# Stochastic approaches within a High Resolution Rapid Refresh Ensemble
# Part II: Expanded Evaluation

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## Introduction

It is well known that global and regional numerical weather prediction ensemble systems are under-dispersive, producing unreliable and over-confident ensemble forecasts. Typical approaches to alleviate this problem include the use of multiple dynamic cores, multiple physics suite configurations, or a combination of the two. While these approaches may produce desirable results, they have practical and theoretical deficiencies and are more difficult and costly to maintain. An active area of research that promotes a more unified and sustainable system for addressing the deficiencies in ensemble modeling is the use of stochastic physics to represent model-related uncertainty.

## Stochastic Methods

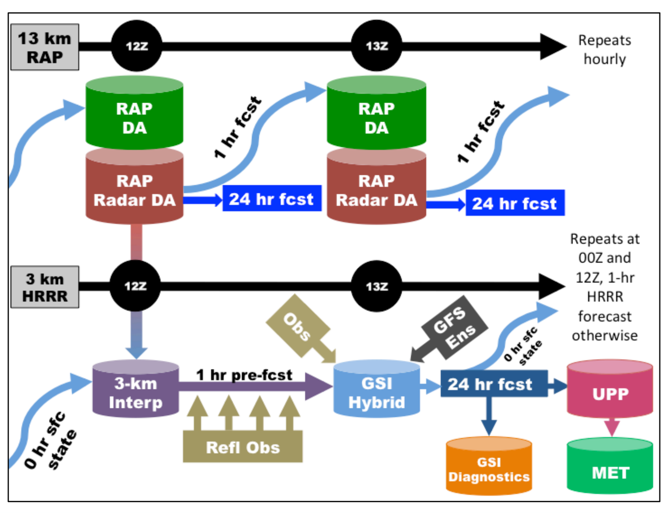
Several stochastic methods were tested in the HRRR ensemble system.

- Stochastic Parameter Perturbations (SPP): Perturbs parameters directly in the physics scheme with the parameter either fixed throughout the integration or varying randomly in time and space; addresses parameterization uncertainty at its source.
- Stochastic Kinetic Energy Backscatter (SKEB): Introduces random perturbations to streamfunctions and potential temperature tendencies in order to represent model uncertainty arising from unresolved subgrid-scale processes; based on the rationale that a small fraction of the model dissipated energy interacts with the resolved-scale flow and acts as systematic forcing.
- Stochastic Perturbation of Physics Tendencies (SPPT): Perturbs the parameterized tendency of physical processes (temperature, zonal and meridional winds, humidity) with multiplicative noise; based on the notion that equilibrium assumptions no longer hold with decreasing grid spacing and the subgrid-scale state should be sampled rather then represented by the equilibrium mean.

## Experiment Design

***The focus of this study is to assess the model performance when using a variety of stochastic approaches within a convection-allowing ensemble at 3-km grid spacing across the Contiguous United States (CONUS).***

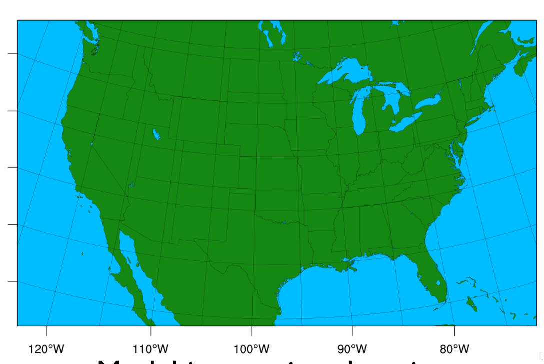
- **Workflow:**
  The end-to-end forecast components consisted of the Weather Research and Forecasting (WRF) Preprocessing System (WPS), Gridpoint Statistical Interpolation (GSI) data assimilation, Advanced Research WRF (WRF-ARW), Unified Post Processor (UPP), and Model Evaluation Tools (MET).




