Deltares
Enabling Delta Life

Effect of coastal resolution on global estimates of tidal energy dissipation

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20 september 2017

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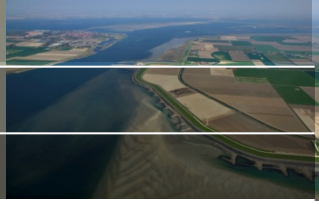

- The GTSMv2.0 model
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- Coastal resolution – Are tidal dynamics represented with 5km?
  - Further refinement globally
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- Conclusions
- Future work

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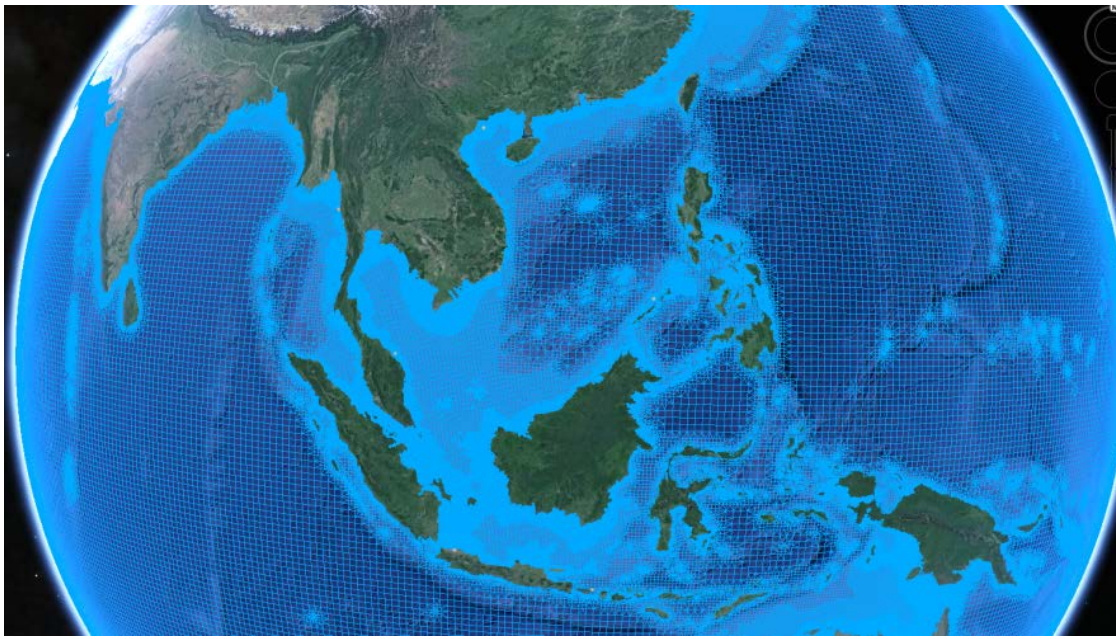
The GTSMv2.0 model

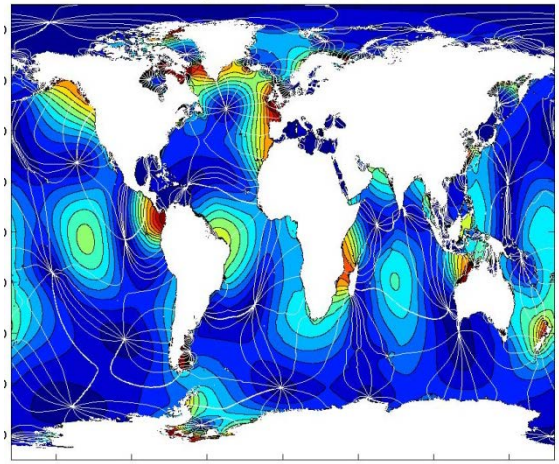
Global Tide Surge Model:

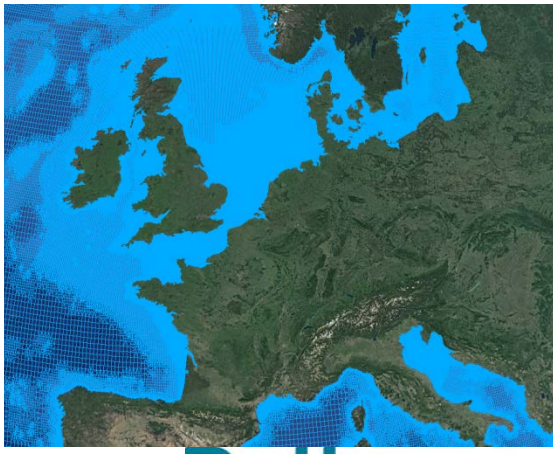
- 2D barotropic model
- Unstructured global grid: 50 km deep waters, 5km at the coast (~4M nodes)
- GEBCO 2014 bathymetry (~1km)
- TGF driven, no assimilation

Runtimes in 8 cores
~1hour/week



- Tidal Validation/Verification:
  - ~20cm for coastal stations (UHSLC)
  - ~ 7 cm in deep waters (FES2012)
- Surge Validation: *A global reanalysis of storm surges and extreme sea levels*(Muis et al. 2016)





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The GTSMv2.0 model - Major developments

Self Attraction and Loading effect

- Reduction of errors in tidal representation of ~50 % in coastal stations and ~60% in deep waters

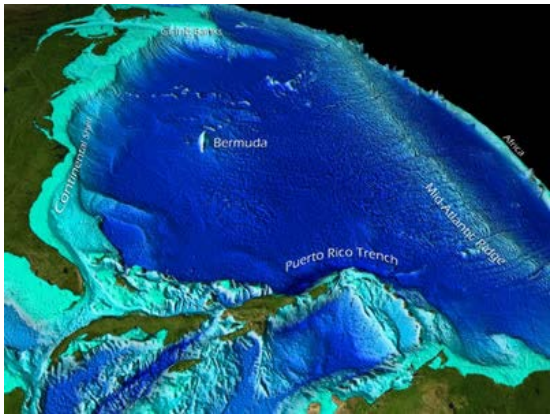
$$\frac{\partial \mathbf{u}}{\partial t} + \frac{1}{h}\left(\nabla \cdot (h\mathbf{u}\mathbf{u}) - \mathbf{u}\nabla \cdot (h\mathbf{u})\right) = -g\nabla\left(\xi - \xi_{EQ}\right) + \Phi_{SAL} + \nabla \cdot \left(\nu\left(\nabla\mathbf{u} + \nabla\mathbf{u}^T\right)\right) + \frac{\tau}{h}$$

- Minimal increase of computational time (<3%)

Barotropic tidal energy dissipation through generation of internal tides

- Dominant in **deep waters** (1TW out of 3.5TW) $\tau_{IT} = C\rho\kappa^{-1}N(\nabla h \cdot u)\nabla h$
- Dissipation =f (Stratification, **bathymetry gradient**, cross-slope flow)

