Evaluation of Rapid Refresh Forecast System Ensemble Designs

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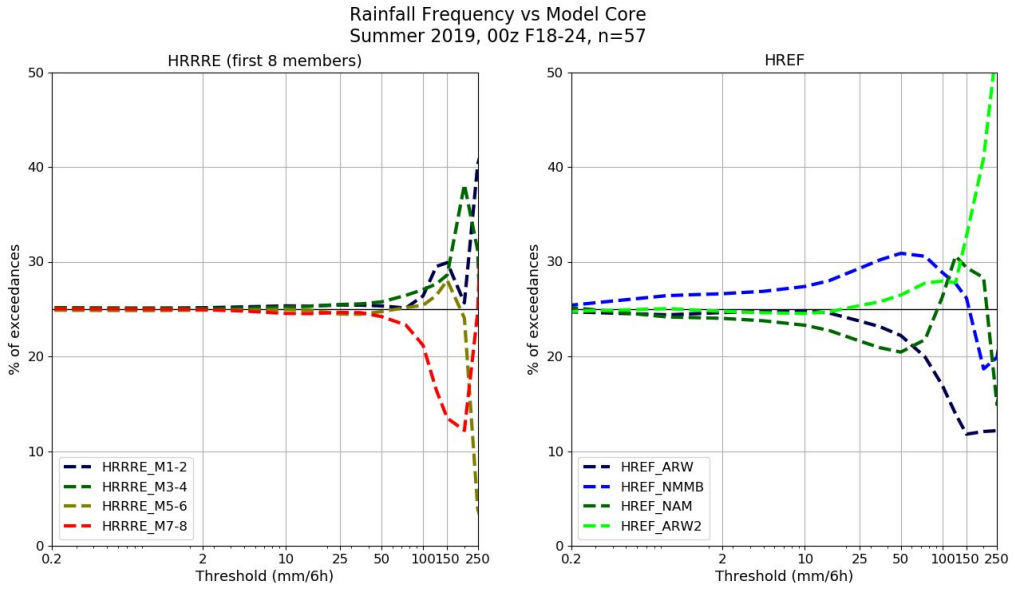
Forecast Ensemble Characteristics

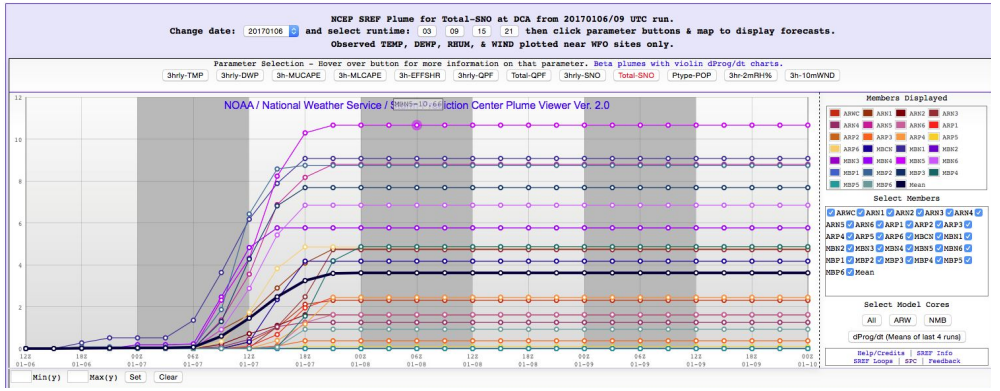
- Deterministic forecasts represent only one possible realization of a forecast outcome “i.e. swing and hit/miss”
- Model forecast ensembles are a common technique to (potentially) capture all possible forecast outcomes (spread)
  - Each ensemble member solution equally likely
  - Diversity of solutions proportional to mean forecast error of day
  - Control (deterministic) member solution should fall within envelope of all member solutions

- **UFS provides common model framework to compose single model ensembles and address challenge of underdispersion**
- Ensemble design is active research:
  - Initial and/or lateral boundary perturbations
  - Time-lagging across multiple initialization cycles
  - Multi- and/or stochastically perturbed physics
  - Multimodel (dynamic core diversity)



CONUS forecasted precipitation biases between members for a single-model ensemble (left) and multi-model HREF ensemble (right)

Regional ensembles (SREF and HREF) can generate “artificial” spread through biases resulting in multi-modal distributions or regularly favored members that are not ideal

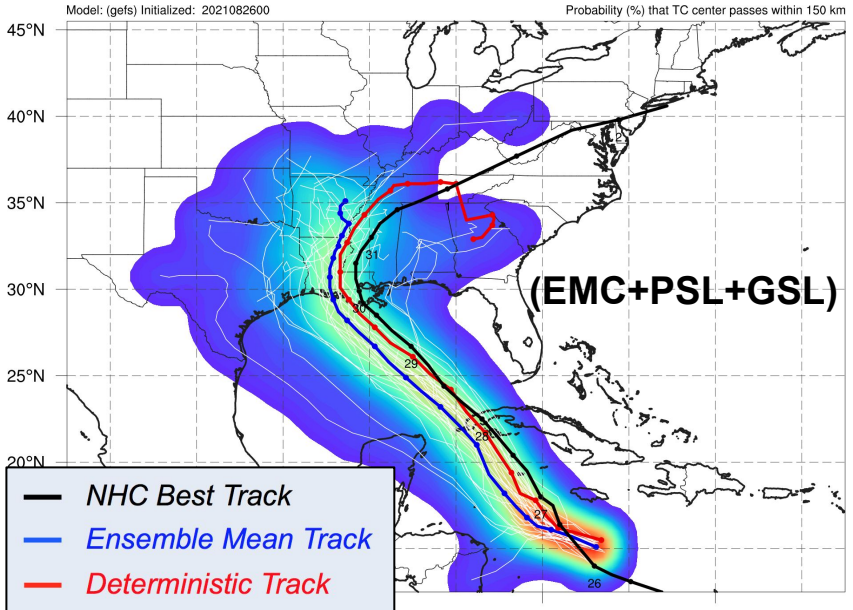


Forecasted snowfall timeseries at DCA across multi-model SREF ensemble with separation by model above/below mean (black)

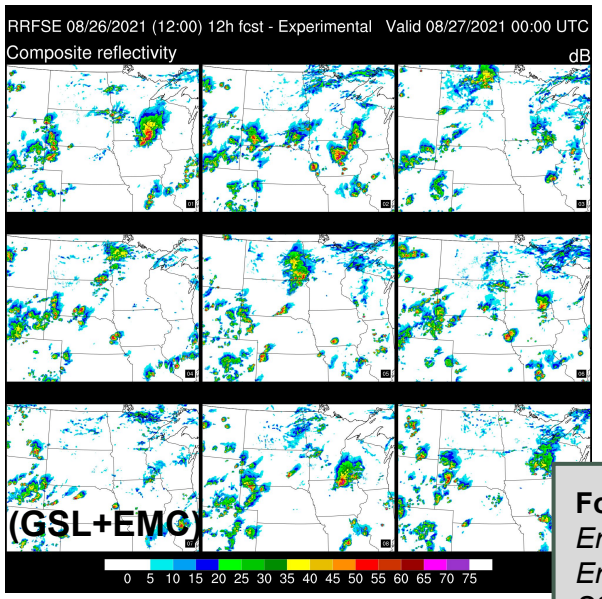
Forecast Ensembles

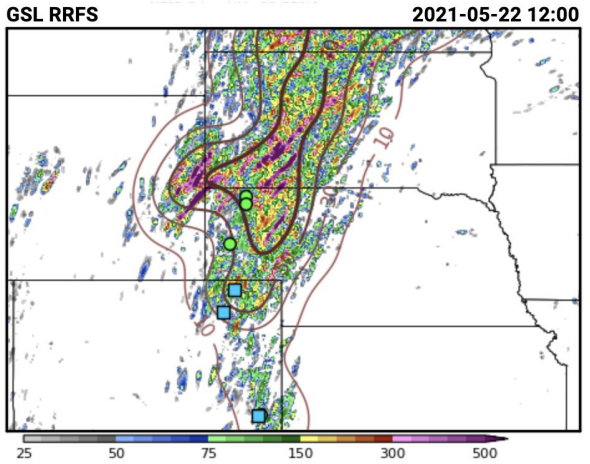
Current and future UFS-based single-model ensemble forecast systems

GEFS (days-to-weeks)



