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Preparations for the 2nd IGS Reprocessing Campaign

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Abstract. The Analysis Centers (ACs) of the International GNSS Service (IGS) are now completing their first collective reanalysis of the history of global network GPS data collected since 1994. A consistent set of the latest models and methodology is being used to generate GPS satellite orbits, Earth orientation parameters (EOPs), station coordinate time series, and station and satellite clocks. These results have been contributed to the new ITRF2008 multi-technique terrestrial reference frame and EOP combination. Preparations will begin during 2010 for the next IGS reprocessing effort. Despite the major progress achieved in the first IGS reanalysis, further analysis improvements remain to be implemented. The list includes: add GLONASS as well as GPS observations; adopt a new reference frame based on ITRF2008; update the IGS antenna calibrations based on the first reprocessing results and other sources; use the new EGM2008 geopotential model with perhaps revised time-varying coefficients; implement a model for previously neglected higher-order ionospheric effects; consider the satelllite dynamical effects of Earth albedo reflection and re-radiated thermal emissions; apply various refinements in modeling tropospheric delays; include station displacements due to the S1 and S2 atmospheric pressure tides; use a new model for the subdaily EOP tidal variations, if available; reconsider the handling of EOP constraints and *a prioris* by ACs; incorporate all recommended higher-order relativistic effects; and revisit the treatment of all analysis constraints to remove as many as possible and to understand better the effects of those that remain. Other operational aspects need to be evaluated also, such as how best to treat non-tidal loading station displacements, whether to continue forming weekly SINEX solutions or to move instead to daily integrations, and more consistent and rigorous methods to combine AC solutions.

1. Observational Data

- In addition to GPS data, include data from the Russian GLONASS system, if enough ACs can contribute.
- Include reprocessed tide gauge solutions from groups using global networks & IGS analysis conventions (as with repro1).
- Also continue to include other high-quality global network solutions that are consistent with IGS analysis standards (as with repro1).
- Results will continue to rely on ionosphere-corrected carrier phase observables, with code pseudorange observations included to estimate clocks (for undifferenced processing).

2. Pseudorange Biases

- Consider whether the IGS should change its bias convention from P1/P2 code observables, which maintains consistency with the GPS system (mainly for clocks). But does a realistic alternative exist?
- Consider whether to adopt an absolute delay scale for differential code biases rather than the present zero-mean datum for satellite biases. This would depend on cooperation with BIPM & timing labs having absolutely calibrated GNSS receivers.
- IGS currently monitors (P1 – P2) code biases for satellites/stations & (P1 – C1) code biases for satellites, as byproducts of ionosphere mapping.
- Add (P2 – C2) satellite biases to IGS standards based on observations of GPS IIR-M satellites, similar to current (P1 – C1) biases. [IGS Bias & Calibration Working Group]
- Consider adding delay bias monitoring for GNSS receivers, as well as for satellites. But is this practical? [IGS Bias & Calibration Working Group]
- Should the IGS consider tracking phase biases too, to facilitate undifferenced phase ambiguity resolution methods by PPP users?

3. Terrestrial Reference Frame

- Define a new IGS08 reference frame, closely related to ITRF2008, to replace IGS05. [IGS Reference Frame Working Group]
- IGS08 could be a subset of the ITRF2008 positions & velocities for a specified set of well-behaved, globally distributed reference stations.
- All discontinuities since 1994/1995 will be documented in SINEX format for the IGS08 stations.
- Aim for at least 150 reference frame stations in IGS08.
- Will ask operators of IGS08 reference stations to minimize future changes except for major, well-controlled upgrades.

4. New Antenna Calibrations

- Update satellite & ground antenna phase center offsets (PCOs) & phase center variations (PCVs) in new igs08.atx file. [IGS Antenna Working Group]
- Derive new GPS satellite PCO values consistent with IGS08 frame by back-solving repro1 SINEX files with fixed ITRF2008 scale.
- Derive new GLONASS satellite calibrations based on CODE & ESOC AC solutions.
- Consider whether to include azimuthal PCVs for satellites.
- Adopt new IGS08 & igs08.atx system in IGS operational products by mid-2010.
- Level of consistency with IGS05/igs05.atx system needs to be determined.

5. Update Geopotential Model

- Adopt EGM2008 model, to degree & order 12, consistent with updated *IERS Conventions*.
- New values for C_{20} , C_{21}, & S_{21} (& their time derivatives) may be recommended.
- Models for annual variations of some low-degree coefficients may also be recommended.
- Details to be finalized in pending update of *IERS Conventions,* Chapter 6.
- Include effects of Earth & ocean tides as well as Earth & ocean pole tides.

