NOAA Global Systems Laboratory

# A History of Operational NWP Improvements

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# GSL: A History of Operational NWP Improvements

**2008:** First radar reflectivity assimilation in operational NCEP model (13-km RUC)

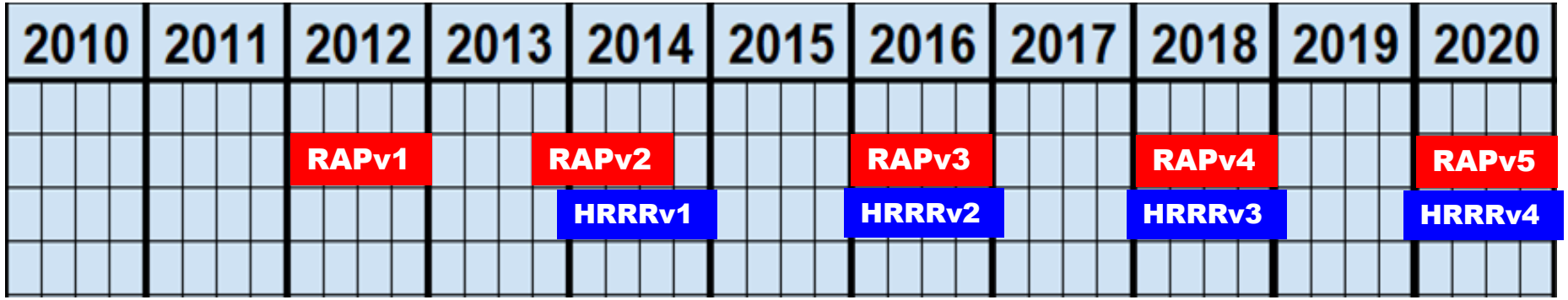
**2012:** Community-based 13-km RAP at NCEP

**2014:** First storm-scale model in operations at NCEP (3-km HRRR with radar DA)

**2016, 2018:** Significant data assimilation and physics enhancements (direct broadcast radiance data in RAP, hybrid/ensemble data assimilation, reduced diurnal biases)

**2020:** First storm-scale ensemble assimilation in operational NCEP model (HRRRDAS), first in-line smoke DA and prediction capability in operational NCEP model, GSL contribution of aerosol member to GEFSv12 implementation

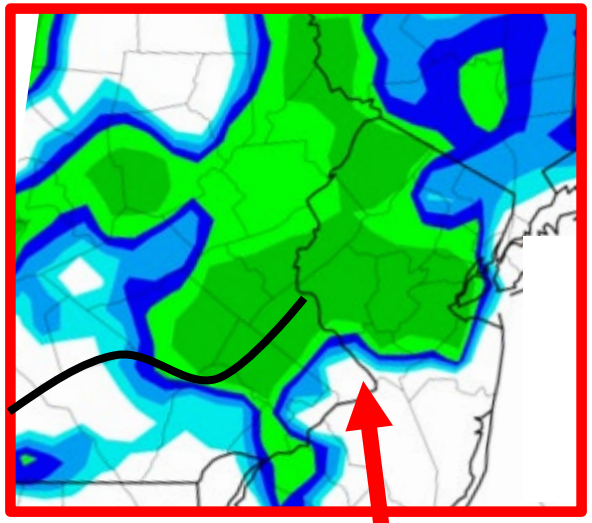
***Timeline of NCEP operational RAP/HRRR implementations***



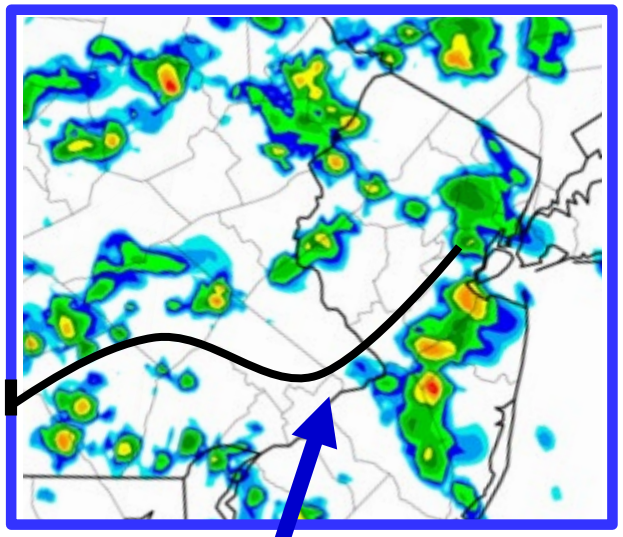

**Major progress for short-range prediction of convection and other hazardous weather**

# What GSL Improvements to NWP Look Like:

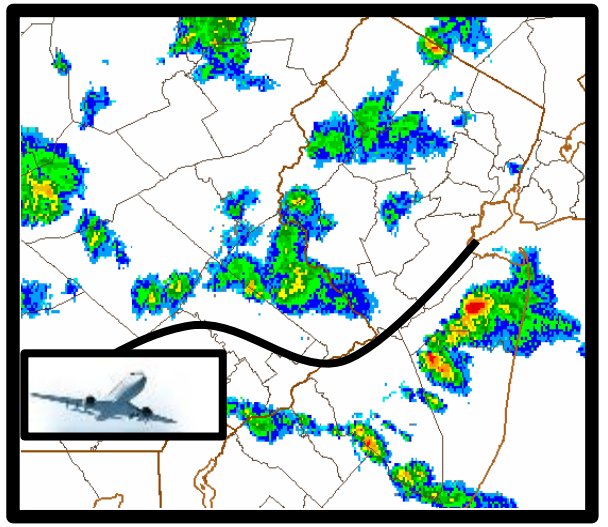
**2012**
**RAP v1 13-km**



**2014**
**HRRR v1 3-km**

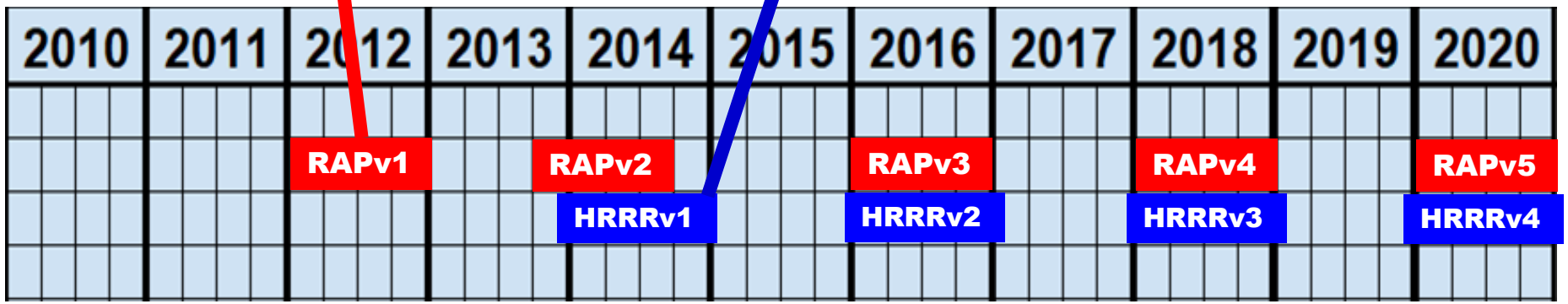


**Reality**



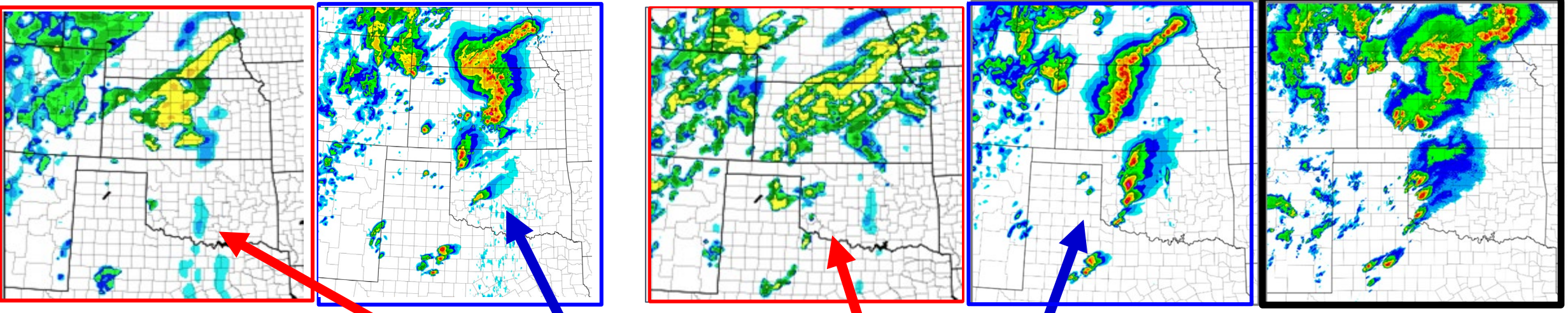
**Aviation Application Collaboration:** FAA, NCAR, MIT/LL, AWC

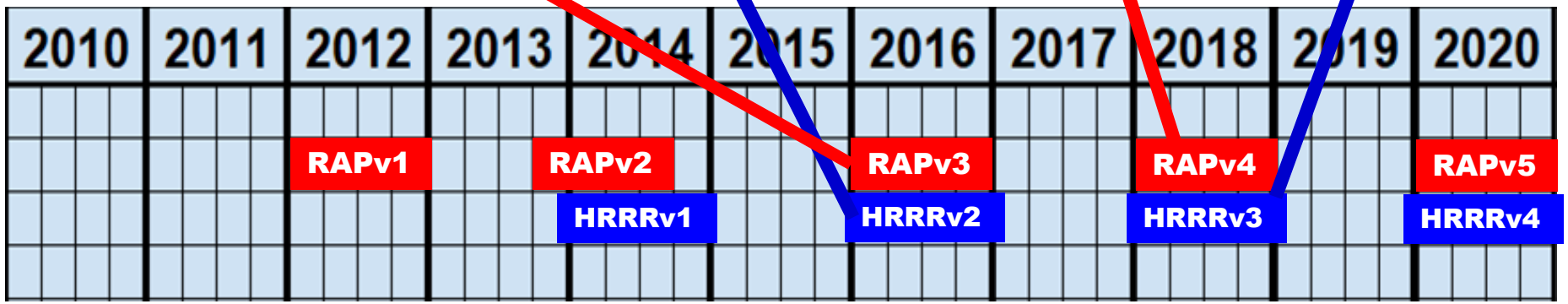
**Benefits:** less delays, better fuel usage, contributions to safety




