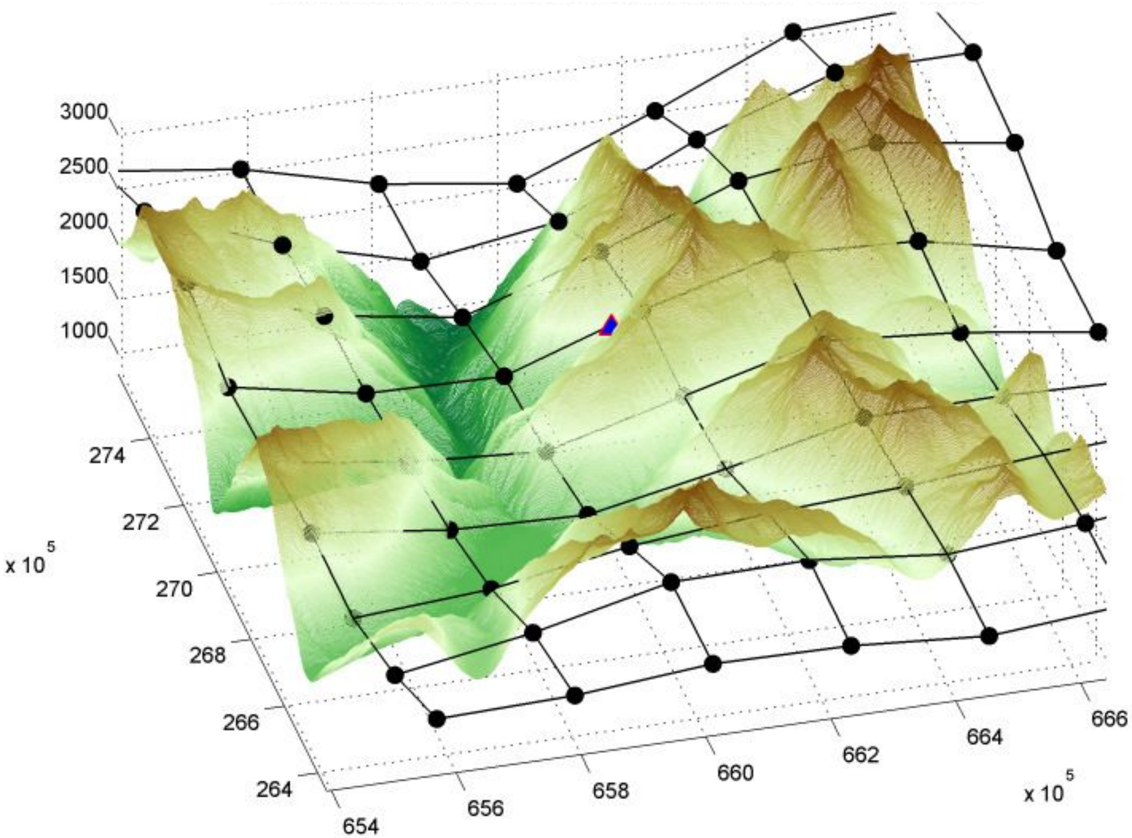
OVERVIEW OF POST-PROCESSING TECHNIQUES FOR IMPROVING ATMOSPHERIC PREDICTIONS AND EXTENDING APPLICATIONS TO SPACE WEATHER VARIABLES

Stefano Alessandrini, Nicholas Pedatella
Research Applications Laboratory (RAL), High Altitude Observatory (HAO)
NSF National Center for Atmospheric Research
(NCAR, Boulder CO)

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Model post-processing

- In many cases, models do not faithfully reproduce reality
- Systematic errors occur due to low resolution or when specific physical processes are not resolved
- **Solution**: Numerical forecasts can be corrected through post-processing



The basic idea is to determine a statistical relationship that links forecasts to reality — usually defined by in-situ measurements

Glahn, H. R., and D. A. Lowry, 1972: The use of model output statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203–1211

Statistical Post-Processing for Weather Forecasts

- **Purpose**: Corrects systematic biases and improves the reliability of raw numerical weather prediction (NWP) outputs.
- **Techniques**:
  - *Bias correction* (e.g., Model Output Statistics, quantile mapping, Analog Ensemble)
  - *Ensemble calibration* (e.g., Bayesian Model Averaging, Ensemble Model Output Statistics, Analog Ensemble)
  - *Machine learning* approaches (e.g., regression, neural networks)
- **Benefits**:
  - Sharper, more reliable forecasts
  - Improved representation of forecast uncertainty
  - Better decision-making for weather-dependent applications

