



# High Frequency Tidal EOP from Space Geodesy and Ocean Modeling.

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Newcastle Upon Tyne, UK



# Goals



- Redo/Expand 1996 solution
- Compare results with models
  - IERS2003 Conventions
  - Ray Got4.7
  - Egbert TPX0.7
- Compare results with other solutions
  - GPS: Steigenberger
  - VLBI: Boehm (formerly English)
- Study effect of Libration



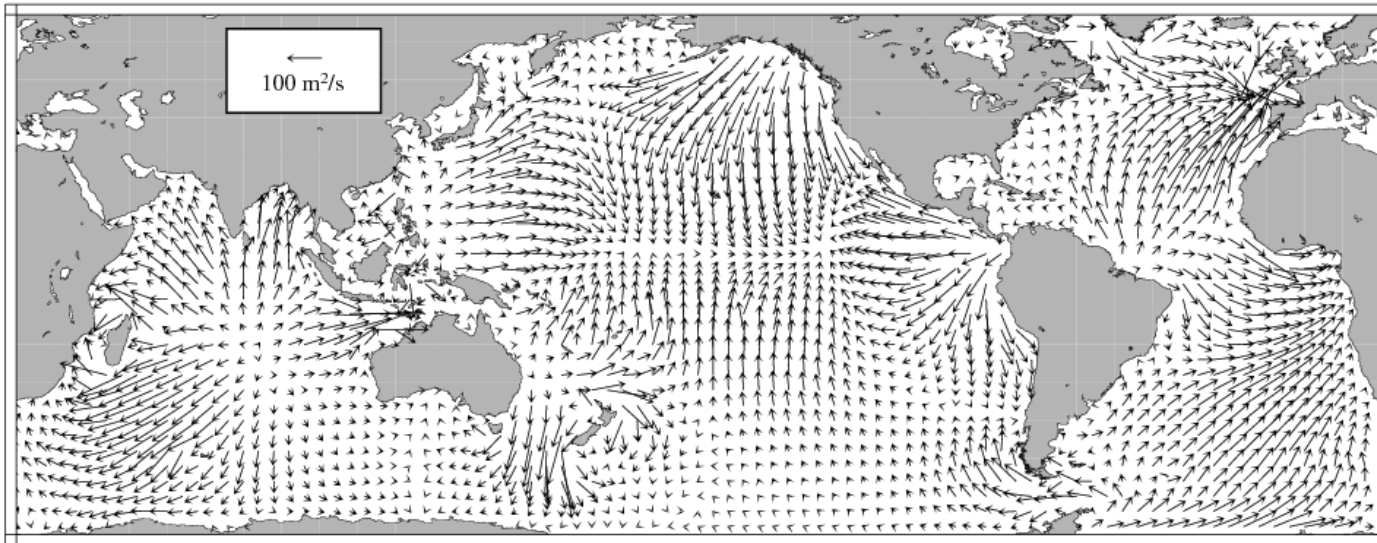
# Differences Between Approaches



	<b>Model</b>	<b>Measurement</b>
How Derived	Satellite Altimetry	Estimated from Space Geodesy data
Intermediate Step	Tidal Model	None (Gipson) Hourly EOP Estimates (Steigenberger, English)
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

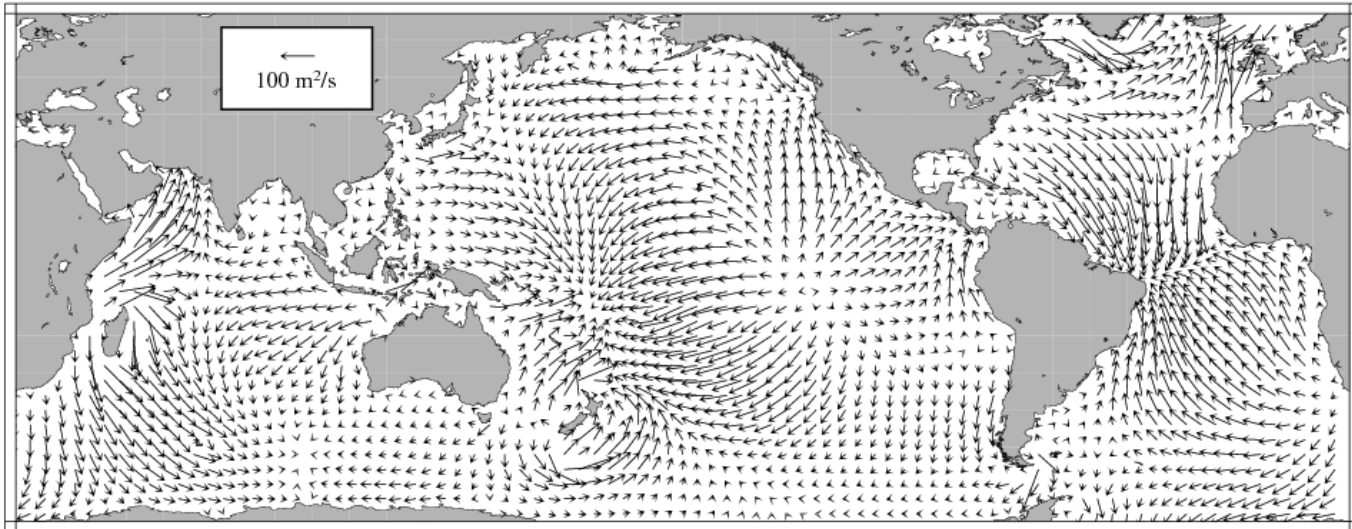


# Volume Transport M2 Tide (Moon over Greenwich)





# Volume Transport M2 (45 degree meridian)





## Deficiencies with 2003 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 accounting for libration.
  - Affects diurnal PM and semi-diurnal UT1
  - Easily rectified by using Chao, et al. (GRL, 1991)
- No terdiurnal and higher constituents
  - Expected to be (*and are*) very small because they are shallow water.



## Features of 2010 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: 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.

