Data Assimilation Experiments of Radio Occultation Data using a Mesoscale LETKF System

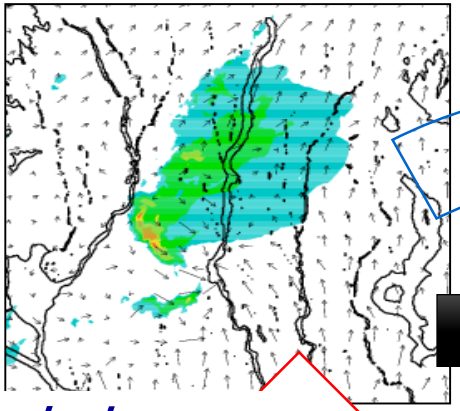
-How to assimilate RO data with LETKF-

Hiromu SEKO*, Masaru KUNII* and Toshitaka TSUDA**

Meteorological Research Institute, Japan Meteorological Agency

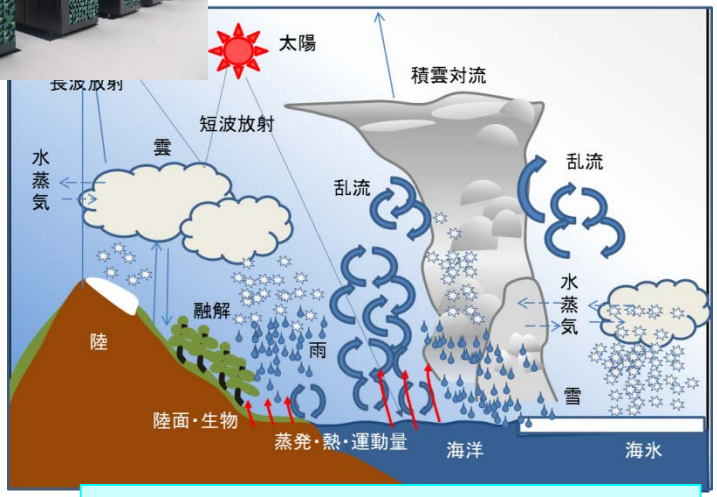
**** Research Institute for Sustainable Humanosphere, Kyoto University***

To improve numerical weather forecast



Super computer

3. Numerical model



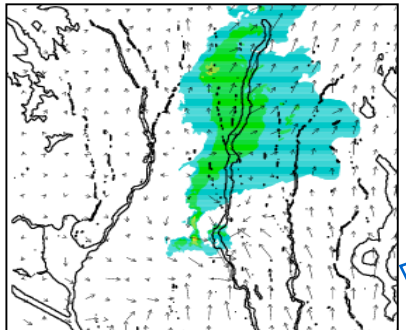
Development of numerical model

Observation

Obs. data

Data assimilation

Analysis or initial condition



Forecast or First guess

Model fields are modified to be closer to the actual fields by data assimilation.

Data Assimilation

Broadly speaking…

- **Data assimilation** =

Getting analysis field from observation and forecast (first guess)

Analysis = Forecast (First guess) + Coeffi cients × [Observation − Forecast]

- **Coefficients are estimated by the ratio of forecast error and observation error**

$$\text{Coefficients} = \frac{\text{Forecast error}}{\text{Forecast error} + \text{Observation error}}$$

$$\mathbf{K} = \mathbf{B}\mathbf{H}^{\mathrm{T}}\left(\mathbf{H}\mathbf{B}\mathbf{H}^{\mathrm{T}} + \mathbf{R}\right)^{-1}$$

H:observation operator,
B:forecast error, R:observation error

EnKF and Variational methods

Variational methods

$$J = \frac{1}{2}\left(\mathbf{x}-\mathbf{x}_f\right)^{\mathrm{T}}\mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}_f\right)+\frac{1}{2}\left(\mathbf{y}-H\left(\mathbf{x}\right)\right)^{\mathrm{T}}\mathbf{R}^{-1}\left(\mathbf{y}-H\left(\mathbf{x}\right)\right)\left(+J_c\right)$$

Analyzed field (x) is obtained by searching the field of which *J* takes minimum value.

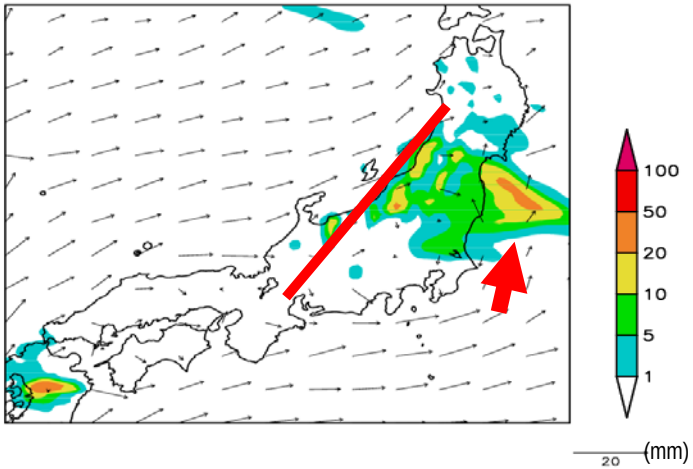
First term : distance from forecast x_f.

