High-Precision Comparisons of Bottom-Pressure & Altimetric Tides

Richard Ray

NASA Goddard Space Flight Center

OSTST meeting – San Diego October 2011

Two independent measurements of M2 amplitudes:

32.067 cm

32.074 cm

“When it comes to four-figure accuracies, it is no longer oceanography.”

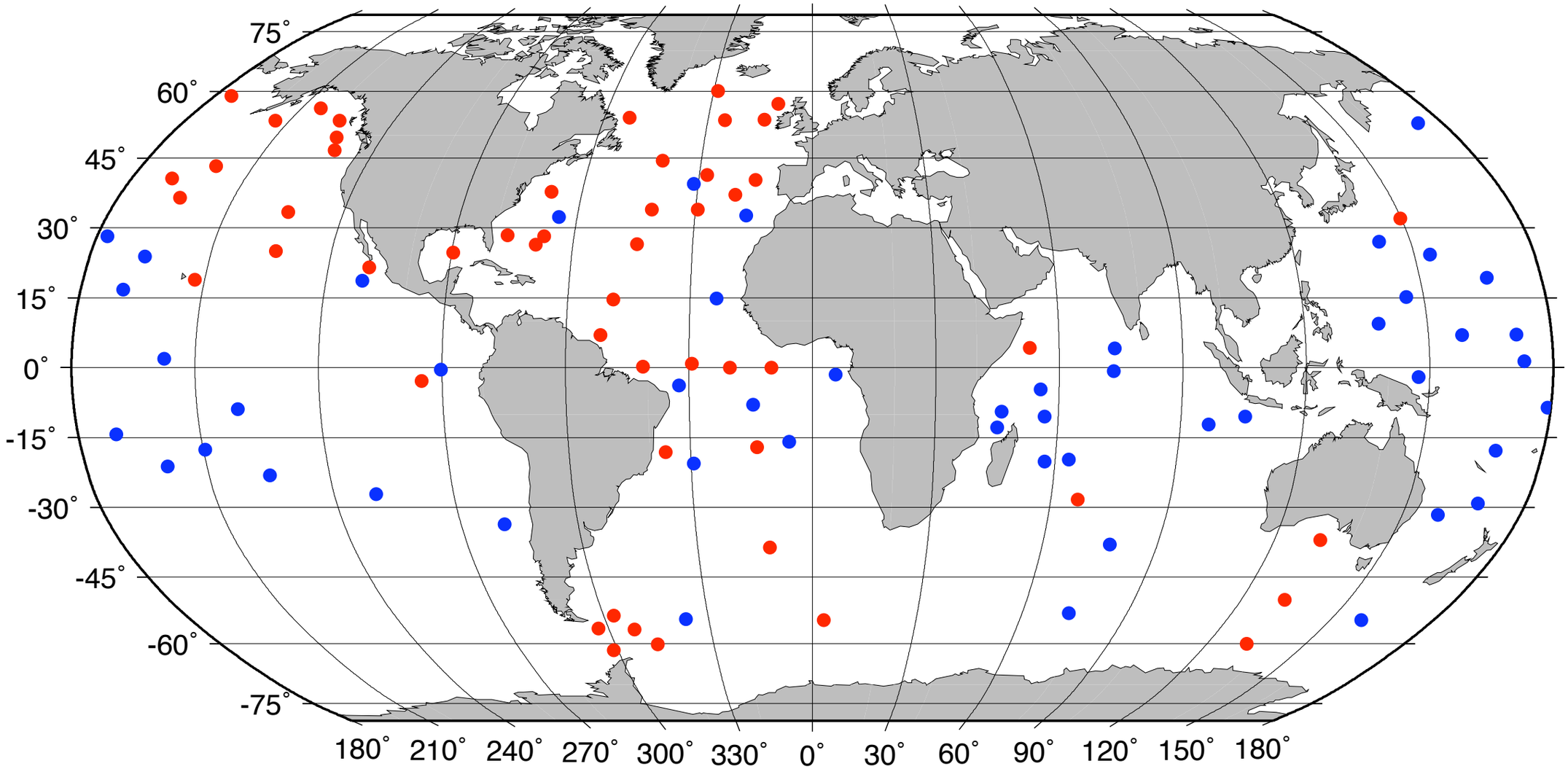
– Walter Munk

***Affairs of the Sea*, 1980**

“Looking at everything with a sharply improved precision is a good [path to] making important contributions.”

