DENSIFICATION OF THE IERS TERRESTRIAL REFERENCE FRAME THROUGH REGIONAL GPS NETWORKS

WORKSHOP PROCEEDINGS

NOVEMBER 30 – DECEMBER 2, 1994

International GPS Service for Geodynamics

Association Internationale de Géodésie
Union Géodésique et Géophysique Internationale

International Association of Geodesy
International Union of Geodesy and Geophysics

IGS Central Bureau
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California U.S.A.

Edited by
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The research described in this publication was sponsored by many international agencies who actively participate in the International GPS Service for Geodynamics. The proceedings from this workshop were prepared and published by the IGS Central Bureau at the Jet Propulsion Laboratory, California Institute of Technology and sponsored by the National Aeronautics and Space Administration.

FOREWORD

Ruth E. Neilan

In late 1993, the International GPS Service for Geodynamics (IGS) began discussing a new initiative, the densification of the global GPS network through regional activities. The initiative targets the expansion and accessibility of the terrestrial reference frame and has two integral parts:

- densification of the IGS global network by incorporating more GPS stations/networks at the regional level;
- linkage of these regional stations or networks directly to the global terrestrial reference frame

The primary objective is to provide users worldwide with increased access to the extremely consistent reference frame supported by the infrastructure of the IGS. The conceptual groundwork for this initiative was developed during the October 1993 Ottawa Workshop, hosted by Natural Resources of Canada, home institution of the IGS Analysis Center Coordinator, Jan Kouba.

This initiative, termed 'Regional Densification', was reviewed and discussed at the March 1994 IGS Governing Board Meeting in Paris, France. It was clear from the discussion and splinter session that steps should be taken as soon as possible to organize this initiative, especially given the rapid growth in the number of new, high-precision geodetic GPS stations. The Central Bureau, and Geoffrey Blewitt, of the University of Newcastle upon Tyne, were requested by the Governing Board to jointly develop a plan for this new activity. As part of the plan, the Central Bureau offered to host a workshop at the end of 1994 to concentrate on the broad range of issues associated with the densification.

During the remainder of 1994, the first year of operations for the IGS, the overall focus was on increasing the accuracy and reliability of IGS orbit determination, and improving the estimation of station locations and velocities for the IGS network. The significance of the densification initiative became more apparent during this time as the Central Bureau consulted with Blewitt and others. Based on these ideas, the workshop was clearly defined and conducted during December 1994.

Without the guidance and advice of Ivan Mueller, this workshop would not have been the success that it was. Contributions during the planning stages from the IGS chairperson, Gerhard Beutler, were equally valuable.

Jim Zumberge was responsible for coordinating the technical program of the workshop and editing these Proceedings. His assistance with all aspects of the Central Bureau is very valuable and greatly benefits the IGS. Many thanks to Geoff Blewitt for his contributions to organizing the workshop. Rob Liu's efforts in co-editing these Proceedings are appreciated, and I should note that he is also responsible for maintaining the Central Bureau Information System (CBIS) on a daily basis, with the assistance of Werner Gurtner and Mike Urban. Thanks to Priscilla Van Scoy, the Administrator of the Central Bureau, for keeping all of the details in perspective (and for bringing order out of chaos). On behalf of the Central Bureau, many thanks to all of the authors and participants that joined in the workshop.

And so, it is with pleasure that I present the Proceedings from this workshop, the first IGS event to be held at NASA's Jet Propulsion Laboratory, the home office of the IGS Central

Bureau. Over the next few years wc can anticipate other IGS initiatives that will call for apt identification of the issues, in-depth discussions with our partners, and consensual decision-making as we choose the correct path to follow. It is precisely thc sense of collaboration and community within the IGS that makes it work so very well, and also makes it a rewarding, enjoyable experience for al l of us.

Ruth E. Neilan
Director, IGS Central Bureau
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March, 1995

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EXECUTIVE SUMMARY

J. F. Zumberge and G. Beutler

A workshop entitled "Densification of the ITRF through Regional GPS Networks" was held at the Jet Propulsion Laboratory (JPL) in Pasadena, California from November 30 through December 2. Sponsored by the Central Bureau (CB) of the International GPS Service for Geodynamics (IGS), the purpose of the workshop was to discuss how the IGS could best accommodate the rapidly growing number of Global Positioning System (GPS) terrestrial sites. That is, data from receivers at these sites are potentially valuable in the densification of the IERS (International Earth Rotation Service) terrestrial reference frame (ITRF). The organization of the data flow and analysis were the major topics of the workshop, which was attended by more than 50 persons representing North America, Europe, Australia, and Asia.

The Agenda was centered around the following four position papers, which were prepared and distributed in advance to the attendees:

1) "Densification of the IGS Global Network"
J. F. Zumberge, R. E. Neilan, I. I. Mueller

2) "Constructing the IGS Polyhedron by Distributed Processing"
G. Blewitt, Y. Bock, J. Kouba

3) "Network Operations, Standards and Data Flow Issues"
W. Gurtner and R. E. Neilan

4) "Densification of the ITRF through Regional GPS Networks: Organizational Aspects"
G. Beutler, J. Kouba, R. E. Neilan

The first major conclusion from the workshop was that at least one, and ideally two Associate Analysis Centers (AAC's) should perform weekly comparisons and combinations of the coordinate solutions of all IGS Analysis Centers (AC's) and of future AAC'S that may analyze parts of the densified IGS network.

In view of the fact that the seven existing IGS AC's are in principle ready to produce weekly free-network coordinate solutions, and considering that the Department of Surveying of the University of Newcastle, represented at the workshop by Geoffrey Blewitt, and the Institute of Geophysics and Planetary Physics of Scripps Institution of Oceanography, represented at the workshop by Yehuda Bock expressed their interest to act as AAC's during such a pilot phase, it was decided to establish a pilot phase for AAC'S as early as possible in 1995. The ITRF section of the IERS, represented by Claude Boucher, Pascal Willis, and Zuheir Altamimi, promised to accompany this pilot phase by regularly analyzing the products of these AAC'S.

The second major conclusion of the workshop was that IGS stations should be permanent stations wherever possible. (Although near real-time data transmission is desirable, permanent receivers with less-than real-time data communications would be acceptable, too.) In order to obtain the necessary global coverage, which is currently sparse in several regions, it was recommended that the CB write a Call for Participation (CFP) identifying regions for the IGS network densification. This CFP shall be sent out in March 1995.

Although not all problems concerning the densification of the IGS network could bc addressed at the workshop, the workshop will be remembered as the principal milestone of this ambitious project. The workshop demonstrated that the innovative spirit within the IGS and the firm wish to work together in an international and truly global frame continues to be strong.

AGENDA

Densification of the ITRF through Regional GPS Networks

A Workshop
sponsored by

The Central Bureau of
The International GPS Service for Geodynamics

1994 November 30 - December 2
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA, 91109 USA

Building 180, Conference Room 101

Wednesday November 30

1:15 pm - 2:OOpm	Registration	
2:00 pm - 2:10 pm	Welcome	Neilan
2:10 pm - 2:20 pm	Greetings from the Chairman	Beutler
2:20 pm - 2:45 pm	Position Paper Rationale and Goals of the Workshop	Zumberge / Blewitt
2:45 pm - 3:45 pm	POSITION PAPER 1 Densification Issues: Rationale and design, network expansion, permanent versus epoch GPS, and the needs of the IGS user.	Zumberge / Neilan / Mueller
3:45 pm - 4:00 pm	break	
4:00 pm - 5:15 pm	POSITION PAPER 1 APPENDIX Statements of ideas, status, expectations, and concerns from those associated with GPS networks or densification sites (e.g. Johansson, Tsuji, Shimada, Bock, Kouba, Neilan, Reigber, Ambrosius, Manning, Engen, Carter, Dragert).	Chair: Bock
6:30 pm	Reception at Athenaeum	

Thursday December 1

8:30 am - 9:00 am	coffee	
9:00 am - 10:00 am	POSITION PAPER 2 Distributed Processing Concept, Regional Analysis, and Network Combination	Blewitt / Bock / Kouba
10:00 am - 10:45 am	POSITION PAPER 2 APPENDIX A 5-minute summaries of Regional Analysis Results using IGS Products (e.g., Johansson, Tsuji, Ambrosius, Brockmann, Bock, Herring, Morgan, Hurst, Kouba).	Chair: Johansson
10:45 am - 11:00 am	break	
11:00 am - 12:15 pm	POSITION PAPER 2 APPENDIX B Statements of ideas, expectations and concerns from those impacted by distributed processing (prospective associate analysis centers, global analysis centers, data centers, IERS, etc.).	Chairs: Rothacher / Zumberge
12:15 pm - 2:OOpm	lunch	
1:00 pm - 2:00 pm	tour of JPL's Space Flight Operations Facility (optional)	
2:00 pm - 3:00 pm	POSITION PAPER 3 Network Operations, Standards, and Data Flow Issues	Gurtner / Neilan
3:00 pm - 3:45 pm	POSITION PAPER 3 APPENDIX A Status reports on network and data operations: current statistics, system developments, monumentation, Internet report, etc.	Chair: Morgan
3:45 pm - 4:00 pm	break	
4:00 pm - 5:00 pm	POSITION PAPER 3 APPENDIX B Statements of ideas, expectations and concerns from those affected (analysis centers, network centers, regional operators, and data centers).	Chair: Nell

Friday December 2

8:30 am - 9:00 am	coffee
9:00 am - 10:00 am	POSITION PAPER 4 — Beutler / Kouba / Neilan Organization and Participation under the IGS Umbrella
10:00 am - 10:45 am	POSITION PAPER 4 APPENDIX — Chair: Kouba Statements of ideas, concerns and expectations by participants and potential participants
10:45 am - 11:00 am	break
11:00 am - 12:00 pm	CONCLUDING SESSION — Chair: Blewitt Summaries of position papers, concerns, and discussion of unresolved issues.
12:00 pm - 12:15 pm	CLOSING REMARKS — Beutler
12:15 pm - 2:OOpm 1:00 pm - 2:00 pm	lunch tour of JPL's Von Karman Auditorium (optional)
2:00 pm - 5:30 pm	POST-WORKSHOP ACTION ITEMS — Chair: Mueller How to resolve issues identified in CONCLUDING SESSION; plan and draft Call for Participation; etc. Position Paper authors and Chairpersons of follow-up Appendices should be present.

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Position Paper 1
Densification of the IGS Global Network

James F. Zumberge, Ruth E. Neilan (Jet Propulsion Laboratory, California Institute of Technology),
Ivan I. Mueller (The Ohio State University)

I Introduction

In October 1993, forty-eight sites were listed in Table 5 of *IGS Processing Center standard report requirements and product formats* [Zumberge and Goad, 1993]. The table indicated sites from which GPS data were analyzed by at least one of the seven IGS Analysis Centers. Currently there are over 70 permanently operating GPS receivers with site log entries at the IGS Central Bureau Information System (CBIS). Several of the new sites[1] provide coverage in previously isolated regions, But by the far the most rapid growth has been in dense regional networks. Sites listed in the CBIS are only a small fraction of the total; dense networks are emerging in a number of regions, including Japan, southern California, Scandinavia, South America, and Central Asia.

The IGS *global* network is described in the following excerpt from the IGS Terms of Reference:

> 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.

Given the recent expansion, have we reached a set of Core Stations? On what basis does one separate the global network into Core and Fiducial components?

We begin in Section II of this paper by considering, from a purely geometric point of view, the distribution of points on a sphere. These considerations are applied to the current and planned IGS network.

In Section III we review the prospects for expanding the global network.

In Section IV we look at the relationship between the size of the Core network, and the quality of products that result. What is the cost and value of fixing satellite parameters determined from a global solution in the analysis of regional data?

We conclude with a Summary and Discussion,

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[1] Including Arequipa, Peru; Easter Island in the South Pacific; Macquarie Island; Davis and Casey, Antarctica; Kitab, Uzbekistan; and Kerguelen, Indian Ocean.

II GEOMETRICAL CONSIDERATIONS

Uniform Distributions

Imagine N stations uniformly distributed over the globe. What do we mean by "uniform"? What is the spacing of such stations? Given some point at random on the globe, how far is it from the nearest station?

We can associate the surface of the Earth with a square of length

$$L = \sqrt{4\pi r_e^2},$$

where $r_e \approx 6370$ km is the mean Earth radius, so that the area of the square equals the surface area of the Earth. On this square we position N stations in a square array, separated by distance $d = L/\sqrt{N}$ (Figure 1). Thus the relationship between N and d is

$$d = 2\, r_e \sqrt{\pi/N}\ , \qquad [1]$$

and is shown in Figure 2.

Roughly, 32 well distributed stations are spaced at 4000 km. To reduce the spacing by a factor of 2 requires an increase in the number of stations by a factor of 4. We would expect [1] to represent a sphere reasonably well for large N. How well does it represent a sphere for arbitrary N? We show also in Figure 2 the spacing vs. number of vertices for the five regular polyhedra. To better than 10%, [1] predicts the values for these intrinsically uniform distributions, so [1] is quite good even for N as small as 4.

To assess the uniformity of a particular set of stations, it is not obvious how one would calculate the station spacing, so Figure 2 by itself is not particularly well suited to assessing uniformity. For this we can use the distance-to-nearest-site function.[2] Suppose of N sites the n^{th} has co-latitude θ_n and longitude ϕ_n. Then, at an arbitrary location (θ,ϕ), the quantity

$$r_n(\theta,\phi) \equiv r_e \cos^{-1}[\sin\theta \sin\theta_n \cos(\phi-\phi_n) + \cos\theta \cos\theta_n] \qquad [2]$$

is approximate y the great-circle distance from (θ,ϕ) to the n^{th} site.

Now, take

$$r(\theta,\phi) \equiv \min [r_1, r_2, \ldots r_N] \qquad [3]$$

as the distance from (θ,ϕ) to the nearest site. Finally, compute therms value over the globe:

$$\zeta \equiv (4\pi)^{-1/2} \left[\int d\phi \int d\theta \sin\theta\, r^2(\theta,\phi) \right]^{1/2} \qquad [4]$$

Note that ζ can be calculated for any given distribution of sites. In the large-N limit, we can ignore curvature and use Figure 1 to calculate

$$\zeta = d/\sqrt{6}$$

[2] For an alternative mathematical discussion of uniformity on the sphere, consult Mueller 1993].

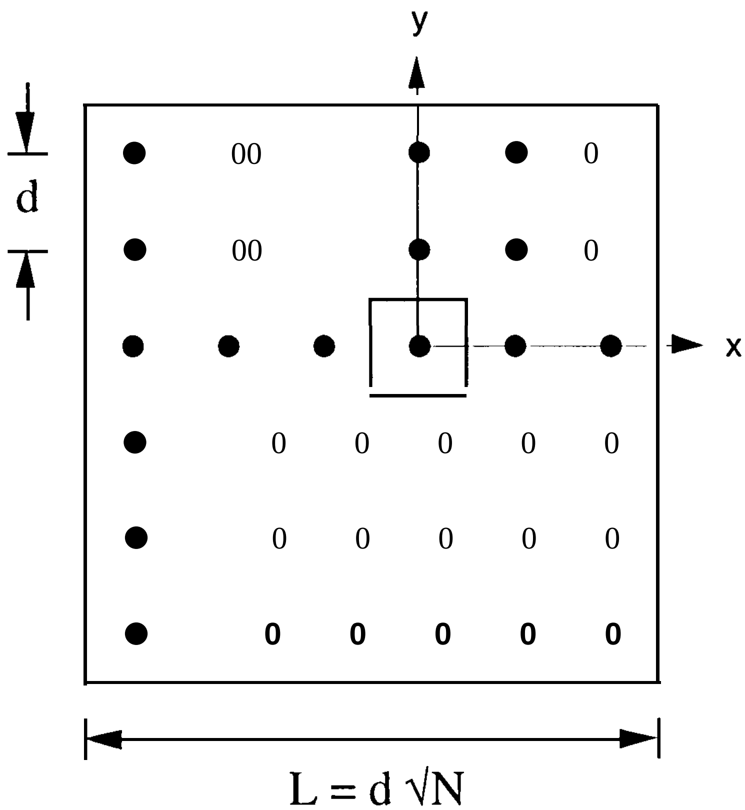

Figure 1 A square array containing N equally spaced sites with separation d. If wc associate this area with the surface of the Earth, wc obtain d = 2 r_e (n/N)"*. The site at the center of the shaded area is the closest site to any point within the shaded area. The root-rncan-square value of $(x^2+y^2)^{1/2}$ over the shaded area is $\zeta = d/\sqrt{6}$.

as an approximate relationship between station spacing and. rms distance to nearest site for uniformly distributed sites. To achieve ζ = 2000 km requires ≈ 21 well-distributed sites; ζ = 1000 km requires= 85 well-distributed sites. Of course, physical geography prevents us from achieving the "well-distributed" ideal, but these relationships nevertheless provide a framework for discussions of physically realizable networks.

Current and Future Distribution of IGS Stations

Shown in Figure 3 is a world map with existing and potential sites for IGS stations. The existing stations are indicated as solid (IGS fiducials[3]) and open circles; they reflect the recent inclusion of important sites on or near the Antarctic coast, and the first site in central Asia at Kitab, Uzbekistan. The map also reflects dense coverage in Europe and North America.

Given the current set of sites, one possible algorithm for including stations in an operational global solution would be as follows:

1. Begin by including only the thirteen IGS fiducials.

[3]The term "fiducial" in this context is different from that in the Terms of Reference, and means a station whose position is assumed known very accurately in the determination of GPS ephemerides.

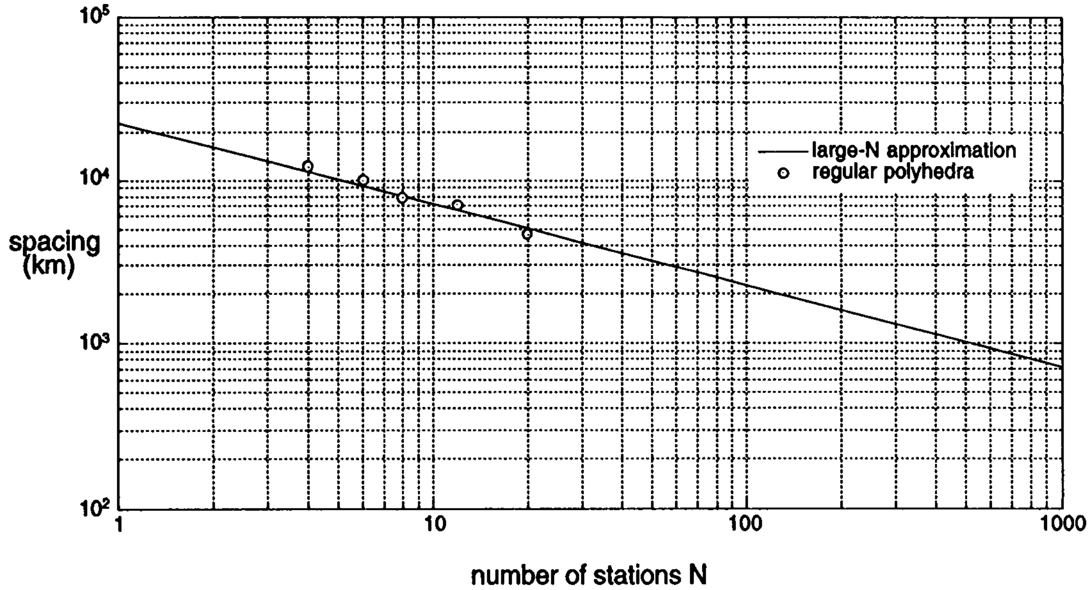

Figure 2 The relationship between station spacing and number of stations for uniformly distributed sites. The solid line gives the large-N approximation, while the open circles correspond to regular polyhedra. The large-N approximation predicts the polyhedra values to within 10%.

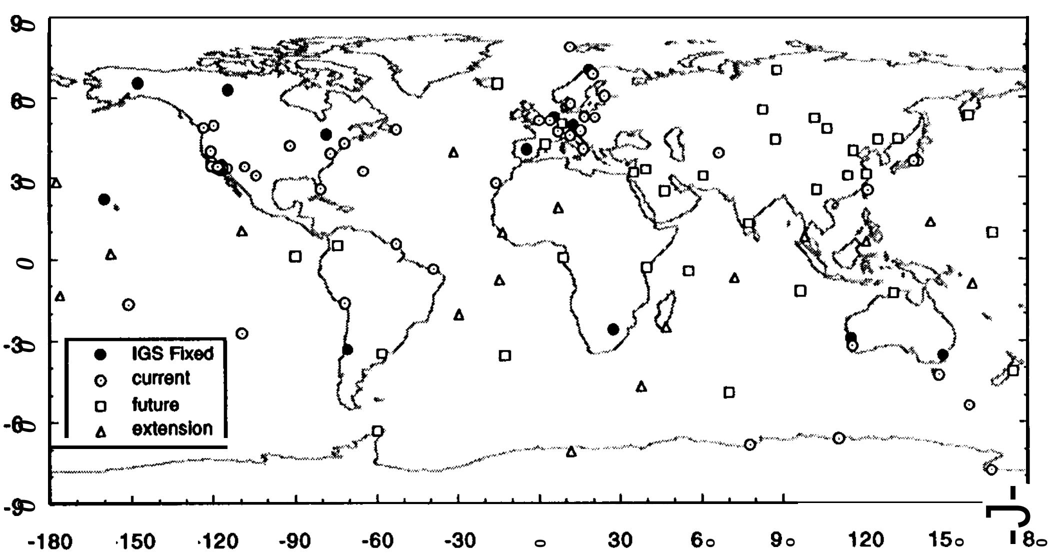

Figure 3 The IGS Global Network: circles (solid and open) indicate sites currently (1994 October) in operation, with solid circles indicating sites whose coordinates are tightly constrained by all Analysis Centers. Open squares indicate planned sites (from the *Planned or Proposed Future Stations* table in the March 1994 edition of the IGS Colleague Directory). (Kerguelen, at latitude ≈ 50°S and longitude ≈ 70°E became operational in November, 1994.) The open triangles suggest a possible extension by drawing on other existing networks.

2. Determine which of the remaining stations is furthest from the group of included stations. ("Furthest" is defined as the maximum distance from the nearest included station.) Add this station to the group.

3. Repeat step 2 until the number of stations reaches a predetermined number, or until the "isolation" of the last-included station falls below some threshold.

Shown in Table 1 is the result of this algorithm applied to the current set of IGS stations, as well as the isolation of the just-added site. The rms-distance-to-nearest-site function ζ is also given as the network expands according to the above algorithm.

With the current set of IGS stations, the transition between "global" and "regional" occurs somewhere for $20 \leq N < 30$. In this region, the isolation of added stations, while still above 1500 km, becomes small compared to the isolation of regions of the world with poor coverage.

Table 1 If one begins with the 13 IGS fiducials (solid circles in Figure 3), and successfully adds the "most isolated" sites, the following table results. The rms-distance-to-nearest-site function, ζ, is plotted in Figure 4. [Note that the algorithm will pick one of two very closed stations solely on the basis of which is more isolated. Thus Tskuba (N = 23) is chosen over Usuda solely because it is slightly further from Taipei.]

N	ID	location	isolation (km)	ζ (km)
14	tai w	Taipei (Taiwan)	6047	324 I
15	dav1	Davis (Antarctica)	5016	3075
16	fort	Fortaleza (Brazil)	4665	2941
17	pama	Pamatai (Tahiti)	4425	2756
18	kit3	Kitab (Uzbekistan)	4352	2621
19	eisl	Easter Island (South Pacific)	3759	2537
20	mcmu	McMurdo (Antarctica)	2696	2466
21	rmc5	Richmond (Florida)	2271	2421
22	mac 1	Macquarie Island	2198	2405
23	tskb	Tskuba (Japan)	2146	2355
24	stjo	Saint John's (Canada)	1933	2335
25	areq	Arequipa (Peru)	1858	2315
26	kour	Kourou (French Guiana)	845	2303
27	masl	Maspalomas (Canary Islands)	750	2278
28	brmu	Bermuda (North Atlantic)	701	2274
29	al bh	Alberthead (Canada)	562	2271
30	cas 1	Casey (Antarctica)	395	2265
31	mdo 1	McDonald (Texas)	292	2258
32	nlib	North Liberty (Iowa)	169	2257
33	mets	Mctsahovi (Finland)	1080	2254
34	nyal	Ny Alesund (Norway)	1048	2244
35	mate	Matera (Italy)	991	2227
36	hob2	Hobart (Australia)	835	2225
37	godc	Greenbelt (Maryland)	777	2225
38	onsa	Onsala (Sweden)	699	2225
39	joze	Jozefoslaw (Poland)	662	2224
40	quin	Quincy (California)	641	2224
41	WCS2	Westford (Massachusetts)	601	2224
42	pie1	Pie Town (New Mexico)	557	2223
43	zimm	Zimmerwald (Switzerland)	474	2223
44	hers	Herstmonceux (England)	404	2223

Such regions, of course, contribute heavily to ζ.

Plotted in Figure 4 is ζ vs. number of stations, for a variety of distributions. The straight (on a log-log plot) dotted line is the large-N approximation for uniform distributions, given by [1] and [5]:

$$\zeta = r_e \sqrt{2\pi/3N} \ .$$

Two of the five regular polyhedra (the icosahedron, N = 12, and dodecahedron, N = 20) are plotted as the large open circles, and fall within –1 % and +5% of the dotted line, respectively. (The other regular polyhedra all lie within 3% of the dotted line.) The small open circles give the value of ζ vs. N as given in Table 1. From Figure 4 it is clear again that, with the current number of available stations, the improvement in uniformity with increasing N decelerates rapidly above N = 20.

Turning again to Figure 3, we show, as open squares, planned sites from the *Planned or Proposed Future Stations* table in the March 1994 edition of the IGS Colleague Directory. Additionally, we show as open triangles a possible extension by drawing on other existing networks, including dense regional GPS networks, tide gauge networks, and the DORIS tracking network (Appendix). These candidates are listed in Table 2.

Table 2 Candidates for Extension of the IGS Global Network

site	region
Îles Wallis	equatorial Pacific Ocean
Ascension Island	South Atlantic Ocean
Guam	equatorial Pacific Ocean
Novolazarevskaya	Antarctica
Marion Island	South Indian Ocean
Clipperton Island	North Pacific Ocean
Honiara	equatorial Pacific Ocean
Kiritimati (Christmas Island)	equatorial Pacific Ocean
Ilha de Trindade	South Atlantic Ocean
Jolo	Phillipines
Arlit	Niger
Ko Taphao Noi	Thailand
Conakry	Guinea
Tôlanaro	Madagascar
Flores	Azores
Midway Island	North Pacific Ocean
Diego Garcia	Indian Ocean

If we imagine for the moment that there are operating receivers at all of the sites shown in Figure 3, we can apply the same algorithm of site selection. The resulting ζ-vs.-N curve is shown as the solid line in Figure 4. Note the continuous decline in ζ as N increases up to about N ≈ 75, at which point $\zeta \approx$ 1300 km. This number agrees well with the one suggested by Mueller in the Proc.of the 1993 IGS Workshop (see footnote 2).

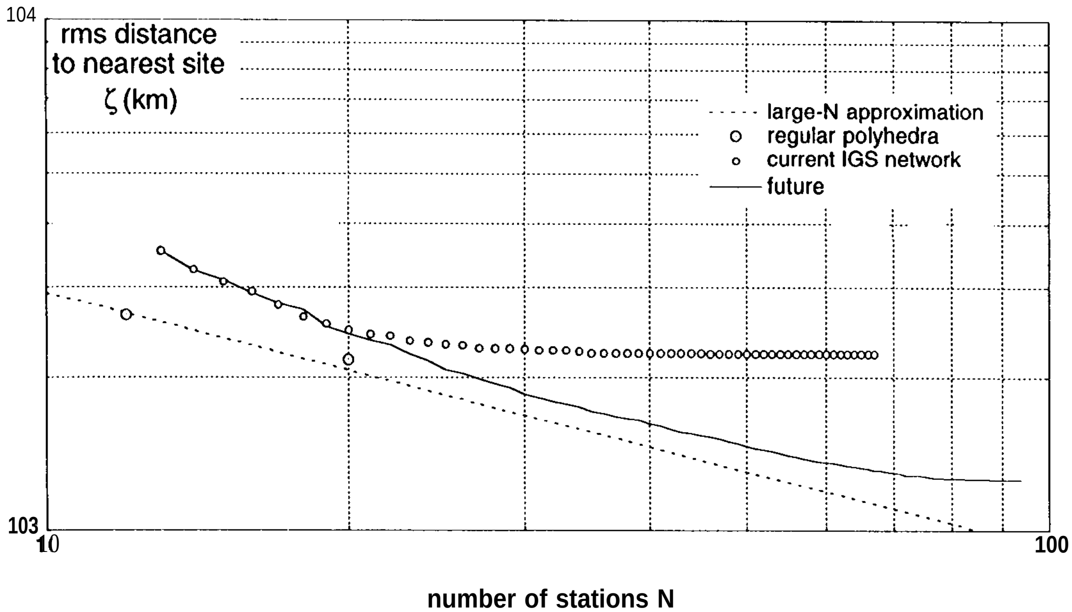

Figure 4 The **rms-distance-to-nearest-site** function, ζ, vs. number of stations: both axes are **logarithmic**. The ideal of uniformity (from Figure 1) is given as the straight **dashed** line. Two of the five regular polyhedra (the **icosahedron**, N = 12, and **dodecahedron**, N = 20) are plotted as the large open circles, and fall within –1 % and +5% of the dotted line, respectively. (The other regular polyhedra are all within 3% of the dotted line.) The small open circles give the value of ζ, beginning with the IGS fiducial network (N = 13), and increasing the network by adding in succession the most isolated sites. The solid line follows the same algorithm of site selection, but draws from sites in the "future" and "extension" list of sites.

III Prospects for Network Densification

As mentioned earlier, the progress made by the IGS is truly remarkable. High accuracy GPS ephemerides, Earth rotation parameters, etc., are routinely generated and made available to users in a short time, The rate of requests for information from the IGS Central Bureau—hundreds of file retrievals per day—is one measure of this progress. Naturally, the primary area of emphasis of the IGS is on the completion of a global, geographically well distributed network. Inspection of the current set of IGS stations show that we continue to be limited in the areas of Russia, China, India, and Africa.

