VVM-AQUA
ISSUES AND RESULTS

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CMMAP Team Meeting

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MOTIVATION

- As ocean measurements are rather sparse in space and time, an LES will be used to supplement data.
- After trying to borrow the LES of another institution, we have chosen to redesign the VVM (Jung and Arakawa, 2008) for use in the ocean.
  - The new model will be called VVM-Aqua
  - This allows easy access to those who have previously used the model.
    - Special thanks to Mingxuan, Celal, and Joon-hee
- The goal is to develop an entrainment parameterization for use in the ocean component of the GCM.
  - The VVM-Aqua will also be used to test certain assumptions in this parameterization.
  - The parameterization will be used in a prognostic thermocline depth model.

TO-DO LIST

- New Equation of State
  - For now we choose a linear equation of state

$$\rho = \rho_o\left(1-\alpha\left(T-T_o\right)+\beta\left(S-S_o\right)\right);\quad \rho_o \equiv 1000\,kg\,m^{-3};\quad T_o = 15^oC;\quad S_o = 35PSU;\quad \alpha = 2x10^{-4}\,{}^oC^{-1};\quad \beta = 7.6x10^{-4}\,PSU^{-1}$$

  - Salinity added (this and new passive tracer live with temperature)
- Parameterization of Solar Heating
  - Two Choices:
    - Simple two band exponential with constant extinction based on Jerlov water type (Paulson and Simpson 1977).
    - Coefficients based on vertical profile of turbidity (predicted in the VVM-Aqua).
- "Flip" Vertical advection.
- Sub-grid mixing scheme (Smagorinsky), no mixing for Ri > 0.25

$$\kappa = \left(0.17\Delta\right)^2 f\left(Ri,j\right)\sqrt{2S_{ij}S_{ij}};\ \Delta = \left(dx\,dy\,dz\right)^{1/3};\ f\left(Ri,j\right) = \begin{cases}\sqrt{1-Ri/0.25} & j=3\\ 1 & else\end{cases}$$

- Stokes Vortex Force

ISSUES

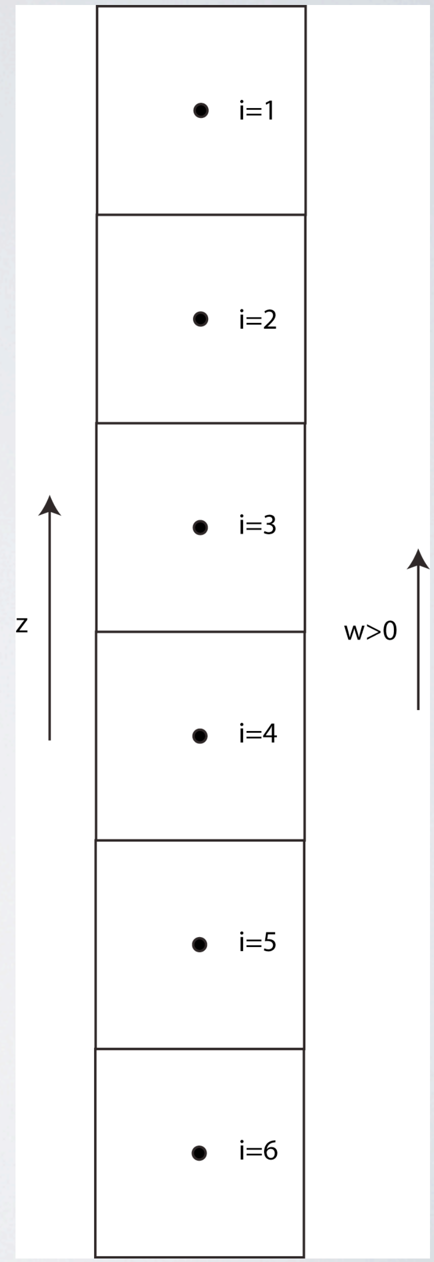
- Since height increases toward the surface and positive vertical velocity also points toward the surface, there will be a number of sign changes in the VVM.
  - The definition of what is upstream changes from the atmosphere to ocean. Not a conceptually difficult issue, but it did take time.
- When non-constant coefficient diffusion was introduced, the structure of the VVM had to be altered to accommodate this change.
  - In the model we calculate the effect of diffusion on momentum and then compute the effect on vorticity. For example, we first calculate

$$\nabla \bullet \left(\kappa_u \nabla u\right) \quad \text{and} \quad \nabla \bullet \left(\kappa_w \nabla w\right)$$

