenance of the terrestrial reference frame used by the IGS.

This concept was considered to be very reasonable, and the hope was expressed that it will get the official blessing from the full IERS directing Board.

Summary

The agenda of the 4th IGS oversight Committee meeting was heavily leaden. Much of the work necessary for the establishment of the IGS could be accomplished (e.g. proposal to IAG), further activites could be initiated (e.g. combined orbits, definition of the IAG Polyhedron).

The interface between the future IGS and the IERS could be defined. If accepted by the Directing Board of IERS in May, it will be an excellent basis for a fruitful collaboration between the two organisations.

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Chapter 2

The Networks (Core and Fiducial) and Data Management

IGS SERVICE: EPOCH '92 REGIONAL CENTER IN BRAZIL

Eduardo W. Bergamini*

The basic topology, organization, operation and results obtained with the configuration of a Brazilian Fiducial GPS network and a Regional Center, in support to the IGS Service EPOCH '92 Campaign, is presented in this paper. Essentially, based on Internet and, even, on Bitnet data communication services, it was possible, in a relatively short period, at a very low cost, to achieve the goals of the EPOCH '92 Campaign. It is felt that considerable experience was obtained in the Campaign, probably, with direct benefit in future IGS Service activities that may involve Brazil in its worldwide topology.

INTRODUCTION

The decision of Brazilian institutions to gather effort to participate of the EPOCH '92 Campaign was motivated by a genuine spirit of cooperation. With very limited resources, inspired on a document[1] issued by IAG, it was possible to start a coordinated plan, among seven different organizations which led to the effective participation of Brazil in the mentioned Campaign, with a network of Fiducial GPS stations and a Regional Center.

A brief presentation is given of the involved institutions and of their" functional participation in the Campaign. It is followed by the IGS Service topology characterized in Brazil, with such involvement. The basic scheduling and operational management of the service executed in support to EPOCH '92 is, then, presented. This is followed by a brief compiling of the data products that were obtained. At the conclusion of this work, limitations and problems encountered are commented. Considerations on the continuity of the service are also made, in view of future IGS Service activities.

PARTICIPATING INSTITUTIONS

The only way to materialize the Brazilian participation in the EPOCH '92 Campaign in view of the shortage of time and, by far, of financial resources for it, was to obtain the support, to the best extent, of the existing topology of the Brazilian academic and research data network infrastructure. As a result, according to the plan established by the IGS Service Steering Committee[1], the following entities, described in Table 1,

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* Line of R&D in Computer Engineering, Instituto National de Pcsquisas Espaciais, Av. dos Astronautas 1758, 12227-010 São José dos Campos, SP, Brazil

respectively, enumerated with their Functional Capability and Institutional Identity, were those effectively involved in the realization of the EPOCH '92 Campaign.

Table 1

PARTICIPATING INSTITUTIONS

No.	FUNCTIONAL CAPABILITY	INSTITUTIONAL IDENTITY
1.	GPS Fiducial Station 'PARA' ; TRIMBLE LI, L2 with P-Code; at UFPr, Curitiba, PR, Brazil.	Department of Geosciences, Federal University of Paraná (UFPr), Curitiba, PR, Brazil.
2.	GPS Fiducial Station 'BRAS; TRIMBLE LI, L2 without P-Code; at IBGE, Brasilia, DF, Brazil.	Research and Analysis Division, Department of Geodesy, IBGE, Rio de Janeiro, RJ, Brazil.
3.	GPS Fiducial Station 'UEPP'; TRIMBLE LI, L2 without P-Code; at UNESP, President Prudente, SP, Brazil.	Dep. of Cartography, UNESP, President Prudente, SP and Dep. of Transport Engineering, EPUSP-PTR, São Paulo, SP, both institutions, in Brazil.
4.	IGS Service Network Regional Center, at INPE, São José dos Campos, SP, Brazil.	REDACE-IGS and RECODI-IGS Services, ENCOMP/INPE, São José dos Campos, SP, Brazil.
5.	IGS Service Network (Data) Center, at NASA Greenbelt, MD, USA.	Crustal Dynamics Data Information System - CDDIS, GSFC, NASA, Greenbelt, MD, USA.
6.	Center Node of 'An Academic Network at São Paulo - ANSP', at São Paulo, SP, Brazil.	ANSP/FAPESP - 'Fundação de Amparo a Pesquisa do Estado de São Paulo', São Paulo, Brazil.
7.	Node of 'National Research Network - RNP', at CNPq, Brasilia, DF, Brazil.	RNP/CNPq - 'National Center for Scientific and Technological Research', Brasilia, DF, Brazil.

In the above list, items (l), (2) and (3) characterized the Fiducial GPS network which was configured. The management of the centralized, data acquisition and product elaboration was executed by the resources indicated in item (4), who represented the IGS Service Network Regional Center. Item (5) mentions the entity who played as the corresponding IGS Service Network (Data) Center to the Regional Center, indicated in item (4). The entity presented in item (6) acted the physical resource who: concentrated and stored data managed by the Regional Center (item (4)); was accessed by 'PARA' and 'UEPP' GPS Fiducial stations, remotely; was accessed by the data network node entity mentioned in item (7) which, in turn, was accessed, "off line", by the GPS Fiducial station 'BRAS' (item (2)).

SERVICE TOPOLOGY

The effective topology of the network configured by INPE IGS Service Regional Center for EPOCH '92 is represented by its basic structure in Fig. 1. It is interesting to notice that even Bitnet, text oriented data transfer e-mail service, had to be used in order to obtain a viable configuration of the network, for the 'PARA' GPS Fiducial Station. Even more serious limitation had to be faced with use of an "off line" (floppy disk media) access, to incorporate the 'BRAS' GPS Fiducial Station in the network.

SERVICE SCHEDULING AND OPERATIONAL MANAGEMENT

The basic functional phases and time scheduling followed by the Regional Center, in coordination with the network of Fiducial Stations in order to transfer data files, is represented in the scheme of Fig. 2. The same scheme also considers the scheduling of data transfer from the Regional Center to the so called Network Center. However, due to operational limitations, this last aspect could not be observed on a daily basis, as planned. It is expected that, with the same basic detail, such operational data transfer sequencing management and time scheduling will serve for future IGS Service Campaigns, on an end-to-end basis, among all the participating entities of the network, with the Regional Center.

DATA PRODUCTS

The Directory of data product files generated by the INPE IGS Regional Center, as a result of the EPOCH '92 Campaign, are classified in four (4) different types, defined by:

1. PRODUCT 00: General Information.

   This PRODUCT contains: list of complete addresses of the participating institutions and their main contacts; abstract description of the so called "IGS EPOCH" '92 Campaign Regional Archive Catalog"; abstract description of the Campaign (fiducial) station data files (S, O and N) addressing; pertinent comments.

2. PRODUCT 01: IGS EPOCH '92 Campaign Regional Archive Catalog.

   The PRODUCT contains a table indicating the (3) Station Data contents available, from 1992 Julian days 207 to 221, in the Regional Center. This table follows the specific for'mat recommended by the IGS EPOCH '92 Campaign Steering Committee[1].

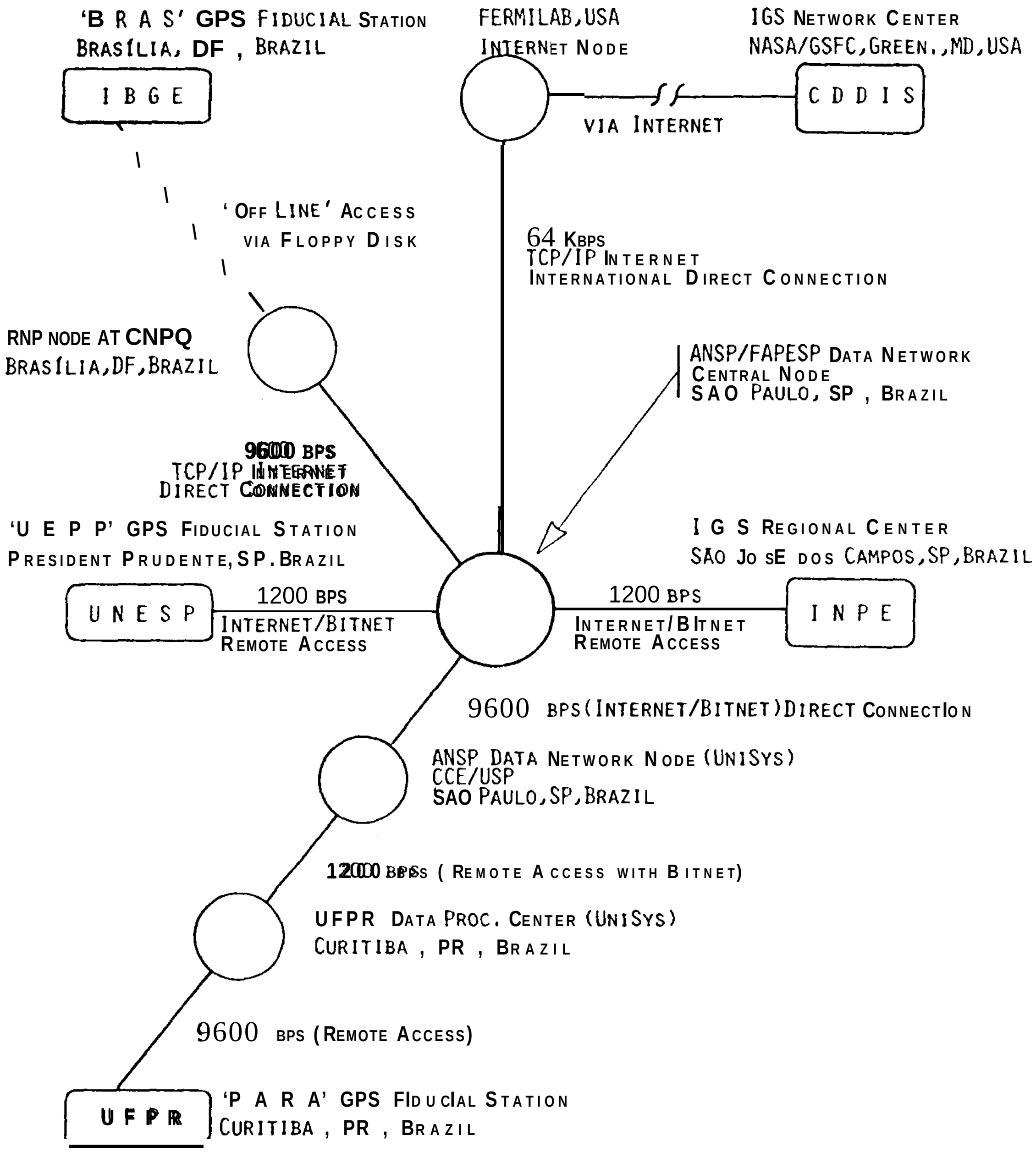

Fig. 1 Basic Topology of the Regional Center Network.

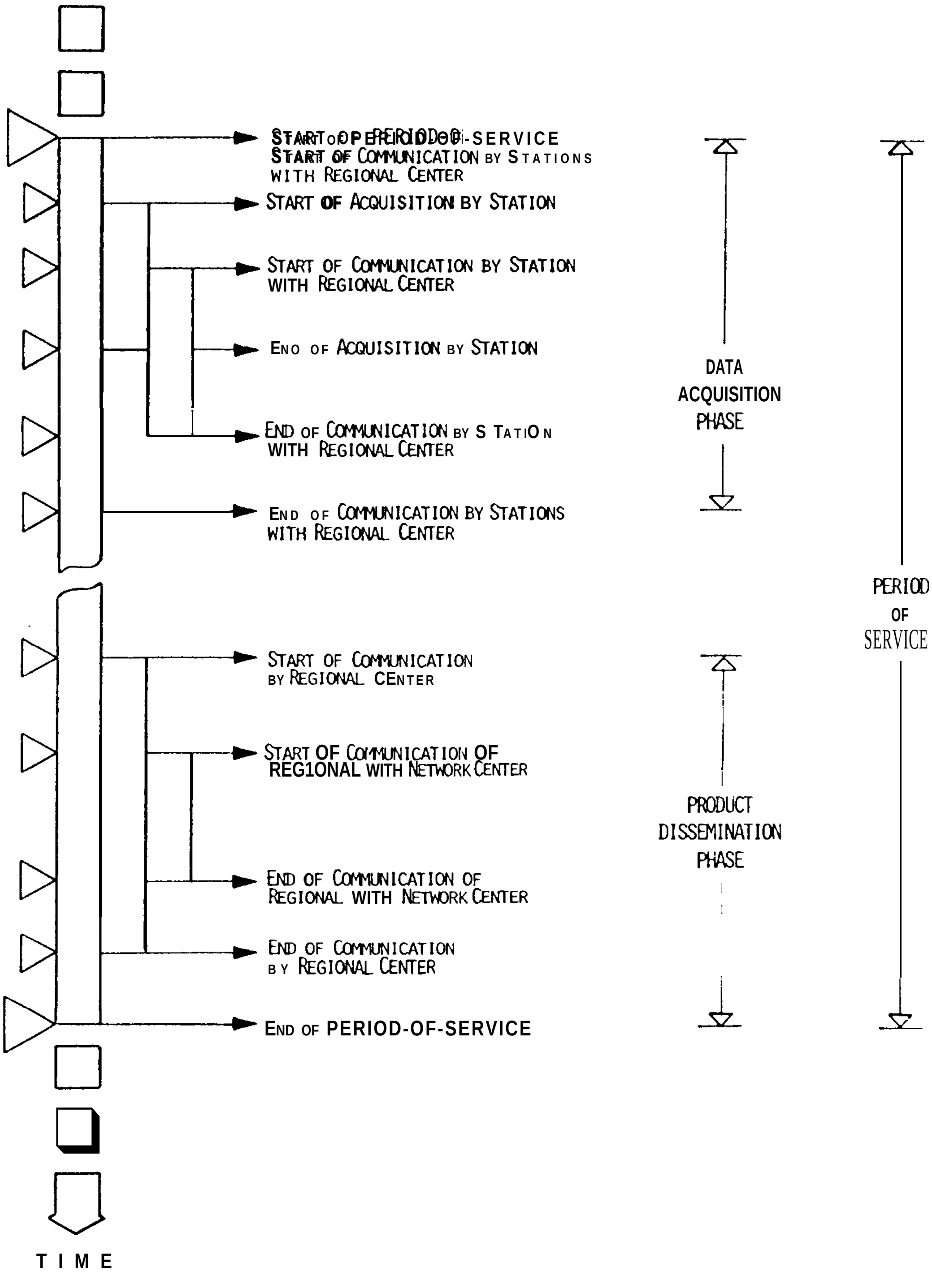

Fig. 2 Basic Time Scheduling for IGS Service Data Transport Management by the Regional Center (INPE, Brazil).

3. PRODUCT 02: IGS EPOCH '92 Campaign Station Data.

Contains the set of three (S, O and N) data files for each Julian day, from 207 to 221, in RINEX Format, Version 2, as generated by each of the three participating Fiducial Stations ('BRAS', 'PARA' and 'UEPP'), with the original Summary (S) files added with a header, generated by the (INPE) Regional Center, containing brief explanation of the standardized file naming scheme.

4. PRODUCT FT2: RINEX Format Version 2 Data Description Records (DDRs).

Contains on a table like format[2], in plain English language, the descriptors of the Header and Data Records for the RINEX (Version 2) Observation and Navigation Data Files.

All the contents of the above mentioned PRODUCTS 00,01 and 02 files were duplicated at the CDDIS IGS Network Center, located at NASA/GSFC, Greenbelt, MD, USA, besides being kept in the current Directory of Products of INPE IGS Regional Center.

CONCLUSIONS

The decision of participating in the IGS EPOCH '92 on the part of Brazil was significantly healthy, in spite of possible, pending odds at that time which, at the end, did not prevail, in view of extreme shortage in financial resources and of an all new initiative it demanded, although in a modest scale, if compared with the worldwide involvement. Not to mention other critical situations, instances like: transporting bit oriented files through simple (partial) Bitnet links, in a reliable fashion, which demanded special encoding/decoding schemes, compatible with different machines and operating systems environment, across the data network nodes and accesses, which had to be faced and solved in a short time, in view of the naturally rigid scheduling of the EPOCH '92 Campaign. By far, besides acquiring and delivering all expected data, (with exception of the first, **207** Julian day of 1992, for one of the three GPS Fiducial Stations) originated from the networked Fiducial Stations, perhaps the best result is that it can be. said that a pioneering IGS Service Regional Network with its local Regional Center could be assembled and become operational although, yet, in a modest scale. Plans are under way to expand, gradually, the current network. It is concretely expected that a fourth GPS Fiducial Station, originated from NOAA/Geosciences Laboratory (Rockville, MD, USA), to be located at INPE/Fortaleza, CE, Brazil, may be joining the current Brazilian network, in the near future. Internally to INPE, the so called REDACE-IGS (for Data Acquisition) and RECODI-IGS (for product Collection and Dissemination) Services are those being maintained to honor the institutional compromise as a Regional Center for the IGS Service, not only for internal, genuinely Brazilian, GPS mission oriented initiatives, but, naturally, for predictable, upcoming, new IGS Service Campaigns, inaugurated with EPOCH '92, in support to the international IGS community.

ACKNOWLEDGMENTS

The author wishes to explicitly express his gratitude not only for the institutional support received in this initiative but also, not the least, to all other institutions mentioned in Table 1, of this text, The spirit of cooperation among all the mentioned institutions was the vital guarantee for the results obtained. In particular, the author also expresses his

gratitude to Mr. Fernando Acedo Del Olmo Imossi and Mr. João B. Diehl, for their support in the final preparation of this paper. Mr. Diehl had a fundamental participation in the technical work at INPE, that led to the assembly and operation of the IGS Regional Center for EPOCH '92.

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THE IGS CORE AND FIDUCIAL NETWORKS: CURRENT STATUS AND FUTURE PLANS

Ruth E. Neilan[1] and Carey E. Noll[2]

The backbone of the IGS is the global network of continuously operating stations that contribute data to the IGS processing centers for generation of the precise products. In addition, the densification of the network for the extension of the common GPS terrestrial reference frame is currently dependent on the periodic occupation of some sites to establish known points easily accessible to users. This paper will describe the current status of the global network, the future implementation plans of the continuous network and provide a summary of the Epoch'92 GPS campaigns.

INTRODUCTION

Since the beginning of the IGS in 1990, the continuous GPS global tracking network has increased in size from about 15 stations to the current network of over 40 precision stations, all continuously operating with near-real time data retrieval and access. Subsequent processing of the data from **these stations by** the seven IGS processing centers provides information to the IERS for the determination of GPS station locations in the common terrestrial reference frame, currently ITRF'91. Importantly, users who tie local or regional GPS networks into the IGS network can then ensure that results are consistent with ITRF'91 enabling meaningful comparison of results between various users of the IGS data and data products. During Epoch '92, July 27 to August 8, 1992, many agencies deployed regional campaigns to tie to the IGS frame and to establish 'fiducial' IGS points that could be occupied at a later time. The activities of the IGS continuous network and the Epoch measurements are summarized below, as well as a perspective on the future distribution of the network required to support IGS activities and objectives.

THE IGS NETWORK

The current IGS network of operational stations is shown in Figure 1 and listed in Table 1.

---

[1] Ruth E. Neilan, IGS Central Bureau, Telecommunications Science and Engineering Division, Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 238-540, 4800 Oak Grove Drive, Pasadena, CA 91109, USA.
Internet ren@logos.jpl.nasa.gov, Tel: 818-354-8330, FAX: 818-393-6686.

[2] Carey E. Nell, IGS Network Data Center, Goddard Distributed Active Archive Center, NASA Goddard Space Flight Center, Code 902.2, Greenbelt MD 20771, USA.
Internet: noll@cddis.gsfc.nasa.gov, Tel: 301-286-9283, FAX: 301-286-4943

The current definition of an IGS Core station is a station instrumented with a precision P-code receiver necessary for the orbit determination process which complies with the IGS standards and is capable of delivering data within a specified time period to the data centers (nominally within 24 hours to the operational data center and within 72 to the network data centers). Many stations have been implemented recently which meet the quality standards and criteria for data delivery; however, not all are necessary for the orbit determination, due to geographic location. At the Bern workshop in March '93, it was clear that there are major gaps in the network: the Southern hemisphere (only 9 of the 42 stations are located here), and poor coverage within Russia, China and India, which have no stations. Figure 2 shows the proposed expansion of the network over the next two years. Table 2 lists the IGS interagency draft implementation plan which is still being developed and discussed.

THE EPOCH'92 NETWORK STATIONS

The planning of the IGS campaign included a time period where the IGS routine processing could be depended upon for the densification of the network in support of scientific investigations. One of the questions that faced the Oversight Committee planning the campaign was how to handle all of the IGS Epoch'92 data -- no agency wanted to be responsible for, nor could afford, the massive task of collecting all of the data. JPL's previous experience with the GIG'91 GPS campaign in support of the IERS demonstrated that this was an extremely difficult and costly task and the IGS recommended that regional coordinators be established to catalog the data for a particular global region. It was up to the regional coordinator to decide whether or not to collect all of the data at a regional data center, or simply to keep track of the location of the data. This scheme has met with limited success and we are still in the process of cataloging the data from Epoch '92.

We would like to complete the Epoch '92 catalog as soon as possible and therefore solicit the information below from all participants. Each regional coordinator and responsible agency participating in the campaign is requested to collect the information described in Table 3, as well as providing the following:

- GPS data location (RINEX format)
- GPS Observation and Daily Log Sheets
- GPS Station Information Report
- Map of the Network

Figure 3 maps the location of Epoch'92 measurements that the authors have compiled to date. Table 4 lists these Epoch'92 locations and responsible agencies.

Epoch '92 was also a time when anti-spoofing (AS) was activated on the NAVSTAR GPS constellation for a number of days. This caused some serious problems in the regular processing of the GPS data.

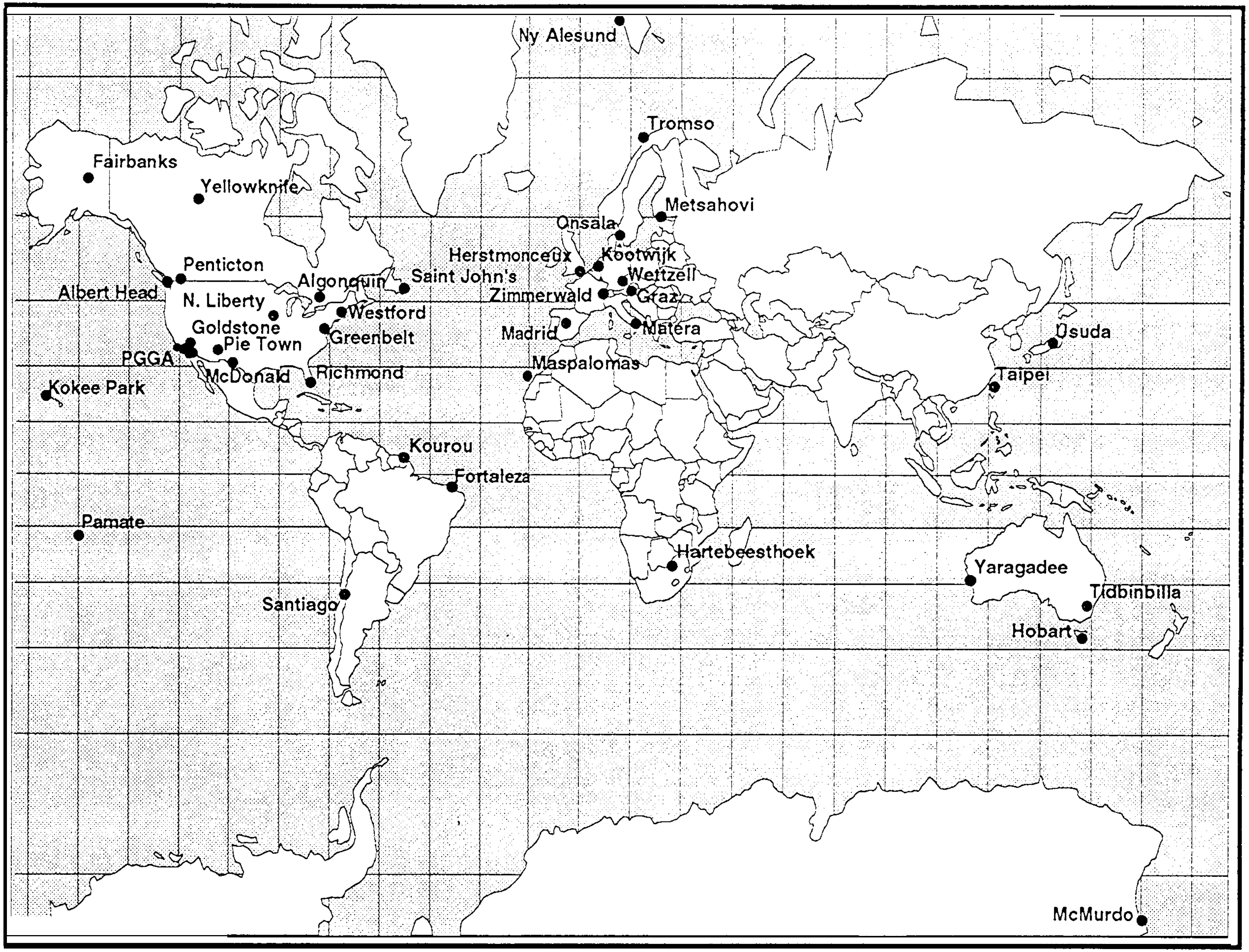

Fig. 1 Current IGS international GPS tracking network (June **1993**).
A precision P-code receiver network consisting of **41** stations.

Table 1
THE IGS GLOBAL TRACKING NETWORK
CURRENT OPERATING STATIONS

* Denotes IGS Core Station, 1992

	Site Name	Location	Agency	Longitude	Latitude
*1	Algonquin	Ontario, Canada	EMR/CGS	W7804	N4557
2	Albertheád	B. C., Canada	EMR/GSC	W 123 29	N 4823
*3	Fairbanks	Alaska, USA	NASA/JPL	W 14729	N6458
4	Fortaleza	Brazil	NASA/JPL	W 3835	s 0345
*5	Goldstone	California, USA	NASA/JPL	W 116 47	N 3514
6	Graz	Austria	ISRO	E 15 29	N4704
7	Greenbelt	Maryland, USA	NASA/JPL-GSFC	W7649	N3901
*8	Hartebeesthoek	South Africa	CNES	E2742	S 2553
9	Herstmonceux	East Sussex, U.K.	RGO	E 00 20	N5052
10	Hobart	Tasmania	NOAA	E 14726	S4248
11	JPL Mesa	Pasadena, CA, USA	NASA/JPL	WI181O	N34 12
*12	Kokee Park	Kuai, Hawaii, USA	NASA/JPL	E 20020	N 2210
*13	Kootwijk	Delft, Netherlands	DUT	E 0548	N 5210
*14	Kourou	French Guyana	ESA/ESOC	W 5237	N0508
*15	Madrid	Spain	NASA/J PI.	W 04 15	N4025
16	Maspalomas	Canary Islands	ESA/ESOC	W 15 38	N2746
17	Matera	Italy	ISA	E 1642	N4038
18	McDonald	Texas, USA	NASA/JPL	w 10401	N3040
*19	McMurdo	Antarctica	NASA/JPL	E 16640	S 77 51
20	Metsahovi	Finland	FGI	1;2423	N60 13
21	North Liberty	Iowa, USA	NASA/JPL	W 91 30	N41 48
*22	Ny Alesund	Spitzbergen Island	SK	E 11 51	N7855
23	Onsala	Sweden	0s0	E 11 55	N 5723
*24	Pamate	French Polynesia	CNES	W 15102	S 1644
25	Penticton	B. C., Canada	EMR/GSC	W 119 37	N49 19
26	Pie Town	New Mexico, USA	NASA/JPL	W 10807	N34 18
27	Pinyon Flat	California, USA	SIO/JPL	W 116 27	N 3336
28	Quincy	California, USA	NASA/JPL	W 12056	N3958
*29	Richmond	Florida, USA	NOAA/NGS	w 8023	N 2536
30	Saint John's	Newfoundland, Canada	EMR	W 5241	N 4736
*31	Santiago	Chile	NASA/JPL	w 7040	s 3309
32	Scripps	California, USA	SIO	W 117 15	N 3252
33	Taipei	Taiwan	IES	E 13132	N 25 01
*34	Tidbinbilla	Australia	NASA/JPL	E 14858	S 3523
*35	Tromso	Norway	SK	E 1856	N6940
*36	Usuda	Japan	ISAS	E 13822	N3608
37	Vandenberg	California, USA	SIO/JPL	W 12029	N 3433
*38	Westford	Massachusetts, USA	NOM	W71 29	N4237
*39	Wettzell	Germany	IfAG	E 1252	N4908
*40	Yarragadee	Australia	NASA/JPL	E 11520	S 2902
*41	Yellowknife	NW Terr., Canada	IMU	W 114 28	N6228
42	Zimmerwald	Switzerland	BfL	E 0727	N4652

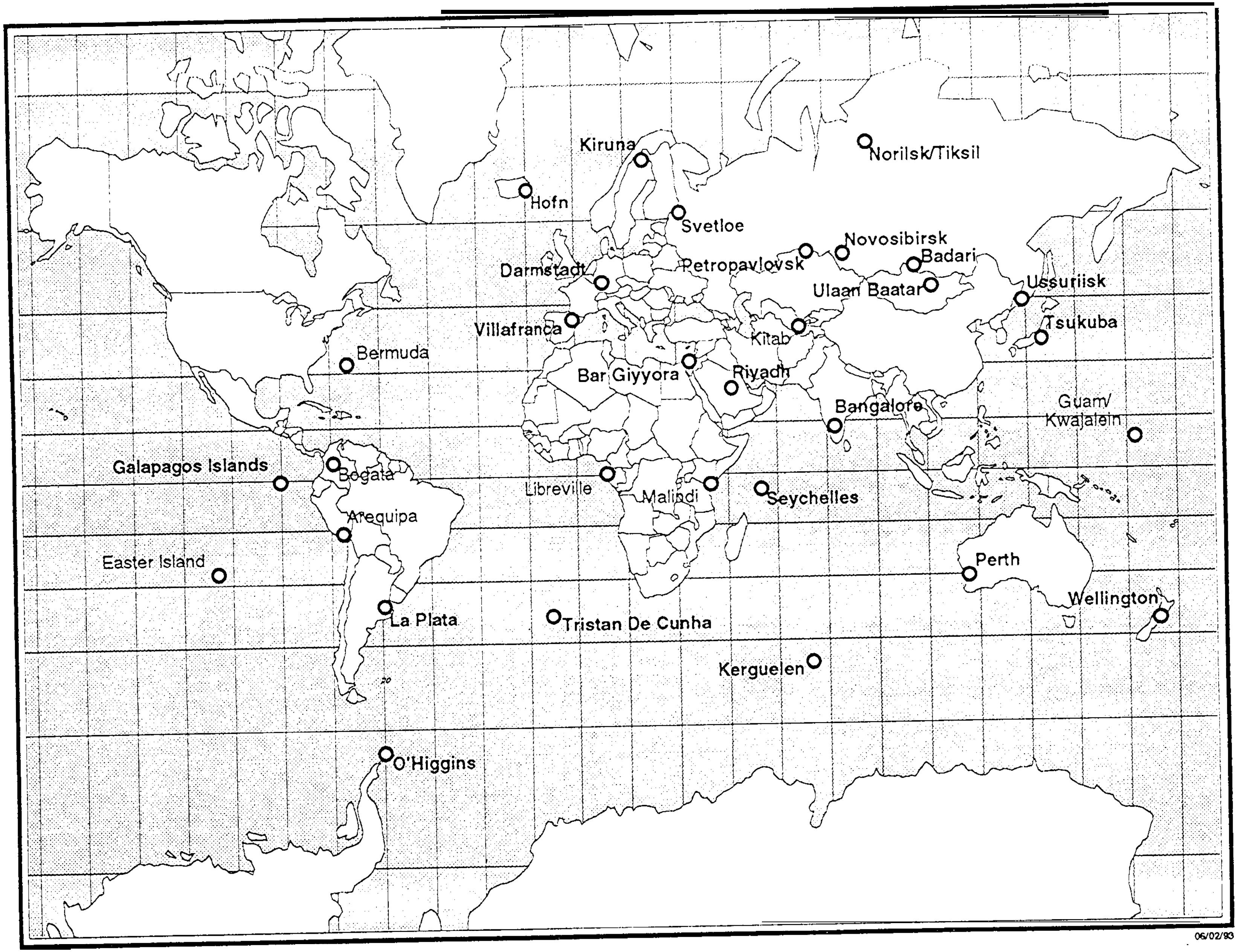

Fig. 2 Future expansion of the IGS international GPS tracking network. A proposed implementation of a precision P-code receiver network consisting of 31 additional stations. Underlined stations are to be implemented in 1993.

Table 2
THE IGS GLOBAL TRACKING NETWORK
FUTURE PROPOSED STATIONS

* Station installed, resolving communications problems.

Site Name	Location	Agency	Longitude	Latitude	Date
Arequipa	Peru	NASA/JPL	W 71 29	S 1627	1/94
Badari	Russia	IAA/JPL	E 10214	N 51 46	93
Bangalore	India	GFZ	1;7740	N 1259	
Bar Giyyora	Israel	Survey of Israel	133505	N 31 43	
*Bermuda	Caribbean	NOAA/NGS	W 64 39	N3221	4/93
Bogota	Columbia	NASA/JPL	w7405	N 04 38	1/94
Darmstadt	Germany	ESA/ESOC	E0840	N 49 51	
*Easter Island	Chile	NASA/JPL	w 10923	S 2708	4/93
Galapagos Islands	Ecuador	NASA/JPL	W8937	s 0054	
Guam/Kwajalein	U.S. Territory	NASA/JPL	1116728	N0923	
Hofn	Iceland	SK	W 15 00	N6430	
Kerguelen	French Territory	CNES	E 7016	s 4921	1/94
Kiruna	Sweden	ESA/ESOC	E 20 15	N 6753	10/93
*Kitab	Uzbekistan	GFZ	E 6653	N 3908	6/92
La Plata	Argentina	GFZ	w 5730	s 3515	1/94
Libreville	Gabon, Africa	CNES	E 09 16	N 00 14	
Malindi	Kenya, Africa	ESA/ESOC	1;4008	s 0314	12/93
Novosibirsk	Russia	GFZ	E 83 05	N 5500	12/93
Norlisk/Tiksil	Russia	ESA/ESOC	1;8802	N6921	'94
O' Higgins	Antarctica	IfAG	w 5954	S 6319	
Perth	Australia	ESA/ESOC	E 11549	S 3158	
Petropavlosk	Uzbekistan	GFZ	E 69 08	E 5432	
Riyadh	Saudi Arabia		E4642	N 24 41	
Seychelles	Island	NASA/JPL	E 5530	S 04 41	
Svetloe	Russia	IAA/JPL	1;2024	N 5430	'93
Tristan De Cunha	U.K. Territory		111230	s 3715	
Tsukuba	Japan	GSI	E 14005	N 3606	'93
Ulaan Baatar	Mongolia	GFZ	E 10652	N 4754	
Ussuriisk	Russia		E 13234	N4404	
Villafranca	Spain	ESA/ESOC	110240	N 42 15	'94
Wellington	New Zealand	DOSLI	E 17447	S41 16	

Table 3
EPOCH CATALOG INFORMATION FIELDS

Sample station information

Requested Field	Information
4-Character ID	PARA
Station Name/Geographic Location	Parana
Country	Brazil
Mark Inscription &/or Monument Number	2591105
Latitude	-25.4479
Longitude (East)	-49.2305
Receiver Type	Trimble 4000 STD
Receiver Source Agency	UFPR
Observing Agency	UFPR
Data Center	UFPR
Processing Center	IBGE/UFPR
Start Date	25-July-92
End Date	08-August-92
Number of Days	15
Received by Regional Coordinator or other location (mark with X)	IBGE
Observing Logs	x
Station Information	x
GPS Data:	x
Format	RINEX
Regional Data Center	IBGE
Network Data Center	CDDIS
Co-location (mark with X)	
VLBI	
SLR	
DORIS	
PRARE	
Other Instrumentation:	
Operations contact	Milton Campos

Table 4
EPOCH 92 STATION LOCATIONS

Project	Region	Number of Stations	Point of Contact
Australia	Australia	45	AUSLIG
Bar Giyyora	Israel	1	IfAG/CDDIS
Brazil	Brazil	3	INPE/CDDIS
Brussels	Austria	1	ROB
DMA Tracking	Global	5	DMA
DORIS	Global	14	IGN
Tien-Shan	CIS	40	GFZ
WINGS	Japan	170	ERI/Univ. Tokyo

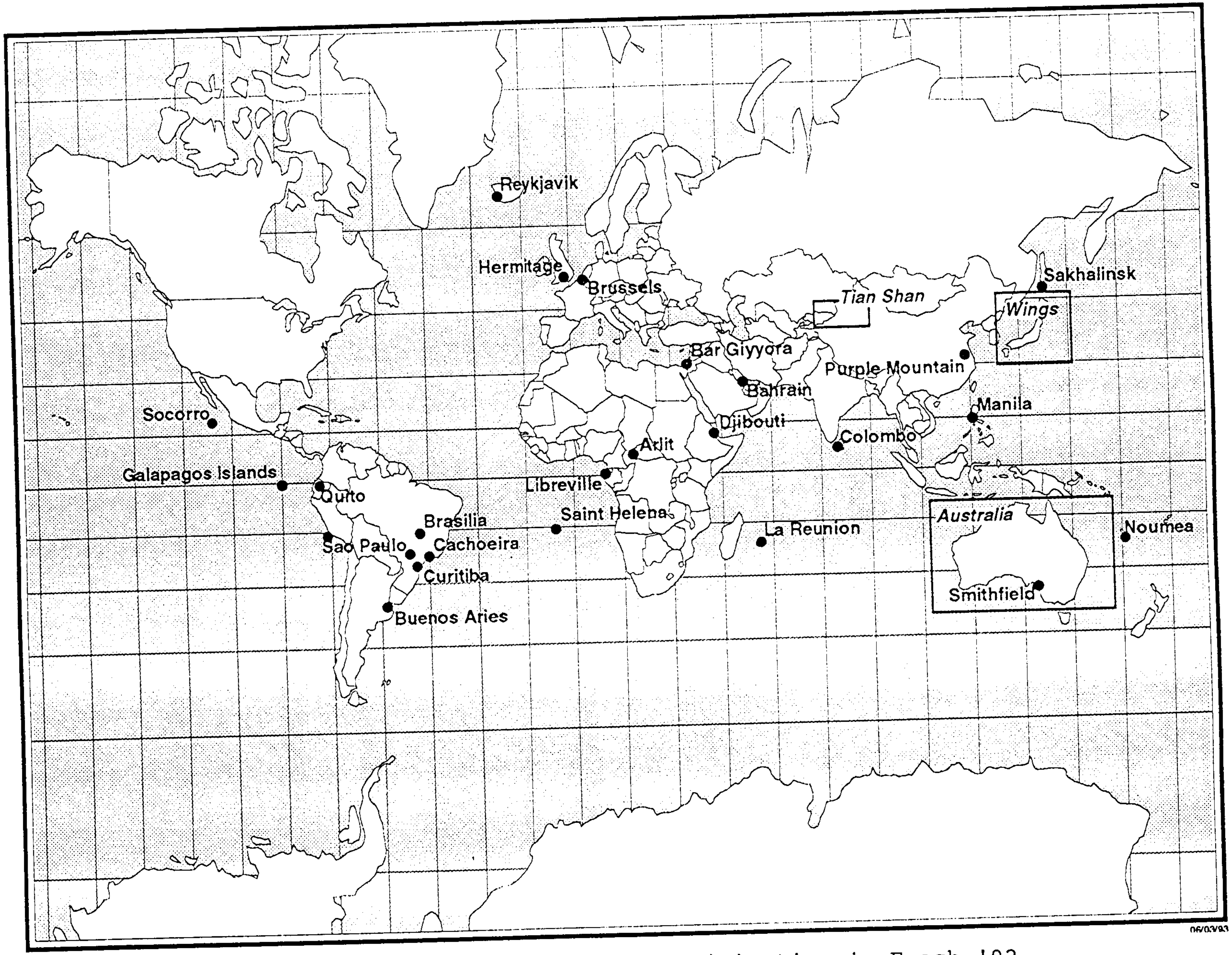

Fig. 3 International participation in Epoch '92

CONCLUSION

As more and more permanent, continuously operating stations are installed, the number of stations which can be considered ‘core’ also increases. Already we are realizing an incredible expansion of this network, which has grown from about 15 stations in early 1991 to over 40 stations in early 1993. We expect that IGS Analysis Centers will ultimately select a subset of the available network stations best suited for generating their products. This selection will depend on the reliability and data quality of the stations, as well as stations with the most desirable global distribution. The location of new, additional stations will no doubt be driven by economics and politics, but it is the issue of communications that really must be addressed in the future for economical, efficient and rapid data retrieval.

ACKNOWLEDGMENT

The authors would like to recognize and thank all of the participants in the IGS who have made the IGS Campaign and Pilot Service and Epoch’92 such a success. On behalf of the IGS, we also want to express our appreciation to the many station operators and their agencies who have worked to collect and transmit such high quality data for the geodynamics community. Wc also thank Peter Morgan for his efforts in collecting the Epoch ’92 data, this is truly a difficult task and his enthusiasm is greatly appreciated.

