Multidecadal oscillations of the meridional overturning circulation in presence of bottom topography...

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Outline

We revisit here the influence of bottom topography on intrinsic decadal-scale variability of the ocean thermohaline circulation, using various models based on different vertical coordinates (z, sigma, and isopycnal) and sub-grid scale parameterizations.
Idealized geometry (rectangular flat-bottom basin) ocean models forced by prescribed buoyancy/heat fluxes show generic bifurcations towards multidecadal oscillations when the overturning circulation is large enough or the eddy-diffusivity reduced (above some critical Peclet number U L / KH). These oscillations are rationalized through a large-scale baroclinic instability, the decadal period being related to the propagation of long baroclinic Rossby waves across the basin along the model equivalent of the North Atlantic drift front. A few studies have pointed out a potential damping influence of bottom topography on these oscillations. This could be expected through the interaction of westward propagating Rossby waves with bottom topography, such as a Mid-Atlantic Ridge.
Here we first set up different models with different vertical coordinates to assess the generic property of these oscillations. Decadal variability appears ubiquitous, although specific models setups raise questions on what is a realistic oceanic parameter regime at low-resolution O(1°). Then we introduce various idealized bottom topography (bowl, ridge) with increasing amplitude to assess their influence on the oscillations. In contrast with our initial hypothesis, there is no systematic damping influence of large bottom topographic structures like mid-basin ridge.
Finally these results are in good agreement with the analysis of ocean basin modes in a 2-layer shallow water model including bottom topography (Ferjani et al. 2012, poster XY383): a detailed energy budget of the decadal modes damping through eddy viscosity and diffusivity, and bottom interaction show the former largely predominates.

Experiments with the sigma-coordinates model ROMS

Numerical experiments are performed with the Regional Ocean Modeling System (Shchepetkin and McWilliams 2005), based on topography-following sigma coordinates. The model configuration spans 5120 km in longitude and 4468 km in latitude on a Cartesian beta-plane centered at 40°N, 3800 m deep. We use around 1° horizontal resolution (grid 59x54) and 20 sigma levels. Temperature only is used, and surface heat flux are prescribed as a linear function of latitude varying from 50 W/m^2 equatorward to -50 W/m^2 poleward. There is no wind forcing. The initial temperature is uniformly 4°C. The model is integrated for at least 1000 yr. The reference simulation uses 10^{-4} (10^{-3}) m^2/s vertical mixing for tracer (momentum); 700 ($5\ 10^4$) m^2/s horizontal mixing for tracer (momentum); and no-slip boundary conditions.
As for simulations previously described in planetary-geostrophic and primitive-equations (MOM) models, the integrations leads to multidecadal variability (periods in the 20-50yr range). Introducing bowl-shape bottom topography with amplitudes ranging from 10 to 400m, we observe absolutely no clear damping influence on the oscillations (Figure 1). Standard deviation of kinetic and potential energy do not show any trend with the amplitude of the topography, but rather surprising variations that needs to be more precisely analyzed. Simulations with larger amplitude topography are underway.