  - Then we can compute the tendency for y-vorticity (η) as

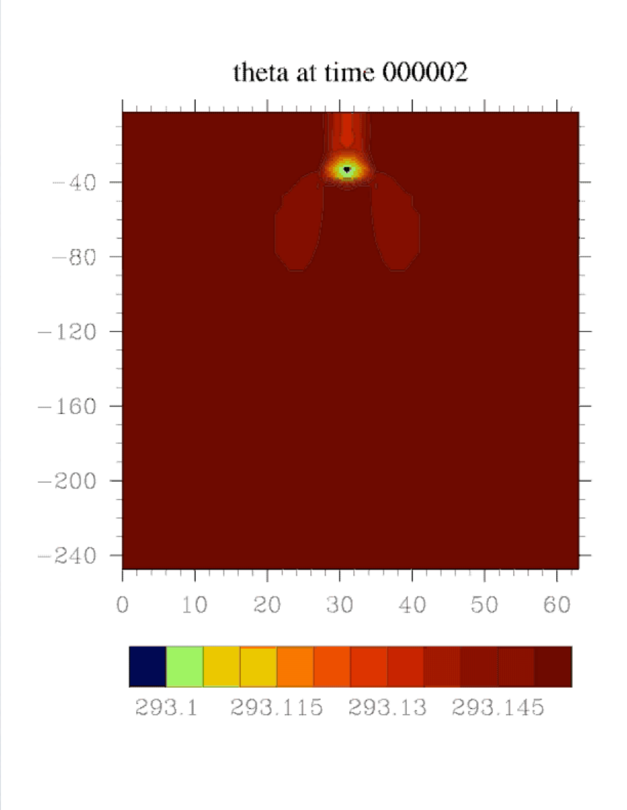
$$\frac{\partial}{\partial x}\left(\nabla \bullet \left(\kappa_w \nabla w\right)\right) - \frac{\partial}{\partial z}\left(\nabla \bullet \left(\kappa_u \nabla u\right)\right)$$

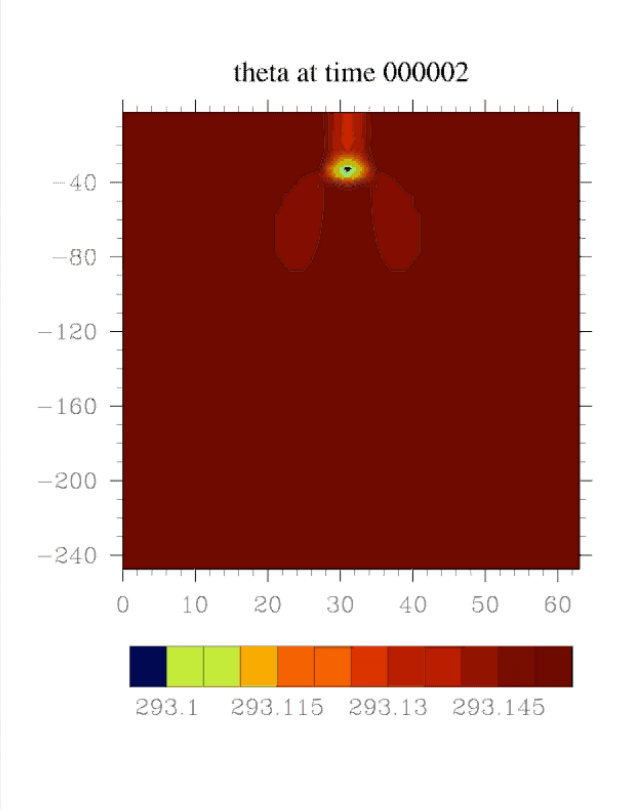
  - This change also allowed for easier implementation of surface fluxes.