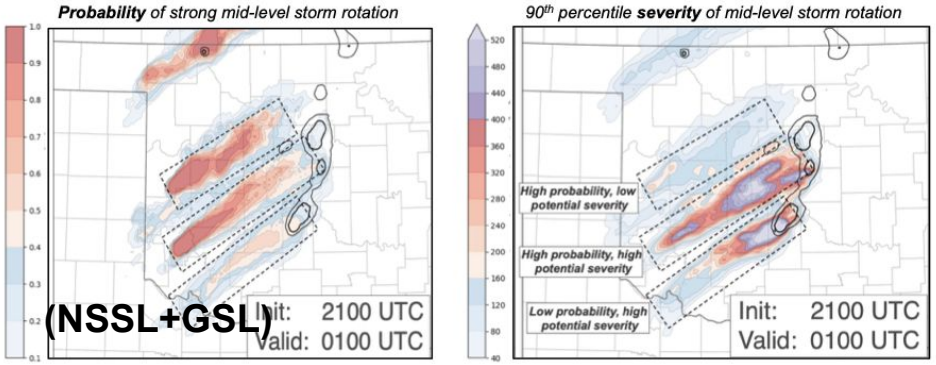
RRFS (hours-to-days)





Forecasted convective updraft rotation (m^2/s^2)
Ensemble maximum value (colorfill)
Ensemble neighborhood probability (contours)
Storm reports for hail (green) and winds (blue)

WoFS (minutes-to-hours)

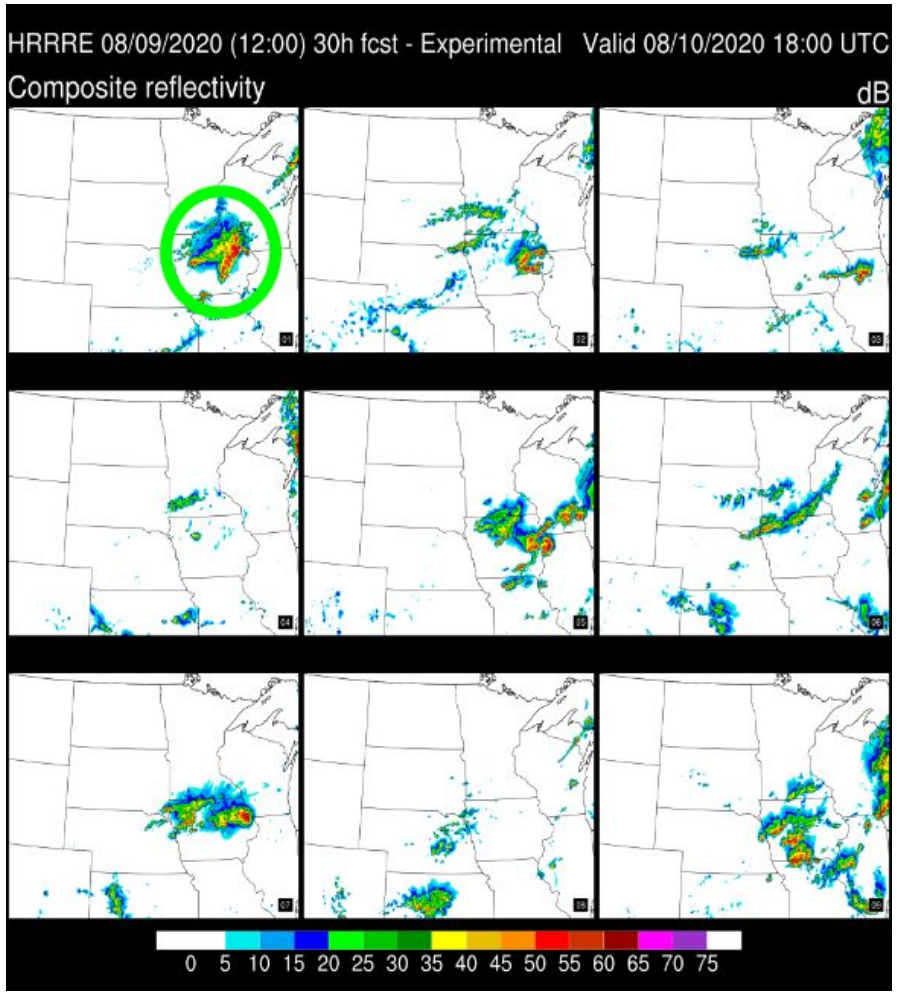


UFS ensemble research challenges:

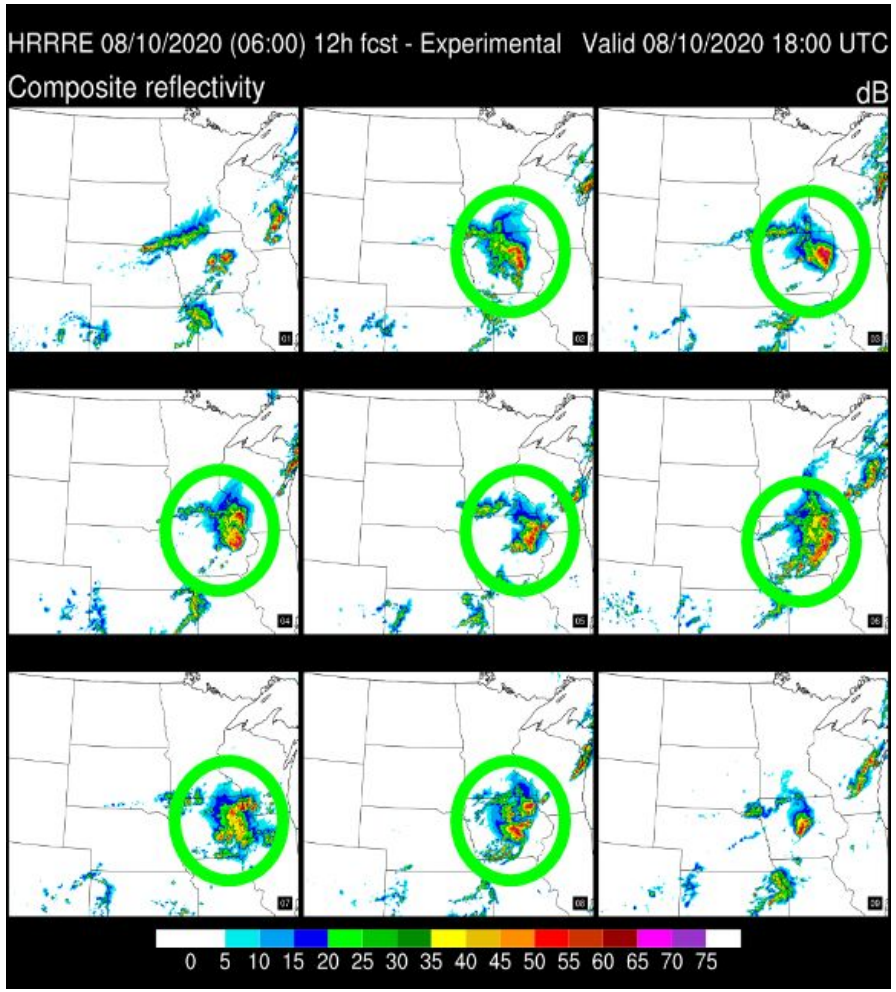
- **Optimal ensemble spread-skill**
- **Optimized code (more members)**
- **Consistent probabilities across scales**
- **Distribution and communication of ensemble information**

Ensemble DA & Forecasting ⇒ Better Probabilities

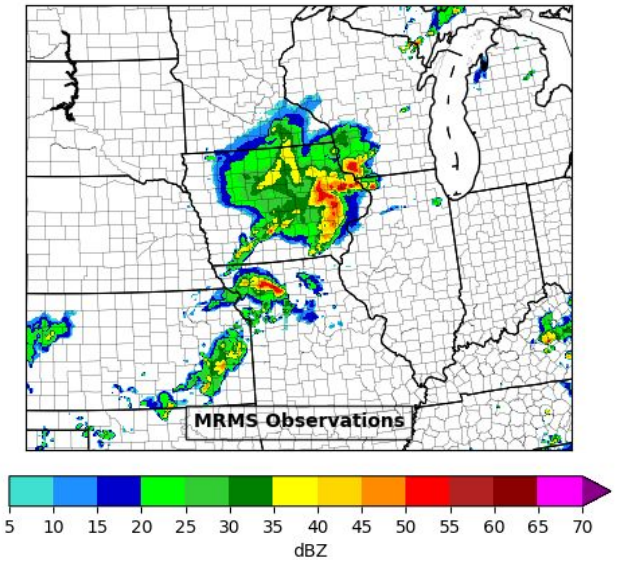
30-h lead-time: get 1 hit



12-h lead-time: 7 of 9 hits



Radar observations



- Longer forecasts show low likelihood for a large impact event
- Shorter forecasts decreased spread, increased confidence
- Stochastic physics to create spread

