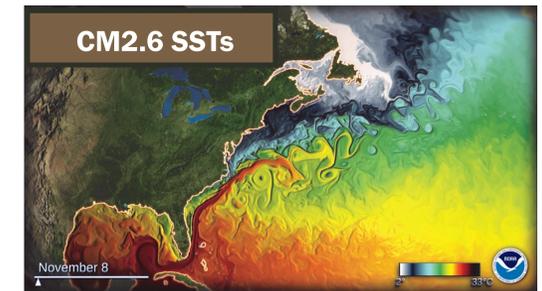




Ocean circulation features of the GFDL CM2.6 & CM2.5 high-resolution global coupled climate models

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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 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.

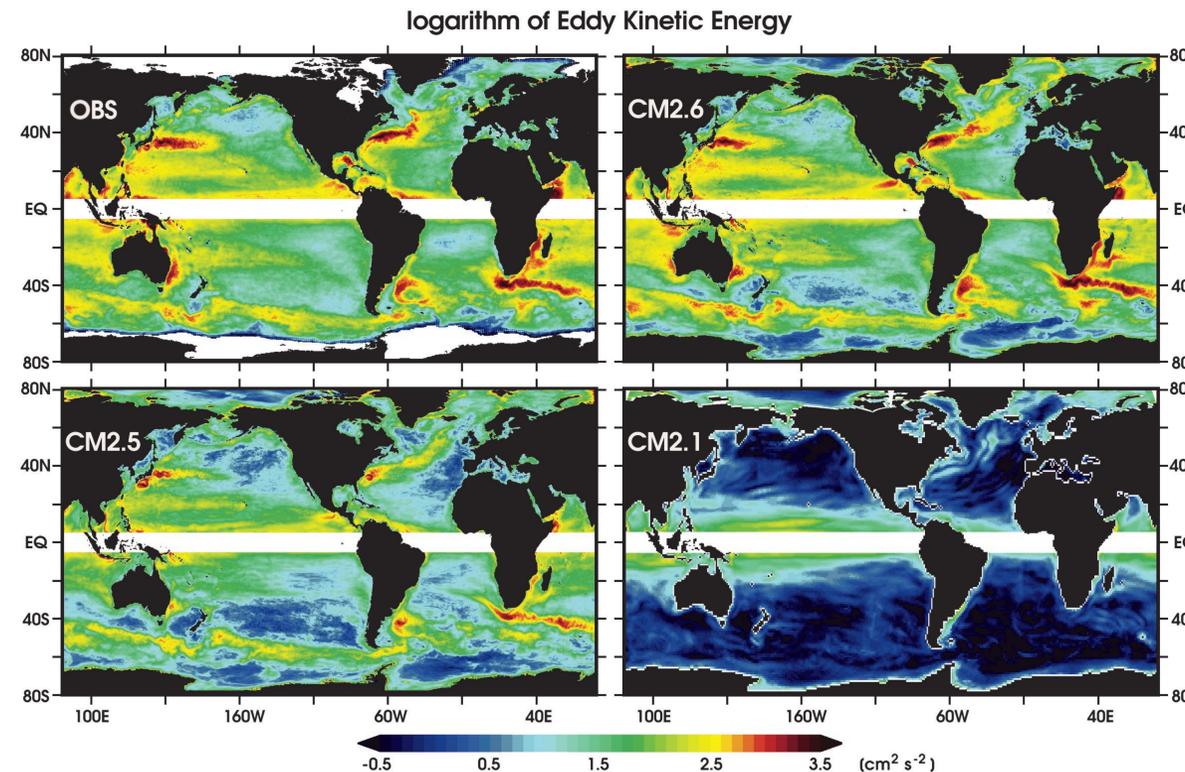
Summary of the grid resolutions used in the GFDL CM2.6 and CM2.5 global climate models. Also listed for comparison, the previous-generation GFDL CM2.1 model's grid resolution.

model	atmosphere	ocean
GFDL CM2.6 (currently 'beta' level)	50km cubed-sphere grid; 32 levels	~10km in tropics to 3km in polar areas (square) tri-polar; 50 levels
GFDL CM2.5 (Delworth et al., 2011, J. Climate, in press)	50km cubed-sphere grid; 32 levels	~25km in tropics to 9km in polar areas (square) tri-polar; 50 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; 50 vertical levels

CM2.6 & CM2.5: common ocean features

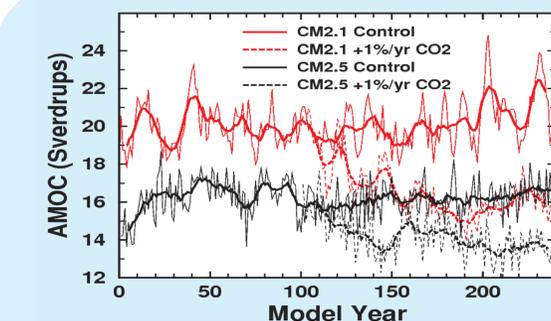
- ▶ No parameterization for the effect of meso-scale eddies.†
- ▶ No explicit lateral diffusion and no prescribed background vertical diffusion.
- ▶ Vertical mixing is determined by K-profile parameterization (KPP) scheme (Large, et al., 1994).
- ▶ Schemes for internal tide mixing (Simmons, et al., 2006)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

† 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 the three GFDL climate models and satellite observations (LeTraon et al., 1998). 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. CO2 is increased 1% yr⁻¹ compounded to doubling (70 yr) & then held constant in the '+1%/yr CO2' 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 in the coarser resolution CM2.1 model. However, in both CM2.5 and CM2.1, the oceanic poleward heat flux in the Atlantic peaks at about 1.0x10¹⁵ Watts (1PW) - a value less than the ~1.3PW of recent observational estimates (Johns et al., 2011).

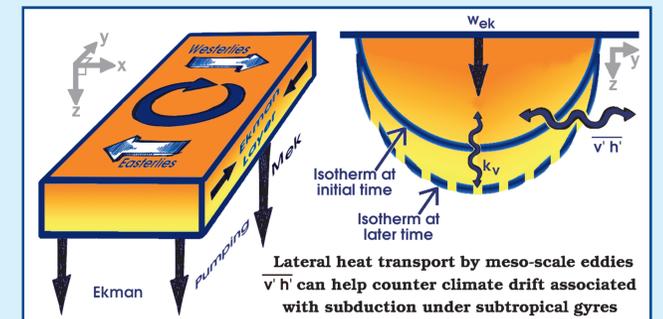
In idealized +1% yr⁻¹ CO₂ experiments, the AMOC weakens more in CM2.1 (-25%) than in CM2.5 (-15%) (fig. to left). Accordingly, surface temperatures in the subpolar North Atlantic warm more quickly in CM2.5. Ongoing studies are exploring the sensitivity of CM2.5's Atlantic circulation (time mean and internal variability) to Denmark Strait bathymetry (Zhang, et al., 2011) and Labrador Sea stratification.

A link between eddies & climate drift?

A similar temperature drift pattern is 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 increasing 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 which does not fully resolve eddies and which has no meso-scale parameterization. Less drift is seen in CM2.6 (which explicitly resolves meso-scale eddies) and 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 (reducing $\overline{v'h'}$) exhibits more than twice the rate of drift of the standard CM2.1 run - also consistent with the hypothesis.



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