

**59-Day Oscillations,  $\beta'$ , and All That  
– or –  
Subtle  $S_2$  Errors from Satellite Altimetry**

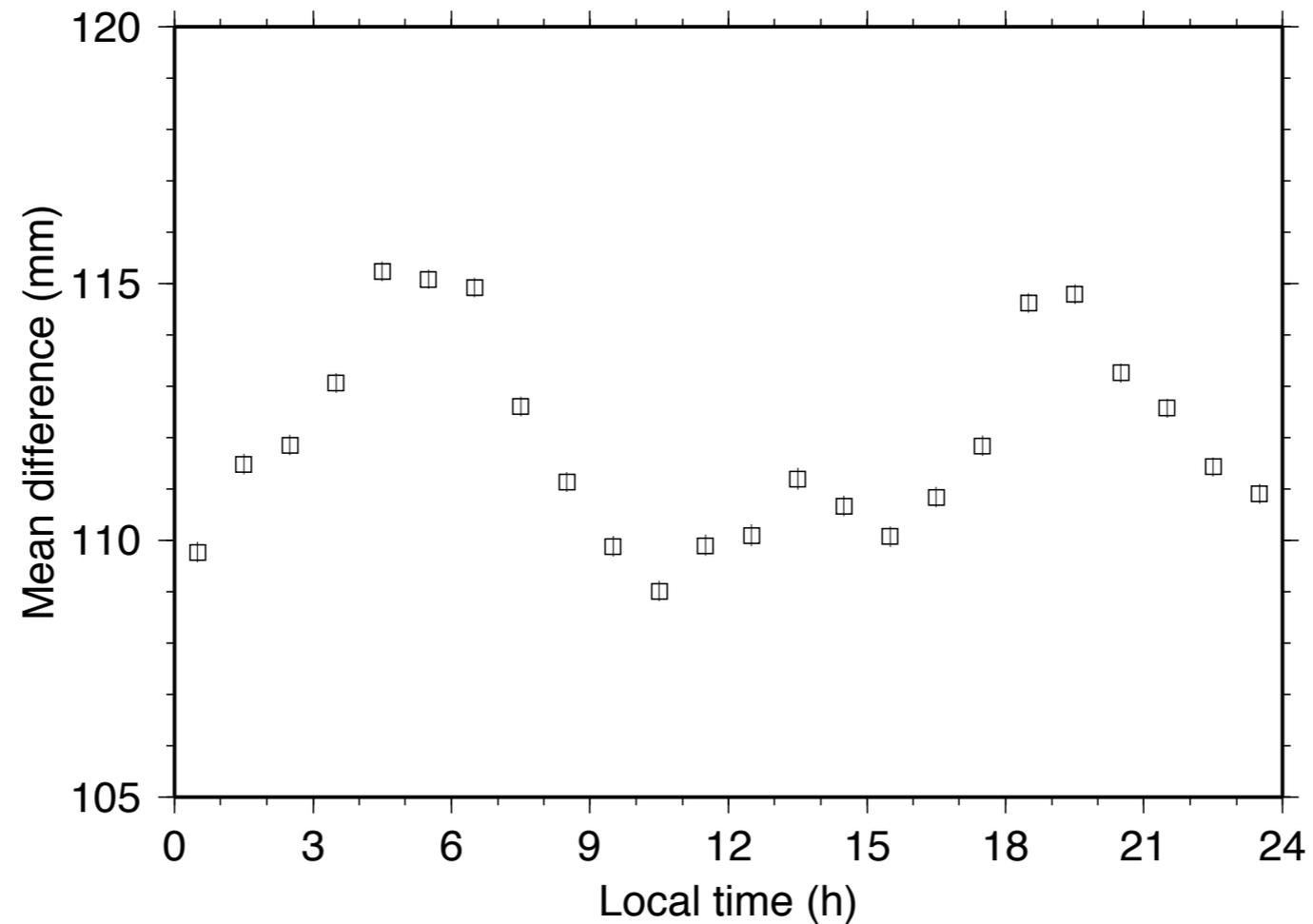
**Richard Ray**  
*NASA Goddard Space Flight Center*

