38th Conference on Weather Analysis and Forecasting

利用四維變分雷達資料同化系統分析宜蘭冬季強降水2021年11月26日個案研究

2024.09.05

吳孟杰(Meng-Jie, Wu)　廖宇慶(Yu-Chieng, Liou)

Department of Atmospheric Sciences, College of Earth Sciences, NCU

Radar Meteorology Laboratory

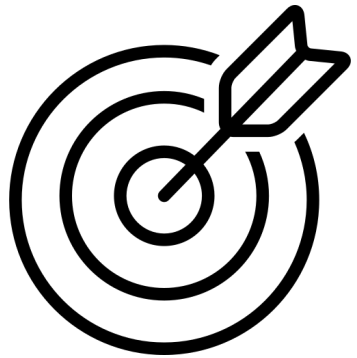
Rainfall in Yilan

Heavy rainfall ***from fall to winter season*** have been investigated by many studies.

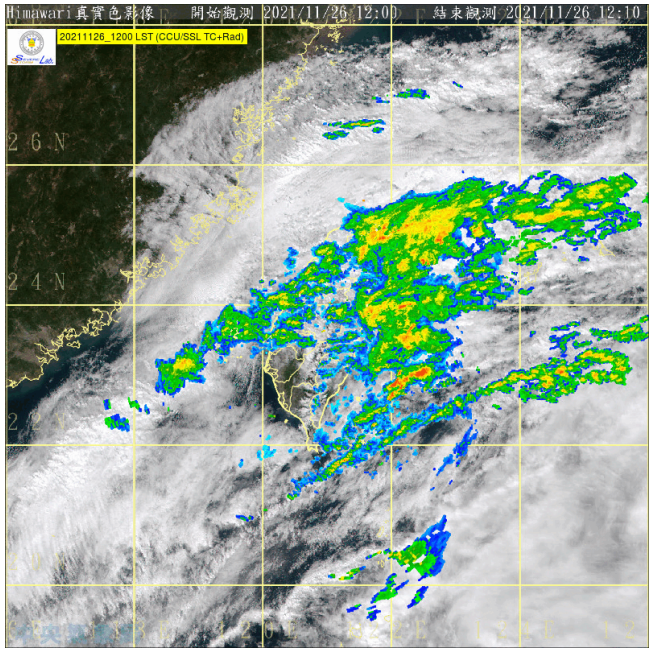
- ***OBS***: *Surface, sounding, radar sites etc.*
- ***Model***: *MM5, WRF, TaiwanVVM*
- ***DA***: *WRF LETKF,* ***IBM_VDRAS*** ***(this study)***

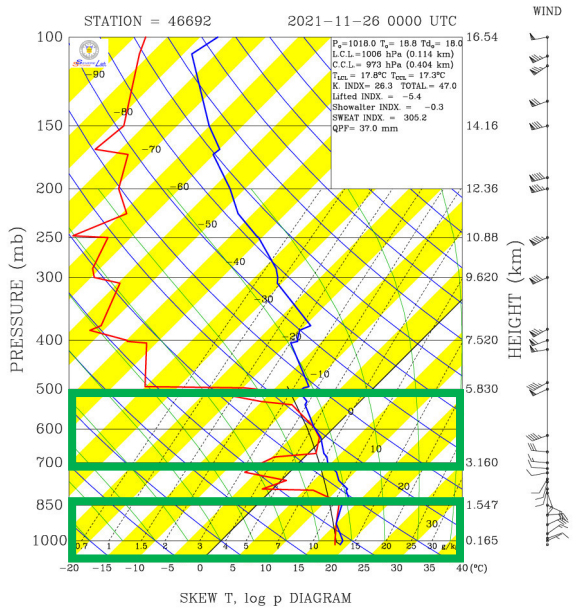
OBJECTIVES

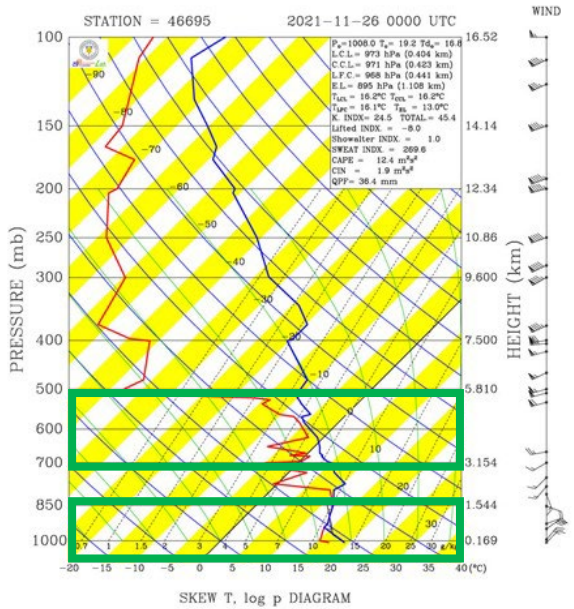
- **Evaluate its ability to simulate winter heavy rainfall in Yilan.**
  - Verify with observations
- **Use IBM_VDRAS to get complete 3D meteorological fields.**
  - Produce analysis in high spatial & space resolutions
  - Offer kinetics / thermodynamics / microphysics processes
  - Understand evolution of heavy rainfall in winter season

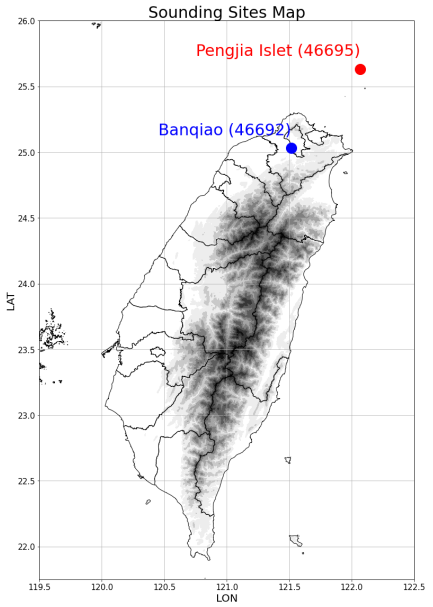


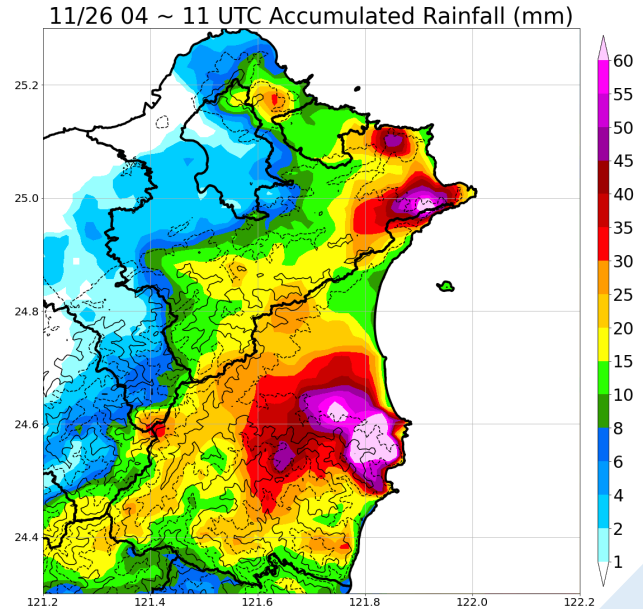
- ***Synoptic environment: (from sounding)***
  - ✓ Mid-level SW flow (850hPa ↑) & Low-level NE monsoon (850hPa ↓)
- ***Period during 04Z ~ 11Z on 11/26:***
  - ✓ Significant rainfall occurred in Yilan Plain and Suao. (> 60 mm)
  - ✓ Sufficient observations. (Ex: TEAM-R / NTU X-pol etc.)
- ***What makes this case special?:***
  - ✓ Mid-level SW wind carrying moisture interact with terrain & NE wind.





