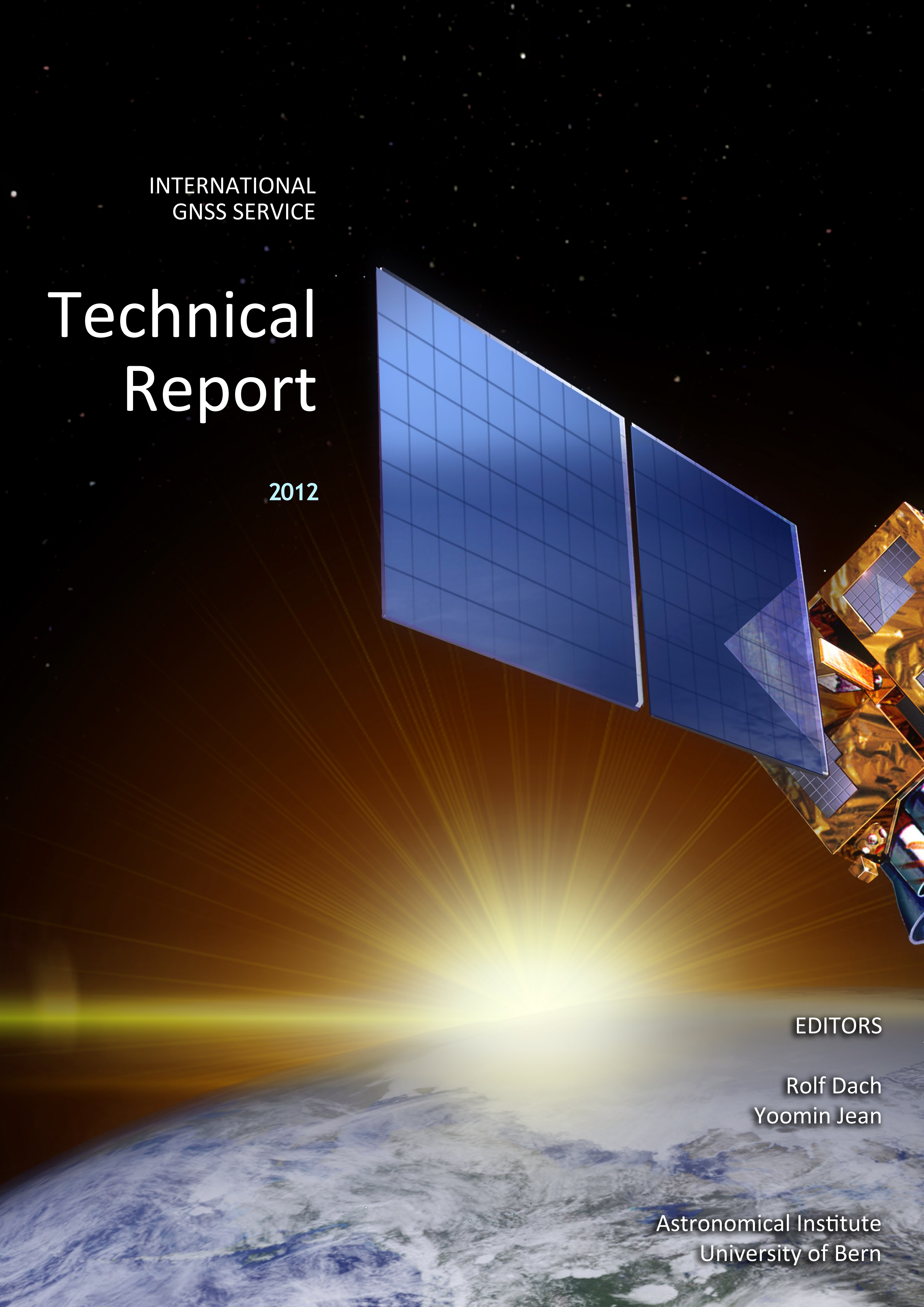

INTERNATIONAL
GNSS SERVICE

Technical Report

2012

EDITORS

Rolf Dach
Yoomin Jean

Astronomical Institute
University of Bern

International GNSS Service

Technical Report 2012

IGS Central Bureau

http://www.igs.org

Editors: R. Dach, Y. Jean
Astronomical Institute, University of Bern

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IGS Central Bureau
Jet Propulsion Laboratory, M/S 238–540
4800 Oak Grove Drive
Pasadena, CA 91109–8099 USA

Tel: +1 – 818 – 354 – 2077
Fax: +1 – 818 – 393 – 6686
E–mail: cb@igs.org

http://www.igs.org

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

International GNSS Service

International Association of Geodesy
International Union of Geodesy and Geophysics

Edited by Rolf Dach, Yoomin Jean
Astronomical Institute, University of Bern, Switzerland,
Compiled in February and March, 2013.

Abstract

Applications of the Global Navigation Satellite Systems (GNSS) to Earth Sciences are numerous. The International GNSS Service (IGS), a federation of government agencies, universities and research institutions, plays an increasingly critical role in support of GNSS–related research and engineering activities. This Technical Report 2012 includes contributions from the IGS Governing Board, the Central Bureau, Analysis Centers, Data Centers, station and network operators, working groups, pilot projects, and others highlighting status and important activities, changes and results that took place and were achieved during 2012.

This report is available online as PDF version at
https://files.igs.org/pub/resource/technical_reports/2012_techreport.pdf.

The IGS wants to thank all contributing institutions operating network stations, data centers or analysis centers or supporting the IGS in any other form. All contributions are welcome. They guarantee the success of the IGS also in future.

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Part I

Executive Reports

The Development of the IGS in 2012
The Governing Board's Perspective

U. Hugentobler

Technische Universität München
Institut für Astronomische und Physikalische Geodäsie
Arcisstr. 21; 80333 Munich; Germany
e–mail: urs.hugentobler@bv.tum.de

1 Introduction

The year 2012 was a successful year for the IGS. The most prominent event was the IGS Workshop in Olsztyn, Poland, in July where a wide range of activities associated with the IGS were presented and discussed. Focus areas at the workshop as well as in several Governing Board meetings were the challenging multi-GNSS activities organized in IGS' Multi–GNSS Experiment (MGEX) as well as the preparations for the launch of the IGS Real-time Service. Essential for the IGS are all the operational activities, including the maintenance of the tracking network by the station operators with the support of the Network Coordinator, the data holding for free access at the Data Centers, the data analysis and operational preparation of highest–precision products at the Analysis Centers, the coordination and supervision of the activities by the Product Coordinators, and finally the work contributed by the Working Groups focusing on various topics of high relevance for the IGS, and the Central Bureau assuming responsibility for the general management and day-to-day operations of the IGS. Important work in 2012 in addition includes the preparation of updated site guidelines, the preparations for the upcoming next reprocessing undertaking, the definition of the goals and objectives for the Strategic Plan 2013–2016, the fostering of the interactions with neighboring organizations as well as the presentation of IGS activities and strategy at a number of workshops and conferences.

2 IGS Operational Activities

Although the following sections focus on recent IGS accomplishments, the IGS could not exist without the daily, routine activities performed by the various operational components of the service. About 440 stations are maintained and operated globally by many institutions and station operators, making tracking data available at different latencies, from daily RINEX files to real–time streams for free public use. The IGS tracking data amount held by each of the four global Data Centers on permanently accessible servers increased in the last year by over 1 Tb (15 million files). Significant additional storage capabilities are provided by regional Data Centers. Twelve Analysis Centers and a number of Associate Analysis Centers utilize tracking data from 70 up to more than 350 stations to generate and to control the quality of highest–precision products up to four times per day. Product Coordinators combine these products on an operational basis and assure the quality of the products made available to the users. Nearly 700 IGS final, rapid, ultra–rapid and GLONASS–only product files as well as 140 ionosphere files are made available per week as well as daily troposphere files for more than 300 stations. The interest of users on IGS products is documented by the download statistics that records typically over 150 000 file (25 Gb) downloads per day (CDDIS statistics). The Central Bureau assumes responsibility for day–to–day management, interaction with station operators, and answering to a typical number of 150–200 questions and requests from users per month. All these activities are performed all year and day–by–day, with high redundancy and reliability based on the pooled resources of more than 200 institutions worldwide. Only the day–by–day contribution of a large number of engaged individuals makes this impressive undertaking possible.

3 IGS Workshop 2012 in Olsztyn, Poland

The most prominent IGS event in 2012 was, without doubt, the IGS Workshop that took place in Olsztyn, Poland, from 23–27 July. The workshop was attended by about 230 participants and was a great success. It took place in the excellent facilities of the University of Warmia and Mazury and in a lovely region of Poland. The workshop, organized by Andrzej Krankowski and his team, was accompanied by a diversified social program, including an ice breaker party, conference dinner, city tour, sailing regatta, visits in castle, planetarium, and observatory; with excellent weather experienced all week.

The workshop format developed by the Scientific Organizing Committee led by Shailen Desai, JPL, was excellent as it left ample room for interaction and discussions, and the scientific program found the appropriate balance between the different topics of interest to the IGS today. The mornings were devoted to plenary sessions with invited presentations focusing on selected topics covering the wide scope of the IGS. Lunch time followed by poster sessions allowed time for discussion and interaction between the participants, while the splinter sessions in the second half of the afternoon allowed the working groups to meet, discuss their “hot” topics and formulate their recommendations.

The scientific sessions covered the status and achievements of the IGS Multi–GNSS Experiment; the IGS network infrastructure and real–time activities; modeling of observations and station motions; modeling of atmosphere delays and applications; space vehicle dynamics and attitude; clock modeling and time scale realization; antenna calibration; geodetic applications of IGS products; the relevance of the IGS for the geodetic and wider community. Jointly with the IGS Workshop the meeting of the WG-A "Compatibility and Interoperability" of the International Committee on GNSS (ICG) took place, which was an opportunity for interaction and exchange between IGS and system providers.

The workshop presentations, posters, and recommendations can be found at `http://www.igs.org/presents/poland2012/`. A short workshop summary may be found in IGSMAIL #6635 .

4 Events and Highlights in 2012

The IGS Governing Board met a total of four times in 2012. A GB business meeting took place on April 25 during the EGU General Assembly in Vienna, a regular meeting (July 22) and a wrap–up GB meeting (July 27) was associated with the IGS Workshop in Poland, and finally the regular end-of-year meeting took place on December 2 during the AGU Fall Meeting in San Francisco. The IGS Executive Committee - consisting of Urs Hugentobler, Chuck Meertens, Ruth Neilan, Chris Rizos, Tim Springer and with regular participation of John Dow and Steve Fisher and of WG Chairs as required — has met ten times in 2012 by teleconference.

The Multi–GNSS Experiment (MGEX) is one of the key projects of the IGS and shows significant progress since its launch in February 2012. The focus of this cornerstone experiment is the data flow, the understanding of observables, the characterization of the tracking equipment, and the generation of products, targeting the launch of a Pilot Project in 2015. To achieve this goal contributions from all IGS components are essential. The project is open and everybody who is interested to contribute is invited to join. After the IGS workshop, Robert Weber stepped down as Chair of the GNSS WG which coordinates MGEX. The GB thanked Robert for his engagement over many years and welcomed Oliver Montenbruck from DLR/GSOC, Germany, as the new Chair of the working group that was renamed to Multi–GNSS WG. The very successful Workshop on GNSS Biases held in Bern from January 18–19 addressed very significant issues related to the implementation of multi–GNSS within IGS.

The upcoming IGS Real–Time Service is our second key project. The redundancy concept is convincing and the demonstrated product accuracy mature for the launch of the Service. Initial Operational Capability is planned for early 2013, providing real–time GPS orbit and clock corrections as well as experimental GLONASS corrections, with Full Operational Capability later in 2013. The Service will rapidly develop into a Multi–GNSS Service. Its focus are geophysical applications, e.g., natural hazards monitoring in the framework of GGOS, but it will support a large variety of applications in positioning, navigation, time transfer, system monitoring and others. NRCan committed to support Mark Caissy for another year as the Chair of the RT WG to allow for continuity in leadership in the process of launching the RT Service, while ESA continues the support of Loukis Agrotis as the RT ACC.

The IGS/RTCM RINEX WG is preparing a plan for the transition from RINEX 2.11 to RINEX 3.0x over the next few years. While tracking data from GNSS–capable equipment shall be solely available in RINEX 3 after a target date to be specified, tracking data from legacy receivers will continue to be available in RINEX 2 for the foreseeable future. The IGS GB affirmed the transition to RINEX 3 and the further elaboration of the transition plan.

The Infrastructure Committee invested much effort in a thorough revision of the IGS Site Guidelines. The guidelines were available for public review and were approved at the July GB meeting subject to final comments being integrated. At its July meeting the GB assigned Robert Khachikyan, CB staff member, as Network Coordinator. With this, one of the key positions within the IGS CB is again filled. Finally, the GNSS Research Center at Wuhan University joined the IGS as a new Analysis Center.

Summaries of the GB meetings may be found in IGSMAIL #6635 and IGSMAIL #6706. Table 1 lists the important events in 2012.

Table 1: IGS events in 2012

January 18-19 IGS Workshop on GNSS Biases

February 1 Start of MGEX

April 25 GB Business Meeting in Vienna (EGU)

July 22 40th GB Meeting in Olsztyn, Poland

- Robert Khachikyan assigned as Network Coordinator

July 23-27 IGS Workshop in Olsztyn, Poland
joint Meeting with ICG WG-A "Compatibility and Interoperability"

July 27 GB Workshop Wrap-up Meeting

- Oliver Montenbruck assigned as Chair of the Multi–GNSS WG
- approval of new Site Guidelines

December 2 41^{st} GB Meeting in San Francisco (AGU)

- Steve Fisher assigned as IGS CB Secretary

5 Strategic Planning

During 2012 the new IGS Strategic Plan 2013–2016 was developed by the IGS CB and EC as an updated version of the current Strategic Plan 2008–2012, including elements that allow for a better monitoring and reporting of progress. As a preparatory step a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was performed by members of the GB and selected stakeholders, analyzing strengths, weaknesses and opportunities of the IGS, and threats that the IGS faces. The analysis resulted in three goals that essentially correspond to the goals formulated in the current plan. The goals are further sub-divided into several objectives which in turn are decomposed into initiatives. Targets and measures are being defined allowing to assess the status of each objective with respect to the target for regular monitoring by the GB. At the same time the CB prepared a Progress Report for the period 2008–2012 that records and quantifies, based on the annual implementation plans, the progress made by the IGS in the different fields addressed by the Strategic Plan. The final version of the two documents will be available early 2013.

6 Governing Board Membership

In 2012 no elections took place. The GB membership of Steve Fisher as IGS CB Secretary was approved by the Board. Given the successful review of the work of the IGS Working Groups and Pilot Projects documented with the very successful IGS Workshop in Olsztyn, the GB extended the terms of those WG and PP Chairs whose terms terminated end of 2012 by another two years.

Table 2 lists the members of the IGS Governing Board for 2012.

7 Outreach

The IGS is well represented on the GGOS Coordinating Board. It plays a leadership role in the International Committee on GNSS (ICG), in particular by co–chairing Working Group D on Reference Frames, Timing and Applications, and by participating in the planning for the International GNSS Monitoring and Assessment System (iGMAS). The IGS is also well represented in the International Earth Rotation & Reference Systems Service (IERS) and in IAG Sub–Commission 1.2 on reference frames, in the RTCM SC104, and others.

IGS has been involved with many outreach activities in 2012. The following list provides a selection of presentations at international meetings and articles in geospatial magazines. In addition the IGS CB together with the RT WG prepared a one-pager that states the reasons for the IGS involvement in real–time activities. The IGS was also given visibility as session organizers of, or presenters in, IGS–related sessions at conferences such as those of the EGU in Vienna and AGU in San Francisco.

Presentations at international meetings

- PPP–RTK Symposium, March 12–13, Frankfurt/Main, U. Hugentobler:
  “From GPS to GNSS — Challenges and Prospects”.
- FIG Working Week, May 6–10, Rome, R. Neilan:
  “The IGS in Support of Science and Society — new Roles, New Challenges, New Products”.
- 3rd China Satellite Navigation Conference, May 15–19, Guangzhou, C. Rizos:
  “The IGS in the Multi–GNSS Era: New Roles, New Products, New Challenges”.
- Asia Oceania Geoscience Society, August 13–17, C. Rizos and R. Neilan:
  “New Roles, New Challenges and New Products for the International GNSS Service (IGS)”.
- 3rd Colloquium Galileo Science, August 31–September 2, Copenhagen, R. Weber:
  “The IGS Multi-GNSS Global Experiment”.
- INTERGEO, October 9–11, Hannover, C. Rizos:
  “The International GNSS Service (IGS): Supporting the Geospatial Industry”.
- ICG–7, November 5–9, Beijing, C. Rizos:
  “The IGS: A Multi-GNSS Service”.

Articles

- Caissy, M., L. Agrotis, G. Weber, M. Hernandez–Pajares, U. Hugentobler: “Coming Soon: The IGS Real-Time Service”, *GPS World*, June 2012.
- Rebischung, P., J. Griffiths, J. Ray, R. Schmid, X. Collilieux, B. Garayt: “IGS08: the IGS realization of ITRF2008”, *GPS Solutions*, 16(4):483–494.
- Rizos, C.: “GNSS Service Analysis Workshop Held in Poland”, *GIM International Magazine*, November 2012.
- Weber, R., U. Hugentobler, R. Neilan: “IGS M–GEX — The IGS Multi-GNSS Global Experiment”, Proceedings of the *3rd International Colloquium on Scientific and Fundamental Aspects of the Galileo Program.*

One–pager

- “Why Is IGS Involved in Real-Time GNSS?” (`ftp://igs.org/pub/resource/pubs/IGS_why_in_RT.pdf`)

8 Outlook

The year 2013 again promises a number of highlights. In the beginning of 2013 Initial Operational Capability for the IGS Real–Time Service will be declared as a new open service. Full Operational Capability is planned later in 2013. Rapid progress is expected in the Multi–GNSS Experiment which prepares IGS to a seamless integration of the new and upcoming GNSS constellations into its processing chains and products. Also for the beginning of 2013 the launch of the second reprocessing campaign (repro2) is planned for which a multitude of preparatory steps were performed in 2012 by the Analysis Center Coordinator and Reference Frame Coordinator together with the Analysis Centers. Finally the new Strategic Plan 2013–2016 will be implemented early 2013. For 2014 we can already look forward to our next workshop at JPL in Pasadena, CA, coinciding with the 20th anniversary of the IGS.

The IGS GB thanks all participants and supporters of the IGS for their efforts invested in the past year. Only with the continuous efforts of the network operators, operators of data centers and analysis centers, the product coordinators, WG, PP and committee chairs and members, the Central Bureau, and the continuous support by numerous institutions worldwide the IGS can remain in the leading position in a rapidly developing GNSS environment.

Table 2: IGS Governing Board Members 2012 (∗: voting members, EC: Executive Committee)

Member	Institution	Country	Function
∗ Urs Hugentobler (EC)	Technische Universität München	Germany	Board Chair, Analysis Center Representative
∗ Zuheir Altamimi	Institut National de l'Information Géographique et Forestière	France	IAG Representative
Felicitas Arias	Bureau International des Poids et Mesures	France	BIPM/CCTF Representative
∗ Claude Boucher	Institut National de l'Information Géographique et Forestière	France	IERS Representative
∗ Carine Bruyninx	Royal Observatory of Belgium	Belgium	Network Representative
Mark Caissy	Natural Resources Canada	Canada	Real-Time WG Chair
∗ Yamin Dang	Chinese Academy of Surveying and Mapping	China	Appointed
∗ Shailen Desai	Jet Propulsion Laboratory	USA	Analysis Center Representative
∗ Bruno Garayt	Institut National de l'Information Géographique et Forestière	France	Reference Frame Coordinator, IGS Representative to IAG Sub–commission 1.2
∗ Jake Griffiths	NOAA, National Geodetic Survey	USA	Analysis Center Coordinator
Christine Hackman	United States Naval Observatory	USA	Troposphere WG Chair
∗ Gary Johnston	Geoscience Australia	Australia	Network Representative
Andrzej Krankowski	University of Warmia and Mazury in Olsztyn	Poland	Ionosphere WG Chair
Ken MacLeod	Natural Resources Canada	Canada	IGS/RTCM RINEX WG Chair
∗ Chuck Meertens	UNAVCO, Inc.	USA	Appointed
Oliver Montenbruck since July 2012	DLR/German Space Operations Center	Germany	Multi–GNSS WG Chair
∗ Ruth Neilan (EC)	IGS Central Bureau, Jet Propulsion Laboratory	USA	Director of IGS Central Bureau, Secretary
∗ Carey Noll	Goddard Space Flight Center	USA	Data Center Representative, Data Center WG Chair
∗ James Park	Korean Astronomy and Space Science Institute	South Korea	Appointed
∗ Chris Rizos (EC)	University of New South Wales	Australia	President of IAG
Ignacio Romero	ESA/European Space Operations Centre	Germany	Infrastructure Committee Chair
Stefan Schaer	Federal Office of Topography	Switzerland	Bias and Calibration WG Chair

Table 2: IGS Governing Board Members 2012 (∗: voting members, EC: Executive Committee), cont.

Member	Institution	Country	Function
Ralf Schmid	Deutsches Geodätisches Forschungsinstitut	Germany	Antenna WG Chair
Tilo Schöne	Deutsches GeoForschungsZentrum Potsdam	Germany	TIGA WG Chair
∗ Ken Senior	Naval Research Laboratory	USA	Clock Product Coordinator
∗ Tim Springer (EC)	ESA/European Space Operations Centre	Germany	Analysis Center Representative, IGS Representative to IERS, Chair of Associate Members Committee
Robert Weber until July 2012	Vienna University of Technology	Austria	GNSS WG Chair
∗ Richard Wonnacott	Chief Directorate: National Geospatial Information	South Africa	Appointed
Marek Ziebart	University College London	UK	Space Vehicle Orbit Dynamics WG Chair

IGS Technical Report 2012
Central Bureau

R. Neilan[1], *S. Fisher*[1], *R. Khachikyan*[2], *J. Ceva*[3],
A. Craddock[3], *N. Donnelly*[5], *D. Maggert*[4] *and G. Walia*[1]

[1] NASA/Jet Propulsion Laboratory, Caltech, Pasadena, California
[2] Raytheon, Inc.
[3] SBAR, Inc.
[4] UNAVCO, Inc
[5] Land Information New Zealand (LINZ)

1 Introduction

The IGS Central Bureau (CB) is hosted at the California Institute of Technology/Jet Propulsion Laboratory and is funded by NASA. The Central Bureau supports IGS management focusing on two principal functions:

1. executive management of the service, including international coordination and outreach, and
2. coordination of IGS infrastructure, including the IGS tracking network and related information management systems.

Specific responsibilities of the Central Bureau are outlined in the IGS Terms of Reference: `http://igs.org/organization/orgindex.html` .

The CB has been strengthened in 2012. Additional resources provided by NASA have enabled an expansion of CB staff. The CB Director is now partially tasked within the NASA's Space Geodesy Project. Her efforts within the IGS are now backfilled by other staff members: Juan Ceva came on board part time in April, Allison Craddock in September, both part time; and Steve Fisher has been fully dedicated to IGS since November. Robert Khachikyan was appointed Network Coordinator at the 40th GB meeting in Poland. Dave Maggert at UNAVCO supports IGS and network coordination, and provides extremely valuable support to the IGS CB and IGS in general. Nic Donnelly interned (on loan from LINZ) at the CB in early 2012 gaining insight into CB tasks and made good progress in a path forward for definition of geodetic meta–data.

2 Network Status

The Central Bureau currently monitors 440 official IGS stations of which approximately 84% are actively transmitting data. Only 244 stations are GPS only. All others are GNSS. Approximately 107 IGS stations transmit real–time data to the IGS Real Time Pilot Project.

16% data missing are due to temporary outages, while others are actively being worked on to restore operation. Eighteen of these stations are NGA stations for which we are evaluating data prior to release to Analysis Centers. The NGA stations currently have two issues that must be addressed.

1. Use of uncalibrated antenna and radome equipment. The IGS Antenna Working group is actively working with NGS for it to become one of the official IGS antenna calibration institutions. Once details are corrected, this issue becomes addressed.
2. Data contains $\frac{1}{2}$ cycle phase slip that affects geodetic solutions. Which is a RINEX violation, although data can possibly be processed by the Analysis Centers temporarily until manufacturer produces a receiver firmware update. A single AC confirmed its successful processing, but others need to verify.

Three new important stations have been added to the IGS network providing not only real–time service, but also a GNSS observation data.

BRUX	Brussels, Belgium
KAT1	Katherine, North Territory, Australia
MGUE	Malargue, Argentina

Due to number of RF stations retiring from service and position discontinuities, IGb08 was adopted on GPS week 1709 (07 Oct 2012). IGb08 includes 33 stations affected by position discontinuities from IGS08 and 3 new stations co–located with decommissioned IGS08 stations. This update increases the number of usable RF stations by about 36 and the number of usable core stations by about 15. The primary goal is to stabilize the RF alignment of the IGS products.

The Central Bureau is now hosting an official real–time caster that is accessible worldwide. We are in alpha test mode of this new service to ensure integrity is passed and verification and validation of products are blessed. This new service works in conjunction with the primary IGS real–time caster by ingesting direct feeds from the IGS Real–Time Analysis Centers. The current streams accepted are IGS clocks, orbits, and the IGS combination from two different analysis centers.

Site Guidelines have been completed with the exception of the real–time section, which is in progress.

A number of Central Bureau Information System (CBIS) improvements are in progress:

- The new http://www.igs.org is being tested and enhanced for its promised capabilities on an external stage server. This not only addresses accessibility issues, but also allows working group chairs to maintain their area of workspace including station operators for their site logs.
- The new IGS Network station list and summary page is open for testing by the Analysis Centers. So far outcome has been positive.
  - Its data is supplied by the CB Site Log Manager database.
  - A full history of a site's performance is also available.
  - http://igs.org/network/network.php

3 Activities in 2012

The CB has supported IGS broadly throughout 2012. Principal activities have included:

January

- Participated in Bias and Calibration Workshop in Bern, and the joint IGS RTCM meeting just prior.
- M–GEX project support and website initiated.

February – March

- Attended UNAVCO Science Workshop in Boulder and organized a one day workshop with Nic Donnelly there on geodetic meta–data, joint with Fran Boler, lead of the Seamless Archive project.
- Neilan and Donnelly met with SOPAC personnel in San Diego to discuss meta–data approach and an initial demonstration.
- Preparations for IGS workshop in July began.
- Meeting of the US PNT Advisory Board in Washington, DC focused on LightSquare spectrum issue, was attended by Neilan(and Beutler).
- Network performance metrics were specified. Development of improved network pages began.

April – May

- Neilan attended the EGU in Vienna, and the GGOS Coordinating Board Meeting.
- Neilan was elected to Vice–Chair of GGOS.
- Neilan (and Rizos) attended FIG meeting in Rome, delivered an invited IGS presentation.
- Neilan, Fisher (and Rizos) in cooperation with the Real–time Working Group drafted one–page statement on IGS involvement with Real–time GNSS.
- Plan to renew IGS Strategic Plan is developed.

- Began compiling IGS bibliography.
- IGS contribution to IERS 2011 Annual Report was prepared.
- Network performance prototype web pages developed.

June

- Extensive preparations for the IGS workshop in Poland. IGS Institute is able to process Workshop registrations, which required significant development and handling.
- GGOS held a strategic retreat in Frankfurt, facilitated by CB, which is resulting in a task matrix aligned with GGOS goals and objectives.
- CB contribution to 2011 Technical Report was prepared.
- 2013 Strategic planning process is initiated.
- 2012 SIP mid year review conducted.

July

- Provided significant support to IGS Workshop.
- CB personnel supported the technical aspects of the workshop, compiled workshop archive of Workshop proceedings: http://igs.org/presents/poland2012/
- Organized and managed the GB meetings, minutes and actions, follow–up on many workshop actions (into August).
- Khachikyan assigned as Network Coordinator to be reviewed in a years time.
- 2012 Workshop accounting completed, registration funds transferred to UWM.

August

- Neilan (and Rizos) attended the AOGS meeting in Singapore. An IGS invited presentation was given by Rizos, Neilan participated in the IAG Executive, visited Earth Observatory Singapore, NTU hosted by S. Erikson. Rizos and Dawson, met with deputy director Paramesh.
- IGS Strategic Planning web questionnaire was opened, requesting broad feedback from IGS stakeholders.
- 2008–2012 extensive analysis of progress completed in preparation for Strategic Plan Development. Impact of IGS activities on strategic goals and objectives was conducted.

September

- US PNT Advisory Board attended by Ceva as observer.
- Strategic planning questionnaire closes, draft summary developed.
- CB develops plan for Real–time Service support — caster and website.
- Integrated review comments into 40th GB minutes.
- IGS Institute 2011 financial report and non–profit compliance report prepared and submitted to US Internal Revenue Service.
- CB participates in GGOS Frankfurt retreat preparations

October

- ICSU World Data System Scientific Committee in Taiwan on Margins of the CO–DATA meeting. Accreditation criteria and application developed further, IGS expected to move to Network Member, rather than regular member, due to the extensive structure of the IGS.
- Central Bureau responsibility and accountability matrix, work assignments and position descriptions developed.
- Planning meeting at UNAVCO. CBIS back–up process reviewed.
- Strategic planning strengths, weaknesses, opportunities and threats (SWOT) analysis was conducted, including feedback from the Governing Board members and other IGS participants and stakeholders.
- Real–time Service web hosting service and portal system was procured/configured.
- 2012 Workshop proceedings and recommendations were finalized and posted on the web.
- Fisher was assigned CB Management duties.

November

- IGS participated in ICG–7 in Beijing (Altamimi, Rizos, Neilan) with our FIG partners (Lilje and Higgins). Very productive meeting. WG–D on Reference Frame, Timing and Applications proposed 4 recommendations, all passed. Discussions continued on IGS as supporting real–time monitoring and assessment within the IGMAS committee of ICG.
- Draft Progress Report of IGS 2008–2012 was prepared and circulated for comment.
- SWOT summary analysis distributed to the GB.
- New SP goals, objectives, tasks, targets and measures proposed, discussed at the 41st GB meeting.
- Preparations for all IGS meetings in San Francisco, including GGOS meetings, AC splinter, Trop splinter, and IDS GB meeting.
- Organization of GGOS reception, hosted by IGS and UNAVCO, with a special "Ignite GGOS 2012!" session led by Craddock.
- 2013 Strategic plan goals drafted.
- RT product caster set–up, testing initiated.
- Governing Board meeting preparations.
- IGS rebranding initiated.
- Seamless archive discussions initiated with UNAVCO, soon with Data Centers.

December

- Demonstration RT website set–up for GB.
- Progress Report of IGS 2008–2012 was completed.
- All CB staff attended/supported 41st Governing Board meeting Dec. 2 and other IGS/IAG/GGOS related splinter meetings around AGU.
- IERS Directing Board meeting attended by Fisher.
- 41st GB minutes were drafted and circulated for comment.
- Provided focused support to Real–time Service launch.

4 Plans for 2013

- Publish IGS Strategic Plan 2013–2016
- Develop reporting mechanism based on the plan
- Develop annual implementation plan of the SP
- Modernize IGS website, migrate to outside (of JPL) servers, implement new collaborative features
- Support Real–time Service launch — implement real–time processes and support at the website
- ICG engagement to continue and expand
- Assist in Meta–Data Workshop, joint with GGOS and FIG
- Preparations for IAG 150th Meeting in Potsdam early Sept
- Prepare for 2014 IGS 20th Anniversary Workshop, Pasadena
- Improve visibility of IGS within ION
- Greater engagement with Asian Pacific region
- Continue support of IGS EC and GB meetings
- Improve support to WG and PP chairs for better information systems

Part II

Analysis Centers

Analysis Center Coordinator

J. Griffiths and K. Choi

NOAA National Geodetic Survey
1315 East–West Highway
Silver Spring, Maryland USA
e–mail: igs.acc@noaa.gov

1 Summary of Main ACC Activities

In 2012, IGS core products (see Tab. 1) were combined and distributed in a timely manner. To ensure continued production of high-quality IGS products, the Analysis Center Coordinator (ACC) performed high–level oversight and quality control of Analysis Center (AC) products, combination performance, and maintenance of the ACC website with updated plots. Also performed was coordination among ACs to assimilate changes made by them and to ensure that the best analysis models and procedures are used, along with coordination among the other relevant IGS components, preparation of component reports, and coordination of the IGS 2$^{\text{nd}}$ reprocessing campaign.

2 Events Impacting Product Quality and Reliability

With the exception of a few unusual delays, delivery of all IGS products was generally uninterrupted. The addition of new ACs to the IGS Ultra–rapid and Rapid products has improved their reliability. However, the overall high quality of those two products was unchanged from 2011. In contrast, two changes made to the Final products in preparation for the 2nd IGS reprocessing campaign (IG2; http://acc.igs.org/reprocess2.html) had significant impact. The following sub-sections summarize these two changes, along with the other events impacting the IGS products in 2012.

Table 1: IGS core product series with latency, issue times and data spans.

ID, Series	Latency	Issue times (UTC)	Data spans (UTC)	Remarks
IGA: Ultra-Rapid (observed half)	3 – 9 hr	at 03:00, 09:00, 15:00, 21:00	−24 hr at 00:00, 06:00, 12:00, 18:00	• for near real–time apps • GPS & GLONASS • issued with following IGU
IGU: Ultra-Rapid (predicted half)	real–time	at 03:00, 09:00, 15:00, 21:00	+24 hr at 00:00, 06:00, 12:00, 18:00	• for real–time apps • GPS & GLONASS • issued with prior IGA
IGR: Rapid	17 – 41 hr	at 17:00, daily	±12 hr at 12:00	• for near–definitive, rapid apps • GPS only
IGS: Final	12 – 19 d	weekly, each Thursday/Friday	±12 hr at 12:00 for 7 d	• for definitive apps • GPS & GLONASS

2.1 Delays in Product Delivery

While product flow and generation were generally uninterrupted in 2012, there were a few delays, outlined as follows:

- **Delays in Ultra-rapid products**:
  - 1–July [1695_0_00 & 1695_0_06] due to logical error in ACC ftp retrieval scripts
    - no gap in product availability due to 24 hours of predictions
  - 3–July [1695_2_00] combination failure due to absence of both IGU Data Centers (DCs)
    - Ultra–rapid orbits were provided, but based on only 1 AC
    - NASA/CDDIS planned outage & unexpected power outage at BKG DC
    - added backup DC at Royal Observatory of Belgium for increased redundancy
  - 26–Sep [1707_3_18 thru 1707_4_06] due to power outages at off–site location hosting the ACC servers

    - no gap in product availability

- **Delays in Rapid products**
  - 19–Oct [1710_4] due to ACC failure to correct for issues in RINEX global broadcast navigation (BRDC) file
    - BRDC file issues happen from time to time; this is the first missed issue in nearly 5 years
    - delayed products by ≈ 118 minutes
  - 25–Nov [1715_6] due to bug in combination procedures
    - orbit weight archive decreased in size, two records per day, till empty
    - delayed products by ≈ 82 minutes

2.2 New Analysis Centers

The AC at the National Geodetic Survey (NGS) developed an Ultra–rapid product and began contributing to the IGA/IGU combinations. Their real–time orbit predictions currently contribute with weight and perform near the middle of the group of ACs (Fig. 1). NGS Ultra–rapid ERPs continue to be excluded since they are significantly noisier than nearly all other ACs (e.g., see Y–pole differences in Fig. 2).

The space geodesy group at Wuhan University (WHU) in China formed an AC in 2011 and began contributing Ultra-rapid and Rapid products to the IGS combinations in 2012. Their GPS and GLONASS orbits contribute fully to the Ultra-rapid combinations; the GPS part is currently performing amongst the top three ACs (Fig. 1). WHU Ultra-rapid ERPs continue to be excluded as they often have very large departures (e.g., see Fig. 2). WHU GPS Rapid products are included for comparison in the IGR combinations.

The added redundancy from the additional new Ultra–Rapid and Rapid ACs helps to improve the reliability of these products lines.

2.3 Switch to Daily SINEX Integrations

Starting August 19, 2012 (GPS Wk 1702, Day 0), the IGS Final products are based on daily terrestrial reference frame (TRF), or SINEX, integrations, marking a switch from the long-standing approach using weekly frames (Kouba and Mireault, 1997; Beutler et al., 1993; Ferland at al., 2000; Kouba et al., 1998). The switch to daily TRFs was in response to continued debate about the effects of non–tidal loading displacements on the IGS products. Therefore, in order to facilitate further study of these effects, the IGS adopted an approach to base the Final products on daily AC SINEX integrations. This will allow for various models to be applied at the combination level, which should facilitate progress toward conventional models in the future.

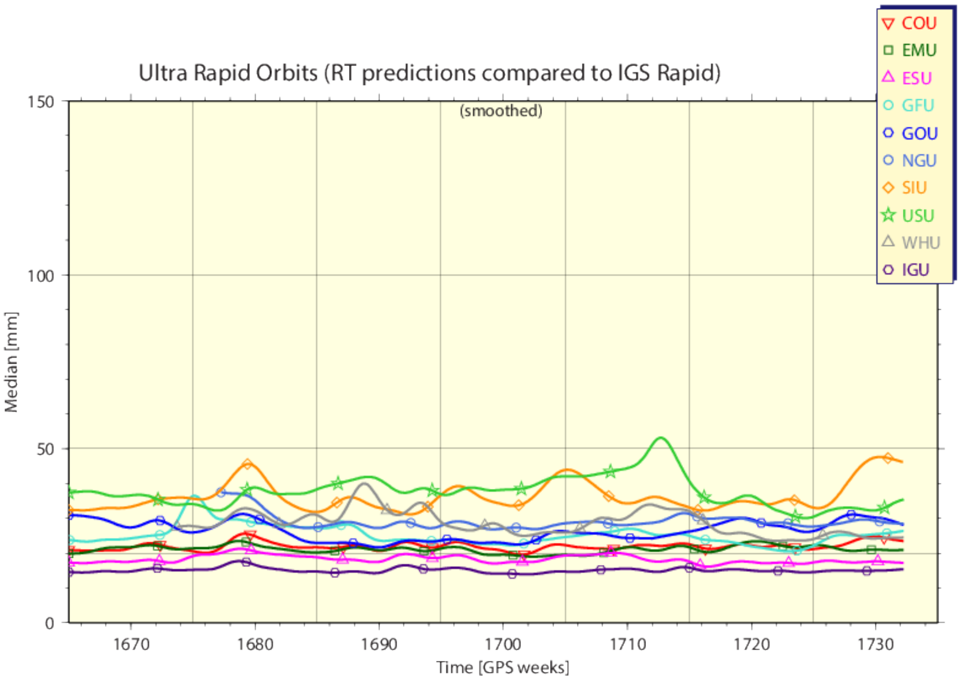

Figure 1: Median of the ensemble of GPS satellite orbit residuals from the 48 h IGA/IGU combination.

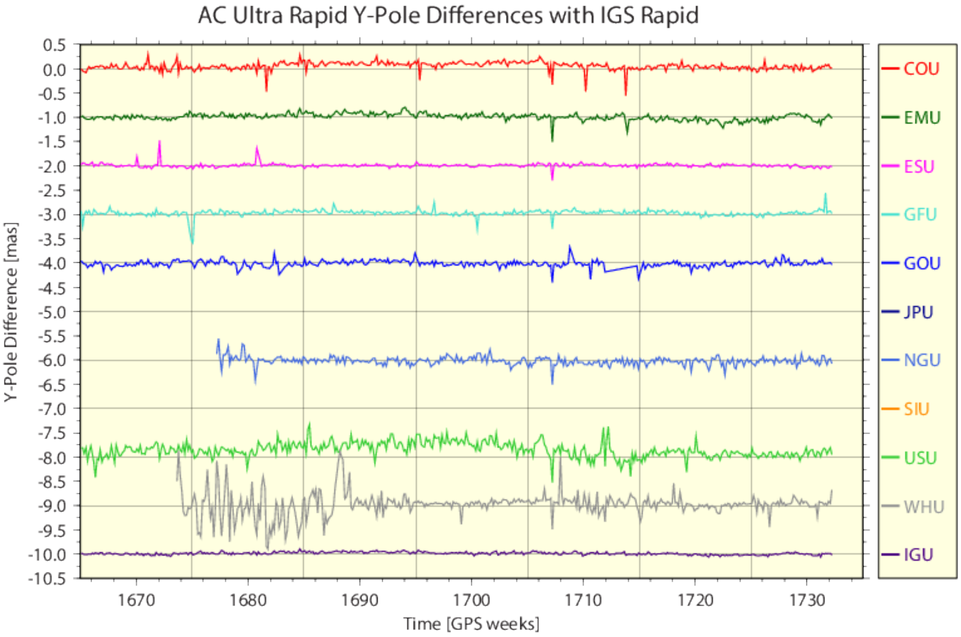

Figure 2: Y–pole differences from the 24 h IGA ERP combination.

Products based on daily TRFs could be up to $\sqrt{7} \approx 2.6$ times noisier than those based on weekly frames. Test combinations from before the switch indicated that there would be no noticeable impact on the ERPs. Furthermore, the RMS of GPS orbits would increase by ≈ 0.5 mm; and the RMS for the ensemble of station and satellite clocks would increase by about 2.5 ps. Meanwhile, kinematic PPP results indicated that there would be no noticeable change in the overall composite orbit and clock accuracy. Thus, most users should not have noticed a change with the new orbits and clocks. The RMS of station position residuals from the SINEX combination increased by a factor of up to 1.5, mostly in East & Up, but much less than if the IGS errors were dominantly white noise. The North residuals were generally less affected by the switch. Thus, the gain in temporal resolution should be offset by little additional noise on station positions. Of course, the total product errors, including systematic effects, are much larger than these small changes. For more details, see IGSMAIL #6613.

Since the adoption of daily TRFs, the relative performance of AC products remains consistent with the preliminary findings of the test period conducted before the switch. However, a comprehensive study of the impact on the IGS operational products should be made now that more than 30 weeks have passed since the switch.

This switch to daily SINEX integrations marks the largest of changes to the IGS Final products since 2000, when the IGS began using TRF and ERP rotations to pre-align AC orbits (IGSMAIL #2750). This event also marks a major step toward improved inter–AC consistency w.r.t. providing truly daily products according to long-standing IGS conventions. This is a major accomplishment and it is important to recognize the ACs for their tremendous efforts in the switch to daily products.

2.4 Adoption of IGb08

Starting October 7, 2012 (GPS Wk 1709, Day 0), the IGb08 update to IGS08 is used for IGS products. The update was made to recover core reference frame stations that were impacted by station position discontinuities induced mostly by anthropogenic sources. See IGSMAIL #6663.

2.5 Other ACC Activities Impacting Product Quality

Study of Rotational Offset Between IGU and IGR

The IGV (test IGU GLONASS combination) was introduced on September 9, 2010, but not widely advertised given its “experimental” status. The IGV SP3 file is mixed, with GPS and GLONASS orbits and only GPS clocks. This experimental product began with igv1601_4_06.[sum, sp3] and continues today. A recent test development in the production of the IGV was intended to improve rotational alignment, esp. in RZ, with the Rapid orbit products, but the results were inconclusive.

Rotational misalignment of the IGS Ultra–rapid GPS orbit has been noticed for several years. In 2010, the ACC quantified these errors (see IGSMAIL #6053), documenting large RZ scatter (≈ 12.7 mm @ GPS) between the IGA and IGR. The underlying frame for the IGU is intended to be similar to that of the IGR by transferring the terrestrial frame to the orbits via fixing the *a priori* positions of the reference frame stations. Given the similarity in the orbit determination strategies and even some common AC contributions, one should expect nearly the same orbit performance of the IGRs and IGAs. Besides a small difference in *a priori* EOP latency, the other main effect is probably the inclusion of the 24–hour orbit predictions when aligning the IGU AC orbits. Rotational variations in the prediction phase are much larger than these during the observed phase.

Starting with the IGV for 1693_1_18 (18 June 2012) and ending with the IGV for 1721_3_06 (2 January 2013), a modified test combination procedure was adopted where systematic AC orbital frame differences were determined using only the observed orbits instead of the full 48 hours. The Helmert parameters determined in this process were then imposed on the full 48 hours for the final IGV combination, eliminating the opportunity for orbit prediction errors to corrupt the AC orbit frame alignments. The residual statistics and AC weights continued to be based on the full 48 hours. Results from this test combination approach were inconclusive, suggesting that other errors dominate the rotational offset with the other IGS orbits.

Study of Final Orbit Misalignment

This study was primarily motivated by biases and scatter in the AC Final orbit X– and Y–rotations (RX and RY), as illustrated for ESA, NGS and SIO in Fig. 3. Also, rather surprising results presented by Jim Ray and his colleagues at IGS Workshops and the 2012 EGU General Assembly (2010, 2011, and 2012; `http://acc.igs.org/studies.html`) provided additional motivation. Those presentations showed a rotational misalignment between the IGS orbits and the IGA/IGR orbits, especially in RX and RY. Unexpectedly, the IGR and IGA were more consistent with one another and more accurate than the IGS. A few ideas were proposed to explain the results, including the possibility that procedural issues exist in the Final orbit combination.

At the AC level, the Ultra–rapid and Rapid procedures transfer the terrestrial frame to the orbits by tightly constraining the *a priori* positions of the IGb08 reference frame stations. The Finals AC procedures use a no–net rotation (or other removable) constraint, satisfied over the IGb08 core network. At the combination level, prior to August 19, 2012 (GPS Wk 1702, Day 0), the main procedural difference between the Final orbits and the Ultra-rapid and Rapid orbits is that AC SINEX and AC ERP X– and Y–rotations were applied

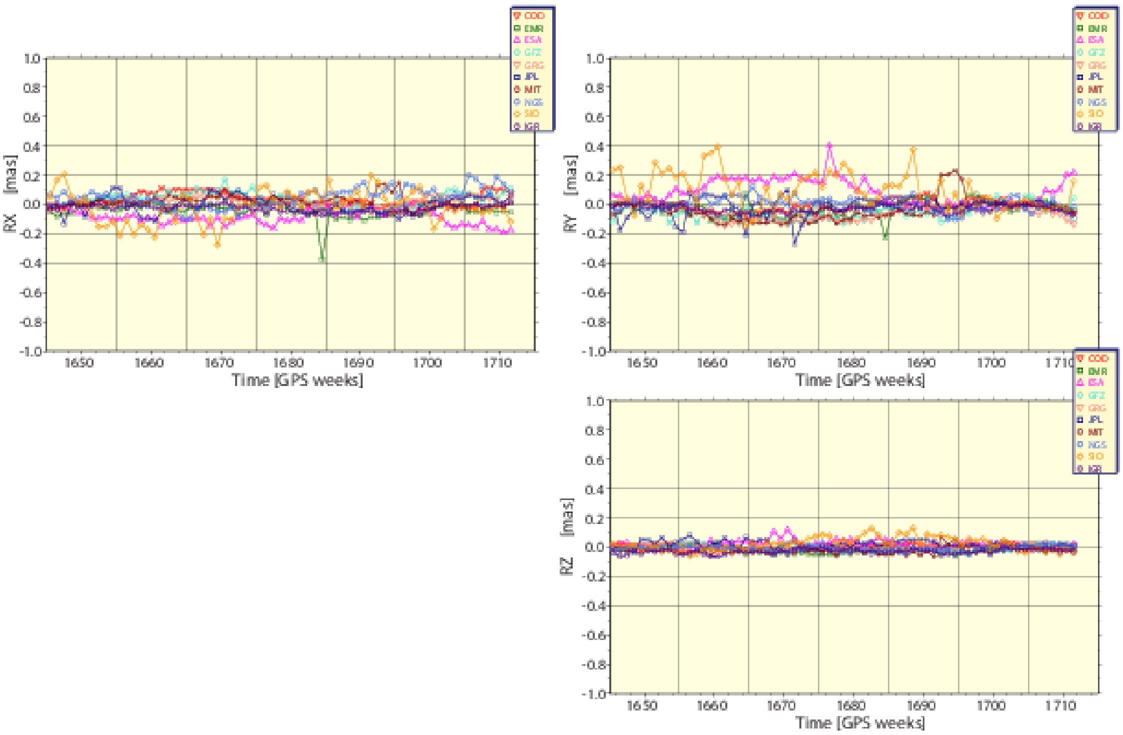

Figure 3: AC rotational offsets from the IGS Final orbit.

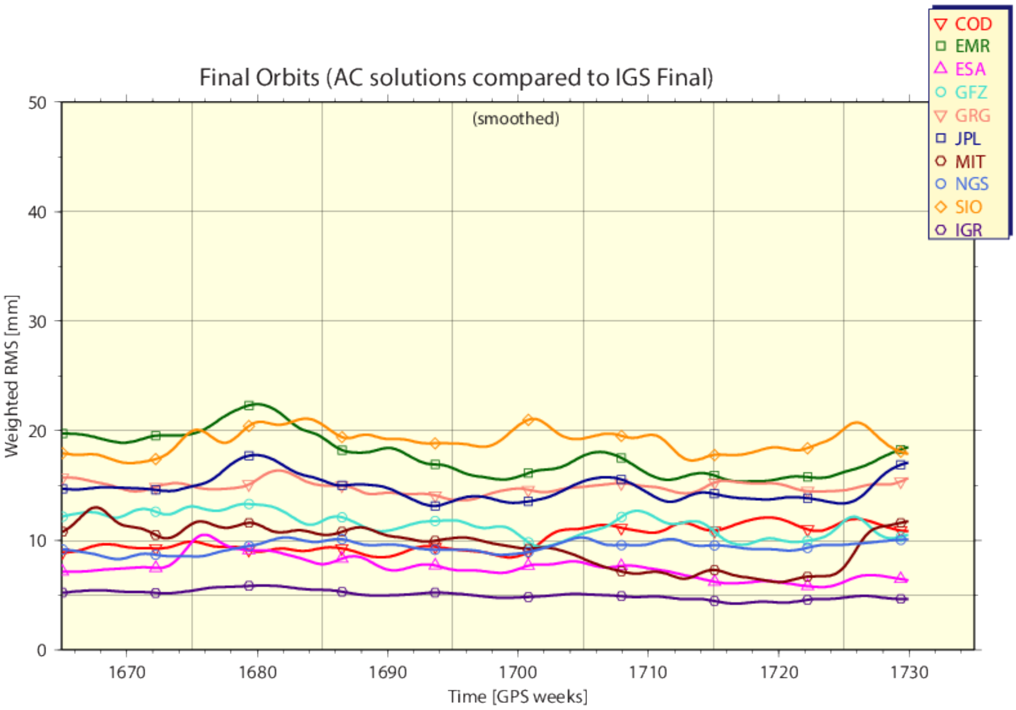

Figure 4: WRMS of AC orbit residuals w.r.t. IGS Finals.

for the Final orbits. This study reviewed the Final orbit combination model and found two issues: the signs used for the AC SINEX X– and Y–rotations were incorrect and the AC ERP rotations were no longer necessary since the switch to daily TRFs. More details are available in a report at `http://acc.igs.org/orbits/acc_report_final_rotations.pdf`.

