Accuracy Assessment of Global Ocean Tide Models

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Introduction

Our knowledge of the dynamics of ocean tides as well as their impact on the general circulation has improved considerably since the launch of Topex/Poseidon twenty years ago.

This presentation/paper provides a new accuracy assessment of state-of-the-art global tide models, including purely empirical, purely hydrodynamic, and dynamical models constrained by observations.

The goal is to quality-assess modern global tide models and to understand some of their limitations by comparing them against a **number of independent test data sets** representing both the deep ocean and shallow seas.

Participating Models

This presentation:

Investigated Models

Model	Type[a]	Resolution	Dimensions	Authors
DTU10	E	7.50′	2881 × 1441	*Cheng and Andersen*
EOT11a	E	7.50′	2881 × 1441	*Savcenko and Bosch*
FES2012	H	3.75′	5761 × 2881	*Lyard and Carrère*
GOT4.8	E	30.00′	720 × 361	*Ray*
HAM12	H	7.50′	2881 × 1441	*Taguchi, Zahel, Stammer*
OSU12	E	15.00′	1440 × 720	*Fok and Shum*
TPXO8	H	2.00′	10800 × 5401	*Egbert and Erofeeva*

Follow up to

Shum et al., 1996

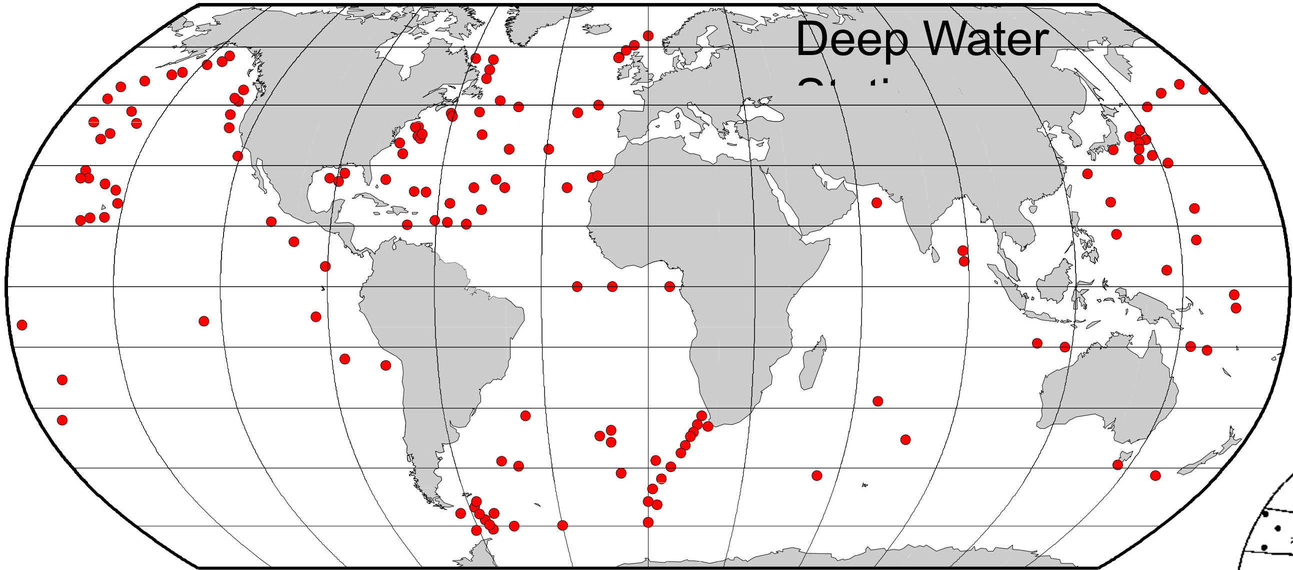
SHUM ET AL.: ACCURACY ASSESSMENT OF RECENT OCEAN TIDE MODELS

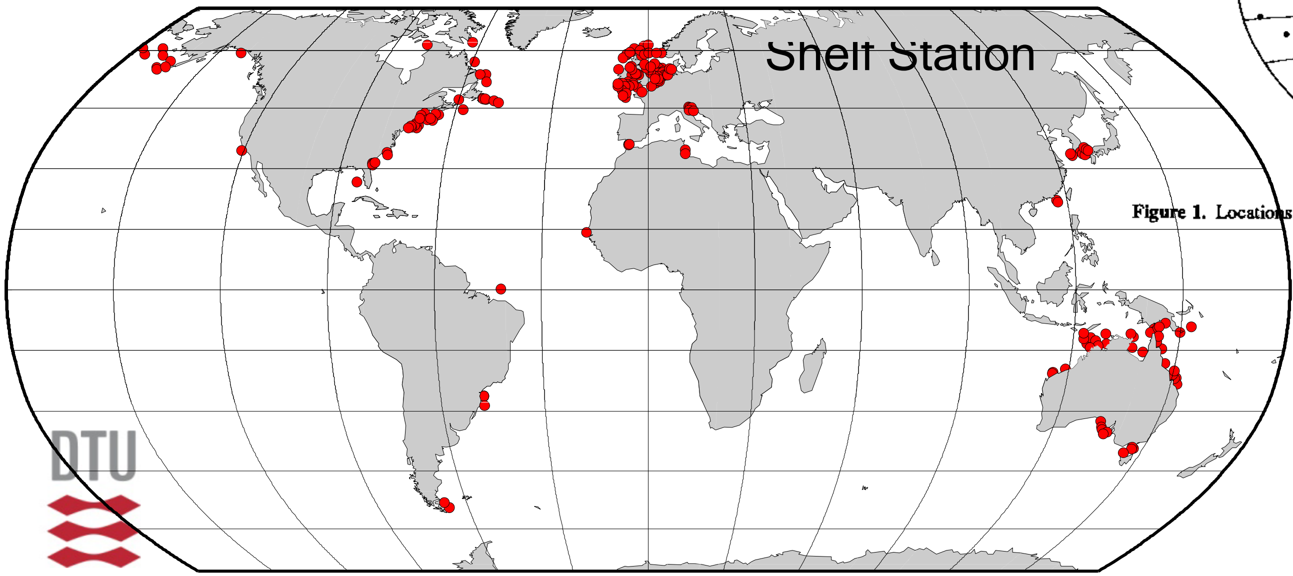
distribution of T/P altimetry by data centers
ınd precise analysis.
l to be two overlapping groups of researchers
ɛw tidal models. The first group includes
in tides in their own right, for example, for
ssipation, while the second group contains
equire simply an efficient "tidal correction
" algorithm prior to other oceanographic and

