To which degree do the details of stochastic perturbation schemes matter for convective-scale and mesoscale perturbation growth?

WAVES TO WEATHER

LMU

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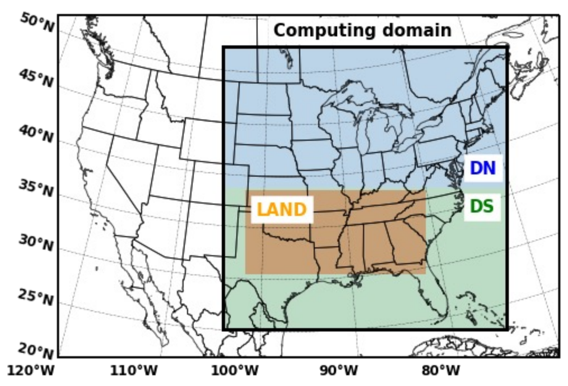
Take Home Messages

1. Early in the forecasts, the two stochastic parameterizations have different effects:
   - PSP scheme responds to boundary layer turbulence and produces strong perturbations and error growth in phase with the diurnal cycle of convection
   - SPPMP produces perturbations in regions with existing precipitation that grow more slowly with lead time, independent of the time of day
2. Differences between the two stochastic schemes are short-lived, and within a day of simulation, the amplitude and structure of differences are similar. This is associated with saturation of error growth on small scales (up to about 50 km).
3. No additive perturbation growth beyond the first hours is discernible using both schemes in parallel.
4. The locations and amplitudes of upscale error growth are determined by the synoptic-scale dynamics, independent of the details of the stochastic physics.

Experimental Design

- WRF @ 3 km grid spacing
- Model physics as in HRRR
- no Cu parameterization
- Stochastic Microphysics
- PSP scheme
- Ensemble size N=7
- no IC and LBC uncertainty



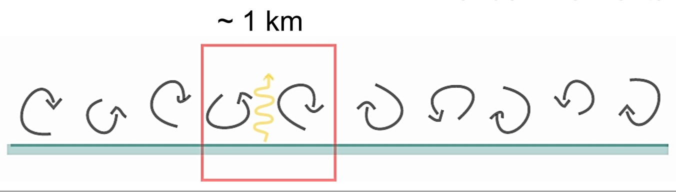
Physically based Stochastic Perturbations PSP (Hirt et al. 2019)

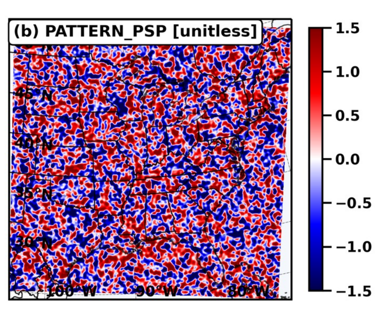
$$\partial_t \Phi |_{PSP} = \alpha_{tuning} \eta_t \frac{l_{eddy}}{\delta x_{eff}} \sqrt{\overline{\Phi'^2}}$$