Second term: distance from observation y. (*H*: observation operator)

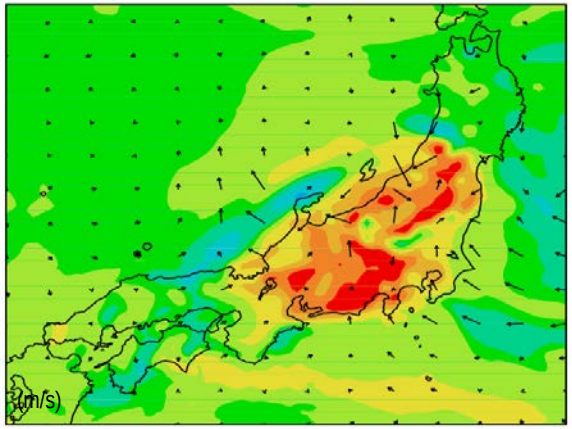
RO improves rainfall forecast.

Seko, H. et al: Improvement of rainfall forecast by assimilations of ground-based GPS data and radio Occultation data, 2010., SOLA, 6, 81-84.

Rainfall region



Increment of water vapor



EnKF and Variational methods

EnKF

Coefficients K $= \mathbf{B}\mathbf{H}^{\mathrm{T}}\left(\mathbf{H}\mathbf{B}\mathbf{H}^{\mathrm{T}}+\mathbf{R}\right)^{-1} \approx \mathbf{X}_f\left(\mathbf{H}\mathbf{X}_f\right)^{\mathrm{T}}\left[\left(\mathbf{H}\mathbf{X}_f\right)\left(\mathbf{H}\mathbf{X}_f\right)^{\mathrm{T}}+(m-1)\mathbf{R}\right]^{-1}$

Forecast error (B) was produced from ensemble forecasts.

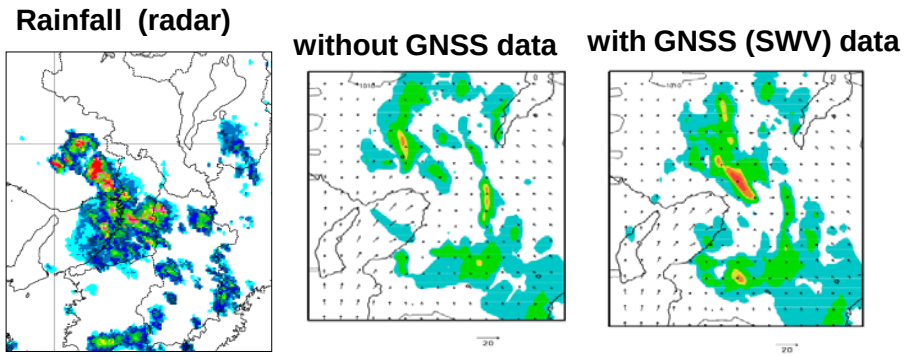
$$\mathbf{B} \approx \mathbf{X}_f \mathbf{X}_f{}^{\mathrm{T}} /(m-1)$$

Merits of EnKF

EnKF provides multi scenarios, which brings several merits;
Probability forecast, decrease the miss rate of forecast, and so on.
Assimilation method of RO data should be developed.

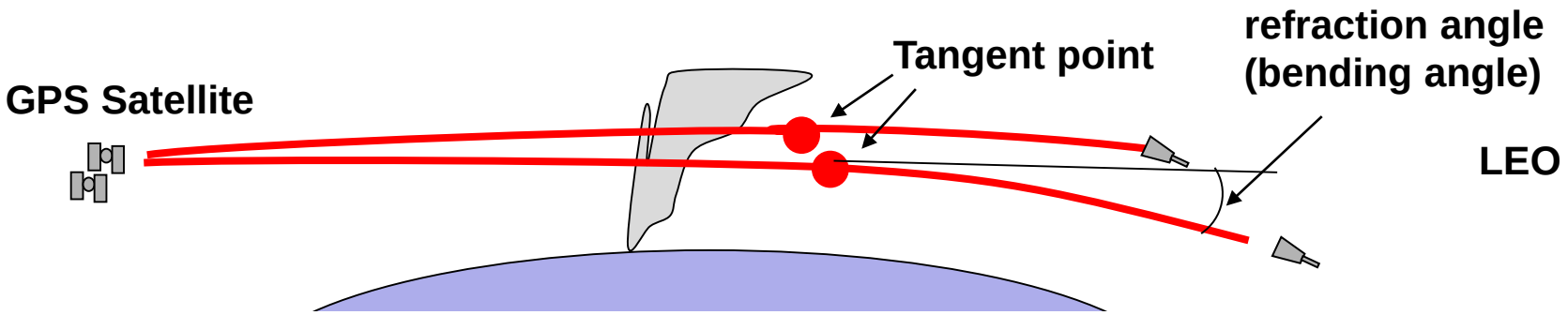
Ground-base GNSS data was assimilated by LETKF system.

Seko, H. et al., Development of a Two-way Nested LETKF System for Cloud Resolving Model, Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications II, pp. 489-507



Radio Occultation data

- While LEO satellites rise from the horizon or descends in the horizon, radio waves between the GPS satellites and LEO satellite scan the atmosphere (and the ionosphere) successively from the height of the receiver to the ground.
- Vertical profile of the refractive index is obtained from temporal changes of refraction angles (RO data).



- Humid airflow is supplied to rainfall systems, when heavy rainfall occurs.
- Observation over the sea is needed to improve numerical forecasts.
- Occultation data is expected to be useful.

