Preliminary Test of a Quasi-3D Advection Algorithm

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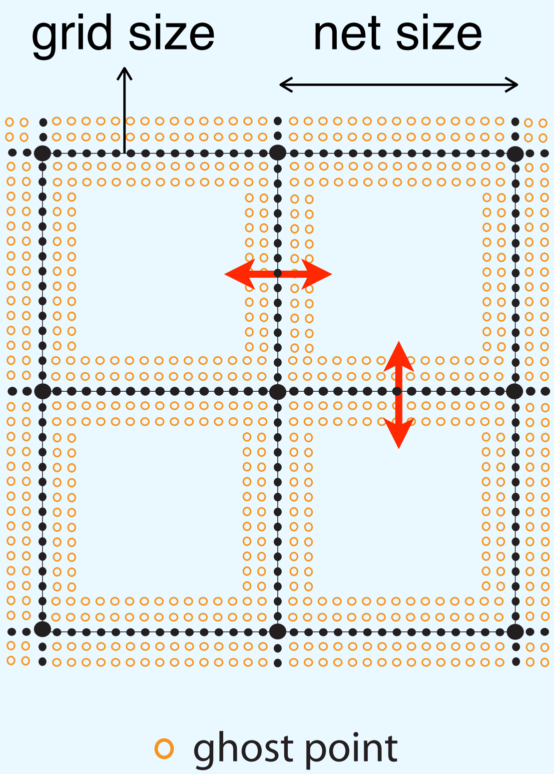


*In the quasi-3D MMF,
we apply an identical 3D algorithm
to all of grids.*

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

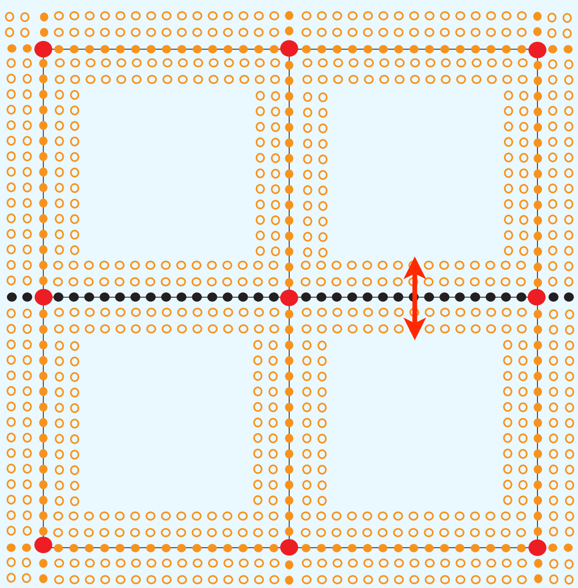
$\bar{q}$: background field identified by the application of a regression/interpolation technique to the present grid-point values,
(synoptic-scale fields)

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

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

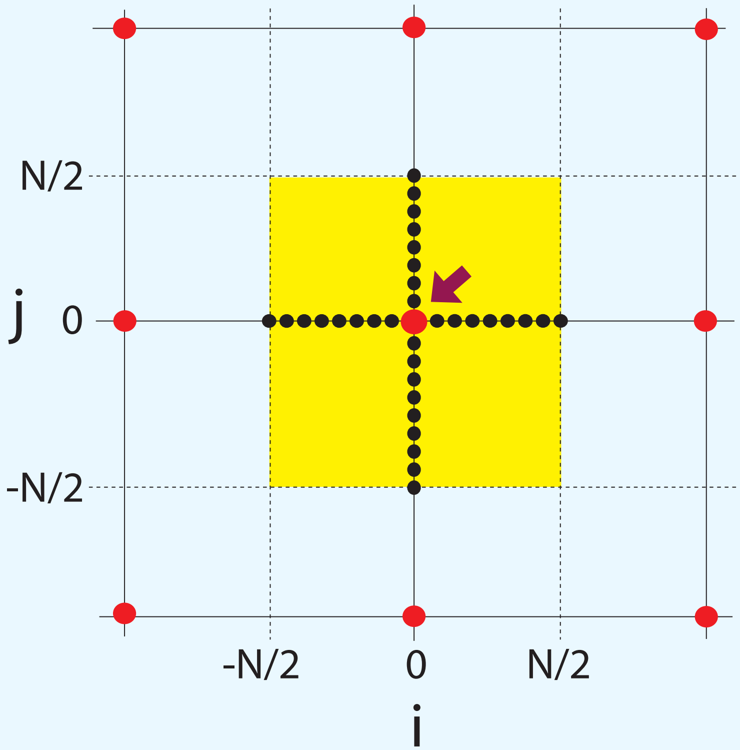


Unlike background field,
deviation field is not smooth
so that its values at the ghost points
can not be estimated by a simple
regression/interpolation technique.

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



$$q_{reg} = \alpha i + \beta j + \gamma$$

At the point (0,0)

$$\alpha = \frac{\partial q_{reg}}{\partial i} \quad \beta = \frac{\partial q_{reg}}{\partial j} \quad \gamma = q_{reg}$$

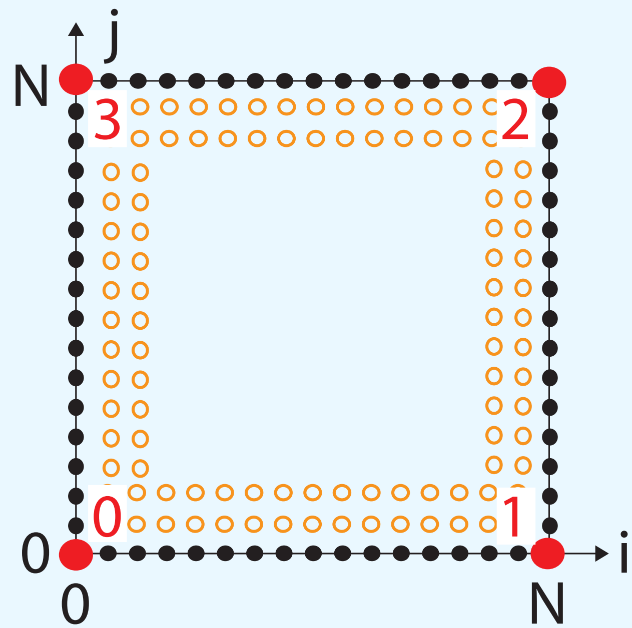
At all intersection points, α, β, and γ are obtained.

This relationship is applied only to intersection points.

i and j are nondimensional x and y

Determination of Background Fields (Continued.)

