Robustness of the interdecadal variability of the overturning circulation in presence of eddy turbulence and bottom topography

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Outline

Intrinsic interdecadal variability arises spontaneously in idealized ocean circulation models when the overturning (dissipation) is large (low) enough, at low resolution. The existence of a critical threshold for the horizontal eddy diffusivity in the range of observational estimates legitimates some doubt on the relevance of such oscillations in the climate system. In addition, bottom topography may add some damping to the variability. Previous idealized experiments are reproduced with adequate horizontal resolution to resolve mesoscale eddies using different numerical models (ROMS, HYCOM), and implementing different values of vertical diffusivity (controlling the overturning) and various shapes of bottom topography. Interdecadal variability is ubiquitous in these simulations and appears even more robust to low vertical diffusivity and bottom topography when mesoscale eddies are resolved. Attempt is made to rationalize the changes in the variability period and structure through linear stability analysis. Simplified shallow-water models also suggest a weak damping role of the topography.

Experiments with increasing horizontal resolution

Numerical experiments are performed with the Regional Ocean Modeling System (Shchepetkin and McWilliams 2005), based on topography-following sigma coordinates, for simulating an idealized thermally-driven ocean overturning circulation at various resolution. 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 conducted a series of experiments with increasing resolution from around 1° horizontal resolution (grid 59x54) and 20 sigma levels, down to 10km resolution (512x448 grid) and 40 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 several hundred years to millenials depending on resolution. The reference simulation uses 10^{-4} (10^{-3}) m^2/s vertical mixing for tracer (momentum), but experiments with 3 10^{-5} and 10^{-5} are also performed. The 1° experiment uses 700 (5 10^4) m^2/s horizontal mixing for tracer (momentum), whereas at higher resolution, no explicit values are prescribed and implicit mixing is controlled by the advection scheme. We use no-slip lateral boundary conditions. As for simulations previously described in planetary-geostrophic and primitive-equations (MOM) models, the integrations leads to spontaneous multidecadal variability on periods in the 20-50yr range (Huck et al. 2001), whatever the resolution. Time series are shown in Fig. 1, spatial patterns in Fig. 2. All the experiments for various resolutions and vertical diffusivity values are summarized in Table 1 through the intensity and variability of the Meridional Overturning cell, showing the robustness and coherence of the interdecadal variability.

