Stochastic Approaches within the High-Resolution Rapid Refresh Ensemble

Isidora Jankov

CIRA/Colorado State University affiliated with NOAA/ESRL/GSD
Evan Kalina, Joseph Olson, Jeff Beck, David Dowell, Trevor Alcott, Judith Berner and Curtis Alexander

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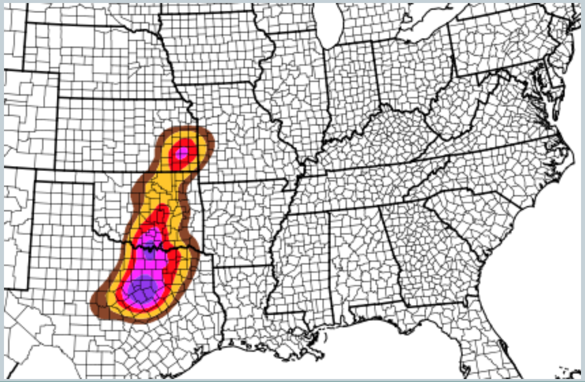
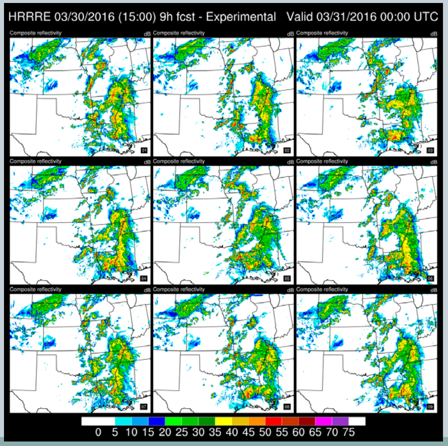
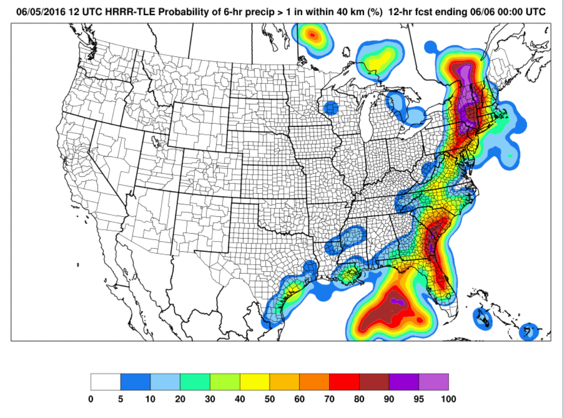
EMC Collaborator: Jacob Carley





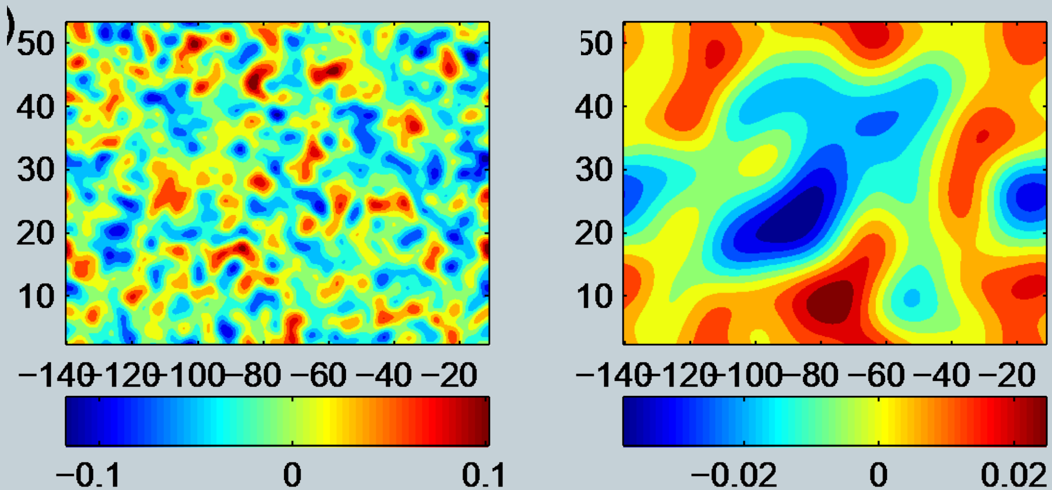


Motivation

- Model uncertainty usually addressed by use of multi-dynamic core and/or multi-physics approaches
- Issues with mixed-physics approaches
  - Maintenance
  - Inconsistent ensemble system (some schemes closer related than others)
  - Each member has a unique climatology and mean error
- NOAA/NCEP moving toward a more simplified/unified operational system
  - Single dynamic core
  - Single physics suite with stochastic perturbations?
- Stochastic approaches of interest:
  - Stochastic Kinetic Energy Backscatter (SKEB)
  - Stochastic Perturbation of Physics Tendencies (SPPT)
  - Stochastically Perturbed Parameterizations (SPP)

SPP

- **Stochastically Perturbed Parameterizations (SPP):** Perturbs parameters/variables 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.
- Spatially and temporally correlated patterns applied to a parameter or a set of parameters within one or more physics schemes.
- 150km spatial and 6-hr temporal de-correlations used



An example of 20km and 150km spatial de-correlation lengths from left to right, respectively

Jankov et al. Stochastically Perturbed Parameterizations in a HRRR-Based Ensemble, accepted for publication in MWR.

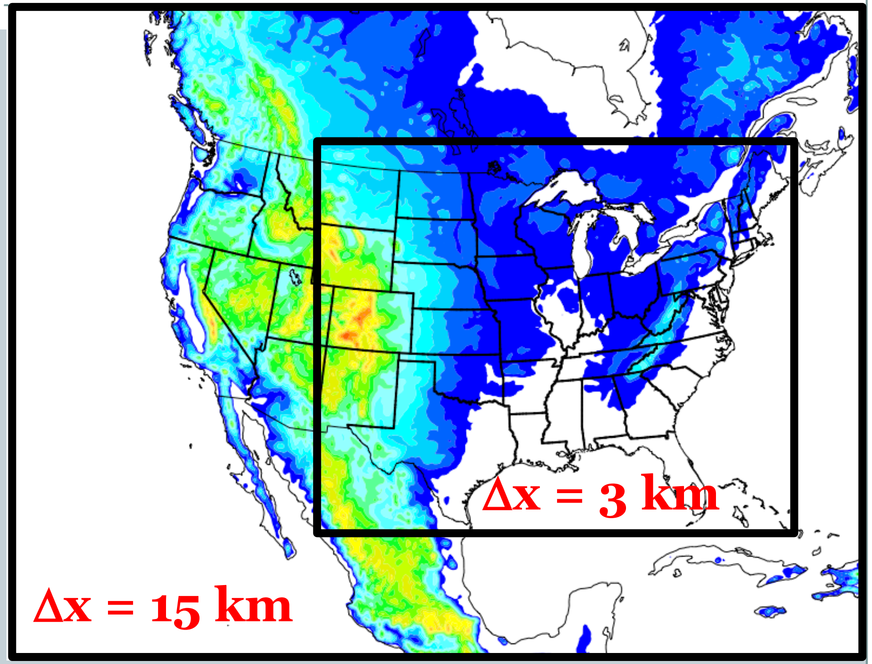
2018 HRRRE Analysis and Forecast System

Nested 15-km and 3-km domains

36 members initialized at 0300 UTC
- Initial mean from GFS (atmos.) and RAP-HRRR (soil)
- Atmospheric perturbations from GFS ensemble (GDAS)

Hourly cycling with EnKF DA
- 0300 – 0000 UTC (21 hours)
- Conventional observations both domains
- Reflectivity observations 3-km domain only
- Analysis variables: U, V, PH, T, MU, QVAPOR, QCLOUD, QICE, QRAIN, QSNOW
- BC perturbations, posterior inflation

