Ocean Modeling

Gokhan Danabasoglu
Senior Scientist and Oceanography Section Head
National Science Foundation National Center for Atmospheric Research (NCAR)
gokhan@ucar.edu

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Topics

Part I (today)

- Global Earth system models;
- Ocean modeling challenges and properties;
- Governing equations and approximations;
- Discretizations;
- Vertical coordinates;
- Grid examples

Part II (Thursday)

Parameterizations

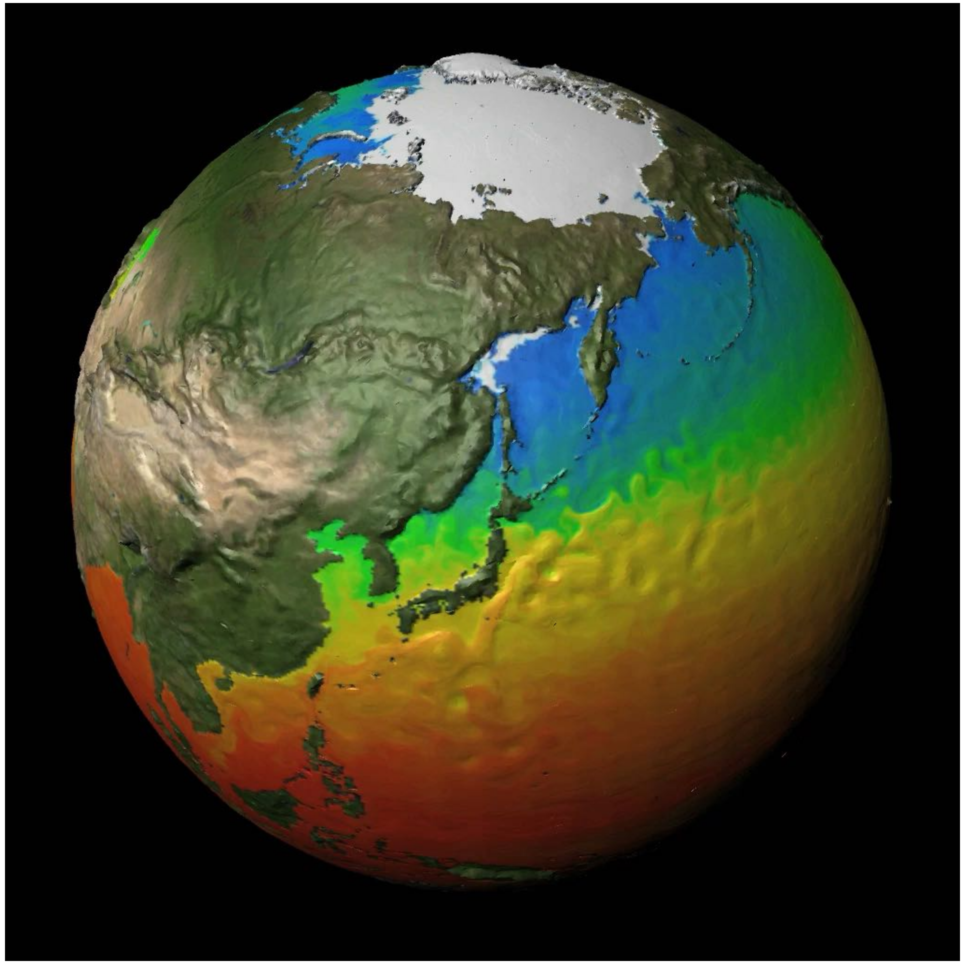
Global Earth System Models

Global Earth System Models

A virtual laboratory for experimentation ….

General purposes include:

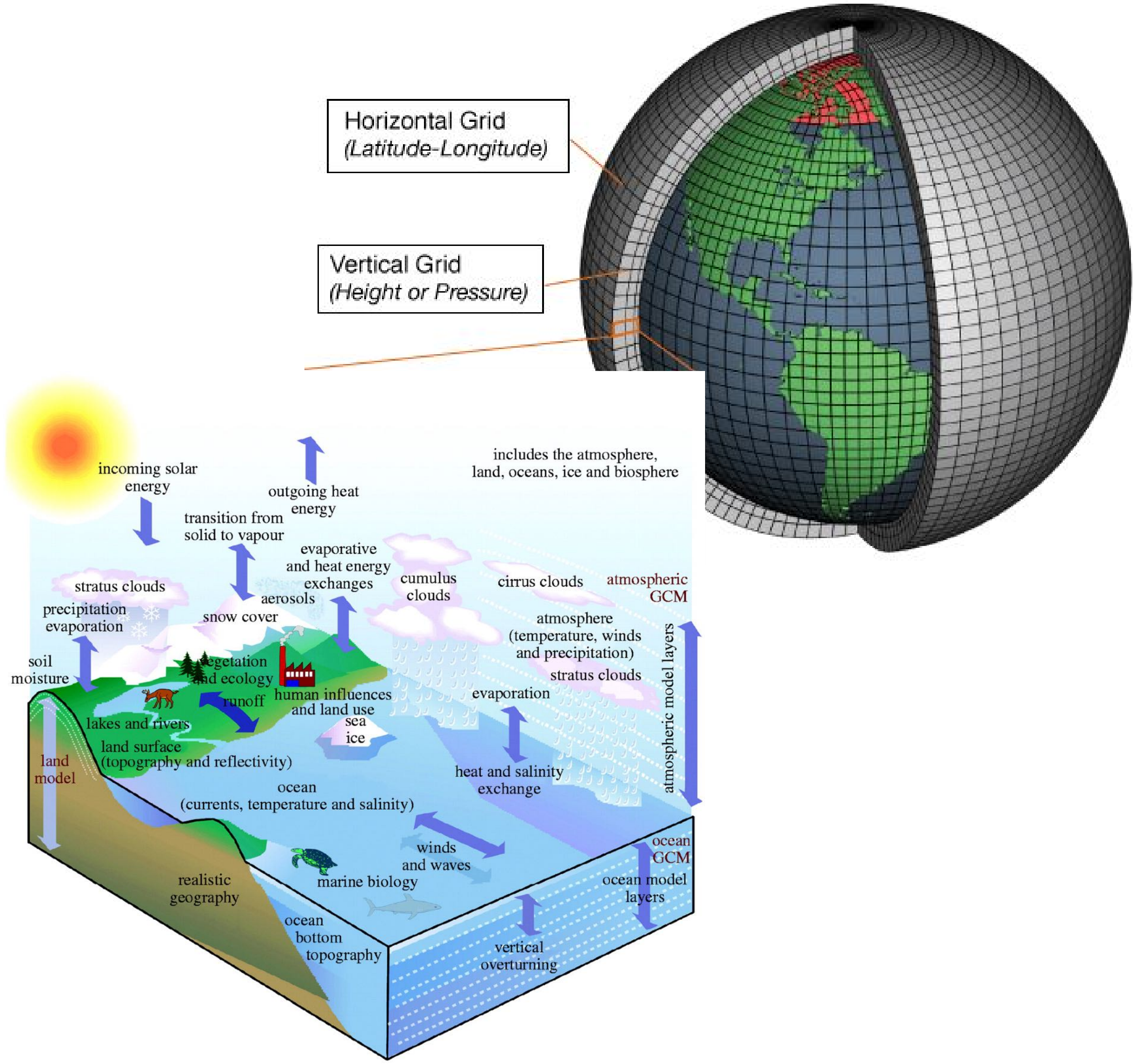
- Providing scientific understanding of the past and present observed events and changes;
- Simulating future climate change and its impacts;
- Making future predictions of climate changes and variability; and
- Providing actionable, societally-relevant information.



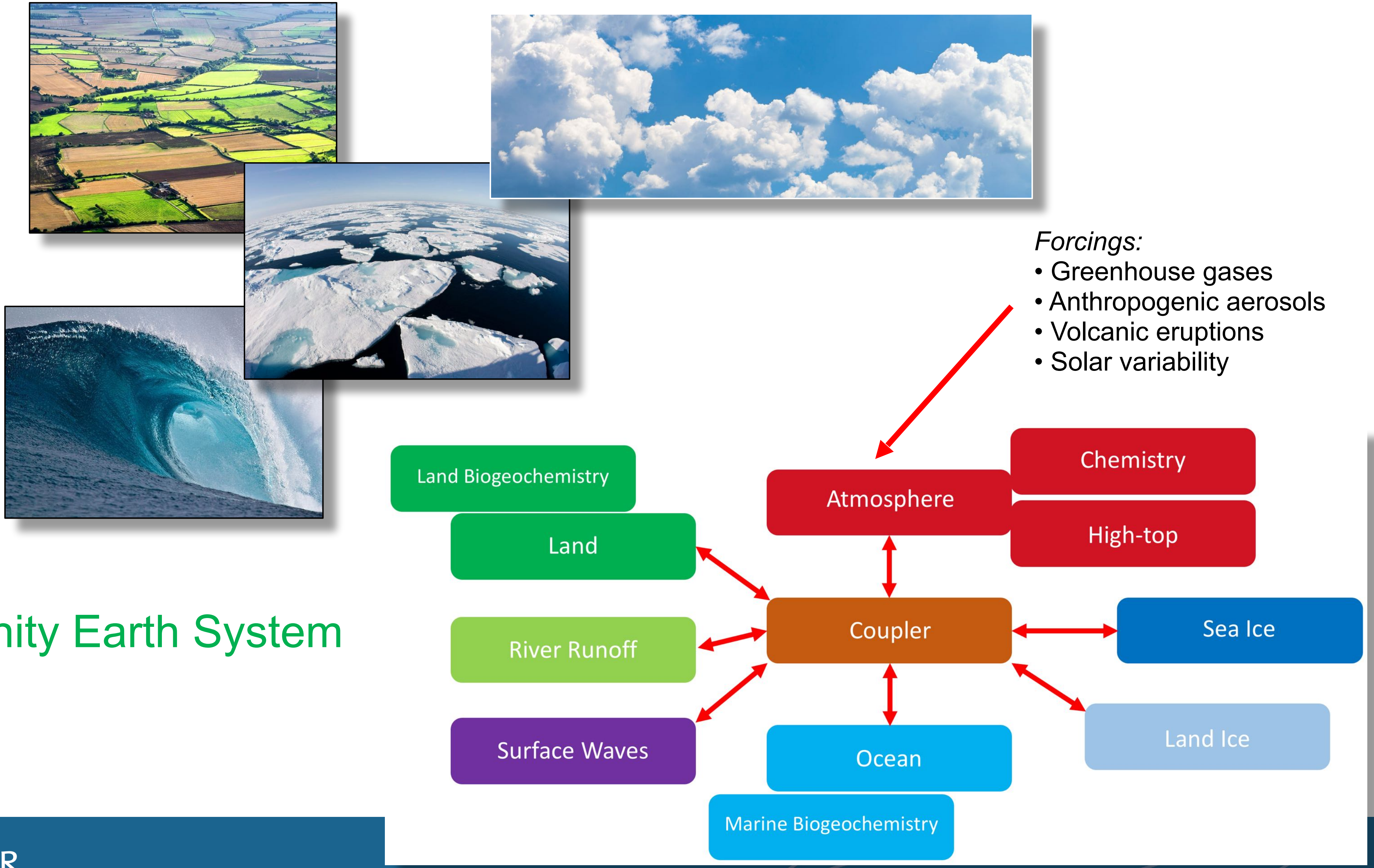
Small and Scheitlin

Global Earth System Models

- The models use physical equations to simulate key fields and processes in the atmosphere, ocean, land, sea-ice, land-ice, …
- Processes that remain below the grid resolution need to be parameterized.
- Build on our understanding of processes from observations and highly-detailed models (e.g., process models, large eddy simulations).



Global Earth System Models



Forcings:
- Greenhouse gases
- Anthropogenic aerosols
- Volcanic eruptions
- Solar variability

Land Biogeochemistry

Land

River Runoff

Surface Waves

Atmosphere

Chemistry

High-top

Coupler

Sea Ice

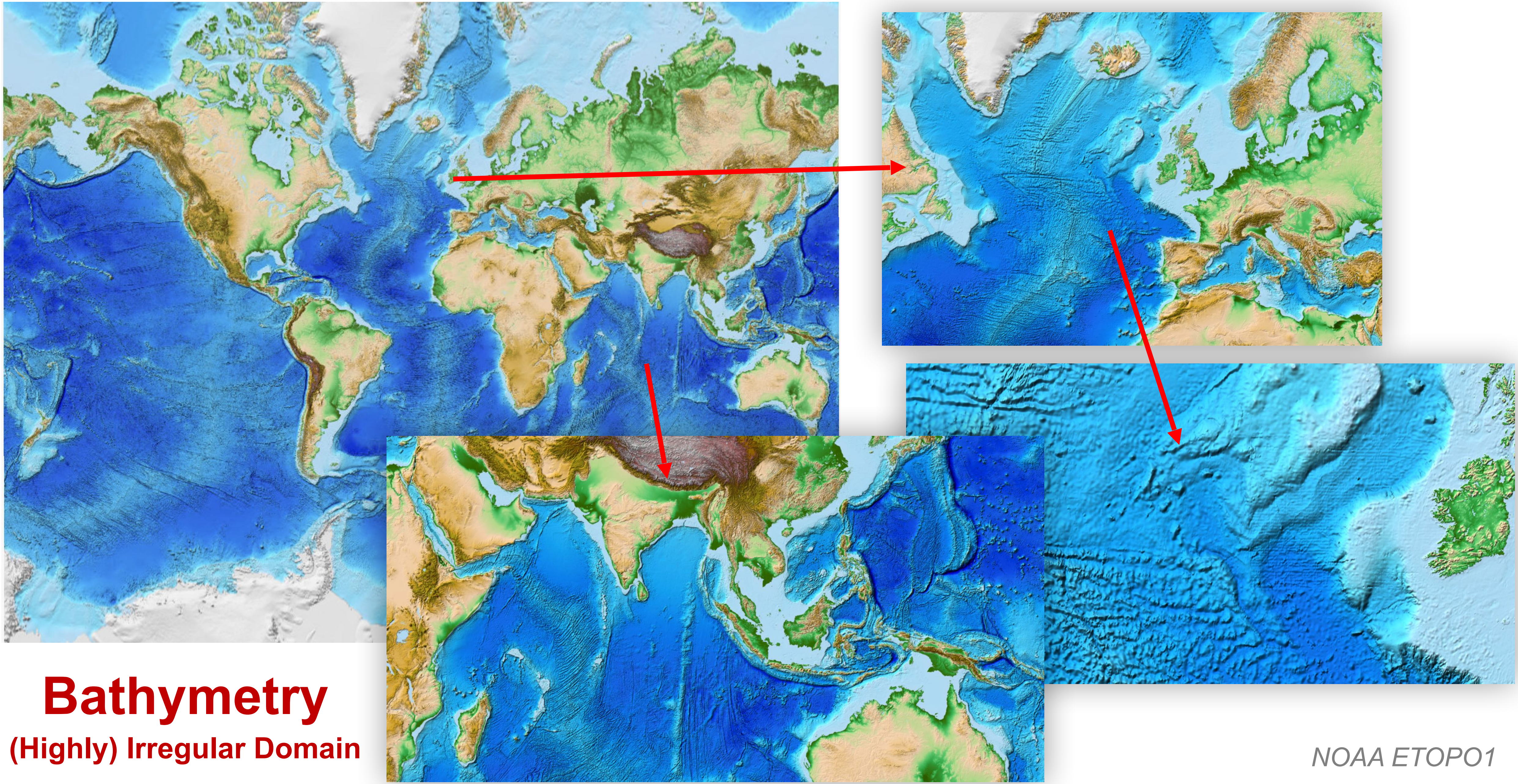
Land Ice

Ocean

Marine Biogeochemistry

Community Earth System Model

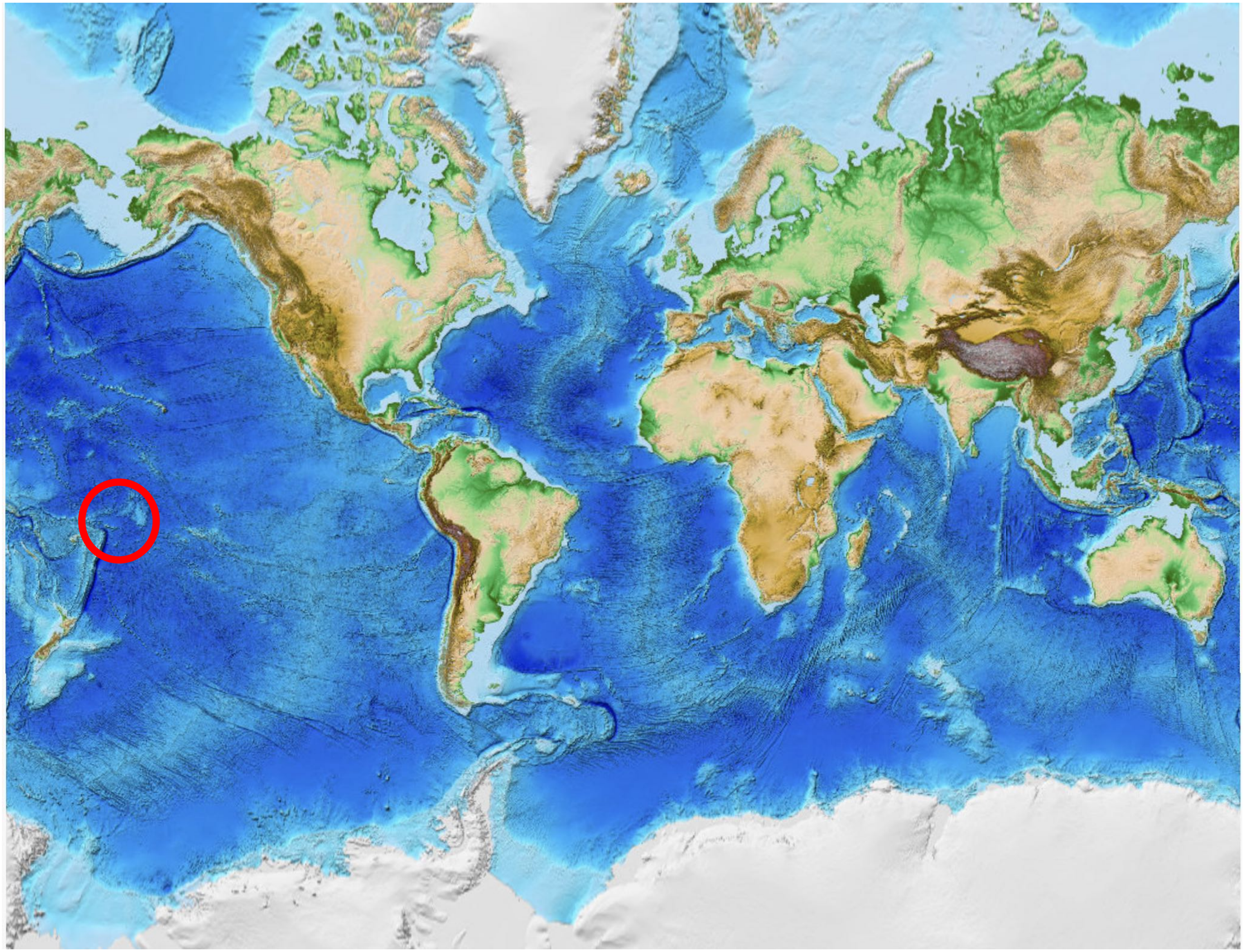
Ocean Modeling Challenges



Bathymetry

(Highly) Irregular Domain

NOAA ETOPO1



Bathymetry

Representation in the Ocean Models

Remains rather ad-hoc with each group / model applying their own method, that is, no accepted best practice

Processes are usually not (well) documented

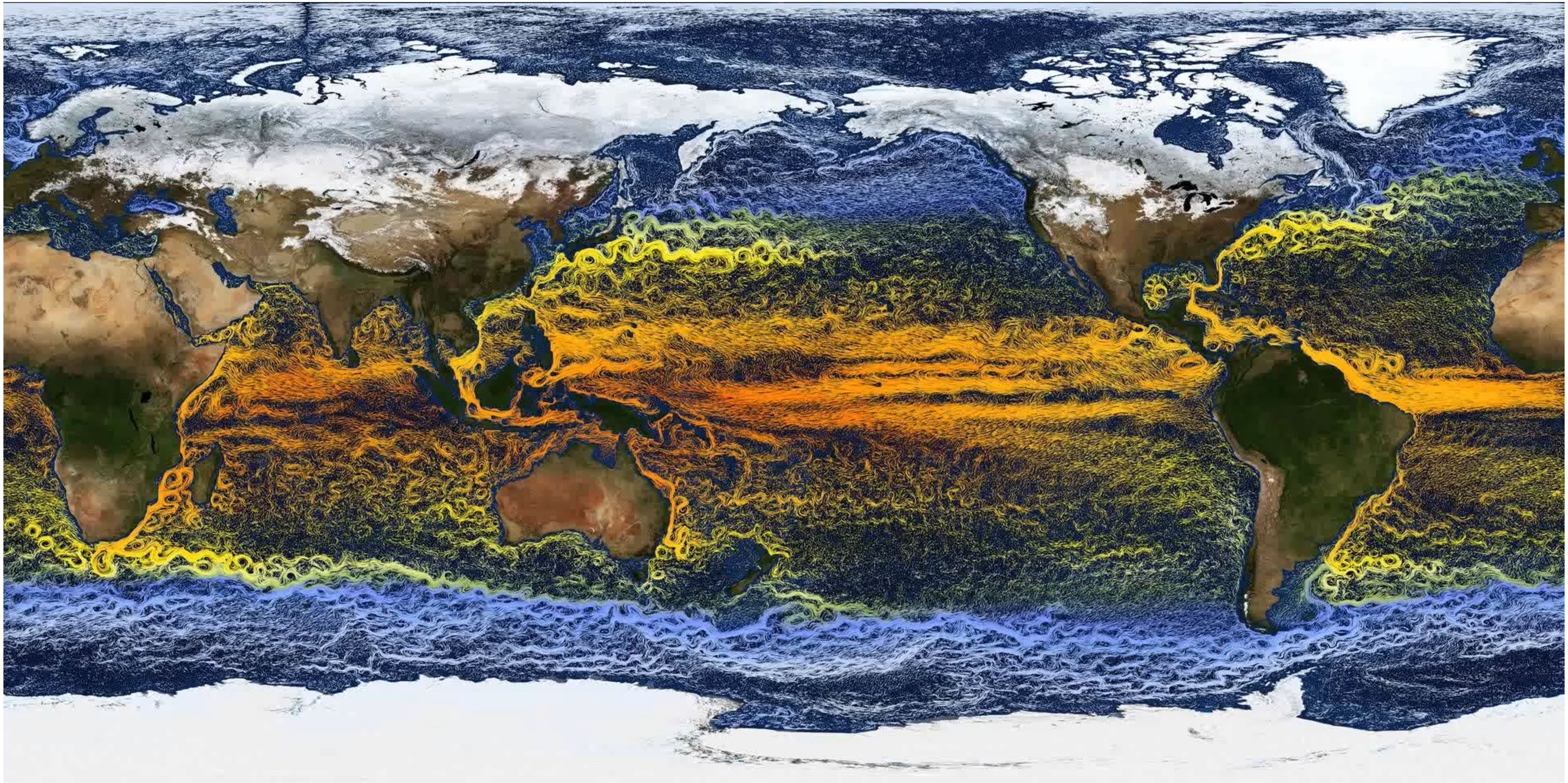
Once created, usually used for many many years

Involves quite a bit of trial-and-error to obtain reasonable transports across various channels, straits, etc.