**“S2 is our punishment.” –Florent Lyard**

**OSTST meeting – Venice      Sept. 2012**

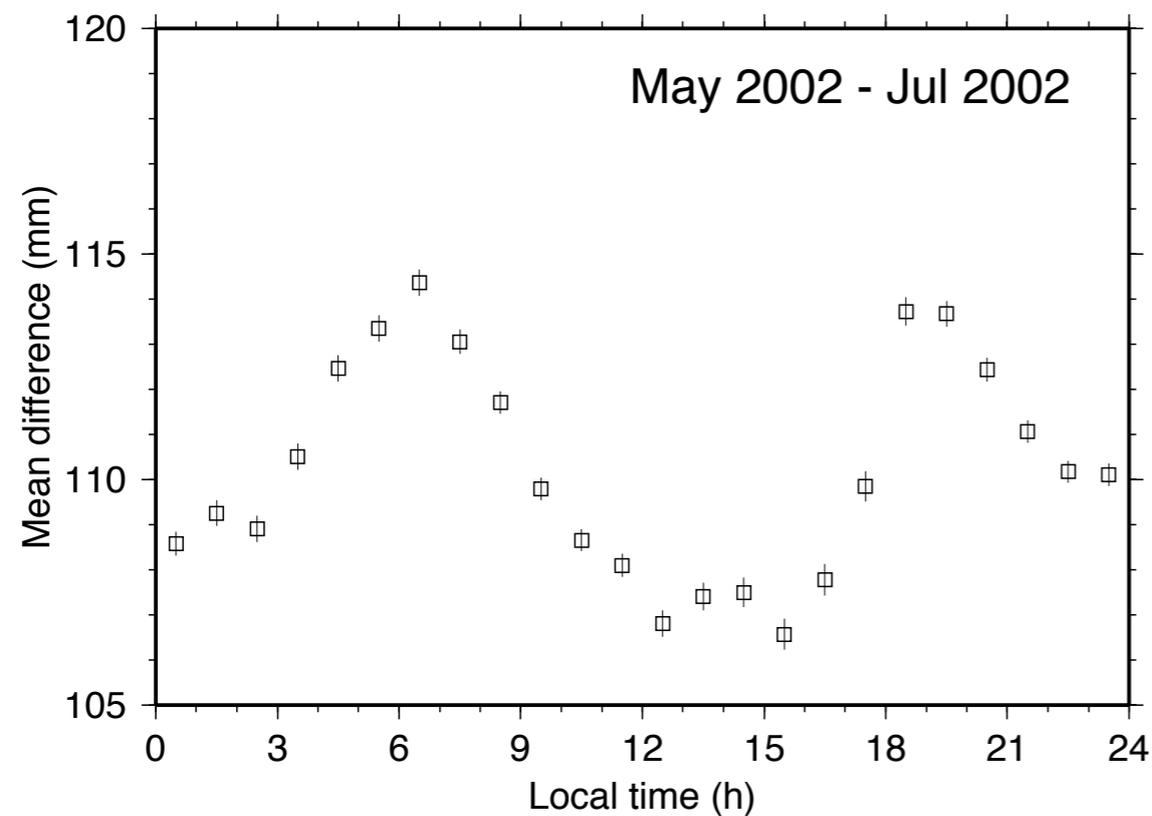
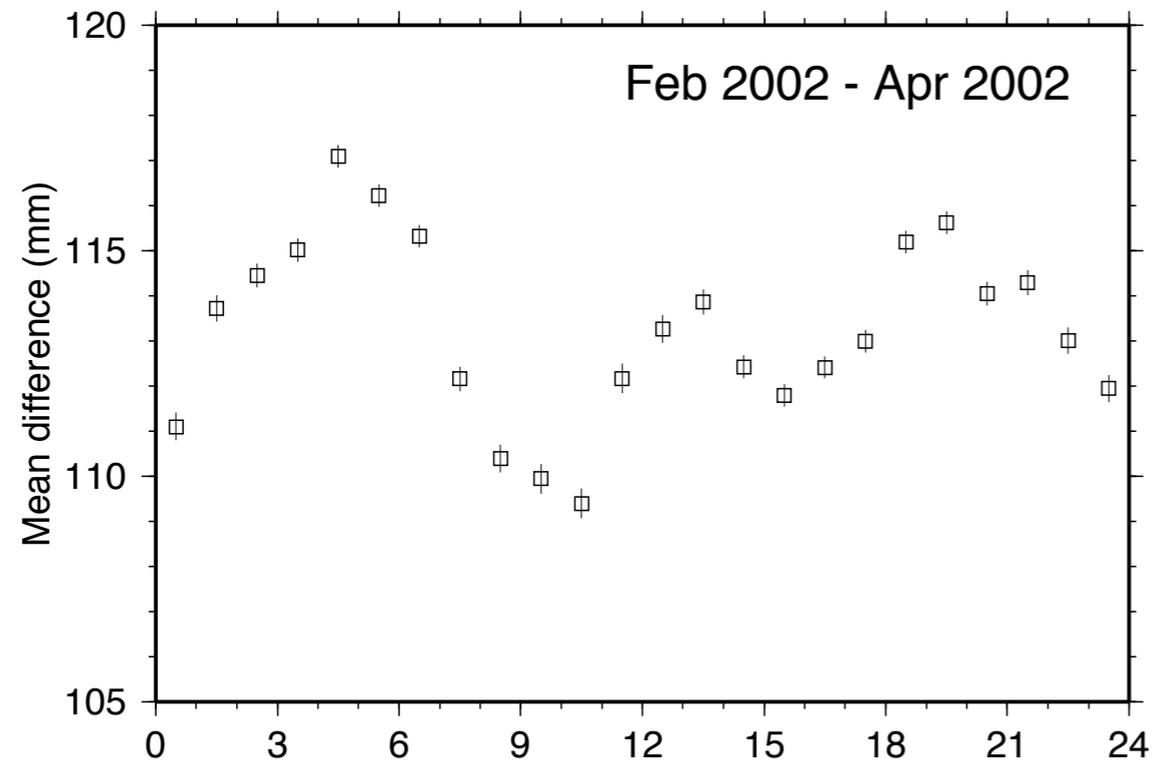
# Mean Jason – Topex Sea-surface Height Differences as Function of Local Time

Jason-1 cal/val period Feb–July 2002



**NOTE: Results are independent of tide corrections!**

**From OSTST meeting, Hobart, March 2007**



## Mean Jason – Topex SSH Differences as Function of Local Time

In T/P and Jason, these errors map  
mostly into ~60-day periods.

