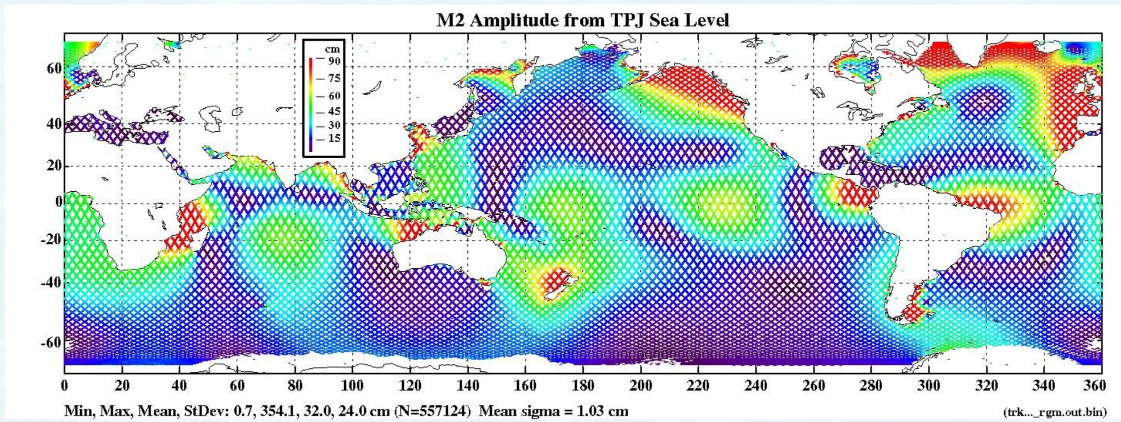
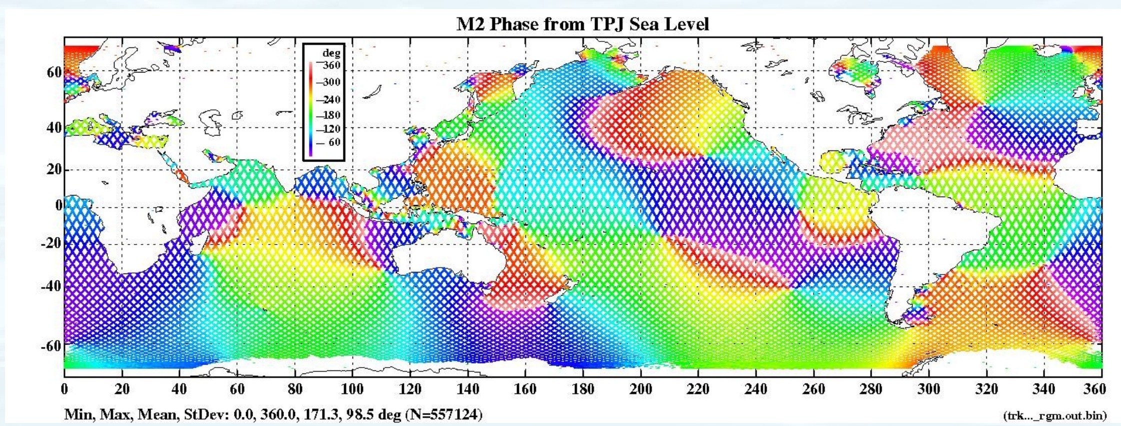
Seasonal modulation of M2 tide in shallow seas from TPJ data and numerical model

Josef Cherniawsky[1], Malte Müller[2] and Michael Foreman[1]





[1]*Institute of Ocean Sciences, Fisheries & Oceans Canada, Sidney, BC, Canada*
[2]*School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada*

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What factors modify M_2 on seasonal or longer time scales?

- Gravity, ~1% of M_2, through the influence of solar parallax on the Moon's orbit (Cartwright, 1968).
- Seasonal changes in depth from storm surges (Huess and Andersen 2001).
- Changes in bottom friction, or vertical viscosity, from changes in stratification. This effect varies significantly in time and place, acting on all time scales, up to the lunar nodal period of 18.6 years (e.g. Foreman et al. 2006) and extending well beyond its source regions. For example, Foreman et al. (1995) found that M_2 in Victoria, BC, varies seasonally by about 6%, possibly due to enhanced estuarine stratification and reduced friction from large annual Fraser River runoff.
- Or any combination of the above.

Cartwright, D., *Proc. Trans. R. Soc. London, A*, 263: 45-74, 1968.

Foreman, M.G.G., R.A. Walters, R.F. Henry, C.P. Keller and A.C. Dolling, *J. Geophys. Res*., 100: 721-740, 1995.

Foreman, M.G.G., P.F. Cummins, J.Y. Cherniawsky and P. Stabeno, *J. Mar. Res*., 64: 797-818, 2006.

Huess, V., and O.B. Andersen, *Geophys. Res. Lett.*, 28: 567-570, 2001.

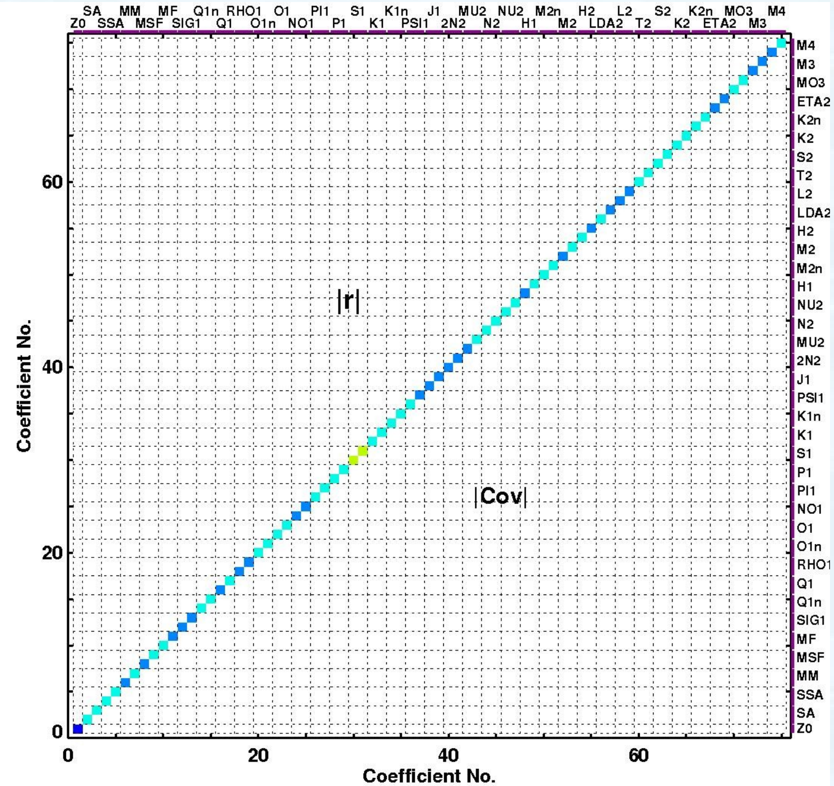
	Doodson numbers	frequency [hr^{-1}]	T_{al} [day]
Z_0	0 0 0 0 0 0	0.000000000	9.916
S_a	0 0 1 0 0-1	0.000114074	10.192
S_{sa}	0 0 2 0 0 0	0.000228159	10.485
M_m	0 1 0-1 0 0	0.001512152	15.490
M_{sf}	0 2-2 0 0 0	0.002821933	30.189
M_f	0 2 0 0 0 0	0.003050092	36.168
σ_1	1-3 2 0 0 0	0.035908722	21.812
Q_{1n}	1-2 0 1-1 0	0.037212374	68.682
Q_1	1-2 0 1 0 0	0.037218503	69.383
ρ_1	1-2 2-1 0 0	0.037420874	104.648
O_{1n}	1-1 0 0-1 0	0.038724526	46.015
O_1	1-1 0 0 0 0	0.038730654	45.706
NO_1	1 0 0 1 0 0	0.040268594	23.775
π_1	1 1-3 0 0 1	0.041438513	71.514
P_1	1 1-2 0 0 0	0.041552587	88.925
S_1	1 1-1 0 0 1	0.041666672	117.545
K_1	1 1 0 0 0 0	0.041780746	173.322
K_{1n}	1 1 0 0 1 0	0.041786875	177.856
ψ_1	1 1 1 0 0-1	0.041894820	329.834
J_1	1 2 0-1 0 0	0.043292898	32.763
$2N_2$	2-2 0 2 0 0	0.077487097	22.534
μ_2	2-2 2 0 0 0	0.077689468	20.311
N_2	2-1 0 1 0 0	0.078999249	49.548
ν_2	2-1 2-1 0 0	0.079201620	65.251
H_1	2 0-1 0 0 1	0.080397327	74.786
M_{2n}	2 0 0 0-1 0	0.080505272	62.648
M_2	2 0 0 0 0 0	0.080511401	62.076
H_2	2 0 1 0 0-1	0.080625475	53.058
λ_2	2 1-2 1 0 0	0.081821182	21.033
L_2	2 1 0-1 0 0	0.082023553	20.640
T_2	2 2-3 0 0 1	0.083219259	50.626
S_2	2 2-2 0 0 0	0.083333333	58.772
K_2	2 2 0 0 0 0	0.083561492	86.661
K_{2n}	2 2 0 0 1 0	0.083567624	87.780
η_2	2 3 0-1 0 0	0.085073644	40.400
MO_3	3-1 0 0 0 0	0.119242055	26.324
M_3	3 0 0 0 0 0	0.120767101	38.079
M_4	4 0 0 0 0 0	0.161022801	31.038