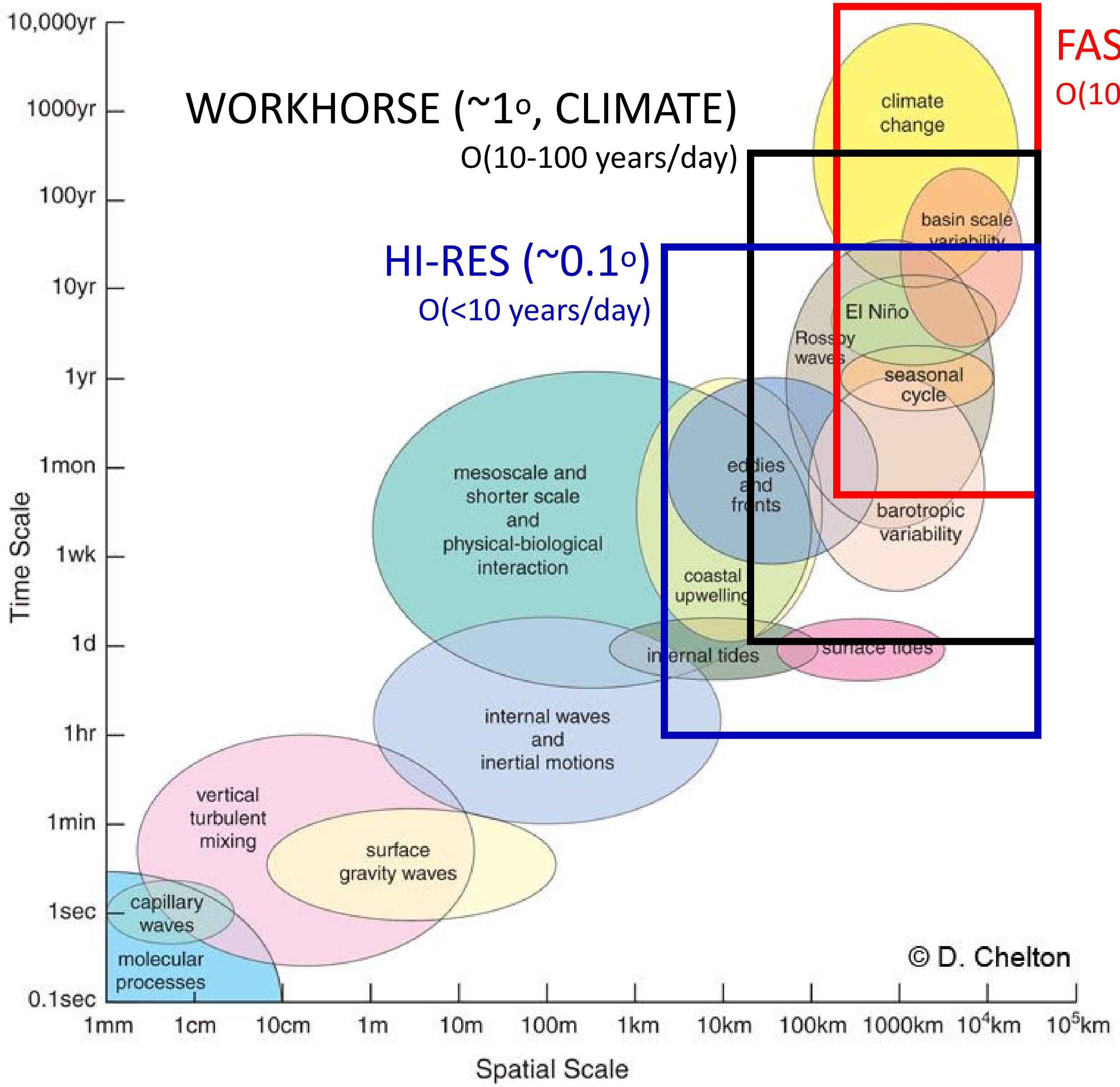
Details matter

NOAA ETOPO1

Land boundaries exert strong control on ocean dynamics



NCAR and TAMU



© D. Chelton

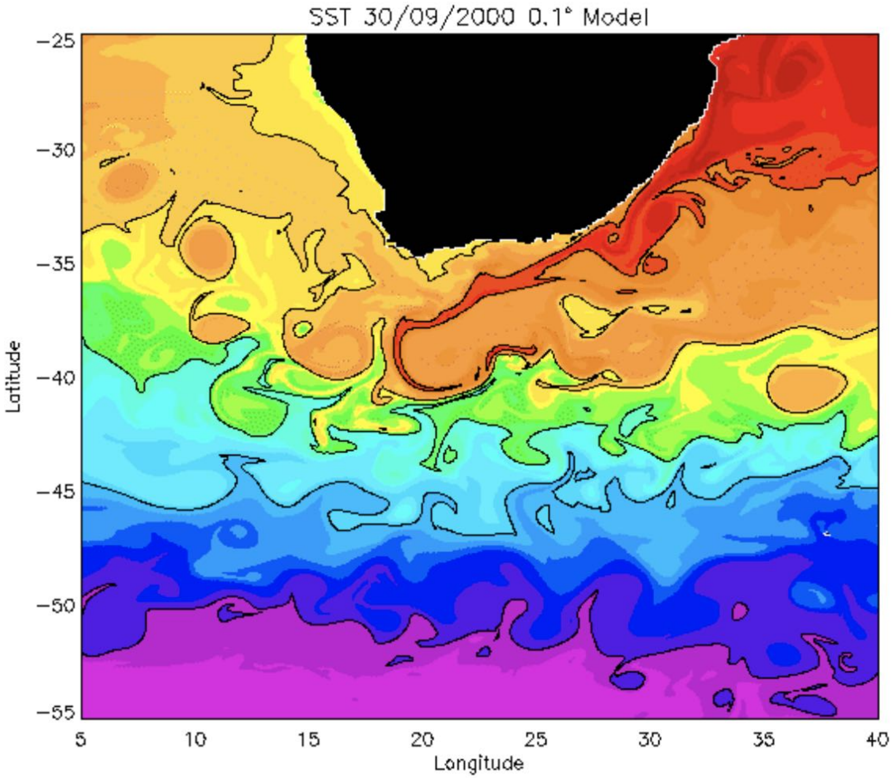
FAST (~3^o)
O(100-1000 years/day)

WORKHORSE (~1^o, CLIMATE)
O(10-100 years/day)

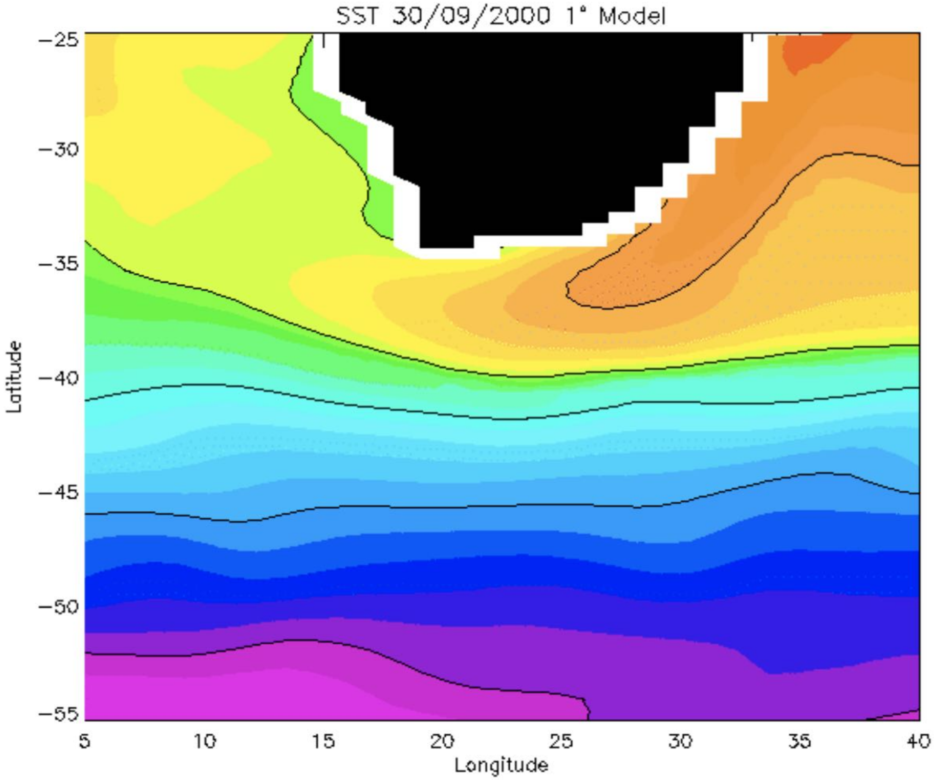
HI-RES (~0.1^o)
O(<10 years/day)

Sea Surface Temperature (SST)

$\Delta x = 0.1^{o}$



$\Delta x = 1.0^{o}$

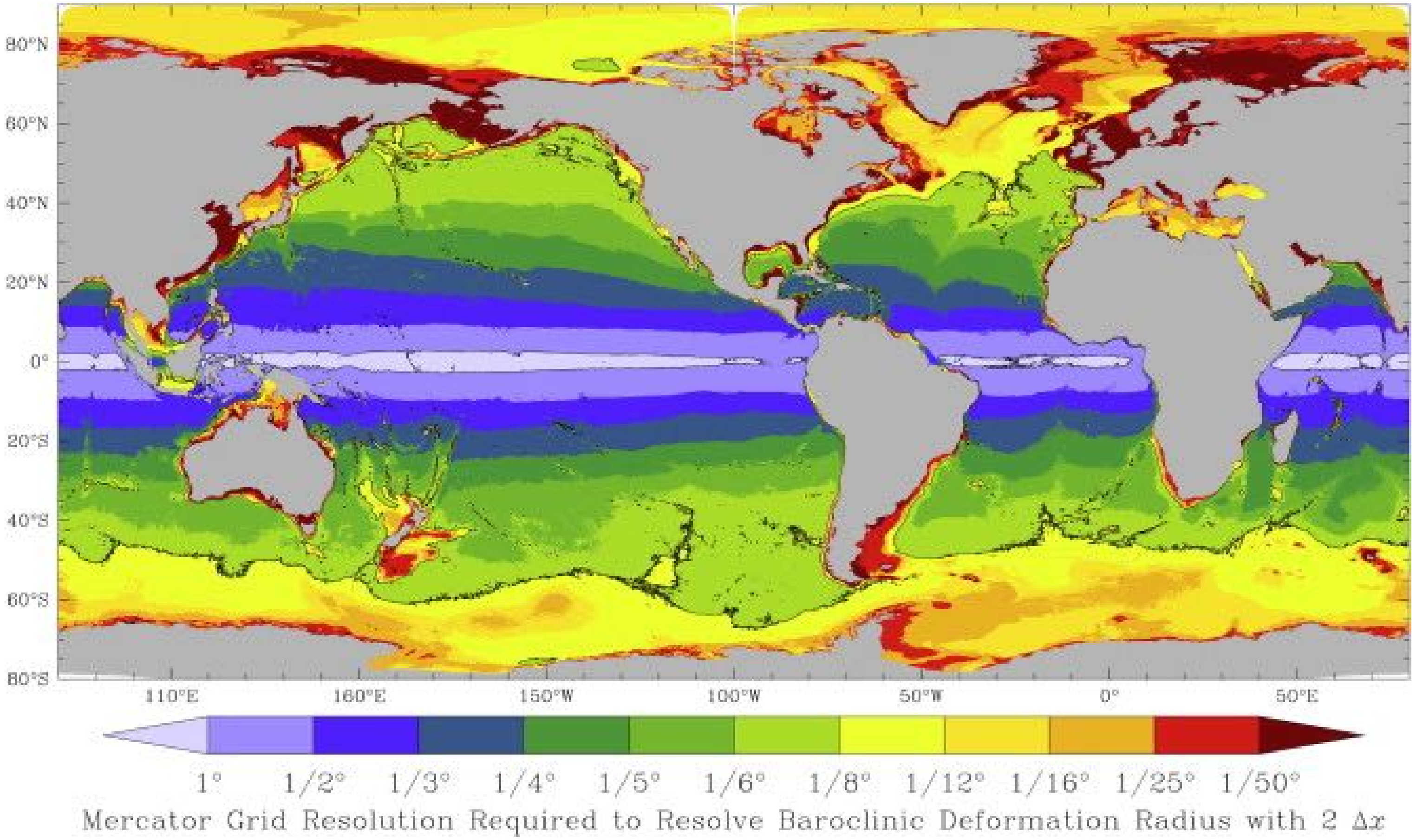


Mixing associated with sub-gridscale turbulence must be parameterized.

The density change from top to bottom is much smaller in the ocean than in the atmosphere: 1.02 to 1.04 gr/cm^{3}.

This makes the Rossby radius (R_d) much smaller – 100s to 10s km.

$$R_d = \frac{NH}{\pi f}$$



Hallberg (2013)

Equilibration Timescale

Mixing across density surfaces is extremely small once water masses are buried below the mixed layer base.

Scaling argument for deep adjustment time (**diffusive timescale**):

$$H^2/\kappa = (3500\text{ m})^2 / (1 \times 10^{-4}\text{ m}^2/\text{s}) = O\text{ (4,000) years}$$

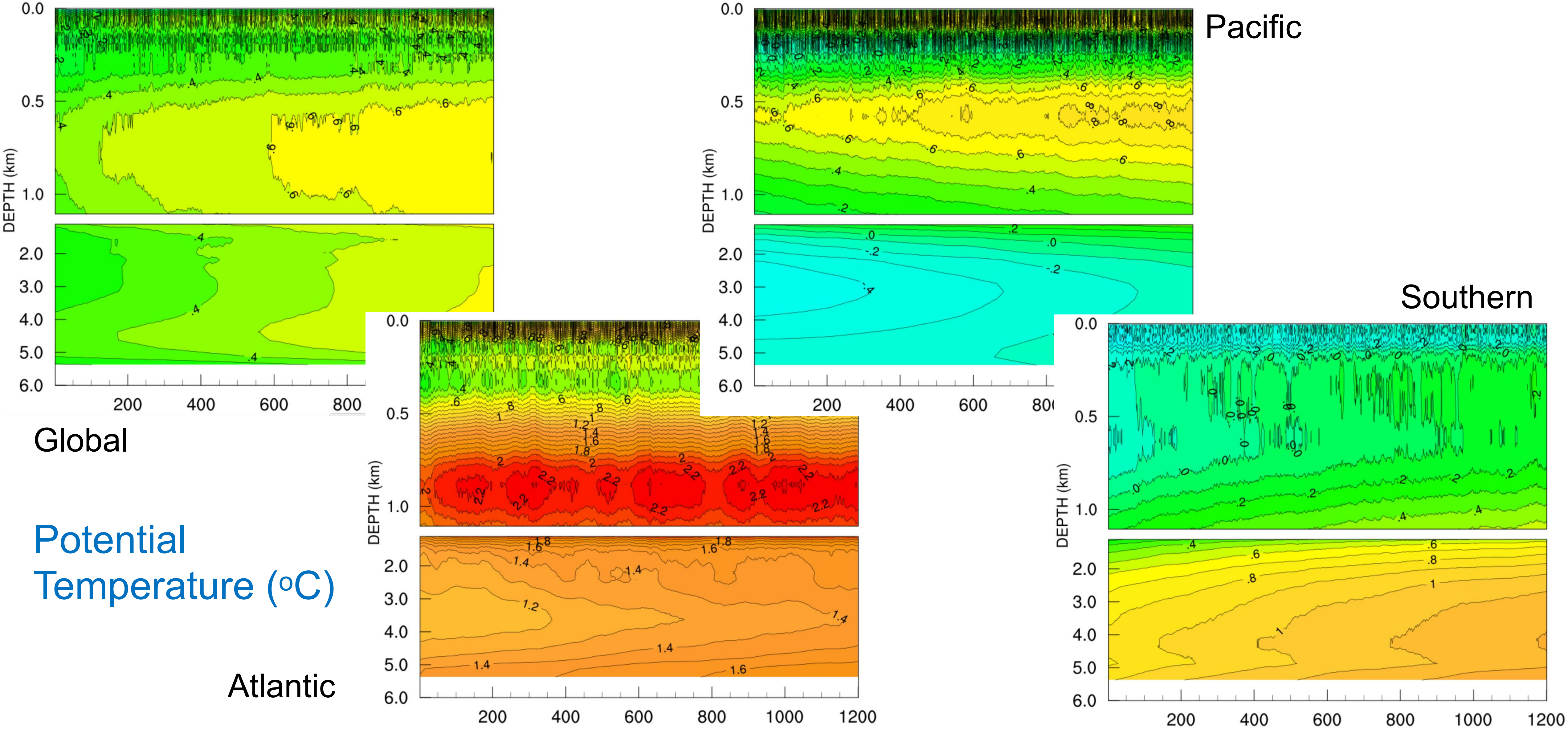
Tidal mixing can reduce this time scale in certain regions.

$$k_v = k_{\text{bg}} + \frac{\Gamma \varepsilon}{N^2}$$

Bottom line for climate ……

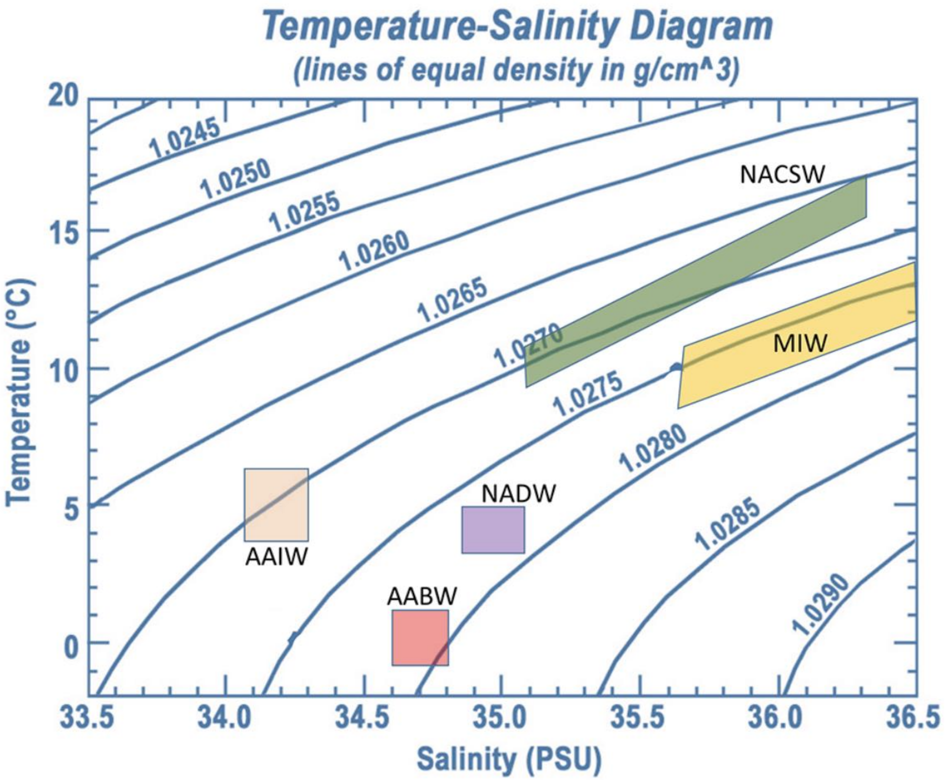
- Performing long “equilibrium” simulations are not practical, particularly at eddy-resolving / permitting resolutions
- Must live with deep / abyssal ocean not being at equilibrium in most simulations

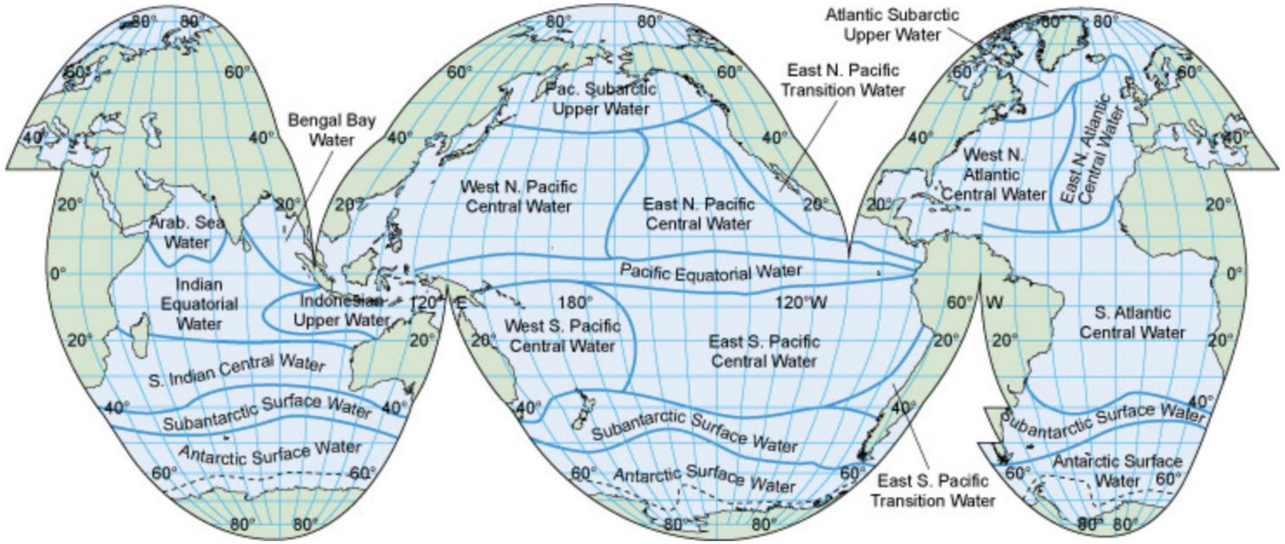
Approach to Equilibrium in CESM2 Fully-Coupled Simulations

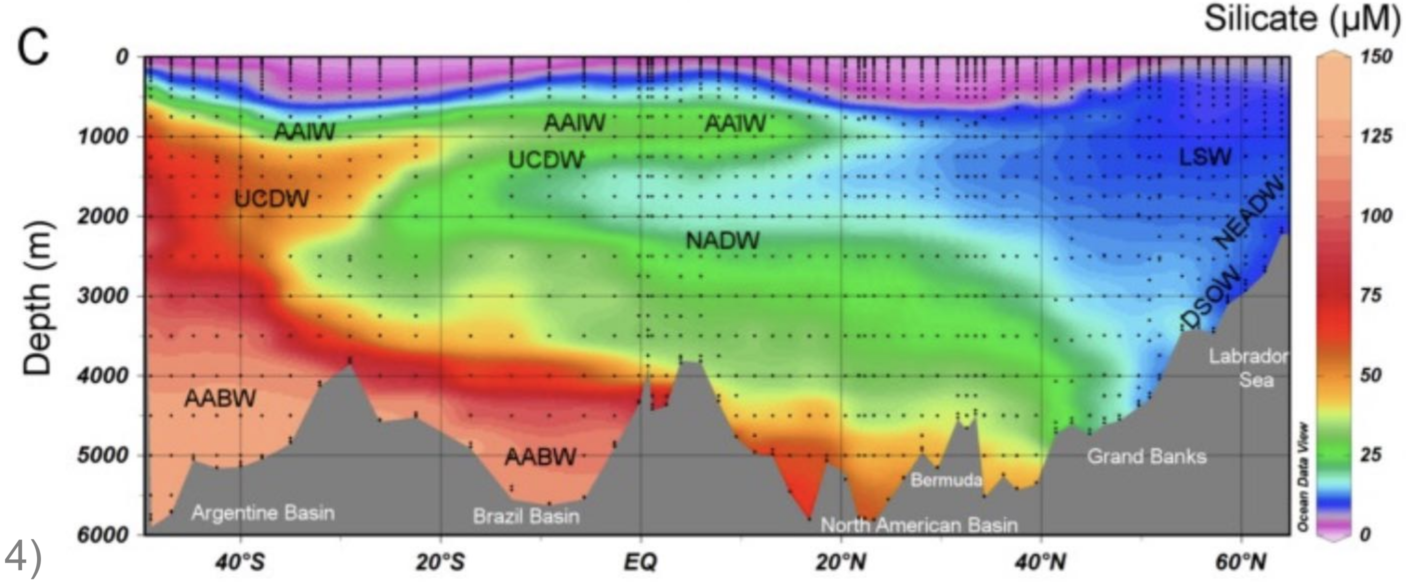


Potential Temperature (oC)

Because of weak interior mixing, water masses can be named and followed around in the oceans





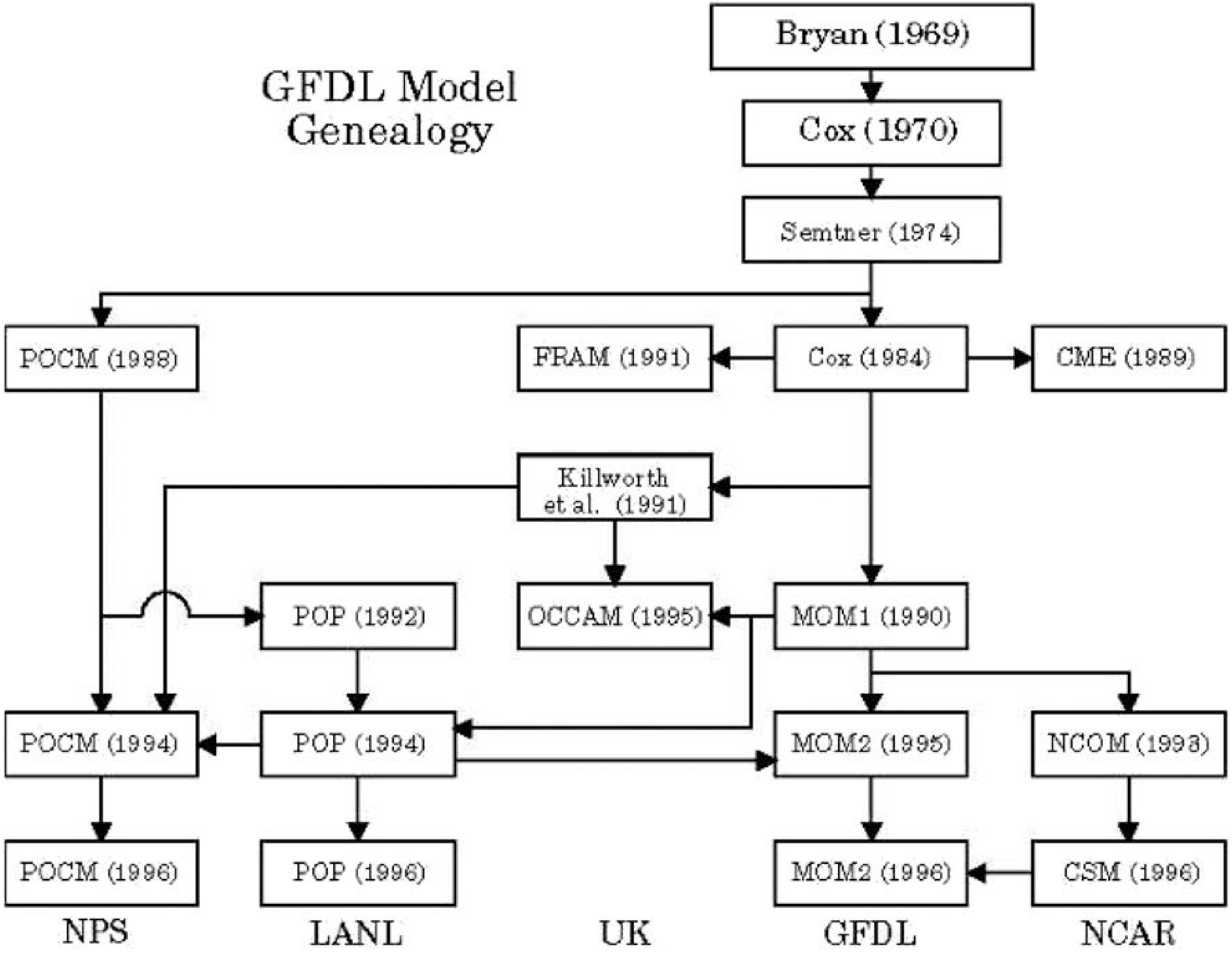


Rijkenberg et al. (2014)

Some Ocean Properties

- The heat capacity of the ocean is much larger than the atmosphere. This makes it an important heat reservoir;
- The ocean contains the memory of the climate system → important implications for decadal prediction studies.
- No change of state of seawater – form ice when temperature is below freezing point (as a function of salinity).
- The ocean density is a nonlinear (complicated) function of temperature, salinity, and pressure.

Early History of Ocean Modeling



Credit Bert Semtner

Languages

FORTRAN

C++

Julia

Governing Equations

7 equations in 7 unknowns:

3 velocity components

potential temperature

salinity

density

pressure

Plus: 1 equation for each passive tracer, e.g. CFCs, Ideal Age.

Approximations

Hydrostatic: Variations in density are considered too small to affect inertia but are important in terms of affecting buoyancy, simplifying the equation for the vertical velocity component.

When vertical accelerations are small compared to the gravitational acceleration, the hydrostatic approximation is valid.

When ocean becomes statically unstable, vertical overturning should occur, but cannot because vertical tendency has been excluded. This mixing needs to be parameterized.

Boussinesq: Density differences are not important except for when they are multiplied by the gravitational acceleration. The sound waves are ignored.

Continuity (incompressible form): Cannot deform seawater, so what flows into a control volume must flow out.

Approximations

Thin-shell: The ocean depth is neglected compared to the Earth's radius.

Together with horizontal motions >> vertical motions, the thin-shell approximation of the Coriolis force results in retaining only the horizontal components due to horizontal motions.

Spherical Earth: Geopotential surfaces are assumed to be spheres.

Turbulent closures: Subgrid scale processes can be parameterized in terms of the resolved large-scale fields / features.

