Ocean Modeling II

Parameterized Physics

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NCAR

PARAMETERIZATIONS IN CESM2 POP2

- Vertical mixing (momentum and tracers)
  - surface boundary layer
  - interior
- Lateral mixing: mesoscale eddies (tracers)
- Horizontal viscosity (momentum)
- Overflows
- Submesoscale eddies (tracers)
- Estuary box model parameterization
- Solar absorption

VERTICAL MIXING SCHEME: K-PROFILE PARAMETERIZATION (KPP)

1994

- Unresolved turbulent vertical mixing due to small-scale overturning motions parameterized as a vertical diffusion.

- Guided by study and observations of atmospheric boundary layer

$$\partial_t X = -\partial_z \overline{w'X'} \xrightarrow{\text{parameterize}} \overline{w'X'} = -K_x \partial_z X$$

where K_x represents an "eddy diffusivity" or "eddy viscosity"

VERTICAL MIXING SCHEME: K-PROFILE PARAMETERIZATION (KPP)

- KPP is not just a vertical diffusion scheme because the scalars (Temp and Salinity) have non-local or "countergradient" terms γ_x

$$\overline{w'X'} = -K_x(\partial_z X - \gamma_x)$$

- KPP involves three high-level steps:
  1. Determination of the boundary layer (BL) depth: *d*
  2. Calculation of interior diffusivities: υ_x
  3. Evaluation of boundary layer (BL) diffusivities: K_x

- Diffusivity throughout the boundary layer depends on the surface forcing, the boundary layer depth, and the interior diffusivity.

- KPP produces quite large diffusivities below the boundary layer, which mixes temp and salinity quite deep in times of very strong surface wind stress, such as strong midlatitude atmosphere storms.

VERTICAL MIXING SCHEME: K-PROFILE PARAMETERIZATION (KPP)

I. BL depth *d* is minimum depth where the bulk Richardson # (Ri_b) referenced to the surface equals a critical Richardson # (Ri_{cr}=0.3).

$$Ri_b(d) = \frac{\left[B_r - B(d)\right]d}{\left|\mathbf{V}_r - \mathbf{V}(d)\right|^2 + V_t^2(d)}$$

Stabilizing buoyancy difference

Destabilizing velocity shear

unresolved shear

B_r : near-surface reference buoyancy

$\mathbf{V}_r$: near-surface reference horizontal velocity

$V_t(d)$: velocity scale of (unresolved) turbulent shear at depth *d*

Ri measures the stability of stratified shear flow. "Boundary layer eddies with mean velocity $\mathbf{V}_r$ and buoyancy B_r should be able to penetrate to the boundary layer depth, *d*, where they first become stable relative to the local buoyancy and velocity."

VERTICAL MIXING SCHEME:
K-PROFILE PARAMETERIZATION (KPP)

2. Calculation of interior diffusivities

$$\upsilon_x(d) = \upsilon_x^s(d) + \upsilon_x^w(d) + \upsilon_x^d(d) + \upsilon_x^c(d) + \upsilon_x^t(d)$$

υ_x : interior diffusivity at depth *d* (below the boundary layer)

υ_x^s : (unresolved) shear instability

υ_x^w : internal wave breaking

υ_x^d : double diffusion

υ_x^c : local static instability (convection)

υ_x^t : tidal mixing

Superposition of processes sets interior vertical diffusivity, υ_x, below the surface boundary layer.

VERTICAL MIXING SCHEME:
K-PROFILE PARAMETERIZATION (KPP)

Verification example at Ocean Weather Station Papa (50°N, 145°W):

Large et al (1994)

Equatorial Circulation of a Global Ocean Climate Model with Anisotropic Horizontal Viscosity

William G. Large, Gokhan Danabasoglu, James C. McWilliams, Peter R. Gent, and Frank O. Bryan

National Center for Atmospheric Research, Boulder, Colorado

JPO 2001

(Manuscript received 6 August 1999, in final form 3 May 2000)

LAPLACIAN HORIZONTAL VISCOSITY

Isotropic, spatially varying coefficient in Cartesian coordinates

$$D(U) = (A\, U_x)_x + (A\, U_y)_y$$

$$D(V) = (A\, V_x)_x + (A\, V_y)_y$$

ANISOTROPIC HORIZONTAL VISCOSITY

$$\partial_t u + \ldots = \partial_x (A \partial_x u) + \partial_y (B \partial_y u)$$

$$\partial_t v + \ldots = \partial_x (B \partial_x v) + \partial_y (A \partial_y v)$$

Need the viscosity matrix to be symmetric in order to satisfy a number of constraints on the viscosity.

Small *B* in *u* equation does not diffuse strong, but thin, equatorial currents, such as the equatorial undercurrent.

Small *B* in *v* equation does not diffuse strong, but thin, western boundary currents, such as the Gulf Stream.

Mesoscale eddy mixing of tracers: Gent-McWilliams (GM) parameterization

150 JOURNAL OF PHYSICAL OCEANOGRAPHY VOLUME 20

1990

Isopycnal Mixing in Ocean Circulation Models†

PETER R. GENT AND JAMES C. MCWILLIAMS

National Center for Atmospheric Research, Boulder, Colorado*

20 March 1989 and 14 August 1989

ABSTRACT

A subgrid-scale form for mesoscale eddy mixing on isopycnal surfaces is proposed for use in non-eddy-resolving ocean circulation models. The mixing is applied in isopycnal coordinates to isopycnal layer thickness, or inverse density gradient, as well as to passive scalars, temperature and salinity. The transformation of these mixing forms to physical coordinates is also presented.

