臺灣區域再分析資料混合方案與遞增式分析更新技術之應用與評估

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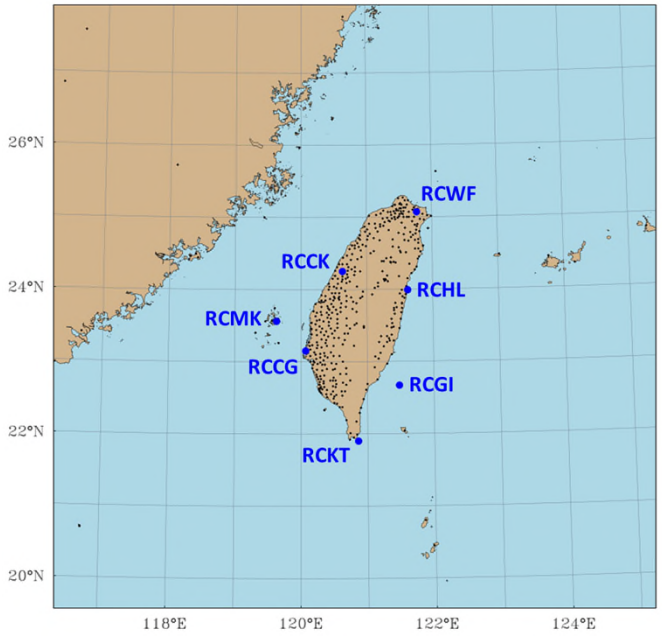
2025年9月2日
114年天氣分析與預報研討會

Outline

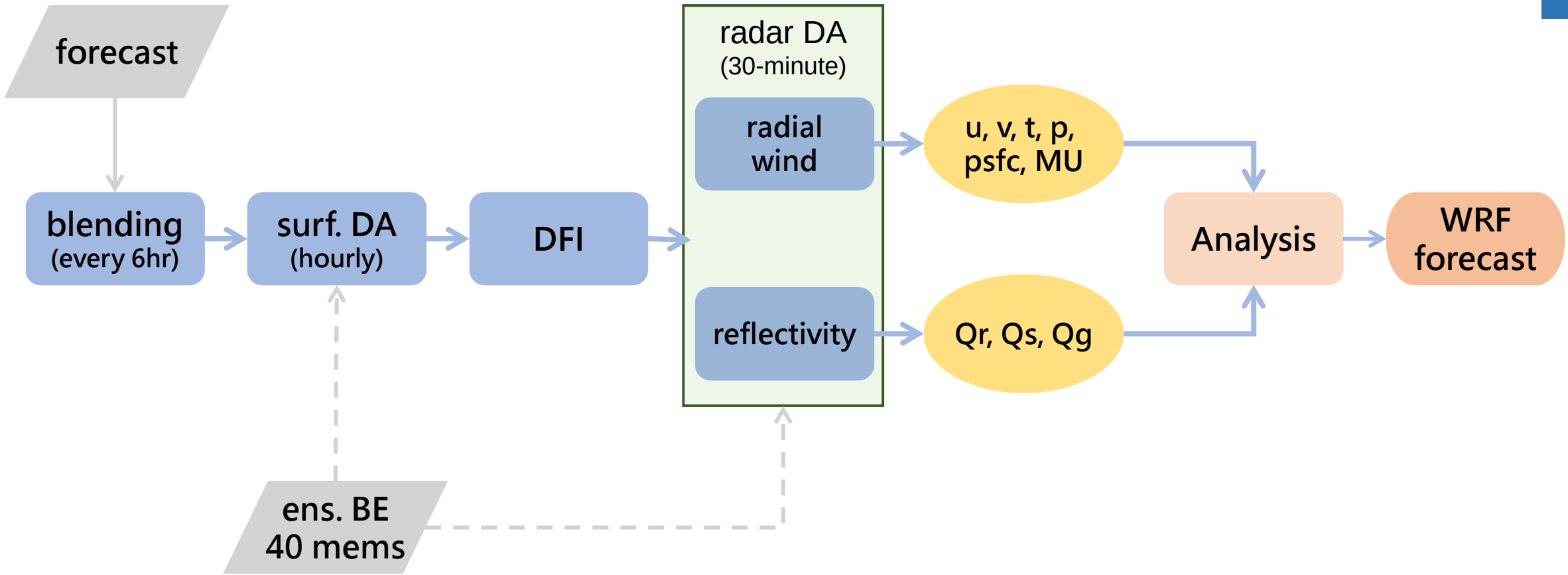
- **Introduction**
  - CWA Operational RWRF
  - Blending scheme, IAU, and IBU
  - CWA RWRF for Reanalysis (candidate version)
- **Evaluations** of IBU, IAU+IBU, with/without DFI
- **Results**

CWA Operational RWRF



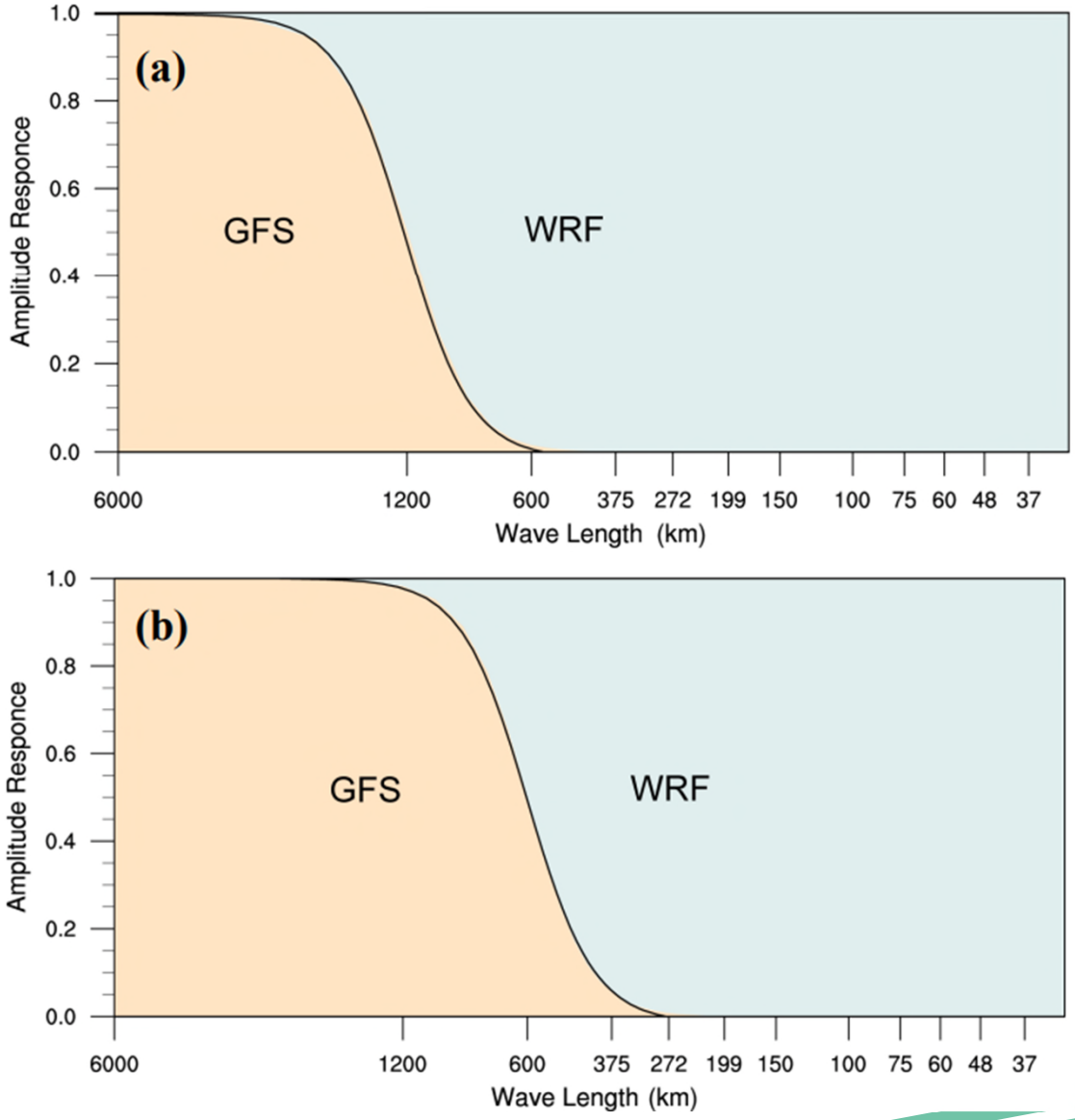
- Based on WRF and WRFDA
- **2-km resolution** for the Taiwan area
- **Hybrid 3DEnVar** coupled with RWRF-LETKF members
  - 30-minute cycle for radar DA
  - Hourly cycle for surface DA
- **6-hourly blending with the GFS downscaling**
  (Hsiao et al. 2015; Jiang et al. 2021)
- 13-hour forecasts initialized every hour
- **Radar data assimilation:**
  - Reflectivity (through hydrometeor retrievals) and radial velocity
- **Surface data assimilation:**
  - Temperature, humidity, winds (Chen et al. 2020)

CWA Operational RWRF flowchart



Blending Scheme

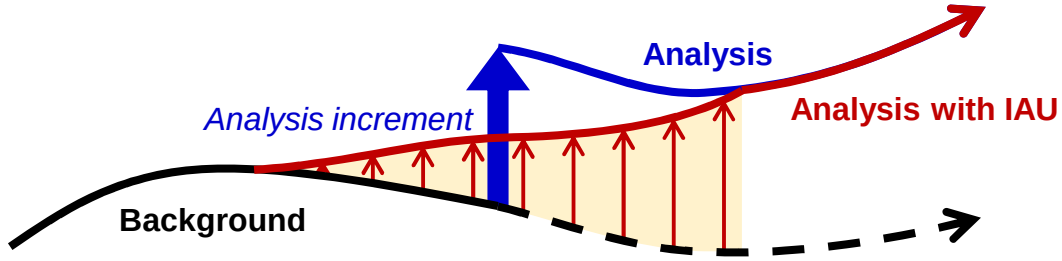
- **Purpose:**
  Reduce large-scale drift in regional model
  GFS large scales + WRF small scales
  → better short-range forecasts
- **Method:**
  Spatial filter + merge
  (Large → Global) + (Small → Regional)
- **Implementation:**
  Blend on Background (pre-DA) or Analysis (post-DA)
- **Cut-off Length:**
  Large (~1200km): more regional detail
  Small (~600km): Stronger global influence
- **Limitation:**
  May cause temporal discontinuity

