IGS

INTERNATIONAL GPS SERVICE

TOWARDS REAL-TIME NETWORK, DATA, AND ANALYSIS CENTRE 2002 WORKSHOP

Proceedings

Ottawa, Canada

April 8 - 11, 2002

IGS Central Bureau

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California Institute of Technology
Pasadena, California U.S.A.

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Ressources naturelles Canada
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Foreword

Almost ten years after the first IGS Analysis Workshop, the Geodetic Survey Division (GSD) of Natural Resources Canada had the pleasure to host the IGS community for a second time. The enthusiasm and large number of participants that convened in Ottawa April 8 to 11, 2002 for the first combined IGS Network, Data and Analysis Center Workshop are strong indications of the importance and vitality of the IGS. Both of which can only be strengthened by the willingness of all IGS contributors to respond to changing requirements as demonstrated by the adoption of the many workshop's recommendations in support of a path "Towards Real-Time".

I am thankful to all those who have contributed to the workshop's position papers, presentations and posters documented in the pages that follow. Their hard work was essential to stimulate the numerous discussions and support the recommendations agreed upon during the workshop. The valued help of all session chairs in organizing the technical programme and ensuring its smooth delivery is also gratefully acknowledged. Sponsorship of social events by Leica Geosystems, Nanometrics, NovAtel Inc., Thales Navigation, Topcon/Javad, Trimble Navigation Canada and Natural Resources Canada, was much appreciated. These events were quite successful in facilitating dialogue and nurturing relationships essential to the collegial IGS spirit. I am also thankful for the support received from the Natural Resources Canada, Earth Science Sector's management team and help provided by my many colleagues at GSD both of which were, of course, vital to the workshop's success.

Pierre Tétreault
Chair IGS Workshop 2002
Ottawa, February 2003

Abstract

An all-components - network, data and analysis centers - IGS workshop to address current and future IGS challenges was held in Ottawa, Canada, April 8-11, 2002. The programme, in addition to the planning needed to strengthen and improve the current Service, focused on the steps needed to develop a real-time component of the IGS. The four-day agenda was divided into eleven technical sessions:

- workshop opening addresses,
- real-time application and products,
- real-time data and products exchange,
- data center issues,
- network issues,
- posters,
- reference frame,
- receiver and satellite antenna calibrations,
- ground based GPS ionospheric estimation,
- low earth orbiters,
- review of IGS products.

These proceedings document the current status of IGS activities and proposed approach in moving towards real-time, a path that the IGS is evidently already embarking on through future collaboration and working group discussions.

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Presentations and Additional Papers

Session 1: Review of IGS Analysis Products

Session 7: Reference Frame

Session 8: Receiver and Satellite Antenna Calibration

Session 9: Data Center Issues

Session 10: Posters

AGENDA

Date:April 8-11, 2002
Ottawa, ON, CA

Monday April 8th, 2002 - AM

8:30 a.m.	NRCan	Welcome
9:00 a.m.	G. Beutler	IAG Issues
9:20 a.m.	C. Reigber	IGS Strategic Planning
9:40 a.m.	G. Gendt	Troposphere Working Group
9:55 a.m.	J. Ray	Precise Time Transfer Project
10:10 a.m.	J. Slater	International GLONASS Pilot Project
10:25 a.m.		Coffee break

Real Time Applications and Products
Chairs: Yoaz Bar-Sever and John Dow

10:45 a.m.	Y. Bar-Sever and J. Dow	Introduction
11:00 a.m.	N. Romero et al.	Ultra-Rapid Orbits at ESOC, Supporting Real-Time Analysis
11:20 a.m.	R. Muellerschoen	JPL Real Time OD Products
11:40 a.m.	R. Pacione et al.	The Italian Near-Real Time GPS Fiducial Network for Meteorological Applications
12 noon	H. van der Marel	What about using GPS for Weather Forecasting?

Lunch

Monday April 8th, 2002 – PM

Real Time Applications and Products (cont'd)

1:45 pm.	E. Powers et al.	Real-Time Ultra-Precise Time Transfer to UTC Using the NASA Differential GPS System
2:10 pm.	B. Wilson	Near Real Time Ionospheric Products
2:20 pm.	P. Héroux	Real-Time Delivery of the Canadian Spatial Reference System - Strategy and Applications
2:40 pm	Y. Bar-Sever	Natural Hazard Applications
2:50 pm	J. Dow	Galileo Status
3:00 pm.	Bar-Sever / J. Dow	Discussion
3:15 pm		Coffee break

Real-Time Data/Products Exchange
Chairs: Mark Caissy and Ron Muellerschoen

3:35 pm	M. Caissy	Session Overview and what we hope to achieve
3:40 pm.	M. Caissy and R. Muellerschoen	Position Paper
4:10 pm	G. Weber	Real-Time Streaming of Differential Corrections via Internet
4:30 pm	K. MacLeod	Internet GPS Data Relay
4:50 pm	G. Hedling and R. Hanssen	Real-Time Permanent GPS Networks in Northern Europe
5:10 p.m.	Caissy/Muellerschoen	Discussions / Questions and Answers
6 pm		Reception Sponsors Leica Geosystems, Nanometrics, NovAtel Inc., Thales Navigation, Topcon/Javad, Trimble Navigation (Canada) and Natural Resources Canada

Tuesday, April 9, 2002 – A.M.