2011

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The Gent–McWilliams parameterization: 20/20 hindsight

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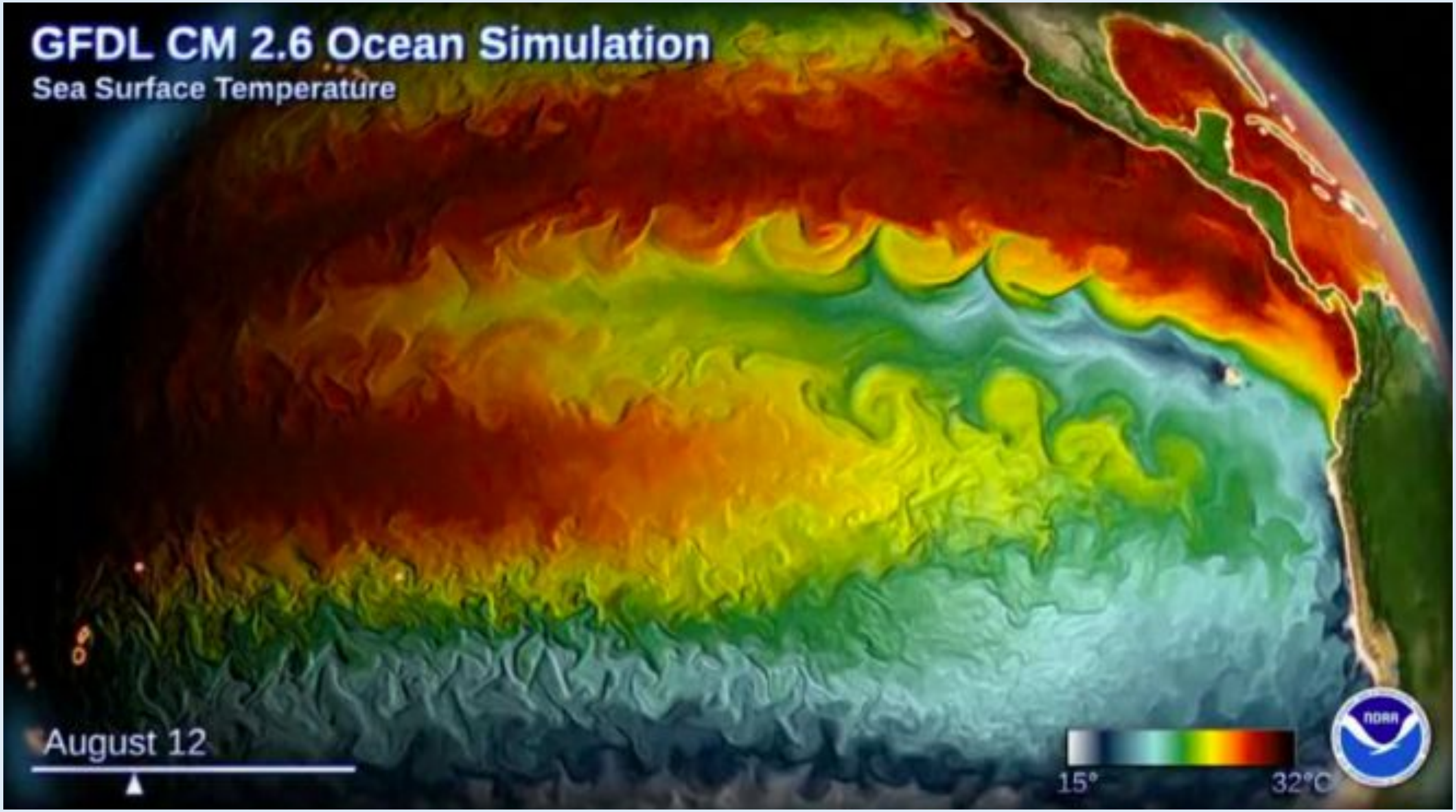
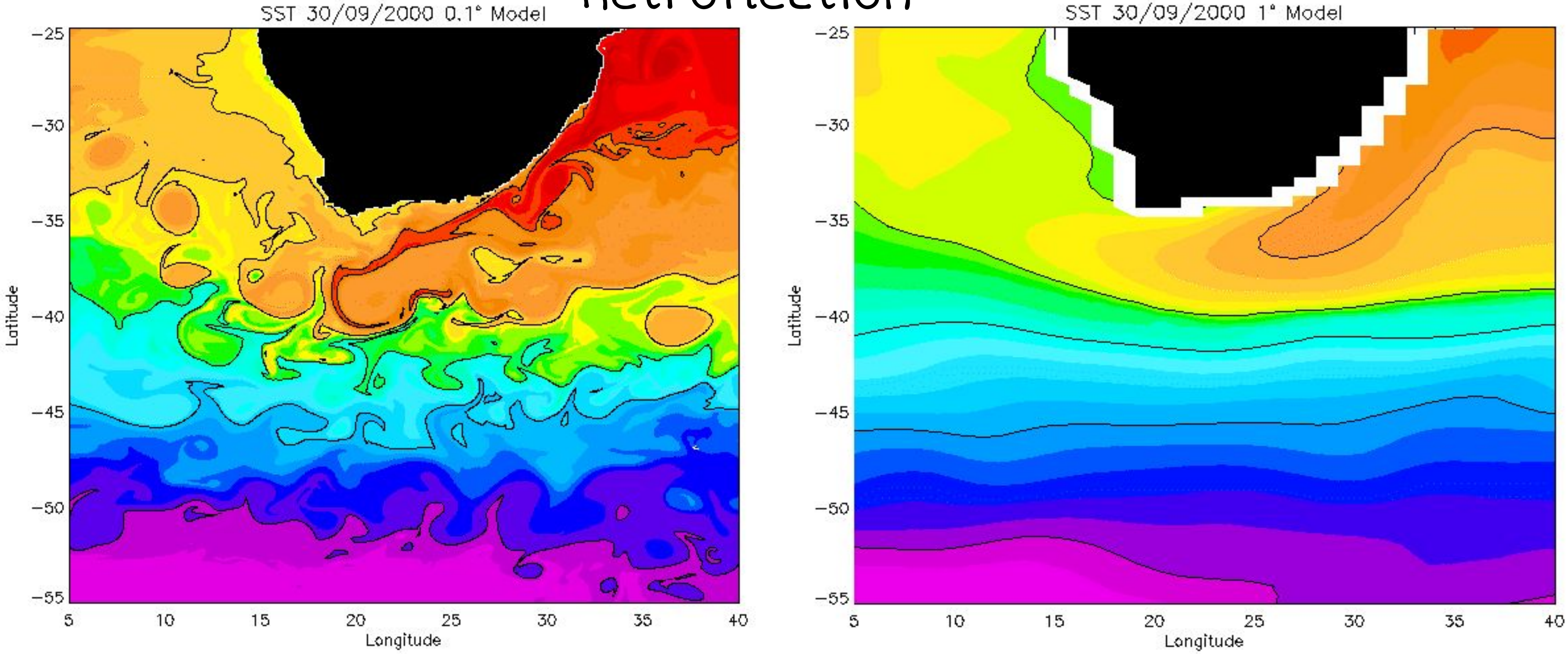