Correcting the two issues found in this study had a significant impact on the quality of the IGS Final orbits. Although the scatter was not impacted (Fig. 4), the changes in the rotational offsets of the AC orbits are much clearer (e.g., see Y–rotations in Fig. 5). In addition, the ACC Final PPP results indicate that the Final orbits are now much more consistently aligned with the IGS frame (IGb08) than before (Fig. 6), reducing the rotational offset by up to 20 μas in RX and RY.

Starting with GPS Wk 1702, Fig. 5 shows that there is a high level of inter–AC agreement, with ESA and GFZ being possible exceptions. However, what is starkly clear from Fig. 5 is that the orientation of the ESA orbits is quite different from the other ACs. Since ESA dominates the combination, the orientation of the Final orbits disagrees with the other ACs and the IGRs by nearly equivalent amounts. ESA is currently investigating the cause of their rotational offsets relative to the other ACs. However, it is critical to note that these features could not be seen before the switch to daily TRFs and when the SINEX rotation problems existed in the Final orbit combination. This fact is illustrated in Figure 6 with the improved average RX and RY offsets starting at Wk 1702 . Figures 5 and 6 highlight advantages of 1) improved inter-AC agreement with the switch to daily TRFs and 2) correct pre–alignment of AC orbits in the Final orbit combination.

2.6 Preparations for IGS 2nd Reprocessing (IG2)

Preparations for the next reprocessing are underway. The past year was spent establishing a set of minimum analysis standards (see items in black at `http://acc.igs.org/reprocess2.html`), which was finalized at the IGS Workshop in Olsztyn, Poland. Since then, the ACs have worked to implement these minimum standards. Thus far, ACs have generally implemented nearly all of the minimum standards. Though a few still need to adopt models for 2nd–order ionosphere effects, Earth radiation (visible and infrared) and satellite thrusting due to signal transmission along the antenna bore site.

In addition to the minimum analysis standards, other models are proposed and can be adopted as each AC chooses. These are printed in red at the IG2 website. The following preliminary schedule for IG2 was discussed at the AC splinter meeting in San Francisco, CA on December 4, with an aim to submit IGS SINEX products to the IERS in early 2014 for the next ITRF:

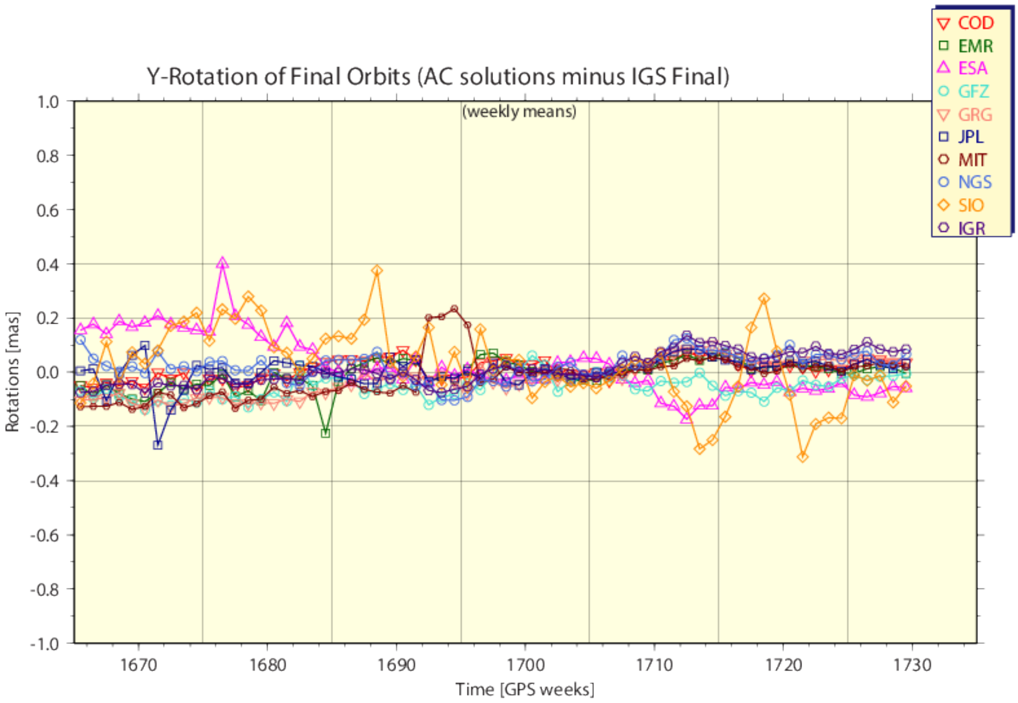

Figure 5: AC orbit Y-rotation offsets w.r.t. IGS Finals.

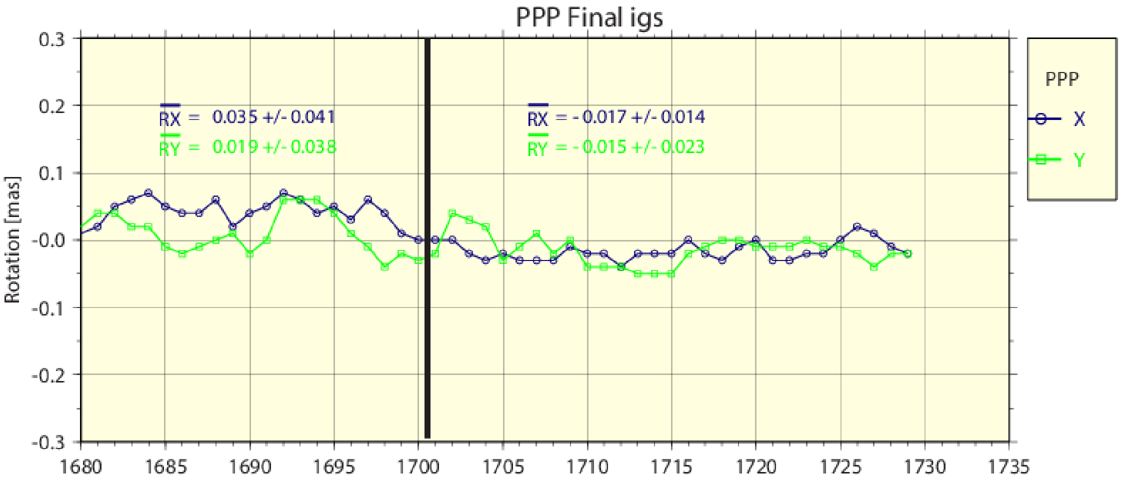

Figure 6: X, Y and Z Helmert rotations between PPP results using the IGS products and IGb08 (see more at http://acc.igs.org/index_igsacc_ppp.html).

Time period (2013)	Objective
January thru May	Implement remaining minimum analysis standards
June thru August	Initial processing of 1994.0 thru 2013.3 and possibly submit to IGS for test combinations
September thru November	ACs finalize their submissions and submit to IGS

3 User Interest in IGS Products

A recent analysis of the statistics for IGS product downloads at NASA's Crustal Dynamics Data Information System (CDDIS) indicates that the IGS Ultra–rapid GPS orbits and ERPs are more than twice as popular as the next most downloaded product, the IGS Final GPS products (Tab. 2).

Table 2: IGS product download rates from NASA GSFC/CDDIS (statistics courtesy of Carey Noll). The statistics include the IGS core products, along with those from the 1st reprocessing (IG1), the GLONASS Final orbits (IGL) and an experimental mixed GPS plus GLONASS Ultra-rapid products (IGV).

Product	GNSS	Total Hits	SP3 (%)	ERP (%)	CLK (%)	SNX (%)	SUM (%)
IGU/IGA	GPS	11,711,506 ($\approx 4 \times 2,927,877$ daily)	93.7	3.1	n/a	n/a	3.2
IGS+IG1	GPS	1,359,656	60.7	6.8	24.8	5.8	2.0
IGR	GPS	887,986	65.6	8.7	16.9	n/a	6.4
IGL	GLO	225,515	99.1	n/a	0.3	n/a	0.6
IGV	GPS & GLO	223,562	95.0	n/a	n/a	n/a	5.0

4 Publications and Meeting Presentations

The following sub–sections highlight a selection of papers and presentations from 2012 that are relevant to the quality of the IGS products (see full list at `http://acc.igs.org/studies.html`).

4.1 Antenna Calibrations

- Impact of different individual GNSS receiver antenna calibration models on geodetic positioning (2012)
  by Q. Baire, E. Pottiaux, C. Bruyninx, P. Defraigne, W. Aerts, J. Legrand, N. Bergeot, and J. M. Chevalier, poster presentation at the European Geosciences Union 2012 General Assembly

- Extension of the GPS satellite antenna patterns to nadir angles beyond 14° (2012)
  by A. Jäggi, F. Dilssner, R. Schmid, R. Dach, T. Springer, H. Bock, P. Steigenberger, Y. Andres, and W. Enderle, poster presentation at the European Geosciences Union 2012 General Assembly

- GNSS Absolute Antenna Calibration at the National Geodetic Survey (2012)
  by G. Mader, and A. Bilich, poster presentation at the European Geosciences Union 2012 General Assembly

- Impact of individual GNSS antenna calibration used in the EPN on positioning (2012)
  by Q. Baire, E. Pottiaux, C. Bruyninx, P. Defraigne, W. Aerts, J. Legrand, N. Bergeot, and J. M. Chevalier, presentation at the EUREF 2012 Reference Frame Sub-commission for Europe Symposium, Paris, 6–8 June 2012

- GNSS antenna offset field test in Metsähovi (2012)
  by U. Kallio, H. Koivula, S. Nyberg, P. Häkli, P. Rouhiainen, and V. Saaranen, presentation at the EUREF 2012 Reference Frame Sub-commission for Europe Symposium, Paris, 6–8 June 2012

- Differences between GPS receiver antenna calibration models and influence on geodetic positioning (2012)
  by Q. Baire, W. Aerts, C. Bruyninx, E. Pottiaux, and J. Legrand, presentation at the Fall 2012 American Geophysical Union Meeting

- Towards better GNSS observations at the new IGS reference station BRUX (2012)
  by W. Aerts, Q. Baire, C. Bruyninx, J. Legrand, and E. Pottiaux, invited presentation at the Fall 2012 American Geophysical Union Meeting

4.2 Earth Rotation Parameters

- High–accuracy subdaily ERPs from the IGS (2012)
  by J. Ray and J. Griffiths, presentation at the European Geosciences Union 2012 General Assembly
- High–frequency signals of oceans and atmosphere in Earth rotation (2012)
  by S. Böhm, presentation at the European Geosciences Union 2012 General Assembly

4.3 Ionosphere Modeling and Products

- Intercomparison of approaches for modeling second order ionospheric corrections using GNSS measurements (2012)
  by M. Garcia–Fernandez, M. Butala, A. Komjathy, and S. Desai, poster presentation at the Fall 2012 American Geophysical Union Meeting

4.4 Orbit Modeling and Products

- IGS preparations for the next reprocessing and ITRF (2012)
  by J. Griffiths, P. Rebischung, B. Garayt, and J. Ray, presentation at the European Geosciences Union 2012 General Assembly
- Modeling of the GIOVE-B clock as a tool for studying radiation pressure models (2012)
  by U. Hugentobler, O. Montenbruck, C. Rodriguez–Solano, and P. Steigenberger, poster presentation at the European Geosciences Union 2012 General Assembly
- Multi–technique combination at observation level with NAPEOS (2012)
  by M. Otten, C. Flohrer, T. Springer, and W. Enderle, presentation at the European Geosciences Union 2012 General Assembly
- Non–conservative GNSS satellite modeling: long-term behavior (2012)
  by C. Rodriguez–Solano, U. Hugentobler, P. Steigenberger, K. Sosnica, and M. Fritsche, poster presentation at the European Geosciences Union 2012 General Assembly
- Characterizing GPS Block IIA shadow and post-shadow maneuvers (2012)
  by J. Weiss, Y. Bar–Sever, W. Bertiger, S. Desai, N. Harvey, and A. Sibthorpe, poster presentation at the European Geosciences Union 2012 General Assembly
- Rotational errors in IGS orbit & ERP products (2012)
  by J. Ray, J. Griffiths, P. Rebischung, J. Kouba, and W. Chen, presentation in orbit modeling plenary session at IGS 2012 Workshop, Olsztyn, Poland

- Do annual geopotential variations affect IGS products? (2012)
  by J. Ray, S. Bettadpur, J. Ries, T.–S. Bae, X. Collilieux, T. van Dam, K. Choi, and J. Griffiths, presentation for the AC/RF/CP WG Splinter Meeting at the IGS 2012 Workshop, Olsztyn, Poland
- IGS classic products, status and towards the future (2012)
  by J. Griffiths and K. Choi, presentation in opening plenary session at IGS 2012 Workshop, Olsztyn, Poland
- The impact of temporal geopotential variations on the GPS constellation (2012)
  by S. Melachroinos, F. Lemoine, J. Nicholas, N. Zelensky, D. Chinn, O. Bordyugov, B. Beckley, and S. Luthcke, poster presentation at the Fall 2012 American Geophysical Meeting
- Space tie and local tie for combined GNSS-SLR analysis (2012)
  by D. Thaller, K. Sosnica, R. Dach, and A. Jäggi, poster presentation at the Fall 2012 American Geophysical Meeting
- Sub–daily Alias and Draconitic Errors in IGS Orbits (2012)
  by J. Griffiths and J. Ray, GPS Solutions, doi: 10.1007/s10291-012-0289-1

5 Events in 2013

- Maintain existing products, as usual.
- Perform comprehensive analyses to establish IGS/IGR/IGU errors since the switch to daily TRFs and corrections to the IGS Final orbit combination.
- Coordinate second reprocessing campaign, along with performing combinations of the repro2 orbits and clocks. The project is expected to deliver combined SINEX files to the IERS by early 2014. This will require coordinated processing and delivery of AC products to Data Centers and test combinations.
- Investigate possibility of GLONASS clock combinations using s/w and results from Bias Working Group.

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Center for Orbit Determination in Europe (CODE)

R. Dach[1], S. Schaer[2]

S. Lutz[1], M. Meindl[1], H. Bock[1], E. Orliac[1], L. Prange[1],
D. Thaller[1], L. Mervart[a], A. Jäggi[1], G. Beutler[1]

E. Brockmann[2], D. Ineichen[2], A. Wiget[2]

G. Weber[3], H. Habrich[3], W. Söhne[3], J. Ihde[3]

P. Steigenberger[4], U. Hugentobler[4]

[1] Astronomical Institute, University of Bern, Bern, Switzerland
E–mail: `code@aiub.unibe.ch`
[2] Federal Office of Topography swisstopo, Wabern, Switzerland
[3] Federal Agency of Cartography and Geodesy,
Frankfurt a. M., Germany
[4] Institut für Astronomische und Physikalische Geodäsie,
Technische Universität München, Munich, Germany

1 The CODE consortium

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following four institutions:

- Astronomical Institute, University of Bern (AIUB), Bern, Switzerland,
- Federal Office of Topography swisstopo, Wabern, Switzerland,
- Federal Agency of Cartography and Geodesy (BKG), Frankfurt a. M., Germany, and
- Institut für Astronomische und Physikalische Geodäsie, Technische Universität München (IAPG, TUM), Munich, Germany.

The operational computations are performed at AIUB whereas reprocessing activities are usually carried out at IAPG, TUM. All solutions and products are produced with the latest development version of the Bernese GNSS Software (Dach et al., 2007).

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[a] Institute of Geodesy, Czech Technical University in Prague, Czech Republic

2 CODE products available to the public

A wide variety of GNSS solutions based on a rigorous combined GPS/GLONASS data processing scheme is computed at CODE. The products are made available through anonymous ftp:
`ftp://ftp.unibe.ch/aiub/CODE/` or `http://www.aiub.unibe.ch/download/CODE/`
An overview of the files is given in Tab. 1.

Table 1: CODE products available through anonymous ftp.

CODE *ultra–rapid* products available at `ftp://ftp.unibe.ch/aiub/CODE`

`COD.EPH_U`	CODE ultra–rapid orbits, updated every 6 hours
`COD.ERP_U`	CODE ultra–rapid ERPs belonging to the ultra–rapid orbit product
`COD.TRO_U`	CODE ultra–rapid troposphere product, troposphere SINEX format
`COD.SUM_U`	Summary of stations used for the latest ultra–rapid orbit
`COD.ION_U`	Last update of CODE rapid ionosphere product (1 day) complemented with ionosphere predictions (2 days)
`COD.EPH_5D`	Last update of CODE 5–day orbit predictions, from rapid analysis, including all active GLONASS satellites

CODE *rapid* products available at `ftp://ftp.unibe.ch/aiub/CODE`

`CODwwwwd.EPH_R`	CODE rapid orbits
`CODwwwwd.EPH_P`	CODE 24–hour orbit predictions
`CODwwwwd.EPH_P2`	CODE 48–hour orbit predictions
`CODwwwwd.EPH_5D`	CODE 5–day orbit predictions
`CODwwwwd.ERP_R`	CODE rapid ERPs belonging to the rapid orbits
`CODwwwwd.ERP_P`	CODE predicted ERPs belonging to the predicted 24–hour orbits
`CODwwwwd.ERP_P2`	CODE predicted ERPs belonging to the predicted 48–hour orbits
`CODwwwwd.ERP_5D`	CODE predicted ERPs belonging to the predicted 5–day orbits
`CODwwwwd.CLK_R`	CODE rapid clock product, clock RINEX format
`CODwwwwd.TRO_R`	CODE rapid troposphere product, troposphere SINEX format
`CODwwwwd.SNX_R.Z`	CODE rapid solution, SINEX format
`CORGddd0.yyI`	CODE rapid ionosphere product, IONEX format
`COPGddd0.yyI`	CODE 1–day or 2–day ionosphere predictions, IONEX format
`CODwwwwd.ION_R`	CODE rapid ionosphere product, Bernese format
`CODwwwwd.ION_P`	CODE 1–day ionosphere predictions, Bernese format
`CODwwwwd.ION_P2`	CODE 2–day ionosphere predictions, Bernese format
`CGIMddd0.yyN_R`	Improved Klobuchar–style coefficients, RINEX format
`CGIMddd0.yyN_P`	1–day predictions of improved Klobuchar–style coefficients
`CGIMddd0.yyN_P2`	2–day predictions of improved Klobuchar–style coefficients
`P1C1.DCB`	CODE sliding 30–day P1−C1 DCB solution, Bernese format, containing only the GPS satellites
`P1P2.DCB`	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites
`P1P2_ALL.DCB`	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing all GPS and GLONASS satellites and all stations used
`P1P2_GPS.DCB`	CODE sliding 30–day P1−P2 DCB solution, Bernese format, containing only the GPS satellites

Table 1: CODE products available through anonymous ftp (cont.).

CODE *final* products available at `ftp://ftp.unibe.ch/aiub/CODE/yyyy/`

`yyyy/CODwwwwd.EPH.Z`	CODE final GNSS orbits, CODE's official IGS orbit product
`yyyy/CODwwwwd.ERP.Z`	CODE final ERPs belonging to the final orbits
`yyyy/CODwwwwd.CLK.Z`	CODE final clock product, clock RINEX format, with a sampling of 30 sec for the satellite and reference (station) clock corrections, but 5 minutes for all remaining station clock corrections
`yyyy/CODwwwwd.CLK_05S.Z`	CODE final clock product, clock RINEX format, with a sampling of 5 sec for the satellite and reference (station) clock corrections, but 5 minutes for all remaining station clock corrections
`yyyy/CODwwwwd.SNX.Z`	CODE daily SINEX product
`yyyy/CODwwwwd.TRO.Z`	CODE final troposphere product, troposphere SINEX format
`yyyy/CODGddd0.yyI.Z`	CODE final ionosphere product, IONEX format
`yyyy/CODwwwwd.ION.Z`	CODE final ionosphere product, Bernese format
`yyyy/CODwwww7.SNX.Z`	CODE weekly SINEX product
`yyyy/CODwwww7.SUM.Z`	CODE weekly summary files
`yyyy/CODwwww7.ERP.Z`	CODE ERPs from a weekly solution
`yyyy/COXwwwwd.EPH.Z`	CODE precise GLONASS orbits (for GPS weeks 0990 to 1066)
`yyyy/COXwwww7.SUM.Z`	CODE weekly summary files of GLONASS analysis
`yyyy/CGIMddd0.yyN.Z`	Navigation messages containing improved Klobuchar–style ionosphere coefficients
`yyyy/P1C1yymm.DCB.Z`	CODE monthly P1−C1 DCB solutions, Bernese format, containing only the GPS satellites
`yyyy/P1P2yymm.DCB.Z`	CODE monthly P1−P2 DCB solutions, Bernese format, containing all GPS and GLONASS satellites
`yyyy/P1P2yymm_ALL.DCB.Z`	CODE monthly P1−P2 DCB solutions, Bernese format, containing all GPS and GLONASS satellites and all stations used

Note, that as soon as a final product is available the corresponding rapid, ultra–rapid, or predicted products are removed from the anonymous FTP server.

With GPS week 1706 CODE started to generate a pure one–day solution (label "COF") in addition to the usual three–day long–arc solution (label "COD"). A detailed description is given in Sect. 3.2 of this report. The result files from both series are submitted to the IGS data centers hosting the products. The files are listed in Tab. 2.

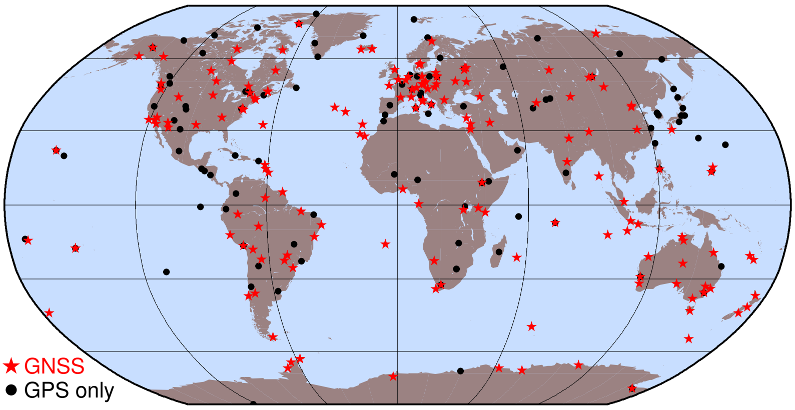


Figure 1: Network used for the GNSS final processing at CODE by the end of 2012.

The network used by CODE for the final processing is shown in Fig. 1. About 70% of the stations support GLONASS (red stars).

Table 2: CODE final products available in the product directories of the IGS data centers.

Files generated from three–day long–arc solutions:

`CODwwwwd.EPH.Z`	GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a long–arc analysis
`CODwwwwd.ERP.Z`	GNSS ERP (pole, UT1−UTC) solution belonging to the COD–orbit files in IGS IERS ERP format
`CODwwwwn.SNX.Z`	GNSS daily coordinate/ERP/GCC from the long–arc solution in SINEX format
`CODwwwwd.CLK.Z`	GPS satellite and receiver clock corrections at 30–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format
`CODwwwwd.CLK_05S.Z`	GPS satellite and receiver clock corrections at 5–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format
`CODwwwwd.TRO.Z`	GNSS 2–hour troposphere delay estimates obtained from the long–arc solution in troposphere SINEX format
`CODwwww7.ERP.Z`	GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COD–ERP solutions of the week in IGS IERS ERP format
`CODwwww7.SUM`	Analysis summary for 1 week
`CODwwww7.SNX.Z`	GNSS weekly station coordinates, SATAs, GCCs, and daily sets of ERPs in SINEX format stacked from the seven long–arc solutions of the week

Files generated from pure one–day solutions:

`COFwwwwd.EPH.Z`	GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a pure one–day solution
`COFwwwwd.ERP.Z`	GNSS ERP (pole, UT1−UTC) solution belonging to the COF–orbit files in IGS IERS ERP format
`COFwwwwd.SNX.Z`	GNSS daily coordinate/ERP/GCC from the pure one–day solution in SINEX format
`COFwwwwd.CLK.Z`	GPS satellite and receiver clock corrections at 30–sec intervals referring to the COF–orbits from the pure one–day analysis in clock RINEX format
`COFwwwwd.CLK_05S.Z`	GPS satellite and receiver clock corrections at 5–sec intervals referring to the COF–orbits from the pure one–day analysis in clock RINEX format
`COFwwwwd.TRO.Z`	GNSS 2–hour troposphere delay estimates obtained from the pure one–day solution in troposphere SINEX format
`COFwwww7.ERP.Z`	GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COF–ERP solutions of the week in IGS IERS ERP format
`COFwwww7.SUM`	Analysis summary for 1 week
`COFwwww7.SNX.Z`	GNSS weekly station coordinates, SATAs, GCCs, and daily sets of ERPs in SINEX format stacked from the seven pure one–day solutions of the week

Note, that the `COD`–series is identical with the files posted at CODE's anonymous ftp server, see Tab. 1.

3 Changes in the daily processing for the IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. The last technical report was published in Dach et al. (2012).

In Sect. 3.1 we give an overview of important development steps in the year 2012. Section 3.2 provides details on the biggest change in the processing scheme and modelling, which results in the parallel submission of the traditional three–day long–arc and a new pure one–day solution series.

Table 3: Selected modifications of the CODE processing, in 2012.

Date	DoY/Year	Description
14-Feb-2012	045/2012	Reduce baseline lengths for ambiguity resolution in rapid processing
14-Feb-2012	045/2012	Several problems concerning GPS quarter–cycle bias handling solved
29-Mar-2012		GPS quarter–cycle bias handling changed: No ambiguity resolution at all for satellites with (potential) quarter–cycle problems
23-Apr-2012	114/2012	Maximum 300 (instead of 250) stations allowed for final processing
22-Jun-2012	174/2012	SINEX daily solution from rapid processing stored without regularization
01..04-Jul-2012		Serious leap second problem in the software ultra–rapid 18:00 submission of day 186 is OK again.
10-Jun-2012	162/2012	Daily SINEX files based on one–day and three–day orbital arcs started for parallel test processing Transform ERP to offset and drift in SINEX files (NEQ representation)
02-Aug-2012		FES2004 ocean tidal loading coefficients updated (small changes with respect to the prev. file)
05-Aug-2012	218/2012	Troposphere gradient values in Troposphere SINEX
19-Aug-2012	232/2012	All NEQs are normalized at the diagonal for inversion
16-Sep-2012	260/2012	List of model changes for *all product lines*: • Troposphere gradient model from TANZ to Chen and Herring (1997) • IERS 2010 conventions (Petit and Luzum, 2010) including, e.g., new potential models for orbit integration: Earth: from JGM3. to EGM2008; Ocean tides: from OT_CSR30 to OT_FES2004 Update of the subdaily pole and nutation model List of model changes for *final product line*: • Vienna non–tidal atm. pressure loading (Wijaya et al., 2011) with scaling factors (forced to zero for IGS product generation) • CODE weekly solution only for solution verification • CODE traditional three–day solution bases on three–day coordinate set instead of weekly coordinates after an automated verification of the fiducial sites • Start a new pure one–day solution series in parallel with the label COF for orbits, ERP, SINEX, and clocks with a fully automated verification of the datum stations • GLONASS–GPS translation parameters are deleted from the normal equations for IGS product generation • Delete parameters for long–term monitoring instead of constrain them during the product generation • Numerous consistency tests for all product generation steps
16-Sep-2012	260/2012	Magnetic pole table updated using GMPOLE program (1980–2015)
16-Sep-2012	260/2012	ANTEX model update from IGS08_1700 to IGS08_1706 with changed Z–offset values for a subset of satellites
07-Oct-2012	281/2012	Use IGb08 instead of IGS08 for geodetic datum definition
07-Oct-2012	281/2012	Minor change in ambiguity resolution
11-Nov-2012	316/2012	Bugfix for computation of formal error of pole rates and LOD (all ERP files contained wrong formal errors)

3.1 Overview of changes in the processing scheme in 2012

Table 3 gives an overview of the major changes implemented during the year 2012. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (`ftp://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn`).

Several other improvements not listed in Tab. 3 were implemented, too. Those mainly concern data download and management, sophistication of CODE's analysis strategy, software changes (improvements), and many more. As these changes are virtually not relevant for users of CODE products, they will not be described in detail.

3.2 Details on selected model changes

Test solutions for weeks 1692 to 1705

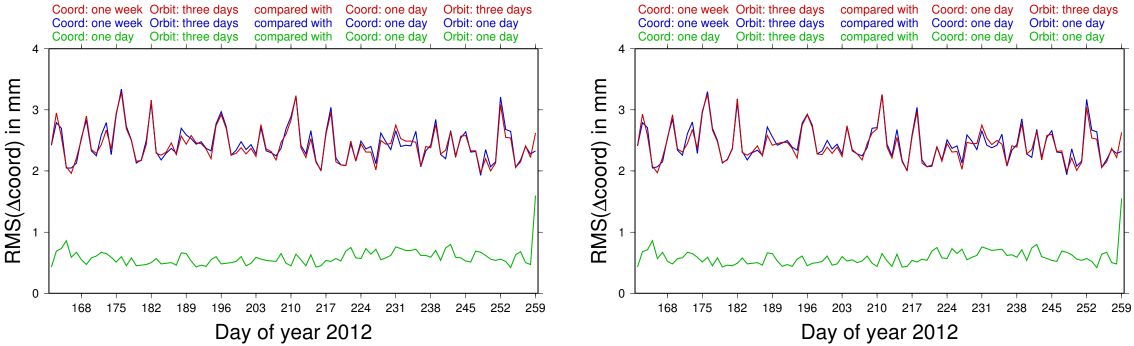
The biggest update of the IGS processing scheme at CODE was initiated by the transition from weekly to daily coordinates for the IGS final product series, which is motivated by the opportunity to correct for non–tidal atmospheric pressure loading at post–processing level. This deep change in the IGS product generation was prepared by a ten–week parallel test campaign.

Two solution series have been generated by CODE for this test campaign:

- A pure one–day solution where the datum definition was based on the verified set of datum stations from the weekly solution.
- A three–day long–arc solution where the coordinate, troposphere, Earth rotation, and geocenter coordinate parameters for the first and third day have been pre–eliminated before connecting them with the parameters for the middle day. The datum definition was also based on the verified set of datum stations from the weekly solution.

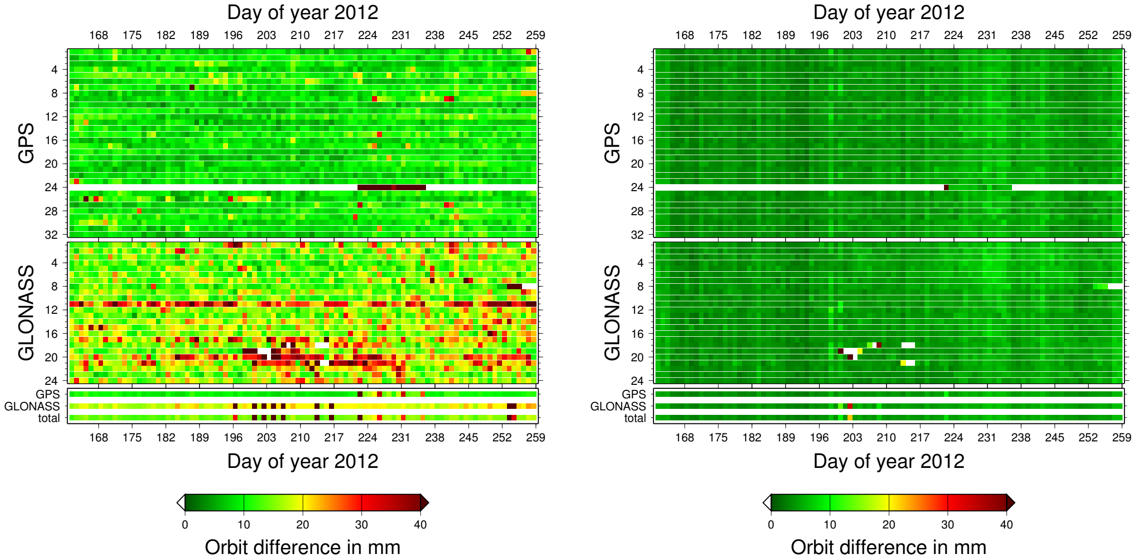
In both cases the GNSS–translation parameters have been introduced from the weekly solution. The traditional solution as it has been computed by CODE since years based on three–day long–arcs for the orbits and the weekly coordinates (daily estimates for the Earth rotation parameters also from the weekly solution) is the third solution for comparisons. The main question for this test period was how the shorter (and therefore noisier) coordinate estimates may degrade the orbit quality.

From the numerous comparisons done at CODE at that time the differences in the station coordinates are provided in Fig. 2 and the differences in the GNSS satellite orbits in Fig. 3. The main conclusions from this comparison are in short:



(a) RMS of direct differences (b) RMS after a seven–parameter transformation

Figure 2: Coordinate comparison of the two test solutions and the traditional CODE solution.



(a) Three–day long–arc orbits with one–day coordinates wrt. pure one–day solution for orbits and coordinates

(b) Three–day long–arc orbits with one–day coordinates wrt. three–day long–arc orbits with weekly coordinates

Figure 3: RMS from the orbit differences over the three coordinate components.

- The RMS between the one–day and the weekly coordinates are mainly dominated by stations where the repeatability is also higher when the weekly coordinate solutions are generated. The datum definition is consistent for all solutions.

- In the pure one–day solution the differences of the orbits of individual satellites may become huge with respect to three–day long–arc solutions especially for satellites that are only marginally observed (unhealthy) or due to observation scenarios during repositioning events of GPS satellites. In general the differences for GLONASS satellites are bigger than for GPS satellites.

- The solution with a three–day long–arc orbit but one–day coordinate estimates keeps the benefit from CODE's traditional three–day long–arc orbit but is also equivalent to a pure one–day solution regarding the station coordinates.

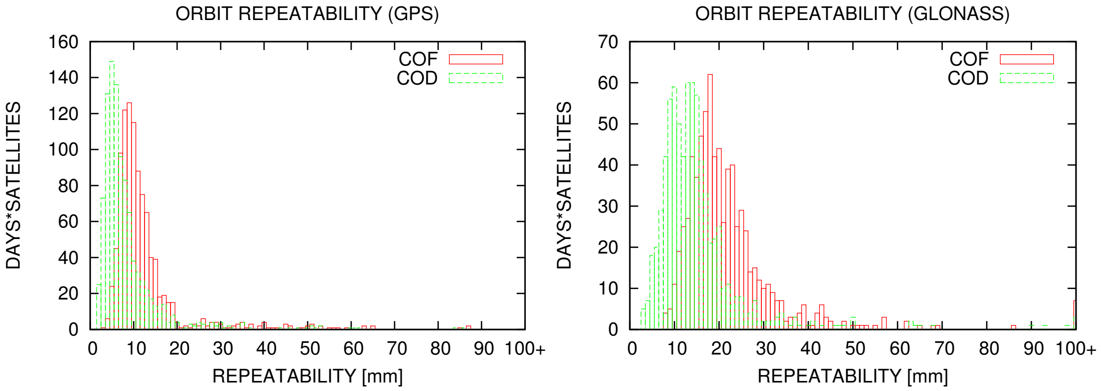
Having these figures and conclusions in mind CODE proposed the three–day long–arc orbit solution with coordinates reduced to the middle day by pre–elimination to the analysis center coordinator as the new contribution to the IGS final products.

New set of solutions since week 1706

There are several pros and cons for solutions with long–arc orbits and pure one–day solutions. The analysis center coordinator did not accept the multi–day solution as proposed by CODE. Finally it has been agreed

- to start a new product series from CODE as a pure one–day solution with the label COF that is used for the reference frame generation and as contribution to the GPS final orbits and
- to continue the series of the three–day long–arc solution from CODE with the label COD that is used as contribution to the GLONASS orbit product from the IGS.

The first of the two solutions should be more consistent with the contributions of the other analysis centers supposed that also all other groups do not apply any continuity condition to their parameters at the day boundaries. The second solution offers by construction smoother orbit products over the day boundaries and better orbits for all GLONASS and marginally observed GPS satellites.



(a) GPS (b) GLONASS

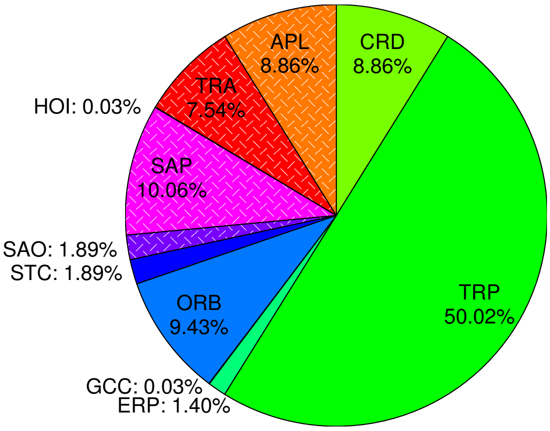
Figure 4: Histogram for the RMS of a three–day orbit fit during 30 days using the COF pure one–day (red bars) and the COD three–day long–arc solution (green bars).

This is illustrated in Fig. 4 where the RMS of an orbit fit over three consecutive days of the COD and COF solutions for all 56 satellites during 30 days (day 252 of year 2012 to day 016 of year 2013) is plotted in a histogram. Due to the continuous arc over three days the RMS for the COD solution is in general smaller than for the COF solution. Extreme outliers on the level of several decimeters and even up to one meter do only appear in the one–day COF solution for individual satellites that are observed only by a very limited number of stations or during a repositioning event close to midnight. The RMS limit of 2.0 cm is exceeded in 8.2% for the COF pure one–day and in 5.0% for the COD three–day long–arc solution for the GPS satellites. Assuming a limit of 3.5 cm for GLONASS orbit fits there are 7.8% above for the COF pure one–day and only 3.5% for the COD three–day long–arc solution series.

Optimized product generation since GPS week 1706

After pre–processing of the observation files of one day the final normal equation containing all parameters is set up. In the final procedure of CODE typically about 1,600,000 observations from approx. 260 stations and 56 (sometimes only 55) satellites are processed to derive approximately 24,000 parameters where about half of them are remaining ambiguity parameters that are immediately pre–eliminated.

A reasonable amount of the remaining parameters are so–called monitoring parameters that are not solved in the daily GNSS solutions but they shall be included in the normal equations for an evaluation in long–term solutions. These parameters have traditionally been heavily constrained when computing the solution for the day.



List of parameters in the internal one–day normal equation from CODE

CRD:	Station coordinates	789
TRP:	Site–specific troposphere parameters	4457
ERP:	Earth rotation parameters	125
GCC:	Geocenter coordinates	3
ORB:	Orbital elements	840
STC:	Stochastic orbit parameters	168
SAO:	Satellite antenna offset parameters	168
SAP:	Satellite antenna patterns	896
HOI:	Higher–order iono scaling parameters	3
TRA:	GNSS–translation parameters	672
APL:	Scaling factors for Vienna APL model	789
	Total number of parameters	8910

Figure 5: Number of parameters of different types in a typical final one–day solution from CODE (in this example from day 350 of year 2012), where the shaded parameters are only introduced for long–term studies. Note, the ERPs are available with an hourly resolution in a piece–wise linear representation.

The new generation scheme of the daily solution is a multiple–step procedure:

1. All parameters are set up in one single normal equation file that is only stored but not inverted.
2. From a copy of the fully blown normal equation all monitoring parameters are deleted (removal of the columns and rows related to the parameter in the normal equation).
3. Adapt the resolution in time (e.g., for Earth rotation parameters) and if needed pre–eliminate further parameters (e.g., troposphere parameters) in the reduced normal equation applying a parameter transformation.
4. Inversion of the reduced normal equation to obtain the result files for the daily solution.

Figure 5 shows the number of parameters in a typical one–day final solution from CODE where it becomes clear that more than a quarter of the parameters are only introduced for long–term studies. The removal of those parameters in step 2 of the new processing scheme saves a significant amount of computing time.

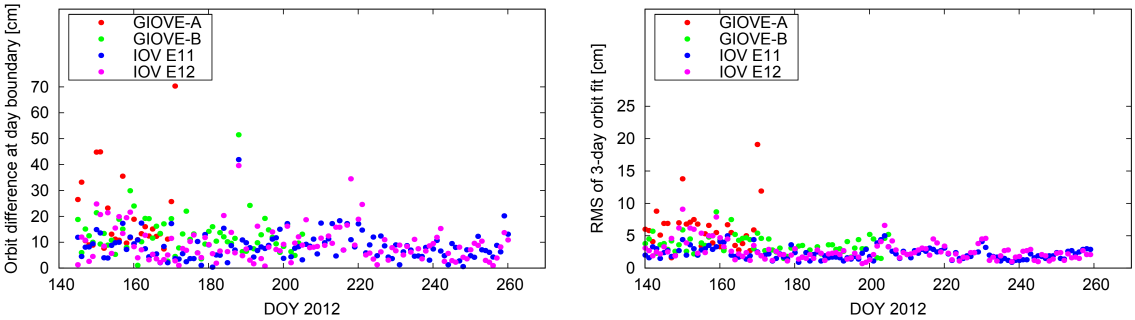
The disadvantage from this approach is, that the procedure with the parameter removal needs to be repeated several times to include, e.g., satellite antenna offsets in the resulting SINEX–file. For that reason several implementations of these procedures were needed in parallel. To guarantee the consistency the resulting coordinates are requested to be identical at the 0.01 millimeter level.

Nevertheless, this change of the algorithm leads to a significant reduction of the processing time even if more parameters (“Scaling factors for Vienna APL model”) are computed and the datum definition is verified for each individual solution (which means the normal equation is solved twice, once including all fiducial sites for verification and once only with the accepted datum stations for the final solution). In addition, after the removal of the parameters they do no longer have any influence on the solution which was not the case before applying the heavy contraints with the pre-elimination.

Analogue procedures are introduced for the generation of the three–day solutions.

4 CODE contribution to the IGS–MGEX campaign

In 2012 the IGS started its “Multi–GNSS EXperiment” (MGEX). An increasing number of new or upgraded tracking stations (about 50 in late 2012) contributes to this project. These stations comply with the IGS standards (e.g., correct equipment information, RINEX data format) and support the RINEX 3 data format version, new signal types for the established GNSS (e.g., L5 for GPS), and new GNSS, such as Galileo, BeiDou, and QZSS. These data are freely available and are well suited to prepare for future developments in GNSS processing.



(a) Position differences at the day boundaries from consecutive orbit solutions

(b) Three–day long–arc fit of the orbits from consecutive days

Figure 6: Quality assessment of the Galileo orbits from the CODE triple–system solution for IGS–MGEX.

CODE contributes to MGEX by providing a triple–system orbit solution including GPS + GLONASS + Galileo on a non–operational basis. The processing procedure has been derived from the CODE rapid processing chain: All Galileo tracking stations are added to the usual GPS+GLONASS rapid process in a separate cluster and a combination is done on normal equation level by stacking all common parameters.

In January 2013 the CODE MGEX products of the GPS–weeks 1690 to 1720 (days 150 to 364 of year 2012) are available at `ftp://cddis.gsfc.nasa.gov/gnss/products/mgex` using the solution ID “com” for the CODE–MGEX solution. Further updates and an extension of the product for Galileo clock corrections are in preparation.

The plots in Fig. 6 may give an impression of the current status of the Galileo orbit quality in the CODE solution. An independent validation based on SLR–measurements over all weeks showed an RMS of the residuals of about 8 cm for each of the two Galileo IOV satellites (E11 and E12).

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All publications, posters, and presentations of the *Satellite Geodesy* research group at AIUB are available at `http://www.bernese.unibe.ch/publist` .

NRCan Analysis Center Report for 2012

Y. Mireault, B. Donahue, R. Ghoddousi–Fard,
P. Tétreault, F. Lahaye

Natural Resources Canada, Geodetic Survey Division
615, Booth Street, Ottawa, ON, Canada K1A 0E9
Yves.Mireault@nrcan.gc.ca

1 Introduction

In 2012, the Geodetic Survey Division of the Natural Resources Canada (NRCan–GSD) continued its contribution to the International GNSS Service. NRCan–GSD is also responsible for the maintenance of the National horizontal, vertical and gravitational reference frames as well as providing the means of accessing these data in Canada. This report addresses the major product changes and events that occurred within NRCan during the year 2012.

2 Review of 2012

Readers are referred to the Analysis Coordinator web site (`http://acc.igs.org`) for historical combination statistics of the NRCan–AC products.

2.1 Ultra–Rapid, Rapid and Final Products

There were no major changes made to NRCan–AC Ultra–Rapid and Rapid core products in 2012. However, a few changes to the Final GPS processing strategy are worth mentioning. To be consistent with the upcoming "Repro 2" campaign, the Final GPS orbit strategy was updated. Major changes included:

- Software upgrade to JPL's GIPSY–OASIS v6.1.2;
- Start processing independent days and use of IGR orbits and Bulletin A as a priori values (previous strategy used extrapolated NRCan's ERPs and previous day NRCan's orbits);
- Earth Albedo model turned on;
- Switch from a 7–day to a 1–day TRF submissions (SINEX).

Table 1: NRCan–AC processing Events and Changes in 2012

Calendar Date	GPS Wk (day)	Products	Events / Changes
2012-Feb-15	1675 (3)	Ultra–Rapid, Rapid, Final	CC2nonCC (version 6.4).
2012-Apr-18	1684 (3)	Ultra–Rapid, Rapid, Final	CC2nonCC (version 6.5).
2012-Jul-01	1695 (0)	Ultra–Rapid, Rapid, Final	Leap Second.
2012-Jul-01	1695 (0)	GPS Final	• JPL's GIPSY–OASIS v6.1.2 • Processing independent days and using IGR orbits and bulletin A as a priori values; • Earth Albedo model
2012-Aug-19	1702 (0)	Ultra–Rapid, Rapid, Final	Switch from 7day to 1day TRF submissions (SINEX).
2012-Oct-07	1709 (0)	Ultra–Rapid, Rapid, Final	IGb08 reference frame and antenna calibration (from IGS08).

Routine processing, product generation and software maintenance were shared among GSD staff. More information about the strategies used and the various products generated can be found in (Meindl at al., 2012). Also, Tab. 1 above gives a short summary of important changes and events in 2012.

Time was devoted to the final development and testing of a new Ultra–Rapid GNSS orbit solution. This product should be available on an hourly basis sometime in 2013. At the same time, we started developing an Ultra–Rapid GNSS clock solution. Testing will most likely start in early 2013. Hopefully, this new product will be available by the end of 2013. Finally, NRCan is currently preparing for the "Repro 2" campaign.

2.2 Real–Time Products

There were no major changes made to the real–time RTCM–SSR format correction feed delivered to the Real–Time Pilot project for comparison and combination, other than switching to the agreed upon 5 second interval and small improvements to the message encoding algorithm.

3 Precise Point Positioning (PPP)

Recent modeling improvements in the NRCan–PPP software include:

- Autonomous second and third order ionosphere correction; the autonomy comes from the estimation of the station Differential Code Bias (DCB) (P1−P2) to correct the slant delays necessary for the computation of the high–order corrections; Vertical Total Electron Content (TEC) is also estimated as a random walk;
- Pole tide modeling using input x and y pole offsets (e.g. from IGS Final)
- Input and use of C2 pseudoranges corrected for P2−C2 biases

One use of NRCan–PPP is CSRS–PPP, the online GNSS service offered by NRCan. Although CSRS–PPP is aimed primarily at Canadian users to provide improved positions in Canada's national reference frame NAD83 (CSRS), it can also be used, and in fact, is used worldwide for improved ITRF positioning in either static or kinematic mode. The online positioning service is based on the PPP processing methodology and the use of precise GPS orbits and clocks estimates. In addition to NRCan's rapid and hourly GPS orbits and clocks, IGS Final GPS orbits and 30 second clocks are used for data observed after December 16, 2007 and IGS "Repro 1" products are used for any data observed between January 2, 1994 and December 15, 2007. Since August 14, 2011 CSRS–PPP also processes GLONASS data using NRCan's GLONASS orbits and 30 second clocks.

4 Ionosphere and Satellite DCB Monitoring

Near–real–time global ionosphere maps continue to be generated internally every 15 minutes in the form of spherical harmonic coefficients with degree and order 15 . Performance is monitored and improvements are made when required. Recently, the number of stations used increased to about 145 (RT–IGS stations and Canadian RT stations). Daily global IONEX maps generation using all IGS stations is planned.

Statistics of phase rate variation for all RT–IGS stations are being computed in near–real–time as a proxy for phase scintillation studies.

GPS P1−P2, P1−C1 and P2−C2 DCBs continue to be estimated daily and smoothed as weekly moving averages. Since January 1, 2013, receiver specific P1−C1 GPS DCBs are being generated daily.

