Assessing model uncertainty through stochastic parameter perturbations within the Thompson microphysics scheme as part of a High Resolution Rapid Refresh ensemble

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Motivation

- Model-related uncertainty often addressed by multi-dynamic cores, physics suites, or a combination
  - May produce desirable results, but does have deficiencies and is resource-intensive
- As the US moves to a sustainable unified operational forecasting system, alternative options for creating spread among members is desirable
  - Stochastic perturbation schemes include
    - Stochastic-Kinetic Energy Backscatter (SKEB)
    - Stochastic Perturbations of Physics Tendencies (SPPT)
    - Stochastic Parameter Perturbations (SPP)

Represent the effect of unresolved subgrid-scale variability and added *a posteriori*

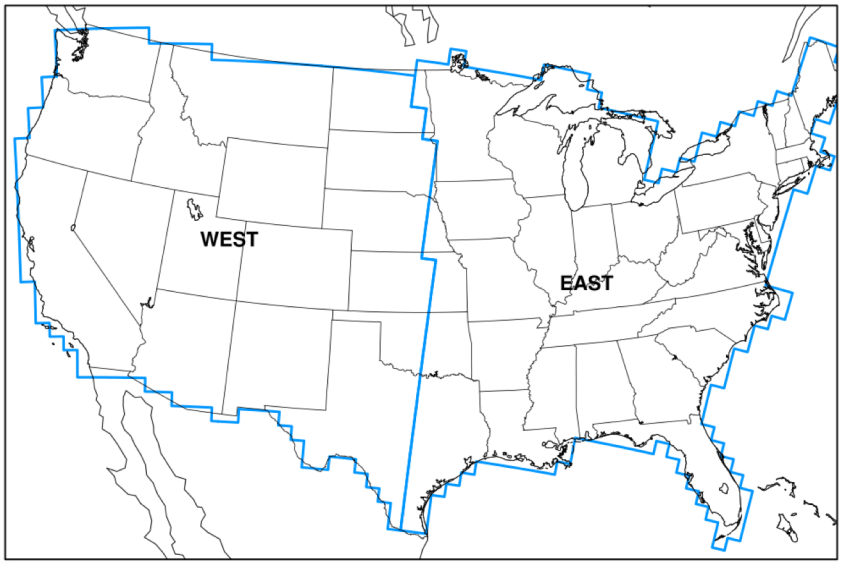
Targets parameter uncertainty in the physical parameterization scheme directly

Experiment Design

- **Model:** WRFv3.9.1+
- **Test period:** 2 May–31 Jul 2017 00 UTC initializations (every other day); 36 h forecasts

  1 –31 Dec 2016 00 UTC initializations daily; 36 h forecasts
- **Model domain:** 3-km grid spacing, CONUS domain
- **Members:** 1 control member (no SPP) and 7 perturbed members
- **Observations:** RAP BUFR point observations (sfc and upper-air temp, dew point, and wind speed); Gridded Multi-Radar/Multi-Sensor composite reflectivity and precipitation accumulation analyses

Physics Suite (operational HRRR)	
Microphysics	Thompson aerosol-aware*
SW/LW Radiation	RRTMG
Land Surface Model	RUC
Planetary Boundary Layer	MYNN2

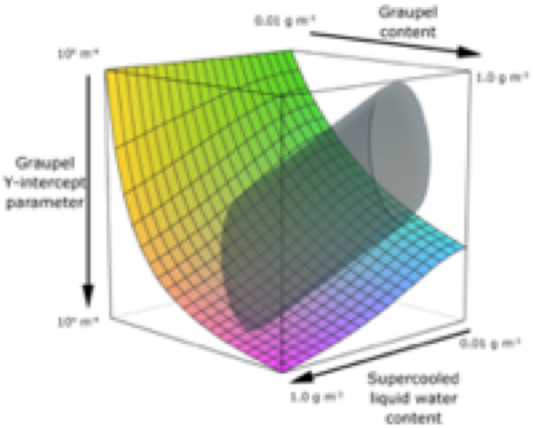


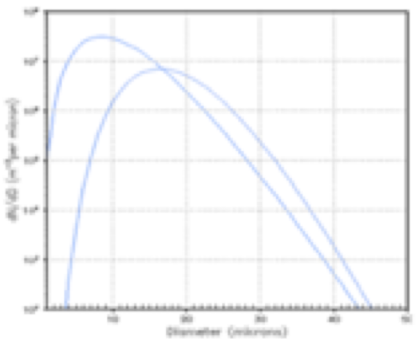
*SPP applied

Experiment Design, cont.

