Application of Stochastic Parameter Perturbation (SPP) Scheme in YSU PBL Parameterization.

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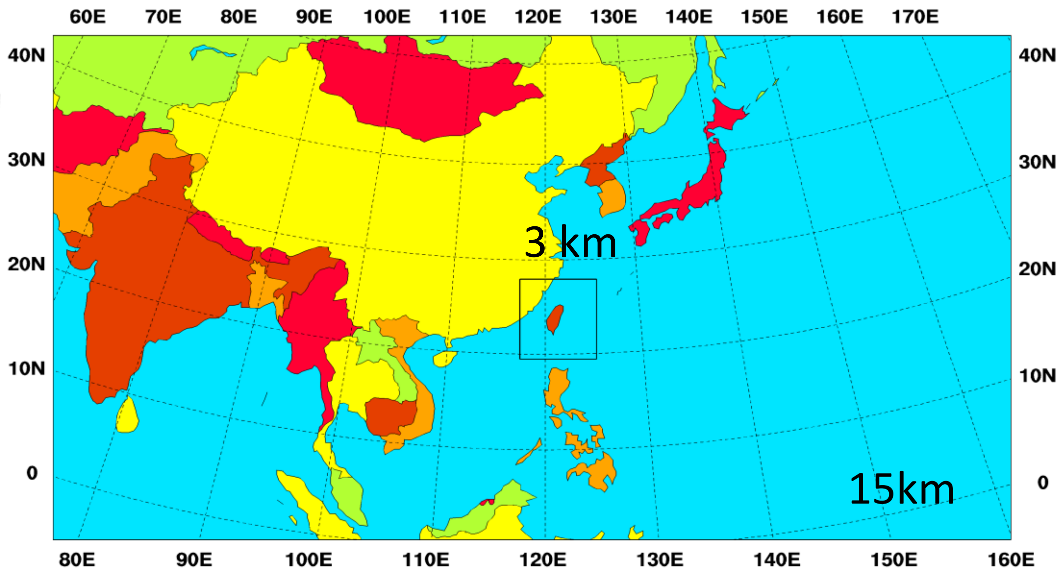
WEPS model setting

WRF Ensemble Prediction System

Member numbers: 20 members

- Grid spacings: 15/3 km
- Update every 6 hr (00, 06, 12, 18 UTC)
- Forecast Length: 120 hr
- Vertical level: 52 levels & Model top at 20 hPa
- Model Version：WRF v3.8.1



IC

perturb

- Random pertrubation
- EnKF
- Global ensemble down scaing
- ……

LBC

perturb

- Global ensemble down scaing
- SKEB
- ……

Model

pertrub

- **Multi-physics parameters**
- Multi-model
- SKEB
- SPPT
- ……

Why not use Multi-physics?

- Multi-physics ensemble can provide greater dispersion and improve forecast skill (e.g., Hacker et al. 2011b; Berner et al. 2011, 2015)

- Model updates in WRF make it difficult for a multi-physics ensemble to preserve the dispersion relationship.

- Additionally, in order to perform statistical post-processing, it is necessary to ensure that the random variables are uniformly distributed and independent. However, multi-physics may make the post-processing more complex, as each ensemble member has different mean errors and climate characteristics, which could be a potential reason for the greater variability of these ensembles. (e.g., Eckel and Mass 2005; Berner et al. 2015)

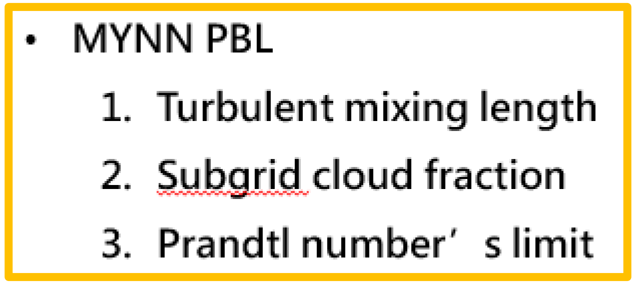
Why use SPP ?

- SPP, targets this shortcoming. SPP is implemented by modifying select (typically uncertain) physical parameters or variables with perturbations that are either fixed in time and/or space (Hacker et al. 2011) or that evolve according to chosen decorrelation time and/or length scales (Bowler et al. 2009; Ollinaho et al. 2017; Jankov et al. 2017; Jankov et al. 2019).

- Comparison of the SPPT and the SPP approaches within the ECMWF ensemble forecasts demonstrated more skillful 2-m temperature associated with SPP and for shorter-range forecasts (Ollinaho et al. 2017). The work also pointed to the weakness of SPPT in terms of the lack of explicit perturbations for low levels and at the surface, where large model errors occur.(Bouttier et al. 2012)

- The three available SPP scheme in WRF：
  1. Grell-Freitas cumulus scheme (SPP_CU)
  2. MYNN PBL scheme (SPP_PBL)
  3. RUC LSM (SPP_LSM)

example



- MYNN PBL
  1. Turbulent mixing length
  2. Subgrid cloud fraction
  3. Prandtl number’ s limit

Introduction about SPP

$$X^* = [1 \pm r(x,y,t)]\ X$$

X can be a variable or parameter, and r is a 2D perturbation field

$$r(x,y,t) = \sum_{k=-K/2}^{K/2} \sum_{l=-L/2}^{L/2} r_{k,l}(t) e^{2\pi i (kx/X + ly/Y)}, \qquad (2)$$

(Palmer et al. 2009)

$$r_{k,l}(t+\Delta t) = \alpha r_{k,l}(t) + g_{k,l}\varepsilon_{k,l}(t). \qquad (3)$$

$$g_{k,l} = F_0 e^{-4\pi \underline{L} \rho^2_{k,l}} \text{ with } F_0 = \left\{ \frac{\eta^2_{k,l}[1-(1-\alpha)^2]}{2\sum_k \sum_l e^{-8\pi\kappa\rho^2_{k,l}}} \right\}^{1/2}. \qquad (4)$$

