同化臺灣地區沿岸近地表雷達資料之效益評估

Evaluation of the Benefits of Data Assimilation for Near-Surface Coastal Radar Data in Taiwan

114年天氣分析與預報研討會 Sep. 3rd Taipei, Taiwan

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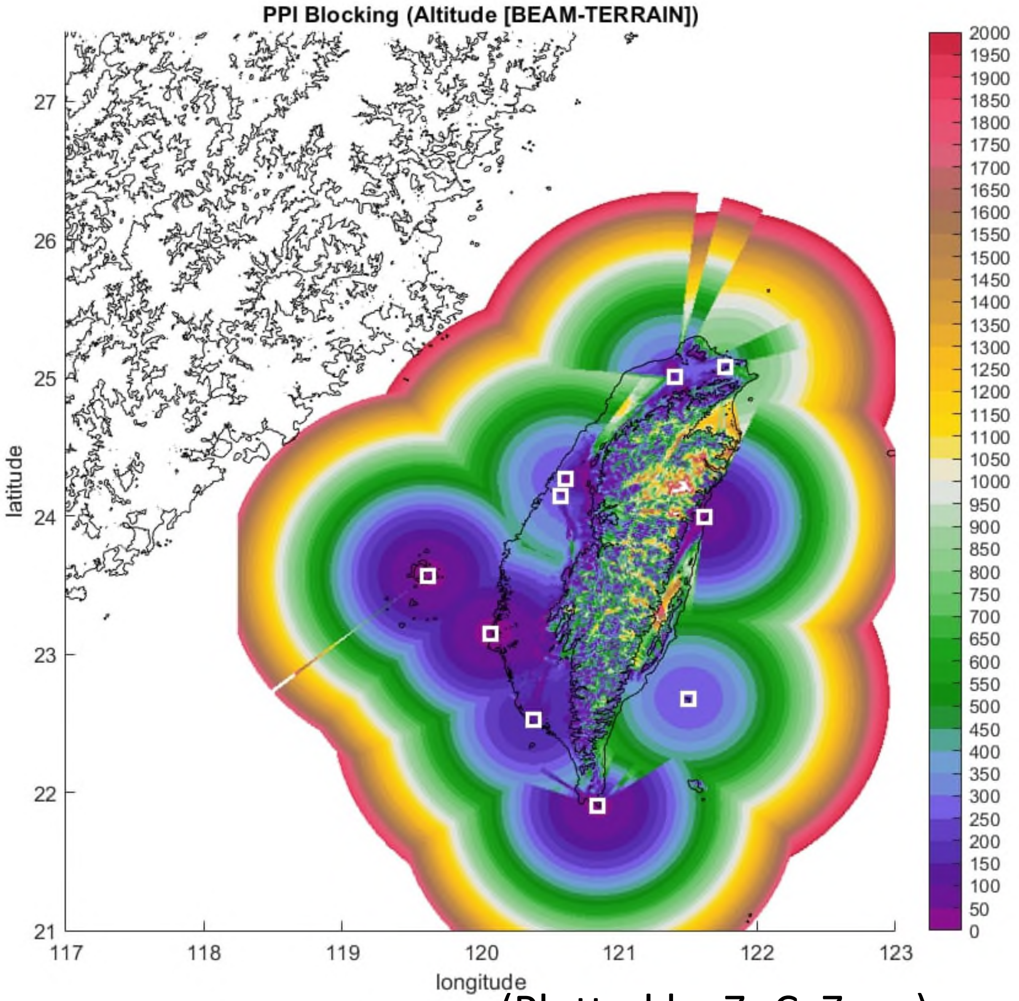
Introduction

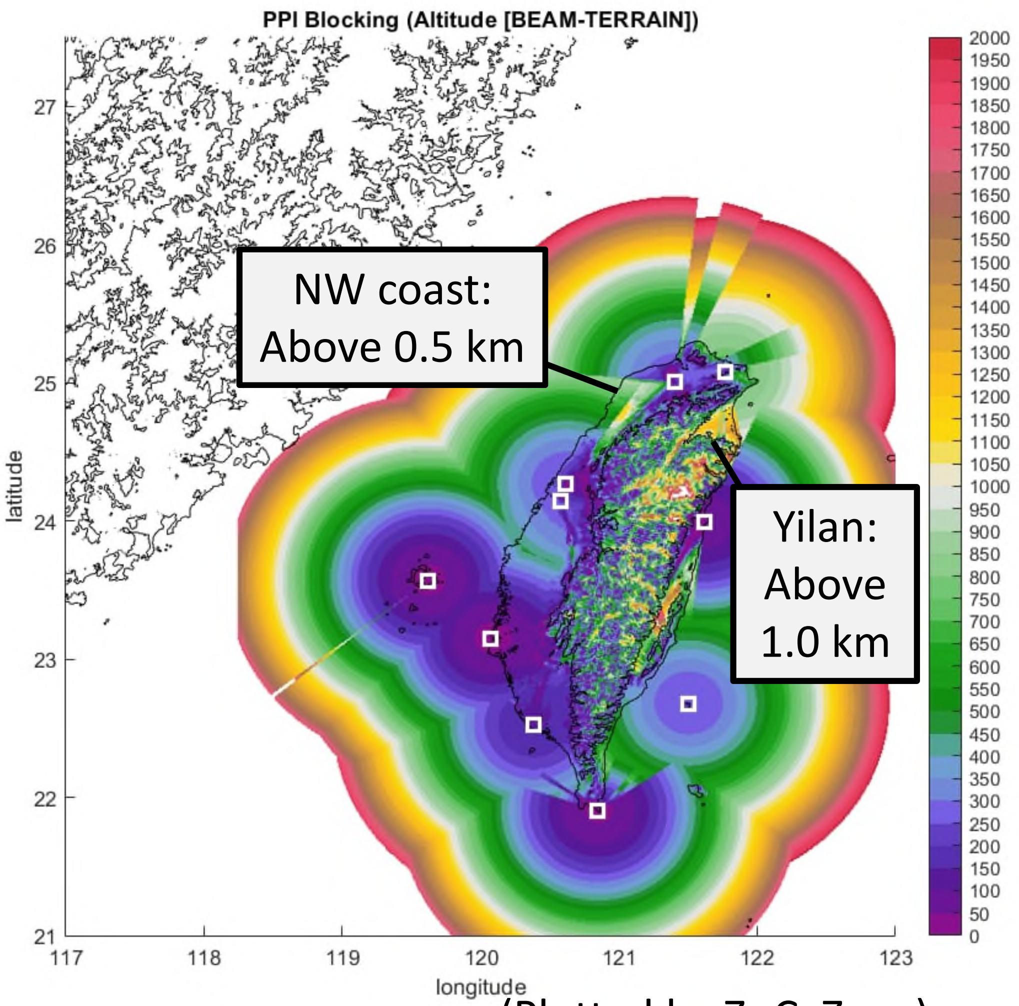
Gap of the Operational Observation



(Plotted by Z.-C. Zeng)

- Weather radar with high spatial-temporal resolution offers an advantage in the construction of three-dimensional meteorological structures.
- Dual-polarization radar observation provides more comprehensive determination of cloud microphysics structures.
- However, near surface area are often lack the radar observation due to the terrain blockage and the lowest altitude of the observation plane.
- The scarcity of the radar data may limit the description of low-level dynamics and microphysics; also, impacts the accuracy of radar data assimilation.

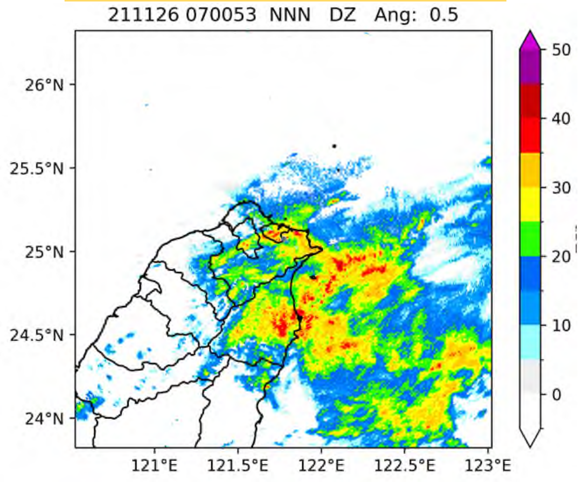
Gap of the Operational Observation



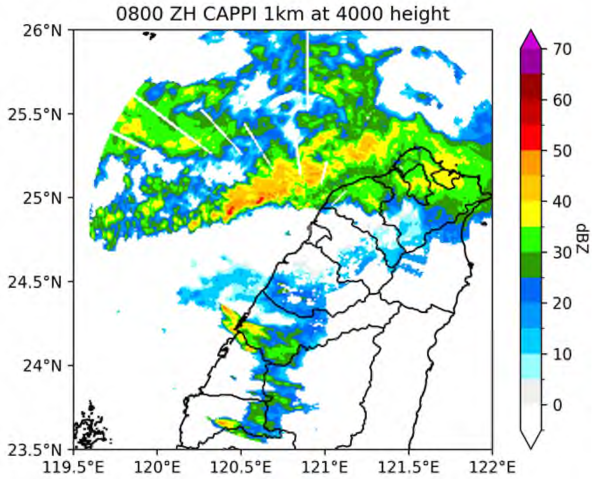
(Plotted by Z.-C. Zeng)

- Significant rainfall events often happened at northwestern coast and Yilan during the Mei-Yu season and winter, respectively.
- However, Yilan and northwestern coast are two regions which are lack of the low-level radar data.

2021YESR IOP2



2022 TAHOPE IOP3



Motivation and Purpose

NCAR S-POL
(S-band Dual Polarization Doppler Radar)

- ✓ S-Band
- ✓ **Dual-polarimetric Radar**
- ✓ SoWMEX, **TAHOPE**…

Photo by H.-E., Lin

TEAM-R (Taiwan Experimental Atmospheric Mobile Radar, since 2008)

- ✓ X-Band
- ✓ **Dual-polarimetric Radar**
- ✓ SoWMEX, **YESR, TAHOPE**…

- By employing the experimental mobile radar, the dynamic and microphysics structure at blockage region could be well observed. So, ***what is the added value of assimilating low level radar data?***
- Two cases are selected to investigate how **additional gap-filling dual-polarization radar data** affects the results of data assimilation and model forecasts.

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WRF-LETKF Radar Assimilation System (WLRAS) (Tsai et al. 2014)

Local Ensemble Transform Kalman Filter (LETKF)

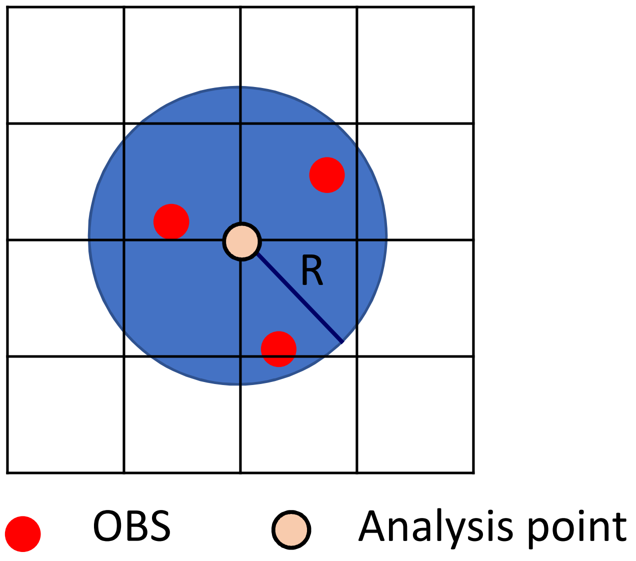
(Hunt et al. 2007)

- ✓ **Deterministic EnKF**
- ✓ Ensemble mean:

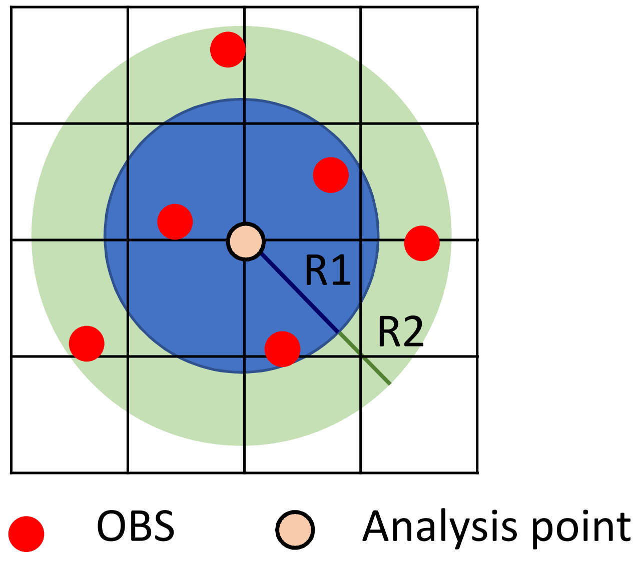
$$\bar{x}_a = \bar{x}_b + X_b \bar{w}$$
$$\bar{w} = \tilde{P}_a Y_b^T R^{-1}(y_o - H\bar{x}_b)$$