- ➢ Mid-ocean ridges and trenches (e.g. Mid-Atlantic Ridge)
- ➢ Continental shelves (e.g. Bay of Biscay)
- ➢ Island chains (e.g. Hawaiian Ridge)



Both physical processes are key to obtain good tidal propagation results

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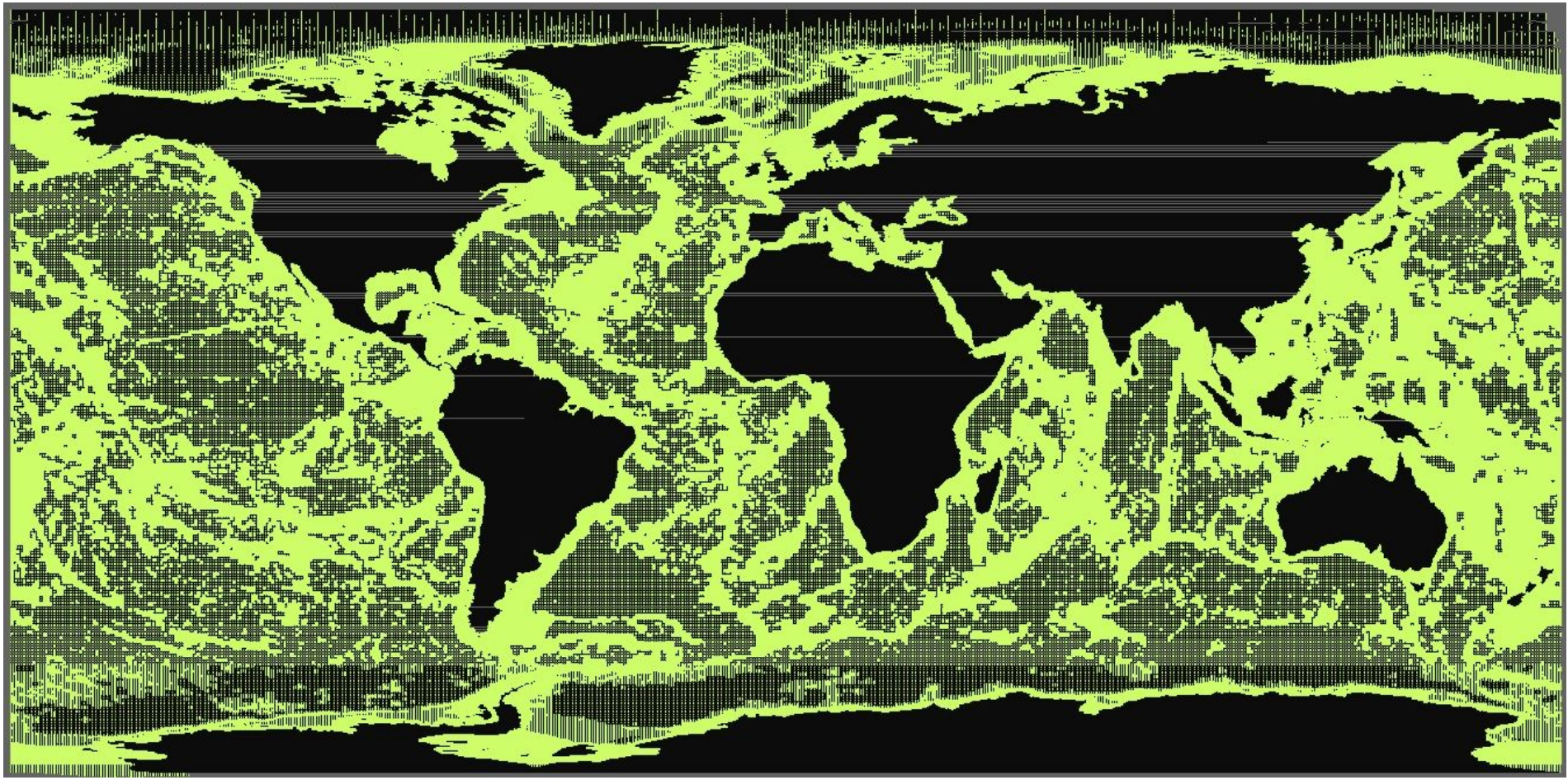
Grid

Bathymetry gradient based refinement:



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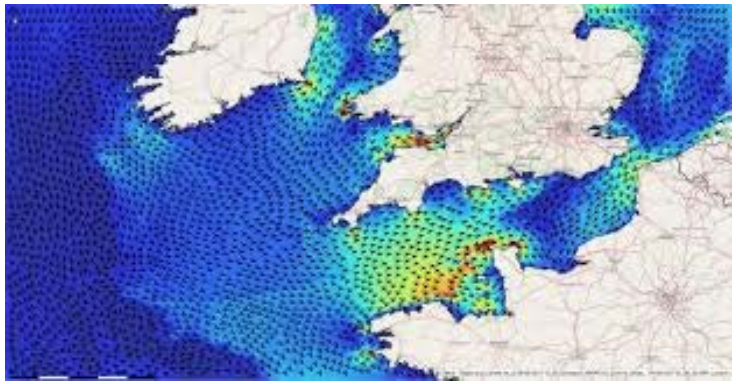
The GTSMv2.0 model - Applications

- Widely used for research (e.g. TC induced surge, global reanalysis of extreme sea levels)
- Bathymetry/Geodesy (e.g. altimeter data reduction, vertical reference planes/geoid)
- Boundary conditions for regional models/ Ready-to-go regional models
- Surface currents – Prediction tool for the Dutch team in the Volvo Ocean Race



- Climate change studies using climate models (e.g. EC-Earth)
- Operational forecasting - **GLOSSIS**

