Combined orbits and clocks from the IGS 2nd reprocessing

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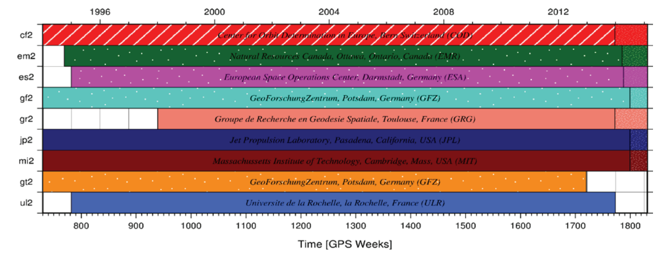
1. OVERVIEW

In early 2015, the Analysis Centers (ACs) of the International GNSS Service (IGS) completed their second reanalysis of the full history of globally distributed GPS and GLONASS data collected since 1994. The suite of reprocessed AC solutions includes daily product files containing station positions, Earth rotation parameters, satellite orbits and clocks. This second reprocessing—or repro2—provided the IGS contribution to ITRF2014; it follows the successful first reprocessing, which provided the IGS input for ITRF2008. For this poster, we will discuss the newly combined repro2 GPS orbits and clocks. We also revisit our previous analysis of orbit day-boundary discontinuities with several significant changes and improvements. (1) Orbit discontinuities for the contributing ACs were studied in addition to those for the IGS repro2 combined orbits. (2) Apart from homogeneous reprocessing with updated analysis models, the main difference compared to the IGS Final operational products is that NOAA/NGS inputs were not submitted for the IGS reprocessing, yet they contribute heavily in the operational orbits in recent years. Also, during spring 2016, the ESA modified their orbit model so that it is no longer consistent with the one used for reprocessing. (3) A much longer span of orbits was available now, up to 11.2 years for some individual satellites, which allows a far better resolution of spectral features. (4) The procedure to compute orbit discontinuities has been further refined to account for extrapolation edge effects, improved geopotential fields, and to allow for spectral analysis of a longer time series of jumps. The satellite position time series used are complete enough that linear interpolation is necessary for only sparse gaps. So the key results are based on standard FFT power spectra (stacked over the available constellation and lightly smoothed). However, we computed Lomb-Scargle periodgrams to provide higher frequency resolution of some spectral peaks and to permit tests of the effect of excluding eclipse periods. From this test, we found that the effect of eclipses is negligible; we do not discuss the matter further in this poster.

2. AC CONTRIBUTIONS

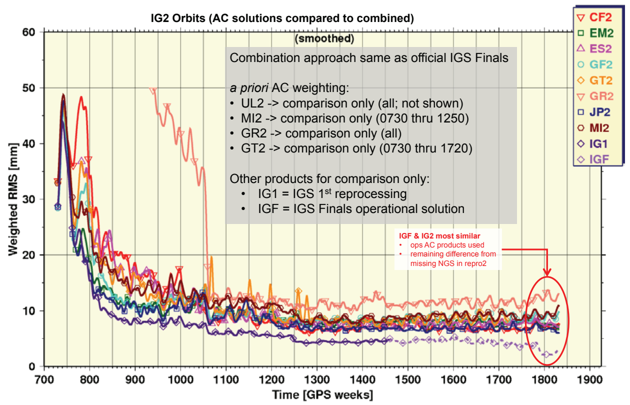


- 7 Operational Centers
  - COD, ESA, GFZ (GF2), GRG, JPL, MIT
- 2 TIGA Centers for densifying ITRF2014 with GNSS stations at tide-gauges
  - GFZ (GT2), ULR

LEGEND	
slash:	snx, sp3, erp [brdc clk in sp3]
dots:	snx, sp3, clk (5m), erp
solid:	snx, sp3, clk (30s), erp
hachure:	operational products

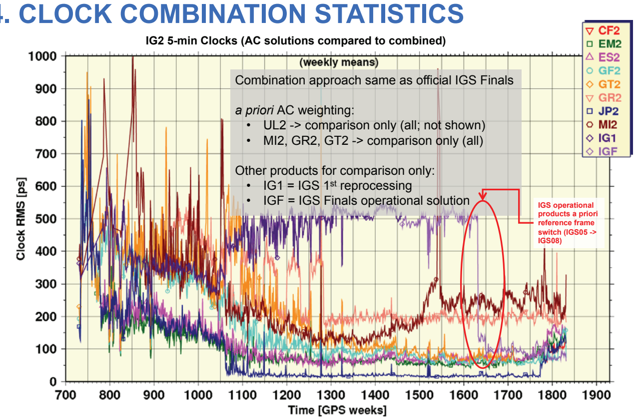
Robust number of contributing ACs to form combined orbit products. Reduced redundancy amongst clock contributing ACs compared to IGS Finals operational products could cause added noise in 5-min clocks. PPP analysis is performed (Panel 7) to assess whether the added noise is significant. JP2 only usable 30-sec clock AC from GPS Wk 1061 until GPS Wk 1773 when AC operational products were used to extend series to GPS Wk 1831.