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The ESA/ESOC IGS Analysis Centre

*T. A. Springer, L. Agrotis, J. Feltens, M. van Kints, N. Romero,
F. Dilssner, C. Flohrer, W. Enderle, R. Zandbergen*

European Space Operations Centre
Darmstadt, Germany

1 Introduction

The IGS Analysis Centre of the European Space Agency (ESA) is located at the European Space Operations Centre (ESOC) in Darmstadt, Germany. The ESA/ESOC Analysis Centre has been involved in the IGS since its very beginning in 1992.

In this report we give a summary of the IGS related activities at ESOC in 2012.

2 ESA IGS Analysis

2.1 ESA Products

The ESA/ESOC IGS Analysis centre contributes to all the core IGS analysis centre products, being:

- Reprocessed Final GPS products (repro1)
    - Provided from 1995 to 2008
    - Based on 24 hour solutions using 150 stations
    - Consisting out of Orbits, Clocks (30 s), coordinates, and EOPs
- Final GNSS (GPS+GLONASS) products
    - Provided weekly. normally on Friday after the end of the observation week.
    - Based on 24 hour solutions using 150 stations
    - True GNSS solutions simultaneously and fully consistently processing of GPS and GLONASS measurements, using a total of around 55 GNSS satellites
    - Consisting out of Orbits, Clocks (30 s), coordinates, Ionosphere, and EOPs

- Rapid GNSS (GPS+GLONASS) products
  - Provided daily for the previous day.
  - Available within 3 hours after the end of the observation day
  - Based on 24hour solutions using 110 stations
  - True GNSS solutions simultaneously and fully consistently processing of GPS and GLONASS measurements, using a total of around 55 GNSS satellites
  - Consisting out of Orbits, Clocks, coordinates, Ionosphere, and EOPs
- Ultra–Rapid GNSS (GPS+GLONASS) products
  - Provided 4 times per day covering a 48 hour interval; 24 hours of estimated plus 24 hours of predicted products.
  - Available within 3 hours after the end of the observation interval which start at 0, 6, 12, and 18 hours UTC.
  - Based on 24 hours of observations using 110 stations
  - True GNSS solutions simultaneously and fully consistently processing of GPS and GLONASS measurements, using a total of around 55 GNSS satellites
  - Consisting out of Orbits, Clocks, and EOPs
  - Seperate Ionosphere estimates and predictions
- Real–Time GNSS services
  - Generation of two independent real–time solution streams
  - Analysis Centre Coordination
  - Generation and dissemination of the IGS Real Time Combined product stream
- GNSS Sensor Stations
  - A set of 10 globally distributed GNSS sensor stations
  - Station data available in real–time with 1 second data sampling

Besides these core products ESA is very active in different working groups. Most notably are our efforts in the Real–Time pilot project where besides being one of the analysis centres we are also responsible for the analysis centre coordination. Also our efforts in the scope of the antenna calibarations and satellite orbit modeling working groups are significant. Furthermore, we will significantly contribute to the IGS MGEX efforts.

An up to date description of the ESA IGS Analysis strategy may always be found at:
`ftp://dgn6.esoc.esa.int/products/esa.acn`

2.2 Main Changes in 2012

The main changes in our processing in 2012 were the following.

- Increase the number of stations from 110 to 150 for the ESA Final products (April)
- Change from weekly to daily SINEX (station coordiantes and Earth Rotation Parameters) solutions for the final products

- Update of reference frame from ITRF2008 to the IGS internal realisation of the ITRF2008
- Switch to NAPEOS version 3.7 (November)
  - Improved Ambiguity Resolution improvements and enhancements now giving rise to almost always 98% of resolved ambiguities compared to 90% before
  - Impoved handling of intersystem biases; particularly important for GLONASS
- Upgrade of the ESA/ESOC GNSS Sensor Station network

2.3 ESA Product Highlights

The main highlight of the ESA/ESOC Analysis Centre products is that they are one of the best products available from the individual IGS analysis centres. Secondly the ESA products are one of the most complete GNSS products. In fact ESA was the first IGS analysis centre to provide a consistent set of GNSS orbit *and* clock products. Our GNSS products constituted the very first products that could, and are, used for true GNSS precise point positioning. In particular for this purpose, the sampling rate of our final GPS+GLONASS clock product is 30 seconds.

Another special feature of the ESA products is that they are based on completely independent 24 hour solutions. Although this does not necessarily lead to the best products, as in the real world the orbits and EOPs are continuous, it does provide a very interesting set of products for scientific investigations as there is no aliasing and no smoothing.

An other unique feature of our products is that our rapid products are, besides being one of the best rapid products, also one of the most timely available product. Normally our GNSS rapid products are available within 2 hours after the end of the observation day whereas the official GPS–only IGS products become available only 17 hours after the end of the observation day, a very significant difference.

3 ESA Reprocessing

ESA/ESOC has participated in the first IGS reprocessing efforts (repro1) for the IGS contribution to the realisation of the International Terrestrial Reference Frame 2008 (ITRF08). For this reprocessing effort ESA has processed all historic GNSS data of the IGS from 1994 to 2008. Meanwhile we have repeated the reprocessing using the ITRF08 station coordinates and the corresponding IGS08 antex corrections for the receiver and transmitter antennas. In this reprocessing the years 1994 to 2008 are done using only GPS observations, but from 2009 the reprocessing does fully include the GLONASS observations and are true GNSS solutions.

The products from the first ESA official reprocessing efforts based on the ITRF05 reference frame are available from the official IGS data centres (label "es1"). The most recent ESA reprocessing products, currently based on the ITRF08, are available from our ftp `ftp://dgn6.esoc.esa.int/igs/repro2` (label "es2").

Currently only the orbit products are made available. Other products are available on request. An interesting difference between our "es1" and "es2" reprocessing is that, as mentioned before, from 2009 our "es2" products are GNSS products. Also for our "es2" products we do generate 30 second clock estimates. We generate these high–rate clock products because we are also very active in processing GNSS data from Low Earth Orbiting (LEO) receivers. For LEO processing high–rate clocks are very much needed to get accurate orbits based when using the well–known PPP approach for precise orbit determination.

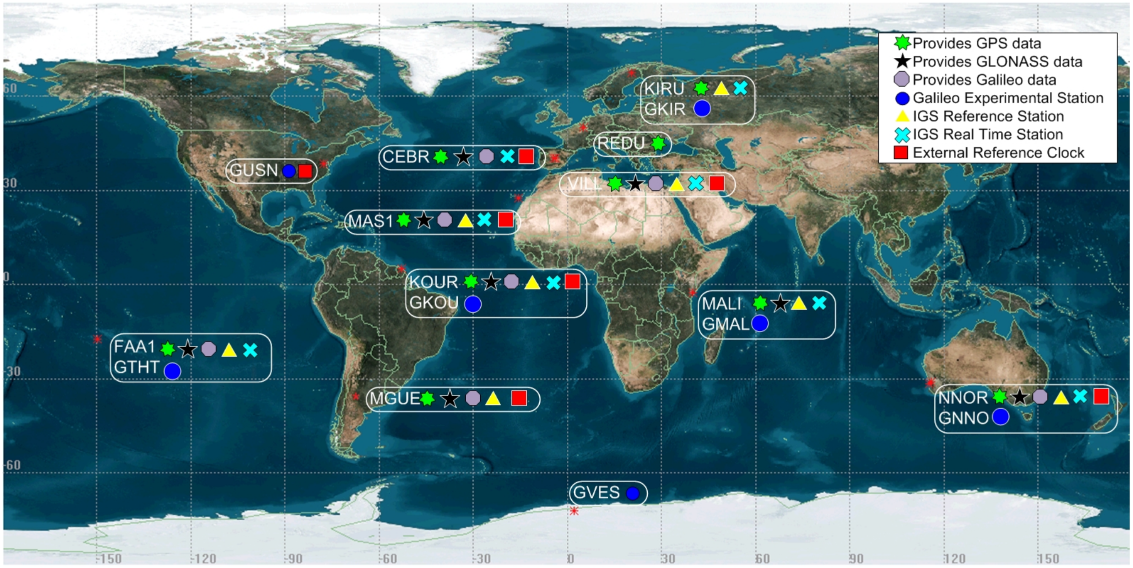
4 GNSS Sensor Station Upgrade

ESA/ESOC is operating a network of globally distributed GNSS sensor stations, supporting internal and external projects (i.e. GRAS GSN, IGS, Tracking Antenna Positioning and Monitoring) as well as distributing the data for the scientific community (IGS and EUREF).

Following the evolution of GNSS systems, new satellites and signals are being made available to the user segment, including new civilian signals for GPS (L2C and L5), CDMA modulation for GLONASS (L3) and development of new constellations (Galileo, BeiDou, QZSS).

Until 2010 the ESOC GNSS sensor stations were limited to tracking either GPS or GPS and GLONASS. It was recognized that the ESOC GNSS sensor station network needed to be upgraded with state–of–the art technology. This should allow ESOC to keep its high–level of quality and reliability in GNSS operations. The upgrade not only envisages the replacement of the station equipment of the current GNSS network, but also an expansion of the number of stations in order to enhance the geographical coverage.

To fulfil this purpose a dedicated assessment was made, trading off between the technical requirements and the commercial market costs of the GNSS equipment required for the upgrade. This resulted in the procurement of 25 Septentrio PolaRx4 receivers and 25 Septentrio Choke Ring MC antennas, for which a deployment schedule was drafted in early 2012. For the upgrade, the new Septentrio antennas are furthermore complemented by 4 Leica AR25.R4 antennas, procured earlier, in 2011.


Provides GPS data
Provides GLONASS data
Provides Galileo data
Galileo Experimental Station
IGS Reference Station
IGS Real Time Station
External Reference Clock
KIRU
GKIR
REDU
CEBR
GUSN
VILL
MAS1
KOUR
GKOU
MALI
GMAL
FAA1
GTHT
MGUE
NNOR
GNNO
GVES
60
30
0
-30
-60
-150
-120
-90
-60
-30
0
30
60
90
120
150

29/01/2013

Figure 1: Status of the ESOC GNSS sensor stations as of January 2013

Current upgrade status and way forward

Figure 1 shows the status of the ESOC GNSS sensor stations as of January 2013. Of the existing ten GNSS sensor stations operated and maintained by ESOC within the existing network, 7 were upgraded in 2012 to multi–GNSS receivers and antennas. The remaining 3 (REDU, KIRU and MAL2) are planned to be upgraded in the first quarter of 2013. Building forth on the activities for the existing network, negotiations with several third parties were initiated during 2012, with the objective of consolidating cooperative agreements that allow for the deployment of our new ESOC GNSS equipment at external hosting.

5 Real Time Activities

Over the last 10 years, ESOC has embarked on a program to build a Real Time GNSS software and network (receiver) infrastructure. RETINA (system for REal TIme NAvigation) has been modeled after ESOC's experiences in Real Time satellite control systems and includes many of the elements for data processing, archiving and visualisation that are common to such systems.

ESOC is utilising this infrastructure by participating in the IGS Real Time Pilot Project, assuming the roles of Real Time Analysis Centre, RT Observing Station Data Provider and Analysis Centre Coordinator (ACC). In the latter role, ESOC has been generating and disseminating the IGS Real Time Combination stream after processing the Real Time solutions from up to ten Analysis Centres.

Included in the combination solutions are two streams generated by the ESOC Real Time Analysis Centre. One of these uses orbit information generated by the NAPEOS software, Springer at al. (2009), which is operated under RETINA scheduling control and provides orbit updates every 2 hours. The second ESOC solution stream uses the IGS rapid orbit product, which is updated every 6 hours.

ESOC has been contributing Real Time measurements from eight of its GNSS sensor station network; New Norcia, Perth, Cebreros, Villaranca, Kiruna, Maspalomas, Malindi and Kourou. Major upgrades are now in progress to the receiver network, to migrate to multi–GNSS receiver types and to introduce RTCM streaming capabilities. This has resulted in disruptions to the data from some of the sites.

Participation in the IGS Real Time activities has stimulated the involvement of ESOC in the development of standards and formats for GNSS data and products. ESOC has been instrumental in the decision of the IGS to join the Radio Technical Commission for Maritime Services (RTCM), which is the primary standards setting organisation for Real Time GNSS services. NRCan and ESOC are the two agencies that represent the IGS at the RTCM meetings. Work with the RTCM has focused on the following areas:

- Development of standards and formats for transmission of multi–constellation observations in Real Time (RTCM–MSM)
- Development of standards and formats for the transmission of Real Time orbit and clock products (RTCM–SSR)

In addition, the IGS took a high–level decision to form a joint RTCM–IGS working group for the further development of the RINEX observation format. The terms of reference of this WG have been negotiated by ESOC and approved by the IGS Governing Board and by the RTCM. The RINEX working group, chaired by NRCan and ESOC, is now actively working on the definition of a new version of the RINEX format, RINEX 3.02.

The highlight of this year's (2012) Real Time ACC activities was the preparation for launching the official IGS Real Time service. ESOC will retain the ACC role in this service, which will be launched in the first quarter of 2013. In order to ensure a high availability for this service, combination processes are now running simultaneously at two servers external to ESOC, in the UK and in Canada (NRCan).

6 Ionosphere Modeling Activities

ESA/ESOC contributes with IONEX products to the IGS Ionosphere Working Group since its inception in 1998, initially with daily global ionospheric TEC maps in final mode (11 days latency). The ESA/ESOC activities for the ionosphere in the frame of the IGS can be summarised as follows:

- **1998:** Start routine delivery of global ionospheric TEC maps (11 day latency).

- **Spring 2004:** Start routine delivery of daily global ionospheric TEC maps in rapid mode (1 day latency).
- **December 2005:** Start routine delivery of TEC maps in 2–hour time resolution, i.e. since then each ESA IONEX file provides 13 TEC and RMS maps per day.
- **March 2009 – January 2010:** ESA Study: "GNSS Contribution to Next Generation Global Ionospheric Monitoring" (Feltens at al., 2009; Feltens et al., 2010).
- **September 2009:** Commence submission of IONEX files containing 1 and 2 days ahead predicted TEC maps in 2 hour time resolution.
- **July 2010:** Commence combination of predicted Ionosphere Associate Analysis Centres (IAACs) TEC maps and submission of combined predicted IGS IONEX files in 2 hour time resolution.
- **February 2011:** Commence submission of ESA IONEX files with 1–hour time resolution.

ESOC employs the Ionosphere Monitoring Facility (IONMON) for its ionosphere processing. IONMON algorithms were initially devoted to single layer approaches. Since 1999, investigations were undertaken into the direction of 3D ionosphere modelling. Starting with an extended Chapman profile approach, in the subsequent years the concept for a multilayer modelling was developed, combining empirical surface functions to describe the horizontal structures of the ionosphere with vertical profile functions, which should, to some limited extent, also allow for a physical interpretation of results. It was foreseen that this new modelling should process TEC data from GNSS combined with observed electron density profiles from different sources, namely CHAMP, F3/COSMIC and ionosonde in least squares fits. In relation to these IONMON developments, from March 2009 to January 2010 the ESA Study *"GNSS Contribution to Next Generation Global Ionospheric Monitoring"* was conducted, Feltens at al. (2009) and Feltens et al. (2010), working out recommendations for a new ionosphere monitoring system, identifying potential users, and practical and scientific applications in terms of, among others:

- Potential ionospheric observation data sources, e.g., TEC from GNSS and radio beacons, LEO topside TEC, electron density profiles from LEO radio occultation, ionosondes, and more.
- Near–Real–Time (NRT) and Real–Time (RT) suitability.
- Predictability of the ionosphere's state.
- Physical interpretability.

6.1 Current Activities

Presently the IONMON is integrated into the ESOC NAPEOS software. These activities are almost finished and the inclusion in NAPEOS will enable the IONMON to nearly double the number of ground stations that can be used. In addition the NAPEOS integration will enable IONMON to process all GNSS data; currently it can only process GPS data. Figure 2 compares, for one example day (17th January 2013, 18:00 UT), an old IONMON TEC and RMS map with their counterparts computed with the IONMON integration in NAPEOS. It clearly demonstrates the improvements, which are primarily visible when comparing the RMS maps. The high peaks still visible in the IONMON/NAPEOS RMS map (in Fig. 2 bottom right) indicate those areas where there are hardly any GNSS receivers available, namely South Atlantic and Pacific. Also, once included in NAPEOS, the least squares fit for 3D modelling will be replaced by a least squares interpolation in order to assimilate different kind of ionospheric observation data into a background model. It turned out that, in spite of including F3/COSMIC and CHAMP electron densities in addition to GNSS TEC observables, the data coverage is still not dense enough to perform a reliable least squares fit. In addition, the change from least squares fitting of observation data to an observation data assimilation into a background model will allow for an easy enhancement of time resolution, e.g., from 1 hour to several minutes.

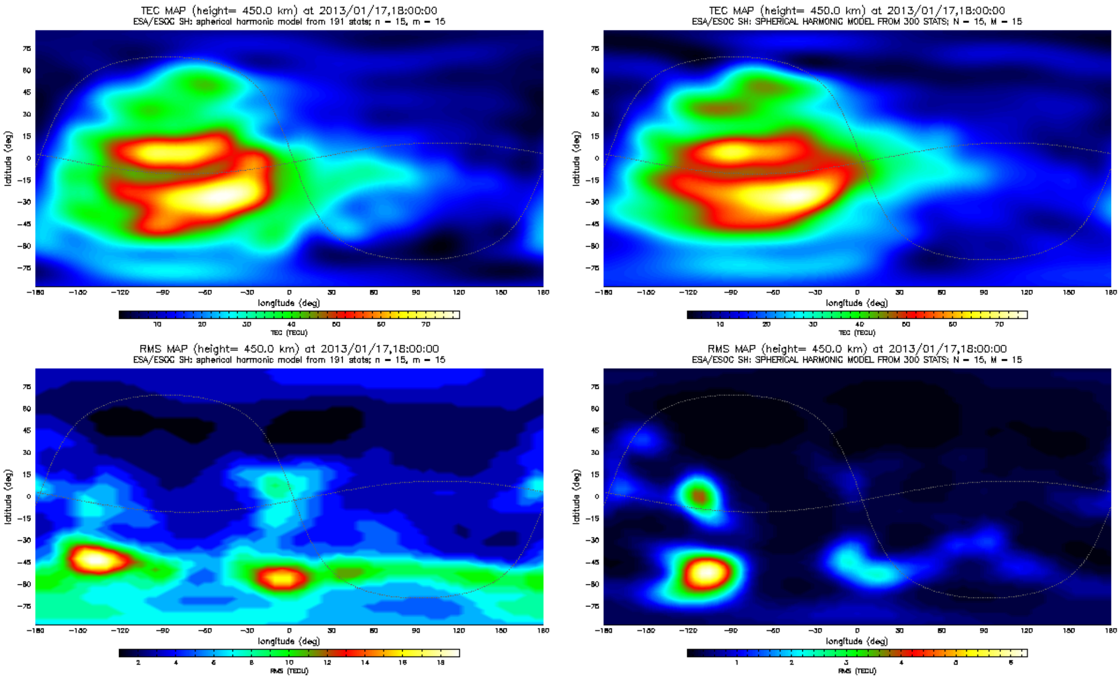

TEC MAP (height= 450.0 km) at 2013/01/17,18:00:00
ESA/ESOC SH: spherical harmonic model from 191 stats; n = 15, m = 15
TEC MAP (height= 450.0 km) at 2013/01/17,18:00:00
ESA/ESOC SH: SPHERICAL HARMONIC MODEL FROM 300 STATS; N = 15, M = 15
RMS MAP (height= 450.0 km) at 2013/01/17,18:00:00
ESA/ESOC SH: spherical harmonic model from 191 stats; n = 15, m = 15
RMS MAP (height= 450.0 km) at 2013/01/17,18:00:00
ESA/ESOC SH: SPHERICAL HARMONIC MODEL FROM 300 STATS; N = 15, M = 15
latitude (deg)
75
60
45
30
15
0
−15
−30
−45
−60
−75
longitude (deg)
−180
−150
−120
−90
−60
−30
0
30
60
90
120
150
180
TEC (TECU)
10
20
30
40
50
60
70
RMS (TECU)
2
4
6
8
10
12
14
16
18
RMS (TECU)
1
2
3
4
5
6

Figure 2: Improved IONMON performance due to integration into NAPEOS (number of ground stations almost doubled, GLONASS in addition to GPS), top left: TEC old IONMON, top right: TEC IONMON/NAPEOS, bottom left: RMS old IONMON, bottom right: RMS NAPEOS/IONMON

6.2 Future Activities

Once being converted from least squares fits to data assimilation, the 3D model will be enhanced for NRT and RT processing and the current background model will commenced to be upgraded for physics–based approaches, partially by exploiting already existing algorithms of the current 3D IONMON version. The implementation of physically funded formulae will also be essential for the construction of sophisticated prediction methods. In parallel to the tasks described above, activities are already ongoing to establish a new model for the plasmasphere in a cooperative effort with the German Aerospace Center (DLR) in Neustrelitz, Germany. This plasmasphere model will complement the 3D IONMON. In addition, initial test runs producing 3D IONEX files have been performed successfully.

7 Summary

The European Space Operations Centre (ESOC) of the European Space Agency (ESA) Analysis Center has continued to produce "best in class" products for the IGS in 2012. Practially all products are generated using the Navigation Package for Earth Orbiting Satellites (NAPEOS) software. NAPEOS is a state of the art software that is highly accurate, very efficient, robust and reliable. It enables ESA/ESOC to deliver the high quality products as required for the IGS but also for the other space geodetic techniques DORIS and SLR. This is important because besides being an IGS Analysis Centre, ESA/ESOC is also an Analysis Centre of the IDS and the ILRS.

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Feltens, J., M. Angling, N. Jackson–Booth, N. Jakowsk, M. Hoque, C. Mayer, M. Hernández–Pajares, A. García–Rigo, R. Orús–Perez, A. Aragón–Ange, J. M. J. Zornoza. Recommendations for a New European Ionosphere Monitoring System. *DOPS–SYS–RP–5001–OPS–GN* Issue 1/0, 20 January 2010.

GFZ Analysis Center of IGS
Annual Report for 2012

G. Gendt, Z. Deng, M. Ge, T. Nischan,
M. Uhlemann, G. Beeskow, A. Brandt

Helmholtz–Zentrum Potsdam
Deutsches GeoForschungsZentrum (GFZ)
Department 1: Geodäsie und Fernerkundung
Telegrafenberg A 17, 14473 Potsdam, Germany;
e–mail: `gendt@gfz-potsdam.de`

1 Summary

During 2012 the standard IGS product generation was continued with minor changes in the software EPOS–8.

It was demonstrated to process Galileo data provide by the M–GEX activity.

2 Products

The list of products provided by GFZ is summarized in Tab. 1.

3 Changes in the processing

EPOS–8 is following the IERS Conventions 2010 (Petit and Luzum, 2010). Recent changes are listed in Tab. 2.

The station network used in the processing is shown in Fig. 1. For the IGS Final, Rapid and Ultra Rapid about 200, 110, and 90 sites are used, respectively, whereas the sites providing GLONASS data is steadily increasing.

Table 1: List of products provided by GFZ AC.

Final (GLONASS since week 1579)

gfzWWWD.sp3	Orbits for GPS/GLONASS satellites
gfzWWWD.clk	5–min clocks for stations and GPS/GLONASS satellites
gfzWWW7.erp	
gfzWWW7.snx	
gfzWWW7.sum	Summary file — including Inter–Frequency Code Biases (IFB) for GLONASS
gfzWWWD.tro	1–hour ZPD estimates

Rapid (GLONASS since week 1579)

gfzWWWD.sp3	Orbits for GPS/GLONASS satellites
gfzWWWD.clk	5–min clocks for stations and GPS/GLONASS satellites
gfzWWWD.erp	

Ultra (every 3–hours; provided to IGS every 6 hours; GLONASS since week 1603)

gfuWWWD.sp3	Adjusted and predicted orbits for GPS/GLONASS satellites
gfuWWWD.erp	

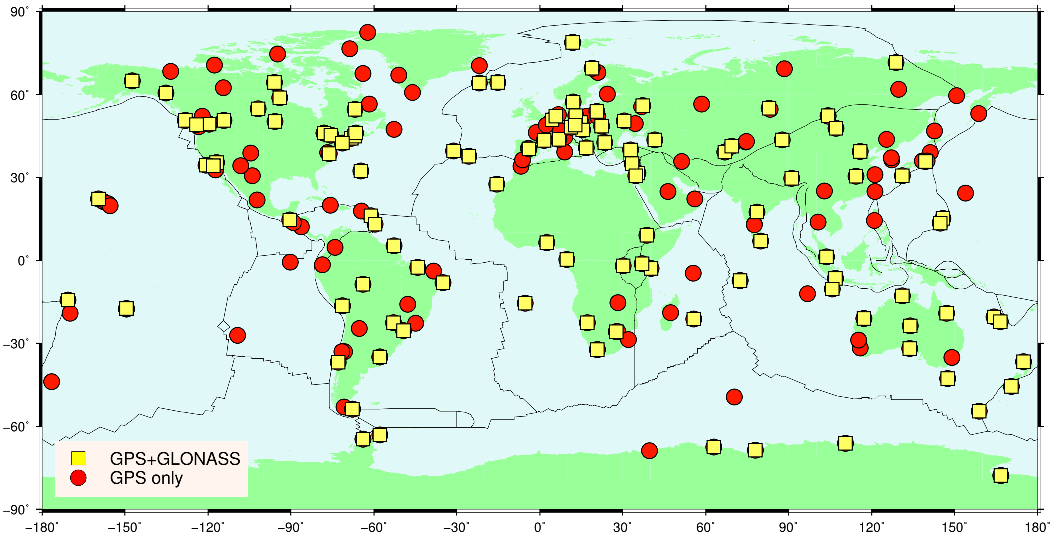


Figure 1: Used IGS stations for combined GPS+GLONASS data processing (GLONASS tracking sites are marked with yellow squares).

Table 2: Recent Processing changes.

Date	IGS	IGR/IGU	Change
2012-02-13	1674	1674.0	ZPD with 30–min sampling, internally
2012-08-22	1701	1702.3	Bug fix (since 1666) in handling pole tide and atmosphere loading tide S1,S2; most visible in station clock behaviour

Table 3: Number of stations and processing time for different GFZ products.

IGS Product	# of sites	# of sites incl. GLONASS	Duration
Ultra	90	50	≈ 1 h
Rapid	110	70	≈ 2 h
Final	200	110	≈ 4 h

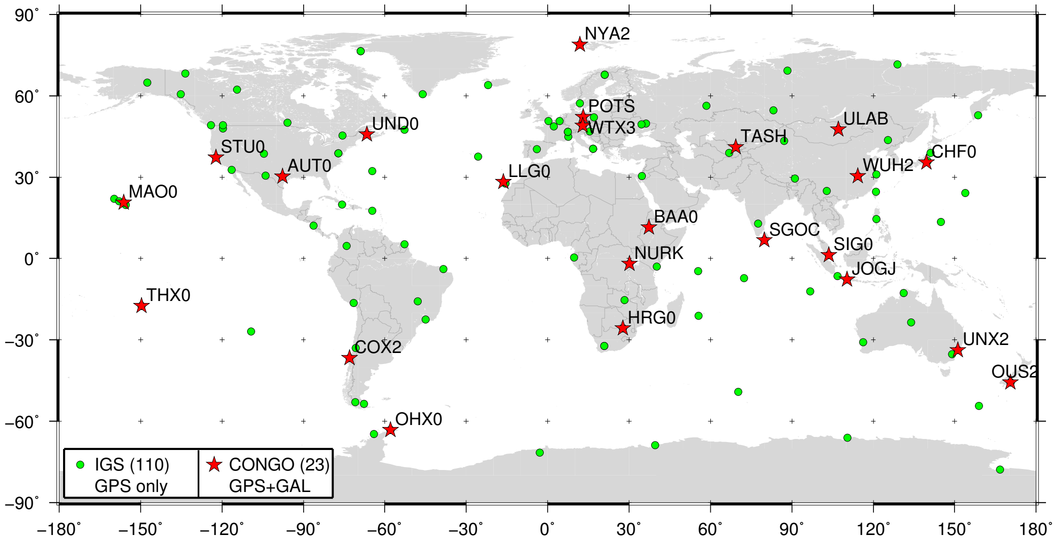

90˚
60˚
30˚
0˚
−30˚
−60˚
−90˚
−180˚
−150˚
−120˚
−90˚
−60˚
−30˚
0˚
30˚
60˚
90˚
120˚
150˚
180˚
NYA2
POTS
WTX3
UND0
STU0
AUT0
MAO0
LLG0
TASH
ULAB
CHF0
WUH2
BAA0
SGOC
SIG0
NURK
JOGJ
THX0
HRG0
COX2
UNX2
OUS2
OHX0
IGS (110)
GPS only
CONGO (23)
GPS+GAL

Figure 2: Global network of IGS (green) and CONGO (red) stations, which were set up for data processing. The 23 CONGO stations realize a good global coverage for practical GALILEO orbit determination purposes.

4 Processing of M–GEX data

The capability to process Galileo Data has been demonstrated in Uhlemann et al. (2012). One of the main goals of this study was the precise orbit & clock determination of GALILEO's Giove (E01/E16) and IOV (E11/E12) satellites and also the investigation of station tracking behaviour and orbit issues. The observation data mainly stem from the modern "COoperative Network for GNSS Observation" (CONGO), but includes all upgraded GFZ tracking stations which are contributing to MGEX campaign (see Fig. 2). Finally it can be stated that Galileo satellite orbit accuracies below 10 cm can be reached with the chosen processing/network setup.

5 Reprocessing activities

For the IGS reprocessing 2 some improvements were implemented into the latest GFZ software version EPOS–P8 (Tab. 4).

GPS data of the globally distributed IGS tracking network of 307 stations for the time span from 1994 until end of 2012 were reprocessed (Fig. 3). In the past year GFZ has prepared the reprocessing of the TIGA GPS network. The data will be analyzed in addition to the IGS network with about 30 overlapping sites for co–location. About 500 GNSS stations are available in the TIGA FTP server `http://www.sonel.org`. The distribution of the TIGA stations is given in Fig. 4.

Table 4: Model for reprocessing (difference to routine processing).

Model	Comment
2^{nd} order iono	2^{nd} order ionosphere correction
GPT2	New empirical meteorological model
VMF	Using 6–hour VMF grid files
EGM2008	Updated geopotential filed (IERS2010)
FES2004 model	New geopotential ocean tide model
Albedo (antenna thrust)	Method from C.J. Rodriguez-Solano

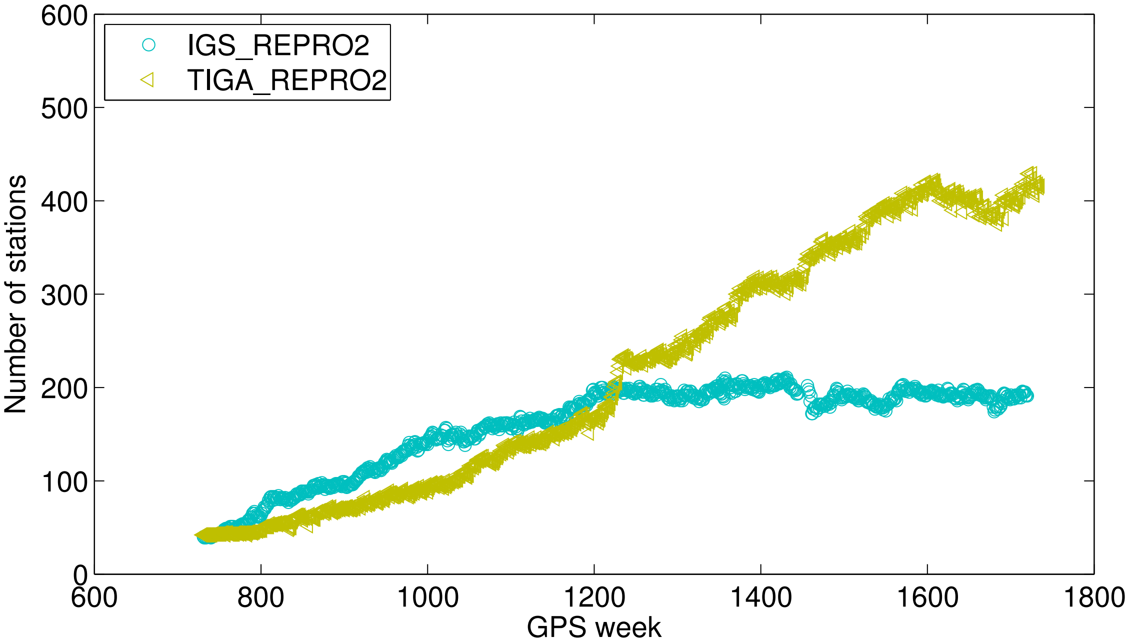
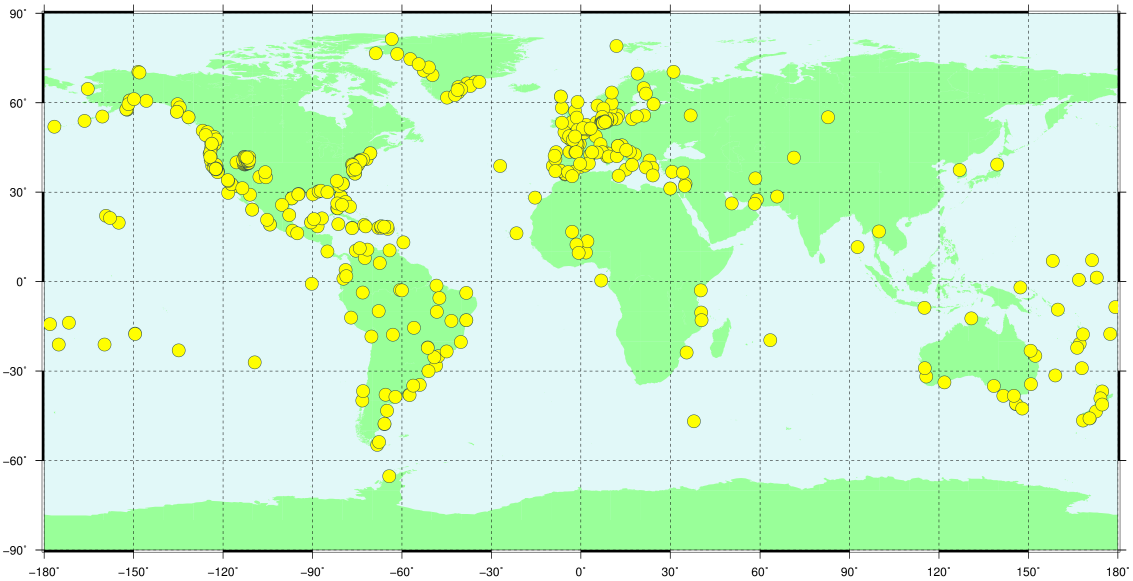


Figure 3: Number of stations in IGS and TIGA reprocessing 2.


90˚
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0˚
-30˚
-60˚
-90˚
-180˚
-150˚
-120˚
-90˚
-60˚
-30˚
0˚
30˚
60˚
90˚
120˚
150˚
180˚

Figure 4: Distribution of TIGA stations.

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CNES–CLS IGS Analysis Center Report 2012

S. Loyer[1], *F. Perosanz*[2] , *H. Capdeville*[1], *A. Mezerette*[1],
F. Mercier[2], *J.–C. Marty*[2]

[1] Collecte Localisation Satellites, 31520 Ramonville Saint Agne, France
[2] Centre National d'Etudes Spatiales, 31400 Toulouse, France

1 Introduction

The common CNES–CLS French team joined officially the group of the IGS Analysis Centers in May 2010. The main motivation was to both participate in the improvement of the combined IGS products as well as to promote an innovative undifferentiated ambiguity fixing approach (Laurichesse and Mercier, 2007; Laurichesse et al., 2009) which has been implemented into the GINS CNES/GRGS software (Marty et al., 2011). We contribute to the final GPS and GLONASS products and our processing strategy is described in Loyer et al. (2012). More information on our AC activity can also be found at: `http://www.igsac-cnes.cls.fr`.

2 Products

"GRG" products are listed in Tab. 1. From the user point of view, the GPS clock offsets delivered in `GRGwwwwn.CLK` files have the unique property to keep the integer nature of phase ambiguities in the ionosphere–free phase combination (Loyer et al., 2012). A preliminary step in which Wide–Lane ambiguities are fixed is however needed. This is straightforward by using the associated `grgwwww7.WSB` file containing the so called "Wide–Lane satellite Biases" available at `ftp://ftpsedr.cls.fr/pub/igsac`. As a consequence, GRG products allow now ambiguity fixing in single receiver PPP mode (i–PPP) down to 30 s sampling (Petit et al., 2011; Lescarmontier, 2012; Fund et al., 2012). Starting week 1686, `WSB` information was included in the header of the `CLK` files.

Table 1: List of GRG final products delivered weekly

grgwwww7.ERP	ERP (pole, UT1–UTC) solution for 1 week in IGS IERS ERP format
grgwwww7.SUM	Analysis summary for the week
grgwwww[0-6].SNX	Daily solutions for EOP and Stations coordinates in SINEX format with complete information (covariance and constraints)
grgwwwwn.SP3	Daily GNSS ephemeris/clock at 15–min intervals (GPS + GLONASS since week 1617, GPS–only before)
grgwwwwn.CLK	Daily GPS clock at 30–sec intervals
grgwwww7.WSB	Weekly updated daily GPS wide–lane satellite biases

3 Changes to processing and standards

Our processing changes are driven by the double objective of improving our products and following the IGS and ITRF standards. Table 2 summarizes 2012 main events.

In 2012 we implemented the daily processing of the TRF (with all others AC's). One other major product evolution concerns our clock products (CLK files). Before week 1701, GRG products were inconsistent with those from other ACs and were rejected from the clock product combination. After investigation, we discovered that the GRG reference frame weekly solution was suffering from a large translation offset (up to 2 cm) in the Z direction versus the IGb frame. Following the recommendations from the IGS ACC, starting week 1701, GRG reference frame has been corrected from this Z translation. The corresponding CLK products became compatible with other ACs solution and started taking part into the combined IGS clock product (Fig. 1).

Table 2: Evolution of Processing Standards at the GRG IGS AC in 2012.

GPS week	Description
1674	Bootstrapping method to fix wide–lane ambiguities
1677	A priori pole coordinates derived from IGS rapid products
1686	GPS clock sampling from 300 s to 30 s Start including WSB satellite biases values in CLK files header
1692	Non Rotating Origin implemented for Earth rotation modeling
1701	GRG CLK product start contributing to the IGS clock combination
1702	Daily SINEX files delivering (see IGSMAIL #6613)
1709	Adoption of IGb08 reference frame (see IGSMAIL #6663)

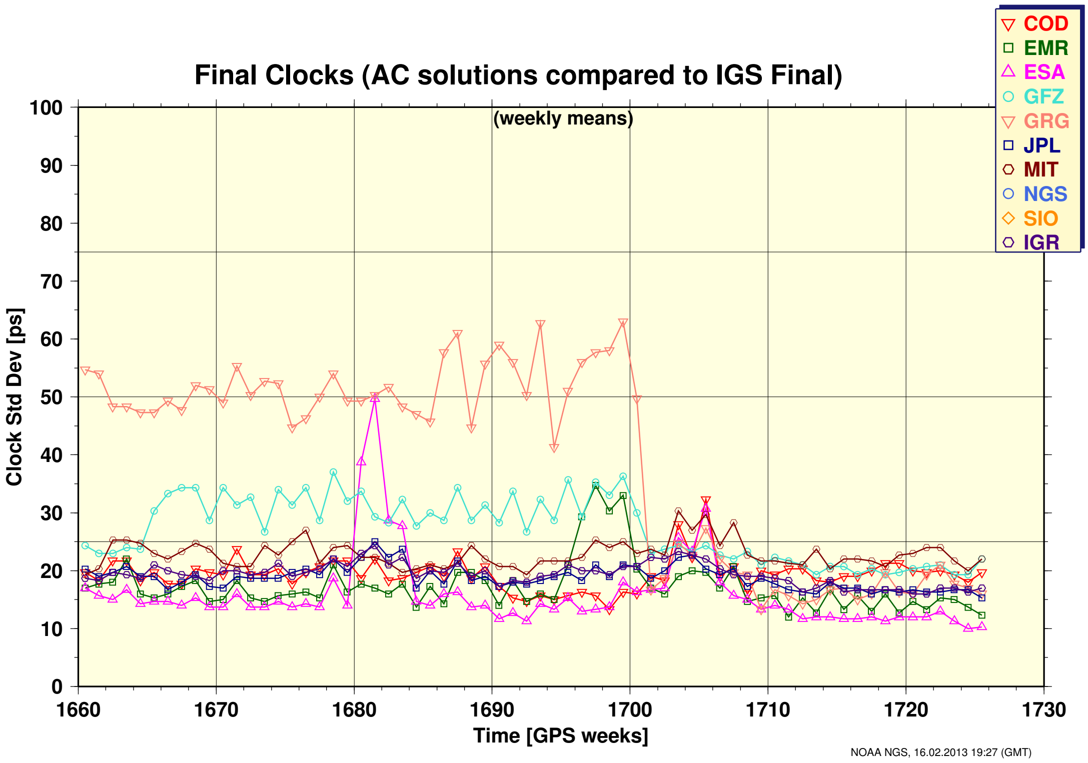

Figure 1: Final clock products standard deviations.

4 IGS M–GEX campaign data analysis

Following an initiative of the GNSS IGS Working Group, the M–GEX campaign started in February 2012 (see GNSS WG section). CNES–CLS AC positively responded to the call for participation with the main objective of evaluating the observations and computing satellite orbits from the under–deployment Galileo system. Because only two IOV Galileo satellites were in orbit, we processed GPS and Galileo data together. Thanks to M–GEX, data from a dense and multi–GNSS network became available. RINEX observation files were in the 3.0 format which had to be implemented into our different softwares. Because receivers from several manufacturers were available we started observing the Galileo–GPS Inter–System Biases (ISB) estimated from different equipment. IOV 1 and IOV 2 results were consistent. Discrepancies between manufacturer receiver technologies generate inconsistencies at the level of several meters in the ISB estimation (Fig. 2). Nevertheless, clock and orbit solutions could be computed, as they rely mainly on phase measurements information.

Figure 3 shows for example, that both IOV 1 and IOV 2 on–board atomic clocks were switched from the rubidium to the maser oscillator. The quality of the Galileo orbits we are producing since July 2012 is at the level of few decimeters (Fig. 4) illustrating

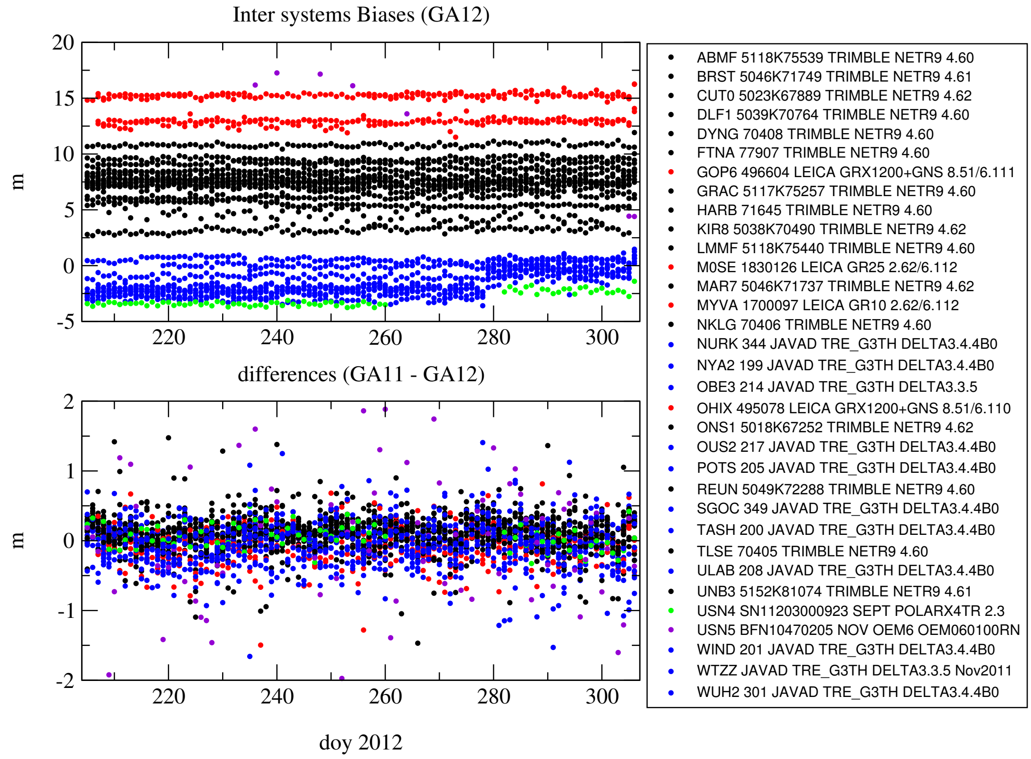

Figure 2: Upper plot: Observed Galileo (E12 = IOV 2) ionosphere–free inter–system biases on pseudo range observations relatively to BRUX receiver (one point per receiver and per day). Bottom plot: Observed Galileo inter–system biases between IOV 1 and IOV 2.

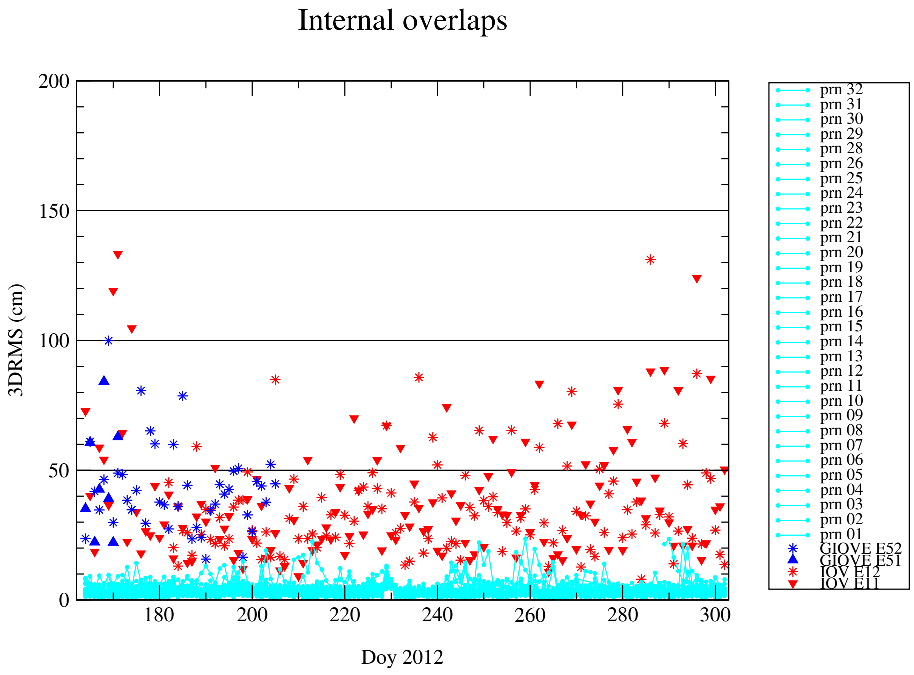

Figure 3: 3D RMS 6h orbit overlapping from 30 h solutions. Blue triangles and stars corresponding respectively to GIOVE E51 and E52 satellites. Red triangles and stars corresponding respectively to IOV E11 and E12.

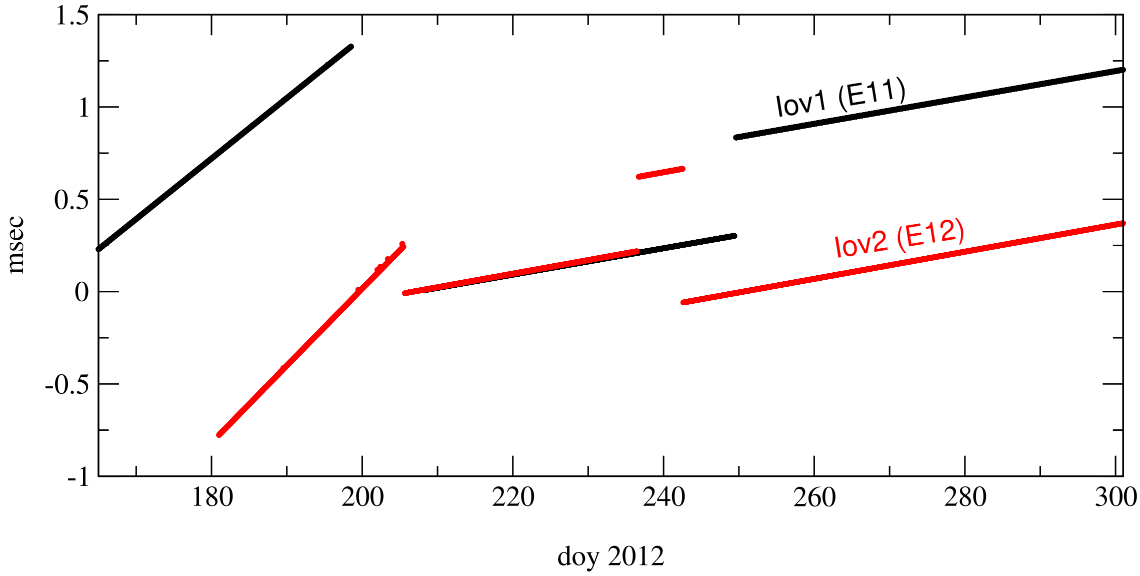

Figure 4: IOV 1 and IOV 2 satellite clock offsets estimated relatively to GPS time within the orbit determination process.

the capability to estimate precise Galileo orbits even during the constellation deployment phase. GRG Galileo orbit and clock products (called "GRM") are available at: `ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex` .

