Preliminary Test of a Quasi-3D Advection Algorithm

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In the quasi-3D MMF, we apply an identical 3D algorithm to all of grids.

Decomposition of Fields

To estimate the values of a prognostic variable, $q$, at ghost points, we decompose the $q$ field as

$$q = \bar{q} + q'$$

where

$\bar{q}$: background field identified by the application of a regression/interpolation technique to the present grid-point values, (synoptic-scale fields)

$q'$: deviation of $q$ from $\bar{q}$ that must be statistically estimated.  (clouds and their mesoscale organization)
Decomposition of Advection Term

Using the Cartesian coordinate \((x, y)\), the 2D advection equation on a horizontal plane can be written as

\[
\frac{\partial q}{\partial t} = - \left( \mathbf{V} \cdot \nabla q + \bar{u} \frac{\partial q'}{\partial x} + \bar{v} \frac{\partial q'}{\partial y} + u' \frac{\partial q'}{\partial x} + v' \frac{\partial q'}{\partial y} \right)
\]

Unlike background field, deviation field is not smooth so that its values at the ghost points can not be estimated by a simple regression/interpolation technique.

Our problem is to estimate the terms involving deviation field at the ghost points.
**Determination of Background Fields**

**Step 1:** Linear regression analysis of the present grid-point values

\[ q_{\text{reg}} = \alpha i + \beta j + \gamma \]

At the point (0,0)

\[ \alpha = \frac{\partial q_{\text{reg}}}{\partial i} \quad \beta = \frac{\partial q_{\text{reg}}}{\partial j} \quad \gamma = q_{\text{reg}} \]

At all intersection points, \( \alpha, \beta, \) and \( \gamma \) are obtained.

This relationship is applied only to intersection points.

i and j are nondimensional \( x \) and \( y \)
**Step 2: Interpolation of regressed fields**

\[
qN^4 = (i - N)(j - N) \left\{ \left[ (q_1 - q_0) - N(\partial q / \partial i) \right]_1 i^2 + \left[ (q_3 - q_0) - N(\partial q / \partial j) \right]_3 j^2 + q_0 N^2 \right\} \\
+ i(j - N) \left\{ \left[ (q_1 - q_0) - N(\partial q / \partial i) \right]_0 (i - N)^2 - \left[ (q_2 - q_1) - N(\partial q / \partial j) \right]_2 j^2 - q_1 N^2 \right\} \\
+ ij \left\{ - \left[ (q_2 - q_3) - N(\partial q / \partial i) \right]_3 (i - N)^2 - \left[ (q_2 - q_1) - N(\partial q / \partial j) \right]_1 (j - N)^2 + q_2 N^2 \right\} \\
+ (i - N) j \left\{ - \left[ (q_2 - q_3) - N(\partial q / \partial i) \right]_2 i^2 + \left[ (q_3 - q_0) - N(\partial q / \partial j) \right]_0 (j - N)^2 - q_3 N^2 \right\}.
\]
Estimation of Deviation Fields at Ghost Points

**Hypothesis**

The degree and orientation of cloud organization can be estimated from the past history at the intersection and neighboring grid points.
When clouds are organized into bands, the correlation between X and Y at present and near future can be estimated from the past time correlation between them.

**Step 1:** Linear regression analysis of past history at the intersection and neighboring grid points

- linear regression: \( Y = a + bX \)

where

- \( X \): first/second/third-order finite differences of \( q' \) in \( x \)
- \( Y \): first/second/third-order finite differences of \( q' \) in \( y \)

e.g. The relation between the first-order finite differences of \( q' \) in \( x \) and \( y \) defines the orientation angle of cloud organization.
Estimation of Deviation Fields at Ghost Points (Continued.)

Step 2: Interpolation of regression parameters to all grid points

Step 3: Estimation of deviation fields at the ghost points

\[ \hat{q}'_{i,j+1} = q'_{i,j} + \frac{(Y_1 + Y_2)}{2} \]

\[ \hat{q}'_{i,j-1} = q'_{i,j} - \frac{(Y_1 - Y_2)}{2} \]

\( Y_1 \): estimated first-order finite difference in \( y \)
\( Y_2 \): estimated second-order finite difference in \( y \)
Description of the model

“A new 3D cloud model based on the vorticity equation”
Joon-Hee Jung and Akio Arakawa

- **Governing equation**: 3D anelastic vorticity equation

- **Advection of vorticity and scalar variables**: partially 3rd-order scheme, enstrophy bounded for 2D plane flow