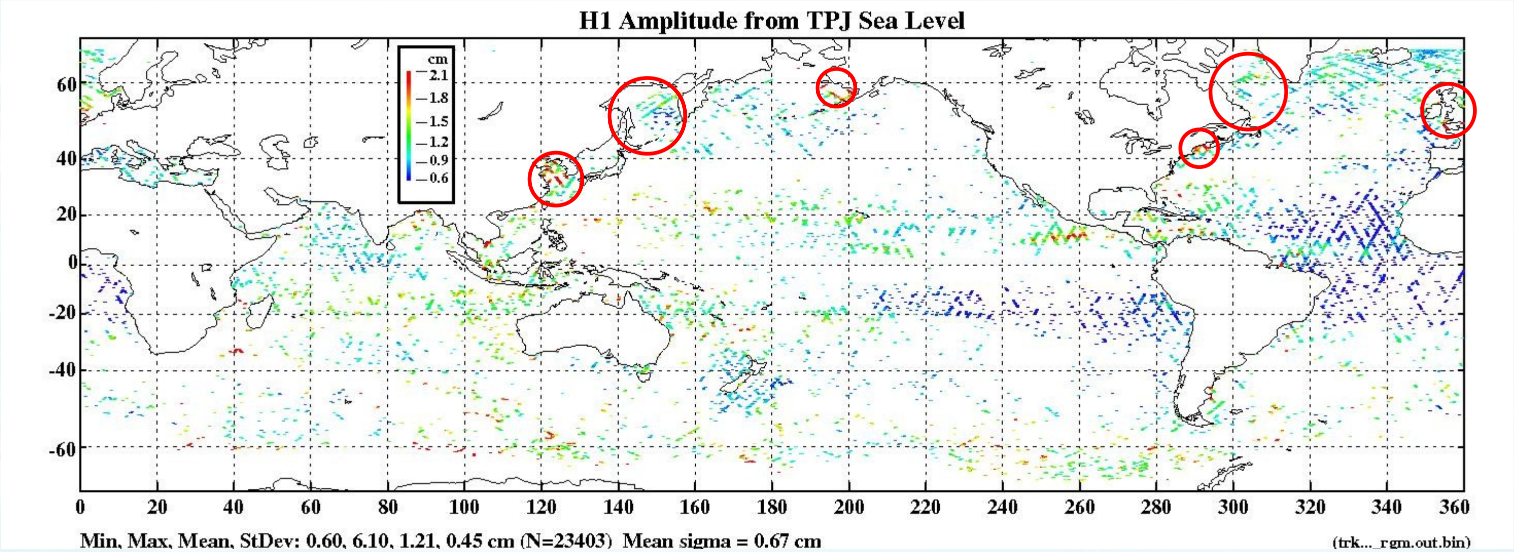
Harmonic analysis: this table lists the tidal constituents selected for analysis[1] of alongtrack TOPEX/Poseidon/Jason-1/Jason-2 (TPJ) data (observation period: 20 Sep 1992 – 6 June 2010).

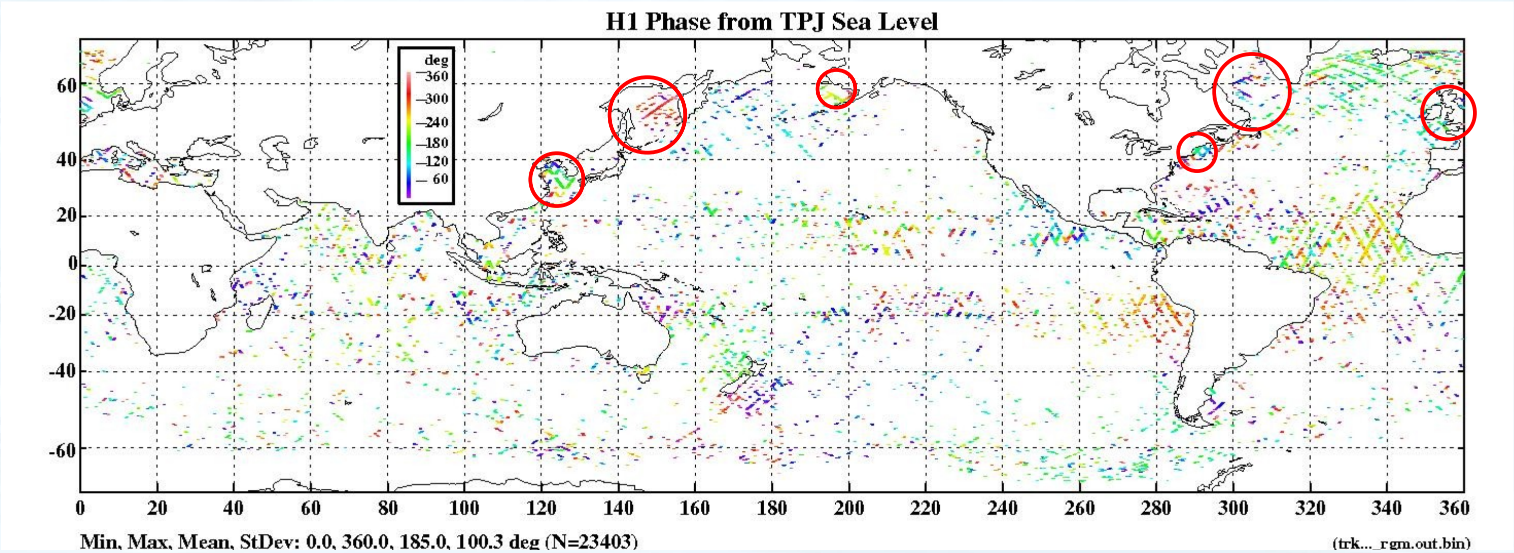
It includes Sa and annual satellites of M_2: $\mathbf{H_1}$ and $\mathbf{H_2}$, which differ from M_2 in 4th (annual, 365.25 d) and 6th (period of perihelion, 20940 yr) Doodson numbers.

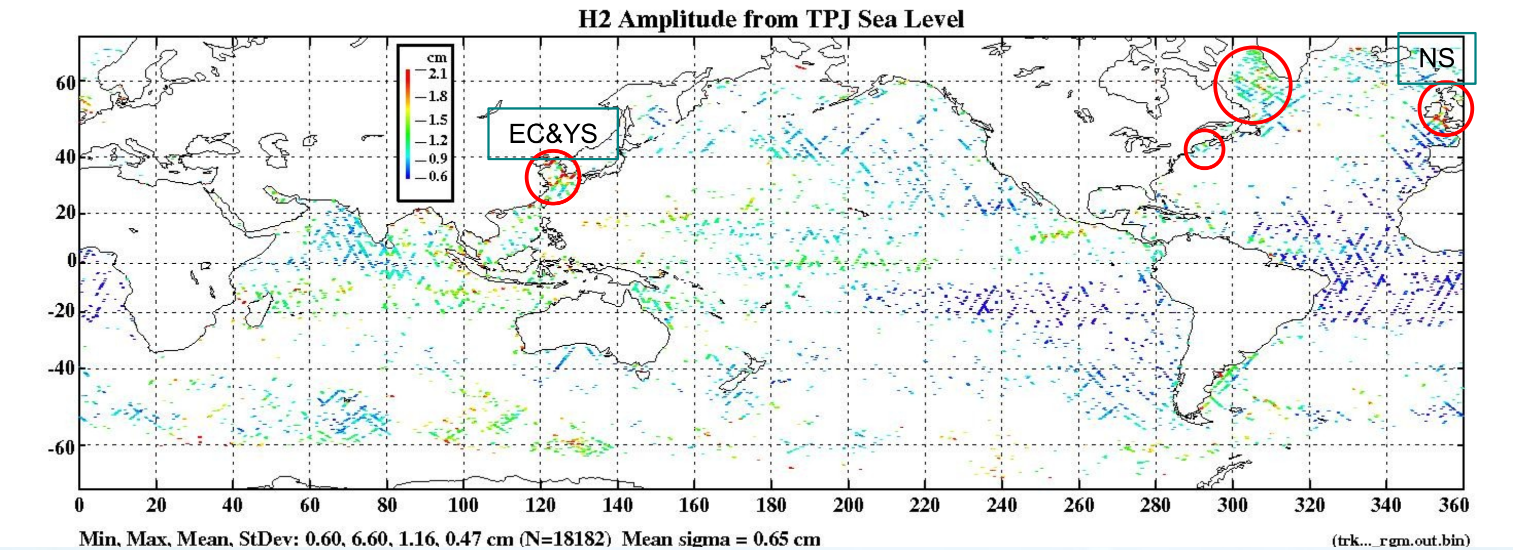
The 17.6-yr time period is long enough and the constituent error covariance matrix (shown below) is nearly diagonal.