- ✓ Perturbation:

$$X_a = X_b W$$
$$W = [(n-1)\tilde{P}_a]^{\frac{1}{2}}$$



Mixed Localization (Tsai et al. 2014)



Updated Variables	U, V	PH, T	q_v, q_c, q_i, N_c	q_r, q_s, q_g, N_r
H. L. (km)	36	12	24	12
V. L. (km)	4			
Inflation	1.08			

Polarimetric Radar Data Simulator (PRDS; Jung et al. 2008a, 2010)

Raindrop

Direct Integration (Jung et al. 2010)

$$Z_{hh,x} = \frac{4\lambda^4}{\pi^4|K_w|^2}\int N_x(D)\left(A\left|f_{hh,x}(\pi)\right|^2 + B\left|f_{vv,x}(\pi)\right|^2 + 2C\left|f_{hh,x}(\pi)\right|\left|f_{vv,x}(\pi)\right|\right)dD$$

$$Z_{vv,x} = \frac{4\lambda^4}{\pi^4|K_w|^2}\int N_x(D)\left(A\left|f_{vv,x}(\pi)\right|^2 + B\left|f_{hh,x}(\pi)\right|^2 + 2C\left|f_{hh,x}(\pi)\right|\left|f_{vv,x}(\pi)\right|\right)dD$$

- x: hydrometeor species
- λ: Radar wavelength
- K_w: Dielectric coefficient
- A, B *and* C: Canting coefficient
- $|f_{hh}|$ and $|f_{vv}|$: Scattering Amplitude (By **T-matrix method**, Vivekanandan et al. 1991)

Ice particles

Scattering Amplitude Fitting (Jung et al., 2008a)

$$N_X(D_X) = N_{0,X}D_X^{\mu}\exp(-\Lambda_X D_X) \qquad |f_{hh}| = \alpha_{hh,x}D_x^{\beta_{hh,x}} \qquad |f_{vv}| = \alpha_{vv,x}D_x^{\beta_{vv,x}}$$

α_x and β_x : fitting coefficient

$$Z_{hh,x} = \frac{4\lambda^4 N_{0,x}}{\pi^4|K_w|^2}\left(A\alpha_{hh,x}^2\frac{\Gamma(\mu_x+2\beta_{hh,x}+1)}{\Lambda_x^{\mu_x+2\beta_{hh,x}+1}} + B\alpha_{vv,x}^2\frac{\Gamma(\mu_x+2\beta_{vv,x}+1)}{\Lambda_x^{\mu_x+2\beta_{vv,x}+1}} + 2C\alpha_{hh,x}\alpha_{vv,x}\frac{\Gamma(\mu_x+\beta_{hh,x}+\beta_{vv,x}+1)}{\Lambda_x^{\mu_x+\beta_{hh,x}+\beta_{vv,x}+1}}\right)$$

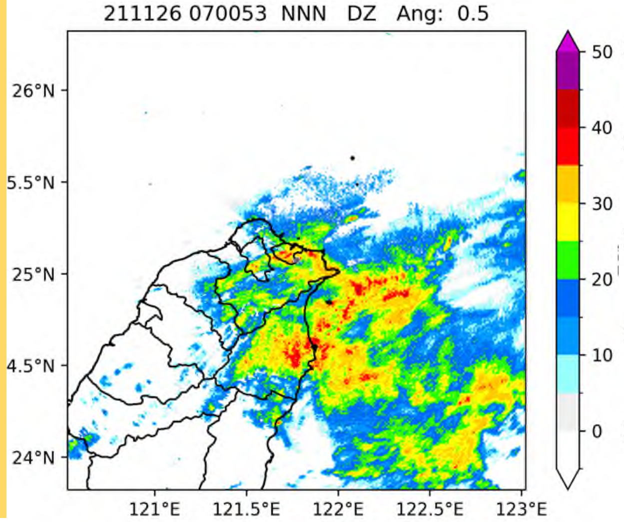
$$Z_{vv,x} = \frac{4\lambda^4 N_{0,x}}{\pi^4|K_w|^2}\left(A\alpha_{vv,x}^2\frac{\Gamma(\mu_x+2\beta_{vv,x}+1)}{\Lambda_x^{\mu_x+2\beta_{vv,x}+1}} + B\alpha_{hh,x}^2\frac{\Gamma(\mu_x+2\beta_{hh,x}+1)}{\Lambda_x^{\mu_x+2\beta_{hh,x}+1}} + 2C\alpha_{hh,x}\alpha_{vv,x}\frac{\Gamma(\mu_x+\beta_{hh,x}+\beta_{vv,x}+1)}{\Lambda_x^{\mu_x+\beta_{hh,x}+\beta_{vv,x}+1}}\right)$$

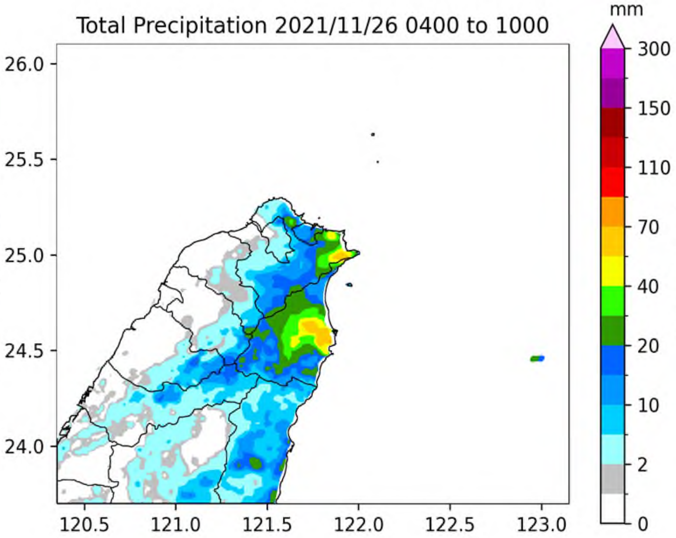
Dual-pol Parameters

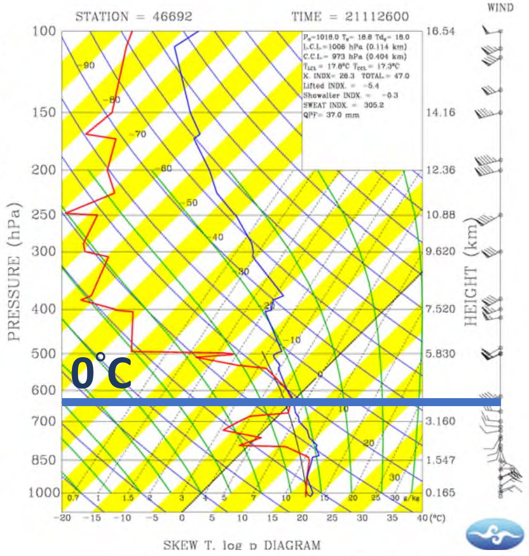
$$Z_{HH} = \log_{10}\left(\sum Z_{hh,x}\right) \qquad Z_{VV} = \log_{10}\left(\sum Z_{vv,x}\right) \qquad Z_{DR} = \log_{10}\left(\frac{\sum Z_{hh,x}}{\sum Z_{vv,x}}\right)$$

Case Studies

2021YESR IOP2

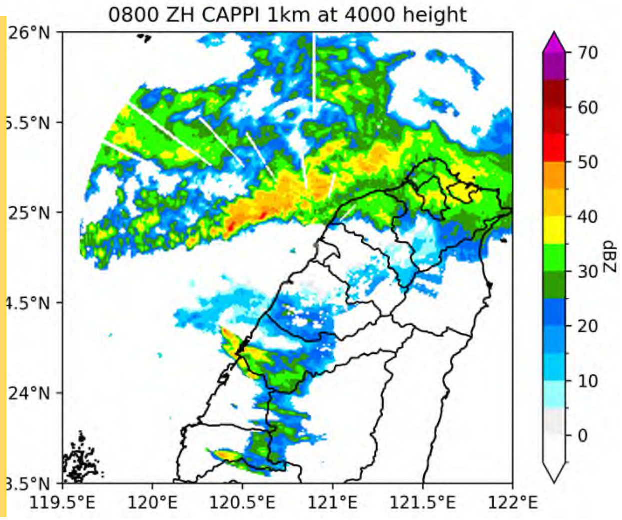


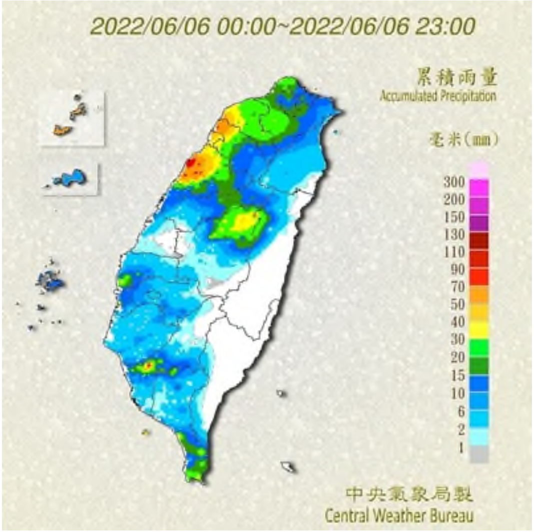


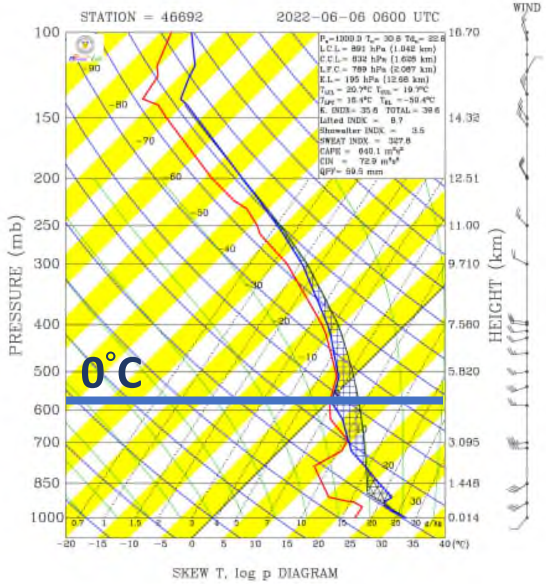


- Shallow-convection systems kept popping up, causing moderate rainfall happened at Yilan.
- Two moist layers (0-1.5km, 3.5~4.5km). 0°C is about 3-4 km height.

2022 TAHOPE IOP3

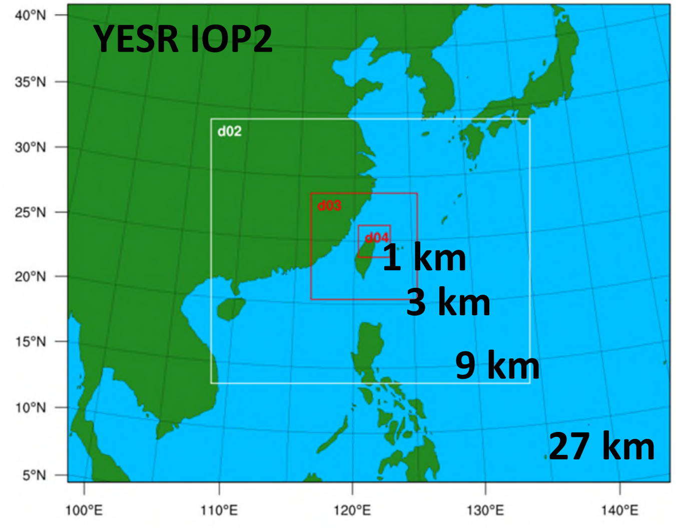


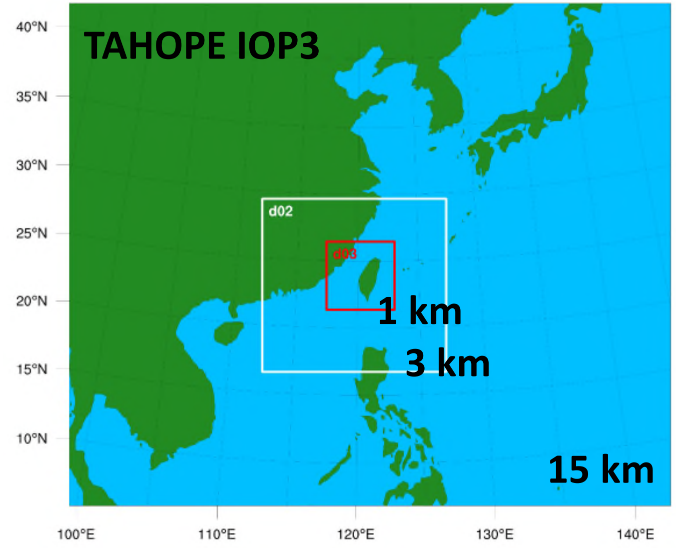




- Meso scale system induced by the Mei-Yu front, causing rainfall happened at north-west coast.
- 0°C level: about 4-5 km height.