Global Ocean Tide Models

Table 1 lists 10 global ocean tide model
which were used in this study. In Table 1,
ocean tide model solutions computed fr
accurate orbits using improved models,
Gravity Model (JGM-3) gravity field model
perturbation model computed from T/P ti

Modern Ground Truth Data Sets





Compare:
Shum et al., 1996

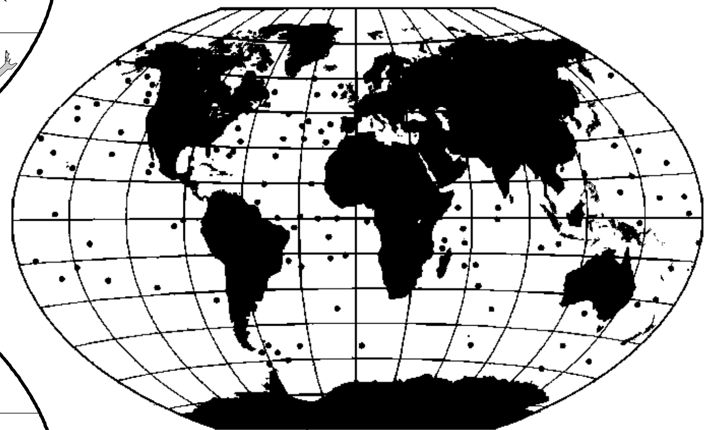


Figure 1. Locations of selected ocean tide observations at 49 island tide gauges and 53 bottom pressur

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RMS Differences, Deep Ocean

RMS Differences (cm) with Deep-Ocean Bottom-Pressure Data

	Q1	O1	P1	K1	N2		S2	K2	M4
			Pre-Topex/ Poseidon						
NSWC (SCHWIDERSKI)	0.290	0.874	0.638	1.292	1.153		1.779	0.660	
			Early Topex						
CSR3.0	0.230	0.502	0.252	0.585	0.375		0.607	0.470	
			Modern Models						
GOT4.8	0.165	0.296	0.234	0.423	0.252		0.369	0.209	0.089
OSU12	0.507	0.626	0.249	0.704	0.723		0.811	0.361	0.139
DTU12	0.226	0.277	0.292	0.449	0.274		0.415	0.383	0.089
EOT11a	0.232	0.317	0.224	0.404	0.335		0.428	0.365	0.282
HAM12	0.160	0.317	0.199	0.373	0.245		0.397	0.176	
FES2012	0.216	0.309	0.355	0.471	0.342		0.407	0.223	
TPXO.8	0.153	0.310	0.181	0.442	0.201		0.338	0.151	0.069
Bootstrap σ	0.013	0.018	0.012	0.018	0.018		0.024	0.018	0.008

RMS Differences, Shelf Seas

RMS Differences (cm) with Gauges in SHELF SEAS

	Q1	O1	P1	K1	N2	S2	K2	M4
				European Shelf				
CSR3.0	1.07	2.10	0.54	1.67	5.09	5.61	2.38	
GOT4.8	0.93	0.92	0.55	1.30	1.97	2.51	1.09	2.80
OSU12	1.11	1.24	0.69	1.53	1.77	4.04	1.29	2.10
DTU10	0.83	0.81	0.51	1.27	2.17	2.38	0.92	2.74
EOT11a	0.85	0.83	0.50	1.24	2.13	3.43	1.13	3.16
HAM12	0.92	1.96	0.47	1.14	1.65	2.64	0.92	
FES2012	0.88	0.82	0.71	1.19	1.39	1.94	0.63	2.22
TPXO.8	0.88	0.72	0.46	1.21	1.58	1.70	0.74	0.42
Bootstrap σ	0.05	0.08	0.07	0.11	0.20	0.46	0.14	
				Elsewhere				
CSR3.0	1.22	2.47	1.44	4.97	6.02	7.98	2.70	
GOT4.8	0.70	1.43	0.96	1.78	1.96	3.06	1.64	1.39
OSU12	1.01	1.63	0.94	1.96	1.88	2.99	1.15	1.50
DTU10	0.82	1.60	1.13	1.97	1.83	2.86	1.62	1.41
EOT11a	0.74	1.65	0.78	1.84	1.86	3.67	1.36	1.41
HAM12	1.01	1.31	0.80	2.02	2.04	2.92	1.57	
FES2012	0.86	1.83	0.96	1.91	1.63	3.01	1.13	1.04
TPXO.8	0.82	1.05	0.82	1.49	1.99	1.92	1.11	0.43
Bootstrap σ	0.09	0.36	0.09	0.24	0.16	0.43	0.19	

STD between individual models

Table 4. Standard Deviations of Differences Between Tidal Models

	Q1	O1	P1	K1	N2	M2	S2	K2	TTL
Global	0.26	0.78	0.41	1.37	0.56	2.07	1.00	0.37	0.97
> 1000m	0.18	0.37	0.22	0.62	0.26	0.37	0.34	0.22	0.37
< 1000m	0.46	1.72	0.89	3.16	1.25	5.14	2.40	0.77	2.26

SHUM ET AL.: ACCURACY ASSESSMENT OF RECENT OCEAN TIDE MODELS

Table 2. Standard Deviations of Differences Between Tidal Models

Area	M_2	M_2 (<50 cm)	K_1
Global	2.29	1.92	0.89
(>1000 m)	0.97	0.97	0.69
(<1000 m)	9.78	7.90	2.76

Values are given in centimeters.

