High-Resolution Rapid Refresh (HRRR) Model: Some Results and an Outlook

Dave Turner

NOAA's Atmospheric Science for Renewable Energy Program Manager

ASRE is a Large Team

- **Global Systems Lab**
  - Joe Olson
  - Stan Benjamin
  - Curtis Alexander
  - Ken Fenton
  - Eric James
  - Terra Ladwig
  - Mike Toy

- **Physical Sciences Lab**
  - Jim Wilczak
  - Laura Bianco
  - Irina Djalalova
  - Bianca Adler
  - Tim Myers

- **Global Monitoring Lab**
  - Kathy Lantz
  - Joe Sedlar
  - Laura Riihimaki
  - Kelly Balmes

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  - Alan Brewer
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  - Tim Myers

Student Interns

Jake Lindblom (South Dakota School of Mines)
Allison van Ormer (Univ North Carolina at Charlotte)
Reagan Mendeke (Univ Oklahoma)

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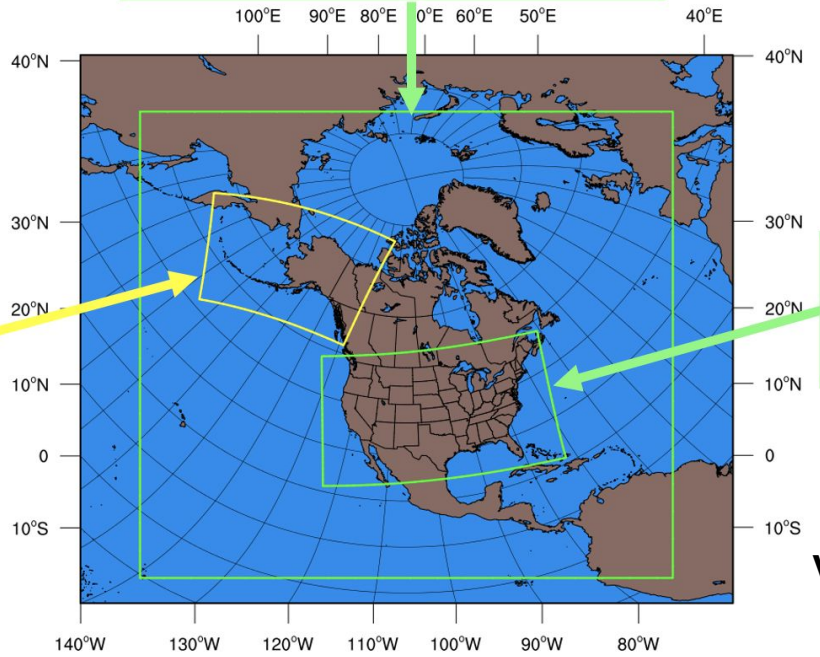
ASRE-related Model Improvement

RAP/HRRR: *Hourly-Updating* Weather Forecast Suite

13-km Rapid Refresh (RAPv5) – forecasts out to 51h

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh Alaska (HRRR-AK) – forecasts out to 48 hr



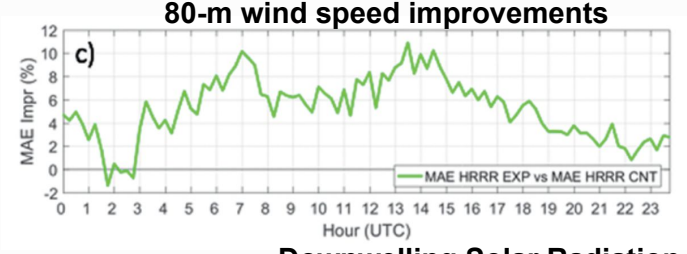
Initial & Lateral Boundary Conditions

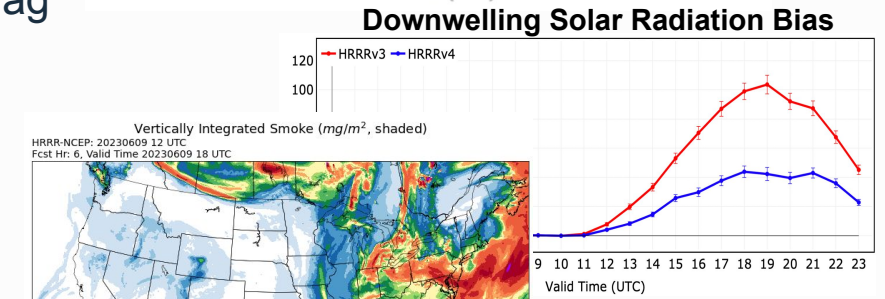
3-km High-Resolution Rapid Refresh (HRRRv4) – forecasts out to 48h

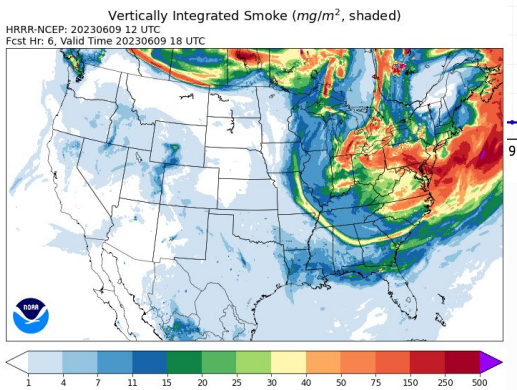
Version 4 became operational at NWS in Dec 2020

Primary Improvements to HRRR.v4

- Extended maximum forecast lengths to 48 h
- Local mixing lengths
- Non-local mixing via mass flux improvements
- Implementation of small-scale gravity wave drag
- Improved treatment of subgrid-scale clouds
- Large reduction of shortwave radiation bias
- Smoke emission / transport from wildfires
- New vertical advection scheme
- Improved conservation of variables
- Improvements to stability functions
- Coupled atmospheric model to a wave model



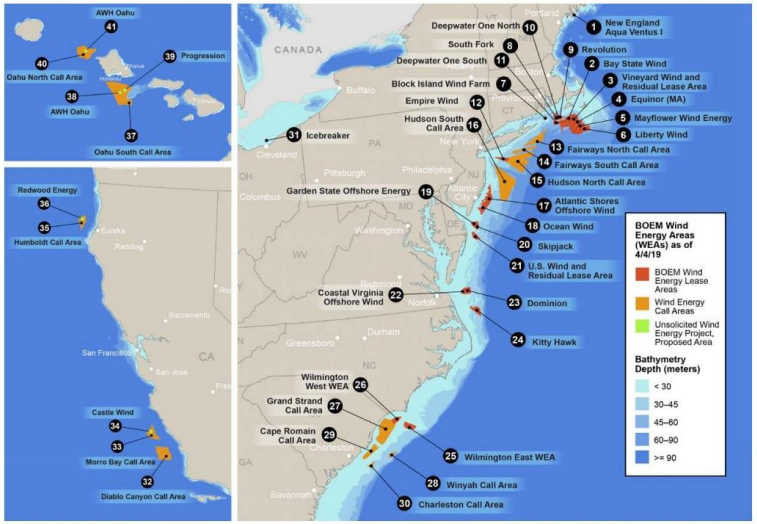


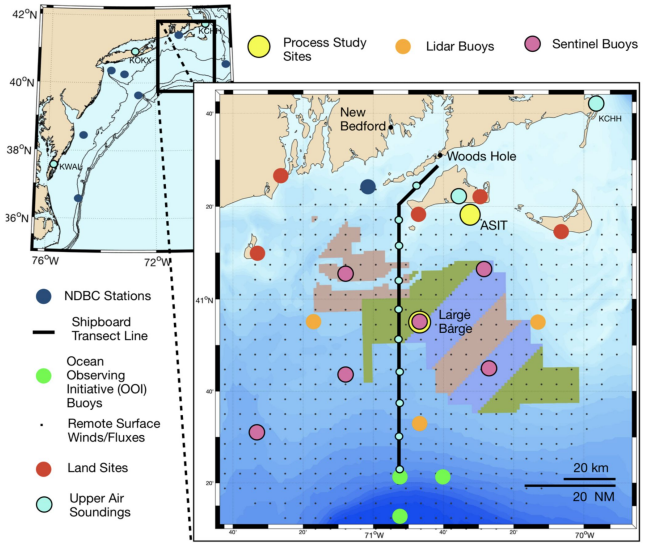


- *Taking a unified approach to improve the model (wind and solar, all seasons and locations, regional and global, etc) which is resulting in marked forecast improvements*

Application #1: Offshore wind forecasts

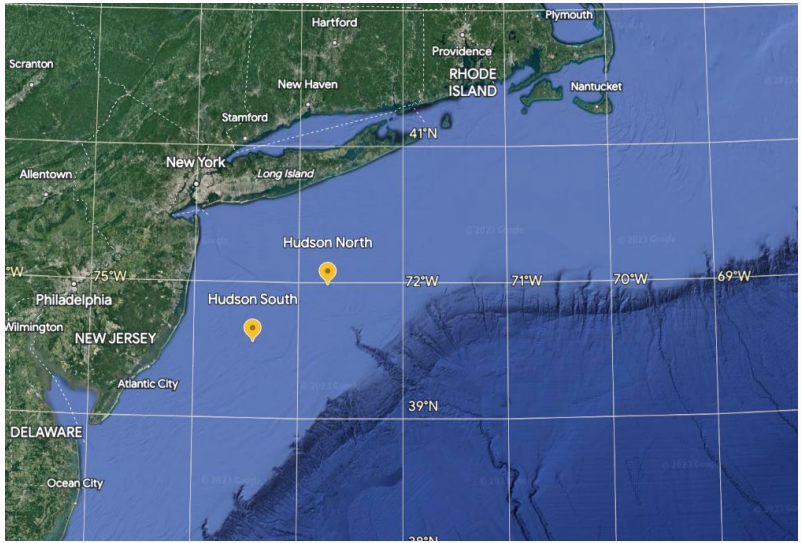
- Wind Forecast Improvement Projects (WFIP) -- joint field campaign and analysis with DOE
- WFIP-1 (2011-2012) focused on model initialization
- WFIP-2 (2016-2017) focused on improving model performance in complex terrain
- WFIP-3 (2024-2025) is targeting offshore wind characterization
    - Expect to see a huge increase in offshore wind generation in next decade
    - Improve understanding of physical processes that directly affect wind resources off the US East Coast
    - Incorporate this new understanding into foundationa