Governing Equations

Zonal momentum

$$\frac{\partial}{\partial t}u + \mathcal{L}(u) - (uv\tan\phi)/a - fv = -\frac{1}{\rho_0 a\cos\phi}\frac{\partial p}{\partial\lambda} + \mathcal{F}_{Hx}(u,v) + \mathcal{F}_V(u)$$

Meridional momentum

$$\frac{\partial}{\partial t}v + \mathcal{L}(v) + (u^2\tan\phi)/a + fu = -\frac{1}{\rho_0 a}\frac{\partial p}{\partial\phi} + \mathcal{F}_{Hy}(u,v) + \mathcal{F}_V(v)$$

Advection operator

$$\mathcal{L}(\alpha) = \frac{1}{a\cos\phi}\left[\frac{\partial}{\partial\lambda}(u\alpha) + \frac{\partial}{\partial\phi}(\cos\phi\, v\alpha)\right] + \frac{\partial}{\partial z}(w\alpha)$$

Zonal viscosity

$$\mathcal{F}_{Hx}(u,v) = A_M\left\{\nabla^2 u + u(1-\tan^2\phi)/a^2 - \frac{2\sin\phi}{a^2\cos^2\phi}\frac{\partial v}{\partial\lambda}\right\}$$

Meridional viscosity

$$\mathcal{F}_{Hy}(u,v) = A_M\left\{\nabla^2 v + v(1-\tan^2\phi)/a^2 + \frac{2\sin\phi}{a^2\cos^2\phi}\frac{\partial u}{\partial\lambda}\right\}$$

Divergence operator

$$\nabla^2\alpha = \frac{1}{a^2\cos^2\phi}\frac{\partial^2\alpha}{\partial\lambda^2} + \frac{1}{a^2\cos\phi}\frac{\partial}{\partial\phi}\left(\cos\phi\frac{\partial\alpha}{\partial\phi}\right)$$

Vertical viscosity

$$\mathcal{F}_V(\alpha) = \frac{\partial}{\partial z}\mu\frac{\partial}{\partial z}\alpha$$

Governing Equations

Continuity

$$\mathcal{L}(1) = 0$$

Hydrostatic

$$\frac{\partial p}{\partial z} = -\rho g$$

Equation of state (nonlinear)

$$\rho = \rho(\Theta, S, p) \rightarrow \rho(\Theta, S, z)$$

Active & passive tracers

$$\frac{\partial}{\partial t}\varphi + \mathcal{L}(\varphi) = \mathcal{D}_H(\varphi) + \mathcal{D}_V(\varphi)$$

Horizontal diffusion

$$\mathcal{D}_H(\varphi) = A_H \nabla^2 \varphi$$

Vertical diffusion

$$\mathcal{D}_V(\varphi) = \frac{\partial}{\partial z}\kappa\frac{\partial}{\partial z}\varphi,$$

Boundary Conditions

Surface:

Momentum and tracer fluxes are determined by bulk formulae.

Fully-coupled or surface forcing datasets

Volume conserving models convert freshwater fluxes to virtual salt fluxes.

Bottom / Lateral:

No tracer fluxes except for geothermal heating

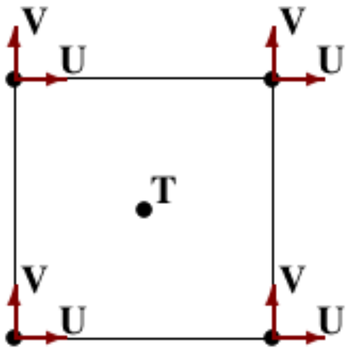
No flow into rocks

Usually no slip flow on lateral boundaries

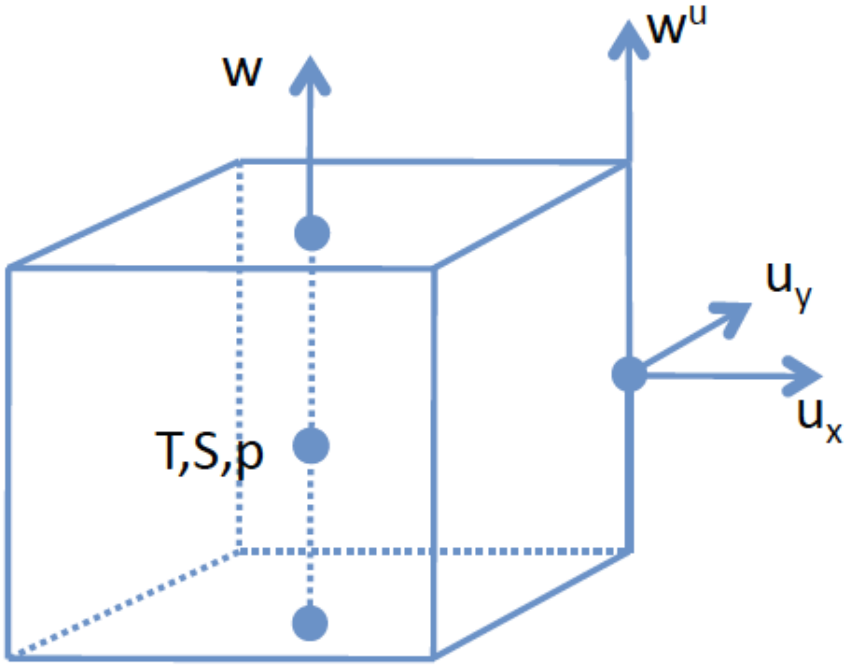
Quadratic bottom drag

Discretizations

Arakawa B-grid



Top view



Used in POP2

Advantages

Naturally accommodates no-slip boundary conditions

Better dispersion of Rossby waves at coarse resolutions (than the C-grid)

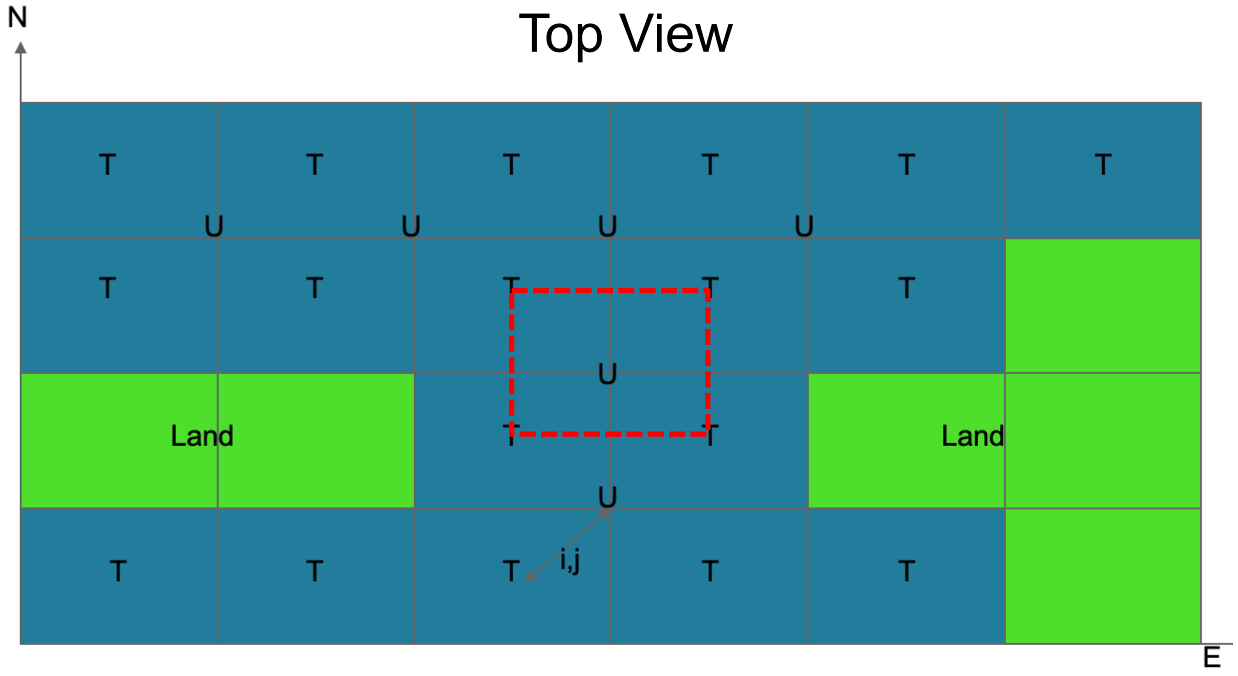
Smaller truncation errors in the computation of the Coriolis terms

Disadvantages

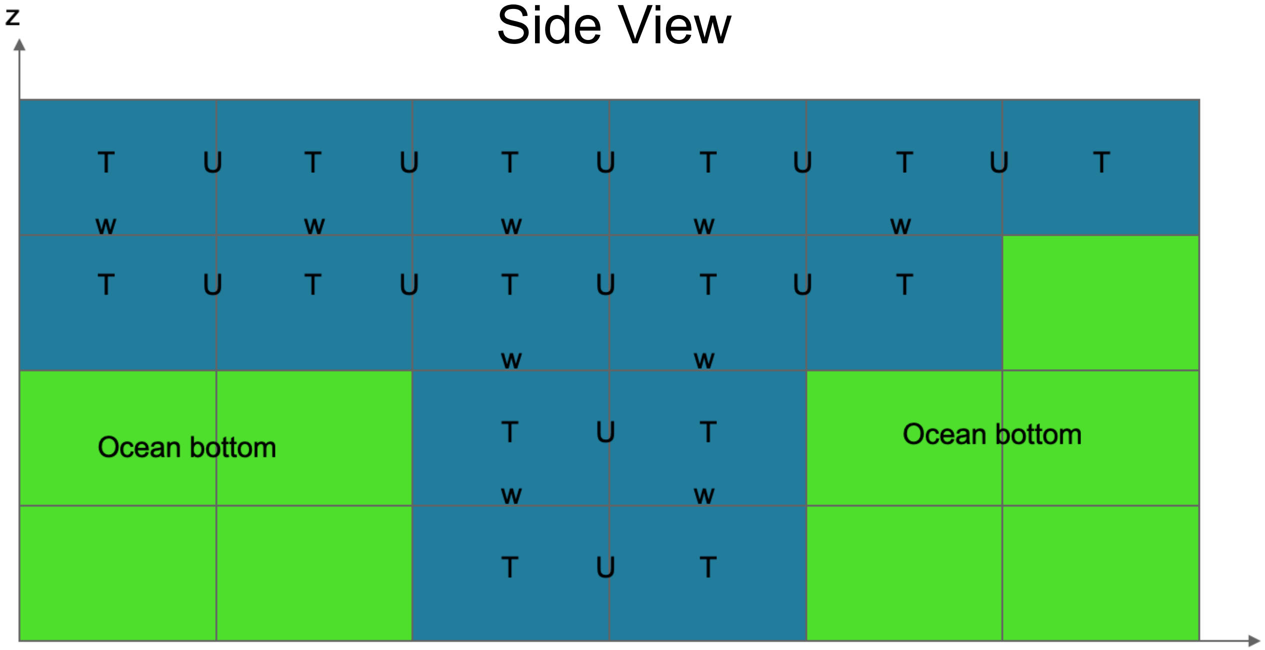
Cannot represent single-point channels

Larger truncation errors in the pressure gradient terms

Discretizations



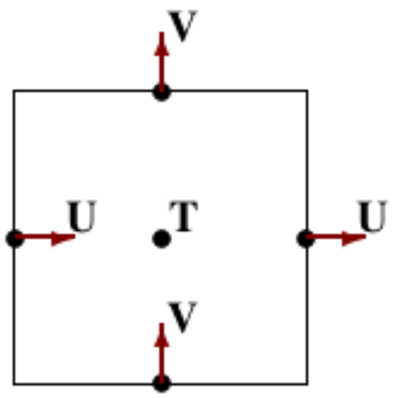
T = tracer grid / point
U = velocity grid / point



From POP2

Discretizations

Arakawa C-grid



Top View

Advantages

Natural discretization for some fields

Allows single-point channels

Disadvantages

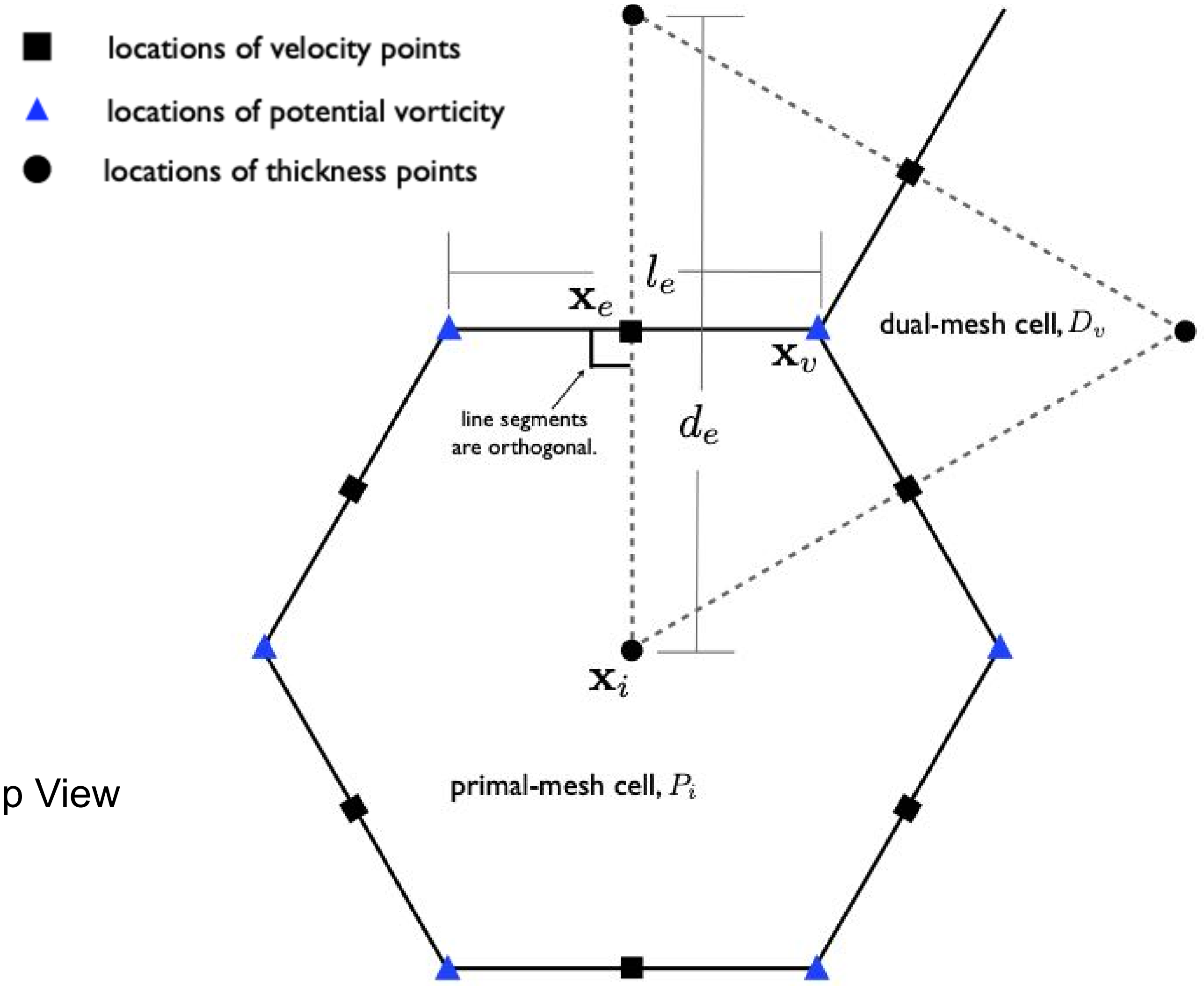
Coriolis terms requires horizontal averaging, making the inertial gravity waves (related to Coriolis force) less accurate

Poorer dispersion of Rossby waves at coarse resolutions (than the B-grid)

Used in MOM6

Discretizations

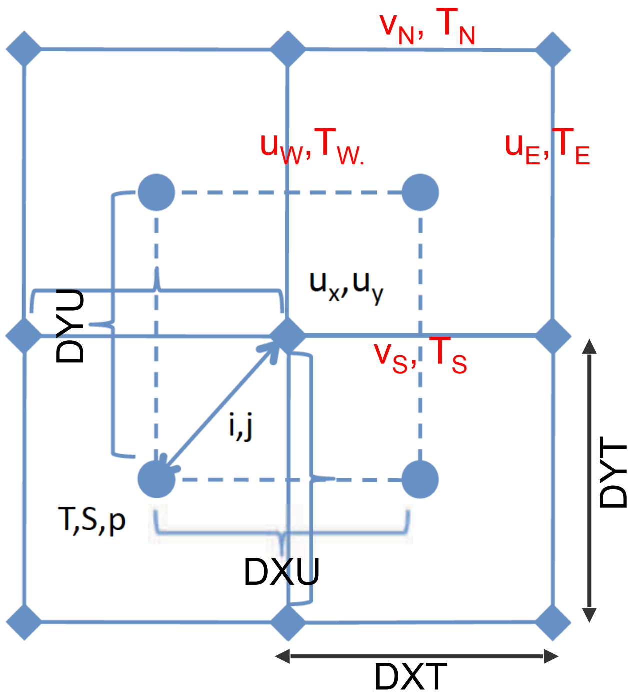
Arakawa C-grid

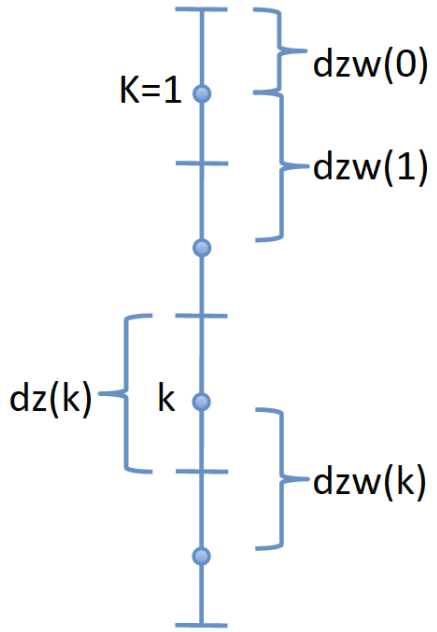


Top View

Used in MPAS

A Discretization Example





Central advection is usually used for the momentum equations

Tracers generally employ a scheme that does not create extrema, e.g., third-order upwind scheme

$$ADV_{i,j,k} = -\,(u_E\, T_{*E} - u_W\, T_{*W})\,/\,DXT - (v_N\, T_{*N} - v_S\, T_{*S})\,/\,DYT - (w_k\, T_{*T} - w_{k+1}\, T_{*B})\,/\,dz$$

$$u_E(i) = (u_{i,j}\, DYU_{i,j} + u_{i,j-1}\, DYU_{i,j-1})\,/\,2$$

$$v_N(j) = (v_{i,j}\, DXU_{i,j} + v_{i-1,j}\, DXU_{i-1,j})\,/\,2$$

$$T_{*E} = ½ * (T_{i+1,j} + T_{i,j})$$

A Time Discretization Example

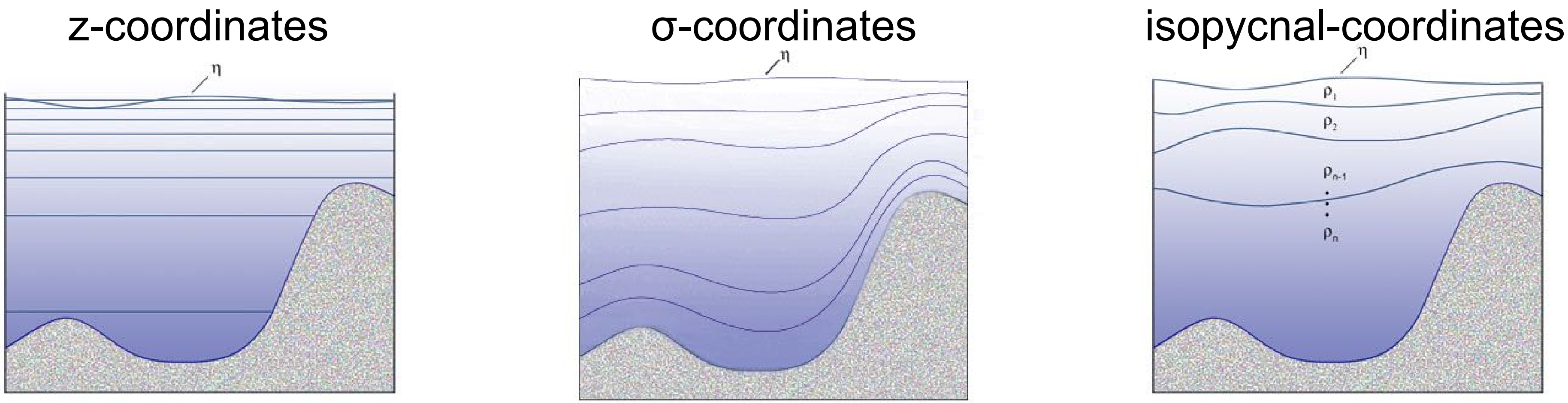
Leap Frog Time Stepping

$$\frac{X^{t+1} - X^{t-1}}{2\ dt} = D^{t-1} + ADV^{t} + SRC^{t,t-1}$$

Split modes need to be occasionally eliminated via time-averaging or Robert filter time steps.

Vertical Coordinates

The choice of a vertical coordinate system is **one of the most important** aspects of a model's design. There are several vertical coordinate systems in use:


z-coordinates σ-coordinates isopycnal-coordinates

From: https://www.oc.nps.edu/nom/modeling/vertical_grids.html

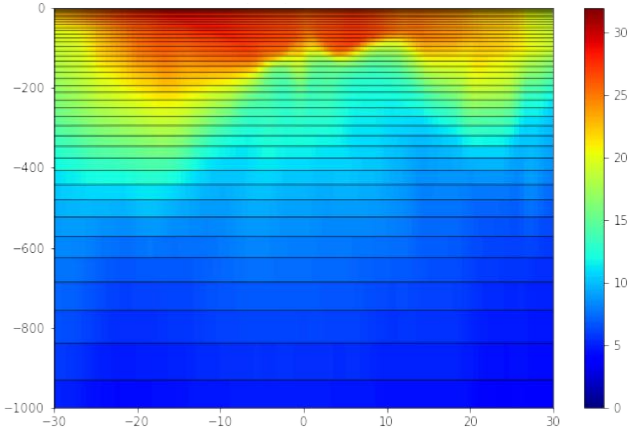
Each one has its advantages and disadvantages, which has led to the development of **hybrid** coordinate systems.

This is an area of very active research and development in numerical ocean models.

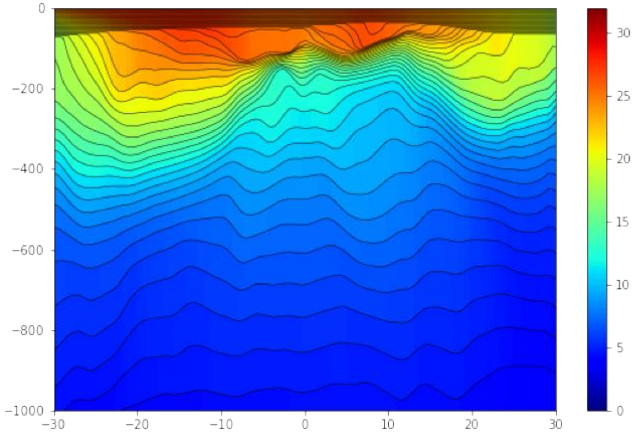
Vertical Coordinates

MOM6

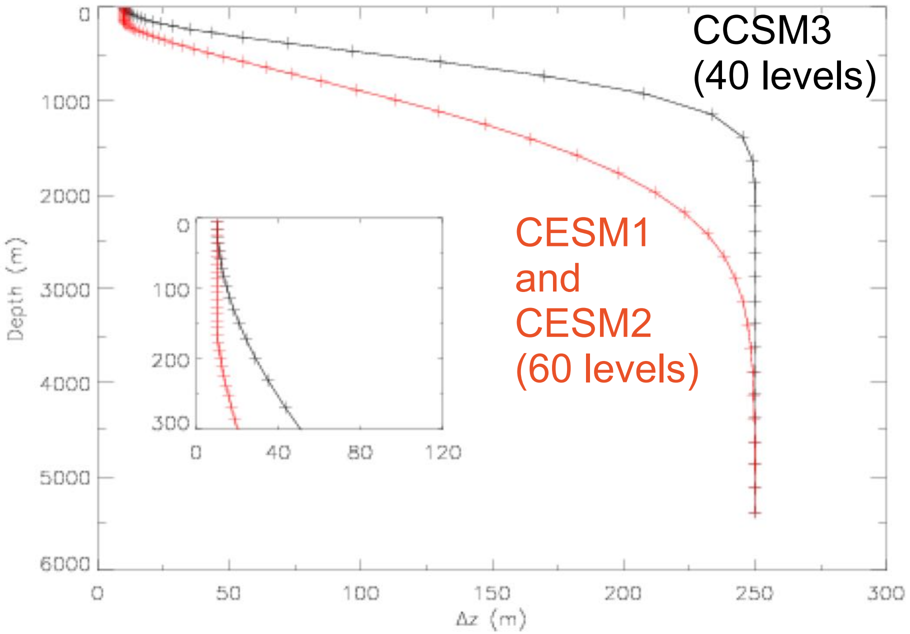
z*-coordinates, 65 levels



Hybrid (z*/rho), 75 levels



z-coordinates



POP2

Vertical Coordinates

The newer generation of the ocean models tend to use the Arbitrary Lagrangian-Eulerian (ALE) method in the vertical.

ALE method provides a variety of options.

When fully Eulerian, the configuration is a level coordinate system, i.e., z-like.