**Major progress for short-range prediction of convection and other hazardous weather**

# What GSL Improvements to NWP Look Like:

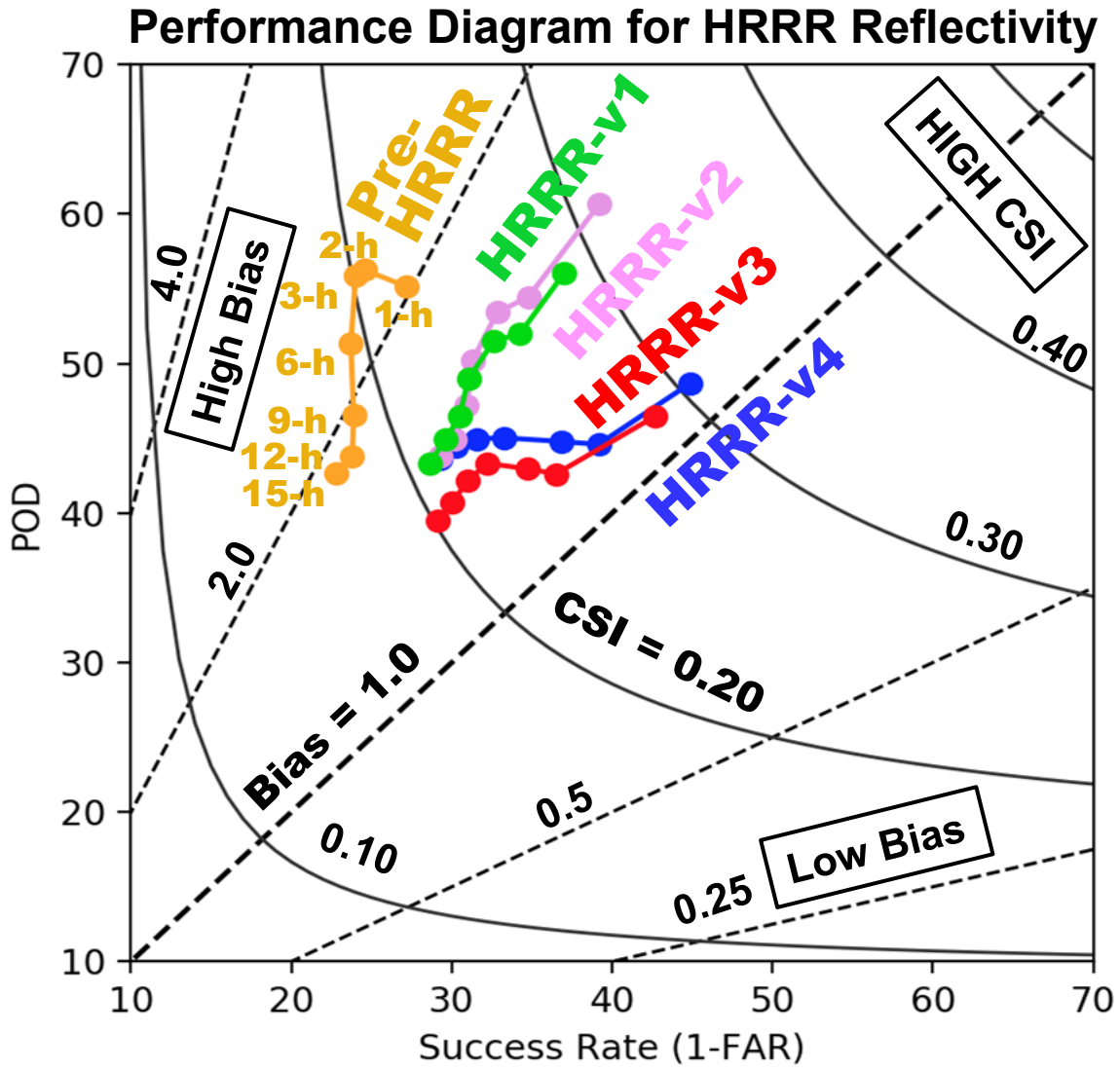



**Severe Weather App Collaboration:** SPC, NSSL, OU/CAPS, EMC

**Benefits:** improved severe weather guidance, contributes to safety

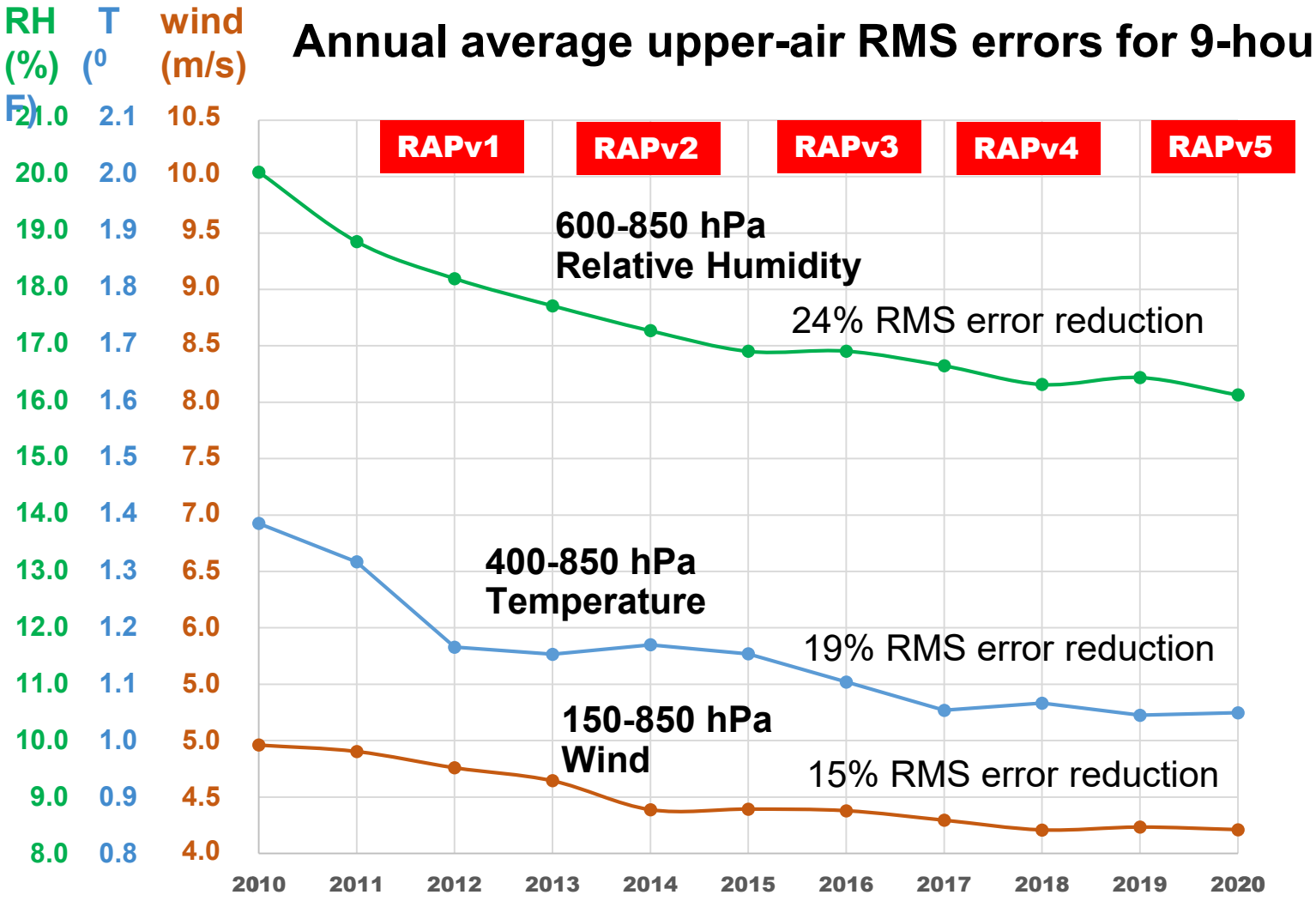
# Ongoing Improvements in HRRR Forecasts




- Performance diagram shows CSI / bias
- Illustrates five generations of HRRR skill
- Pre-HRRR: very high bias, low CSI
- HRRRv1: better bias, improved CSI,
- HRRRv2: CSI even better, bias still high
- HRRRv3: bias much better (reduced), some reduction in CSI
- HRRRv4: better CSI, similar bias

# Ongoing Improvements in RAP Forecasts

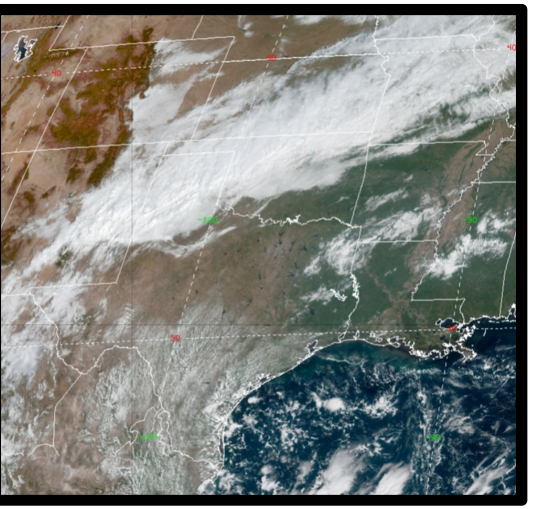
**Annual average upper-air RMS errors for 9-hour RAP forecasts**



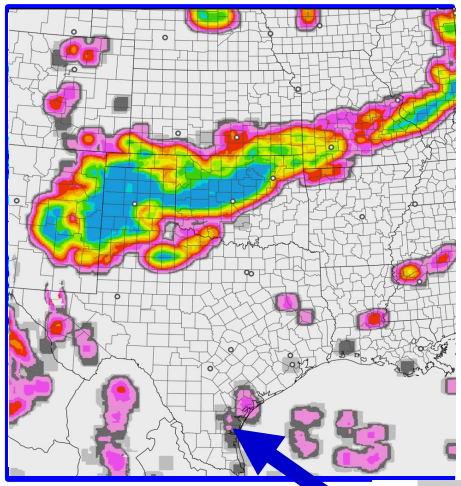

- Annual average 9-h upper-air RMS error
- Rawinsonde verification on RAP domain
- RAP implementations indicated at top
- Errors computed for GSL real-time RAP, some year-to-year variability
- Reduced errors for all three variables
- Error reduction for 10 year period shown
- Increasing role of global model partial cycling to gain further error reductions