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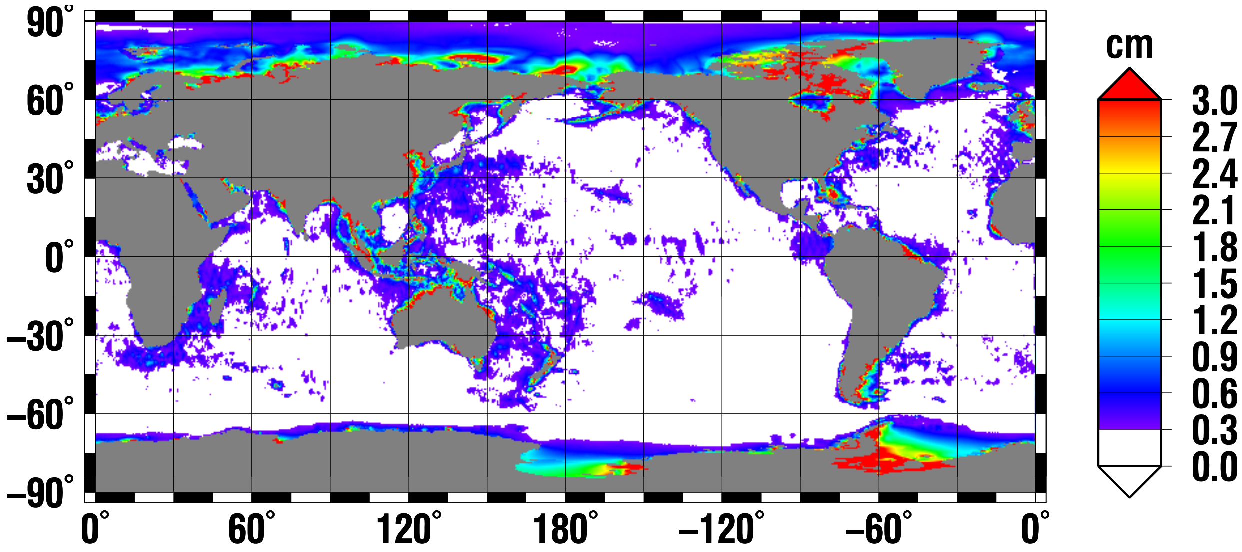
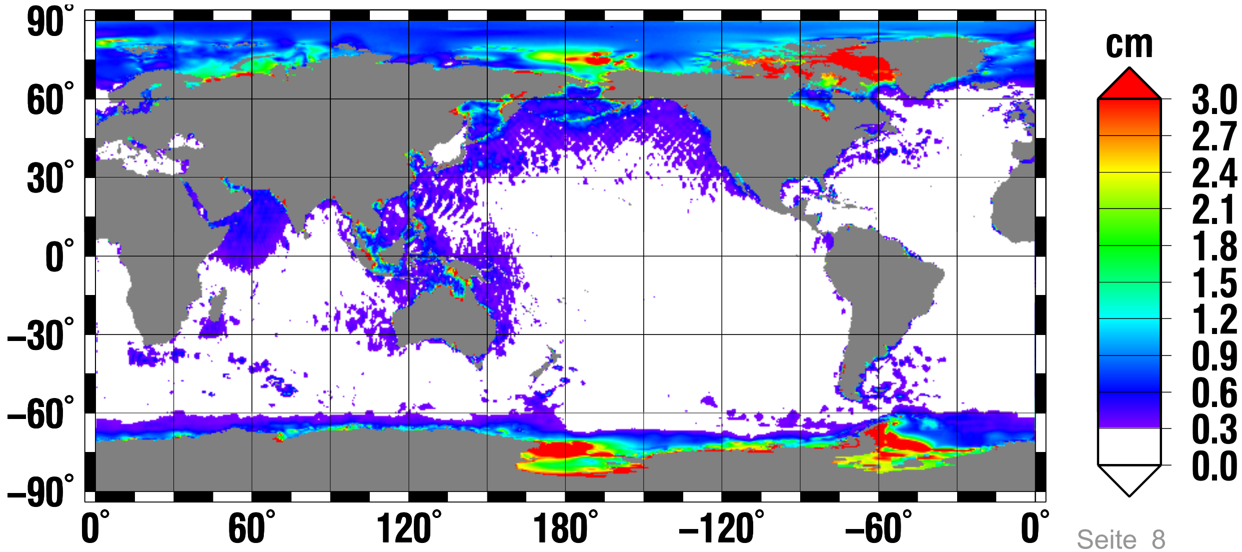
STD between individual models

M2



Enhanced inter-model discrepacies reside especially in high latitudes, but also around the Indonesian Archipelago.

