IGS Preparations for the Next Reprocessing and ITRF

- what is IG2?
- who will contribute?
- expected performance
- remaining issues

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How will IG2 Differ from IG1?

- more details at http://acc.igs.org/reprocess2.html -

- **Longer data span (~1994 thru mid-2012)**
  - IG2 + operational prods thru 2013 -> IGS contribution to next ITRF
- **Updated models, frames & methodologies**
  - IERS 2010 Conventions
  - IGS08.SNX/igs08.atx framework (possibly updated version – IGb08)
  - AC SINEX files based on 1d TRF integrations (w/ consistent non-TRF products)
    - improve sampling of non-tidal loading displacements
    - reduces distortions in non-TRF prods (slightly noisier)
    - but no non-tidal atmospheric loading at obs eqn
  - some ACs to apply 2nd order iono corrections
  - Earth-reflected radiation pressure (albedo) modelling
    - reduce ~2.5 cm radial bias w.r.t. SLR *[e.g. Urschl et al., 2007; Zeibart et al., 2007]*
  - satellite-attitude modelling by all clock ACs
  - satellite antenna PCOs included in long-term TRF stacking
- **Sub-daily alias and draconitic errors will remain**
  - *[e.g. Griffiths & Ray, in prep]*
  - new diurnal & semi-diurnal EOP tide model needed
- **Final preps and initial processing by mid-2012**
- **Expect to deliver SINEX files for next ITRF by late 2013**

Expected AC and IG2 Products

- more details at http://acc.igs.org/reprocess2.html -

- **Daily GPS orbits & satellite clocks**
  - 15-minute intervals (SP3c format)
  - clocks in IGS timescale
- **Daily satellite & tracking station clocks**
  - 5-minute intervals (clock RINEX format)
  - in IGS timescale
- **Daily Earth rotation parameters (ERPs)**
  - from SINEX & classic orbit combinations (IGS erp format)
  - x & y coordinates of pole
  - rate-of-change of x & y pole coordinates (should not be used due to sensitivity to subdaily tidal errors)
  - excess length-of-day (LOD)
- **Weekly (IG2 only) & daily terrestrial coordinate frames with ERPs**
  - with full variance-covariance matrix (SINEX format)
- **May also provide (TBD)**
  - daily GLONASS orbits & satellite clocks
  - 30-second GPS clocks in IGS timescale
  - ionosphere maps, tropospheric zenith delay estimates
  - new bias products

Who will Contribute to IG2?

- more details at http://acc.igs.org/reprocess2.html -

- **All IGS Final-product Analysis Centers:**
  - **CODE/AIUB – Switzerland**
  - **EMR/NRCan – Canada**
  - **ESA/ESOC – Germany**
  - **CNES/GRGS – Toulouse, France**
  - **GFZ – Potsdam, Germany**
  - **JPL – USA**
  - **MIT – USA**
  - **NGS/NOAA – USA**
  - **SIO – USA**

- **Plus 1 reprocessing Center**
  - **ULR – University of La Rochelle TIGA (tide gauges), France**

- **Plus 1 Center contributing to TRF only:**
  - **GFZ TIGA – Potsdam, Germany**

COMPARISON OF EXPECTED AC DATA USAGE

ANALYSIS CENTER	SYSTEM	OBS TYPE	ORBIT DATA ARC LENGTH	DATA RATE	ELEVATION CUTOFF	ELEVATION INVERSE WGTS
CODE	GPS + GLO	DbDiff (weak redundant)	24 + 24 + 24 h	3 min	3 deg	$1/\cos^2(z)$
EMR	GPS	UnDiff	24 h	5 min	10 deg	none
ESA	GPS + GLO	UnDiff	24 h	5 min	10 deg	$1/\sin^2(e)$
GFZ (& GTZ)	GPS + ?GLO?	UnDiff	24 + 24 + 24 h	5 min	7 deg	1/2sin(e) for e < 30 deg
GRG	GPS	UnDiff	24 h	5 min	10 deg	none
JPL	GPS	UnDiff	3 + 24 + 3 h	5 min	7 deg	none
MIT	GPS	DbDiff (weak redundant)	24 h (SRPs over 9d)	2 min	10 deg	$a^2 + (b^2/\sin^2(e))$ a,b from site residuals
NGS	GPS	DbDiff (redundant)	24 h	30 s	10 deg	$[5 + (2/\sin(e))\ \text{cm}]^2$
SIO	GPS	DbDiff (weak redundant)	24 h	2 min	10 deg	$a^2 + (b^2/\sin^2(e))$ a,b from site residuals
ULR	GPS	DbDiff (weak redundant)	24 h	3 min	10 deg	$a^2 + (b^2/\sin^2(e))$ a,b from site residuals

COMPARISON OF EXPECTED AC SATELLITE DYNAMICS

ANALYSIS CENTER	NUTATION & EOPs	SRP PARAMS	VELOCITY BRKs	ATTITUDE	SHADOW ZONES	EARTH ALBEDO
CODE	IAU 2000A$_{R06}$; BuA ERPs	D,Y,B scales; B 1/rev	every 12 hr + constraints	nominal yaw rates used	E+M: umbra & penumbra	? applied ?
EMR	IAU 2000A$_{R06}$; BuA ERPs	X,Y,Z scales stochastic	none	yaw rates estimated	E: umbra & penumbra	applied
ESA	IAU 2000; BuA ERPs	D,Y,B scales; B 1/rev	none; Along, Along 1/rev accelerations	nominal yaw rates used	E+M: umbra & penumbra	applied + IR
GFZ (& GTZ)	IAU 2000; GFZ ERPs	D,Y scales	@ 12:00 + constraints	yaw rates estimated	E+M: umbra & penumbra	applied + AT
GRG	IAU 2000; IERS C04 & BuA ERPs	D,Y scales; X & D 1/rev	stoch. impulse during ecl.	yaw rates estimated	E+M: umbra & penumbra	applied + IR
JPL	IAU 2000A$_{R06}$; IERS C04	X,Y,Z scales stochastic	none	yaw rates estimated	E+M: umbra & penumbra	applied
MIT	IAU 2000; BuA ERPs	D,Y,B scales; B(D,Y) 1/rev	none; 1/rev constraints	nominal yaw rates used	E+M: umbra & penumbra	applied
NGS	IAU 2000; IGS PM; BuA UT1	D,Y,B scales; B 1/rev	@ 12:00 + constraints	none; del eclipse data	E+M: umbra & penumbra	applied + AT
SIO	IAU 2000; BuA ERPs	D,Y,B scales; D,Y,B 1/rev	none; 1/rev constraints	nominal yaw rates used	E+M: umbra & penumbra	applied
ULR	IAU 2000; BuA ERPs	D,Y,B scales; D,Y,B 1/rev	none	nominal yaw rates used	E+M: umbra & penumbra	applied