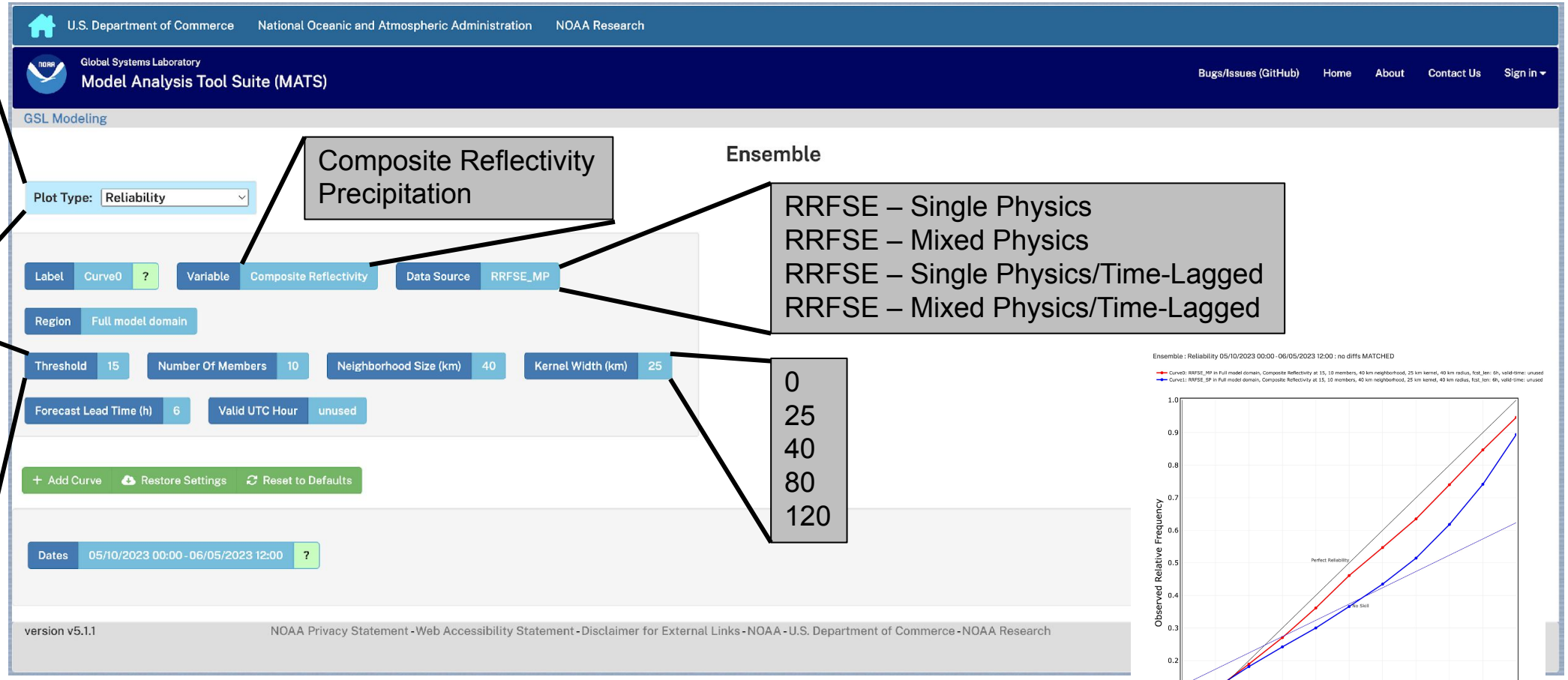
Ensemble Verification and Visualization

GSL Ensemble Development Tools

https://esrl.noaa.gov/gsd/mats/ensemble

Time Series
Leadtime
Threshold
Valid Time
Grid Scale Probability
Reliability
Histogram
Contour
Contour Diff

15
20
25
30
35
40
45
50
55
60



Composite Reflectivity
Precipitation

Ensemble

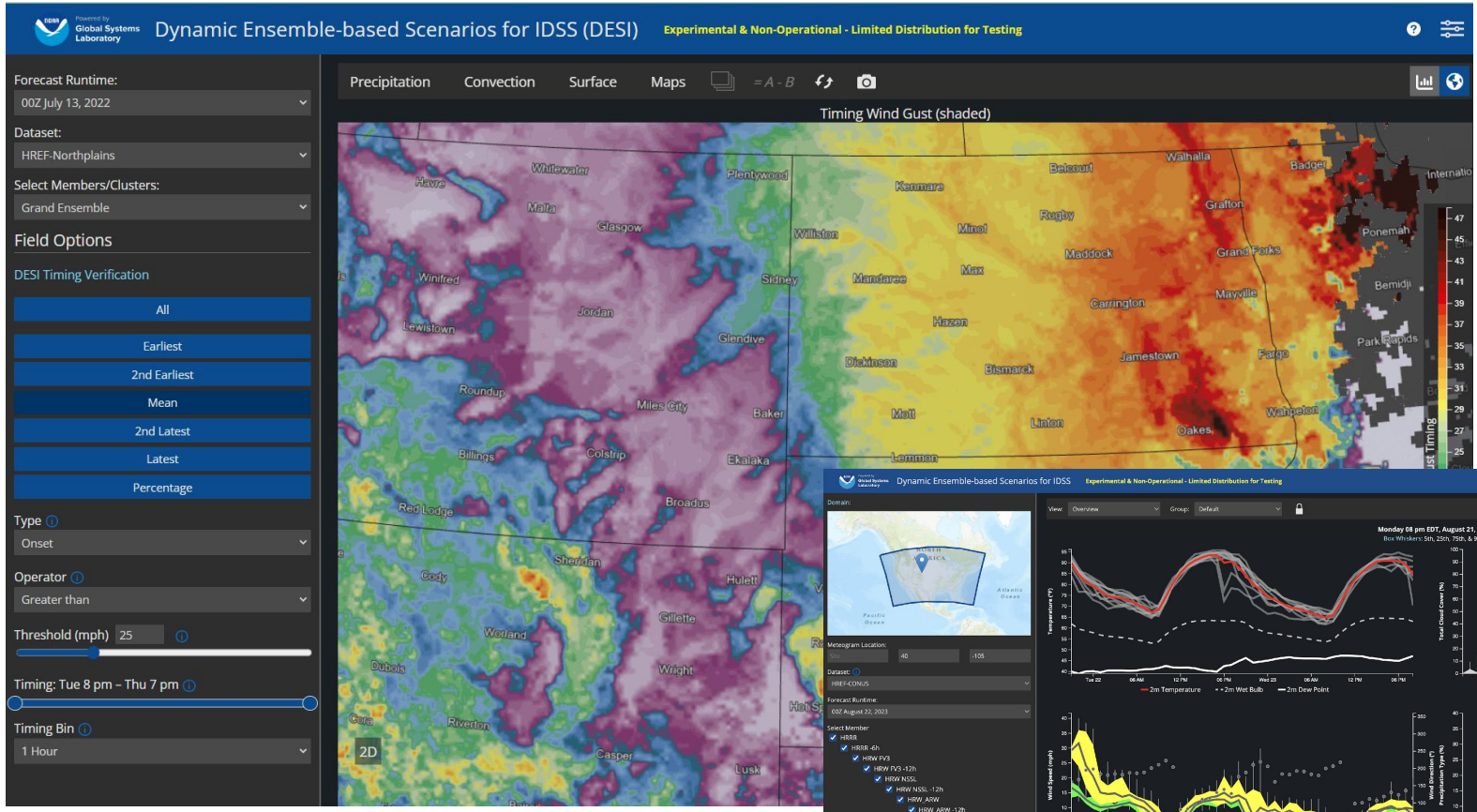
RRFSE – Single Physics
RRFSE – Mixed Physics
RRFSE – Single Physics/Time-Lagged
RRFSE – Mixed Physics/Time-Lagged

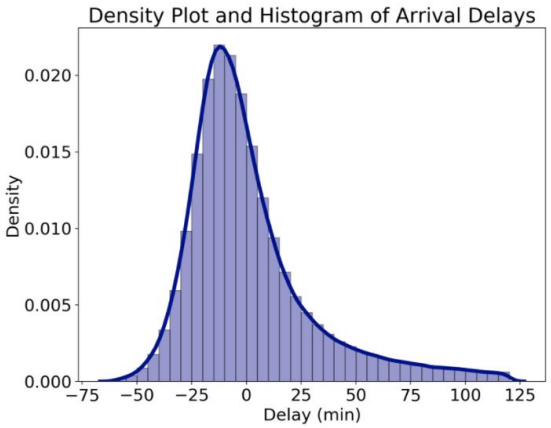
0
25
40
80
120

GSL Ensemble Development Tools

https://sites.gsl.noaa.gov/desi/

Ensemble map views
(example of timing of wind gusts)