Forecasts: 9-members some out to 48 and some 18 forecast hours

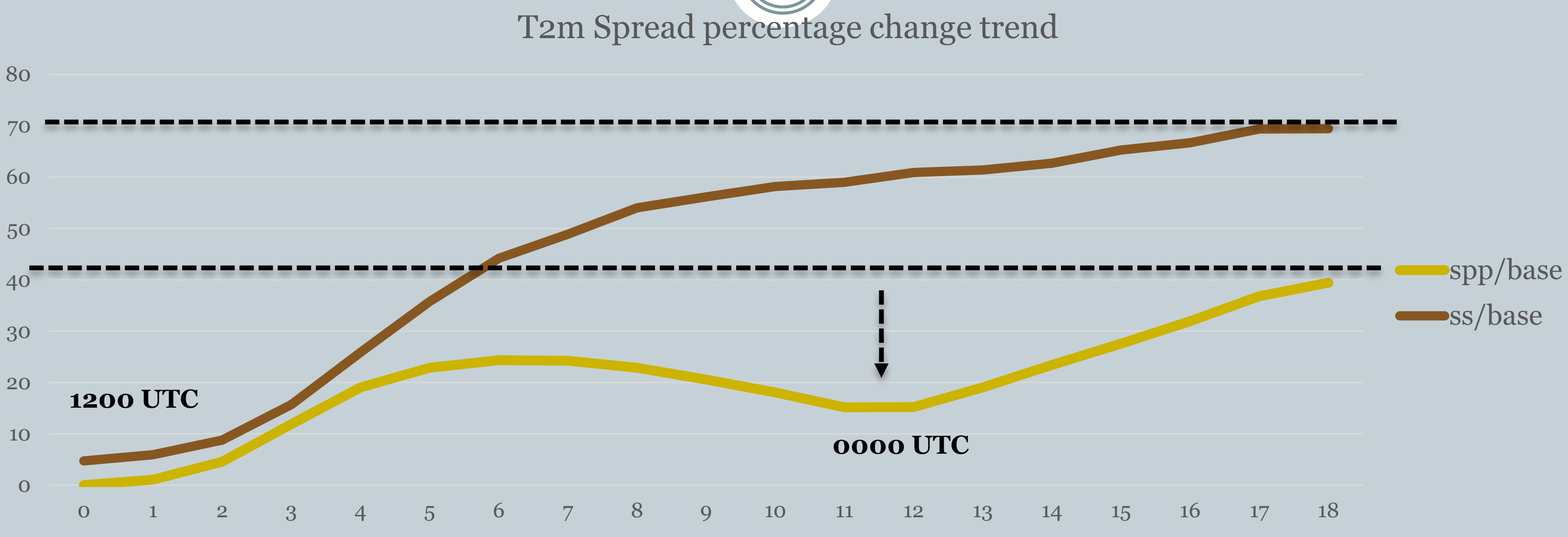


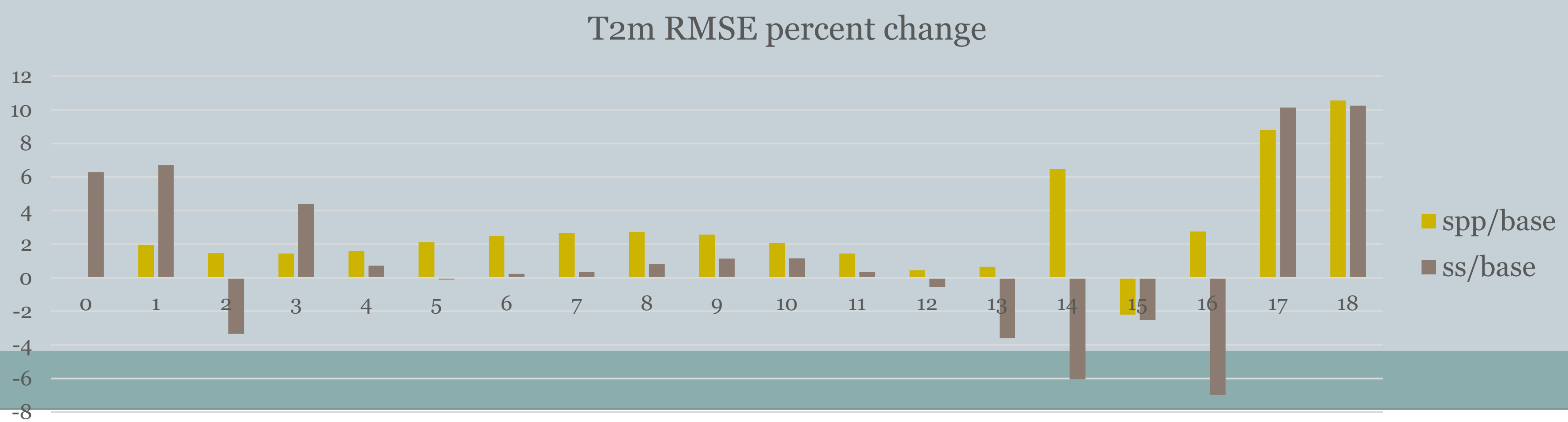
HRRRE Sources of spread:
- IC perturbations from 36 GDAS members
- Random BC perturbations
- Soil moisture perturbations
- Hourly relaxation to prior spread after EnKF analysis

HRRRE Experiment Design

- Retrospective runs (5 cases: late September and early October)
- 1200 UTC initializations and 18hr lead times
- Improved computational efficiency for stochastic approaches within WRF-ARW (~5% additional cost)
- SPP included in more schemes:
  - MYNN PBL
    - Mixing length, roughness lengths, cloud fraction, Prandtl number, exchange fluxes
  - RUC LSM
    - Vegetation Fraction, Soil Moisture, Albedo, Emissivity
  - Thompson Microphysics
    - Intercept and shape parameters for graupel and cloud water distribution
    - Level of supersaturation at which aerosols activate
    - Mass diameter relationship for ice crystals
  - RRTMG SW
    - Cloud droplet effective radii
- Focus on surface variables (2-m T, 2-m MR, 10-m Wind and precip.)
- Experiments:
  - **spp** : includes SPP in all schemes
  - **ss**: SKEB + SPPT
  - **all**: SKEB+SPPT+SPP (not included in the discussion)
  - **baseline**: HRRRE with no stochastic
- How spp compares to ss?

2-m Temp. Spread and Error changes compared to the HRRRE baseline





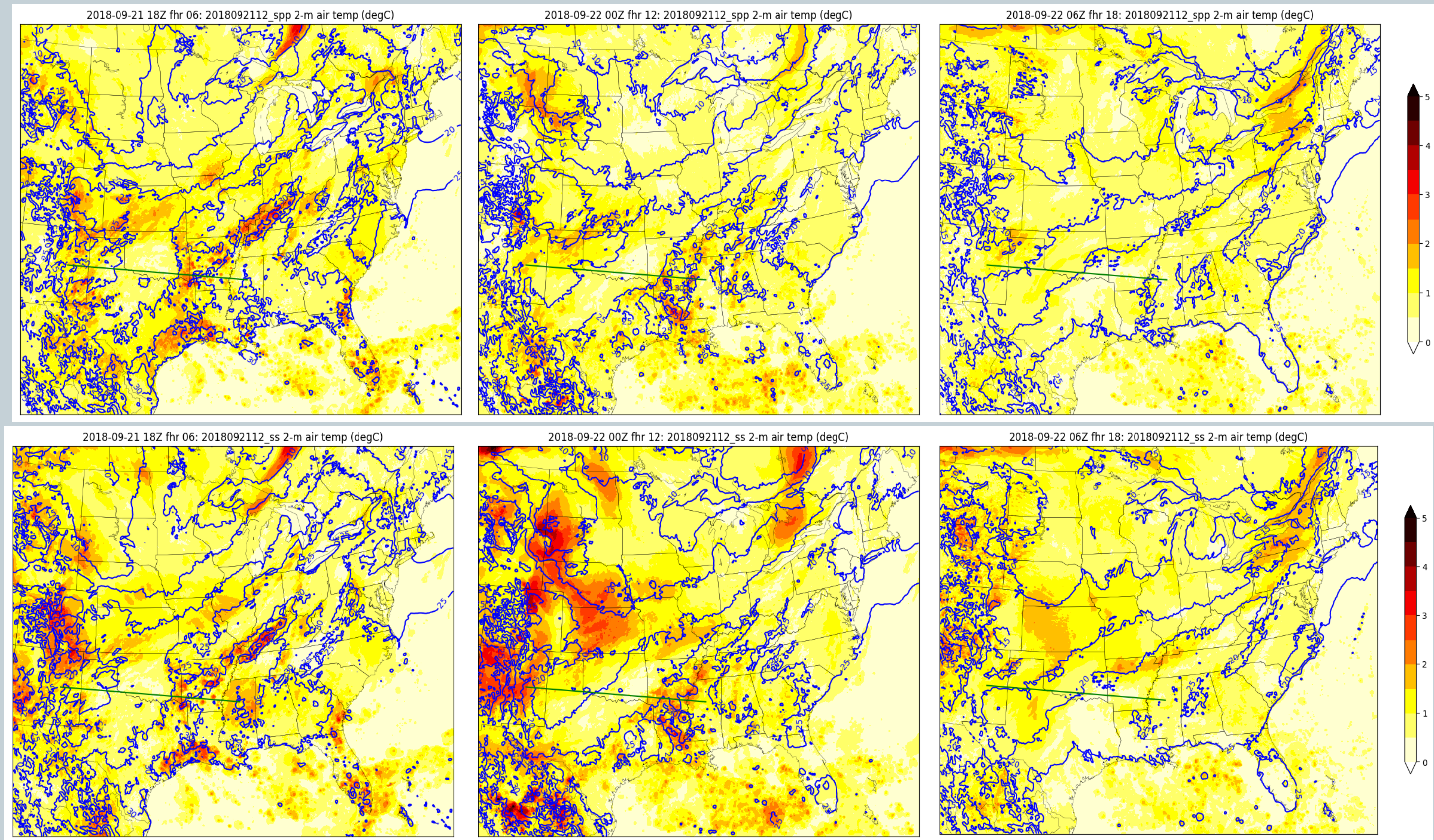
2-m T Spatial Spread Distribution

1800 UTC **0000 UTC** **0600 UTC**

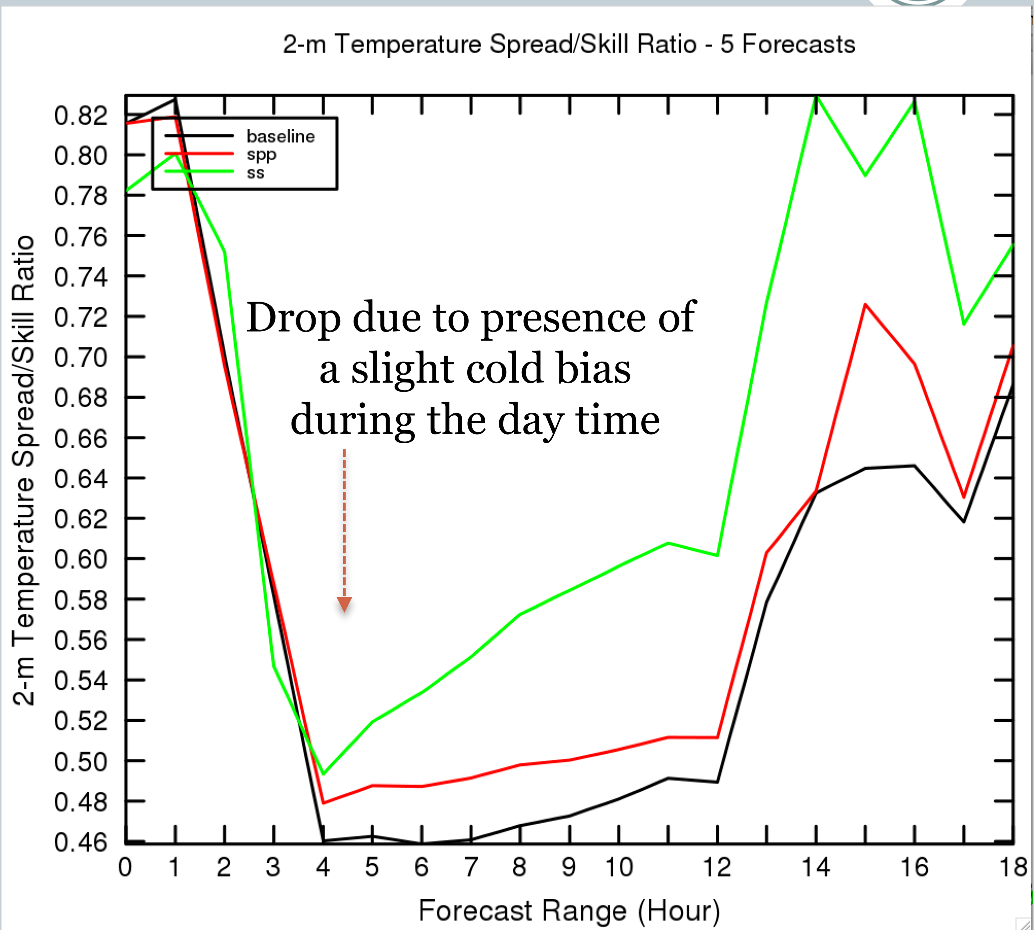
SPP

20180921
1200 UTC Init.