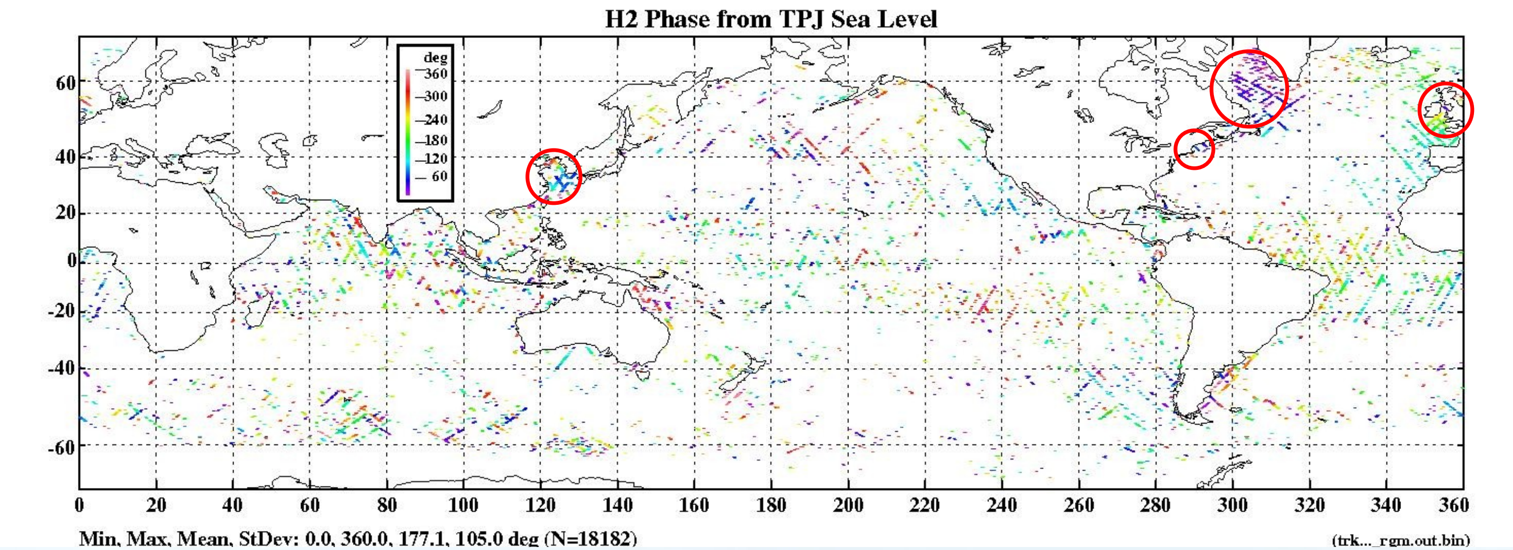
[1]Cherniawsky et al., *J. Atmos. Oceanic Tech*., 2001.




H1 Amplitude from TPJ Sea Level
cm
2.1
1.8
1.5
1.2
0.9
0.6
Min, Max, Mean, StDev: 0.60, 6.10, 1.21, 0.45 cm (N=23403) Mean sigma = 0.67 cm
(trk..._rgm.out.bin)


H1 Phase from TPJ Sea Level
deg
360
300
240
180
120
60
Min, Max, Mean, StDev: 0.0, 360.0, 185.0, 100.3 deg (N=23403)
(trk..._rgm.out.bin)


H2 Amplitude from TPJ Sea Level
cm
2.1
1.8
1.5
1.2
0.9
0.6
EC&YS
NS
60
40
20
0
-20
-40
-60
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
Min, Max, Mean, StDev: 0.60, 6.60, 1.16, 0.47 cm (N=18182) Mean sigma = 0.65 cm
(trk..._rgm.out.bin)


H2 Phase from TPJ Sea Level
deg
360
300
240
180
120
60
60
40
20
0
-20
-40
-60
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
Min, Max, Mean, StDev: 0.0, 360.0, 177.1, 105.0 deg (N=18182)
(trk..._rgm.out.bin)

Comparison between numerical model results and altimeter data

Numerical model details and processing[1]:

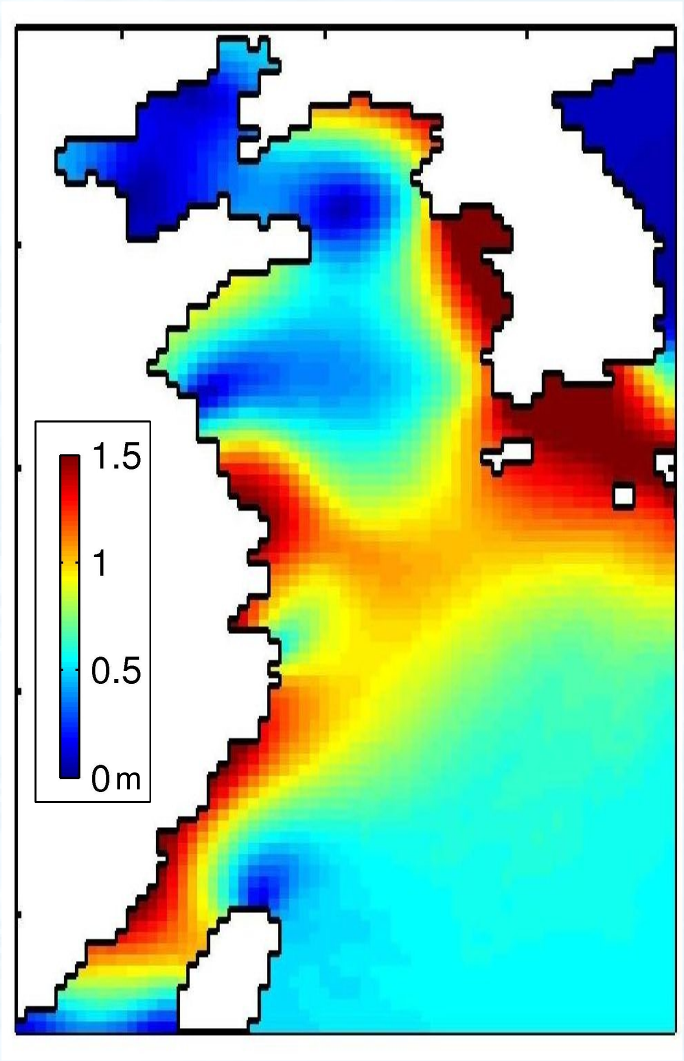
- global ocean circulation model (MPI-OM) is forced with climatological surface forcing[2] and explicit forcing by complete luni-solar tidal potential[3]
- 40 vertical z-levels (6 in the upper 50 m) and tripolar sperical grid with almost uniform 0.2° resolution
- vertical eddy viscosity coefficient is represented by a Richardson number dependent parameterization

