Heavy rainfall prediction during the Meiyu seasons in Taiwan with the WRF-LETKF system: what we have learned from the SoWMEX IOP8 event

Shu-Chih Yang[1,2],
Shu-Hua Chen[3], Hsiang-Wen Cheng[1], Chih-Chien Tsai[4],
, Takemasa Miyoshi[5], and Keiichi Kondo[5]

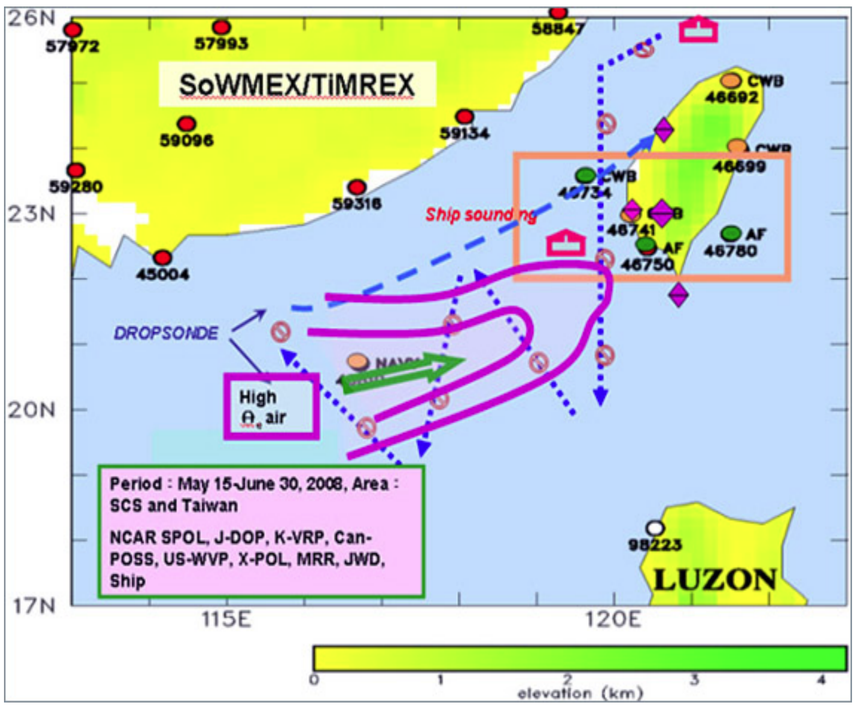
[1] Depart. Of Atmospheric Sciences, National Central University, Taiwan
[2]GPS Science and Application Research Center, Taiwan
[3] University of California at Davis, USA
[4] Taiwan Typhoon Flood Research Institute, Taiwan
[5] AICS/RIKEN, Japan

DALAB
NCU Data Assimilation and Predictability Lab

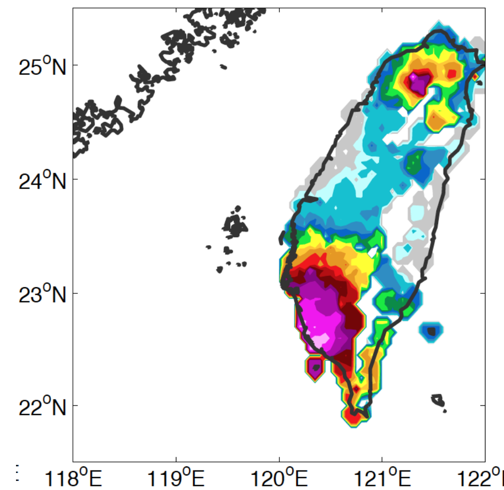
Motivation

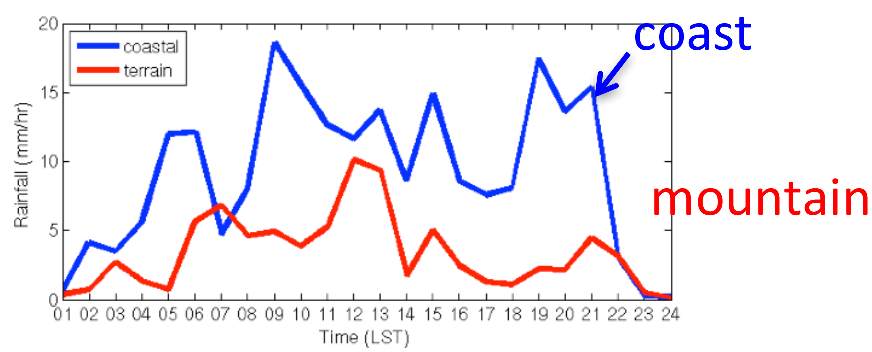
Predicting the heavy rainfall during Meiyu seasons

- Mei-Yu precipitation in Taiwan is a product of multi-scale interactions among convective cloud, Mei-Yu front, southwesterly jet, and the topography effect (SoWMEX /TiMREX).
- Heavy rainfall prediction during Meiyus is challenging.



Rainfall accumulation on 2008/06/16



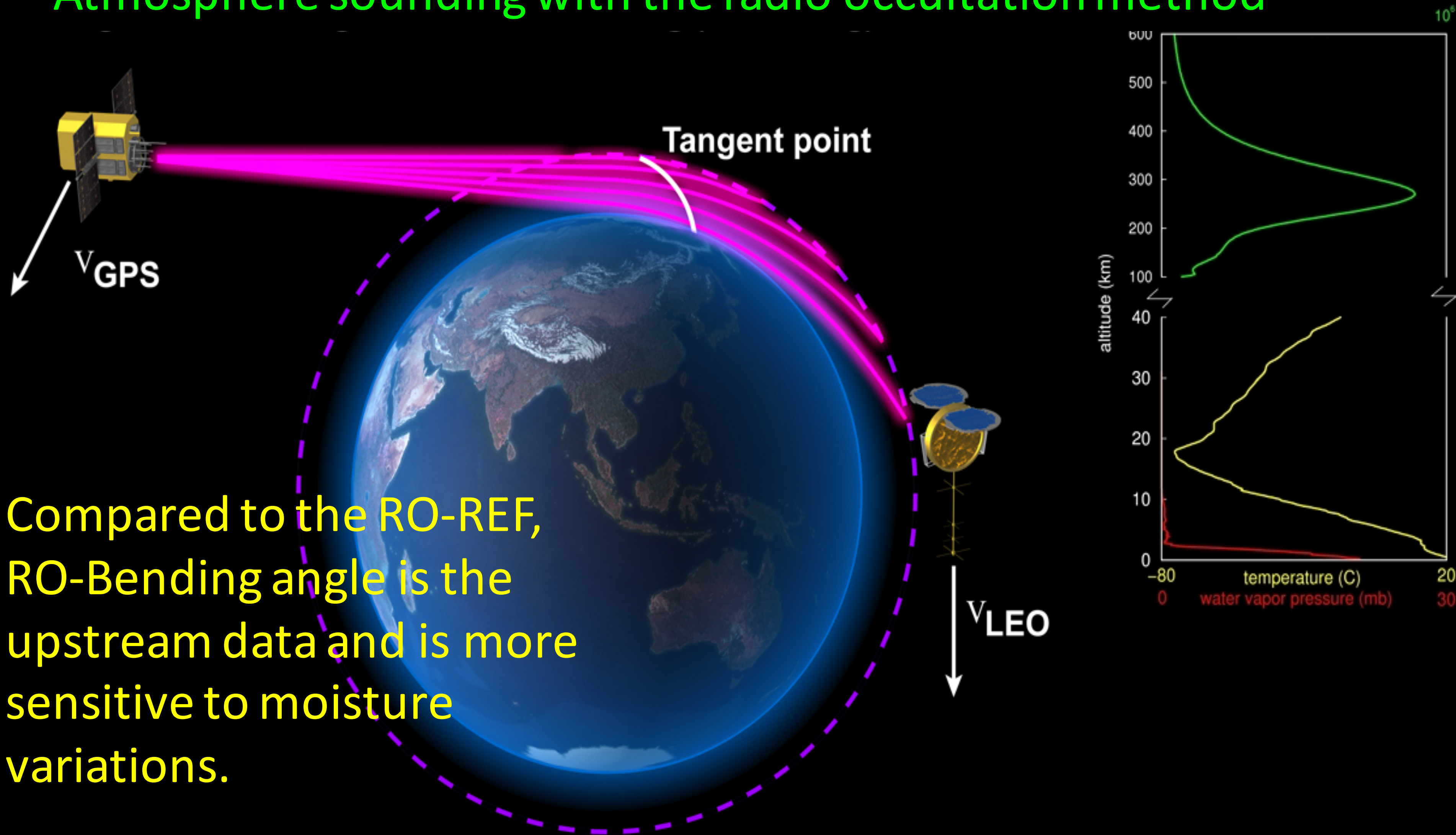


Outline

1. Impact of GPS-Radio Occultation data
2. Rainfall prediction with the dual-resolution, dual-scale assimilation
3. Further improvement with the radar data assimilation

Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC)