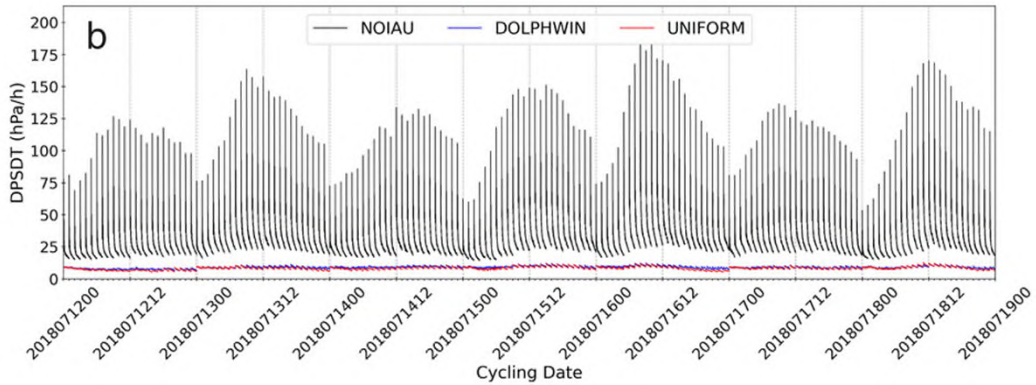


Wang et al. (2014)

Incremental Analysis Update (IAU)

- **Purpose:**
  Gradually apply increments
  → reduce imbalance, initialization shock, and spurious gravity waves
  → Improve forecast stability & skill
- **Implementation:**
  Add (Injected) analysis tendencies as forcing during the assimilation window
  Forcing = (Analysis – Background)
- **Without / With IAU:**
  Without IAU → surface pressure shows strong oscillations (initialization shock)
  With IAU → smoother evolution, reduced noise

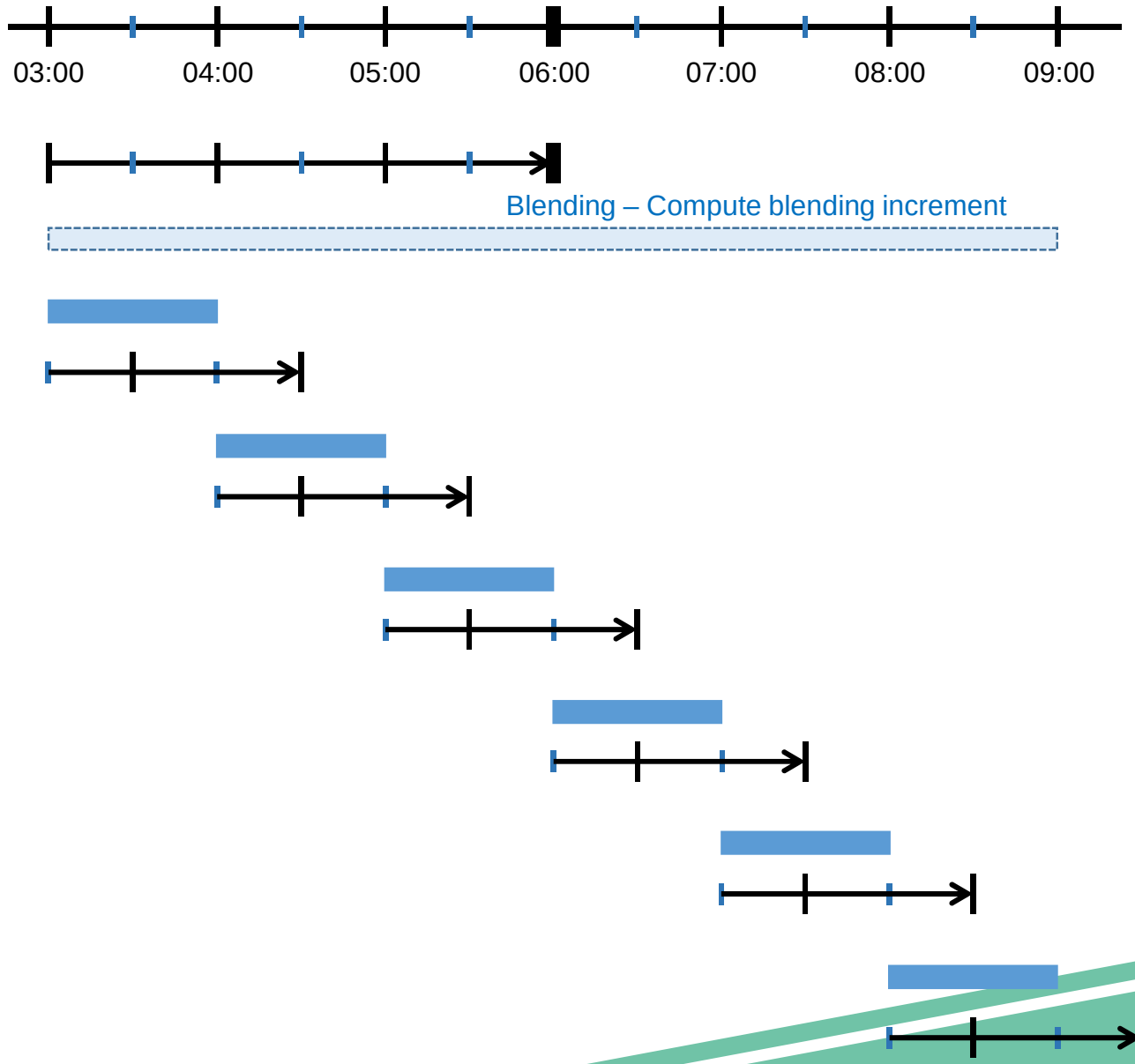




Chen et al. (2023)

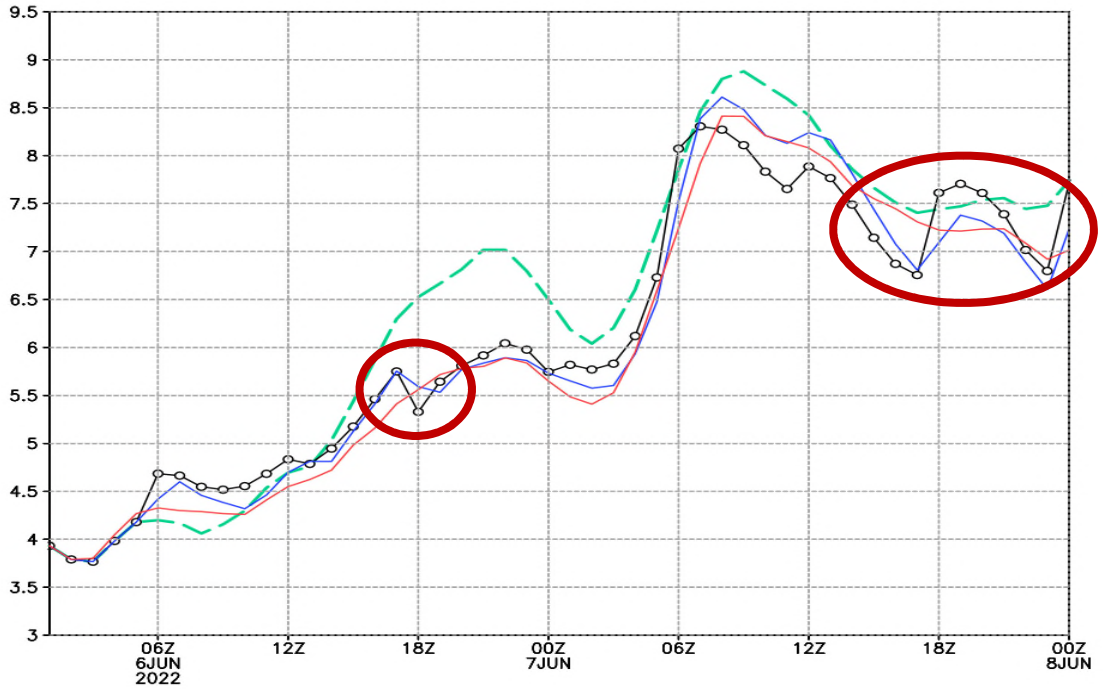
Incremental Blending Update (IBU)

- **Concept:**
  Fix temporal discontinuity problem by introducing **IBU**
- **Method:**
  Global: NCEP GFS analysis @ 00, 06, 12, 18
  Regional: RWRF 3-h forecast valid at same times
  Blending Increment = After – Before
- **Implementation:**
  Increment distributed over 6-h window
  Applied gradually during forecast [0, +60 min] each cycle
- **Purpose:**
  Leverage blending benefits while avoiding temporal discontinuity

