Joint WRF/MPAS Users' Workshop, June 11-14, 2019

Implementation of Incremental Analysis Updates in an 1-hr cycling forecasting system

Min Chen[1], Xiang-Yu Huang[2], Wei Wang[3]

[1]Institute of Urban Meteorology, CMA, Beijing

[2]Meteorological Service Singapore, Centre for Climate Research Singapore

[3]National Center for Atmospheric Research, Boulder, Colorado

OUTLINE

- Introduction
- WRF/IAU Coupling
- 1-hr Updated Cycling System
- IAU Configuration and Test
- Results
  - Initialization Performances
  - Spin-up/Spin-down Features
  - Impact on Data Assimilation
  - Precipitation Forecasts
- Conclusions and Discussion

01 Introduction of IAU

- Developed by *Bloom et al. (1996)*
- Widely used in atmospheric and oceanic applications. In Atmospheric Research:
  - Demonstrated identical to incremental digital filtering (IDF) for linear models with time-invariant coefficients *(Polavarapu et al. 2003)*
  - Physical-space statistical analysis system (PSAS) analysis *(Zhu et al. 2003)*
  - MM5 3DVAR *(Lee et al. 2006)*
  - A hybrid of nudging and IAU implemented in ensemble Kalman filter *(Bergemann & Reich, 2010)*
  - EnKF with 4DIAU *(Lei & Whitaker, 2012)*
  - IAU-based NASA/GSFC 4D-Var *(Zhang et al. 2015)*
  - Real-time1-km ARPS assimilating increments produced by 3DVAR with cloud analysis using IAU *(Stratman &Brewster, 2017)*
  - The convective scale NWP system for Singapore (SINGV). SINGV-DA runs with 3h cycle, using 3D-Var FGAT followed by IAU over a 2h-span. uniform.

02 WRF/IAU Coupling

□Bloom et al. (1996):

For an arbitrary prognostic variable Φ, its tendency is

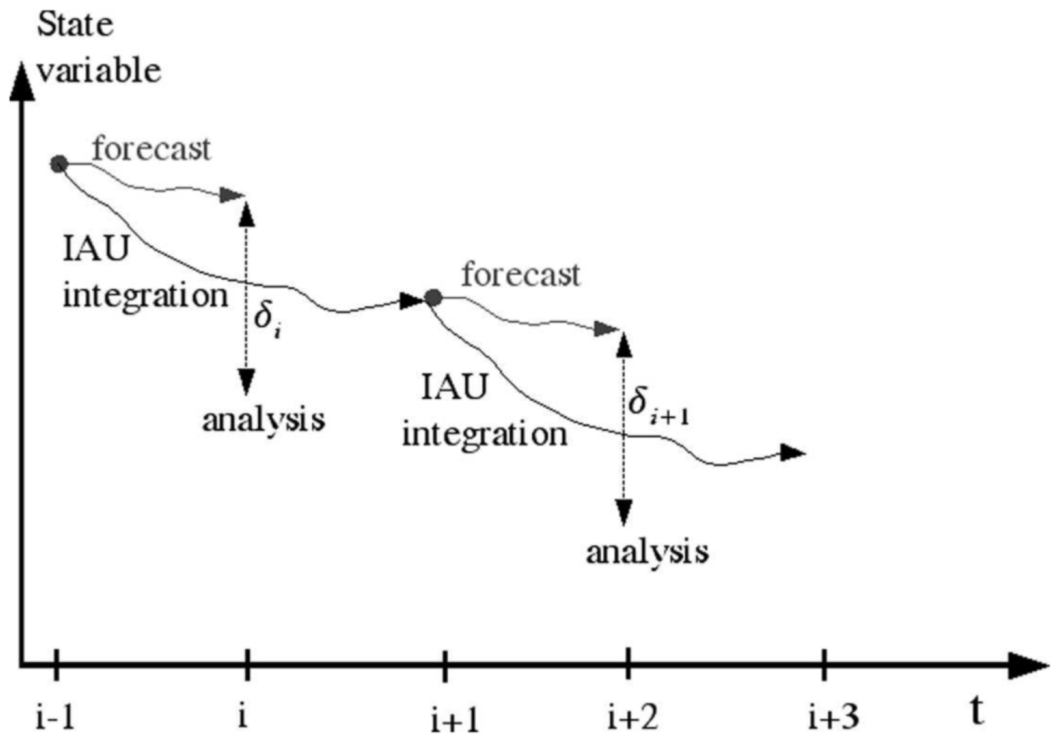
$$\frac{\partial \Phi}{\partial t} = \left(\frac{\partial \Phi}{\partial t}\right)_{dynamics} + \left(\frac{\partial \Phi}{\partial t}\right)_{physics} + \lambda(t) \cdot \delta\Phi_{IAU}$$

$\delta\Phi_{IAU}$ is analysis increments

$\int_0^{\Delta t_c} \lambda(t)=1$, where Δt_c is the duration of analysis increments integration

□ In WRF, the RK3 integration takes the form of 3 steps to advance a solution $\Phi(t)$ to $\Phi(t+\Delta t)$. IAU is implemented as increments as:

$$\Phi(t + \Delta t) = \Phi(t + \Delta t) + \lambda(t) \cdot \delta\Phi_{IAU}$$



(Ourmieres, et al., 2006)

δ_i represents analysis increment at t=i

02 WRF/IAU Coupling--*how to implement?*

Data Assimilation

./Gen_analysis_increments
–fg wrfinput_d01
–an wrf_3dvar_output_d01.radar
–out ./analysis_increment_d01

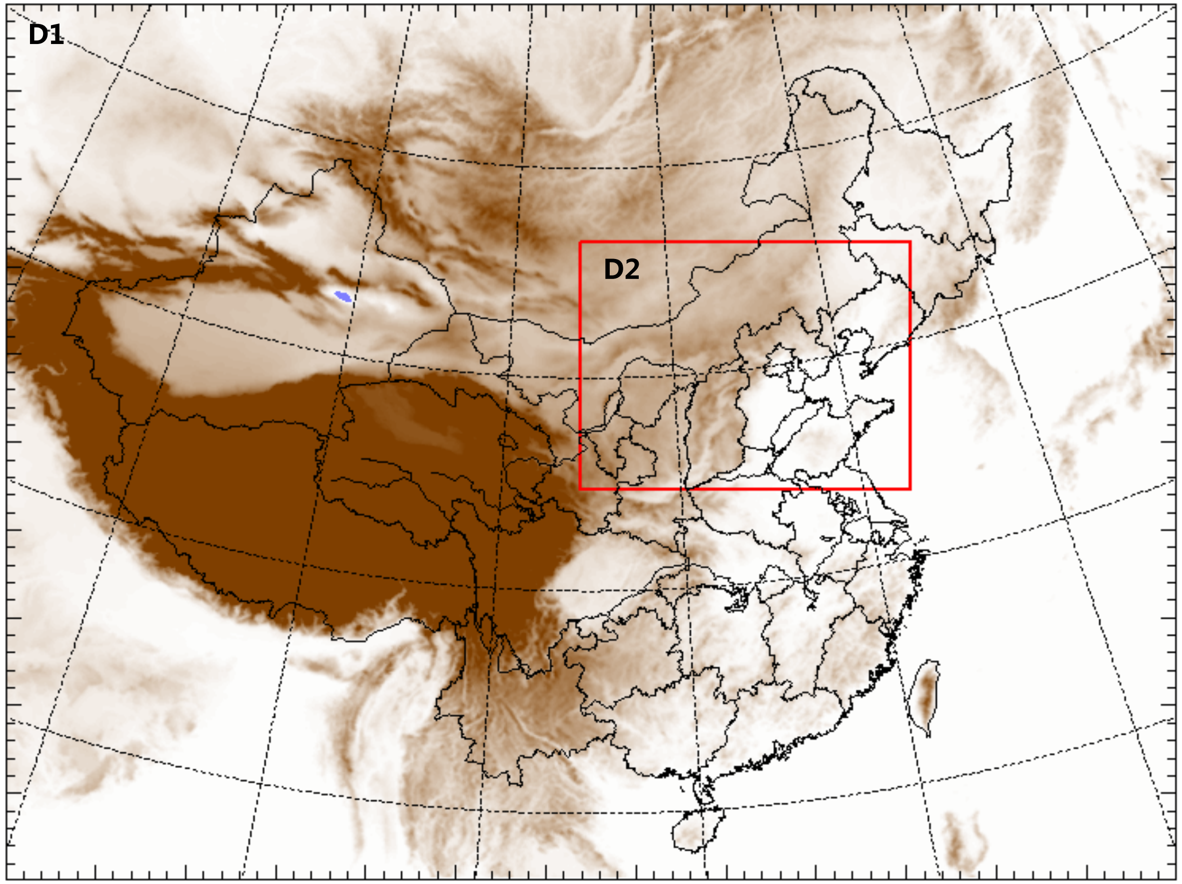
Analysis_increment_d01

&time_control
Auxinput21_inname=analysis_increments_d<domain>
Io_form_auxinput21=2
Iau=.true.
Iau_xtime=7200
Iau_nfilt=6
Iau_cutoff_seconds=7200
/