*Please see G. Thompson's poster on Wed afternoon for more details!

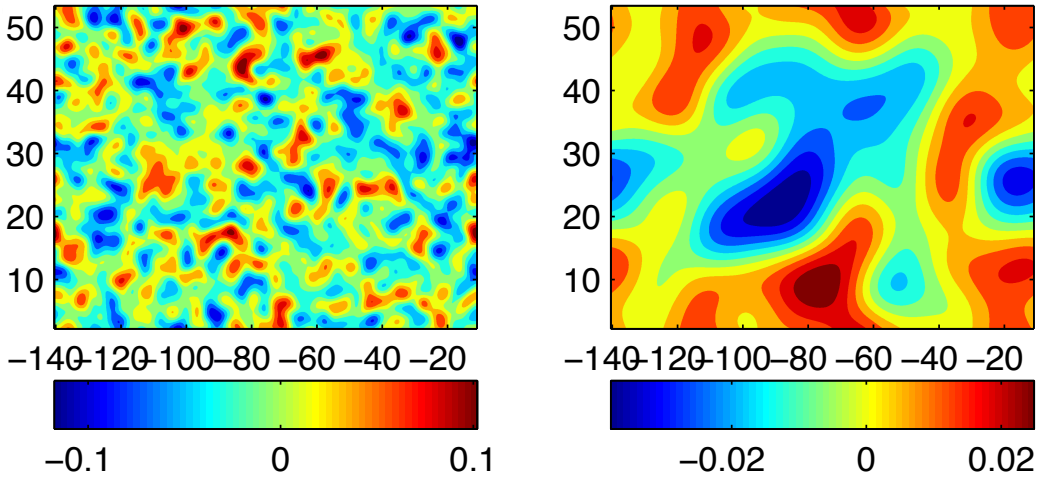
- **SPP technique applied to:**
  - Graupel treatment: Parameters that fundamentally control the size spectra of the graupel/hail hybrid category
  - Cloud water distribution: Value of the shape parameter of the generalized gamma distribution of the cloud water variable
  - Cloud Condensation Nuclei (CCN) activation: Vertical velocity only for the purpose of determining what number of CCN activate based on a look-up table





SPP Pattern Definition

- Spatially and temporally correlated pattern is fully determined by namelist parameters, including:
  - De-correlation length scale
  - De-correlation time scale
  - Gridpoint standard deviation (maximum constrained)
- Experiments run with 100 km length scale and 2 h time scale



Example SPP patterns at varying length scales (20 and 150 km)

Traditional and Ensemble Verification

What is the impact on ensemble spread with SPP applied to three parameters in the Thompson microphysics scheme?

Focus for this presentation:

Test period: Warm season

Fields:

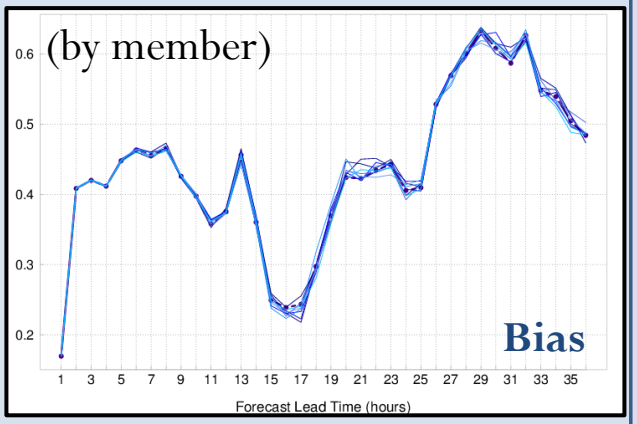
Surface temperature, dew point temperature, and wind speed