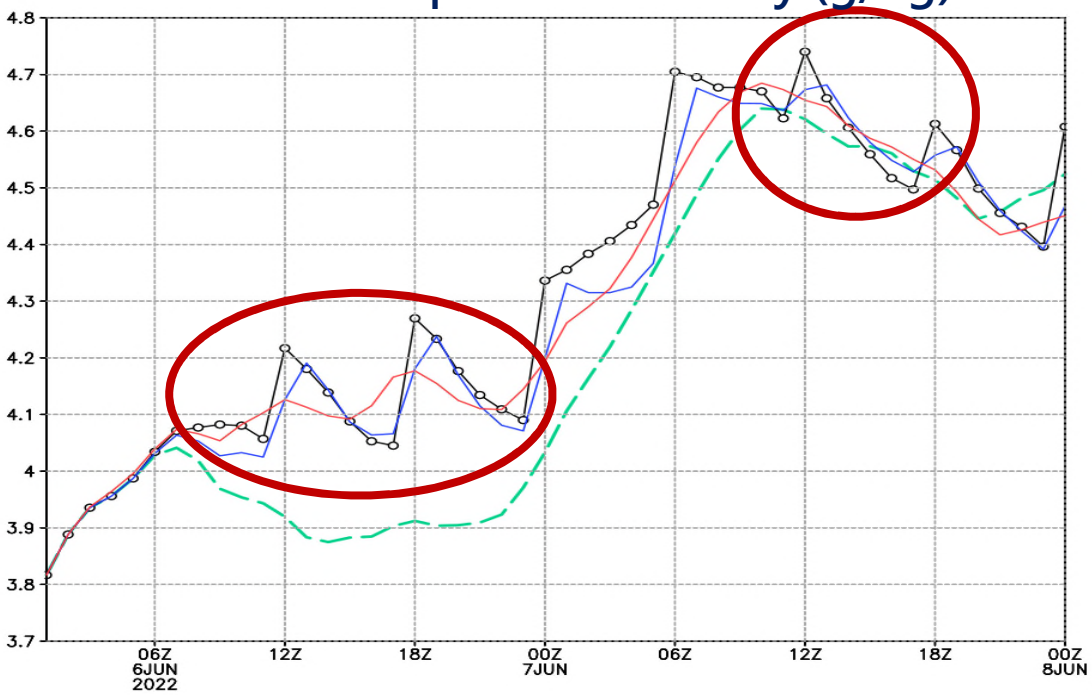


No-DA Experiments: Effects of Different Blending Approaches
Area-averaged variables in hourly analysis

300-hPa U-wind (m/s)



500-hPa specific humidity (g/kg)



- No Blending: Shows biases, blending remains necessary for regional model
- Traditional Blending: Causes temporal discontinuities
- IBU: Reduces discontinuities, with larger windows giving better results

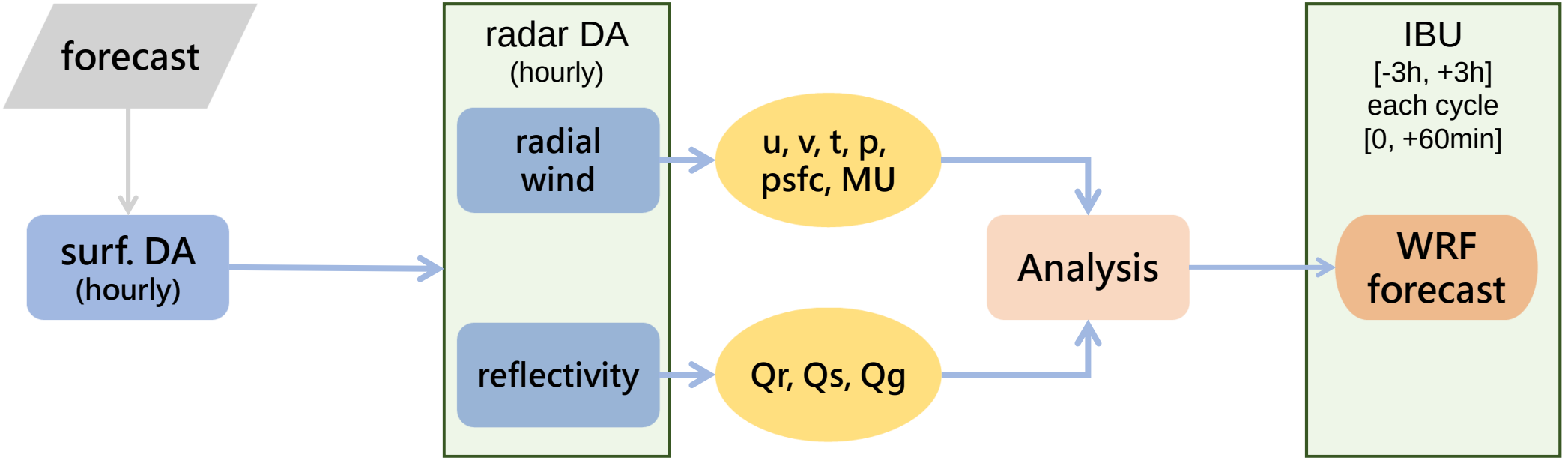
No blending

Every-6-h traditional blending
(same as current RWRF OP)

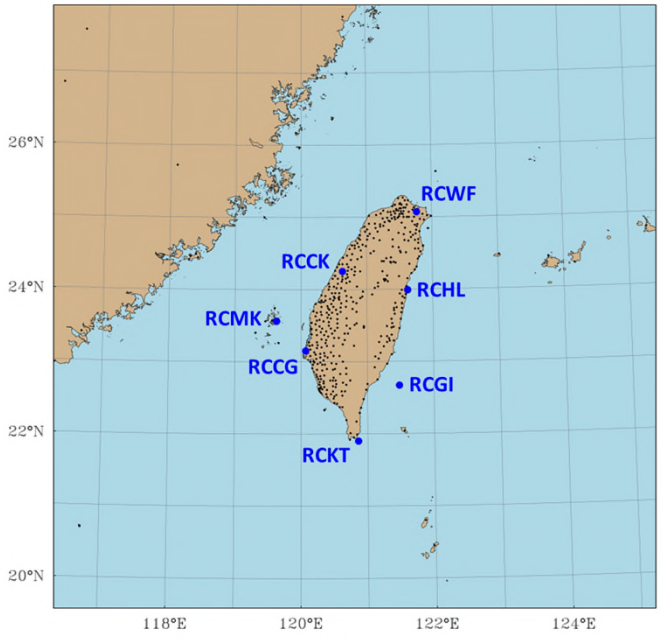
Every-6-h IBU with 1-h [-0.5h, +0.5h] window

Every-6-h IBU with 6-h [-3h, +3h] window

CWA Reanalysis RWRF flowchart (candidate version)



CWA RWRF for Reanalysis (candidate version)

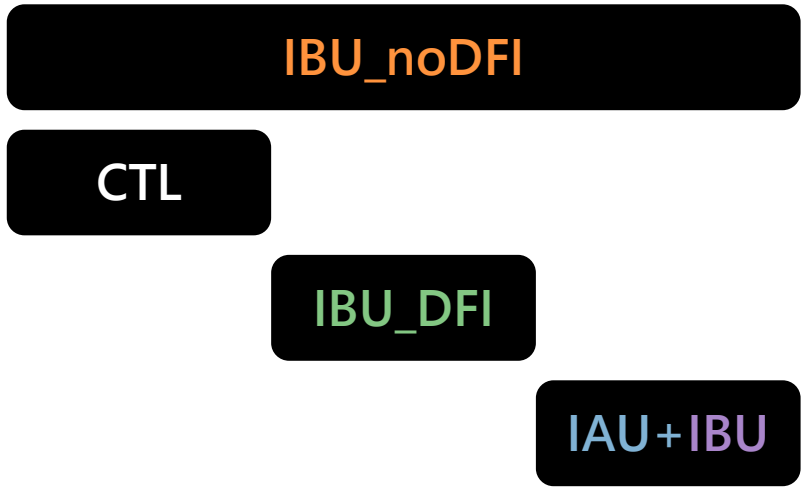


- 2-km resolution for the Taiwan area
- **3DVar** data assimilation
  - Hourly cycle for surface and Radar DA
- **6-hourly Incremental Blending Update (IBU)**
  - Increment distributed over 6-h window
  - Applied gradually during forecast [0, +60 min] each cycle
- **WRF/OP51** and **WRFDA/improved observation operators (sfcopt 2)** (will be applied to operational RWRF next year)
- **Radar data assimilation:**
  - Reflectivity (through hydrometeor retrievals) and radial velocity
- **Surface data assimilation:**
  - Temperature, humidity, winds

