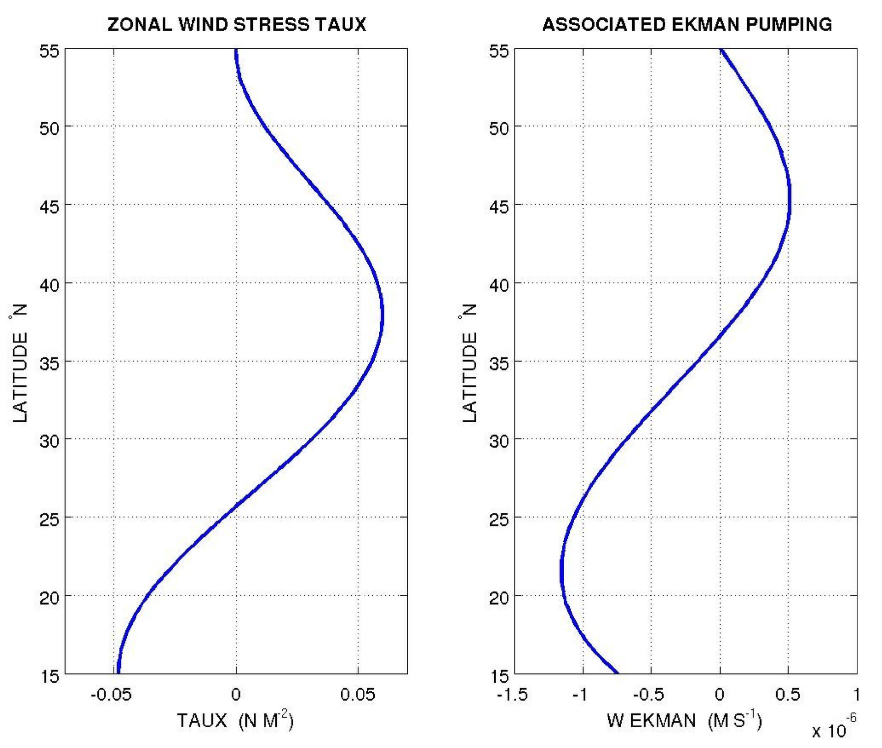
Influence of horizontal and vertical model resolution on ocean intrinsic variability in idealized wind-forced double-gyre

Thierry Huck*, Yves Morel†, Eric Chassignet‡, Steven Herbette*, Mathieu Le Corre*, Patrice Bellec*

*LOPS (UMR CNRS IFREMER IRD UBO), Brest; †LEGOS, Toulouse; ‡COAPS, FSU, Tallahassee

Abstract

A series of numerical experiments with a shallow-water model based on HYCOM is run at increasing horizontal and vertical resolution under constant double-gyre wind forcing. The level of kinetic energy (mostly turbulent) varies greatly with resolution with no sign of convergence up to 1/48°. The low-frequency intrinsic variability, on interannual periods, also varies widely depending on horizontal and vertical resolution. Preliminary diagnostics are shown that illustrate the different regimes and how energy transfers between horizontal and vertical scales.



Idealized model & configuration

► shallow water model: isopycnal MICOM-like setting (no mixed layer, no thermodynamical forcing) with HYCOM (HYbrid Coordinate Ocean Model) for parallel efficiency (with help from Alan Wallcraft)

► idealized shoe-box geometry: Cartesian, flat bottom, mid-latitude beta-plane 15-55°N, Atlantic basin size 6600km×4480km×3800m