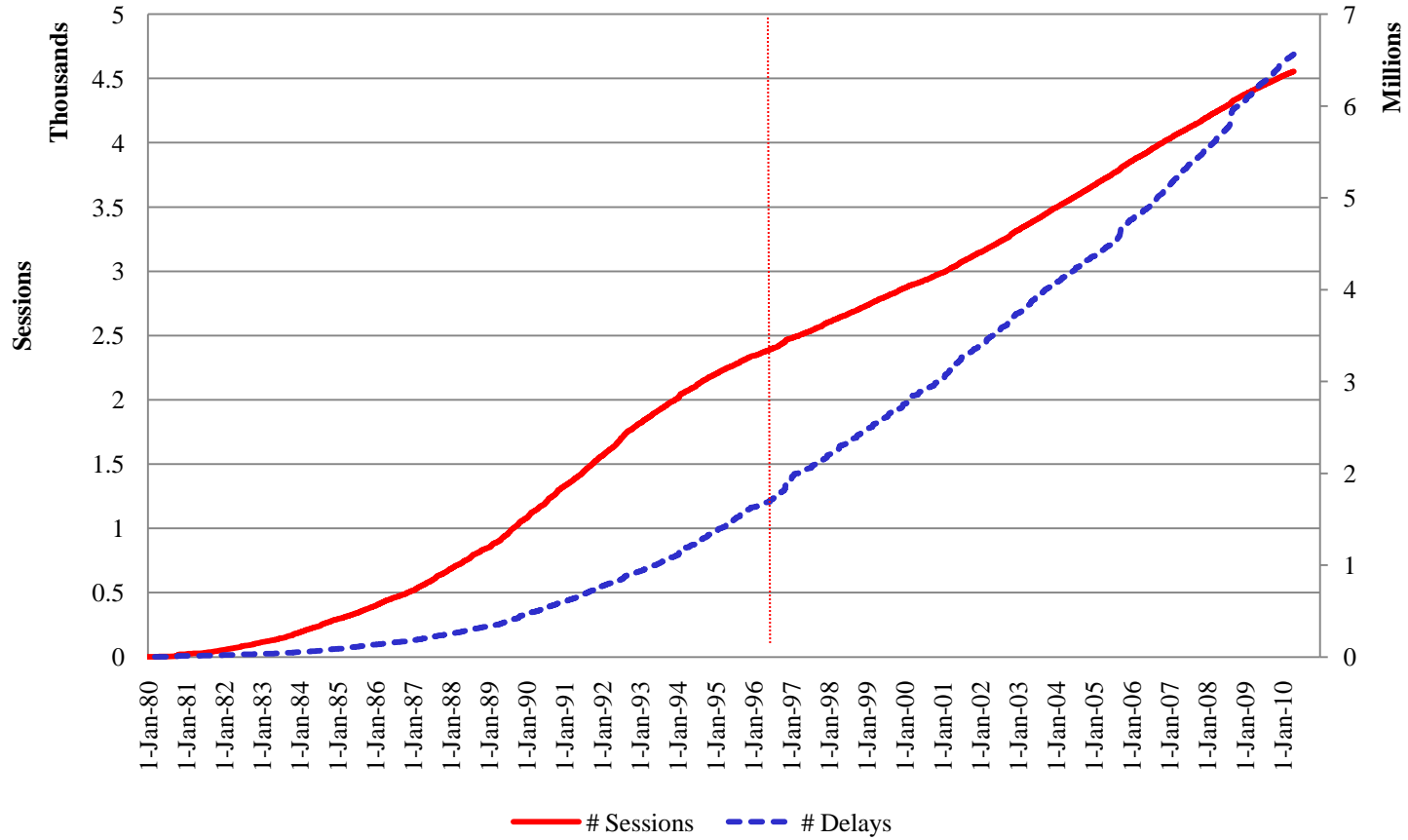
Estimated 10 “zero-terms” per component/band.



