Reprocessing Issues, Standardization, New models

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1 Motivation and Introduction

Since the official start of the IGS on 1 January 1994, considerable improvements in the processing strategies and modeling of global GPS solutions have been achieved. Due to the changes at the individual IGS analysis centers (ACs) during these years the resulting time series of global geodetic parameters are inhomogeneous, inconsistent and additionally degraded by changes in the realization of the reference frame. A geophysical interpretation of these long series and the realization of a high-accuracy global reference frame are therefore difficult and problematic. Two major changes in the IGS processing are planned for the very near future: (1) the transition from relative phase center corrections for receiver antennas only to absolute phase center corrections for receiver and satellite antennas and (2) the transition from ITRF2000 to ITRF2005. Both changes will be implemented in parallel and are expected to introduce a significant discontinuity in all IGS products.

In view of these deficiencies, the IGS has decided to perform a reprocessing of the global IGS tracking network since its inception. This reprocessing follows the recommendation 2.9 of the 2004 IGS Workshop in Berne: "The ACs should be prepared to reprocess the IGS data. The detailed procedure should be discussed after the absolute antenna phase center variation models are decided ..." *Nikolaidis* (2002) and *Steigenberger et al.* (2006) have already demonstrated the benefits of a complete and homogeneous reprocessing. To generate a consistent set of reprocessed IGS products a number of common standards should be fulfilled by the analysis centers participating in the IGS reprocessing. Some of these issues have already been discussed and a consensus has been reached. The scope of this paper is to summarize these recommendations as well as to list the topics that have to be discussed before the start of the actual reprocessing effort.

2 Participating Institutions

The call for participation was announced in IGSMAIL 5157 in July 2005. The institutions which have already agreed to participate in the IGS reprocessing are listed in Table 1. Due to the lack of computer resources and/or man power some of the IGS ACs will not contribute to the reprocessing project at the moment but might join at a later date.

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Table 1: Institutions participating in the IGS reprocessing effort.

Abb.	Institution	Key personell	Software
EMR	Natural Resources Canada (NRCan)[a]	R. Ferland, B. Donohue	GIPSY
ESA	European Space Agency[a]	I. Romero	NAPEOS (BAHN)
GFZ	GeoForschungsZentrum (GFZ) Potsdam[a]	G. Gendt, M. Ge	EPOS
NCL	University of Newcastle upon Tyne[b]	P. Clarke	TANYA
NGS	National Geodetic Survey[a]	J. Ray	page5
PDR	GFZ Potsdam/TU Dresden[c]	M. Fritsche, P. Steigenberger	Bernese
SIO	Scripps Institution of Oceanography[a]	P. Fang, P. Jamason	GAMIT
UNT	University of Nottingham	N. Teferle	Bernese

[a] IGS Analysis Center
[b] IGS Global Network Associate Analysis Center
[c] formerly TU Munich/TU Dresden (TUM/TUD)

3 Stations

Although the tracking networks of the IGS ACs participating in the reprocessing effort will probably be very similar to those of the routine IGS processing, the ACs are encouraged to review their station selection and add stations meeting the following criteria:

Station selection

- Reference frame stations (former and current)
- Co-locations with other space-geodetic techniques: DORIS, SLR and VLBI
- Timing sites [1]
- NGA (National Geospatial-Intelligence Agency, formerly NIMA) sites [2]
- TIGA (Tide Gauge Benchmark Monitoring) sites [3]

ACs need to provide the number of stations they can confidently process and the number of stations which they would be willing to change or that are open for suggestions. It would be an optimum if each IGS station could be analyzed by at least 3 ACs.

RINEX observation data and station information In view of the upcoming reprocessing station operators have already been asked to check whether all historical data of the corresponding stations is available at the IGS data centers (IGSMAIL 5263). As the correctness of the information on the equipment operated at the individual stations (particularly of the antenna eccentricities and the antenna as well as radome type) is crucial for a successful reprocessing, station operators are kindly asked to check the complete history of the station equipment documented in the station log files. Horizontal antenna offsets should also be handled consistently by the ACs. The recommendation is to apply these

[1] https://goby.nrl.navy.mil/IGStime/
[2] http://earth-info.nga.mil/GandG/sathtml/index.htm
[3] http://adsc.gfz-potsdam.de/tiga/index_TIGA.html

offsets although they are not contained in the `igs.snx`[4] file at the moment but only in the station log files.

4 Common Standards

The analysis centers should fulfil a number of common standards to generate a consistent set of reprocessed IGS products. In view of future IERS combination efforts as well as future ITRF computations the standards used for the IGS reprocessing should be compatible with those of the other space-geodetic techniques DORIS, SLR and VLBI to the extent possible. The following standards should be implemented by the ACs participating in the IGS reprocessing (some of the recommendations are based on the IGS AC meeting held during the AGU on 7 December 2005 but some topics still have to be discussed). A detailed summary of the recommendations is given in Appendix A.