SS

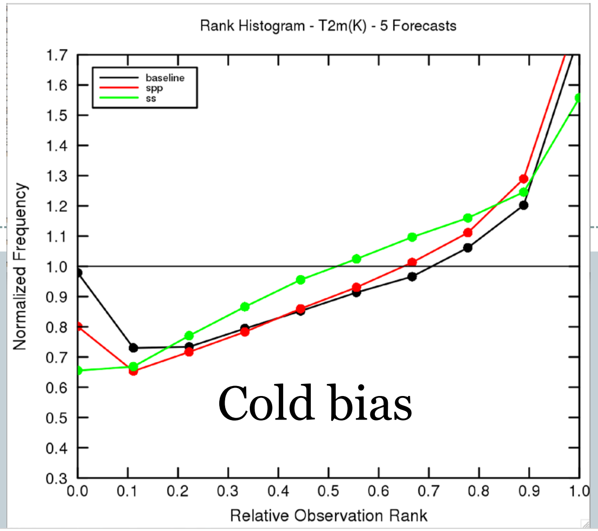


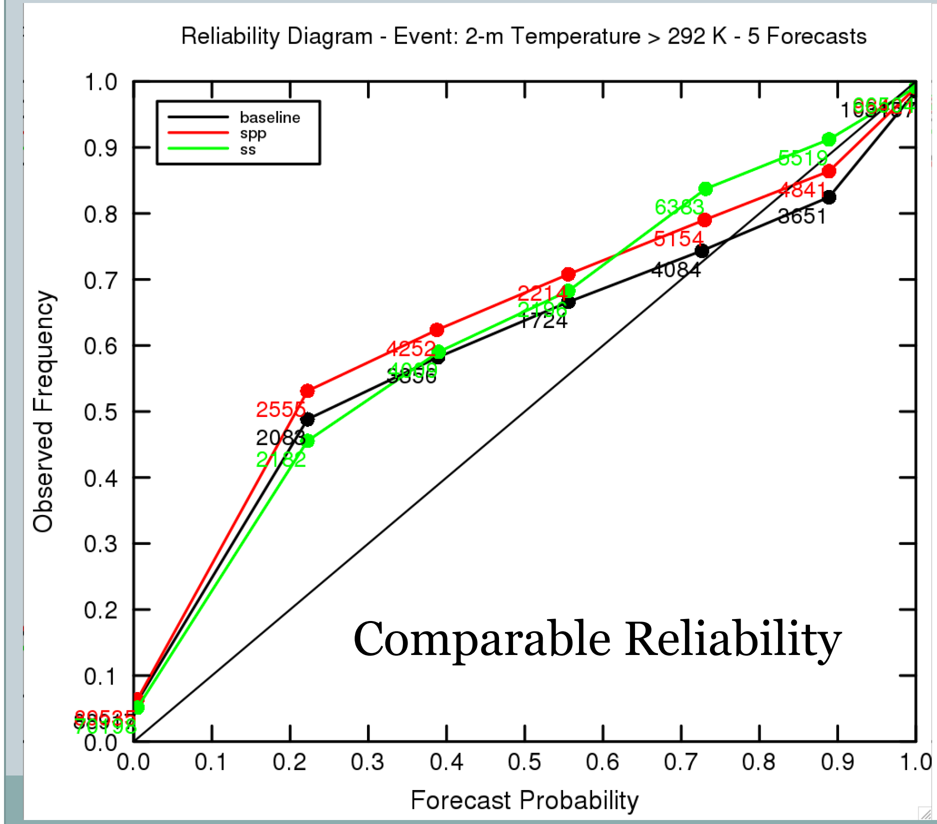
Spread/Skill Ratio 2-m Temp.

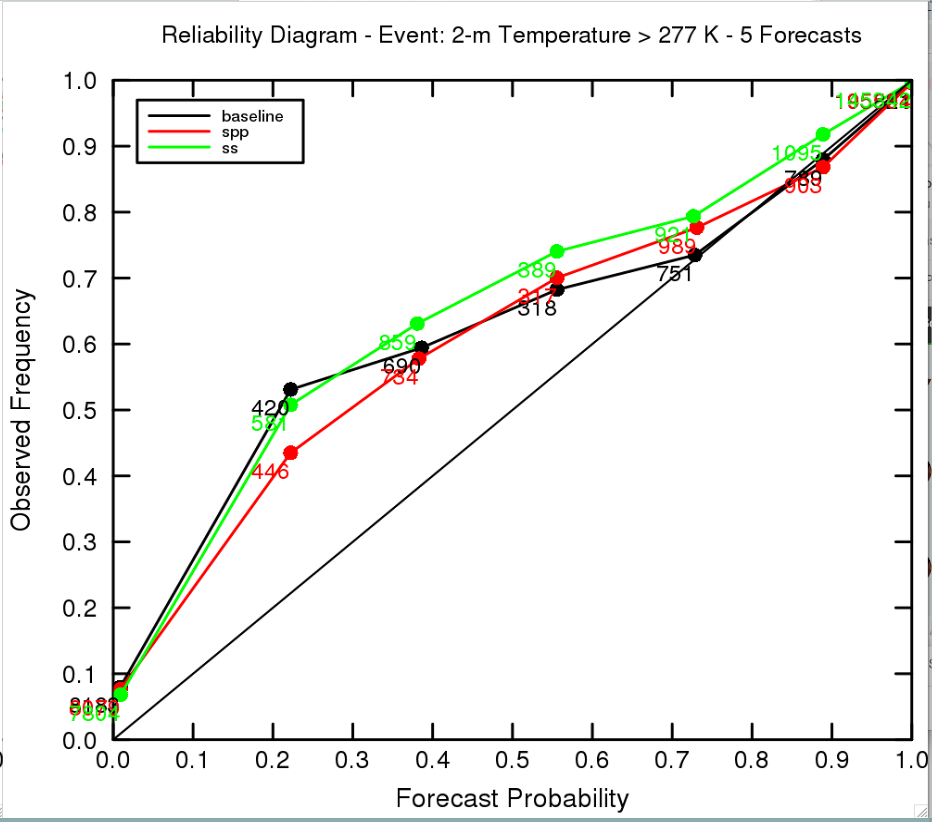


- Initial decrease in spread/skill ratio related to slight cold bias during the day time
- Experiments characterized with higher Spread/skill ratio compared to the baseline
- Improved ratio due to increase in spread
- Perfect value of 1

2-m Temp. Reliability



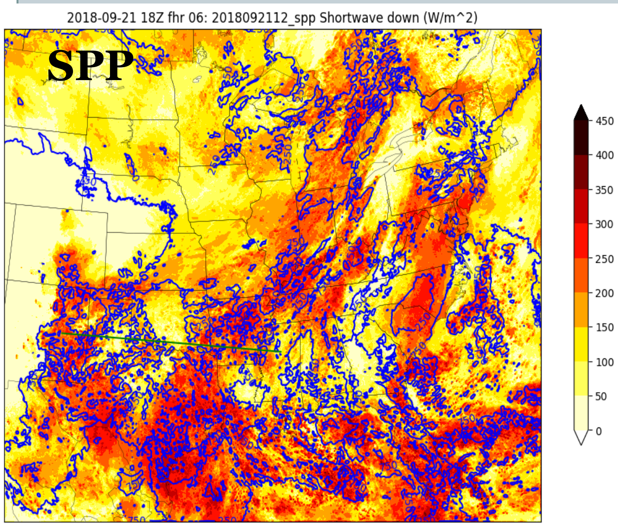


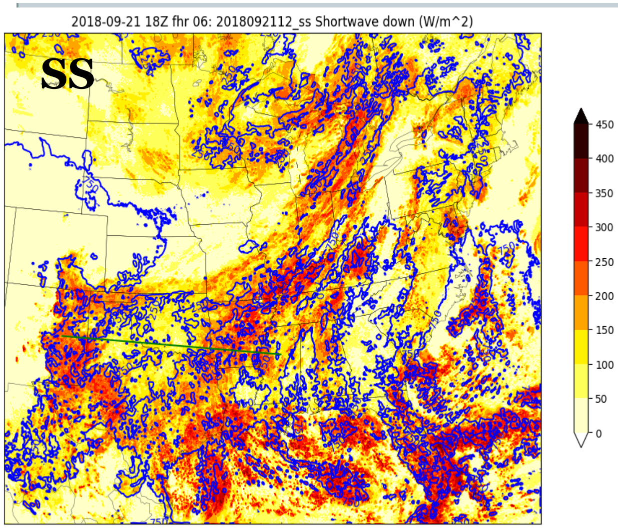


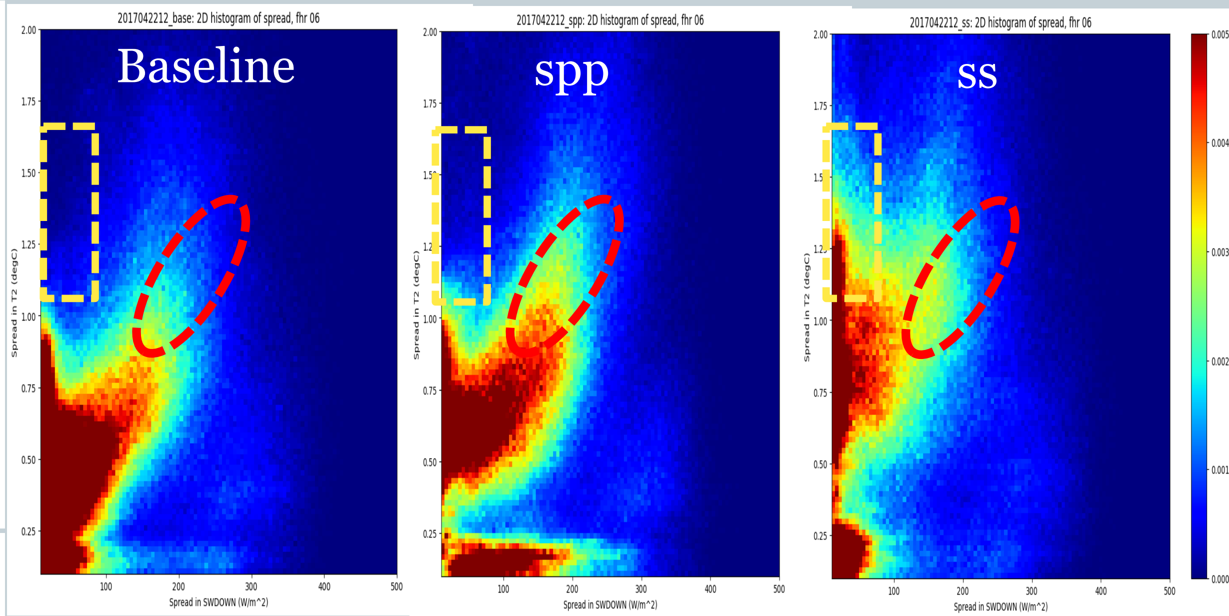
Short-Wave Down & 2-m Temp. Spread

Relationship between spread in 2-m temperature (y-axis) and shortwave down (x-axis) Valid time: 22 April 2017 18 UTC (6-hr forecast)