Real-Time Data/Products Exchange (cont)
Chairs: Mark Caissy and Ron Muellerschoen

8:50 a.m.	Caissy/ Muellerschoen	Formats Discussion
9:00 a.m.	Caissy/ Muellerschoen	Discussion / Recommendations
9:30 a.m.		Coffee Break

Data Center Issues
Chairs: Carey Noll and Loïc Daniel

9:50a.m.	C.Noll	Introduction and Overview of Data Center Issues
10:05 am	L. Daniel/E. Gaulué	Ideas and Perspectives for the Present and Future IGS Data Network Management
10:25 am	H. Habrich	Data Center Security Issues
10:45 am	Michael Scharber	GPS Seamless Archive Center (GSAC) - Streamlining data/metadata exchange in the GPS community
11:05 am	C. Noll/L. Daniel	Discussion
11:20 am		Network Issues (Vendors)

Lunch

Tuesday April 9th, 2002 - PM

Network Issues
Chairs: Angelyn Moore and Mike Schmidt

1:30 p.m.	A. Moore	Introduction
1:40 p.m.	L. Combrinck	Africa Update
1:50 p.m.	P. Zhang and H. Sun presented by P. Fang	China Update
2:05 p.m.	R. Neilan	GPS Modernization
2:15 p.m.	L. Estey and W. Gurtner	RINEX Readiness for GPS Modernization
2:25 p.m.	Discussion Panel Moore, Schmidt, Neilan, Estey and Gurtner	GPS Modernization Impact on IGS, RINEX and IGS Metrics
2:55 p.m.	Moore / Schmidt	Wrap-Up / Action Items

Poster Session

Chair: Pierre Tétreault

3:30 Poster Sessions

Wednesday, April 10, 2002 AM

Reference Frame
Chairs: Zuheir Altamimi and Rémi Ferland

8:30 a.m.	R. Ferland	IGS Reference Frame Coordinator Report
8:45 a.m.	S.Y. Zhu	Possible Reasons for the Scale Error in the GPS Frame
9:00 a.m.	R. Ferland	Regional Networks Densification
9:15 a.m.	H. Habrich and C. Bruyninx	EUREF Approach
9:30 a.m.	M. Craymer	NAREF Approach
9:45 a.m.	Z. Altamimi	ITRF2000 Summary and Some Regional Solutions Evaluation
10:10 a.m.		Coffee break

Receiver and Satellite Antenna Calibrations
Chairs: Gerry Mader and Markus Rothacher

10:30 a.m.	M. Rothacher and G. Mader	Satellite and Receiver Antenna Calibrations
10:45 a.m.	M. Schmitz et al.	Absolute Receiver Antenna Calibrations with a Robot
11:00 a.m.	G. Mader	Calibration of Satellite Antenna Offsets at the Ground

11:15 a.m.	R. Schmid and M. Rothacher	Estimation of Satellite Antenna Phase Center Variations
11:30 a.m.	P. Elosegui, K.-D. Park et al	Multipath Characteristics of GPS Signals as Determined from the Antenna and Multipath Calibration System: Preliminary Results
11:45 a.m.	Rothacher/Mader	Discussion

Lunch

Wednesday, April 10, 2002 PM

Ground-Based GPS Ionospheric Estimation
Chairs: Joachim Feltens and Brian Wilson

1:30 pm	J. Feltens	Ionosphere Working Group Report and Outlook
1:50 pm	S. Schaer	TEC Maps and DCBs Analyses, Comments on Combination Weights
2:00 pm	P. Héroux	NRCan Evaluation of IGS/IAAC TEC Maps
2:10 pm	B.Wilson	
2:20 pm	B. Wilson for G. Hajj	Assimilating Occultation Data into a Global Assimilative Ionosphere Model (GAIM)
2:30 pm	J. Feltens / B. Wilson	Discussion
2:50 pm	S. Schaer	Short COD Presentation
2:55 pm.	P. Héroux	Short NRCan Presentation
3:00 pm	J. Feltens	Current Status of ESOC Ionosphere Modelling and Planned Improvements)
3:05 pm.	B. Wilson	Investigation of the 1/f^3 Higher Order Ionospheric Effect and Planned Improvements
3:10 pm	J. Feltens for M. Hernandez-Pajares Et al.	UPC Ionospheric Activities: TEC Maps, Real-Time Corrections and Radio-Occultations Retrieval
3:15		Coffee break

Low Earth Orbiter
Chair: Henno Boomkamp

3:35 p.m.	H. Boomkamp	IGS LEO Pilot Project Status
3:50 pm.	S.Y. Zhu	The Usefulness of Combined GPS+LEO Processing
4:05 pm.	B. Schutz	LEO Activities at CSR
4:20	U. Hugentobler	LEO Processing Status at AIUB
4:35 pm	M. Rothacher	Comparison of Kinematic and Reduced Dynamic CHAMP Orbits Using Zero and Double Differences
4:50 pm	H. Boomkamp	LEO Processing at ESOC
5:00 pm	H. Boomkamp	Discussion