$\Phi \in \{T, q_v\}$

subgrid standard deviation

$\eta(x, y, t)$ random horizontal eddy field



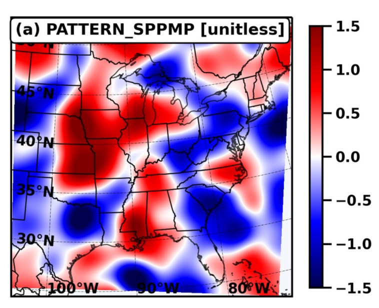


***PSP** random pattern with **15km** spatial and **10min** temporal scales*

Stochastic Microphysics SPPMP

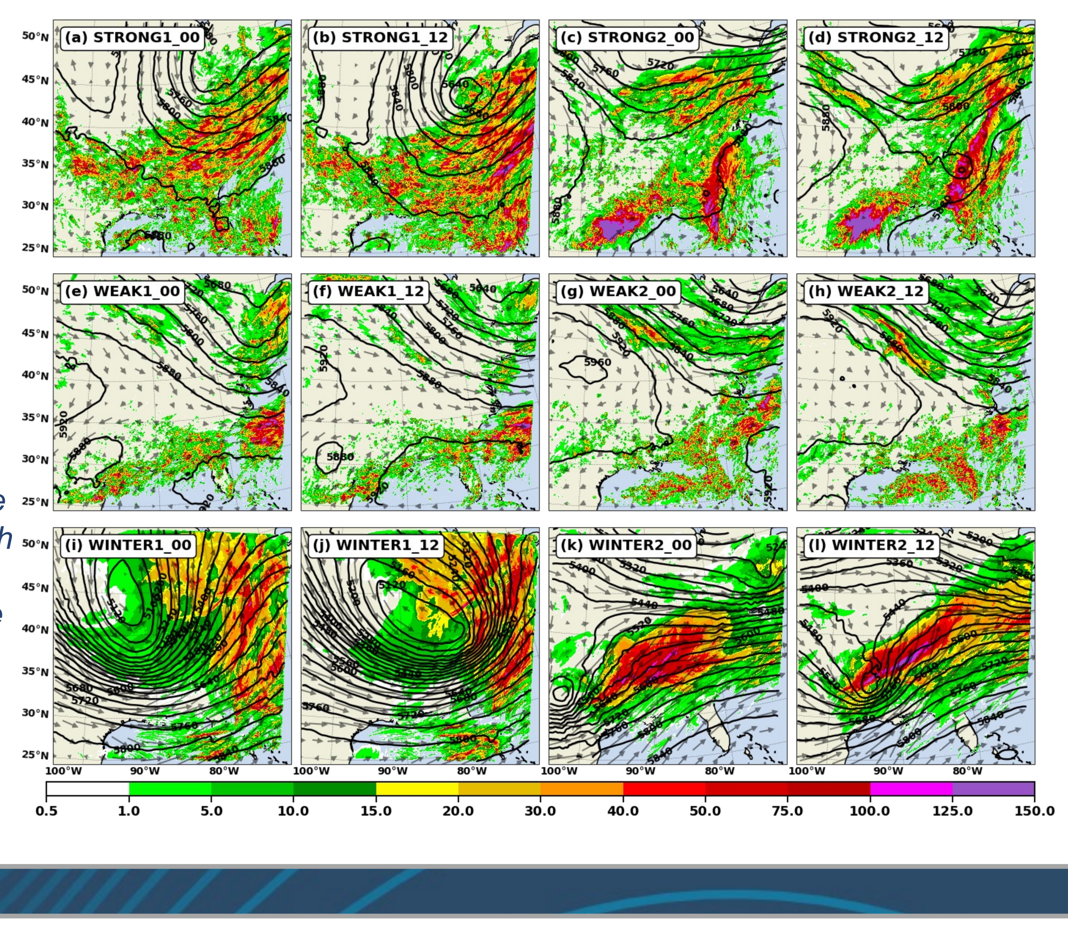
(Thompson et al. 2021)

Parameters	Magnitudes
Cloud droplet shape parameter	±2.0
Graupel and hail intercept parameters	±0.75
Vertical velocity for cloud condensation nuclei activation	+0.375
Activation of ice nuclei concentration	+13.5



