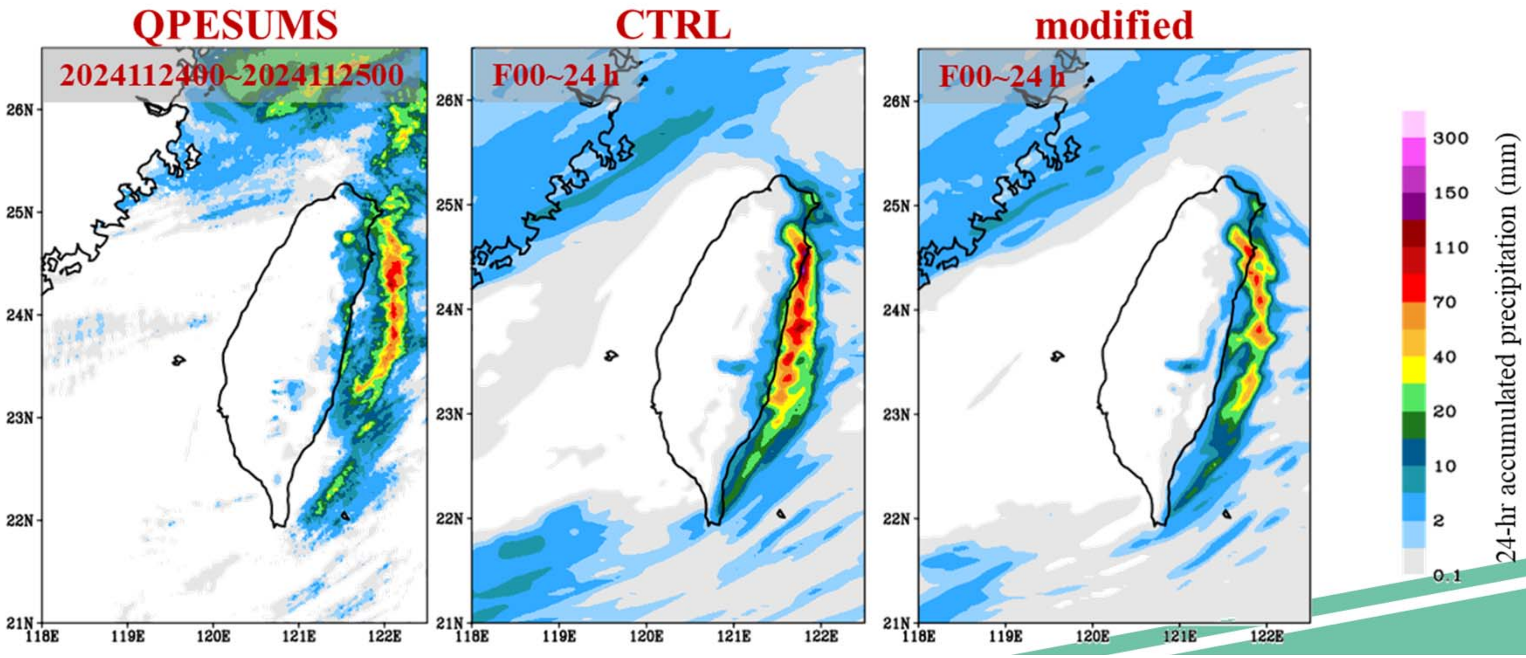
改進中央氣象署TGFS臺灣東部線狀對流線預報：調整邊界層參數化方案之擾動擴散

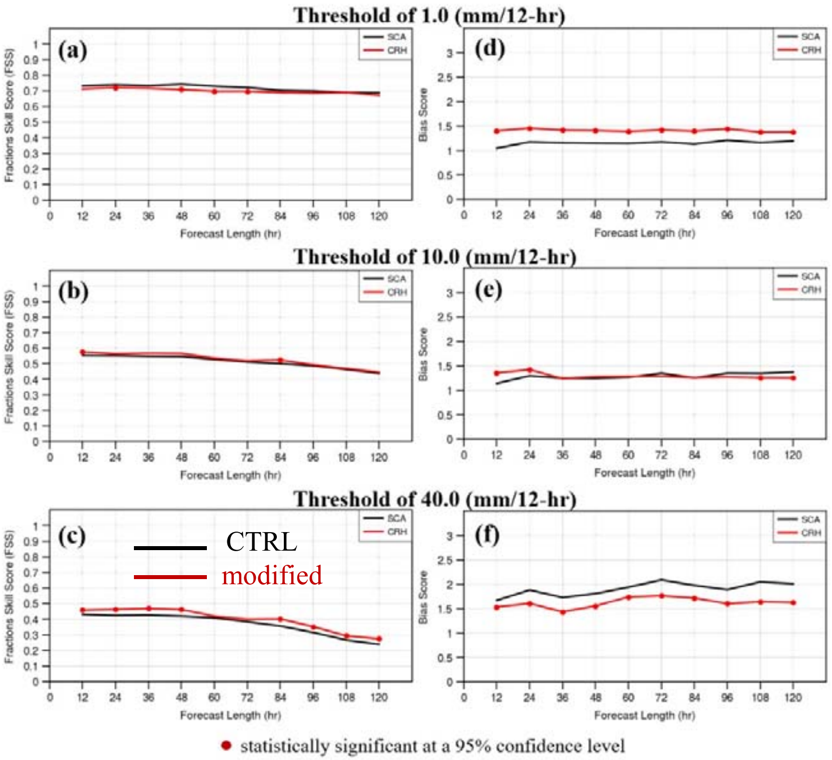
林昌鴻 蕭玲鳳
中央氣象署科技發展組

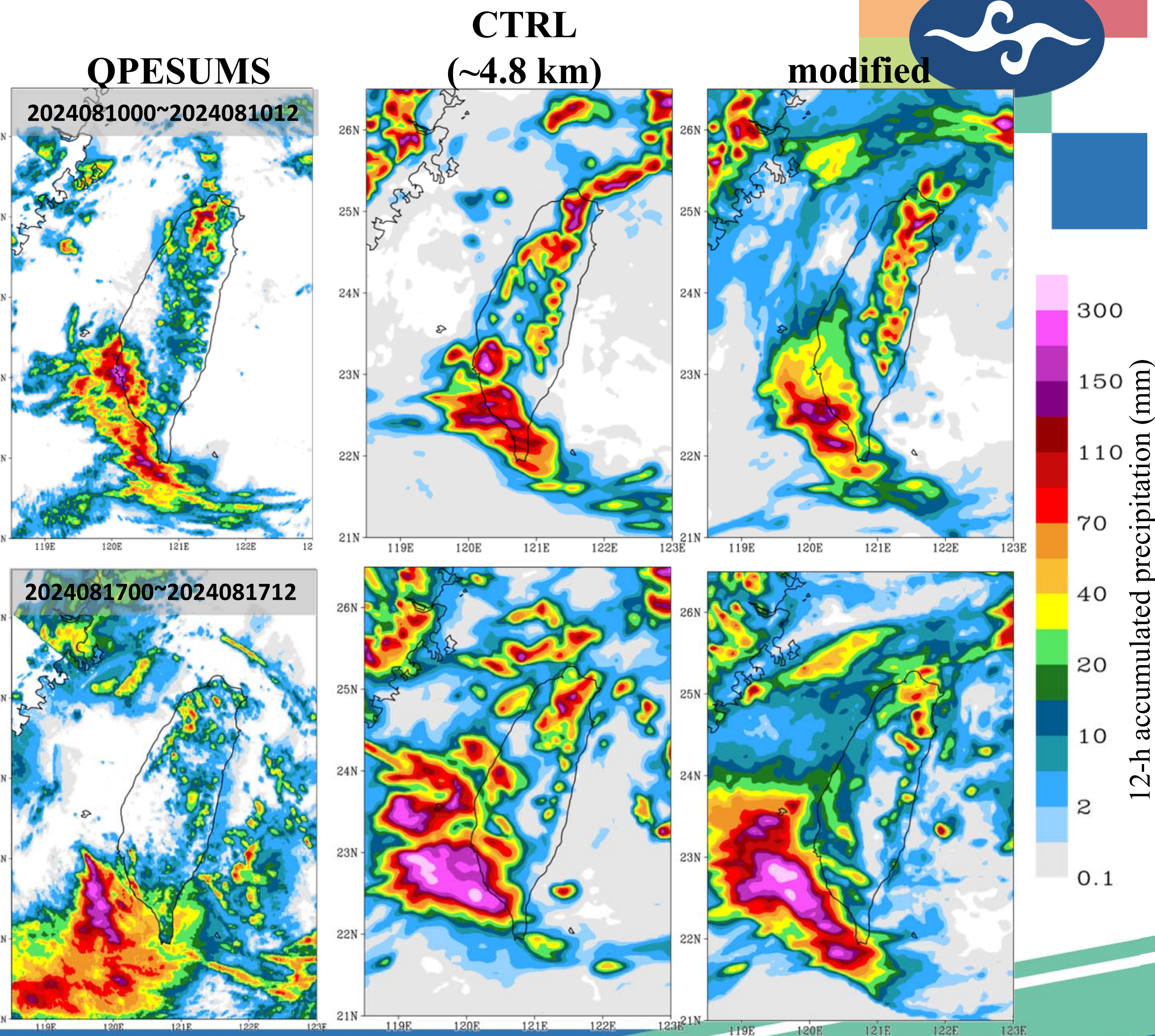


summertime precipitation forecasts

- Numerous modifications to the Tiedtke deep convection scheme successfully reduce summer heavy rainfall bias
- This work is being prepared for submission to the GMD:

(Lin C-H, Hsiao L-F, and Lien G-Y: Evaluating Modifications to Tiedtke Cumulus Parameterization for Improving Precipitation Forecast in the Nested Grid of Taiwan Global Forecast System (TGFS v1.1), 2025.)

