Current status and future plans for stochastic representations of model uncertainties in the Korean Integrated Model

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1 Introduction

- An ensemble forecasting combines multiple individual forecasts, e.g. "ensemble members," each predicting the atmospheric state with slight variations. The goal of ensemble forecasting is to capture the inherent uncertainty of a deterministic forecasting system by sampling from the probability distribution of potential future atmospheric states.
- Therefore, it is essential to accurately represent the sources of uncertainty that impact the forecast. These uncertainties arise from errors in both the initial conditions and the forecast model formulation, and their proper representation is a critical component of ensemble forecasting.
- At the Korea Institute for Atmospheric Prediction Systems (KIAPS), the ensemble system comprises 50 perturbed forecasts. The perturbed forecasts are generated by each starting from a uniquely perturbed set of initial conditions, designed to represent uncertainty in the analysis of the initial state.
- In addition, the forecast model itself includes stochastic perturbations to represent model uncertainties, which arise due to simplifications made necessary by constraints on resolution, efficiency and/or our knowledge of some processes (Lock et al. 2019).
- This study introduces the stochastic representation schemes of model uncertainties in KIM and presents the results of numerical experiments. We provide a preliminary examination of the results, with a particular focus on the sensitivities of the model to stochastically perturbed physical tendencies (SPPT) and stochastically perturbed parameterizations (SPP) schemes.

2 Stochastic representations of model uncertainties

The formulation of SPPT

$$\mathbf{p} = (1 + \mu r)\mathbf{p}_D$$

- $\mathbf{p}$: the perturbed tendencies
- $\mathbf{p}_D$: the unperturbed net physics tendencies for the four prognostic model variables (temperature (T), specific humidity (q) and wind (u & v) components)
- r : the random pattern, which is drawn from a Gaussian distribution with mean of zero and standard deviation
- μ : the optional tapering function that depends on the model level only

Details are in Palmer et al. (2009) and Berner et al. (2009).

The formulation of SPP

$$\xi_j = \exp(\Psi_j)\,\hat{\xi}_j, \qquad \Psi_j \sim \mathcal{N}(\mu_j, \sigma_j^2)$$

- j : an integer index ranging from 1 to K, with $K \leq 35$
- $\hat{\xi}_j$: the unperturbed value of the jth parameter
- ξ_j : the perturbed value of the jth parameter
- Ψ_j : the perturbations sample a Gaussian distribution with a mean μ_j and a standard deviation σ_j

Details are in Ollinaho et al. (2017) and Lang et al. (2021).

Table 1. Perturbed parameters for SPP in KIM.

Physics	Name	Role of parameter
Surface and boundary layer	conpr	Excess constant for surface prandtl number
	xkzminh	Background difficulty for heat
	brcr_sb	Richardson number for stable boundary over land
	rl2	Mixing length in free atmosphere
	rlamdz	Asymptotic length scale
	rlam	Threshold for rlamdz
	rlam2	Threshold for rlamdz
	karman	Von Kármán constant
	brcr_sbro	Richardson number for stable boundary over ocean
	qlcr	Threshold for cloud liquid water
	var	Standard deviation of subgrid orograophy
	cf	Coefficient for turbulent orographic form drag
Convection	pgcon	Convective momentum transport for deep convection
	beta1 (c0t)	Cloud-rain autoconversion rate for deep convection
	xlamb	Entrainment rate for deep convection
	xlamb_s	Entrainment rate for shallow convection
	xlamud	Detrainment rate for deep convection
	lmin	Downdraft starting level
	pgcon_s	Convective momentum transport for shallow convection
	dtconv	Adjustment time scale
	cinpcr	Threshold for trigger condition
	dthk	Threshold for trigger condition
	cinacrmx	Threshold for trigger condition
Cloud and large-scale precipitation	qimax	Cloud ice threshold for conversion of ice to snow
	qc0	Cloud water threshold for autoconversion of cloud to rain
	prevp	Evaporation rate of rain
	psdep	Sublimation rate of snow / deposition rate of snow
Radiation	decorr_len	Cloud vertical decorrelation length
	xrel	Effective radius of cloud water
	xrei	Effective radius of cloud ice
	xres	Effective radius of snow
	aod3d	Aerosol optical thickness

3 Preliminary results

Summary of the experiments for SPPT

Table 2. Configurations of random forcing tuning parameters for the experiments using SPPT: τ the time decorrelation scale, L the spatial auto-correlation scale, σ the standard deviation in grid-point space, and μ the tapering function.