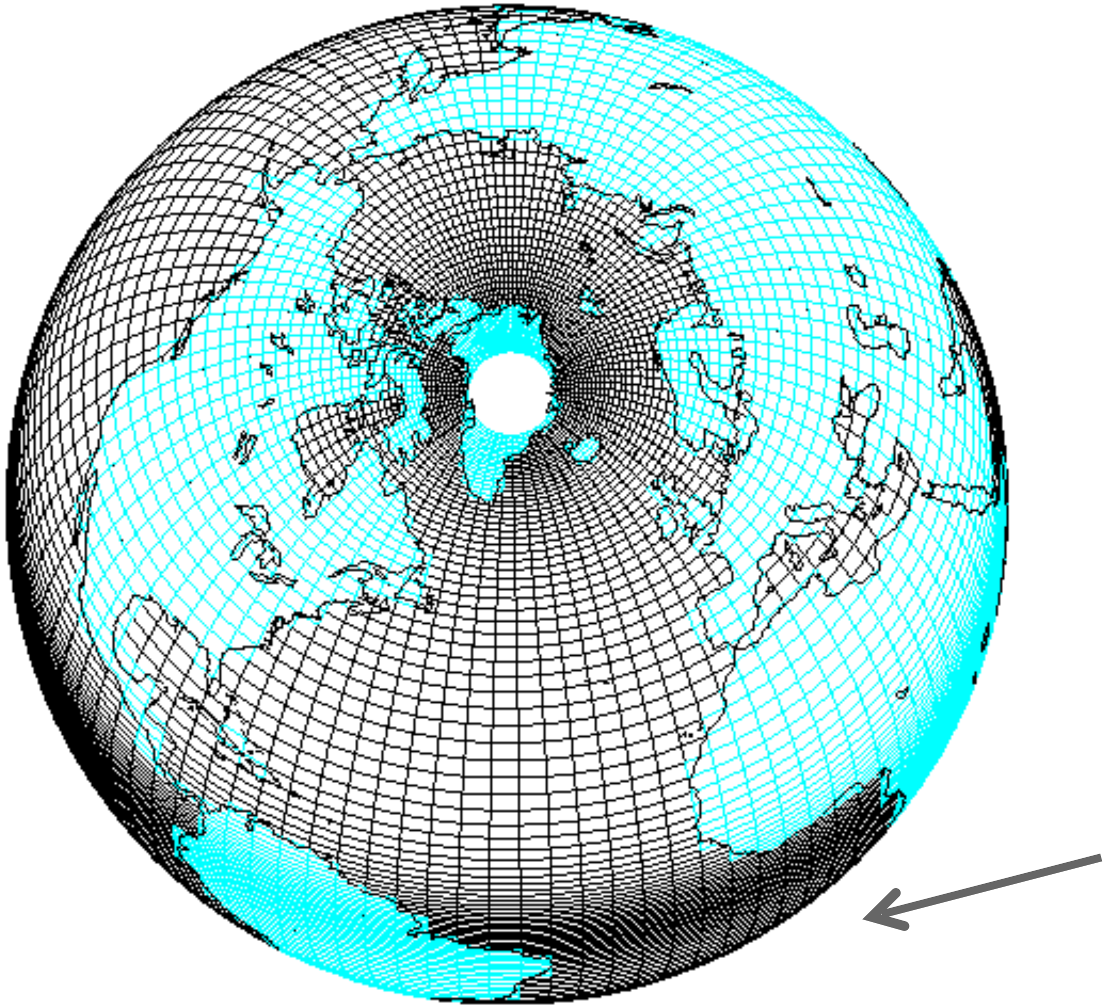
When fully Lagrangian, the configuration is such that the mesh moves with the fluid and there is no “explicit” transport in the vertical.

In between, other vertical grid configurations are possible.

MOM6 and MPAS use this method.

Model Grid Examples

Displaced Pole



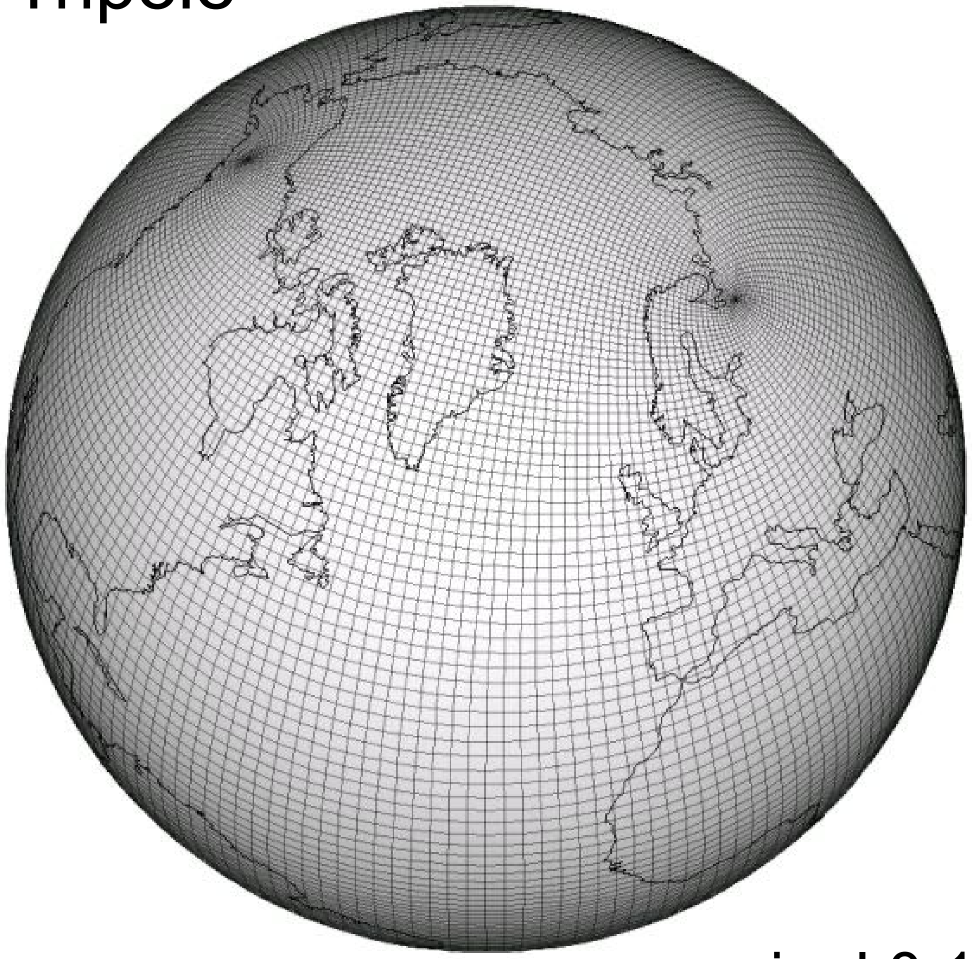
Climate workhorse: nominal 1°

Testing / paleo: nominal 3°

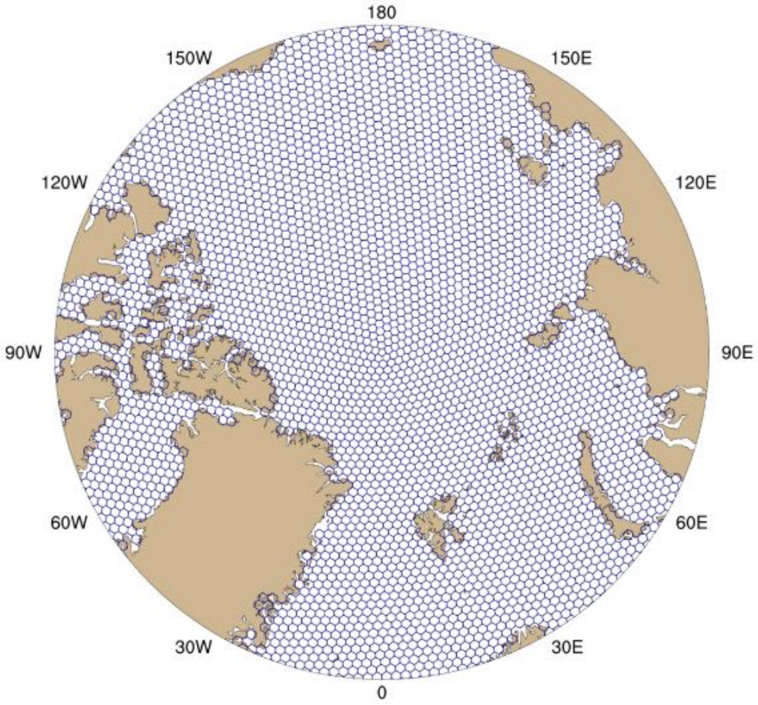
Equatorial refinement
(0.3° / 0.9°)

Model Grid Examples

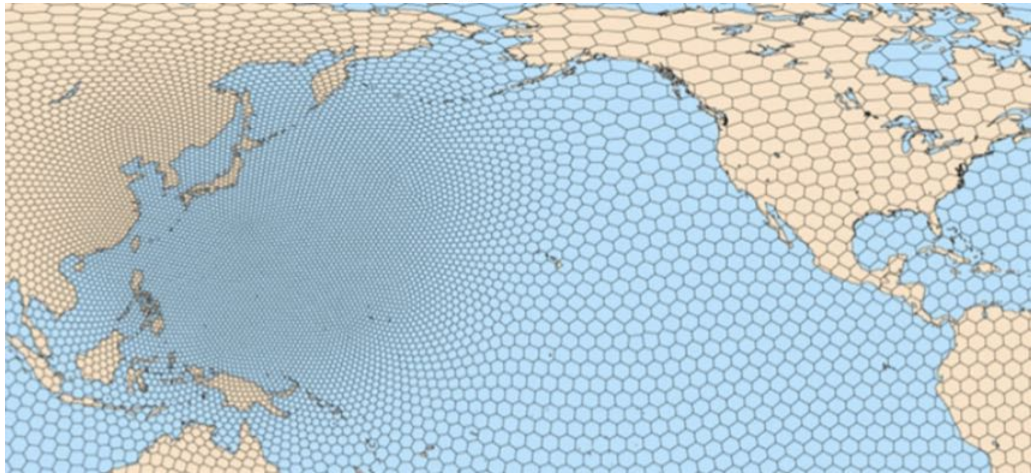
Tripole



nominal 0.1°



MPAS



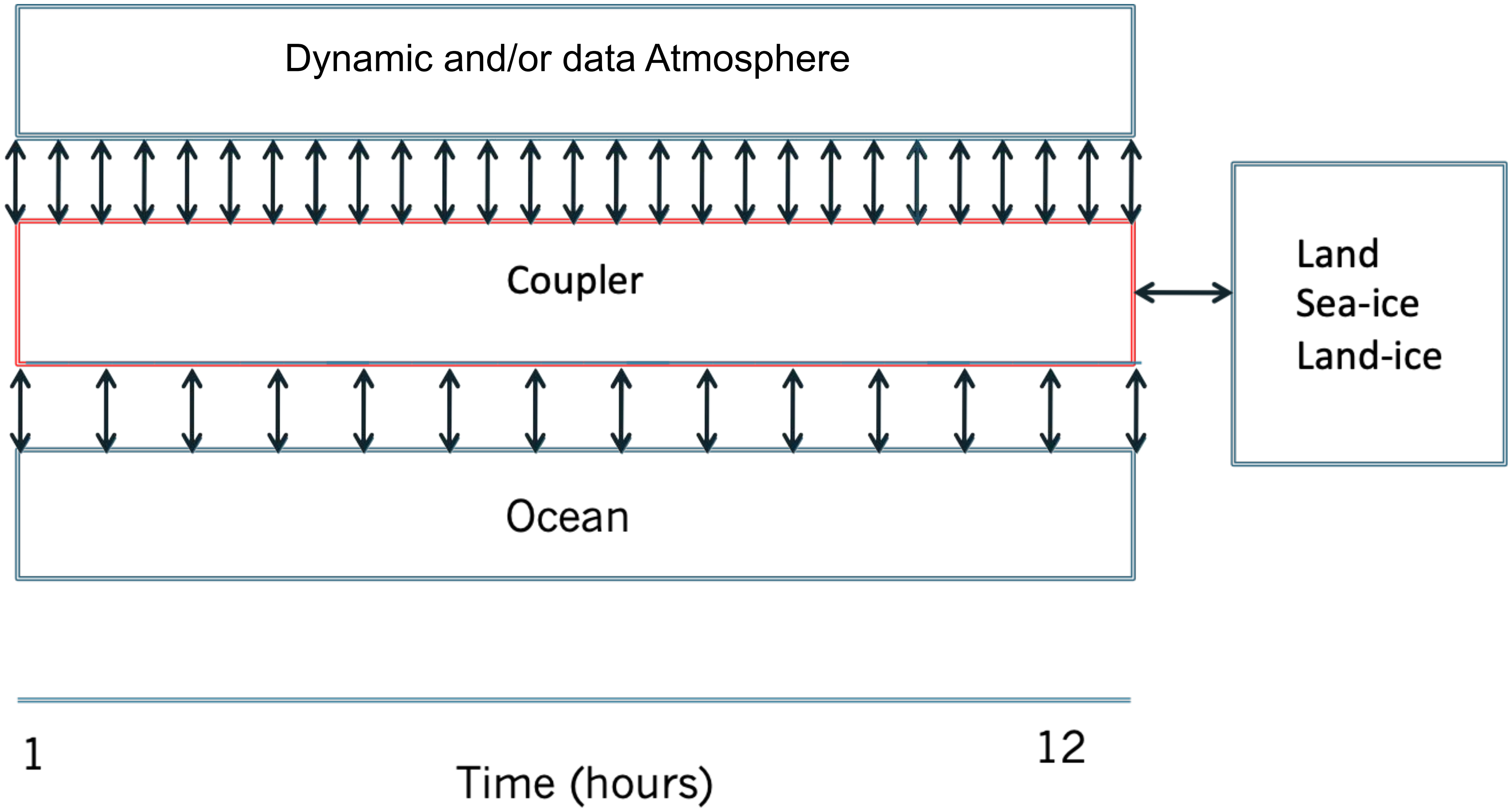
A Common Practice: Barotropic & Baroclinic Split

Issue: Courant-Friedrichs-Lewy (CFL) stability condition associated with fast surface gravity waves.

  - $u(\Delta t/\Delta x) \leq 1$
  - Barotropic mode $\sqrt{gH}$ ~200 m/s

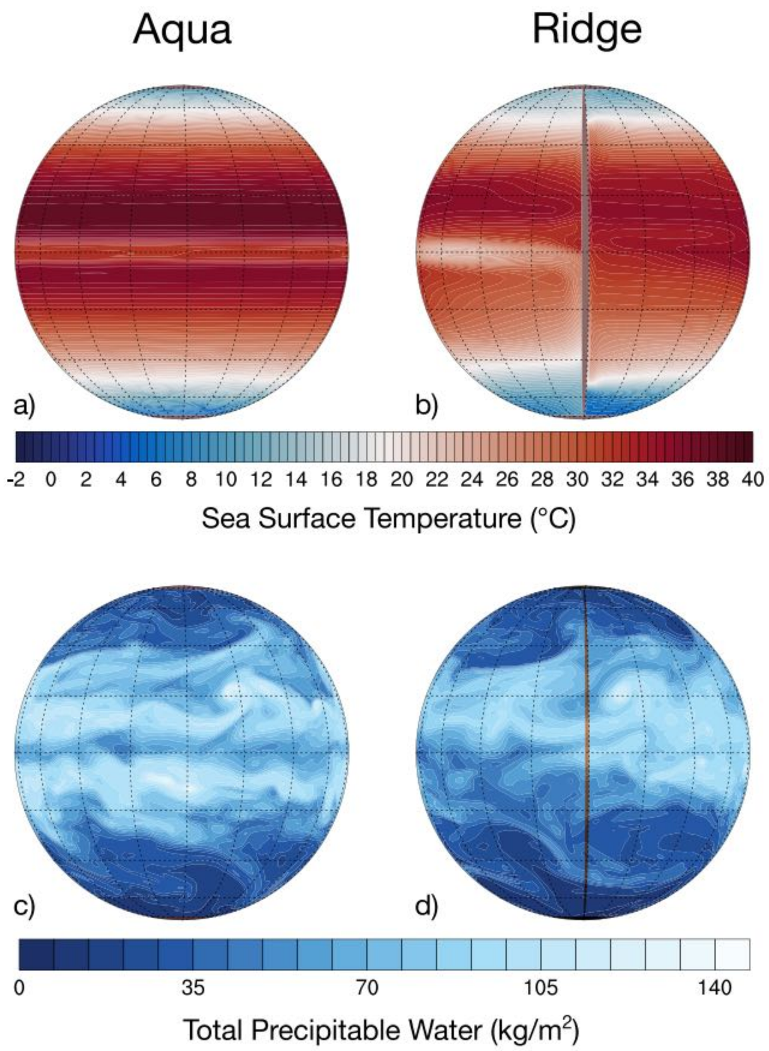
- Split flow into a depth averaged barotropic and a vertically varying baroclinic component
- Solve the barotropic equation implicitly
- Fast moving gravity waves are filtered out, but that's okay because they don't impact climate

A Coupling Schematic



All flux exchanges are done conservatively.

Simplified Configurations

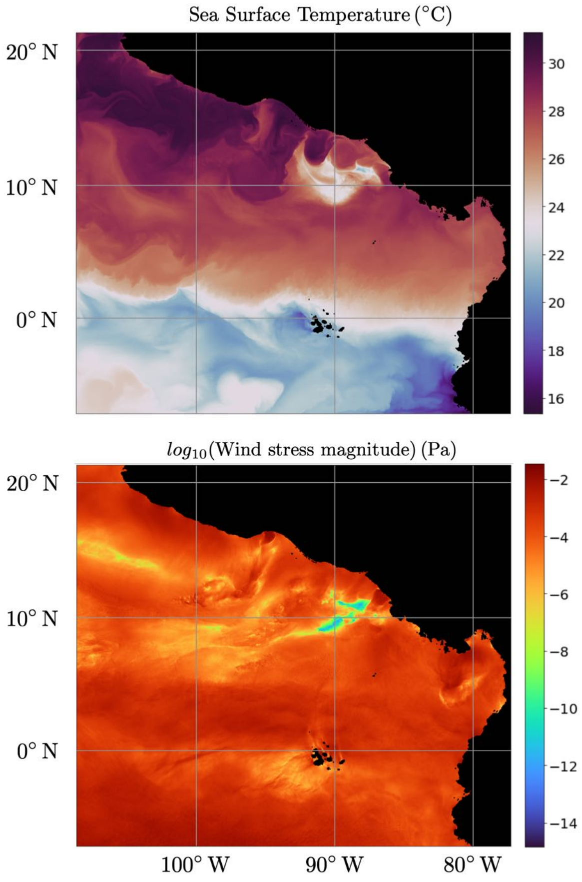


Wu et al. (2021)

Regional Configurations

Eastern Tropical Pacific

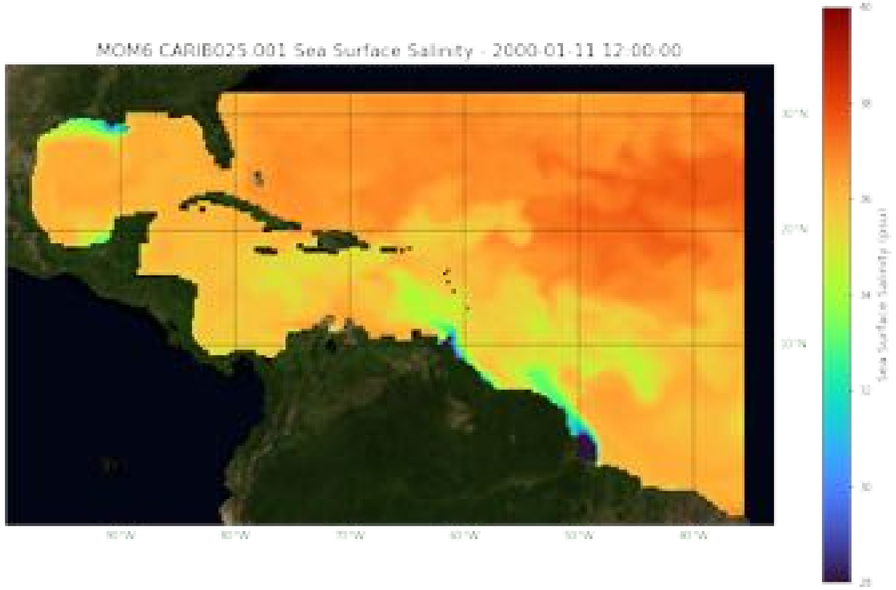
CESM-MOM6 (1 km) Driven by MPAS-A (3 km)



Bachman et al.

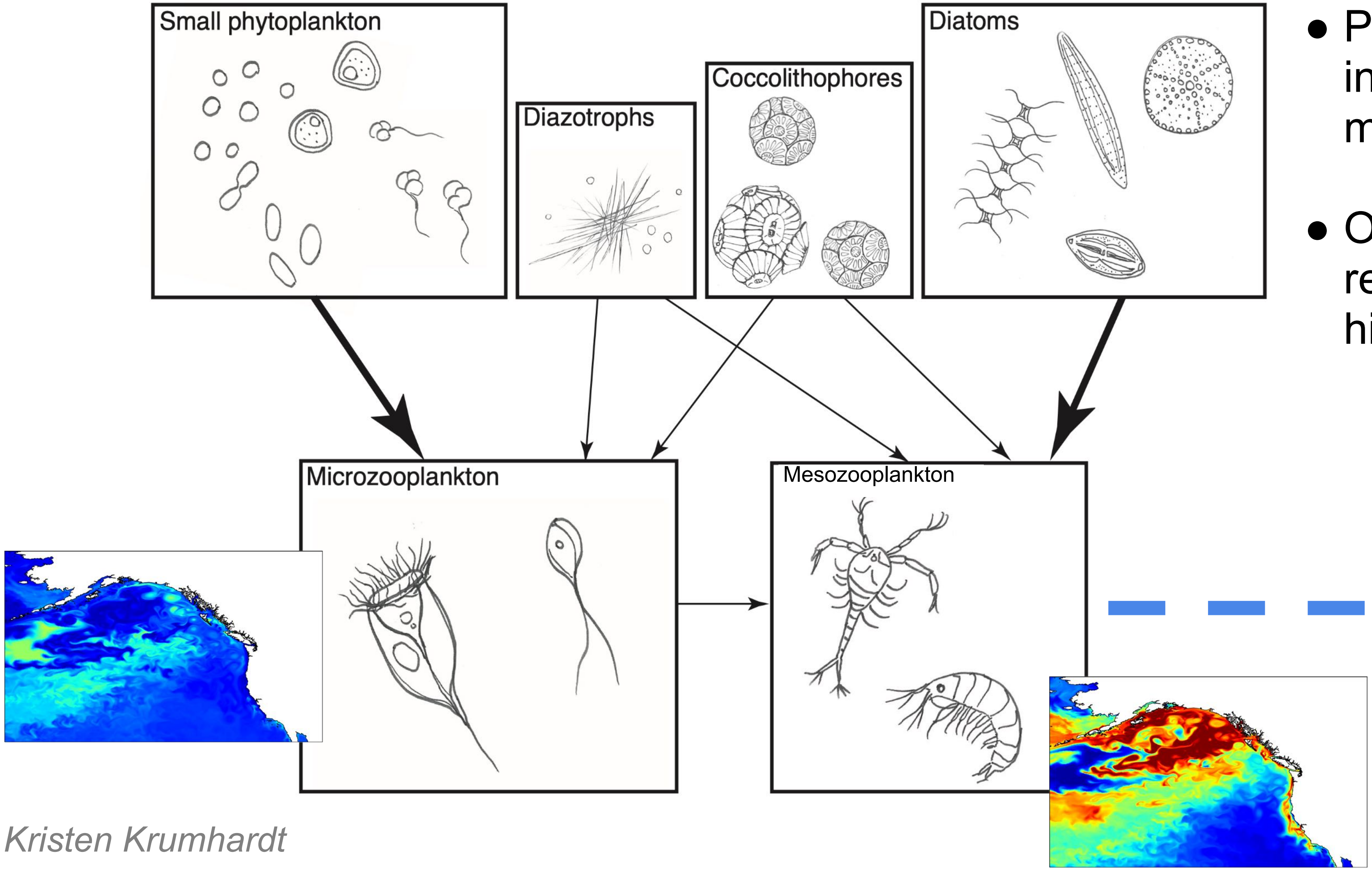
Caribbean Sea/Gulf of Mexico

MOM6 (25 km) Driven by CESM-LE (100 km)



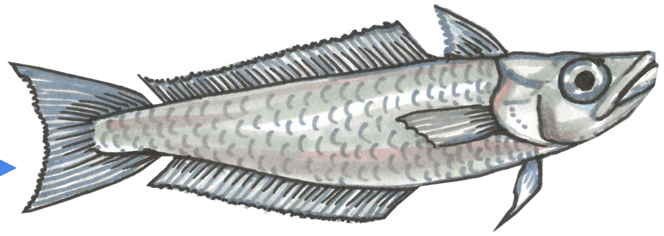
Seijo et al.

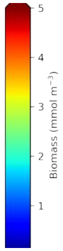
Expanding the MARBL Marine Ecosystem to Link to a Fisheries Model



- Partitioning zooplankton group into microzooplankton and mesozooplankton
- Offers improved estimates of food resources for fish and other higher trophic levels

FEISTY fish model

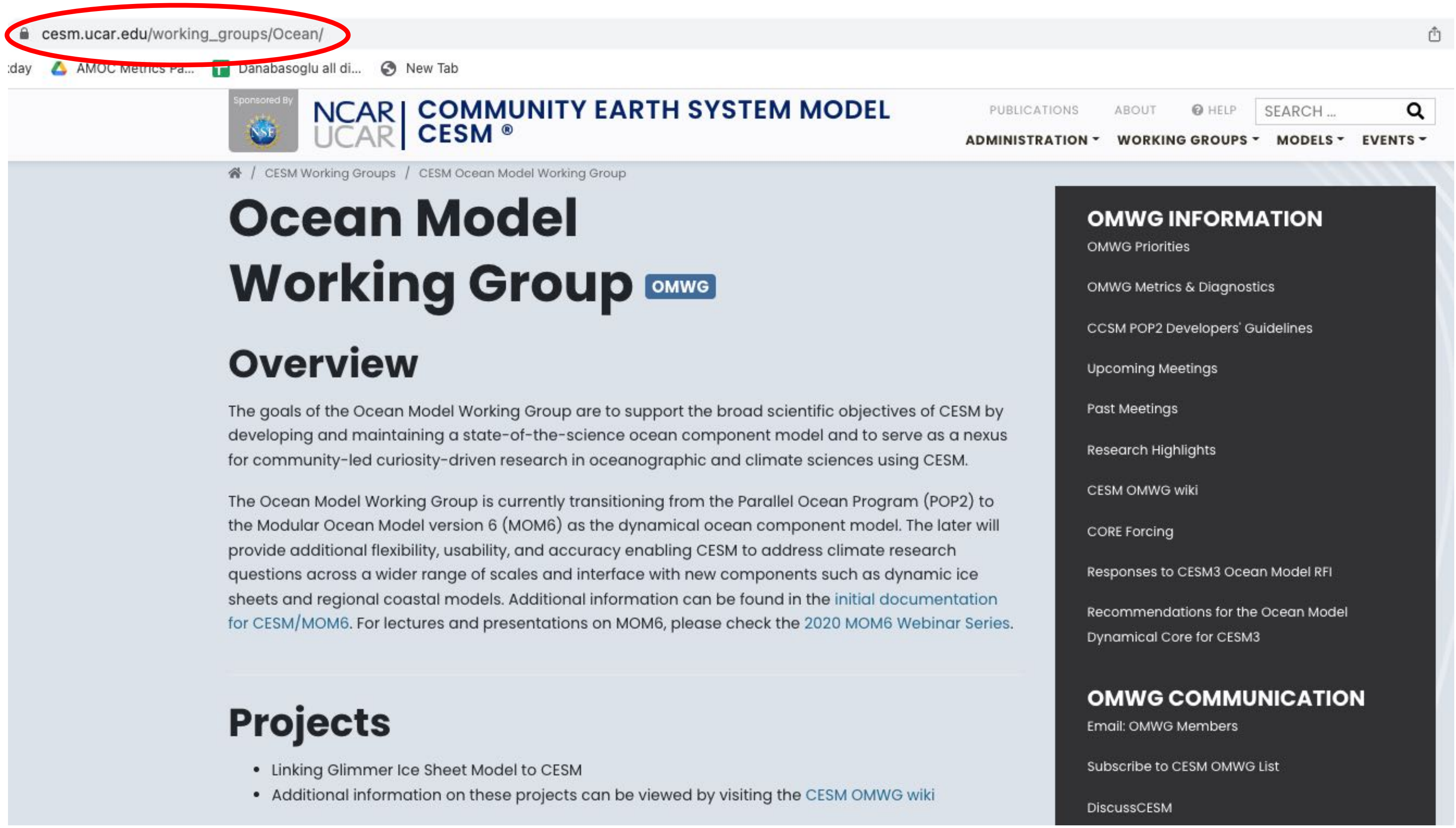




MARBL: Marine Biogeochemistry Library (Long et al. 2021, JAMES)

FEISTY: Fisheries Size and Functional Type Model (Petrik et al. 2019, Prog. Oceanogr.)