— Irwin Shapiro
Response to Bowie Medal, 1994

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.

New “ground truth” dataset

137 stations.

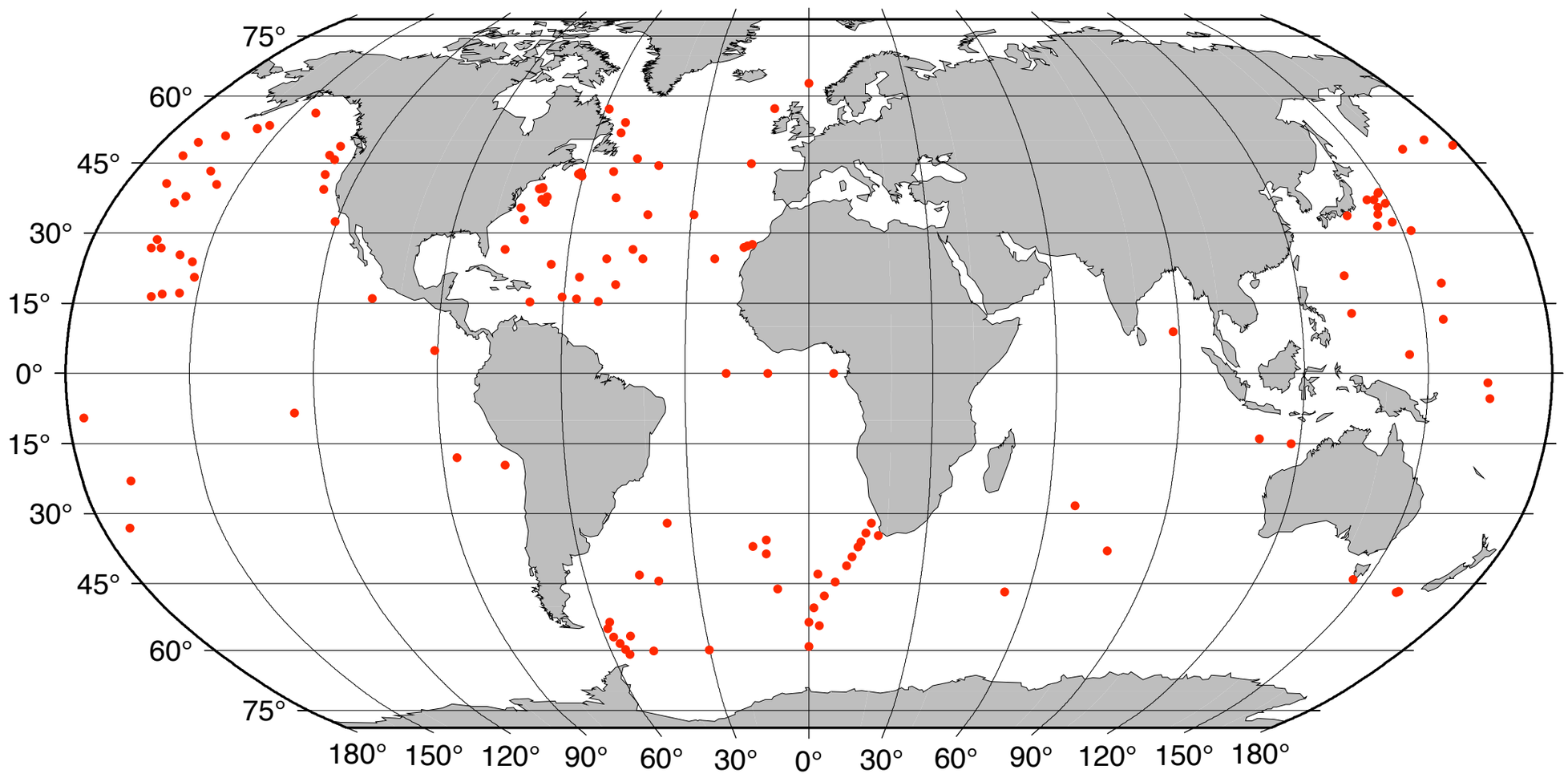
Only bottom-pressure stations.

No short time series — All > 90 days.

