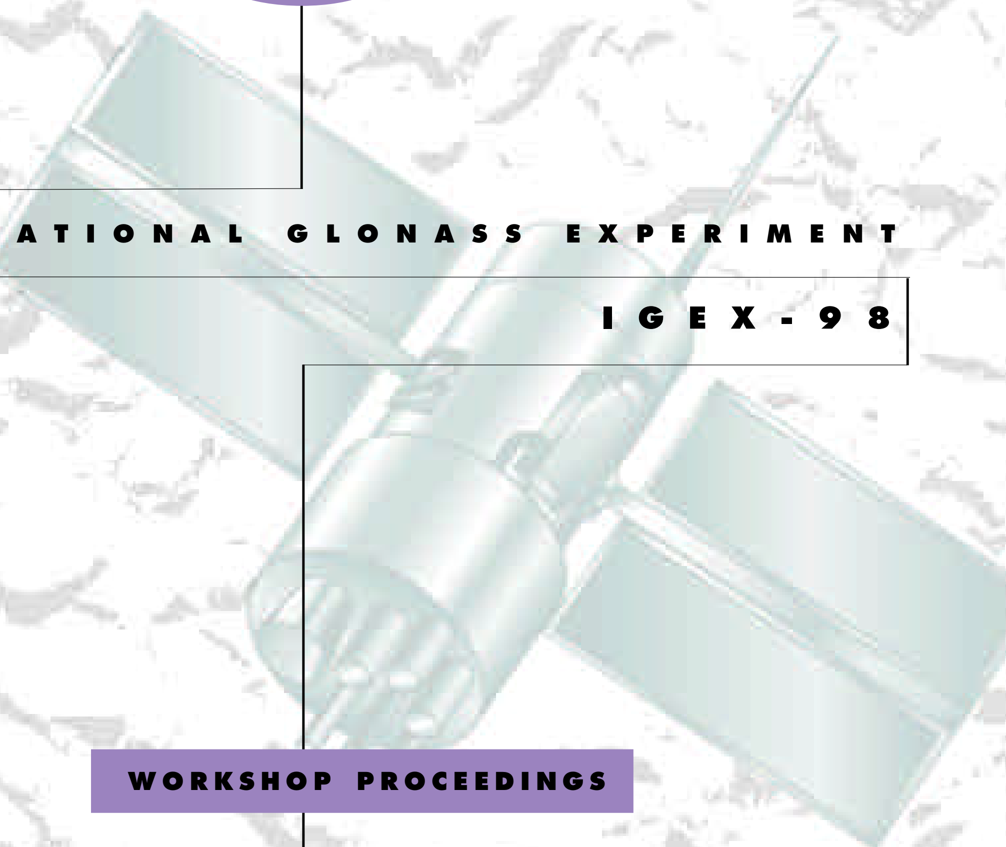
IGS

INTERNATIONAL GLONASS EXPERIMENT

IGEX-98



WORKSHOP PROCEEDINGS

SEPTEMBER 13-14, 1999

NASHVILLE, TENNESSEE, U.S.A.

IGS Central Bureau

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

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Acknowledgement

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Abstract

The first coordinated international campaign to collect and analyze GLONASS satellite data was held from October 19, 1998 through April 19, 1999. This International GLONASS Experiment (IGEX-98) was jointly sponsored by the International Association of Geodesy's (IAG) Commission VIII for the International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG), the Institute of Navigation's (ION) GLONASS-GPS Interoperability Working Group, the International GPS Service (IGS), and the International Earth Rotation Service (IERS). The IGEX-98 Steering Committee, the ION and the IGS organized a joint workshop on September 13-14, 1999 to discuss the results of IGEX-98 and possible plans for the future. This workshop was held in conjunction with the ION Satellite Division's 12th International Technical Meeting GPS-99 in Nashville, Tennessee (U.S.).

Workshop topics included receiver technology, tracking network operations, time and time transfer, precise orbit determination, reference frame comparisons, and plans for future exploitation of GLONASS.

