



High Frequency Tidal EOP form Space Geodesy and Ocean Modeling.

John Gipson
NVI, Inc./NASA GSFC



Goals



- Redo/Expand 1996 VLBI estimates of HF-EOP at tidal frequencies
- Compare results with predictions based on Tidal Models.
 - IERS2010 Conventions
 - Ray Got4.7
 - Egbert TPX0.7
- Compare results with other Space Geodesy Estimates
 - GPS: Steigenberger
 - VLBI: Boehm 2009 (nee Englich)
 - VLBI: Artz (2012 Solution)
- Study effect of Libration



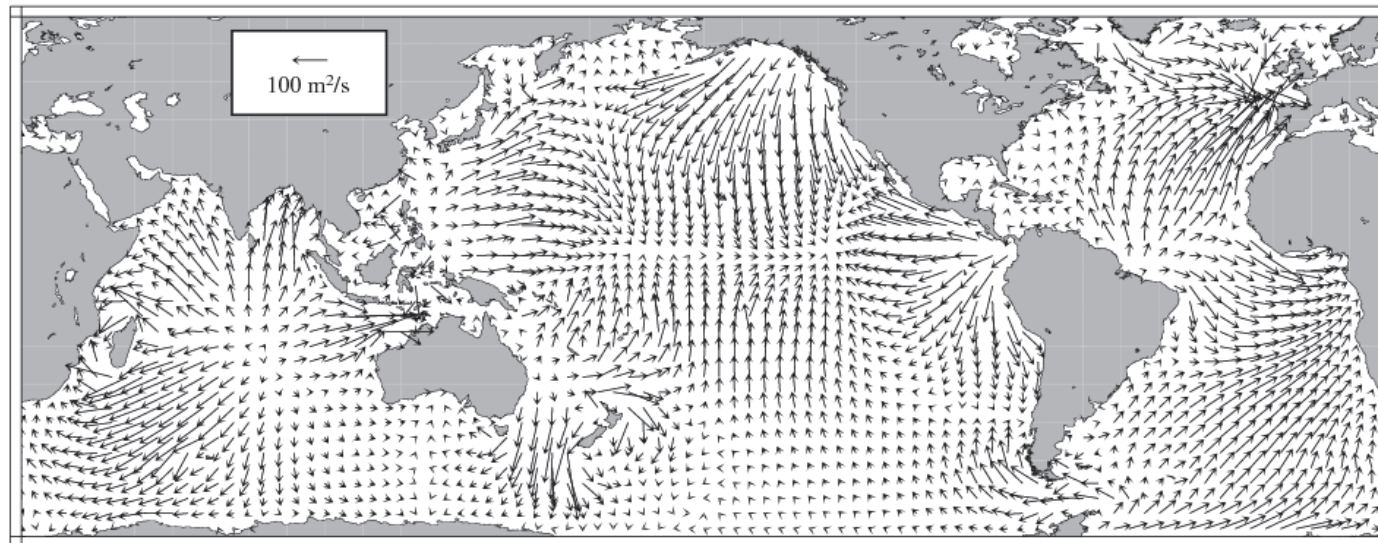
Differences Between Approaches



	Model	Measurement
How Derived	Satellite Altimetry	Estimated from Space Geodesy data
Intermediate Step	Tidal Model	None (Gipson, Artz) Hourly EOP Estimates (Steigenberger, Englich)
Math	Global Integration of ocean heights, currents	Standard Least Squares
Functional Form	Ortho-tides	Tidal Lines
Number of Parameters	12x3	2x3xNum_Lines
Assumption	EOP determined by large tides	Tidal lines (except sidelobes) are independent

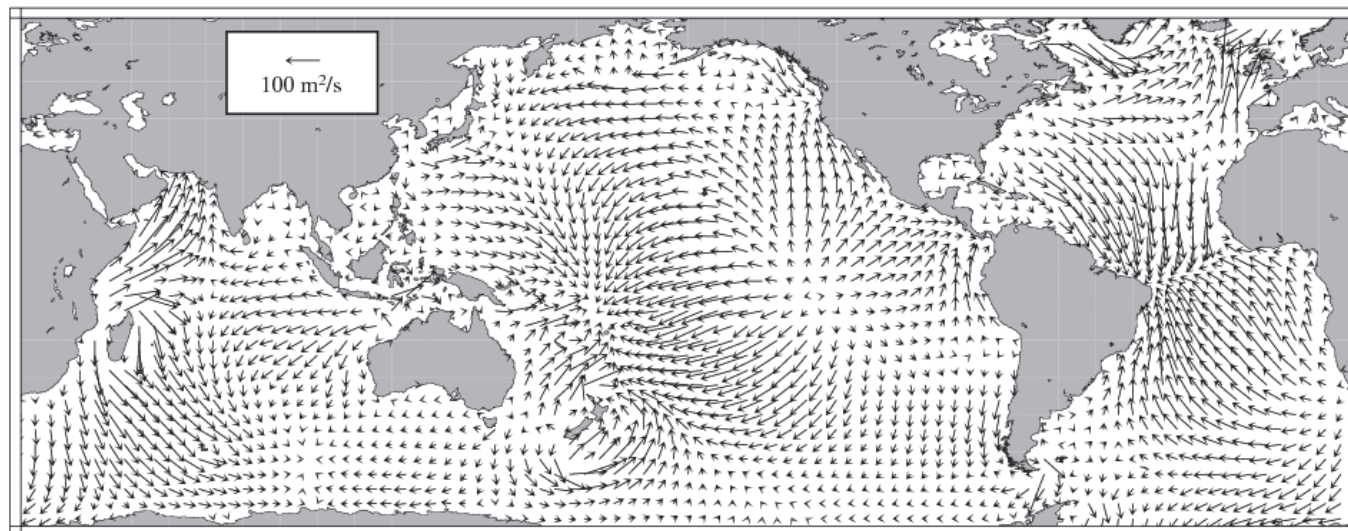


Volume Transport M2 Tide (Moon over Greenwich)





Volume Transport M2 (45 degree meridian)





Deficiencies with 2010 IERS Model



- No tidal atmospheric constituents (S1, S2, S3)
 - But large model uncertainties (de Viron et al)
 - Potentially large effect in PM.
 - All atmospheric constituents have large seasonal variations which induces extra power at P1, K1, R2, T2...
- No S1 ocean tide constituent.
 - Could be fixed by using Ray & Egbert (JPO, 2004)
- No terdiurnal and higher constituents
 - Expected to be very small because they are shallow water.



2014 VLBI Solution



Almost all data from 1979 through April 2014:

8.7 million observations (vs 1.8 million for 1996)

5425 sessions (vs 2540 for 1996)

35 years (vs 17 for 1996)

Almost all terms in the 2003 IERS standards. (Except S1 atm.)

Estimated UT1 & PM tidal terms directly

UT1: 41 diurnal, 30 semi-diurnal terms

PM: 41 prograde diurnal, 30 prograde semi-diurnal and 30 retrograde diurnal.

Imposed constraints on sidebands that differ by only 1-2 cycles over time span.

Estimated 10 “zero-terms” per component/band.



Features of 2014 Solution



Almost all data from 1979 through April 2014:

6.6 million observations

4554 sessions

31 years

Almost all terms in the 2010 IERS standards. (Except S1 atm.)

Estimated UT1 & PM tidal terms directly

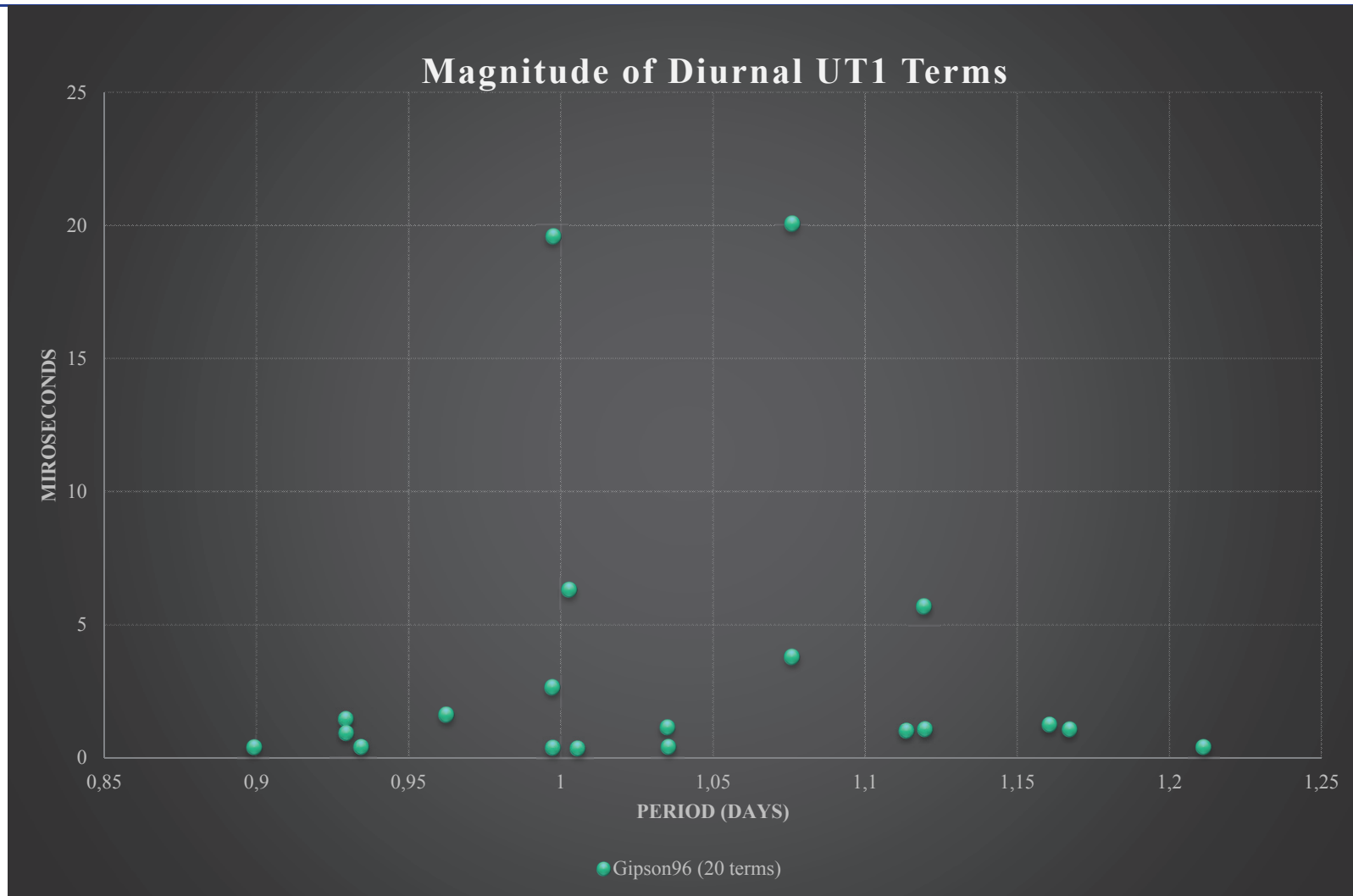
UT1: 40 diurnal, 30 semi-diurnal terms

PM: 40 prograde diurnal, 30 prograde semi-diurnal and 30 retrograde diurnal.