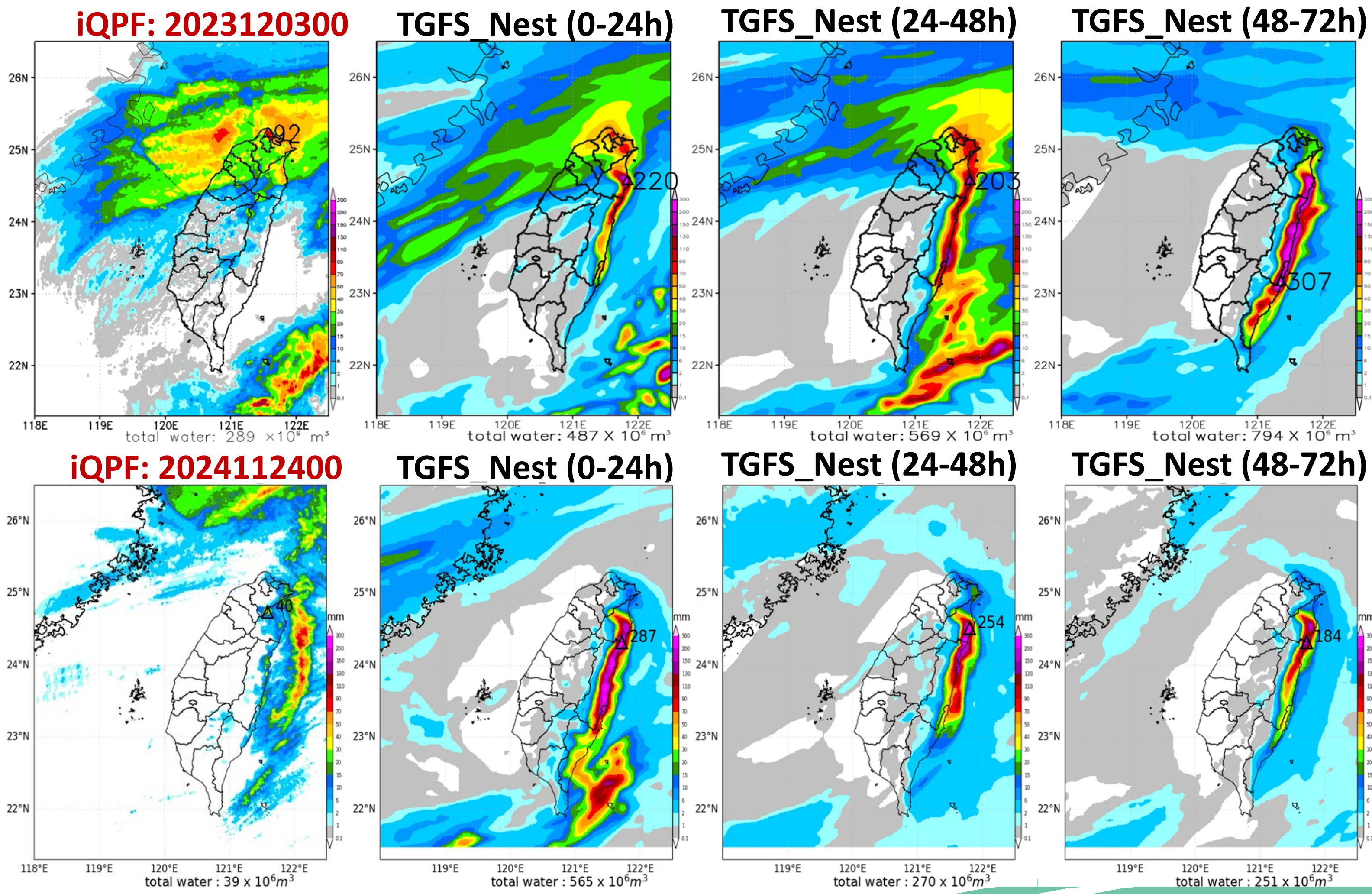




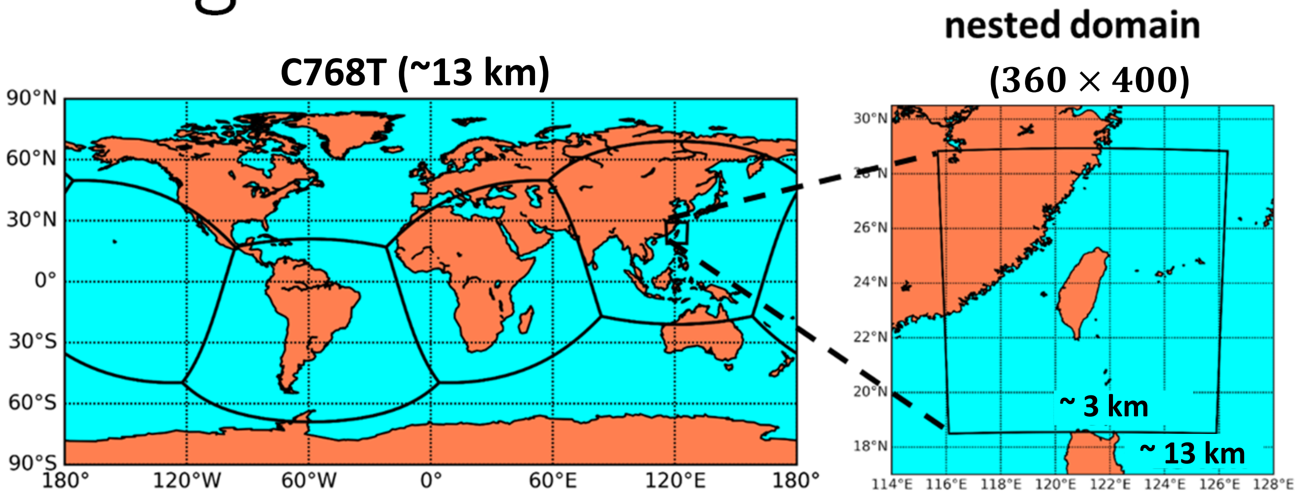
motivation

- The TGFS nested domain often produces unrealistic precipitation on the windward side of terrain in winter
- may undermine forecaster's confidence

24-hr accumulated precipitation (mm)



Model configuration



- The initial and boundary conditions are provided by the TGFSv1 analysis data.
- one-way nested domain run
- 64 vertical levels with a model top at 0.2 hPa
- physics suite:
  - hybrid EDMF PBL scheme
  - Tiedtke convection scheme (scale-awareness)
  - GFDL microphysics scheme
  - RRTMG radiation scheme

previous observational study:

- the recirculation pattern east of the mountain range
- When the prevailing airflow from the east encounters the mountain range, the lower-level airflow curls down, forms a vortex roll (or band) and thus generates a reverse flow near the sea surface.

(Alpers et al. 2010)

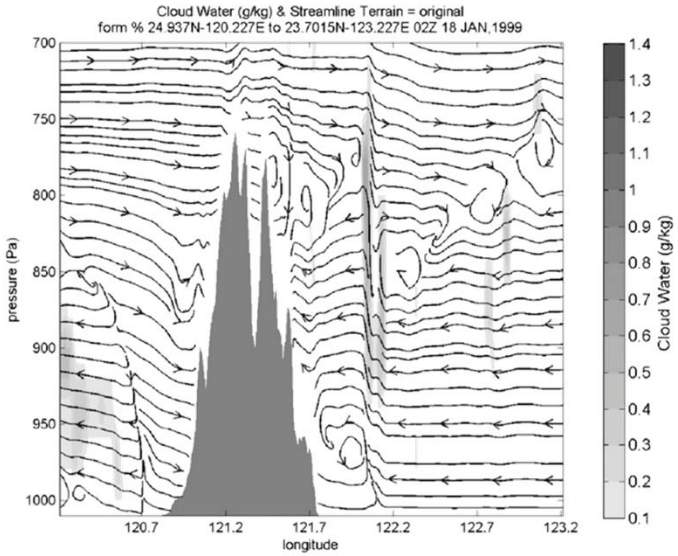


Fig. 2. Vertical cross section of the simulated streamlines and cloud water content (gray shading; g kg^{-1}) along a transect through northern Taiwan at 0200 UTC 18 Jan 1999.

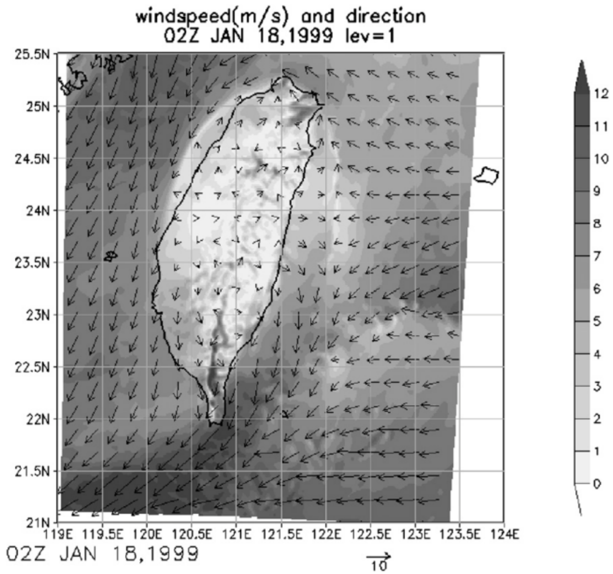


Fig. 3. Simulated wind velocity (vectors) and wind speed (grayscale shading; m s^{-1}) at the lowest model level at 0200 UTC 18 Jan 1999.