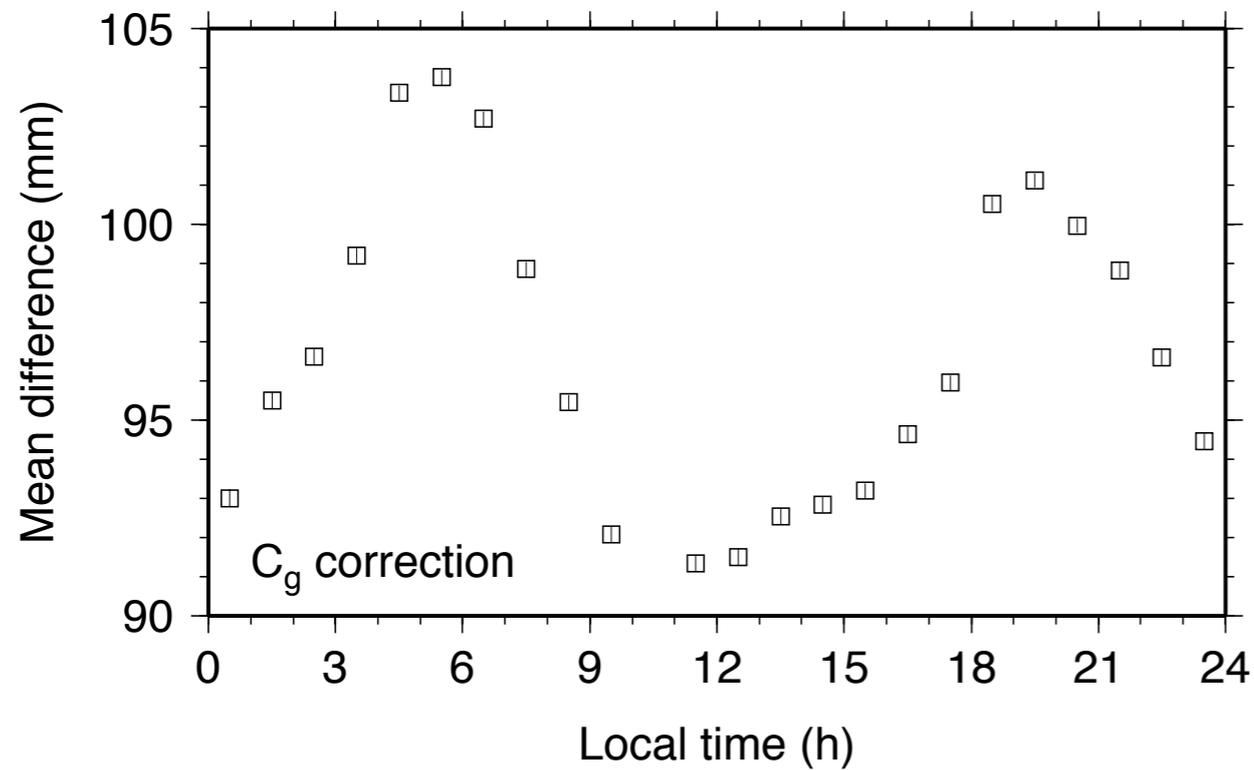
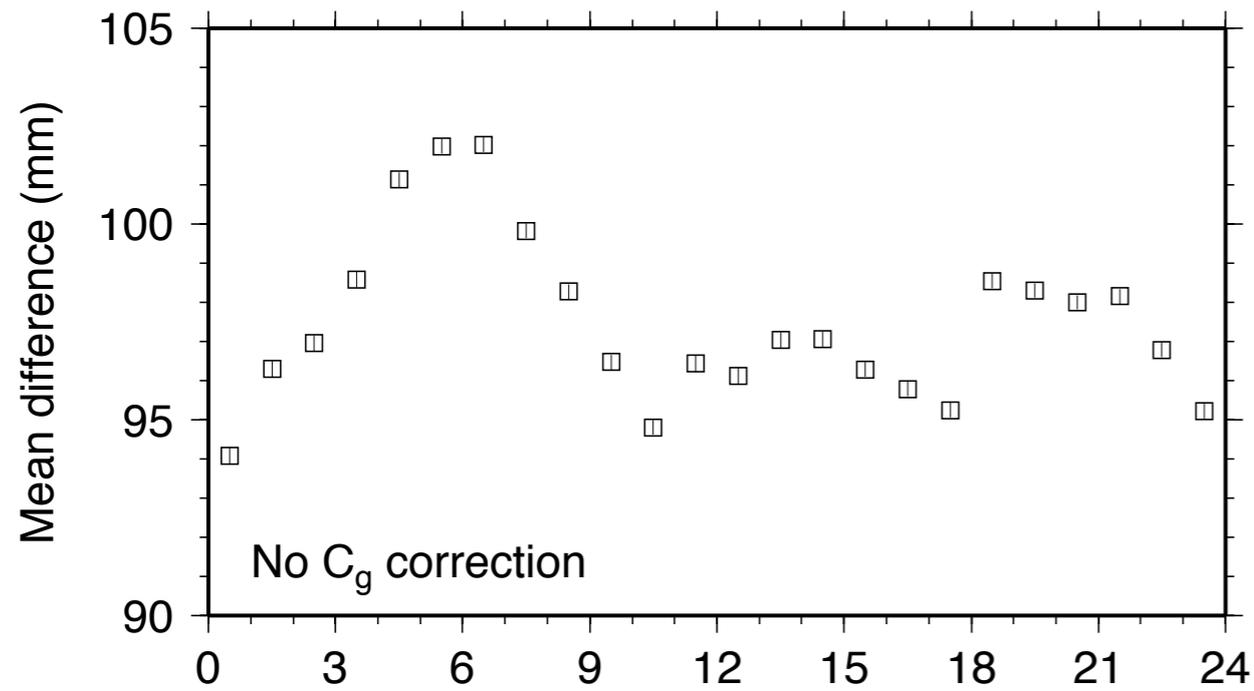
**Sun-synch maps them into long periods.**