Three procedures in data assimilation of RO data

(1) Conversion from tangent point data to path data

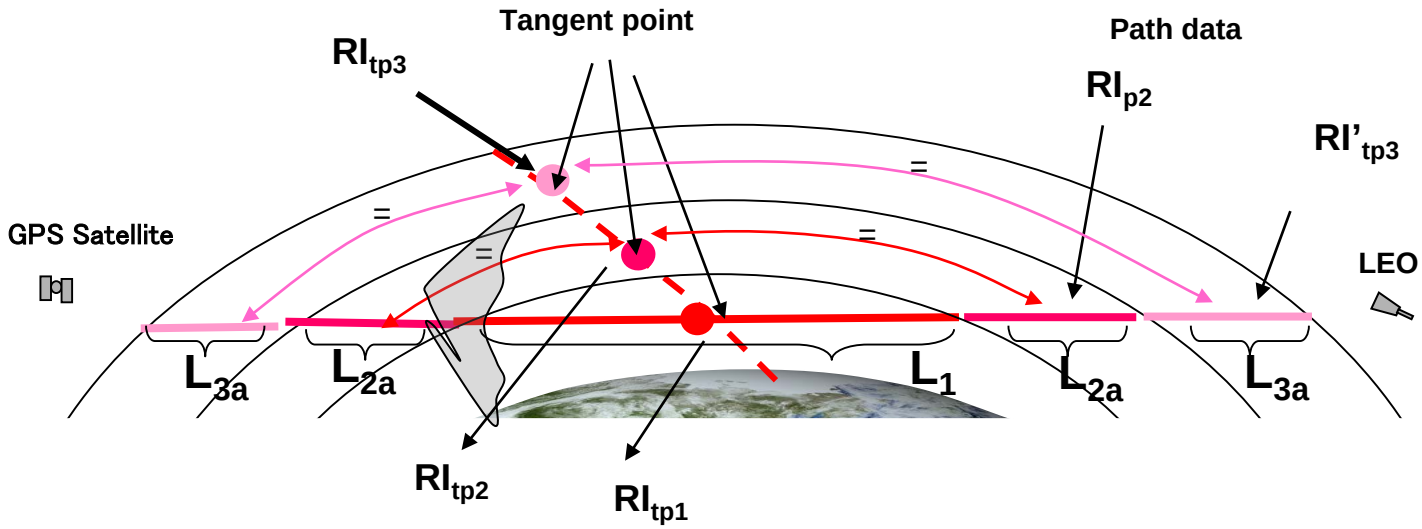
Assumption of spherical uniform distribution of the atmosphere is not always valid.

(2) Conversion from path data to grid point data

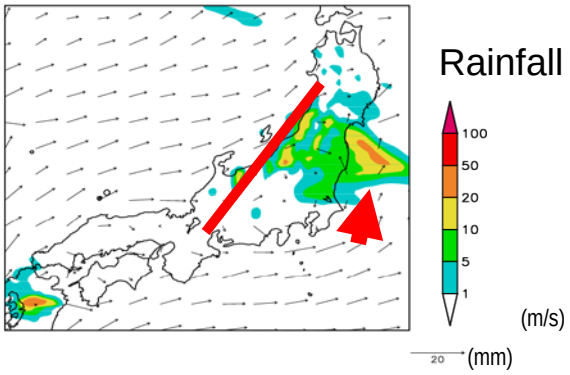
LETKF system can not assimilate non-local data, such as path data

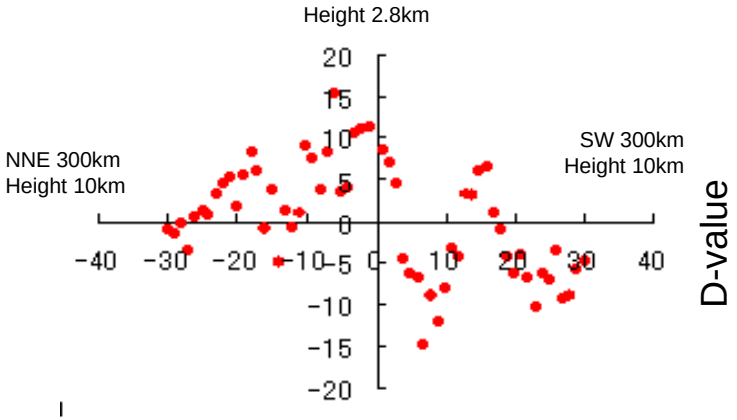
(3) Assimilation using LETKF system

Conversion from tangent point data to path data



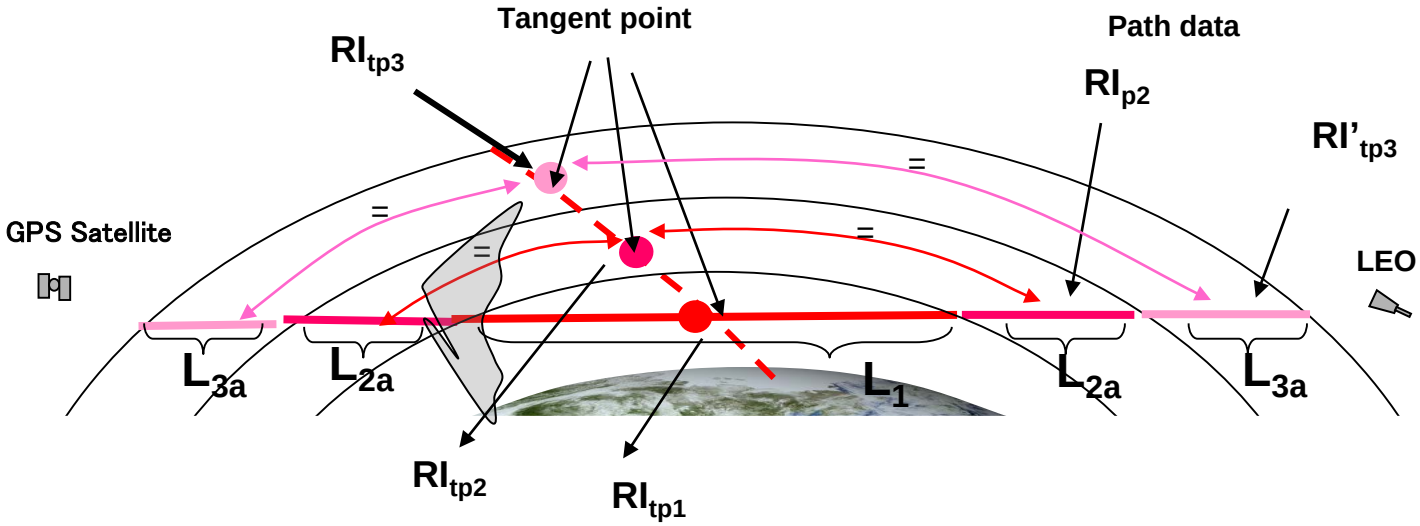
Assumption of spherical uniform distribution is used in producing tangent point data





