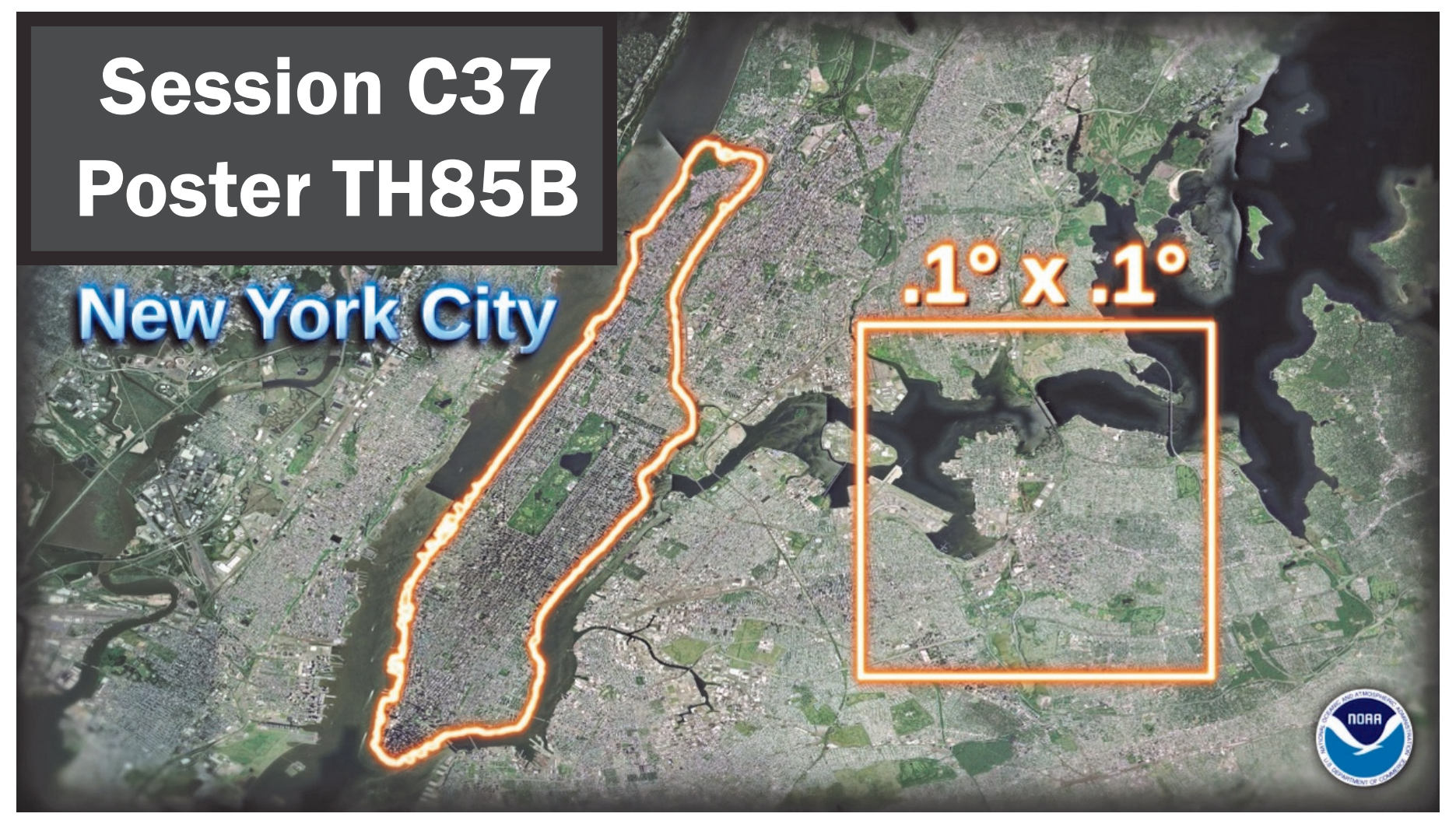

Ocean circulation features of the GFDL CM2.6 & CM2.5 high-resolution global coupled climate models

