Impact of the assimilation of GPS slant total delay observations on a local heavy rainfall forecast

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To predict actual MCSs with Cloud Resolving Nonhydrostatic 4D-Var Assimilation System (NHM-4DVAR), we develop the method to assimilate GPS Slant total delay observation which include the information of pressure, temperature, and water vapor.

Model

- Forward model : NHM (full nonhydrostatic model)
- Adjoint, tangent linear model :
  - Dynamic frame work
  - Cloud microphysical process (Warm rain)
  - Lateral boundary conditions

Control variables

Wind (u,v,w), surface pressure, potential temperature, nonhydrostatic pressure, total water, relative rain water, pseudo relative humidity (for lateral boundary)

Observational data

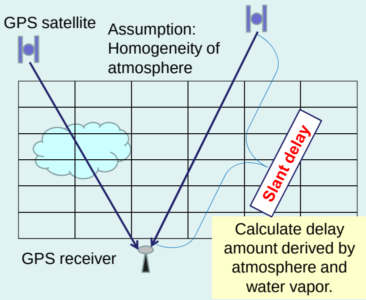
GPS precipitable water vapor (**GPS-PWV**),
GPS zenith tropospheric delay (**GPS-ZTD**),
GPS slant total delay (**GPS-STD**)

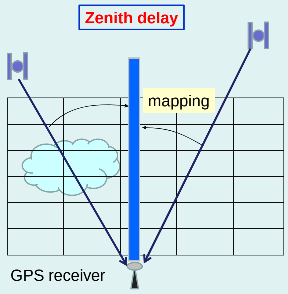
Horizontal resolution : 2 km

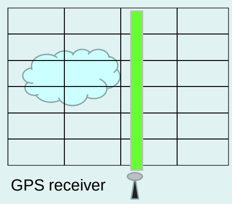
Characteristics of PWV, ZTD, and STD

	GPS-PWV	GPS-ZTD	GPS-STD
Water vapor	yes	yes	yes
Pressure, temperature	no	yes	yes
Direction	zenith	zenith	satellite
Difficulty to the assimilation	easy	easy – difficult	difficult
Model resolution	coarse – fine	coarse - fine	fine

What is the slant delay?







How to assimilate the GPS-STD?

(a) Refractive index

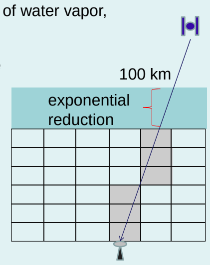
$$(n-1)\times 10^6 = \underbrace{K_1\left(\frac{P_d}{T}\right)}_{\text{Dry}} + \underbrace{K_2\left(\frac{P_v}{T}\right) + K_3\left(\frac{P_v}{T^2}\right)}_{\text{Wet}}$$

P_d : Partial pressure of dry air, P_v : Partial pressure of water vapor,
T : Temperature, K_1, K_2, K_3: Constants

(b) Integration along the pass of a radio wave

$$\Delta L = \int_L [n(s)-1]ds + [S-G]$$

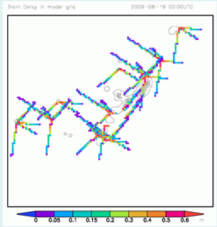
G : Distance in a straight line between the GPS satellite and the receiver.
S : Real length of propagation root of radio wave.
Assumption : S = G



(c) Assumption

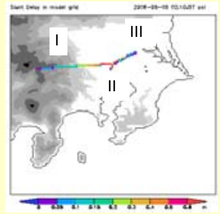
- Linear path assumption (S=G)
- Amount of delay becomes ZERO at the height of 100 km over the model top with exponential reduction.

Example of GPS-STD

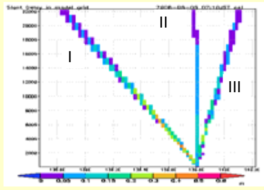


Lines indicate GPS slant path in the model, and crossing points indicate GPS observation sites. Colors show the delay amount on each model grid.