# Features of 2010 Solution

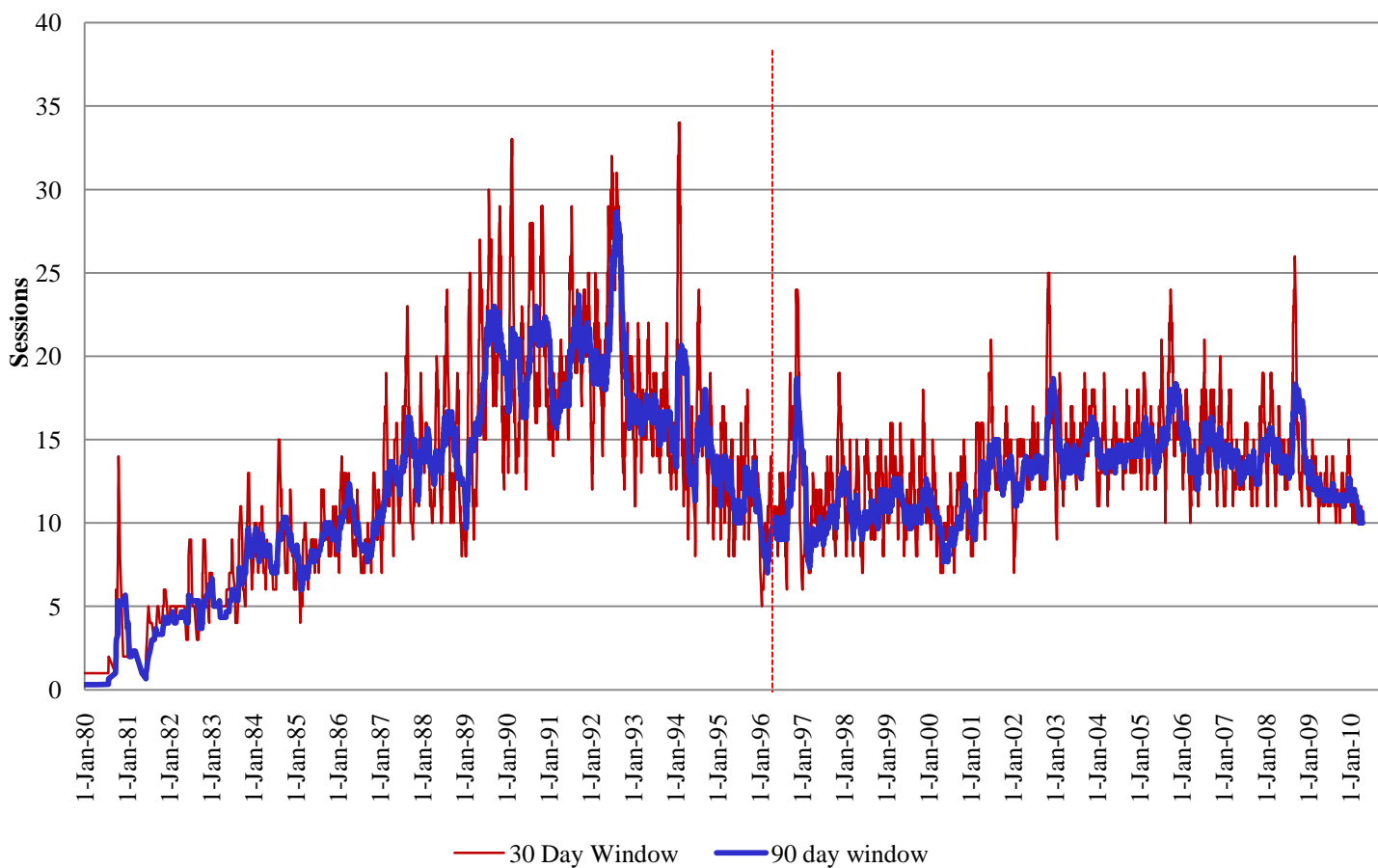


## Cumulative VLBI Data





## 24 Hour VLBI Sessions Per Month





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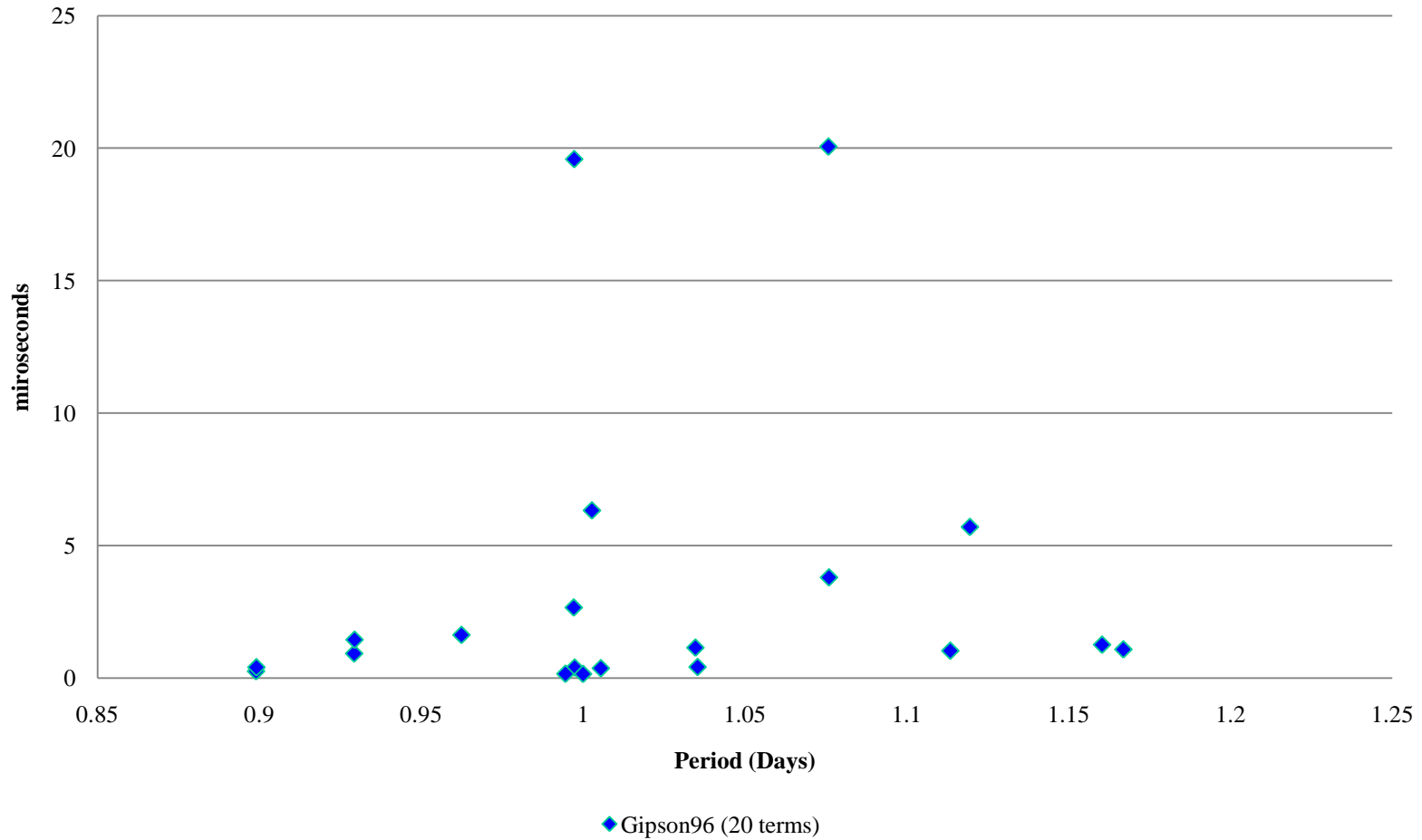
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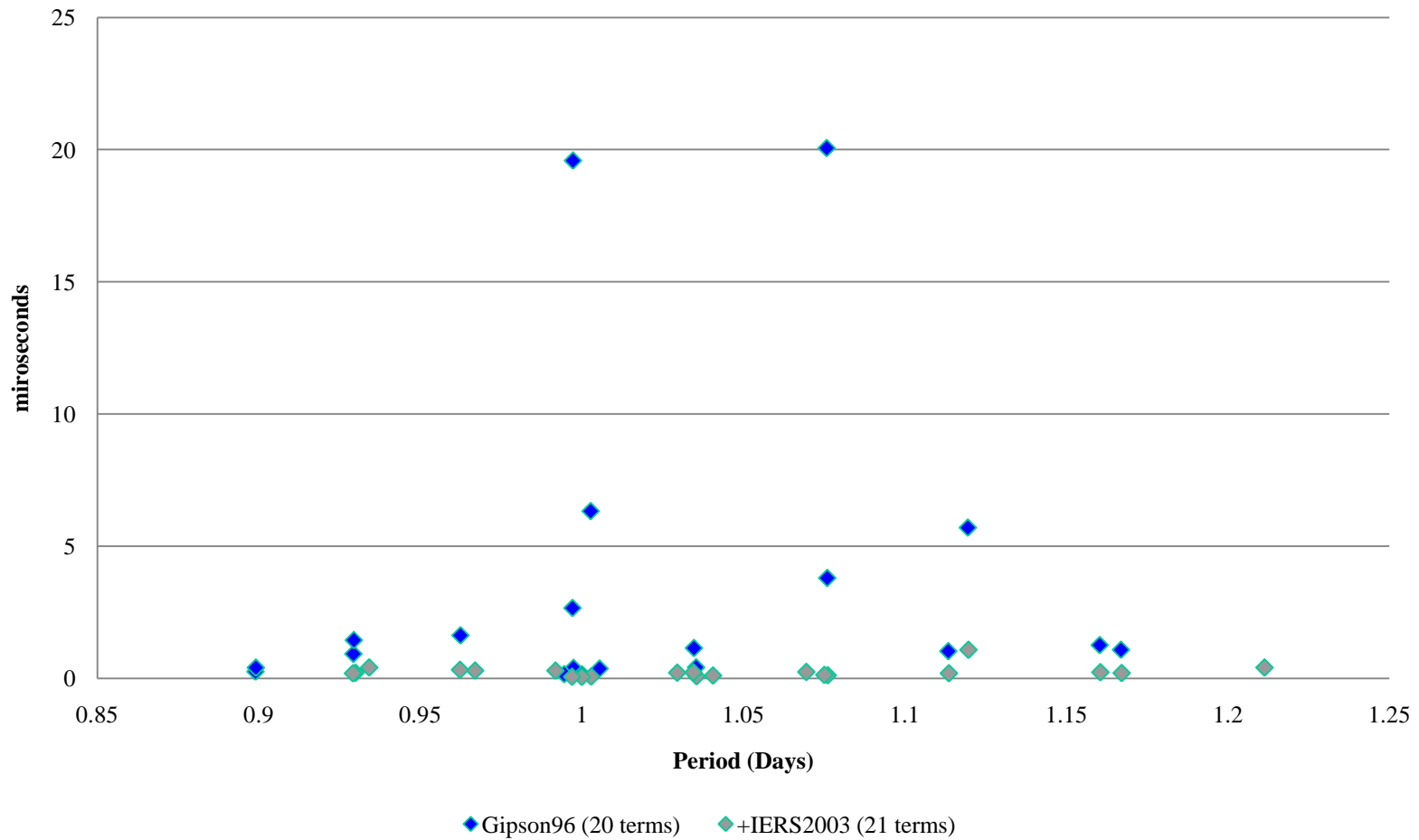


# 2010 Tidal UT1 Estimates from VLBI





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# 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
<b>K1</b>	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.**

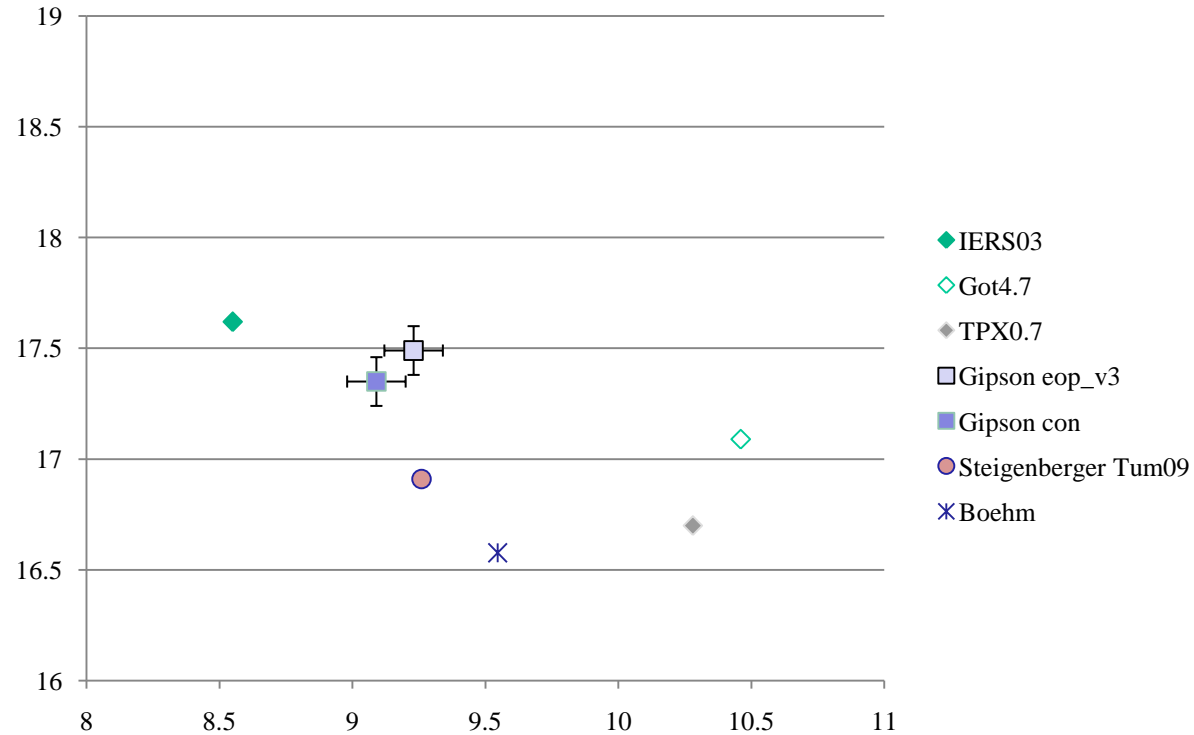
**Over shorter periods need to impose constraints to reliably separate.**