Thursday, April 11, 2002 AM

Review of IGS Products
Chairs: Jim Ray and Robert Weber

8:30 a.m.	J. Kouba	Sub-Daily EOP Effect
8:45 a.m.	J. Ray	Clock Issues, IERS Conventions
9:00 a.m.	Ken Senior	New Clock Alignment
9:20 a.m.	Robert Weber	Combination Issues, Product Latency
9:45 a.m.	Tom Yunck	Long-Term Consistency of IGS Products
10:00 a.m.	S. Hilla	SP3 Format Update
10:10 a.m.	J. Ray / R. Weber	Discussion
10:30 a.m.	Coffee	

Summary of Recommendations / Closing Discussion

Chairs: Angelyn Moore and Robert Weber

Thursday, April 11, 2002 PM

1:30 pm	Session Chairs/GB Members Wrap-Up Meeting

List of Participants

NAME	*ORGANIZATION*
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Workshop Recommendations
2002 IGS Network, Data and Analysis Center Workshop, Ottawa, Canada (April 8-11, 2002)

Compiled by A. Moore and R. Weber

Real-Time Products and Applications (J. Dow and Y. Bar-Sever)

A variety of applications including weather prediction, ionospheric weather monitoring, satellite and terrestrial navigation, earthquake and volcano monitoring, positioning of structures, surveying, timing and earth orientation would benefit from the availability of Real-Time (RT) GPS raw data products and from RT or Near Real-Time (NRT) products computed from them. In view of this trend towards real time, the relevant IGS elements should press ahead with the development of:

1. the infrastructure needed to transfer in real time raw GPS data from a sub-set of the stations of the global network to servers located at those IGS Analysis Centres interested in participating in this new activity;

2. the software needed to generate, quality check and disseminate RT and NRT orbit, clock and other products (Global Ionospheric Map (GIM), Total Zenith Delay (TZD), ...)

An appropriate project structure should be set up within the IGS to coordinate and execute this work (for example the Real-Time Working Group (RTWG)).

As an interim measure, the AC's and the AC Coordinator are encouraged to:

review the current latencies of the classical orbit and clock products (ultra-rapid, rapid, final) and assess whether it is appropriate to modify these in view of the increased availability of hourly stations and whether it is still necessary to maintain separate rapid and final products.

reduce as soon as feasible the latency of the ultra-rapid productsfrom the current 12 hours to 3 hours.

Real-Time Data/Products Exchange (M. Caissy and R. Muellerschoen)

It is recommended that the IGS community guided by the RTWG move forward on two fronts with the goal of completing phase 1 of the RTWG's charter.

1. Involve the broadest membership as possible from within the IGS community.

2. Move forward on the development of a prototype for data and product exchange incorporating the design presented in the position paper with the following additional recommendations based on discussions at the workshop:

    - It is recommended that the RTWG investigate the impact of using Transmission Control Protocol (TCP) in place of User Datagram Protocol (UDP) in order to assess the value of using TCP in the post-prototype phase of IGS real-time processes.

    - It is recommended that the RTWG investigate the impact that the choice of UDP may have on our ability to traverse firewall implementations at institutes where the use of UDP is discouraged or denied.

    - It is recommended that due to the demonstrated interest from global data centres, they be involved on a voluntary basis, at the prototype stage, in a demonstration of the concept of distributed data centres.

Data Center Issues (C. Noll and L. Daniel)

DAT1: A Subset of Data Centres (DC)s should participate in RTWG's prototype efforts

DAT 2: Establish a DC Working Group

- to evaluate metadata storage and exchange as well as monitoring and bug tracking
- to create and maintain the
    a) topology of data flow up to Global Data Centres (GDC)
    b) DC requirements and guidelines

DAT 3: GDCs and Regional Data Centres (RDC)s should participate in GPS Seamless Archive Centre (GSAC) effort

DAT 4: Integrate GPS/Glonass data flow into IGS paths

Network Issues (A. Moore and M. Schmidt)

NET 1: Form an IGS industry panel with representation from manufacturers of equipment used in IGS

NET2: Implement associate regional networks and associate applications networkers

NET3: ACs and Pilot Project (PP) / Working Groups (WG)s should communicate to the Network Coordinator (NC) recommended equipment guidelines (e.g. radome types, non DM antennas,...) and recommended degree of enforcement

NET 4: Reference Frame Working Group (RFWG) should recommend conventions for reporting time series discontinuities

NET5: IGS should keep abreast of and prepare for GPS modernization; When equipment and signal availability schedule is clear, a phased adoption at IGS sites should be coordinated

NET6: Form a RINEX task force

Reference Frame (R. Ferland and Z. Altamimi)

REF FR 1
Test in detail the various proposed combination/constraining approaches (fixing-minimum constraints-combined) to align regional solutions to the ITRF. Use various regions and time spans. Agree on one proposition to be recommended for all regions.

Antenna Calibration: (M. Rothacher and G. Mader)

CALIB 1
Review and adopt the new IGS Phase Centre Variation (PCV)-format for receiver and satellite antenna phase centre corrections. (envisaged date for adoption Jan, 1st, 2003).

CALIB 2
Adopt absolute antenna PCV for receiver antennas and new satellite antenna offsets and patterns after conducting a thorough test campaign (envisaged date for adoption Jan, 1st, 2003).

CALIB 3
Set up a so-called 'Antenna WG' to keep track of antenna issues in general and to organise the transition to absolute phase center variations in particular.