**From OSTST meeting, Hobart, March 2007**

# Mean Jason – Topex SSH Differences

## Jason-1 CalVal Period

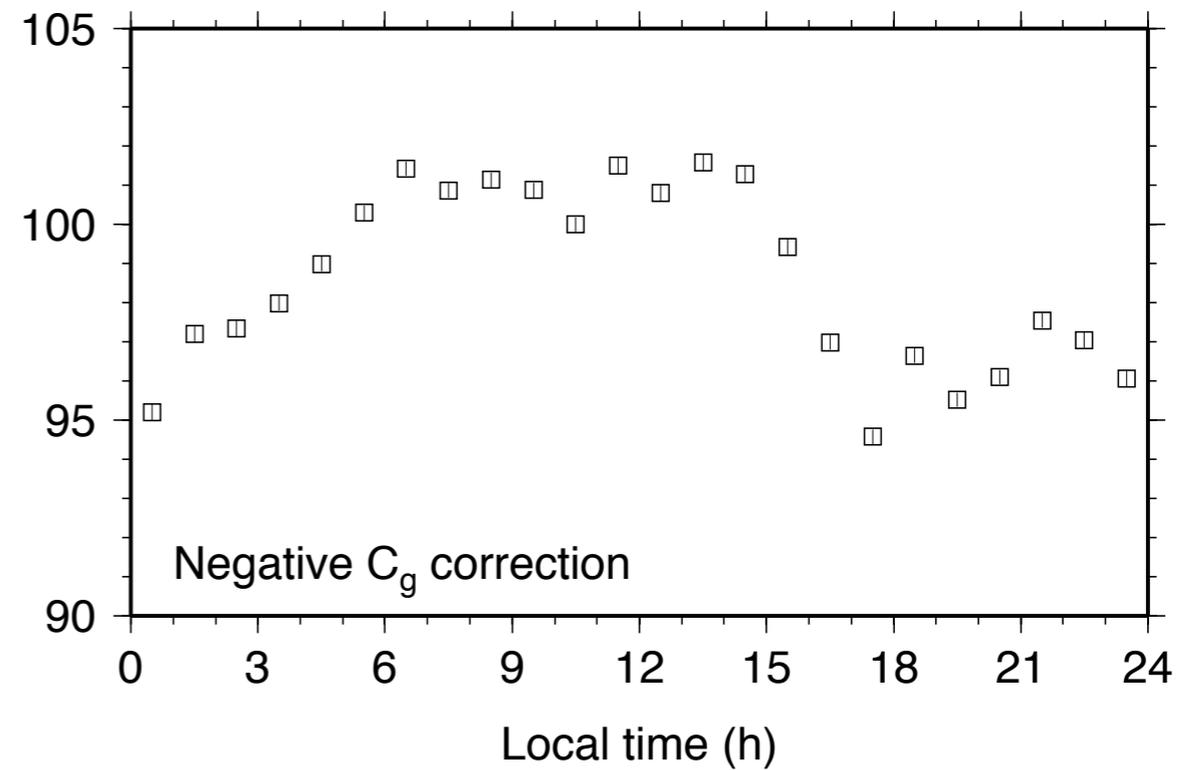
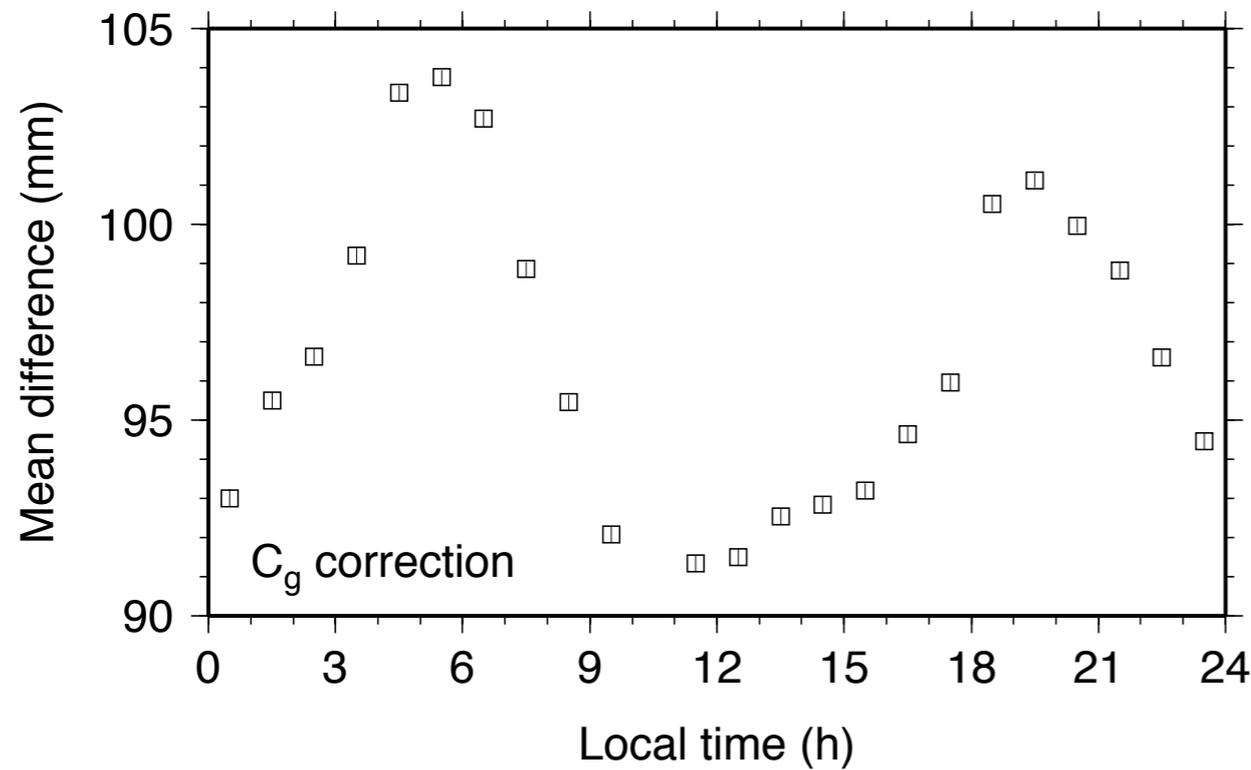
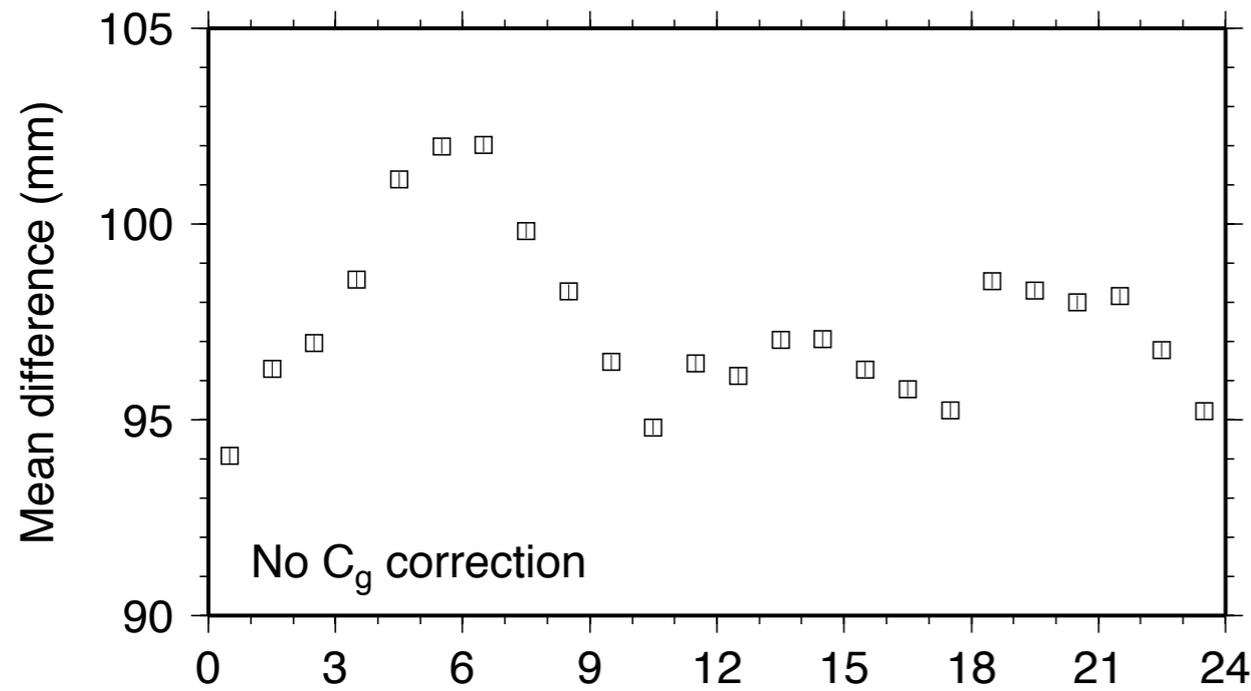
Updated Sept 2012  
Topex: MGDR-B data  
Jason: GDR-C data  
GSFC Std1007 orbits  
Only corrections are: SSB and MSS



# Mean Jason – Topex SSH Differences

## Jason-1 CalVal Period

Updated Sept 2012  
Topex: MGDR-B data  
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Only corrections are: SSB and MSS



**What are the implications for  
producing  $S_2$  models from altimetry?**

# GOT Experiments

## Extracting $S_2$ Tides from Altimetry

	GOT4.7	GOT4.8	GOT4.9	GOT4.10
Uses TOPEX	✓	✓	✓	
Uses J1-J2				✓
Corrects $S_2$ dry-trop		✓	✓	✓
Applies T/P $C_g$			✓	

All solutions otherwise made as consistent as possible

(although some things have changed: e.g. editing & orbits).

All solutions use same prior tide model.

