Data Assimilation Experiments of Radio Occultation Data and Ground-based GPS Data Using JMA Meso-4dvar System

-Impacts on Heavy Rainfall in Japan-

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1. Motivations

- Heavy rainfalls often occur when humid airflows are supplied from the sea.
- 'Water vapor distribution over the sea' and 'Vertical profile of water vapor' are important for accurate forecasts of heavy rainfalls.
- GPS data is expected to be useful data, because it provides this information.
- Impacts of GPS radio occultation data and ground-based GPS data on forecasts of heavy rainfalls are investigated in this study.

2. Torrential Rainfall on 16 July 2004

- Almost every year, heavy rainfalls are caused by Baiu front (Figs. 1a and 1b) .
- On 16 July 2004, Baiu front crossed the northern Japan caused the heavy rainfall.
- At Ohyu, rainfall amount of 133 mm/day was observed (Fig. 1c).

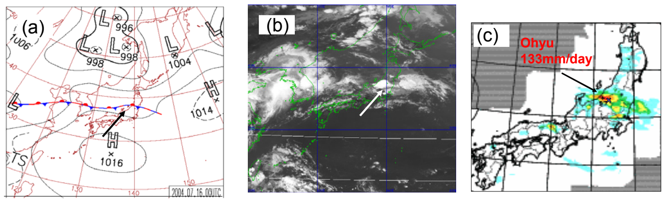


Fig. 1: (a) Weather chart at 9 JST 16 July 2004 and (b) cloud distribution at 12 JST 16 July 2004. (c) 3-hour rainfall distribution at 18 JST 16 July observed by JMA conventional radars.

3.GPS Radio Occultation Data (RO data)

- CHAMP(Challenging Mini-Satellite Payload), Level 3 data (profiles of refractive index(RI)) was used as assimilation data. RI is a function of temperature and water vapor. RI is expected to improve rainfall forecasts.

a. Tangent Point Data → Path Data

- RI at tangent points (point closest to the earth on the path) was provided from GFZ. In the estimation of tangent point data, spherical uniform distribution was assumed.
- Using the first guess data of this heavy rainfall case, we investigated the assumption of spherical uniform distribution of RI (Figs. 2 and 3).
- RO occurred near the rainfall band at 12 JST, just before the occurrence of the heavy rainfall.
- Assumption of spherical uniform distribution was not accurate in this case.
- Path data that does not need to satisfy the assumption is more correct.
- Thus, path data was reproduced from tangent point data by path-length weighting average (Fig. 4).

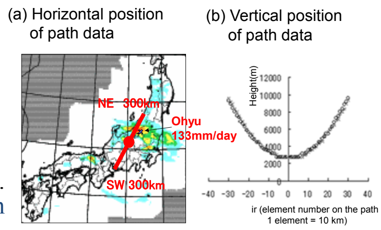


Fig.2: Positions of RO data observed at 12 JST 16 July.

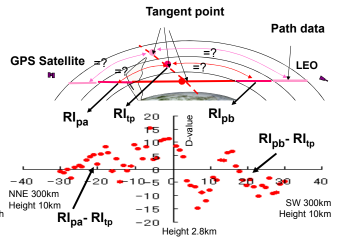
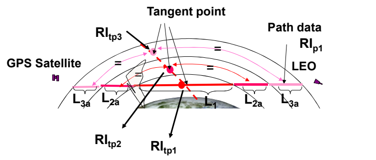


Fig. 3: Difference of RI from the spherical uniform distribution.

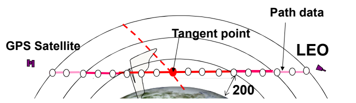


$$RI_{p1}=\frac{L_{3a}RI_{tp3}+L_{2a}RI_{tp2}+L_1RI_{tp1}+L_{2b}RI_{tp2}+L_{3b}RI_{tp3}}{L_{3a}+L_{2a}+L_1+L_{2b}+L_{3b}}$$

Fig. 4: Schematic illustration of the estimation of path data.

b. First guess of Path Data

- First guess was produced by averaging RI on the path (Fig. 5).



$$RI_{first\_guess\_of\_path}=\frac{\sum_{i=1}^{n(height<10km)}RI_{first\_guess\_of\_point}}{n}$$

-n is the total number of elements under the height of 10km.

Fig. 5: Schematic illustration of the estimation of first guess values of RO data.

c. Correlation of Observation Error

- Observation error has vertical correlation. In general, thinning of the data is performed. However, thinning might remove the informative data.
- Observation error covariance was produced and used in the assimilation.

d. Observed and First guess Profiles of the Path Data

- Observed RI was larger than that of first guess below 5 km (Fig. 6).
- The rainfalls is expected to be intensified by the assimilation of this RO data.

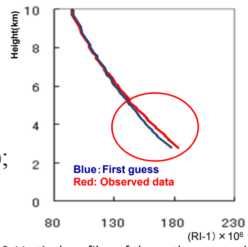


Fig. 6: Vertical profiles of the path-averaged RIs. Vertical axis is tangent point height.

4. Ground-based GPS data

- Zenith Total Delay was obtain from GEONET data of GSI. Procedures are as follows (Fig. 7);
  1. Slant total delays (STD) were converted to values of zenith direction.
  2. By applying the mapping function, the Zenith Total Delay (ZTD) was estimated.
  3. Residuals (the differences from the modeled delay) were also obtained.
  4. We retrieved STD from ZTD, mapping function and residuals.
  5. Precipitable Water Vapor(PWV) and Slant Water Vapor(SWV) are estimated using surface pressure and temperature from ZTD and STD (Fig. 8).
- First guess was produced by integrating water vapor along the path.
- PWV on the northern side of heavy rainfall was smaller than the observed ones (Fig. 9).