COMPARISON OF EXPECTED AC TIDAL MODELS

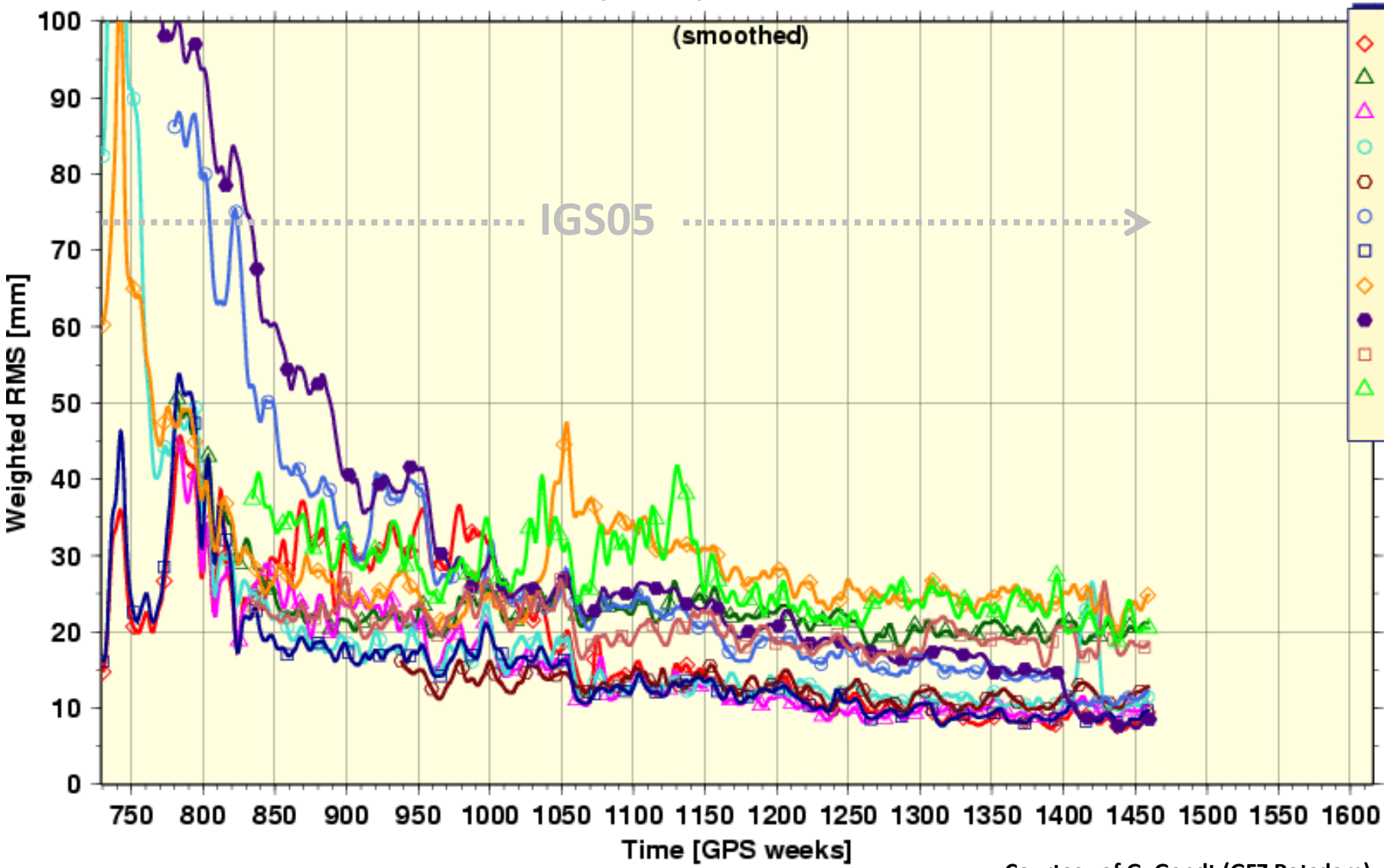
ANALYSIS CENTER	SOLID EARTH	EARTH POLE	OCEAN LOAD	OCEAN POLE	OCEAN CMC	SUBDAILY EOPs
CODE	IERS 2010; dehanttideinel.f	eqn 23a/b mean pole	FES2004; hardisp.f	none	sites & SP3	IERS 2010; subd nutation
EMR	IERS 2010	eqn 23a/b mean pole	FES2004; hardisp.f	none	sites & SP3	IERS 2010
ESA	IERS 2010; dehanttideinel.f	eqn 23a/b mean pole	FES2004; hardisp.f	none	sites & SP3	IERS 2010 & PMsdnut.for
GFZ (& GTZ)	IERS 2010	eqn 23a/b mean pole	FES2004	none	sites & SP3	IERS 2010; PMsdnut.for
GRG	IERS 2010	eqn 23a/b mean pole	FES2004	none	sites & SP3	IERS 2010
JPL	IERS 2010	eqn 23a/b mean pole	FES2004; hardisp.f	none	sites & SP3	IERS 2010
MIT	IERS 2010	eqn 23a/b mean pole	FES2004	none	sites & SP3	IERS 2010
NGS	IERS 2010; dehanttideinel.f	eqn 23a/b mean pole	FES2004; hardisp.f	none	sites & SP3	IERS 2010 & PMsdnut.for
SIO	IERS 2010	eqn 23a/b mean pole	FES2004	none	sites & SP3	IERS 2010
ULR	IERS 2010	eqn 23a/b mean pole	FES2004	none	sites & SP3	IERS 2010

COMPARISON OF EXPECTED AC GRAVITY FORCE MODELS

ANALYSIS CENTER	GRAVITY FIELD	EARTH TIDES	EARTH POLE	OCEAN TIDES	OCEAN POLE	RELATIVITY EFFECTS
CODE	EGM2008; C21/S21 due to PM	IERS 2010	IERS 2010	IERS 2010 – FES2004	none	dynamic corr & bending applied
EMR	EGM2008	IERS 2010	IERS 2010	IERS 2010 – FES2004	none	no dynamic corr; bending applied
ESA	EIGEN-GL05C	IERS 2010	IERS 2010	IERS 2010 – FES2004	none	dynamic corr & bending applied
GFZ (& GTZ)	JGM3; C21/S21 due to PM	IERS 2010	IERS 2010	IERS 2010 – FES2004	none	no dynamic corr & bending applied
GRG	EIGEN GL04S; C21/S21 due to PM	IERS2010	IERS 2010	IERS 2010 – FES2004	none	dynamic corr; bending applied
JPL	EGM2008; C21/S21 due to PM; C20, C30, C40	IERS 2010	IERS 2010	IERS 2010 – FES2004 Desai & Yuan	IERS 2010; eqn 6.23a	dynamic corr & bending applied
MIT	EGM2008; C21/S21 due to PM	IERS 1992; Eanes Love #	none	none	none	no dynamic corr; bending applied
NGS	EGM2008	IERS 2010	IERS 2010	IERS 2010 – FES2004	none	dynamic corr & bending applied
SIO	EGM2008; C21/S21 due to PM	IERS 1992; Eanes Love #	none	none	none	no dynamic corr; bending applied
ULR	EGM2008; C21/S21 due to PM	IERS 1992; Eanes Love #	none	none	none	no dynamic corr; bending applied

Expected Performance of IG2?