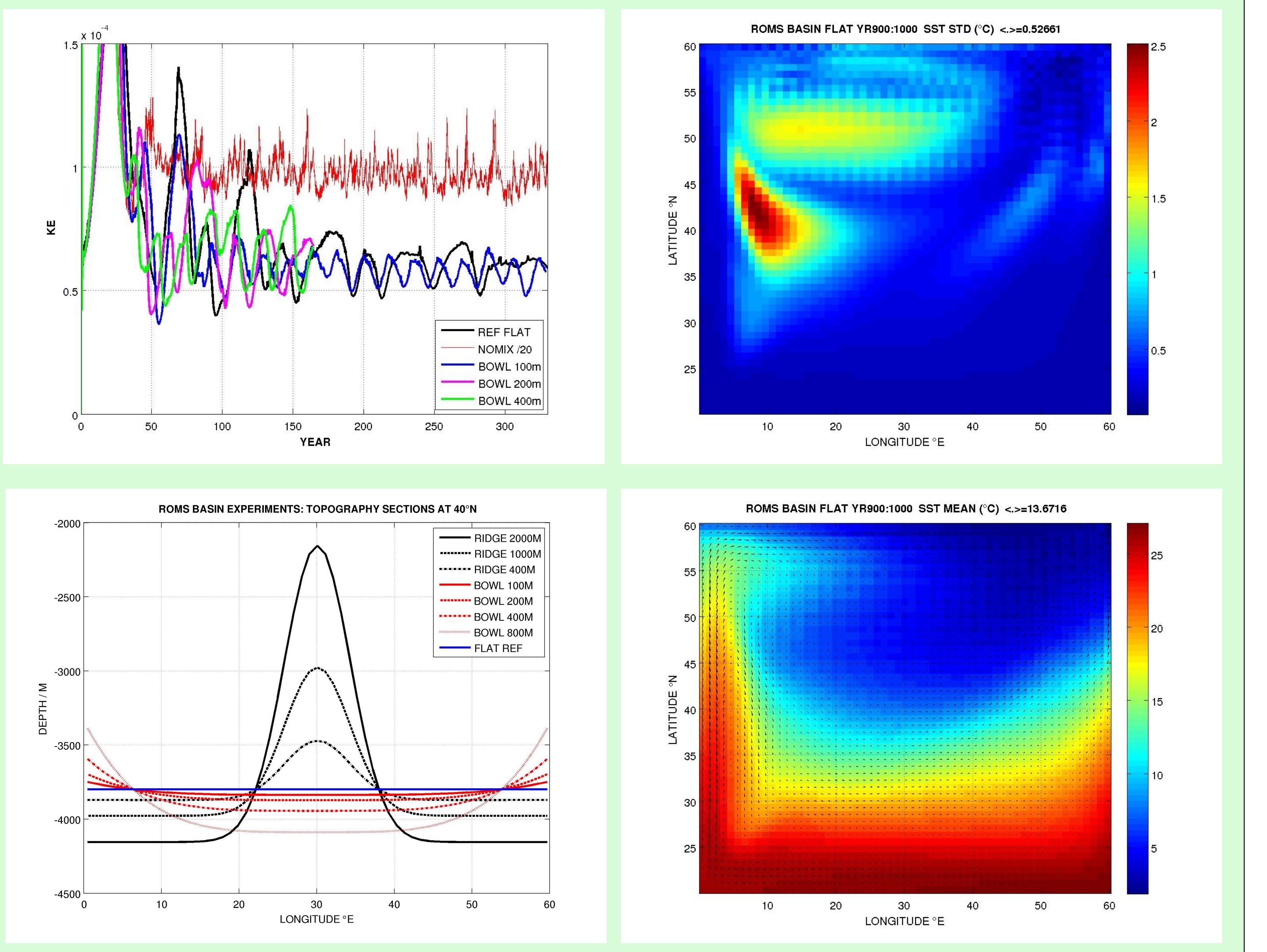

Figure 1: (a) Total kinetic energy as a function of time in ROMS for the flat-bottom reference case, the case with no explicit horizontal mixing (KE is divided by 20 here!), and bowl-shape bottom-topography with amplitude of 100, 200 and 400m. (c) Bowl-shape and ridge typical topography. (b) Standard deviation of SST and (d) mean SST and surface velocities for the reference case.

Note that if eddy viscosity and diffusivity are let to the model implicit numerical schemes (as advised by some ROMS/IRD people), the regular oscillations are replaced by higher frequency noisy variability. Much higher resolution simulations are required to properly address this issue and alleviate the critical role of eddy dissipation coefficients: these are underway and will be reported .

