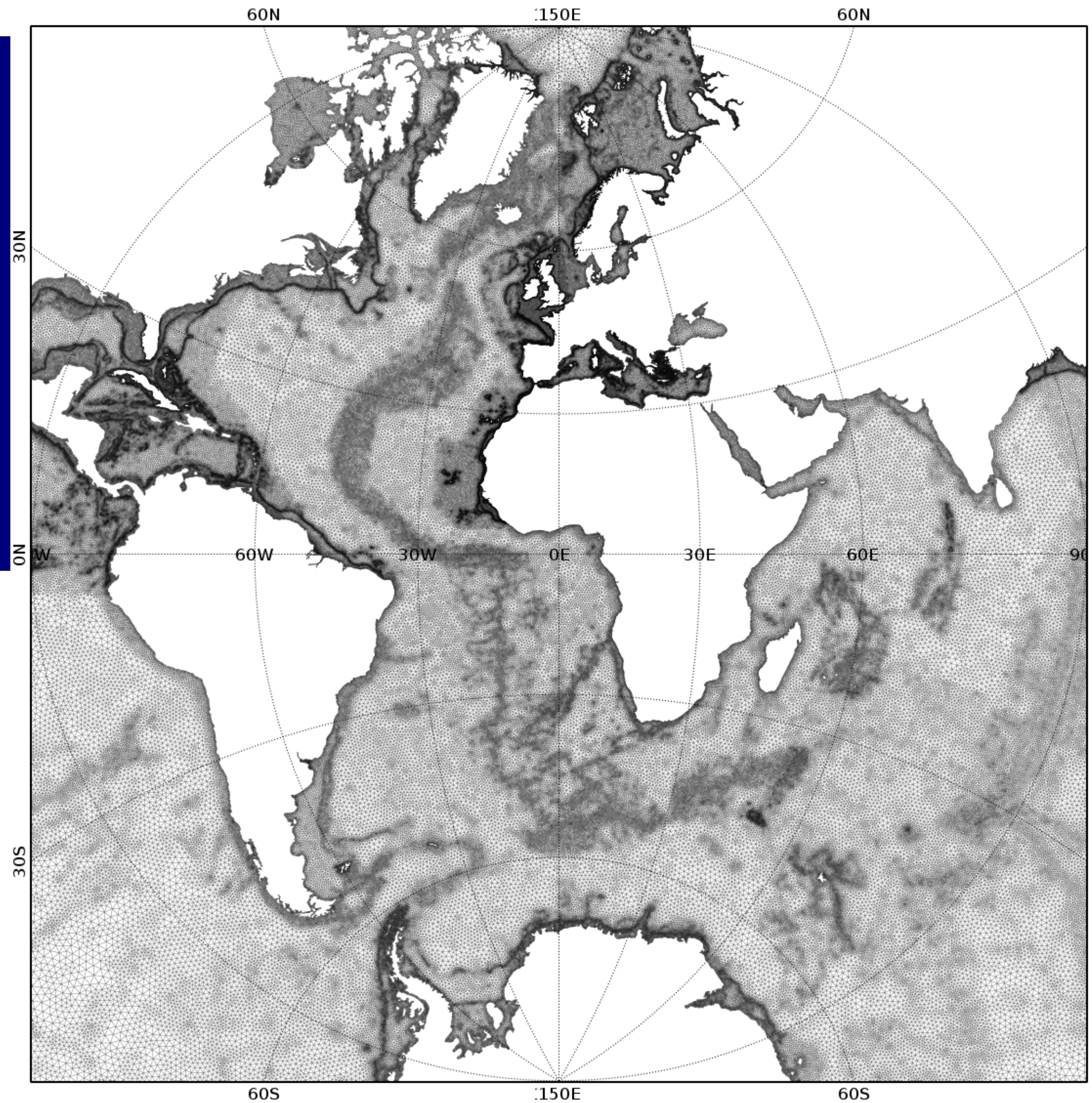
Non-hydrostatic impact on tides and other considerations…



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What will be necessary for SWOT in addition to usual efforts

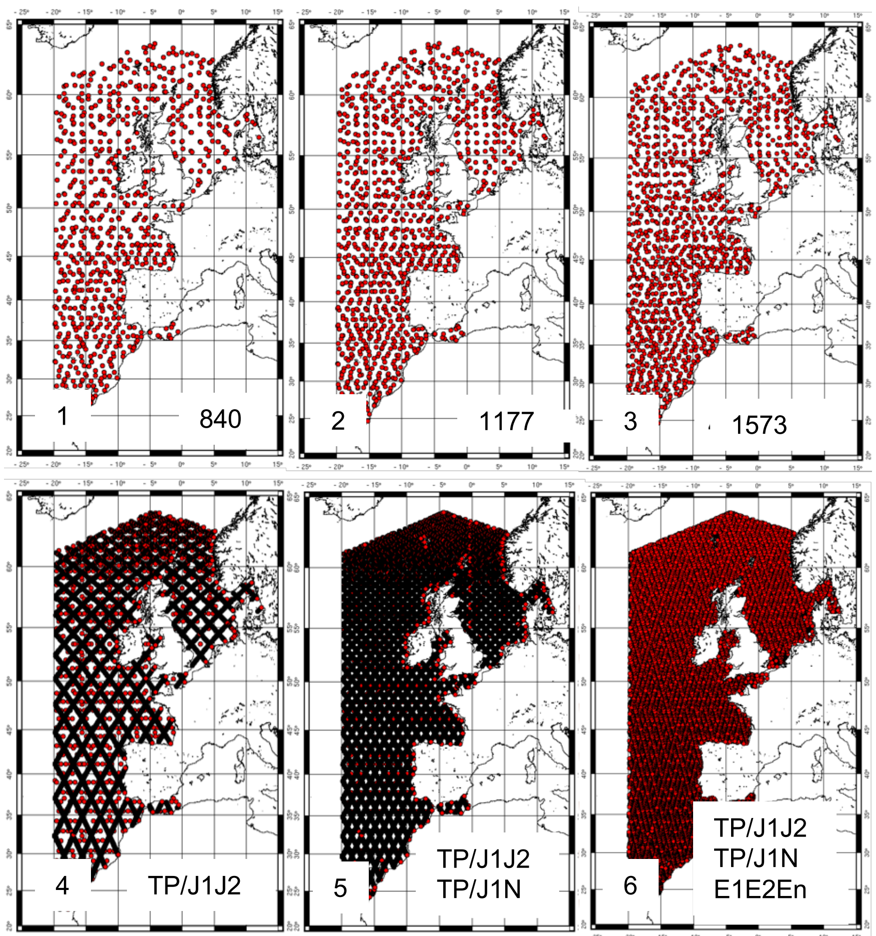
- Improve global harmonic atlases
  - More resolution (1 km along shorelines?)
  - Extend tidal spectrum
  - Keep improving prior hydrodynamic modelling (to compensate for data assimilation malfunctioning), including neglected terms (so far)
    - Improve bathymetry
    - Improve loading self-attraction, atmospheric forcing
    - Non-hydrostatic effects
    - Tidal sensitivity to mean dynamic topography

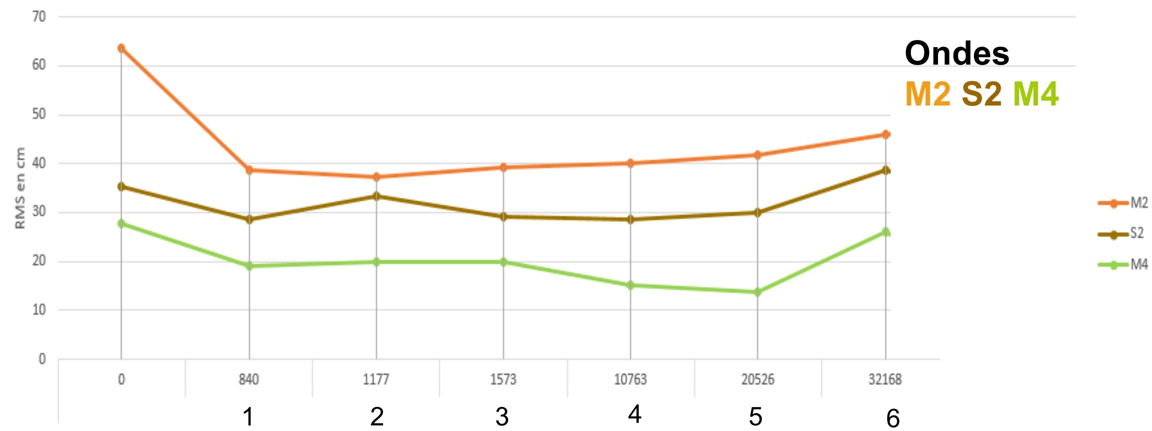
- Develop accurate dedicated near-shore/estuarine configuration
  - Non-harmonic, non-stationary -> time-stepping hind cast
  - Local MDTs, vertical referencing (geoids, …), river discharge forcing
  - New methods to characterize/predict tides in estuaries?
  - Add phase-resolving swell/waves ?

- Similar efforts needed for storm surges
  - Evaluate atmospheric forcing efficiency
  - Include tides in simulations then
    - Remove a pure tidal simulation?
    - Remove only constituents taken into account in operational tidal corrections?
  - Deploy data assimilation ?

Data assimilation: sober versus massive

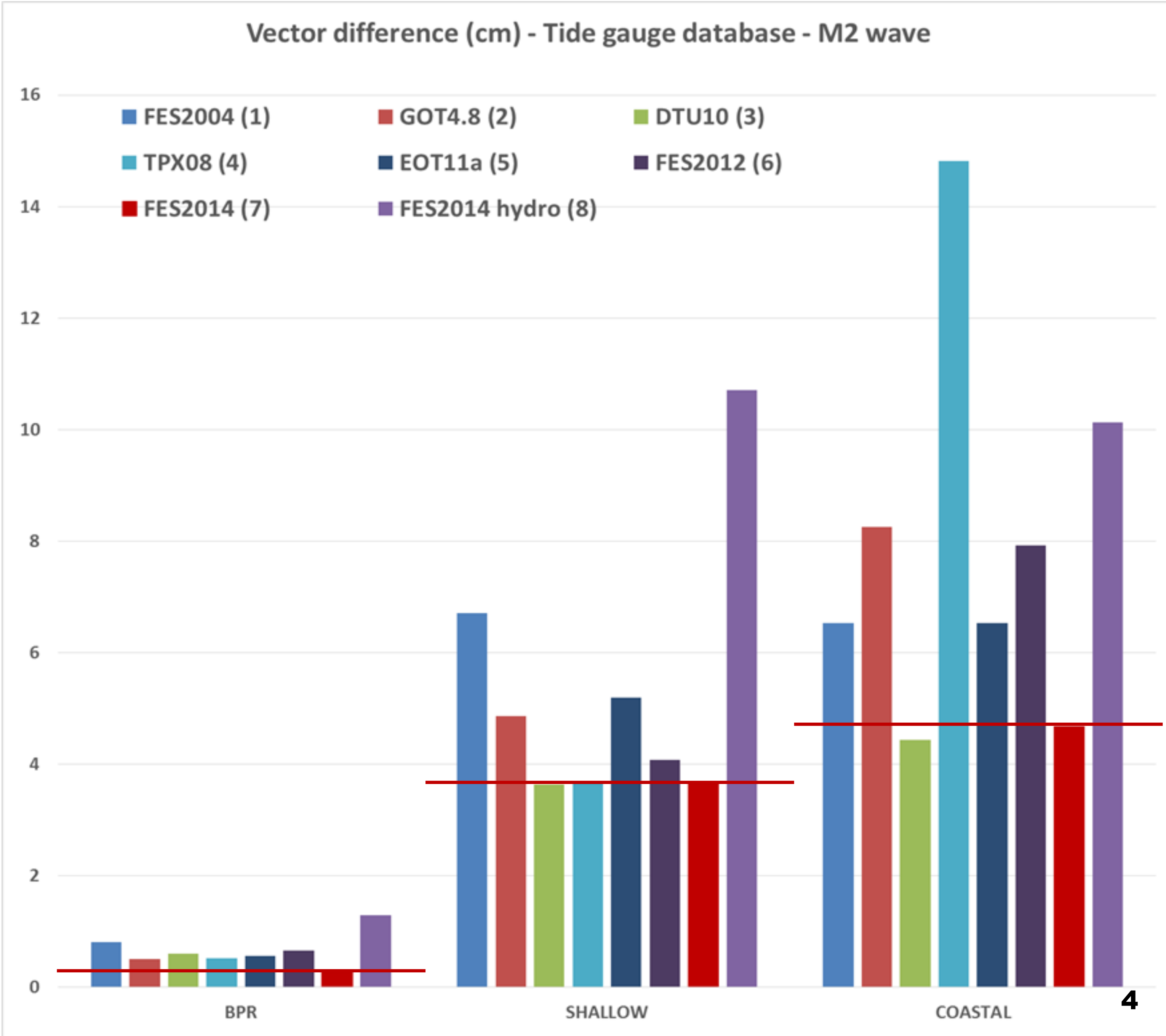
North-East Atlantic regional assimilation comparisons against tide gauges