# New Capabilities in the Most Recent HRRR

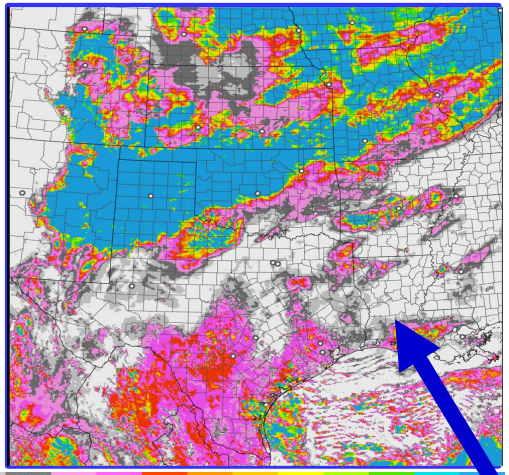
**Reality**



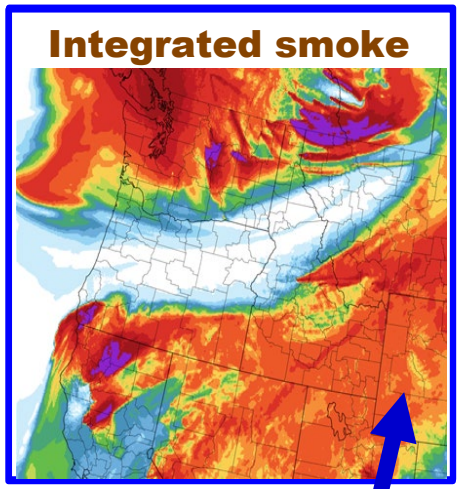
**2018**
**HRRR v3 3-km**



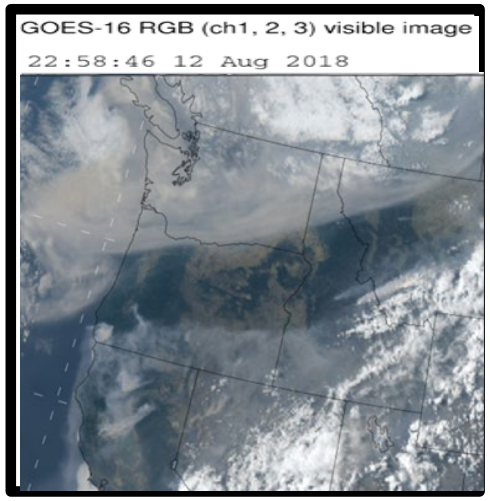
**2020**
**HRRR v4 3-km**




**2020**
**HRRR v4 3-km**

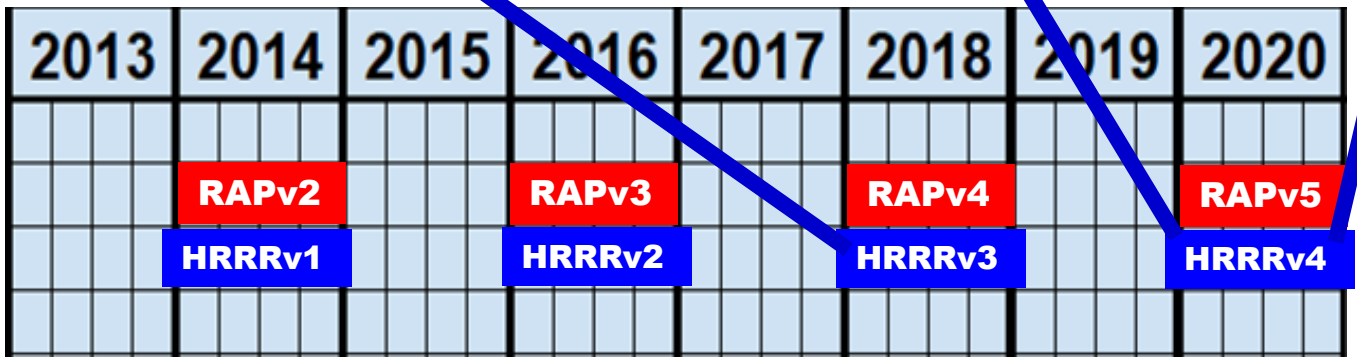



**Reality**




**Improved cloud / ceiling forecast capability**

**Benefits:** Aviation users, NWS and other users

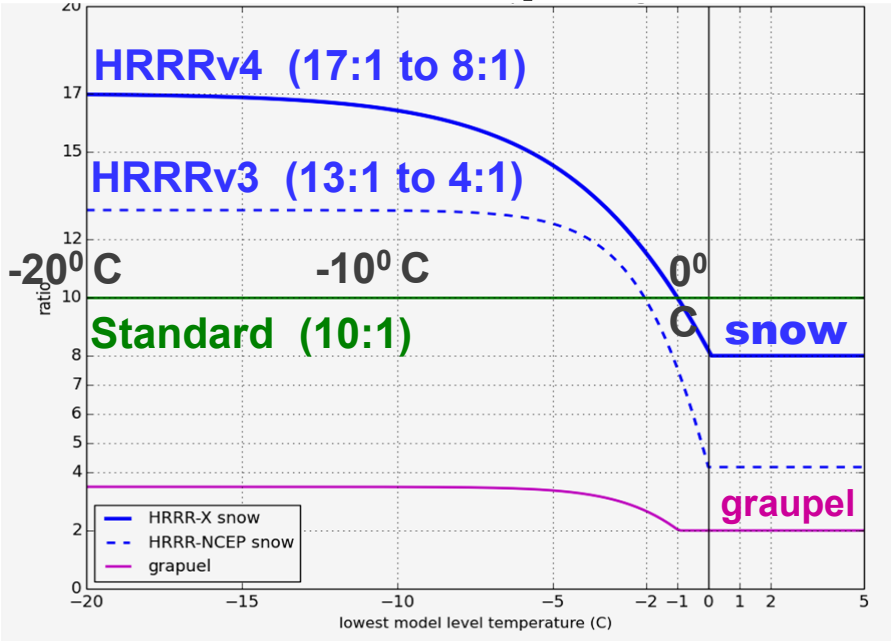


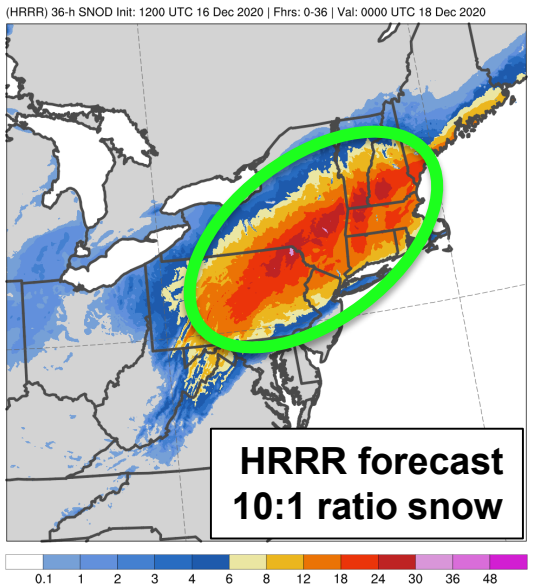

**Smoke prediction capability**

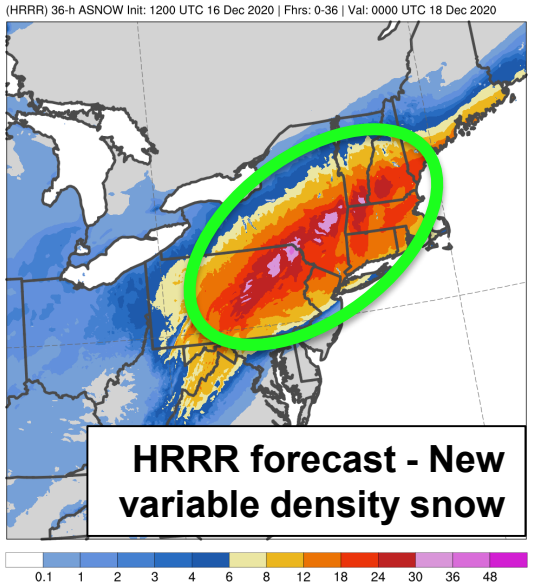
**Benefits:** Many users including NWS, state and local entities, etc.

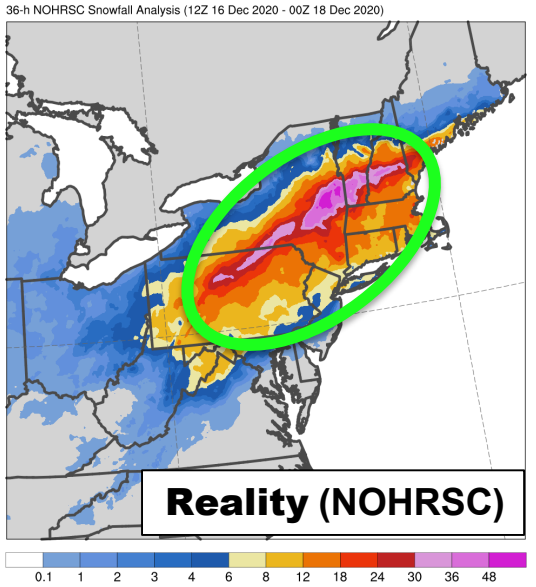
# Better Snow Forecasts: Variable Density Snow Accumulation

## Diagnostic formulation for snow-to-liquid ratio




**HRRR 36h-h total snow accumulation from 1200 UTC 16 Dec. 2020**

**"The HRRR's variable density snow algorithm far and away out-performs any other method to convert liquid QPF into snowfall.** We place our highest confidence on this method when issuing winter storm warnings and winter weather advisories, and over the past 2 winters it has not let us down."

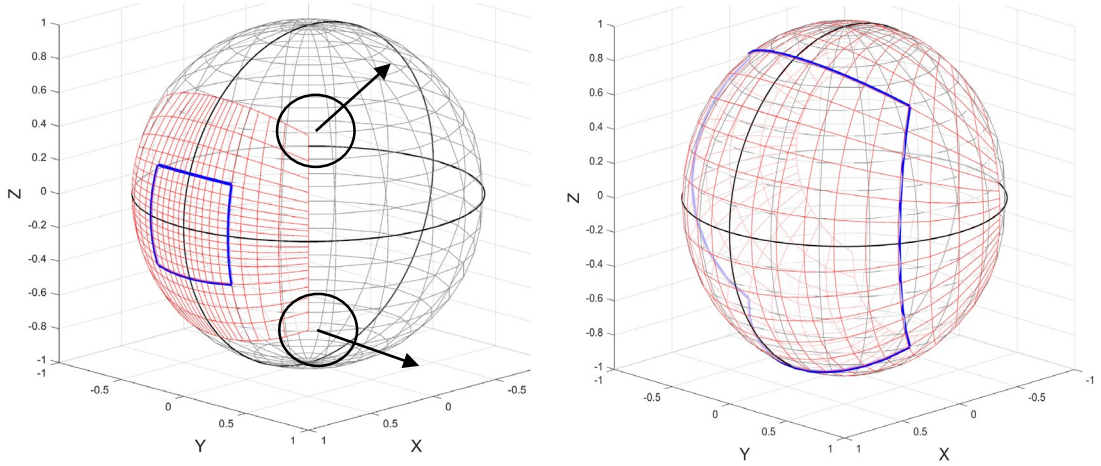
**Paul Schlatter**
**Science and Operations Officer**
**Denver/Boulder Weather Forecast Office**