5 Future plans

As recommended by the IGS ACC, second order ionosphere effects as well as satellite antenna thrust models have been implemented in our software but are still under evaluation. Our AC will participate in the REPRO2 campaign. Thus, a consistent set of GRG GPS orbit/clock/WSB products will be available to users who may be interested in processing passed campaigns in an i–PPP mode.

We will continue the investigations on the various signals biases within the GPS, GLONASS and Galileo systems. The final goal is to fix ambiguities at the zero–difference level from any GNSS system. We will also continue to contribute to the discussions on the biases and format definition.

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JPL IGS Analysis Center Report, 2012

S. Desai, W. Bertiger, B. Haines, D. Kuang,
C. Selle, A. Sibois, A. Sibthorpe, and J. Weiss

Jet Propulsion Laboratory; California Institute of Technology
4800 Oak Grove Drive, M/S 238–600; Pasadena, CA 91001, U.S.A.
e–mail: `shailen.desai@jpl.nasa.gov`
phone: +1 – 818 – 354 – 6102

1 Introduction

In 2012, the Jet Propulsion Laboratory (JPL) continued to serve as an Analysis Center (AC) for the International GNSS Service (IGS). We contributed orbit and clock solutions for the GPS satellites, position, clock and troposphere solutions for the ground stations used to determine the satellite orbit and clock states, and estimates of Earth rotation parameters (length–of–day, polar motion, and polar motion rates). This report summarizes the activities at the JPL IGS AC in 2012 and our preparations for the 2013 IGS reprocessing campaign.

Table 1 summarizes our contributions to the IGS Rapid and Final products. All of our contributions are based upon daily solutions centered at noon and spanning 30–hours. Each of our daily solutions is determined independently from neighboring solutions, namely without applying any constraints between solutions. We started generating and delivering daily SINEX files starting with GPS week 1702.

Table 1: JPL AC Contributions to IGS Rapid and Final Products.

Product	Description	Rapid/Final
jplWWWWd.sp3	GPS orbits and clocks	Rapid & Final
jplWWWWd.clk	GPS and station clocks	Rapid & Final
jplWWWWd.tro	Tropospheric estimates	Rapid & Final
jplWWWWd.erp	Earth rotation parameters	Rapid(d=0−6), Final(d=7)
jplWWWWd.yaw	GPS yaw rate estimates	Rapid & Final
jplWWWWd.snx	Daily SINEX file	Final
jplWWWW7.sum	Weekly solution summary	Final

The JPL IGS AC also generates Ultra–Rapid orbit and clock products for the GPS constellation (Weiss et al., 2010). These products are generated with a latency of less than 2 hours and are updated hourly. Although not submitted to the IGS, our Ultra–Rapid products are available in native GIPSY formats at `ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products/ultra`.

2 Processing Software and Standards

The JPL AC continues to utilize the GIPSY/OASIS software package to generate our contributions to the IGS. Starting February 5, 2012, we used GIPSY/OASIS version 6.1.2 to generate our IGS contributions. A complete description of our current processing approach can be found at: `http://igscb.jpl.nasa.gov/igscb/center/analysis/jpl.acn`. Of note, we continue to use empirical GPS solar radiation pressure models developed at JPL instead of the DYB–based strategies that are commonly used by other IGS analysis centers. This choice is based upon an extensive evaluation of various internal and external metrics after testing both approaches with the GIPSY/OASIS software (Sibthorpe et al., 2011).

3 Preparations for 2013 IGS Reprocessing Campaigns

In November 2012 we completed a preliminary reanalysis of historical GPS data from August 16, 1992 to present in the IGS08 reference frame, and made these products publically available. They are available at `ftp://sideshow.jpl.nasa.gov/pub/jpligsac` in IGS formats, and at `ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products/Final` in native GIPSY formats. A notable benefit of these preliminary reprocessed IGS08–products is that they include our so–called "wide–lane phase bias" (WLPB) file for the entire time span of the products. The WLPB files enable single–receiver phase ambiguity resolved positioning when used with the GIPSY/OASIS software (Bertiger et al., 2010) and our GPS orbit and clock products. Also of note, high–rate (30–second) GPS clock products in native GIPSY format were also generated in this preliminary reanalysis for the period May 5, 2000 to present. They are also generated operationally in native GIPSY format for our Rapid and Final solutions.

Figures 1 and 2 provide a measure of the precision of the GPS orbit and clock products from this preliminary reanalysis, and are compared to our submissions to the last IGS05 reprocessing campaign. Products from our preliminary reanalysis have demonstrated an average variance reduction of 25% and 12% in GPS satellite orbit and clock precision for 1996–2011, respectively (Desai et al., 2011). Furthermore, an additional 0.6 satellites per day are included in our preliminary IGS08 reanalysis compared to our IGS05 submissions. Results for 1992–1995 are especially affected by the sparse availability and distribution of the ground network.

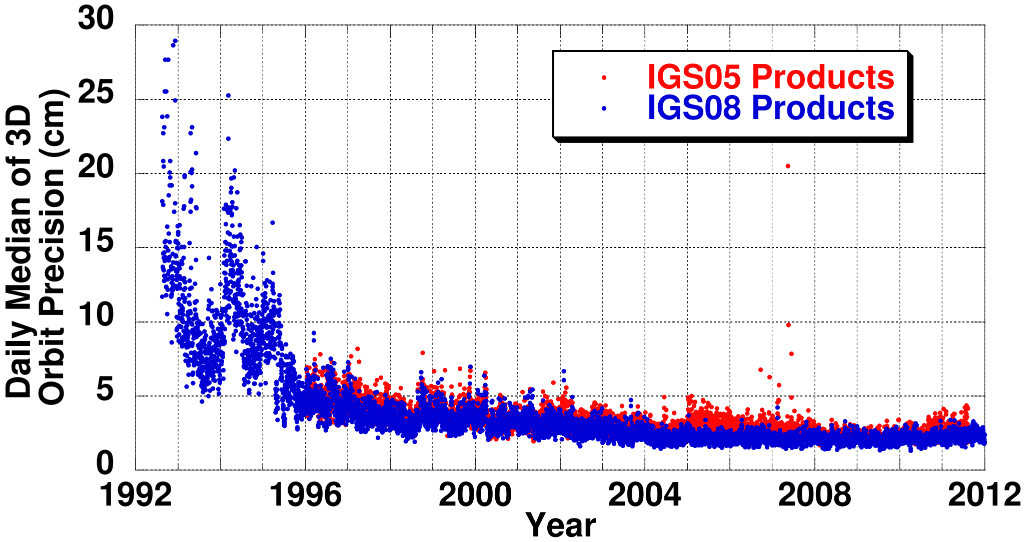

Figure 1: GPS satellite orbit precision of preliminary reanalysis of historical data from August 16, 1992 to present. Precision is measured as RMS of 3–D orbit overlap differences for each GPS satellite using middle 5 hours of 6–hour daily overlap.

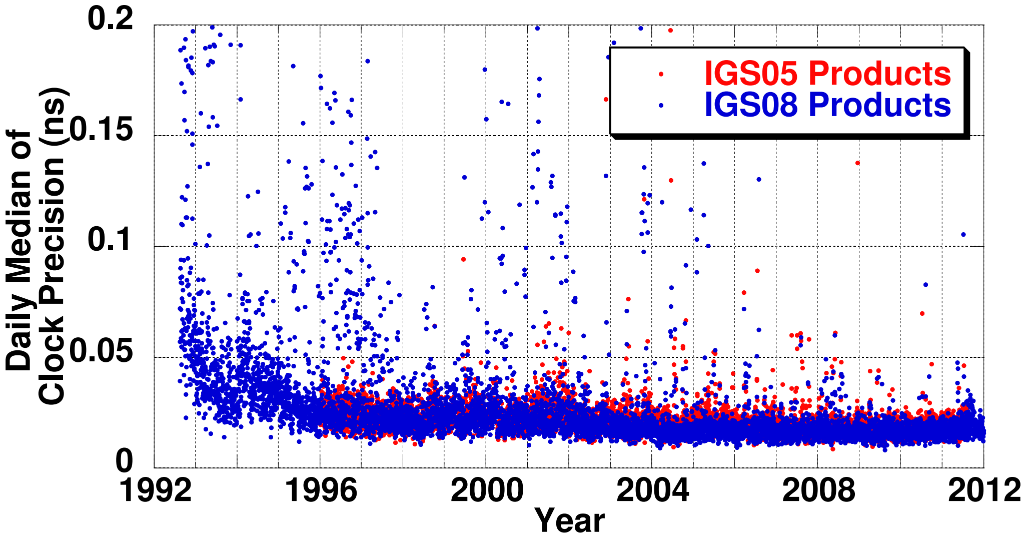

Figure 2: GPS satellite clock precision of preliminary reanalysis of historical data from Aigust 16, 1992 to present. Precision is measured as RMS of clock overlap differences for each GPS satellite using middle 5 hours of 6–hour daily overlap.

Our contributions to the 2013 reprocessing campaign are expected to benefit from the results and experience gained from our preliminary analysis. We expect to apply the following changes to our processing standards for JPL's contributions to the 2013 reprocessing campaign.

1. Second order ionospheric corrections (Garcia–Fernandez et al., 2012).
2. S1/S2 atmospheric loading corrections.
3. Modified empirical solar radiation pressure models, e.g. (Sibthorpe et al., 2010).
4. Antenna thrust models.

Development and testing of these changes started in 2012 and are expected to be completed in early 2013. We will deliver the full suite of products listed in Tab. 1 to the 2013 IGS reprocessing campaign, and also include high–rate (30–second) GPS clock products for 1996 onwards. We also plan to include high–rate (30–second) GPS clock products in our operational deliveries to the IGS before the end 2013.

4 Future Activities

Our primary focus in 2013 is to develop, test, and tune our software and processing standards in support of the second IGS reprocessing campaign, and to deliver products to the IGS for at least 1994–2012.

5 Acknowledgments

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MIT IGS Analysis Center Report for 2012

T. A. Herring, R. W. King

Room 54–820A, MIT
77 Massachusetts Avenue, Cambridge, MA 02139
e–mail: tah@mit.edu; phone: +1 617 253 5941

1 Introduction

In this report, we discuss the changes from our MIT analysis that have been made during the 2012 and some of the results obtained for satellite phase center variations, ground–based radome changes, and the changes when we moved to daily processing. Overall, except for changes due to daily processing, our analysis procedures have remained the same as reported in last year's report.

We look in some detail at the results when the radome was removed from YAR2 for 128 days between days 144–272 of 2012. The results of this analysis are currently inconclusive based on global analysis of these data. Local analysis of the data indicates that the impact of the radome is rather small (dNEU 0.6, 1.5 and −2.0 mm) but the systematic multipath at the site, not changed by removing the radome may have a bigger impact.

2 MIT products

MIT generates weekly submissions to the IGS final orbit and clock products. With the switch to daily processing, our submissions consist of (where WWWW is GPS week and [0−6] are the values between 0 and 6):

mit<WWWW>7.sum which is a summary file consisting of site statistics (phase and position root–mean–square (RMS) scatters, RMS scatter of clock fits to linear trends of the reference clocks for each day of the week, RMS scatters of the orbit overlaps (3.75 hrs on both sides of each orbit) and Earth orientation parameters (EOP) estimates in IERS standard format.

mit<WWWW>7.erp.Z Earth rotation parameters for 9–days IERS format

mit<WWWW>[0-6]. sp3.Z Daily GPS satellite orbits tabulated at 15 minute intervals with satellite clock estimates.

mit<WWWW>[0-6].clk.Z Daily GPS satellite clocks tabulated at 30–second intervals for the satellites and reference ground station. Other ground station clocks are tabulated at 15 minute intervals.

mit<WWWW>[0-6].snx.Z Daily coordinate and EOP SINEX file with minimum constraints applied to orient the solution to the IGS08 reference frame.

We also make available through `ftp://everest.mit.edu` binary global files for daily and weekly solutions, radiation parameter constraints, and position time series. GAMIT/GLOBK users can directly use these products. The global position and orbit files have estimates of the satellite phase centers, loosely constrained, and are a resource for analyzing the estimates of the these offsets. The estimates of the phase centers should be tightly constrained if consistency with the IGS models is needed. The files containing process noise values for solar radiation parameters can be used to apply similar orbital constraints to those used in the MIT analysis (see discussion below).

3 Analysis methods

Our approach to forming networks has remained the same as reported last year. We still use six networks each with 50 stations and network with two overlapping sites between each pair of networks. Since the networks are formed dynamically each day there is variation's day–to–day in the selection of sites. We do have a core list of stations, including the IGS reference sites and selected clock sites, which will be included in the network if they are available. This year we also added additional sites around Antarctica but have now become available and who's data are available through the international archives. In figure 1 we show the distribution of sites used throughout the year in the MIT processing. Because of the dynamic site distribution not all sites are used all the time, there is however a core group of sites, shown in magenta, that are used in nearly every day of processing.

3.1 Switch to daily processing

Starting on GPS week 1702, day 232 of 2012, August 19, the MIT processing was switched to daily ITRF estimates. The implementation of this change was done primarily by introducing process noise into the daily position estimates in the MIT weekly solutions. Prior to the switch, the MIT orbits were determined using a smoothing Kalman filter with the station positions estimated, but not varying, during the week. With the daily processing, the same type of analysis is performed accept that process noise, in the form of a random walk allowing one meter changes each day, was introduced into the Kalman filter run. With the implementation of the daily processing, daily SINEX files are generated and submitted without daily orbit files.

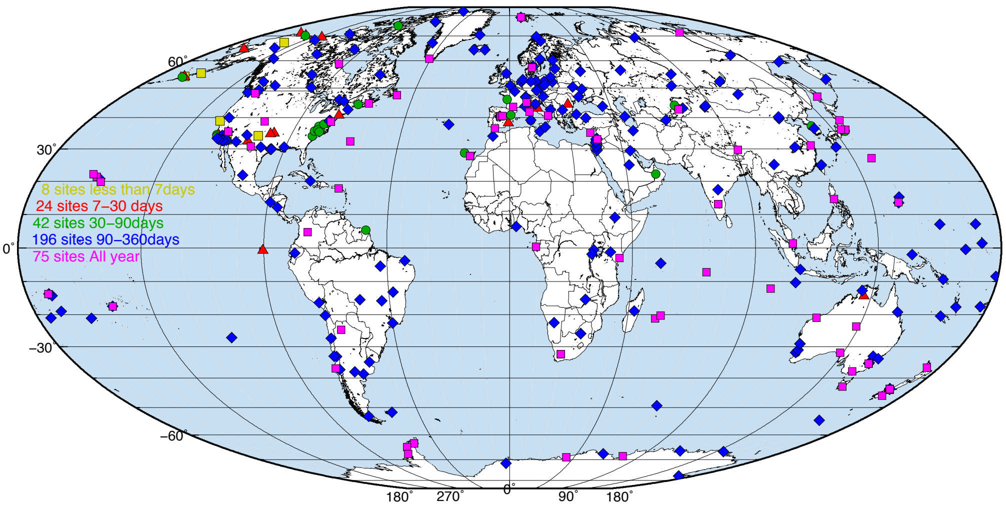

Figure 1: Distribution of sites used during 2012 in the MIT processing. Sites that are not used all the time arise because of availability of data and the selection criterion used to form global networks. Sites that appear only a few times occur because of lack of data from sites in the region that would normally be used in the processing. A total of 345 sites were included in the processing during the year.

3.2 Solar radiation parameter estimation and Clock Estimation

The procedures used in the MIT analysis for determining the solar radiation pressure parameters and the clock estimates remain unchanged from last year's report. The values of the once–per–revolution solar radiation parameter process noise values are available from the `ftp://everest.mit.edu` ftp site in the `MIT_SRP` folder. Even with the daily processing, one set of parameters is used from each week unless there is a specific issue that needs to be manually accounted for

3.3 Position estimate quality after switch to daily processing

In Tab. 1, we compare the median we did RMS scatters of the position estimates for the period in 2012 after the change to daily processing (August 19) with the corresponding period from 2011 went weekly processing was being carried out. This seems to be little impact on the position RMS scatter of switching to daily processing. The slight degradation might be due to the weekly solutions forcing positions to not change during the week. In the daily processing, the site positions are able to change day–to–day during the week. In general we conclude that daily processing has not impacted the position WRMS significantly. In terms of orbit agreement, the MIT daily orbits are more consistent with the IGS final orbit after the change. The only change in the MIT processing was the treatment of the station positions being stochastic during each of the weekly processing runs.

Table 1: Median weighted RMS (WRMS) scatter of MIT position estimates for the periods Aug 19−Dec 31, 2012 (after switch to daily processing) and the same interval in 2011 when weekly processing was performed. In both analyses, the orbits from the MIT solutions were used in the position determinations.

Analysis	North (mm)	East (mm)	Height (mm)	# sites
Daily 2012/8/19 to 2012/12/31	1.3	1.4	4.8	286
Daily 2011/8/19 to 2011/12/31	1.3	1.3	4.6	316

4 Ancillary analyses

4.1 Satellite phase center characteristics

In our routine analyses we also estimate positions of the satellite phase centers. For the products that we submit to the IGS, including SINEX files, the phase center offsets are tightly constrained to their values given in the ANTEX file. In Tab. 2, we give the mean values of the adjustments to the XYZ positions of the satellite phase center locations since the adoption of the IGS08 system for the 2012 processing. Due to the week selection, up to 49 weekly estimates are available. Analysis of the temporal behavior of the offsets show there are systematic variations with time and in the X and Y components suggest that there are yaw modeling errors that are being absorbed into the phase center position estimates. We are still analyzing results.

We are saving the average values of the phase residuals as a function of elevation angle at individual stations and as a function of nadir angle for satellites. In Fig. 2, we show the average residuals, for the last 60 days of 2012, as a function of nadir angle for PRN 16 (noted last year for having systematic residuals) and PRN 24 (latest Block IIF satellite to launch). While the magnitude of the patterns is small, they are indicative of small remaining errors in the satellite antenna phase center models. Since there are variations in the estimates of the positions of the phase centers relative to center of mass between satellites of the same type, variations in the nadir dependence could also be expected. (The phase residuals are generated with the nominal phase center position and hence some part of the pattern seen does reflect possible offsets in this location. In the case of PRN 16, the estimated offset is quite small and would have only a small effect on the pattern).

4.2 Radome removal tests: YAR2

During 2012, radomes were removed for YAR2, FAIR, and GODE to determine the impact of the radome on the positions estimates. We are looked at the changes in the positions

Table 2: Mean values of the adjustments to the IGS08 phase center locations based on analysis of data after GPS week 1632.

PRN	Type	Mean dX (mm)	RMS (mm)	Mean dY (mm)	RMS (mm)	Mean dZ (mm)	RMS (mm)	#
01	IIF	−2.5	9.4	−19.4	14.6	−72.9	69.0	49
02	IIR–B	33.3	30.3	−5.9	10.5	−53.6	73.1	49
03	IIA	5.6	21.6	−4.8	26.1	5.6	82.9	49
04	IIA	−7.9	18.9	23.6	10.1	−88.4	71.9	49
05	IIR–M	25.9	31.4	−3.7	9.8	−48.6	66.5	49
06	IIA	−0.7	19.8	−5.7	13.2	−2.0	7.3	49
07	IIR–M	18.6	11.2	4.3	8.6	−31.7	57.5	49
08	IIA	−14.7	13.5	51.1	30.2	−53.4	67.9	49
09	IIA	−22.6	7.8	3.4	13.4	−96.6	61.0	49
10	IIA	−5.3	19.4	14.2	10.6	−93.2	56.9	49
11	IIR–A	−3.6	17.0	−14.5	8.3	50.8	83.6	49
12	IIR–M	36.0	19.4	−14.5	9.0	−109.4	49.3	49
13	IIR–A	20.0	21.0	−2.1	8.5	10.4	50.8	49
14	IIR–A	26.1	24.4	−1.7	7.6	−8.2	61.4	49
15	IIR–M	31.2	24.6	−5.1	10.4	−95.3	84.3	49
16	IIR–A	40.8	24.9	−10.8	9.9	−3.1	81.4	49
17	IIR–M	31.6	31.3	−4.6	8.4	−52.9	67.7	49
18	IIR–A	40.1	29.9	−6.1	10.1	−54.8	86.8	49
19	IIR–B	37.6	33.5	−9.3	11.4	−17.2	56.4	49
20	IIR–A	29.4	33.7	−2.2	10.5	32.3	62.7	49
21	II–A	28.8	33.1	2.0	10.2	−40.8	77.1	49
22	IIR–B	25.0	29.2	2.5	15.0	−70.1	73.7	49
23	IIR–B	38.6	23.6	−2.4	7.4	−7.1	43.9	49
24	IIF	−2.8	16.6	−31.5	5.8	−293.5	53.8	8
25	IIF	−10.7	11.5	−29.8	15.4	−122.6	69.6	49
26	IIA	−10.5	19.3	4.3	23.6	−123.4	88.0	49
27*	IIA	−19.6	7.3	37.8	13.1	−91.0	53.8	40
28	IIR–A	23.5	22.0	3.7	7.2	−16.5	55.6	49
29	IIR–M	37.6	33.0	−7.9	9.9	−77.1	87.3	49
30	IIA	−2.8	17.0	−9.6	19.4	13.6	66.3	49
31	IIR–M	18.9	11.7	0.0	7.8	−39.9	59.8	49
32	IIA	9.5	20.9	39.4	21.7	−15.4	69.6	49

* PRN 27 was assigned to SV 49 (block IIR–M) on 2012-10-18; the estimate here is for the Block IIA SV 27 assigned to this PRN until this date.

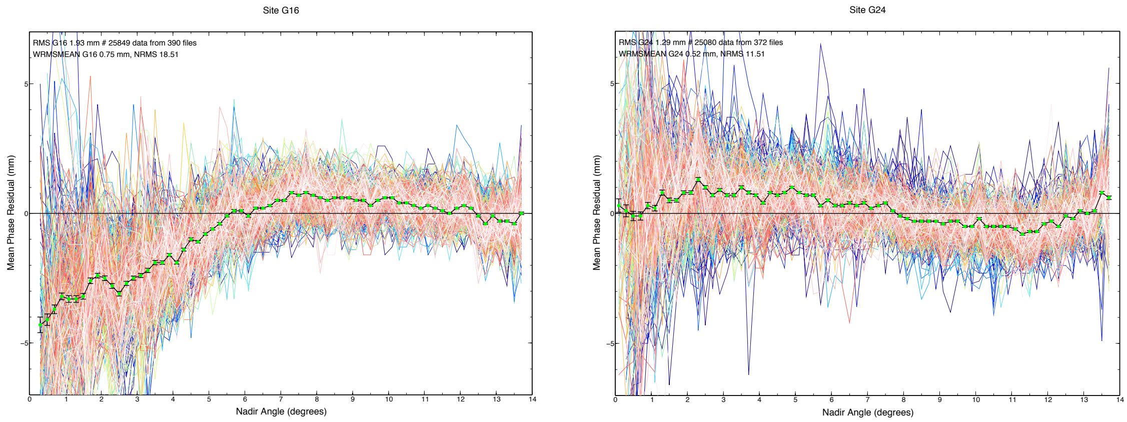

Figure 2: Average phase residuals to PRN 16 (left) and PRN 24 (right) as function of nadir angle. Each line is from one day of data and the color of line progresses from blues to reds as a function of time. The green dots show the average values. The phase center location is fixed to the IGS08 value, with average estimate of the adjustment to those values given in Tab. 2. (Values in Tab. 2 not applied to the phase residuals).

during these intervals and the effect on the phase residuals. All three of these sites have systematic phase residual dependence on elevation angle. FAIR is the worst, followed by YAR2 (shown in Fig. 3) and then GODE. Removing the radomes had no clear effect on the phase residuals. The position changes in general were several millimeters and not clearly above the levels of correlated noise. Results for YAR2 are shown in Fig. 4 where changes of 2 mm and −5 mm (averages of before and after values) in east and height seem significant. Short baseline processing the YAR2−YARR baseline for 8 days before and

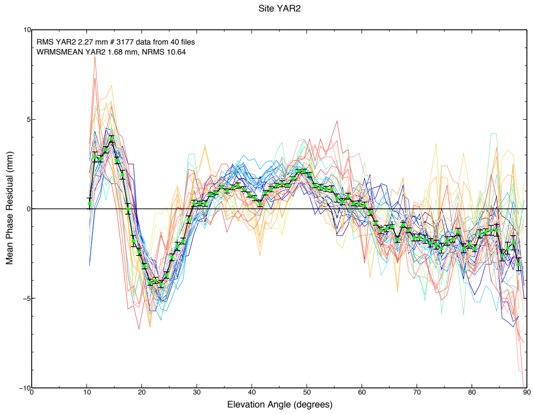

Figure 3: Average phase residuals as a function of elevation angle at YAR2 during the interval when the radome was not on the antenna. Visually, the averages residuals look the same when the radome is present.

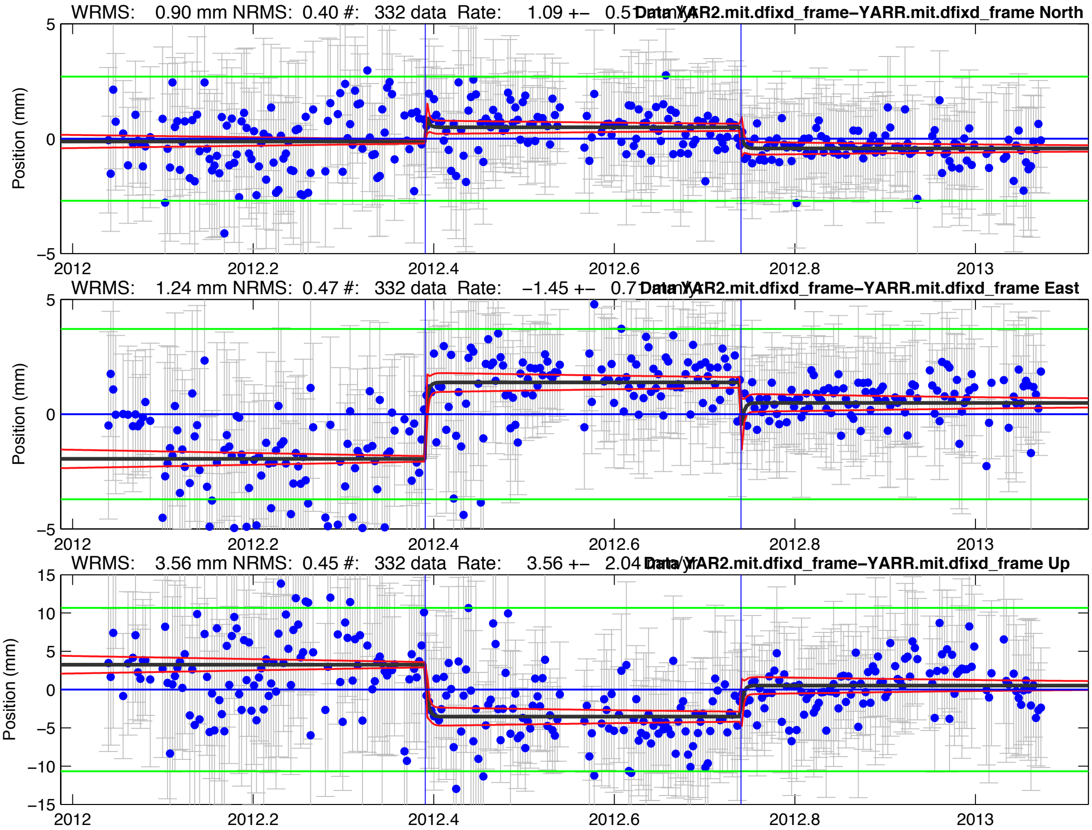

Figure 4: Time series in North, East and Up of difference in position between YAR2 and the nearby YARR sites (≈ 4 m separation) during the periods with (start and end) and with a radome over the antenna. Most of the times these two sites are not processed together. The offsets when the radome is removed and replaced are N 0.7,−0.9 mm, E 3.3,−1.0 mm and U −6.7,4.0 mm and are symmetric.

10 days after the radome change show offsets of 0.6, 1.5 and −2.0 mm in North, East and Up. The uncertainties of these estimates are 0.2 mm NE and 0.4 mm U. There is also small offset in the atmospheric delay that will be correlated with the height estimates. These values are likely to be more robust than the global processing where normally YAR2 and YARR are in different networks in the processing. We are still looking that the other sites. Their offsets are of similar size but they do not have nearby sites that can be used for short baseline processing.

United States Naval Observatory Analysis Center Report 2012

C. Hackman, S. Byram, V. Slabinski, and J. Tracey

United States Naval Observatory
3450 Massachusetts Avenue Northwest
Washington DC 20392 USA
e–mail: christine.hackman@usno.navy.mil
phone: 202 762 1428

1 Introduction

The United States Naval Observatory (USNO), located in Washington, DC, USA has served as an IGS Analysis Center (AC) since 1997, contributing to the IGS Rapid and Ultra–rapid Combinations since 1997 and 2000, respectively. USNO contributes a full suite of rapid products (orbit and clock estimates for the GPS satellites, earth rotation parameters (ERPs), and receiver clock estimates) once/day to the IGS by the 1600 UTC deadline, and contributes the full suite of ultra–rapid products (post–processed and predicted orbit/clock estimates for the GPS satellites; ERPs) four times/day by the pertinent IGS deadlines.

USNO has also coordinated IGS troposphere activities since 2011, producing the IGS Final Troposphere Estimates and chairing the IGS Troposphere Working Group (IGSTWG).

The USNO AC is hosted in the GPS Analysis Division (GPSAD) of the USNO Earth Orientation Department (EOD). Dr. Christine Hackman, GPSAD chief, directs AC activities, chairs the IGSTWG, and serves on the IGS Governing Board. Dr. Sharyl Byram oversees production of the IGS Final Troposphere Estimates. All GPSAD members, including Dr. Victor Slabinski and Mr. Jeffrey Tracey, participate in AC work. Mr. Jim Rohde joined GPSAD in 2012 as a contractor.

USNO AC products are computed using Astronomical Institute of the University of Bern Bernese GPS Software (Dach et al., 2007)[1]. Rapid products are generated using a combination of network solutions and precise point positioning (PPP; Zumberge et al., 1997).

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[1] Prior to 2009, the rapid products were computed using Jet Propulsion Laboratory (JPL) GPS Inferred Positioning System (GIPSY) Webb and Zumberge (1997).

Ultra–rapid products are generated using network solutions. IGS Final Troposphere estimates are generated using PPP.

GPSAD also generates a UT1−UTC–like quantity, *UTGPS*, five times/day. UTGPS is a GPS–based extrapolator of VLBI–based UT1−UTC measurements. The IERS[2] Rapid Combination/Prediction Service uses UTGPS to improve post–processed and predicted estimates of UT1−UTC. Mr. Tracey oversees UTGPS. For more information, please contact the AC.

USNO rapid, ultra–rapid and UTGPS products can be downloaded immediately after computation from `http://www.usno.navy.mil/USNO/earth-orientation/gps-products` . IGS Final Troposphere estimates can be downloaded at `ftp://cddis.gsfc.nasa.gov/gps/products/troposphere/zpd` .

2 Developments in 2012

The USNO AC began incorporating measurements from the Russian GLONASS GNSS into processing in 2011 (Byram and Hackman, 2012b,c). Dr. Sharyl Byram completed development of USNO combined GPS/GLONASS ultra–rapid and rapid products in 2012. The USNO ultra–rapid products are now under study at the IGS for possible inclusion in the IGS “IGV” GPS/GLONASS ultra–rapid combination. The USNO rapid GPS/GLONASS products are thus far distributed only internally, as the IGS does not compute analogous estimates.

GPSAD ultra–rapid predictions could provide high–precision real–time PNT to users. GPSAD began testing position/timing accuracy achievable using its ultra–rapid predicted values in 2012 (Hackman and Matsakis, 2012; Hackman, 2012b,c,d). 7−9 mm position precision and ns–level timing accuracy were achieved in initial PPP tests (Hackman, 2012b). Significant improvements in satellite clock prediction accuracy should enable significant improvements in position accuracy (Hackman, 2012c,d).

Division personnel (C. Hackman, S. Byram, V. Slabinski, J. Tracey) wrote/delivered over a dozen publications/presentations in 2012, representing USNO at scientific– and defense–oriented symposia such as the IEEE International Frequency Control Symposium, IGS 2012 Workshop, American Geophysical Union 2012 Fall Meeting, Office of Naval Research Science and Technology Partnership Conference, Precise Time and Time Interval Systems and Applications Meeting, Institute of Navigation (ION) Position, Location and Navigation Symposium, ION Joint Navigation Conference, and AAS Division on Dynamical Astronomy.

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[2] International Earth Rotation and Reference Systems Service

3 Publications/Presentations in 2012 Pertaining to USNO IGS Work

Byram, S. and C. Hackman. Computation of the IGS Final Troposphere Product by the USNO. *IGS Workshop 2012*, 23–27 July 2012, Olsztyn, Poland, 2012a.

Byram, S. and C. Hackman. GNSS-Based Processing at the USNO: Incorporation of GLONASS Observations. *IGS Workshop 2012*, 23–27 July 2012, Olsztyn, Poland, 2012b.

Byram, S. and C. Hackman. High-Precision GNSS Orbit, Clock and EOP Estimation at the United States Naval Observatory. Proc. *2012 IEEE/ION Position Location and Navigation Symposium*, 659-63, 2012c.

Church, W. (V. Slabinski, mentor). GPS Satellite Orbits: Solar Radiation Force Evaluation Software. USNO Professional Seminar, 16 August 2012.

Hackman, C. GPS Code/Carrier-Phase Time Frequency Transfer. *IEEE International Frequency Control Symposium Tutorials*, 149 pp, 2012a.

Hackman, C. Near-Real-Time and Other High-Precision GNSS-Based Orbit/Clock/Earth-Orientation/Troposphere Parameters Available from USNO. Proc. *2012 ION Joint Navigation Conference (JNC)*, 1274-1288, 2012b.

Hackman, C. Impact of Orbit, Clock, and EOP Errors in GNSS Precise Point Positioning. *2012 Fall Meeting, AGU*, San Francisco, CA, USA, 03–07 December, 2012c.

Hackman, C. Accuracy/Precision of USNO Predicted Clock Estimates for GPS Satellites. Proc. *44th Ann. Precise Time and Time Interval (PTTI) Systems and Applications Meeting*, pp. 94–99, 2012d.

Hackman, C. and S. Byram. IGS Troposphere Working Group 2011. IGS Technical Report 2011, 211-8, 2012.

Hackman, C., S. Byram, V. Slabinski, and J. Tracey. United States Naval Observatory Analysis Center Report 2011. IGS Technical Report 2011, 99-106, 2012a.

Hackman, C. and D. Matsakis. Precision and Accuracy of USNO GPS Carrier Phase Time Transfer: 2012 Update. Proc. *2012 IEEE International Frequency Control Symposium*, 94–99, 2012.

Hackman, C., V. J. Slabinski, J. C. Tracey, and S. M. Byram. USNO Analysis Center Progress 2010-2. *IGS Workshop 2012*, 23–27 July 2012, Olsztyn, Poland, 2012b.

Slabinski, V. LAGEOS Satellite Drag: the Eclipse Season Mystery Remains. 43rd Meeting of the *American Astronomical Society Division on Dynamical Astronomy*, oral presentation #4.04, 2012.

4 Product Performance 2012

Figures 1-4 show the 2012 performance of USNO rapid and ultra–rapid products, with summary statistics given in Tab. 1. USNO rapid orbits had a median weighted RMS (WRMS) of 17 mm with respect to (wrt) the IGS rapid combined orbits. The USNO ultra–rapid orbits had median WRMSs of 22 mm (24–h post-processed segment) and 49 mm (6–h predict) wrt the IGS rapid combined orbits.

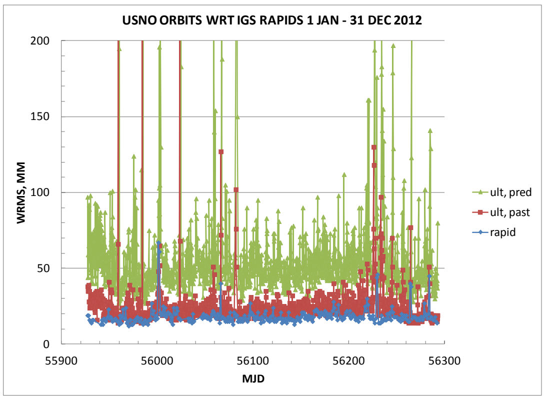

Figure 1: Weighted RMS of USNO GPS orbit estimates with respect to IGS Rapid Combination, 2012. "Ult, past" refers to 24–hour post–processed section of USNO ultra–rapid orbits. "Ult, pred" refers to first six hours of ultra–rapid orbit prediction.

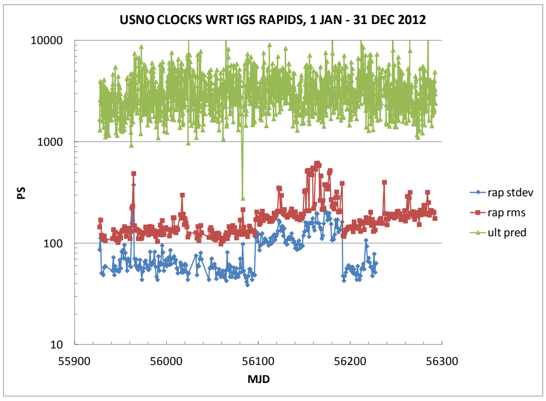

Figure 2: RMS/standard deviation of USNO rapid GPS clock estimates and RMS of USNO ultra–rapid GPS clock predictions with respect to IGS Rapid Combination, 2012.

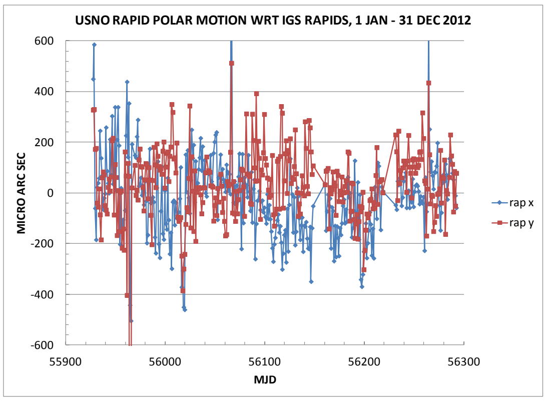

Figure 3: Difference between USNO rapid polar motion estimates and IGS Rapid Combination, 2012.

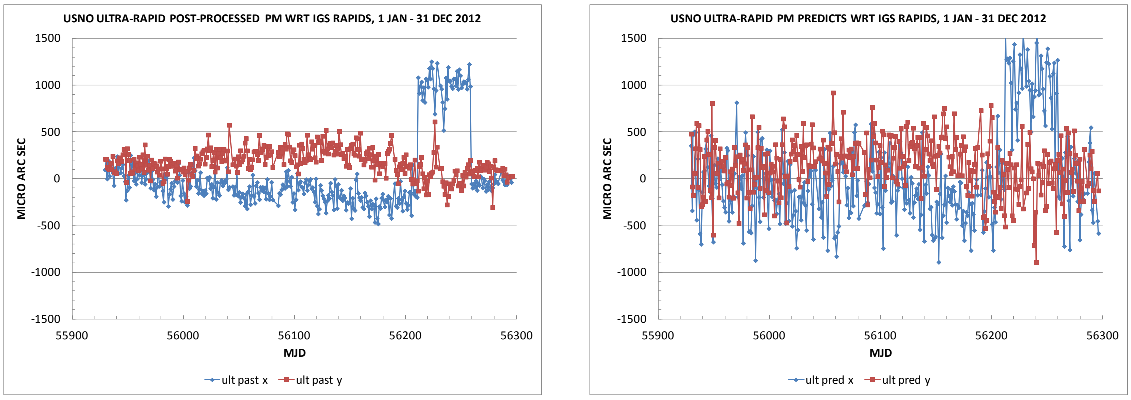

Figure 4: Difference between USNO ultra-rapid polar motion estimates and IGS Rapid Combination, 2012.

Table 1: Accuracy/Precision of USNO Rapid and Ultra–Rapid Products: 1 Jan – 31 Dec 2012. All statistics computed with respect to IGS Combined Rapid Products.

USNO GPS satellite orbits			**USNO GPS–based polar motion estimates**			**USNO GPS–based clock estimates**	
Statistic: median weighted RMS difference units: mm			Statistic: RMS difference units: 10^{-6} arc sec			Statistic: median standard dev. and RMS of difference units: ps	
rapid	ultra–rapid		rapid	ultra–rapid		rapid	ultra–rapid
	past 24 h	6–h predict		past 24 h	24–h predict	past 24 h	6–h predict
17	22	49	x:166 y:195	x:402 x:175[A] y:226	x:510 x:355[A] y:319	STDEV: 67[B] RMS: 164	RMS: 2929

[A] Omitting data from MJD 56211–58 during which time USNO ultra–rapid PM–x values took a large excursion from IGS rapid values. USNO ultra–rapid PM–x values have since returned to normal.

[B] Computed for 1 Jan – 28 Oct 2012; IGS ceased publishing this statistic thereafter.

USNO rapid clocks had a 67 ps standard deviation (STDEV) and 164 ps RMS wrt IGS combined rapid clocks. USNO ultra–rapid clock predictions (first six h) had a 2929 ps RMS wrt IGS combined rapid clocks.

USNO rapid polar motion (PM) estimates had RMS differences wrt IGS rapid combined values of (x, y) 166 and 195 micro arc sec. USNO ultra–rapid PM estimates differed from IGS rapid combined values (x, y) by 402 and 226 micro arc sec for the 24–h post–processed segment and 510 and 319 micro arc sec for the 24–h predict. The ultra-rapid PM–x values took large excursions from the IGS rapid values during MJDs 56211−58 as Fig. 4 shows. When values from these dates are omitted the ultra-rapid RMS PM-x residuals reduce to 175 and 355 micro arc sec for the post–processed and predicted segments, respectively, comparable to the PM–y residuals.

USNO ultra–rapid PM residuals improved sufficiently toward the end of 2012 to become comparable in size to those of other ACs and are thus under consideration for re–inclusion in the IGS ultra-rapid combination, having been given zero weight during 2012.

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Zumberge, J. F., M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb. Precise Point Positioning for the Efficient and Robust Analysis of GPS Data from Large Networks. *J. Geophys. Res.*, 102(B3):5005–17, 1997.

WHU IGS Analysis Center Technical Report 2012

C. Shi, M. Li, Q. Zhao, X. Lei, J. Liu

GNSS Research Center of Wuhan University, China

1 Introduction

Wuhan University Analysis Center (WHU) was officially authorized by IGS organization on 8th August 2012 after an intensive evaluation of more than half a year. As a consequence, this is our first contribution to the IGS technical reports. The main motivations to become an IGS Analysis Center were to evaluate the performance of the PANDA (Positioning And Navigation Data Analyst) software package developed by Wuhan University and to contribute to the discussions on GNSS processing strategy, model refinement, etc.

This report introduces the WHU Analysis Center and gives an overview of the WHU activities during 2012.

2 WHU IGS Analysis Center

WHU is located at the GNSS Research Center of Wuhan University, China. All the solutions and results are produced by the latest development version of the PANDA software. Up to now, WHU mainly contributes to the IGS ultra–rapid and rapid products, including GPS/GLONASS satellite orbits and clock errors as well as ERPs (Earth Rotation Parameters).

2.1 Developments

The development of WHUIGS Analysis Center is summarized in Tab. 1.

Table 1: Developments of WHUIGS Analysis Center

2011–12	WHU IGS AC application submitted to IGS
2012–02	GPS ultra–rapid solutions submitted to ACC, including satellite orbits, clock errors and ERP parameters
2012–08	WHU AC officially authorized by IGS, ultra–rapid solutions weighted in the ACC combination
2012–09	GPS/GLONASS ultra–rapid products weighted in the ACC combination
2012–10	GPS/GLONASS rapid solutions submitted to ACC, including satellite orbits, clock errors and ERPs

2.2 PANDA software

PANDA software package is capable of simultaneously processing various types of measurements from GNSS, SLR, KBR, star trackers and accelerometers in order to estimate ground station coordinates, ZTDs, ERPs and orbits for GNSS satellites, LEOs and GEOs. Various methods for kinematic, dynamic and reduced–dynamic precise orbit determination of LEO satellite orbits are developed in this software package.

PANDA software package includes two core modules, the orbit integrator and the state estimator. In the orbit integrator module, Runge–Kutta approach is used to estimate initials and Adams–Moulton multi–step approach to estimate corrections. Perturbations of non–spheric earth gravity, earth tide and ocean tide, solar and planet point mass as well as relativity are modeled by IERS Conventions 2010 (Petit and Luzum, 2010). The yaw attitude modeling for GLONASS was implemented according the model provided by ESOC (Dilssner et al., 2011).

Both least–squares estimator (for post–processing) and square–root information filter(for real–time processing) are implemented in the state estimator module (Liu and Ge, 2003). In order to speed up the data processing, an efficient approach of removal and recovery of station coordinate and ambiguity parameters is employed in the least–squares estimator (Shi et al., 2010). Besides, the ambiguity–fixing can also be performed in network mode or single point mode which would improve the positioning accuracy significantly for WHU final solutions.

3 WHU Analysis Products

3.1 Products

The list of products provided by WHU is summarized in Tab. 2.

Table 2: List of products provided by WHU

WHU rapid GNSS products	
whuWWWD.sp3	Orbits for GPS/GLONASS satellites
whuWWWD.clk	5–min clocks for stations and GPS/GLONASS satellites
whuWWWD.erp	ERPs

WHU ultra–rapid GNSS products	
whuWWWD_HH.sp3	Orbits for GPS/GLONASS satellites;provided to IGS every 6 hours
whuWWWD_HH.erp	observed and predicted ERPs provided to IGS every 6 hours

The WHU rapid GNSS products are provided daily for the previous day which produced available within 2 hours after the end of the observation day. Both GPS and GLONASS data are processed simultaneously to produce rapid satellite orbits. About 55 satellites are included in daily processing. The accuracy of GPS rapid orbits are shown in Fig. 1 and the weighted RMS is about 15 mm.

The WHU ultra–rapid products are based on the combination of the 6–hour normal equation using global hourly IGS data, including satellite orbits, clock errors and ERPs. The ultra–rapid products consist of a 48–hr orbit file (24 h estimated and 24 h predicted) along with a 2–day ERP file (the first day is estimated and the second day is predicted).

The quality of the WHU ultra–rapid products are shown in Fig. 2. The accuracy of the ultra–rapid products are 3 cm for the prediction orbit, measured as a WRMS compared to the IGS ultra–rapid orbits (IGU).

3.2 Processing strategy

The routine processing of WHU is based on a least–squares estimation solution of IGS station data in RINEX format. And the selection of ground stations depends on the availability and the past performance of raw data as well as the required time delay according to the type of products. For the rapid and ultra–rapid solutions, about 120 and 110 stations are used, respectively, which are shown in Fig. 3.

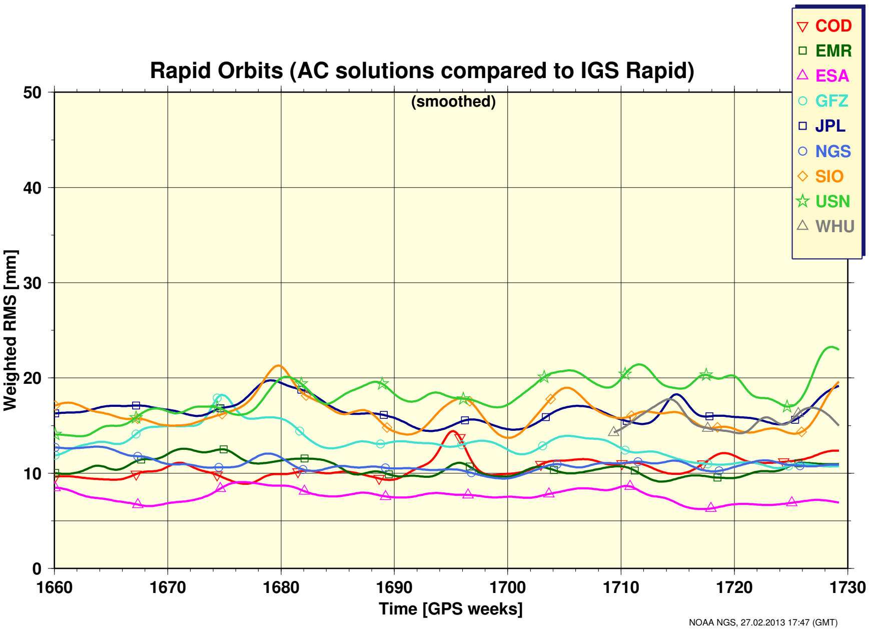


Figure 1: Weighted RMS of WHU rapid orbits.