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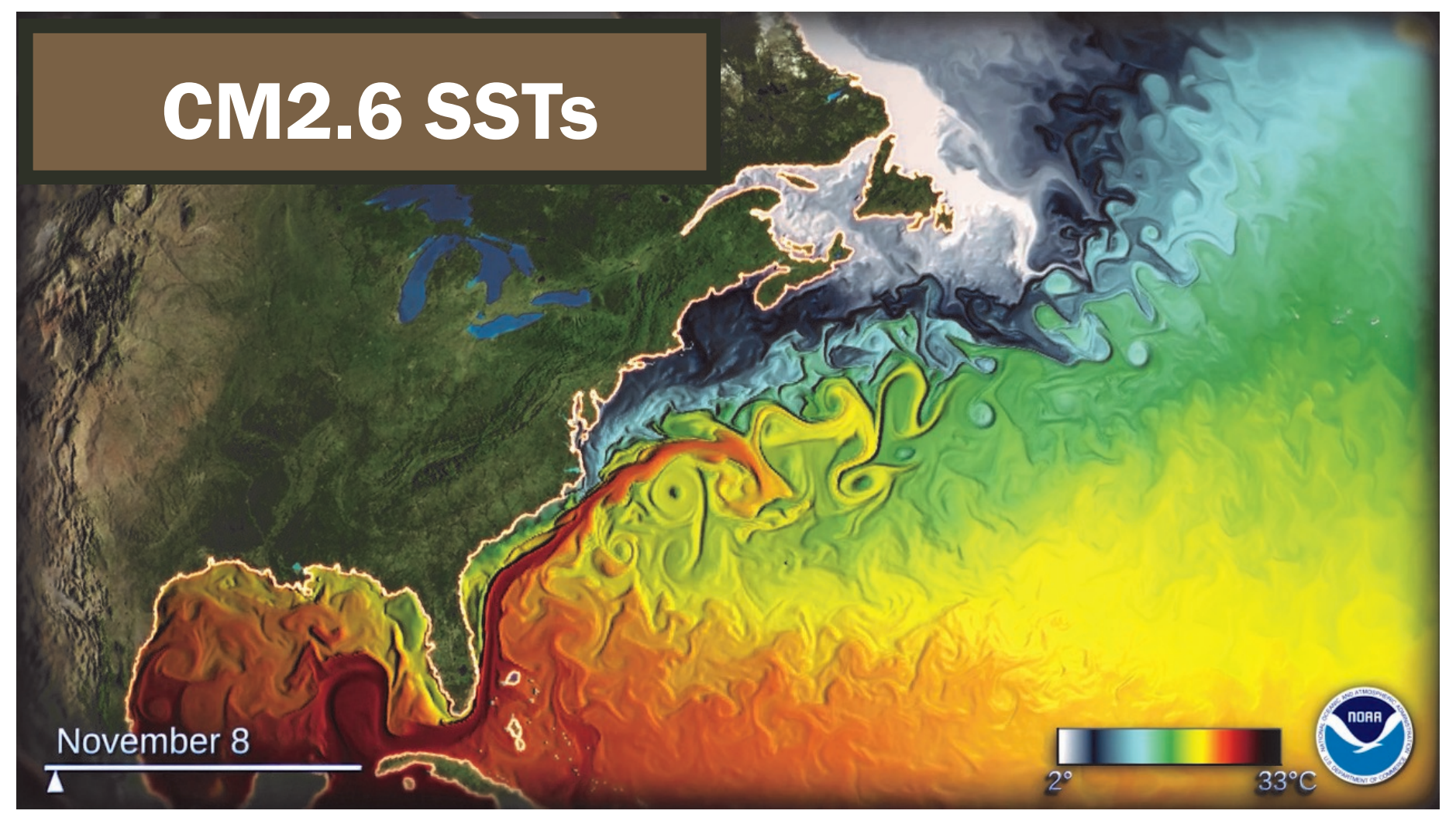

New models — new 'parameter space'

Sustained model development efforts and the availability of enhanced computer resources have allowed researchers at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) to construct a pair of new, higher resolution, global models of the coupled physical climate system. Known as CM2.5 and CM2.6, these models are being applied to problems spanning seasonal-to-interannual up to decadal-to-century time scales.