- **Retrospective Forecasts:**
  HRRR forecasts were initialized hourly with RAP model data and continuously cycled surface states; every 12 hours (at 00 and 12 UTC) 24 hour forecasts at hourly increments were produced from 18 - 27 May 2016.

- **Configuration Settings:**
  A single physics suite configuration based on the operational High-Resolution Rapid Refresh (HRRR) was used with ensemble members produced by employing stochastic methods. An 8-member ensemble was used for this test.

| Physics Suite | HRRR Operational Configuration |
|---|---|
| Microphysics | Thompson aerosol-aware (opt 28) |
| Radiation (sw/lw) | RRTMG (opt 4) |
| Sfc Layer | MYNN (opt 5) |
| LSM | RUC (opt 3) |
| PBL | MYNN2 (opt 5) |

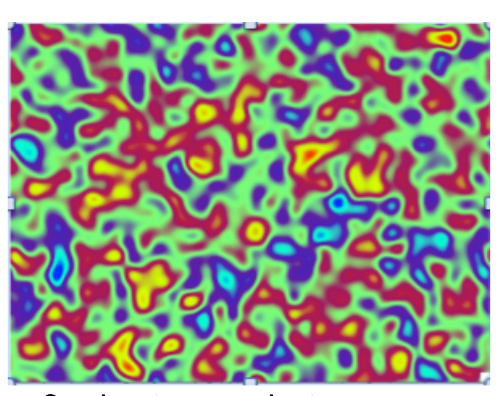


Model integration domain

- **Stochastic Namelist Settings:**
  User specified namelist parameters defining the stochastic perturbations:
  - gridpt_stddev_spp
  - stddev_cutoff_spp
  - lengthscale_spp
  - timescale_spp

***The focus for this test was to investigate perturbations of physics parameters within the Planetary Boundary Layer (PBL) and Land Surface Model (LSM) schemes.***

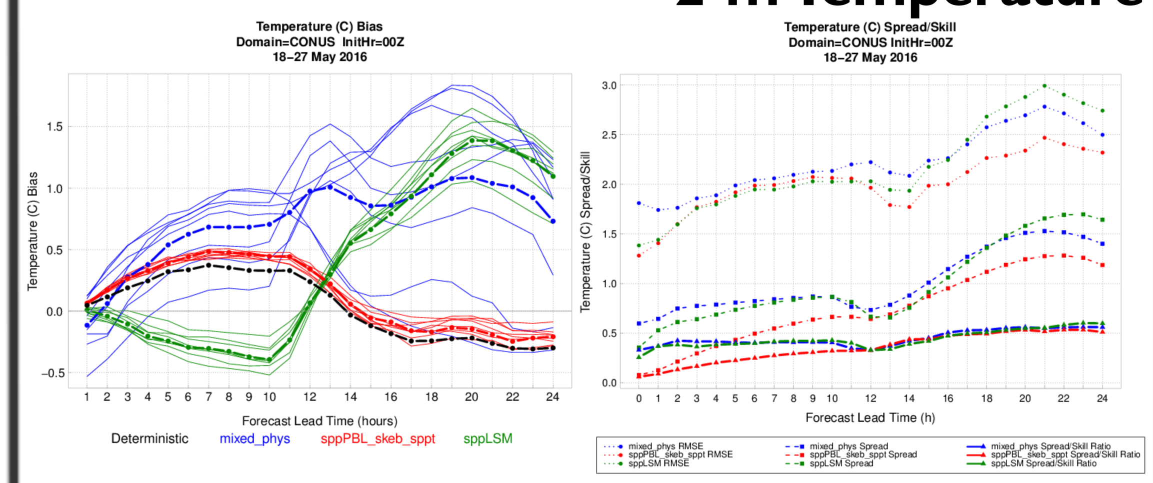
The sensitivity to different values for the temporal and spatial de-correlation lengths was tested and the results are described in the companion paper ***"Stochastic approaches in a High Resolution Rapid Refresh Ensemble. Part I: Sensitivity testing"*** by Jankov et al.