α is the linear autoregressive parameter,

$$\alpha = \exp(-\Delta t/\underline{\tau})$$

$\rho_{k,l} = \sqrt{k^2/X^2 + l^2/Y^2}$ the effective radial wavenumber

$\eta^2_{k,l}$ the spectral variances

gridpt_stddev_rand_pert

a gridpoint perturbation variance of σ^2

length scale_rand_pert

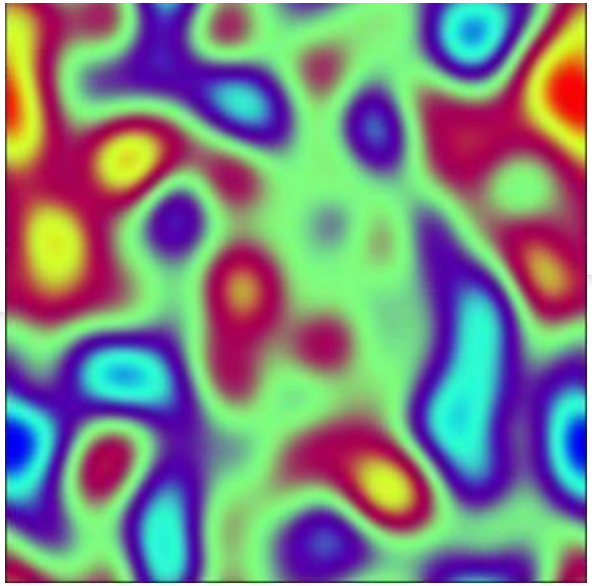
horizontal length scale L

time scale_rand_pert

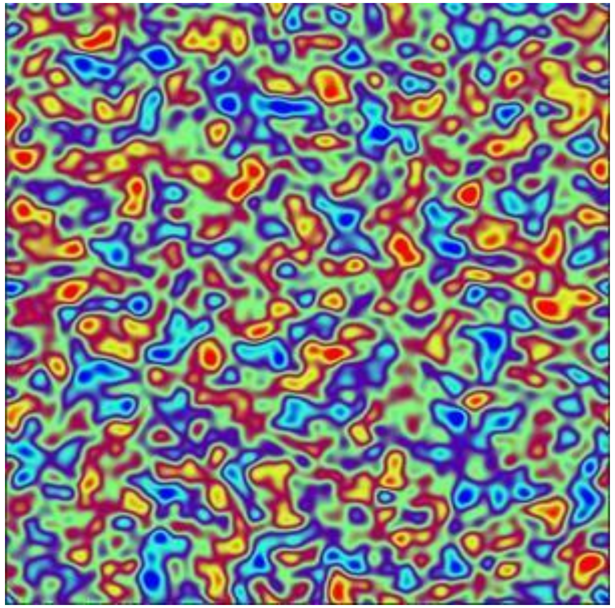
temporal decorrelation time τ

stddev_cutoff_rand_pert

To prevent extreme values in a Gaussian distribution.



lengthscale_spp_pbl = 50,000



lengthscale_spp_pbl = 10,000

Recap of our major goal & Lessons learned

- To replace the multi-physics strategy currently employed in WEPS, we aim to use a single physics with SPP approach.
- To *gradually* replace the multi-physics strategy with a single physics plus SPP approach, we plan to start with the PBL scheme.

- Lessons learned from past experiences:
  - ➢In 2021, CWA evaluated the use of MYNN PBL with SPP in place of the multi-PBL approach, aiming to achieve a better skill-to-spread ratio for the CWA EPS while not doing harm to the overall forecast performance.
  - ➢Results showed that while the skill-to-spread ratio remains similar to the multi-PBL approach, larger errors were identified in the near-surface wind forecasts when MYNN PBL with SPP was used.
  - ➢We then compared MYNN PBL to YSU PBL in a deterministic setup using WRFD, it was found that MYNN indeed performs slightly worse than YSU in near-surface wind forecasts over the Taiwan.

SPP variable setting

Field	Host Parameterization Scheme	Field type	Length scale (km)	Temporal scale (hours)	Percent magnitude perturbation (for one standard deviation)
K_M	YSU-PBL	Diagnostic	150	6	±30%
r_c	YSU-PBL	Diagnostic	150	6	±30%
zfacent	YSU-PBL	Diagnostic	150	6	±30%
Z_{NT} *and* Z_L	MM5 similarity-sfclay	Diagnostic	150	6	±50%
U^*	MM5 similarity-sfclay	Diagnostic	150	6	±10%
pfac and pfac_q	YSU-PBL	Fixed parameter	150	6	±30% (from 2 between 1 and 3)
brcr_sb	YSU-PBL	Fixed parameter	150	6	±30% (from 0.25 between 0.1 and 0.5)
pgrow	YSU-PBL	Fixed parameter	150	6	±30% (from 0.15 between 0.075 and 0.3)

▲Table 1: List of stochastically perturbed fields.

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Momentum diffusion coefficient

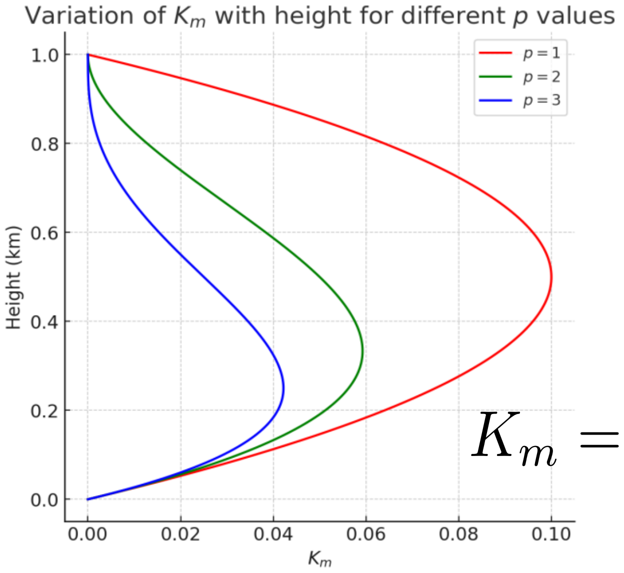
$$K_m = \kappa w_s z \left(1 - \frac{z}{h}\right)^p$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right) - \overline{(w'c')}_h\left(\frac{z}{h}\right)^3\right]$$