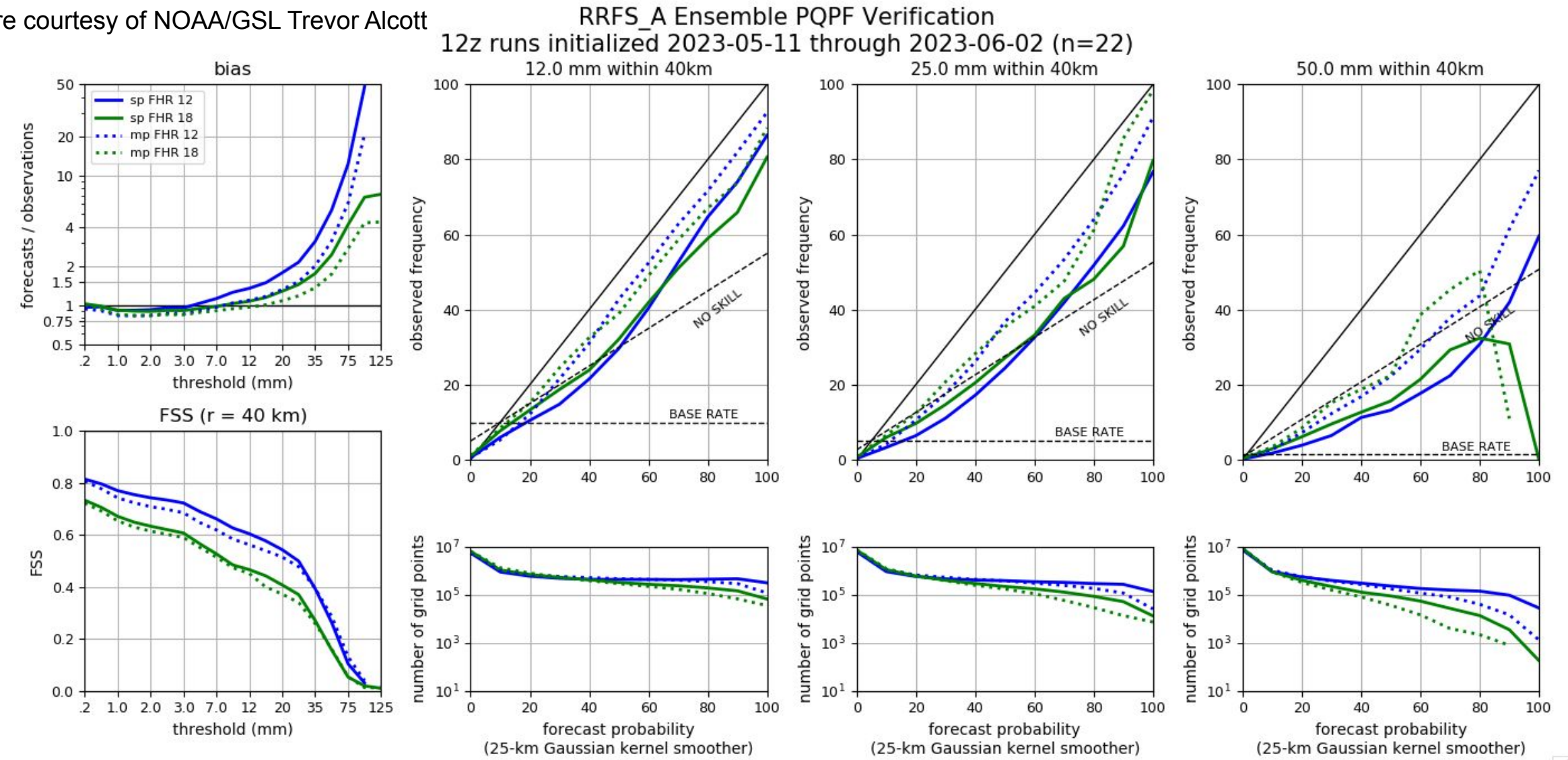


Ensemble meteograms at points

RRFSE PQPF
Single vs Multi-Physics Tests

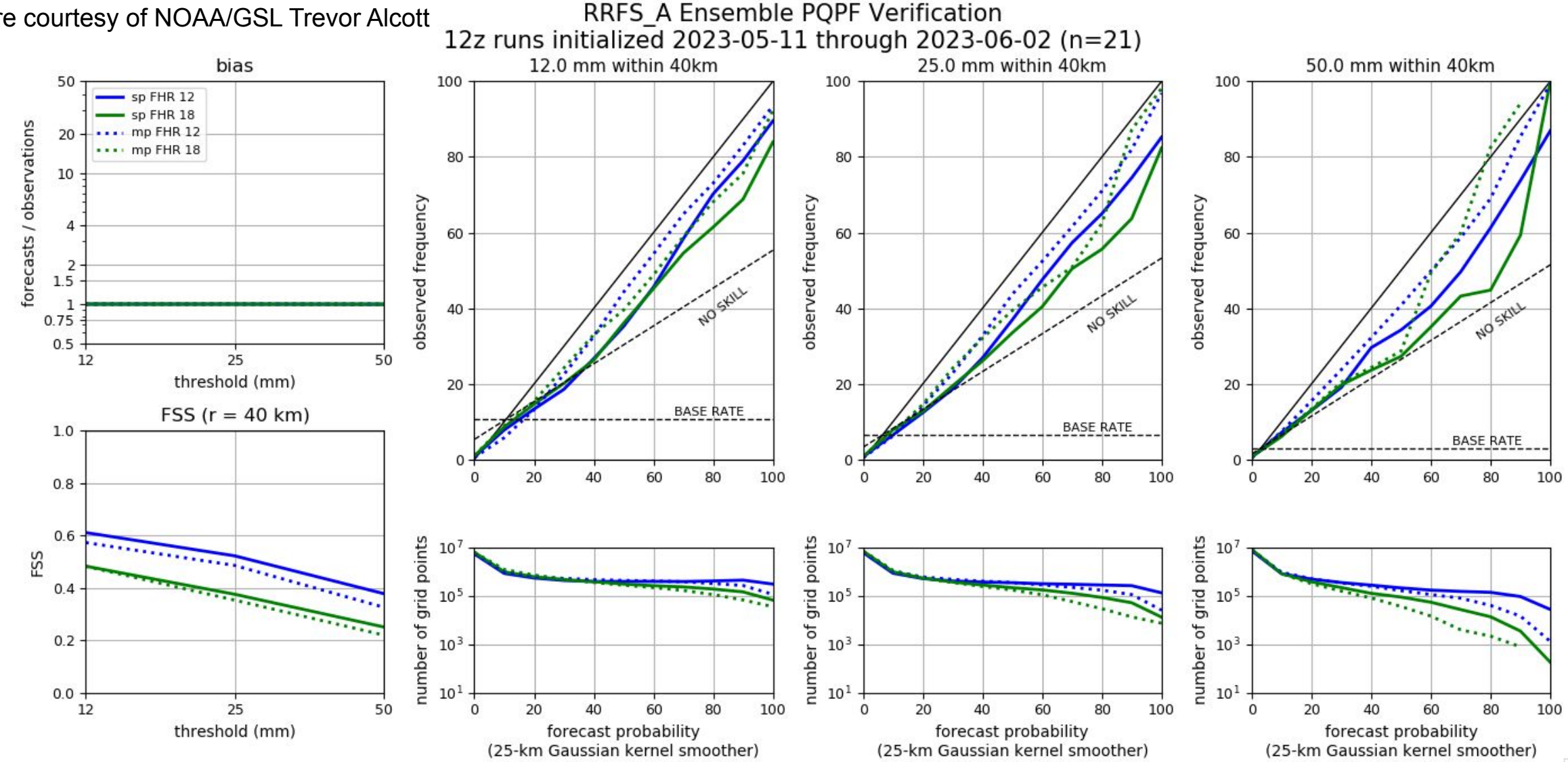
Raw 12z PQPF forecasts – May 2023

Figure courtesy of NOAA/GSL Trevor Alcott



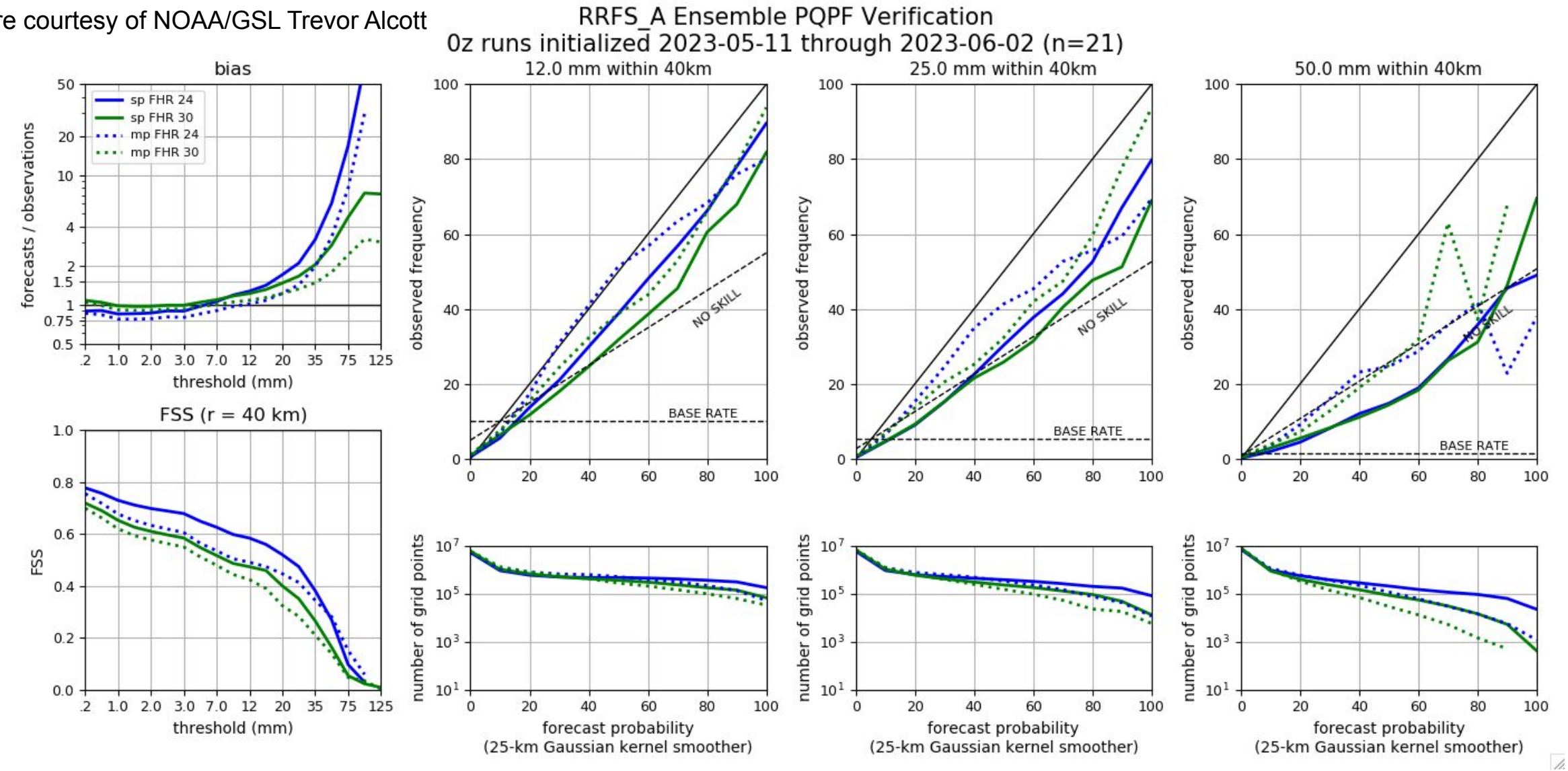