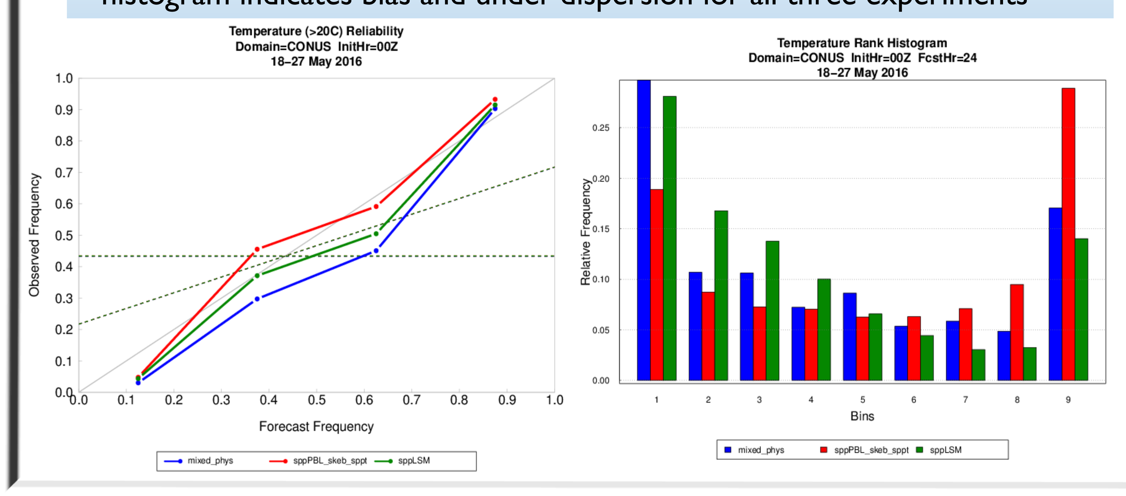
Stochastic perturbation pattern with 150 km spatial de-correlation

- **Verification Comparison:**
  Verification against point and gridded observations was conducted using the Model Evaluation Tools (MET) software package and the performance of several stochastic approaches (sppLSM and sppPBL) was compared to a baseline multi-physics cold-start ensemble. The multi_phys baseline included a mix of PBL (ACM2, MYJ, MYNN, YSU) and LSM (Noah, RUC) options.

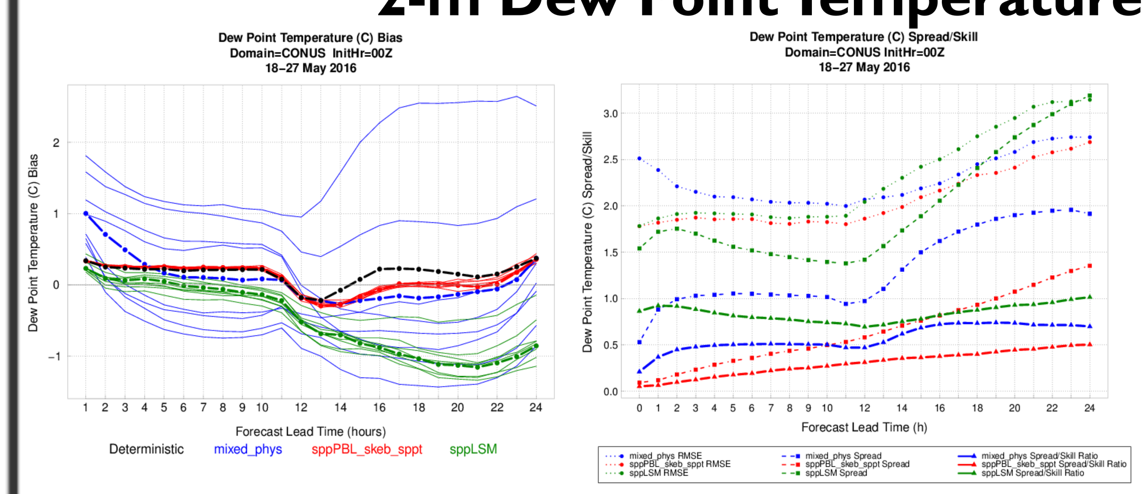
## HRRR Ensemble Results
## 2-m Temperature