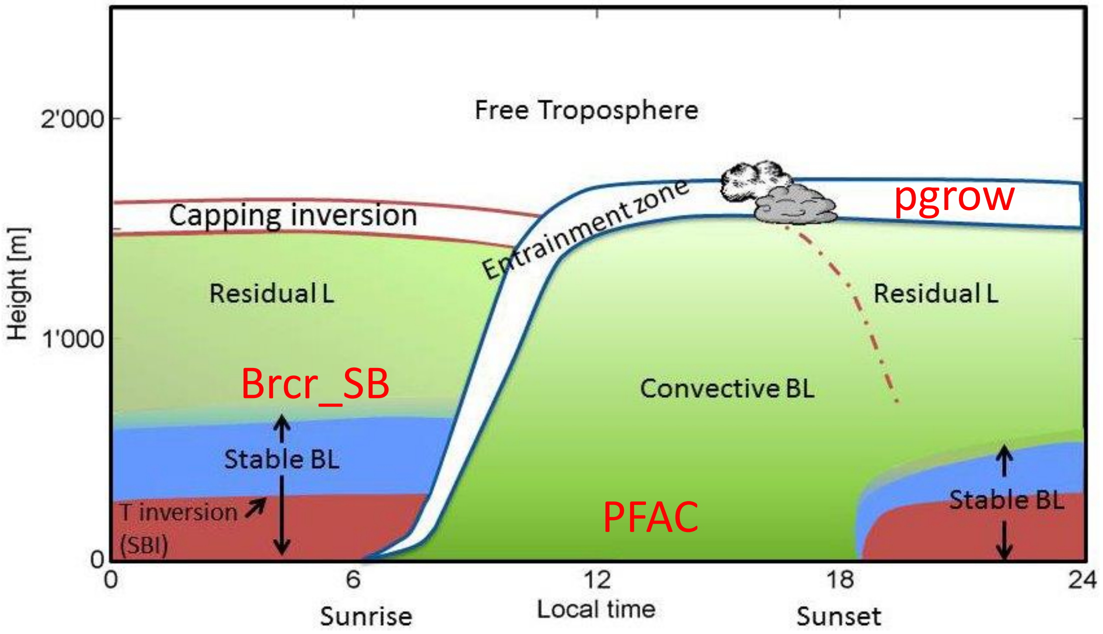
Contour gradient

1. **ZNT**
   →roughness Length change with time, effect on ZL(ocean)
2. **ZL(land)**
   → roughness Length effect on land
3. **U***
   → Friction velocity can increase variations in surface fluxes.

SPP variable setting



$$K_m = \kappa w_s z \left(1 - \frac{z}{h}\right)^{\boxed{p}}$$



pfac and pfac_q	YSU-PBL	Fixed parameter	150	6	±30% (from 2 between 1 and 3)
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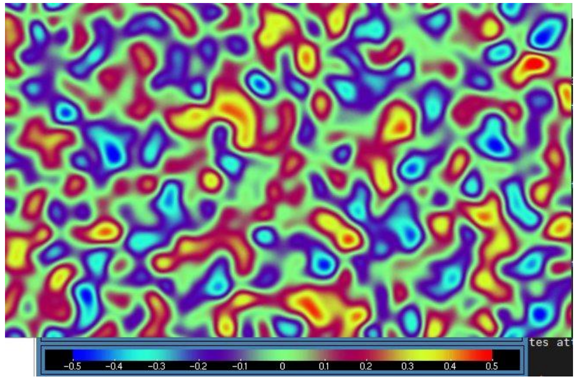
Parameter test

Parameter test: 1 case (2024011400)

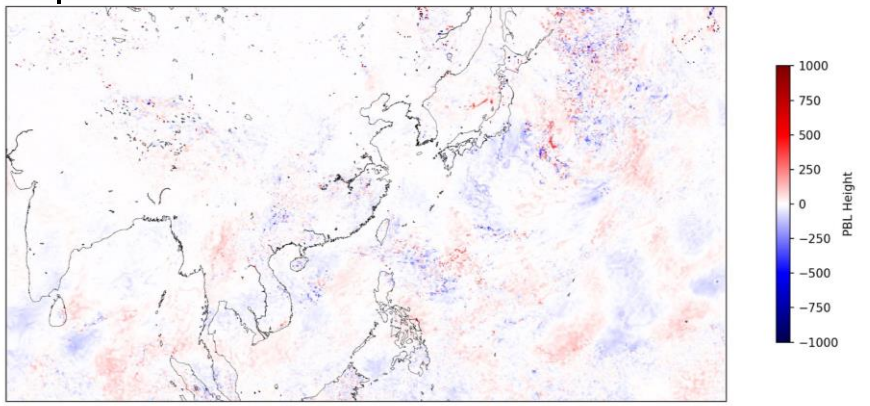
- To check the parameter we can use.
- Just one member and PBL perturb

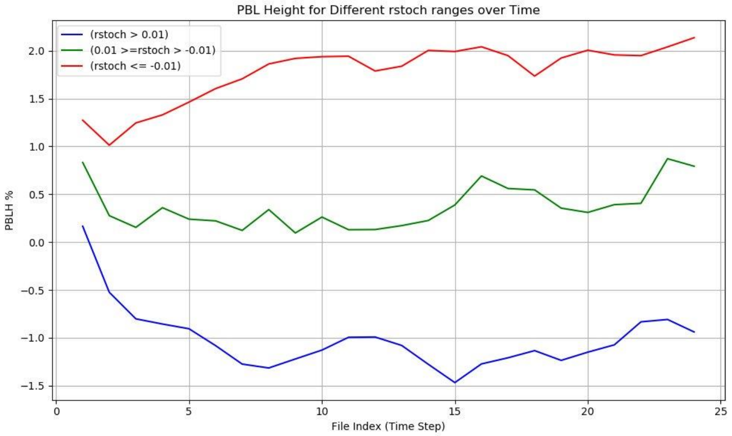
- The SPP implementation within the PBL scheme created physically consistent changes in the model state.