Both the IGS Governing Board and the International Association of Geodesy agreed that the next step for IGS to accomplish (together with IERS) is the extension and densification of the IERS Terrestrial Reference Frame (ITRF) so that a large number and globally distributed GPS reference stations be made available to the users at, say, every few (1-3) thousand km.

One way to accomplish this is through soliciting cooperation with groups that have been involved in GPS surveys in certain geographic regions where IGS core stations are not yet available.

The questions are (i) how can one integrate geodetic solutions from the growing number of regional GPS campaigns into the ITRF for the above purpose and (ii) how can such cooperation best be organized?

The IERS/IGS Workshops March 21 – 26, 1994 in Paris started to address the first question and it will be addressed again at this Workshop.

The second question was addressed at a special organizational meeting on March 24, 1994 in Paris, where it became clear that the most practical way to collaborate to densify and extend the ITRF through IGS/IERS is to utilize some of the observations made or to be made at certain selected locations within regional networks, especially in geographic areas where IGS currently does not have core stations. Such utilization of the observations will be mutually beneficial for reasons which do not have to be repeated here.

As a first step it was decided to prepare a map with all currently feasible or seemingly feasible station locations indicated. After assessing what may become available in the near future in terms of stations, a decision will have to be made on how the observations can be best utilized to extend the ITRF.

This map is shown in the Appendix (Figure A 1) and is based on information from various organizations engaged in regional GPS surveys, the Doris tracking network, and tide gauge networks (Appendix, Table A 1). The stations in Table 2 have been selected from the map as candidates for the densification of the global ITRF.

Action is also needed to provide for geographic areas that still appear to be “stationless” on the maps in the Appendix. The final goal remains to provide ITRF reference at every few thousand kilometers over the globe.

A rigorous and dependable network of ITRF stations is best served through continuously operating stations where this is economically feasible. A number of the regional campaign areas are in the process of making the transition from conventional “campaign” projects to investigations that install permanent stations in the area of interest. The remainder of the network observations are then obtained by a roving set of field GPS receivers.

For example, a standard regional network might have contained 30 points observed in three four-day bursts or phases with 12 receivers, three at fixed locations and nine moving to the next set of stations after each burst. This method of operation can be very costly and requires careful planning and execution for a once-per-year measurement. In many cases the principal investigators would now prefer the temporal resolution and resulting precision provided by a continuous network of stations. Program sponsors are also reviewing this method as being an extremely cost-effective way to provide high quality scientific data.

Some agencies (e.g. NASA, NSF, and GFZ) are in the process of considering a mix of GPS observations (continuous/fixed/semi-permanent), and are beginning to implement continuous stations in certain project areas. By implementing one to three receivers in an area, two to three additional receivers can be used to occupy the remaining network stations, requiring less resources and enabling a flexible schedule. Note that this method is not being touted for all types of GPS investigations. It is very unlikely that continuous networks would ever completely replace the need for episodic or point measurements. However, the IGS will benefit from incorporating the regional stations at the appropriate spacing into the reference frame dataset, and the scientific investigator will profit by having at least one station in their locally dense network tied into the IGS framework.

Similar network operations have been undertaken by various national agencies, including the Natural Resources of Canada’s Active Control Network, the Norwegian Mapping Authority’s SATREF network, the Swedish control network, and the Australia Surveying and Land Information Group (AUSLIG) network. These are prime examples of a larger-scale regional framework accessible to local users. These operational networks would be very good test cases for the IGS combination process in terms of reference frame extension.

There are certain to be some areas of interest, however, where the lack of basic facilities would not permit or support continuous station operation (e.g. lack of power, communications, etc.). In these cases, it is conceivable that episodic GPS data collected at least once per year could be folded into the process for determination of the reference frame, station coordinates and velocities.

A partial list of projected stations that have a high probability for installation (or resolved communications) before the end of calendar 1995 is given in Table 3.

In summary, the expansion of the network is progressing and the IGS is focusing on both the global network extension and its densification. Stations will continue to be implemented for both continuous and episodic measurements. The main decision will have to be made on the best approach at utilizing these station observations to extend the ITRF.

Table 3 Planned Expansion of the IGS Network in 1995

site	region	agency
Bangalore	India	GFZ
Bar Giyyora	Israel	NASA
Brasilia	Brazil	IBGE/NASA
Ensenada	Baja Mexico	NASA
Galapagos Islands	Ecuador	NASA
Guam	Equatorial Pacific Ocean	NASA
Hyderabad	India	Univ. of Bonn
Lhasa	Tibet China	IfAG
Mauna Kea	Hawaii	NASA
O'Higgins	Antarctica	IfAG
Shanghai	China	SAOINASA
St. Croix	Virgin Islands	NASA
Thule	Greenland	NASA
Tian Shari Mountains	Central Asia	NSF/NASA
Xian	China	Xian Observatory

IV DATA ANALYSIS RESULTS

In the Section II we showed that, with the current status of the IGS network, we are limited to fewer than 40, certainly, and, fewer than 30, arguably, well-distributed global sites. The idea of "well distributed" is based entirely on geometrical considerations.

If (i) our modeling were perfect and (ii) we had unlimited computational resources, the simultaneous analysis of data from all sites would allow the rigorous estimation of all parameters of interest. Such an analysis, involving data from R receivers and T transmitters, has $(RT)^3$ as the leading term in cpu cost.[4] Current computational resources limit[5] R to about 50.

[4] The least squares determination of *n* parameters from from m measurements requires a number of arithmetic operations proportional to ***n2m.*** In the case of GPS phase data, the number of measurements scales with the

One technique that has recently been implemented at the Jet Propulsion Laboratory involves a 2-step procedure. The first step is to use the algorithm described in Section II to determine a set of stations from which global parameters can be estimated. Data from receivers not included in this set are then analyzed, one station at a time, with GPS ephemerides and clocks fixed at their values determined in the global solution. Note that the fixing of all satellite-specific parameters is necessary to allow the one-receiver-at-a-time processing, which is very efficient, in that it scales linearly with the number of receivers.

Shown in Table 4 are the median daily repeatabilities that result from this "precise point positioning", for the period 1994 Sep 20 - Ott 21. These compare well with daily repeatabilities of stations whose data are included in the global solution.[6]

Table 4 22 stations were analyzed using the precise point positioning method on ten or more days during the period 1994 Sep 20 – Ott 21. The daily repeatability of the point-positioned solution is computed for each station. Half of the stations had repeatabilities less than the values in the table.

component	median repeatability (mm)
north	4.9
east	7.0
vertical	17.1

The current strategy used in the Flinn processing at JPL, on which Table 4 is based, is the result of on-going research. One aspect of that research consisted of analyzing data from a ten-day period in 1994 July with several strategies, of which three are summarized in Figure 5.

The operational Flinn solution includes data from all of the sites in the figure[7], and serves as the "truth" case. This strategy has ζ = 2674 km.[8]

The second strategy determines satellite parameters based only on theIGSfiducials(~=3516 km), shown as solid circles in Figure 5. The estimates of GPS clocks and ephemerides are used in precise point positioning of the remaining sites. The results are then compared with the corresponding values from the Flinn solution.

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product of R and T. There is also at least one phase ambiguity parameter per receiver-transmitter pair, so that n scales with RT as well. Note that this relation applies even if satellite parameters are not estimated.

5 This limit is only temporary, in our opinion.

[6] The resolution of double-difference ionsophere-free phase ambiguities to integer values has not been performed in the analyses which result in Table 3. Ambiguity resolution can provide a significant improvement in repeatabilities. A current operational problem with ambiguity resolution, however, is the need to consider data from different receivers simultaneously, so that one cannot take advantage of the point-positioning efficiency. The need to consider double-difference integer phase ambiguities can be traced to transmitter- and receiver-specific phase delays. If the transmitter-specific phase delays are sufficiently stable (temporal variations small compared to the L1 and L2 wavelengths) and can be calibrated, it would be possible to resolve single-difference phase ambiguities, and thus regain the computational efficiency associated with point positioning.

[7] With the exception of Easter Island. Data from that remote site were not available in near enough real time to be included in the Flinn processing.

[8] Excluding the site at McMurdo, Antarctica, which was used on only one of the ten days,

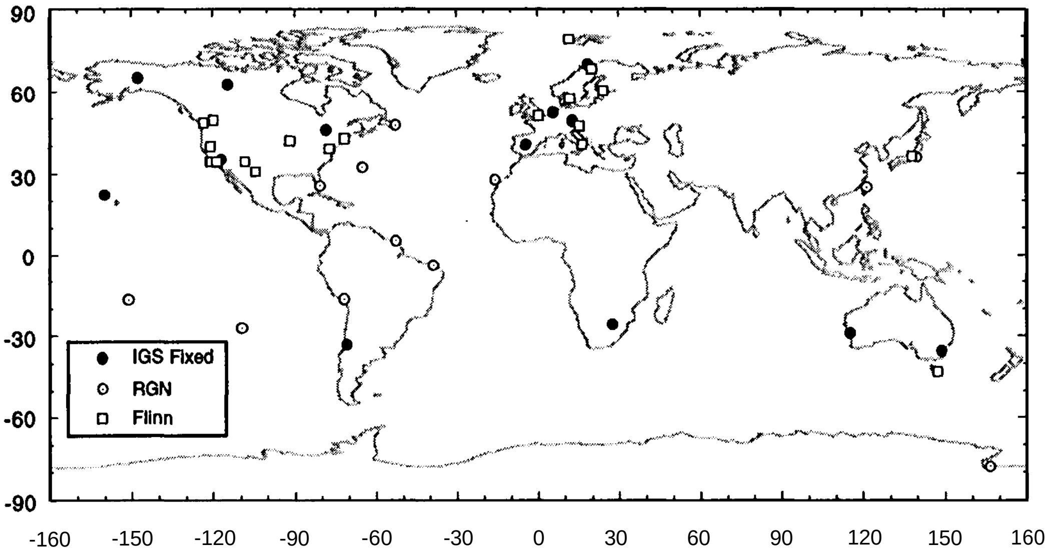

Figure 5 Networks used in various strategies for the analysis of data from 1994 Jul 10-19. All strategies use data from the 13 IGS fiducials. The reduced global network (RGN) solution uses, in addition, data from sites indicated by the open circles. The operational Flinn processing used still more stations, indicated by the open squares. Data from the site at Easter Island, about 3800 km off the coast of Chile in the South Pacific Ocean, were used only in the RGN strategy. Data from McMurdo were used on only one of the ten days.

The third strategy, (RGN for "reduced global network") consists of the IGS **fiducials** and additional isolated sites; it has ζ =2713 km, only slightly larger than that for **Flinn**, but with 24 stations instead of 45, allowing a tremendous savings in cpu burden.

For either the IGS or RGN solution, let x_{cnd} be the point-positioned estimate of coordinate c of station n on day d, and let x°_{cnd} be the corresponding estimate from the operational **Flinn** solution. Consider the distribution of

$$\delta_{cnd} \equiv x_{cnd} - x^\circ_{cnd} \;.$$

An outlier-insensitive estimate of the distribution's standard deviation is given by

$$\sigma_c \equiv {}^1/2\,(\delta_{+c} - \delta_{-c})\;,$$

where δ_{+c} (δ_{-c}) is the value above (below) which **15.87%** of the **δ's** lie. [The median μ is the value above (below) which **50%** of the **δ's** lie.]

These indicators of how well the precise-point-positioning strategy can reproduce the rigorous **Flinn** results are given in Table 5 and plotted in Figure 6. Note the reduction by a factor of approximately 3 in σ for all components as one moves from the sparse 13-station IGS fiducial global network to the improved RGN distribution. It is obviously of interest to know whether a similar reduction would occur if the global network were expanded further, with a reduction in rrns distance to nearest site of $\zeta \approx$ 1500 km, as shown in Figure 4 for N $\approx$ 50. Figure 6 shows a speculative extrapolation to lower ζ.

Table 5 The operational **Flinn** solution consists of parameters estimated from the simultaneous consideration of data from all of the stations (except Easter Island) in Figure 5. The "IGS" solution estimated satellite ephemerides and clocks by simultaneously considering data from the 13 IGS **fiducials** only. Parameters from other stations are then determined from precise point positioning. The RGN solution includes additional stations for the determination of satellite parameters.

	deviation from **Flinn** (mm)			
	IGS(~=3516 km)		RGN (ζ = 2713 km)	
component	μ	σ	μ	σ
north	-0.2	5.6	-0.7	2.0
east	1.0	18,3	0.8	5.2
vertical	16.1	27.8	5.2	11.2

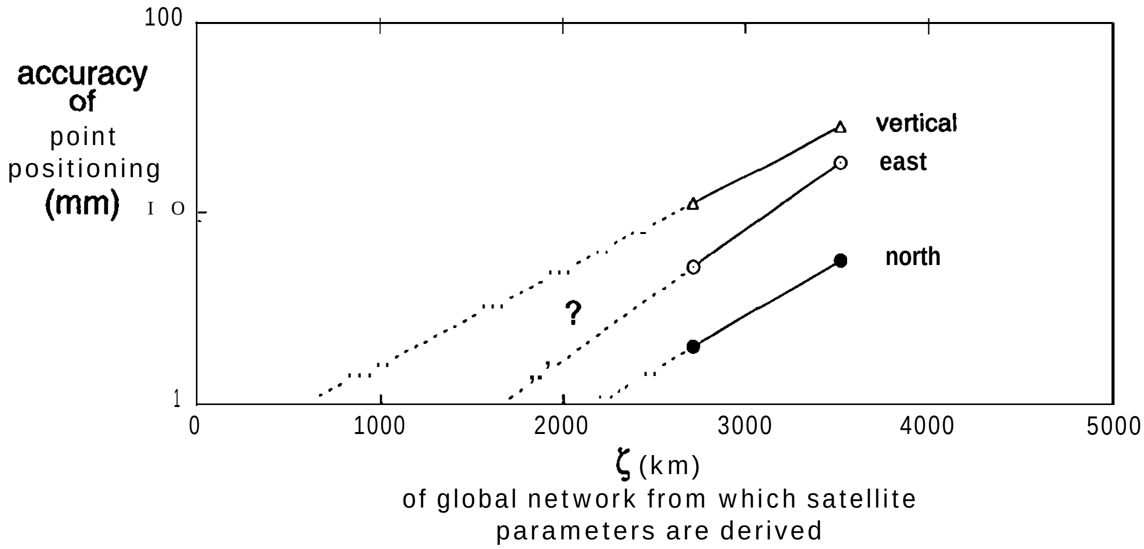

Figure 6 The accuracy of point positioning as a function of the distribution of sites in the global network from which satellite parameters are derived. The dotted line gives a speculative extrapolation.

V SUMMARY AND DISCUSSION

We have described a quantitative method of assessing the geometrical uniformity of points on a sphere, and have applied this to current and future distributions of IGS sites. We conclude that, at present, no more than about 30 of the ≈ 70 sites with site log entries at the IGS Central Bureau Information System can be considered global. The prospects for continued expansion of the global network are good, however, with plans for additional sites in areas of the globe with currently poor coverage.

We have also shown that, given data from ≈70 receivers, of which only about 30 are globally distributed, an efficient analysis strategy is to determine satellite parameters—ephemerides *and* clocks—from the global sites, then point position each of the remaining sites. The saving in cpu cost is roughly an order of magnitude, and the results are substantially the same as the simultaneous reduction of *all* data. Such point positioning would be an ideal task for (regional) Associate Analysis Centers to be established. In certain regions these could be part of current Analysis Centers.

We believe that GPS clock solutions have been undervalued by the IGS. Sufficiently accurate clock solutions allow a tremendous savings in cpu because, together with fixed orbits, they obviate the need to consider data from multiple receivers simultaneously. Similarly, double-difference techniques can be reduced to single difference techniques, where the single difference is necessary only to remove the effects of *receiver* clock error.

Because of selective availability, clock solutions are noisy with about 80-ns rms variation. Unlike orbits, which can be interpolated quite accurately given estimates every 15 minutes, clock solutions at 15-minute intervals are worthless *except* at the times where they were determined. We recommend that the IGS consider operating a number (6 to 12 with good global distribution) of its stations at a 10-second data interval, so that estimates of GPS clocks *every* 10 seconds could be routine. On this time scale clocks are smooth, so that interpolation is feasible.

The assignment of 30 – 40 stations to the core group in the IGS Terms of Reference seems to be based on one of two assumptions: either (i) beyond 30 or 40 stations there is only marginal improvement in estimations of satellite ephemerides and clocks or (ii) the computational burden of a global solution with more than 30 or 40 stations is prohibitive. Neither of these assumptions is necessarily true. The most desirable situation is a permanently installed receiver with near-real-time communications. Such a station would be "core" or "fiducial", depending on whether its data are used in the determination of global parameters or not, respectively. Second most desirable would be a permanent installation with less-than-real-time communications, requiring periodic labor to retrieve the data. The least desirable situation is the intermittent occupation of a site. Costs associated with these three possibilities are clearly site specific, and one needs to consider the trade-off between different kinds of costs (communications vs. labor, for example) in determining how to treat an individual site. The last two situations are clearly in the fiducial category.

Finally, we remark that a global network of continuously operating GPS receivers is valuable for reasons in addition to those mentioned in the Terms of Reference. Data from the network has the potential to be used in estimating the global distribution of precipitable water vapor content (through estimation the wet troposphere delay), and total electron content (through the ionosphere combination of phase and pseudorange observable). Real-time navigation, especially for aircraft, will also rely increasingly on GPS networks. To the extent that the cost of network expansion can be shared among those with different interests, cooperation obviously ought to be encouraged.

ACKNOWLEDGMENT

The work described in this paper was carried out in part by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Zumberge, James F., and Clyde C. Goad, Position Paper 1, *Proceedings of the IGS Analysis Center Workshop.* J. Kouba, cd., Ottawa, Canada, October 1993.

APPENDIX

Shown in Figure Al are networks indicated in Table Al submitted as a result of the solicitation of the organizational meeting in Paris on March 14, 1994. The authors would like to thank the contributors for their efforts.

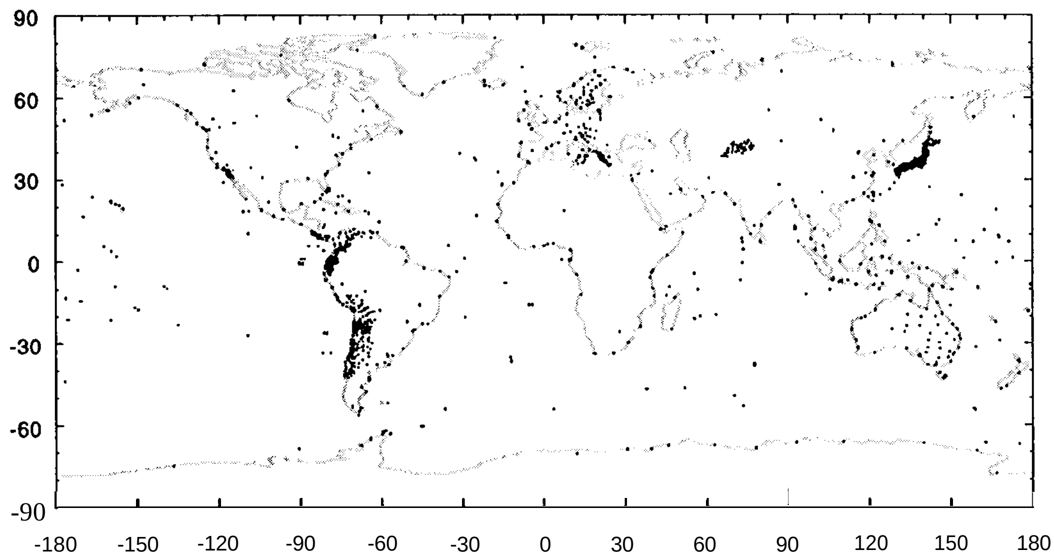

Figure Al Networks listed in Table Al.

Table Al Networks shown in Figure Al.

region	contributor	affiliation
global (current IGS)	R. Neilan	Jet Propulsion Laboratory
global (planned or proposed IGS)	R. Neilan	Jet Propulsion Laboratory
Epoch '92	C. Nell	Goddard Space Flight Center
Central and South America, Mediterranean	H. Drewes	Deutsches Geodaesie ForschungsInstitut
North America (Canada)	R. Duval	Natural Resources Canada
Europe (Sweden)	J. Johansson	Onsala Space Observatory
Baja California, Central and South America	S. Fisher	Unavco/NASA
Europe (Norway, Iceland, Greenland)	G. Preiss	Norwegian Mapping Authority
Asia, Indonesia, South America	C. Reigber	GeoForschungsZentrum
North America (western Canada)	M. Schmidt	Natural Resources Canada
Asia (Japan)	S. Shimada	National Research Institute for Earth Science and Disaster Prevention
Asia (Japan)	H. Tsuji	Geographical Survey Institute
global (tide gauges)	W. Carter	NOAA
global (tide gauges)	P. Morgan	University of Canberra
global (Doris, tide gauges, GPS)	C. Boucher	Institut Geographique National

POSITION PAPER 1 APPENDIX

Yehuda Bock, chair

The follow-up session to the first Position Paper consisted mainly of presentations which described plans for GPS expansion in specific regions (see Al for figures and diagrams).

Mark Schenewerk described the current NOAA plans to distribute the geodetic-quality U.S. Coast Guard (USCG) data from their differential GPS navigation tracking sites. These data will be taken from -50 sites around the coast of the continental U. S., the Great Lakes, Alaska, and Hawaii at a 5-second interval, in near real time, using Ashtech Z12 receivers. They will be available via Internet and modem from the National Geodetic Survey (NGS) as the USCG sites become operational during 1995. Additionally, 6 U.S. Corps of Engineer sites, identical to the USCG sites but covering the Mississippi River watershed, will be installed and distributed in a like manner. Finally, an agreement is in place for a similar cooperative distribution scheme between NGS and the Federal Aviation Administration as their Wide Area Augmentation System becomes operational later in the decade.

Boudewijn Ambrosius described the plans of WEGNET, which include 1000-km spacing of GPS receivers in Europe with an IGS-like infrastructure. A total of some 60 receivers, spanning Greenland to mid Asia, of which 15 would be IGS stations, is contemplated. Collocation with other space geodetic techniques is planned where possible. The stations would follow IGS guidelines.

Ramesh Govind, representing AUSLIG, described the IGS goings-on in Australia. The following fourteen stations comprise the Australian Regional GPS Network (ARGN): Cocos Island, Darwin, Karratha, Alice Springs, Townsville, Yaragadee, Cedun, Tidbinbilla, Hobart, Macquarie Island, Mawson, Davis, Casey, and Wellington. With the exception of Townsville, all sites are installed and are currently either operational or being fieldtested. Its is intended that data from Cocos Island, Darwin, Hobart, Tidbinbilla, Yaragadee, Davis, and Casey be freely available to the IGS through anonymous ftp. Data from the remaining stations, designated as local sites, will not be freely available, but may be made available on request for specific projects that are of benefit to AUSLIG and Australia. An Associate analysis Center is being established to routinely process these data with the intention of submitting the results to the IERS.

Hiro Tsuji described the status of GSI's nationwide GPS array in Japan. It consists of 210 GPS permanent stations, with 15-km spacing in central Japan, and with 120-km spacing in other areas. To process large amount of data, distributed processing using GAMIT and GLOBK is implemented. The array is already operational, and detected coseismic deformations associated with the October 4 Kurile Islands earthquake.

Roman Galas spoke of a number of stations in Asia that GFZ is working to get operational, including Zvenigorod, Dudinka, Krasnojarsk, Petropavlovsk, La Plata, and Beijing.

Hermann Drewes described the SIRGAS project which was established in October 1993 in order to define and realize a geodetic reference system for South America. Under the participation of all South American countries, two working groups have been made up, one for the establishment of a continental reference frame consisting of about 50 GPS stations, the other for defining a geocentric geodetic datum and connecting together all the national control networks. It is anticipated that the reference frame will be well embedded in the IGS and serve as a regional densification of ITRF. A GPS SIRGAS pre-campaign, including 14 stations from

Venezuela to Chile, was performed in February 1994. The main campaign is planned from May 26 to June 4, 1995. Two global data centers have been selected, one at DGFI (Munich/Germany) the other at IBGE (Rio de Janeiro/Brazil). Four institutions in Europe and North America have been asked to serve as data processing centers.

Jan Johansson reported on the status of the Swedish permanent GPS network **(SWEPOS).** The network was established by the **Onsala** Space Observatory (Chalmers University of Technology) and the National Land Survey of Sweden. Presently the network consists of 20 station with an average spacing of 20 km The operation of the station and the data handling as well as archiving is carried out following recommendations from IGS. The daily data processing uses the IGS combined orbits. **Onsala** Space Observatory and Smithsonian Astrophysical Observatory also runs the annual DOSE GPS campaign in order to investigate the present-day postglacial rebound in **Fennoscandia.** The network consists of about 55 sites in Scandinavia, Finland, Baltic region, and Russia and involves about 8 groups.

Teruyuki Kato commented on the present status of WING (Western Pacific Integrated Network of **GPS),** which includes 1000-km spacing of GPS receivers in the western Pacific area. About 10 sites are planned, among which two or three sites are ready to archive continuous data, He commented that the data transmission is the greatest problem in the area because most of the sites are located at remote and isolated small islands or in countries where good communication lines such as INTERNET or even telephone lines are not well established. However, the geodesists in the area are eager to collaborate with IGS for geodetic works in the region. WING covers countries such as Japan, China, Russia, Taiwan, Philippine, Micronesia, **Palau,** Malaysia, and Indonesia.

Jan Kouba of Natural Resources Canada, described the Canadian work to integrate regional GPS stations and networks in the IGS framework (see Figures 1 and 2).

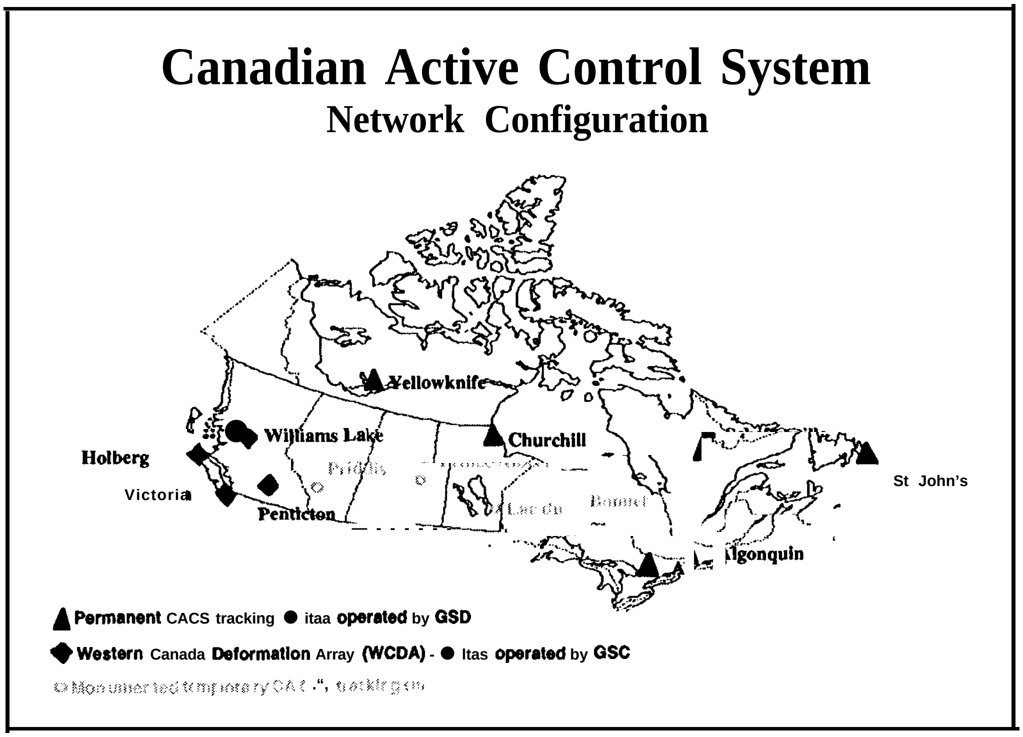

Figure 1 Map submitted by Jan **Kouba.**

ITRF INTEGRATION STRATEGIES

Global processing

Includes globally distributed IGS stations
Estimated EOP, orbits, station coordinates, station and satellite clock parameters.
At cm or ppb precision level

Regional baseline processing

Uses IGS orbits.
Processes regional network using differential carrier phase.
For special geodetic and geodynamic applications.
At mm or ppb precision level.

Point positioning processing

Uses CACS/IGS orbits and clocks.
Processes code and carrier with single point approach.
For wide area positioning and navigation.
Precision currently at the meter level.

Figure2 Outline submitted by Jan Kouba.

Wolfgang Schlüter of Institut Für Angewandte Geodasie discussed plans for implementation of permanent TurboRogue receivers, with emphasis on densification on the Asian continent.

Suriya Tatevian of the Russian Academy of Sciences reported on the status of the Russian network of IGS stations, as well as plans for future expansion.

Randolph Ware gave an overview of activities by the University Navstar Consortium (UNAVCO). UNAVCO provides equipment, technical and logistical support to university investigators making use of GPS for geosciences research. Since 1986, UNAVCO has supported more than one hundred domestic and international GPS surveying projects. Data from IGS and other continuous monitoring sites are being used increasingly in GPS surveying projects supported by UNAVCO. Ware said that it is time to define ways in which IGS and UNAVCO can work effectively together. Coordination of regional and global reference frames is one example. UNAVCO looks forward to defining ways to cooperate with IGS and improve the productivity of its support activities.

POSITION PAPER 2
CONSTRUCTING THE IGS POLYHEDRON BY DISTRIBUTED PROCESSING

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Yehuda Bock (Scripps Institution of Oceanography)
Jan Kouba (Natural Resources Canada)

ABSTRACT

The IGS Terms of Reference recognizes the need to densify the global reference frame and to monitor the deformation of the "IGS Polyhedron." This is central to the IGS primary objective to support geodetic and geophysical research activities. The key technical issue is how to implement the geodetic computations in a manner which is both accurate and efficient, Previous work outlines a hierarchy and methodology for distributing the processing burden among regional analysis groups, and integrating regional GPS solutions into a unified global framework [Blewitt, et al., 1993a]. We further develop these ideas, and design a prototype for an operational system. Such a system could be implemented in the near future as part of a pilot IGS program for densification that would merge the analysis of the global GPS network and permanent regional stations.