6. Improved Satellite Attitude Modeling

- Consistent modeling of attitude changes is needed, especially for GPS IIA satellites.
- Deviations mostly degrade IGS combined clock products.

7. New Model for Albedo Accelerations

- Effects of reflected & re-radiated thermal energy from the Earth probably should be modeled.
- Rebound thrust from satellite transmitters should also be considered.
- Possible model options & effects being evaluated by *ad hoc* group coordinated by M. Ziebart.
- Neglect of effect might account for radial bias of IGS orbits compared to SLR ranges.
- Actions await outcome of studies & recommendations.

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8. Relativity Corrections

- All relativistic corrections recommended by the *IERS Conventions* should be included.
- Should include at least the Schwarzschild & de Sitter terms of the "dynamical corrections" in Eqn (12) of Chapter 10.
- However, the Lense-Thirring correction is very small for GNSS satellite altitudes.

9. EOP Modeling Changes

- Implement improved model for subdaily EOP variations, if available. Errors in the present model cause significant long-period alias errors due to 24-hr processing cycle.
- Subdaily UT1 libration due to the triaxiality of the Earth's figure should be included & added to the *IERS Conventions*.
- It is presently not clear if an improved model is feasible from geophysics & oceanography alone. But empirical models based on space geodesy are not very consistent with each other & can absorb technique-dependent systematic errors (especially near S1, S2, K1, & K2 tides).
- The AC treatments of *a priori* UT1 (& any constraints) need to be critically evaluated.
- Evaluate the potential utility of estimating a daily UT1 acceleration term. This must consider any impacts on the orbit adjustments & long-term stability.
- Adequate AC modeling of nutation & the celestial pole needs to be verified.

10. Station Position Displacements

- Implement model for loading due to S1 & S2 atmosphere pressure tides. This requires handling of the net effect on geocenter motion of the Earth-fixed frame for SP3 orbits.
- Implement IERS model for ocean pole tide loading.
- Consider best treatment for non-tidal loading displacements. Should these be integrated into the stacking of weekly SINEX solutions, for instance?
- Consider a model for the thermal expansion of monuments & nearby bedrock (Yan *et al.*, *Geophys. Res. Lett.*, **36** L13301, 2009). Annual amplitudes for bedrock variations can reach 1.3 mm level.
- Probably update model for mean pole motion using a cubic fit, depending on *IERS Conventions.* Same pole model should be used for geopotential field effect.

11. Include Higher-Order Ionospheric Effects

- Ionospheric propagation effects should include 2nd & 3rd order terms according to revised *IERS Conventions*, Chapter 9.
- Development of a set of standardized routines by an *ad hoc* group is being coordinated by M. Hernandez-Pajares.
- These routines will be offered to all ACs as a reference standard. First version currently being evaluated.

12. Review Tropospheric Propagation Modeling

- Consider using *a priori* hydrostatic zenith delays derived from numerical weather models, such as provided in gridded form by the Technical University of Vienna.
- Consider using empirical mapping functions based on retrieval coefficients from numerical weather models, such as provided by the Technical University of Vienna for the VMF1 mapping function model.
- Implement an *a priori* model for horizontal gradients in the tropospheric delay, at least for the mean hydrostatic component, if available.

13. Reconsider AC Constraints & Procedures

- Review which constraints ACs apply, especially hidden or unremovable ones.
- Pay particular attention to constraints on orbit & UT1/LOD parameters. Also consider the effect of differences in arc lengths used & the issue of implicit smoothing.
- Try to eliminate or minimize as many constraints as possible.
- For constraints that are retained, try to understand their impacts on results better.

14. Implementation by ACs

- Results from 1st reprocessing campaign (repro1) should be thoroughly evaluated for any "lessons learned".
- New models should be available, agreed, & ready to implement during 2010.
- To the greatest extent feasible, new models should be distributed in the form of software routines that can be integrated into AC processing engines or used for independent testing.
- AC coding changes will begin in 2010 & extend into 2011.
- Implementation date of major model changes (apart from IGS08/igs08.atx adoption) in operational IGS processing should be carefully coordinated to ensure maximum self-consistency. The repro2 campaign will reanalyze data from 1994/1995 up to this implementation date.
- Implementing thermal expansion models will require updated station log files to provide more detailed antenna monumentation information.

15. Reconsider IGS Combination Strategy

- Are more internally self-consistent & rigorous combination methods feasible for the suite of IGS products? For instance, the (TRF + EOP) combination is presently rigorous & separated from the (orbit + clock) combination, which is not rigorous.
- Should the TRF integration interval be shortened from 7 d to 1 d?
- In what ways should non-tidal loading effects be incorporated, or not?