# Effect of Imposing Constraint



## UT1 K1





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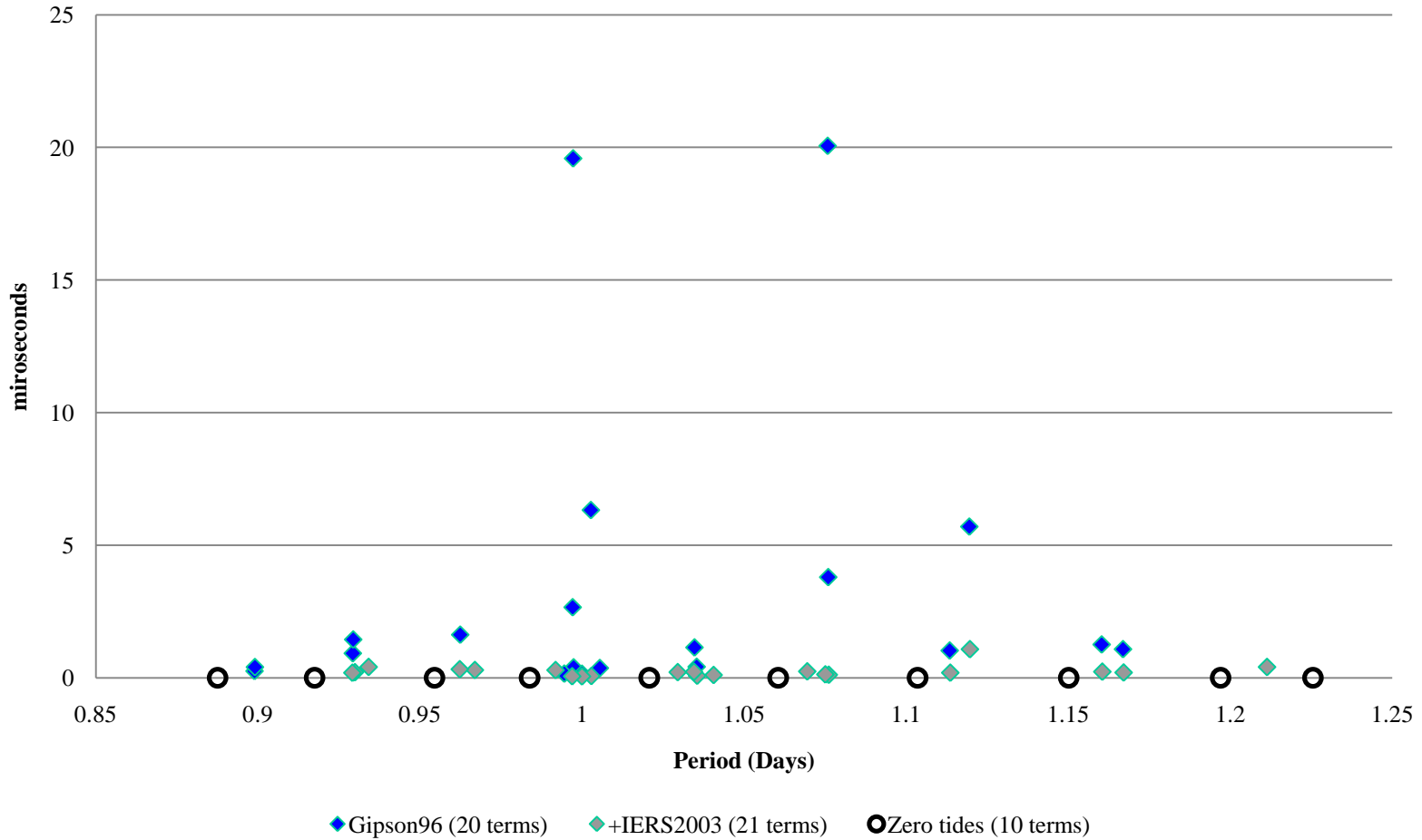
PM: 41 prograde diurnal, 30 prograde semi-diurnal and 30 retrograde diurnal.