RAL doing AI for Decades: DICast®

***D**ynamic*
***I**ntegrated*
*fore**Cast***
System

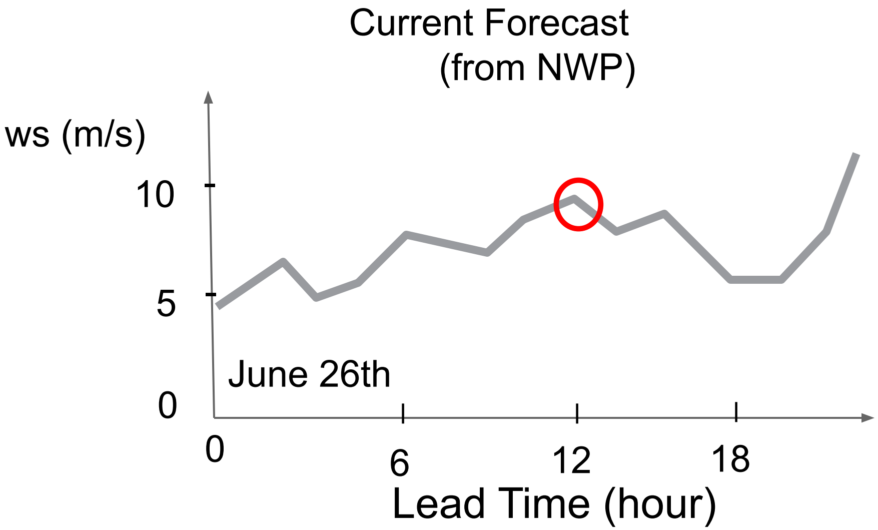
DICast® In a Nutshell

- *Machine-Learning Post-processer of model data*
  - *Create predictive relationships between model output,*

Recent Advances:
- Probability of Precipitation
- Uncertainty quantification
- Cloud ceiling added as tuned variable
- Tune MSLP and GHI using 2 km global analysis

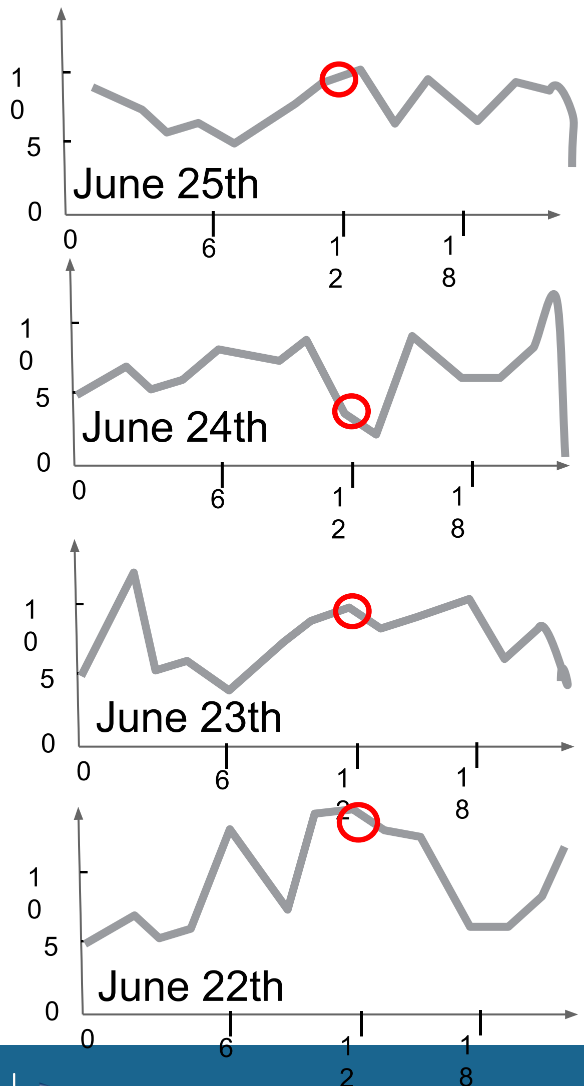
- *Originally developed for The Weather Channel (now The Weather Company - part of IBM) to produce public-oriented forecasts*
- *Development started in 1999 in Research Applications Program*
- *Used in many other projects*