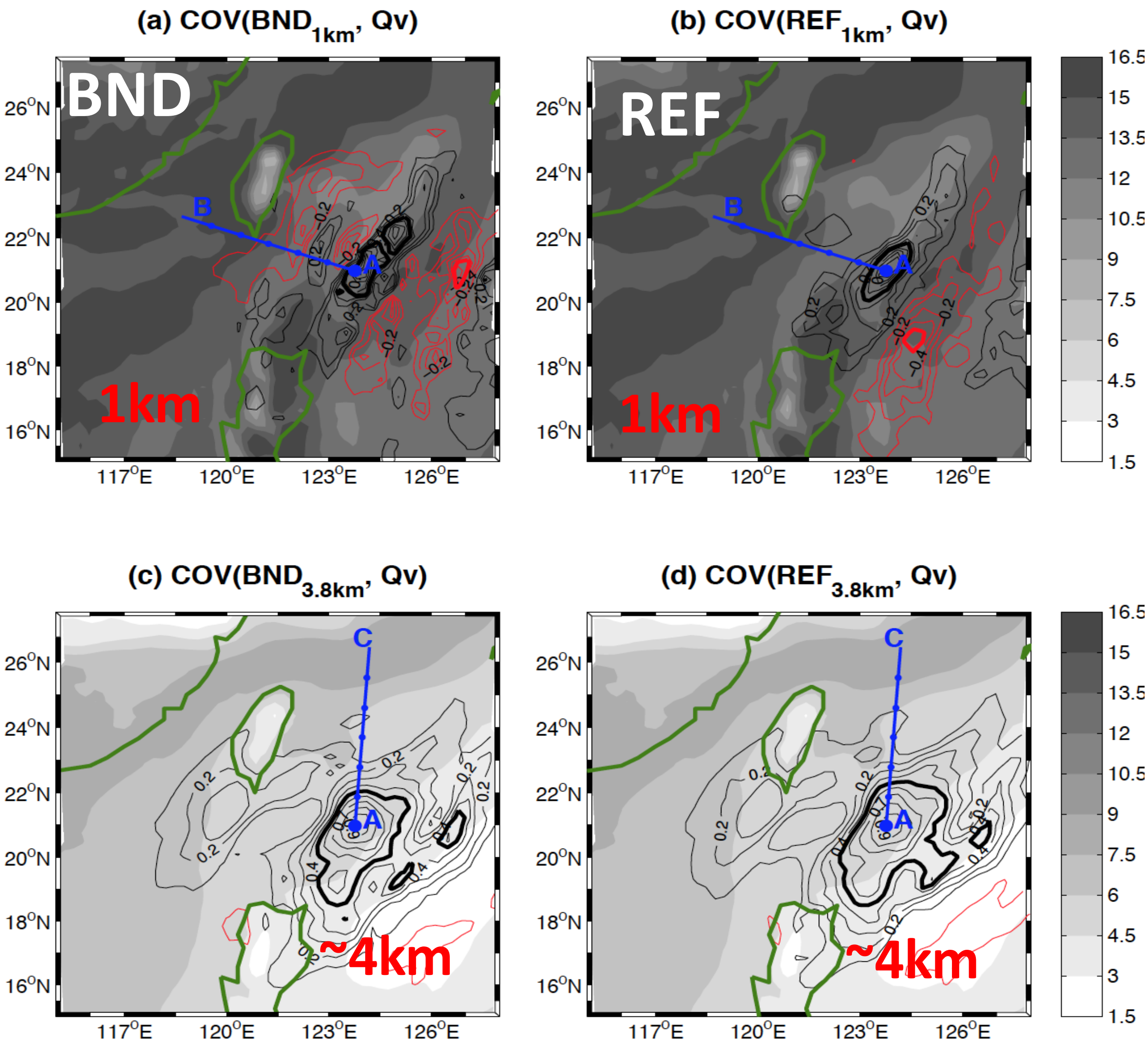
Atmosphere sounding with the radio occultation method



Compared to the RO-REF, RO-Bending angle is the upstream data and is more sensitive to moisture variations.

Refractivity vs. Bending angle

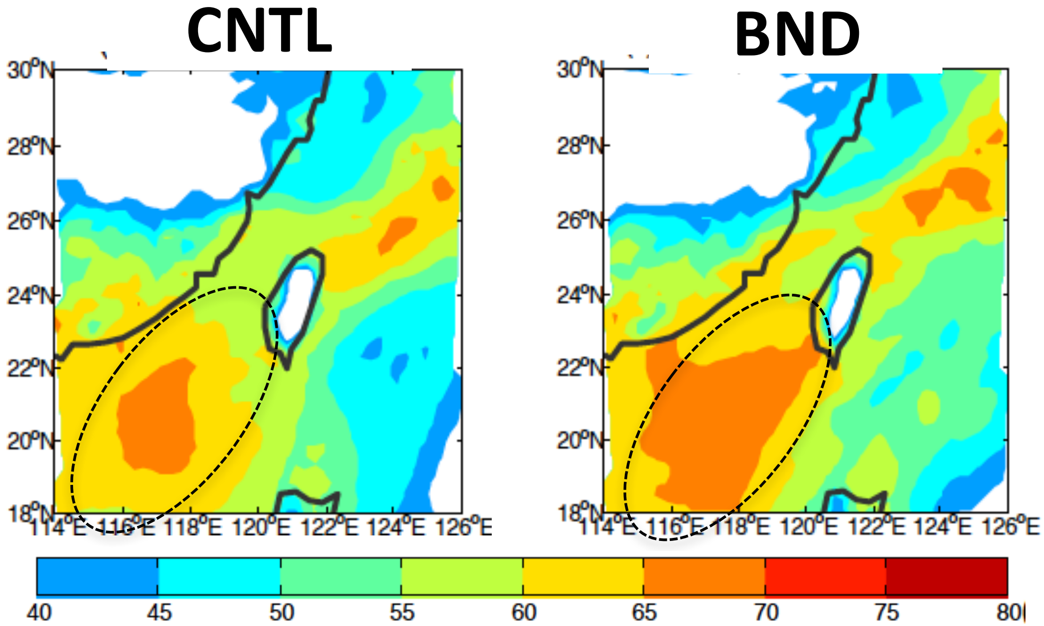
Qv (shading) vs. COV(y_b, Qv) (contour)

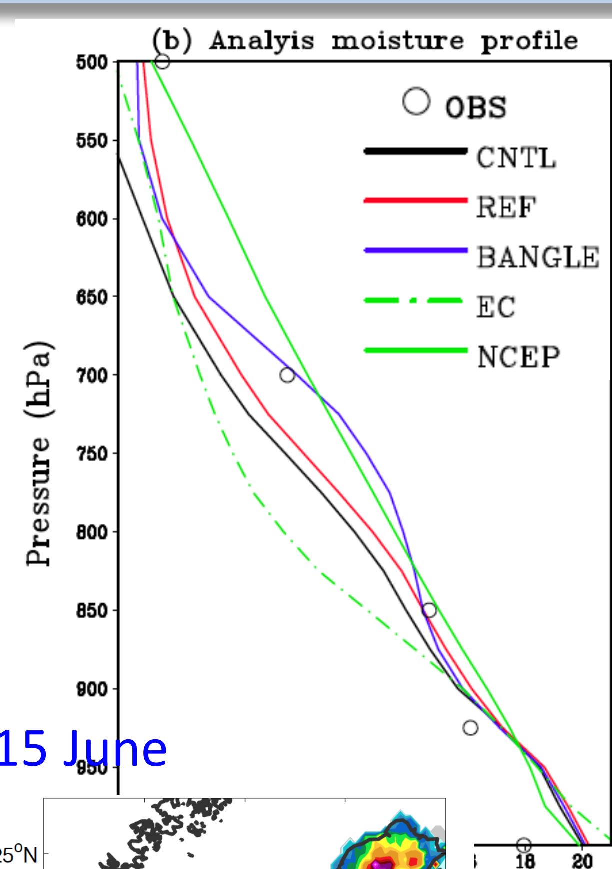


BND has the great potential to improve the low level moisture field!

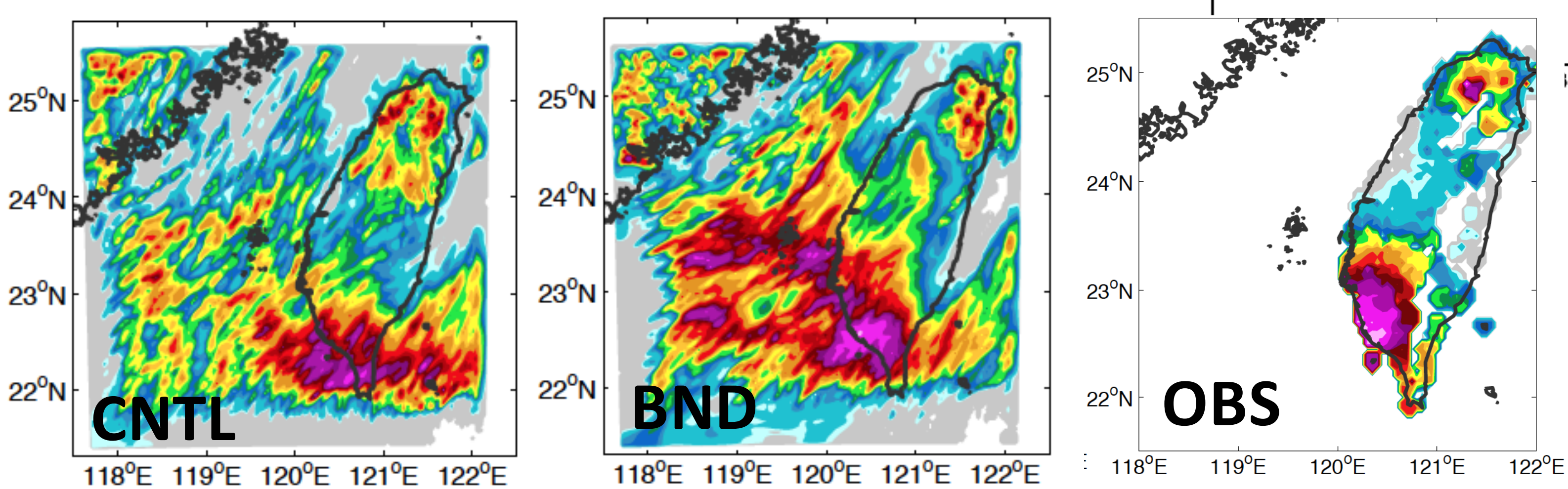
Moisture analysis (27km) and rainfall forecast (3km)

Total precipitable water at 1200UTC 15 June





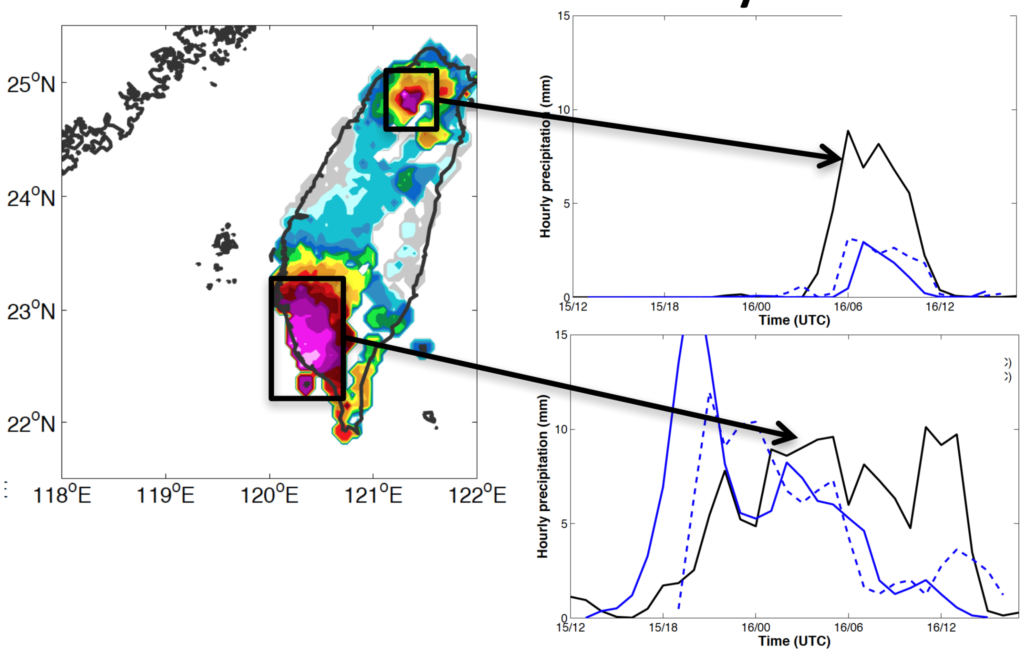
Mean rainfall prediction initialized at 1200UTC 15 June



