Development of a Model Blending Capability for the United States Air Force

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Motivation

- Current NWP framework has a couple critical shortfalls:
  - Vulnerability to disruptions
    - Network outages
    - Nefarious attacks
  - The vast amount of NWP data is underutilized by forecasters and other end users
    - Many forecasters use data that is easy to access and dependable
    - Ensemble model data can be difficult to utilize

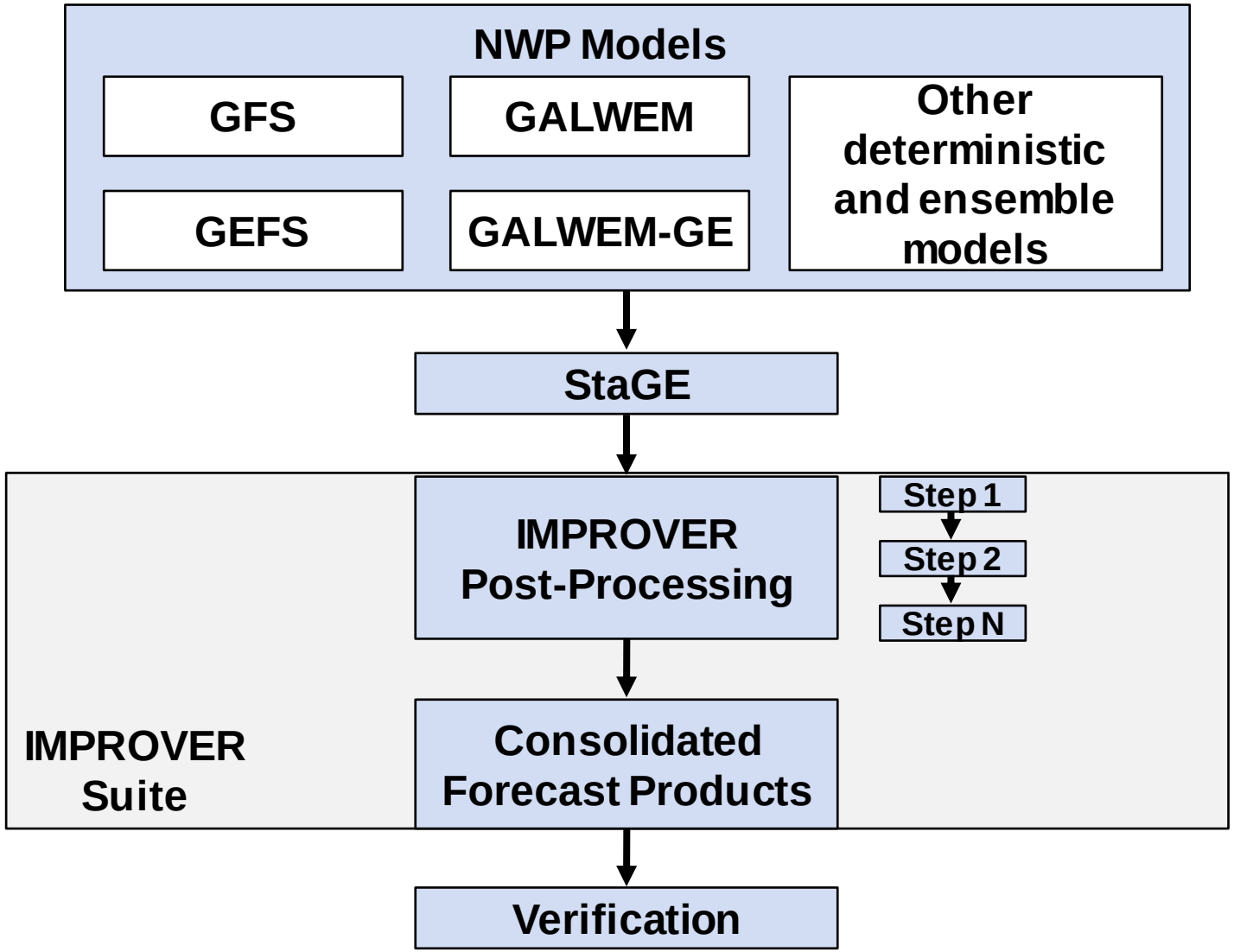
- For mitigation, we are investigating NWP model blending solutions to provide unified weather data to forecasters and other users
  - Seamlessly combine all NWP data available into one dependable output stream to users
    - Reduces the bandwidth requirements of data delivery
  - Little disruption to forecasters when an individual NWP model becomes unavailable
    - Increases resiliency in event of loss of NWP data from external providers