Accumulated precipitation ≥2.54 mm

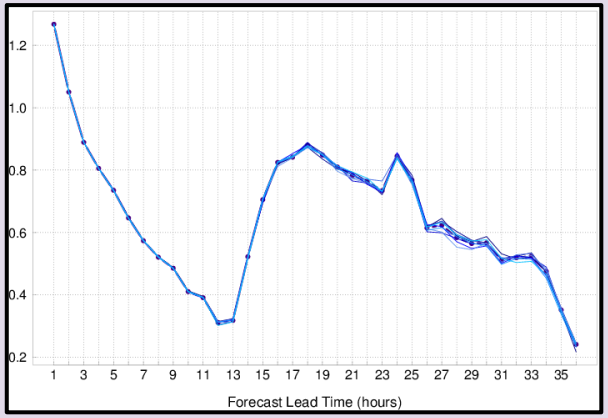
Verification domain: East

Surface Analysis – Bias, Spread/Skill

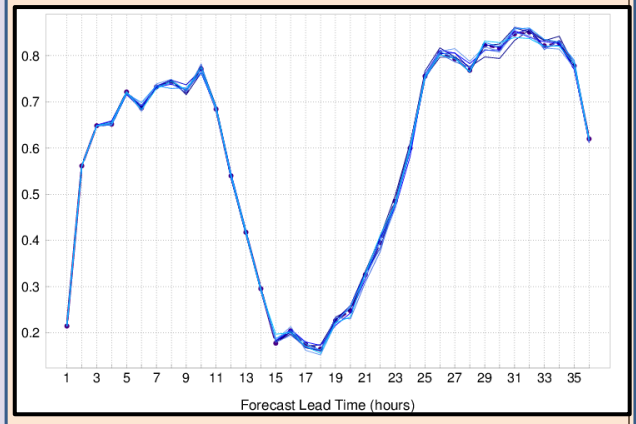
2m temperature



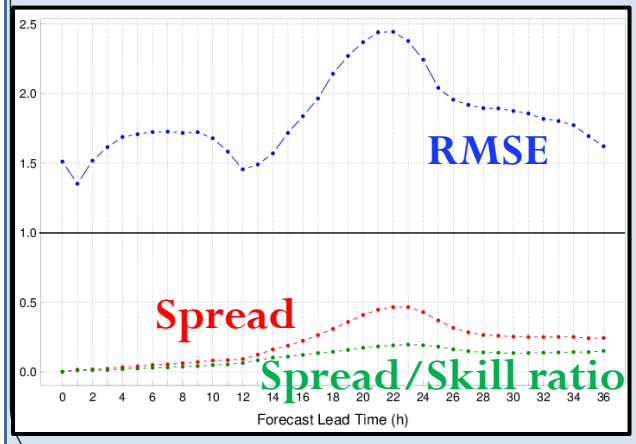
2m dew point temperature

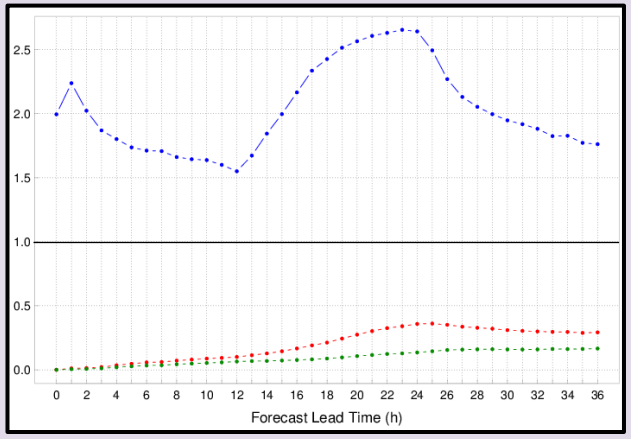


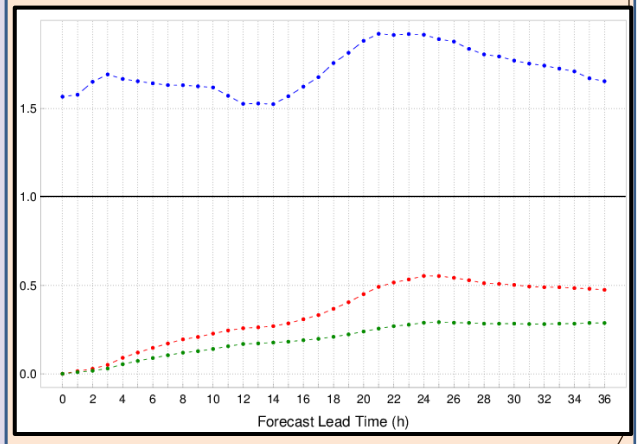
10m wind speed



- Positive bias for each; diurnal signal; minimal variability among members
- Spread increases with lead time faster than RMSE, resulting in better ratio