1800 UTC

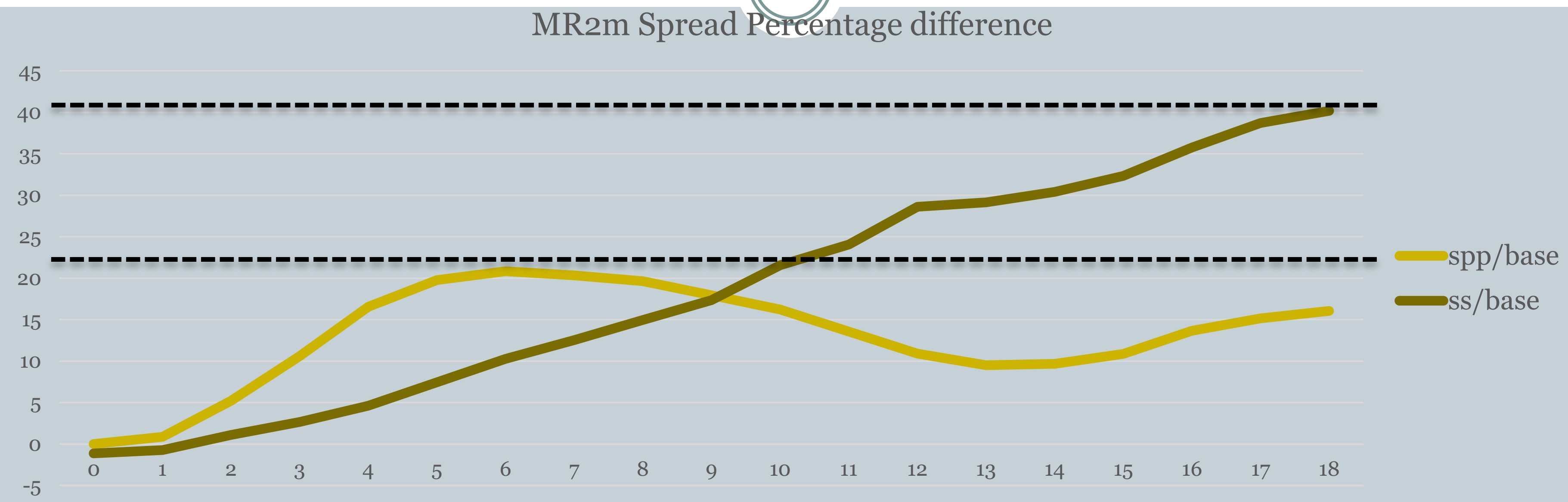


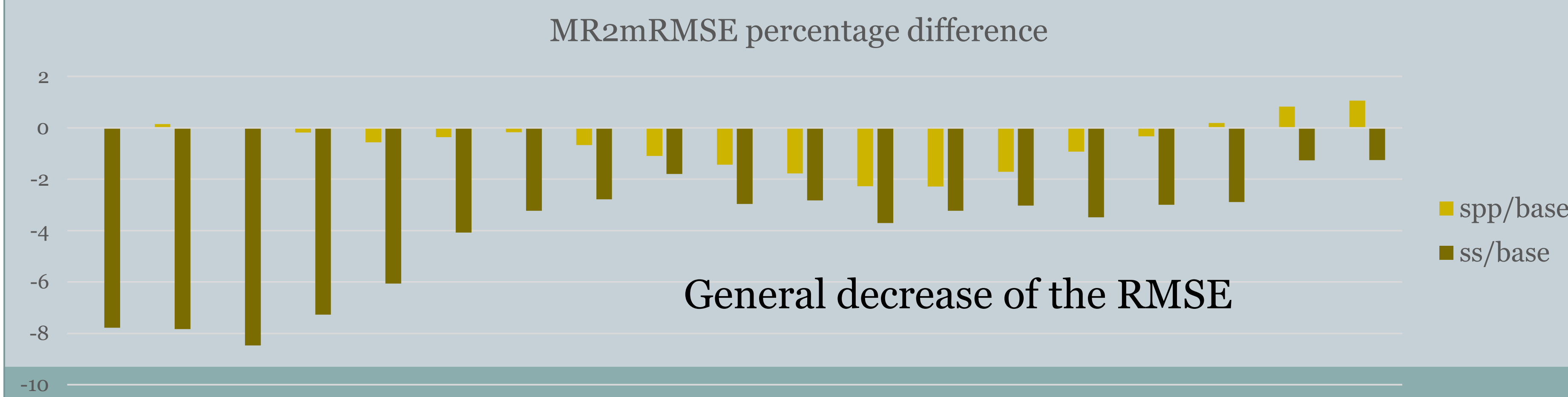




- spp has larger SWD spread compared to baseline & ss
- Number of points in spp with large spread in SWD but not correlated with 2-mT
  - Not enough time to affect 2-m T (6-hr forecast initialized at 1200 UTC)
  - Pattern spin up
- ss has the largest 2-m T spread but not correlated with spread in SWD

