CURRENT POSITIONING ACCURACY USING SPACE GEODESY

- **Assessment methodologies**
  - comparison metrics for precision & accuracy evaluations
- **Example of estimates for IGS orbit precision**
- **Absolute accuracy limitations**
- **Progress in geodetic precision & accuracy**

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Comparison Types for Quality Assessments

Precision metrics
(internal)

Overlapping arcs
- for dynamical parameters
- data correlations usually ignored

Independent analyses
- different software & procedures
- data correlations usually ignored

Differences at arc boundaries
- for dynamical parameters

Repeatabilities
- for static or linear parameters
- but few parameters truly linear

MORE RELIABLE

Accuracy metrics
(external)

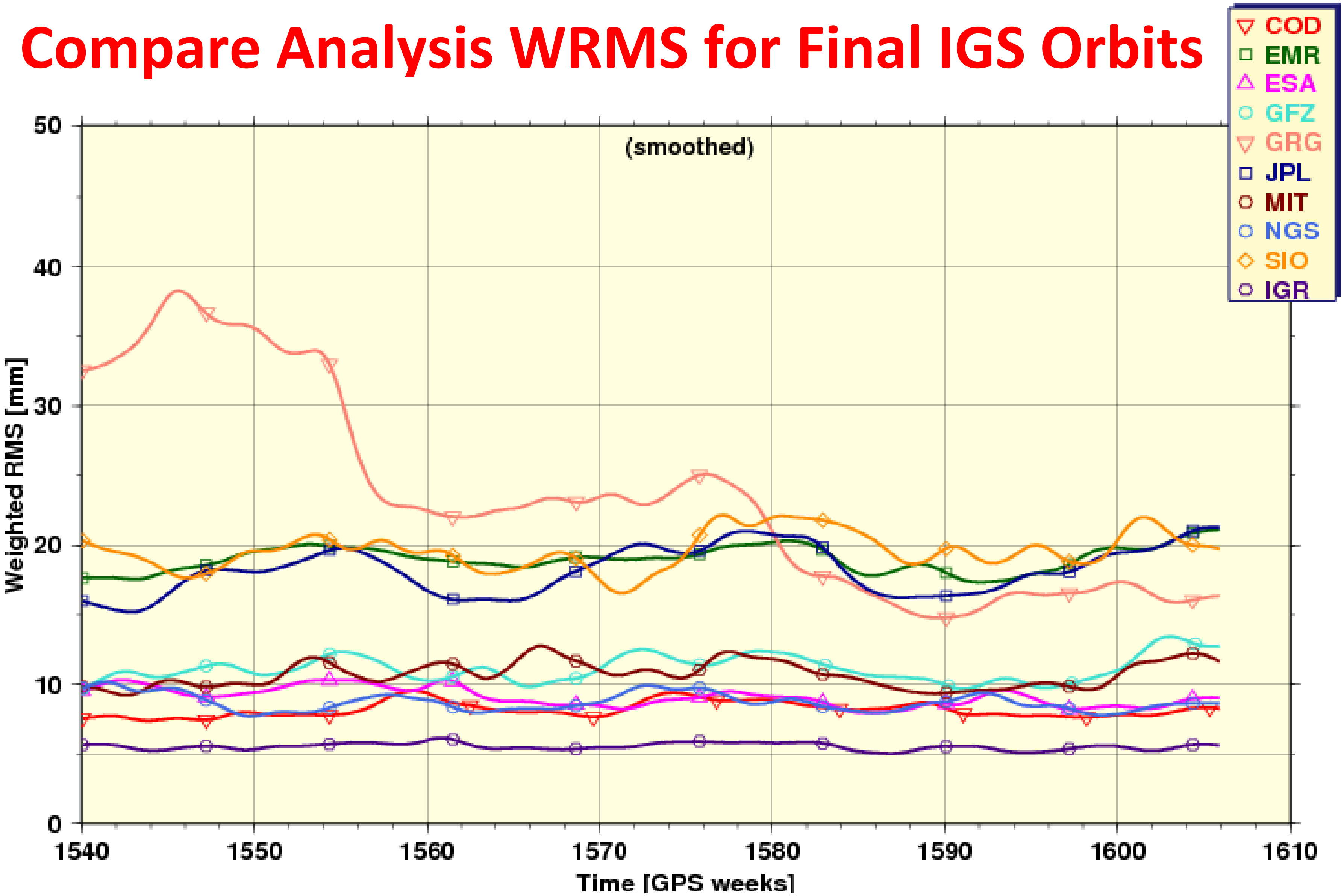
Independent techniques
- requires methods of comparable accuracy
- errors in comparison links often dominate