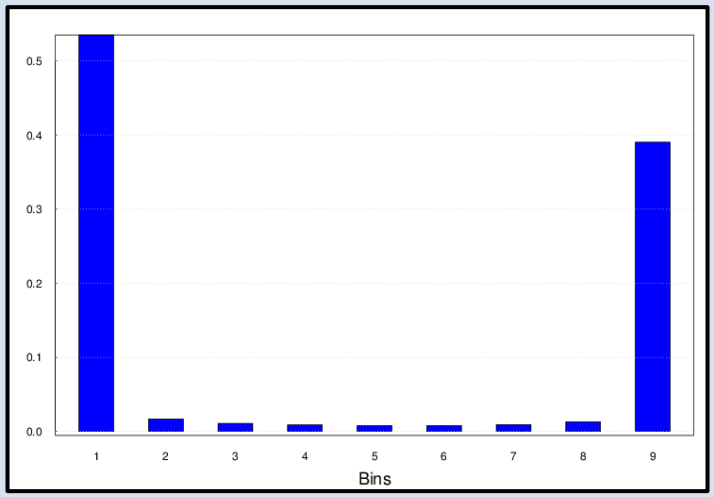






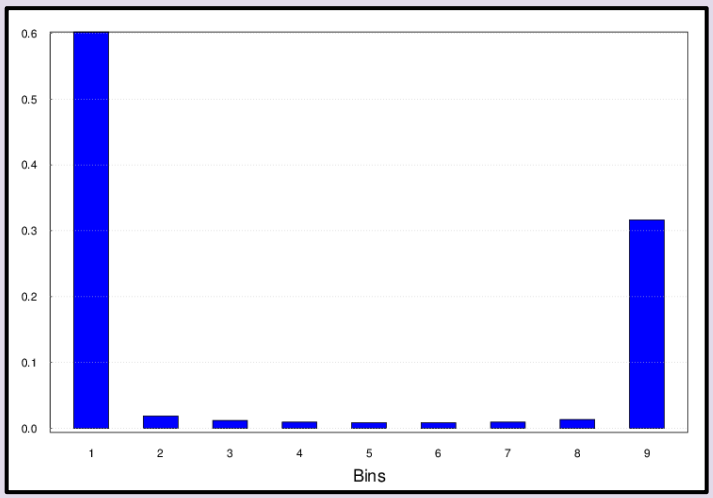
Surface Analysis – Rank Histogram

2m temperature



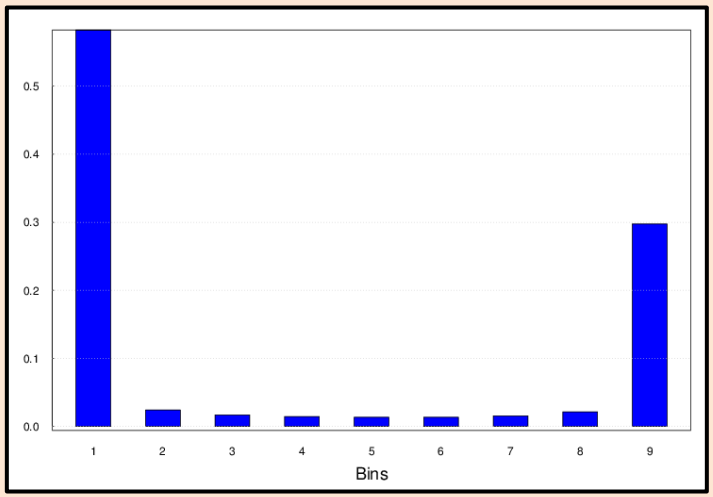
Forecast hrs 6-30

2m dew point temperature



- U-shaped histogram denotes under-dispersive ensemble for all variables

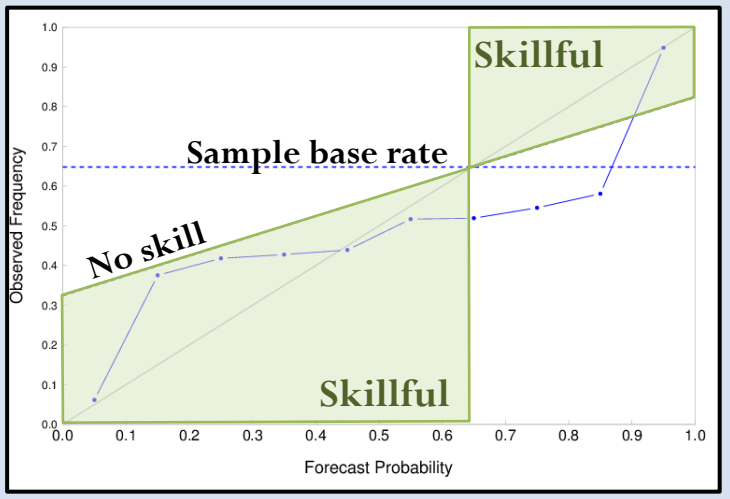
10m wind speed