- 1->3 subsampling of TP/J1J2 TPNJ1N E1E2En xovers;
- 4->6 idem plus along-track ;

- All altimetry data do not have the same accuracy
  - TP/J1J2J3 still the most accurate
  - E1E2En can degrade the solution
  - but remain usefull for (short wavelength) non-linear constituents
- Proper barotropic/baroclinic separation can be challenging, especially near continents (filtering issue)
- Idem for non-tidal signal at tides aliased frequencies

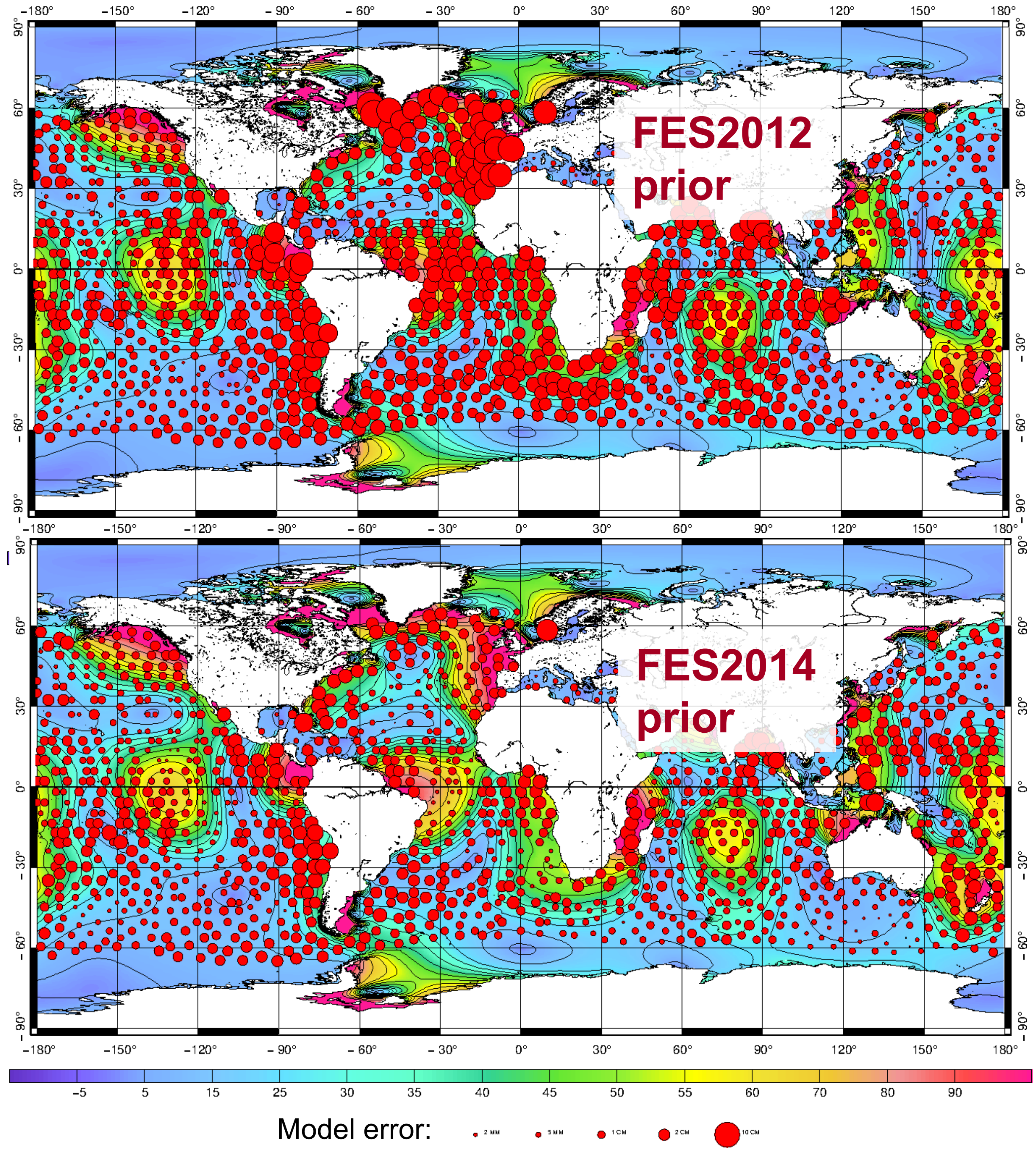


Vector difference (cm) - Tide gauge database - M2 wave
FES2004 (1)
GOT4.8 (2)
DTU10 (3)
TPX08 (4)
EOT11a (5)
FES2012 (6)
FES2014 (7)
FES2014 hydro (8)
16
14
12
10
8
6
4
2
0
BPR
SHALLOW
COASTAL

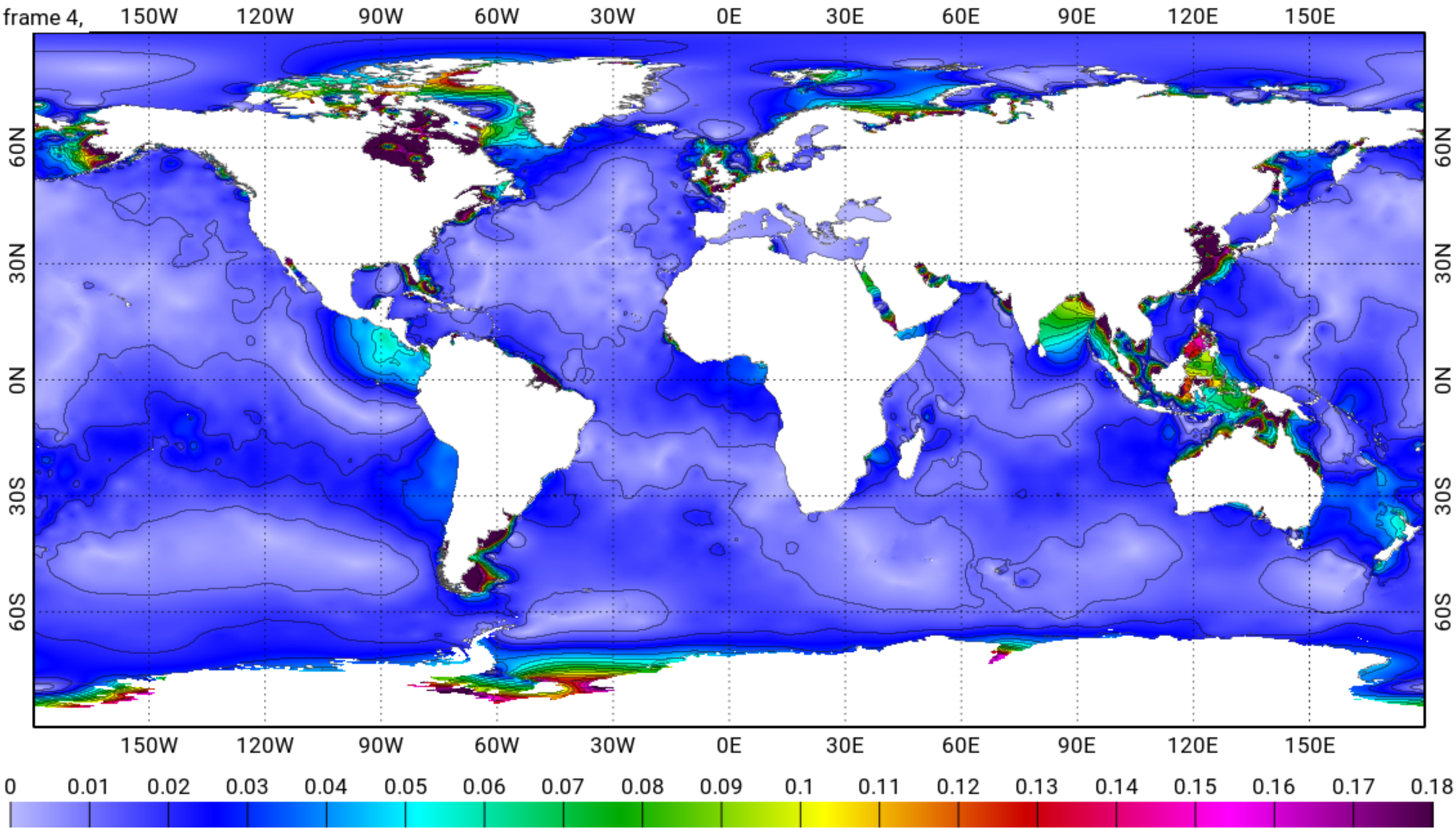
Hydrodynamical simulation accuracy improvement

