Intrinsic low-frequency (co)variability of SLA, MOC, and SST: impacts of mesoscale turbulence and wind forcing

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OUTLINE

Intrinsic multidecadal variability arises spontaneously in idealized low-resolution ocean circulation models forced by surface buoyancy fluxes, when the overturning (dissipation) is large (low) enough. A series of ROMS simulations is performed with resolution increasing up to eddy-resolving (10 km) and various diapycnal diffusivities : this multidecadal intrinsic variability is a **generic ubiquitous feature**, at least in this flat-bottom geometry. The addition of a climatological wind forcing has a strong impact on the mean horizontal and vertical circulation, and on the variability : **intrinsic variability is shifted to the intergyre in eddying simulations**, **and interannual eddy-driven variability emerges**. The large-scale SST/SSH anomalies now propagate eastward at the intergyre and cyclonically around the subpolar gyre, in analogy with observations and OGCM simulations.

ROMS MODEL SETUP

The hemispheric domain spans 5120 km in longitude and 4468 km in latitude on a beta-plane centered at 40°N (3800 m uniform depth). Resolution is increased from 85km and 20 sigma levels, up to 10km and 40 levels with no-slip lateral boundary conditions. Temperature only is used; surface heat fluxes vary linearly in latitude from 50 W/m^2 at the equator to -50 W/m^2 near the pole. Initial temperature is uniformly 4°C. The model is integrated for several hundred/thousand years depending on resolution. The reference simulation uses Kv=10^{-4} (10^{-3}) m^2/s tracer (momentum) vertical mixing; experiments with 3.10^{-5} and 10^{-5} are also performed. The 85 km experiment uses Kh=700 (5.10^4) m^2/s horizontal mixing for tracer (momentum); at higher resolution, no explicit values are prescribed and implicit mixing is controlled by the advection scheme.

THERMAL FORCING – NO WIND

Simulations at all resolutions exhibit spontaneous multidecadal variability at periods in the 20-50 yr range (Huck et al. 2001) as previously obtained in planetary-geostrophic and primitive-equations models. Time series are shown in Fig. 1.

