Ocean Modeling I

Ocean Modeling Basics
The Parallel Ocean Program (POP)

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Topics

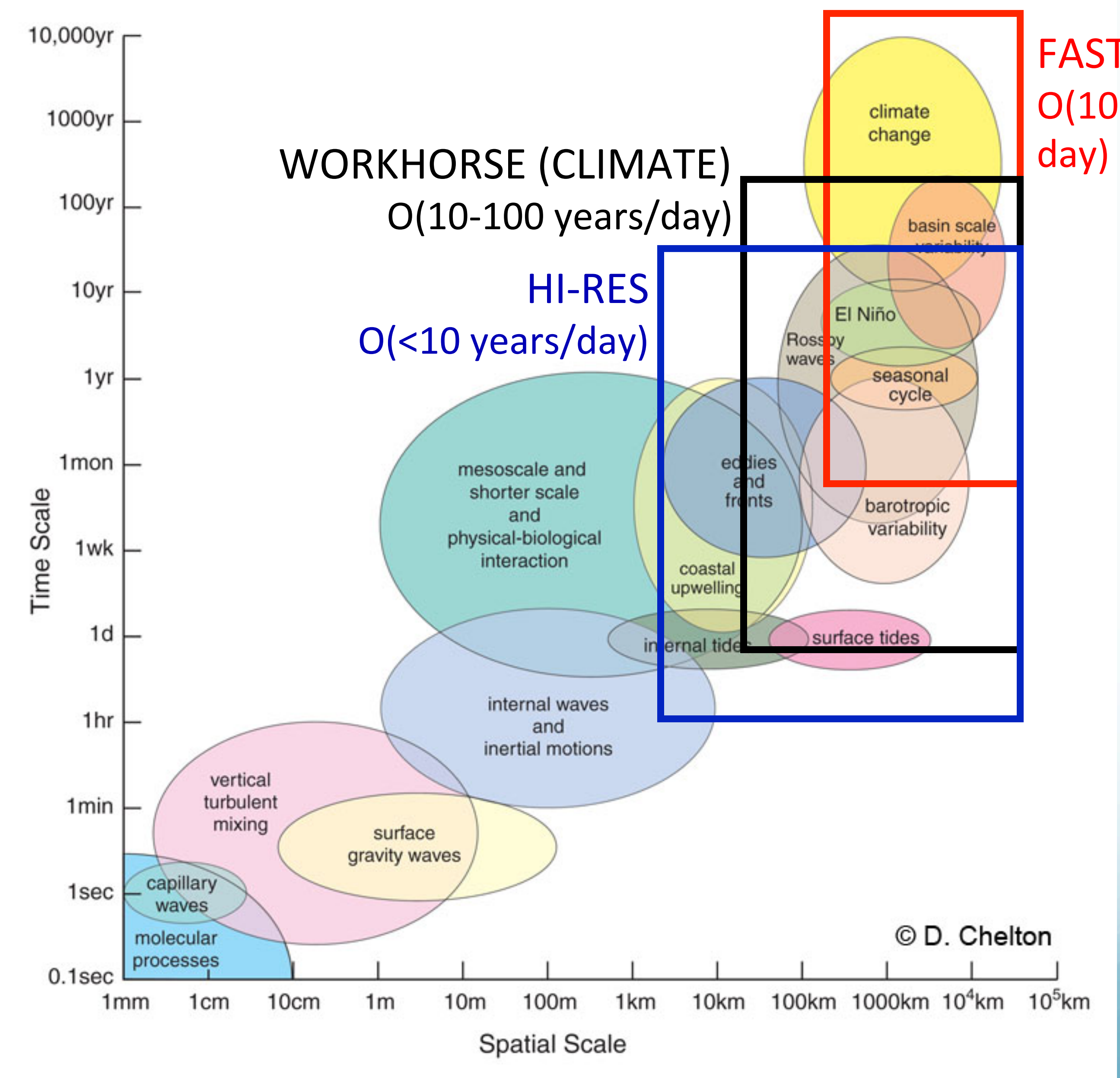
- Obstacles for ocean modeling
- Ocean properties
- The ocean and climate
- Equations of motion
- Ocean model grid
- Boundary conditions
- Timescales of flow
- Advection schemes
- Model Results

- Parameterizations => next lecture

Ocean Modeling Obstacles

Irregular Domain

Ocean Modeling Obstacles



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FAST
O(100-1000 years/day)

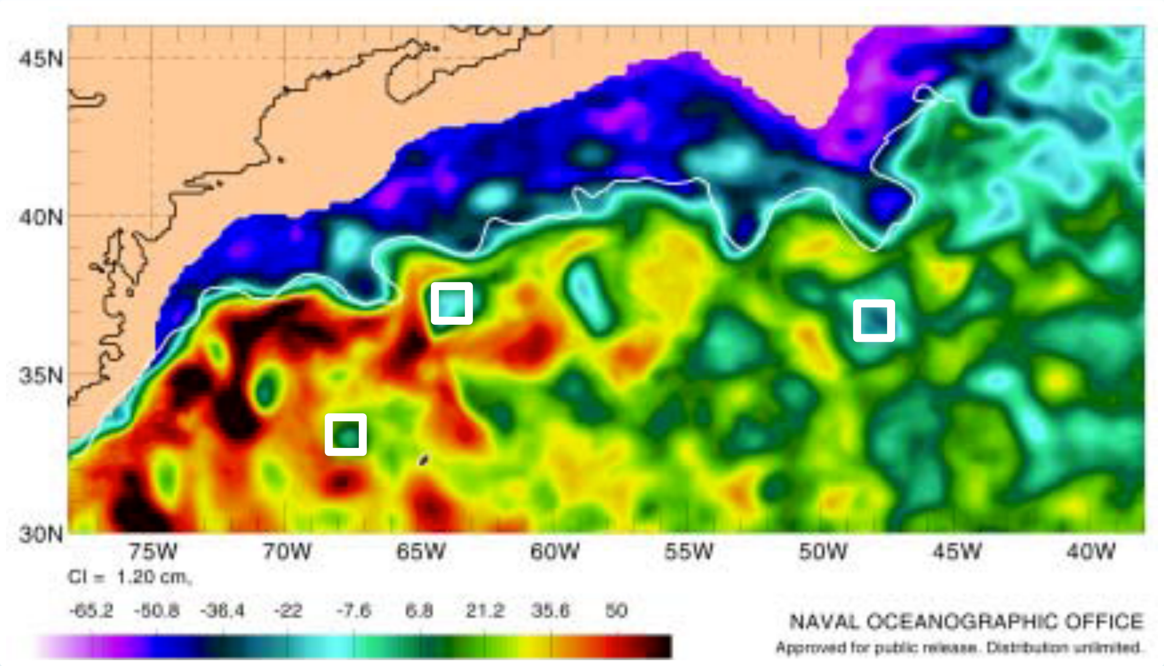
WORKHORSE (CLIMATE)
O(10-100 years/day)

HI-RES
O(<10 years/day)