Metrological traceability
- to base SI units, ideally
- rarely attempted
- not practical for distances > ~1 km

Precision via Comparison of Independent Analysis

Example using IGS Final Orbits

Compare Analysis WRMS for Final IGS Orbits



- **Could be interpreted to imply few-mm IGS orbit precision**
  - **but only shows sub-daily, quasi-random WRMS differences**
  - **ignores systematic, common-mode, & long-term (>1 d) errors**

Compare IGS Rapid vs Final Orbits

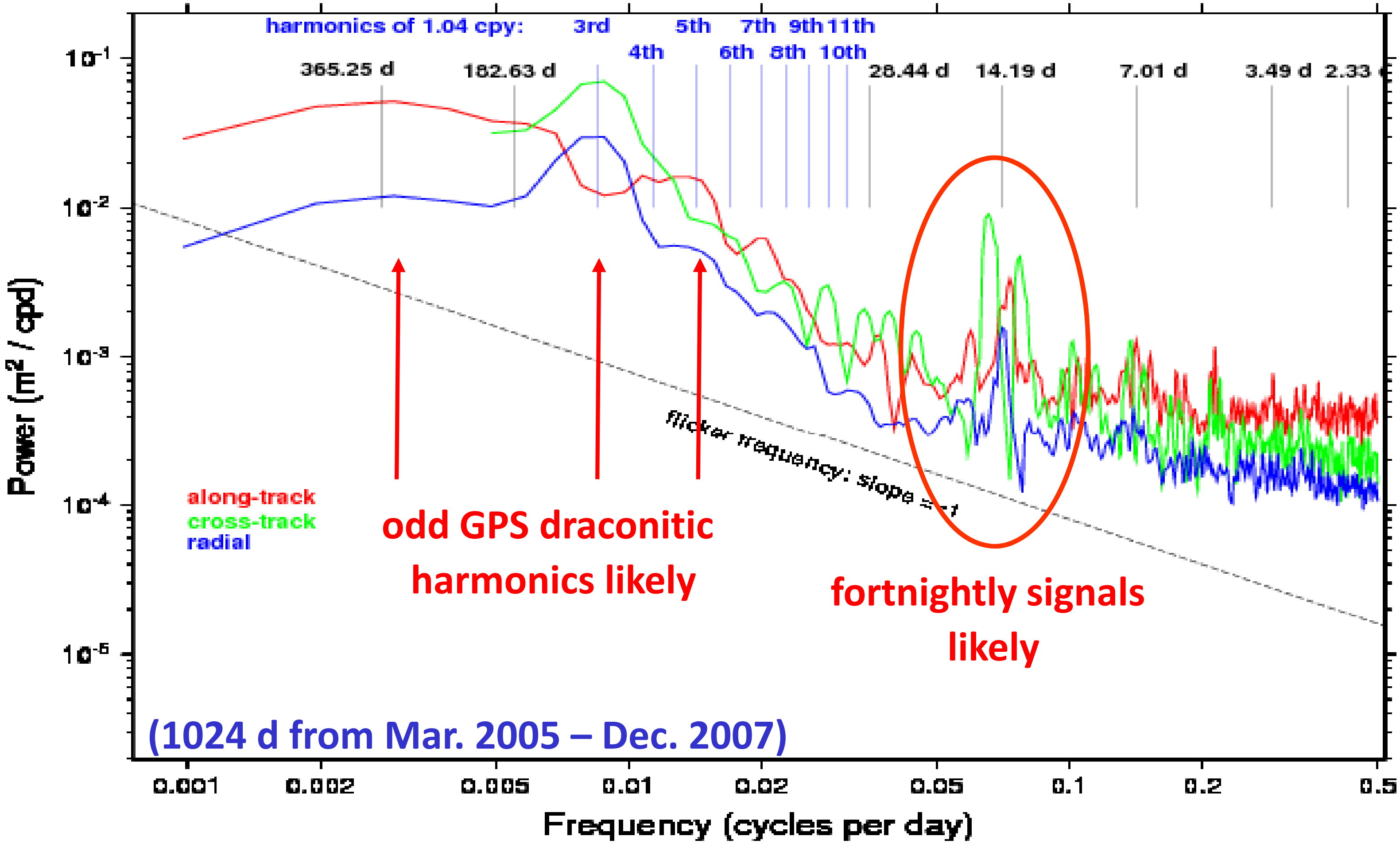
Rapid Orbit Diffs (mm) wrt IGS (2009)											
	DX	DY	DZ	RX	RY	RZ	SCL	RMS	WRMS	MEDI	TOTAL ERROR
mean	-0.3	0.3	0.2	0.5	**-5.3**	**-4.6**	1.2	5.8	**5.6**	5.1	**11.9**
std dev	0.7	0.8	1.2	**4.7**	**3.6**	**4.6**	1.0	0.7	0.7	0.7	