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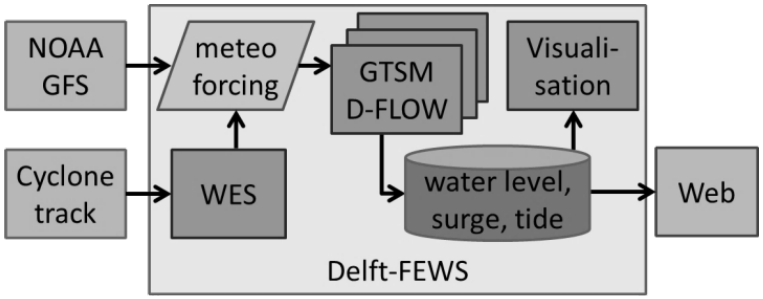
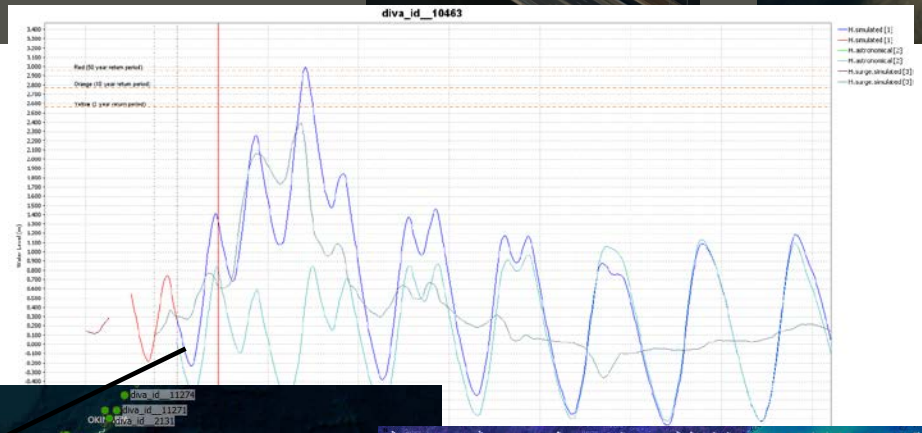
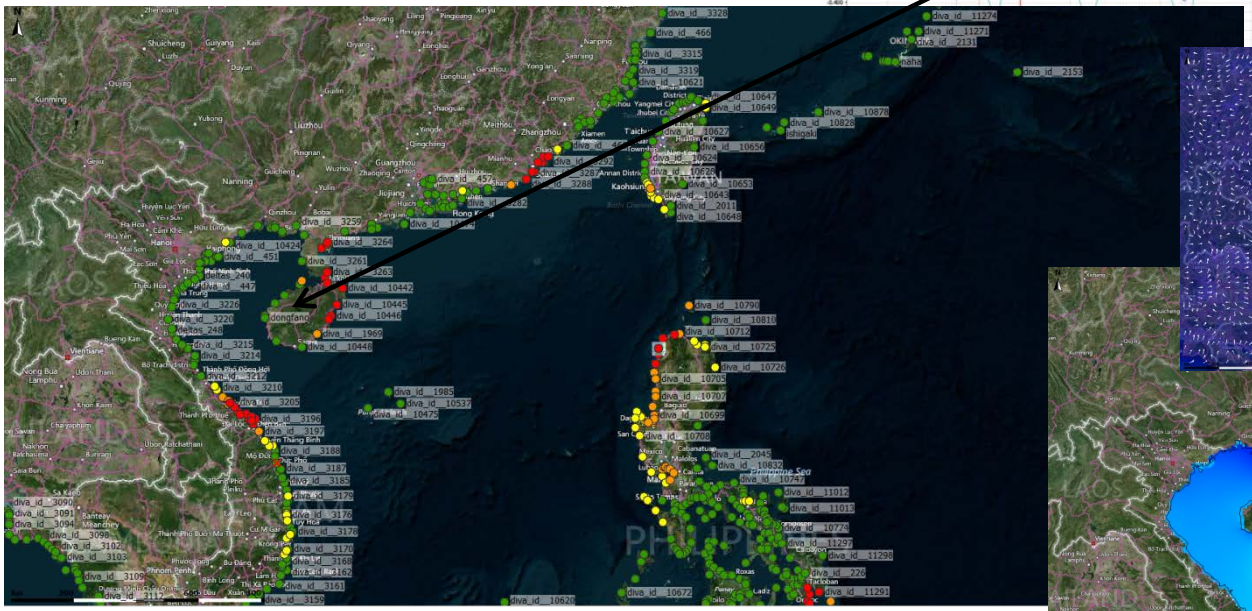
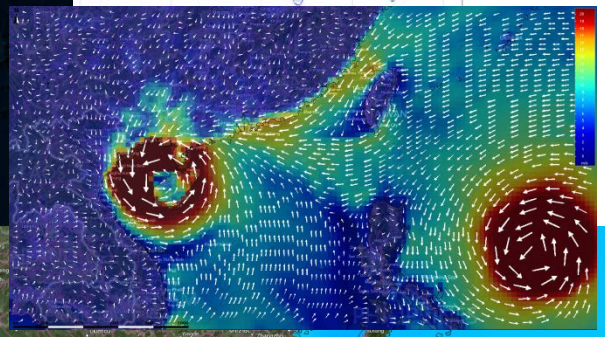
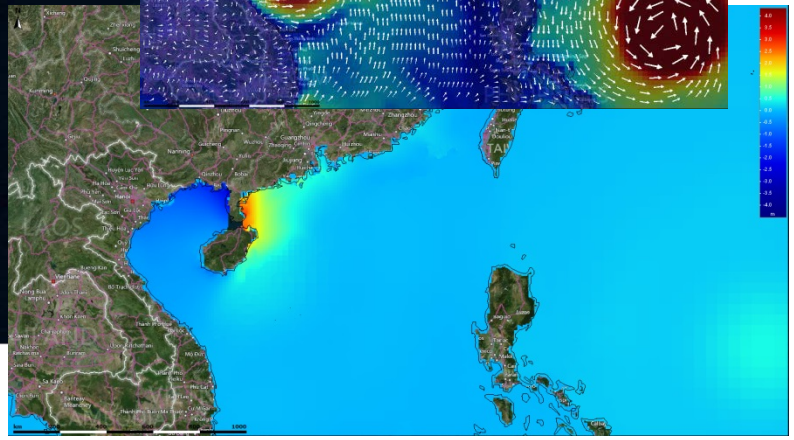
GLOSSIS – SARIKA (Oct 2016)











- 4 times a day, 10 day forecast
- NOAA GFS (3h time-step, 10 day forecast)
- 16000 DIVA segments, near real-time IOC and satellite data
- Threshold defined based on return periods for high-water

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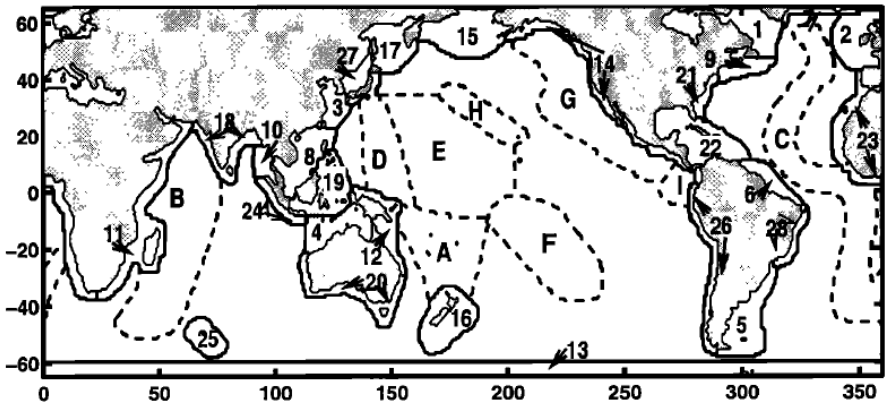
Today: Coastal resolution study

Coastal resolution – Are tidal dynamics represented with 5km grid size?