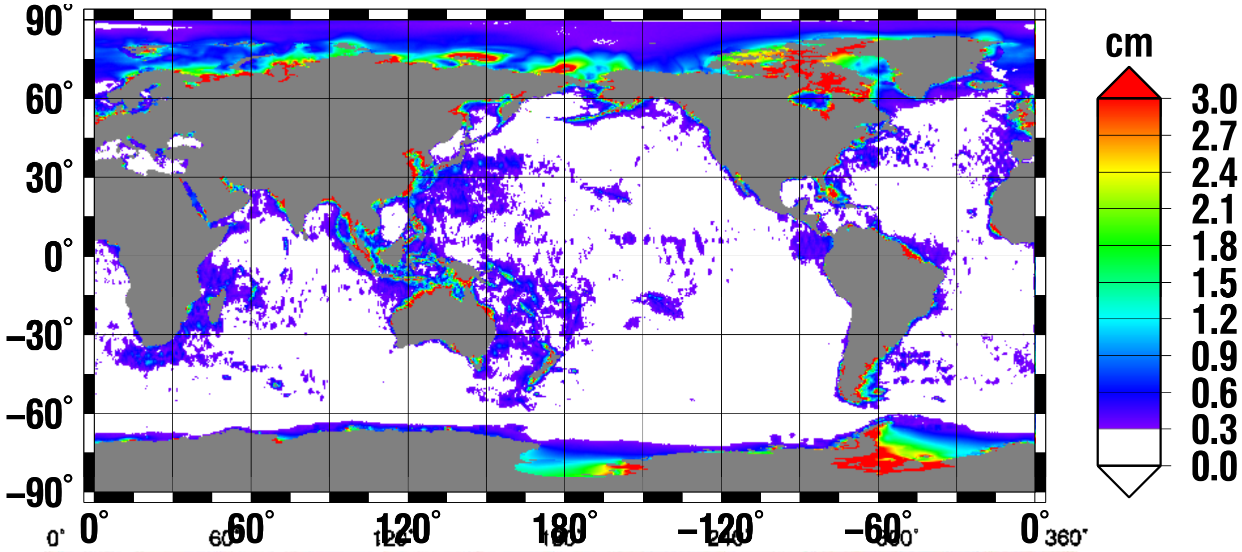
K1



DTU

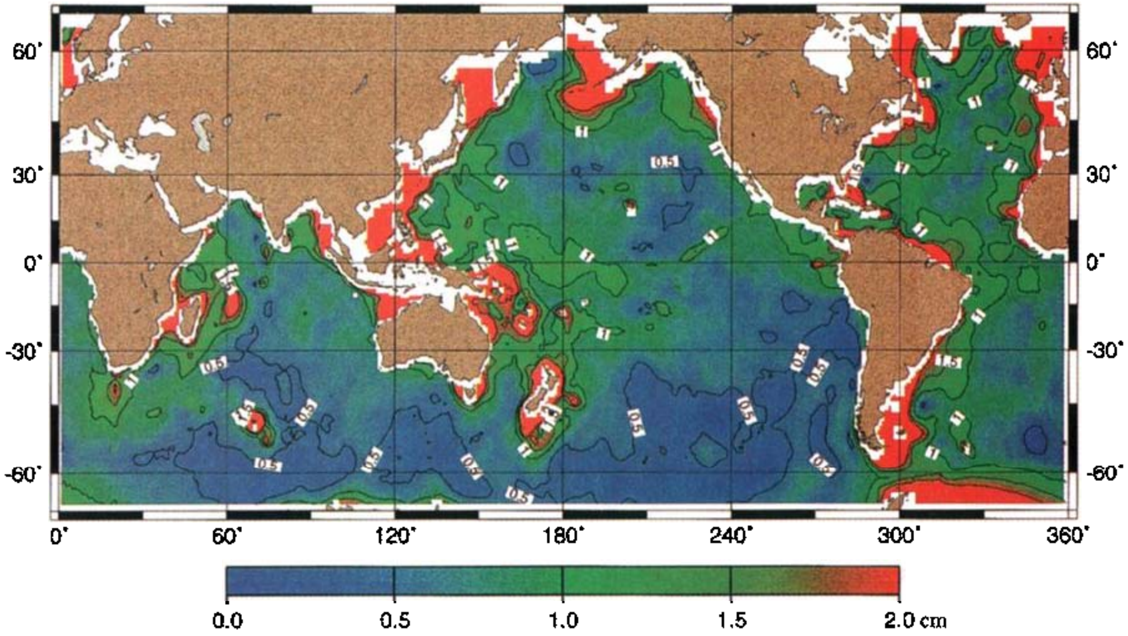
M2 STD between individual models

This paper



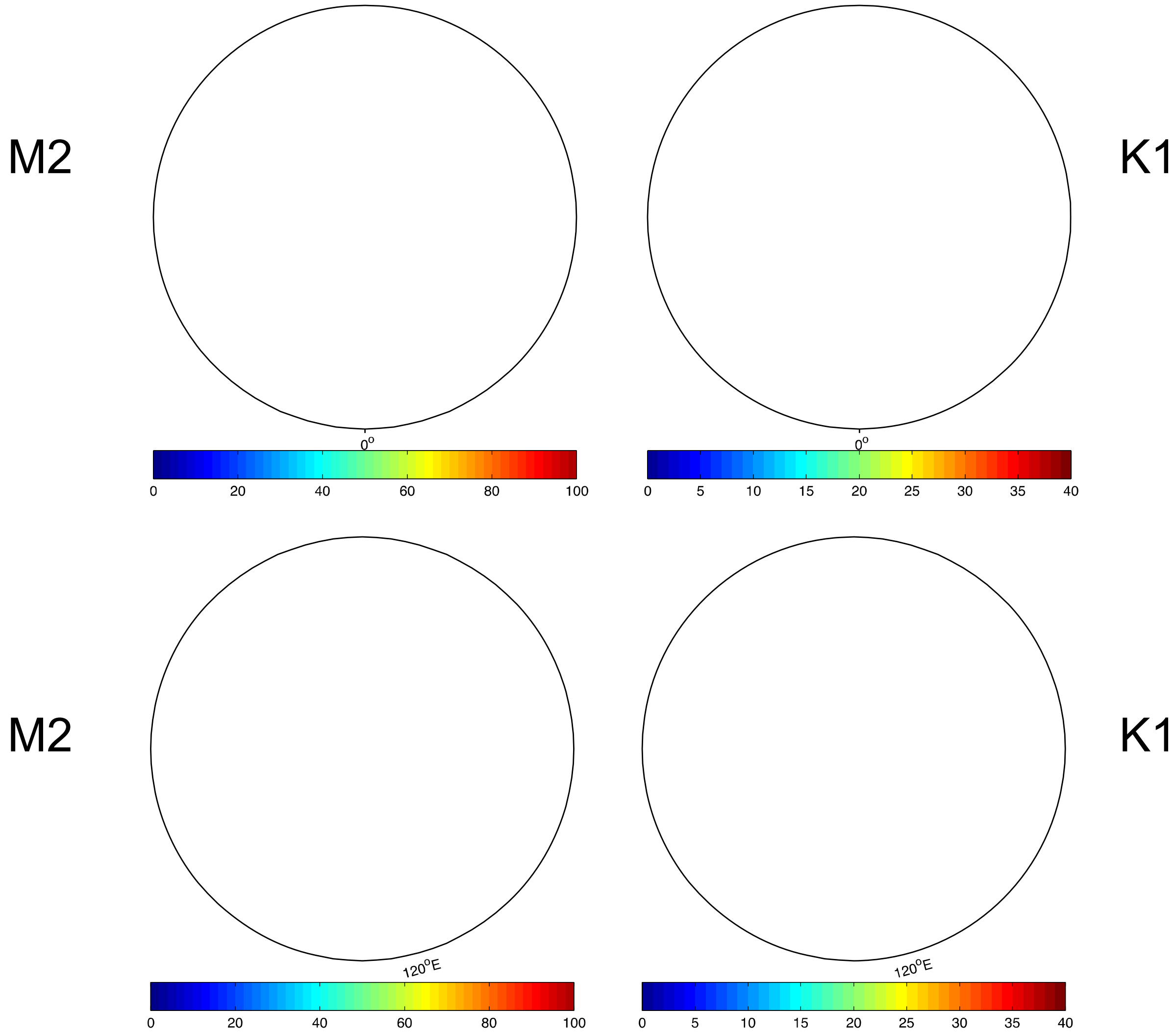
Clear improvements relative to Shum et al. in inter-model consistency.

Shum et al., 1996



Arctic and Antarctic M2 and K1 Tides

Amplitude of M2 and K1 tidal components evaluated from tide gauge