GFDL climate model with ocean resolution of 0.1°

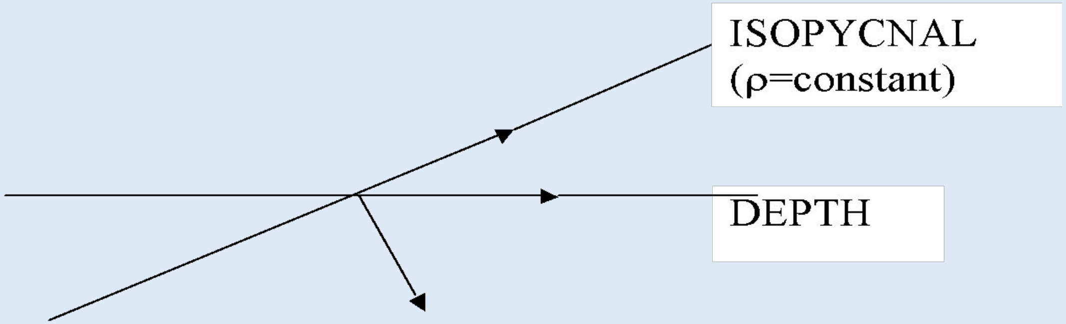
Why is GM needed?

Agulhas Retroflection



O(1°) models do not resolve the 1st baroclinic deformation radius away from the equatorial regions, and hence lack the mesoscale turbulence which mixes temperature, salinity and passive tracers in the real ocean.

Why is GM needed?



Isopycnal slopes are small $O(10^{-3})$ at most

Ocean Observations suggest mixing along isopycnals is $\sim 10^7$ times larger than across isopycnals.

- Early ocean models parameterized the stirring effects of (unresolved) mesoscale eddies by Laplacian *horizontal* diffusion with $K_H = O(10^3\ m^2/s)$, whereas the vertical mixing coefficient $K_v = O(10^{-4}\ m^2/s)$.

- Horizontal mixing results in excessive diapycnal mixing, which degrades the ocean solution: e.g. Veronis (1975) showed that it produces spurious upwelling in western boundary current regions which "short circuits" the N. Atlantic MOC.

- Thus, was a recognized need to orient tracer diffusion in z-coordinate models along isopycnal surfaces, to be consistent

The GM Parameterization

$$\frac{\partial T}{\partial t} + (\underline{u} + \underline{u}^*).\underline{\nabla} T = \kappa \nabla_{\rho}^{2} T$$

$$w^* = -\underline{\nabla}.(\kappa \underline{\nabla} \rho / \rho_z), \underline{\nabla}.\underline{u}^* = 0.$$

GM (1990) proposed an eddy-induced velocity $\underline{u}^*$ in addition to diffusion along isopycnal surfaces.

GM impacts

Gent et al. (JPO, 1995): Eddy-induced velocity (v*,w*) acts to flatten isopycnals and minimize potential en

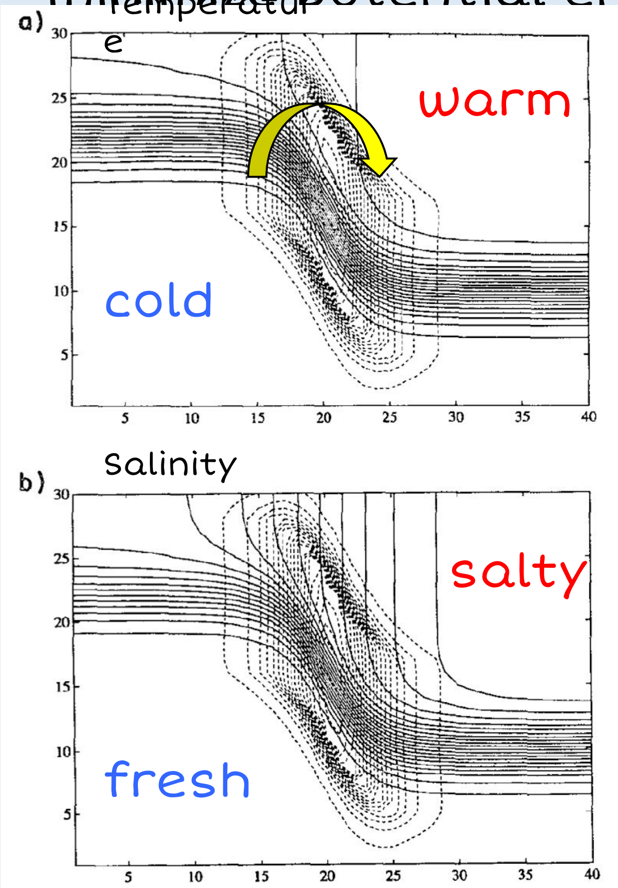


FIG. 3. Initial states of (a) temperature and (b) salt [contour interval one-quarter that of (a)]. Both panels also show the streamfunction $\kappa\rho_x/\rho_z$ for the parameterized eddy-induced transport velocity.