Kristen Krumhardt



Ocean Model Working Group OMWG

Overview

The goals of the Ocean Model Working Group are to support the broad scientific objectives of CESM by developing and maintaining a state-of-the-science ocean component model and to serve as a nexus for community-led curiosity-driven research in oceanographic and climate sciences using CESM.

The Ocean Model Working Group is currently transitioning from the Parallel Ocean Program (POP2) to the Modular Ocean Model version 6 (MOM6) as the dynamical ocean component model. The later will provide additional flexibility, usability, and accuracy enabling CESM to address climate research questions across a wider range of scales and interface with new components such as dynamic ice sheets and regional coastal models. Additional information can be found in the initial documentation for CESM/MOM6. For lectures and presentations on MOM6, please check the 2020 MOM6 Webinar Series.

Projects

- Linking Glimmer Ice Sheet Model to CESM
- Additional information on these projects can be viewed by visiting the CESM OMWG wiki

OMWG INFORMATION

OMWG Priorities

OMWG Metrics & Diagnostics

CCSM POP2 Developers' Guidelines

Upcoming Meetings

Past Meetings

Research Highlights

CESM OMWG wiki

CORE Forcing

Responses to CESM3 Ocean Model RFI

Recommendations for the Ocean Model Dynamical Core for CESM3

OMWG COMMUNICATION

Email: OMWG Members

Subscribe to CESM OMWG List

DiscussCESM

Thank You!

Contact: gokhan@ucar.edu

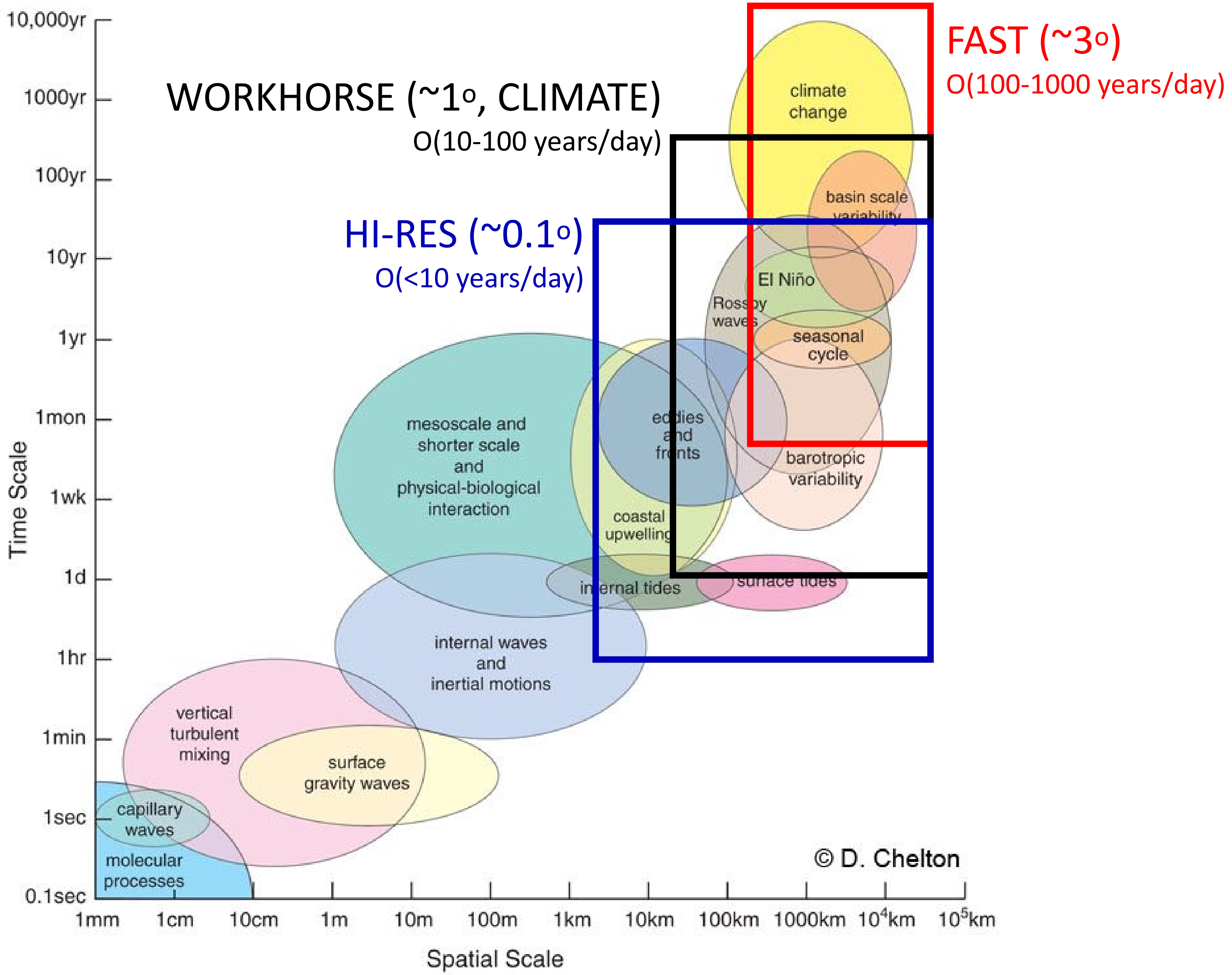
Topics

Part I (Tuesday)

- Global Earth system models;
- Ocean modeling challenges and properties;
- Governing equations and approximations;
- Discretizations;
- Vertical coordinates;
- Grid examples

Part II (Today)

Parameterizations



WORKHORSE (~1°, CLIMATE)
O(10-100 years/day)

FAST (~3°)
O(100-1000 years/day)

HI-RES (~0.1°)
O(<10 years/day)

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Parameterizations ….

- Accomplish physical effects of unresolved subgrid scale processes, usually expressed in terms of resolved fields;
- Physically-based and justified;
- As simple as possible / as inexpensive as possible; and
- As few parameters as possible

- Development,
- Implementation,
- Verification,
- Impacts

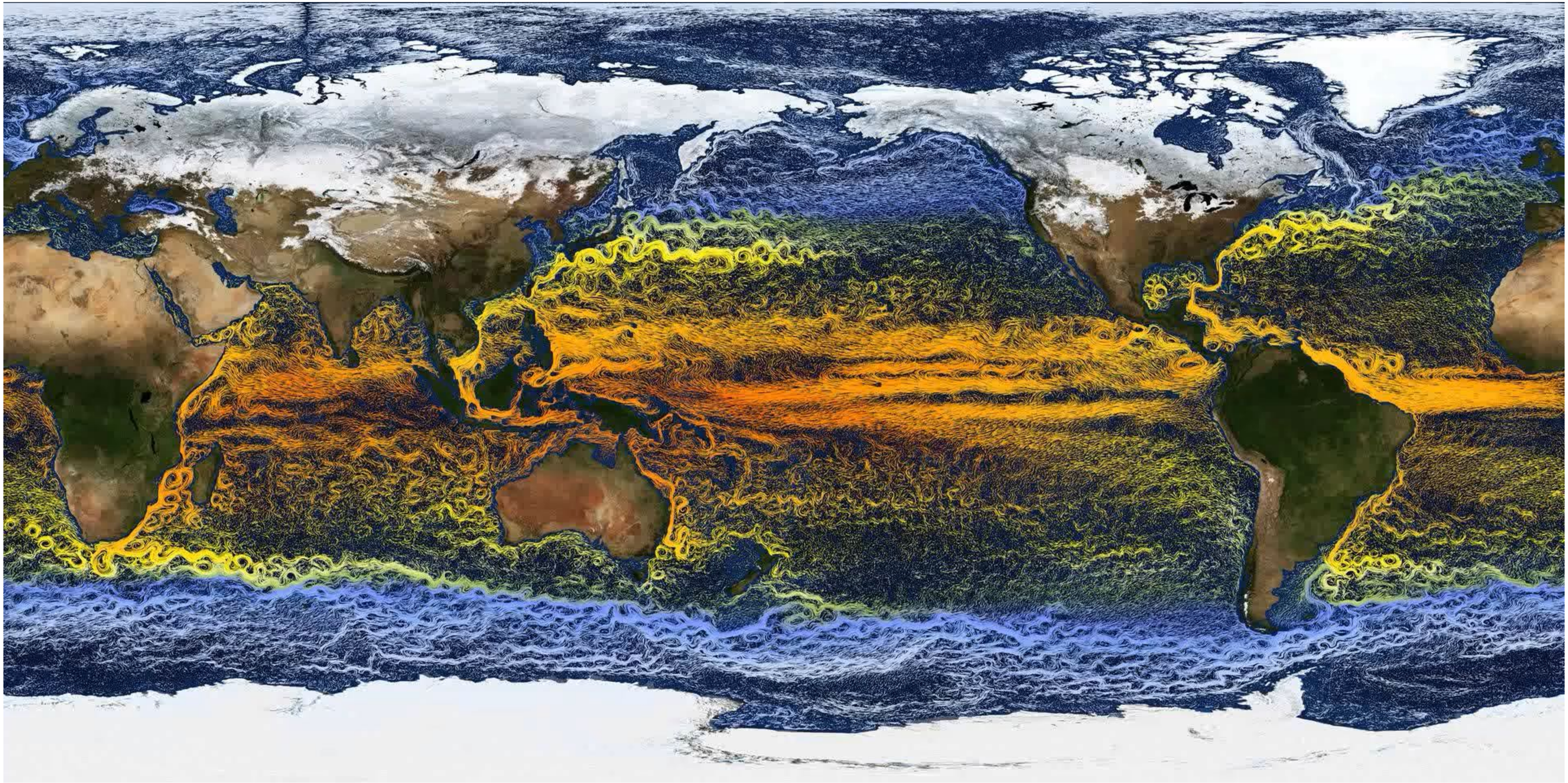
Parameterizations in Ocean Models

- Mesoscale eddies (tracers)
- Horizontal viscosity (momentum)
- Vertical mixing (momentum and tracers)
  - surface boundary layer,
  - interior (tidal mixing)
- Overflows
- River runoff & estuaries

- Submesoscale eddies (tracers)
- Solar absorption
- Langmuir circulation associated with surface waves
- Bottom boundary layer

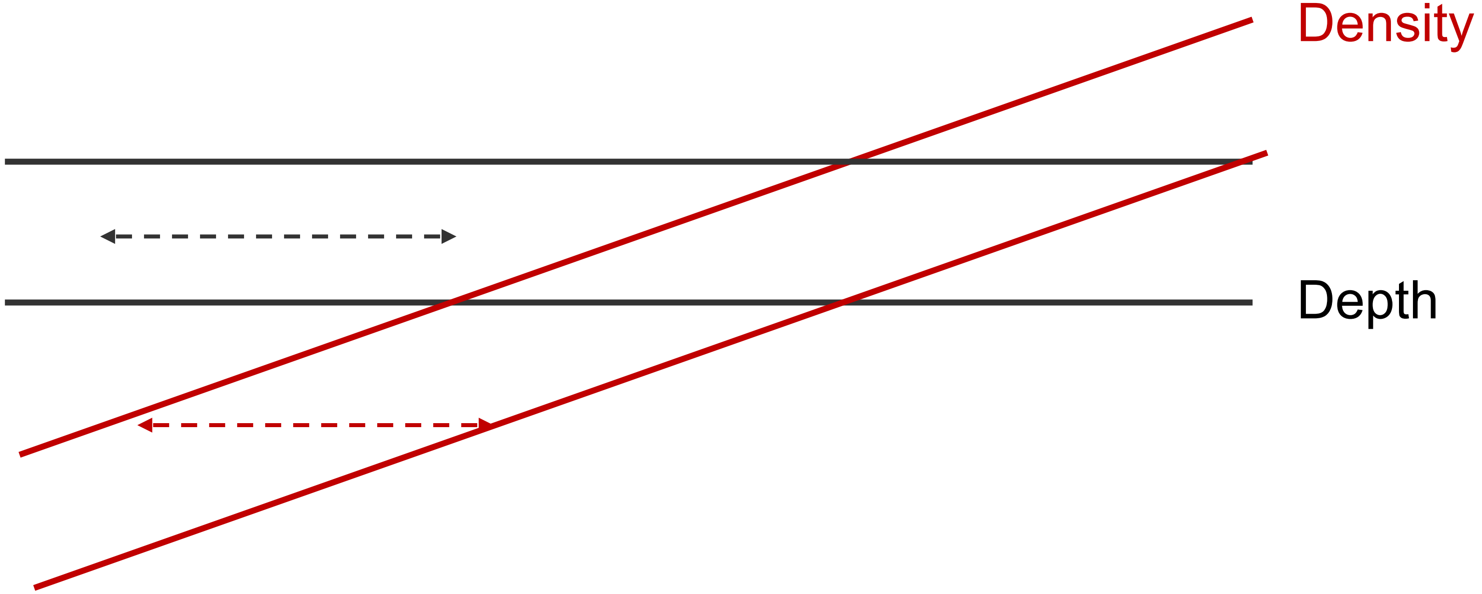
Mesoscale Eddy Parameterization

Land boundaries exert strong control on ocean dynamics



NCAR and TAMU

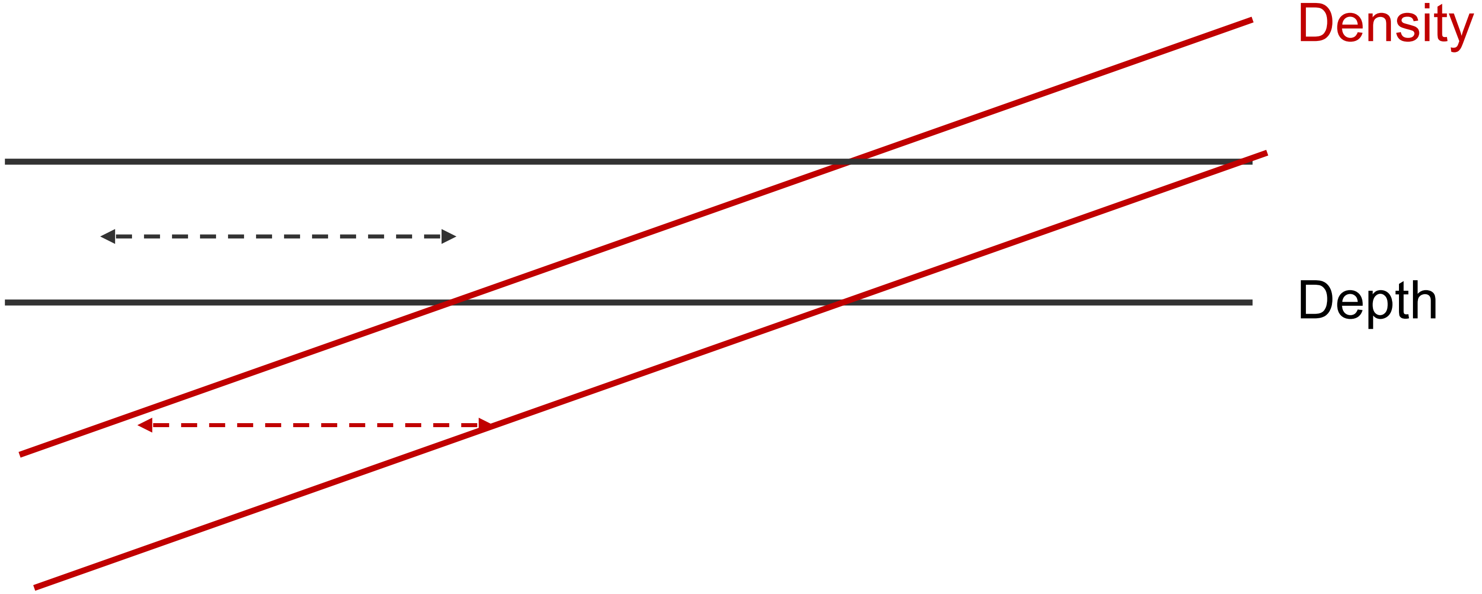
Mixing of Tracers



Ocean observations suggest mixing along isopycnals is ~10^7 times larger than across isopycnals.

Horizontal mixing causes spurious diapycnal mixing.

Mixing of Tracers



Redi (1982), Cox (1987)

Mesoscale Mixing Parameterization
Gent & McWilliams (1990; GM90)

GM90 proposed that eddies advect, as well as diffuse, tracers.

The form of the eddy-induced velocity, u*, v*, w*, was chosen because it ensures a global sink of potential energy.

In the above equations, *T* is a generic tracer, **s** is the 2D isopycnal slope vector, and K is the isopycnal diffusion tensor.

There are two diffusivities: A_I: isopycnal in K; A_{ITD}: thickness

Mesoscale Mixing Parameterization
Gent & McWilliams (1990; GM90)

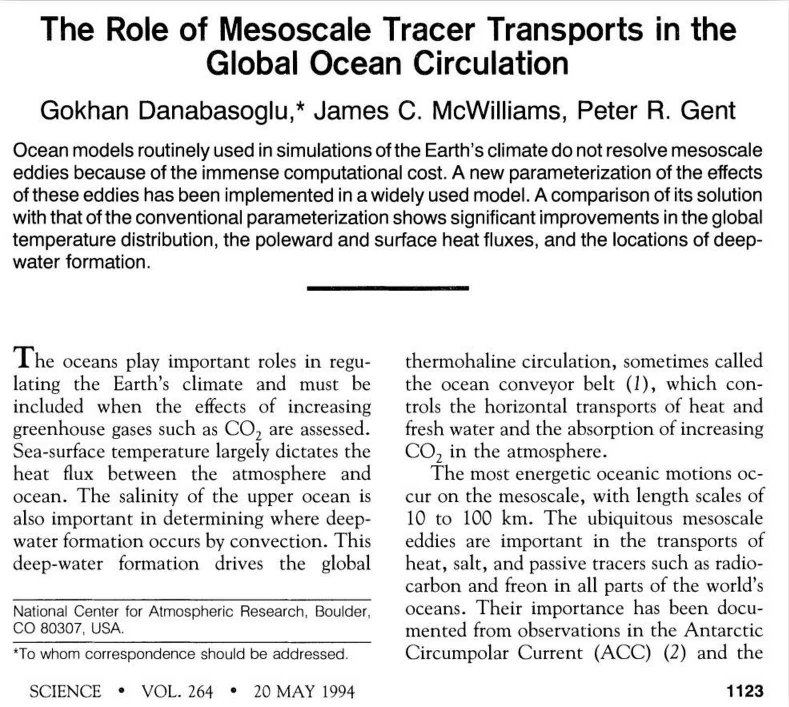
Mimics effects of unresolved mesoscale eddies as a sum of

- diffusive mixing of tracers along isopycnals (Redi),
- an additional advection of tracers by a divergence-free eddy-induced velocity,

Valid for the adiabatic ocean interior,

Flattens isopycnals, thereby reducing potential energy,

Eliminates any need for horizontal diffusion.



The Role of Mesoscale Tracer Transports in the Global Ocean Circulation

Gokhan Danabasoglu,* James C. McWilliams, Peter R. Gent

Ocean models routinely used in simulations of the Earth's climate do not resolve mesoscale eddies because of the immense computational cost. A new parameterization of the effects of these eddies has been implemented in a widely used model. A comparison of its solution with that of the conventional parameterization shows significant improvements in the global temperature distribution, the poleward and surface heat fluxes, and the locations of deep-water formation.

The oceans play important roles in regulating the Earth's climate and must be included when the effects of increasing greenhouse gases such as CO_2 are assessed. Sea-surface temperature largely dictates the heat flux between the atmosphere and ocean. The salinity of the upper ocean is also important in determining where deep-water formation occurs by convection. This deep-water formation drives the global thermohaline circulation, sometimes called the ocean conveyor belt (*1*), which controls the horizontal transports of heat and fresh water and the absorption of increasing CO_2 in the atmosphere.

The most energetic oceanic motions occur on the mesoscale, with length scales of 10 to 100 km. The ubiquitous mesoscale eddies are important in the transports of heat, salt, and passive tracers such as radiocarbon and freon in all parts of the world's oceans. Their importance has been documented from observations in the Antarctic Circumpolar Current (ACC) (*2*) and the

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National Center for Atmospheric Research, Boulder, CO 80307, USA.

*To whom correspondence should be addressed.

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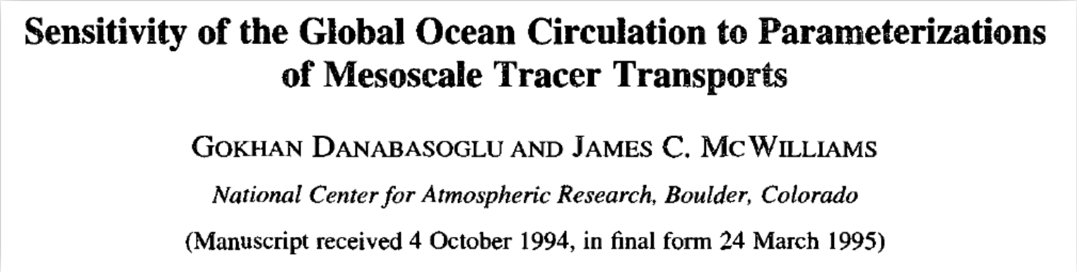


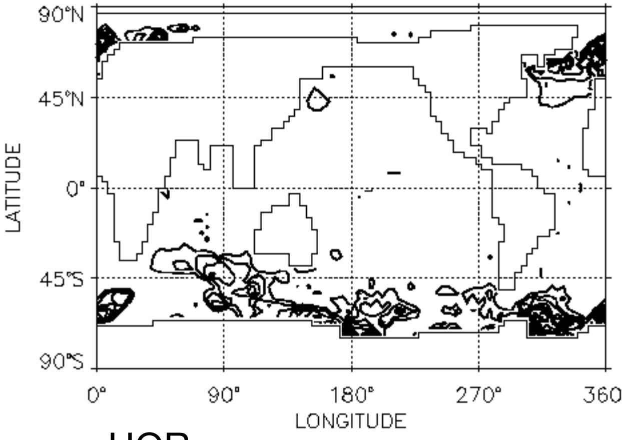
Sensitivity of the Global Ocean Circulation to Parameterizations of Mesoscale Tracer Transports

GOKHAN DANABASOGLU AND JAMES C. MCWILLIAMS

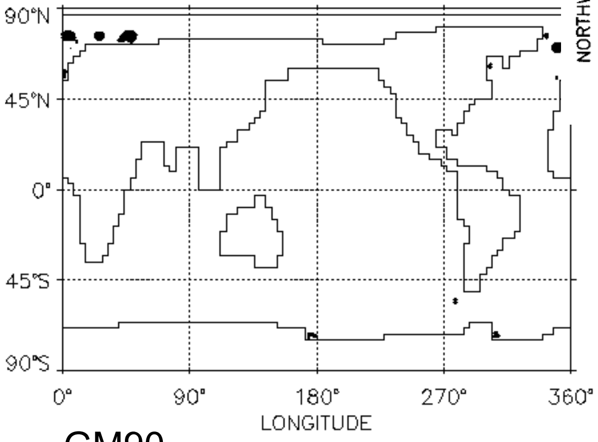
National Center for Atmospheric Research, Boulder, Colorado

(Manuscript received 4 October 1994, in final form 24 March 1995)

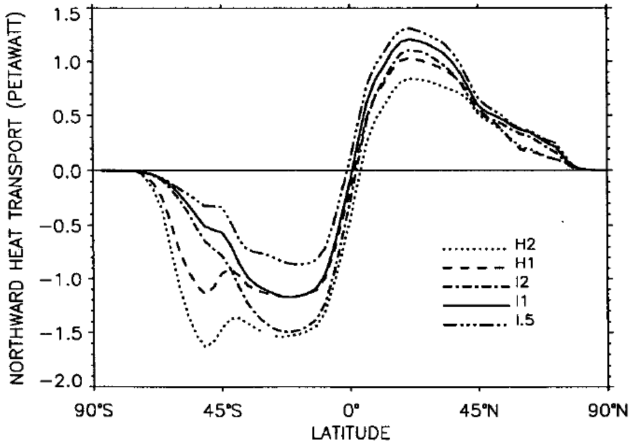
Deep Convection



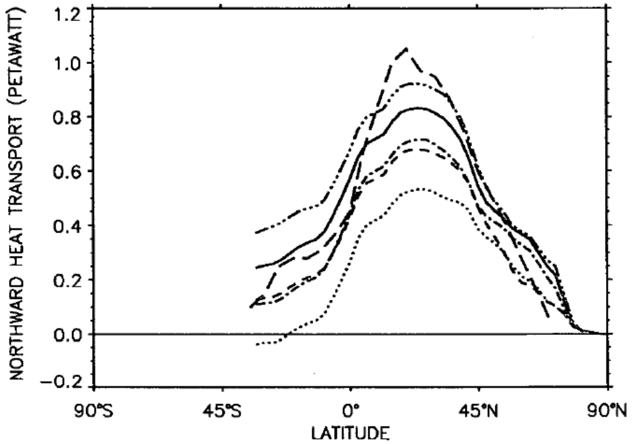
HOR



GM90



GLOBAL

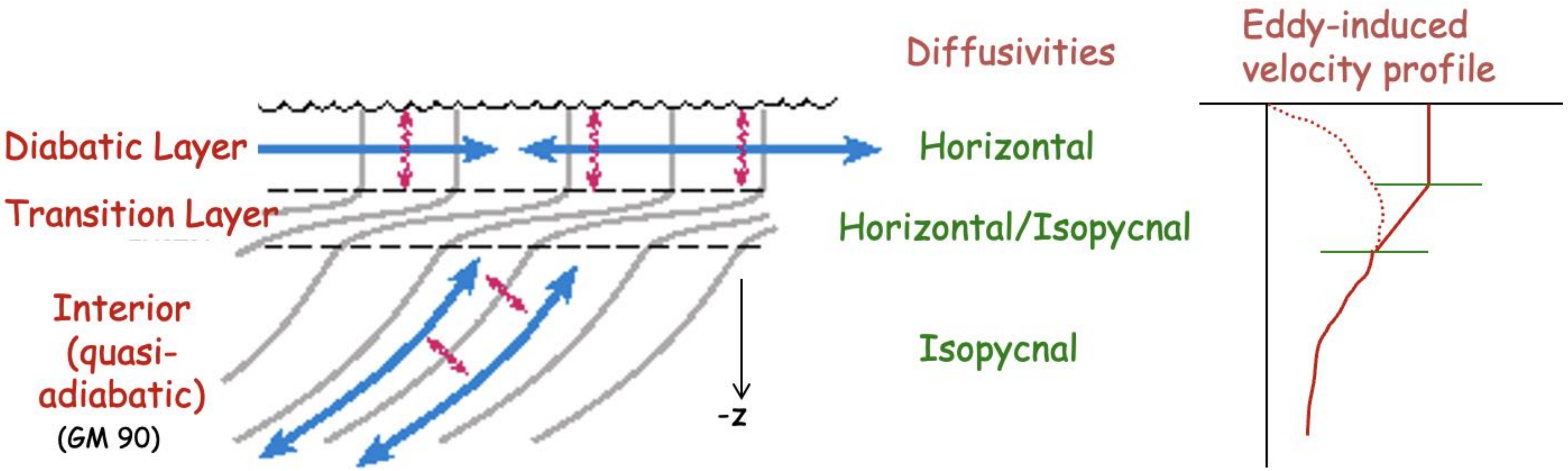


ATLANTIC

4°x3°x20L ocean model

Near-Surface Eddy Flux (NSEF) Scheme

GM90 is valid only in the quasi-adiabatic ocean interior, therefore the usual practice has been to taper both A_I and A_{ITD} to zero as the surface is approached.