Ocean Modeling Obstacles

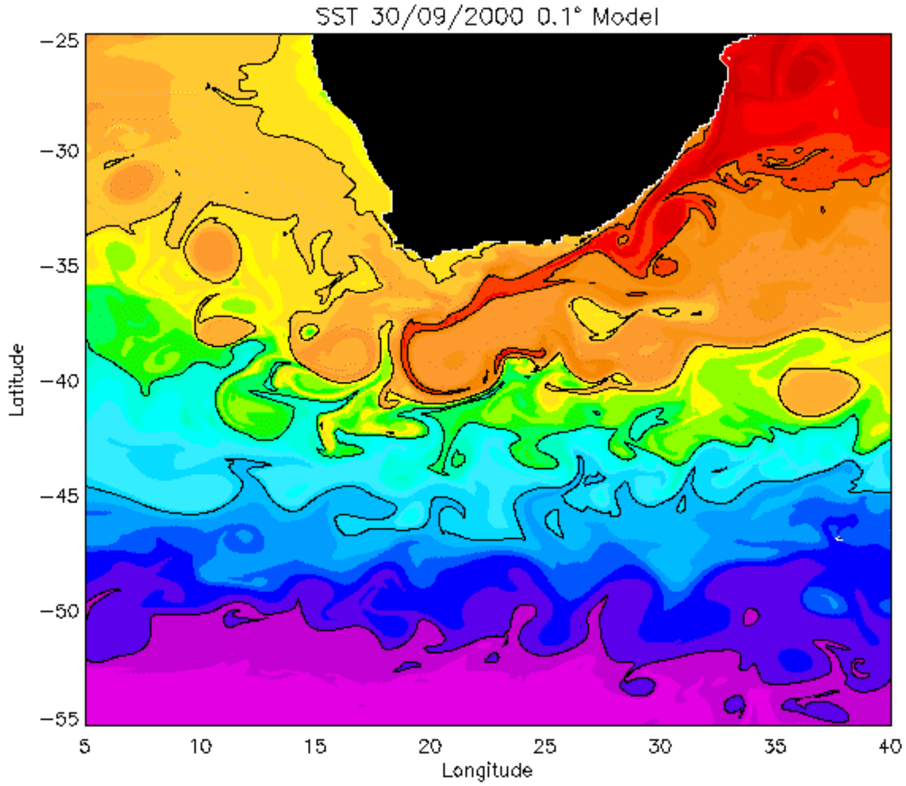
Spatial Scales of Flow

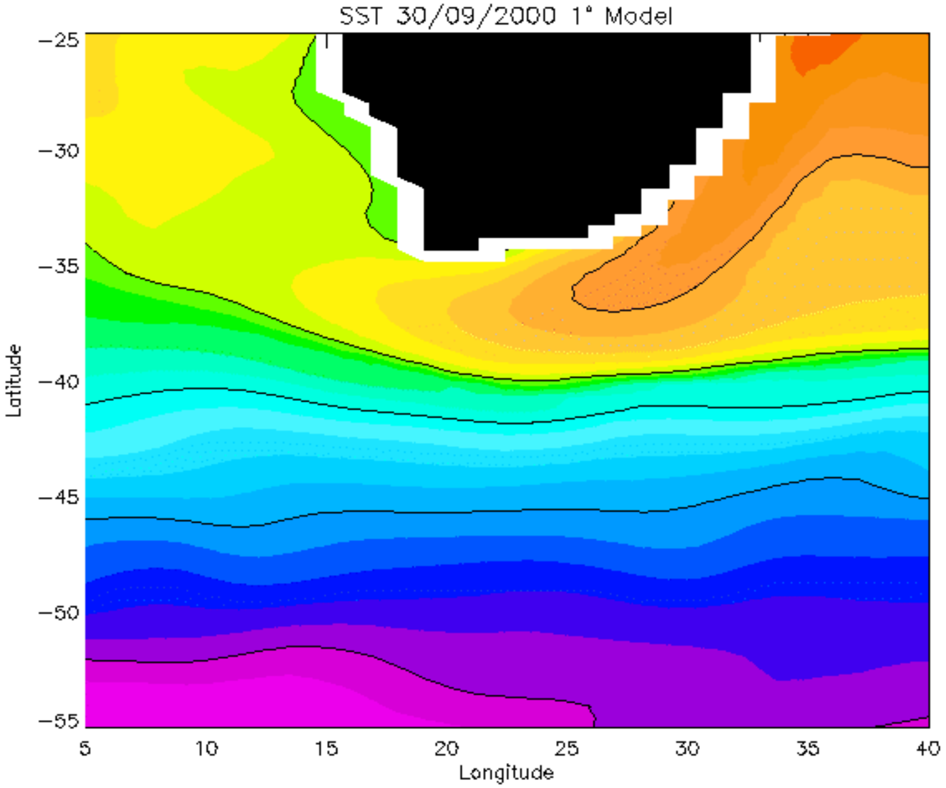
Eddy length scales <10km



Ocean Modeling Obstacles

Spatial Scales of Flow
Eddies


SST 30/09/2000 0.1° Model


SST 30/09/2000 1° Model

Ocean Modeling Obstacles

Equilibration Timescale

Scaling argument for deep adjustment time :

$$H^2/\kappa = (5000\text{m})^2 / (10^{-5}\ \text{m}^2/\text{s})$$
$$= O(10{,}000\ \text{years})$$

Bottom Line for Climate

- Obtaining equilibrium at eddy resolution is not practical
- Must live with deep ocean not being at equilibrium in most simulations

Ocean Properties

- No change of state of seawater – form ice when temperature <-1.8°C
- The density change from top to bottom is much smaller than the atmosphere – 1.02 to 1.04 gm/cc. This makes the Rossby radius much smaller – 100s to 10s km.
- There is extremely small mixing across density surfaces once water masses are buried below the mixed layer base. This is why water masses can be named, and followed around the ocean.
- The ocean is a 2 part density fluid (temp and salt).

Ocean Properties

- Top to bottom lateral boundaries. Leads to WBC (heat transport) leaving little for eddies.
- The heat capacity of the ocean is much larger than the atmosphere. This makes it an important heat reservoir.
- The atmosphere contains more intrinsic variability than the ocean. The ocean is primarily forced by the atmosphere.

What is needed from the ocean to get climate change correct?

- Air-sea coupling (sst feedbacks).
- Need to get heat uptake correct.
- Need good representation of meridional transport of heat (and other properties): circulation, including the meridional overturning circulation (MOC).
- Representation of carbon cycle (storage of CO2 (uptake), CaCO2): Need a good subgrid scale parameterizations (particularly vertical mixing scheme) to get correct mixed layer depths and upwell nutrient rich water.

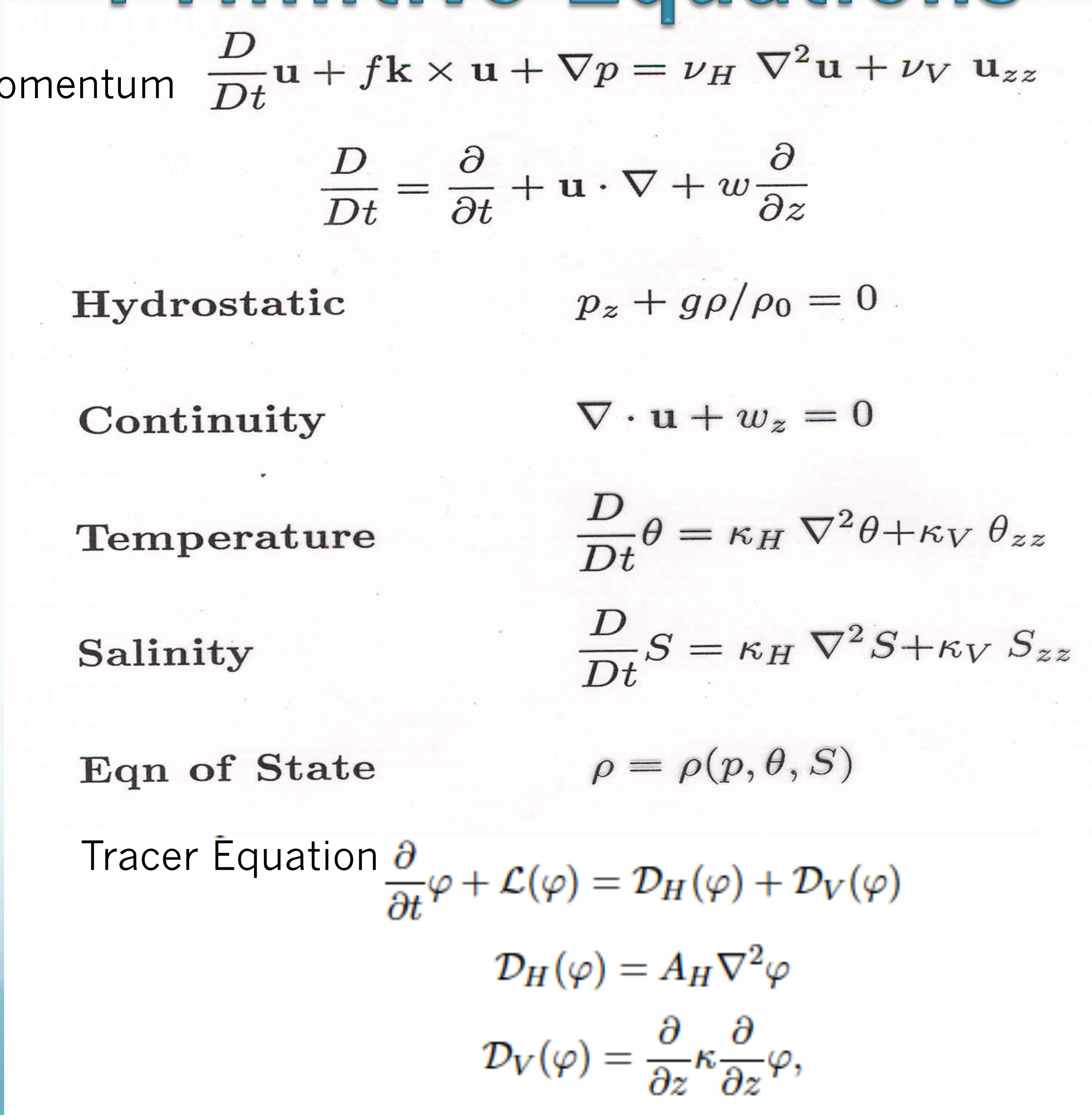
Primitive Equations

7 equations in 7 unknowns :

{u,v,w} ,	3 velocity components
θ,	potential temperature
S,	salinity
ρ,	density
p,	pressure

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

Primitive Equations



Momentum $$\frac{D}{Dt}\mathbf{u} + f\mathbf{k}\times\mathbf{u} + \nabla p = \nu_H\ \nabla^2\mathbf{u} + \nu_V\ \mathbf{u}_{zz}$$

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \mathbf{u}\cdot\nabla + w\frac{\partial}{\partial z}$$

Hydrostatic $$p_z + g\rho/\rho_0 = 0$$

Continuity $$\nabla\cdot\mathbf{u} + w_z = 0$$

Temperature $$\frac{D}{Dt}\theta = \kappa_H\ \nabla^2\theta + \kappa_V\ \theta_{zz}$$