Outline

- Motivation
- IMPROVER Overview
- IMPROVER R&D for USAF
- Summary

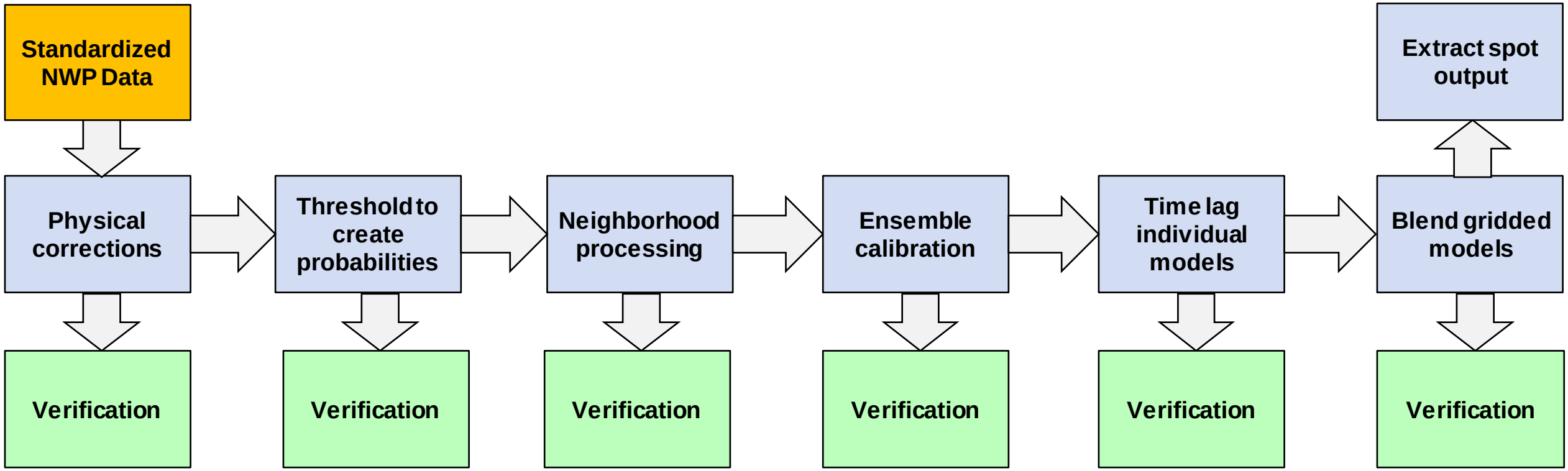
IMPROVER Technology Overview

- IMPROVER has been developed by the UK Met Office
  - Flexible, modular, and open source
- StaGE standardizes NWP data into common format for IMPROVER
- IMPROVER applies a series of processing steps
  - Processing chain varies dependent on weather product
- Probabilistic forecasts are output
  - Customized to be mission-specific
- IMPROVER Suite manages a series of workflows to run in an operational environment



IMPROVER – Integrated Model post-PROcessing and Verification
UK – United Kingdom
StaGE – Standard Gridding Engine
GFS – Global Forecasting System
GEFS – Global Ensemble Forecasting System
GALWEM – Standard Gridding Engine

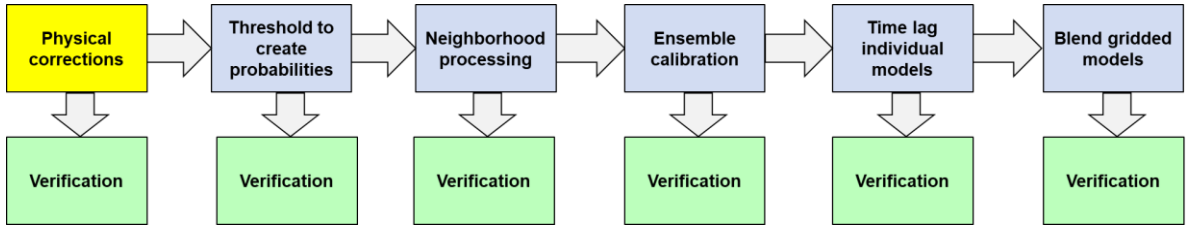
Typical IMPROVER Processing Chain

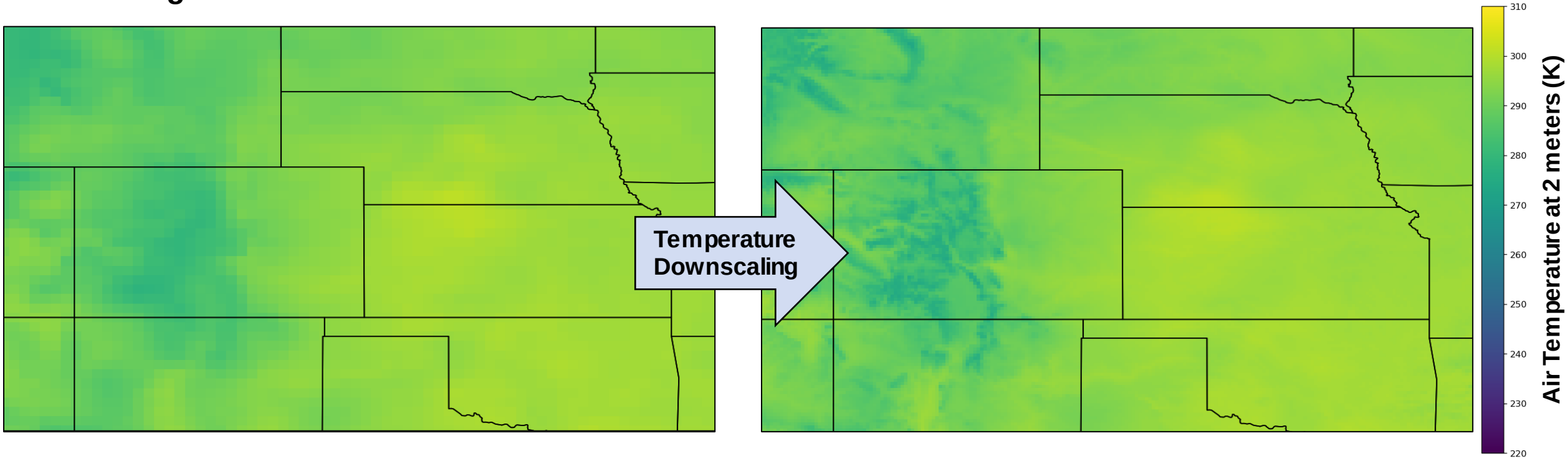


- Processing chain varies dependent on deterministic/ensemble output and diagnostic
- Verification can be performed after each step to monitor change in skill