Configuration of Ensemble Simulation



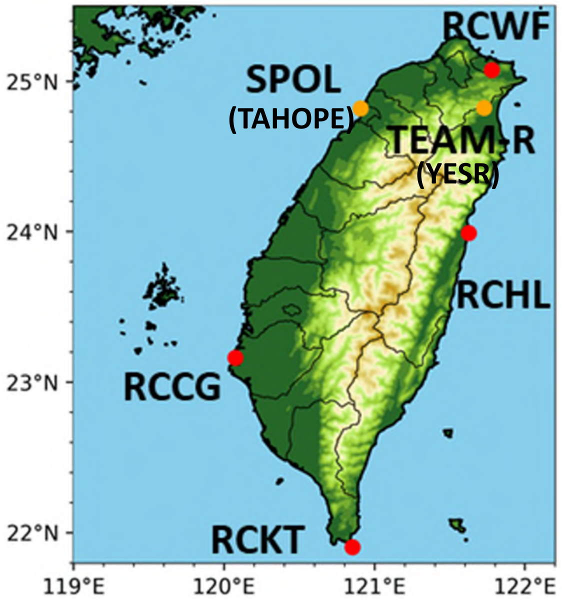


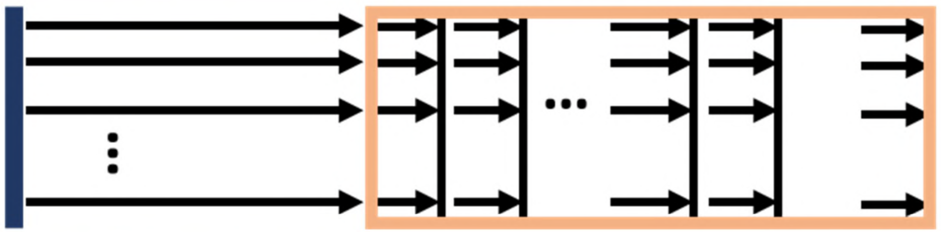
	YESR IOP2	TAHOPE IOP3
WRF Version	V 4.1.3	V 3.9.1
Start time	2021-11-25 12 UTC	2022-06-05 18 UTC
End time	2021-11-26 04 UTC	2022-06-06 06 UTC
IC. & BC.	NCEP FNL 0.25°	
Vertical levels	52 levels from surface to 10hPa	
Ens. Members	128	50
Perturbation method	WRFDA cv3	
Nesting	2-way nesting	
Physics	MP: WDM6 (Lim and Hong, 2010) LW: RRTM scheme SW: Dudhia scheme BL: YSU scheme	

Configuration of Experiments

Period of DA cycle:
YESR IOP2: 15 mins, 17cycles
TAHOPE IOP3: 12 mins, 11cycles

	Assi. data	σ_o
Vr	Full volume, $< 3 \times \sigma_o$	3(m/s)
Z_{HH}		5(dBZ)
Z_{DR}	<3 (4) km in winter (summer) case, $< 3 \times \sigma_o$	0.2(dB)





25th Nov. 2021 1200 UTC	26th Nov. 2021 0400 UTC	26th Nov. 2021 0800UTC	YESR IOP2
5th Jun. 2021 1800 UTC	6th Jun. 2021 0600 UTC	6th Jun. 2021 0800UTC	TAHOPE IOP3

Experiments	Assi. parameter	Assi. Radar
VrZ_noL	Vr and Z_{HH}	Operational Radar
VrZ_plusL		Opt. Radar + TEAM-R (YESR) or SPOL (TAHOPE)
VrZZ_noL	Vr, Z_{HH} and Z_{DR}	Operational Radar
VrZZ_plusL		Opt. Radar + TEAM-R (YESR) or SPOL (TAHOPE)

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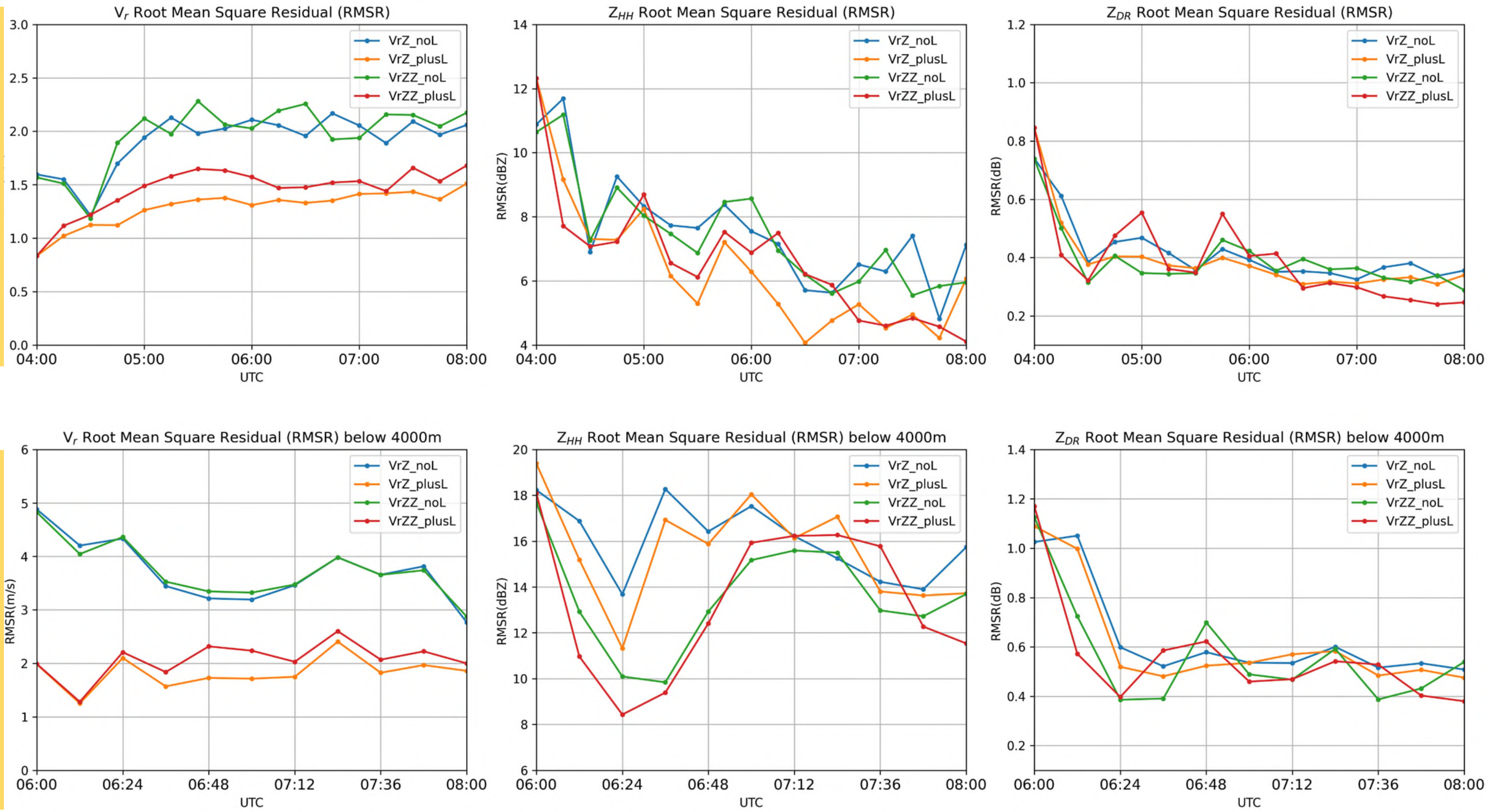
Result & discussion

Root Mean Square Residual (RMSR)

Calculated **at OBS points below melting layer**

	Vr (m/s)	Z_{HH} (dBZ)	Z_{DR} (dB)
YESR IOP2			
TAHOPE IOP3			

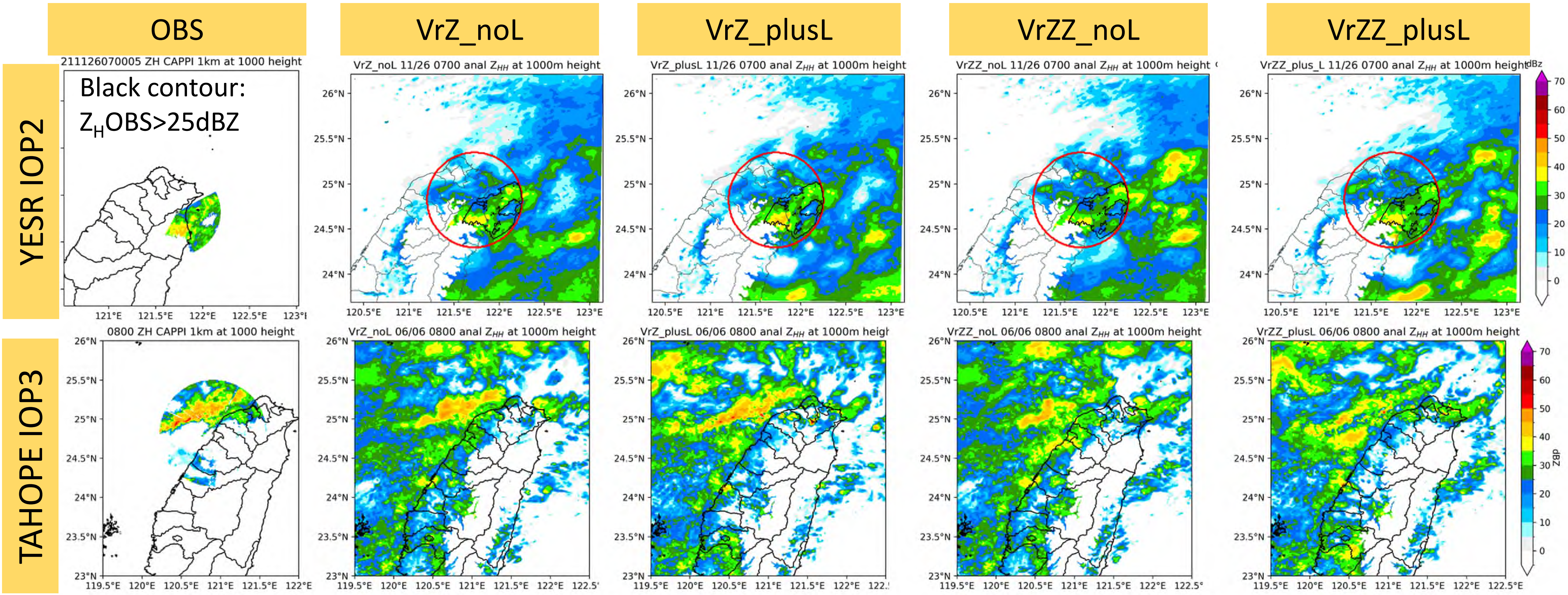


$$RMSR = \sqrt{\frac{\sum (y^o - H\bar{x}^a)^2}{n}}$$

- Assimilating low-level radar data effectively reduces the V_r RMSR.
- When Z_{DR} is assimilated into the model, the Z_{HH} RMSR becomes lower overall.
- Z_{DR} in different experiments are comparable.