**From 7 Jan 2021 EMC Model Evaluation Group Briefing**

**Shannon Shields, Marcel Caron, Chris McIntosh, Geoff Manikin, Alicia Bentley, Logan Dawson**

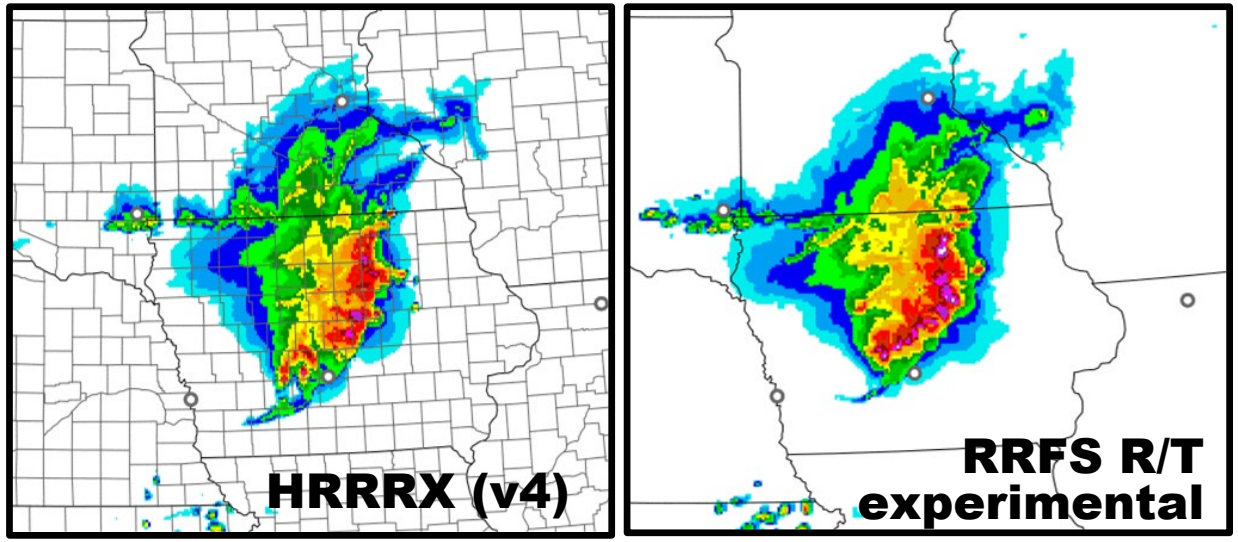
# GSL: Strong Engagement on Unified Forecast System

## Coordination with EMC on Extended Schmidt Gnomonic grid for Short-Range Weather App




## GSL scale-aware physics suite (contribution or testing)

| Physical Process | Parameterization |
|---|---|
| **Microphysics** | **Aerosol-aware, radiation-coupled Thompson-Eidhammer** |
| **Surface/Boundary Layer (PBL)** | **Scale-aware MYNN-EDMF** |
| **Short/Longwave Radiation** | **RRTMG or ML Emulator** |
| **Land Surface Model (LSM)** | **RUC (9 level) or Noah-MP** |
| **Gravity Wave Drag** | **GSL drag suite** |
| **Cumulus (for coarse resolution)** | **Scale-aware Grell/Freitas (GF)** |

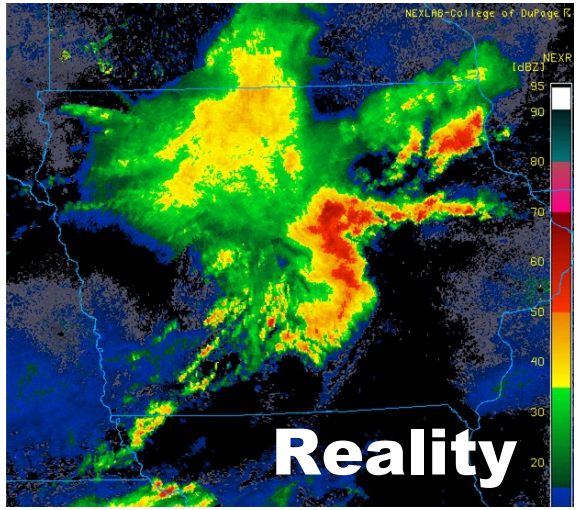



**Init. 1200 UTC 10 Aug. 2020**
**5-h forecast reflectivity**

UFS

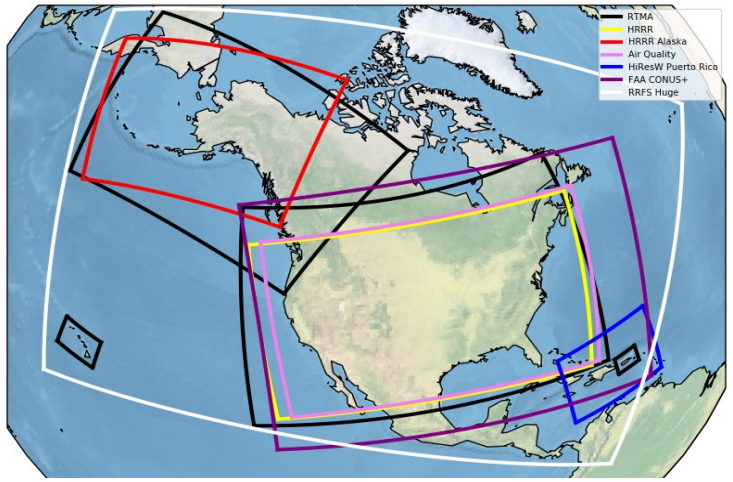
**Common Community Physics Package**

GSL real-time RRFS forecast for IA/IL derecho event




**1200 UTC 10 Aug. 2020**
**observed reflectivity**

# GSL: Key Role in UFS Regional Development

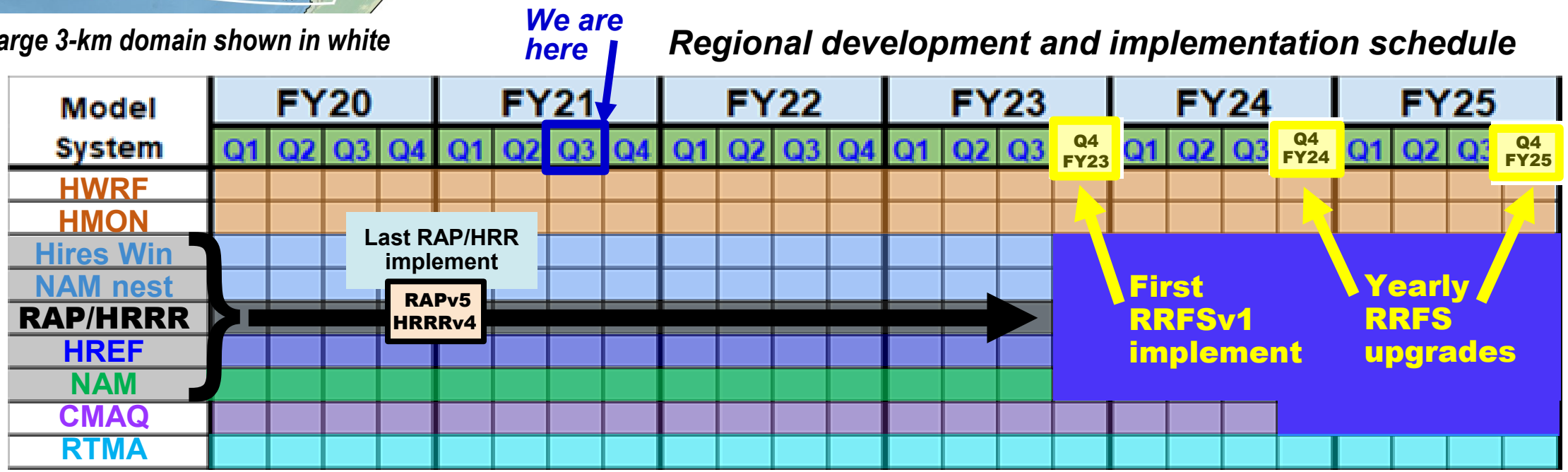



*RRFS large 3-km domain shown in white*

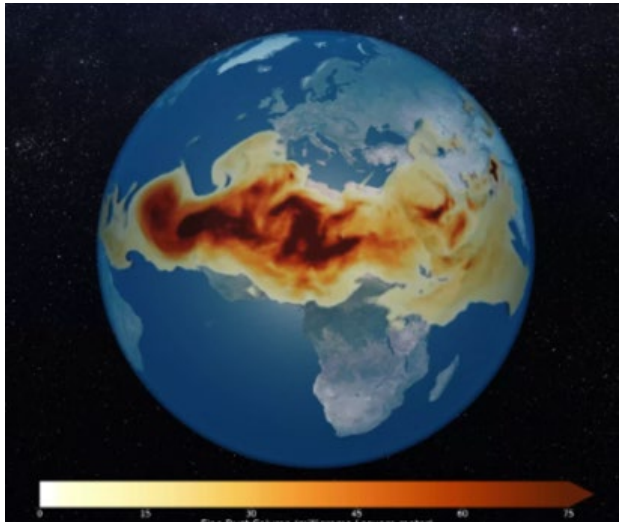
**Rapid Refresh Forecast System (RRFS)**

- Consolidation of all regional models
- 3-km ensemble data assimilation with JEDI **(HRRRDAS is prototype)**
- 3-km ensemble forecasts **(HRRRE is prototype)**
- GSL: key research for many RRFS capabilities (hourly cycling, radar / lightning DA, cloud analysis, use of GOES and DBnet data, smoke)

***Regional development and implementation schedule***



# GSL: Key Role in UFS Global Development

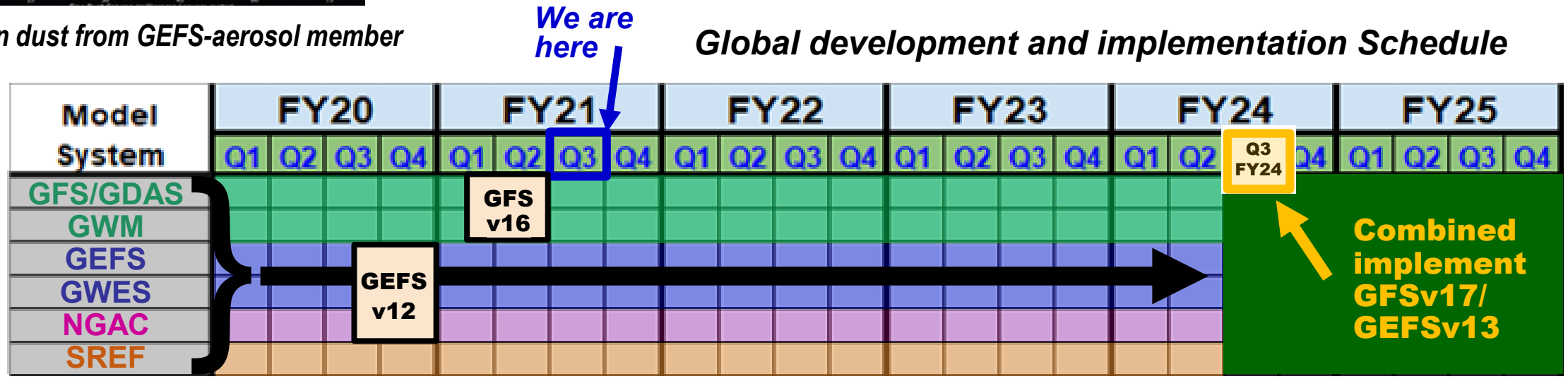


*Saharan dust from GEFS-aerosol member*

**Contributions to global model systems (GFS, GEFS)**

- GEFS member with GOCART aerosol package **(GEFSv12)**
- Common Community Physics Package for different schemes **(CCPP)**
- Development of in-line aerosol and chemistry modules for UFS
- Development of candidate scale-aware physics suites for UFS
- Development toward improved sub-seasonal capability for UFS