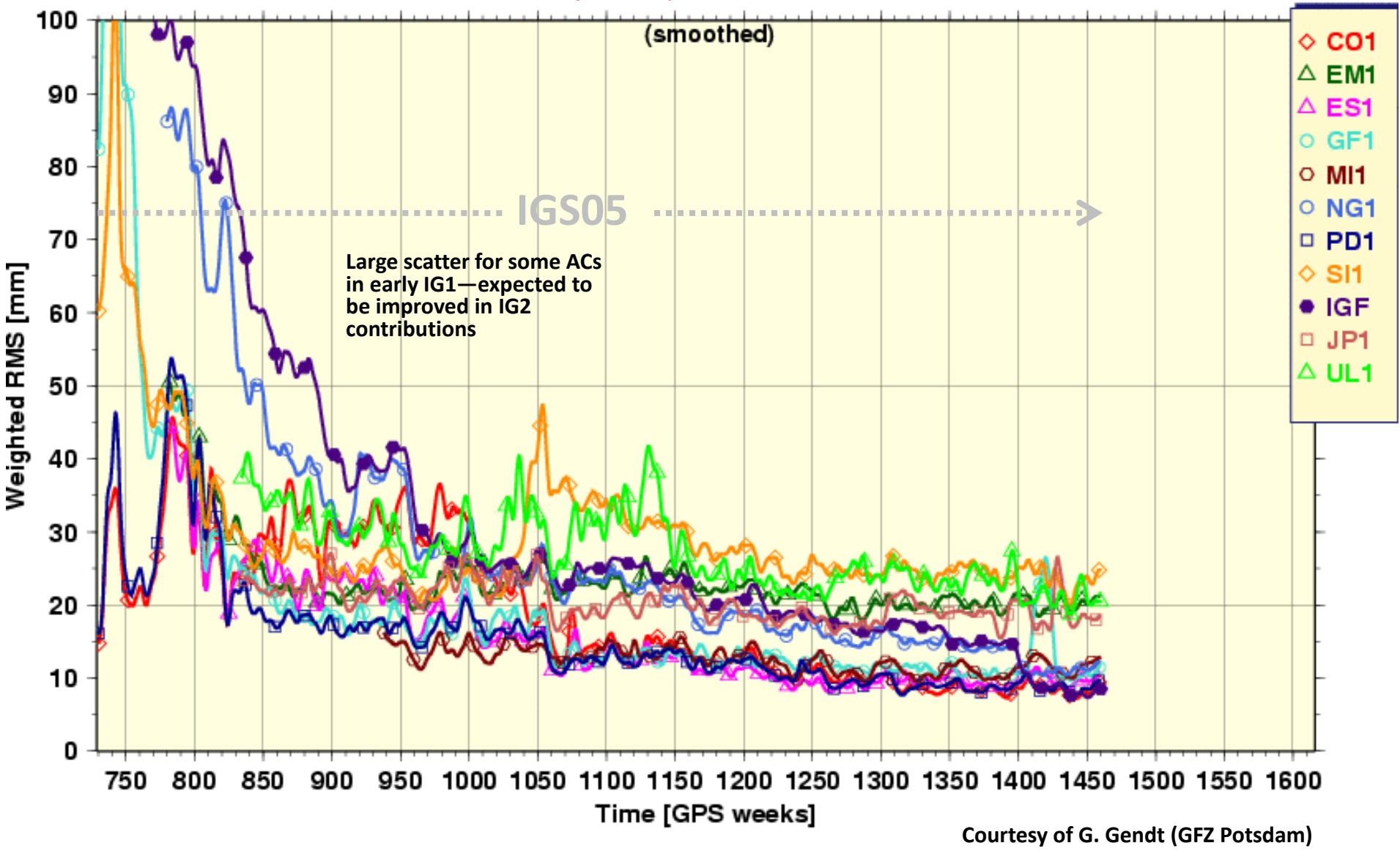
- WRMS of AC repro1 orbits wrt IG1 -



Courtesy of G. Gendt (GFZ Potsdam)

Expected Performance of IG2?

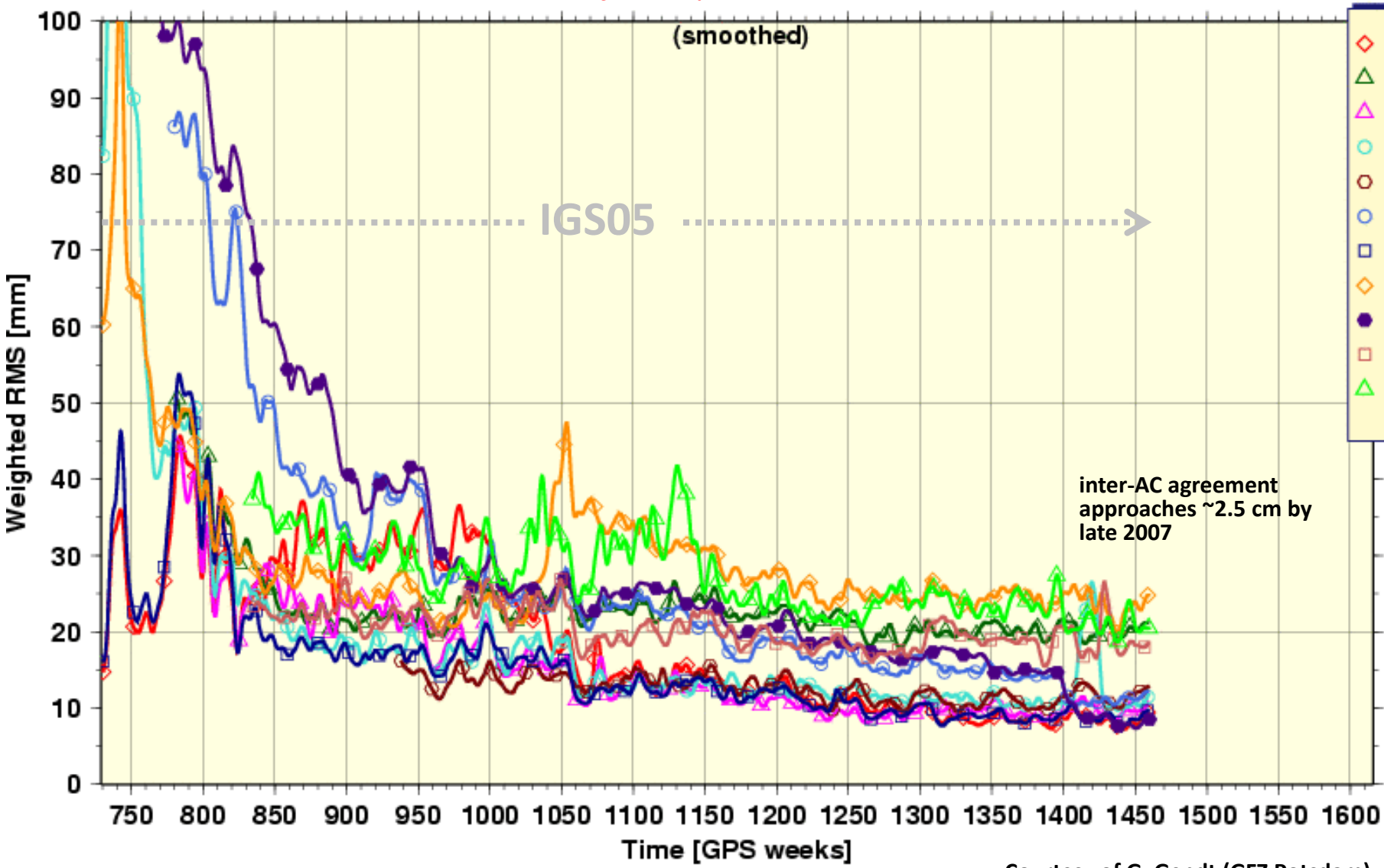
- WRMS of AC repro1 orbits wrt IG1 -



Courtesy of G. Gendt (GFZ Potsdam)

Expected Performance of IG2?