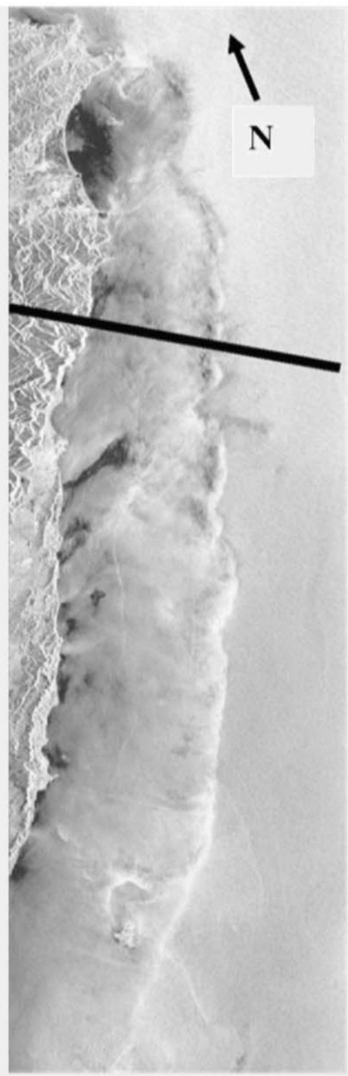
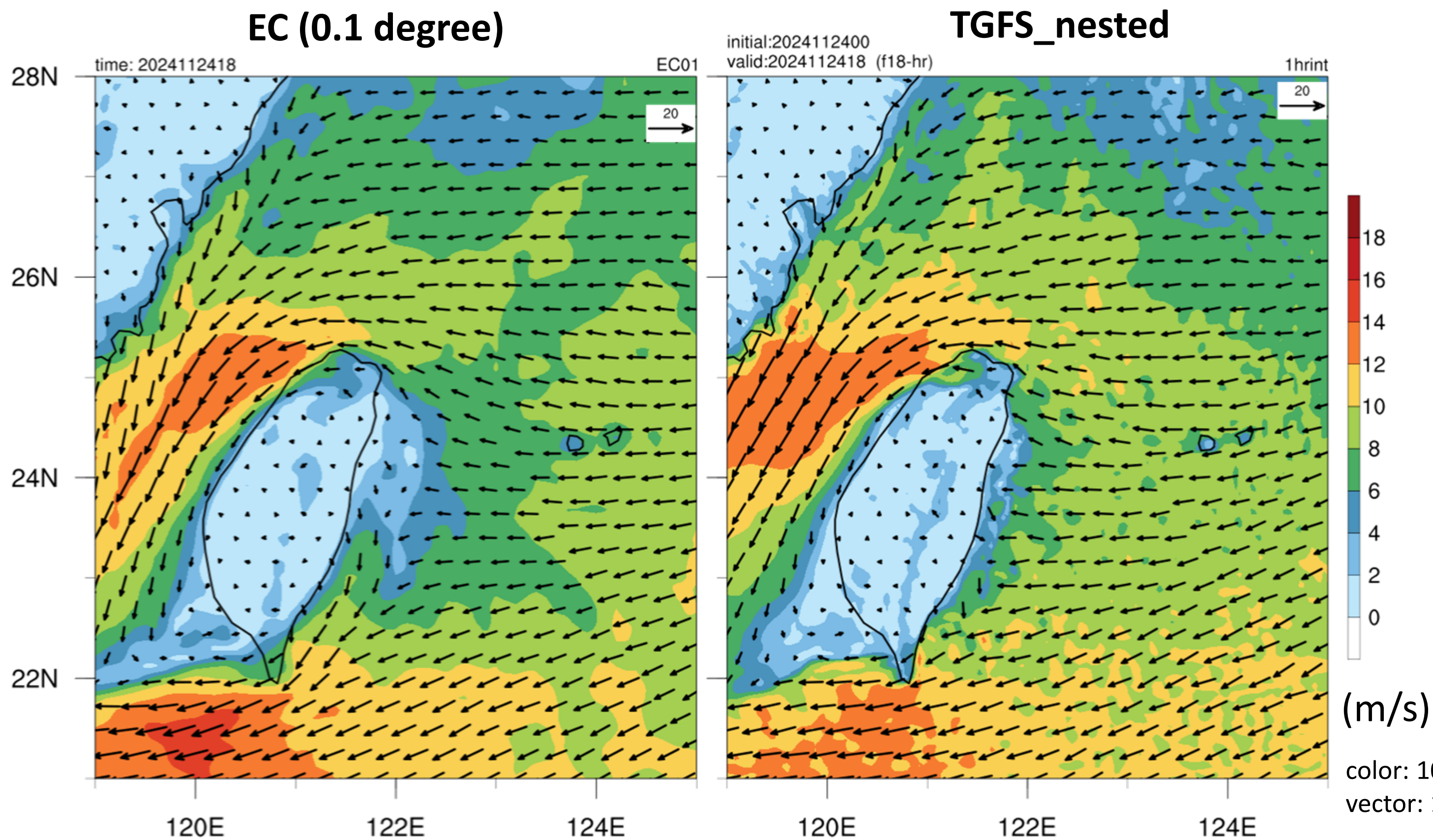


Fig. 1. *ERS-2* SAR strip acquired at 0225 UTC (1025 LST) 18 Jan 1999 over the east coast of Taiwan. The imaged area is 380 km × 100 km. The thick dark line inserted in the SAR image denote the transect along which vertical profiles of streamlines and cloud water density are calculated by using the MM5 model (see Fig. 2).

10-m wind (2024112415; f18-h)



color: 10-m wind speed (m/s)
vector: 10-m wind direction (20 m/s)

- overestimate the easterly wind flow and failed to represent the northerly wind along the offshore of east coast.
- **less blocking effect?**

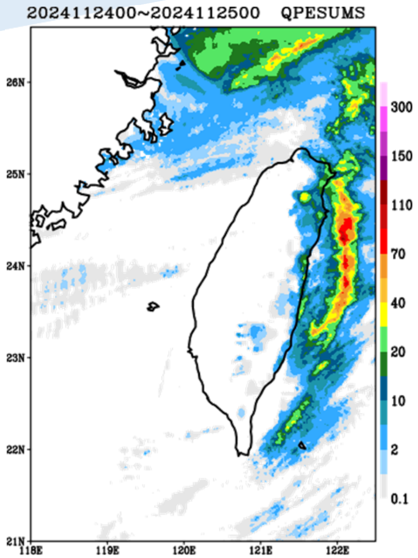
adjustment of hybrid-EDMF PBL scheme

- a constant factor α to lower the value of K_m:

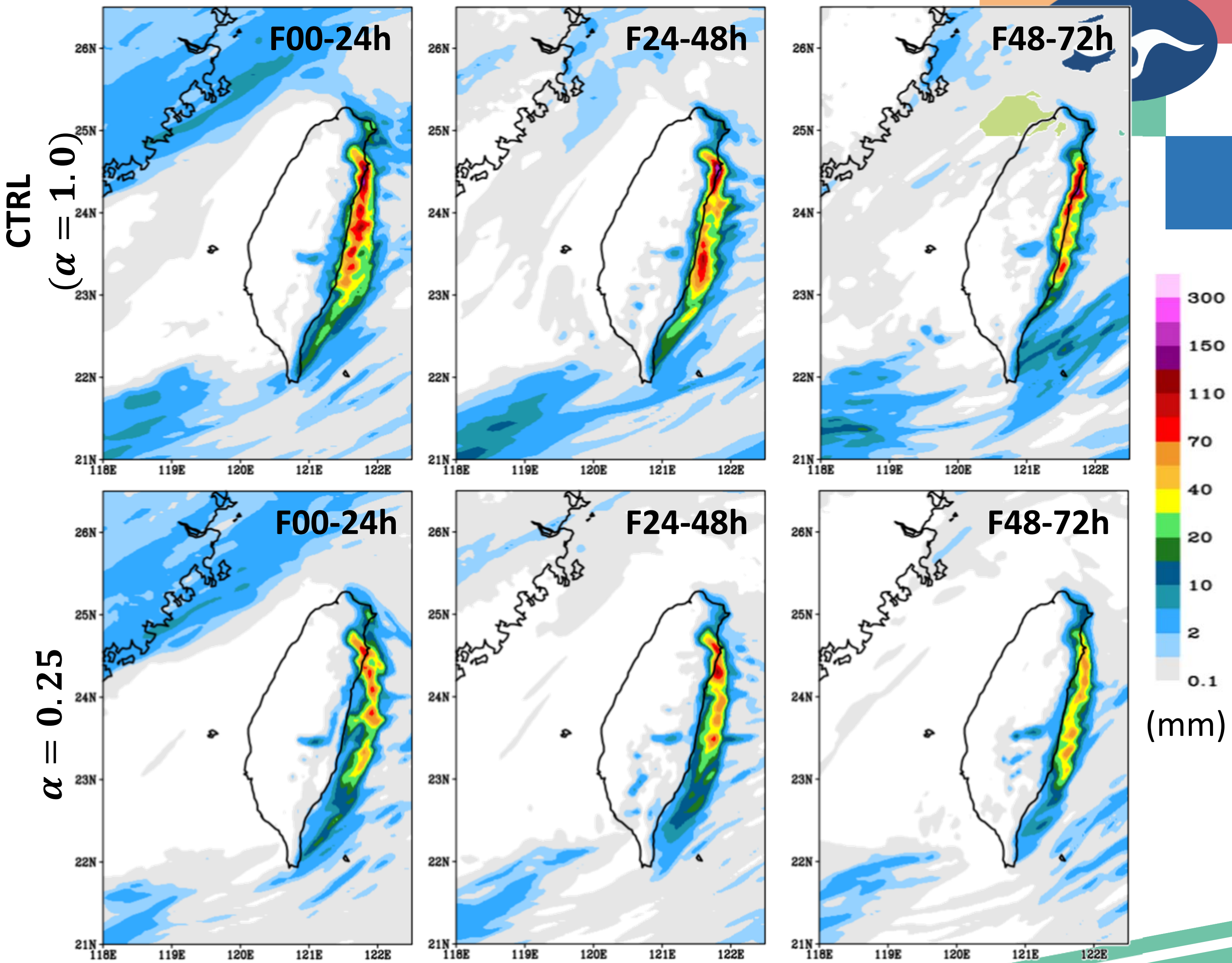
$$K_m = \kappa w_* \boldsymbol{\alpha} z \left(1 - \frac{z}{h}\right)^2$$

κ: von Karman constant (= 0.4)
w_*: mixed-layer velocity scale (eq. 6 from Troen and Mahrt 1986)
h: PBL height
z: height above the surface

eddy diffusivity for heat: $K_t = K_m \frac{1}{P_r}$



24-hr accumulated precipitation (mm)



- a constant factor α to lower the value of K_m:

$$K_m = \kappa w_* \alpha z \left(1 - \frac{z}{h}\right)^2$$

$$K_t = K_m \frac{1}{P_r}$$

κ: von Karman constant (= 0.4)
w_*: mixed-layer velocity scale
(eq. 6 from Troen and Mahrt 1986)
h: PBL height
z: height above the surface

adjustment of hybrid-EDMF PBL scheme

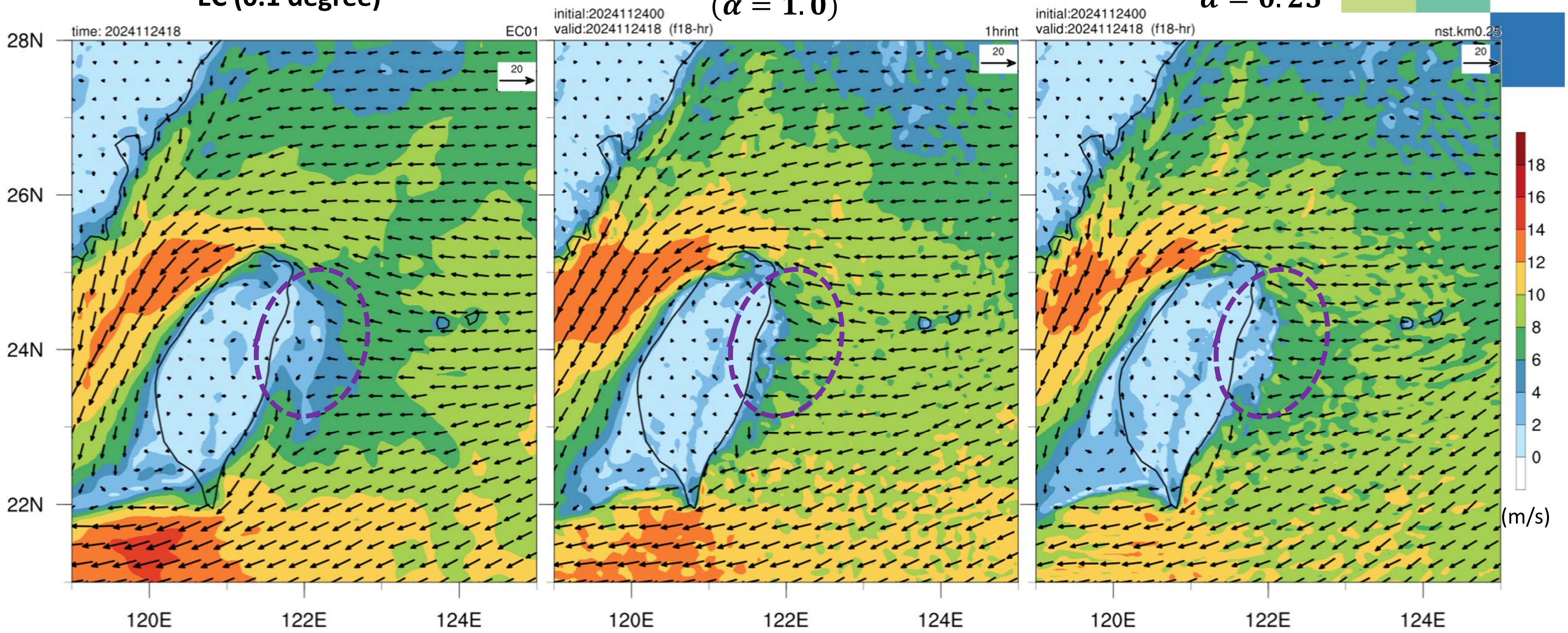
- At 500 m above the surface, the **eddy diffusivity for momentum (K_m)** in the hybrid-EDMF PBL scheme is approximately **4 times larger than that derived from flight-level observations of a few hurricanes** (Zhang et al. 2011).