Yang et al. 2014

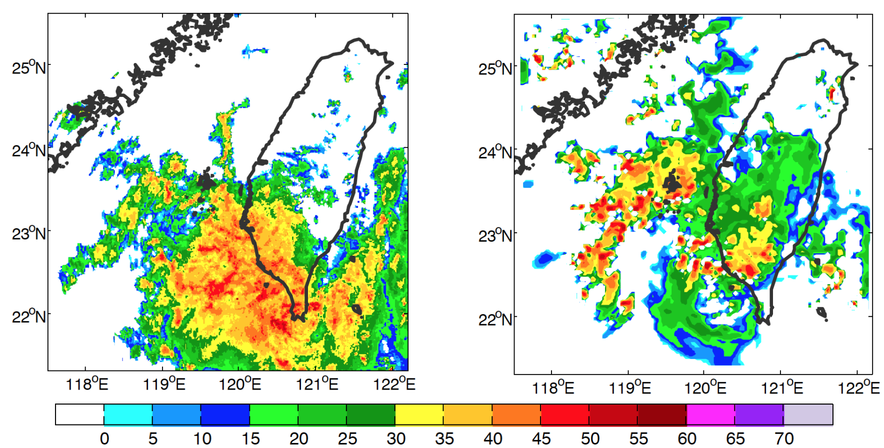
Short-term precipitation intensity

Hourly rainfall



Observation
Forecast initialized at 15/12Z)
Forecast (initialized at 15/18Z)

QPESUM 16 0300UTC **Max Reflectivity (Forecast)**

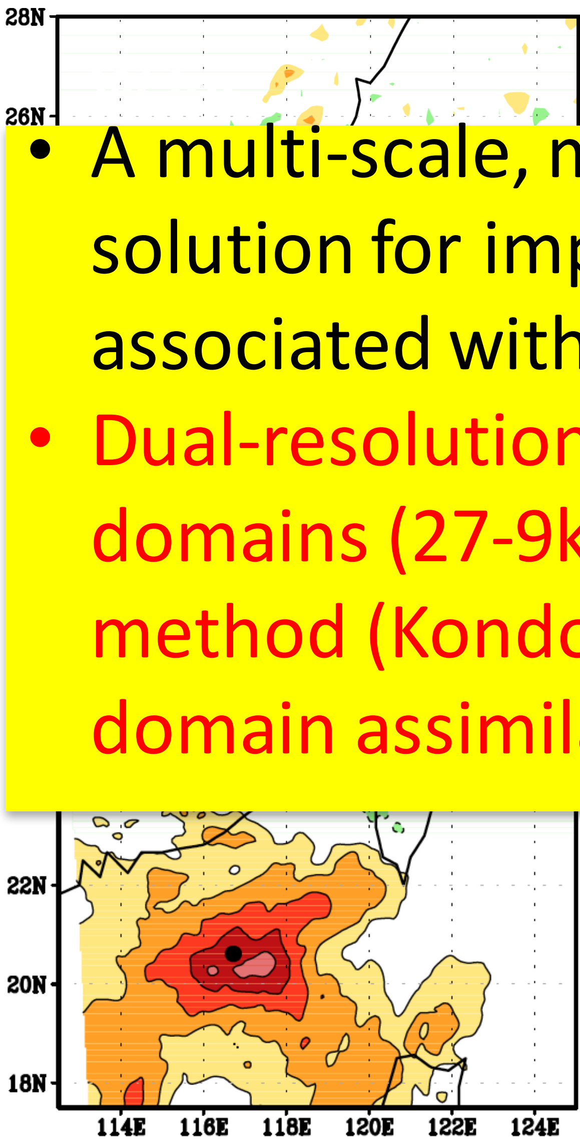


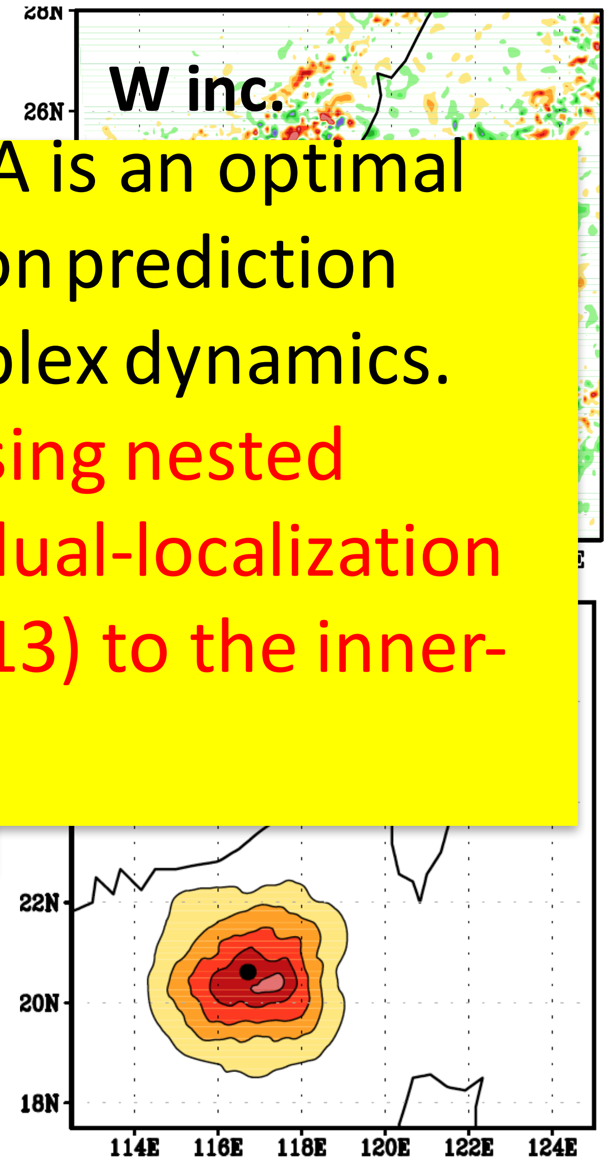
- Less optimal in short-term rainfall intensity!
- Need to better represent the convective-scale characteristics!

Dilemma in representing convective precipitation during Mei-Yus

Low-resolution (27km), large localization

High-resolution (9km), small localization





- A multi-scale, multi-resolution DA is an optimal solution for improving convection prediction associated with multi-scale complex dynamics.
- Dual-resolution, dual-scale DA using nested domains (27-9km) applying the dual-localization method (Kondo and Miyoshi, 2013) to the inner-domain assimilation.

transport

Upstream info.

Multi-scale localization in ensemble-based data assimilation (Kondo and Miyoshi, 2013)

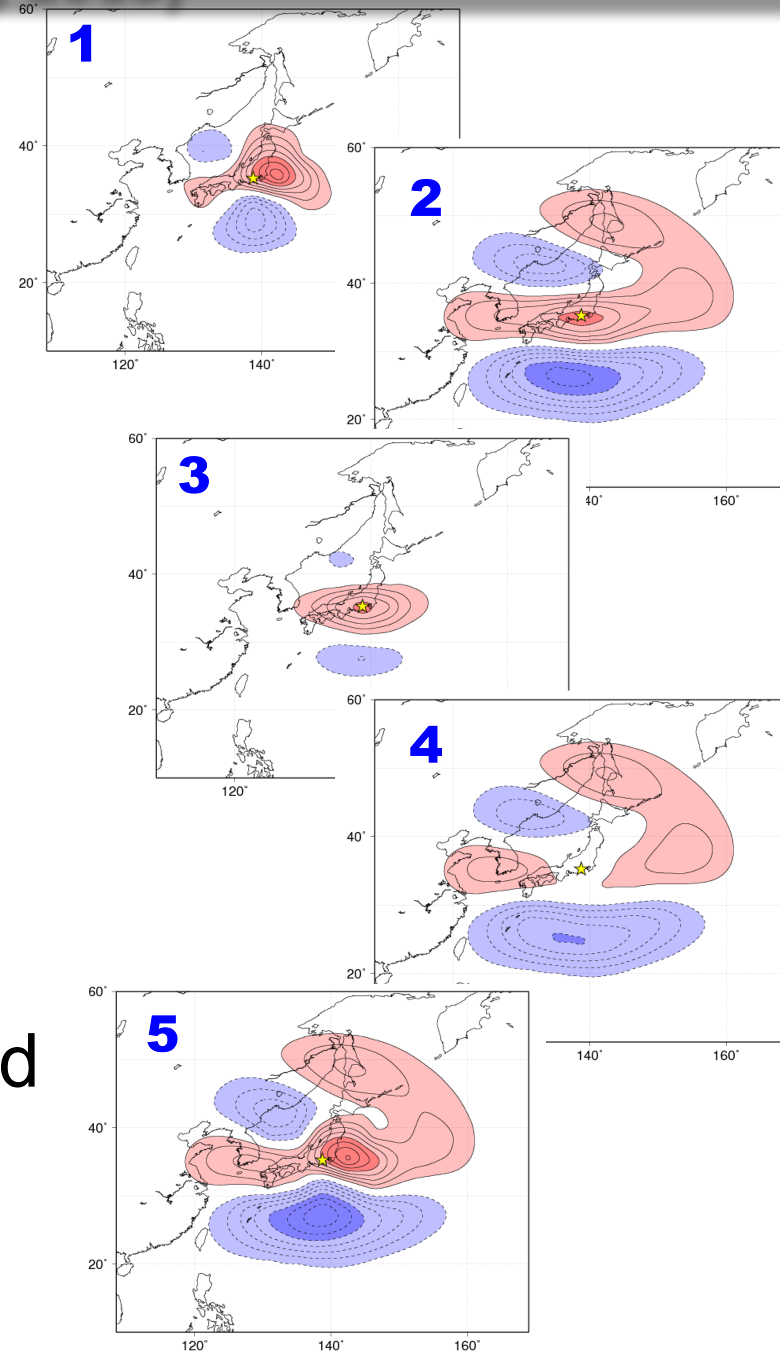
1. Compute the analysis increment regularly (with smaller-scale localization)