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

Many time series reanalyzed.

– 71 by me.
– 14 by Doug Luther.
– 27 by Proudman Lab. (via GLOUP database)



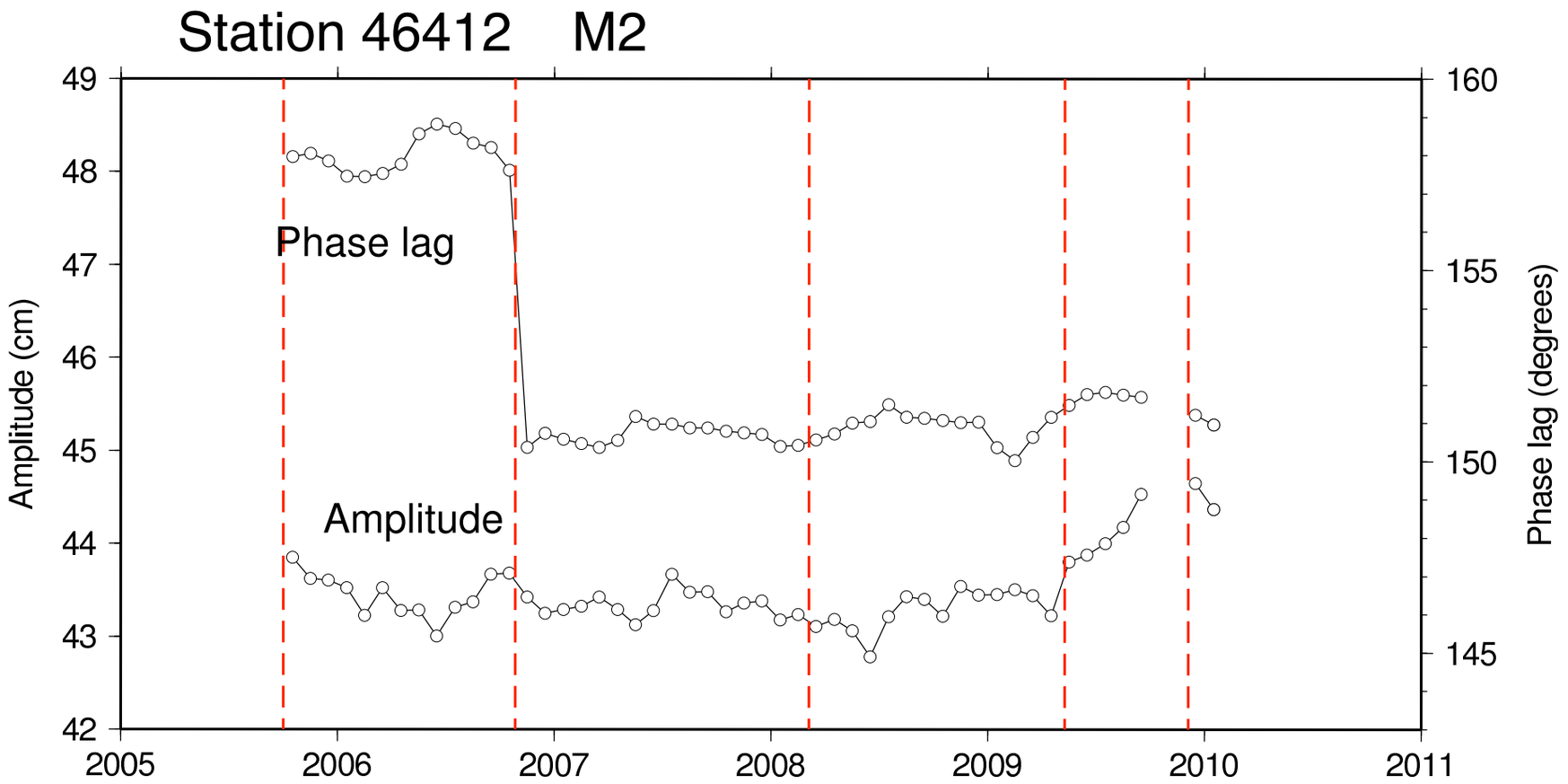
DART Tsunami Network Is Invaluable

But….