- **Net daily constellation rotations are leading orbit error**
  - **must come mostly from modelling of satellite dynamics**
  - **RY & RZ non-zero mean biases support this view**
- **Suggests short-period (<1 d) orbit precision > 11.9/√2 ≈ 8.4 mm**
- **But possible common-mode IGR/IGS errors not visible here**
  - **mainly long-period (> 1 d) errors**
  - **e.g., due to Reference Frame or analytical form of empirical orbit model**

Precision via Differences at Arc Boundaries

Example using IGS Final Orbits

A,C,R Spectra of IGS Orbit Differences at Midnights

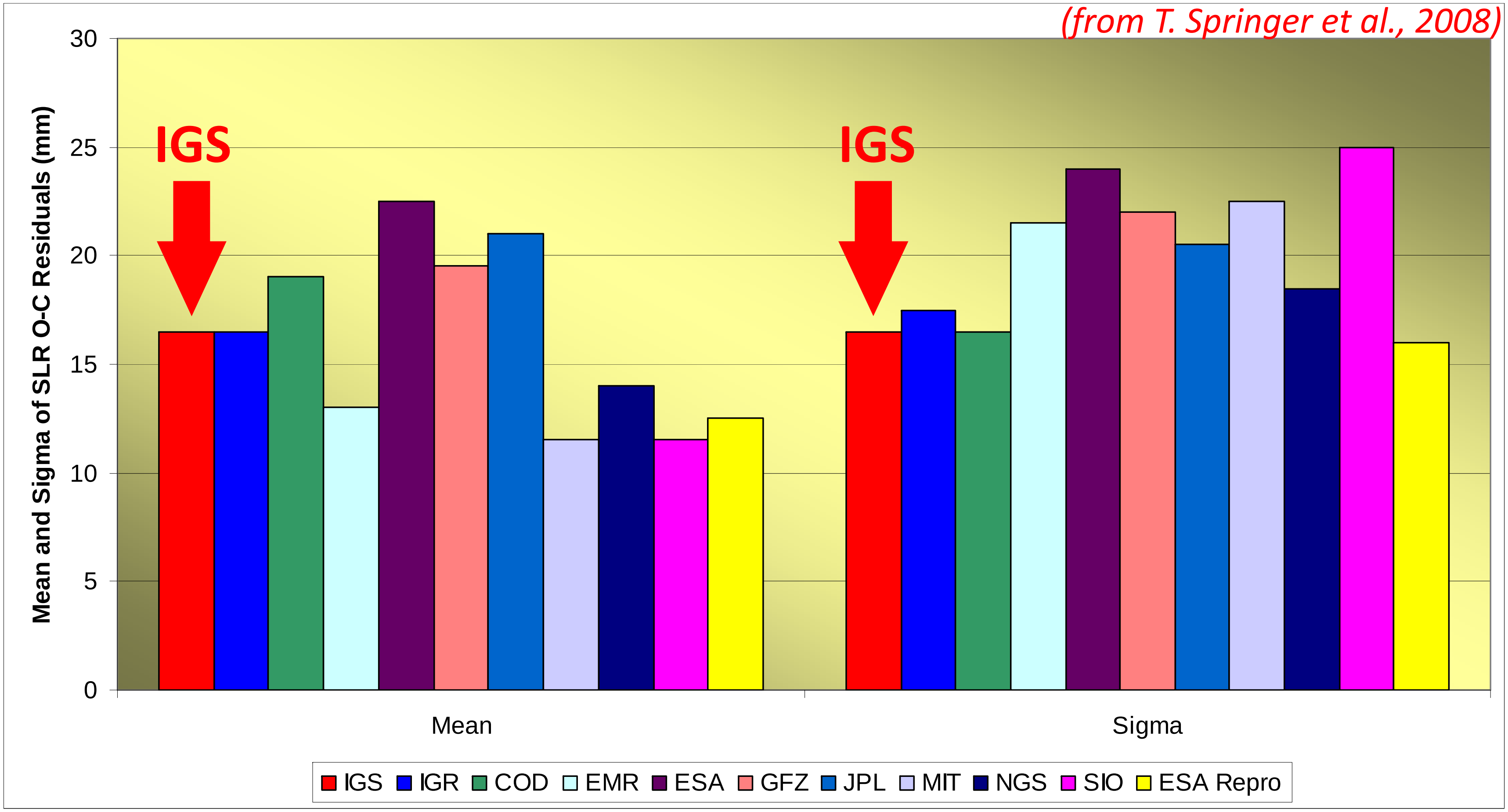


- Long-period errors dominate => IGS orbit 1D accuracy ~2 cm
  - draconitic signatures from orbit mismodeling leak into station positions
  - fortnightly signals could be aliases of subdaily tidal EOP errors
- Background errors follow ~flicker noise on seasonal time scales
  - transition to whiter noise for <14 d