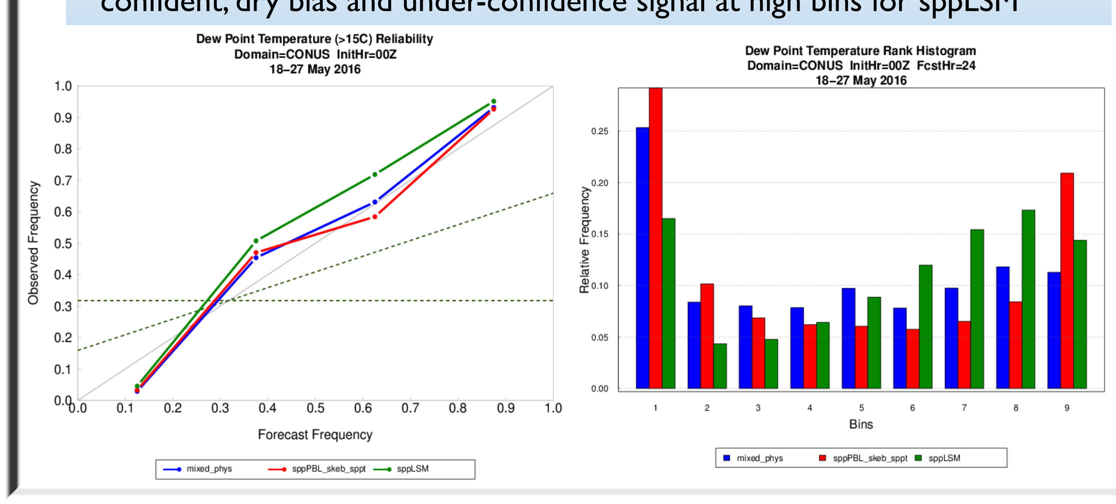
- sppLSM exhibits a high bias during the daytime hours; sppLSM provides similar spread-skill ratio compared to mixed_phys
- sppLSM and sppPBL are more reliable compared to mixed_phys; rank histogram indicates bias and under-dispersion for all three experiments



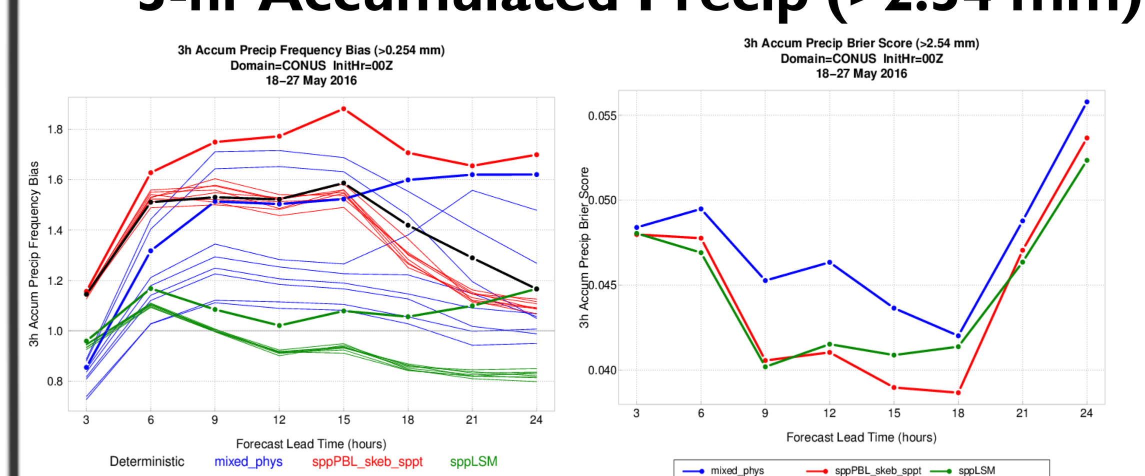
## HRRR Ensemble Results
## 2-m Dew Point Temperature