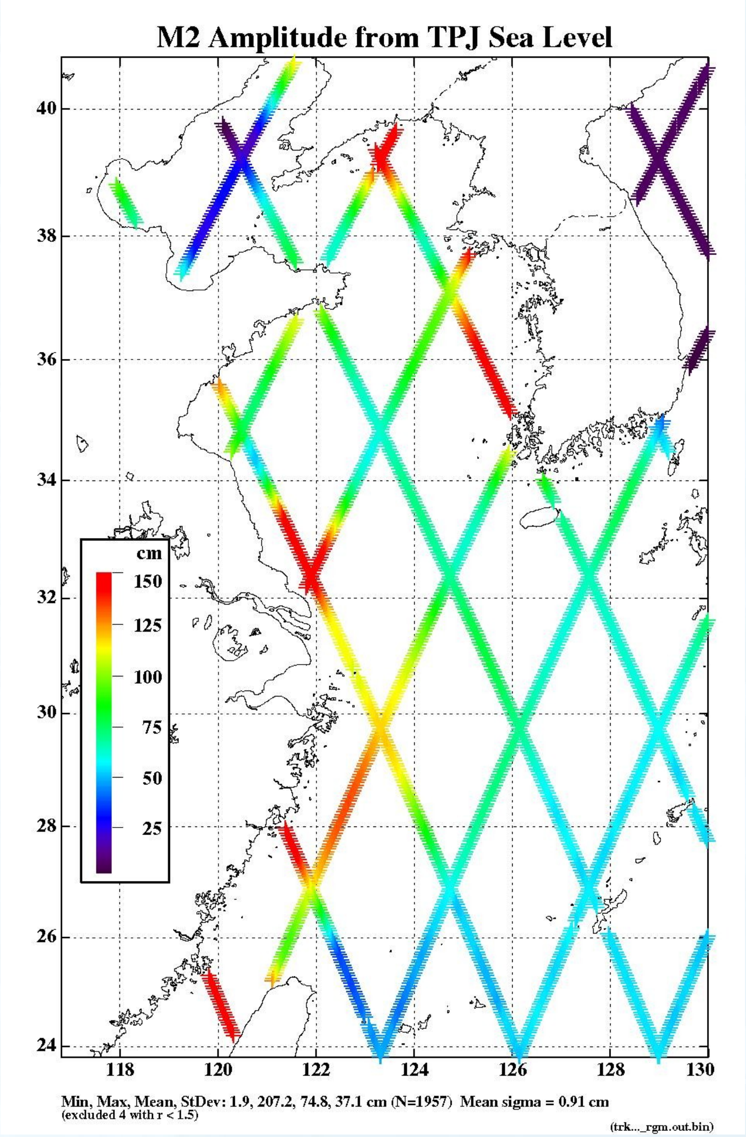
$$E_z = E_0(1 + C \cdot Ri)^{-2} + E_b, \qquad Ri = N^2 \, (\partial U/\partial z)^{-2}$$

- after a spin up period, 2 years of model output are analysed using close to 100 constituents, which include H1 and H2.

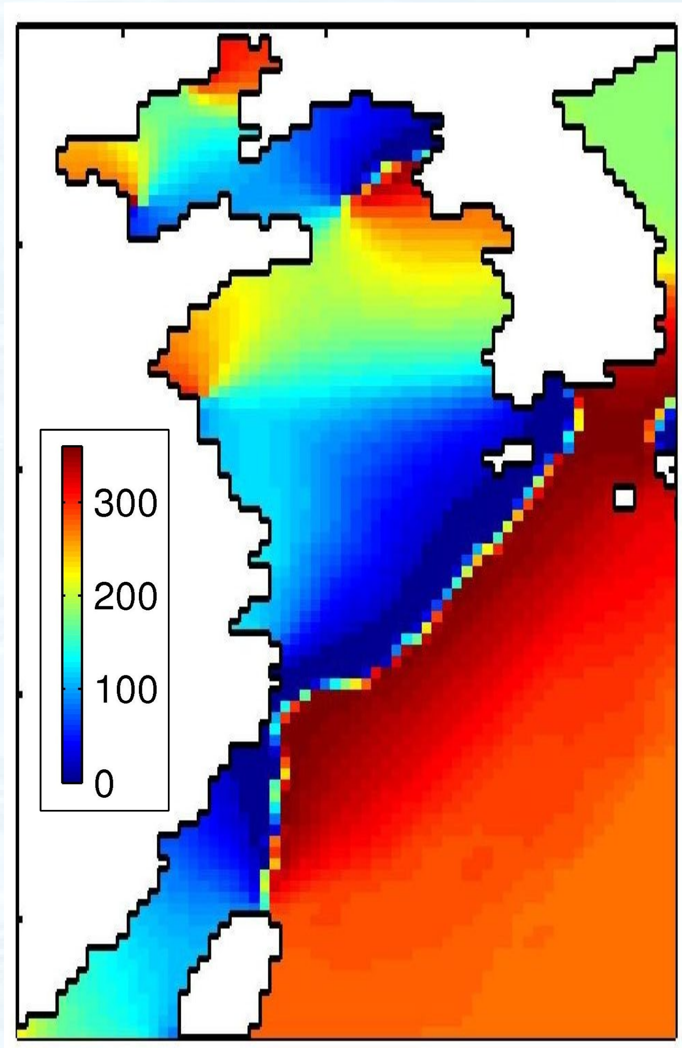
[1]Muller, M., et al., Seasonal variability of the main lunar tidal constituent in shallow seas (in preparation).
[2]Röske, F., A global heat and freshwater forcing dataset for ocean models, *Ocean Modelling*, 11, 235-297, 2006.
[3]Thomas, M. J., J. Sundermann, and E. Maier-Reimer, *Geophys. Res. Lett.*, 28, 2457–2460, 2001