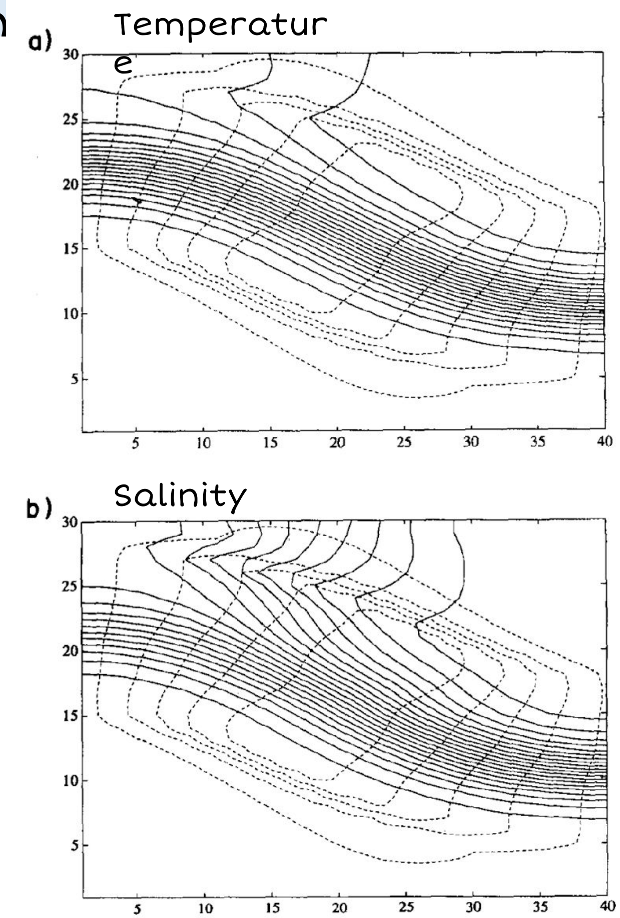


FIG. 4. Distributions of (a) temperature and (b) salt after an integration time of $20\Delta s^2/\kappa$. Both panels also show the streamfunction $\kappa\rho_x/\rho_z$ for the parameterized eddy-induced transport velocity. Contour intervals are the same as in Fig. 3.