BUBBLE TEST

- The first test of the model is a bubble test. In the ocean case, we consider a negatively buoyant (cold) bubble.
- We have tested third (your right) and fifth (left) order advection. It is evident that the 5th order scheme better preserves the variance.
  - Adds about 0.07 seconds per time step (30% increased burden)



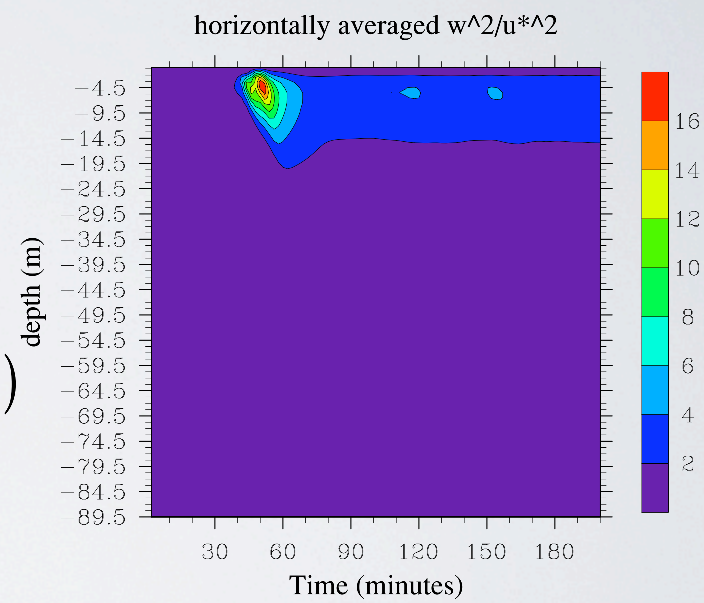


ISSUES II - LANGMUIR CELLS

- In oceanographic literature, langmuir cells are most commonly parameterized by the Stokes Vortex Force (Craik 1977 and Leibovich 1977). This is given by

$$u_s \times \omega$$

- where u_s is the parameterized stokes (wave) drift and ω is the 3-D vorticity
- To use in VVM-Aqua, we need to discretize $\nabla \times (u_s \times \omega)$ this turns out to be difficult, and involves a lot of interpolation. However, this method creates a normalized w^2 of over 16, scalings suggest ~1.4.
  - Problem is due to discretization of $\partial(u_s \zeta)/\partial z$
  - Would be beneficial to use the current model code discretization, since there is a similar term.