Estimated 10 “zero-terms” per component/band.

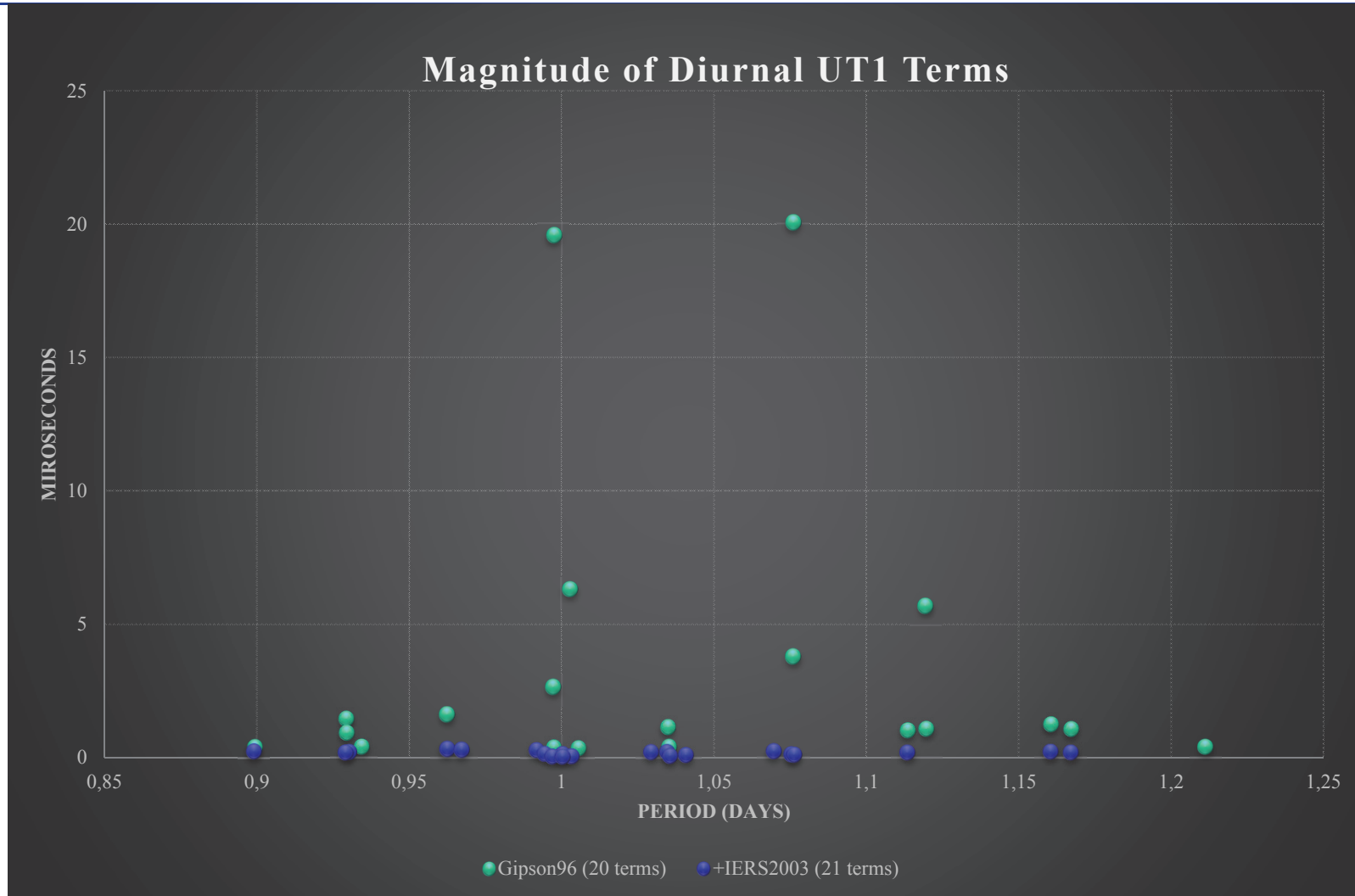


2014 Tidal UT1 Estimates from VLBI



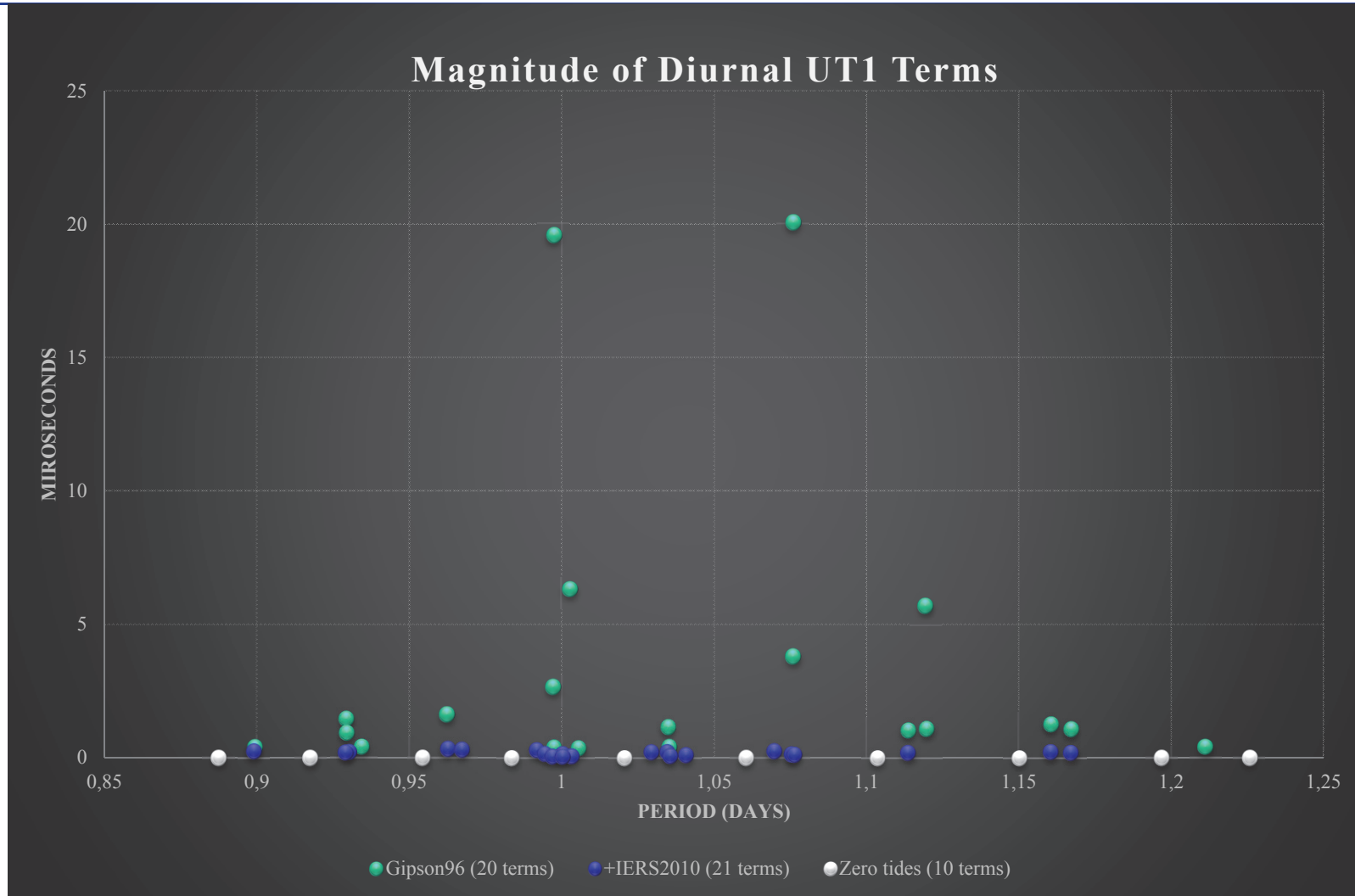


2014 Tidal UT1 Estimates from VLBI



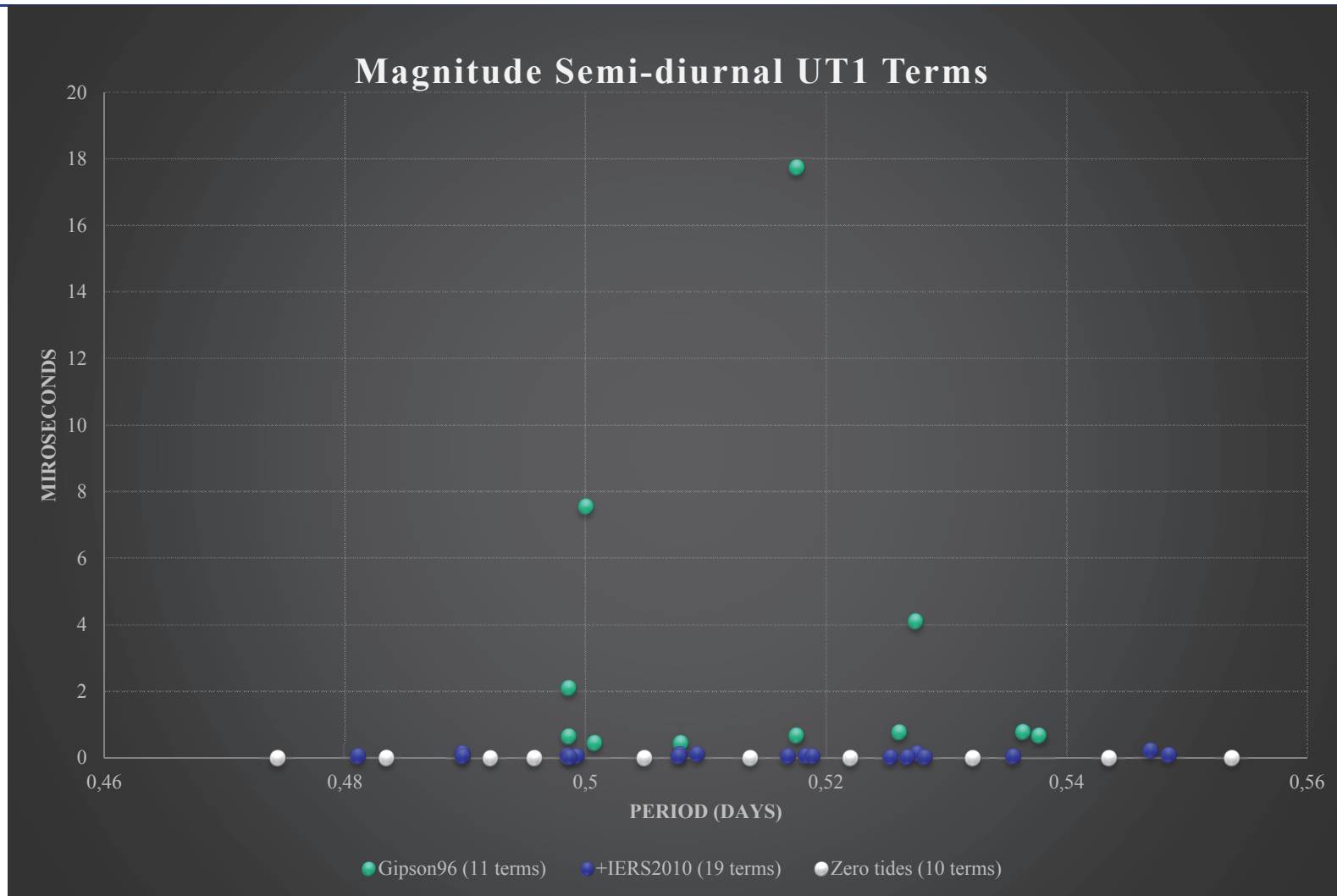


2014 Tidal UT1 Estimates from VLBI





2014 Tidal UT1 Estimates from VLBI





Features of 2014 Solution



Almost all data from 1979 through April 2014:

- 6.6 million observations

- 4554 sessions

- 35 years

Almost all terms in the 2003 IERS standards. (Except S1 atm.)

Estimated UT1 & PM tidal terms directly

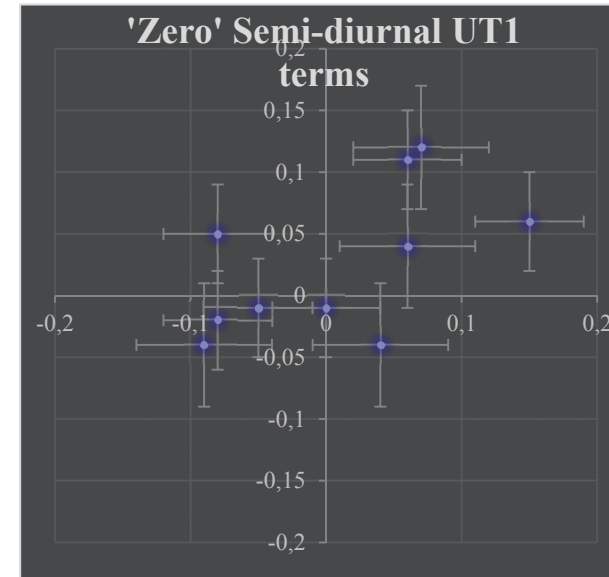
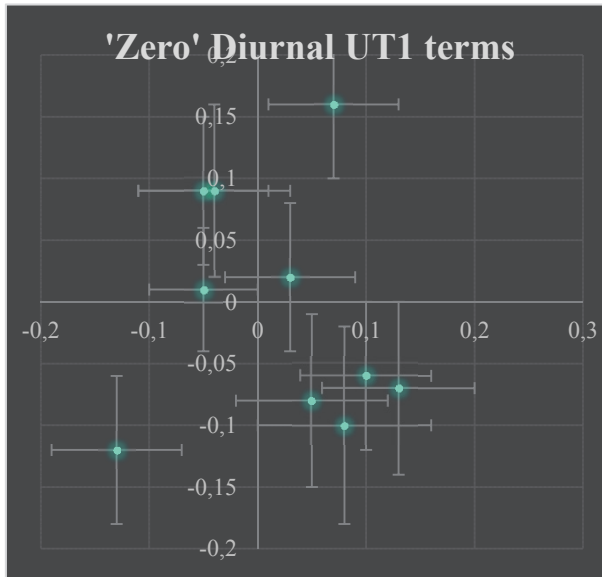
- UT1: 40 diurnal, 30 semi-diurnal terms

- PM: 40 prograde diurnal, 30 prograde semi-diurnal and 30 retrograde diurnal.

Estimated 10 “zero-terms” per component/band.