<u>During IAU integration (WRFV3.9.1):</u>
IF (grid%iau .and. domain_clockisiaustoptime(grid)) then
*Grid%F_2=Grid%F_2+Grid%IAU_F*hn*
Where F represents
U/V/T/~~W~~/~~P~~/MU/PH/QV/QC/QR/QS/QI
ENDIF

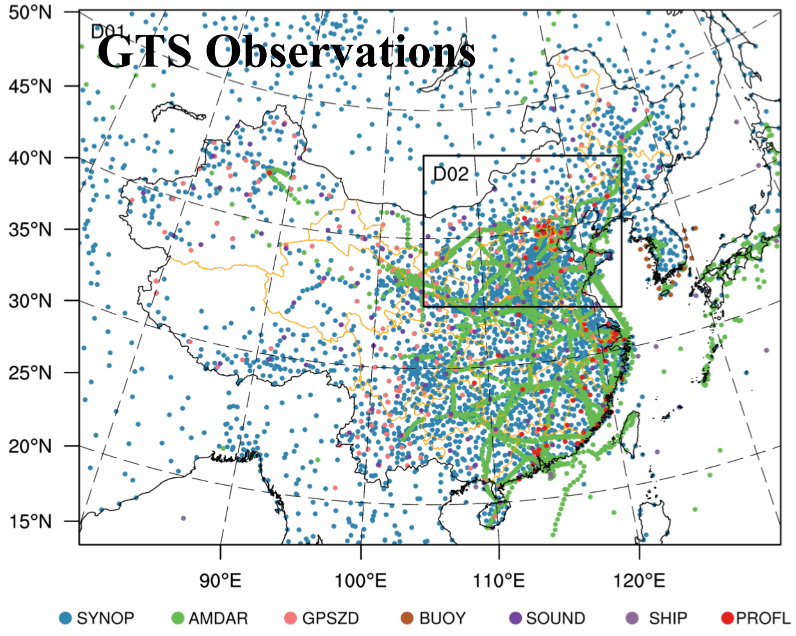
Normal Integration

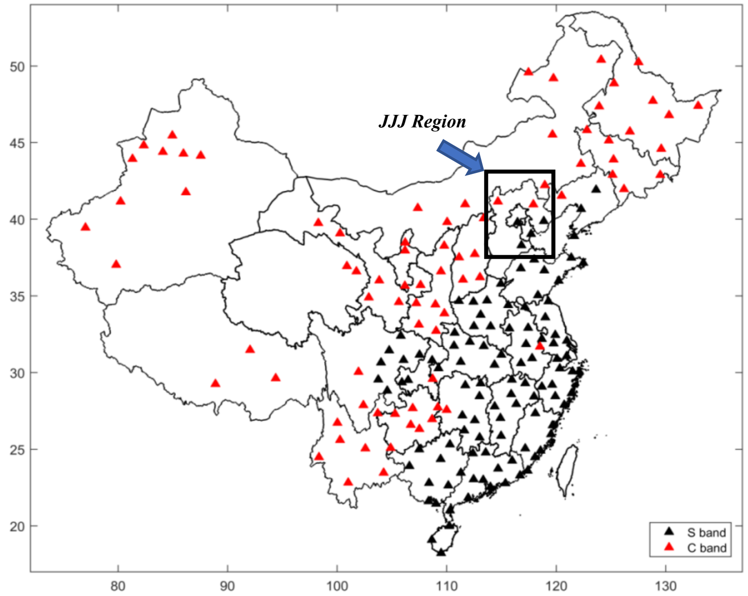
03 1-hr Updated Cycling System



- Model Configuration
  - WRF Version 3.9.1
  - One-way nested domains
    - 9km: 649x500
    - 3km: 550x424
    - 51 sigma levels
  - Physical Parameterizations
    - RRTMG for both SR and LR
    - Thompson microphysics
    - K-F cumulus scheme for d01
    - YSU PBL scheme
    - Noah LSM
  - ***See Poster P47***
- Initial and boundary conditions: 12-hr ECMWF forecasts (0.25 degree)

03 1-hr Updated Cycling System

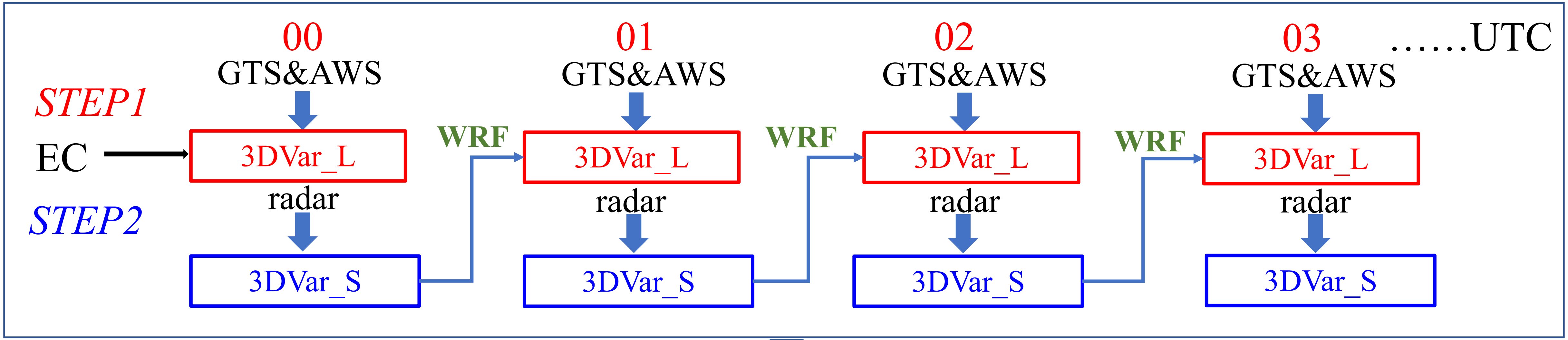


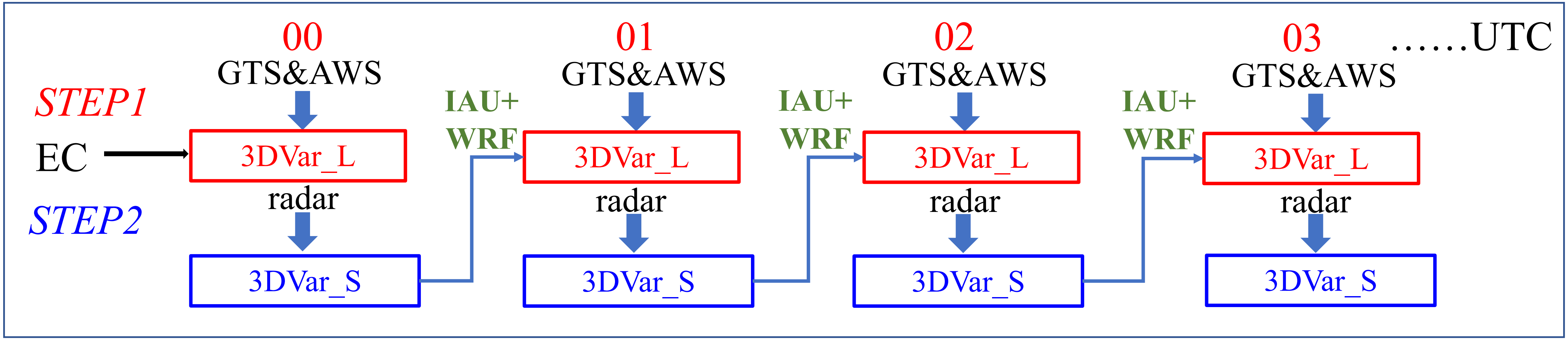


- Data Assimilation
  - WRFDAV3.8.1
  - U/V Control Variables
  - Data Assimilated
    - Conventional GTS Observations
    - Radar reflectivity mosaic
    - Radial velocity and reflectivity from 7 Doppler Radar in Beijing-Tianjin-Hebei (JJJ) area
  - Two-step 3DVAR assimilation

