Estimating The Eddy Diffusivity Tensor

Follow-Up to a Discussion at the December 2006 OMWG meeting
The Concept
(outlined by Baylor Fox-Kemper in December)

• Apply the methodology of Plumb and Mahlman (1987) to estimate the three dimensional distribution of all nine components of the eddy diffusivity tensor

• In 2D, assert same eddy diffusivity applies to two tracers:

\[
\begin{bmatrix}
    v' \tau_1' & v' \tau_2' \\
    w' \tau_1' & w' \tau_2'
\end{bmatrix} = -\begin{bmatrix}
    K_{yy} & K_{yz} \\
    K_{zy} & K_{zz}
\end{bmatrix} \begin{bmatrix}
    \tau_{1,y} \\
    \tau_{2,y}
\end{bmatrix} - \begin{bmatrix}
    \tau_{1,z} \\
    \tau_{2,z}
\end{bmatrix}
\]

• Then

\[
\begin{bmatrix}
    K_{yy} & K_{yz} \\
    K_{zy} & K_{zz}
\end{bmatrix} = -\begin{bmatrix}
    v' \tau_1' & v' \tau_2' \\
    w' \tau_1' & w' \tau_2'
\end{bmatrix} \begin{bmatrix}
    1 \\
    \tau_{1,y} & \tau_{2,y} \\
    \tau_{1,z} & \tau_{2,z}
\end{bmatrix} - \begin{bmatrix}
    \tau_{2,z} & -\tau_{2,y} \\
    -\tau_{1,z} & \tau_{1,y}
\end{bmatrix}
\]
• Extend to 3D and elaborate following Bratseth (1998)
  – Use more than minimum number of tracers (3) to make the problem formally over-determined
  – Find solution for $K$ that minimizes:

\[
J_u = \sum_i W_{ui} (u'q_i' + K_{xx} \frac{\partial q_i}{\partial x} + K_{xy} \frac{\partial q_i}{\partial y} + K_{xz} \frac{\partial q_i}{\partial z})^2
\]

\[
J_v = \sum_i W_{vi} (v'q_i' + K_{yx} \frac{\partial q_i}{\partial x} + K_{yy} \frac{\partial q_i}{\partial y} + K_{yz} \frac{\partial q_i}{\partial z})^2
\]

\[
J_w = \sum_i W_{wi} (w'q_i' + K_{zx} \frac{\partial q_i}{\partial x} + K_{zy} \frac{\partial q_i}{\partial y} + K_{zz} \frac{\partial q_i}{\partial z})^2
\]
The Opportunity

• Following December meeting proposal prepared and sent to IBM Watson Research for use of large Bluegene system:
  – John Dennis (NCAR/CISL)
  – Frank Bryan (NCAR/CGD)
  – Baylor Fox-Kemper (MIT-> CU)
  – Mat Maltrud (LANL)
  – Julie McClean (Scripps/LLNL)
  – Synte Peacock (U. Chicago -> NCAR/CGD)

• Our proposal selected from pool of projects across all disciplines
  – Awarded 110 “rack days” (1 rack = 2k Pes)
  – Very restrictive storage constraints
The Experiment

• Global 0.1° forced ocean simulation based on configuration of Maltrud and McClean (2005) except:
  – Partial bottom cells
  – Climatological monthly mean forcing

• Integration:
  – 10-15 years physics spin-up
  – 5 years passive tracer spin-up
  – 5 year sampling of tracers and fluxes (seasonal statistics)

• Data recovered by portable RAID system via FedEx
Research Challenges and Opportunities

- Defining initial tracer distributions and forcing to keep tracers independent:
  - $\Theta$, S, PV, IA, $\sim z$, $\sim \phi$, $\sim \cos(\lambda)$
  - Preliminary experiments currently underway with 0.4˚ model

- Dealing with rotational component of eddy tracer flux?

- Defining the averaging/coarsening procedure (conservation, dependence of the results on scales etc)

- Optimization methods
\[
\frac{\partial q_i}{\partial t} = -\nabla \cdot (\vec{u} q_i) + \ldots + \gamma_i(\vec{x})[q_i(t_0) - q_i] \\
q_i(t_0) \propto \phi
\]
Technical Challenges

• Need to run on 16k to 32k PEs
  – Excellent scalability demonstrated on BGW with POP benchmark

• But:
  – Need scalable parallel IO (basically done)
  – Finding problems at high processor counts in POP communication infrastructure (have leads for fixes)
  – Apparent memory leak in vendor MPI implementation currently precluding long runs