Estimates of UT1 “0” terms



Formal Errors:

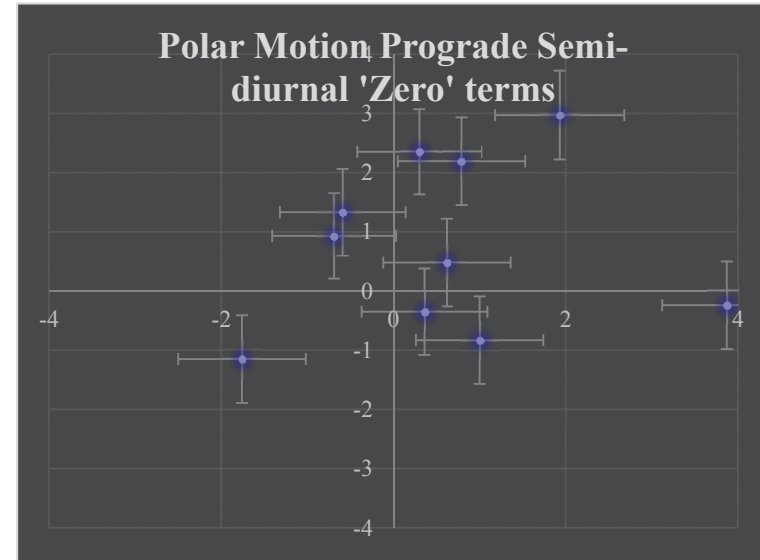
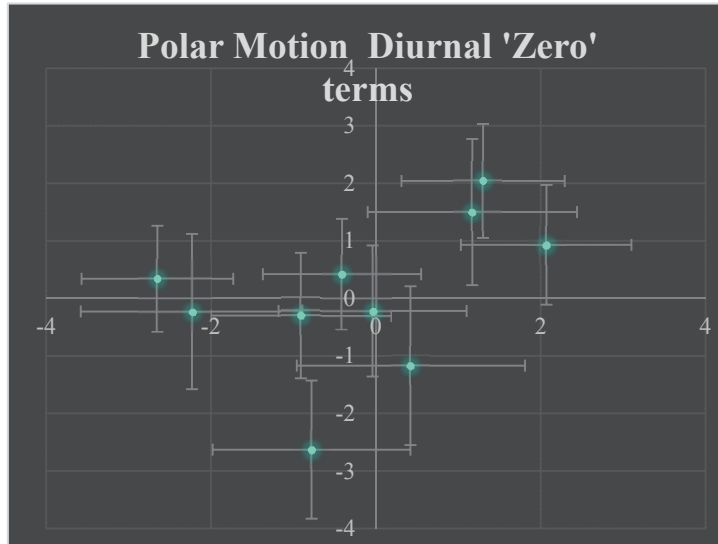
Diurnal tides ~ 0.07 microseconds.

Semidiurnal tides ~ 0.04 microseconds.

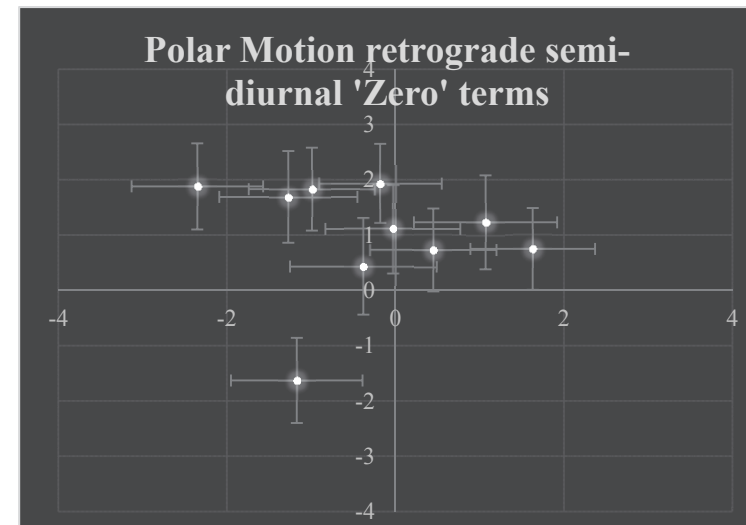
Actual errors maybe twice as large.



Estimates of PM “0” terms



Error in
Diurnal Tides ~ 1.2 micro-arcseconds
Semi-diurnal Tides ~ 0.8 micro-arcseconds





Sidelobe Issue in Tidal Potential



	Fundamental Arguments						Doodson	Period (CPD)	Freq.	Years to Separate
	1	0	0	0	0	1	165.545	0.9974159	1.002590795	18.71
K1	1	0	0	0	0	0	165.555	0.9972695	1.002737976	18.74
	1	0	0	0	0	-1	165.565	0.9971233	1.002884999	18.74

- Many terms in the tidal potential differ by only 1-2 cycles over periods of ~ 18 yr.
- If time span less than 18 years, need to impose constraints on HF-EOP variation to separate.