We now introduce a mid-basin ridge that we expect to disturb Rossby waves westward propagation. It has a Gaussian shape as a function of longitude, with a width of 20% of the basin extent, and amplitude varying between 200 and 2000m. Bottom depth is adjusted such that the basin volume remains constant. Once again, the effect is clearly not as strong as expected, and no trend is found. There is clearly some efficient damping for small ridge (200-400m) but the variability gets back to the flat-bottom level for larger amplitude (800-1600m), before decreasing strongly for 2000m. Work is underway to clarify these results (resonance, change in mean state...).

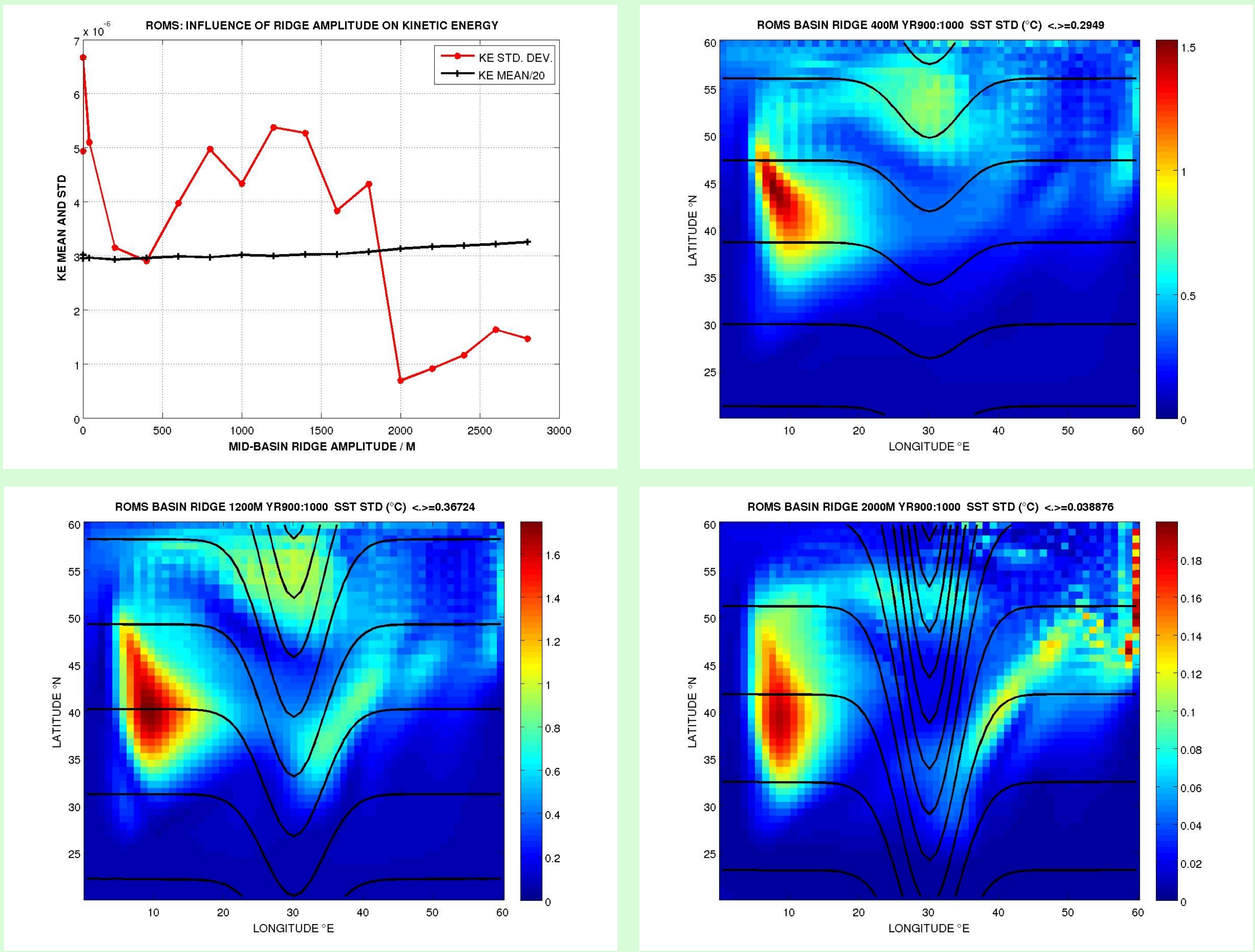

Figure 2: (a) Total kinetic energy mean and standard deviation as a function of the mid-basin ridge amplitude in ROMS (note mean KE mean is divided by 20). Standard deviation of SST for the experiments with ridge amplitude (b) 400, (c) 1200 and (d) 2000 m, with contours of f/H superimposed showing some topographic "steering" in the eastern basin.