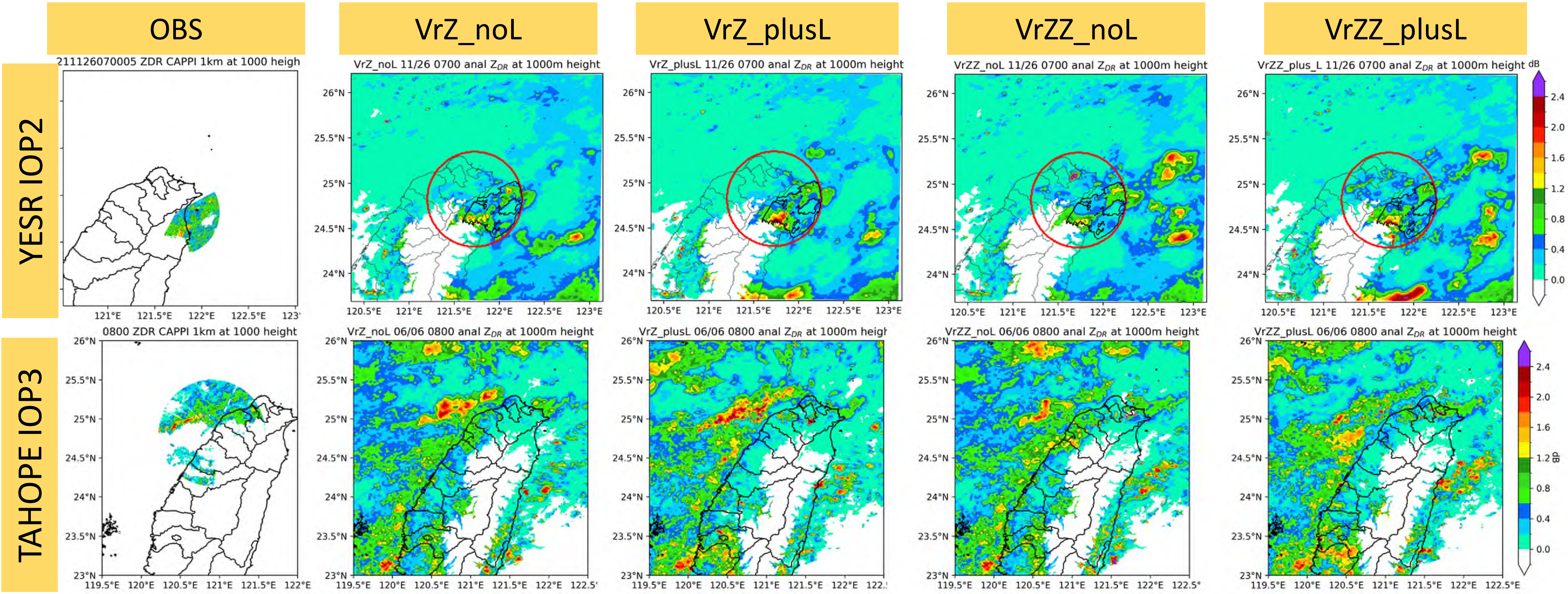
Result & discussion

Low-level Z_{HH} Performance at 1-km height



- Assimilating low-level radar data leads analyzed Z_{HH} close to the observation.
- Assimilating Z_{DR} into model decrease the intensity of Z_{HH}, especially in the summer case.

Low-level Z_{DR} Performance at 1-km height

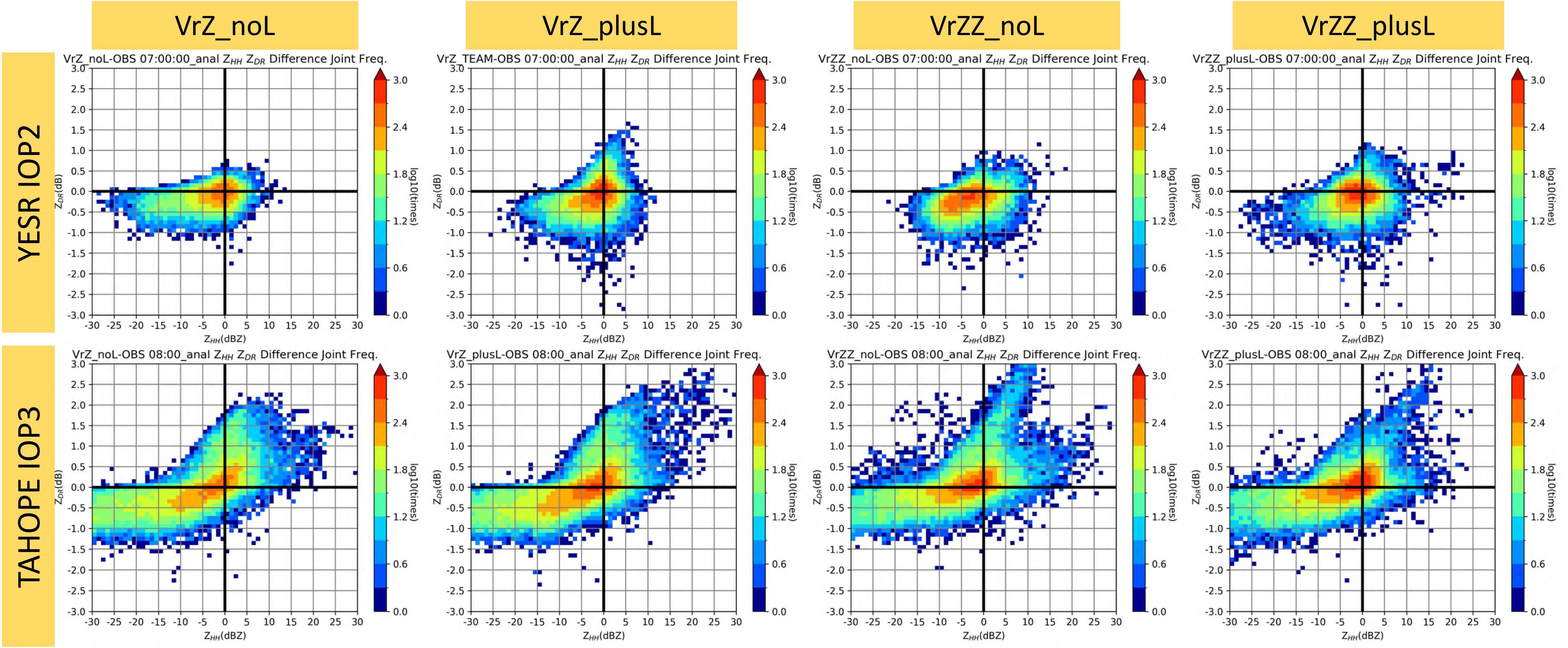


- Assimilating low-level conventional radar data leads analyzed Z_{DR} higher.
- Assimilating Z_{DR} into model decrease the intensity of Z_{DR}, especially in the summer case, which decreases the overestimation of the analyzed Z_{DR}.

Result & discussion

Z_{HH} – Z_{DR} Difference Between Exps. and OBS

Calculated **at OBS points below melting layer**



- Overall, assimilating not only low-level radar data but also Z_{DR} decreases the difference between analyses and model.
- However, obvious differences remain even after both datasets are assimilated in the summer case.

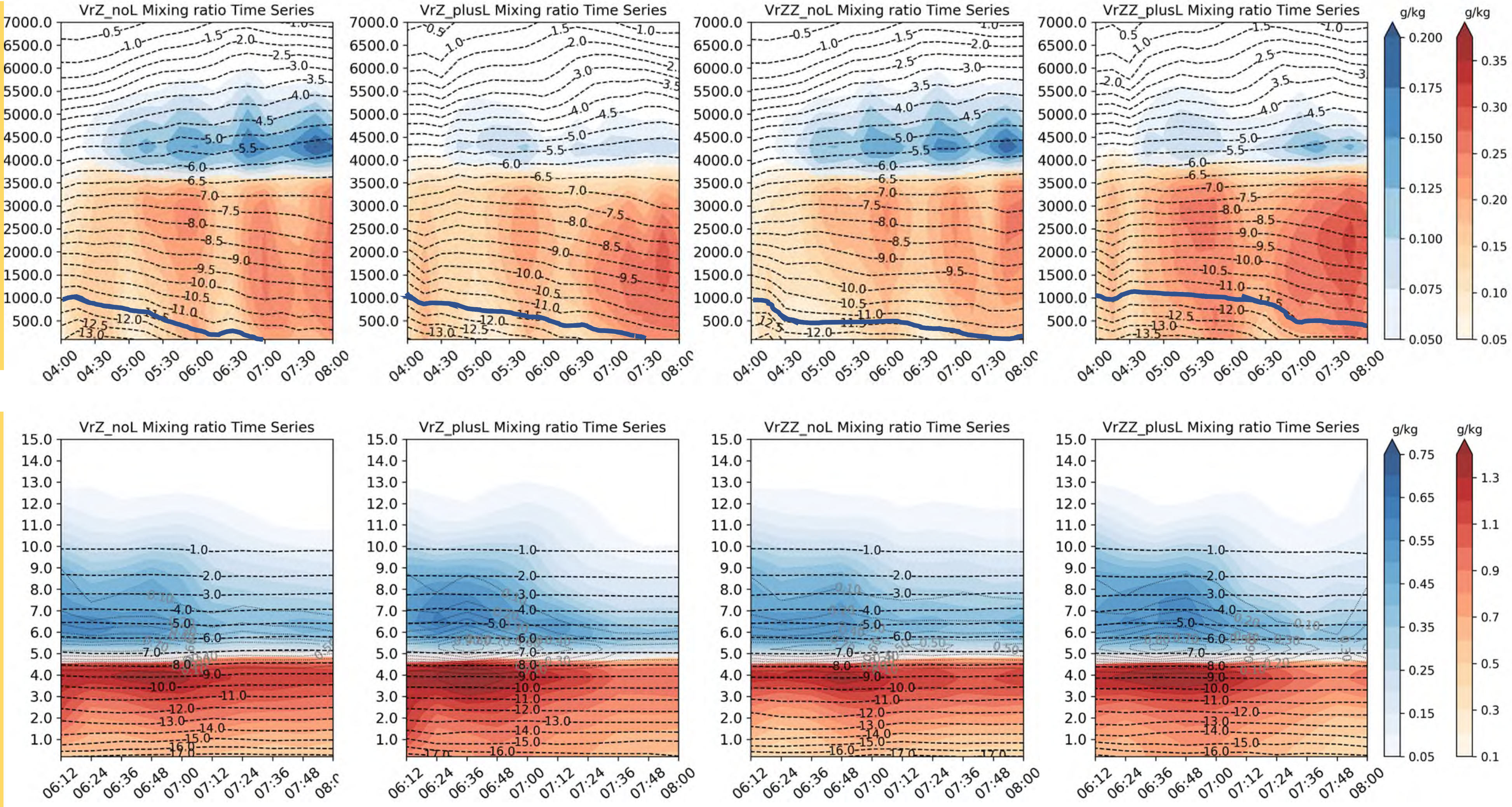
Result & discussion

Hydrometeor Mixing Ratio Time Series

VrZ_noL	VrZ_plusL	VrZZ_noL	VrZZ_plusL

YESR IOP2

TAHOPE IOP3(conv.)



- X-axis : Time (UTC)
- Y-axis : Height
- Red shaded: q_r (g/kg)
- Blue shaded: q_s (g/kg)
- Dashed line: q_v (g/kg)

✓ Winter Case:

Assimilating low-level radar data and Z_{DR} together would enhance the low-level q_r and q_v . Also, decrease q_s in the winter case.

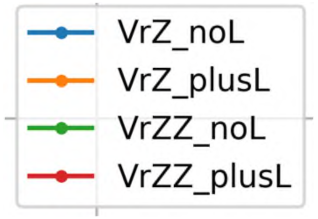
✓ Summer Case:

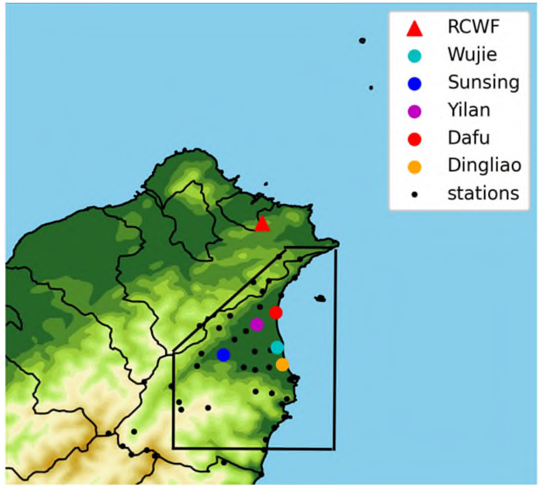
Assimilating low-level radar data would enhance q_r, but assimilating Z_{DR} would decrease it at the same time.