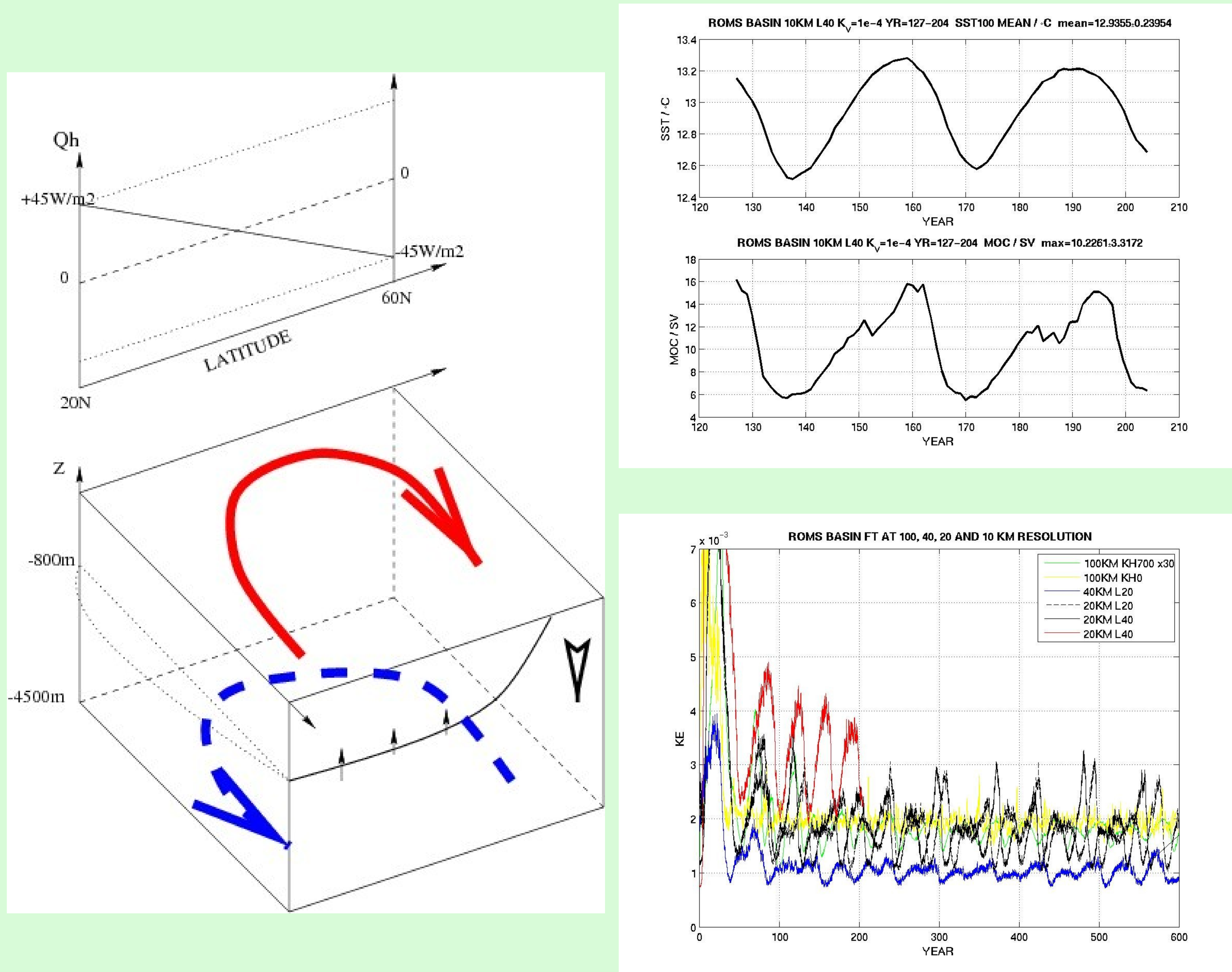

Figure 1: (a) Schematic of the numerical experiment: surface thermal forcing and resulting horizontal circulation in the upper and lower layers. (b) Basin-averaged Sea Surface Temperature (0-100m) and maximum of the Meridional Overturning Circulation streamfunction, all based on annual mean fields, for the 10 km reference case. (c) Total kinetic energy as a function of time in the reference case for the whole range of horizontal and vertical resolutions (note KE is multiplied by 30 for the lower resolution with KH=700 m2/s).