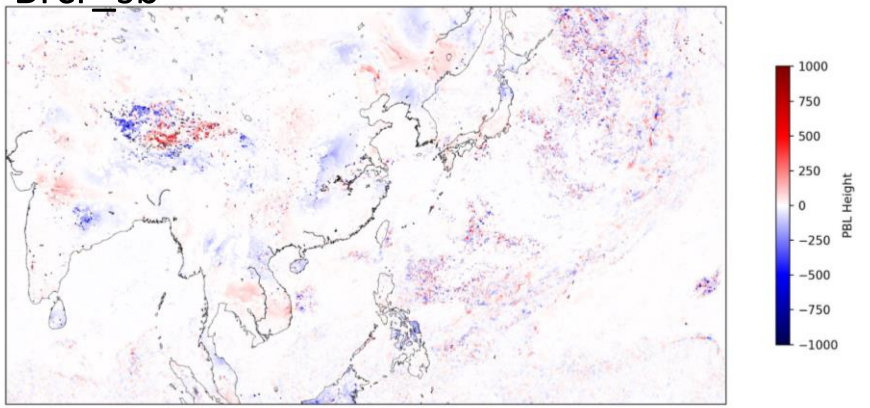
Jankov, I., J. Beck, J. Wolff, M. Harrold, J. B. Olson, T. Smirnova, C. Alexander, and J. Berner, 2019: Stochastically Perturbed Parameterizations in an HRRR-Based Ensemble. *Mon. Wea. Rev.*, **147**, 153–173, https://doi.org/10.1175/MWR-D-18-0092.1.

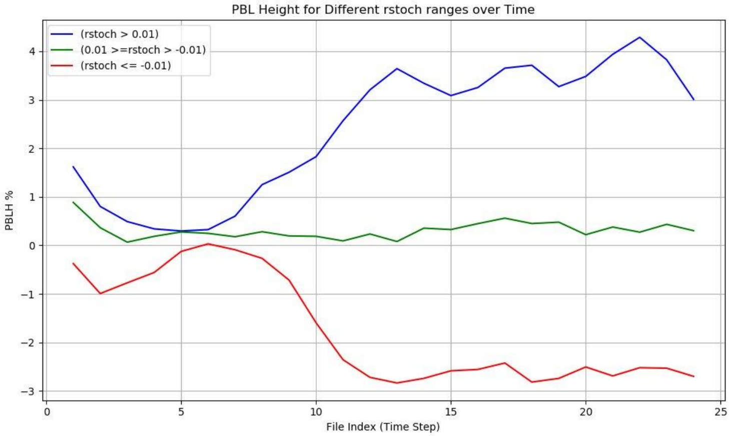
pfac



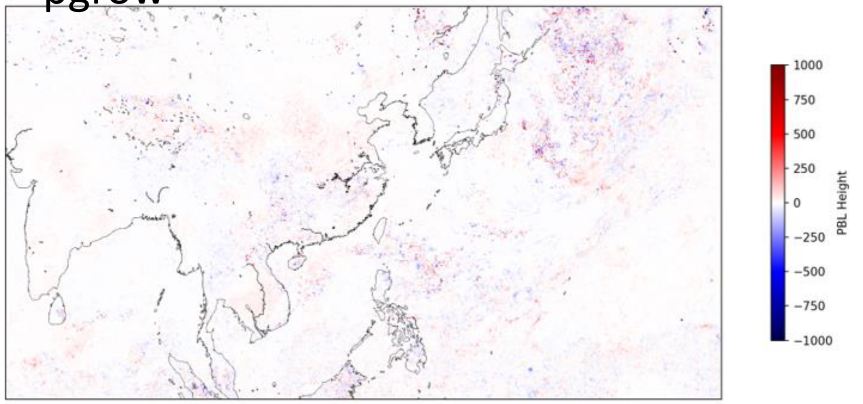


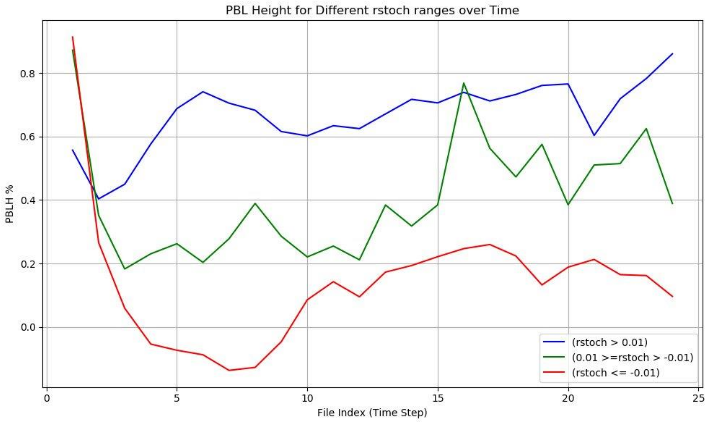
Brcr_sb





pgrow





Experiment setting

- Longer test: 40 case (summer & winter)
  - To execute more cases to get consistent results
  - 20 members and have all perturb
  - Summer cases (KOINU) : 2023 0930 00Z ~ 1005 12Z
  - Winter cases (Cold front) : 2024 0101 00Z ~ 0107 12Z
  - 12hr interval & 72 hr fcst

Yn	All members use **Y**SU but **N**o SPP
YP1	All YSU-spp used **diagnostic fields**
YP2	All YSU-spp used **fixed parameters**
YP4	All fields in YSU-SPP combined

YSU-SPP experiment

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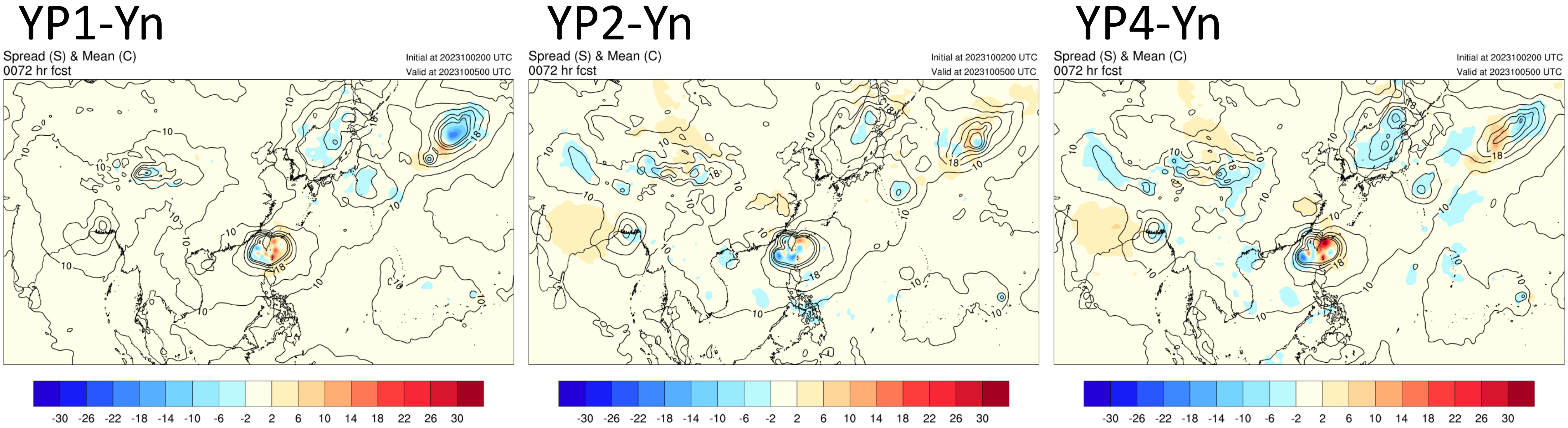
YP1	All YSU-spp used **diagnostic fields**
YP2	All YSU-spp used **fixed parameters**
YP4	All fields in YSU-SPP combined

▲Table 2: YSU-SPP experiment setting.