I INTRODUCTION

Statement of the Problem

The continued proliferation of permanently operating, high precision GPS stations presents both an opportunity and a challenge. There is an opportunity to produce a reference frame which is dense, reasonably uniform in distribution and quality, accurate (few mm), and readily accessible to GPS users [Blewitt, *et al.*, 1993a]. The IGS Terms of Reference calls this reference frame the "IGS Polyhedron," which would have approximately 200 stations at the polyhedron's vertices. Such a network would be ideal for monitoring variations in the Earth's shape, and for providing kinematic boundary conditions for regional and local geodetic studies. The challenge is to be able to analyze cohesively the data from an ever increasing number of receivers, such that near-optimal solutions can be produced. Although ideally all data would be analyzed simultaneously to produce a single solution, in practice this is computationally prohibitive.

The objective of this paper is to describe a specific plan which could be implemented by the IGS within months rather than years. We focus on a simple implementation of previous ideas which could evolve into a more complex process as IGS gains more experience in this area.

Distributed Processing Approach

This paper builds on the work presented at the IGS Analysis Center Workshop in Ottawa of November 1993 [Blewitt, *et al.*, 1993a], which set out to address this challenge and listed issues that would have to be resolved, A distributed processing approach was presented, which, at the algorithm level, partitions the problem into manageable segments, and, at the organizational level, delegates responsibility to analysis centers who would naturally have an interest in the quality of the solutions. Another characteristic of this approach is a level of redundancy, such that a meaningful quality assessment can be made by other, independent groups. We regard the introduction of distributed processing as a natural evolutionary step in the analysis operations of the IGS.

Scope

So that we can be concise, we assume the reader has already studied Blewitt, *et al.* [1993a], which we still consider essentially valid.[9]

Several of the issues concerning IGS network densification which were noted in the Ottawa position paper are now being addressed by other IGS participants at this workshop. To avoid unnecessary duplication of effort, this paper will focus on the technical aspects of distributed processing, and on a practical implementation that can be achieved in the near future.

We present a prototype model of how a pilot system for densification might operate. We also discuss the impact that such a design would have on IGS participants (current and future), and finally propose a "strawman" implementation schedule as a starting point for discussion.

Design Goal

Because of its importance and simplicity, we reiterate the design goal set forth previously:

Any customer of IGS should be able to produce efficiently and accurately a regional solution that would be globally consistent. The proposed system would enable analysts of regional networks to (i) incorporate IGS global products into regional data processing for purposes of accuracy, efficiency, and consistency; and (ii) merge regional network solutions into global IGS network solutions as a means to densify the terrestrial reference frame. For geodynamics investigations, the user should also be able to construct a consistent time-series of coordinates for both the user's station(s) and for the surrounding IGS stations.

II GENERAL APPROACH

Terminology

Our terminology has evolved since the Ottawa Workshop to be more consistent with the IGS Terms of Reference. The proposed system has a distributed design involving three types of analysis center. Figure 1 illustrates how the new system might be considered as a natural extension to the existing scheme for IGS Analysis Centers (AC's), without significantly increasing the burden on existing operations.

<u>IGS Analysis Centers (AC's)</u> would operate much as today, routinely producing orbital parameters and Earth orientation parameters (EOP) in a standard frame, and annually producing a GPS global network solution which is submitted to the International Earth Rotation service (IERS) for incorporation into the IERS Terrestrial Reference Frame (ITRF). AC's should be minimally disturbed by the extensions to the current system, but new activities would include the submission of weekly free-network solutions, and possibly other products to be decided. AC's have the option of including selected regional stations in their global analysis (discussed later).

<u>Type 1 IGS Associate Analysis Centers (T1's)</u> would analyze specific regional cluster(s) of stations following certain standards and flexible guidelines. T 1's would provide free-network solutions to IGS, but in the role of IGS users, they would of course be free to impose any constraint they wish for their own research and internal purposes. IGS should provide the means for T 1's to impose meaningful constraints for this purpose.

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[9] See also Blewitt, *et al.* [1995].

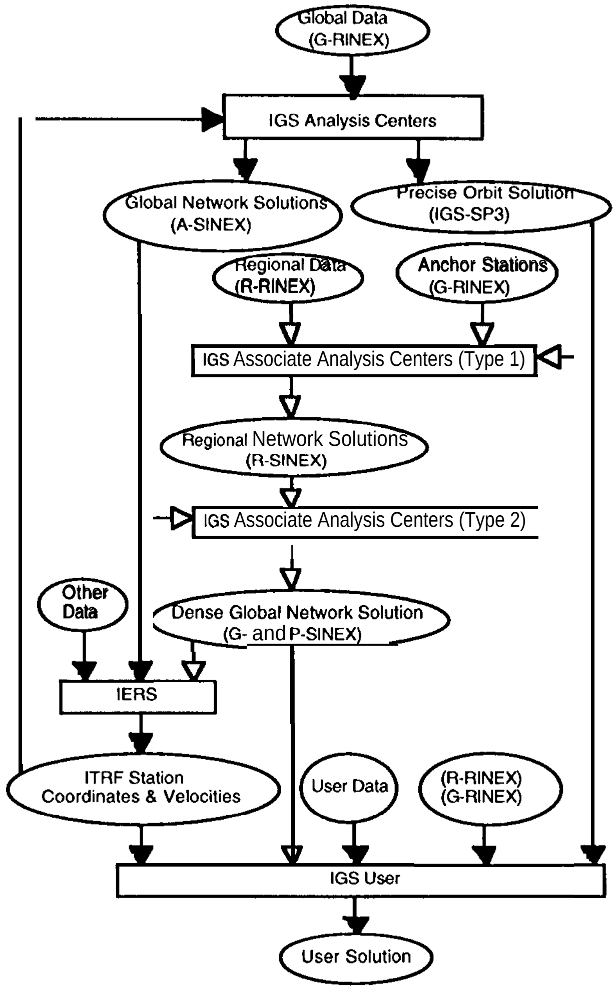

Figure 1 The main components of the proposed system. Rectangles denote analysis; rounded boxes denote data. Symbols with solid lines already exist.

Type 2 IGS Associate Analysis Centers (T2's) would take weekly free-network solutions from all of the AC and T1's, and produce combined network solutions. T2's would conduct reference frame investigations, assess the quality of AC and T1 solutions, and provide feedback using quality statistics. T2's would submit findings to the IGS Central Bureau, who will then work with the T2's and the IERS Central Bureau to produce an annual update to the standard frame. This standard frame (based on ITRF) would then used by AC's for orbit/EOP production, and by IGS users for network constraints.

Note that it expected that groups will serve in two or three of the above capacities.

We now define terminology with regard to networks. It would be helpful if the IGS participants could agree to standardize this terminology. Figure 2 illustrates the relationships between station sets, and the caption describes these relationships in more detail.

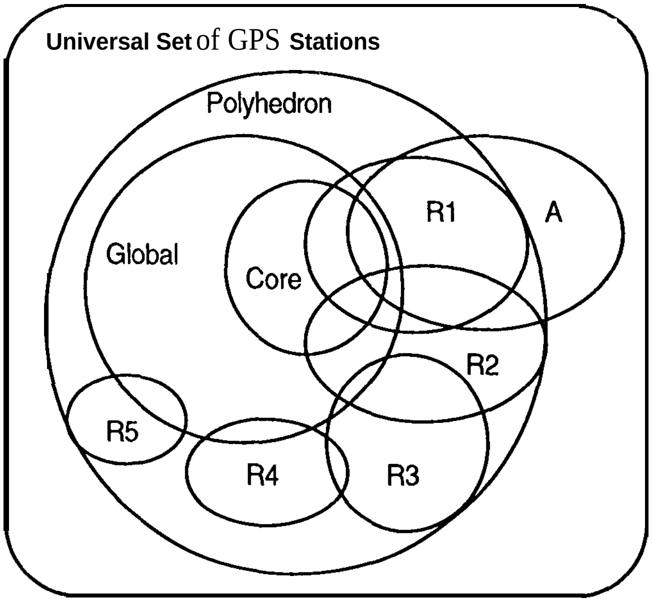

Figure 2 Relationships between networks. The IGS Polyhedron is defined as the union of the IGS Global Network and all IGS Regional Networks. The Core Network is a subset of the Global Network. Regional Networks (Rl, R2,...) all intersect with the Global Network, and can intersect with each other to varying degrees (e.g., R5 is isolated, but does contain global stations). As an example, a permanent GPS array A (dotted line) contains IGS stations (intersection with Polyhedron) and non-IGS stations (outside Polyhedron).

The term IGS Global Network (or simply "global network") refers only to stations which are used by AC's to produce precise orbits and have been defined by IGS as global network stations. The IGS Global Network is considered a first-order geodetic network whose coordinate solutions should not be affected by lower-order networks (e.g., regional GPS analysis). Since the global network plays this role, quality assurance is essential. As a first step, we suggest that an IGS station be considered part of the global network if it is analyzed , by at least 3 AC'S. As a future step, we suggest the stations must have been routinely analyzed by at least 3 AC's for at least 3 months, and the 3 sets of solutions for this station's coordinates have been shown to be consistent to within 10 mm. We must get away from the common notion that a station suddenly becomes part of the IGS Global Network once its data appears at the IGS Data Centers.

The IGS Core Network is a selected subset (currently 13 stations) of the IGS Global Network which is analyzed by all AC's, and which is used to define the reference frame of the precise orbits and Earth rotation parameters, by the adoption of a standard set of coordinates.

The term IGS Regional Network has a very different meaning than a particular group's regional network. The IGS Regional Network consists of at least 3 global network stations, plus a selected subset of other stations within a given region. It may be as small as 3 global network stations plus 1 other station. The actual selection should be approved by the IGS by some procedure yet to be established, All stations in an IGS Regional Network are considered "IGS Stations" and must meet IGS standards. We hope that individual IGS Regional Networks can be defined at the December 1994 Pasadena Workshop. (Note that AC's may produce solutions for an IGS Regional Network as part of their standard orbit production, rather than by a separate analysis).

The term IGS Polyhedron refers to the concatenation of the IGS Global Network and all IGS Regional Networks. It is envisaged that the IGS Polyhedron will be a well-distributed set of approximately 200 stations, separated by approximately 1,000-3,000 km.

Note that if we follow the above definitions, it is still possible for a station whose data appears at an IGS Data Center to not be part of the IGS Polyhedron. This is inevitable, since IGS Data Centers are run by organizations with other requirements apart from IGS (e.g., national interests, scientific research, etc.). We recommend that stations be identified by letters "G" and "R' in databases to refer to their official IGS status as stations in the IGS Global Network or an IGS Regional Network. This is important for Associate Analysis Centers and users who are only interested in IGS stations. If a new station has already been planned as a Global Network Station, but has not had time to be fully approved, then it should be temporarily considered an IGS Regional Station, and be labeled "R". Otherwise T1's may assume they can use these stations as 1 of the 3 mandatory global stations. It also assures that they are counted as part of the IGS Polyhedron.

Analysis

Global Analysis. The free-network approach fixes no station coordinates when deriving the solution [Herring, *et al.*, 1991; Heflin, *et al.*, *1992]*. The scale is well defined by fixing the speed of light and GM to standard values. The Earth center-of-mass (x_{cm}, y_{cm}, z_{cm}) is by definition at the origin, provided we simultaneously estimate orbits and station coordinates, with Stoke's coefficients of degree 1 set to zero:

$$
\begin{aligned}
(C_{11} = 0) &\Leftrightarrow (x_{cm} = 0) \\
(S_{11} = 0) &\Leftrightarrow (y_{cm} = 0) \\
(C_{10} = 0) &\Leftrightarrow (z_{cm} = 0)
\end{aligned}
$$

If, in addition to orbits and station locations, the pole position is estimated, then "loose" a priori constraints (to be defined below) should be applied to the solution in order to avoid possible numerical problems. It is also important to keep the free network within a few meters of convention (ITRF) so that linear transformations can still be applied to the network solution. The datum is defined only after all solutions are combined-into one, otherwise we would be faced with the difficult situation where solutions submitted by different analysis groups have different sets of constraints. For the routine production of orbits and EOP, global analysis centers could save a lot of processing time if they first produce the loosely constrained solution to extract the free-network and EOP estimates; then fix a subset of stations to recommended coordinates, and extract the orbits and EOP in the standard frame. Alternatively, tight constraints could be applied for orbit production, and then removed later to produce a free-network solution. In this case, care should be taken so that precision is not lost when removing the constraints. (For example, it is important to preserve information on the apparent motion of the geocenter).

Loose Constraints. Loose constraints are applied in the form of a nominal value with an a priori standard deviation, Blewitt *et al. [1993a]*, recommended that (i) at least 3 stations (but less than 100) be loosely constrained with a 10 meter a priori standard deviation, and that (ii) constraints should only be applied to stations whose nominal values are consistent with ITRF to better than a meter.

An Anchor Station is any Global Network Station that (i) is routinely analyzed by at least three AC's, and (ii) is listed in the ITRF. T1's should use at least three anchor stations in the reduction of the regional network data, to allow for robust network combinations, and for the assessment of errors, by comparing T 1 and AC solutions for the vectors between anchor stations. Apart from quality control, the assessment of errors will allow for better weighting schemes to be developed for network combinations, and for detection and first-order correction of anomalous regional network rotations and distortion (possibly due to AC orbit errors). The list of anchor stations should grow to be sufficiently globally distributed and dense such that any potential regional survey can be contained within a polygon of at least three anchor stations, with at least one of them within 2000 km of the regional network.

Regional Analysis. For reasons of consistency, accuracy, and quality assurance, we recommend that T 1's fix the GPS orbits to the IGS official solution, which is produced under the supervision of the IGS Analysis Coordinator by combining IGS orbit solutions from the various AC's. For regional net work estimation we recommend including at least three anchor stations so that network origin, orientation and scale can be monitored and corrected, and so that network distortions caused by remaining orbit errors can be corrected to first order. (Fixing 9 anchor station coordinates effectively constrains 3 origin parameters+ 1 scale+ 3 orientation angles + 2 horizontal shear strains). We recommend the three (or more) anchor stations be constrained with an a priori standard deviation of 10 meters, but the nominal values should be consistent with the ITRF at the level of 1 meter or better. It is important that no coordinates be fixed in the solution.

Network Analysis. Our implicit assumption is that regional networks will add very little additional information to the determination of orbits or EOP. We should also note that it would be undesirable to adjust further the globally-determined anchor station coordinates based on regional network solutions, because the same data would be used twice. Therefore, in combining regional with global solutions, we recommend that the global estimates for the anchor stations and their covariance matrix elements remain unperturbed by the regional solution, and that the solution be only augmented by those regional stations that are not anchor stations. Before augmentation, T2's should ensure reference frame consistency between global and regional solutions, using the anchor stations.

Parameterization of submitted solutions cannot be as flexible as first thought [Blewitt, *et al.*, 1993a] if we are to implement a system in the near future, but we must make allowances for the fact that different software packages work in fundamentally different ways. We recommend the use of Cartesian station coordinates for exchanging solutions, augmented with full variance-covariance information. The station coordinates should be (nominal + estimate), and the variance-covariance information should be in the form of standard deviations, plus a correlation matrix. This method was chosen since it lends to easier interpretation to the eye, which is an important criterion for exchange formats. The transformations from this to other equivalent representations has already been given by Blewitt, *et al. [1993a].*

Format. Work has been in progress for several years by many patient individuals working towards a universally acceptable solution format for space geodetic coordinate solutions. We are not so patient, and need a workable exchange format quickly. It is crucial that we not spend to much time discussing this issue, but that we quickly agree to a common format *specific to IGS analysis,* and get to work writing format translators. Even if a common format emerges in the next couple of years, we predict the IGS format will be a defacto standard which leading software will recognize. Analogous to the "receiver independent exchange format" (RINEX) [Gurtner, 1994], we propose to call this format the "software independent exchange format" (*SINEX*). We include here a strawman specification for SINEX. Appendix A contains a description of our prototype format.

III SPECIFIC PLAN

Analysis Centers (AC's)

Input. AC's will continue to get all their data from the IGS Data Centers. Typically, these will not include all of the IGS Global Network, but will include all of the Core Network. IGS Regional Station data may also be included in the global solution, allowing AC's to play the role of a T 1 without having a separate analysis stream. In 'this case, regional stations are simply treated as estimated global stations.

Products. AC's will produce *weekly* fiducial-free network solutions which contain both the estimates and the full variance-covariance information in SINEX format (Appendix A). *SINEX files also contain eccentricity information which was assumed in the analysis.* In cases where we discover that eccentricity data have errors, we could therefore easily correct the solutions. We call these AC-produced solution files "*A-SINEX*". These would be deposited at the data centers each week. Typically, they will not include all global IGS stations, but *AC's should only submit solutions for official designated "IGS Polyhedron" stations.* This implies that it is acceptable (indeed better) if AC's include *official* IGS Regional Stations in their analysis and AC-SINEX files, but any other station should be removed. The deadline for submission will be the same as that for orbit solutions. AC's would include relevant information in the IGS Report which is currently submitted every week. The format of this report is left to the discretion of the AC for now. If a problem or something unusual happens (e.g., to affect the delivery of a product), the AC will mail an IGS Mail with appropriate information.

Feedback. AC's will receive feedback from the Associate Analysis Centers (AAC's). AC's would send IGS Mail with explanations should an AAC detect problems with AC products. AC's should take corrective action as soon as possible. AC's will continue to provide feedback to network centers and users via IGS Mail in the same way as is done now.

Responsibility. The AC's have the responsibility to produce high quality estimates and error estimates for a subset of IGS Global Stations, and possibly additional IGS Regional Stations. Although AAC's will perform quality control functions, it is assumed that AC's will perform appropriate quality control before releasing their products to anyone.

Type 1 Associate Analysis Centers (T1's)

Input. T1 's will get data from a regional set of stations which abide by IGS standards. Moreover, they are obliged to analyze data from at least 3 well-distributed IGS Global Stations in the region ("Anchor Stations"). The regional data may be obtainable from IGS data or network centers, but may also be available outside normal IGS channels. The Anchor Station data will be available from IGS Data Centers. Most often, T1's will naturally analyze data from a regional network with which they are direct] y associated. T 1's will reduce their regional network data using IGS precise orbits, available at the IGS data centers. As there is little evidence to the contrary, we will assume that orbits from the IGS rapid service are acceptable for this purpose.

Products. T1's will produce *weekly* fiducial-free regional network solutions (including 3 global stations) which contain both the estimates and the full variance-covariance information in SINEX format (Appendix A). Since T 1's must wait for official IGS orbits before reducing their data, the deadline for submission to IGS data centers will initially be 2 weeks following the availability of IGS orbits. Although solutions for all regional stations could be made electronically available at T 1's, *the T1's should only submit solutions for official designated "IGS Polyhedron" stations to the data centers each week.* In many cases for regional networks, this might include only 3 global stations plus 1 or 2 regional stations. We call regional solution files "*R-SINEX*". T1's would also compose and deposit a summary report to the IGSCB. The format of this report is left to the discretion of the T1 for now. If a problem or something unusual happens (e.g., to affect the delivery of a product), the T1 will mail an IGS Mail with appropriate information.

Feedback. T1's will provide feedback to the AC's directly. T1's are in a good position to evaluate the official IGS orbit product, and report on any problems found. T 1's will receive feedback from T2's and take corrective action as necessary.

Responsibility. The T 1's have the responsibility to produce high quality estimates and error estimates for a subset of regional stations that have been assigned to the "IGS Polyhedron." Although T2's will perform quality control functions, it is assumed that T1's will perform appropriate quality control before releasing their products to anyone. It should be emphasized that as far as IGS is concerned, T 1's only have the responsibility to IGS to produce solutions for officially designated IGS stations. Distribution of other products from the regional network to users will fall outside of the IGS purview.

Type 2 Associate Analysis Centers (T2's)

Input. T2's will get A-SINEX and R-SINEX files from IGS Data Centers. A-SINEX files from the AC's should be available at the same time as the AC's deposit their orbit solutions. Regional R-SINEX files from the T1's are expected to be available from T 1's within 2 weeks of the release of the IGS official orbits (see above). T2's should on not circumvent this process, for example, if they play a dual role (as an AC or T1). It is important that input data files be consistent for all participants, and circumventing the process will undoubtedly lead to confusion, and unresolved discrepancies. T2's will also use official IGS standards (which default to IERS standards in many cases), such as reference frame definition, This information and necessary updates will be made available via IGS Mail from the IGS Central Bureau. Importantly, care must be taken with eccentricity data (e.g. antenna heights, phase center offsets). This data should appear in every SINEX file to assure consistency. Only official values available from the IGSCB should be used, but in the event that data on input SINEX files differ from IGSCB values, then the appropriate correction should be applied for the output SINEX files. The general rule is that all information must be available externally (from IGSCB or IGS Data Centers). Any need to use internal information sources should be regarded a serious problem.

Products. T2's should attempt to produce solutions for *all* IGS Polyhedron Stations on a weekly basis. A set of *weekly* global network solutions will be deposited at the IGS Data Centers in SINEX format (Appendix A). This will be constructed by combining the estimates from a variety of AC's. This weekly submission will be in the form of a fiducial-free solution. These files are called "*G-SINEX*", referring to the IGS Global Network. In a second set of submissions, the T2's will incorporate *all* IGS Regional Network solutions into the global solution. These solution files are called "*P-SINEX*" referring to the "IGS Polyhedron." Since T2's must wait for AC's and T 1's to generate their products, the deadline for the two types of solutions is different. The first set of solutions (global network, "G-SINEX") should be submitted within 1 week of the deadline for delivery of A-SINEX files, i.e., at about the time IGS precise orbits become available. The second set (IGS polyhedron, "P-SINEX") should be submitted within 1 week of the delivery of R-SINEX files. T2's would also compose and mail an IGS Report along with any solution. The report should contain statistics concerning internal consistency between groups, and external consistency with the current ITRF. The format of this report is left to the discretion of the T2 for now. If a problem or something unusual happens (e.g., to affect the delivery of a product), the T2 will mail an IGS Mail with appropriate information. Final] y, T2's will construct kinematic solutions of the form x = X.+ v(t – to) and submit these to IERS for incorporation into ITRF.

Feedback. T2's will provide feedback to the AC's and T1's via the usual means of IGS Reports and Mail. This feedback should take place within days rather than weeks in order for it to be useful. T2's are in a good position to evaluate eccentricity data and consistency between the various groups. T2's will receive feedback from other groups who are checking for consistency (i.e., other T2's and IERS), and will take corrective action as necessary.

Responsibility. The T2's have the responsibility to produce high quality estimates of *all* IGS polyhedron station coordinates and velocities (global+regional), including error estimates which accurately reflect the quality of the solution. It is assumed that T2's will perform appropriate quality control before releasing their products to anyone. T2's have the responsibility to try to identify discrepancies between solutions from T1's and AC's, and notify these groups about the problem.

Processing Cycle

We are now in a position to look at the processing cycle from the point of view of the various IGS participants. Table 1 illustrates this.

Week	Data Center	Analysis Center (AC)	Type 1 Associate Analysis Center (T1)	Type 2 Associate Analysis Center (T2)
0	G-RINEX (Global)	Process G-RINEX (+R-RINEX option)	R-RINEX (Regional)	—
1	—	—	—	—
2	A-SP3 A-SINEX	Deposit A-SP3 Deposit A-SINEX	—	Process A-SINEX
3	IGS-SP3 G-SINEX	—	Process IGS-SP3 with G-RINEX + R-RINEX	Deposit G-SINEX
4	R-SINEX	—	Deposit R-SINEX	Process R-SINEX with G-SINEX
5	P-SINEX (Polyhedron)	—	—	Deposit P-SINEX

Table 1 The Distributed Processing Cycle. Key: G-RINEX = global station data; R-RINEX = regional station data; A-SP3 = precise orbits produced by an Analysis Center; A-SINEX = global network solutions produced by an Analysis Center; IGS-SP3 = official IGS orbits; G-SINEX = combined global network solution; R-SINEX = regional network solution; P-SINEX = polyhedron (global+ regional) solution

Based on IGS experience to date, the processing cycle is most naturally described in units of weeks. The time delay between data acquisition and the final submission of weekly IGS Polyhedron solutions (P-SINEX files) is 5 weeks. However, recall that G-SINEX files should be available at about the same time as IGS precise orbits (2-3 weeks after data acquisition). This is important, since the AC's will receive feedback concerning orbits and stations synchronously. The cycle is longer for incorporation of additional regional stations, but this is because T1's must wait for IGS SP3 files before they can begin processing. It is therefore preferable, wherever possible, for regional stations to be processed by AC's and therefore be included in the G-RINEX files.

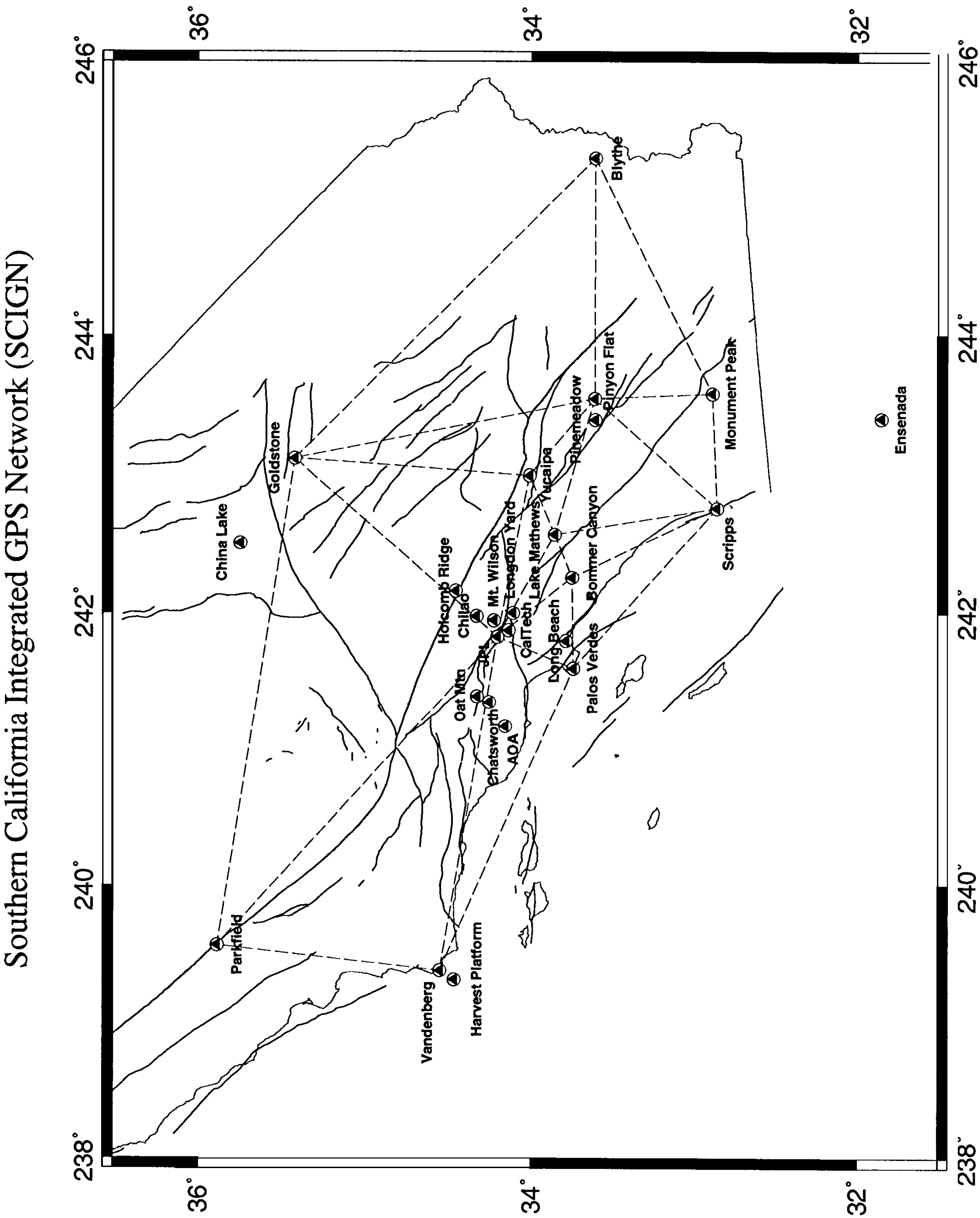

Figure 3 Map of the Southern California Integrated GPS Network

IV EXAMPLE

Introduction

We present an example of the hierarchy of distributed processing based on the analysis of North American and California permanent station data at the S10 Analysis Center (AC).

The IGS Global Data Centers at CDDIS and S10 archive data from several Continental U.S. sites operated by NASA (e.g., Goddard, North Liberty, McDonald Observatory, and Pie Town). Also archived are data from California including the NASA sites at Quincy and Mammoth Lakes in northern California and the 22 sites of the Southern California Integrated GPS Network (SCIGN). SCIGN (Figure 3) consists of sites distributed over all of southern California (the Permanent GPS Geodetic Array – PGGA, including the IGS Core Station at Goldstone) and a denser network in the Los Angeles Basin (the Dense GPS Geodetic Array - DGGA), established after the January 17, 1994 Northridge earthquake. PGGA results after the June 28, 1992 Landers earthquake were the first demonstration of sub-centimeter-level computation of coseismic displacements with respect to the ITRF and demonstrated the synergism between regional clusters and the IGS [Blewitt, et *aL,* 1993b; Bock, *et al.,* 1993].

S10 is also responsible for analyzing SCIGN data. Initially, it was manageable to process the IGS global data and California data in a simultaneous adjustment. Today, the S10 AC analyzes data daily from about 60 stations, with an additional 15 SCIGN stations expected to be on-line within a few months. As described below, a distributed processing scheme has been implemented to handle this growing data set.