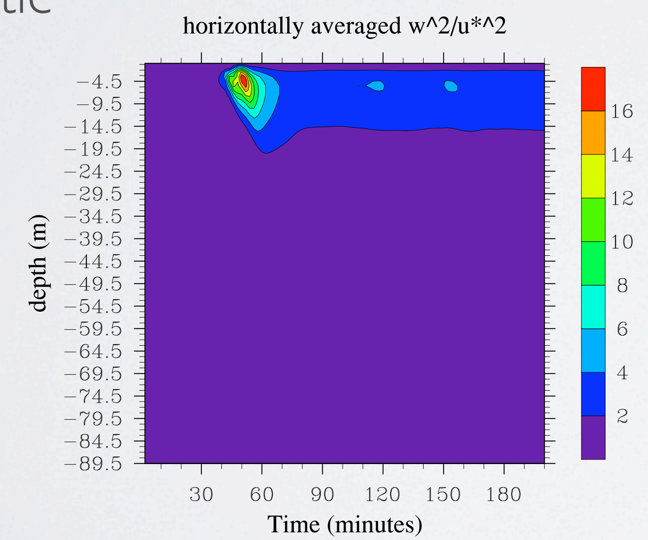


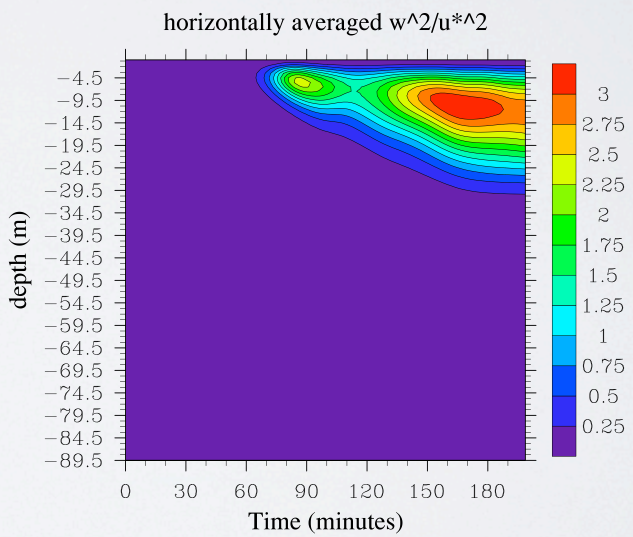
ALTERNATIVE SOLUTION

- To take advantage of the current model code, we begin from the momentum equation with the stokes vortex force and rederive the vorticity equations.
- The new equations can be written as in the standard VVM-Aqua, except

$$u \rightarrow u + u_s \qquad v \rightarrow v + v_s$$

- This allows use of the current model code. The change in the previous plot is dramatic