With simple quantile mapping

Figure courtesy of NOAA/GSL Trevor Alcott



Raw 00z PQPF forecasts – May 2023

Figure courtesy of NOAA/GSL Trevor Alcott



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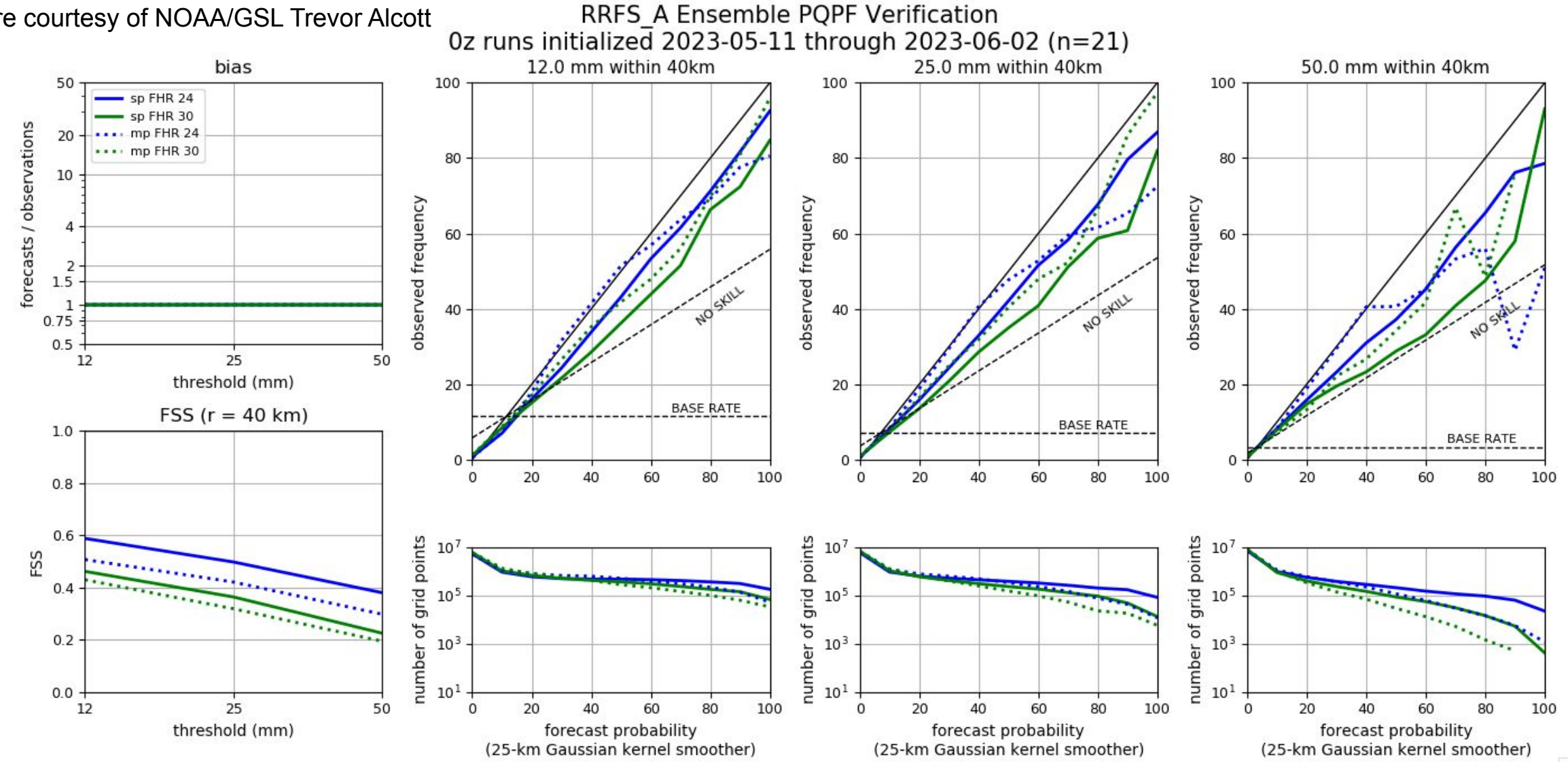
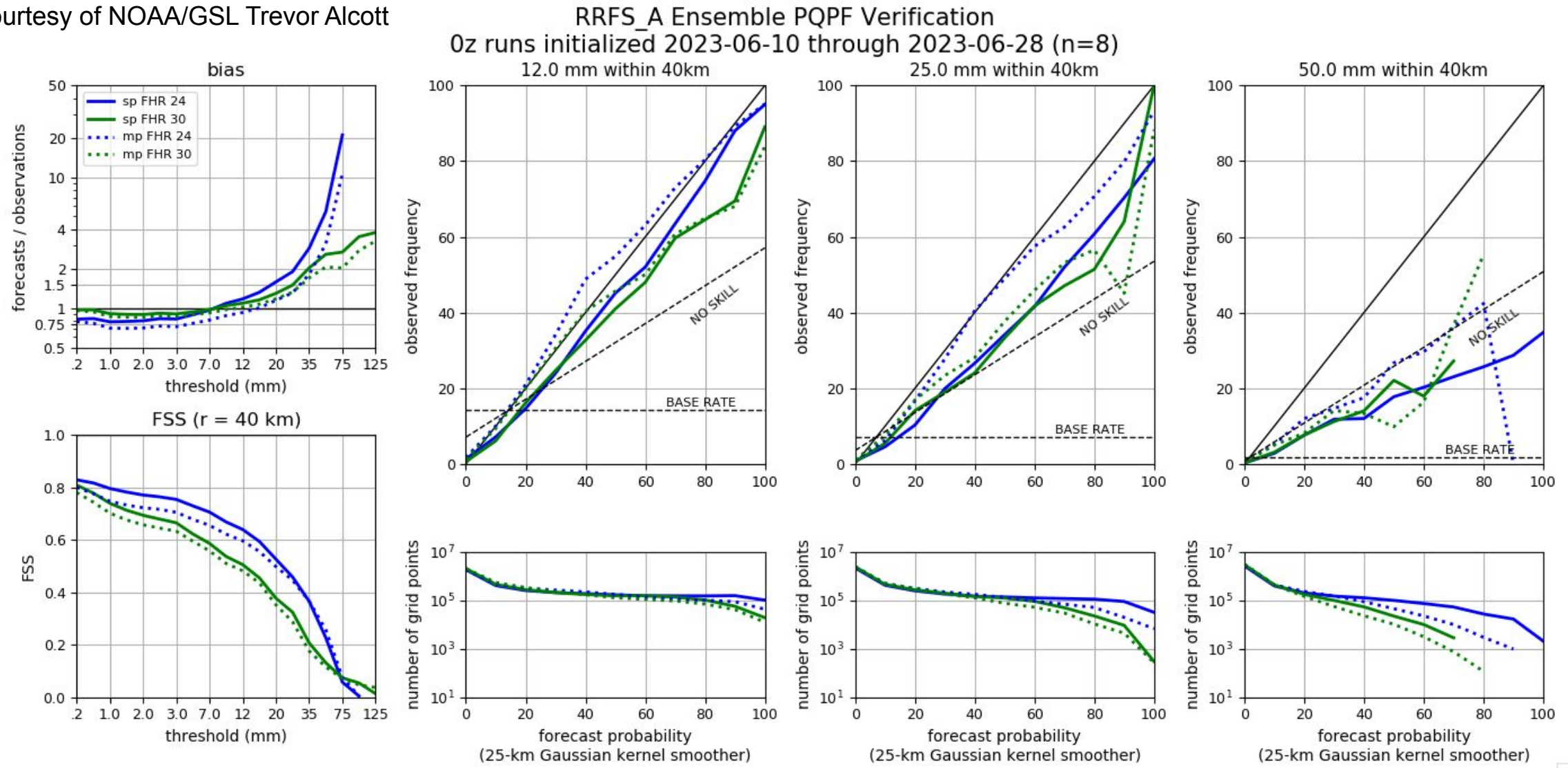