- Indication of high bias (esp for dew point, wind speed) with more obs in first compared to last bin

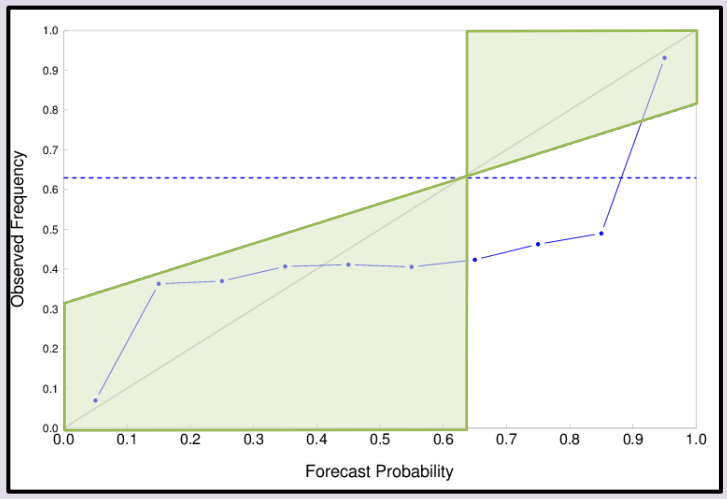
Surface Analysis – Reliability

2m temperature ≥ 20 °C



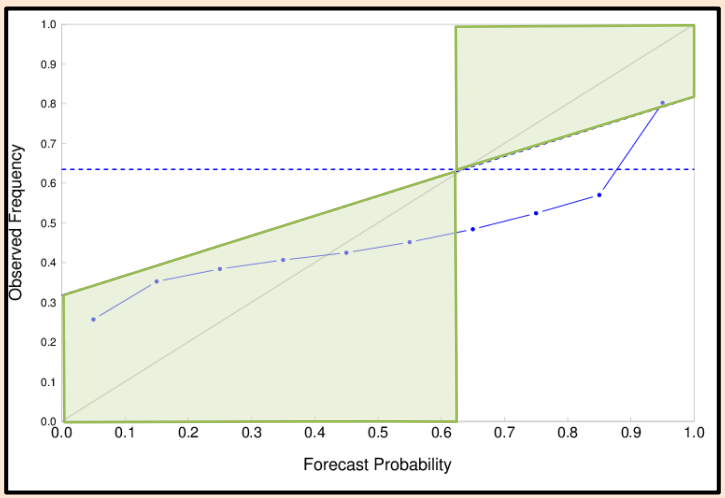
Forecast hrs 6-30

2m dew point temperature ≥ 15 °C



- Positive slope: As forecast probability increases, so does the observed frequency