Distributed Analysis - Global Solution

The S10 AC analyzes data daily from the 13 IGS Core Stations and about 20 others chosen on the basis of global distribution and data quality. The analysis, using the GAMIT GPS software [King and Bock, 1994], is performed in independent twenty-four hour (0-24h UTC) segments using the ionosphere-free phase observable (without ambiguity resolution). Estimated parameters include station coordinates, satellite initial conditions, piecewise continuous tropospheric zenith-delays (one every 2 hours per site), polar motion, polar motion and Earth rotation rates, and phase ambiguity parameters. In a loosely-constrained adjustment, the portion of the variance-covariance matrix for station, orbital parameter, and Earth orientation parameters is recorded in an *"A-SIMM"* file.[10]

For each GPS week, daily ***A-SINEX*** files are input to the GLOBK software [Herring, 1994] to estimate refined estimates of station position, and daily orbital elements and Earth orientation. The orbits and Earth orientation are mailed to the appropriate IGS locations and the S10 AC work for that week is done. The ***A-SINEX*** files are stored on the S10 archive for use by other GAMIT/GLOBK users.

Distributed Processing - Regional and Local Solutions

The *"SIO Tl"* then goes to work. The *regional* PGGA data are analyzed daily from five IGS stations already used in the global analysis (Algonquin, Bermuda, Goldstone, Kokee Park, and Penticton). For good measure, we include the sites in North Liberty, Pie Town, McDonald Observatory, Quincy, Mammoth Lakes and 4 sites of the northern California Bay Area Regional Deformation (BARD) array., for a total of about 30 stations. This analysis is also performed with the GAMIT software. In this analysis, though, the orbits from the S10 AC and

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[10] e.g. **Feigl,** et ***al.*** [1993].

the coordinates of the five IGS stations are tightly constrained to facilitate ambiguity resolution for the California stations. Once these ambiguities are resolved, an ***R-SINEX*** file is computed in a loosely constrained adjustment as described above

The ***local*** DGGA data are then analyzed in a completely parallel way with two overlapping PGGA stations. Currently, data from 15 stations are analyzed in this solution. Thus, the ***SIO T1*** computes and archives two sets of *R-* ***SINEX*** files for each day, for use by GAMIT/GLOBK users of the Southern California Earthquake Center **(SCEC).**

Distributed Processing- Integration of Solutions

It is now the turn of the "***SIO*** 72". For each GPS week, the seven ***A-SINEX*** files and the 14 ***R-SINEX*** files are input to the **GLOBK** software, to produce a set of daily **ITRF** positions for the California stations, and weekly solutions for the North American NASA stations. The **ITRF** coordinates of the **IGS** Core Stations are tightly constrained so that their values are not adjusted. An example of a recent time series of station coordinates computed using this approach is shown in Figure 4.

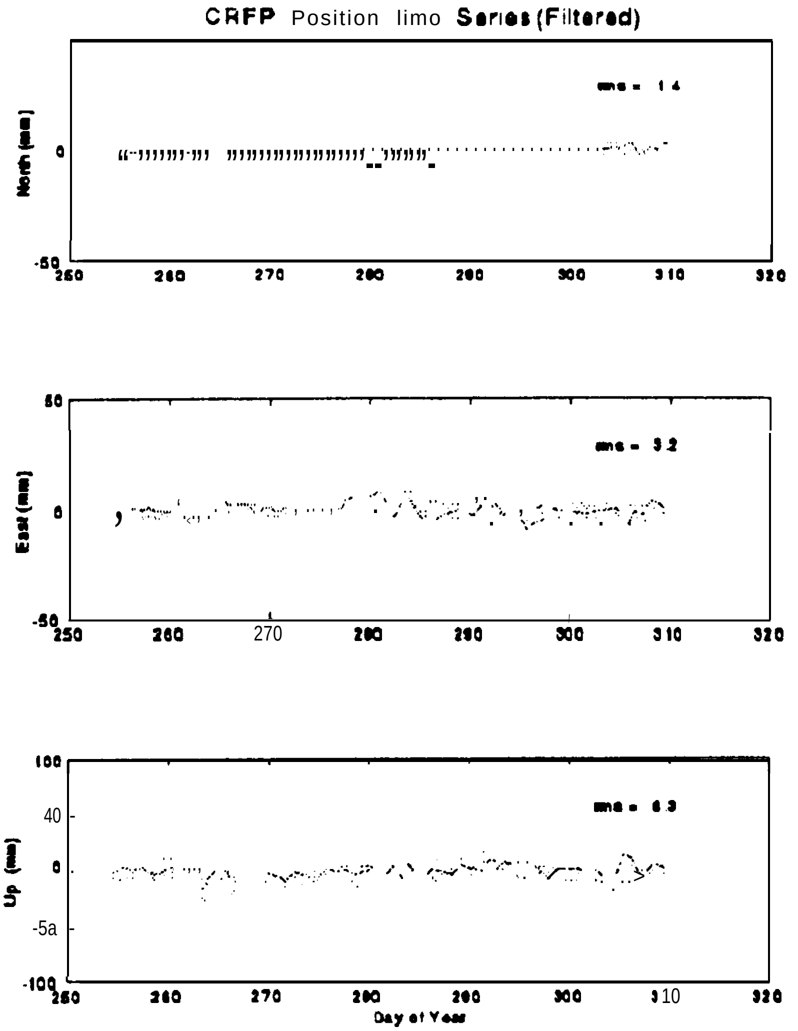

Figure 4 Position time series for the **Yucaipa** PGGA station computed using a distributed processing scheme. Each point represents a solution based on 24 hours of data. Error bars represent one standard deviation.

The archived *A-SINEX* and *R-SINEX* files were used, for example, by Hudnut, *et al.* [1994] in combination with *SINEX* solutions from GPS field surveys to determine coseismic slip associated with the Northridge earthquake.

By achieving a uniform *SINEX* format, one could conceive of another T2 combining these *SINEX* files with those produced by other *T1's*, not necessarily using the same GPS software. In fact, the GLOBK software can now accept *SINEX* files produced by the GIPSY software (called *STACOV* files) [Herring, 1994]. In this way the IGS Polyhedron can easily grow.

V IMPACT ON PARTICIPANTS

Analysis Centers

Analysis Centers already produce estimates of station coordinates as part of the analysis for producing precise orbits. Therefore the impact is not that great. If they do not already do so, AC's should be able to produce a GPS network solution in a fiducial-free mode. AC's must also start to perform a routine quality control on their network solutions, and form weekly estimates of station coordinates. Finally, AC's must augment their current weekly IGS Report to include information on their station coordinate solution. It is important at this stage that AC's only report on official IGS stations. AC's may also be asked to include additional IGS Regional Stations into their routine analysis wherever possible.

There will be a positive impact on AC's due to this activity. AC's will benefit from receiving feedback from AAC's who use their products. This should help to improve consistency and reduce analysis blunders (e.g., use of incorrect antenna height). It will also provide another independent measure of the quality of their work,

Type 1 Associate Analysis Centers

Although Type 1 Associate Analysis Centers do not already exist as IGS entities, many potential T1's do already exist as working analysis groups. New T1's simply have to operate according to IGS standards; but existing groups will undoubtedly have to modify their operations. For example, some groups may have to begin using official IGS orbits to produce their regional solutions rather than using their own estimated orbits. Modifications might also be necessary to produce fiducial-free solutions. They may have to begin including data from at least 3 global IGS stations in their network. They will undoubtedly have to modify their operation in order to write out a solution file that *only* contains IGS Polyhedron stations. Finally, they will have to design and fill out an IGS Report every week, and send it off to an IGS Data Center with their solution. Moreover, there would need to be (less frequent) IGS Mail Messages of the type we already see when configurations change (e.g., with station hardware, or analysis software).

Type 2 Associate Analysis Centers

It is fair to say that no Type 2 Associate Analysis Centers exist in the form described in this document. It is true that some groups perform their own internal combinations of solutions, but this is far different than taking many solutions from different groups and software packages, and forming a coherent product with appropriate error estimates. It is likely that T2's face the biggest challenge in this development, considering that AC and T1-type operations are already maturing. For this reason, we suggest a phased implementation (see below, part 5).

It is not thought that many T2's are necessary. A minimum of 2 is required in order to provide an intercomparison of results, which inevitably leads to a better product. We suggest 3 T2's might be a reasonable number.

Data Centers

Data centers will not receive any more RINEX files than they already do as a result of this scheme. Regional RINEX files (R-RINEX) will be archived and made available by T 1 's. In fact, some RINEX files which are currently archived by IGS Data Centers may be dropped as global stations if they are no longer being processed by at least 3 AC's. Moreover, some of these RINEX files may not even be selected as part of the IGS Polyhedron.

Data centers will need to prepare to make available the various weekly SINEX files. Each AC will deposit one SINEX file every week. Each T2 will deposit a G-SINEX file and a P-SINEX file. Each T1 will deposit an R-SINEX file.

Network Centers

Many regional networks would be automatically taken care of by operating organizations. On the other hand, there may be special cases (e.g., remote sites) where no obvious operating organization can be found, and network centers maybe called upon to retrieve and manage data from these stations.

IGS Central Bureau

The IGS Central Bureau will need to develop and enhance databases to assist AC's and AAC'S. The goal should be to remove any necessity for AC's to go elsewhere for essential information. For example, it should be straightforward for T2's to check eccentricities in received SINEX files against official values kept by the IGSCB, and apply corrections as necessary. The IGSCB should consider a parallel set of files: one for human readability (like the station reports), and one for machine readability. Updates to these files should be announced by the IGSCB via IGS Mail. The IGS Central Bureau will also need to form the interface between T2's and IERS (with respect to ITRF submissions). Importantly, the IGSCB should give IGS users guidelines as to how to use IGS products, and where to go to get R-RINEX files for regional fiducial control. Finally, the IGSCB should collect and publish various statistics on the performance of AC's and AAC'S.

IGS Governing Board

AAC'S should have appropriate representation on the IGS Governing Board. The GB should also take an active role on getting new sites in areas of low receiver density. It is recommended that the GB make good use of the T1's as regional advocates for IGS, in terms of education, advice, and awareness.

International Earth Rotation Service

It is suggested that IERS receive P-SINEX solutions from the T2's every month in order to assess the quality of the solutions. IERS should also receive annual submissions of terrestrial reference frame solutions from T2's, as well as from AC's (as is currently done). IGS and IERS participants are expected to interact very closely, especially over the first few months of T2 operations, in particular to resolve local tie problems.

VI SCHEDULE FOR IMPLEMENTATION

Mainly because of the burden imposed on new T2 Analysis Centers, we suggest a phased implementation. As a first step, T2's will only deal with producing G-SINEX files. As part of this step, we would encourage AC's to include Regional Network stations in their routine processing. In this way we can get started on the IGS Polyhedron solution without requiring additional regional analysis. It is anticipated that there will be a period of at least a few months when all kinds of problems will emerge from the intercomparison of global station coordinates.

We suggest that the T2 pilot phase commences April 1995, and that the inclusion of T1 operations into the processing cycle be delayed until a few months after the T2's commence work. After one year of operation, the pilot phase should be assessed, perhaps at a joint IERS/IGS workshop (March 1996).

In order to speed up densification of the ITRF, it is suggested that a call for proposals be issued in early 1995 for new stations in geographical areas that are currently sparse.

Finally, one thing that is very urgent is to define the SINEX format, and write appropriate format translators, For our schedule to work, the SINEX format would have to be finalized by February 1995.

Table 2 Schedule for Implementation

Date	Event
Jan-95	Final schedule for pilot phase. T2's identified for pilot phase.
Feb-95	SINEX defined.
Mar-95	Final guidelines for pilot phase. CFP for ITRF expansion issued.
Apr-95	T2 pilot phase begins
Jul- 95	CFP for T1 pilot program
Aug-95	Deadline for T1 proposals
Sep-95	Acceptances issued
Oct-95	T1 analysis begins
Mar-96	Pilot phase ends
Apr-96	Joint IGS/IERS Workshop?

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Many ideas in this paper originated in the Ottawa Workshop position paper, and we therefore acknowledge the valuable contribution of Gerd Gendt. We would like to thank Jie Zhang, Peng Fang and J. Behr for providing research material. GB would like to thank Bill Carter, Geosciences Laboratory, the National Oceanographic and Atmospheric Administration for financial support of research carried out at the University of Newcastle upon Tyne. Research at S10 is supported by the National Aeronautics and Space Administration (NAG5- 19 17), the National Science Foundation (EAR 92 08447), the Southern California Earthquake Center USGS cooperative agreement (14-08-00001 -A0899) and the U.S. Geological Survey (1434 -92-G2196).

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APPENDIX: SOFTWARE INDEPENDENT EXCHANGE FORMAT (SINEX)

(a) The format be ASCII, with up to 80 characters per line.

(b) The covariance matrix be represented as an upper triangular correlation matrix where the diagonal elements are the standard deviations. The upper triangular array is written out column by column (write column i for all rows 1 to i before moving to column $i+1$) so that the position of the matrix element is independent of the number of parameters. Since parameters can be very correlated in free-network solutions, correlation coefficients should be quoted to 15 significant digits.

(c) Each component of the estimate vector be the full estimate, meaning that it is the a priori plus the delta estimate. This approach is attractive since it is likely that different groups will use different a priori values, and we only need to know the full estimate when combining solutions. (assuming they are close enough for validity of linearity), and (e.g., when a new station is established). For the record, a priori values and their constraints (a priori standard deviations) should also be stored in the file. This might be useful, for example, if it is suspected that the basic assumption of linearity might be violated, or if a priori constraints might have had a significant and undesirable effect.

(d) The estimate refer to the monument, except for those cases where the ARP (antenna reference point) is defined to be the monument.

(e) The basic unit be the meter for coordinates, radians for X and Y polar motion, and seconds for excess length of day estimates.

(f) Each file include for every station identifier the eccentricity vector from the monument to the ARP, and the assumed LC phase center offset, and the starting date for this information (to allow for changes in antennas). This information needs to be given explicitly because eccentricity vectors and phase center offsets may be in error, may be inconsistent between groups, or may get updated by new surveys or antenna measurements.

(g) Standard 6-character station identifiers be used in the station coordinate parameter names. Characters 1-4 should uniquely identify the monument. Characters 5-6 should be an "occupation number," used to force separate solutions for different epochs. In the context of permanent networks, the "occupation number" needs to be changed only if the station undergoes coseismic displacement, or if the antenna is moved or changed. In the traditional context of field campaigns, this number might be used to identify experiment number. Note that every 6-character station identifier must have the information specified in item (f) above. Note also, that if the antenna offset is changed in a known way, then this constraint can be applied as a last step. In the limit that the offset change is perfectly known, the two solutions will be adjusted to the same value (since they both refer to the same monument). In this case, it is acceptable to remove the redundant information so long as a flag is set to indicate this along with the information given in (f) above. This flag indicates that more than one antenna height or type was used for that estimate, and therefore the eccentricity information given in this file is incomplete.

(h) The header of the file include the epoch of the solution, start and stop time of input data, number of parameters, institutional identifier, date produced, a flag to indicate whether or not velocity parameters are included, a code number to indicate presence and types of constraint, a unique solution identifier, a quality control code, and optionally a descriptive character string. An ambiguity resolution identifier will indicate whether the solution has been bias-fixed (integer carrier phase biases) or remains bias-free (real-valued carrier phase biases).

POSITION PAPER 2 APPENDIX A
REGIONAL ANALYSIS RESULTS USING IGS PRODUCTS

Jan Johannson, chair

Following Position Paper 2 an appendix session was intended to give all individual groups the possibility to present 5-minute summaries of any ongoing or planned regional GPS activities including GPS data analysis based on IGS products (see A97 for figures and diagrams). As many as 14 different groups announced that they had material to present, Many extensive programs involving regional GPS data analysis are run by organizations already involved in the IGS infrastructure as analysis centers. However, a large number from the continuously growing group of other organizations mainly concentrating their activities on regional or local activities were also present. These presentations functioned as valuable information on activities in geographical areas not covered by the IGS as well as feedback on the quality of the IGS products. Below follows a brief summary of the presentation in the session based on notes taken by Mike Heflin (JPL), Kenneth Jaldehag (0S0), and Jan Johansson (0S0).

Detlef Angermann (GeoForschungsZentrum, Potsdam) gave a description of the 3 networks presently observed by GFZ. A 70 point network in Central Asia has been observed in 1992 and 1994, First preliminary results of the deformation analysis was presented at the 1994 AGU fall meeting. A new network in South-East Asia, including 40 sites, was observed near the end of 1994. A large network consisting of some 190 sites in South America (SAGA) has been observed in 3 campaigns 1993-1994. The data have been analyzed with the EPOS 34 software developed at GFZ. The data analysis is done both using fixed IGS orbits and Earth Orientation Parameters (EOP) as well as global solutions. In the SAGA '94. campaign repeatabilities of 2 mm horizontal and 5 mm vertical were obtained.

Yehuda Bock (University of California/SIO, La Jolla, CA) presented results from about 200 days of GPS measurements in a California network. The data were analyzed using GAMIT with the distributed processing approach described in Position Paper 2. The results presented demonstrated North, East, and Up repeatabilities of 1.2, 2.8, and 4.4 mm, respectively, using this processing approach.

Elmar Brockmann (Astronomical Institute University of Berne) gave an extensive paper entitled "Combining regional Sites in Europe: Experiences at CODE". Using a test data set from October 1994, including 6 regional sites, different methods of combining regional sites with the global network have been studied. The methods were 1) combining only the Normal Equations (NEQ) for coordinates (orbits and ERP's from CODE) 2) combination using both coordinates and troposphere parameters (orbits and ERP's from CODE), or 3) correct combination where regional stations will contribute to orbits and ERP's. Results from a comparison study of the influence of the regional sites on orbit parameters were presented.

Boudewijn Ambrosius (Delft University of Technology) presented results from the WEGENER project. A total number of over 90 sites has been observed in a GPS campaign in the Mediterranean area. The results obtained by GPS show mm-level agreement with those obtained from Satellite Laser Ranging (SLR) data. Furthermore, a subnet of the IGS network consisting of about 20 stations has been used to "check" the quality of the IGS products. The daily helmert transformation gives residuals of 3 – 4 mm in horizontal components. A systematic signal (semi-annual sinusoidal signal) in the height component for the Madrid station was reported. The group in Delft has also done some preliminary tests utilizing the precise point positioning technique proposed by Jim Zumberge at JPL. Using only P-code data, a 10-to 15-cm coordinate agreement was achieved.

Herb Dragert (Geological Survey of Canada) discussed the Canadian active control system network and showed results from obtained from several baselines in the network. In particular the nonlinearity in the time series of the baseline Alberthead to Penticton was presented. The overall results agree with models of geodynamics.

Ken Hurst (Jet Propulsion Laboratory) outlined the plans for a future 200- to 300-station permanent GPS array in the Los Angeles Basin area. The network presently in use consists of 23 stations. The network is intended to evaluate seismic hazards and seismic activity in general. When fully established the average spacing between the stations will be about 10 km. So far the data have been analyzed with different strategies. The importance of a rapid turnaround from data acquisition to results for this type of project was stressed. The point positioning technique, using IGS produced satellite orbits and clocks, will be tested extensively.

Teruyuki Kato (University of Tokyo) gave a status report on the WIN project. The project is utilizing permanent GPS stations in order to study seismic activities. The Bernese Software is used for the data processing. The results obtained from GPS data analysis show good agreement with the NUVEL- 1 model except in Taiwan. A poster presentation of this project was also available in meeting room.

Izabella Kulhawczuk (Norwegian Mapping Authority) reported tests using the GIPSY software with different analysis strategies including both no-fiducial global solutions as well as regional solutions based on IGS precise orbits. Furthermore, a GPS campaign was carried out in September 1994 including about 65 sites in order to improve the national reference system in Norway and the links to EUREF and ITRF. The scientific activities include participation in the DOSE and WEGENER projects on postglacial rebound and sea level studies in the region.

Peter Morgan (University of Canberra) described the Australian GPS network. The network covers a very large region. Data collection and retrieval are important topics. Internet connection is anticipated to be established to all stations. There are plans for both permanent and episodic occupation of sites. Presently, an investigation of different antennas, receivers, and pillars is undertaken. Eventually all tripod setups will be replaced by permanent pillars. Results obtain from GPS data processing using GAMIT reveal an offset between regional and global analysis strategies for some sites. This is probably due to the sparse number of GPS stations in th Southern Hemisphere resulting in degraded IGS orbit accuracy. The conclusion is that orbit improvement is important in the Southern Hemisphere.

Hiro Tsuji (Geographical Survey Institute) reported that the 210 station permanent network in Japan is operational. The network will support studies of seismic hazards and seismic activity on the Japanese Islands. For the GPS data processing GAMIT is used in a regional analysis strategy using IGS produced orbits. For rapid turnaround the precise ephemerides from NGS are used. The IGS combined orbits are also used when they come available on computer networks. As an example, one earthquake detected in the result obtained from GPS data analysis was reported. A poster accompanied this oral presentation.

Susanna Zerbini (University of Bologna) gave a description of the WHAT-A-CAT project. The project, which involves 5 different groups, has the purpose to study tectonics in Mediterranean area (Hellenic Arc). So far 3 GPS campaigns has been performed in 1990,92, and 94. In the WHAT-A-CAT 1994 campaign about 20 sites in Italy and 20 site in Greece were observed. The data have been processed in a regional processing strategy. The results were presented at the Istanbul meeting. Prof. Zerbini also reported on the SELF project intended for Sea Level studies which involves 6 different organizations.

Pascal Willis (Institut Géographique National) reported on activities performing GPS observations at DORIS stations. Further campaigns are planned for observations at tide-gauge benchmarks and establishment of reference points in French territories.

Bob Schutz (University of Texas, Austin) presented results from GPS observations in South America. The GPS data were processed with strategy where the satellite orbits, produced JPL, where held fixed. One station, Santiago, was additionally fixed to ITRF coordinates. The results obtained show a North, East, and Vertical scatter of about 2, 5, and 10 mm, respectively. The baseline length repeatability was 2.73 mm + 9 ppb. The results probably suffered from the fact that different types of GPS receivers and antennas had to be mixed for these observations.

Jan Johansson (Onsala Space Observatory) presented results obtained fro the Swedish permanent GPS network **(SWEPOS).** The network was established in July 1993 and the average spacing between stations is 20 km. Daily solutions are produced using a set of 25-30 regional sites together with the **IGS** combined orbits. The results obtained from about one year of observations demonstrates horizontal repeatability on the order of 2 mm within the Swedish network. The vertical repeatability is about 3 times greater, GPS campaigns are run annually in Fennoscandia and the Baltic region in order to study **crustal** movements associated with postglacial rebound and studies of sea level change. In collaboration with the National Land Survey a densification of the Swedish reference network is carried out.

POSITION PAPER 2 APPENDIX B

James Zumberge, Markus Rothacher, chairs

The presentation of Position Paper 2 by Blewitt included questions, discussions, and a short presentation by co-author Bock, with the result that Position Paper 2 Appendix A started late. Also, Position Paper 2 Appendix A contained several more contributors than originally expected.

The end result is that, because of time constraints, there was no formal Position Paper 2 Appendix B.

POSITION PAPER 3
NETWORK OPERATIONS, STANDARDS AND DATA FLOW ISSUES

Werner Gurtner (Astronomical Institute, University of Bern, Switzerland)
Ruth E. Neil an (Jet Propulsion Laboratory, California Institute of Technology)

ABSTRACT

This paper describes the basic structure of IGS operations. It defines the stations, network data flow, data centers and processes within the Central Bureau Information System (CBIS) for monitoring the IGS operations. This paper incorporates the handling of additional GPS stations and data into the IGS system for the densification of the international reference frame. Instructions and a checklist for joining and participating in the IGS are included. A revised summary of station standards is included in the appendix.

I OVERVIEW

The number of stations in the continuous GPS tracking network of the IGS has more than doubled over the last two years, growing from roughly 23 stations in 1992 to 70 stations in late 1994. The expansion of the network over this time reflects, to a large extent, the availability of electronic communication networks and telephone links to support data flow in a timely manner. Figure 1 shows the current and planned stations of the IGS network. In general, the data from the operational stations depicted on the map are available to users within 24 hours. Quite noticeable are the gap areas that do not have any permanent GPS stations (Russia, China, India, Africa, islands, etc.). Many of the proposed stations for these areas have been delayed in implementation, primarily due to a lack of reliable, cost-effective communication systems. These are the areas that must be targeted for completion of a solid, evenly distributed Global IGS Network. Two documents that summarize the current status of the electronic connectivity are included in the Appendix as a reference when considering the extension of the IGS network and possible data retrieval paths. These are a map of connectivity and a table that details by country the type of connections available.

A new initiative of the IGS, and the focus of the December 1994 IGS workshop, is the organization and processing of data from 250 to 300 new regional stations for the purpose of extending the IERS Terrestrial Reference Frame (ITRF). The investment costs of implementing a GPS station are small compared to other techniques for achieving comparable precision. With GPS receiver prices decreasing dramatically, the costs for an entire station's equipment (in 1994 U.S. dollars) is on the order of $28,000 to $32,000. There are also many installations where equipment is even more cost effective-for example, local or regional monitoring in the U.S.—where these costs, depending upon monumentation, can be up to 30% less. These kinds of costs make continuous GPS measurements extremely affordable for many applications. We are just beginning to see an explosion in the number of continuous networks, and thus many new stations, that can contribute to defining a truly global reference frame accessible worldwide. In our experience, the limitations for any type of GPS station continue to be in the areas of data access and communications. The expected increase in the number of stations warrants careful consideration of the handling and management of GPS data. Even within the hierarchical structure of the IGS distributed data system, these will become increasingly important functions.

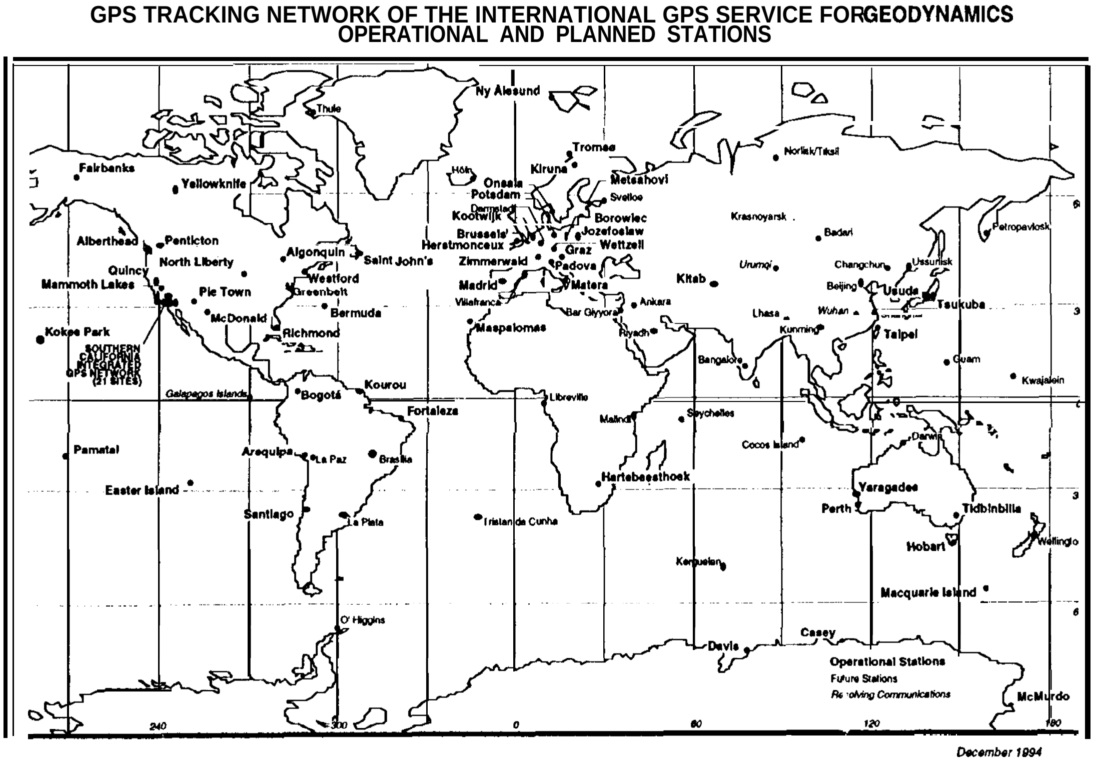

Figure 1 Network Map of the International GPS Service for Geodynamics, December 1994. Operational and Planned Stations.

II STATIONS

Current classification of the GPS stations are based on use by the IGS Analysis Centers and the GPS community, and these classifications can potentially change from year to year. There are three station categories - Global, Regional, and Local - which are described in more detail below. These station categories have been defined over the past year and a half for efficient handling of the data and for ease of access to all associated information, data and data products.

Station categories will be reviewed each year in December and will remain in effect until the next evaluation period. New stations will be categorized when they become available and then evaluated at the scheduled period with all the other stations.

To be considered as an IGS station the basic standards for station implementation must be followed [Neilan, *et al.,* 1991; IGS Central Bureau, 1993]. Included in the Appendix is a summary of the revised standards released in 1991.

Global Stations

The definition of a global station is based on the following criteria:

- Data from the stations are analyzed by two or more IGS Analysis Centers that are not on the same continent or analyzed by a majority of Analysis Centers,

- The station's data are used for daily estimation of orbits, Earth rotation parameters and station positions and velocities,

- The station is separated from any other IGS station by more than 2000 km,

- The station data must be available at the Global Data Centers.

These stations provide the primary structure for the GPS contributions to the International Terrestrial Reference Frame.

The Global Network needs an "even" distribution of about 50 stations, which corresponds roughly to a station separation in the range of -1500 to -2500 km.

Regional Stations

The regional stations are those available to the IGS for processing and will be processed by one Analysis Center (AC) or Associate Analysis Center (AAC) only for reference frame extension. The selection of these stations depends primarily on the geographic location. These stations' data are used for the determination of the ITRF, but not necessarily for orbits or Earth rotation parameters. The data must be easily accessible and are intended to be located at a Regional Data Center (described below). In most cases it is desirable that these stations be continuously operating.

In some rare cases, these stations maybe measured on a periodic basis, no less frequent than once per year. These stations should be committed to by the sponsoring agency, for observations, analysis and inclusion into the ITRF on an annual basis. These episodic stations can offer potentially valuable locations for the extension of the ITRF, and must be able to be included into the process determined by the ACS and AACS for this purpose.

Regional Stations will number between 200 to 250 stations with a station separation of -500 to -1250 km.