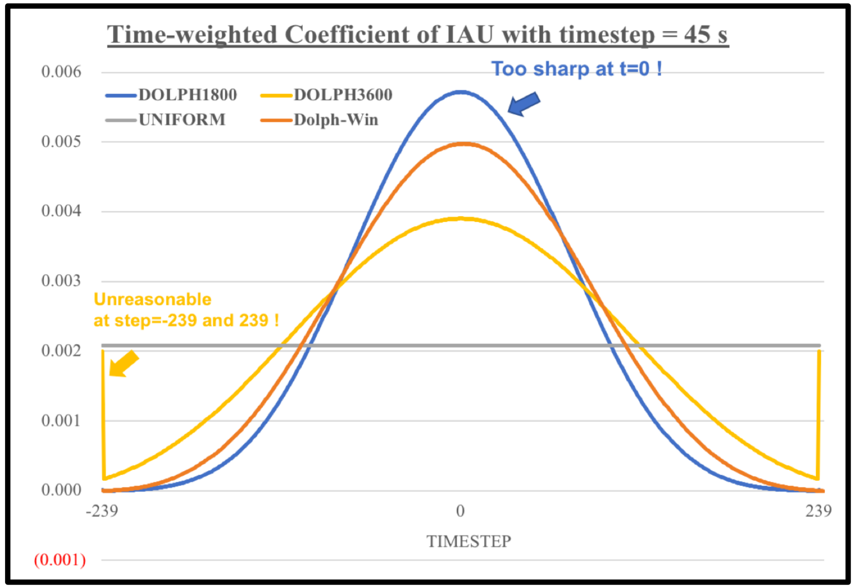
	Data Assimilated	Len_Scaling	Var_scaling
Step I 3DVAR_L	GTS data	1	1
Step II 3DVAR_S	Radar Reflectivity Radial Velocity	Len_scaling=0.5 $(u,v,\ t_w,\ p_{su},\ q')$ Len_scaling=0.7(q_r)	Var_scaling=0.5 $(u,v,\ t_w,\ p_{su},\ q')$

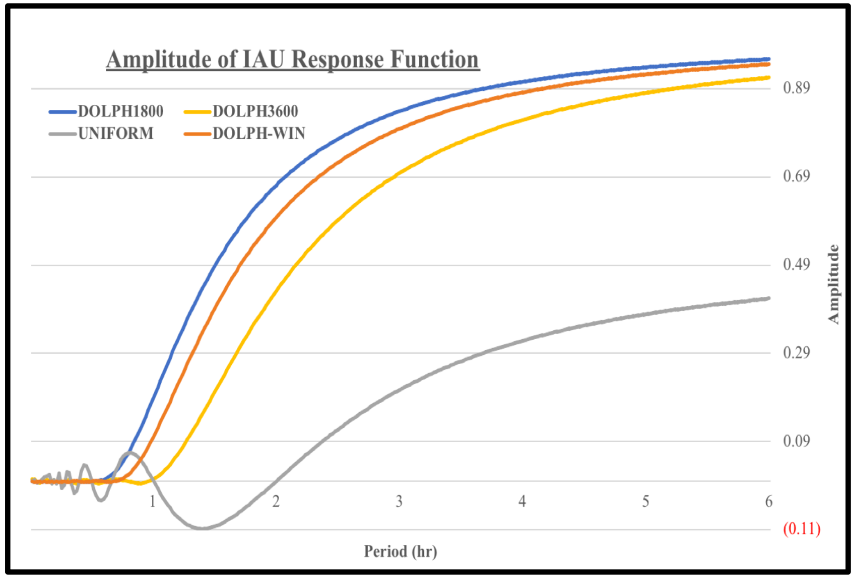
03 1-hr Updated Cycling System





04 IAU Configuration---time-weighted coefficients





- The time-weighted coefficient $hn(\lambda(t))$, where $\int_0^{\Delta t_c}\lambda(t)=1$, Δt_c is the duration of analysis increments integration, corresponding to IAU_xtime in WRF.
- In WRF, the coefficients (*hn*) are derived by the sub dfcoef with different cutoff and IAU_xtime configuration.
- With *IAU_xtime=7200 s*, selections of *hn*
  - *Uniform:* hn=1/NSTEPS
  - *DOLPH1800:* Dolph filter with cutoff 1800 s
  - *DOLPH3600 :* Dolph filter with cutoff 3600 s
  - *Dolph-Win:* Dolph-chebyshev window with cutoff=7200 s
- Coefficients:
  - ***Uniform: no transition accumulation of analysis increments, although it's the most popular selection in IAU implementations***
  - *DOLPH1800*: better transition but too sharp at t=0
  - *DOLPH3600*: better transition but unreasonable at starting and ending timestep
  - ***Dolph-Win: the most reasonable***
- Amplitude:
  - DOLPH1800 and Dolph-win efficiently remove the short wave < 1h period with reasonable amplitudes kept untouched
  - DOPLPH3600 filtered too much
  - Uniform: 50% amplitudes loss and distortion of short waves

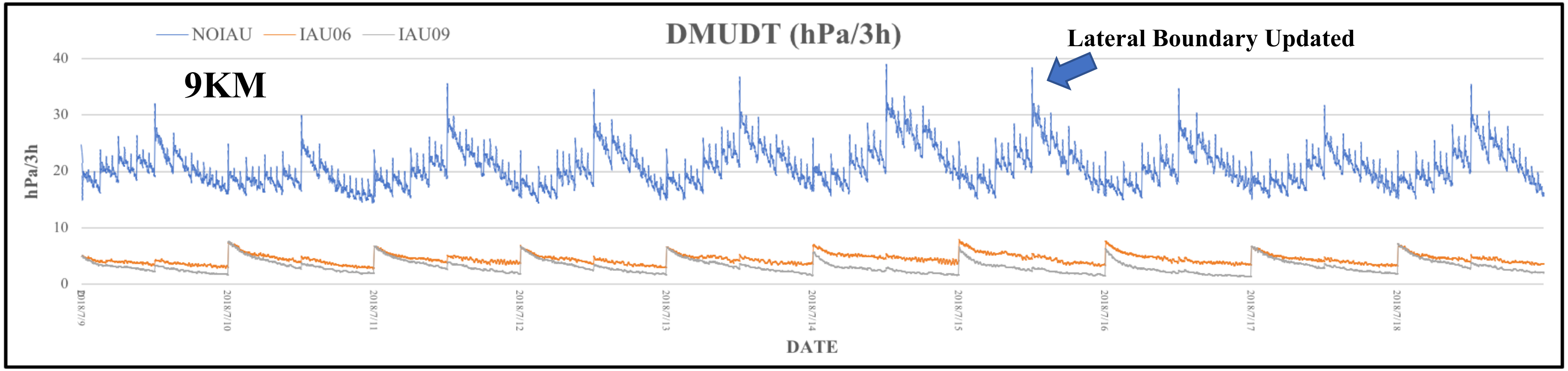
04 IAU Experiments

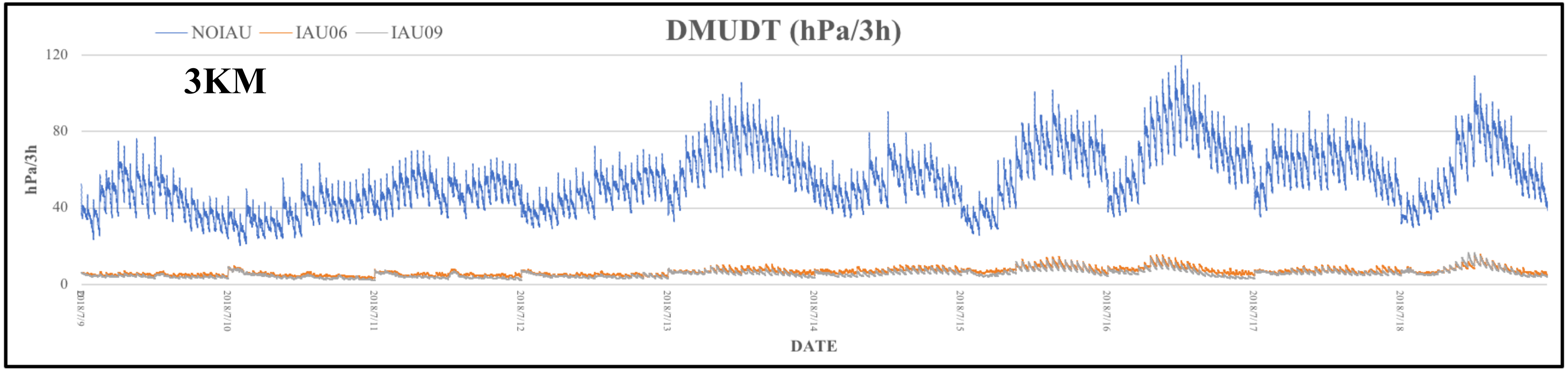
Experiment ID	Description	IAU-Related

NOIAU	☐ 1-hr updated cycles initiating during 00UTC 9 ~ 23UTC 18 July 2018, totally 240 cycles
	☐ Lateral boundary updated at 00/12UTC
	☐ Partial cycle initiated at 00UTC
	☐ Integration Time: t=6hrs
	☐ Data assimilated:
	  ☐ 9km: GTS+Radar RF Mosaic
	  ☐ 3km: GTS+Radar RV+RF in JJJ region
		NO IAU

IAU06		☐ IAU_XTIME=7200 s, corresponding to time window t=-1~1h ☐ Dolph-chebyshev window Filter (nfilt=6) with cutoff=7200 s
IAU09		☐ Uniform coefficients ☐ Same time window as IAU06