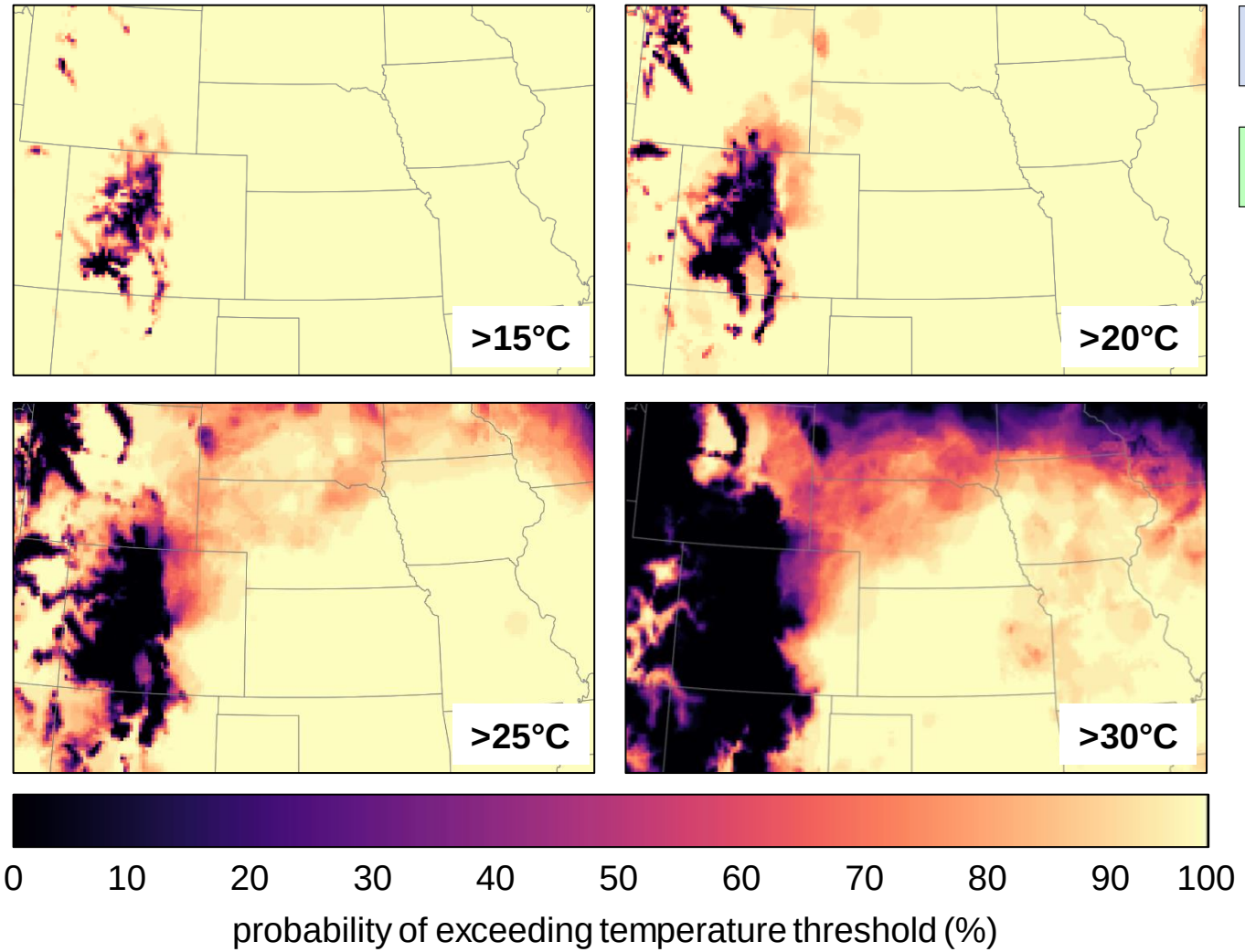
Physical Corrections

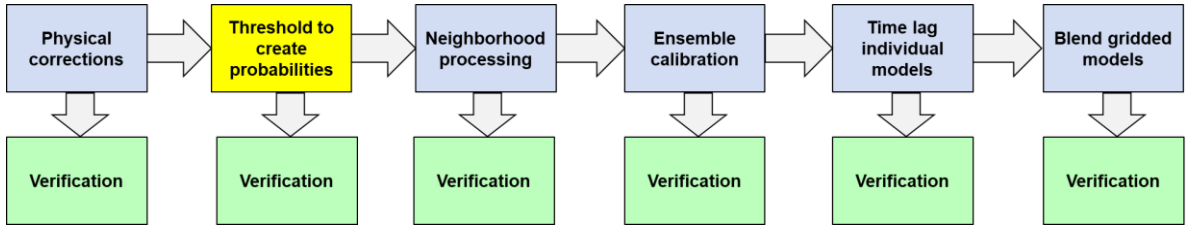
- **Various physical corrections applied to model output**
  - **Temperature**
  - **Wind downscaling**
  - **Melting level for snow**