- Highest resolution in existing Global Tide Models is 6-7km
- Propagation speed depends on bathymetry
- Dissipation through bottom friction (shallow waters) influences amphidromic point locations

Experiments

- Higher coastal resolution: 2.5km and 1.25km worldwide (**9M nodes!**)
- Local to remote impacts: 0.6 and 0.3km in Australia (**10.5M nodes..!**)
- Look at sensitivity in terms of tidal dissipation: defined areas around the globe (Egbert and Ray, 2001) + above $\pm 66°$ lat estimates



- Bottom friction dissipation: 1-29 coastal areas (plus high latitudes = 31 areas)
- Internal tides “dissipation”: A-I deep ocean areas (note: quite large areas)

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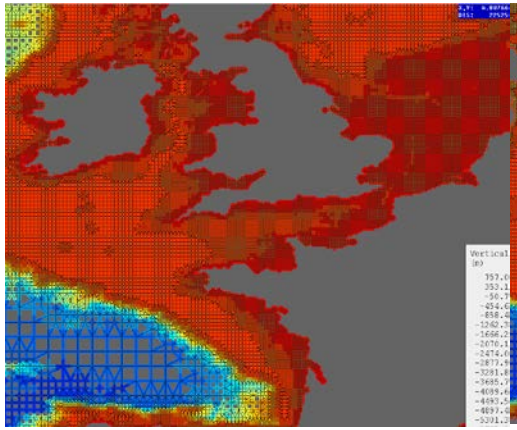
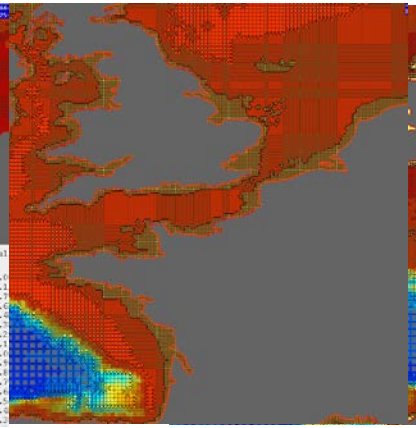
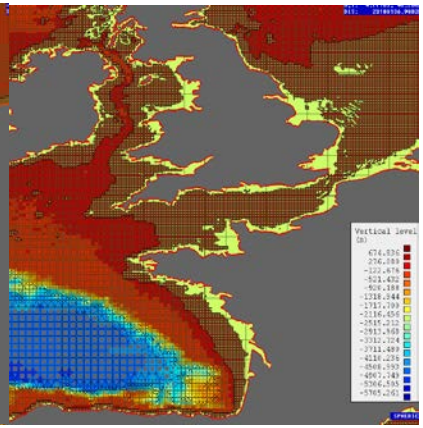
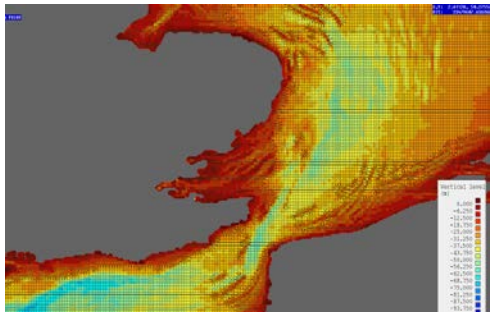
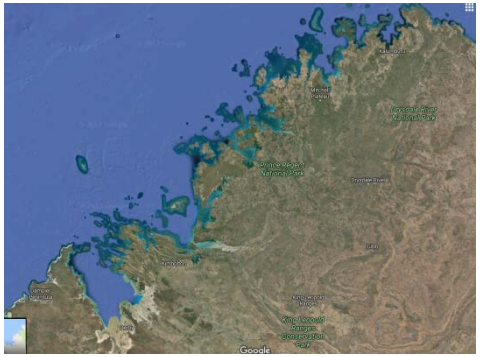
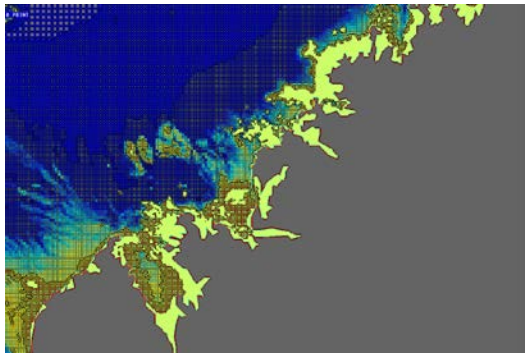
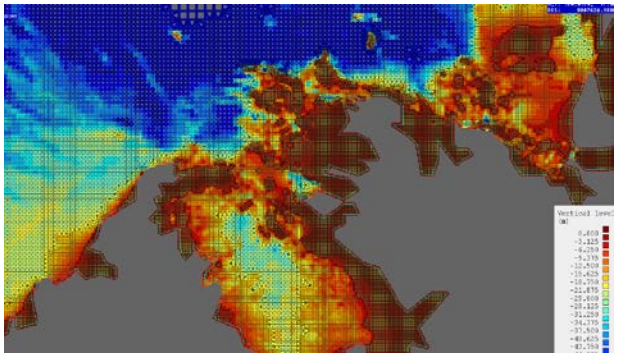
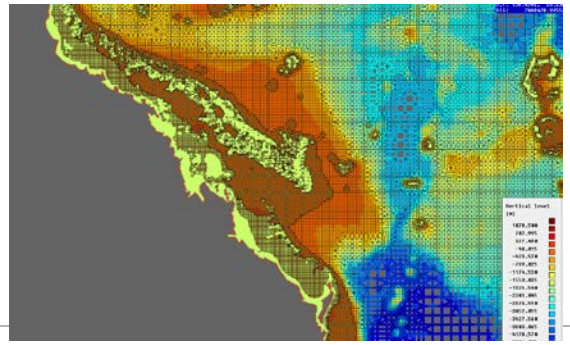
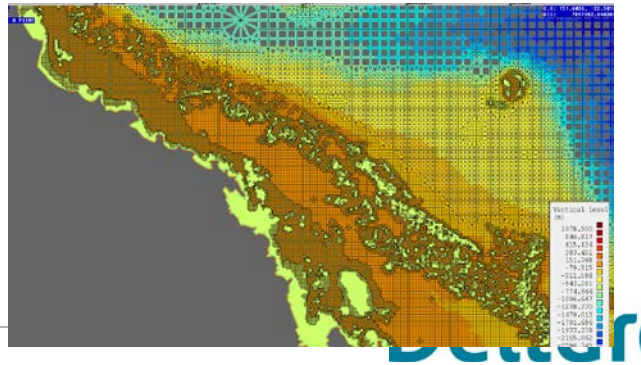
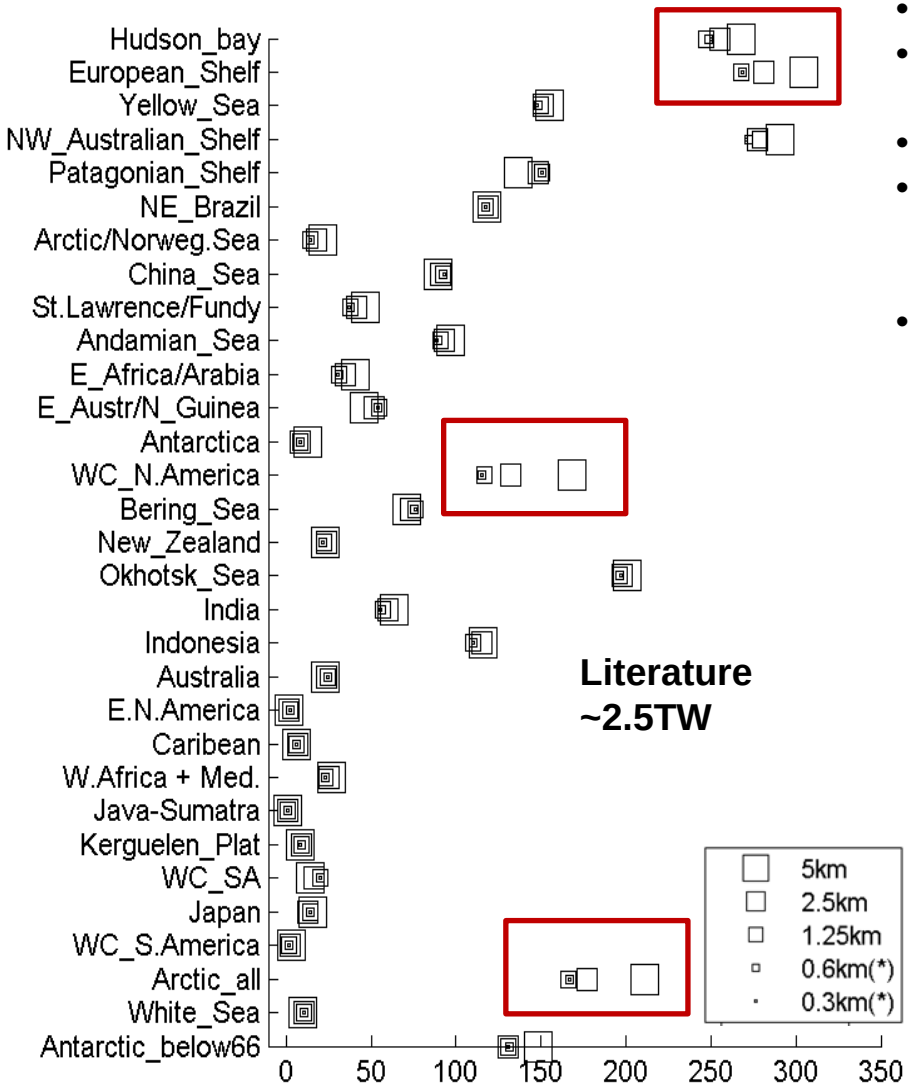
Increased grid resolution