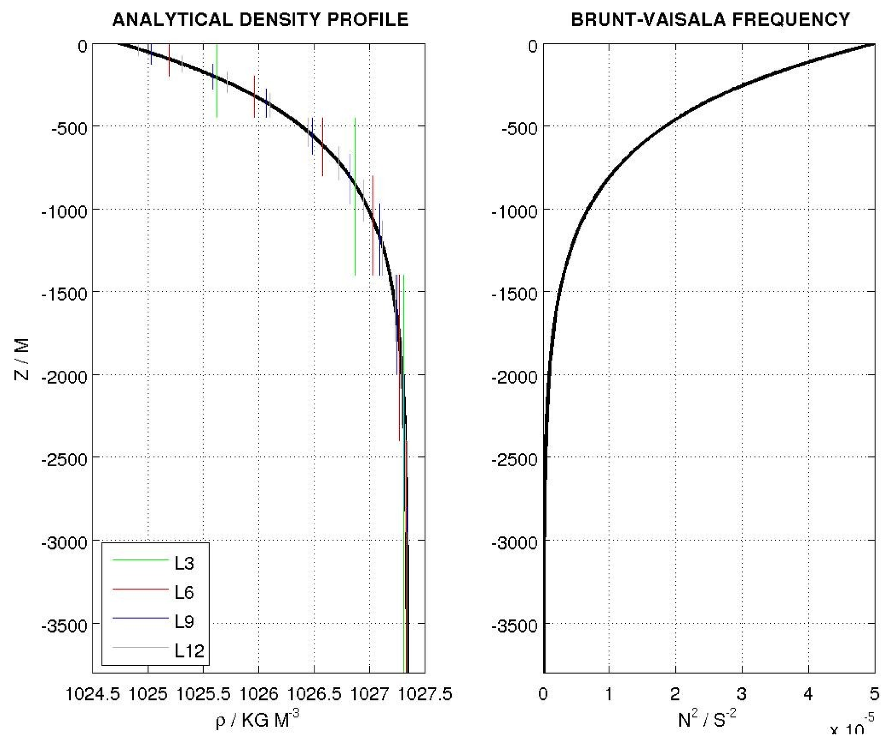
► constant wind forcing: analytical non-symmetric double gyre, constant in time (no seasonal cycle, no synoptic nor stochastic component), westerlies peaking at 0.06 N m^{-2} (maybe 30% weaker than climatology)

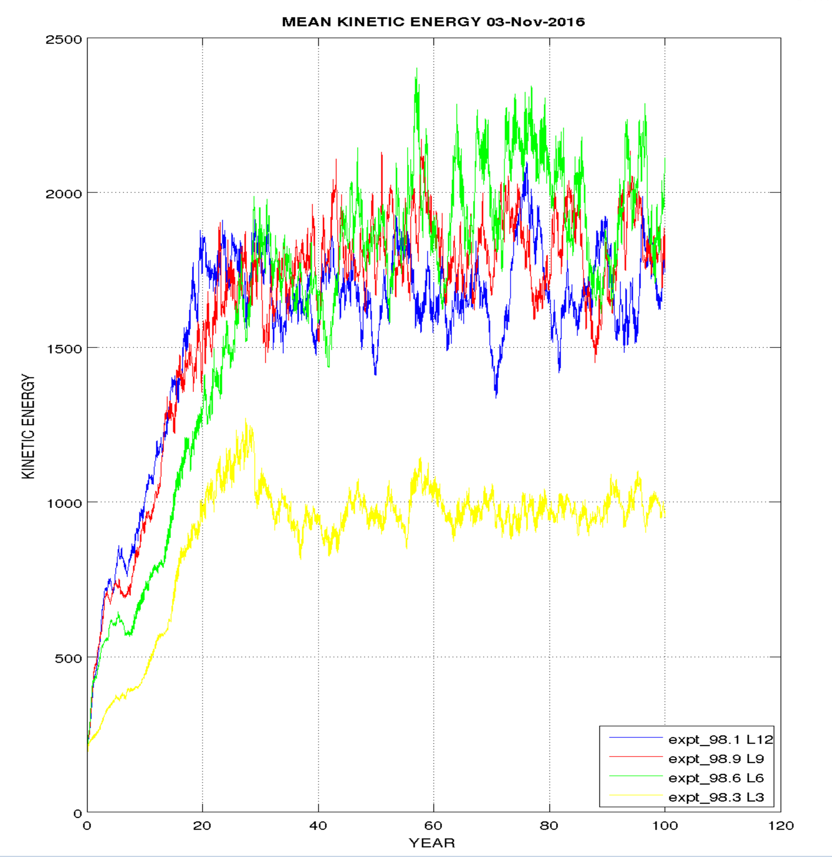
► subgridscale params: modified split Quick momentum advection, deformation-dependent and speed-dependent biharmonic viscosity only, no-slip lateral boundary conditions, quadratic bottom friction.

► series of numerical experiments with horizontal resolution increasing from 1° to 1/48° and vertical resolution from 3 to 12 layers run for 100 yr.