Raw 00z PQPF forecasts – June 2023

Figure courtesy of NOAA/GSL Trevor Alcott



With simple quantile mapping

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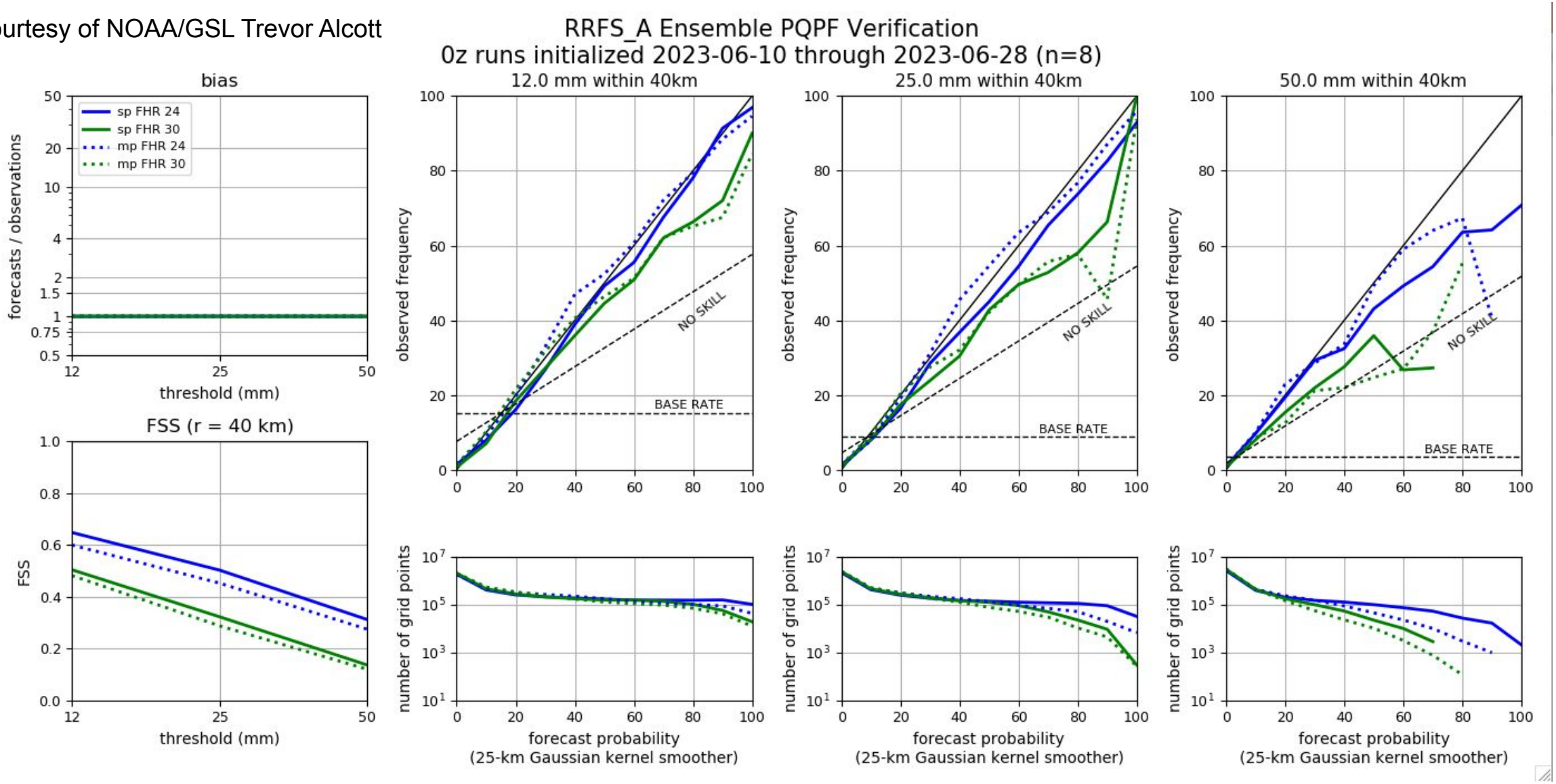
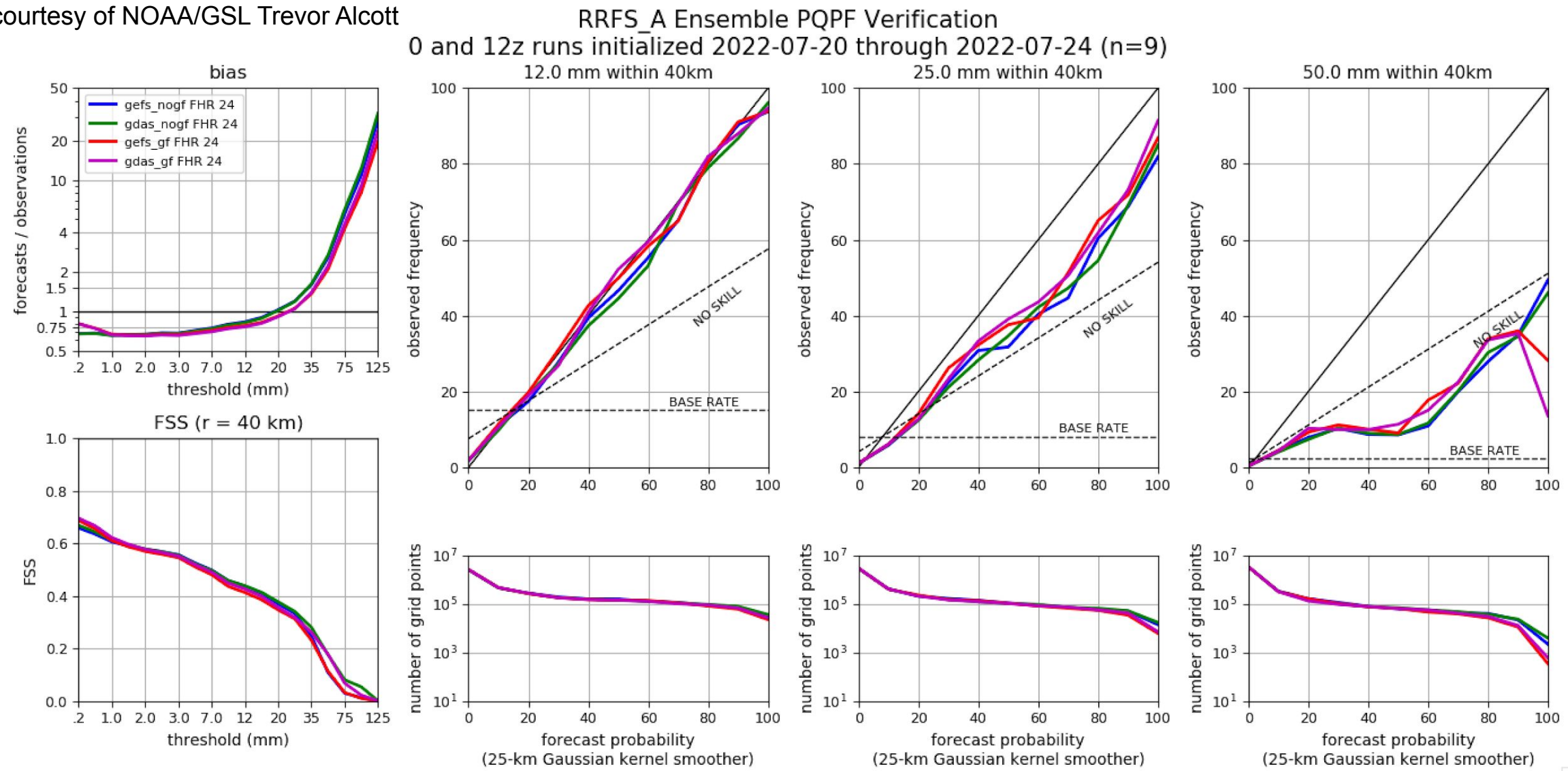