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Session 7: Future Plans

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Acronyms and Abbreviations

Preface

Although the first GLONASS satellite was launched in October 1982 and the constellation had 24 healthy satellites for a brief period in early 1996, as of 1997 there had been no coordinated international effort to track GLONASS satellites and thoroughly explore their potential uses. Certainly by the late 1980s efforts were underway in numerous organizations to evaluate time transfer capabilities, develop combined GLONASS/GPS receivers, and investigate methods for combining GPS and GLONASS data. GLONASS had the potential to provide redundancy and integrity, in conjunction with GPS, for civil aviation applications. It could improve efficiency and accuracy in surveying applications. In addition, one of the major advantages of GLONASS compared to GPS for the civil user community is the fact that the GLONASS signals are not degraded. However, even in 1997, there was still a scarcity of portable commercial receivers, incomplete information about the timing and positioning reference systems used in GLONASS, no precise ephemerides, and no software readily available to process GLONASS data. The interoperability of GLONASS and GPS remained a significant issue.

The Institute of Navigation (ION) tried to address some of these problems by creating the GLONASS-GPS Interoperability Working Group, which held its first meeting in September 1996. Over 100 people attended that meeting including representatives of receiver manufacturers, universities, research institutions and government agencies. In September 1997, at the International Association of Geodesy (IAG) Scientific Assembly in Rio de Janeiro, the International GPS Service (IGS) and the International Association of Geodesy's Committee for Coordination of Space Techniques in Geodesy (CSTG) formed a steering committee to plan an international GLONASS experiment (IGEX-98). The Steering Committee was chaired by Pascal Willis of the Institut Géographique National in France. ION and the International Earth Rotation Service joined IGS and IAG in sponsoring this experiment. The major objectives were to collect GLONASS data for several months from a worldwide network of tracking stations, compute precise orbits, evaluate receivers, resolve geodetic reference frame and time system issues, and apply the data to other areas of interest. A Call for Participation was issued in January 1998, and after a slight delay to allow time for installation of some of the receivers, the campaign began in October 1998 and continued for six months until April 1999. Participants represented 25 countries and approximately 80 organizations.

Plans for IGEX-98 included a workshop to be held after the experiment ended, to bring participants together to discuss their experiences and present the results of their work. A Workshop Organizing Committee was formed to develop a program and organize the meeting. Its members included Werner Gurtner (University of Berne), Wlodzimierz Lewandowski (BIPM), Pratap Misra (M.I.T. Lincoln Laboratory), Ruth Neilan (JPL), Carey Noll (NASA GSFC), James Slater (NIMA), Robert Weber (University of Technology, Vienna), and Pascal Willis (IGN). The workshop took place on September 13-14, 1999 in Nashville, Tennessee (U.S.A.) in conjunction with the ION GPS-99 meeting there. IGS, ION and NASA co-sponsored the workshop, which was attended by over 80 people. The presentations were divided into seven sessions: GLONASS Status and Operations, Receiver Technology, Network Operations, Time and Time Transfer, Orbit Determination, Applications, and Future Plans. A number of poster papers were also contributed.

At the end of the workshop, several resolutions were presented by Gerhard Beutler (University of Berne), on behalf of the IGEX Steering Committee, in order to obtain a consensus on possible future GLONASS activities. The participants were overwhelmingly in favor of continuing to maintain a tracking network and production of precise orbits as a pilot service under the auspices of the IGS. It was also clear from the paper submitted by the Russian Ministry of Defense that Russia would like to maintain some constellation of GLONASS satellites, but economic constraints are having a severe impact on its ability to do this. For now, the international community will continue to try to exploit the benefits of the GLONASS satellites as long as they remain viable.

On behalf of the IGEX-98 Workshop Organizing Committee, we would like to thank all the participants in IGEX-98, whose diligent efforts and enthusiastic support made the experiment such a success. We hope that we can continue to learn from and build on the work accomplished during this very fruitful experiment.