Application #1: Offshore wind forecasts

- Initial evaluation of 80-m wind speed forecasts from HRRR using buoy-mounted Doppler lidars
- 14 months of data from Jan 2021 to Mar 2022



Courtesy of Tim Myers and Allison van Ormer

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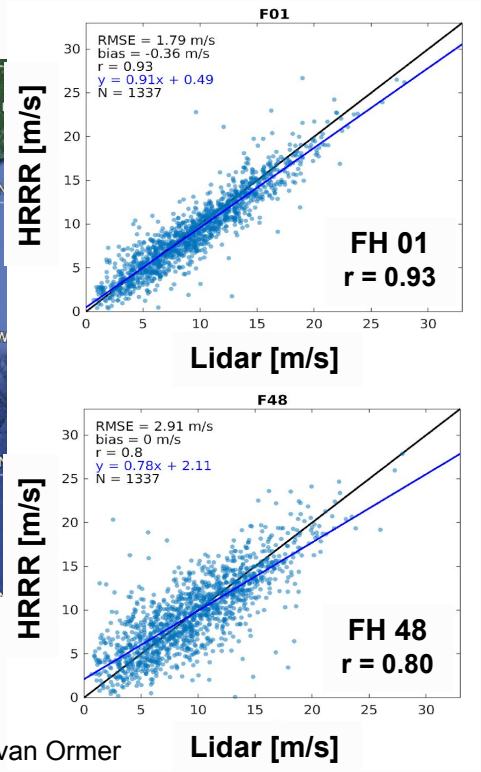

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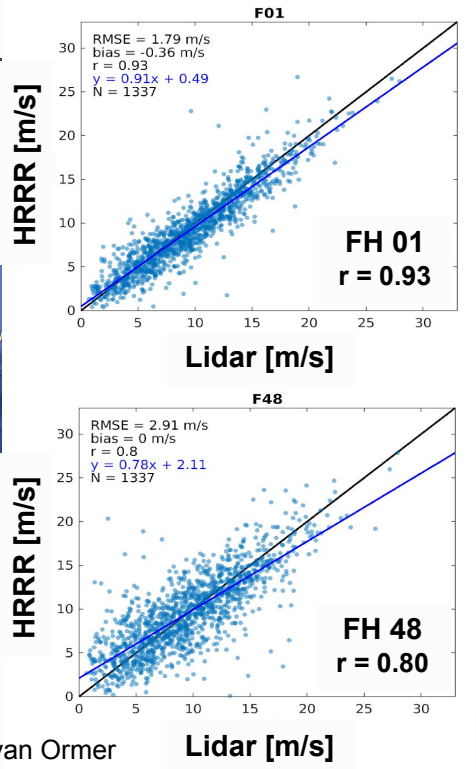
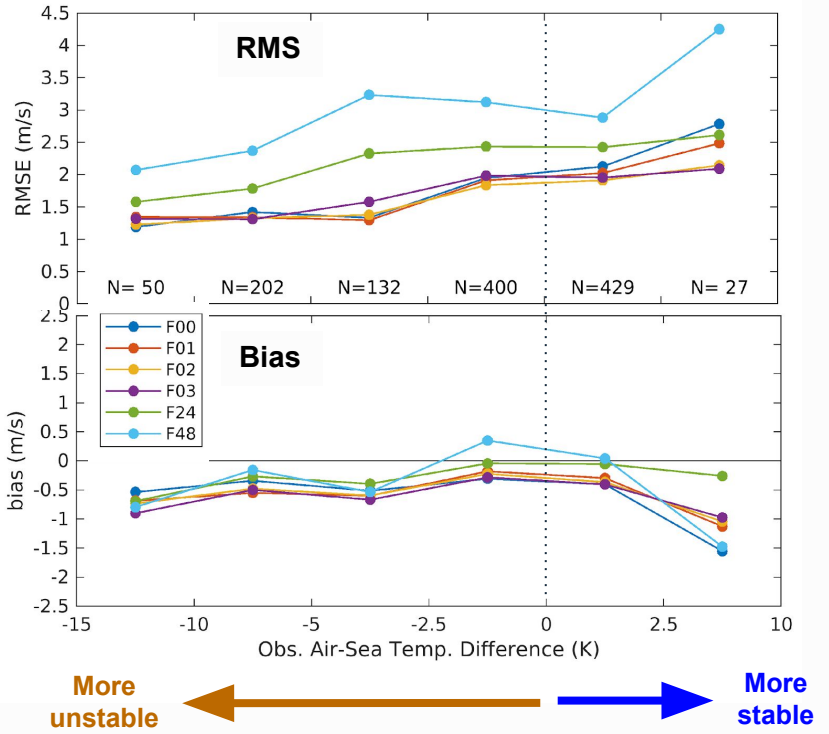
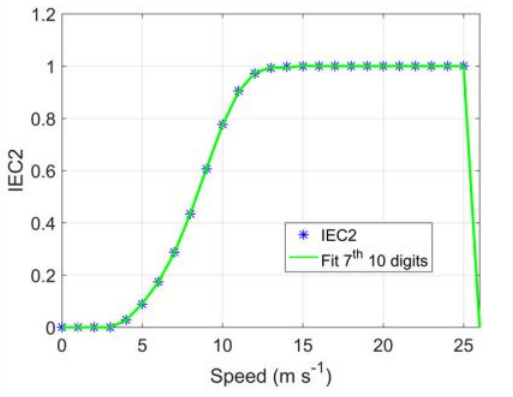




Courtesy of Tim Myers and Allison van Ormer

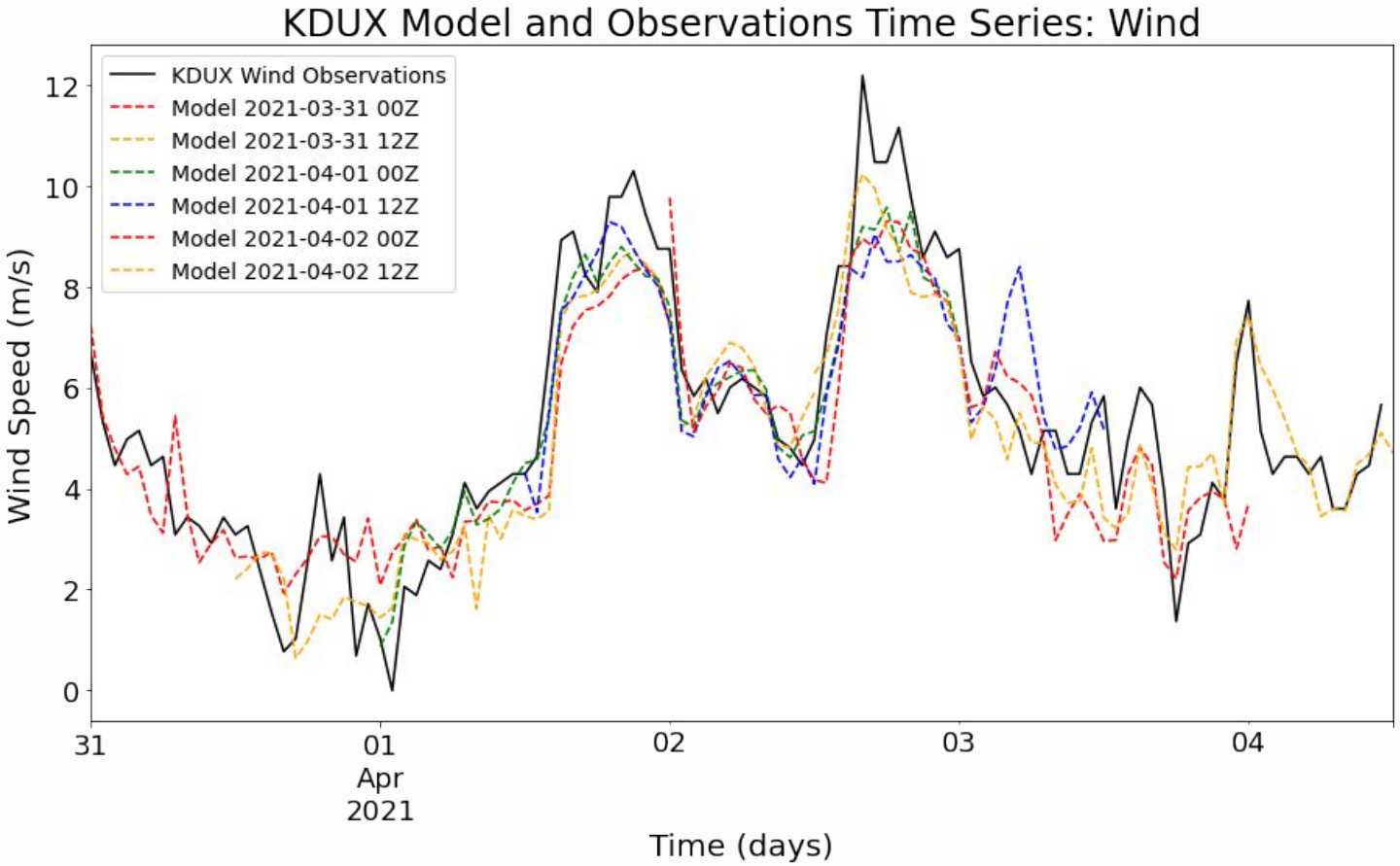
Application #2: Land-based wind ramp forecasts

- Forecasting rapid changes in wind-produced power (ramps) very important when integrating wind energy into the electric grid
- Verifying a NWP's ability to forecast the existance / intensity of wind ramps is not usually done
- Student project: look at wind ramp forecast from HRRRv4 in the Central Plains
  - Use 10-m level as a proxy for hub-height
  - Only evaluate the model at locations where wind turbines are within 10 km of a surface met station
  - Initial time period: Jan 2021 through Dec 2021