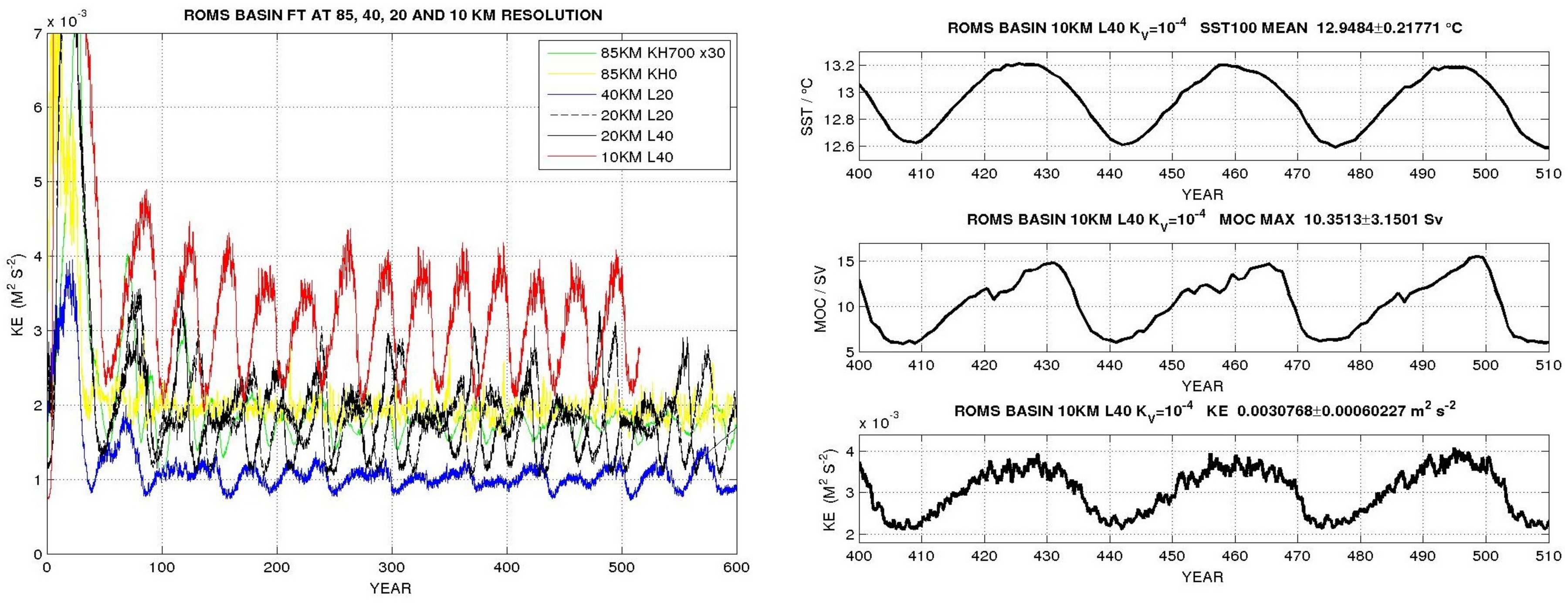


*Figure 1: (**left**) Kinetic Energy in the reference case for the whole range of horizontal and vertical resolutions (KE is multiplied by 30 for the lower resolution with explicit diffusivity Kh=700 m2/s). (**right**) Basin-averaged Sea Surface Temperature (0-100m) and maximum of the Meridional Overturning