2-m MR Spread changes compared to the HRRRE baseline





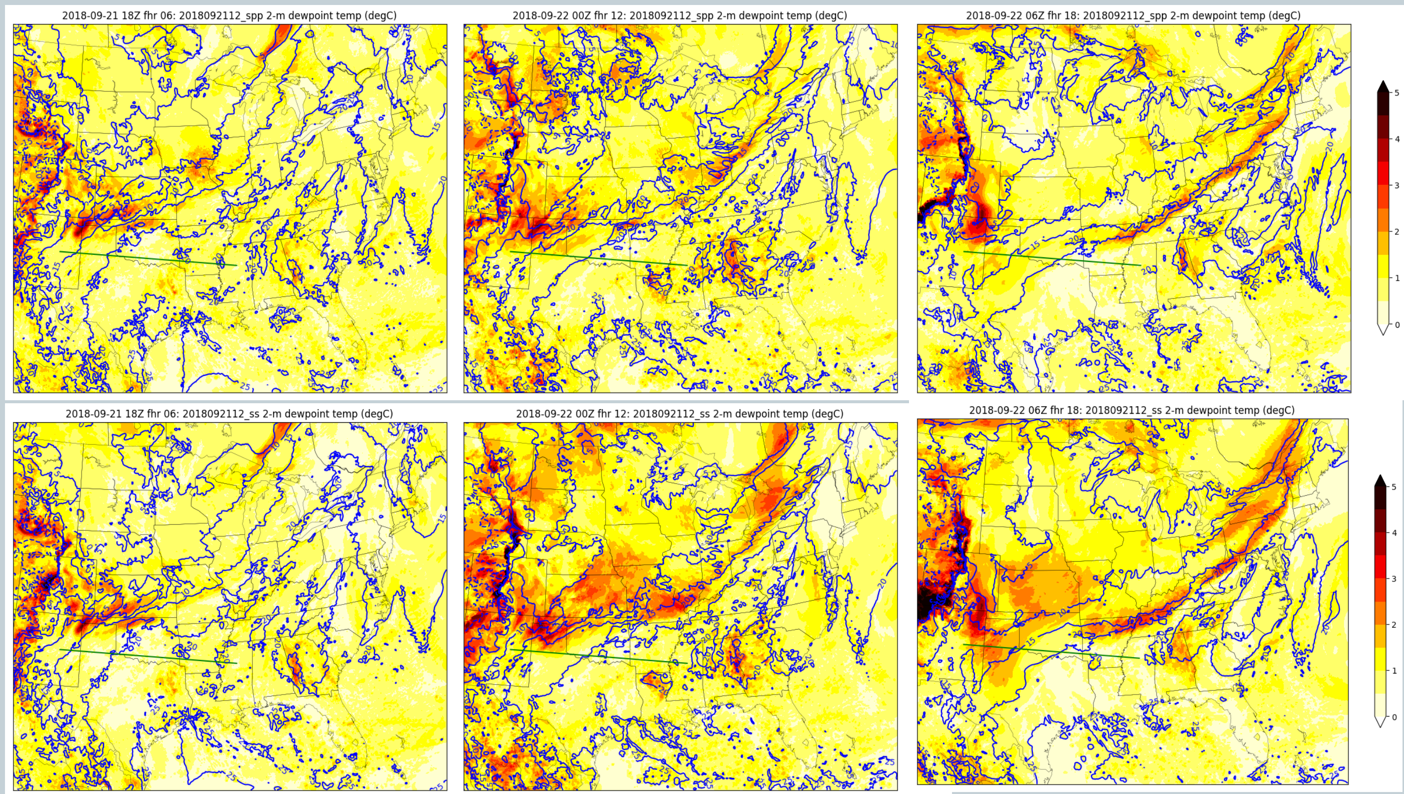
2-m MR Spatial Spread Distribution

1800 UTC | 0000 UTC | 0600 UTC

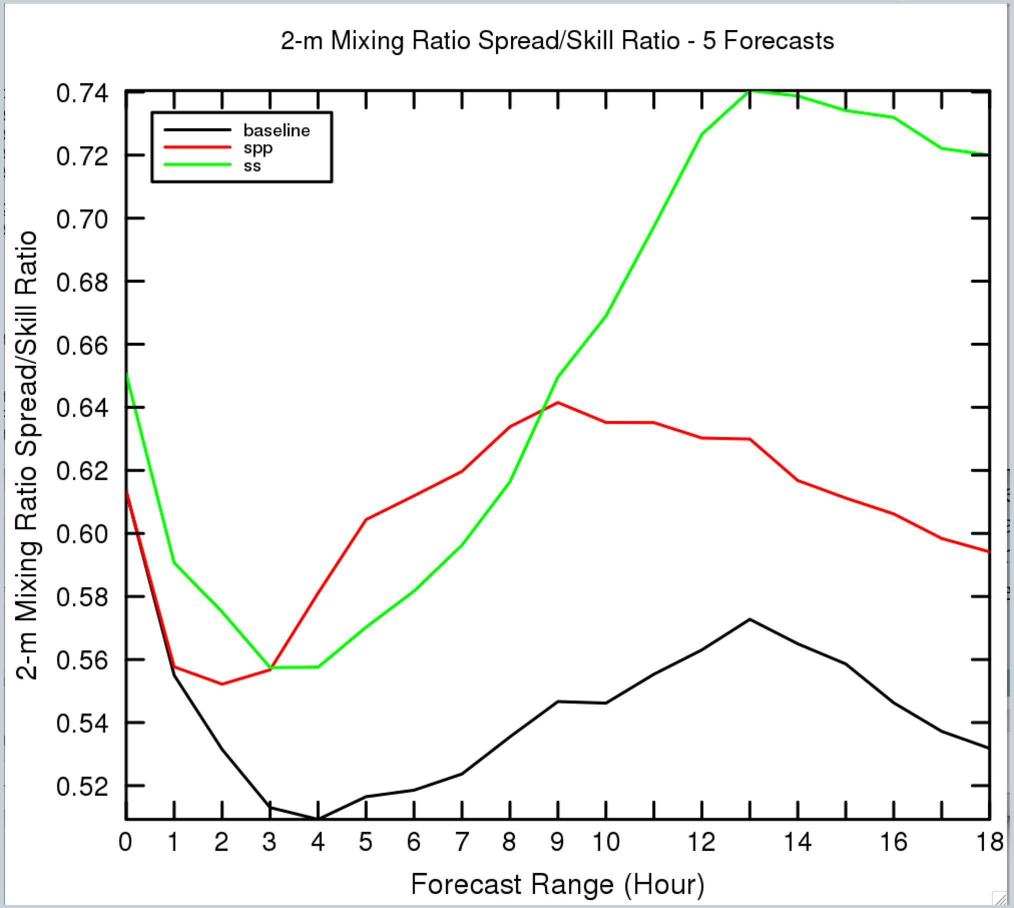
SPP

20180921
1200 UTC Init

SS

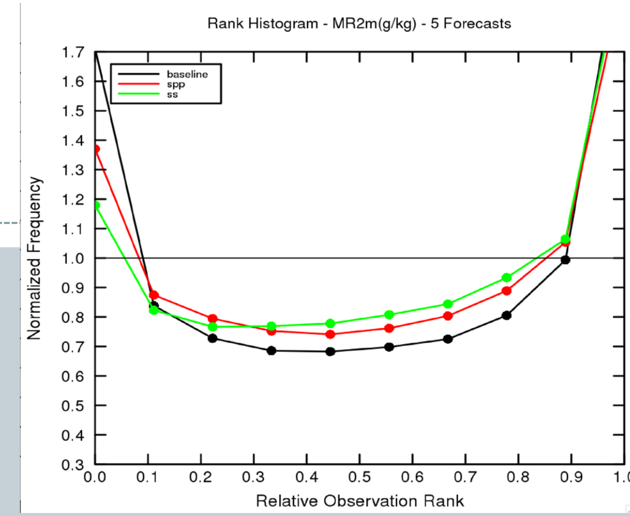


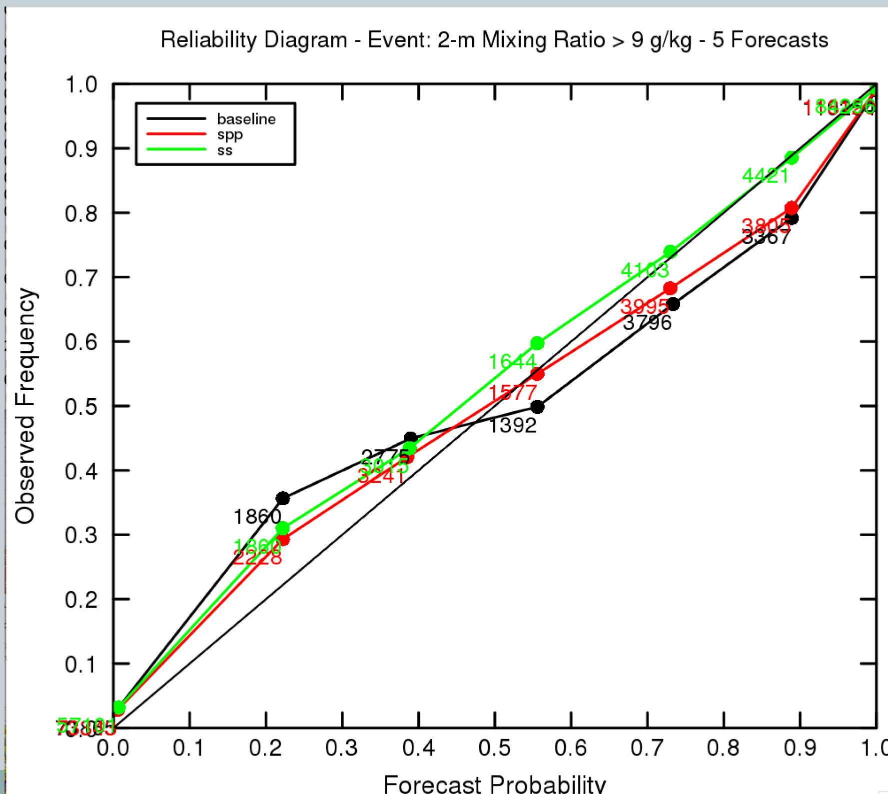
Spread/Skill Ratio 2-m MR

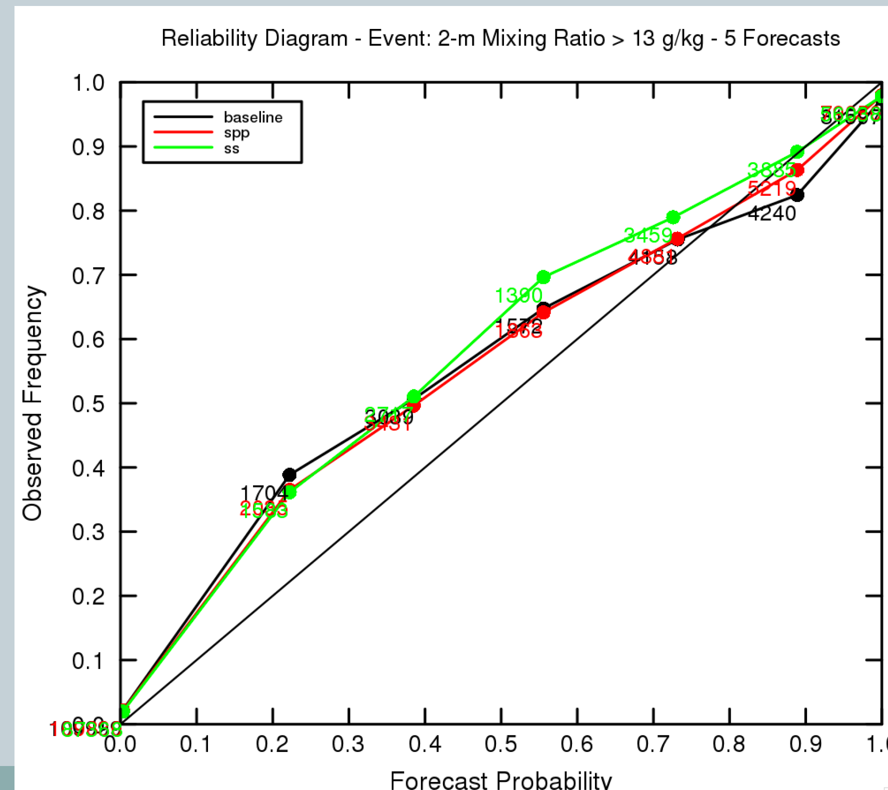


- Both experiments characterized with higher Spread/skill ratio compared to the baseline
- Perfect value of 1