Comparison between GPS-ZTD and GPS-STD assimilations on single observation experiment

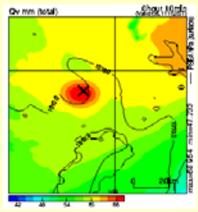


Compere assimilation of one ZTD observation or three STD observations.
I, II, III: Slant path

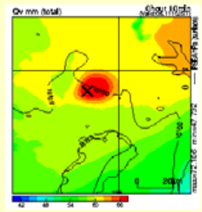


Vertical cross section from south (STD).

Horizontal distribution of PWV

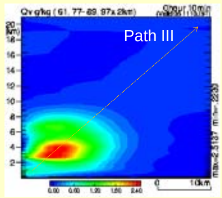


GPS-ZTD assimilation

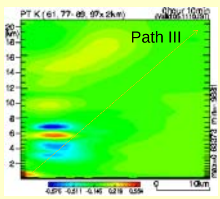


GPS-STD assimilation

Similar maximum and distributions both in 2 results.
-> comparable effect
Oval but deformed PWV distribution in STD
<- effected by slant distribution and each elevation



Vertical cross section of mixing ratio of water vapor of GPS-ZTD – GPS-STD along the path III.

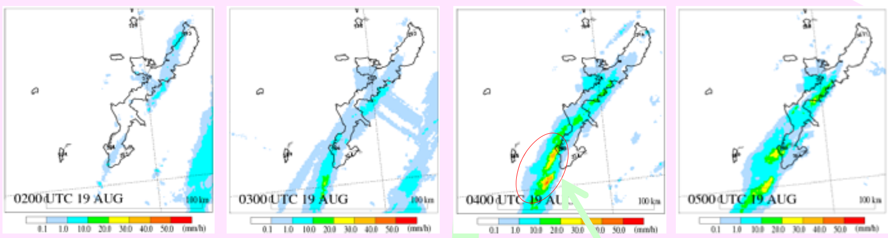


Same as left figure, but temperature.

Recognize increment on the slant path.
-> desirable result

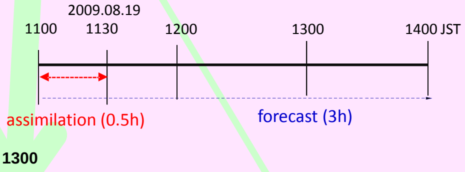
Real assimilation experiment

Radar observation

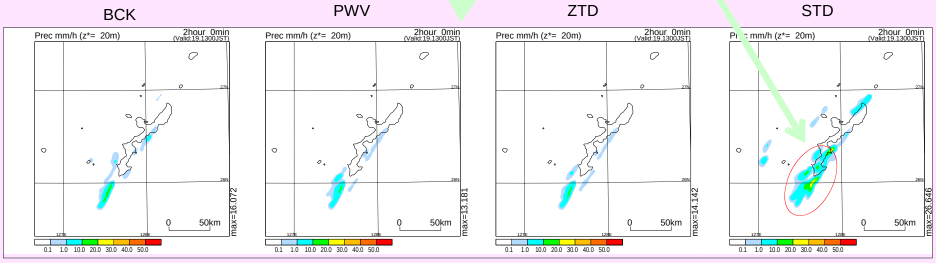


Observational Data

- GPS-PWV (10 min interval)
- GPS-ZTD (10 min interval)
- GPS-STD (10 min interval)



Result



Forecast by STD Assimilation:
- Reproduce the rainband existed on south of Okinawa island.
- Reproduce line shape of the rainband.

Forecasts by PWV or ZTD Assimilation:
- Slightly modification from the first guess field.

Summary

- **Develop the GPS Slant Delay Assimilation for NHM-4DVAR.**
- **Comparable result in the single observation experiment which is used STD or ZTD.**
- **Confirm the slant-shaped increment in STD assimilation.**
- **In real observation assimilation experiment, only STD assimilation shows line-shaped rainband in the forecast.**

GPS data were provided by the Geospatial Information Authority of Japan.

References

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- Shoji, Y., 2009: A study of near real-time water vapor analysis using a nationwide dense GPS network of Japan. J. Meteor. Soc. Japan, **87**, 455-477.