All solutions also use same GFO, ERS-1/2 data in shallows, polar seas.

# New pelagic “ground truth” dataset

**144 stations.**

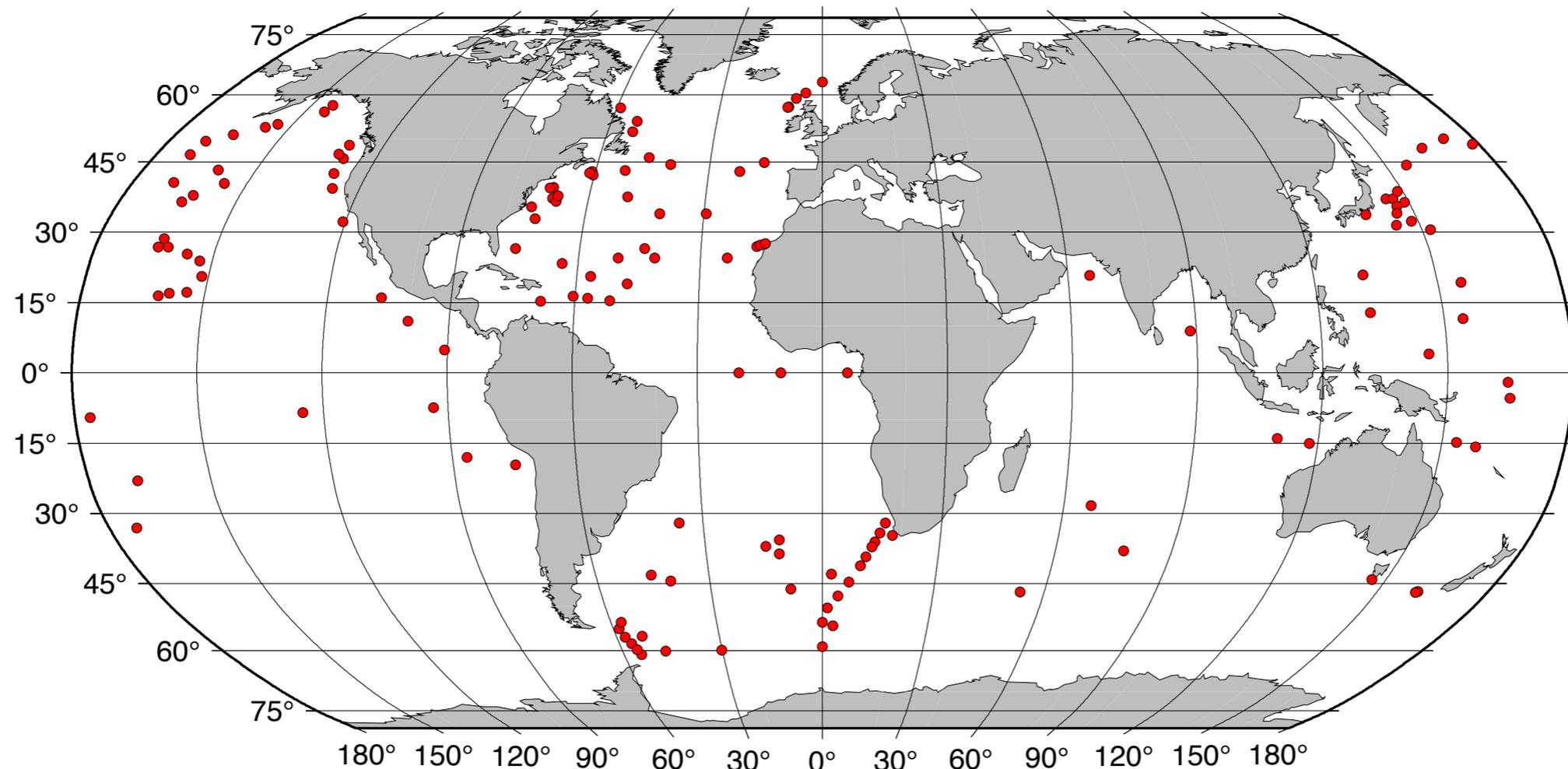
**Only bottom-pressure stations.**

**No short time series — All > 90 days.**

80% are one year or longer. 65% are two years or longer.

**Many time series reanalyzed.**

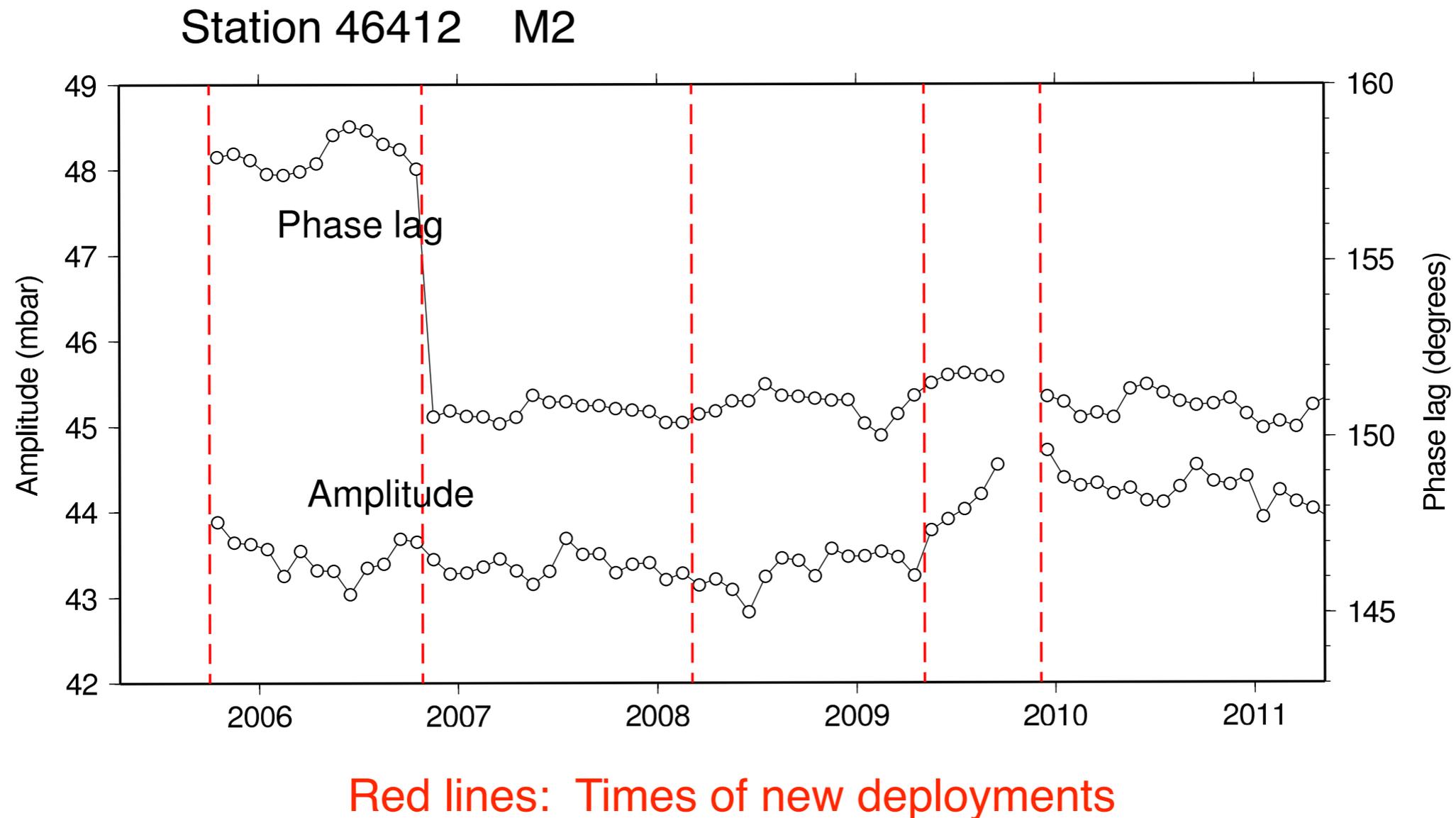
- 74 by me.
- 14 by Doug Luther.
- 27 by Proudman Lab. (via GLOUP database)