• One approach:

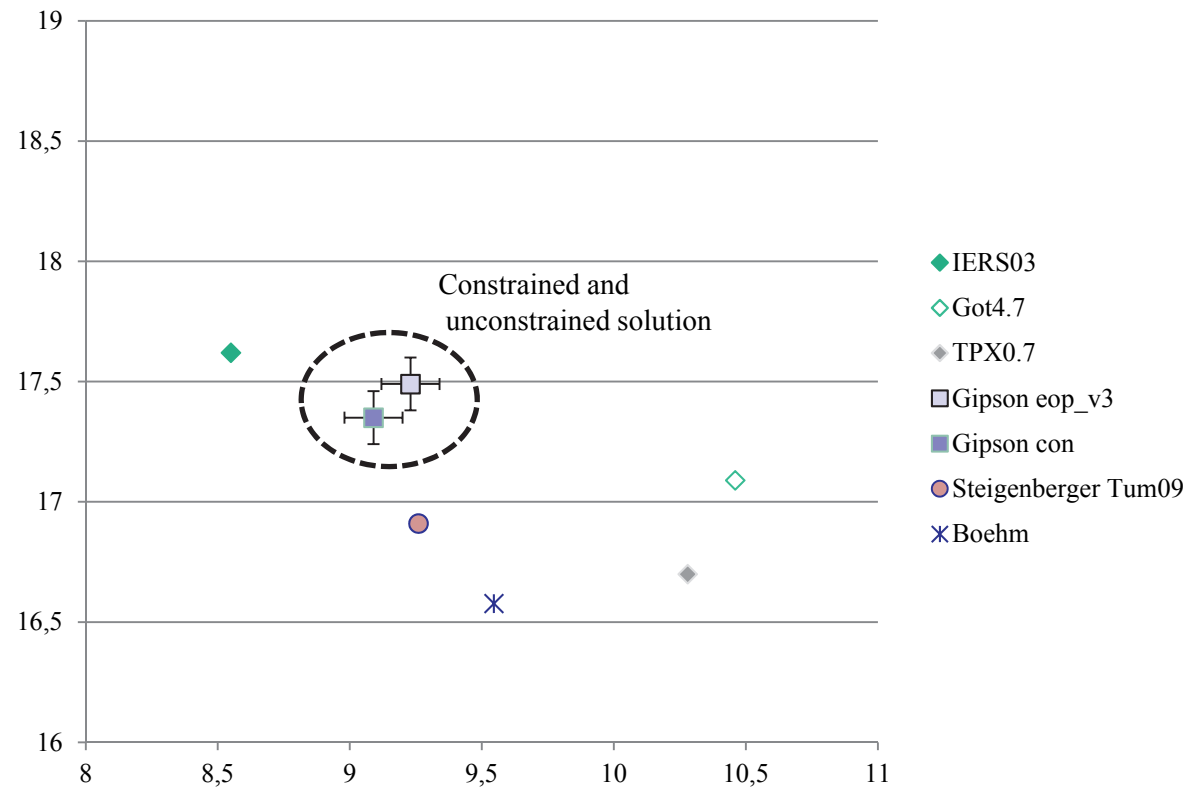
Ratio of amplitude of main-terms and sidelobes constrained to be equal to ratio of corresponding terms in the tidal potential.



Effect of Imposing Constraint (2010 Solution)



UT1 K1





Features of 2014 Solution



Almost all data from 1979 through April 2010:

- 6.6 million observations

- 4554 sessions

- 31 years

Almost all terms in the 2003 IERS standards. (Except S1 atm.)

Estimated UT1 & PM tidal terms directly

- UT1: 40 diurnal, 30 semi-diurnal terms

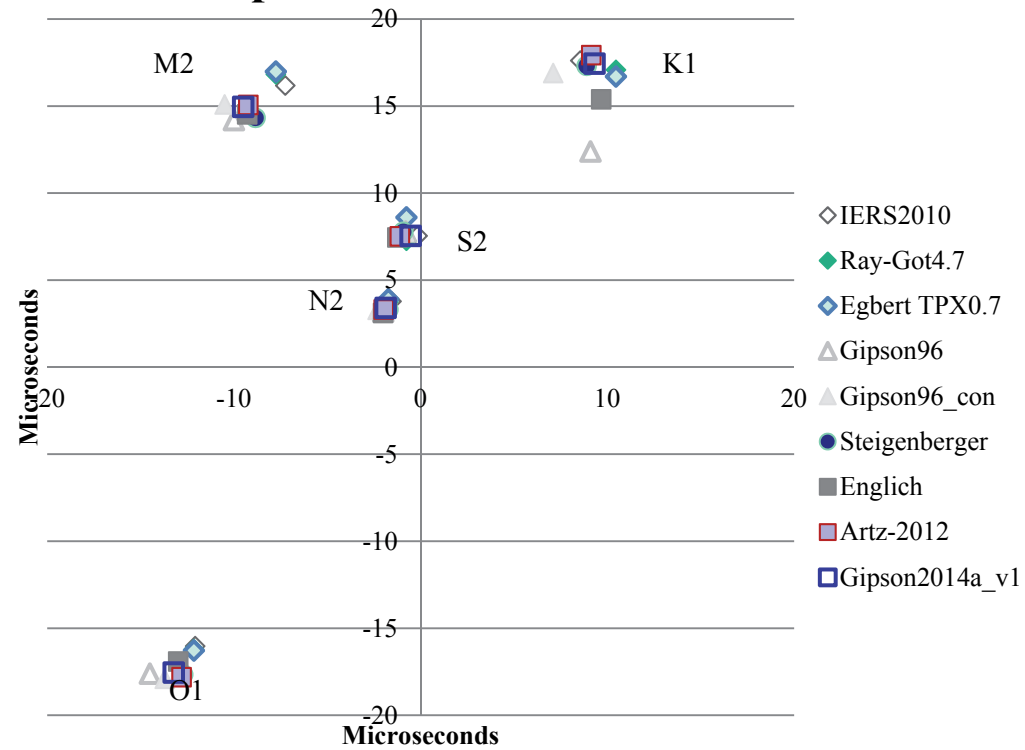
- PM: 40 prograde diurnal, 30 prograde semi-diurnal and 30 retrograde diurnal.

Estimated 10 “zero-terms” per component/band.

Did not impose constraints on sidebands.



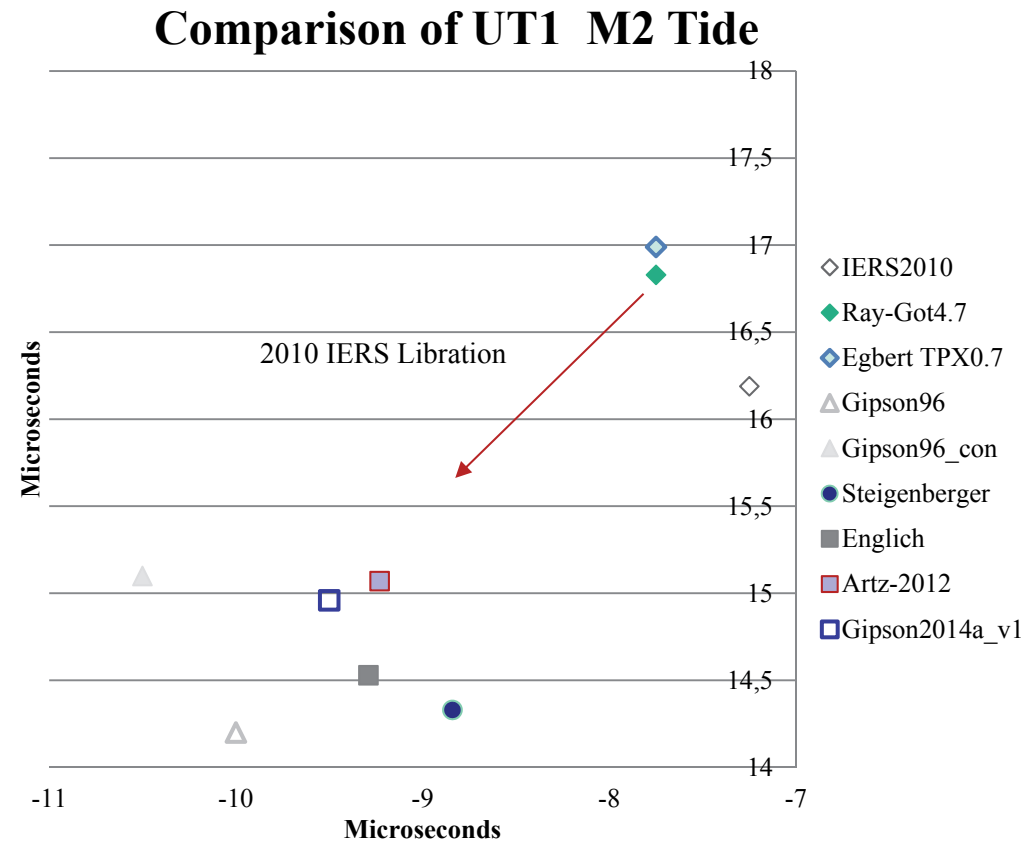
Comparison of UT1



Error bars are smaller than symbols.



Some Large Differences



Tidal models do not include libration (although included in IERS10 as a separate effect).