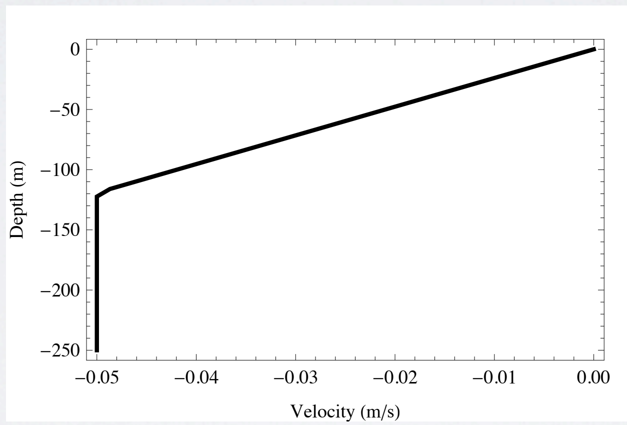




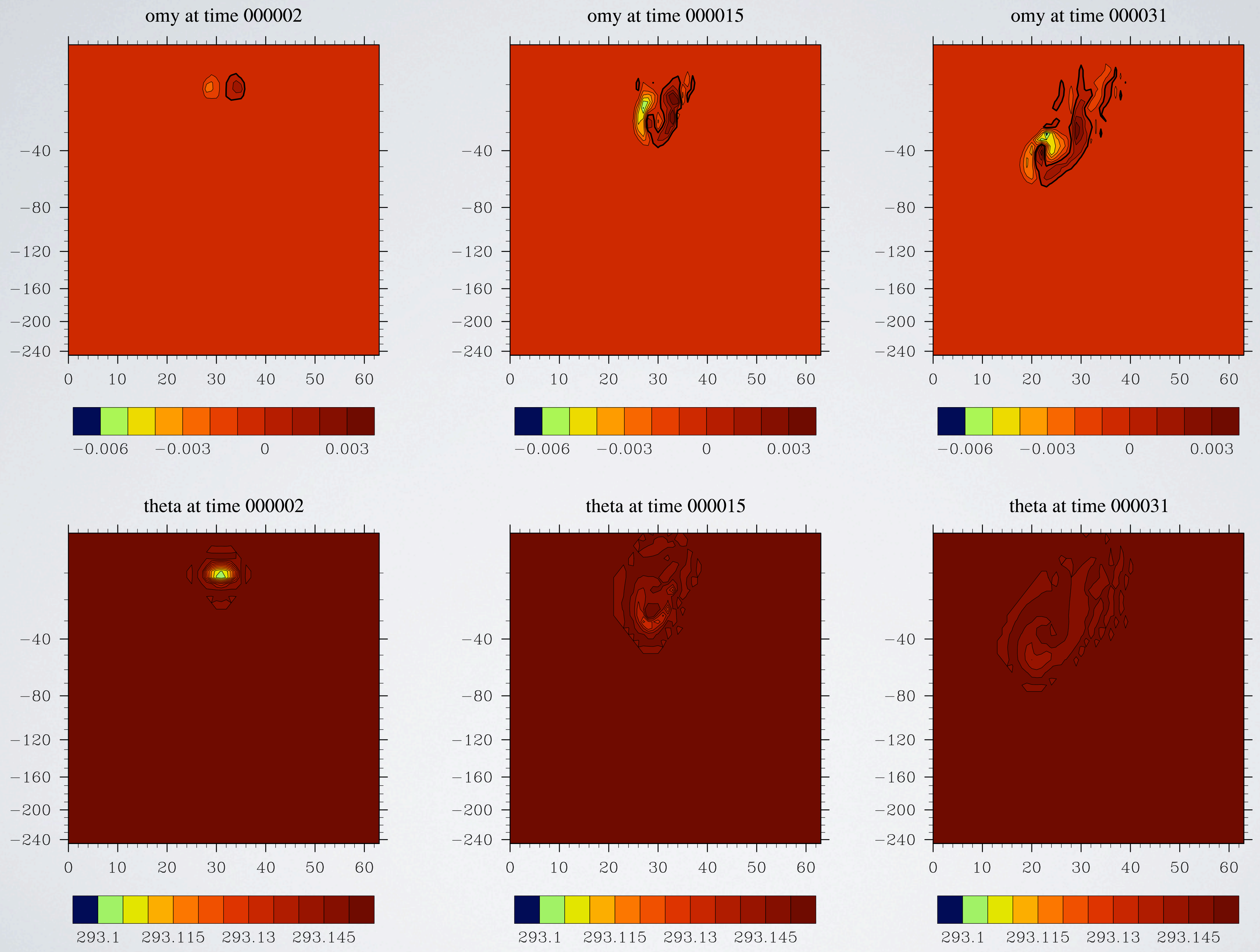
- Further, the changed equations suggest that the stokes vortex force will act like a mean shear flow

BUBBLE IN SHEARED FLOW

- Applied shear is given by the following profile.



- Again, it is a negatively buoyant bubble, y-component of vorticity and temperature are plotted in vertical cross sections through the middle of the domain


omy at time 000002
omy at time 000015
omy at time 000031
−40
−80
−120
−160
−200
−240
0 10 20 30 40 50 60
−0.006 −0.003 0 0.003
theta at time 000002
theta at time 000015
theta at time 000031
293.1 293.115 293.13 293.145

LANGMUIR SET UP

- The model is initialized with a 30 meter deep mixed layer and constant stratification below (no salinity). ($u_* = 0.0061$)
- At the surface a weak destabilizing heat flux (-5 W/m2) is imposed and a constant wind stress ($u = v = 0$) and a Coriolis parameter of $10^{-4}s^{-1}$ is included
- The stokes drift is parameterized as a monochromatic wave