***Global development and implementation Schedule***



NOAA Global Systems Laboratory

# Towards the Grand Challenge: Prediction Across Scales

Curtis Alexander
Chief, Assimilation and Verification Innovation Division

Global Systems Laboratory

# GSL Grand Scientific Challenge

*Provide actionable environmental information through the delivery of global storm-scale predictions and innovative decision support capabilities to serve society.*

→ **Predict Earth-system seamlessly across space and time scales**

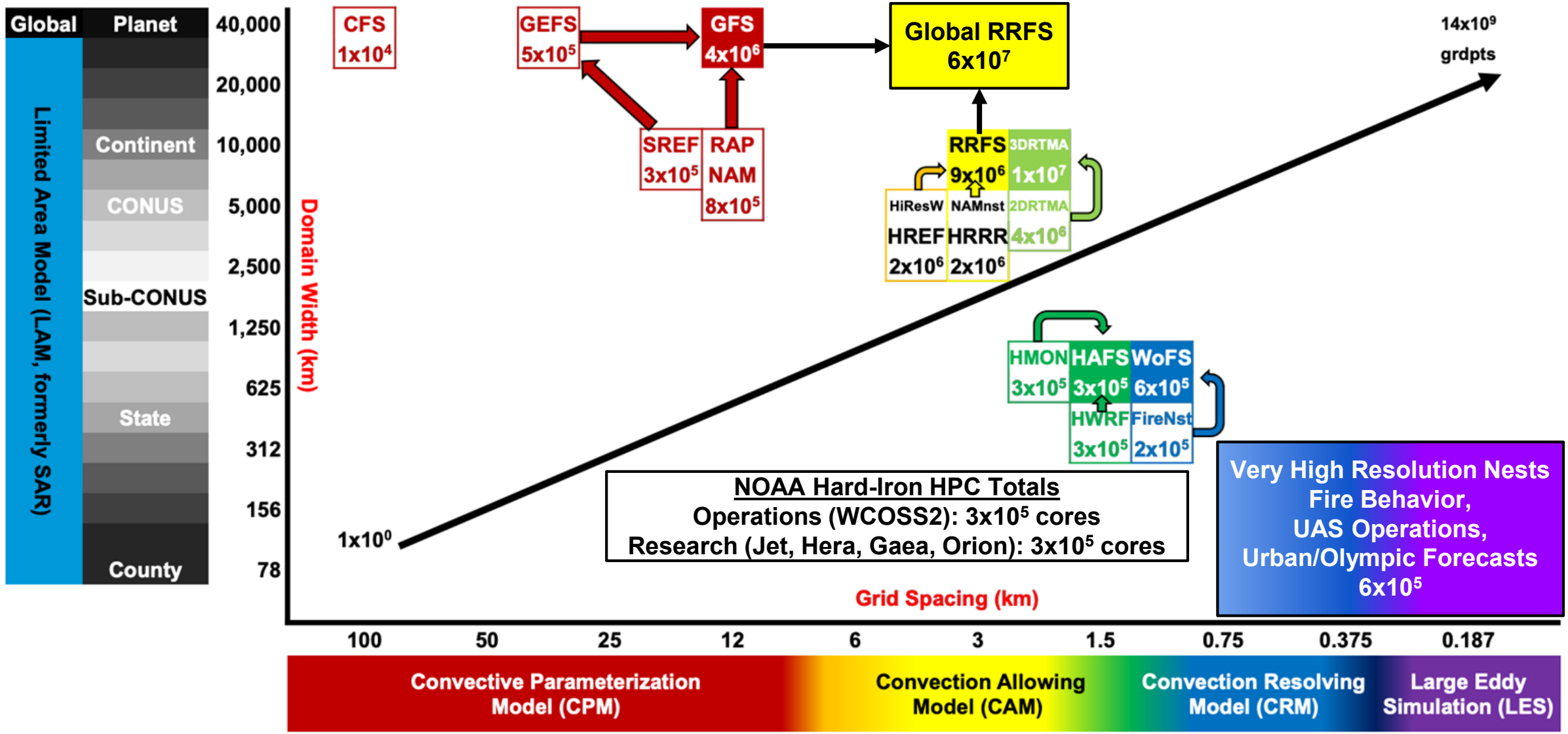
Rapidly-updating global DA
Strongly-coupled data assimilation
Multi-scale ensemble-based analysis
Contribution to community-based JEDI

↔

Fully coupled earth system model
Scale-aware physical parameterizations
Representation of uncertainty
Community-based CCPP and UFS

Advanced technologies (AI, ML) for computational efficiency in advancing DA/modeling
Explore exascale computing challenges to manage O($10^6$) obs and O($10^{7-8}$) gridpoints
Research-grade model system with complex physics/chem for process understanding
Develop non-Gaussian analysis techniques like particle filtering for non-linear problems

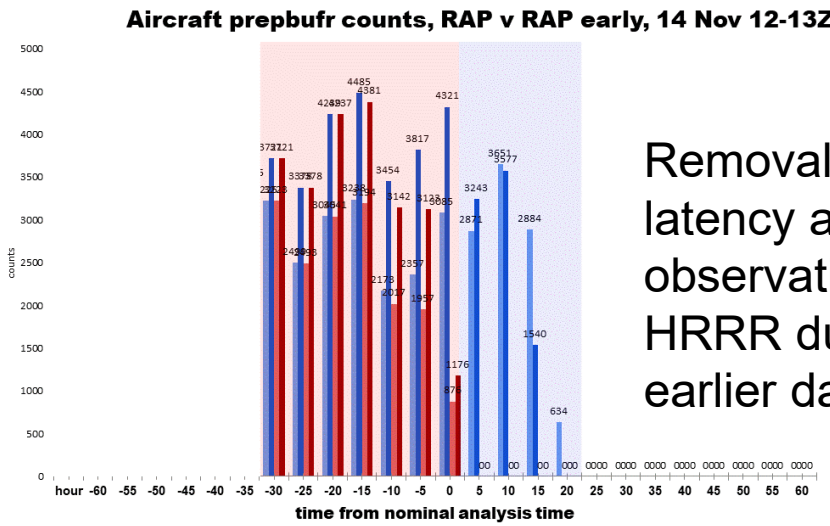
# Scales of Prediction Systems



# A Global Rapidly Updating Storm-Scale Model

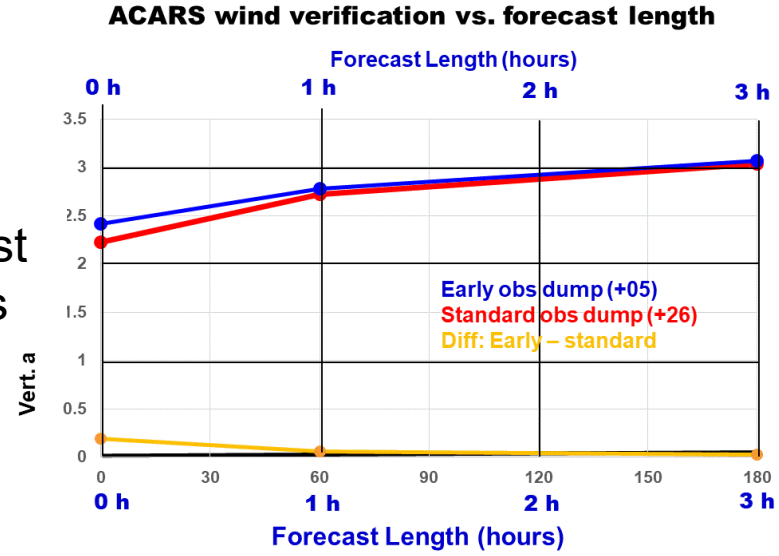
Transition from 6-hr to 1-hr global data assimilation cycles at 13 km scale

- Collaboration underway between GSL, PSL, EMC and JCSDA
- Produce hourly global “data dumps”
- Test assimilation strategies to
  - mitigate noise from frequent analyses
  - produce lower-latency shorter-term forecasts with smaller obs windows
  - collect more latent observations for longer-term forecasts to “do no harm”




Removal of higher latency aircraft observations (red) in HRRR due to 20 min earlier data cutoff

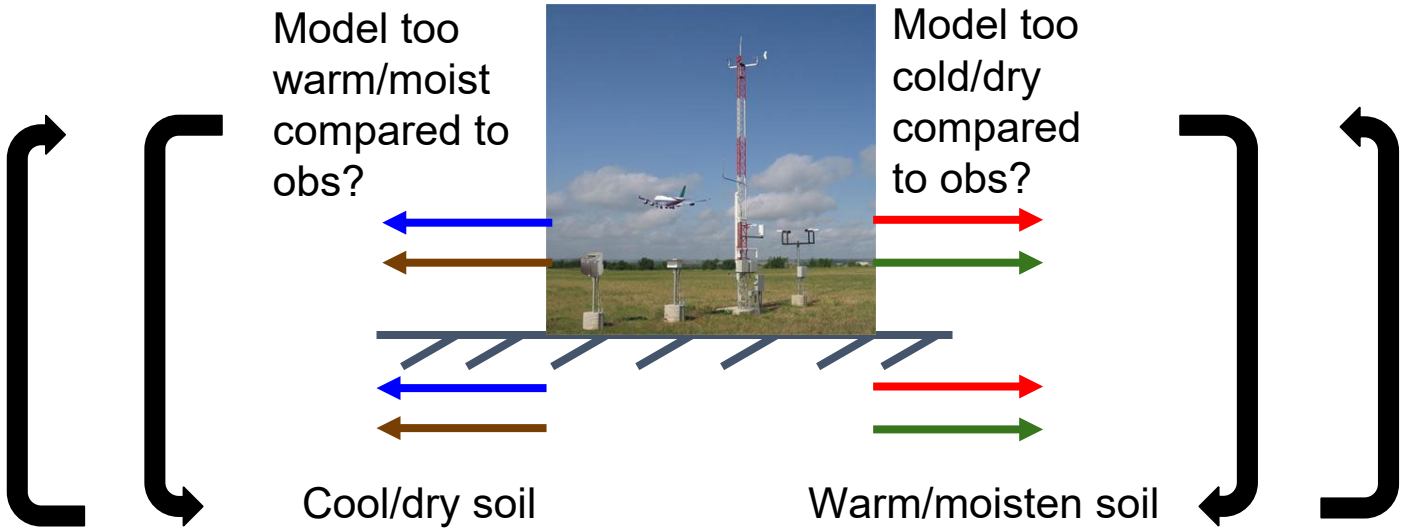
Small increase in HRRR wind forecast error from data loss