The AnEn algorithm

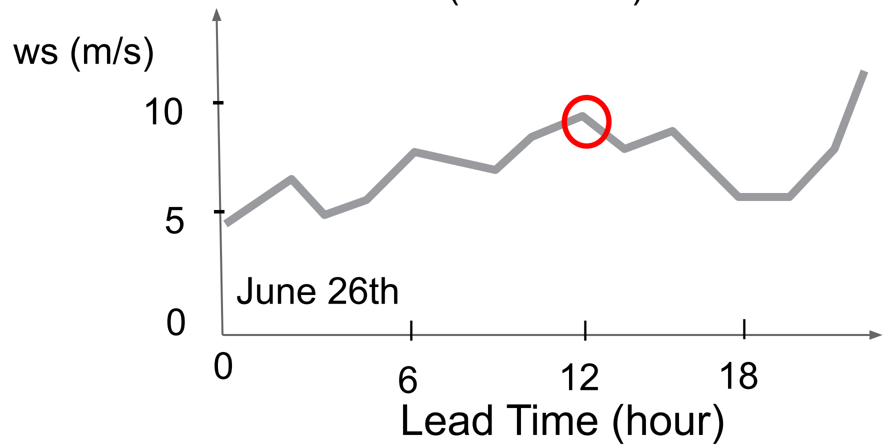


The AnEn algorithm

Past Forecasts

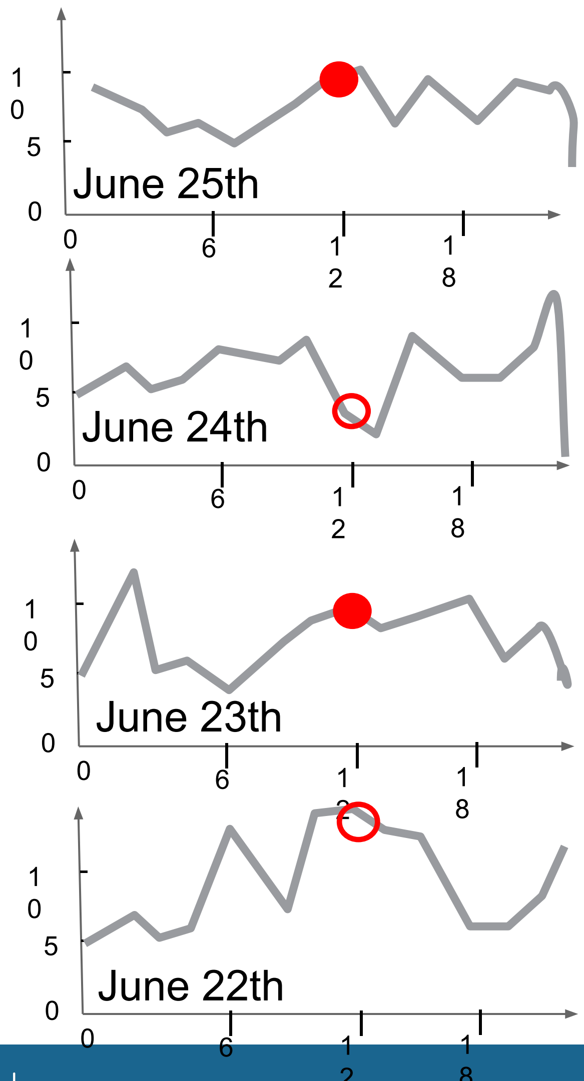


Current Forecast
(from NWP)