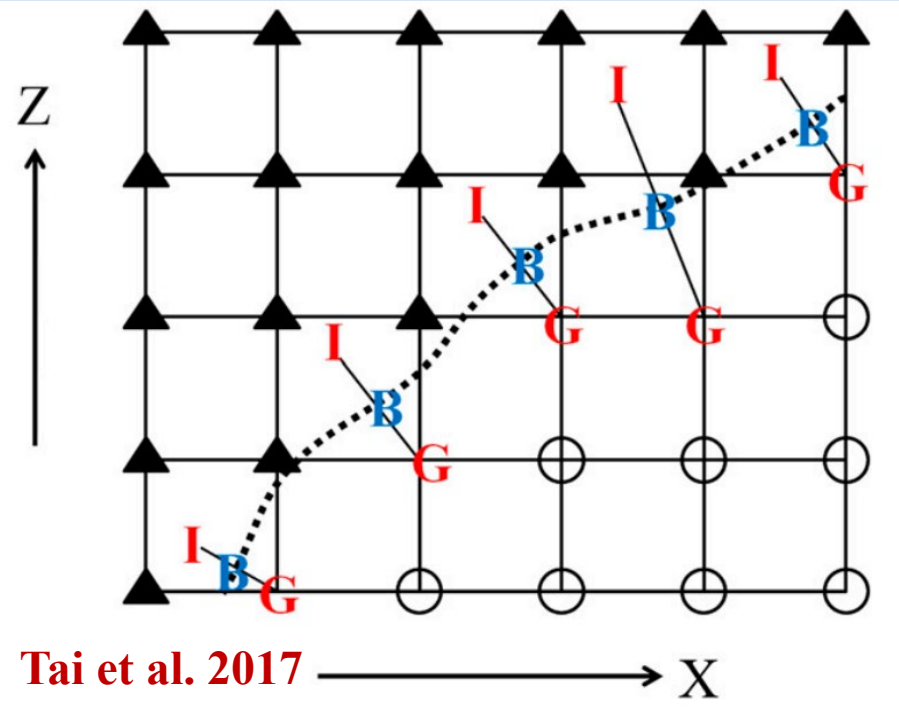




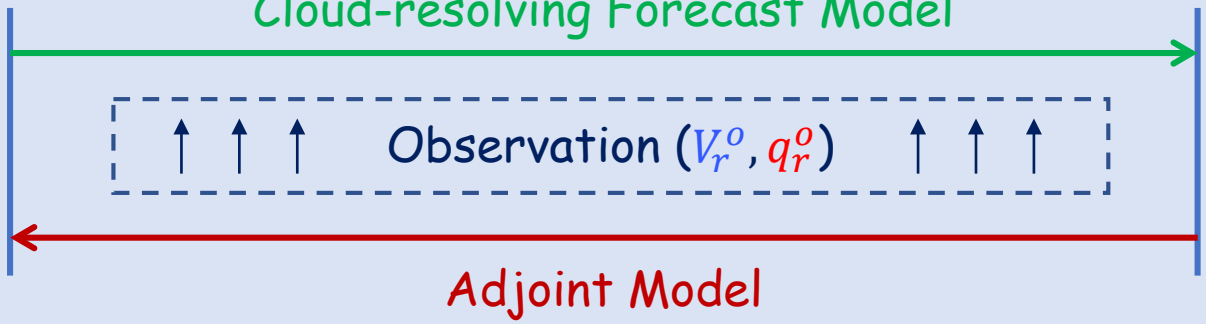


IBM_VDRAS

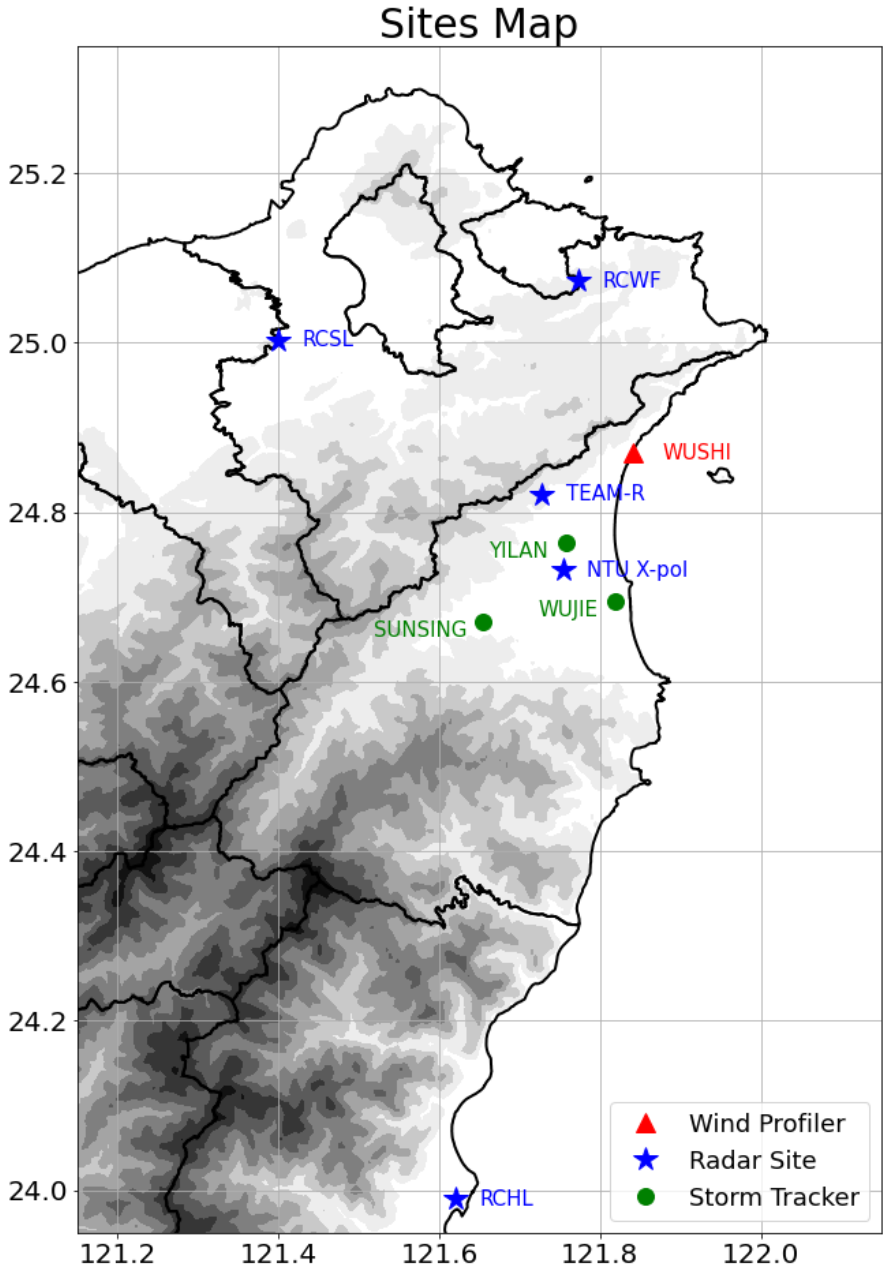
Immersed Boundary Method + Variational Doppler Radar Analysis System



$$J = \frac{1}{2}(\boldsymbol{x_o} - \boldsymbol{x_b})^T B^{-1}(\boldsymbol{x_o} - \boldsymbol{x_b}) + \frac{1}{2}\sum_{\sigma,t}\left[\eta_v(V_r - V_r^o)^2 + \eta_q(q_r - q_r^o)^2\right] + J_p + J_{mb}$$



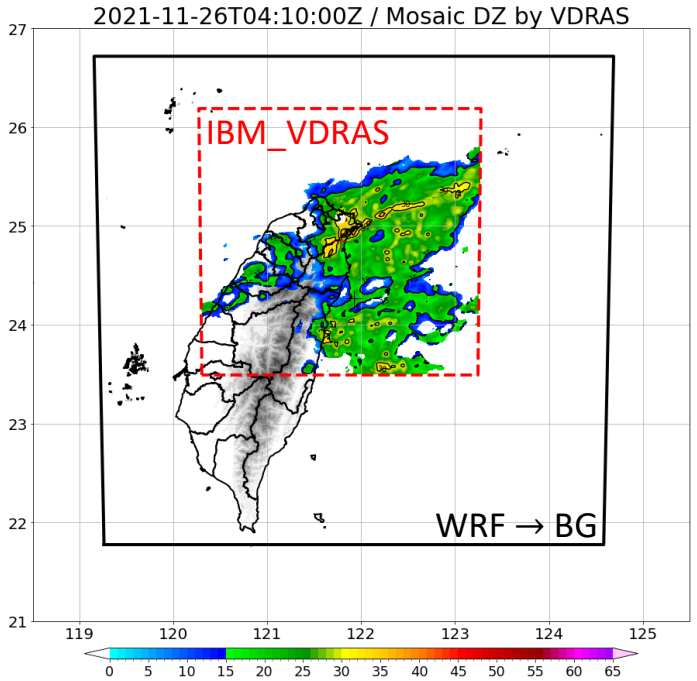
Use IBM to resolve terrain on a Cartesian Coordinate