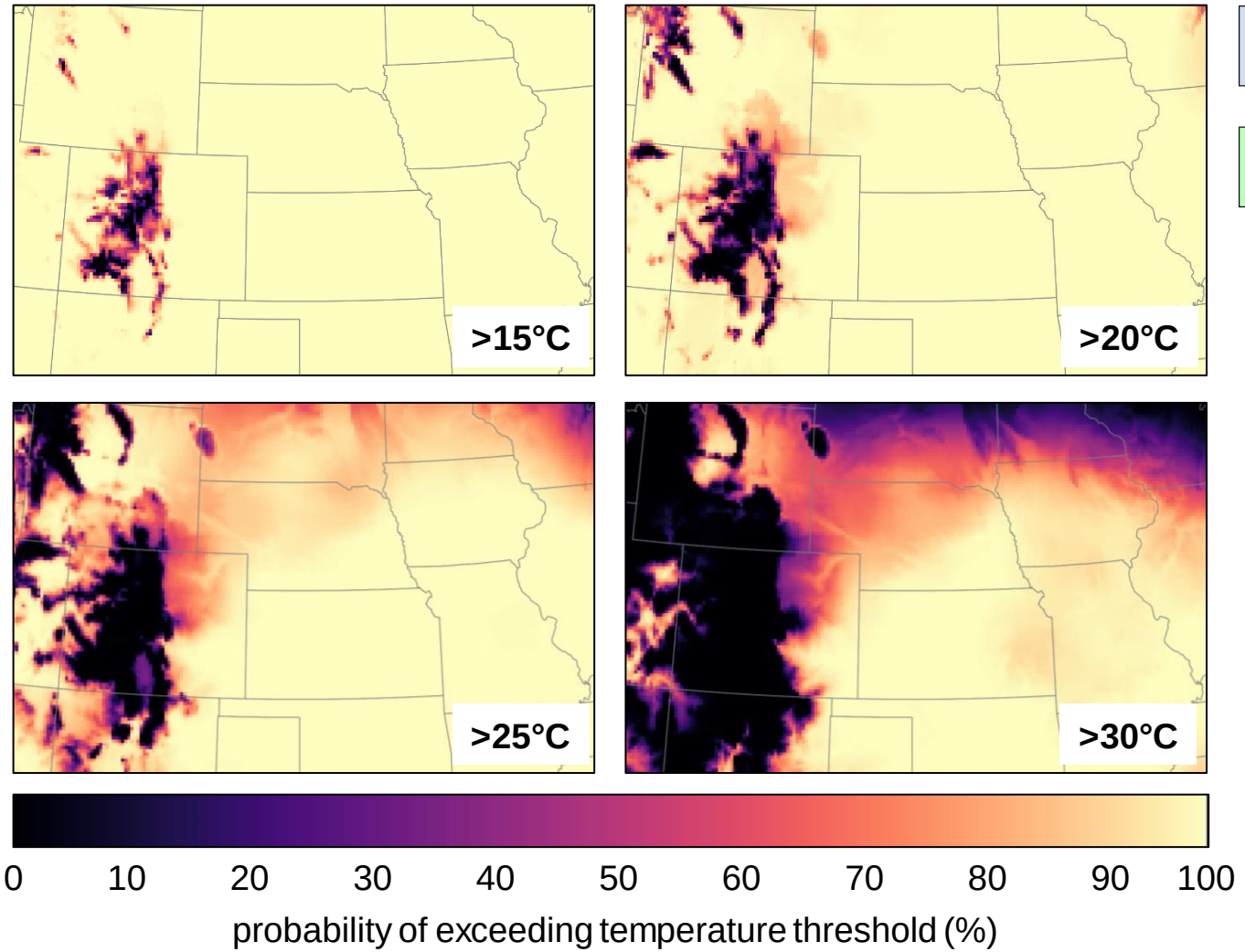
Thresholding to Create Probabilities

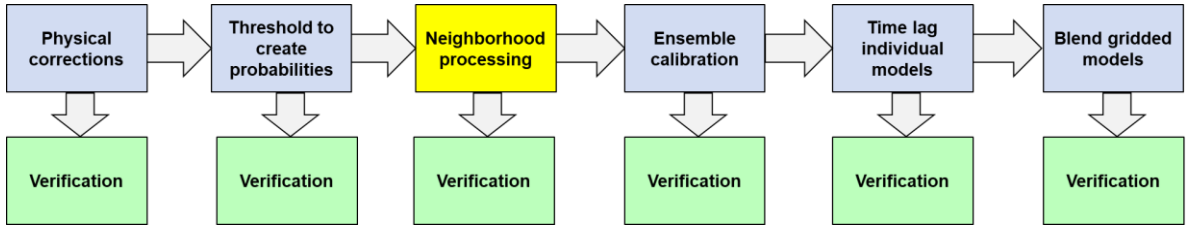




- **Thresholding NWP ensemble members**
  - **Create probabilities of whether value has been exceeded**
- **Provides forecasters with confidence in forecast**
- **Particularly useful for high impact weather conditions**

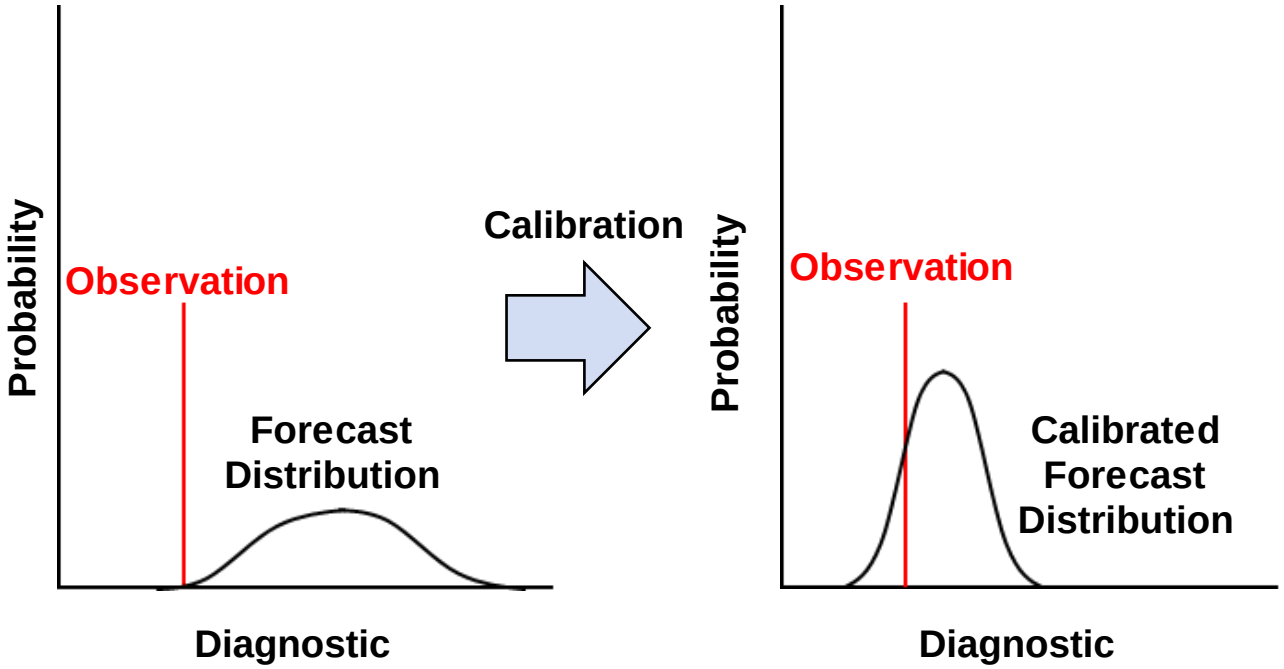
Neighborhood Processing (Topographic-Aware)



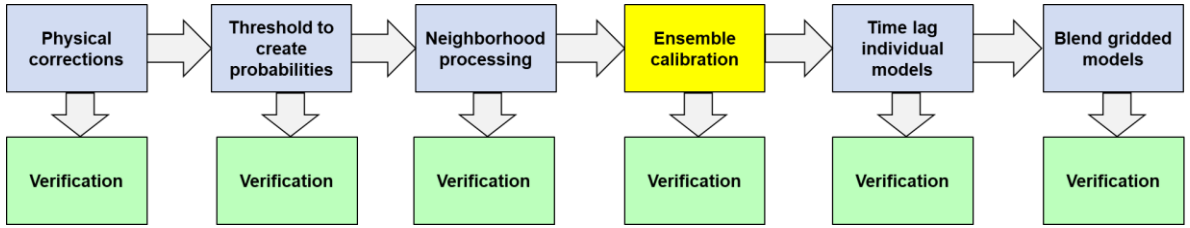


- Applies a spatial filter over the domain
  - Customizable shape and radii
  - Adaptable based on forecast horizon
- Applies smoothing across defined elevation bins within radius
- Accounts for spatial uncertainty in the forecast while preserving certainty relating to topographic details