Summary of IGS Orbit Precision & Accuracy

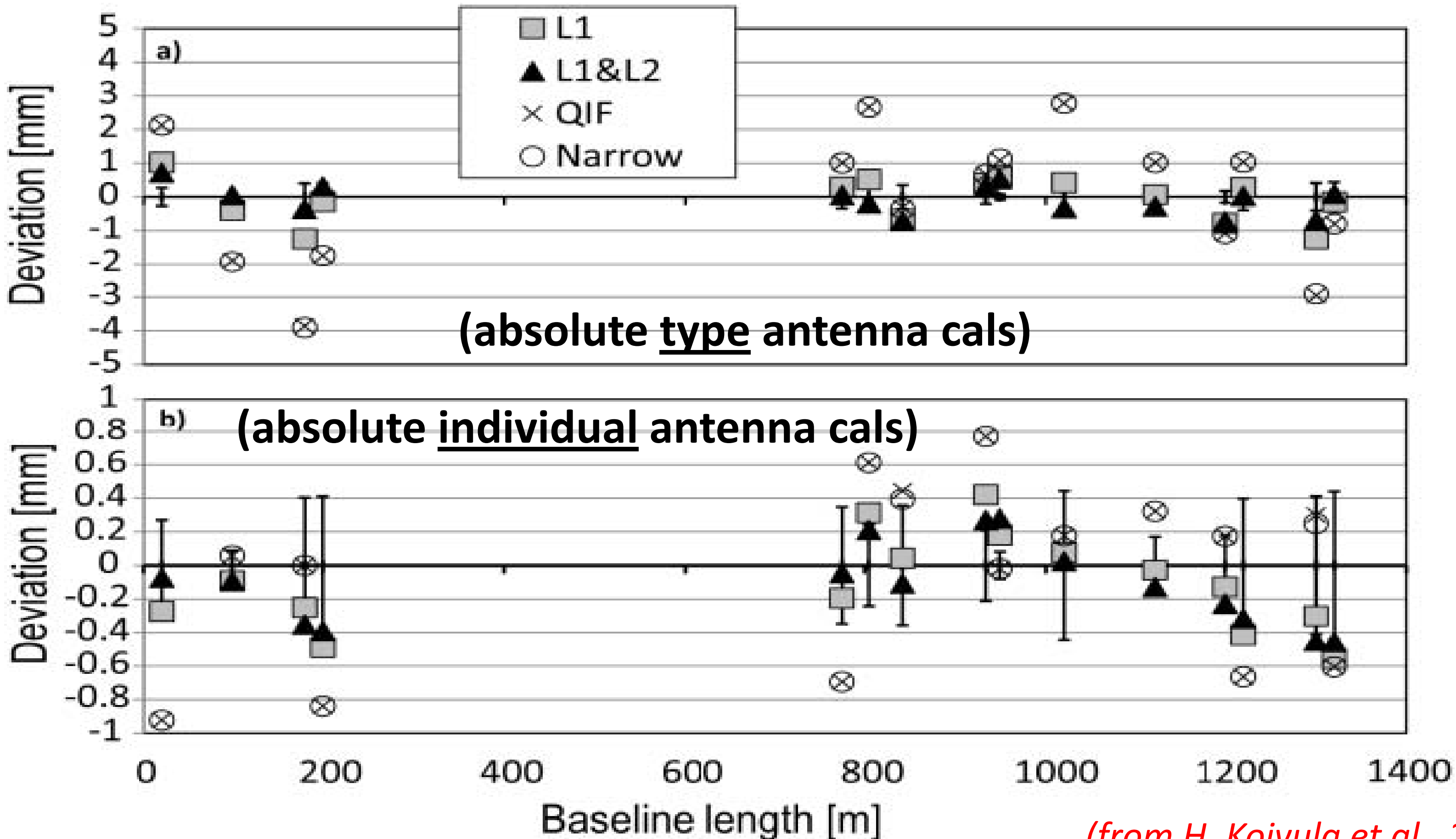
- **Final GPS orbit accuracy ~2 cm in recent years**
  - mostly long-period (odd draconitics) errors in C- & A-track directions
  - short-period precision ~1 cm, mostly due to orbit rotation errors