Step 2: Interpolation of regressed fields

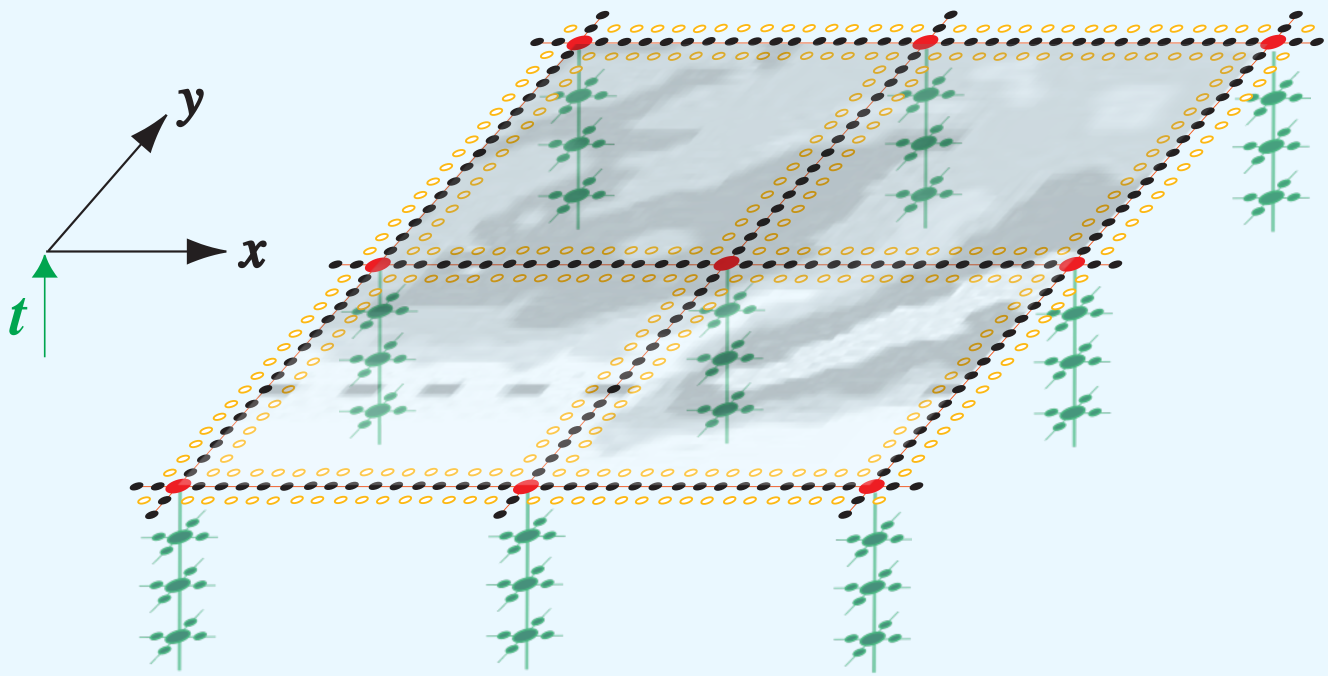


$$
\begin{aligned}
qN^4 = \; & (i-N)(j-N)\left\{\left[(q_1 - q_0) - N(\partial q/\partial i)_1\right]i^2 + \left[(q_3 - q_0) - N(\partial q/\partial j)_3\right]j^2 + q_0 N^2\right\} \\
& + i(j-N)\left\{\left[(q_1 - q_0) - N(\partial q/\partial i)_0\right](i-N)^2 - \left[(q_2 - q_1) - N(\partial q/\partial j)_2\right]j^2 - q_1 N^2\right\} \\
& + ij\left\{-\left[(q_2 - q_3) - N(\partial q/\partial i)_3\right](i-N)^2 - \left[(q_2 - q_1) - N(\partial q/\partial j)_1\right](j-N)^2 + q_2 N^2\right\} \\
& + (i-N)j\left\{-\left[(q_2 - q_3) - N(\partial q/\partial i)_2\right]i^2 + \left[(q_3 - q_0) - N(\partial q/\partial j)_0\right](j-N)^2 - q_3 N^2\right\}
\end{aligned}
$$

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.



Estimation of Deviation Fields at Ghost Points (Continued.)

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

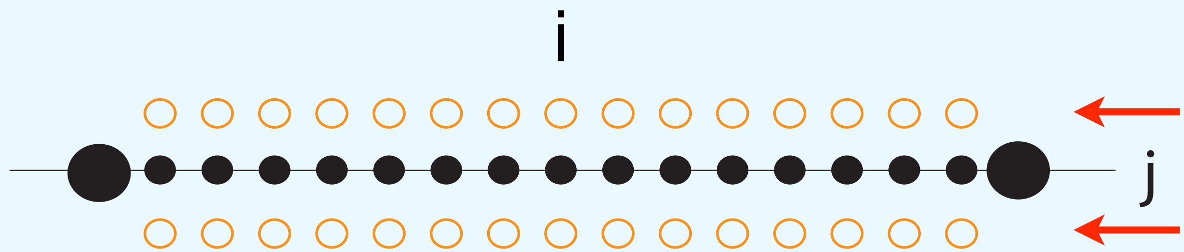
Y: first/second/third-order finite differences of q′ in y

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



$$\widehat{q'}_{i,j+1} = q'_{i,j} + (Y_1 + Y_2)/2$$

$$\widehat{q'}_{i,j-1} = q'_{i,j} - (Y_1 - Y_2)/2$$

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"