CALIB 4
Avoid to the extent possible any change in the antenna setup at IGS permanent sites. Whenever possible the same antenna type should be installed in case of replacement due to malfunctioning of older hardware.

Ground-Based Ionospheric Estimation (J. Feltens and B. Wilson)

ION 1:
Start with the delivery of a combined IGS Ionosphere Product (asap / when?)

ION 2:
Combined IGS Total Electron Content (TEC) maps should be produced with an overlap of one day to decrease jumps at the day boundaries.

ION 3:
Global Ionospheric Associate Analysis Centres (IAAC)s TEC maps should cover all parts of the world.

ION 4:
Explore the use of ENVISAT and JASON satellites for validation of IGS Ionosphere Products.

ION 5:
In view of NRT Monitoring of the Ionosphere the distribution of ground stations as well as the data flow (latency) has to be improved.

IGS-LEO (H. Boomkamp)

IGS-LEO 1:
Explore in detail the impact of GPS-LEO data on the classical IGS products in combination solutions.

IGS-LEO 2:
Explore the latency requirements for tracking data availability as well as delivery of current IGS products to support LEO data processing (e.g. for atmosphere sounding).

IGS-Products (J. Ray and R. Weber)

PROD 1 (Time Scale)
Adopt a new time scale for IGS Final and Rapid Products to achieve continuity at day boundaries and allow for a direct link to UTC. (envisaged date of adoption: July 1,2002)

PROD 2 (New SP3 format)
Review and adopt a new version of the SP3 format. To serve the user community keep both the old and the new format in parallel for a period of at least 1 year. (envisaged date of adoption: July 1,2002)

PROD 3: (GLONASS data processing)
Intensify the ability to process data from combined GPS/GLONASS tracking sites. ACs and AACs are encouraged to provide orbit and clock submissions in order to ensure a reliable combined IGS GLONASS orbit and clock product.

PROD 4: (IGU products)
In view of upcoming NRT- needs explore and implement a more frequent update of the IGU -Ultra Rapid Products. An update cycle of 3 hours (currently 12 hours) for IGU products is envisaged. Investigate the option of different update cycles for orbits (6 hours) and clocks (3 hours). In addition explore the possibility of decreasing the latency of IGU products from currently 3 hours to 2.5 hours as well as the submission of 5-minutes rinex-clock files.

Executive Summary
2002 IGS Network, Data and Analysis Center Workshop, Ottawa, April 8-11, 2002.

P. Tétreault, P. Héroux and J. Kouba

The workshop, re-scheduled from October 2001, was held at the Courtyard Marriott hotel in the heart of Ottawa's popular Byward market area. The 3.5 day workshop regrouped more than 100 participants and was organized around the central theme "Towards Real Time". The technical program included the following eleven sessions:

1. Opening
2. Real-time applications and products
3. Real-time data/products exchange
4. Data center issues
5. Network issues
6. Poster session
7. Reference frame
8. Receiver and satellite antenna calibrations
9. Ground based GPS ionospheric estimation
10. Low Earth Orbiters (LEO)
11. Review of IGS Products

Altogether nine position papers corresponding to the above sessions were presented and all but one were available at the workshop www site (http://www2.geod.nrcan.gc.ca/~pierre/igs_workshop.html) prior to the start of the workshop. The following contains brief summaries of each session, followed by a draft of workshop recommendations, which were compiled at the end of the workshop by the Network and Analysis Center Coordinators, A. Moore and R. Weber, along with the session chairs.

Opening Session

The workshop participants were welcomed by the Assistant Deputy Minister (ADM), Dr. Irwin Itzkovitch, of the Department of Natural Resources Canada (NRCan) who outlined Canada's approach to the national reference frame delivery and maintenance, which are inherently based on NRCan's Geodetic Survey Division (GSD) GPS and VLBI programs. NRCan's participation to IGS is viewed as crucial and mutually beneficial to both parties. After the ADM's introduction, there was a short welcoming address by Norman Beck, Chief of the Active Control Section. Professor Gerhard Beutler, the first chair of the IGS Governing Board (GB) and currently the first vice president of IAG, followed with a brief presentation reminding the workshop participants that it was in Ottawa, almost nine years ago, that many IGS initiatives and products were initiated. However, his main message was about the role the IGS and other IAG services will play within a new, reorganized, and increasingly multidisciplinary IAG and its IGGOS Pilot Project. He reminded us, in his usual witty way, that the workshop theme "Towards Real-Time"

implied that there must also be some unreal-times. Professor Christoph Reigber, the current chair of the IGS GB, addressed the workshop on behalf of the board and summarized the recent strategic planning (SP) exercise. He confirmed that real time IGS data and products were likely to play an increasingly stronger role to satisfy various and important projects, like LEO missions, atmospheric monitoring, etc. The enhanced role of IGS Central Bureau (CB) was also envisioned in the IGS SP, which is currently available from IGS CB. The SP report was, for the first time, distributed during the workshop.