**Imposed constraints on sidebands that differ by only 1-2 cycles over time span. (*But I didn't need to.*)**

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

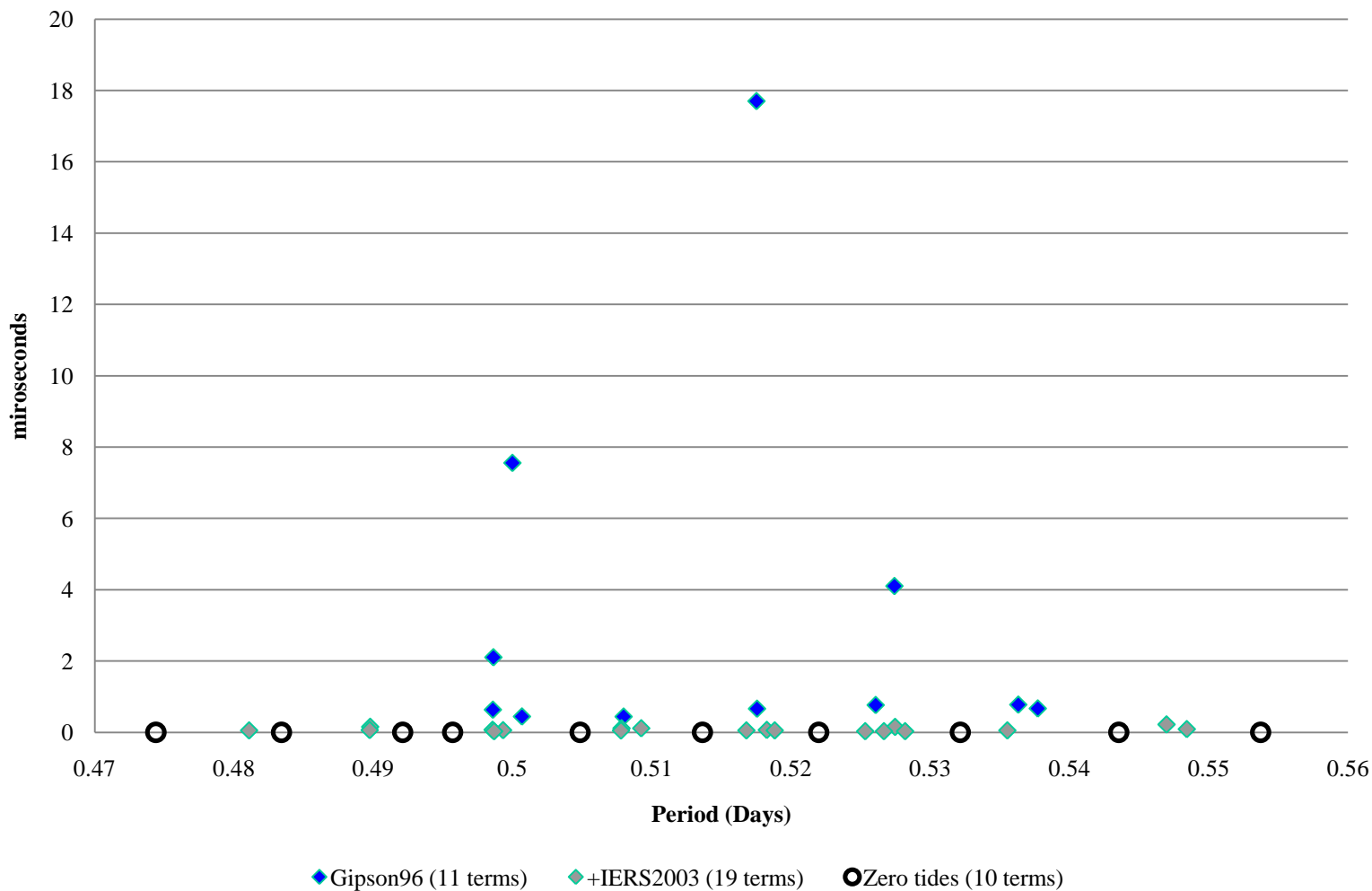


# 2010 Diurnal UT1 Estimates from VLBI





# 2010 Semi-Diurnal UT1 Estimates from VLBI

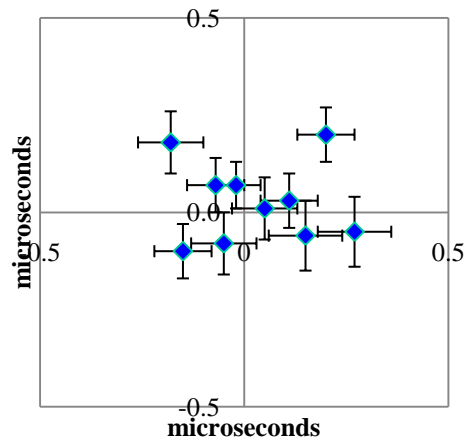




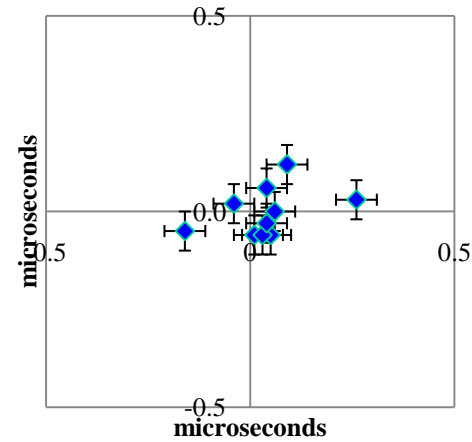
# Estimates of UT1 "0" terms



'Zero' UT1 Diurnal Terms



'Zero' UT1 Semidurnal Terms

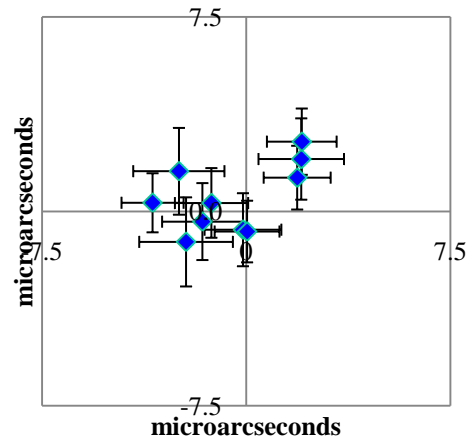




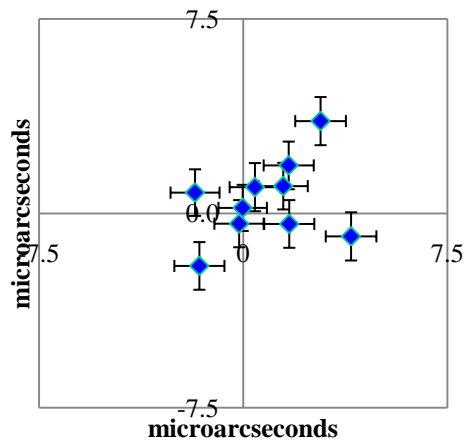