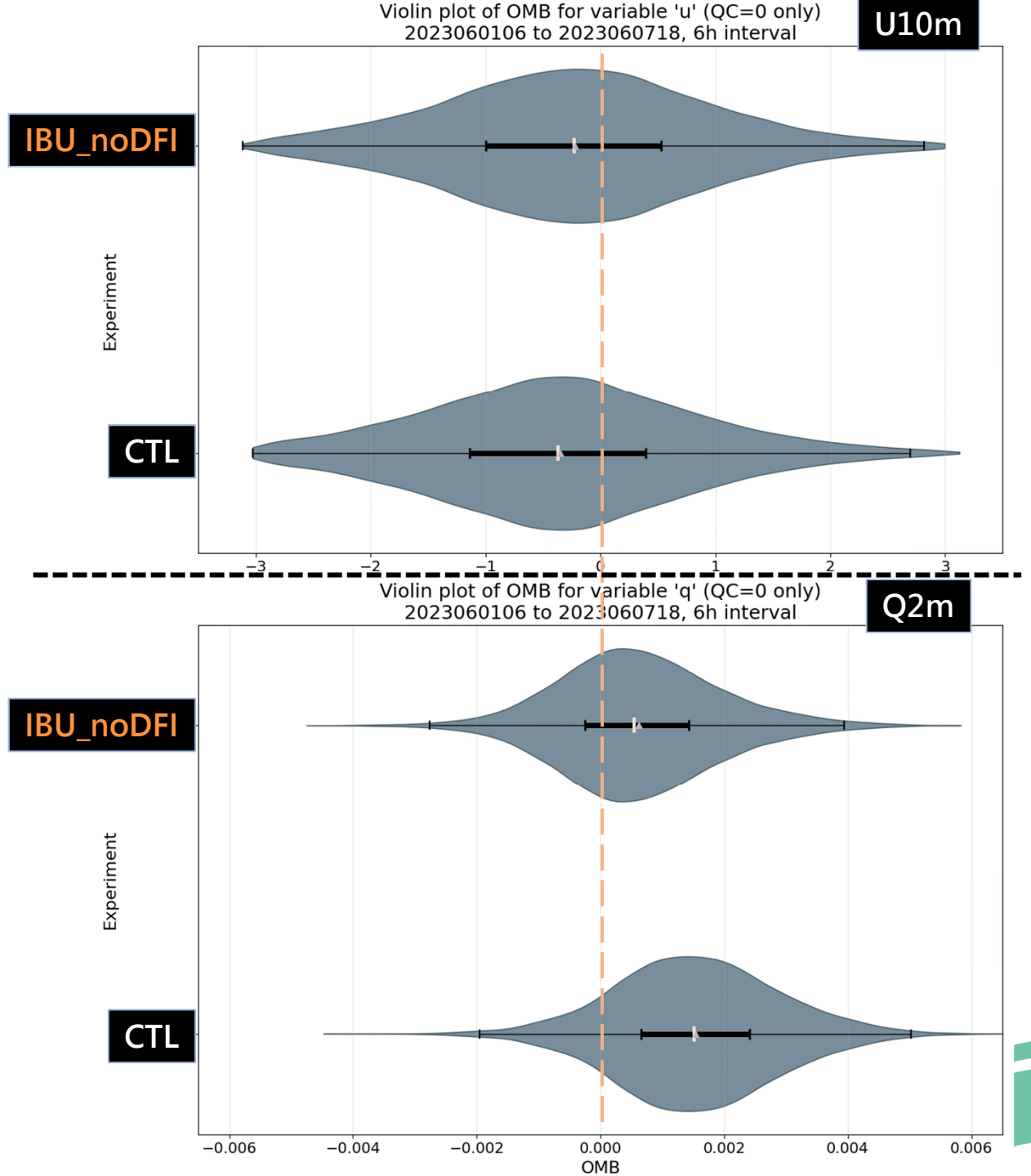
- **Experiment Periods:**
- 2023/06/01 03 – 06/07 23 UTC
  - Afternoon convection
- 2025/07/03 03 – 07/10 23 UTC
  - Typhoon Danas

	CTL	IBU (noDFI)	IBU (DFI)	IAU+IBU (noDFI)	IAU+IBU (DFI)
DFI	O	X	O	X	O
IAU	X	X	X	O	O
Blending	Original	IBU	IBU	IBU	IBU

- CTL: Closest to OP (with DFI, original blending)
- CTL vs. IBU: evaluate benefit of IBU
- IBU w/o DFI: examine the role of DFI
- IAU + IBU: evaluate the impact of IAU



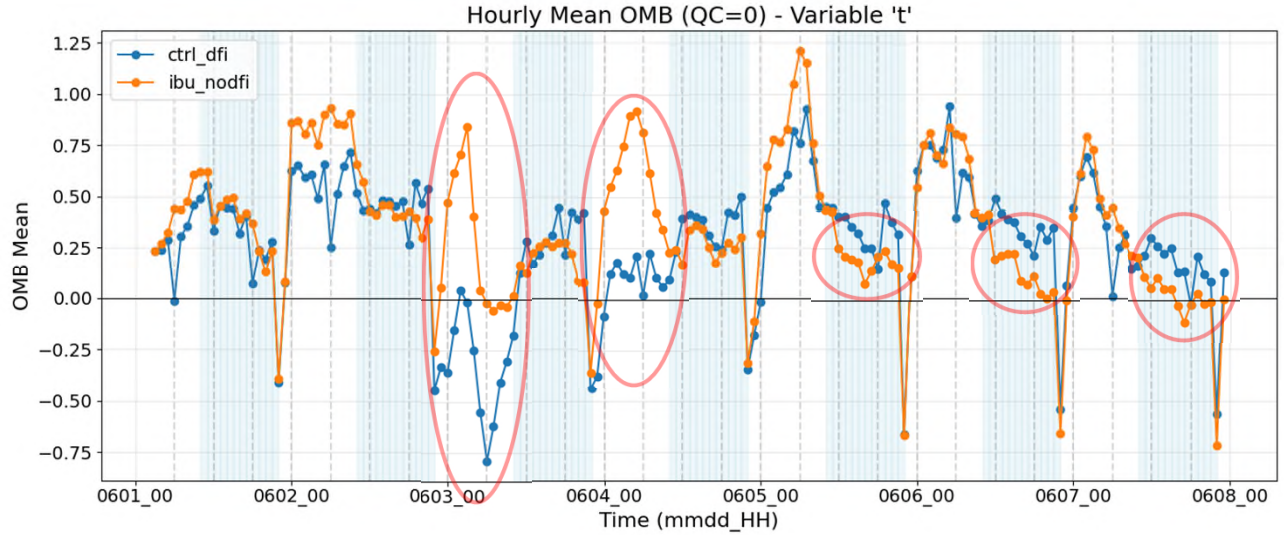
- **OMB statistics:**
- IBU has little impact on observation assimilation rate
- At 00 06 12 18Z, IBU significantly improves Q2m and slightly improves U10m
- IBU shows no significant impact on T2m and V10m

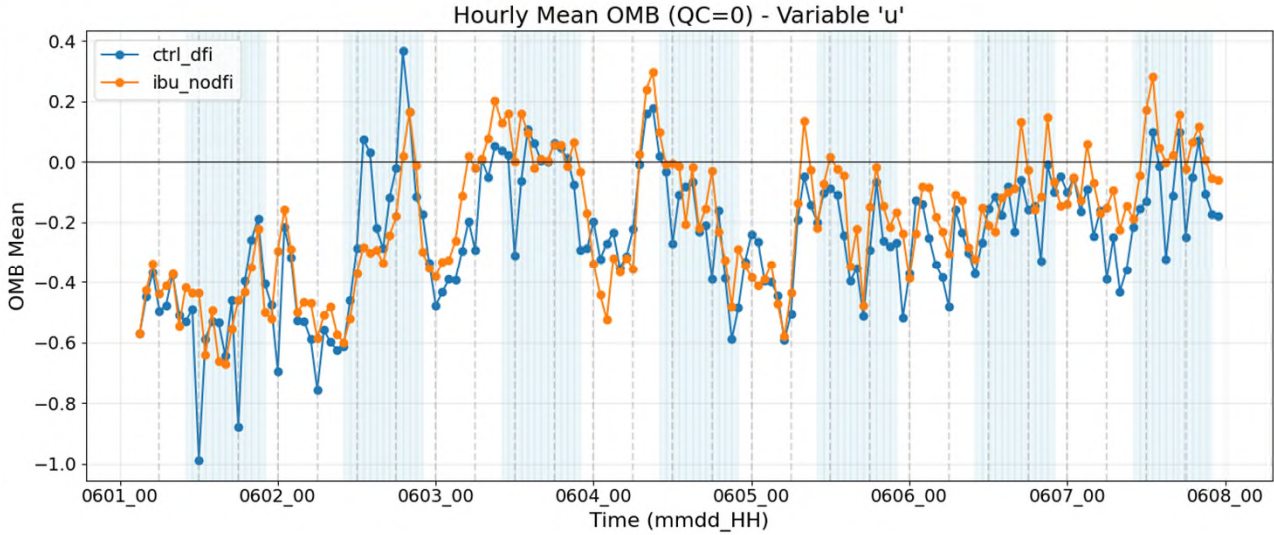


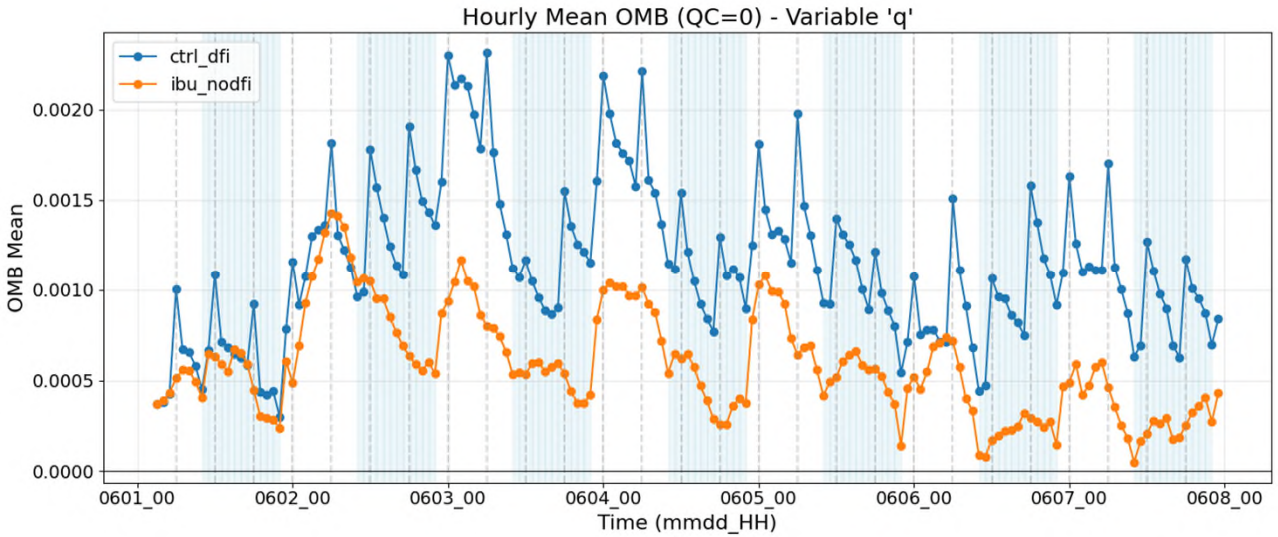
assimilation rate (pass gross check)
from 2023060103 to 2023060723 in 1h, all obs: 104233