Libration



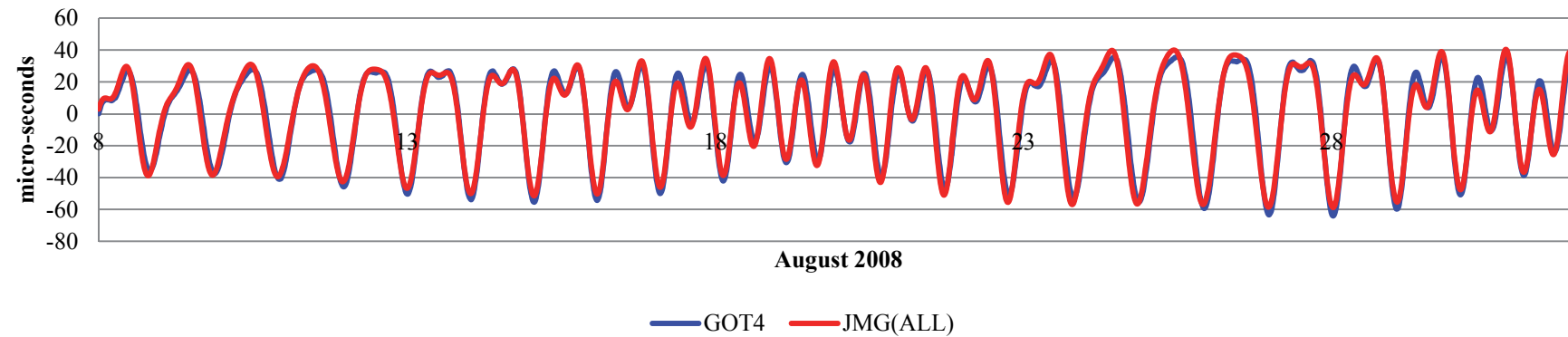
- Due to Triaxiality of Earth.
- Estimates include libration, Tidal models do not.
- Dominate effect on PM is diurnal tides:
 - O1, K1, P1,...
- Dominate effects on UT1 is semi-diurnal
 - M2
- IERS 2003 conventions include PM libration, but not UT1.
- IERS 2010 conventions include both.



Comparison of Model and Measured



UT1 Predictions



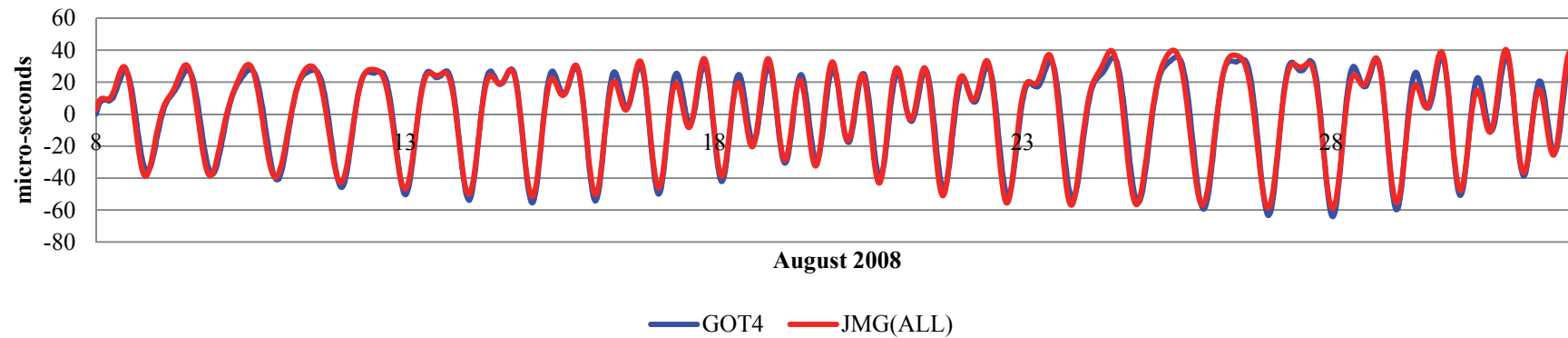
Models agree very well if you just plot them together



Comparison of Model and Measured

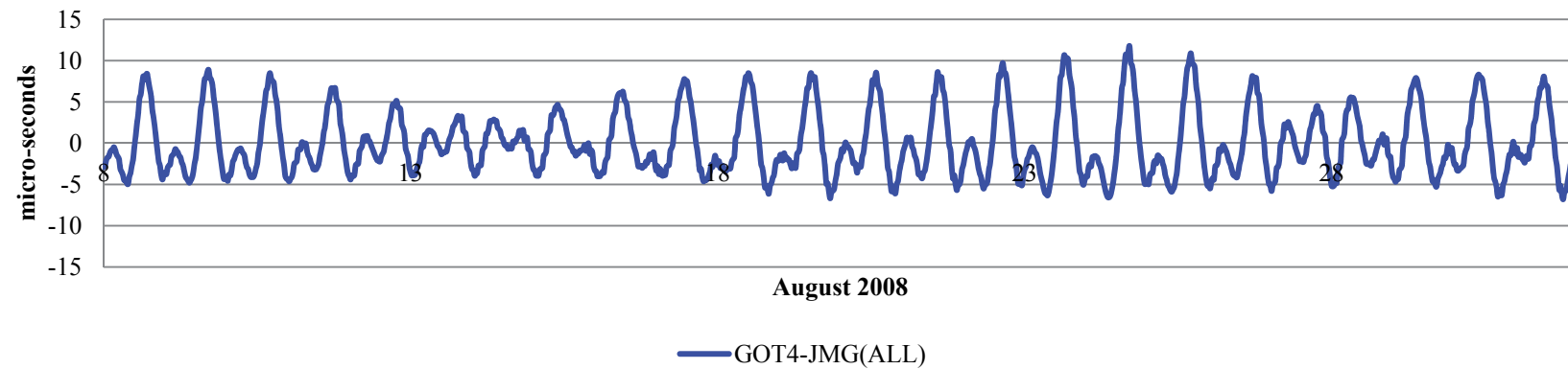


UT1 Predictions



RMS= 4

Difference in UT1

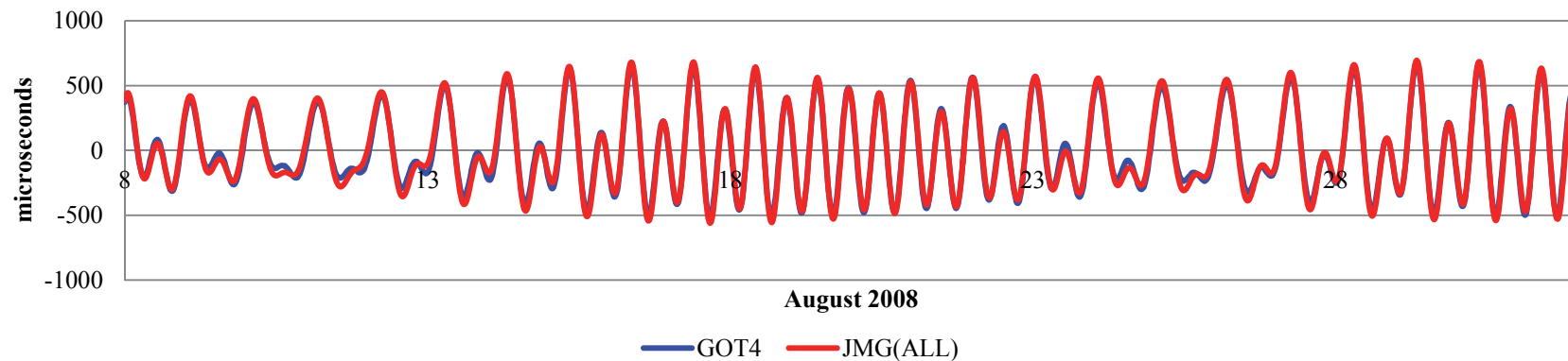




Comparison of Model and Measured

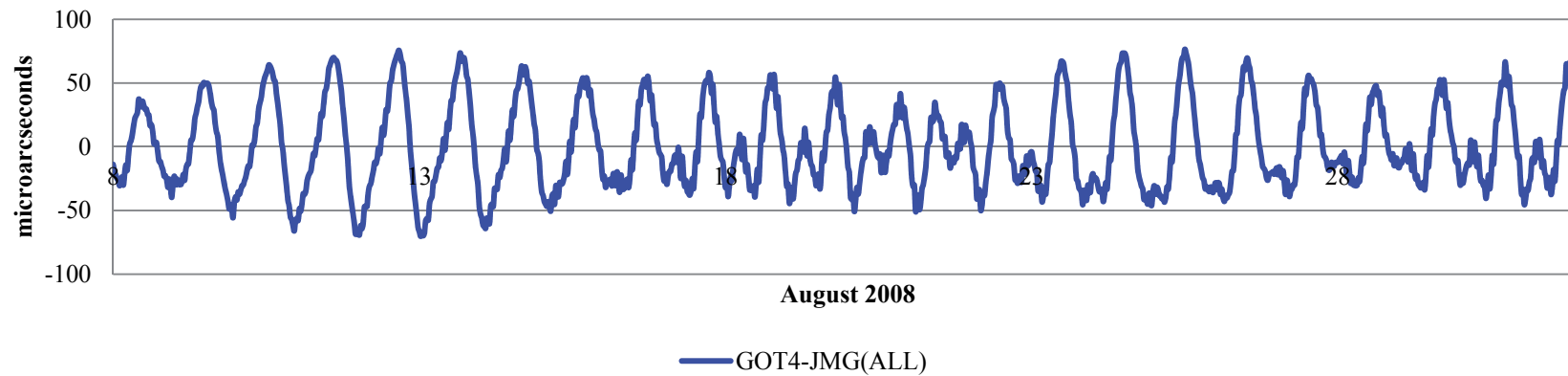


X Pole Predictions



RMS= 33.7

Difference in Xpole





UT1 Differences: IERS



Space Geodesy Estimates Include Libration

	IERS2010	GOT4.7 (Ray)	TPX0.7 (Egbert)	Tum08A (Steigen.)	Englich	Artz	2014a_v1 (Gipson)
IERS2010		2.3	2.5	3.2	4.1	3.3	3.4
GOT4.7 (Ray)	2.3		1.5	3.6	3.6	3.3	3.4
TPX0.7(Egbert)	2.5	1.5		3.8	3.8	3.7	3.6
Tum08A(Steigenberger)	3.2	3.6	3.8		2.3	1.2	1.2
Englich	4.1	3.6	3.8	2.3		2.8	2.4
Artz	3.3	3.3	3.7	1.2	2.8		0.2
2014a_v1(Gipson)	3.4	3.4	3.6	1.2	2.4	0.2	

- Based on calculating RMS difference between hourly values of time series for 18.7 yrs
- Models are in general agreement
- Estimates are in general agreement
- Models and estimates differ
- Can't distinguish models based on agreement with estimates