Ensemble Calibration

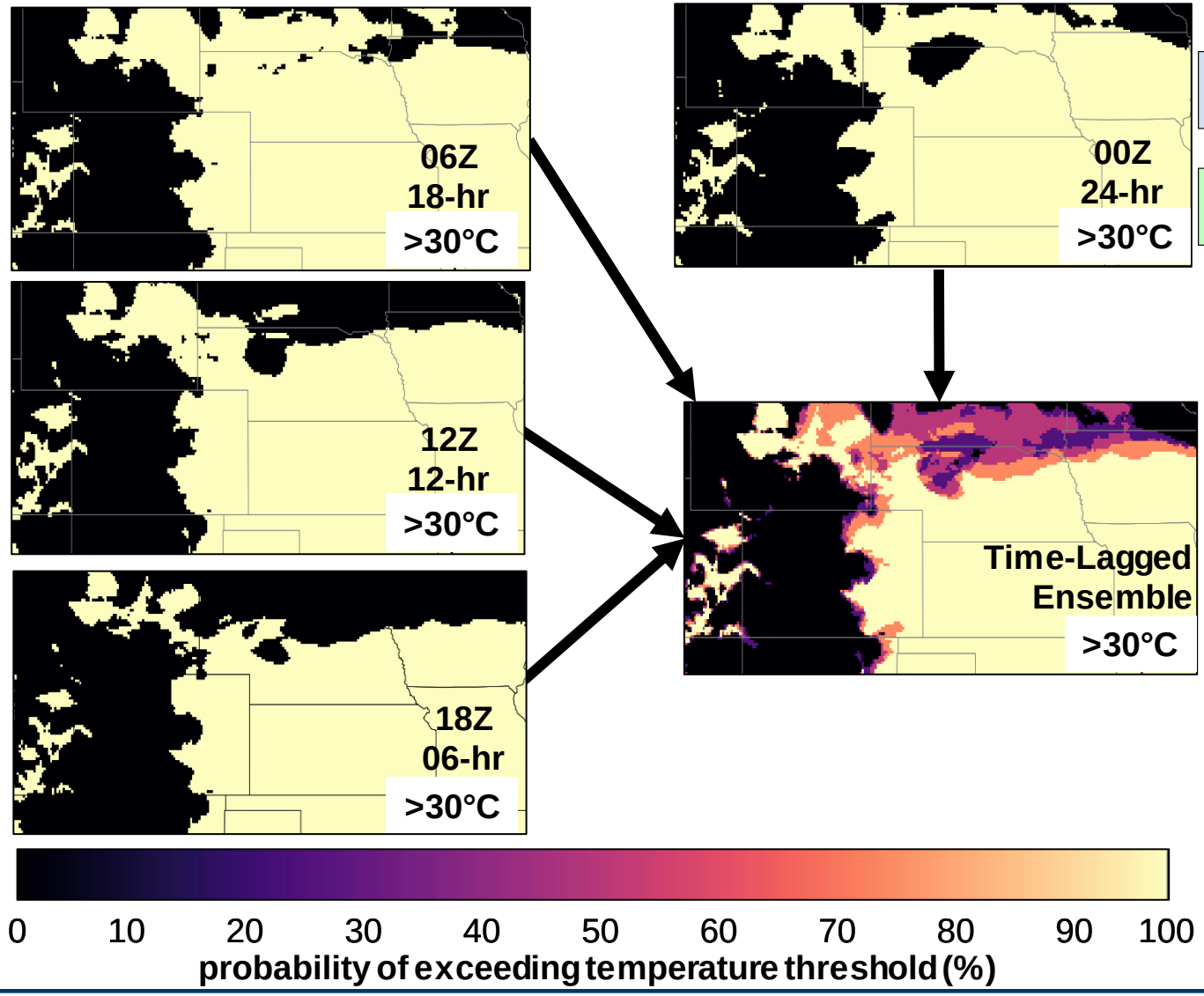


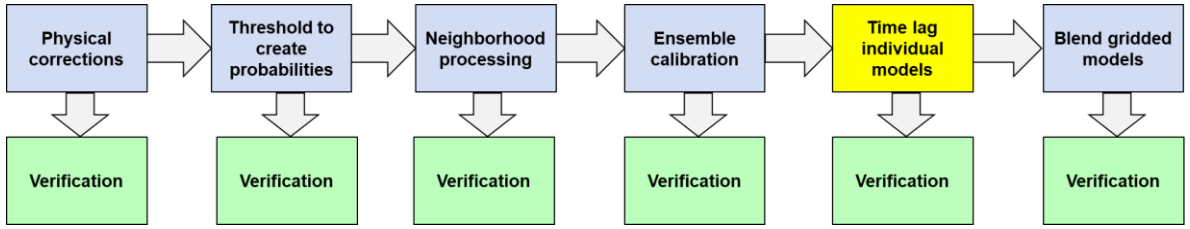
Example of EMOS calibration



- **Ensemble Model Output Statistics (EMOS) for calibrating the ensemble forecasts**
  - **Performed at each grid point independently**
  - **Applies a bias correction**
  - **Often reduces spread**
- **Reliability calibration**
  - **Calibrates probabilistic forecasts without degrading resolution**