3. ORBIT COMBINATION STATISTICS



WRMS agreement between IG2 & IG1/IGF orbits at the 5 mm level for most of repro2 span; early years range from 50 mm to 10 mm WRMS agreement.

4. CLOCK COMBINATION STATISTICS



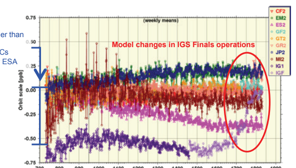
Weekly means of the daily AC clock RMS values from the repro2 5-min clock combination. The shift in RMS for IGF at the time of IGS05 -> IGS08 switch also corresponds to frame origin (Tz) and rotation (Rz) offset (see PPP analysis in Panel 7).

5. ORBITAL FRAME

Scale

- AC orbit scale drifts
  - EM2, JP2 similar scale used by GIPSY
  - ES2 similar to IG1/IGF (Wks 1050-1550)

IG2 orbit scale consistent with current operational Finals?



Translations

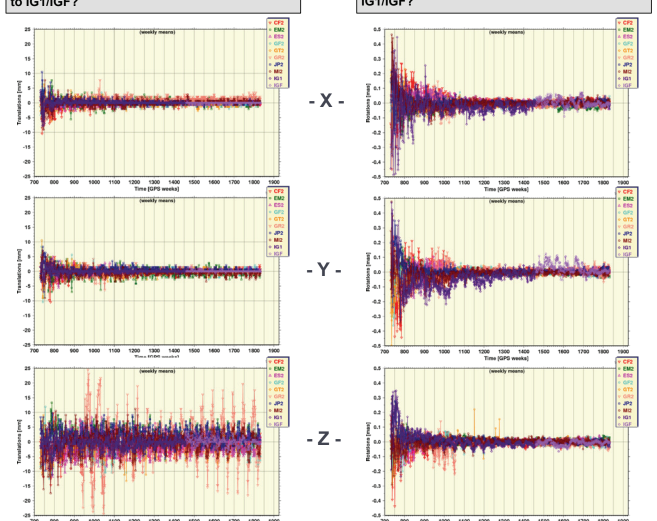
- Large annual motion in GR2 Tz offsets
- Other ACs show smaller ~annual Tz motions but with various phases
  - Up to +9/-5 mm offsets

IG2 improved Tx & Ty origin stability compared to IG1/IGF?

Rotations

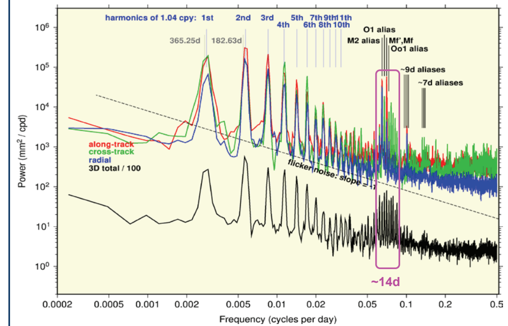
- Large offsets in early years: CF2, ES2, GT2
- Periods of spurious rotations for GF2
- Large offsets for IG1 and IGF until Wk 1702 (switch to daily products & combo s/w bug fix)

IG2 improved rotational stability compared to IG1/IGF?



6. ORBIT DAY-BOUNDARY DISCONTINUITIES

IG2 COMBINED ORBITS



Power spectra for ~11.22 years (2003.90 – 2015.12) of IG2 orbit day-boundary discontinuities

Annual, semi-annual, and harmonics of GPS draconitic year (351.6d), up to at least 10th

9-peak comb near 14d:
- sub-daily EOP tide alias (M2,O1,Oo1) errors and Mf/Mf' direct tide errors present possibly frequency shifted due to draconitic orbital frame rotation
- other spectral peaks in 14d band, in particular, in cross-track, are unexplained (see details in tables to right)

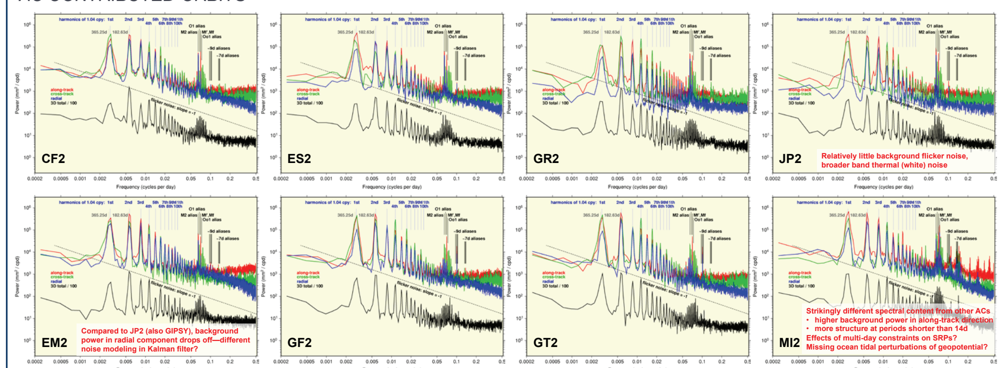
Table 1. Details for 14d band.