- Single case: initial at 2023/10/02 00Z, 72 hr fcst.



▲Figure 4: Mean (contours) and spread (shading) differences at 850 hPa between YP1, YP2, and YP4 relative to Yn on 2 October, for the 72-hour forecast.

Synoptic-Scale Verification (15 km)

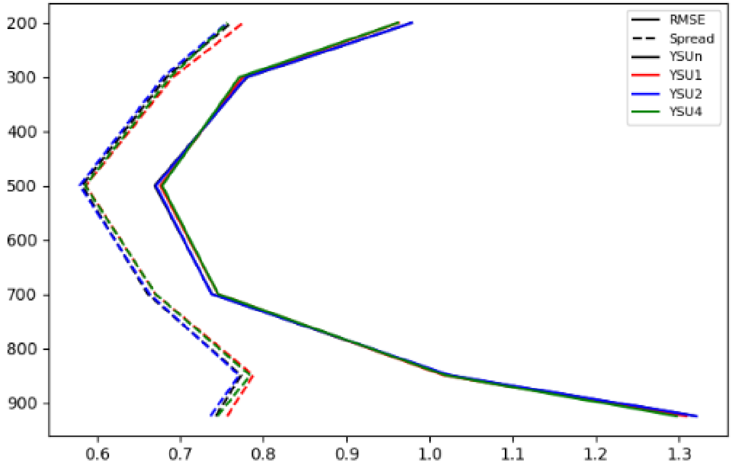
YP1 & YP4 have larger spread in 15 km.

○Summer cases (KOINU) : 2023 0930 00Z ~ 1005 12Z

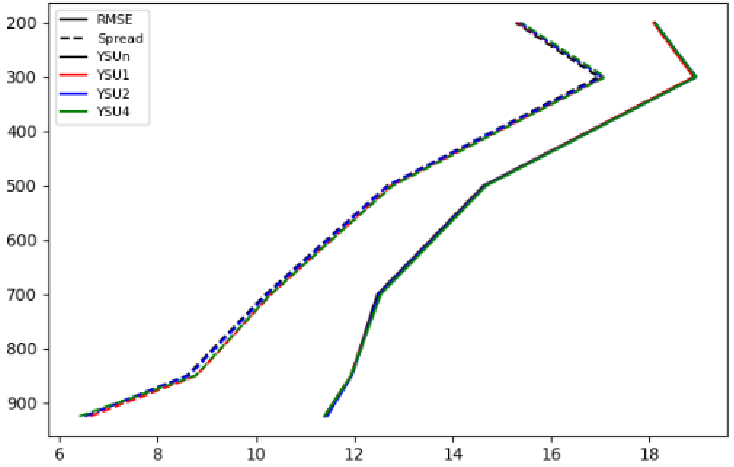
— **RMSE** ⍰ **SPREAD** — Yn — YP1 — YP2 — YP4

48h

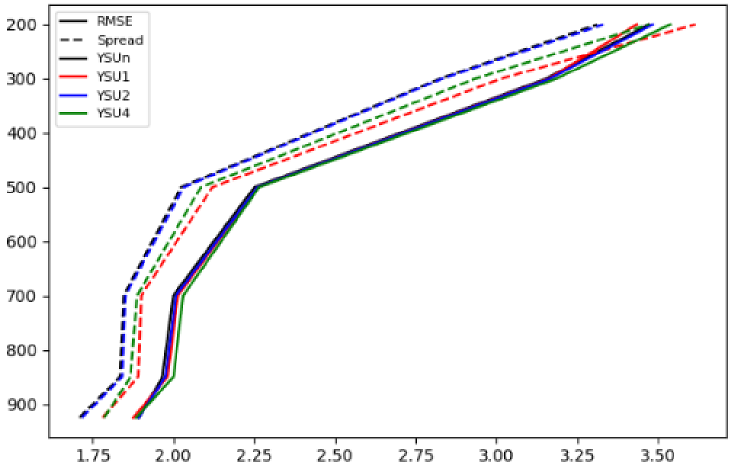
RMSE&SPREAD forTemperature (K)



RMSE&SPREAD for Mixing ratio (g/kg)



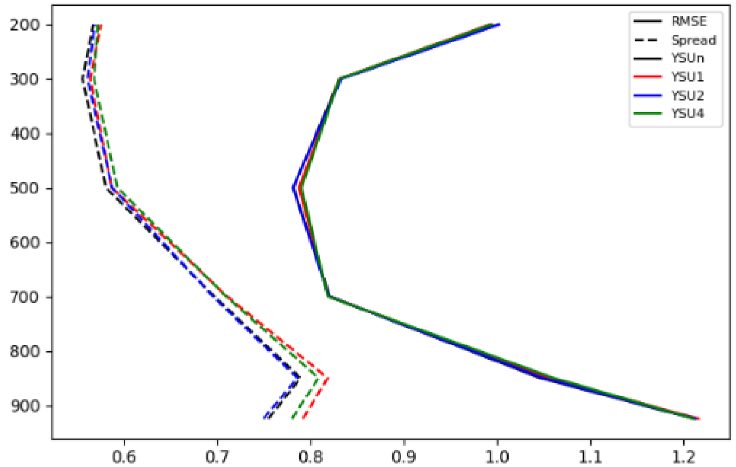
RMSE&SPREAD for Wind Speed (m/s)