Experiments	τ (d)	L (km)	σ	μ	Variables
SPPT1	0.25	500	0.42	on	T, q
SPPT2	3	1,000	0.14	on	T, q
SPPT3	30	2,000	0.048	on	T, q
SPPT1_x3	0.25	500	0.42	off	u, v, T, q
SPPT0	control experiment with perturbations to initial conditions only				

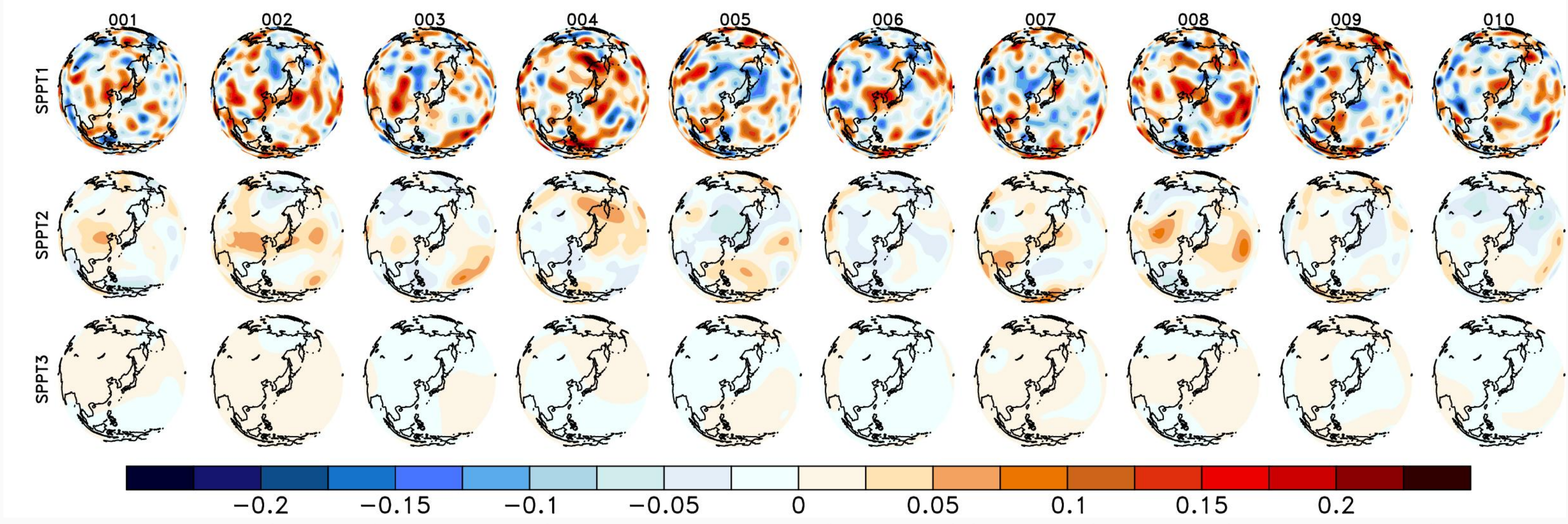

Figure 1. Example random perturbation patterns of ensemble member numbers 1 to 10 from SPPT1 to 3.