- In the operational HWRF after 2012, $\boldsymbol{\alpha = 0.5}$ (Tallapragada et al. 2014)

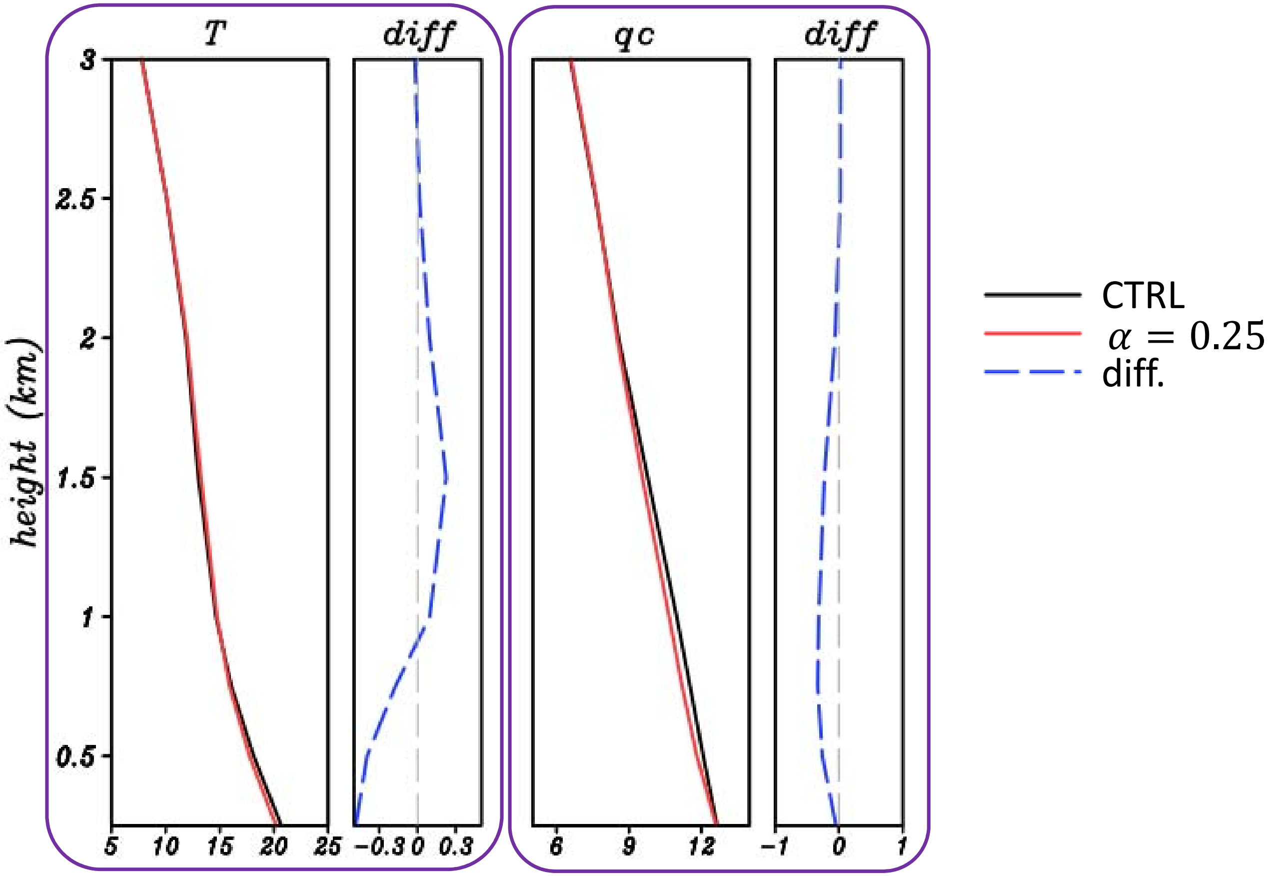
- $\alpha = 0.25$ matches best with observations of K_m in idealized HWRF simulations. (Zhang et al. 2012; Gopalakrishnan et al. 2013; Zhang and Mark 2015)

10-m wind (2024112418; f18-h)

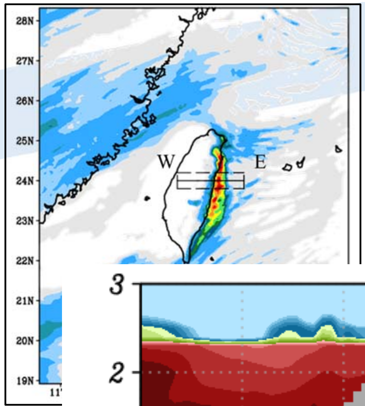
color: 10-m wind speed (m/s)
vector: 10-m wind direction (20 m/s)



domain-averaged temperature and water vapor at 24-h forecast, initialized 20–24 Nov 2024



- less vertical transfer of heat and moisture produces a colder and drier low-level atmosphere, stabilizing the PBL.