IERS2003 Conventions The conventions published by *McCarthy and Petit* (2004) as well as their latest updates (available at the IERS conventions center[5]) should be implemented in the software packages used for reprocessing.

Reference frame IGS05 (the IGS realization of ITRF2005) will be available a few weeks after the release of ITRF2005 and should be used for the IGS reprocessing. Due to the small number of datum stations in the beginning former stable datum stations, which are not active anymore, should also be used in the early years.

Antenna phase center model The transition from the relative phase center model still used by the IGS to an absolute model was one of the recommendations of the 2004 IGS workshop in Berne (*Schmid et al.*, 2005). The IGS will switch to the absolute model together with the transition to ITRF2005/IGS05. The latest absolute antenna calibration model `igs05_wwww.atx`[6] (`wwww` stands for the GPS week of the latest modification, at the moment `igs05_1365.atx`, see IGSMAIL 5318) for receiver and satellite antennas should also be used for the IGS reprocessing. This model contains satellite-specific z-offsets and block-specific x-/y-offsets as well as block-specific nadir-dependent phase center variations for the satellite antennas. For all receiver antennas used within the IGS as well as for a number of antenna/radome combinations absolute phase center offsets and variations are given in that file, too. Radome calibrations should be applied if given in the ANTEX file. For antenna/radome combinations, where no calibration values are available, the values of the antenna without radome should be used.

Mapping functions Although recent mapping functions like the isobaric mapping function (IMF, *Niell* (2001)) and the Vienna mapping functions (VMF, *Boehm and Schuh* (2004) and VMF1, *Boehm et al.* (2006b)) allow for a more realistic modeling of the atmosphere (input data from numerical weather models) these mapping functions are not yet a standard within the IGS. The effort to implement these mapping functions and in particular

[4] `ftp://igscb.jpl.nasa.gov/igscb/station/general/igs.snx`
[5] `http://tai.bipm.org/iers/convupdt/convupdt.html`
[6] `ftp://igscb.jpl.nasa.gov/pub/station/general/pcv_proposed/`

the handling of the weather model data might be the reason for that. Despite its deficiencies the *Niell* (1996) mapping function (NMF) is still used by most IGS ACs. The Global Mapping Function (GMF) developed by *Boehm et al.* (2006a) is a compromise between the IMF/VMF and the old NMF. It is based on mean values of weather model data but is as easy to use as the old NMF (input arguments are time, longitude, latitude and height of the station and the zenith distance). Systematic effects, especially in the southern hemisphere, can be reduced by using this mapping function. A FORTRAN subroutine for this mapping function is available at `http://www.hg.tuwien.ac.at/~ecmwf1/gmf.f`.

Discussion Still use the old NMF or switch to GMF?

Higher order ionospheric corrections Although several authors have demonstrated the systematic influence of the higher order ionospheric corrections (*Kedar et al.*, 2003; *Fritsche et al.*, 2005), these corrections should not be considered at the moment.

Atmospheric tides Due to the lack of an accurate model the atmospheric S_1 and S_2 tides should not be applied.

Non-tidal loading As there are no common standards up to now it is recommended not to consider atmospheric, non-tidal ocean and hydrological loading at the moment. For time series with daily resolution (see Section 5.4) an a posteriori correction of these loading effects would be possible.

Differential code biases In principle one can distinguish three classes of receivers concerning the code registration on L_1: C1-receivers with cross-correlation technique (e.g., Rogue and TurboRogue) track the C/A-code on L1, P1-receivers (e.g., Ashtech, AOA Benchmark ACT) on the other hand directly track the P-code. Some recent receiver models (e.g., Leica and Trimble) also only provide the C/A-code and not the P-code on L_1. The bias between these types of measurements is different for each satellite and has to be considered when estimating satellite clocks or solving ambiguities using code measurements. P1-C1 differential code biases (DCBs) are provided by the CODE IGS AC since April 2000 (IGSMAIL 2827). Monthly values determined by CODE are used by the IGS and these DCB values are updated whenever new satellites are launched. The latest update took place in November 2005 after the launch of PRN17 (IGSMAIL 5260). RINEX observation files can be corrected for the biases with the converter utility `cc2noncc`[7], see IGSMAIL 2744. For the IGS reprocessing, historic DCB values before April 2000 are necessary. DCBs have also been determined in the TUM/TUD reprocessing (*Steigenberger et al.*, 2006) and could be used in principle for the IGS reprocessing after a careful validation. This validation as well as the combination of the daily DCBs will be done by CODE. Due to the small number of stations the DCB estimates are rather noisy in the early years. Therefore, it was proposed not to use these unstable DCB estimates but to use a mean value for the first two years or even extrapolate from 1996 backwards. The exact procedure will be defined during the validation and combination process.