Salinity $$\frac{D}{Dt}S = \kappa_H\ \nabla^2 S + \kappa_V\ S_{zz}$$

Eqn of State $$\rho = \rho(p,\theta,S)$$

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

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

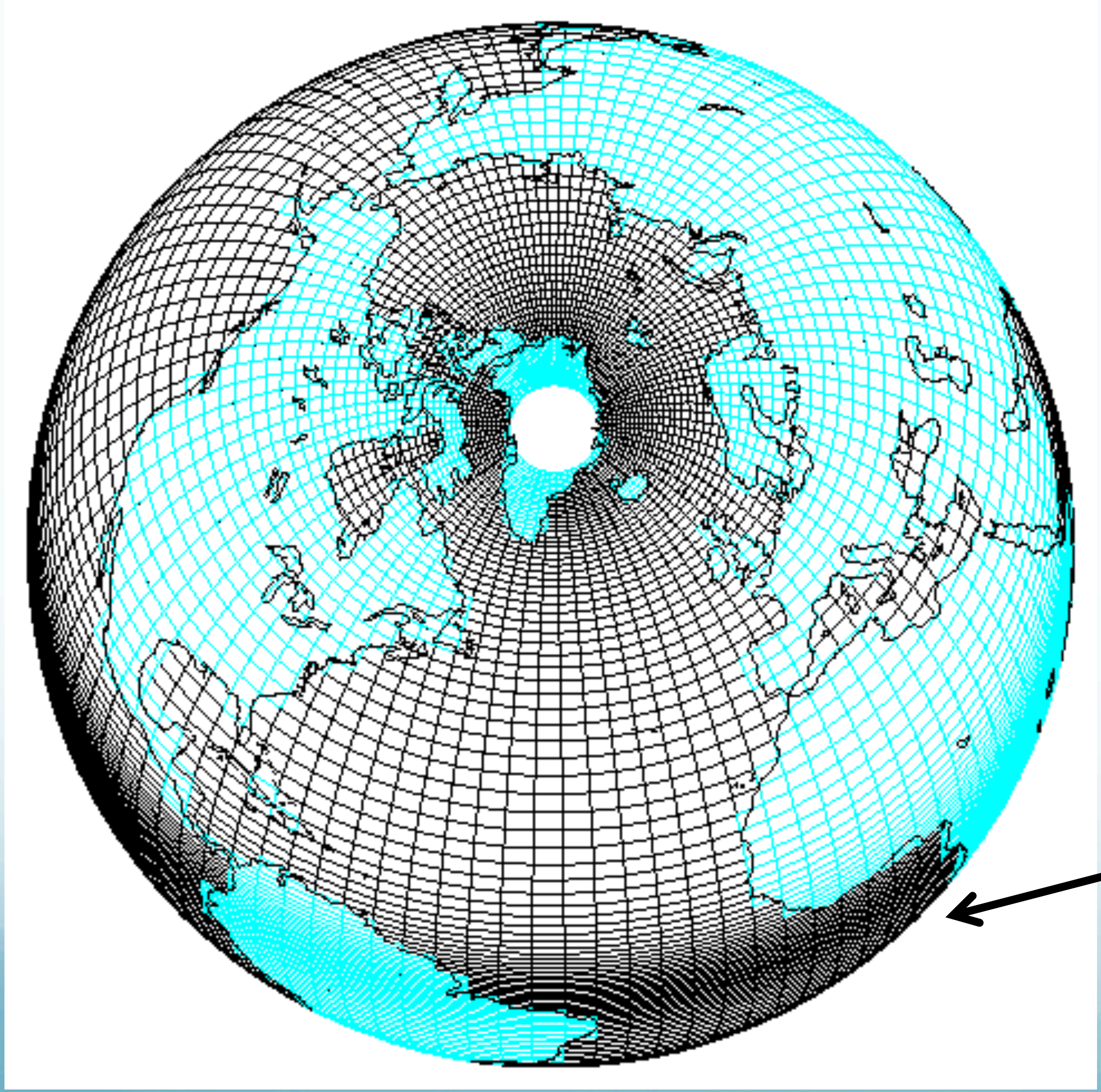
$$\mathcal{D}_V(\varphi) = \frac{\partial}{\partial z}\kappa\frac{\partial}{\partial z}\varphi,$$

Primitive Equations

- Continuity: can't deform seawater, so what flows into a control volume must flow out.
- Eqn of state: density dominated by T in upper tropical ocean; by S at high latitudes and deep.
- Hydrostatic: when ocean becomes statically unstable ($\rho_z>0$) => vertical overturning should occur, but cannot because vertical acceleration has been excluded. This mixing is accomplished by a very large coefficient of vertical diffusion.

Model Grid

displaced pole



gx1: climate workhorse
nominal 1° (~1°)
gx3: testing
nominal 3° (~3.6°)

Ex. T62_gx3v7

Equatorial refinement
(0.3° / 0.9°)