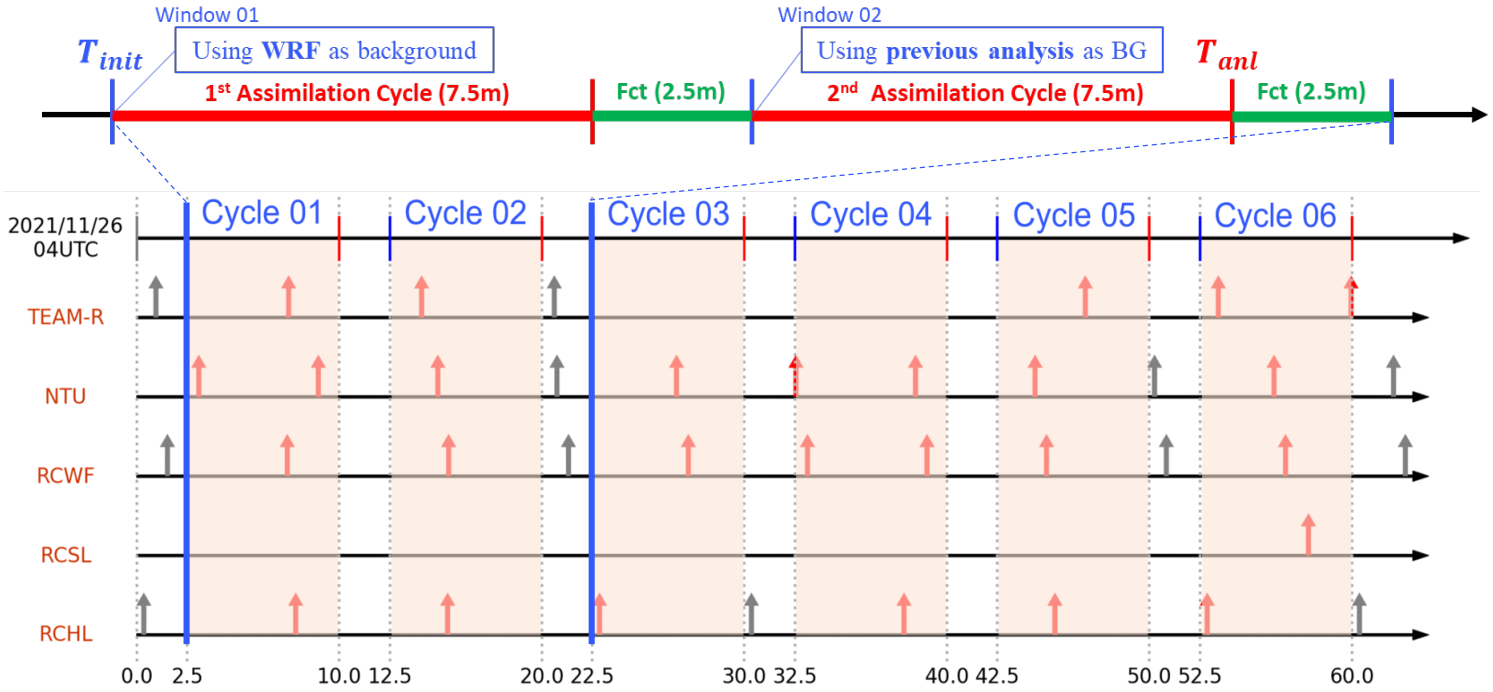


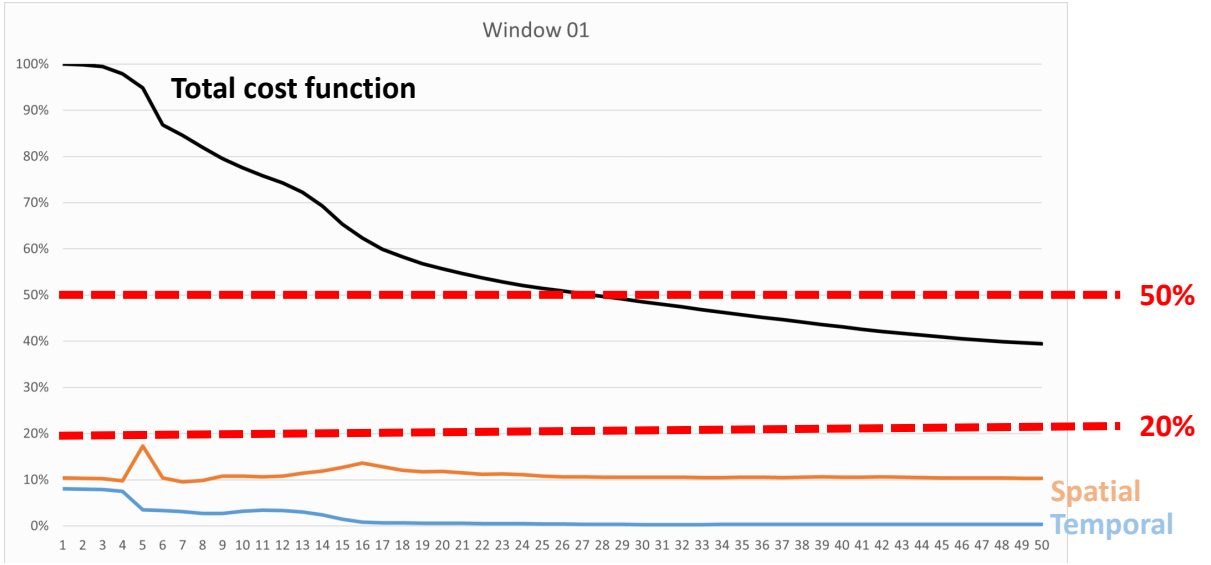
Storm Tracker

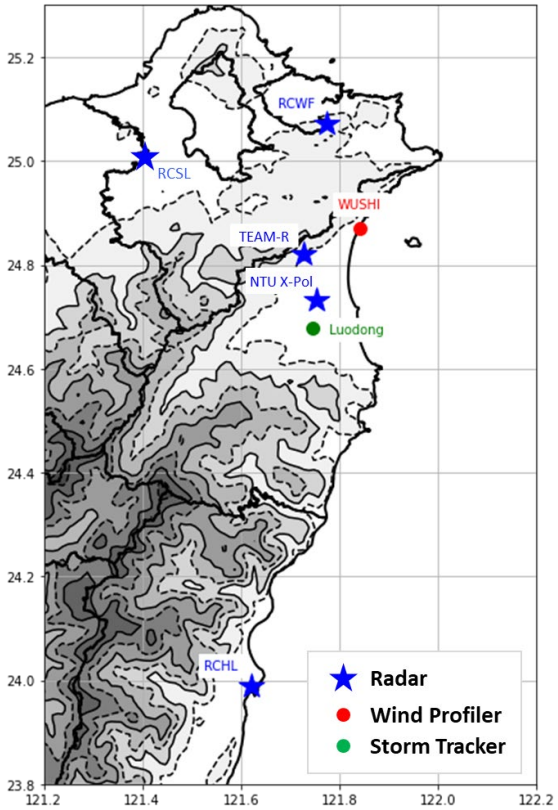
Research	TEAM-R	(24.82083, 121.72861)	400 m
	NTU X-Pol	(24.73250, 121.75472)	66 m
Operational	RCWF	(25.07306, 121.77306)	765 m
	RCHL	(23.99000, 121.62000)	63 m
	RCSL	(25.00389, 121.40056)	298 m

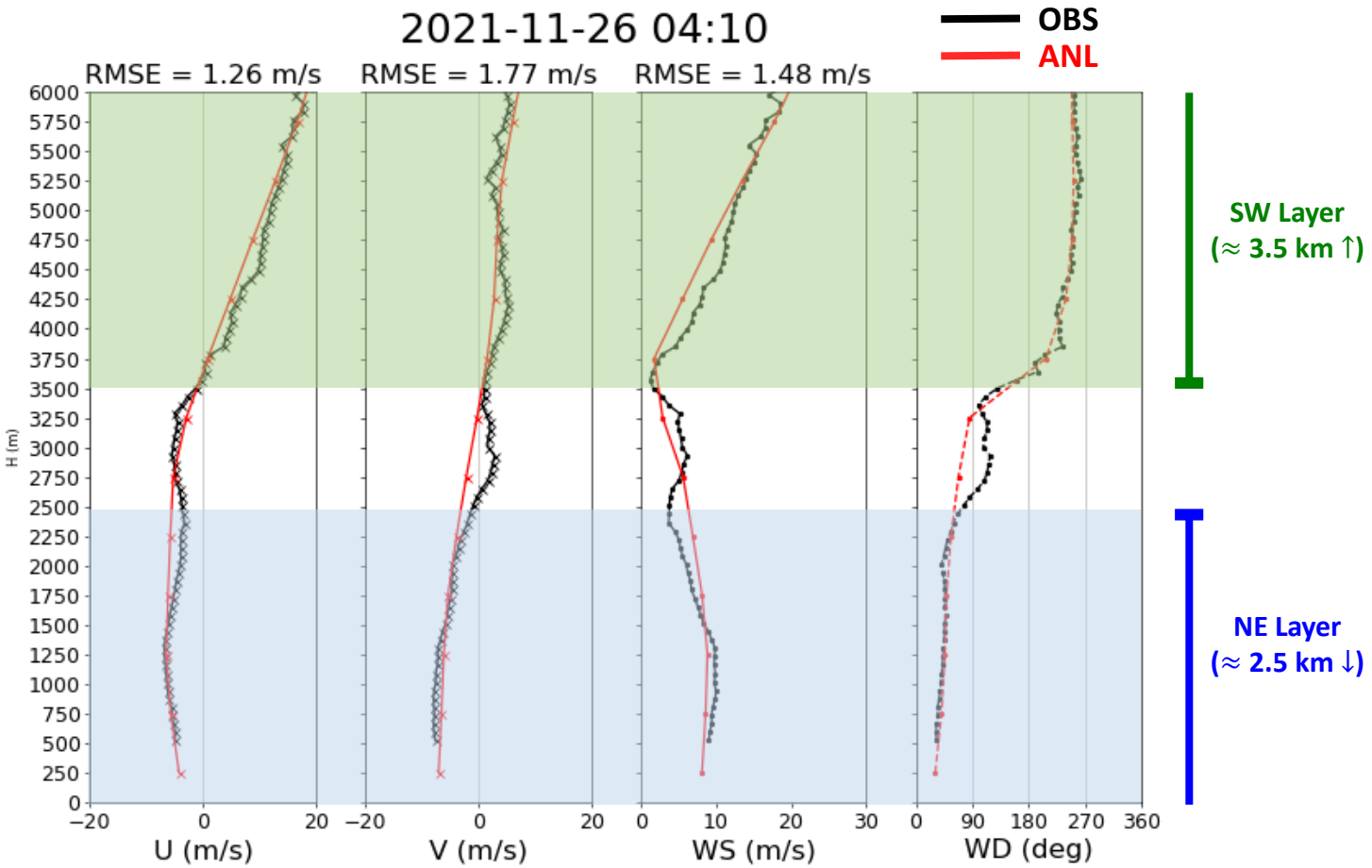
IBM_VDRAS Configuration			
Res.	HOR.	1km x 1km	301 x 301
	VER.	0.5km	30 layers (0.25 km ↑)
Computation time $0.75\ \frac{days}{cycle} \times 41\ cycles \approx 31 days$			