- **Results consistent with independent SLR range residuals:**



Absolute Accuracy of GPS Positioning

The "Good": GPS vs EDM SI-Traceable Accuracies

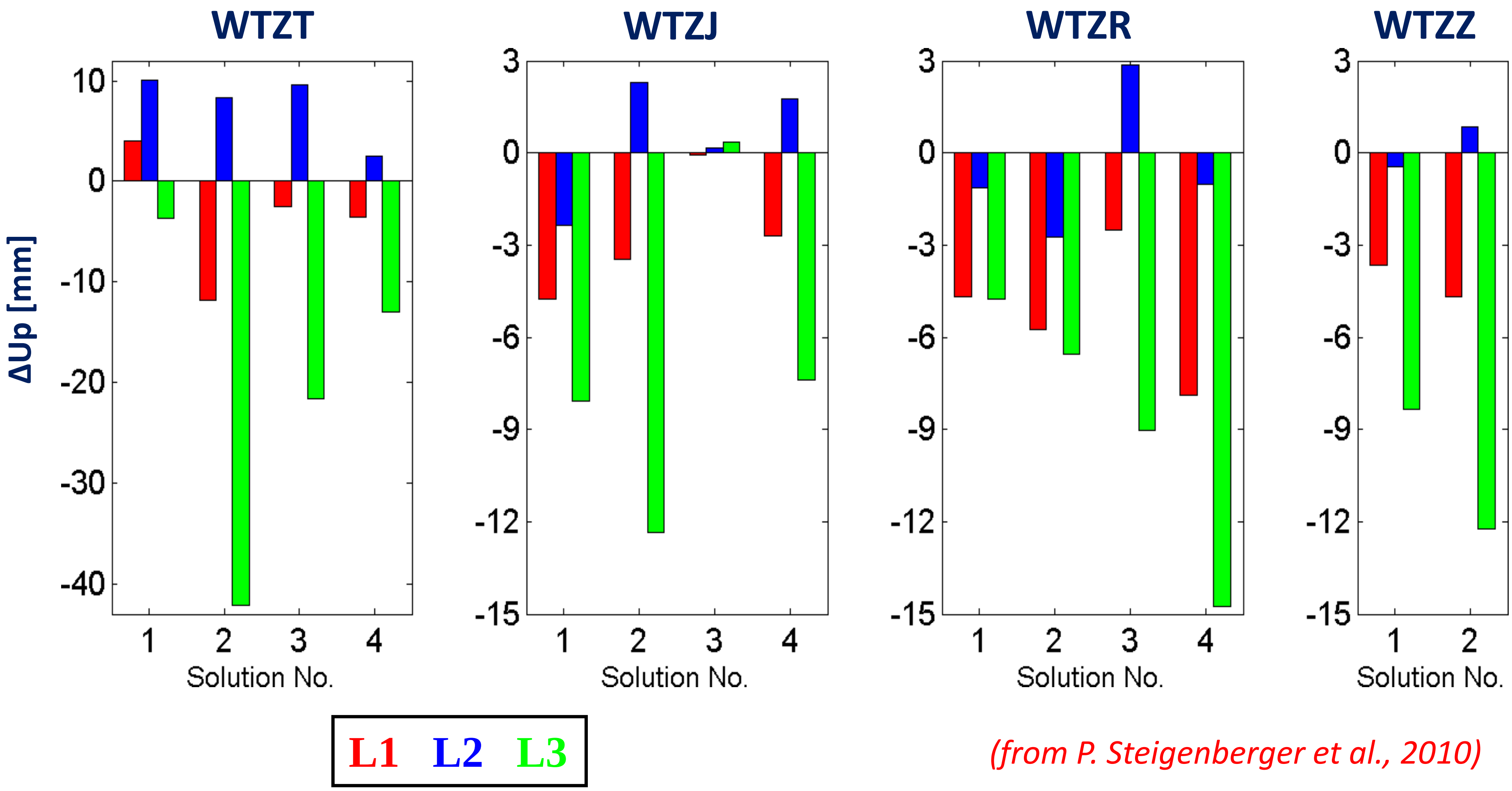


(from H. Koivula et al., 2009)

- **Best accuracy using L1-only & individually calibrated antennas**
  - **RMS is 0.3 mm up for baselines between 20 and 1320 m**
  - **L1/L2 solution with type cals only slightly worse (RMS = 0.4 mm)**
- **But such local accuracies not easily related to global scales**

The "Bad": GPS Heights vs Local Surveys

- **Differences between GPS baselines (w.r.t. WTZA) & local surveys**
- **L3 iono-free combination shows largest differences, up to few cm**
- **Near-antenna multipath effects probably main cause of biases**



(from P. Steigenberger et al., 2010)