[7] `https://goby.nrl.navy.mil/IGStime/cc2noncc/cc2noncc.f`

5 Analysis Strategy

The start of the data to be used in the IGS reprocessing will coincide with the start of the IGS as an official service on 1 January 1994. It will only include GPS (not GLONASS) at the present time. A link to the template for the documentation of the analysis strategies of the individual ACs is given in Appendix B.

5.1 Parameters and Products

Table 2 gives an overview of the products, formats and sampling rates of the IGS reprocessing. The obtained SINEX files should include the following parameters

- Station coordinates
- Earth rotation parameters (polar motion, polar motion rates, length of day)
- Satellite antenna offsets (at least SATA_Z)

As homogeneously reprocessed long time series of troposphere zenith delays are valuable for atmospheric, solar and climate studies, the troposphere zenith total delays should be provided in the SINEX_TRO format with a two hour resolution.

Product	Format	Sampling
Orbits	SP3c	15 min
Clocks	RINEX_CLK	5 min/30 sec
Station coordinates	SINEX	7 d/1 d
Earth rotation parameters	SINEX	1 d
Tropospheric zenith delay	SINEX_TRO	2 h

Table 2: Products, formats and sampling of the IGS reprocessing.

Satellite orbits should be provided in SP3c format including satellite clocks. Several users have asked for an overlap period for the orbits, at least the inclusion of the 24:00 epoch in the sp3 file should be considered. High-rate clocks would be an interesting product as they would allow fully consistent precise point positioning (PPP) applications over the complete history of the IGS. On the other hand the time and effort for the generation of this product might be too large for some ACs.

Discussion Overlap for orbits?
Sampling rate of the satellite clocks: 5 min/30 sec?

5.2 Ionosphere Products

Ionosphere parameters will not be considered in this IGS reprocessing. A separate reprocessing will be conducted by the ionosphere working group, as the ionospheric products can be decoupled from the other products.

5.3 Handling of Discontinuities

Many station coordinate time series are affected by discontinuities. Some of them are related to earthquakes but the major part of the discontinuities is caused by equipment changes or the reason is even unknown. There are four different ways to treat discontinuities in the weekly SINEX files:

- Exclude the station before the discontinuity
- Exclude the station after the discontinuity
- Exclude the station for the whole week
- Include two coordinate sets in the SINEX file (before and after the discontinuity)

The latter approach minimizes the loss of observation data and is therefore recommended. When using daily instead of weekly SINEX files, the handling of discontinuities is easier and more flexible, see Section 5.4. A list of discontinuities is maintained by Remi Ferland and available at `ftp://macs.geod.nrcan.gc.ca/pub/requests/sinex/discontinuities`. The file `CONFIRMED.snx` contains a list of confirmed discontinuities and `PROBABLE.snx` a list of probable discontinuities.

Discussion Handling of discontinuities when using weekly SINEX files?

5.4 Weekly vs. Daily SINEX Files

At the moment weekly SINEX files including station coordinates and Earth rotation parameters are standard within the IGS. A preliminary agreement exists to submit only weekly SINEX files, but it is still worth considering to switch to daily SINEX files providing a higher temporal resolution of the time series and some other advantages (see list below). The decision to produce daily rather than weekly SINEX files certainly makes a significant difference in the volume of data. On the other hand there are a number of advantages of daily files:

- More flexibility concerning a rigorous combination with other techniques, e. g. session-wise SINEX files from VLBI
- Better continuity of Earth rotation parameters (*Ferland*, 2006)
- A posteriori corrections of high-frequency unmodeled effects (e.g., atmospheric loading) are more accurate
- The loss of observation data due to discontinuities and outliers can be minimized:
    - · Weekly outlier stations can sometimes be tracked down to one daily problem
    - · Stations with discontinuities have to be excluded for only one day
- Weekly SINEX files can be generated from daily files but not vice versa

The daily files could be combined per AC and per week and then the current procedure could be used. The current procedure for the SINEX combination could be applied directly to daily files with only minor changes required (*Ferland*, 2006).

Discussion Daily or weekly SINEX files?

5.5 Combination

The combination tasks of the IGS reprocessing are listed in Table 3. The combination of the reprocessed SINEX files will be done by NRCan and NCL. Orbits and clocks will be combined by the IGS ACC like for the routine IGS products. The combination of the tropospheric zenith delay is still open. All products shall be immediately combined and validated to identify problems as soon as possible. All combination summaries will be electronically distributed and archived.