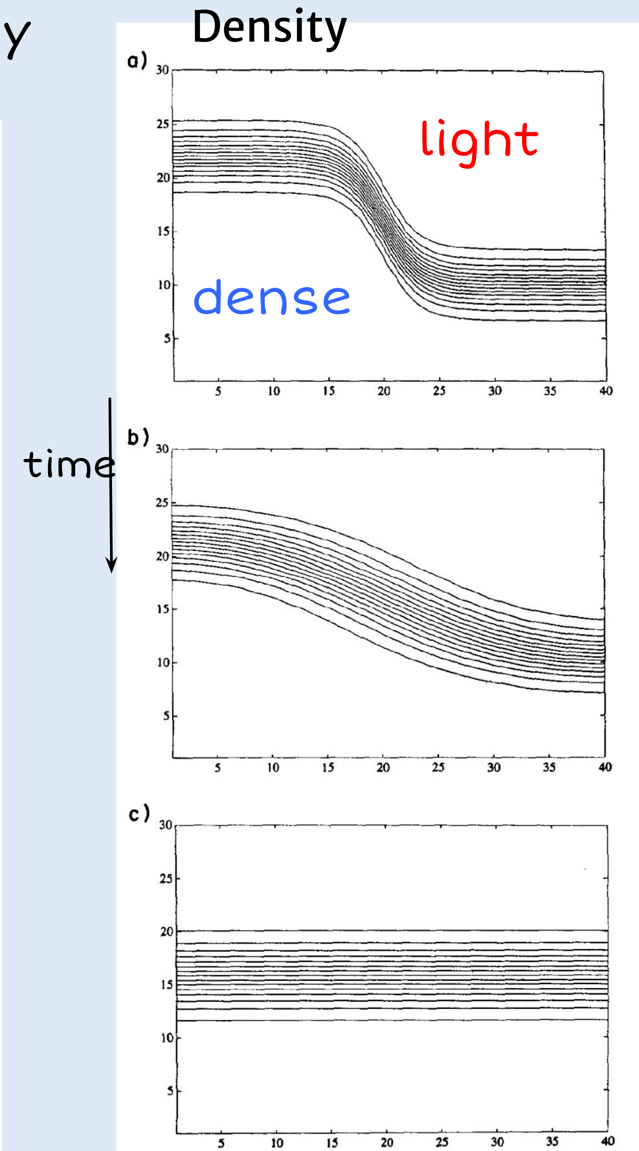
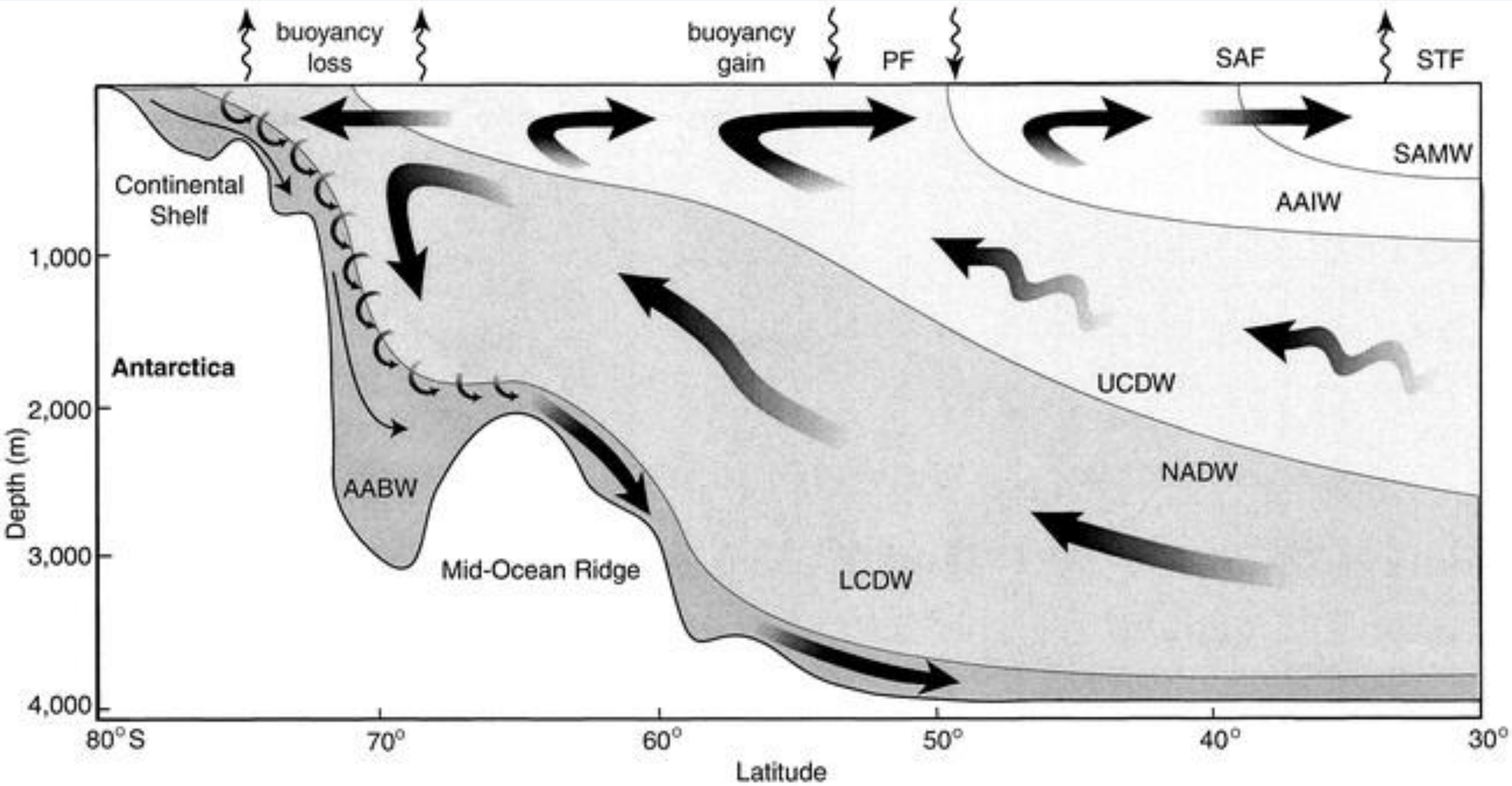


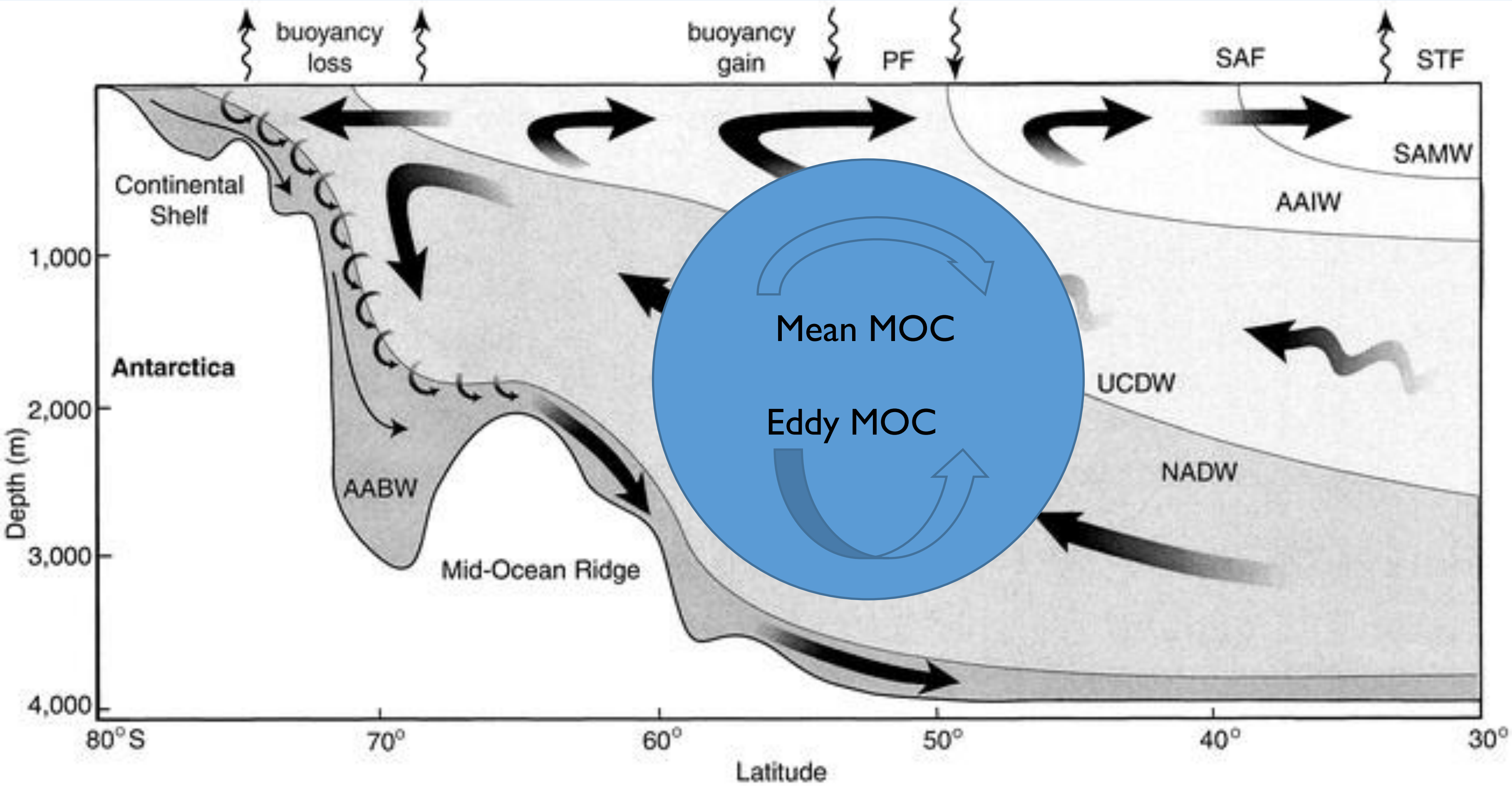
FIG. 5. Density distribution at various times of the integration. (a) Initial, (b) $20\Delta s^2/\kappa$, and (c) $1000\Delta s^2/\kappa$.