A goal of this development path is to explore a new 'parameter space' of global climate models at GFDL — one that includes very energetic ocean flows (see figure to right). In the ocean component, higher spatial resolution and model configuration choices together allow sharper gradients to be maintained than in prior models. We plan to use this suite of models to study topics including the role of ocean eddies in climate and climate change.

Grid resolution & model features

Based on MOM 4.1, the GFDL CM2.5 model's ocean resolution is nominally one-quarter of a degree. The CM2.6 model's ocean has horizontal resolution that is nominally one-tenth of a degree (see table below). While the global CM2.5 ocean model can be considered 'eddy-permitting', the CM2.6 model's ocean is 'eddy-resolving'. Both global climate models employ an atmospheric model with cubed sphere geometry having approximately 50km horizontal resolution (C180) and 32 vertical levels.

Summary of the grid resolutions used in the GFDL CM2.6 and CM2.5 global climate models. Also listed for comparison, the previous-generation GFDL CM2.1 model's grid resolution.

model	atmosphere	ocean
GFDL CM2.6 (currently 'beta' level)	50km cubed-sphere grid; 32 levels	'square grid': 11km at Equator, <5km at 65°, etc.; tri-polar north of 65°N; 50 z* levels
GFDL CM2.5 (Delworth *et al.*, 2011, J. Climate, in press)	50km cubed-sphere grid; 32 levels	'square grid': 28km at Equator, 12km at 65°, etc.; tri-polar north of 65°N; 50 z* levels
GFDL CM2.1 (Delworth *et al.*, 2006, J. Climate)	2° longitude by 2.5° latitude; 24 levels	1° longitude by 0.33-1° latitude; Tri-polar north of 65N; 50 vertical levels

CM2.6 & CM2.5: similar configurations

- No parameterization for the effect of meso-scale eddies.†
- Very low, scale-selective viscosity, no explicit lateral diffusion, no prescribed background vertical diffusion.
- Vertical mixing is determined by K-profile parameterization (KPP) scheme (Large *et al.*, 1994).
- Schemes for internal tide mixing (Simmons *et al.*, 2006) & coastal tide mixing (Lee *et al.*, 2006).
- Use of higher-order monotonic advection scheme.
- The ocean and atmosphere model components exchange updated surface fluxes once an hour.