Local Stations

These are GPS stations that augment the Global and Regional stations above. In most cases these stations are from 1) regional campaigns on an episodic basis, or 2) dense permanent arrays of continuously operating stations. These stations may submit their station information forms, or stations listings (similar to the IGS Station List), for inclusion on the Central Bureau Information System. These forms include points of contact for inquiring about the data. (This does not mean that the data or products from these stations are freely available to the IGS community. In these cases the IGS is acting only as an information clearing house, encouraging nonduplication of GPS points due to absence of information. For example, in considering an area for GPS measurements, it would be possible to check the CBIS to see if there are any existing or planned points close to the area being considered.).

For local stations from a permanent array the daily data holdings should be collected from their respective (local) data center and made available on the CBIS. This is a CBIS process that accesses a text file generated by the (Local) data center and can display to users the daily availability of the local network data.

III DATA FLOW, COMMUNICATIONS AND ACCESS

The data flow between the stations and the users, especially the IGS Analysis Centers, is mostly organized in a hierarchical structure as shown in Table 1. Detailed data flow diagrams are available at the IGS Central Bureau Information System CBIS (Internet: igscb.jpl.nasa.gov, directory: /igscb/data/network). The Appendix includes a network data flow chart for all stations currently in the IGS network.

```
Station
|
Operational Center (OC)
|
Local Data Center (LDC)          --> Local user
|
Regional Data Center (RDC)       --> Regional user
|
Global Data Centers (GDC)        --> User (e.g. Analysis Center AC)
```

Table 1 Hierarchical Data Flow Structure of the IGS Network

Operational Center (OC)

The Operational Center receives or collects the data from all the stations which it is responsible for. The data transmission between the stations and the OC may use dial-up lines, permanently switched telephone lines, Internet, satellite communications, etc. In most cases the transmitted data are in their receiver-dependent raw form, either in records in a near-real-time mode or as files accumulated several times per day or once per day shortly after midnight UTC.

The Operational Center checks the data, samples the data to the standard 30 second epochs if necessary, reformats the data into RINEX [Gurtner, 1993] files (Receiver Independent Exchange Format), and sends the data as compressed RINEX files (one observation file per station per day, one navigation message file per station per day, or one daily concatenated navigation message file) through Internet to the nearest Regional Data Center, or in some cases to a Local Data Center. Most of the OC's have automated these procedures so that the data leave the OC within a few hours after midnight of Universal Time Coordinate (UTC).

The Operational Centers are also required to maintain a station log file for each station. An up-to-date copy of a station log file is available at the CBIS (directory: /igscb/station/log). Some stations perform the tasks of the Operational Center for themselves.

An Operational Center description file will be available at the CBIS (/igscb/center/oper/'center'.ocn).

Examples of Operational Centers: CIGNET/NGS, Statens Kartverk, JPL.
Examples of sites without a separate OC: Herstmonceux HERS, Zimmerwald ZIMM, Metsahovi METS.

Local Data Center (LDC)

In many parts of the world, dense local networks of permanent GPS stations have been installed or are in the process of being installed. Examples are: California Permanent GPS Geodetic Array (PGGA), Norway, Sweden, CEI (Central Europe Initiative). These networks may serve a number of purposes, ranging from deformation monitoring, to reference stations for geodetic positioning, to (real-time) navigation.

The data of such networks are usually collected by an organization that often acts as both the Operational Center (for station implementation, maintenance, and data preprocessing) and Local Data Center (for data redistribution and archiving). As IGS is not necessarily interested in all such sites, only a subset of the data may be forwarded to the nearest Regional Data Center (or, exceptionally, directly to one of the three Global Data Centers).

Some of these Local Data Centers are openly accessible, and they follow the same conventions for the file naming (example: NRCan, CEI Graz). Other LDC'S don't support open access at all (e.g., Statens Kartverk) or only support access to a limited number of sites (like AUSLIG).

The Central Bureau Information System may contain the station log files of those stations not included in the official IGS network, if these stations adhere to the IGS standards.

If this information is available, the Central Bureau includes a data center description file, as well as the standard data holding information file, into the CBIS (see below).

Regional Data Center (RDC)

A Regional Data Center collects all data of interest to people in a particular region, such as the IfAG (Institut fur Angewandte Geodäsie) RDC, which contains all of the key data of interest to the greater part of Europe. The RDC receives or collects the data from LDC's, OC's, or, in some cases, directly from the stations.

The data from the Global Network (i.e., the data used by several Analysis Centers or users in various parts of the world) are forwarded to one of the three Global Data Centers.

Regional Data Centers are openly accessible through anonymous ftp or through ftp by user account / password. They keep all regional data on-line for some period of time (e.g., 30 days). Older data are available through special arrangements with the Centers. Regional Data Centers are also required to provide daily reports of the data holdings to the Central Bureau (see below).

A data center description file containing all information about contacts, access, data organization (directory structure), etc., is available at the CBIS (/igscb/center/data/'center'.dcn) and should be completed by each data center.

Global Data Center (GDC)

Global Data Centers are required to have the data from stations defined as the Global Stations on-line for a minimum of 30 days [IGS Central Bureau, 1993]. (October 1993, Analysis & Network Operations Workshop). These files are openly accessible through anonymous ftp or through ftp by user account/password. Older data are available through special arrangements with the Centers.

The GDC's receive or collect the data from the Regional or Local Data Centers or, exceptionally, even from Operational Centers (e.g. CNES --> IGN, ESOC --> CDDIS). They equalize their data holdings among themselves in order to have the same global data sets available.

Products generated by the Analysis Centers and the Analysis Center Coordinator are deposited with the GDC and must be available on-line for at least 12 months (in standard SP3 format for at least 6 months and, after that, in either compressed or standard SP3 format).

Global Data Centers are also required to provide daily reports of their data and product holdings to the Central Bureau (see below).

There are currently three Global Data Centers:

- CDDIS (Crustal Dynamics Data information System at Goddard Space Flight Center, NASA, Greenbelt, U. S. A.)
- IGN (Institut Geographique National, Paris, France)
- S10 (Scripps Institution of Oceanography, San Diego, U. S. A.)

A data center description file containing all information about contacts, access, data organization (directory structure), etc., is available at the **CBIS** **(/igscb/center/data/'center'.dcn)**.

Data Holdings

In order to know where and when specific data are available the Regional and Global Data Centers provide the Central Bureau a daily updated file containing a coded entry for every

```
****** B B B G H J K K K M M M M M N O P T U W Z
 I F A G  O R  R R  E O I I O A A  A A  E Y N O R P E I
****** R U U A R Z R T S D S S T T A S T O A   T M
        1 4   S Z S E U 3 G R 1 P E S   L A   S M D T M
*********  Last Update: 18-NOV-94 06:20 (Day 322)
9 4 - 3 2 1   .   .   1 1 1 . 1 . . . . . 1 1 1 1 . 1 1 1 1
94-320  . . 1 1 1 . 1 1 1 . 1  . 1 1 1 1 1 1 . 1 1
94-319 2 . 1 1 1 2 1 1 1 1 1 . 1 1 1 1 1  1 1 . 1
94-318 2 . 1 1 1 2 1 . 1 2 1 . 2 1 1 1 1 1 . 1 1
94-317 2 . 1 1 1 2 1 1 1 2 1 . 3 1 1 1 1  1 . 1 1
94-316 3 .  1 1 1 2 1 1 1 4 1 . 4 1 1 2 1 1 . 1 1
94-315 2 .  1 1 1 2 1 1 1 3 1 . 5 1 1 1 1 1 . 1 1
94-314 2 .  1 1 1 2 1 1 1 1 1 . 1 1 1 4 1 1 7 1 1
94-313 2 . 1 1 1 2 1 1 1 1 1 . 1 1 1 1  1 1 1 1 1
94-312 3 .  1 3 1 2 1 1 1 1 1 . 1 1 1 1  1 1 2 1 1
```

Table 2 Example of a Data Holding file for the IfAG Regional Data Center.

RINEX observation file received at the respective center. In Table 2 the four character station names are listed vertically across the top, and the year-day number listed on the left. The coded numbers in the table show the arrival date of the files (1 = within 1 day, 2 = within two days after data collection, etc.) These up-to-date data holding files are available at the **CBIS** **(/igscb/data/holding/'center'.syn)**.

The Central Bureau maintains monthly and annual global summaries of the data holdings (directory: **/igscb/data/holding,** files: glob'mmyy'.syn and glob'yyyy'.syn). In Table 3 the data center three-letter acronyms are listed across the top of the table, and the station four-character names are listed on the left. The number in the body of the table corresponds to the total number of days available from that station at the particular data center.

Product Holdings

In order to know where and when specific products are available, the Global Data Centers provide the Central Bureau a daily updated file containing a coded entry for every product file (i.e., ephemerides, Earth rotation parameters, summary files) received at the respective center. The code shows the arrival date of the files (1 = within 3 days, 2 = within 6 days after data collection, etc.) These up-to-date product holding files are available at the CBIS (/igscb/product/holding/'center'.prd).

As the CBIS also collects the combined IGS orbits, a product holding file for the CBIS is available, too (cbis.prd). Table 4 shows the product availability at CDDIS. Across the top of the table are the three character acronyms for the various Analysis Centers and for the IGS combined product (IGS); below that is a coded line, where wwww is the GPS week number, d is day of the week, followed by the date and the day of year (cloy). The code 'oes' shows the delays in the availability of the orbit files ("o"), the Earth rotation parameter files ("e"), and the summary files ("s") in units of 3 days.

```
*************************************************************
            IGS Data Directory for NOV 1994
*********** Last Update: 17-NOV-94 08:00 (Day 321) *********
```

	AUS	CDD	CIG	EMR	GRZ	IFA	IGN	JPL	S10
ALBH	.	16	.	16	.	.	15	16	13
ALGO	.	16	.	16	.	.	15	16	13
AOA1	.	16	.	.	.	.	.	16	13
ARE1	.	.					.	.	11
AREQ		16	:	:	:	:	15	16	.
BLYT	.	.	.	.	.	.	.	.	13
BOGT	.	9	.	.	.	.	.	9	5
BOR1	.	.	.		15	15	.	15	10
BRMU	.	16	15	:	.		15	16	13
BRUS	.	16	.	.	.	16	15	16	13
CARR	.	16	.	.	.	.	.	16	13
CAS1	16	16	.	.	.	.	.	16	13
CASA		.		15	.	.	.	15	12

Table 3 Example of a Monthly Data Holding File for Various Data Centers

Episodic Data

With the exception of the Epoch'92 campaign, the IGS currently does not keep track of episodic data nor are the Analysis Centers processing such data. If non-permanent stations will be included into the IGS Regional Network, station log files and information about the whereabouts of the data have to be submitted to the Central Bureau. In order to comply as much as possible with the procedures for the permanent operations, the data should be available at the Regional Data Centers following at least the rules for off-line data, The data holding information could be included into the standard files, as well.

Other episodic data (i.e., of sites not included into the IGS Regional Network) are not the primary responsibility of the IGS.

Data Archiving

The archiving of regional data (permanent or episodic) should be performed by the Regional Data Centers following the same rules set up for the global data,

```
*'k****************  *****************  *****************  *****************  *
                     IGS Product Availability at CDDIS
*************** Last Update : 18-NOV-94 04:07 (Day 322) *************

                       COD  EMR  ESA  GFZ  IGR  IGS  JPL  NGS  S10
wwwwdddmyydoy          oes  oes  oes  oes  oes  oes  oes  oes  oes

0774-7     .     .     ...  .22 . . . . . . . . . . . . . . . . .2. . . .
0774-6 12-NOV-94 316   . . . 2 . . . . . . . . . . . . . . . . .  2.2 . . .
0774-5 11-NOV-94 315   . . . 3 . . . . . . . . . . . . . . . . .  3.3 . . .
0774-4 10-NOV-94 314   . . . 3 . . . . . . . . . . . . . . . . .  3.3 . . .
0774-3 9-NOV-94 313    . . . 3 . . . . . . . . . . . . . . . . .  2.2 . . .
0774-2 8-NOV-94 312    . . . 3 . . . . . . . . . . . . . . . . .  3.3 . . .
0774-1 7-NOV-94 311    . . . 4 . . . . . . . . . . . . . . . . .  2.2 . . .
0774-0 6-NOV-94 310    ...  4 . . . . . . . . . . . . . . . . .   2.2  ...
0773-7     .     .     .33  .22  .33  .22 . . .   .55  .34 .2.   .44
0773-6  5-NOV-94 309   3..2..  3..  2..  .  .  .  5..  3..  2.2 4..
0773-5 4-NOV-94 308    4..2..  3..  3..  .  .  .  5..  3..  2.2 5..
0773-4 3-NOV-94 307    4..3..  3..  3..  .  .  .  5..  4..  2.2 5..
0773-3 2-NOV-94 306    4..3..  4..  3..  .  .  .  6..  4..  3.3 5..
0773-2 1-NOV-94 305    5..3..  4..  4..  .  .  .  6..  4..  3.3 6..
0773-1 31-OCT-94 304   5..3..  4..  4..  .  .  .  6..  5..  2.2 6..
0773-O 30-OCT-94 303   5..4..  5..  4..  .  .  .  7..  5..  2.2 6..

******************************************************************
```

Table 4 Availability of the IGS Products (Orbits, ERP's and Summary Files) at the CDDIS.

IV ANALYSIS & ASSOCIATE ANALYSIS CENTERS

Analysis Centers

Analysis Centers of the IGS commit to producing orbits and Earth rotation parameters on a regularbasis and sending theseto the Analysis Center Coordinator for incorporation into the IGS Official Orbit. Requirements and specifications for Analysis Centers were revised and clarified at the Ottawa Analysis CenterWorkshop, 0ctober1993[Kouba, 1993].

Associate Analysis Centers

AssociateAnalysis Centersaregroups that commit to providing special processing for the IGS, such as addressed in this workshop. These include processing and analysis for:

- Reference frame extension,
- Station locations and velocities fortheRegional IGS Stations,
- Ionospheric analysis,
- Ad-hoc testing/evaluation ofthe IGS products and data,
- Special studies

Checklist For Becoming An IGS Station

This procedure can be used for any GPS station, global, regional or local, and serves as a step-by-step guide of what should be done as well as the point of contact and help for each step. The procedure extends to Local Stations with the exception that the data do not (necessarily) have to be available on-line, and that IGS does not take any responsibility for completeness, correctness, nor for data processing.

- Contact the Central Bureau concerning the intent to install the station, the schedule for implementation, and a statement of desire for the station to be considered as part of the IGS network. The proposed four-character identifier should also be included for confirmation by the CB. (Mail a message to igscb@igscb.jpl.nasa.gov)

- Central Bureau will reflect this on the schedule of future or proposed stations.

- IGS standards should be followed in installing the station.

- Once the station is installed and operational, a communication should be addressed to the CB indicating data availability. The CB will assist in the designation of the four-character station identifier to prevent duplication.

- If the new station is part of a network, the responsible Operational Center has to update the center description form (download /igscb/center/oper/' center' .ocn from igscb.jpl.nasa.gov, modify, and send via e-mail to igscb@igscb.jpl.nasa.gov)

- If the station is part of a new network, the new Operational Center has to create a center description form (download /igscb/center/oper/BLNKFORM.OCN from igscb.jpl.nasa.gov, modify, and send via e-mail to igscb@igscb.jpl.nasa.gov)

- Create a station log (download /igscb/station/general/BLNKFORM.LOG from igscb.jpl.nasa.gov); many examples are available in /igscb/station/log.

- This log form should be forwarded to the IERS with a request for a DOMES number; this is the numbering system that is used by the IERS to keep track of all stations in the terrestrial reference frame. At this time, these files are forwarded to Zuheir Altamimi at the IERS (altamimi@uranus.ign.fr). You will be assigned a DOMES number for the station and any other monument or reference marker located at the site.

- These updated files should then be sent to the Central Bureau to be included into the CBIS. Files should be e-mailed to:
  igscb@igscb.jpl.nasa.gov

- When the information is available on the CBIS an announcement should be prepared by the implementing agency for distribution through IGSMail.

- Whenever there is an update or change to the information contained in the station log file, the current log file should be downloaded from the CBIS (/igscb/station/log) and modified by adding the new information and the modification date. This file should be sent back to the Central Bureau and again an announcement of the modification should be made through an IGS Mail message.

- Data holdings can be viewed by accessing files at the CBIS, for example: /igscb/data/holding/glob0994 .syn

- Stations within the IGS station categories will be reviewed each year in terms of use and potential reclassification.

Sending IGS Mail

IGS Mail Messages

The IGSMail system is an automated electronic mail handling procedure. Users should if observe the following guidelines:

- List a short subject of the message at the standard e-mail prompt; do not leave blank.

- Prepare the message, include an "Author line" as the FIRST line of the message body, containing left-justified the keyword "Author: " followed by your name.

  Examples:

  Author: C. Nell/ CDDIS
  or
  Author: David Jefferson

- If the author line is missing, the message will not be handled automatically, Mail the message to:

  igsmail@igscb.jpl .nasa.gov

Note that the Central Bureau Information System moved to in November 1994, the new address is:

igscb.jpl.nasa.gov (IP# 128.149.70.171)

Messages to the IGS Central Bureau

Requests to be included in the IGS Mail service, or questions regarding IGS Mail or the CBIS, can be directed to:

igscb@igscb.jpl .nasa.gov

The Central Bureau can also be contacted via faxat818-393-6686.

Accessing the Central Bureau Information System

The IGS Central Bureau Information System (CBIS), accessible via Internet, provides necessary information to both IGS contributors and the public organizations and individuals who use IGS orbits and tracking data. Summarized global data holdings are updated daily in the information system, indicating the source and dates of observations and how to access them. Also available are IGS products, including accurate and highly reliable IGS GPS orbits, Earth rotation parameters, tracking station coordinates and velocities, and satellite and receiver clock information.

The CBIS is accessible through anonymous ftp at:

igscb.jpl.nasa.gov (Internet address 128.149,70.17 1)

in the directory /igscb. The files README.TXT, TREE.TXT and IGSCB.DIR in the main directory provide on-line help and current directory and file information. For World Wide Web users, the required URL is:

http: //igscb.jpl.nasa. gov/

Hypermedia client programs, like Lynx and NCSA Mosaic, are freely available and allow for easy navigation and file retrieval.

Becoming An IGS Data Center

Institutions desiring to become a data center for the IGS should send a letter to the Central Bureau with copies to the IGS Chair (Prof. Gerhard Beutler at the University of Bern, Switzerland). The letter should indicate the intent to perform data center functions (either Global, Regional or Local) and a commitment to provide these activities for at least four years. The letter proposal should indicate the resources available for this purpose. The proposal will be reviewed by the IGS Governing Board and the Central Bureau will notify the institution of the Governing Board decision and recommendations. The Institution will complete the appropriate data center forms described above and forward to the CBIS.

If for any reason an institution is unable to continue the data center tasks, a letter should be sent to the CB indicating the change and notification to the IGS community, with as much advance notice as possible.

Becoming An IGS Analysis Or Associate Analysis Center

Institutions desiring to become an Analysis Center or Associate Analysis Center for the IGS should send a letter proposal to the Chair of the IGS with copies to the Analysis Center Coordinator and the Central Bureau. The proposing letter should indicate the intent of the analysis and the considered time period of performance, the specific analysis to be performed, and a summary of the resources available for the analysis functions described. The Governing Board will review the proposal, and the institution will be notified by the Chair of the IGS and the Central Bureau. The institution will create a document detailing the center and its analysis procedures which will be included in the CBIS (e.g., see /igscb/center/analysis/'center'.acn). A new directory with appropriate forms for Associate Analysis Centers will be developed on the CBIS.

ACKNOWLEDGMENT

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REFERENCES

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IGS Central Bureau. "Summary Recommendations of the IGS Networks Operations Workshop, October 18-20, 1993." Available from the Central Bureau.

Kouba, Jan, ed. *Proceedings of the IGS Analysis Center Workshop.* Ottawa, Canada, October 1993.

Neilan, Ruth E. *et al.*, "International GPS Service for Geodynamics: Standards for Data Acquisition and Sites." February 1991.

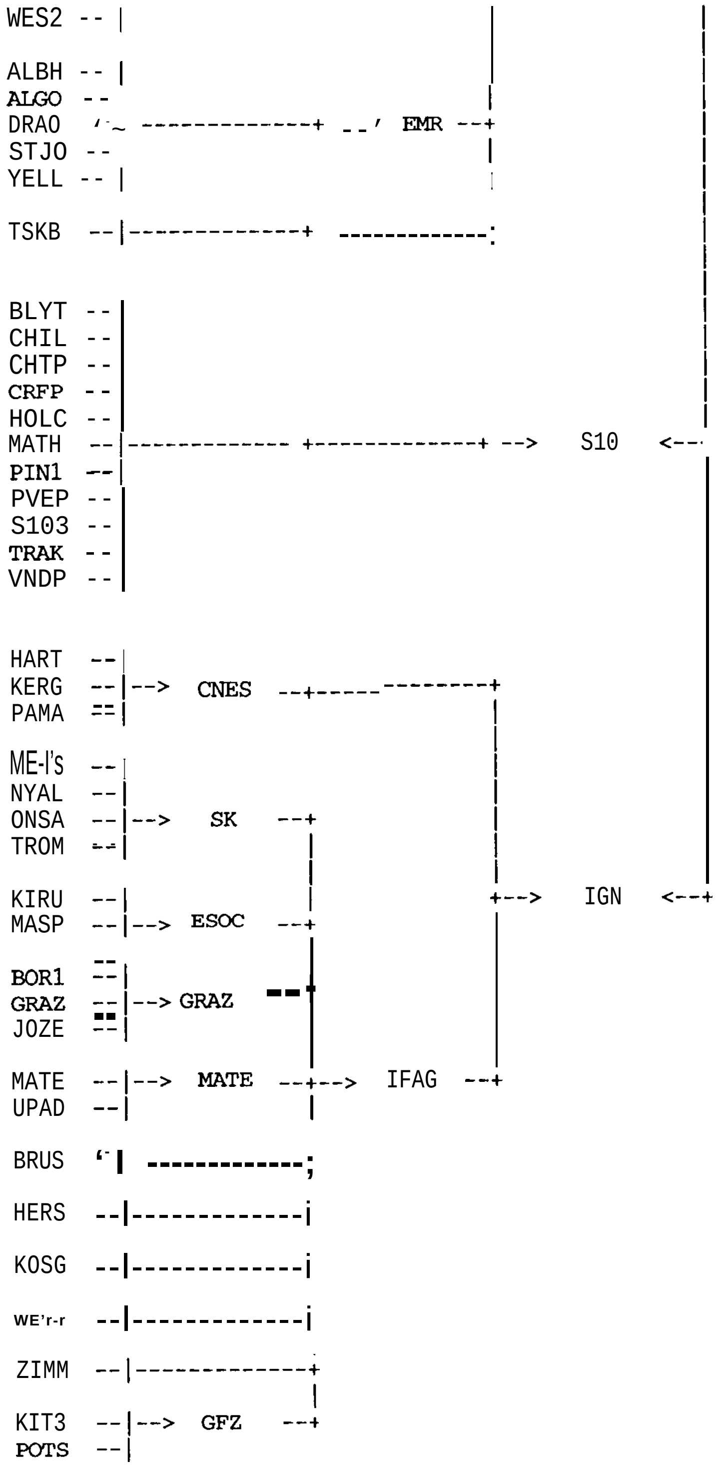
APPENDIX

IGS Data Flow

The chart below shows the data flow from the stations, listed by four character identifier on the left, through the OC/LDC (Operational Center/Local Data Center), the RDC (Regional Data Center) and onto the GDC (Global Data Center).

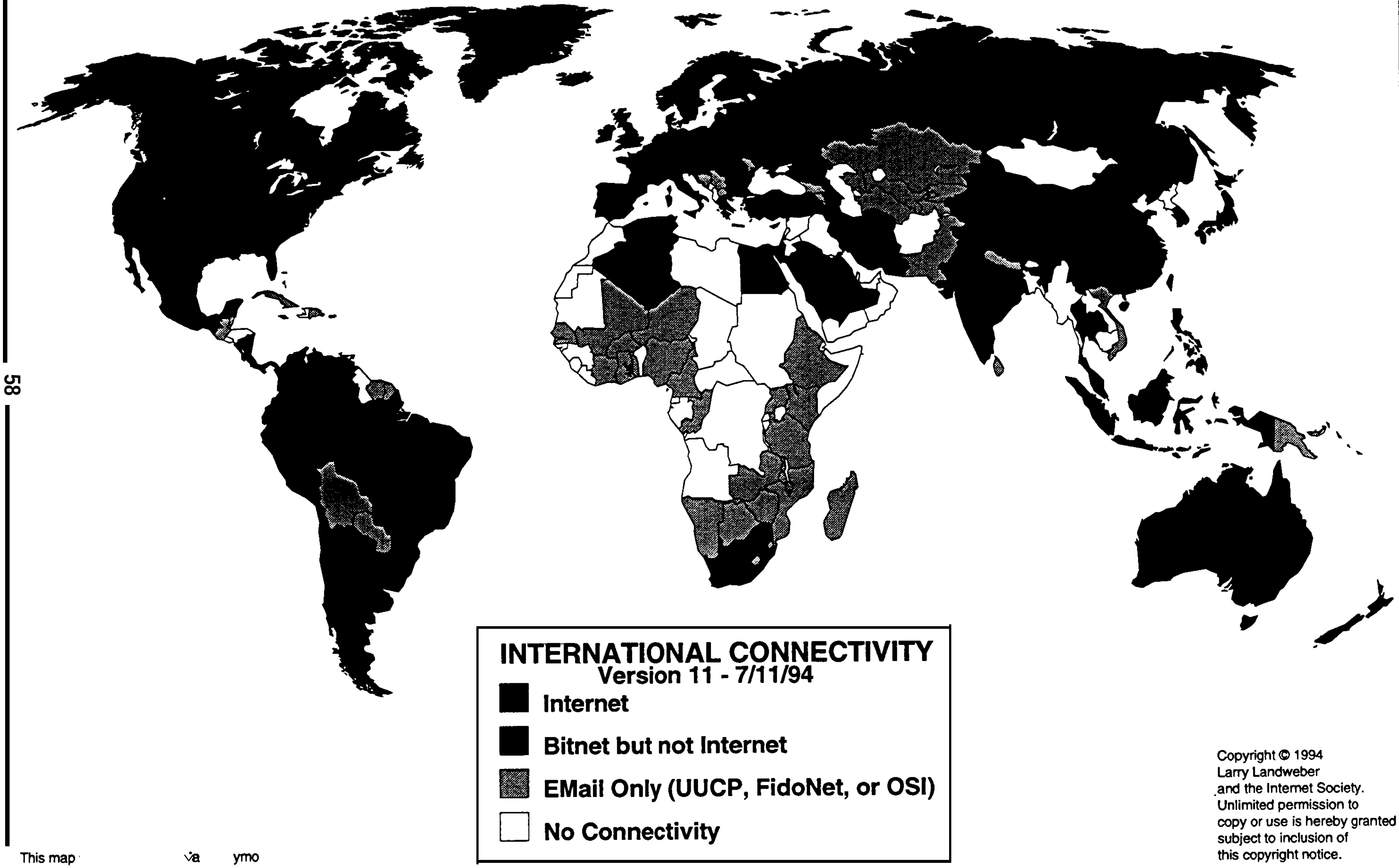
```
station      OC/LDC        RDC            GDC

MADR --|
GOLD --|--> DSN   --+
TIDB --|            |
                    |
AOA1 --|            |
AREQ --|            |
BOGT --|            |
CARR --|            |
CASA --|            |
CIT1 --|            |
FAIR --|            |
GODE --|            |
HARV --|            |
JPLM --|            |
KOKB --|------------+  --> JPL --+
LBCH --|                         |
MCMU --|                         |
MDO1 --|                         |
NLIB --|                         |
OATT --|                         |
PIE1 --|                         |
QUIN --|                         |
SANT --|                         |
USUD --|                         |
WLSN --|                         |
YAR1 --|                         |
                                 |
CASl --|                         |
DAV1 --|                         |
HOB2 --|------------+  -->  US   --+--> CDDIS <--+
MAC1 --|                         |               |
                                 |               |
KOUR --|--> ESOC  --+------------+               |
PERT --|                         |               |
                                 |               |
BRMU --|                         |               |
FORT --|                         |               |
RCM5 --|------------+  --> NGS  --+               |
TAIW --|                         |               |
```



Status of the Internet

On the following pages are 1) a map of connectivity and 2) table of services available by country.



This map · √a ymo
recto

INTERNATIONAL CONNECTIVITY
Version 11- July 11,1994

Please send corrections, information and/or comments to:

Larry Landweber
Computer Sciences Dept.
University of Wisconsin - Madison
1210 W. Dayton St.
Madison, WI 53706
lhl@cs.wise.edu
FAX 1-608-265-2635

Include details, e.g., on connections, sites, contacts, protocols, etc.

Thanks to the many people from around the world who have provided information. This version (postscript, ditroff, text forms, maps in postscript) and earlier versions may also be obtained by anonymous ftp from ftp.cs.wise.edu in the connectivity_table directory.

In the following, "BITNET" is used generically to refer to BITNET plus similar networks around the world (e.g., EARN, NET-NORTH, GULFNET, etc.).

SUMMARY

NUMBER OF ENTITIES WITH INTERNATIONAL NETWORK CONNECTIVITY= 152
NUMBER OF ENTITIES WITHOUT iNTERNATIONAL NETWORK CONNECTIVITY = 86

BITNET
- Col. 2 (Entities with international BITNET links.)
- b: minimal, one to five domestic BITNET sites, 18 entities
- B: widespread, more than five domestic BITNET sites, 34 entities

1P INTERNET
- Co]. 3 (Entities with international 1P Internet links.)
- I: = operational, accessible from entire open 1P Internet, 75 entities

UUCP
- Col. 4 (Entities with domestic UUCP sites which are connected to the Global Multiprotocol Open Internet.)
- u: minimal, one to five domestic UUCP sites, 59 entities
- U: widespread, more than five domestic UUCP sites, 70 entities

FIDONET
- Col. 5 (Entities with domestic FIDONET sites which are connected to the Global Multiprotocol Open Internet)
- f: minimal, one to five domestic FIDONET sites, 27 entities
- F widespread, more than five domestic FIDONET sites, 62 entities

Os1
- Col. 6 (Entities with international X.400 links to domestic sites which are connected to the Global Multiprotocol Open Internet).
- o: minimal, one to five domestic X.400 sites, 8 entities
- O: widespread, more than five domestic X.400 sites, 23 entities

An entity is a geographical area that has an ISO two letter country code (ISO 3166). These country codes are included in the Table below for each entity (Cols 8-9). Note that the 1S0 codes do not always agree with the top level DNS (Domain Name) code(s) used for a particular entity.