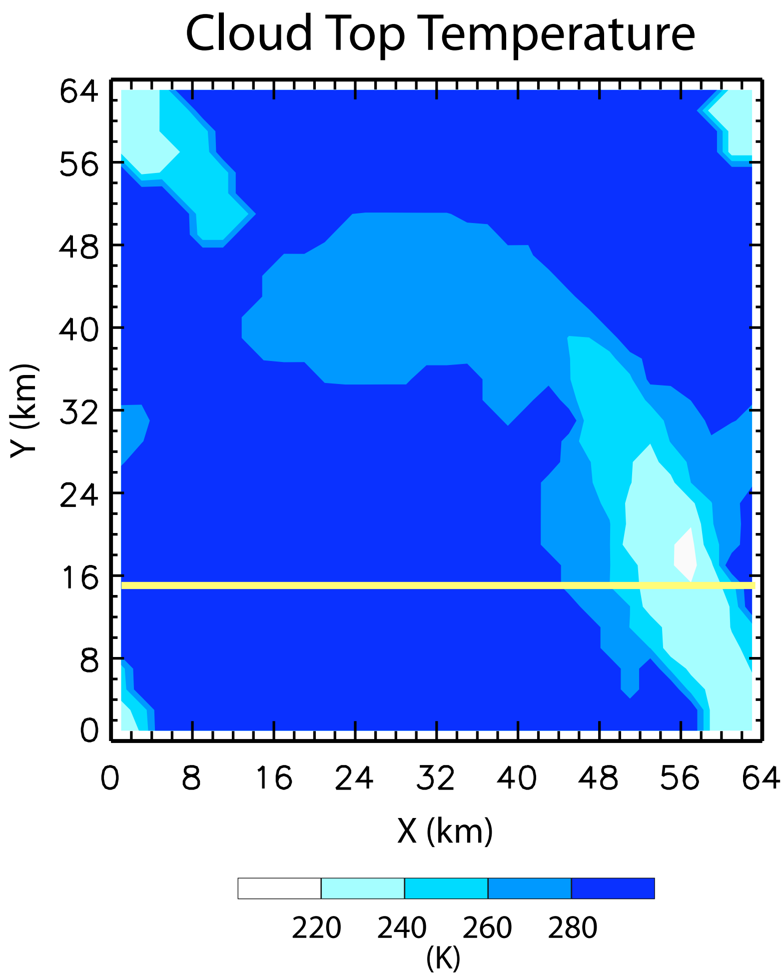
Joon-Hee Jung and Akio Arakawa

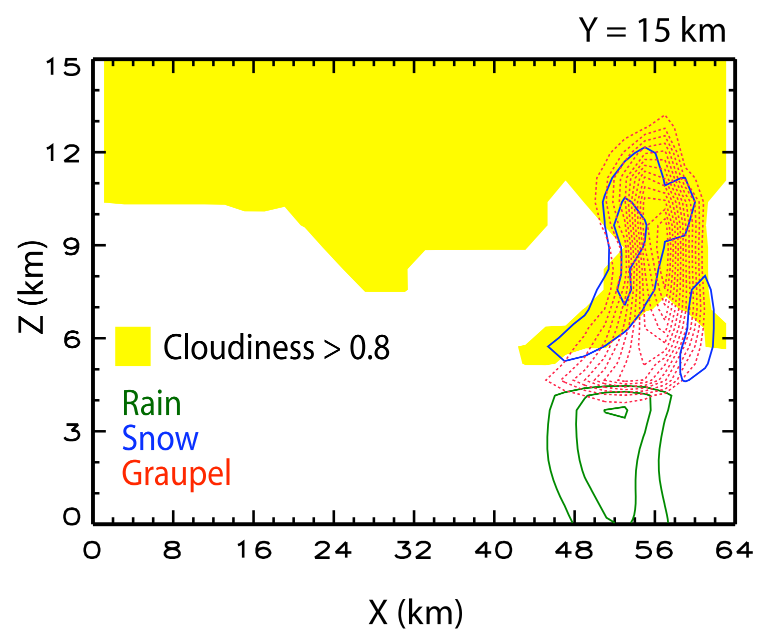
- **Governing equation:** 3D anelastic vorticity equation
- **Advection of vorticity and scalar variables:**
  partially 3rd-order scheme, enstrophy bounded for 2D plane flow
- **Time differencing:** second-order Adams-bashforth
- **Column physics:** UCLA/CSU/University of Utah CSRM
  - bulk ice-phase 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

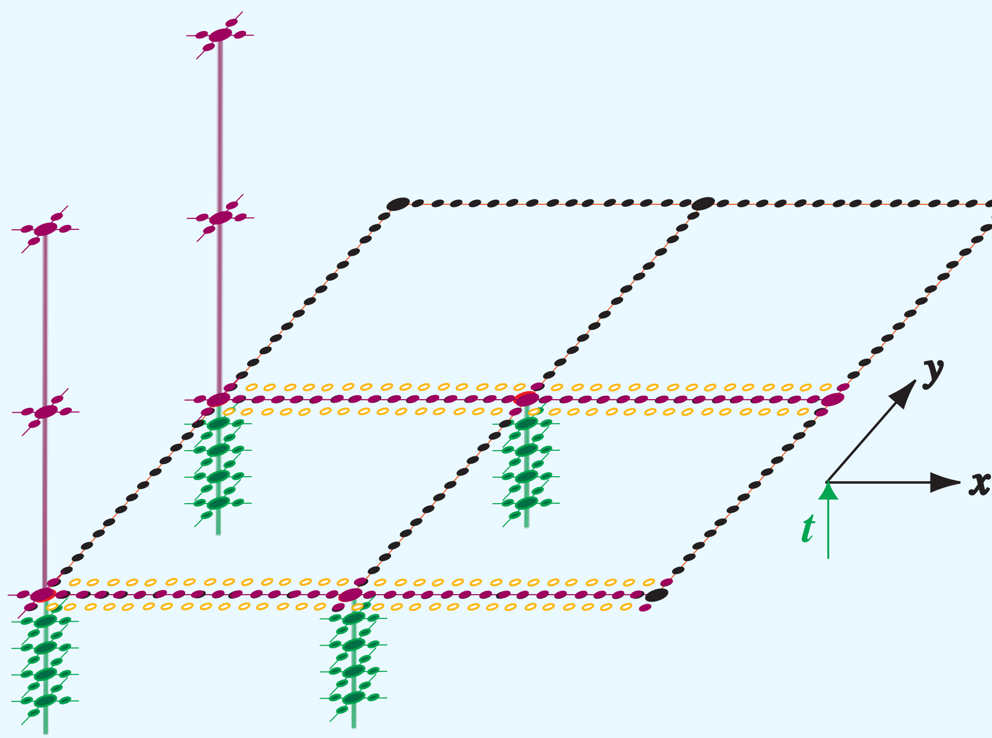
- **Domain size:** 64 km x 64 km x 18 km (height)
- **Horizontal resolution:** 2 km
- **Vertical resolution:** 34 layers with a stretched vertical grid
- **Lower-boundary:** ocean surface with a fixed temperature
- **Initial condition:** the GATE Phase-III mean sounding
- **Condition for solar radiation:** 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)