***SPPMP** random pattern with **150km** spatial and **2h** temporal scales*

Six Cases



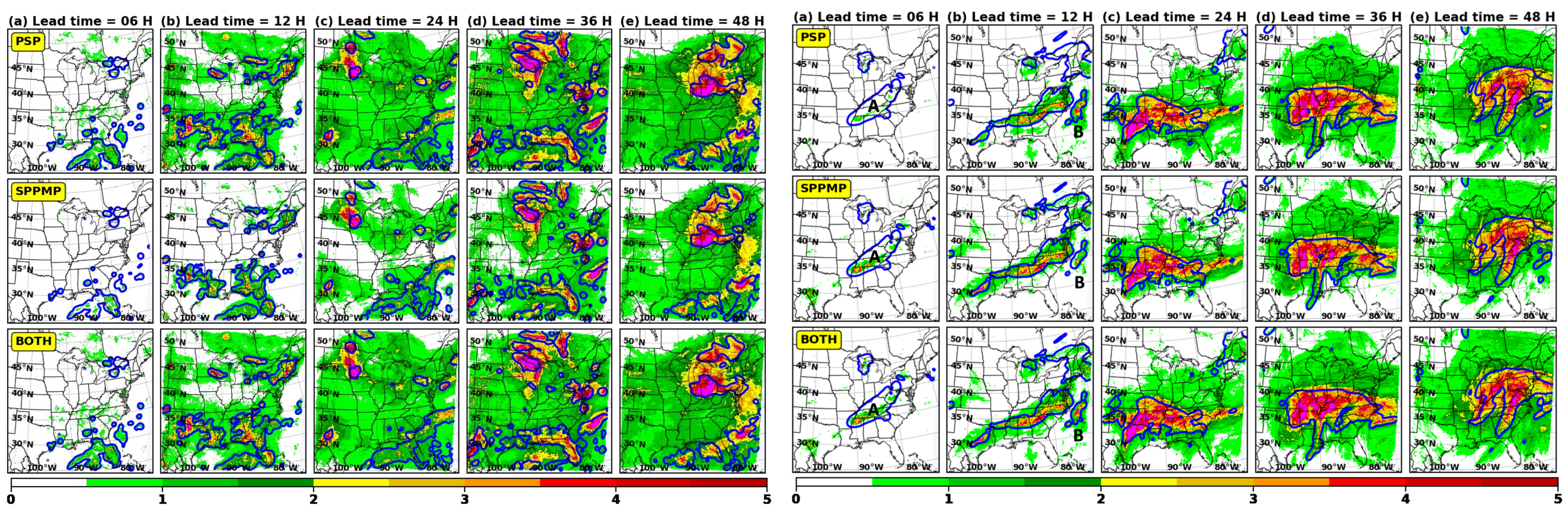
***500-hPa geopotential height** valid at the initial time for each case (contours, m), along with **the two-day accumulated precipitation** (shaded, mm).*

References

Hirt, M. et al. (2019) Stochastic parameterization of processes leading to convective Initiation in kilometer-scale models. Mon. Wea. Rev., 147, 3917–3934.
Chen, I. et al. (2025) To which degree do the details of stochastic perturbation schemes matter for convective-scale and mesoscale perturbation growth? Mon. Wea. Rev., 153, 447–469.
Thompson, G. et al. (2021) A Stochastic Parameter Perturbation Method to Represent Uncertainty in a Microphysics Scheme. Mon. Wea. Rev.,149,1481–1497.

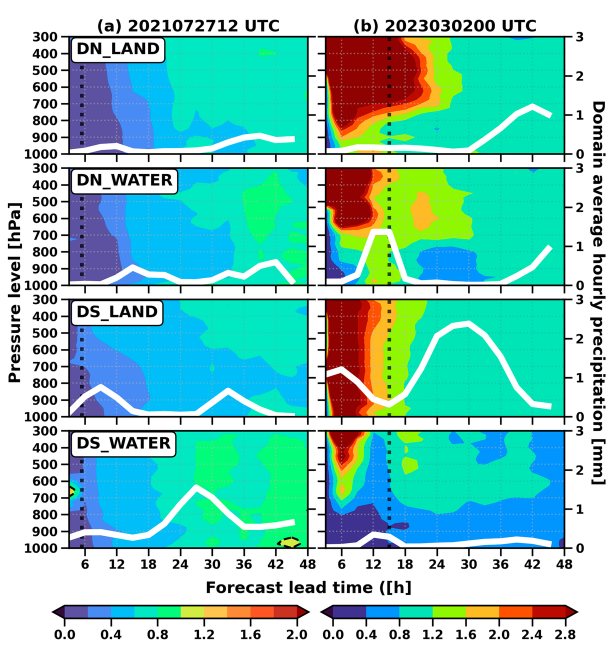
A. Summer vs Winter Case

$$RMDTE = \sqrt{\sum_{k=z_1}^{z_2} \frac{p(k+1)-p(k)}{p(z_1)-p(z_2)} \frac{1}{2}\left[\Delta u^2 + \Delta v^2 + \frac{c_{pd}}{T_r}\Delta T^2\right]}$$