M2 RMS (TP/J1/J2 xovers)
Deep ocean 2.4 cm
Shelf seas 9.3 cm

M2 RMS (TP/J1/J2 xovers)
Deep ocean 1.3 cm
Shelf seas 5.5 cm



M$_2$ FES2014: hydrodynamic versus assimilated

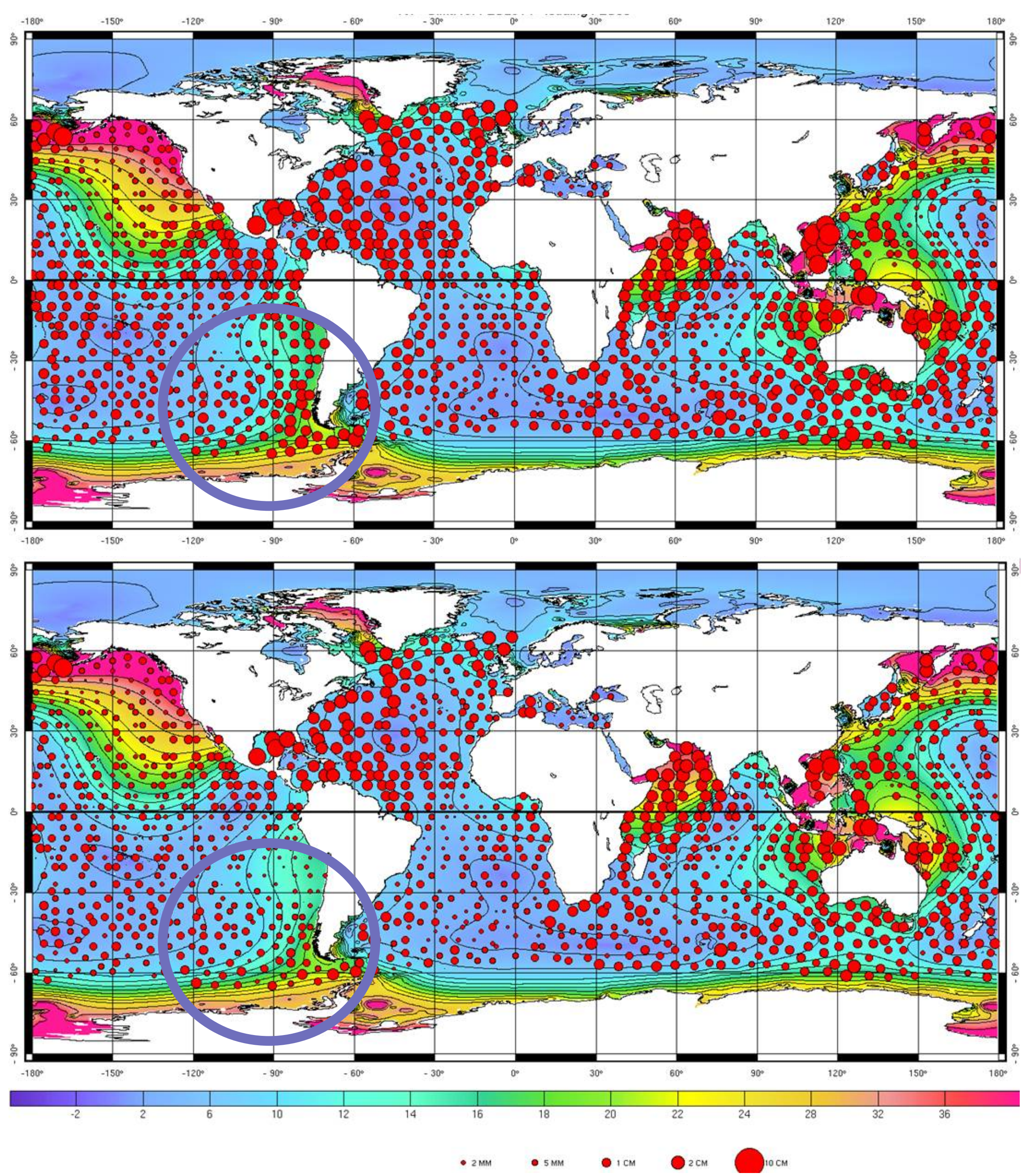


K1 forced with FES99 LSA

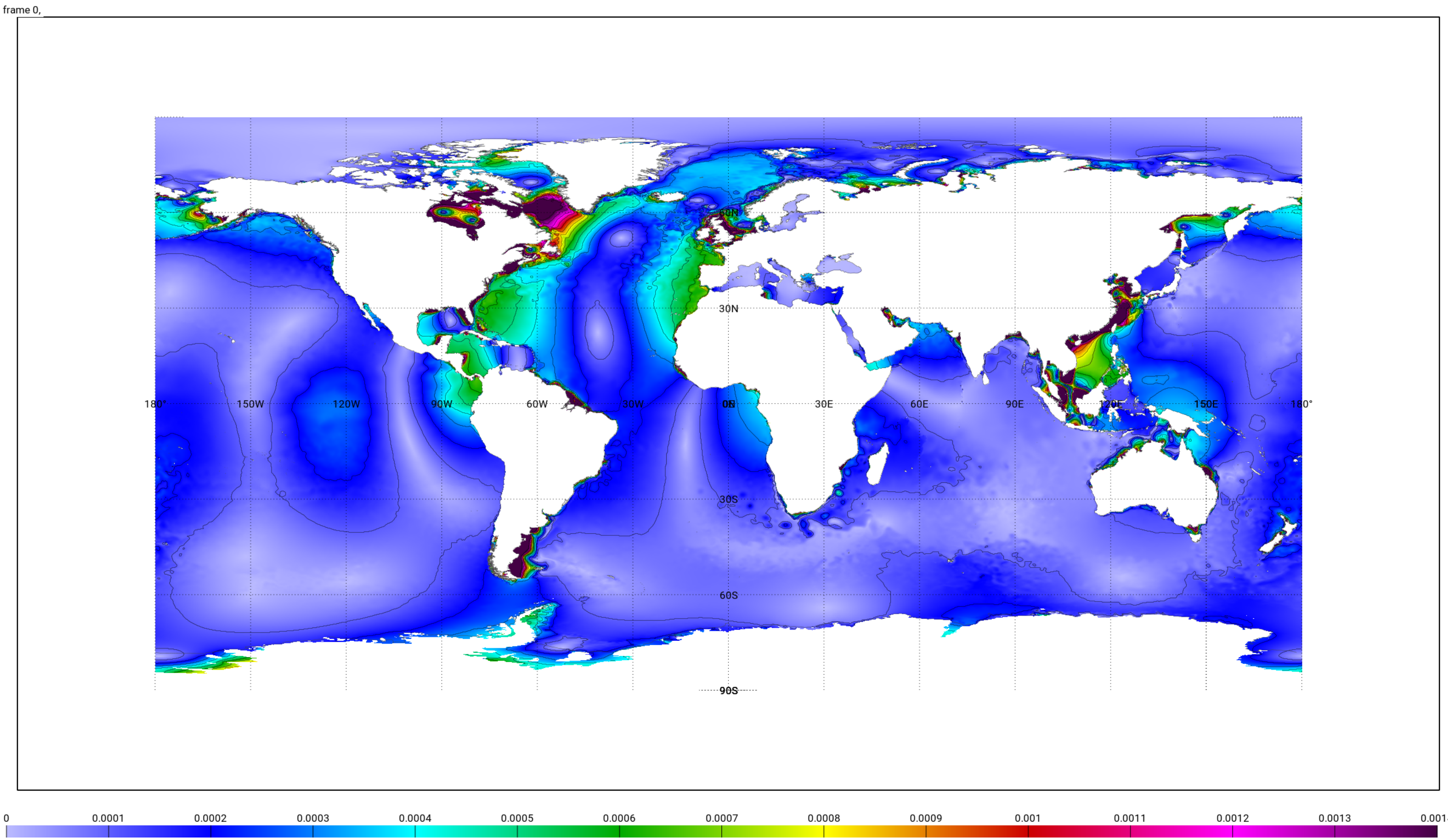
Error ~9mm RMS (deep ocean)

K1 forced with FES2014 LSA
(courtesy of JP Boy)

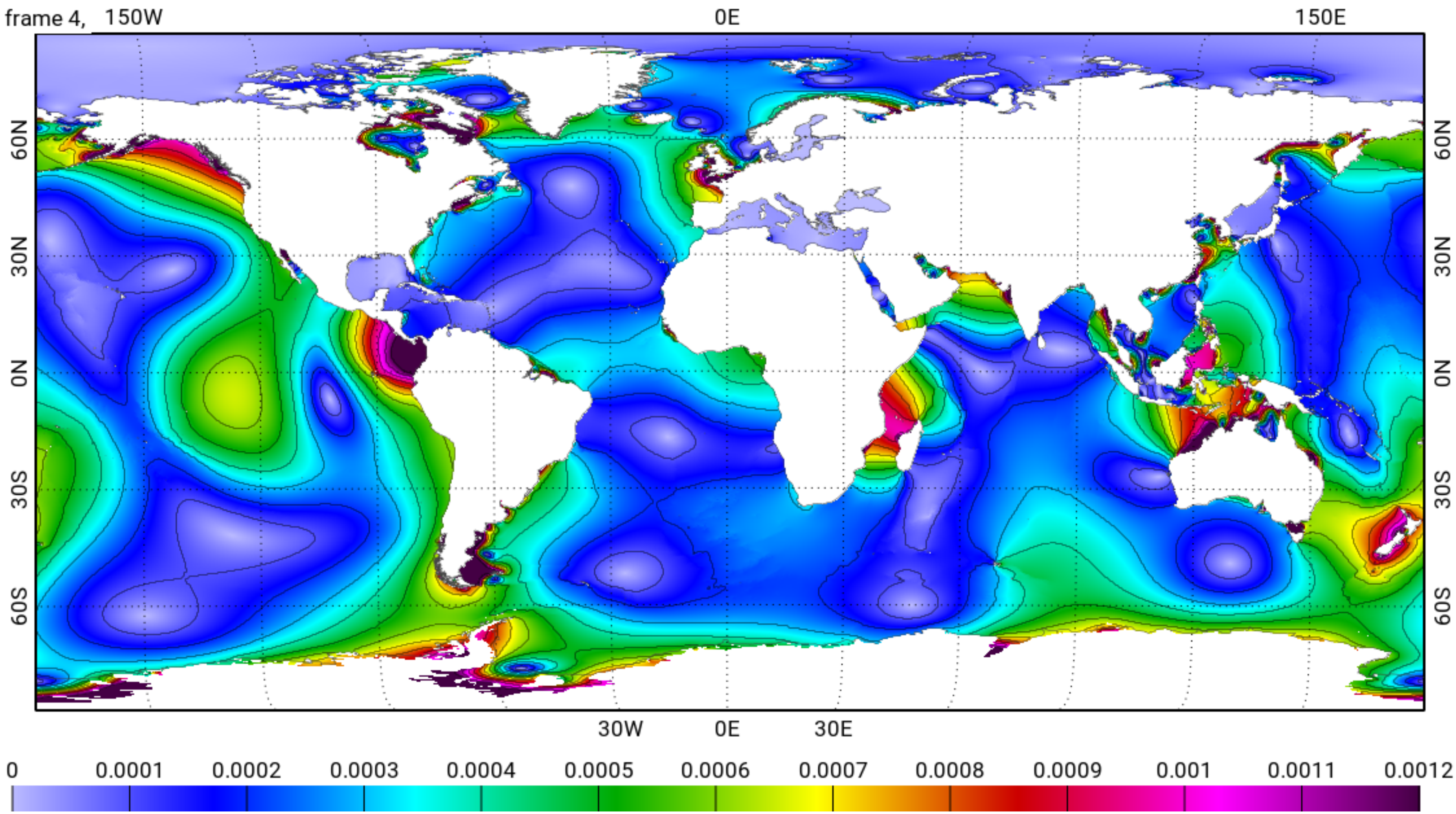
Error ~8mm RMS (deep ocean)