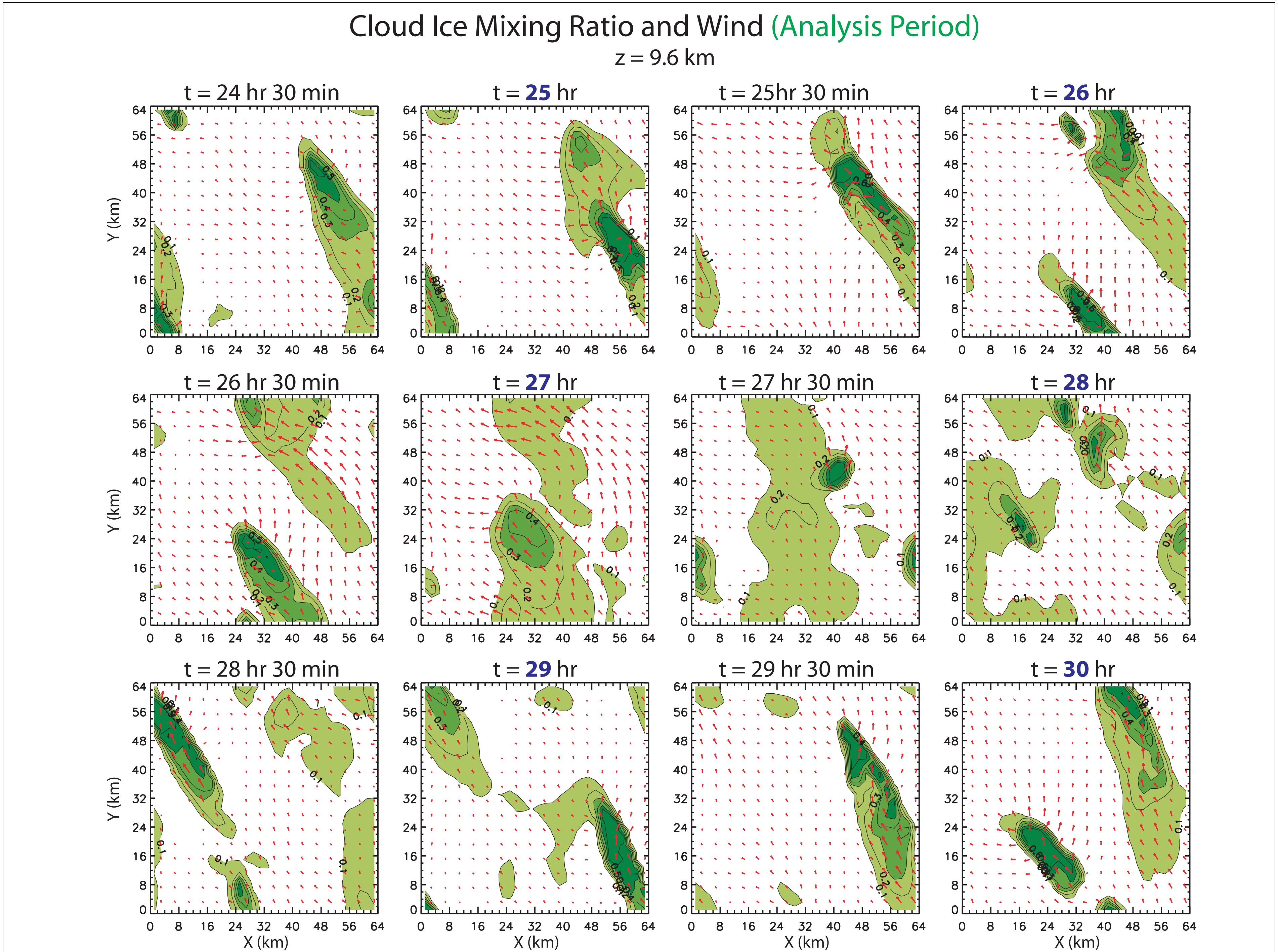




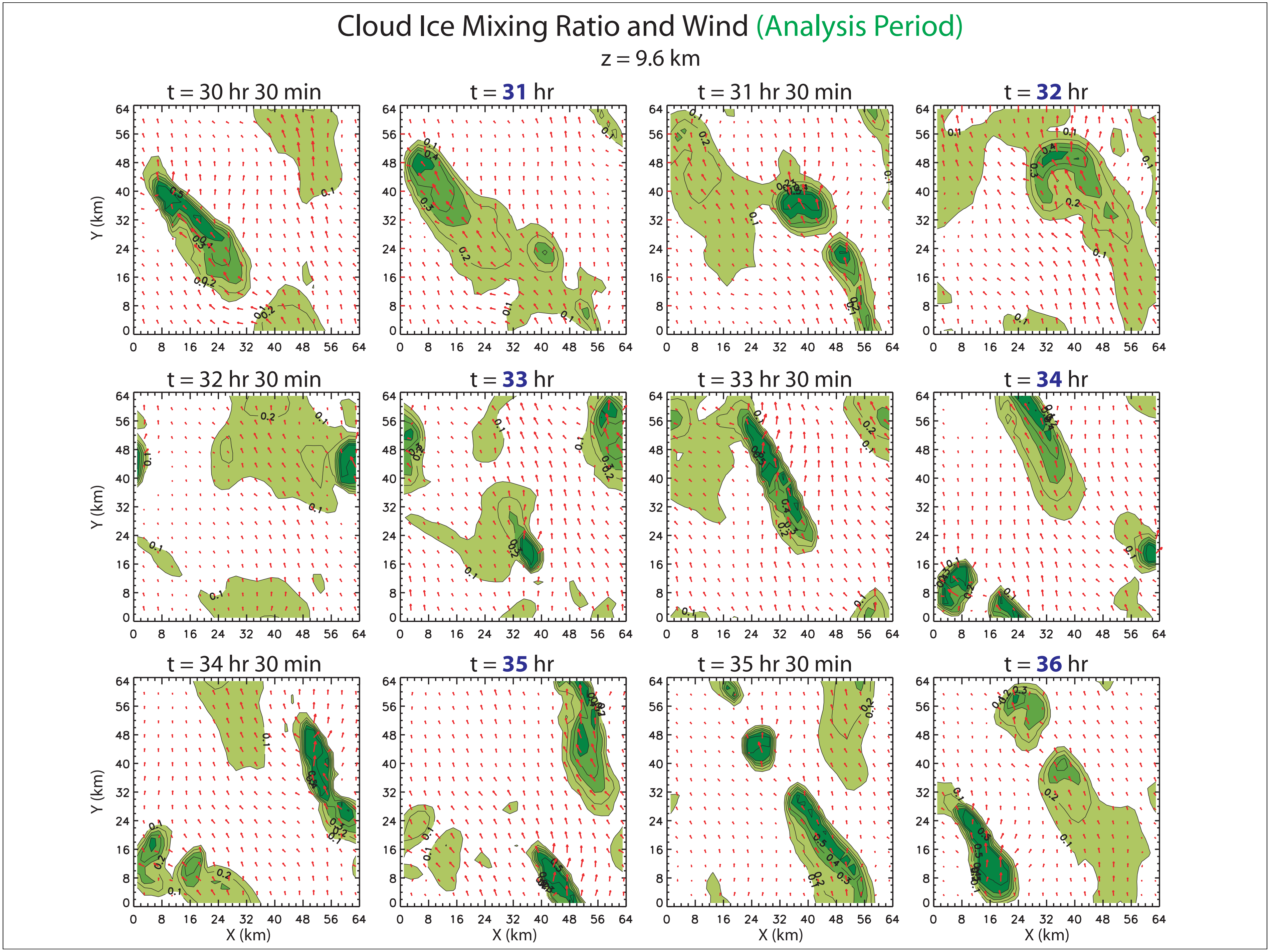
Regression Analysis of Past History at the Intersection Points and Application of the Result to All Grid Points