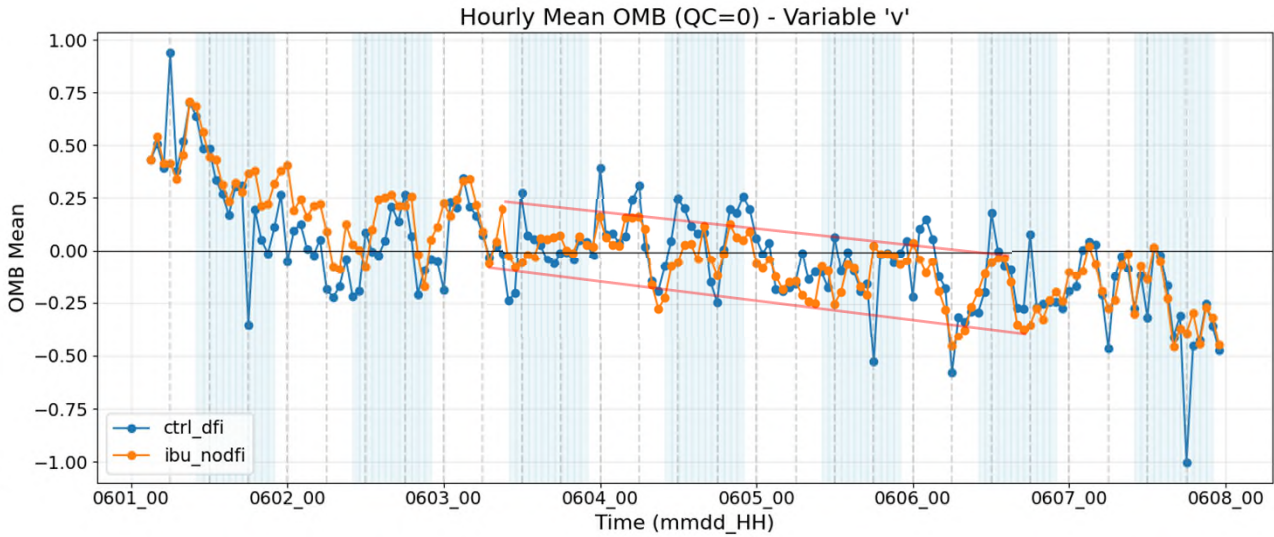
1hr	T2m	Q2m	U10m	V10m
CTL	98.66%	91.85%	80.14%	79.99%
IBU_noDFI	98.54%	92.23%	80.09%	79.80%

Hourly Mean OMB during Experiment Periods









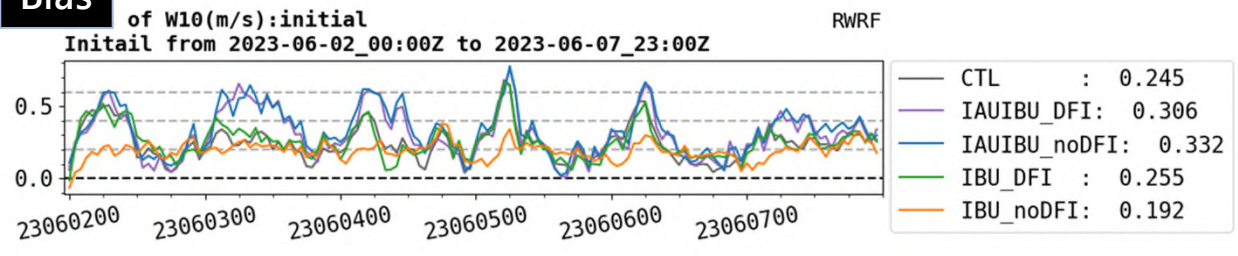
- **UV10m**: OMB fluctuations are reduced; U10m is generally closer to zero
- **T2m**: IBU shows some positive OMB bias during daytime, but reduces nighttime positive OMB bias
- **Q2m**: Overall improved, correcting the dry bias in CTL and clearly removing 6-hour discontinuities

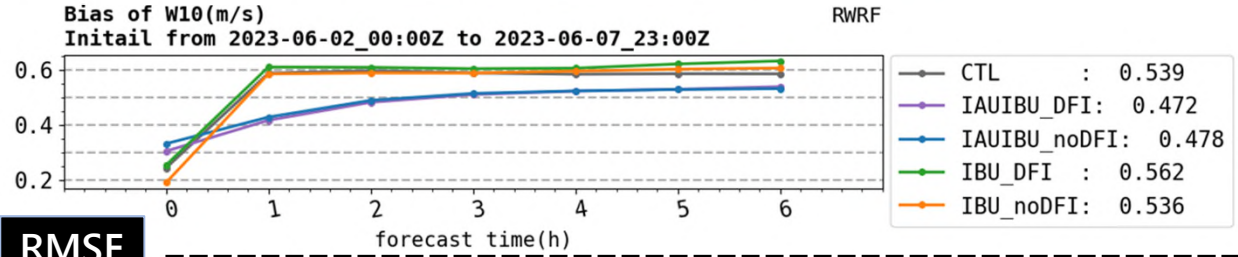
10-m Wind Speed Verification (Surface Obs.)

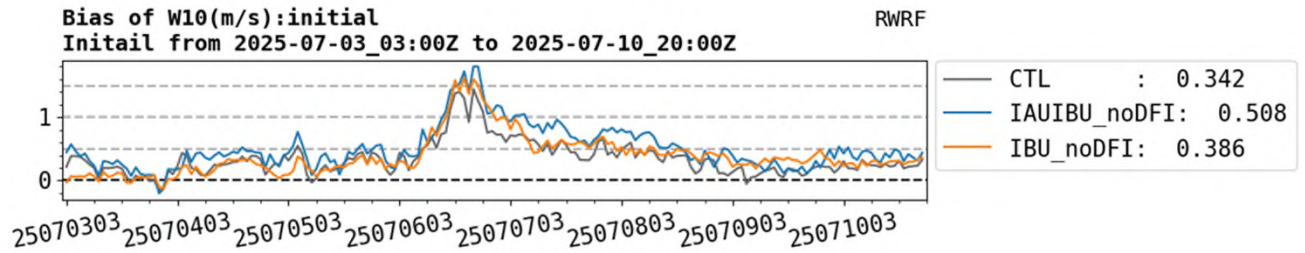
2023 06/02-07 Afternoon convection
analysis and 1-6 h forecasts

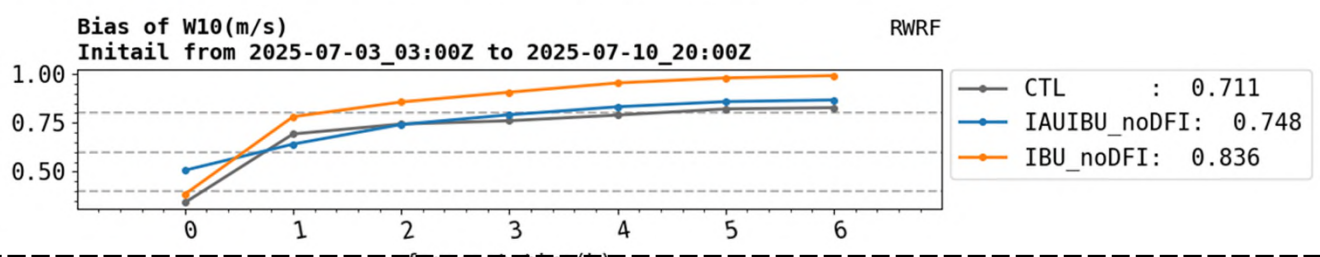
2025 07/03-10 Typhoon Danas
analysis and 1-6 h forecasts