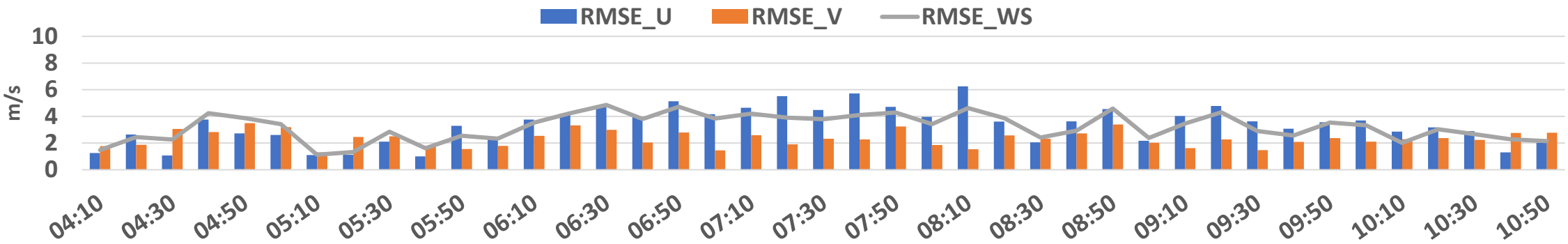




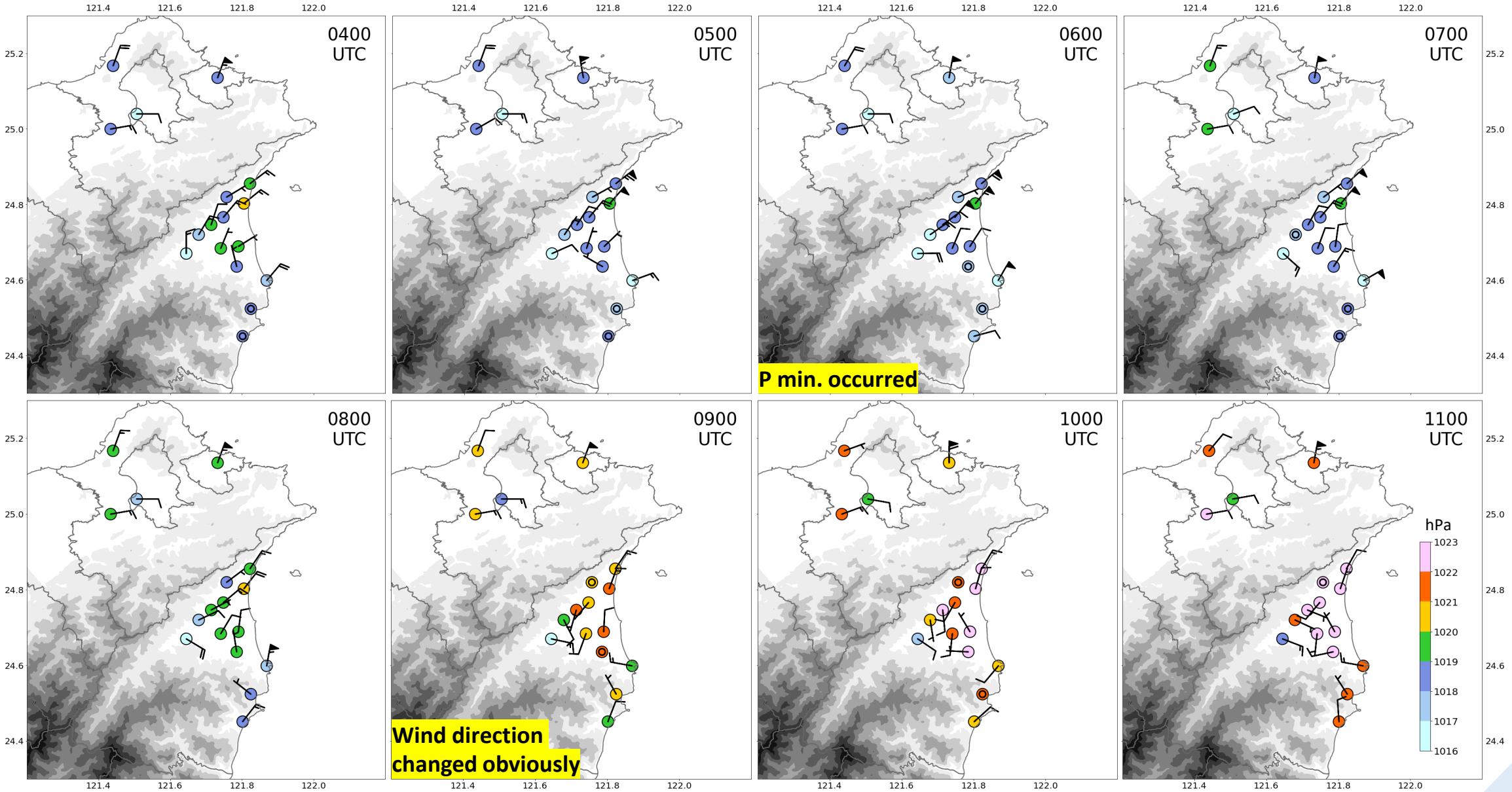



RCWF
RCSL
WUSHI
TEAM-R
NTU X-Pol
Luodong
RCHL
Radar
Wind Profiler
Storm Tracker

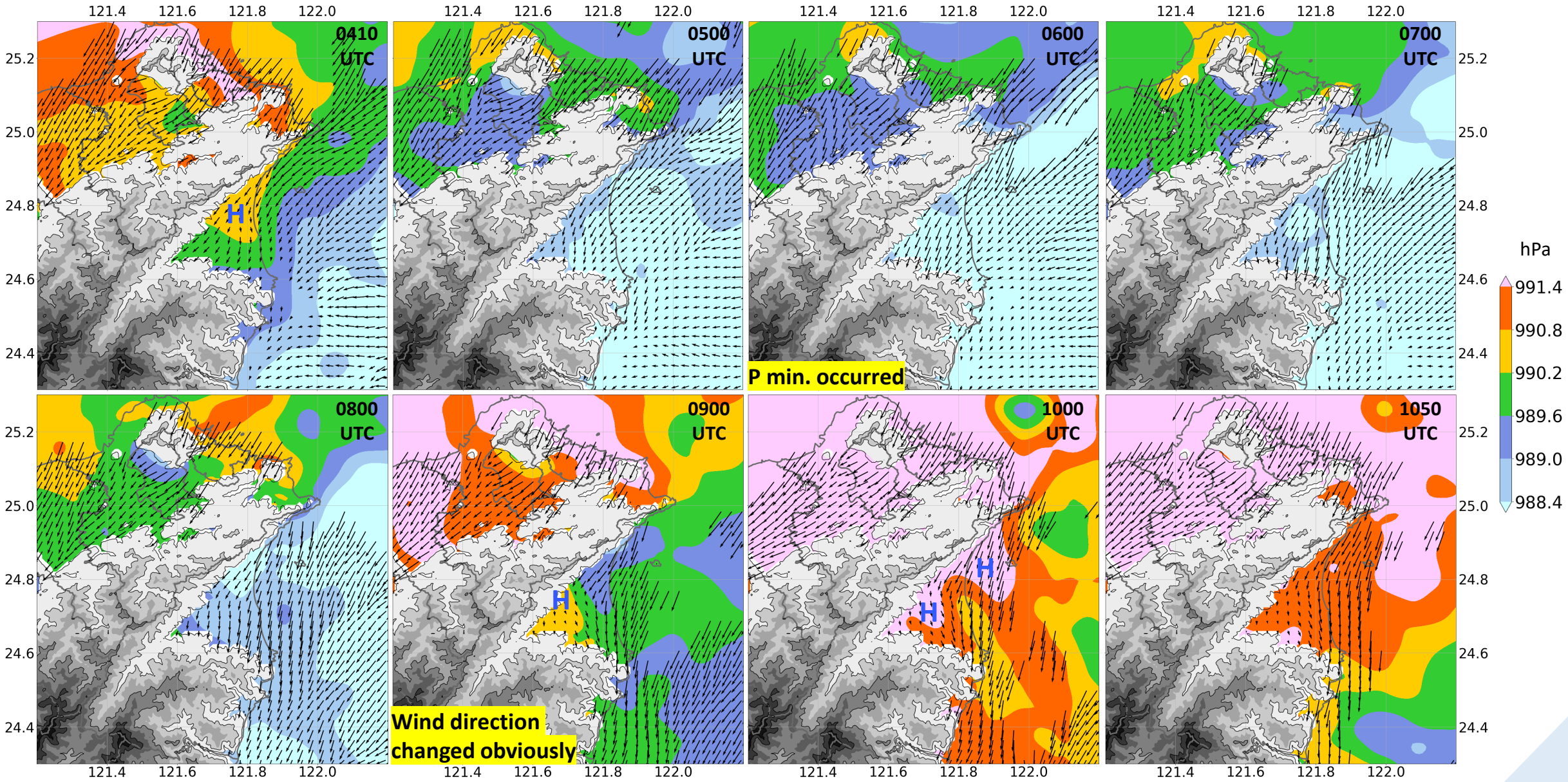

2021-11-26 04:10
OBS
ANL
RMSE = 1.26 m/s
RMSE = 1.77 m/s
RMSE = 1.48 m/s
H (m)
U (m/s)
V (m/s)
WS (m/s)
WD (deg)
SW Layer
(≈ 3.5 km ↑)
NE Layer
(≈ 2.5 km ↓)