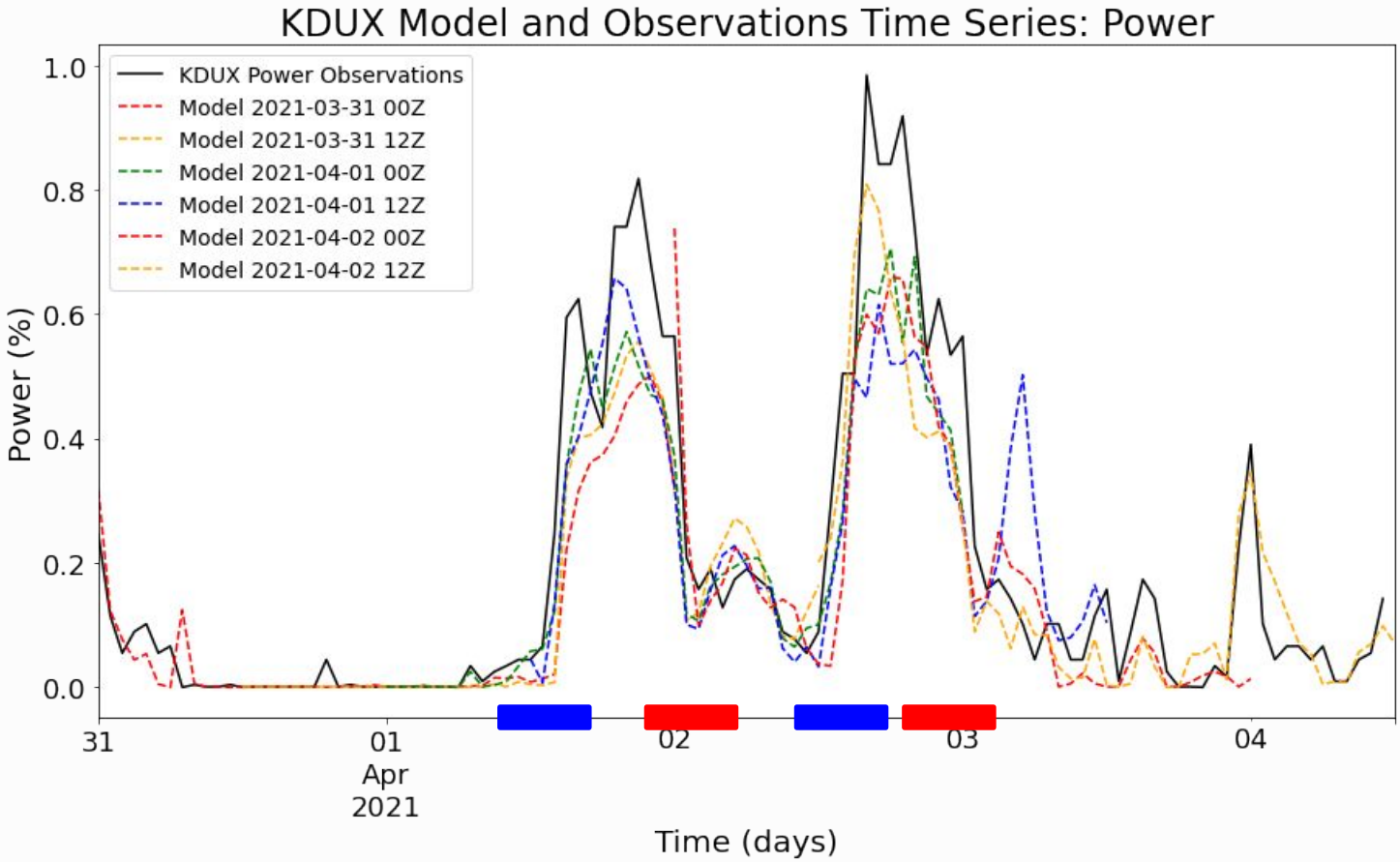


Courtesy of Jake Lindblom, Reagan Mendeke, Laura Bianco, and Irina Djaialova

Example: Changing wind speeds over 4 days…

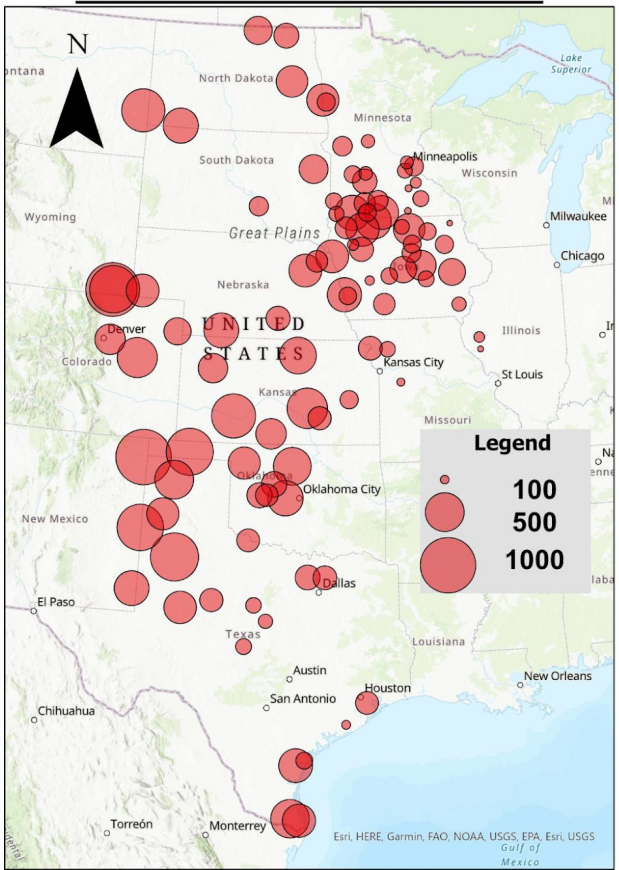


Example: ...results in 2 up-ramps and 2 down-ramps



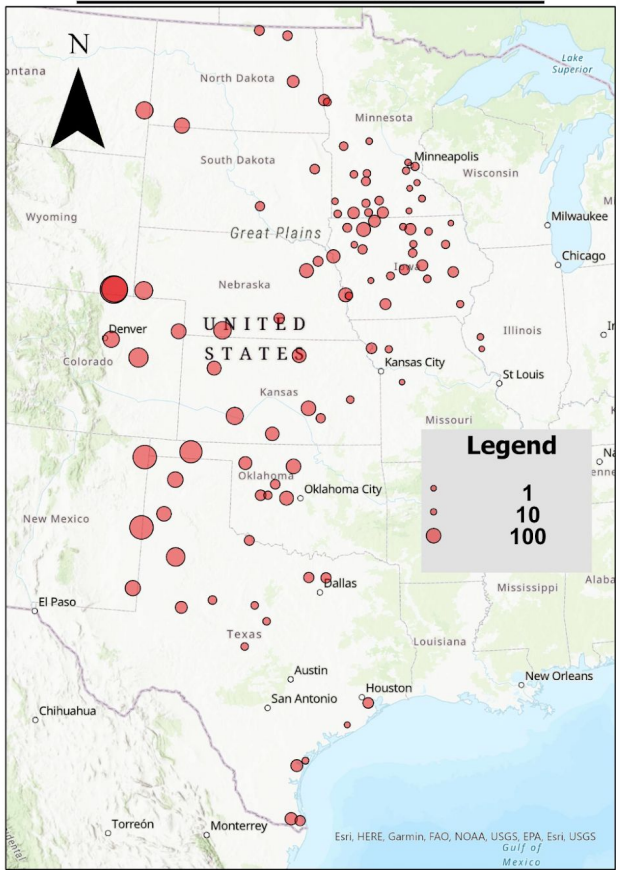
Number of Ramp Events in 2021 by $\Delta Power/\Delta Time$

ΔPower/ΔTime = 30% / 120 min



Ramp Events Distribution

ΔPower/ΔTime = 60% / 120 min



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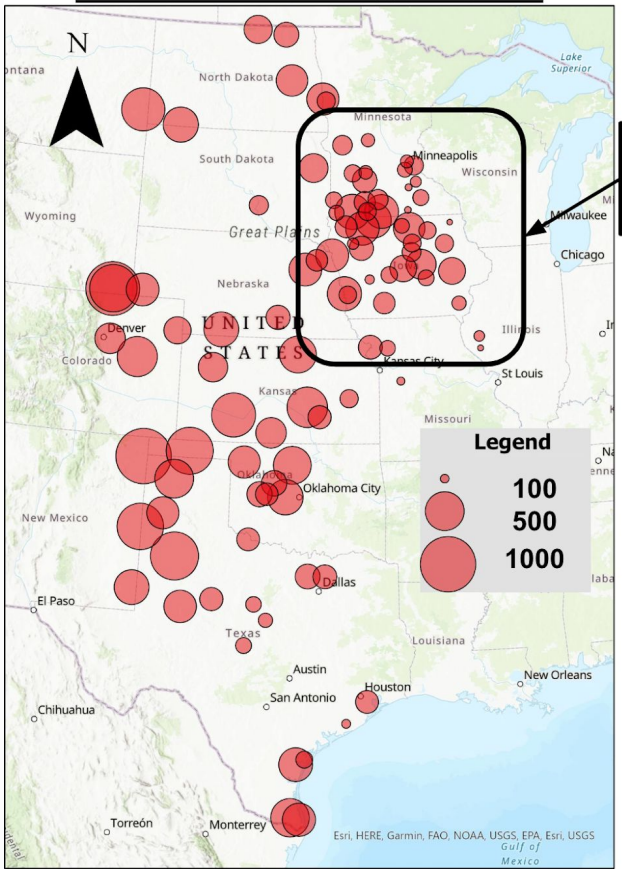
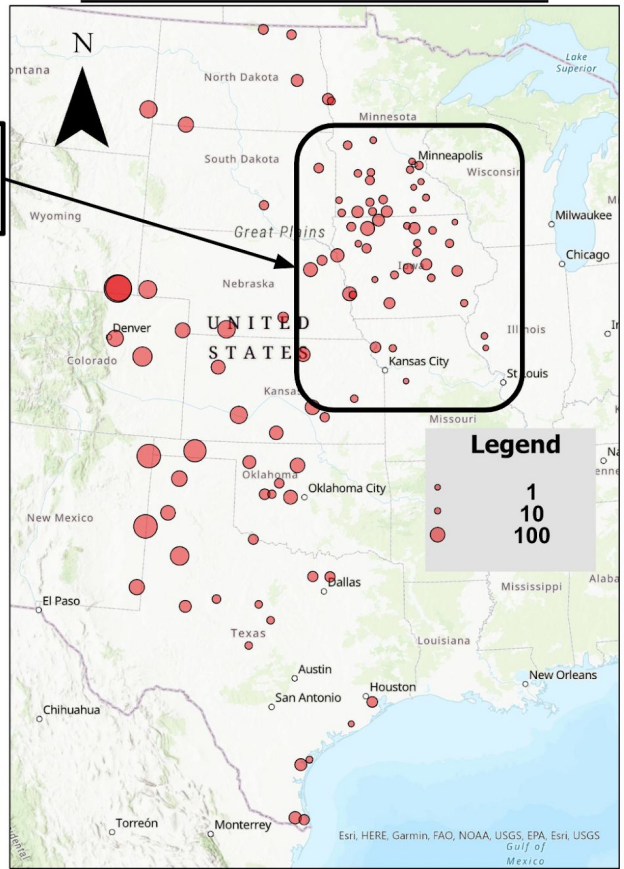