10m wind speed ≥ 2 ms^{-1}

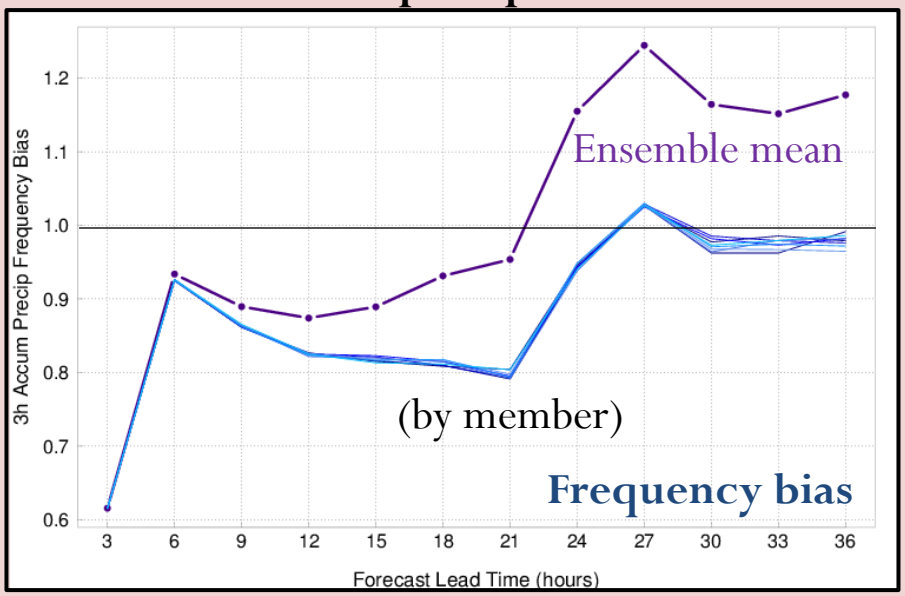


- Under-forecast low probabilities, over-forecast high probabilities: Common with under-dispersion

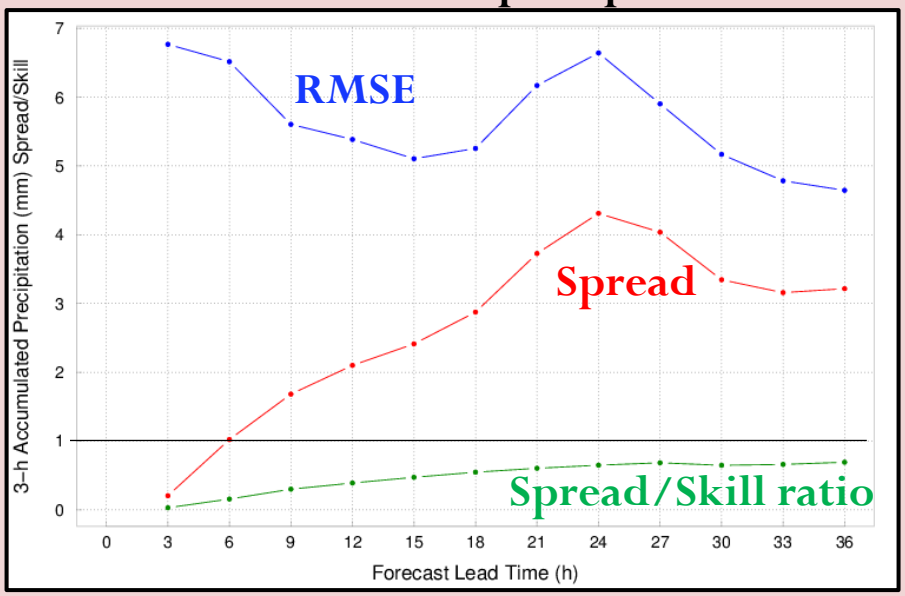
*Thresholds selected to yield sample climatology of ~ 60%