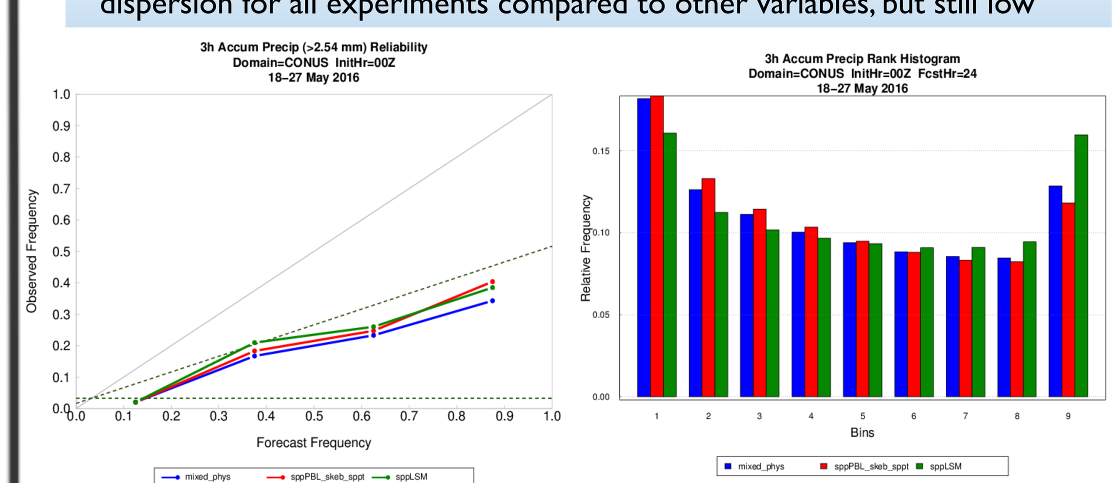
- sppLSM exhibits a dry bias during the daytime hours; sppLSM has the best spread-skill ratio throughout the forecast period
- sppPBL and mixed_phys have better reliability, with sppLSM slightly under-confident; dry bias and under-confidence signal at high bins for sppLSM



## HRRR Ensemble Results
## 3-hr Accumulated Precip (>2.54 mm)



- sppLSM has lowest frequency bias; best BS noted for sppLSM and sppPBL overnight/early morning with decrease in skill during the afternoon/evening
- All 3 experiments exhibit poor reliability with large over-confidence; better dispersion for all experiments compared to other variables, but still low