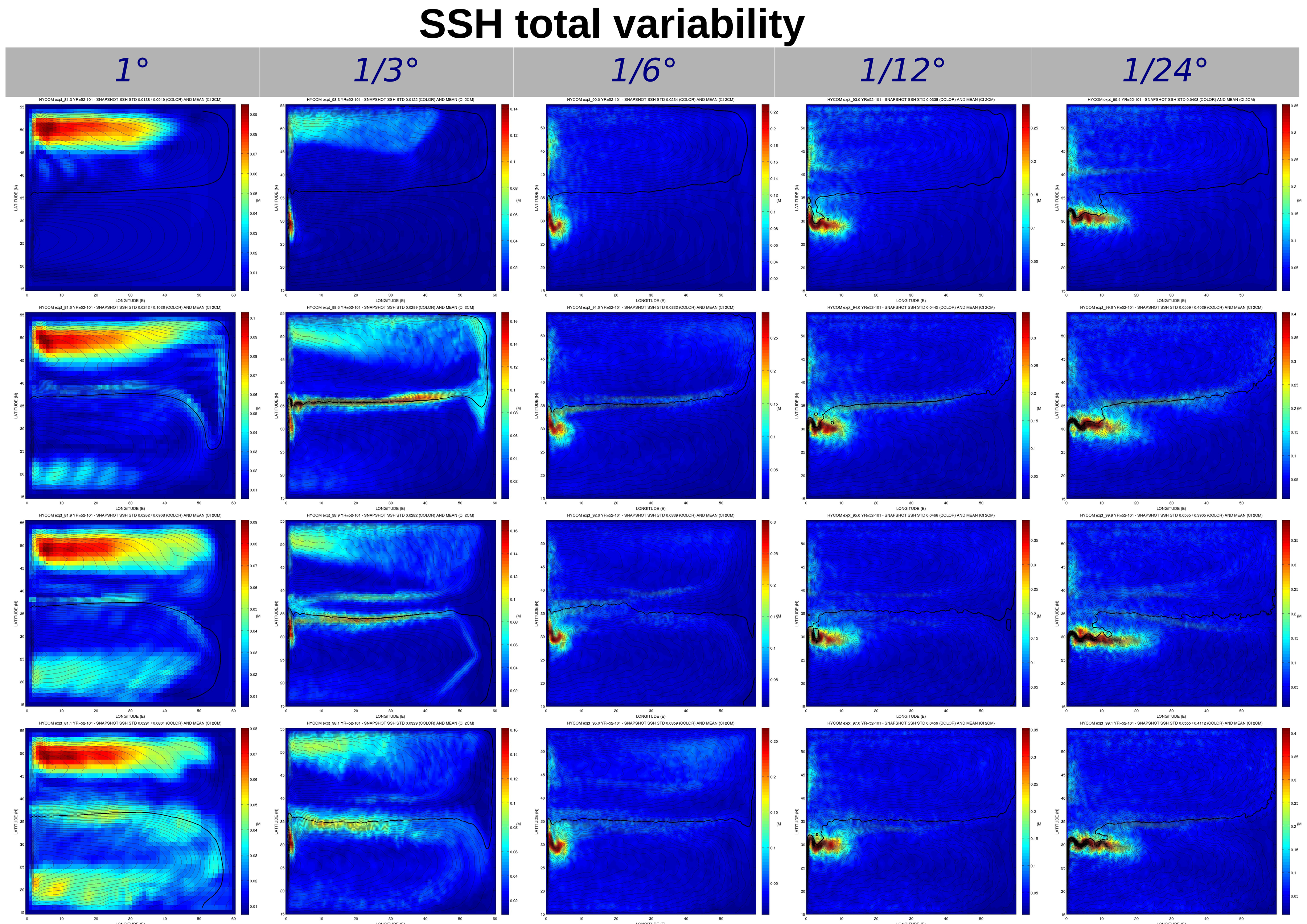
► layers thickness choosed arbitrarily as sublayers of initial 3 layers (L3: 450 950 2400; L6: 200 250 350 600 1000 1400; …)

► layers density averaged over layers depth range from analytical density profile "à la Gill" $\rho-\rho_0 = \delta_\rho \exp(z/d)$ with δ_ρ=2.5 kg m^{-3}, d=500 m