NSEF replaces the usual approach of applying near-surface taper functions for the diffusivities.

Ferrari et al. (2008, J. Climate), Danabasoglu et al. (2008, J. Climate)

Spatially Varying Eddy Diffusivities

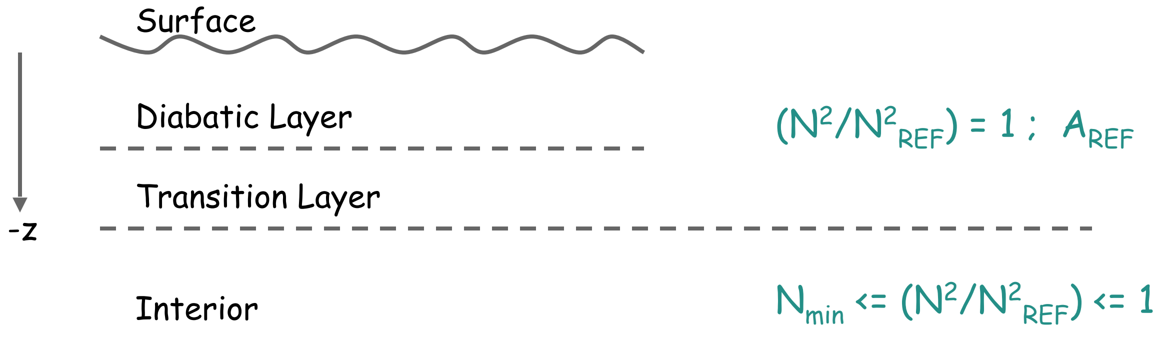
Observations indicate that mesoscale eddies are upper-ocean intensified.

$$A = A_{REF} \; (N^2 / N^2_{REF})$$

N^2: Local buoyancy frequency,

N^2_{REF}: Reference buoyancy frequency just below the transition layer,

A_{REF}: Constant reference value of A within the surface diabatic region.



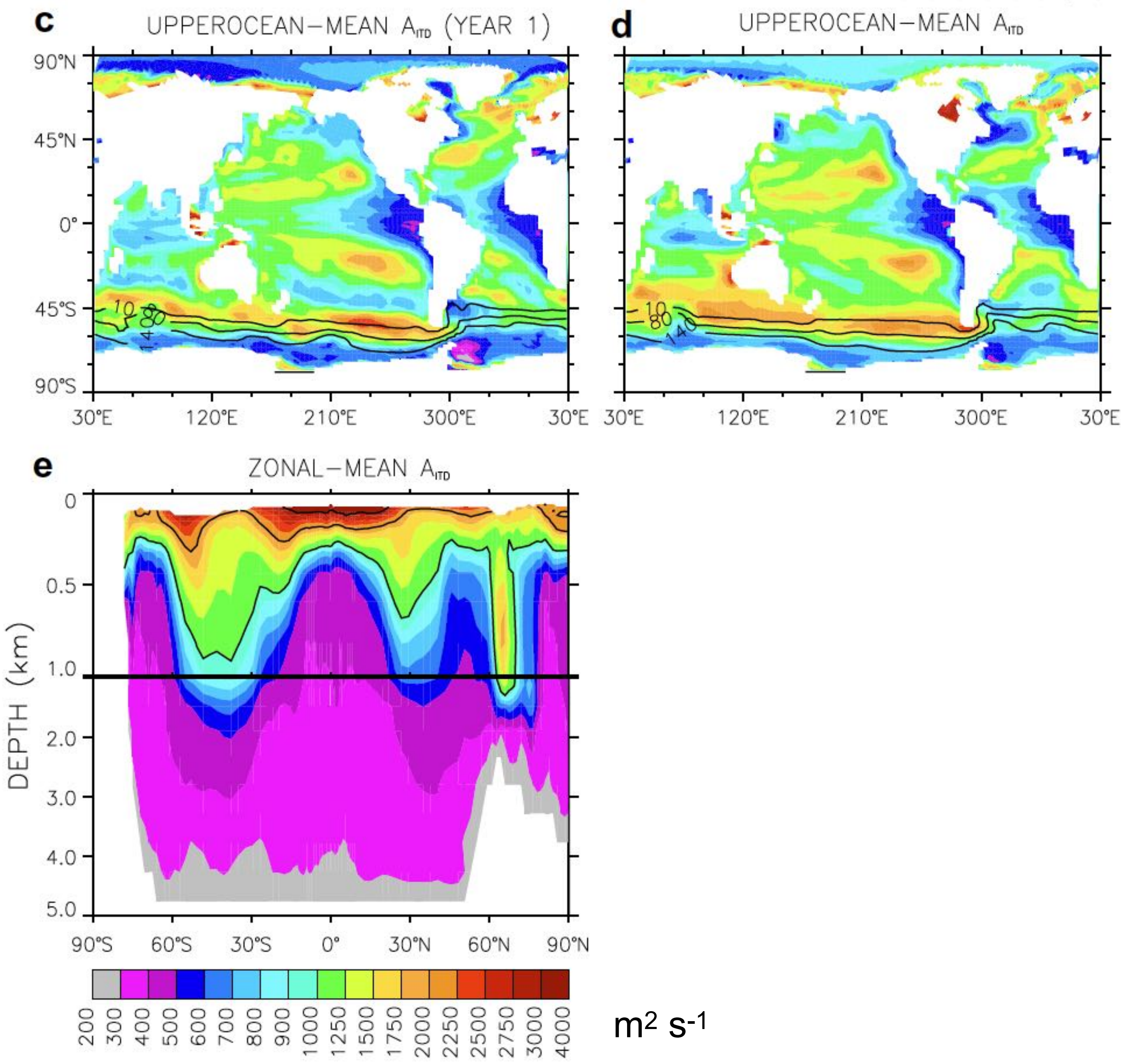
$(N^2/N^2_{REF}) = 1 \; ; \;\; A_{REF}$

$N_{min} <= (N^2/N^2_{REF}) <= 1$

N_{min} is a lower limit, $N_{min} = 0.1$.

Ferreira et al. (2005, JPO)

Spatially Varying Eddy Diffusivities



$m^2\ s^{-1}$

Danabasoglu & Marshall (2008, Ocean Modelling)

Horizontal Viscosity Parameterizations

Horizontal Viscosity

Spatially uniform, isotropic, Cartesian, Δ=250km grid for illustration

$$D(U) = A\ U_{xx} + A\ U_{YY}$$

$$D(V) = A\ V_{xx} + A\ V_{YY}$$

Grid Re (Diffuse Noise) → $A > 0.5\ V\ \Delta$ = 100,000 m^2/s

Resolve WBC (Munk Layers) → $A > \beta\ \Delta^3$ = 80,000 m^2/s

Diffusive CFL → $A < 0.5\ \Delta^2 / \Delta t$ = 8000,000 m^2/s

Realism (EUC, WBC) → $A \sim$ physical = 1,000 m^2/s

Anisotropic Horizontal Viscosity (A ≠ B)

Need to have B very small near the equator where there are fast, thin zonal currents; e.g. the equatorial undercurrent.

If B is too large, then this current becomes too wide and slow.

Guiding principle: Minimally Numerically Viscous;
Maximally Physically Viscous

Large et al. (2001, JPO), Jochum et al. (2008, JGR)

Anisotropic Horizontal Viscosity

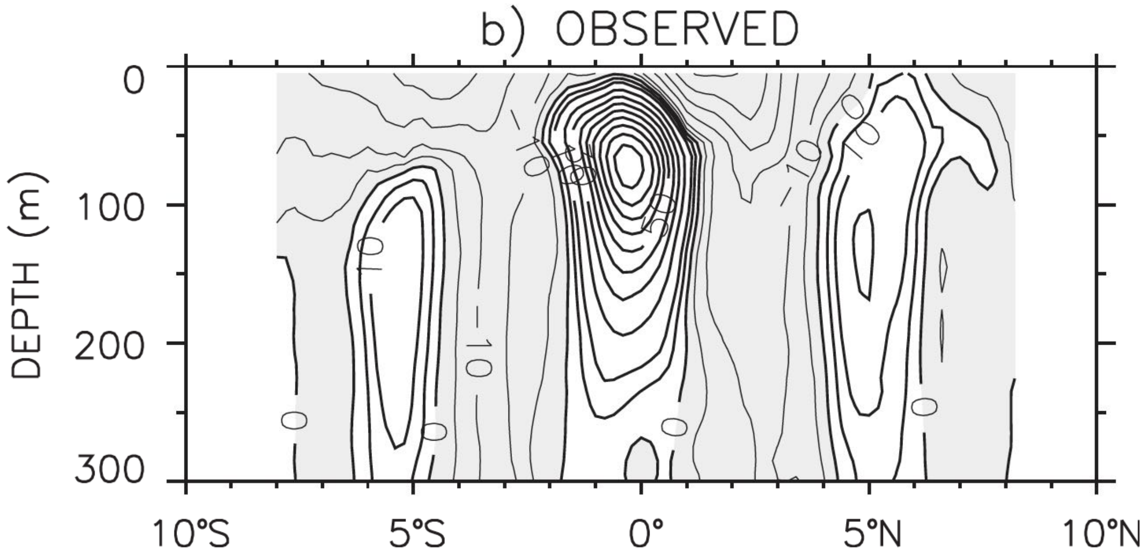
Grid Re (Diffuse Noise) → Live with the “noise”

Resolve WBC (Munk Layers) → $A = B = \beta\ \Delta^3$, only near WBC

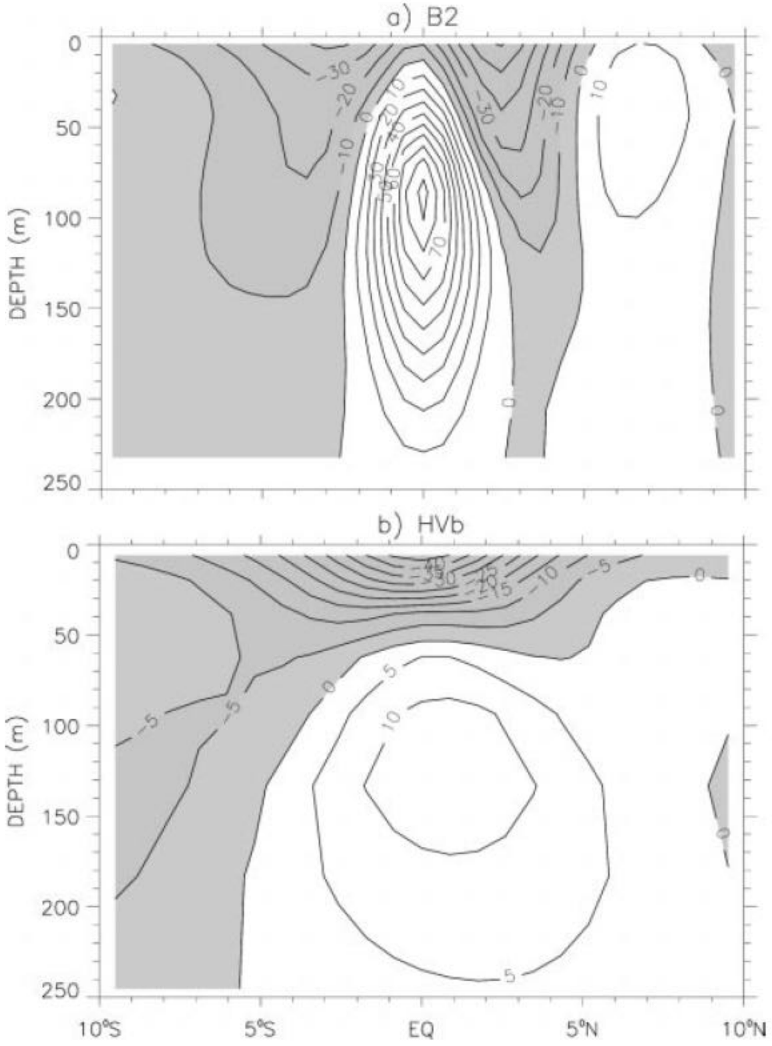
elsewhere:
Realism (EUC, WBC) → $A = 300\ m^2/s$
$B = 300\ m^2/s$ in the tropics
$= 600\ m^2/s$ polewards of 30^o

Obey diffusive CFL

Anisotropic Horizontal Viscosity



Pacific Equatorial Undercurrent



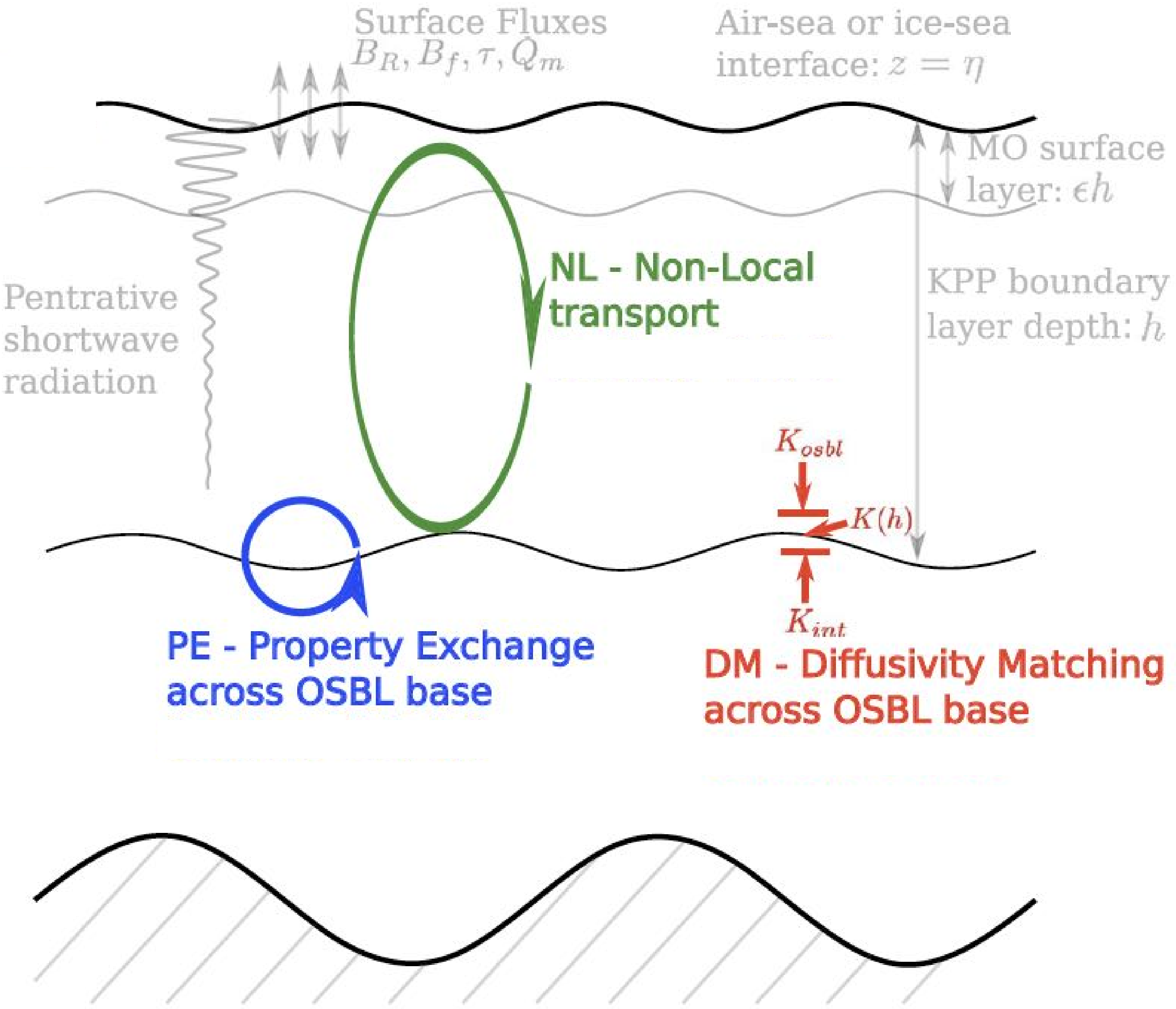
Anisotropic

Isotropic

Vertical Mixing Parameterizations

Vertical Mixing Parameterization
K-Profile Parameterization (KPP)

Large, McWilliams, and Doney (1994, Rev. Geophys.)



Van Roekel et al. (2018, JAMES)

Vertical Mixing Parameterization
K-Profile Parameterization (KPP)

Large, McWilliams, and Doney (1994, Rev. Geophys.)

A first-order turbulent closure scheme

$$\partial_t X = -\,\partial_z \overline{w'X'}$$

$$\overline{w'X'} = -\,K_x\,\partial_z X$$

where K_x is a vertical eddy diffusivity / viscosity

KPP involves three high-level steps:

1. Determination of boundary layer depth,
2. Calculation of interior diffusivities,
3. Evaluation of boundary layer diffusivities.

K-Profile Parameterization

The boundary layer depth, h, is determined based on a bulk Richardson number,

$$\mathrm{Ri_b} = \frac{(b_{\mathrm{sl}} - b(z))\,(-z + \eta)}{|\mathbf{u}_{\mathrm{sl}} - \mathbf{u}(z)|^2 + V_t^2(z)}$$

b_{sl}: near-surface buoyancy,

$b(z)$: boundary layer buoyancy profile,

$\mathbf{u}_{sl}$: near-surface reference horizontal velocity,

$\mathbf{u}(z)$: boundary layer horizontal velocity profile,

V^2_t : velocity scale of turbulent (unresolved) velocity shear

h is equated to the smallest value of -z at which the bulk Ri equals $Ri_{cr}=0.3$.

K-Profile Parameterization

Interior Mixing

- Shear instability: K_X^s
- Internal wave breaking: K_X^w
- Double diffusion: K_X^d
- Local static instability (convection): K_X^c
- Tidal mixing: K_X^t

$$K_X(\text{interior}) = K_X^s + K_X^w + K_X^d + K_X^c + K_X^t$$

K-Profile Parameterization

$$K_X(l) = h \;\; w_X(l) \;\; G(l)$$

with

$l = d / h$,

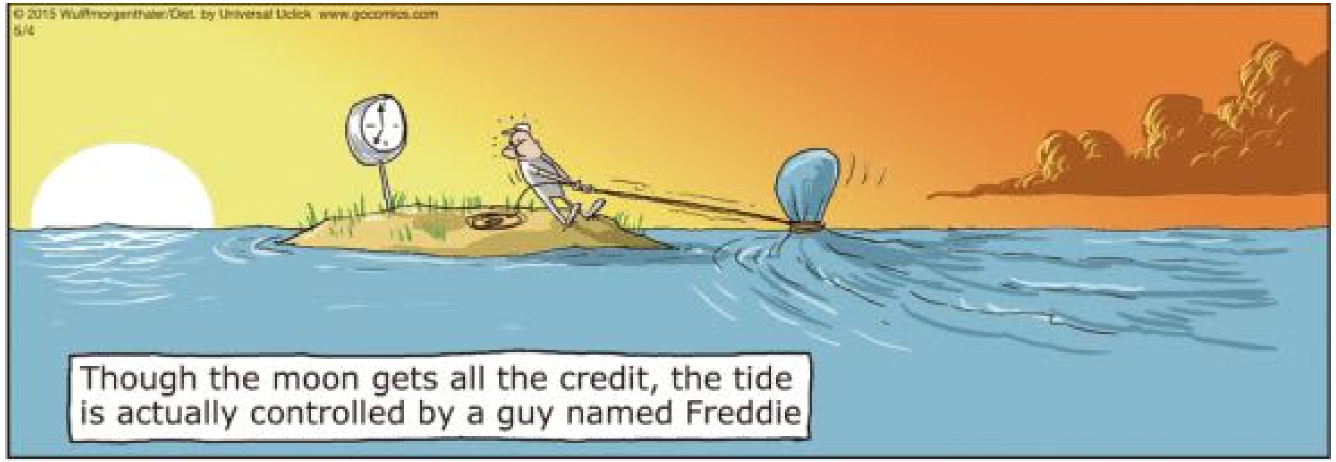
$w_X(l)$: turbulent velocity scale,

$G(l)$: cubic shape function.

Interior mixing at the base of the boundary layer influences the turbulence throughout the boundary layer.

There is also a non-local counter-gradient term: $\overline{w'X'} = - K_x \, (\partial_z X - \boldsymbol{\gamma}_x)$

Tidal Mixing



Tidal Mixing

[based on Jayne & St. Laurent (2001, GRL); St. Laurent et al. (2002, GRL); Simmons et al. (2004, Ocean Modelling)]

Vertical diffusivity due to background and tidal mixing:

$$k_v = k_{\mathrm{bg}} + \frac{\Gamma \varepsilon}{N^2}$$

where *N*: buoyancy frequency,

Γ (=0.2): canonical mixing efficiency of turbulence.

$$\varepsilon = \frac{q E(x, y) F(z, H)}{\rho} \qquad F(z, H) = \frac{e^{-(H-z)/\zeta}}{\zeta(1 - e^{-H/\zeta})}$$

with ζ = 500 m

where q (=1/3): local dissipation efficiency,

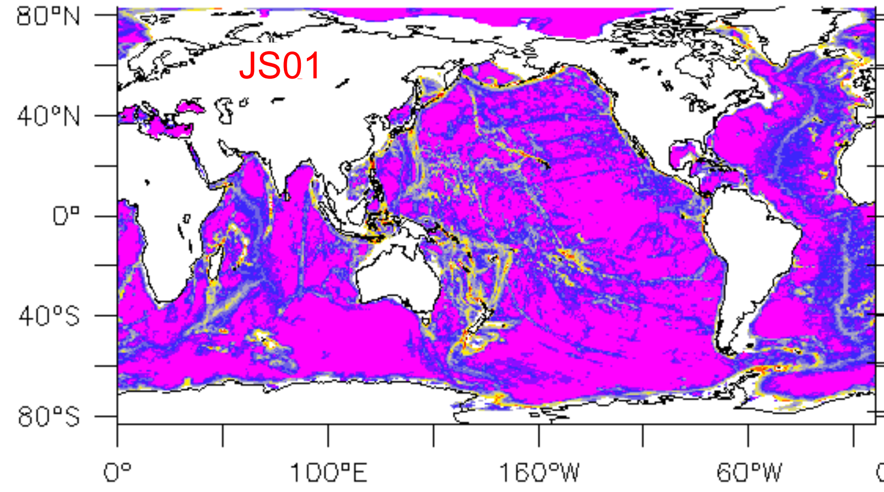
ρ: density,

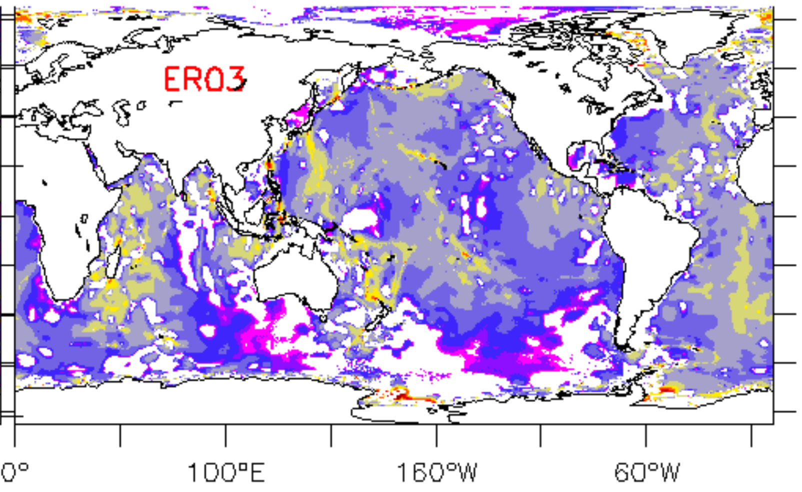
E: energy flux out of the barotropic tide,

F: vertical distribution (decay) function

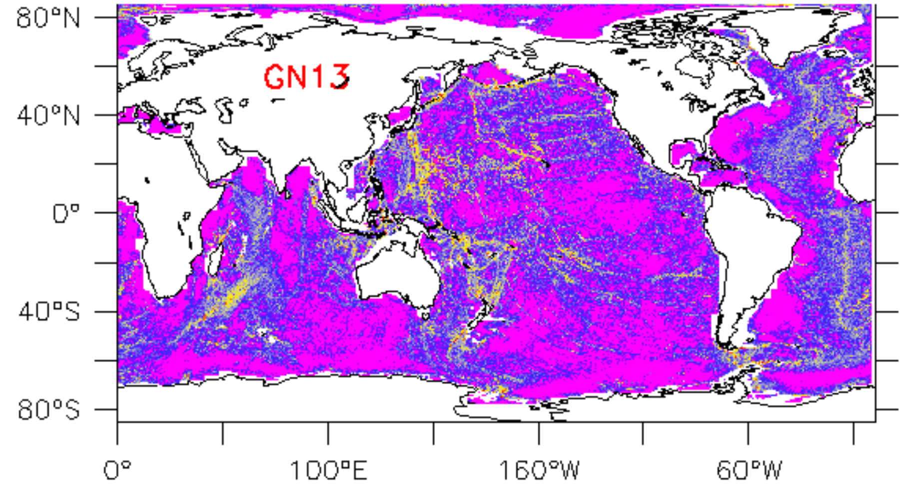
Dissipation Energy Flux from the Barotropic Tides

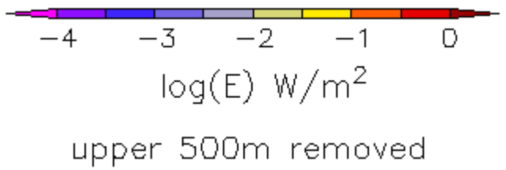
Jayne & St. Laurent (JS01): Estimated using a barotropic tide model with parameterized internal wave drag; 8 tidal constituents





Egbert & Ray (ER03): Estimated from assimilation of satellite altimetry data into a hydrodynamic model; 4 tidal constituents





Green & Nycander (GN13): Estimated using a high-resolution (1/8° x 1.8°) barotropic tide model with parameterized internal wave drag; 4 tidal constituents

Tidal Constituents (TCs)

Four TCs:

- Semi-diurnal lunar and solar tides, M2 and S2, respectively, with *q* = 1/3,
- Diurnal tides K1 and O1 with *q* = 1 polewards of 30^{o} latitude

$$\varepsilon = \frac{1}{\rho} \sum_{z' > z}^{H} \sum_{\mathrm{TC}} q_{\mathrm{TC}} E_{\mathrm{TC}}(x, y, z') F(z, z')$$

The 18.6-year Lunar Nodal Cycle can be represented.