RMSE_U
RMSE_V
RMSE_WS
m/s

Pressure (hPa) & wind by CWA sites



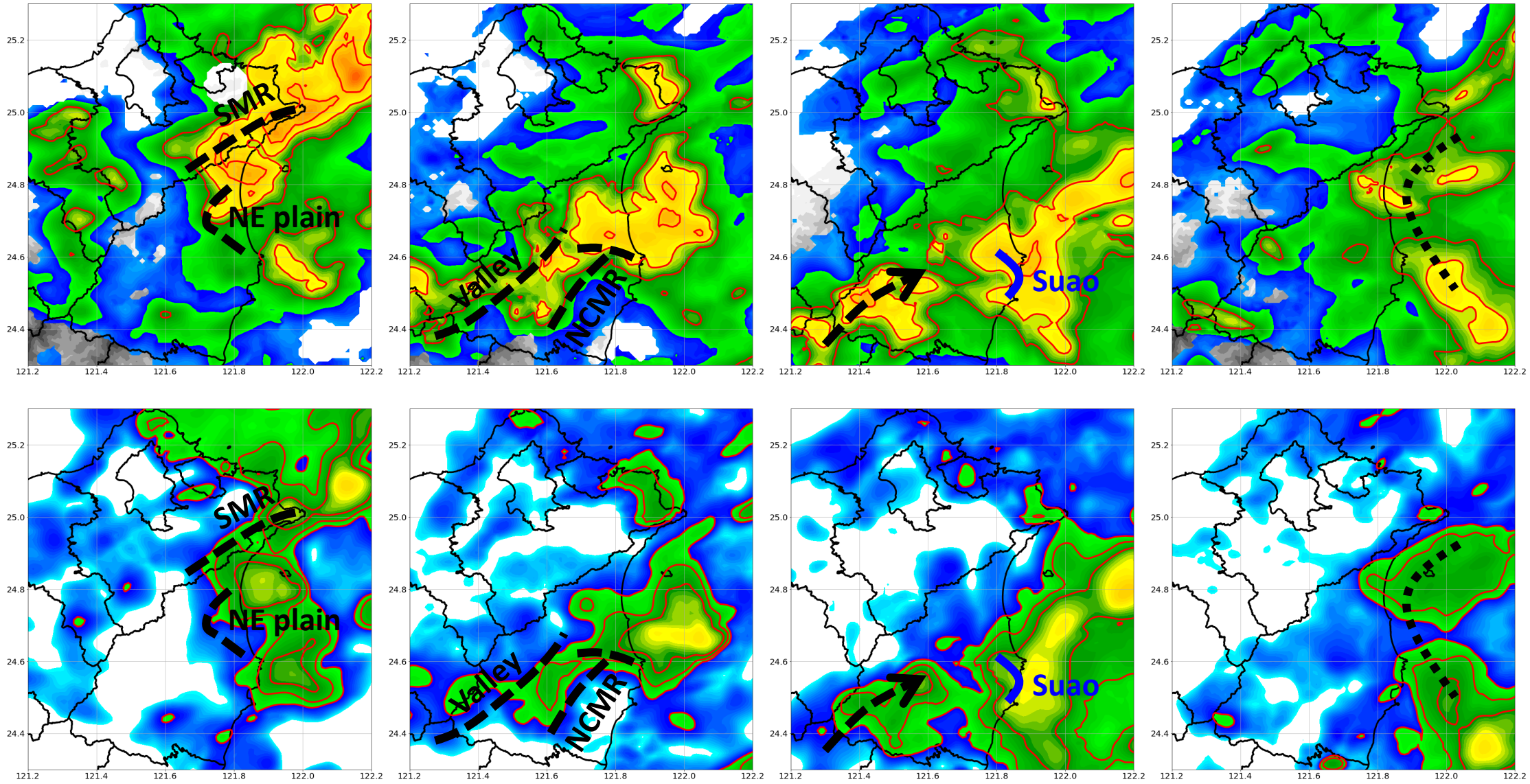
Pressure & wind by IBM_VDRAS analysis at Z = 250m



S1 [04 - 05] 0430 UTC	S2 [05 - 07] 0600 UTC	S3 [07 - 10] 0830 UTC	S4 [10 - 11] 1030 UTC

OBS
[25, 30, 35] dBZ

ANL
[15, 20, 25] dBZ



Notes:

Verification in various fields shows IBM_VDRAS has ability to simulate heavy winter rainfall

Key questions:

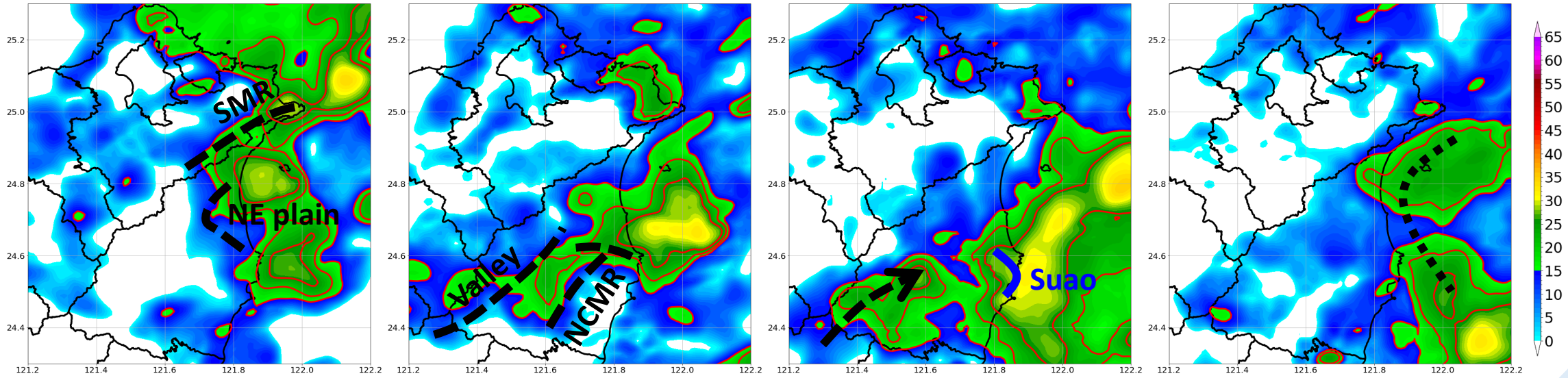
Why systems along SMR moved northeasterly in *Stage 1*?

Why systems developed along NCMR & Valley in *Stage 2*?

Why cells in valley weakened & moved eastward in *Stage 3*?

