IGS Analysis Center Workshop 2008 Recommendations

Session: Pending & proposed model changes

IGS Core Products

- For more robust products IGS needs to:
  - recruit new or improved IGU ACs & more IGR clock ACs
  - investigate improved near-RT & predicted ERPs, esp UT1 variations

- IGS should prepare for future combination requirements by inviting proposals to build new ACC 2.0 system for use in 2012

- If GGOS UAW recommendations are adopted, IGS should:
  - not change existing SINEX parameter names
  - enforce backwards format compatibility
  - not use over-constrained parameterizations
  - continue to enforce principle of software independence

- IGS urges the IERS to set up inter-service SINEX & combinations WG to:
  - investigate technique-specific systematic errors
  - develop new methods & approaches (e.g., D. Lavallee presentation)
  - maintain SINEX format

AC Modeling Documentation

- AC must regularly update their analysis summaries:
  - EMR 23 Jan 2002
  - GFZ 27 Feb 2003
  - JPL 13 Apr 2004
  - SIO 31 Oct 2005
  - (USNO 12 Sep 2006)

- Suggest suspending ACs with no updates by 30 Sep 2008
  - if processing summary is older than 2 years
  - submissions would be rejected from IGS products after Sep 2008

- Rescind AC status if no updates by 31 Dec 2008
  - would need to formally rejoin IGS ACs after Dec 2008

- *Future IGS progress requires firm understanding of AC modeling*

Troposphere Modeling

- Use at least GPT for *a priori* pressure
  - to derive *a priori* hydrostatic zenith delay
  - but preferably use local pressure measurements
  - or use interpolated values from 6-hr NWM fields

- Mapping functions
  - use at least GMF dry & GMF wet
  - but preferably use VMF1
  - or use any others based on data from NWMs

- Investigate using direct line-of-sight raytracings
  - need high-resolution NWMs

- Note correlations between tropo modeling & pressure loads
  - VMF1 & NWMs must be used to study load signals in coordinate time series

Higher-order Ionospheric Terms

- Higher-order ionospheric correction terms (I2+) should be incorporated as a standard IGS AC model

- The I2+ correction should be applied consistently
  - with GNSS products (e.g., satellite orbits & clocks) computed after applying I2+ corrections to GNSS measurements

- The I2+ correction should be computed in a simple & accurate way
  - the magnetic field should be computed from a more realistic model (such as the IGRM) than a dipolar one
  - the slant ionospheric delay (STEC) can be computed from VTEC maps (such as those computed by IGS in IONEX format)
  - it can be preferable – esp. for low elevations, low latitude sites, or when no external GIM or TEC source is available (e.g., real-time) – to compute STEC from the carrier-smoothed geometry-free combination of pseudoranges Pi(P4), corrected by the corresponding inter-frequency biases

Refined Orbit Modeling

- *a priori* Earth radiation pressure modeling should be adopted as a standard approach

- Satellite antenna thrust should be applied in the dynamical modeling

- Refinements in Earth radiation pressure models should be explored

Session: Pending & proposed product changes

Clock Products WG:

• Utilize the new (version 2.0) IGS timescale algorithm in the reprocessed combination clock products – provided enough clock ACs contribute.

• The IGS should consider a new UT1/LOD product (e.g., for scientific applications)?

Iono WG:

Currently the following actions may be considered:

- Increasing of the temporal resolution of global TEC maps from 2 hours to 1 hour
- Include available GLONASS satellite and receiver DCB estimates in the IGS combined final (IGSG) and rapid (IGRG) ionosphere products.
- Encourage IGS iono ACs to join IGS reprocessing efforts in terms of generation of global TEC and GNSS DCB results starting from 1994.0 (in particular for correction of higher order ionospheric effects).
- Recommend at least one adequate procedure for correction of higher order ionospheric effects.

Session: Other analysis center developments & studies of general interest

- Refine the dynamical modeling of GNSS orbits by improving radiation pressure models and including albedo models.

- Urge IERS to provide an improved subdaily ERP tide model.

- Understand the impact of piecewise linear representation of time-varying parameters with respect to modeling using offset and drift.

- Undertake an effort to include site pictures in station site logs.

Session: Reanalysis campaign

REPRO-1. Future IGS reference frame realizations should include active and inactive high quality stations, going back to the IGS beginning.
This way the stability over time, having sufficient RF stations in early years, should be improved.