Southern Hemisphere zonal wind jet



Baroclinic instability produces ACC eddies that try to flatten the isopycnals and produce a MOC that opposes the mean flow MOC.

Southern Hemisphere zonal wind jet



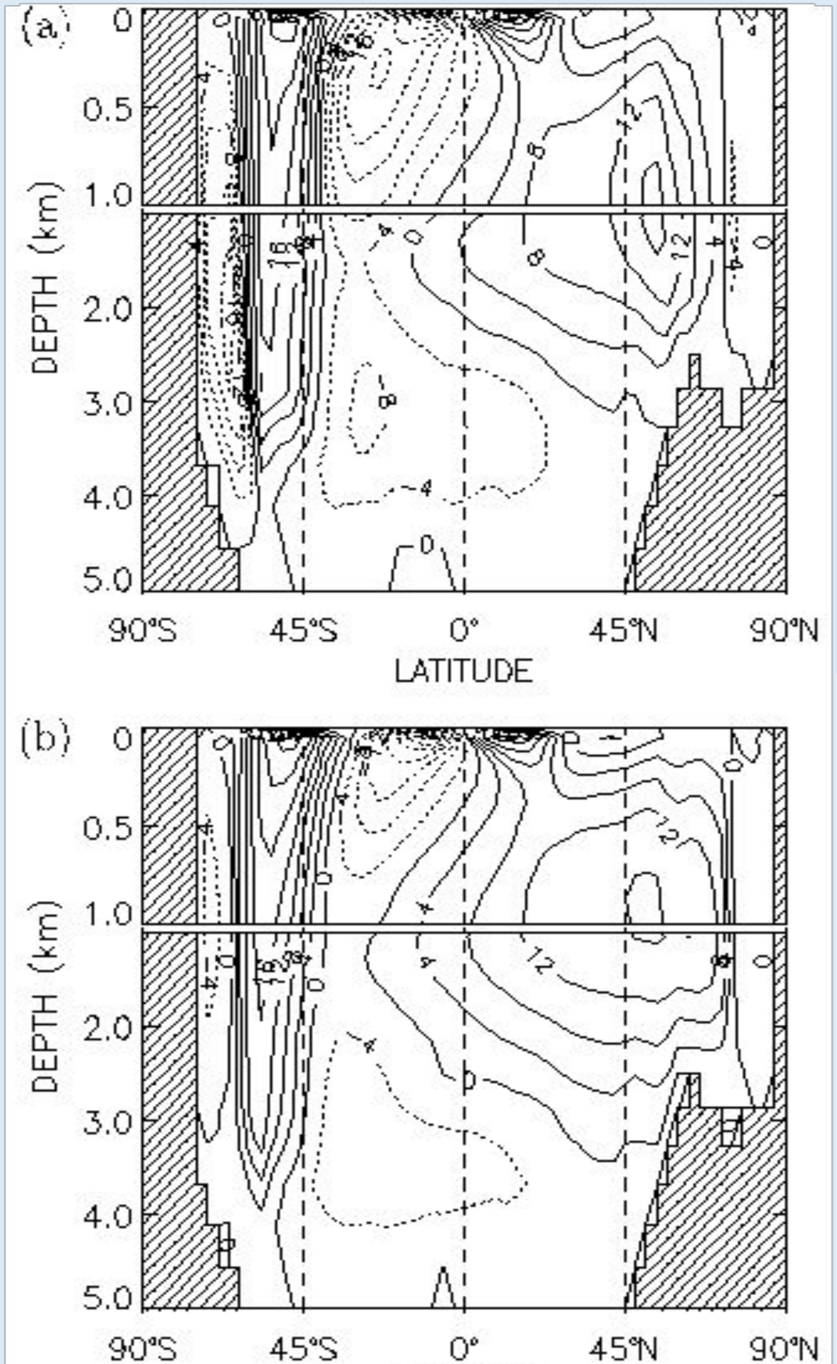
Baroclinic instability produces ACC eddies that try to flatten the isopycnals and produce a MOC that opposes the mean flow MOC.