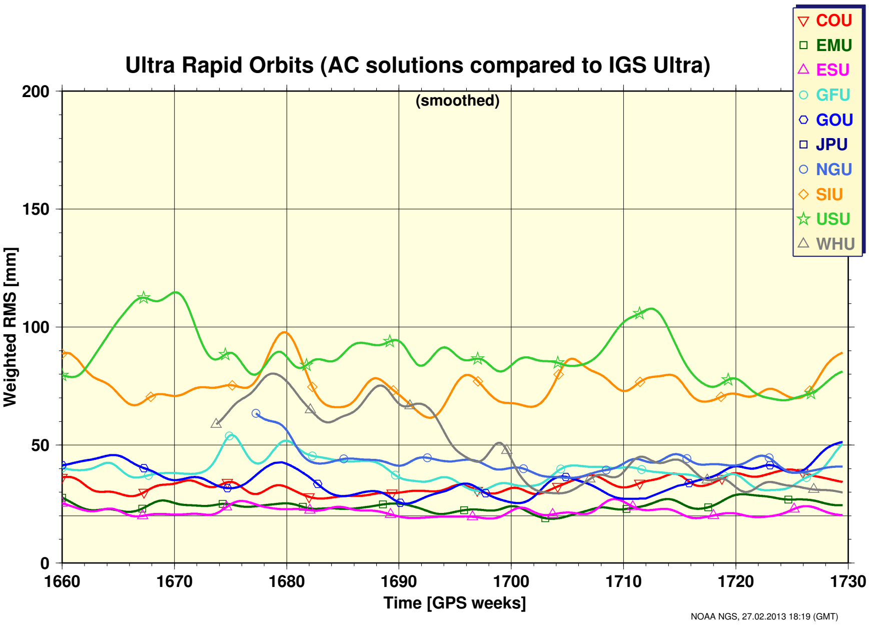
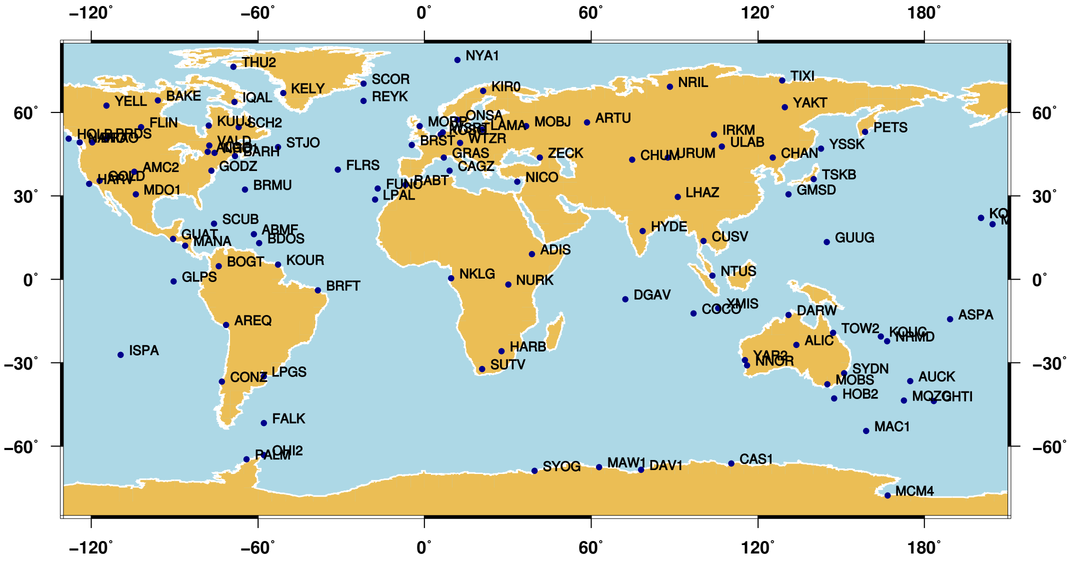


Figure 2: Weighted RMS of WHU ultra–rapid orbits.


–120˚
–60˚
0˚
60˚
120˚
180˚
60˚
30˚
0˚
–30˚
–60˚
THU2
NYA1
SCOR
REYK
KELY
KIR0
YELL
BAKE
IQAL
NRIL
TIXI
YAKT
FLIN
KUUJ
SCH2
ONSA
LAMA
MOBJ
ARTU
IRKM
ULAB
PETS
PRDS
VALD
BARH
STJO
MORP
BRST
WTZR
GRAS
CAGZ
ZECK
CHUM
URUM
CHAN
YSSK
AMC2
GODZ
FLRS
NICO
TSKB
GMSD
HARV
GOLD
MDO1
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DARW
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NRMD
ALIC
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HARB
SUTV
YAR2
NNOR
CONZ
LPGS
SYDN
MOBS
AUCK
HOB2
MQZG
CHTI
FALK
MAC1
PALM
OHI2
SYOG
MAW1
DAV1
CAS1
MCM4

2013 Feb 27 16:18:19

Figure 3: Ground stations used for WHU rapid and ultra–rapid products.

For the IGS submissions the estimated parameters are:

- the station coordinates,
- the satellite state vectors,
- station and satellite clock errors, estimated as time-dependent parameters (one value for every observation epoch),
- the Earth rotation parameters: x and y pole position and rates and length of Day,
- the solar radiation pressure parameters with BERN model,
- the zero-differenced carrier phase ambiguities for the ionospheric-free linear combination,
- the GPS–GLONASS receiver biases (for the GPS/GLONASS combined processing),
- the tropospheric zenith delay for every station every 2 hours with north and east horizontal gradients.

4 WHU contributions to BeiDou

The BeiDou satellite system was initiated on April 13, 2007 with the launch of the first MEO satellite. At the beginning of October 2012, the first phase had been almost completed. A total of 15 BeiDou navigation satellites have been successfully launched. The WHU has been processing BeiDou data since 2011 and providing precise BeiDou orbits

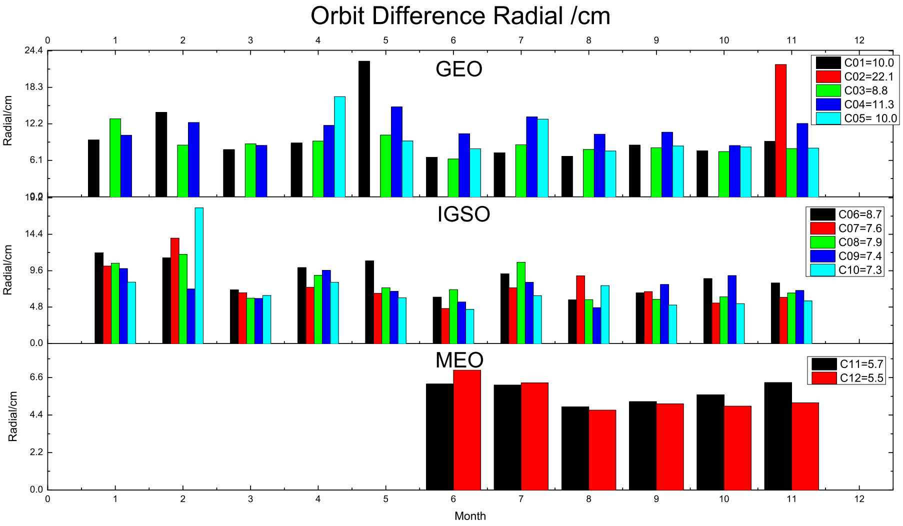

Figure 4: BeiDou orbit overlap statistics of the radial component in 2012 (unit: cm).

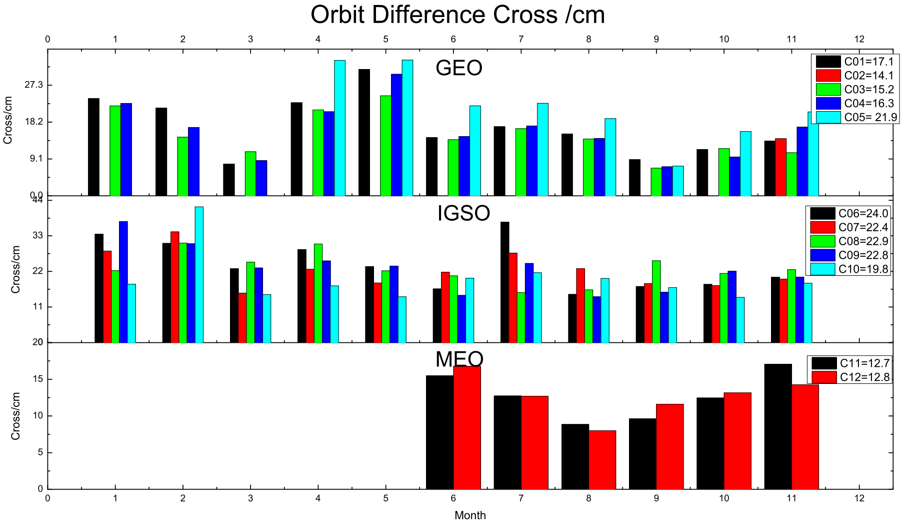

Figure 5: BeiDou orbit overlap statistics of the cross–track component in 2012 (unit: cm).

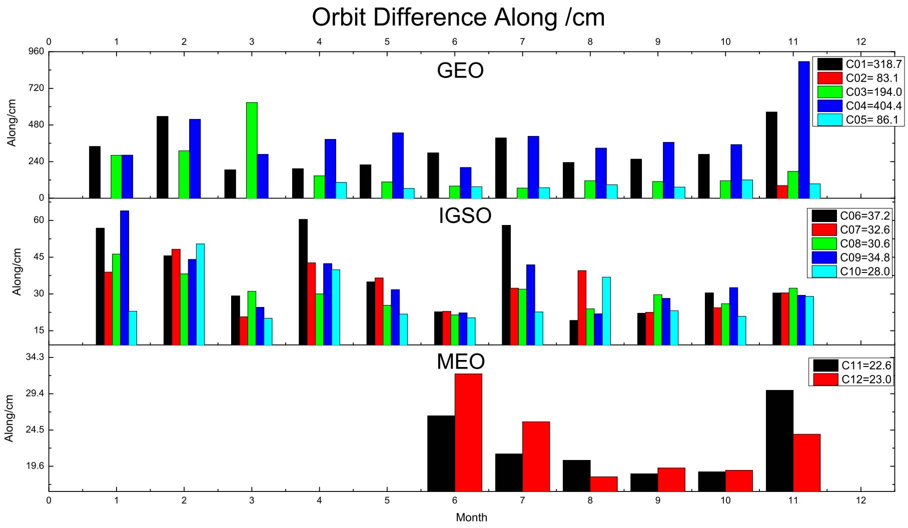

Figure 6: BeiDou orbit overlap statistics of the along–track component in 2012 (unit: cm).

based on the BeiDou Experimental Tracking Network (CETN) which is built by WHU since this time (Shi et al., 2012).

As no BeiDou precise satellite orbits are available up to date, overlapping arcs comparison is used to analyze the accuracy of satellite orbits estimated by WHU. The monthly RMS values of the differences in the radial, cross–track and along–track component for GEO/IGSO/MEO satellites are shown in Fig. 4 ∼ Fig. 6, respectively. Results show that the RMS of radial component is better than 10 cm and the cross–track is better than 20 cm.

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EUREF Permanent Network

C. Bruyninx[1], *H. Habrich*[2], *A. Kenyeres*[3],
W. Söhne[2], *G. Stangl*[4], *C. Völksen*[5]

[1] Royal Observatory of Belgium (ROB), Brussels, Belgium
E–mail: `C.Bruyninx@oma.be`
[2] Bundesamt für Kartographie und Geodäsie (BKG), Frankfurt am Main, Germany
[3] FOMI Satellite Geodetic Observatory, Budapest, Hungary
[4] Institute for Space Research, Graz, Austria
[5] Bavarian Academy of Science and Humanities, Munich, Germany

1 Introduction

The IAG (International Association of Geodesy) Regional Reference Frame sub–commission for Europe, EUREF, is responsible for defining, providing access and maintaining the European Terrestrial Reference System (ETRS89 Bruyninx et al., 2009). The EUREF key infrastructures are the EUREF Permanent GNSS Network (EPN) and the United European Levelling Network (UELN). The EPN is a network of continuously operating GNSS reference stations maintained on a voluntary basis by EUREF members. Its primary purpose is to provide access to the ETRS89 by making publicly available the GNSS tracking data as well as the precise coordinates of all EPN stations. The EPN cooperates closely with the International GNSS Service (IGS, Dow et al., 2009); EUREF members are participating to the IGS Real–Time Pilot Project, the IGS GNSS Working Group, the IGS Antenna Calibration Working Group, the Troposphere Working Group, the IGS Multi GNSS Experiment (MGEX), and the IGS Infrastructure Committee.

The EUREF Technical Working Group (TWG) defines the general policy of the EPN following proposals by the EPN Coordination Group. This Coordination Group consists of the Network Coordinator (managing the EPN Central Bureau), Data Flow Coordinator, Analysis Coordinator, Reference Frame Coordinator, Troposphere Coordinator, Chair of the Real–time Analysis project, and Chair of the reprocessing project. The EPN Reference Frame coordinator is a new position created by the EUREF TWG at its 2012 spring meeting. He is responsible for generating regularly an updated long–term EPN position and velocity product, the classification/categorization of EPN stations according to their quality and the densification of the EPN using solutions from national permanent GNSS networks (see Kenyeres, 2012a; Kenyeres et al., 2012).

2 Tracking Network

2.1 New Stations

By the end of 2012, the EPN network consisted of 244 continuously operating GNSS reference stations (Figure 1) from which 34% also belong to the IGS. Before inclusion in the EPN, the Central Bureau checks the data quality, meta–data, data availability and latency, and the availability of absolute antenna calibrations for the proposed station. As soon as a station fulfils all requirements, the station is included in the EPN. Data communication problems, influencing the reliable upload to the EPN data centres (regional and local ones) is one of the main reasons delaying the integration of a new station in the EPN. However, almost all proposed stations are accepted in the EPN within six months after their initial proposal. Interested station managers can check EPN guidelines for a proposed station to become an EPN site at `http://www.epncb.oma.be/_networkdata/proposed.php`.

Five new stations were integrated in the EPN network in 2012: BRUX, MELI, RIO1, SUR4, and TOR2. They are indicated with triangles in Figure 1. More details are provided in Table 1. Four of them are replacements of decommissioned EPN stations (mostly due to construction work near the antenna).

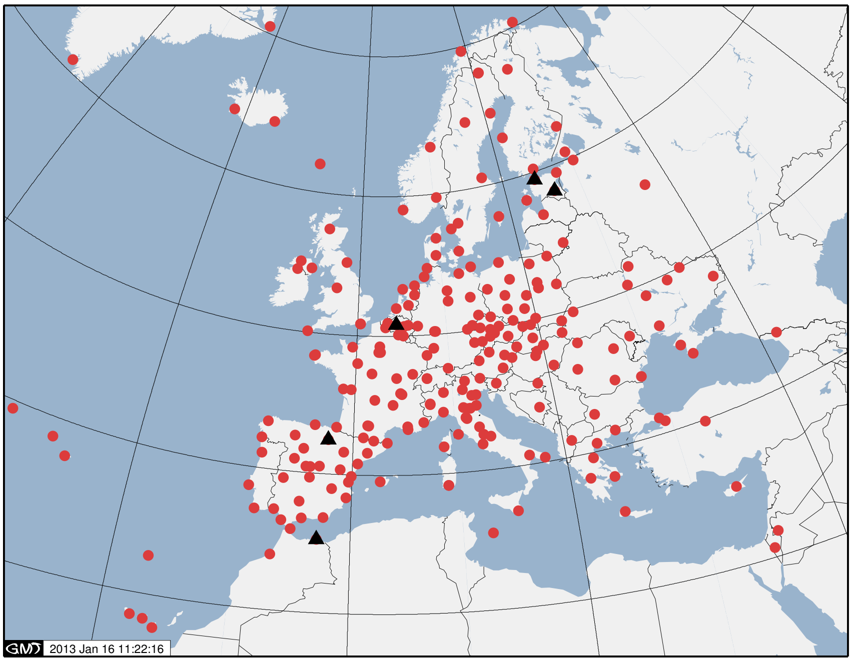

Figure 1: EPN tracking stations, status Dec. 2012. ▲ indicate new stations included in the network in 2012.

Table 1: New stations included in the EPN in 2012.

4Char–ID	Location	Replacement or New	Sat. Tracking	Antenna Calibration used in EPN analysis
BRUX	Brussels, Belgium	BRUS	GPS+GLO+GAL	Individual from Univ. Bonn
MELI	Melilla, Spain	new	GPS+GLO+GAL	Individual from GEO++
RIO1	Logrono, Spain	RIOJ	GPS+GLO+GAL	Individual from GEO++
SUR4	Tallinn, Estonia	SUUR	GPS+GLO	Type mean from IGS
TOR2	Tõravere, Estonia	TORA	GPS+GLO	Type mean from IGS

2.2 Multi–GNSS Tracking

All new stations added to the EPN in 2012 are equipped with GPS/GLONASS tracking equipment, bringing the percentage of the EPN stations providing GPS+GLONASS data to 68%. In addition, 67 EPN stations (Figure 2) operate equipment that is certified "Galileo–ready", but presently only 25 of them upload RINEX v3 data including Galileo observations to data centre maintained by the BKG. In addition, 27 of the 29 new antennas/radomes (new stations or replacements at existing stations) introduced in the EPN during 2012 are already capable to track new signals from multiple GNSS and will not require any additional hardware upgrade in the near future.

Already today 75 EPN stations have the capability of tracking GPS L5, but only 32 of them are actually providing RINEX v2.11 data including L5 (see Figure 3). Station managers have been reluctant to activate L5 tracking because of possible conflicts with the national RTK services they provide.

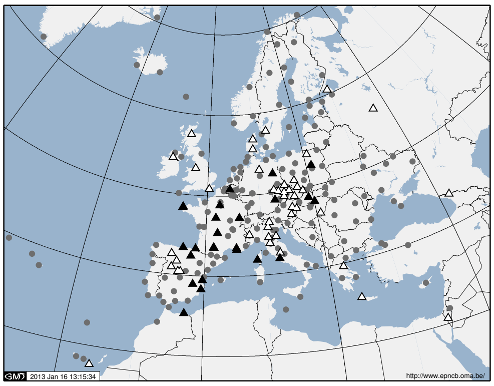

Figure 2: EPN tracking stations capable of tracking Galileo: ▲ submitting RINEX v3 data to EUREF; △ not (yet) submitting RINEX v3 data to EUREF.

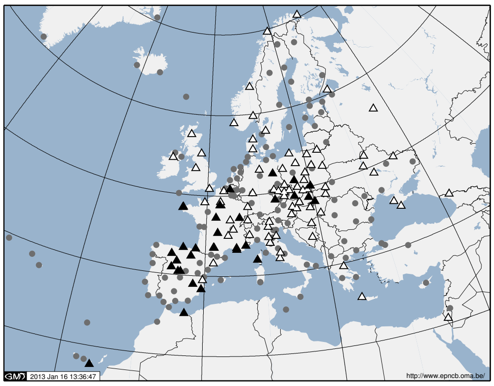

Figure 3: EPN tracking stations capable of tracking L5 indicated with △; those in addition including L5 in their RINEX v2.11 data are indicated by ▲.

2.3 Antenna Calibration Models

In addition to the type mean antenna calibrations, the EPN uses since November 2006 the original individual antenna calibrations which are linked to a specific antenna/radome type and antenna serial number. They can be considered as the best possible calibration for a specific antenna/radome combination. Historically, 81 individual calibrations are available within the EPN. The majority of new antennas introduced in the EPN (new stations or antenna replacements) have now individual antenna calibrations. The antenna calibration file used within the EPN (`ftp://epncb.oma.be/pub/station/general/epn_08.atx`) contains the individual antenna calibrations complemented with the type mean calibrations from the IGS. Moreover, the original calibration files, as provided by the calibration agencies (including for some stations calibrations on the Galileo frequencies) are also available from the EPN CB, e.g. `http://www.epncb.oma.be/_networkdata/siteinfo4onestation.php?station=BRUX`).

In the end of 2012, individual calibrations were used at 60 EPN stations amongst which 18 (ANKR, BRUX, BUCU, BZRG, GANP, HOFN, METS, NICO, ORID, PENC, POTS, REYK, SASS, SOFI, WARN, WROC, WTZR, and ZIM2) are also belonging to the IGS. Consequently, due to the usage of resp. individual and type mean calibrations for these stations in the EPN and IGS, the EPN and IGS analysis is not consistent. Inconsistencies are generally below the 2 mm level. However, for the up–component, SOFI, SASS and WTZR have differences of resp. −1 cm, 6 mm, and 4 mm.

3 Data Analysis

3.1 Routine Processing

A total of 17 EPN Local Analysis Centres (LACs) submit weekly free–network solutions (SINEX format) for an EPN subnetwork to the EPN Analysis Coordinator. The majority of the EPN analysis centres use the Bernese V5.0 software. The EPN Analysis Coordinator combines the EPN subnetwork solutions into the weekly combined EPN solution. This weekly solution is tied to the most recent IGS realisation of the ITRS and is used as input for the EPN Reference Frame Coordinator who computes a multi–year EPN solution, updated each 15 weeks, and providing up–to–date EPN positions and velocities allowing to categorize EPN stations as:

- Class A stations with positions at 1 cm accuracy at all epochs of the time span of the used observations;
- Class B stations with positions at 1 cm accuracy at the epoch of minimal variance of each station.

Following the EUREF "Guidelines for EUREF Densifications" (Bruyninx, 2010), only Class A EPN stations can be used for densifications of the ETRS89. In 2012, one EUREF densification campaign, EUREF BE/2011, has been validated by the TWG.

In addition, a smaller group of the LACs is also providing a rapid solution that is provided less than 24 hours after the last observations to the EPN Combination Centre. Here, the different solutions are combined into an EPN rapid solution.

3.2 EPN Reprocessing

In addition to the routine EPN analysis described above, the EPN also finalized it first reprocessing in 2012 (EPN–REPRO1, Völksen, 2011) including the EPN data from GPS week 834 till 1408 using the software packages Bernese v5.0 (Dach et al., 2007), GAMIT (Herring et al., 2007) and GIPSY/OASIS II (Blewitt, 2008). This reprocessing used the `epn_05.atx` antenna calibration model (EPN individual calibrations complemented with igs05.atx type mean calibrations) and IGS orbits from the first IGS reprocessing effort or directly from one of analysis centers contributing to the IGS reprocessing. The EPN reprocessing was based on the data available from the historical data EPN center at EPN CB/ROB (`ftp://ftp.epncb.oma.be/pub/obs/`). This data center has been setup specifically in support of EPN reprocessing activities. The RINEX header info of all files in the historical data center is corrected following the station log and for that reason the data are delayed with a few months compared to the operational data centers. The historical data center does not only contain data from an EPN station for the period it is (has been) included in the EPN, but also contains pre–EPN data for some stations. These data were picked up by the EPN Local Analysis Centers for their reprocessing. Based on their results, some of the pre–EPN data were identified as useful. This information will be the basis for contacting station managers with a proposal to advance the official start of the station within the EPN and consequently extend the quality checks and metadata checks at the EPN CB for that station.

The EPN–REPRO1 weekly combined SINEX product has been included into the official ITRF2008 and IGS08 densifications.

Beside position time series, zenith total delay (ZTD) parameters are available from EPN–REPRO1. Thanks to EUREF's Memorandum of Understanding with EUMETNET — the organization of the European National Meteorological Services — ZTD time series derived from radiosonde data of several stations in the vicinity of EPN stations is also available back to 1996. Moreover, VLBI combined ZTD solutions provided by EGVA, the European VLBI Group for Geodesy and Astrometry, for nine co–located stations could be used for comparison and are available on the EPN station–related webpage.

The EPN LACs are prepared to start another reprocessing campaign (EPN–REPRO2). So far this activity has been delayed due to unavailability of reprocessed orbits and ERPs in the IGS08. But the situation is currently changing since reprocessed orbits and ERPs are slowly becoming available like products from the Center for Orbit Determination in Europe (CODE) and the Jet Propulsion Laboratory (JPL).

4 Densification of the ITRF/IGS08

An intermediate EPN densification solution of the ITRF2008 was generated based on the weekly EPN–REPRO1 results (GPS week 834–1408) and the routine EPN weekly solutions (GPS week 1409–1631) both computed using the `epn_05.atx` antenna model (Kenyeres, 2012a,b). This solution was however never provided to the EUREF user community because it was not consistent with the recent `epn_08.atx`/`igs08.atx` calibration model. To generate a solution consistent with `epn_08.atx`, weekly EPN solutions before GPS week 1632 had to be corrected to take into account the position offset caused by the switch from `epn_05.atx` to `epn_08.atx` model. Similar to what was done by (Rebischung et al., 2012) for the IGS, a PPP (Precise Point Positioning) analysis was used within the EPN to compute the position offsets for the full hisotrical EPN data set (Baire et al., 2011). Of course, no correction is necessary for stations with individual calibrations. The corrected SINEX files, together with the routinely generated weekly EPN SINEX solutions (from GPS week 1632 on) were used as input for the EPN densification solution IGS08_C1680 which was expressed in both IGS08 and ETRF2000. Although the IGS and EPN dataset and processing strategies are slightly different the global ITRF/IGS and their regional densification solutions have shown perfect agreement. The densification solution is updated every 15 weeks.

The related files can be downloaded from the `ftp://epncb.oma.be/pub/station/coordinates/EPN/` and include a discontinuity table and associated residual position time series. More details can be found in `http://www.epncb.oma.be/_productsservices/coordinates/`.

5 Densification of the EPN

To take advantage of the many national agencies that routinely analyze the data from national GNSS networks consisting of stations not all included in the EPN, EUREF decided in 2010 to initiate a densification of the EPN. The main target of this work beyond the homogenization of the national networks is to realize a dense continental–scale velocity field. This product will support the better realization of the ETRS89 and it will be an important input for the IAG WG on “Integration of Dense Velocity Fields in the ITRF”. In the meantime several countries (Poland, Estonia, Latvia, Slovakia, Hungary, Austria, Bulgaria, Czech Republic, France and Italy) provide weekly SINEX solutions to the EPN Reference Frame Coordinator. These solutions are combined with the weekly EPN solution and then stacked to obtain consistent cumulative position/velocity solutions for a densified EPN network. The expected number of stations will definitely exceed 1000. Thanks to EUREF’s Memorandum of Understanding with CEGRN (Central European GPS Geodynamic Reference Network), also weekly permanent and bi–annual campaign CEGRN SINEX solutions were submitted and included. This work is still in progress (see Kenyeres et al., 2012).

6 EPN Real–time Analysis Project

The EPN Project on "Real–time Analysis" focuses on the processing of the EPN real–time data to derive and disseminate real–time GNSS products (`http://www.epncb.oma.be/_organisation/projects/RT_analysis/`). The EPN regional broadcaster at BKG (`http://www.euref-ip.net`) is broadcasting satellite orbits in the ETRS89 (realization ETRF2000). Based on these orbits users can directly derive real–time coordinates referred to ETRS89 at the level of a few decimetres (more details are given in Söhne and Weber, 2011).

One aim of the project is to increase the reliability of the EPN real–time data flow and to minimize the possibility of regional broadcaster's outage. For this purpose, two additional regional broadcasters have been put in operation, one at ASI (Italian Space Agency, `http://euref-ip.asi.it/` and one at ROB (Royal Observatory of Belgium, `http://www.euref-ip.be/`). Based on the existence of three regional broadcasters, several stations started uploading their data in parallel to all of the broadcasters.

7 Conclusions

The EPN tracking network is becoming a real multi–GNSS tracking network with a total of 68% of the stations tracking GPS and GLONASS signals. In addition, also the large majority of the new antenna/radome pairs introduced in the EPN over the last year is capable of tracking multiple GNSS.

The technical implementation of EPN real–time data flow has been realized in the past years. Still, with respect to their analysis, the achieved level of accuracy is yet not competitive to the classical post analysis. But improved software, models and algorithms might close the gap between the classical post analysis and the real–time analysis in the years to come.

With the inclusion of pre–EPN data in the EPN–REPRO1 activity, the stations with valuable pre–EPN data can now be identified and included in the EPN. In addition, a complete reprocessing of all historical EPN data has allowed computing improved station positions and velocities that can be used for national densifications of the ETRS89.

More information on the EPN can be found at `http://www.epncb.oma.be/`.

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IGS Regional Network Associate Analysis Centre for SIRGAS (IGS RNAAC SIR)

L. Sánchez

Deutsches Geodätisches Forschungsinstitut (DGFI)
Alfons–Goppel–Str. 11, D–80539 Munich, Germany
e–mail: `sanchez@dgfi.badw.de`

SIRGAS was initially realized by two GPS campaigns, one in 1995 (SIRGAS95) with 58 stations, and one in 2000 (SIRGAS2000) with 184 stations. SIRGAS95 included only 10 continuously operating GPS stations, while SIRGAS2000 comprised 29. During the last decade, most of the Latin American countries decided to qualify their national reference frames by installing more and more permanent GPS (now GNSS) stations, with the main requirement of integrating them into the continental reference frame consistently. According to this, the present realisation of SIRGAS is a network with more than 300 continuously operating GNSS stations, 59 of which formally belong to the IGS global network and other 40 are included in the IGS reprocessing campaign 2 to improve the IGS station coverage in the Latin American and Caribbean regions. The weekly processing of the continuously observing GNSS SIRGAS stations started in June 1996 under the responsibility of the *IGS Regional Network Associate Analysis Centre for SIRGAS* (IGS RNAAC SIR) operated by the *Deutsches Geodätisches Forschungsinstitut* (DGFI). Due to the increasing number of stations, it was necessary to involve more processing centres to guarantee a sustainable, reliable and redundant computation of the entire SIRGAS network. In this way, the weekly processing of the SIRGAS Reference Frame is now a shared activity between 10 SIRGAS Analysis Centres, 9 of them under the responsibility of Latin American organisations. This report describes strategy and quality of the SIRGAS products generated during the year 2012.

1 Introduction

The SIRGAS Reference Frame at present comprises 300 continuously operating GNSS stations (Fig. 1). It is continuously processed on a weekly basis to generate (Sánchez et al., 2012b):

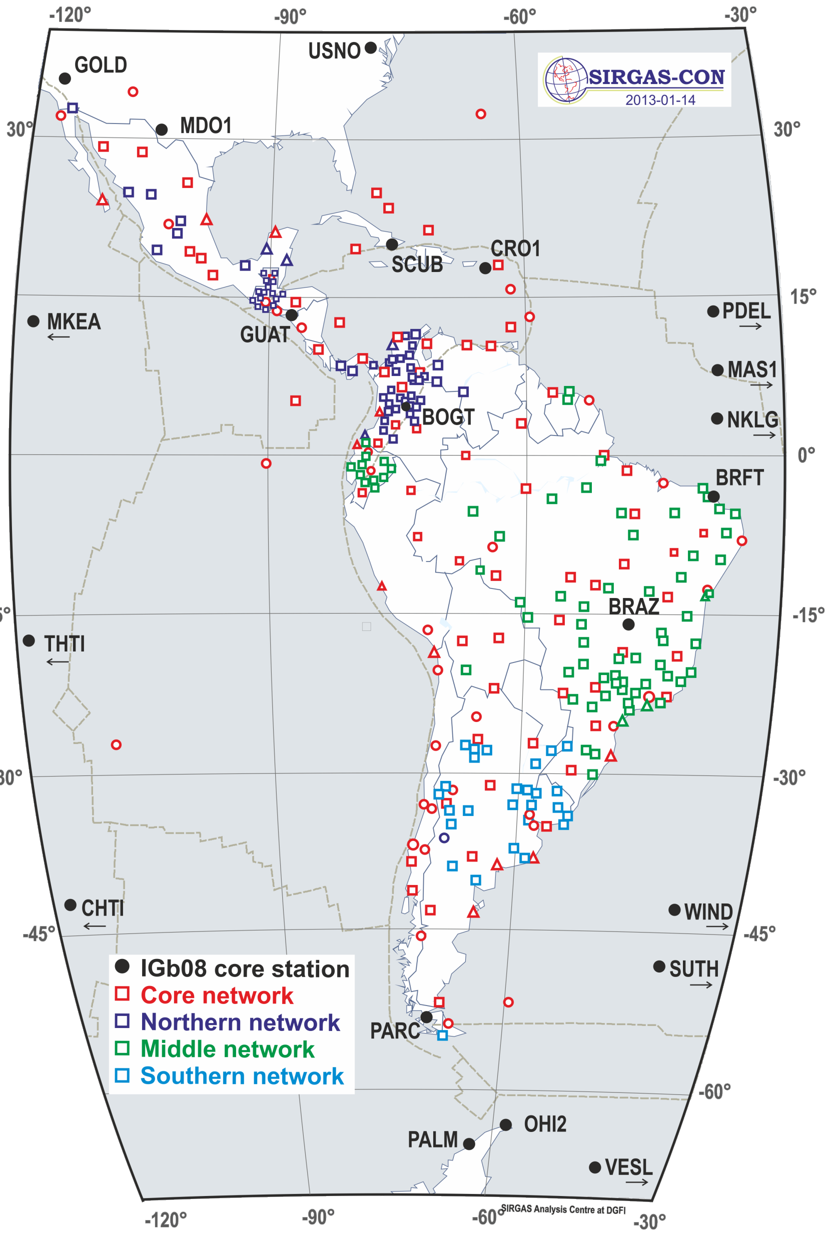
-120°
-90°
-60°
-30°
USNO
GOLD
SIRGAS-CON
2013-01-14
MDO1
30°
30°
CRO1
SCUB
15°
MKEA
GUAT
PDEL
MAS1
NKLG
BOGT
0°
BRFT
BRAZ
-15°
-15°
THTI
-30°
-30°
CHTI
WIND
-45°
-45°
SUTH
● IGb08 core station
☐ Core network
☐ Northern network
☐ Middle network
☐ Southern network
PARC
-60°
OHI2
PALM
VESL
-120°
-90°
-60°
SIRGAS Analysis Centre at DGFI
-30°

Figure 1: SIRGAS Reference Frame (status 2013–01–14).

1. Loosely constrained weekly solutions for further combinations of the network (e.g. integration into the IGS polyhedron, computation of cumulative solutions, etc.). These solutions are delivered weekly to the IGS in SINEX format to be combined together with those generated by the other IGS Global and Regional Analysis Centres. They are named `sirwwww7.snx` (wwww stands for the GPS week);
2. Weekly station positions aligned to the same reference frame in which the IGS GNSS orbits are given; i.e. the IGS Reference Frame. These positions are applied as reference values for surveying applications in Latin America. Their name is `siryyPwwww.crd` (yy indicates the last two digits of the year).
3. Multi–year solutions providing station positions and velocities to estimate the kinematics of the reference frame and as support for applications requiring time–dependent coordinates. They are identified by `SIRyyPnn.SNX` (nn being the number of the cumulative solutions computed in one year).

Due to the large number of stations, the analysis strategy of the SIRGAS Reference Frame is based on the combination of individual solutions including different networks (Brunini et al., 2012): One core network with 120 stations distributed over the whole continent, and different densification sub-networks distributed regionally on the northern, middle, and southern part of the continent (Fig. 1). These sub-networks (i.e. clusters) are individually processed by 10 SIRGAS Analysis Centres: the core network is computed by DGFI (responsible for the IGS RNAAC SIR), the other sub–networks by the SIRGAS Local Processing Centres: CEPGE (Ecuador), CIMA (Argentina), CPAGS-LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGM (Chile), IGN (Argentina), INEGI (Mexico) and SGM (Uruguay). The weekly combination of the individual solutions is carried out by the SIRGAS Combination Centres: DGFI and IBGE. The distribution of the SIRGAS stations within the individual clusters guarantees that each station is included in three solutions.

2 Routine analysis of the SIRGAS Reference Frame

The different SIRGAS Analysis Centres follow the same standards for the computation of loosely constrained weekly solutions. INEGI (Mexico) and IGN (Argentina) work with the software GAMIT/GLOBK (Herring et al., 2010), all the other 8 Processing centres use the Bernese GPS Software V. 5.0 (Dach et al., 2007). The main characteristics of the analysis strategy are (e.g. Costa et al., 2012a; Sánchez et al., 2012a):

- Elevation mask and data sampling rate are set to 3° and 30 s, respectively.
- Absolute calibration values for the antenna phase centre corrections published by the IGS are applied (http://www.igs.org/igscb/station/general/pcv_archive/).

- Satellite orbits, satellite clock offsets, and Earth orientation parameters are fixed to the combined IGS weekly solutions (Dow et al., 2009, `http://www.igs.org/igscb/product/`).
- Solution of phase ambiguities for L1 and L2.
- Reduction of periodic site movements due to ocean tide loading according to the FES2004 ocean tide model (Letellier, 2004). The corresponding values are provided by M. S. Bos and H.-G. Scherneck at `http://holt.oso.chalmers.se/loading/`.
- The Niell (1996) dry mapping function is applied to map the a priori zenith delay (dry part), which is modelled using the model from Saastamoinen (1973). The wet part of the zenith delay is estimated at a 2 hour intervals within the network adjustment and it is mapped using the Niell wet mapping function.
- Daily free normal equations are computed by applying the double differences strategy. They are afterwards combined for generating a loosely constrained weekly solution for station positions (all station coordinates are loosely constrained to ±1 m). Stations with large residuals in the weekly combination (more than ±20 mm in the N–E component, and more than ±30 mm in the height component) are reduced from the normal equations.
- The individual loosely constrained solutions are made available for their combination in SINEX format. They are identified following the IGS nomenclature, i.e. `cccwwww7.snx`: ccc stands for the abbreviation of the processing centre and wwww for the GPS week. These solutions are available at `ftp://ftp.sirgas.org/pub/gps/SIRGAS/`.

At the moment, SIRGAS is aligning its computation procedures to the new standards released by the IGS for the reprocessing campaign 2. The different SIRGAS Analysis Centres are updating the corresponding analysis software and it is expected to start the reprocessing of the SIRGAS Reference Frame by May 2013. In the same way, the computation (updating) of multi-year solutions is stopped until the entire network is totally reprocessed with respect to the IGS08 (IGb08) Reference Frame (Sánchez, 2012).

3 Weekly solutions of the SIRGAS Reference Frame

The loosely constrained weekly solutions delivered by the individual SIRGAS Analysis Centres are integrated in a unified solution by the SIRGAS Combination Centres: DGFI and IBGE. The DGFI (i.e. IGS RNAAC SIR) combination strategy corresponds to (Fig. 2, Sánchez, 2012):

1. Individual solutions are reviewed/corrected for possible format problems, station inconsistencies, utilization of erroneous equipment, etc.

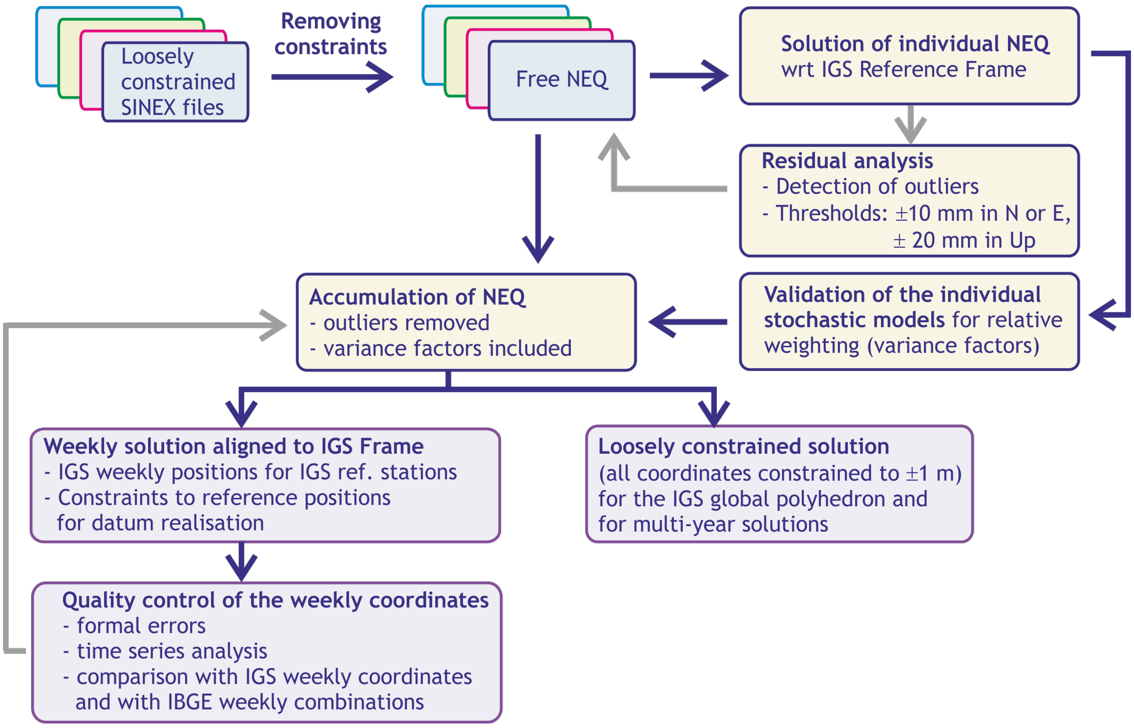
Loosely constrained SINEX files
Removing constraints
Free NEQ
Solution of individual NEQ wrt IGS Reference Frame
Residual analysis
- Detection of outliers
- Thresholds: ±10 mm in N or E, ± 20 mm in Up
Validation of the individual stochastic models for relative weighting (variance factors)
Accumulation of NEQ
- outliers removed
- variance factors included
Weekly solution aligned to IGS Frame
- IGS weekly positions for IGS ref. stations
- Constraints to reference positions for datum realisation
Loosely constrained solution
(all coordinates constrained to ±1 m)
for the IGS global polyhedron and for multi-year solutions
Quality control of the weekly coordinates
- formal errors
- time series analysis
- comparison with IGS weekly coordinates and with IBGE weekly combinations

Figure 2: Combination of the weekly solutions delivered by the SIRGAS Analysis Centres.

2. Constraints included in the delivered normal equations are removed. In this way, unconstrained (condition free, non–deformed) normal equations with correct station information are available for combination.

3. Individual normal equations are separately solved with respect to IGS Reference Stations included in the SIRGAS Frame (Fig. 1). In this case, the IGS Reference Station positions are constrained to the IGS weekly coordinates (`igsyyPwwww.snx`).

4. Station positions obtained in 3 for each cluster are compared with the IGS weekly values and with each other to identify possible outliers.

5. Stations with large residuals (more than ±10 mm in the north or east components, and more than ±20 mm in the height component) are reduced from the normal equations. Steps 3, 4, and 5 are iterative.

6. Variances obtained in the final computation of step 3 are analysed to estimate scaling factors for relative weighting of the individual solutions.

7. Once inconsistencies and outliers are reduced from the individual free normal equations, a combination for a loosely constrained weekly solution for station positions

(all station coordinates constrained to ±1 m) is computed. This solution is submitted to IGS for the global polyhedron and stored to be included in the next multi-year solution of the SIRGAS Reference Frame.

8. Finally, a weekly solution aligned to the ITRF is computed. As in step 3, the geodetic datum is defined by constraining the coordinates of the reference stations to the positions calculated within the IGS weekly combinations (`igsyyPwwww.snx`). The applied constraints guarantee that the coordinates of the reference stations do not change by more than ±1.5 mm within the SIRGAS adjustment.
9. The accumulation and solution of the normal equations are carried out with the Bernese GPS Software V.5.0 (Dach et al., 2007).
10. Resulting files of this procedure are:

`SIRwwww7.SNX`:	SINEX file of the loosely constrained weekly combination.
`SIRwwww7.SUM`:	Report of weekly combination.
`siryyPwwww.snx`:	SINEX file for the weekly combination aligned to the IGS Frame.
`siryyPwwww.crd`:	Final SIRGAS-CON station positions for week wwww.

The loosely constrained combinations as well as the weekly SIRGAS–CON coordinates are available at `ftp://ftp.sirgas.org/pub/gps/SIRGAS/` or at `http://www.sirgas.org`.

4 Quality control of the SIRGAS Reference Frame weekly solutions

The generation of the weekly SIRGAS products (i.e. loosely constrained combinations and station positions aligned to the IGS reference frame) at DGFI includes a quality control at two levels (Sánchez et al., 2012a): Firstly, the individual solutions delivered by the SIRGAS Processing Centres are analysed to establish their quality and consistency. This includes a survey about date of delivery, processed stations, log file observance, etc. Once the individual solutions are reviewed and free of inconsistencies, their combination is carried out by applying the procedure summarized in Sect. 3 . Then, the second quality control concentrates on the results of this combination. Here, the main objective is to ascertain the accuracy and reliability of the weekly solutions for the entire SIRGAS network.

4.1 Quality control of the individual solutions

The consistency between the different individual solutions is evaluated by means of:

- Mean standard deviations of station positions after solving the individual solutions with respect to the IGS Reference Frame (Fig. 3). These values represent the formal errors of the individual solutions.

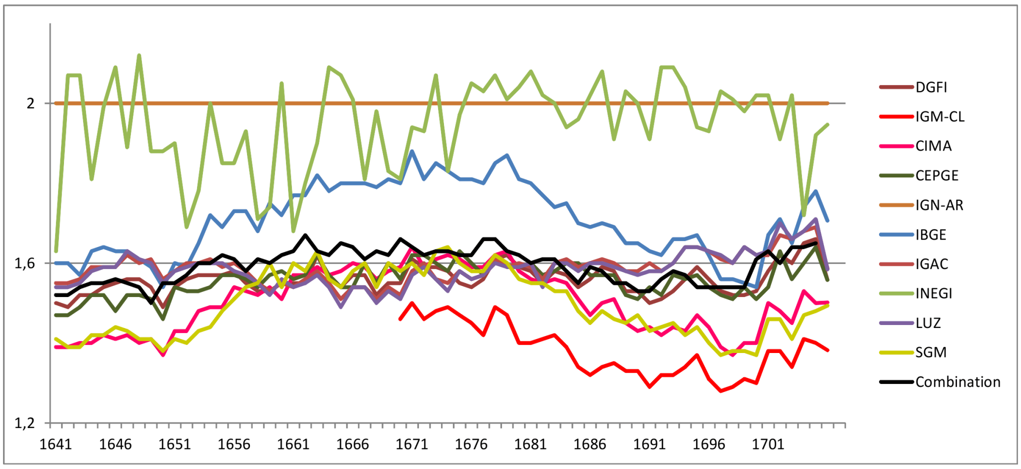

Figure 3: Mean standard deviations [mm] of station positions after solving the individual solutions and their combination with respect to the IGS Reference Frame (Time span: GPS weeks 1641–1705).

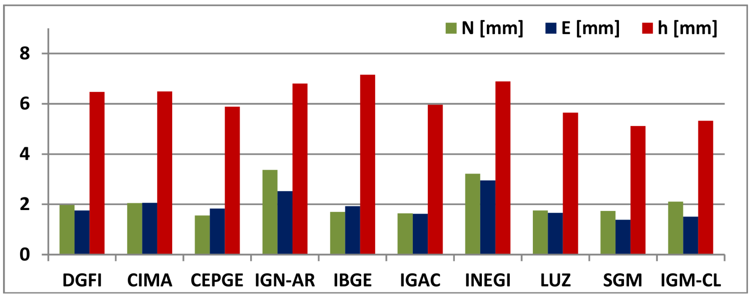

Figure 4: Mean RMS values for the weekly repeatability of station positions in the solutions delivered by the SIRGAS Analysis Centres (Time span: GPS weeks 1641–1705).

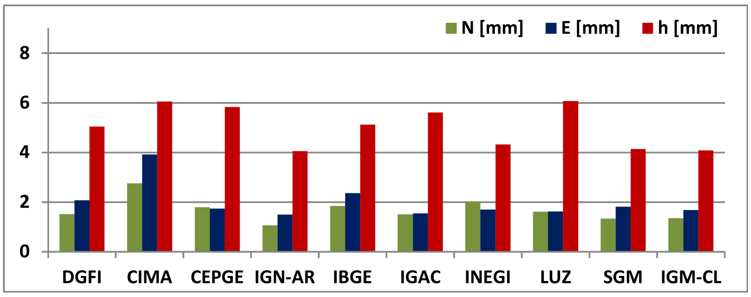

Figure 5: Mean RMS values after comparing the station positions between the individual solutions delivered by the SIRGAS Analysis Centres and the IGS weekly solutions (Time span: GPS weeks 1641–1705).

- Weekly repeatability of station positions for each Processing Centre to assess the individual precision of the weekly solutions (Fig. 4).
- Comparison with the IGS weekly coordinates for common stations to estimate the reliability of the individual solutions (Fig. 5).

In general, the RMS values derived from the station position time series and with respect to the IGS weekly coordinates indicate that the accuracy of the individual solutions is about ±2 mm in the North and the East, and ±5 mm in the height (Figs. 4, 5). Regarding the standard deviations (Fig. 3) obtained after solving the individual normal equations with respect to the IGS Reference Frame, one can observe that Processing Centres applying the Bernese GPS Software present values of $\approx \pm 1.6$ mm, while Processing Centres using GAMIT/GLOBK have values of about 2.0 mm.

4.2 Evaluation of combined (final) SIRGAS solutions

The quality evaluation of the weekly station positions computed for the SIRGAS Reference Frame is performed according to the following criteria:

- Mean standard deviation for station positions after aligning the network to the IGS Reference Frame indicates the formal error of the final combination (Fig. 3);
- The weekly coordinate repeatability after combining the individual solutions provides information about the internal consistency of the combined network (Fig. 6);
- Time series analysis for station coordinates allows to determine the compatibility of the combined solutions from week to week (Fig. 6);
- Comparison with the IGS weekly coordinates (`igsyyPwwww.snx`) indicates the consistency with the IGS global network (Fig. 6);
- Comparison with the IBGE weekly combination (`ibgyyPwwww.snx`) fulfils the required redundancy to generate the final SIRGAS products (Fig. 6).

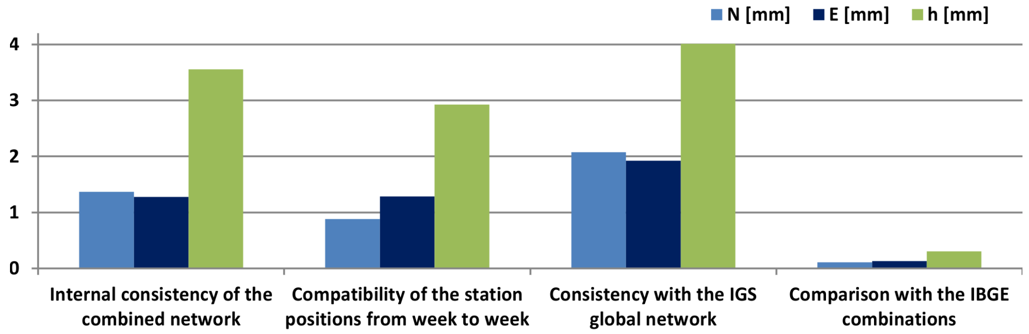

Figure 6: Quality control of the weekly station positions computed for the SIRGAS Reference Frame (mean RMS values for the period covered by the GPS weeks 1641 to 1705).