REPRO-2. Discontinuity table shall be updated to be consistent with reprocessed solutions in coordination with the users. It shall be published at the IGS GDCs.

REPRO-3. The IGS absolute antenna calibration file should be updated before the start of each new reprocessing campaign, including all available robot calibrations for receiver antennas and satellite-specific antenna offsets available in the SINEX files of the previous reprocessing campaign.

REPRO-4. IERS domes numbers shall be used in the SINEX files. For the clock solutions a unique 4-character ID (RINEX file name) shall be used.

Open issues from the 2006 workshop

- Troposphere product and combination
- Differential Code Biases back to 1994

Other issues

- How best to deal with other densification needs: what is IGS role in providing PPP & other services?
- Ionosphere maps
- 30 s clocks: at least 3 ACs needed for combination (currently 2 ACs)

Session: Progress in receiver calibrations & future developments

IGS Convention and user guideline development

- Convention on observation combinations (modernized GPS signals, Galileo) and products (orbit/clock, iono/trop….)
- Convention on bias estimates (products)
- User community need to understand the convention and proper use of IGS products
- Increased user community participation should be considered
- Stable or able to monitor reference should be established for bias estimates

Absolute receiver bias calibration is becoming increasingly important as the increase of GNSS signals along with biases

- Current effort should be continued and increased to develop standard and convention
- In-receiver bias calibration should be investigated, long-term stability is more important if removal is difficult
- Firmware bias should be given special attention

Multi-constellation bias determination

- GLONASS products (some confusion….)
- Bias estimates for GLONASS
- Inter-system bias/offset estimates

Actions should be taken to further improve IGS products to support demanding applications

- These applications don't tolerate current small systematic biases in IGS products
- Basic research efforts are needed to understand better GNSS biases and develop new modeling methodologies
- Phase bias determination and real-time products should be investigated to support real-time OTF PPP

Differential code biases are typically treated as solved-for parameters with one equation to remove rank deficiency. To ensure solutions that make most physical sense (and may be avoid leaks of some signal into the solved for parameters),

- Physical constraints should be introduced (may be they are already??) in the adjustment, e.g. based on the DCBs expected stability
- Reference for DCBs should also be based on physical considerations e.g. could be from the measured values for an ensemble of receivers

IGS should monitor the stability of receiver delays. Continuous monitoring of differential code bias (DCB) values with respect to P1-C1 and P1-P2 must be continued.

Time lab stations available in the IGS network should not only be considered for clock analysis, but also for ionosphere analysis (for monitoring of the corresponding receiver P1-P2 code biases).

GLONASS satellite and receiver DCB results should be included in IGSG IONEX products.

Absolute receiver calibration with respect to C1 (and also C2) would be desirable.

IGS C2 data availability has to be improved.

cc2noncc is capable to correct RINEX observation data for GPS P1-C1 bias values only. IGS users (and in particular the ACs) should be prepared to apply corresponding code bias corrections in their own GNSS analysis software (in order to cope with P2-C2, other GNSS, RINEX 3, etc.).

For IGS reprocessing, AS-free periods in -1994, 1995 (3), 1997 must be considered.

File format for DCB data exchange.

Use of RINEX 3?

Quarter-cycle phase bias issue!

Recommendations from Position Paper:

1. Study the effects of long-delay multipath by comparing co-located dual-frequency P(Y)-code-based measurements with dual-frequency C/A- and L2C-based measurements (cf. Section 2.2.1).
2. Adopt the minimum IGS receiver requirements schedule outlined in Section 3.1.
3. Request from commercial receiver vendors either (1) a detailed measurement description, or (2) adoption of a standardized measurement technique (cf. Section 4.1.2).
4. Compare the performance of at least one software GNSS receiver against that of a traditional receiver via signal simulator tests (such as those conducted in Montenbruck, Garcia-Fernandez, and Williams [*GPS Solutions*, **10**, 2006]) and via co-location with traditional IGS receivers (cf. Section 5.1.2).
5. Establish an IGS format for exchange of digitally-sampled IF data (i.e., the data stored to disk by digital storage receiver like the one schematized in Fig. 7).
6. Form an IGS Software Receiver Working Group.