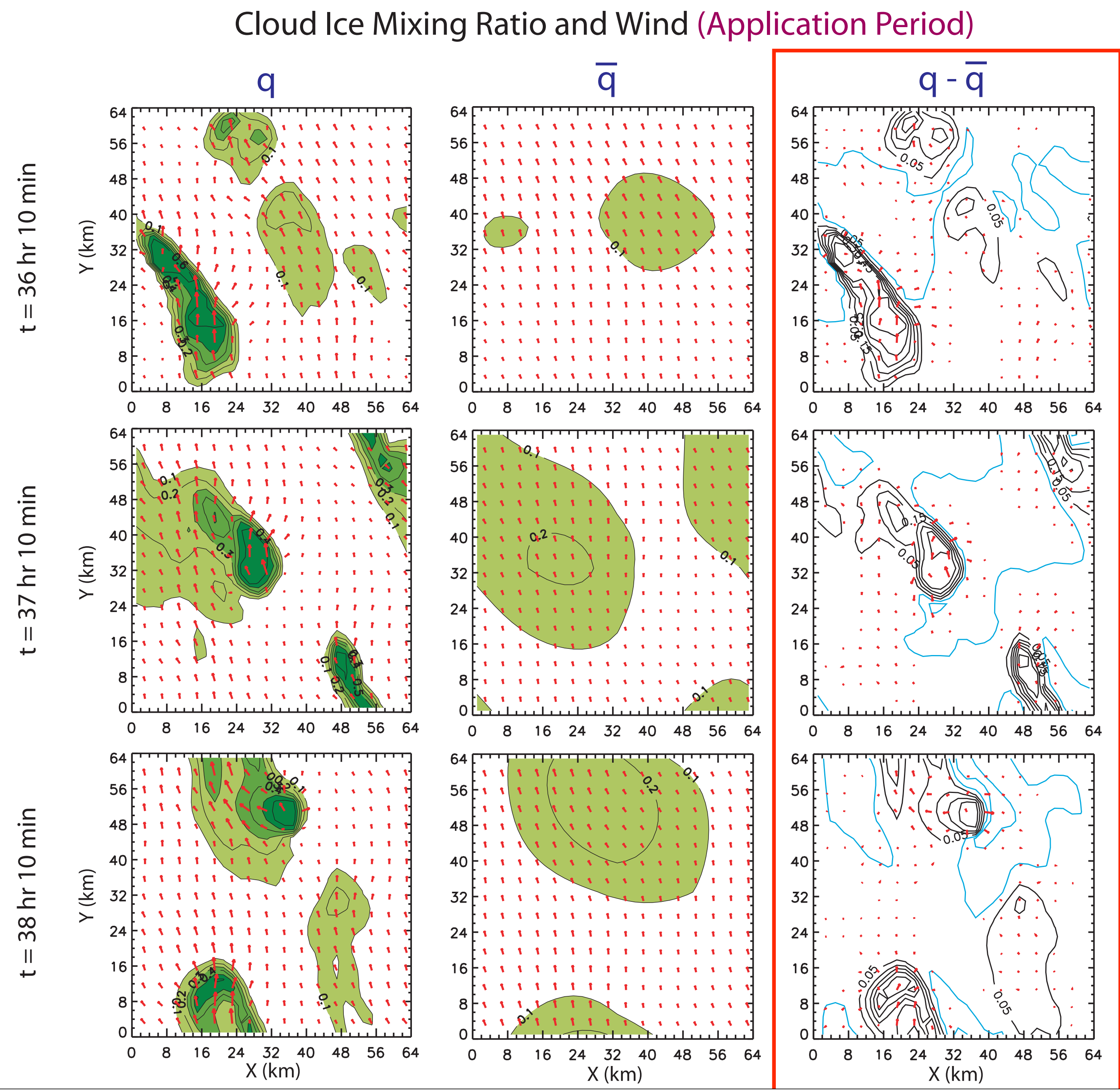


- analysis period : 24h ~ 36h (data frequency - every 10 minute)
- application period: 36h ~ 39h (data frequency - every 1 hour)



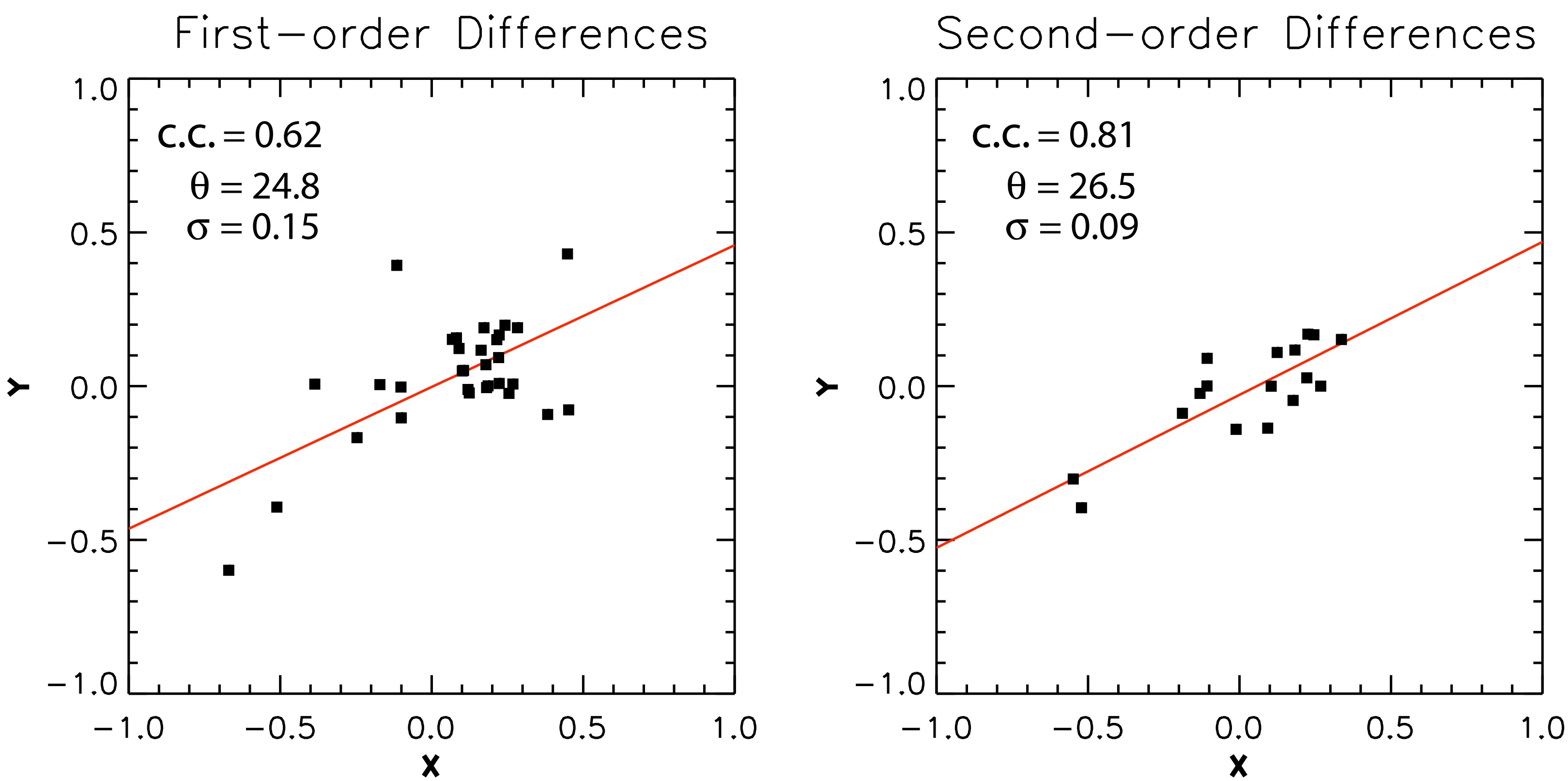
Cloud Ice Mixing Ratio and Wind (Analysis Period)
z = 9.6 km
t = 24 hr 30 min
t = 25 hr
t = 25hr 30 min
t = 26 hr
t = 26 hr 30 min
t = 27 hr
t = 27 hr 30 min
t = 28 hr
t = 28 hr 30 min
t = 29 hr
t = 29 hr 30 min
t = 30 hr
Y (km)
X (km)