2. Compute the analysis increment with smoothed ensemble perturbations
   (with larger-scale localization)

3. Compute the analysis increment with smoothed ensemble perturbations
   (with smaller-scale localization)

4. Take the difference between 2 and 3

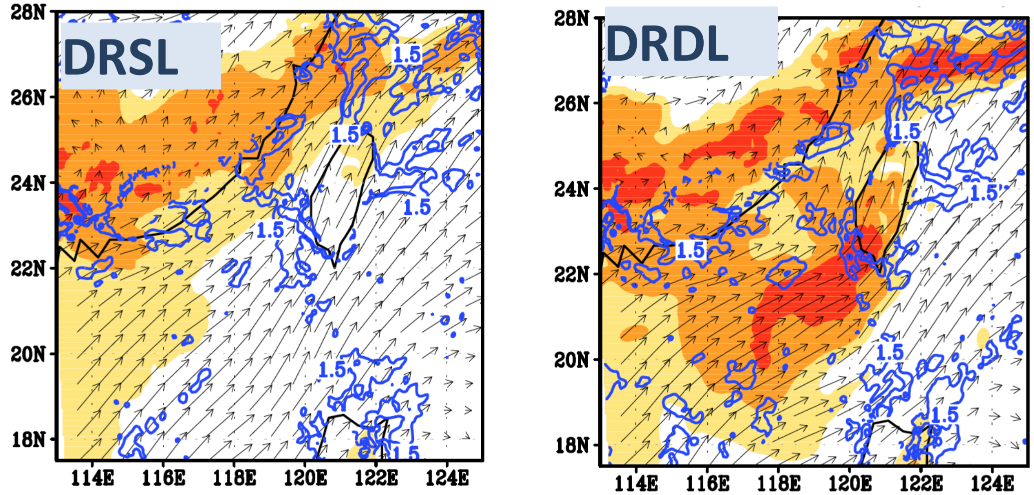
5. Add 1 and 4



Moisture transport in high-resolution grid

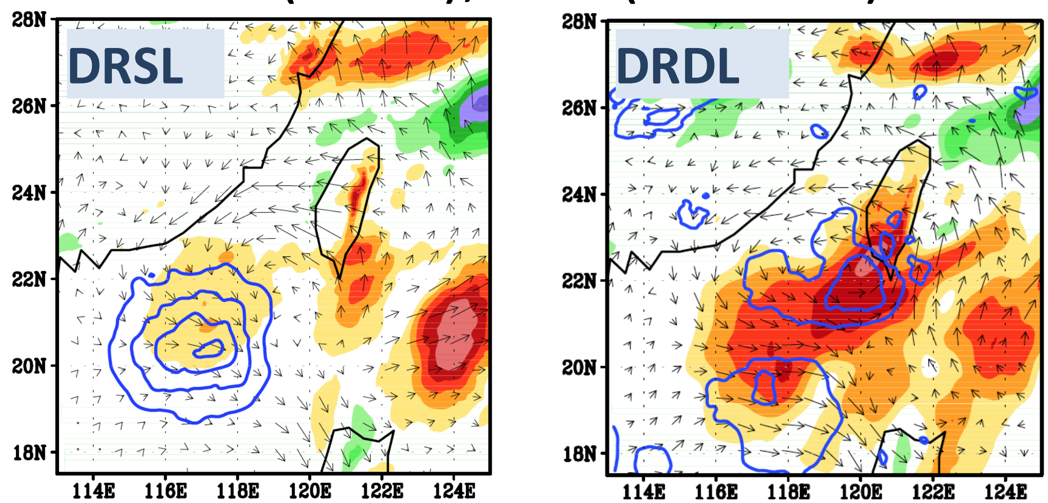
Qv at 750hPa (color) and convergence at 975hPa (contour)

Dual RES
Single LOC



Dual-RES
dual-LOC

Qv Inc. (color), U>0 (contour)

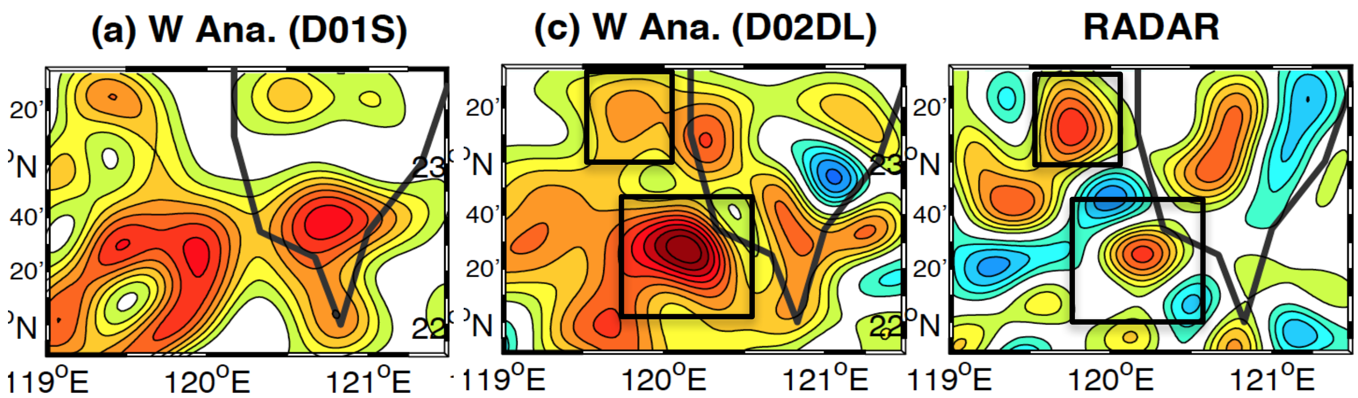


Convective-scale corrections in high-resolution grid

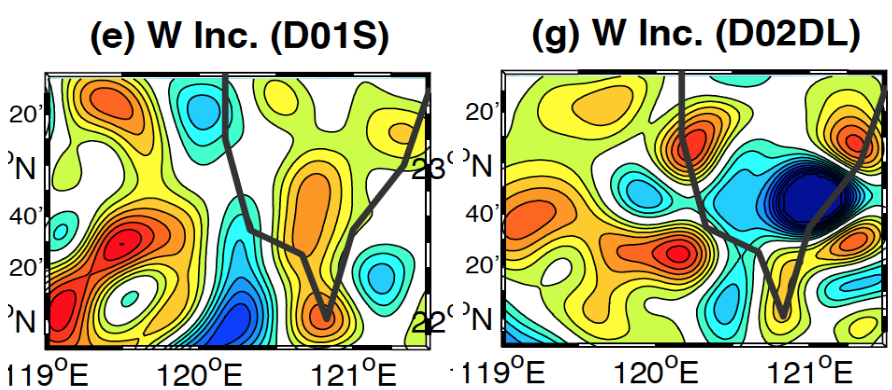
Single RES, single LOC

dual RES dual LOC

WISSOM

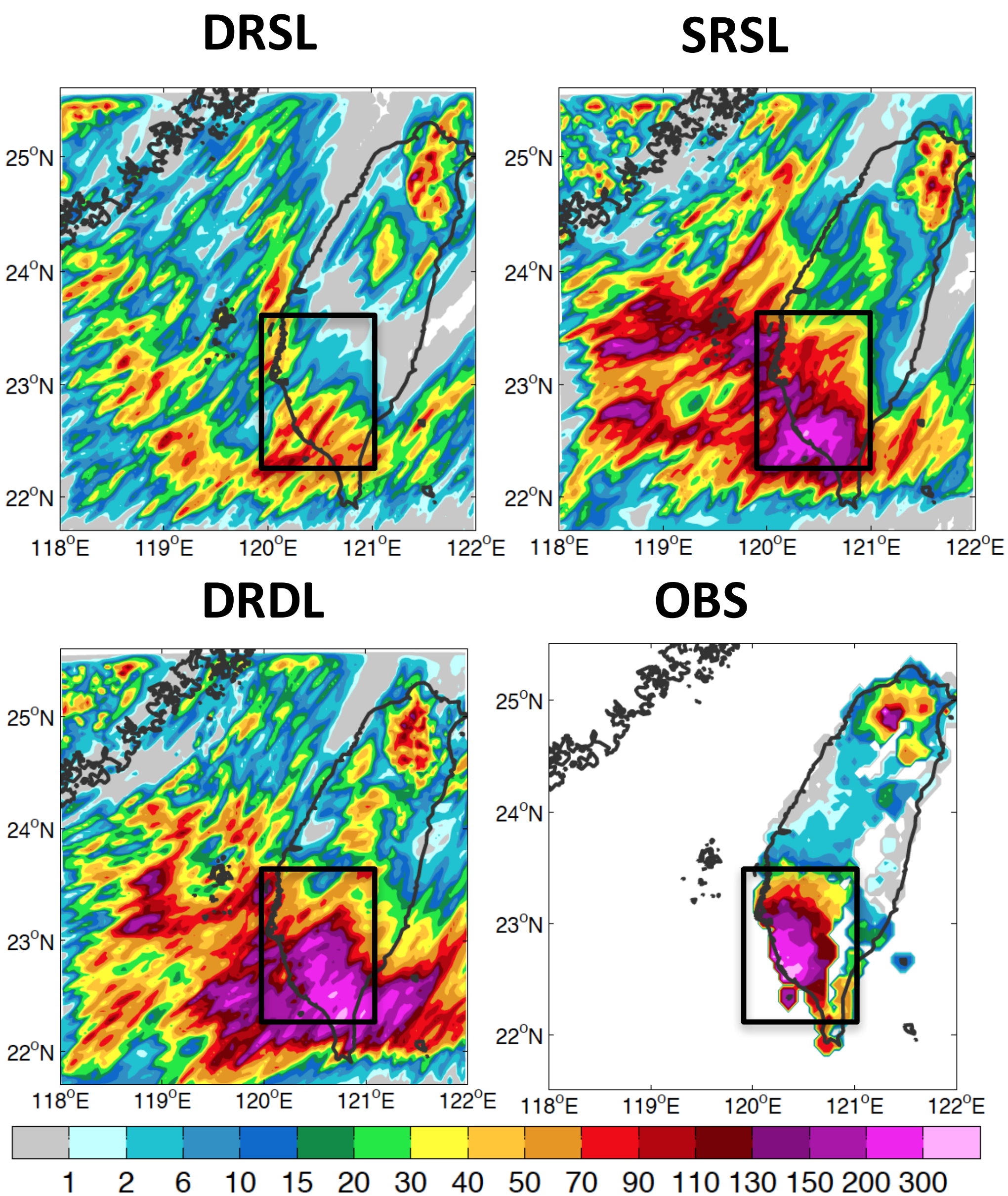


Analysis increment



DRDL can better represent the convective-scale characteristics of vertical velocity!