Circulation streamfunction, both based on annual mean fields, and KE as described earlier, for the 10 km case : The three evolve almost in phase.*

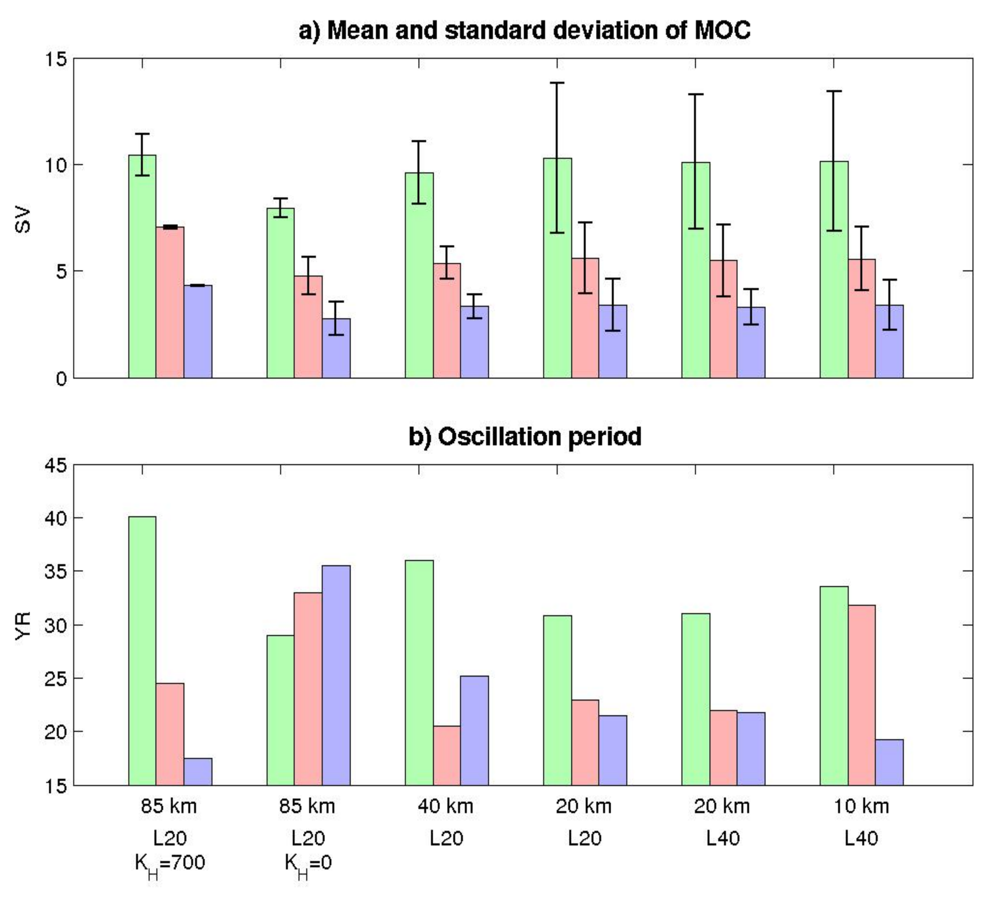


Fig. 2: (top) MOC mean amplitude and variability (error bar) at various resolutions/vertical diffusivities : 10^{-4} (green), 3.10^{-5} (red), 10^{-5} m^2/s (blue).