Ramp Events Distribution

Lower Frequencies
- **MN/IA/MO region**

ΔPower/ΔTime = 60% / 120 min



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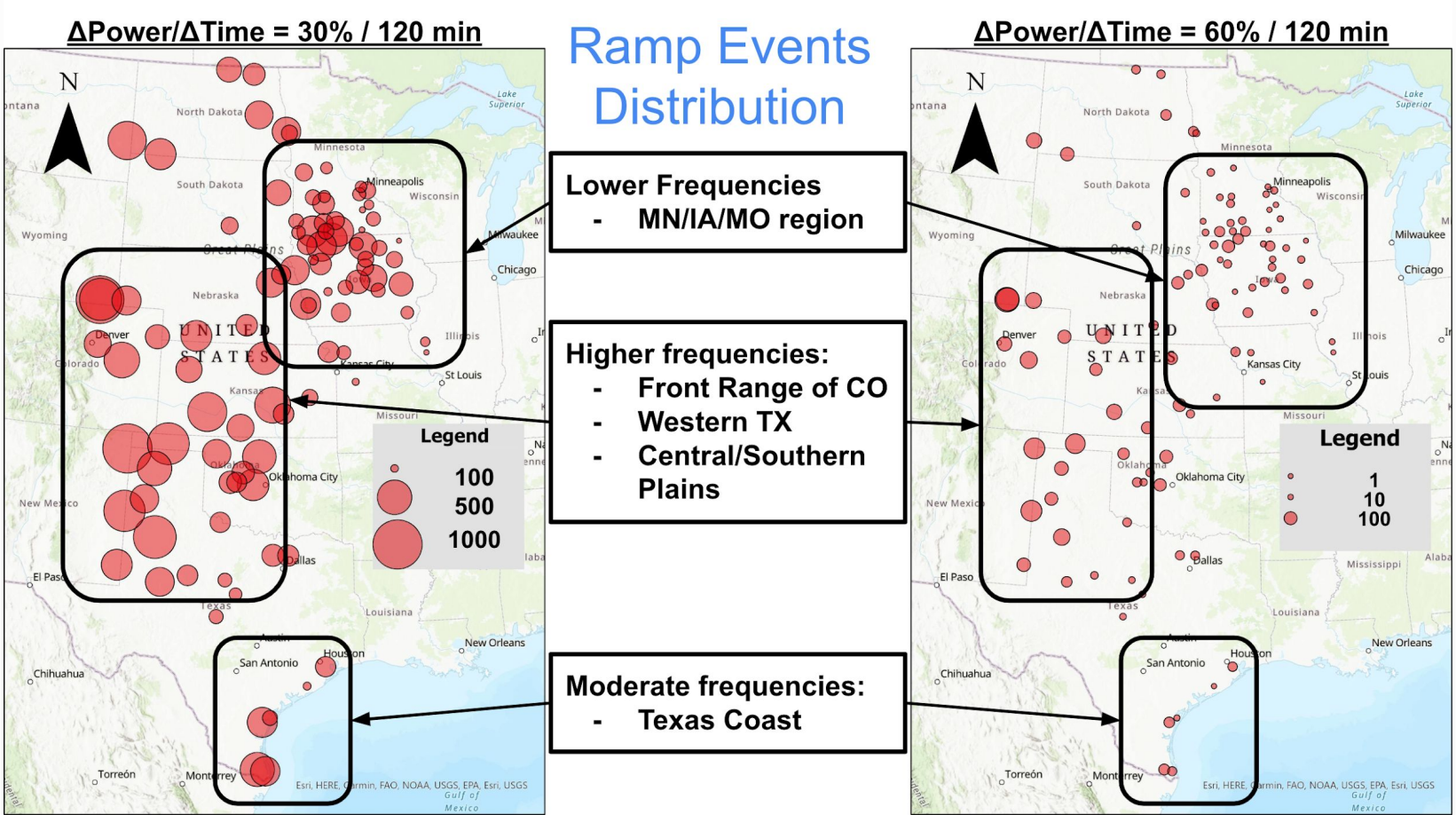
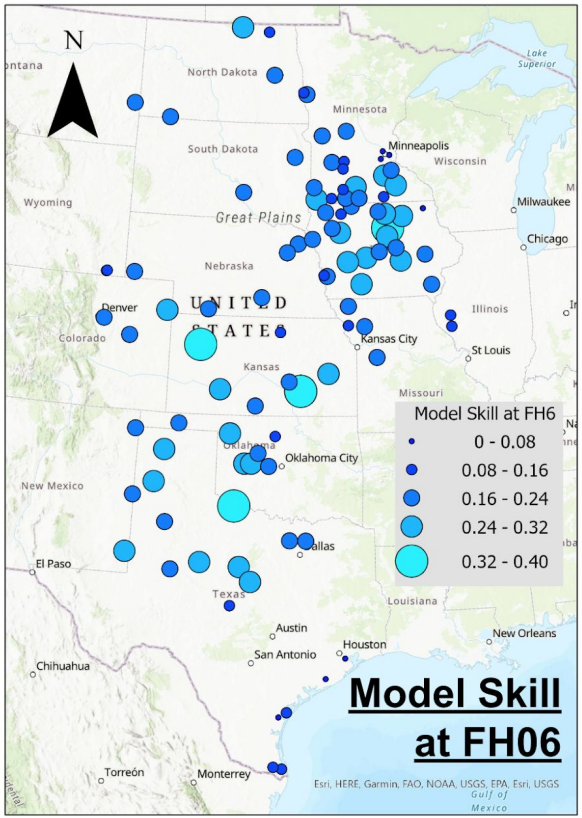
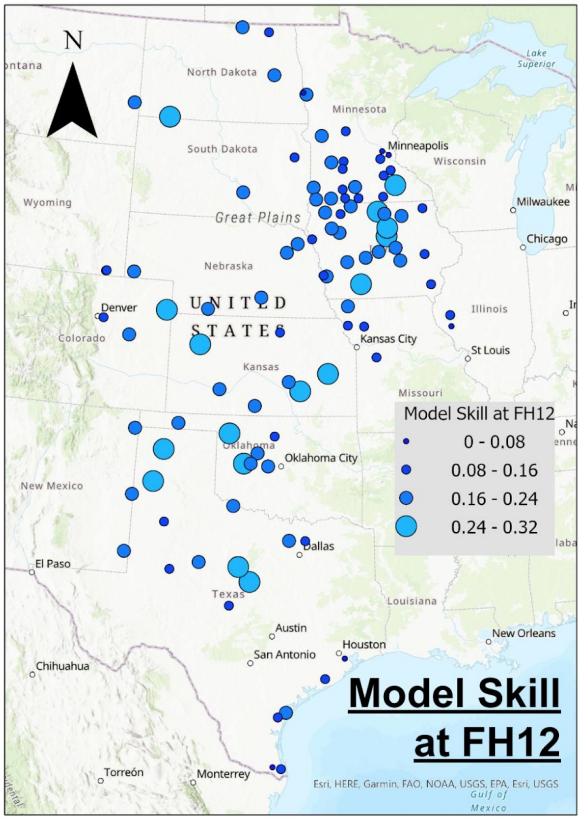