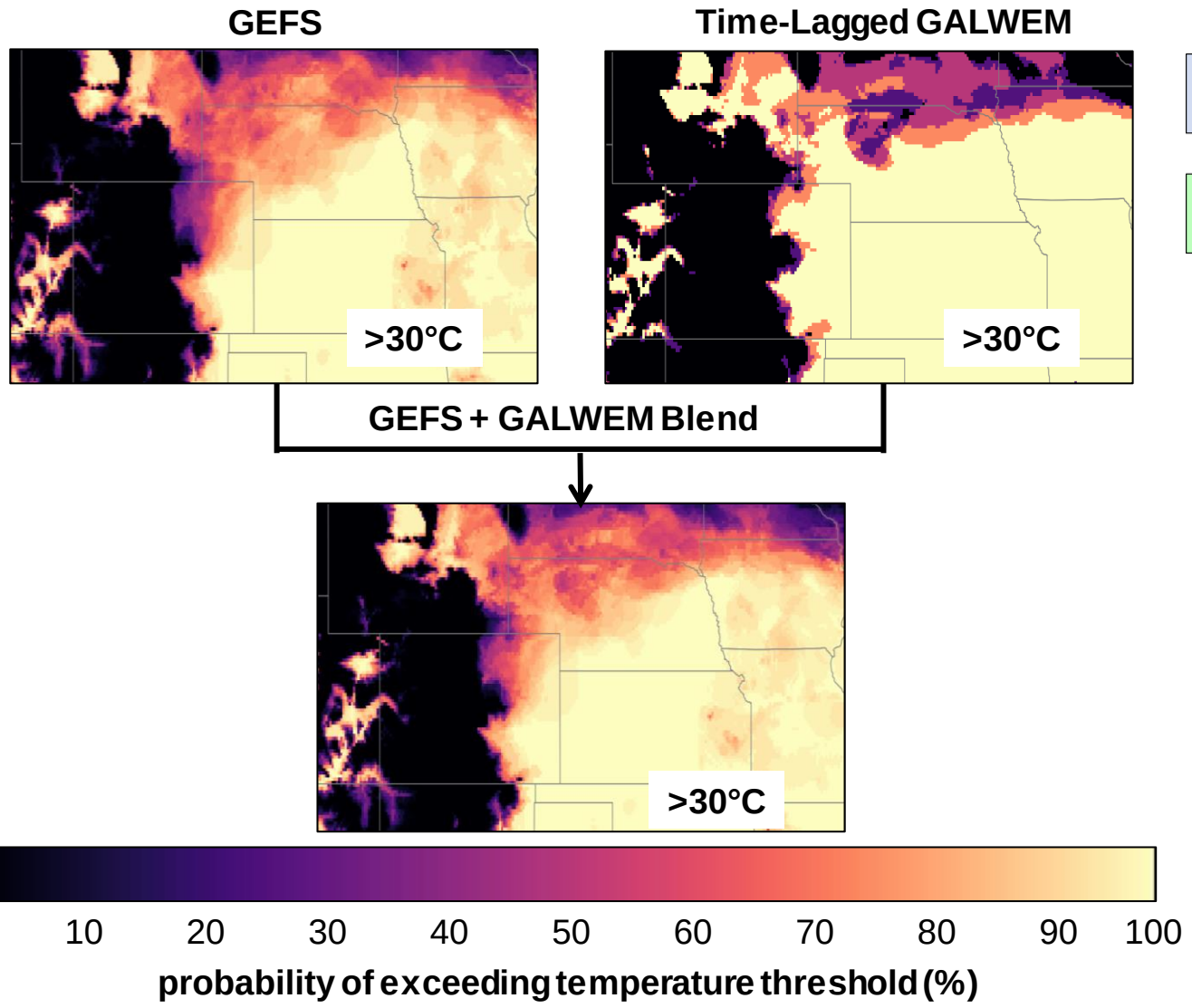
Time-Lagged Ensemble

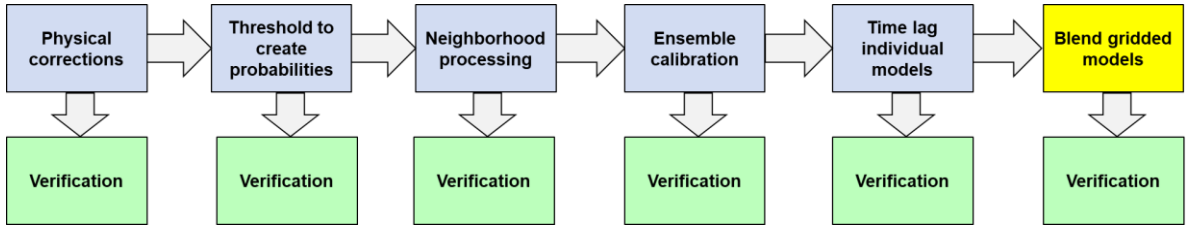




- Combines multiple model cycles together
  - Equal weighting at all grid points
- Method of assessing variability of model from run-to-run
- Informs forecaster of confidence over previous model cycles

Blend Gridded Models





- **Combines multiple models together for one consolidated output**
- **Method of assessing inter-model variability**
- **Informs forecaster of consistency between various models**

GALWEM – Global Air-Land Weather Exploitation Model

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Adapting IMPROVER for USAF

- **IMPROVER has primarily been used for public weather service applications by the UK Met Office, BoM, and MSS**
  - **Focused on:**
    - **Ground-level forecasts**
    - **Use of regional models**
    - **IMPROVER domain at high-resolution over a specific country**

- **The USAF has different weather prediction needs**
  - **Forecasts globally for potential operations anywhere**
  - **Forecasts of both ground-level and aloft conditions**
  - **Weather conditions impactful to aviation**
    - **Turbulence**
    - **Icing**
    - **Ceiling and visibility**

Modifications are necessary to adapt IMPROVER for USAF applications

BoM – Australian Bureau of Meteorology
MSS – Meteorological Service of Singapore
UM – Unified Model

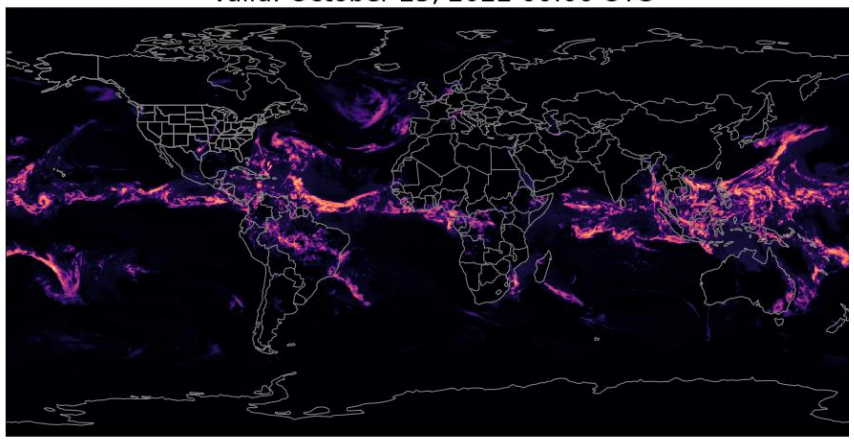
Recent IMPROVER R&D for the USAF

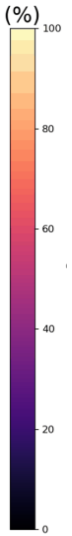
- Determined suitability of IMPROVER for addressing USAF requirements
  - Ensured model data used by USAF (GEFS and GALWEM) can be ingested into IMPROVER
    - Needed to develop capability to process GRIB2 inputs through StaGE
  - Established processing chains for select surface-level products (2-m temperature, 10-m wind speed)
  - Verified accuracy of IMPROVER output compared to current USAF forecasts
- Assessed the ability of IMPROVER to be integrated into the USAF's operational environment
  - Initially targeting HPC deployment
    - Interested in execution on cloud-based environment
- Determined ability to produce weather products tailored to USAF needs, specifically weather aviation hazards
  - Initial focus was on developing a global lightning probability product