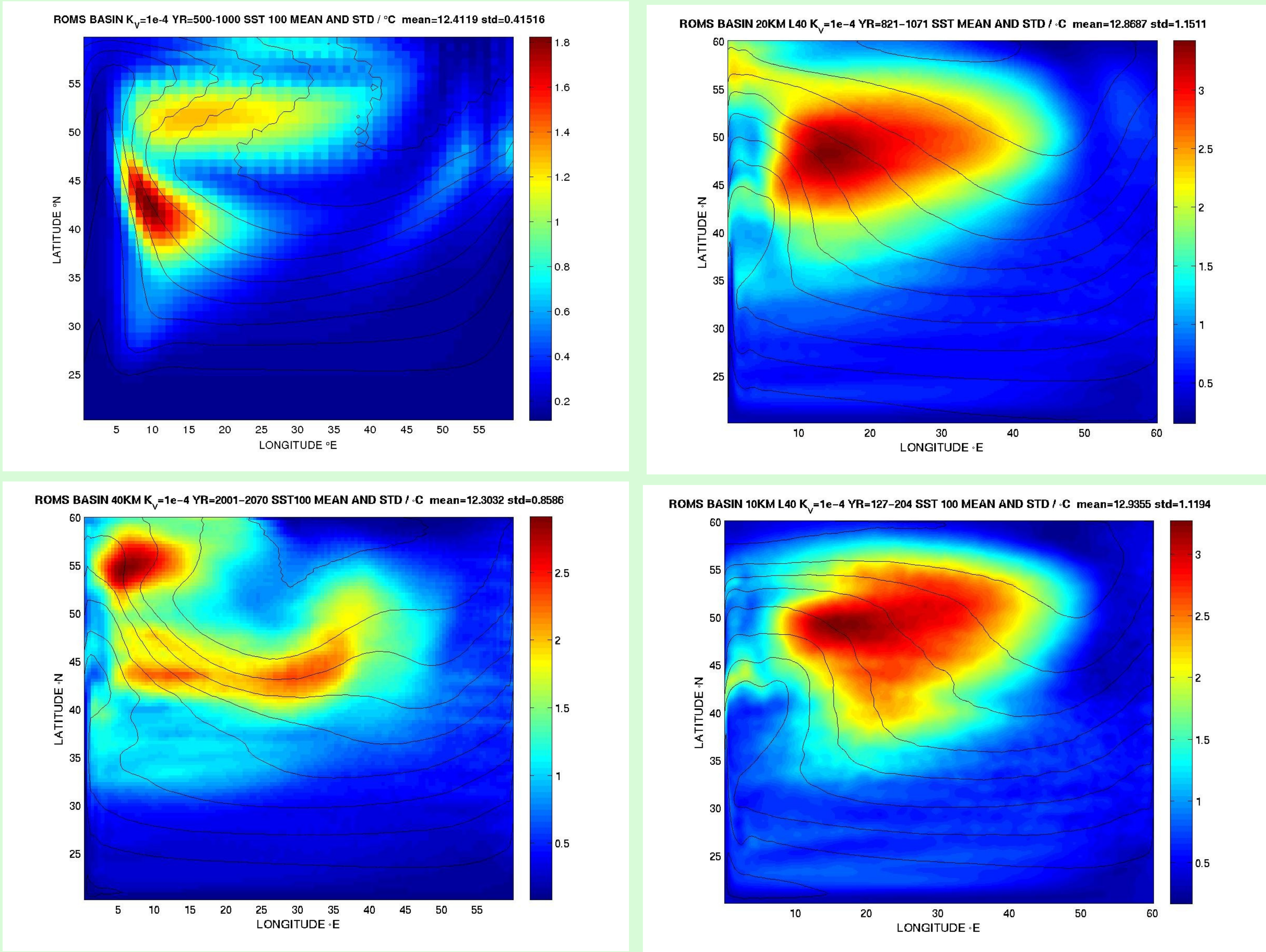

Figure 2: SST (0-100m) mean (contours) and standard deviation (color) for the 85, 40, 20 and 10 km experiments, based on annual mean fields. Note the color scale varies between the experiments. Even the mean temperature show large changes with resolution.

Diapycnal (vertical) diffusivity	10^{-4} m^2/s	3 10^{-5} m^2/s	10^{-5} m^2/s
85km L20 KH=700m2/s	10.43±0.99 Sv	7.05±0.08 Sv	2.56±0.01 Sv
85km L20 KH=0	7.93±0.43 Sv	4.76±0.89 Sv	2.66±0.76 Sv
40km L20	10.21±1.07 Sv	5.44...	3.19...
20km L20	10.30±3.52 Sv	5.59±1.65 Sv	-
20km L40	10.11±3.15 Sv	5.48±1.68 Sv	3.50±1.04 Sv
10km L40	10.23±3.30 Sv	-	4.82±2.08 Sv

Table 1: Meridional Overturning Streamfunction amplitude and variability (mean ± standard deviation) for the 85, 40, 20 and 10 km experiments, depending on the vertical diffusivity coefficient, based on annual mean fields. Oscillations are more robust to low vertical diffusivity (and overturning) with resolved eddy turbulence than without.

Experiments with bottom topography

We now introduce various shapes of bottom topography to test the robustness of the oscillations (Winton 1997, Huck et al. 2001). For **bowl-shape topography** with amplitudes ranging from 10 to 400m, we observe absolutely no clear damping influence on the oscillations. 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. 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. Clarifying the results is underway: resonance, change in mean state.