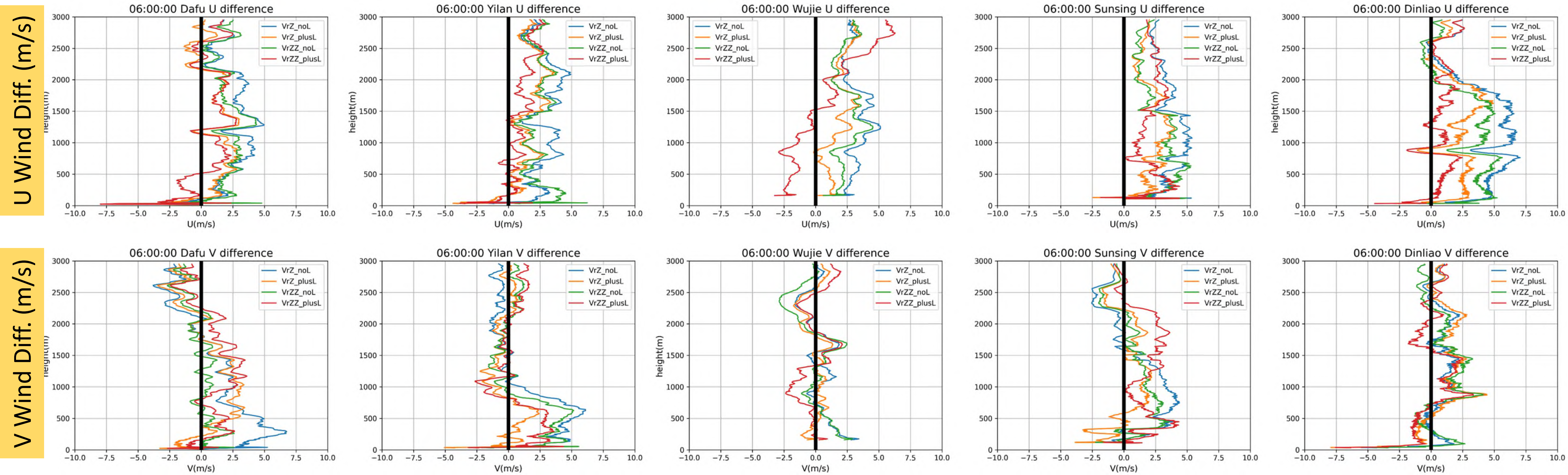
Result & discussion

Dynamics Validation in YESR IOP2

- Validate model by Storm Tracker data
- Assimilating low level radar data can improve U wind under 1500m and maintain the V wind error.
- Assimilating Z_{DR} into model can improve low level wind structure as well.
- Overall, VrZZ_plusL has the best dynamics structure.





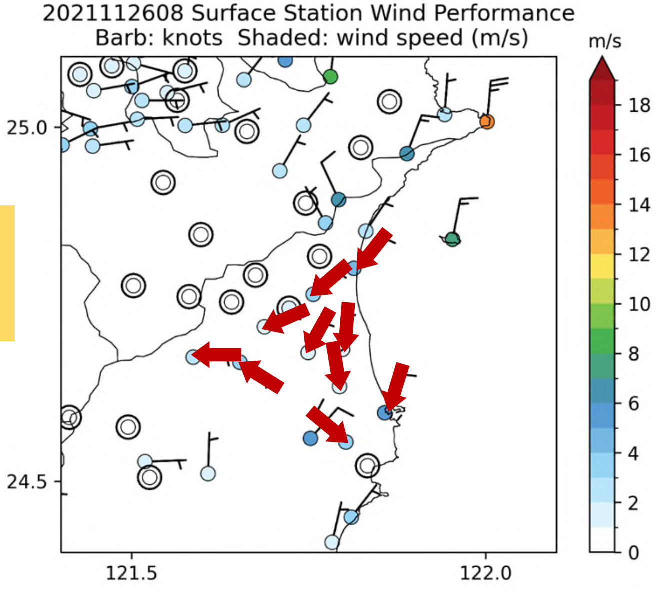


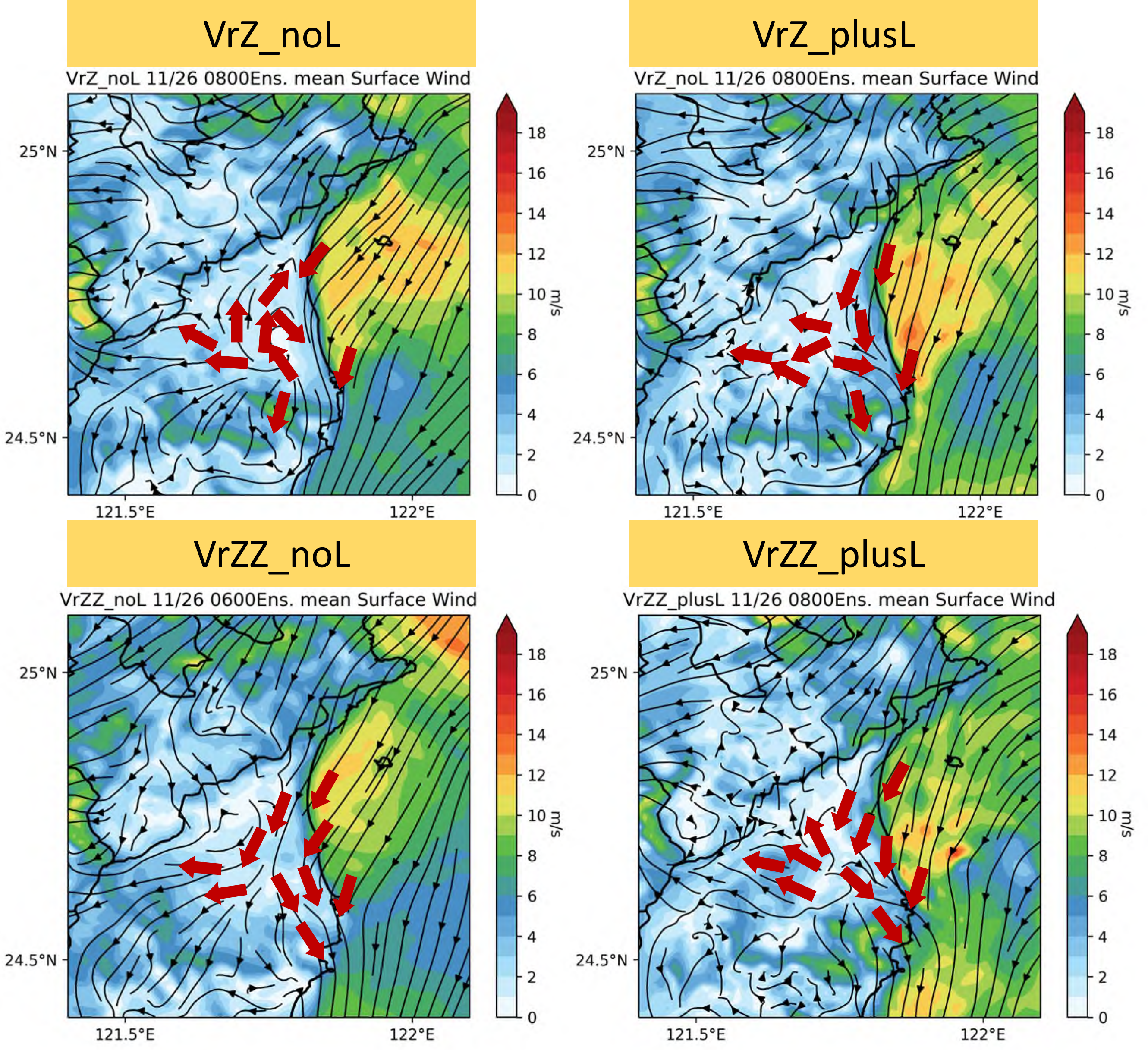
Performance with different DA methods

Dynamics Validation in YESR IOP2

0800UTC (Cycle17)

Surface Station

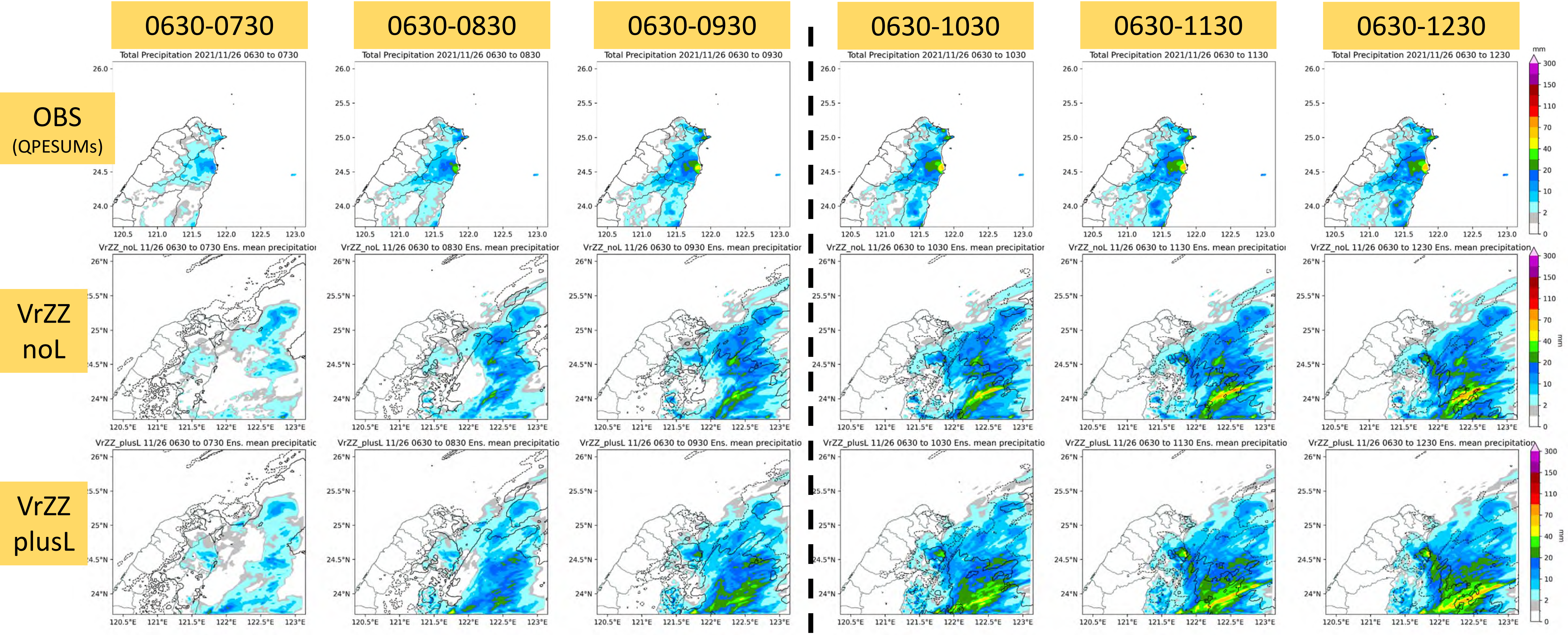




- Assimilating low-level radar data produces near-surface circulation patterns that closely resemble the observations at the final analyses.