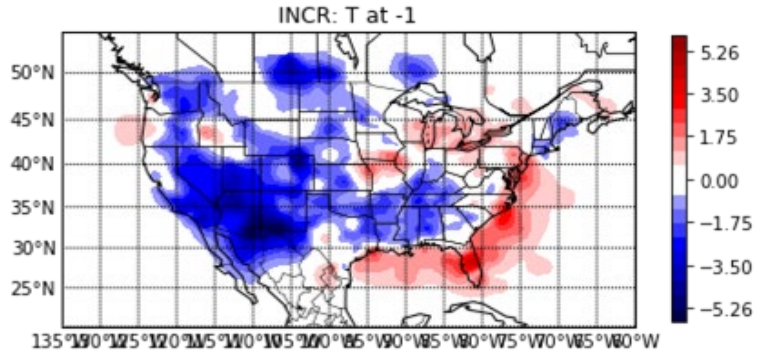
# A Global Rapidly Updating Storm-Scale Model

Effective DA using surface (and other) observations including coupled data assimilation

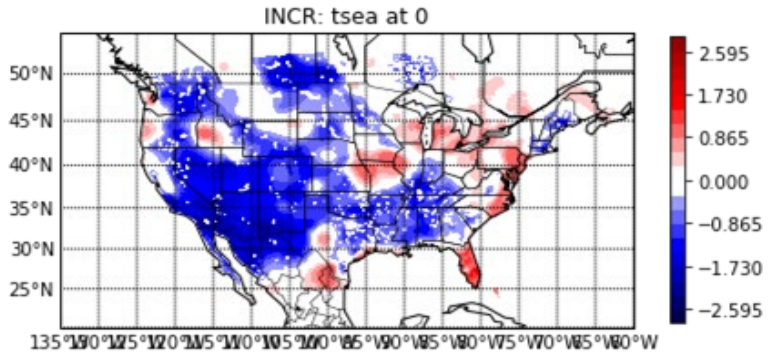
## RAP/HRRR 1-way coupled DA Soil Adjustment




From soil temp/moisture observations (i.e. SMAP)




Atmos Temp Increment (K)




Soil Temp Increment (K)

→Cross-covariances between atmosphere and land via JEDI Ensemble Kalman Filter (EnKF)

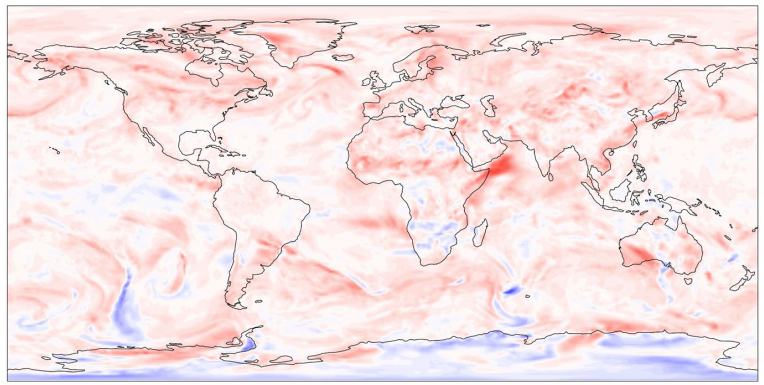
# A Global Rapidly Updating Storm-Scale Model

Global storm-scale (3 km) forecasts with scale-aware physics suite:

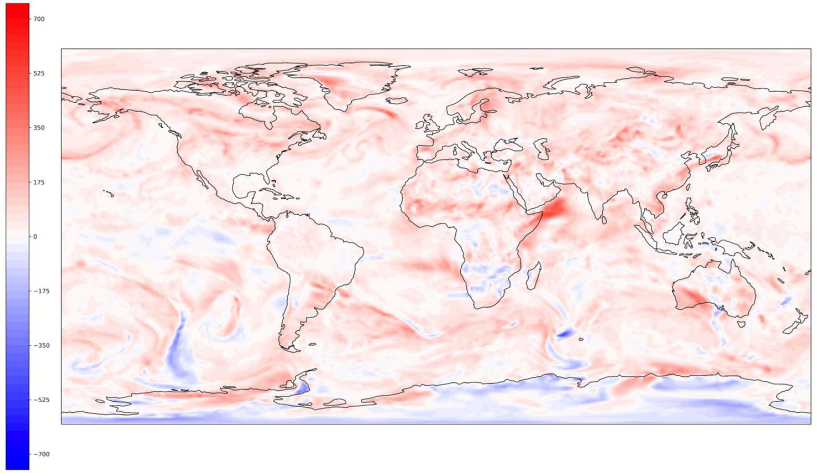
- SW/LW Radiation: RRTMG
- Microphysics: Thompson
- Boundary Layer: MYNN
- Surface Layer: GFS
- Land Surface Model: Noah

96 hr (4 day) global 3 km fcst
13,068 processors (363 nodes)
6 hrs of wall clock time per 24 hr fcst

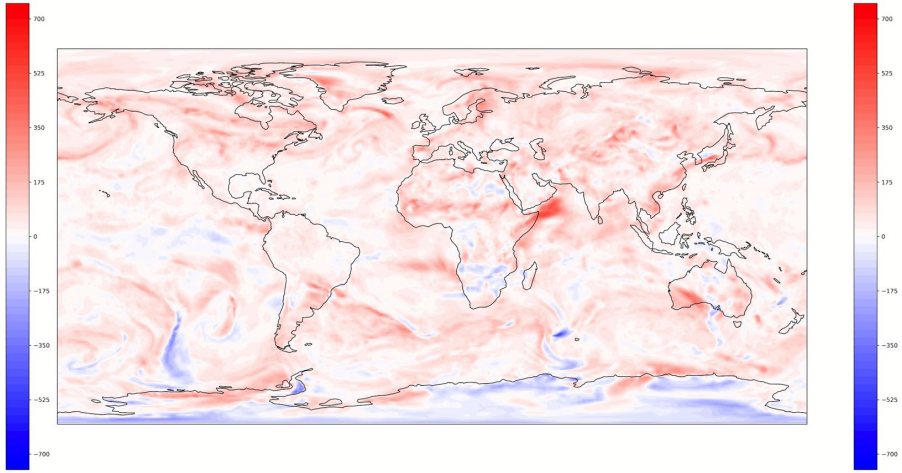
Hourly animation of storm-relative helicity



