Transport in CAM

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Climate & Global Dynamics
Why focus on transport in CAM?

• Several dynamical cores have been/are being integrated into CAM: MPAS, HOMME, GFDL cubed-sphere, EULAG, ...
  Idealized testing of dynamics solvers –> transport

• **Accurate** tracer transport is becoming increasingly important (modern microphysics schemes, more prognostic chemical species, ...) – large gradients, features collapse to the grid scale, ...

• Tracer transport can account for most of the computational cost of “resolved” scale dynamics computations
  - e.g., 26+ tracers to prognose in CAM5; 126+ in chemistry version

  **Multi-tracer efficiency** is becoming increasingly important

⇒ Develop new challenging, idealized test cases
⇒ Test existing and develop new transport algorithms
community asked to bring solutions to new test suite

Passive & inert idealized 2D transport test cases designed to assess (among other things):

1. ‘minimal’ resolution,
2. ability of transport scheme to preserve filaments,
3. ability of the transport scheme to preserve pre-existing functional relations between species (e.g., N$_2$O-NO$_y$, family of species, ...),

under challenging flow conditions

\[
\begin{align*}
\mathbf{u}(\lambda, \theta, t) &= \kappa \sin(2\lambda) \sin(2\theta) \cos(\pi t/T) + 2\pi \cos(\theta)/T \\
\mathbf{v}(\lambda, \theta, t) &= \kappa \sin(2\lambda) \cos(\theta) \cos(\pi t/T),
\end{align*}
\]

(Nair and Lauritzen, 2010, JCP).
Community asked to bring solutions to new test suite

Passive & inert idealized 2D transport test cases divided into three categories that are designed to assess:

1. numerical order of convergence and 'minimal' resolution,
2. ability of the transport scheme to transport 'rough' distributions,
3. ability of transport scheme to preserve filaments,
4. ability of the transport scheme to preserve pre-existing functional relations between species,

under challenging flow conditions

\[ u(\lambda, \theta, t) = \kappa \sin^2(\lambda) \sin(2\theta) \cos(\pi t/T) + 2\pi \cos(\theta)/T \]

\[ v(\lambda, \theta, t) = \kappa \sin(2\lambda) \cos(\theta) \cos(\pi t/T) \]


NCAR Workshop (March, 2011)

NCAR = National Center for Atmospheric Research

CSLAM = Conservative Semi-Lagrangian Multi-tracer scheme

Lauritzen et al. (2010, JCP), Harris et al. (2011), Lauritzen et al. (2011, JCP)
community asked to bring solutions to new test suite

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2. ability of transport scheme to preserve filaments,
3. ability of the transport scheme to preserve pre-existing functional relations between species (e.g., N2O-NOy, family of species, …),

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(Nair and Lauritzen, 2010, JCP).
Initial conditions
tracer 1: cosine bells   tracer 2: correlated cosine bells \[ \Psi(\chi) = a\chi^2 + b \]

Preserving pre-existing functional relation between tracers under challenging flow conditions

Lauritzen and Thuburn (2011, QRJMS)
Preserving pre-existing functional relation between tracers under challenging flow conditions

**Initial conditions**

- tracer 1: cosine bells
- tracer 2: correlated cosine bells

\[ \Psi(\chi) = a\chi^2 + b \]

Lauritzen and Thuburn (2011, QRJMS)

Truncation errors introduce mixing

Lauritzen and Thuburn (2011, QRJMS)
Preserving pre-existing functional relation between tracers under challenging flow conditions

Classification of mixing on scatter plot:

a. Mixing that resembles `real' mixing – convex hull (red area)
b. Everything else is spurious unmixing

Thuburn and McIntyre (1997, JGR)
Preserving pre-existing functional relation between tracers under challenging flow conditions

Note: 1. **Max value decrease**, 2. Unmixing even if scheme is shape-preserving, 3. No expanding range unmixing
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Tracer density simulated with monotone CSLAM

![Graph showing tracer density](image1)

Tracer density simulated with monotone CSLAM

![Graph showing tracer density](image2)
MPAS – 1.1 degree - CFL 0.7

CAM-FV – 1 degree – CFL 1.6

Cam-SE – 1 degree – CFL 0.3

CSLAM – 1 degree – CFL 5.5

'`Smearing' of extrema (preservation of filaments)\n
MPAS – 1.1 degree - CFL 0.7

CAM-FV – 1 degree – CFL 1.6

Range-preserving unmixing

CAM-SE – 1 degree – CFL 0.3

CSLAM – 1 degree – CFL 5.5
Expanding range unmixing
`Minimal’ resolution:
( = average resolution at the equator for which $l_2=0.033$)

<table>
<thead>
<tr>
<th>Model</th>
<th>Resolution</th>
<th>Domain</th>
<th>CFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAM-FV</td>
<td>0.75</td>
<td>(lat-lon)</td>
<td>&gt;1</td>
</tr>
<tr>
<td>CAM-SE</td>
<td>1.1</td>
<td>(cubed-sphere)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>MPAS</td>
<td>0.7</td>
<td>(Voronoi)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>CSLAM</td>
<td>1.5</td>
<td>(cubed-sphere)</td>
<td>&gt;1</td>
</tr>
</tbody>
</table>

Mainly for efficiency reasons we are implementing CSLAM in CAM-SE (SCIDAC effort): CSLAM permits large CFL numbers and only require one communication per tracer time-step instead of three for spectral element advection (CAM-SE). However, CSLAM needs a larger halo!
References


It is key that tracer features collapse to smaller scales (as in nature)

This setup uses a 4th-order non-linear relation $\Psi(\chi) = ax^4 + b$.