# DART Tsunami Network Is Invaluable

**But....**

- 1. Data can be noisy (because of acoustic & satellite links?)**
- 2. Small station movements over time**



# Correcting tidal amplitudes when time series consists of *mean* values

$$\text{amplitude error} = \frac{1}{T} \int_{-T/2}^{T/2} \cos(2\pi t/P) dt = (P/\pi T) \sin(\pi T/P)$$

$P$  = tidal period       $T$  = averaging interval

See, for example, Malin & Chapman, *Geophys. J. Royal Astr. Soc.*, 19, 15, 1970

For hourly values, amplitude correction factors are:

Diurnal: 1.00286

Semidiurnal: 1.0115

Terdiurnal: 1.02617

Quarterdiurnal: 1.0472

**Recent POL data: 15-minute means**  
**ASTTEX, KESS data: hourly means**

**DART data: 15-minute spot values**  
**Old IAPSO data: ??????**

**RMS differences (cm)**  
model GOT4.7

	Q1	O1	P1	K1	N2	M2	S2	K2
Old 102-station set	0.27	0.77	0.36	1.02	0.64	1.45	0.92	0.40
New 144-station set	0.17	0.30	0.23	0.43	0.26	0.53	0.49	0.21

# RMS Differences (cm)

## S2 Bottom pressure vs. Altimetry

	GOT4.7	GOT4.8	GOT4.9	GOT4.10
None	1.11	1.00	0.99	0.98
Haurwitz-Cowley analytic	0.56	0.36	0.47	0.35
ECMWF 6-h (Ray-Ponte)	0.56	0.36	0.47	0.34
ECMWF 3-h*	0.58	0.36	0.49	0.32
MERRA*	0.50	0.31	0.40	0.32
NCEP CFSR*	0.70	0.50	0.60	0.45

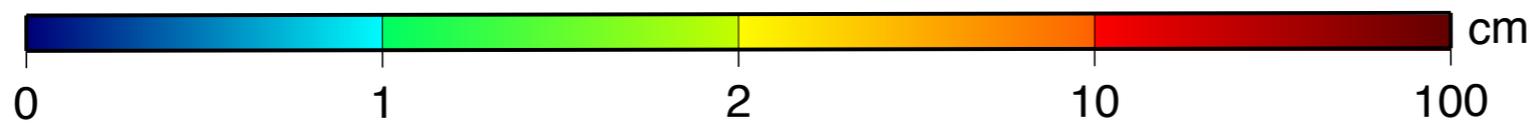
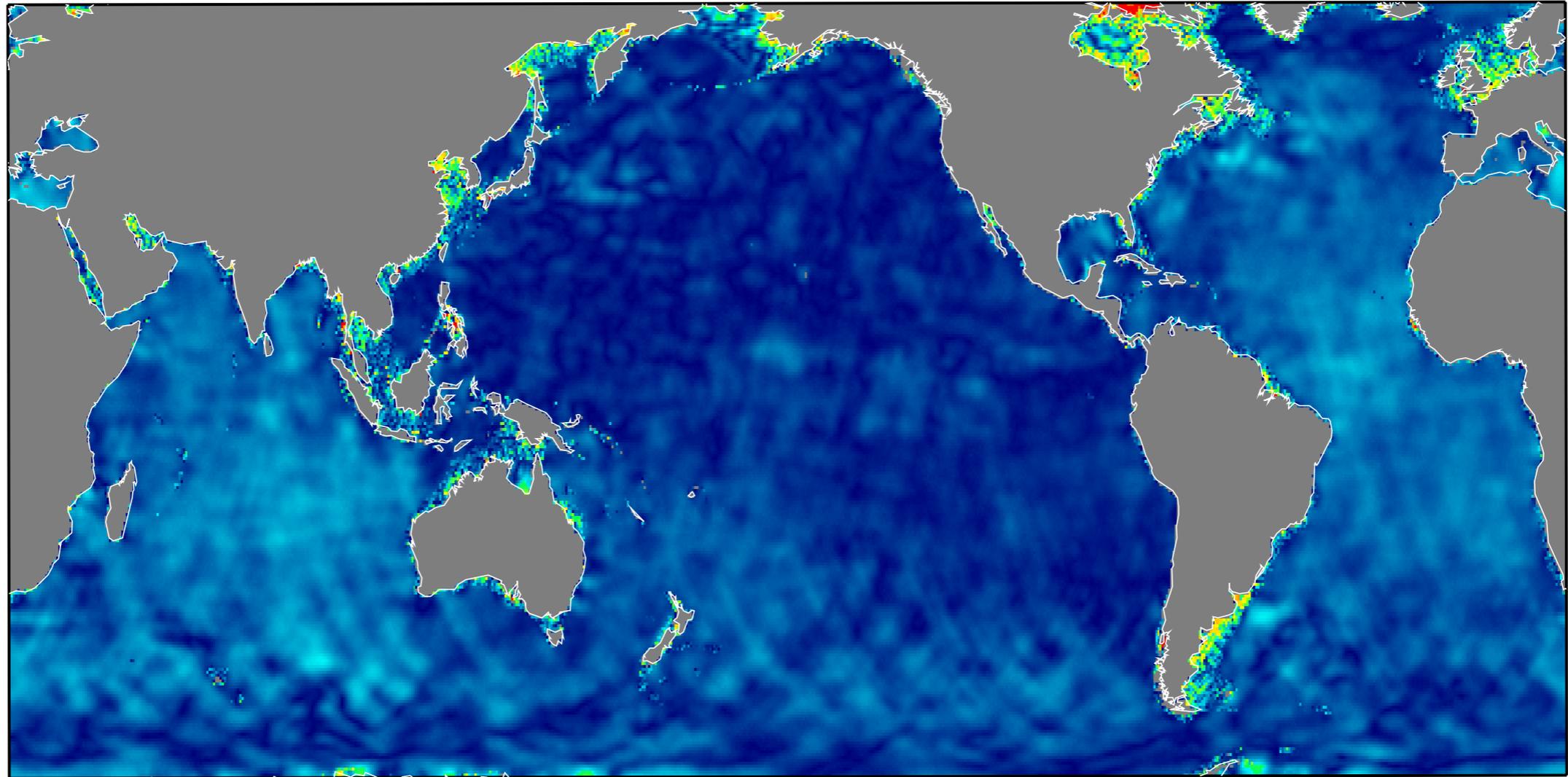
\* Courtesy J.-P. Boy