Mean MOC amplitude is controlled by vertical diffusivity: MOC$\propto$Kv$^{1/2}$. When mesoscale eddies are resolved, interdecadal variability appears even more robust to low vertical diffusivity and overturning. The mean circulation and spatial structure of the variability largely change as reslution increases (along with the reduced viscosity and diffusivity), but there is no clear impact on the main oscillation period (Fig. 2). The mechanism proposed for these oscillations, involving westward propagating Rossby waves in the subpolar region and its feedback on the mean circulation (e.g. Sévellec and Fedorov 2012), is unaffected by turbulence and remains centered on the polar front, which is displaced to the south (Fig. 3).

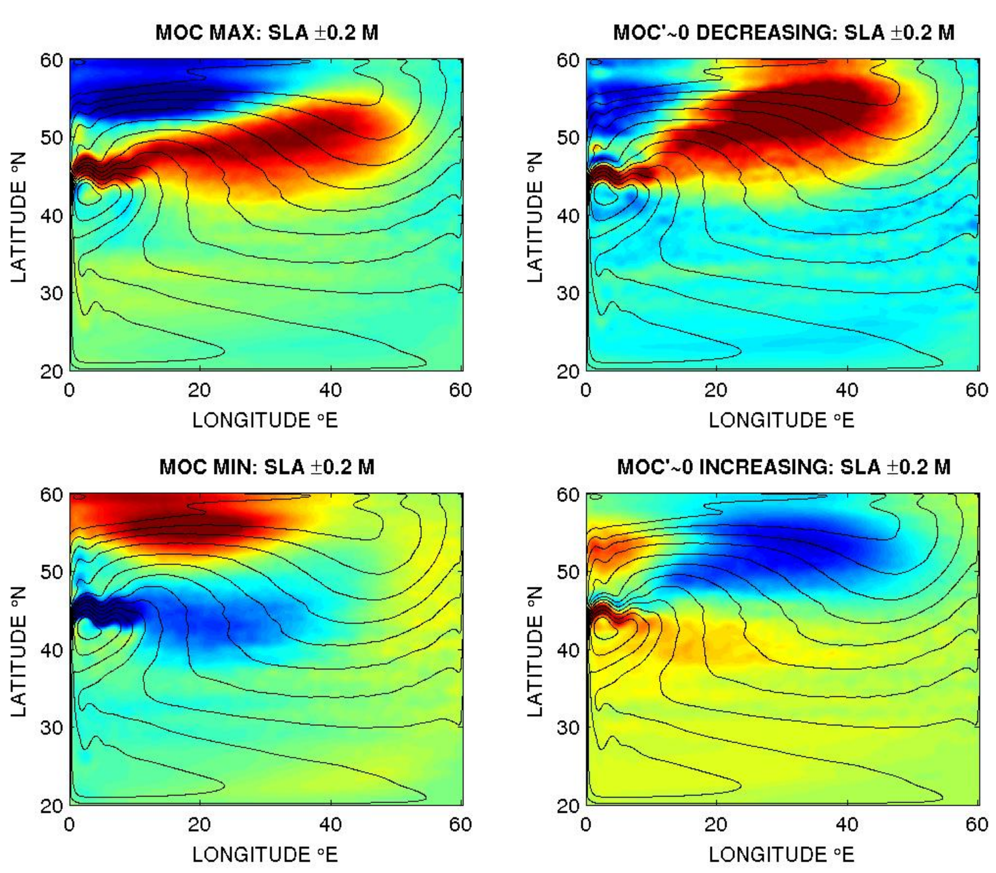
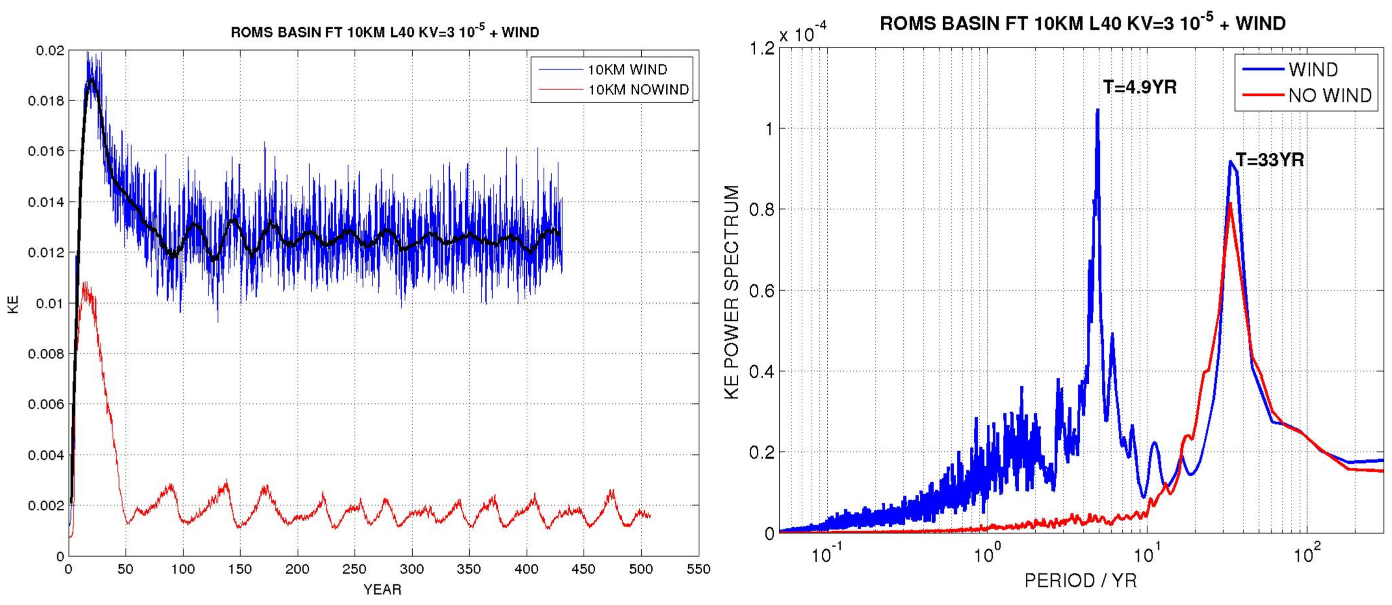