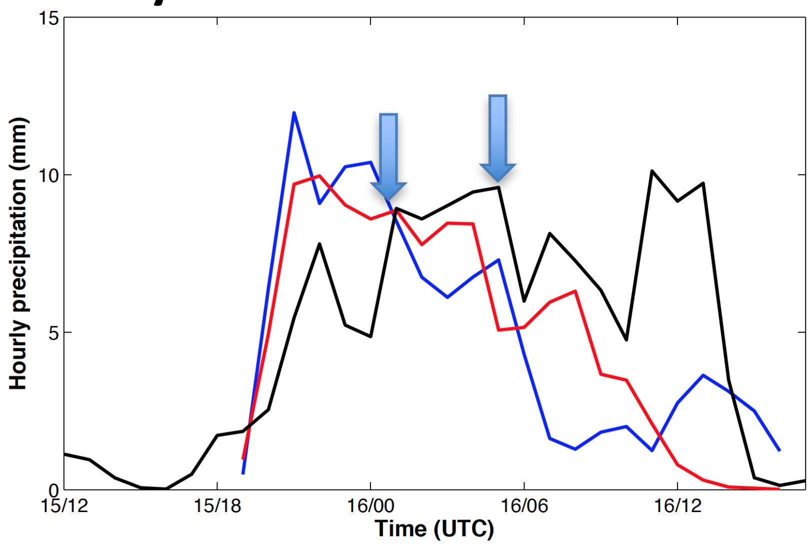
24-h accumulated precipitation on 06/16/ 2008

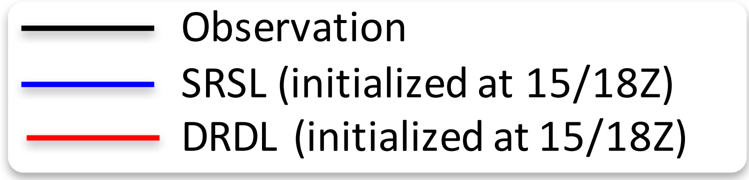


- The correct description about large-scale moisture transport helps to predict the overall intensity and location of accumulated rainfall.
- The rainfall amount is significantly reduced in DRSL.