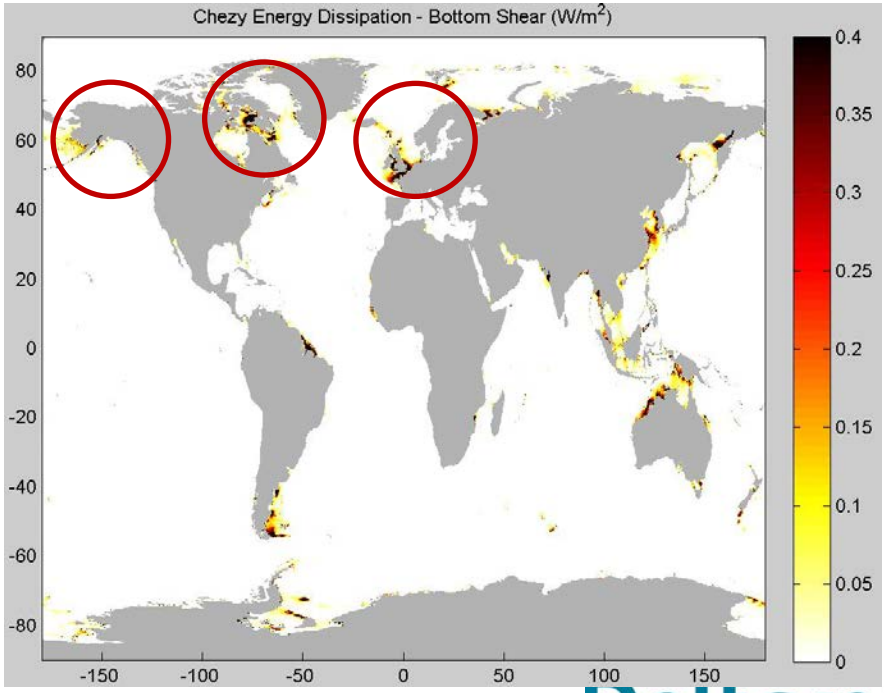








Results – Bottom friction dissipation areas

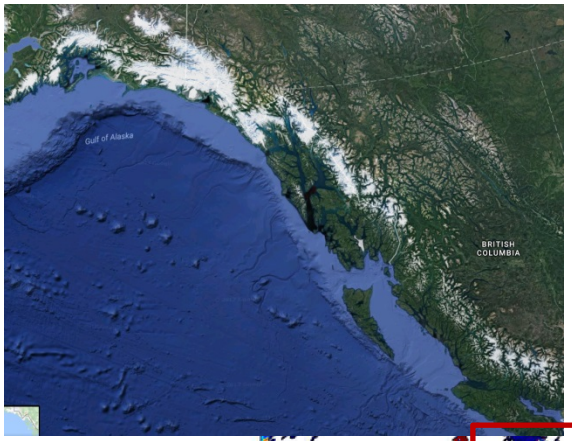


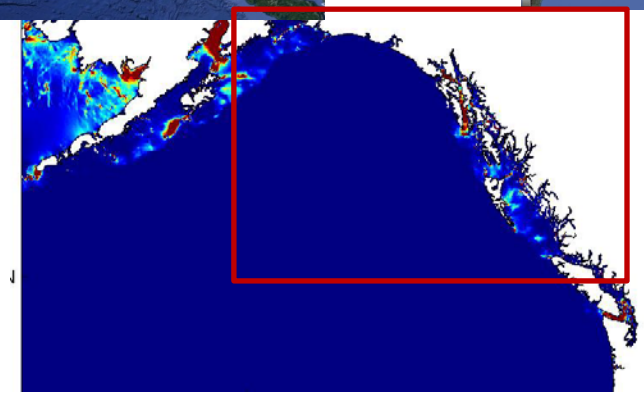
- Total 1.25km = 99% of 2.55TW
- Big differences from **5km to 2.5km** in many places and globally (2.76 to 2.55TW).
- 1.25km shows differences locally (2.6 to 2.55TW)
- 0.6km and 0.3km coastal resolutions in Australia show no meaningful impact globally or locally (boring! but relieving)
- Polar latitude areas non-negligible (~7%)