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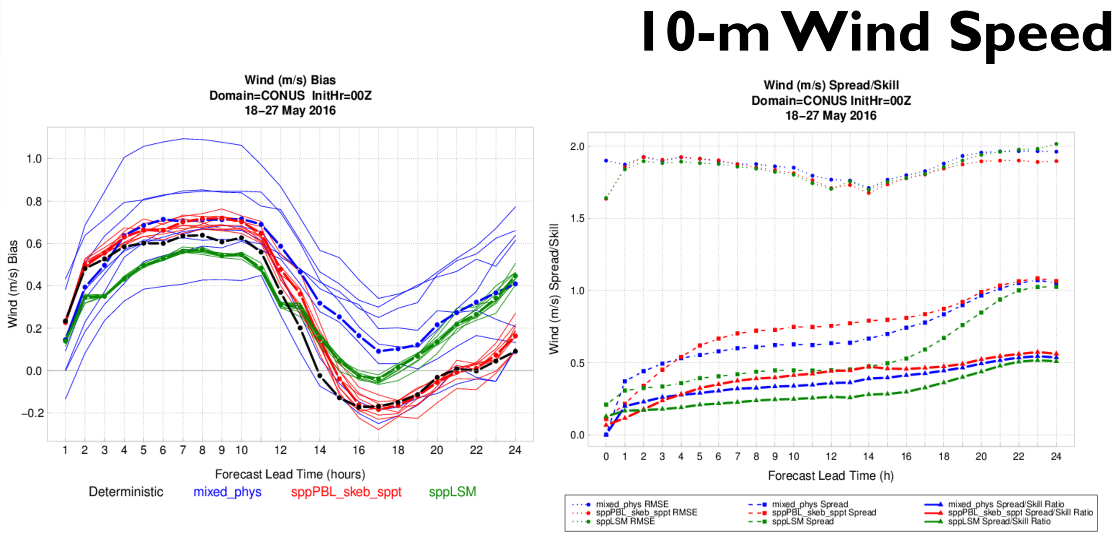
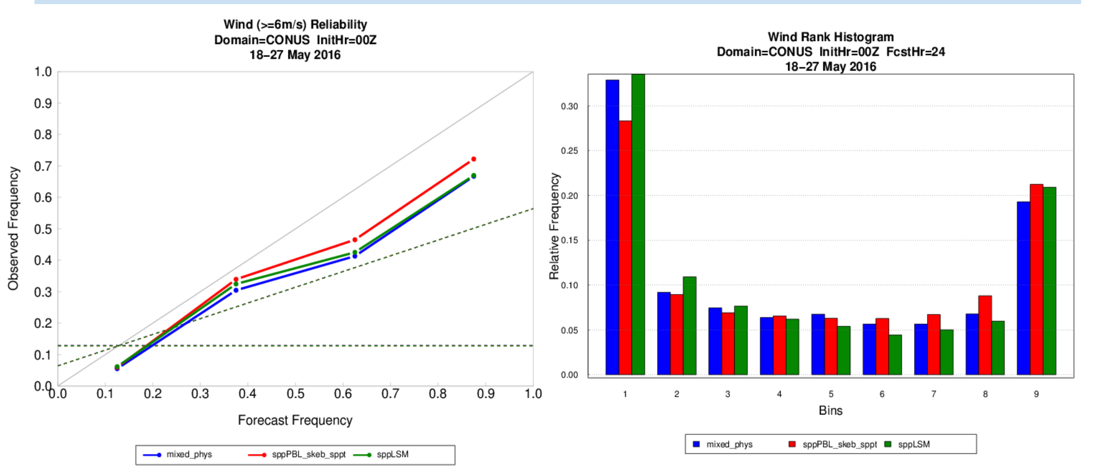
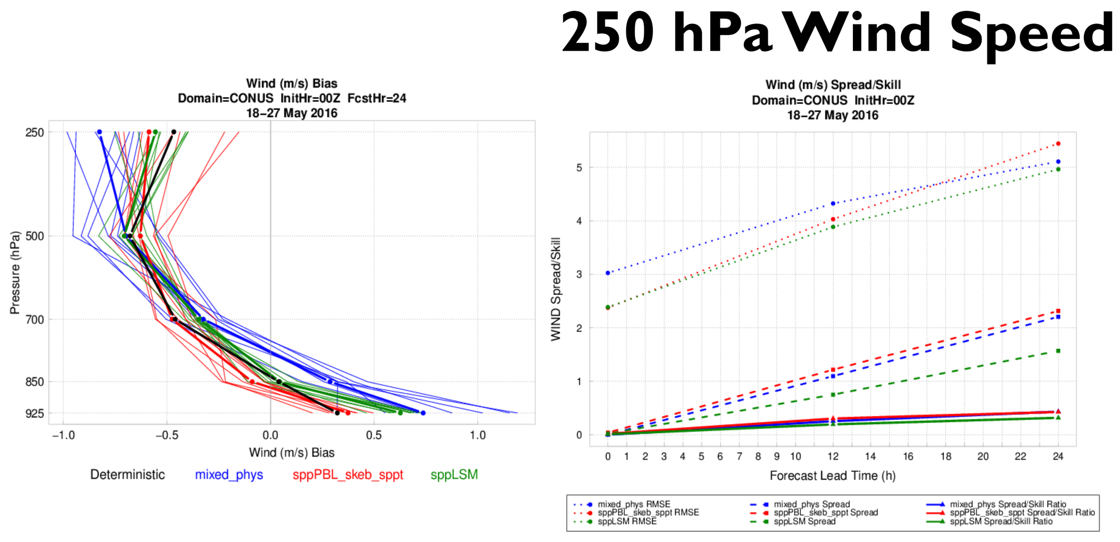
## HRRR Ensemble Results
## 10-m Wind Speed