UT1 Differences: IERS+Libration



Space Geodesy Estimates Include Libration

	IERS2010	GOT4.7 (Ray)	TPX0.7 (Egbert)	Tum08A (Steigen)	Englich	Artz	2014a_v1(G ipson)
IERS		2.3	2.5	2.2	3.1	2.5	2.6
GOT4.7 (Ray)	2.3		1.5	2.7	2.5	2.6	2.6
TPX0.7(Egbert)	2.5	1.5		2.4	2.2	2.5	2.2
Tum08A(Steigenberger)	2.2	2.7	2.4		2.3	1.2	1.2
Englich	3.1	2.5	2.2	2.3		2.8	2.4
Artz	2.6	2.6	2.5	1.2	2.8		0.2
2014a_v1(Gipson)	2.6	2.6	2.2	1.2	2.4	0.2	

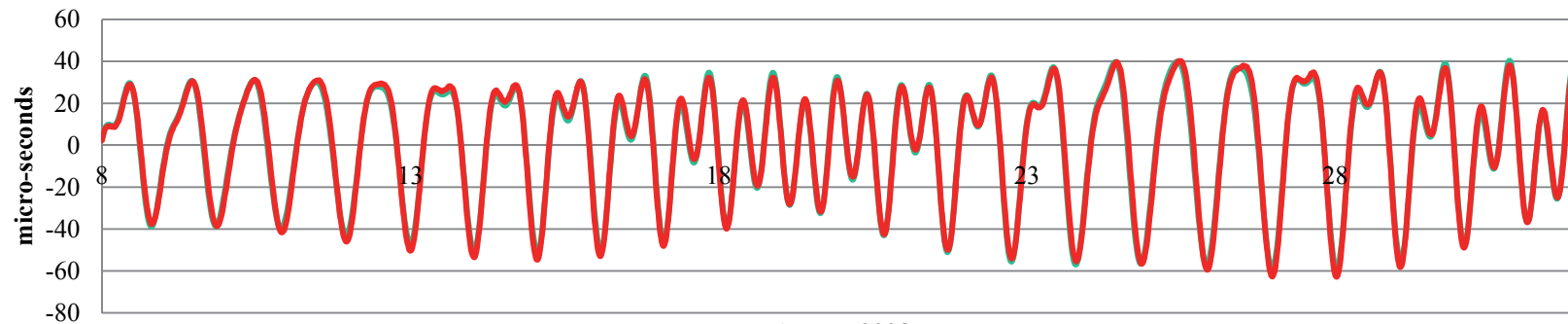
- Based on calculating RMS difference between hourly values of time series for 18.7 yrs
- Models are in general agreement
- Including libration improves agreement



Effects of Ortho-tide assumption

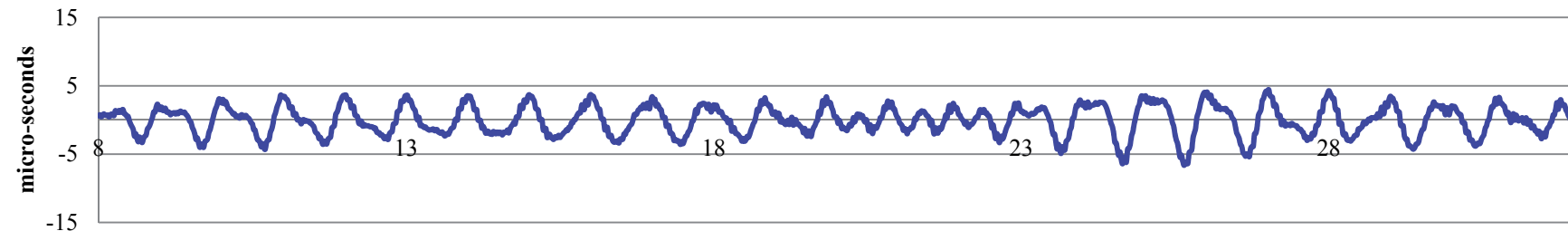


UT1 Predictions



RMS= 2.1

Difference in UT1

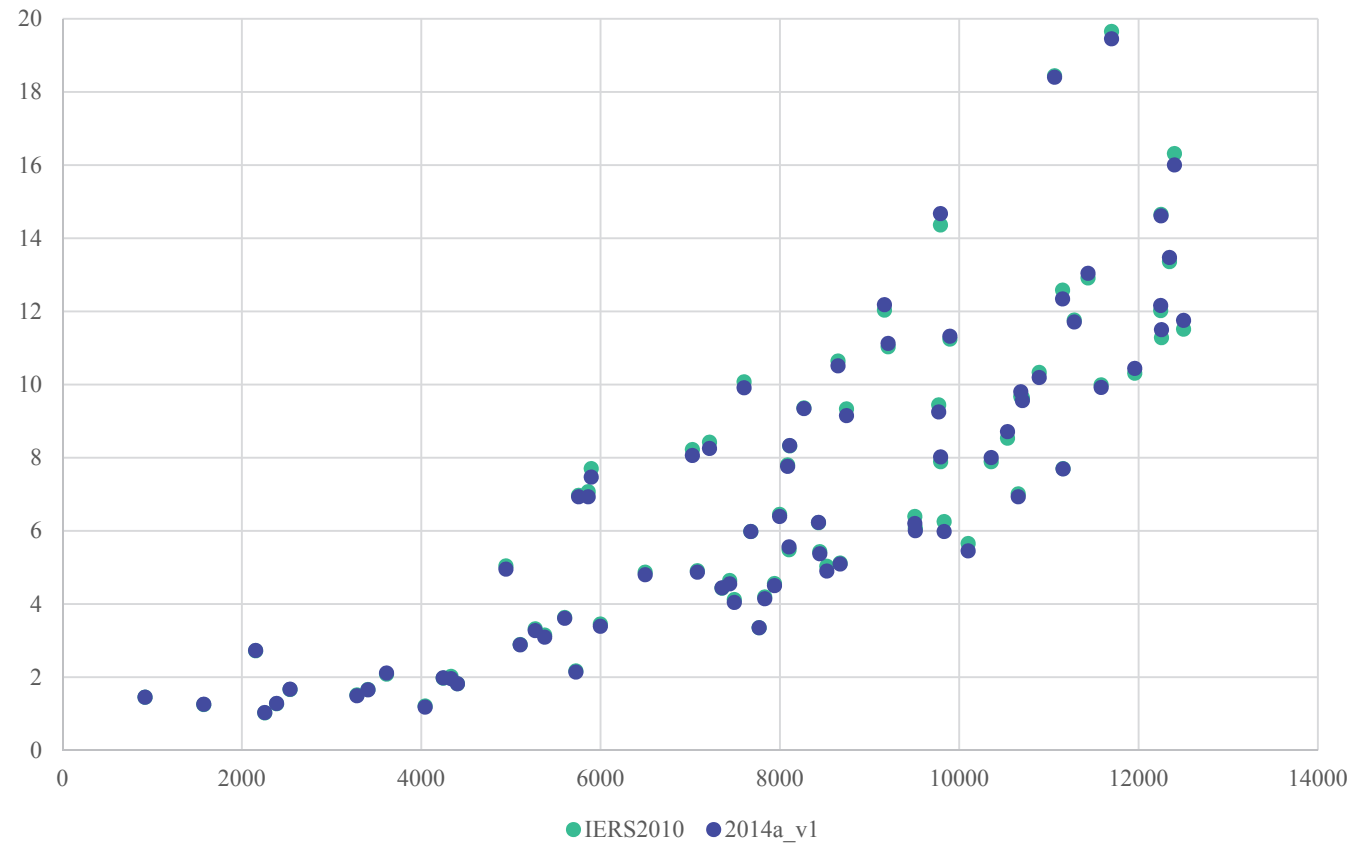




Empirical Model Reduces Baseline Scatter



Baseline Scatter for CONT11

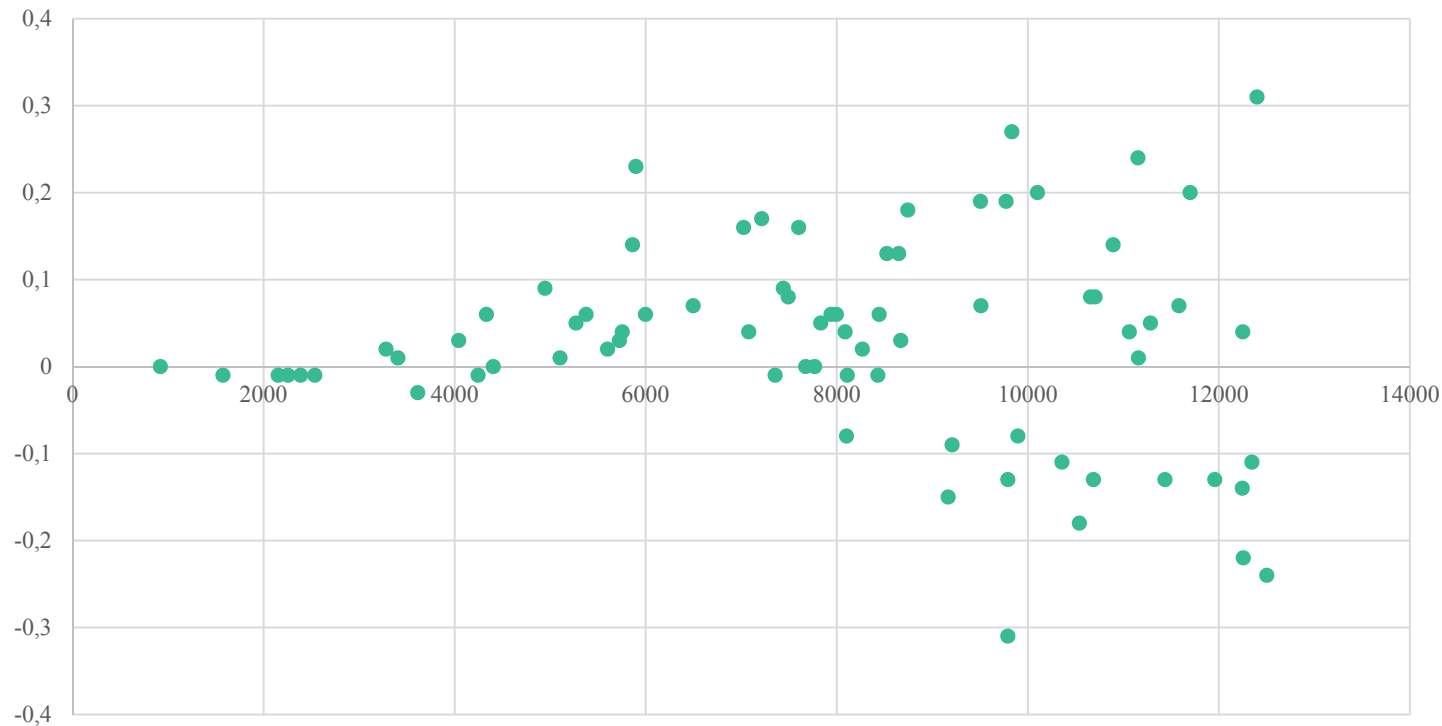




Empirical Model Reduces Baseline Scatter



Difference in Baseline Scatter for CONT11
IERS2010-2014a_v1 (VLBI)