stations. Relatively large uncertainties remain in the in situ estimate.



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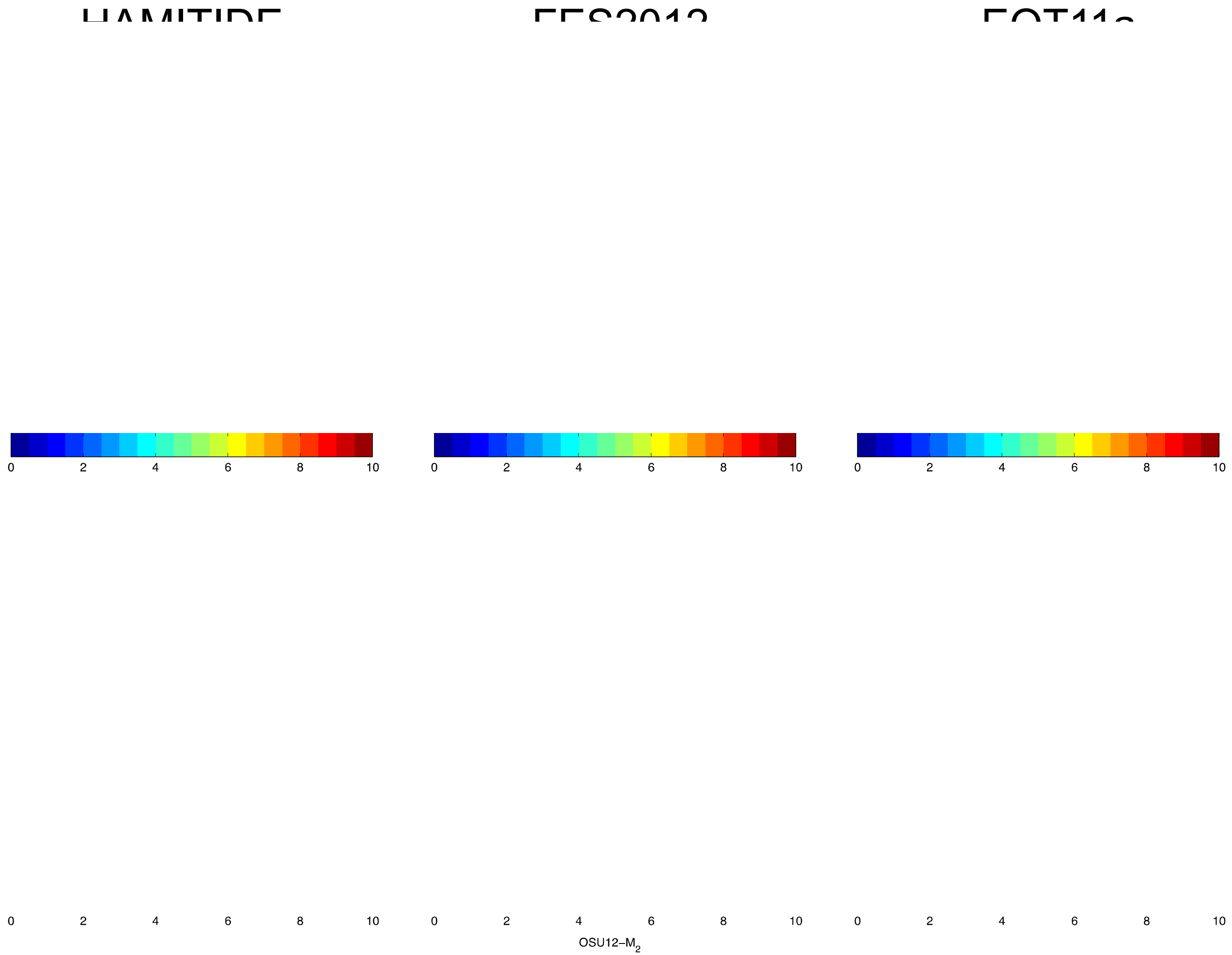
Vector Differences Arctic M2 Tide



Vector differences between in situ and interpolated M2 tide amplitude for 60 tide gauges. Significant part of the differences could results from tide gauge untertainties.