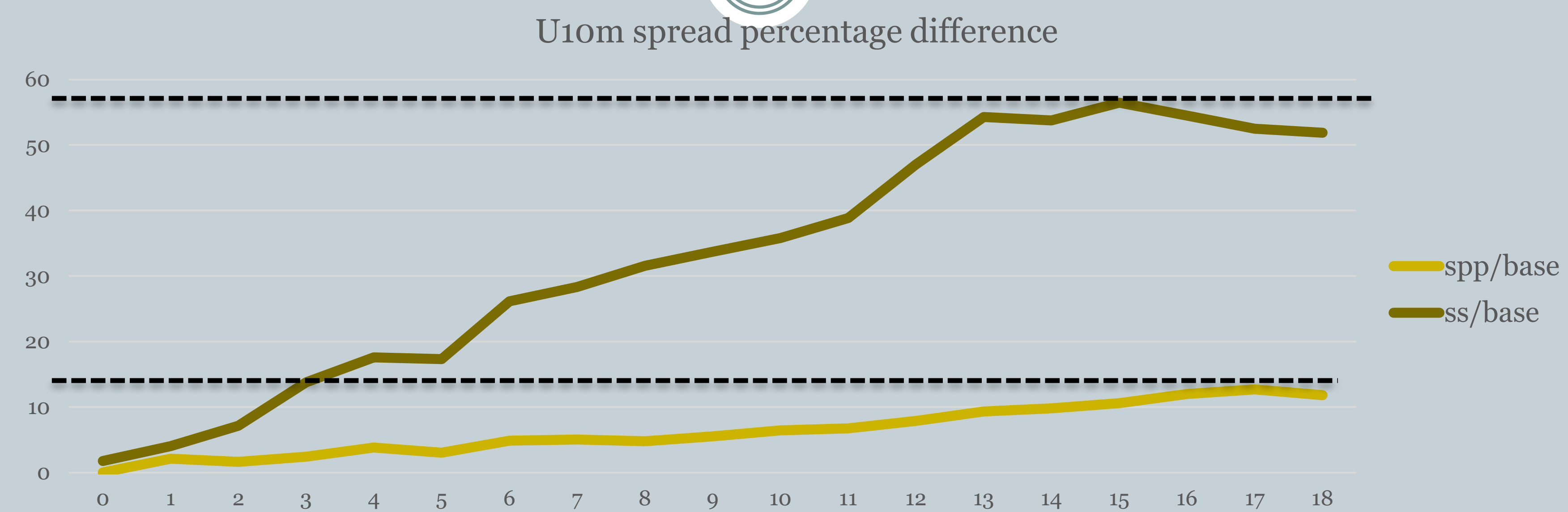
2-m MR Reliability

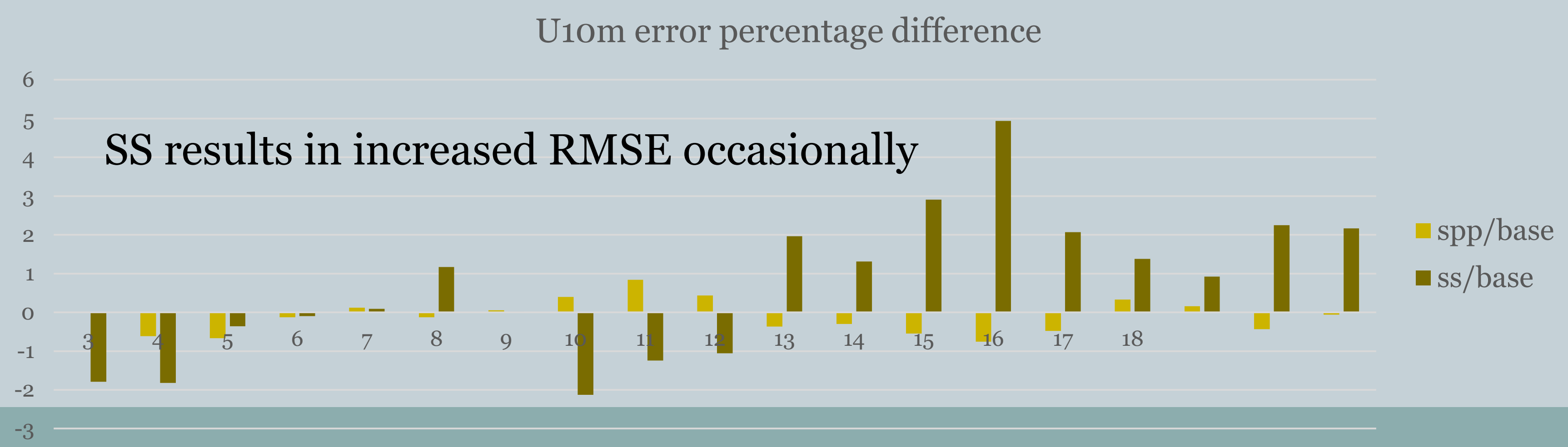






10-m U Spread changes compared to the HRRRE baseline





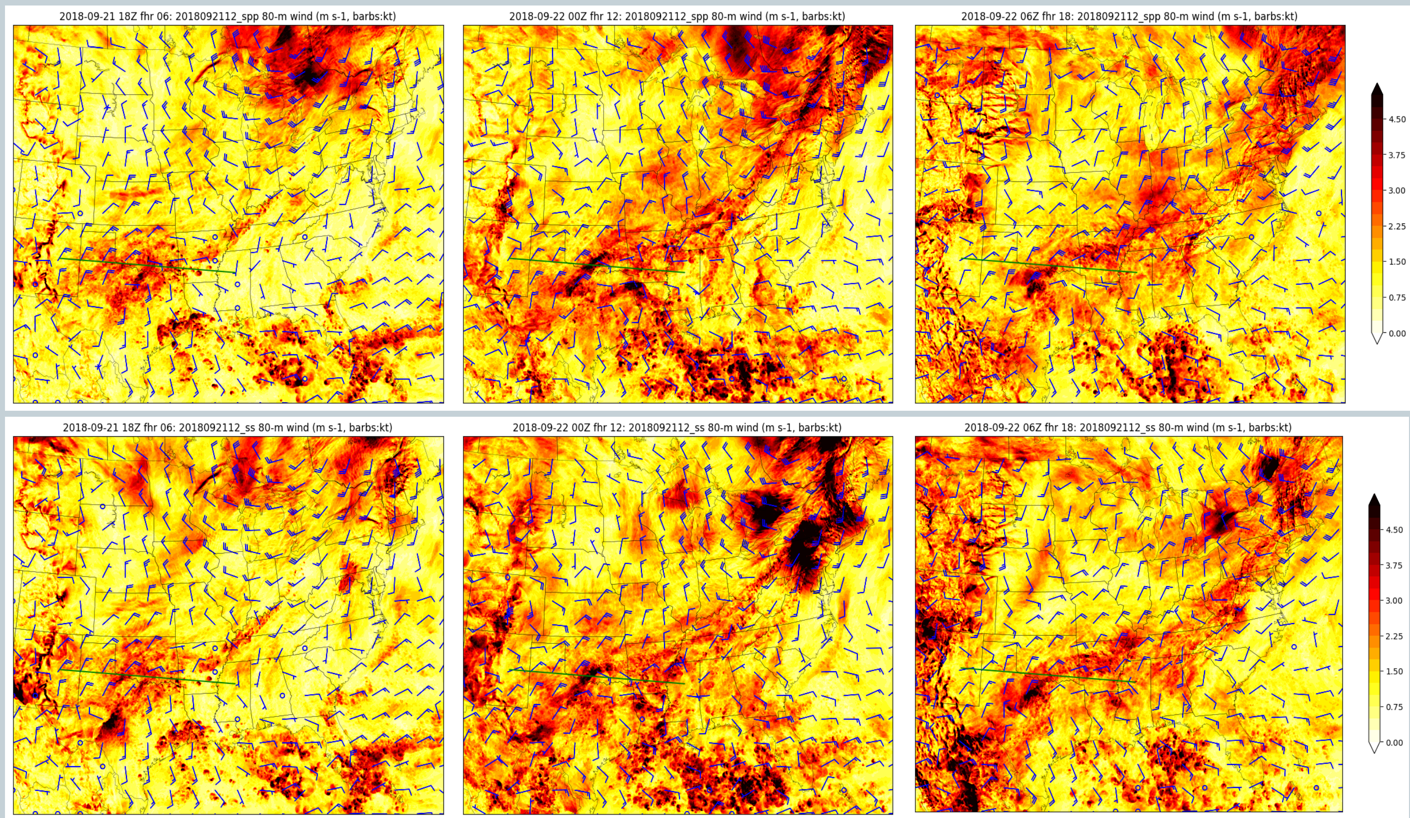
10-m U Spatial Spread Distribution

1800 UTC **0000 UTC** **0600 UTC**

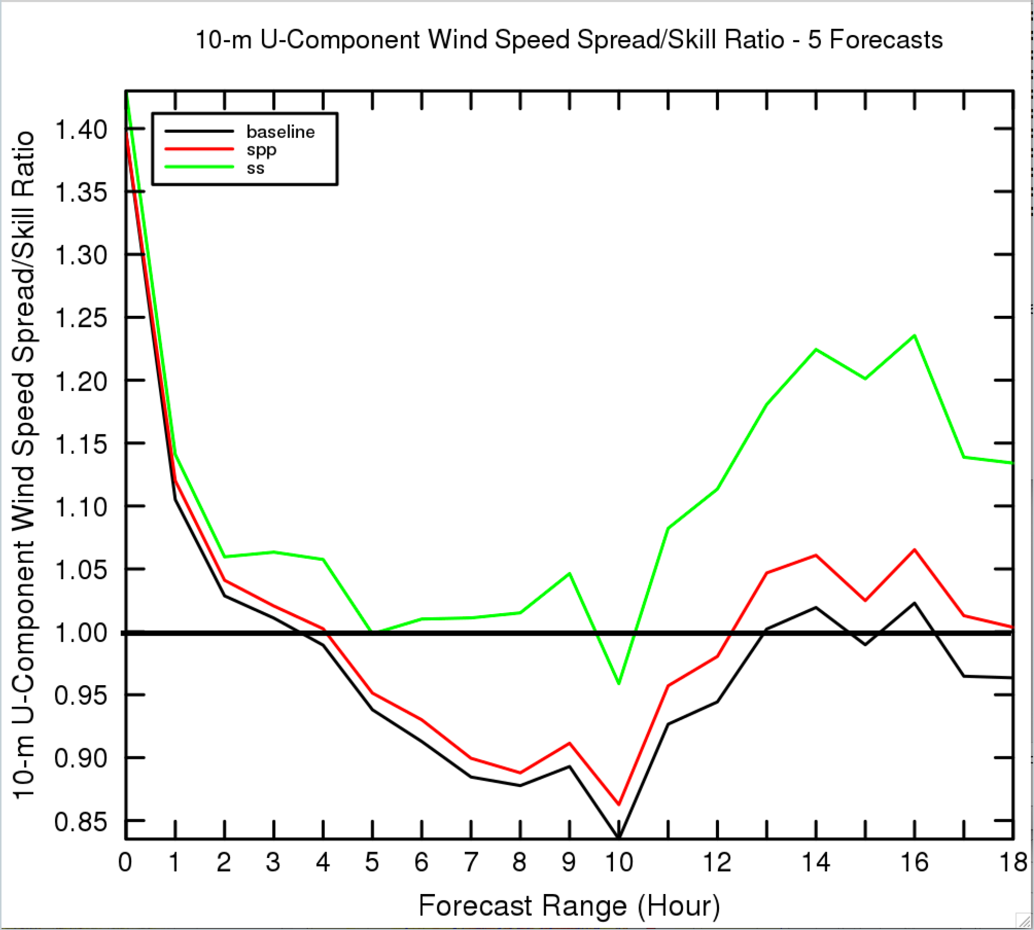
SPP

20180921
1200 UTC Init

SS

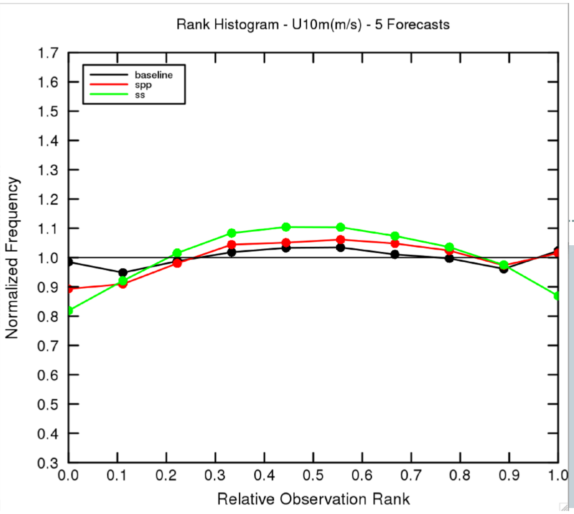


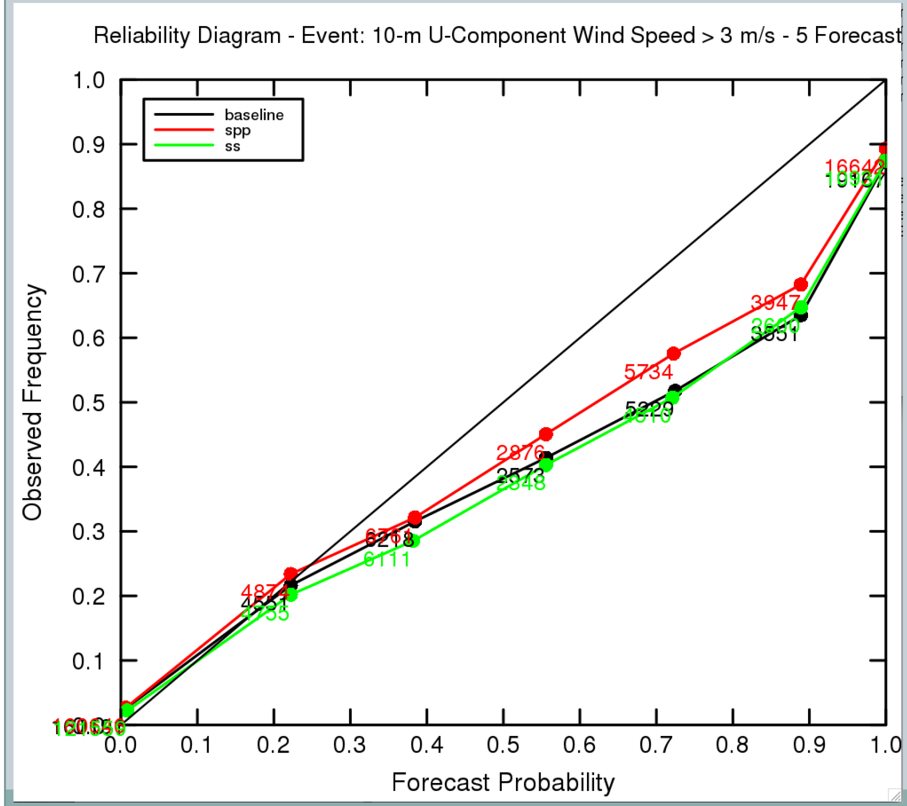
Spread/Skill Ratio 10-m U

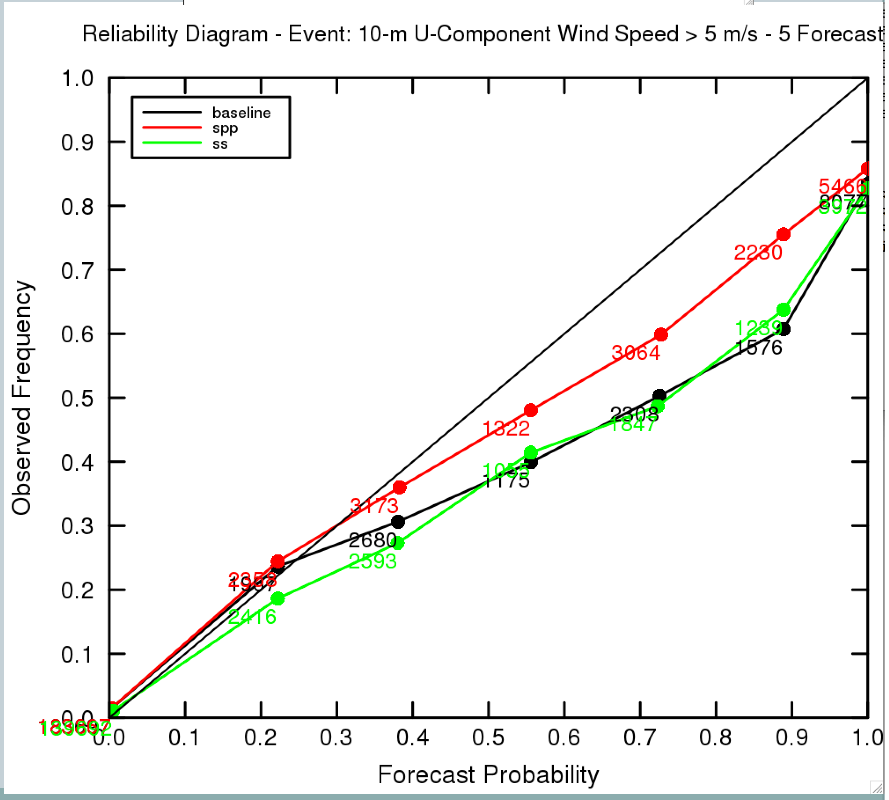


- Higher spread/skill values compared to other variables
- Diurnal cycle
- Minimal impact of **spp** on the spread/error ratio which is already high
- Over-dispersion from **all** and **ss**
- Perfect value of 1