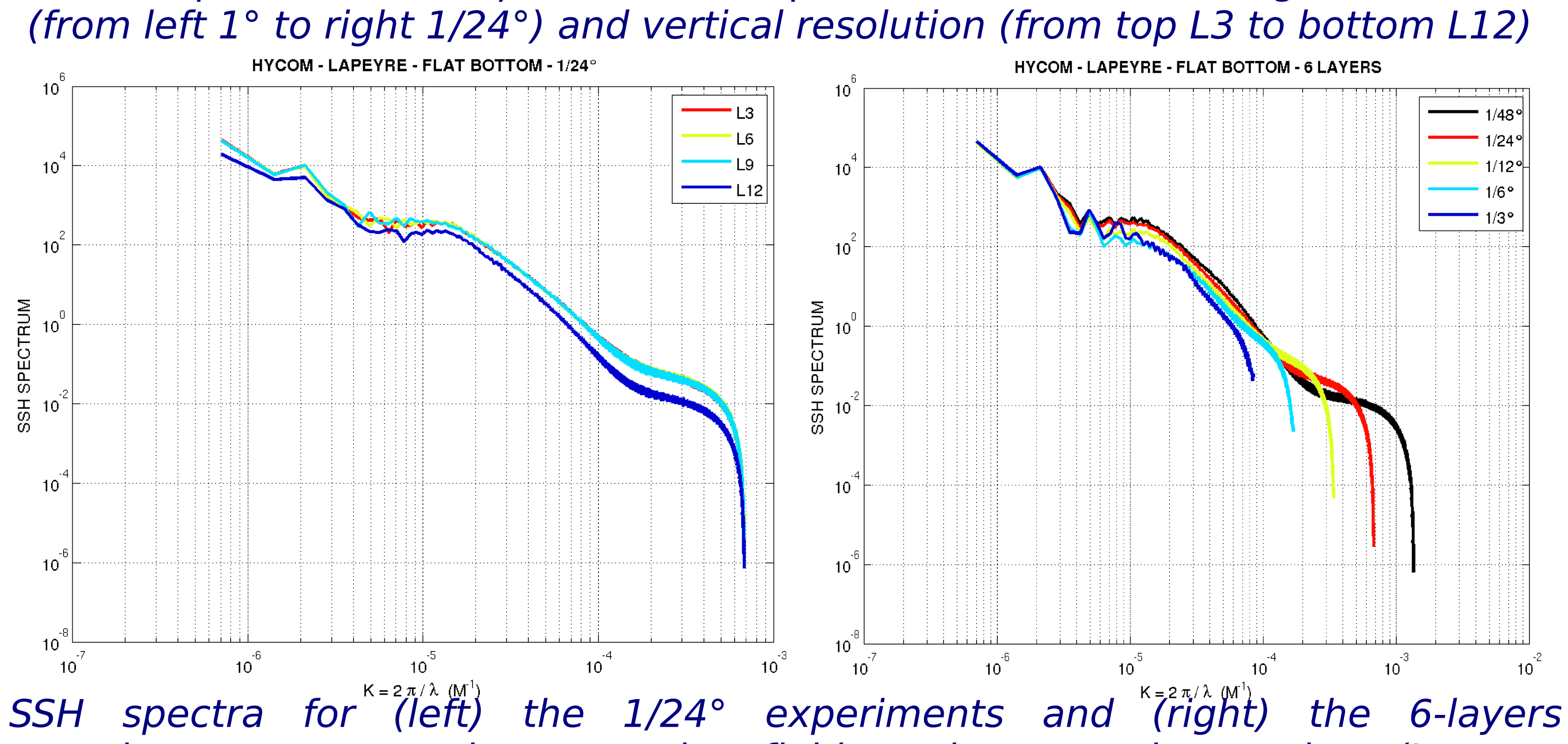




SSH total variability



SSH mean (contours, CI 2 cm) and standard deviation (colorbar, in cm, varies with experiments) computed from snapshot fields, for increasing horizontal (from left 1° to right 1/24°) and vertical resolution (from top L3 to bottom L12)