Progress in Geodetic Precision & Accuracy

Progress in Geodetic Precision & Accuracy

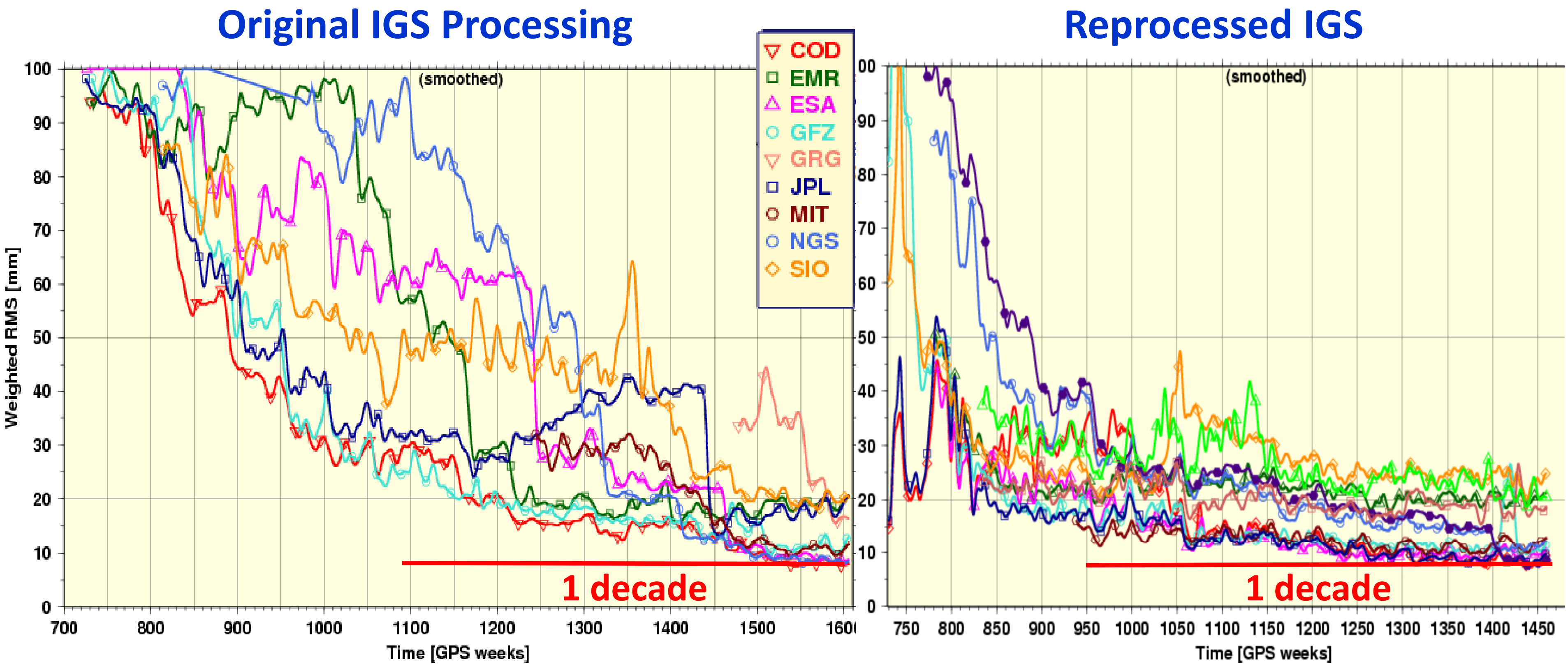
- *"Since the advent of the space age, we have seen remarkable improvements in positioning, navigation, and timing of approximately one order of magnitude each decade with no indication that this rate of progress is abating."*
  - U.S. National Research Council (2010), *Precise Geodetic Infrastructure*
  - attributed to B. Chao : "ten-fold advancement every decade in the last two or three decades" (*EOS*, 2003)
  - statement originated with T. Clark (~1990)

- Original statement by T. Clark was true, but not now
  - IGS orbits improved by ~2 x in past decade due to analysis upgrades
  - other factors added another ~1.5 x improvement, for ~3.5 x total
  - but positioning improvements have been smaller

- Current IGS precision probably in plateau phase

- Significant future progress will require new technologies
  - need better multipath mitigation (esp near-field) & orbit models