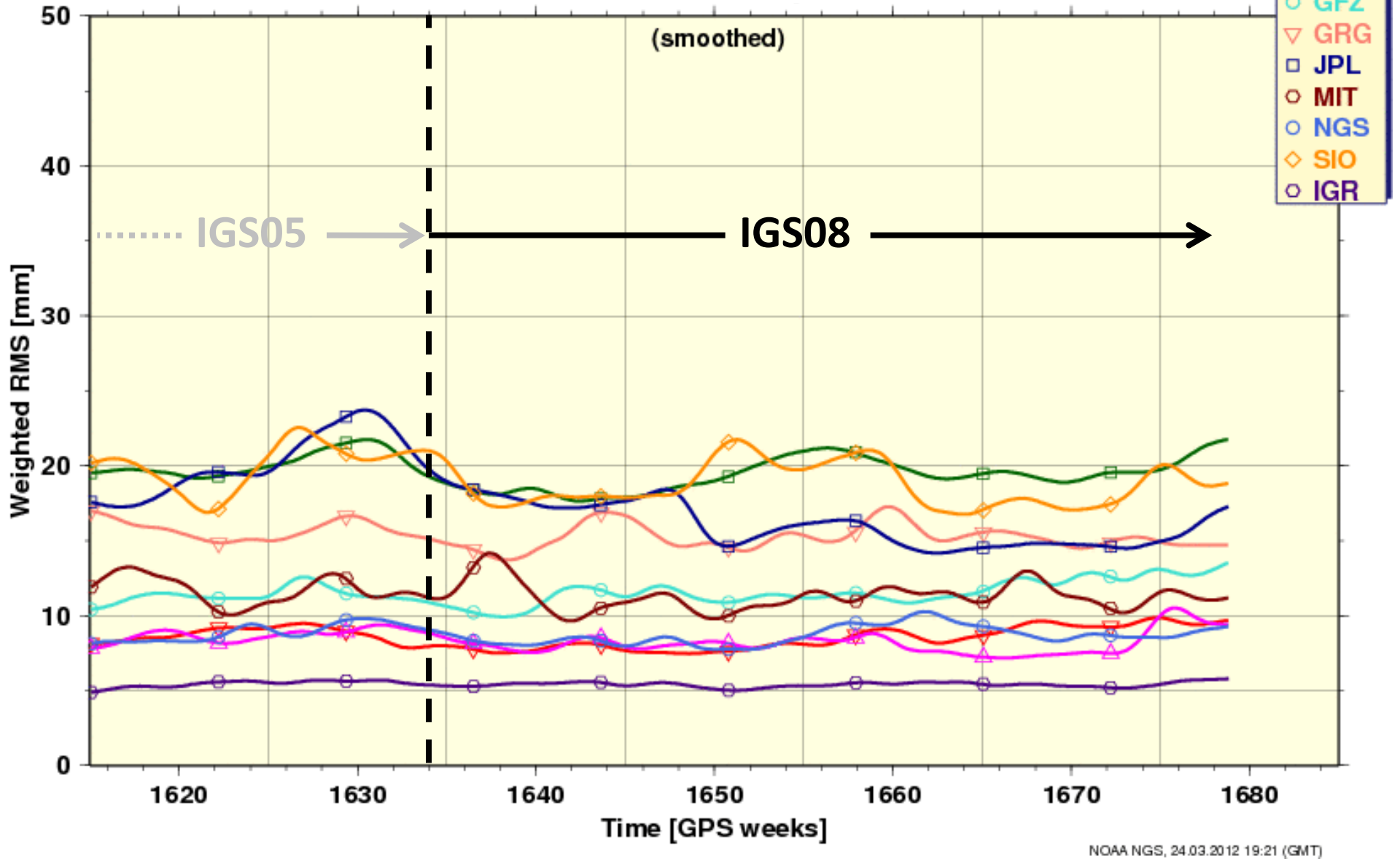
- WRMS of AC repro1 orbits wrt IG1 -



Courtesy of G. Gendt (GFZ Potsdam)

Expected Performance of IG2?

- WRMS of current AC orbits wrt IGS -



Expected Performance of IG2?

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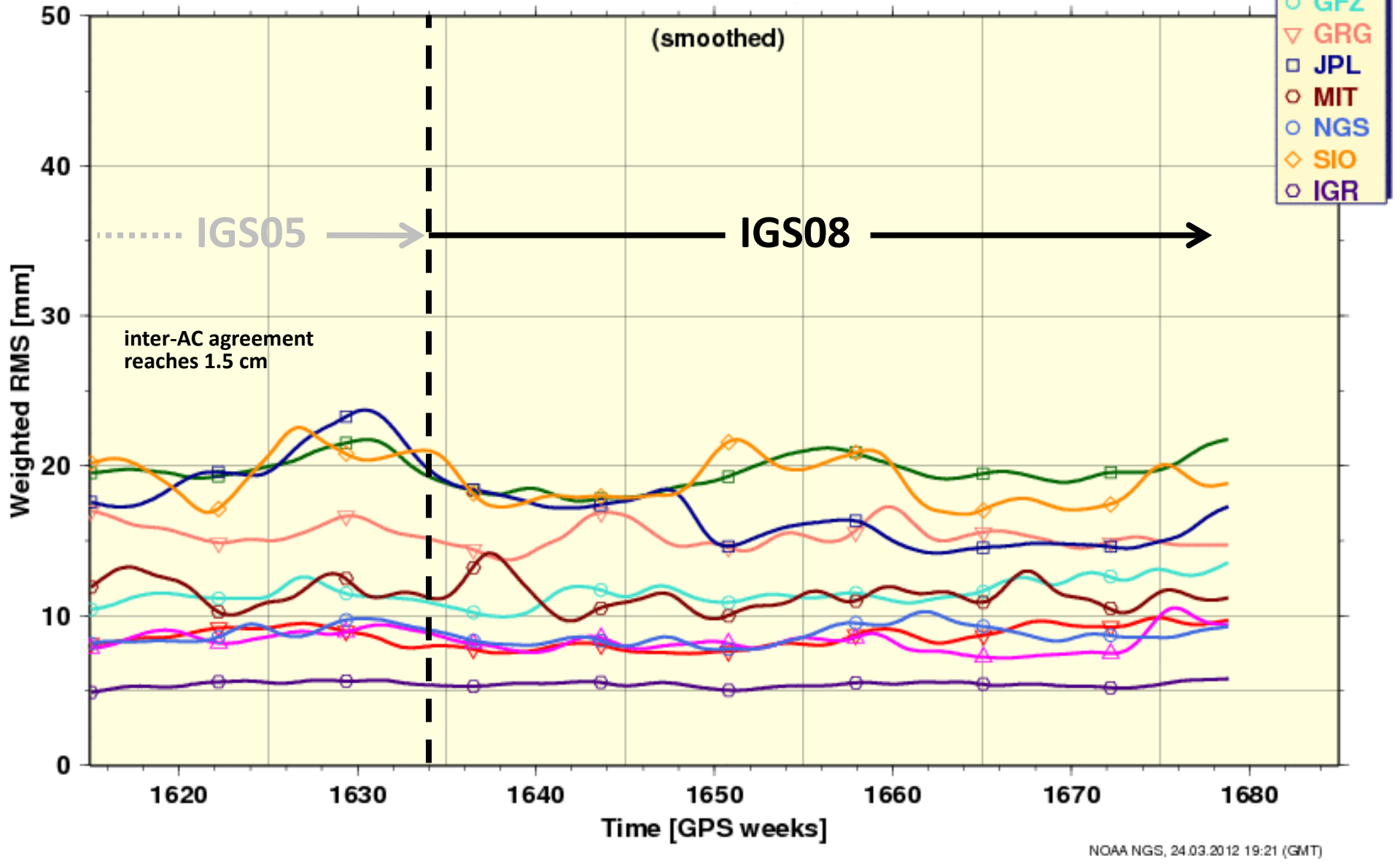