Experiments with the isopycnal-coordinates model HYCOM

Similar numerical experiments are now performed with the HYbrid Coordinate Ocean Model v2.2.18 (Bleck 2002), for a mid-latitude basin extending from 20°N to 60°N, 60° wide, with around 1° horizontal resolution (spherical grid 47 x 41), 3800 m deep discretized through 22 hybrid layers. Temperature only is used, salinity is constant. The surface heat flux is prescribed as a linear function of latitude with zero net flux, varying from 47 W/m^2 at 20°N to -92 at 60°N. There is no wind forcing. The initial temperature is a horizontally-uniform stratification from 4°C at the bottom to 15°C at the surface. The model is integrated for at least 1000 yr.

Default parameters/parametrizations turned out to be highly inadequate for our idealized setting. Using only temperature (constant salinity), isopycnals are isotherms, hence isopycnal mixing has absolutely no effect. We had to rely on much higher values for layer thickness horizontal mixing to mimic our horizontal eddy diffusivity. In the absence of wind forcing, the use of KPP vertical mixing was not a good choice, and the large values of diapycnal mixing required to drive a realistic overturning in a single hemisphere basin were imposed through the background diapycnal mixing.

We have first tested the influence of the various parameters to retrieve our previous sensitivitry analysis of the oscillations (Huck et al. 1999). The overturning circulation strongly depends on the background diapycnal mixing and requires values O(10^{-4} m^2/s) to reach reasonable values of 13 Sv. The horizontal thickness diffusion has a damping role for very large values corresponding to 700-1000 m^2/s.

- Then we introduce a bowl shape geometry up to the surface. The variability is not significantly modified, standard deviation of total kinetic energy even increasing by 30%, but not changing for SST (0-100m).

We finally move on to mid-basin ridge geometry of the same shape as for ROMS, and amplitude varying from 100 to 1400m.