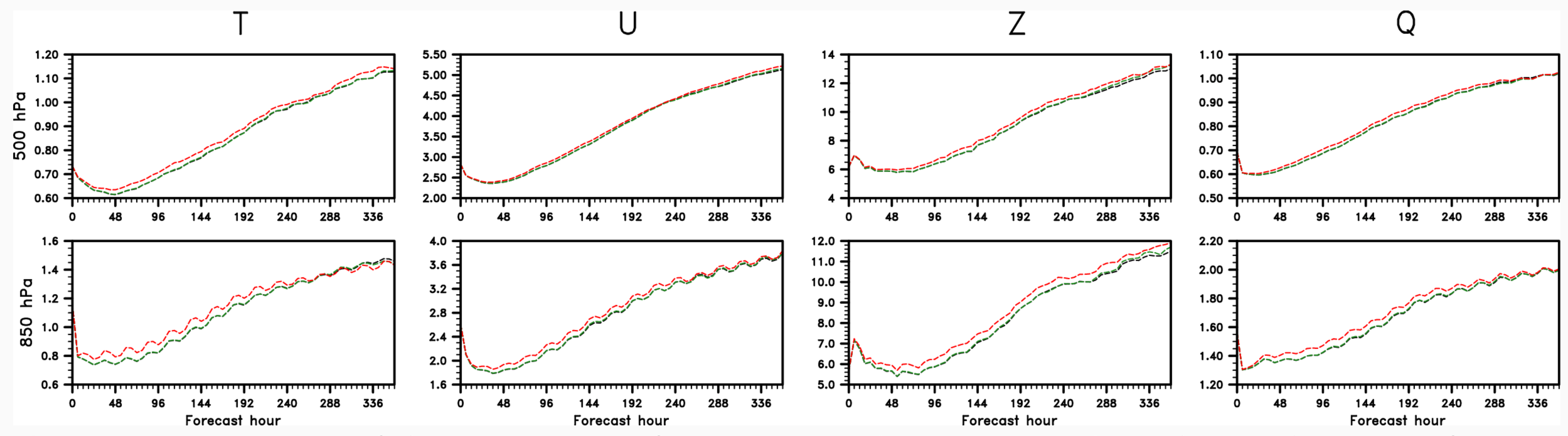

Figure 2. Time series of the experiment for T, U, Z, and Q at 500 and 850 hPa to hour 360 for ensemble spread over the Tropics (20˚S–20˚N). Experiments: SPPT0 (black), SPPT1 (green), SPPT3_x3 (red). Results are from 10 start dates covering February 2011–2020.

Summary of the experiments for SPP

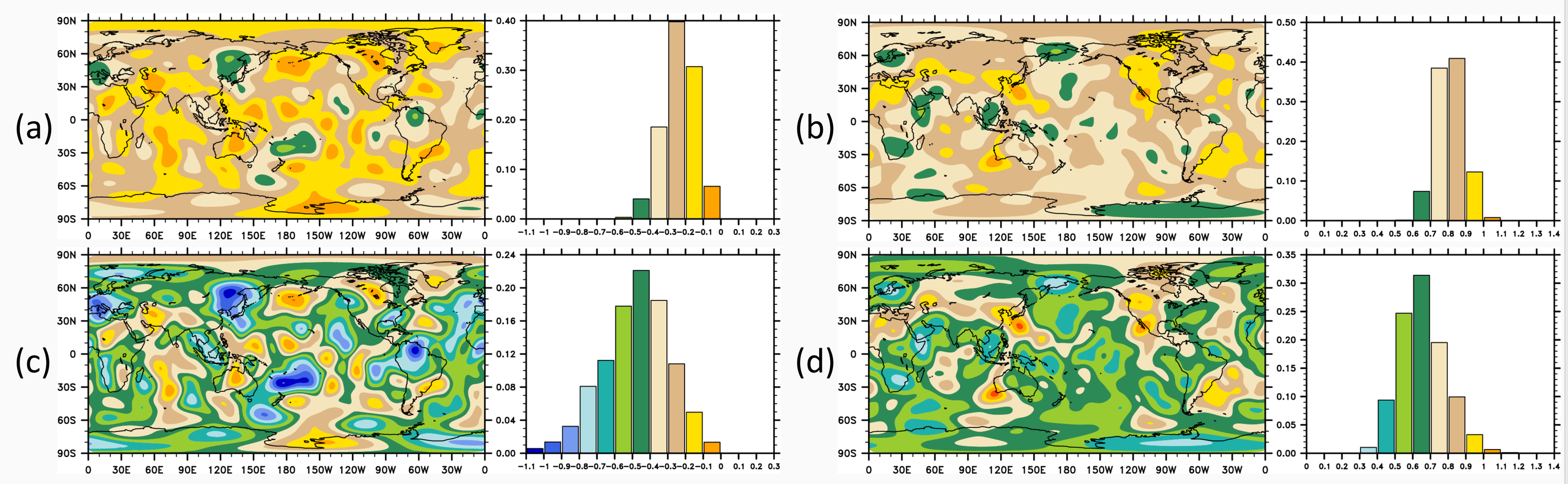

Figure 3. Examples of (a, c) normally and (b, d) log-normally distributed perturbation patterns with standard deviation of (a, b) $\sigma = 0.7$ and (c, d) 1.0, where the mean equals the unperturbed value (e.g., $\mu = -\sigma^2/2$).