ABBREVIATIONS

ACRONYM	AGENCY
AUSLIG	Australian Survey and Land Information Group
BfL	Bundesamt fur Landestopographie (Federal Topography), Switzerland
CDDIS	Crustal Dynamics Data information System, GSFC, USA
CGS	Canadian Geodetic Survey, EMR, Canada
CNES	Centre National de Etudes, Toulouse, France
DMA	Defense Mapping Agency, USA
DOSLI	Department of Survey and Land Information, Wellington, New Zealand
DUT	Delft University of Technology, Netherlands
EMR	Energy Mines and Resources, Canada
ERI	Earthquake Research Institute, University of Tokyo
ESA	European Spaece Agency
ESOC	European Space Operations Center
FGI	Finnish Geodetic Institute, Finland
GFZ	GeoforschungsZentrum Institute, Potsdam, Germany
GSC	Geological Survey of Canada, EMR, Canada
GSFC	Goddard Space Flight Center, USA
GSI	Geographical Survey Institute, Tsukuba, Japan
IAA	Institute of Applied Astronomy, St. Petersburg , Russia
IBGE	Instituto Brasileiro de Geografia de Estatistica, Brazil
IES	Academia Sinica, Institute of Earth Sciences, Taiwan
IfAG	Institut fur Angewandte Geodasie, Frankfurt, Germany
IGN	Institut Geographique National, Paris, France

INPE	Instituto National de Pesquisas Espaciais, Brazil
ISA	Italian Space Agency, Matera, Italy
ISAS	Institute for Space and Astronautic Science, Sagamihara, Japan
ISRO	Institute for Space Research Observatory, Graz, Austria
JPL	Jet Propulsion Laboratory, USA
NASA	National Air and Space Administration, USA
NGS	National Geodetic Survey, USA
NOAA	National Oceanic and Atmospheric Administration, USA
OSO	Onsala Space Observatory, Sweden
RGO	Royal Greenwich Observatory, UK
ROB	Observatoire Royal de Belgium, Brussels, Belgium
SIO	Scripps Institution of Oceanography, San Diego, CA, USA
SK	Statens Kartverk, Norwegian Mapping Authority, Norway
UFPR	University Federal de Parana, Brazil

THE ITALIAN GPS FIDUCIAL NETWORK

G. Bianco[1], A. Cenci[2], L. Garramone[3], F. Vespe[1]

[1] Agenzia Spaziale Italiana, Centro di Geodesia Spaziale, Matera (Italy)
[2] Telespazio S.p.A., Roma (Italy)
[3] Telespazio S.p.A, c/o ASI/CGS, Matera (Italy)

ABSTRACT

Within 1993 the Italian Space Agency (ASI) will establish a Fiducial GPS network in Italy in order to locally densify the global IGS network and support local studies concerning: crustal movements, GPS Orbit predictions, local geoid, sea level measurements, monitoring of seismic and volcanic sites.
In the first part we will describe some scientific projects of local interest in which ASI is directly involved and how the fiducial network will support them. In the second part we will summarize the main features of the network.

INTRODUCTION

Since 1990 the ASI's Center for Space Geodesy (CGS), located near Matera, is involved in several national and international GPS projects.
In 1991 the CGS took part in the first global international GPS GIG/IERS campaign and a proposal to participate in the IGS as Core Station, Regional data Center and Analysis Center, was submitted to the IAG and accepted by the Oversight Committee. In particular the CGS' role was confirmed as: Core Station for the collocation of the most important Space Geodesy Techniques (SLR and VLBI); Regional Data Center for the data collections of Spanish and Italian Fiducial stations during the "EPOCH 92" campaign; Associate Analysis Center for products of regional interest. We are currently planning to increase our contribution to the Service as the experience of the CGS team in data archiving and processing activities matures.
Moreover ASI has developed a national GPS receiver and is currently developing the "HIPPO-SIM" software package for multipurpose GPS mission simulation and analysis (Geodesy, Orbital Prediction of GPS and LEO satellites).
The present work will enhance the importance of the establishment of a fiducial GPS network for the strong scientific interest of the Mediterranean area from the geophysical point of view.

THE REGIONAL PROJECTS

In the last few years ASI has been involved in some projects of Regional interest. In particular two campaigns (1991-92) have been performed in the framework of the TYRGEONET (TYRrhenian GEOdetic NETwork) Consortium. The goal is to investigate the tectonic behavior of the Tyrrhenian area, the Southern part of Italy(Sicily, Calabrian arc) and the Appennines traverse. The large size tectonic movements due to the friction between the African and Eurasian plate is presently much better understood thanks to the the continuous efforts performed by the WEGENER Consortium. TyrGeoNet, on the other hand, is aiming to the understanding of tectonics of smaller areas.

Major geodynamic events regarding the central Mediterranean area are the Alpine orogenesis, the rotation of the Sardo-Corso continental block, the oceanization of the Tyrrhenian continental crust and its collapse with the formation of an internal basin [1][2].

The seismicity is particularly high along the Calabrian arc and in the eastern part of Sicily. This activity is both due to the tectonic movements that are still bending the area and a gravitational deepening of the lithosphere toward the sub-lithospheric mantle. The deep seismic activity is interrupted in the southern part of the Taormina fault, so it could be supposed that it breaks the subduction plane between the Adriatic and the African plate. The southern part of Appennines has a tensional axis SW-NE oriented; while the northern and central parts show both tensional and compressional behavior [1].

The most dramatic Alpine seismic area is the Friuli. Its axis of compressional stress is N-S oriented.

TyrGeoNet aims to create an historical series of data in order to well understand how the Tyrrhenian sea opening is occurring and so looking at the deformation field of the Italian peninsula where tectonic stress is still active and induces strong seismicity [1].

The sites involved in the TyrGeoNet campaigns are mainly distributed along the West-East axis crossing the Appennines (range of latitudes: 38°-420) and in the Tyrrhenian area. Some SLR sites are included in the network, such as Matera, Cagliari, Lampedusa and Grasse. This large size network collected with SLR site should improve the determination of the GPS satellites orbital parameters.

Another project concerns the study of the effects of ground subsidence occurring in the area of Venice. The magnitude of such height variations is of few centimeters/year (i.e. smaller than the height precision of GPS measurements) and therefore an historical time series of data is needed. We cannot achieve these absolute information by only establishing a local network because the Venice surroundings are unstable. The only way to have this information is to include Venice in a fiducial GPS network to get the absolute height variations and then to tie it to a network of tide gauges for the monitoring of the mean sea level.

The national defense mapping agency (IGM) is re-building a geodetic dense network by means of GPS. Within the 1995 the whole Italian territory will be surveyed. The network consists of about 860 points at a distance of about 20 Km. IGM plans to introduce in the network sites where other Space Geodetic techniques are located.

Finally a GPS task-force is ready at CGS in order to monitor periodically the areas of seismic, volcanic and hydrogeological interest.

THE GPS FIDUCIAL NETWORK

A Regional permanent network, such as the one we are establishing in Italy, must comply with some critical requirements. In particular, the points of the network must be in sites of geophysical interest and suitable to enhance the effects which are under investigation. It must include some sites (three at least) connected to a larger global network (VLBI, SLR or GPS) in order to avoid mis-rotations of the local one and to improve the quality the GPS orbits over the area. Another requirement is to make the data quickly available to the users in order to support studies involving smaller size networks. Finally the sites must be preferably included in a manned structure to assure at least a low level of maintenance and protection.
The Master station will be located at the CGS where a fixed GPS receiver is operating, collocated to an SLR and a VLBI station. The whole data set of the network will be collected, processed, archived and distributed together with the products. We are planning to use several electronic communication links for the distribution of the products. Other fixed receivers will be installed at Medicina (northern Italy) and Noto (Sicily) where VLBI antennas are located, and at the mobile SLR site of Cagliari (Sardinia).
Other two stations will be installed at Venice (ISDGM/CNR) and Geneva under the management of the "Istituto Idrografico dells Marina" where a tide gauge has been operating for about 50 years. The last two stations are suitable to connect the measurements of the mean sea level to the network (fig. 1).

TECHNICAL CHARACTERISTICS

The Italian GPS fiducial network will be based on high performance GPS receivers. In particular, we are currently evaluating the performances of the Italian receivers, designed and built by Elettronica under ASI management.
The receivers will be remotely controlled by the Master Center through a Personal Computer, modem and telephone line (as shown in fig. 2). An archiving facility for the data storage and distribution will be located at the Master Center as well.
The external links for the data distribution will be assured by DECnet and/or Internet connections.
The receivers will be full time operational. A power supply battery with its charger is foreseen in order to allow the continuity of the acquisition. The technical characteristics of the Italian GPS fiducial network are summarized in Tab. 1.
It is planned that the installation of the receivers will be completed within 1993.

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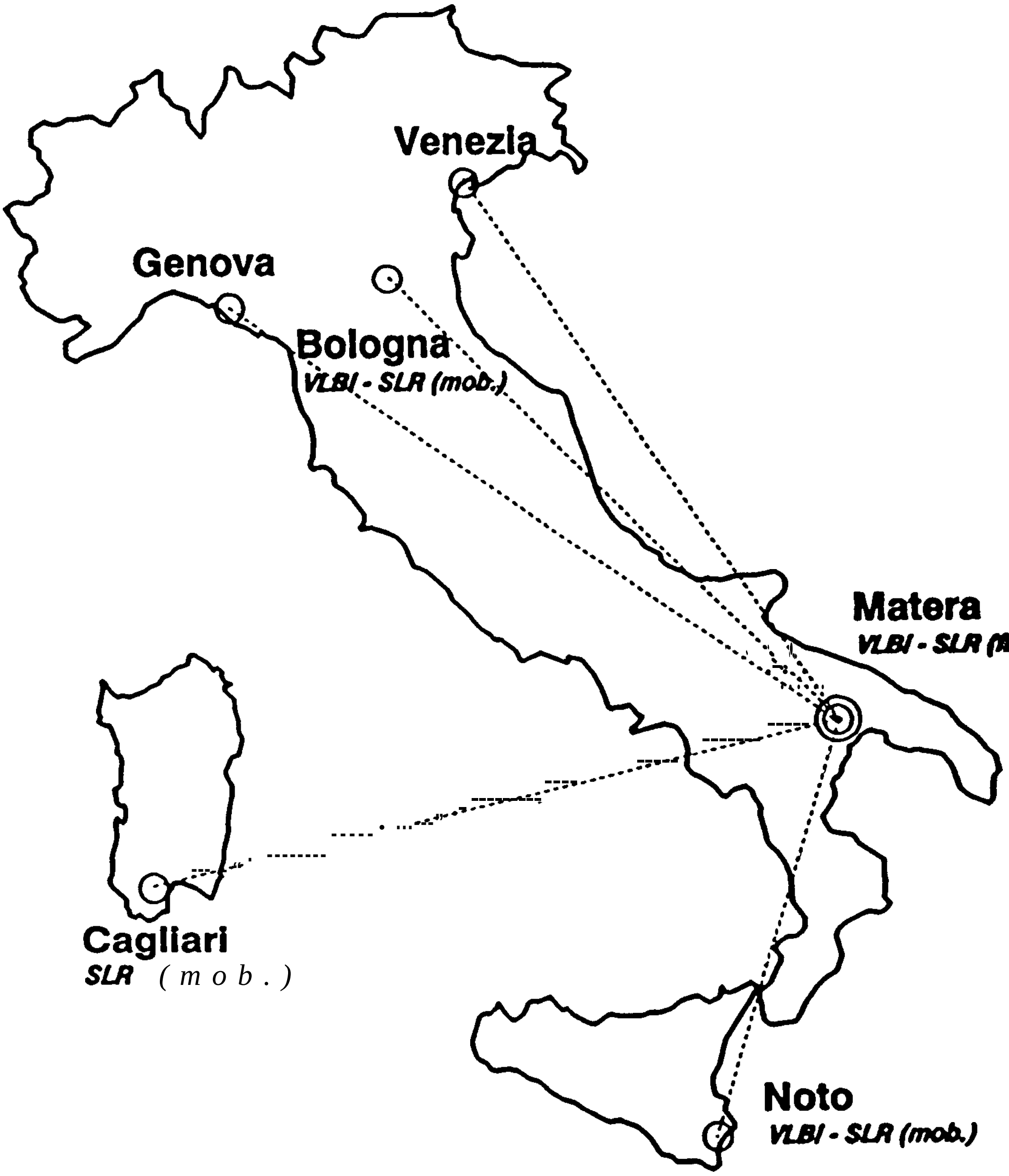

Fig. 2- THE SITES OF THE ITALIAN GPS NETWORK

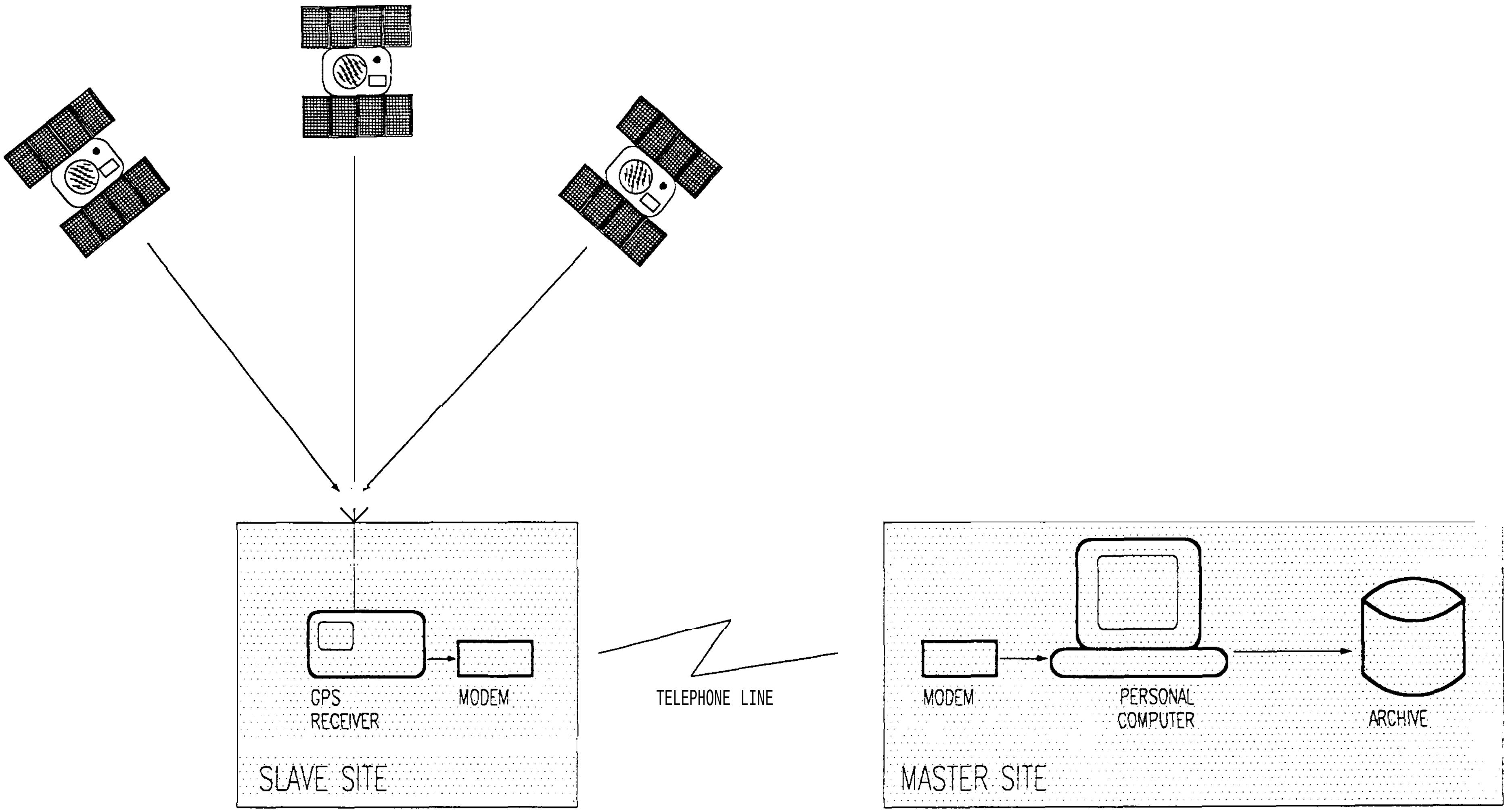

Fig. 2- REMOTE CONTROL AND DATA ARCHIVING: BASIC CONCEPT

TABLE 1, -- GPS FIDUCIAL NETWORK: TECHNICAL FEATURES

SITES	**Medicina (Bologna), Noto (Sicily), Cagliari, Venezia, Geneva, Matera**
RECEIVERS	**High performance geodetic GPS receivers (Turbo Rogue or The Italian GPS Receiver: AEGEOS-P)**
RECEIVER CONTROL	**Remote from the Master Station by using a Pers. Computer**
ACQUISITION	24 **hours/day**
MASTER AND DATA CENTER	**MATERA**
CONNECTION TO THE DATA CENTER	**Modem and Telephone line**
DATA DISTRIBUTION	**Electronic Mail (DECNET, SPAN and INTERNET)**
INSTALLATION	**Within 1993**

CANADIAN ACTIVE CONTROL SYSTEM DATA ACQUISITION AND VALIDATION

PIERRE HEROUX, MARK CAISSY, JOE GALLACE
CANADA CENTRE FOR SURVEYING
DEPARTMENT OF ENERGY, MINES AND RESOURCES
615 BOOTH STREET
OTTAWA, ONTARIO, CANADA KIA 0E9

The Geodetic Survey Division of the Canada Centre for Surveying in collaboration with the Geological Survey of Canada is implementing a network of remotely controled stations tracking Global Positioning System (GPS) satellites which is known as the Active Control System (ACS). Stations located in Algonquin Park (ONT.), Yellowknife (N. W.T.), Penticton (B.C.), St John's (NFLD.) and Albert Head (B. C.) are presently operational. Each station of this network is equipped with a high precision dual frequency GPS receiver and an atomic time standard. The data is transfered daily to a central processing and storage facility in Ottawa via ground or satellite communication links.

The front end data analysis is done at the ACS station level in two phases. The first phase assesses the quality of GPS dual-frequency code and carrier phase observations by forming two inter-frequency linear combinations of the raw observable. These combinations are essentially free of any biases common to both frequencies and have been used successfully to detect carrier phase cycle slips, establish code multipath levels and monitor daily ionospheric activity. The second phase is a single-point positioning program that uses the knowledge of the ACS station position and atomic clock behavior to monitor GPS/ACS system performance and integrity. The EMR precise GPS ephemeris and clock corrections are used during post-processing in the single-point positioning program to analyse internal consistency and achievable accuracy.

ACS DATA ACQUISITION

The current ACS configuration consists of five remotely controled Active Control Points (ACPs) located near Algonquin Park (ONT.), Yellowknife (N. W.T.), Penticton (B.C.), St John's (NFLD.) and Albert Head (B. C.) with communication links to the processing centre in Ottawa. The ACPS are equipped with Rogue dual frequency GPS receivers. At predetermined times, data is transferred from the acquisition sites to the Master ACS (MACS) centre in Ottawa. Once the data has been received from all sites for a given 24 hour period, processing is begun. Information produced during this pre-processing phase is stored in files for quick reference and problem detection.

In Yellowknife, a micro-computer is connected directly to a Rogue receiver which extracts the data at regularly scheduled intervals. The computer then transmits the data to Ottawa over a DECNET satellite link. In Penticton, St John's and Albert Head, Rogue receivers are connected to high speed modems and accessed through conventional phone lines. Data from Algonquin Park is relayed via satellite to a public packet switching network (DATAPAC). Data from all sites are also sent to the Crustal Dynamics Data Information Service (CDDIS) using an automated File Transfer Protocol (FTP) over INTERNET.

For the purpose of daily data validation and performance monitoring, two separate programs have been developed to evaluate and report on GPS data quality. The first one uses combinations of dual-frequency code and carrier phase measurements to assess the level of ionospheric activity and multipath. This program also detects and corrects cycle slips of the carrier phase to a level corresponding to code quality and ionospheric activity. The second program is a single-point positioning program that uses dual-frequency code observations and broadcast ephemeris to evaluate receiver position and clock parameters. A priori knowledge of the receiver location and clock behavior is used to assess the performance of the GPS system and the effects of Selective Availability (SA) and Anti-Spoofing (AS). The information obtained is subsequently used in precise orbit computations. Finally, the precise orbits and clock corrections from EMR daily orbit processing based on the GIPSY II package developed at the Jet Propulsion Laboratory are fed back into the single point positioning algorithm. This post-processing provides a quality check on the daily solutions for satellite precise orbits and clocks as well as station clock performance monitoring.

ACS DATA VALIDATION

The GPS Ionosphere and Multipath Program (GIMP) has been developed for the ACS to evaluate and report the ionospheric and code multipath conditions prevailing at a site where GPS dual frequency carrier phase and code observations are collected. It also detects and estimates cycle slips in the carrier phase from the ionospheric delay and widelane combinations of the carrier and code measurements. This program uses single station observations, is fast to execute and gives a quick look at receiver tracking performance.

Program GIMP uses two linear combinations of dual frequency code and carrier observations from a single station and one satellite. The first is a combination of L1/L2 carrier phases representing the ambiguous inter-frequency ionospheric delay also known as the narrowlane combination. The second is a combination of L1/L2 code and carrier observations known as the widelane [1]. While this combination is essentially free of ionospheric effects, it is affected by code multipath. Nevertheless, because of inter-frequency differencing, both combinations are to a large extent free of receiver and satellite clock effects as well as orbital errors. Non-dispersive effects such as tropospheric delays also cancel out. Given stable ionospheric conditions and a low multipath environment, these time series can be used for cycle slip detection and correction.

IONOSPHERIC EFFECTS

The change in inter-frequency carrier phase observation over a time interval At can be written :

Where: $\lambda \phi_{2-1}$ (At) = change in inter-frequency carrier phases $\lambda\phi_{2-1}$

$dion_{2-1}(\Delta t)$ = change in ionospheric delay $dion_{2-1}$

$\varepsilon_{\phi 2-1}(\Delta t)$ = change in carrier multipath and noise $\varepsilon_{\phi 2-1}$

$\lambda\, N_{2-1}(t)$ = initial inter-frequency carrier phase ambiguity

We see that over the time interval At, the change in inter-frequency carrier phases $\lambda\phi_{2-1}$ equals the sum of the changes in ionospheric delay $dion_{2-1}$, carrier multipath and noise $\varepsilon_{\phi 2-1}$. The initial inter-frequency carrier phase ambiguity λN_{2-1} remains constant as long as the data is cycle slip free. A cycle slip on either L 1 or L2 will cause a step of 5.4 cm $(\lambda_2 - \lambda_1)$ in the time series. In order to detect cycle slips with this narrowlane combination, it is essential that the ionospheric and carrier multipath variations over the time interval At be below this threshold.

Assessing the level of ionospheric activity is important if this combination of dual-frequency carrier phases is used to detect cycle slips. As mentioned earlier, cycle slips on L1 or L2 will introduce discontinuities that are multiples of 5.4 cm. To ensure detection at the cycle level, variations of less than this threshold over the sampling interval are required.

The ionospheric delay variations observed from the dual-frequency carrier phases of all satellites tracked daily are combined to obtain an average daily ionospheric gradient for each ACP. This value is normalised to mm/sec to accommodate various sampling rates. Figure 1 shows the daily ionospheric gradients for Yellowknife and Algonquin ACP's. Yellowknife is at 62.5 degrees of northern latitude in the auroral zone while Algonquin is in the southern part of Canada at 46 degrees north. The ionospheric gradient in Yellowknife varies from 1-2 mm/see and can display large daily variations. As for Algonquin, the gradient varies between .4 and .8 mm/see and is relatively stable. With these figures, one can expect ionospheric variations over 30 seconds of the order of 3-6 cm in Yellowknife and 1-3 cm in Algonquin. This can affect cycle slip detection capability.

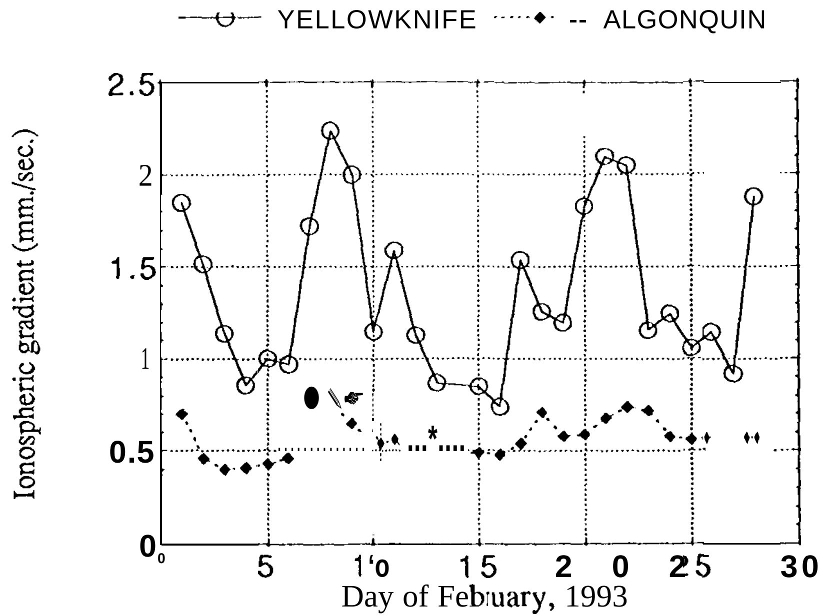

Figure 1. ionospheric Gradient - February 1993- Yellowknife & Algonquin

MULTIPATH EVALUATION

The time variation of the code and carrier widelane[2] combination can be expressed as:

$$\lambda_4 [\phi_2(\Delta t) - \$1 \ (At)] + [\tau_2(\Delta t) + \tau_1(\Delta t)]c/2 = 0.03\, d_{ion2-1}(\Delta t) + \varepsilon_{mpath}(\Delta t) + \lambda_4 [N_2(t) - N_1(t)]$$

Where:

$\lambda_4 [\phi_2(\Delta t) - \phi_1(\Delta t)]$ = widelane combination of dual frequency carrier phase

$[\tau_2(\Delta t) + \tau_1 (At)]\ c/2$ = average pseudorange

$0.03\ d_{ion2-1}\ (At)$ = ionospheric delay

$\varepsilon_{mpath}\ (At)$ = combination of code and carrier noise and multipath

$\lambda_4 [N_2(t) - N_1(t)]$ = initial carrier widelane ambiguity

As long as the carrier phases are cycle slip free, the code/carrier widelane ambiguity remains constant for a given satellite. Therefore, it is possible to look at observed widelane ambiguity variations over the sampling interval or with respect to a mean value computed for an arbitrary reference time. By setting the reference time to the arc's initial epoch, an arc multipath variation estimate is obtained by differencing the multipath observed at each epoch and the updated mean arc value. The interval variations show mainly the high frequency component of multipath whereas the arc value will represent the low frequency component.

The quality of the widelane combination is important for cycle slip detection and correction, as cycle slips in the L1 or L2 carriers introduce steps that are multiples of 86 cm into the widelane time series. However, if cycle slips occur simultaneously on both frequencies, they cannot be detected by the widelane combination. Given this 86 cm threshold for cycle slip detection, widelane time series variations smaller than 20-3-0 cm are desirable. Figure 2 shows code multipath variations for two satellite arcs observed at Algonquin on February 26, 1993. The first arc is for PRN 13 and was tracked in P-code mode. Generally, the quality of ranges observed in this mode is 10-20 cm RMS over the arc, with multipath effects varying between 5 and 50 cm depending on satellite elevation. The second arc is for satellite PRN 25, observed in cross-correlation mode due to anti-spoofing. The C/A code range errors are at 2 metre RMS over the arc and multipath at lower elevations causes range errors of several metres. This significantly affects our ability to detect cycle slips from the code/carrier widelane combination.

While this approach to monitoring the quality of the observable is useful, it is limited by the fact that an initial bias on either code or phase cannot be resolved due to the time differencing technique used. In order to resolve this ambiguity, a known receiver position must be introduced.

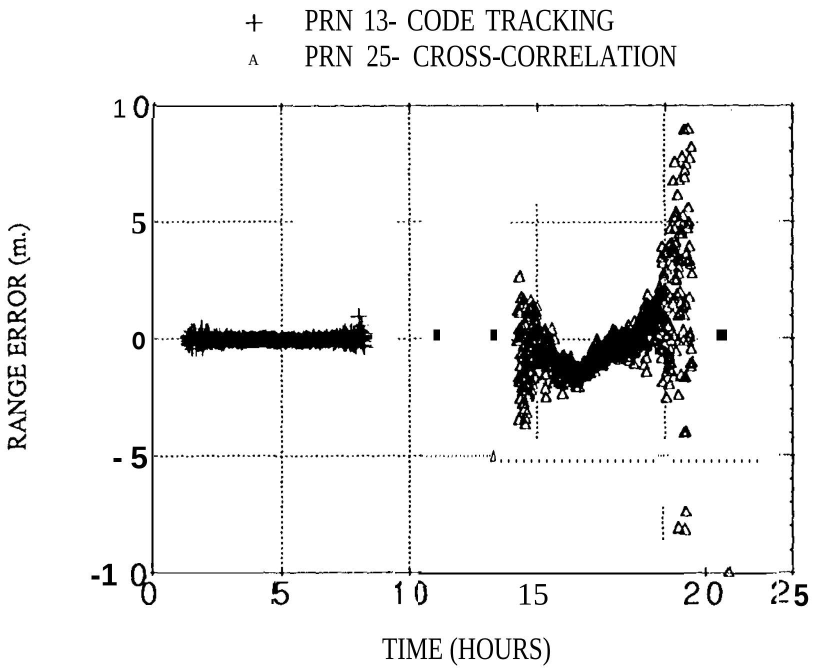

Figure 2. P-CODE .vs. CROSS CORRELATION TRACKING
PRNs 13 and 25- Algonquin ACP - February 26, 1993

RECEIVER TRACKING PERFORMANCE

A summary of GPS receiver tracking performance is provided by GIMP on a daily basis for all ACP's. Figure 3 shows a sample of the summary for the Yellowknife ACP on February 26, 1993. The header gives the data file name and station with the observing date and data rate. The receiver tracking performance is reported by arc and satellite PRN number. The arc statistics include the start and end epoch, the number of data points per arc, the number of gaps and cycle slips detected. The ionospheric gradient is represented by RMS (cm.) for the sampling interval in mm/sec. The one second gradient is useful for comparing ionospheric activity from receivers using different sampling rates. The RMS for the interval and arc multipath are given in metres in the last 2 columns. The last line of the table combines information from all observed arcs and is entered into a monthly station file.

A 24 hour tracking table provides a visual representation of observed satellite arcs in ascending PRN order. Any asterisk (*) represents 20 minutes of P-code data while the (x) indicates cross-correlation tracking. The hat sign (A) shows the occurrence of cycle slips. Such satellite tracking table may be used to weight ranges in the precise orbit solution. For Rogue receivers, a channel tracking table identifying the PRN number tracked on each channel is also provided.

```
------------------------------------------------------------------------
      GPS Ionosphere and Multipath Program (GIMP-18/06/1992)
------------------------------------------------------------------------
File    : data/93feb26algo.std                          Data Rate:    30 sec.
Station:         ALGO SPACE COMPLEX ALGONQUIN PARK ONT : Date      : 26/ 2/1993
------------------------------------------------------------------------
SAT     START       END        #OBS. #GAP #C.S.  IONOSPHERIC        MULTIPATH
PRN #   TIME        TIME                         VARIATIONS       INTVL     ARC
     (hh:mm:ss)  (hh:mm:ss)                     (cm.) (mm./s.)    (m.)    (m.)
------------------------------------------------------------------------
 1    12:15:30.   19:14: 0.    827    2     2    1.87    .62      1.45    1.51

 2     0: 0: 0.    5:10:30.    622    0     0     .75    .25       .09     .08

 3     7:23: 0.   12:29:30.    610    1     0    1.11    .37       .11     .10
 3    18: 4:30.   19:59:30.    231    0     0    2.61    .87       .27     .22
                                           .
                                           .
29     4:37:30.    6:53: 0.    273    1     0     .88    .29       .19     .15
29    17: 3: 0.   22:45: 0.    685    0     0    1.73    .58      1.66    1.67
------------------------------------------------------------------------
       0: 0: 0.   23:59:30.  18671   54    27    1.71    .57      1.17    1.18
------------------------------   --------------------------------------
                        SATELLITE TRACKING TABLE
------------------------------------------------------------------------
 1                                       Xxxxxxxxxxxxxxxxxxxxxx
 2  *************** *
 3                      ****************               ******
11  *******                              A*********              **********
12        *A*********                  *************** ^
13     ****************  *****
14      *6************                            xxxxxxxxxxxxxxx
15  ***********A*                            xxxxxxxxxx                ****
16              **************  ******
17.                      ***********xxxxxxx                   xx
18             ***********                              *****^*******^*^*
19  *****^                ^^                                xxxxxxxxxxxxx
20             **********  *^                **************A
21                                ^**xxxxxxxxxxxxxxxx
22                         *^^                        *************** ****
23                            ******xxxxxxxxxxxx^
24           A***********  *********6
25                                           xxxxxxxxxxxxxxxxxxxxxx
26  ******               *************xxxxxx                            ^
27  .........               *******^                               Xxxxxxxx
28  **                           .***x*****                ***
29              *******^                               Xxxxxxxxxxxxxxxxx
    77678866666666668888666567768977767888998888988878877866788878666776667656

-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-
    0  2     4     6     8     10    12    14    16    18    20    22    24
------------------------------------------------------------------------
  (*) P-Code Tracking, (x) Cross-Correlation Tracking, (") Cycle-Slip
```

Figure 3. Receiver Tracking Performance
AlgonquinACP -February 26,1993

SINGLE POINT POSITIONING

A near real-time single-point positioning program using GPS pseudo-ranges and broadcast ephemeris provides valuable information for ACS data validation and system performance monitoring. Observed GPS pseudo-ranges for all satellites at an epoch are used to derive the receiver's three dimensional position and clock offset with respect to GPS time. The unconstrained solution, where the receiver's coordinates and clock offset are considered unknown provides time series of estimated range residuals, receiver positions and clock offsets. The pre-processing mode, where the receiver's coordinates and clock offset are fixed is also used for troubleshooting. With stable clocks, the offset and drift can usually be predicted from previous day.

Single-point positioning using GPS pseudo-ranges, broadcast ephemeris and precise positions of tracking stations is used:

- to assess and monitor the quality of the broadcast ephemeris using range corrections computed from a network of known stations. This allows for the estimation of the effects of Selective Availability (SA) and allows for GPS system performance evaluation;

- to evaluate receiver clock performance;

- to provide a priori estimates of receiver and satellite clock corrections for EMR orbit processing;

- to identify periods where Anti-Spoofing is activated and assign corresponding weight to range and phase measurements for P or C/A code tracking;

- to independently assess the quality of the precise ephemeris and clock corrections derived from EMR orbit calculations using a global tracking network. This is the final and effective test of the precise orbits and clocks. It also facilitates precise monitoring of the station clocks.

The post-processing is completely independent of EMR orbit solution and simulates the usual navigation software that computes position and local receiver clock offset at each epoch when 4 or more satellites are visible. The precise satellite positions and clock offsets in the SP3 format are presently available at 15 minute intervals for which station positions are also computed. The ionospheric free combination of the dual frequency ranges was computed after removing the receiver inter-frequency calibration delay. The tropospheric delay was obtained using Hopfield's model for mean atmospheric parameters (temperature = -10 deg. C., pressure = 950 millibars, relative humidity = 10%). Such simplifications are likely responsible for some of the systematic trends in the mean daily positions. Incorporating the precise orbit and clock corrections into the single-point positioning software improved precision considerably and required amendments to the reduction model to account for effects which were previously neglected.

Figure 4 shows ionospheric and tropospheric delay along the signal path of PRN 21 during a 6 hour arc over station Algonquin on January 19, 1993. Effects of periodic relativity term and range residuals are also presented. When the systematic effects are removed range residuals vary between -23.6 and 69.7 cm with 20.0 cm RMS which corresponds to the P-Code tracking multipath error estimated earlier.

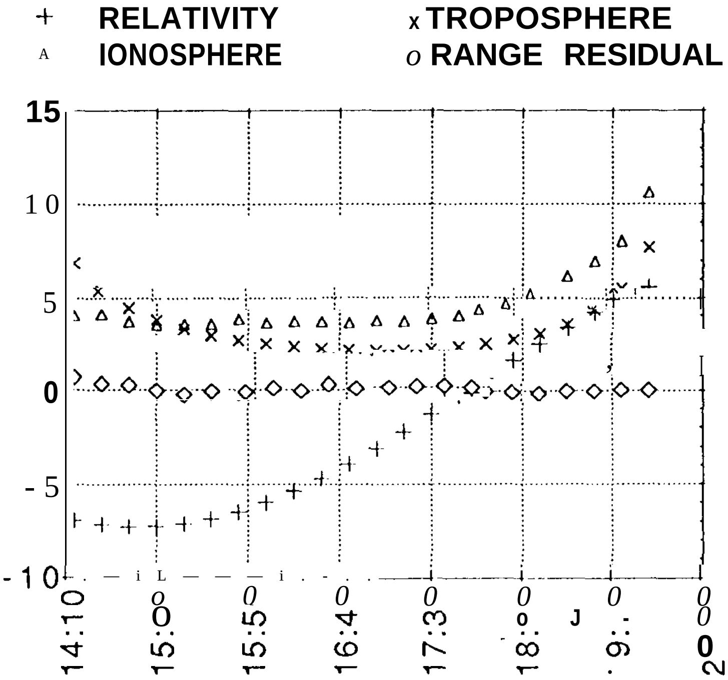

Figure 4. Range Residuals - PRN 21 - Algonquin - January 19, 1993
Relativity, Ionospheric and Tropospheric Effects

Figure 5 shows the differences between calculated positions at 15 minute intervals and the IGS adopted ITRF 1992.5 coordinates for station Algonquin on January 19, 1993. Each one of the positions presented here is independent and was computed using satellites above the 15 degree elevation angle mask at the specified epoch. Obviously, during the day a number of different satellite combinations of varying geometry were used. Using precise ephemeris and clock corrections does not produce discontinuities when combination of satellites changes. Along the X, Y and Z axis, the RMS of the variations about the mean are 31.8, 59.1, 45.9 cm. These variations are consistent with a 20 cm code error when considering the geometric dilution of precision. The daily mean offsets from the adopted coordinates of Algonquin were -10.6 cm, -25.4, and -2.7 cm in the X, Y and Z components, which is likely due to the simple tropospheric modeling combined with multipath and orbit/clock errors.

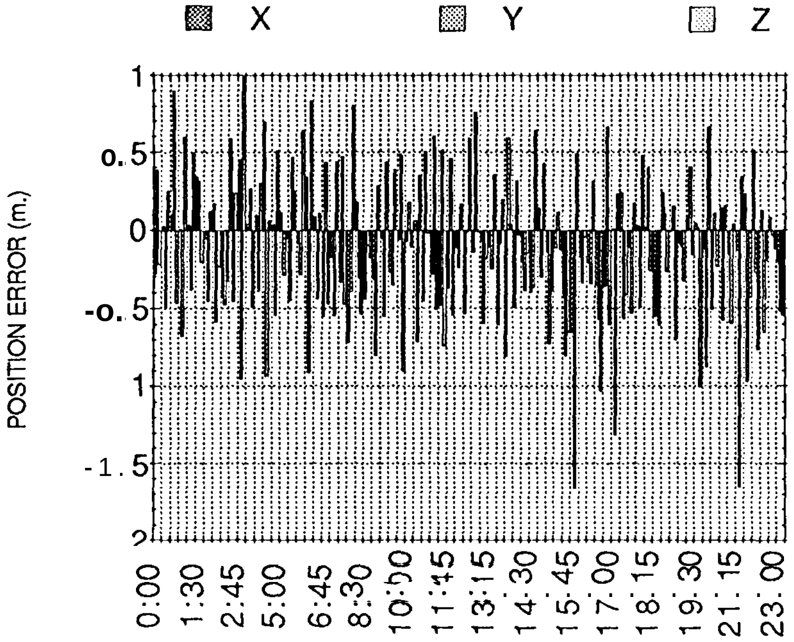

Figure 5. Single Point Positioning - Algonquin - January 19, 1993

To show the consistency of results the observations from January 17 to 26 were processed for station Algonquin and the results are presented in Figure 6. Most daily means agreed with the adopted Algonquin position at the 10 cm level along all 3 components with the exception of January 18 and 24, when differences for the X and Y coordinates reached the 20-30 cm level. These differences have not been explained yet and further investigation is required. Nevertheless, the precision presently attainable with the use of precise ephemeris in a single-point mode is remarkable. This will greatly enhance the ability to analyze errors affecting wide area differential GPS.

CONCLUSION

ACS data acquisition processes have been automated and data validation procedures incorporated to monitor the quality of GPS data in support of the precise orbit computations. Navigation type single-point positioning using precise orbits and clock corrections during post-processing provides precision better than 1 metre and daily means agree with a priori coordinates at the 20 cm level.

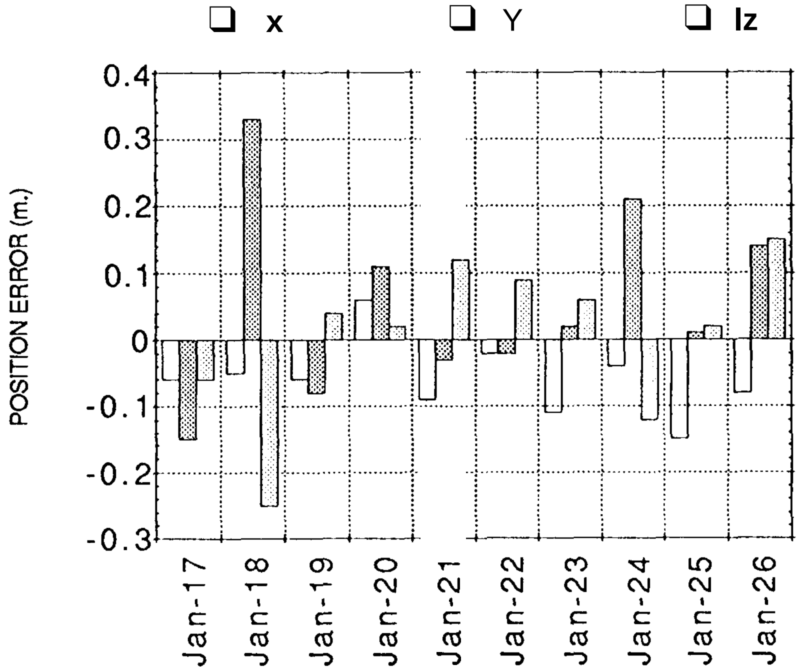

Figure 6. Single Point Positioning - Algonquin - January 17-26,1993

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Activity of Borowiec IGS Fiducial Station

Waldemar Jakś, Krzysztof Zeller

Astronomical Latitude Observatory
Space Research Centre
Polish Academy of Sciences
Borowiec, POLAND

This paper presents few facts from the history of the Astronomical Latitude Observatory Borowiec, connected with its different activity areas. Next we focus on the International Geodynamics Service tasks and show some results of works aimed at hardware and software improvement. Present state of the equipment is shown here and campaigns in which Borowiec observatory took part are mentioned. In the last part of this work there are plans for the nearest future in the frame of IGS activitiy.