# Estimates of PM "0" terms



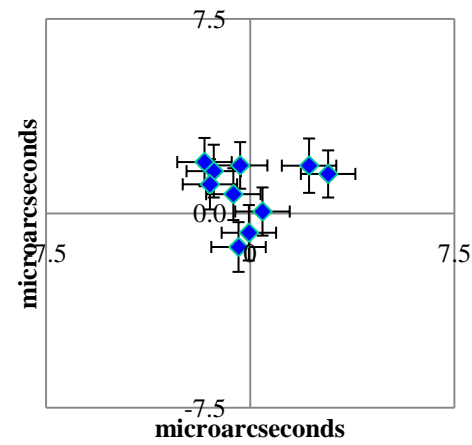
'Zero' PM Diurnal



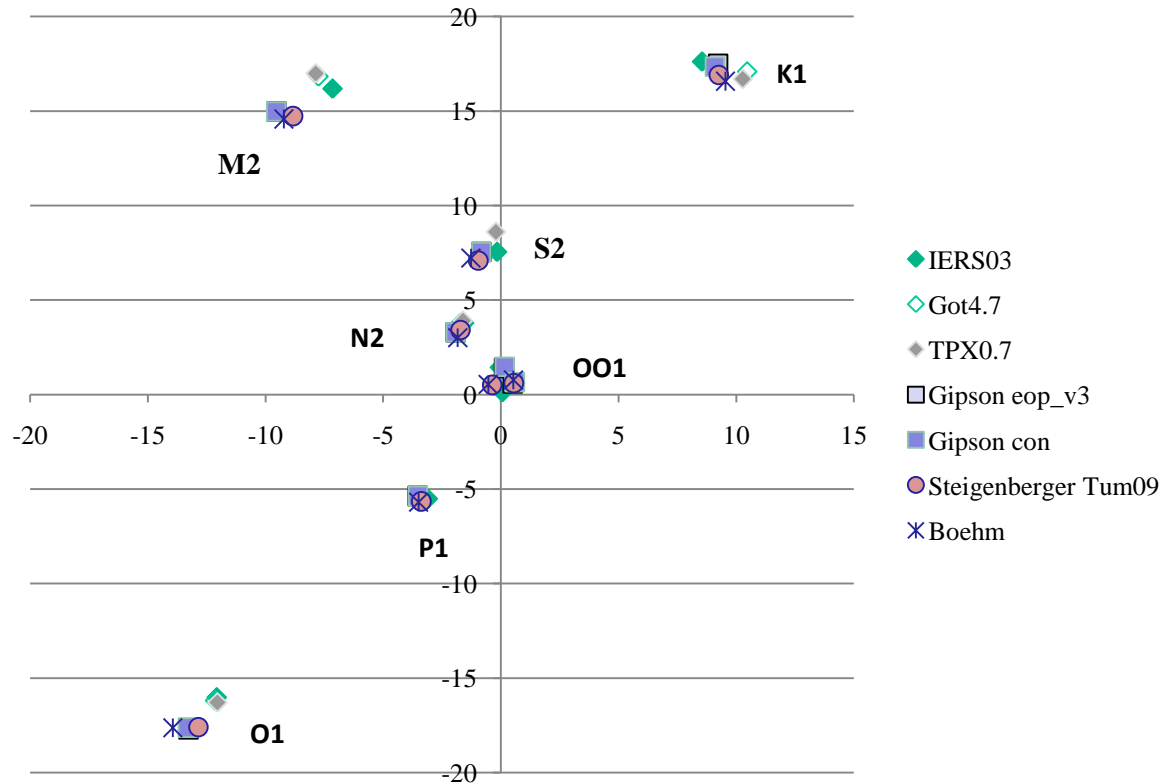
'Zero' PM Prograde Semidiurnal



'Zero' PM Retrograde Semidiurnal



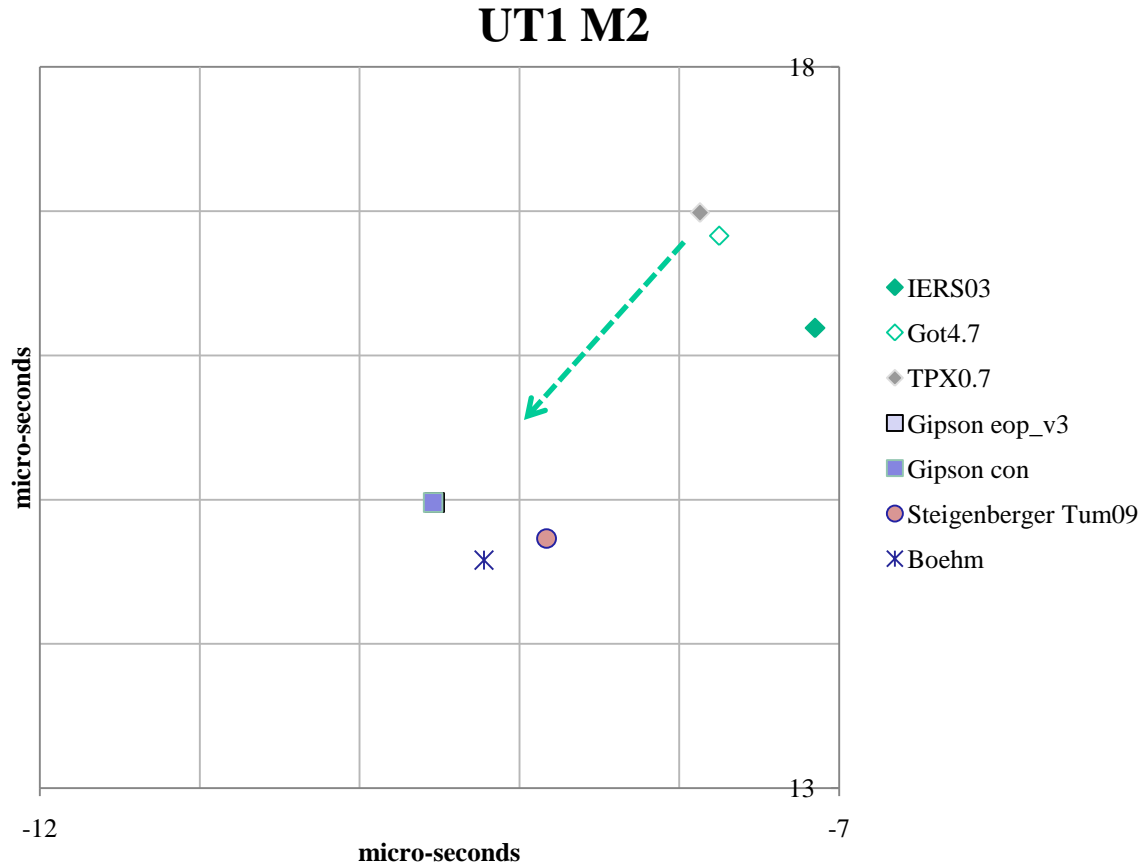
## Comparison UT1 Terms



*Error bars are smaller than symbols.*



# Some Large Differences

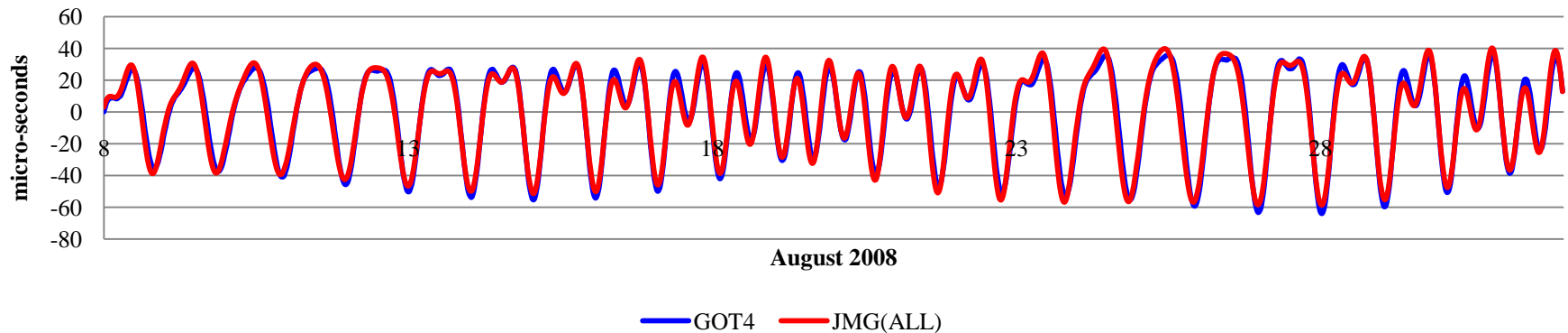




# Comparison of Model and Measured



## UT1 Predictions



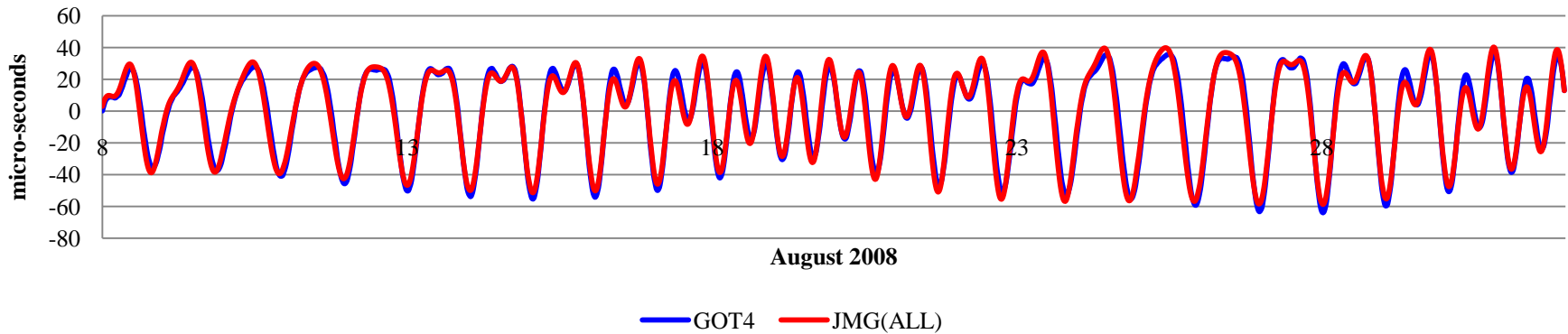
Models agree very well if you just plot them together