Precipitation Analysis – Bias, Spread/Skill

3h accum precip ≥ 2.54 mm



3h accum precip

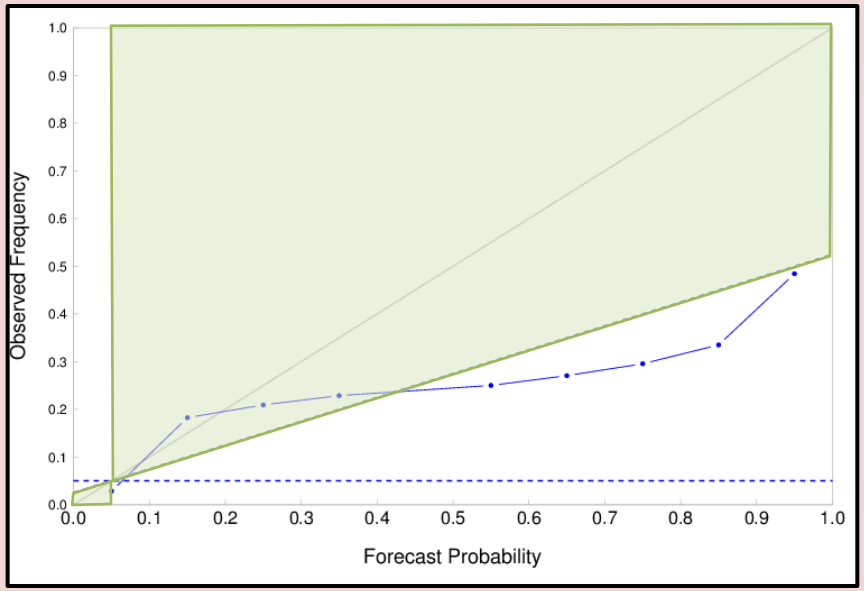


- General low to neutral bias throughout the forecast
- Some variability in the bias values by member late in the period

- Spread quickly increases with lead time
- Large portion of RMSE being accounted for through spread produced by MP perturbations

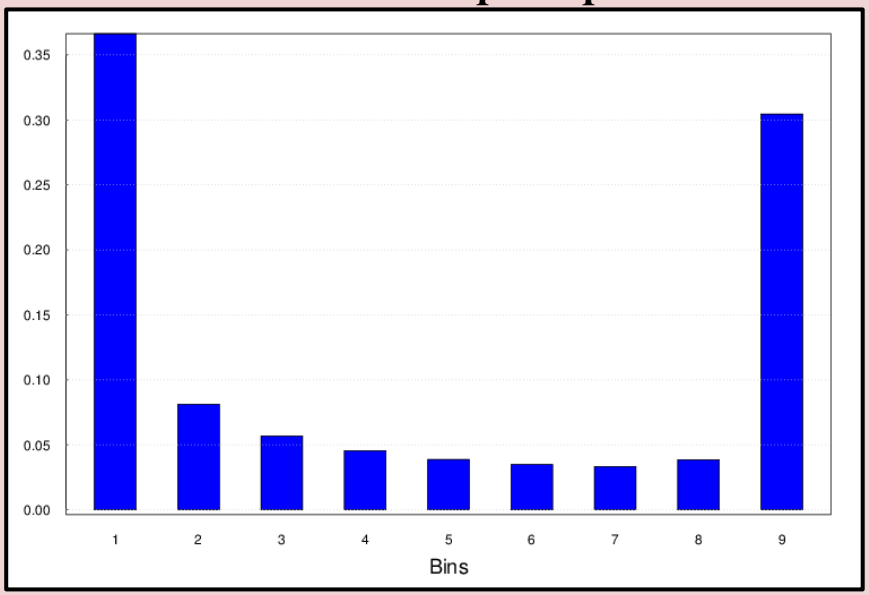
Precip Analysis – Reliability, Rank Histogram

3h accum precip ≥ 2.54 mm



- Ensemble probabilities not well calibrated
- Tendency to over-forecast the probability of precip occurrence