The mean standard deviation of the combined solutions agrees quite well with those computed for the individual contributions (Fig. 3), i.e. the quality of the individual solutions is maintained and their combination does not deform or damage the internal accuracy of the entire SIRGAS network. The coordinate repeatability in the weekly combinations provides an estimate of the accuracy (internal consistency) of the weekly combinations of about ±1.4 mm in the horizontal component and about ±3.6 mm in the vertical one. The RMS values derived from the time series for station positions and with respect to the IGS weekly coordinates indicate that the reliability of the network (external precision) is about ±2.0 mm in the horizontal position and ±4.0 mm in the height. The differences with respect to the IBGE weekly combinations are within the expected level (less than 0.5 mm). Costa et al. (2012b) present a description about the IBGE combination strategy.

Acknowledgments

The operational infrastructure and results described in this report are possible thanks to the active participation of many Latin American and Caribbean colleagues, who not only make the measurements of the stations available, but also operate SIRGAS Analysis Centres processing the observational data on a routine basis. This support and that provided by the International Association of Geodesy (IAG) and the Pan–American Institute for Geography and History (PAIGH) is highly appreciated. More details about the activities and new challenges of SIRGAS, as well as institutions and colleagues working on can be found at `http://www.sirgas.org`.

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Part III

Data Centers

Infrastructure Committee Report 2012

I. Romero

ESA/ESOC, Navigation Support Office, HSO–GN, Darmstadt, Germany

1 Introduction

The Infrastructure Committee (IC) was established in March 2009 and it is set with the task of studying and advising on infrastructure issues to the IGS Governing Board and the IGS Network Coordinator (NC). The latest status and recent progress of the Committee is detailed below for 2012.

Chair:

Ignacio (Nacho) Romero, ESA/ESOC, Ignacio.Romero@esa.int

Membership:

Current Members appointed 3 April, 2011 for terms up to Dec 2013:

- Carine Bruyninx (ROB)
- Lou Estey (UNAVCO)
- Gary Johnston (GA)
- Ignacio (Nacho) Romero — Chairman — (ESA/ESOC)
- Mike Schmidt (NRCan)
- Georg Weber (BKG)

Ex–officio Members:

- Steve Fisher — Central Bureau
- Jake Griffiths — Analysis Center Coordinator
- Mark Caissy — Real time Working Group Chair
- Bruno Garayt — Reference Frame Coordinator
- Carey Noll — Data Center Working Group Chair
- Ken Senior — Clock Products Coordinator

2 Activities in 2012

During 2012 the Infrastructure Committee has been involved in many different activities as detailed in the sections below.

2.1 IGS Site Guidelines

The IC has continued the IGS Site Guidelines refinement with the IGS Central Bureau. The guidelines have been presented at the Governing Board meeting in July 2012, and they are waiting for publication by the IGS Central Bureau after further review by the Real–Time Pilot Project (RTPP), to adapt the real–time station guidelines to the latest know–how.

2.2 IGS 2012 Workshop Participation

Helped and supported the *IGS Workshop* in July 2012 with two presentations ("IGS Network Challenges" and "RINEX Working Group report", the latter on behalf of the RTPP), plus presented an IC poster on the un–calibrated Dome test campaign, and run a RINEX technical meeting and an IC forum.

2.3 Radome–Off Test Campaign

The IC has continued to support the test campaign to assess the impact of un–calibrated domes at co–located sites (together with IGS Central Bureau, Analysis Center Coordinator, Reference Frame Working Group and Antenna Working Group).

Table 1: Participating Radome–off Test Campaign (2011–2013)

Station	Removal	Re–installation
CRO1	01–Apr–2011	24–Jun–2011
TSKB	01– Jul –2011	30–Aug–2011
TSK2	01– Jul –2011	30–Aug–2011
AREQ	19–Aug–2011	03–Feb–2012
FAIR	28–Apr–2012	04–Aug–2012
YAR2	28–Apr–2012	28–Sep–2012
GODE	06– Jul –2012	30–Jan–2013
MDO1	On–going	

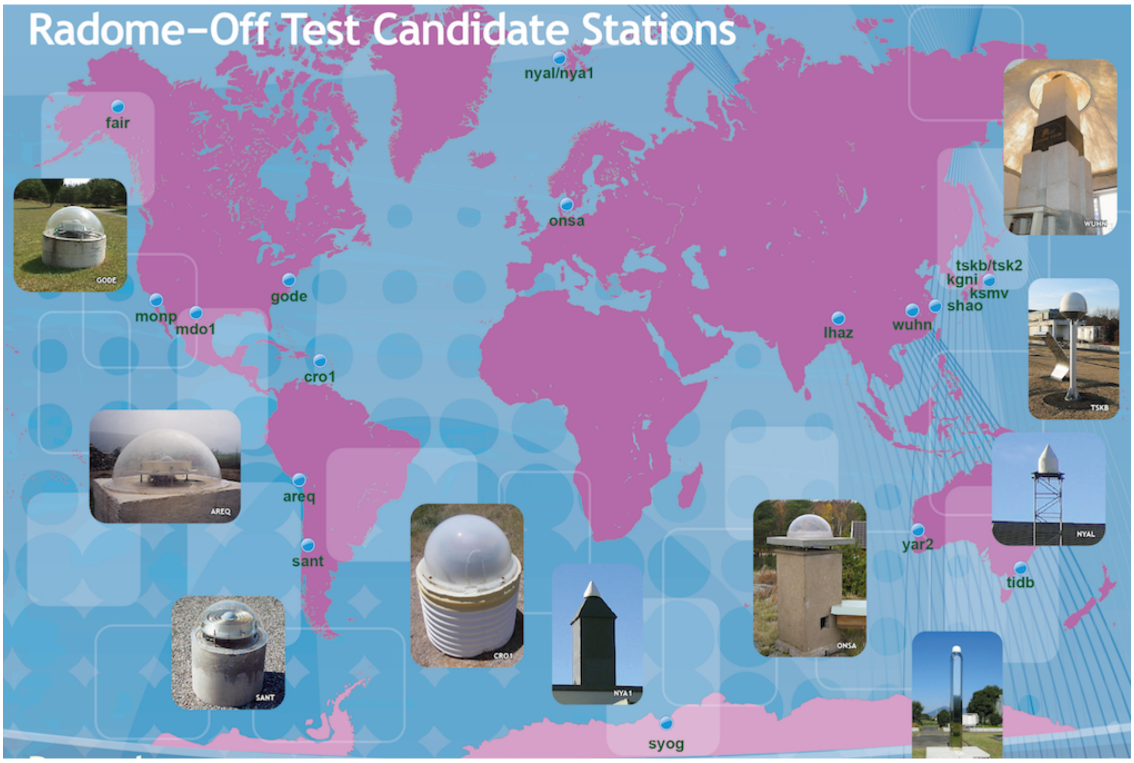
Radome–Off Test Candidate Stations
nyal/nya1
fair
onsa
gode
monp
mdo1
cro1
lhaz
wuhn
tskb/tsk2
kgni
ksmv
shao
areq
sant
yar2
tidb
syog
GODE
AREQ
SANT
CRO1
NYA1
ONSA
WUHN
TSKB
NYAL

Figure 1: Co–located stations with uncalibrated radomes

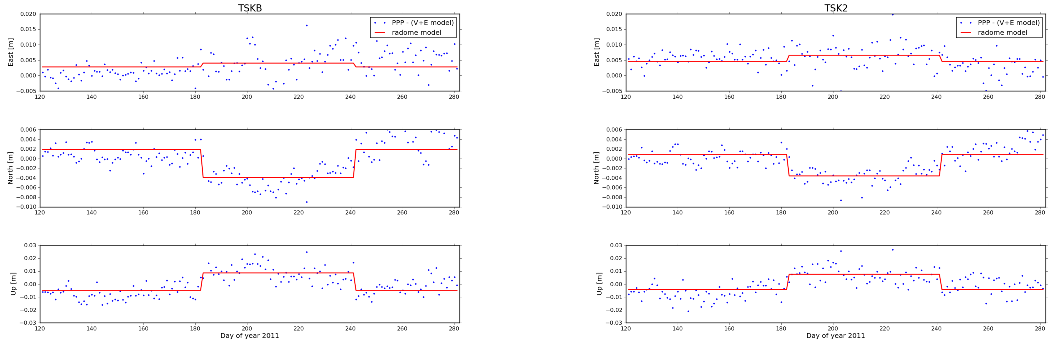

Figure 2: Initial processing of uncalibrated radome effect at TSKB and TSK2 (courtesy of Reference Frame WG Chair).

This test campaign aims to find the effect on the marker positions of the uncalibrated radomes installed over the GNSS antennas at co–located sites (sites which have more than one geodetic technique). The effect will be studied by removing the uncalibrated radomes for a number of weeks and then reinstalling them. It was hoped that most of the stations shown in Fig. 1 would participate, and that careful post–processing and analysis will show an effect due to the radomes that can later be added to correct the co–location tie vectors at each location to aid in the ITRF generation. So far the stations in Tab. 1 have participated in the experiment.

We hope that additional stations will join during 2013, which will be the last year of this experiment in advance of the upcoming ITRF2013 version. The preliminary analysis of the data has found some significant effect that can be calibrated as shown in Fig. 2 .

2.4 Station Issues

Over 2012 the IC has supported the IGS Central Bureau (R. Khachikyan, D. Maggert) on *station issues*; handling un–calibrated Antenna+Dome pairs, helping to find ways forward on the NGA station issues, recovering long–term dormant stations, etc.

In particular for the *NGA stations* the IC together with the IGS NC have been able to clarify that there is a half–cycle issue with the phase data, which the NGA will correct before publishing the data in the official IGS repositories. Additionally the previously unknown ITT antenna used at most of the NGS sites has now been calibrated by the NGS, and the calibration has been accepted by the IGS Antenna Working Group for inclusion into the official ANTEX calibration file during 2013 ahead of the 2$^{\text{nd}}$ IGS data reprocessing campaign.

Participated in the *Real–Time Pilot Project telecons* and discussions on the RTCM–"Multi Signal Message" definition to ensure full compatibility of the streaming standard and of the RINEX 3.02 format and file naming.

3 Continued activities for 2013

During the upcoming year the IC will finalize the un–calibrated radome experiment for co–located stations and promote in–depth analysis with the Reference Frame Working Group with the aim of publishing a set of corrections for the "tie" vectors between the GNSS monument and the other co–located technique.

Additionally the IC together with the Real Time Pilot Project will promote continued progress on the streaming and *RINEX data formats* to accommodate the new Navigation systems (QZSS, etc), and help the IGS in the second reprocessing campaign to take place during 2013 by ensuring all infrastructure issues are addressed in a timely manner.

Move forward with the implementation of the IC Workshop recommendations:

1. *MGEX shall remove the RINEX 2 data requirement and work only with RINEX 3 data*, and that the MGEX requests to the DCs that other past RINEX 3 data appeals be stored together with the MGEX data moving forward.
2. That the IC fully *supports and encourages the new fulltime Network Coordinator at the IGS Central Bureau.*
3. The IC and Network Coordinator will work to *strengthen ties with regional networks to promote the "Network of Networks"* from the IGS.
4. The IC together with the RINEX WG shall investigate together with others the issue of *unique GNSS station identification* (4 char ID codes, etc) and propose a possible way forward for the IGS.
5. That the RINEX WG shall continue to iterate in the proposed direction for *new RINEX 3 data filenames*, incorporating any new GNSS station identifier.
6. The IC will promote that the RINEX WG shall keep the *RINEX 3 format open at all times as a "working draft" and to publish "formats"* as needed.

4 Conclusions

The IC continues to be a relevant part of the IGS in providing advice and support to the Network Coordinator and the ACC. It is also the place where other parts of the IGS turn for coordination and ways forward on infrastructure issues. The IC tries to bring long–term issues to satisfactory conclusions and provides a forum of ideas and infrastructure suggestions for the IGS Governing Board.

CDDIS Global Data Center Technical Report 2012

C. Noll

NASA Goddard Space Flight Center, Code 690.1
Greenbelt, MD 20771 USA
Carey.Noll@nasa.gov

1 Introduction

The CDDIS is NASA's data archive and information service supporting the international space geodesy community. For over 30 years, the CDDIS has provided continuous, long term, public access to the data (mainly GNSS–Global Navigation Satellite System, SLR–Satellite Laser Ranging, VLBI–Very Long Baseline Interferometry, and DORIS–Doppler Orbitography and Radiopositioning Integrated by Satellite) and products derived from these data required for a variety of science observations, including the determination of a global terrestrial reference frame and geodetic studies in plate tectonics, earthquake displacements, volcano monitoring, Earth orientation, and atmospheric angular momentum, among others. The specialized nature of the CDDIS lends itself well to enhancement to accommodate diverse data sets and user requirements. The CDDIS is one of NASA's Earth Observing System Data and Information System (EOSDIS) distributed data archive centers; EOSDIS data centers serve a diverse user community and are tasked to provide facilities to search and access science data and products.

The CDDIS serves as one of the primary data centers and core components for the geometric services established under the International Association of Geodesy (IAG), an organization that promotes scientific cooperation and research in geodesy on a global scale. The system has supported the International GNSS Service (IGS) as a global data center since 1992. The CDDIS activities within the IGS during 2012 are summarized below; this report also includes any recent changes or enhancements made to the CDDIS.

2 System Description

The CDDIS archive of IGS data and products are accessible worldwide through anonymous ftp. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is available to users 24 hours per day, seven days per week. The CDDIS computer system consists mainly of incoming, outgoing, and processing servers. All ftp and web access is performed on the outgoing server. Data centers, stations, and analysis centers push files to the CDDIS incoming server. Processing of incoming files for the on–line archive is performed in a separate environment that also includes a database server for managing metadata extracted from incoming data.

In 2011, the CDDIS staff procured new server hardware to further enhance the capabilities of the system and ensure a robust archive environment. The new system is fully redundant with the primary and secondary/failover system located in different buildings on the GSFC campus. Each system utilizes a distributed functionality (incoming, outgoing, processing, database, and map servers) and is configured with a local backup system as well as a full backup system located in a third building at GSFC. The archive is equipped with a 32 Tbyte RAID storage system and is scaled to accommodate future growth. The new server configuration became operational in May 2012.

3 Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to GNSS data from the global IGS network as well as the products derived from the analyses of these data in support of both operational and working group/pilot project activities. Approximately 7 Tbytes of the CDDIS archive are devoted to GNSS data (6.5 Tbytes), products (250 Gbytes), and ancillary information. All data and products are accessible through subdirectories of `ftp://cddis.gsfc.nasa.gov/gnss` (a symbolic link to `ftp://cddis.gsfc.nasa.gov/gps`).

3.1 GNSS Tracking Data

The user community has access to the on–line archive of GNSS data available through the global data center archives of the IGS. Over 50 operational and regional IGS data centers and station operators make data (observation, navigation, and meteorological) available in RINEX format to the CDDIS from selected receivers on a daily, hourly, and sub–hourly basis. The CDDIS also accesses the archives of the other three IGS global data centers, Scripps Institution of Oceanography (SIO) in California, the Institut Géographique National (IGN) in France, and the Korea Astronomy and Space Science Institute (KASI) to retrieve (or receive) data holdings not routinely transmitted to the CDDIS by an operational or regional data center. Tables 1 and 2 on page 131 summarizes the types of GNSS data archived at the CDDIS.

Data, in RINEX V2.10 or V2.11 format, from GPS and GPS+GLONASS receivers are archived within the GNSS directory structure `/gnss/data`.

Table 1: GNSS Data Type Summary.

Data Type	Sample Rate	Data Format	Available On–line
Daily GNSS	30 sec.	RINEX and compact RINEX	Since 1992
Hourly GNSS	30 sec.	Compact RINEX	2+ years
High–rate GNSS	1 sec.	Compact RINEX	Since May 2001
Satellite GPS	10 sec.	Compact RINEX	Since 2002

Table 2: GNSS Data Archive Summary for 2012.

Data Type	Avg. No. Sites/Day	Avg. Vol./Day	Total Vol./Year	Directory Location	Latency of Majority of Data
Daily GNSS	475	985 Mb	340 Gb	`/gnss/data/daily`	1 hour
Hourly GNSS	290	310 Mb	105 Gb	`/gnss/data/hourly`	10 minutes
High–rate GNSS	155	1800 Mb	565 Gb	`/gnss/data/highrate`	10 minutes
LEO GPS	1	0.5 Mb	200 Mb	`/gnss/data/satellite`	10 days

The CDDIS archives four major types/formats of GNSS data, all in RINEX format, as described in Tab. 1 . Daily RINEX data are quality–checked, summarized, and archived to public disk areas in subdirectories by year, day, and file type; the summary and inventory information are also loaded into an on–line database. Nearly 170 K daily station days from 525 distinct GNSS receivers were archived at the CDDIS during 2012. A complete list of daily, hourly, and high–rate sites archived in the CDDIS can be found in the yearly summary reports at URL `ftp://cddis.gsfc.nasa.gov/reports/gnss/`.

Within minutes of receipt, the hourly GNSS files are archived to subdirectories by year, day, and hour. These data are retained on–line indefinitely; the daily files delivered at the end of the UTC day contain all data from these hourly files and thus can be used in lieu of the individual hourly files. A total of 320 hourly sites (2.5 M files) were archived during 2012.

High–rate (typically 1–second sampling) GNSS data are archived in files containing fifteen minutes of data and in subdirectories by year, day, file type, and hour. Many of these data files are created from real–time streams. Data from 170 high–rate sites (5 M files) were also archived in the CDDIS in 2012.

The CDDIS generates a global broadcast ephemeris file on an hourly basis. This file is derived from the site–specific ephemeris data files for each day/hour. These files are appended to a single file that contains the orbit information for all GNSS satellites for the day up through that hour. This merged ephemeris data file is then copied to the day's subdirectory within the hourly data file system. Within 1–2 hours after the end of the UTC day, after sufficient station–specific navigation files have been submitted, this

Table 3: GNSS MGEX Data Archive Summary for 2012.

Data Type	Avg. No. Sites/Day RINEX 3/2	Avg. Vol./Day	Directory Location Data
Daily GNSS	45/5	200 Mb	`/gnss/campaign/mgex/data/daily`
Hourly GNSS	23/6	50 Mb	`/gnss/campaign/mgex/data/hourly`
High–rate GNSS	17/5	370 Mb	`/gnss/campaign/mgex/data/highrate`

concatenation procedure is repeated to create the daily broadcast ephemeris file, using daily site–specific navigation files as input. The daily file is copied to the corresponding subdirectory under the daily file system. Users can thus download this single, daily (or hourly) file to obtain the unique navigation messages rather than downloading multiple broadcast ephemeris files from the individual stations.

The CDDIS successfully submitted a proposal to the IGS Multi–GNSS Experiment (MGEX) call for proposals for archive and distribution of data and products. During 2012 the CDDIS expanded its data archive and distribution service to include data from participating multi–GNSS receivers, products derived from the analysis of these data, and required metadata for the experiment. These data include newly available signals (e.g., Galileo, QZSS, SBAS, and BeiDou). The CDDIS data ingest procedures were modified to accommodate these new data sets, the majority of which are archived in RINEX V3; some sites have delivered data in RINEX V2 in support of MGEX. The CDDIS developed new software to extract metadata from incoming data files since the software package currently used for summarization and metadata extraction on RINEX V2 data, teqc, will not process data in RINEX V3 format. The summary of the MGEX data holdings at the CDDIS are shown in Tab. 3.

The CDDIS archived data from space–borne GPS receiver data from selected missions (e.g., SAC–C, CHAMP, Jason–1, ICESat). In 2012 additional ICESat GPS receiver data and attitude files were archived.

3.2 IGS Products

The CDDIS routinely archives IGS operational products (daily, rapid, and ultra–rapid orbits and clocks, and weekly ERP and station positions) as well as products generated by IGS working groups and pilot projects (ionosphere, troposphere, real–time clocks). The CDDIS currently provides on–line access through anonymous ftp or the web to all IGS products generated since the start of the IGS Test Campaign in June 1992 in the file system `/gnss/products`; products from GPS+GLONASS products are available through this filesystem. Products derived from GLONASS data only continued to be archived at the CDDIS in a directory structure within the file system `/glonass/products`.

Table 4: GNSS Product Summary.

Product Type	Number of ACs/AACs	Volume	Directory

Orbits, clocks, ERP, positions	13+Combinations	830 Mb/week	`/gnss/products/WWWW`
			(GPS, GPS+GLONASS)
			`/glonass/products/WWWW`
			(GLONASS only)

Troposphere	Combination	2.5 Mb/day, 860 Mb/year	`/gnss/products/troposphere/YYYY`
Ionosphere	4+Combination	4 Mb/day, 1.5 Gb/year	`/gnss/products/ionex/YYYY`
Real–time clocks	Combination	6.0 Mb/week	`/gnss/products/rtpp/YYYY`

The CDDIS also continues to archive combined troposphere estimates in directories by GPS week. Global ionosphere maps of total electron content (TEC) from the IONEX AACs are archived in subdirectories by year and day of year. Real–time clock comparison products have been archived at the CDDIS in support of the IGS Real–Time Pilot Project since 2009. Table 4 above summarizes the GNSS products available through the CDDIS.

3.3 Supporting Information

Daily status files of GNSS data holdings, reflecting timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath, continue to be generated by the CDDIS. By accessing these files, the user community can receive a quick look at a day's data availability and quality by viewing a single file. The daily status files are available through the web at URL `ftp://cddis.gsfc.nasa.gov/reports/gps/status` . The daily status files are also archived in the daily GNSS data directories. In preparation for the analysis center's second reprocessing campaign, the CDDIS has developed site–specific reports detailing missing data. Station operators and operational data centers can consult these lists (`ftp://cddis.gsfc.nasa.gov/gnss/data/daily/reports`) and if available, supply missing files to the CDDIS for inclusion in the global data center archives.

Ancillary information to aid in the use of GNSS data and products are also accessible through the CDDIS. Weekly and yearly summaries of IGS tracking data (daily, hourly, and high–rate) archived at the CDDIS are generated on a routine basis. These summaries are accessible through the web at URL `ftp://cddis.gsfc.nasa.gov/reports/gps`. The CDDIS also maintains an archive of and indices to IGS Mail, Report, Station, and other IGS–related messages.

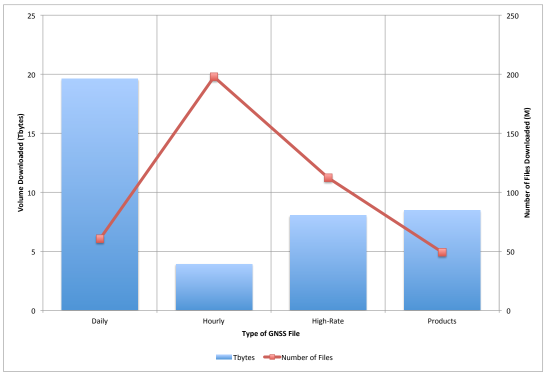

Figure 1: Number and volume of GNSS files transferred from the CDDIS in 2012.

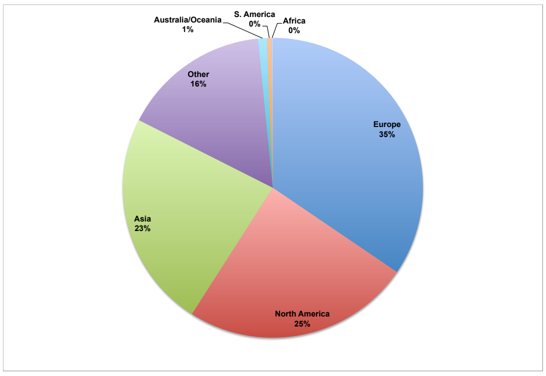

Figure 2: Geographic distribution of IGS users of the CDDIS in 2012.

4 System Usage

Figure 1 summarizes the usage of the CDDIS for the retrieval of GNSS data and products in 2012. This figure illustrates the number and volume of GNSS files retrieved by the user community during 2012, categorized by type (daily, hourly, high–rate, products). Over 420 million files (40 Tbytes), excluding robot downloads, were transferred in 2012, with an average of over 35 million files per month. Figure 2 illustrates the profile of users accessing the CDDIS IGS archive during 2012. The majority of CDDIS users are from hosts in Europe and North America.

5 Recent Developments

The CDDIS is cooperating in the development of Geodetic Seamless Archive Centers (GSAC) with colleagues at UNAVCO, SIO, and the University of Nevada at Reno. The activity provides web services to facilitate data discovery within and across participating archives. A prototype implementation of these GSAC web services at the CDDIS has been developed and should be operational in early 2013. In addition, the CDDIS is currently implementing modifications to the metadata extracted from incoming data and product files pushed to its archive. These enhancements have facilitated cross discipline data discovery by providing information about CDDIS archive holdings to other data portals such as Earth Observing System (EOS) Clearinghouse (ECHO) and future integration into the Global Geodetic Observing System (GGOS) portal.

6 Publications

The CDDIS staff attended several conferences during 2012 and presented papers on or conducted demos of their activities within the IGS, including:

> Noll, C., P. Michael, M. Dube, N. Pollack. An Update on the CDDIS. *2012 IGS Analysis Workshop*, Olsztyn, Poland, July 2012.
>
> Noll, C., M. Dube, P. Michael, N. Pollack, L. Tyahla. Improvements to the Crustal Dynamics Data Information System. Abstract IN43B–1515 presented at *2012 Fall Meeting, AGU*, San Francisco, Calif., 03–07 Dec., 2012.

Electronic versions of this poster and other publications can be accessed through the CDDIS on–line documentation page on the web at URL `http://cddis.gsfc.nasa.gov/reports.html`.

7 Future Plans

The CDDIS will continue to support the IGS MGEX. The experiment is an excellent opportunity to prepare the data centers for archive of data in RINEX V3.

The CDDIS is supporting the IGS Real–Time Pilot Project as a data center. During 2012, the CDDIS purchased hardware to implement an NTRIP Castor for the transmission of real–time data streams from stations to users. CDDIS has set up a dedicated server for this task. This service will be tested during early 2013. Possible future activities include capturing the streams for generation of 15–minute high–rate files for archive at the CDDIS.

In 2013, the IGS analysis centers will begin work on the second IGS reprocessing campaign (repro2). The CDDIS will provide support through upload of files from the ACs and online archive of these products (`/gnss/products/WWWW/repro2`).

The CDDIS generates and updates status files, (`/gnss/data/daily/YYYY/DDD/YYDD.status`) that summarize the holdings of daily GNSS data. These files include a list of stations. The archive status files of CDDIS GNSS data holdings reflect timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath. The user community can receive a snapshot of data availability and quality by viewing the contents of such a summary file. The CDDIS will enhance this information by providing additional files that list stations not providing data for the particular day.

8 Contact Information

To obtain more information about the CDDIS IGS archive of data and products, contact:

Ms. Carey E. Noll
Manager, CDDIS
Code 690.1
NASA GSFC
Greenbelt, MD 20771

Phone: (301) 614–6542
Fax: (301) 614–6015
E–mail: Carey.Noll@nasa.gov
WWW: http://cddis.gsfc.nasa.gov
http://cddis.nasa.gov

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IGN data center report 2012

A. Duret, and B. Garayt

Institut National de l'Information Géographique et Forestière
IGN SGN, 73 avenue de Paris, 94165 Saint-Mand'e cedex, France
E-Mail: anne.duret@ign.fr, bruno.garayt@ign.fr

The IGN Global Data Centre (GDC) has been designed and implemented in answer to both the Analysis Centers and the surveying user community requirements, for post–processing and real-time applications. The GNSS observations from all the IGS network stations and from the low earth orbit satellites, as well as the IGS products are archived and available at IGN GDC. The IGN data center is handled by the geodetic and leveling department (SGN) which is the operational service of geodesy of the National Institute of Geographic and Forest Information (IGN).

So as to have a more reliable data flow and a better availability of the service, two identical configurations with the same data structure have been setup in two different locations in IGN. Each configuration has:

- FTP deposit server for data and analysis centers uploads,
  - Special authentication is necessary to access.
  - Please contact the IGN team at
  - igsadm@ign.fr if you are not registered in.
- FTP anonymous access to the GNSS observations and products,
- Fully independent Internet links.

The two configurations are in mirroring using VPN connections.

As soon as they are available, GNSS observations and IGS products uploaded at IGN deposit servers by the data and analysis centers are pushed to the public FTP servers.

A mirroring is performed with the other GDCs and between the two IGN sites to complete the archive (see Fig. 1).

The anonymous ftp servers can be access through:

- ftp://igs.ensg.eu for the Marne–la–Vall'ee site
- ftp://igs.ign.fr for the Saint–Mand'e site

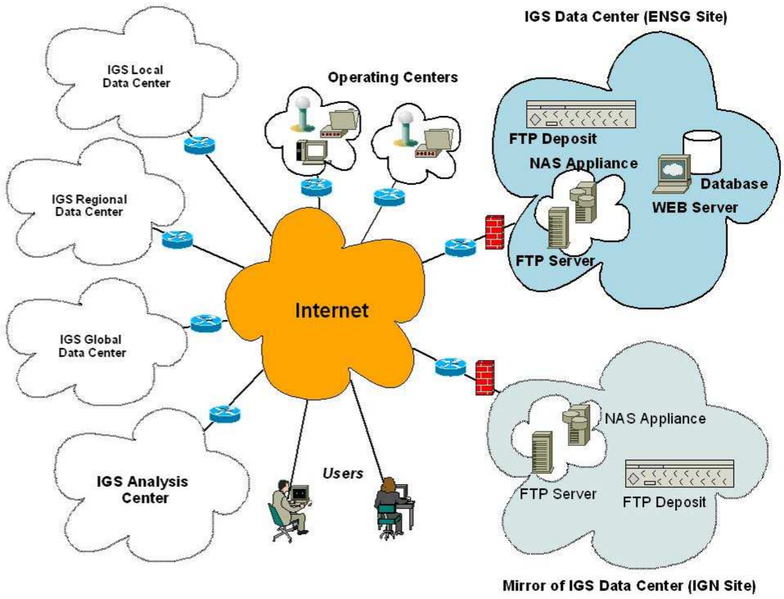

IGS Data Center (ENSG Site)
IGS Local Data Center
Operating Centers
FTP Deposit
NAS Appliance
Database
WEB Server
FTP Server
IGS Regional Data Center
Internet
IGS Global Data Center
NAS Appliance
IGS Analysis Center
Users
FTP Server
FTP Deposit
Mirror of IGS Data Center (IGN Site)

Figure 1: Principle of mirrowing between the two IGN sites.

Since the beginning of the year, the IGN DC is contributing to the IGS MGEX project. Data and products are publicly available using anonymous connections at both sites within the following data structure:

- M–GEX site logs: `/pub/igs/data/campaign/mgex/log`
- Daily 30–second files:
  - `/pub/igs/data/campaign/mgex/daily/rinex3/YYYY/DDD`
  - `/pub/igs/data/campaign/mgex/daily/rinex2/YYYY/DDD`
  - `/pub/igs/data/campaign/mgex/daily/raw/YYYY/DDD`
- Hourly 30–second files:
  - `/pub/igs/data/campaign/mgex/hourly/rinex3/YYYY/DDD`
  - `/pub/igs/data/campaign/mgex/hourly/rinex2/YYYY/DDD`
  - `/pub/igs/data/campaign/mgex/hourly/raw/YYYY/DDD`
- 15–minute 1–second files:
  - `/pub/igs/data/campaign/mgex/highrate/rinex3/YYYY/DDD`
  - `/pub/igs/data/campaign/mgex/highrate/rinex2/YYYY/DDD`
  - `/pub/igs/data/campaign/mgex/highrate/raw/YYYY/DDD`
- Products: `/pub/igs/products/mgex/WWWW/`

Where `YYYY`, `YY` are the year, `DDD` is the day of year, and `WWWW` the GPS week.

A deposit ftp area is available under request at `ftp://igsdepot.ign.fr` for data uploads.

Part IV

Working Groups, Pilot Projects

IGS Antenna Working Group

R. Schmid

Deutsches Geodätisches Forschungsinstitut
Alfons–Goppel–Str. 11, 80539 München, Germany
E-mail: `schmid@dgfi.badw.de`

1 Preparations for the second IGS reprocessing campaign

In 2013, the IGS will perform its second comprehensive reprocessing campaign (repro2). In order to have the best possible antenna phase center information available for repro2, the IGS model `igs08.atx` was updated with satellite–specific z–offsets for all satellites launched since the release of the original model (Sect. 1.1). Besides, subtype calibrations for `JPSREGANT` antennas were introduced that show significant differences (Sect. 1.2).

1.1 Update of satellite–specific z–offsets

Since the adoption of `igs08.atx` in April 2011, one GPS (G063) and five GLONASS satellites (R742–R746) had been launched. For all those satellites, block mean values were applied until September 2012. In GPS week 1706 (16 September 2012), those were updated with satellite–specific z–offset estimates (see IGSMAIL #6650 and Tab. 1) provided by Paul Rebischung (IGN). As R743 was not put into operation until 17 September 2012, it could not be considered for the reanalysis. In contrast, the z–offsets of G062 and R801 were additionally reanalyzed, as the available estimates had been based on limited data. All other active satellites were fixed to `igs08.atx` values.

The updated values were estimated from operational SINEX files of six ACs (CODE, ESOC, GFZ, MIT, NGS and NRCan), CODE and ESOC being the only to provide offset estimates for the GLONASS satellites. Figure 1 shows the weekly z–offset estimates for G063. Usually, the quality is worse in the beginning, as the number of tracking stations is limited as long as the newly launched satellite is not set healthy.

From the weekly estimates weighted mean values per AC were derived (see Tab. 1). The maximum differences between ACs are below 5 cm for all satellites, also for those with the shortest lifetime. Due to this very good agreement and due to the fact that not all ACs analyzed the same amount of data, unweighted mean values per satellite were derived

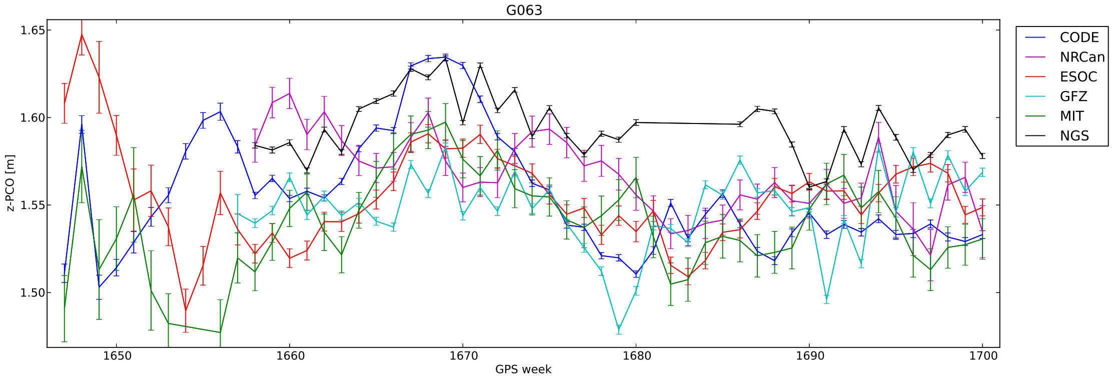


Figure 1: Weekly z–offset estimates [m] from operational SINEX files of six ACs for G063 (courtesy of P. Rebischung).

for `igs08.atx`. In some cases those final values differ considerably from the block mean values used before (correction of about 30 cm for R746 and R801), and in all cases the corrections are significant.

1.2 Consideration of `JPSREGANT` antenna subtypes

Sometime in 2000, Javad changed the setup of two of its `JPSREGANT` antenna types (`JPSREGANT_DD_E`, `JPSREGANT_SD_E`). However, the introduction of these new subtypes did not produce a new name definition and proper recognition within the IGS. Since the adoption of `igs05.atx` in November 2006, mean phase center corrections over the two subtypes were in use for both antenna types. Therefore, all stations equipped with one of the `JPSREGANT` antenna types were affected by a vertical bias of up to 2 cm since that time.

In order to solve that problem, several things had to happen at the same time:

- provision of subtype calibrations in `igs08.atx`
- correction of the antenna type in the affected site logs
- correction of the station coordinates in the course of an update of the IGS reference frame realization

After the correct subtypes actually installed at the affected IGS stations had been identified in most cases, the correction of the site logs could be carried out in conjunction with the switch from IGS08 to IGb08 in GPS week 1709 (7 October 2012):

- `JPSREGANT_DD_E1`: `CONZ` (RA0178), `DLFT` (RA0077), `DWH1` (RA0083), `MDVJ` (RA0195), `MTBG` (RA0085), `STR2` (???005), `UNB1` (RA0193), `UNBJ` (RA0193)
- `JPSREGANT_DD_E2`: `CAGZ` (RRA052), `KOU1` (RRA31)

Table 1: Satellite–specific z–offset estimates for the seven latest GPS/GLONASS satellites (compare IGSMAIL #6650). Besides the number of weekly estimates, the weighted mean per AC is given together with its RMS. The column `igs08.atx` shows the (block mean) values used before the update and Δigs08 is the difference between the new and the old value. All values in [m].

sat.	launch	AC	no. of weeks	weighted mean	weighted RMS	AC mean	`igs08.atx`	Δigs08
G062	28.05.10	CODE	102	1.5808	0.0221	**1.5973**	1.6632	−0.0659
		ESOC	102	1.5901	0.0240			
		GFZ	99	1.5986	0.0303			
		MIT	98	1.5875	0.0277			
		NGS	93	1.6078	0.0241			
		NRCan	81	1.6190	0.0258			
G063	16.07.11	CODE	54	1.5596	0.0344	**1.5613**	1.6500	−0.0887
		ESOC	54	1.5520	0.0225			
		GFZ	44	1.5477	0.0221			
		MIT	51	1.5451	0.0251			
		NGS	38	1.5946	0.0177			
		NRCan	43	1.5689	0.0208			
R742	02.10.11	CODE	43	2.3805	0.0288	**2.3811**	2.4500	−0.0690
		ESOC	42	2.3816	0.0369			
R744	04.11.11	CODE	36	2.5609	0.0322	**2.5631**	2.4500	+0.1131
		ESOC	36	2.5653	0.0437			
R745	04.11.11	CODE	35	2.6413	0.0294	**2.6372**	2.4500	+0.1872
		ESOC	35	2.6330	0.0322			
R746	28.11.11	CODE	34	2.7655	0.0322	**2.7436**	2.4500	+0.2936
		ESOC	33	2.7217	0.0327			
R801	26.02.11	CODE	20	2.0908	0.0246	**2.0668**	1.7500	+0.3168
		ESOC	17	2.0427	0.0448			

- `JPSREGANT_SD_E1`: `DLFT` (RA0043), `KHAJ` (RA0032), `MOBJ` (RA0033), `MOBK` (RA0033), `NOVJ` (RA0038), `NOVM` (RA0038), `SUNM` (RA0024), `ZIMJ` (RA0059)

- `JPSREGANT_SD_E2`: `DREJ` (RA0290, RA0292, RA0293), `FFMJ` (RA0294), `HUEG` (RA0291, RA0310), `TITZ` (RA0291, RA0311), `WTZJ` (RA0295)

- `JPSREGANT_SD_E`: `IRKJ` (RA0225(?); not corrected due to contradictory information)

More details are given in IGSMAIL #6662.

2 Updates and content of the antenna phase center model

In case the satellite constellation changes or new receiver antenna calibrations become available, the absolute antenna phase center model of the IGS has to be updated. The GPS week of the release date is coded in the model name (`igs08_wwww.atx`). Table 2 lists 12 updates in 2012. Further details can be found in the corresponding IGSMAILs whose numbers are also given.

Table 3 gives an overview of the data sets contained in the IGS phase center model. The numbers refer to `igs08_1719.atx` that was released in December 2012. For GPS and GLONASS, there are 71 and 84 file entries, respectively. These numbers are bigger than the number of actual satellites, as certain satellites were assigned with different PRN codes or almanac slots, respectively.

For Galileo, BeiDou and QZSS, the IGS model does still not provide any information. During the IGS Workshop in Olsztyn it was recommended to adopt conventional phase center offset (PCO) values for these new satellite antenna types. However, this will also require an update of the ANTEX format to consider manufacturer–defined spacecraft body frames and attitude modes. For the time being, conventional PCO values for new GNSS can be found on the web pages of the IGS Multi–GNSS Experiment (`http://www.igs.org/mgex/`).

Apart from the satellite antennas, the IGS model also contains phase center calibration values for 242 different receiver antennas. 152 of them are certain combinations of an antenna and a radome, whereas the remaining 90 antenna types are not covered by a radome. As Tab. 3 shows, `igs08_1719.atx` contains, among others, 106 absolute robot calibrations and 90 converted field calibrations.

As the IGS Site Guidelines ask for elevation– and azimuth–dependent calibration values down to 0° elevation, 141 different antenna types (106 `ROBOT` + 32 `COPIED` + 3 `CONVERTED`) are currently approved for the installation at new or upgraded IGS stations. The remaining 101 types are no longer allowed, but their calibration values are still necessary for existing installations (see Sect. 3) as well as for reprocessing purposes.

Table 2: Updates of the phase center model `igs08.atx` in 2012.

week	date	IGSMAIL	change
1673	30-JAN-12	6533	Added G049 (G24) Decommission date: G024
1682	02-APR-12	6564	Added G032 (G24) Decommission date: G049 (G24) Added `NOV533+CR NOVC`
1685	26-APR-12	6576	Added G037 (G24) Decommission date: G032 (G24)
1699	02-AUG-12	6634	Added R801 (R26) Added `RNG80971.00 NONE`
1700	06-AUG-12	6640	Added G049 (G24) Decommission date: G037 (G24)
1706	05-SEP-12	6650	z-offset updated: G062, G063, R742, R744, R745, R746, R801 (see Sect. 1.1)

1707	24-SEP-12	6662	Added R743
			Decommission date: R729
			Added `ASH701023.A NONE`
			`JPSREGANT_DD_E1 NONE`
			`JPSREGANT_DD_E2 NONE`
			`JPSREGANT_SD_E1 NONE`
			`JPSREGANT_SD_E2 NONE`
			`LEIGS08PLUS NONE`
			(compare Sect. 1.2)

1708	05-OCT-12	6670	Added G065 Decommission date: G049 (G24)
1710	18-OCT-12	6676	Added G049 (G27) Decommission date: G027
1711	23-OCT-12	6679	Added R712 (R08) Decommission date: R743

1717	03-DEC-12	—	Added `LEIAR20 NONE`
			`LEIAR20 LEIM`
			`TIAPENG3100R1 NONE`

1719	19-DEC-12	—	Added `LEIGS14 NONE`

Table 3: Number of data sets in `igs08_1719.atx` (released in December 2012).

satellite antennas	number	receiver antennas	number
GPS	71	`ROBOT`	106
GLONASS	84	`FIELD`	90
Galileo	0	`COPIED`	32
BeiDou	0	`CONVERTED`	14
QZSS	0		

3 Calibration status of the IGS network

Table 4 shows the percentage of IGS tracking stations with respect to certain calibration types. For this analysis, 440 IGS stations as contained in the file `logsum.txt` (available at `ftp://igs.org/igscb/station/general/`) on 11 January 2013 were considered. At that time, 100 different antenna/radome combinations were in use within the IGS network. The calibration status of these antenna types was assessed with respect to the phase center model `igs08_1722.atx` that was released in January 2013.

In the meantime, absolute robot calibrations comprising elevation– and azimuth–dependent PCVs down to the horizon are available for a bit more than three quarters of all IGS stations. About 8% of the stations are still equipped with antenna types for which purely elevation–dependent PCVs derived from relative field calibrations have to be applied. Besides, about 15% of the antennas in the IGS network are either covered by an uncalibrated radome or represent an unmodeled antenna subtype.

The latter category of stations is particularly disadvantageous in case the antenna is co–located with other space geodetic instruments. Therefore, several IGS entities cooperatively organized a campaign to quantify the impact of the uncalibrated radome by removing it for about two months at important co–location sites (Romero et al., 2012).

Table 4: Calibration status of 440 stations in the IGS network (`logsum.txt` of 11 January 2013, `igs08_1722.atx`) compared to former years.

date	absolute calibration (azimuthal corrections down to 0° elevation)	converted field calibration (purely elev.–dependent PCVs above 10° elevation)	uncalibrated radome (or unmodeled antenna subtype)
DEC 2009	61.4%	18.3%	20.2%
MAY 2012	74.6%	8.2%	17.2%
JAN 2013	**76.8%**	**7.7%**	**15.5%**

The improvement between 2009 and 2012 (compare Tab. 4) is mainly related to the transition from `igs05.atx` to `igs08.atx` in 2011, as several additional robot calibrations could be considered at that time. Since then, the problem associated with the `JPSREGANT` antennas (Sect. 1.2) could be nearly solved, and some inadequate antenna installations were upgraded or decommissioned.

References

Romero I., P. Rebischung, J. Ray, R. Schmid, S. Fisher, and J. Griffiths. The IGS campaign to measure position corrections for uncalibrated IGS radome stations. *IGS Workshop 2012*, 23–27 July 2012, Olsztyn, Poland, 2012.

Activities of IGS Bias and Calibration Working Group

S. Schaer

Swiss Federal Office of Topography swisstopo
Seftigenstrasse 264, CH–3084 Wabern, Switzerland
stefan.schaer@aiub.unibe.ch / stefan.schaer@swisstopo.ch

1 Introduction

The IGS Bias and Calibration Working Group (BCWG) coordinates research in the field of GNSS bias retrieval and monitoring. It defines rules for appropriate, consistent handling of biases which are crucial for a "model–mixed" GNSS receiver network and satellite constellation, respectively. At present, we consider: P1–C1, P2–C2, and P1–P2 differential code biases (DCB). Potential quarter-cycle biases between different phase observables (specifically L2P and L2C) are another issue to be dealt with. In the face of GPS and GLONASS modernization programs and upcoming GNSS, like the European Galileo and the Chinese BeiDou, an increasing number of types of biases is expected.

The IGS BCWG was established in 2008. More helpful information and related internet links may be found at `http://igs.org/projects/bcwg/`. For an overview of relevant GNSS biases, the interested reader is referred to (Schaer, 2012a).

2 Activities in 2012

- Regular generation of P1–C1 bias values for the GPS constellation and maintenance of receiver class tables was continued at CODE/AIUB.
- The organization and realization of a first **IGS Workshop on GNSS Biases** was a key challenge and achievement in 2012 (see also Section 3).
- The tool developed for direct estimation of GNSS P1–C1 and P2–C2 DCB values could be completed. This tool was considerably further developed to be able to cope with all possible RINEX data scenarios, specifically with historical data, where we got confronted with numerous problems and anomalies.

- A complete GPS/GLONASS DCB reprocessing was carried out at CODE on the basis of 1990–2011 RINEX data. The outcome of this P1–C1 and P2–C2 DCB reprocessing effort is: daily sets, a multitude of daily subsets, and in addition monthly sets.
- Analysis and combination of these remarkably long time series must be seen as a medium-term (or long–term) goal.
- The outdated (reliably working) GNSS DCB combination/estimation processing environment at CODE was completely redesigned in 2011/2012.
- Direct P1–C1 and P2–C2 bias results for GPS and GLONASS are now generated on a regular basis and made available at:
  `ftp://ftp.unibe.ch/aiub/CODE/`
- The ambiguity resolution scheme at CODE was extended to GLONASS for three resolution strategies. It is essential that self–calibrating ambiguity resolution procedures are used. Resulting GLONASS DCPB results are collected and archived.
- More experience could be gained concerning station-specific GLONASS–GPS intersystem translation parameters, which are estimated and accumulated as part of CODE's IGS analysis.
- GPS quarter-cycle biases are still a serious issue (see, e.g., IGSMAIL #6583).
- Finally, the RINEX observation data monitoring was completely revised at CODE in order to cope with the increasing number of possible GNSS observables (Schaer et al., 2012). Examples of new result files are:
  `ftp://ftp.unibe.ch/aiub/igsdata/odata2_day.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/odata2_receiver.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/y2012/odata2_d335.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/y2012/odata2_d335_sat.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/ndata2_day.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/ndata2_receiver.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/gdata2_day.txt`
  `ftp://ftp.unibe.ch/aiub/igsdata/gdata2_receiver.txt`

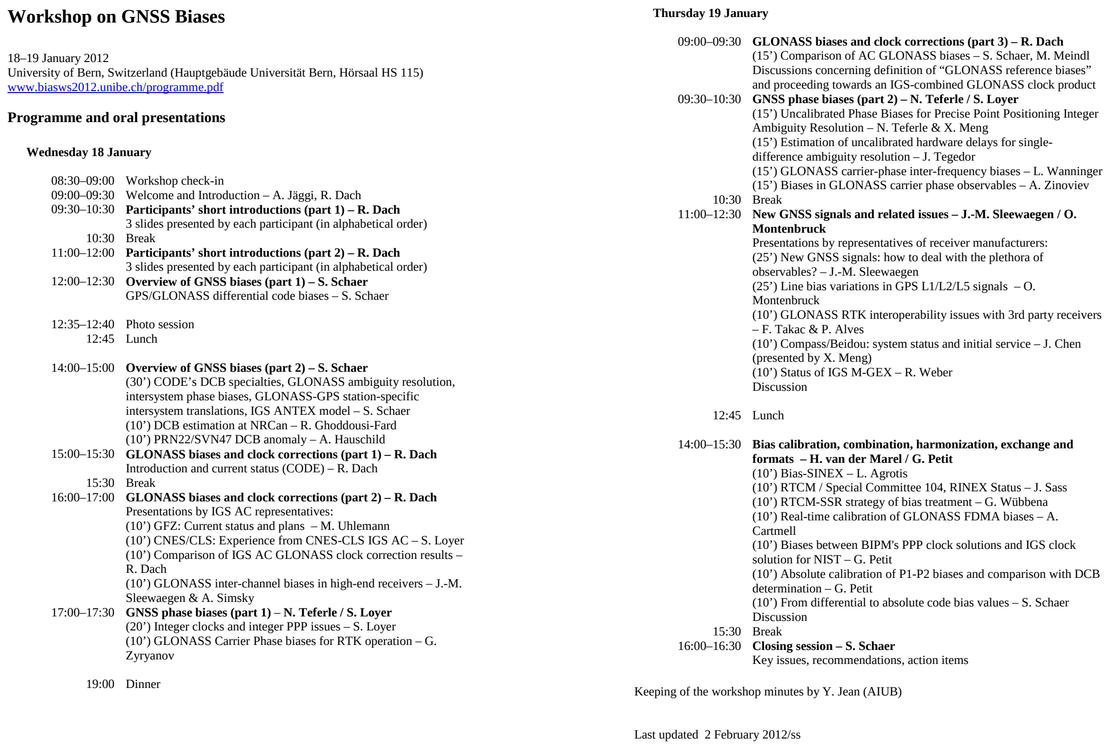
3 IGS Workshop on GNSS Biases 2012

This workshop was held at the University of Bern on 18–19 January 2012. All related information, including all presentations, may be found at:

http://www.biasws2012.unibe.ch

One main focus of this workshop was on biases specific to GLONASS:

- IGS AC GLONASS inter–frequency code bias results were compared for the first time. It could be shown that the generation of an IGS–combined GLONASS clock product should be possible (even with current IGS AC GLONASS clock products).
- The "GLONASS interoperability issue" was another key subject. There was finally a clear consensus that the causing bias must be addressed as differential code–phase bias (DCPB).