Following the opening remarks, three working group (WG) and pilot project (PP) status reports were presented since they were not assigned individual sessions during the workshop; namely the Tropospheric WG, Precise Time Transfer PP and the International GLONASS (IGLOS) PP. The Tropospheric WG, chaired by G. Gendt of GeoForschungsZentrum (GFZ), has been producing official IGS products of combined tropospheric zenith path delays for several years, but is now concentrating on near real-time (NRT) tropospheric products in conjunction with accelerated IGU orbit production and delivery. J. Ray of the United States Naval Observatory (USNO) who co-chairs the Precise Time Transfer PP, presented a status report (posted on the workshop www site). The objective of realizing an IGS time scale and aligning the IGS clock products to UTC has been reached and other goals such as timing receiver calibration and increased participation of timing labs in PP are progressing well. The plan calls for formal adoption of the IGS time scale and the correspondingly aligned IGS combined clock products by the end of 2002. The new improved alignment has helped to identify daily clock discontinuities at some stations, which represents a valuable and efficient quality check and provides an impetus for further investigation of some station installations. Finally, J. Slater of NIMA gave the status of the IGLOS PP. Currently, there are only 6-7 operational GLONASS satellites, and only 3 Analysis Centres (AC), are routinely computing the satellite orbits, which are combined by the AC Coordinator (Robert Weber) with a delay of one or two months. This is hardly acceptable, more GLONASS satellites, ACs and faster GLONASS combinations are needed. Ultimately, IGLOS should be integrated into the routine IGS operation and products.

Real-Time Applications and Products

Tropospheric and LEO applications have the most demanding requirements for IGS data and products within 1 to 3 hours. Initially, the session position paper called for IGS Ultra rapid orbit solutions with delays of no more then 1 hour. However, from the discussions following the position paper, it became clear that the proposed 1 hour delay was unrealistic, given the status of the current data delivery schedule as well as AC workload. ACs quickly compromised on a 3 hour-delay. A presentation on Ultra rapid processing given by N. Romero of ESA initiated discussion on the omission, by most ACs, of a relatively high number of satellites from the ultra rapid solution. This goes directly against the standing IGS policy adopted in 1998 specifying that the IGS orbit products should be as complete as possible and include even marginal satellites with appropriate accuracy codes. R. Muellerschoen of JPL gave an impressive presentation on the JPL real time orbit/clock solutions supporting NASA's wide area (worldwide) DGPS. The JPL/NASA system is designed to support all NASA navigation needs at or below 10 cm.

The NASA system can also be utilized for sub ns time transfers, provided that calibrated receivers are utilized as outlined in a presentation by E. Powers of USNO. Two European presentations on NRT tropospheric solutions, relying on IGU products, within the scope of the
COST716 project (http://www.knmi.nl/onderzk/index.html), were given by R. Pacione and H. van der Marel. The real time needs for ionospheric TEC information were described by B. Wilson of JPL. P. Heroux of GSD outlined the Canadian approach to national reference system delivery/maintenance, which is also moving towards real time and relies on IGS and VLBI. Real time and near real time requirements for natural hazard monitoring were presented by Y. Bar-Sever of JPL. His presentation clearly showed the complementarily nature of seismic monitoring and continuous GPS precise positioning. Namely, GPS provides monitoring at low frequencies with periods of hours to days where seismology becomes biased or completely fails.

Real-Time Data/Products Exchange

This was the first opportunity for the newly created IGS Real-Time Working Group (RTWG) to share its initial findings and formulate future plans. The results of an initial investigation, which are summarized in the position paper, were presented by M. Caissy on behalf of RTWG. They suggested that IGS adopt UDP (User Datagram Protocol) for Internet real time GPS data streaming since it has been tested and successfully used by both JPL and NRCan. The UDP (unicast or multicast) protocols, unlike the more standard TCP/IP, do not require point to point connections, and consequently are more efficient than TCP/IP (no opening/closing connections, smaller packet size overhead etc.). This is true, in particular, for smaller intermittent packets typically seen in GPS real time data stream. On the downside UDP, unlike TCP/IP, does not include receipt acknowledgements and/or retransmission, which may be needed for product delivery. G. Weber of BKG and G. Hedling of Lantmateriverket demonstrated the use of TCP/IP in their presentation of an operational RT DGPS system in Europe. K. MacLeod of GSD described UDP operational tests at NRCan. Following these presentations, security issues and firewall problems were discussed quite extensively in this and the following DC session. In the end, there seemed to be general agreement that both the UDP and TCP/IP protocols for RT data exchange should be researched and prototypes developed by RTWG for IGS. A solid interest was shown by both IGS DCs and ACs since this development could lead to timely, robust and redundant near RT or RT data streaming directly to the interested DCs and ACs.

Data Center Issues (DC)

Overall DC statistics, performance and current issues, and the GSFC DC in particular, were summarized by C. Noll of GSFC. For example, most of the recent LEO (GPS) data are now available at the GSFC DC. The need for the establishment of a DC WG was also raised. (It was subsequently formalized by the IGS GB at its April 11 meeting, and will be chaired by C. Noll). Firewalls and security issues were discussed extensively as well as the somewhat confusing data management at DC (found to be inadequate in particular for new, uninitiated users). This was shown in a presentation by E. Gaulue of IGN. H.

Habrich and M. Scharber summarized status and new developments at the BKG and SIO DCs, respectively. The GPS Seamless Archive Center (GSAC) developments at SIO are maturing and look promising. It was also pointed out that the GLONASS/GPS data streams will soon be integrated at the RINEX level as previously planned and announced.