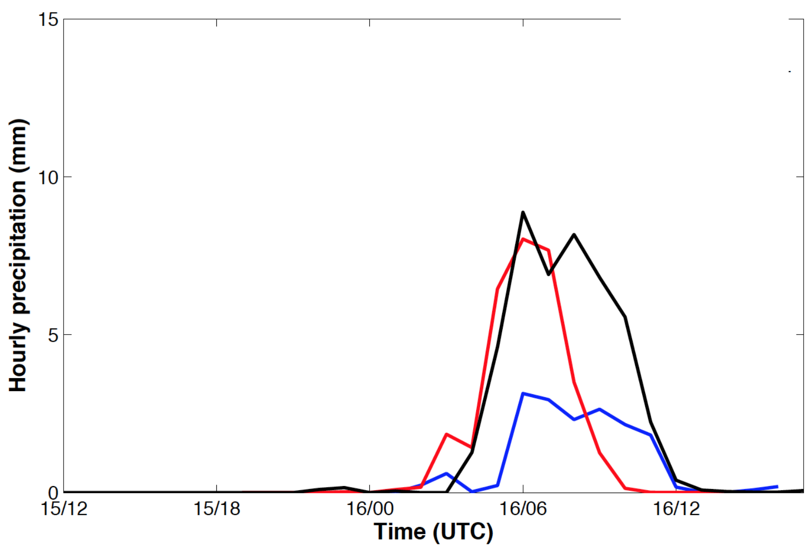
Short-term precipitation intensity

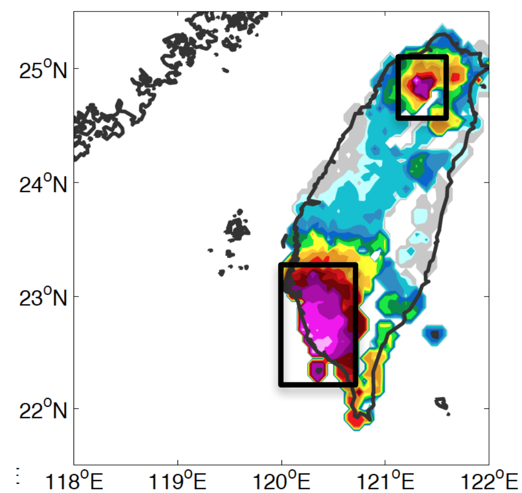
Hourly rainfall at southwestern TW





Hourly rainfall at northern TW

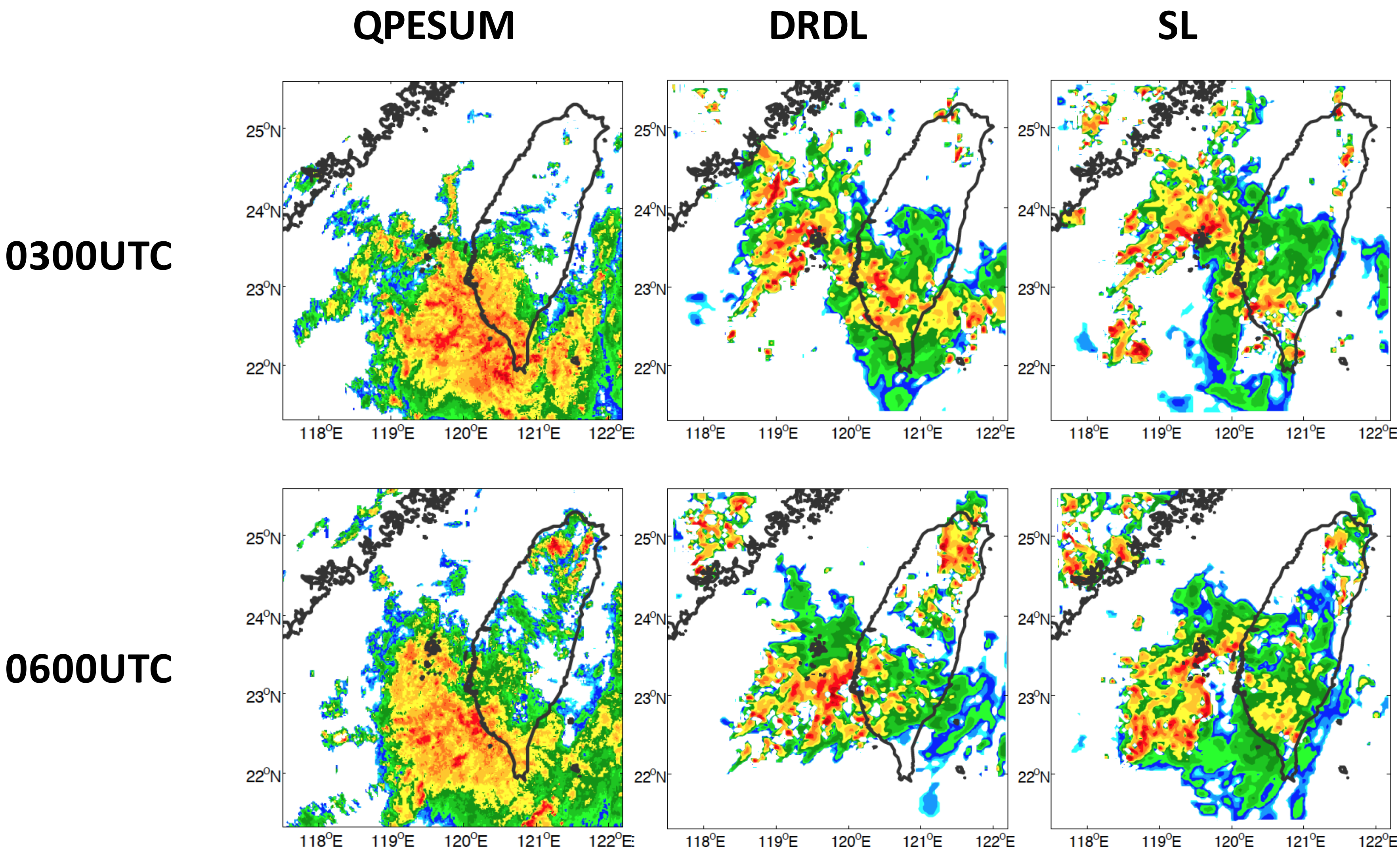




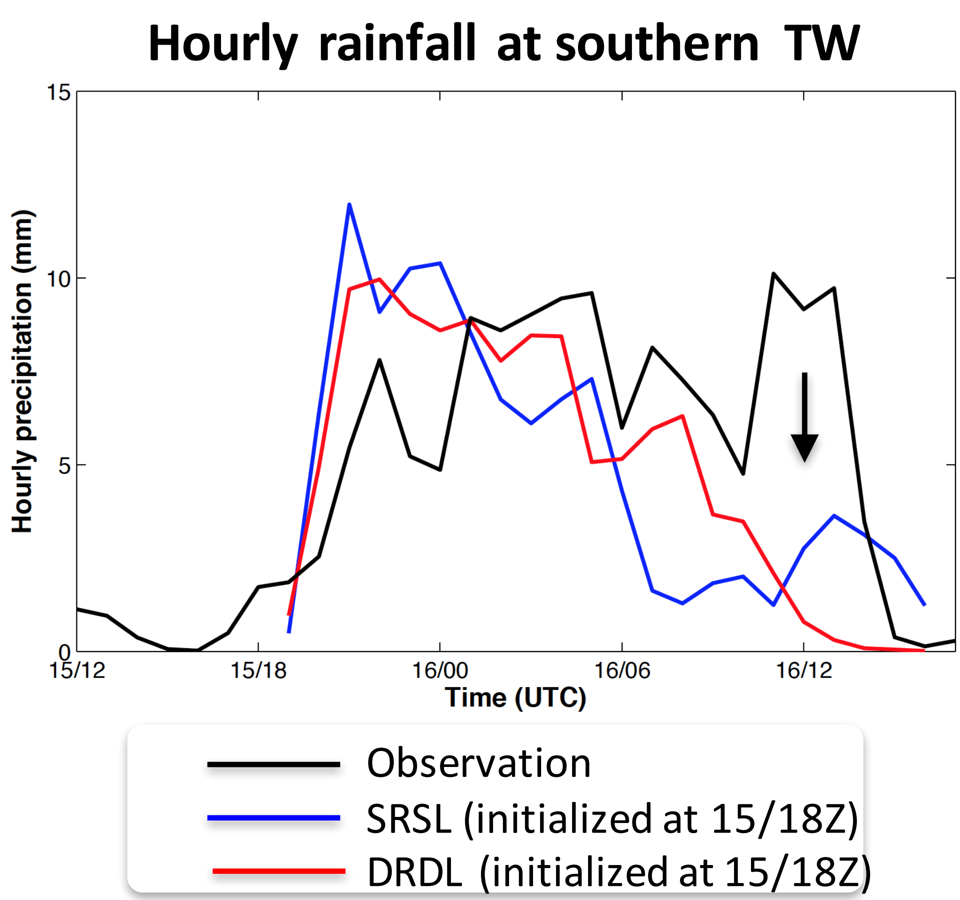
The DL method helps better represent the short-term precipitation intensity!

Short-term precipitation intensity

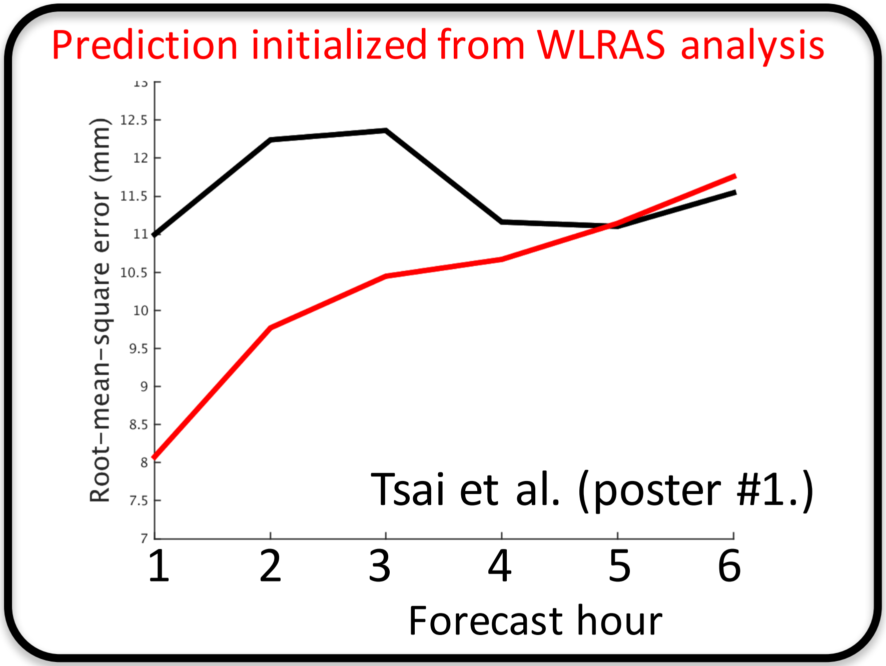
The DL method helps better represent the short-term precipitation intensity!



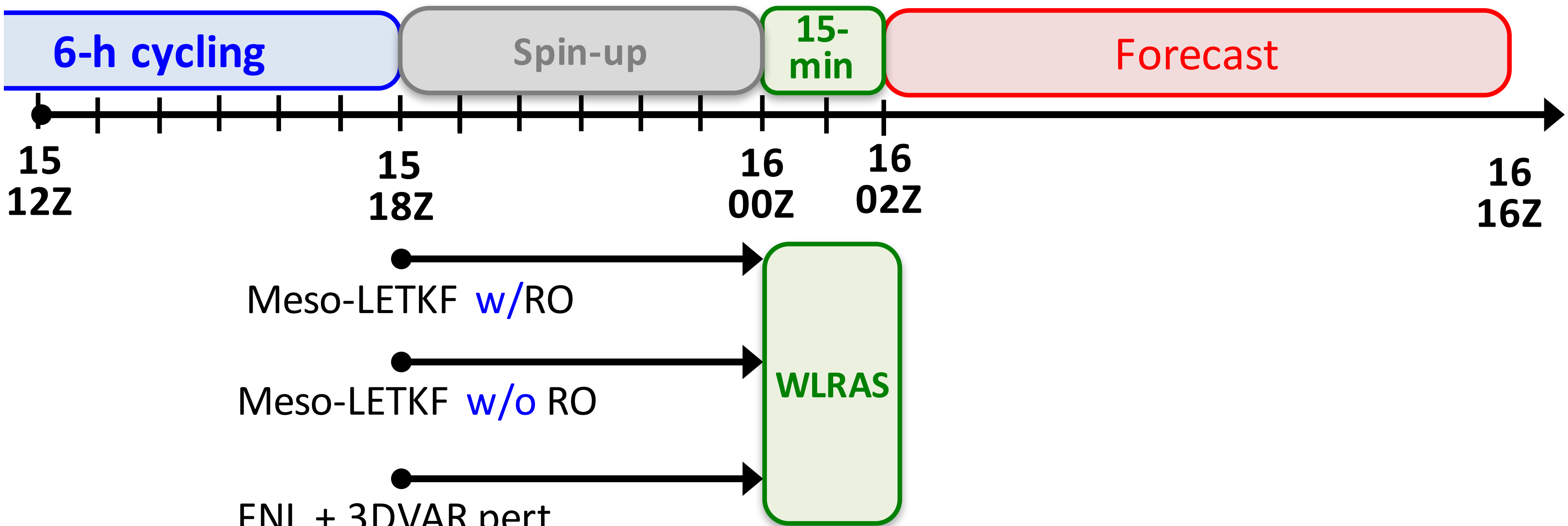
Short-term precipitation intensity



- Unable to capture the intense rainfall at evening
- Can we further improve the rainfall prediction with radar assimilation?
- The observation impact on the heavy rainfall prediction from radar data assimilation is < 6-hr.

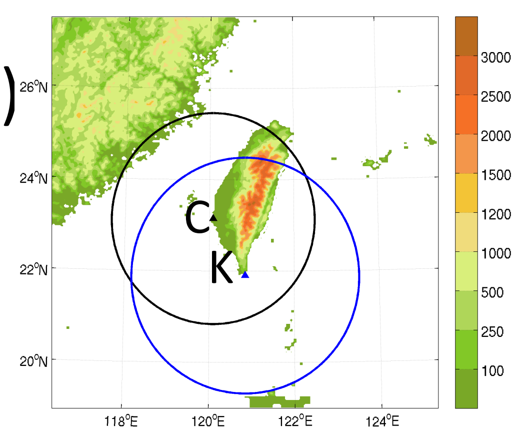


Experiment setup

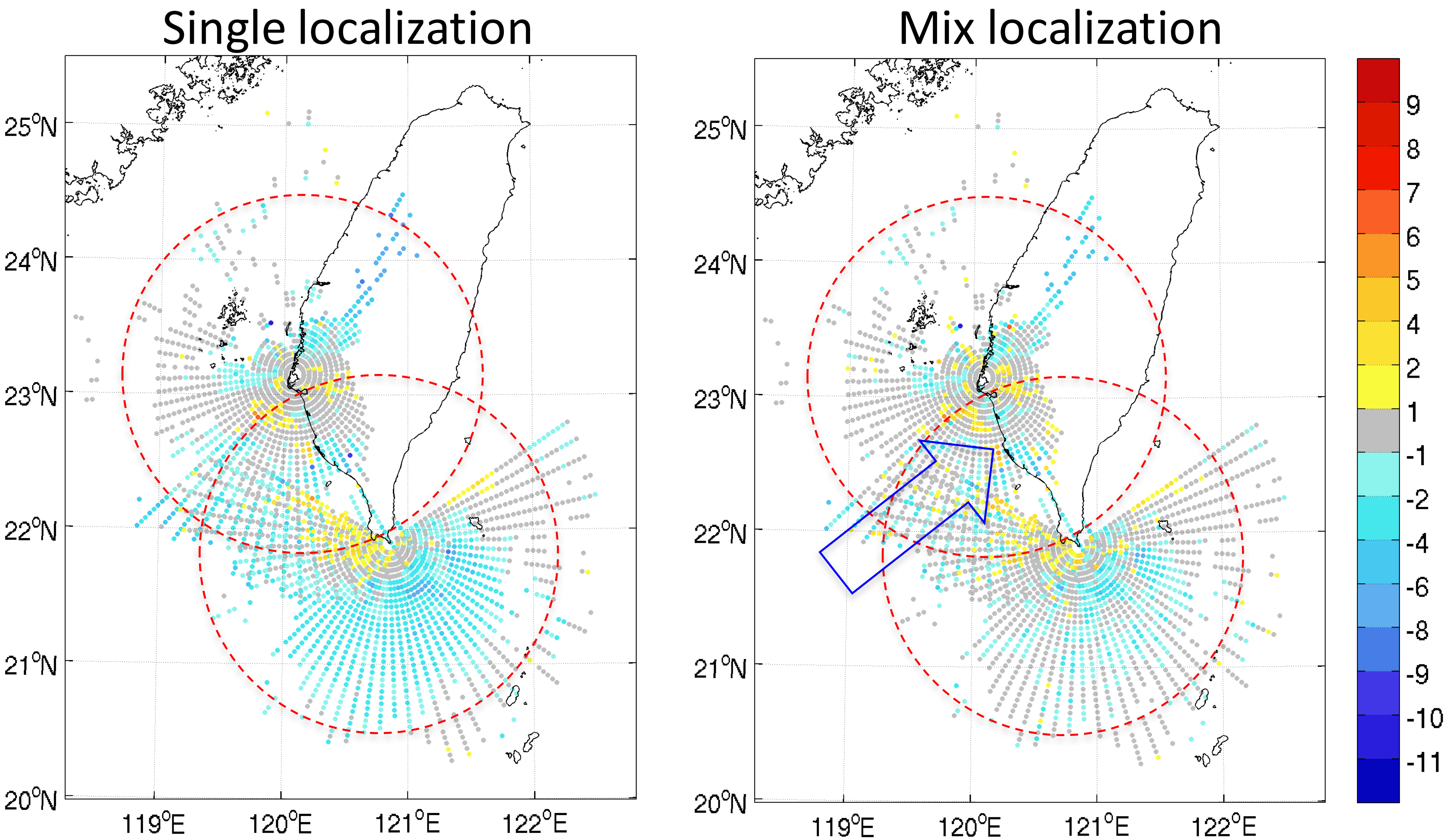


WRF-LETKF Radar Assimilation System (WLRAS, poster #1)