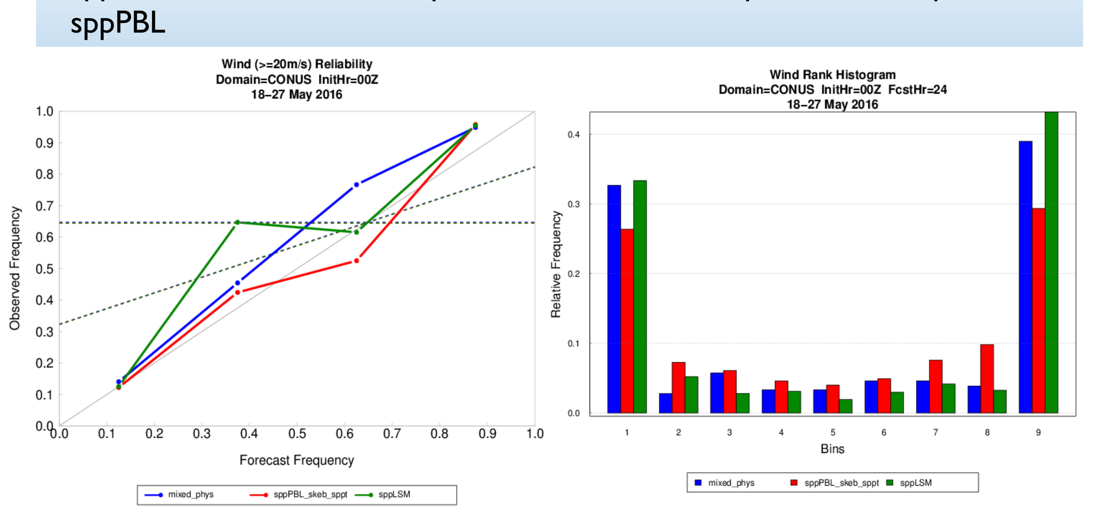
- All experiments have a large high bias overnight, decreasing during the daytime; sppPBL has better spread-skill ratio due to larger spread
- While all experiments are over-confident, sppPBL has highest reliability; all three experiments are under-dispersive



## HRRR Ensemble Results
## 250 hPa Wind Speed



- sppPBL generally smaller bias than mixed_phys near surface and aloft; spread-skill ratio similar for all experiments at 250 hPa
- sppPBL most reliable; all experiments are under-dispersive but improved for sppPBL



## Summary

The testing presented here focused on stochastic perturbations of soil moisture at the initial time and PBL perturbations (mixing length, aerodynamic roughness length, thermal/moisture roughness length, mass fluxes, Prandtl number, and cloud fraction) applied throughout the forecast to assess the impact on spread for near-surface and upper-level variables. In general, results indicated that the:

- **sppLSM experiment impacts low-level temperature and dew point temperature; however, a bias is noted in these fields during the daytime hours when these perturbations are employed**
- **sppPBL (including SPPT and SKEB) experiment has the largest impact on winds, both near-surface (likely due to the SPP approach) and aloft (likely due to the SPPT and SKEB methods)**

## Future Work

- Continue testing LSM and PBL perturbations
- Apply perturbations to a variety of microphysics parameters
- Combine LSM, PBL, and microphysics SPP approaches, along with SKEB and/or SPPT techniques

**Ultimately, the goal is to further tune these perturbations to construct a HRRR-based stochastic physics ensemble at convection-allowing scales with optimal performance for all forecast variables and levels that is comparable or beats the multi-physics/multi-core High Resolution Ensemble Forecast version 2 (HREFv2) performance.**

## Acknowledgments

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