Network Issues

Following the DC session, the invited vendors, who also sponsored Monday night's ice-breaker reception, made short presentations on their latest GPS receiver and related hardware developments. Some of the current or new receivers are, or will be capable of stand-alone station monitoring and include internet (IP) communication software. Also discussed was the current IGS standard P1/P2 pseudorange pair, which poses some additional complications for some receivers, which observe C1 rather than P1 pseudoranges. As pointed out by some vendors, P1 observable would make their receiver more expensive. Perhaps, in the future, IGS should cooperate more closely with manufacturers when adopting standards such as the P1/ P2 pseudoranges. The P1-C1 differences, when used inconsistently with the fixed IGS orbit/clock product in undifferenced processing, will result in significant position and receiver clock errors.

The network issues session was introduced by the IGS CB Network Coordinator, A. Moore. Solid progress has been made on data availability, timeliness and integrity, though some improvements are still possible. With the continuous addition of tracking stations in dense regional networks, the concept of associated IGS network was put forward. This proposition, paralleling AACs, would allow inclusion of new stations in regions already saturated with IGS stations. It would ensure that IGS becomes open to new participation and provide a model for manageable growth of IGS networks. L. Combrinck gave an update on the situation in Africa. He reminded participants that, with the exception of very few nations (like South Africa), the African situation, particularly the communication/internet infrastructure, is very fragile and not likely to improve in the near future. P. Fang of SIO, on behalf of Chinese colleagues, gave an update on the situation in China. While there are many suitable stations and considerable interest in China, reflecting on all IGS components, the situation remains difficult, primarily stemming from political decisions/willingness to release/exchange appropriate data and information to IGS. R. Neilan, Director of IGS CB, summarized the status of the GPS modernization, including the new L2CS and L5 frequencies, which could potentially revolutionize GPS. Currently, there are 12 Block IIR with L2CS and 6 Block IIF satellites (with the additional L5 frequency) planned to be launched. The GPS modernization and the new GPS III benefit from healthy competition by GALILEO. J. Dow of ESA presented a status on GALILEO. Phase I, covering all system development and initial tests has been approved by EC. The system is quite complementary and designed to be interoperable with GPS as far as the broadcast frequencies are concerned, yet offers a satellite constellation different from GPS (e.g. 27+3 satellites with 14h22m orbits). The full operation is envisaged for 2008. IGS input into GALILEO design is ensured and considered important. L. Estey of UNAVCO, indicated in his presentation that RINEX is ready and flexible enough (thanks to the recent revisions), to

accommodate the GPS modernization and its new frequencies. At the end of this session, participants were once again reminded that the promised integration of GPS/GLONASS observations for GPS/GLONASS stations would take effect shortly at all DCs. No integration of GPS/GLONASS orbits into a single sp3 file is being considered at this time, according to R. Weber, the current AC Coordinator.

Poster Session

The poster session was intended for ACs to exchange their recent experience and compare their approaches. Most ACs presented at least one poster, usually highlighting significant changes implemented since the last AC workshop, held in September, 2000 in Washington DC. In addition to the AC posters, there were also poster presentations on regional and global station solutions, near real time orbit and tropospheric processing, LEO (CHAMP) orbit comparisons as well as the latest information on the recently launched GRACE mission. During the poster presentation, which was held in the AGU poster tradition, i.e. with cold (Canadian) beer, there was also a demonstration of GPS.C - the Canadian RT DGPS system.

Reference Frame (RF)

The current IGS RF Coordinator, R. Ferland of GSD, gave a progress report on Reference Frame (RF) WG activity. The production of the IGS station combined products (both weekly and cumulative) is proceeding smoothly, though some AC solutions had to be excluded from geocenter monitoring due to problems with the removal of constraints from their SINEX submissions. This identified problem should be corrected as soon as possible. Nevertheless, the IGS geocenter solutions agree quite well with the independent SLR solutions. The recent switch (on December 02, 2001) to ITRF2000 and its IGS00 realization has been quite smooth. Currently, the IGS combination already includes about 200 stations and satisfies the target IGS Station Polyhedron of about 200-250 stations. The size of this globally distributed polyhedron network was derived independently and allows for precise relative determinations over baselines of about 2000 km. For these reasons, additional back substitutions to derive polyhedron stations, as originally envisaged, is no longer necessary. This goal, in fact, is already being met in a single combination step. The RFWG, on behalf of IGS, also took part in the IERS PP aimed at testing of EOP/ITRF alignment. Since the IGS orbit, clock, station and ERP combinations were designed to be consistent with the ERP/ITRF, it was not surprising to see a high degree of agreement in submitted solutions, with the IGS adopted minimum constrain approach showing one of the best consistency/results. S. Y. Zhu of GFZ looked into the apparent difference of a few ppb between GPS and ITRF scales. He concluded that it cannot be due to GM or a common satellite antenna offset, as in both cases the resulting scale effect is negligible in GPS global analyses. This has confirmed earlier tests done by various ACs. In terms of regional station integration, an unresolved and open question remains "what should be the recommended approach for continental AAC to integrate RNAAC solutions into the IGS realization of ITRF (i.e. the IGS station polyhedron)? R. Ferland addressed this problem in his scond presentation. The two main options considered ere: constraining (consistently with the IGS variance-