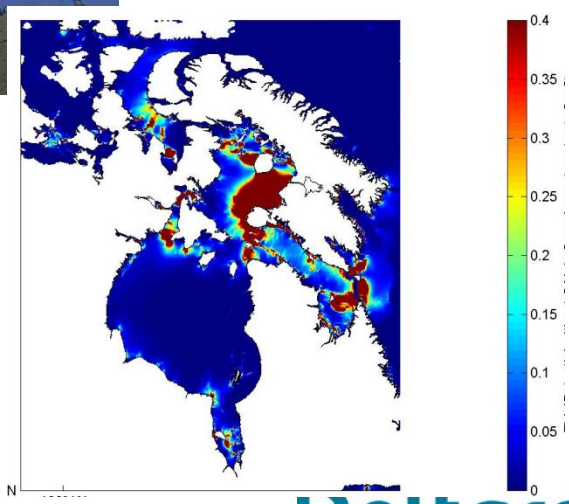


Results – Bottom friction dissipation areas

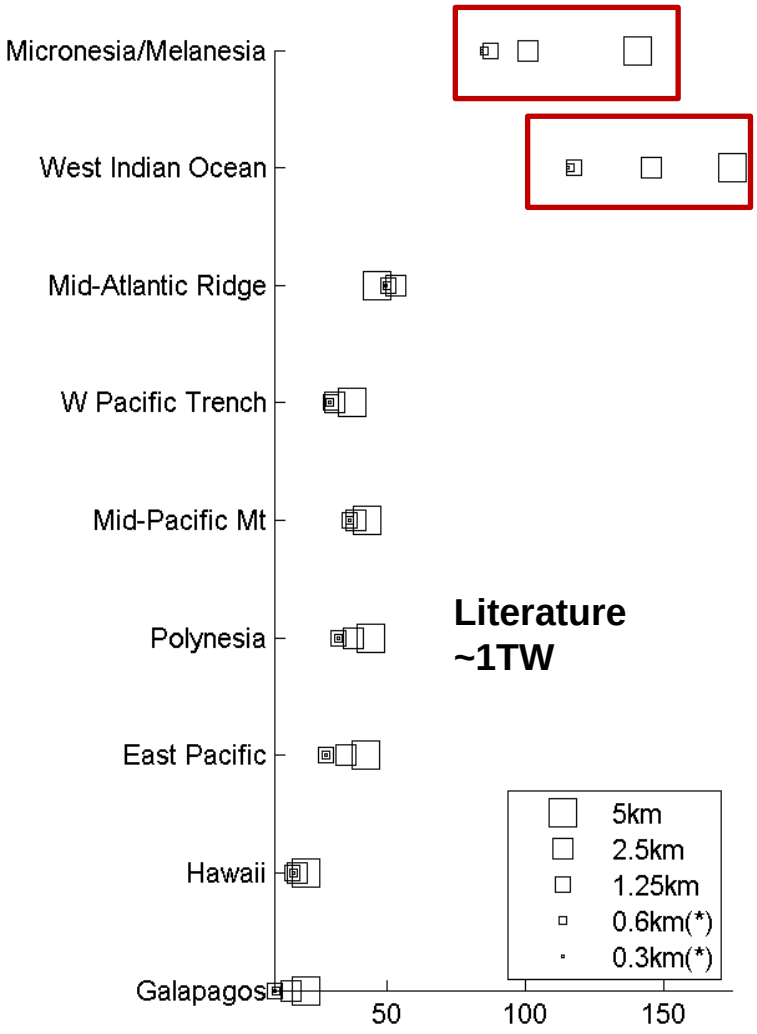
- West Coast North America, Hudson Bay, European Shelf, Arctic…Common features?
  - High latitudes, connection to Arctic
  - Narrow passages and connections potentially affected by resolution
  - Indirect effect of non-converged internal tides “dissipation” areas: Explore more in detail.