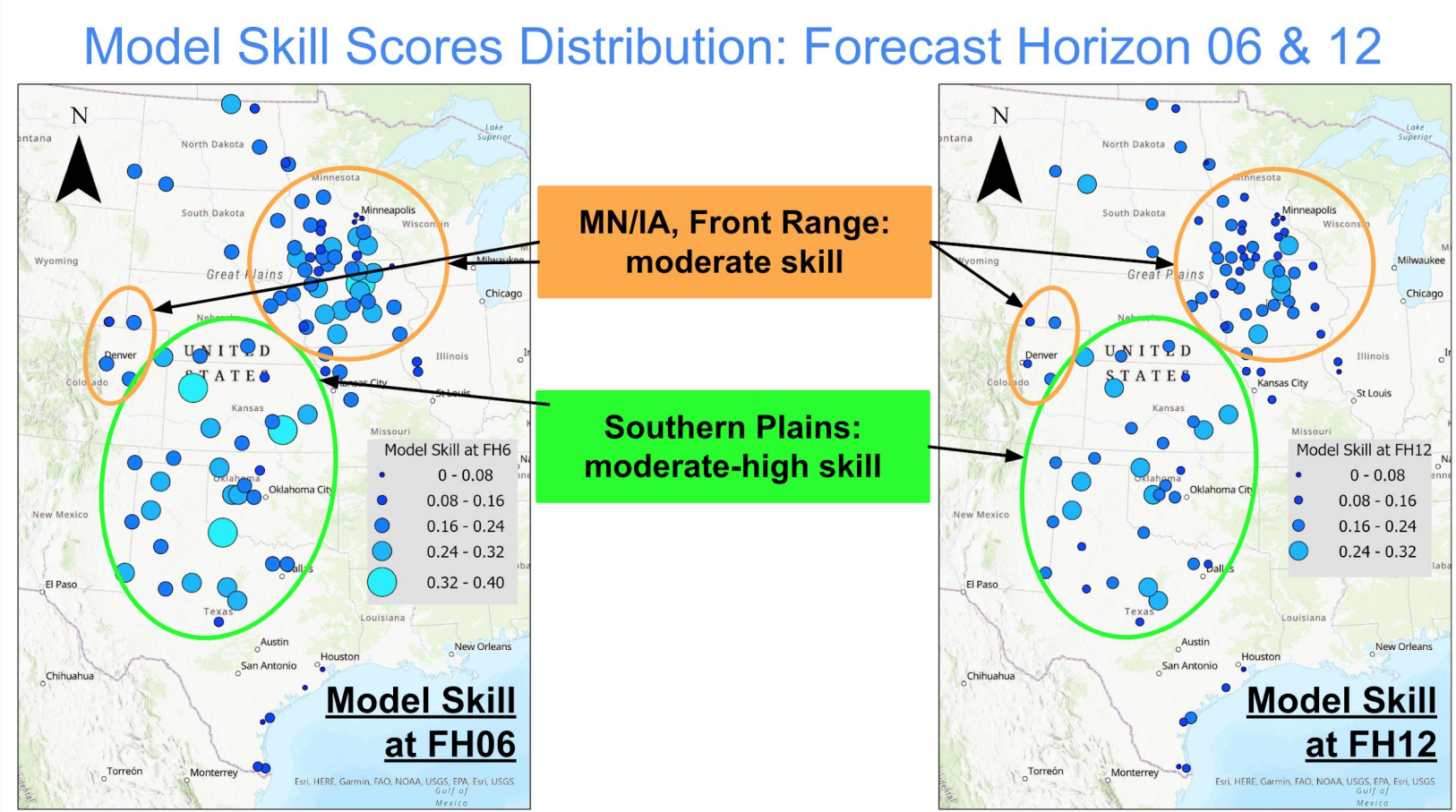
Model Skill Score: Forecast hours 06 and 12

Model Skill Scores Distribution: Forecast Horizon 06 & 12



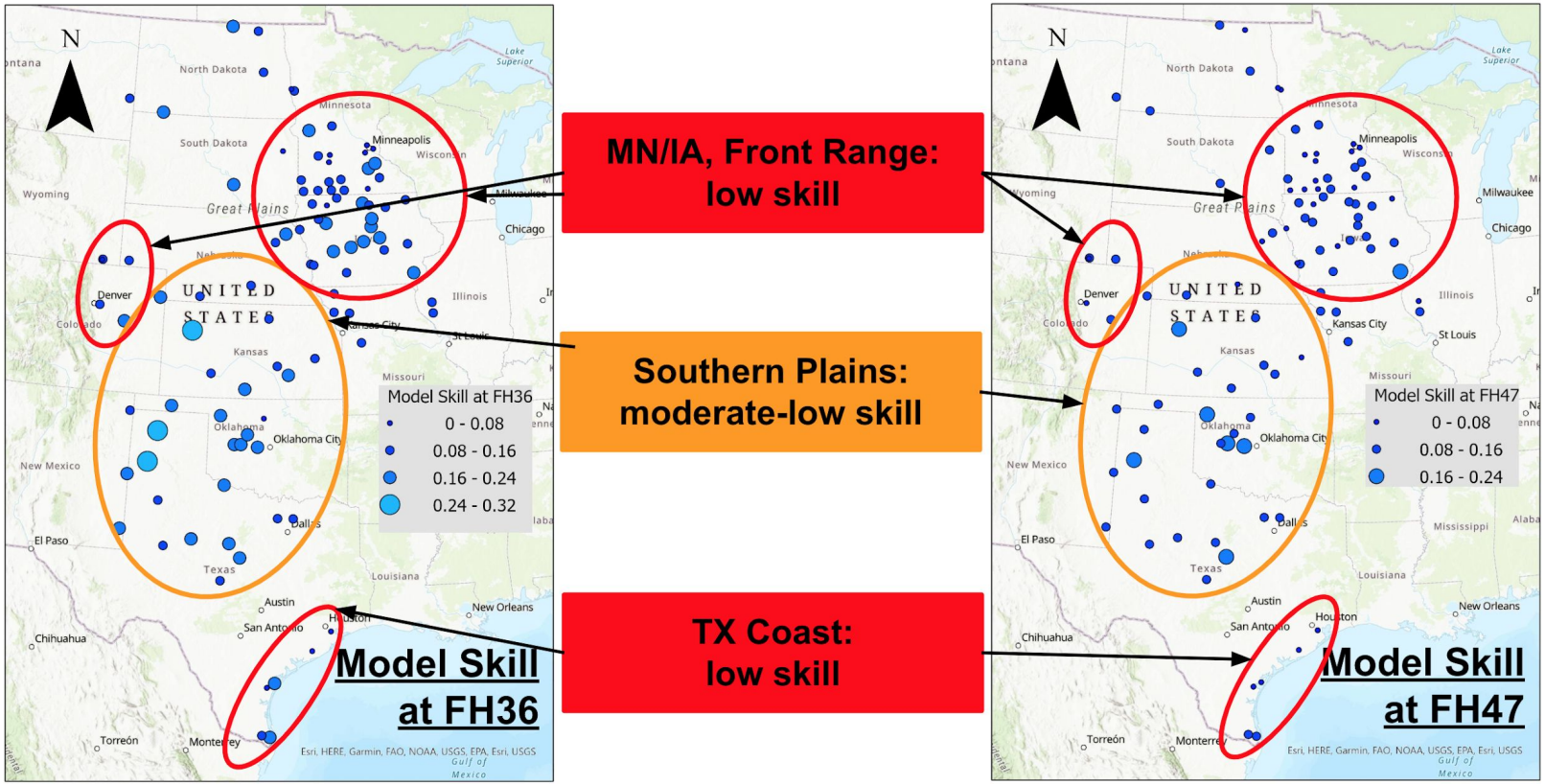


Model Skill Score: Forecast hours 06 and 12



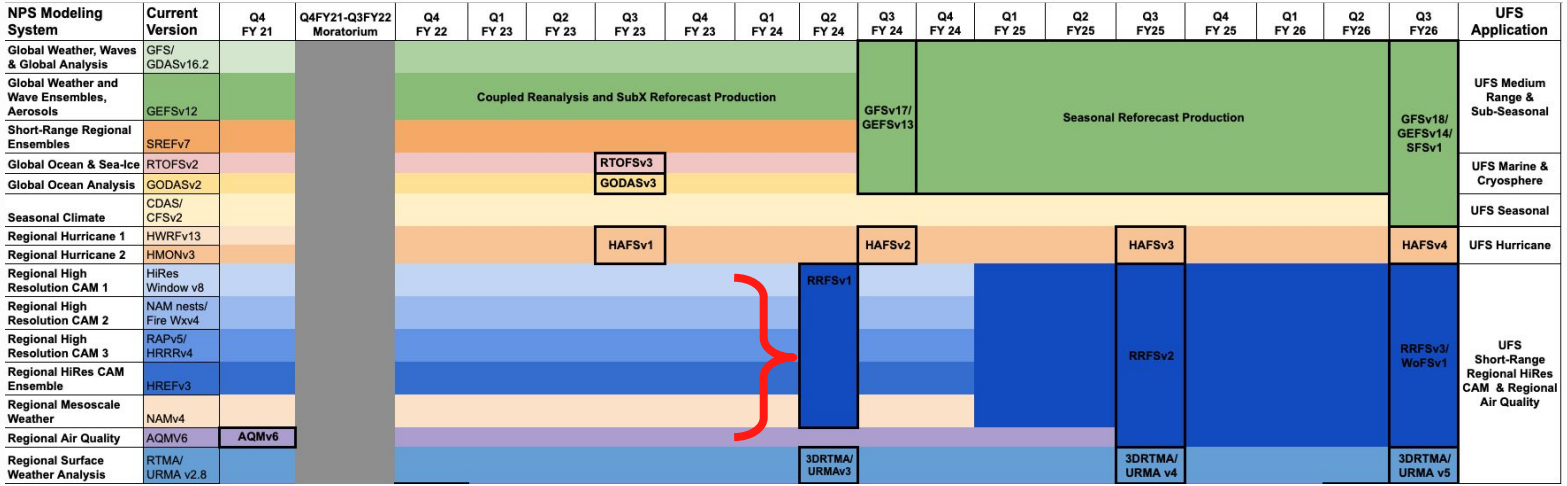
Model Skill Score: Forecast hours 36 and 47

Model Skill Scores Distribution: Forecast Horizon 36 & 47



NOAA's Future Storm-scale Operational Model

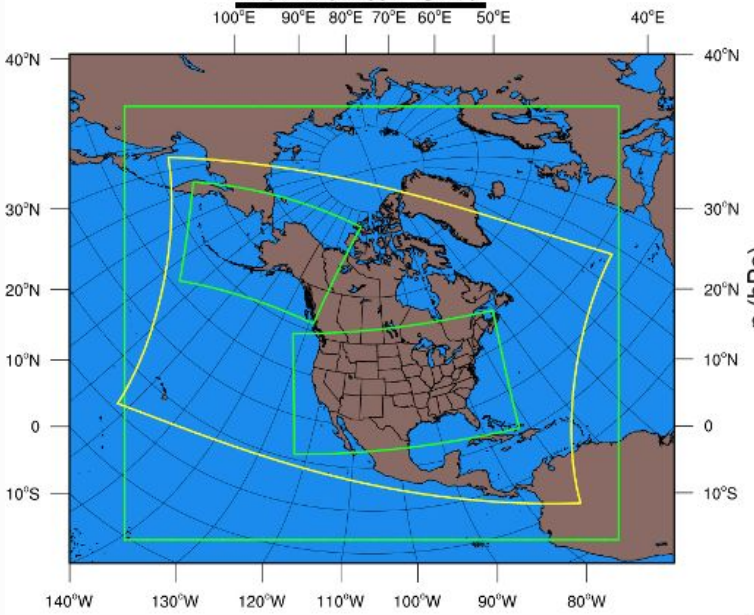
- Moving towards a Unified Forecast System (UFS)
- Common dynamic core used in all models (FV3 adopted)
- Global Forecast System already using FV3 (operational 2019)
- Rapid Refresh Forecast System (RRFS) being developed to replace the HRRR
- Target: RRFS replaces HRRR (and all other NOAA storm-scale models) in Nov 2024



RRFS Design Elements

Big Domain!