Network connections have been reported but not confirmed to Bangladesh, Jordan, and Mongolia and so are omitted from the table. Activity is underway to connect Lebanon, Guyana, and St. Vincent and the Grenadines but no definitive information has been received. Haiti has an email link but it does not fit into any of the categories of the table.

-----	AF	Afghanistan (Islamic Republic of)
-----	AL	Albania (Republic of)
-I---	DZ	Algeria (People's Democratic Republic of)
-----	AS	American Samoa
-----	AD	Andorra (Principal ity of)
-----	A O	Angola (People's Republic of)

-----	AI	Anguilla
-I ---	AQ	Antarctica
--u--	AG	Antigua and Barbuda
BIUF-	AR	Argentina (Argentine Republic)
--u--	AN	Armenia
---f-	AW	Aruba
- IUFO	AU	Australia
BIUFO	AT	Austria (Republic of)
b-U--	AZ	Azerbaijan
--u --	BS	Bahamas (Commonwealth of the)
b----	BH	Bahrain (State of)
-----	BD	Bangladesh (People's Republic of)
--u --	BB	Barbados
b-UF-	BY	Belarus
BIUFO	BE	Belgium (Kingdom of)
--U --	BZ	Belize
-----	BJ	Benin (People's Republic of)
--U f-	BM	Bermuda
-----	BT	Bhutan (Kingdom of)
--U f-	BO	Bolivia (Republic of)
--u --	BA	Bosnia-Herzegovina
--uf-	BW	Botswana (Republic of)
-----	BV	Bouvet Island
BIUFO	BR	Brazil (Federative Republic of)
-----	IO	British Indian Ocean Territory
-----	BN	Brunei Darussalam
bIUF-	BG	Bulgaria (Republic of)
--u--	BF	Burkina Faso (formerly Upper Volta)
-----	BI	Burundi (Republic of)
-----	KH	Cambodia
--u--	CM	Cameroon (Republic of)
BIUFO	CA	Canada
-----	Cv	Cape Verde (Republic of)
-----	KY	Cayman Islands
-----	CF	Central African Republic
-----	TD	Chad (Republic of)
BIUF-	CL	Chile (Republic of)
-Iu-O	CN	China (People's Republic of)
-----	Cx	Christmas Island (Indian Ocean)
-----	CC	Cocos (Keeling) Islands
BIu--	CO	Colombia (Republic of)
-----	KM	Comoros (Islamic Federal Republic of the)
--u --	CG	Congo (Republic of the)
--u--	CK	Cook Islands
bIuf -	CR	Costa Rica (Republic of)
--u f-	CI	Cote d'Ivoire (Republic of)
-IuFo	HR	Croatia
--U--	CU	Cuba (Republic of)
bI---	CY	Cyprus (Republic of)
BIUF-	CZ	Czech Republic
BIUFO	DK	Denmark (Kingdom of)
-----	DJ	Djibouti (Republic of)
-----	DM	Dominica (Commonwealth of)
--U f-	DO	Dominican Republic
-----	TP	East Timor
-Iu--	EC	Ecuador (Republic of)
bIU--	EG	Egypt (Arab Republic of)
-----	Sv	El Salvador (Republic of)
-----	GQ	Equatorial Guinea (Republic of)
-----	ER	Eritrea
-IUF-	EE	Estonia (Republic of)
---f-	ET	Ethiopia (People's Democratic Republic of)
-----	FK	Falkland Islands (Malvinas)

--u--	FO	Faroe Islands
-Iu --	FJ	Fiji (Republic of)
BIUFO	FI	Finland (Republic of)
BIUFO	FR	France (French Republic)
--u--	GF	French Guiana
--u --	PF	French Polynesia
-----	TF	French Southern Territories
-----	GA	Gabon (Gabonese Republic)
-----	GM	Gambia (Republic of the)
--UF-	GE	Georgia (Republic of)
BIUFO	DE	Germany (Federal Republic of)
--uF-	GH	Ghana (Republic of)
-----	GI	Gibraltar
BIUFO	GR	Greece (Hellenic Republic)
-I-f-	GL	Greenland
--u--	GD	Grenada
b-uf -	GP	Guadaloupe (French Department of)
-I-F-	GU	Guam
--u --	GT	Guatemala (Republic of)
-----	GN	Guinea (Republic of)
-----	GW	Guinea-Bissau (Republic of)
-----	GY	Guyana (Republic of)
-----	HT	Haiti (Republic of)
-----	HM	Heard and McDonald Islands
-----	HN	Honduras (Republic of)
BI-F-	HK	Hong Kong
BIUFo	HU	Hungary (Republic of)
-IUFo	IS	Iceland (Republic of)
bIUfO	IN	India (Republic of)
-IuF-	ID	Indonesia (Republic of)
b----	IR	Iran (Islamic Republic of)
-----	IQ	Iraq (Republic of)
BIUFO	IE	Ireland
BIUF-	IL	Israel (State of)
BIUFO	IT	Italy (Italian Republic)
--u --	JM	Jamaica
BIUF-	JP	Japan
-----	JO	Jordan (Hashemite Kingdom of)
--UF-	KZ	Kazakhstan
---f-	KE	Kenya (Republic of)
--u--	KI	Kiribati (Republic of)
-----	KP	Korea (Democratic People's Republic of)
BIUFO	KR	Korea (Republic of)
-I ---	KW	Kuwait (State of)
--U--	KG	Kyrgyz Republic
-----	LA	Lao People's Democratic Republic
-IUF-	LV	Latvia (Republic of)
-----	LB	Lebanon (Lebanese Republic)
--u--	LS	Lesotho (Kingdom of)
-----	LR	Liberia (Republic of)
-----	LY	Libyan Arab Jamahiriya
-I-f-	LI	Liechtenstein (Principality of)
- IUFO	LT	Lithuania
bIUFo	LU	Luxembourg (Grand Duchy of)
-I-F-	MO	Macau (Ao-me'n)
--u--	MK	Macedonia (Former Yugoslav Republic of)
--u --	MG	Madagascar (Democratic Republic of)
---f-	Mw	Malawi (Republic of)
bIUF-	MY	Malaysia
-----	Mv	Maldives (Republic of)
--U--	ML	Mali (Republic of)
--u --	MT	Malta (Republic of)
-----	MH	Marshall Islands (Republic of the)

-----	MQ	Martinique (French Department of)
-----	MR	Mauritania (Islamic Republic of)
--uf-	Mu	Mauritius
-----	YT	Mayo t te
BIuF-	MX	Mexico (United Mexican States)
-----	FM	Micronesia (Federated States of)
--uF-	MD	Moldova (Republic of)
-----	MC	Monaco (Principality of)
-- —-.	MN	Mongolia
-----	MS	Montserrat
-----	MA	Morocco (Kingdom of)
--U f-	MZ	Mozambique (People’s Republic of)
-----	MM	Myanmar (Union of)
--Uf -	NA	Namibia (Republic of)
-----	NR	Nauru (Republic of)
--u--	NP	Nepal (Kingdom of)
BIUFO	NL	Netherlands (Kingdom of the)
--u--	AN	Netherlands Antilles
-----	NT	Neutral Zone (between Saudi Arabia and Iraq)
--U--	NC	New Caledonia
-IUF-	NZ	New Zealand
- Iu- -	NI	Nicaragua (Republic of)
--u--	NE	Niger (Republic of the)
---f-	NG	Nigeria (Federal Republic of)
--u--	NW	Niue
-----	NF	Norfolk Island
-----	MP	Northern Mariana Islands (Commonwealth of the)
BIUFO	NO	Norway (Kingdom of)
-----	OM	Oman (Sultanate of)
--U--	PK	Pakistan (Islamic Republic of)
-----	Pw	Palau (Republic of)
bIuF-	PA	Panama (Republic of)
--u--	PG	Papua New Guinea
--u--	p y	Paraguay (Republic of)
-IUf -	PE	Peru (Republic of)
- IuF-	PH	Philippines (Republic of the)
-----	PN	Pitcairn
BIUF-	PL	Poland (Republic of)
bIUFO	PT	Portugal (Portuguese Republic)
bIUF-	PR	Puerto Rico
-----	QA	Qatar (State of)
-Iu--	RE	Re’union (French Department of)
BIuf-	RO	Romania
BIUF-	RU	Russian Federation
-----	RW	Rwanda (Rwandese Republic)
-----	SH	Saint Helena
-- ---	KN	Saint Kitts and Nevis
--u--	LC	Saint Lucia
-----	PM	Saint Pierre and Miquelon (French Department of)
-----	VC	Saint Vincent and the Grenadines
--u--	WS	Samoa (Independent State of)
-----	SM	San Marino (Republic of)
-----	ST	Sao Tome and Principe (Democratic Republic of)
B----	SA	Saudi Arabia (Kingdom of)
--U f-	SN	Senegal (Republic of)
--u--	SC	Seychelles (Republic of)
-----	SL	Sierra Leone (Republic of)
BIuF-	SG	Singapore (Republic of)
bIUF-	SK	Slovakia
-IUFO	S1	Slovenia
--u--	SB	Solomon Islands
-----	so	Somalia (Somali Democratic Republic)
- IUFO	2A	South Africa (Republic of)

```
BIUFO ES    Spain (Kingdom of)
--U-- LK    Sri Lanka (Democratic Socialist Republic of)
----- SD    Sudan (Democratic Republic of the)
--u-- SR    Suriname (Republic of)
-I --- SJ   Svalbard and Jan Mayen Islands
--u-- Sz    Swaziland (Kingdom of)
BIUFo SE    Sweden (Kingdom of)
BIUFO CH    Switzerland (Swiss Confederation)
----- SY    Syria (Syrian Arab Republic)
BIuF- TW    Taiwan, Province of China
--u-- TJ    Tajikistan
---f- TZ    Tanzania (United Republic of)
-IUF- TH    Thailand (Kingdom of)
--u-- TG    Togo (Togolese Republic)
----- TK    Tokelau
--u-- TO    Tonga (Kingdom of)
--u-- TT    Trinidad and Tobago (Republic of)
bIUfo TN    Tunisia
BI-F- TR    Turkey (Republic of)
--u-- TM    Turkmenistan
----- TC    Turks and Caicos Islands
----- TV    Tuvalu
---F- UG    Uganda (Republic of)
-IUF- UA    Ukraine
----- AE    United Arab Emirates
bIUFO GB    United Kingdom (United Kingdom of Great Britain and Northern Ireland)
BIUFO US    United States (United States of America)
----- UM    United States Minor Outlying Islands
-IUF- UY    Uruguay (Eastern Republic of)
--UF- UZ    Uzbekistan
--u-- w     Vanuatu (Republic of, formerly New Hebrides)
----- VA    Vatican City State (Holy See)
-IU-- VE    Venezuela (Republic of)
--u-- VN    Vietnam (Socialist Republic of)
----- VG    Virgin Islands (British)
---f- VI    Virgin Islands (U.S.)
----- WF    Wallis and Futuna Islands
----- EH    Western Sahara
----- YE    Yemen (Republic of)
--uf- YU    Yugoslavia (Socialist Federal Republic of)
----- ZR    Zaire (Republic of)
---f- ZM    Zambia (Republic of)
--uf - ZW   zimbabwe (Republic of)
```

Position Paper 3 Appendix B

Carey E. Nell, chair

QC Program. A program, called QC, has been developed by UNAVCO that will check observation data and generate various statistics on the data. W. Gurtner recommends that all operational data centers run this program as part of their automated data processing procedures. Versions of the QC program have been written and tested for various platforms (UNIX, VMS, PC). Some data centers expressed concerns with running the QC program itself, preferring instead to modify their existing software to produce the desired results. The QC program produces an output file as shown in the attachment. This file has the same naming convention as the observation (0) and navigation (N) files, e.g., ssssdddv.yyS, where ssss is the site name, ddd is the day of year, v is the file sequence number, and yy is the year. The idea is to have the QC program executed as close to the data as possible, i.e., immediately after converting the raw data to RINEX. This procedure will help to ensure that only complete data files are transmitted to the regional and global data center levels. The QC program can also be used as an operational tool on a daily basis to peruse the health of the IGS network, New GPS data producers can be encouraged to utilize this program from the start.

Review of Data Transmission. P. Morgan suggested that in light of the inclusion of the QC output file with the transmission of the daily observation and navigation files, a new way to transmit data may be in order. He suggested that the IGS may want to adopt a packaging program, such as TAR or ZIP, that would concatenate and compress the observation, navigation, and summary files into a single file. The regional or global data center would then break apart these files for use by the user community. If the S file is placed as the last file in the package, the regional or global data center can verify that a complete transmission occurred by perusing and verifying the contents of the S file. Options for a new data transmission method, as well the QC program, will be studied by the Communications Working Group (P. Morgan, W. Gurtner, K. Stark, C. Nell, and J. Kouba); recommendations will be made to the IGS Governing Board by July 1995.

Implementing Data Flow for New Sites. The IGS needs to define the data flow for a new station coming on-line, prior to operation if possible. Often data centers see new sites showing up, without prior arrangements being made for the disposition of the data, The goal in defining a data flow is to minimize the traffic on the Internet and the redundant transmission of data. This topic is closely coupled with the classification of stations in the IGS Network (e.g., global, regional, registered). Obviously, global sites need to be available at the global data center where regional or registered sites do not. However, how and when are new sites classified? One suggestion was to have the Analysis Coordinator poll all Analysis Centers to ascertain their interest in analyzing data from a new site. The important item here is that the IGS Central Bureau must be informed of new sites as soon as possible, before they are ready to transmit data, and must then inform the Analysis Coordinator. Finally, after recommendations by the AC, the Central Bureau should inform all data centers of the new site and its designated data flow path.

Core Sites. The Analysis Centers recommended that the number of core sites to be used for routine orbit production be increased from thirteen to at least fifteen. Backup and redundant sites should also be identified, perhaps collocated with SLR or VLBI, but the coordinates of these sites should not be held fixed.

IGS Reports. I. Mueller stated that the IGS Reports produced by the Analysis Centers are quite useful and encouraged NGS to begin routine weekly submission of these reports. M. Schenewerk will relay this message to his colleagues at NGS.

Proposed New IGS Products. The new products proposed in Position Paper 2, covariance matrices and IGS site coordinates, should not pose a burden on the Global Data Centers. These files will not be larger than the orbit files now produced by the Analysis Centers.

Sampling Rate. Questions arose about increasing or decreasing the sampling rate of receivers in the IGS network. Are users requesting a higher sampling rate, or should the IGS lower the sampling rate in order to save data transmission costs? W. Gurtner reports that the Zimmerwald receiver samples data at one second; users requesting these data can obtain the data. For the IGS, the Zimmerwald data is decimated to thirty seconds; the undecimated data are then discarded. Other receiver agencies may adopt similar policies, but for now, no IGS-wide change in sampling rate was recommended.

RINEX Originator. W. Prescott wanted to publicly commend the efforts of W. Gurtner and company in the design and maintenance of RINEX. He believes that without such a coordinated effort and standard, universally recognized format, the IGS could not have become the successful service that it now is. This recommendation was followed by a round of applause for Werner.

Figure 1 Rinex Header

```
     2              OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
TRRINEXO V2 .4.7 VM AIUB                22-Nov-94 09:24     PGM / RUN BY/DATE
BIT 2 OF LLI (+4) FLAGS DATA COLLECTED UNDER "AS" CONDITION COMMENT
Z IMM                                                       MARKER NAME
                                                            OBSERVER / AGENCY
2691                TRIMBLE 4000SSE      5.68               REC # / TYPE / VERS
0                   4000ST L1/L2 GEOD                       ANT # / TYPE
  4331297.2640   567555.5480  4633133.8904                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1 / 2
     5    Cl    L1    L2    P2    P1                        #/TYPES OF OBSERV
    30                                                      INTERVAL
  1994     6    19     0     1   30.000000                  TINE OF FIRST OBS
                                                            END OF HEADER
END OF HEADER
```

Figure 2 QC Program Output

```
QC v3 by UNAVCO Summary File: U:[WORK]ZIMM1700 .94S Receiver type: trimble 4000sse
    +--------------------------------------------------------------------------------+
S  1|                    -##########I+                 1###########+               |
A  2|  ################+                                  I######+                 |
T  4|##++                  I#####-I+                                I############|
E  5|             +####################+                                          |
L  6|                      .###################+                                  |
L  7|           ###########+                               1###########++          |
I  9|         #I##################I+                                              |
T 12|          *******************++                                              |
E 14|                                                 ###################+ |
  15|                                                .##################++         |
  16|#############+                 I####+                                   I#I |
  17|    +####I+                 1###############+                                |
  18|#####+                                                       I#############|
  19|#########+                               +IIII+                    I#######|
  20|                 ###################++,                                      |
  21|            +##II##++                   I###############P                    |
  22|                                ##################I                    +II++|
  23|          ##########+                1############+                            |
  24|#####+                I##########+                               +I#######|
  25|                           -#############++                  I#######+        |
  26| ###################+                                                         |
  27|*************+                                                          |****|
  28|                                    1#################++                      |
  29|#+                                                       S###############I |
  31|                                          ###################+                |
 CLK|C CC CC CCC CC CC CC CCCC c c  C c c c c c c c c c c c c c c  c c c  C c c c CC C|
    +--------|--------|--------|--------|--------|--------|--------|--------+
    00:01                                                               23:59

Time of First Epoch in File (year,month,day,hour) :94   6 19 0: 1
Time of Last Epoch in File (year,month,day,hour)  :94   6 19 23:59
Observation Interval for File (in seconds)                30
Elevation cutoff for qc                                   10
Total number of observations expected                  20040
Total number of observations in file                   19724
Total number of points deleted                           824
Data collection percentage                                93
RINEX vs qc point pos cliff [Km]                        0.04
Average MP1                                       : 0.46134
Average MP2                                       : 0.68757
# of points for MP moving average                         50
Average clock drift [msec/hr]                         -2.087
Average time between resets [rein]                :   28.751
Number of detected slips                                  85
Observations per slip                                    232
    first epoch    last epoch    hrs   dt  #expt  #have  %  mp1  mp2   o/slp
SUM 94 6 19 0: 1 94 6 19 23:59 23.96 30 20040 19724 98 0.46 0.69    232
Meaning of flags:
I slip detected on iono phase       S multipath slip MP1 andMP2
R multipath slip on MP1 only        P multipath slip on MP2 only
C clock reset / slip (oPtional)     G gap in data
- Sv up but no data found           + sv data but below elev mask
  L1 C/A only no A/S                ; L1 C/A only A/S
: L1 P only no A/S                  , L1 P only A/S
- L1 C/A L2 P no A/S                # L1 C/A L2 P A/S
* L1 P L2 P no A/S                  Y L1 P L2 P A/S
```

POSITION PAPER 4
t) ENSIFICATION OF THE ITRF THROUGH REGIONAL GPS NETWORKS: ORGANIZATIONAL ASPECTS

Gerhard Beutler (Astronomical Institute, University of Berne, Switzerland)
Jan Kouba (Natural Resources, Canada)
Ruth E. Neilan (Jet Propulsion Laboratory, USA)

Abstract

Today, after only two years of operation, the coordinate series produced by the Analysis Centers of the *International GPS Service for Geodynamics* (IGS) are valuable contributions for the realization of the *IERS Terrestrial Reference Frame.* The consistency and the precision achieved in the analyses of the existing IGS network are already comparable to the results of the other space techniques. Also, the costs for the user equipment (not of the. space segment (!)) are much lower than in the case of VLBI and SLR. Should the IGS be successful to *densify the ITRF through regional GPS networks,* there can be little doubt that the GPS will be a very powerful contributor to the future, realization of the ITRF, and that it will play the *key role* when *making the ITRF accessible to a growing user community.*

The present final version of Position Paper 4 (in a series of four papers prepared for the IGS workshop *Densification of the ITRF through Regional GPS Networks)* was modified in order to take into account the conclusions from the other position papers and the discussions and decisions of the December 1994 workshop.

In any case, such a densification *has to be based on the experiences gained during two years of IGS operations.* Moreover one has to consider that

- *the IERS is responsible for the establishment of the ITRF*,
- *the IGS Central Bureau acts as the GPS coordinator for the IERS, in particular the IGS coordinates the GPS contribution to the IERS*,
- in many geographic areas there already exist *regional organizations* which are responsible for the realization and maintenance of the reference frame in this specific region.

In section 1 we review the development of the IGS. In particular we look at the impact of the terrestrial reference frame(s) on the IGS products generated on a daily basis (orbits and Earth rotation parameters). We summarize the improvements (concerning the coordinates of the tracking network) emerging from the experiences gained during two years of IGS processing. In section 2 we review the IGS terms of reference to remind ourselves of the IGS responsibilities before anal yzing the implications of different network densities and discussing the organizational implications. In section 3 we summarize the principles to be observed for a densification and we summarize the action items from the organizational point of view.

I EXPERIENCES BASED ON TWO YEARS OF IGS OPERATIONS

The 1992 IGS Test Campaign started on 21 June 1992, and ended on 23 September 1992. The receivers of the global IGS network were not turned off in September 1992 and the IGS Analysis Centers continued to turn out their results as well. The IGS Oversight Committee decided in October 1992 to formally establish the *IGS Pile? Service,* which started on 1 November 1992. It ended on 31 December 1993, yielding its place to the official IGS that started on 1 January 1994.

During the 1992 IGS test campaign a two weeks interval around August 1 was reserved for the so-called *Epoch '92* campaign. The purpose of the campaign actually was a first densification of the Global Network. Although there were interesting results in particular regions or of particular analyses, the main purpose, a general densification of the network, could not be achieved. We learned from this experiment that the organizational and the logistic aspects of a densification based on a campaign-type GPS experiment are extremely difficult to handle. One possible conclusion is to *use permanent tracking sites only for the purpose of densification*. The 1992 IGS test campaign, Epoch' 92, and the IGS Pilot Service are documented [Beutler and Brockmann, 1993].

Let us analyze the *Global IGS Operations* between June 1992 and December 1994. It was extremely important and helpful that the IGS series of earth rotation parameters were continuously analyzed by the IERS (Rapid Service Subbureau and IERS Central Bureau). These weekly resp. monthly analyses published in the IGS-report-series helped to reveal inconsistencies in the results of the IGS Analysis Centers. The impact of the actual realization of the terrestrial reference frame became obvious when the seven IGS Analysis Centers started using the ITRF 92 [Boucher, *et al.*, 1993a] instead of the ITRF 91 on January 1, 1994, and, when (at the same time) they started fixing (or heavily constraining) *essentially the same set* of station coordinates using *the same information for the local ties.* Figure 1, extracted from the weekly IGS-reports of the IERS Rapid Service Subbureau, shows the offsets of the IGS Analysis Centers' pole estimates relative to the IERS Rapid Service Subbureau's solution (which is based on a combination of VLBI, SLR, and GPS).

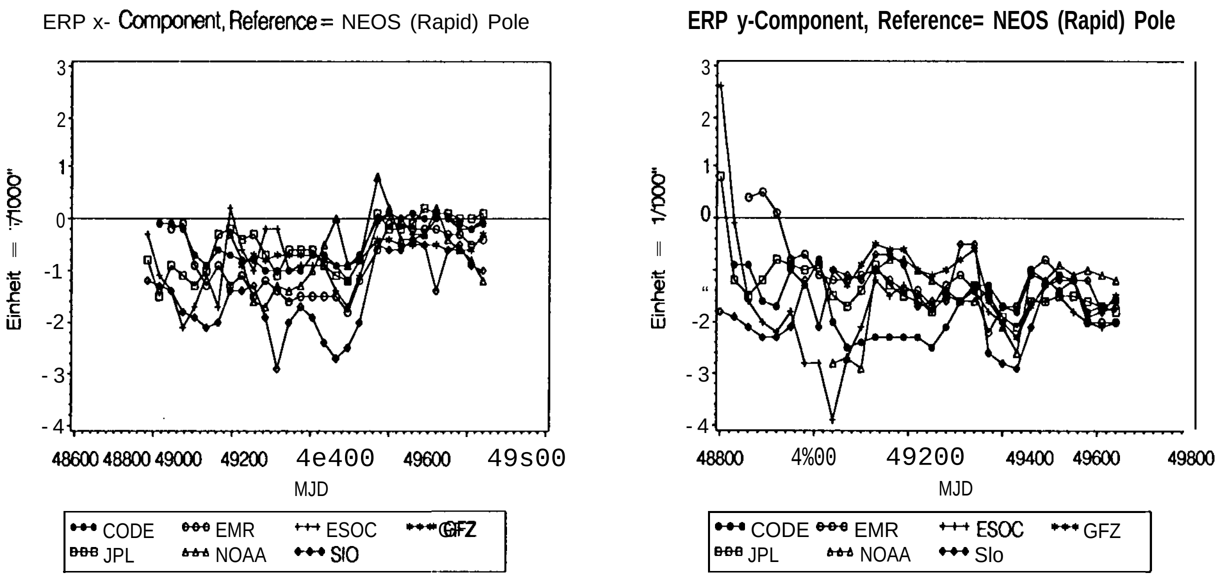


Figure 1 Development of the monthly means of the earth rotation parameters x and y of the IGS Analysis Centers relative to the IERS Rapid Service Subbureau.

Clearly the consistency of the individual IGS series but also the consistency between the series became much better after January 1, 1994 (MJD=49'353): The differences between the individual series were reduced from more than 3 mas to less than 1 mas in the x- and y-estimates of the pole. The conclusion is thus clear: the terrestrial reference frame is of greatest importance for the computation of the earth rotation parameters, the consistency of different series is in principle dictated by the quality of the terrestrial network.

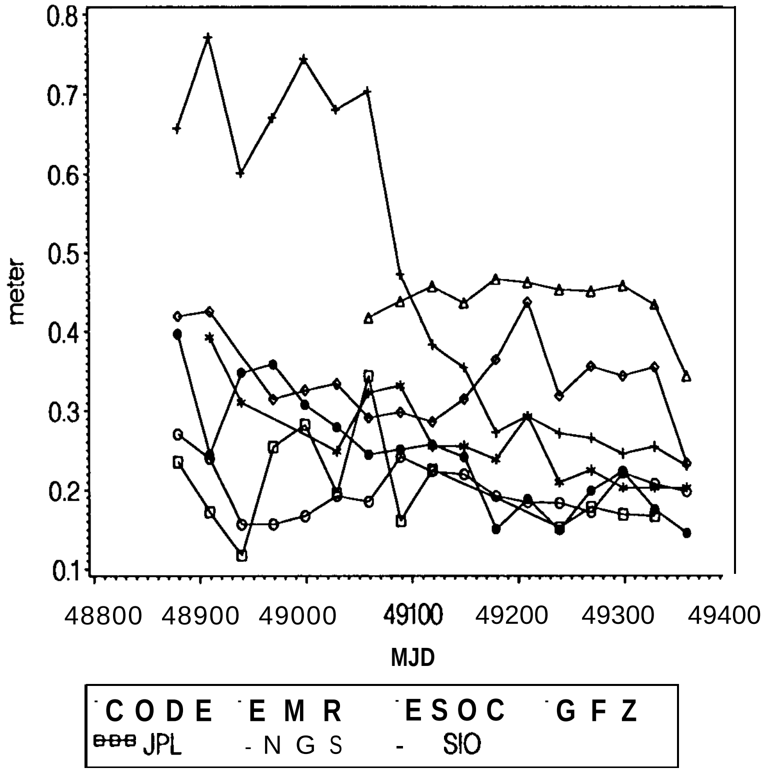


Figure 2 Development of the orbit quality of the IGS Analysis Centers between September 1992 and December 1993 based on the Orbit Comparisons through 7 parameter **Helmert** transformations.

It was a serious problem that at the beginning of the IGS activities in Summer 1992 the orbits were not regularly compared. The situation was considerably improved during the IGS Pilot Service, when the Analysis Center Coordinator started comparing the daily orbit files through similarity transformations. During this phase the orbit consistency came down from the 1 m – 50 cm level roughly to the 20 cm level (after taking out the rotations between the series). This development may be seen in Figure 2, where the orbit quality of the individual solutions is shown between June 1992 and December 1993. The quality of the individual series was estimated from the rms errors of the 7 parameter Helmert transformations between all possible pairs of daily solutions (SP3 files delivered to the IGS Global Data Centers).

The analyses, published every week in the IGS-report-series, were stimulating indeed. They were to a high degree responsible for the quality improvement of the individual series. The results underlying Figure 2 also were responsible for the development of *the combined IGS orbit:* the consistency achieved made it clear that (after transformation to a common reference) a combined orbit would make sense and that outliers of individual centers could easily be removed. At the 1993 IGS Analysis Center Workshop in Ottawa it was therefore decided that the main duty of the new Analysis Center Coordinator would be the production of a *combined, official IGS orbit* [Beutler, *et al.*, 1994]. [11] Today we are looking back at about one year of orbit combination. Figures 3 and 4 show that the consistency of the individual orbit series, documented by the (weighted) rms error relative to the combined IGS orbit, again could be improved. At the end of 1994 the combined IGS orbit and the best individual series have a quality of about 10 cm rms per satellite coordinate.

[1]1 See also **Kouba** [1993].