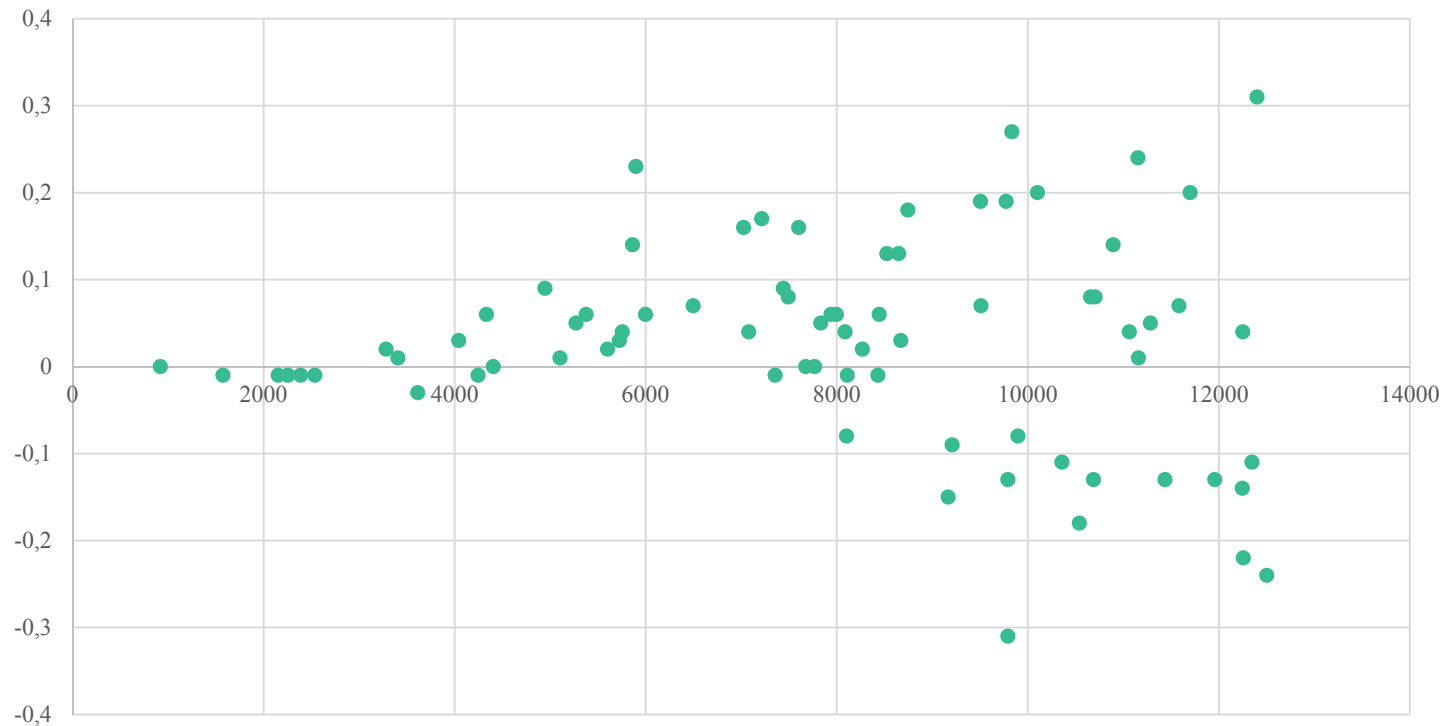
If a point is above 0, then Empirical model is better.



Empirical Model Reduces Baseline Scatter



Difference in Baseline Scatter for CONT11
IERS2010-2014a_v1 (VLBI)



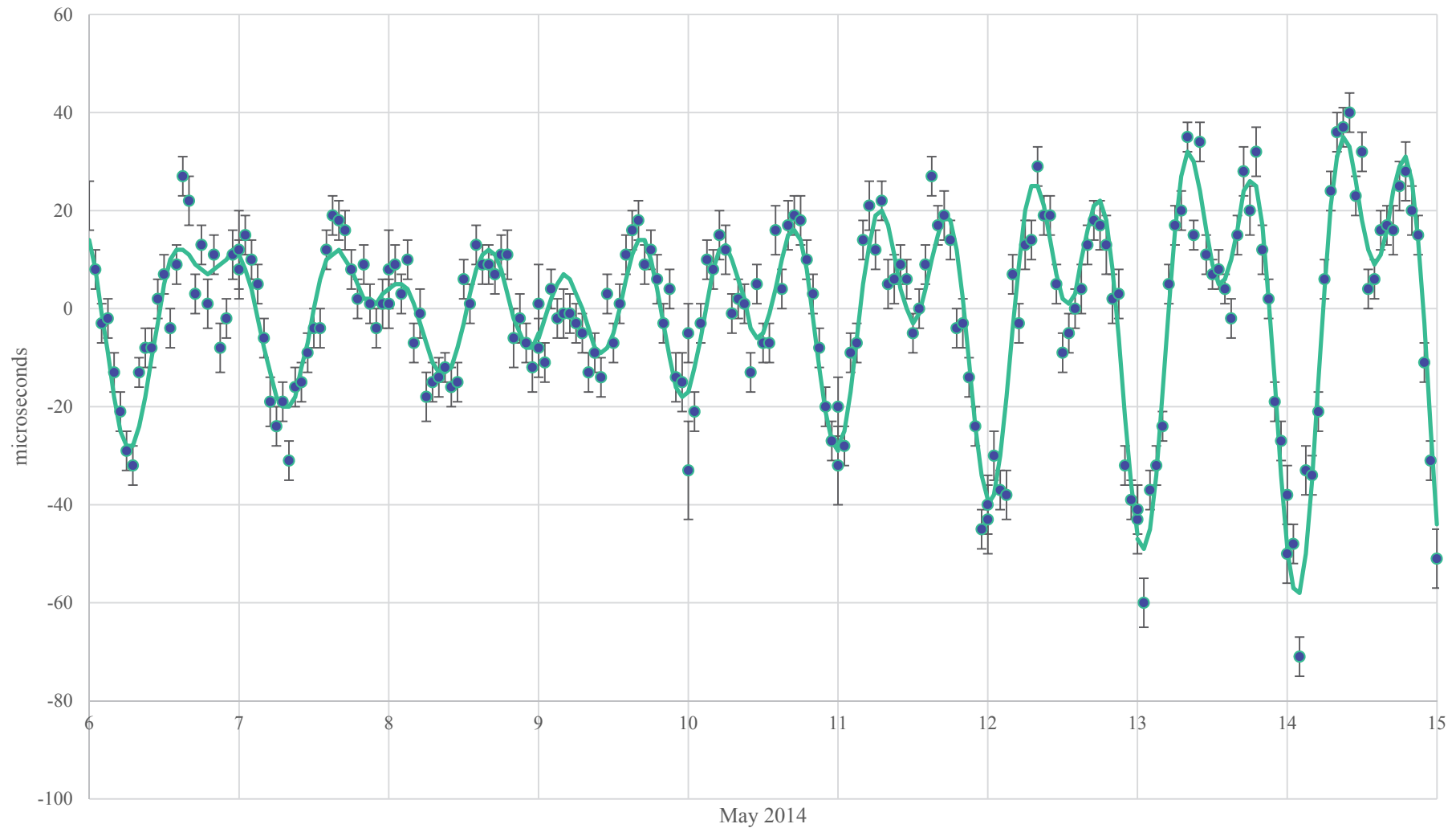
If a point is above 0, then Empirical model is better.