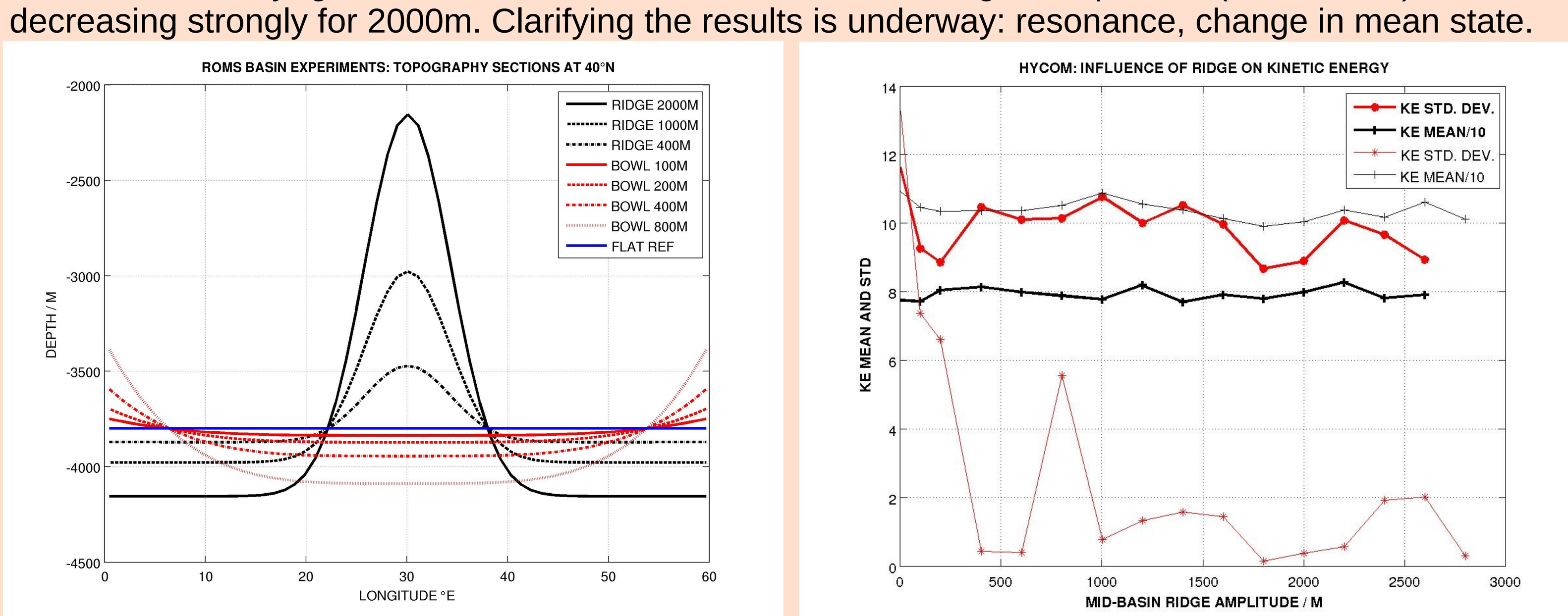

Figure 3: (left) Profiles of bowl-shape and mid-basin ridge topography. (right) Total kinetic energy mean and standard deviation as a function of the mid-basin ridge amplitude in 2 series of HYCOM experiments, one with low diapycnal mixing 10^{-5} m²/s (MOC~4-5 Sv) and very low thickness diffusion 0.05 m²/s (bold), one with large values, 10^{-4} m²/s (MOC~10-13 Sv) and 700 m²/s respectively (thin).