S1 [04 - 05] 0430 UTC	S2 [05 - 07] 0600 UTC	S3 [07 - 10] 0830 UTC	S4 [10 - 11] 1030 UTC

ANL
[15, 20, 25] dBZ

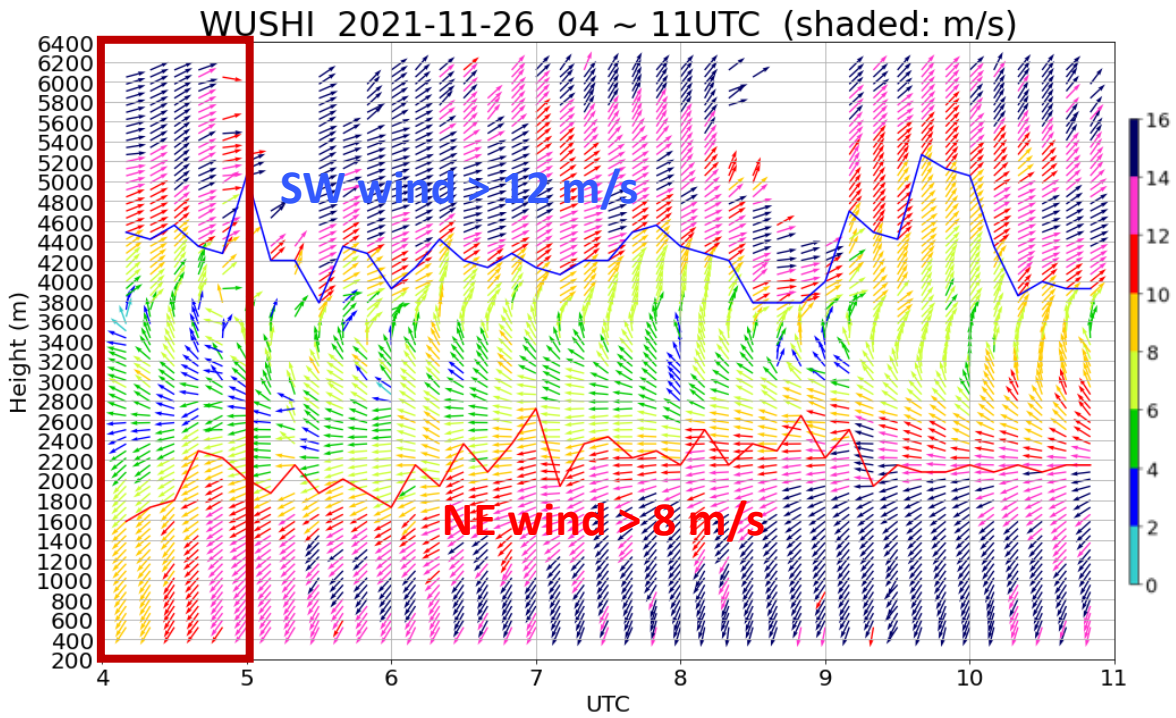


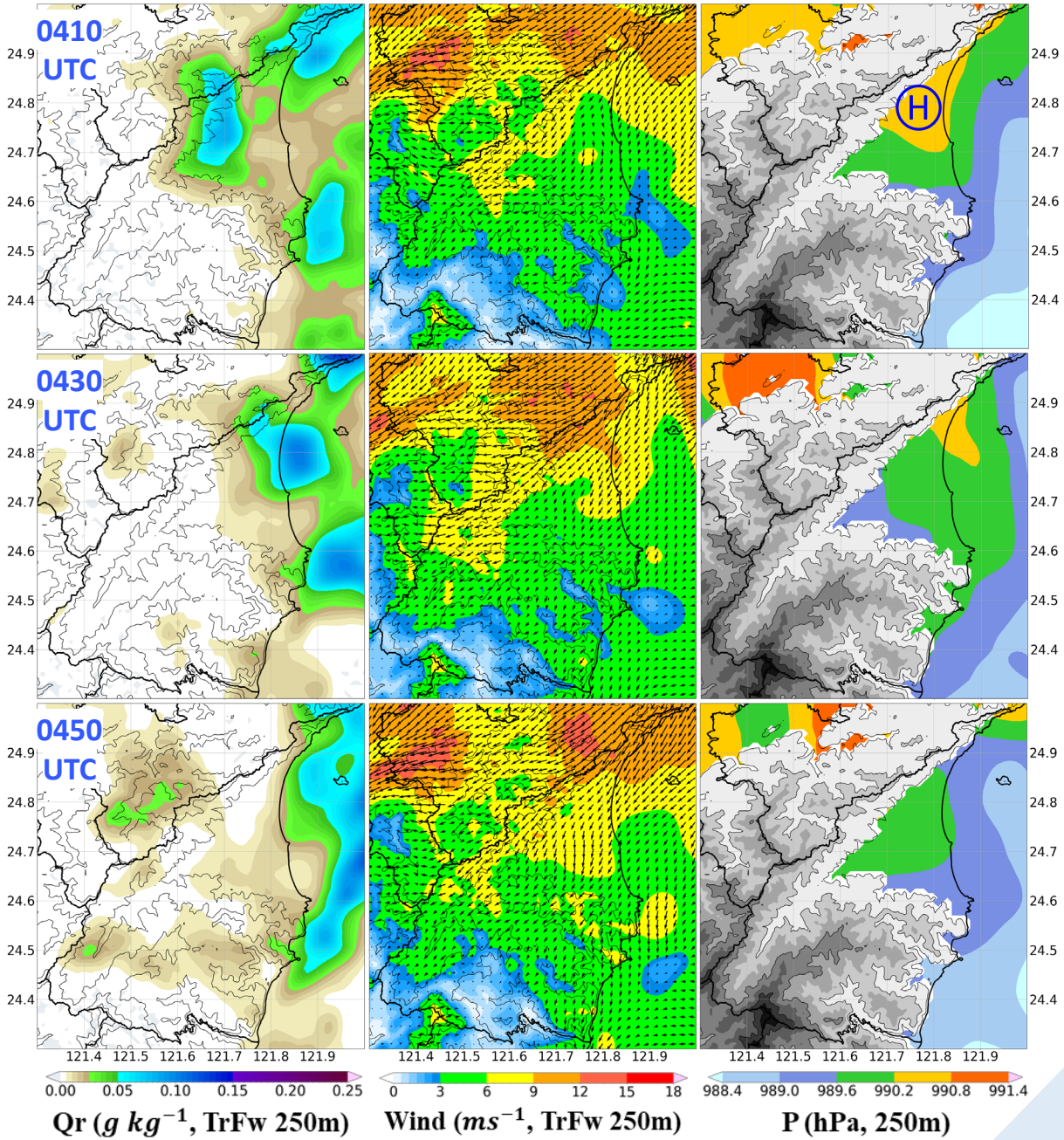
❖ **Why systems along SMR moved northeasterly in *Stage 1*?**

✓ Weaker low-level NE wind +

Stronger mid-level SW wind +

Local high pressure block flow





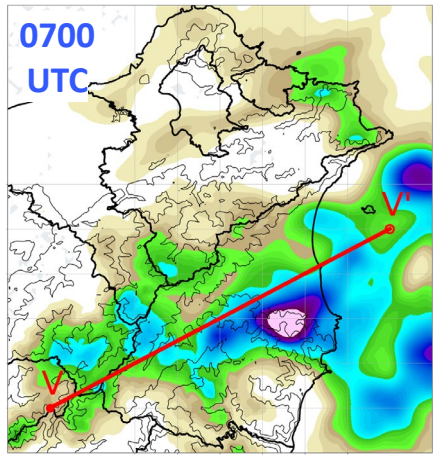
❖ **Why systems developed along NCMR in**

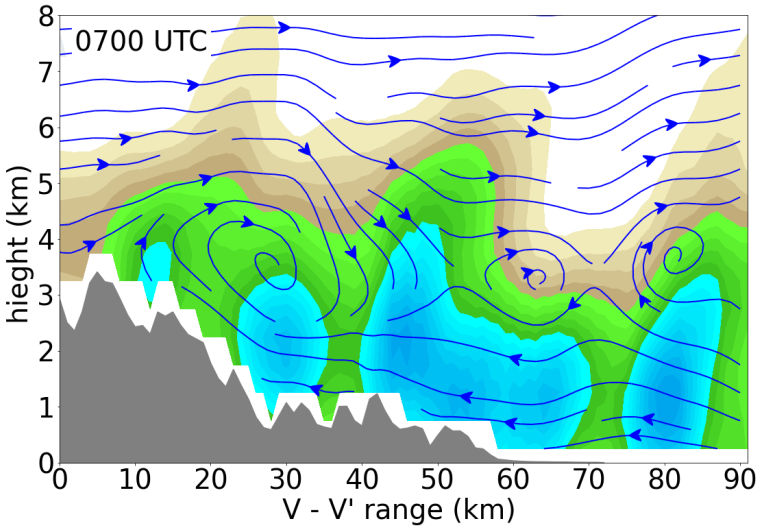
***Stage 2*?**

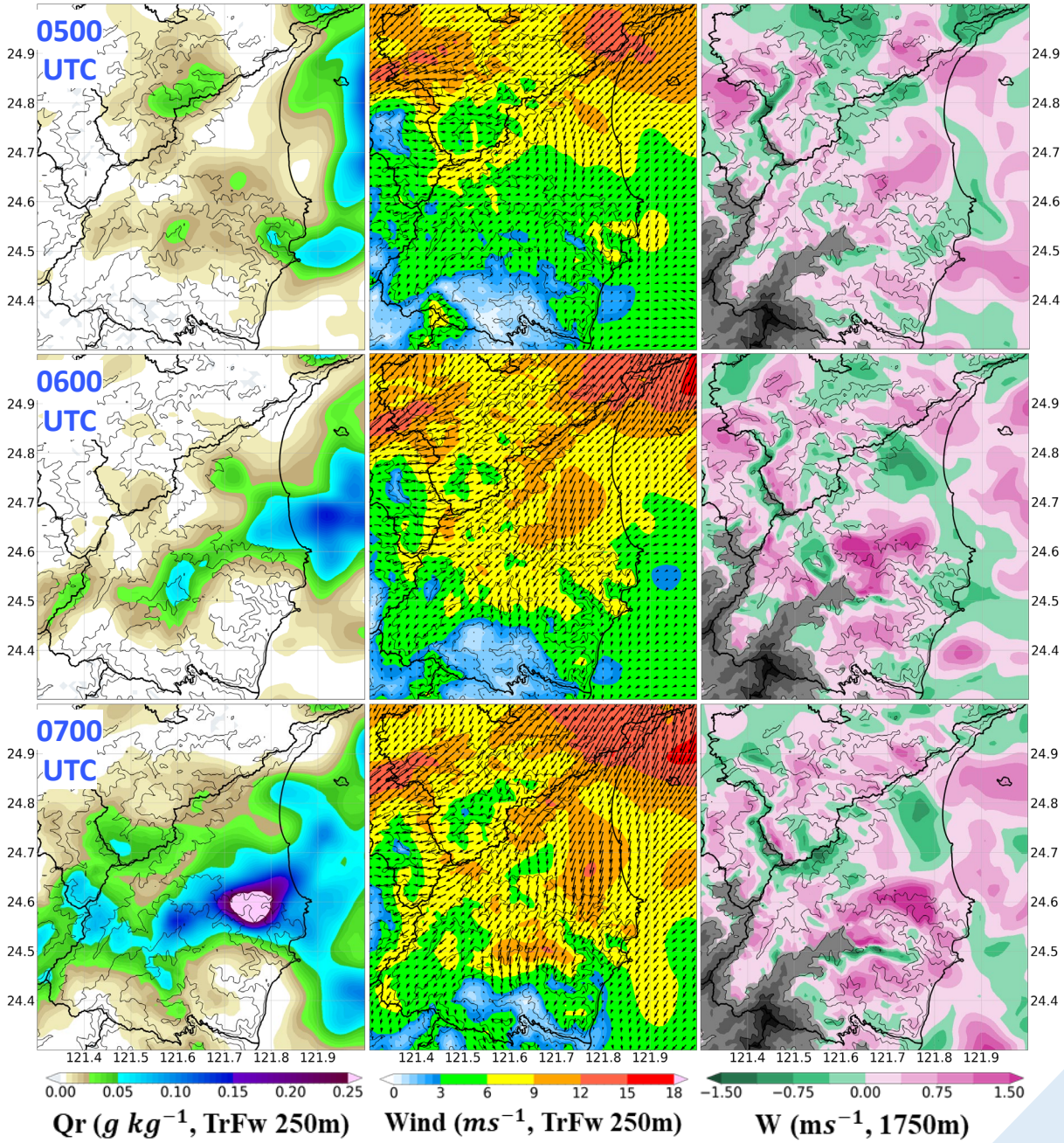
✓ Low-level NE enhance

→ Vertical motion induced by terrain

→ Cells initiated along NCMR







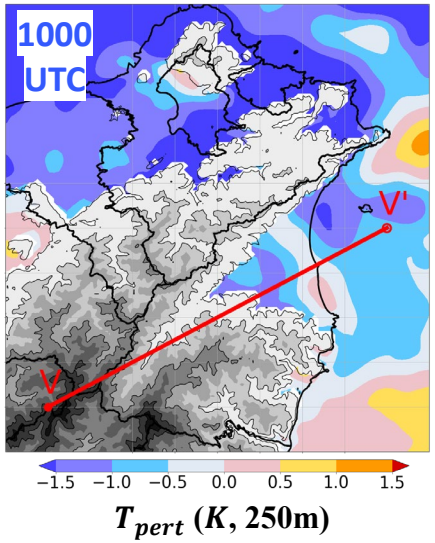
❖ **Why cells in valley weakened & moved east in**