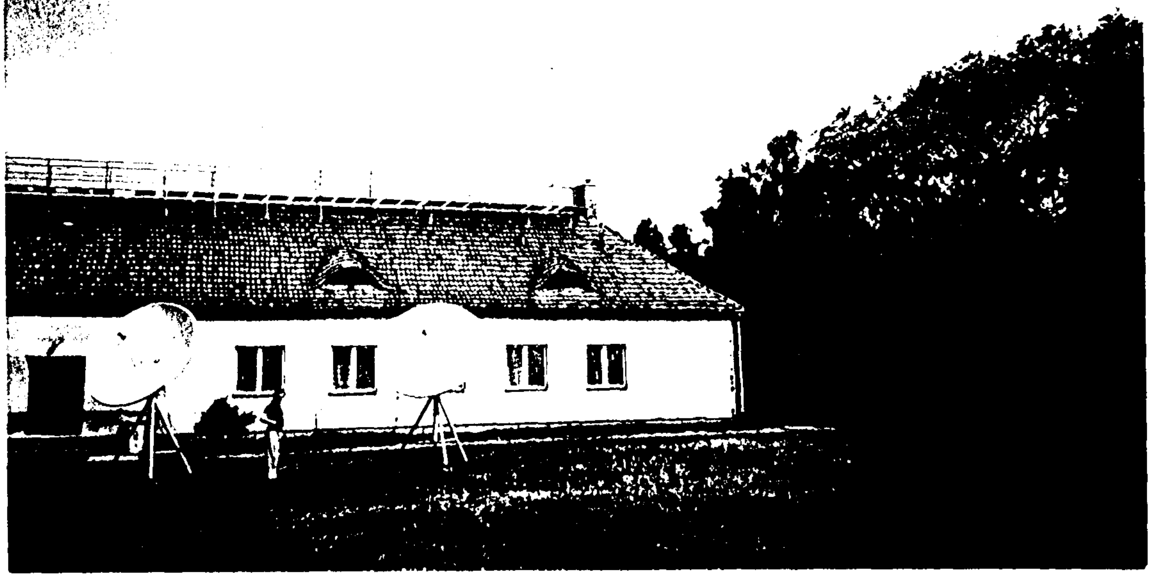


Photo. 1. General view of Borowiec Observatory.

INTRODUCTION.

Astronomical Latitude Observatory in Borowiec (photo. 1) was established in 1957. At the very beginning only classical optical observations were performed with transit instrument and zenith telescope, but later Danjon's astrolabic was used as well. Few years later also photographic technics was introduced to take pictures of satellites against a background of stars with SBG camera. As the weight of classical observations decreased new observation technics were introduced. Such steps were: satellite laser ranging (initially in 1975 of first generation, later second and since 1991 third generation system). Now Borowiec observatory has the laser PY-S2-1O manufactured by CONTINUUM (photo. 2).
It is the unit of following parameters:

Laser transmitter - Nd: YAG
pulse energy -100 mJ (green light)
pulse width -100 ps
repetition rate - 10 Hz
divergence -0.4 mrad

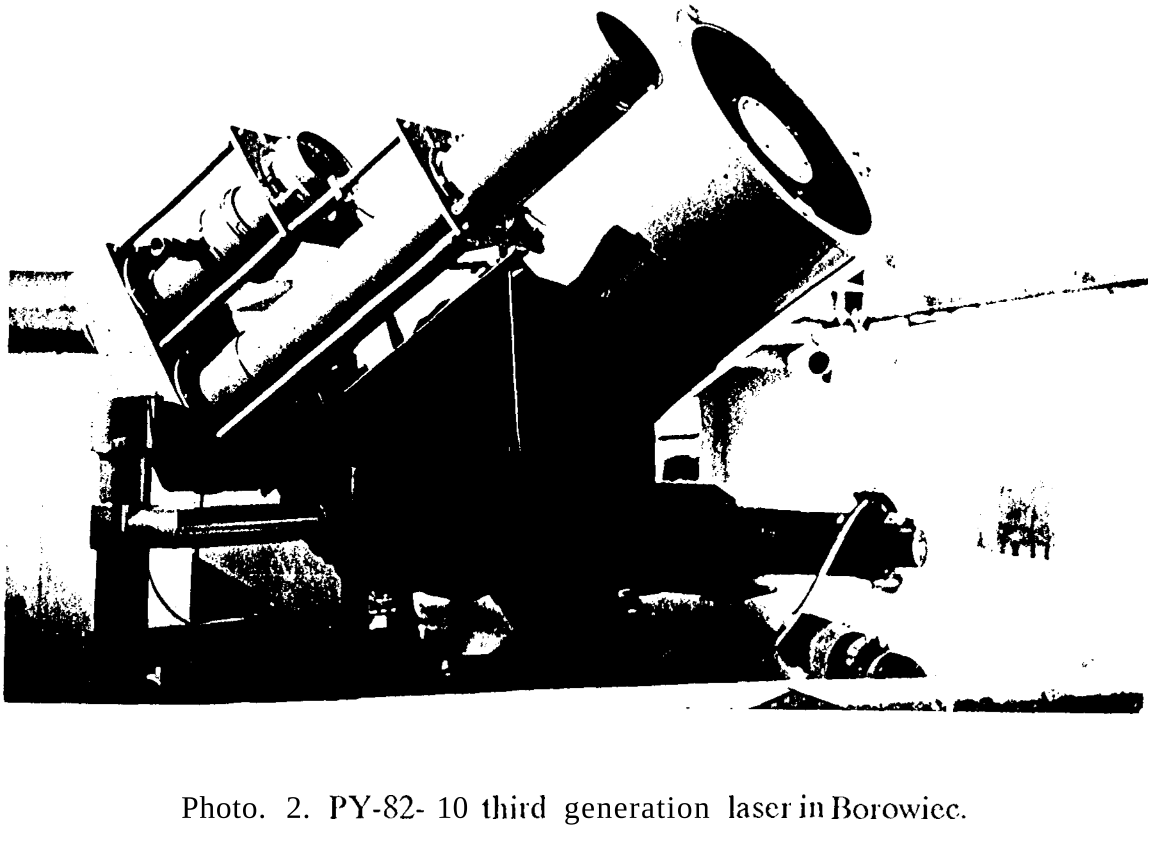


Photo. 2. PY-82- 10 third generation laser in Borowiec.

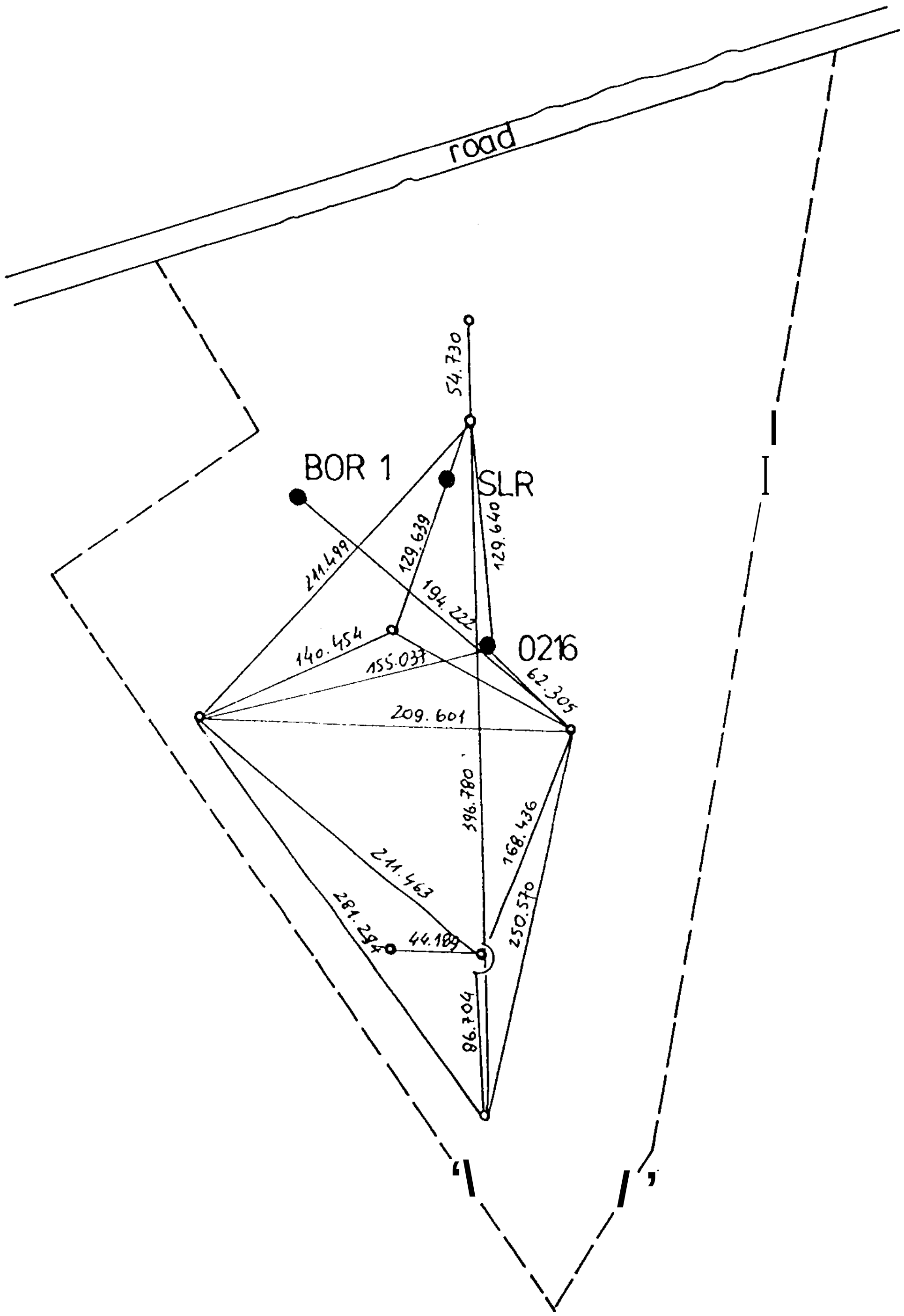
Moount
  tracking - LAGEOS and low satellites; step by step mode
  encoder resolution - 1.8 arcsec
Receiver
  diameter of mirrors -65 cm (primary), 20 cm (secondary)
  field of view -5 arcmin
Photomultiplier - RCA 8852
Time Interval Counter - 100ps accuracy
Time Base - GPS Time Receiver, Cesium Frequency Standard

Its contol software is a results of cooperation between Borowiec and Kootwijk, Holland observatories.

Observations of the Navy Navigation Satellite System satellites with doppler receivers DOG-2 and DOG-3 were performed from 1977 to 1990. These receivers were made in Poland by Space Research Centre in cooperation with Institute of Aviation Warsaw, Poland. When the doppler observations were terminated, instead of them observations of the Global Positioning System (GPS) satellites started. Participation in many international and national observation campaign gave us different technics observation data. This material was used not only for our own elaboration but was open to other persons and institutions. In this way the points located on Borowiec territory were connected to all Polish observatories, a number of European stations and few out of Europe points. Of course older technics results are interesting only from historical point of view.
Presently we have got two important technics in our observatory: Satellite Laser Ranging and Global Positioning System. There are 7811 laser station and two GPS sites: BORO (also marked as 0216 EUREF network point) and BOR1. The second one was established specially for participation in International Geodynamics Service works.

BOROWIEC ACTIVITY IN IGS PROGRAM.

After few years of GPS technics development which was visible in groving number and range of GPS observation campaigns, number of sold receivers and hardware and software improvement, an initative was presented to establish global frame of GPS monitoring and control. Space Research Centre of Polish Academy of Science owned two dual frequency TRIMBLE 4000SST receivers and TRIMVEC + firm software bought with receiver . (Now we have got also Bernese ver.3.4 program). On Borowiec observatory area we have calibration point network. One point is situated on astronomical pillar, two of them on steel pipe tops and and others on concrete plates buried 1 meter below ground level.
Map 1 shows the calibration network points. We decided to response for President Ivan Mueller call and expressed our readiness to carry on core station and processing center tasks in Borowiec. Finaly our proposal was accepted but as fiducial not core station.



Map 1. The GPS calibration network in Borowiec.

Sending answer we decided to meet the installation and equipment requirements. Because of this reason the new marker BOR1 was fixed. It is situated on the main building roof (photo. 4). The previous main GPS marker BORO which is known also as 0216 EUREF is 150 meters away. Concrete 30 years old astronomical pillar (photo. 3), at which BORO GPS point is fixed, secures antenna fixing repeatability with accuracy of 0.5 mm, its stability and resistance against ground water and meteorological conditions changes. They total height is 3 meters but only 1 meter is above ground level. The GPS point BOR1 is on the top of internal carry wall. In this case the receiver is in the building in the room 7 meters below antenna level, which causes that 10 meter antenna cable can be used. The building has got 220V AC outlets and emergency power source (diesel generator). Rooms are dry, their relative humidity never exceeds 50%. There is no ferromagnetic materials inside the wall on which BOR1 is situated. Until March 1993 Borowiec station has had two dual frequency TRIMBLE 4000SST receivers which will be replaced by 4000SSE The Borowiec observatory has got two cesium frequency standards: Rhode and Schwarz and since last week OSCILLOQARTZ Eudics 3020. Each of them can be used instead of internal receiver frequency standard. Our local time scale is connected to BIPM Paris with accuracy up till 50 nsec using, GPS time signal receiver made by NAVI Poznań Poland (photo. 5) and LORAN C receiver.

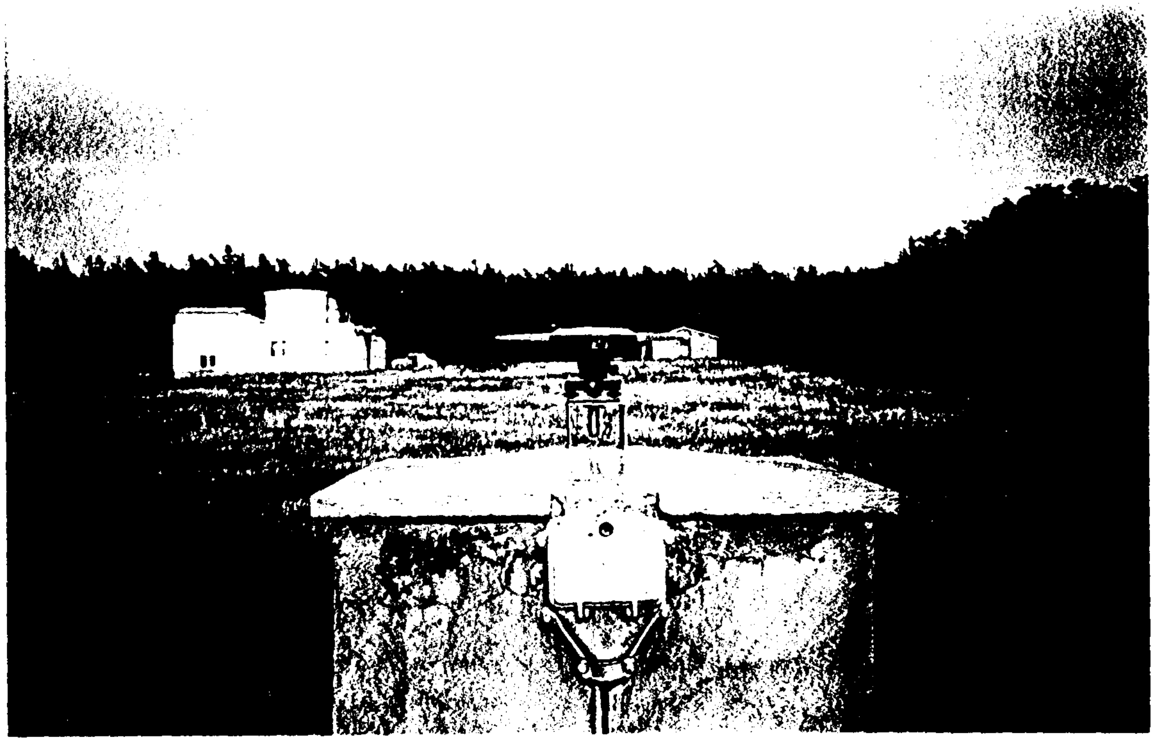


Photo. 3. The BORO GPS site against a background of laser building.

NAV1 is Borowiec observatory permanent partner. NAVI makes prototype high parameters electronic equipment. Its team has rich experiences originated from DOG -2 and DOG-3 doppler receivers.

Comunicaton lines with Borowiec are realized throught INTERNET and BITNET networks. We have access to their outlets in Poznań city (20 km north of Borowiec). At the spot we have modem EVEREX with some FTP.

Borowiec took part in GPS observation campaign also before IGS. The first campaign was Organized on vector Borowiec - Józefosław (about 300 km length) using borrowed from Germany WM102 receivers. The next campaigns were BALTNAV'90 and Baltic Sea Level '90. In both Of them We had TRIMBLE dual frequency receivers borrowed from Germany and two own TRIMBLE 4000SST receivers in 13 SL'90 campaign. The BALTNAV campaign vectors (vectors between stations Borowiec, Lamkówko, Poland and Potsdam, Germany) were elaborated using TRIMVEC+ software but BSL'90 campaign was elaborated with both TR IMVEC and Bernese software. We get some experiences with ASII-I'EC11 receivers during observations on Borowiec -- Borowa Góra basis. They were carried on in frame of cooperation with Institute of Geodesy and Cartography Warsaw, Poland using four dual frequency receivers: two TRIMBLE and two AS] I-l-lX1 I. The results were obtained using following programs: Bernes, TRIMVEC+ and GPPS. In 1992 EUREF-POL GPS observation campaign was organized. This project aimed at the creation of the fundamental] geodetic network for Poland connected with the European reference frame.

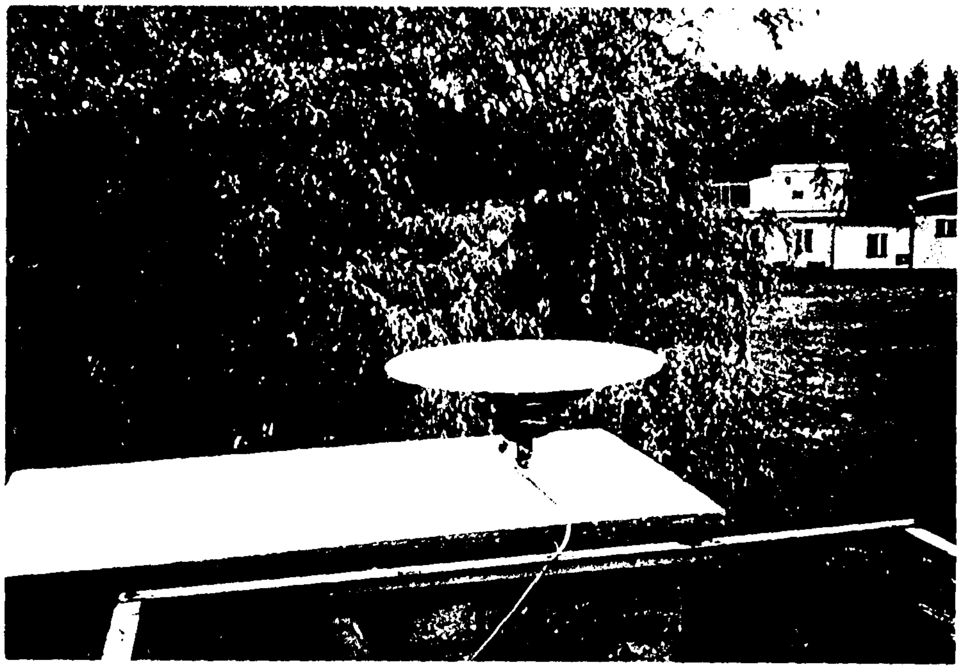


Photo. 4. The BOR1 GPS site on the main building roof.

In frame of IGS activity Borowiec station took part both in two global GPS campaigns: first GIG'91 and EPOCH'92. During GIG'91 campaign we observed in Borowiec and Kiev Ukraina with TRIMBLE 40000 SST dual frequency receivers. All day observation data we have sent to the Data Center in University of Colorado Boulder, USA. We also computed vector Borowiec - Kiev using TRIMVEC+ software. We have obtained following results as average values of all days:

dx	sig	dy	sig	dz	sig	dh	sig
-225510.292	.135	920696.3S4	.1S2	-132850.996	.160	105.585	.197

During EPOCH'92 campaign we carried on observation only in Borowiec using also two dual frequency receivers (one of them, borrowed from Warsaw University of Technology, with P code on BOR1 point). We have sent data to the regional Data Center in Institute for Space Research of Austrian Academy of Sciences Graz Austria.

Photo. 5. The GPS time receiver made by NAVI Poznań, Poland

The surveing among laser, main and auxiliary GPS points are performed periodically. BORO site coordinates are known from BSL'90 campaign results with accuracy of few centimeters in ITRF-91 coordinate system.

x	y	z
3738396.939	1148286.001	5021752.057

Below vector BORO - BOR1 is shown. The results are averaged from several GPS sessions in March 1992.

dx	sig	dy	sig	dz	sig	dh	sig
-38.386	.006	-112.264	.006	63.405	.003	7.544	.007

Coordinates of vector from BORO to 7811 (laser) are computed from optical surveying that was performed with few millimetre accuracy.

dx	dy	dz	dh
-64.110	-39.603	63.725	5.793

FUTURE PLANS.

Taking into account real possibilities GPS Borowiec observatory group has in view as follow:

- Carrying on permanent GPS observations.
- Performing of Associate Processing Center tasks for regional geodynamic research.
- Determination of Borowiec coordinates in Terrestrial Reference Frame using SLR and GPS observation data.
- Monitoring of Central European geodynamic points vectors.
- Modelling of Satellites time scale changes to improve broadcast data quality
- Technical improvement:
  Upbraiding TRIMBLE 4000SST receivers to P-code units.
  Purchase of high quality meteo sensor unit
  Purchase of new equipped with modem computer system to increase reliability of connections to INTERNET and BITNET nets.

CONCLUSIONS.

Borowiec observatory is prepared to function as permanent fiducial GPS station.It is the only Polish site with two technics SLR and GPS. Experiences gathered during earlier campaigns with different technics and results of GPS data analysis are good forecast for playing an important role in the IGS program.

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IGS RELATED ACTIVITIES AT THE GEODYNAMIC OBSERVATORY GRAZ LUSTBÜHEL

Peter Pesec*, Günter Stangl**

Considerable work and financial resources have been invested in preparing the observatory Graz Lustbühel for a solid participation in the IGS test campaign. This paper gives an excerpt of the preparatory works and operational aspects during the test campaign. It further summarizes the organisation of that part of EPOCH'92 for which our institute took over the responsibility, and comments on the "voluntary observation period" having been added to the official campaign. Finally some problem areas are addressed which may become significant during the forthcoming phase of the IGS service, especially in the context of geodynamics research.

INTRODUCTION

Having been involved in the business of satellite geodesy for now more than-25 years the geodynamic observatory Graz-Lustbühel has been established as the primary Austrian reference site for space–related activities. It is connected to the 1st order national triangulation and precise levelling network, it is part of the Austrian absolute gravity network, and it joins respective ionospheric research projects conducted by the Institute for Meteorology and Geophysics of the University at Graz and tropospheric modelling undertaken by the Central Institute for Meteorology and Geodynamics in Vienna.

11 years ago a 3rd generation laser ranging station was set to operation. In a continuous update process the accuracy of this laser has been improved to sub-centimeter level, the

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*Institute for Space Research, Dept. Satellite Geodesy, Lustbühelstraße 46, A-8042 Oraz
**Federal Office for Metrology and Surveying, Lustbühelstraße 46, A-8042 Graz

present efforts aim at touching the millimeter level by introducing two wavelengths in order to account for the dry part of the troposphere.

GPS-activities started 8 years ago with first Micrometer measurements in the vicinity of the observatory followed by the first large-scale GPS-campaign DÖNAV, where 14 TI-4100 receivers were used to measure 54 sites in Germany, Austria and some neighboring countries. Since then Graz participated in numerous regional campaigns and organized the first attempt to determine an Austrian geodynamic network. In order to reduce time and manpower consumption the TI-4100 was interfaced to a PC. The monitoring software allowed for a completely unattended operation which proved to be very valuable during the IGS precursor campaign GIG 91, In the same year Graz applied for acting as a core-station and a regional data center within the planned IGS test-campaign[1].

PREPARATORY WORK

Hardware Innovations

Beginning of February 1992 we ordered three ROGUE SNR-8C receivers, which were delivered mid of March 1992. One receiver which is shared by the Federal Office for Metrology and Surveying, Vienna was installed at the observatory, its antenna is centered to the primary reference point, thus increasing the height eccentricity from formerly 1.873 m (TI-4100) to 2.068 m (ROGUE antenna ground plate). Two further receivers are designated for monitoring local crustal movements as part of the program “National Decade for Natural Desaster Reduction”. All three ROGUE receivers were tested locally showing agreement with the “ground truth” within ± 2 mm in all components. First regular observations started mid of May 1992.

Mid of February 1992 a new IBM 320H Rise System 6000 (AIX 3.1) was installed. The original capacity of 1.420 GByte is presently being extended by adding a second external 2 GByte disc. 5 PC’S linked to the Rise System and a microwave bridge by ethernet thin wire TCP/IP allow for optional internal FTP/Telnet operations as well as external FTP transfer, incoming mail and data are served by the Rise System and distributed to the local PCs (Fig. 1).

Software Improvement

The first step was to create an adequate software for automatic data downloading (via CONAN), Rinex conversion, and data storage. This menu driven software is written in quick-basic, operates on a PC-486, and takes benefit of the Procomm X-modem transfer protocol. Procomm command files are optionally created in such a way that binary data are automatically downloaded every 12 hours at O UT and 12 UT. After distribution of these files to potential users the data are converted to ASCII, rinexed and stored as 12-hour files. At midnight UT the two files are merged to a Rinex day-file and transferred to the IBM workstation. The UNIX "cron" controls the further operation. It checks and compresses the data-file, stores it into the public memory, and initiates FTP data-transfer to any preselected destination. In this software-version the proper operation of the ROGUE-receiver is controlled by a notebook in the field-mode.

The second task was to include facilities for automatic input of certain options like eg. changing the sample rate and receiving the operating status, just by using a notebook as a single external device. The problem was simply solved by extending the Procomm command-file to switch between <CON AN> and <FIELD> and incorporating certain commands which enable special interrogation sequences with the receiver like eg. to detect the receiver time for immediate actions as data-downloading and storage capacity control.

Further activities concern the updating of the UNIX-version of the Bernese Software 3.4, which is still under way and not yet completely solved, as our UNIX-FORTRAN compiler reacts very sensitively on non-standard FORTRAN programming.

Site Control

In order to meet the requirements of IGS site-standards a great deal of work has been done on site control as the observatory is located on alluvial sediments. Two fiducial networks were designed to connect the observatory to neighboring sites monumented in outcropped rocks. The first configuration consists of 3 additional sites with average distances of 20 km which will be remeasured on an annual basis (student training). The second configuration uses 4 sites of the Austrian geodynamic reference network with average distances of about 40 km. This control network will be reobserved every 5 years.

THE 1992 IGS TEST CAMPAIGN

The ROGUE receiver at Graz started quasi-continuous measurements on a try and error basis on DOY 147 (May 26th, 1992). During this period the download software was tested and updated. In parallel first communication links were examined and tested. We remember well, when the system manager of the University Berne set the internet address if our workstation on the watch-list as our "cron" continuously interrogated the Bernese “root”. The momentary solution was very easy ! We changed our device and thus changed the internet number.

By DOY 161 (June 9th, 1992) all the software-tests were completed, the receiver started its regular observations. First successful communications to AIUB in automatic mode were demonstrated mid of June, just in time !

Measurements and Data Archiving

During the whole IGS test campaign the ROGUE-receicer operated very satisfactorily. Some data-loss occurred during a weekend when, after reinitialization, the receiver could not overcome the open sky search mode during antispoofing. A second day was devoted to the remeasurement of the centering elements between the GPS- and the Laser-site, as Werner Gurtner urged us to reduce the residuals between the Laser- and the GPS-solution by all means. By the way, he was partly right ! We found a trivial mistake in the centering elements communicated about 10 years ago which reduced the residuals in the castings from 35 mm to 15 mm - a fine example of the confidence of GPS-methods on a continental scale.

As it was reported that the CONAN software did not reproduce the data correctly in case of antispoofing we changed our program for downloading data in “hidden” mode during weekends. For a 1 Mbyte storage capacity this resulted in a maximal download interval of about 90 minutes and a multiple merging of Rinex-files.

On 3rd of August we installed an additional P-code Ashtech receiver, which was placed at disposal by Ashtech Inc. This receiver operated continuously until October 10th, 1992. Problems emerged during some weekends when antispoofing prevented full P-code operation. Further problems came up when we tried to connect the receiver to an external frequency standard, which resulted in a continuous lock-on lock-off procedure in L1. Thus we were forced to use the internal wrist-watch.

Data storage was accomplished in a twofold way. Binary data were simply stored on floppies, Rinex-data were stored at the IBM workstation for further distribution and saved on cartridges at a later stage.

Communication

As stated earlier the first communication link was established to AIUB Berne. This link was used during waiting for the operation of the data center at IFAG. Unfortunately, even then it was very difficult to send data to Frankfurt on a regular scale as the slow transmission rate led, very frequently, to timeout problems, Thus we contacted IGN to retrieve our data in order to speed up the data-flow. Finally, IFAG could improve the communication lines considerably giving only some problems during weekends.

EPOCH ’92: PART CENTRAL EUROPE

During the Columbus meeting our department announced its willingness to act as a data collection center for up to 25 stations and to compute baseline-solutions for these stations. In particular, we proposed to serve stations in Austria, Bulgaria, Croatia, CSFR, Hungary, Romania, Northern Italy, Poland, Slovenia and the Union of Independent States. It was further stated that epoch '92 would provide an excellent opportunity to establish a basic geodynamic reference-network, which is supported by precise orbits and which could be used for the control of already existing networks like e.g. EUREF-East and the determination of new stations in ITRF. In order to establish a reasonable station distribution it was announced to merge the forwarded national proposals and to recommend further stations for filling available gaps. The position of the fiducial stations should ultimately depend on the national needs, but, following the specifications of IGS, they should provide an excellent "geodynamic" monument ation and firm ties to the national horizontal networks and levelling lines.

Station Distribution

April 1992 a questionnaire was sent out to all available potential candidates in the above mentioned countries. We received response from about 70 % of the addressees. Kiev, Sofia and Bucharest indicated their interest, but without having own receivers at their disposal. Finally, the Geodetic/Cartographic Institute in Warsaw provided one receiver for the observations in Plana near Sofia. Altogether 20 stations took part in the measurements, some receivers changed their position between week 1 and week 2 of epoch '92. The geographical distribution of the sites is shown in Fig. 2. The main oberservation period was defined between 06.45 UT and 17.45 UT for the first week and between 06.15 UT and 17.15 UT for the second week. An optional observation period was proposed between 20.00 UT and 03.00 UT. No definite sample rate was suggested except that it had to be a divisor of 30 seconds, starting with a full minute.

Data–Management

We received the data through various channels (FTP, floppies, ..) and in different formats (raw data, Rinex). By October 10th all data have been merged in a common format and placed at disposal in compressed form. Due to the antispoofing problem just arising during the weekend between the first and the second week we decided to cancel all weekend-data and to form two data-blocks for week 1 and week 2 for each station. The termination of data preprocessing was communicated by IGS-mail no. 119.

Receiver Comparison

It could be expected that a bulk of different receiver-types would contribute to this campaign. Therefore, we felt it to be our duty to check various receiver combinations in local "error-free" networks as well as over a medium size distance, and, eventually, to belie the popular concept of receiver-homogeneity. Pairs of all available receiver-types observed in two mini-networks located in Graz and about 50 km west of Graz. The results show clearly that the influence of combining different receiver-types is below the measurement noise for arbitrary distances[2].

First Computations

A report on first results is given during this workshop[3].

"VOLUNTARY CONTINUATION"

The IGS test campaign 1992 officially ended in October 1992. As we found out that the continuation of the measurements and the regular data-transfer did not restrict the efficiency of our department in any way - except some routine controls during weekends and holidays - we decided to continue this service for, presently, unlimited time. By end of 1992 we received a request from JPL to provide binary ROGUE data in quasi-real-time. We started regular distribution to JPL during the first week of January 1993, but maintaining the regular data transfer of rinexed data to IFAG Frankfurt. The direct data-transfer from Graz to JPL has proved to be very reliable except that the "import" directory linked to our account at JPL has refused direct access for about 10 % of all transmissions.

DISCUSSION AND OUTLOOK

Leafing in the bulk of IGS mails and reports coming in nearly every day everbody can see that the enthusiasm and effort of the whole community seems to be unbroken by now, thus, providing excellent conditions for the planned regular IGS service.

In this context we would like to address a future problem area which will affect permanently observing observatories. It has been clearly demonstrated that such a worldwide undertaking can work and will work. However, concentrating on the word "geodynamic" in IGS we have to face to problem of tropospheric modelling as a limiting factor of height determination. Strictly speaking each observatory has to provide, together with the GPS phase-data, the tropospheric delay along the line of sight. This implies that each station should feel responsible for acquiring meteo-data within a cylinder of say 40 km around the station in a four-dimensional digital model. Corrections should be computed according to a well-defined procedure (like laser normal-points) and added to the phase-data (eventually we need RINEX 3).

We at Graz will follow this idea. A four-dimensional digital meteo-model is already available. It is, furthermore, planned to install a water vapour radiometer at the observatory within the next year.

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FIGURE CAPTIONS

Figure 1: EDV environment at the geodynamic observatory Graz-Lustbühel

Figure 2: Final station distribution for the part of Epoch '92 coordinated by Graz.

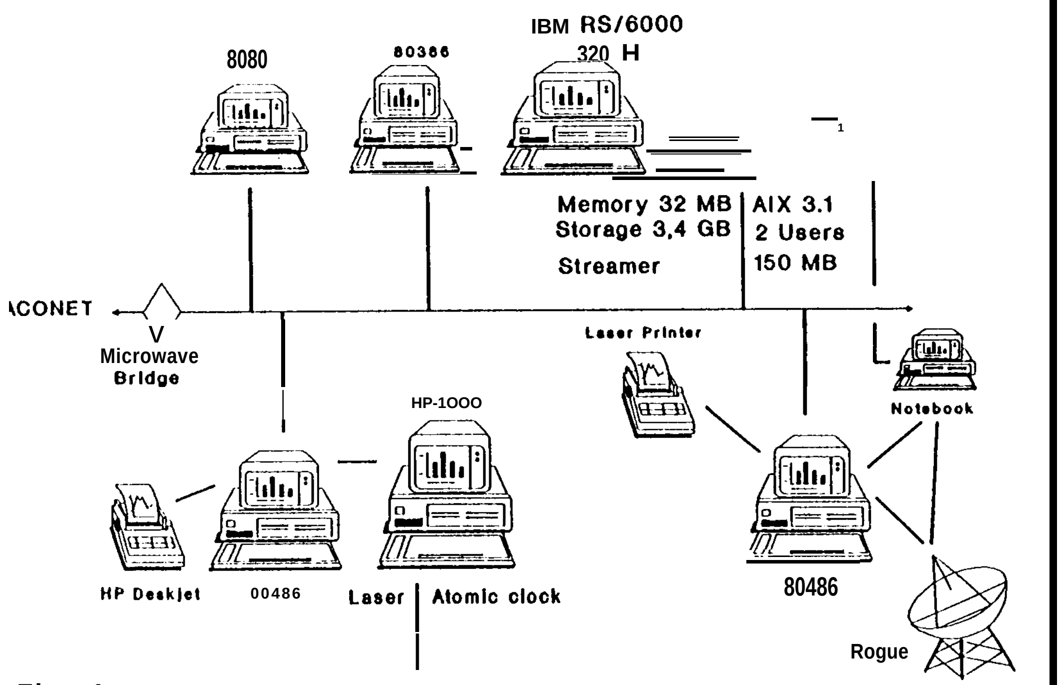

IBM RS/6000
320 H
8080
80386
Memory 32 MB
Storage 3,4 GB
Streamer
AIX 3.1
2 Users
150 MB
ACONET
Microwave
Bridge
Laser Printer
Notebook
HP-1000
HP Deskjet
00486
Laser
Atomic clock
80486
Rogue

Fig. 1

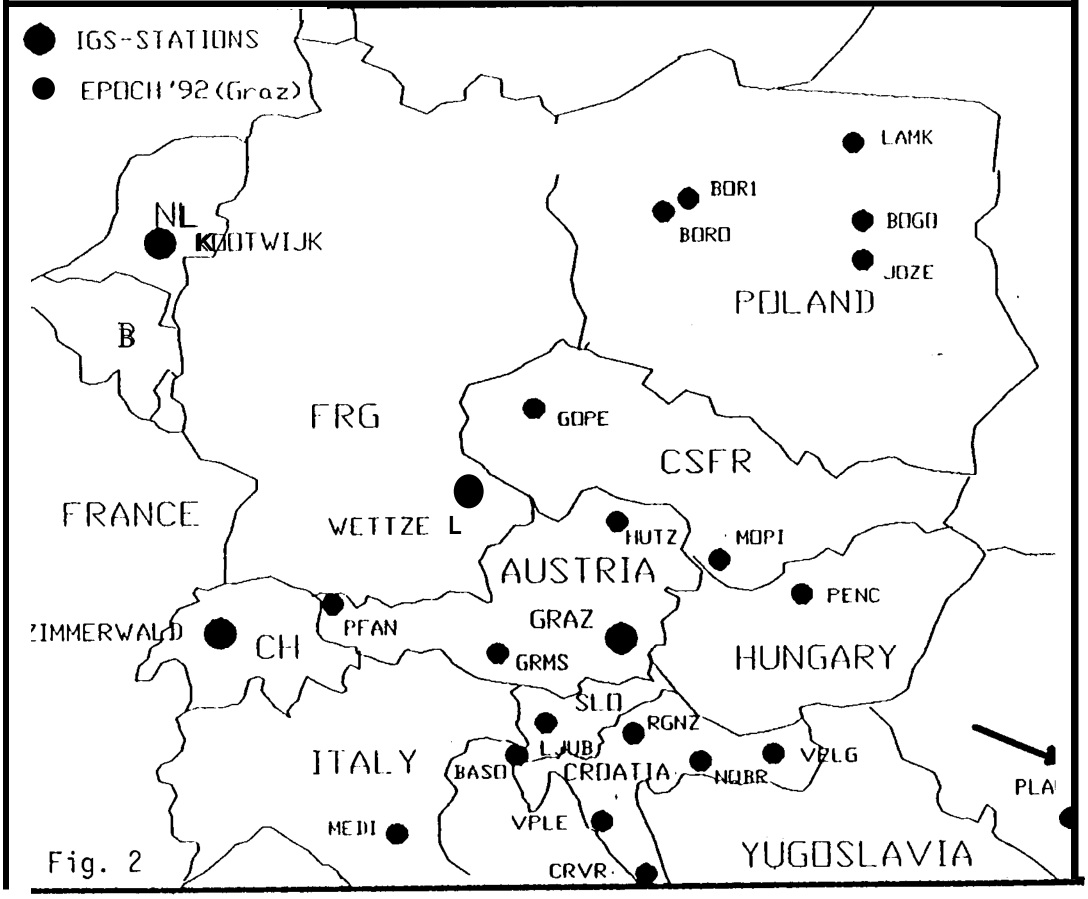

IGS-STATIONS
EPOCH '92 (Graz)
LAMK
BOR1
BORO
BOGO
JOZE
POLAND
NL
KOOTWIJK
B
FRG
GOPE
CSFR
FRANCE
WETTZELL
HUTZ
MOPI
AUSTRIA
PENC
ZIMMERWALD
CH
PFAN
GRAZ
GRMS
HUNGARY
SLO
RGNZ
LJUB
VPLG
ITALY
BASO
CROATIA
NOBR
PLA
MEDI
VPLE
CRVR
YUGOSLAVIA

Fig. 2

THE IGS POLYHEDRON: FIDUCIAL SITES AND THEIR SIGNIFICANCE

Ivan I. Mueller
Department of Geodetic Science
The Ohio State [University, Columbus,OH 43210-1247, USA

The IGS Polyhedron is defined by lGS Fiducial Stations at its vertices. According to the IGS nomenclature such sites may be occupied intermittently and repeatedly at certain well defined epochs for the purposes of determining the site's coordinates and monitoring changes in the baseline-lengths, i.e., the deformation of the polyhedron.

The significance of such a network of stations is two fold: The geometric significance is in the global extension of the International Terrestrial Reference Frame for better accessibility and increased accuracy. The geophysical significance is in the monitoring of the deformation of the polyhedron for the purpose of better understanding our active planet.

To accomplish these goals the Fiducial stations must be distributed over the entire globe in some geometrically well defined pattern. Additional sites are also required in dynamically active areas of our planet.

INTRODUCTION

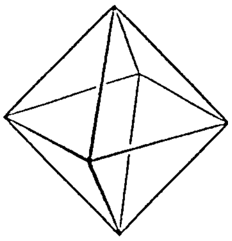
The IGS Polyhedron is defined by lGS Fiducial Stations at its vertices. According to the IGS Campaign nomenclature such sites are occupied repeatedly and intermittently at certain well defined epochs, rather than continuously as the Core Stations are. The purposes of GPS observations at the Fiducial sites are the repeated determinations of coordinates and baseline-lengths between the sites to monitor the deformation of the polyhedron.The significance or scientific goals of such a network of Fiducial stations are both geodetic (geometric) and geophysical.

The geodetic goals are the global extension (for better access) of the International Terrestrial Reference Frame (ITRF) maintained by the International Earth Rotation Service (IERS), and to increase its accuracy. The key factor to increase the ITRF's accuracy is in the better determination of the sites' velocities which, as it is explained below, can be accomplished primarily by increasing the number of vertices of the polyhedron (representing the surface of the earth) and thereby its robustness.