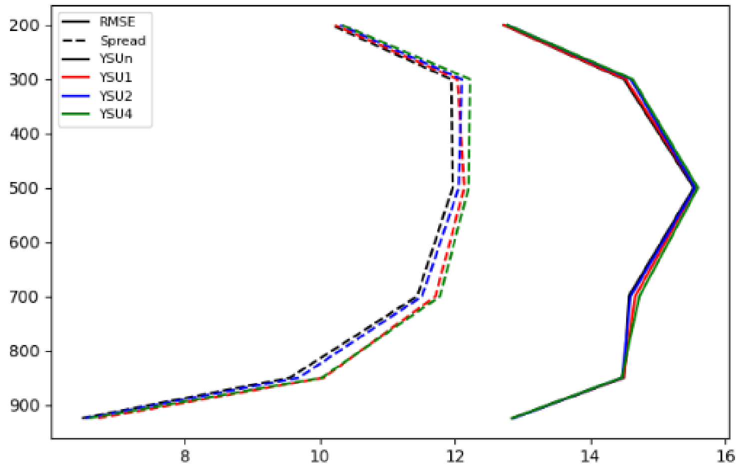
○Winter cases (Cold front) : 2024 0101 00Z ~ 0107 12Z

48h

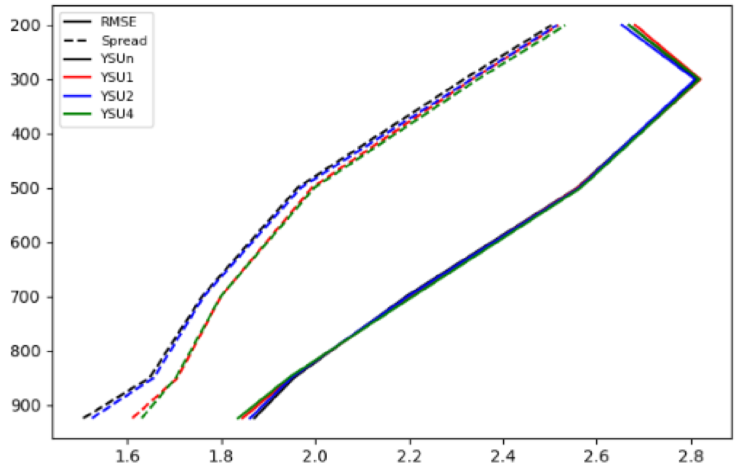
RMSE&SPREAD forTemperature (K)



RMSE&SPREAD for Mixing ratio (g/kg)



RMSE&SPREAD for Wind Speed (m/s)

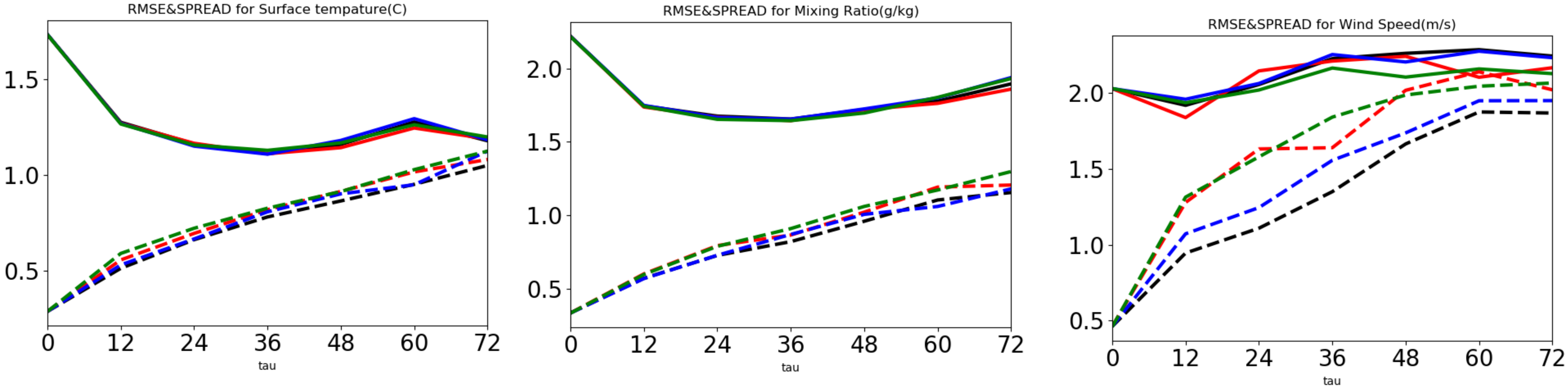


Surface Verification (3 km)

YP4 shows a larger spread near the surface and reduces the typhoon wind speed RMSE.