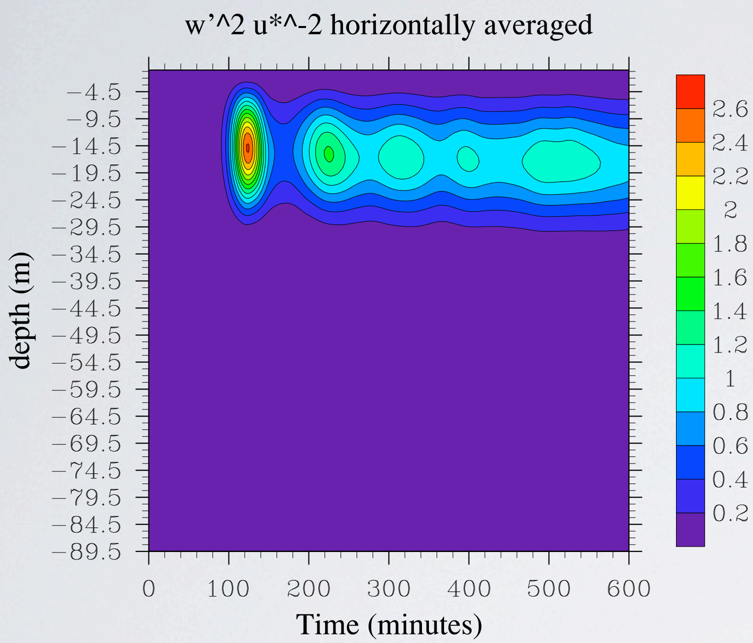
$$u_s(z) = U_s e^{-2kz}; \quad U_S = 0.068 ms^{-1}, k = 0.105 m^{-1}$$

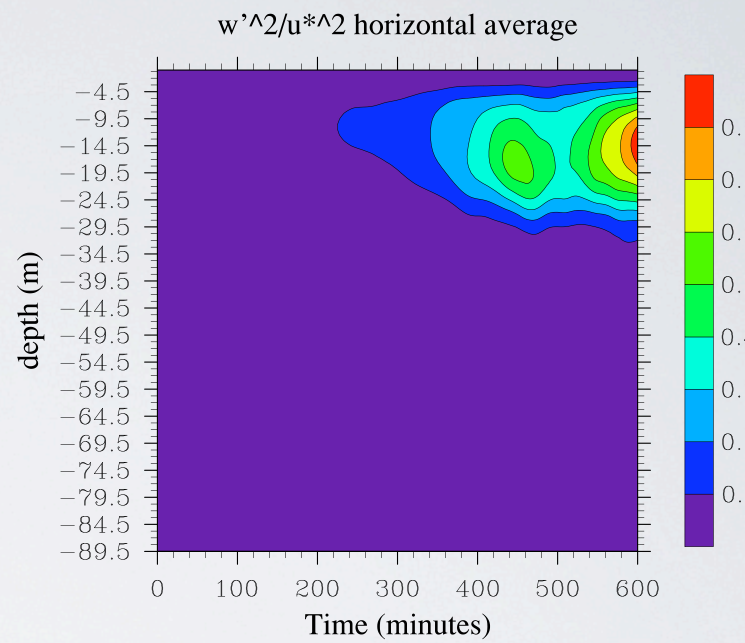
- We also have,

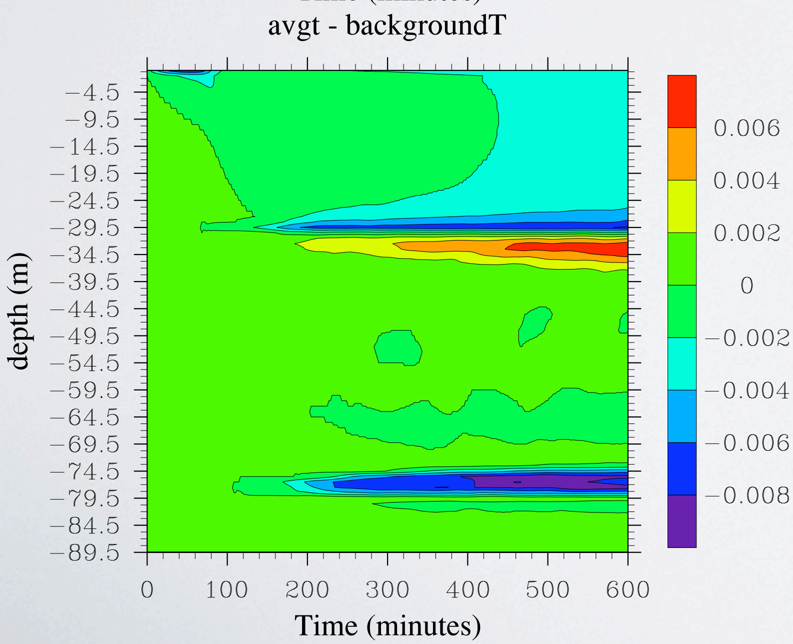
$$\Delta x = \Delta y = 5m; \ \Delta z = 1m; \ \Delta t = 1s; \ nx = ny = 64; \ nz = 90$$