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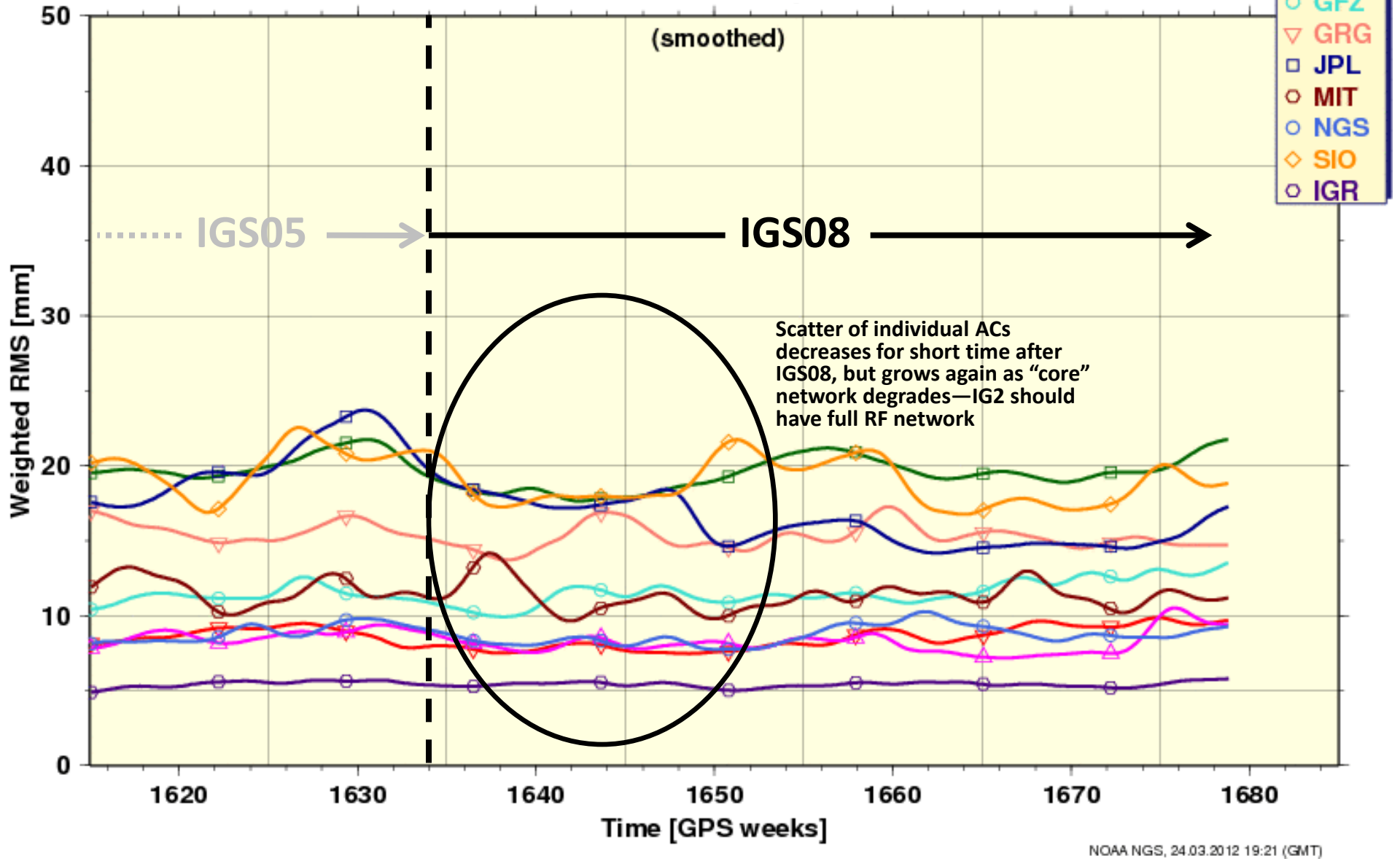
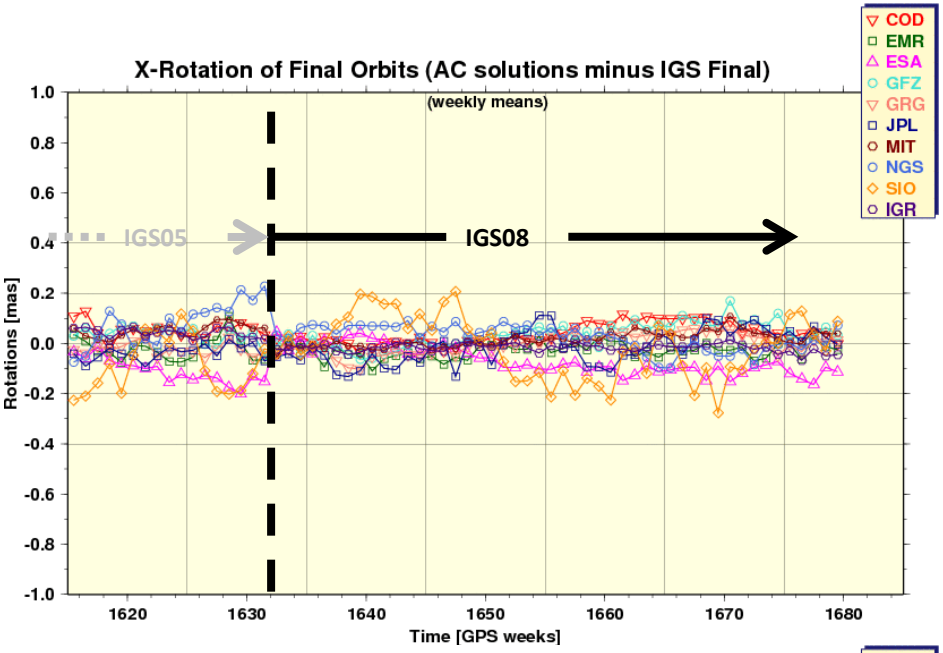
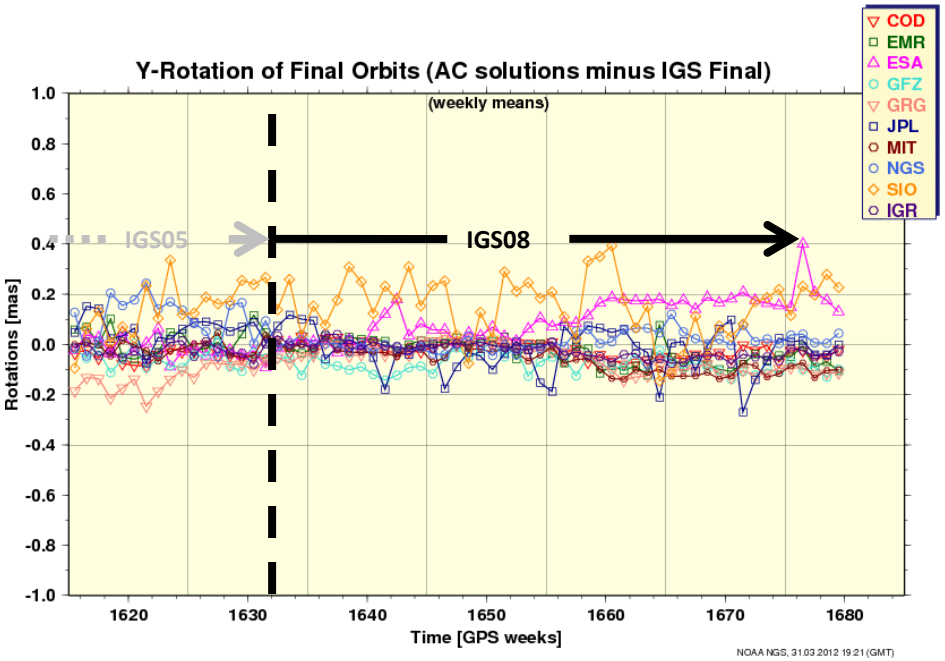
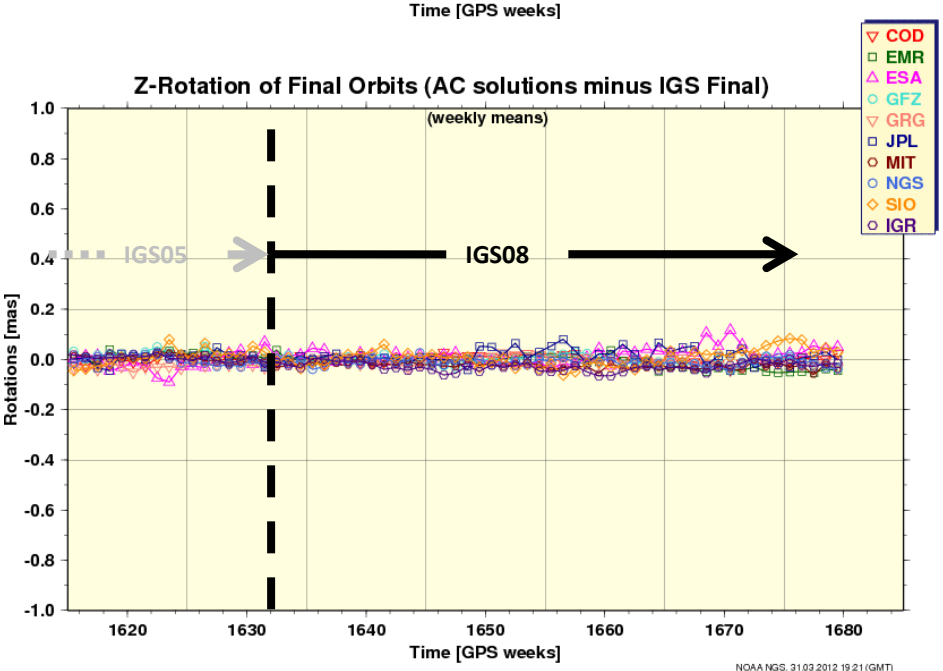