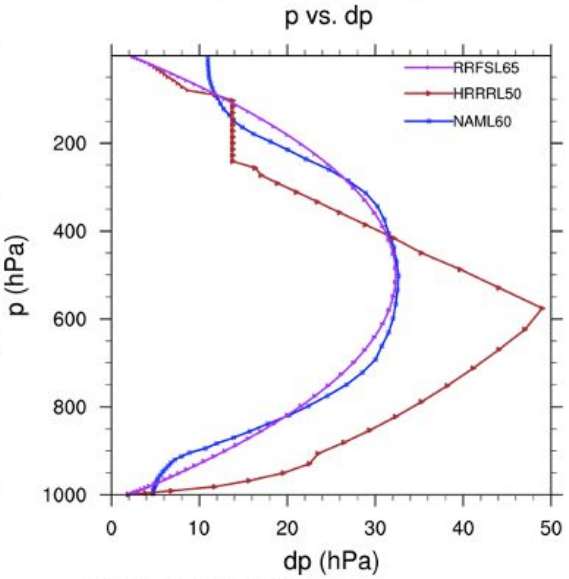
Horizontal Grid



- GFS→RAP→HRRR (three distinct integration domains)
- GFS→RRFS (two distinct integration domains)
- Larger CAM domain covering oceanic regions

Better Vertical Resolution

Vertical Grid



- 65 vertical levels
- More vertical resolution than HRRR
- Higher model top (2 mb) than HRRR
- Same lowest level (~8 m AGL)

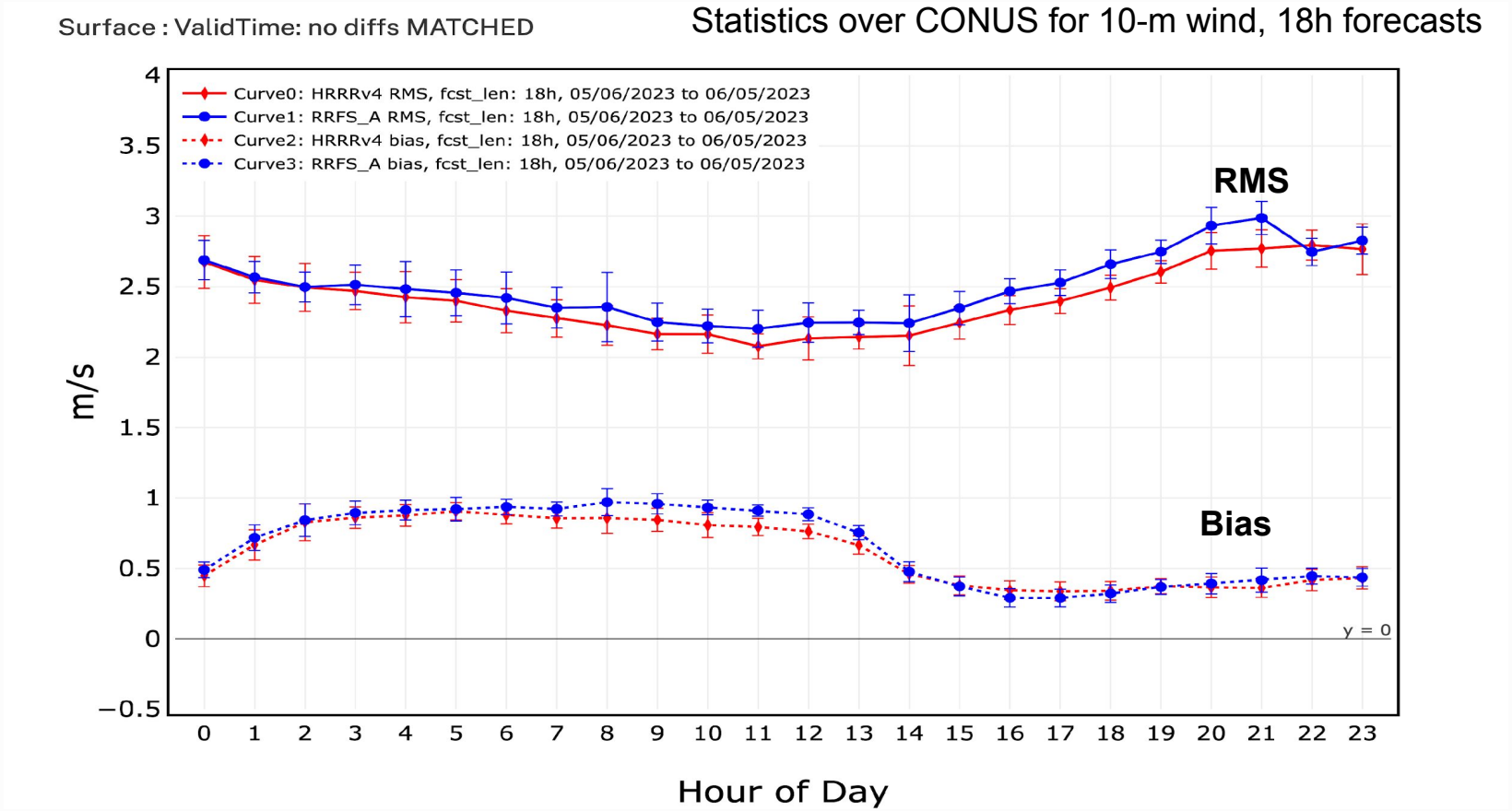
Essentially same physics

Model Physics

Physics	SCHEME	REFERENCE
PBL/Turbulence	MYNN-EDMF	Olson et al. (2019)
Surface Layer	MYNN	Olson et al. (2021)
Microphysics	Thompson-Eidhammer	Thompson and Eidhammer (2014)
Aerosols	Thompson-Eidhammer	Thompson and Eidhammer (2014)
Shallow Convection	MYNN-EDMF	Angevine et al. (2020)
Gravity Wave Physics	UGWP.v1: Small Scale and Turbulent Orographic Form Drag	Toy et al. (2021)
Land Model	Noah-MP	Niu et al. (2011)
Land Use	VIIRS	-
Large Lakes	FVCOM	Fujisaki-Manome et al. (2020)
Small Lakes	FLake	Mironov (2008)
Near-Surface Sea Temperature	NSST	Fairall et al. (1996), Derber and Li (2018)
Long and Short Wave Radiation	RRTMG[2]	Iacono et al. (2008), Mlawer (1997)

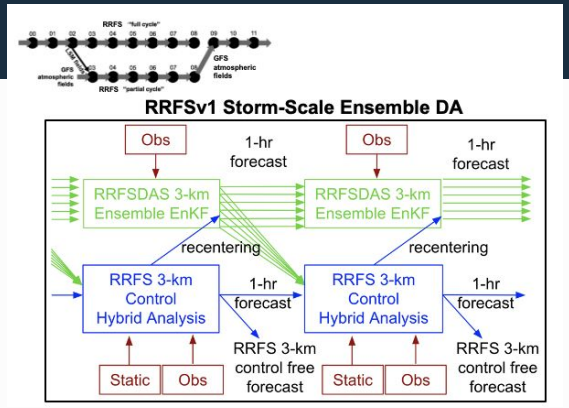
- Origin largely in HRRR physics
- Adopting CCPP interface