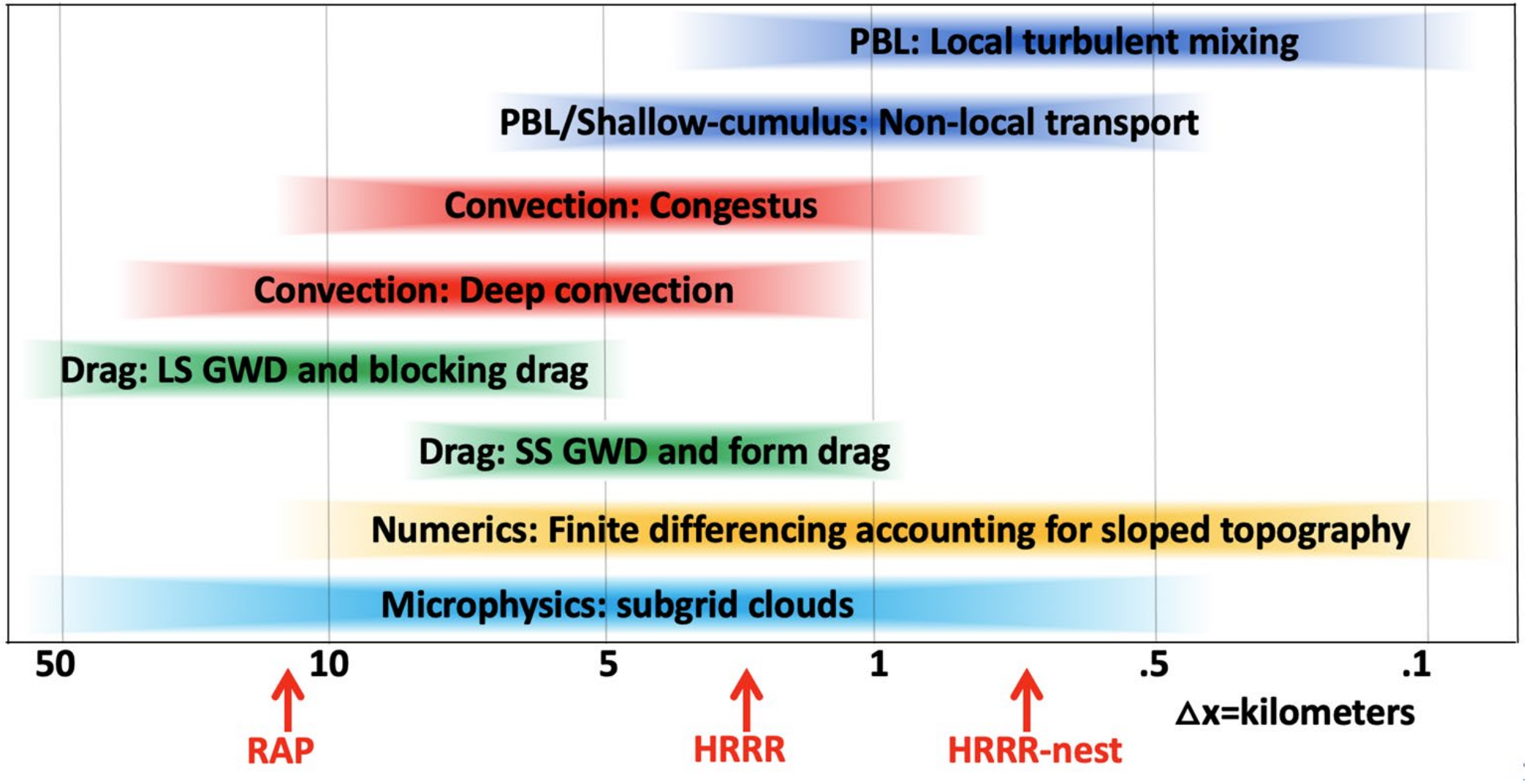
Hourly animation of reflectivity



Hourly animation of clouds



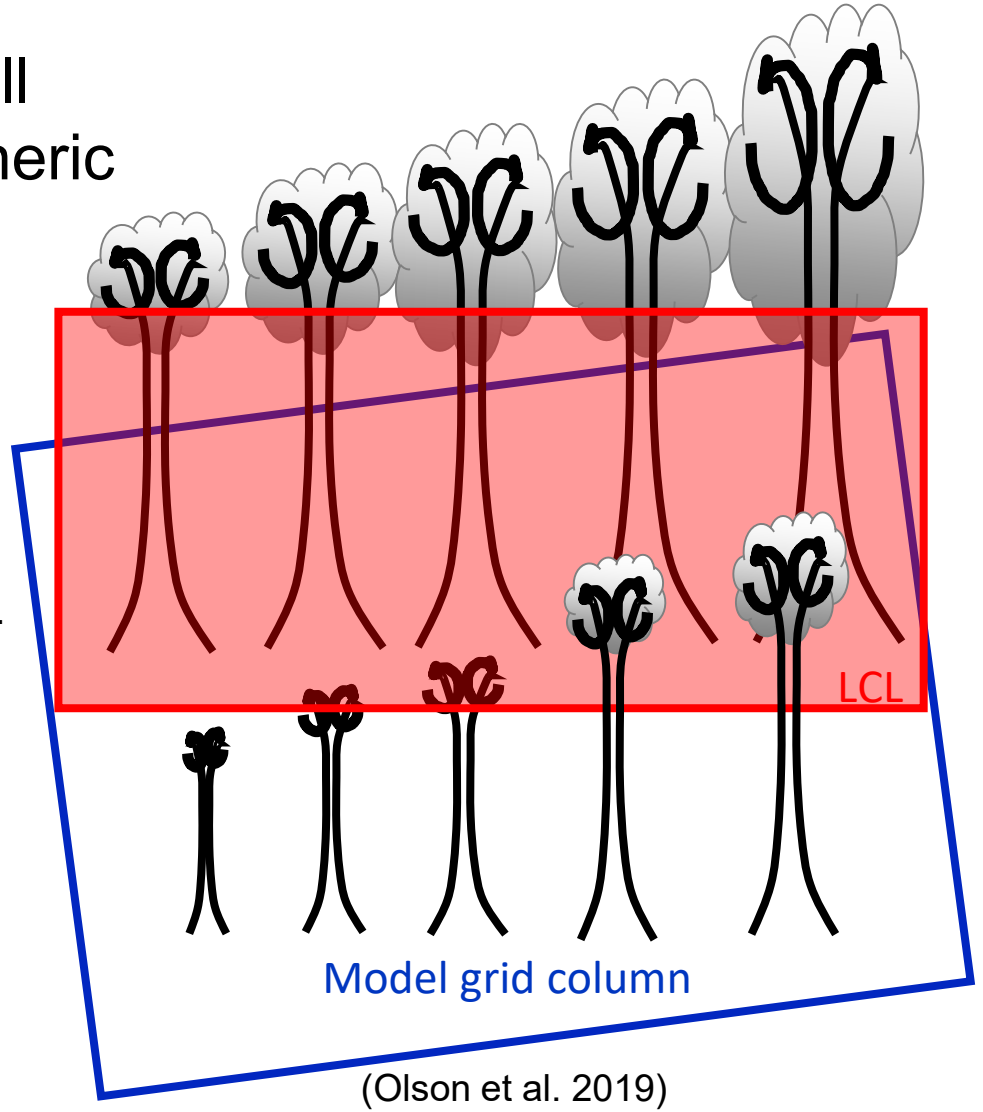
# Spatial Scales of Varying Scheme Behavior



# Scale-Aware MYNN Boundary Layer Scheme

Uses a spectral plume model to explicitly represent all plume sizes that are likely to exist in a given atmospheric state/model grid configuration:

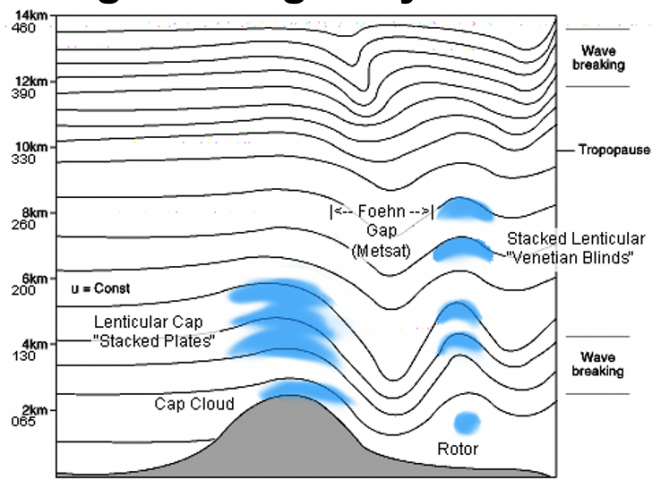
- Maximum number of plumes active in a single grid column: 10
- Diameters: 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 m
- Maximum plume size is determined as:
  - MIN(PBLH, cloud ceiling, $\Delta x$)
- Plumes can form shallow-cumulus clouds only if they surpass LCL




(Olson et al. 2019)

# Drag Suite

**Large-scale gravity waves**

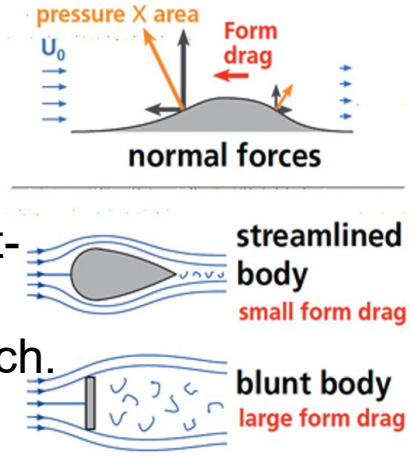



**Flow blocking**


**Small-scale gravity waves**

Adapted from original version provided by Gert-Jan Steeneveld, Delft Univ. of Tech.

**Form Drag**




Traditionally used components

- Large-scale GWD and flow blocking drag taper off by $\Delta x = 5$km

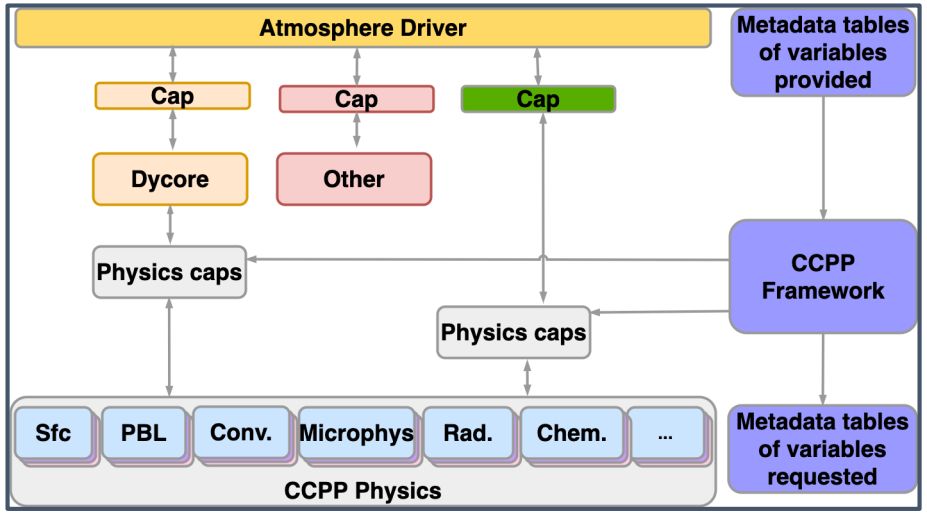
New components:

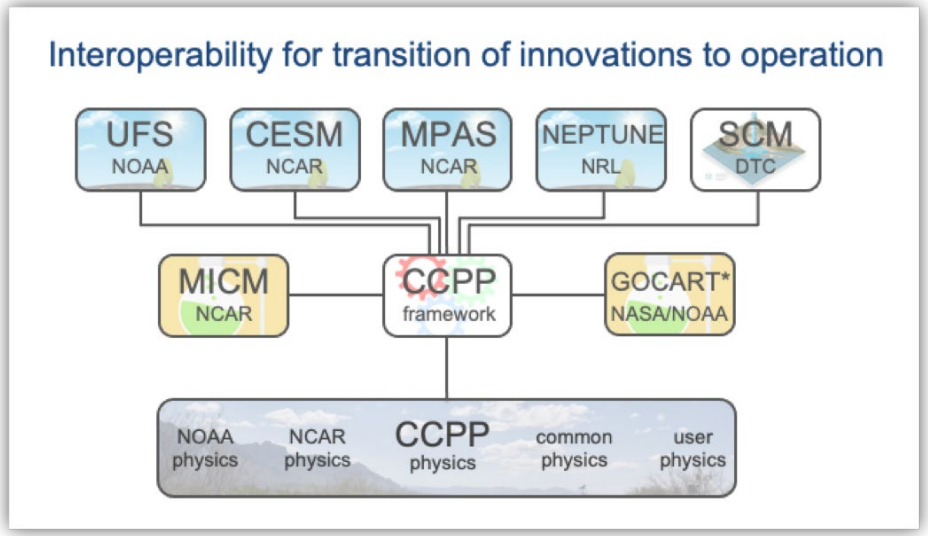
- Small-scale GWD and form drag can be used down to $\Delta x = 1$ km

Adapted from Beljaars et al. (2004)

# Enabling Model Physics Infrastructure: CCPP

- CCPP is an open-source and publicly supported library of physical parameterizations with associated framework for use in weather and climate prediction models
- Parameterizations have been contributed by a wide range of developers
- CCPP facilitates research and development through interoperability, adoption of clear interfaces, and support for hierarchical system  development
- Uses documented interfaces (metadata) to lower the bar for adding new schemes and transferring them between models
- Chosen as infrastructure for atmospheric physics and possibly chemical processes in the UFS
- Developed by NOAA and NCAR (Part of the NCAR-NOAA MoA)