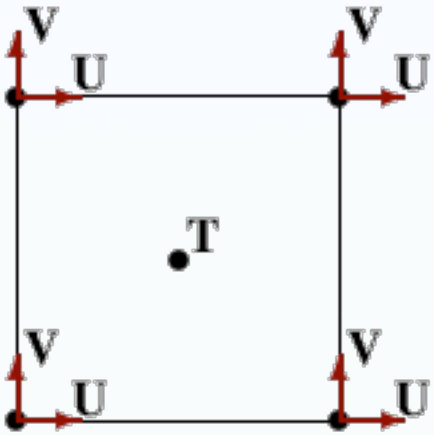
Model Grid

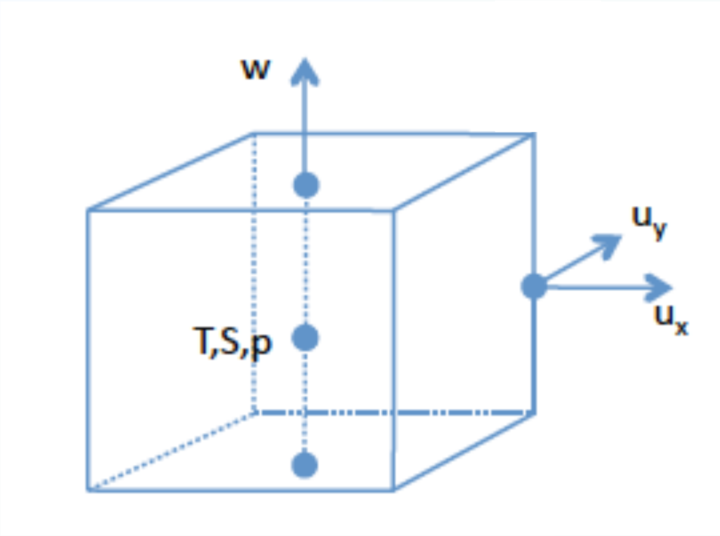
tripole

tx0.1

Finite Differencing Grid

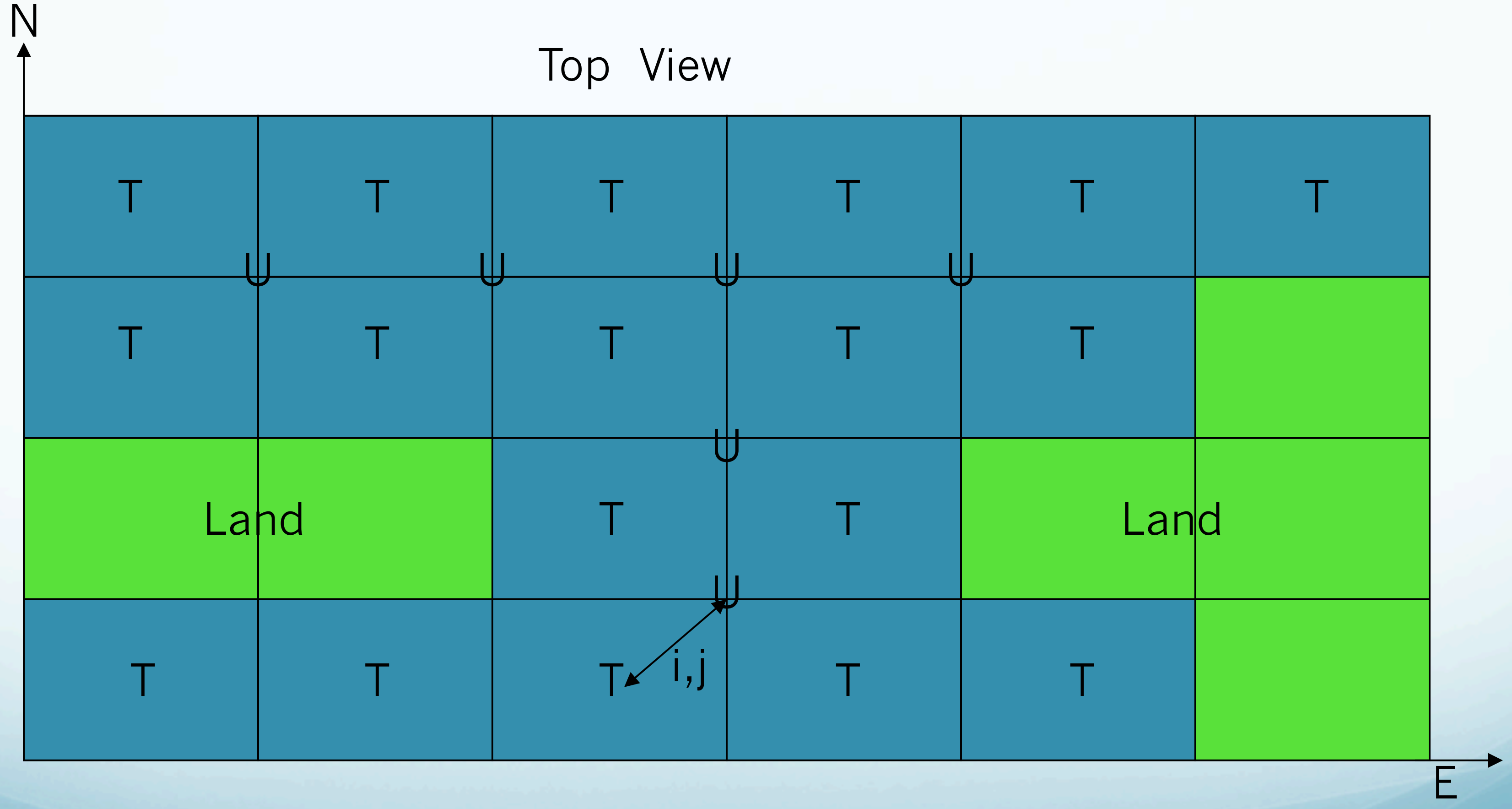
B-grid



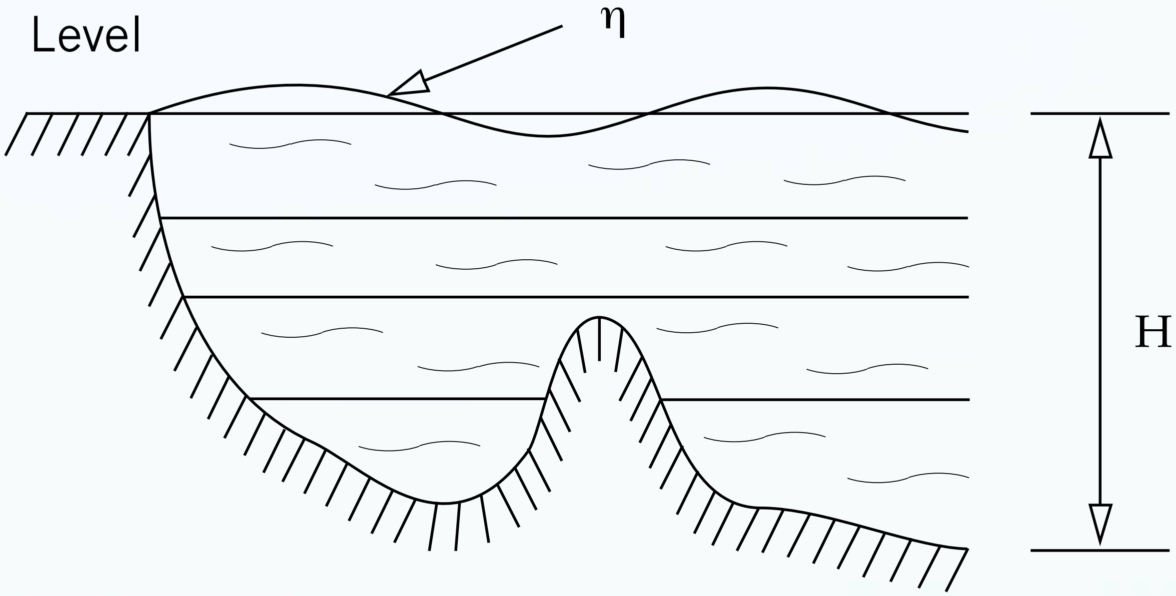


Model Grid

B-grid
T=tracer grid, U=velocity grid

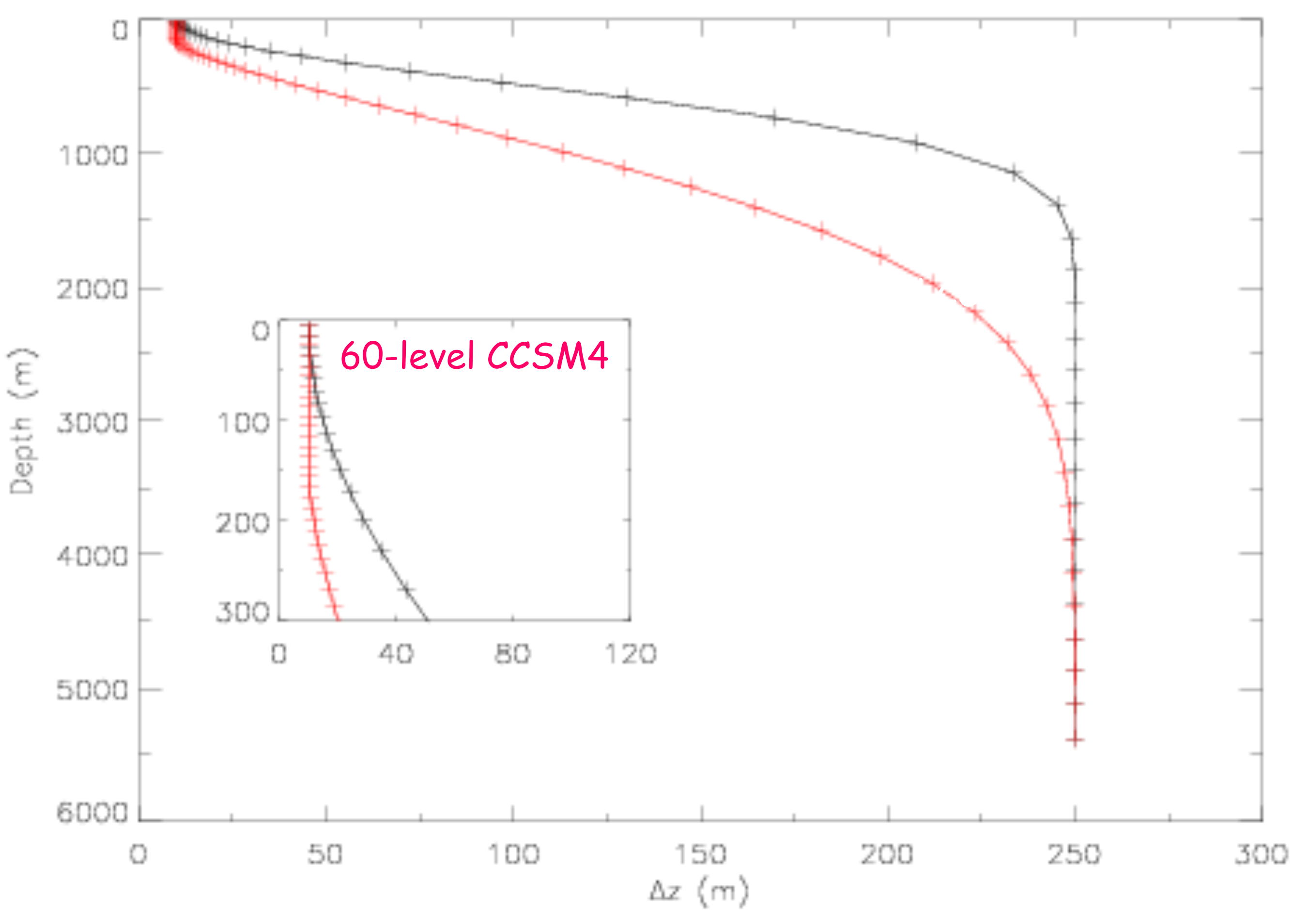


Vertical Coordinate



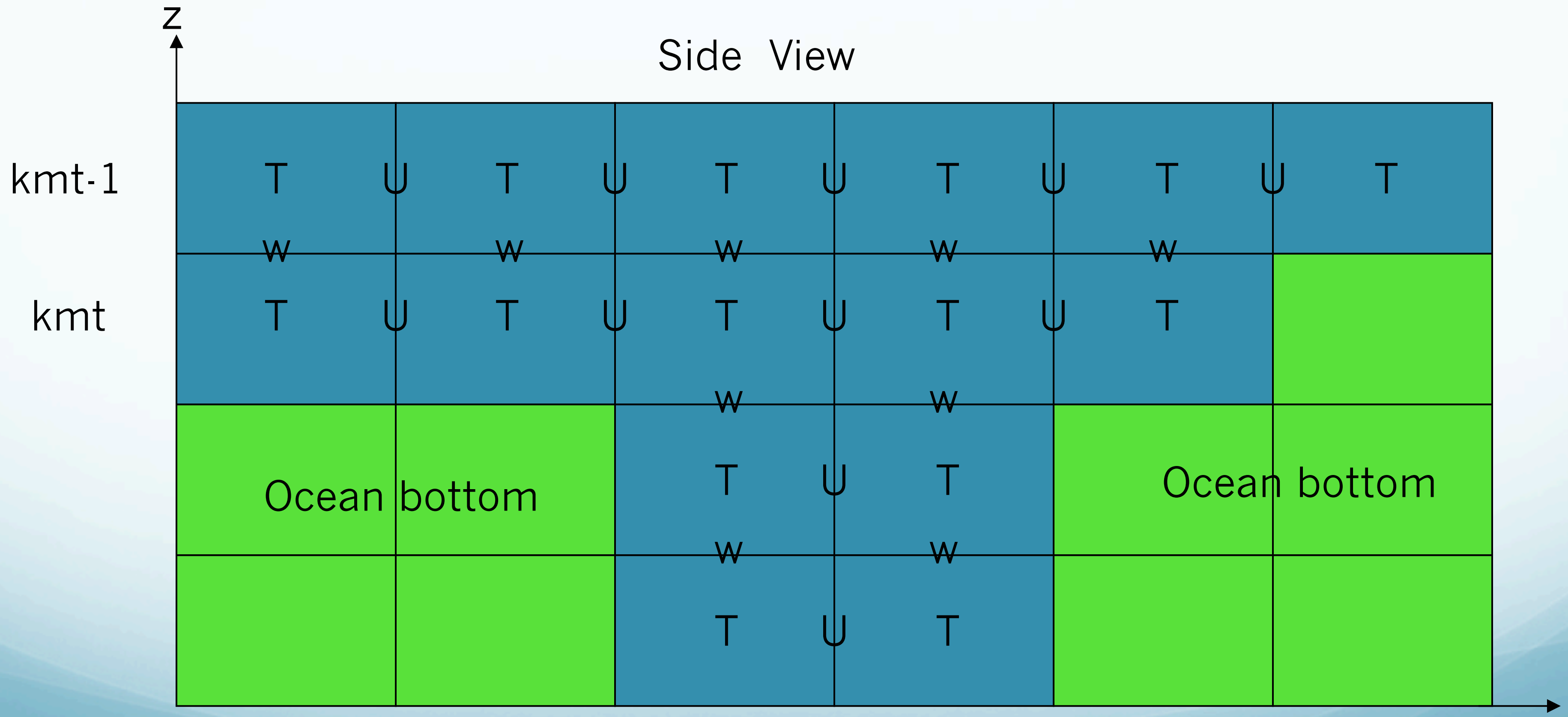
z-Coordinate Model

Model Vertical Grid

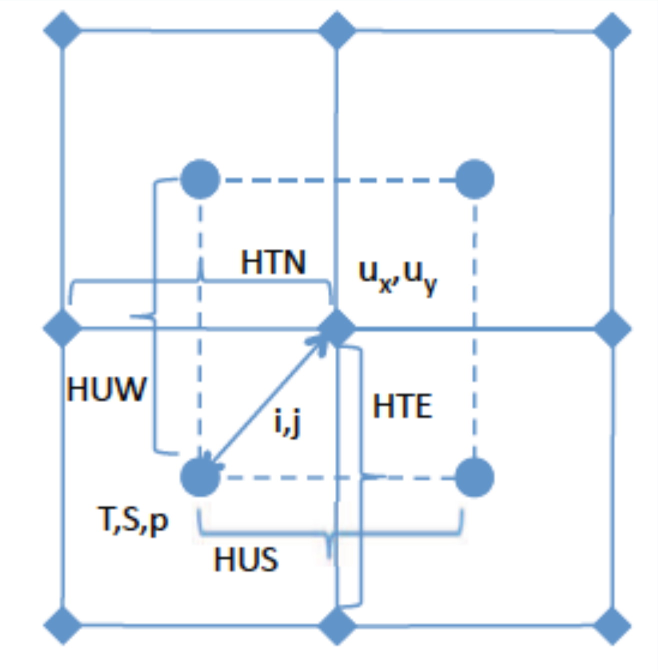


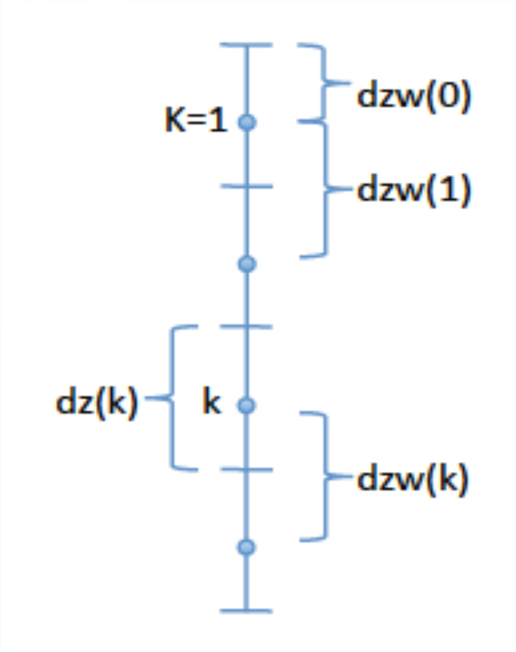
Model Grid

B-grid
T=tracer grid, U=velocity grid



Discretization





$$ADV_{i,j,k} = -\,(u_E\, T^*_E - u_W\, T^*_W)/DXT - (v_N\, T^*_N - v_S\, T^*_S)/DYT - (w_k\, T^*_T - w_{k+1}\, T^*_B)/dz$$

$$\begin{aligned}
u_E(i) &= (u_{i,j} DYU_{i,j} + u_{i,j-1} DYU_{i,j-1})/(2DXT_{i,j}) \\
u_W(i) &= u_E(i-1) \\
v_N(j) &= (v_{i,j} DXU_{i,j} + v_{i-1,j} DXU_{i-1,j})/(2DXT_{i,j}) \\
v_S(j) &= (v_{i,j\text{-}1} DXU_{i,j} + v_{i-1,j-1} DXU_{i-1,j})/(2DXT)
\end{aligned}$$

$$T^*_E = ½ * (T_{i+1,j} + T_{i,j})$$

Advection

Current practice:

- Momentum: centered differencing (2nd order)
- Tracers: upwind3 scheme (3rd order)
    - Concerned with keeping within physical limits

Baroclinic & Barotropic Flow