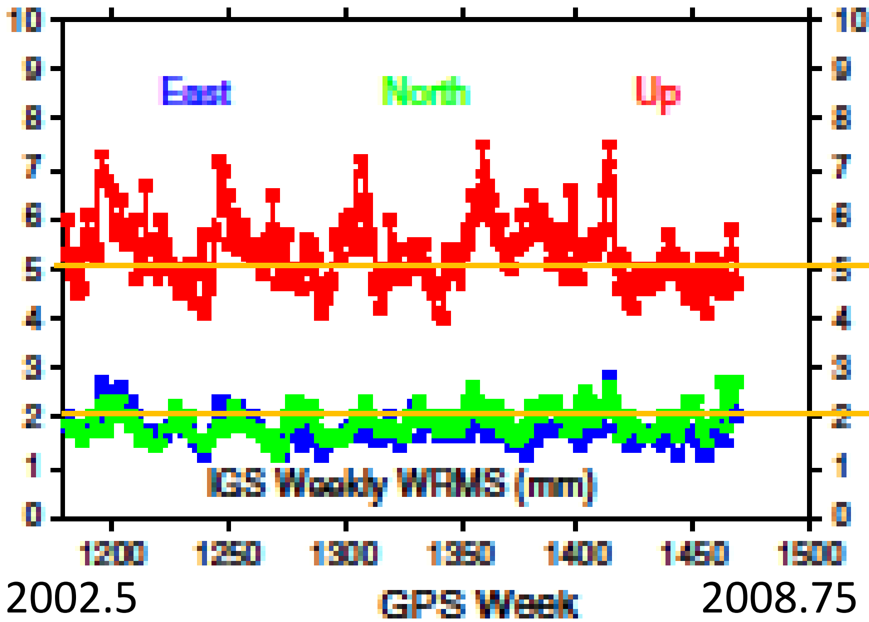
Progress in Orbit Precision



- IGS orbits improved by ~3.5 x over past decade in original processing
- Homogeneous reprocessing improved orbits before 2007
- Reprocessed orbits improved by only ~1.5 x over last decade

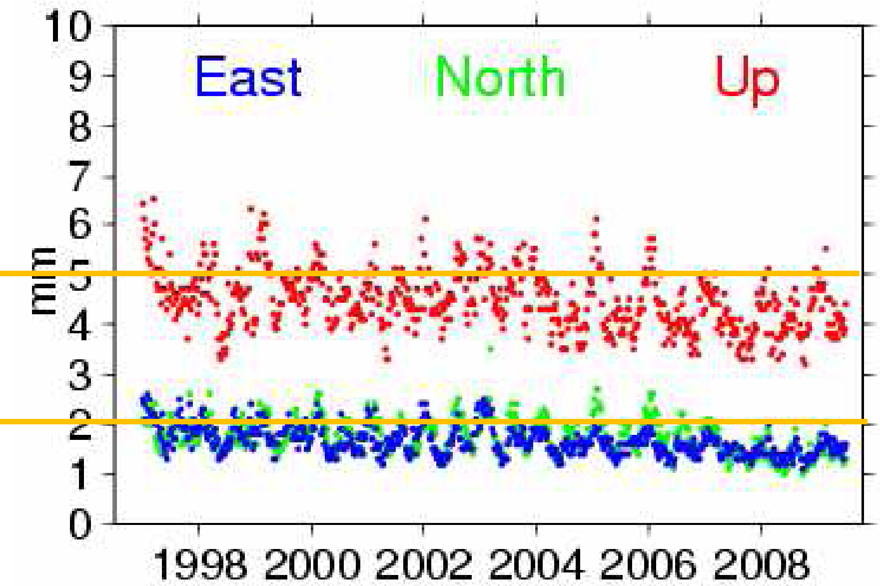
Progress in Positioning Precision

Original IGS Processing



(from Z. Altamimi & X. Collilieux, 2009)

Reprocessed IGS (ITRF2008)



(from Z. Altamimi et al., 2010)

- **Moderate positioning improvements from homogeneous reprocessing by IGS**
- **But repeatability improved only slightly over last decade**
- **IGS positioning results now at or near plateau level**

Summary & Conclusions

- Used with care & thoroughness, internal methods can provide reasonable geodetic accuracy measures
  - but estimates often optimistic due to neglect of correlations, etc
- IGS Final orbit accuracy is ~2 cm (1D RMS)
  - rotational & long-period (draconitic) errors dominate
  - <~1 d precision is ~1 cm
- Precision/repeatability of GNSS positions now in plateau phase
  - ~1.5 mm for N & E, ~4 mm for U – average of weekly integrations
  - ~4-5 mm for N & E, ~11 mm for U – average of daily integrations
  - accuracy on global scales is much poorer than over short baselines due to antenna effects, mainly
- Significant future progress will require new technologies
  - need better multipath mitigation (esp antenna near-field) or calibrations
  - orbit models can probably be improved but impacts are unclear
  - future "decade per decade" improvements are not likely