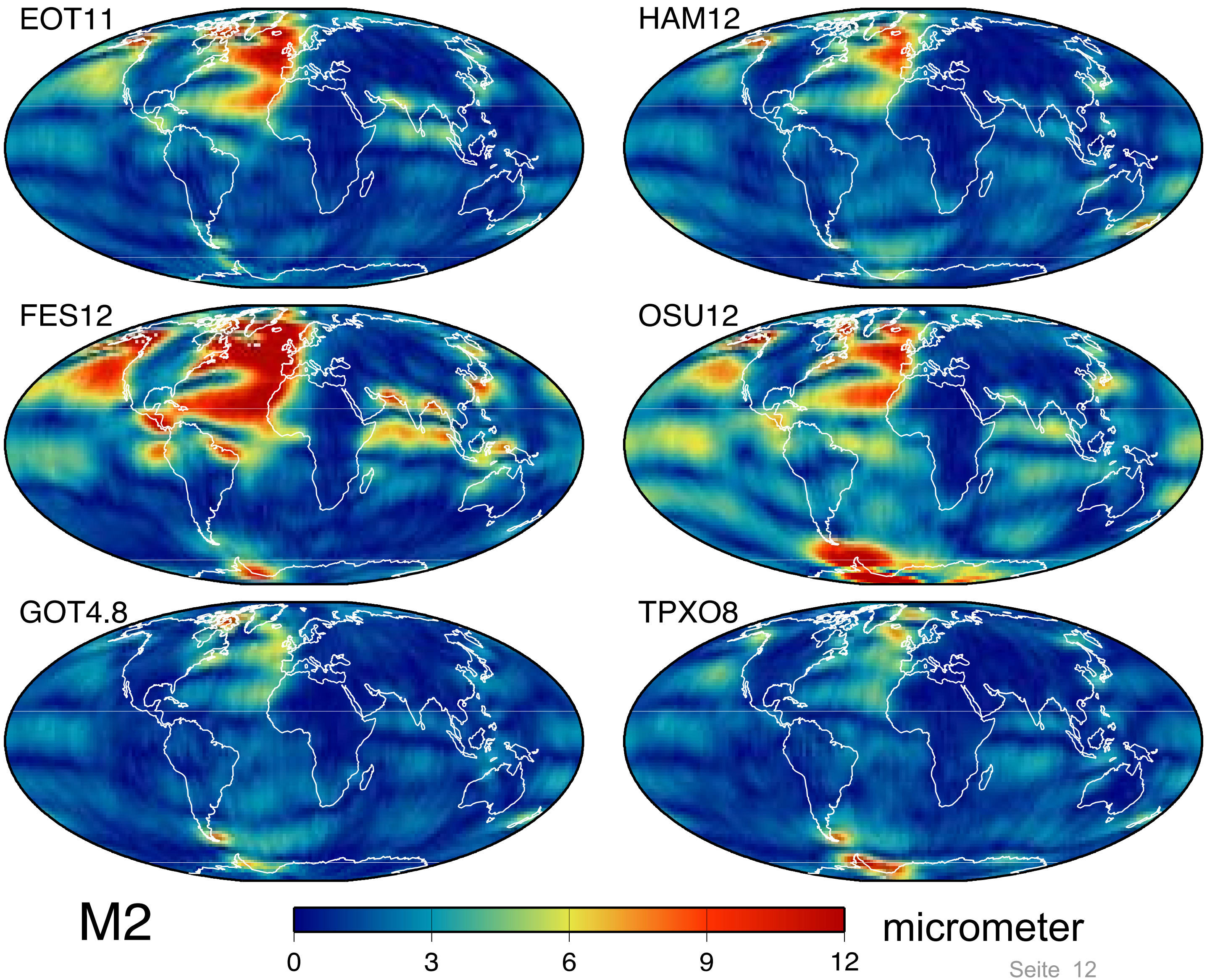
Favoring TPXO in Arctic

DTU

M2 Test against GRACE DAta

GRACE tests show all models are still imperfect.

GRACE tends to favor GOT4.8, but EOT11, HAM12, and TPXO.8 also look good.



Test with Satellite Ranging Data

For long wavelength error as they imply orbit error modelling

SLR orbit tests suggest:

EOT11, HAM12, GOT4.8 are all good.

TPXO8 is best for Starlette, but less good for Stella & Larets.