Assumption of spherical uniform distribution is notalways valid.

Conversion from tangent point data to path data



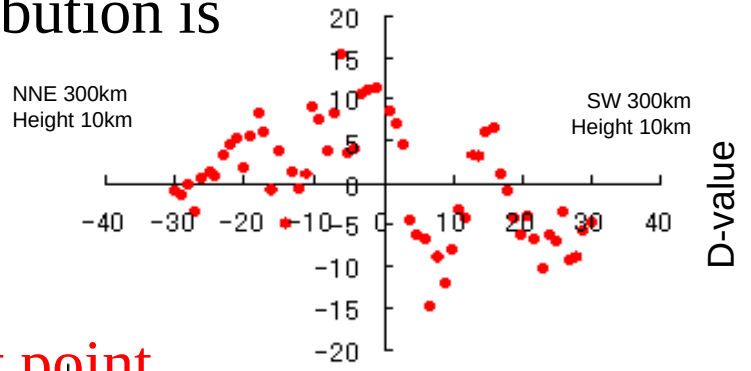
$$RI_{tp1} = \frac{RI_{p1}(L_{3a} + L_{2a} + L_1 + L_{2b} + L_{3b}) - (L_{3a} + L_{3b})RI_{tp3} - (L_{2a} + L_{2b})RI_{tp2}}{L_1}$$

Assumption of spherical uniform distribution is used in producing tangent point data

$$RI_{p1} = \frac{L_{3a}RI_{tp3} + L_{2a}RI_{tp2} + L_1RI_{tp1} + L_{2b}RI_{tp2} + L_{3b}RI_{tp3}}{L_{3a} + L_{2a} + L_1 + L_{2b} + L_{3b}}$$

Path data was reproduced from tangent point data by path-length weighting average.

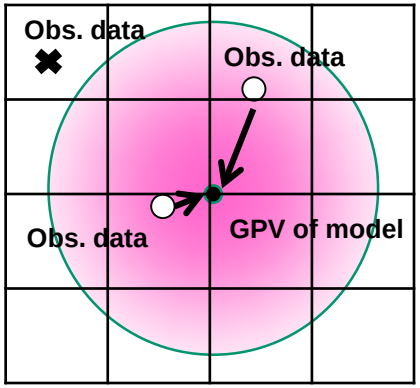
Height 2.8km



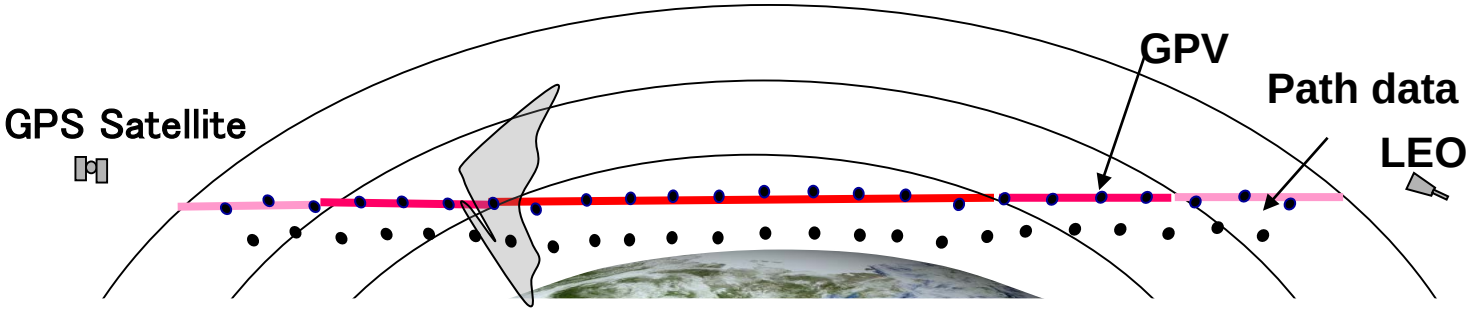
Assumption of spherical uniform distribution is not always satisfied.

Conversion from path data to grid point data

- LETKF system assimilates observation data at each grid point of the numerical model.
- LETKF can not assimilate non-local data, such as path data.



Value of path data is distributed to GPVs along the path using the information obtained by ensemble forecasts.