James Slater and Carey Noll
Co-Chairs, IGEX-98 Workshop
Organizing Committee

Executive Summary

The International GLONASS Experiment (IGEX-98) was conducted from October 19, 1998 to April 19, 1999. This was the first coordinated international campaign to track GLONASS satellites and to produce precise orbits for them. A workshop was held on September 13-14, 1999 in Nashville, Tennessee (U.S.A.) for participants to discuss their experiences and present the results of their work.

Two key factors that allowed this experiment to go forward at this time were the availability of new portable, geodetic-quality, dual-frequency GLONASS receivers and software to process GLONASS data. A third critical element was the existing infrastructure of the International GPS Service (IGS), which provided the operational framework and knowledge base for this experiment. The major accomplishments of IGEX-98 were as follows:

a. A global tracking network was established for the first time. Over 60 GLONASS tracking stations and 30 Satellite Laser Ranging (SLR) observatories in 25 countries participated in the campaign.

b. Six months of continuous data were collected by these stations and archived at NASA's Goddard Space Flight Center (GSFC) in the U.S. and the Institut Géographique National (IGN) in France, and are available for use by anyone.

c. Precise orbits were computed by 11 Analysis Centers using both the SLR and GLONASS receiver data, with resulting accuracies of 20-50 cm. A combined orbit was computed at the University of Technology, Vienna from the individual solutions provided on a regular basis by a subset of the Analysis Centers. The precise orbits from all the Analysis Centers are archived at NASA GSFC and IGN.

d. Three commercial manufacturers and one university produced dual-frequency GLONASS receivers, which were operated and given their most thorough testing and evaluation as a result of IGEX.

e. A number of different software packages (e.g., BAHN, Bernese, GIPSY) that were designed for GPS observations can now process GLONASS data and compute GLONASS orbits routinely.

f. The RINEX and SP3 data exchange formats have been expanded to include GLONASS data.

g. Datum transformations relating PZ-90 to WGS 84 and ITRF reference frames were derived by several groups using a global distribution of data for the first time.

Motivation and Objectives

Both the navigation and scientific communities have an interest in exploiting GLONASS, primarily as an augmentation to GPS. Thus, four organizations jointly sponsored IGEX-98 – the IGS, the Institute of Navigation (ION) through its GLONASS-GPS Interoperability Working Group, the International Association of Geodesy's Commission VIII (International Coordination of Space Techniques for Geodesy and Geodynamics), and the International Earth Rotation Service. The objectives of the experiment were:

- Collection of a globally-distributed GLONASS data set over a long time period, primarily using dual-frequency GLONASS receivers collocated with GPS stations
- Precise orbit determination at the meter level or better
- Receiver evaluation
- Software development
- Reference frame comparisons between the GLONASS PZ-90 system, the GPS WGS 84 system, and the International Terrestrial Reference Frame (ITRF)
- Time and time transfer applications
- Stimulus for other scientific applications.

The uncertain future of GLONASS and the advanced age of many of the operational satellites in the constellation provided part of the motivation for organizing this experiment at this time, rather than at a later date. In September 1998, just prior to the start of the experiment, there were 14 healthy GLONASS satellites. Despite the successful launch of three new satellites in December 1998, at the time of the IGEX-98 Workshop in September 1999, there were only 11 healthy satellites available. However, combining the GPS and GLONASS constellations meant that 35-40 satellites were accessible to users. In this way, IGEX-98 provided a real test case for combining two similar yet distinct satellite constellations into a Global Navigation Satellite System.

Campaign Organization and Operations

Lessons learned from similar GPS campaigns in the past and the operational infrastructure of the IGS were invaluable in the planning and execution of IGEX-98. An IGEX Steering Committee, chaired by Pascal Willis of IGN, took advantage of this collective knowledge and the operational procedures that had been worked out over the years for GPS to carry out this project. Guidelines were issued for receiver installation, data communications and data formats. Well-defined ITRF coordinates were required for each site. A data flow scheme was designed so that tracking data would be forwarded to local, regional and global data centers. An observation sampling rate of 30 seconds was selected and RINEX was designated as the standard data format. This required some small modifications to the RINEX standard. The manufacturers provided software to convert the GLONASS receiver internal formats to RINEX. A few of the problems encountered during the experiment were related to RINEX conversion. The tracking protocol called for continuous (24 hours/day, 7 days/week) tracking, and data transmission once per day from each station. Conventions were also established for station, receiver and antenna identification, and station documentation.