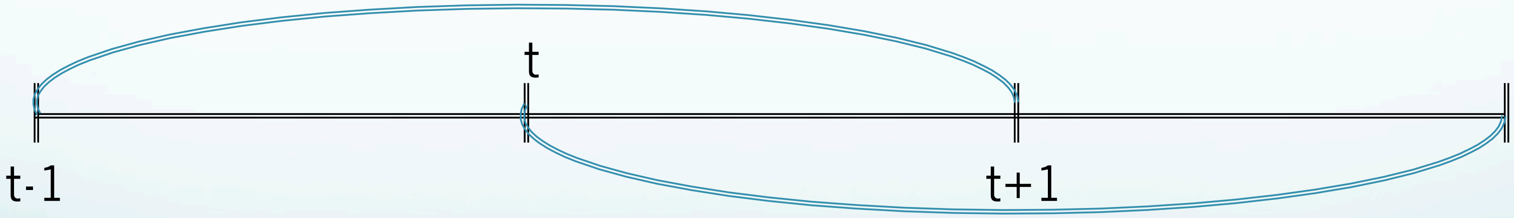
- Issue : Courant-Friedrichs-Lewy (CFL) stability condition associated with fast surface gravity waves.
  - $u(\Delta t/\Delta x) \leq 1$
  - Barotropic mode $\sqrt{gH} \sim 200$m/s
- Split flow into depth average barotropic (<U>) plus vertically varying baroclinic (U')
- Fast moving gravity waves are filtered out, but that's okay because they don't impact climate

Barotropic and Baroclinic Flow

$$U = \langle U \rangle + U'$$

- <U> : solved implicitly by solving the vertically integrated momentum and continuity equations
- U' : use a leapfrog time stepping to solve

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



- Occasional time averaging to eliminate the split mode

Boundary Conditions

- Free surface
  - Flux exchanges at surface: momentum and tracer
  - because we conserve volume, if one place comes up another must come down
- Ocean bottom
  - Topography
  - Bottom normal velocity is zero
- Lateral boundaries (open/closed)
  - Flow normal to solid boundary is zero

Surface Forcing

- Fully coupled mode (B compset)
- Forced ocean (C compset) or ice-ocean (G compset)

Common Ocean-ice Reference Experiments (CORE)