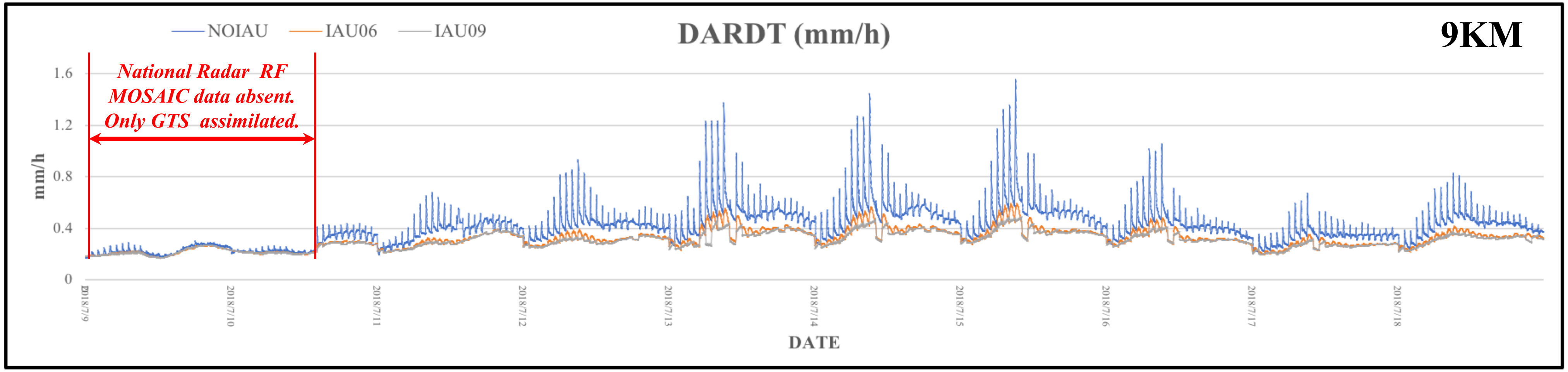
05 Results---Initialization Performances

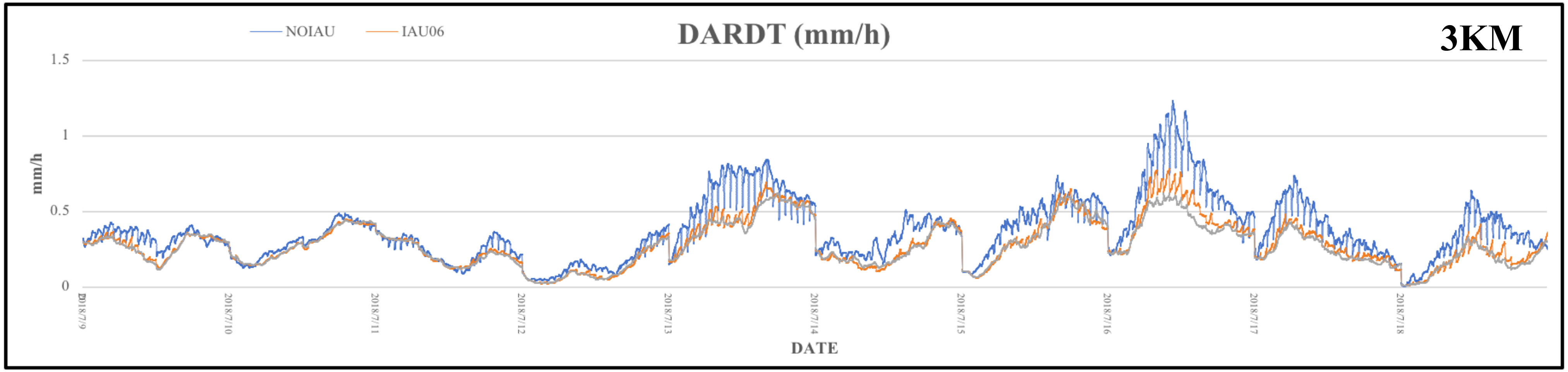




- DMUDT: Domain-average perturbation dry air mass in column, representing the balance state of the model
- The consecutive 0~1h DMUDT time series for the total 240 cycles
- Both IAU schemes reasonably reduced the noise to reasonable level