Based on 37 tropical BP stations.

Bootstrap uncertainty of RMS values ~ 0.03 cm

# S2 Vector Differences GOT4.8 - GOT4.10

S2



**Basin-scale differences approaching 1 cm.**

# Summary Statements

**1. Jason and Topex are inconsistent at S2, at the level of 5-10 mm, independent of Topex Cg correction.**

**Applying current Cg correction makes inconsistency worse.**

**2. Testing S2 tide models is difficult because of confounding effects.**

**2. GOT4.8 and 4.10 are more accurate S2 models than 4.7 or 4.9, but I do not know whether 4.8 or 4.10 is better.**

**3. GOT4.7 is consistent with T/P MGDR-B (without Cg).**

## Questions

**1. What Cg correction should be used for T/P?**

**2. What S2 model(s) are recommended for altimeter corrections?**

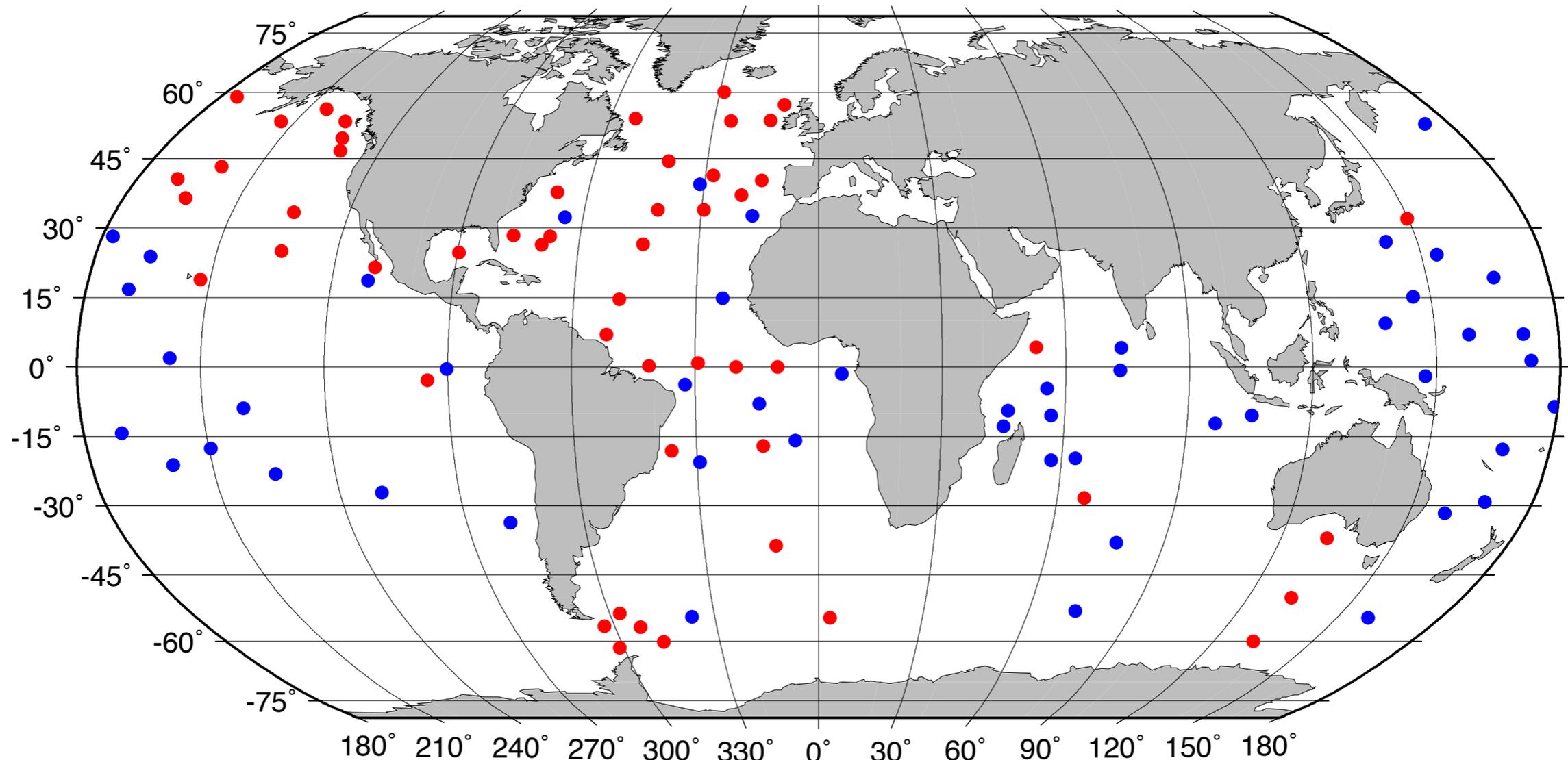
**3. Is using different S2 models for Jason vs Topex acceptable?**

**(otherwise we must live, for now, with 'large' 59-d oscillations in MSL)**

**4. What should the tidal community do???**

# Backups

# Old 102-station Deep-ocean Tidal Validation Dataset



52 Bottom pressure stations

50 Island tide gauges

Constructed mainly by David Cartwright and Christian Le Provost  
Used by Shum et al (JGR, 1997) and many others.

Best altimeter-based tide models have  $M_2$  RMS = 1.5 cm.