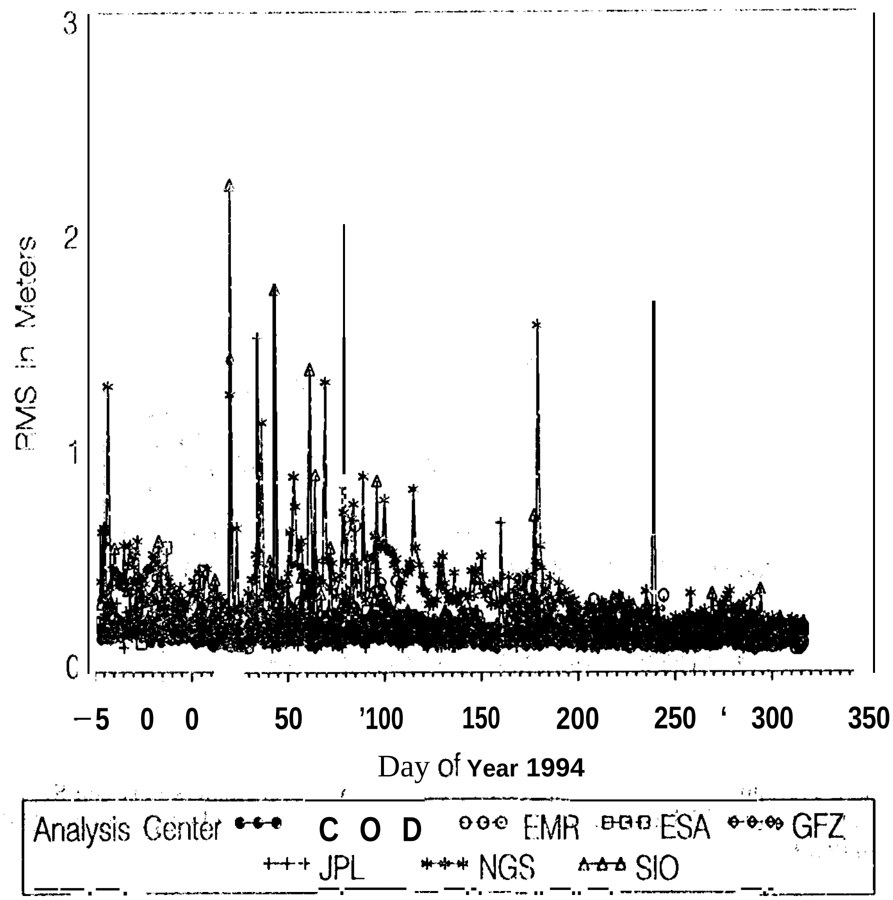


Figure 3 Development of the Orbit Quality of the IGS Analysis Centers between November 1993 and November 1994 based on the Orbit Combination produced by the IGS Analysis Center Coordinator. All orbits included.

We conclude that orbits and earth rotation parameters are in excellent shape mainly because regular controls and comparisons were performed. We have seen that after a while the consistency of the orbits was such that a *combined IGS orbit* could be produced. This combined orbit is a blessing for the user community, which no longer has to make the distinction between individual series. It is a blessing for the IGS Analysis Centers as well, because every center may claim to contribute in the appropriate way to one and the same official IGS product. We might conclude from Figure 1 that a similar procedure, i.e. the production of a combined IGS pole, would make sense for the polar motion, too. Such a *combined IGS pole* might easily be produced together with the IGS orbits.

To a certain degree a similar development as in the case of orbits and earth rotation parameters may be observed for the satellite (and potentially the receiver) clocks, too. The production of combined IGS clock corrections is very stimulating for those centers basing their analysis on the zero-difference observable. It would not be amazing if the other centers would start producing clock information, too, in the near future. Such developments show that the screening-, comparing-, and combination-processes are *the keys to improve the IGS products.*

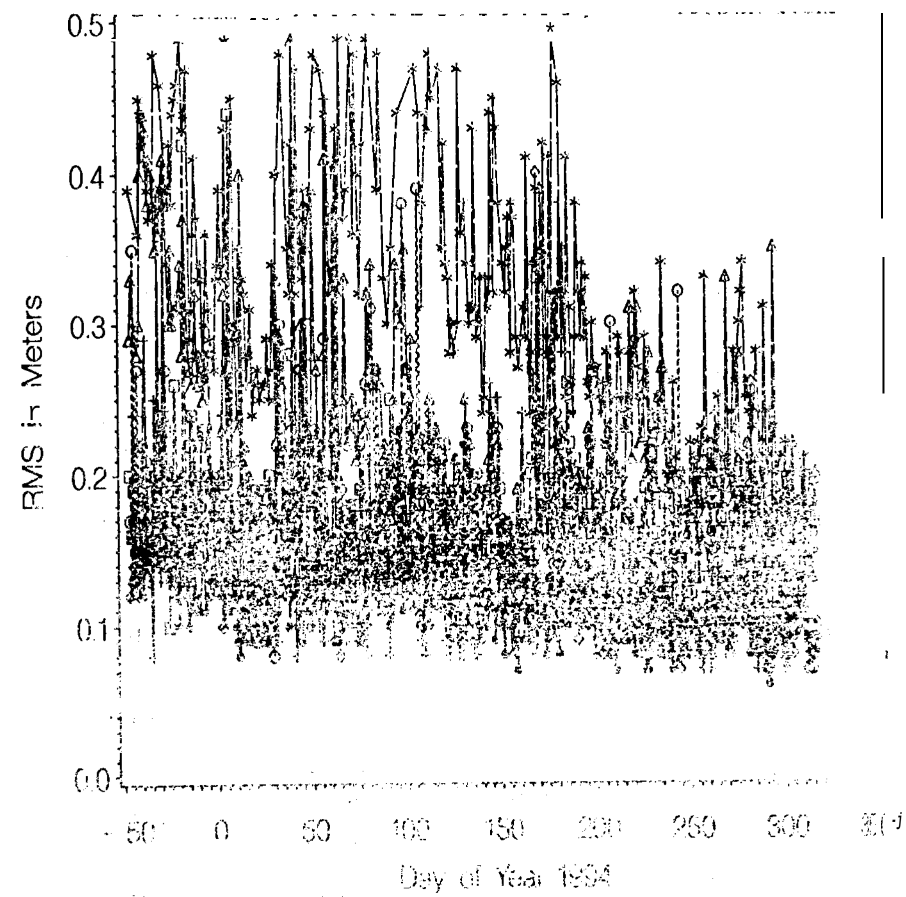


Figure 4 Development of the Orbit Quality of the IGS Analysis Centers between November 1993 and November 1994 based on the Orbit Combination prepared by the IGS Analysis Center Coordinator. Only orbit sets better that 50 cm rms per satellite coordinate included.

Let us conclude this review of two years of IGS operations by looking at the coordinates (and velocities) of the sites of the permanent IGS tracking network. The procedure is *in principle* similar to that used for the earth rotation parameters: The IGS analysis centers send their *annual* solutions to the IERS where they are used together with the results of the other space techniques to produce the ITRF. A few peculiarities of the process should be mentioned, however:

- Initially, some of the Analysis Centers had no intention to [illegible] the site coordinates of the permanent IGS network. It was argued that these coordinates should be taken over from other space techniques (VLBI, SLR) and that the GPS should only be used in the densification step.

- Coordinates are very slowly varying. Until now the [illegible] annual basis to the IERS, which makes sense from the geodynamical point of view. The drawback is a long delay in the feed-back loop.

- Orbits and earth rotation parameters for each Analysis Center are [illegible] fixed or closely constrained set of coordinates. The constraints and the [illegible] are not necessarily identical for all IGS Analysis Centers. [illegible] make sense to compare directly the coordinates as they are routinely turned out every day by all IGS Analysis Centers.

Station	n-s	e-w	up
Transformation (a)			
GRAZ 11 001M002	-0.0004	-0.0001	0.0020
HERS 13212M007	-0.0014	0.0012	0.0034
KOSG 13504M003	0.0014	-0.0010	0.0002
MADR 13407S012	-0.0017	-0.0001	-0.0009
MATE 12734M008	0.0001	-0.0003	0.0048
TROM 10302M003	0.0016	0.0008	-0.0033
WETT 14201M009	0.0007	0.0005	-0.0065
ZIMM 14001M004	-0.0008	0.0013	0.0005
ONSA 10402M004	-0.0003	-0.0019	-0.0013
METS 10503S011	0.0011	-0.0012	0.0078
NYAL 10317M001	0.0022	-0.0029	0.0019
MASP 31303M001	-0.0033	0.0014	0.0000
JOZE 12204M001	0.0011	0.0024	-0.0085
rms for trafo (a)	0.0016	0.0015	0.0044
Transformation (b)			
GRAZ 11001M002	-0.0095	0.0078	0.0126
HERS 13212M007	-0.0027	0.0088	0.0182
KOSG 13504M003	0.0087	-0.0017	0.0039
MADR 13407s012	-0.0036	0.0035	0.0013
MATE 12734M008	-0.0073	-0.0067	0.0176
TROM 10302M003	0.0086	-0.0001	0.0022
WETT 14201M009	-0.0059	-0.0086	-0.0232
ZIMM 14001M004	0.0055	0.0037	-0.0170
ONSA 10402M004	**-0.0070**	**-0.0153**	**-0.0270**
METS 10503S011	0.0008	0.0064	0.0072
NYAL 10317M001	0.0124	0.0022	0.0042
rms for trafo (b)	0.0076	0.0075	0.0156
Transformation (c)			
GRAZ 11001M002	0.0004	-0.0007	0.0043
HERS 13212M007	0.0004	0.0027	0.0026
KOSG 13504M003	0.0056	0.0012	0,0000
MADR 13407s012	-0.0069	0.0007	0.0120
MATE 12734M008	-0.0025	-0.0062	0.0059
TROM 10302M003	0.0031	0.0064	-0.0044
WETT 14201M009	0.0004	-0.0007	-0.0020
ZIMM 14001M004	-0.0002	0.0041	-0.0093
ONSA 10402M004	-0.0051	-0.0095	**-0.0026**
METS 10503S011	-0.0033	0.0013	0.0117
NYAL 10317M001	0.0016	-0.0009	0.0004
MASP 31303M001	0.0070	-0.0018	-0.0048
JOZE 12204M001	-0.0006	0.0034	-0.0138
rms for trafo (c)	0.0039	0.0042	0.0075

Table 1 Residuals in meters of seven parameter Helmert transformations between the European part of the IGS subnet as computed by the CODE Analysis Center (using the nine first months of 1994) and (a)theEuropean part ofthe IGS subnet of stations as computed by CODE (using the last nine last months of 1993), (b) the ITRF 92, (c) the ITRF 93.

In view of the consistency the IGS reached in the domains of the *pole, orbits,* and *clocks we* have to ask ourselves whether the procedure set up for the coordinates is satisfactory. By comparing GPS solutions made by one and the same agency but stemming from different time periods (e.g., from different months) we know that the GPS- and agency- internal consistency is of the order of a few millimeters per coordinate, whereas differences on the centimeter level still exist between the GPS solutions and the official ITRF coordinates. This fact is documented in Table 1 where we see that the residuals of a seven-parameter Helmert transformation between two nine-month GPS solutions are substantially smaller than the residuals corresponding to the transformation between the 1994 GPS solution and either the ITRF 92 coordinates [Boucher, *et al.,* 1993a] or ITRF 93 coordinates [Boucher, *et al.,* 1993b]. That the ITRF 93 is clearly superior to the ITRF 92 (and that the coordinate updating process converges) follows by comparing the residuals of transformations (b) and (c)in Table 1. This fact also documents that the GPS starts playing a very important role in the process of defining the more recent (and the future) versions of the ITRF.

On the other hand Table 1 also illustrates that we are still suffering from reference frame inconsistencies in the broadest sense. Most of these inconsistencies have nothing to do with the IERS producing these coordinate sets, but with GPS internal inconsistencies and with inconsistencies between the GPS and the other space techniques. Today we do *not* know e.g. for sure whether all the IGS Analysis Centers are actually using the same information concerning the local ties. Most of the problems might “easily” be removed by performing at regular intervals (e.g., each week or each month) transformations between free coordinate solutions of all centers. In a first step we would find out which coordinates (center coordinates, GPS eccenters) are used by different agencies. We would also quickly find out about antenna eccentricity problems between different centers. There can be little doubt that such a procedure would lead to a comparable improvement in coordinate consistency as in the case of orbits and Earth rotation parameters.

Let us therefore draw the following conclusions:

- In order to improve the consistency of all IGS products and independent on the degree of densification agreed upon it would be highly desirable to establish a regular (e.g., weekly) coordinate comparison service.

- The coordinates and the associated variance-covariance matrices of free adjustments as delivered by the Analysis Centers should in a first step be compared through transformations. Discrepancies (point id’s, antenna heights, epoch of the coordinates, etc.) should be removed, and the results regularly summarized in IGS-reports.

- If a degree of coordinate consistency comparable to that of the orbits and of the Earth rotation parameters is reached, the same free network solutions may be used to produce combined IGS coordinate sets.

- Such combined coordinate sets should not replace the submitting of the individual series to the IERS neither the production of the ITRF by the IERS. It would guarantee that the individual series going into the official ITRF solutions are much more consistent than they are now.

- Combined, official set of IGS coordinates would play a similar role for the user community as the combined orbits. User-friendliness is an important aspect, too.

II DENSIFICATION OF THE IGS NETWORK IN VIEW OF THE IGS RESPONSIBILITIES

In this section we first extract the essential parts concerning a densification of the existing IGS network from the terms of reference (section 2.1). In section 2.2 we briefly discuss two extreme cases for a network densification considered to be realistic at present. In section 2.3 we discuss the organizational aspects as a function of the network density.

The network densification in view of the IGS terms of reference

The *IGS terms of reference* [IGS Central Bureau, 1994] state that

- the primary goal of the IGS is to provide a service to support, through GPS data products, geodetic and geophysical research activities.

- the 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
  - scientific satellite orbit determination
  - ionosphere monitoring

- The IGS accomplishes its mission through the following components:

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

- the Network of tracking stations 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.
  - 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 Core and Fiducial Stations located at the vertices.

All considerations concerning the densification of the IGS network (called Core network above) have to be based on the extract of the terms of reference reproduced above. Naturally we have to take into account the experiences gained during the last two years.

The primary goal of the densification of the IGS network undoubtedly is *the realization of global accessibility to and the improvement of the IERS Terrestrial Reference Frame.* This leads immediately to the question of the required network density. Let us deal with the two aspects separately: The improvement of the ITRF is going beyond the GPS as a technique. The IERS is responsible for this part. For the other aspect, the global accessibility, the IGS is responsible, at least where GPS is concerned. We need to know whether (a) 3000 km, (b) 2000 km, (c) 1000 km (d) 500 km spacing between the sites of the IGS network is sufficient for regional GPS networks. In the next section we will see that only the spacings (a) and (b) are realistic.

The number of sites in the future IGS Network

The following considerations are meant to fix the order of magnitude for the densification, only. The aspect of receiver spacing was considered in detail in Position Paper 1 (Zumberge et *al.,* 1995), where a special measure (the ζ-measure) was introduced to describe the quality of a global geodetic network,

The distribution of the sites on the globe should be as regular as possible. We are reminded that the vertices of regular polyhedra are optimal for that purpose [Mueller, 1993]. In order to get an impression of the orders of magnitude we use the icosahedron (consisting off= 20 triangles (faces), v = 12 vertices, e = 30 edges) as a starting point for our discussions. The length 1 of the edges of an icosahedron with its vertices on the surface of the Earth is 1 ≈ 6700 km. Undoubtedly a polyhedron of 12 vertices is not a good candidate for the IGS polyhedron.

Let us therefore partition each of the equilateral triangles of the icosahedron into four congruent equilateral triangles. Projecting the resulting v = 30 new vertices (one on each edge of the icosahedron) onto the surface of the sphere (central projection) and adding them to the original 12 vertices we obtain a new polyhedron consisting of f' = 4. f (almost) equilateral triangles, v' = v + e = 42 vertices, and e' = 20 e + 3 · f = 120 edges. This new polyhedron is not regular (either five or six edges meet in the vertices, the edges are not all of equal length). The differences in the lengths of the edges are not important for our purpose, however. This new polyhedron with v' = 42 vertices is an interesting candidate to play the role of the IGS polyhedron:

- the edges' length of about 1' ≈ 3500 km is sufficient to guarantee a substantial number of interferometric observations relative to the neighboring receivers.
- A receiver brought to an arbitrary point of the Earth would not be farther away than about 2000 km from the nearest IGS sites. This is a distance which allows a relative positioning with the GPS *within the centimeter in all coordinates within a few days.*
- The number of vertices (42) is ***not frightening.*** It is the order of magnitude which is handled today by the IGS Data Centers and Analysis Centers. We may thus conclude that the IGS would have *no problems* handling such a minimum solution *with the existing structure* already.

This *minimum **IGS** network* is closely related to what is called a core *network* in the IGS terms of reference. It is a subset of the network which is analyzed by the IGS Analysis Centers.

Let us go one step beyond this minimum polyhedron. If we partition each triangle of our minimum IGS network in the same way as we did it with the icosahedron and if we project the new vertices on the surface of the Earth, we again obtain a new relatively regular polyhedron consisting of triangles only. This polyhedron has v" = 162 vertices, e" = 480 edges, and f" = 320 faces.

This new network has a spacing between receivers of about 2000 km. The lengths of the baselines would not pose major problems to the user of the IGS: Most baselines we are dealing with today in the global analyses are at least of this length. The big advantage of the new network is the improved accessibility to the ITRF: A receiver at an arbitrary point of the Earth's surface would be at maximum at 1000 km from the nearest IGS site(s), and 1000 km baselines are easily handled today even with relatively modest software packages.

The next partition of the polyhedron (leading to a spatial separation of the IGS sites of about 1000 km) would already result in a polyhedron with 542 vertices, a number which is beyond the scope of present capabilities.

At present we therefore consider a polyhedron with v" = 150-250 vertices as the ***maximum*** *size* for IGS network. This maximum number takes into account that a certain degree of redundancy is necessary and that there is a demand for a higher density in some parts of the world (e.g., North America and Europe).

Terminology and Organizational Aspects of the Densification

At the workshop and at the IGS Governing Board (GB) meeting following the workshop (December 6, 1994 in San Francisco) the issue of terminology for the IGS network and the IGS stations was discussed. It was felt that the terminology used in the terms of reference, i.e. the terms *Core Station* and *Fiducial Station* should be changed and simplified. Let us try to summarize the result of these discussions:

- For IGS *external use* only the term *IGS Station is* relevant. It is not necessary to make the distinction between two types (e.g., *Core and Fiducial*) for the outside world. It is important for the user of IGS products, however, *that precise and reliable ZTRF coordinates and velocities are available for this site and that tracking data may be retrieved (with an acceptable delay) for this site for any given epoch.*

- The set of IGS Stations forms the IGS network.

The distinction between two types of stations, i.e. Global and Regional IGS sites, may be needed and used internally within IGS in regards to operational and technical considerations. The IGS (Associate) Analysis Centers producing free network solutions are e.g. requested to include at least three IGS Stations which were in turn included over a long time period in several solution series of IGS analysis centers (such stations were labeled *Global* in Position Paper 2 (Blewitt *et al.*, 1995)). Also there are consequences for the data management: Only the data of the latter station type have to be stored by the IGS Global Data Centers, the data of the regional sites are handled by regional centers. The information where the data for an IGS Regional Station is available must be stored in the CB Information System and is thus easily accessible for all IGS users. However, all the IGS stations must be conforming to the same IGS standards and provide users with equally precise access to the ITRF.

The above definition assumes that every IGS station is analyzed by at least one IGS (Associate) Analysis Center. This implies that, if a candidate IGS station is coming up, the Central Bureau will poll the IGS (Associate) Analysis Centers as to their intent on using the data of the new station in their solutions. If at least one (A)AC will process the data on a routine (daily) basis the station is considered an IGS Regional Station and is asked to forward the data to the nearest regional data centers. If the station turns out to be used by a certain number of ACS, the regional data center are asked to forward the data of the candidate IGS site to the Global Data Center(s). *If no IGS (Associate) Analysis Center will process the data of the candidate station, the station cannot be considered as an IGS station.*

It was discussed at length whether or not it is necessary to specify a ***minimum*** distance to the closest existing IGS site for a *new* station coming up. Most of the attendants of the workshop and most GB members know that such a minimum distance would make sense: there is obviously no point of establishing new stations at a distance of only a few tens of kilometers of existing sites. On the other hand the only drawback of *not* specifying such a minimum distance consists of a possibly irregular spacing between stations. This probably is of little interest to the IGS user, on the other hand: he is interested to include as many IGS sites with precise and reliable coordinates and velocities as possible into his regional/local analysis. The problem of unnecessary data transfer should be dealt with, because the data of IGS Regional Sites are no longer flowing up to the Global Level.

We believe that at present the structure of the task outlined above is sufficient. It may be necessary in future to add a third level of IGS stations, which might be called a local level. The only difference of *such IGS Local Sites* as compared to IGS Regional or Global Sites would be the location of the data. If reliable and precise coordinates are available in addition to the station's tracking data in a data center below the regional level (and the user again finds this information in the CBIS) such a station may be used in very much the same way as Regional and Global IGS sites.

This hierarchical concept will work, provided we manage to structure the dataflow as outlined above.

Let us conclude this section with a few remarks concerning the next steps of the densification process:

- The *existing* IGS Network of about 60 stations is far from its ideal shape. There must be a high priority given to filling in the gaps (southern hemisphere, Eastern Europe, Asia). Each station showing up in one of the gaps will automatically be analyzed by at least some of the (at present seven) Analysis Centers. The recommendations of position paper 1 should be followed to fill in these gaps.

- Only permanent tracking sites should be considered as candidates for the IGS Network.

- *The network **densification** asks for frequent and regular comparisons/combinations of the coordinate solutions produced by the IGS Analysis Centers and by future Associate Analysis Centers.* Such a combination, when done properly, is a major undertaking, requiring resources and continuous commitment. One or two separate organizations must take care of this task in the operational phase. Such centers will have to work closely together with the IGS Analysis Center Coordinator and the ITRF section of the IERS.

- The IGS densified network consisting of 100 or more stations will involve many different institutions and therefore with utmost certainty also different receiver types. The combination of different receiver/antenna types will be an important issue in future. Thus, the problem has to be addressed by the IGS in future.

- The realization of a relatively dense IGS network will be an ambitious project. It only may be successful if the interfaces with the IERS on one hand and with the regional networks on the other hand are set up carefully and in close collaboration with the corresponding organizations.

III SUMMARY, CONCLUSIONS, ACTION ITEMS

Two years of IGS operations show that frequent and regular comparisons of the results produced by the IGS Analysis Centers were and are the key for accurate and reliable products. Furthermore the official IGS orbits prove that combined products are beneficial to the user community. From such experiences one has to conclude that the coordinates produced by different IGS Analysis Centers should be checked in the same way as the orbits and the Earth rotation parameters. It was recommended at this workshop that weekly coordinate comparisons should be performed in order to reach a coordinate consistency level comparable to that of the orbits and the Earth rotation parameters. It is clear that such a coordinate comparison must be built up in close collaboration with the IERS.

It was decided to use essentially the structure as proposed in Position Paper 2 (Blewitt, 1995). The following conclusion and action items concerning the coordinate comparison/combination were drawn resp. proposed at the workshop and confirmed at the Governing Board on December 6, 1994:

- *Workshop Conclusion No 1*: One, ideally two Associate Analysis Centers shall perform weekly comparisons and combinations of the coordinate solutions of all IGS Analysis Centers and of future Associate Analysis Centers analyzing parts of the densified IGS network. As suggested by (Blewitt et al., 1995) an agency performing coordinate comparisons and combinations in the way described in position paper 2 is called an *Associate Analysis Center of type-2 (AAC type-2),* agencies analyzing and contributing parts of the (densified) IGS network are called *Associate Analysis Centers of type-1 (AACs type-l).*

The following facts had to be considered when planning the action items for the implementation of the AACS of type-2:

- Seven IGS ACS are in principle ready to produce weekly so-called free coordinate solutions as proposed by in Position Paper 2 (Blewitt, 1995). These solutions are ready to be used by AACS type-2.

- In view of this favorable situation it seemed advisable to follow the suggestions made by (Blewitt, 1995) and to establish a *pilot phase for AACs type-2* to last for one calendar year early in 1995.

- It was assumed necessary that candidates for AACS of type-2 should have a sound experience in regular IGS processing. Therefore, only a small group of individuals and agencies had to be contacted for the organization of the pilot phase for AACS type-2.

- The Department of Surveying of the University of Newcastle, represented at the workshop by G. Blewitt and the Institute of Geophysics and Planetary Physics of Scripps Institution of Oceanography, represented at the workshop by Y. Bock, expressed their interest to act as AACS type-2 during such a pilot phase.

- The IERS is responsible for the maintenance of the ITRF. It was considered important that the ITRF section of the IERS (the IGN in Paris) would accompany the test phase of AACS type-2 by analyzing the products of AACS of type-2.

Based on these considerations the following action items were agreed upon at the GB meeting following the workshop:

- The GB chair was asked to write letters to the seven ACS, the two institutions mentioned above, and to the University of Texas (AC during the 1992 IGS test campaigning) to ask for participation in the test phase for AACS type-2.

- G. Blewitt was asked to propose a specific timetable for the pilot program by the end of January 1995 (Blewitt, 1995).

- C. Boucher from the ITRF section (at the IGN) formally agreed to accompany the test phase of AACS type-2 by analyzing the coordinate series produced by the AACS type-2 at regular (probably monthly) intervals.

The permanent IGS tracking network was considerably growing since 1992. The *number* of permanent sites (about 60 today) would be sufficient to buildup what was presented in section 2 as *the minimum solution for the IGS Global Network* with a spacing between sites of about 3500 km. However, although the actual distribution of IGS sites was much improved since 1992, we are still far away from an ideal distribution in the sense of a regular polyhedron.

The problem of obtaining the desired coverage for the IGS network was addressed in detail in Position Paper 1 (Zumberge et al., 1995). Concerning the instrumentation of future IGS sites the following conclusion was drawn:

- *Workshop Conclusion No. 2:* IGS stations should be permanent stations wherever possible. Although near real-time data transmission is desirable, permanent receivers with less-than real-time data communications would be acceptable, too.

In order to actually obtain the necessary coverage it was decided at the GB meeting to take the following action:

- The CB was asked to draft a ***Call for** Participation **(CFP)*** identifying regions for the IGS network densification. This CFP together with follow-up letters to agencies working in areas of special interest to the IGS are to be sent out in March 1995.

- The tide gauge project of IAPSO [Carter, 1994] is of special interest to the IGS to obtain the necessary coverage in the oceans (tide gauges on islands). A close cooperation between IAPSO and IGS seem to be of particular interest in this context.

The densification of the IGS network leads to a considerable growth of the daily processing workload. It must be the primary goal of the IGS to *avoid the situation that data are collected but not analyzed.* This is why we ask that each site with an IGS label has to be included in the solution series of at least one (A)AC. It seems clear that this additional work has to be done by new IGS Associate Analysis Centers of type-1 (using the terminology in Blewitt, 1995). It was recommended at the workshop that a Call for Participation should be issued for AACS of type 1. On the other hand it seemed premature to send out such a call *before* having clearly defined the duties of such AACS of type-1 and before having a clear picture of the densified network. Based on these considerations the following actions were invoked at the GB meeting in December 1994:

- A format working group consisting of G. Blewitt, Y. Bock, C. Boucher, W. Gurtner, and J. Kouba will come up with a *Software Independent coordinate solution EXchange format,* tentatively called SINEX (!). This format has to be available at the beginning of the AAC type-2 pilot phase.

- The expectations to an IGS AAC of type-1 are given in Position Paper 2. An extract will be included in the CFP for AACS of type- 1.

- The expectations to an IGS site are given in Position Paper 3 (Gurtner and Neilan, 1995).

- A Call For Participation for AACS type-1 will be delayed until the pilot program has had a few months of operation.

Not *all* the problems in the area of the densification of the IGS network could be addressed at the 1994 IGS workshop *Densification of the ITRF through Regional GPS Networks.* But the workshop will be remembered as the principal milestone of this ambitious project—provided the actions outlined in this section are executed in a timely fashion. There can be little doubt that this will be the case. The workshop clearly documented that the innovative spirit within the IGS and the firm wish to work together in an International, truly Global Frame are still as strong as in the early days of the IGS. The workshop participants wish to thank the Jet Propulsion Laboratory and—of course—the Central Bureau of the IGS in particular, for hosting the 1994 IGS workshop.

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POSITION PAPER 4 APPENDIX

Jan Kouba, chair

This session consisted of two presentations. Claude Boucher described his view of cooperation and coordination between the IGS and IERS in achieving an expanded international reference frame.

Jean Dickey described a proposed Crustal Deformation Bureau under consideration by the IAG.

Written versions of these follow.

Claude Boucher. The Realizations of the International Terrestrial Reference System (ITRS): A Challenge for a Joint IERS / IGS Solution

For more than 6years, the International Earth Rotation Service (IERS) has achieved annual realizations of the International Terrestrial Reference System (ITRS), formally recommended by the IAG and IUGG since the Vienna General Assembly in 1991. Many things have been progressively improved during these 6 years, even 10 if we consider the BIH activity since 1984 in the frame of the MERIT campaign. In addition, further important issues are coming on the floor now:

- the International GPS Geodynamic Service (IGS) and its plans to use regional networks for densification

- the official inclusion of DORIS as anew technique contributing to IERS

This is a good opportunity to undertake a review and critical discussion on the work done by IERS on the Terrestrial System and to identify improvements to be realized.

The IERS Central Bureau has undertaken to establish a report containing a critical analysis of the present work, as well as a set of recommendations, and to design an implementation plan within IERS (between the Central Bureau, the analysis centers and others such as IGS), in order put into practice the previous recommendations. The purpose of this present paper is to discuss specific interfaces with IGS and to see how IGS can greatly contribute to these improvements.

Fundamental concepts

One of the major tasks of the IERS is to realize the IERS Terrestrial Reference System (ITRS) using results of space techniques (SLR, LLR, VLBI, GPS, DORIS), as well as auxiliary informations, such as local surveys between co-located instruments. Such realizations are called reference frames, specifically the IERS Terrestrial Reference Frames (ITRF), which consists into:

- a network of instruments and/or related ground markers
- a set of coordinates, which can be of the following types:
  - position at epoch t0 : XO
  - position at epoch t0 and velocity : XO, V
  - time series of positions: Xk

For the last case, we can consider in particular:

- daily (d)
- monthly (m)
- quarterly (q)
- yearly (y)

Several types of frames can be considered, depending on various options. For instance, we can consider:

- an individual solution, which is characterized by:
  - a specific technique (L, M, R, P, D)
    a model/software/analysis center
  - a raw data set (type of data, period...)
  - a reference system which was selected to express coordinates

- a combined solution for a given technique, which combines several individual solutions of the same technique
- a combined solution, using individual or combined solutions for several techniques

We shall note x-solution (x = L, M, R, P, D) an individual solution for the technique x, xC-solution a combined solution for x, and C-solution a combined solution, Furthermore, we shall call an I-solution any solution assumed to be expressed directly into ITRS, and with the previous typology, we shall speak of xI-, xCI or CI-solutions. Furthermore, a solution will be described as a set of parameters together with their variance-covariance matrix. The parameters included in the solution can be:

x : station position/velocities
E EOP
R: radiosources
S: satellite state vector

We propose to define three types of ITRF solutions to be produced by the Central Bureau:

- primary solutions, which will be established by using all good quality individual solutions of all techniques, providing XE parameters, and"XER parameters for VLBI. The combination will be performed rigorously and provide a complete result in X, E and R parameters, as well as transformation parameters from individual terrestrial/celestial systems into ITRS/ICRS. In such a solution, coordinates will be taken as XR, V for the result, needing to select a reference epoch tR. Input solutions will be accepted as XO or (X0,V), whether t0 is or is not equal to tR. Full covariance will be available at least for Xo,V, in order to compute rigorously X and its variance at any epoch for any station.
- complete solutions, which will use all available data, including regional solutions from IGS or similar data.
- time series solutions, which will use time series of station coordinates from various techniques (daily, monthly, quarterly, annual).