Session: Progress in antenna calibrations

1. At IGS stations, it should no longer be allowed to install antenna types or antenna/radome combinations that are not absolutely alibrated. If a new station is set up or an old antenna is replaced, station operators are asked to choose an antenna type that shows a robot calibration (or the consistent results of a different calibration procedure of comparable quality) within the IGS antenna calibration file or to provide an absolute type calibration. (An exception could only be made for those antenna types that are already in use within the IGS and whose calibration values cannot be updated for that reason.)

2. It should be avoided to add additional converted field calibrations to the absolute IGS antenna correction file. Exceptions may be calibrations for antenna/radome combinations that are already in use within the IGS. NGS is encouraged to provide its calibrations in the ANTEX format.

3. z-offsets for newly launched satellites are estimated from weekly SINEX files. At least half a year of data should be available. The Analysis Centers are encouraged to add (constrained) phase center offset estimates to their SINEX files. Major prerequisite for new individual z-offsets is the consistency with the offsets contained in the operational model.

4. Before the start of a new reprocessing campaign, the absolute antenna correction file has to be updated with all available robot calibrations as well as with z-offsets (and PCVs) for the latest satellites from an analysis of weekly SINEX files.

5. The SINEX format has to be extended in order to allow for satellite antenna phase center variation estimates and for GLONASS receiver antenna phase center corrections (additional SITE/GLO_PHASE_CENTER Block).

6. The IGS Antenna Working Group as well as the Analysis Centers are encouraged to analyze azimuth-dependent phase center variations of the satellite antennas as well as differences between the 'horizontal' offsets (x, y) of individual satellites. It is an ultimate goal to combine ground- and space-based satellite antenna maps in order to make profit of the azimuth-dependence and the bigger maximum nadir angle. JPL is encouraged to provide its maps in the ANTEX format.

7. The next major revision of the absolute IGS antenna correction file will contain receiver antenna calibrations for the mean GLONASS frequencies. The Antenna Working Group will check their correctness. The Analysis Centers should be prepared to use such values.

8. The Antenna Working Group should investigate the feasibility of group delay calibrations.

Session: Real-time & near-real-time user requirements

1. E-GVAP recommends IGS to support PPP strategy with high quality adequate products.
2. The 'real-time' clocks will be interesting future product for using in GPS meteorology. NRT clocks for current needs.
3. NRT GPS ZTD product for NWP
4. Requirements for “Costal real-time GPS network” (next slide)
5. For climate applications, no need for RT/NRT, but to produce the ZTD product with long-term stability, high quality, and reduced diurnal bias, to increase the temporal coverage, to co-locate with radiosonde stations, to increase the sfc met data.
6. Desirable product additions: NRT TEC with short term prediction (Grid or spherical harmonic coefficients and user algorithm), Sub daily EOP, Reference frame with periodical term included
7. Possible improvements: Clocks without discontinuities and to Supply satellite DCB in SP3

Session: Real-time & near-real-time IGS products

• It is strongly recommended that GNSS receivers be collocated at Global Climate Observing System (GCOS) Upper-Air Network (GUAN) sites and UA Reference (GRUAN) sites for independent verification and validation of critical climate observations.

• Individuals assimilating GNSS observations into atmospheric models should be aware that if an atmospheric model analysis or prediction is used to determine or modify the mapping functions used to estimate the zenith neutral delay, then the errors in the atmospheric model and the errors in the GNSS observations assimilated into the model are correlated, and the degree of correlation may not be well understood. Geodesists should utilize improved (i.e. more realistic) atmospheric models to reduce systematic errors in the mapping functions.

• The IGS should acknowledge the importance of the continuously growing number of NRT PPP users who especially require a more precise and robust IGU clock product. Therefore, efforts should be made to encourage ACs to continue (or start) their participation in the IGS Ultra-rapid clock products. NRT PPP users also need a higher IGU clock rate (i.e. from 15min to 5min and ultimately 30sec) and a more frequent IGU combination update (i.e. going from 4 to 8 updates per day).