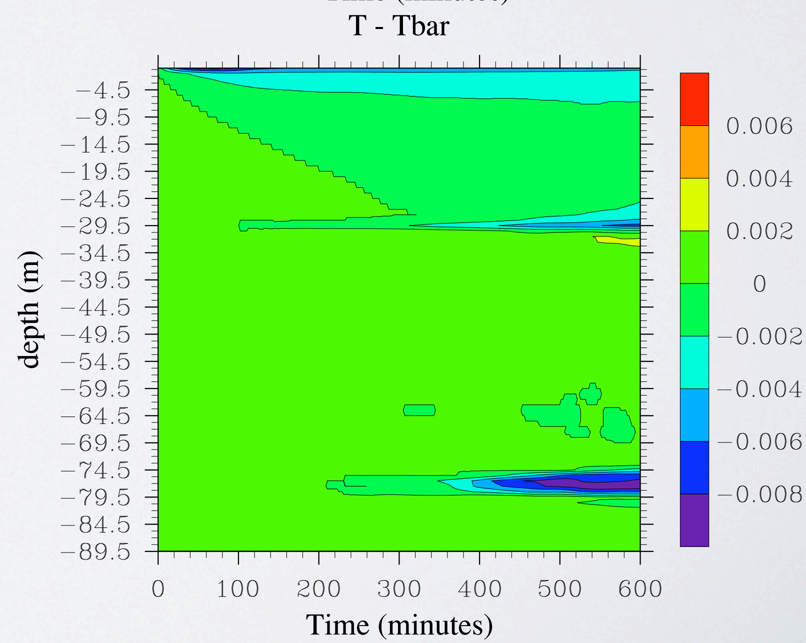
- Further, a sponge layer is included in the bottom 1/3 of the domain.