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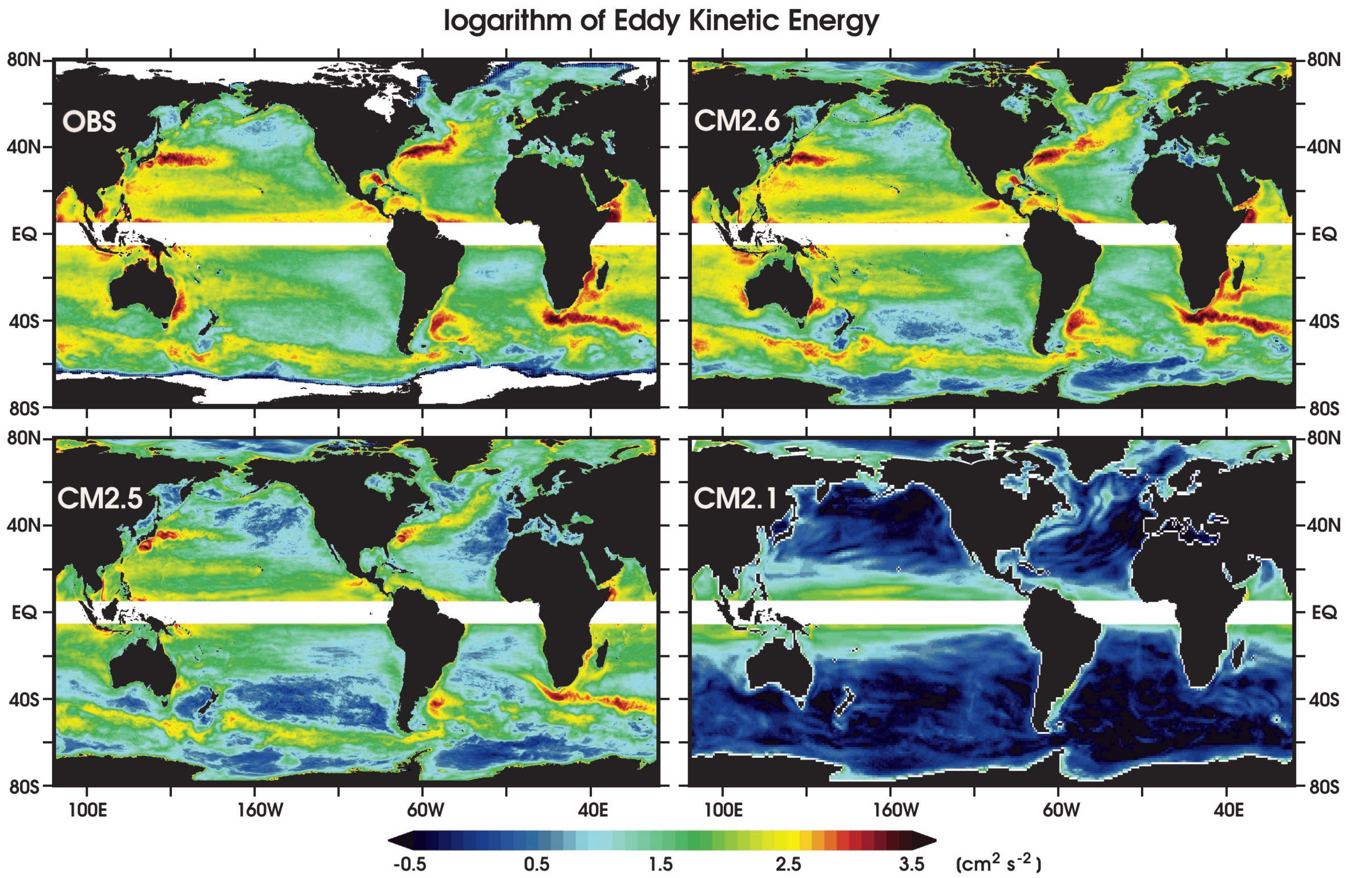
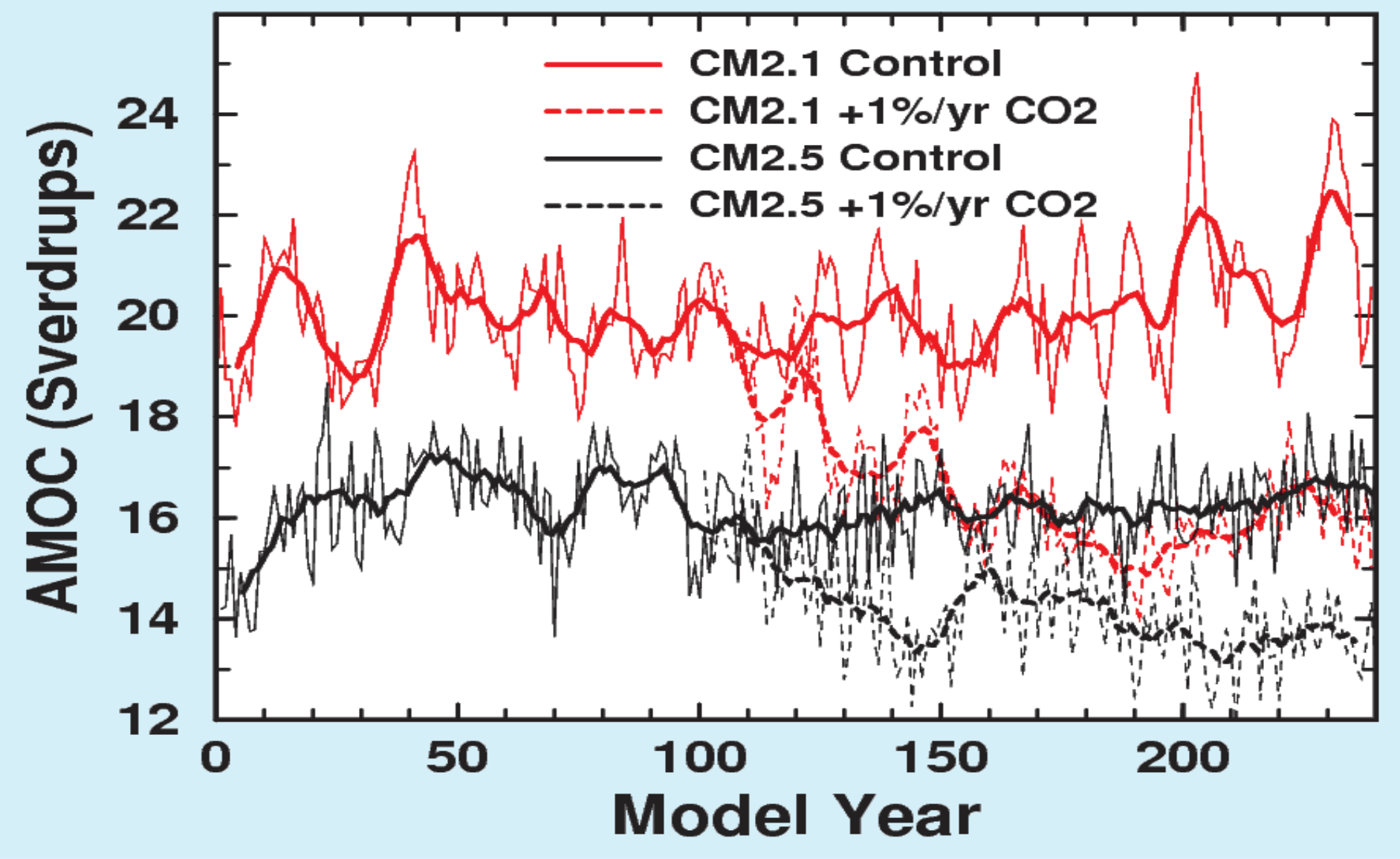
† Though not optimal for an eddy-permitting model such as CM2.5, omitting a meso-scale eddy parameterization facilitates comparisons of CM2.5 with CM2.6's eddy-resolving ocean simulation.