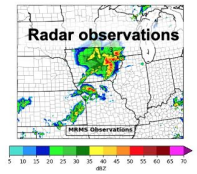
Wind Speed Comparison: HRRRv4 vs RRFS

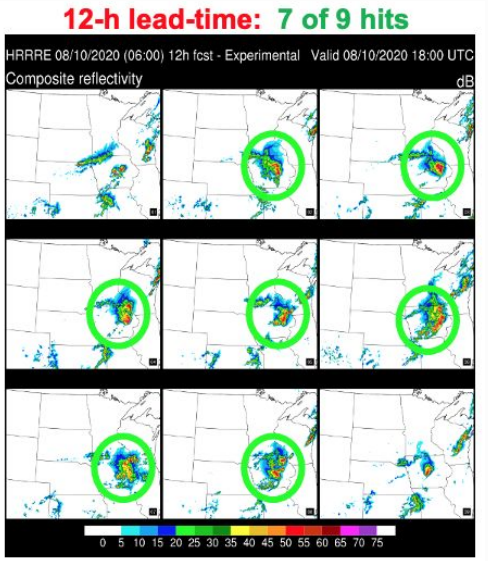


More RRFS Features

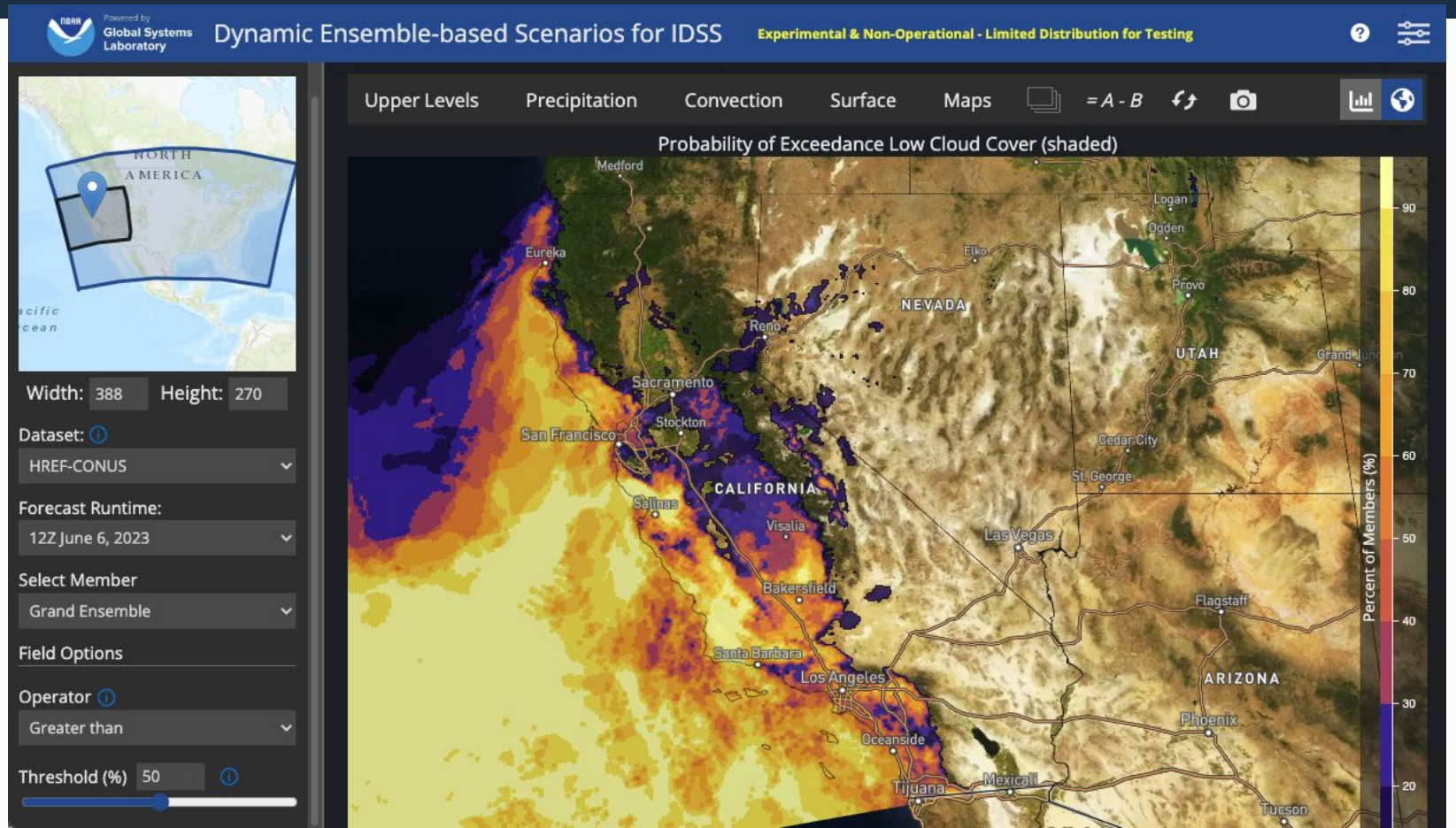
- Assimilates many different types of observations
  - Profiles (radiosondes, aircraft, profilers)
  - Radar and lightning
  - Surface (land-based and from buoys/ships)
  - Satellite
- Improved storm-scale ensemble DA method
- Land-surface “moderately coupled” DA
- Cloud DA (non-variational currently; working to improve)
- Post-processing diagnostics (e.g., wind gust potential)
- Ensemble predictions
  - 10-members, each doing 60-h forecasts
  - Will be evaluating these for wind/solar energy Fx



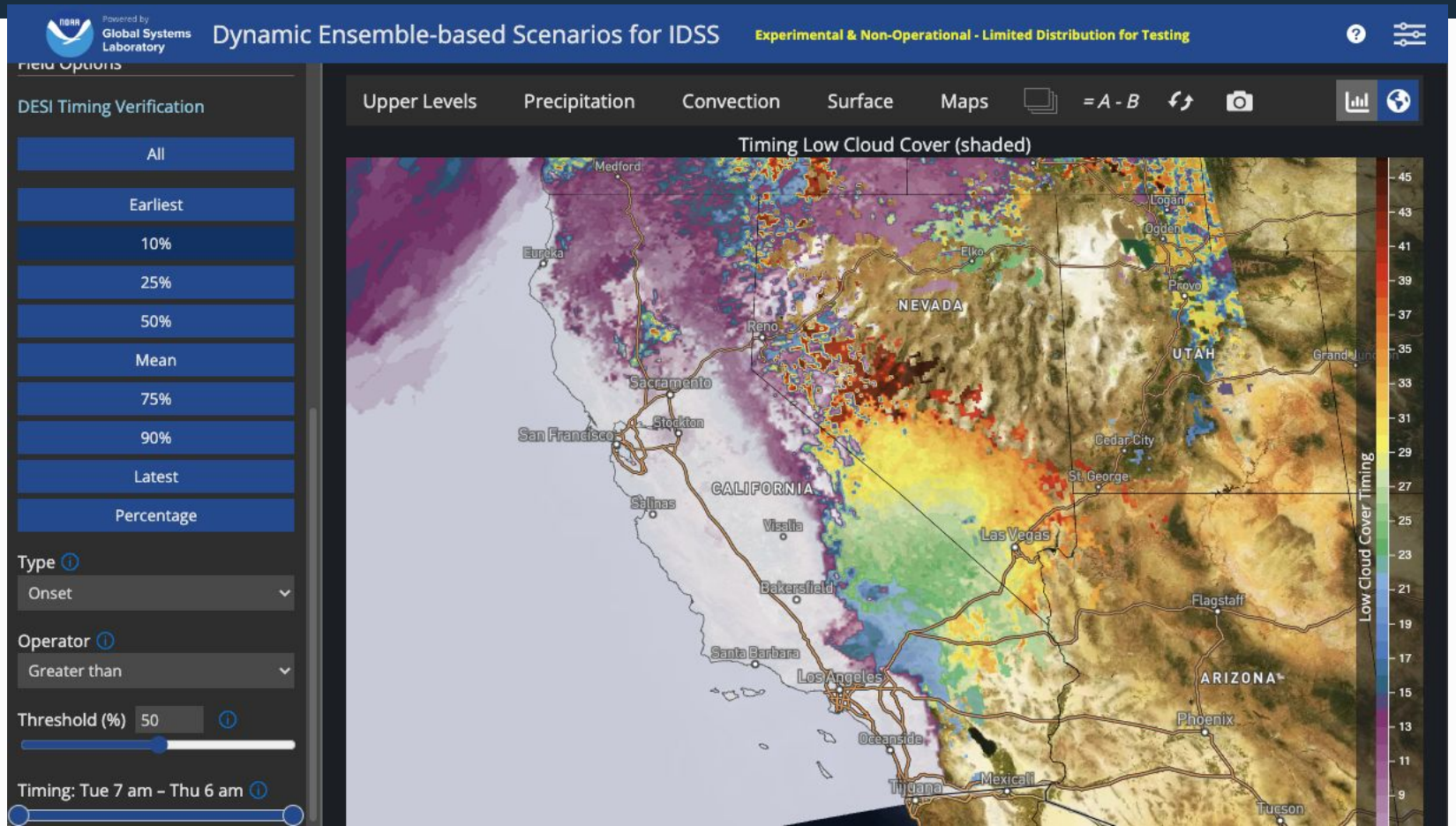




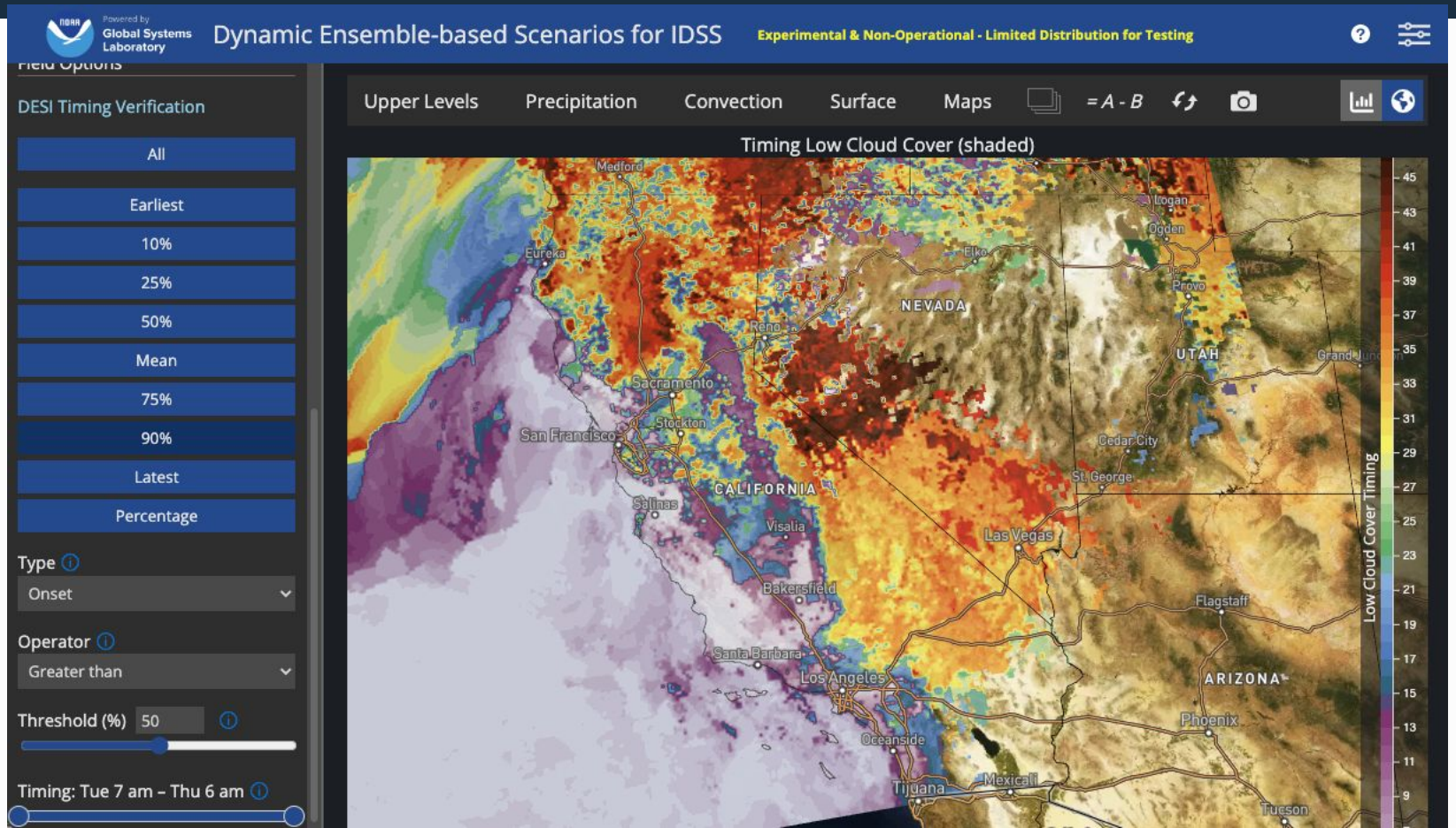
Ensemble: Probability Low Cloud Cover > 50%