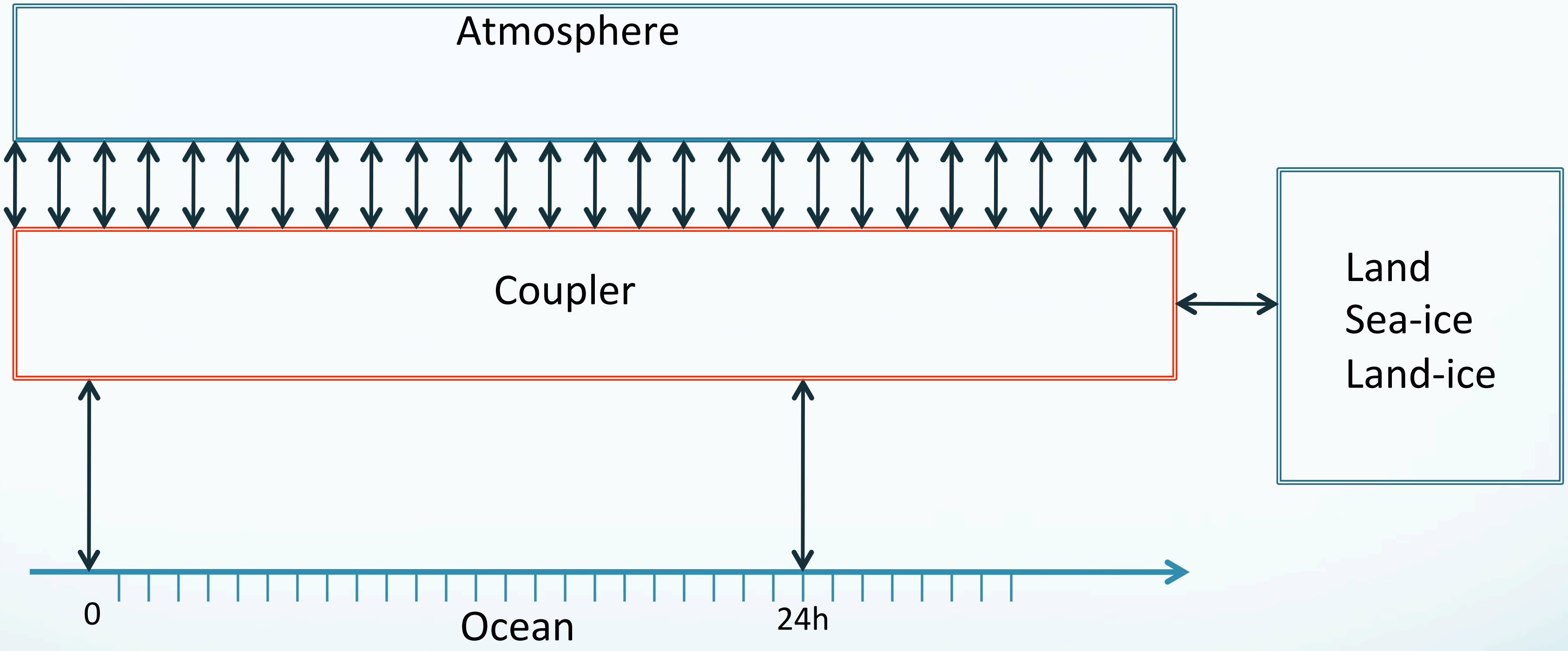
Large and Yeager, NCAR Technical Note (2004)

Large and Yeager, *Climate Dynamics* (2009)

- Interannual forcing (43 years)
  - http://data1.gfdl.noaa.gov/nomads/forms/mom4/CORE.html
- Normal Year Forcing (-CNYF): good for model testing
  - Don't' have to run as long as IAF
  - Control of surface

Influence of Forcing

Air-Sea Coupling

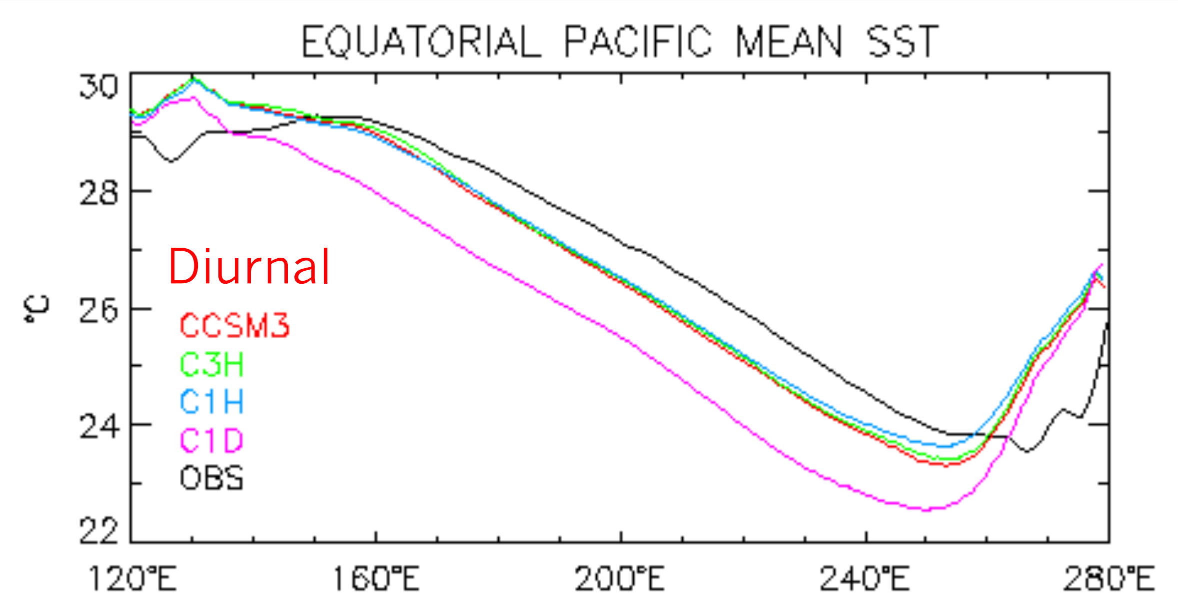


SW distributed across daylight hours (lat, long, day of year)

Danabasoglu et al. (*J. Clim.*, 2006)
CCSM3 Special Issue

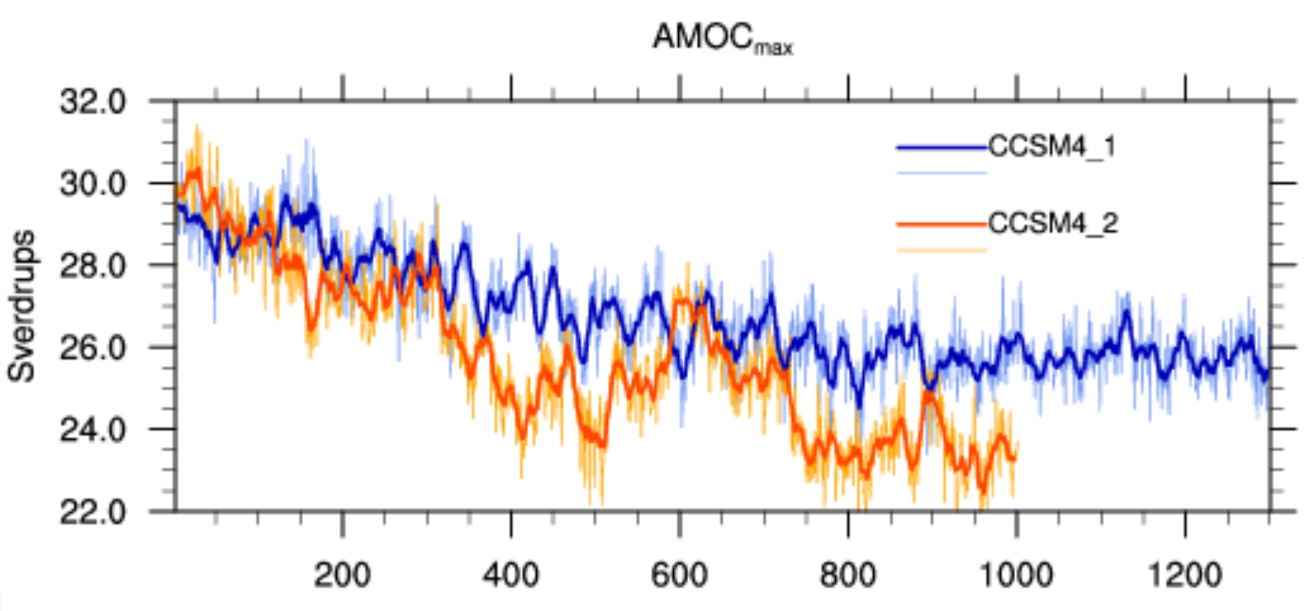
Influence of Forcing

Air-Sea Coupling



Influence of Forcing

Atlantic Meridional Overturning Circulation (AMOC)