1. Data can be noisy (because of acoustic & satellite links?)

Many thanks to Andreas Macrander, AWI, for cleaning up DART data

2. Small station movements over time



Red lines: Times of new deployments

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 $\qquad$ $T =$ 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 137-station set	0.16	0.29	0.23	0.44	0.26	0.53	0.50	0.20

Can we use these precise data to study air and earth tides?

— Bottom pressure recorders sensitive to air tides.

— Altimetry is sensitive to earth tides.

Detection of air tides in BP–altimeter differences

RMS Differences (cm) with respect to GOT4.7

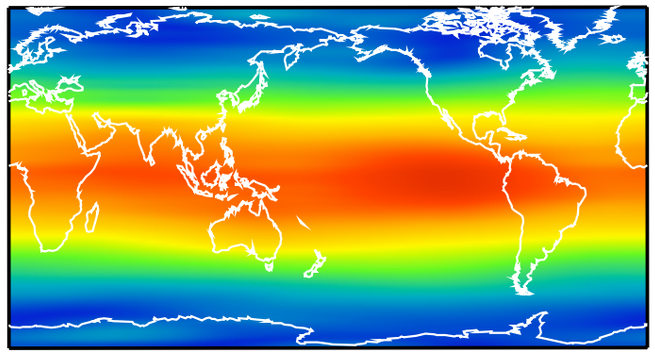
	P1	S1	K1	T2	S2
Before removing air tides from BP	0.188	0.454	0.276	0.151	1.083
After removing air tides from BP	0.196	0.291	0.254	0.132	0.567
Bootstrap 1-σ	0.011	0.018	0.019	0.008	0.034

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.

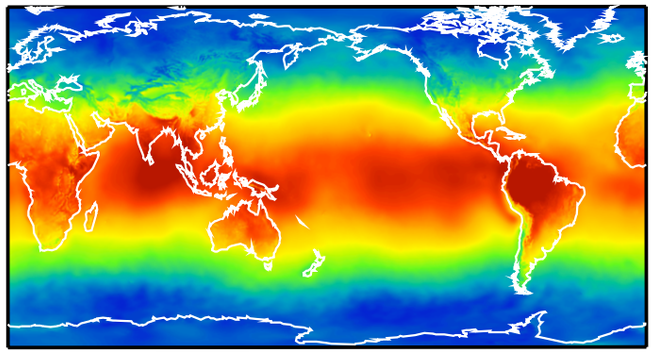
Air tide clearly detected for S1, T2, S2.

S2 Barometric Tide

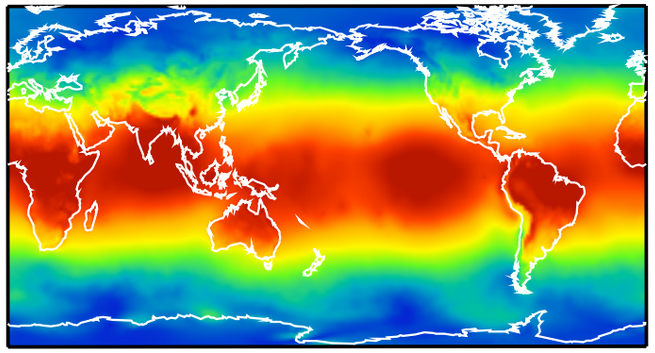
ECMWF 6-hr
(Ray-Ponte 2003)



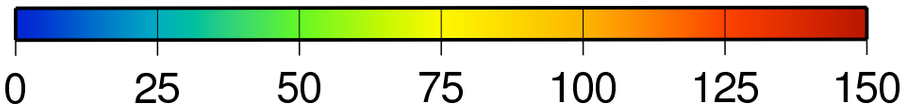
ECMWF 3-hr
(J.-P. Boy)