Expected Performance of IG2?

- Rotational scatter of AC orbits wrt IGS -







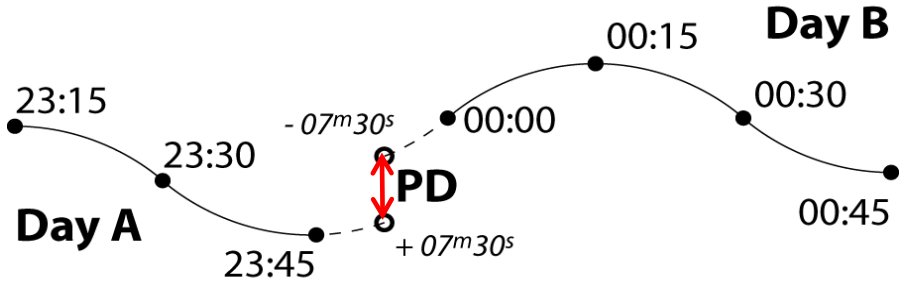
- **First ~15 weeks of IGS08, scatter in most AC rotations quite small**
  - **increase in scatter correlated w/decrease in # of "core" stations**
- **Rotational errors for single AC distort the combined orbit (see RY for ESA @ ~1660)**
  - **long-term orientation of IG2 orbit frame maybe improved over IG1, but rotational scatter still dominates**

Expected Performance of IG2?

- IGS orbit jumps as measure of orbit inaccuracy -

- **Lack of an independent "truth" for IGS orbits**
  - can compute discontinuities between daily orbit sets
  - doing so aliases sub-daily differences into longer-period signals
  - approach can reveal systematic errors

- **Orbit jumps**
  - fit orbits for each day with BERNE (6+9) orbit model
  - parameterize fit as $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ plus **3 SRPs per SV component**