Bias

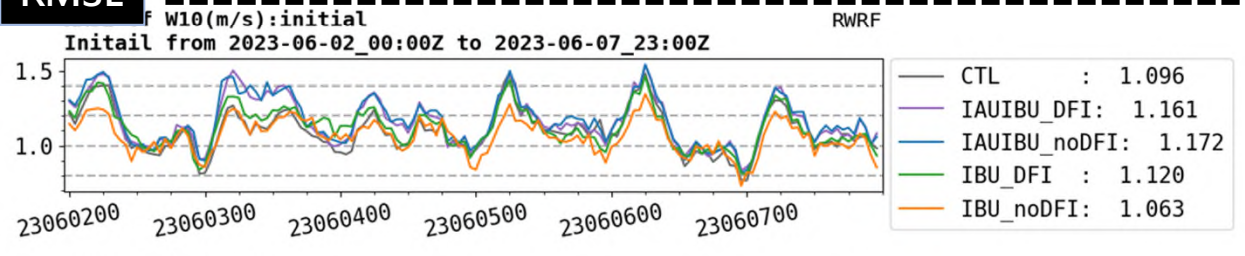


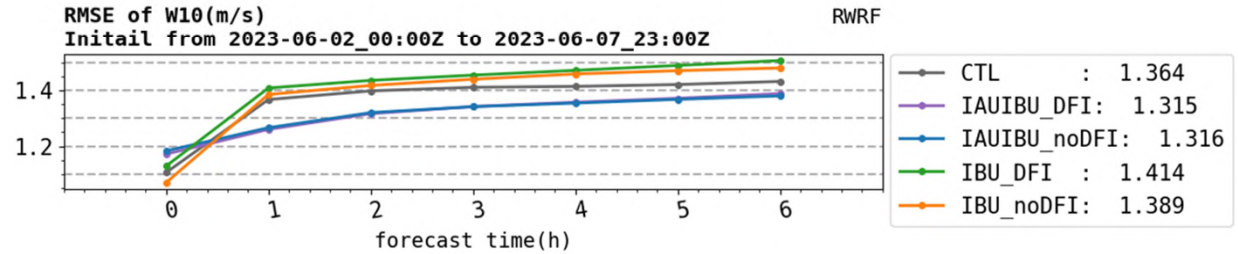


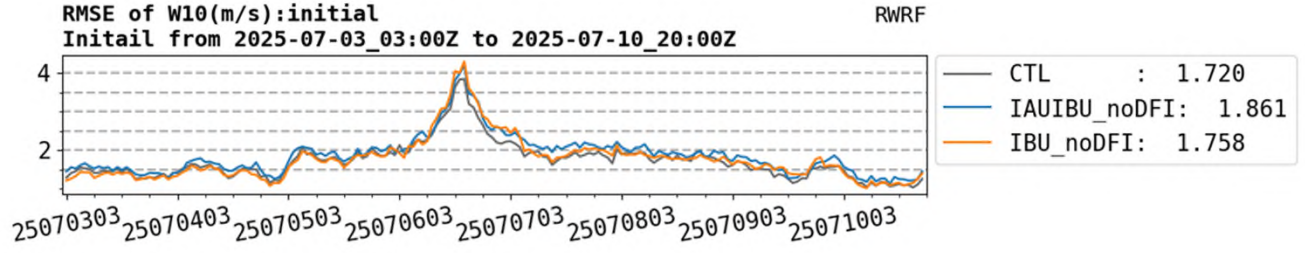


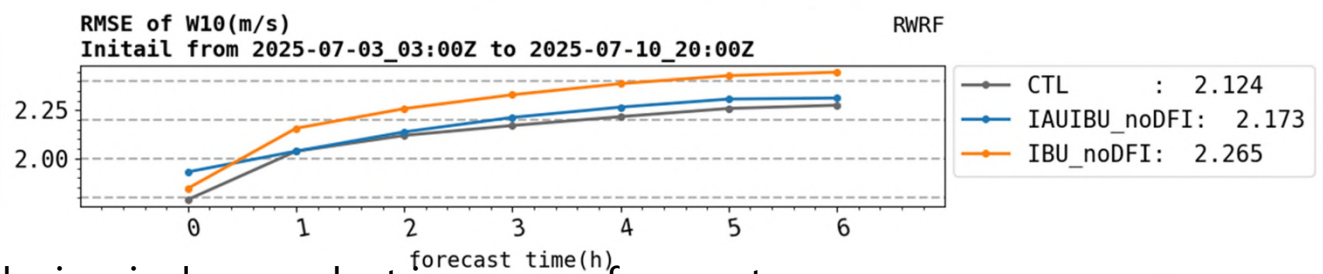


RMSE









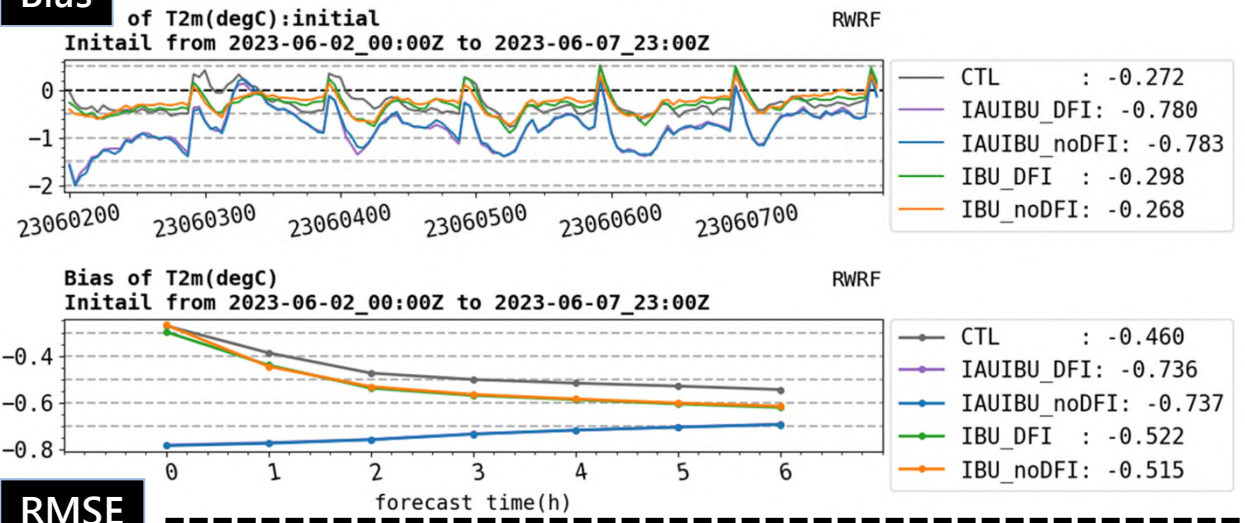
- IBU experiment reduces analysis wind errors but increases forecast errors
- For reanalysis applications, this trade-off is acceptable

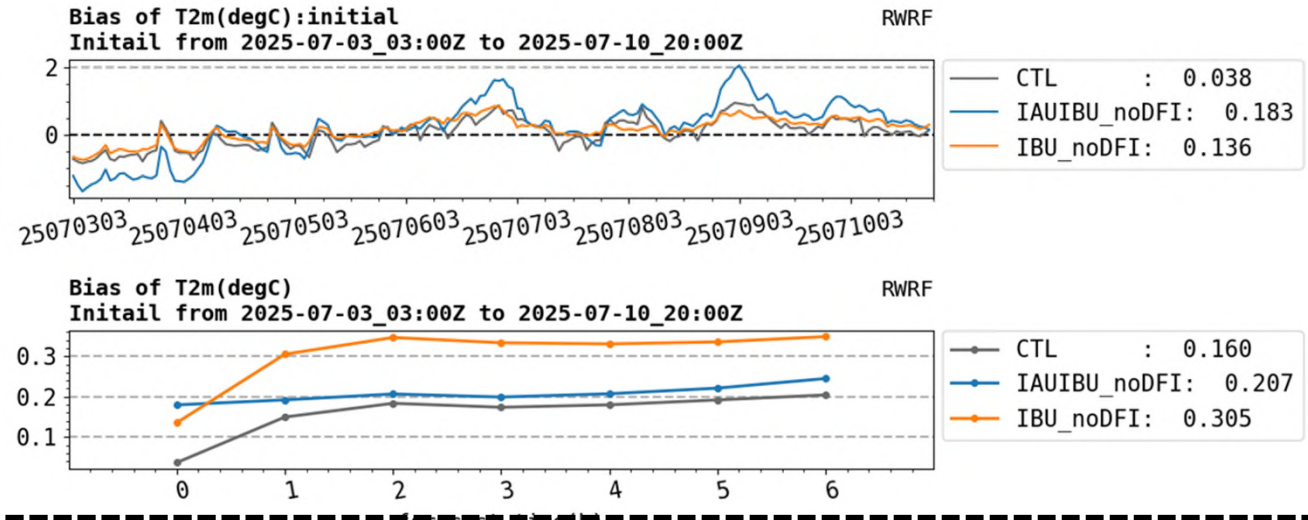
2-m Temperature Verification (Surface Obs.)

2023 06/02-07 Afternoon convection
analysis and 1-6 h forecasts

2025 07/03-10 Typhoon Danas
analysis and 1-6 h forecasts

Bias





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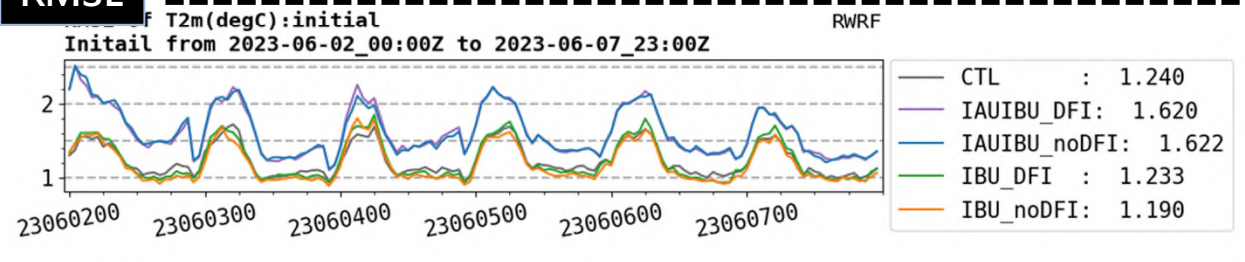
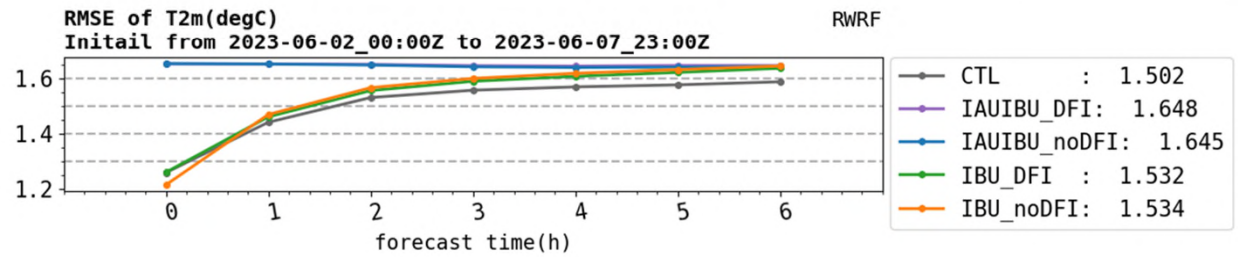
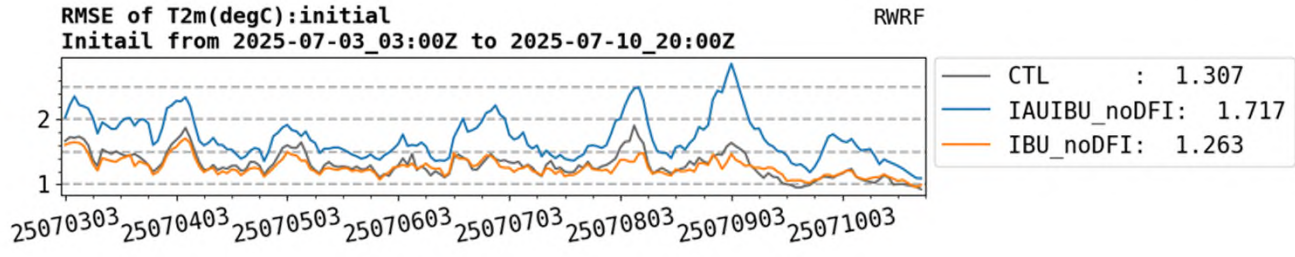
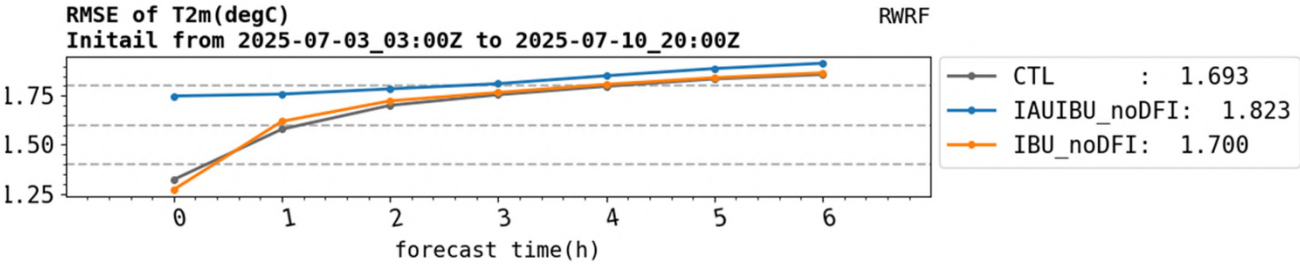