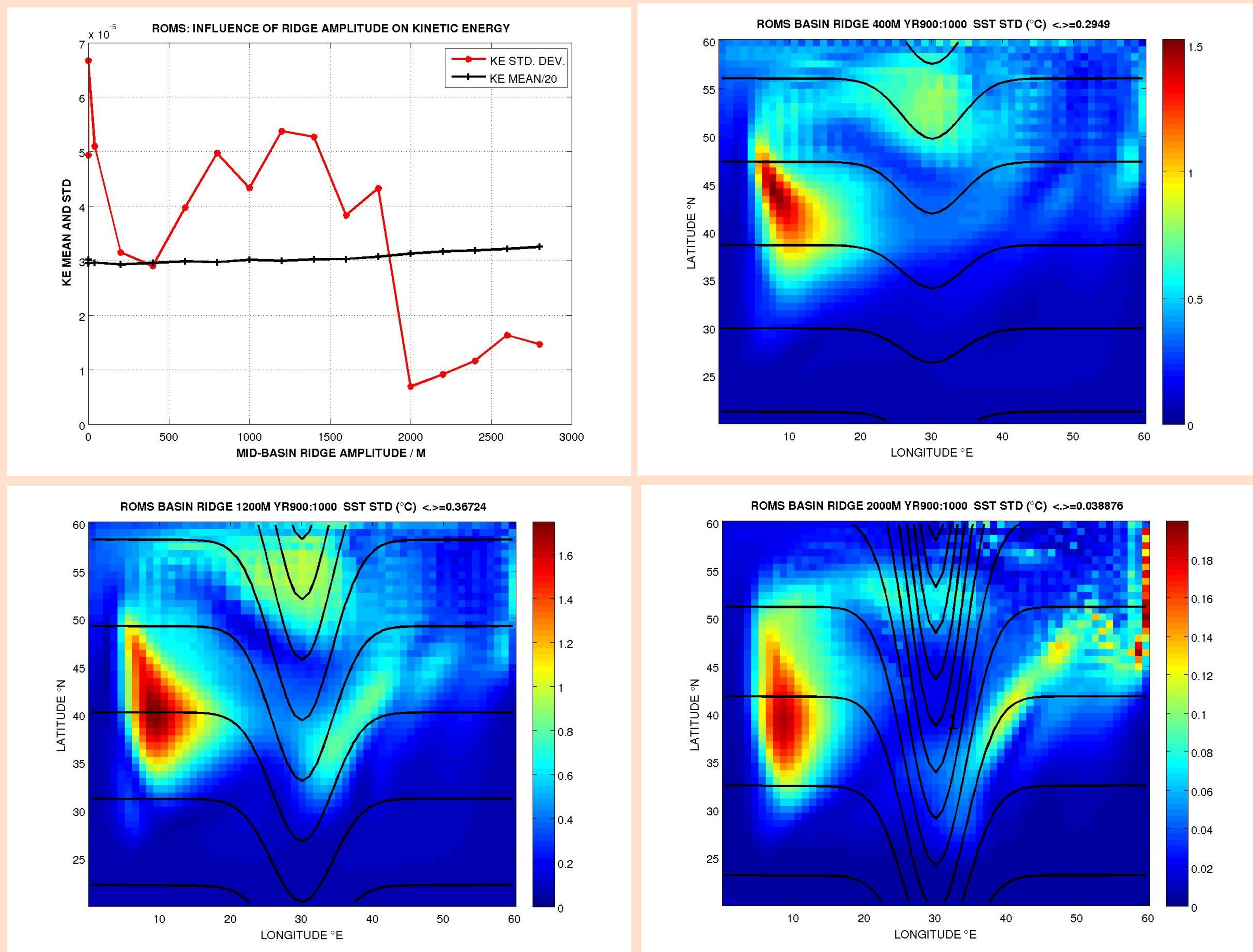

Figure 4: (a) Total kinetic energy mean and standard deviation as a function of the mid-basin ridge amplitude in ROMS experiments (note mean KE mean is divided by 20). Standard deviation of SST for the experiments with ridge amplitude (b) 400, (c) 1200 and (d) 2000 m, with contours of f/H superimposed showing some topographic "steering" in the eastern basin.

Discussion and Conclusion

Our large series of simulations 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). Resolving mesoscale eddies, hence introducing a small-scale high-frequency wavemaker, does not disturb the coherence of the large-scale multidecadal variability (as suggested in LaCasce and Pedlosky 2004 for instance), but rather makes the latter more robust to low values of eddy diffusivity and overturning. Regarding bottom topography, 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 previous settings. Clearly, bottom topography may not have as much a systematic 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).

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