In all these types of solutions, local surveys should be preferably used as G-solutions, i.e. set of coordinates with full covariance at a given epoch. Several such solutions can be used for one site in case of repeated surveys or partial surveys at various epochs.

Status and clans of the IERS Central Bureau

Up to now, the basic strategy used by IERS and previously by BIH was to compute each year a new complete solution using the data submitted by the analysis centers for the Annual report. We refer to the IERS Annual Reports and Technical Notes for further details. The most recent solution (ITRF93) has been issued recently (see IERS TN 18). The new strategy which is proposed by IERS Central Bureau is:

a) To compute a satisfactory primary solution (target ITRF95) and to keep it as a reference.
b) To continue yearly submissions for IERS Annual Reports. In case of the terrestrial system, evaluation of solutions will be done. If enough new material exist, a complete solution may be produced, using also other materials.
c) The publication of these complete solutions may not be done annually. Such solution will be put in the lTRS by use of the current reference solution.
d) In addition, with the cooperation of some analysis centers, some time series solutions will be computed, also in ITRS through the use of the reference solution. They could be produced on a regular basis, like other operational products of IERS.

Furthermore, we consider it is very important to adopt for ITRF solutions a quality code which would be attributed using several criteria to be specified, in cooperation with analysis centers and some users. For the ITRF94 solution, we plan an intermediate stage: this will be a complete solution using X-parameters expressed in Xo, V with full covariance.

Proposals for the IERS/IGS cooperation about TRF

The relations between IGS and IERS can be expanded for the benefit of both Services. We can summarize them by the following items:

IERS to IGS

- ITRS is adopted by IGS
- IERS ERP are used by IGS global analysis centers
- ITRF is used by IGS global analysis centers either directly or to convert their own GPS derived frame into ITRS
- IERS products will also be used by IGS regional analysis centers

Up to now either annual solutions or dedicated solutions (ITRF-P solutions) were used. In the future there will be a choice. We suggest to use the reference solution (ITRF95) and not change it every year. Furthermore, the fact that full consistency between ERP and TRF is now ensured by IERS is important for IGS users.

IGS to IERS (for TRF)

- IGS global analysis centers will contribute to primary solutions if they provide the relevant XE-matrix. A standard exchange format is proposed: ISEF (see appendix)
- IGS global or regional analysis centers will contribute to complete solutions with X-solutions submitted in ISEF.
- IGS global analysis centers may also contribute to time series solutions

IERS Standard Exchange Format (ISEF)

The International Earth Rotation Service (IERS) is permanently collecting, exchanging and disseminating various data. The need to use standard formats and to document them is clear, considering:

- the various groups involved in IERS: stations, networks, coordinating centers, analysis centers, central bureau and sub-bureau
- the user's community

Therefore, a set of rules is established and published under the label IERS Standard Exchange Format (ISEF). Several versions will be considered. This document presents the ISEF. 1, dealing with the exchange of analyzed data (EOP, station positions,...).

1. Data types. Three types of data can be identified for IERS:

a) raw data
b) analyzed data
c) auxiliary data

Raw data consist into the various measurements analyzed by the IERS analysis centers or the central bureau. They are relevant to one of the techniques presently considered by IERS:

- SLR data
- LLR data
- VLBI data
- GPS data

- DORIS data

The necessity of standardization is under the responsibility of the IERS technique coordinator. Currently, each technique has at least one standard exchange format (ex. MERIT2 for SLR, MARK3 for **VLBI,** RINEX for **GPS...).** We should also consider local survey data as a potential other type (terrestrial or **GPS).** Presently, only results will be considered, in the **auxiliary** data type.

Analyzed data are information generated by any analysis center participating to IERS, basically analysis centers for the various techniques, the central bureau and sub-bureau. This is also the type of data which are disseminated by IERS to the user's community.

Auxiliary data include any data used to describe a specific solution, in particular the model used, referring to the IERS Standards. They also include station description and occupancy information, as well as local eccentricities.

In summary, the various types of information handled by **IERS** are:

A Raw data
- AL SLR data
- AM LLR data
- AR VLBI data
- AP GPS data
- AD DORIS data
- AG geodetic ground survey

B Analyzed data
- BE EOP data (ERP, precession, **nutation)**
- BX SSC data (station positions and velocities)
- **BC** RDS data **(radiosources** positions)
- **BI** global analysis (combined solutions including several of the previous types, as well as **covariance)**

C Auxiliary data
- Cs Model parameters
- CG station description and local eccentricities

2. **ISEF.** 1: Exchange of analyzed data. An analyzed data set will be defined as a sequence of scalar numerical parameters (xi), i= 1,N, where N is the dimension of the data vector, together with

- a list of labels Li
- a list of scalars Ck giving the **variance-covariance** information between the parameters.

Li gives the description of the parameter Xi. Ck gives the **variance-covariance** information. A possible recommended procedure will be to give the matrix (correlation coefficient and standard deviations in the diagonal) corresponding to Xi, scanning the upper triangle by columns:

cl = **s1**
C2 = **cor1,2**
C3 = S2
C4 = **cor1,3**
C5 = cor2,3

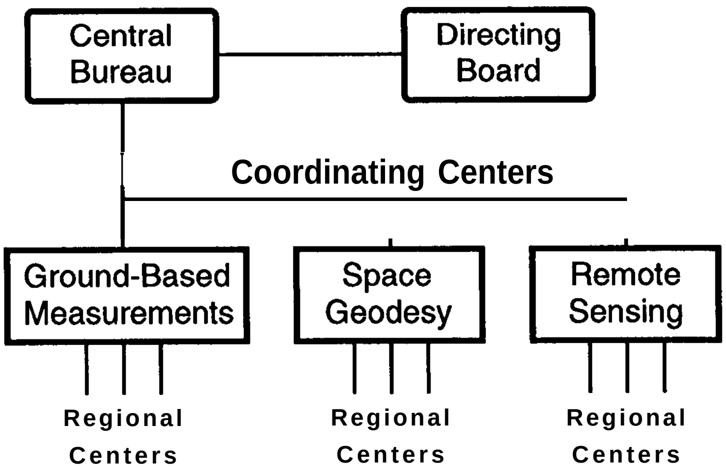
Jean Dickey

With maturing space technologies (GPS and others) and the wealth of data now available, the International Association of Geodesy (IAG) is considering the formation of a Crustal Deformation Bureau (CDB) in which the demands would be met by a network of centers (see Figure on following page). Such a Bureau would be of great interest to the International GPS Service for Geodynamics (IGS) and close links would be established with it. The structure proposed parallels that of the International Earth Rotation Service (IERS). These coordinating centers are suggested based on three measurement types: classical terrestrial, space geodetic, and remote sensing techniques. Further, the data archiving would be based at regional centers. A Central Bureau would act as the main contact point; activities would be overseen by a Directing Board. Remote sensing techniques (such as Interferometric Synthetic Aperture Radar) are now under development. One could envisage this service being formed in a two step process with the first two coordinating centers being formed at the outset of the CDB and the third center based on Remote Sensing initiated later as the techniques evolve and mature.

We envisage the scope of the Bureau to encompass both marine and continental crustal deformation. As such, it would serve the following associations: IAG, IASPEI, IAVCEI, IAPSO, IAHS, and IAGA, IAG being the leading association. Linkages would be made with the ICL, IERS, and the IGS.

* Review Board studying this issue consists of J. Dickey, Chair, C. Boucher, M. Feissel, C. Reigber, and T. Tanaka.

CRUSTAL DEFORMATION BUREAU



CONCLUDING SESSION

Geoff Blewitt, chair

It was suggested by the chair that, if we were to progress quickly towards a densification of the reference frame, then the concluding session should focus on highlighting any issues which needed resolution as soon as possible. The intention was to then have a post-meeting working group (chaired by Ivan Mueller) discuss the issues in detail. This working group would then provide recommendations for resolutions to the GB, who would meet the following week in San Francisco.

Using this approach, it was felt that the IGSCB would receive recommendations that reflected the thoughts of the workshop participants. There was a consensus to proceed in this way, especially in view of the time limitations. The listed topics were restricted to those having a direct bearing on densification.

The following topics were noted to be in need of resolution:

(1) The "IGS Network" needs to be defined, particularly our vision of how it might look in the future.

- Specify those regions where IGS would welcome densification initiatives.
- Should we have a call for participation to install new IGS stations?
- Which agencies might be able to respond?

(2) Should we have a "pilot phase" to assess the distributed processing approach proposed by Position Paper 3?

- What period of time? 1 year?
- Should we start by just analyzing global network solutions produced by the current Analysis Centers?
- Who is interested in participating (Associate Analysis Centers of Type 2)?
- We need to define a software independent exchange format for solutions (SINEX).
- We need guidelines for participation.

(3) How are we to organize regional analysis (Associate Analysis Centers of Type 1)?

- Call for participation?
- Should it be delayed until Type 2 activities are underway?
- Who might be able to participate?
- We need guidelines for participation.

(4) To improve clarity, we should agree on conventional terminology. For example, what exactly do the following terms mean?

- Global Network
- IGS Network
- Core Network
- Regional Network

Although not directly relevant to the concluding session, it was noted that, recently, there has not been a good forum for discussion of technical issues, such as communications technology. It was generally felt that this should be addressed by a future IGS workshop, perhaps similar to the IGS Workshop of 1993 held in Berne (i.e., with contributed presentations rather than position papers).

Other Contributions to Position Paper 1 Appendix

MARK SCHENEWERK

National Oceanic and Atmospheric Administration

COAST GUARD STATIONS

RECEIVERS:

TWO (2) ASHTECH Z12 RECEIVERS AT EACH SITE

SAMPLING RATE:

A2 5 SECOND PLANNED (1 SECOND POSSIBLE)

TRANSMISSION TO CENTRAL FACILITY:

AT&T FTS2000, X.25 PACKET SERVICE

DATA TRANSMITTED AFTER EACH SAMPLE - NO ON SITE STORAGE

AMOUNT OF DATA TRANSFERRED:

~5 Mbytes/DAY/STATION

COAST GUARD STATIONS

CENTRAL FACILITY:

***CURRENTLY*:** **HP WORKSTATION WITH 14 Gbytes OF STORAGE**

***EXPECTED EXPANSION*:** **SECOND WORKSTATION FOR CONTINUOUS COMPUTATION OF INTERSTATION BASELINES.**
SECOND COMPLETE CENTRAL FACILITY AT SECOND SITE FOR REDUNDANCY WITH AUTOMATIC SWITCHING TO REDUNDANT SITE IF PRIMARY GOES OUT

A3 DATA DISTRIBUTIONS:

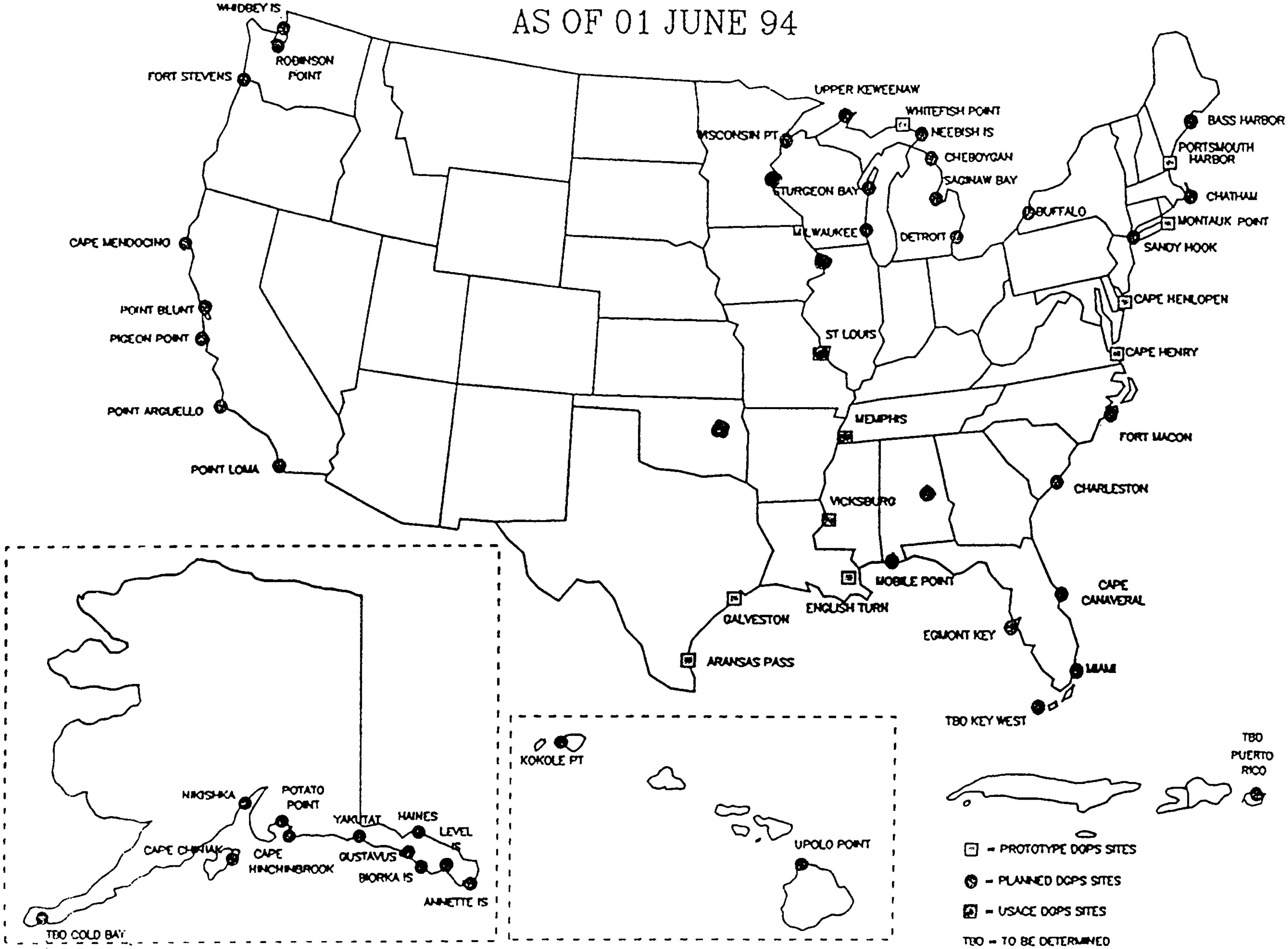
HOURLY RINEX FORMAT FILES FOR EACH STATION EACH HOUR.
THREE (3) WEEKS ON-LINE, ON HARD DISK FOR INTERNET ACCESS.

RAW RECEIVER FORMAT FILES ON CD ROM FOR ARCHIVING AND DISTRIBUTION.

TIME FRAME:

STATIONS EXPECTED TO BEGIN OPERATING BY JAN-FEB, 1995. ALL STATIONS (~50) EXPECTED TO BE OPERATING BY THE END OF THE 1995 CALENDAR YEAR.

PROPOSED DGPS SITES
AS OF 01 JUNE 94



ADDITIONAL PLANS

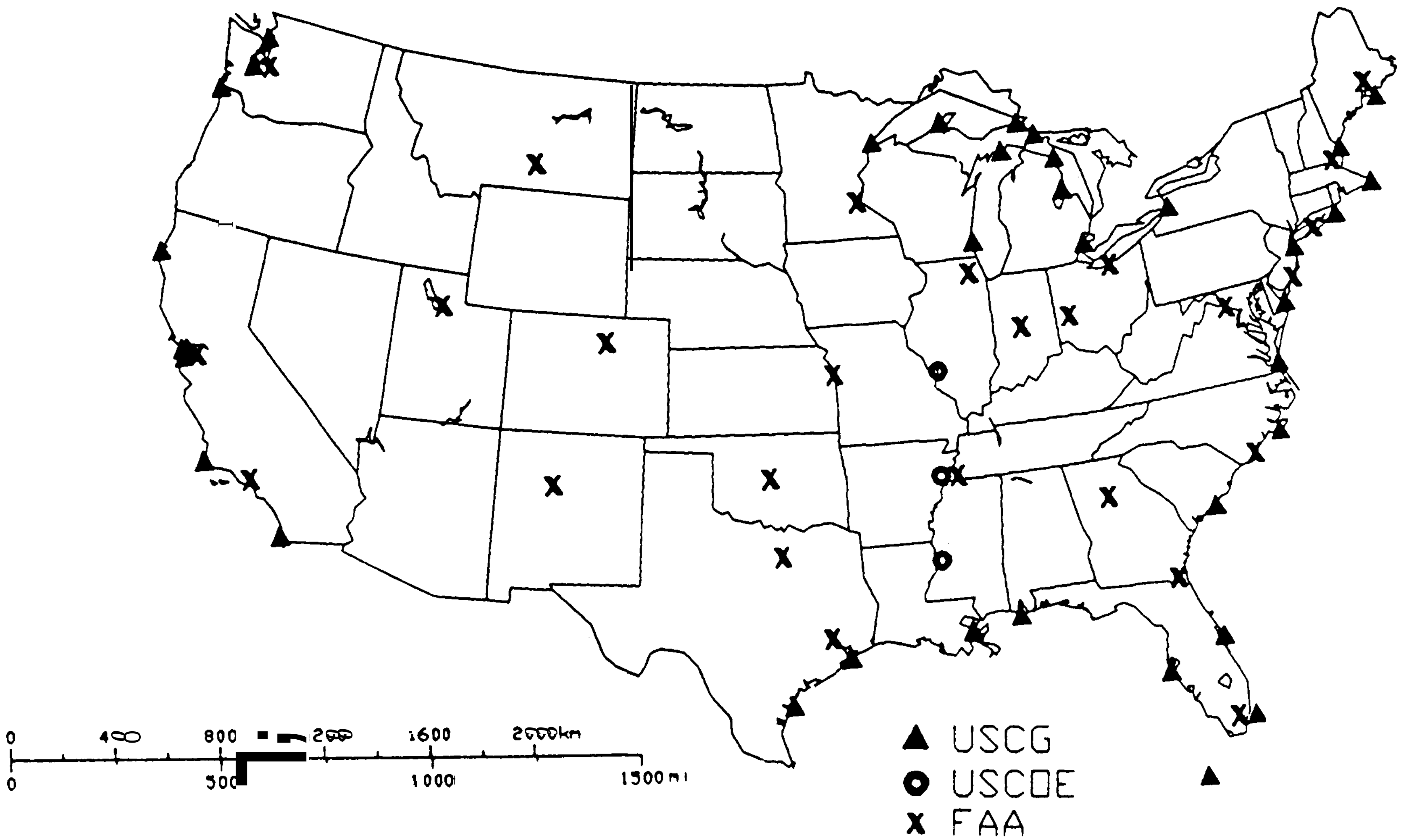
- U.S. ARMY CORP OF ENGINEERS (COE) IS HAVING ADDITIONAL STATIONS ESTABLISHED BY THE COAST GUARD BEGINNING IN 1994 ON INLAND WATERWAYS. STATIONS TO BE IDENTICAL TO OTHER COAST GUARD STATIONS. ESTIMATED TO BE ABOUT 15 ADDITIONAL STATIONS CREATED IN 1995-1996 TIME FRAME.

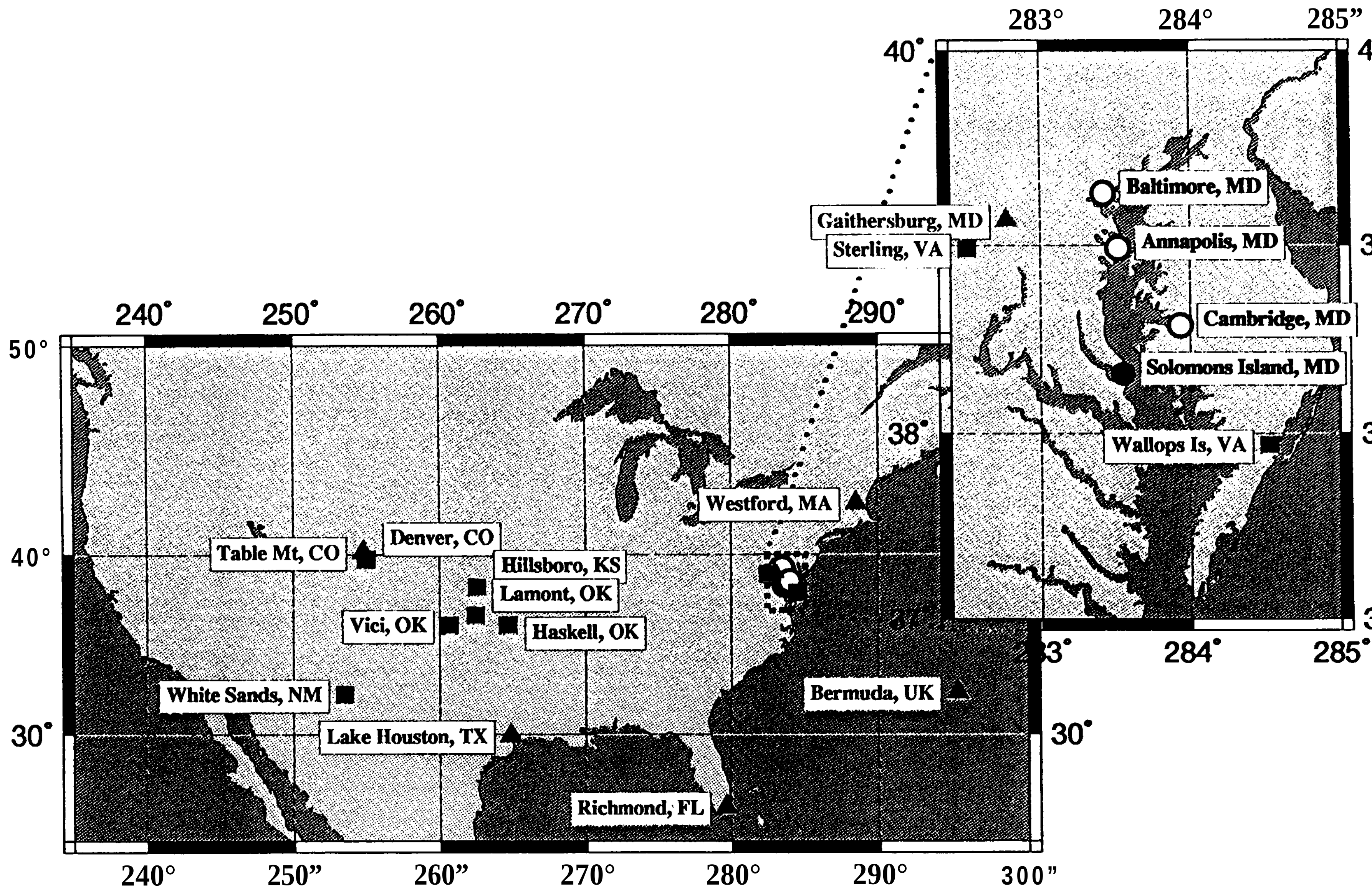
- APPROXIMATELY 30 FAA WIDE AREA AUGMENTATION SYSTEM (WAAS) STATIONS WILL BE ESTABLISHED BETWEEN 1995 AND 1997. DATA TO BE MADE AVAILABLE FOR "AFTER THE FACT COMPUTATION" THROUGH NGS LIKE COAST GUARD STATIONS.

- AUGMENTATION STUDY FUNDED BY DEPT. OF TRANSPORTATION (JUST COMPLETED) RECOMMENDS THAT COAST GUARD/COE TYPE STATIONS BE EXTENDED NATIONWIDE. 20 - 30 ADDITIONAL STATIONS EXPECTED.

- AUGMENTATION STUDY RECOMMENDS THAT ALL STATIONS ESTABLISHED BY THE DEPT. OF TRANSPORTATION BE COMPATIBLE WITH NOAA CONTINUOUSLY OPERATING REFERENCE STATION (CORS) REQUIREMENTS, I.E. PROVIDE CODE AND CARRIER PHASE INFORMATION NEEDED FOR AFTER THE FACT POSITIONING.

US CIVIL DGPS SITES





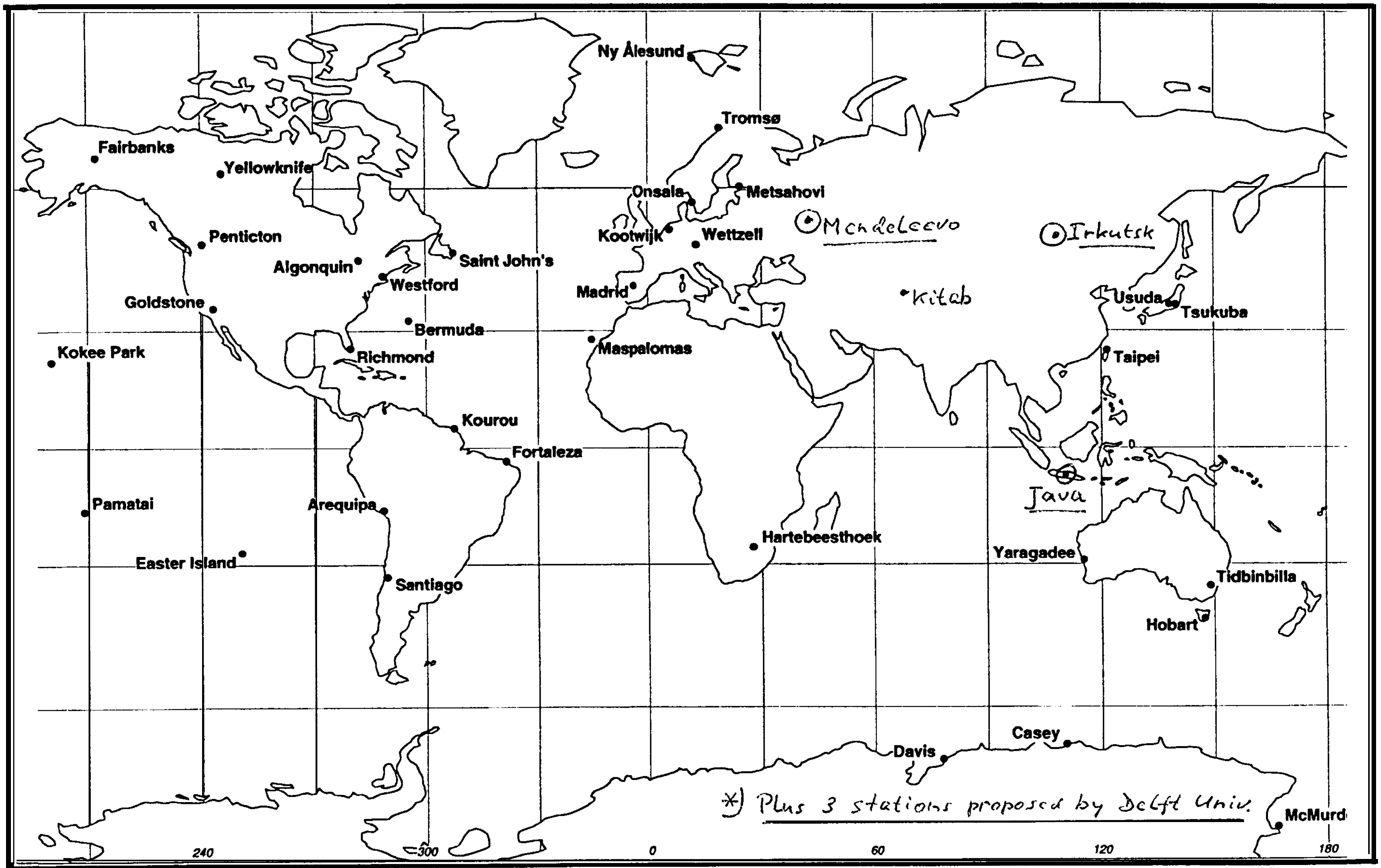
Gaithersburg, MD
Sterling, VA
Baltimore, MD
Annapolis, MD
Cambridge, MD
Solomons Island, MD
Wallops Is, VA
Westford, MA
Table Mt, CO
Denver, CO
Hillsboro, KS
Lamont, OK
Vici, OK
Haskell, OK
White Sands, NM
Bermuda, UK
Lake Houston, TX
Richmond, FL

Other Contributions to Position Paper 1 Appendix

BOUDEWIJN AMBROSIUS

Delft University of Technology

GPS TRACKING NETWORK OF THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS
GLOBAL STATIONS † *)



† Processed by either 1) two or more IGS Analysis centers on another continent
or 2) a majority of Analysis Centers.

September 1994

WEGENER goals:

- Observe crustal motions in the Mediterranean area
- Study post-glacial uplift in Fennoscandia
- Monitor changes in mean sea level
- Study regional deformations
- Monitor ice sheets in Greenland
- ???

WEGNET guidelines:

- Paraphrase as much as possible on the IGS philosophy
- Aim for a cooperative network
- Aim for a permanent “real-time” network
- Densify the current IGS network in the region to approx. 1000 km spacing
- Establish higher-density networks in special areas of interest
- Build on IGS infrastructure for data retrieval, storage and analysis
- Establish analysis centers with well defined tasks and products
- Disseminate data products on a semi real-time basis

WEGNET stations:

- Region extending from Greenland to mid-Asia
- Total of about 60 stations
- Includes about 15 IGS stations
- Maximum collocation with SLR/VLBI and tide-gauge sites
- Communications infrastructure required
- Rogue/TurboRogue receivers preferred

PRELIMINARY MAP OF WESNET STATIONS