Above: Eddy kinetic energy (EKE) is calculated from sea surface heights (SSH) available from satellite observations (LeTraon *et al.*, 1998) and from three GFDL climate models. SSHs are sampled once every 7 days for five years. Near-surface currents are deduced from SSH fields assuming geostrophy. Eddy velocities are computed as deviations from the long term mean, from which EKE is calculated.

The map of observed EKE shows rich structure, with high EKE in boundary currents and some interior areas. The eddy-resolving CM2.6 model does an excellent job of simulating the observations in pattern and magnitude. CM2.5's EKE pattern resembles observations, but is somewhat lower in magnitude. In contrast, the coarse resolution CM2.1 model forms no eddies, except in parts of the deep tropics.



Above: thin lines = annual AMOC values, thick lines = 10 year means. 'Control' experiments (solid) are run with 1990 forcing conditions. CO_2 is increased 1% yr^{-1} compounded to doubling (70 yr) & then held constant in the '+1%/yr CO_2' warming experiments (dashed).

Simulating the AMOC in a warming world

Though CM2.5's ocean is more energetic overall, the Atlantic Meridional Overturning Circulation (AMOC) is more vigorous and variable in the coarser resolution CM2.1 model. However, in both CM2.5 and CM2.1, the poleward heat flux in the Atlantic basin peaks at about $1.0x10^{15}$ Watts (1PW) - a value less than the ~1.3PW of recent observational estimates (Johns *et al.*, 2011).

In idealized +1% yr^{-1} CO_2 experiments, the AMOC weakens more in CM2.1 (-25%) than in CM2.5 (-15%) (fig. to left). Accordingly, surface temperatures in the subpolar North Atlantic warm more quickly in CM2.5.

Additional studies are exploring the sensitivity of CM2.5's Atlantic circulation (time mean and internal variability) to Denmark Strait bathymetry (Zhang *et al.*, 2011) and Labrador Sea stratification.

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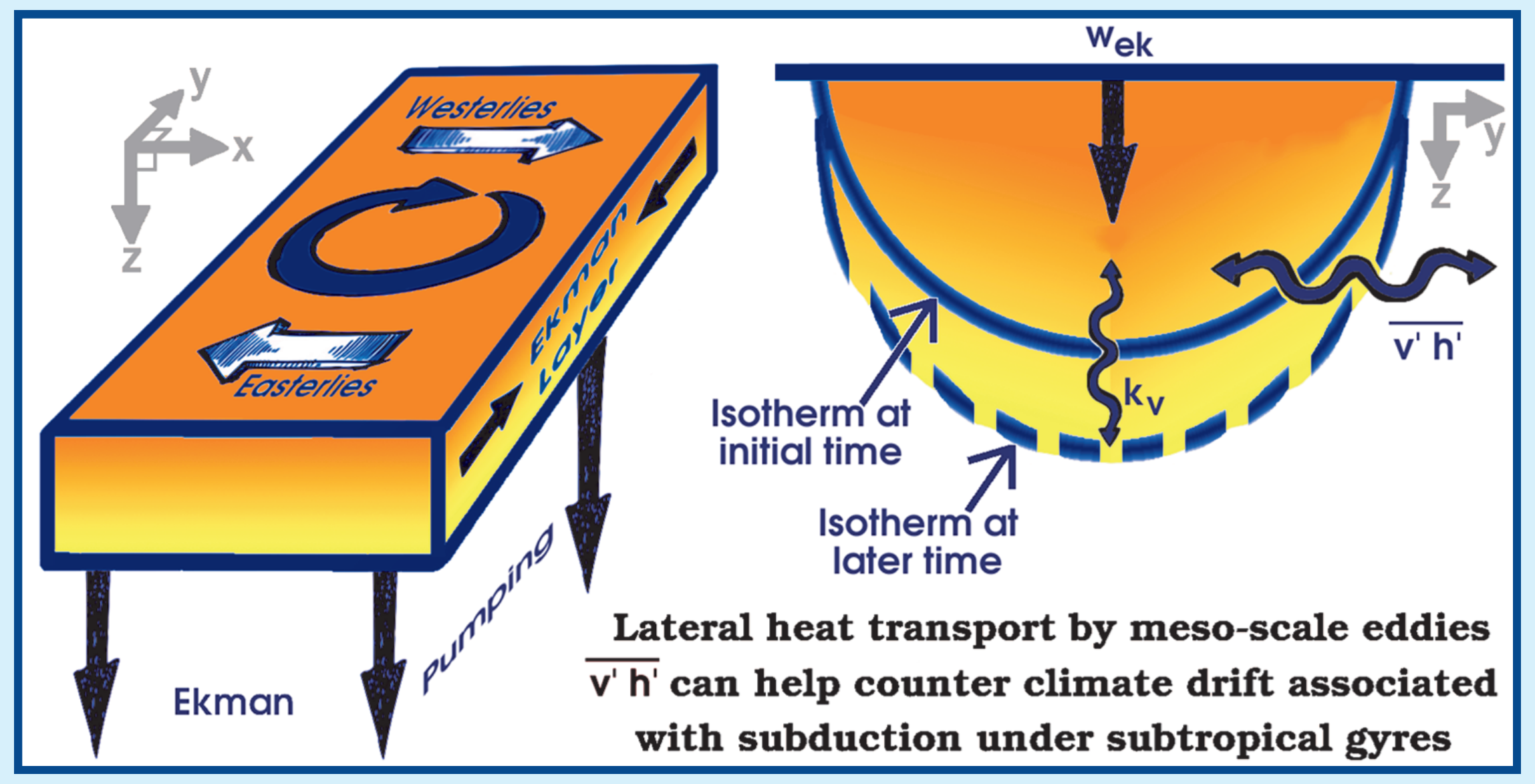
A link between eddies & climate drift?