10-m U Reliability





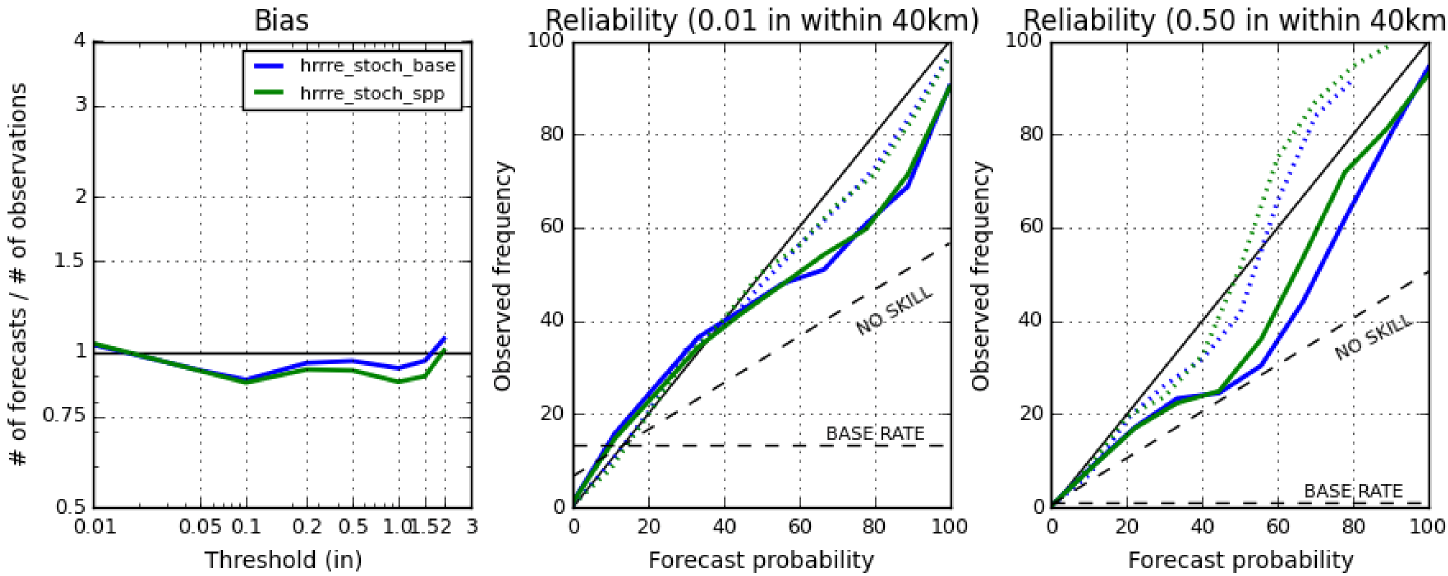


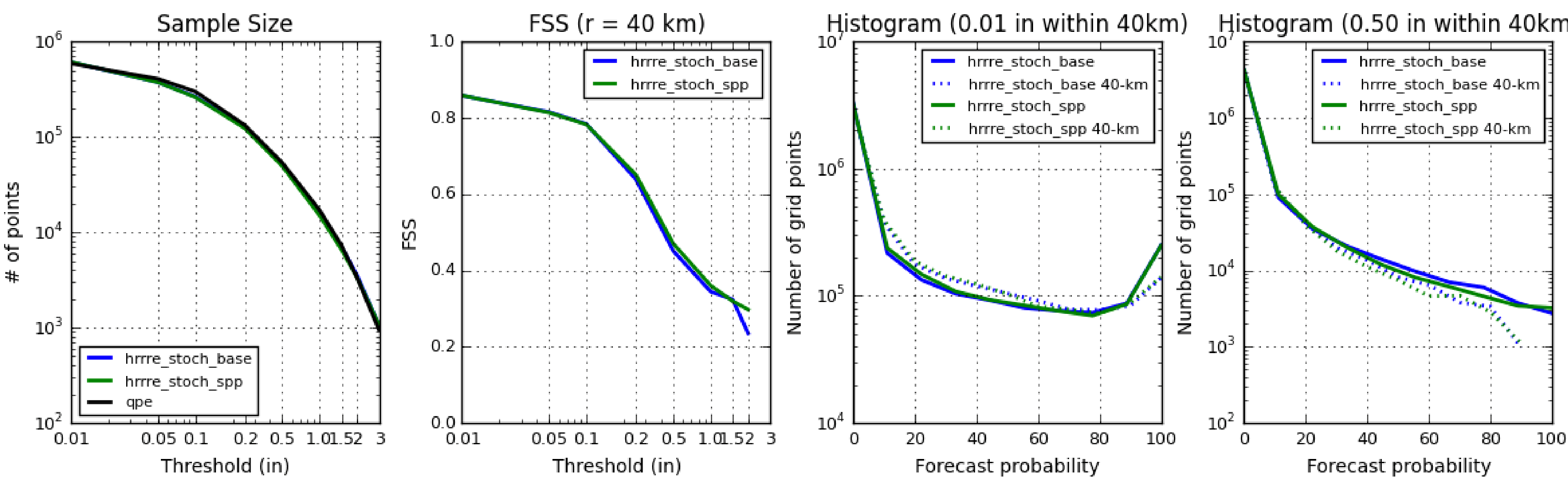
Precipitation

Ensemble PQPF Verification

12-18-h QPF vs Stage-IV QPE

2018-09-21 to 2018-10-04
(n=4)





Summary and Next Steps

- Real time cases-good HRRRE (**baseline**) performance during the period
- **ss** characterized with larger spread for all variables of interest, resulting in over-dispersion for 10-m wind
- Comparable performance between **spp** and **ss** in terms of forecasts sharpness and reliability for variables of interest
- **spp** shows beneficial impact on precipitation reliability at higher thresholds after 12-hr lead time

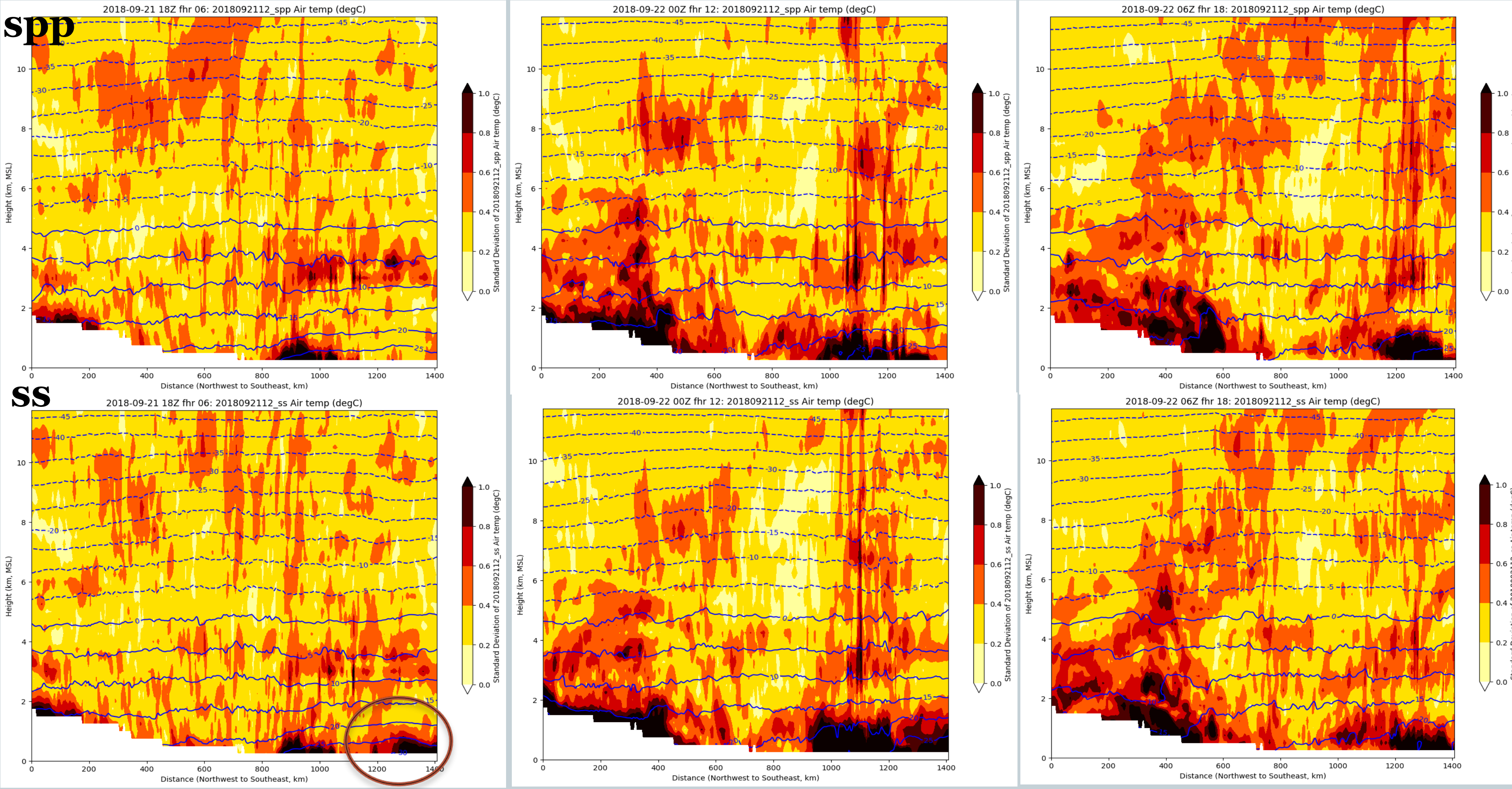
*There is evidence that the **spp** approach accounts for more realistic representation of model error at the process level*

- Next Steps
  - Add SPP to additional variables and parameters (e.g. long wave radiation)!!!!
  - Collect IC and BCs for a larger data sample (convective season retro)
  - Add **spp** to HRRRE data assimilation 36-member ensemble