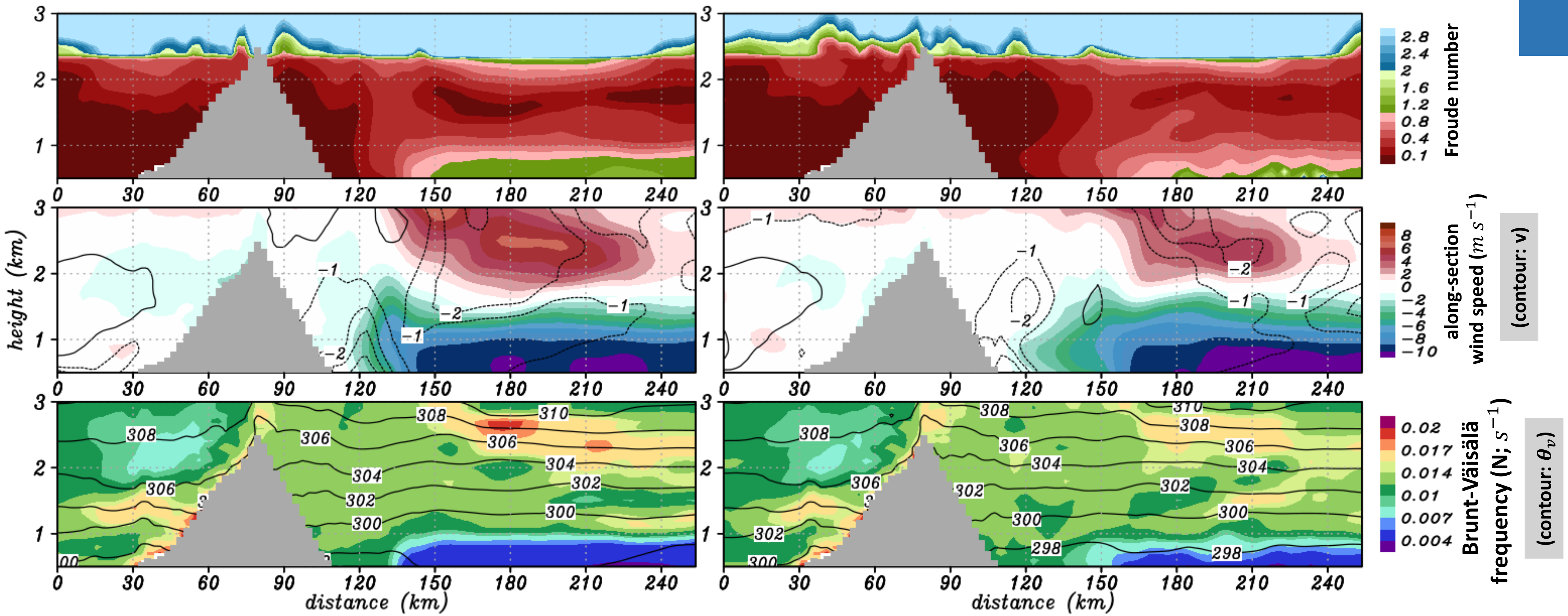
Averaged vertical cross-section

2024112412 (f12-h)

CTRL

$(\alpha = 1.0)$

$\alpha = 0.25$

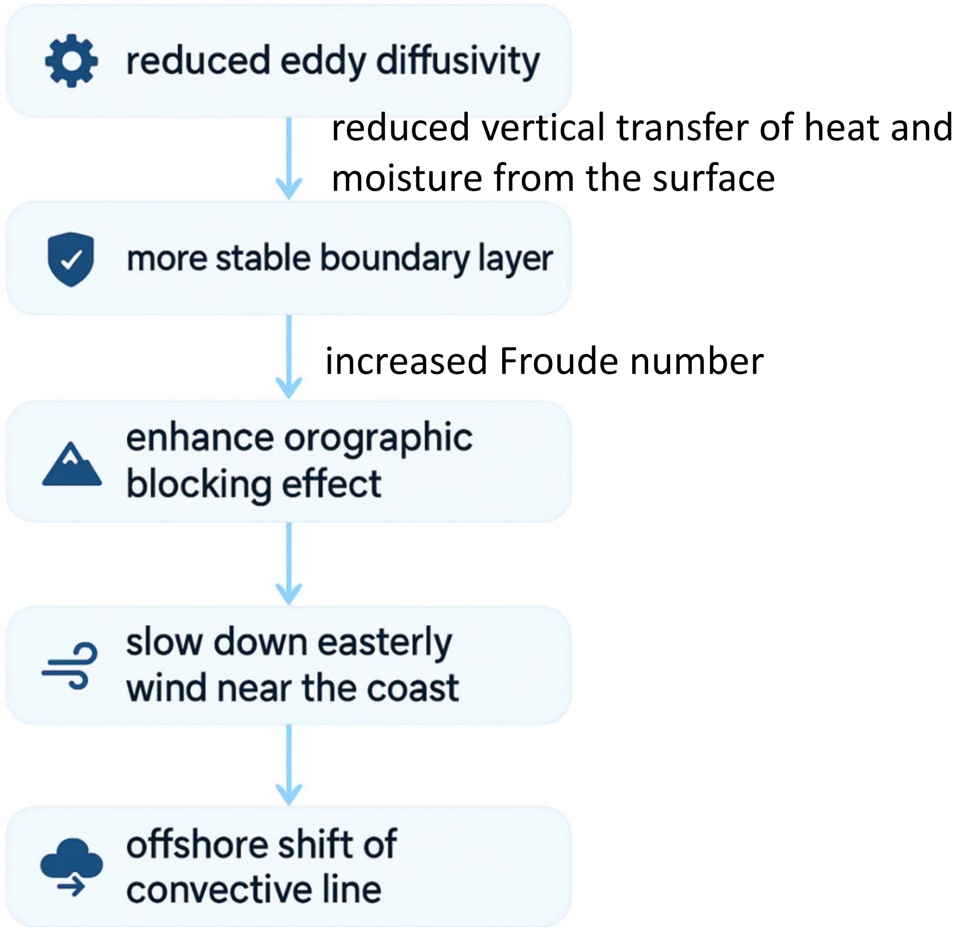


more stable environment (higher N) increases the orographic blocking (lower Froude number), which decreases easterly wind near the coast

mechanism causing the offshore shift of convective line

- Less diffusion in PBL (K_m and K_t) increases the gradients between surface layer and PBL:
  - lower temperature and moisture (less vertical transfer from surface)
  - less momentum transfer from the high-wind level, concentrated at around 0.5-km

- the more stable environment enhances the orographic blocking effect, significantly slowing down the easterly wind near the coast and resulting in an offshore shift of the convective line.