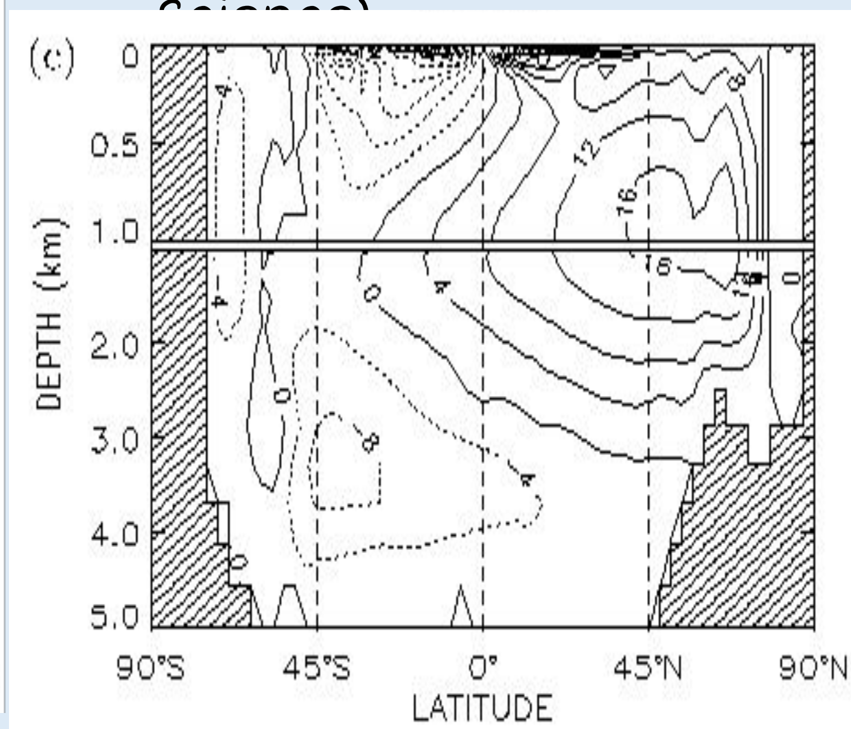
Impacts of GM

(a) Horizontal Diffusion, MOC (**u**)

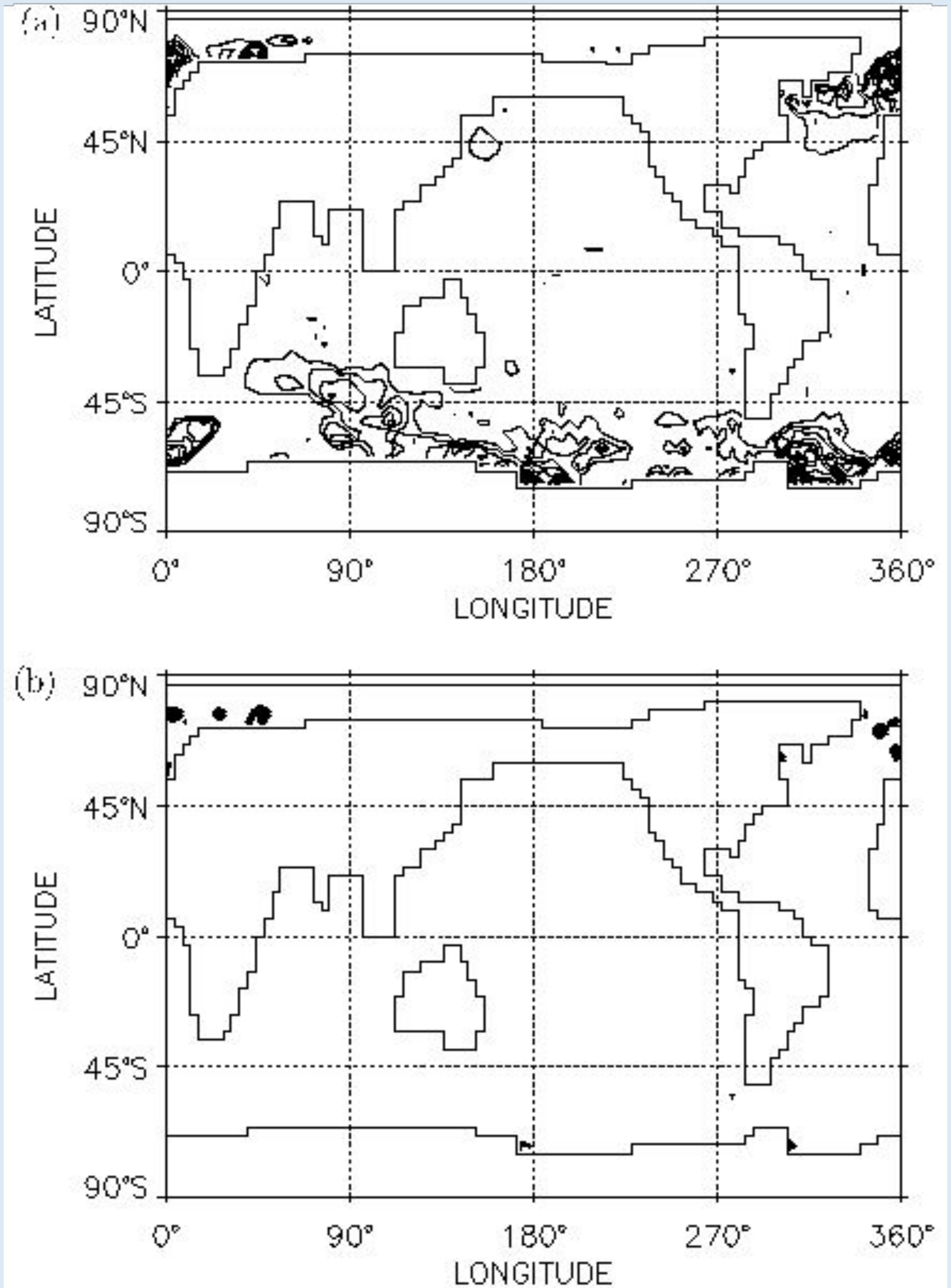
(b) GM, MOC (**u**)