Fig. 3: SLA (-20 to +20 cm) for the 4 consecutive oscillation phases in the 10 km experiment with Kv= 3 10^{-5} m²/s: (top left) MOC maximum, (top right) small MOC anomaly decreasing, (bottom left) minimum MOC, (bottom right) small MOC anomaly increasing. Background mean sea level (black contours) shows the upper circulation.

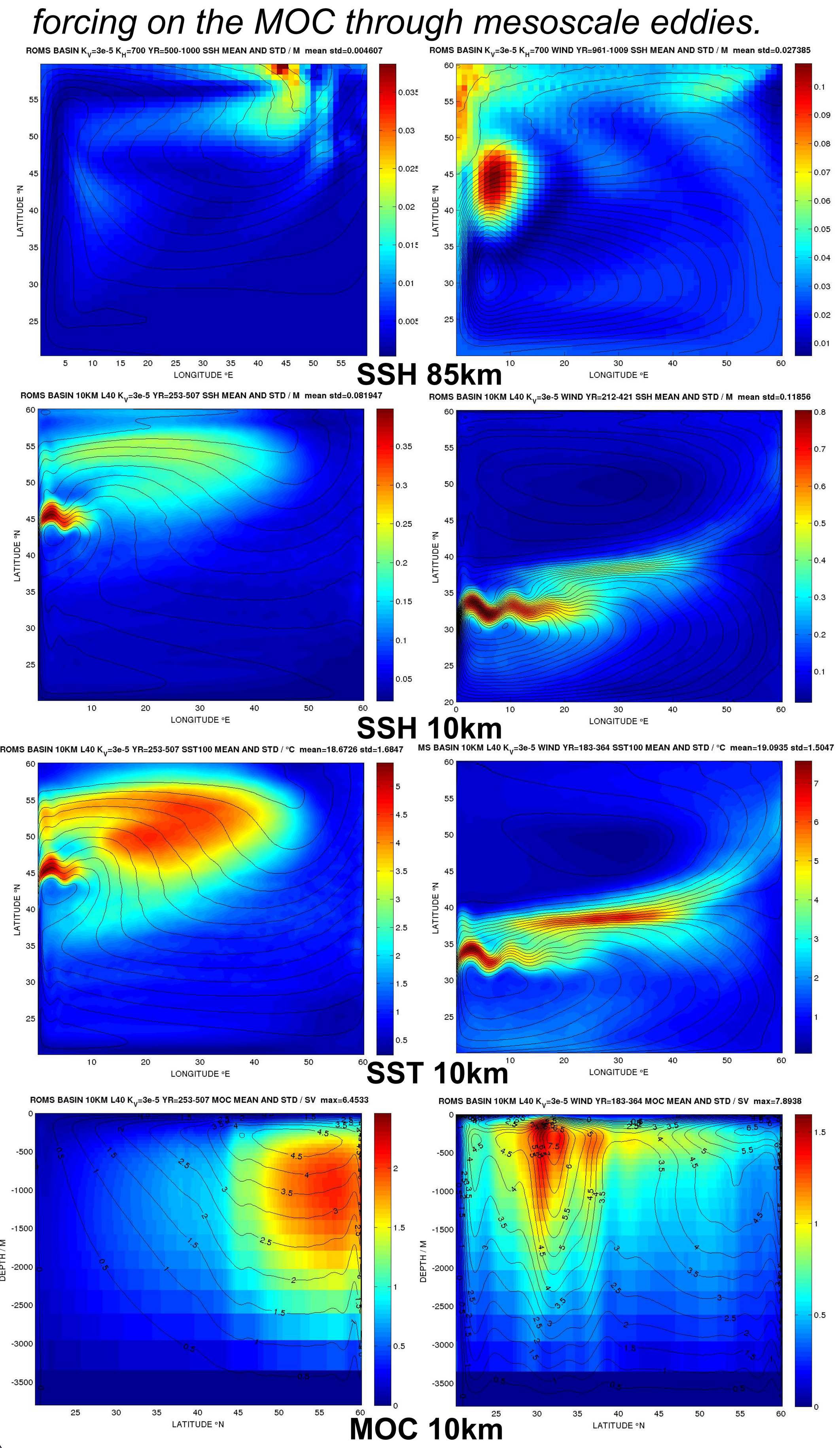
THERMAL FORCING AND CLIMATOLOGICAL WIND

The wind forces a subpolar gyre. **Eddy-driven interannual (4-5 yr) intrinsic variability** appears on the intergyre (Hazeleger & Drijfhout 2000), except at 85 km resolution. Periods around **30yrs remain present**, but SST/SLA multidecadal variability shifts to the intergyre, where anomalies propagate eastward then cyclonically around the subpolar gyre, i.e. a **more realistic path** (Sutton&Allen 1997, Vianna&Menezes 2013). Kv=3 10^{-5} m²/s.