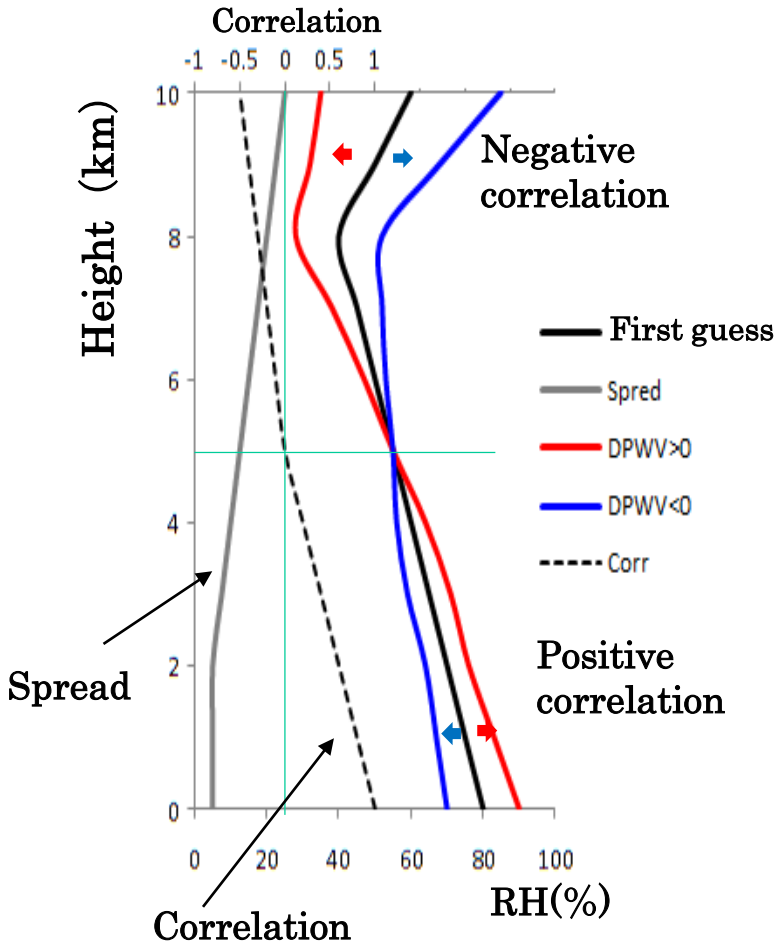


Conversion from path data to grid point data

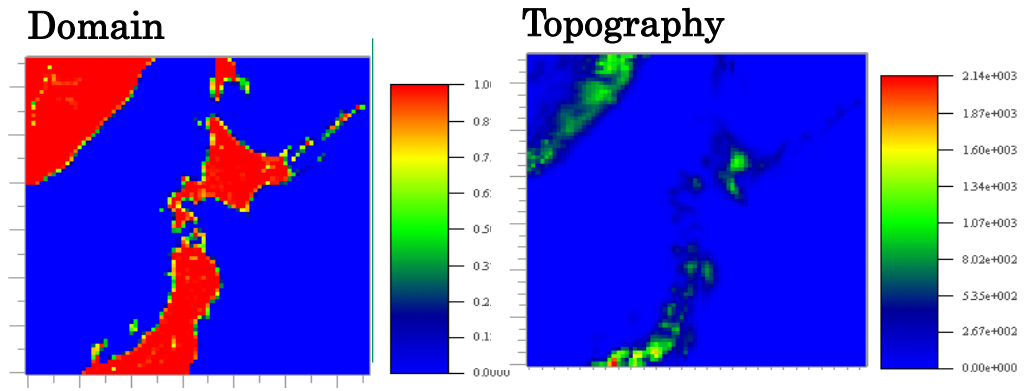
When the correlation of first guess GPV and path data is positive and the observation is larger than first guess, increment from first guess should be positive.

Increment is larger, when the spread of GPV, and the correlation between GPV and path data are larger.

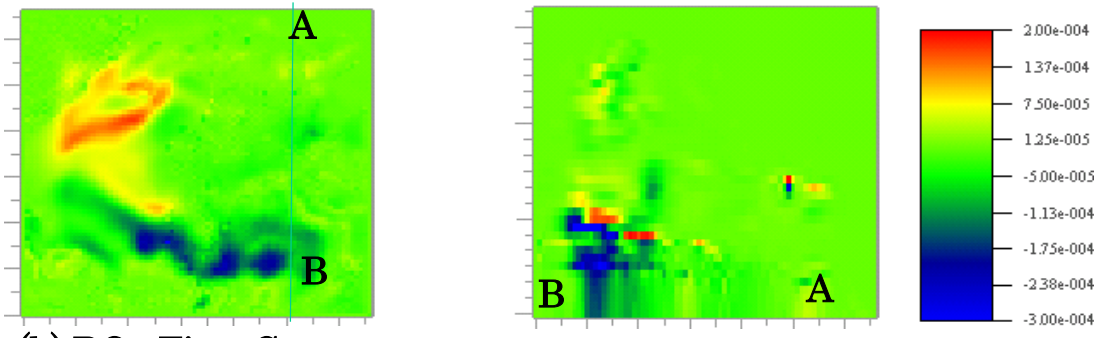
Path data produced from the estimated GPVs should be equal to the observed path data.