The geophysical goal is the monitoring of the deformation of the IGS Polyhedron to improve the understanding of our active planet, more specifically the structure of the continents and their evolution, the interaction between the solid earth and its fluid envelopes (sea level and ice monitoring), etc.

Figure 1. Examples of Optimal or Near-optimal Polyhedra

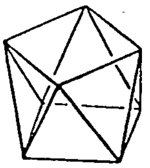
6



Octahedron

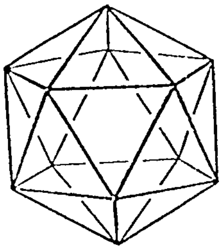
Faces:
8 triangles
Vertices:
6, each with 4
edges meeting
Edges
12
Dihedral angle:
109”28’

8



Antiprism

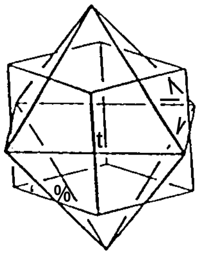
12



Icosahedron

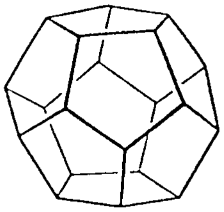
Faces:
20 triangles
Vertices
12, each with 5
edges meeting
Edges:
30
Dihedral angle:
138” 11’

14*



Cube:
6 faces, 8 vertices, 12 edges
Octahedron:
8 faces, 6 vertices, 12 edges

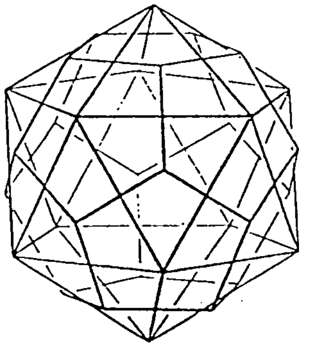
20*



Dodecahedron

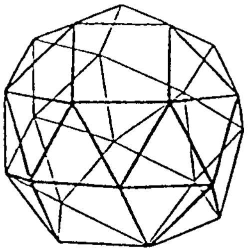
Faces:
12 pentagons
Vertices:
20, each with 3
edges meeting
Edges:
30
Dihedral angle:
116°34’

32*



Dodecahedron:
12 faces, 20 vertices, 30 edges
Icosahedron: -
20 faces, 12 vertices, 30 edges

24



Snub cuboctahedron

Faces:
32 triangles } 38 total
6 squares
Vertices:
.24, each with 5
edges meeting
Edges
60
Dihedral angles:
142”59’ (square-triangle)
153” 14’ (triangle-triangle)

* near optimal

Fejes Toth ,1964 , Regular Figures

To accomplish these goals the Fiducial Stations ideally should be distributed over the entire globe in a well defined geometric' pattern discussed below. Additional sites are also required in the dynamically active regions of our planet.

One of the shortcomings of the IGS 1992 Campaign has been the lack of observations at significant number of Fiducial Sites during the *Epoch* 1992 phase of the campaign designated with the above goals in mind. The purpose of this brief presentation is to generate more interest and subsequent participation in this aspect of the future Service.

GEODETIC CONSIDERATIONS

On the Terrestrial Reference Frame

The internationally accepted terrestrial reference frames are to be defined by an adopted set of spatial coordinates of global networks of observatories and their motions, or by some equivalent way (Mueller, 1989; Kovalevsky and Mueller, 1981). The observing stations define the vertices of a fundamental polyhedron whose deformation and movement with respect to a Terrestrial Reference Frame (TRF) is monitored through periodic re-observations.

The functions of the TRF are twofold. The first, requiring only a subset of the polyhedron vertices (Core Stations), is to monitor the motions common to all stations (e. g.,polar motion and earth rotation) of the polyhedron. The second, involving all (Core and Fiducial) stations, is to monitor the internal motions or deformations of the polyhedron. Of course, both functions are integrally related.

The latter function raises the problem of how the observatories should be distributed on the surface of the earth so that the polyhedron is geometrically optima]. Of course, the distribution of "real world" stations are always constrained by practical considerations. However, it still seems useful to first find the optimal distribution disregarding these constraints and then a "real world" network's anticipated performance can be estimated by comparing it to the optimal network.

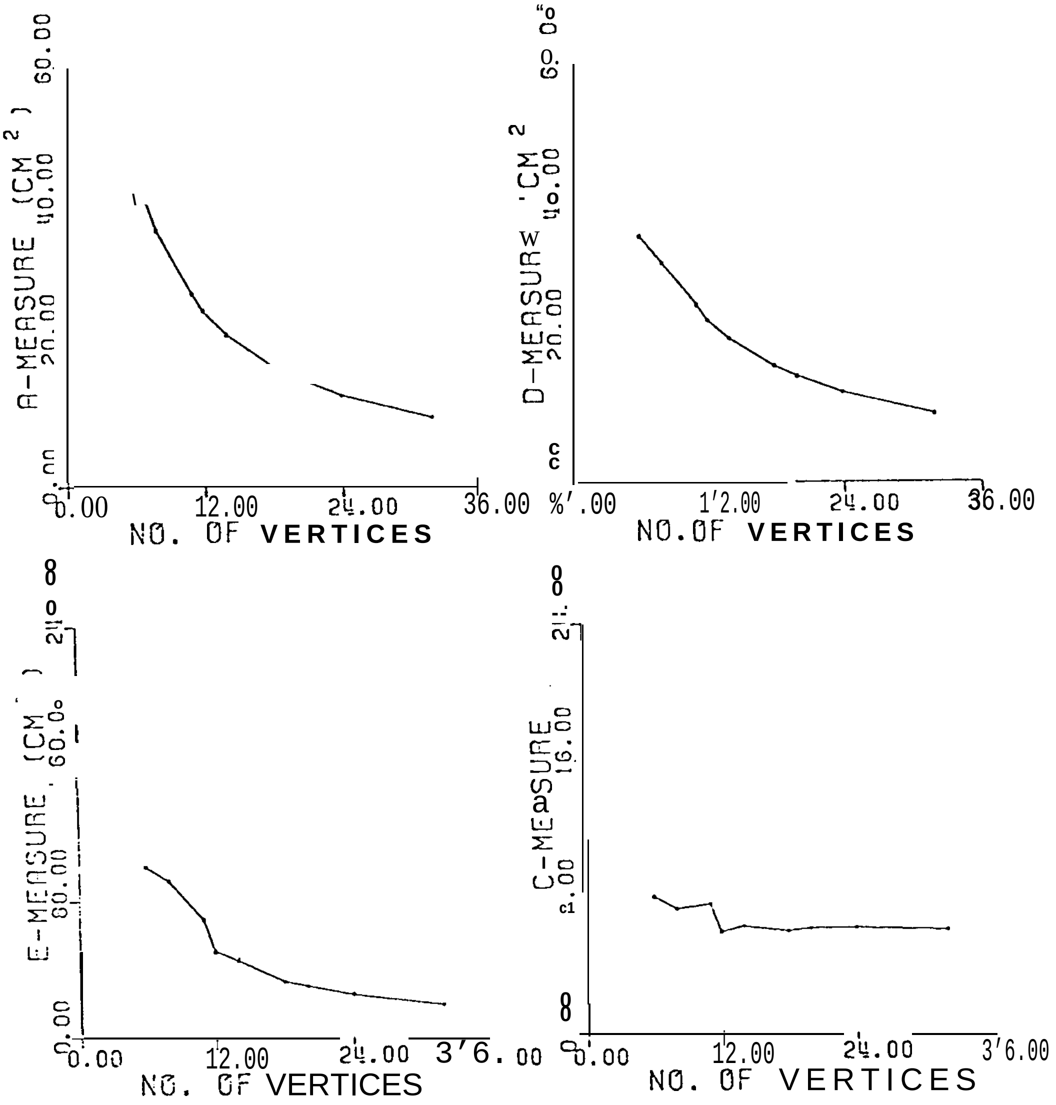
Such a study on optimal polyhedrons was conducted in conjuction with the MERIT Campaign (Mueller et.al., 1982). The purpose of the study was to recommend the disposition of satellite laser ranging (SLR) stations and Very Long Baseline Interferometers (VLBI) available or anticipated at the time to meet the above optimality considerations. These observatories formed the basis of the ITRF in 1988 when the IERS started its official role. The results of this study are valid, although somewhat incomplete, today and arc repeated below as a reminder that "nothing is really ncw under the sky".

On Optimal Polyhedra

If a global network of stations is to well define a robust polyhedron (or a TRF), then it is plausible that choosing their optimal locations reduces to the problem of distributing them on the surface so that they are, in some sense, as far apart as possible from one another. On the sphere, although it may not be obvious, this translates to the requirement that the polyhedron of n vertices should be *regular*, i.e., all of its faces should be of one kind of congruent regular polygon. Only five such polyhedra exist the *Platonic solids (see* Fig. 1): The tetrahedron (n=4), octahedron (6), cube (8), icosahedron (12), and the dodecahedron (20). Semiregular polyhedra that can be inscribed in a sphere exist for other n values (Pearce and Pearce, 1978). It can be shown that the geometric criterion of regularity is well represented statistically by minimizing the determinant of the

Figure 2. Design Measures of Optimality

(Assumed baseline-precision: 10 cm)



covariance matrix of the deformation (change of the coordinates of the n points as determined from changes in the baseline-lengths) raised to the power of 1 /3n-6. This optimality is referred to as the *D-Measure*. However, in general broader optimal criteria dealing with the set of baselines defining the polyhedra can be established, instead of the regularity consideration.

An accepted definition for distributing n points on a sphere so that they are as far apart as possible from each other is that the shortest distance between any two vertices is maximized (Fejes Toth, 1964). This geometric criterion, which is the statistical equivalent of minimizing the average variance of the deformation is referred to as the *A-Measure*. This problem has not been solved in general, but exact solutions have been proposed for n = 13 through 16,20,42 and 122.

A second criterion is that the average distance between vertices is maximized. It turns out that only the regular polyhedra with triangular faces (n = 4, 6, 12) meet both distance criteria, the cube the second, and the dodecahcdron neither. This geometric criterion is the statistical equivalent to both the maximum eigenvalue (*E-Measure*) and the ratio of minimum and maximum eigenvalues (*C-Measure*).

The IGS Polyhedron

The above referenced study (Mueller et.al., 1982) calculated all four Measures for n = 14, 18, and 32 as well as for the SLR and VLBI stations contemplated at the time (see Fig. 2). It is seen that Measures *A* and D strongly indicate improvement in optimality with increasing n. Measure f also indicates improvement but much slower, while Measure *C* appears to be independent of the number of vertices.

Simple-minded extrapolation of the results could lead to an estimate of n where optimality, using any of the above measures, could be reached (based on Fig.2, say around .S0-60). There would be little point of increasing the number of Core and Fiducial Stations beyond this number for the purposes described. It would be useful to repeat the computations to reflect current needs vs. 1982, find the optimal n number and draw the map of the. “ideal” IGS Polyhedron. Such a plan should he part of the IGS proposal to the IAG.

GEOPHYSICAL CONSIDERATIONS

The IGS Polyhedron as described above may need to be amended by Fiducial Stations in dynamically active regions of the earth to understand better our active planet. Such regions include those of post glacial rebound and of current tectonic activity. Additional sites may be the bases of monitoring global sea level changes and movements of large ice sheets.

Reasons for such additional stations and suggestions for their locations is beyond the scope of this presentation. important material may be found in (National Research Council, 1992 and 1993).

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CDDIS DATA ARCHIVING AND DISTRIBUTION ACTIVITIES FOR THE 1992 IGS CAMPAIGN

Carey E. Noll†
Maurice P. Dube•

The Crustal Dynamics Data information System (CDDIS) has served as a global data center for the international GPS Geodynamics Service (IGS) since its start in June 1992. iGS analysis centers and users of their products have access to the on-line and near-line archive of GPS data available on the CDDIS. The facility is accessible from remote, worldwide locations through various electronic networks permitting users to easily transfer data. The flow of iGS data to the CDDIS, the system's architecture, and its archiving and access procedures are described.

INTRODUCTION

The Crustal Dynamics Data Information System (CDDIS) has been operational since September 1982, serving the international space geodesy and geodynamics community. This data archive was initially conceived to support NASA's Crustal Dynamics Project; since the end of this successful program in 1991, the CDDIS has continued to support the science community through the follow-on program, the Dynamics of the Solid Earth (DOSE). The main objectives of the CDDIS are to store all geodetic data products acquired by NASA programs in a central data bank, to maintain information about the archival of these data, and to disseminate these data and information in a timely manner to authorized investigators and cooperating institutions. Furthermore, science support groups analyzing these data sets submit their resulting data sets to the CDDIS on a regular basis. Thus, the CDDIS is a central facility providing users access to raw and analyzed data to facilitate scientific investigation. An on-line, interactive menu-driven system has been designed which allows users to browse information about the system and contents of the archive.

In mid-1991, the CDDIS responded to the Call for Participation issued by the International Association of Geodesy (IAG) of the International Union of Geodesy and Geophysics (IUGG). This call requested proposals for participation in the International Global Positioning System (GPS) Geodynamics Service (IGS). The main objective of the IGS is to demonstrate the near real-time capacity of the global GPS community to retrieve data and produce products (e.g., satellite ephemerides, Earth rotation parameters, etc.) that are of value to a broader community. Proposals were requested for agencies to become hosts of GPS receivers, serve as data centers on various levels of collection, archive, and dissemination, and perform data processing and analysis activities for the

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† **Carey** E. **Noll, Goddard DAAC Facility, NASA/Goddard Space Flight Center, Code 902.2,** Greenbelt, MD 20771.

• Dr. Maurice P. Dube, Hughes/STX Corporation, 4400 Forbes Boulevard, Lanham, MD 20706.

generation of IGS products. In the fall of 1991 the CDDIS was selected to serve as one of three global, or network, data centers for the IGS, supporting daily GPS data from the core observatories. The Scripps Institution of Oceanography (S10) in La Jolla, California and the Institut Géographique National (IGN) in Paris, France were also designated as IGS global data centers.

The first IGS campaign, known as the 1992 IGS Test Campaign, was held June 21 through September 23, 1992. Data from over thirty "core" sites were regularly retrieved and archived during this period; in addition, many fiducial stations located worldwide participated in Epoch '92, a more intense two-week period during the middle of the test campaign. The CDDIS began support of the IGS at the start of the IGS test campaign; the system continues to archive data for the IGS at the present time.

COMPUTER ARCHITECTURE

The CDDIS is operational on a dedicated Digital Equipment Corporation (DEC) VAX 4000 Model 200 currently running the VMS operating system. This facility currently has over two Gbytes of on-line magnetic disk storage and 650 Mbytes of on-line rewriteable optical disk storage. The CDDIS is located at NASA's Goddard Space Flight Center and is accessible to users 24 hours per day, seven days per week. The CDDIS is available to users globally through the electronic networks using DECnet (VAX/VMS networking protocol) and TCP/IP (Transmission Control Protocol/Internet Protocol), through dial-in service (300-, 1200-, 2400- and 9600-baud) and through the GTE SprintNet system. Furthermore, users can communicate with the CDDIS staff from other global electronic networks such as TELEMAIL, BITnet, and MARK III, or through the fax and TELEX systems.

In 1990a rewriteable optical disk system was procured and installed on the CDDIS VAX system[4]. This unit contains two 5.25" optical disk drives with a capacity of 325 Mbytes per platter. Additional 650 Mbyte (325 Mbytes on each of two disk sides) disks are near-line by simply dismounting a disk and flipping it over to access the other side; a library of previously created and archived optical disks is also near-line. To users of the system these drives appear like any other magnetic disk drives. The device supports a typical VMS directory file structure and allows files created thereto be deleted with full recovery of space allocation after deletion. These optical disks have been the primary media utilized to store GPS data for the IGS campaign. Approximately three weeks of GPS tracking data can be stored on a single side of one of these platters; hence, four to six weeks of the most recent data are accessible to the IGS community at one time. As the platters become full, they are taken off-line and new platters are initialized and made available for processing. The older data continues to be stored on these optical disks and thus can easily be requested for mounting and downloading, providing the request will not severely impact the access to the current data set.

ARCHIVE CONTENT

The CDDIS began archiving GPS tracking data in early 1992 in support of the NASA program, Fiducial Laboratories for an International Natural Science Network (FLINN). The user community for this archive has now expanded to include the International GPS Geodynamics Service, IGS. The role of the CDDIS in the IGS is to serve as one of three global data centers that archive the daily GPS data from the observatories located worldwide. In this capacity, the CDDIS is responsible for archiving and providing access to both GPS data from core IGS sets as well as the products derived from the analysis of these data. The CDDIS has also archived data from sites not designated as core sites but could be of interest to the IGS community. In addition, the CDDIS has supported data from selected Epoch '92 sites.

GPS Tracking Data

Subscribers to the IGS have access to the on-line and near-line archive of GPS data available through the three network archives. Regional data centers were also selected by the IGS. The charter of these institutions is to interface directly to the GPS receiver, transmit the data, convert the data to the Receiver INdependent EXchange (RINEX) format, compress the RINEX files, and transfer the data to a designated global data center. To minimize traffic on the electronic networks and to provide consistently re-formatted data, a single regional data center is responsible for interfacing *to* a particular site for the IGS and then forwarding these data to one of the three global data centers. For the CDDIS, the Jet Propulsion Laboratory (JPL) in Pasadena, California, NOAA's Cooperative International GPS Network (CIGNET) Information Center (CIC) in Rockville, Maryland, the Energy, Mines and Resources (EMR) in Ottawa, Canada, and the European Space Agency (ESA) in Darmstadt, Germany submit data from selected receivers on a daily basis. In addition, the CDDIS accesses the remaining two global data centers, S10 and IGN, to retrieve data holdings not routinely transmitted to the CDDIS by a regional data center. These data are summarized and archived to rewriteable optical disk in daily subdirectories; the summary/inventory information is also loaded into an on-line data base. The map in Fig. 1 depicts the global sites participating in the IGS campaigns thus far whose data is available from the CDDIS; Table 1 lists in detail these sites with data availability and classification information.

In general, the data delivered to and archived on the CDDIS during the IGS Test Campaign was available to the user community within 72 hours after the observation day, well within the requirements established by the IGS.

The CDDIS GPS tracking archive consists of observation and navigation files in compressed RINEX format as well as summaries of the observation files used for data inventory and reporting purposes. During the IGS Test campaign, a total of nearly 5,400 observations were received, processed, and archived from an average of 40 sites per day. Since the start of the IGS Pilot in November 1992, the CDDIS manages data from approximately 35 sites per day. Each site produces approximate y 0.5 Mbytes of data per day; thus, one day's worth of GPS tracking data, including CDDIS inventory information, totals nearly 20 Mbytes. The entire IGS Test Campaign totals approximately 2.5 Gbytes in size.

IGS Products

Data analysis centers, such as JPL, ESA, EMR, the University of Texas at Austin/Center for Space Research, the Geodatishes Forschungs Zentrum (GFZ) in Germany, and others, retrieve the GPS tracking data daily to produce IGS data products. The CDDIS also archives these IGS products, such as the daily and weekly precise satellite ephemerides and the Earth rotation parameters. These files are sent to the CDDIS by the IGS analysis centers, stored in individual accounts, and are then copied to a central disk archive, generally in uncompressed ASCII format. The Analysis Coordinator for the IGS can then access the CDDIS on a regular basis to retrieve these products and generate reports on data quality and statistics on product comparisons. Furthermore, users interested in obtaining precision orbits for use in general surveys and regional experiments can also obtain these data. The ephemerides and Earth rotation parameters are typically delivered to the CDDIS within one to three weeks of the end of the observation week.

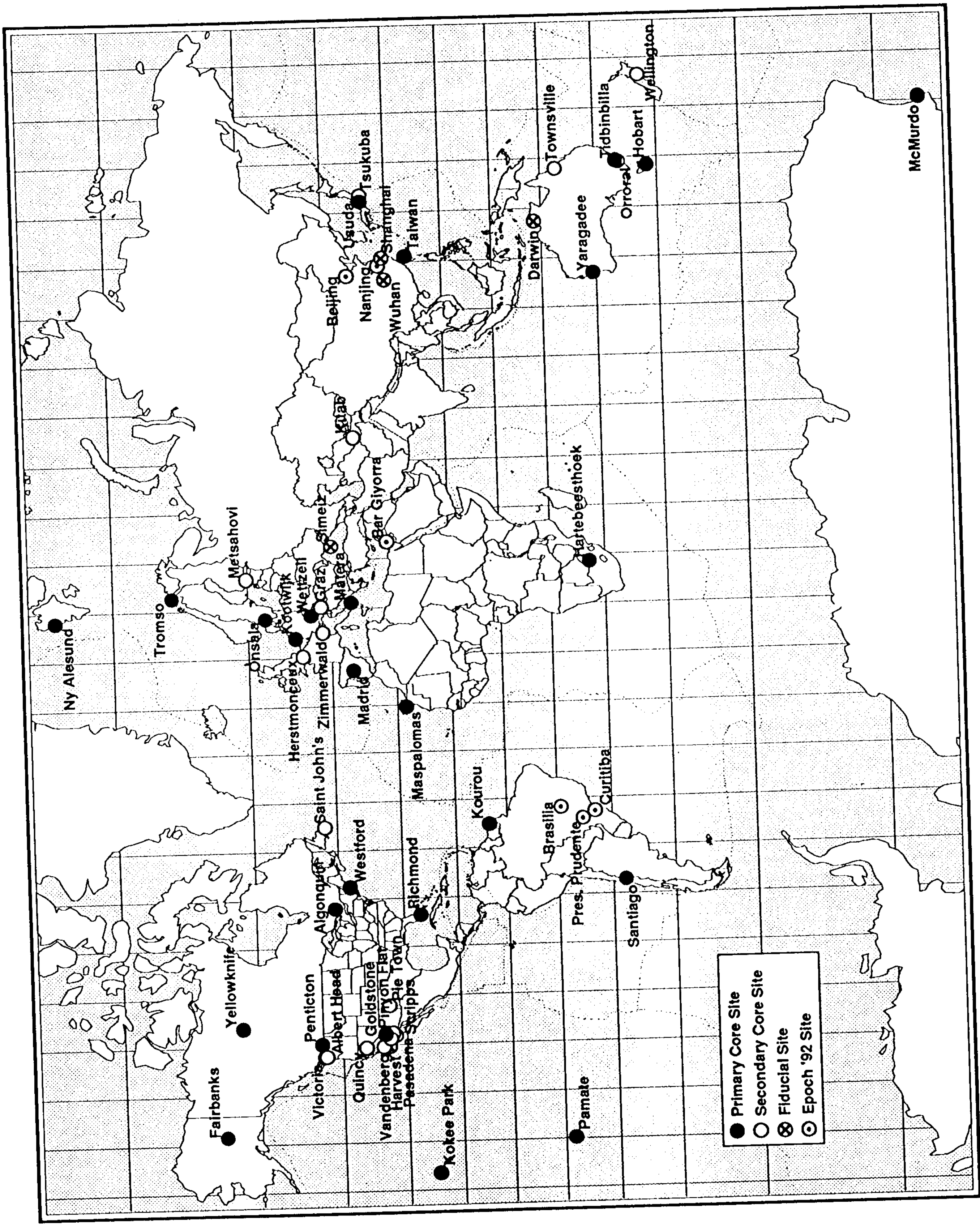
Ny Alesund
Tromso
Onsala
Metsahovi
Kootwijk
Wettzell
Herstmonceux
Zimmerwald
Graz
Simeiz
Matera
Madrid
Maspalomas
Bar Giyorra
Kitab
Hartebeesthoek
Beijing
Usuda
Tsukuba
Shanghai
Nanjing
Wuhan
Taiwan
Darwin
Yaragadee
Townsville
Tidbinbilla
Orroral
Hobart
Wellington
McMurdo
Saint John's
Westford
Algonquin
Richmond
Kourou
Brasilia
Pres. Prudente
Curitiba
Santiago
Yellowknife
Fairbanks
Penticton
Albert Head
Victoria
Goldstone
Quincy
Vandenberg
Harvest
Pasadena
Scripps
Pinyon Flat
Pie Town
Kokee Park
Pamate
● Primary Core Site
○ Secondary Core Site
⊗ Fiducial Site
⊙ Epoch '92 Site

Table 1
GPS NETWORK DATA HOLDINGS OF THE CDDIS
(June 14, 1992 *through March 13, 1993)*

Site Name	North Latitude	East Longitude	Mon. Name	Site Type	Receiver Type	start Date	End Date	No. Ohs.
Albert Head, Canada	48' 23'	-123”29	ALBH	S	Rogue SNR-8C	07-May-92	—	298
Algonquin, Canada	45”57’	-78”04’	ALGO	P	Rogue SNR-8	23-Feb-92	—	375
Bar Giyorra, Israel	31”43’	35” 05'	BARG	E	Trimble 4000ST	30-Jul-92	08-Aug-92	7
Beijing, China	39”37’	115“ 89’	GV2A	E	Ashtech LM-XII0C	27-Jul-92	05-Aug-92	9
Brasilia, Brazil	-15“ 57’	-47”53	BRAS	E	Trimble 4000SST	25-Jul-92	08-Aug-92	15
Carr Hill, CA	35”53’	-120”43	CARR	s	Rogue SNR-8000	15-Nov-92	05-Dec-92	13
Curitiba, Brazil	-25”27’	-49”14’	PARA	E	Trimble 4000SST	26-Jul-92	09-Aug-92	15
Darwin, Australia	-12”50’	131”07’	DARW	c	Ashtech LM-XII3	17-Jun-92	06-Aug-92	51
Fairbanks, AK	64”58’	-147″29′	FAIR	P	Rogue SNR-8	01-Jan-92	—	414
Goldstone, CA	35”25’	-116″ 53′	GOLD	P	Rogue SNR-8	01-Jan-92	—	422
Graz, Austria	47”04’	15″29′	GRAZ	s	Rogue SNR-8	15-Jun-92	—	267
			GRAA	c	Ashtech LM-XII3	14-Aug-92	10-Ott-92	53
Hartebeesthoek, S. Africa	-25”53’	27”42’	HART	P	Rogue SNR-8	01-Jan-92	—	414
Harvest Platform, CA	24”28’	-120” 41’	HARV	c	Rogue SNR-8000	01 -Sep-92	—	177
Herstmonceux, Gr. Britain	50”52’	00”20	HERS	s	Rogue SNR-8C	14-Feb-92	—	279
Hobart, Tasmania	-42”48’	147”26’	HOBA	P	MiniMac 2816AT	26-Apr-92	01-Feb-93	235
			HOB1	P	Rogue SNR-8000	01-Mar-93	—	11
Kitab, Uzbekistan	39”08’	66”53	KITA	s	Rogue SNR-8	1O-JUI-92	04-Sep-92	67
Kokee Park, HI	22”07’	-159”39’	KOKB	P	Rogue SNR-8	01-Jan-92	—	325
			KOK2	P	Rogue SNR-8	02-Feb-93	09-Feb-93	8
Kootwijk, The Netherlands	52”10’	05”48	KOSG	P	Rogue SNR-8	01 -Jan-92	—	424
Kourou, French Guiana	05”17’	-52”43	KOUR	P	Rogue SNR-8C	09-Aug-92	—	118
Madrid, Spain	40”25’	-04”14’	MADR	P	Rogue SNR-8	01-Jan-92	—	431
Maspalomas, Canary Is.	27”45”	-15”37	MASP	P	Rogue SNR-8C	22-Jun-92	—	260
Matera, Italy	40”38’	16”42’	MATE	P	Rogue SNR-800	04-Apr-92	—	325
McMurdo, Antartica	-7750’	166”40’	MCMU	P	Rogue SNR-8	21-Feb-92	—	361
Metsahovi, Finland	60” 13’	24 “ 23	METS	s	Rogue SNR-8C	26-Apr-92	—	315
Mojave, CA	35”19’	-116”53	MOJ 1	c	MiniMac 2816AT	22-Jun-92	30-Sep-92	100
Nanjing, China	32”04’	118”50’	HT15	E	Ashtech LM-XII0C	24-JIJ-92	09-Aug-92	17
North Liberty, 1A	41”46’	-91 “ 35’	NLIB	s	Rogue SNR-8000	05-Mar-93	—	7
Ny Alesund, Norway	78”55”	11” 51’	NYAL	P	Rogue SNR-8	01-Jan-92	—	329
Onsala, Sweden	57’23”	11”55	ONSA	P	Rogue SNR-800	01-Jan-92	—	432
Orroral, Australia	-35”38’	148”56’	ORRO	c	Ashtech LM-XII3	21-Jun-92	17-Jul-92	45
Pamate, French Polynesia	-1734’	-149”34’	PAMA	P	Rogue SNR-800	01-Jan-92	—	414
Pasadena, CA	34’12’	-118”10’	JPLM	s	Rogue SNR-8	01-Jan-92	—	414
Penticton, Canada	49”19’	-119”37	DRAO	P	Rogue SNR-8	14-Jun-92	—	272
Pie Town, NM	34”18’	-108”07	PIE1	s	Rogue SNR-8000	30-Dec-92	—	73
Pinyon Flat, CA	33”36’	-116' 27'	PIN1	s	Ashtech P/LM-XII3	19-oct-92	—	123
			PINY	s	Rogue	01-Jan-92	19-Aug-92	223
President Prudente, Brazil	-22”07’	-51”25	UEPP	E	Trimble 4000SST	26-Jul-92	08-Aug-92	14
Quincy, CA	39”58’	-120”56’	QUIN	s	Rogue SNR-8000	07-Sep-92	—	148
Richmond, FL	25”36’	-80”23	RCM2	P	Rogue SNR-8	18-Jul-92	—	150
			RCM3	P	Rogue SNR-8000	01-Mar-93	—	13
			RCMA	P	MiniMac 2816AT	26-Apr-92	29-Jul-92	50
Saint John’s, Canada	47’35’	-52”40	STJO	s	Rogue SNR-8C	01-Mar-92	—	351
Santiago, Chile	-33”09’	-70”40	SANT	P	Rogue SNR-8	24-Feb-92	—	367
Shanghai, China	31”06’	12t” 12’	SHAN	c	MiniMac 2816AT	25-Jul-92	10-AUQ-92	16

Table 1 (continued)

Site Name	North Latitude	East Longitude	Mon. Name	Site Type	Receiver Type	Start Date	End Date	No. Ohs.
Scripps, CA	32’52’	-117’16’	Slol	S	Rogue	02-Jan-92	18-Jun-92	93
			SIO2	S	Ashtech P/LM-XII3	18-Ott-92	18-Jan-93	72
			SI02	S	Trimble 4000 SSE	19-Jan-93	—	48
Simeiz, Ukraine	44’43’	34’01’	SIME	C	Trimble 4000ST	28-Aug-92	23-Oct-92	42
Taiwan	25’01’	121”32’	TAIW	P	Rogue SNR-800	26-Apr-92	—	301
Tidbinbilla, Australia	-35”23	148’58’	TIDB	P	Rogue SNR-8	01-Jan-92	—	416
Townsville, Australia	-19”15’	146”48’	TOWN	S	Trimble 4000ST	26-Apr-92	05-Dec-92	174
Tromso, Norway	69’39’	18”56	TROM	P	Rogue SNR-8	01-Jan-92	—	421
Tsukuba, Japan	36’ 06’	140”05”	TSUK	S	MiniMac 2816AT	19-Jun-92		257
Usuda, Japan	36’07’	138”21”	USUD	P	Rogue SNR-8	01-Jan-92	—	416
Vandenberg, CA	34”33’	-120”36	VNDP	S	Ashtech P/LM-XII3	18-Ott-92	12-Jan-93	76
			VNDP	S	Rogue	22-Jan-93	—	12
Victoria, Canada	48”38’	-123″27	PGC1	C	Rogue SNR-8C	14-Jan-92	21-Aug-92	152
Wellington, New Zealand	-41”16’	174″46′	WELL	S	Trimble 4000ST	26-Apr-92	05-Dec-92	176
Westford, MA	42’36’	-71″29	WES1	P	MiniMac 2816AT	22-Jun-92	02-Nov-92	133
			WES2	P	Rogue SNR-8000	01-Mar-93	—	13
Wettzell, Germany	49”08’	12’52	WETT	P	Rogue SNR-800	19-Jan-92	—	402
Wuhan, China	30’ 30’	114”30’	WUHA	C	MiniMac 2816AT	23-Jun-92	30-Sep-92	71
Yaragadee, Australia	-2902’	115”20’	YAR1	P	Rogue SNR-8	01-Jan-92	—	402
Yellowknife, Canada	62”28’	-114”28	YELL	P	Rogue SNR-8C	10-Jan-92		425
Zimmerwald, Switzerland	46’52’	07’27’	ZIMM	S	Trimble 4000SST	15-Jun-92	—	184
			ZIMA	C	Ashtech P/LM-XII3	28-Jul-92	03-oct-92	58
Totals:		69 occupations at 58 sites						13,591 ohs.

Type of IGS Site: P Primary Core site S Secondary Core site C Contributing site E Epoch ’92 site

Supporting information

The CDDIS also copies all IGS MAIL and IGS REPORT messages to central disk areas. Index files to these messages were created and are updated as new messages are posted to the IGS community. Users can search the appropriate index file by date of message, author, institution, or title string to determine the number of the message of interest. Users can then list the contents of any selected message and, if required, electronically transfer the message to their home computer.

ARCHIVE PROCEDURES

As stated previously, the IGS data are deposited daily on the CDDIS computer system from the four regional, or processing, data centers, JPL, CIGNET, EMR, and ESA. These data are transferred via network communications, typically using the TCP/IP protocol, in compressed RINEX format and are placed into four individual accounts on the CDDIS.

Flow of Data

Software was written to automatically process the incoming IGS data on a daily basis. The programs are run on the CDDIS VAX system in batch mode, and are queued to run automatically at certain times of the day, every day, to check the receiving areas for new

IGS data. These new GPS data files are then processed; that is, the data are transferred to the correct daily subdirectories on the optical disk, the observation data are then decompressed and summarized, and finally the summary information is loaded into the CDDIS data base. The summary process performs elementary data checking and extracts information that can be used to inventory the data in the CDDIS. These data archiving procedures are illustrated in Fig. 2.

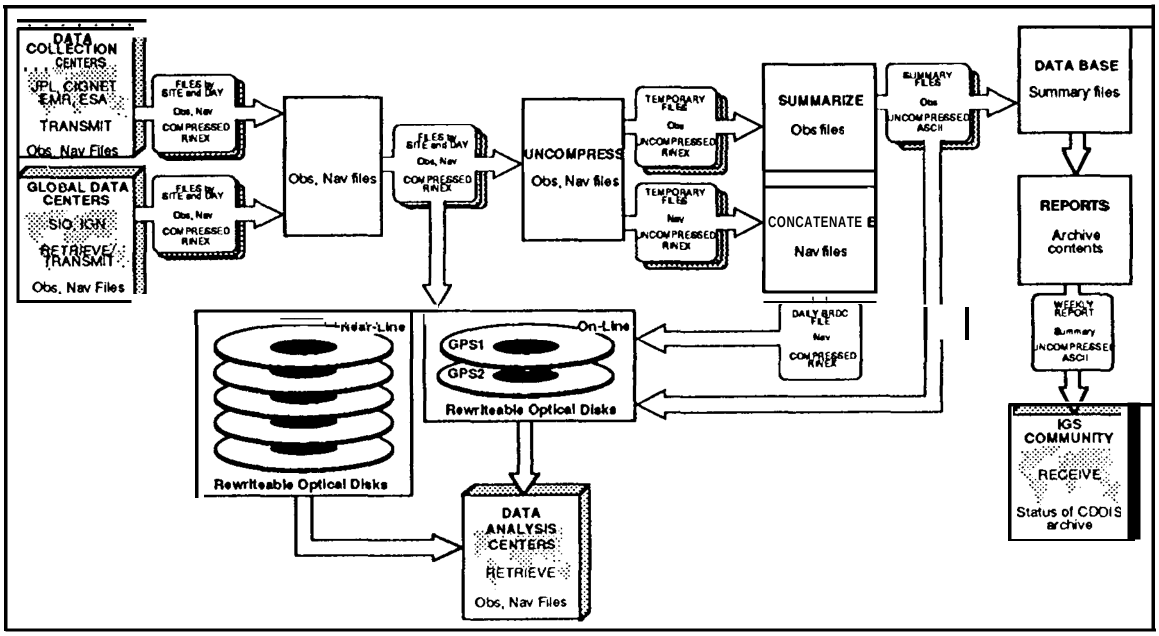

Fig. 2 Flow of IGS GPS data through the CDDIS.

The main idea of this archive software is to obtain the current date from the computer system, convert this date to day of the year, and then use this day to check for new IGS data files (which contains the day of the year in the IGS filename). The day of the year also appears in the name of the daily subdirectories on the optical disks. The program has a list of given IGS data file names and for a given day will automatically go down the list and denote which files are or are not on the optical disk. Then the program will check the receiving areas for new IGS data, that is, data that is not already on the optical disk. New IGS data will then be processed as described above. Therefore, once the current date is known, it is easy for the program to check for several days of new IGS data in the receiving areas. In this case, the software starts from six days back from the current date and ends with the previous day. For example, if the current date is 20-Feb- 1993 (corresponding to day051) the program will then look for all new IGS data from day 045 to day 050.

The directories of the regional data center accounts on the CDDIS are also checked manually every day to verify that all the IGS data has been processed properly. Data that has not been processed by the automated programs (such as older or replacement data) are then processed manually. Occasionally, replacement data is supplied by a processing center, and in this case, the original IGS data file is deleted from the optical disk and is replaced with the new one. Difficulties, however, can arise if regional centers do not explicitly notify the CDDIS that replacement data has been sent. Often duplicate data files are delivered which then requires manual intervention in the data processing procedures to determine if in fact the files are duplicates or replacements of previously issued files.

For each day, there is one observation and, typically, one ephemeris data file for each IGS site. The ephemeris data files for a given day are decompressed and then concatenated into one large ephemeris file, which contains all the ephemeris information for that day. This daily ephemeris data file, in compressed form and named BRDC*ddd*0.*yy*N_Z (where *ddd is* the day of year and yy is the year), is then copied to the optical disk in the ephemeris subdirectory for that day.

The regional data centers also deposit status files every day to the CDDIS. These status files contain information, such as file size, status, and satellite information, for each IGS site processed for that day by the center. The CDDIS merges the individual status files together to make one daily file. The daily status files are then copied to the optical disk archive. Users can list the contents of these files to determine general information about the daily observations.

A majority of the GPS data utilized by IGS analysis centers are deposited by the four processing centers. The CDDIS also retrieves data from the other two Global Data Centers, S10 and IGN, supporting the IGS. In addition, these two data centers access the CDDIS on a daily basis to extract any data not delivered to or retrieved by their institutions.

The CDDIS generates weekly reports utilizing the summary information available in the on-line data base. These reports are stored on optical disk with the GPS data and are also sent to the IGS community via the IGS MAIL and REPORT facilities.

Timeliness

An important goal of the IGS is to provide analysis centers timely access to the GPS tracking data. The initial requirements stated that data from core sites was to be available for analysis through the global data centers within 72 hours of the end of the observation day. The IGS Pilot Service tightened this requirement and has requested that data be made available within 48 hours. To meet this objective it is imperative that regional data collection centers retrieve data from the receivers as regularly and in as automated a fashion as possible. Data retrieval and transmission must be routine and programmed to allow for consistent flow of data on a daily basis. Upon arrival at the CDDIS, these data must be processed quickly and made available to the user community. The CDDIS typically processes data within hours of receipt via automated procedures. The graphs shown in Fig. 3 illustrate the timeliness of the global tracking network for the 1992 IGS Test Campaign. These statistics are shown for three groups of sites: the full complement archived at the CDDIS, those sites designated as “prime” or “secondary” core sites, and those sites designated as “prime” *core* sites only. Table 1 lists the designation of all sites archived in the CDDIS. These statistics were derived by comparing the time tag on the file delivered to the CDDIS with the actual date of the data. The line graph shown as an overlay shows the number of distinct sites represented in each category.

ACCESS PROCEDURES AND REQUESTING DATA

The CDDIS has established a general user account which permits remote access to the archive of IGS data and products to the analysis groups. Authorized users of this account can retrieve data currently on-line by establishing remote connections from their home institution. The CDDIS supports the DECnet and TCP/IP network protocols as well as the KERMIT and XMODEM data transfer programs for dial-up access. The chart shown in **Fig.** 4 illustrates access statistics for the CDDIS data archive during a recent month (statistics for the IGS Test Campaign itself were unavailable for use). The line graph overlay shows the total number of host accesses per day, whether for general browsing or actual file transfer. During the IGS Test, the CDDIS was accessed on a daily basis by five distinct computers; since the start of the IGS Pilot Service, this access has increased **to** an average of fourteen hosts.

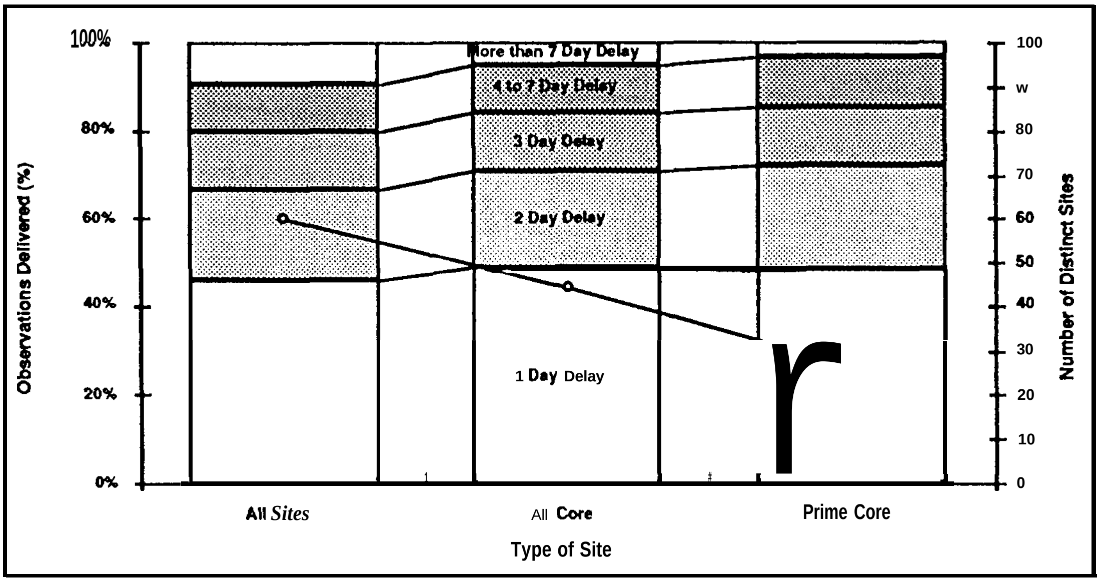

Fig. 3 Data delivery statistics for the IGS Test (14-Jun-92 through 31-Ott-92)

Users interested in data from time periods currently not on-line can submit a special request to the CDDIS. The staff will then attempt to satisfy this request in the most efficient method possible, either by temporarily placing the requested data on-line or by sending magnetic tapes to users.