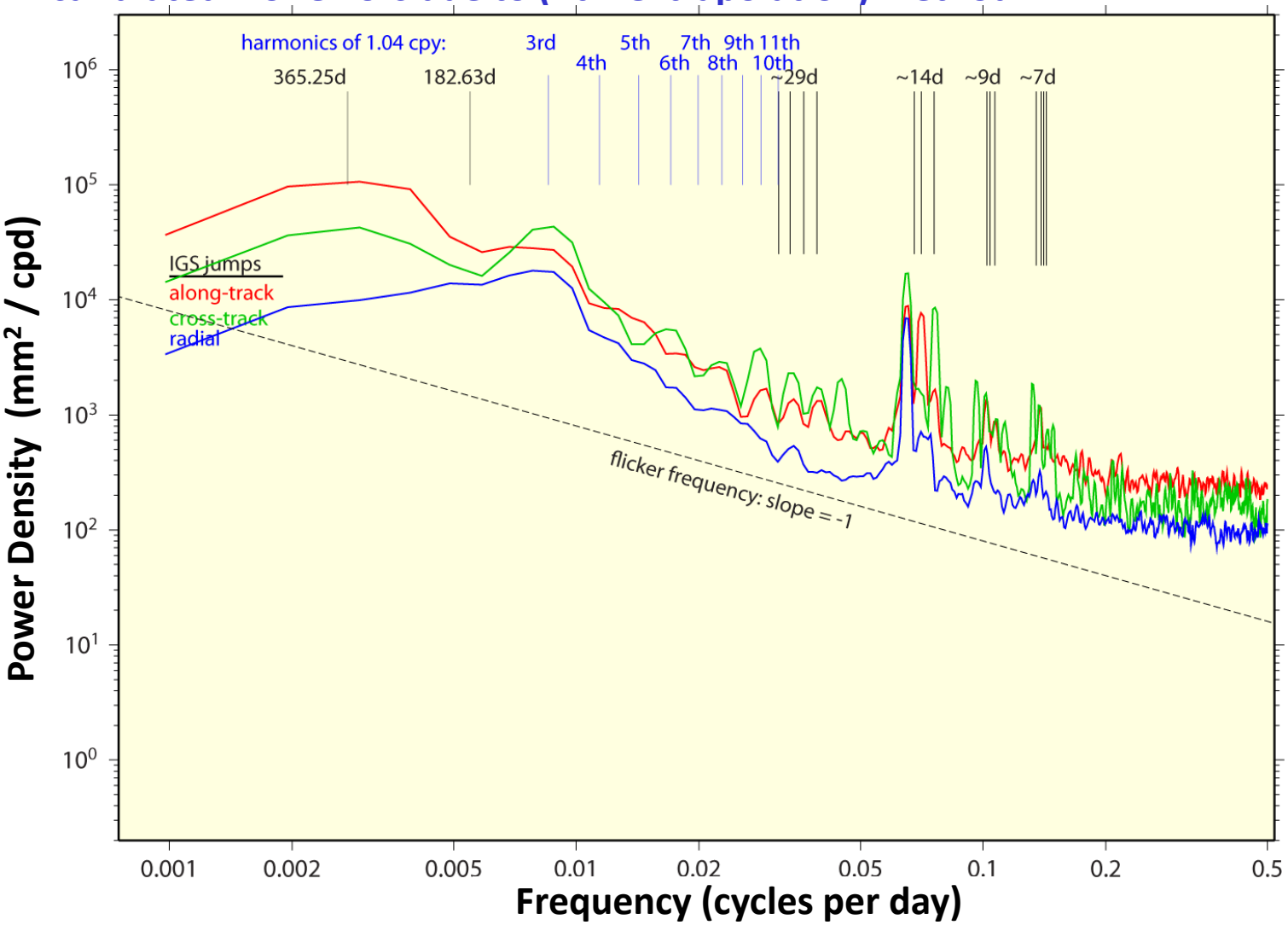
  - fit 96 SP3 orbit positions for each SV as pseudo-observations for Day A
  - propagate fit forward to 23:52:30 for Day A
  - repeat for Day B & propagate backwards to 23:52:30 of day before
  - compute IGS orbit jumps at 23:52:30

- **Compute IGS orbit jumps over recent ~5.6 yr span**

Expected Performance of IG2?

- IGS orbit jumps as measure of orbit inaccuracy (cont.) -

- **IGS orbit jumps computed from Berne model fit to adjacent days**
  - **compute spectra for each SV orbit jump set, stack & smooth**
  - **"calibrated" for errors due to (fit + extrapolation) method**



Expected Performance of IG2?

- IGS orbit jumps as measure of orbit inaccuracy (cont.) -

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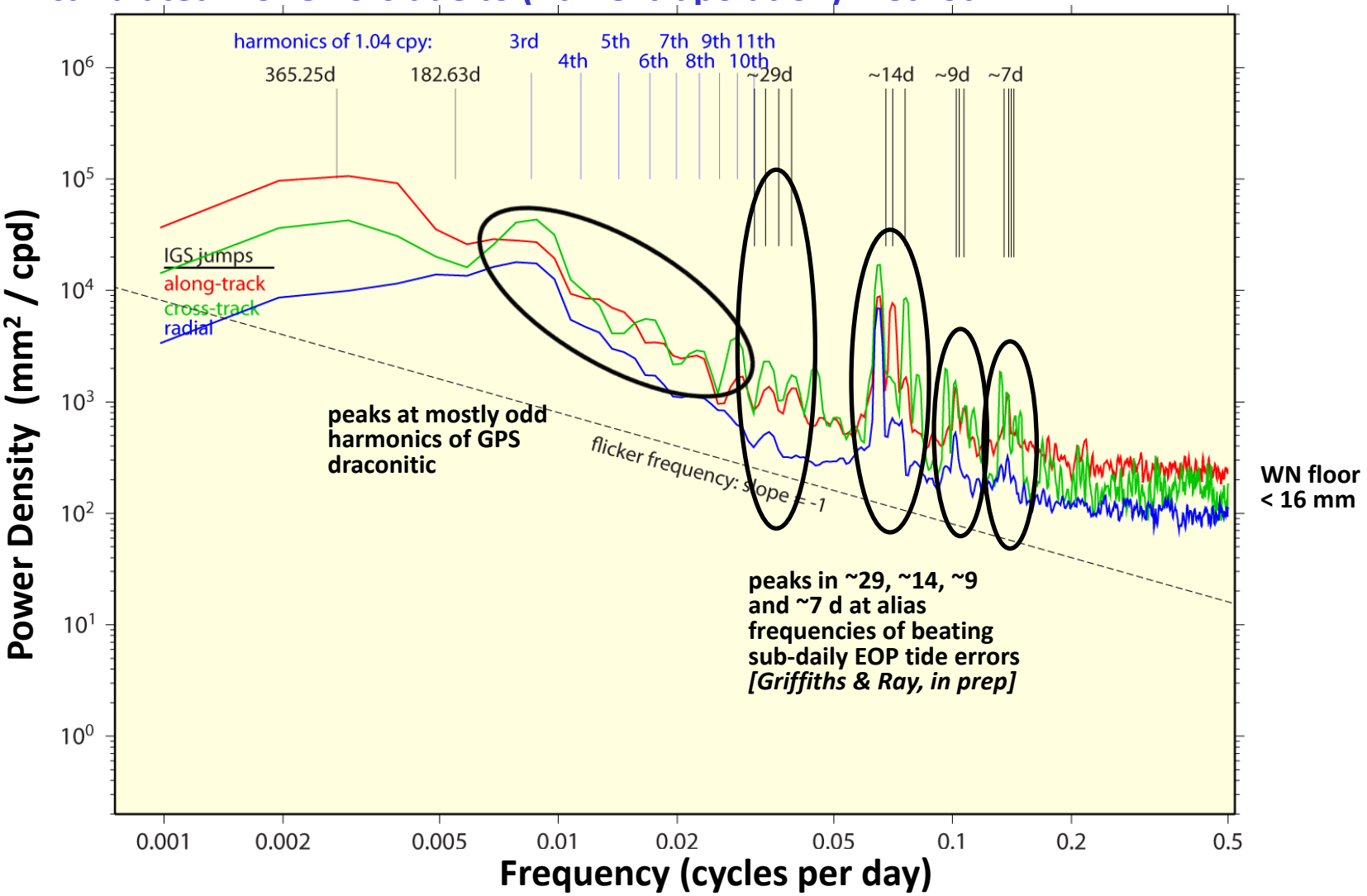
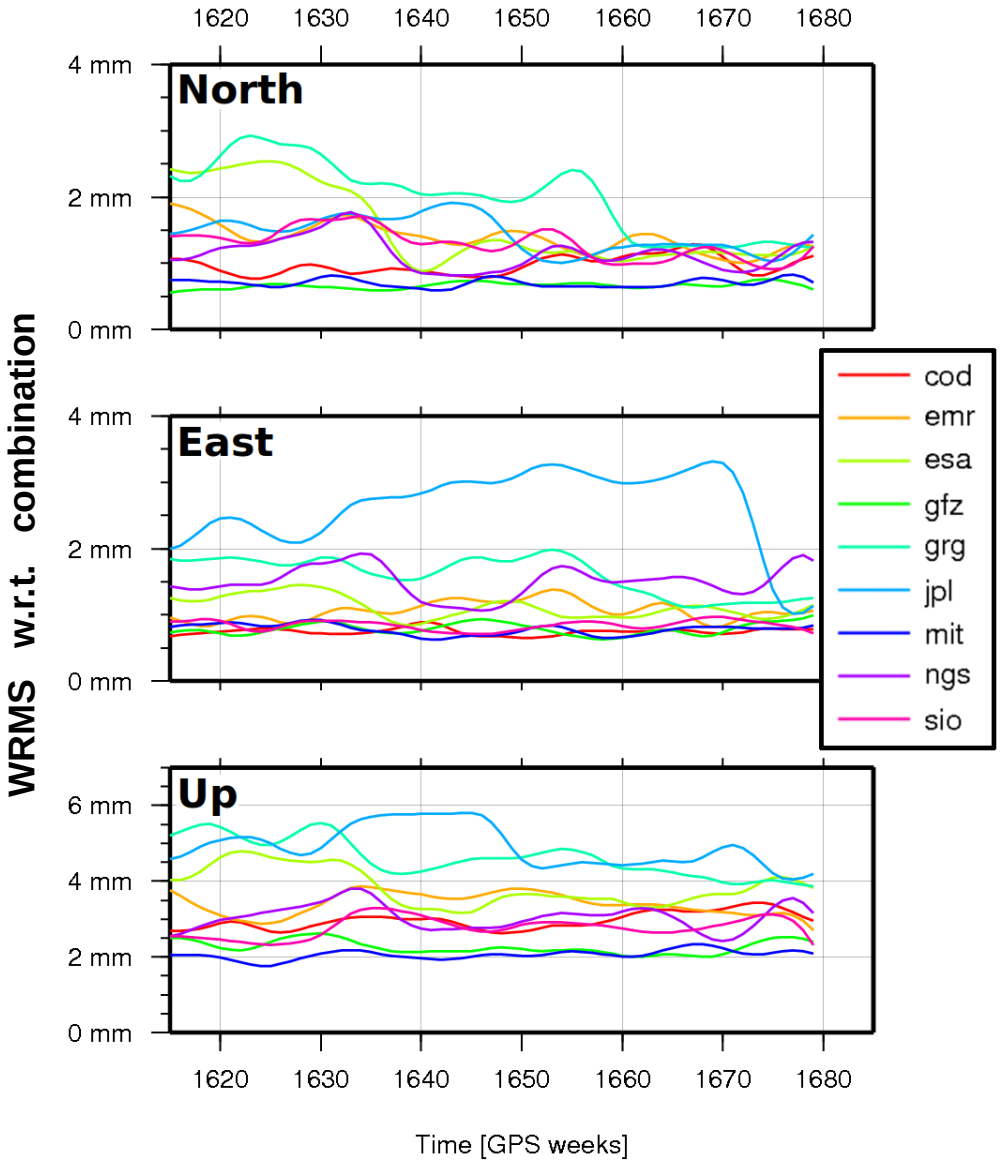