M_2 tide: impact of mean dynamic topography



M$_2$ tide: impact of non-hydrostatic pressure

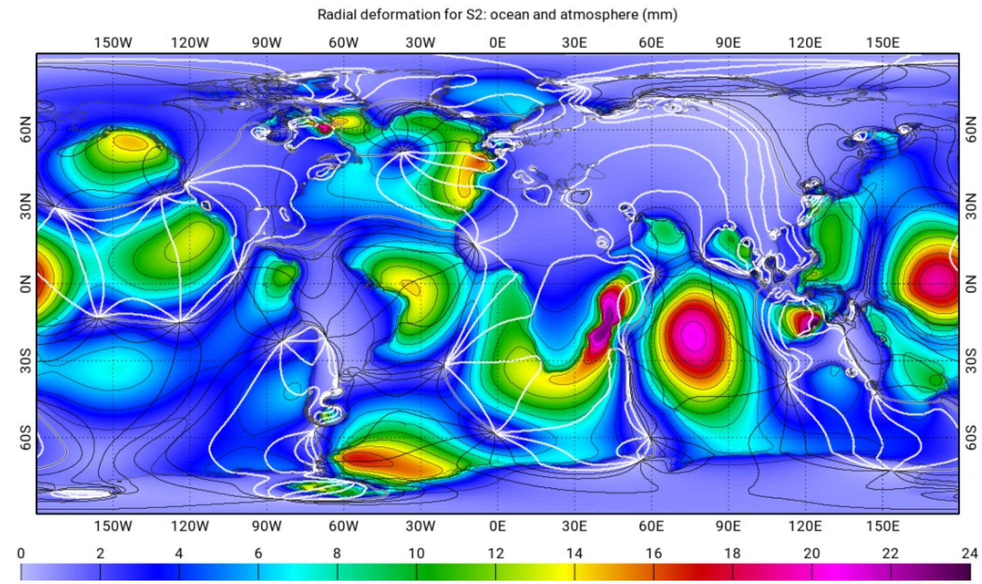


~0,5 mm improvement, all basins

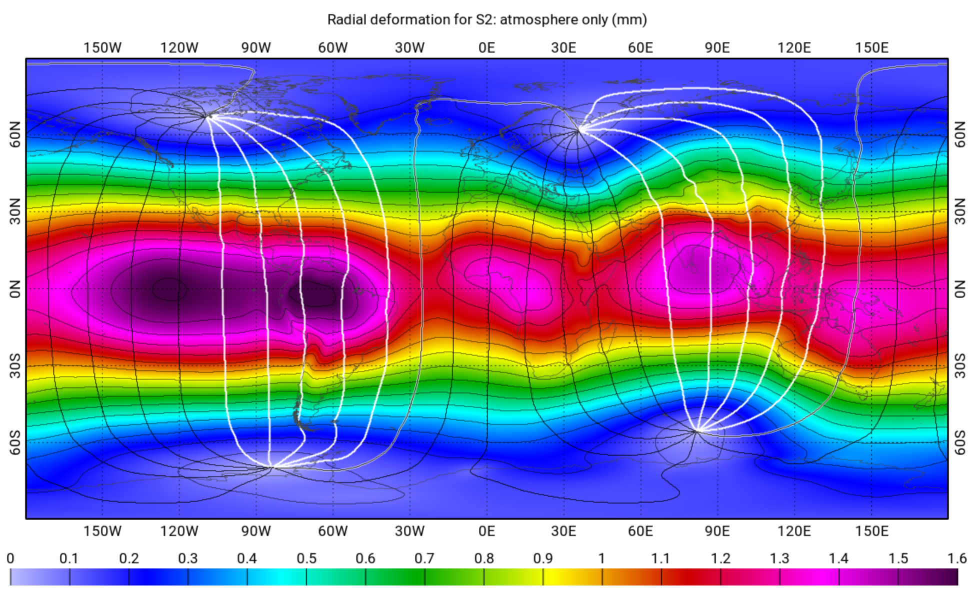
Radial deformation

Atmospheric contribution to tides, S_2

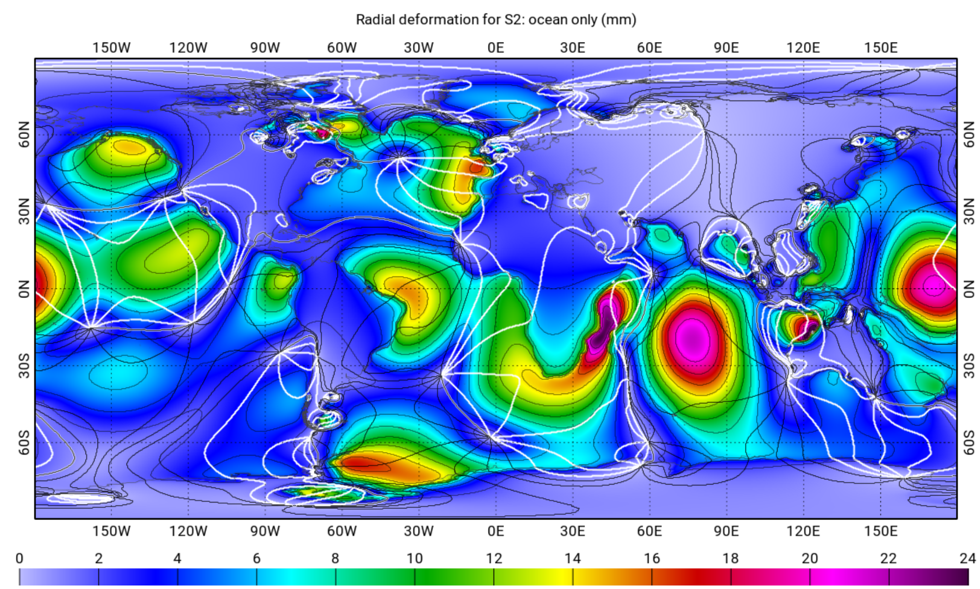
- S_2 atmospheric pressure forcing already in tidal forcing
- Not yet in loading/self-attraction terms
  ~10% of oceanic LSA
- Nor in altimetry correction



S_2 ocean sea level contribution (mm)

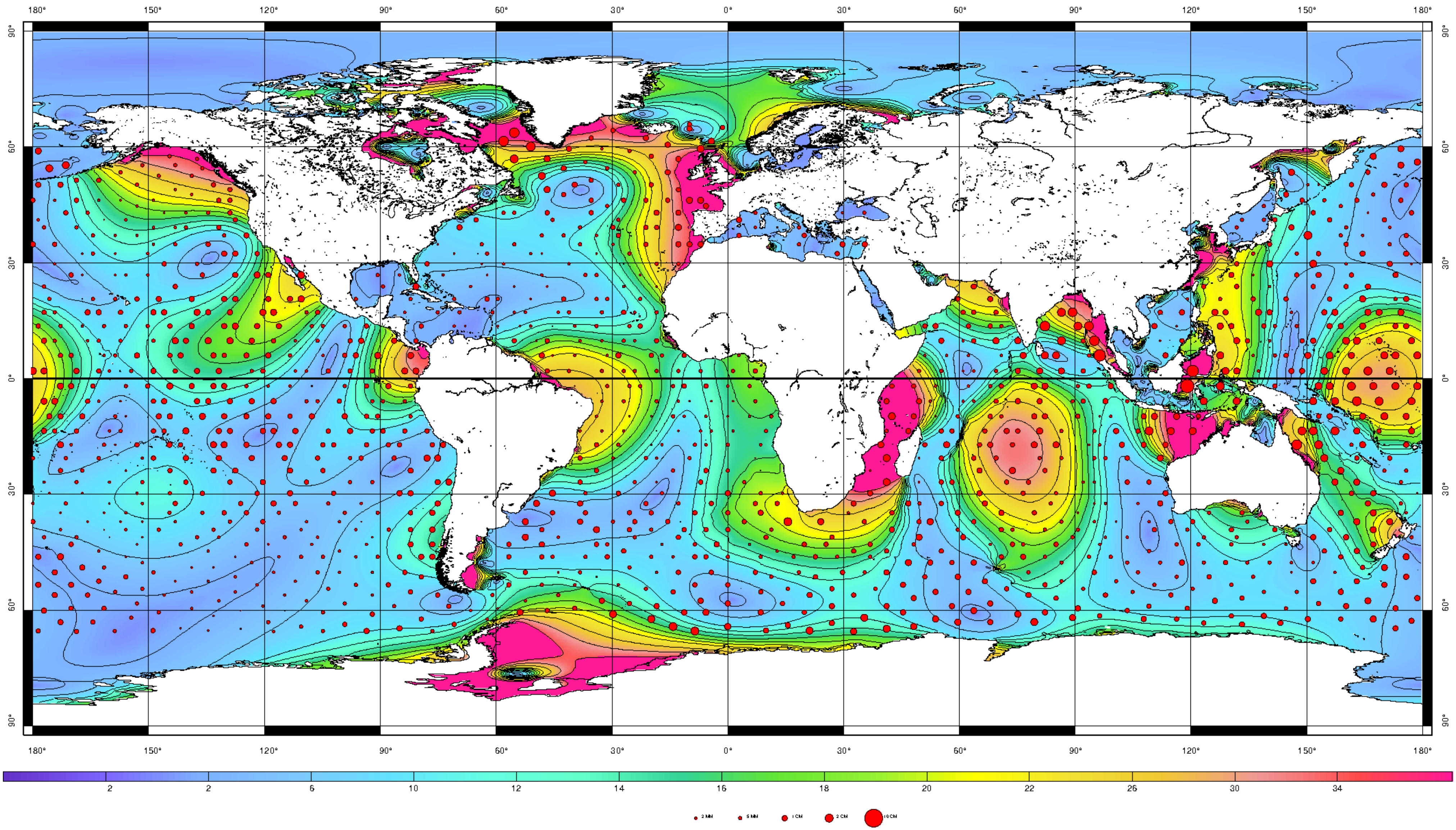


S_2 atmospheric pressure contribution (mm)

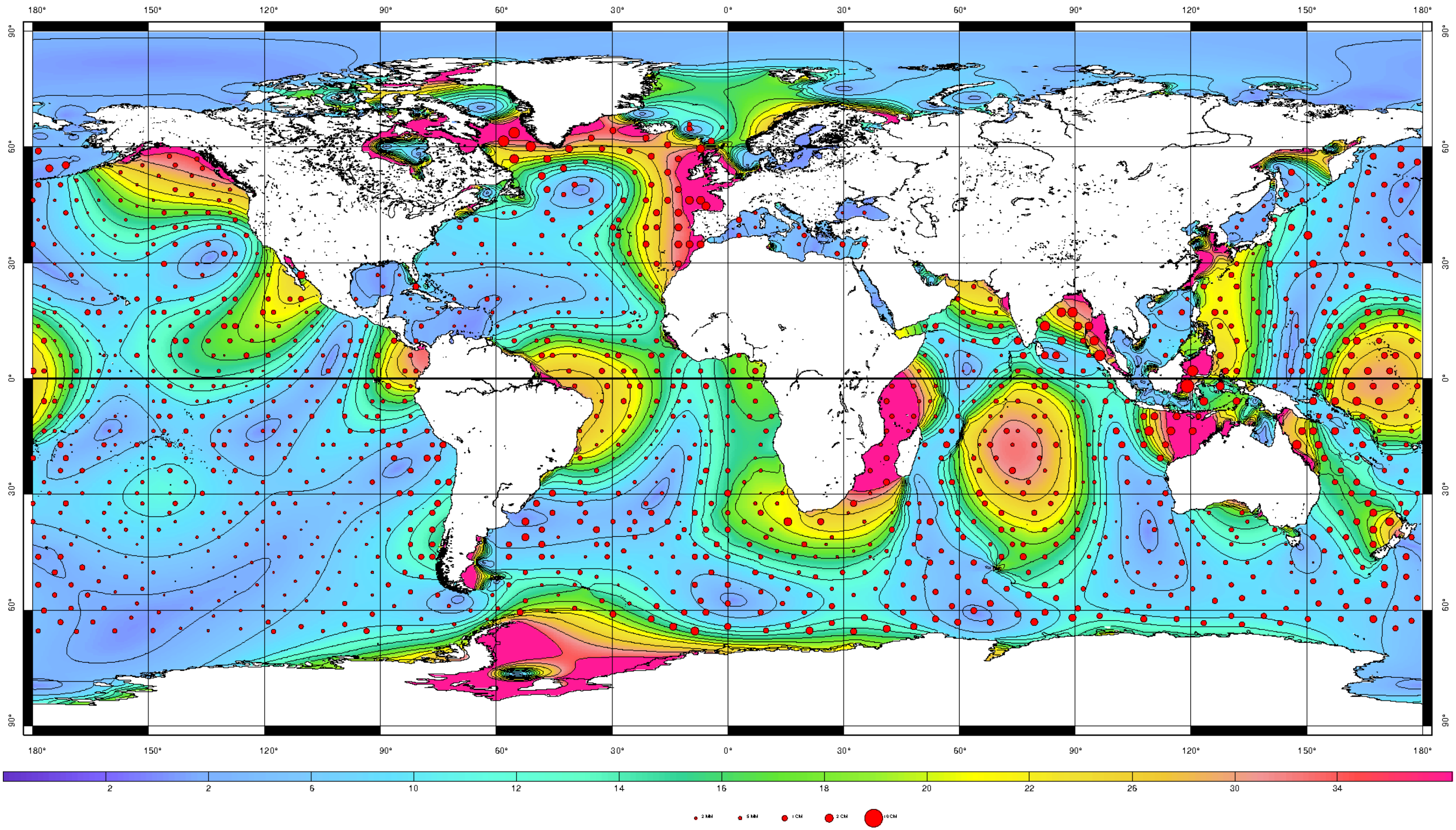


S_2 combined deformation (mm)