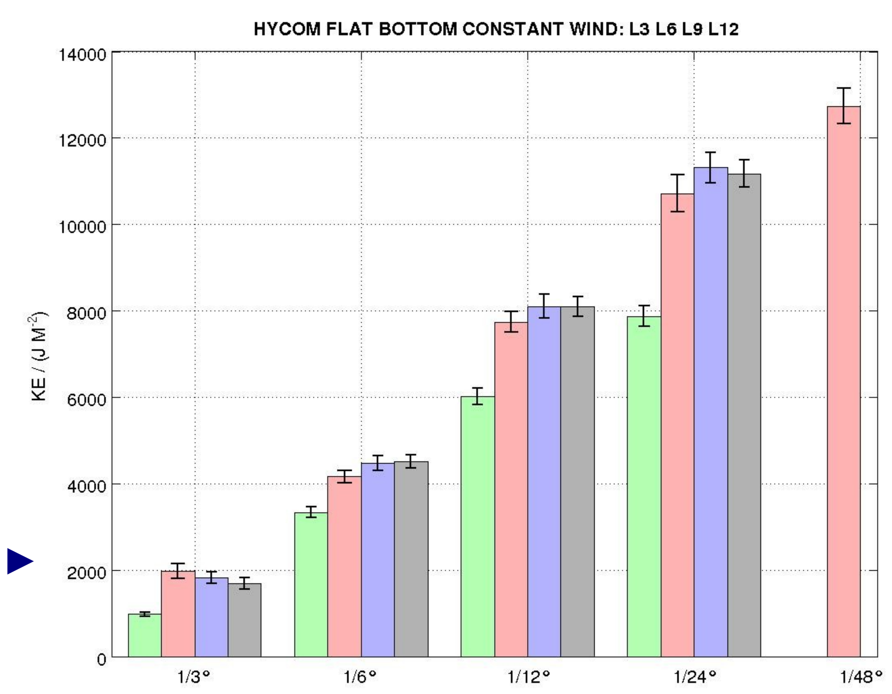


SSH spectra for (left) the 1/24° experiments and (right) the 6-layers experiments, computed on snapshot fields and averaged over time (Lapeyre 2009 method).

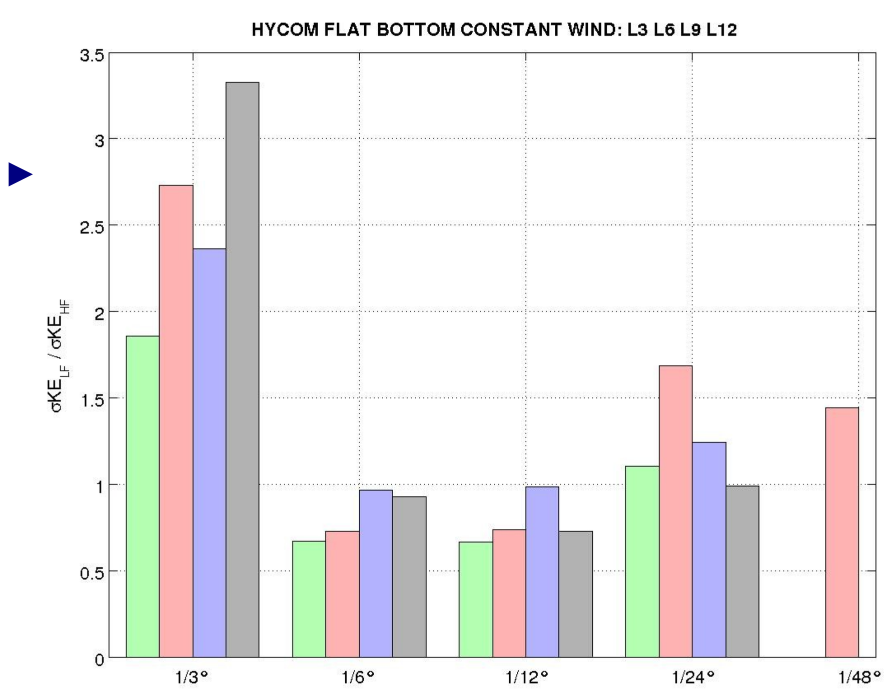
Total Kinetic Energy

Total Kinetic Energy (KE, mostly turbulent), computed online daily, shows variations on various time scales from interannual (low-frequency, LF hereafter, computed on annual means) to monthly (high frequency, HF hereafter, computed as the residual from running-mean annual means).