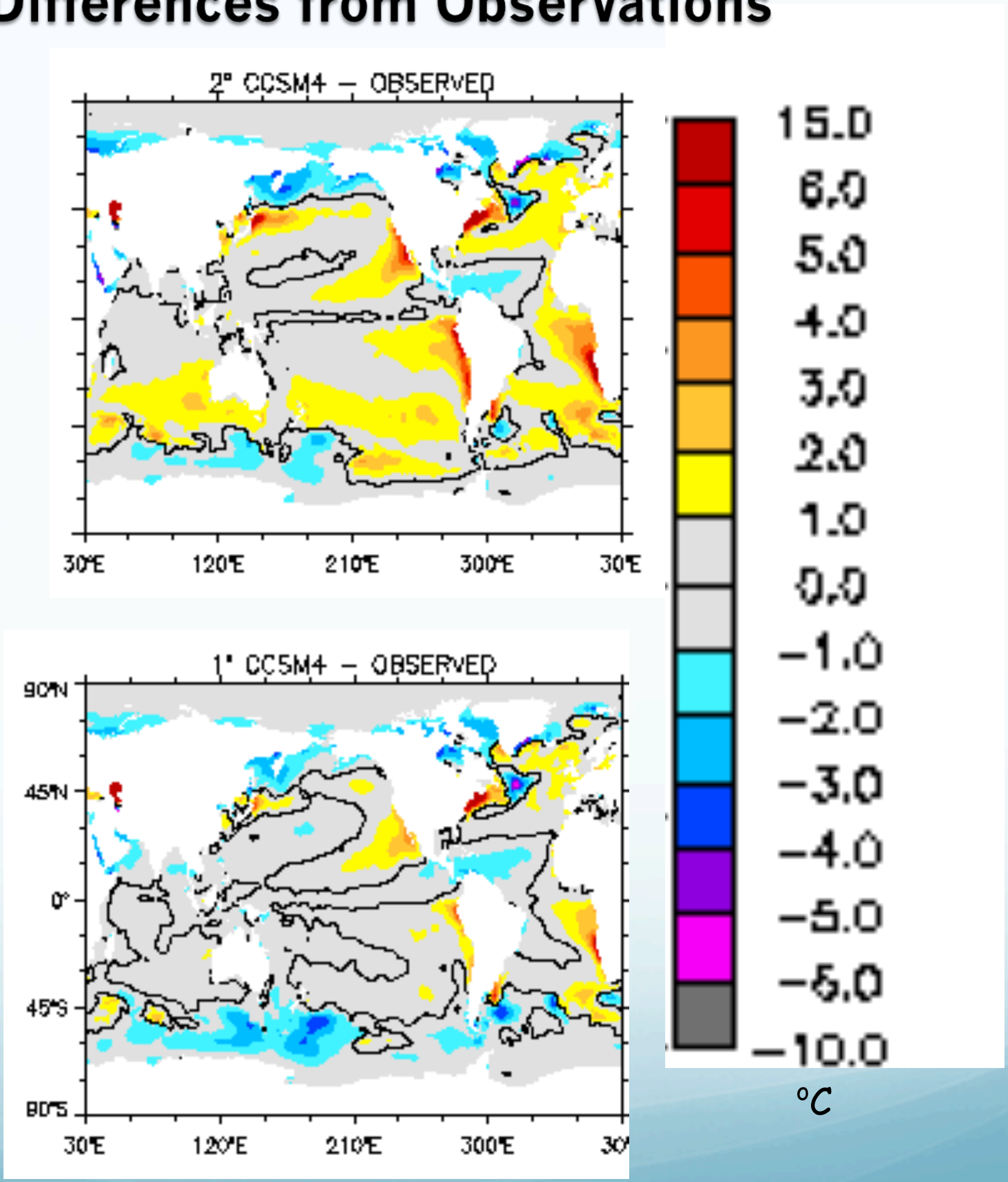


CCSM4_1: 1° : blue line

CCSM4_2: 2° red line

Influence of Forcing

SST Differences from Observations



2° atmosphere

mean= 0.63°C

rms= 1.44°C

1° atmosphere

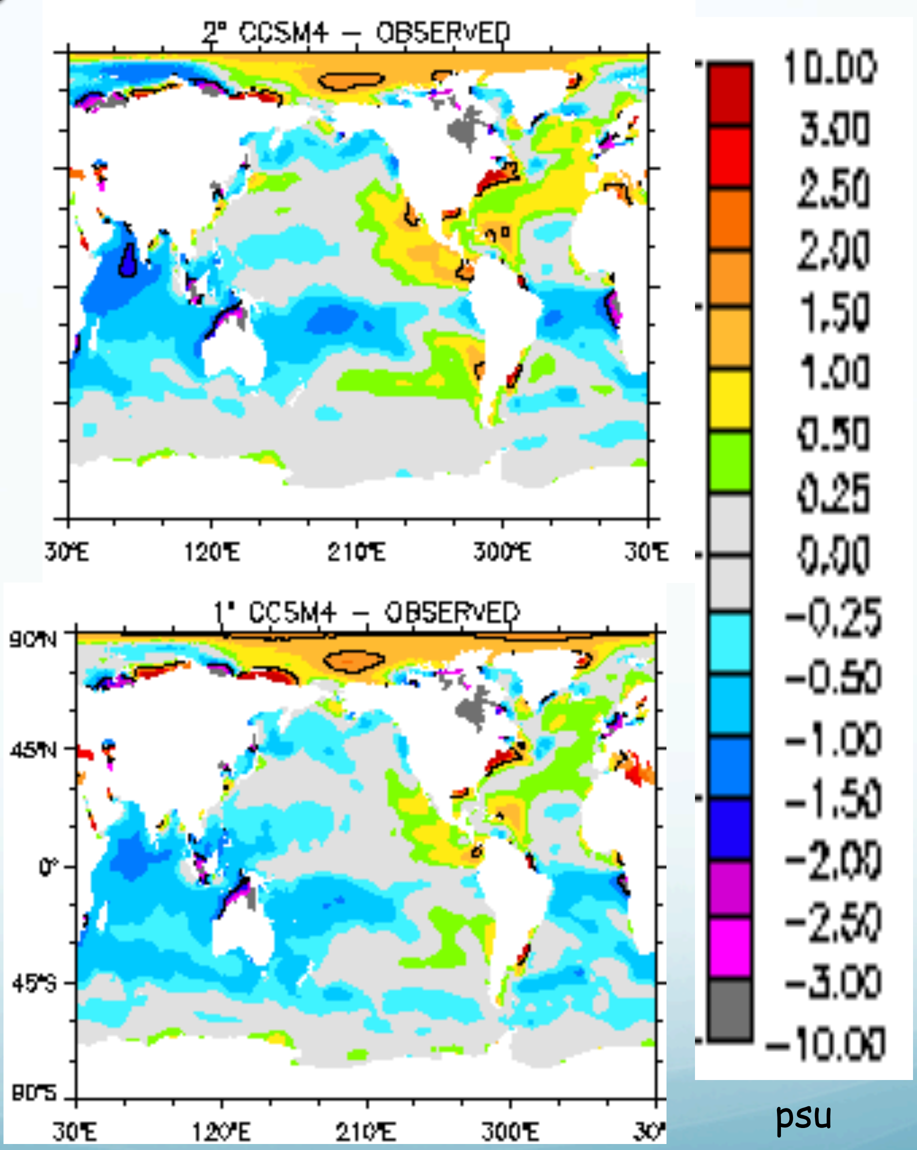
mean= -0.01°C

rms= 1.07°C

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

Influence of Forcing

Salinity Differences from Observations



2° atmosphere

mean= -0.13

rms= 0.80

1° atmosphere

mean= -0.19

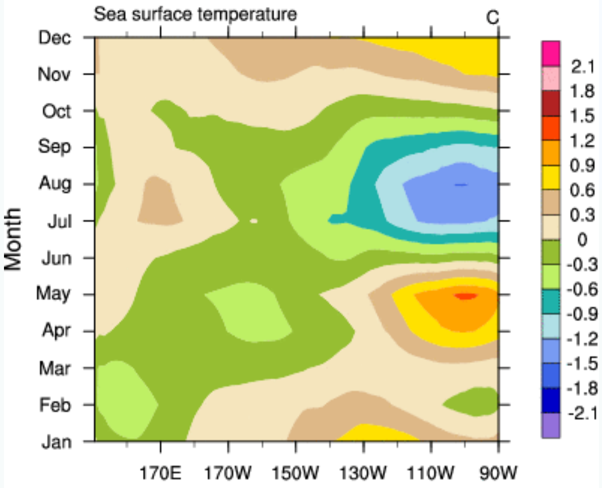
rms= 0.75

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

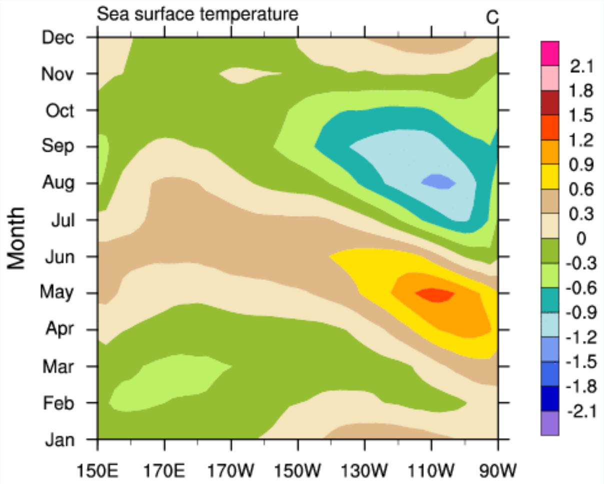
Influence of Forcing

Annual Cycle of SST in the Equatorial Pacific

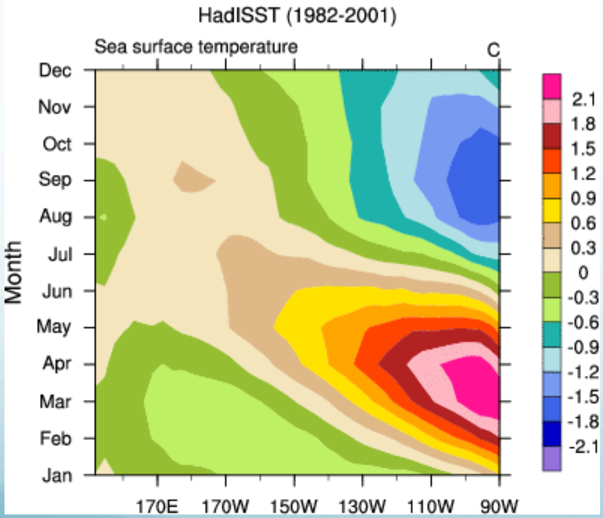
CCSM3



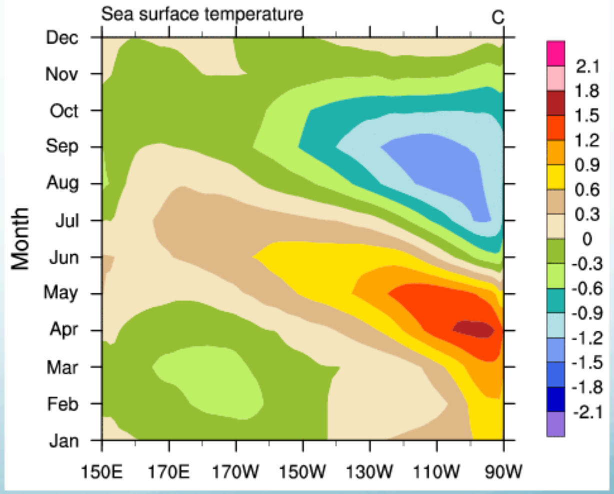
2° CCSM4



Observations