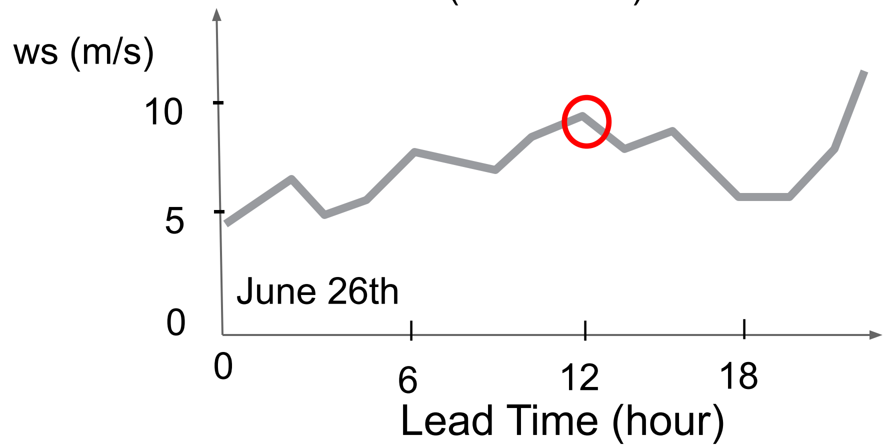


The AnEn algorithm

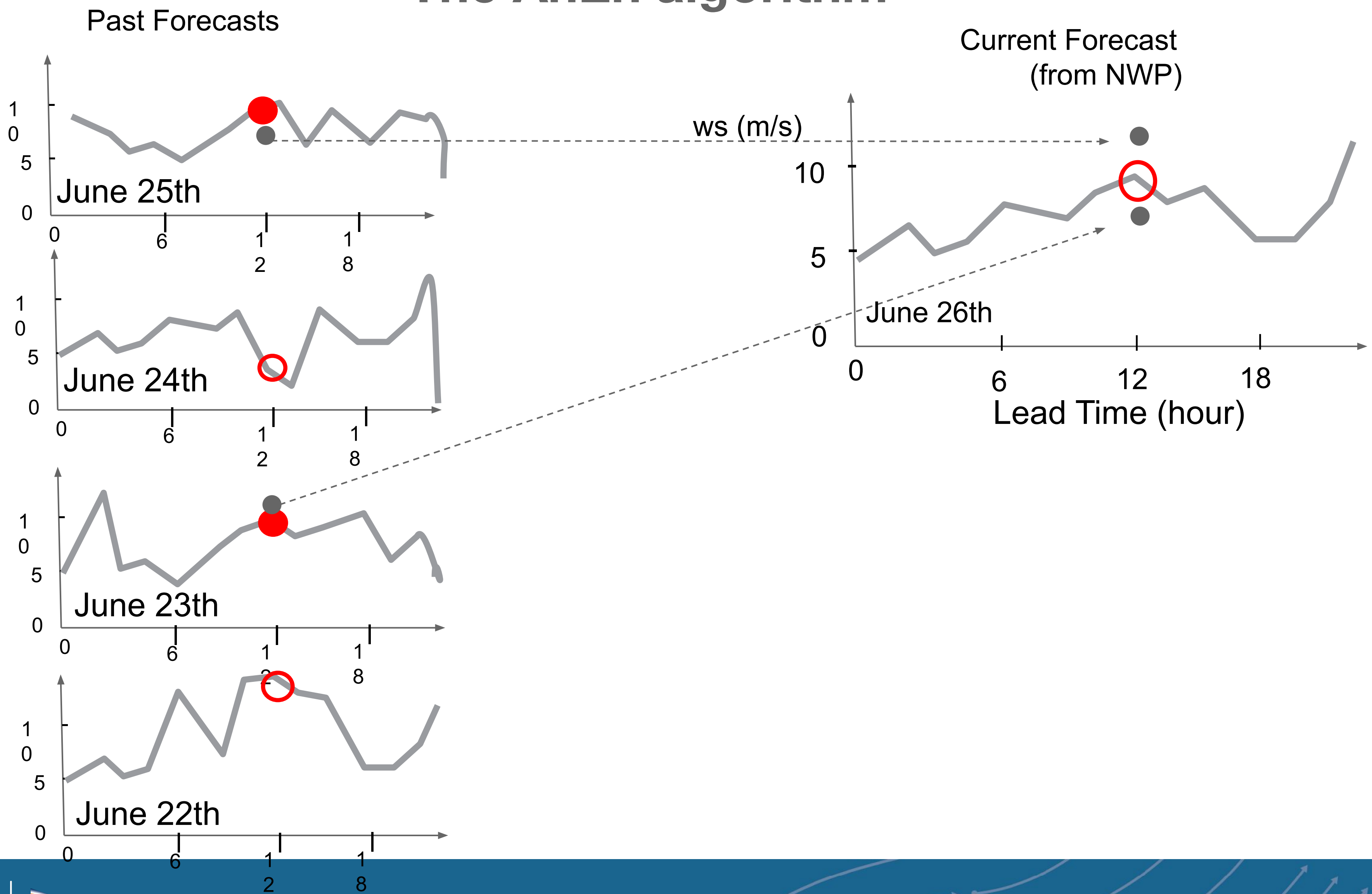
Past Forecasts



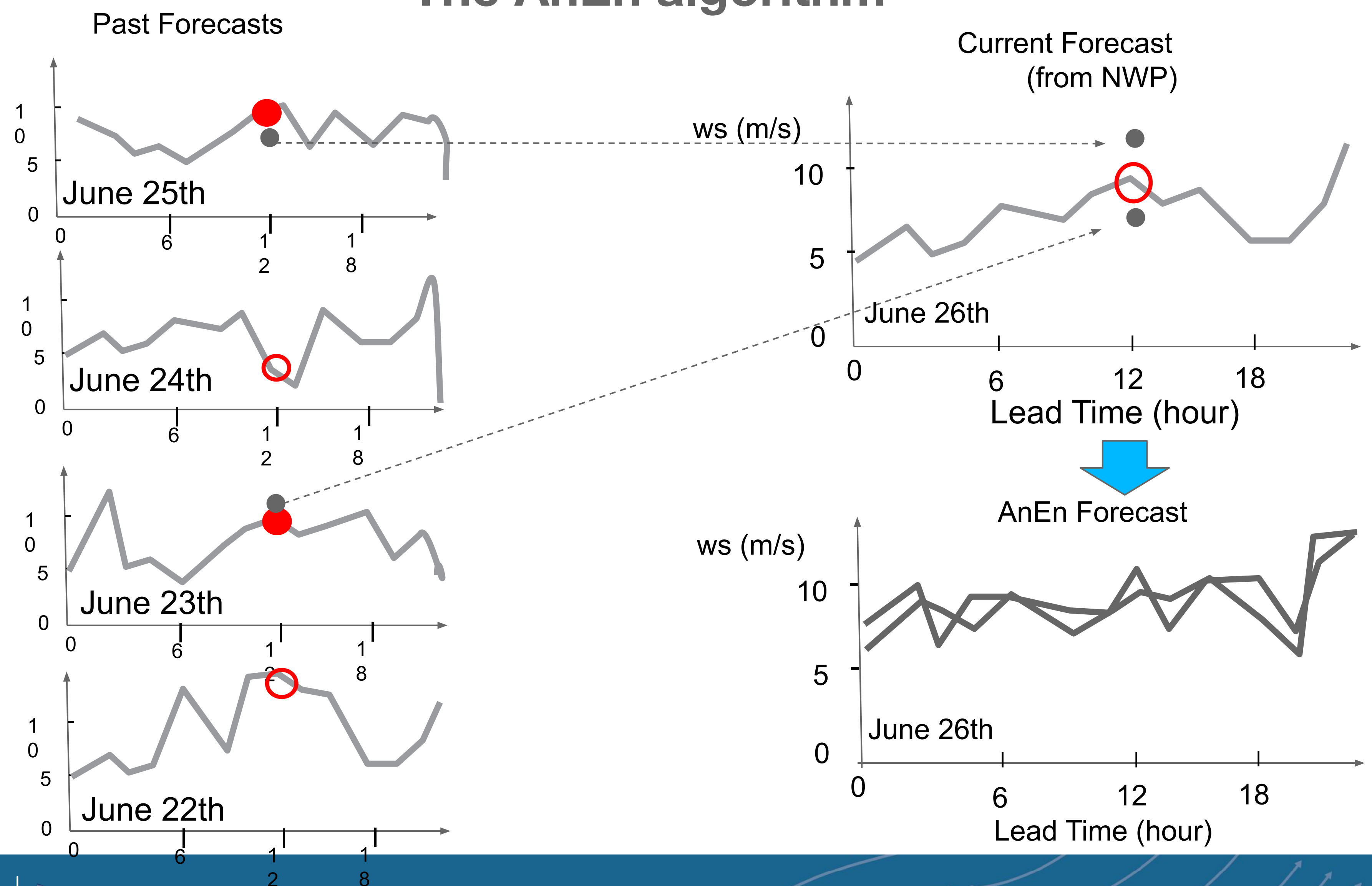
Current Forecast
(from NWP)