Cloud Ice Mixing Ratio and Wind (Analysis Period)
z = 9.6 km
t = 30 hr 30 min
t = 31 hr
t = 31 hr 30 min
t = 32 hr
t = 32 hr 30 min
t = 33 hr
t = 33 hr 30 min
t = 34 hr
t = 34 hr 30 min
t = 35 hr
t = 35 hr 30 min
t = 36 hr
Y (km)
X (km)



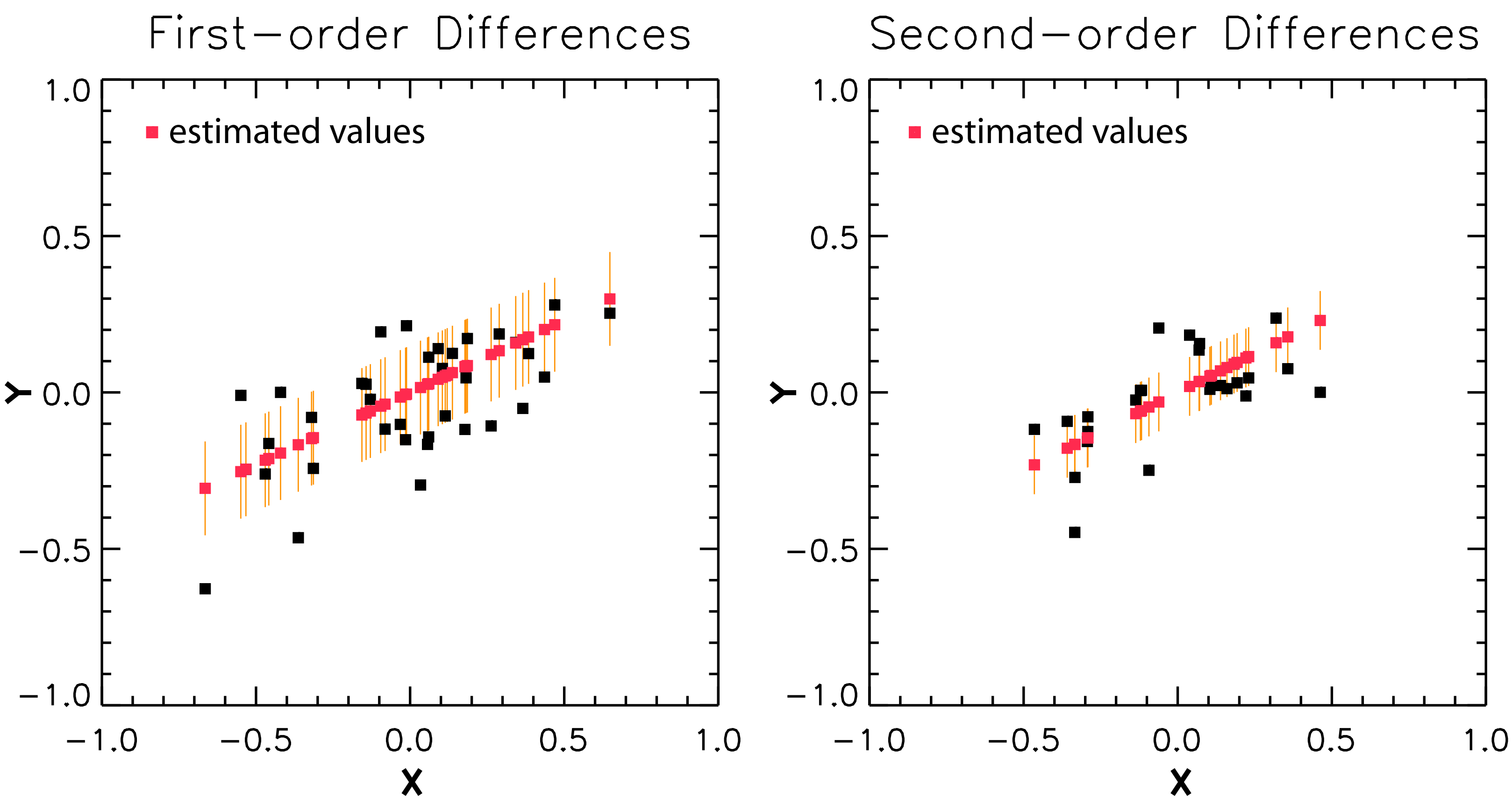
Cloud Ice Mixing Ratio and Wind (Application Period)
q
$\overline{q}$
$q - \overline{q}$
t = 36 hr 10 min
t = 37 hr 10 min
t = 38 hr 10 min
Y (km)
X (km)
0
8
16
24
32
40
48
56
64