Using the successful model of the IGS, an organizational structure was put in place that included data centers to store and distribute data and products, and analysis centers to compute precise satellite orbits and other products. A Data Center Coordinator (C. Noll, NASA), Analysis Center Coordinator (R. Weber, University of Technology, Vienna) and Network Coordinator (W. Gurtner, University of Berne) oversaw the operation.

An e-mail reflector (IGEXMail) set up at IGN in France was the primary means of communication among the participants. Tracking station status, progress reports, instructions, requests for assistance and all other public information about the experiment were transmitted via this e-mail system. In addition, web sites at IGN and ION were used to post documents of general interest.

In order to archive and distribute IGEX data and products to the user community, Global Data Centers were established at NASA (Crustal Dynamics Data Information System (CDDIS)) and at IGN. Daily files of tracking data were received by the Global Data Centers directly from stations or through operational (local) and regional data centers in Australia, Germany and Taiwan. In addition, the CDDIS generated daily GPS and GLONASS broadcast ephemeris files. Analysis Centers forwarded precise ephemerides, satellite clock information and computed station coordinates to the Global Data Centers for storage and dissemination to users.

One other organizational aspect of IGEX-98 was the inclusion of the SLR community in the experiment. Since all the GLONASS satellites are equipped with arrays of corner cube reflectors, laser tracking data are a very important independent source of orbit information. Through coordination with the International Laser Ranging Service and the Russian Space Agency, nine GLONASS satellites were included in the global schedule for satellite laser observations and SLR stations were requested to track these satellites during the IGEX campaign. Thirty stations collected 6,639 passes and 36,330 normal points of data during the campaign period. These data were archived at the CDDIS and at the EuroLAS Data Center in Germany.

Geodetic-quality, dual-frequency receivers from three manufacturers and one university were fielded during the campaign. Of these, only the receivers from 3S Navigation had been operated for long periods of time prior to the experiment. Ashtech Z-18 and Javad Positioning Systems (JPS) receivers were deployed extensively for the first time, while the University of Leeds used the opportunity to test its new ESA/ISN receiver built for the European Space Agency. Notably, all of these receivers were designed to track both GLONASS and GPS satellites simultaneously in a variety of configurations.

Some work done at the Goddard Space Flight Center extended the characterization of a standard Dorne-Margolin choke ring antenna to GLONASS frequencies. Results indicated that the location of the antenna reference point is a function of frequency, which would thus introduce small systematic biases into the data reduction. Another interesting characteristic of the receivers was the time offset, computed within each receiver, between GPS system time and GLONASS system time. Each receiver type

(Ashtech Z-18s or JPS, for example) had a characteristic offset value that was unique to that receiver type. This value varied only slightly within each receiver type, but was distinctly different between receiver types (e.g., between Ashtech and JPS) - the result of differences in receiver firmware and hardware. Although some problems were encountered with receivers at various sites, primarily due to firmware bugs and incorrect format conversions, on the whole, the receivers performed exceptionally well.

Integrity monitoring of the satellites was addressed by groups in the U.S., The Netherlands and Russia. It was noted that there have been a number of maintenance lapses by the GLONASS control segment that include a lack of navigation message updates and anomalous information loaded into the navigation messages. These groups are also developing tools to monitor system performance and data quality.