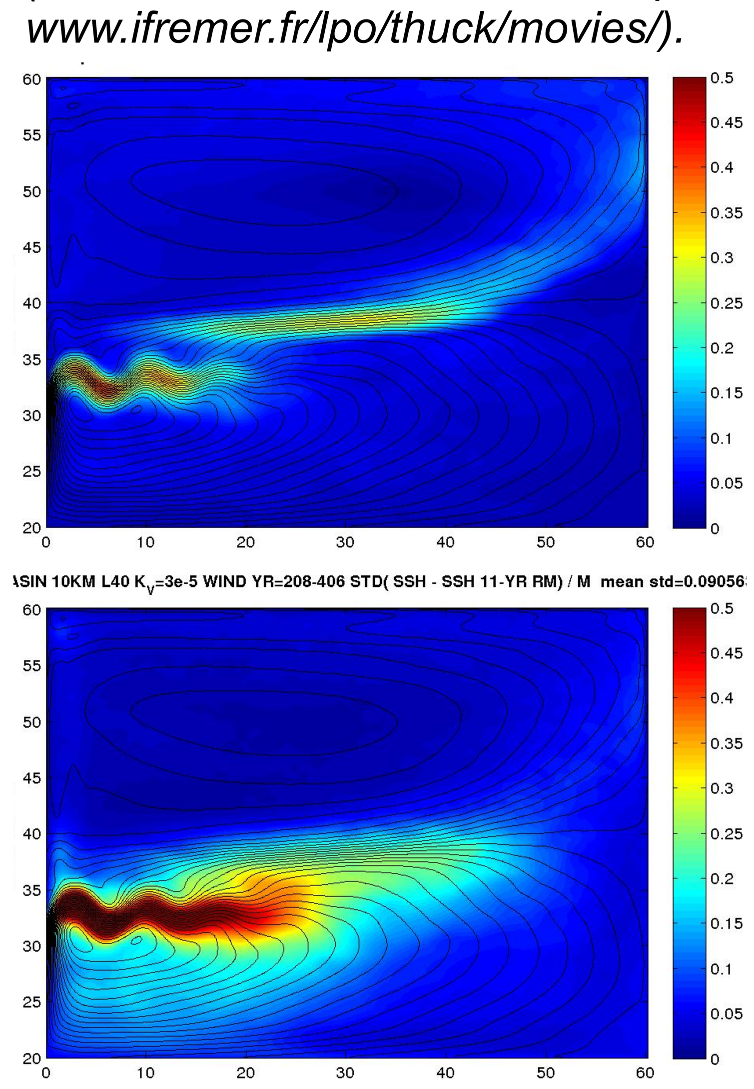
*Figure 4: (**left**) Kinetic Energy in the 10km run for Kv=3 10^{-5} m²/s, with/without wind forcing (the 10-yr running mean in black shows the multidecadal period). (**right**) KE Power Spectrum.*



Mean circulation and variability without (left) and with (right) wind forcing (Kv=3.10^{-5} m²/s): Mean (contours) and standard deviation (color) of SSH (m) at 85 km and 10 km, SST (0-100m, K) and MOC (Sv) at 10 km. Diagnostics are based on annual-mean fields. Note the influence of wind forcing on the MOC through mesoscale eddies.



SSH standard deviation (color, m) of multidecadal (top) and interannual (bottom) signals. Mean SSH in contours. 10 km run, Kv=3 10^{-5} m²/s. (see animation at http://www.ifremer.fr/lpo/thuck/movies/).



These wind-forced simulations show the coexistence of two mechanisms of variability, at interannual and multidecadal timescales. Separating both signals and identifying their dynamical origin will have **implications for the analysis of SSH (as well as SST and MOC) intrinsic variability in observational datasets, and in the OGCM simulations performed within the CHAOCEAN project.**

(see Penduff et al's poster)

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DISCUSSION - CONCLUSION

Resolving eddies introduces a small-scale high-frequency wavemaker, but does not disturb the coherence of **intrinsic large-scale multidecadal variability** (as suggested by e.g. LaCasce and Pedlosky 2004). This makes the latter more robust to low eddy diffusivities and overturning. This intrinsic multidecadal variability may have a role in the **observed North Atlantic climate variability** as suggested by Sévellec and Fedorov (2013). A mesoscale eddies and wind forcing produce a prominent interannual variability that is located at the intergyre, and makes the detection of multidecadal signals more difficult. Ongoing work may provide some hints to clearly separate the two signals.

Adding complexity (i.e. eddies, wind forcing) into idealized simulations reveals key processes producing intrinsic variability, and improves the agreement with observations. Such experiments complement those where the complexity of OGCM simulations is decreased (e.g. suppression of mesoscale, interannual forcing); this is how the **CHAOCEAN** project expects to improve our understanding of intrinsic variability in the real ocean and its imprint of observational datasets.