The AnEn algorithm



The AnEn algorithm



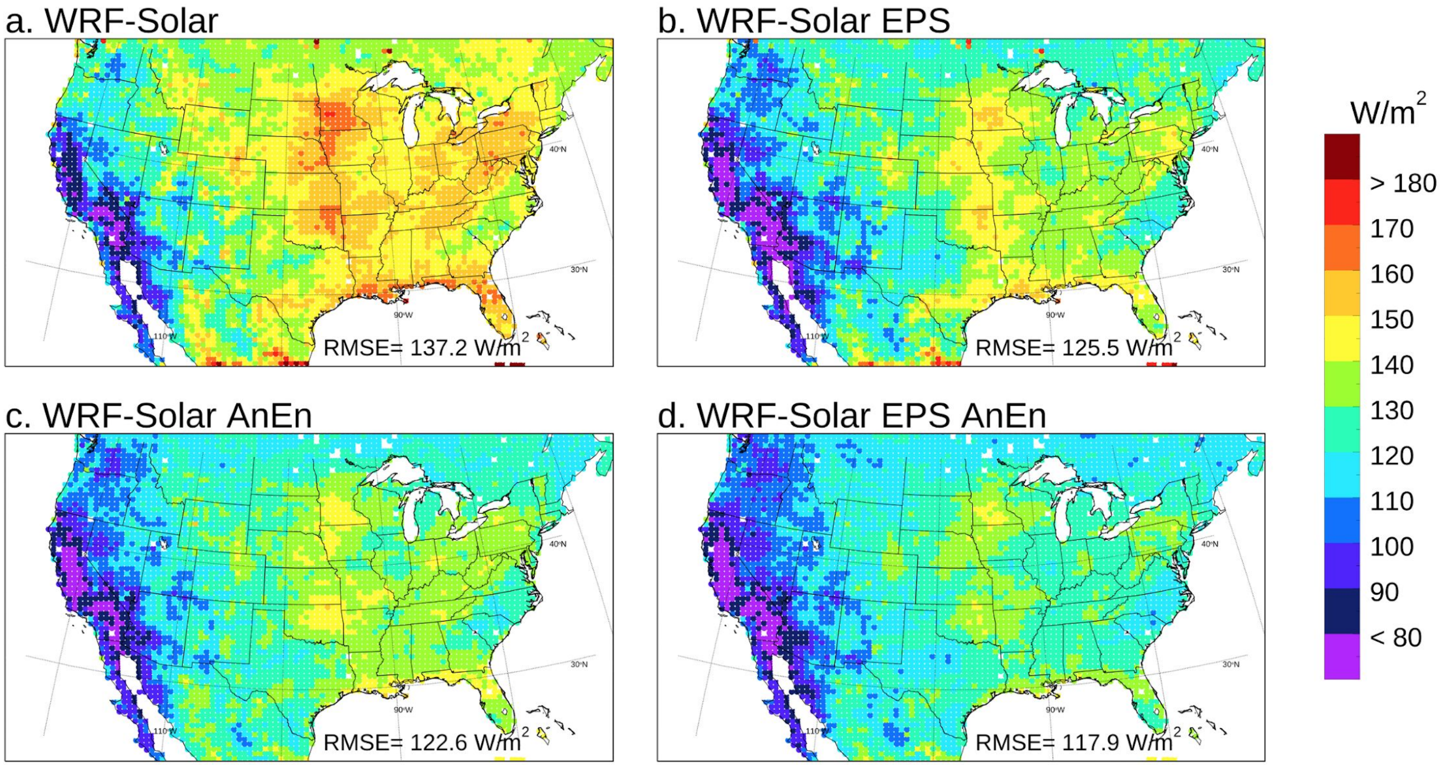
Applications of AnEn

- Short-term predictions of:
  - 10- and 80-m wind speed, 2-m temperature, etc.
    Delle Monache et al. MWR 2011, 2013 Alessandrini et al. MWR 2019
    Junk et al. MZ 2015 Sperati et al. QJMS 2017
  - Wind power
    Alessandrini et al. RE 2015, Davo et al. SE 2016
  - Solar GHI
    Alessandrini et al. SE 2015 and 2022 Alessandrini et al. ATM 2023
    Kim et al. ATM 2022
  - Load
    Alessandrini et al. ICEM 2015
  - Air quality predictions (ground level ozone, surface $PM_{2.5}$)
    Djalalova et al. AE 2015, Delle Monache et al. JGR 2016, Golbazi et al. AE 2024
  - Tropical cyclones track, intensity, rapid intensification
    Alessandrini et al. MWR 2018, Lewis et al. ATM 2021
- Downscaling, resource assessment:
  - Wind speed
    Vanvyve et al. RE 2015 Zhang et al. AE 2015
    Sperati et al. WE 2024
  - Rainfall reanalysis
    Keller et al. AMC 2017