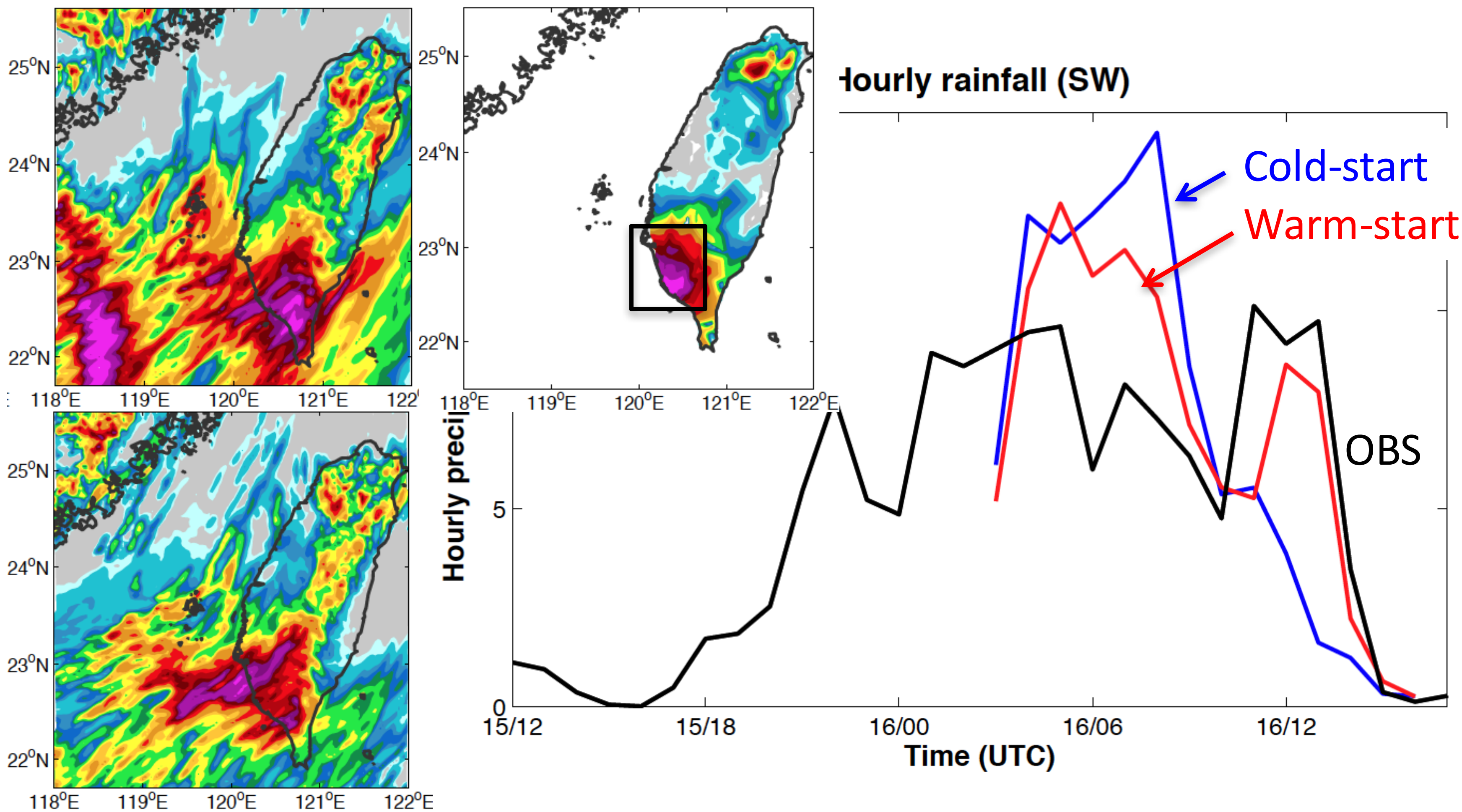
- 15-min analysis cycle performed at the 3-km domain
- Assimilate both Vr and Zh
- Mix localization (U,V large, W, Qr small)
- Radar at Chigu and Kengtin



O-A (Vr) at 0.5 degree (~ 1km)

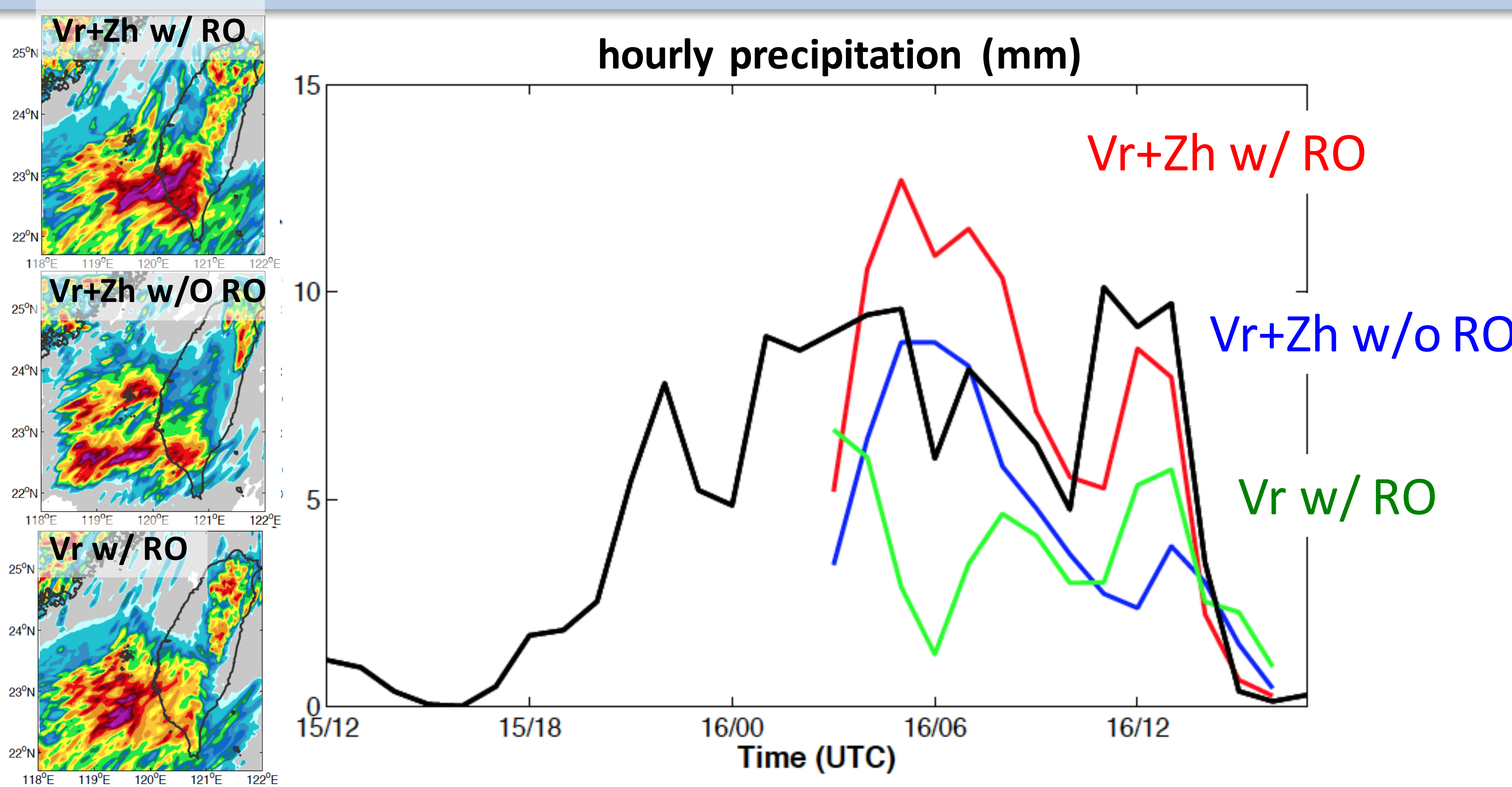


Precipitation prediction



The duration of heavy rainfall can be improved with a better environment condition, provided by the WRF-LETKF analysis with RO-bending angle!