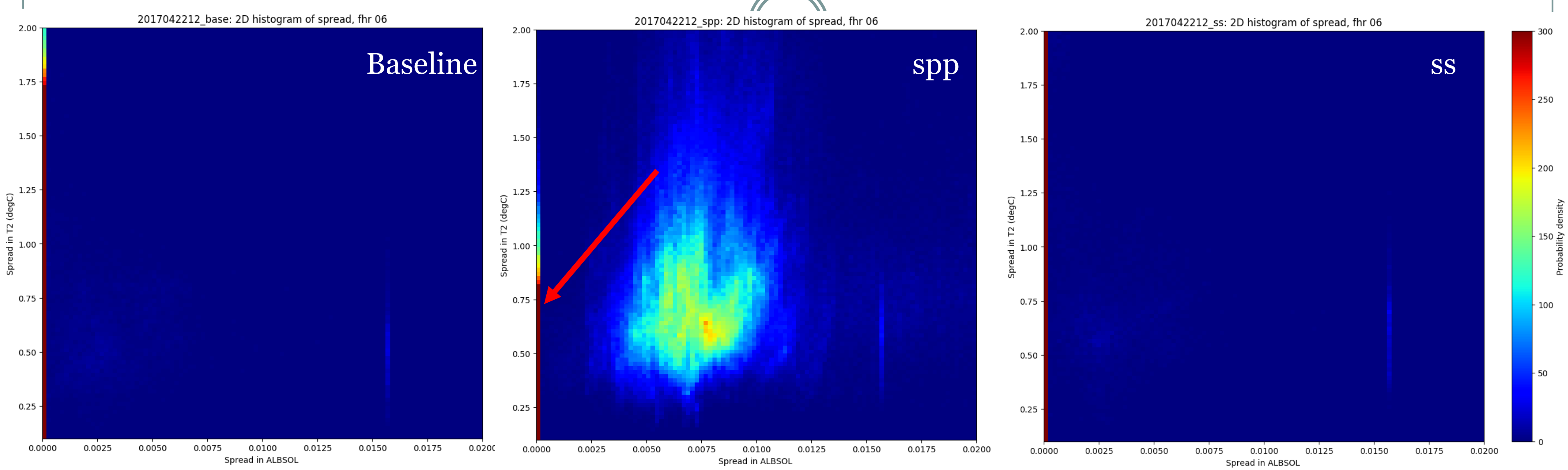
THANKS!!!

Temperature Spread Cross-Sections

1800 UTC	0000 UTC	0600 UTC

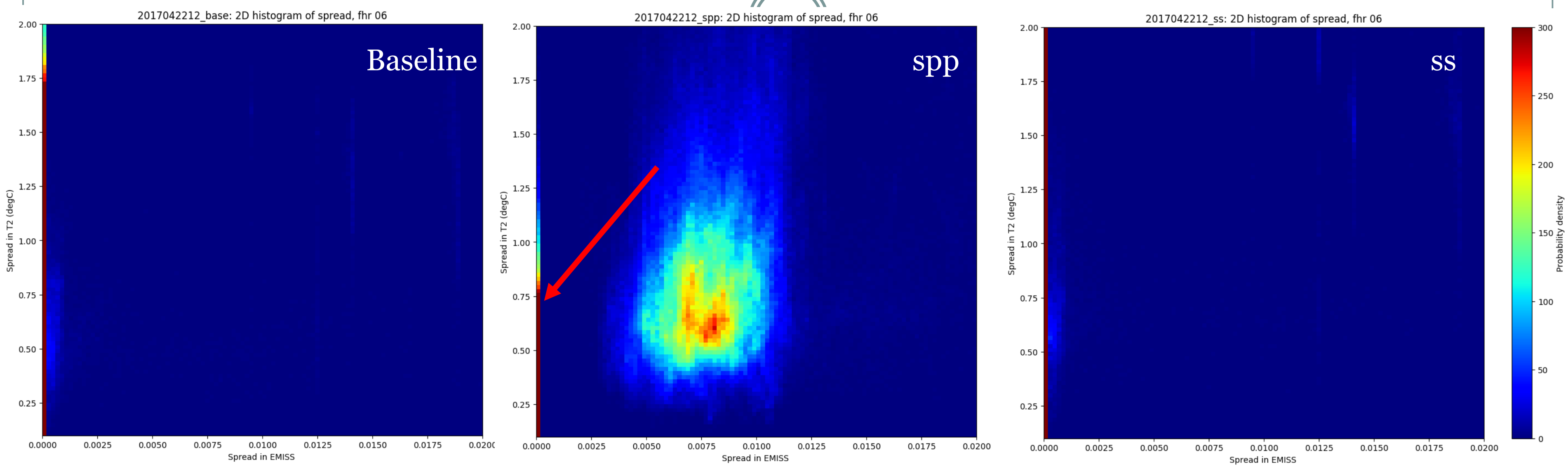


Relationship between spread in 2-m temperature and albedo
Valid time: 22 April 2017 18 UTC (6-hr forecast)



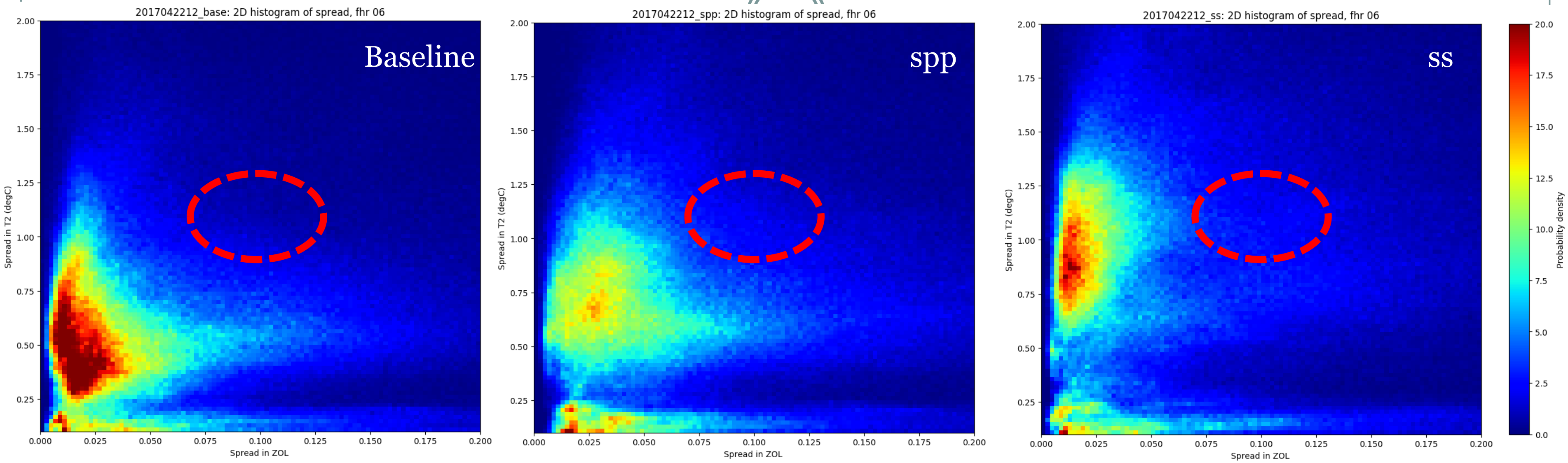
Interestingly, there is only a weak dependency between the amount of spread in T2 and the spread in albedo. It seems like we should be getting more out of this perturbation. Also, many points are not perturbed at all (red arrow), but this might be because we only perturb albedo over land. Oddly, albedo varies for a few points in the baseline and ss despite the fact that there are no albedo perturbations in those experiments. Time-varying albedo due to snow melt?

Relationship between spread in 2-m temperature and emissivity
Valid time: 22 April 2017 18 UTC (6-hr forecast)



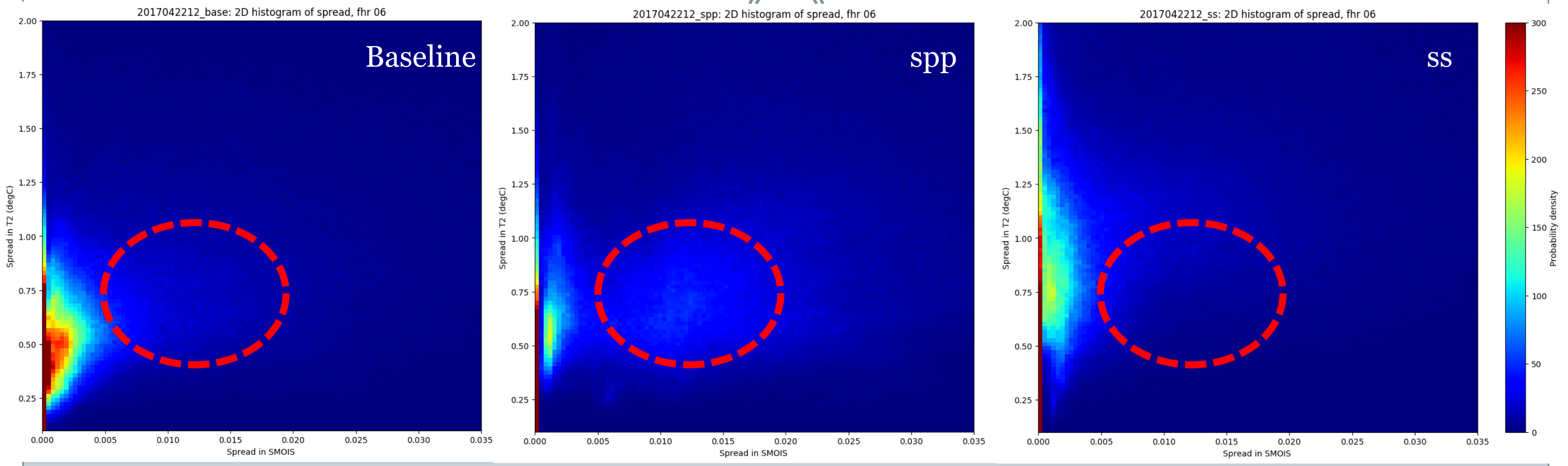
There is only a weak dependency between the amount of spread in T2 and the spread in emissivity. We are only weakly perturbing emissivity, so maybe that is why. Also, many points are not perturbed at all (red arrow), but this might be because we only perturb emissivity over land. Oddly, there is some spread in emissivity in the baseline and ss. Time varying snow cover?

Relationship between spread in 2-m temperature and z/L
Valid time: 22 April 2017 18 UTC (6-hr forecast)



We are perturbing ZNT (roughness length) rather than L (Obukhov length), but the perturbations in ZNT don't make it into the history file since we apply the perturbations to ZNTstoch. These perturbations then modify ZOL (z/L). Spp and ss both exhibit more points with large T2 and ZOL spread (e.g., red circled area) than the baseline does. On average, however, spread in T2 is associated with more ZOL spread in spp than in ss (compare x-axis location of warmest colors for 0.5 < T2 spread < 1.5 degC in spp versus ss).

Relationship between spread in 2-m temperature and soil moisture (top layer)
Valid time: 22 April 2017 18 UTC (6-hr forecast)



Soil moisture is perturbed in all three experiments (we think) at the initial time. However, spp perturbs it slightly more (still only at the initial time). This additional perturbation has an obvious beneficial impact on the T2 spread (red circle).