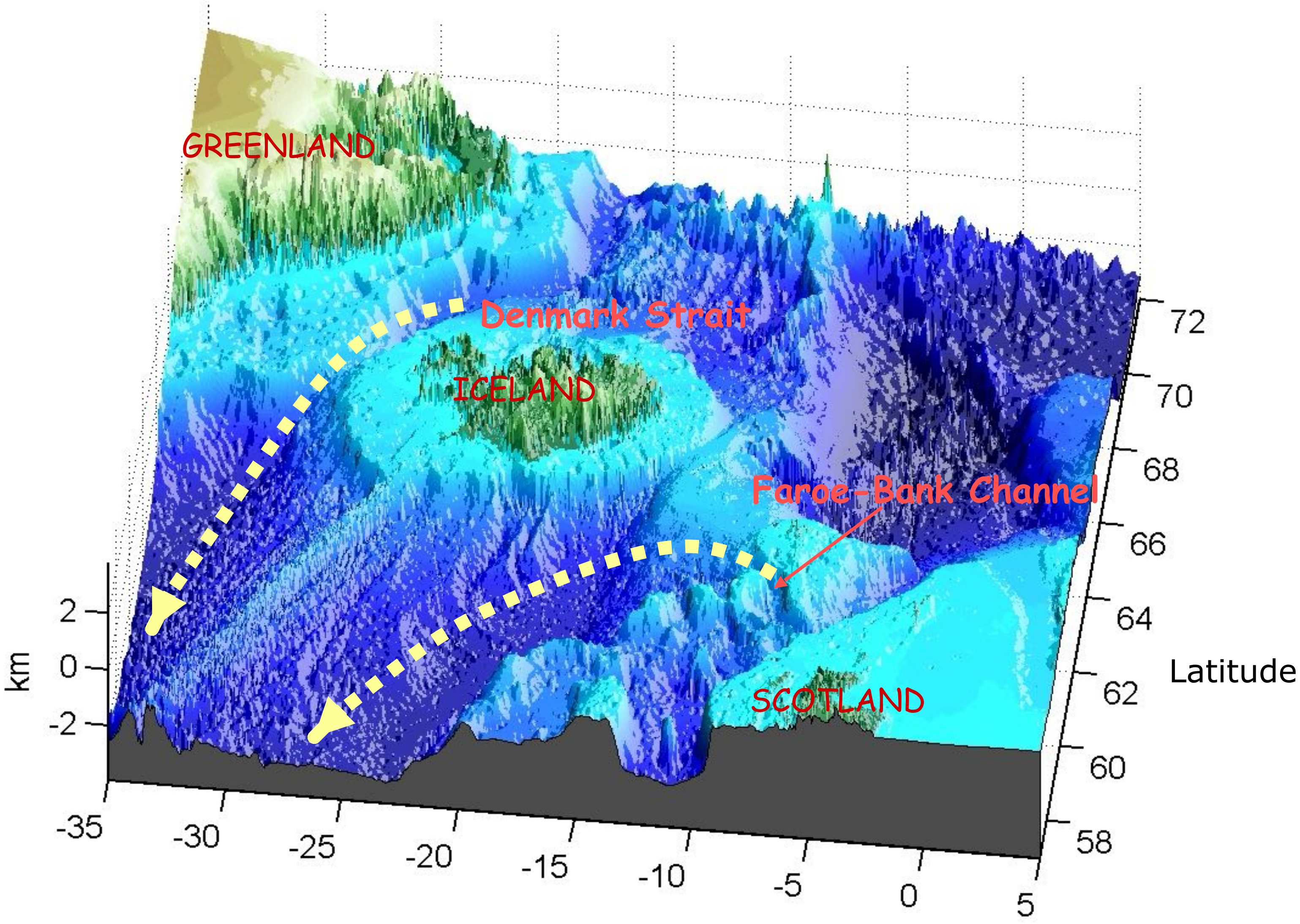
Regularization of Tidal Diffusivities

$$k_v = k_{\mathrm{bg}} + \frac{\Gamma \varepsilon}{N^2}$$

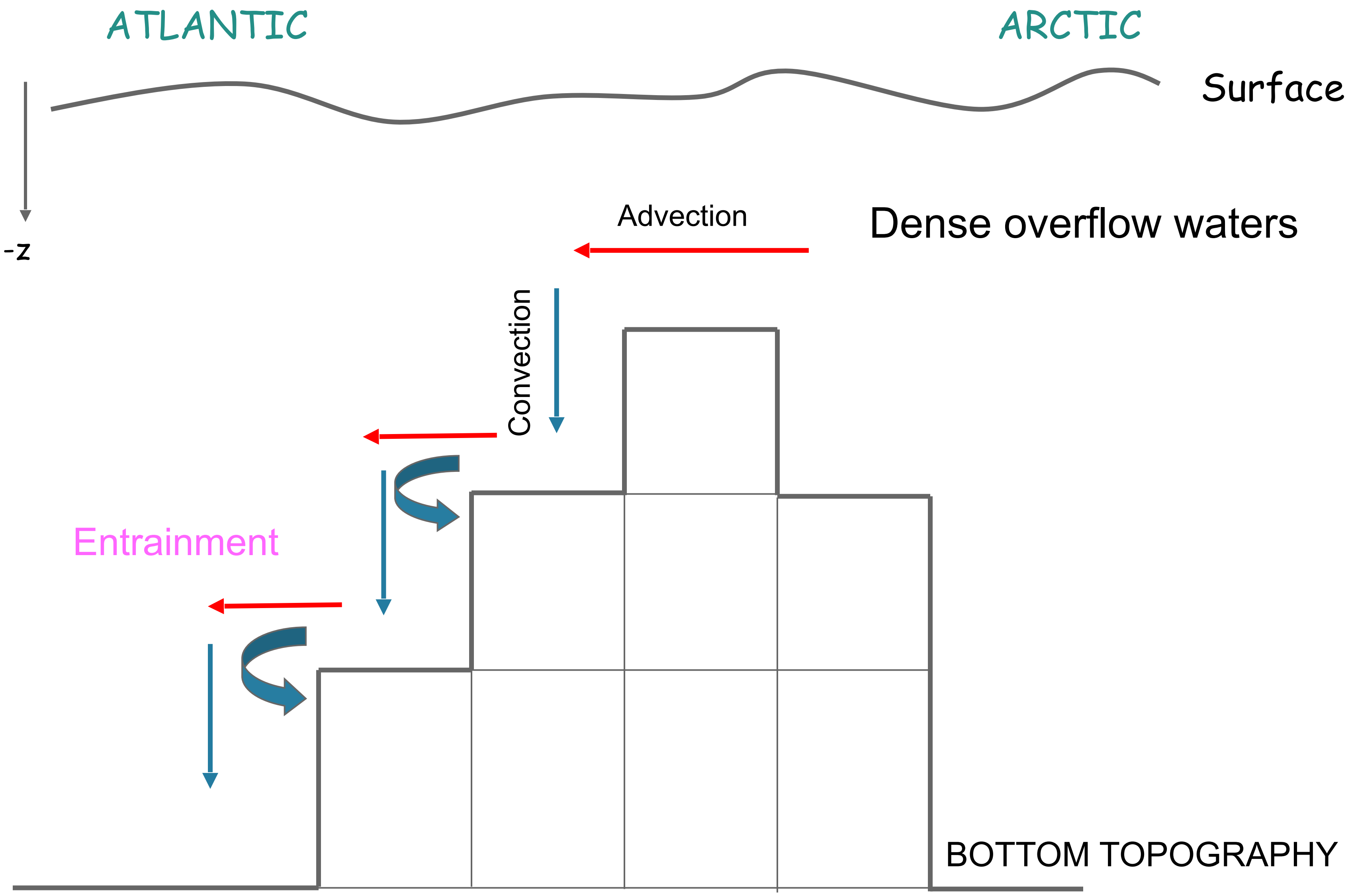
- Limit minimum value of N^2, e.g., 10^{-8} s^{-2}
- Limit k_v using $k_v = \min(k_v, k_{max})$, e.g., $k_{max} = 100$ cm^2 s^{-1}
- Limit both
- …

Overflow Parameterization

Gravity Current Overflows



from Jim Price



ATLANTIC

ARCTIC

Surface

-z

Advection

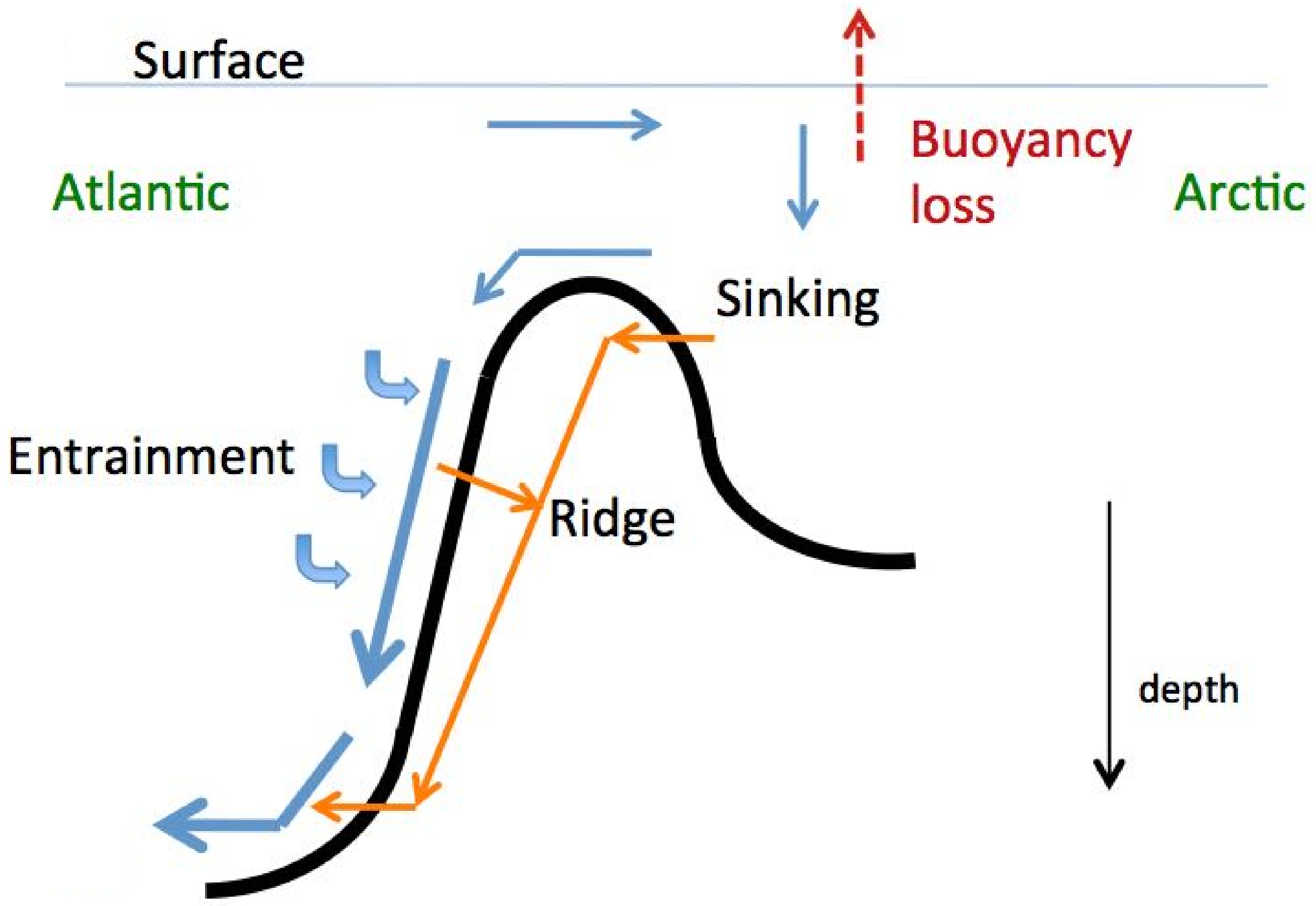
Dense overflow waters

Convection

Entrainment

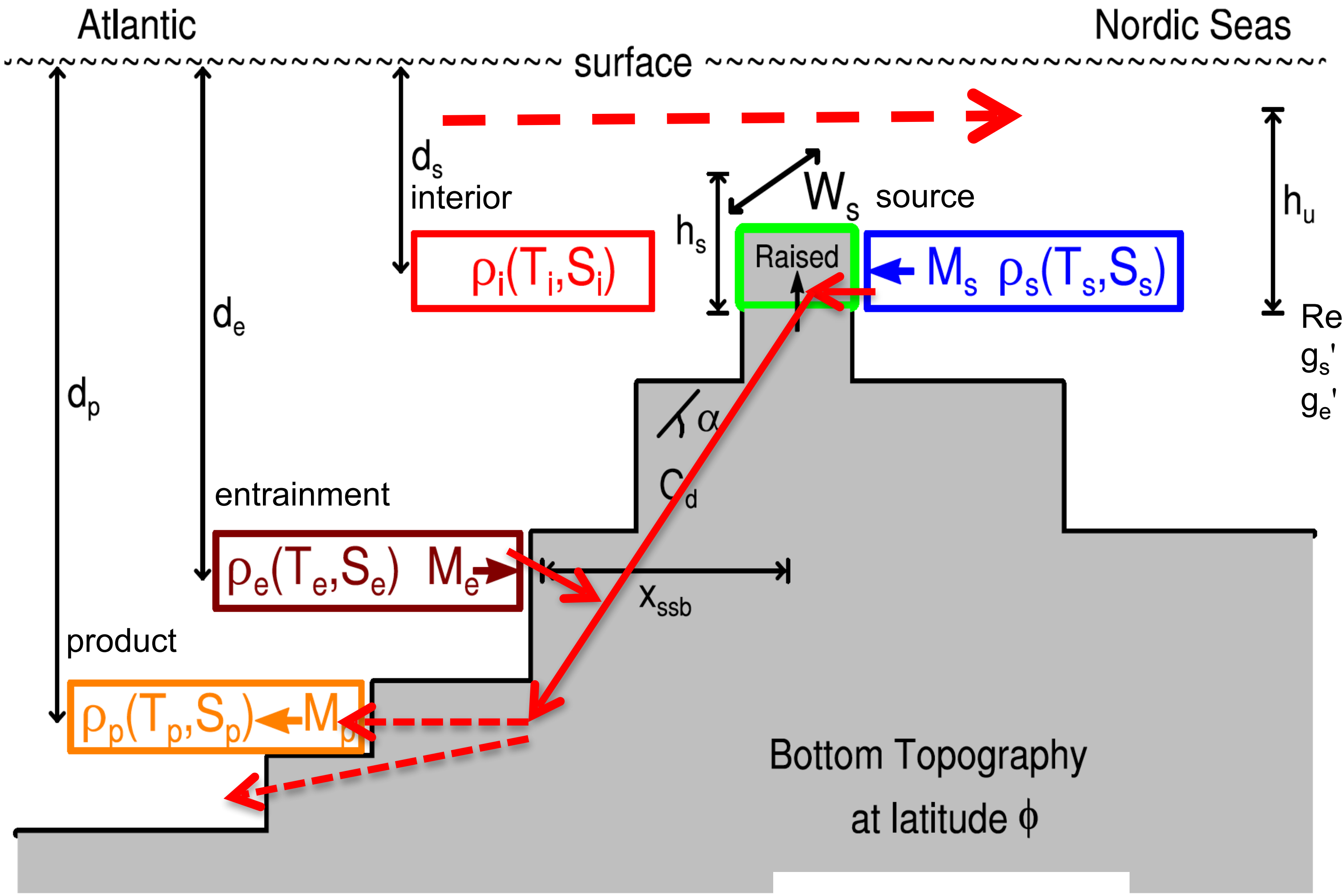
BOTTOM TOPOGRAPHY

Gravity Current Overflow Parameterization



Based on Price & Yang (1998); described in Briegleb et al. (2010, NCAR Tech. Note) and Danabasoglu et al. (2010, JGR)

Overflow Parameterization Schematic



Reduced Gravities:
$g_s' = (g/\rho_o)\,(\rho_s - \rho_i)$
$g_e' = (g/\rho_o)\,(\rho_s - \rho_e)$

$$M_s = \frac{g_s' h_u^2}{2f}$$

$$M_p = M_s + M_e,$$

$$\begin{aligned} T_p &= T_s(1-\vartheta) + T_e\vartheta, \\ S_p &= S_s(1-\vartheta) + S_e\vartheta \end{aligned}$$

$$M_e = M_s\left(\{g_e'\mathcal{F}(\alpha, f, C_d, M_s, W_{ssb})\}^{2/3} - 1\right)$$

$$\vartheta = \frac{M_e}{M_s + M_e} = \frac{M_e}{M_p}.$$

Equatorward Volume Transports

Ocean-only Simulations

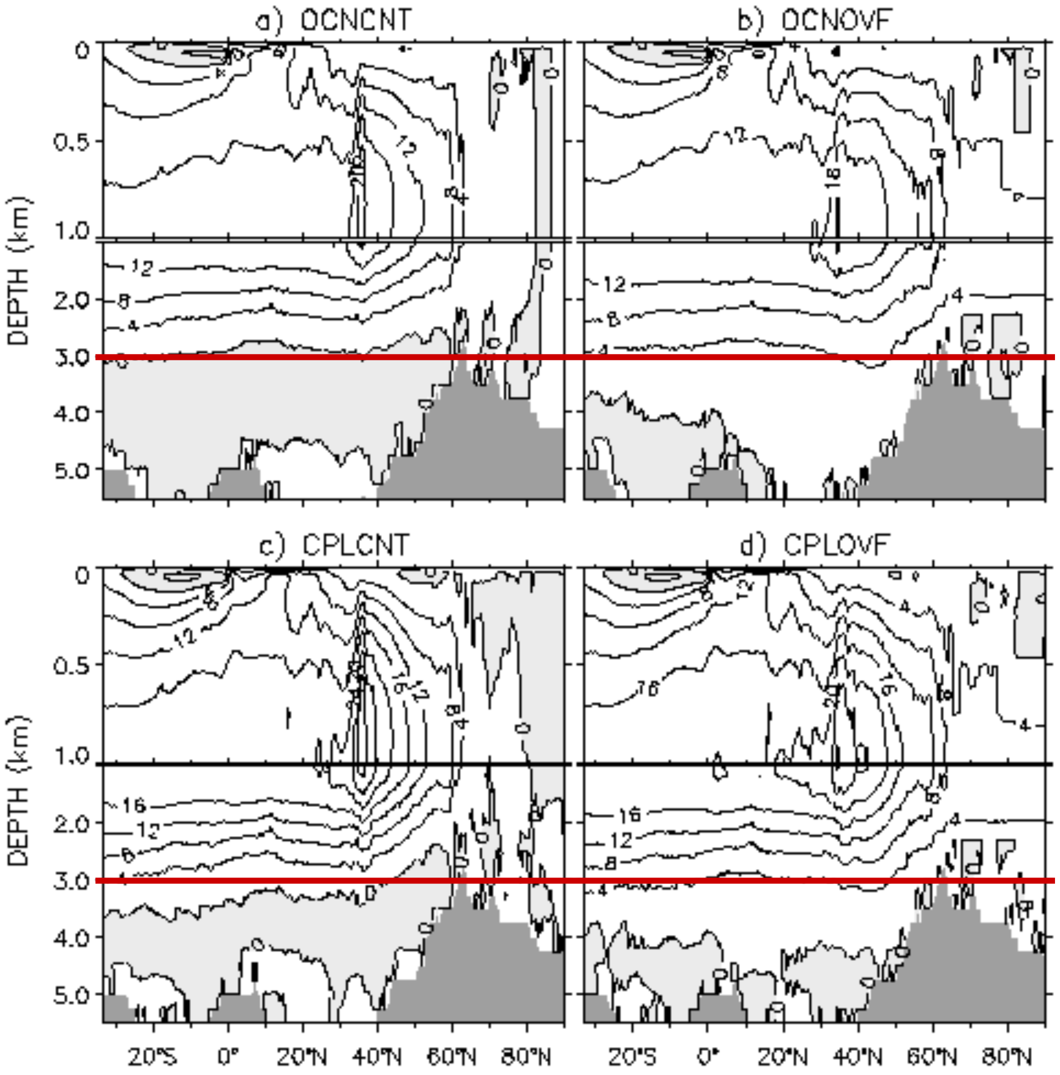
$\sigma_o \geq$	44^oW 27.80	49.3^oW 27.80	49.3^oW 27.74	69^oW 27.80
no overflows	5.3	3.5	17.3	0.2
with overflows	10.7	9.3	26.7	2.0
observations	13.3 Dickson and Brown(1994)	14.7 Fischer et al. (2004)	26 ± 5 Fischer et al. (2004)	12.5 Joyce et al. (2005)

All in Sv

Atlantic Meridional Overturning Circulation (AMOC)

Ocean-only
(no overflows)

Coupled
(no overflows)



Ocean-only
(with overflows)

Coupled
(with overflows)

in Sv (10^6 m^3 s^{-1})

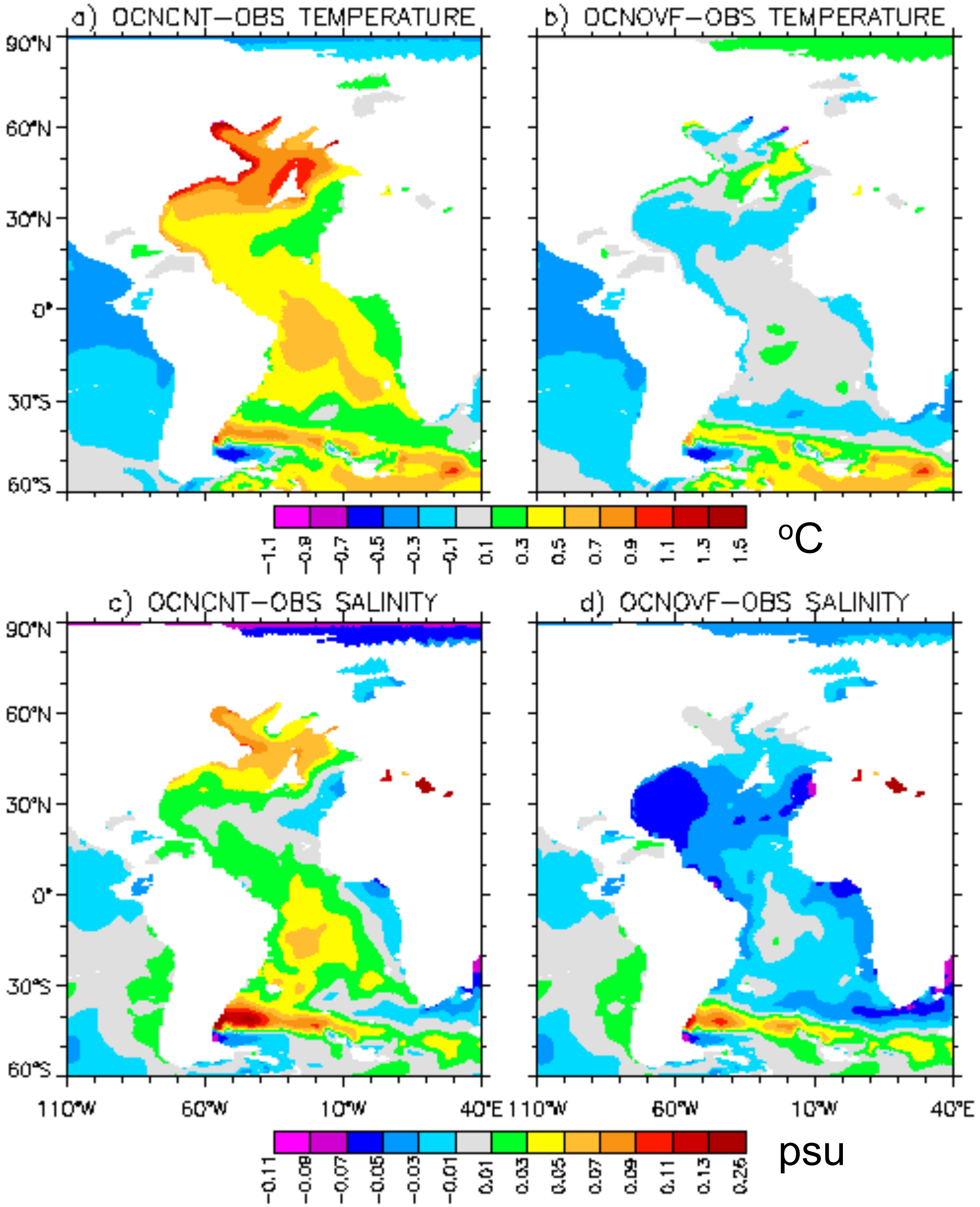
Temperature and Salinity Differences from Observations at 2650-m Depth

mean= 0.45^{o}C

rms= 0.50^{o}C

mean= -0.04^{o}C

rms= 0.13^{o}C



mean= 0.02 psu

rms= 0.03 psu

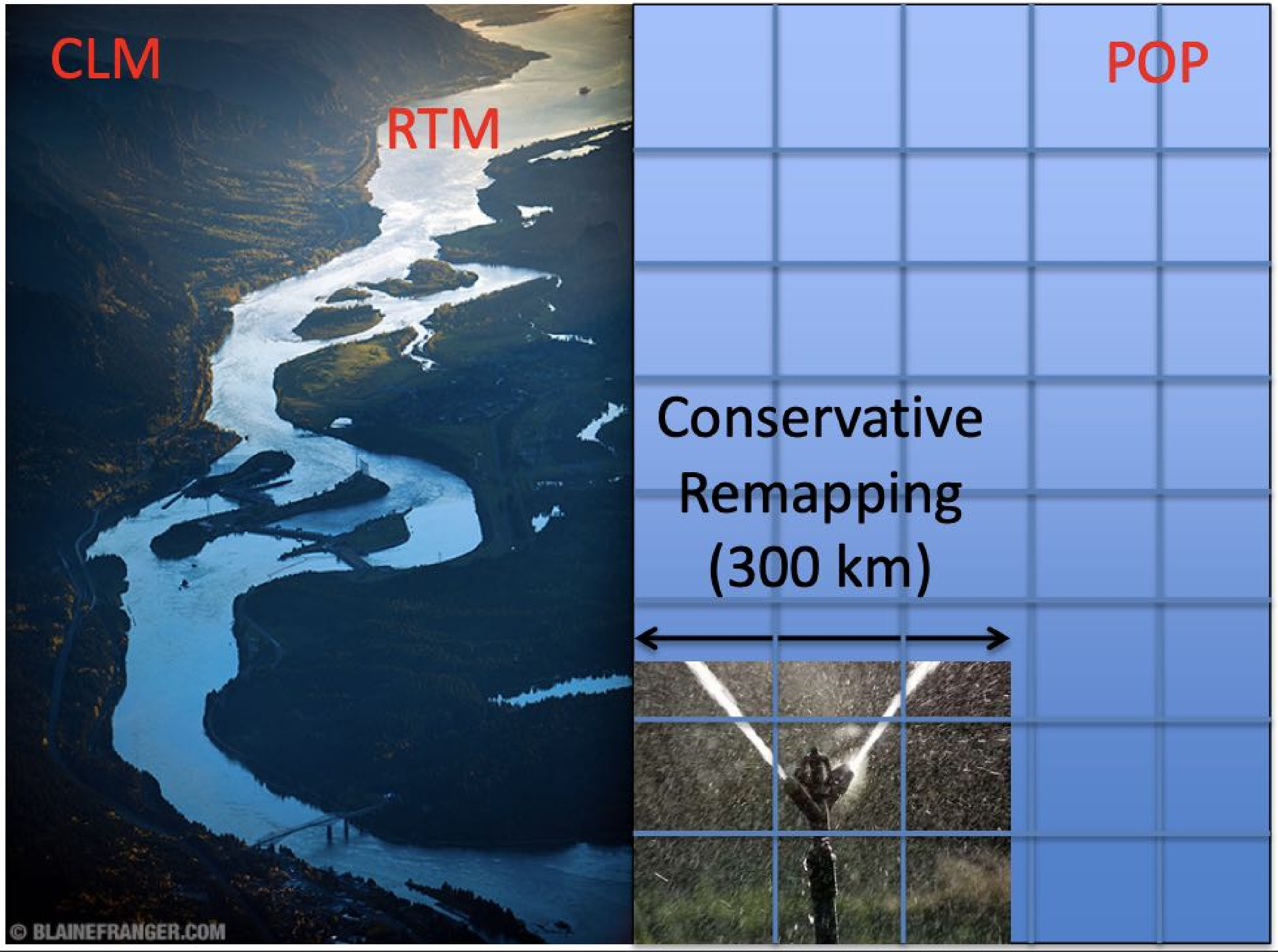
mean= -0.03 psu

rms= 0.03 psu

Obs: Levitus et al. (1998), Steele et al. (2001)