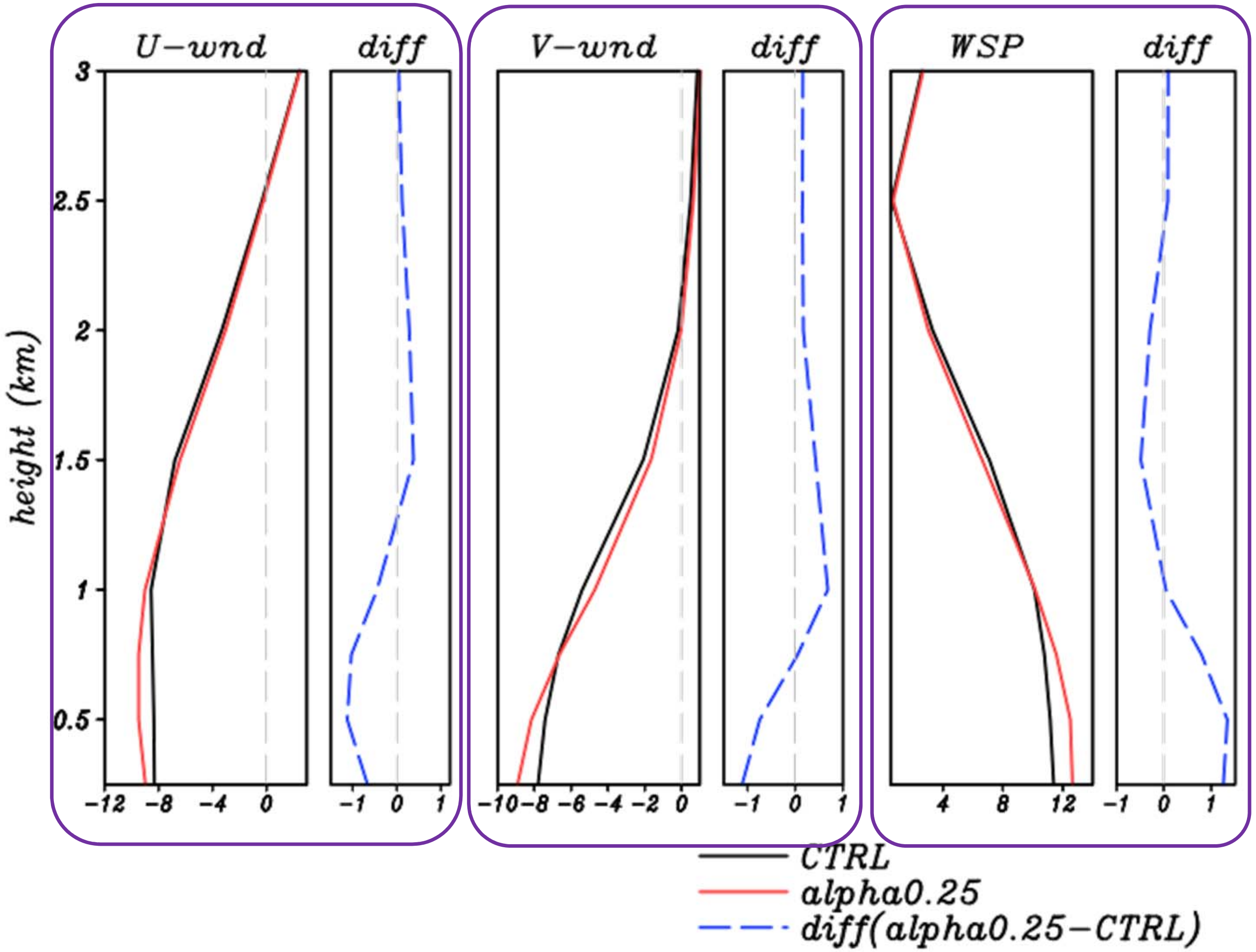
- Height-relative form of Froude number (Viale et al. 2013; Riley Dellaripa et al. 2020; Marín et al. 2021; Cornejo et al. 2024):

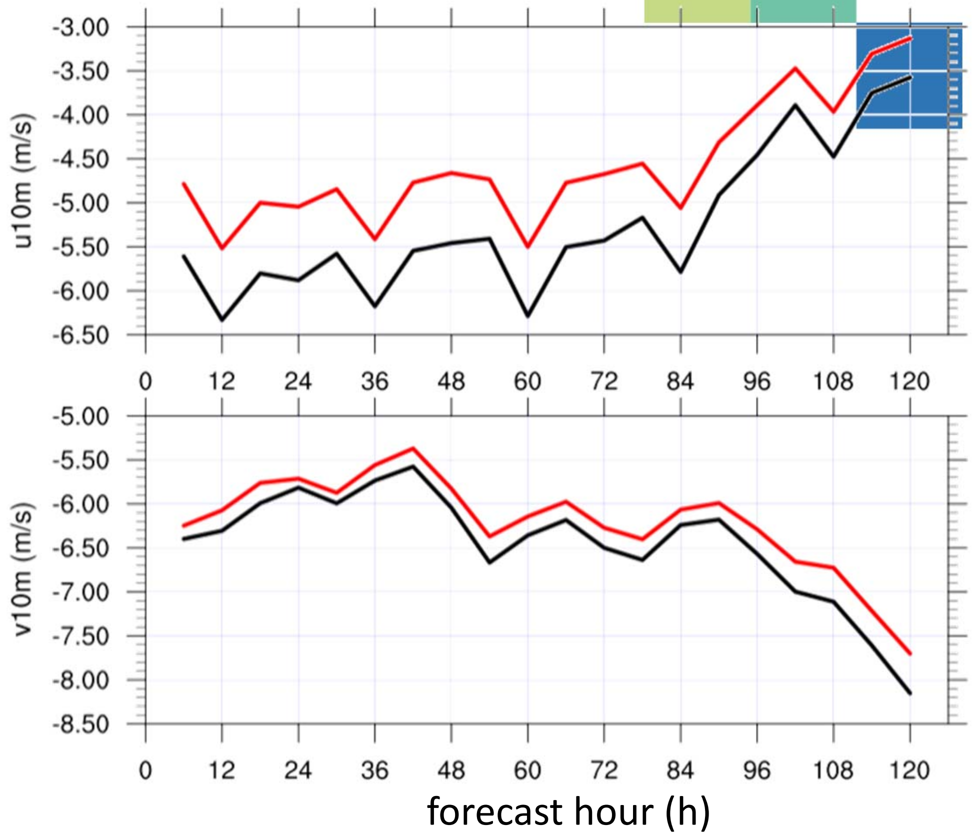
$$Fr(z) = \frac{U(z)}{N(z)(h - z)}$$

Brunt-Väisälä frequency : $N = \left(\frac{g}{\theta_v}\frac{\partial \theta_v}{\partial z}\right)^{1/2}$

U: along-cross-section wind speed (m/s)
h: peak terrain height of the cross section (m)

Average of horizontal wind at 24-hr forecast initiated from Nov. 20 to 24 2024 over the entire nested domain





- Horizontal wind is increased around 0.5-km height and reduced at higher levels and near the surface due to the less vertical transfer (less dissipation).