Sensitivity experiments

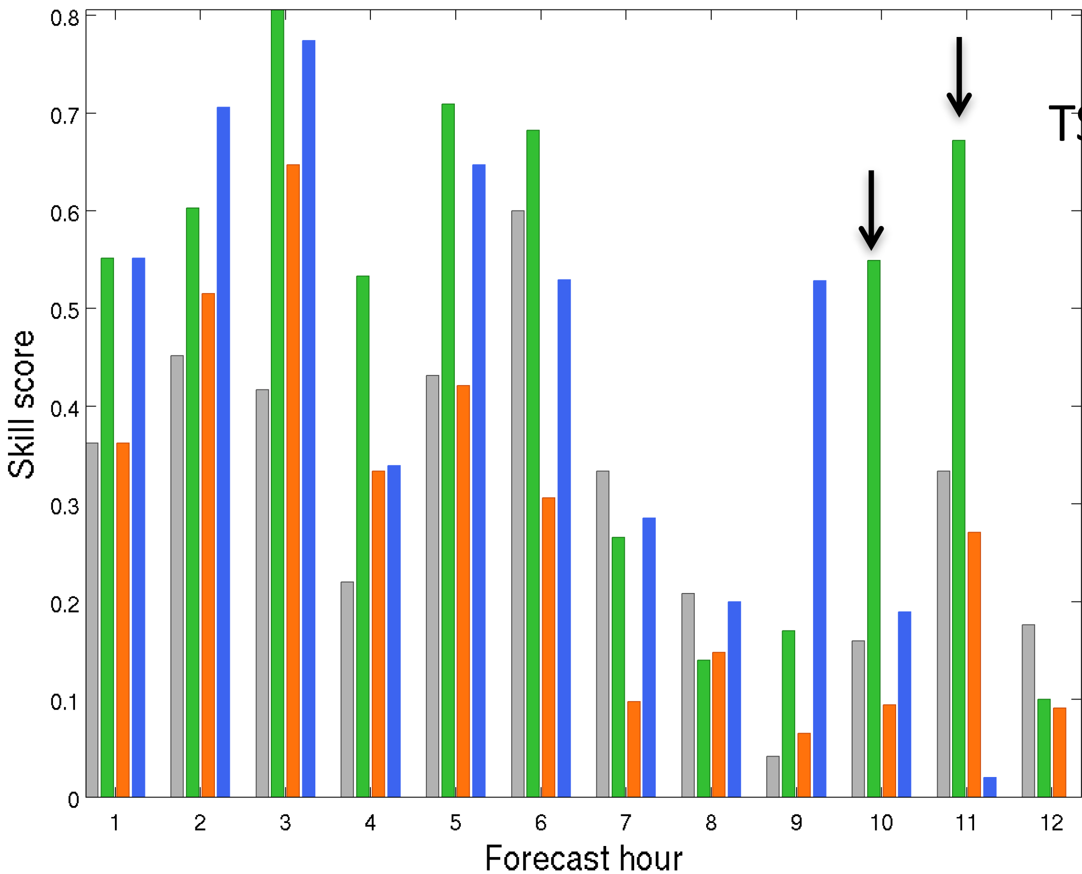


- The environment for radar assimilation is critical for the performance of WLRAS
- Zh is critical for precipitation intensity prediction

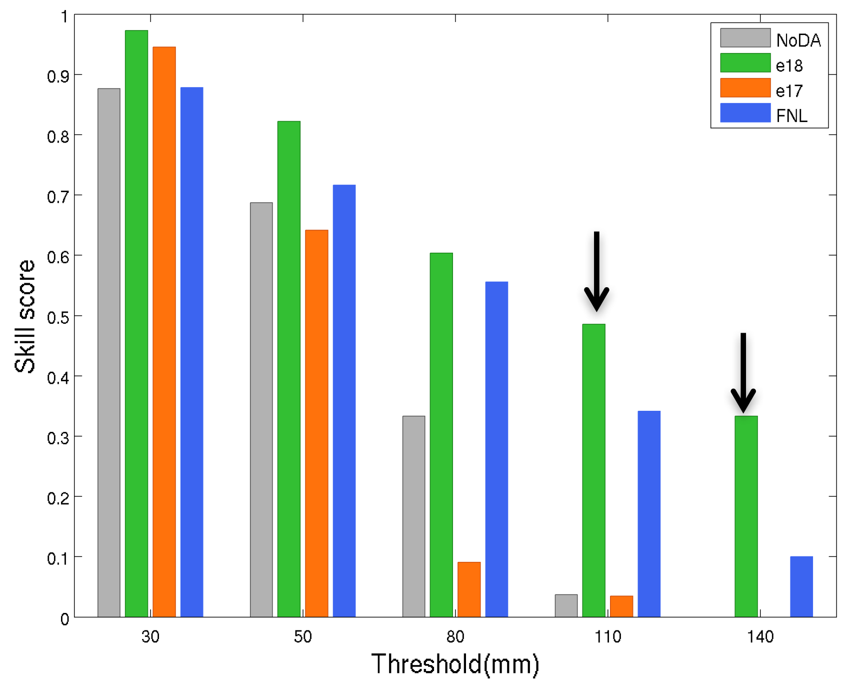
Forecast skill

NoDA
LETKF W/RO
LETKF W/O RO
Cold start

Hourly TS score (5mm/hr)



TS based on 13-h rainfall accumulation

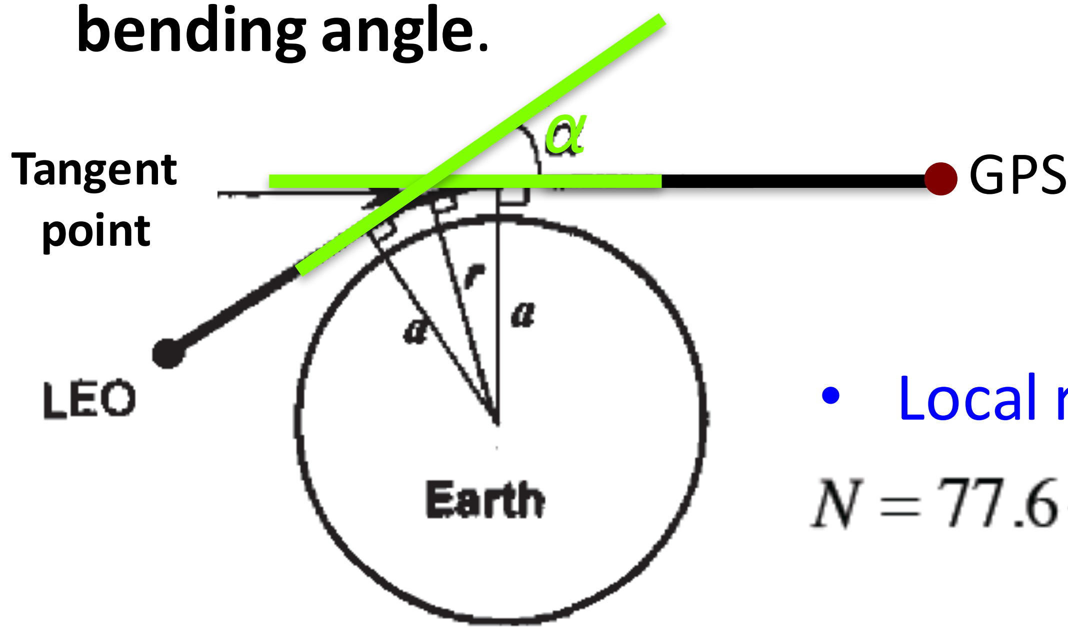


Conclusion

- To predict the heavy rainfall during the Meiyus, both the synoptic-scale moisture transport from South China Sea and convective-scale corrections from offshore to coastal region are important.
  - Assimilation of RO-bending angle has a capability of recovering a deeper moist layer.
  - The DRDL WRF-LETKF framework can further improve the short-term heavy rainfall prediction (intensity and timing)
- Assimilation of the radar data improves the rainfall nowcasting. However, how we initialize the ensemble greatly affects the forecast skill.
  - Such issue can be avoided when the radar assimilation is initialized from an ensemble better represents the dynamical (environment) uncertainties.

Observation operators for RO

Local RO operators are used to simulate the **refractivity** and **bending angle**.



- Local refractivity

$$N = 77.6\frac{P}{T} + 3.73\times10^{5}\frac{P_w}{T^2}$$

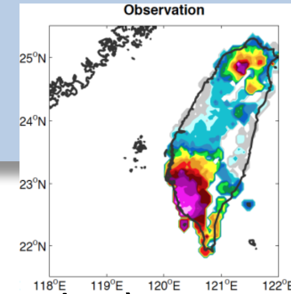
- Local bending angle (Chen et al., 2010)

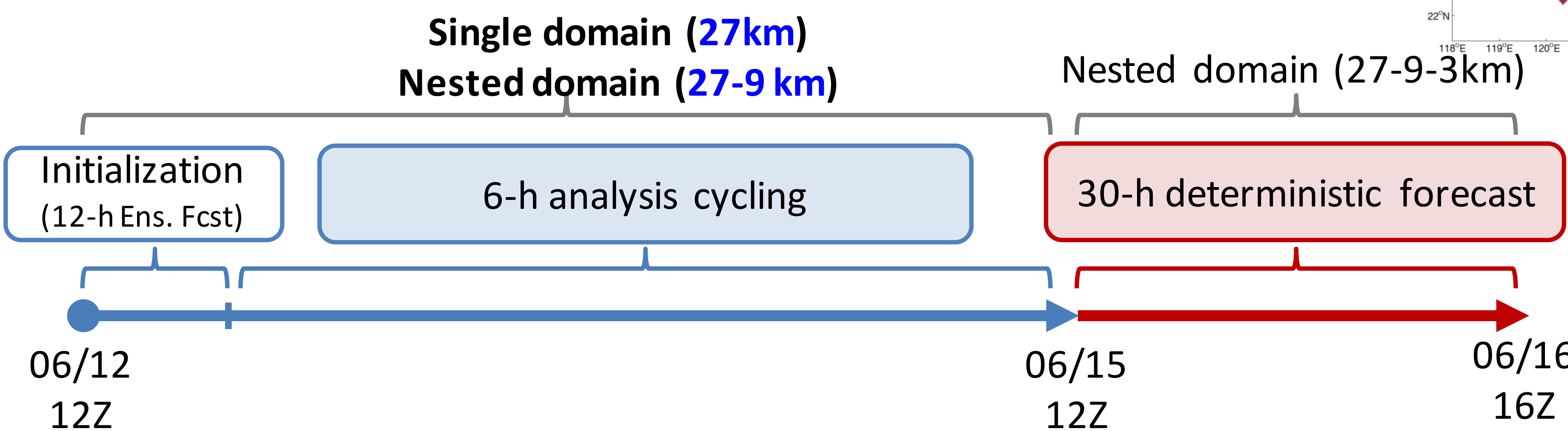
Kursinski et al. (1997): $\alpha(a) = -2a\int_a^\infty \frac{d(\ln n)/dx}{(x^2-a^2)^{1/2}}dx, \quad x = nr$

(1) Below model top: $\Delta\alpha = -2a\frac{d\ln n}{dx}\frac{1}{\sqrt{(x+a)}}\int_{x_i}^{x_{i+1}}\frac{1}{\sqrt{(x-a)}}dx$

(2) Above the model top: α is computed following Healy and Thépaut (2006)

Experiment setup
(heavy rainfall on 16 June, 2008)





ARW-WRF v3.3.1 with YSU PBL + GCE ensemble microphysics + GD ensemble cumulus parameterization schemes

EXPS	outer	inner
SRSL	360km	N/A
DRSL	360km	60km
DRDL	360km	360-60km