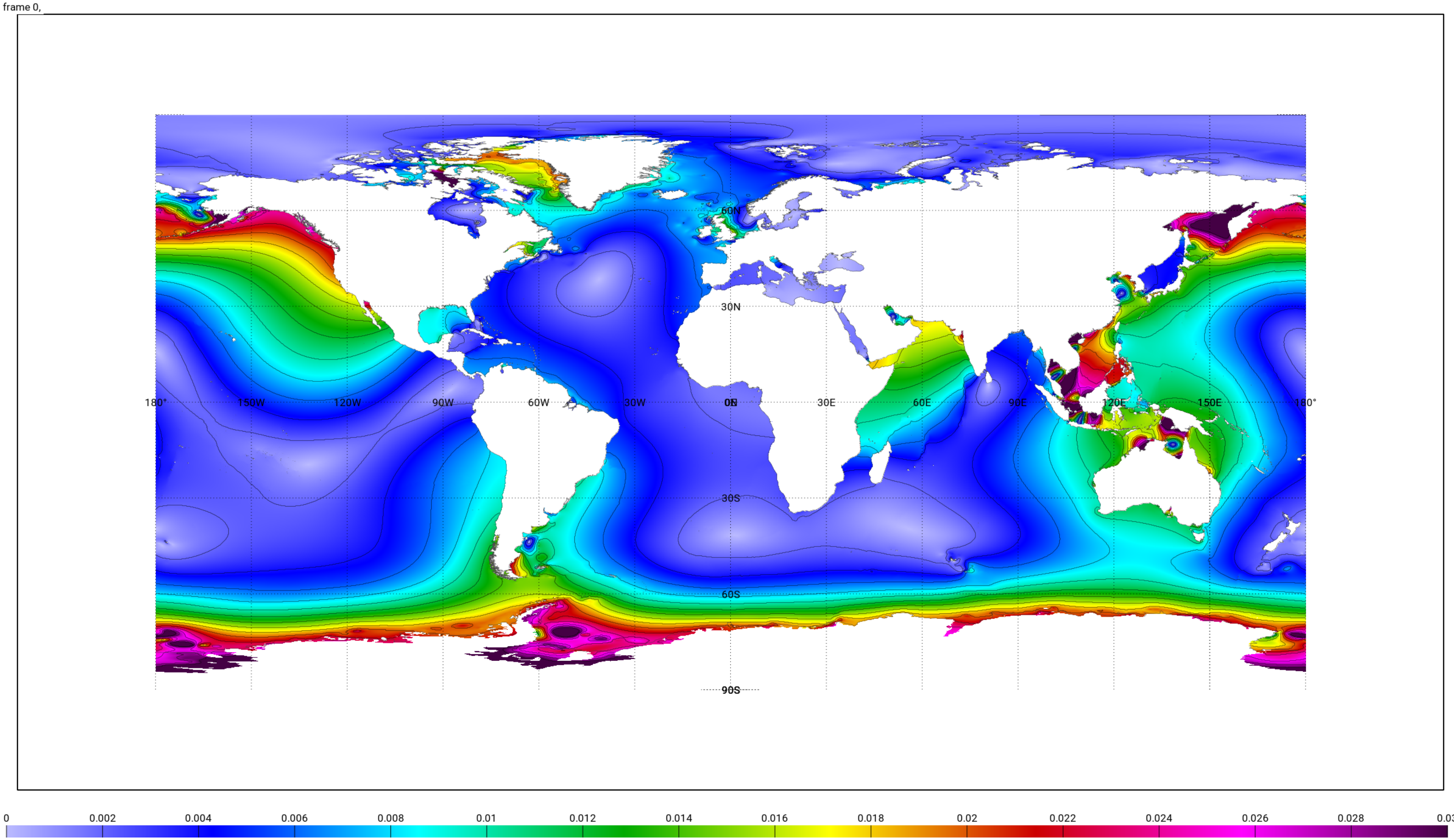
S2 tide: without atmospheric loading/self-attraction



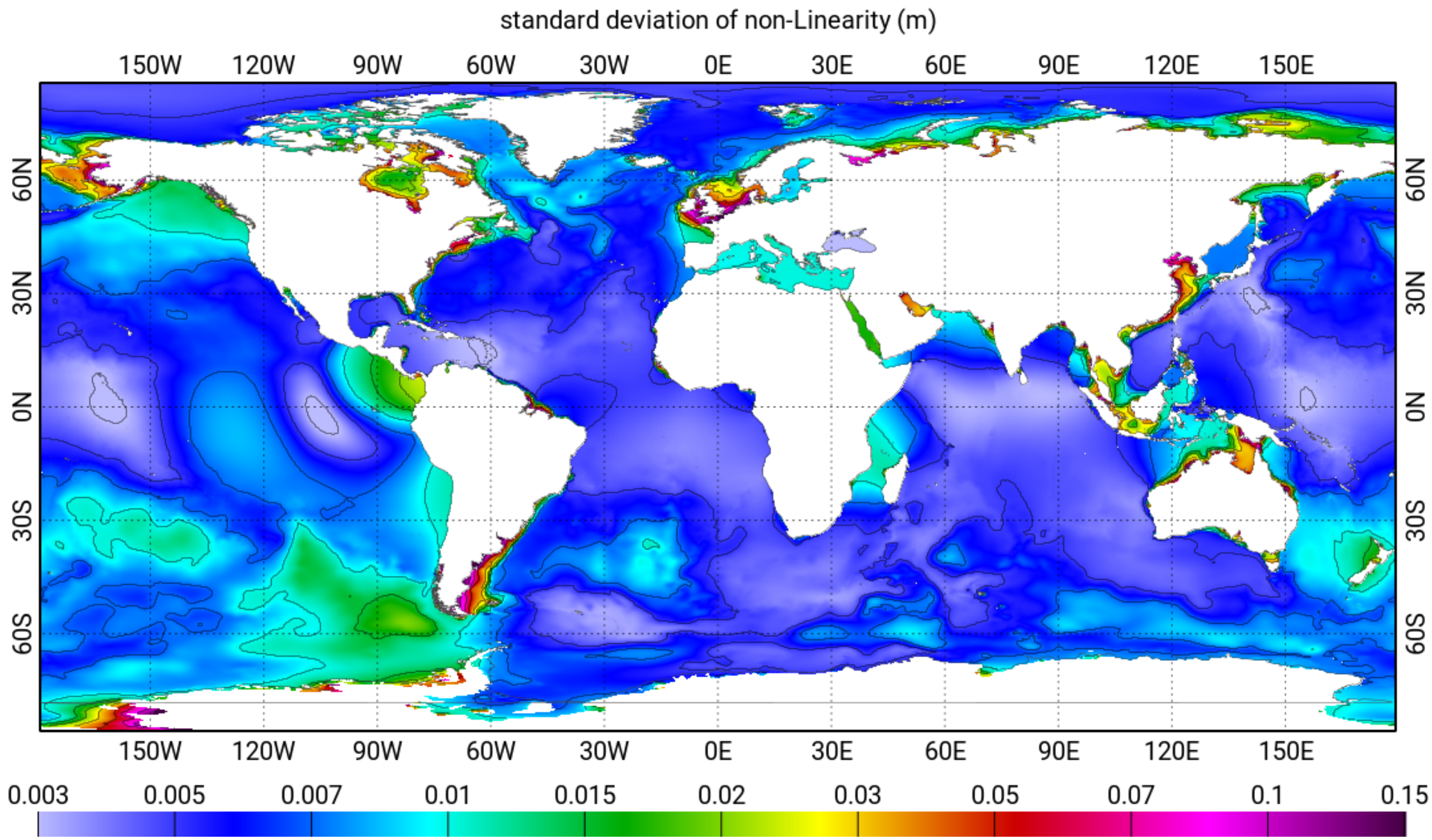
S2 tide: with atmospheric loading/self-attraction



K_1 tide: impact of frequency-dependent Love numbers (in astronomical potential)



Storm surge operational configuration upgrade (SALP, GRACE,etc…)



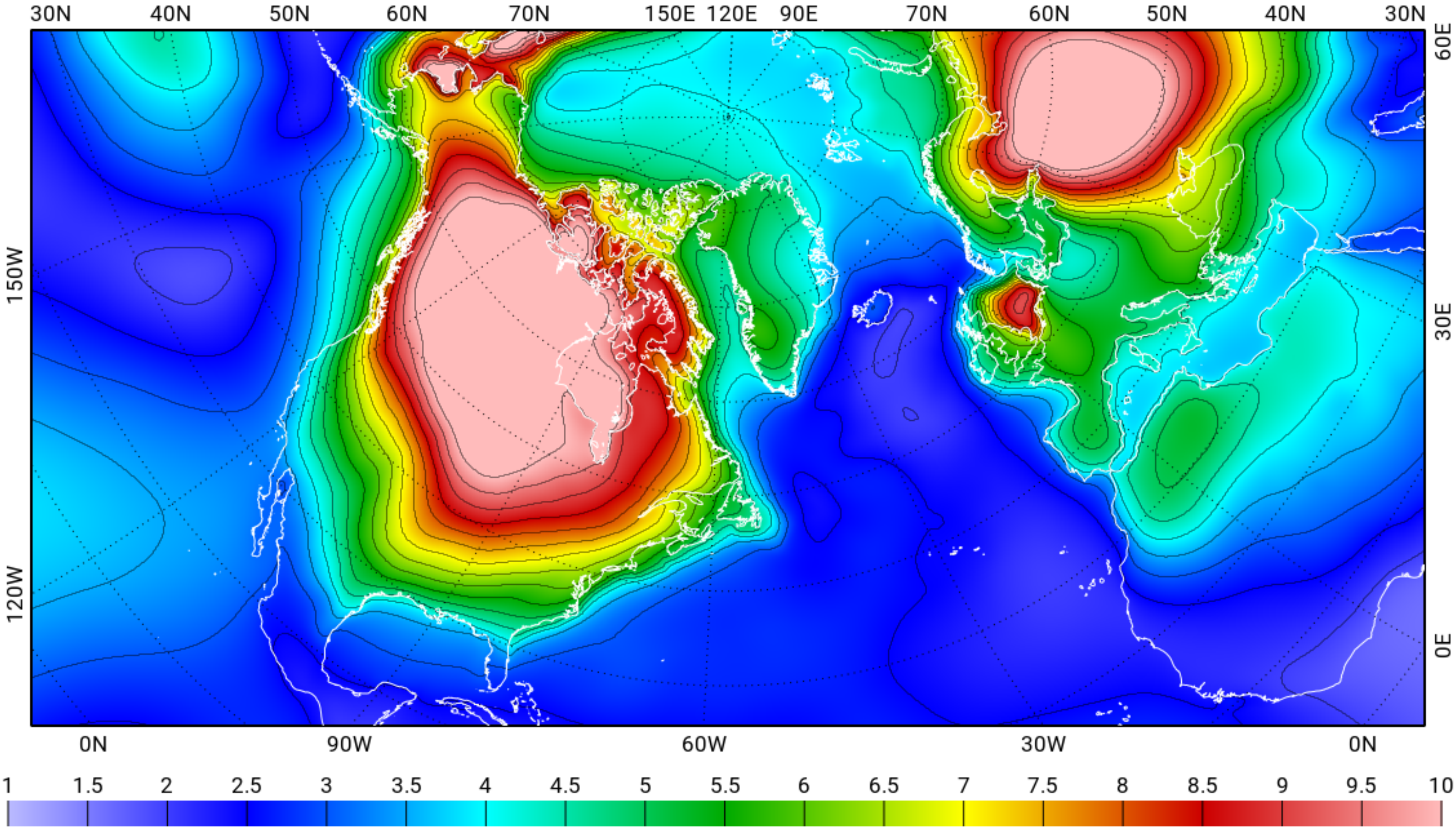
- Forcing
  - ERA, ECMWF OP, LWDA, etc..
  - Bulk, WW3 stress
- Grid configuration
  - Bathymetry
  - Resolution
  - MPI performances
- Dynamics
  - Tidal non-linearities
  - Loading/self-attraction
- Validation against
  - tide gauges
  - altimetry residuals