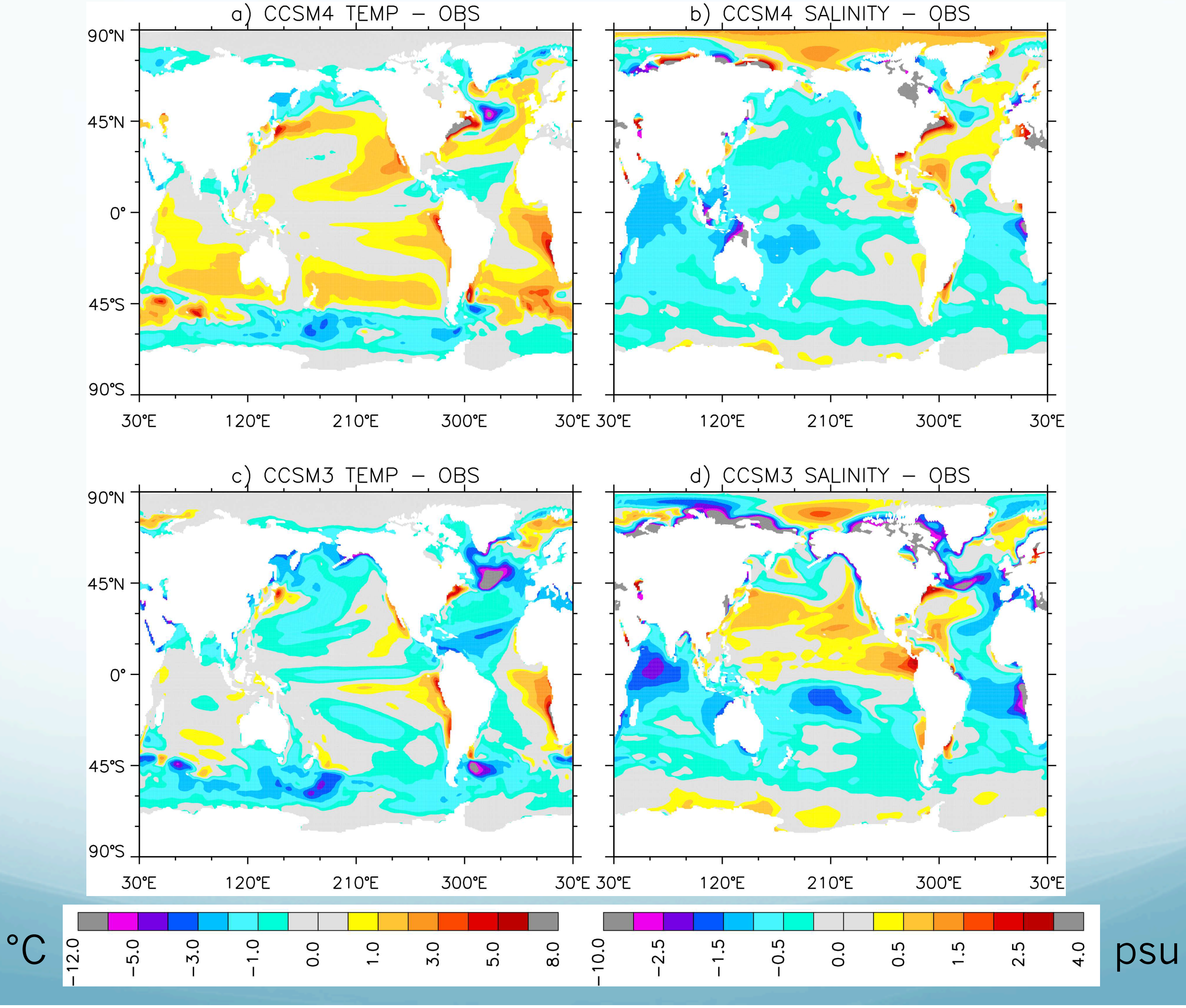


1° CCSM4



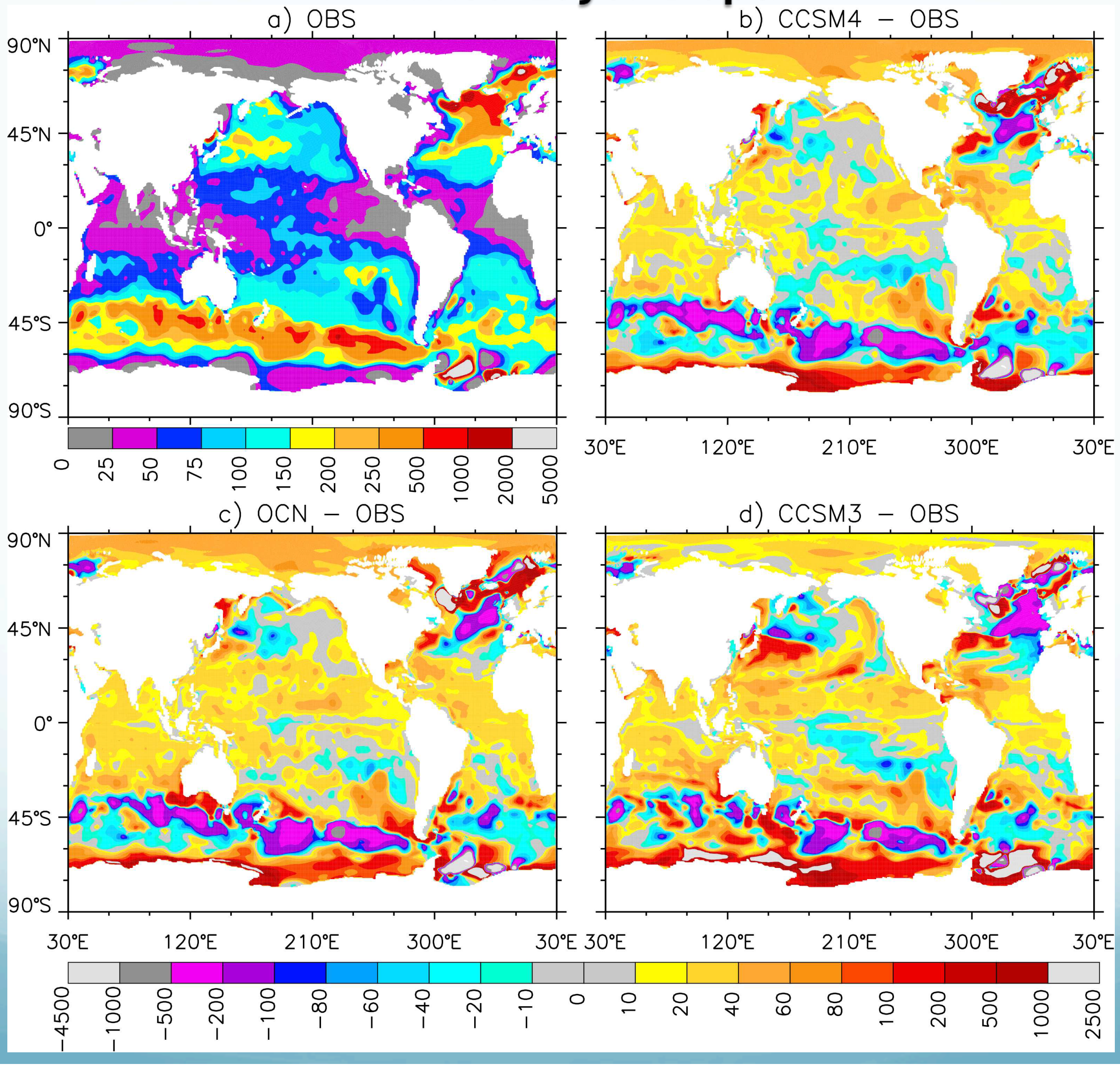
Model Biases

SST and Salinity Differences from Observations



Model Biases

Mixed Layer Depth



meters

Friday’s breakout session

Sea-ice, Ocean, and Land-ice

- Create and run a low-resolution ice-ocean with ecosystem case.
  - Check on model’s progress
  - Create a clone
- Customize output
- Change the namelist
  - turn off tidal mixing
  - Change anisotropic viscosity alignment
  - Change snow and sea ice albedo
- Data Analysis

Helpful Guides

http://www.cesm.ucar.edu/models/cesm1.0/pop2/

CESM Webpage for POP

- POP2 User Guide
- Ocean Ecosystem Model User Guide
- POP Reference Manual
- Ocean Ecosystem Reference Manual (coming soon)

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