LANGMUIR TEST

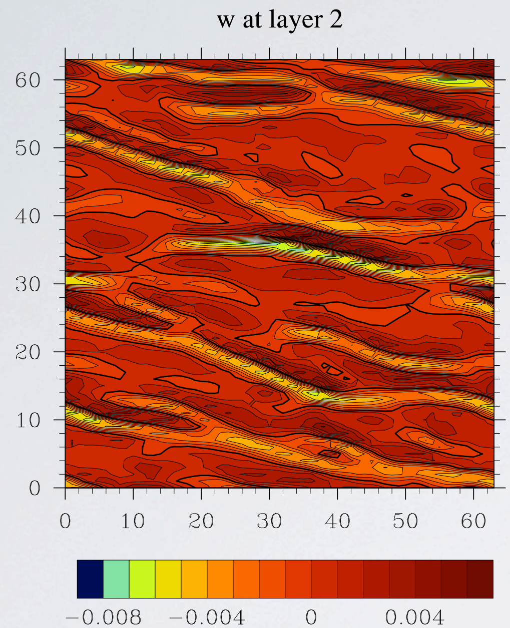


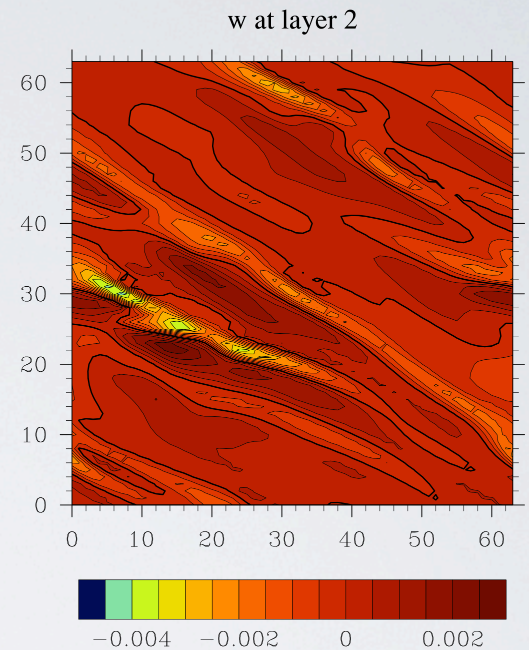


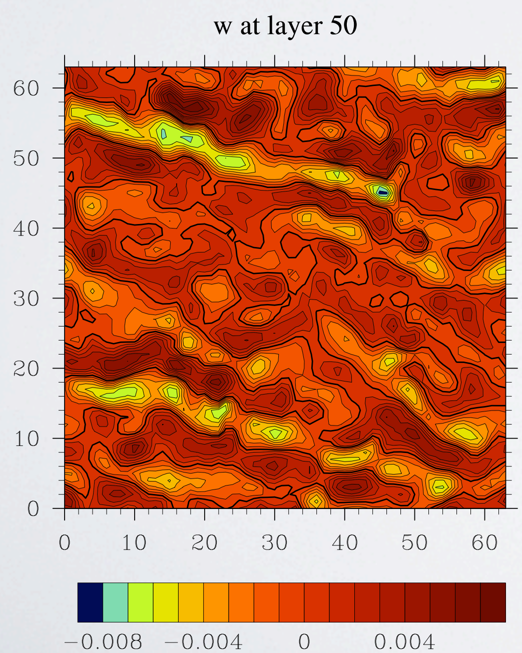


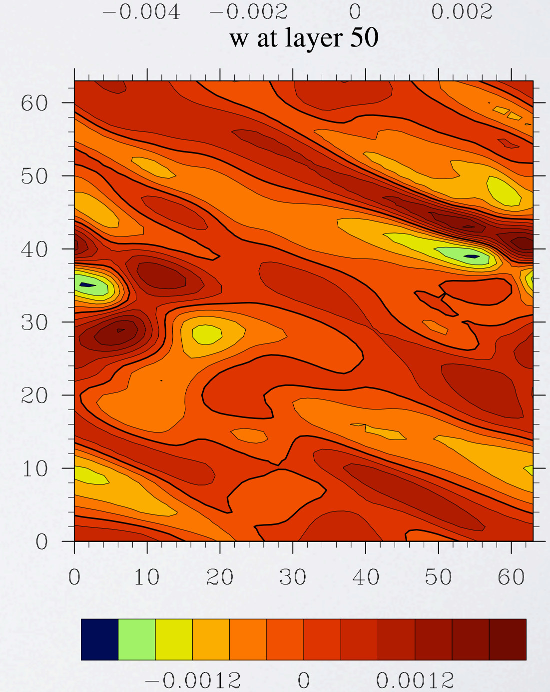


LANGMUIR TEST II









RECAP AND FUTURE DIRECTIONS

- The bubble tests and langmuir tests yield encouraging results.
- The next step is to use the VVM-Aqua to verify a prognostic model of thermocline depth for the ocean GCM.
  - In particular, the focus will be on representation of the diurnal cycle in the GCM and how the vertical distribution of particulate matter (turbidity) can influence the diurnal cycle.
    - We will also conduct tests separating the effects of changing salinity and temperature on entrainment.