Precise Orbit Determination

A major accomplishment of IGEX-98 was the production of precise orbits for all of the operational GLONASS satellites for every day of the campaign. Due to the similarity between GPS and GLONASS, assimilating GLONASS data into GPS software was relatively straightforward. Eleven organizations generated orbits using a variety of software. The organizations, software (when known) and data types processed are summarized below:

Analysis Center	Software	Data Type
Bundesamt fuer Kartographie und Geodaesie (BKG)	Bernese	Phase
Center for Orbit Determination in Europe (CODE)	Bernese	Phase
European Space Agency/ European Space Operations Center (ESA/ESOC)	BAHN	Phase/Code
GeoForschungsZentrum (GFZ)	EPOS.P	Phase
Jet Propulsion Laboratory (JPL)	GIPSY/OASIS	Phase/Code
University of Olsztyn, Poland	TOP	Phase/Code
University of Texas, Center for Space Research (CSR)	GIPSY/OASIS;UTOPIA	Phase; SLR
Australian Surveying and Land Information Group (AUSLIG)	MICROCOSM	SLR
United Kingdom SLR Facility (NERC)	SATAN	SLR
Russian Mission Control Center (MCC)/GEO-ZUP		SLR
University of Technology, Vienna		Combined

Six of these Analysis Centers – BKG, CODE, ESA, GFZ, JPL and MCC - were able to generate orbits on a more or less routine basis. The orbits from the MCC were the only ones from these six Analysis Centers that were based on SLR observations alone. Despite using different processing schemes, different software and various data types, all of these efforts produced orbits well below the one meter accuracy objective. In fact, the orbit solutions over the entire period were consistent at the 20-30 cm level. The solutions submitted by the six centers were weighted and combined into one final daily solution at the University of Technology in Vienna, Austria. Note that the requirement that ITRF coordinates be available for all IGEX stations ensured that the precise orbits would also be in the ITRF.

The availability of independently-computed orbits derived from the laser observations provided a measure of truth for orbit evaluations. Orbits computed from the SLR data by NERC, for example, had post-fit residual RMS values of about 6-10 cm. The University of Texas CSR similarly computed RMS values of 3 cm for SLR normal point residuals over the campaign, although there was considerable week-to-week variation.

Using its SLR-based orbits in conjunction with the receiver-based orbits from the Analysis Centers, CSR computed weighted RMS range residuals (SLR minus receiver measurements) of about 10 cm, indicating a radial orbit accuracy of that magnitude. The CSR noted RMS orbit differences in the radial, along-track and cross-track directions of approximately 10 cm, 40 cm and 45 cm when comparing their laser-based orbits with the receiver-based orbits of the other Analysis Centers. Comparisons of AUSLIG's SLR orbits with CODE precise orbits produced similar values – 14 cm, 75 cm and 51 cm.

Several issues were raised as a result of the orbit processing. The solar radiation pressure modeling, in particular, and force modeling in general need to be improved for GLONASS. At least half a dozen different models or variations of models were used by the Analysis Centers for radiation pressure. A new analytical model was proposed in an independent effort unaffiliated with the Analysis Centers. In addition, JPL reported finding a different pattern of Y-bias for GLONASS than for GPS. CSR's computations appeared to indicate a small, unexplained bias between SLR measurements and microwave receiver-based measurements, and NERC discussed a possible explanation for this, based on ranging-system-dependent biases induced by the retroreflector arrays on the satellites.

Reference Frame Comparisons

The availability of precise GLONASS orbits in the ITRF reference frame provided the means for several of the groups to compute transformations between the Russian PZ-90 reference frame and ITRF. CODE, BKG and JPL all computed 7-parameter transformations between the broadcast PZ-90 orbits and their respective precise ITRF orbits. All found the rotation about the z-axis to be the most significant parameter. BKG also noted a time-dependence to the transformation parameters for x-, y- and z-rotations and y-translation. An extensive study done by GEO-ZUP and the Mission Control Center in Russia shows this time dependence with longer term fluctuations that exceed one year, and attributes this to the way Earth Orientation Parameters are introduced into the operational GLONASS orbit determination process by the GLONASS System Control Center (SCC). The GEO-ZUP work is based on comparisons of laser-based orbits with averaged post-processed GLONASS SCC ephemeris data and with broadcast orbits. The reported results show z-translation and z-rotation to be the most significant parameters. Another independent approach, using the range measurements to the GLONASS satellites from known WGS 84 (ITRF) sites to compute transformation parameters, also identified the z-axis rotation as the dominant parameter.