RMS Residuals (cm)

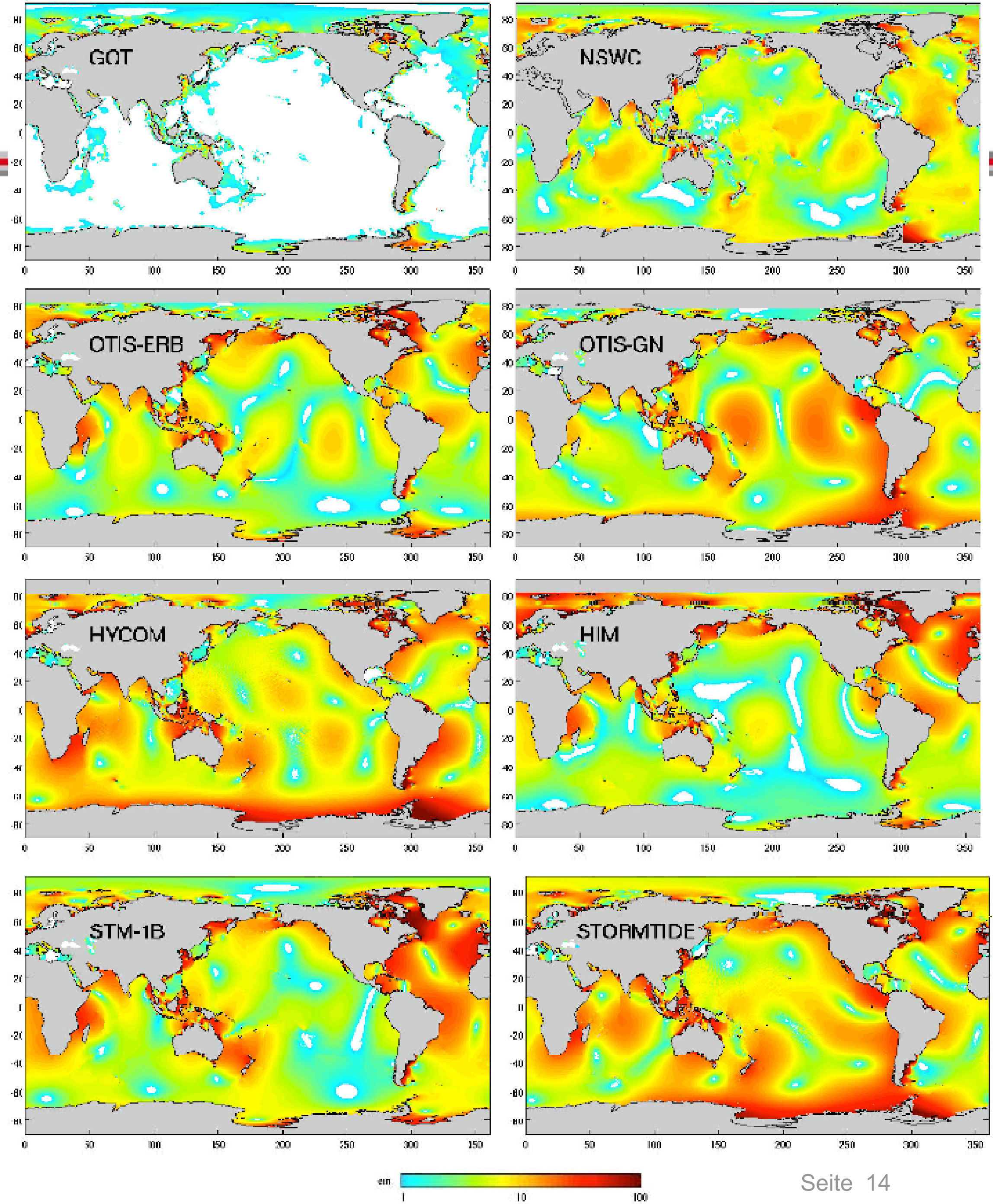
	Starlette	Lageos-1	Stella	Larets
NSWC	5.717	1.168	5.108	5.382
GOT4.8	3.343	1.154	3.096	3.483
OSU12	3.673	1.158	4.043	4.093
EOT11a	3.443	1.152	3.238	3.561
HAM12	3.375	1.149	3.267	3.496
FES2012	3.500	1.154	3.464	3.676
TPXO.8	3.307	1.148	3.435	3.825

- **HAM12, EOT11, and GOT4.8 all perform well.**
- **TPXO.8 is best for Starlette, but not for sun-synch Stella or Larets**

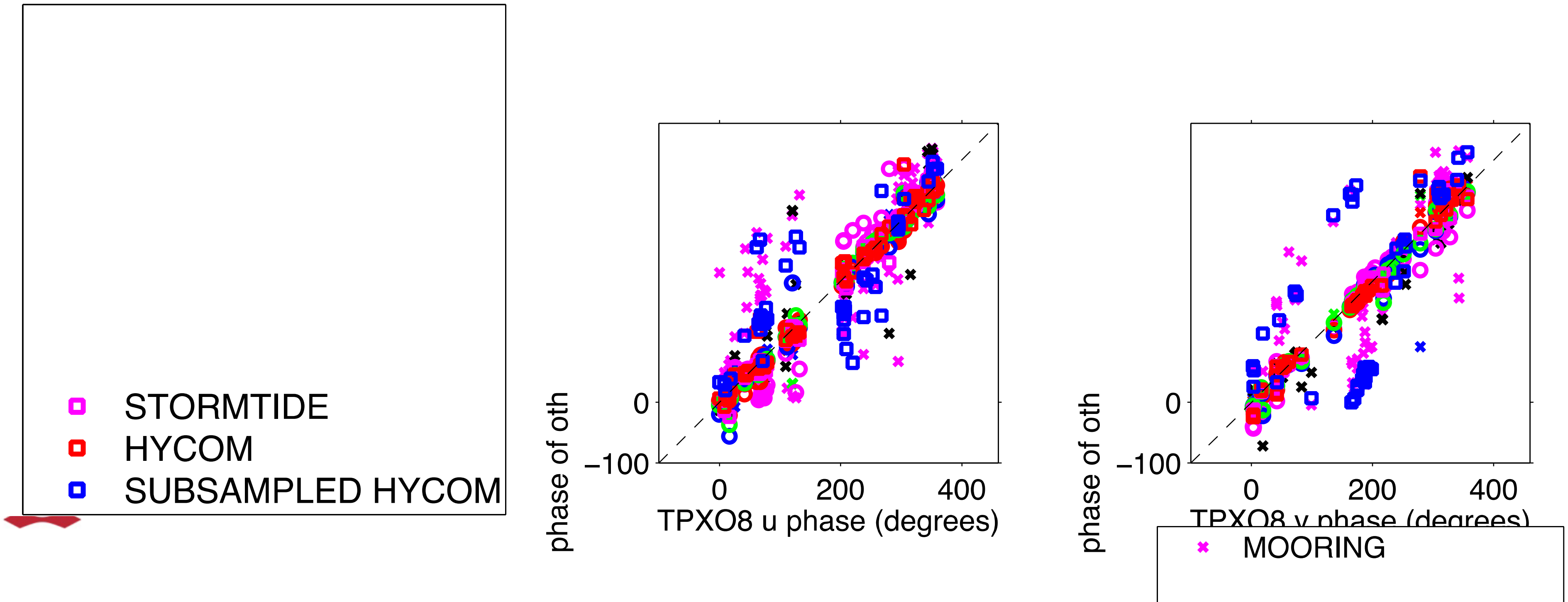
DTU10 excluded as it has values over land (for coastal interpolation)