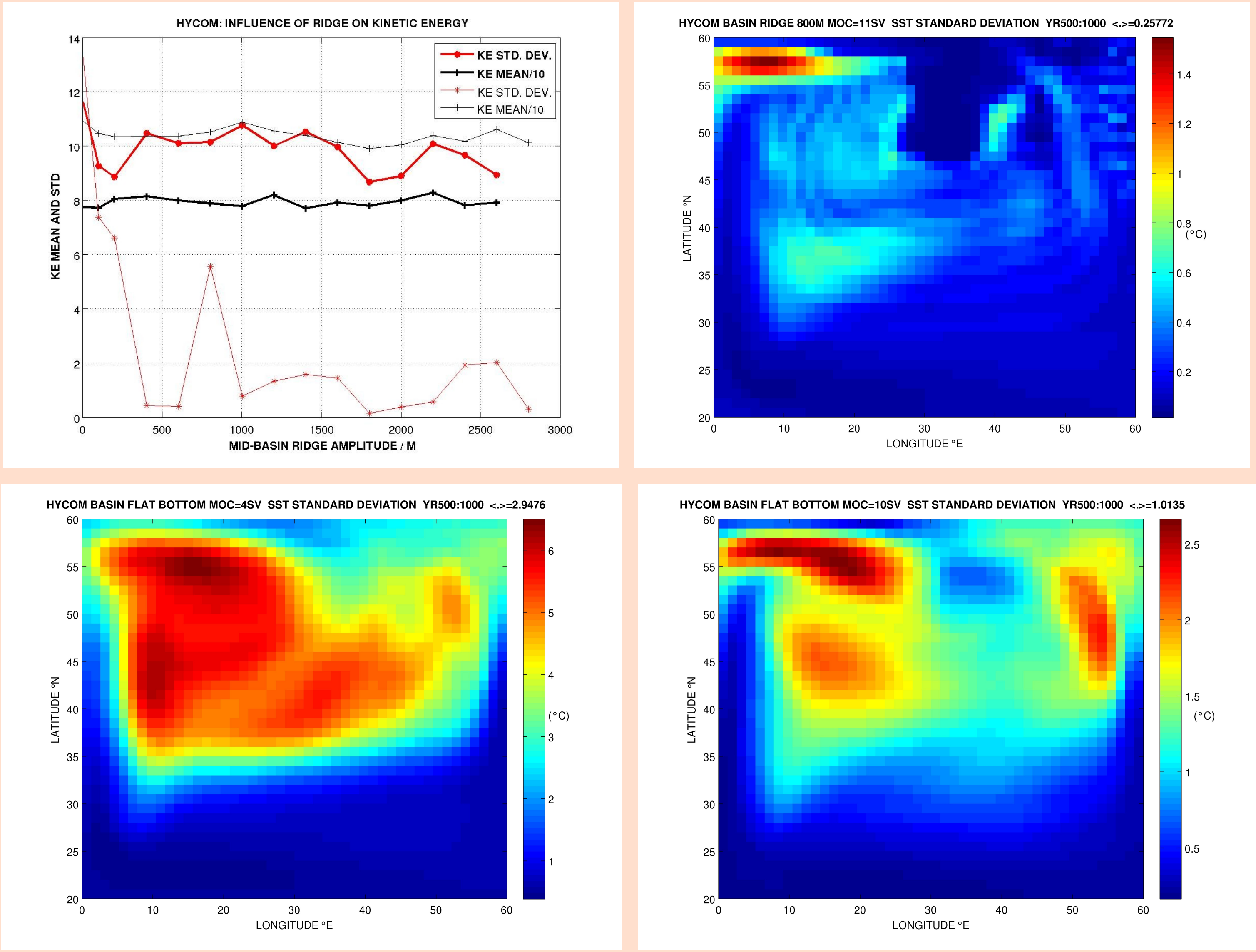

Figure 3: (a) Total kinetic energy mean and standard deviation as a function of the mid-basin ridge amplitude in 2 series of HYCOM experiments, one with low diapycnal mixing 10^{-5} m²/s (MOC~4-5 Sv) and very low thickness diffusion 0.05 m²/s (bold), one with large values, 10^{-4} m²/s (MOC~10-13 Sv) and 700 m²/s respectively (thin). Standard deviation of temperature averaged over the upper 100m for the flat bottom (c) low and (d) high diffusivities, and (b) with a 1000m high mid-basin ridge.

Unfortunately, the choice of parameters used for the 2 series of experiments does not match the ROMS experiments, such that the behavior is not exactly the same. But clearly, the damping role of bottom topography is not as regular as expected, in a similar way as the experiments with ROMS.

Conclusion

Our result with ROMS and HYCOM contrast with our expectations when we initiated this work, based on a few 'old' experiments with bottom topography using coarse resolution z-coordinate MOM model (Winton 1997, Huck et al. 2001). At this point we do not know if it is a model bias, for example the large bottom steps enhancing bottom topography influence on decadal variability, or just some bad luck in the old settings. Clearly, bottom topography may not have as much a damping role on the decadal variability as we thought, and this is in agreement with recent work on basin modes energy balance (Ferjani et al. 2012 submitted). We still believe this genuine intrinsic multidecadal variability of the ocean thermohaline circulation may have a role in the observed North Atlantic climate varibility, on decadal to multidecadal periods. Work will be pursued to compare more thoroughly the results from the different model types as has been done for steady-state (Park and Bryan 2000, 2001) and more realistic configurations (Dynamo project)

Aknowledgments.
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