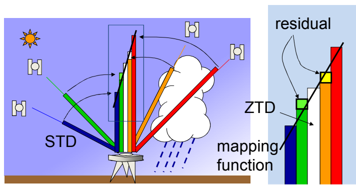


Fig. 7: Schematic illustration of the estimation of PWV.

$$ZTD = ZHD + ZWD$$

$$ZHD = 10^{-6}\frac{R}{m_d}g_m P_{sfc}$$

$$g_m=\frac{\int\rho(z)g(z)dz}{\int\rho(z)dz}$$

$$ZWD = \Pi^{-1}\times PWV$$

$$\Pi=\frac{10^5}{R}\left(k_2-k_1\frac{m_v}{m_d}+\frac{k_1}{T_m}\right)$$

$$T_m=\frac{\int\frac{P_v}{T}dz}{\int\frac{P_v}{T^2}dz}$$

$$T_m\approx 70.2+0.72T_{sfc}$$

Fig. 8: Estimation method of PWV.

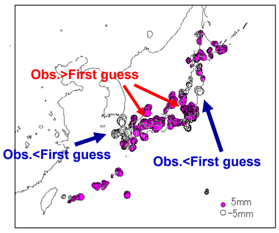


Fig. 9: D-value of PWV from 12 JST to 15 JST.

5. Results -Rainfall Regions Predicted from Analyzed Fields-

- Hydrostatic version of JMA meso 4-dvar system was used.
- **CNTL**: Heavy rainfall was not reproduced by assimilation of conventional data (Fig. 10).
- **RO**: Rainfall was intensified as expected by the D-value (observation-first guess) of RI profile (Figs. 6, 11 and 12). But, Eastern part of rainfall region is too strong. Moist SE-ly flow enhanced the intensity of the rainfall.
- **PWV**: Rainfall was intensified as expected by the D-value distribution of PWV. (Figs. 9, 11 and 12). Eastern part of rainfall region was weaker than RO. Weak SE-ly flow reduced 3hour-rainfall, though water vapor was increased.
- **SWV**: Increment became more significant when SWV was used. Water vapor on eastern side of northern Japan was decreased
- **Vertical Distribution**: When RO data was assimilated, water vapor was increased at the low-level. SWV modified the vertical distribution, but not so much (Fig 13).
- **RO+SWV**: When RO and SWV data were assimilated, the rainfall region was most similar to the observed one.

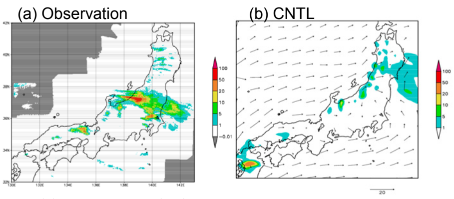


Fig. 10: (a) Three-hour rainfall from 15 JST to 18 JST 16 July 2004, which was observed by conventional radar and rain gauge data. (b) Three-hour rainfall and horizontal wind near surface predicted from the analyzed fields of conventional data(**CNTL**).

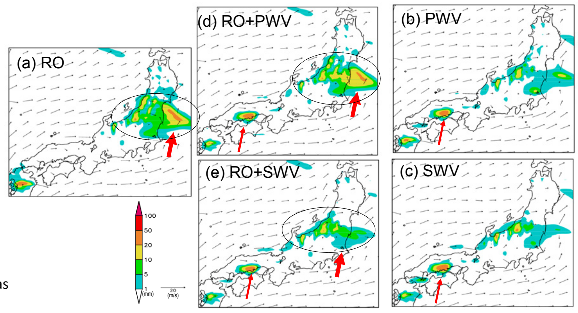


Fig. 11: Reproduced 3-hour rainfall of forecast time from 0 to 3 hours reproduced from the analyzed fields. Valid time is 15 to 18 JST 16 July 2004.

6.Summary

- Assimilation method of path data was developed.
- In this study, the vertical correlation of observation error was also considered.
- When RO data and ground-based GPS data were assimilated simultaneously, rainfall forecast and water vapor fields were more improved.

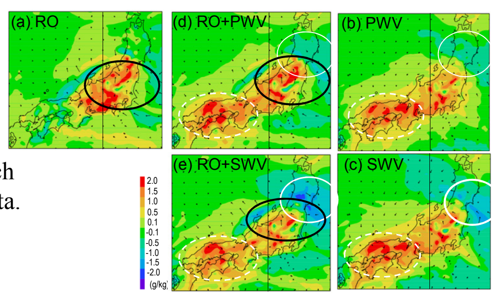


Fig. 12:Horizontal distributions of the difference of analyzed water vapor from '**CNTL**' at the height of 21 m. Black lines indicate the position of the vertical cross sections of Fig. 13.

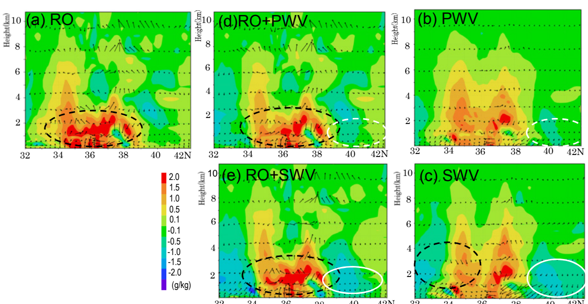


Fig. 13: Vertical distribution of the difference of analyzed water vapor from '**CNTL**' at the latitude of 138 deg. Vectors represent horizontal wind direction and velocity.

Acknowledgements

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References

- Seko et al.; Improvement of Rainfall Forecast by Assimilations of Ground-Based GPS Data and Radio Occultation Data", *SOLA*, Vol. **6**, pp.81-84 (2010) .