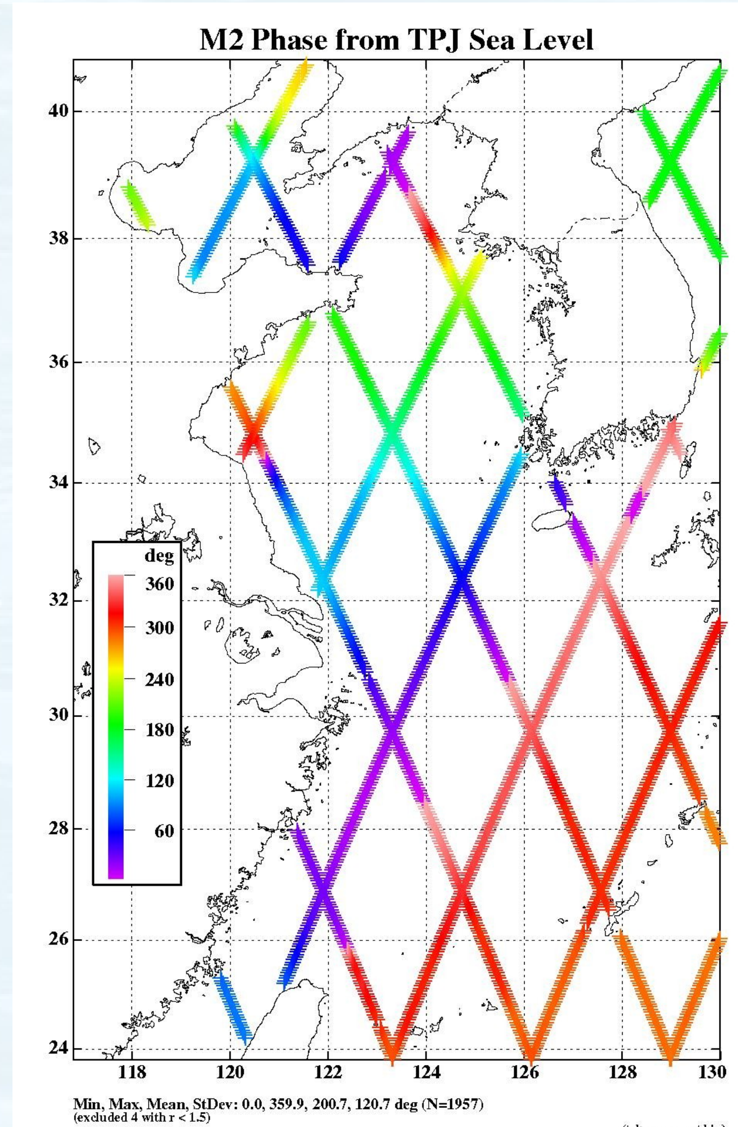
Model M2 amplitude



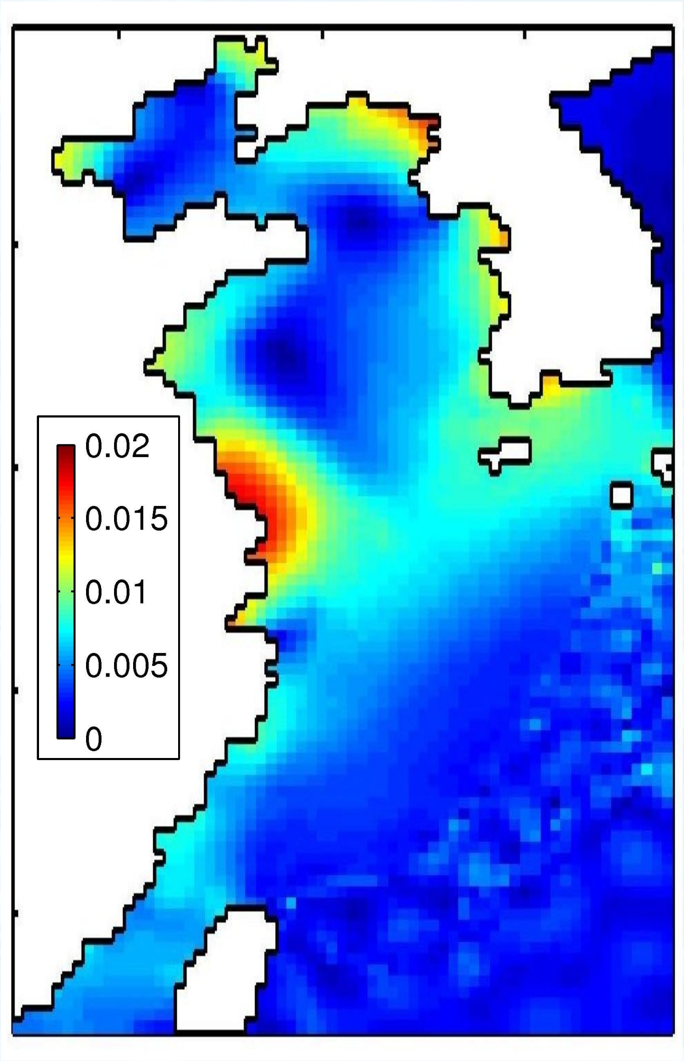


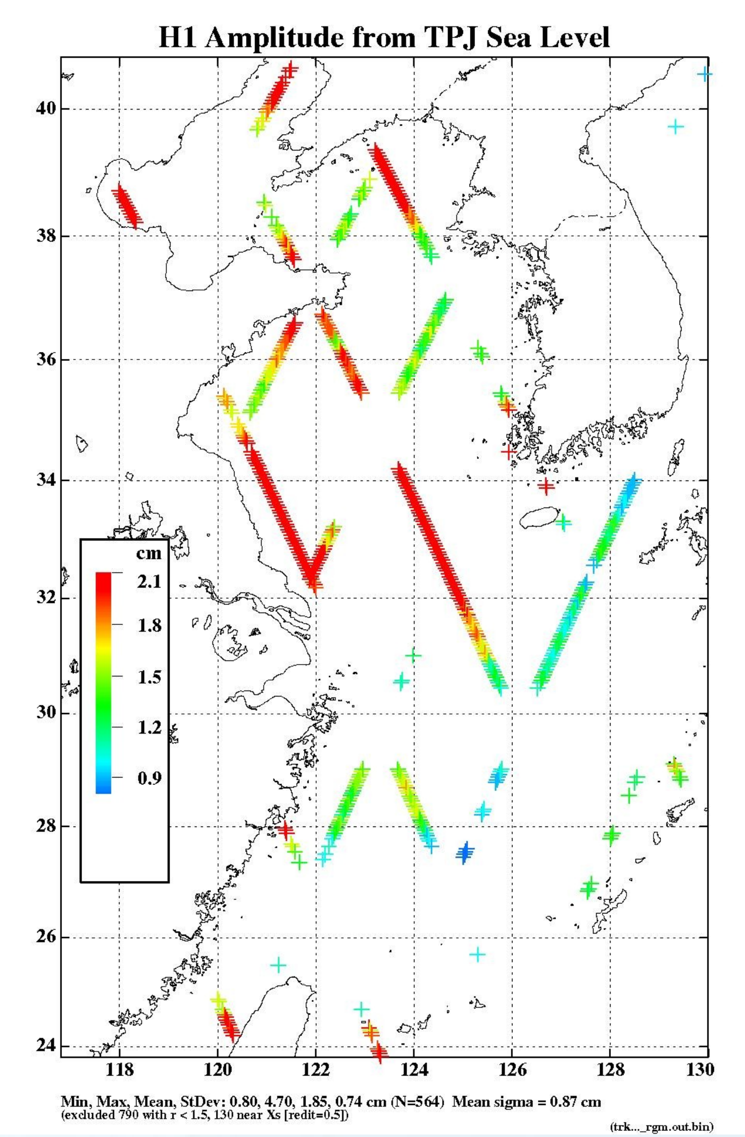
Model M2 phase



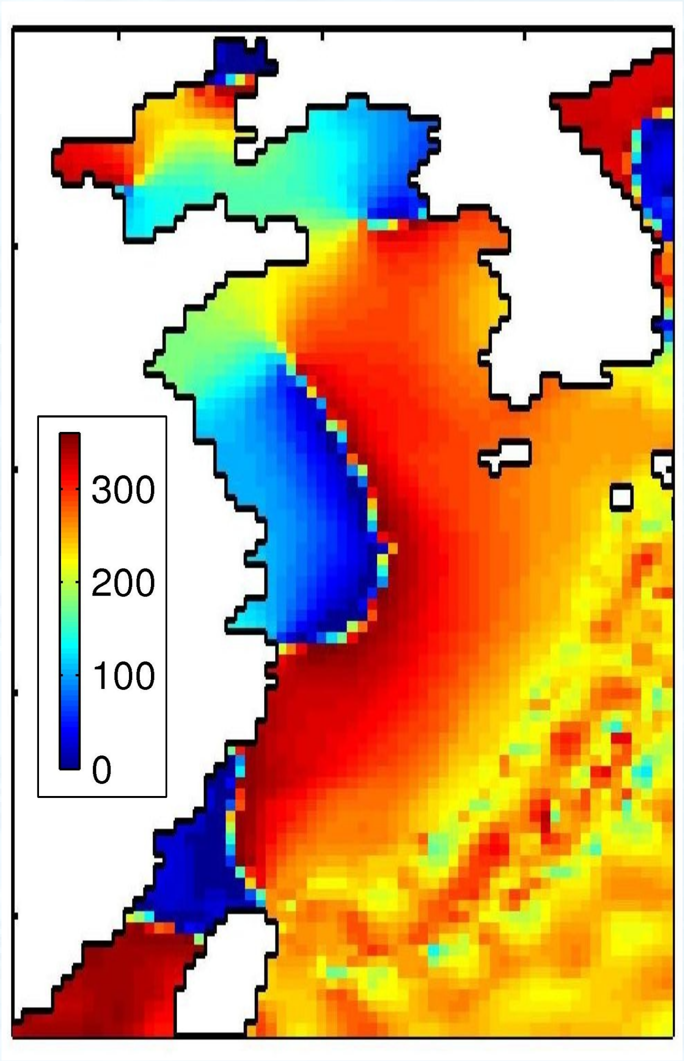


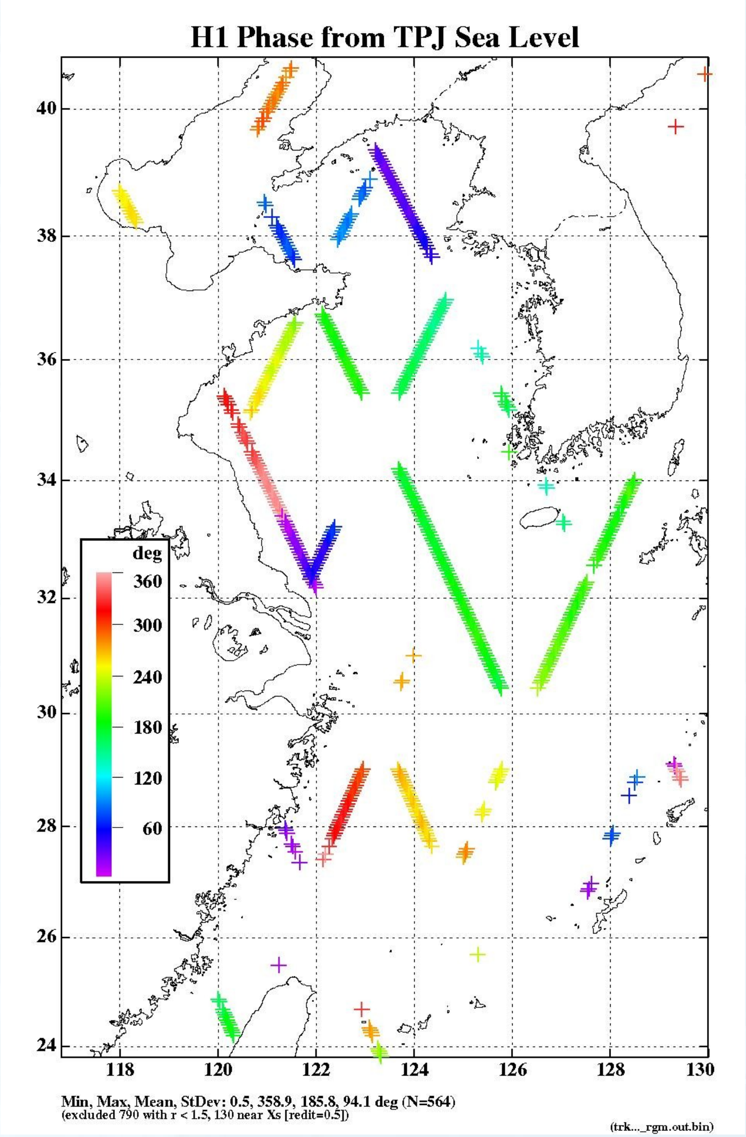
Model H1 amplitude



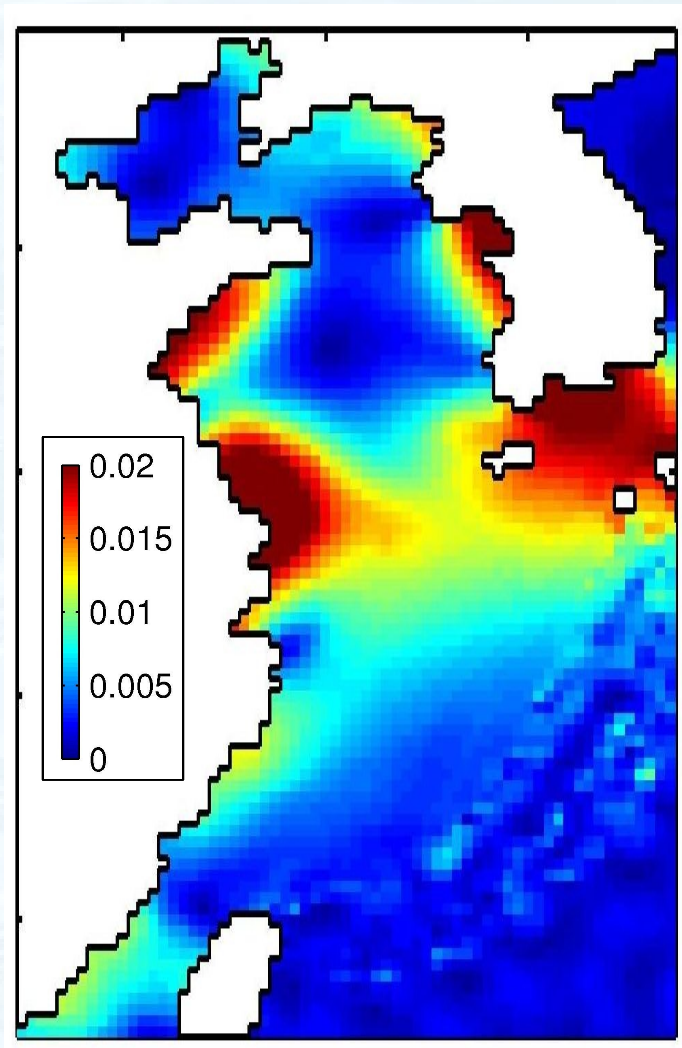


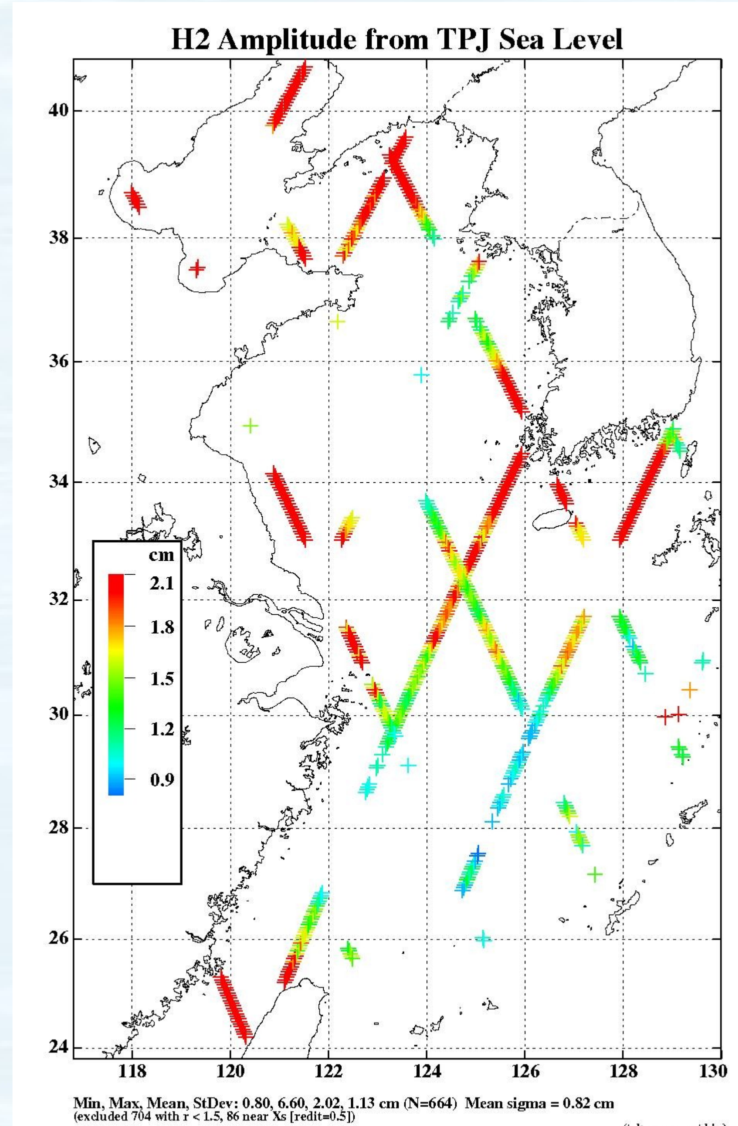
Model H1 phase



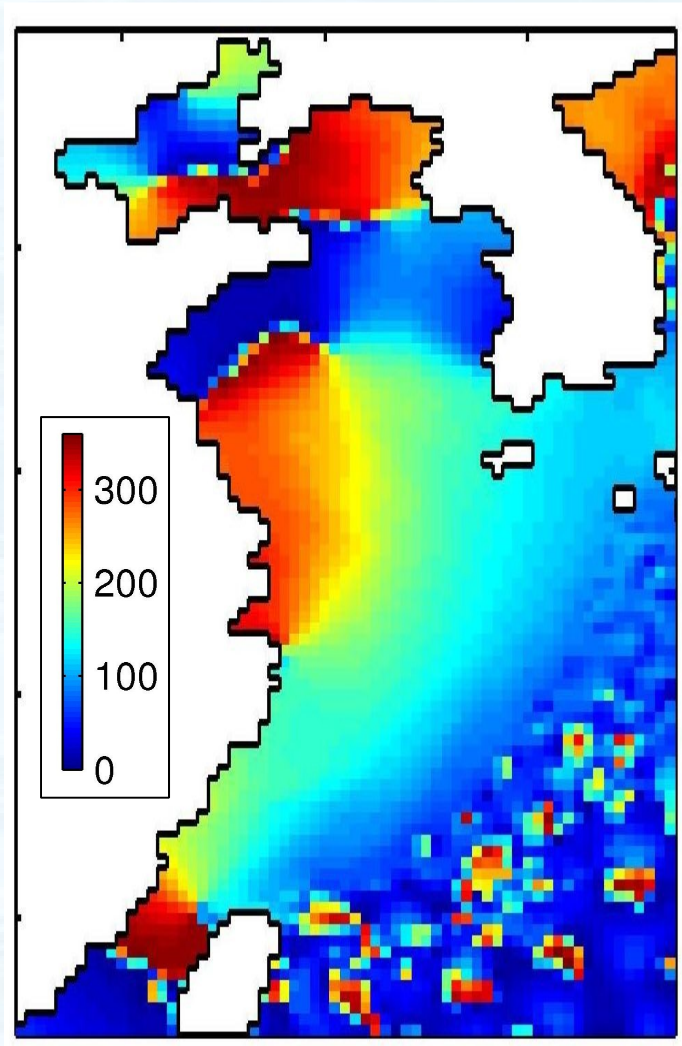


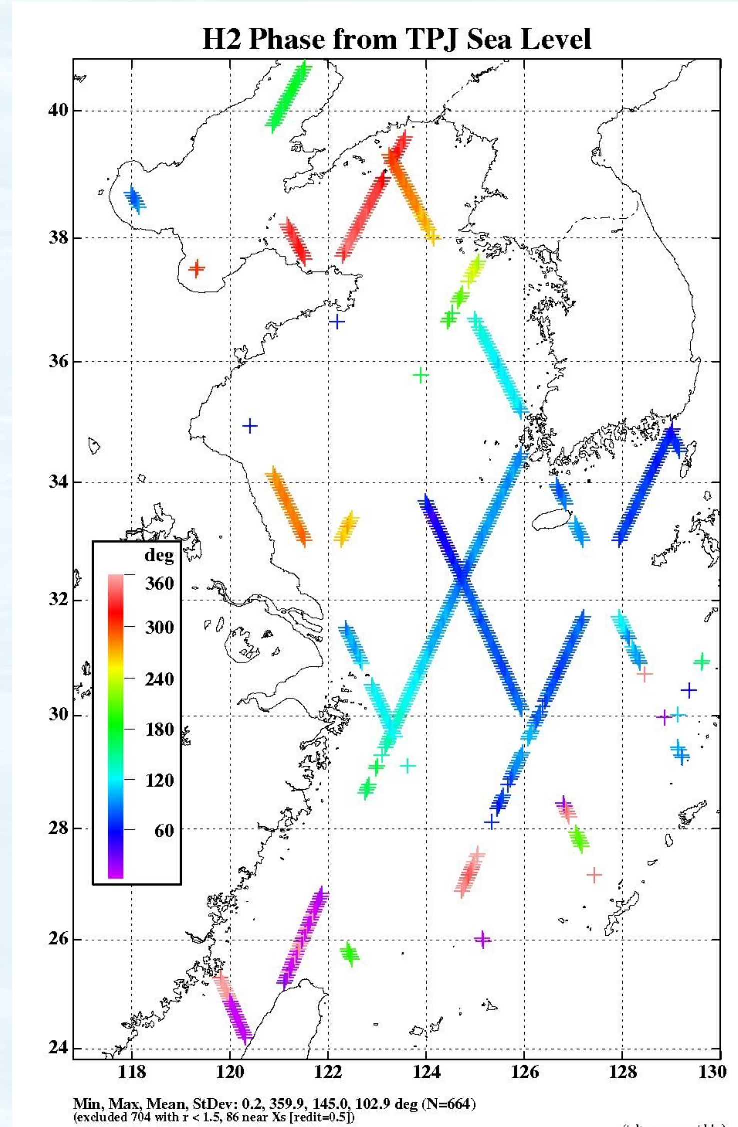
Model H2 amplitude



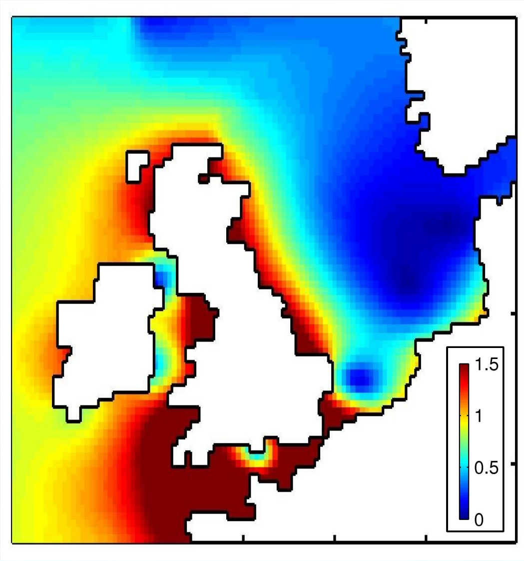


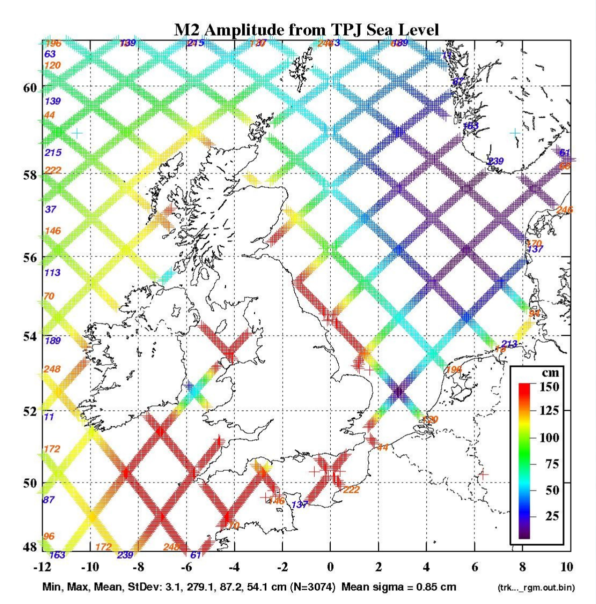