The CDDIS is an open archive which serves a wide user community interested-in space geodesy and geodynamics data. Therefore, any interested users are permitted access to the archive of GPS data and products. The IGS Steering Committee has drafted policies for the distribution of IGS data and products. The CDDIS in principle agrees with the general policy which states that the IGS archives are open to all users but that the data and products are not to be sold by any group after retrieval.

FUTURE PLANS

The CDDIS staff is currently investigating alternatives for providing improved access to the archive of GPS tracking data. One option is to increase the amount of on-line disk space available for storage of the tracking data. Because the current archive has been written to rewriteable optical disk, the CDDIS is studying optical disk jukebox technology. These devices can hold anywhere from sixteen to over eighty platters at one time, thus providing on-line access to many gigabytes of data.

A second alternative is the use of CD-ROM technology for data distribution. The CDDIS staff could utilize a CD-ROM pre-mastering facility which would also have the capability to write a limited number of CD-ROMs. Approximately four to six weeks worth of GPS tracking data would fit on a *single* CD. This CD-ROM technology could provide a convenient, affordable alternative to users who do not require near real-time access to the GPS tracking data.

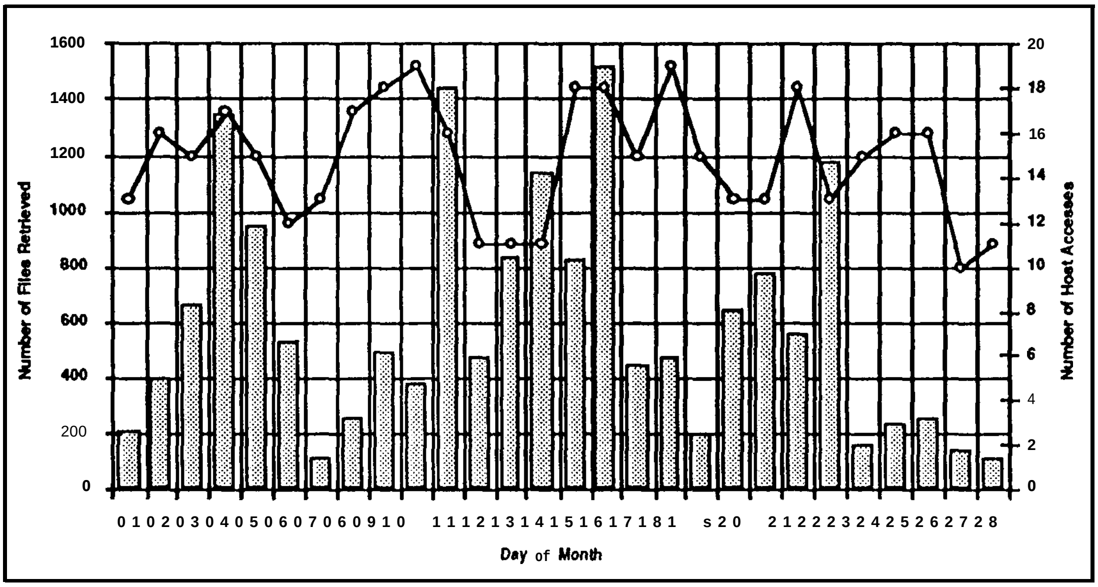

Fig. 4 Statistics of CDDIS archive access (February 1993)

CONCLUSION

The proposed concepts of the IGS, in particular the real-time availability of a global set of GPS tracking data, were realized during the 1992 IGS Test Campaign. The three global data centers successfully provided the main interface between the IGS data and the user. The CDDIS, in particular, learned a great deal from the test campaign. New archiving procedures, such as automation of data transfers, were developed for the IGS and are now utilized in other CDDIS activities. The success of the 1992 IGS Test Campaign lives on in the current IGS Pilot Service; the CDDIS continues to serve the IGS community and to improve user access to the data archive.

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GPS GLOBAL TRACKING NETWORK OPERATIONS AT JPL DURING THE 1992 IGS EXPERIMENT AND BEYOND

Dave Starr*, Steve DiNardo*, Garth Franklin*, Lucia Iriks*, Ulf Lindqwister*, Tom Lockhart*, and Mark Smith**

The JPL GPS Network Operations center provides resource in personnel and equipment to support the activities of maintaining, collecting and sharing data from a global network of GPS receivers. This is done in cooperation with many agencies around the world with data being exchanged via networks, During the IGS campaign, from 21 June 1992 to 23 September 1992, JPL collected approximately 1000 station days of data from 10 globally distributed GPS sites. The average time of data acquisition from the receiver to final distribution of the data was 27 hours during the campaign. Currently data is collected, processed and distributed from a 15 globally distributed stations. It is our intention for the foreseeable future to support and keep up the operation of the GPS Global Tracking Network.

INTRODUCTION

The GPS Network Operations center at JPL provides resources for the collection, distribution and maintenance of GPS data from a global network of GPS receivers. This includes the ability to remotely diagnosis receiver problems, communicate with receivers and operators of receivers, to automatically collect, process and distribute data for 14 stations in the IGS network. This amounts to 35 megabytes of raw, finished data and products daily.

JPL GPS NETWORK OPERATIONS

Station Support

As part of our effort in the development, deployment and maintenance of the FLINN network and other NASA owned receivers Rogue depoting operation has been created at JPL. The depot provides for receiver diagnostics and repair. This facility includes the ability to test, repair and calibrate the Rogue SNR-8, SNR-800 and SNR-8000 (Turbo Rogue) GPS receivers. The ability to provide working spares to keep the network up and running is also another requirement for maintaining a continuous data flow from each site. The depot also maintains a history on each receiver's performance and problems so that failure modes and trends can be identified and corrected either in hardware or for future releases of the firmware.

In addition to the hardware maintenance, software maintenance and diagnostics also continue at JPL. An example is on August 8 1992 Anti Spoofing was turned on for the

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* **Tracking Systems and Applications Section, Jet Propulsion Laboratory, California Institute of** Technology, Mail Stop 238-700,4800 Oak Grove Drive, Pasadena, CA 91109

first of many times to come. This serendipitously uncovered an anomaly in the Rogue receiver software. A team of was formed at JPL to address the problem. The error was isolated, corrected and tested. Once the new code was validated firmware (PROM's) were made and distributed to 28 Rogue sites within the GPS Global Network. A general network upgrade was planned for and implemented on 5 February 1993. Currently 27 of the 28 Rogue sites are known to have been upgraded to the new software (Menix 7.3).

Support by telephone for local operations or directly to remote Rogue's are continuing for diagnosing receiver problems. This support of the global network is primarily for the NASA owned or operated receivers but is available to other users of the Rogue receivers. Rogue experts at JPL with the aid of local personnel can often resolve receiver problems at remote locations [ref 1]. This prevents the receiver from having to be returned for repair and keeps the site up time maximized. For NASA owned or operated sites (and other sites on request) the receivers periodically -called over telephone lines using modems for preventative maintenance. In addition telephone communication upload logs, when available, and data files are analyzed for indications of receiver or other site problems. In many cases a call to the local personnel will then allow for the confirmation and correction of the problem and coordination for the receipt of replacement parts can be performed.

Site Catalog

A network of this complexity naturally produces a significant amount of site information. As a result we have developed a site catalog for the global network. The text portion of this catalog has five tables similar to that of the Crustal Dynamics VLBI catalog. Information in the text portion of the catalog contains site names, locations, contacts, coordinates both geodetic and geocentric, monument information, site tie information and contacts, as well as receiver information (hardware type), and antenna height. Other information soon to be added in a database includes site occupation history, software and hardware configuration, communications paths and survey information. Much of this information will be put on-line the near future. Currently it resides on hard copy only.

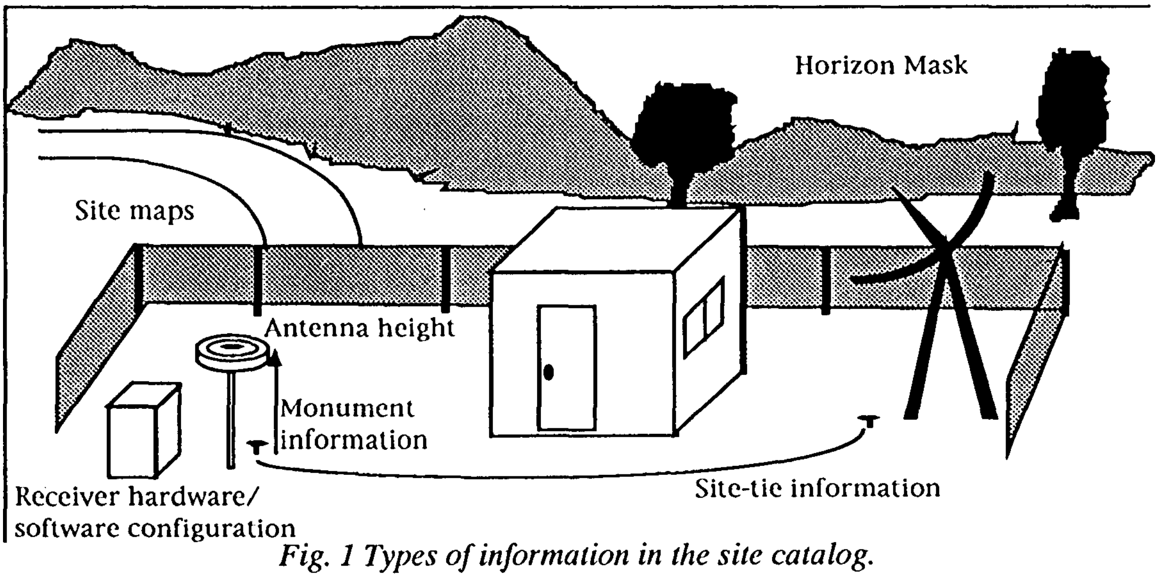

Fig. 1 Types of information in the site catalog.

Communications

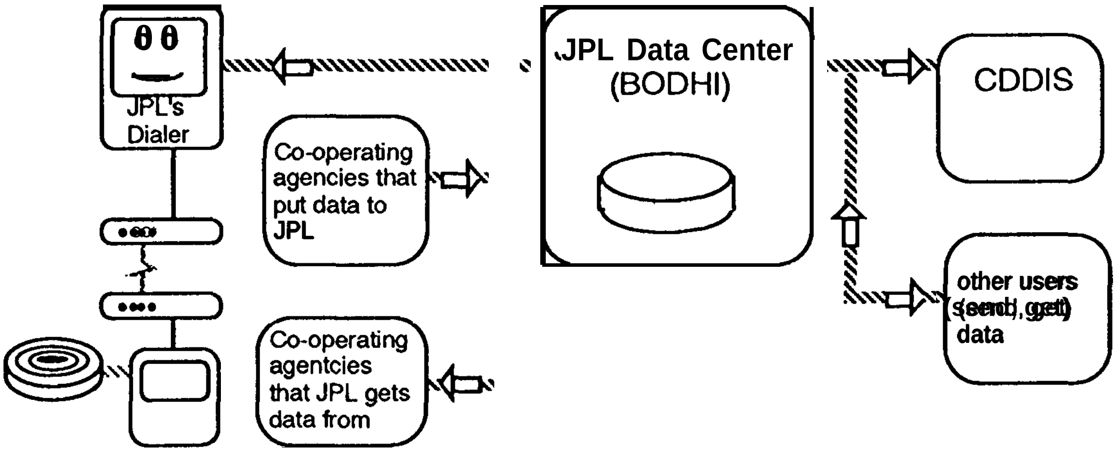

Fig 2. The JPL Data Handling Facility has 3 basic parts; data acquisition, data processing and storage, and data distribution.

As of **this** writing JPL, is obtaining data from 35 Rogue receivers globally of which JPL/NASA provides data from 15. The remaining 20 receivers are operated by various other agencies around the world in which data sharing is common place. The volume of data that flows in and out of the data center is approximately 70 megabytes of raw and finished data daily. The data arrives via the phone system and computer networks. The data leaves via computer networks to other users. Agencies with which we share data are CDDIS, CNES, DELFT, EMR, ESOC, GFZ, IFAG, NGS, 0S0, S10 and SK. These agencies either allow us to retrieve data from their computers or place data onto our computers in a timely manner. And in turn we place data onto other computers or allow others to retrieve data from our systems.

Of the 15 sites that we provide data from 11 of the sites are called up over the phone, 3 are associated with the Deep Space Network and 1 is operated under contract and the data is delivered to JPL. A

JPL/NASA Dialed Sites - phone line transfer Fairbanks, Harvest, JPL Mesa, Kokee, North Liberty, Pie Town, Quincy, Santiago, Usuda, Vandenberg, Yaragadee
JPL/NASA DSN Sites - network transfer Goldstone, Madrid, Tidbinbilla
JPL/NASA Contracted Sites - network transfer McMurdo
Sites Provided by Other Agencies - network transfer Kootwick, Onsala, Graz, Metsahovi, NyAlison, Tromso, MasPalomas, Kouru,Hartebestok, Pamati, Hersmoncueax, Materia, Taiwain, Westford, Hobart, Alberthead, Algonquin, Penticton, St.John, Yellowknife

Fig 3. How station data arrives at JPL

typical daily phone call to one of the 11 sites for data off-loading takes approximately 12 minutes and transfers about 350 kilobytes of CONAN binary format data (the data spans 24 hours at a 30 second sample rate) . At 6 hour intervals the data is off loaded from the dialing computer to the processing computers. What is happening here is shown in figure 4. The remaining 4 sites arrive via a combination of networks that are part of JPL or contracted out. Some of the sites for which we provide data is provided as a courtesy of other on going projects that use GPS data (such as the Topex/Poseidon Experiment). Data from the remaining 20 sites is provided by other agencies and the raw data arrives at JPL via global computer networks.

Data Handling

The goal of the JPL GPS Data Handling Facility is to provide a consistently handled set of data and products to its customers in a timely manner. The GPS data collected and processed by JPL is used by many projects both within and outside of JPL of which the iGS community is one significant customer.

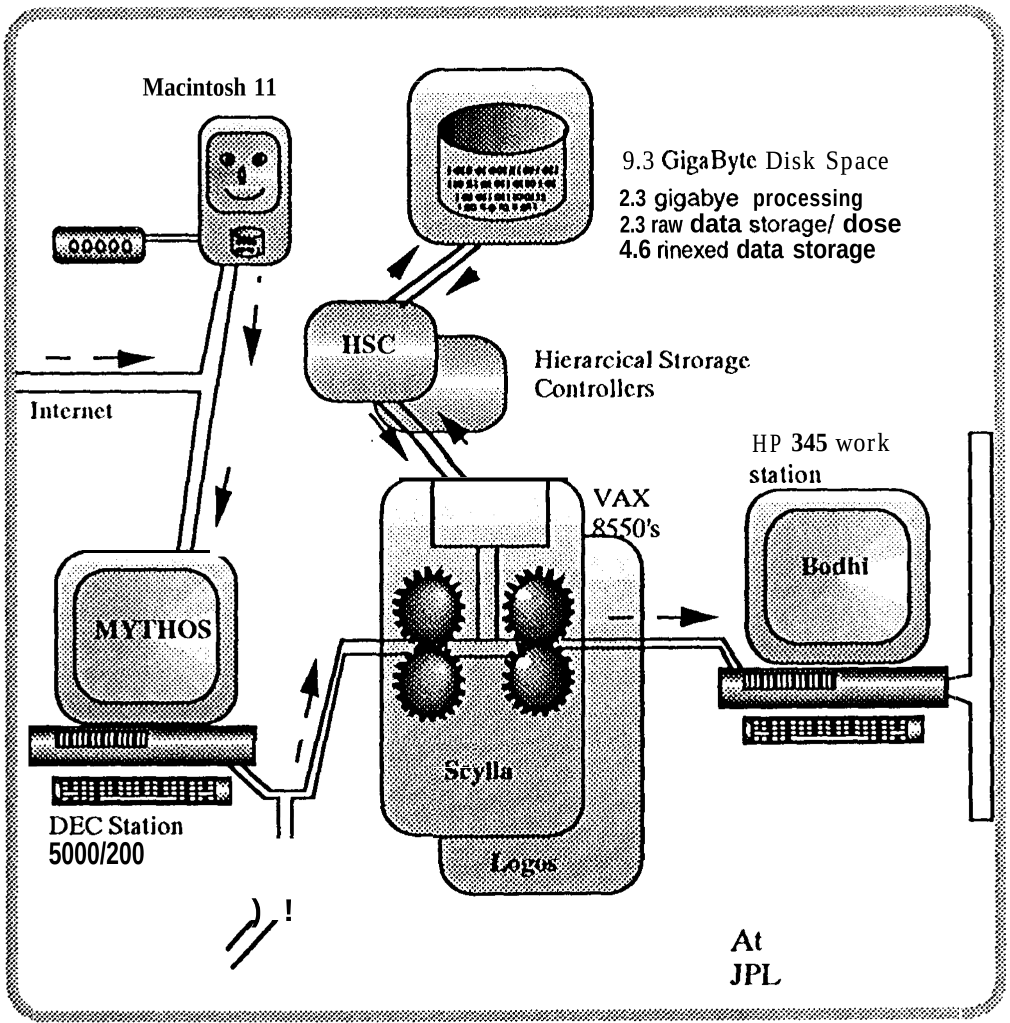

Fig 4. Current hardware configuration of BODHI.

The data processing at JPL is performed on a VAX cluster using the VMS 5.5 operating system. The data communications is handled by one node using TGV Multinet Software. The data being deposited into the import area by any of several agencies is scanned once an hour at 35 minutes past the hour. If new data has arrived during the previous hour, all the relative information for each site-day is collected together and scheduled for execution on one of the batch queues. The impact on the computer resources for the conversion is minimal owing to coincidental fact the UT midnight time tag occurs as the staff at JPL is finishing for the day. The conversion process from raw data to RINEX format starts shortly after zero UT when the first data files arrives from some of the cooperating agencies. By 16:00 UT most of the data that is going to arrive for the previous day has arrived and has been processed into the RINEX format [ref 2].

The transmission of data from JPL to the CDDIS (the GPS archive at Goddard Space Flight Center) occurs during the night, and is so timed as to cause minimal network impact at both JPL and at CDDIS. This distribution process is fully automated and sends a UNIX compressed version of the RINEX formatted daily data files plus a listing of what files where made available for a given day and the size of the data files. The transmission of 15 stations of compressed RINEX data to CDDIS prior to the 1st of March 1993 used to take about 50 minutes of clock time. On the 28th of February we connected to the JPL fiber optic network (FFDI) ring which allows a 100 megabit per second data transfer out of the data center. Data transmission now requires about 15 minutes of clock time for a normal days worth of data. The overall performance of our network is such that RINEX files for 12 of the sites arrive at CDDIS within 12 hours of being collected. The other 4 sites are delayed to when the data is being collected. The average data turn around time for the entire 35 station network is on average a little over 26 hours at JPL.

At the Data Handling Facility the data flows from the import directories to a processing directory to the finished products area, and to the data transmission area. The processing of the data from raw to compressed RINEX takes approximately 12 minutes of CPU time on a VAX 8550 and about 22 minutes of clock time per 24 hour station file. The processing sequence first decompresses the raw data then scans the data for start and stop times, and finally renames the file to an internal format. The data for this site is then merged with data from the previous day to generate the RINEX file. This merging of the data allowed us to account for any overlap of midnight if the data file has multiple parts or is not terminated on the midnight UT boundary. The data files are then compressed using a VMS version of the UNIX compression routine.

IGS 92 SUPPORT

The JPL Data Handling Facility has been on-line since late 1991 and is capable of processing all Rogue receiver data to RINEX received at JPL. During the 1992 campaigns starting with the extended IGS campaign on June 21st and the intensive 2 week Epoch 92 campaign starting on July 28 we processed into RINEX all Rogue GPS data received. This allowed the center to serve as a backup site for other centers that may have experienced difficulty during the campaigns. However only a subset of this data was provided to CDDIS during this time frame as requested. Data from the following sites was provided during the campaign: Goldstone California, Madrid Spain, Tidbinbilla Australia, Fairbanks Alaska, JPL Mesa California, Kokee Hawaii, McMurdo Antarctica, Santiago Chile, Usuda Japan, and Yaragadee Australia. For the 105 day period starting with 21 June 1992, Figure 5 shows the number of available days, all of which was delivered to the CDDIS. The average data turnaround was less than 27 hours during EPOCH 92.

In addition to providing data to the IGS community, technical support was provided during the entire IGS campaign (and beyond) to help keep the receivers up and running. This proved to be a substantial amount of work as Anti Spoofing (AS) was turned on and an error was discovered in the Rogue code. A work around was found by off loading the receiver every four hours which bypassed the erroneous software loop. The software for the Rogue portion of the global network has now been corrected and upgraded to new software.

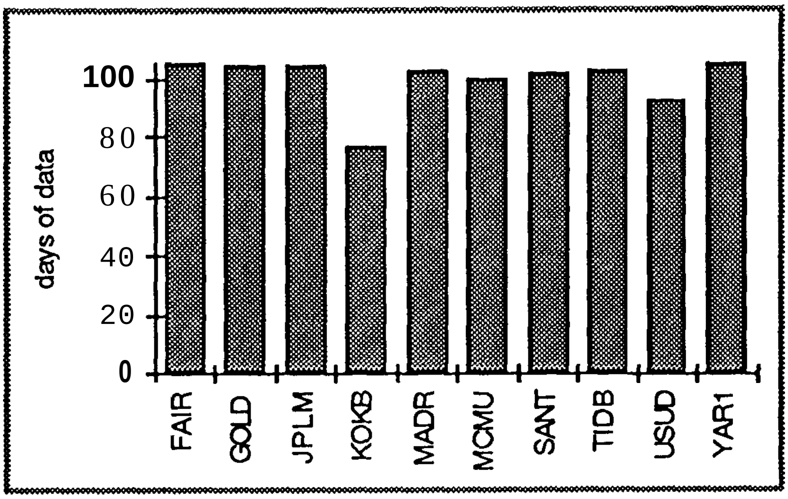

Fig 5 *Days of data per site delivered to CDDIS*

BEYOND TOMORROW

As the clock rolls into the future, we will continue operate a viable and expanding network of GPS receivers. As the network currently exist with a number of stations being owned and or operated by JPL/NASA and others being owned and operated by other agencies so it will be in the future. Sharing of the resulting data will improve the robustness of the solutions and products. JPL envisions a network of nearly 200 stations globally, being operated and maintained much as the current network is using cooperation with other agencies. We have recently installed Turbo Rogues at North Liberty Iowa and Pie Town New Mexico(part of the North American Fiducial network). At Easter Island another installation is currently underway (in cooperation with the Chilean University Centero de Estudios Espaciales). Other global sites to be installed in the future may include Kwajalein, Seychelles, Arequipa and Bogota as well as continued expansion in the North American Fiducial Network [ref 3].

As the data continues to be received from around the globe we will continue to process the data into RINEX for redistribution, continue to provide precise orbits and other products that are currently being produced as well as adding more Earth platform products. One of the products we hope to add in the near future is precision baselines between stations. In addition to the work currently being done for the geodetic community we are supporting a number of other efforts that will require faster data turnaround, which the geodetic community will benefit from. This includes the acquisition of more powerful computers and additional disk space at our processing center.

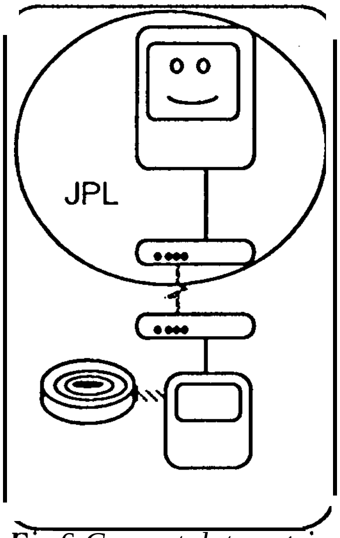

Fig 6 Current data retrieval methods.

The ability to get this much data in and out of anywhere requires a sophisticated network. Data arriving via the telephone lines does not only tax the telephone network but also has become expensive. Although the telephone network is reliable in many parts of the world, it is not as reliable or of the quality required for data transmission in other parts of the globe. Even though computer networks are becoming more prevalent globally they are not every where we would like to place a receiver. As a result a combination of solutions will be required to return GPS data in a timely manner and at reasonable cost from the more remote areas of the world. In some cases an unusual solution may have to be found. There are a number of ways to off load receiver data. The phone network usually involves a modem and expensive overseas phone calls. In many cases a local area network such as InterNet is available nearby, hence all that is required is a local phone call to bring the data to the nearest InterNet node.. The data would then be retrieved from the remote node via the networks for processing at the center.

As the Rogue and Turbo Rogue receivers are not currently capable of interfacing to a network an intermediary is required. This intermediary may be a terminal server which speaks the appropriate protocols for the network it is attached to, or another computer that has data gathering capabilities. The computer allows for a number of different options such as local storage of the data if the communications network (phone or other) goes out for extended periods of time. The retrieving data from other collocated instruments may require periodic or even continuos off loads of the data). Or the computers may operate as a regional dialer, where network connections are not practical at each site in an area of the world. Hefty over seas phone charges could be avoided by installing a computer at a site with network access in the desired region, and then using the local telephone lines to access the rest of the sites. The data for the entire region would then be off loaded over the network from one computer and take just a few minutes as opposed to several hours of phone calls.

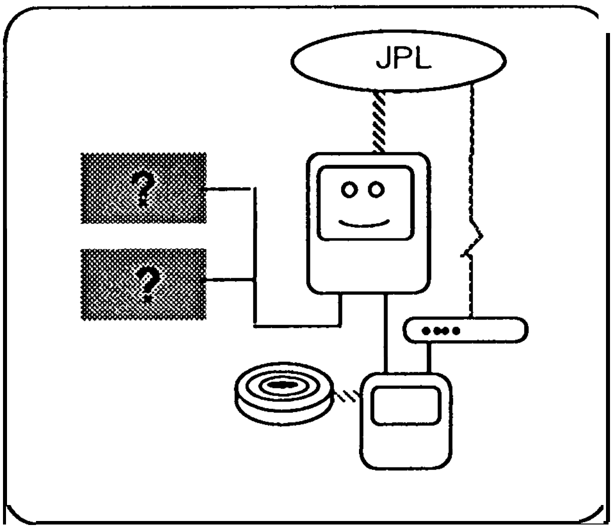

Fig 7. Future connections for data retrieval.

Once this data is in house there is a significant amount of other data that is required to make use of the GPS data. This other data called Meta data consists of some of the information in the site catalog and on other bulletin boards. In the not so distant future we hope to have available an on-line database with most if not all of the required information not only for the geodetic community but for all of the other tasks we currently and in the future will be supporting.

ACKNOWLEDGMENT:

We would like to thank the various agencies for their contributions of data and information to the many different tasks and projects being developed or underway at JPL. These agencies include CDDIS, CNES, DELFT, EMR, ESOC, GFZ, IFAG, NGS, 0S0, S10 and SK. In addition we extend our thanks to the many individuals who without their efforts this experiment and program would not have succeeded. The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautical and Space Administration.

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Chapter 3

Processing Centers Reports

SCRIPPS ORBIT AND PERMANENT ARRAY CENTER: REPORT TO '93 IGS BERN WORKSHOP

Yehuda Bock, Peng Fang, Keith Stark, Jie Zhang,
Joachim Genrich, Shimon Wdowinski and Shelley Marquez[1]

The Scripps Orbit and Permanent Array Center (SOPAC) began producing, in August 1991, daily precise GPS satellite ephemerides and polar motion in support of the Permanent GPS Geodetic Array (PGGA) in southern California. Scripps had already served as an independent archive of GPS tracking data for the scientific community since 1990. In June 1992 we joined the International GPS and Geodynamics Service (IGS) as one of three Global Data Centers and one of several Analysis Centers. In August 1992, we became the Orbit Facility for the University NAVSTAR Consortium (UNAVCO) with the task of providing precise GPS satellite ephemerides for worldwide crustal deformation projects, funded by the U.S. National Science Foundation. We have supplied our products on a regular basis to other groups such as the International Earth Rotation Service (IERS) and the North American Rapid Earth Orientation Service (NEOS), and to individual scientific investigators. Our products are especially valuable to users of the GAMIT/GLOBK suite of GPS software since disparate regional campaigns can be rigorously linked to the International Terrestrial Reference Frame through the full variance-covariance matrices output from our routine PGGA/IGS solutions. We disseminate our data and products to the scientific community by means of anonymous ftp over INTERnet. We also disseminate orbital and other positioning information to non-scientific users (primarily in California), for example, through the Southern California Earthquake Center (SCEC) Outreach Program. We have installed a PC-based bulletin board service (BBS) to disseminate these products to general subscribers. We describe in this paper the components of an "integrated positioning system" that we have developed over the last four years.

INTRODUCTION

The Scripps Orbit and Permanent Array Center (SOPAC) is the culmination of nearly four years of research and development in support of the Permanent GPS Geodetic Array (PGGA) in southern California[1,2,3].

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[1] Yehuda Bock, Institute of Geophysics and Planetary Physics, IGPP A-0225, Scripps Institution of Oceanography, 9500 Gilman Drive, University of California San Diego, La Jolla, CA 92093, USA.

The PGGA is a network of continuously operating P-code receivers providing an uninterrupted record of crustal motion in near real time (Figure 1). Except for occasional (but too frequent) equipment failures, we monitor data at a 30 second sampling rate to all visible satellites, 24 hours a day, 7 days a week. Once a day the previous 24 hours of data are collected from each site; routine GPS processing of the PGGA and IGS[4] data then provides the site position averaged over the day (0-24^{h}UTC). The time series of these daily positions provides the standard record of crustal deformation. The components of our operational system are depicted in Figure 2.

The near real time aspect of the PGGA and the stringent accuracy requirements demand the rapid determination of precise GPS ephemerides. Before the start of the IGS in June 1992, we were obliged to compute GPS ephemerides at Scripps since there were none available to the scientific community of sufficient regularity, timeliness, nor precision. The estimation of daily polar motion with sub milliarcsecond precision became a straightforward byproduct of this process.

The ability of the PGGA to monitor crustal deformation due to seismicity was demonstrated during the Landers earthquake sequence in June 1992, when small far-field coseismic displacements were accurately detected at all PGGA stations with respect to the International Terrestrial Reference Frame[5,6].

The infrastructure that we have developed in support of PGGA is useful for any regional-scale GPS network, whether campaign oriented or permanent. We have developed an "integrated positioning system" whereby we supply on line all the necessary components to accurately and efficiently position a GPS receiver (or network of receivers) in any part of the world, consistent y within the ITRF91 reference frame. This is particularly useful to geophysical investigators since the tremendous overhead of computing satellite ephemerides and cleaning phase data is dramatically reduced, while ensuring that all regional campaigns can be easily interrelated in a consistent reference frame.

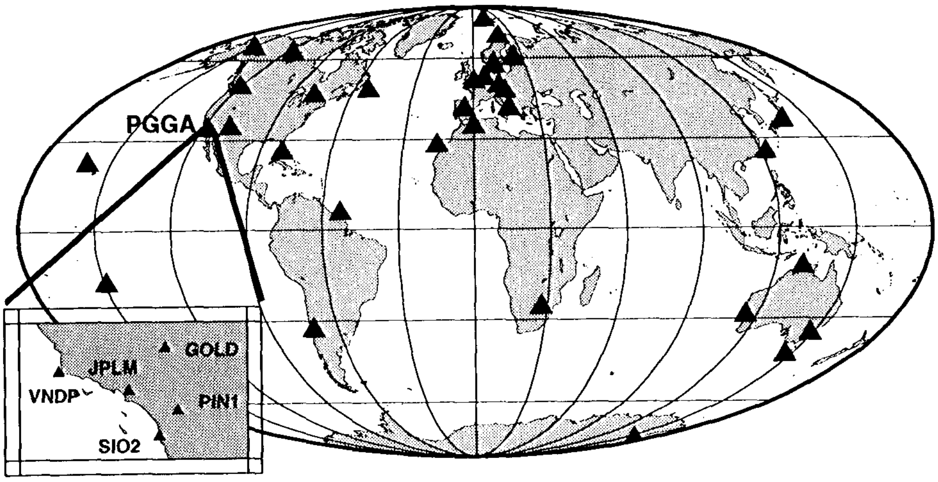

Figure 1: The current IGS tracking network and the southern California PGGA

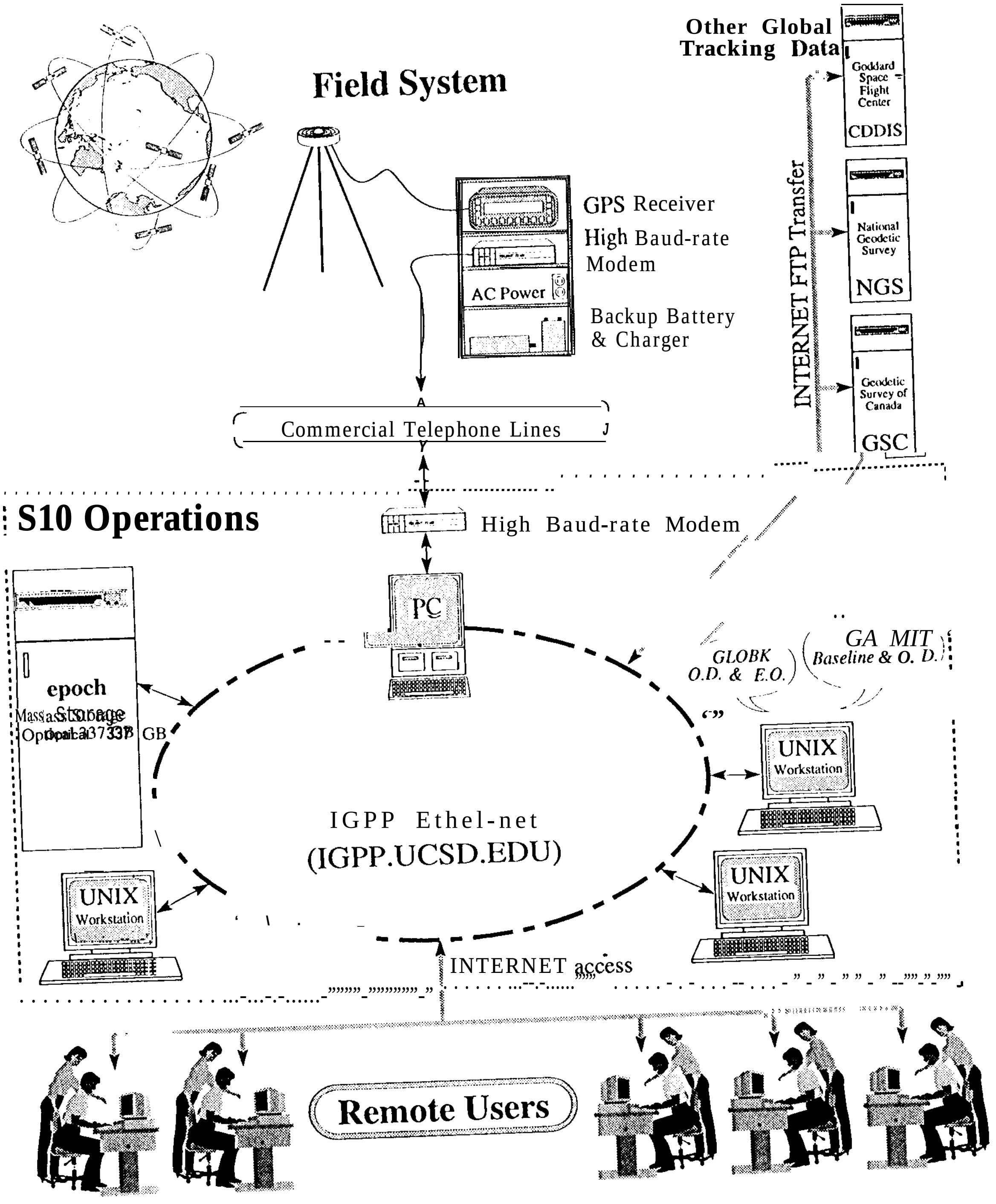

Figure 2: Schematic overview of operations at Scripps Orbit and Permanent Array Center

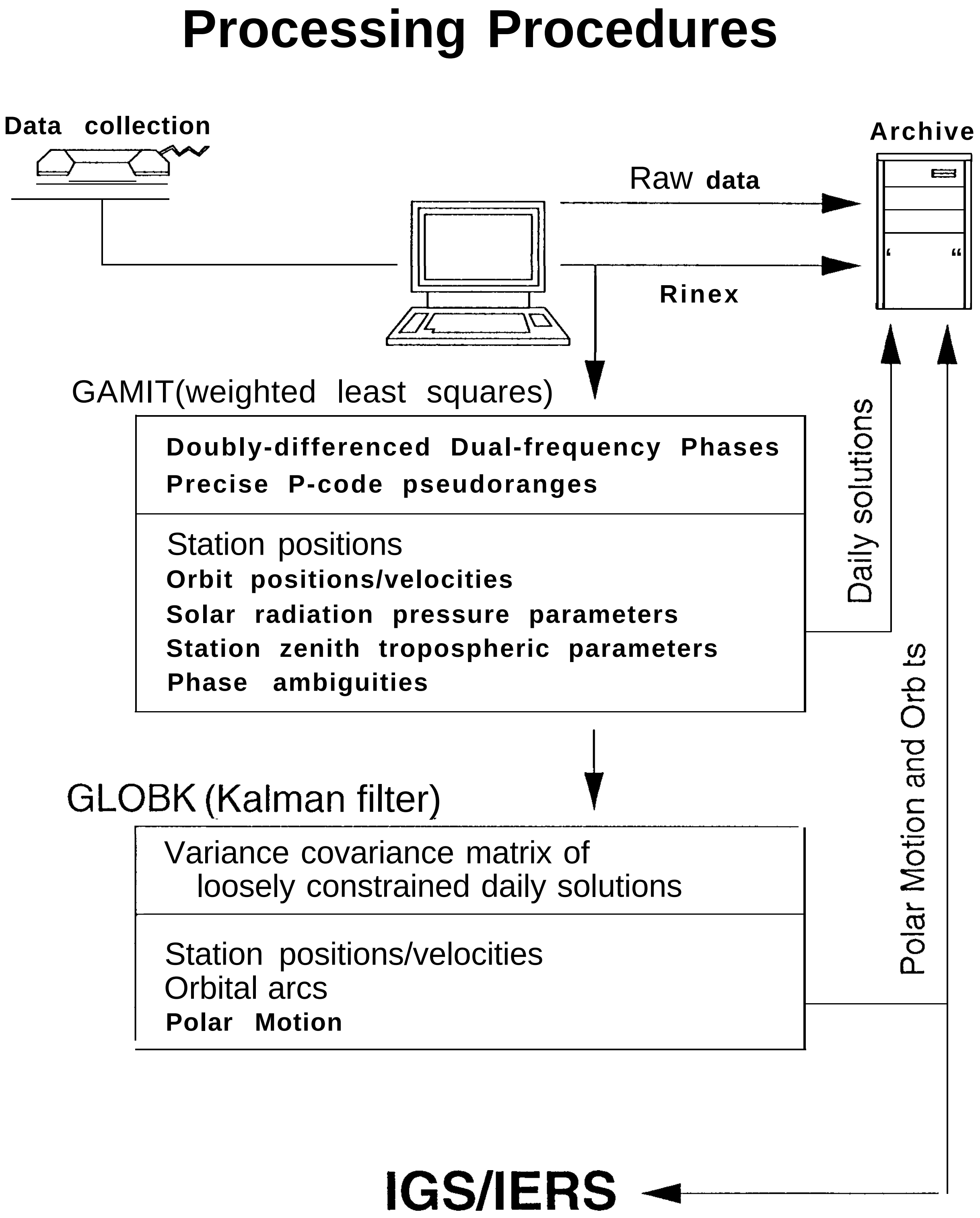

Figure 3: Outline of processing procedures at SOPAC.

ANALYSIS & PRODUCTS

The analysis procedure at Scripps has evolved over the last two years and is based on the cumulative set of more than 500 daily solutions processed since the GIG'91 campaign in early 1991. The processing procedure is shown schematically in Figure 3.

The PGGA and IGS data are analyzed simultaneously, in independent twenty-four hour (0-24^h UTC) segments using the GAMIT GPS software[7]. All parameters (Fig. 3) are given very loose constraints in the GAMIT adjustment and the variance-covariance matrix for station and orbital parameters is recorded in an auxiliary file. In this stage of the processing, therefore, the terrestrial reference frame is essentially undefined. The auxiliary files containing the variance-covariance matrices are then input to the GLOBK software[8] which uses a Kalman filter formulation to estimate some combination of station positions and velocities, orbital elements and earth orientation.

In December 1992, we performed a large GLOBK solution with more than 500 daily solutions computed since January 1991 to estimate a consistent set of coordinates for the PGGA and IGS stations. We attempted to solve for station velocities at all stations but found that these were not well determined. We performed a seven-parameter Helmert transformation between our coordinates and the ITRF91 coordinates determined by the IERS, and chose a subset of stations where the agreement in positions was reasonable (less than 20 mm rms) after transformation. The coordinates of these sites (transformed into ITRF91) and the corresponding IERS velocities (essential y NNR NUVEL- 1) then defined one realization of the ITRF91 terrestrial reference frame that we denote as pgga_921205.itrf91.