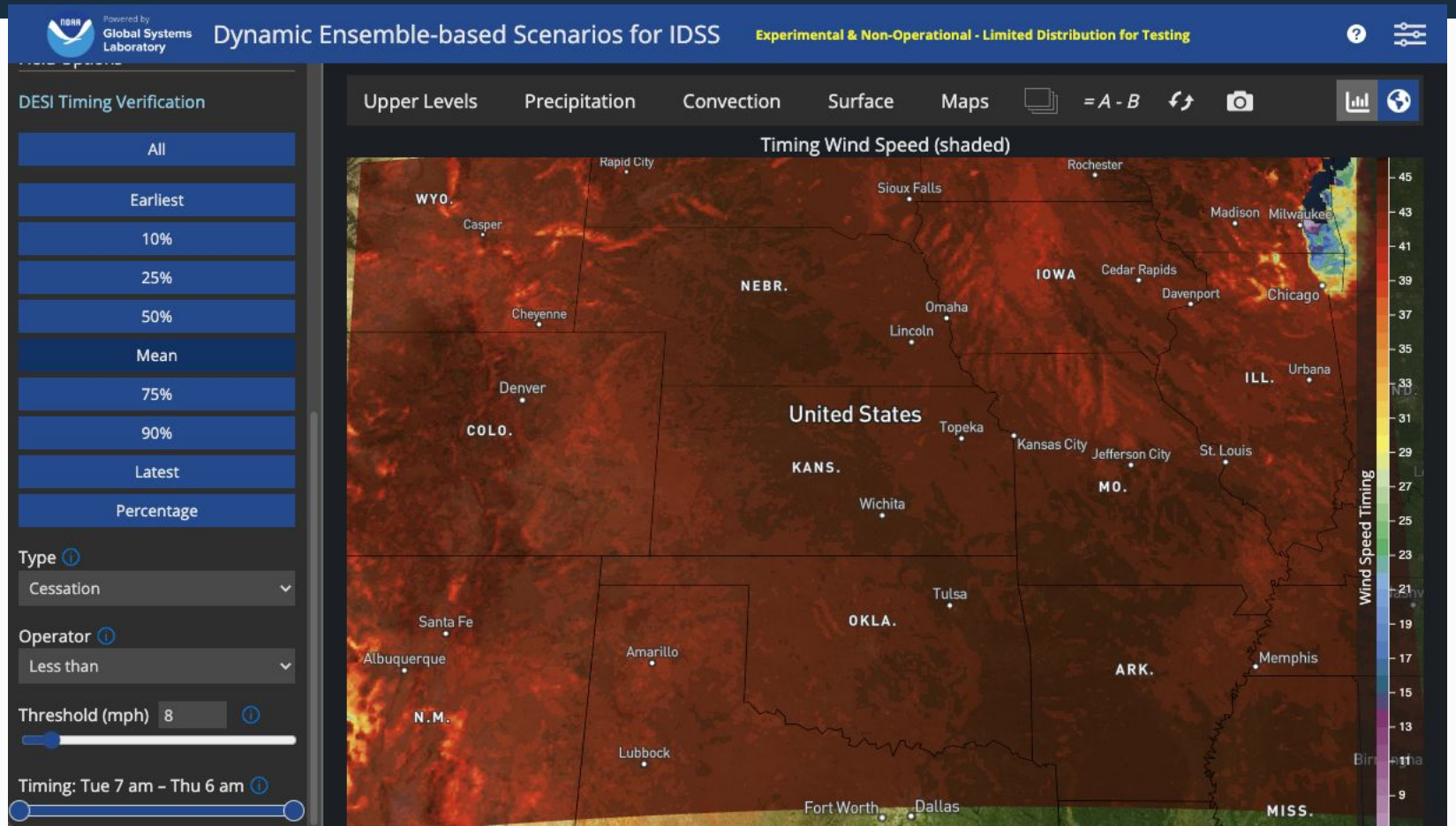
Ensemble: Low Cloud Timing (early onset)



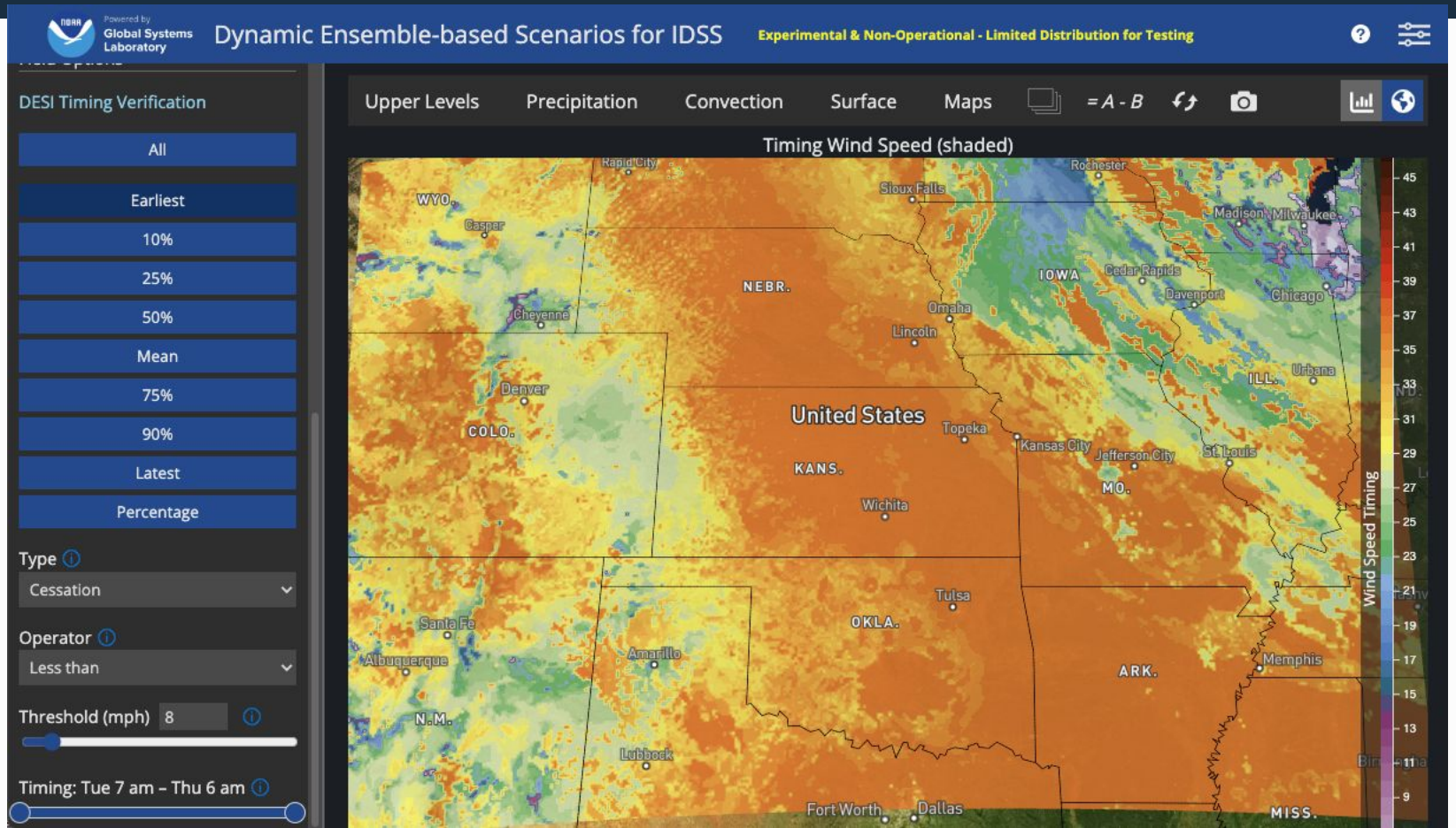
Ensemble: Low Cloud Timing (late onset)



Ensemble: WSPD > CutIn (Mean timing)



Ensemble: WSPD > CutIn (Earliest timing)



Ensemble: WSPD > CutIn (Latest timing)

Summary

Dave.Turner@noaa.gov

- Version 4 of the HRRR became operational Dec 2020
  - Longer forecasts, marked improvements to DA and physics
  - Many new / improved products: smoke (impacts on radiation), precip type
  - Decent agreement in hub-height winds off East Coast between HRRR and lidar
  - Evaluating HRRR's ability to capture wind ramp events in the central plains
- Working on RRFS now, which will tentatively replace HRRR in Nov 2024
  - Domain and model's dynamic core is different, physics is essentially from the HRRR
  - Will also include smoke forecasts, will add dust forecasts too
  - Comparison of 10-m winds across the US between HRRR and RRFS looks good
  - RRFS is an ensemble system, allowing probabilities to be assessed
  - Many ways to slice the ensemble output; e.g., fpr timing of events
- Research continues on the atmosphere-surface system (holistic approach)

Questions?

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