Expected Performance of IG2 TRFs?

- RMS of Current AC TRFs wrt IGS -



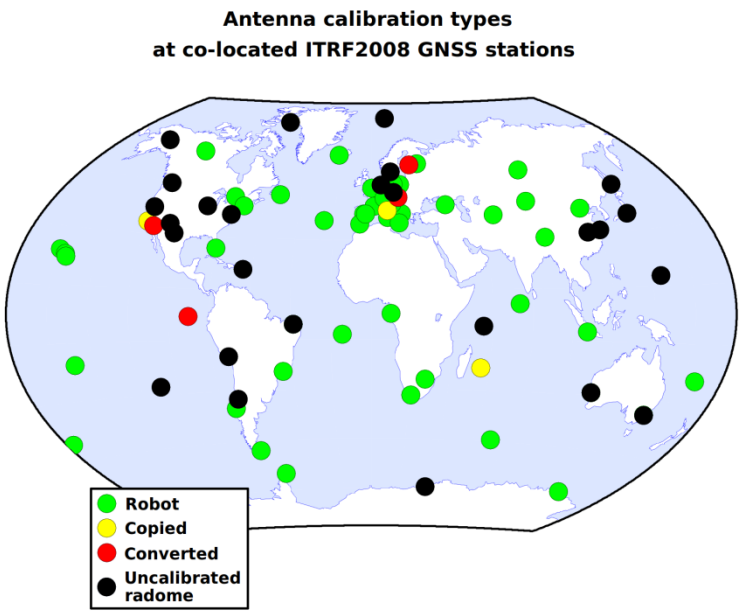
- **Improvement in precision expected from:**
  - horizontal tropo gradients estimated by all ACs
  - 2nd order iono corrections
  - Earth-reflected radiation pressure (albedo) modelling
- **Improvement in accuracy expected from:**
  - igs08.atx (depending on antenna type)
- **Switch to daily AC TRFs:**
  - should not impact quality of weekly combined TRFs (input to ITRF)

IG2 contribution to the next ITRF

- **Contribution to the ITRF scale rate?**
  - satellite PCOs will be included in combination & stacking of IG2 TRFs.
  - assumption that PCOs are constant → "intrinsic GNSS scale rate"

- **No contribution to the ITRF origin yet**
  - remaining unmodeled orbital forces
  - origins of IG2 TRFs likely not reliable enough

- **Systematic errors will remain!**
  - main source: antenna calibrations
    - > 1 cm errors revealed at stations with uncalibrated radomes
    - few mm errors likely at stations with "converted" antenna calibrations
  - will cause trouble in use of local ties for ITRF colocation sites
    - consider to exclude in next ITRF



Summary (1/2)

- Latest models, frames & methods to have largest impact since IG1
  - IERS 2010 Conventions
  - IGS08/igs08.atx framework
  - Earth-reflected radiation pressure (albedo) modelling

  - sub-daily & draconitic signatures will remain

- To result in full history of IG2 products (1994 to present)
  - truly daily products (assuming all ACs remove overconstraints & smoothing):
    - GPS orbits & SV clocks (SP3c) @ 15 min intervals
    - GPS SV and station clocks (clock RINEX) @ 5 min intervals
    - Earth Rotation Parameters (IGS ERP)
    - terrestrial coordinate frames (IERS SINEX)

  - expected delivery for next ITRF -> late 2013

- And possibly some ancillary products
  - GLONASS orbits & clocks
  - 30-second SV & station clocks
  - bias products

Summary (2/2)

- **Generally, IGS aims for ~1 cm orbit & ~1 mm terrestrial accuracies**
  - to meet needs of most demanding user applications

- **Performance of current IGS products quite good**
  - GPS orbits
    - overall <2.5 cm (1D)
    - errors dominated primarily by rotational scatter in AC orbital frames
    - random noise ~1.6 cm
    - sub-daily alias and draconitic errors from IERS diurnal/semi-diurnal tides
  - EOPs *[Ray & Griffiths; G5.1 Monday AM]*
    - PM-x & PM-y: <30 μas
    - dLOD: ~10 μs
  - terrestrial frames (weekly)
    - ~2 mm N&E
    - ~5 mm U

- **IG2 quality should approach current IGS prods, maybe better**
  - quality for later (~2000 -> present) IG2 products will be best
  - early IG2 probably better than IG1 equivalents, but not as good as later IG2

Extra Slides