# Comparison of Model and Measured

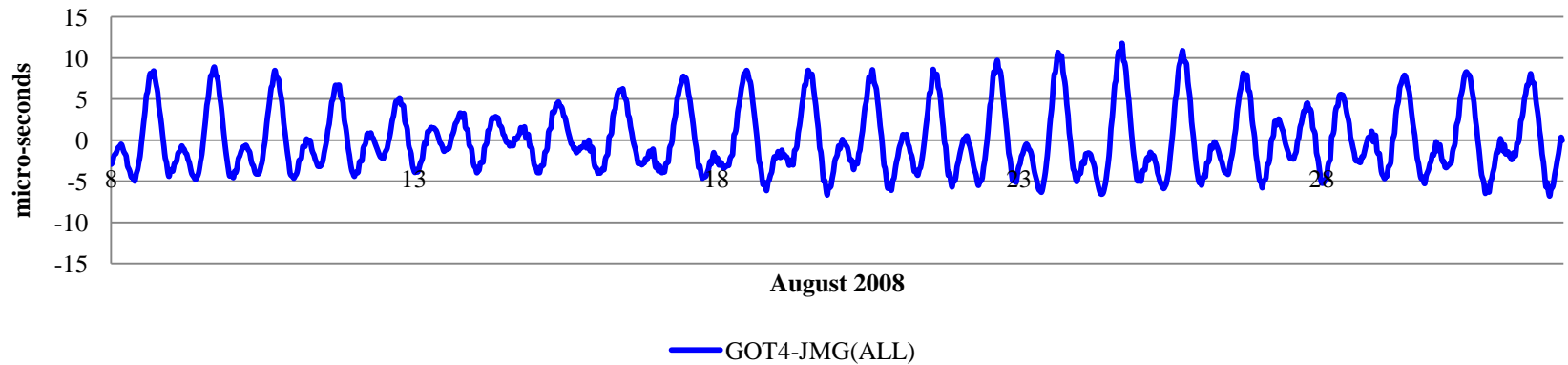


## UT1 Predictions



RMS= 4

## Difference in UT1

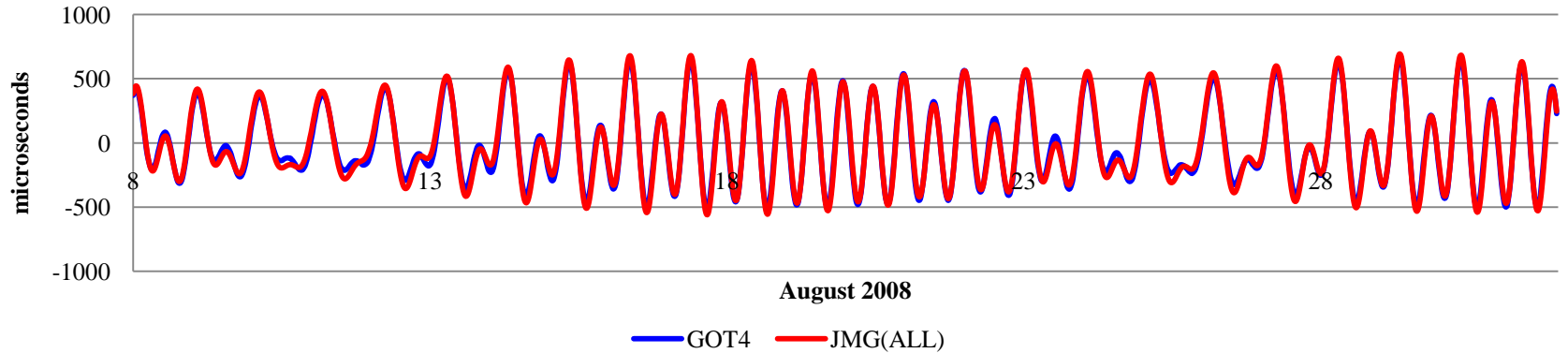




# Comparison of Model and Measured

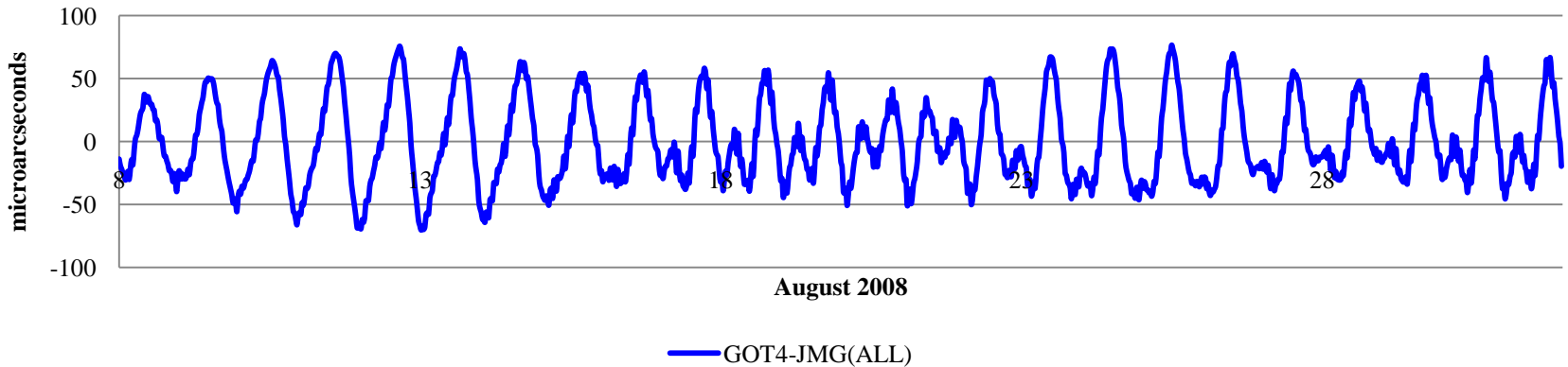


## X Pole Predictions



RMS= 33.7

## Difference in Xpole





# UT1 Differences



## Tidal Estimates Include Libration

### RMS Differences

### UT1

	TPX71	GOT47	IERS	Gip_ortho	Gipson	Steigenberger	Boehm
TPX71		1.3	1.9	2.8	3.4	3.4	4.2
GOT47	1.3		1.7	2.6	3.3	3.1	4.0
IERS	1.9	1.7		2.6	3.3	3.2	4.1
Gip_ortho	2.8	2.6	2.6		1.7	2.0	2.8
Gipson	3.4	3.3	3.3	1.7		2.1	2.7
Steigenberger	3.4	3.1	3.2	2.0	2.1		2.8
Boehm	4.2	4.0	4.1	2.8	2.7	2.8	

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



# X-Pole Differences



## Tidal Estimates Include Libration

X-Pole

	TPX71	GOT47	IERS	Gip_ortho	Gipson	Steigenberger	Boehm
TPX71		14.0	28.5	35.3	39.8	38.5	41.2
GOT47	14.0		27.5	37.6	39.6	35.7	42.6
IERS	28.5	27.5		20.3	25.9	28.9	32.4
Gip_ortho	35.3	37.6	20.3		21.7	35.2	29.3
Gipson	39.8	39.6	25.9	21.7		33.4	28.4
Steigenberger	38.5	35.7	28.9	35.2	33.4		43.4
Boehm	41.2	42.6	32.4	29.3	28.4	43.4	

- Based on calculating RMS difference between hourly values of time series for 18.7 yrs
- Models are in general agreement
- Measurements are in general agreement
- Models and measurements differ
- IERS has best agreement?!!**



# Y-Pole Differences



## Tidal Estimates Include Libration

Y-Pole

TPX71	GOT47	IERS	Gip_ortho	Gipson	Steigenberger	Boehm
TPX71	10.0	31.5	35.7	44.4	39.2	45.9
GOT47	10.0	26.5	31.7	40.6	37.5	43.4
IERS	31.5	26.5	21.6	31.6	27.7	41.1
Gip_ortho	35.7	31.7	21.6	25.7	30.3	36.0
Gipson	44.4	40.6	31.6	25.7	37.2	33.4
Steigenberger	39.2	37.5	27.7	30.3	37.2	51.0
Boehm	45.9	43.4	41.1	36.0	33.4	51.0

- Based on calculating RMS difference between hourly values of time series for 18.7 yrs
- Models are in general agreement
- Measurements are in general agreement
- Models and measurements differ
- IERS has best agreement?!!**