# Detection of air tides in BP–altimeter differences

RMS Differences (cm) with respect to GOT4.7

	P1	S1	K1	T2	S2
Before removing air tides from BP	0.188	0.454	0.276	0.151	1.083
After removing air tides from BP	0.196	0.291	0.254	0.132	0.567
Bootstrap 1- $\sigma$	0.011	0.018	0.019	0.008	0.034

**Major air tides (amplitude ~ 1 mb) are S1, S2.**

**Seasonal sidelines are P1,K1 and T2,R2.**

**Air-tide model based on 3-hr ECMWF.**

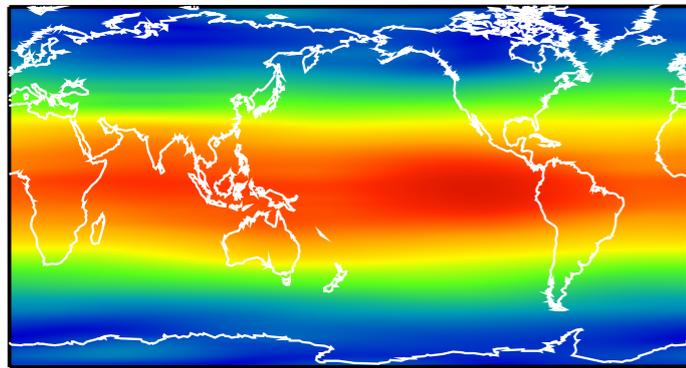
**RMS based on 32 tropical stations.**

Technique does not work for R2 because of no valid altimeter estimate.

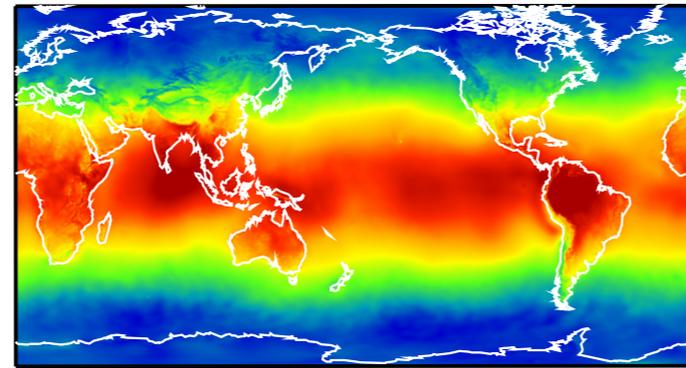
**Air tide clearly detected for S1, T2, S2.**

# S2 Barometric Tide

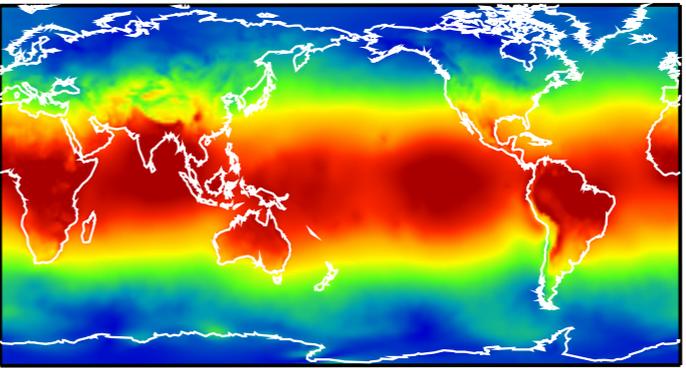
ECMWF 6-hr  
(Ray-Ponte 2003)



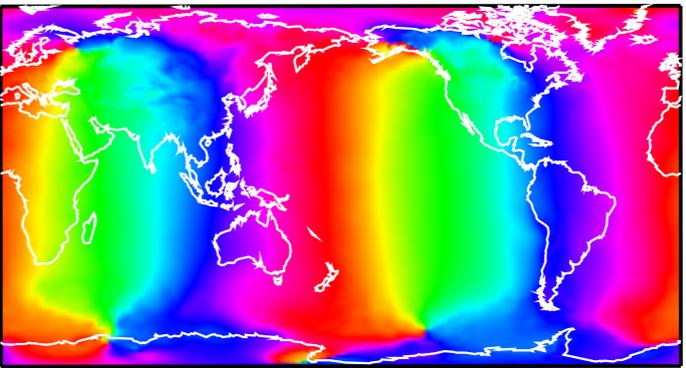
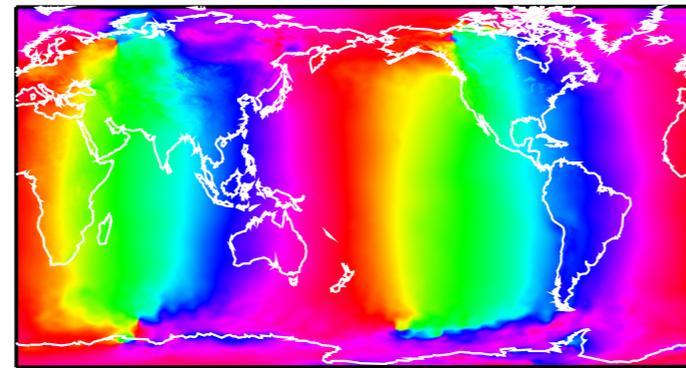
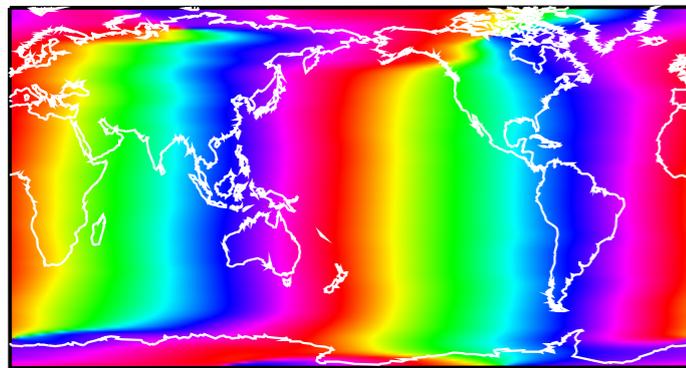
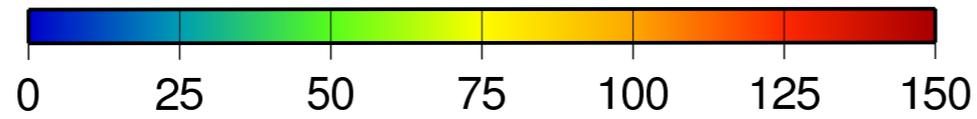
ECMWF 3-hr  
(J.-P. Boy)



MERRA 3-hr  
(J.-P. Boy)



**Amp**  
(Pa)



**Phase**  
(deg)