Models and Hourly Estimates: CONT14

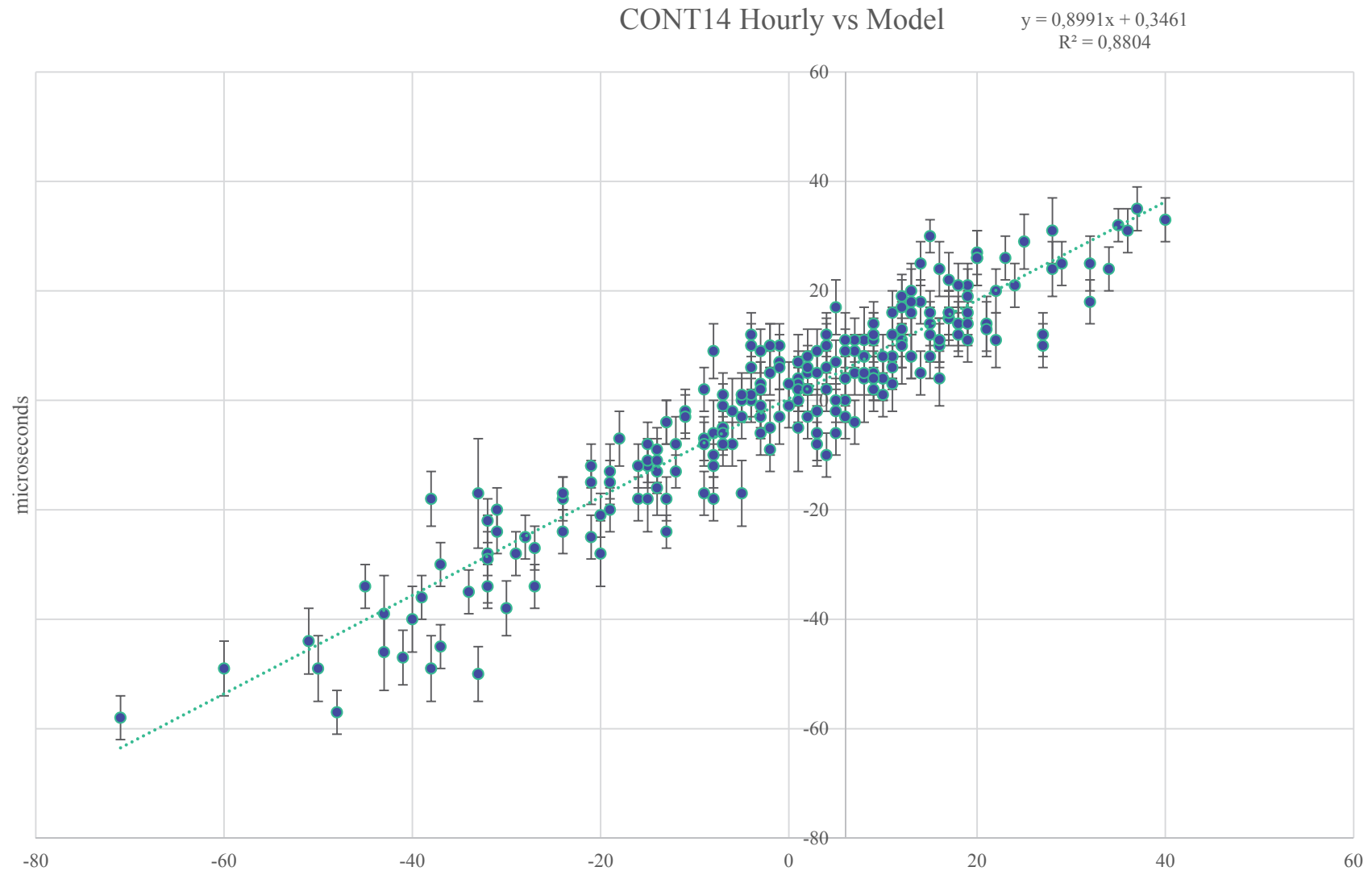


CONT14 UT1





Models and Hourly Estimates: Cont14

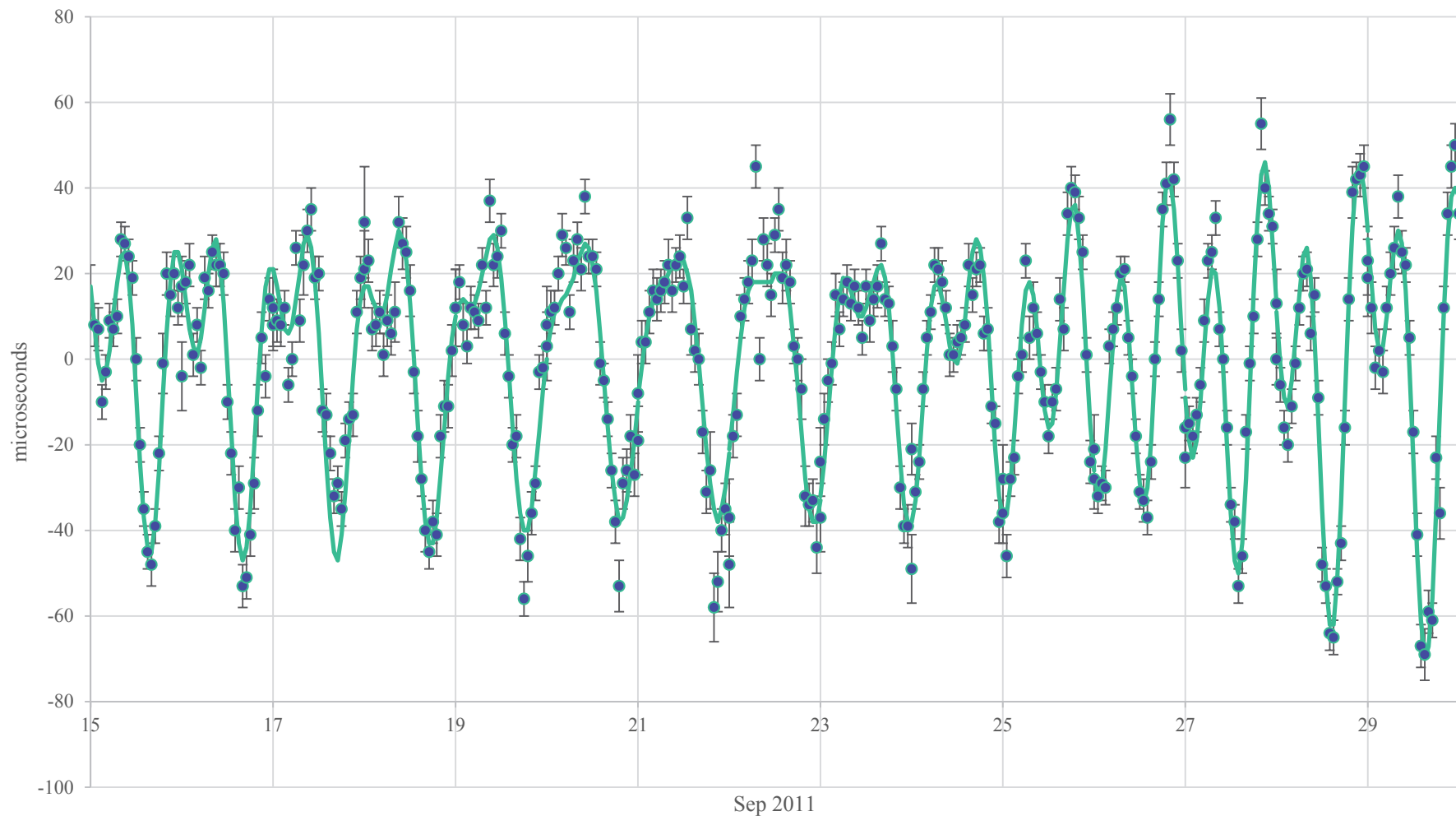




Models and Hourly Estimates: Cont11



CONT11 UT1



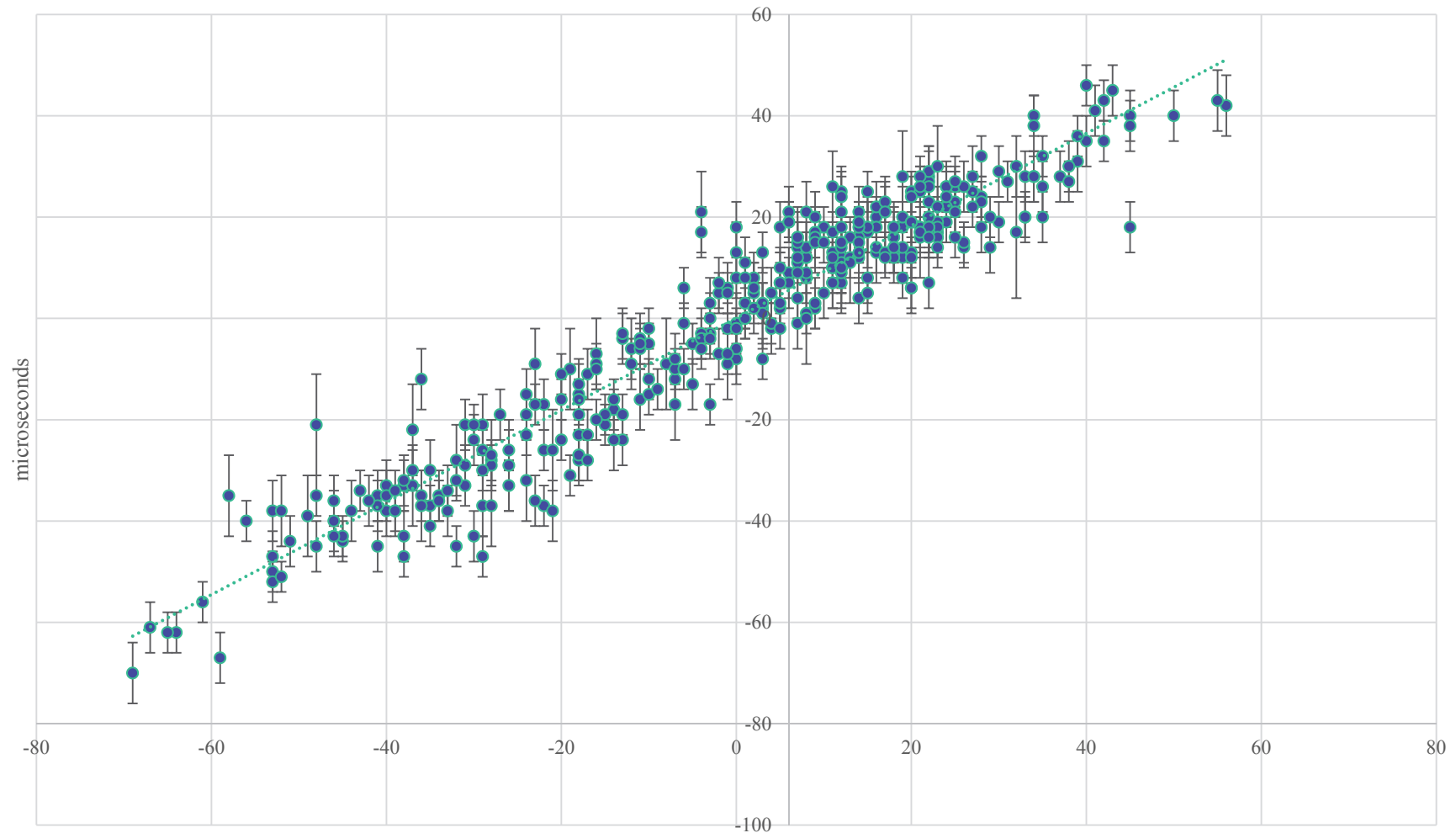


Models and Hourly Estimates: Cont11



$$y = 0,9106x + 0,1187$$
$$R^2 = 0,9152$$

CONT11 Hourly vs Model





Conclusion



- Empirical HF-EOP tidal models derived from VLBI and GPS agree well with semi-empirical tidal models derived from satellite data.
- Empirical models agree better with each other than with semi-empirical models.
- Including libration reduces disagreement between Tidal Models and Empirical Models.
 - Still room for improvement?
- Ortho-tide assumption has real consequences.
- Empirical model has less scatter than IERS2010 standards
- Hourly estimates of EOP from VLBI agree well with model
 - But tend to overshoot. Why?