Applications

One of the immediate applications of dual-frequency GLONASS receivers and precise GLONASS orbits is time transfer. When combined with GPS, GLONASS offers additional satellites that significantly expand the time available for common-mode satellite observations over intercontinental distances and shorter distances as well. In addition, the GLONASS C/A-code and navigation message are free of Selective Availability effects, and the dual-frequency P-code is not encrypted as in the case of GPS. This allows for higher precision measurements and enables one to correct measurements for ionospheric effects.

Another benefit of having precise GLONASS orbits is the ability to compute station coordinates over long baselines. Curtin University of Technology led one evaluation using data collected in the Southern Hemisphere for baseline lengths of 2,200 to 7,700 km. They obtained comparable precisions with GLONASS and GPS. The University of Technology of Vienna noted that the RMS of daily estimates of coordinate components improved from tens of decimeters to a few centimeters using precise GLONASS orbits instead of broadcast orbits. The results were even better when GLONASS data were combined with GPS observations and precise orbits.

Workshop Resolutions and Future Plans for a GLONASS Pilot Service

At the end of the workshop, a number of resolutions were put forth by the IGEX Steering Committee for discussion and a vote regarding continuation of the experiment and the form that this activity should take. The workshop participants voted in favor of all the resolutions with the following results:

1. Global, internationally coordinated GLONASS tracking and orbit determination should continue in the time interval 1999-2003.

2. The International Association of Geodesy’s Committee for the Coordination of Space Techniques for Geodesy and Geodynamics (CSTG) and the International GPS Service (IGS) shall continue to collaborate in an International GLONASS “Pilot Service”. This service will be organized according to the rules stated in the memorandum “IGS Policy for the Establishment of IGS Projects and Working Groups” (available through the IGS Central Bureau Information System at < http://igscb.jpl.nasa.gov>).

3. The International GLONASS “Pilot Service” will be proposed as an IGS Pilot Project, initially for the time period 1999-2003.

4. A new Project Committee will be formed to (a) prepare a charter for the “Pilot Service”, (b) define the duration of the “Pilot Service” as 1999-2003, (c) prepare and send out a new Call For Participation, and (d) officially announce the creation of the “Pilot Service”.

The latter documents together with a list of Project Committee members and the proposed relationship between the Pilot Service and the IGS were sent to the Chairman of the IGS Governing Board with the request to put the proposal on the agenda of the December 1999 Governing Board meeting. The proposal was voted on at the Governing Board meeting and given provisional approval.

The International GLONASS Pilot Service will have the following goals and objectives:

1. Establish and maintain a global GLONASS tracking network
   a. Collocate dual-frequency, combined GPS/GLONASS receivers with dual-frequency GPS receivers or upgrade existing dual-frequency GPS receivers to dual-frequency, combined GPS/GLONASS receivers at existing IGS sites and at new sites
   b. Apply International GPS Service (IGS) network operations standards
   c. Calibrate and evaluate combined GPS/GLONASS receivers and antennas
2. Produce precise (10-cm level) orbits, satellite clock estimates, and station coordinates
   a. Evaluate microwave-derived orbits using SLR observations and orbits
   b. Incorporate SLR observations in routine orbit processing
   c. Obtain initial operational capability of 20-50 cm orbits at Analysis Centers
   d. Receive independent orbit/clock/station solutions from Analysis Centers within three weeks of observations
3. Monitor and assess GLONASS system performance
4. Investigate the use of GLONASS to improve Earth Orientation Parameters
5. Improve atmospheric products of the IGS
6. Fully integrate GLONASS into IGS products, operations and programs.

The Call for Participation will request recommitment from the existing GLONASS stations and will invite new stations to join. Organizations will also be asked to participate as Analysis Centers and Data Centers. Requirements for all these activities will be given in the Call for Participation.