Performance with different DA methods

Precipitation Validation in YESR IOP2



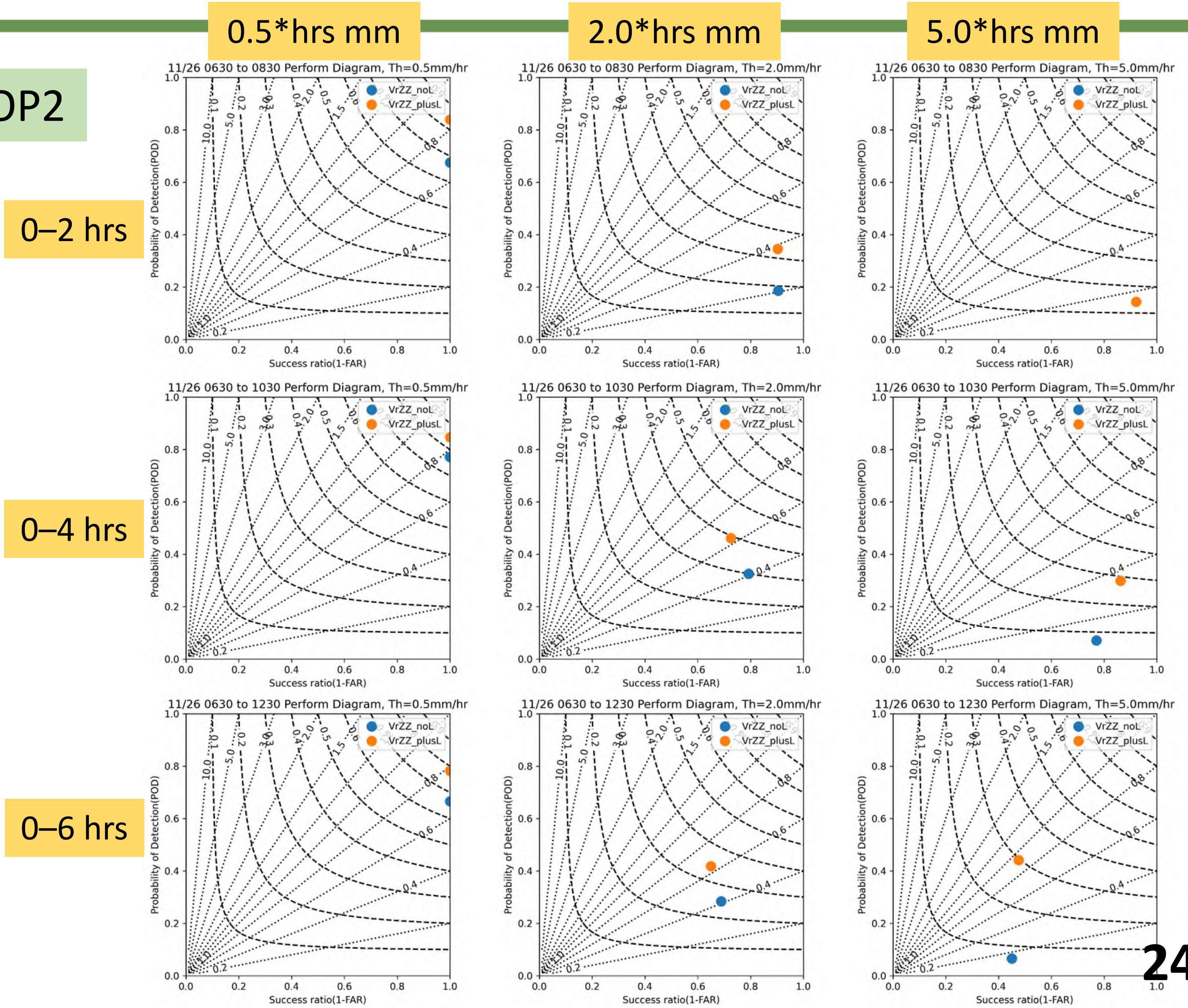
✓ Assimilating low-level dual-pol radar data could improve the rainfall forecasts.

Result & discussion

Precipitation Validation in YESR IOP2

Deterministic forecasts

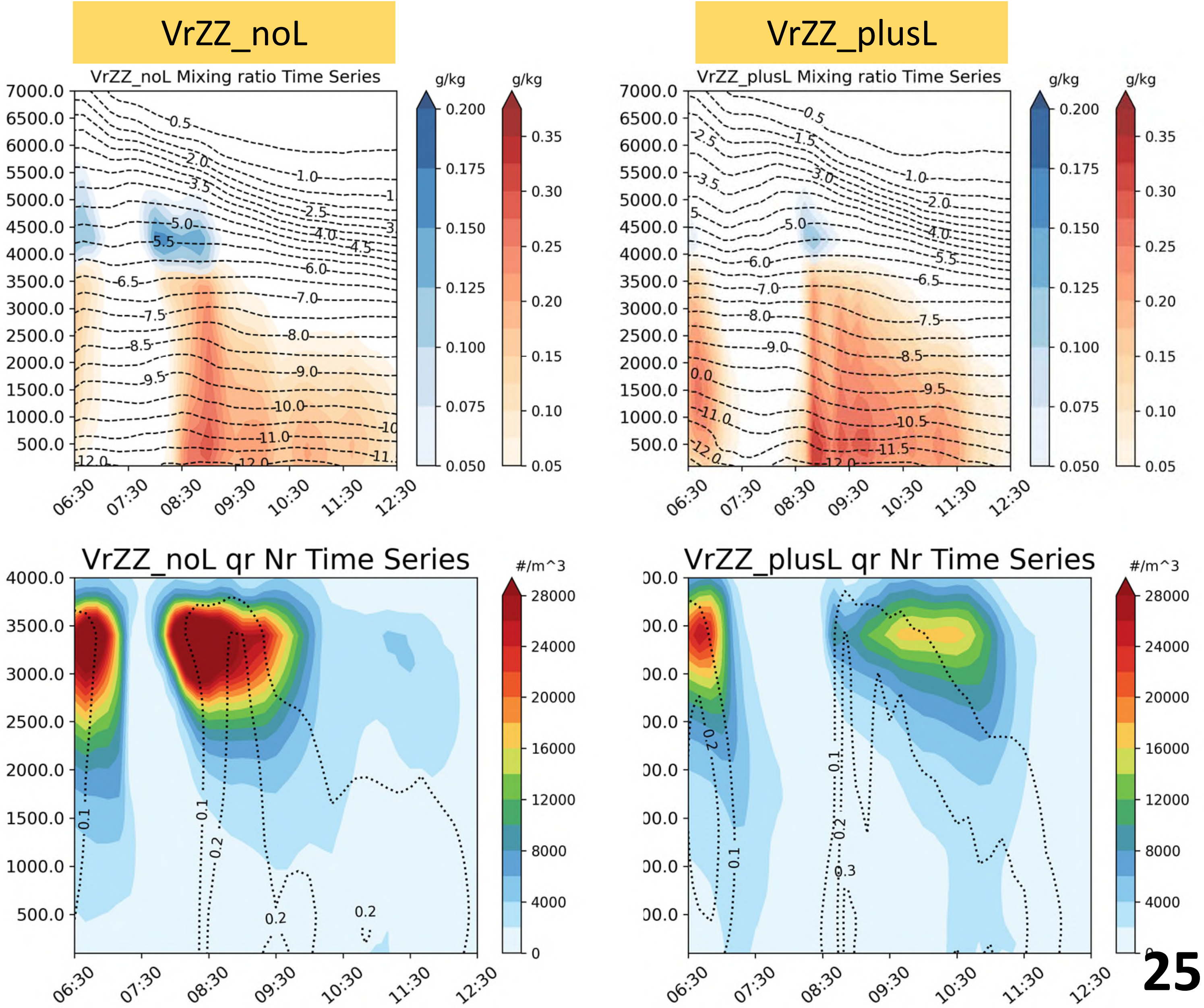
- ✓ VrZZ_noL could present the coverage of the rainfall with low threshold.
- ✓ Assimilating low-level radar data may improve the rainfall forecast under different threshold.



Result & discussion

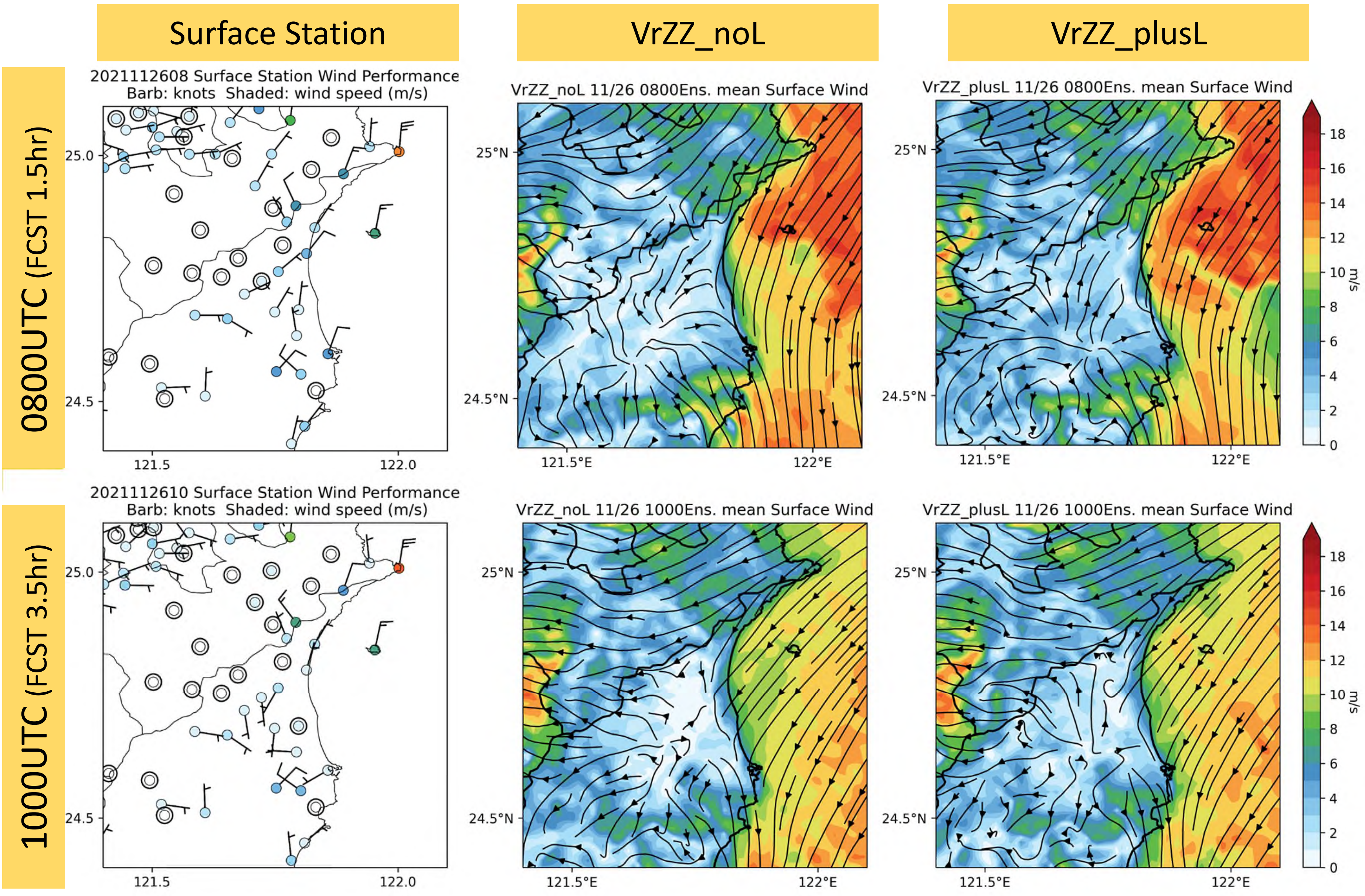
FCST. Hydrometeor Time Series in YESR IOP2

- The enhancement of q_r could be sustained in the first hour in the forecast.
- Much more q_r is simulated after 0830 UTC in the VrZZ_plusL with fewer numbers.
- Analyses of hydrometeors source/ sink terms are needed to describe how data assimilation impact on cloud microphysics.