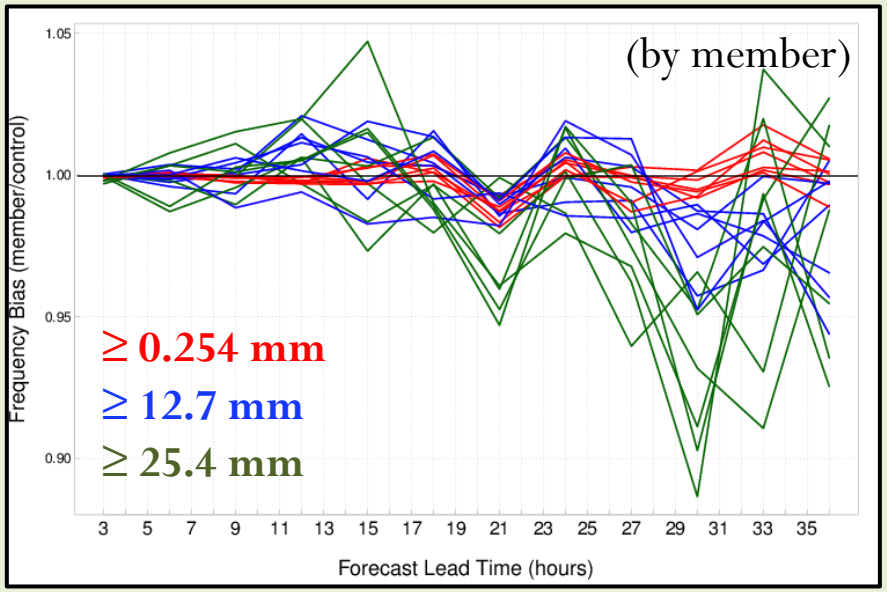
3h accum precip



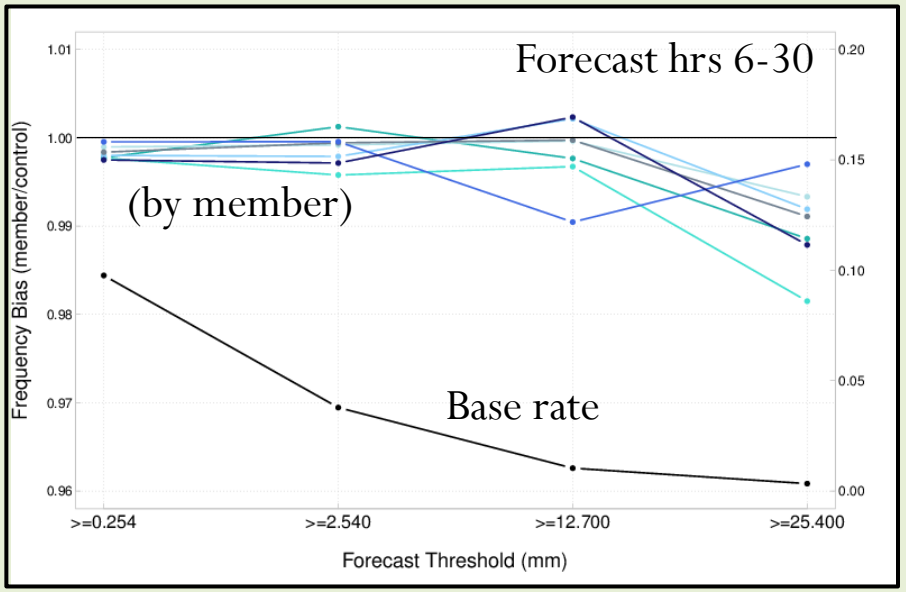
- Ensemble is under-dispersive
- Additional spread in middle bins compared to surface temp, dew point, and wind speed

Comparison to Control – Frequency Bias

3h accum precip



3h accum precip



- Similar spatial coverage (within 2-10%)
- Differences grow with lead time
- Differences grow with threshold (though the base rate is low)

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Summary

- When evaluating deterministic and probabilistic performance of temp, dew point, and wind speed there is little impact on bias with a small increase in spread with forecast lead time
- A significant increase in the spread/skill ratio with lead time was noted for 3-h accumulated precipitation
- To a large extent, ensemble members with MP perturbations replicate the precipitation coverage in the control
- ***Perturbations to parameters in the MP scheme do provide additional spread for targeted variables and should be used in concert with perturbations to other physics parameterizations to provide adequate overall spread***

A detailed final report can be found at:
https://dtcenter.org/eval/ensembles/stoch/

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