Workshop on GNSS Biases

18–19 January 2012
University of Bern, Switzerland (Hauptgebäude Universität Bern, Hörsaal HS 115)
www.biasws2012.unibe.ch/programme.pdf

Programme and oral presentations

Wednesday 18 January

08:30–09:00	Workshop check-in
09:00–09:30	Welcome and Introduction – A. Jäggi, R. Dach
09:30–10:30	**Participants' short introductions (part 1) – R. Dach** 3 slides presented by each participant (in alphabetical order)
10:30	Break
11:00–12:00	**Participants' short introductions (part 2) – R. Dach** 3 slides presented by each participant (in alphabetical order)
12:00–12:30	**Overview of GNSS biases (part 1) – S. Schaer** GPS/GLONASS differential code biases – S. Schaer
12:35–12:40	Photo session
12:45	Lunch
14:00–15:00	**Overview of GNSS biases (part 2) – S. Schaer** (30') CODE's DCB specialties, GLONASS ambiguity resolution, intersystem phase biases, GLONASS-GPS station-specific intersystem translations, IGS ANTEX model – S. Schaer (10') DCB estimation at NRCan – R. Ghoddousi-Fard (10') PRN22/SVN47 DCB anomaly – A. Hauschild
15:00–15:30	**GLONASS biases and clock corrections (part 1) – R. Dach** Introduction and current status (CODE) – R. Dach
15:30	Break
16:00–17:00	**GLONASS biases and clock corrections (part 2) – R. Dach** Presentations by IGS AC representatives: (10') GFZ: Current status and plans – M. Uhlemann (10') CNES/CLS: Experience from CNES-CLS IGS AC – S. Loyer (10') Comparison of IGS AC GLONASS clock correction results – R. Dach (10') GLONASS inter-channel biases in high-end receivers – J.-M. Sleewaegen & A. Simsky
17:00–17:30	**GNSS phase biases (part 1)** – **N. Teferle / S. Loyer** (20') Integer clocks and integer PPP issues – S. Loyer (10') GLONASS Carrier Phase biases for RTK operation – G. Zyryanov
19:00	Dinner

Thursday 19 January

09:00–09:30	**GLONASS biases and clock corrections (part 3) – R. Dach** (15') Comparison of AC GLONASS biases – S. Schaer, M. Meindl Discussions concerning definition of "GLONASS reference biases" and proceeding towards an IGS-combined GLONASS clock product
09:30–10:30	**GNSS phase biases (part 2) – N. Teferle / S. Loyer** (15') Uncalibrated Phase Biases for Precise Point Positioning Integer Ambiguity Resolution – N. Teferle & X. Meng (15') Estimation of uncalibrated hardware delays for single-difference ambiguity resolution – J. Tegedor (15') GLONASS carrier-phase inter-frequency biases – L. Wanninger (15') Biases in GLONASS carrier phase observables – A. Zinoviev
10:30	Break
11:00–12:30	**New GNSS signals and related issues – J.-M. Sleewaegen / O. Montenbruck** Presentations by representatives of receiver manufacturers: (25') New GNSS signals: how to deal with the plethora of observables? – J.-M. Sleewaegen (25') Line bias variations in GPS L1/L2/L5 signals – O. Montenbruck (10') GLONASS RTK interoperability issues with 3rd party receivers – F. Takac & P. Alves (10') Compass/Beidou: system status and initial service – J. Chen (presented by X. Meng) (10') Status of IGS M-GEX – R. Weber Discussion
12:45	Lunch
14:00–15:30	**Bias calibration, combination, harmonization, exchange and formats – H. van der Marel / G. Petit** (10') Bias-SINEX – L. Agrotis (10') RTCM / Special Committee 104, RINEX Status – J. Sass (10') RTCM-SSR strategy of bias treatment – G. Wübbena (10') Real-time calibration of GLONASS FDMA biases – A. Cartmell (10') Biases between BIPM's PPP clock solutions and IGS clock solution for NIST – G. Petit (10') Absolute calibration of P1-P2 biases and comparison with DCB determination – G. Petit (10') From differential to absolute code bias values – S. Schaer Discussion
15:30	Break
16:00–16:30	**Closing session – S. Schaer** Key issues, recommendations, action items

Keeping of the workshop minutes by Y. Jean (AIUB)

Last updated 2 February 2012/ss

Figure 1: Programme of the first IGS Workshop on GNSS Biases, Wednesday 18th (left) and Thursday 19th January 2012 (right).

Figure 2: 37 participants of the IGS Workshop on GNSS Biases on 18th January 2012 in front of the main building of the University of Bern, Switzerland.

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IGS Data Center Working Group 2012

C. Noll

NASA Goddard Space Flight Center, Code 690.1
Greenbelt, MD 20771 USA
Carey.Noll@nasa.gov

1 Introduction

The IGS Data Center Working Group (DCWG) was established in 2002. The DCWG tackles many of the problems facing the IGS data centers as well as develops new ideas to aid users both internal and external to the IGS. The direction of the IGS has changed since its start in 1992 and many new working groups, projects, data sets, and products have been created and incorporated into the service since that time. The DCWG was formed to revisit the requirements of data centers within the IGS and to address issues relevant to effective operation of all IGS data centers, operational, regional, and global.

2 Recent Activities

A Data Center Working Group meeting was held during IGS 2012 Workshop in Olsztyn, Poland. Recommendations where made resulting from presentations during the workshop and from splinter meeting discussions. Major topics discussed were the proposed changes to the RINEX filenaming convention, handling multiple releases of files at the data centers, and archiving RINEX V2 and V3 at the data centers. The IGS DCs recognize that a change in the filenaming convention will enable improved organization of RINEX files, when the unique identification of the station name, file creation approach, and file content becomes visible within the filename. Filename changes directly affect DC operations and therefore an update will be a significant workload for the data centers. A new filename structure will remove some difficulties for DCs in handling RINEX files, but also induce new problems, especially in resubmitted files. To help in the transition to a new filename structure, it was recommended that data centers continue to archive RINEX V2 and RINEX V3 data in separate structures. DCs should also separate high–rate data files created from streams from those created from receivers. IGS users reported to DCs that decompression tools for ".Z" compressed file may no longer run on the newest generation of computers. Therefore, it is recommended once again that the DCs change the standard compression format used within the IGS infrastructure as early as possible.

The DCWG also coordinated product archival, which involved working with the IGS ACC in the final archiving of IGS repro1 products at the IGS Global Data Centers. The WG began coordination on data center infrastructure support for the IGS M–GEX activity. This activity included establishing a directory structure for both data (in RINEX V3 and V2) and products.

3 Future Plans

In 2013–2014, the DCWG will continue to work on addressing recommendations from the IGS 2010 and 2012 workshops. Topics the WG hopes to address follow.

Support of the IGS Infrastructure Committee: A major focus of the DCWG will be to support the IC in its various activities to coordinate the resolution of issues related to the IGS components. These activities will address recommendations from recent IGS Workshops including assessment and monitoring of station performance and data quality, generating metrics on these data.

RINEX filenaming convention: The DCWG will work with the IC and the RINEX WG on the new IGS RINEX filenaming convention.

Data center harmonization: The working group will consider methodologies for ensuring key data sets are available at all GDCs. Following recommendations from the IGS 2010 Workshop, the WG will coordinate with GDCs to ensure all GDCs archive data from all IGS stations as identified on the IGS network website; ODCs push data, and any subsequent resubmissions, from their stations to ALL GDCs and ODCs issues advisory for ALL resubmissions.

Compression: As per a recommendation from the IGS 2010 and 2012 workshops, the DCWG will develop a plan for the introduction of a new compression scheme into the IGS infrastructure by evaluating tests of available tools, surveying the IGS infrastructure, making a recommendation on a new IGS compression scheme, and coordinating recommendations with the IC to develop implementation schedule.

Real–time data streams/high–rate GNSS data handling: IGS data centers must ensure that files generated from these streams are sufficiently reliable. The DCs must also coordinate to ensure consistent copies of high–rate files are archived. This recommendation from 2010 IGS Workshop includes definition and development of 1) tool for comparison of RINEX files from various construction approaches, 2) minimum requirements for acceptance of an accumulated data stream of observations as a RINEX file in IGS data archives, 3) mandatory/optional observation types to be included, 4) procedures to fill the gaps in the case data streams have been interrupted. This activity should be coordinated with the RTPP, ACs, DCs, and IC. A related recommendation resulted from the 2012 IGS Analysis Workshop stating that until the RINEX V3 filenaming convention is finalized, separate directories for distinguishing between files created from streams and by receivers will be established by all DCs.

M–GEX: As the IGS Multi–GNSS Experiment begins, the DCWG will advise and coordinate archival of the experiment's data from other GNSS and products derived from these data sets.

4 Membership

- Carey Noll (NASA GSFC/USA), Chair
- Yehuda Bock (SIO/USA)
- Ludwig Combrinck (HRAO/South Africa)
- Bruno Garayt (IGN/France)
- Jake Griffiths (NOAA/USA), ex–officio
- Heinz Habrich (BKG/Germany)
- Michael Moore (GA/Australia) (tbc)
- Ruth Neilan (JPL/USA), ex–officio
- Markus Ramatschi (GFZ/Germany)
- Jim Ray (NOAA/USA)
- Nacho Romero (ESA/Germany)
- Mike Schmidt (NRCan/Canada)
- Giovanni Sella (NOAA/USA)
- Grigory Steblov (RDAAC/Russia)
- Dave Stowers (JPL/USA)

IGS Ionosphere Working Group
Technical Report 2012

A. Krankowski and R. Sieradzki

Geodynamics Research Laboratory of University
University of Warmia and Mazury in Olsztyn, Poland (GRL/UWM)

1 General goals

The Ionosphere Working group started the routine generation of the combine Ionosphere Vertical Total Electron Content (TEC) maps in June 1998. This has been the main activity so far performed by the four IGS Ionosphere Associate Analysis Centers (IAACs):

- **CODE** Center for Orbit Determination in Europe,
  Astronomical Institute, University of Bern, Switzerland,
- **ESOC** European Space Operations Center of ESA, Darmstadt, Germany,
- **JPL** Jet Propulsion Laboratory, Pasadena, California, U.S.A., and
- **UPC** Technical University of Catalonia, Barcelona, Spain.

Independent computation of rapid and final VTEC maps is used by the each analysis centers: Each IAACs compute the rapid and final TEC maps independently and with different approaches including the additional usage of GLONASS data in the case of CODE (Hernandez–Pajares et al., 2009).

2 Membership

1.	Dieter Bilitza	GSFC/NASA
2.	Ljiljana R. Cander	RAL
3.	M. Codrescu	SEC
4.	Anthea Coster	MIT
5.	Patricia H. Doherty	BC
6.	John Dow	ESA/ESOC
7.	Joachim Feltens	ESA/ESOC
8.	Mariusz Figurski	MUT
9.	Alberto Garcia–Rigo	UPC
10.	Manuel Hernandez–Pajares	UPC
11.	Pierre Heroux	NRCAN
12.	Norbert Jakowski	DLR
13.	Attila Komjathy	JPL
14.	Andrzej Krankowski	UWM
15.	Richard B. Langley	UNB
16.	Reinhard Leitinger	TU Graz
17.	Maria Lorenzo	ESA/ESOC
18.	A. Moore	JPL
19.	Raul Orus	UPC
20.	Michiel Otten	ESA/ESOC
21.	Ola Ovstedal	UMB
22.	Ignacio Romero	ESA/ESOC
23.	Jaime Fernandez Sanchez	ESA/ESOC
24.	Schaer Stefan	CODE
25.	Javier Tegedor	ESA/ESOC
26.	Rene Warnant	ROB
27.	Robert Weber	TU Wien
28.	Pawel Wielgosz	UWM
29.	Brian Wilson	JPL
30.	Michael Schmidt	DGFI
31.	Mahdiă Alizadeh	TU Vienna

3 Products

1. *Final GIM*
   (please note that GIMs also include GPS and GLONASS stations' and satellites' DCBs)
   - combination of CODE, ESA, JPL and UPC iono products conducted by UWM
   - temporal and spatial resolution — at 2 hours × 5° × 2.5° (UT×Lon.×Lat.),
   - availability with a latency of 11 days

2. *Rapid GIM*
    - combination of CODE, ESA, JPL and UPC iono products conducted by UWM
    - temporal and spatial resolution — at 2 hours × 5° × 2.5° (UT×Lon.×Lat.),
    - availability with a latency of less than 24 hours
3. *Predicted GIM* for 1 and 2 days ahead (pilot product)
    - combination of ESA and UPC iono products conducted by ESA
    - temporal and spatial resolution — at 2 hours × 5° × 2.5° (UT×Lon.×Lat.),

4 Key accomplishments

- IGS Global ionosphere predicted products for 1 and 2 days ahead (pilot product). This new IGS products are currently based on predicted ionosphere maps prepared by UPC and ESA.
- IGS Global ionosphere maps with 1 hour and 15 min. time resolution (pilot products). This new IGS products are currently based on ionosphere maps prepared by UPC and ESA.
- IGS Global Ionosphere Maps (GIMs) now include differential code biases (DCBs) for GLONASS satellites.
- The pilot phase of the new IGS ionospheric product — TEC fluctuations maps

5 Recommendations after IGS Workshop 2012, Olsztyn, Poland

- Higher temporal and spatial resolution of IGS combined GIMs - the IAACs (UPC and JPL) agreed on providing their maps in IONEX format, with a resolution of 15 min, 1 degree and 1 degree in time, longitude and latitude respectively.
- Starting a new official/operational product — TEC fluctuation changes over North Pole to study the dynamic of oval irregularities (carried out by UWM to be started as official/routine product after performance evaluation period (end of 2012).
- The new the IAAC from GNSS Research Center (GRC), Wuhan University, China (Hongping Zhang, end of 2012).
- Cooperation with IRI COSPAR group

6 The pilot phase of the new IGS ionospheric product — TEC fluctuations maps

According to the resolution of the IGS Ionosphere Working Group, which has been passed during the IGS Workshop 2012 in Olsztyn, the new ionospheric product — fluctuations TEC map — was made available. The routine generation of the test IGS product for region around the North Geomagnetic Pole has started in March 2013 at Geodynamics Research Laboratory of University of Warmia and Mazury in Olsztyn (GRL/UWM).

The new ionospheric product show the variability of TEC in the ionosphere for range from 55 degrees of the north geomagnetic latitude to the North Geomagnetic Pole. Because of the relationship between the state of the ionosphere, geomagnetic field and local time the TEC fluctuations maps are determined as a function of spherical geomagnetic latitude and magnetic local time. The land mass configuration and the relatively small number of stations make impossible the creating similar product for southern hemisphere at present. For the purpose of the generation of the product the 30 second dual–frequency phase observations from about 180 stations are used. This number contain practically all permanently working observatories at high north geomagnetic latitudes, which belong to IGS/EPN Network, Polenet Network (Greenland) or participate in Plate Boundary Observatory mission (Alaska). It is worth to remember that the distribution of the stations is very irregular (Fig. 1). The very small number of the stations on Russian Federation territory make particularly adverse conditions for the ionospheric studies. Currently the

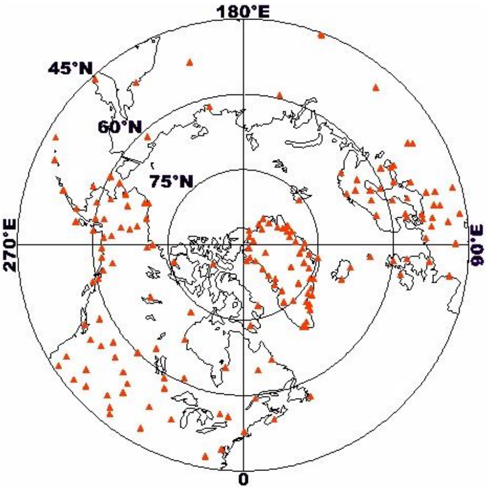

Figure 1: The locations of the stations around the North Geomagnetic Pole.

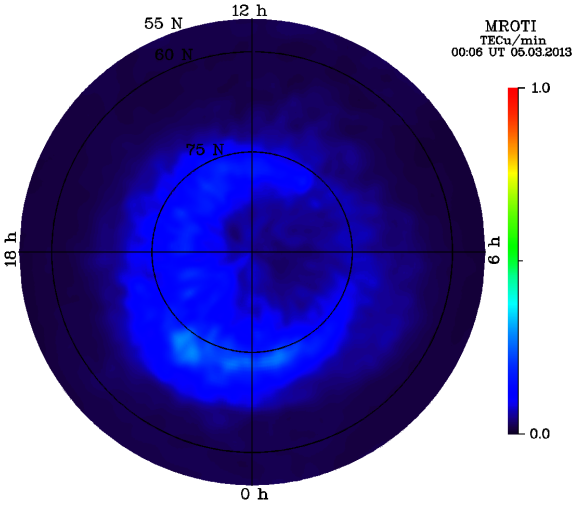

Figure 2: The example 6-hour of the averaged ionospheric variability.

TEC fluctuations maps are generated using phase observations from GPS and GLONASS satellites.

In order to describe the TEC variability in the ionosphere the Rate of TEC (ROT) and its deviation — Rate of TEC Index (ROTI) are used. The ROT is calculated as the difference of two geometry–free observations (L4) for consecutive epochs. The ROTI represents the ROT deviation over 5 minute periods. Both these parameters determine the conditions in the ionosphere for specified time. For the purpose of the new product the two new indices: MROTI and DROTI are applied. First of them is the mean of all ROTI values for specified time window and the second is its deviation. The new parameters are used to estimate the variability in the ionosphere within the presupposed time. The MROTI and DROTI are calculated for the grid with dimensions: 5 degrees (magnetic local time) and 2 degrees (geomagnetic latitude) with shift 2.5 and 1 degree respectively. At present the two types of TEC fluctuations maps are generated: the daily map and 6–hour map. The further shortening of the time resolution cause the occurrence of the areas practically without any observations. Taking into account the dynamics of the high–latitudinal ionosphere, it makes impossible to obtain the reliable information about the conditions for these areas. The final TEC fluctuations maps are written in the modified IONEX format (Sieradzki and Cherniak, 2012). During the pilot phase of the product its graphical form can be found: `http://igsiono.uwm.edu.pl` .

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Multi–GNSS Working Group

O. Montenbruck

DLR, German Space Operations Center
Oberpfaffenhofen
DE–82234 Wessling, Germany;
E–mail: oliver.montenbruck@dlr.de

1 Introduction

In recognition of a rapidly evolving GNSS landscape, the Multi–GNSS Working Group (formerly the GNSS Working Group) has been established to explore and promote the use of new navigation signals and constellations within the IGS. It shall enable an early familiarization with new GNSSs, identify and master relevant challenges, and prepare use of emerging navigation systems in routine IGS products. As set forth in its latest charter of Jan. 2012, the core activity of the MGWG is the performance of the Multi–GNSS Experiment (MGEX) which comprises the build–up of a new network of sensor stations, the characterization of the user equipment and space segment, the development of new concepts and data processing tools, and, finally, the generation of early data products for Galileo, QZSS, BeiDou. To achieve these goals, the Multi–GNSS Working Group interacts closely with other IGS entities, such as the RINEX WG, the Antenna WG, the Data Center WG and the Infrastructure Committee. It helps to develop and implement new standards for multi–GNSS–related work within the IGS.

2 Network

Following a call for participation released in the summer of 2011, the build–up of a new network of multi–GNSS sensor stations has been initiated and made substantial progress in short time. By the end of 2012 the MGEX network comprises roughly 50 stations supporting at least one of the new navigation systems (Galileo, BeiDou, and QZSS) on top of the legacy GPS, GLONASS and SBAS systems. The bulk of stations is provided by former IGS partners such as BKG, CNES, GFZ, GSI, IGN, and LMV (in alphabetical order) that have upgraded/supplemented existing sites with new, multi–GNSS–capable receivers and antennas or started to deploy new multi–GNSS networks (such as CNES

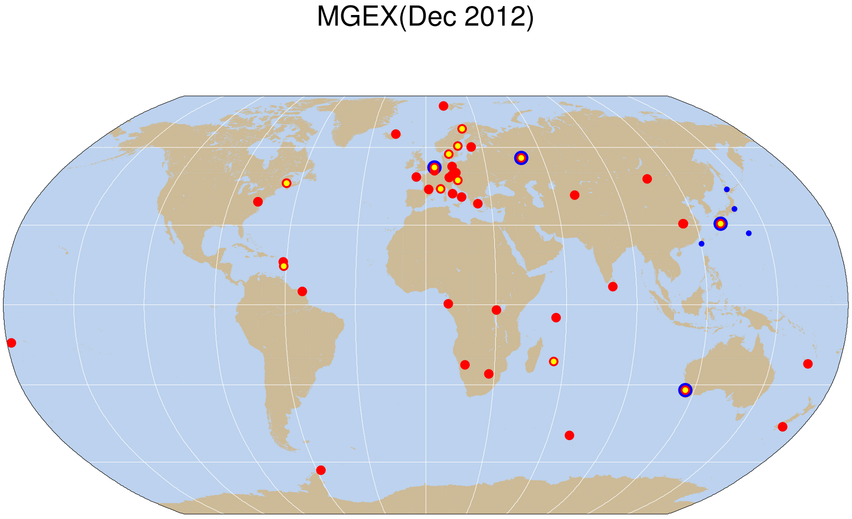

Figure 1: Distribution of MGEX stations supporting tracking of QZSS (blue), Galileo (red), and BeiDou (yellow) as of Dec. 2012.

REGINA network). As shown in Fig. 1, the present set of MGEX stations exhibits an almost global coverage, even though a concentration in Europe and a reduced coverage in the Americas and the West Pacific are obvious. However, this situation is expected to improve soon with announced contributions from DLR (CONGO network), ESA, JAXA (MGM–net), and GA. While most MGEX sites support tracking of the Galileo satellites, only a subset of stations is presently providing data for QZSS and BeiDou. In particular, the regional BeiDou constellation (i.e. the GEO and IGSO) satellites are not well covered by the current network.

Further MGEX sites are encouraged and sites can still be submitted through the MGEX submission form (`http://igs.geolinks.org/mgex`) under the provision of relevant improvements to the capabilities, coverage and homogeneity of the overall network.

In terms of equipment, six basic receiver types and five basic antenna types are presently employed at the MGEX stations (see Tab. 1 and 2). Observation types provided by the individual receivers have been compiled from summary reports generated by AIUB as part of their routine monitoring of RINEX 3 observation files from MGEX stations (see `ftp://ftp.unibe.ch/aiub/mgex/odata2_receiver.txt`). It may be noted that no common standard has yet evolved in terms of supported signals and observation types. This causes certain restrictions for data analysis and product generation. As an example, Galileo orbit and clock products will (at least initially) be based on E1/E5a observations due to a limited coverage with E5b and E5ab tracking.

Selected sites (such as UNB and USNO) offer multiple receivers in short– or zero–baseline configuration to facilitate equipment characterization. Further such installations will be added to the MGEX network as part of proposed extensions.

Table 1: Receiver types in use within the MGEX network (status Dec. 2012). Observation types for Galileo (E), BeiDou (C), and QZSS (J) are based on RINEX 3 observation codes as reported in the submitted data files. They do not necessarily indicate the full tracking capabilities supported by the receivers but rather the observations presently made available to MGEX users from the respective stations.

Receiver Type	Stations	Observations
`IFEN SX_NSR_RT_800`	1	E: 1X,5X,7X,8X,6X C: 2I, 7I
`JAVAD TRE_G3TH DELTA`	12	E: 1X,5X
`LEICA GR10`, `LEICA GR25` and `LEICA GRX1200+GNSS`	8	E: 1X,5X,7X,8Q
`NOV OEM6`	1	E: 1C,5Q
`SEPT POLARX4TR` and `SEPT POLARXS`	3	E: 1C,5Q,7Q,8Q C: 2I,7I
`TRIMBLE NETR9`	26	E: 1X,5X,7X,8X C: 2I,7I,6I J: 1C,1X,2X,5X,6X

Table 2: Antenna types currently employed within the MGEX network (status Dec. 2012).

Antenna Type	Stations
`AOAD/M_T        NONE`	2
`JAV_RINGANT_G3T NONE`	10
`JAVRINGANT_DM   SCI?`	1
`LEIAR25         NONE` and `LEIAR25.R3      LEIT` and `LEIAR25.R4      LEIT`	15
`TRM55971.00     NONE` and `TRM57971.00     NONE` and `TRM57971.00     TZGD`	8
`TRM59800.00     NONE` and `TRM59800.00     SCIS`	15

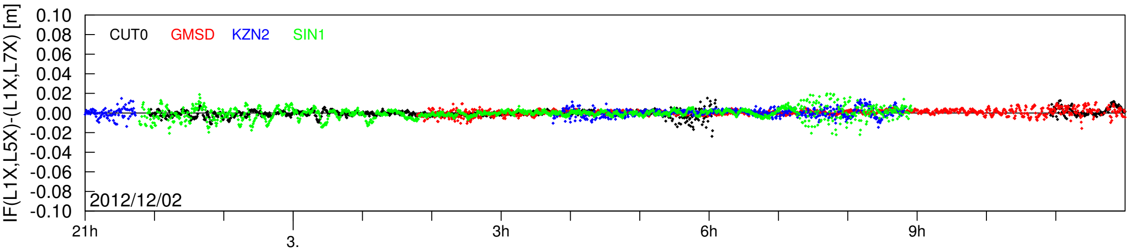

Figure 2: Triple–frequency combination of Galileo IOV–3 observations from various MGEX stations demonstrating a high coherency of E1, E5a, and E5b carrier–phase measurements for the new European navigation satellites (from Montenbruck and Langley, 2013).

While all stations contribute data to offline archives hosted by CDDIS, IGN, and BKG for the MGEX project, a selected subset is also supporting real–time analyses. All real–time streams utilize NTRIP (Networked Transport of RTCM via Internet Protocol) that has emerged as a standard for real–time GNSS data exchange. A dedicated MGEX caster is hosted by BKG in Frankfurt, where native raw data streams received from the individual sites are converted and encoded in a prototype of the RTCM3 Multiple–Signal–Message (MSM) format. While still in a draft status, RTCM3–MSM will enable a harmonized framework for multi–GNSS real–time operations and ensure a seamless conversion to the RINEX 3 offline data format. The new MGEX NTRIP caster provides a basis to gain early experience with the new MSM format and facilitates a timely adaptation of user software. This is further supported through freeware software modules for data conversion provided by BKG as part of its BNC client.

While a systematic quality control and signal analysis has not yet started, first performance assessments of both the ground and space segment have already been reported in Raziq et al. (2012) and Montenbruck and Langley (2013) based on MGEX data.

3 Products

While the newly established MGEX network forms a mandatory prerequisite for multi–GNSS work within the IGS, the MGEX experiment comprises a wider range of activities that are presently established. Foremost, the generation of orbit and clock products for the new constellations is promoted in coordination with new and established IGS analysis centers. Initial Galileo IOV products are already provided by CNES/CLS (Loyer et al., 2012), CODE (Prange et al., 2012), and GFZ (Uhlemann et al., 2012) since mid–2012 and a combined Galileo+QZSS product has recently been added by TUM (Hackel et al., 2012; Steigenberger et al., 2013). Aside from the MGEX network, some of these solutions make complementary use of proprietary multi–GNSS networks to compensate existing coverage limitations and achieve an improved product quality. Based on inter–agency comparisons,

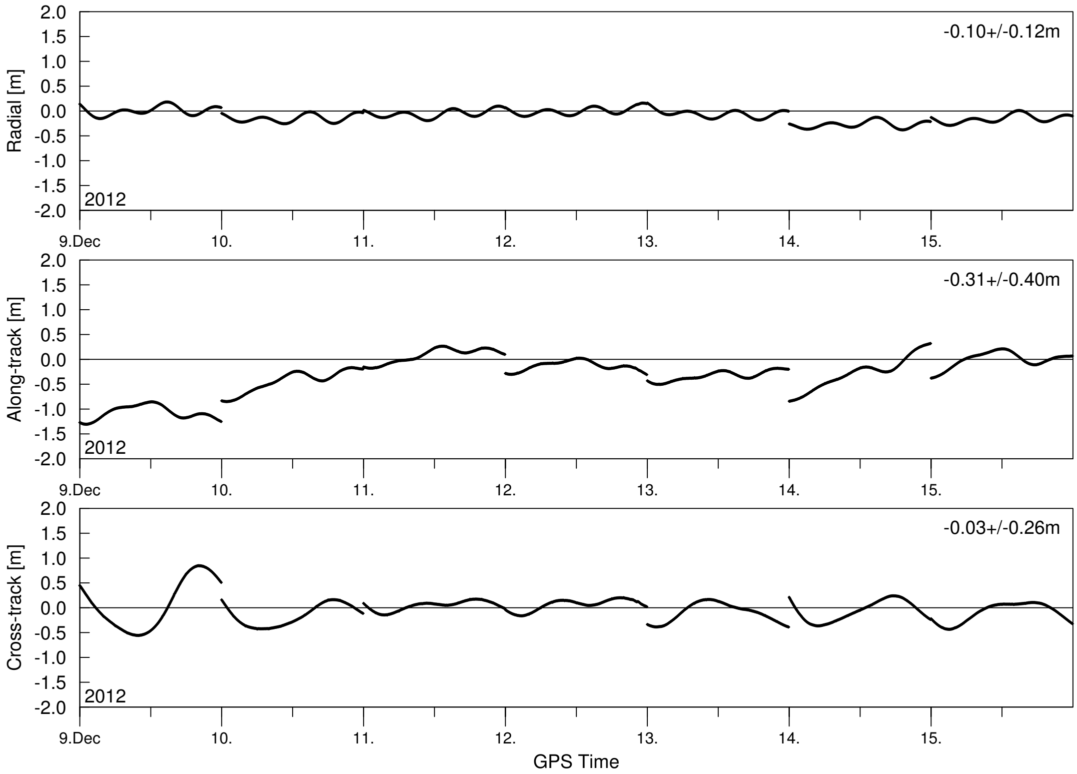

Figure 3: Comparison of TUM orbit products of QZS–1 with final product of JAXA for a one week data arc in Dec. 2012 .

a user equivalent range error (UERE) of a few decimeters is presently achieved by MGEX orbit products of both the Galileo and QZSS satellites (see Fig. 3).

Concerning the Chinese BeiDou system, which has now reached its initial operational capability for a regional service, early orbit and clock determination results have been reported by various Chinese (Zhou et al., 2012) and European (Steigenberger et al., 2012) researchers using data from dedicated regional sensor station networks. An effort will be made to promote the extension of the BeiDou tracking capabilities within the MGEX network and to make MGEX–only or mixed–network–based orbit and clock products for BeiDou accessible to a wider user community through the MGEX data centers.

In the absence of publicly available broadcast navigation data for either Galileo or BeiDou, the MGEX orbit and clock products constitute a significant promotion for the early use of all available navigation systems. Aside from initial positioning experiments they provide a basis for the in–depth characterization of both the space and user segment, and — hopefully — help facilitate an improved interaction with system providers. Early applications of MGEX multi–GNSS products and observations have, for example, been reported in Langley et al. (2012), Nadarajah et al. (2012), and Montenbruck et al. (2012).

4 Standardization

In support of MGEX, the Multi–GNSS WG interacts closely with other IGS working groups to coordinate data formats, processing standards and applicable models for use in multi–GNSS work. Examples include necessary RINEX 3 and RTCM3 extensions for a full support of new GNSS signals and tracking modes as well as the rapidly growing set of diverse broadcast navigation data. Another focus of current work addresses the proper modeling of antenna offsets and phase patterns for receiver and satellite antennas, along with a documentation of constellation–specific coordinate systems and attitude modes. This work is performed in close coordination with the IGS Antenna Working Group.

5 Public Outreach

As a central point for exchange of MGEX–related information with the user community, a dedicated website has been established at `http://igs.org/mgex`. The new web site provides an overview of available MGEX data and products with direct links to the respective archives at IGS data and product centers. Furthermore, users are provided with up–to–date information on the status of emerging navigation satellite systems as well as recommended parameters (e.g. antenna offsets) for a harmonized and consistent processing of MGEX observations.

Through individual members, the Multi–GNSS Working Group is furthermore represented in other boards and bodies such as the International Committee on GNSS (ICG), the IAG and the Multi–GNSS Asia (MGA) project.

Dedicated presentations of the MGEX project have been initiated for the EGU General Assembly (April 2013), ION Pacific PNT meeting (April 2013) and the 4th China Satellite Navigation Conference (May 2013).

Acronyms and Abbreviations

AIUB	Astronomisches Institut der Unversität Bern
BKG	Bundesamt für Kartographie und Geodäsie
CLS	Collecte Localisation Satellites
CNES	Centre National d'Etudes Spatiales
CODE	Center for Orbit Determination in Europe
CONGO	Cooperative Network for GNSS Observation
DLR	Deutsches Zentrum für Luft– und Raumfahrt
GA	Geoscience Australia
GEO	Geostationary Orbit
GFZ	Deutsches GeoForschungsZentrum
GSI	Geospatial Information Authority of Japan
IGN	Institut National de l'Information Géographique et Forestière
IGSO	Inclined Geosynchronous Orbit
ION	Institute of Navigation
JAXA	Japan Aerospace Exploration Agency
LMV	Swedish National Land Survey (Lantmaeteriverket)
PNT	Position, Navigation and Timing
REGINA	REseau GNSS pour l'IGS et la Navigation
MGM–net	Multi–GNSS Monitoring Network
RTCM	Radio Technical Commission for Maritime Services
WG	Working Group

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IGS Reference Frame Working Group Coordinator Report 2012

P. Rebischung[1], *B. Garayt*[2], *X. Collilieux*[1], *Z. Altamimi*[1]

[1] IGN LAREG, Univ Paris Diderot, Sorbonne Paris Cité
5 rue Thomas Mann, 75205 Paris Cedex 13, France
E–mail: `paul.rebischung@ign.fr`
[2] IGN SGN

1 Introduction

The Reference Frame Working Group activities were marked by two main events in 2012. Firstly, on GPS week 1702 (August 19, 2012), the longstanding weekly IGS SINEX combinations were stopped in favor of henceforth daily SINEX combinations. Secondly, an update to the IGS08 Reference Frame, called IGb08, was prepared and adopted on GPS week 1709 (October 7, 2012). The present report reviews these two changes and their consequences on the IGS terrestrial frame products.

2 From weekly to daily terrestrial frames

From 1999 to August 18, 2012, the generation of the IGS final products has been based on the methodology defined by Kouba et al. (1998). During this period, the IGS final Analysis Centers (ACs) were producing terrestrial frame SINEX solutions based on weekly data batches, which were combined by the Reference Frame Working Group Coordinator to form the IGS weekly SINEX solutions (igsyyPwwww.snx). The AC orbit products, while provided on a daily basis, were supposedly referred to the respective AC weekly terrestrial frame solutions, as were the IGS combined orbits to the IGS weekly combined SINEX solutions.

On GPS week 1702 (August 19, 2012), a major change was introduced into this scheme: the IGS final ACs now produce fully independent daily solutions and deliver in particular daily terrestrial frame SINEX solutions. The IGS SINEX combinations are thus now also made on a daily basis. In this section, we review the motives that led to introduce this change, present the new daily SINEX combination products and show results from the latest combinations.

2.1 Motivation

The switch from products based on weekly terrestrial frame integrations to products based on daily terrestrial frame integrations was mainly intended to improve the study of station position displacements and the correction of position discontinuities. Non–tidal atmospheric loading (NT–ATML) effects show for instance sub–weekly variability (`http://acc.igs.org/reprocess2.html`), which was shown to be observable in daily GPS solutions by Tregoning and Watson (2009). The switch to daily terrestrial frames should thus allow meaningful interpretation of the IGS station position time series at sub–weekly frequencies. Daily integrations will also allow a better identification of temporary data outages at GNSS stations, which may partly explain why weekly GNSS station positions do not fit mean NT–ATML modeled displacements as well as an a priori handling of the NT–ATML effect could do (Dach et al., 2011). It is finally worth noting that the increased temporal resolution of the IGS station position time series will probably benefit other applications like, for instance, the study of co– and post–seismic displacements (Lercier et al., 2012).

2.2 Daily SINEX combination products

With the switch from weekly to daily SINEX combinations, a number of changes were made to the nature and naming of the SINEX combination products. Daily combined SINEX solutions are now provided, as well as daily residual files. The combination summaries and the ERP files however continue to be provided on a weekly basis. Note that weekly combined SINEX solutions are still formed, but they now result from a stacking of the seven daily combined solutions. The IGS cumulative solution is still updated weekly by stacking all previous weekly combined solutions. A list of the "official" SINEX combination products since the switch to daily integrations is given in Tab. 1. Also note that most of the time series maintained at `ftp://igs-rf.ign.fr` and `ftp://igs-rf.ensg.eu` (in particular station position time series) are now regularly updated with a daily resolution.

2.3 Recent SINEX combination results

As they reflect the level of agreement of AC solutions with each other, the SINEX combination residuals are traditionally used as precision indicators for the combined products. Figure 1 thus shows the weekly, then daily RMS of the AC station position residuals over year 2012. The main overall feature in Fig. 1 is a general increase of the residual scatters with the switch to daily combinations. Such an increase was of course expected from the reduction of the integration interval, and the residual scatters could have in fact been amplified by a factor $\sqrt{7} \approx 2.6$ if the AC station position time series were consisting of zero–mean white noise.

Table 1: List of the SINEX combination products since the switch to daily terrestrial frame integrations (*yy*=2–digit year; *wwww*=GPS week; *d*=day of the week; *ww*=week of the year)

File	Description
igs*yy*P*wwwwd*.snx	Daily combined SINEX solution
igs*yy*P*wwwwd*.ssc	Daily combined SINEX solution without covariance matrix
igs*yy*P*wwwwd*.res	Residuals between daily AC solutions and daily combined solutions
igs*yy*P*wwwwd*_IGS.res	Residuals between daily AC solutions and IGS cumulative solution
igs*yy*P*wwwwd*_ITR.res	Residuals between daily AC solutions and IGS Reference Frame
igs*yy*P*wwww*.snx	Weekly combined SINEX solution
igs*yy*P*wwww*.ssc	Weekly combined SINEX solution without covariance matrix
igs*yy*P*wwww*.erp	EOPs extracted from the daily combined SINEX solutions
igs*yy*P*wwww*.sum	SINEX combination summary
IGS*yy*P*ww*.snx	IGS cumulative solution
IGS*yy*P*ww*.ssc	IGS cumulative solution without covariance matrix
igs00p03.erp	Accumulated series of combined EOPs

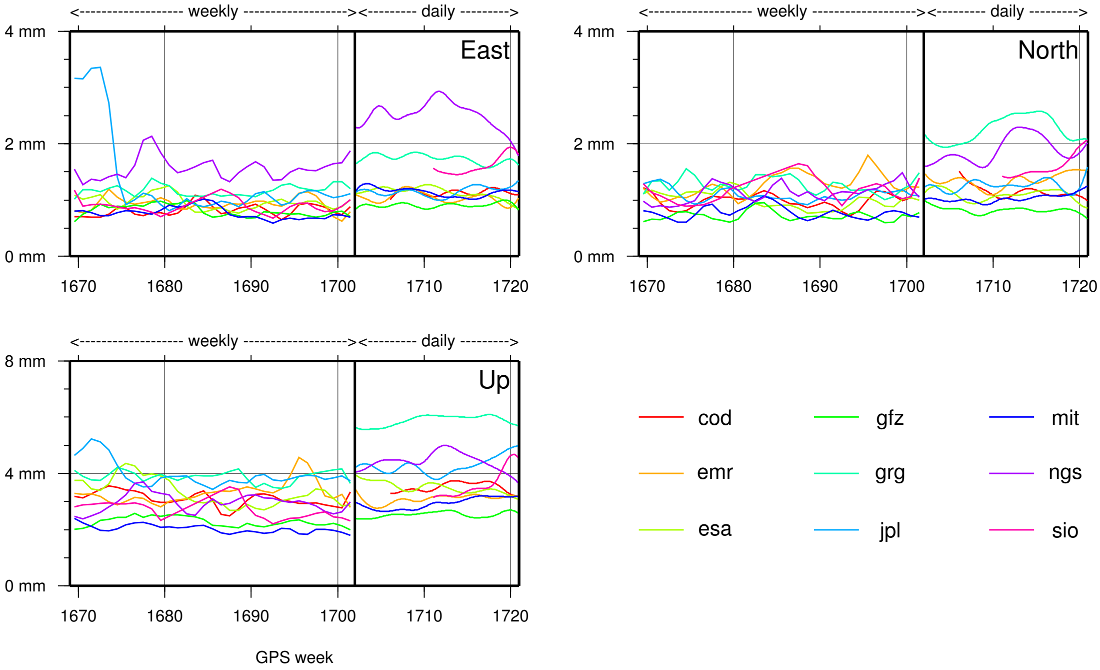

Figure 1: RMS of AC station position residuals over year 2012. The switch from weekly to daily combinations on week 1702 is indicated by the thick vertical black lines. The weekly part and the daily part of each time series were separately low–pass filtered with a 10 cpy cut–off frequency.

Table 2: RMS of AC station position residuals computed over weeks 1683–1701 and over weeks 1702–1720. Bracketed values are the respective ratios. Ratios larger than 1.5 are indicated in bold.

AC	East	North	Up
cod	0.9 mm → 1.1 mm (1.33)	1.0 mm → 1.2 mm (1.18)	3.0 mm → 3.5 mm (1.19)
emr	0.9 mm → 1.1 mm (1.13)	1.4 mm → 1.4 mm (0.96)	3.6 mm → 3.1 mm (0.87)
esa	0.9 mm → 1.2 mm (1.31)	0.9 mm → 1.1 mm (1.23)	3.0 mm → 3.5 mm (1.18)
gfz	0.8 mm → 0.9 mm (1.21)	0.7 mm → 0.8 mm (1.16)	2.2 mm → 2.5 mm (1.15)
grg	1.2 mm → 1.8 mm (**1.50**)	1.3 mm → 2.3 mm (**1.83**)	3.9 mm → 5.9 mm (**1.52**)
jpl	1.0 mm → 1.2 mm (1.14)	1.1 mm → 1.3 mm (1.18)	3.8 mm → 4.3 mm (1.13)
mit	0.8 mm → 1.1 mm (**1.51**)	0.8 mm → 1.0 mm (1.31)	2.0 mm → 2.9 mm (**1.50**)
ngs	1.6 mm → 2.6 mm (**1.66**)	1.2 mm → 1.9 mm (**1.60**)	2.9 mm → 4.5 mm (**1.53**)
sio	0.9 mm → 1.6 mm (**1.78**)	1.3 mm → 1.6 mm (1.23)	2.7 mm → 3.5 mm (1.31)

To get some insight into the impact of the switch to daily integrations on the precision of the combined frames, we quantified the factors by which the combination residual scatters have actually increased. For each AC and each East, North and Up component, a global RMS of residuals was thus computed over GPS weeks 1702–1720 (daily combinations) and compared to another RMS computed over weeks 1683–1701 (weekly combinations). Results are compiled in Tab. 2. The individual residual scatter increase factors are quite disparate, but mostly under 1.5 and all far below $\sqrt{7} \approx 2.6$. This means that the gain in temporal resolution is offset by relatively small additional noise on the IGS combined station positions. But this also points to the presence of biases and/or time–correlated errors in the AC station position residual time series.

Figures 2 and 3 show the AC EOP residuals over year 2012. The behaviors of the AC pole coordinate residual time series do not present remarkable changes with the switch from weekly to daily SINEX combinations. The precision of the IGS combined pole coordinates thus seems marginally affected by the switch. The overall picture is similar for the AC pole rate residuals. The LOD residuals of most ACs however show an increased high–frequency scatter after the switch to daily combinations and some also seem to show more pronounced periodic signals. But longer series will be needed to analyze these changes in detail.

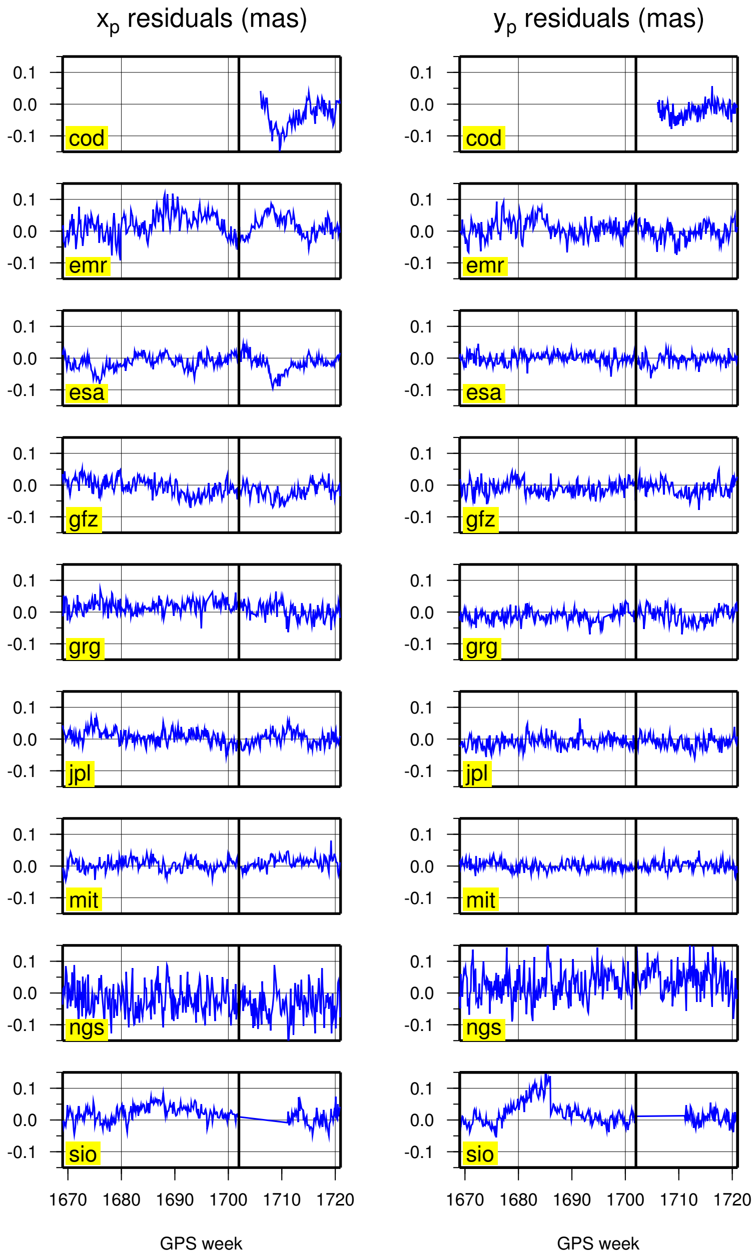

Figure 2: AC pole coordinate residuals over year 2012. The switch from weekly to daily combinations on week 1702 is indicated by the thick vertical black lines.