Result & discussion

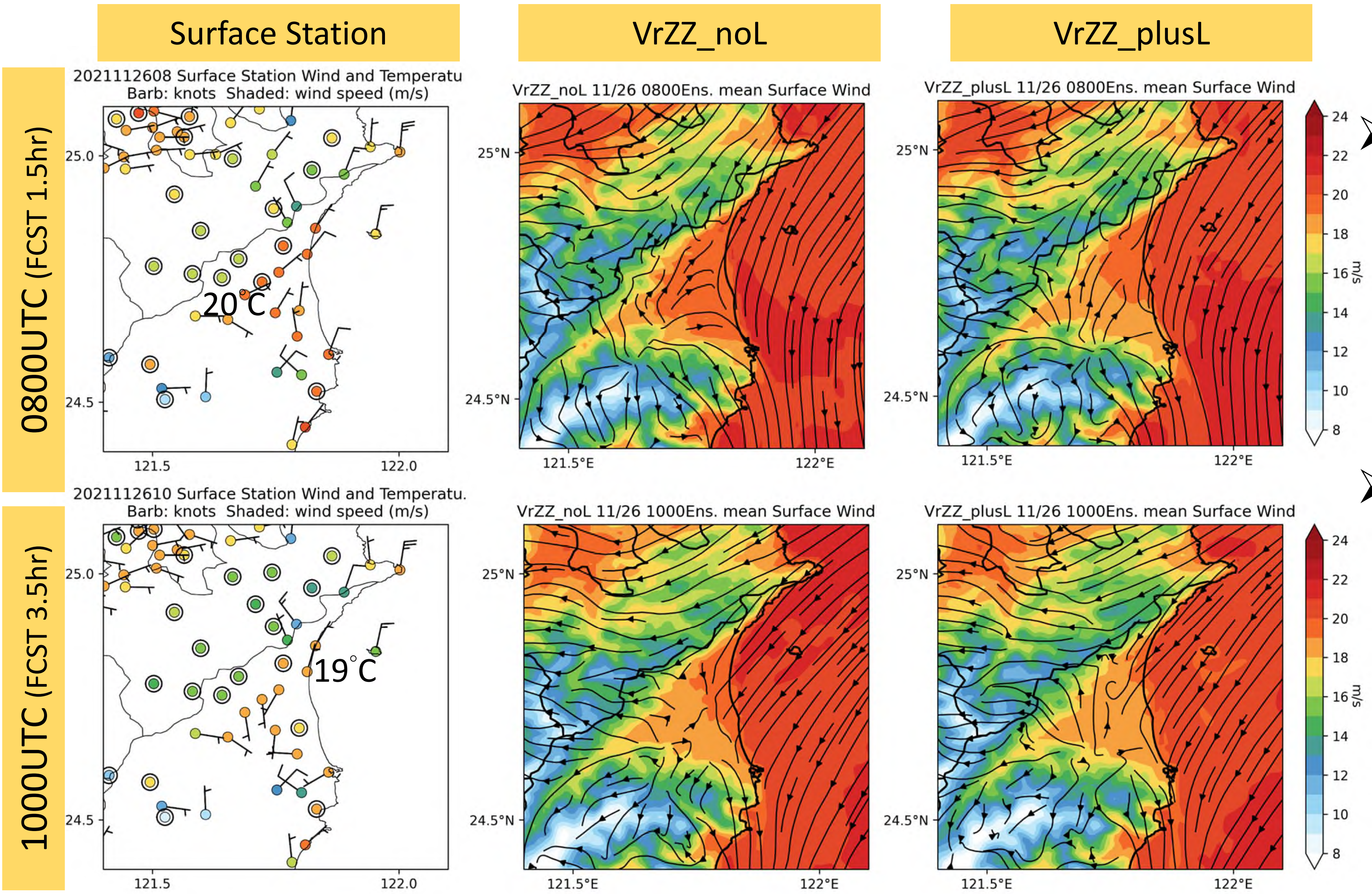
Forecast Dynamics Validation in YESR IOP2



- All experiments simulate the return flow that is not observed at 0800 UTC.
- Assimilating low-level radar data leads to stronger return flow compared to the other.
- Two experiments have similar circulation compared to OBS at 1000 UTC, but the one with additional radar DA has stronger wind speed.

Result & discussion

Forecast Dynamics Validation in YESR IOP2



- Assimilating low-level radar data leads to lower temperature compared to the observation in the Yilan plane at 0800 UTC.
- However, assimilating low-level radar data may decrease the temperature, which is overestimated in VrZZ_noL at 1000 UTC.

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Conclusion

- In this study, the effects of assimilating low-level radar data and dual-pol radar Z_{DR} are evaluated using two rainfall cases that occurred in winter and summer, respectively.
- Assimilating low-level radar data adjusts the low-level circulation toward observation, leading to smaller residual between analyses and observation.
- In the winter case, assimilating low-level Z_{DR} data would lead analyses much closer to the observation, and increase near-surface q_r.
- In the summer case, assimilating low-level radar data and Z_{DR} would decrease Z_{DR} intensity, which is overestimated by other experiments. For the microphysics structure, low-level radar assimilation would increase q_r, but assimilating Z_{DR} would decrease this value, which decreases the overestimation.
- Assimilating low-level radar data can enhance the precipitation forecasts in the winter case.

Future work

- Dynamics validation of TAHOPE IOP3 is on process.
- Analyses of hydrometeors source/sink terms are needed to describe how data assimilation impact on cloud microphysics.
- The dynamical and thermodynamical structures in the forecasts will be examined to further describe how assimilating additional radar data influences simulations.
- Further investigations of the limitation inside MP schemes and forward operator are needed to fix the simulated bias of dual-polarization variables in the summer case.

Thanks for listening!

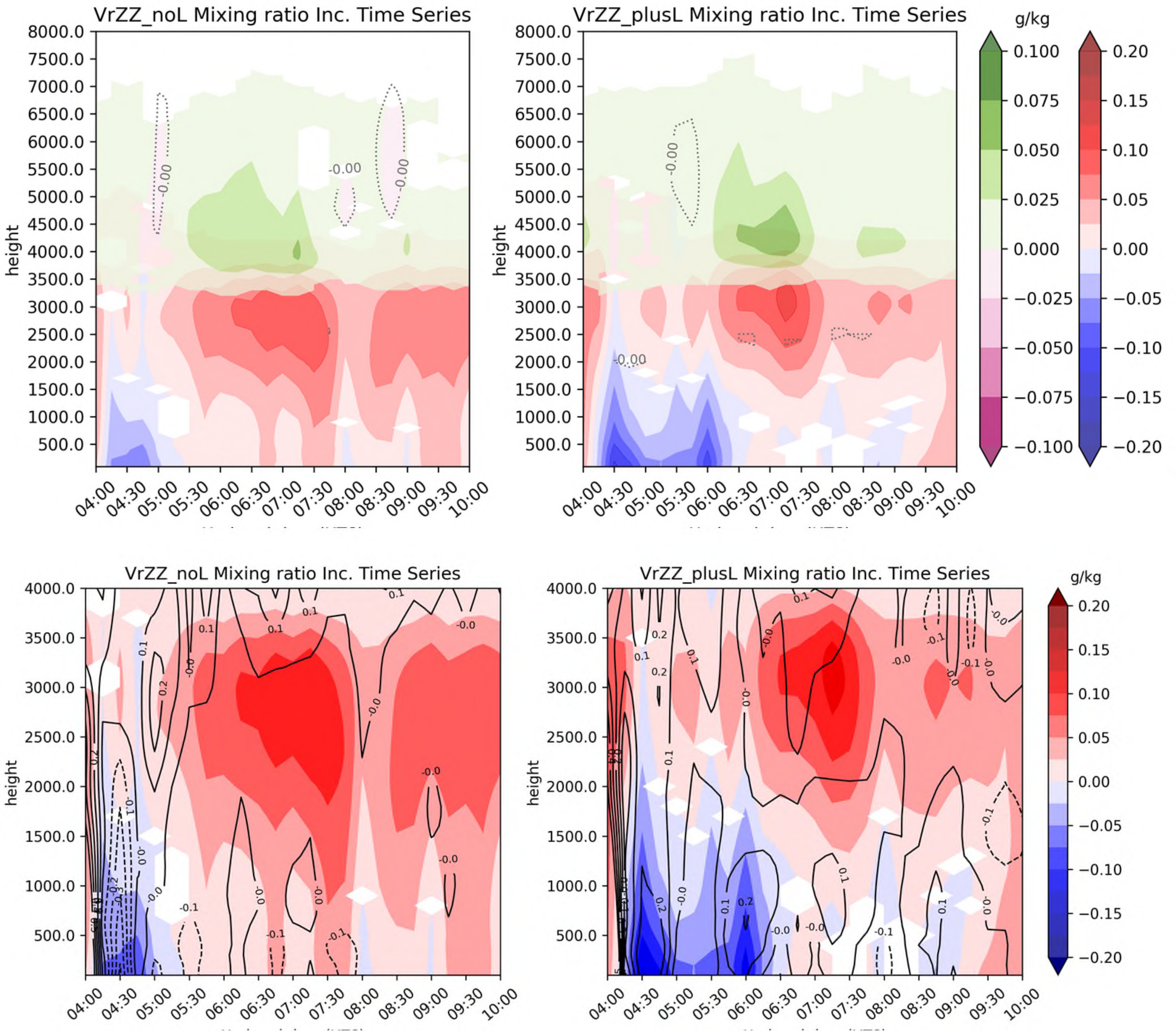
RaMeLab Website

@YES_TEAMR

YESR Mixing Ratio Increment (DA)

Qr (g/kg): blue-red shaded
Qs (g/kg): purple-green shaded
Qv (g/kg): black contour
Qs (g/kg): dotted line

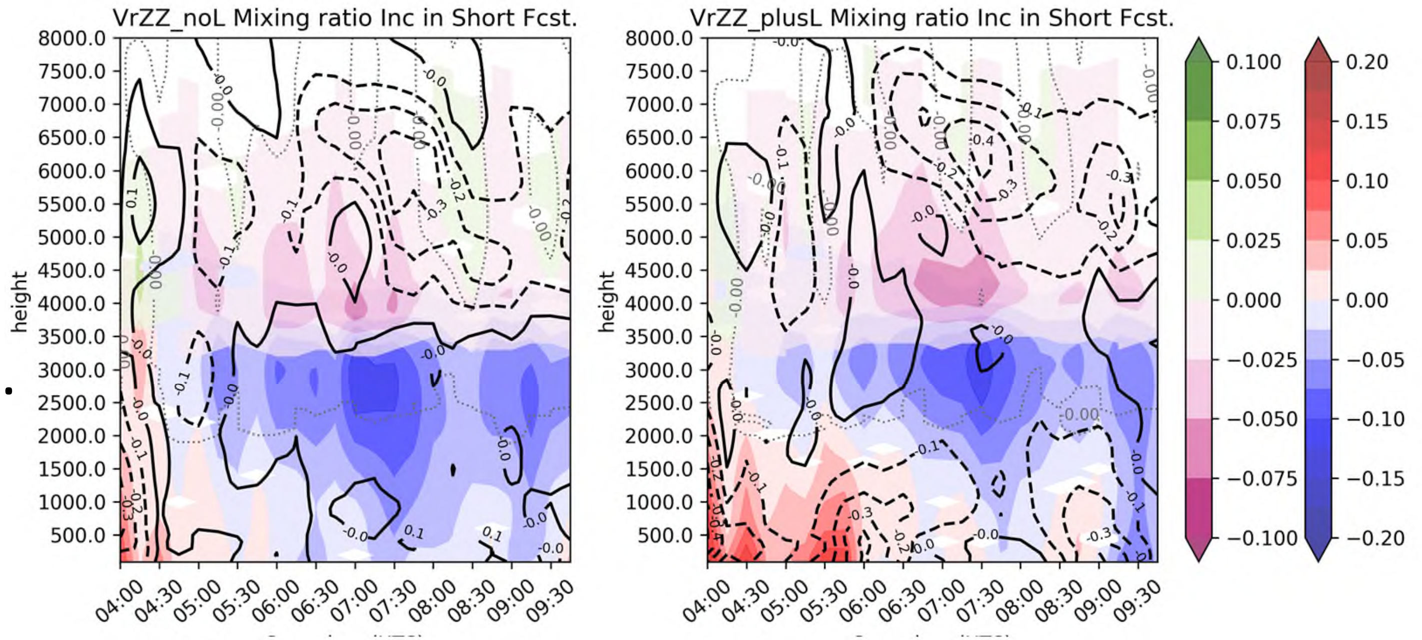
- ✓ Qr has positive increment at 2-4 km.
- ✓ Qs has positive increment above 3.5 km.
- ✓ Assimilate low-level dual-pol radar data into model leads to:
  1. Qr has negative increment nearby surface.
  2. Qr has much more positive increment.
  3. Qv has positive increment nearby surface, which is totally different from VrZZ_noL