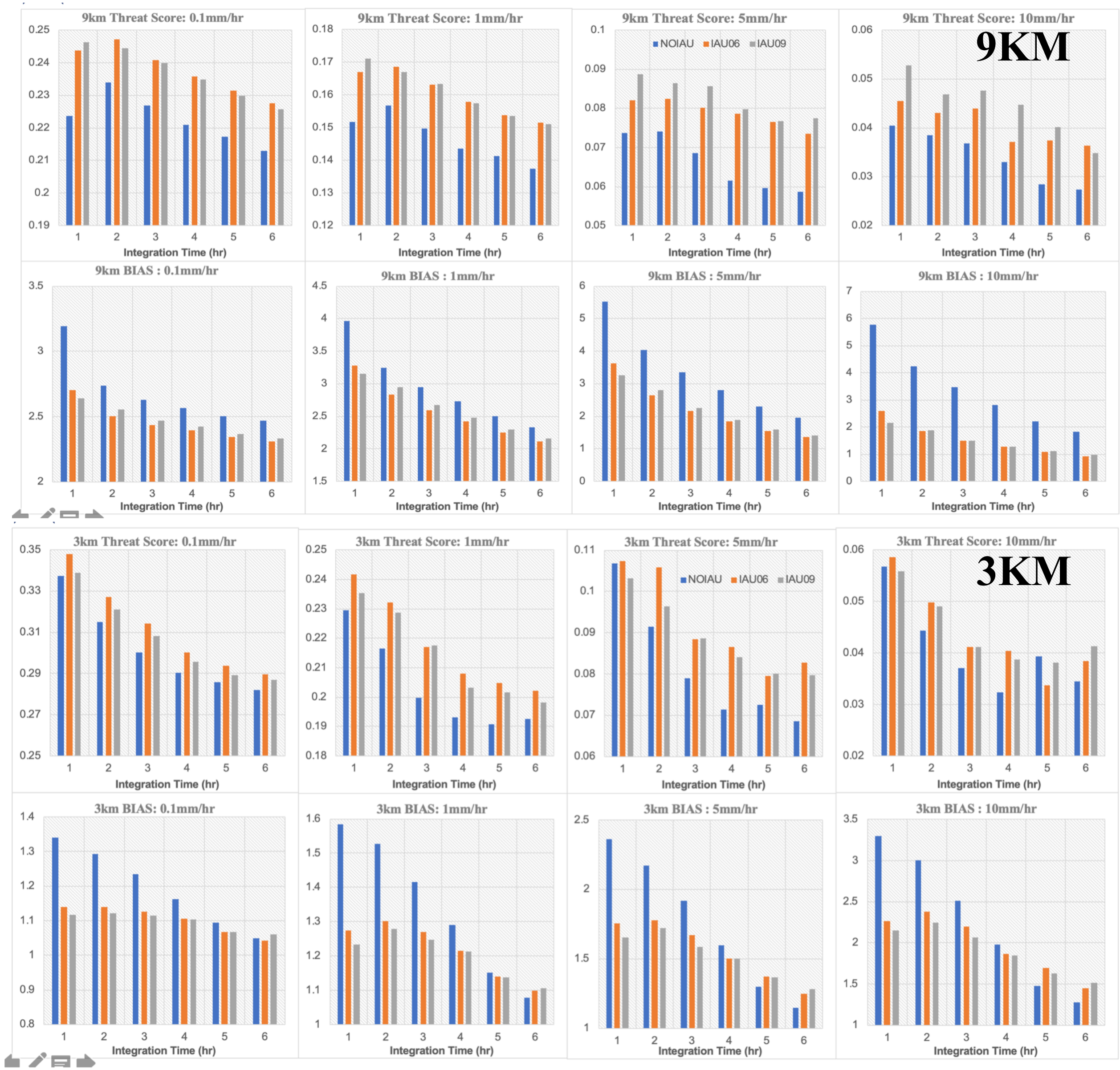
05 Results---Spin-up/Spin-down Features





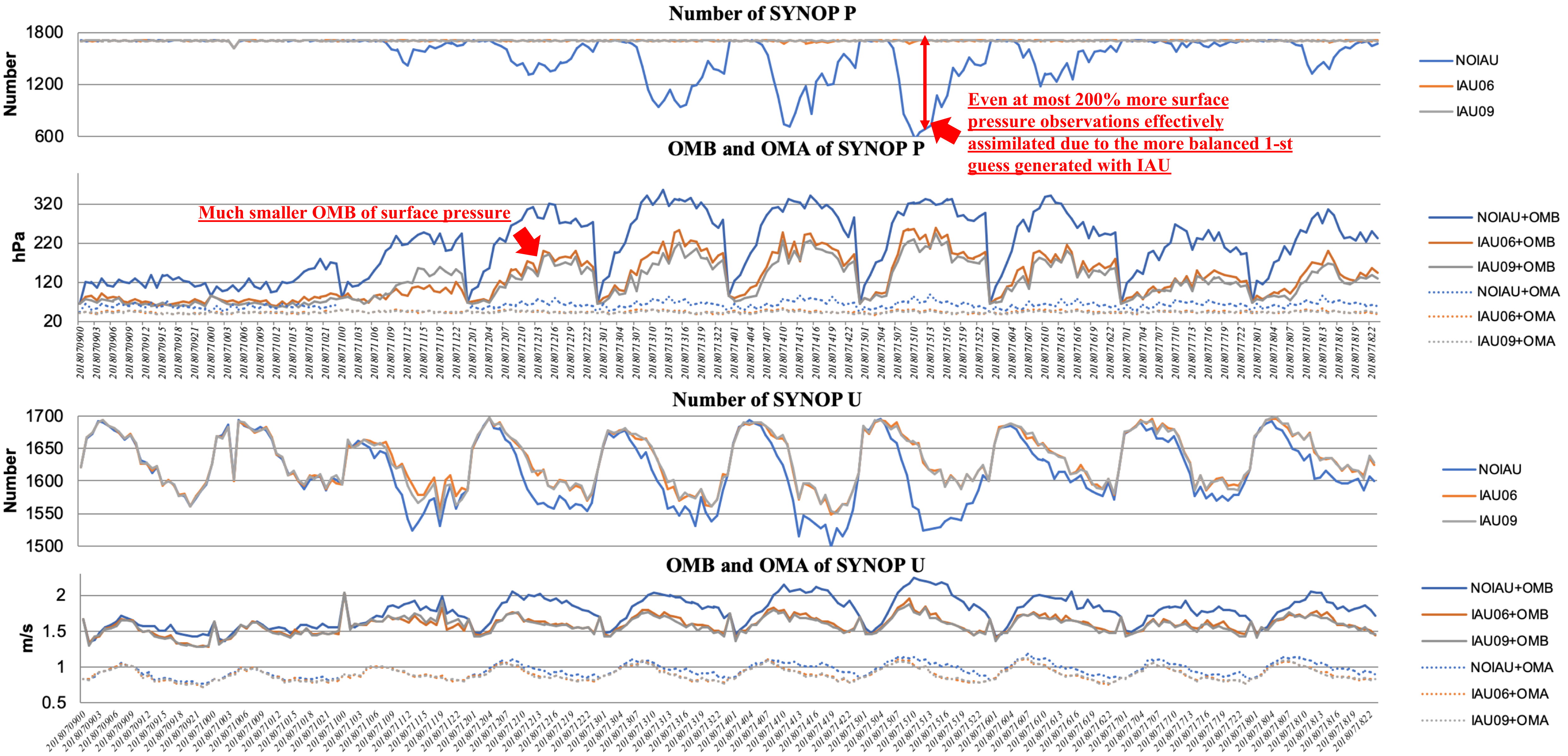
- DARDT: Domain-average hourly precipitation rate
- The consecutive 0~1h DARDT time series for the total 240 cycles
  - NOIAU: High precipitation rates quickly drop within the 1-st forecasting hour.
  - IAU06: Lower precipitation rate
  - IAU09: Lower and stable precipitation rate

05 Results---Precipitation Performances

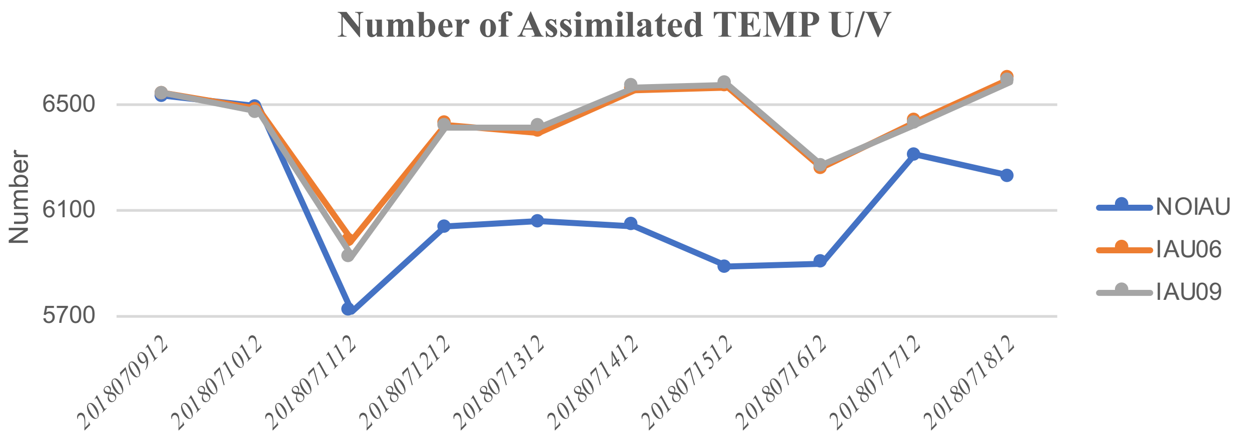


- ☐IAU leads to greatly (10~20%) improved precipitation threat scores, especially for large thresholds.
- ☐Large bias (over-prediction) at the initial forecast hours has been reduced to reasonable and stable level.
- ☐The Dolph-win generally has better performance than the uniform filtering coefficients.

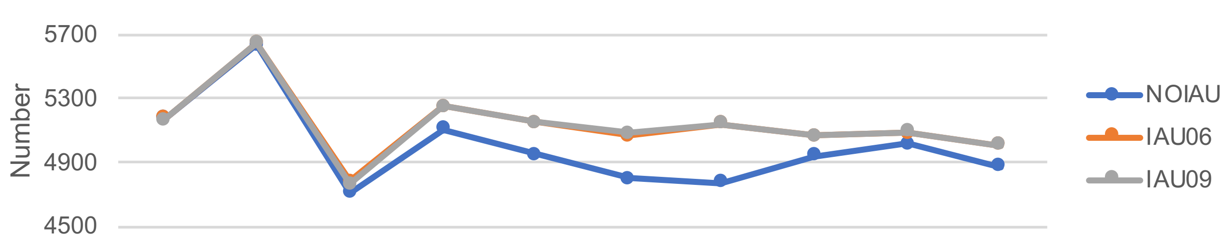
06 Results--- Impact on Data Assimilation: SYNOP