GRIB2 – Gridded Binary edition 2
HPC – High-Performance Computing

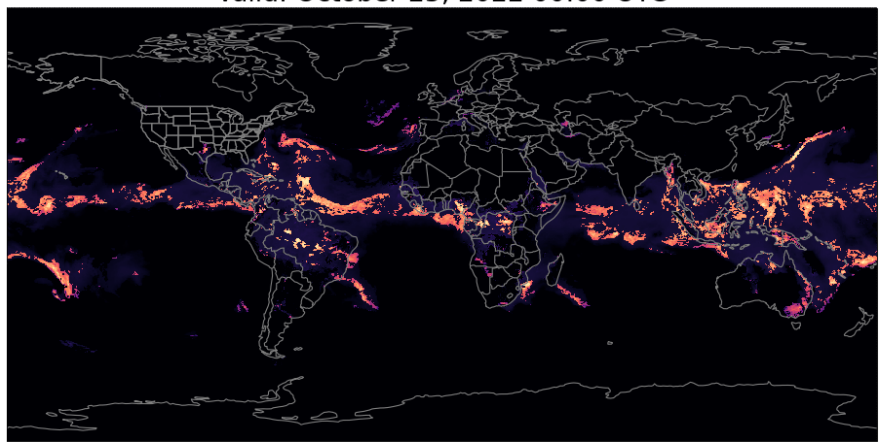
Example Lightning Forecast with Verification

GEFS 20-km Lightning Probability
Forecast cycle: October 25, 2022 00:00 UTC
Valid: October 25, 2022 00:00 UTC

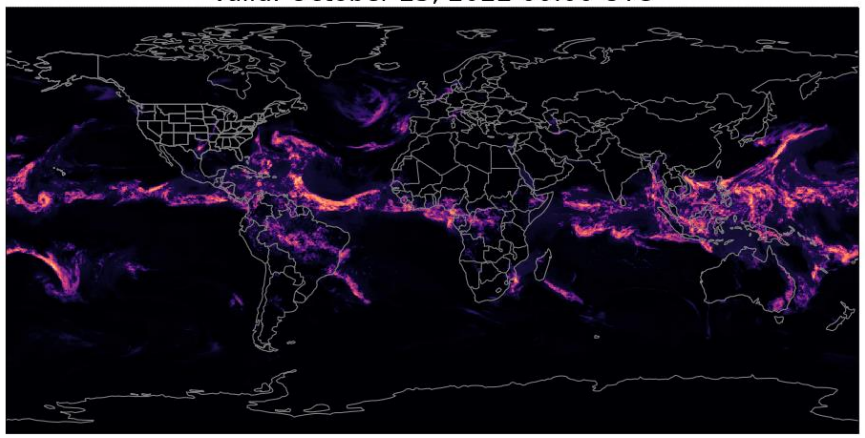




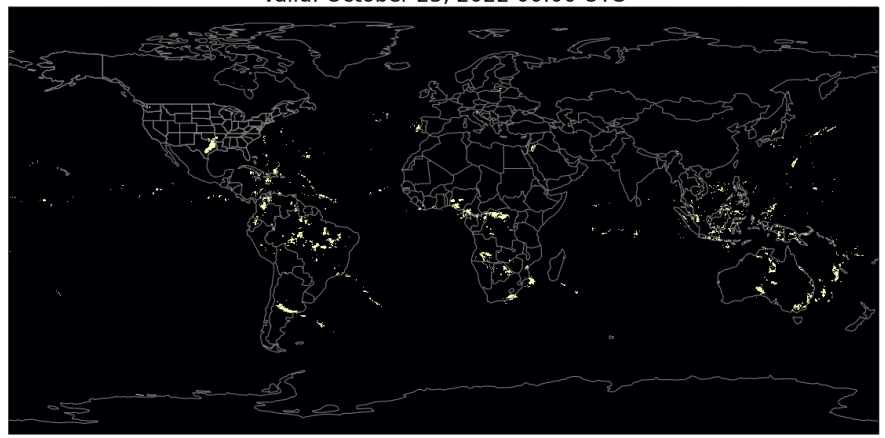
GALWEM 20-km Lightning Probability
Forecast cycle: October 25, 2022 00:00 UTC
Valid: October 25, 2022 00:00 UTC



Blend 20-km Lightning Probability
Forecast cycle: October 25, 2022 00:00 UTC
Valid: October 25, 2022 00:00 UTC