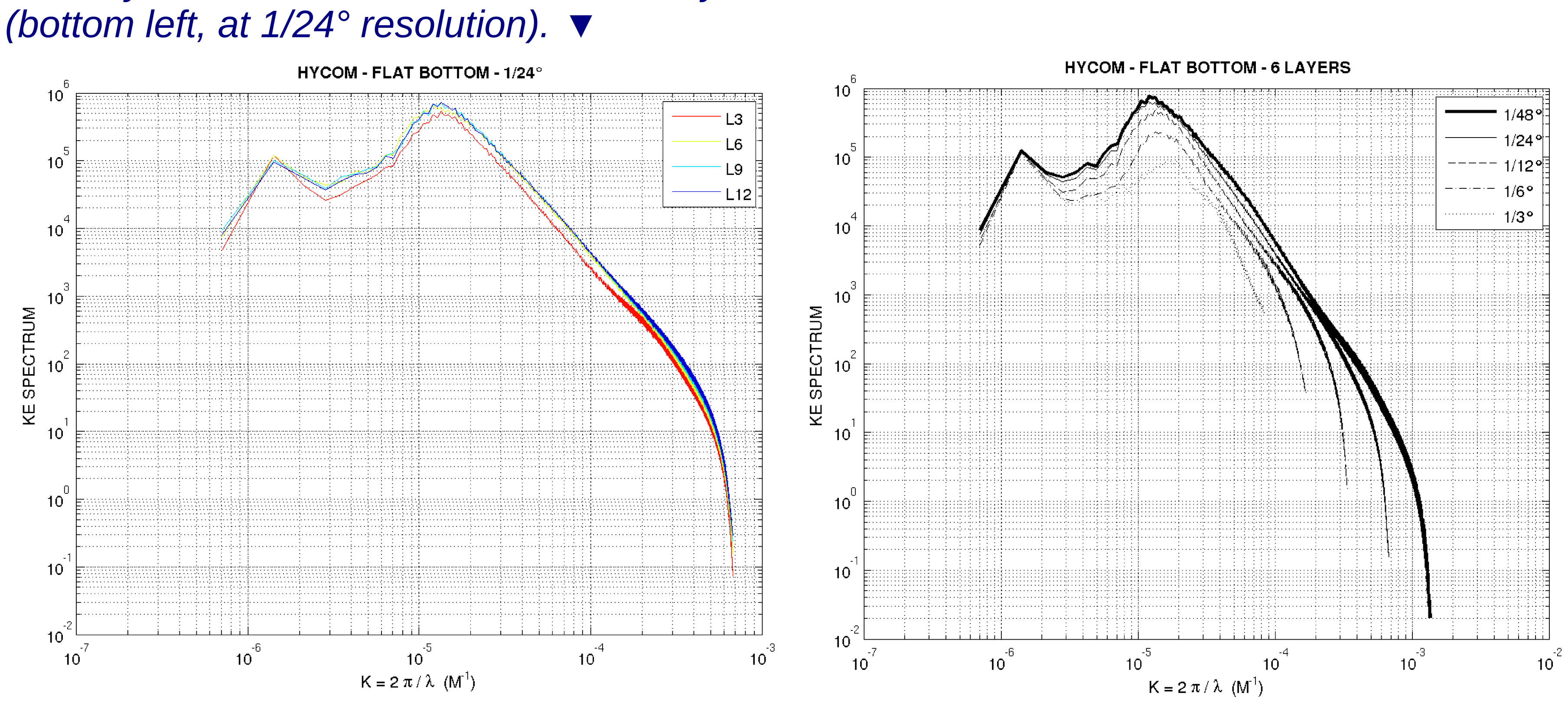
KE mean (bar) and standard deviation (error bar) show regular increase with horizontal resolution with no sign of convergence up to 1/48° (2.3 km). The 3-layer experiments (L3) show a large deficit of KE, mean&std, at all horizontal resolutions. ►