M2 Vector Differences between TPXO and various hydrodynamic models

(range: 0 – 100cm).



Tidal Currents



Summary

We have provided a new accuracy assessment of state-of-the-art global tide models, including purely empirical, purely hydrodynamic, and dynamical models constrained by observations.

Tests were provided in terms of comparisons against bottom-pressure data, selected coastal gauges (primarily in polar regions), independent satellite altimeter data, and satellite gravimeter data.

First time: evaluation of Arctic and Antarctic tides

Also first time: we provide an assessment of tidal currents available from (selected) models by comparing against tidal velocities estimated from current meters located in the deep ocean and from acoustic tomography.

Summary

- **No model is uniformly favored by all tests.**
- Deep-ocean gauges confirm all 7 models are very high quality.

  (Previous standard deep-ocean test dataset now dominated by error in the test stations, not in the new models.)
- Shallow-water gauges tend to favor TPXO8/DTU11, although other models are good, too. They do NOT favor GOT4.8 or OSU12 (probably because these models have coarsest spatial resolutions).
- Largest remaining inter-model discrepancies found at high latitudes.
- Arctic tide might still show enhanced uncertainties due to data quality problems.

Summary

Long-wavelength components of models bearing implications for precise orbit determination were tested by analyzing laser ranging measurements to special geodetic satellites.

- SLR orbit tests suggest EOT11, HAM12, GOT4.8 are all good. TPXO8 is best for Starlette, but less good for Stella & Larets.

- GRACE tests show all models are still imperfect. GRACE tends to favor GOT4.8, but EOT11, HAM12, and TPXO.8 also look good.

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Summary

First time we provide an assessment of tidal currents available from (selected) models by comparing against tidal velocities estimated from current meters located in the deep ocean and from acoustic tomography.

- Velocity tests with moored current meters are not informative; dominated by errors or baroclinicity at moorings?
- Velocity tests with tomographic arrays show assimilation models better than pure hydrodynamic. Also show some interesting systematic differences highlighting errors either in models or in tomography. See poster of Brian Dushaw for more results

This talk provides only an overview about the joint work; detailed results will be presented in form of posters by several co-authors.

DTU

Thank you

Test with Satellite Altimetry

Model	TOPEX/ POSEIDON	TOPEX Interleave	GFO	Envisat	Jason-1 Interleave	Jason-1	Jason-2	Jason-1 GM	Cryosat-2
DTU10	10.11	9.80	10.42	10.05	10.22	9.93	10.11	10.18	10.31
EOT11a	10.12	9.79	10.44	10.04	10.22	9.96	10.10	10.18	10.34
FES2004	10.20	9.88	10.51	10.12	10.33	10.06	10.20	11.26	10.41
FES2012	10.14	9.82	10.44	10.04	10.21	9.94	10.10	10.19	10.31
GOT4.7	10.11	9.80	10.41	10.04	10.23	9.94	10.11	10.18	10.31
GOT4.8	10.11	9.80	10.41	10.04	10.22	9.94	10.11	10.17	10.31
HAMTIDE	10.11	9.82	10.46	10.06	10.23	9.96	10.10	10.17	10.31
TPXO.7.2	10.13	9.85	10.48	10.09	10.26	9.99	10.12	10.18	10.35
TPXO.8	10.14	9.84	10.47	10.09	10.25	9.98	10.11	10.18	10.33
OSU12	10.28	9.63	10.34	10.03	10.44	9.86	10.32	10.51	10.58
Before	34.43	34.43	35.21	34.39	35.12	35.12	34.38	34.02	34.66

No clear conclusion to be drawn from this investigation, but that all models fits altimetry (used for the model) very good.

1) Color bar on GRACE plots are units of micrometers. These are range residuals (not range-rates), so that the anomaly is over the causative body (although there can still be side-lobes).

One important point is that one can NOT infer what the corresponding SSH error is without doing an inversion.

So those big patches of red in the North Atlantic could be a pretty small SSH error, but the range residual is large perhaps because the area is so big.

2) The test data are: (refer to subscripts) TG = tide gauges and ALT = TPXO.8

Yes, the models are really that bad because these are all pure hydrodynamic models -- no data constraints.

(Brian Arbic was the instigator of looking at these models; originally we were just going to test "good" altimeter-based models.)

Thus, on page 16, as you note, GOT and TPXO8 are very close when compared with these hydro models.

But Arbic's point is that hydrodynamic models have really been improving -- they are now almost as good as Schwiderski! I agree that is true progress.

Actually, I'd suggest skipping that (blurry) table 10 (page 15) and just show the color maps (page 16).