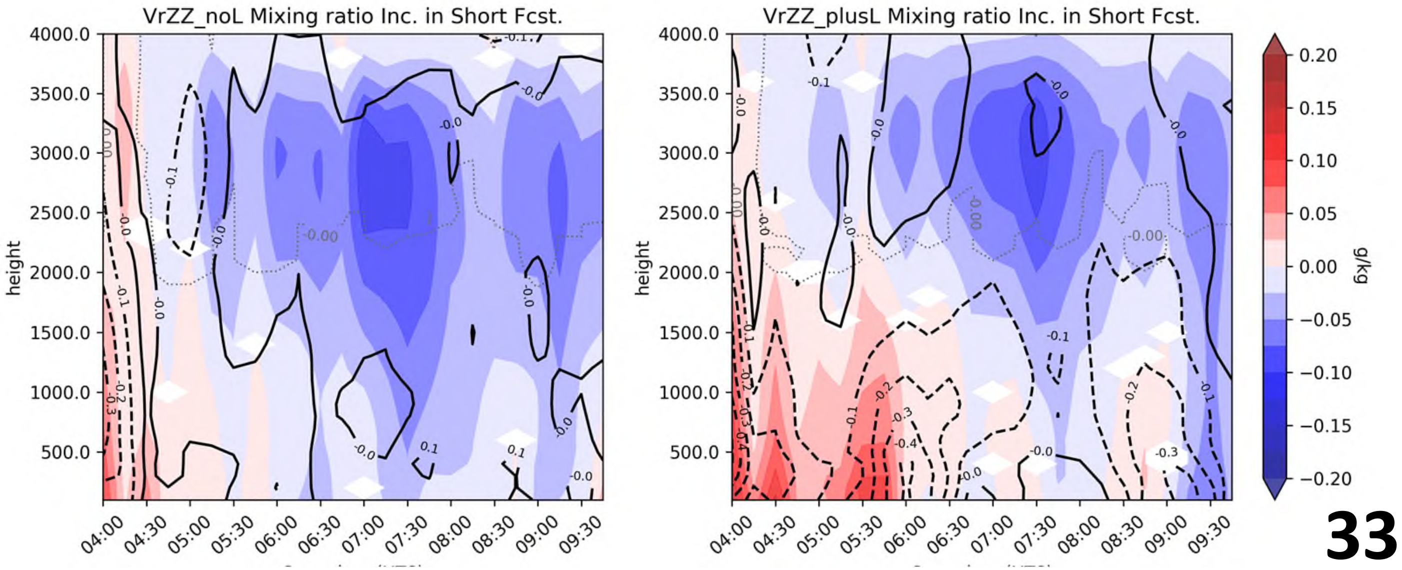


YESR Mixing Ratio Increment (Short Fcst)

Qr (g/kg): blue-red shaded
Qs (g/kg): purple-green shaded
Qv (g/kg): black contour
Qs (g/kg): dotted line

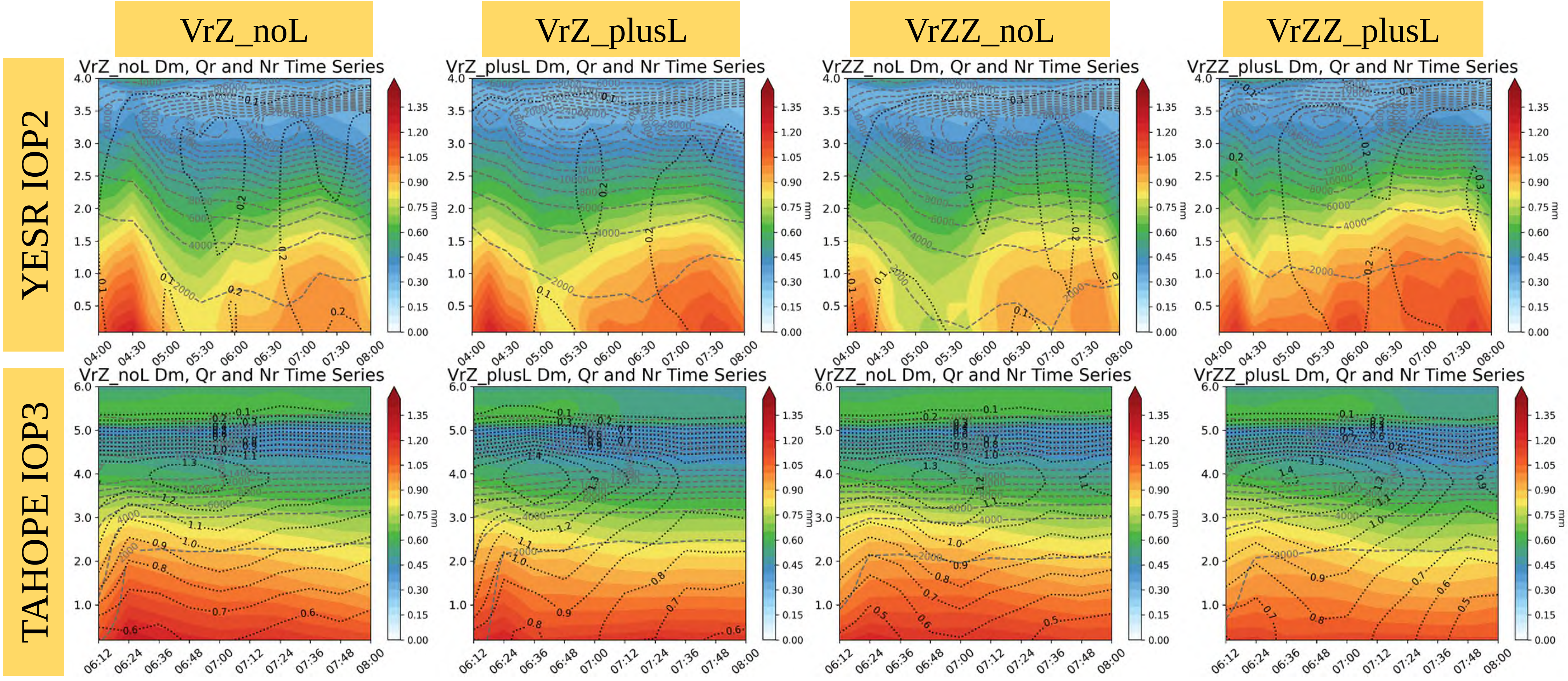
- ✓ Qr has negative increment at 1-4 km.
- ✓ Qs has negative increment above 3.5 km.
- ✓ Assimilate low-level dual-pol radar data into model leads to:
    1. Qr has positive increment nearby surface before 0600 UTC.
    2. Qv has negative increment nearby surface, which is stronger than VrZZ_noL
- ✓ <u>**Short Fcst. dilute the inc. from DA.**</u>





Result & discussion

Time Series of raindrop mass-weighted Mean Diameter



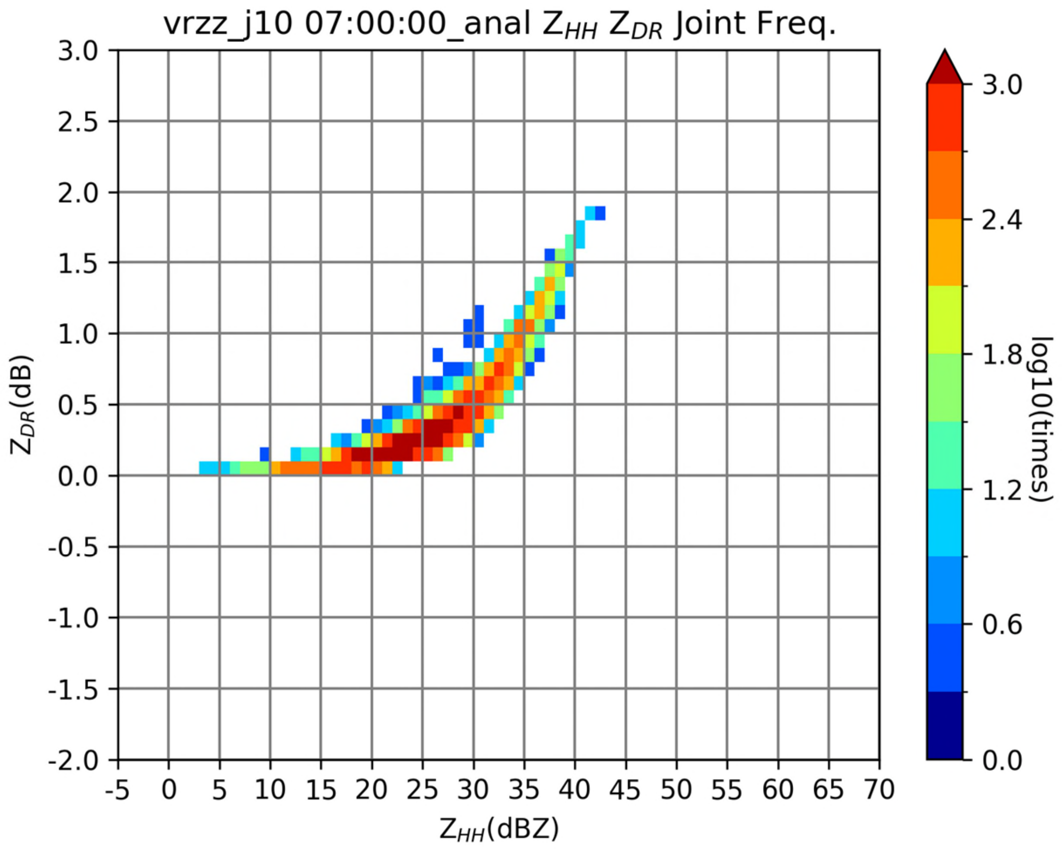
- X-axis : Time (UTC)
- Y-axis : Height
- Shaded : D_{mr} (g/kg)
- Gray Dotted: N_{Tr} (#/m^3)
- Dashed line: q_r (g/kg)

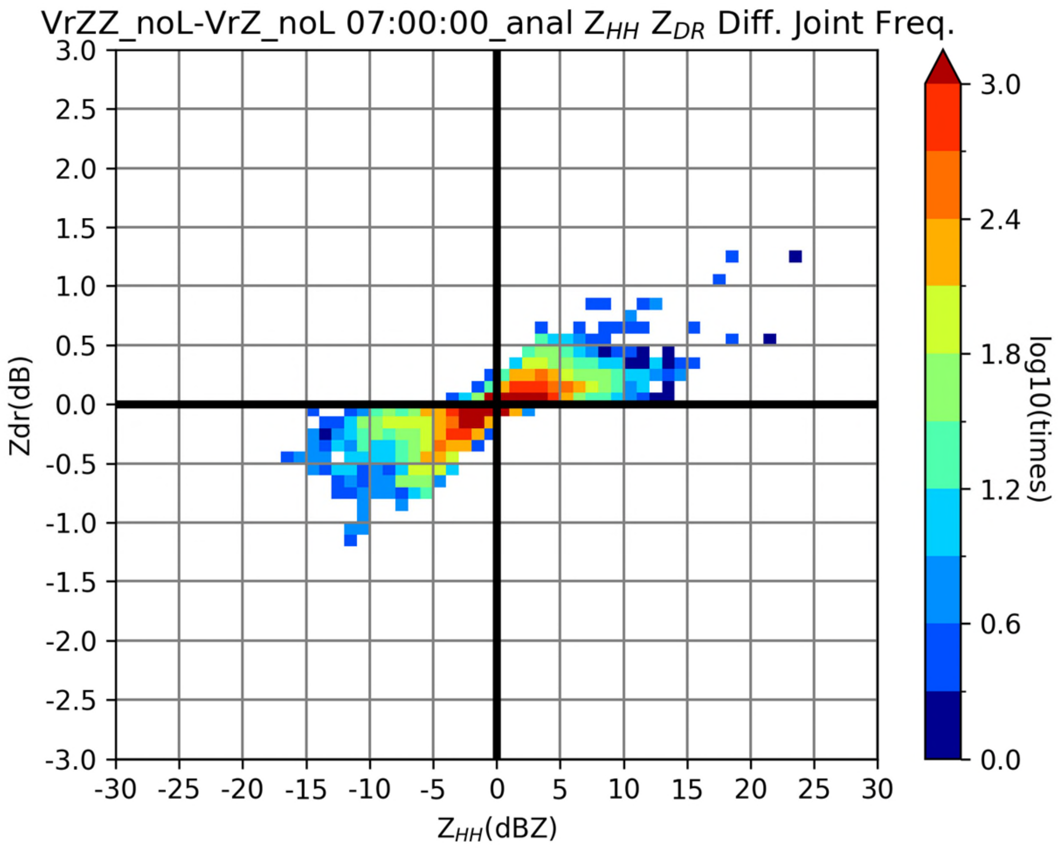
✓ Enhancement of the q_r and decreasing of the N_{Tr} lead the larger D_{mr} when assimilating low level radar data in the winter case.

✓ In the summer case, though the q_r is enhanced, the D_{mr} becomes smaller when assimilating after assimilating low-level radar.

Result & discussion

Same updated direction of Z_{HH} and Z_{DR}





- Z_{HH} and Z_{DR} are high correlated with using the certain setting of forward operator and microphysics scheme.
- The high correlation would leads the updates of Z_{HH} and Z_{DR} at the first and the third quadrant.