Features of the AnEn

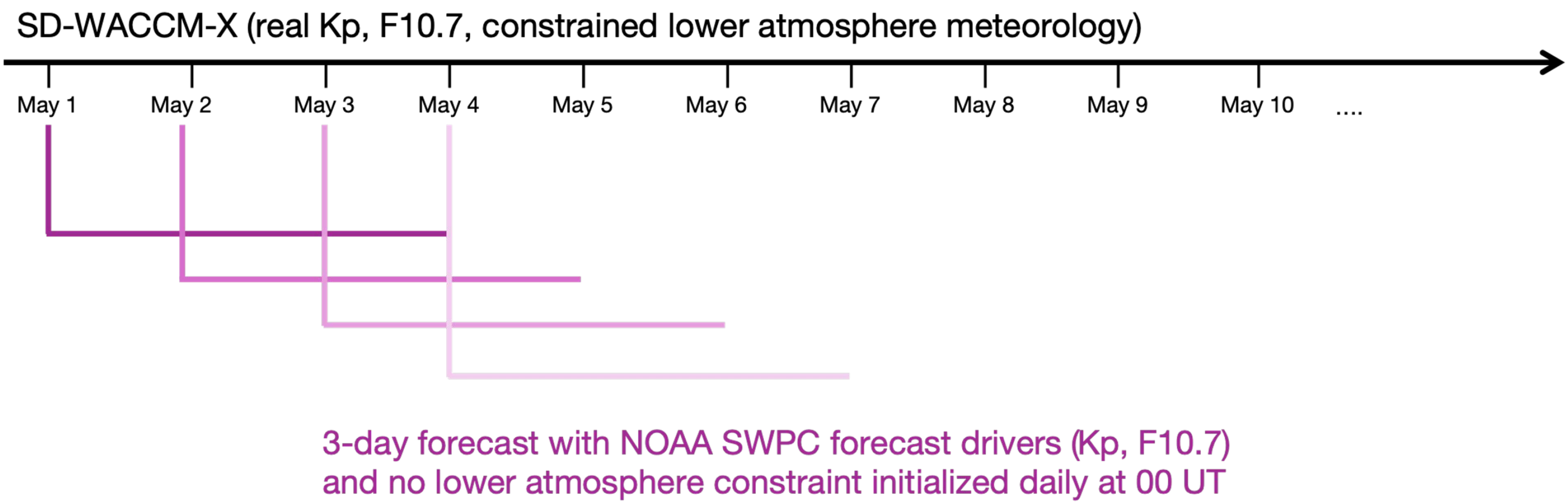
- No need for initial conditions and model perturbation strategies to generate an ensemble.
- AnEn can use a higher resolution model for an ensemble prediction (since only one real-time forecast is needed for AnEn)
- Flow-dependent error characteristics are captured
- Very cheap real-time method compared to a standard meteorological ensemble
- AnEn has proved to generate bias-free reliable predictions on a wide range of applications
- AnEn needs a training dataset of “frozen” model data (computationally expensive but can be done off-line)