Analysis Period: 24h ~ 36h



Realized Y vs. Estimated Y

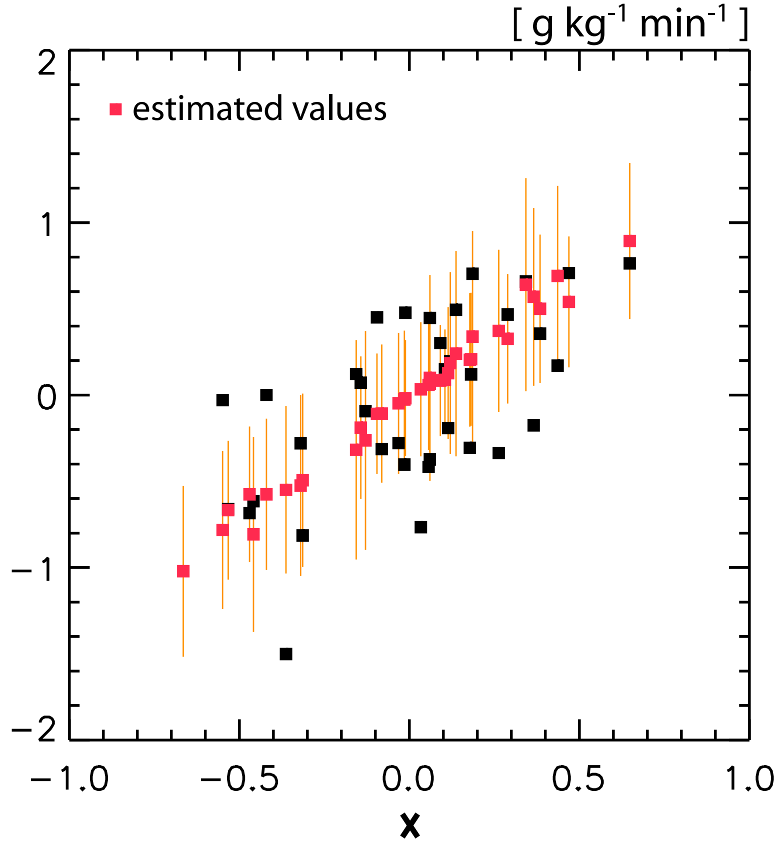
Application Period: 36h ~ 39h



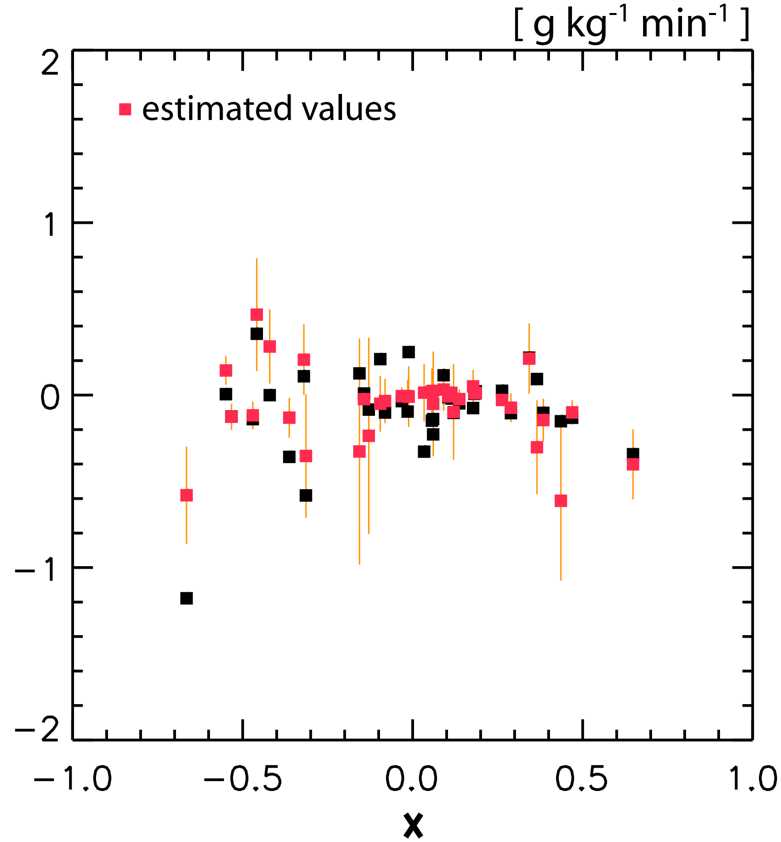
Realized Values vs. Estimated Values

Application Period: 36h ~ 39h

$$\bar{v}\,\frac{dq'}{dy}$$



$$v'\,\frac{dq'}{dy}$$

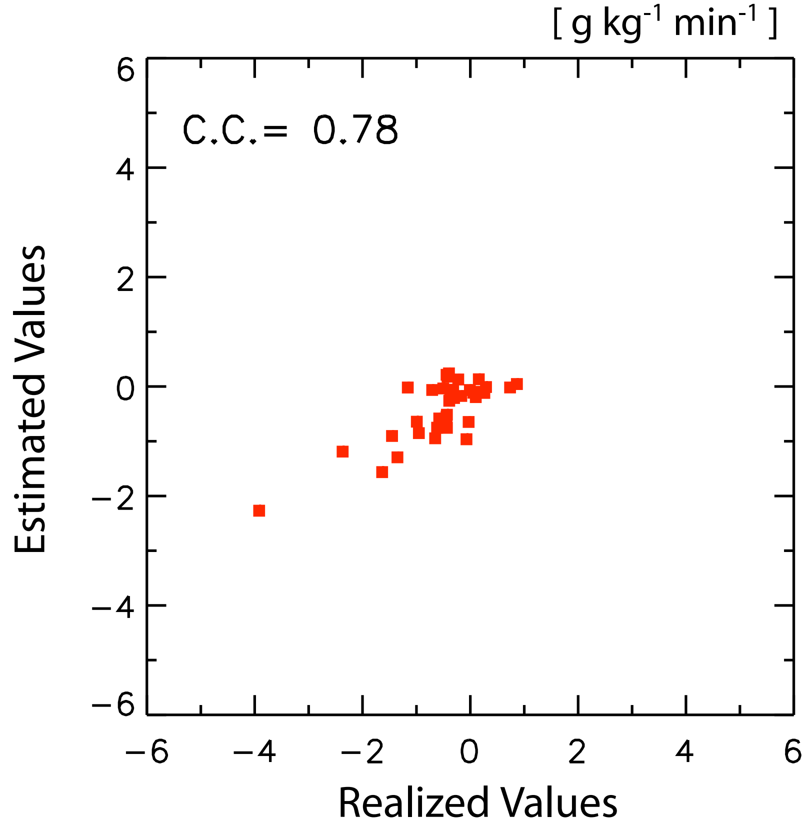


Realized Values vs. Estimated Values

Total Advection

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

Application Period: 36h ~ 39h

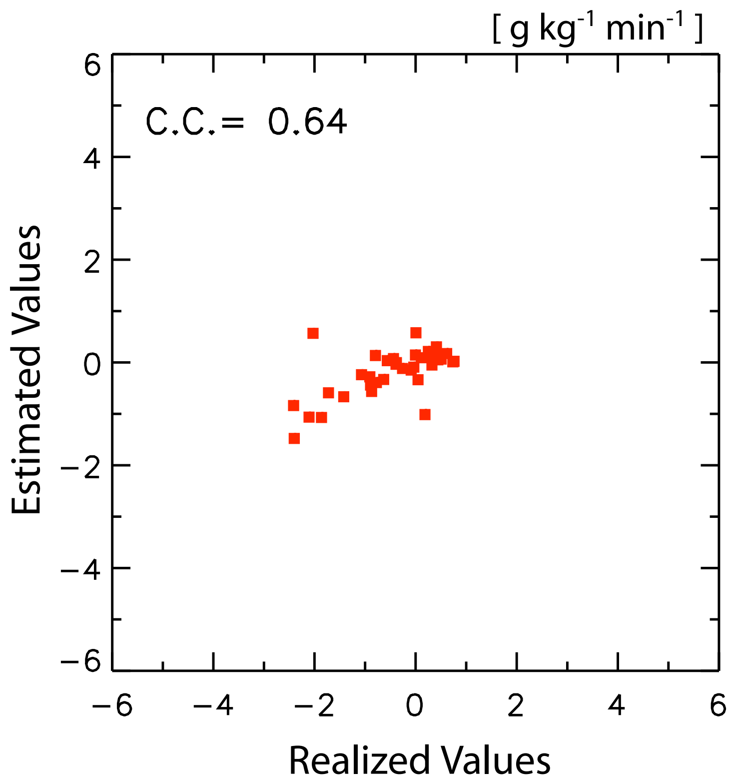


Realized Values vs. Estimated Values