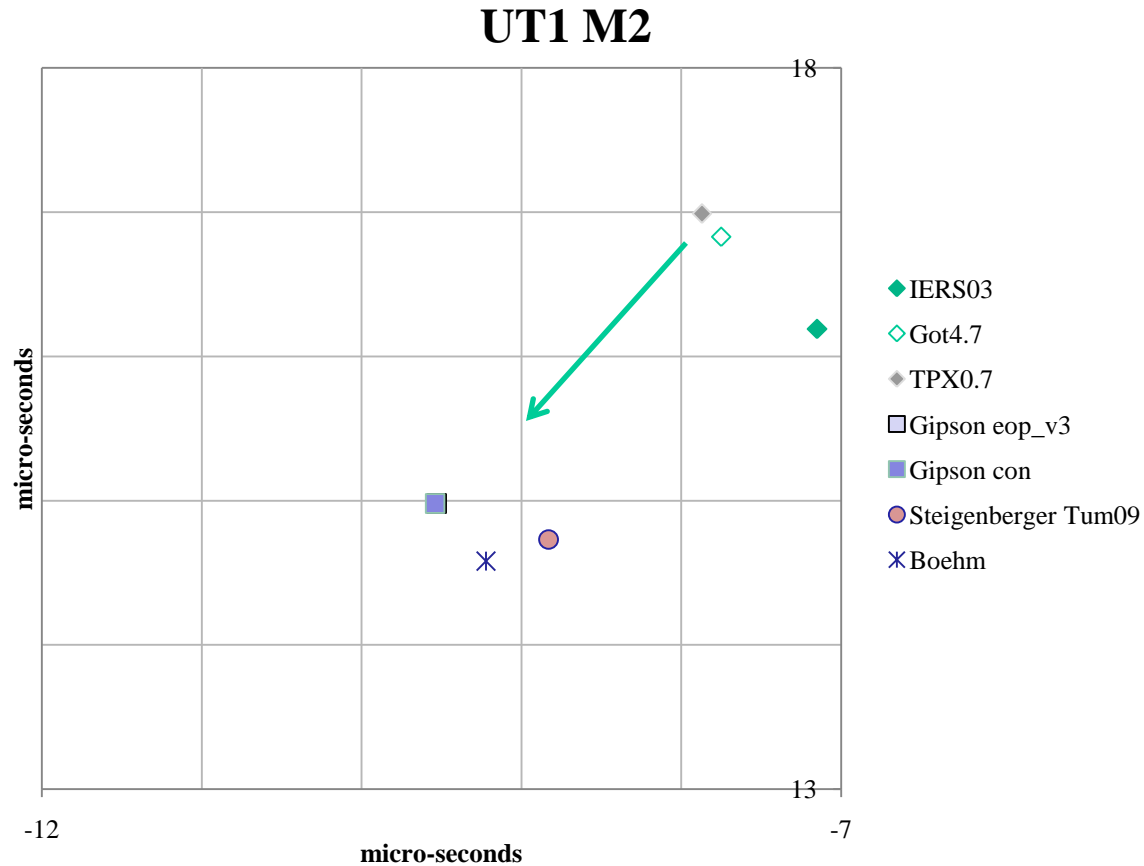
# Libration



- 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



# Libration explains much of the difference





# Correcting for Libration Improves agreement NVI, INC.



## UT1

### Libration

	Gipson	Steigenberger	Boehm
TPX71	3.4	3.4	4.2
GOT47	3.3	3.1	4.0
IERS	3.3	3.2	4.1

### Libration Removed

	Gipson	Steigenberger	Boehm
	2.6	2.6	3.4
	2.8	2.5	3.3
	2.8	2.6	3.5

## X-Pole

### Libration

	Gipson	Steigenberger	Boehm
TPX71	39.8	38.5	41.2
GOT47	39.6	35.7	42.6
IERS	25.9	28.9	32.4

### Libration Removed

	Gipson	Steigenberger	Boehm
	29.4	30.9	34.2
	31.8	30.2	38.1
	28.0	33.7	36.8

## Y-Pole

### Libration

	Gipson	Steigenberger	Boehm
TPX71	44.4	39.2	45.9
GOT47	40.6	37.5	43.4
IERS	31.6	27.7	41.1

### Libration Removed

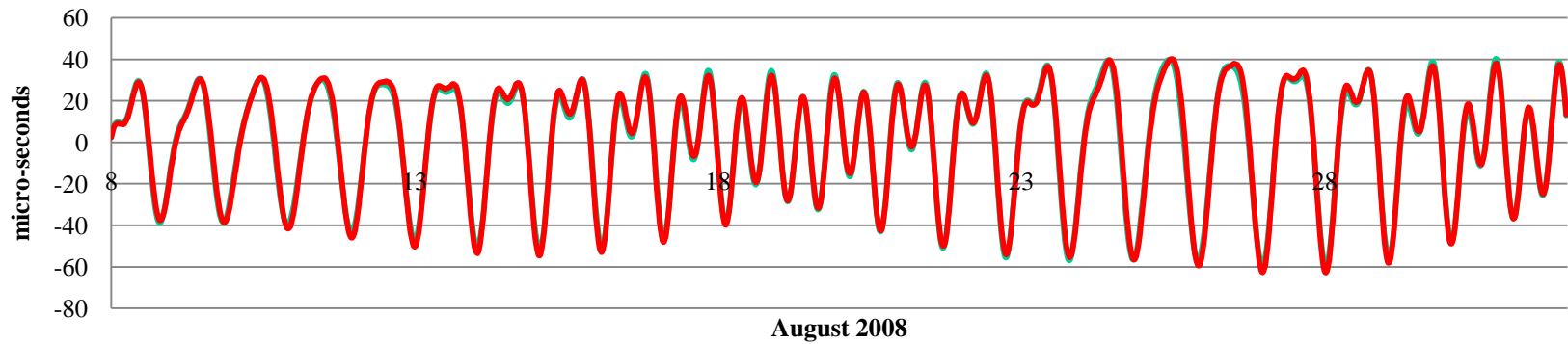
	Gipson	Steigenberger	Boehm
	35.3	31.7	39.7
	33.0	32.2	38.9
	33.3	32.7	44.6



# Effects of Ortho-tide assumption

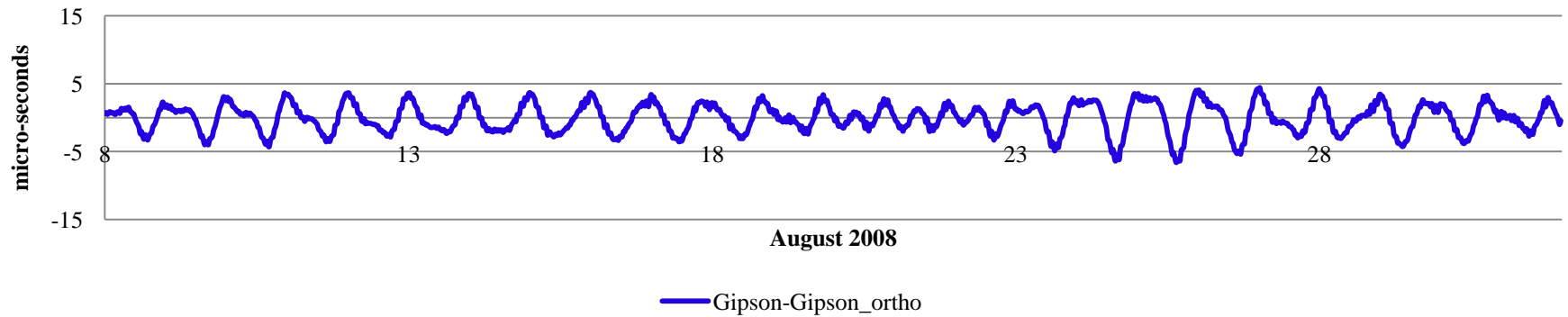


## UT1 Predictions



RMS= 2.1

## Difference in UT1





# 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. **This needs to be included in the IERS conventions.**
- Ortho-tide assumption has real consequences.