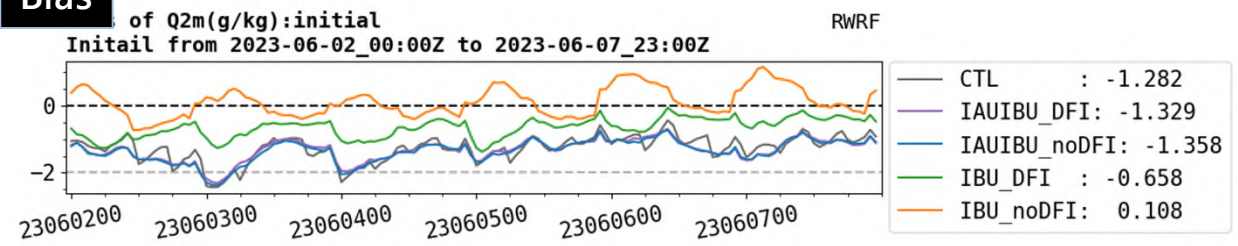
- IAUIBU experiment performs worse
- IBU experiment remains the better option for reanalysis

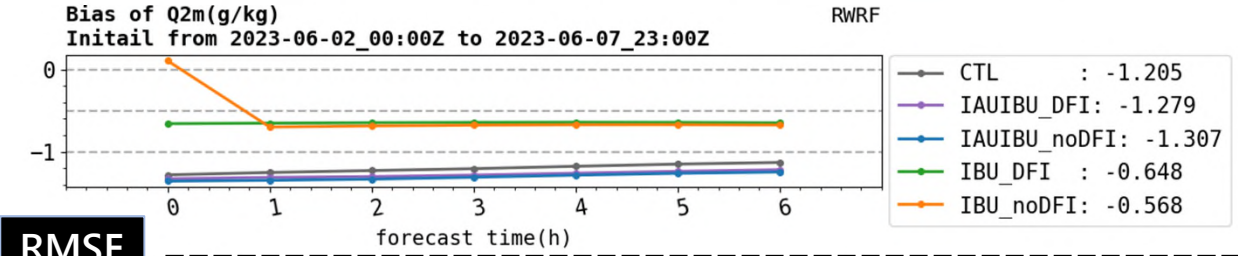
2-m Vapor Verification (Surface Obs.)

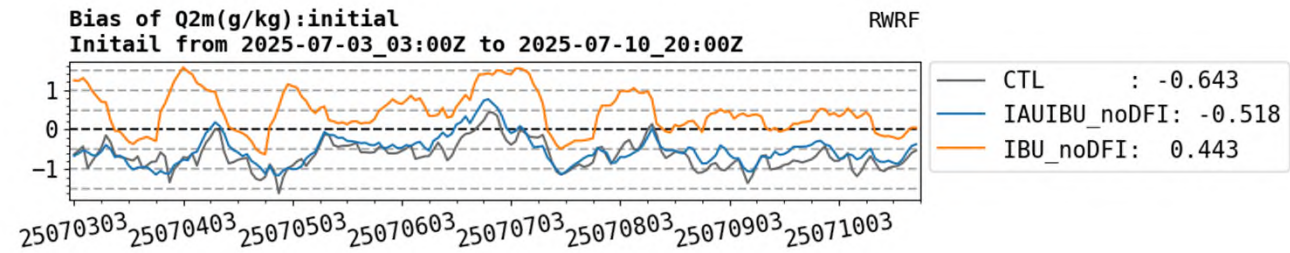
2023 06/02-07 Afternoon convection
analysis and 1-6 h forecasts

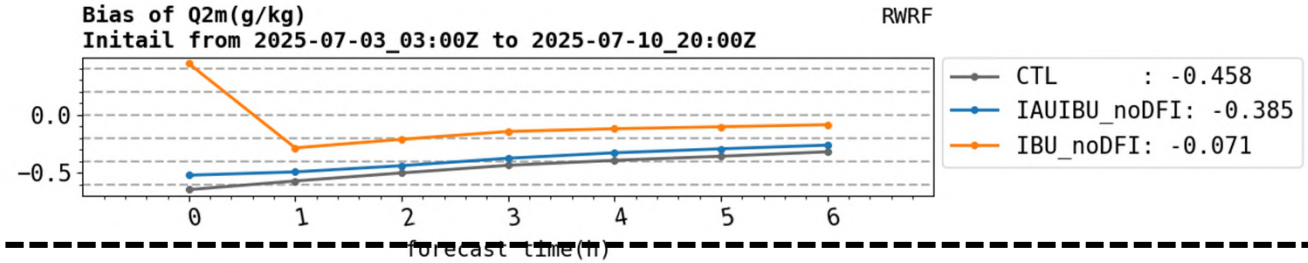
2025 07/03-10 Typhoon Danas
analysis and 1-6 h forecasts

Bias









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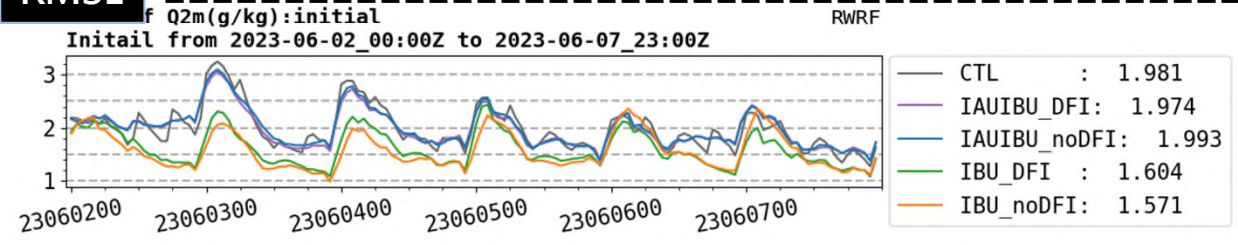
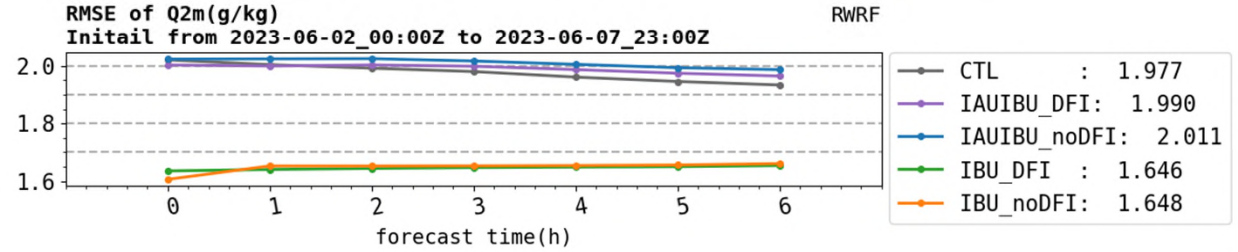
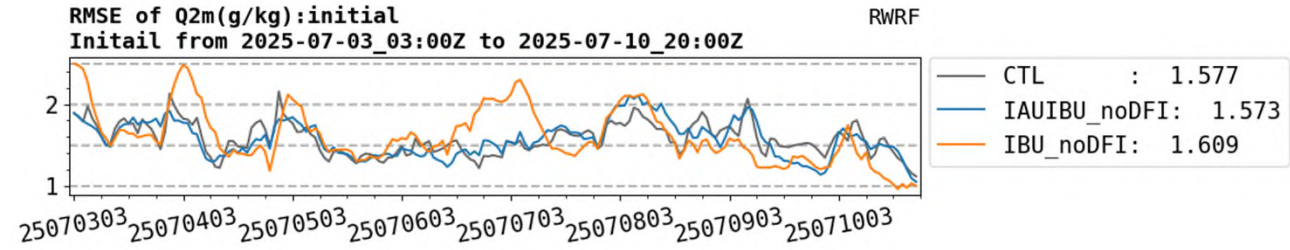
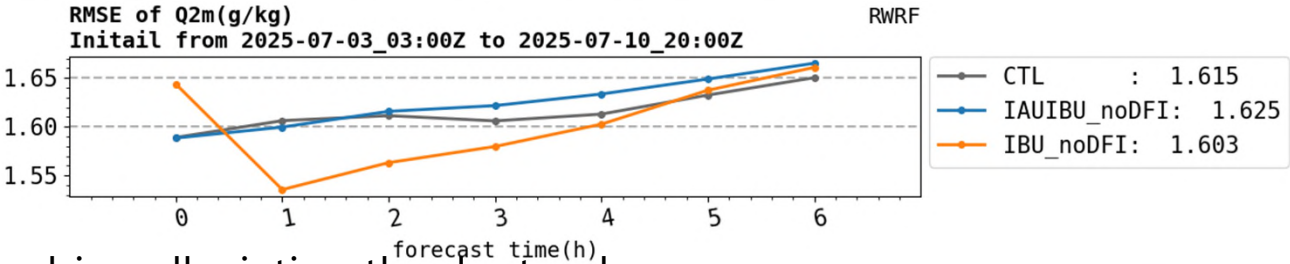