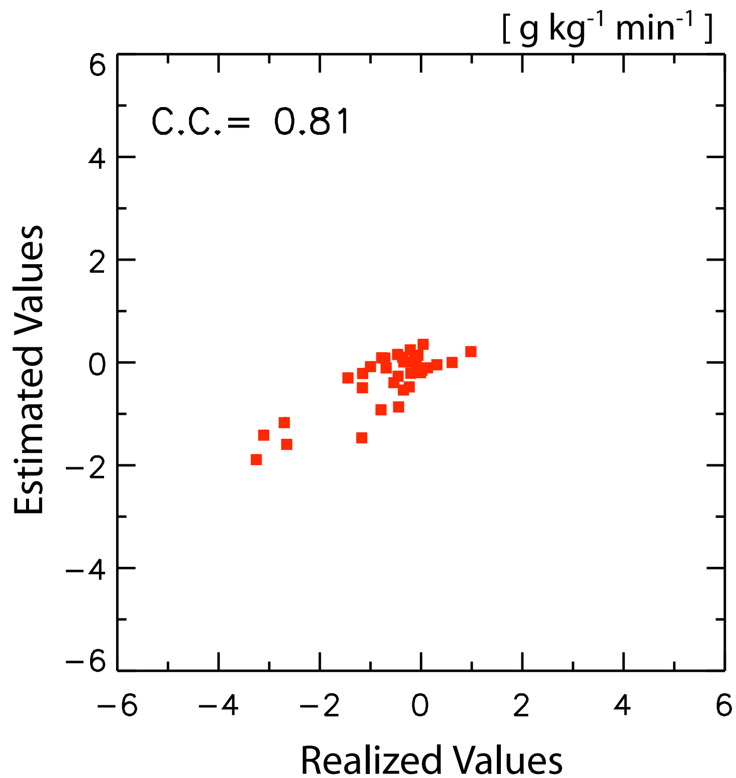
Total Advection

$$\left(\mathbf{v}\cdot\nabla\overline{q} + \overline{u}\,\frac{dq'}{dx} + \overline{v}\,\frac{dq'}{dy} + u'\frac{dq'}{dx} + v'\frac{dq'}{dy} \right)$$

Application Period: 39 h ~ 42h



Application Period: 42h ~ 45h

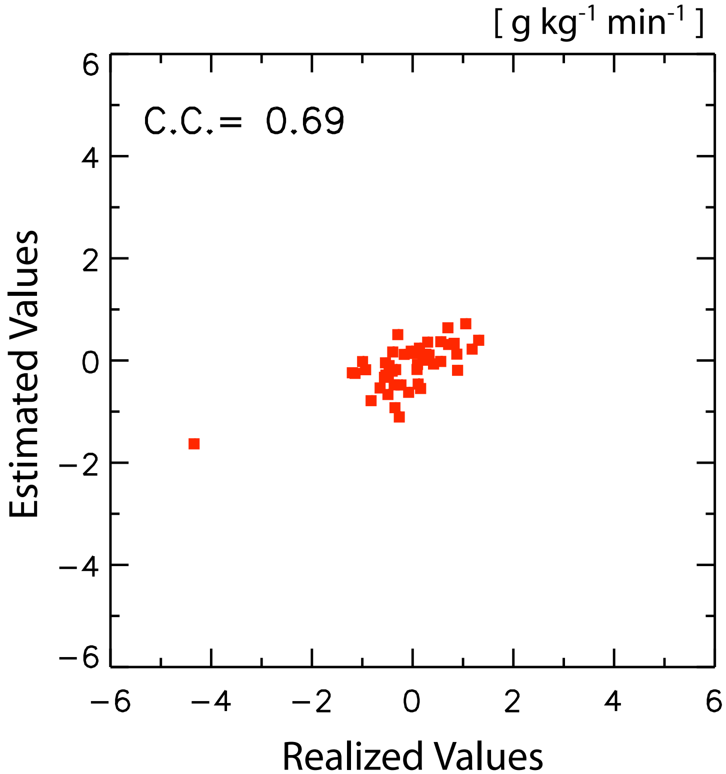


Realized Values vs. Estimated Values

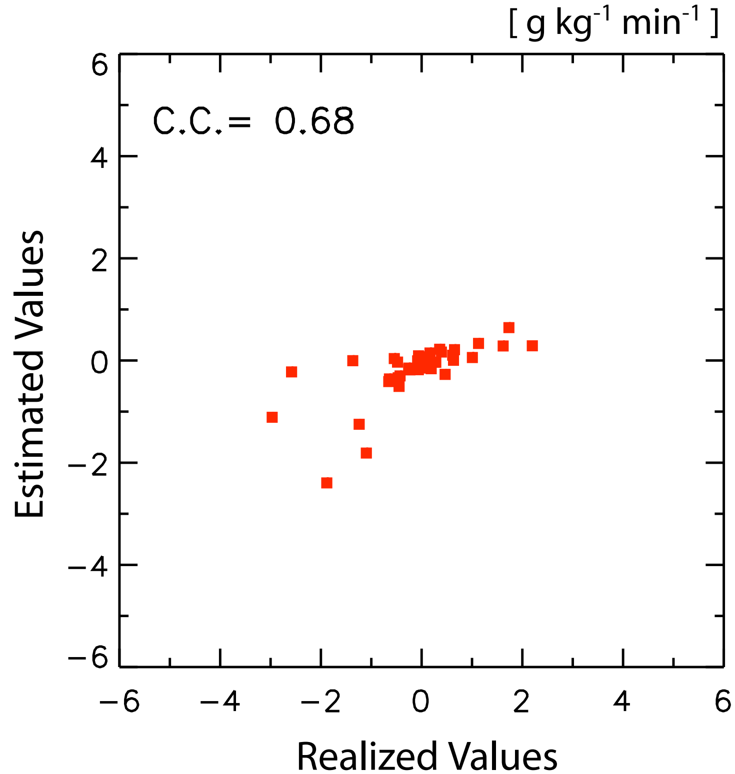
Total Advection

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

Application Period: 45h ~ 48h



Application Period: 48h ~ 51h



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.