Task	Institution	Name
Combination for SINEX	NRCan	R. Ferland
	NCL	P. Clarke
Combination for orbits and clocks	IGS ACC: GFZ	G. Gendt
Combination for timescale	NRL	K. Senior
Combination for tropospheric zenith delay	open	

Table 3: Combination tasks of the IGS reprocessing effort.

Discussion Combination of the tropospheric product?

6 Next Steps and Outlook

A Reprocessing Pilot Project (PP) is planned to start shortly after IGS05 and the absolute phase center model are adopted by the IGS in the official products. It will cover the weeks 1043 till 1055 (first three months of the year 2000). The complete reprocessing will start after possible problems detected within the PP phase have been solved and is expected to last for at least six months to a year.

A complete reprocessing of more than a decade of GPS observation data is certainly a challenging task for the near future. However, the generation of a consistent and homogeneous set of IGS products justifies the time and effort for the IGS reprocessing. This reprocessing should not be a unique task but repeated whenever major changes in the modeling of GPS observations are implemented (e.g., new release of the IERS Conventions, the ITRF, etc).

The conclusions of the discussions during the Session "Reprocessing Issues, Standardization, New models" are summarized in *Romero et al.* (2006).

A IGS Reprocessing Strategy Recommendations

MEASUREMENT MODELS	
Satellite center of mass offsets	Satellite-specific z-offsets and block-specific x- and y-offsets as given in igs05_wwww.atx
Satellite phase center corrections	Block-specific nadir-dependent phase center corrections as given in igs05_wwww.atx
Satellite clock corrections	2nd order relativistic correction for non-zero ellipticity ($\frac{2}{c}\ \mathbf{r} \cdot \mathbf{v}$) applied
RHC phase rotation corr.	Phase polarization effect applied according to *Wu et al.* (1993)
Ground antenna phase center offsets and corrections	Absolute elevation- and azimuth-dependent (when available) phase center variations and offsets for L_1 and L_2 as given in igs05_wwww.atx
Antenna radome calibration	Calibration applied if given in igs05_wwww.atx
Marker/ARP eccentricity	Vertical (dU) *and* horizontal (dE, dN) eccentricities from site logs applied to compute station coordinates
Troposphere a priori model	mapping function: Global Mapping Function (GMF) (*Boehm et al.*, 2006a)
Ionosphere	First-order effect eliminated by forming the ionosphere-free linear combination of L_1 and L_2. Second- and third-order effect not applied.
Tidal displacements	*Solid Earth tidal displacement*: IERS 2003 *Permanent tidal term*: applied in tide model but not included in site coordinates *Pole tide*: IERS 2003, mean pole removed by linear trend *Ocean tide loading*: FES2004 *Ocean tide geocenter*: ocean loading coefficients corrected for center of mass motion of the Earth *Atmospheric tides*: corrections for S_1 and S_2 pressure tides not applied
Non-tidal loadings	*Atmospheric pressure*: not applied *Ocean bottom pressure*: not applied *Surface hydrology*: not applied
Earth orientation variations	*Ocean tidal*: diurnal/semidiurnal variations in polar motion and UT1 applied according to IERS 2003 Tables 8.2 and 8.3 *Atmosphere tidal*: not applied *High-frequency nutation*: prograde diurnal polar motion corrections applied according to IERS 2003 Table 5.1

ORBIT MODELS	
Tidal variations in geopotential	*Solid Earth tides*: IERS 2003, Chapter 6.1, including anelastic effects and step 2 frequency-dependent corrections to Love number k(2,1) *Solid Earth pole tide*: IERS 2003, Chapter 6.2
Relativistic effects	*Dynamical correction*: according to IERS 2003 Chapter 10.2 Equation 1 but Lense-Thirring and geodesic precession terms neglected *Gravitational time delay*: according to IERS 2003 Chapter 11.2 Equation 17

REFERENCE FRAMES	
Time argument	TT/TDT derived from GPS time of observation epochs
Inertial	Geocentric; mean equator and equinox of 2000 Jan 1 at 12:00 (J2000.0)
Terrestrial	The IGS05 reference frame is realized through a set of station coordinates and velocities as given in the corresponding SINEX file.
Interconnection	*Precession*: compatible with IAU2000, see IERS2003 Chapter 5.5 *Nutation*: IAU2000A Nutation Theory

B IGS Reprocessing Strategy Summary

Due to its length the full IGS reprocessing strategy summary is not shown here. It is an updated version of the IGS analysis strategy summary used for the routine IGS processing. The electronic version of the summary as well as an example with some additional comments prepared by Jim Ray are available at `ftp://igscb.jpl.nasa.gov/pub/center/analysis/`. The ACs should use this summary to provide information about their processing strategy.

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