RRFSE PQPF
Convective Parameterization and Global Ensemble Tests

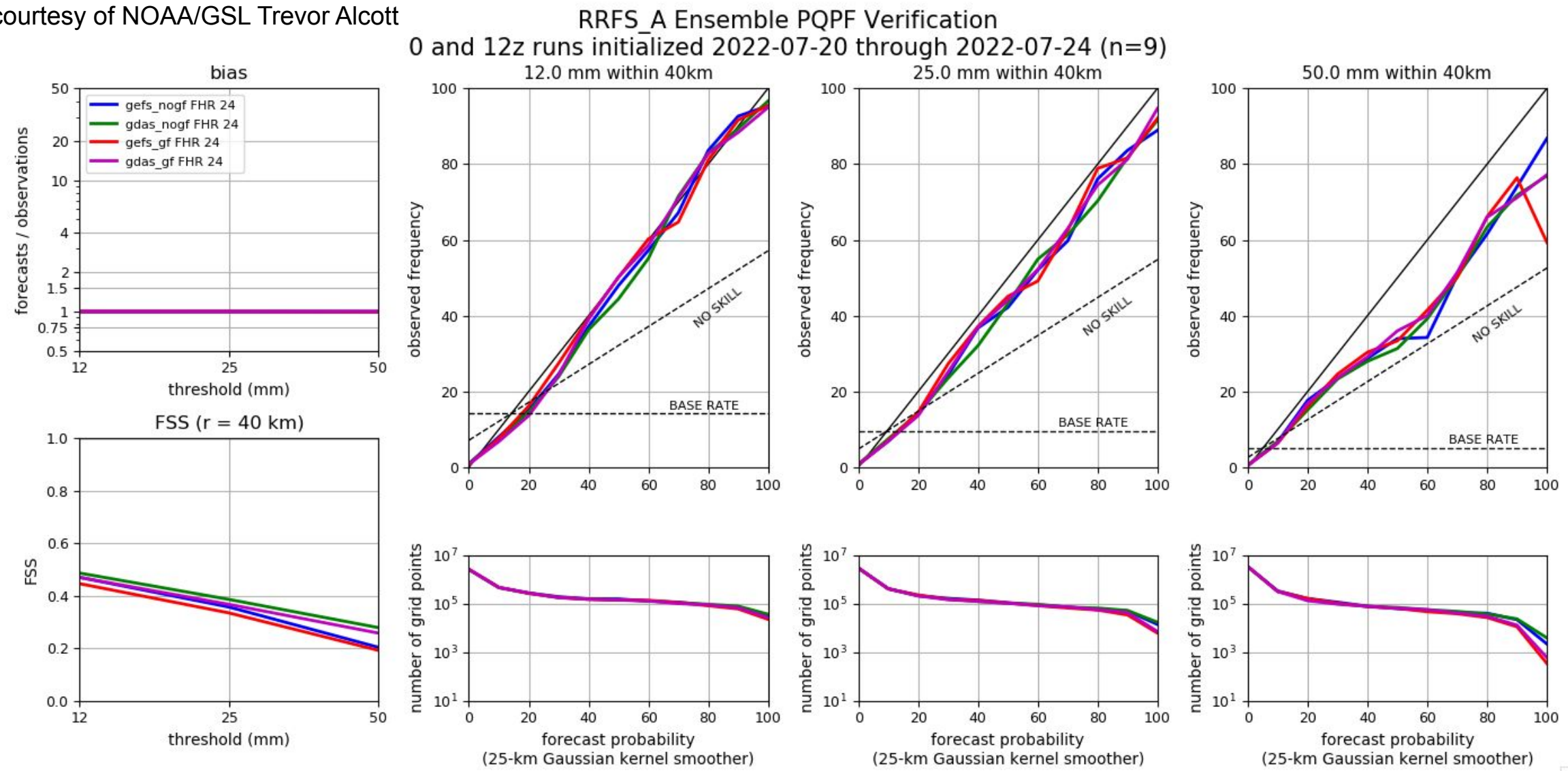
Raw 00/12z 18-24 hr PQPF forecasts - July 2022 Retro

Figure courtesy of NOAA/GSL Trevor Alcott



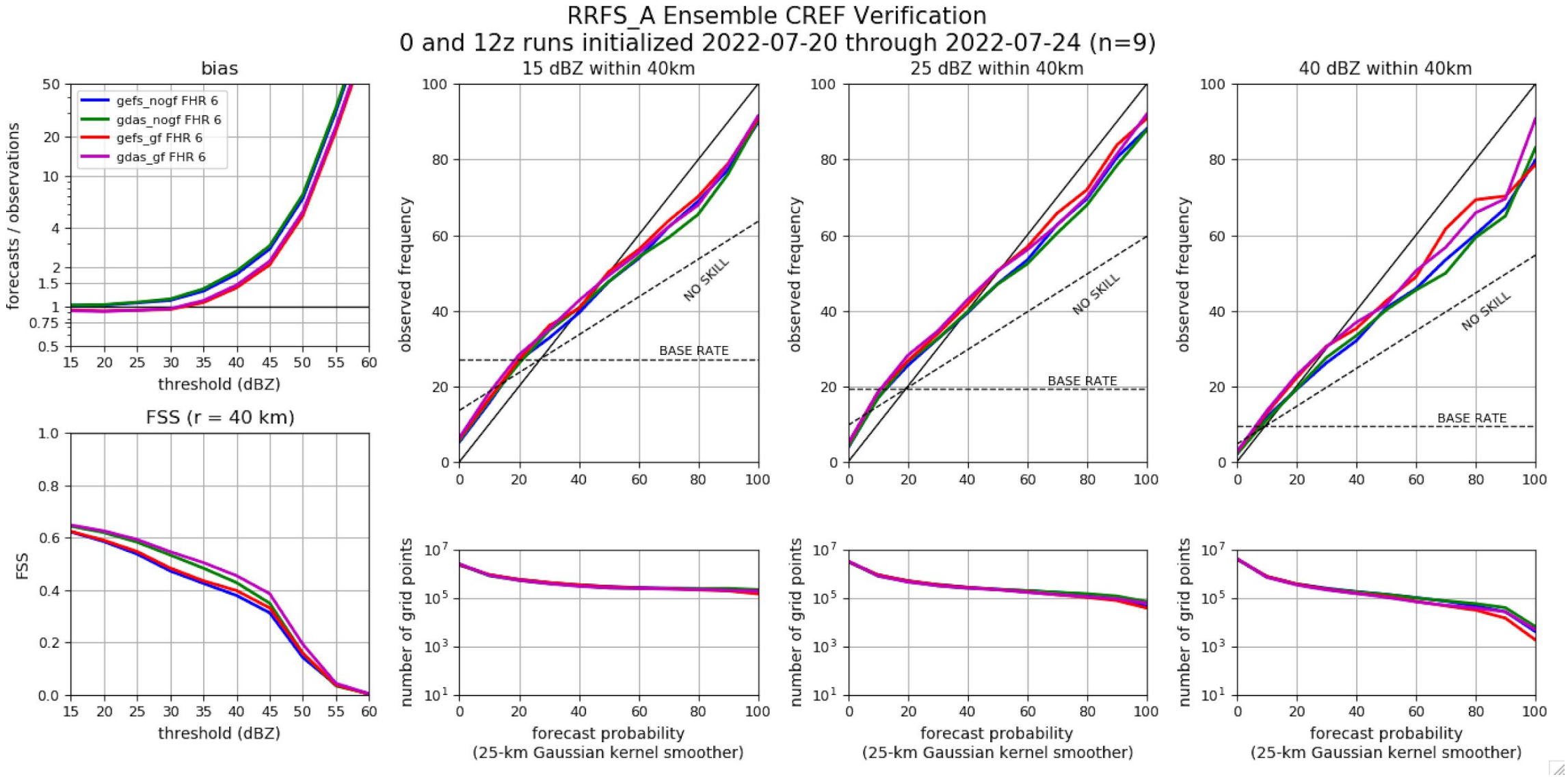
Quantile Map 00/12z 18-24 hr PQPF fcsts – July 2022 Retro