- **Time differencing**: second-order Adams-bashforth

- **Column physics**: UCLA/CSU/University of Utah CSRM
  - bulk ice-phase microphysical parameterization (Lord et al., 1984; Krueger et al., 1995)
  - solar and infrared radiation parameterization (Fu et al., 1995)

- **Surface fluxes**: Flux-profile relationships (Deardorff, 1972)

- **Turbulence**:
  First-order closure (deformation and stability dependent K; Shutts and Gray, 1994)
Control Run

- **Domain size:** 64 km x 64 km x 18 km (height)
- **Horizontal resolution:** 2 km
- **Vertical resolution:** 34 layers with a stretched vertical grid
- **Lower-boundary:** ocean surface with a fixed temperature
- **Initial condition:** the GATE Phase-III mean sounding
- **Condition for solar radiation:** fixed to a typical daytime condition
- **Large-scale forcing:** prescribed advective tendency
- **Perturbation:** small, random temperature perturbations into the lowest model layer
Control ( t = 29 h )

Cloud Top Temperature

Y = 15 km

Cloudiness > 0.8
Rain
Snow
Graupel
Regression Analysis of Past History at the Intersection Points and Application of the Result to All Grid Points

- **analysis period**: 24h ~ 36h (data frequency - every 10 minute)
- **application period**: 36h ~ 39h (data frequency - every 1 hour)
Cloud Ice Mixing Ratio and Wind (Analysis Period)  
$z = 9.6 \text{ km}$
Cloud Ice Mixing Ratio and Wind (Analysis Period)

$z = 9.6 \text{ km}$
Cloud Ice Mixing Ratio and Wind (Application Period)

$q$

$ar{q}$

$q - ar{q}$

$t = 36$ hr $10$ min

$t = 37$ hr $10$ min

$t = 38$ hr $10$ min

$X$ (km)

$Y$ (km)
Analysis Period: 24h ~ 36h

First-order Differences

Y
0.0
-0.5
-1.0
X
-1.0
-0.5
0.0
0.5
1.0

c.c. = 0.62
θ = 24.8
σ = 0.15

Second-order Differences

Y
0.0
-0.5
-1.0
X
-1.0
-0.5
0.0
0.5
1.0

c.c. = 0.81
θ = 26.5
σ = 0.09
Realized Y vs. Estimated Y

Application Period: 36h ~ 39h
Realized Values vs. Estimated Values

Application Period: 36h ~ 39h

\[ \bar{v} \frac{dq'}{dy} \quad \text{and} \quad v' \frac{dq'}{dy} \]

[ g kg\(^{-1}\) min\(^{-1}\) ]
Realized Values vs. Estimated Values

**Total Advection**

\[
\left( \mathbf{v} \cdot \mathbf{\nabla} \mathbf{q} + \mathbf{u} \frac{dq'}{dx} + \mathbf{v} \frac{dq'}{dy} + u' \frac{dq'}{dx} + v' \frac{dq'}{dy} \right)
\]

**Application Period:** 36h ~ 39h

[Graph showing a scatter plot with realized values on the x-axis and estimated values on the y-axis. The correlation coefficient (C.C.) is 0.78.]
Realized Values vs. Estimated Values

Total Advection
\[
\left( \mathbf{v} \cdot \nabla \mathbf{a} + \frac{\partial q'}{\partial x} + \frac{\partial q'}{\partial y} + u' \frac{\partial q'}{\partial x} + v' \frac{\partial q'}{\partial y} \right)
\]

Application Period: 39 h ~ 42h

Application Period: 42h ~ 45h

C.C. = 0.64

C.C. = 0.81
Realized Values vs. Estimated Values

Total Advection

\[
\left( \mathbf{v} \cdot \nabla q + u \frac{dq'}{dx} + \nabla \cdot \mathbf{v} + u' \frac{dq'}{dx} + v' \frac{dq'}{dy} \right)
\]

Application Period: 45h ~ 48h

Estimated Values vs. Realized Values

C.C. = 0.69

Application Period: 48h ~ 51h

Estimated Values vs. Realized Values

C.C. = 0.68
Conclusion

- The degree and orientation of cloud organization can be statistically estimated from the past history at the intersection and neighboring grid points.

- We need to include stochastic component for the case of a large standard deviation, which can be interpreted as the case of nearly-isotropic cloud distribution.