Observed peak	f (cpd) in orbit frame	P (d) in orbit frame	attributed source (see Table 2)
1 (ACR)	0.061994	16.131	???
2 (ACR)	0.064860	15.418	M2 alias P (shown at left)
3 (C)	0.067713	14.768	O1 alias P (shown at left)
4 (ACR)	0.070512	14.181	Mf' tide P (shown at left) + M2 alias R
5 (CR)	0.073364	13.631	??? Oo1 alias ??? (shown at left)
6 (C)	0.076225	13.119	??? Mf' tide R ???
7 (C)	0.079070	12.647	???
8 (C)	0.081898	12.210	???
9 (C)	0.084727	11.803	???

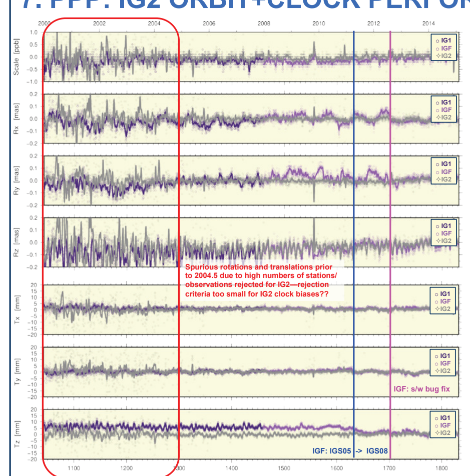
Table 2. Alias and direct tidal errors, and their frequency shifts due to rotating orbital frame.

Expected Peak	in terrestrial frame f (cpd)	in terrestrial frame P (d)	in orbit frame f (cpd)	in orbit frame P (d)	pro/retro
M2 24-hr alias	0.067727	14.765	0.064882	15.412	P
			0.070571	14.170	R
O1 24-hr alias	0.070464	14.192	0.067620	14.788	P
Mf tide	0.073203	13.661	0.070359	14.213	P
			0.076047	13.150	R
Mf' tide	0.073349	13.633	0.070505	14.183	P
			0.076193	13.125	R
Oo1 24-hr alias	0.075940	13.168	0.073096	13.681	P
			0.078784	12.693	R

AC CONTRIBUTED ORBITS



7. PPP: IG2 ORBIT+CLOCK PERFORMANCE



Avg. Scale
- IGF/IG1: -0.15 (± 0.21) ppb
- IG2: -0.04 (± 0.63) ppb

Avg. Rx
- IGF/IG1: -15.6 (± 42.6) µas
- IG2: 0.5 (± 114.8) µas

Avg. Ry
- IGF/IG1: -1.1 (± 48.8) µas
- IG2: -1.4 (± 94.0) µas

Avg. Rz
- IGF/IG1: -66.5 (± 73.0) µas
- IG2: -35.5 (± 195.1) µas

Avg. Tx
- IGF/IG1: 0.91 (± 1.36) mm
- IG2: 0.25 (± 4.77) mm

Avg. Ty
- IGF/IG1: 0.23 (± 1.40) mm
- IG2: 0.52 (± 4.48) mm

Avg. Tz
- IGF/IG1: 4.51 (± 2.54) mm
- IG2: 0.10 (± 3.37) mm

Approach

- Bernese v. 5.2 PPP analysis performed
- Daily coordinates estimated for 163 core IGS14 stations using IG1/IGF and IG2 products
- Three main steps in the analysis:
  - fit satellite positions using the SP3 orbit, IG2 official EOPs and extended CODE (6+9) orbit model
  - preprocess clocks and RINEX observations to detect and eliminate clock jumps and cycle slips
  - data reduction with iterative post-fit cleaning; outliers are phase residuals exceeding 25 mm and code residuals exceeding 2.5 m
- IERS 2010 Conventions generally implemented
- GMF/GPT2 with daily tropospheric delay gradients following Chen and Herring (1997)
- Daily coordinate sets compared to IG2 combined daily SINEX solutions, which are aligned to IGb08

Avg. RMS of coordinate residuals after frame comparison

IG1/IGF products
- E: 4.3 (± 0.96) mm
- N: 2.3 (± 0.82) mm
- U: 6.4 (± 1.43) mm

IG2 products
- E: 4.5 (± 1.39) mm
- N: 2.7 (± 1.43) mm
- U: 6.9 (± 2.04) mm

Compared to IG1/IGF, the IG2 orbits+clocks deliver long-term global coordinate sets that are noisier and also slightly more biased, perhaps due to AC repro2 satellite clock issues prior to 2004.5. Exploring mitigating steps.

For IGS14, the IGS may apply satellite clock corrections consistent with igs08.atx -> igs14.atx APV Z-PCO changes. This may offer potential for PPP users to access IGS14 using IG2 products. Still under evaluation.

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