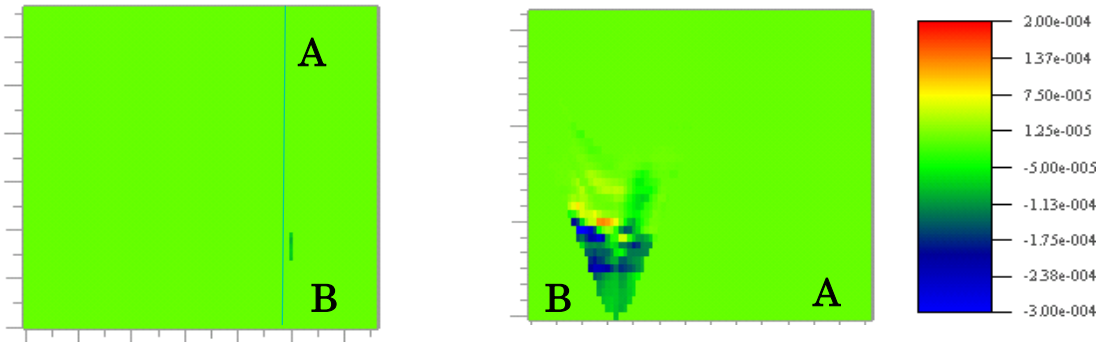
Test of conversion method



(a)True—First Guess



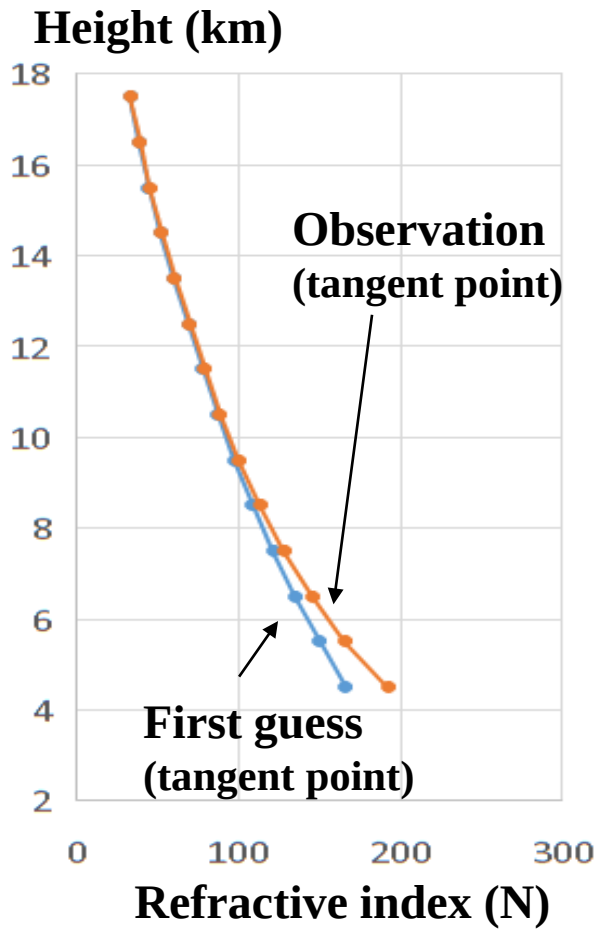
(b) RO—First Guess

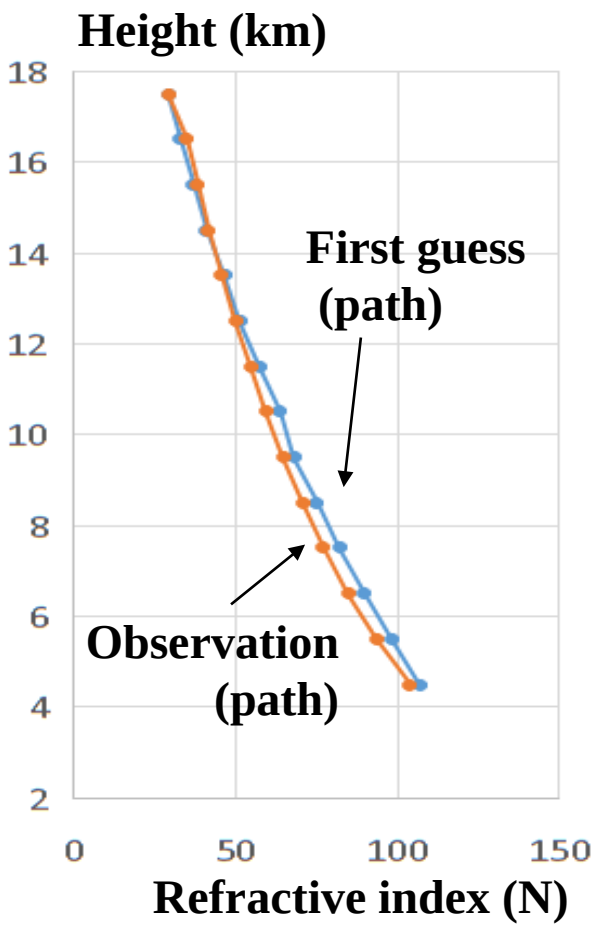


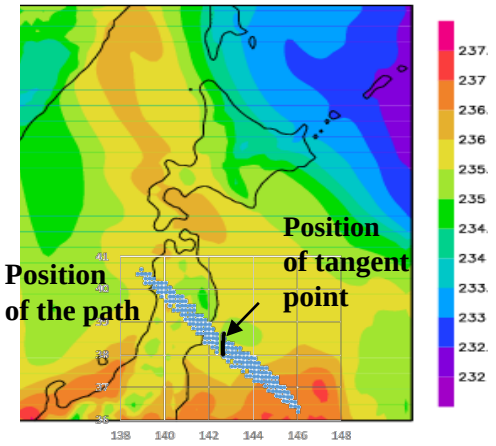
- RO data was produced from True data.
- GPV were estimated from the RO data and information of EnKF forecast by following this method.
- Estimated GPV field were similar to True distributions.
- This is a tomography method using statistical information of ensemble forecasts.