Using this reference frame (by applying tight coordinate constraints), we then performed a GLOBK back filter solution to estimate a consistent set of daily satellite orbits and polar motion for each day since mid-August 1991 when we began routine PGGA analysis. These products were announced in IGS mail # 226. In this solution, we (1) constrained UT1-AT to daily values obtained from IERS Bulletin A[10], (2) solved for one (direct) solar radiation pressure parameter per day and allowed small variations in they-bias radiation pressure parameter from day to day.

Since the beginning of 1993, we have computed our products as follows. We accumulate 7 days of daily GAMIT solutions within one GPS week. We perform a GLOBK solution using pgga_921205.itrf91 as station constraints, with station positions of the IGS stations treated deterministically and (daily) polar motion, satellite orbits and PGGA station coordinates treated as stochastic parameters that are able to adjust freely from day to day. The GLOBK back filter produces a consistent weekly set of daily polar motion, orbits and PGGA station positions with respect to ITRF91. No estimate is made of UT1-AT since these deviations are absorbed into the orbital parameters; rather we constrain the daily earth rotation value according to the rapid service tables mailed each Thursday by the USNO.

We plan to evaluate (and possibly redefine) our realization of the ITRF91 reference frame at approximately three month intervals. The GAMIT/GLOBK approach allows this to be done conveniently and to easily recompute the entire history of orbits and polar motion within this new reference frame.

Our weekly products at-e archived and mailed to IGS, CDDIS, IERS and USNO. The summation file lists the sites used in the analysis, orbit overlap statistics, earth orientation estimates and repeatability statistics for the PGGA sites.

In Figure 4, we show as an example, orbit overlap for PRN 19 for the period since August 1991. The overlap is based on 1 6 hours of rms differences between orbits computed on adjacent days. The spikes in the summer of 1992 correspond to weekends when anti-spoofing (AS) was turned on. Note that the overlap precision improves in time which corresponds to the growth of the global tracking network from about 12 stations in August 1991 to about 30 stations in early 1993.

Our daily determination of pole position is plotted in Figure 5 for the period 14 August, 1991 to 6 March, 1993. Also, indicated are polar motion estimates during GIG '91.

In Figure 6, wc show the time history of the north component of PGGA stations relative to ITRF91, over a two year period starting with GIG '91. We distinguish clearly: (1) interseismic deformation due to plate motion in southern California, and (2) coseismic deformation during the 28 June (day 180) Landers/Big Bear earthquakes which appears clearly as step functions. The Landers earthquake (M_w 7.3, June 28, 1992, 1158 UTC, 34.20°N, 116.44°W), which was closely followed by the Big Bear earthquake (M_w 6.2 1507 UTC), generated surface slip of up to 6 meters[11]; the associated elastic deformation affected all the PGGA sites.

ARCHIVE

We have been archiving PGGA and global tracking data since 1990. We archive the following:

(1) Raw tracking data (when available).

(2) Tracking data in RINEX format

(3) IGS products (.eph, .erp., sum files)

(4) Ephemeris and solution files for GAMIT users.

(5) Clean RINEX files from GPS week 678 onward. Clean RINEX data before this period are available upon request.

(6) Site and antenna information.

(7) Assorted utilities.

All data collected since 1990 are maintained on line and are accessible by the scientific community via anonymous ftp. We have also established a PC-based bulletin board to provide our products to non-scientific users.

To access our archive:
ftp teddy @ucsd.edu (1 32.239. 13.4)
login: anonymous
password: your name
directories: igs_products
problems: contact stark@pgga.ucsd.edu

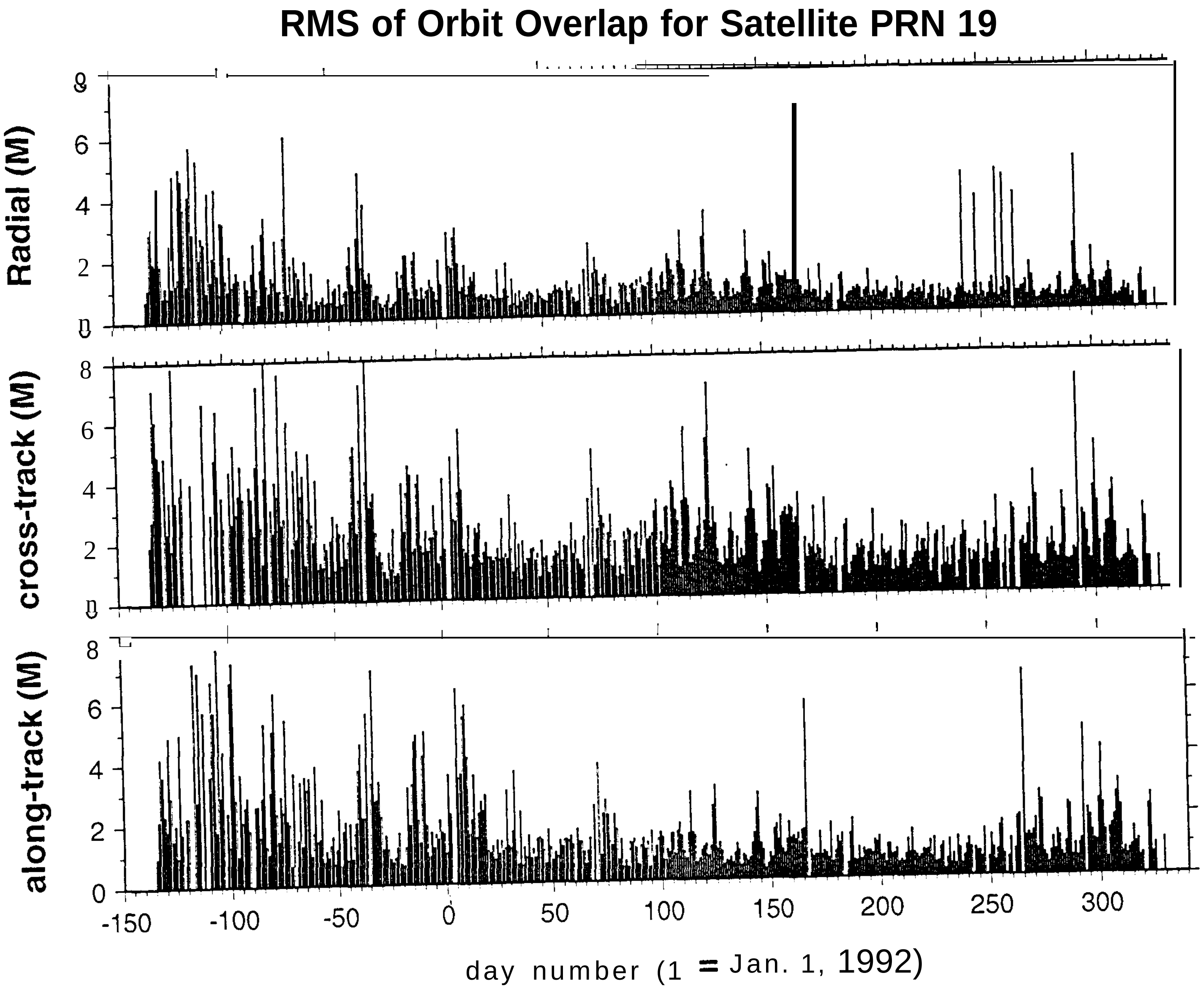
RMS of Orbit Overlap for Satellite PRN 19
Radial (M)
cross-track (M)
along-track (M)
0
2
4
6
8
-150
-100
-50
0
50
100
150
200
250
300
day number (1 = Jan. 1, 1992)

Figure 4

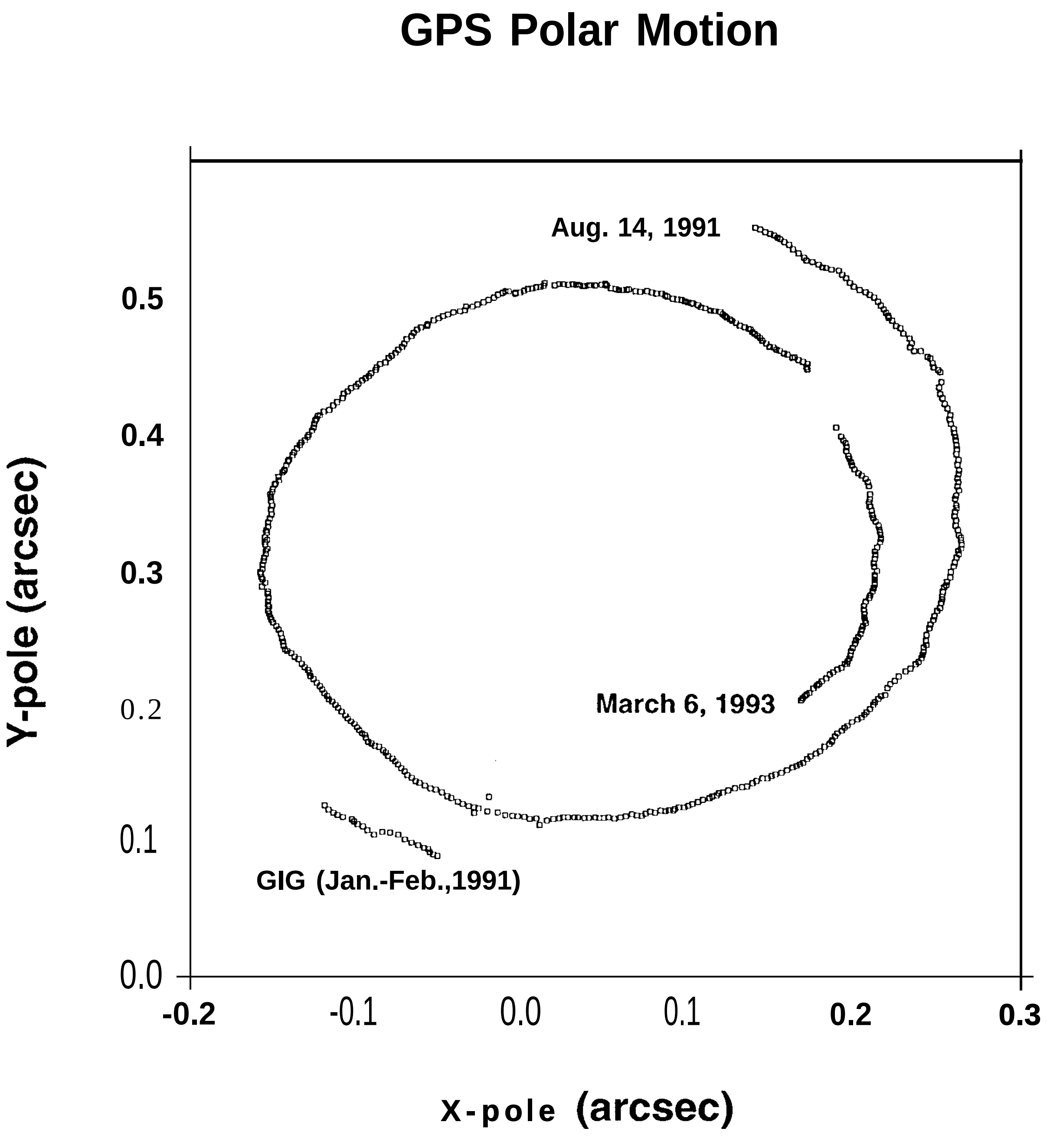
GPS Polar Motion
Aug. 14, 1991
March 6, 1993
GIG (Jan.-Feb.,1991)
0.5
0.4
0.3
0.2
0.1
0.0
-0.2
-0.1
0.0
0.1
0.2
0.3
Y-pole (arcsec)
X-pole (arcsec)

Figure 5

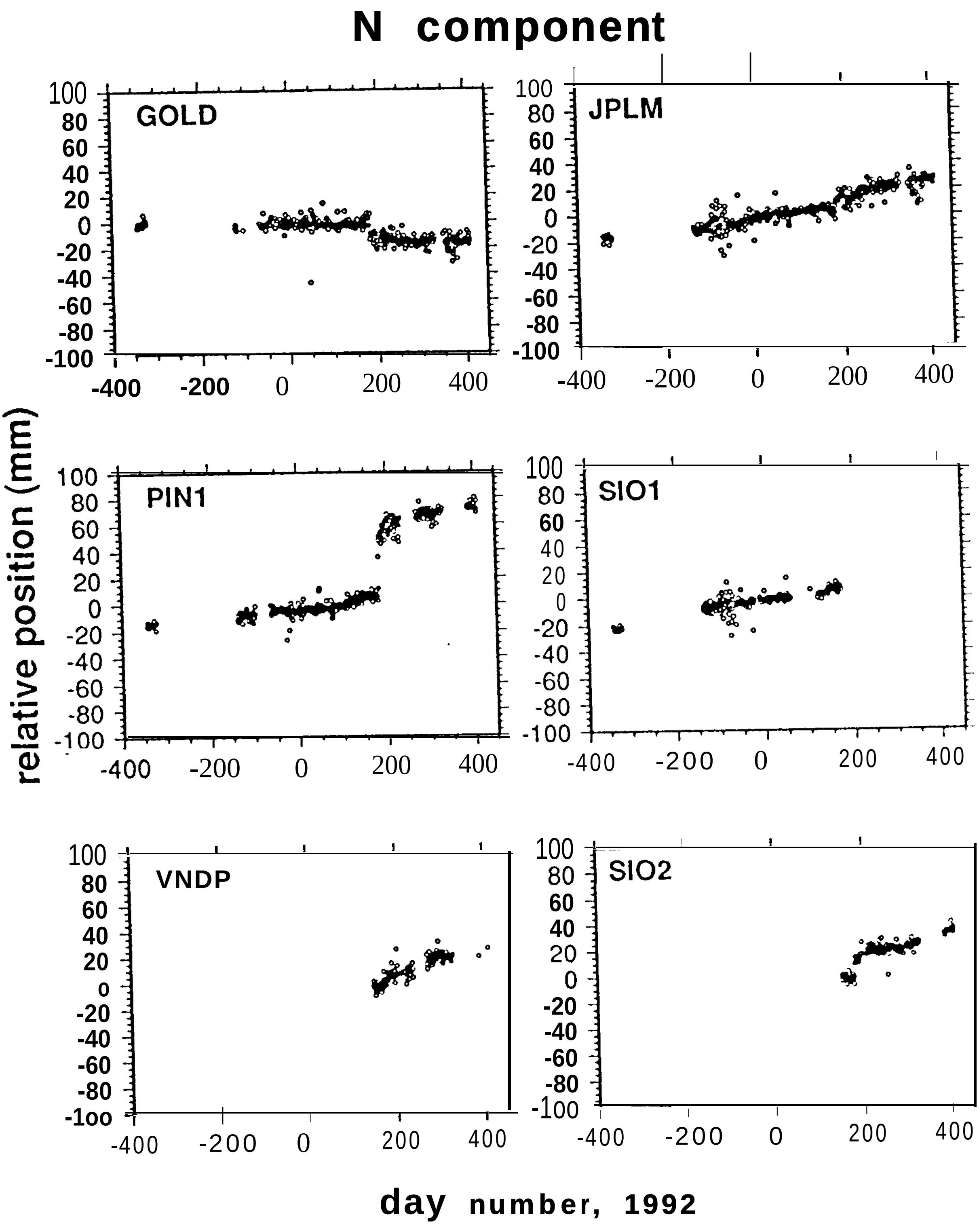
N component
GOLD
JPLM
PIN1
SIO1
VNDP
SIO2
relative position (mm)
day number, 1992
100
80
60
40
20
0
-20
-40
-60
-80
-100
-400
-200
0
200
400

Figure 6

CONCLUSION

The Scripps Orbit and Permanent Array Center provides an integrated positioning system to support high precision geodetic and geodynamic applications worldwide. Our products include raw and clean RINEX data, GPS ephemerides, polar motion, a reference frame based on nearly two years of GPS tracking data, variance-covariance matrices of our daily GPS solutions, and a variety of auxiliary information. All the data generated to date are on line and accessible via anonymous ftp. The use of these products in monitoring the 28 June, 1992 Landers and Big Bear earthquakes by the PGGA indicates that we are able to detect sub-centimeter geophysical signals with respect to the ITRF91 frame.

ACKNOWLEDGMENT

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THE ESOC GPS FACILITY: REPORT ON THE IGS 1992 CAMPAIGN AND OUTLOOK

J.M. Dow[1], T.J. Martin Mur[2], J. Feltens[3], C. Garcia Martinez[2]

The ESOC group participated actively throughout **the** IGS **1992** campaign, both as an Analysis Centre and through the operation of receivers in two stations (Maspalomas and Kourou) which significantly improved the network strength in the Atlantic/South American regions. The paper will discuss the data flow and the processing strategies adopted, and give an overview of the results obtained for orbital and spacecraft parameters, station positions and earth orientation during the period June **1992** until March 1993. The outlook for the future in terms of further receiver deployments and software developments will be outlined. Plans include a continuing contribution to the International GPS Geodynamics Service when the current pilot project terminates.

INTRODUCTION

Having participated in some of the early discussions concerning the establishment of an operational service for generation of high precision GPS orbit parameters (Edinburgh 1989, Ottawa 1990), a proposal was submitted by ESOC in May 1991 in response to the "Call for Participation: International Global Positioning System Geodynamics Service (IGS)", issued by the International Association of Geodesy/International Union of Geodesy and Geophysics (IAG/IUGG). Our proposal was based on two starting points which could provide a significant contribution to the development of such a service:

- the existence of a network of globally distributed ESA ground stations, already equipped with communications, caesium standard timing systems and other relevent infrastructure. Some of these stations are located in regions which were poorly or not at all covered by active GPS receivers;
- a state-of-the-art orbit and geodetic determination software package developed over a number of years at ESOC which was already well proven through extensive processing of data from many satellites, including satellite laser ranging (SLR) from Lageos and

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1. EM/European Space Operations Centre (ESOC), Robert-Bosch-Strasse 5.6100 Darmstadt, Germany
2. GMV S.A. (Spain) at ESOC
3. mbp GmbH at ESOC

Starlette. Although at that time not able to handle GPS data types (pseudo-range and phase), a multi-satellite solution capability was already implemented. Important aspects here were the independence of this software from others in use for GPS analysis, and the possibility of consistent processing of other geodetic satellite data with a single package (SLR and GPS).[1]

As a first step towards deploying receivers, two Mini-Rogue receivers were ordered, and after testing at ESOC in the spring of 1992 were dispatched to the ESA stations in Maspalomas (Gran Canaria, Spain), and Kourou (French Guyana). In parallel, a major effort was undertaken to develop GPS capabilities in our software, and to implement the data communications needed to handle the vast amounts of data involved. The Maspalomas receiver was operational just before the start of the IGS '92 Campaign, and that at Kourou has supplied data regularly to the IGS community since November 1992, following only sporadic success in August of that year due to data communications problems. Almost all of the active IGS analysis centres are now regularly including data from Maspalomas or Kourou or both in their daily computations.

Our first solutions for orbital and polar motion parameters were transmitted to the IGS data base at NASA/GSFC (and polar motion to the IERS) on 24 July 1992 (see IGS Electronic Mail No. 51), about one month after the start of the campaign. By early August the delay with respect to real time was reduced to about 10 days[2]. Along with several other centres, ESOC continued to process IGS data after the decision of the IGS Campaign Committee in October 1992 to continue the IGS activity in the form of an "IGS Pilot Service", which would guarantee continuity of the IGS preparations after the success of the first campaign.

IGS DATA FLOW AT ESOC

Figure 1 summarises the flow of IGS data as far as our activities are concerned. A PC located at ESOC communicates daily shortly after midnight UTC with the receivers at Maspalomas and Kourou. The Maspalomas connection is via high-speed Telebit modems and public telephone lines, while the Kourou link involves an X.25 line which connects the station with ESOC. About 500 kbytes/day per station are involved, and data rates are typically 6 kbit/s over the telephone line 9 kbits/s via the X.25. The compressed, raw Rogue data is transferred by FTP from the PC to the mainframe computer where our processing is performed. The data is decompressed and transformed into standard RINEX format, compressed again (this time with Lempel-Ziv coding), and sent to a mainframe ("XPROFS") from which data transfer to the external community is initiated by FTP. The compressed RINEX files are sent to the Crustal Dynamics Data Information System CDDIS at NASA/GSFC. The total delay between the last measurements being taken at the station and delivery of the preprocessed data to CDDIS is normally less than 5 hours . Special requests from JPL and NGS for raw data files are also currently included in this daily cycle. Data rates between ESOC and NASA/GSFC are typically around 15-25 kbytes/s, which is considerably higher than is at present possible in some inter-European routes.

Computation of orbits and earth orientation parameters (EOP'S) has up till now been on a weekly basis, with seven 24 hour solutions being obtained on Wednesday to Friday for the GPS week ending at midnight on the previous Saturday. Data from up to 26 stations in addition to the two ESA stations are obtained by FTP from CDDIS. Initial values for polar motion and UT 1 are obtained weekly from the IERS/USNO IGS Rapid Service (which in turn uses IGS results in its predictions). The results for the week can then normally be sent out to CDDIS and IERS (Central Bureau in Paris and Washington Sub-Bureau) within 6 days of the end of the week. The orbits are contained in daily files in NGS SP1 format. The naming convention is (for example) for GPS week 687: ESA06877.SUM for a text summary file describing the analysis; ESA06877.ERP for earth orientation results; and ESA0687*.EPH for the orbits (where *=0 is Sunday,..., 6 is Saturday).

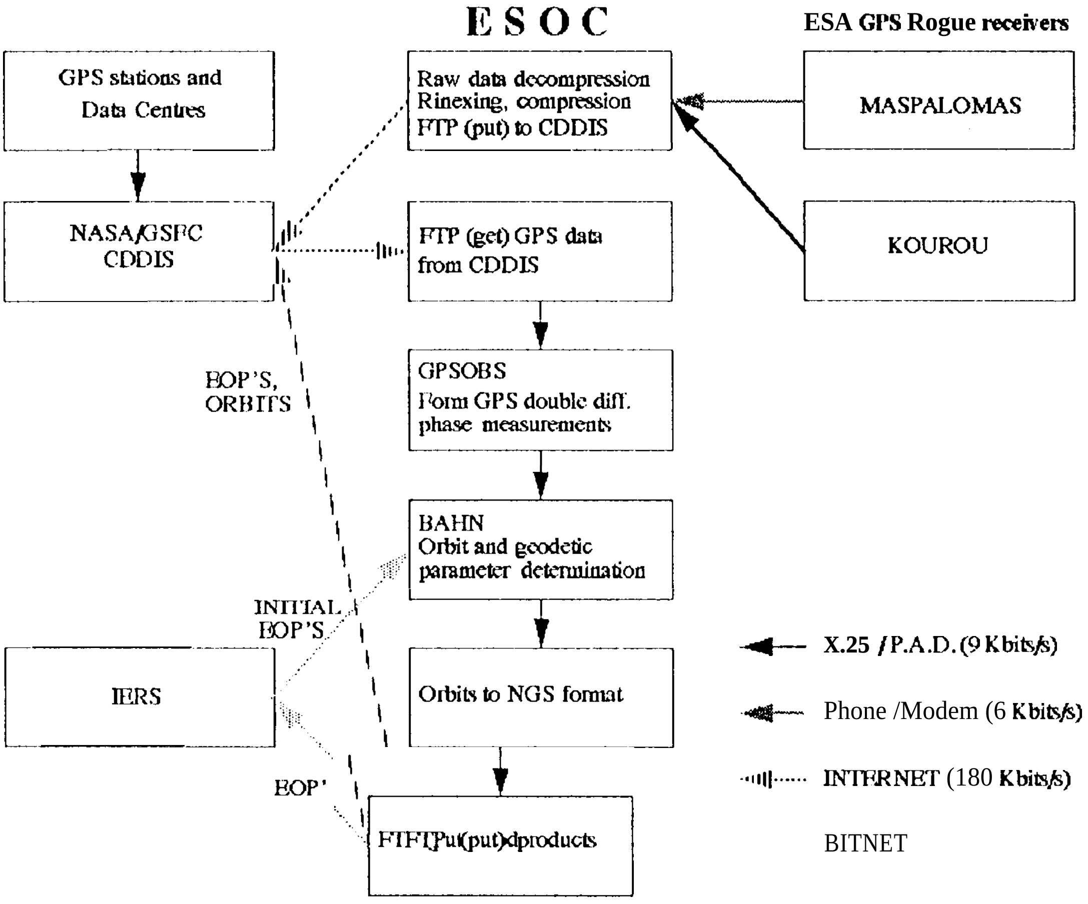


FIGURE 1. *IGS data flow at ESOC*

MASPALOMAS AND KOUROU INSTALLATIONS

The sites at Maspalomas and Kourou are equipped with Mini-Rogue receivers of type SNR-8C (rack-mounted), with associated Dome Margolin antennas of type C 146-6-1 with choke rings. Each receiver takes a 5 MHz input signal from the station timing system, which is based on Oscilloquarz caesium clocks, with long-term drift corrected by a GPS timing receiver. The Rogue receiver and a Telebit 2500 modem are mounted in a rack in the Main Control Room (MCR) of the station.

The Maspalomas installation was made in the week before the start of the IGS campaign, and data was available from 22 June 1992. The antenna is mounted on top of a concrete geodetic monument located some 45 m west of the MCR. The bottom edge of the backplate of the choke-rings is 122 mm directly above the marker on the monument.

Major problems were experienced with down-loading of data from Kourou initially, due to the high noise level in the public telephone lines between Europe and French Guyana. Attempts made from Pasadena to dial up the Kourou modem were also unsuccessful. The installation was made in late July, and data was obtained for a period of 10 days in August, and sporadically thereafter. Only with a completely different approach has it been possible to obtain a reliable data flow. A PC is now connected to the 9.6 kbits/s port of the receiver, and a communications program makes an automatic download into the PC with the XMODEM protocol. This PC is connected to an X.25 line via a PAD (packet assembler-disassembler). The PC at ESOC which dials up the Maspalomas receiver is also connected to the X.25 via a PAD, and the communications software makes a daily automatic download of the Kourou Rogue data using the ZMODEM protocol. At least 160 days of data can be buffered in the Kourou PC, making the download much less time-critical than in the case of Maspalomas.

During the period when communications with the Kourou were not possible, a permanent concrete monument was constructed for the antenna there (see IGS Mail No. 144). The antenna was moved by about -3.0, -1.1, 1.1 m in longitude, latitude, and height respectively from its previous position. The GPS reference point is a mark at the centre of a horizontal metal plate embedded on the concrete monument. The vertical displacement from the reference mark to the backplate of the antenna is 132 mm. The monument is located about 25 m from the MCR Building.

Of the 272 days between day 174 of 1992 and day 79 of 1993, Maspalomas data was lost on only 5 occasions (days 258,360,361,362,363), due in all cases to public telephone line problems. For the same reason, data for days 364-366 (1992), 001-005 (1993) had to be stored locally and transmitted to ESOC on day 007 when telephone communication with the station could be re-established. (A similar problem occurred on day 074 (1993), due to storm conditions at the station. The data were sent to the GPS data bases on day 076.) Overall, 98.2% of the Maspalomas data could be retrieved at ESOC and distributed.

In the case of Kourou, a total of 15 days in August and October could be retrieved via modem, though only days 222-231 (1992) were sent to CDDIS. Since the current autonomous download via PAD was installed on day 323 (1992), until day 79 of 1993 data was lost only during one continuous period between day 363 (1992) and day 003 (1993) due to a receiver PROM replacement problem. The overall data availability was thus 93.1 % since November 1992, and no data at all was lost in this time due to data link problems.

DESCRIPTION OF THE SOLUTIONS OBTAINED

GPS data acquired since the beginning of the IGS 1992 campaign on 21 June 1992 have been analysed to obtain orbits, earth orientation parameters and ground station positions. The terrestrial reference frame is defined by fixing a set of 11 stations whose coordinates have been provided by Boucher and Altamimi[3] in ITRF91. The celestial frame used is J2000.0, and the transformation to the terrestrial frame includes the celestial pole offsets from IERS Bulletin A.

The measurement input consists of double-differenced phase, in the ionosphere-free combination. Linearly independent double-differences are computed starting using the sites shown in Figure 2. Six minute sampling and 20 degree minimum elevation cut-off is applied. Solutions have been computed on all days, including those when AS (anti-spoofing) was applied.

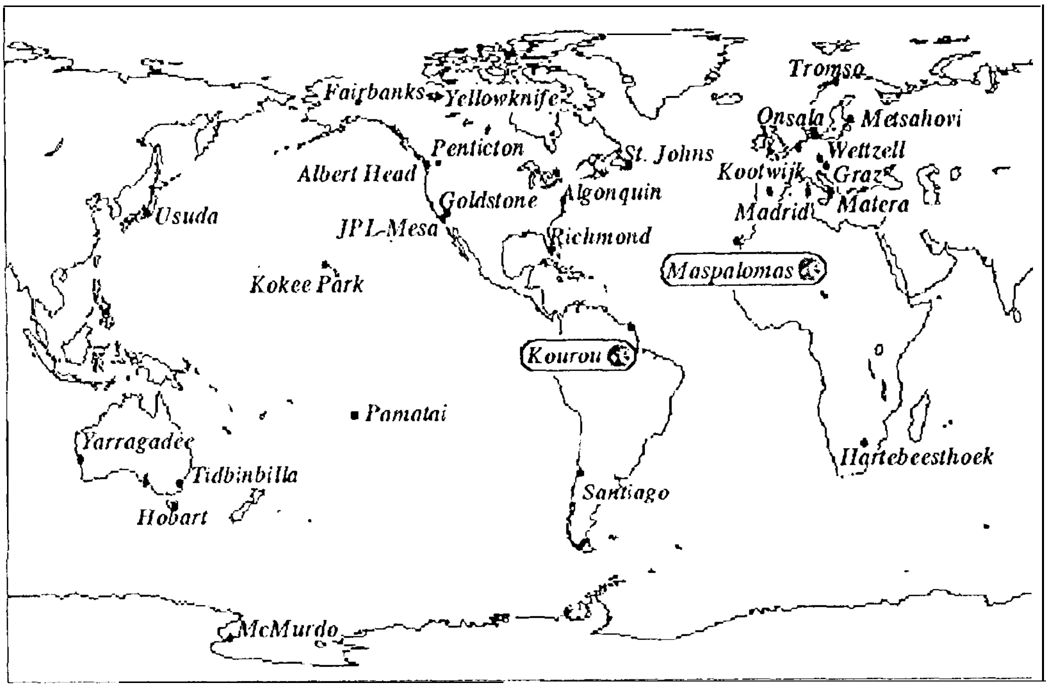


FIGURE 2. Network used for forming double-differenced phase measurements

Models and Constants Used

The recommended IERS Standards[4] are generally followed. Exceptions are that the Nuvel-1 NNR (no net rotation) model is used consistently, and that ocean loading and relativistic corrections are not applied. The GEM-T3 gravity field is used, to n=m=8, including $C_{21}=-0.17\times10^{-9}$, $S_{21}=1.19\times10^{-9}$ with GM=398600,4415 km^3/s^2. Direct luni-solar gravity and solid earth and ocean tides are modelled. The ROCK4(2) radiation pressure and thermal models are used in the formulation of Fliegel et al.[5]

Adjusted Parameters

The parameters adjusted in each daily run are:

Satellite parameters per spacecraft:

- satellite position and velocity at each daily epoch
- scaling factor for the solar radiation pressure model (T 10 or T20)
- Y-bias acceleration

Station-related parameters per ground station:

- station position (if not one of the fixed stations)
- 3-hourly atmospheric zenith delays parameters
- double-difference phase ambiguities as real-valued parameters

Earth orientation parameters

- pole coordinates x_p, y_p and the rate of change of UT1 ("LOD", change in length of day) per day as step function

The solar pressure scaling factors G_x and G_z in spacecraft X- and Z-axes are held fixed to the value 1. The coordinates of the following sites are held fixed: Algonquin, Fairbanks, Goldstone, Hartebeesthoek, Madrid, Matera, Onsala, Santiago de Chile, Wettzell, Yaragadee and Yellowknife.

Changes in Processing Strategy

The history of the changes in the processing strategy since the beginning of IGS '92 areas follows:

- 9 August 1992 (see IGS Mail No. 78): an updated set of coordinates was adopted from IGS Mail No. 65.
- 18 August 1992 (see IGS Mail No. 108): data processing in 30 hour arcs centred on the 24 hours of each UTC day.
- 3 September 1992 (see IGS Mail No. 93): updated station coordinates from IGS Mail No. 90.
- 20 September 1992 (see IGS Mail No. 114): a priori constraints are given to the estimated parameters (satellite position 100 m, velocity 1 m/s, radiation pressure scaling factor 5%, Y-bias 2×10^{-6} N, pole coordinates 5 masec, station positions 20 cm).
- 11 October 1992 (see IGS Mail No. 123): elevation cut-off changed from 10 to 20 degrees.

- 15 November 1992 (IGS Report No. 27): data span reset to 24 hours. LOD estimated daily, with a priori constraint of 0.5 ins/d.

Early in the campaign about 14 stations were being processed daily, but by August 1992, this had increased to more than 20, and since November 1992 between 24 and 28 stations have been included in the daily solutions.

Outline of the Solutions

Earth Orientation.

Figures 3 and 4 are plots of the polar motion and LOD obtained. The results are compared with IERS Bulletin A.

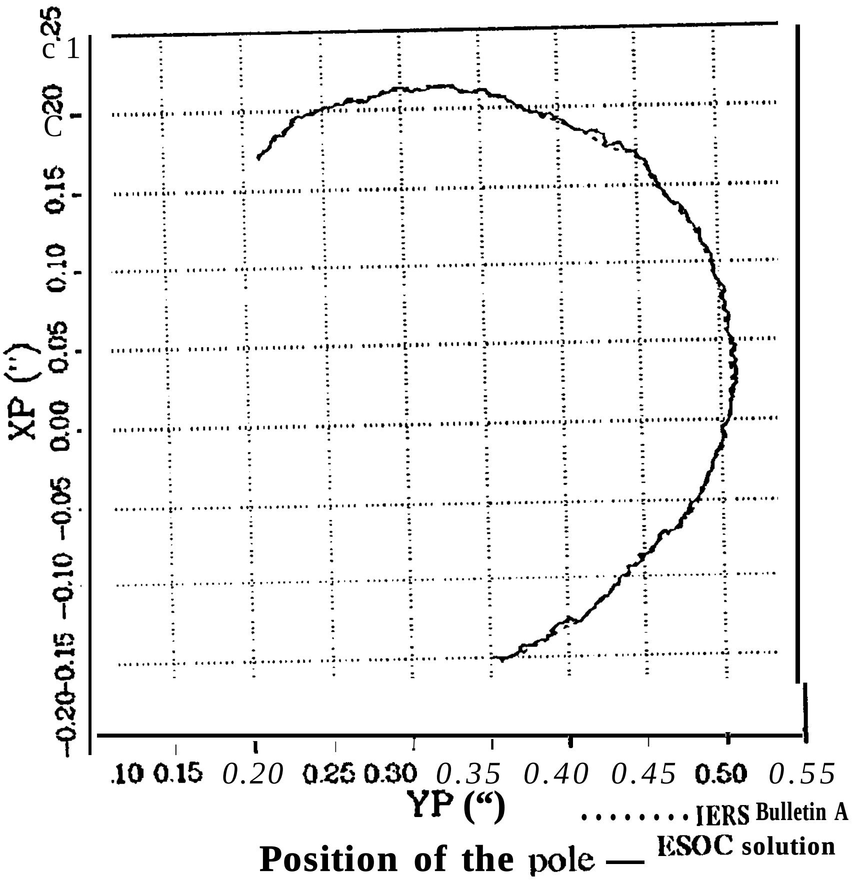


FIGURE 3. Polar motion 21 June 1992 to March 1993, EOP(ESOC)92 P 02

GPS Orbits,

Whereas at the start of the IGS campaign, orbits were being computed for 17 orbiting spacecraft, currently (March 1993) 22 satellite orbits are being determined in each daily run of the software.

One potential way of improving the accuracy of the solutions could be to process longer arcs of data, with possibly finer resolution in some parameters. Figure 5 illustrates a test of

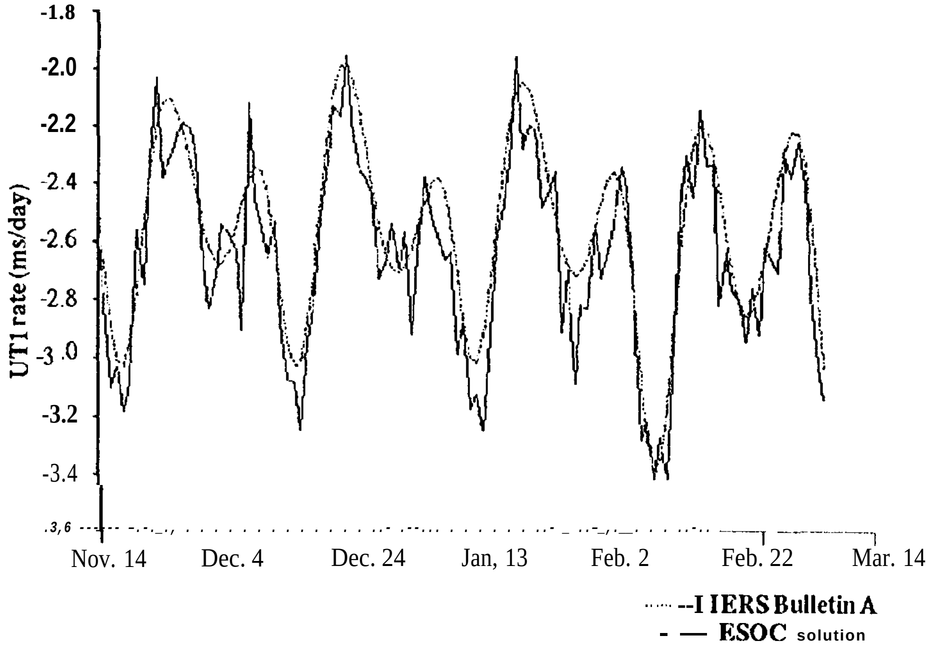


FIGURE 4. UT1 rate 21 June 1992 to March 1993, EOP(ESOC)92 P O

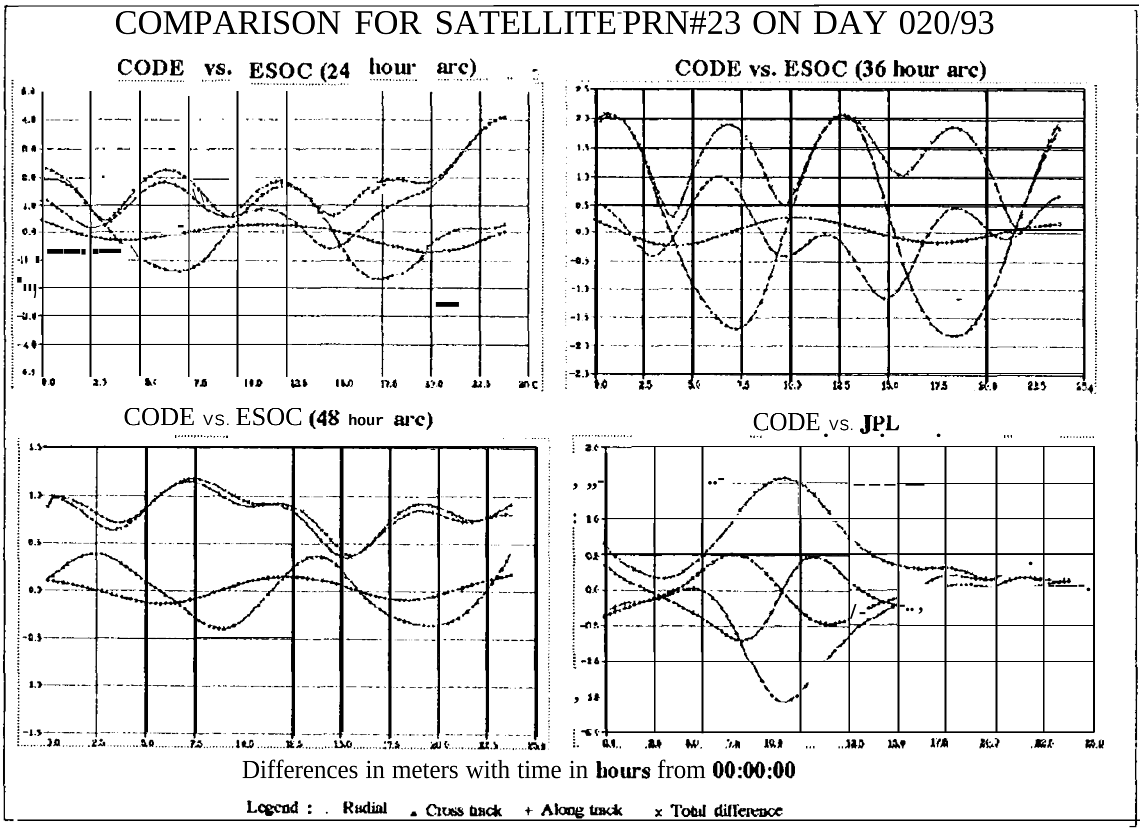
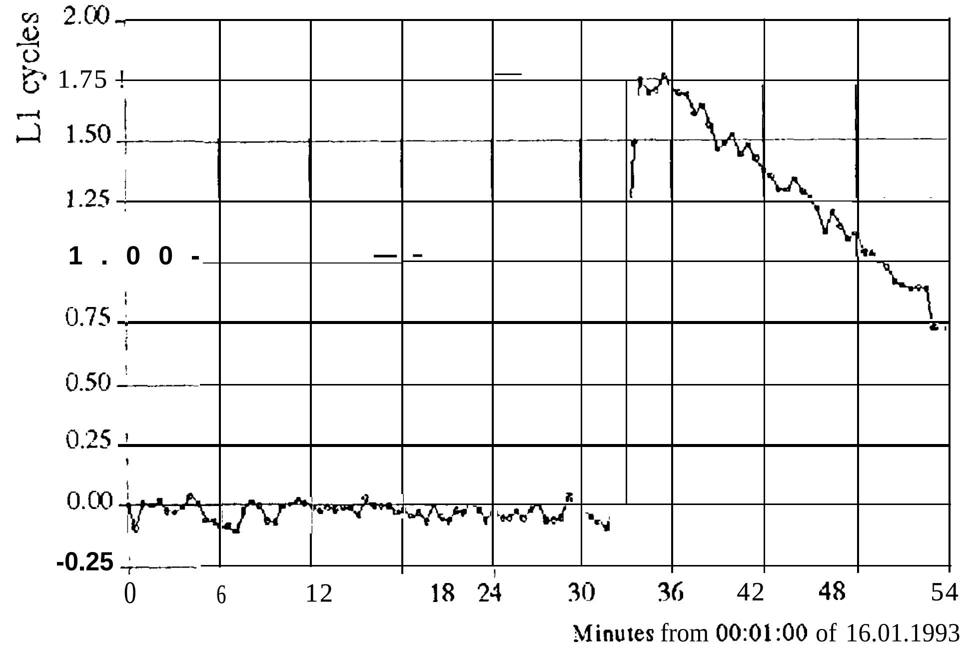


FIGURE 5. Comparison of 24,36 and 48 hour orbit solutions

this. Solutions of 24, 36 and 48 hours are compared with the solutions of the University of Bern (CODE) and JPL, showing that 24 hour arcs are not optimalThe approximate times of orbital maintenance manoeuvres of the GPS spacecraft are usually announced in advance, and can cause major degradation in the solution if not properly modelled. The effect of manoeuvres is easily recognised in the residuals of the double-differences, and even better in triple differences (see Figure 6). The time of the manoeuvre can be determined very accurately from such a plot. Our orbit determination software allows estimation of manoeuvres, so that we are not constrained to omit spacecraft from the solution for this reason. Several cases were announced in our weekly IGS Reports.