— RMSE ? SPREAD — Yn — YP1 — YP2 — YP4

○Summer cases (KOINU) : 2023 0930 00Z ~ 1005 12Z



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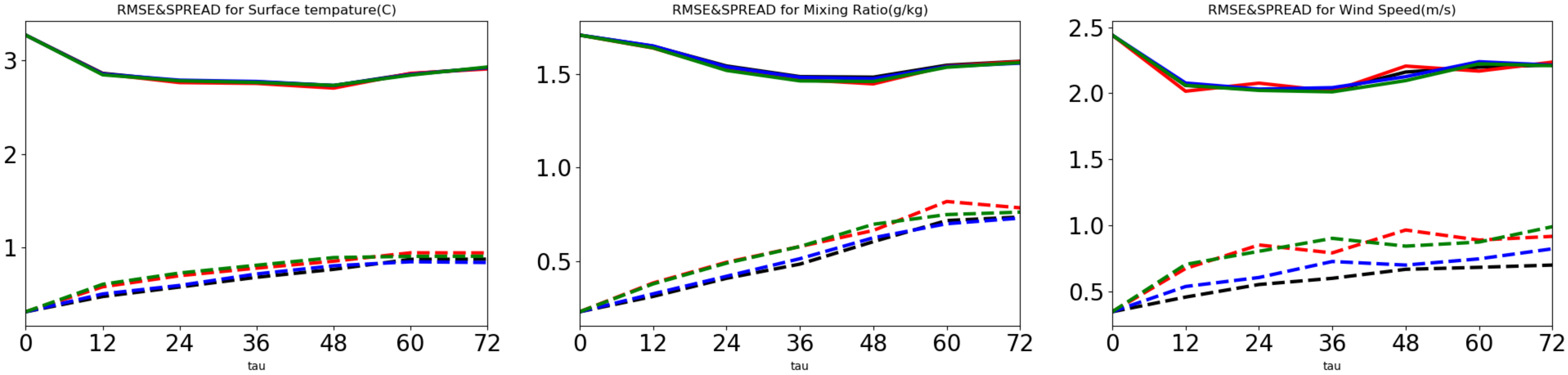
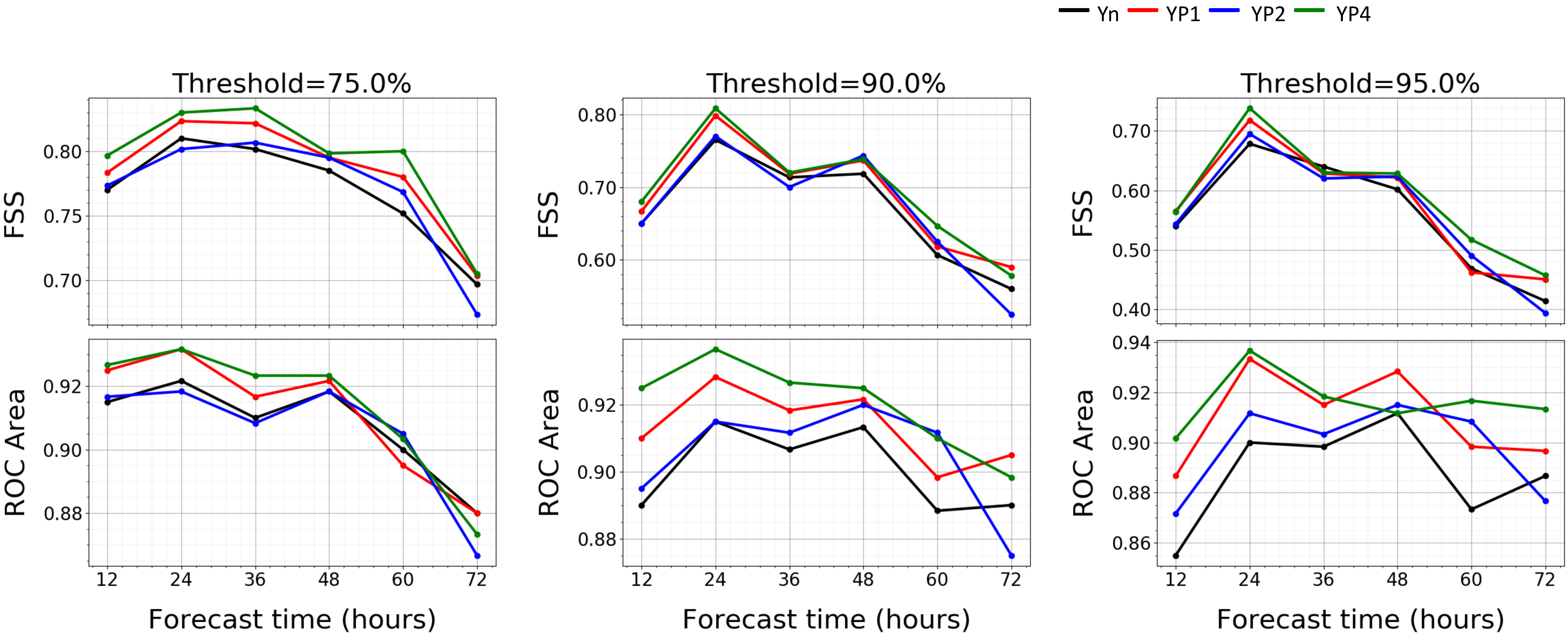


23 0930 00 ~1005 12 (12cases)
12 hr raunfall

YP4 has the best precipitation forecast skill.



Summary

- In response to international trends, the agency has begun transitioning from traditional multi-parameter approaches to SPP methods.

- Among the experiments, the combined configuration (YP4) yielded the best overall performance, particularly for synoptic-scale fields, near-surface variables and precipitation forecasts.

- The current approach will be benchmarked against the multi-physics method. Further development will extend SPP applications to other schemes, such as radiation and microphysics parameterizations.

RRTMG-SPP in HRRR

- RRTMG –SPP is the code in HRRR (Kalina et al. 2021; https://doi.org/10.1175/WAF-D-20-0098.1.)

liquid water path

$$\mathrm{LWP} = \int_{z_{\mathrm{base}}}^{z_{\mathrm{top}}} \rho_a \, q_l \, dz$$