Similar temperature drift patterns are seen early in each of the CM2.1, CM2.5, and CM2.6 control experiments. The global mean ocean drift is characterized by a cool bias appearing in the upper 200m and a warm bias developing between depths of 500 and 900m. The subsurface warming maxima occur in the subtropical gyres. Both the surface cooling and subsurface warming are greater in CM2.5 than in either CM2.1 or CM2.6.

A hypothesis is that wind-driven subduction in the subtropical gyres deepens the thermocline, leading to subsurface warming and enhanced horizontal temperature gradients at depth. The warming continues until other processes are strong enough to balance it. We suspect that lateral heat transport by meso-scale eddies is a key part of this balance (see schematic below). Subduction-enhanced horizontal temperature gradients around the deepened gyres should enhance meso-scale activity. However, if a model lacks sufficient lateral eddy heat transport ($\overline{v'h'}$), it follows that the thermocline would continue to deepen, implying a prolonged movement of heat from the near-surface to the interior.

This hypothesis is consistent with the drift being largest in CM2.5 - a model that does not fully resolve eddies and which has no meso-scale parameterization. Less drift is seen in the eddy-resolving CM2.6 model and in CM2.1 (which uses a variant of the G-M [Gent & McWilliams, 1990] parameterization of eddy effects). An additional CM2.1 experiment without G-M exhibits more than twice the rate of drift of the standard CM2.1 run - also consistent with the hypothesis. More tests will explore the extent to which this mechanism leads to climate drift.



Lateral heat transport by meso-scale eddies $\overline{v'h'}$ can help counter climate drift associated with subduction under subtropical gyres

References

Delworth, T.L., *et al.*, 2006: GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. *Journal of Climate*, 19, 634-674.

Delworth, T.L., *et al.*, 2011: Simulated climate and climate change in the GFDL CM2.5 high resolution coupled climate model. *Journal of Climate*, (in press).

Gent, P.R., and J.V. McWilliams, 1990: Isopycnal Mixing in Ocean Circulation Models. *J. Phys. Oceanogr.*, 20, 150-155.

Johns, W.E., *et al.*, 2011: Continuous, array-based 1497 estimates of Atlantic Ocean heat transport at 26.5°N, *Journal of Climate*, (in press).

Large, W.G., *et al.*, 1994: Ocean vertical mixing: A review and a model with a nonlocal boundary layer parameterization. *Rev. of Geophysics*, 32, 363-403.

Lee, H.C., *et al.*, 2006: Barotropic tidal mixing effects in a coupled climate model: Oceanic conditions in the N. Atlantic. *Ocean Modelling*, 11, 467-477.

Le Traon, P. Y., *et al.*, 1998: An Improved Mapping Method of Multisatellite Altimeter Data. *J. Atmos. Oceanic Technol.*, 15, 522–534.

Simmons, H., *et al.*, 2006: Tidally driven mixing in a numerical model of the ocean general circulation. *Ocean Modelling*, 6, 245-263.

Zhang, R., *et al.*, 2011: Sensitivity of the North Atlantic Ocean Circulation to an Abrupt Change in the Nordic Sea Overflow in a High Resolution Global Coupled Climate Model. *JGR - Oceans* (in press).