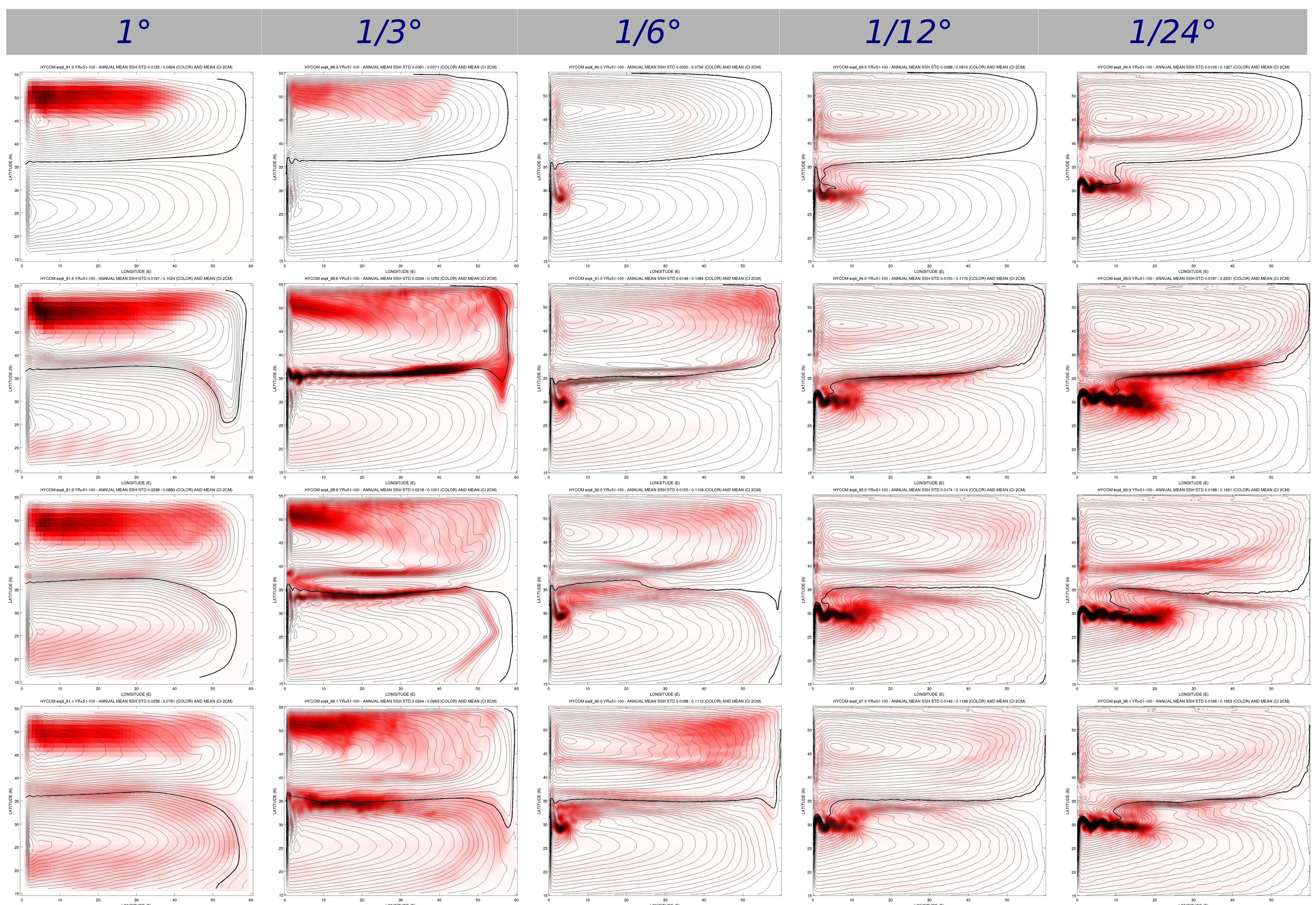
The relative amount of LF and HF variability largely varies among the experiments, it is measured here through the ratio of standard deviation of annual-mean KE (LF) over the std of the residual (HF). Only the 1/3° experiments show prominent LF variability due to insufficient resolution to allow mesoscale turbulence. ►



Energy spectra (bottom right, for the 6-layers case) show the amount of KE increases at all scales with increasing resolution, from the mesoscale (60 km) to the largest scale (3000 km). Depending on the method (Lapeyre 2009, Hanning/Tukey window..), spectra do not vary too much with the number of layers (bottom left, at 1/24° resolution). ▼



SSH low-frequency variability



SSH mean (contours, CI 2 cm) and standard deviation (same colorbar from 0 to 10 cm for all experiments) computed from annual mean fields, for increasing horizontal resolution (from left, 1°, to right, 1/24°) and increasing vertical resolution (from top, L3, to bottom, L12).

Perspectives

► The dominance of interannual variability at 1° to 1/3° horizontal resolution results from the weakness of mesoscale turbulence at such resolutions, even with efficient numerical schemes. The interannual signal can be found at higher resolutions, but is blurred by the intense mesoscale turbulence, such that some kind of filtering is required (EOFs...).

► Are there processes missing that would lead to reasonable convergence of total Kinetic Energy? One candidate could be variable bottom topography, that is critical in the potential vorticity balance. A series of experiments carried out with large-scale bottom topography (continental slope+Mid-Oceanic Ridge) already shows a smaller increase between 1/24° and 1/48° (+12% instead of +18%). Other processes related to the mixed layer and its submesoscale instability, or the coupling of wind stress and currents, may also be influential...

Contact: Thierry.Huck@univ-brest.fr
http://www.ifremer.fr/lpo/thuck/