AnEn for Solar Irradiance (CONUS) sponsored by DOE-NREL

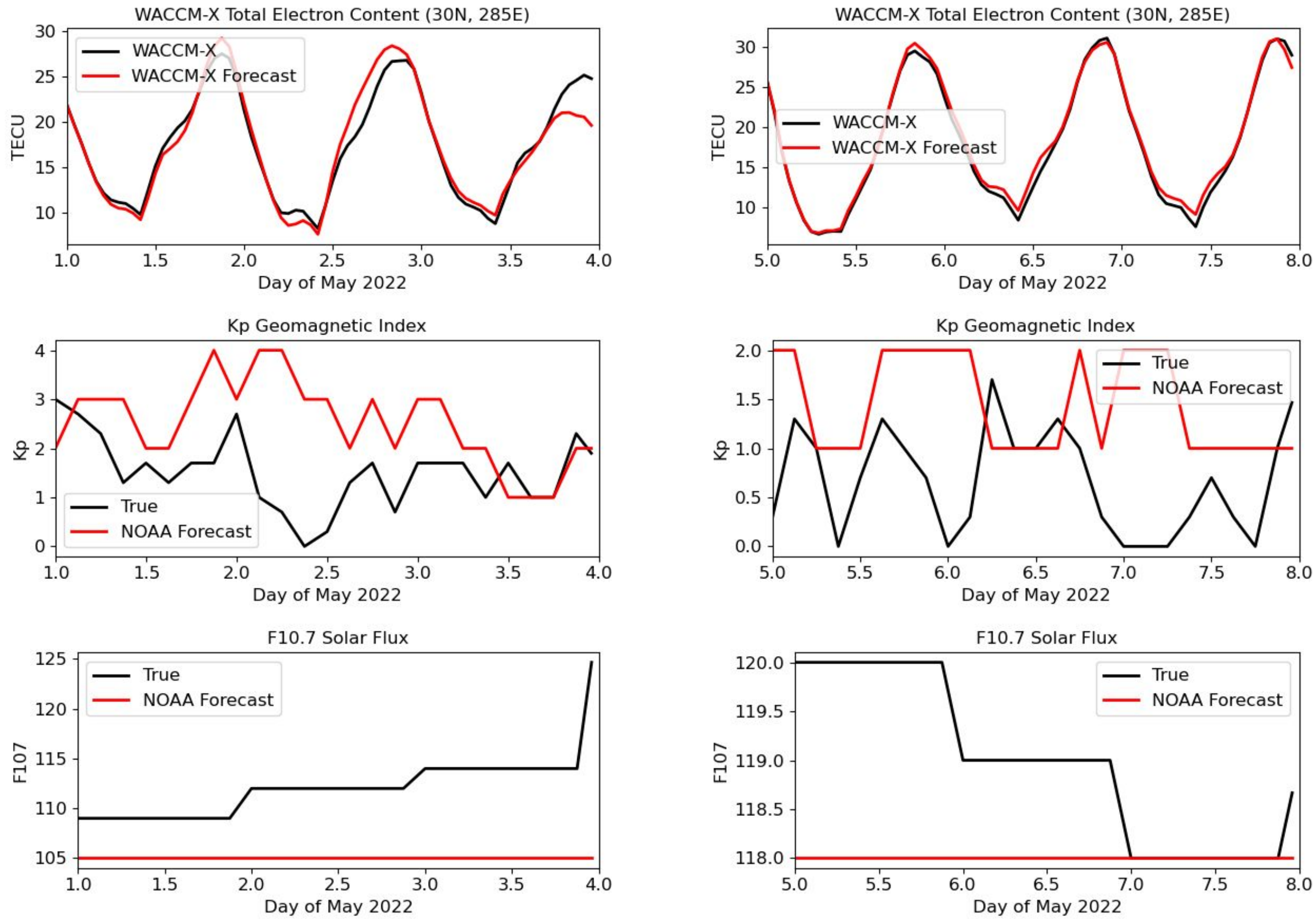


Alessandrini, S., Kim, J.H., Jimenez, P.A., Dudhia, J., Yang, J. and Sengupta, M., 2023. A gridded solar irradiance ensemble prediction system based on WRF-solar EPS and the analog ensemble. *Atmosphere*, *14*(3), p.567.

WACCM-X Forecast Runs



Example WACCM-X forecasts for initialization on May 1 and May 5, 2022



3-day forecasts initialized daily will be performed for May-July 2022 to develop the AnEn, with an initial focus on TEC

Analog Ensemble Adapted for TEC

NSF-NCAR: RAL post-processing techniques to improve NWP forecasts

We are evaluating the application of the Analog Ensemble (AnEn) system, a proven method for surface variables, to improve predictive accuracy for Space Weather.

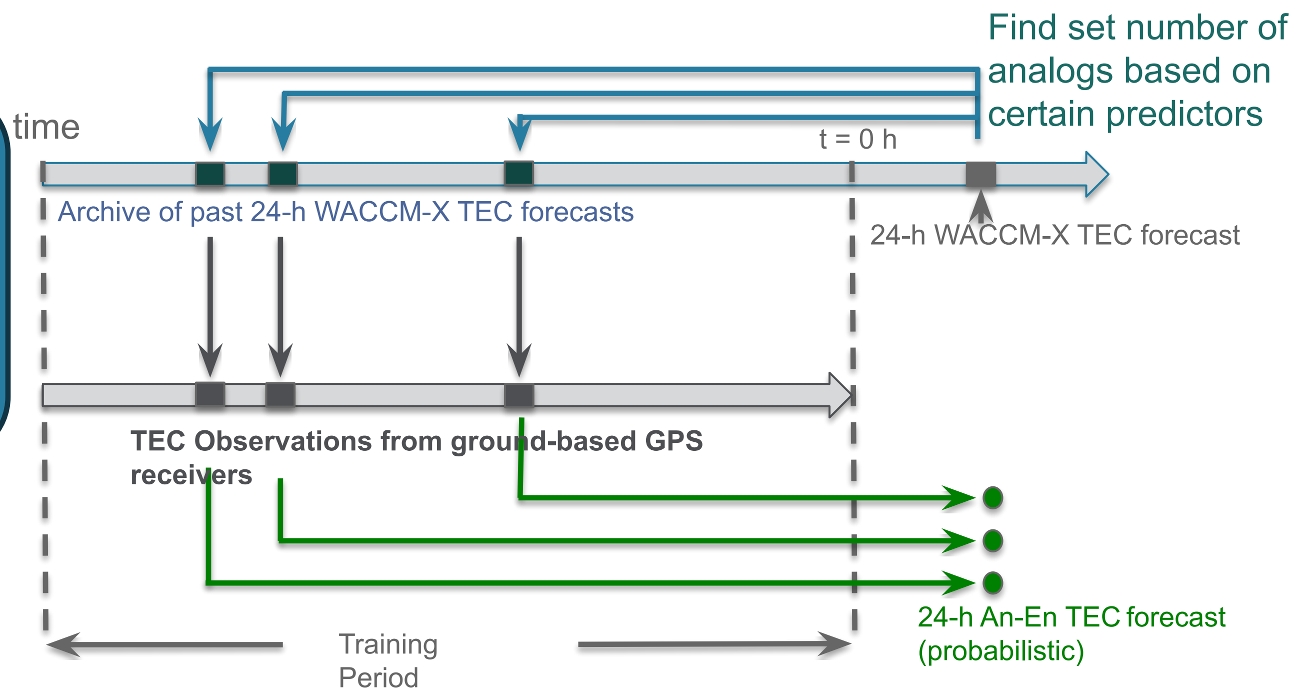
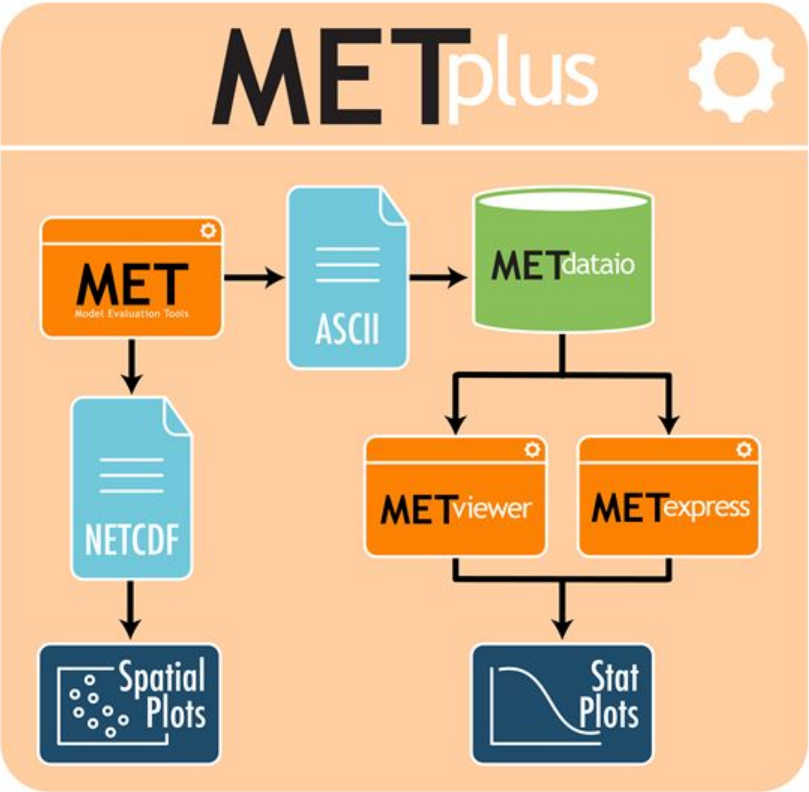