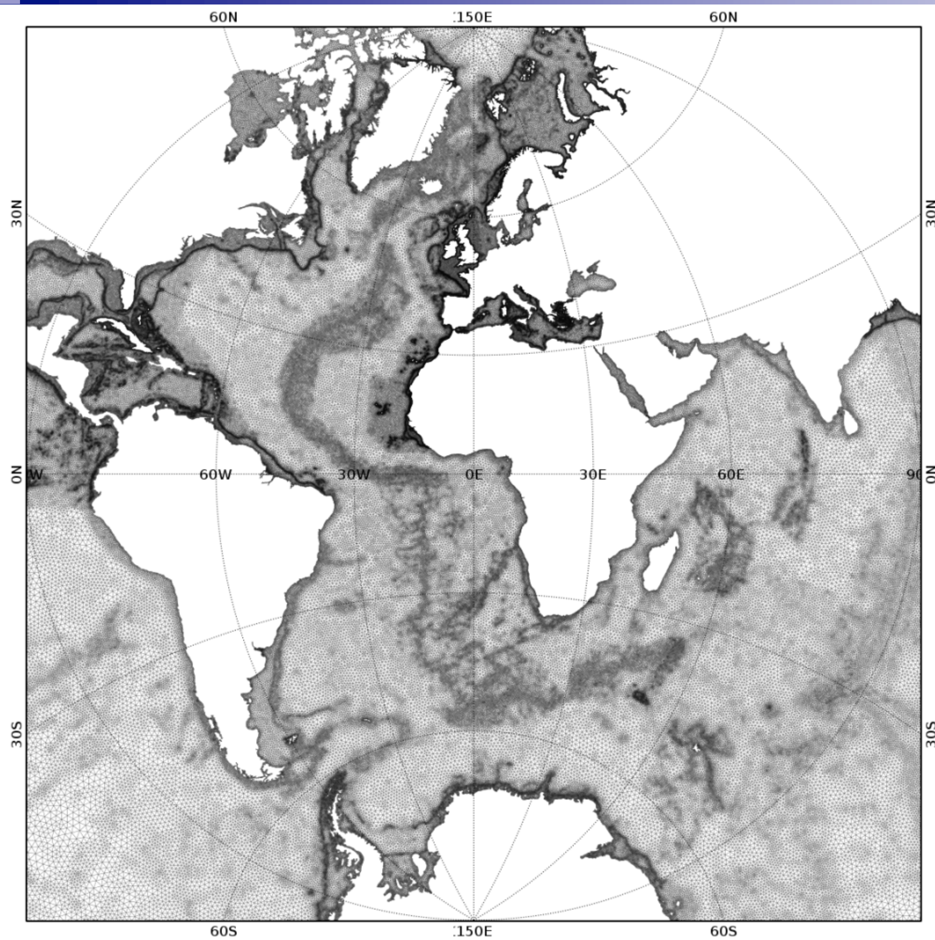
Storm surges validation against tide gauge observations (GLOSS and coastals) residual variance (mm) after TG time series correction (2 years duration)

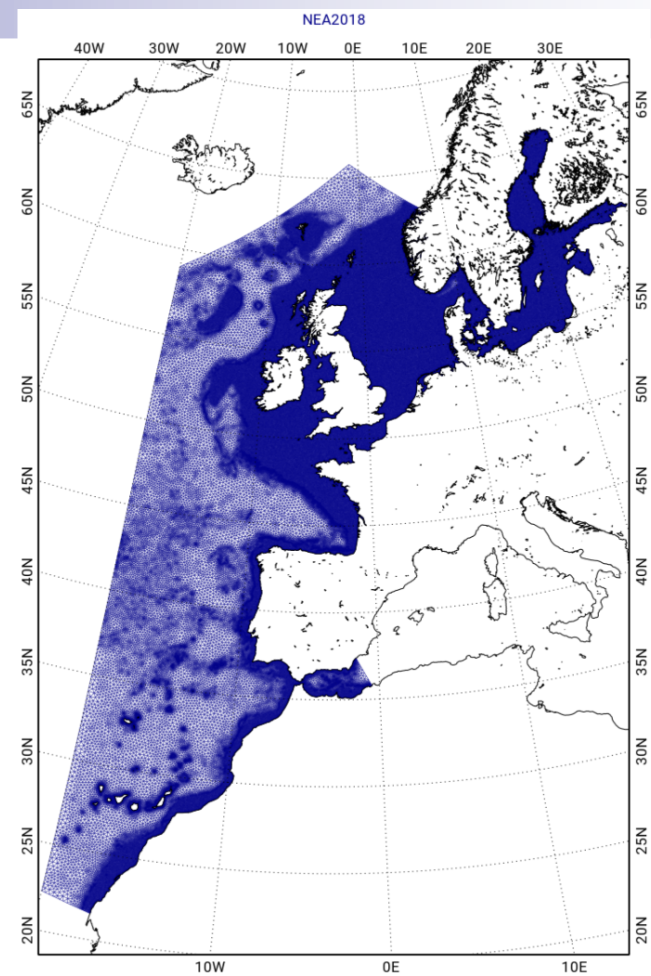
GLOSS global data set	0-∞	0-20j	0.5-20j	60j-∞	30j-60j	10j-30j	5j-10j	0.5j-5j	0-0.5j
no correction	111.4	82.9	76.2	49.2	24.5	38.8	26.8	47.7	23.4
High resolution + ERA5	86.1	44.4	31.2	67.8	12.6	16.6	9.6	21.6	26.3
High resolution grid + LWDA	85.9	42.9	31.0	68.5	12.6	16.6	9.5	21.5	23.9
Medium resolution + ERA5	85.6	45.1	31.7	66.6	12.7	16.6	9.7	22.2	25.8
TP/Jason operational system	88.4	47.8	36.8	61.9	18.4	21.5	10.8	26.2	23.2
Medium resolution + ERA5 + tides	88.7	46.3	33.7	69.1	13.3	18.0	10.7	23.0	25.7

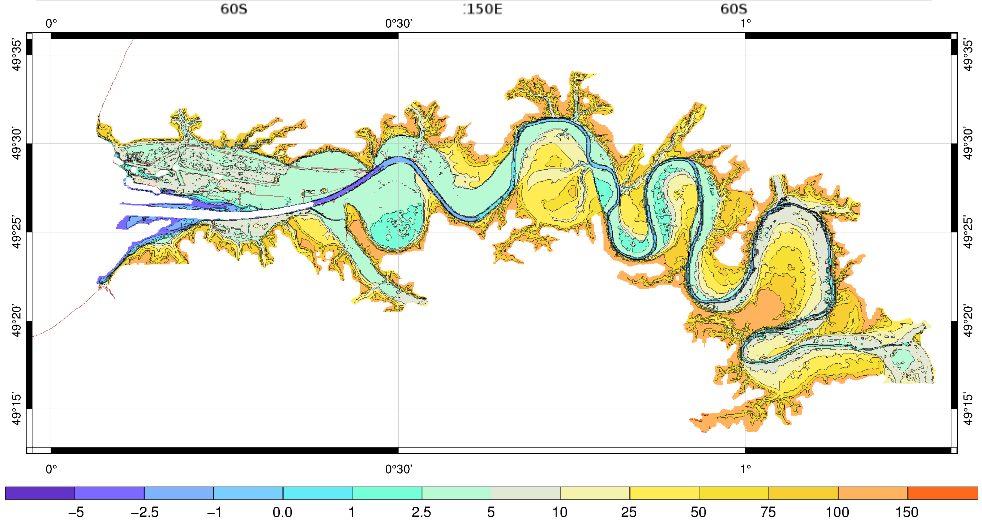
North Sea coastal data set	0-∞	0-20j	0.5-20j	60j-∞	30j-60j	10j-30j	5j-10j	0.5j-5j	0-0.5j
no correction	240.2	206.0	188.9	60.0	45.4	81.1	57.7	143.7	56.9
High resolution + EA	123.2	106.0	80.3	52.5	14.5	27.6	23.7	65.4	55.7
High resolution + LWDA	123.6	106.7	81.2	51.4	15.0	28.5	23.9	65.9	55.9
Medium resolution + ERA5	119.5	102.3	75.2	51.4	14.7	26.7	22.6	60.3	56.3
TP/Jason operational system	148.7	104.6	78.6	71.5	33.4	39.2	23.6	60.3	55.6
Medium resolution + ERA5 + tides	102.9	85.6	62.0	48.2	13.1	23.4	18.9	49.1	47.9

standard deviation of LSA HR+EI_AN 2014/01 (mm)









3 levels of corrections to consider:

Global
Shelf/coastal
Near-shore/estuaries

Try to get only 2

summary

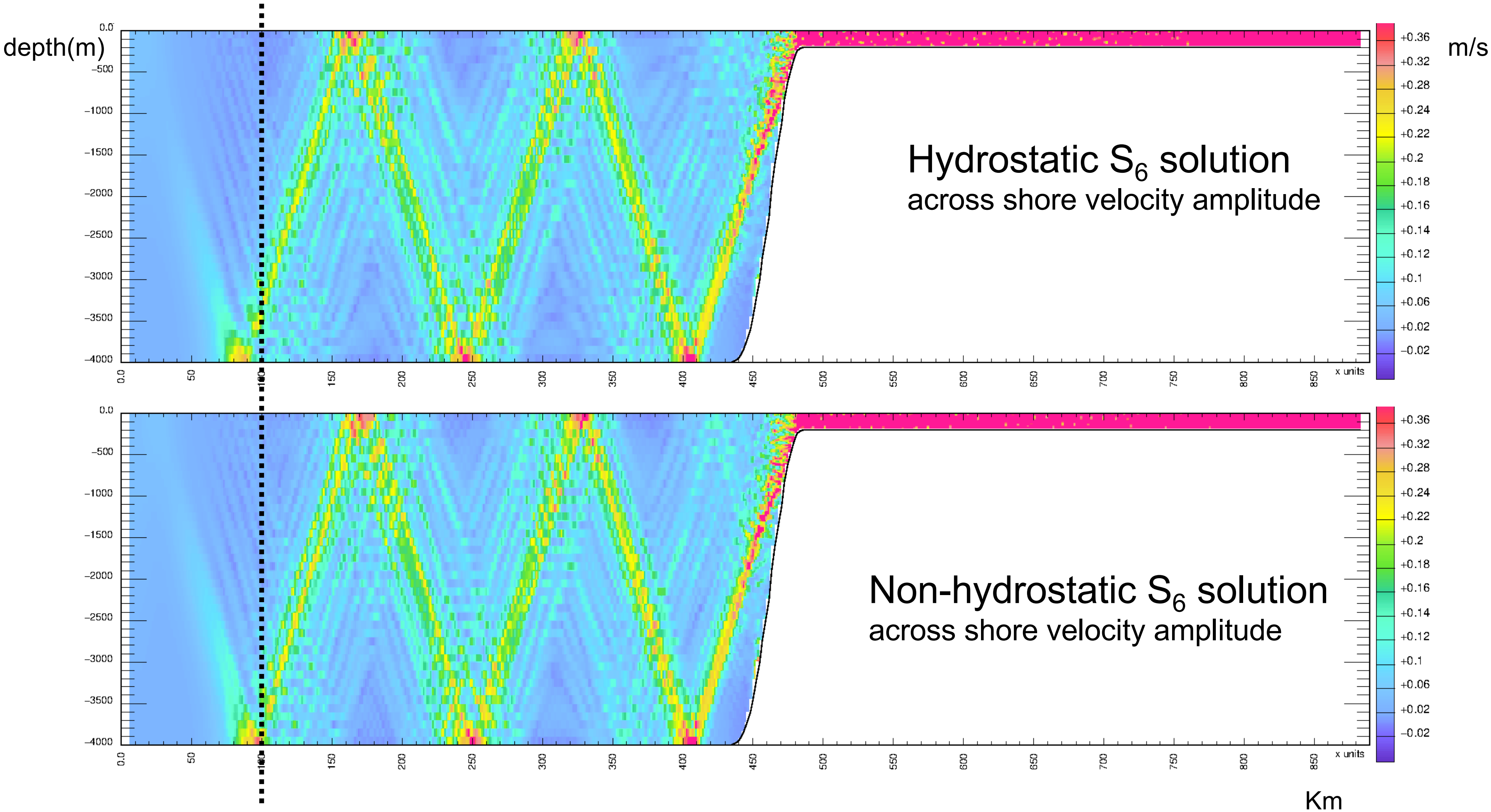
SWOT mission barotropic tidal corrections task will be highly demanding

- Efforts on barotropic modelling/data assimilation to be continued
  - needs to put more focus on regional improvements
  - usually neglected sources of error are being revisited
  - Bathymetry still THE serial killer
  - Assimilation data processing/editing still to be improved (including barotropic/baroclinic separation, consistent loading in data treatment AND model)
  - estuaries/near shore configuration to be implemented in some dedicated sites, with data assimilation, strong collaboration between groups required
  - no certainties yet on the level of accuracy that will be possible in shallow water/high latitude