Estuary Parameterization

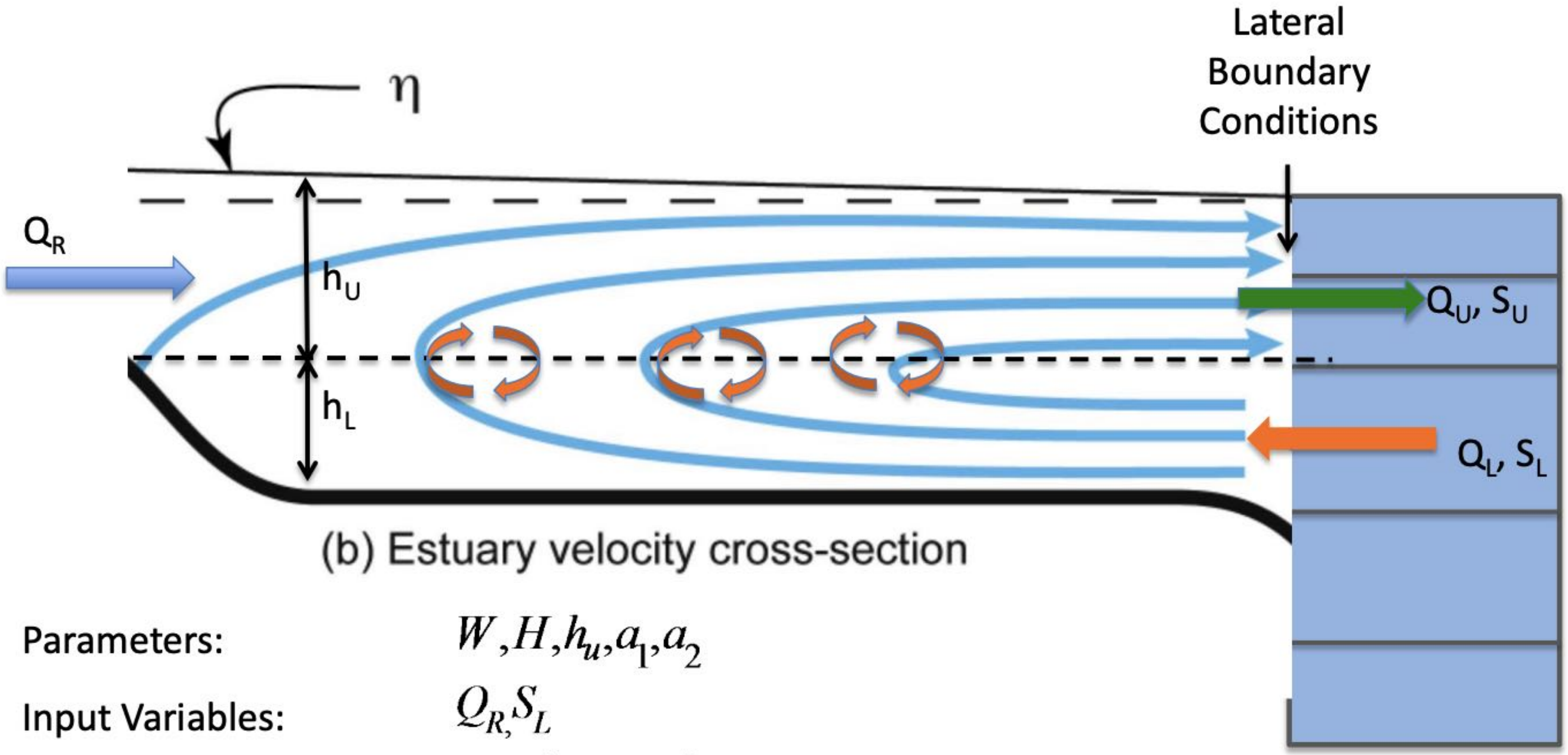
River Runoff and Estuary Box Model



Surface freshwater flux

Sun et al. (2017, Ocean Modelling)

River Runoff and Estuary Box Model



(b) Estuary velocity cross-section

Parameters: W, H, h_u, a_1, a_2

Input Variables: Q_R, S_L

Potential Energy: $\lambda_3 Q_L^3 + \lambda_2 Q_L^2 + \lambda_1 Q_L + \lambda_0 = 0$

Volume Eq: $Q_U = Q_R + Q_L$

Salinity Eq: $Q_U S_U = Q_L S_L$

Lateral boundary conditions

Sun et al. (2017, Ocean Modelling)

GUI & Tools to Support CESM Specialized and Flexible Models Configurations

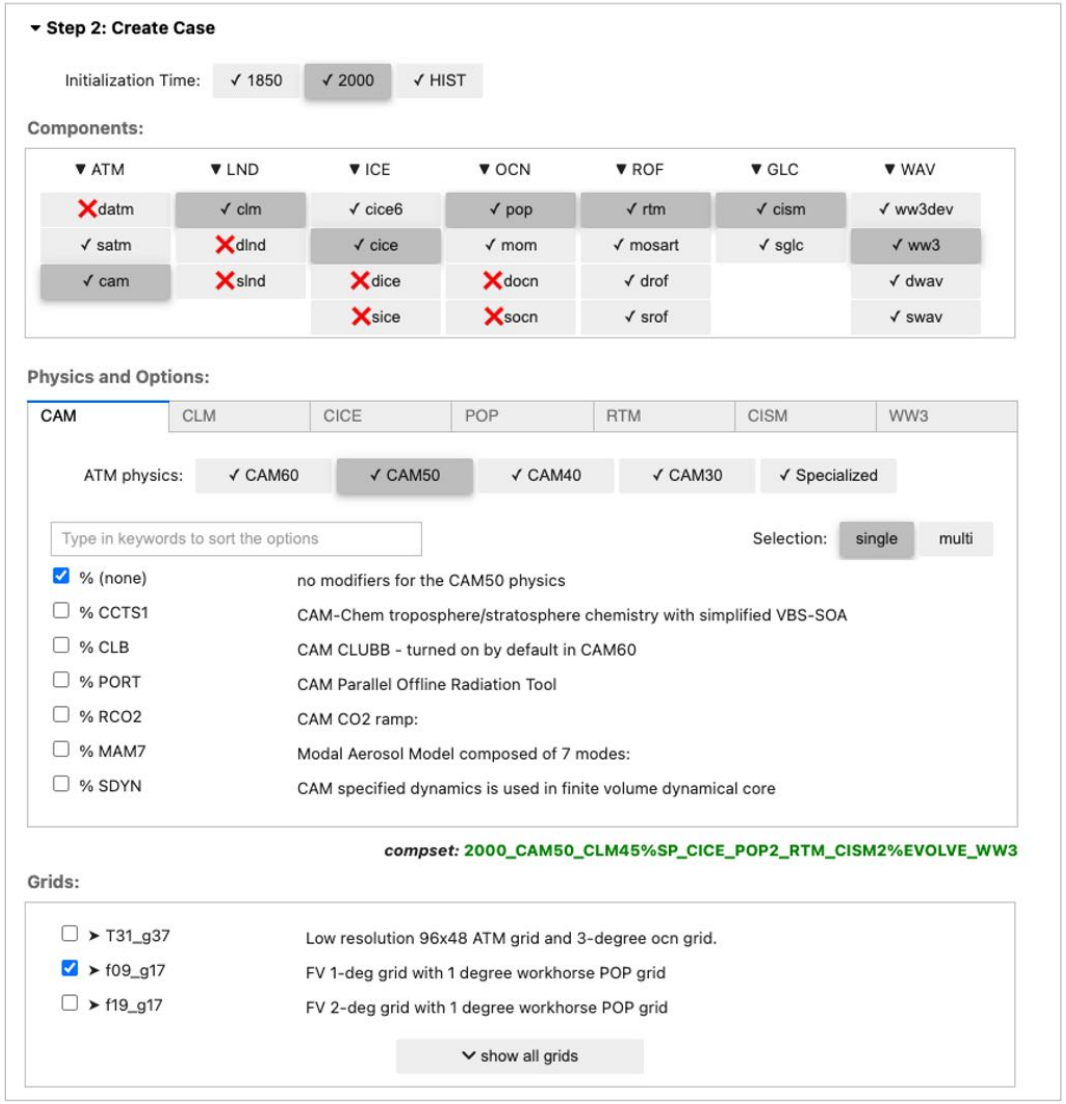
Graphical user interface (GUI) guides users through the process of creating CESM cases

New metadata and logic module to check compatibility of compsets and grids

Custom MOM6 grid and bathymetry generator

Land model tools to facilitate creating surface datasets for custom grids and configurations

Altuntas, Bachman, Simpson, Danabasoglu, Vertenstein, & Dobbins



▾ **Step 2: Create Case**

Initialization Time: ✓ 1850 ✓ 2000 ✓ HIST

Components:

▾ ATM	▾ LND	▾ ICE	▾ OCN	▾ ROF	▾ GLC	▾ WAV
✗datm	✓ clm	✓ cice6	✓ pop	✓ rtm	✓ cism	✓ ww3dev
✓ satm	✗dlnd	✓ cice	✓ mom	✓ mosart	✓ sglc	✓ ww3
✓ cam	✗slnd	✗dice	✗docn	✓ drof		✓ dwav
		✗sice	✗socn	✓ srof		✓ swav

Physics and Options:

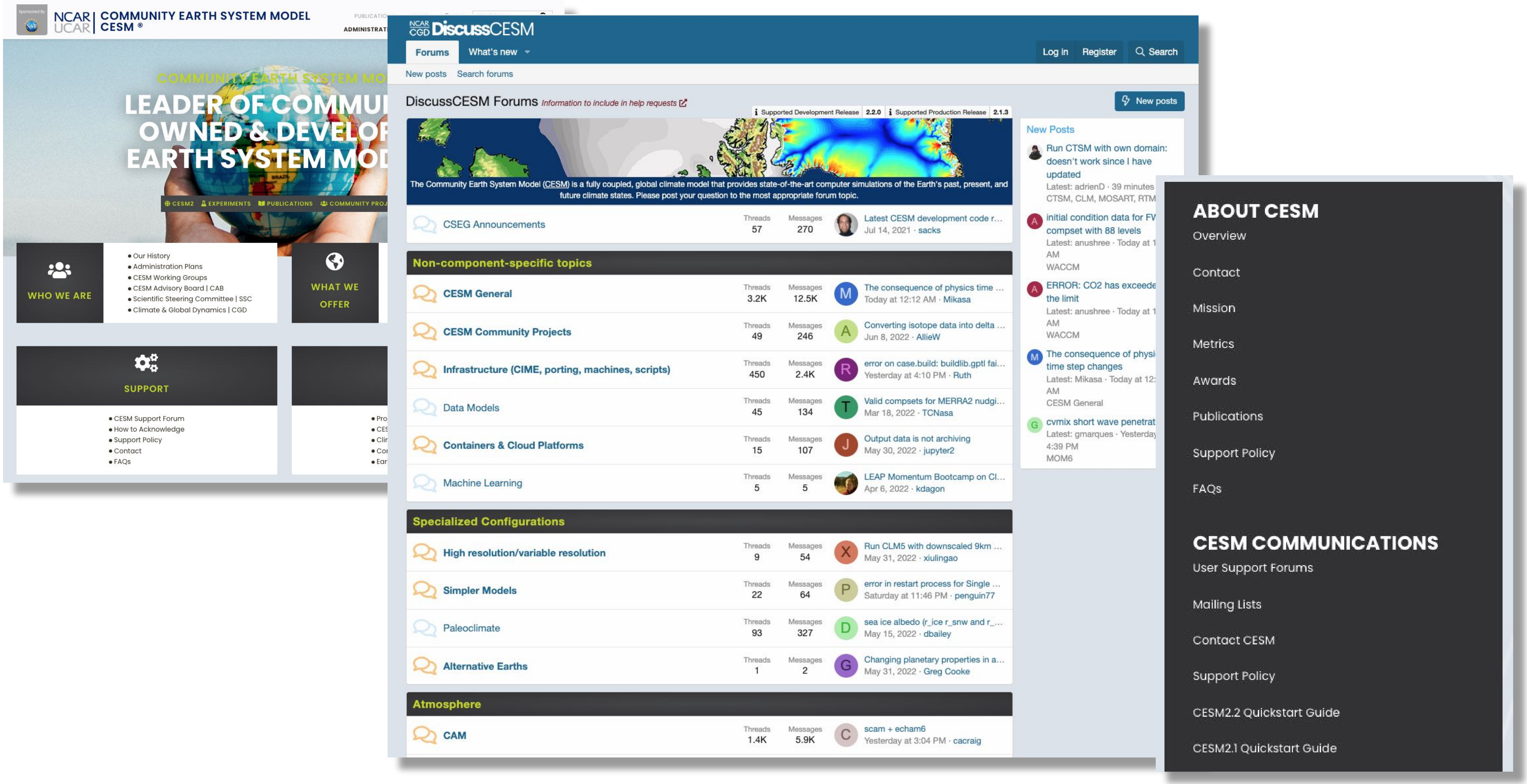
ATM physics: ✓ CAM60 ✓ CAM50 ✓ CAM40 ✓ CAM30 ✓ Specialized

☑ % (none)	no modifiers for the CAM50 physics
☐ % CCTS1	CAM-Chem troposphere/stratosphere chemistry with simplified VBS-SOA
☐ % CLB	CAM CLUBB - turned on by default in CAM60
☐ % PORT	CAM Parallel Offline Radiation Tool
☐ % RCO2	CAM CO2 ramp:
☐ % MAM7	Modal Aerosol Model composed of 7 modes:
☐ % SDYN	CAM specified dynamics is used in finite volume dynamical core

compset: 2000_CAM50_CLM45%SP_CICE_POP2_RTM_CISM2%EVOLVE_WW3

Grids:

☐ ➤ T31_g37	Low resolution 96x48 ATM grid and 3-degree ocn grid.
☑ ➤ f09_g17	FV 1-deg grid with 1 degree workhorse POP grid
☐ ➤ f19_g17	FV 2-deg grid with 1 degree workhorse POP grid



NCAR | UCAR | COMMUNITY EARTH SYSTEM MODEL CESM ®

PUBLICATIO

ADMINISTRAT

COMMUNITY EARTH SYSTEM MO

LEADER OF COMMU
OWNED & DEVELOP
EARTH SYSTEM MOD

CESM2 EXPERIMENTS PUBLICATIONS COMMUNITY PROJ

WHO WE ARE

- Our History
- Administration Plans
- CESM Working Groups
- CESM Advisory Board | CAB
- Scientific Steering Committee | SSC
- Climate & Global Dynamics | CGD

WHAT WE OFFER

SUPPORT

- CESM Support Forum
- How to Acknowledge
- Support Policy
- Contact
- FAQs

- Pro
- CES
- Clir
- Cor
- Ear

NCAR CGD DiscussCESM

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New posts Search forums

DiscussCESM Forums *Information to include in help requests*

Supported Development Release 2.2.0 Supported Production Release 2.1.3

New posts

The Community Earth System Model (CESM) is a fully coupled, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states. Please post your question to the most appropriate forum topic.

Forum	Threads	Messages	Latest
CSEG Announcements	57	270	Latest CESM development code r… Jul 14, 2021 · sacks
Non-component-specific topics			
CESM General	3.2K	12.5K	The consequence of physics time … Today at 12:12 AM · Mikasa
CESM Community Projects	49	246	Converting isotope data into delta … Jun 8, 2022 · AllieW
Infrastructure (CIME, porting, machines, scripts)	450	2.4K	error on case.build: buildlib.gptl fai… Yesterday at 4:10 PM · Ruth
Data Models	45	134	Valid compsets for MERRA2 nudgi… Mar 18, 2022 · TCNasa
Containers & Cloud Platforms	15	107	Output data is not archiving May 30, 2022 · jupyter2
Machine Learning	5	5	LEAP Momentum Bootcamp on Cl… Apr 6, 2022 · kdagon
Specialized Configurations			
High resolution/variable resolution	9	54	Run CLM5 with downscaled 9km … May 31, 2022 · xiulingao
Simpler Models	22	64	error in restart process for Single … Saturday at 11:46 PM · penguin77
Paleoclimate	93	327	sea ice albedo (r_ice r_snw and r_… May 15, 2022 · dbailey
Alternative Earths	1	2	Changing planetary properties in a… May 31, 2022 · Greg Cooke
Atmosphere			
CAM	1.4K	5.9K	scam + echam6 Yesterday at 3:04 PM · cacraig

New Posts

Run CTSM with own domain: doesn't work since I have updated
Latest: adrienD · 39 minutes
CTSM, CLM, MOSART, RTM

initial condition data for FW compset with 88 levels
Latest: anushree · Today at 1
AM
WACCM

ERROR: CO2 has exceede the limit
Latest: anushree · Today at 1
AM
WACCM

The consequence of physi time step changes
Latest: Mikasa · Today at 12:
AM
CESM General

cvmix short wave penetrat
Latest: gmarques · Yesterday
4:39 PM
MOM6

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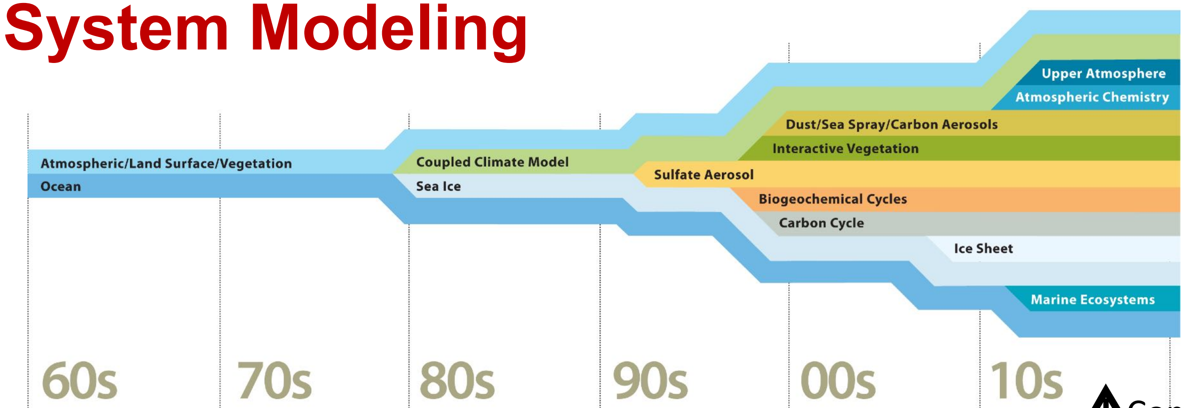
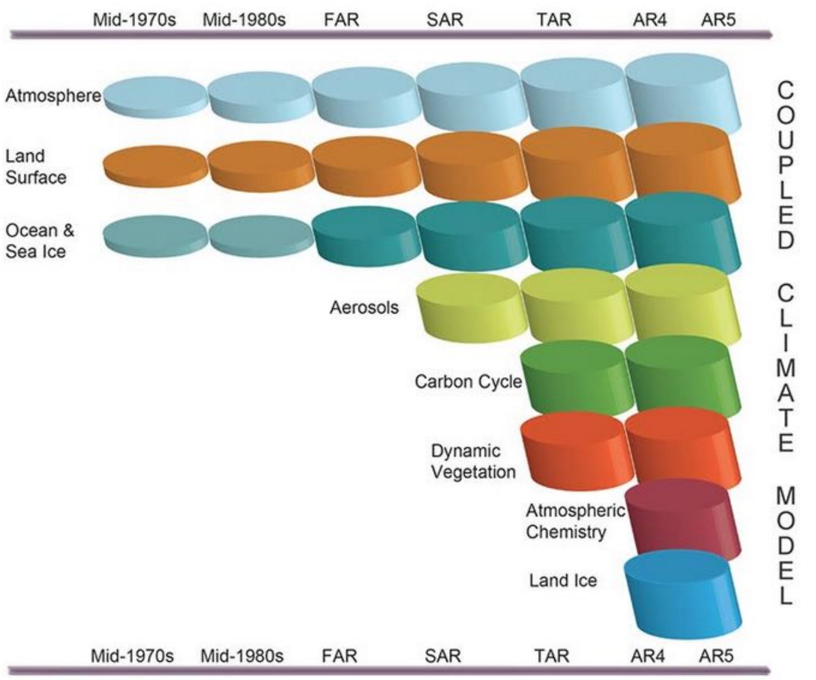
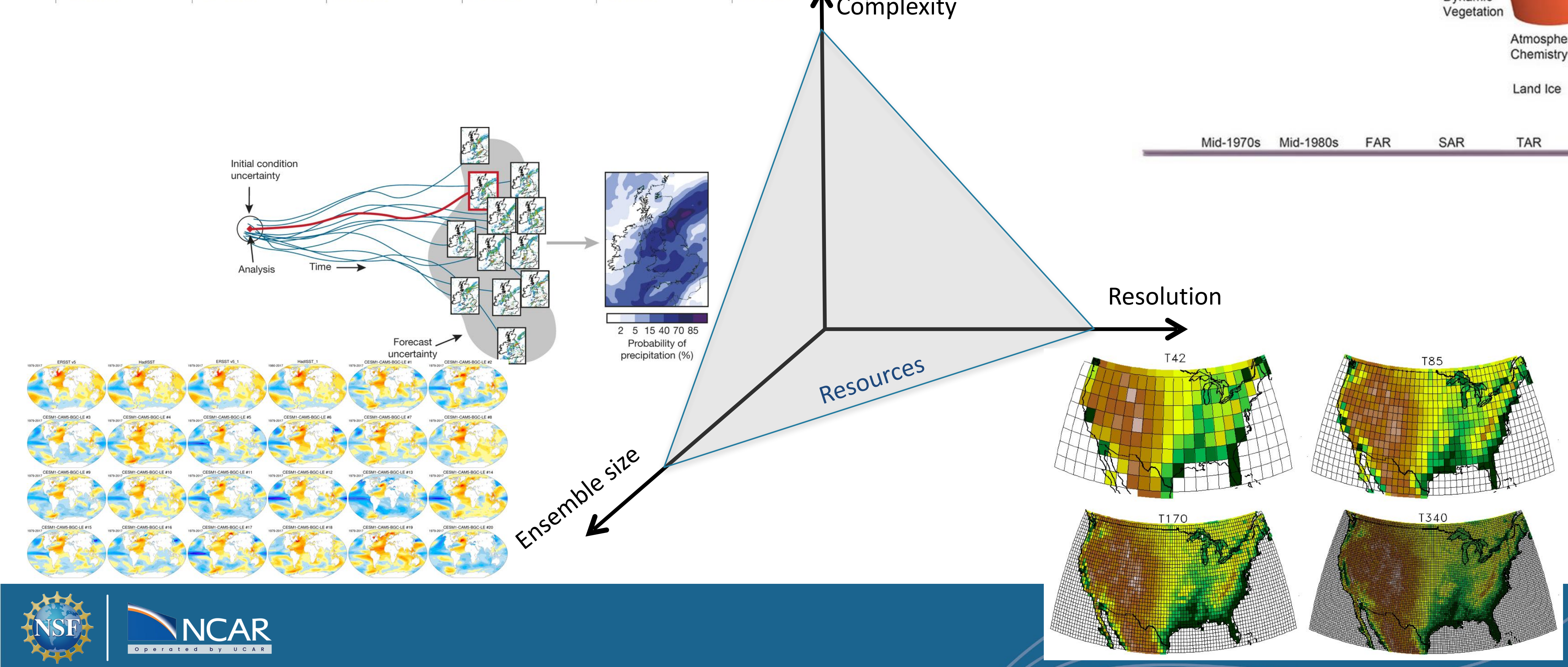
CESM2.2 Quickstart Guide

CESM2.1 Quickstart Guide

Growth of Climate / Earth System Modeling







Thank You!

Contact: gokhan@ucar.edu