(c) GM, MOC (**u+u***)
4° x 3° x 20L ocean model
Danabasoglu et al. (1994, Science)





Impacts of GM



Deep Water Formation

(a) Horizontal Diffusion

(b) GM

In (b), deep water is formed only in the Greenland/ Iceland/Norwegian Sea, the Labrador Sea, the Weddell Sea and the Ross Sea.

4° x 3° x 20L ocean model

Danabasoglu et al. (1994, Science)

GM summary

Mimics effects of unresolved mesoscale eddies as the sum of

- diffusive mixing of tracers along isopycnals (Redi 1982),
- an additional advection of tracers by the eddy-induced velocity $\underline{u}^*$

Scheme is adiabatic and therefore valid for the ocean interior.

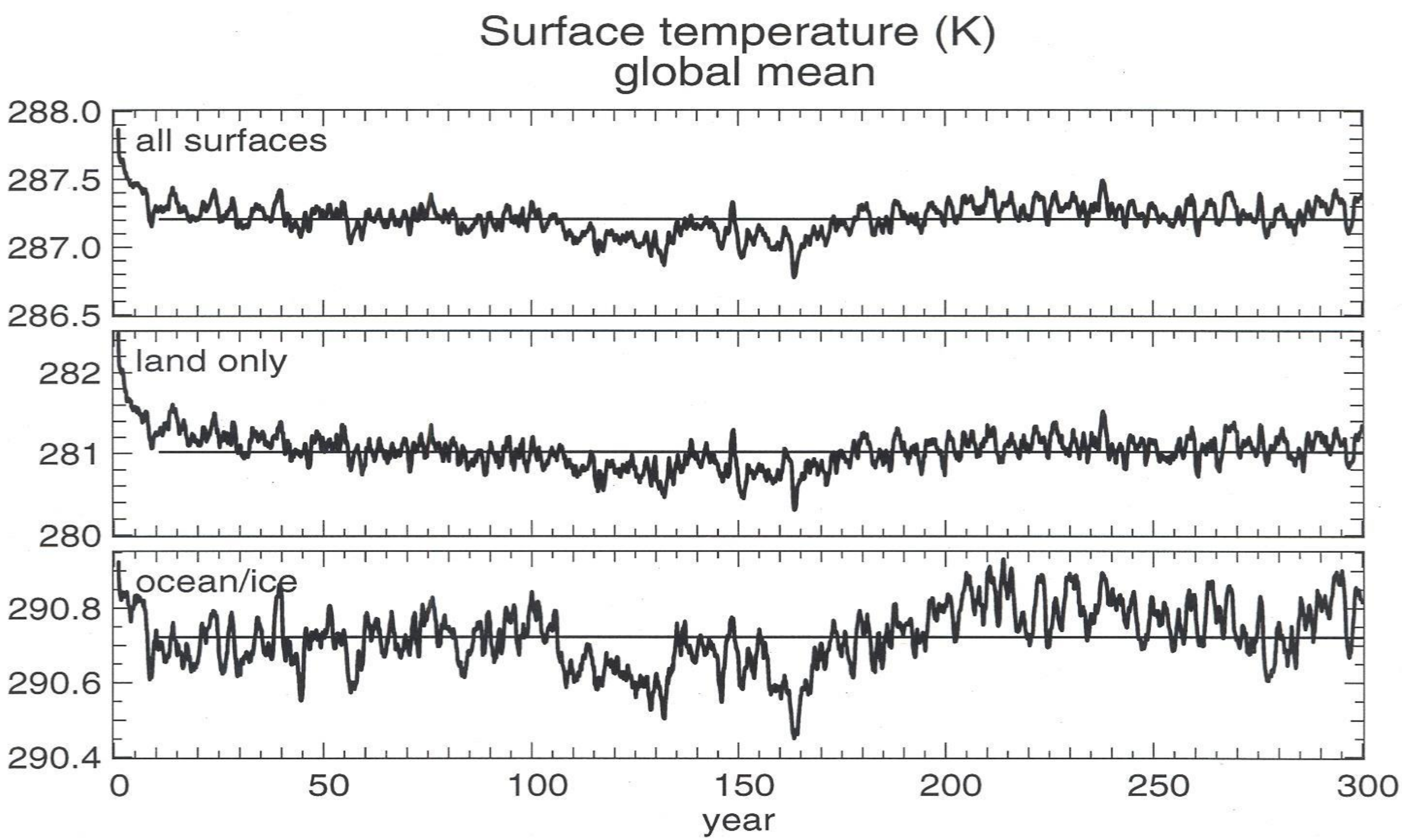
Acts to flatten isopycnals, thereby reducing potential energy.

Eliminates any need for horizontal diffusion in z-coordinate OGCMs

□ eliminates Veronis effect.

CSM1 was the first climate model to produce a non-drifting control run without flux adjustments

FIG 8



Limerick 2004

There once was an ocean model called POP,

Limerick 2004

There once was an ocean model called POP,
Which occasionally used to flop,
But eddy advection, and much less convection,
Turned it into the cream of the crop.