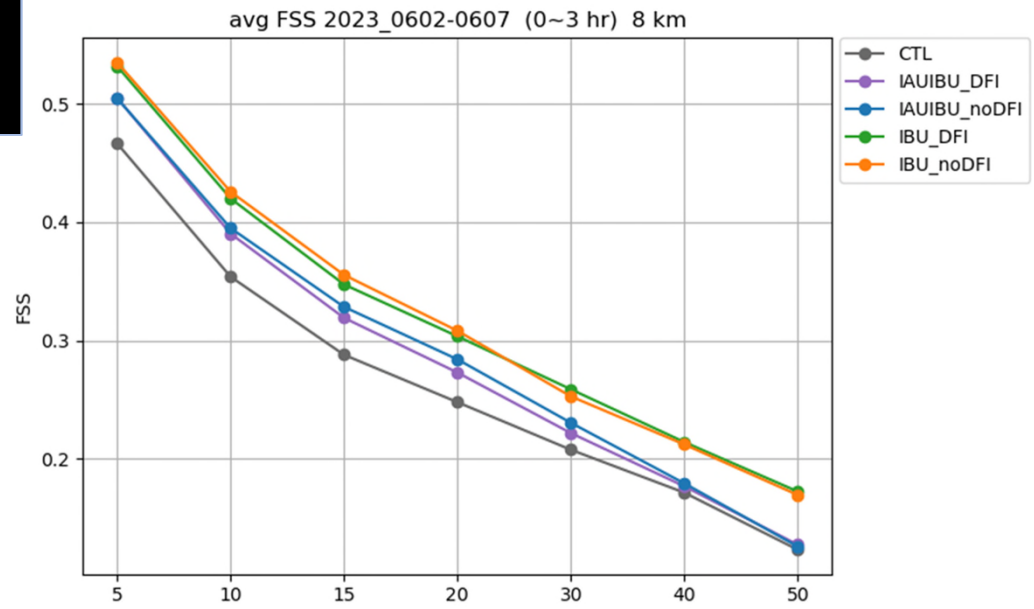
- IBU experiment shows smaller mean bias, alleviating the dry tendency
- DFI makes IBU experiment drier, but has little impact on IAUIBU experiment

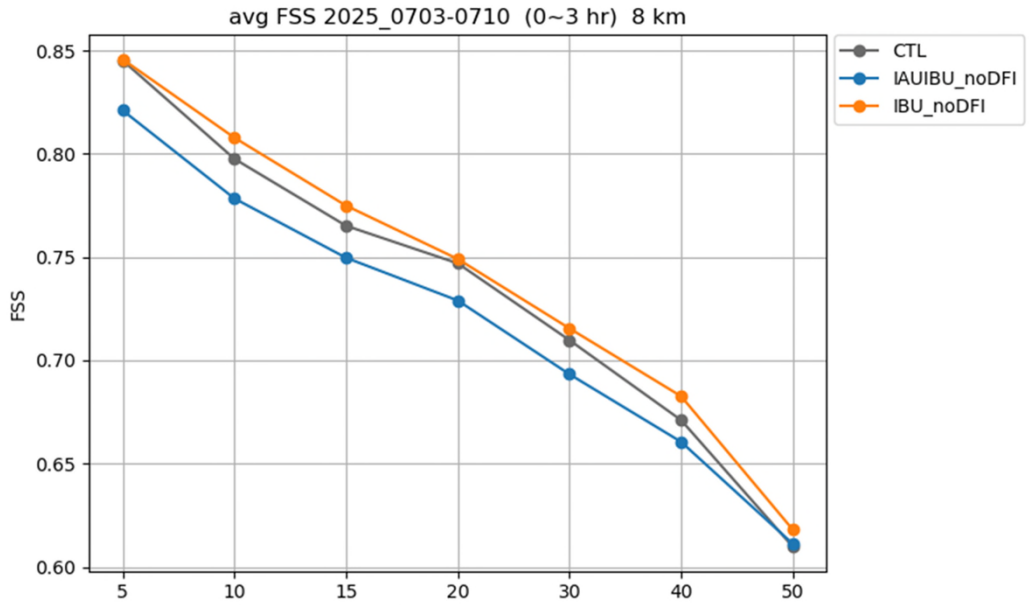
QPF FSS Verification (8-km radius)

2023 06/02-07 Afternoon convection

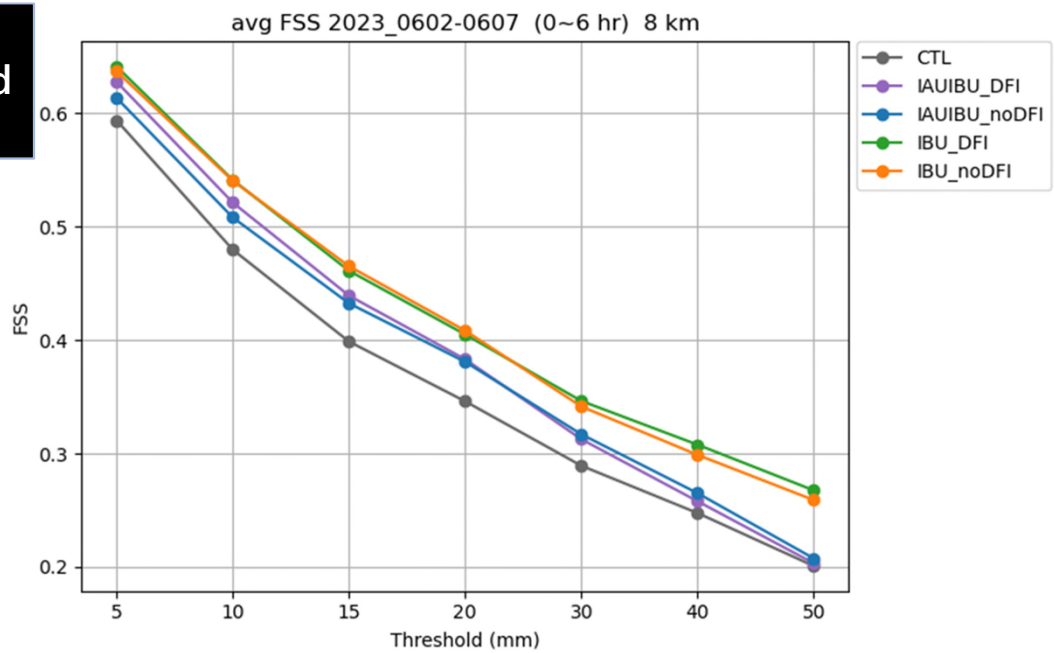
2025 07/03-10 Typhoon Danas

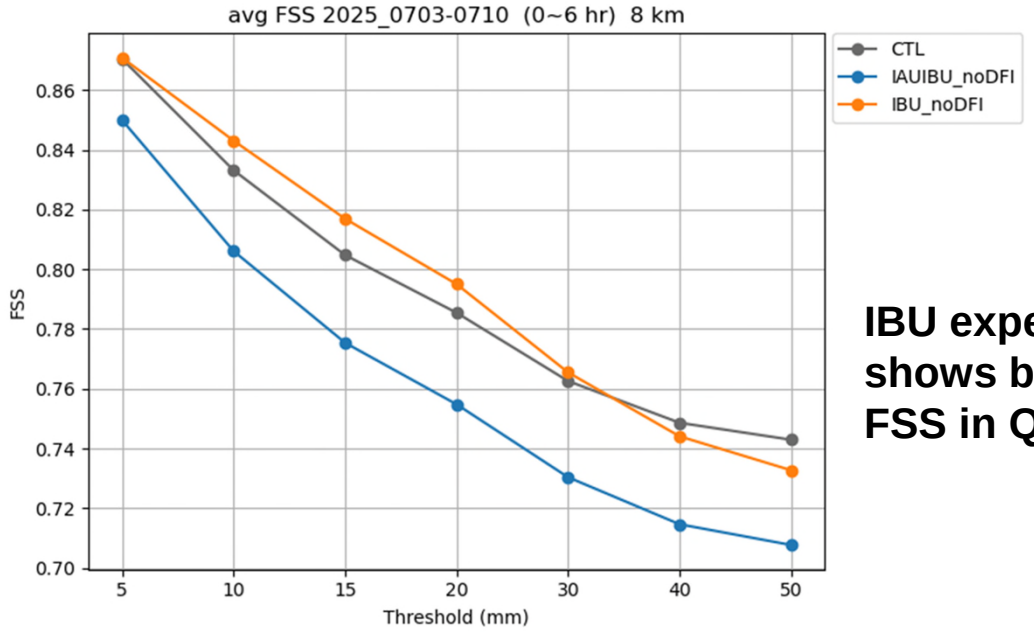
0-3h accumulated rainfall





0-6h accumulated rainfall





IBU experiment shows better FSS in QPF

Conclusions

- A system for Taiwan regional reanalysis is being developed, built largely upon the operational RWRF system, but with some differences in its assimilation workflow:
  - "Incremental Blending Update" (**IBU**) is implemented and used.
  - Digital filter initialization (DFI) is not used.
- Studies on the impacts of IBU and IAU:
  - IBU maintains large-scale benefits as traditional 6-hour blending, while reducing temporal discontinuities from the blending.
  - IBU improves analysis quality of Q2m and Wspd10m and 0-6h QPF (FSS), with a minor trade-off of slightly worse short-range forecast of some variables.
  - Combining IAU with IBU shows no clear advantage.

  → **IBU** is recommended for reanalysis.
- Further testing and optimization will be conducted to finalize the reanalysis system.