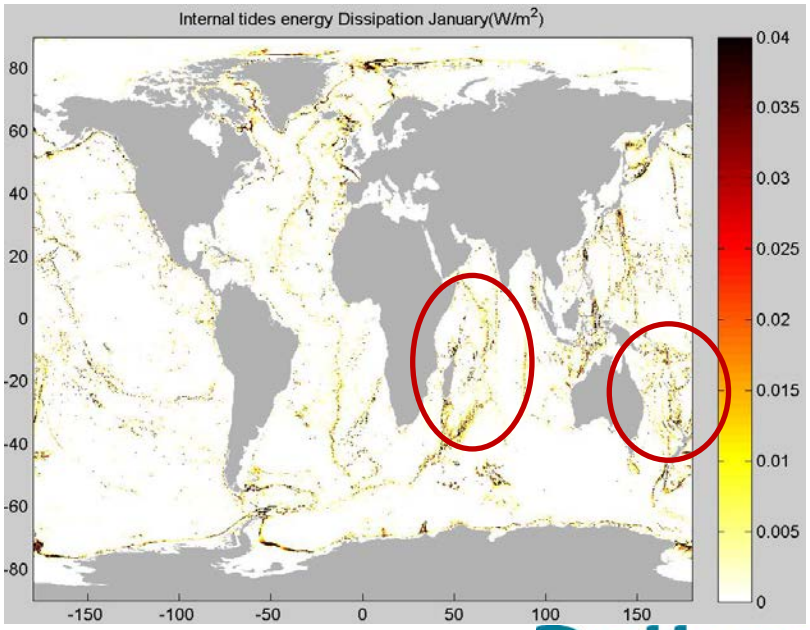




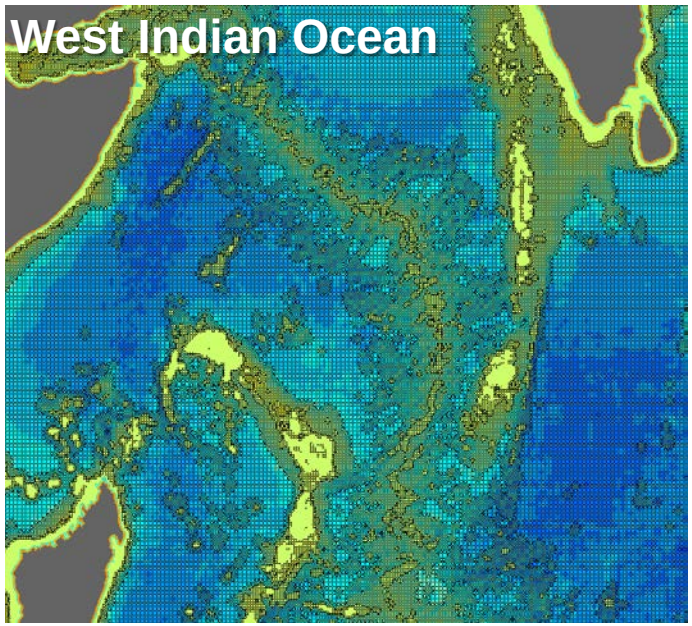
Results – Internal tides “dissipation”

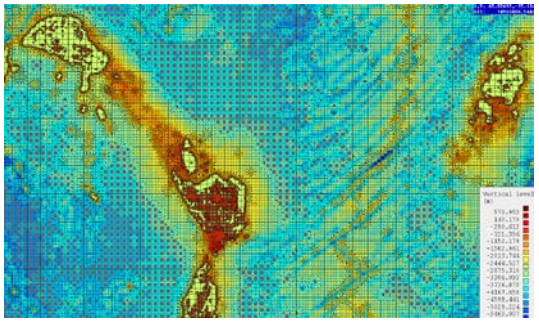


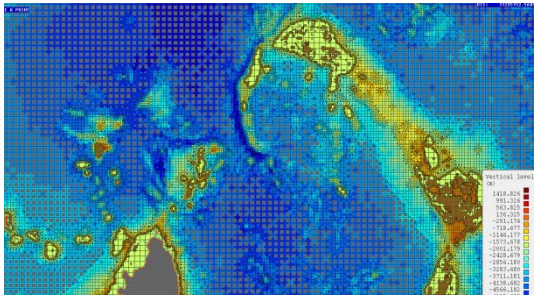
- Total 1.25km = 41% of 1TW – Missing half of the dissipation of the domain, difficult to identify sources
- Big differences from **<u>5km through to 1.25km</u>** in the two main areas and globally (1.52 to 1TW).
- 0.6km and 0.3km coastal resolutions in Australia show no meaningful impact again (no higher resolution in deeper parts)
- Non-converged areas: Several island chains affected by the “coastal” resolution increase.

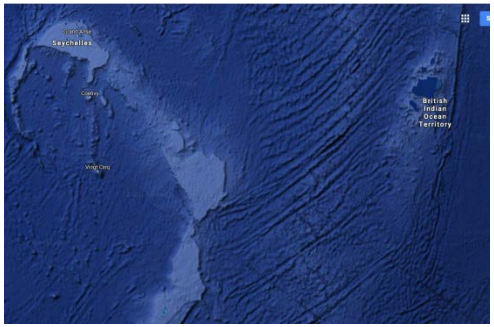


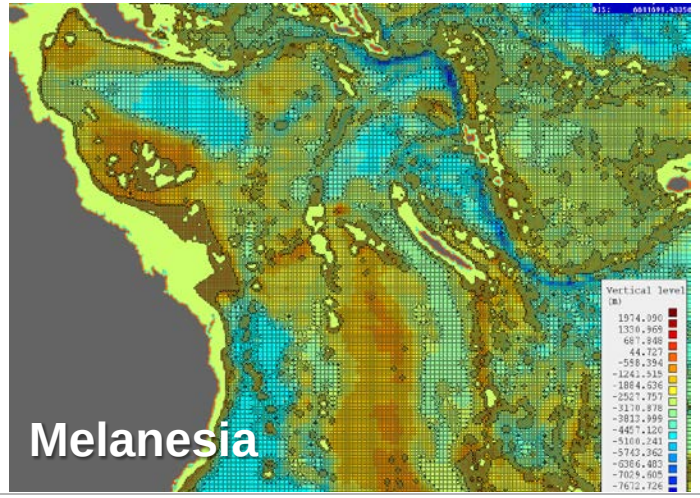
Results – Internal tides “dissipation”