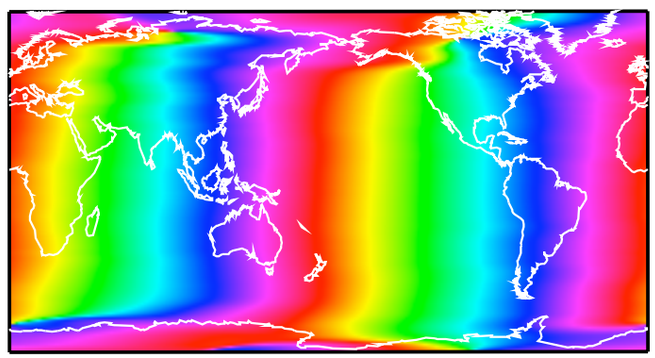


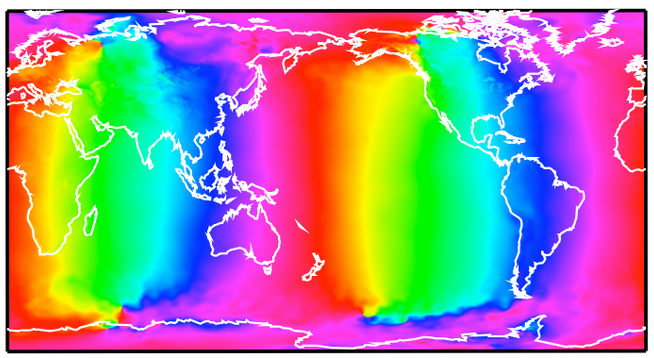
MERRA 3-hr
(J.-P. Boy)

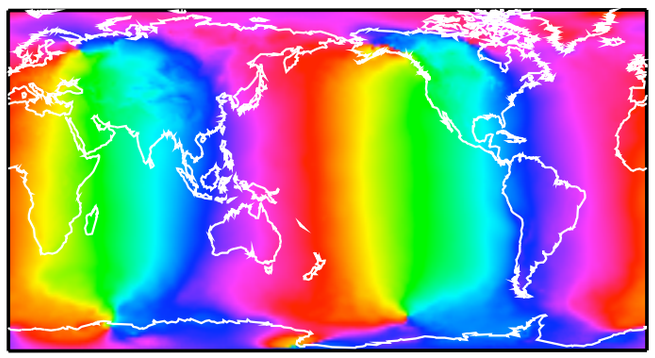


Amp
(Pa)

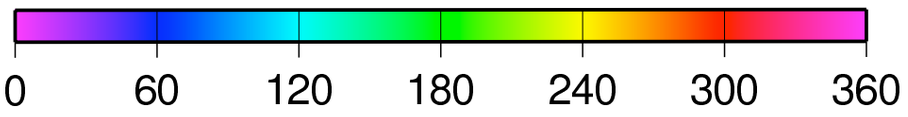








Phase
(deg)



But S2 is problematic for altimetry (β′ effects)

“S2 is our punishment.” –Florent Lyard

Two updates to GOT4.7:

GOT4.8 — corrected S2 air-tide sampling in T/P dry-trop correction.

GOT4.9 — as GOT4.8 but also applied T/P CoM correction (previously ignored).

Which agrees better with BP data?

Note: GOT4.8 better reduces 59-d oscillations in JASON mean sea levels.

RMS Differences (cm)
Bottom pressure vs. Altimetry

	GOT4.7	GOT4.8	GOT4.9
None	1.083	0.988	0.973
Haurwitz-Cowley analytic	0.551	0.356	0.460
ECMWF 6-h (Ray-Ponte)	0.551	0.352	0.461
ECMWF 3-h	0.567	0.349	0.487
MERRA	1.006	0.907	0.896

Bootstrap uncertainty of RMS values ~ 0.05 cm

GOT4.8 is more accurate than GOT4.9;
Different tide models for T/P vs Jason???
The 2 satellites are inconsistent at S2.

Can we use BP-Alt differences to solve for body-tide Love numbers?

body tide = h_2 Φ / g, where h_2 is ~0.6

	Estimate from BP – Altimetry	GDR value	IERS Conventions
M2	0.613 ± 0.043	0.609	0.608
O1	0.610 ± 0.024	0.609	0.603
K1	0.542 ± 0.019	0.520	0.524

- **Clearly detects core-nutation resonance at K1.**
- **Data not sensitive to body-tide lag (expected value ~0.1°).**
- **Uncertainties probably too large to improve seismic-based models.**

Summary

(1) New “ground truth” tidal validation dataset has been constructed from bottom-pressure measurements, with considerable care given to quality of data, length of time series, and reanalysis of tidal signals.

(2) The BP – altimeter differences are markedly superior to previous test datasets.

(3) Motivation was to provide input to Detlef Stammer’s tide-model comparison efforts. But the new dataset has additional applications.

- Testing air tide models.
- Detection of FCN resonance in diurnal earth tides.