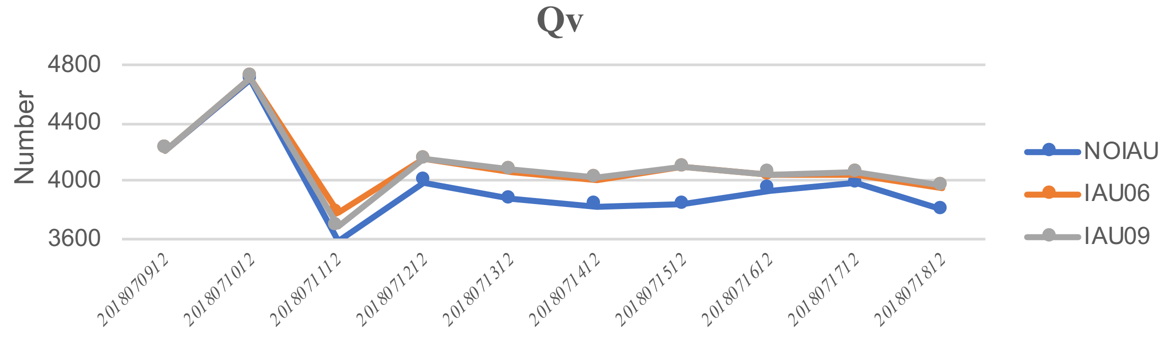


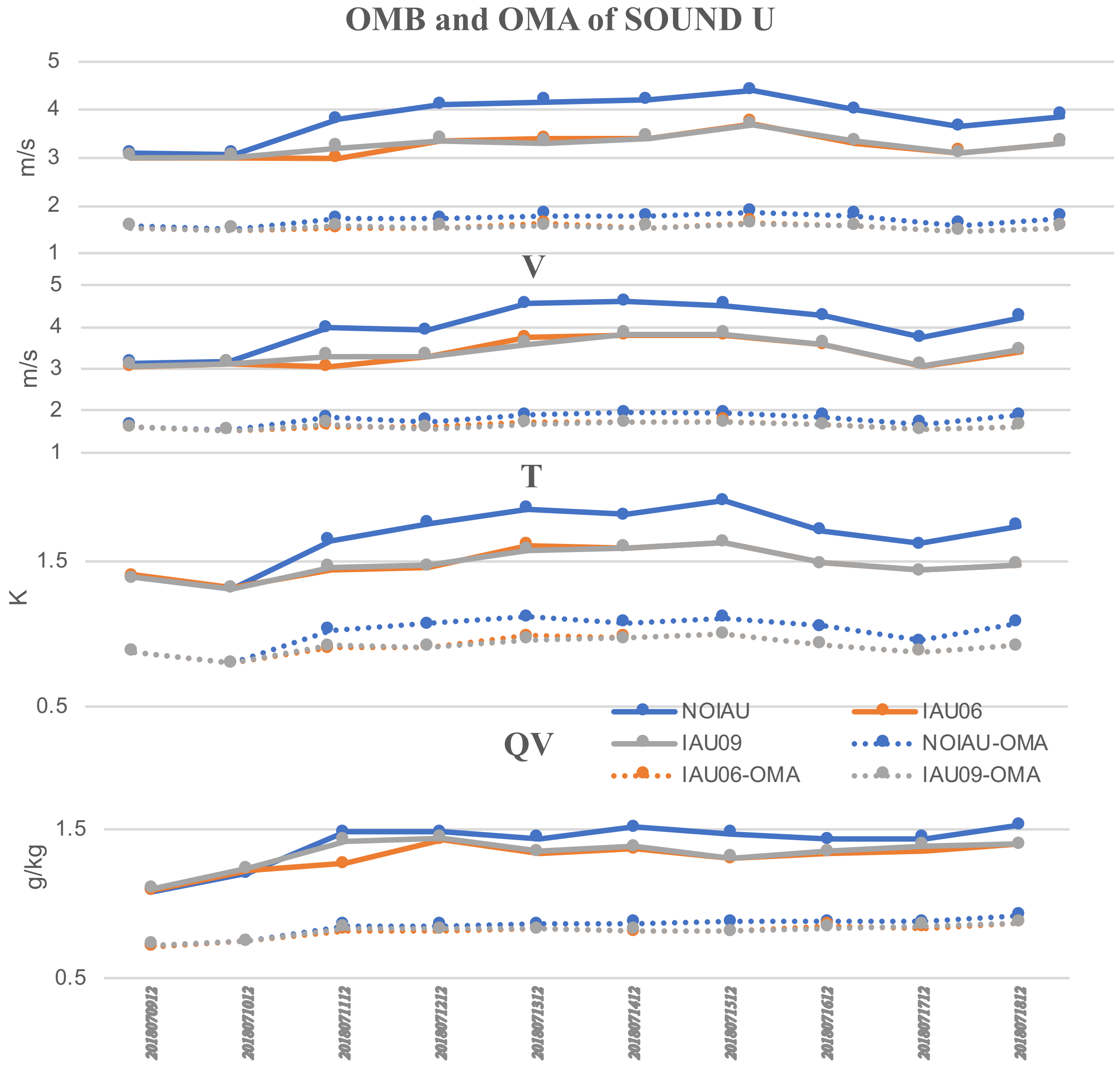
06 Results--- Impact on Data Assimilation: SOUND



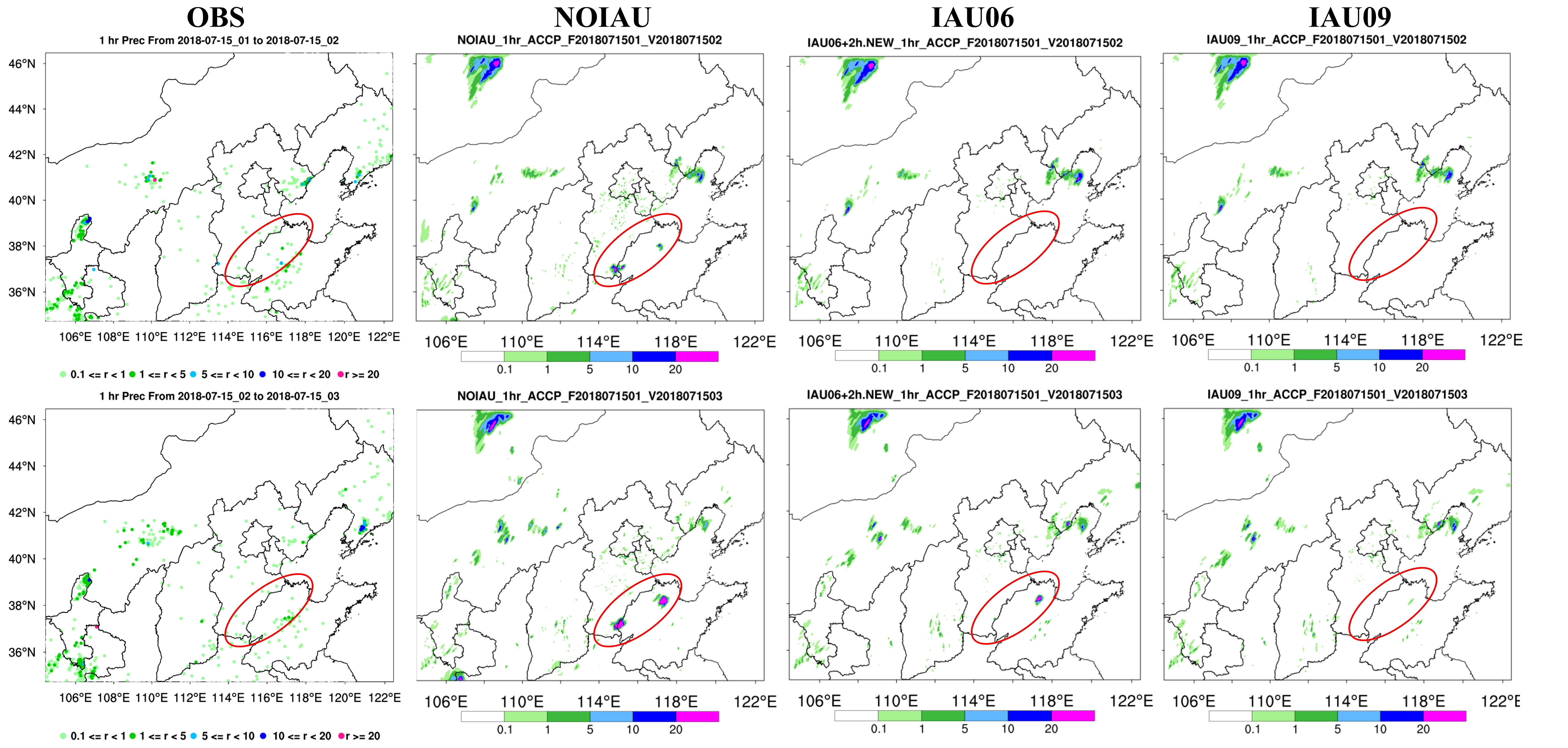
more sounding observations assimilated and reduced OMB with IAU