covariance matrix r even much higher constraints) and minimum constraints suitable for non-global networks, e.g. Blaha's inner constraining type (presented here by Z. Altamimi of IGN). The RFWG will need to perform some additional testing before consensus is reached and a specific method is recommended for integration of regional solutions into the IGS polyhedron. In many respects, EUREF's approach presented by its Director, C. Bruyninx of ROB, should serve as a model for such IGS/ITRF densification. The outline of the newly emerging NAREF initiative, given by M. Craymer of GSD was encouraging, in particular the clear commitment to commence regular submissions to IGS. Finally, M. Rothacher of TUM, the current IERS Analysis Center Coordinator, highlighted the result of the discussions related to the new SINEX
version of 2.0.

Receiver and Satellite Antenna Calibrations

M. Rothacher introduced the session with the position paper presentation. Very significant progress has been made since the 1999 and 2000 AC workshops. Namely, at the 1999 AC workshop, satellite antenna patterns were first identified as a potential cause for the mysterious and unexplained scale bias of about 15 ppb introduced when precise absolute calibrations of receiver antennas were included into global GPS solutions. The absolute (anechoic chamber) and relative antenna calibrations have been recently confirmed by independent, ingenious, and very precise absolute calibrations methods. One of these methods was developed by the Hannover group and uses a robot rotating and tilting a GPS antenna while observing real GPS signal. This method was well described in a presentation by M. Schmitz of Geo++. Calibrating satellite antennas on the ground, due to their size and electronic complexity/adjustment proved to be quite a challenge as seen from the presentation by G. Mader of NGS. However, solving for antenna phase pattern with respect to absolutely calibrated receiver antenna phase center variations (PCV), gave quite precise and repeatable results. Two distinct satellite antenna PCV's, namely for the Block II/IIA and Block IIR satellite types were obtained in that fashion. A separate presentation by R. Schmid of TUM showed that introducing the satellite and receiver antenna PCV's greatly diminishes the 15 ppb scale error. It is important to realize that both receiver and satellite PCV's are subject to an initial (and somewhat arbitrary) datum height (scale) offset, which is commensurate with a common antenna offset, or the scale of GPS. Consequently, the ITRF/VLBI scale can be used to solve/fix this antenna offset convention/datum problem, i.e. consistently with ITRF scale. Another approach to this antenna-offset/datum problem can be imposing the condition that a (weighted) sum of PCV variations, over a certain range of azimuths and elevation angles, be equal to zero. (NOTE: This is in fact how the current (DM) antenna offsets, used as a convention by IGS, have been derived, i.e. it is based on an early antenna chamber calibration, which assumed no elevation and azimuth variations and which gave the current conventional height L1/L2 offsets. It is quite remarkable that this old and crude antenna measurement, in fact, implies a scale that is correct within only 2-3 ppb of the ITRF scale convention.) Another, quite independent approach to antenna PCV calibration, presented by P. Elosegui of Harvard-Smithsonian/Center for Astrophysics, is based on comparing the precise phase observations obtained by the multi-directional GPS antenna under calibration with respect to a directional parabolic one. Since the reference

parabolic antenna is virtually immune (once properly calibrated) to PCV and multipath, while common effects are canceled out through procedure (e.g. the short baseline, delays), the remaining difference is due to multipath as well as to antenna PCV (note any satellite antenna PCV is also eliminated here). The advantage of this method is that it is station specific, unlike the previous approaches, and thus also includes multipath. Potentially, it can also be used for mobile calibrations of IGS sites w/o any interruption or changes to the IGS operations (subject only to the requirement of an antenna splitter at each station).

As a first step towards a significant improvement over the current convention (which uses PCV relative to the DM antenna type), it was proposed that IGS adopt, by January 2003, a new IGS antenna convention (receiver, satellite antenna PCV's and the corresponding height offsets), subject to prior evaluation and testing by ACs. Also discussed during this as well as the Network session was an urgent need to develop clear IGS guidelines on equipment and antenna changes in particular, which should provide sufficient overlaps to ensure a long term continuities of the IGS times series. This is also imperative in view of equipment improvements and the future GPS modernization upgrades.

Ground Based GPS Ionospheric Estimation

The ionospheric group, headed by J. Feltens of ESA is a very active group that had already met earlier this year in Darmstadt, Germany. Consequently the agenda and recommendations were well focused. The most important goal, as outlined in the position paper, is an official production of ionospheric combined product, which has been long in preparation, and which has been maturing quickly as indicated by evaluations utilizing TOPEX TEC data. Currently, the yet unofficial IGS ionospheric combinations are as precise, reliable and complete as the best AAC contributions. There is a clear commitment, after some fine-tuning (e.g. global weighting) to launch this official IGS ionospheric combined product. S. Schaer of CODE AC presented an impressive (and real) ionospheric video. He has also compared station DCB's, furthermore he is also responsible for the official IGS P1-C1 bias estimations. He has also stressed the importance of minimizing discontinuities between daily ionospheric grid maps. An interesting presentation on validation using TOPEX TEC data as well as the assimilation of TOPEX ionospheric profiles into numerical ionospheric models was given by B. Wilson of JPL. He also reviewed past (and published) research on the significance of the neglected (3rd and higher) ionospheric and magnetic terms in two frequency GPS positioning. The effect, under extreme ionospheric conditions, could reach up to 2-cm phase range errors in precise GPS positioning. P. Heroux of GSD also presented a simple but effective approach for ionospheric map quality evaluation utilizing observed and computed P1-P2 delays at a selected set of IGS stations, preferably not included at the ionospheric grid map generation. During subsequent discussions and with regards to daily discontinuities, it was pointed out that it would also be equally beneficial to include the last epoch of each day (24:00) in all IGS daily orbit/clock files as well. This would also enable the detection/mitigation of any orbit/clock daily discontinuities.