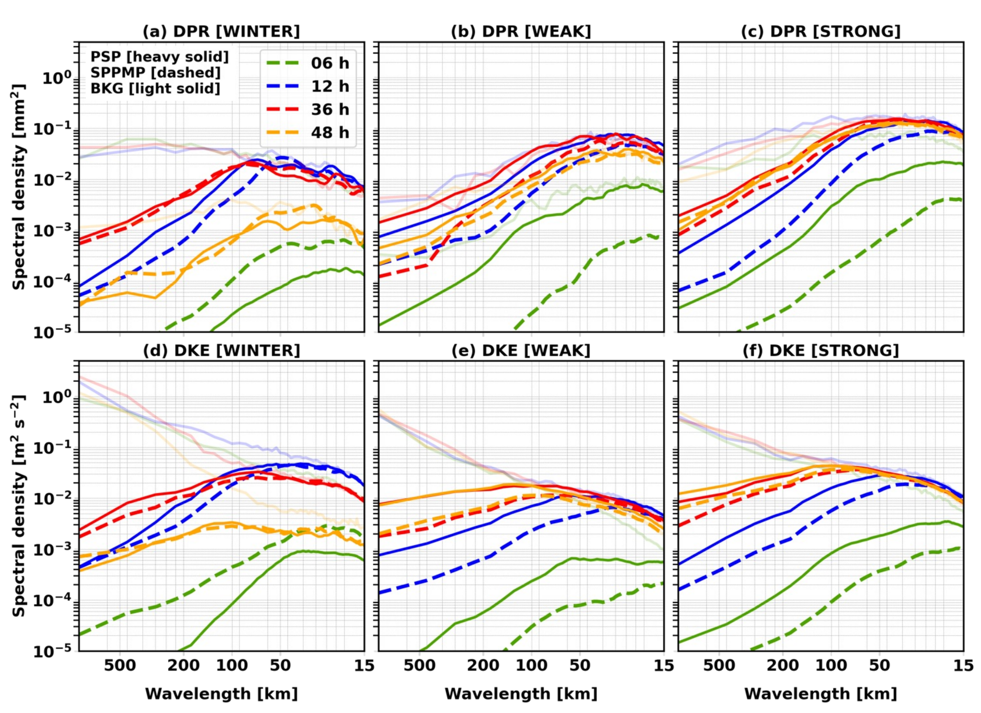
*RMDTE (m s[-1]) and **hourly precipitation** (>0.1mm, blue contours) at various lead times for **WEAK Convection (left) and WINTER (right)** case.*

***Time height diagram** of averaged RMDTE ratio (shaded, SPPMP against PSP) and domain average hourly precipitation rate (mm, white lines, corresponding to the right y-axis) for **WEAK Convection (left) and WINTER (right)** case.*



- Different responses at early lead times (6 to 12 h)
- PSP scheme has a stronger impact in the WEAK case, while SPPMP dominates the WINTER case
- Additive effect only at the beginning of the forecast
- After 24h RMDTE ratio converges to 1 in both cases
- Forecasts become more indistinguishable, not just amplitude but also spatial distribution, showing the importance of the dynamical processes that amplify perturbations over time.