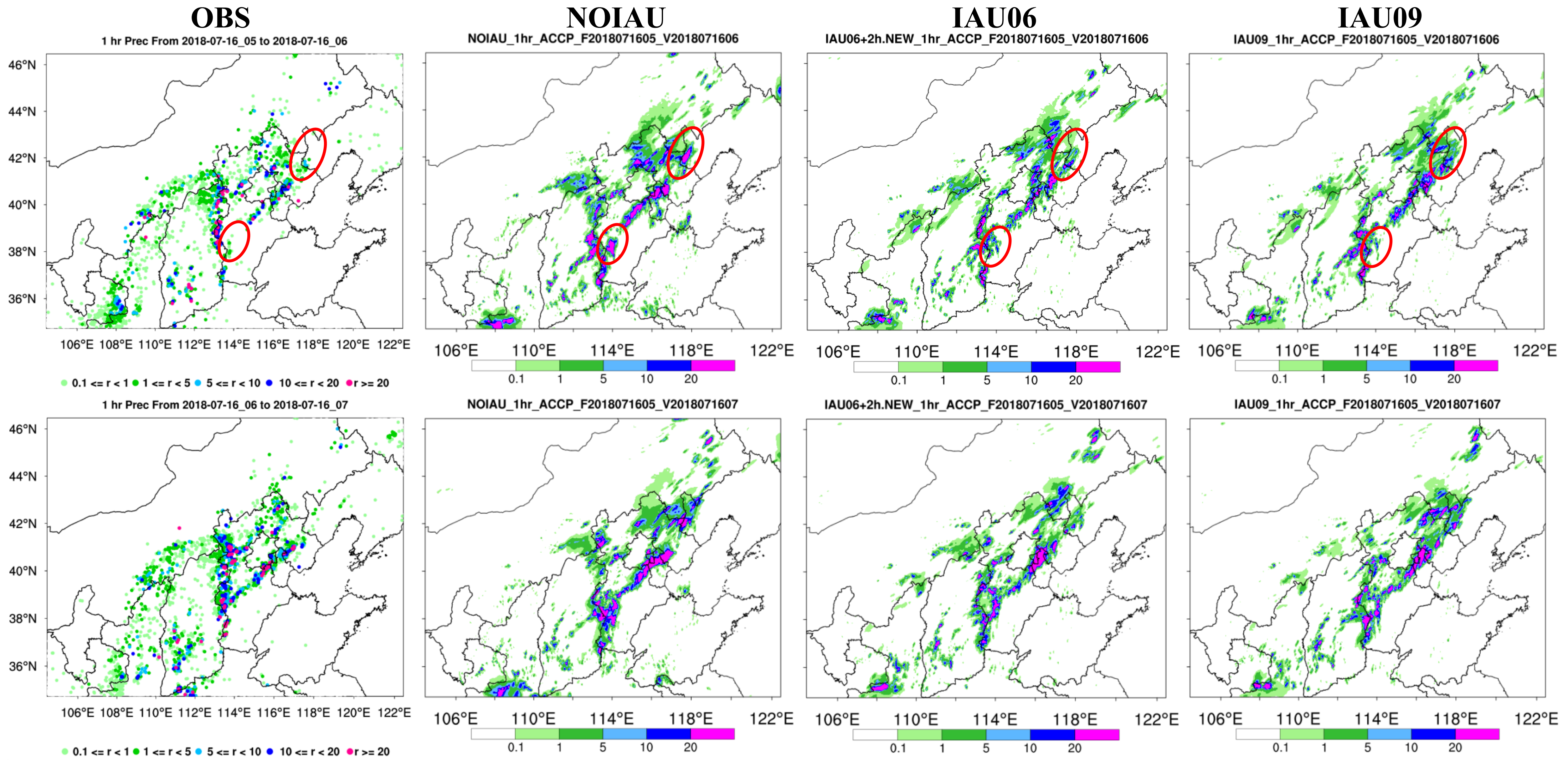




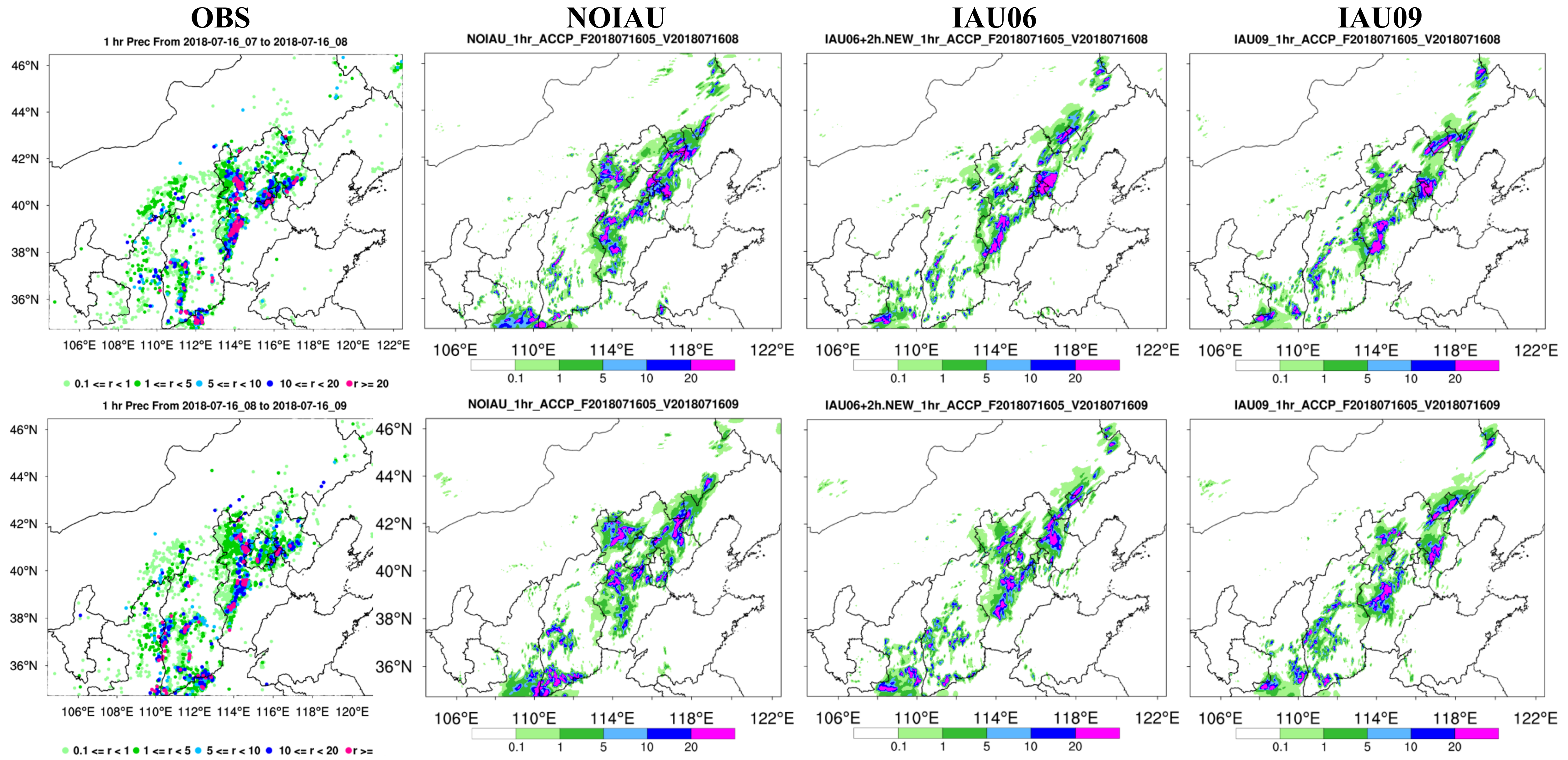
07 CASE1:20180715---Less False Alarm



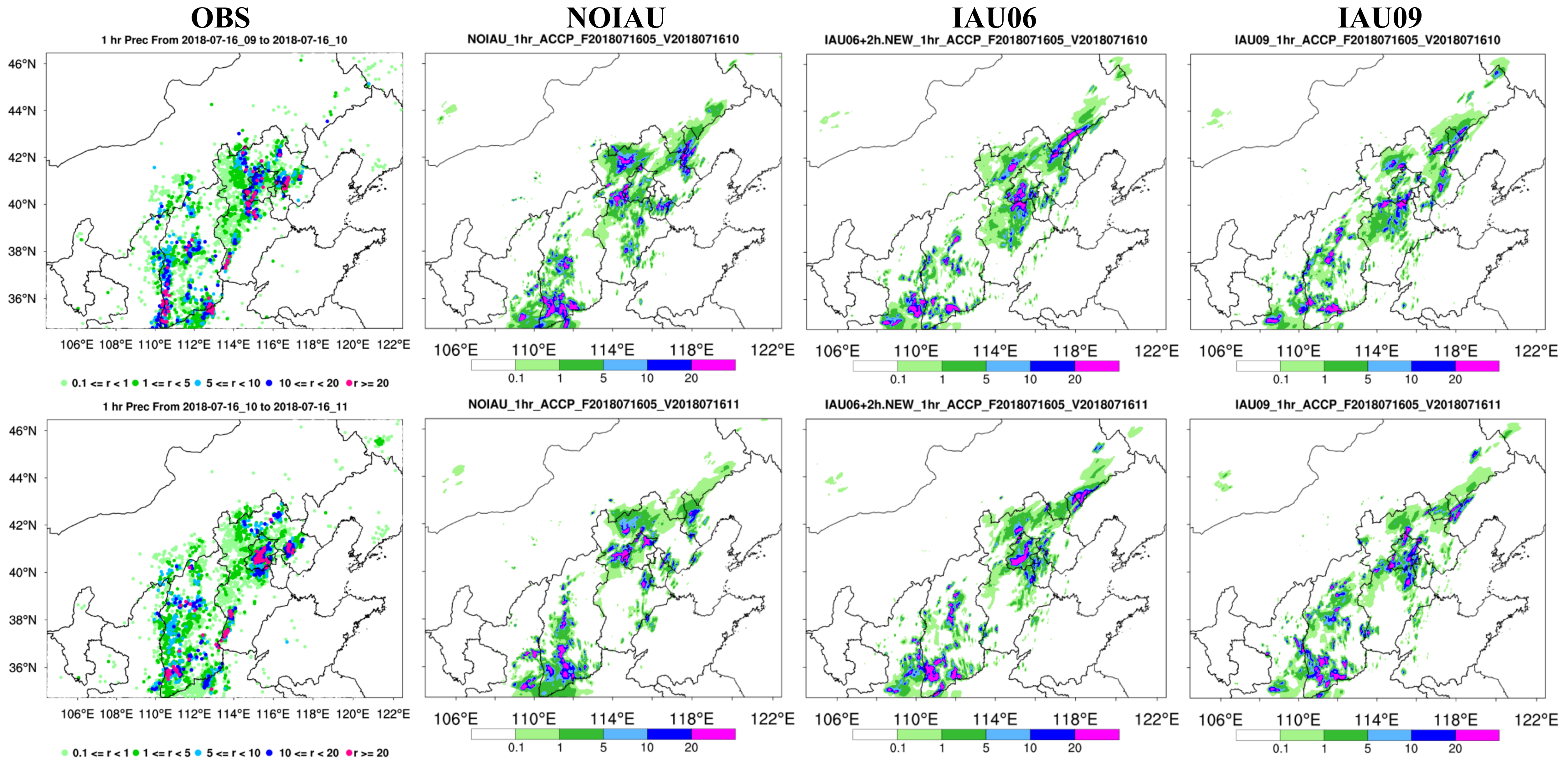
07 CASE2:20180716---Reduced Over-prediction