Model H2 phase



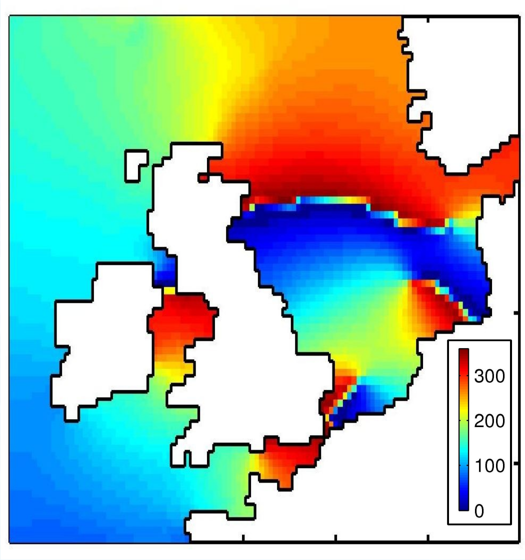


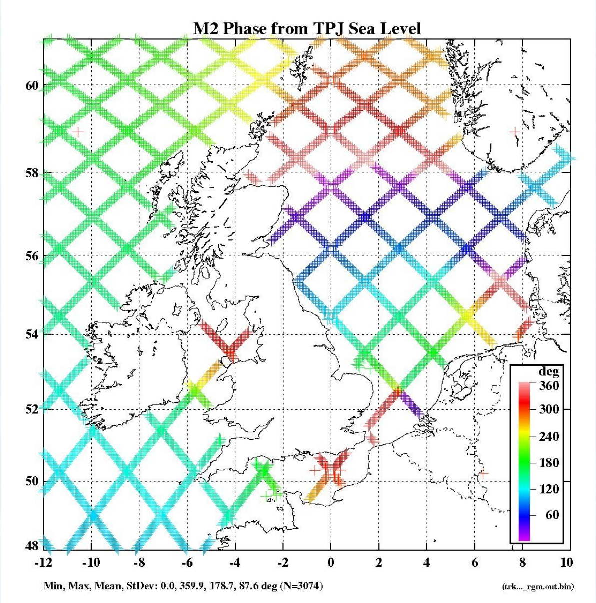
Model
M2 amplitude



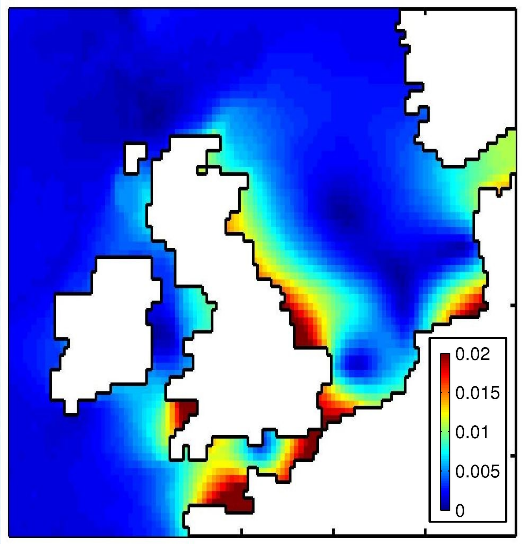


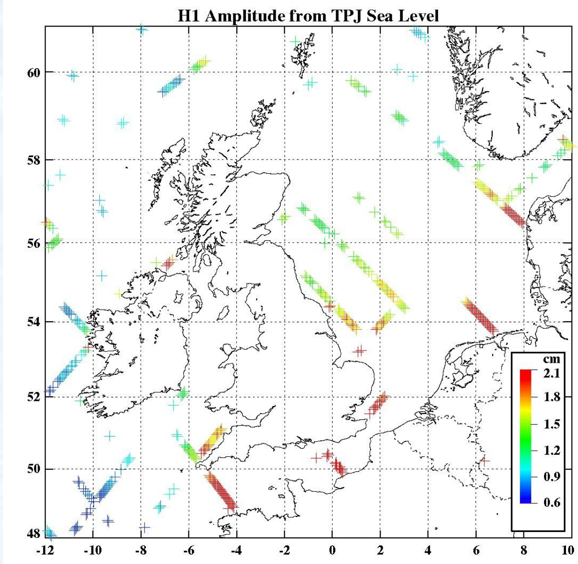
Model
M2 phase



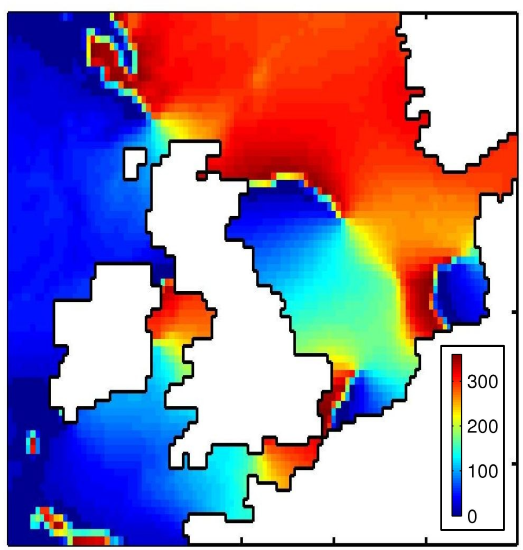


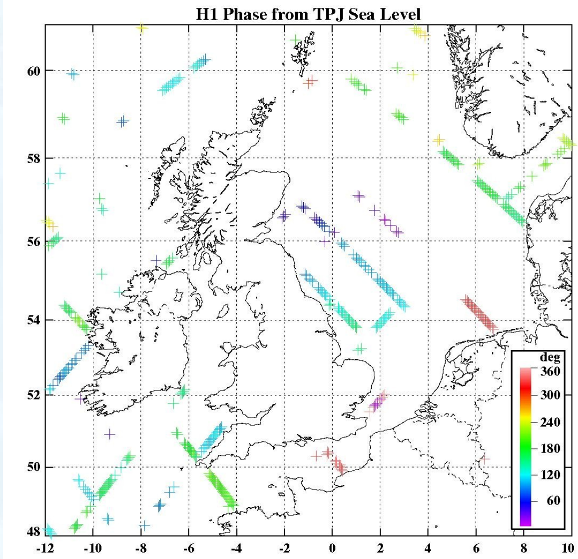
Model
H1 amplitude



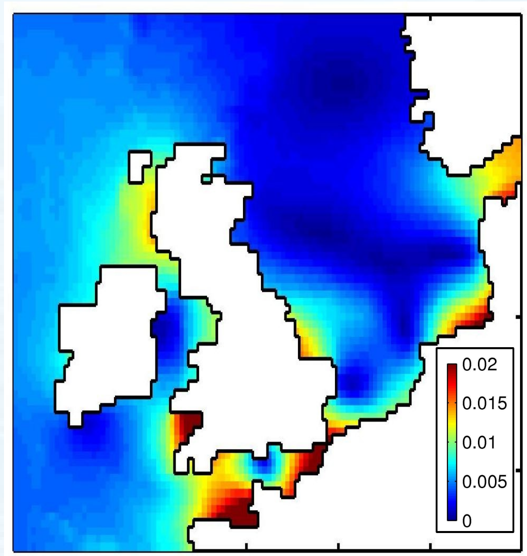


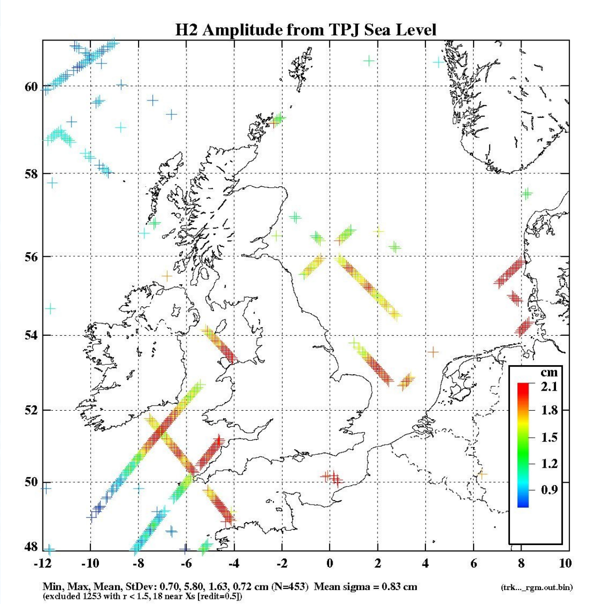
Model
H1 phase



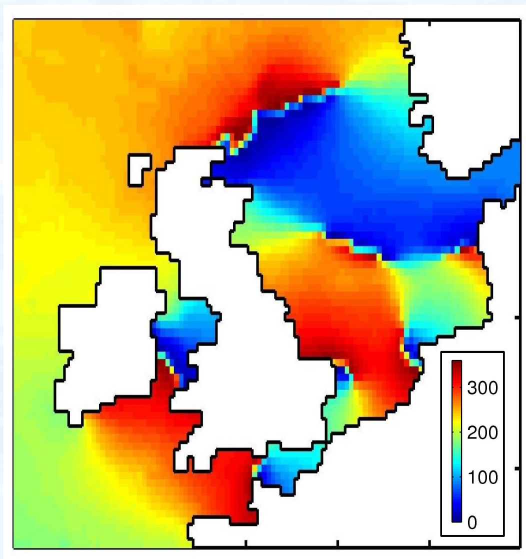


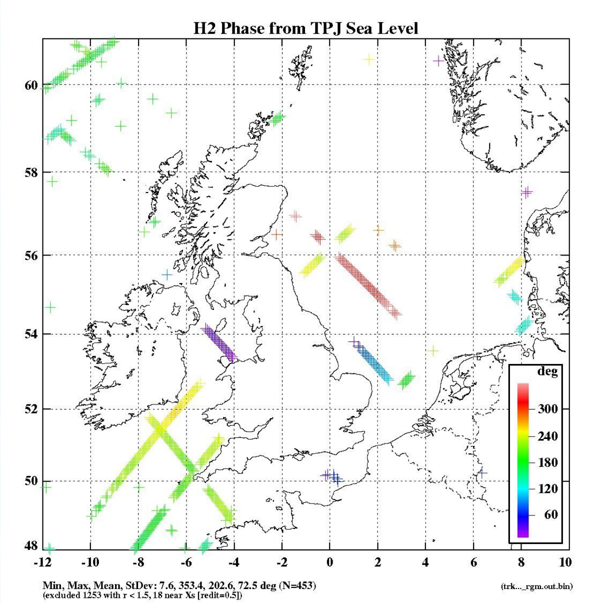
Model
H2 amplitude





Model
H2 phase





Preliminary conclusions:

- It is possible to detect a seasonal cycle of M2, via its satellites H1 and H2 which can be analysed directly from TPJ sea level data.
- However, their small amplitudes (signal/noise ratio) and patchy phase coherence limited the applicability of this analysis to a few select areas, such as East Chine and Yellow Seas and North Sea.
- Comparison between an OGCM-generated H1 and H2 with those derived from altimetry showed a reasonably good agreement (at least, for a first try) in both areas.
- Some disagreements are possibly related to (a) model errors (too coarse resolution in shallow seas, incomplete initialization, forcing errors?), (b) small signal/noise in altimeter derived H1 and H2, or (c) the assumption of stationarity of seasonal cycle.

Future directions?

- Examine H1 and H2 editing and analyses technique to improve signal/noise ratio
- Check the stationarity of these constituents, for example in tide gauge data.
- Improve this model simulation (a longer spin-up, improved surface forcing?).

Obrigado!