Session: Status of real-time & Pilot Project operations

- IGS become a member of RTCM SC 104

- That RINEX 3.0 be used to define RTIGS requirements for streamed data content and observation resolution

- That SP3c and Clock RINEX be used to define RTIGS requirements for streamed content and resolution for state space orbits and clocks

- Process to adopt in the development of RT product formats and protocols for the RT Pilot Project:

    1. Both NTRIP and UDPRelay will support dissemination of the Pilot Project Real Time products
    2. The Pilot Project Analysis and RT-Data Centre participants will initiate a requirements definition phase for formats of all Real Time products that are within the scope of the Pilot Project. The RT-Data Centre participants will also cover the perspective of the User Community.
    3. A prototype format for orbits and clocks will be developed and hosted by the RT Data Centers. The timescale for this will be compatible with the schedule for the availability of the products (by January 2009 for individual ACs and March 2009 for the combination product).
    4. Participants in the RT Pilot Project will take an active role in the definition of final formats to support IGS requirements for all RT products, placing emphasis on influencing the evolution of existing international standards and in particular RTCM.

Session: IGS network issues & challenges

Recommendation 1
The IGS should develop a standard protocol for exchanging information about IGS stations. The IGS CB should maintain the associated machine-readable database populated with information provided by

- IGS station managers: reporting on all kinds of local site effects, tracking problems
- IGS data centers: statistics covering data availability, data latency, completeness of data files and the consistency of the records in the RINEX header and the site logs
- IGS analysis centers: reports on processing problems with specific stations
- IGS working groups and pilot projects
- Other networks sharing a common station with the IGS

Recommendation 2
The IGS station managers should

- Announce when they make major changes at their stations, such as new antenna, etc... before the change is actually made (mandatory for IGS05 reference frame sites).
- Submit site pictures to the IGS Central Bureau; the pictures need to be updated when a change at the antenna, its monument or surroundings occurs.

Recommendation 3
The IGS Central Bureau is encouraged to

- Reduce of the latency when updating site log files
- Maintain of a list with the type of calibration available at each IGS station
- Provide for each IGS station a link to all other external info available for that station
- Maintain realistic IGS station maps based on data availability and not just site log availability
- Maintain a list of 2-AC stations for others ACs to consider.

Recommendation 4
The IGS acceptance process for new stations needs to

- Define "critical world areas": stations from those areas that pass the major criteria should become IGS stations without question
- Define and set up a procedure to regularize high quality non-IGS stations contributing to several AC solutions
- Request site pictures (in all directions) before adding a station to the IGS network.

Recommendation 5
The IGS shall define and set up a process with all other networks who share a common station, to communicate with each other when there's a site log update.

Recommendation 6
The IGS should consider trusting gatekeeper’s data directly and monitoring only the stations not already managed by a competent organization. The IGS will then only deal with the gatekeepers for problems with those stations. The gatekeepers should be certified to be following the IGS standards (at least) through a simple questionnaire and regular spot checks

Recommendation 7
The IGS needs to set up

- A process to define and certify ITRF-quality stations
- Global reference frame quality stations with specific requirements

Session: Improvements in station installations

Site Installation #1

1. Camera (or frequent) time-tagged photos giving details on site environment (ground, sky, antenna), preferably connected to the Internet.
2. Better site metadata (particularly information on depth to bedrock and bracing depth. Follow current IGS Site log and perhaps augment with EarthScope PBO specs and place more emphasis on installation staff filling in these fields in the install log.

Site Installation #2

1. Supersite Footprint. More than one monument at a site to check for site-specific motions and to ensure continuity with new GNSS.
2. A few experimental sites (control network) to learn about impact of equipment changes (preferably distributed on a global scale). Accuracy matters, precision (leaving things alone) is not enough for mm-geodesy.

Session: Data center operations & issues

- Data centers and station operators need clear requirements for data latency from the analysis centers. Data centers will work with stations to meet these requirements.
- ACs should define requirements for data QC and validation at IGS data centers. The data centers need to know, under what circumstances submitted data files should be rejected from the archives.
- Web access is a powerful data discovery tool that could handle the different archive structures present at the IGS data centers. The data centers should survey the community to see if there remains a need for better harmonization of the IGS data center structure and contents.
- IGS data centers should investigate accumulation of data streams as a possible replacement for ftp file transfer of selected IGS data sets (i.e., high-rate 15-minute 1Hz files) with the provision that IGS data centers archive files of identical content.
- TEQC is widely used by IGS data centers to check RINEX files and station performance. With upcoming new formats, e.g., RINEX v3.0, and future satellite systems, e.g., GLONASS and Galileo, an updated version of TEQC is need. We ask UNAVCO to update TEQC to accommodate these new requirements.