As is evident from the workshop proceedings, IGEX-98 was a major success. It achieved all the objectives established at the outset of the project. In general, the results of the experiment and the response from the international community exceeded expectations. Now that the major obstacles that limited the use of GLONASS in the past have been overcome, there are a number of applications that could benefit from the availability of GLONASS observations and orbits. These include atmospheric studies, geodesy, definition of the ITRF, force modeling studies, time transfer and orbit prediction. The combined GPS and GLONASS constellations are also a good model for future Global Navigation Satellite Systems that may consist of several independent, integrated satellite systems. Since many potential applications take advantage of GLONASS as an augmentation to GPS and not as a stand-alone system, the lack of a full constellation is not critical. However, this may become a critical issue if the number of usable satellites drops precipitously and no new launches take place. At this time, a subset of the IGEX-

98 tracking stations, analysis centers, and data centers continues to function on a best effort basis. These will form the core of the new pilot service. The routine availability of GLONASS data and products hopefully will enhance current capabilities to explore a variety of subjects as well as provide a test environment for the integrated use of independent satellite systems.

IGEX-98 Workshop

Nashville, Tennessee
September 13-14, 1999

Program Agenda

Revised 09/10/1999

Monday, September 13

INTRODUCTION, OVERVIEW AND GLONASS OPERATIONS
(Chair: J. Slater, NIMA)

Time

8:30 **Welcome and Introduction**
J. Slater, Chair, IGEX-98 Workshop Organizing Committee

8:45 *ION GLONASS-GPS Interoperability Working Group*
P. Misra, MIT Lincoln Laboratory

9:00 **The GLONASS IGEX-98 Campaign: From Its Genesis to Its Realization**
P. Willis, IGN; J. Slater, NIMA; W. Gurtner, University of Bern; C. Noll, NASA GSFC; G. Beutler, University of Bern; R. Weber, University of Technology, Vienna; R. Neilan, JPL; G. Hein, University FAF Munich

9:30 **GLONASS Operational Status and Plans**
M. G. Lebedev, Coordination Scientific Information Center, Ministry of Defense of the Russian Federation

10:00 **GLONASS Constellation Maintenance, 1998-1999**
G. Cook, Sequoia Research Corp.

10:15 **GLONASS and the International Terrestrial Reference System**
C. Boucher, IGN

10:30 **BREAK**

RECEIVER TECHNOLOGY (Chair: R. Neilan, JPL)

11:00 **An Operational Evaluation of the JPS Legacy Receiver**
P. Finer, W. Carter and R. Shrestha, University of Florida

11:15 **ESA/ISN Dual-Frequency GPS/GLONASS Receiver**
G. Brodin, D. Lowe, P. Daly, University of Leeds; P. Silvestrin, T. Martin-Mur, I. Romero, J. Dow, European Space Agency

Monday, September 13 (cont'd)

Time

11:30 **An Analysis of Dual-Frequency Receivers Used in the IGEX-98 Campaign**
B. Wiley, NIMA

NETWORK OPERATIONS (Chair: W. Gurtner, University of Bern)

11:45 **IGEX Network and Data Processing Organization**
W. Gurtner, University of Bern

12:00 **IGEX-98 Data Flow**
C. Noll, NASA GSFC

12:15 **LUNCH**

1:45 **BKG's Operation of GPS/GLONASS Receivers and Its Regional IGEX Data Center**
H. Habrich, BKG

2:00 **Integrity Monitoring Software for GPS/GLONASS Reference Stations**
K. de Jong, Delft University of Technology

2:15 **PANEL DISCUSSION – TECHNOLOGY, STATION AND NETWORK OPERATIONS**
(Chairs: W. Gurtner, University of Bern; R. Neilan, JPL)

3:45 **BREAK**

TIME AND TIME TRANSFER (Chair: W. Lewandowski, BIPM)

4:15 **Recent Progress in Time Metrology and a Role for GLONASS**
W. Lewandowski, BIPM