Figure adapted from Delle Monache et al. (2013)

What is METplus?

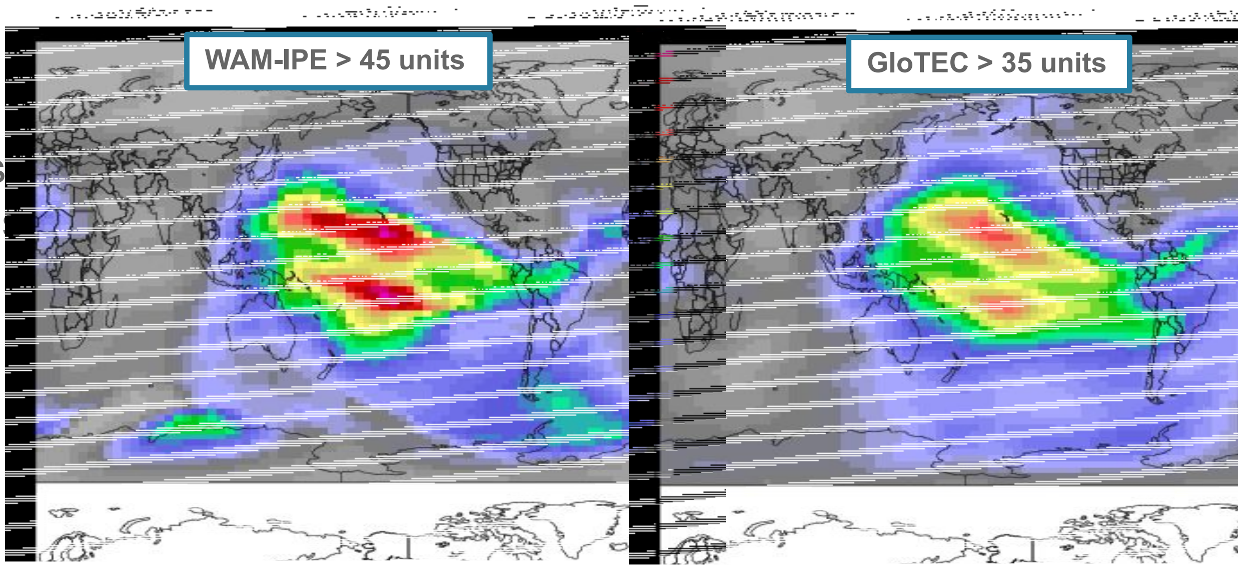
- Over 100 traditional statistics and diagnostic methods for both point and gridded datasets
- 15 interpolation methods
- Applied to many spatial and temporal scales
- Developed to allow for easy sharing of config files for reproducible results
- 3500+ users; US and International
- At the core NOAA's Environmental Modeling Center Verification System for the Unified Forecast System (UFS)



Kindly provided by: J. Vigh and JNT/RAL team

Object-Oriented Comparisons using MODE

- METplus' MODE tool allows object-oriented comparisons of gridded physical models (e.g., WAM-IPE) with an empirical model analysis (GloTEC)



Object-oriented comparisons helped SWPC identify a bias in WAM-IPE in which TEC in high regions was ~10 TEC units greater than GloTEC

Acknowledgment: Tara Jensen, J. Vigh, and NCAR RAL/JNT team

Thank You!

- Email: Alessand@ucar.edu
- https://ral.ucar.edu/directory/stefano-alessandrini