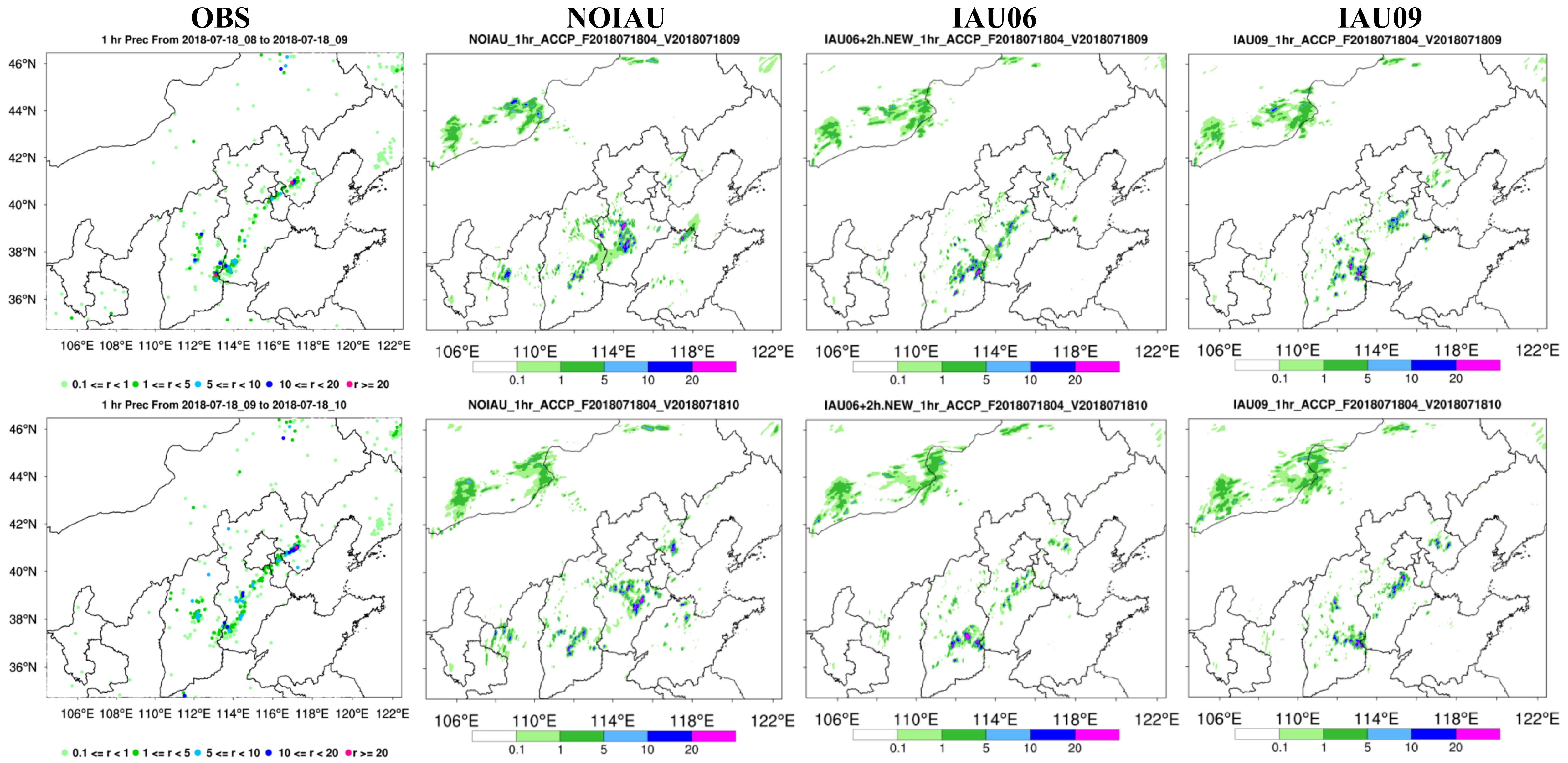
07 CASE2:20180716--- Reduced Over-prediction



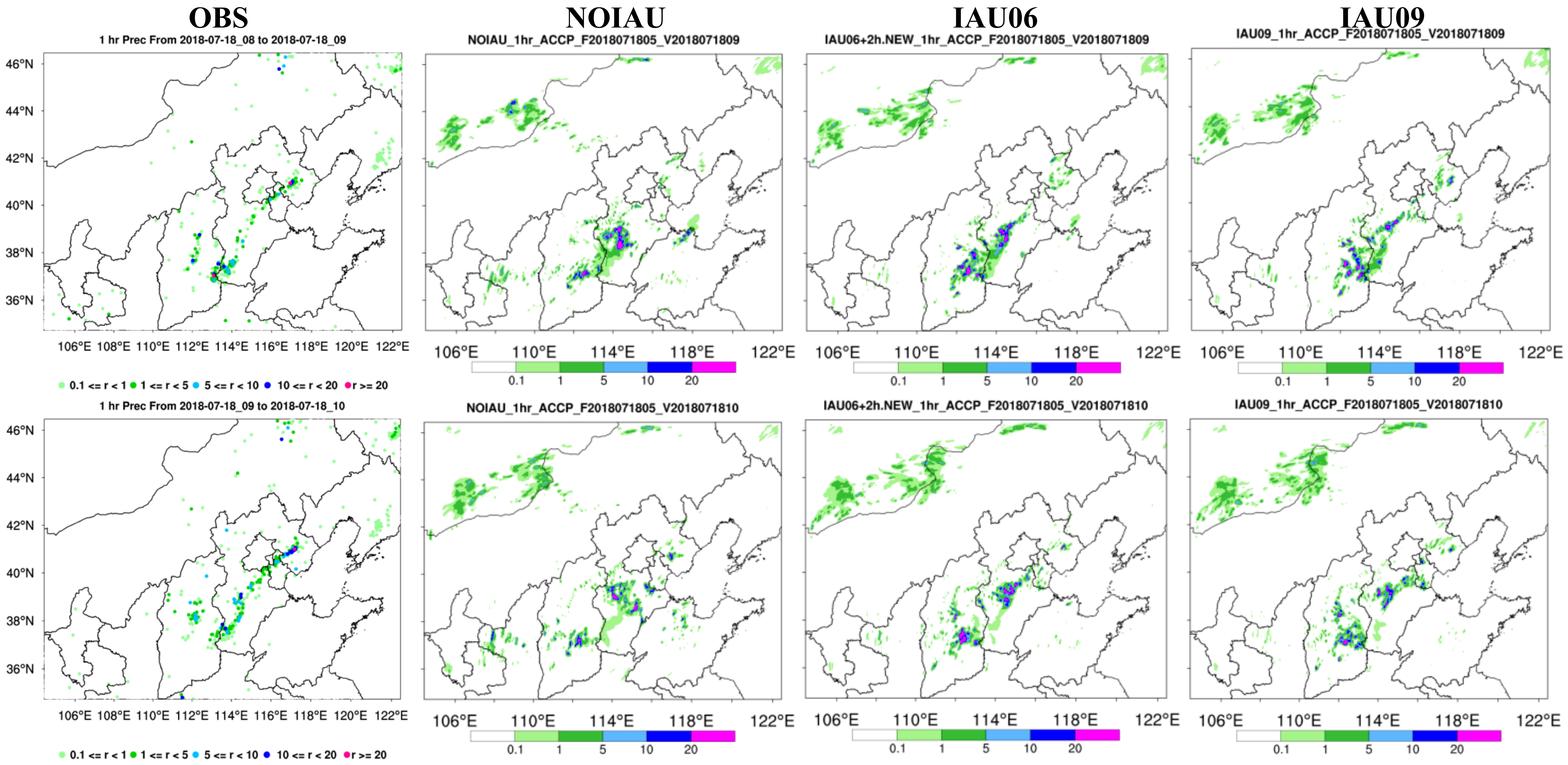
07 CASE2:20180716--- Reduced Over-prediction



07 CASE3:2018071808-10--- Reduced Over-prediction



07 CASE3:2018071808-10--- Reduced Over-prediction



Conclusions and Plans

- An IAU scheme is developed for WRF and implemented in a 1-h cycling forecasting system. IAU is demonstrated as an ideal initialization scheme
  - **<u>Good initialization performances</u>**
    - Reasonable noise level
    - Lower and stable precipitation rates at the initial forecast
  - **<u>More data effectively assimilated due to the more balanced 1-hr forecasts generated with IAU</u>**
  - **<u>Significantly improved precipitation forecast performances</u>**
    - Better threat score and stable bias
    - Less false alarm and reduced over-prediction
- About the IAU configuration:
  - **<u>Dolph-Chebyshev-window filtering coefficients are physically reasonable and better performed over the uniform</u>**

- **Future Work**
  - Implement IAU with EMDIV, the external-mode filter coefficients for mass coordinate model
  - Develop a tendency form of IAU
  - Figure out the impact of IAU on radar data assimilation
  - Carry out real-time experiments and evaluations

Thank you!

mchen@ium.cn