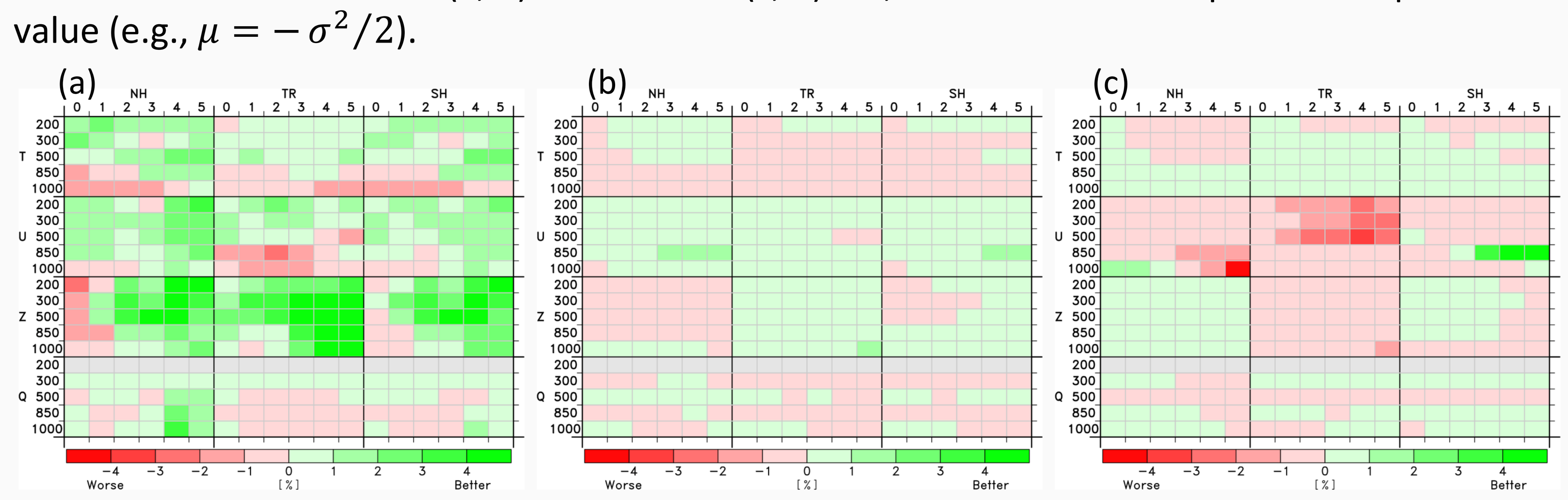

Figure 4. Scorecards of relative changes in (a) RMSE (root-mean squared error), (b) spread, and (c) CRPS (continuous ranked probability score) as a function of lead time (in days) for SPP sensitivity experiment versus control.

4 Summary and plans

- Two stochastic parametrization schemes have been implemented in KIM and their characteristics have been studied on short- and medium-range forecast.
- The revised formulation of SPPT has been proposed, in which the perturbations (r) from SPPT1 are multiplied by a constant value within a dynamically stable range and changed the tapering limits in the boundary and stratospheric layers. This approach leads to small improvements in ensemble spread in the Tropics (Figure 2).
- The revised version of SPP perturbs 32 parameters in the KIM's physical parametrization schemes; the list of the parameter perturbations is given in Table 1. Each perturbed parameter is assigned an individual random field, and different random fields are statistically independent (Lang et al. 2021). The improvement in RMSE does not correspond to an improvement in CRPS (Figure 4).
- As a next step, it will be important to identify the optimal values for the standard deviations of SPP that will reduce error and enhance CRPS.

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