(Left)
Difference of RO and First Guess at z=200m.
(Right)
Vertical cross sections along AB

Results (1):
Conversion from tangent point data to path data





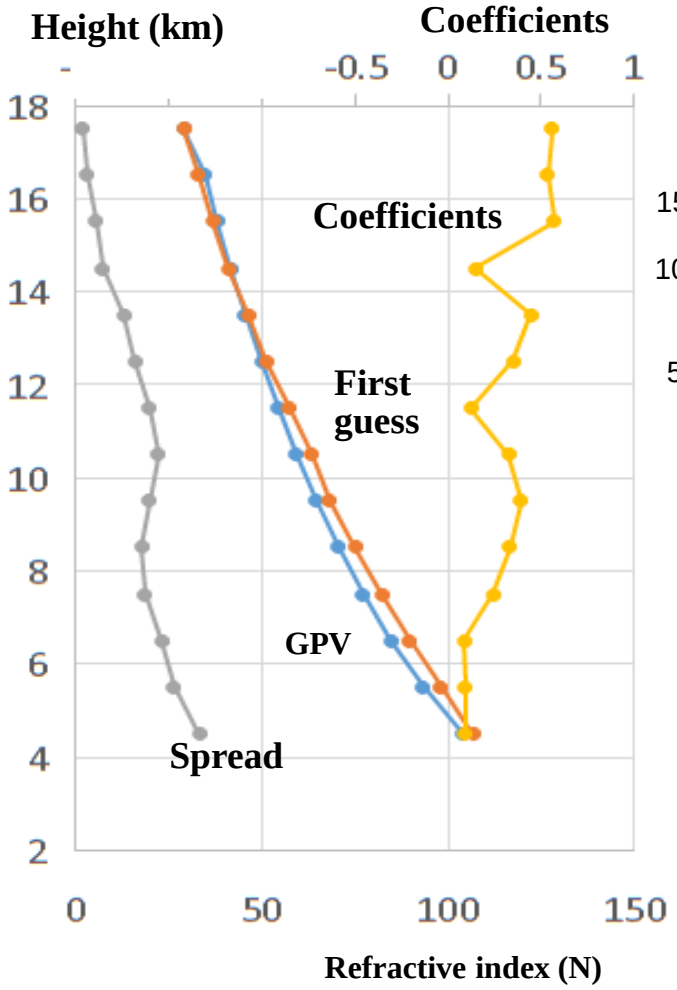


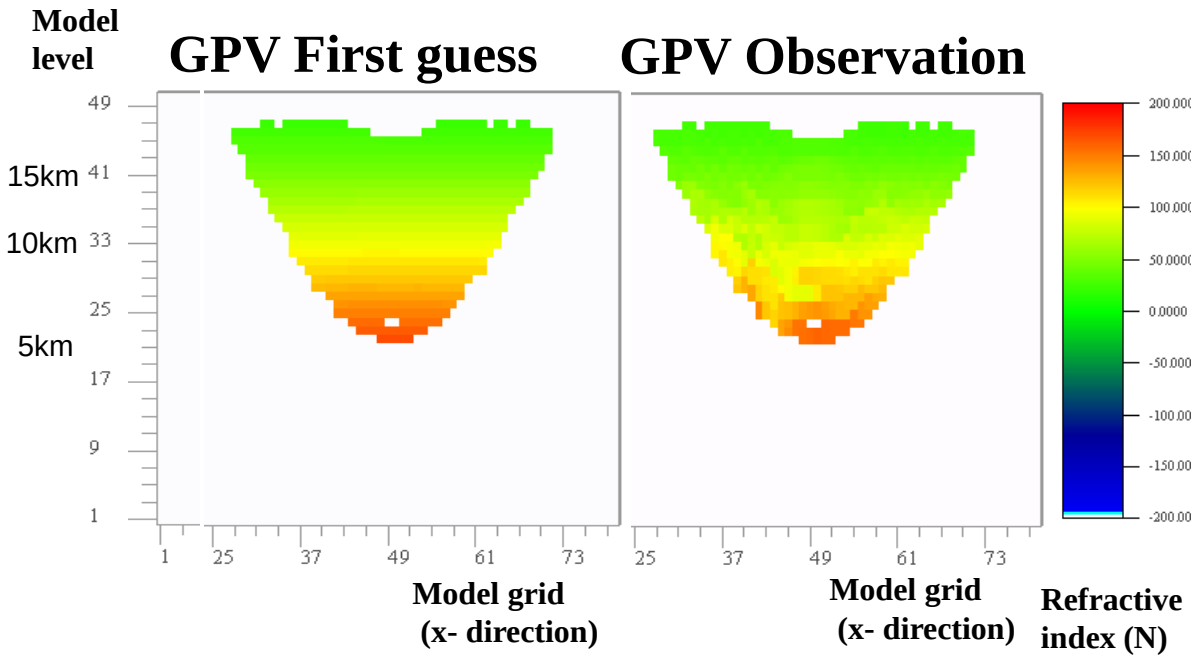
Temperature (first guess)
at z=10km

Temperature was not distributed uniformly.

FORMOSAT/COSMIC data observed on 29 July 2011 was used. First guess of path data was larger than the observed one, while the first guess of tangent point data was smaller.