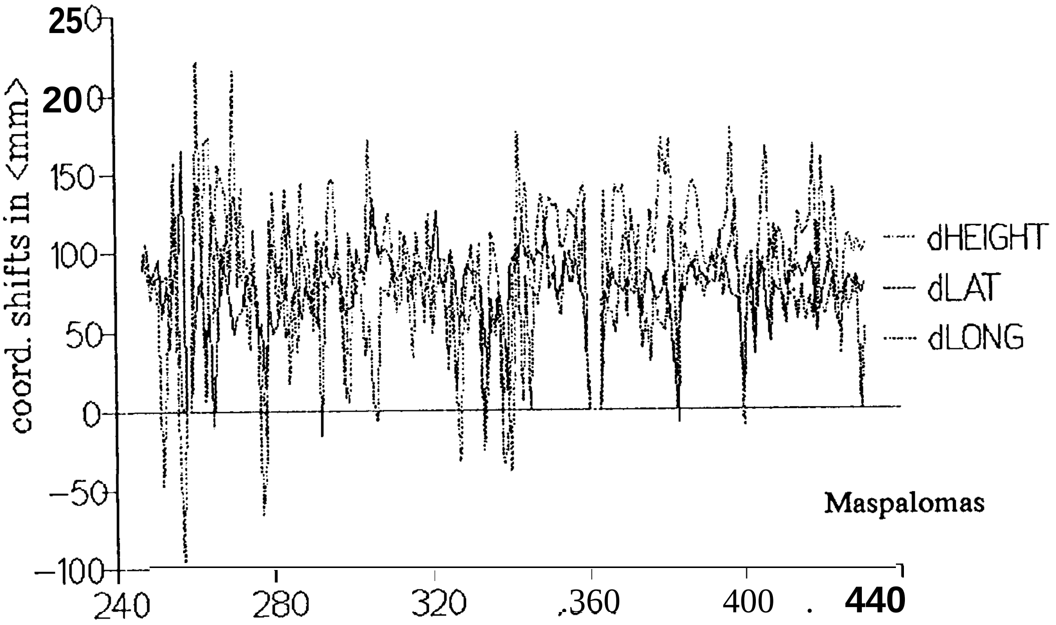

Difference between observed and computed triple differences
for stations Fairbanks and Kokee Park and
satellites PRN#16 and PRN#19

A manoeuvre was estimated at 00:33:30 for satellite PRN#19

FIGURE 6. GPS spacecraft manoeuvre identification using triple differencesStation Coordinate Solutions

Daily estimates of the coordinates of a number of stations are obtained in the solution. Figure 7displays the offsets obtained for Maspalomas and Kourou. The coordinates of the latter are significantly less stable, reflecting its isolated position in the network.

A more systematic approach to deriving a consistent and improved set of station coordinates has been tried recently by combining a total of 33 days of data in a simultaneous solution for the coordinates of 30 stations (Martin Mur et al.[6]). Various approaches were tried in order to optimise the application of constraints, in order to maintain a close agreement with ITRF91 in origin, orientation and scale. These coordinates are now (March 1993) being held fixed in our daily solutions.



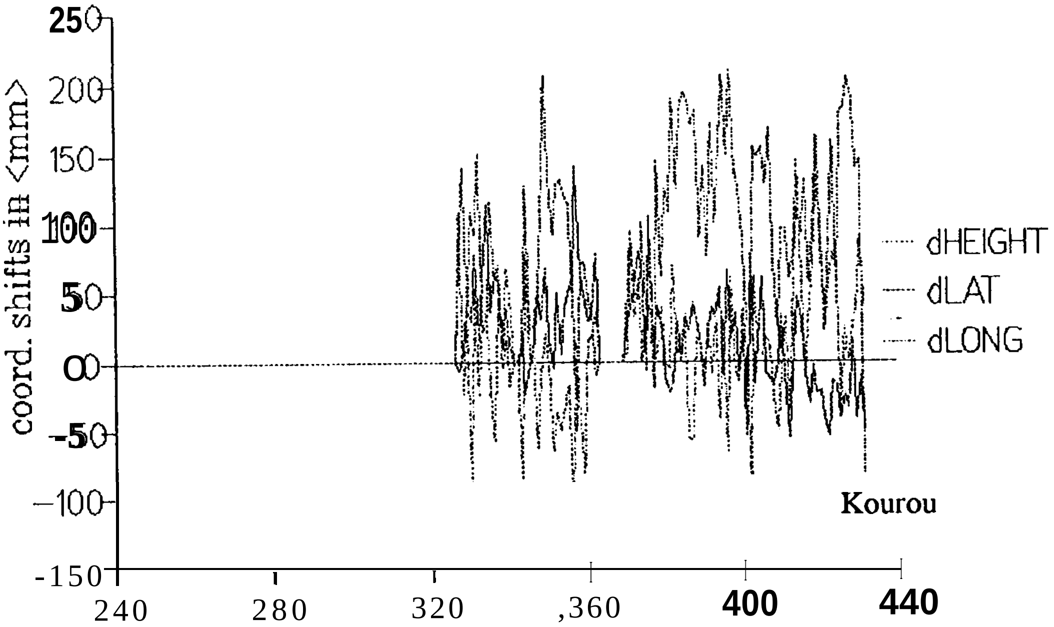


*FIGURE 7. Daily estimates of **Maspalomas** and **Kourou** positions (days from beginning of 1992)*

OUTLOOK

The IGS 1992 campaign was a success to an extent which could not be predicted even shortly before it began. It clearly demonstrated the capabilities of GPS for routine monitoring of earth orientation and station positions with high accuracy and temporal resolution. The daily determinations of the GPS orbits are providing a good foundation for the use of GPS for determining the orbits of near-earth satellites.

Future developments at ESOC in the context of IGS will include further receiver deployments, and improvements in the software capabilities and in the way the software is operated.

Receiver Deployments

The network of stations at which receiver deployment is foreseen is shown in Figure 8. A key site for augmenting the almost zero coverage of the African continent is the Malindi station. A suitable location for a GPS antenna on the Malindi site has been identified, and the installation is planned for late 1993. Installations at Kiruna (Sweden), Perth (Western Australia), Villafranca (Spain) and Odenwald (Germany) will be carried out during spring and summer 1993. Apart from their application to IGS, there is a strong interest in using GPS to improve ionospheric modelling at these sites, which all track ESA satellites in S-band frequencies.

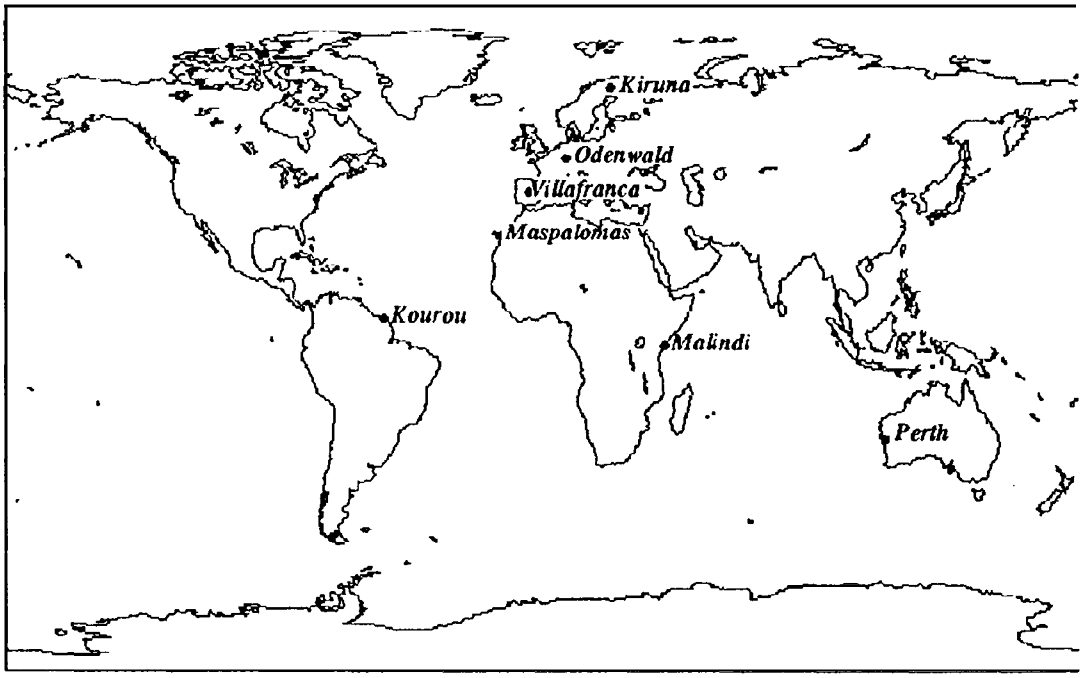


FIGURE 8. ESA ground stations to be equipped with GPS receivers

Software Upgrades

Upgrades to software and processing techniques will include the following:

- Optimisation of the arc length and parameter selection
- Continuing improvement of the station coordinate solutions
- Automation of the IGS operation, in order to allow more time for software development and off-line analysis of special problems. Significant steps have been made in this direction, and preliminary results suggest that automatic operation should soon be possible routinely.
- Conversion of the orbit determination software to a Unix workstation environment is in progress. This will simplify our internal computer interfaces, which currently involve two mainframes and a PC.
- Additional modelling efforts, e.g. ocean loading and better velocity field modelling for all stations; non-gravitational forces.

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IGS DATA PROCESSING AT THE EMR MASTER ACTIVE CONTROL SYSTEM CENTRE

J. Kouba, P. Tétreault, R. Ferland and F. Lahaye
Geodetic Survey Division (GSD),
Surveys, Mapping and Remote Sensing Sector (SMRSS),
Energy Mines and Resources (EMR),
615 Booth St., Ottawa, Ont. Canada, KIA 0E9

ABSTRACT

The EMR Master Active Control System Centre at the Geodetic Survey Division has been processing GPS data from six Canadian sites and selected IGS global core stations and generating precise orbits and EOP on regular basis using GIPSY II since August 1992. The EMR precise orbits and EOP results have been contributed weekly to the IGS Coordinating Centre and the International Earth Orientation Service (IERS). Internal and external comparisons and analysis indicate the precision of the EMR orbit/EOP solutions approaching 20 cm and 0.5 mas, respectively. This precision corresponds to an orbit error contribution of about 2ppb for baseline determinations, which is consistent with the repeatability of EMR daily solutions for unknown station positions.

INTRODUCTION

The Geodetic Survey Division (GSD), SMRSS acquired state of the art computer hardware and software for precise orbit computation to support the Active Control System (ACS). Two orbit determination software packages, MicroCosm (a commercial version of NASA Geodyn 11) and the GIPSY II/ OASIS system developed by the Jet Propulsion Laboratory, were acquired and installed on HP9000/700 series UNIX platforms, The two independent orbit determination systems and the global GPS data set available from the International Geodynamics GPS Service (IGS) have been used to develop EMR orbit estimation strategies. In this way the IGS project considerably enhanced the ACS capabilities and precision.

Since August 1992 the GSD's Master Active Control System (MACS) center has been reducing GPS data from the six Canadian ACS stations augmented with data from up to 12 stations of the IGS global core network. Both GIPSY II and MicroCosm were used initially for comparison of results and after extensive testing, GIPSY II has been adopted for daily processing. The GIPSY 11 processing has been highly automated using UNIX scripts to consolidate and integrate procedures into a single run, greatly simplifying and speeding up the processing. The processing system set up permits addition/deletion of stations, tolerates missing stations/satellites, allows different weighting on different stations, changes of reference station for timing, uses default or specific data directories, archival of the orbit/ EOP solutions in selected IGS formats, etc. Initially, since the prime objective was to generate precise GPS orbits over Canada in the shortest time possible, we used data from all Canadian ACS stations and some 10 globally distributed IGS core stations, from which five stations were constrained at the IGS coordinates (ALGO, FAIR, TROM, WETT, YAR1 in Figure 1). Since October 1992 we have been including three additional stations (HOLB, MCMU and PAMA in Figure 1) and increased the number of constrained stations to 12; DRAO,ALBH, STJO, PAMA, HOLB, KOKB are not constrained. All constrained station coordinates, adopted constants, gravity and radiation pressure models conform to the IGS/ IERS standards [2] [8]. The global ocean loading model due to Pagiatakis [9] has been adopted.

ESTIMATION STRATEGY

The EMR processing is based on undifferenced phase and smoothed pseudorange data at 5 minute sampling intervals using 15“ elevation angle cut off. Both phase and pseudorange observations are considered uncorrelated and weighted according to sigmas(a) computed from the following exponential model first suggested by Euler [4]:

$$\sigma(E) = \sigma_0 + \sigma_1 e^{-(E/E_0)} \tag{1}$$

where E is the elevation angle in degrees E_0 = 20, $\sigma_0 = 4mm$, $\sigma_1 = 15mm$ for phase measurements at all stations and $\sigma_0 = 180mm$, $\sigma_1 = 780mm$ for pseudoranges at most stations, Some stations (e.g. PAMA, STJO, YELL) have higher pseudorange noise due to multipath and are being weighted accordingly. We have also enhanced the GIPSY H software to allow different weighting of satellites, data segment deletion and corrections of biases. This proved to be useful for data reduction as AS satellites can be down weighted, deleted or bias corrected.

We have adopted 24h arcs without any data overlap. For each 24h arc, the initial a priori state vector is taken from the previous day solution and propagated to the beginning of the current day making our estimation process self contained, Broadcast orbits are used only when introducing a new satellite, or after large gaps such as those due to early receiver hardware problems associated with AS tracking. Use of the previous arc solution is not only more accurate than the broadcast orbit initialization, but it also offers a self check on daily solutions and an early indication of orbit errors and/or problems relating to a particular satellite. The differences between the state vector estimates for successive days are typically below 1m and values larger than 1.5m are usually reported in the weekly summary files. In most cases” larger differences have been found for eclipsing satellites. This approach also facilitates another type of orbit modelling and estimation of DUT1. Assigning a priori orbit sigmas of 1m and 0.5mm/s in fact approximates a random walk stochastic process with daily updates and sigmas of 1 m/√day and (.5mm/s)/√day. This is due to the fact that the other sigmas are much smaller, typically below 10cm and 0.03mm/s. As a consequence of the collinearity between DUT1 and the R.A. of ascending orbit nodes, the estimated DUT1 contains the DUT1 changes as well as the orbit node errors common to all satellites with sigmas and correlation characteristic of a random walk process, i.e. the covariance between day i and i+1 is:

$$\sigma^2_{i,\,i+1} = \sigma^2_{i,\,i} \cdot \qquad (2)$$

The variance $\sigma^2_{i,\,i}$ increases approximately with the √i, where i is the number of days since the DUT1 initialization. DUT1 is initialized the first non AS day of the GPS week using the most current USNO/IERS Bull. A values. The summary of estimated parameters, their a priori values and sigmas are listed in Table 1.

Table 1

Summary of estimated parameters, a priori values and sigmas

Parameters	Type	A, priori values	A priori sigma
Stations (X,Y,Z)	Constant	IGS/ITRF91(1 992.5)	50rn/.002-.02m
Pole (x,y)	Constant	IERS/USNO Bull. A	3m
DUT1	Constant	IERS/USNO Bull. A	3m/Fixed: each week
Trop. Zenit. delay	Constant	2.0m	.2m
Satellites states (X,Y,Z,dX,dY,dZ)	Constant	Previous day solution	1 km, 0.005 m/s or 1 m, 0.0005m/s
Sol. rad. (Gx,Gz)	Constant	1.0 (100.0%)	.1 (lo%)
Sol. rad. Gy	Constant	0.0 m/s^2	1.010-9 m/s^2
Phase ambiguity	Constant	0.0 km	300000km
Tropospheric bias	Rand. walk	0.0km	.01m/√h
Station Clock	White noise	0.0 s.	1 s/Fixed:ALGO Maser
Satellite Clock	White noise	0.0 s.	Block I: 0.001 S. Block II: 0.0001s.

PRODUCTS

For every day, on a weekly cycle, EMR has been generating and contributing to IGS/IERS precise orbits/clock in sp3 format and the EOP estimates. In 1992 the days when AS was invoked were not contributed. EMR orbit/EOP results are uploaded weekly onto the NASA CDDIS and the EOP to IERS and USNO. Typically, our products are submitted within one week from the last observation. The orbits/EOP products are also available locally from the EMR analysis centre through anonymous ftp to authorized users. The orientation and to a large extent the scale of the EMR orbit/EOP solutions are nominally those of ITRF91 (epoch 1992.5) as realized through the set of up to 12 stations constrained at the ITRF91 coordinates which are primarily based on VLBI solutions. Also the DUT 1, which is initialized once a week using the most current IERS/USNO Bull. A predictions, is derived mainly from VLBI DUT1 solutions. The satellite clock information included in EMR sp3 orbits is given with respect to the ALGO station which uses a Hydrogen Maser frequency. The ALGO clock error estimates, with respect to GPS time, have typically been within 1 microsecond and are reported with EMR results. The EMR clock solutions in the orbit files had a scale error of 1.0006923 until Jan 10, 1993. When ALGO is not observing, the time reference uncertainty may cause an apparent drift common to all satellites. To prevent possible problems it has been decided to omit such clock solutions and report an error of 99999 microseconds in the sp3 orbit files. Currently we are introducing a new clock estimation strategy and in the future satellite clock errors in EMR orbit/clock solutions will be referred to a mean time reference based on a priori timing information for all GPS satellites and based on selected stable station clocks. A priori clock information is generated daily during the preprocessing and data validation [6]. In this way clock error gaps present in EMR sp3 orbits will be eliminated and the clock errors will be closely related to the GPS time.

Due to the independent daily arc orbit estimation, there are discontinuities between arcs. Typically these are below 1 m and are caused mainly by the current orbit modelling; discontinuities larger than 1.5m are usually reported in the summary reports. Smaller discontinuities between days are also caused by the introduction of a priori EOP drifts derived for a 24h period from the Bulletin A for the pole and DUT1. While this does not affect the EOP solutions based on the full 24h period referred to the middle of the day, it may increase the magnitude of discontinuities when the a priori EOP drifts are incorrect. Since we do take care to utilize the latest EOP predictions, the drift errors are expected to be less than 1 mas (12cm) for the estimated (24h) period.

QUALITY CONTROL AND RESULTS

Quality control is performed in several stages. First, as already mentioned above, the orbit corrections to previous day solutions are typically below 1 m and in effect compare the two adjacent arcs. Secondly, the pseudorange single point positioning based on the precise orbit/clock corrections provides a simple but effective test and quality control at the sub-meter level in addition to accurate monitoring of station clock/receiver performance [6]. The most stringent quality analysis is performed by our collaborators at the Pacific Geoscience Centre (PGC) who utilize the EMR precise orbit/clock corrections, on a daily basis for crustal deformation monitoring of the Cascadia subduction zone on Canada's west coast. Repeatability of a few ppb on baselines ranging from 300 to 600km (ALBH-DRAO, HOLB-DRAO) are routinely obtained using special software and estimation strategies [3], which implies orbit accuracies of a few decimeters. It is interesting to note that systematic trends of a few ppb/year can be seen in observations spanning only several months. Any problems with orbit modelling and EOP solutions are apparent in their results and have been reported to us by PGC. This application demonstrates the importance of global services such as IGS/IERS and the use of independent techniques such as VLBI, SLR for local crustal deformation studies. From the Canadian cluster of stations we are solving for four unknown stations daily (ALBH, DRAO, HOLB and STJO). Figure 2 and 3 summarize the daily repeatability in latitude, longitude, height and distance for the DRAO-YELL (1496km) baseline as compiled from the daily solutions. These are expressed with respect to the ITRF91 (1992.5) coordinates for YELL, and the following improved set of coordinates for DRAO:

x= -2059164 .587m, y= -3621 108.390m and z= 48 14432.423m.

The repeatability is ranging from about 4.2 mm (2.8 ppb) in distance up to 11 .3mm in height. It also indicates a latitude error of a few cm for the YELL ITRF91/IGS coordinates. Figure 4 shows a summary of repeatability for baselines involving all four unconstrained Canadian stations. Table 2 summarizes the individual solutions with respect to the ITRF91 (1992.5) for the same four stations compiled from our daily processing.

Table 2
Repeatability in mm of daily solutions with respect to ITRF91 (1992.5) for all unconstrained Canadian stations

Station	**Latitude**	**Latitude**	**Longitude**	**Longitude**	**Height**	**Height**	**#of sol.**
	Mean	**σ**	**Mean**	**σ**	**Mean**	**σ**	
ALBH	-29	10	-20	13	16	17	112
DRAO	5	9	18	11	-3	16	111
HOLB	14	11	8	14	21	17	108
STJO	24	5	11	15	-16	14	116

The larger sigmas for STJO in Figure 4, are likely due to poor hardware performance and uncorrected cycle slips, in particular in the first half of the sample.

Both IGS and IERS rapid service bureau also provide valuable quality control and feedback on a weekly basis. Orbit comparisons between different series are regularly distributed by the IGS. From variances of the differences obtained by comparison of at least three independent orbit/EOP series one can deduce the RMS of individual series. Using the reported rms_{12} of the differences between the series 1 and 2, and rms_{13}, rms_{23} for the respective differences with the series 3, the rms_1 is:

$$rms_1^2 = (rms_{12}^2 + rms_{13}^2 - rms_{23}^2)/2 \qquad (3)$$

Having more than three series provides a check on the implied assumption of zero correlation between the series. The RMS mean values and their standard deviation based on IGS orbit comparisons for GPS weeks 670-684 for the five analysis centres reporting during this period are given in Table 3. Figure 5 shows the daily variations of the mean RMS analysis for the five analysis centres for the same period; gaps are due to AS related difficulties with the data acquisition and processing.

Table 3
RMS estimates based on IGS orbit comparisons for the GPS weeks of 670 to 684 for AIUB/CODE (Astronomical Inst. Univ. of Bern), EMR, ESA (European Space Agency) JPL (Jet Propulsion Laboratory) and S10 (Scripps Institute of Oceanography).

Centre	Mean RMS (cm.)	Standard dev. (cm.)	#of sol.
AIUB/CODE	32	14	91
EMR	18	5	91
ESA	68	12	83
JPL	26	17	78
S10	32	9	48

The RMS values in Table 3 have been obtained after 7 parameter transformations between series pairs. The RMS of rotations, scale and translations between the series are usually well below 1mas, lppb and 10cm respective y. A random orbital error of 20 cm represent about 2ppb [7] which is consistent with the baseline repeatability seen in Figures 2, 3, 4. Similar precision is also obtained for the navigation solutions with precise orbit/clock [6] corrections.

The EOP solutions by the IGS analysis centres are compared regularly by the central and the rapid service bureau of the IERS. Figure 6 shows differences between EMR -and the IERS (EOP90c04.92 and EOP90C04.93) series. The mean pole coordinate differences are 1.4mas for x and 1.1 mas for y while computed sigmas around the mean are respectively 0.7mas and 0.6mas. Similarly, mean differences of -7.8mas for x and 5.6mas for y, and sigmas of 0.7mas and 0.6mas have been obtained from comparison with the VLBI (NGS) pole coordinate series as reported in the IERS in Bulletin B(60). The large x coordinate difference on January 16, 1993 is most likely due to the low number and weak distribution of stations (13) in the EMR solution. The periodic variations of the LOD differences derived from DUT1 solutions can be attributed to weekly re-initialization of DUT1 using rapid service values and the lack of absolute orientation reference in the GPS system.

CONCLUSIONS

The active participation in the IGS, which promoted standards, facilitated effective data exchange and comparison of results world wide, has enabled EMR to advance the ACS developments, improve accuracy and revise the original system design [1]. The high accuracy of GPS ephemeris obtainable from a relatively sparse network of global core IGS stations (15 to 30) can support wide range of applications and simplify procedures for integration of regional station clusters and field GPS surveys while significantly reducing the need for conventional geodetic control monuments. The IGS 1992 campaign has demonstrated that sub-meter accuracy of GPS ephemeris is practically achievable if (a) high quality of GPS data is assured by using state of the art dual frequency receivers and atomic frequency standards at sites with favorable conditions (low multipath and radio interferences), (b) the global core stations network contains a sufficient number (>15) of fiducial points for which the coordinates are constrained to a consistent set of a priori values derived from complementary space techniques (VLBI, SLR, LLR), and (c) the system orientation is regularly updated using the IERS UT1 determinations based mainly on VLBI which provides the necessary connection to the quasar inertial reference. Further improvement in orbit modelling, near real-time data communication, processing and orbit forecasting will increase accuracy of the results and facilitate their proper integration on the global as well as regional scales. Establishment of a permanent IGS will form the foundation for effective and economical exploitation of GPS for both practical and scientific applications in the future.

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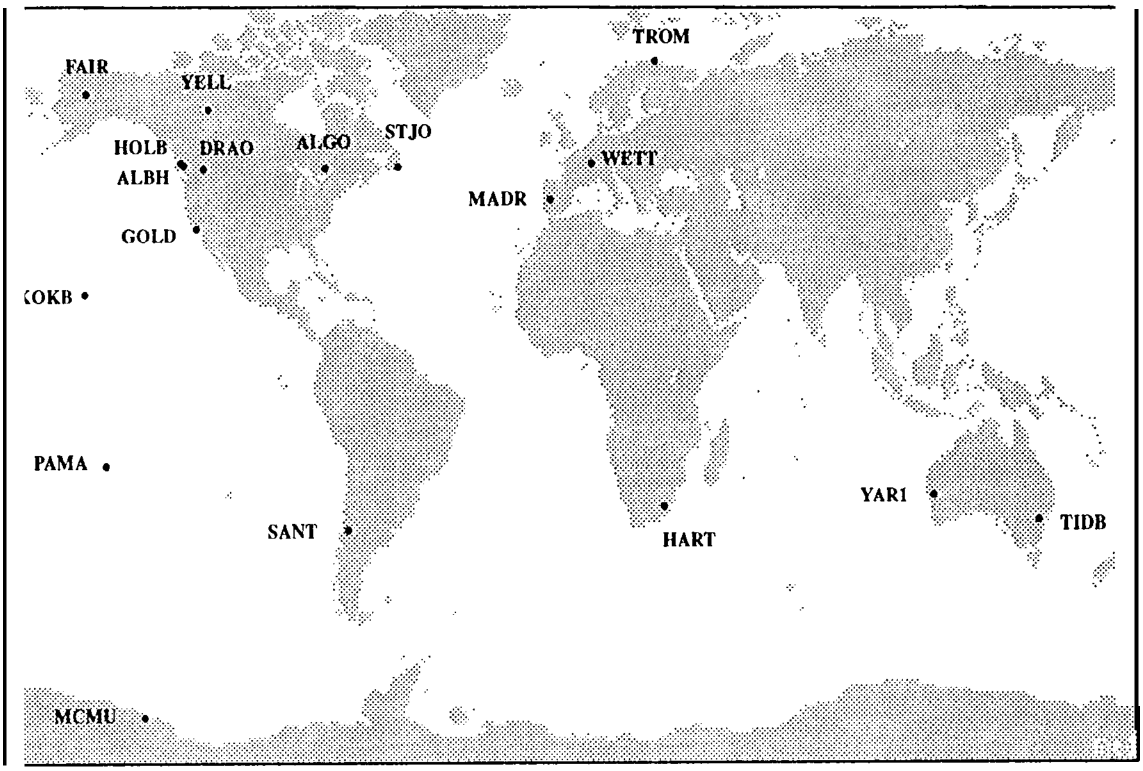

Figure 1: Global Network Used for the EMR Precise Orbit Computation

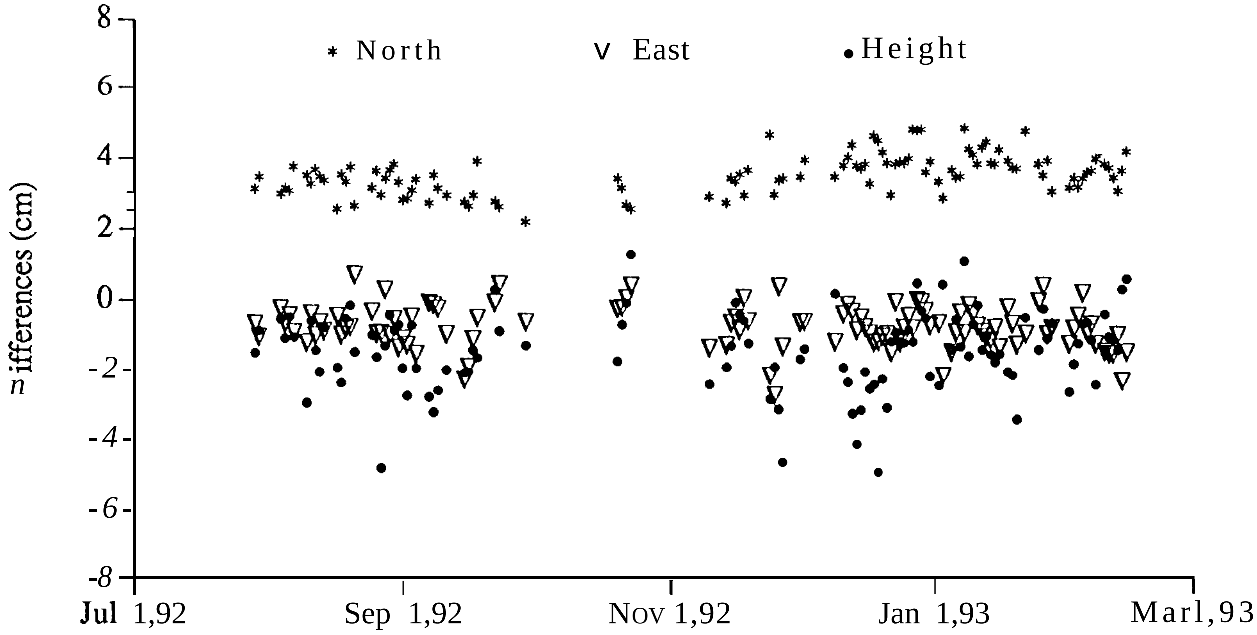

Figure 2: Repeatability of Coordinate Differences for DRAO-YELL Baseline (1496 km)

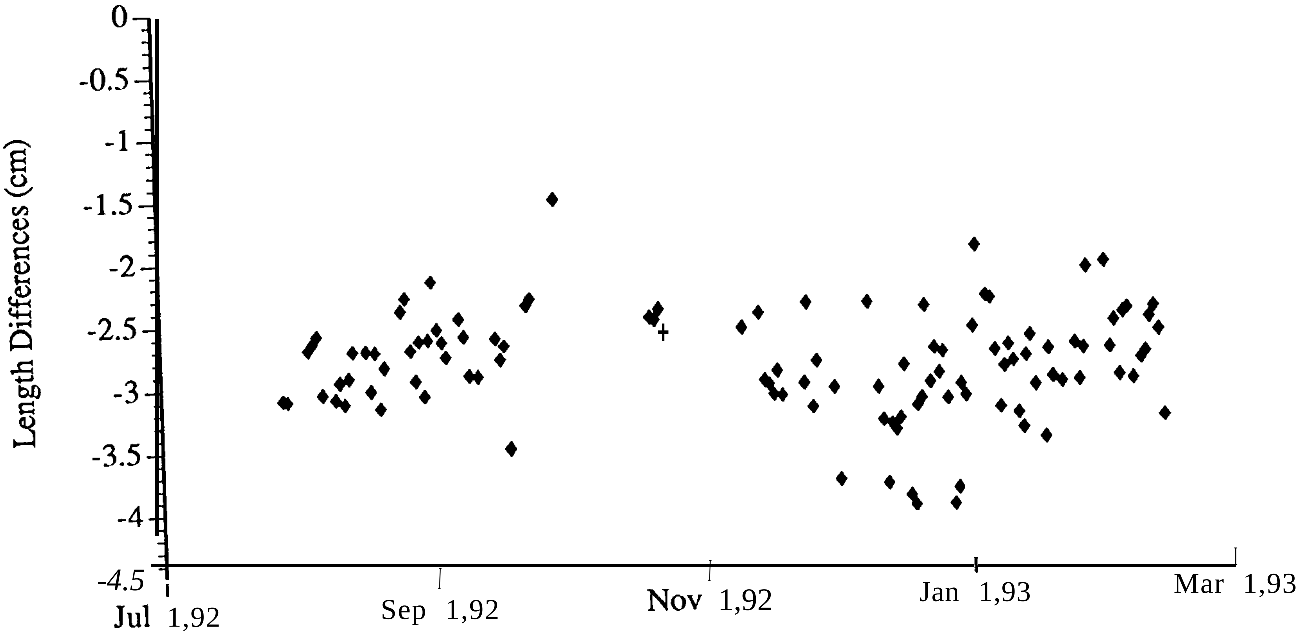

Figure 3: DRAO-YELL Baseline Length Repeatability (1496 km)

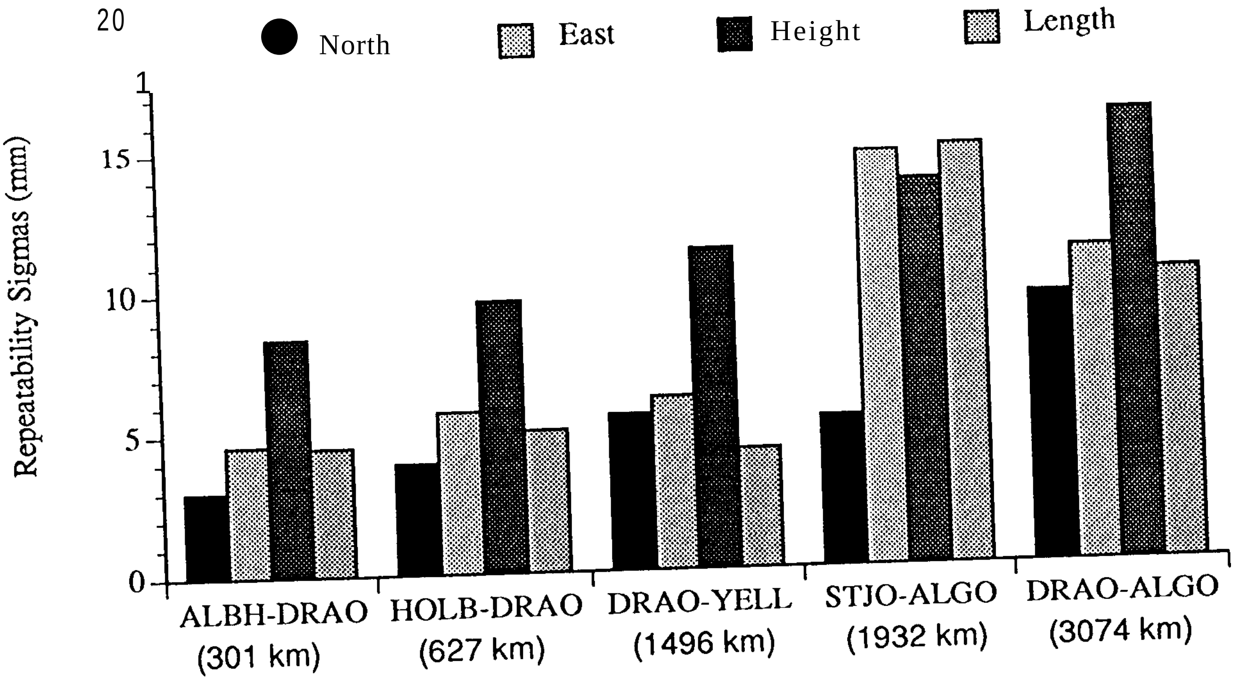

Figure 4: Daily Repeatability of Coordinates Differences and Lengths for Canadian Baselines

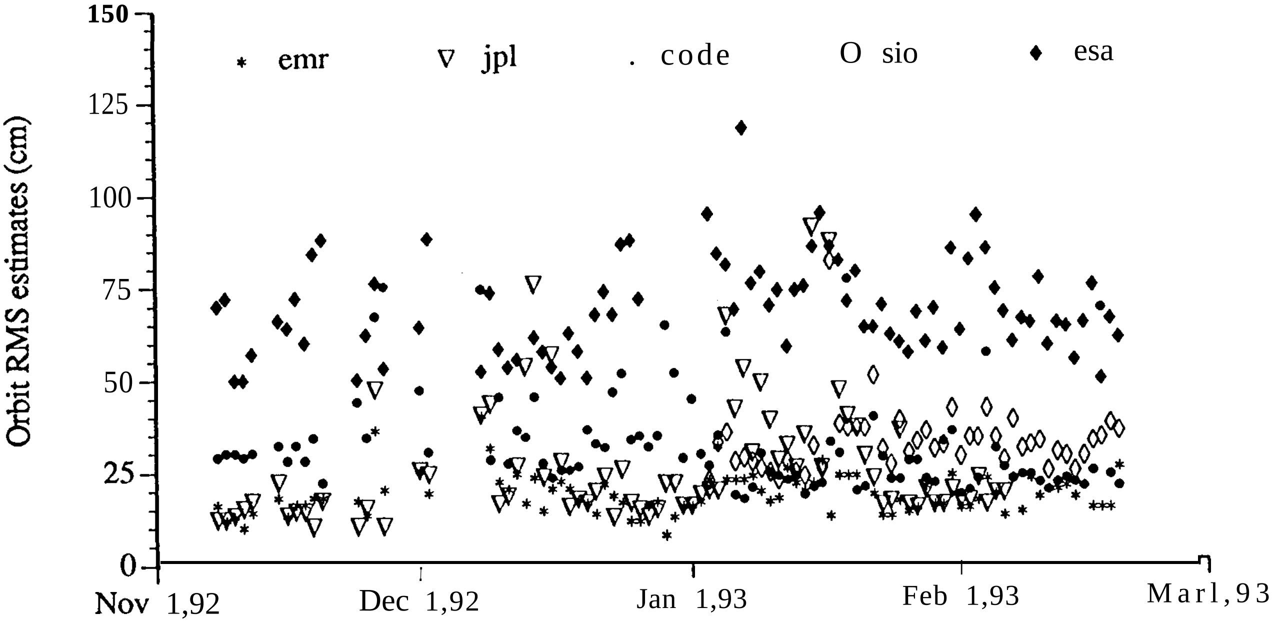

Figure 5: IGS Orbits Comparison

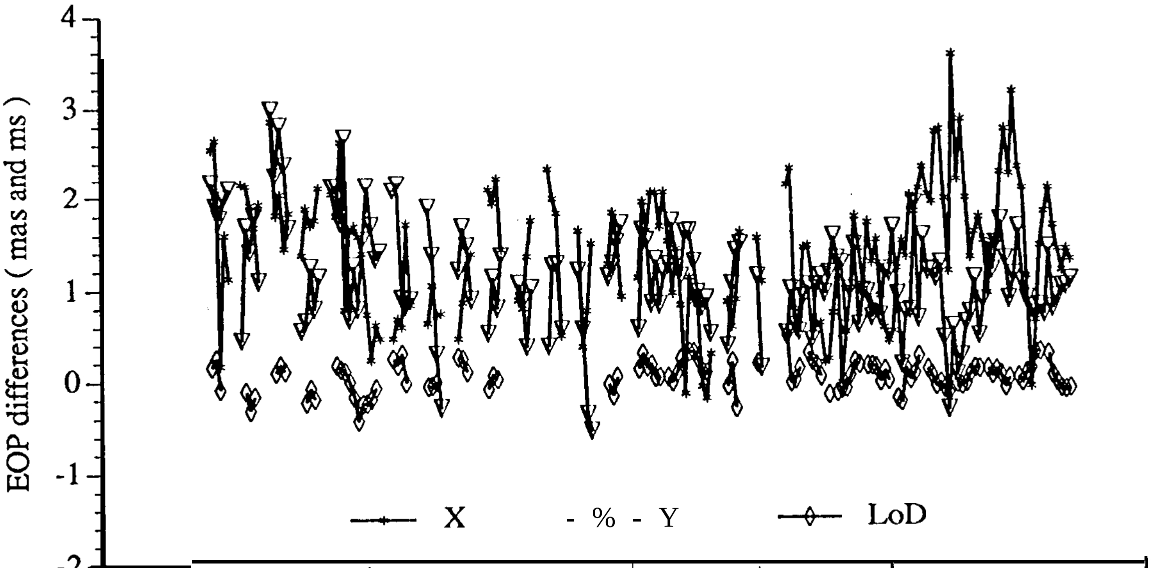

Figure 6: EMR - IERS(EOP90C04.92,EOP90C04.93 series)

Results of the IGS Data Processing at the "Center for Orbit Determination in Europe" (CODE)

M. **Rothacher, G. Beutler, W. Gurtner** *
S. Botton, C. Boucher ‡

Since the official start of the 1992 IGS Campaign on June 21, 1992, till now the IGS processing center CODE (Center for Orbit Determination in Europe) has computed satellite ephemerides and earth rotation parameters (ERPs) for all days, including the days when AS (anti-spoofing] was turned on. 'The highly automated daily processing produces as final results overlapping 3-days solutions using 3-days arcs and the GPS data from about 30 sites of the IGS tracking network. The quality of the ERPs and the consistency of the orbit results over a period of 9 months are presented. As an interesting by-product the estimates of the solar radiation pressure parameters (direct radiation pressure coefficient and y-bias) are available for the same period of time giving valuable information on the long-term variations of these parameters.
During the Epoch '92 Campaign, July 26- August 9, 12 globally distributed DORIS sites were equipped with Ashtech and Trimble receivers by the Institut Géographique National, Paris. The IGS data of the two weeks were reprocessed at CODE including the additional 12 DORIS sites to study, first the impact of the better site distribution (especially in the southern hemisphere) on the ERP and orbit results, secondly, the improvements to be expected from a stochastic orbit modelling. The results of these studies are discussed in this paper.