Low Earth Orbiters (LEO)

Recently, the LEO WG has become very active with the availability of data from several LEO's already in orbit. Steady progress has been realized in CHAMP precise orbit determination (POD) such that the best CHAMP POD test results, based on reduced dynamic methods, are well below the 10 cm precision level. The best kinematic POD (independently determined epoch positions) is approaching the 10 cm precision level. This was shown in the LEO position paper presentation made by H. Boomkamp of ESA and in separate presentations on different LEO POD approaches by B. Schutz of CSR, M. Rothacher of TUM and U. Hugentobler of CODE. This is the first and necessary step of LEO WG. The subsequent goal/aim (as specified in its charter) is the investigation of possible improvements to the IGS core products (orbits/clocks) through simultaneous LEO and IGS data processing. An initial attempt to answer this difficult question was already presented by S. Y. Zhu of GFZ. Clearly, the LEO POD must have the highest possible precision before any meaningful contribution to the current IGS orbit/clock products is made. This is why it was suggested that the WG should concentrate, for the time being, only on one specific LEO satellite. Also benefit/effects and timeliness of the IGS Rapid versus IGS Final orbit/clock combination products were discussed. The question was also raised if IGS Final orbit/clock combination delays should be reduced from the current 2 weeks down to perhaps one week.

Review of IGS Products

Previous sessions and this session's position paper reviewed the IGS products in view of increasing demands on timeliness to satisfy the requirements of near RT applications for LEO POD, troposphere and precise positioning. The IGS core products of combined orbits/clocks and station coordinates aspire to be consistent and conform to current IERS standards. That is the reason for the adoption of the new ITRF2000 and that the official IGS ERP accumulated series (igs00p02.erp), which spans the ITRF94, ITRF96, ITRF97 and ITRF2000, has been transformed into the ITRF2000 realizations. Thanks to the minimum constraint approach adopted for IGS products since 1998, the ITRF96/97 and ITRF97/2000 transformations are nearly exact. A similar transformation of the IGS combined orbit products into the current ITRF realization was also proposed in this session's position paper. Apart from the already proposed 3-hour production cycle for IGU and tropospheric solutions, the main question that remains is the effect of the proposed IERS2000 Conventions on IGS products. J. Kouba of GSD, in his presentation, tested the new subdaily ERP model, which is already available from the IERS2000 Conventions www site, by using independent pole rate solutions. He concluded that the IERS 2000 subdaily ERP model could be adopted since it fits the IGS data as well, or perhaps slightly better, than the IERS96 subdaily ERP model. A detailed report on this testing is available from the workshop website. J. Ray of USNO reviewed the proposal for the new celestial pole (CP) definition which will be included in the new IERS 2000 Conventions. Since there still are some clarifications needed, and since IGS analyses are relatively insensitive to CP, as long as consistent transformations are used going to and from CP, he recommended a "wait and see" approach. There was also a question raised about the need for IGS satellite clock products at a time interval shorter than the current 5-min sampling. Linear interpolation of 5-min satellite clocks is precise at the 0.1 ns rms level, allowing precise kinematic positioning (at any interval) with about 5-10 cm (rms)

precision. This represents only a slight precision decrease from the positioning obtained with the original, not interpolated, satellite clocks. Some participants felt that for the most precise LEO applications, this 5-10 cm precision level may not be acceptable. However, the significant effort and additional computational burden involved with clock determinations at higher rates need to be considered. The IGS time scale and the newly aligned IGS clock (including the sp3) products have reached a mature stage and are ready for adoption by IGS, as clearly and convincingly demonstrated by K. Senior of USNO, the developer of the IGS time scale. R. Weber of TU Vienna /AIUB, the current AC Coordinator summarized all three IGS orbit/clock combinations and also stressed the importance for ACs to include ALL satellites, including the marginal ones, but with proper accuracy codes. This is in particularly important for the IGU combined product, where a number of satellites are routinely excluded by ACs due to a lower accuracy. These missing satellites are badly needed by RT and near RT applications as it was indicated in several presentations during this workshop. T. Yunck of JPL gave an entertaining, but somewhat controversial presentation on the GPS scale and consistency. Finally, S. Hilla of NGS, who took on the challenge to update the SP3 orbit/clock format, presented his SP3 format update proposals. The latest variant, which allows accuracy codes for both orbits and clock at each epoch and is largely backward compatible, seemed to have received the widest acceptance. Though concerns were expressed that the proposed accuracy code exponential base of 1.25 is not compatible with the base of 2 used for the header accuracy codes, and that it did not allow for any x, y, z orbit correlations.