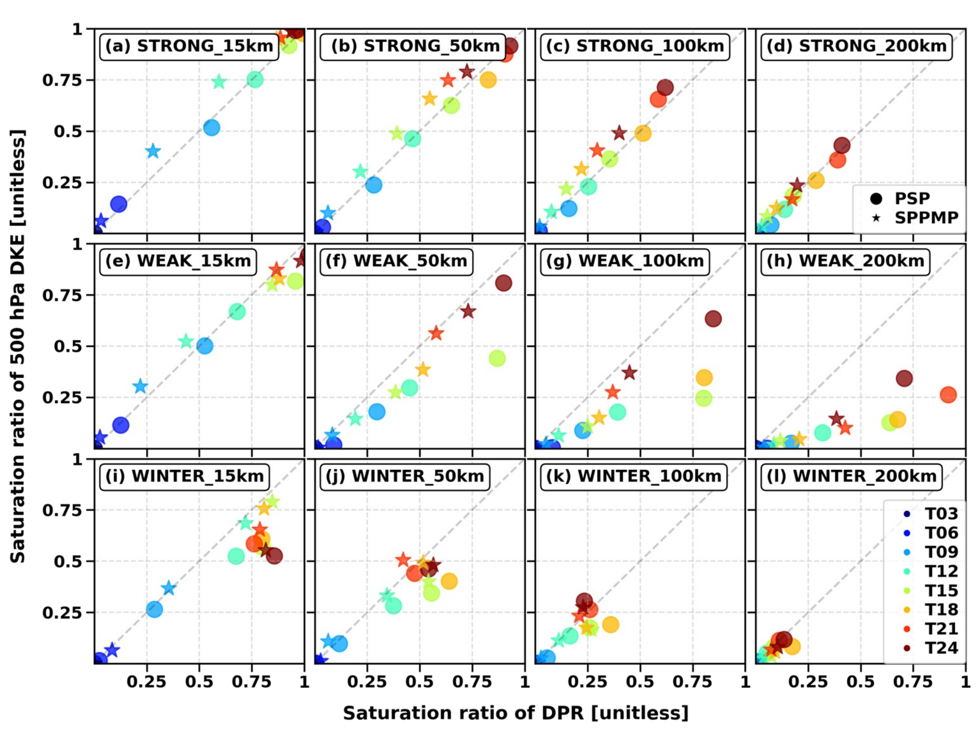
B. Spectra of Precipitation and Kinetic Energy



- WINTER: saturation amplitudes in the PR spectrum at larger scales
- SUMMER: PR spectrum peaks at wavelengths of 30-50km
- ALL: BKE largest for synoptic wavelengths above 500 km
- PSP: faster precipitation and kinetic energy error growth but SPPMP higher amplitudes at 6 h in WINTER
- PSP and SPPMP: difference spectra after 6h have peaks in similar wavenumber bands indicating that spatial length scale of the perturbations does not imprint itself onto the forecasts
- small spatial scales saturate faster and thus have less predictability than larger scales
- wavelengths of 100 km or less are close to saturation after a lead time of 36 h

*Spectra of (top) **background and difference** hourly precipitation and (bottom) kinetic energy for different lead times and weather situations. Each line shows the average of four spectra (two 00 UTC and two 12 UTC runs). The difference fields are computed against unperturbed forecasts.*

C. Saturation Ratios of DKE and DPR



- SUMMER: precipitation and kinetic energy errors saturate at scales < 50km within one day
- WINTER: lower saturation levels indicate higher predictability
- PSP higher saturation levels in DKE and DPR than SPPMP except in WINTER cases with a short lead time

How is an increase in energy error associated with the error in precipitation?

- saturation ratios grows at the same rate < 50km
- WINTER, STRONG: close to the diagonal, but slower progress on larger scales
- WEAK: higher PR saturation ratios than KE, esp. with PSP, pointing to more effective decorrelation of the PR field
- WEAK: **predictability of convection** is less than a day on all scales, not reflected in rapid error growth in larger-scale flow

***Saturation ratios** of difference kinetic energy against difference precipitation at **different forecast lead times** (h, colors) for various **forcing conditions**. Columns are saturation ratios at different **wavelengths**. Different markers denote results of PSP and SPPMP experiments.*

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