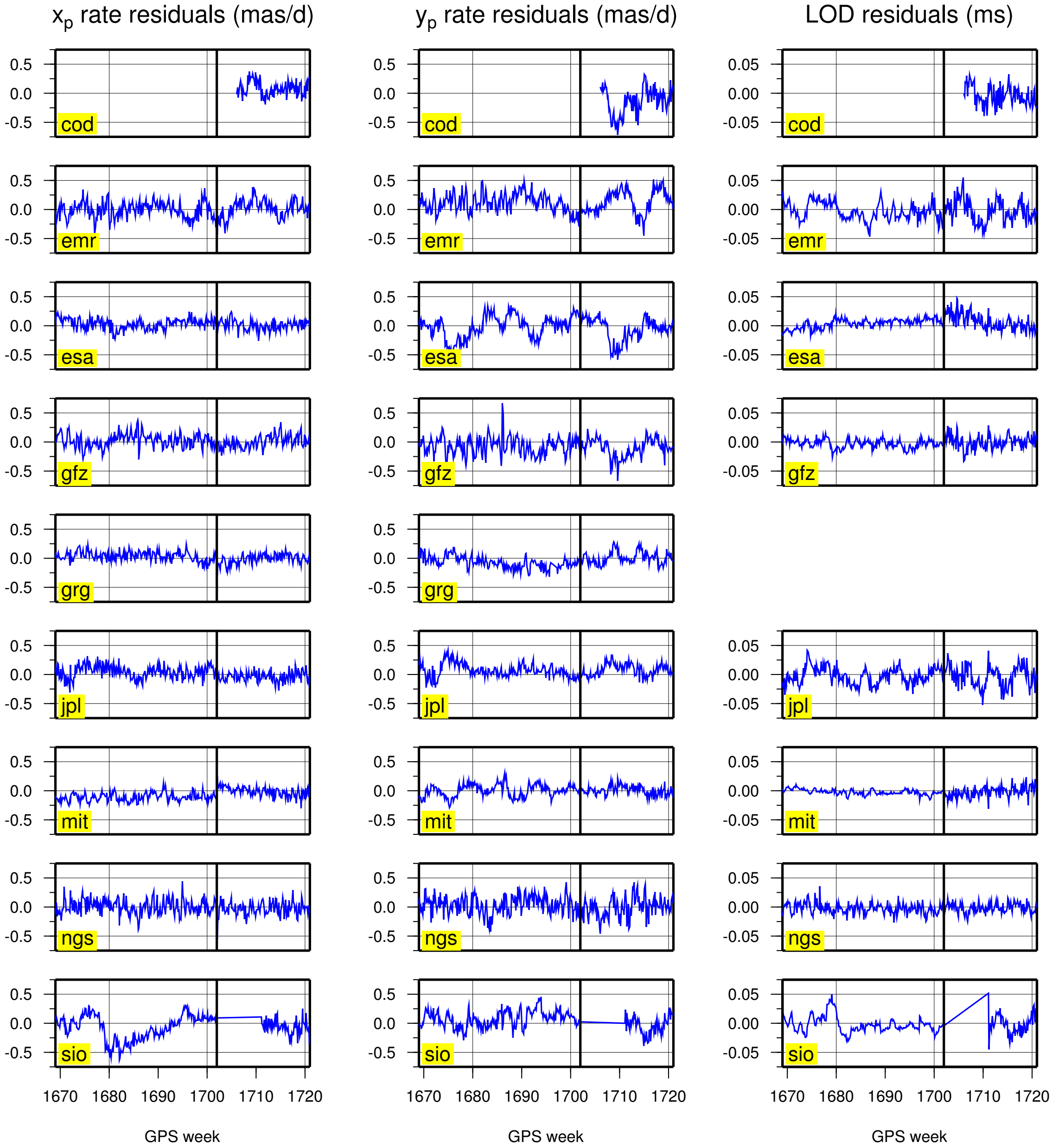

Figure 3: AC pole rate and LOD residuals over year 2012. The switch from weekly to daily combinations on week 1702 is indicated by the thick vertical black lines.

3 IGb08: an update to IGS08

Since the adoption of IGS08 on GPS week 1632 (April 17, 2011; Rebischung at al., 2012), many of the designated reference frame stations have been affected by position discontinuities which made them become unusable as reference frame stations. The IGS08 core network (a well–distributed sub–network of IGS08 stations used in particular for the alignment of the IGS combined SINEX solutions) has thus progressively become sparser. A critical situation was reached in late summer 2012, with only about 50 IGS08 core stations remaining usable out of 91. This situation led the Reference Frame Working Group to prepare an update of IGS08, called IGb08. IGb08 mainly includes new sets of coordinates for 33 IGS08 stations having been affected by position discontinuities since 2009.5, and 3 new stations co–located with decommissioned IGS08 stations. The various changes from IGS08 to IGb08 are described in detail in IGSMAIL #6663.

IGb08 was adopted starting with GPS week 1709 (October 7, 2012). Since then, the number of core stations used to align the IGS daily combined solutions has ranged between 64 and 70. As an illustration, the core networks used to align the IGS combined solutions of October 6 and 7 are compared in Figure 4. One can notice a clear improvement of the core network geometry in Asia, Africa and Oceania. A large area in and around South America however remains uncovered. Hopefully, no other update of IGS08 will be needed before the adoption of a new IGS reference frame based on the next release of ITRF expected in 2014.

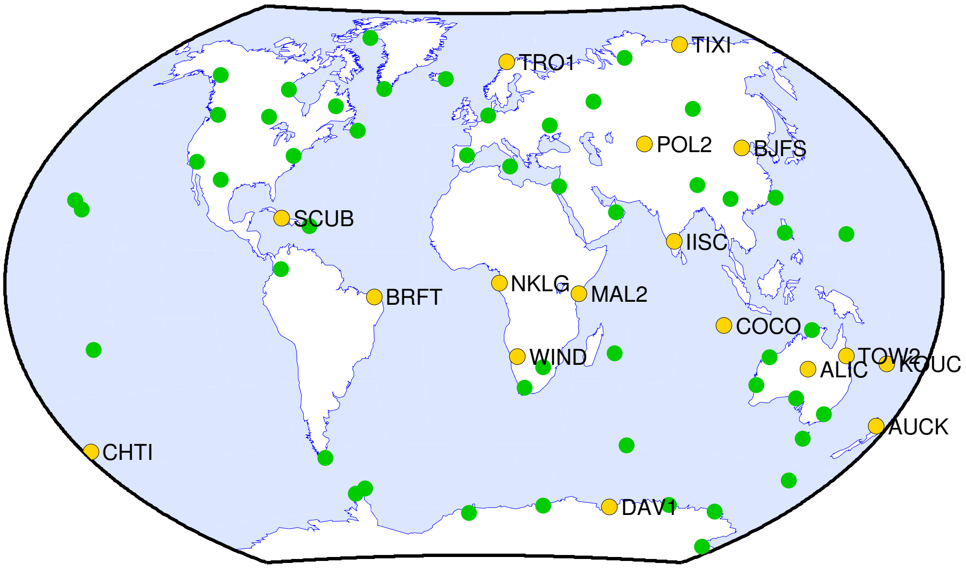

Figure 4: Core networks used to align the IGS combined solutions of October 6 and 7. Green dots are the 50 IGS08 core stations used to align the combined solution of October 6. Yellow dots are the additional 17 IGb08 core stations used to align the combined solution of October 7.

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Tregoning, P. and C. Watson. Atmospheric effects and spurious signals in GPS analyses. Journal of Geophysical Research, 114:B009403, 2009. doi: 10.1029/2009JB006344.

Real–Time Working Group and Real–Time Pilot Project

M. Caissy[1] *and L. Agrotis*[2]

[1] Natural Resources Canada, Geodetic Survey Division
615 Booth Street, Ottawa, Canada K1A 0E9
`Mark.Caissy@nrcan.gc.ca`
[2] European Space Operations Centre

1 Introduction

This Technical Report covers the period beginning January 1, 2012 and ending December 31, 2012. The main focus of the working group and within the pilot project was the completion of steps necessary for the pilot project to transition into an official IGS Real–Time Service (RTS). Considerable progress has been made to date towards achieving the end goal of launching the Service,. This report will focus on the main activities of 2012. The report also illustrates the quality of the Pilot Project products during 2012 — GPS weeks 1669–1721. The report wraps up with a look at plans for 2013.

2 Main Activities of 2012

Much of the work centered on three key activities:

a) Obtaining commitments from Real-Time Pilot Project participants to continue supporting a future RTS and an indication of what level of support could be expected. A form letter and questionnaire was sent to all participating agencies.

b) Writing an article in a prominent GNSS magazine as part of a communication strategy. An article entitled “The International GNSS Real-Time Service” appeared in GPS World’s June Innovation column. (see Further Reading) This article provided both a historical perspective of the IGS real-time initiative and described in some detail the architecture of the RTS, as well as what users can expect.

c) Developing a plan of action with tasks to be completed before a service could be launched. This was the key real-time activity at the IGS Workshop. The plan included both a list of critical path tasks essential to complete before launch of RTS and an ASAP list of tasks considered important but not critical for launch. The critical path consisted of four items:

  i) The development of an RTS website. The Central Bureau was chosen to host the site and the minimum content was identified to be the following:

    - Description of products (along with intended use)
    - Where and how to access products (registration)
    - Suggested tools (BNC tutorial)
    - How to use products (RTCM documents)
    - Product monitoring (availability and quality)

  ii) Provide real-time analysis centres with access to a redundant broadcast ephemeris stream.

  iii) 5-second clocks from all ACs

  iv) A Central Bureau NTRIP Caster with a minimum requirement of having:

    - A registration procedure
    - Sufficient testing in order to assess the quality of service

Items on the ASAP list included:

  e) Additional confirmation of support for RTS.

  f) Further development and execution of a communication strategy aimed in part at manufacturers who will integrate RTCM State Space Representation (SSR) support into their firmware.

  g) Identify a core set of stations used by RTAC's in the generation of real-time clocks so that their stability can be monitored on a daily basis. This has been identified as an issue that if left unchecked, could lead to problems in the future.

3 The Products

Figures 1 and 2 illustrate the accuracy of the RTS orbit and IGS01 clock products respectively. Figures 3 and 4 illustrate representative positioning results using either IGS01 or IGS02 RTS correction products.

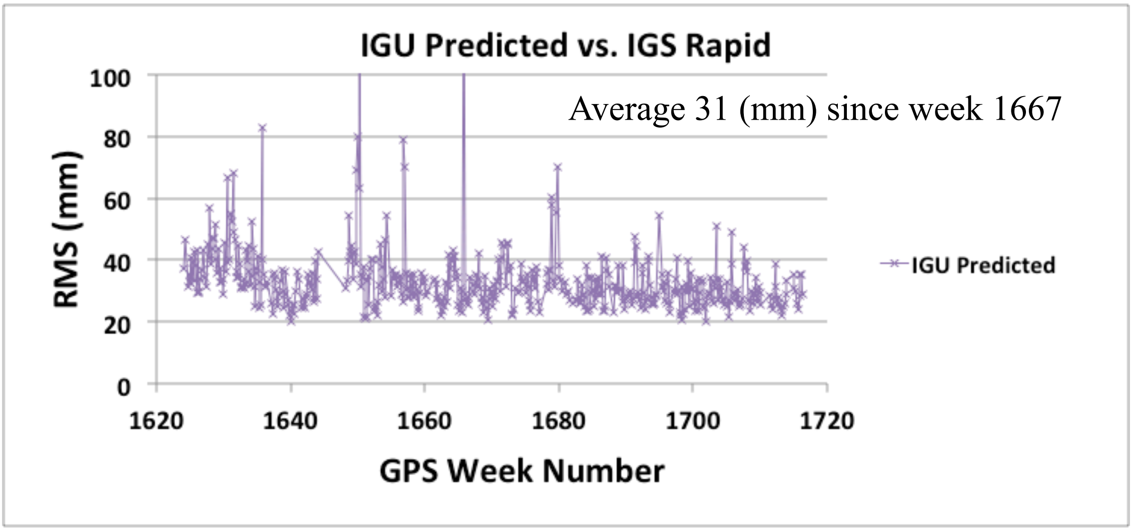

Figure 1: RTS Orbit Comparied to IGS Rapid.

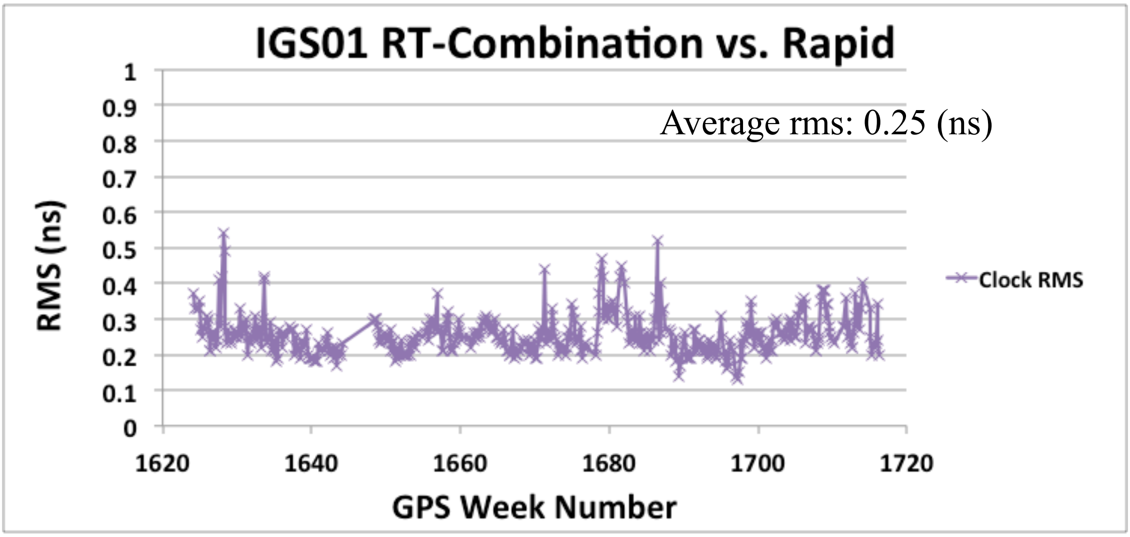

Figure 2: IGS01 Clock compared to IGS Rapid.

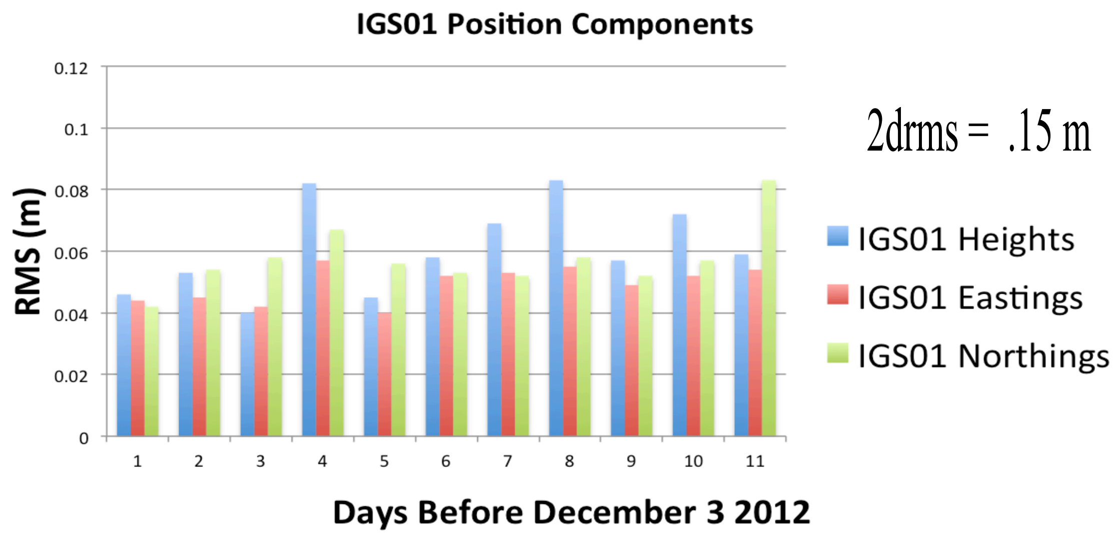

Figure 3: Positioning results using IGS01 clock product.

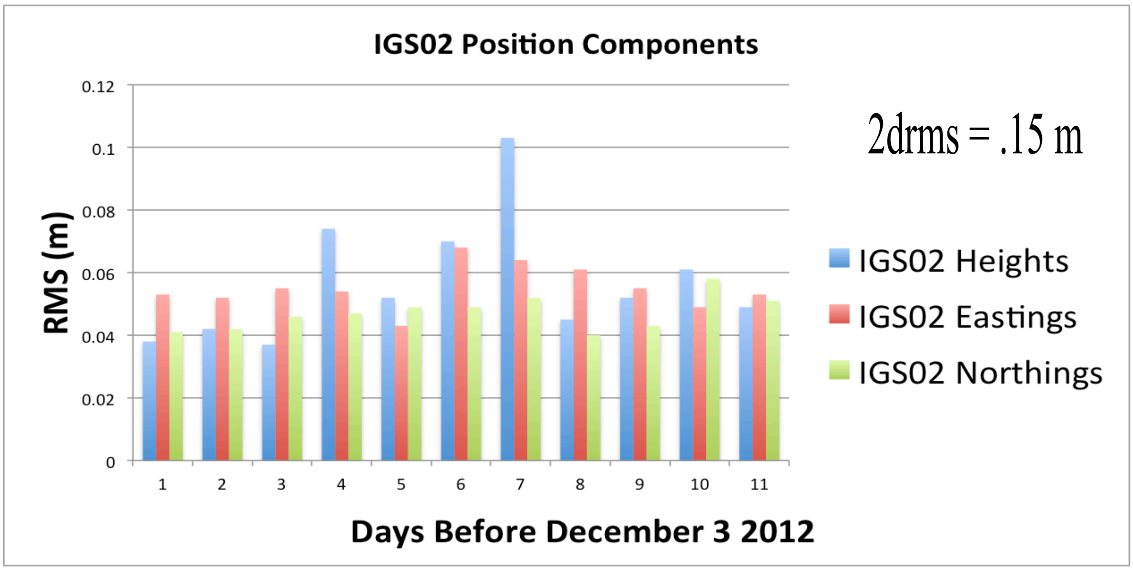

Figure 4: Positioning results using IGS02 clock product.

4 Plans for 2013

The goal is to reach full operating capability by the end of the year. Key to reaching this goal will be the introduction of GLONASS clock and orbit corrections as an official product. The focus will be on monitoring, improving and expanding the service including the introduction of additional product distribution centres as needed.

Further Reading

Caissy, M., L. Agrotis, G. Weber, M. Hernandez–Pajares, and U. Hugentobler. The International GNSS Real–Time Service. *GPS World*, pp. 52–58, 1 June 2012.

Caissy, M. and L. Agrotis. Real–Time Working Group and Real–Time Pilot Project. In M. Meindl, R. Dach, and Y. Jean, editors, *IGS 2011 Technical Reports*, IGS Central Bureau, 2012.

RINEX Working Group 2012 Report

K. MacLeod[1], *L. Agrotis*[2], *and R. Dach*[3]

[1] Natural Resources Canada
E–mail: ken.macleod@nrcan.gc.ca
[2] European Space Operations Centre
E–mail: loukis.agrotis@esa.int
[3] Astronomical Institute, university of Bern
E–mail: rolf.dach@aiub.unibe.ch

The RINEX Working Group (RWG) was formed as a partnership between the IGS and the Radio Technical Commission for Maritime Services, Special Committee 104 (RTCM–SC 104). Currently the working group consists of about 50 members with the numbers equally split between the two groups. Within the IGS the RWG performs two roles: one is the development and documentation of the RINEX data format and the other is to represent the IGS at the RTCM–SC 104 working group.

During 2012 the RINEX 3.02 draft format was updated to support the Quasi Zenith Satellite System (QZSS) and BeiDou (thanks to valuable contributions from both JAXA and the BeiDou office). During the past year the working group received requests from RINEX users for a more general and modern file naming convention. The working group discussed and developed a draft generic file naming convention and it was presented at both the IGS Workshop (July 2012) and at RTCM meetings and received general support. The December release of the RINEX 3.02 draft was updated with the new file naming convention.

Over the past couple of years the RTCM–SC 104 has been developing a binary data format called RTCM–Multiple Signal Format (RTCM–MSM). RTCM–MSM was designed as a binary equivalent to the RINEX 3.01 and 3.0x formats. The design was made as generic as possible so that it could be easily extended to support new signals and constellations. All RTCM–MSM phase observations are phase aligned as they are in RINEX 3.01 and 3.0x. The current documentation supports the GPS, GLONASS and Galileo constellations. All RTCM-MSM observations types (code, phase, Doppler, Signal to Noise Ratio (SNR) and loss of lock) provide measurement resolution suitable for geodetic applications and meet RINEX 3.0x file standards. After many years of work, in February of 2013, the RTCM voted on and passed the RTCM–MSM format and associated documentation.

Summary of the RINEX working group's tasks completed in 2012:

1. RINEX 3.02 Draft released that supports : GPS, GLONASS, GALILEO, QZSS, BeiDou and SBAS
2. RINEX 3.02 Draft released, that describes a new generic file naming convention
3. Contributed to the development of the RTCM–MSM format
4. IGS and RTCM–SC 104 presentations

During the 2013 calendar year the RINEX Working Group will focus its efforts on the following tasks:

1. Finalizing the RINEX 3.02 documentation
    - Submit the RINEX 3.02 documentation to the IGS and RTCM for approval and adoption
    - After the RINEX 3.02 documentation has been approved the RWG will work to gain the support of the RINEX user community
    - Continue to update and improve the RINEX 3.02 documentation.
    - Support and encourage the development of RINEX 3.02 software tools
2. Start the process of defining new RINEX GNSS ephemeris messages to support CNAV etc.
3. Within the RTCM–SC 104 the RWG will contribute to the development of the following binary messages that would enable the creation of a complete RINEX file from either a GNSS receiver stream or an RTCM–MSM file:
    - Station description (RINEX Header)
    - Receiver description and state information such as: serial, model and firmware number and also state information such as temperature, CPU load, number of satellite vehicles tracked and station change control mechanism called: Issue of Data Station (IODS).
    - Antenna Description: serial and model number and IODS.
    - Meteorological Sensor Description and IODS.
    - Meteorological observations and IODS.
    - The IODS is designed to notify both real-time and file based users that a station's equipment or software/firmware has changed and that the change may affect the usability of the observation data.
4. Extension of the RTCM–MSM format to support QZSS and BeiDou.
5. Extension of RTCM–State Space Representation (RTCM–SSR) (GNSS correction orbit and clock corrections) messages to support Galileo, QZSS and BeiDou.

6. Additional RTCM–SSR messages to support atmospheric and ionospheric correction messages: both station and grid types.
7. Development of ephemeris messages to support Galileo, QZSS and BeiDou. Updates to GPS ephemeris to support CNAV.
8. Development of a position report messages that contains accuracy (variance covariance) information.

The Tide Gauge Benchmark Monitoring Project

T. Schöne, R. Bingley, Z. Deng, J. Griffiths, H. Habrich,
A. Hunegnaw, ,M. Jia, M. King, M. Merrifield, G. Mitchum,
R. Neilan, C. Noll, E. Prouteau, L. Sánchez, N. Teferle,
D. Thaller, P. Tregoning, P. Woodworth, G. Wöppelmann

The *Tide Gauge Benchmark Monitoring Project* (TIGA) is concerned with the estimation of vertical geocentric positions, vertical motion and displacements of GNSS stations at or near tide gauges. Geocentric coordinates of tide gauge sensors are necessary for a variety of applications, ranging from sea level change studies, radar altimetry calibrations, sea level hazard monitoring, or the establishment of a World Height System (WHS). More specifics can be found in (Merrifield et al., 2012). Typical Tide Gauge stations are shown at page 190.

The aims of the TIGA Working Group are:

1. Maintain a global virtual continuous GNSS@TG network
    - Select a set of tide gauges equipped with GNSS, with a long and reliable history, useful for both sea level change studies, and e.g. satellite altimeter calibrations. IGS network operation standards should be applied.
    - Promote the establishment of more continuous operating GNSS stations, in particular in the southern hemisphere.
    - Promote the establishment of local ties (leveling) between GNSS and TGBMs.
    - Provide meta information, e.g. on leveling between benchmarks or data access.
    - Provide training to tide gauge operators through workshops, encourage station operators to provide necessary metadata. Through Global Sea Level Observing System (GLOSS) advice station operators about the operation of continuous GNSS@TG stations.
2. Compute precise coordinates and velocities of GNSS stations at or near tide gauges with a significant delay to allow as many as possible stations to participate. Provide a combined solution as the TIGA official product.
3. Study the impacts of corrections and new models on the GNSS processing of the vertical. Encourage other groups to establish, e.g. nearby absolute gravity sites.
4. Provide advice to new applications.

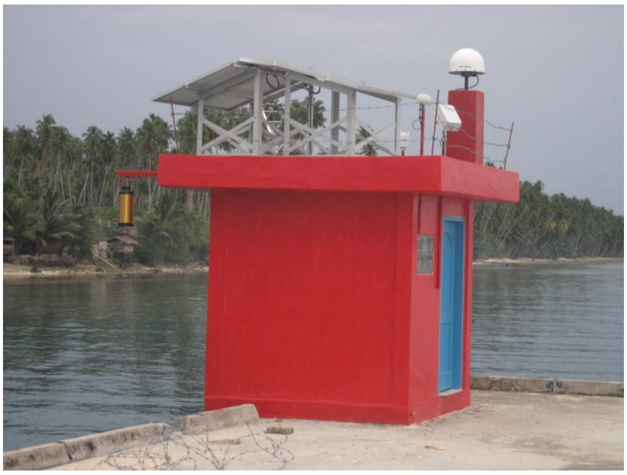

Figure 1: GNSS-controlled Tide Gauge (Tanahbala, Indonesia)

In this example, the GNSS antenna is mounted on the same construction as the tide gauge. The leveled difference between the GNSS antenna reference and the tide gauge benchmark is stable over time. The station coordinates are difficult to use in e.g., reference frame definitions, since the pier may subside and the environment might cause some multipath.

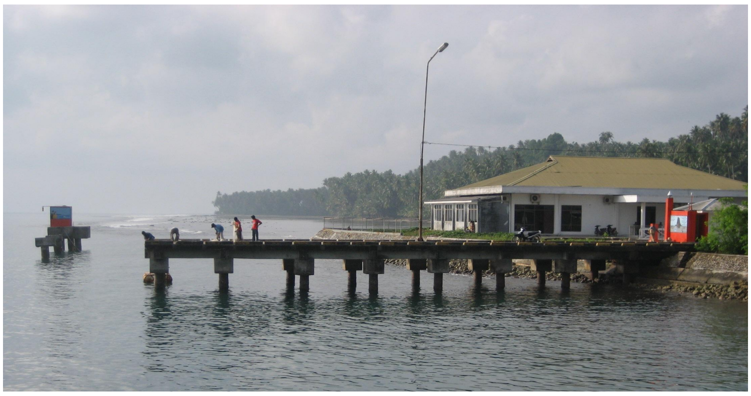

Figure 2: GNSS–controlled Tide Gauge (Telukdalam, Indonesia)

Here, the GNSS station (red building to the right) is placed on stable ground at a land station, while the tide gauge is off-shore. The tie is established using classical spirit leveling.

GNSS and the other space geodetic techniques are only one tool for the determination of vertical rates. Establishing ties to absolute gravity sites near tide gauges is strongly promoted and results will be evaluated as part of the Working Group activities.

Over the past year, the TIGA-WG has prepared the reprocessing of the TIGA network, which will be parallel to the repro2 campaign of the IGS. The software suites used in TIGA for reprocessing (Bernese, EPOS Potsdam, GAMIT/GLOBK) have the latest standards, as agreed during meetings in Olzstyn (June 2012) and San Francisco (December 2012) implemented. Test data have been circulated between groups to ensure consistency in exchange formats.

Significant progress has been made by the SONEL data center (`http://www.sonel.org`), hosted by University of La Rochelle. SONEL acts as a one-stop-shop for GNSS and tide gauge information related to TIGA and to GNSS@TG stations. The portal allows users to access meta data information and data. Frequent updates and information exchange with TIGA Data Center hosted by NASA at CDDIS ensures up-to-date information.

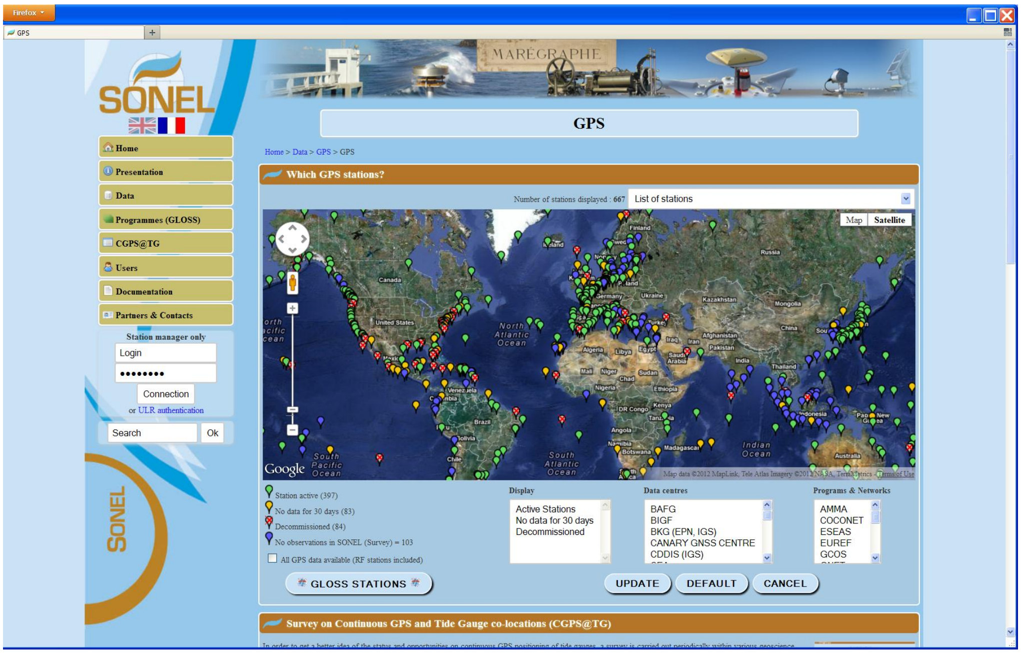
SONEL
MARÉGRAPHE
GPS
Home
Presentation
Data
Programmes (GLOSS)
CGPS@TG
Users
Documentation
Partners & Contacts
Station manager only
Login
Connection
or ULR authentication
Search
Ok
Home > Data > GPS > GPS
Which GPS stations?
Number of stations displayed : 667
List of stations
Map
Satellite
Google
Station active (397)
No data for 30 days (83)
Decommissioned (84)
No observations in SONEL (Survey) = 103
☐ All GPS data available (RF stations included)
Display
Active Stations
No data for 30 days
Decommissioned
Data centres
BAFG
BIGF
BKG (EPN, IGS)
CANARY GNSS CENTRE
CDDIS (IGS)
Programs & Networks
AMMA
COCONET
ESEAS
EUREF
GCOS
GLOSS STATIONS
UPDATE
DEFAULT
CANCEL
Survey on Continuous GPS and Tide Gauge co-locations (CGPS@TG)

Figure 3: The SONEL TIGA data center (University of La Rochelle, France) provides an excellent access point for meta information. The GNSS date base is synchronized with the TIGA Data center at CDDIS (NASA, USA).

In cooperation with SONEL, potential TIGA stations and stations with significant data gaps have been identified. Actions to involve new groups (stations) and to fill data gaps have been done. Norway provided some missing data (formerly ESEAS stations) and the German BfG (`http://www.bafg.de`) agreed to and provided a significant data set of collocated GPS stations from the (German) North Sea offshore area. Also other data providers have filled gaps in the GNSS data base.

Recent TIGA related publications

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Merrifield, M., S. Holgate, G. Mitchum, B. Pérez, L. Rickards, T. Schöne, P. Woodworth, G. Wöppelmann, and T. Aarup. Global Sea Level Observing System (GLOSS). Implementation Plan — 2012, UNESCO/IOC, 41pp. (IOC Technical Series No. 100) (English), 2012. `http://www.unesco.org/ulis/cgi-bin/ulis.pl?catno=217832&set=50929BE4_3_465` .

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Santamaría–Gómez A., M. Gravelle, X. Collilieux, M. Guichard, B. Martín, B. Míguez, P. Tiphaneau, and G. Wöppelmann. Mitigating the effects of vertical land motion in long tide gauge records using a state-of-the-art GPS velocity field. *Global and Planetary Change*, 98–99:6–17, 2012a.

Santamaría–Gómez A., M.–N. Bouin, and G. Wöppelmann. Improved GPS data analysis strategy for tide gauge benchmark monitoring. In: S. Kenyon et al. (Eds.), *Geodesy for Planet Earth*, International Association of Geodesy Symposia, Vol. 136, 2012b. doi: 10.1007/978-3-642-20338-1_2 .

Wöppelmann, G. and M. Marcos. Coastal sea level rise in southern Europe and the non-climate contribution of vertical land motion. *Journal of Geophysical Research*, Vol. 117, C01007, 2012. doi: 10.1029/2011JC007469 .

TIGA Working Group Members in 2012

Name	Entity	Host Institution	Country
Guy Wöppelmann	TAC, TNC, TDC	University of La Rochelle	France
Laura Sánchez	TAC	DGFI Munich	Germany
Heinz Habrich	TAC	BGK, Frankfurt	Germany
Minghai Jia		GeoScience Australia	Australia
Paul Tregoning	TAC	ANU	Australia
Zhiguo Deng	TAC	GFZ Potsdam	Germany
Daniela Thaller	Combination	University of Bern	Switzerland
Norman Teferle	TAC/Combination	University of Luxembourg	Luxembourg
Richard Bingley	TAC	University of Nottingham	UK
Ruth Neilan	IGS Central Bureau	ex officio	USA
Jake Griffiths	IGS AC coordinator	ex officio	USA
Carey Noll	TDC	CDDIS, NASA	USA
Tilo Schöne	Chair TIGA-WG	GFZ Potsdam	Germany
Philip Woodworth	PSMSL	PSMSL, Liverpool	UK
Gary Mitchum	GLOSS GE (new).	University of South Florida	USA
Mark Merrifield	GLOSS GE (past)	UHSLC, Hawaii	USA
Matt King		University of Tasmania	Australia

IGS Troposphere Working Group 2012

C. Hackman and S. Byram

United States Naval Observatory
3450 Massachusetts Avenue Northwest
Washington DC 20392 USA
e–mail: christine.hackman@usno.navy.mil
phone: 202 762 1428

1 Introduction

The IGS Troposphere Working Group (IGSTWG) was founded in 1998. The United States Naval Observatory (USNO) assumed chairmanship of the WG as well as responsibility for producing IGS Final Troposphere Estimates (IGSFTE) in 2011.

Dr. Christine Hackman chairs the IGSTWG. Dr. Sharyl Byram oversees production of the IGSFTEs. Both are part of the GPS Analysis Division (GPSAD) in the Earth Orientation Department at USNO. GPSAD also hosts the USNO IGS Analysis Center.

The IGSTWG comprises approximately 45 members (cf. Appendix A). A revised charter approved by the IGS Governing Board (GB) at the close of 2011 is shown in Appendix B.

2 Product Generation/Improvements/Usage 2012

USNO produces IGS Final Troposphere Estimates for the 350+ stations of the IGS network. **Users downloaded 17.3 million of these files in 2012** (Noll, 2013). Each 24–hr site result file provides five–minute–spaced estimates of total troposphere zenith path delay (ZPD), north, and east gradient components, with the gradient components used to compensate tropospheric asymmetry.

IGS Final Troposphere estimates are generated in Bernese GPS Software (developed at Astronomical Institute, University of Bern, Dach et al., 2007) using precise point positioning (PPP; Zumberge et al., 1997) and the GMF mapping function (Böhm et al., 2006) with IGS Final satellite orbits/clocks and earth orientation parameters (EOPs) as input. Each site–day's results are completed approximately three weeks after measurement collection, that being when IGS Final orbit/clock/EOP estimates become available.

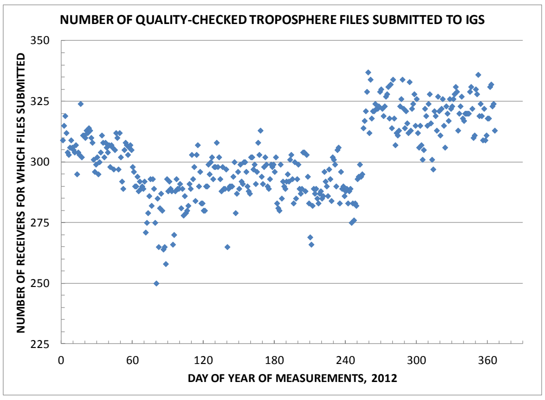

Figure 1: Number of quality–checked IGS Final Troposphere Estimate files submitted to the IGS per measurement day. The number decreased around DOY 60 due to implementation of more–stringent latency requirements, increased near DOY 110 due to an update of the station–processing list, and increased further around DOY 260 due to modernization of the RINEX data import routines.

IGS final troposphere values are viewed as a truth standard by scientists/meteorology laboratories around the world. Inquiries about the estimates were received in 2012 from, for example, the Russian Hydrometeorological University, the Royal Melbourne Institute of Technology (AUS), and the Belgian Institute for Space Aeronomy. Processing improvements were made throughout 2012, therefore, towards improving the number of sites for which estimates were available, and the quality of those estimates.

Result–screening algorithms were made more stringent toward the end of February. The list of stations for which processing is attempted was modernized in April. RINEX import routines were modernized in October. The impact of these improvements on the number of stations for which troposphere values could be successfully computed is shown in Fig. 1. 110458 station result files were submitted by USNO in 2012, or an average of 301 stations per measurement day.

The IGS Final Troposphere files can be downloaded from `ftp://cddis.gsfc.nasa.gov/gps/products/troposphere/zpd`. Dr. Byram presented a poster detailing computations and improvements at the IGS 2012 Workshop (Byram and Hackman, 2012).

3 Troposphere Working Group Activities 2012

The working group (WG) had been reorganized in 2011. The chair therefore in early 2012 designed, distributed and analyzed the results of a survey designed to elicit members' interests, concerns and ability to contribute resources, meanwhile also organizing troposphere plenary (oral), poster and working–group sessions for the July 2012 IGS Workshop.

The IGS Workshop troposphere plenary and poster sessions showcased a wide variety of the latest results in GNSS–based atmospheric estimation, featuring oral presentations on numerical weather modeling, single–frequency–receiver troposphere estimation, and troposphere estimation utilizing both GLONASS and GPS measurements, as well as 17 poster presentations.

The IGS WG meeting was attended by approximately 40 people. Activities of the past 12 months plus survey results were presented. The surveys had revealed significant member curiosity about the true accuracy of IGS Final Troposphere Estimates. A proposal was made therefore to automate comparisons of IGS Final Troposphere Estimates to those obtained from other techniques (e.g., VLBI) or analysis centers (ACs).

After discussion, the WG submitted the following recommendation to the IGS Governing Board:

"By the next IGS Workshop, establish automated, on–going comparison of IGS final troposphere estimates (FTEs) with results from other techniques/ACs with the goal of establishing the accuracy of IGS FTEs."

The board accepted the recommendation.

Work began toward this in Fall 2012 and continued through another splinter WG meeting held in conjunction with the Fall 2012 AGU Meeting (San Francisco, CA). Current project status:

1. The WG will model initial efforts (e.g., stations chosen, corrections applied for non–colocated receivers) after Teke et al. (2011), who performed inter– and intra–technique troposphere comparisons for the CONT08 VLBI campaign similar to what we wish to do.
2. The International VLBI Service (IVS; `http://ivscc.gsfc.nasa.gov`) has agreed to contribute VLBI–based troposphere estimates.
3. The International DORIS Service (IDS; `http://ids-doris.org`) has agreed to contribute DORIS–based troposphere estimates.
4. University of New Brunswick and Technical University of Vienna will contribute numerical weather model–based values.
5. Additional GNSS–based regional–network ZTD values may be available if needed (e.g., NICT Japan–Taiwan–Korea network; EUREF network).
6. Inter–technique comparisons will be generated by Dr. Jan Dousa at Geodetic Observatory Pecný (GOP) with operations to be transferred elsewhere when they exceed GOP capacity.
7. Result files/plots will be hosted at the IGS server.

The WG has set a two–pronged intermediate goal for completion by the European Geosciences Union General Assembly (April 2013). The ideal is to have prototype automated comparisons running by then for a few sites. However, achievement of this goal relies heavily on the efforts of GOP's Dr. Dousa, who is already quite busy. The backup goal is thus to automate transfer of the input ZTD values (IGS, IVS, numerical weather models, etc.) to a central server from which GOP could download them for processing.

4 Publications

Byram, S. and C. Hackman. Computation of the IGS Final Troposphere Product by the USNO. *IGS Workshop 2012*, 23–27 July 2012, Olsztyn, Poland, 2012.

Hackman, C. and S. Byram. IGS Troposphere Working Group 2011. In M. Meindl, R. Dach, and Y. Jean, editors, *IGS 2011 Technical Reports*, IGS Central Bureau, pages 211–218, 2012.

5 Working Group Presentations

Hackman, C. IGS 2012 TWG Splinter Meeting. *IGS Workshop 2012*, 23–27 July 2012, Olsztyn, Poland, 2012.

Hackman, C. IGS 2012 TWG Splinter Meeting. *2012 Fall Meeting, AGU*, San Francisco, CA, USA, 03–07 December, 2012.

The presentations can be obtained by contacting the author.

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Böhm, J., A. Niell, P. Tregoning, and H. Schuh. Global Mapping Function (GMF): A New Empirical Mapping Function Based on Numerical Weather Model Data. *Geophys. Res. Lett.*, 33(7), L07304, 2006. doi: 10.1029/2005GL025546 .

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Teke, K., J. Böhm, T. Nilsson, H. Schuh, P. Steigenberger, R. Dach, R. Heinkelmann, P. Willis, R. Haas, S. García–Espada, T. Hobiger, R. Ichikawa, and S. Shimizu. Multi–Technique Comparison of Troposphere Zenith Delays and Gradients During CONT08. *J Geod* 85:395–413, 2011. doi: 10.1007/s00190-010-0434-y .

Zumberge, J. F., M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb. Precise Point Positioning for the Efficient and Robust Analysis of GPS Data from Large Networks. *J. Geophys. Res.*, 102(B3):5005–17, 1997.

Appendix A — IGS Troposphere Working Group Members

Name	**Institution**	**Country**	**email**
Ahmed, Furqan	Univ. du Luxembourg	Luxembourg	furqan.ahmed@uni.lu
Amirkhani, Mohammad	Islamic Azad Univ. Tehran	Iran	m.amirkhani2008@gmail.com
Bar–Sever, Yoaz	JPL	USA	yoaz.bar-sever@jpl.nasa.gov
Bevis, Mike	OSU	USA	mbevis@osu.edu
Bosser, Pierre	ENSG/DPTS	France	pierre.bosser@ensg.eu
Braun, John	UCAR	USA	braunj@ucar.edu
Byram, Sharyl	USNO	USA	sharyl.byram@usno.navy.mil
Byun, Sung	JPL	USA	sung.h.byun@jpl.nasa.gov
Calori, Andrea	Univ. Roma “La Sapienza”	Italy	calori@mendoza-conicet.gob.ar
Chen, Junping	Shanghai Astronomical Observatory	China	junping.chen@shao.ac.cn
Colosimo, Gabriele	Univ. Roma “La Sapienza”	Italy	gabriele.colosimo@uniroma1.it
Crespi, Mattia	Univ. Roma “La Sapienza”	Italy	mattia.crespi@uniroma1.it
Dick, Galina	GFZ	Germany	dick@gfz-potsdam.de
Dousa, Jan	GOP	Czech	jan.dousa@pecny.cz
Drummond, Paul	Trimble	New Zealand	paul_drummond@trimble.com
Ghoddousi–Fard, Reza	Natural Resources Canada	Canada	rghoddou@nrcan.gc.ca
Guerova, Guergana	Univ. Sofia	Bulgaria	guerova@phys.uni-sofia.bg
Gutman, Seth	NOAA	USA	seth.i.gutman@noaa.gov
Hackman, Christine	USNO	USA	christine.hackman@usno.navy.mil
Heinkelmann, Robert	GFZ	Germany	heinkelmann@gfz-potsdam.de
Herring, Tom	MIT	USA	tah@mit.edu
Hilla, Steve	NGS/NOAA	USA	steve.hilla@noaa.gov
Hobiger, Thomas	Natl. Inst. of Info. & Comm. Tech. (NICT)	Japan	hobiger@nict.go.jp
Langley, Richard	Univ. New Brunswick	Canada	lang@unb.ca
Leighton, Jon	3vGeomatics	Canada/UK	jonny2vests@gmail.com
Liu, George	Hong Kong Polytech. Univ.	Hong Kong	lszzliu@polyu.edu.hk
Moeller, Gregor	TU Wien	Austria	gregor.moeller@tuwien.ac.at
Moore, Angelyn	JPL	USA	angelyn.w.moore@jpl.nasa.gov
Negusini, Monia	Inst. Radioastronomy (IRA); National Inst. Astrophysics (INAF)	Italy	negusini@ira.inaf.it
Nordman, Maaria	Finnish Geodetic Inst.	Finland	maaria.nordman@fgi.fi
Pacione, Rosa	ASI/CGS	Italy	rosa.pacione@e-geos.it
Penna, Nigel	Univ. Newcastle	UK	nigel.penna@newcastle.ac.uk
Perosanz, Felix	CNES	France	felix.perosanz@cnes.fr
Pottiaux, Eric	Royal Observ. of Belgium	Belgium	eric.pottiaux@observatoire.be
Prikryl, Paul	Communications Research Centre, Canada	Canada	paul.prikryl@crc.gc.ca
Rocken, Chris	GPS Solutions	USA	rocken@gps-solutions.com
Santos, Marcelo	Univ. New Brunswick	Canada	msantos@unb.ca
Schaer, Stefan	swisstopo	Switzerland	stefan.schaer@aiub.unibe.ch
Schön, Steffen	Inst. Erdmessung, Leibniz Uni Hannover	Germany	schoen@mbox.ife.uni-hannover.de
Sguerso, Domenico	Lab. Geodesy, Geomatics, GIS; Univ. Genoa	Italy	domenico.sguerso@unige.it
Soudarin, Laurent	Collecte Localisation Satellites	France	lsoudarin@cls.fr
Teferle, Norman	Univ. du Luxembourg	Luxembourg	norman.teferle@uni.lu
Tracey, Jeffrey	USNO	USA	jeffrey.tracey@usno.navy.mil
van der Marel, Hans	TU Delft	Netherlands	H.vanderMarel@tudelft.nl
Wang, Junhong	UCAR/NCAR	USA	junhong@ucar.edu
Willis, Pascal	Inst. Physique du Globe Paris	France	willis@ipgp.fr
Xu, Zong–qiu	Liaoning Tech. Univ.	China	zongqiuxu@gmail.com
Zhang, Shoujian	Wuhan Univ.	China	shjzhangwhu@gmail.com

Appendix B — IGS Troposphere Working Group Charter

IGS TROPOSPHERE WORKING GROUP CHARTER

GNSS can make important contributions to meteorology, climatology and other environmental disciplines through its ability to estimate troposphere parameters. Along with the continued contributions made by the collection and analysis of ground–based receiver measurements, the past decade has also seen new contributions made by space–based GNSS receivers, e.g., those on the COSMIC/FORMOSAT mission [1]. The IGS therefore continues to sanction the existence of a Troposphere Working Group (TWG).

The primary goals of the IGS TWG are to:

- Assess/improve the accuracy/precision of IGS GNSS–based troposphere estimates.
- Improve the usability of IGS troposphere estimates.
  - Confer with outside agencies interested in the use of IGS products.
  - Assess which new estimates should be added as “official” IGS products, and which, if any, official troposphere product sets should be discontinued.
- Provide and maintain expertise in troposphere–estimate techniques, issues and applications.

Science background

The primary troposphere products generated from ground–based GNSS data are estimates of total zenith path delay and north/east troposphere gradient. Ancillary measurements of surface pressure and temperature allow the extraction of precipitable water vapor from the total zenith path delay.

Water vapor, a key element in the hydrological cycle, is an important atmosphere greenhouse gas. Monitoring long–term changes in its content and distribution is essential for studying climate change. The inhomogeneous and highly variable distribution of the atmospheric water vapor also makes it a key input to weather forecasting.

Water vapor distribution is incompletely observed by conventional systems such as radiosondes and remote sensing. However, ground– and space–based GNSS techniques provide complementary coverage of this quantity. Ground–based GNSS observations produce continuous estimates of vertically integrated water vapor content with high temporal resolution over a global distribution of land–based locations; coverage is limited over the oceans (where there is no land). Conversely, water vapor can be estimated from space–borne GNSS receivers using ray tracing techniques, in which case solutions with high vertical resolution (laterally integrated over few hundred kilometers) and good oceanic/land coverage are obtained; these solutions however are discontinuous in geographic location and time.

Be it resolved that the IGS troposphere WG will:

- Support those IGS analysis centers providing official IGS troposphere products.
- Increase awareness/usage of IGS troposphere products by members of the atmospheric, meteorology and climate–change communities. Solicit the input and involvement of such agencies.
- Create new IGS troposphere products as needed (as determined by consultation with the potential user community).
- Determine the uncertainty of IGS troposphere estimates through comparison of solutions with those obtained from independent techniques, or through other means as appropriate.
- Promote synergy between space–based and ground–based GNSS techniques through interaction with researchers in both fields.

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[1] Schreiner, W., C. Rocken, S. Sokolovskiy, S. Syndergaard and D. Hunt, Estimates of the precision of GPS radio occultations from the COSMIC/FORMOSAT–3 mission, *GRL*, 34, L04808, doi:10.1029/2006GL027557, 2007.

[2] Teke, K., J. Böhm, T. Nilsson, H. Schuh, P. Steigenberger, R. Dach, R. Heinkelmann, P. Willis, R. Haas, S. García–Espada, T. Hobiger, R. Ichikawa and S. Shimizu, Multi–technique comparison of troposphere zenith delays and gradients during CONT08, *J Geod*, 85:395–413, doi: 10.1007/s00190–010–0434–y, 2011.

EDITOR

AIUB Astronomical Institute
University of Bern

FOR MORE INFORMATION

IGS Central Bureau
Jet Propulsion Laboratory
M/S 238-540
48 Oak Grove Rd.
PASADENA, CA 91109 USA

www.igs.org
cb@igs.org

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