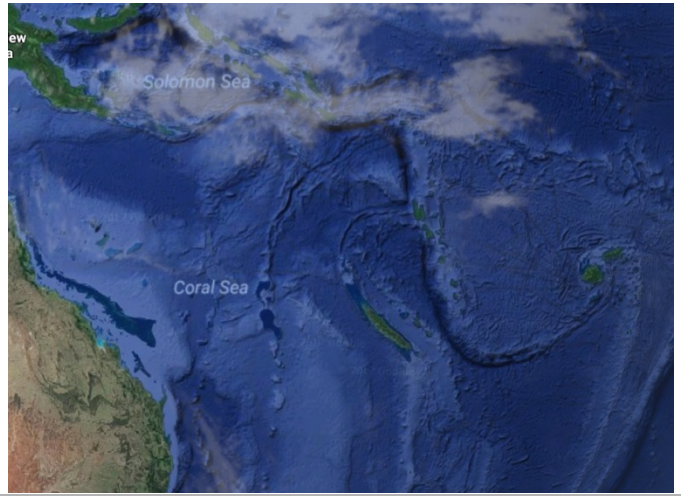












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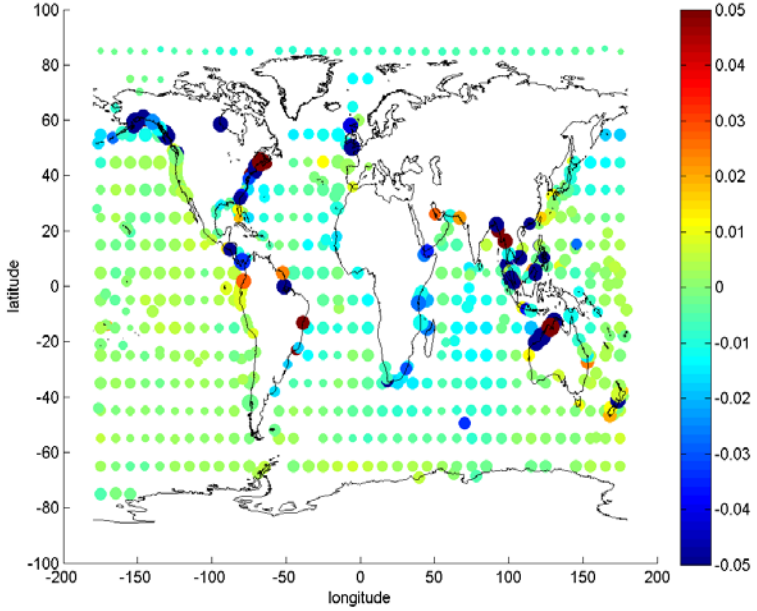
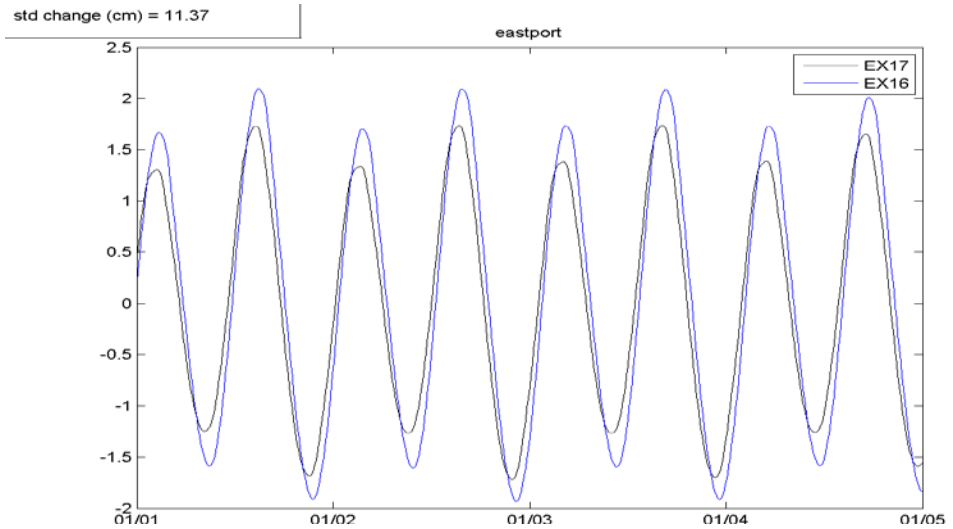
Results – Impact on WL representation

Resolution	BF dissipation (% in polygons) – Literature 2,5TW	IT dissipation (% in polygons) – Literature 1TW	RMS coast (cm)	RMS ocean (cm)
5km	2,75 (99,3%)	1,52 (37,6%)	19,8	7,1
2,5km	2,6 (99,2%)	1,21 (39,5%)	17,8	6,8
1,25km	2,55 (99,0%)	1,00 (40,5%)	17,6	6,7





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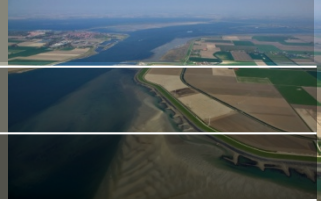
Conclusions



- Step **5km to 2.5km seems crucial** for BF convergence in many places and globally, 1.25km not so crucial.
- 0.6km and 0.3km coastal resolutions in Australia show no meaningful impact globally or locally.
- Places in high latitudes not converged . Common features: connection to Arctic (incl.), narrow passages.
- IT generation not converged in main areas, only ~40% inside polygons. Several small island chains present in these areas which are better represented by the higher resolution.

- Why can be important to **understand where and how much** dissipation takes place?
  - Understand the global system and dependence on local processes
  - BF dissipation: Turbulence – Mixing near the coast, implications for other processes (e.g. primary production)
  - IT generation: Key to sustain circulation and mix upper ocean heat into abyssal depths. ““It is possible that properly accounting for tidally induced ocean mixing may have important implications for long-term climate modeling”” (Egbert and Ray)

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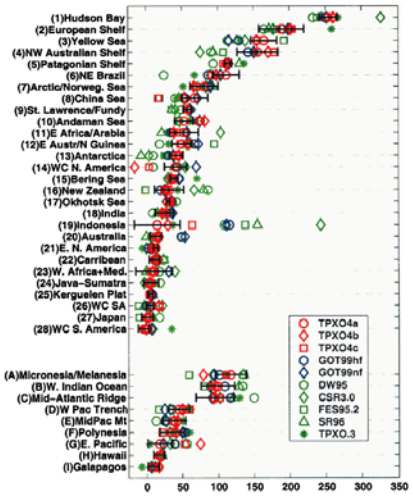
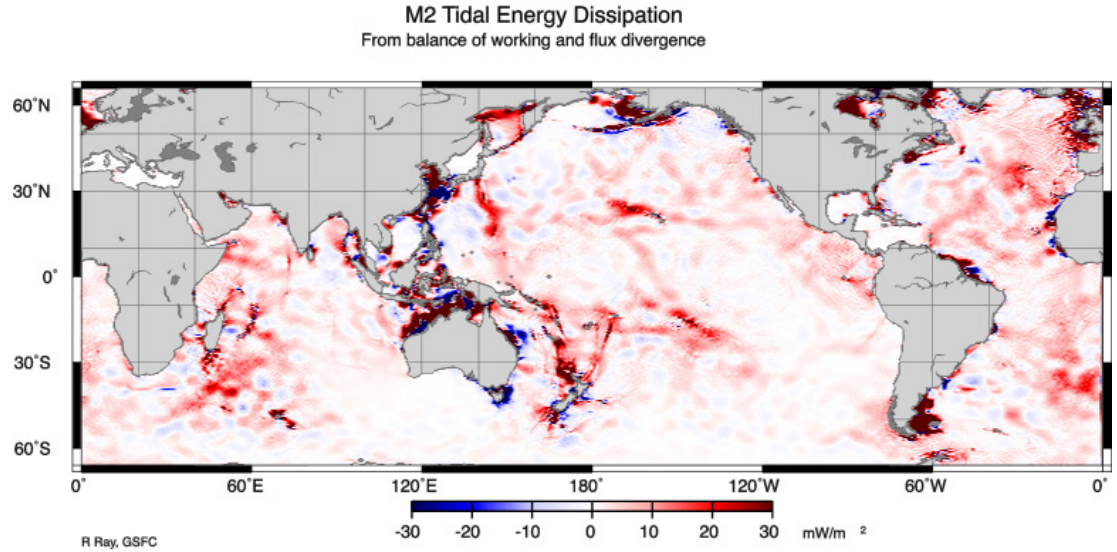
Future work

Resolution study:

- Bottom friction formulation: Combination of Chezy and Manning?
- Comparison with TPXO dataset – M2 dissipation only





- Divide areas in smaller chunks to better assess sensitivities and possible indirect effects
- Australia case not very exciting – Resolution tests using EMODnet 250m bathymetry in Europe (non-converged)

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