4:30 **An Experiment of Transatlantic GLONASS P-Code Time Transfer Using IGEX Precise Ephemerides**
J. Nawrocki, Borowiec Astrogeodynamical Observatory; A. Drozyner, University of Olsztyn; J. Azoubib, W. Lewandowski, BIPM; P. Nogas, Borowiec Astrogeodynamical Observatory

4:45 **Computation of GLONASS Precise Ephemerides for International Time Transfer**
A. Drozyner, University of Olsztyn

7:00 – 10:00 **RECEPTION**

Tuesday, September 14

Time

8:30 **Welcome and Introduction to Workshop Day 2**
C. Noll, Co-chair, IGEX-98 Workshop Organizing Committee

ORBIT DETERMINATION (Chair: R. Weber, University of Technology, Vienna)

8:45 **Results of CODE as an Analysis Center of the IGEX-98 Campaign**
D. Ineichen, M. Rothacher, T. Springer, G. Beutler, University of Bern

9:00 **IGEX Analysis at BKG**
H. Habrich, BKG

9:15 **GLONASS Data Analysis at ESA/ESOC**
T. Martin-Mur, J. Dow, C. Garcia, I. Romero, European Space Agency; P. Daly, University of Leeds; P. Silvestrin, European Space Agency

9:30 **Determination of GLONASS Satellite Orbit at JPL – Approach and Results**
D. Kuang, Y. Bar-Sever, W. Bertiger, K. Hurst, J. Zumberge, JPL

9:45 **GLONASS Orbit Determination at the Center for Space Research**
R. S. Nerem, W. Bamford, R. J. Eanes, K. Key, B. E. Schutz, T. Wynne, University of Texas at Austin

10:00 **GLONASS Precise Orbits as a Result of IGEX-98 Laser Tracking Campaign**
V. Glotov, Russian Mission Control Center; V. Mitrikas, Geo-ZUP; M. Zinkovski, Russian Mission Control Center

10:15 **BREAK**

10:45 **SLR GLONASS Orbit Determination**
R. Govind, J. Dawson, G. Luton, Australian Surveying and Land Information Group

11:00 **Comparison of Precise GLONASS Ephemerides Obtained from the IGEX Campaign**
R. Weber, E. Fragner, University of Technology, Vienna

11:15 **Comparison of Precise SLR Orbits of the GLONASS Satellites with Microwave-based Orbits**
G. Appleby, NERC; T. Otsubo, Communications Research Laboratory; A. Sinclair, NERC

Tuesday, September 14 (cont'd)

APPLICATIONS (Chair: V. Mitrikas, Geo-ZUP)

11:30 **IGEX – A Regional Analysis of Data from the Southern Hemisphere**
M. Stewart, M. Tsakiri, J. Wang, J. Monico, Curtin University of Technology

11:45 **PZ-90 GLONASS to ITRF Transformations as a Result of IGEX-98 Laser Tracking Campaign**
V. Mitrikas, Geo-ZUP; S. Revnivych, M. Zinkovski, V. Glotov, Russian Mission Control Center

12:00 **LUNCH**

1:30 **PZ-90/WGS 84 Transformation Parameters Directly from GLONASS Range Measurements**
U. Rossbach, IfEN

1:45 **Analytical Solar Radiation Pressure Model for GLONASS: Algorithm and Initial Results**
M. Ziebart, University of East London

2:00 **GENERAL DISCUSSION – GPS/GLONASS INTEROPERABILITY ISSUES**
(Chair: P. Misra, MIT Lincoln Laboratory)

3:00 **BREAK**

3:30 **PANEL DISCUSSION – FUTURE PLANS**
(Chairs: G. Beutler, University of Bern; P. Willis, IGN)

Position Paper: The Future of IGEX-98
G. Beutler, University of Bern; P. Willis, IGN

5:00 **SUMMARY AND CLOSING** (J. Slater)

Poster Papers

List of Participants

IGEX-98 Workshop

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