- Present plans
  - New FES atlas to be started
  - 1 or 2 km resolution at shorelines, 5km on shelves, 15 km elsewhere
  - Suitable for providing boundary conditions to near-shore/estuarine models
  - Renewed stom surges operational correction

Non-hydrostatic, 3D frequency-domain solver (T-UGOm)

> NH propagational effect proportional to squared frequency
> to investigate energy transfer from internal tides to internal waves (higher frequencies, solitons?) through non-linear processes



Status of Tide Modeling for SWOT

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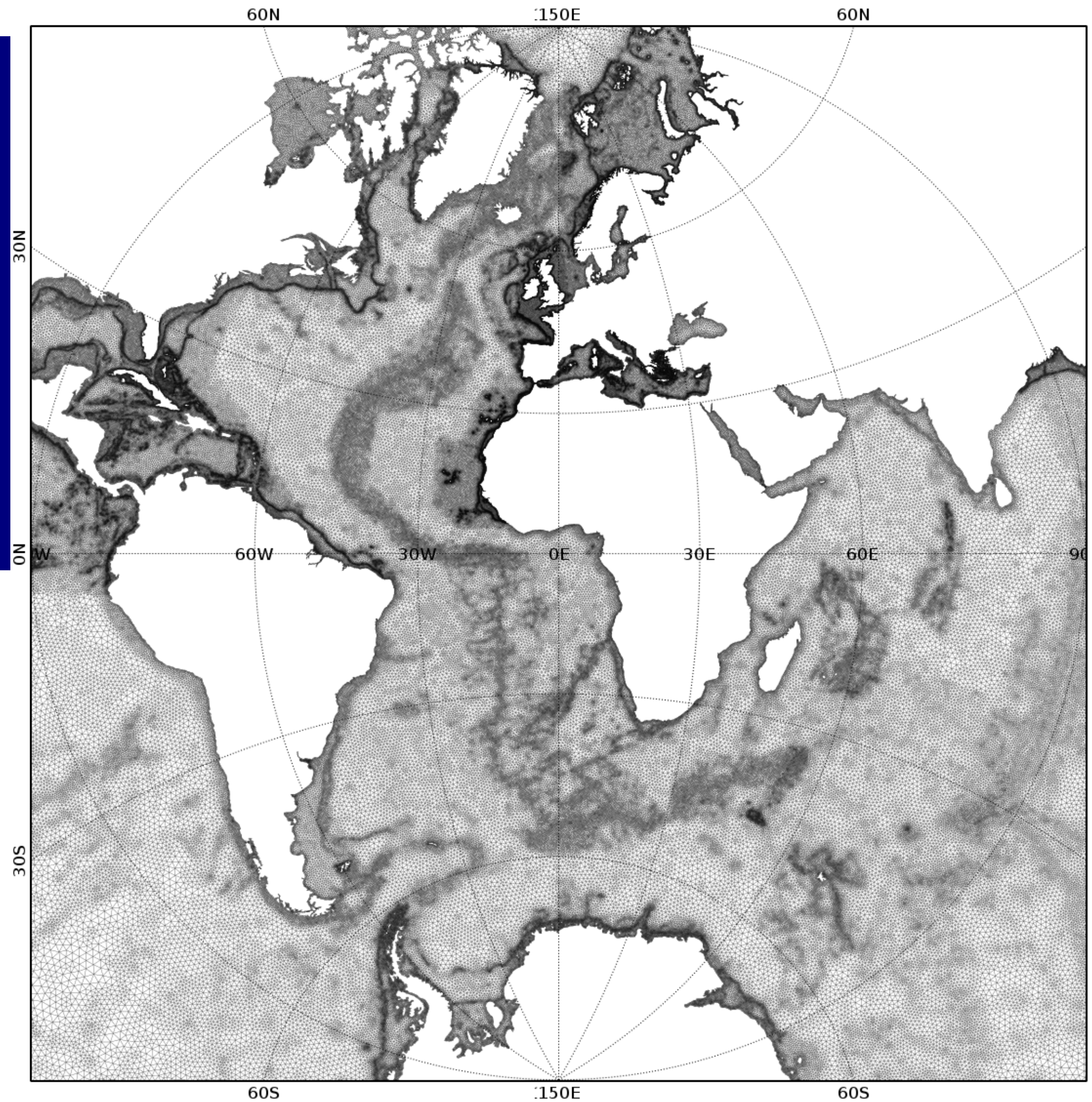
LEGOS

Richard Ray
NASA Goddard Space Flight Center

Special thanks to: Loren Carrère and Ed Zaron

SWOT Science Team Meeting, Montreal June 2018

Barotropic tides : state of the art/some insights for the SWOT mission



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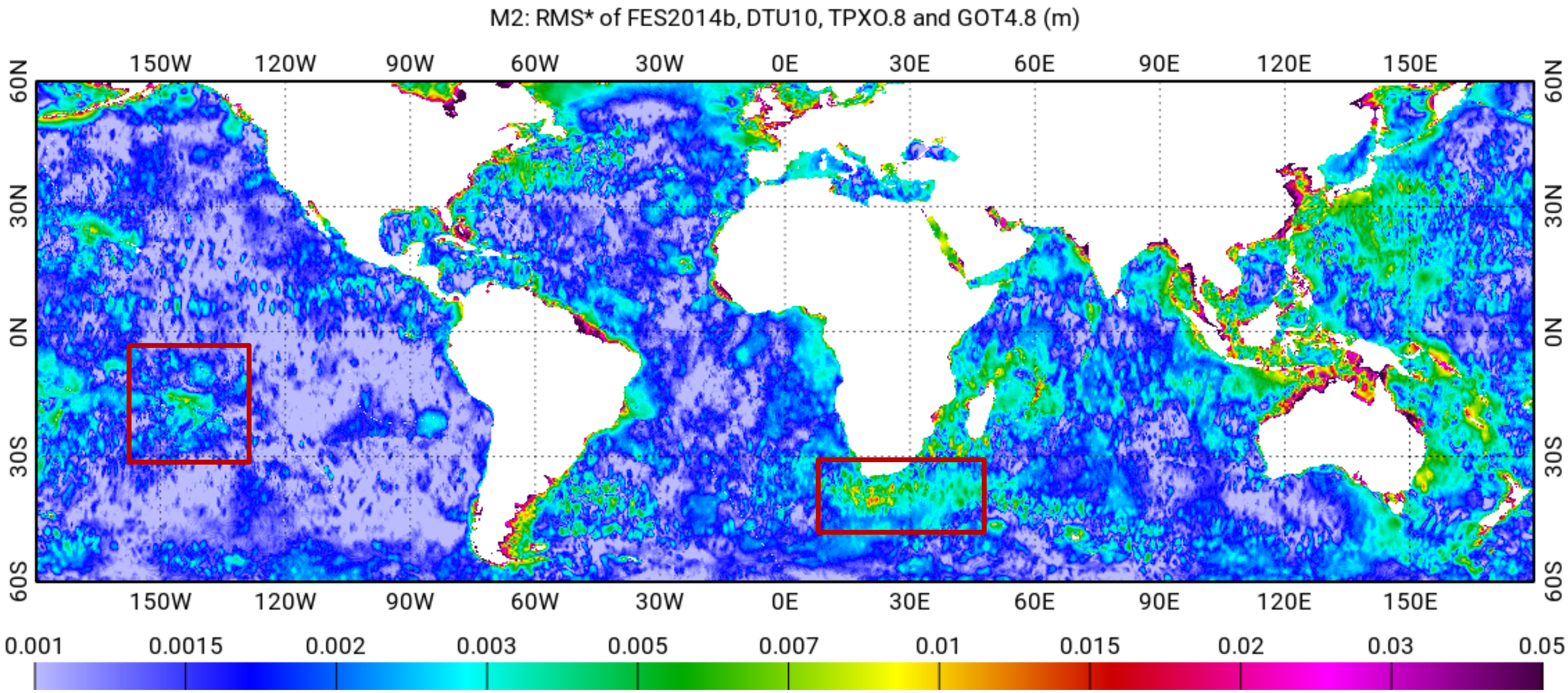
Barotropic tides (and storm surges)

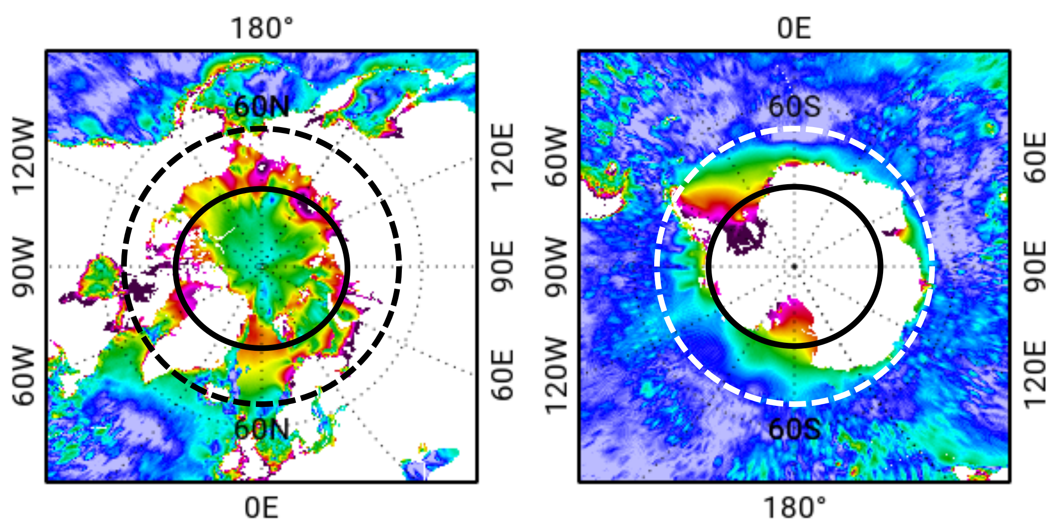
- Present state (nadir altimetry purposes)
  - Deep ocean (primary objective): harmonic atlases, well-defined spectrum
  - Coastal seas (experimental) :harmonic atlases, limited spectrum (omission errors)

- Harmonic atlases
  - Hydrodynamic + data assimilation
    - Hydrodynamic (prior) solution accuracy critical
    - Data assimilation:
      - Sober (use the minimal dataset)
      - Massive
  - Empirical:
    - Based on pre-existing atlases (adjustment)
    - More or less massive data use

- Storm surges
  - Hindcast (time integrated) simulations
  - Accuracy dependent upon:
    - Bathymetry, resolution,.. (as much as the tides)
    - Atmospheric model accuracy, resolution (space and time), wind stress paramerisation
  - No data assimilation so far