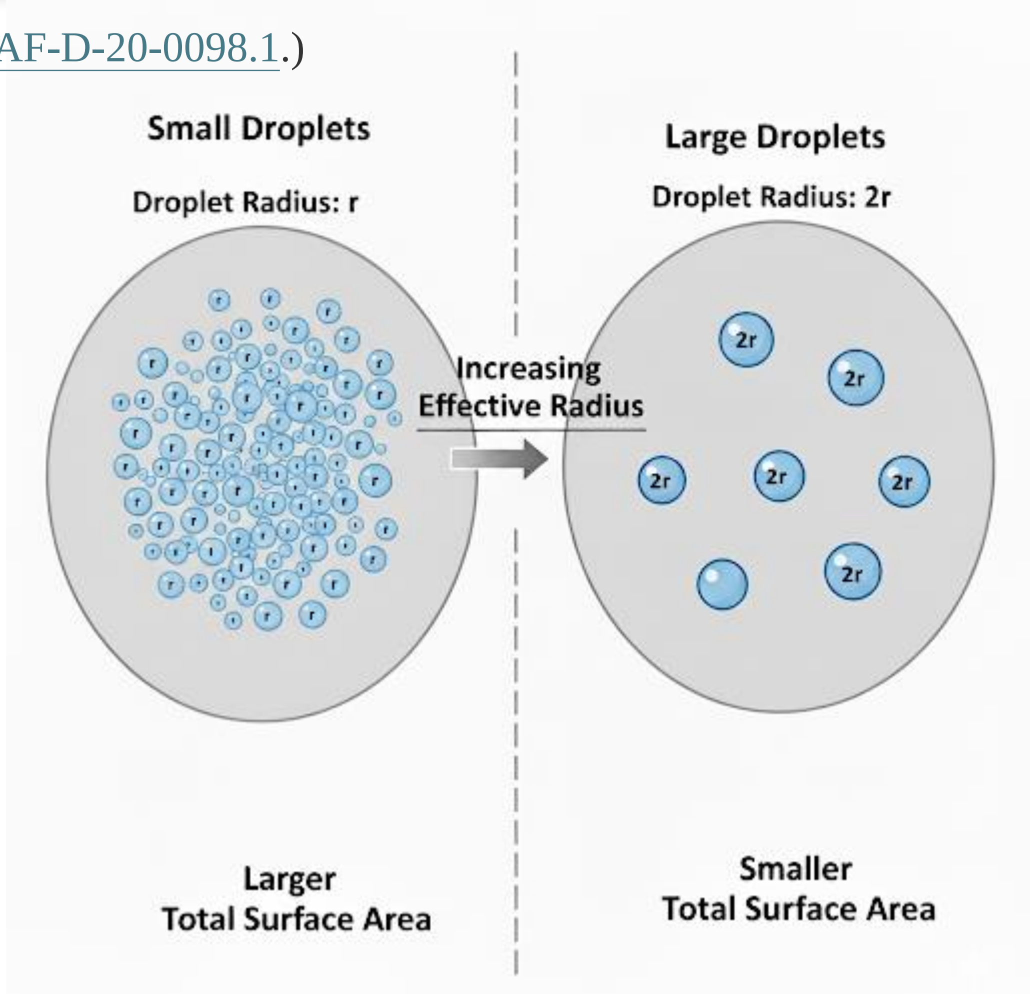
Optical Depth

$$\tau = \frac{3\,\mathrm{LWP}}{2\rho_w r_{\mathrm{eff}}}$$

Liquid water density

effective radius

$$\boxed{r_{\mathrm{eff}} = \frac{\int r^3 n(r)\, dr}{\int r^2 n(r)\, dr}}$$



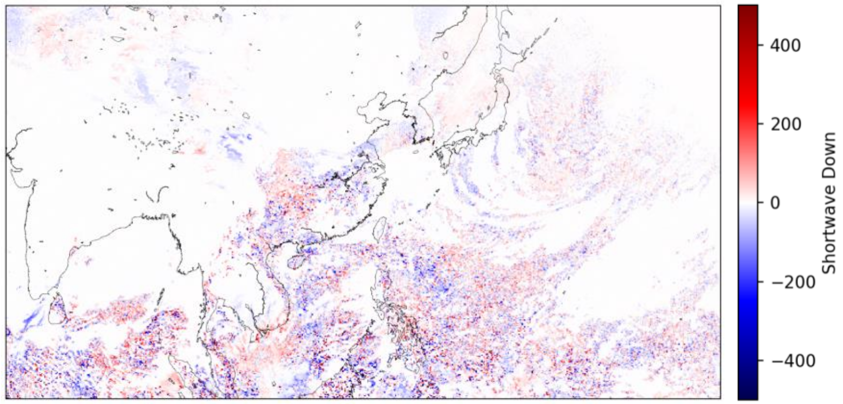
Generate by Gemini 2.5

ccpp-physics/physics/GFS_rrtmg_pre.F90

Dev & Eval of using SPP in WEPS: RRTMG

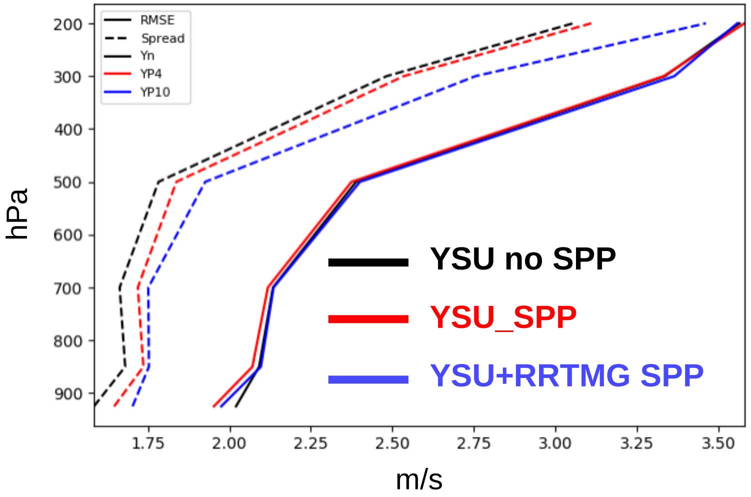
- With help from Judith and Jeff, we successfully incorporated RRTMG-SPP into WEPS based on work done in HRRR.
- Effective radius of hydrometeor variables from the TCWA1 scheme are passed to RRTMG in WEPS to allow the coupling of microphysics and radiation processes (thanks to Tzu-Chin).

Shortwave downward radiation

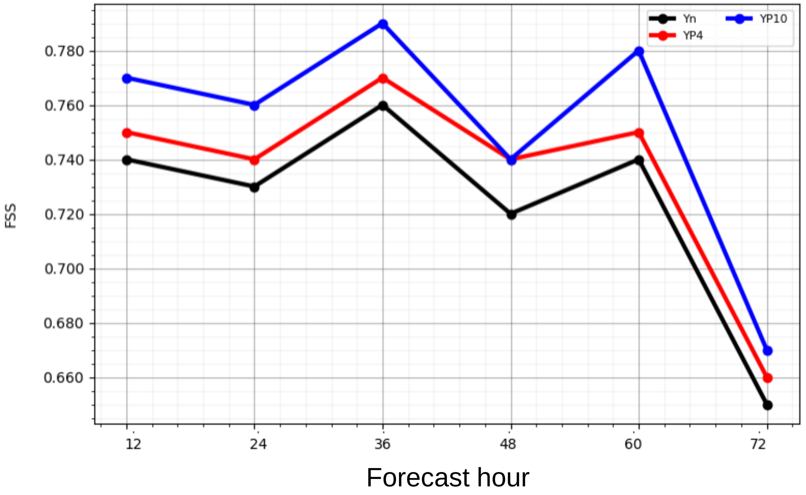


- With RRTMG-SPP in WEPS, forecast wind speed at all levels appear to have larger spread in both 15 km and 3 km domains.
- In addition, WEPS forecasts with RRTMG-SPP lead to higher precipitation forecast FSS.

48-h forecast of wind speed



12-hr accumulated rainfall as Threshold=75.0



Summary

- The SPP of RRTMG scheme have great impact in the place of Q-cloud higher.

- Lower length-scale and time-scale get greater region to perturb

- WEPS forecasts with RRTMG-SPP lead to higher precipitation forecast FSS.