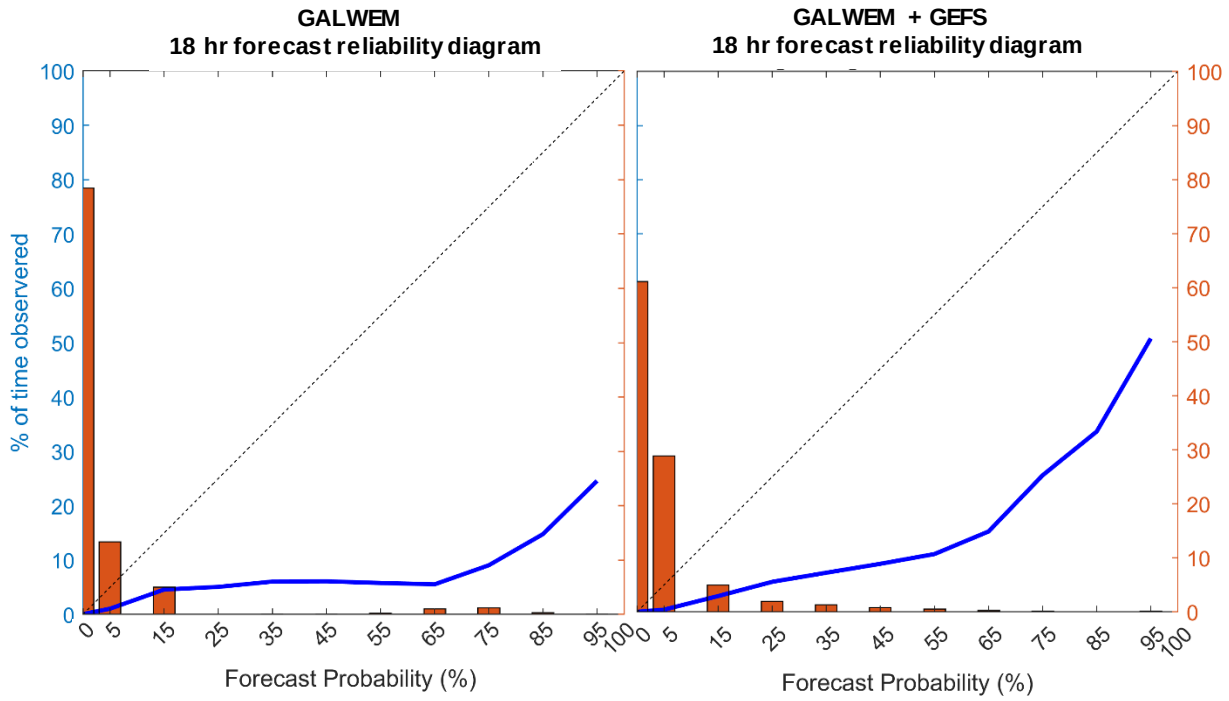


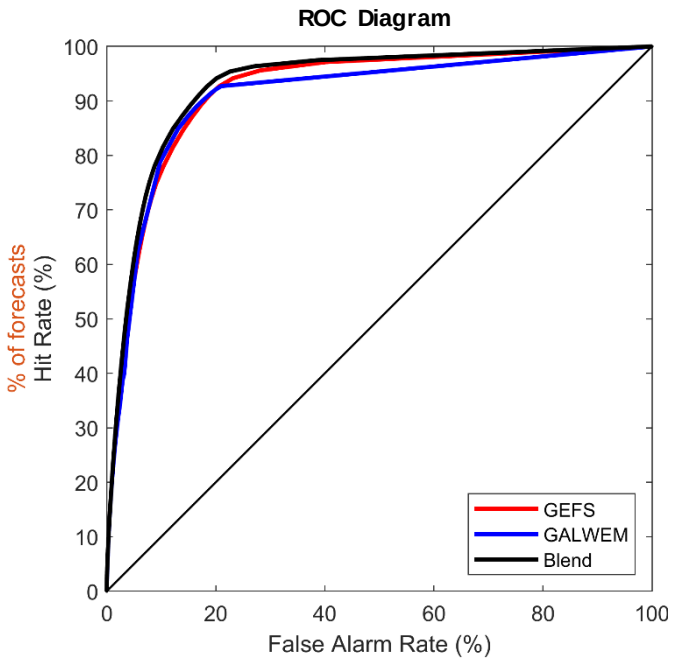
Global Lightning Detection Network
Strike Detections
Valid: October 25, 2022 00:00 UTC

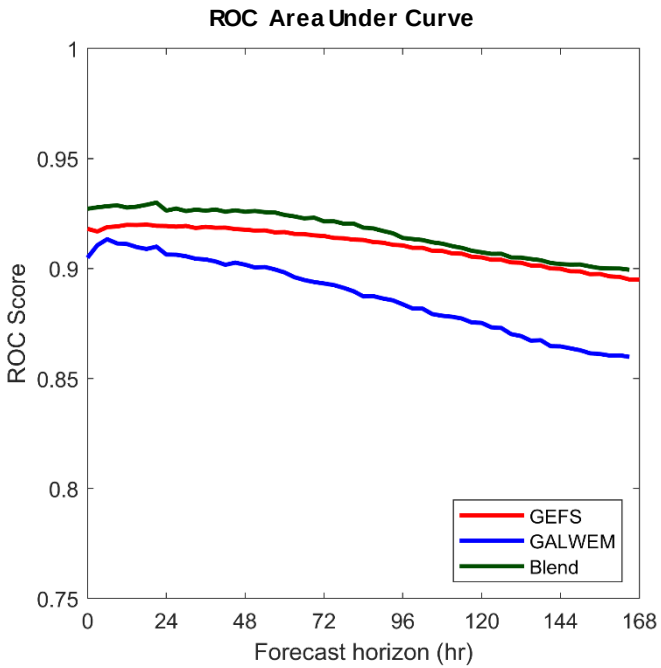


Verification of Lightning Data

- **Verified with Vaisala Global Lightning Detection Network (GLD360) data**
  - **Each ¼° grid box scored independently**
  - **Detection when there was at least one lightning strike in grid cell**







Blended lightning forecast has improved skill compared to GALWEM alone

Ongoing IMPROVER Development for USAF

- **Bringing Canadian GEPS into the model blend**
  - **Establish StaGE configuration and processing for GEPS GRIB2 files**
  - **Producing 2-m temperature, 10-m wind, and lightning forecasts**
- **Investigating calibration methods of these forecasts on global grids**
  - **Leverage reliability calibration for lightning forecasts**
  - **Explore using EMOS for calibrating ensemble forecasts of select products (e.g., 2-m temperature, 10-m wind)**
- **Develop an in flight icing potential hazard product**
  - **Will be a new IMPROVER module**
  - **First IMPROVER product on full 3-D volumetric grids**
- **Establish capability to routinely execute IMPROVER on an HPC environment**
  - **Simplified implementation of a suite**

GEPS – Global Ensemble Prediction System
EMOS – Ensemble Model Statistics

Summary

- **IMPROVER is being explored as a model blending solution for the USAF to mitigate current shortfalls of NWP infrastructure**
  - **Modular framework allows flexible use to suit USAF requirements**
  - **Leverage and strengthen existing partnership with UK Met Office and UM Partners**
- **IMPROVER only supports select NWP models and diagnostic fields**
  - **Initial development includes:**
    - **Blending of global GEFS and GALWEM models used by USAF**
    - **Addition of global lightning probability product based on current USAF algorithms**
    - **Verification of output in comparison to current USAF forecast products**
- **Developing a roadmap for deployment to USAF operations**
  - **Future R&D is expected to further adapt IMPROVER for USAF applications**

Acknowledgements

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