Barotropic models RMS

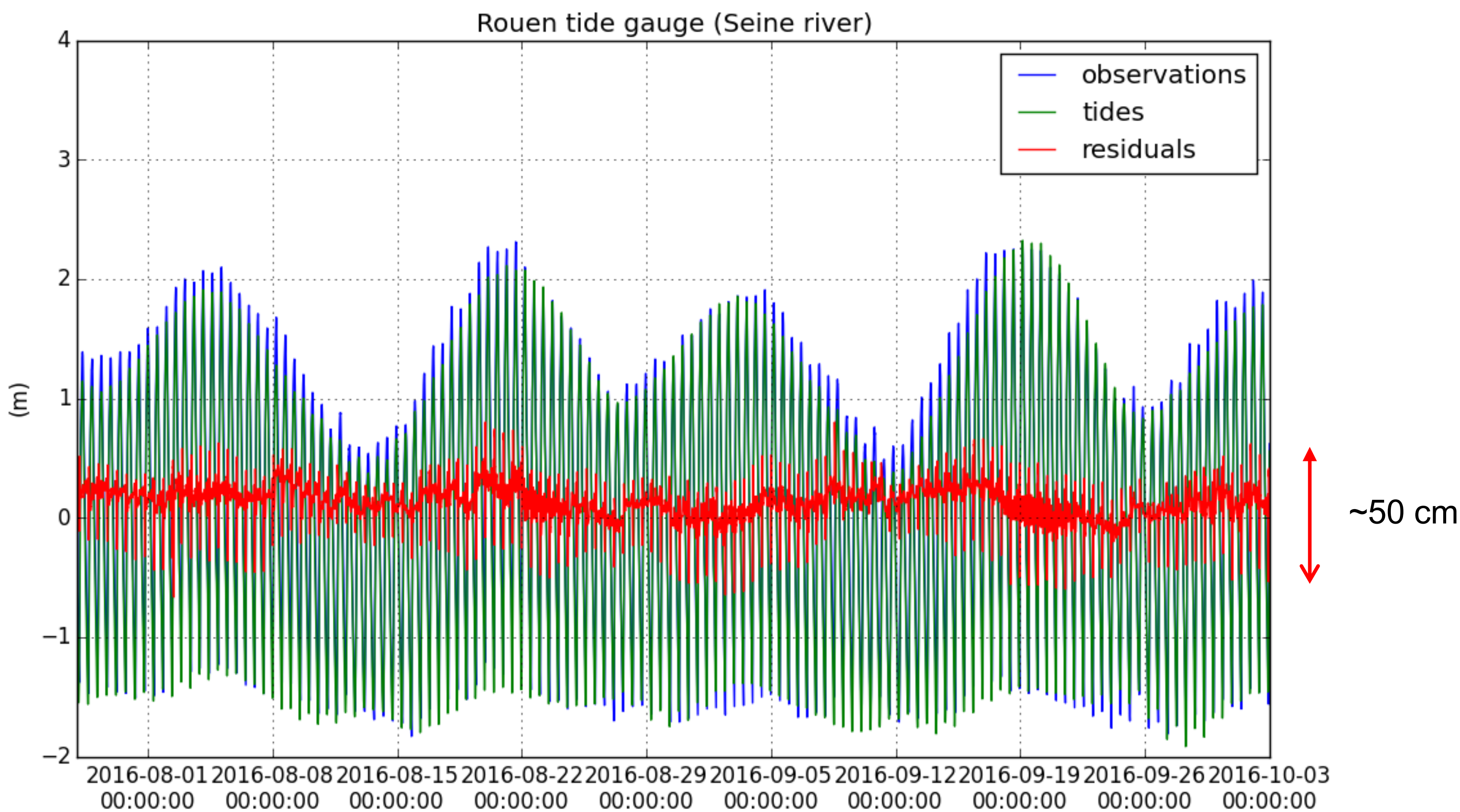




- TP/Jason coverage, deep ocean
  - Models are converged
  - Except in ocean circulation
  - and IT generation regions?
- Shelf/coastal seas
- Polar seas

Tidal anomalies in estuaries

> deficient harmonic method to analyze/predict tides
> low tides not modified in spring/neap cycle
> tide modulation by river discharge fluctuations (increase of tidal residual)

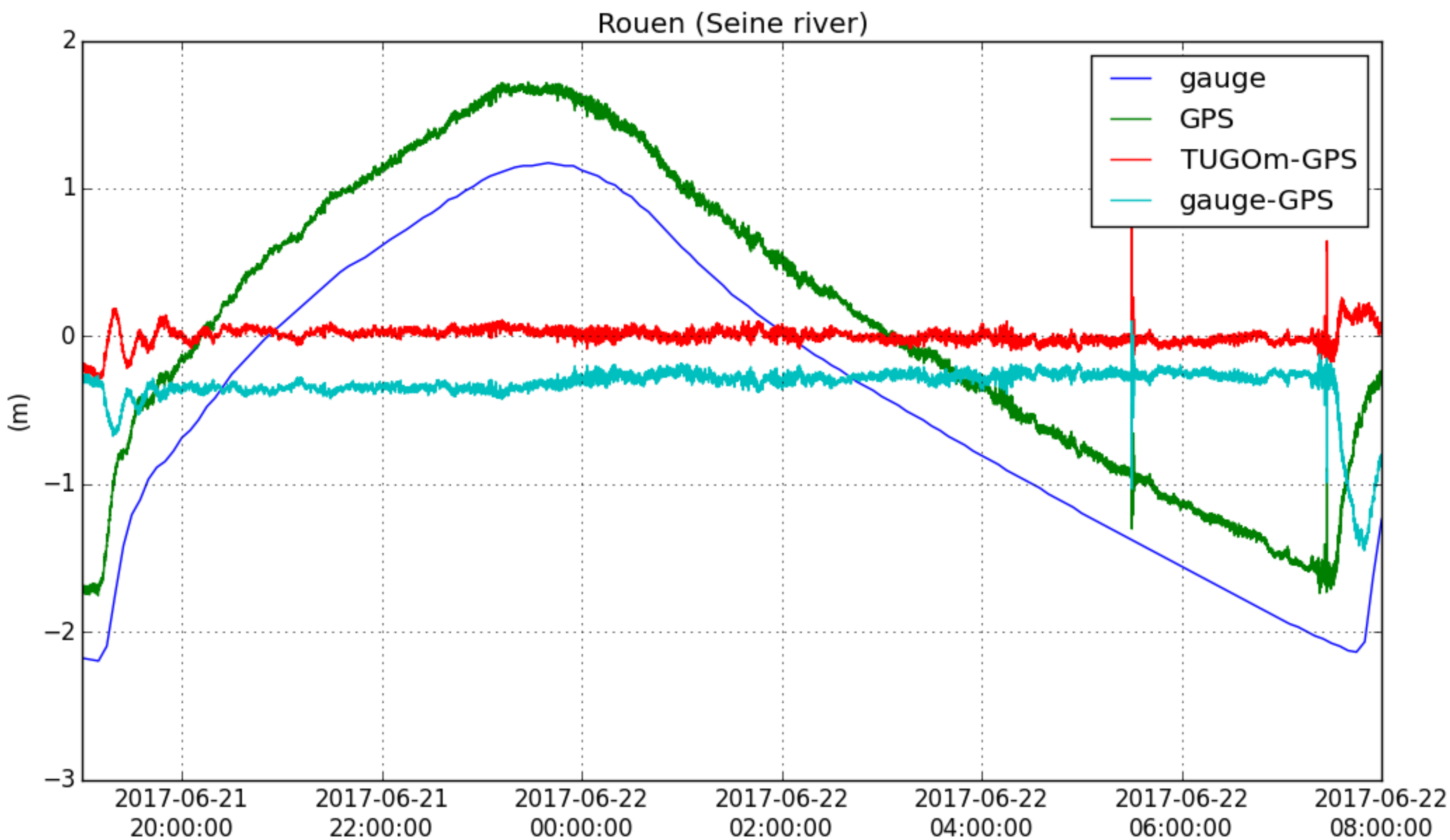


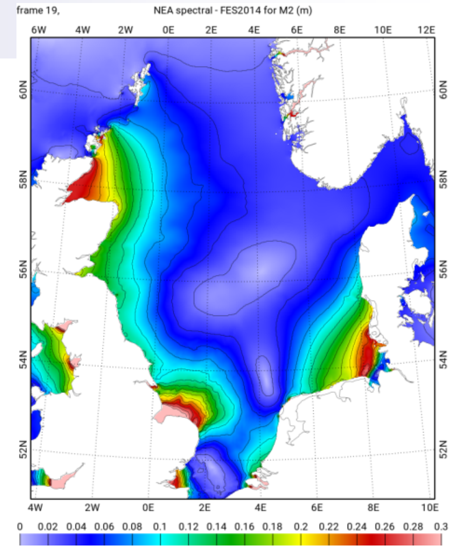
Tidal modelling accuracy in estuaries

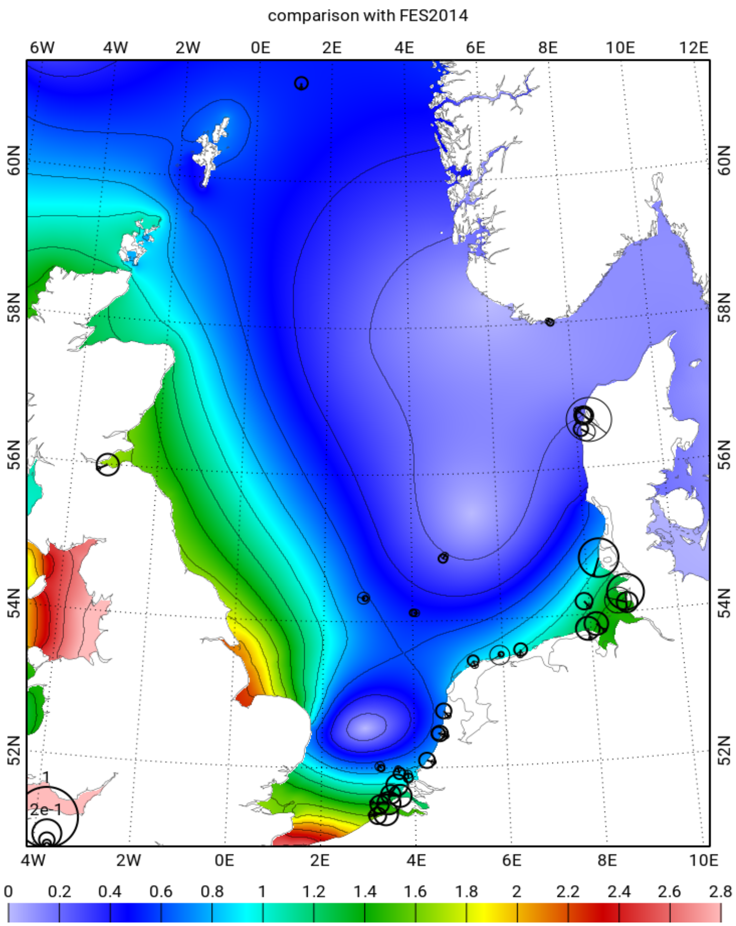
> rapid change of level at ebb/flood transition

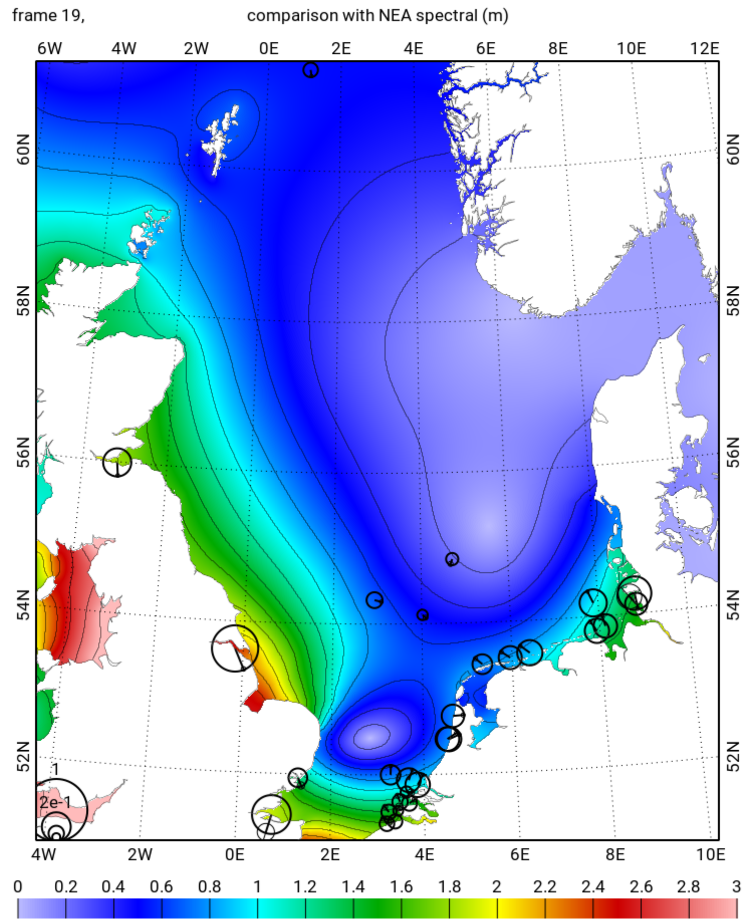
> needs data assimilation (tide gauges)

> with 1 mn time sampling (local resonance oscillation not captured at 5 mn sampling)




frame 19,
NEA spectral - FES2014 for M2 (m)


comparison with FES2014


frame 19,
comparison with NEA spectral (m)