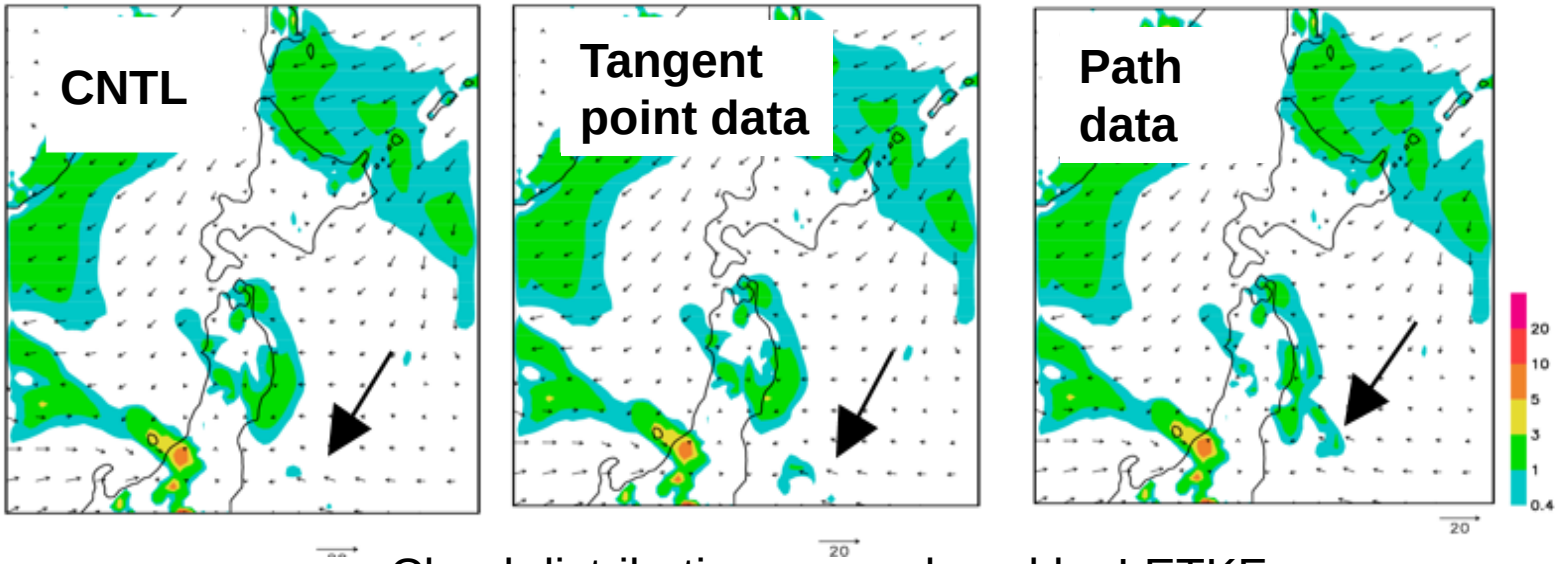
Results (2): Conversion from Path data to GPV



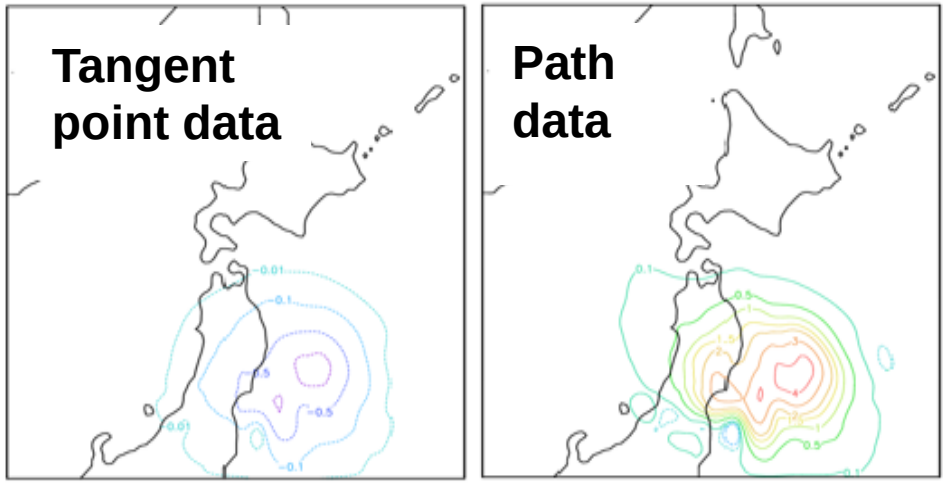


- GPV distribution shows the intense downdraft region occurred from the west.

Results (3): Assimilation results



Cloud distributions reproduced by LETKF.



Different distributions of increment of temperature from CNTL at z=5km

When tangent point data or path data was assimilated, cloud region east of northern Japan was changed

When path data is assimilated, wider region along the path was modified.

Summary

- **Assimilation method of RO path data for LETKF system was developed. In this method, the GPV around the path were produced from observed path data and information of ensemble forecast.**
- **When path data was assimilated, increment region was expanded along the path.**
- **RO data is assimilated, cloud distribution was changed. (not so large because only one path data was added.)**
- **The comparisons of observed and first guess profiles between tangent point data and path data, and the wider modified regions along the path indicate that path data should be used in the mesoscale assimilation.**
- **The number of assimilation experiments of RO should be increased to obtain more conclusive results.**

Thank you for your time

The authors express their gratitude to COSMIC Data Analysis and Archival Center of University Corporation for Atmospheric Research that provided RO data of FORMOSAT/COSMIC, Numerical Prediction Division of JMA that provided the boundary data of LETKF system and conventional observation data. Authors are grateful to Dr. Miyoshi of RIKEN, who provide LETKF system.