Session: Future IGS & inter-technique SINEX combinations: Issues & challenges

Recommendations relating to Internal IGS Activities

COMBI-1: Define and maintain IGS conventions/procedure/guidelines document

COMBI-2: Use agreed set of models (currently IERS 2003)
Essential for both internal (GNSS) and external (other services, IERS) product interface. Recommend that SINEX files detail applied models and procedure. A SINEX block could be defined specifically to include this information.

COMBI-3: Report all apriori constraints, ensure they are removable
Unconstrained solutions are preferred. Loose (2-3 orders of magnitude than the estimates uncertainty) may be used. Inner (origin, orientation, scale) constraints acceptable.

COMBI-4: Minimize equipment changes due to GNSS modernisation
The modernization should be coordinated to minimize equipment changes. Multiple receivers and antennas should be used in parallel at core sites, there should be a clear procedure for handling the processing in these cases.

COMBI-5: Mechanism to contribute and share station discontinuity information
All users of station coordinates time series can potentially contribute to and benefit from this.

Recommendations relating to External Activities (IERS and others)

COMBI-6: Include troposphere parameters in the SINEX files
Natural extension to the existing coordinates parameters, to which they are correlated. They can be combined with estimated troposphere from other techniques such as VLBI and DORIS to good effect. This should be done in conjunction with an upgrade to SINEX Version 2.x

COMBI-7: Provide rapid combined IGS SINEX Product
Include a selected set of stations (important: Wettzell, Kokee Park, Tsukuba) and pole positions to help to improve VLBI UT rapid solution.

COMBI-8: Provide mechanism to stream extended products for inter-technique combinations via IGS
Where IGS ACs can provide extended products (e.g. daily sinex, or normal equations of extended parameterisations) for inter-technique combinations, AND these products are directly related to the IGS products, that these products are streamed via IGS.

Session: Multi-GNSS & regional combined IGS products

1. The IGS shall start studying the opportunity to provide a combined GPS/GLONASS product series (currently orbits, in future clock corrections as far as enough contributions are available):

- There is a strong user need at least for combined orbit but also satellite clock corrections to provide the opportunity of the multi-GNSS-PPP.
- In a first step the combined GLONASS—only products file is completed by the combined GPS—only product file by merging both files. The classical combined GPS—only product files is not effected.
- A study group of experts is asked to develop a multi—GNSS combination software that can manage single system contributions and contributions containing different combinations of the available GNSS in a proper way.

2. Related to the format session the needs of a multi-GNSS processing (not only regarding GPS and GLONASS but also Galileo and Compass) on the file formats shall be considered:
   - **RINEX:** RINEX 3 is defined but still not really in use within the IGS
   - **SP3 orbit:** extension to include more satellites is under discussion already for a long time; it is not clear when the new format will be finalized
   - **clock RINEX:** system specific receiver clock corrections because some of the receivers types show more than a clock offset between the measurements from the two active GNSS
   - **ERP:** there is no need for change
   - **SINEX:** there is no need for change; but possibly it might be nice to indicate the GNSS for some parameters for scientific purposes
   - **Biases:** the world of biases will become much more colors with the planned modernizations of the existing GNSS, with the upcoming new GNSS, and the combinations between the different GNSS (impact to the WG for Bias and calibration)

3. The SINEX format should be extended by a mandatory "reference frame" field in the header record or by a separate "reference frame" block to avoid any ambiguity when used for regional reference frames (e.g., EUREF, NAD83, SNARF and SIRGAS).

4. The link between the RNAAC groups, the AC groups, and the ACC should be improved:
   - RNAAC groups should be informed as early as possible about discussions between the AC groups regarding format changes and model improvements in order to give them time to update their processing to keep the regional analyses consistent with the global analyses.
   - Issues affecting the RNAAC groups should be considered in decisions made by the IGS concerning processing and modelling.

5. The political level of IGS (IGS GB) must decide whether the IGS shall provide an official IGS regional densification product or not. On the other hand, the regional services need to signalize whether they have an interest in such a product for their users or not.
   If such a product is appreciated the GNAAC schedule for the combination of the different RNAAC solutions should be more flexible in consideration of the different RNAAC schedules. Likewise, the RNAAC groups should keep the GNAAC groups informed of their schedules and advise the GNAAC groups of any delays.

6. The visibility of the RNAAC combinations should be improved.

Session: Product file formats & related issues