INTRODUCTION

The Center for Orbit Determination in Europe (CODE) was established by the Astronomical Institute, University of Berne (AIUB), the Federal Institute of Topography (L+ T), the Institut Géographique National (IGN), the Institute of Applied Geodesy (IfAG) to contribute to the IGS (International Geodynamics and GPS Service, see [1, *Beutler* G. *1992*]) as one of the processing centers. In order to process the GPS data of about 30 sites from the IGS tracking network day by day a highly automated procedure was set up at CODE (see [2, *Gurtner W. 1992*]) using as the main tool the *Bernese GPS Software Version* 3.4 (see [3, *Rothacher M. 1993*]). The routine processing at CODE started with the beginning of the 1992 IGS Campaign (June 21, 1992). Up to now every day (including all AS days) was

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* Astronomical Institute, University of Berne
‡ Institut Géographique National, Paris

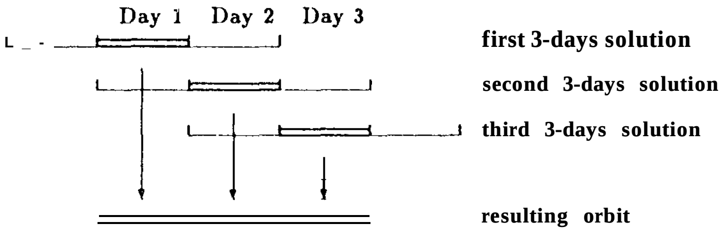
processed and ERP results, satellite ephemerides, and station coordinates were delivered to the IGS network centers.

In autumn 1992 we decided to recompute the IGS data of the Epoch'92 Campaign (July 26 - August 9) as recommended by the IGS oversight committee. In the course of these recomputations we included 12 additional global sites, namely the DORIS sites that were occupied by Ashtech and Trimble receivers during the Epoch'92 event. The IGN organized the observations and the data collection at these additional sites. The data processing was performed jointly by IGN and AIUB. This Epoch'92 data set was then used to compute the coordinates of the DORIS sites to obtain improved orbits for this important time interval, and to test new processing strategies together with a much better global site distribution. The stochastic orbit modelling was one of these new strategies to be tested.

ROUTINE IGS DATA PROCESSING AT CODE

Routine Processing Strategies and Options

The main products of the CODE processing center result from overlapping 3-days solutions according to the following scheme, where the result for the middle day of every 3-days solution is extracted to be delivered to the IGS data centers:



The 3-days solutions are computed using double difference phase observations and the ionosphere-free linear combination. The modelling follows the IG S standards given in [4, *Goad C.* 1992], i.e. the ROCK4/42 radiation pressure model, the GEMT3 earth potential coefficients up to degree and order 8, the gravity of sun and moon, the solid earth tides are used. Every 3-days solution is covered by 3-days satellite arcs. A 3 minute data sampling and an elevation cut-off angle of 20 degrees are used. Most of the VLBI/SLR sites are kept fixed to their ITRF91 coordinate values taking into account the ITRF91 velocity model. For such a 3-days solution the following parameters are estimated:

- Coordinates of the non-VLBI/SLR sites
-6 orbital elements plus the direct radiation pressure coeff. and the y-bias per satellite
-4 troposphere zenith delays per day and site
- Daily values of x- and y-pole coordinates and length of day (LOD)
- Initial carrier phase ambiguities

The approximate size of one 3-days solution may be characterized by 30 sites, 3000 parameters, 80000 double difference observations and a processing time of about 70 minutes on a VAX 4000/90 system (data formatting and preprocessing excluded).

Earth Rotation Parameter Results

Our series of ERP values over the entire period are given in Figure 1 and show a quality of about 1 mas and 0.8 mas respectively for the x- and y-coordinate of the pole compared to the IERS solution C04 (see [5, *Feissel M. 1993]).*

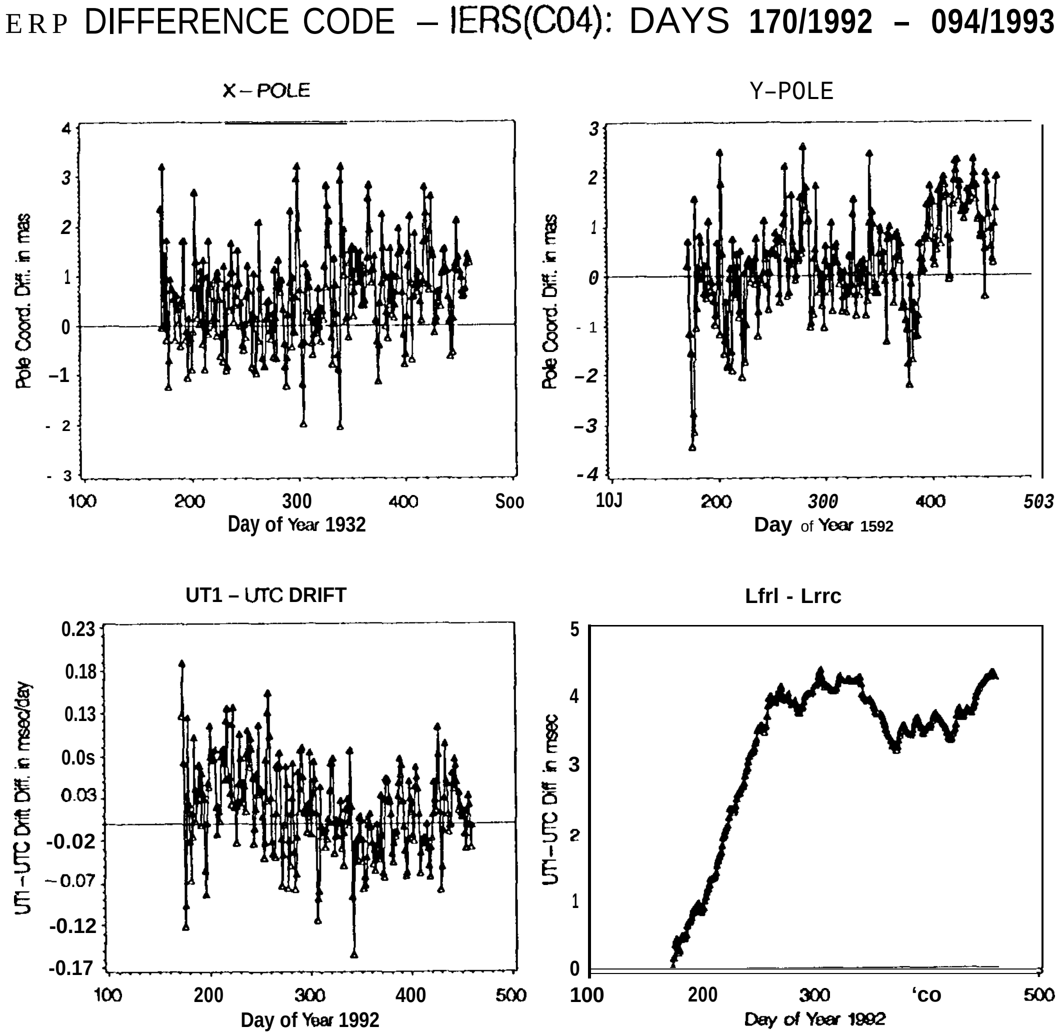


Figure 1: ERPs estimated from CODE Using 3-Days Solutions.

From the very beginning of the 1992 IGS Campaign LOD values were determined at CODE. The estimates of LOD from the 3-days solutions agree with the values of IERS on the 0.05 ins/day level. This LOD accuracy from 3-days solutions is the main reason to use arcs longer than one day. The pole coordinates as well as the orbit results are not considerably improved by using 3-days instead of 1-day solutions. By integrating the LOD values over

time we obtain a UT] -UTC series. Although these UT1-UTC values are deviating more and more from the IERS solution (as it may be expected from a random walk resulting from the integration of the LOD values) and show some long-term variations, the stability is still considerable, compared also to the results obtained using SLR techniques (see [6, ***Gambis** D. 1993]).* It is clear, however, that the long-term stability of our UT1-UTC estimates has to be taken from VLBI solutions.

Orbit Consistency

Because there is no direct method to estimate the orbit quality, most centers use overlapping intervals between subsequent solutions to check the orbit consistency. We perform a check by taking the middle days of three consecutive (overlapping) 3-days solutions and by fitting a new arc of 3 days through these 3 middle days. The rms of this fit is a measure for the consistency (or inconsistencies at the day boundaries) of the orbits. Figure 2 presents results of this check for the entire time interval for satellite 19. In general the consistency is on the 30-40 cm level. The orbit quality becomes somewhat worse during eclipse seasons (days 170-190 and 332-366). This consistency is very similar to the one obtained by comparing our orbits to the orbits of other processing centers (see [7, *Goad C.* 1993]).

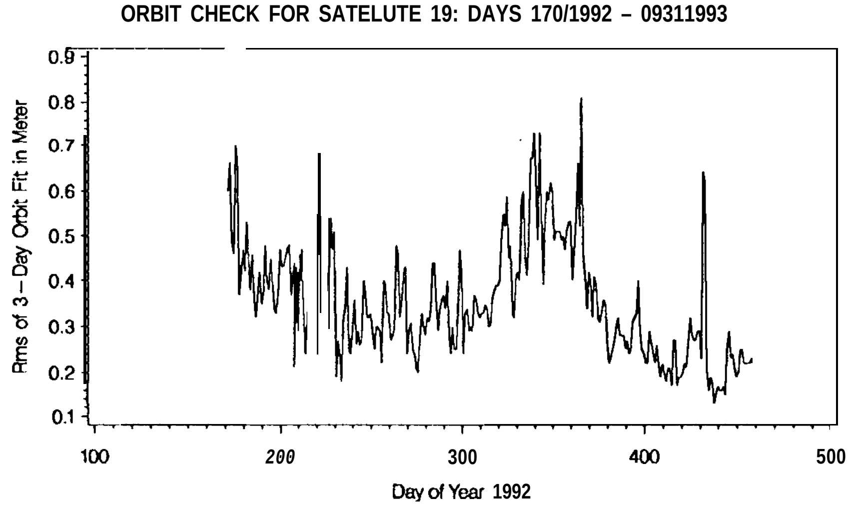


Figure 2: Rms Values of 3-Days Arc Fits Through Three Middle Days of Overlapping 3-Days Solutions for Satellite 19 (eclipse seasons days 170-190 and 332-366).

Radiation Pressure Model Parameters

As a by-product of our 3-days solutions we obtain very accurate estimates of the direct

radiation pressure parameter and the y-bias (acceleration in the direction of the solar panel axis) for each satellite. Having saved the values since the beginning of the 1992 IGS Campaign we dispose now of a time series of about 9 months. This enables us to study the long-term behaviour of these parameters.
In Figure 3 the direct radiation pressure parameters (difference to an a priori value) are presented for two different satellites.

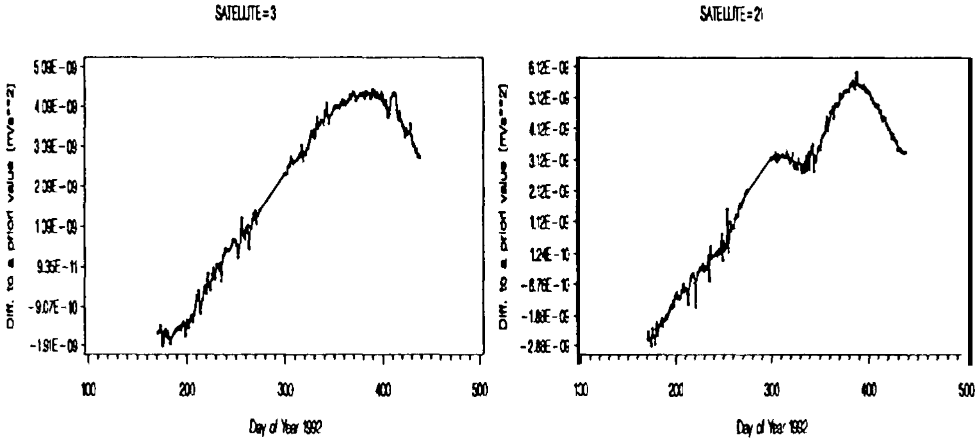


Figure 3: Direct radiation pressure parameters from 3-days solutions for satellites 3 and 21.

Both satellites (and all the other satellites not displayed here) show a common change of radiation pressure over time. This general behaviour common to all **satellites** reflects the change of solar radiation pressure with the varying distance between the sun and the earth (eccentricity of the earth orbit around the sun) according to the simple formula

$$p_0(r) = p_0(r_0)\ .\ \$\ , \tag{1}$$

where

r, r_0: Distance between sun and satellite and distance of one 1 AU (astronomical **unit**) respectively

$p_0(r)$, $p_0(r_0)$: Direct radition pressure parameter at a distance r resp. r_0 from the sun

The earth's perihelion passage (the point nearest to the sun) near the beginning of January, when radiation pressure is expected to be maximal, very neatly coincides with the maxima seen in Figure 3. According to **Eqn.** (1) the maximum difference A p. in **radiation pressure between perihelion and apohelion should be**

$$A\,p_{o} = 4.\ e \cdot p_0(r_0)\ , \tag{2}$$

where e denotes the eccentricity of the earth orbit with a value of 0.0167. The resulting maximum difference of about 6.7 percent of $p_0(r_0)$ or approximately 6.7. $10^{-9} m/s^2$ (setting $p_0(r_0) = 1 \cdot 10^{-7} m/s^2$) is in good agreement with Figure 3.

After having removed the effect of the eccentricity of the earth orbit there still remain considerable systematic in the direct radiation pressure estimates as can be seen from Figure **4** especially for satellite 21 (different scale).

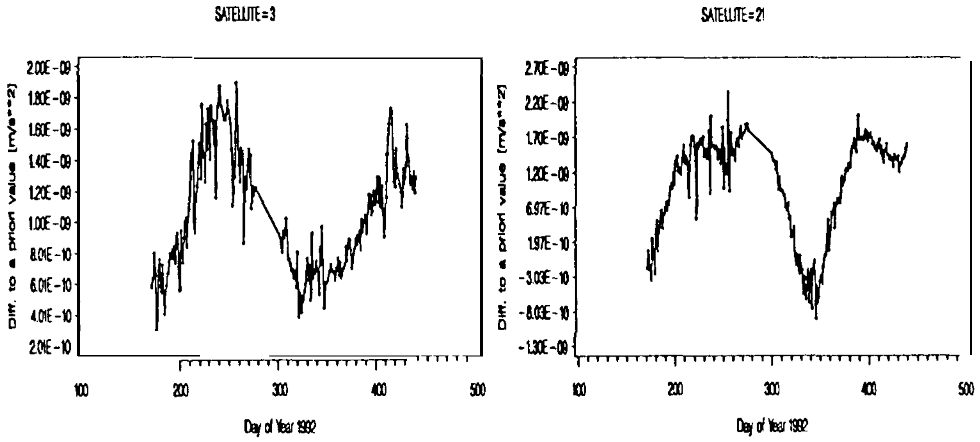


Figure 4: Direct radiation pressure parameters for satellites 3 and 21 after having corrected the eccentricity effect of the earth orbit.

These systematic do not coincide with eclipse seasons. A possible reason might be the changing orientation of the satellite orbit plane with respect to the longitude of the sun causing a variation in the cross-section and the parts of the satellite being irradiated. Obviously the ROCK4 /42 models, used as a priori models, do not efficiently correct these variations. After having removed the systematic part the rms scatter of the p_0-**estimates** is about 10 $10^{-10} m/s^2$.

The y-bias estimates show an even higher consistency of about 4010-1 $^1m/s^2$ as can be seen from the two examples in Figure 5.

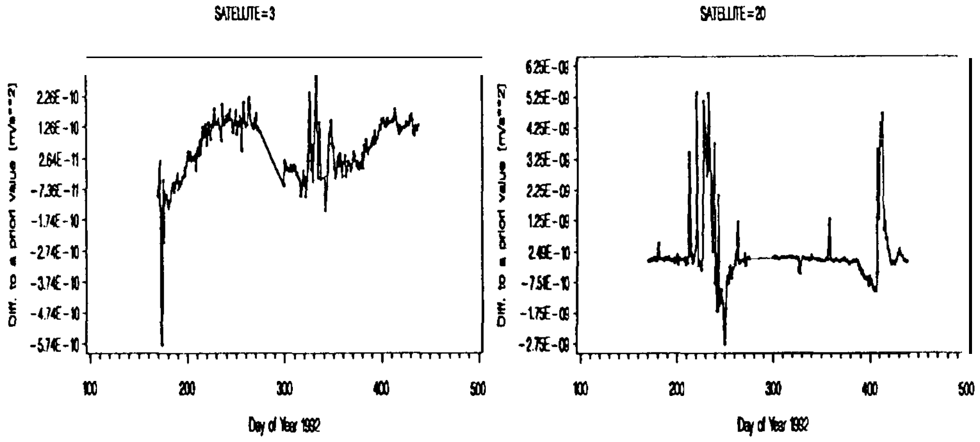


Figure 5: Y-bias parameters for satellites 3 and 20. Eclipse season: days 146-178 and 324-356 for satellite 3, days 214-266 and 387-434 for satellite 20.

Problems are encountered, however, during eclipse seasons (days 146-178 and 324-356 for satellite 3, days 214-266 and 387-434 for satellite 20) indicating that the solar panels of the satellite might be badly oriented during these periods or that still other effects pose difficulties in orbit modelling. Because of the precision of the estimates and the sensitivity of this parameter, it might be used as an indicator of satellite problems.

Figure 6 finally shows the p_0 and y-bias estimates for satellite 29 that was launched on December 18, 1992, and made available on January 5, 1993. The "warming-up" effect is visible in both radiation pressure parameters. Its cause is not clear yet (compare [8, *Fliegel H. 1992]*). Approximately one month after launch the radiation pressure parameter estimates are becoming stable.

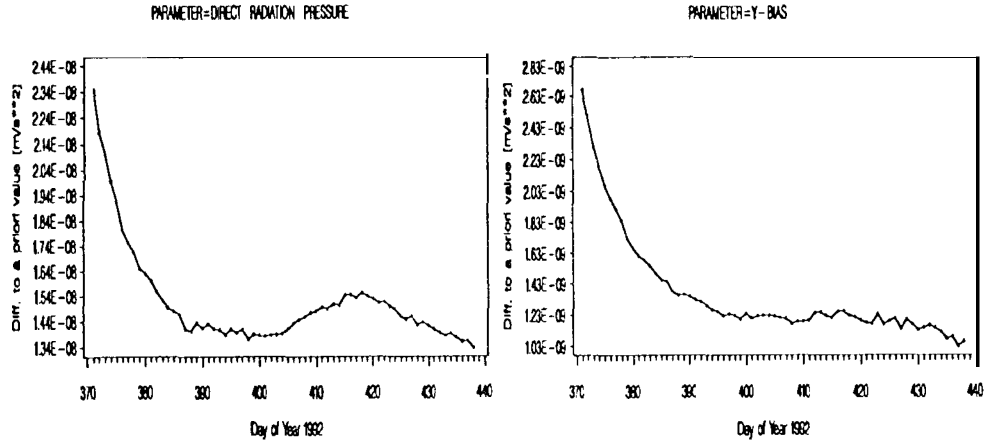


Figure 6: Direct radiation pressure and y-bias parameters for satellite 29 showing the "warming-up" effect after the launch on December 18, 1992.

EPOCH'92 PROCESSING

The Epoch'92 Network

The Epoch'92 Campaign took place from July 26- August 9, 1992. The global sites we used for the recomputation of this period are shown in Figure 7. Besides these IGS core sites 12 DORIS sites, observed by IGN, have been included into the network giving a much better global distribution of sites (especially in the southern hemisphere). These additional 12 sites were equipped with 5 Trimble and 7 Ashtech receivers (most of them having P-code on L_2, but not on L_1).

Epoch'92 Solution Types

Apart from the necessity to compute the best possible orbits for this important time period

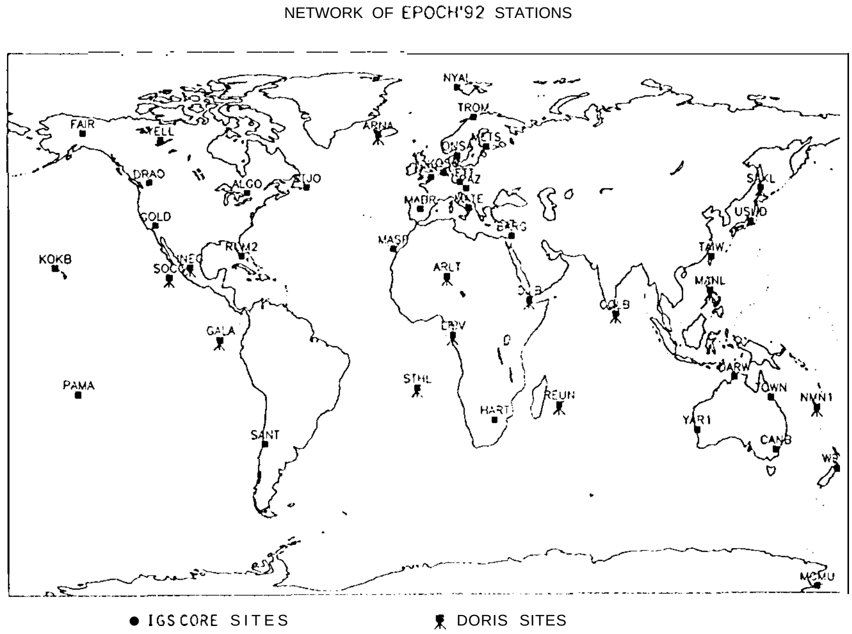


Figure 7: Global Network of IGS Sites plus 12 DORIS Sites.

Solution	Network	Orbit Modelling
1	IGS Network	Deterministic
2	IGS Network + 12 DORIS Sites	Deterministic
3	IGS Network	Stochastic
4	IGS Network + 12 DORIS Sites	Stochastic

Table 1: Epoch'92 Solution Types.

(because **of the many regional campaigns taking place during Epoch'92), it was the main goal of the reprocessing to study**

- the impact of adding the 12 DORIS sites (probably comparable to a future IGS network) on the ERPs, orbits, and coordinates
- **the** quality of the results, if the satellite orbits are modelled "stochastically".

In our "stochastic" approach small velocity changes are estimated once or several times per revolution of the satellite. These velocity changes are set up with a priori constraints. If many of these velocity changes are estimated per revolution, the term "stochastic" becomes meaningful. In the solutions computed here small velocity changes were estimated only once per revolution and only in the radial and along track directions. These changes were constrained by $1.10^{-5} m/s$. All the other options and parameters were the same as the ones outlined in section for the routine processing.
Table 1 lists the 4 solutions that were produced.

Earth Rotation Parameter Results

In Figure 8 the ERP results of the 4 solutions are plotted. The y-coordinate and (less clearly) the x-coordinate of the pole are somewhat smoother if the DORIS sites are included in the solutions. The stochastic orbit modelling on the other hand does not seem to have significant influence on the ERP results. This strong decorrelation between orbit and ERP parameters has been demonstrated by [9, *Springer T. 1993]* as well.

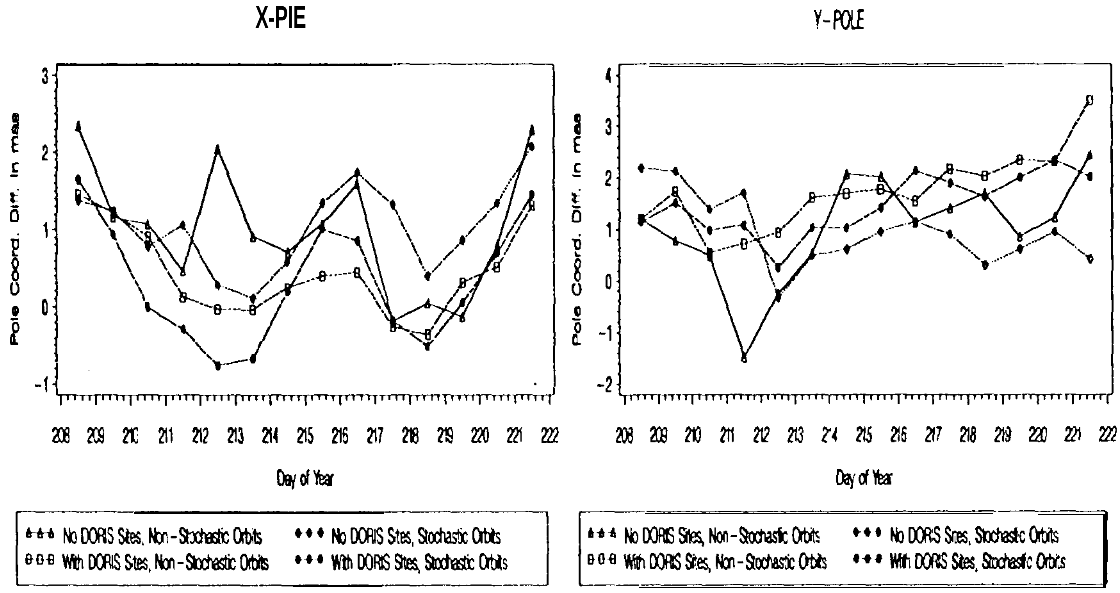


Figure 8: ERPs Differences “CODE” - IERS(C04) obtained from the Epoch’92 Solutions.

Orbit Overlapping Tests

The picture is a totally different one for the orbit quality as can be seen from the rms of the differences between two consecutive 3-days solutions in the along track and radial direction within a 2-hour overlapping interval. given in Figure 9 for all satellites on day 219. Whereas the addition of the 12 DORIS sites does not lead to a large difference in the orbit overlap test (stochastic solution with and without DORIS sites), a drastic improvement is obtained in both components (along track and radial) by estimating stochastic orbit parameters. No improvement is visible in the out-of-plane component, for which no small velocity changes were estimated. With one exception (satellite 17) the orbits of all satellites benefit from the stochastic estimation. To correctly interpret these results it has to be said, too, that due to the estimation of stochastic parameters, the degree of freedom is increased so that the orbits tend to fit better the observations.

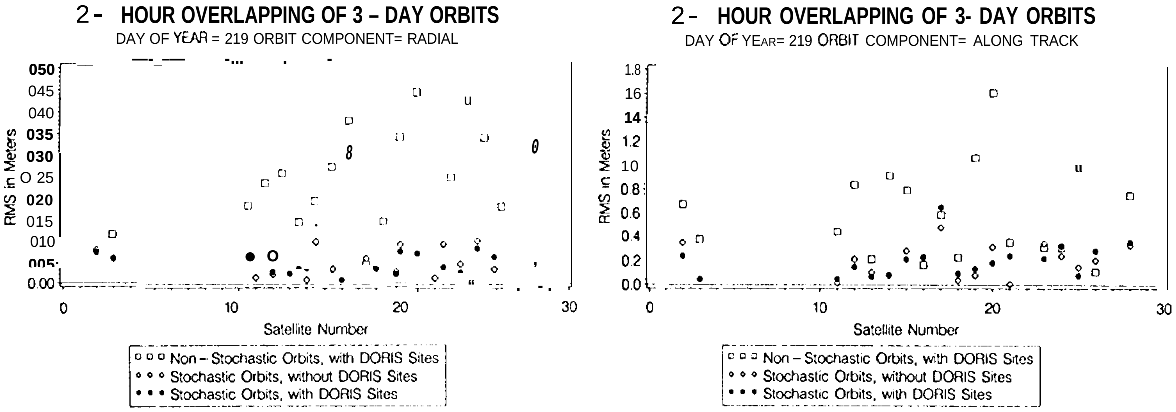


Figure 9: 2-hour Overlapping Tests of Consecutive 3-Days Solutions for day 219 and all satellites.

Baseline Length Repeatabilities

A further indication of whether or not the estimation of stochastic orbit parameters helps, is given by comparing the baseline length repeatabilities for all the global baselines (including the 12 DORIS sites) in the deterministic and stochastic case. Although the improvement from 5.2 ppb to 3.6 ppb is not dramatic, it clearly shows that the modelling of GPS satellites with 3-days arcs may not be achieved by just estimating the initial conditions and two radiation pressure parameters per satellite if highest accuracy is required. At present we are working on model improvement.

CONCLUSIONS

Routine IGS Data Processing

Since the beginning of the 1992 IGS Campaign 9 month of global GPS data were successfully processed at CODE in a highly automated way. The anaysis of the tremendous amount of data shows that global GPS orbits may be obtained with a very stable quality of 0.2 to 0.5 meters. The time series of the direct solar radiation pressure and y-bias estimates from 3-days solutions demonstrate a consistency of about $1.10^{-10} m/s^2$ and $4.10^{-10} m/s^2$ for the direct radition pressure parameters and the y-bias respectively. The change of solar radiation pressure with the changing distance between the sun and the earth (eccentricity of the earth orbit) is clearly visible. After removing this term relatively large systematic, that might be due to the changing orientation of the satellite orbit plane with respect to the sun, still remain. The y-bias estimates show problems during eclipse seasons. Due to the sensitivity of this parameter type it could be used to detect satellites with badly modelled orbits e.g. due to misalignments of solar panels, small thrusts, problems during eclipse seasons (batteries low).

The daily estimates of the pole coordinates agree with VLBI values below the 1 mas level. The rms of the LOD values determined at CODE is about 0.05 msec, showing the strength of the 3-days solutions for LOD estimation.

Epoch'92 Data Processing

The reprocessing of the Epoch'92 IGS data at CODE has shown that the more homogeneous and dense site distribution obtained by adding the 12 DORIS sites considerably improves the quality of the ERP results. Therefore it is important that the present IGS network (with almost no sites in the southern hemisphere) is ameliorated in an International cooperative effort. The gain in orbit accuracy because of the additional sites is small, however. The estimation of stochastic orbit parameters has a considerable impact on the quality of the orbit overlapping tests and improves baseline repeatabilities. An comparable improvement of the ERP results cannot to be seen.

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CSR Results from IGS and EPOCH-92

B. Schutz, P. Abusali, M. Watkins *

This paper summarizes the participation of the University of Texas/Center for Space Research (UT/CSR) in the IGS campaign of June 21 to September 21, 1992. The models and parameters used in the regular operations during the IGS are documented. An adjustment to the reference frame and a new polar motion series were derived in a post-campaign analysis mode and preliminary investigations into orbit effects have been conducted. The IGS data and orbits were used to support network solutions during EPOCH-92.

OPERATIONS DURING IGS

The solution approach used explicit double difference ionospherically corrected phase measurements. One-day arcs were used throughout the campaign in which the GPS position and velocity vectors at 00:00 GPS time of each day were estimated, along with daily pole position, selected stations, GPS y-bias and scale parameter for ROCK4, 2.5 hour zenith delays for each station and double difference ambiguity parameters.

The reference frame used for operations during the campaign was based on the VLBI reference frame (GSFC GLB- 718; Ma et al., 1991) translated, rotated and scaled into the SLR reference frame (UT/CSR 91 L 03; Eanes et al., 1991). The local ties between SLR, VLBI and GPS were taken from Boucher and Altamimi (1992). in the regular solutions; the following Rogue sites were held fixed: Algonquin, Goldstone, Fairbanks, Kauai, Hartebeestock, Onsala, Pinyon, Wettzell and Yaragadee. The following Rogue sites were adjusted: Kootwijk, Kourou, Madrid, Mas Palomas, McMurdo, Ny Alesund, Santiago, St. Johns, Tahiti, Taiwan, Tidbinbilla, Usuda, and Yellowknife. The following codeless receivers were used regularly after Anti-Spoofing was activated on August 1: Hobart, Mojave, Townsville and Wellington. Solutions were performed for Day 173 (Week 650) through Day 259 (Week 662), except for some AS days. Solutions were performed on the following days when AS was activated: Days 214-216 and Day 221. The solutions generally used all Block-I and Block-II satellites; furthermore, PRN 26 was included for the first time in Week 659. Apparent thrusts or other anomalies occurred from time to time and these satellites were excluded from the solution on the day of occurrence.

The IERS Standards (McCarthy, 1992) were generally followed. UT1 was not estimated and the Lageos-SLR series was used in the GPS solutions. The software used was the TEXGAP set of programs.

"all at Center for Space Research, University of Texas at Austin, Austin, TX 78712

ADJUSTED REFERENCE FRAME AND POLAR MOTION

A 54-day subset from Weeks 650-662 was used to determine the site positions of all sites, except Wettzell, Kauai and Fairbanks, which were held fixed. In addition, daily GPS position and velocity vectors, force model y-bias and ROCK4 scale, x and y pole position, 2.5 hour zenith delay and ambiguity parameters were estimated. The resulting solution was reported by Watkins et al. in IGS Electronic Report No. 16. A comparison of ITRF91 to the resulting coordinates shows an RMS difference in the adjusted stations of 13 mm in x, 29 mm in y and 43 mm in z. After removing a bias in the x and y polar motion series, the weighted RMS of the new GPS series with respect to the Lageos-SLR series was 0.71 milliarcseconds in x and 0.59 milliarcseconds in y.

Experiments with estimating diurnal and semi-diurnal polar motion and dUT1 were performed using one day arcs. The resulting series for dUTl shows good agreement with Lageos-derived series (results to be presented at Spring 1993 AGU by M. Watkins).

ORBIT ANALYSIS

Although one-day arcs were used for the operational activities, longer arcs were used to investigate the fidelity of the force and kinematic models. These longer arcs included a 7-day continuous orbital arc with estimation of sub-arc daily polar motion. With a 7-day arc spanning Week 651, each day contained 19-20 of the previously identified station set and contributed about 17,000 to 19,000 double difference measurements at a 2-min interval. For comparison with the 7-day arc, the operational one-day arcs produced double difference RMS values of approximately 12 mm to 18 mm.

Several 7-day arcs were studied, each of which used a different set of estimated parameters. Two cases are presented here:

Case 1) 7-day arc with 12-hr sub-arc parameters of ROCK4 scale and y-bias, daily sub-arc polar motion

Case 2) 7-day arc with empirical once per orbital revolution along track and cross track forces in which amplitude and phase were estimated as daily sub-arc parameters; daily sub-arc polar motion estimated

Approximately 5000 parameters were simultaneously estimated for each case. The double difference RMS of fit for Case 1 was 34 mm and the fit for Case 2 was 14 mm, approximately equivalent to the one-day arc fits. The higher RMS for Case 1 is one indicator of problems with the modeling, presumably errors in the nongravitational modeling are the major contributor. Evidence to support this presumption can be drawn from SLR analyses of the EtaIon satellites which have an altitude similar to GPS (except they are not in deep resonance like G PS). The Et alon satellites are spherical with low area-to-mass ratios. The ability of the empirical models to absorb model errors is indicated by the RMS of Case 2.

EPOCH-92

The data and the orbits for Weeks 653-654 were used to support analyses of a Trimble SST network operated in the Southwest Pacific by M. Bevis et al. This network spans the Tonga

Trench and extends to the New Hebrides and includes baselines ranging in length from a few hundred kilometers to 3500 km, The daily repeatability in baseline length (L) for Days 196-203 (just prior to EPOCH-92), represented by a + b L, was a = 9.7 mm and b = 1.3 ppb. Preliminary solutions during EPOCH-92, which included several AS days, tended to produce higher noise in the double differences by a factor of two. These preliminary solutions suggest some degradation in the network solutions caused by AS effects on the global network, however, the analysis is incomplete and a definitive statement cannot yet be made.

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GLOBAL GEOMETRIC PARAMETERS DETERMINED FROM MULTI-MONTHS GPS DATA

**S. Y. Zhu, Ch. Reigber, D. Angermann, R. Galas, G. Gendt,
W. Sommerfeld, T. Nischan**

GPS data acquired from 16 core stations during IGS92 test campaign have been reanalyzed in order to obtain a homogeneous solution of station coordinates and polar motions. The time duration is from June 21 to October 30. Altogether 3,318,050 (phase plus code) observations with 4 minutes data sampling time have been used in this analysis. The data type used in the processing software is undifferenced ionospheric free combination of phases (and of pseudo–ranges).

The solution is a quasi-long arc one. The overall number of solved for parameters are around 66,000. They are:

1. Daily state vectors of GPS satellites;
2. Daily pole coordinates;
3. Daily solar radiation scale and y-bias for each space vehicle;
4. Tropospheric zenith path delay of each station in a six hour interval;
5. Ambiguities;
6. Station and satellite clock corrections at each epoch;
7. Coordinates of all 16 stations;
8. C20 (and GE);
9. Center of mass corrections of the satellite antenna.

The dynamical models used are:

1. Earth gravity: GEM T3(8*8), with C21 = -0.19 E-9 and $\overline{S21}$ = 1.19E-9;
2. Solid Earth tide: ERS_1 Standard (revised Wahr model);
3. Third bodies: Moon and Sun;
4. Ocean tides: PEGM 121, Schwiderski(19*4);
5. Solar radiation: Rock4, Rock42 + y_bias;
6. Relativistic model: IERS Standard.

The station coordinates are solved as a free net. Three rotation conditions are applied to reduce the singularity problem and to determine the reference frame. Various solutions are generated by using different rotation conditions and/or setting some solved for parameters as fixed. The effect of these different choices on the station coordinate solutions are not significant.

GeoForschungsZentrum Potsdam, **Depart. 1, Telegrafenberg Al 7,** Potsdam, **Germany**

There is a position shift of Usuda station beginning from August, 10. Consequently, two sets of coordinates for this station are estimated with the name Usd 1 and Usd2, respectively.

The station coordinate solution is given in Table 1. Plate tectonic model is not applied, accordingly the coordinates solved should be the mean values during the time span, or in other words the solution refers to the mean epoch MJD 48860.5. The information of local ties and antenna heights we received may not be completely correct. In order to avoid this difficulty, the coordinates given in Table 1 refer to L1 phase center. Table 2 gives the comparisons of a few solutions. The rms in various directions are given in unit cm. Solutions 1 to 3 are computed at GFZ, in which 1 refers to the results of Table 1, while 2 and 3 are the station coordinate solutions when first half and the last half of the data are used, respectively. Solution 4 is from S10 (see IGS Electronic Report, Message No. 97, 16/01/93); only 10 stations are used for the comparison, since other stations seem to have local tie and/or antenna height problem.

Table 1.
GFZ station coordinate solution

Abbr	X	Y	Z
FAIR	-2281621.427	-1453595.684	5756962.014
ALGO	918129.605	-4346071.229	4561977.829
YELL	-1224452.454	-2689216.035	5633638.335
GOLD	-2333614.177	-4641385.419	3676976.455
KOKB	-5543838.324	-2054587.490	2387809.550
TROM	2102941.243	721569.783	5958194.300
WETT	4075578.714	931852.774	4801569.929
YAR1	-2389025.456	5043317.133	-3078531.137
SANT	1769693.278	-5044574.161	-3468321.327
HART	5084633.335	2670370.835	-2768498.470
PAMA	-5245202.240	-3080476.399	-1912828.194
MCMU	-1310696.291	310469.252	-6213368.457
TAIW	-3024782.829	4928938.520	2681235.204
TIDB	-4460996.176	2682557.302	-3674444.103
USD1	-3855262.763	3427432.413	3741020.912
NALL	1202431.688	252626.983	6237772.517
USD2	-3855263.161	3427432.761	3741020.396

As afore mentioned the station USUD has a position change during the IGS test Campaign. Two sets of coordinates for the same station have been computed. Accordingly, the position shift can be determined. Table 3 gives the results computed by GFZ and S10, respectively. The differences are at 1cm level. Since the differences are not affected by the definition of local tie and/or antenna height, it is adequate to use them as an indicator of the accuracy of both S10 and GFZ solutions.

Table 2.
Comparison **of station coordinate solutions (unit cm)**

Solutions	H	N	E	x	Y	z
1 vs. 2	0.7	0.3	0.4	0.5	0.5	0.4
1 VS. 3	0.8	0.6	0.5	0.4	0.7 0.7	
2vs.3	1.4	0.8	0.9	1.1	1.1	1.0
1 VS .4	4.1	1.2	1,7	1.4	2.8	3.3

Table 3.
Position shift of USUD station

USD 1- USD 2	Ax	AY	AZ
SIO	-.409 m	.357 m	–.498 m
GFZ	-.398 m	.349 m	-.516 m
S10 -GFZ	-.011 m	.008 m	.018 m

Anyway, from the comparison results one-may expect that the actual accuracy of the station coordinates of Table 1 is at lcm level in horizontal direction, and a few cm in height.

The pole results are given in Table 4. Figure 1 gives the comparison of the poles of various analyzing centers. The reference is the IERS solution. As we know that the pole solution is sensitive to the underlying reference frame (realized through given station coordinates). In daily solutions if the station coordinates and/or relevant antenna heights provided are not accurate enough, the pole solutions will be distorted consequently. Multi_months long arc solution improves the situation: although the pole is somehow a "local" parameter, the accumulation of multi_days observation does not really reduce the standard error of the pole, but the solution is greatly benifited from the station solution, which provides a homogeneous and accurate reference frame. Comparing our old daily pole products the improvement of the long arc solution is significant. The accuracy of the poles (and of the orbit) depends also largely on the station number and their distribution. In some days, we did not receive data from two southern stations, many data from other southern stations can not be properly used since their clock corrections could not be solved accordingly. As a result, only few data from southern are really used in the solution, In this case the pole and orbit accuracy is degradated. The pole and orbit at AS days are also of lower quality. Beside those days the actual accuracy of the pole solution given in Table 4 can be estimated as at 0.5 mas level or better.