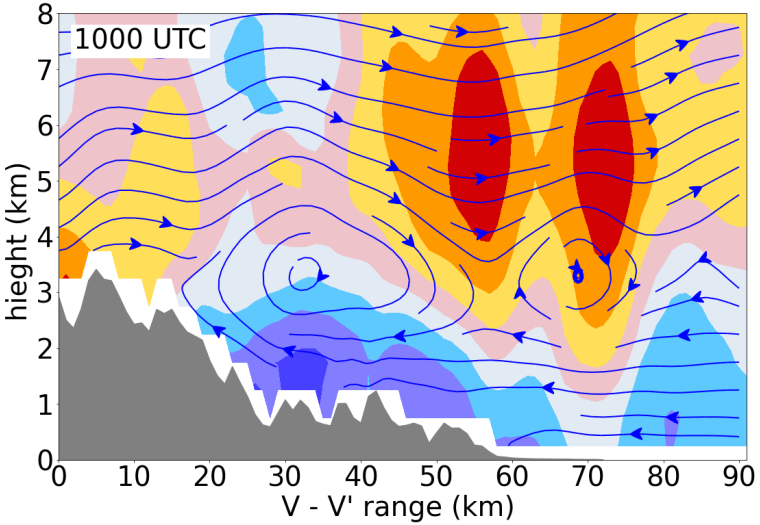
***Stage 3*?**

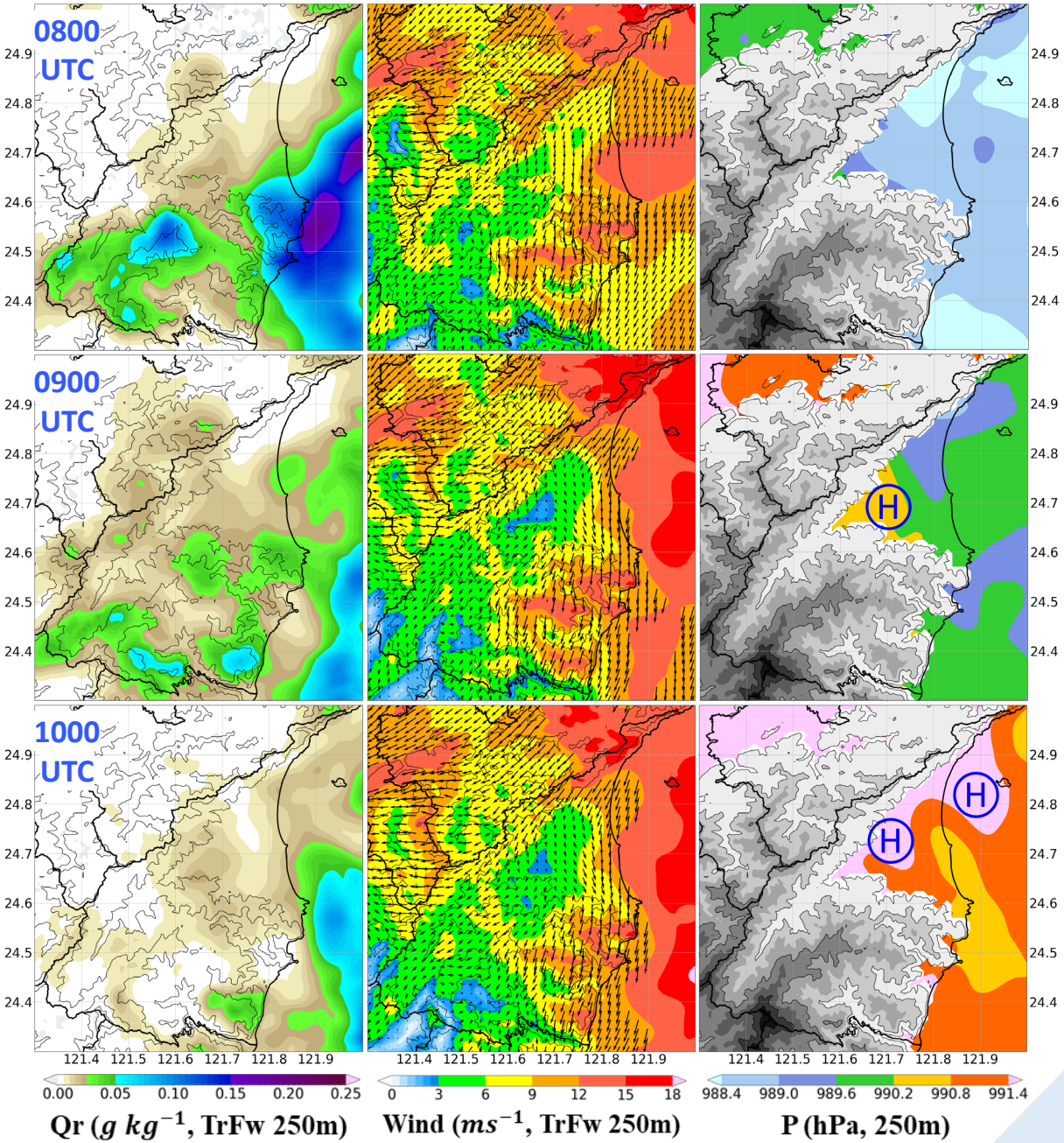
✓ Strong NE-wind move to eastward +

Inland NW flow enhance +

Inland cold air makes high pressure







Perturbation Pressure Analysis for Local High

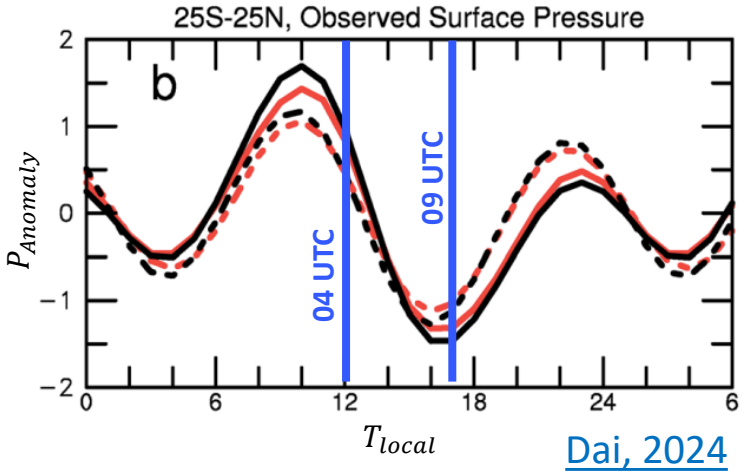
$$P' = P'_B + P'_D$$

$$\nabla^2 P'_B = F_B \equiv \frac{\partial(\rho_0 B)}{\partial z}$$

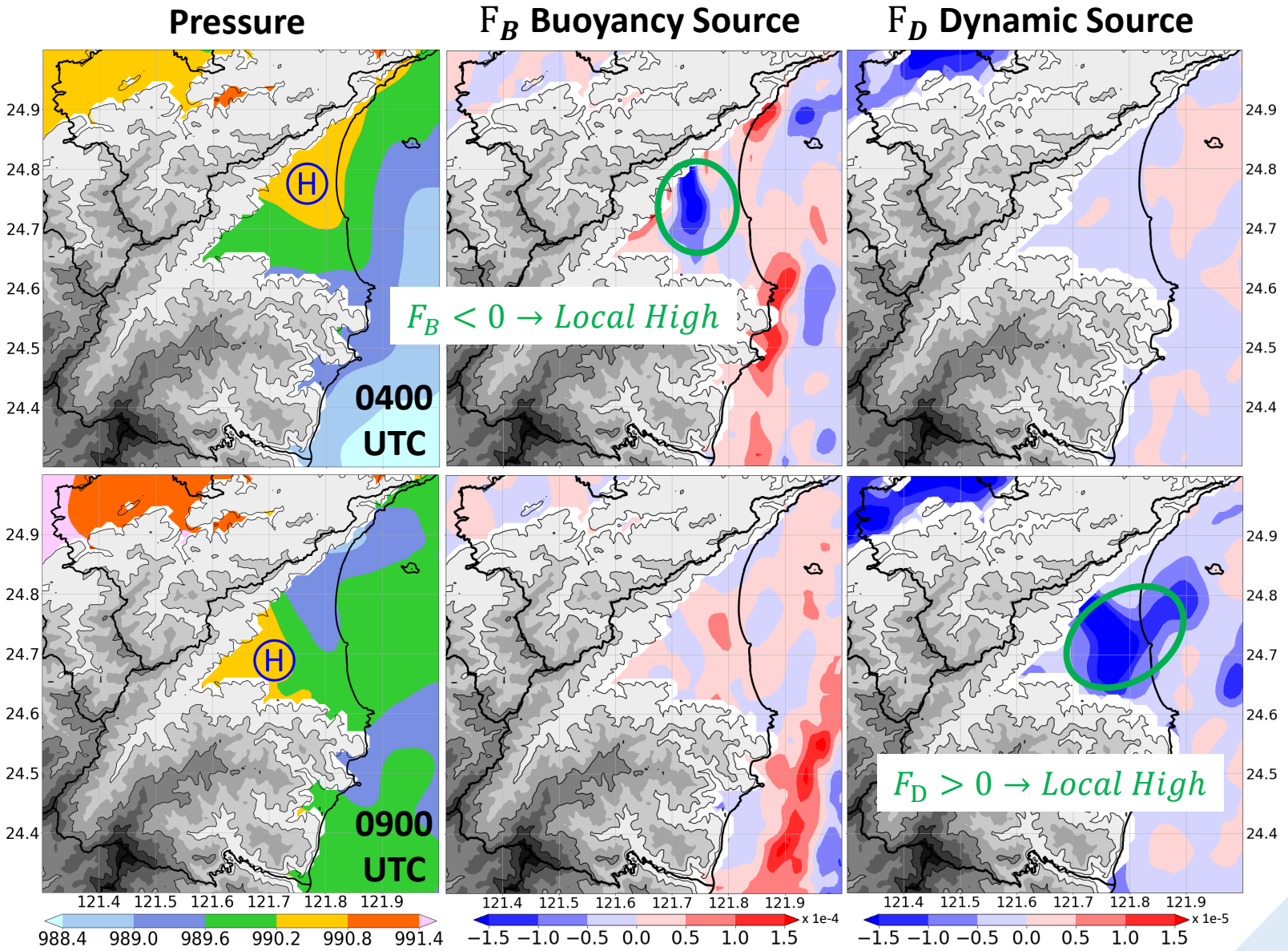
$$\nabla^2 P'_D = F_D \equiv -\nabla \cdot (\rho_0 \mathbf{v} \cdot \nabla \mathbf{v})$$