Figure courtesy of NOAA/GSL Trevor Alcott



RRFSE Composite Reflectivity (CREF) Convective Parameterization and Global Ensemble Tests

Raw 00/12z 6 hr CREF forecasts - July 2022 Retro



RRFS CREF forecasts – May 2023 Retro

Testing Impacts of Convective Parameterization (Green and Blue vs Red) and Global Ensemble GDAS/GEFS on RRFSE (Green vs Blue)

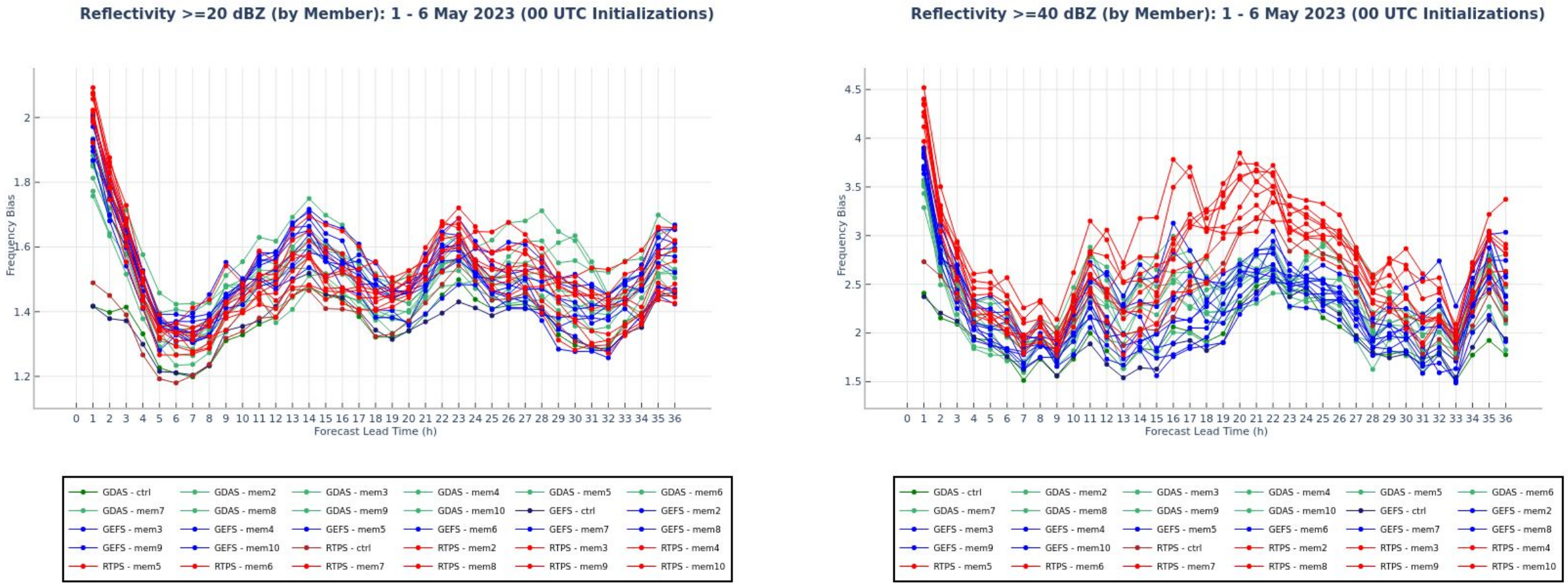
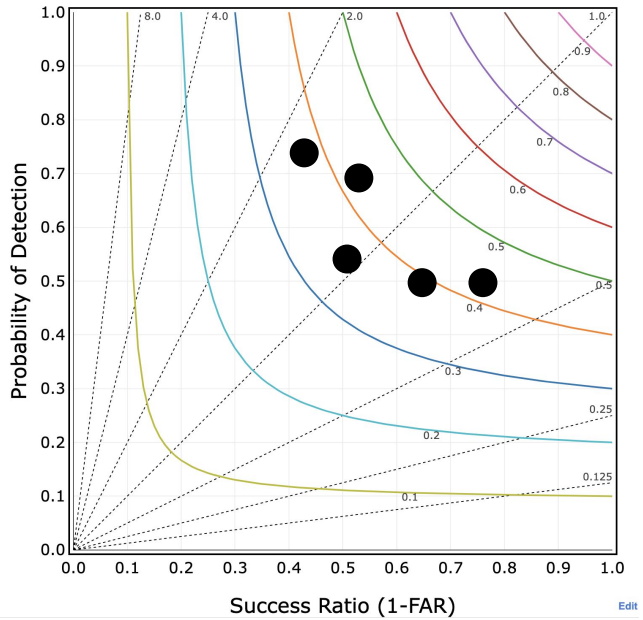


Figure courtesy DTC Jeff Beck

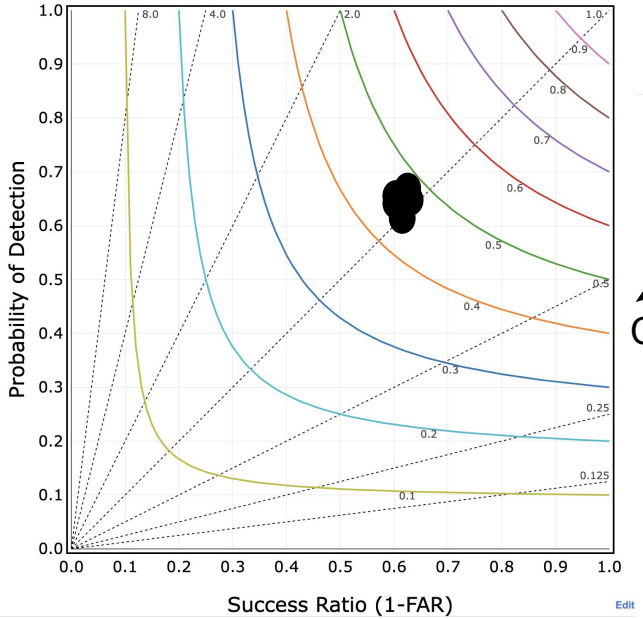
Convective parameterization reduces high reflectivity bias particularly at higher thresholds
Smaller differences between GDAS vs GEFS

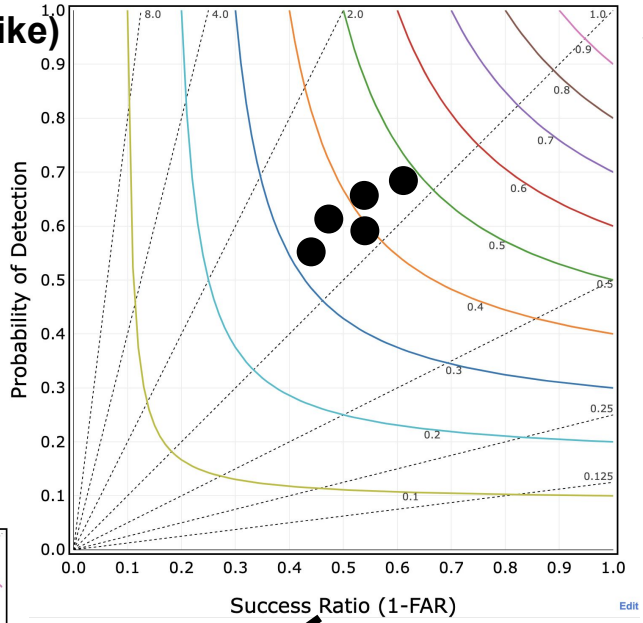
Schematic of Ensemble Design Skill



Mixed Physics/Models/ICs (HREF-like)

- Collection of control members
- Bias a function of member
- Bias correction removes spread
- Skill varies by member
- Not all members equally likely
- Careful selection/maintenance of multiple physics suites needed





Single Physics/Model/Perturbed ICs

- Single control member
- Bias uniform across members
- Bias correction doesn't have to remove spread
- Skill doesn't vary by member
- All perturbed members equally likely
- Single physics suite maintained
- Stochastic physics can increase spread

Increasing sample size

Challenge is to maintain spread-skill of perturbed members

RRFS Ensemble Development Summary

- **Evaluation of RRFS ensemble designs**
  - **Time-Lagging – results generally indicate little negative or positive impact at shorter forecasts**
  - **Single vs Mixed Physics – results similar although stochastic/physics choices still iterating**
  - **GEFS vs GDAS ensemble DA initialization/use – similar results but still preliminary**
  - **Inclusion of convective parameterization – significant reduction in QPF/REFC biases**

- **Standing up more comprehensive ensemble verification, visualization and communication tools**
  - **MATS, METplus, DESI**
  - **Mix of experimental and operational guidance inputs for comparisons**