$$\rightarrow P'_B \propto -\nabla^2 P'_B \propto -F_B$$

$$\rightarrow P'_D \propto -\nabla^2 P'_D \propto -F_D$$



Dai, 2024



❖ **Why systems along SMR moved northeasterly in *Stage 1*?**

✓ Weaker low-level NE wind + Stronger mid-level SW wind + Local high pressure block flow

❖ **Why systems developed along NCMR in *Stage 2*?**

✓ Low-level NE enhance & cells induced by terrain

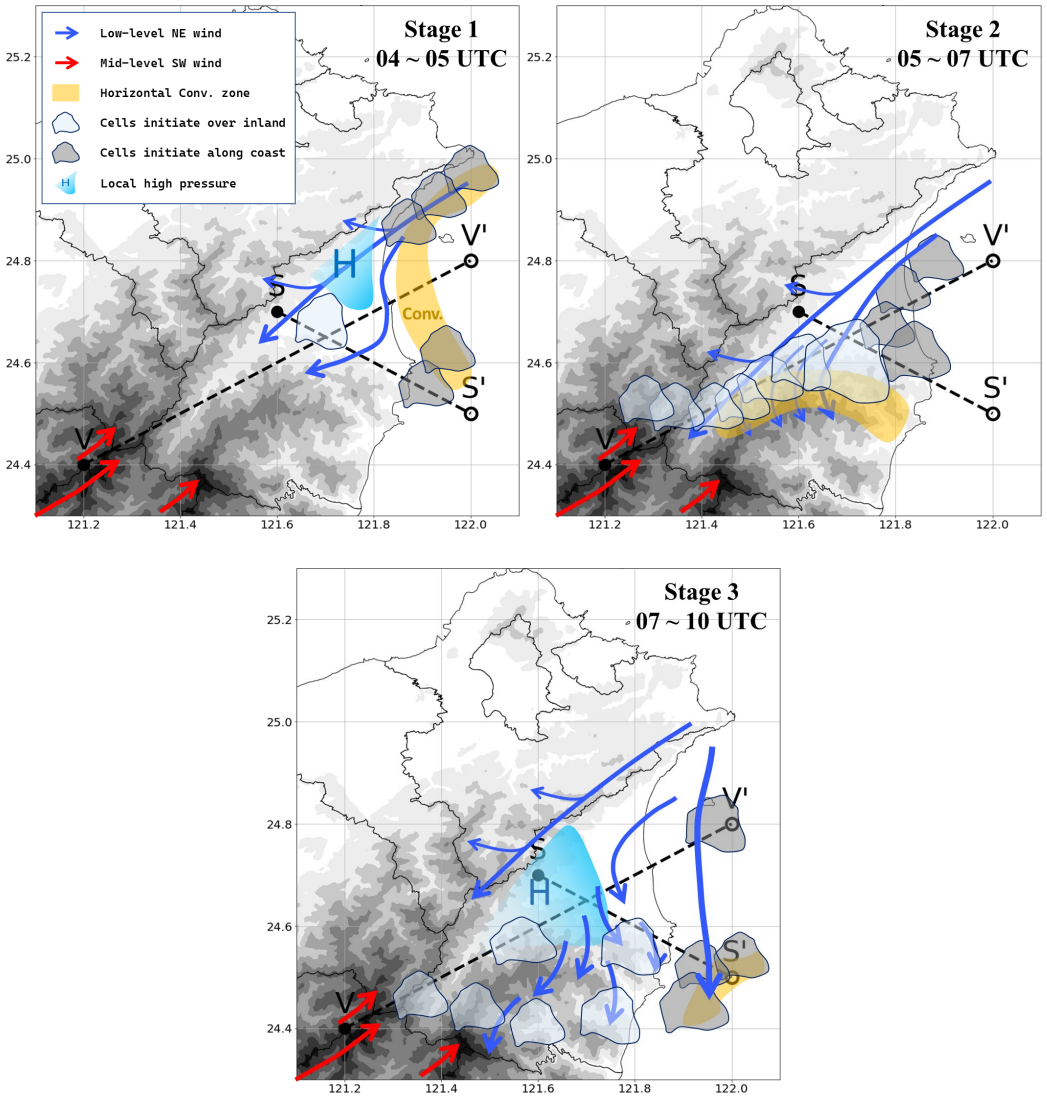
❖ **Why cells in valley weakened & moved east in *Stage 3*?**

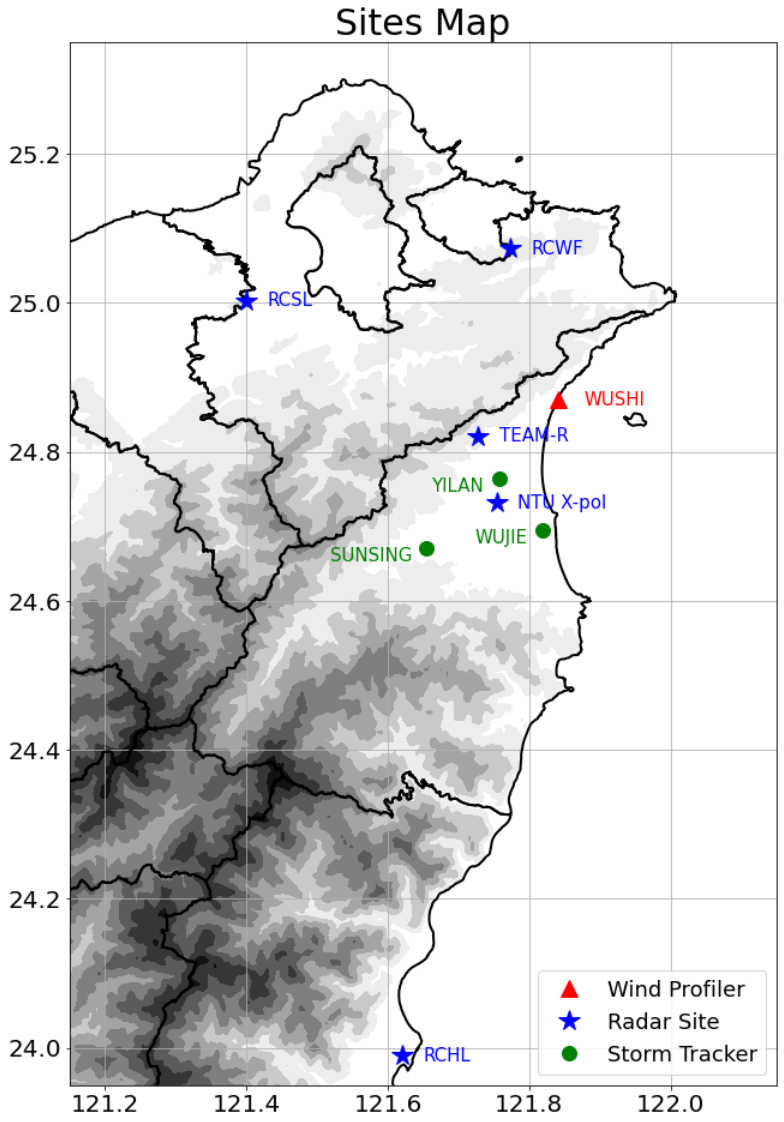
✓ Strong NE-wind move to eastward + Inland NW flow enhance + Inland cold air makes high pressure

❖ **Perturbation pressure analysis shows…**

✓ At 04:10, buoyance source makes northern local high

✓ At 09:00, dynamic source contributes southern local high





- Future works about case study for YESR2021 using IBM_VDRAS
  - Change vertical resolution to resolve return flow near ground.
  - Assimilate more OBS like surface station, radiosonde, etc.