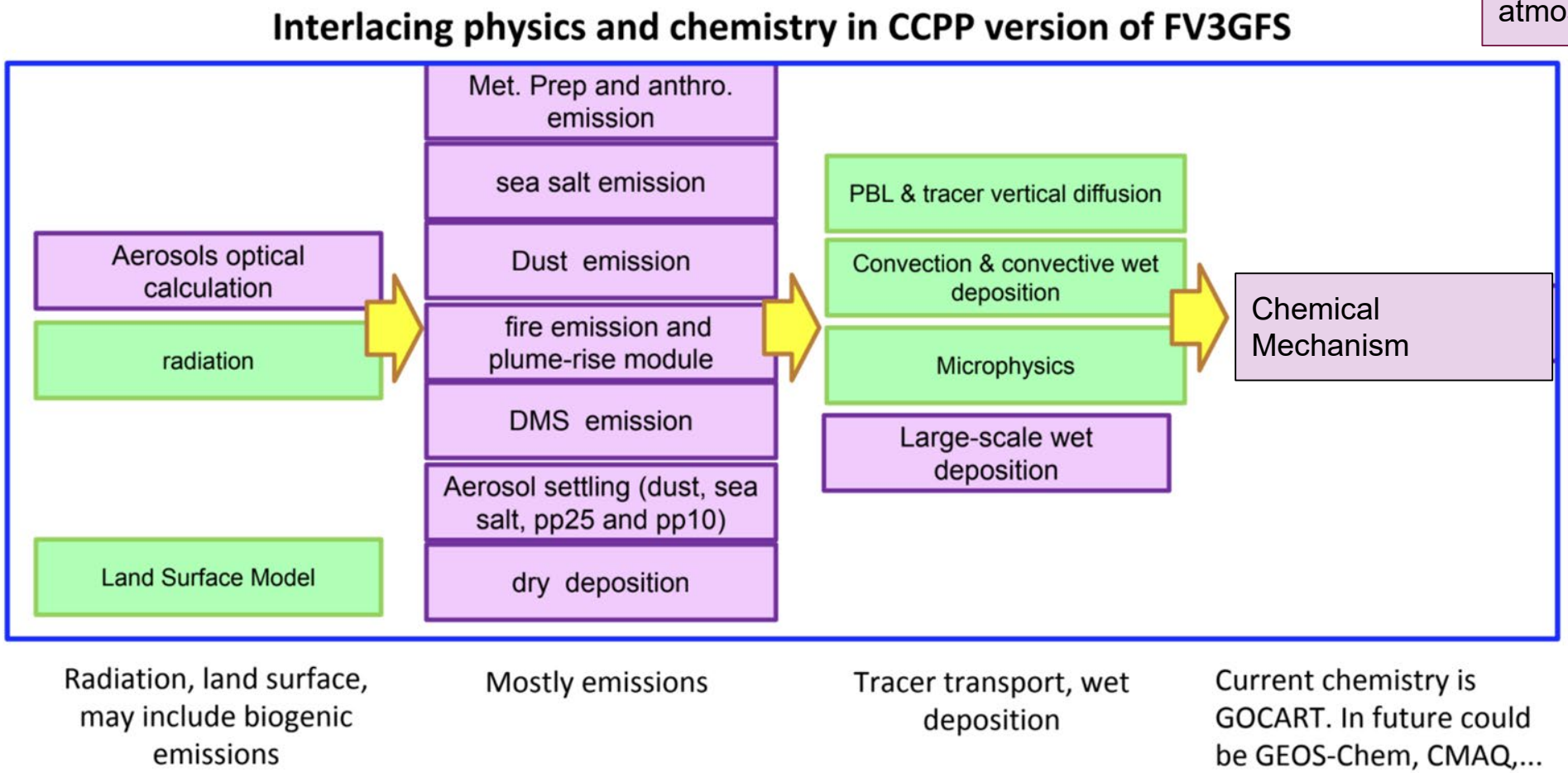



# CCPP Use for Atmospheric Composition

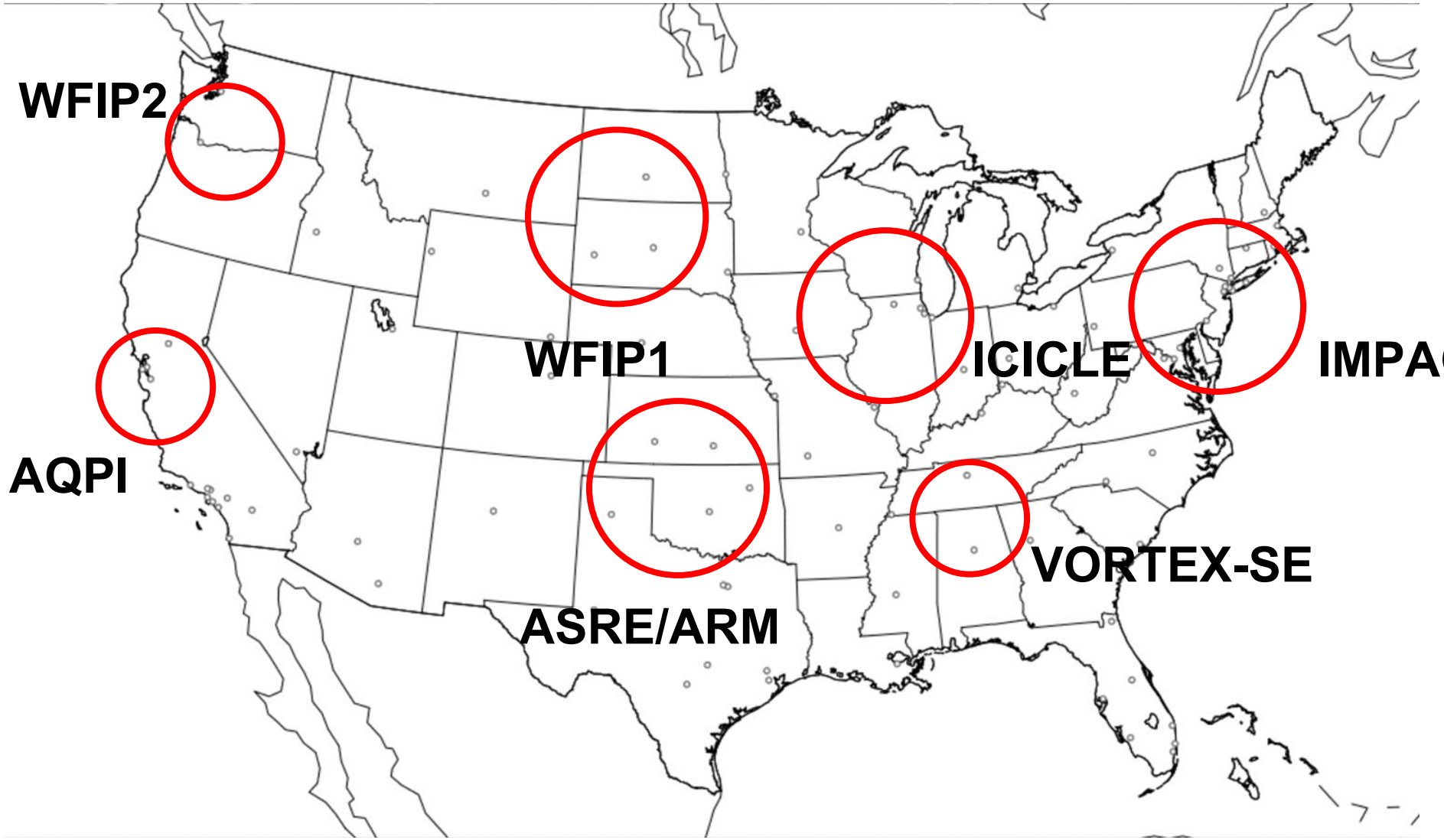
## Physics and Chemistry in a single suite

physics

atmospheric composition



# Very High Resolution (≤ 1 km) Nesting Research




Experiments leveraging ≤ 1-km grid nests

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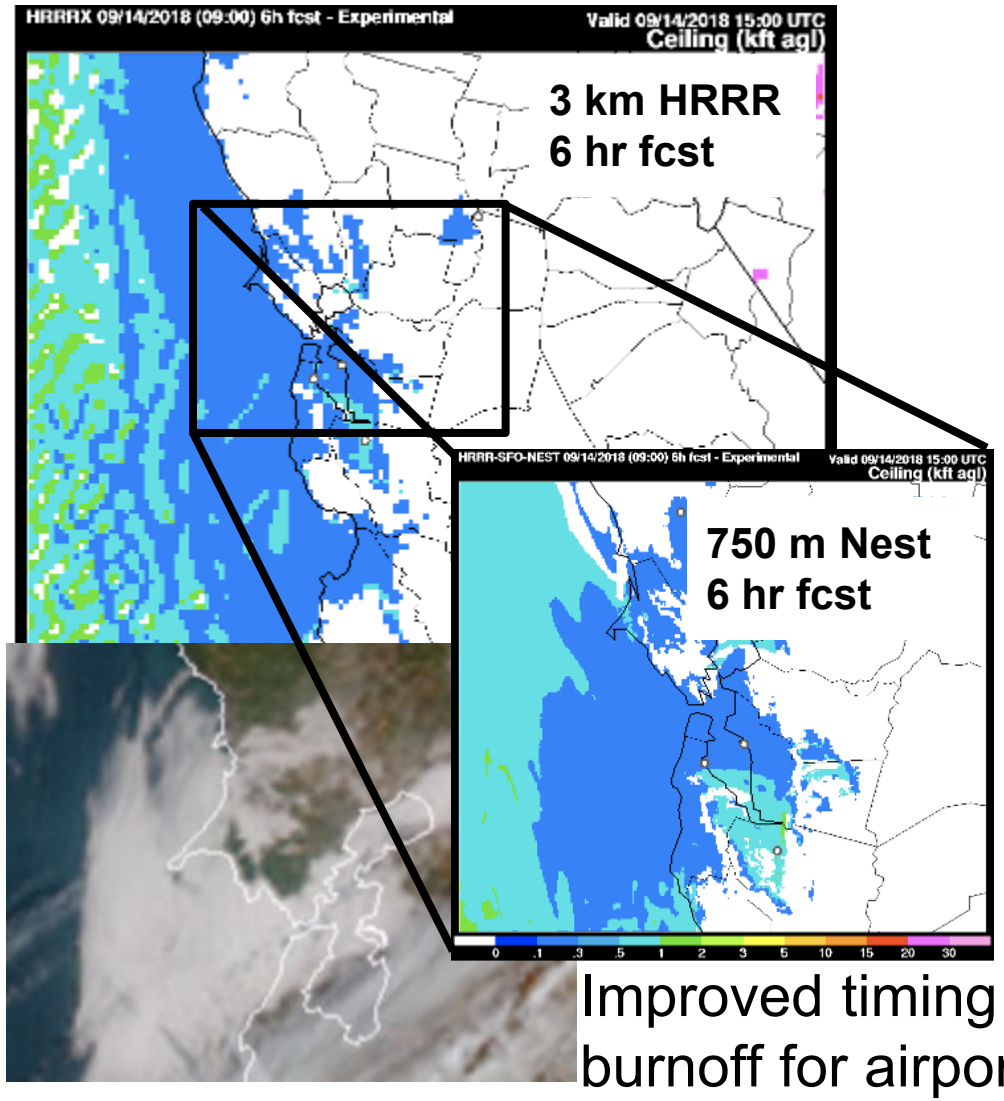
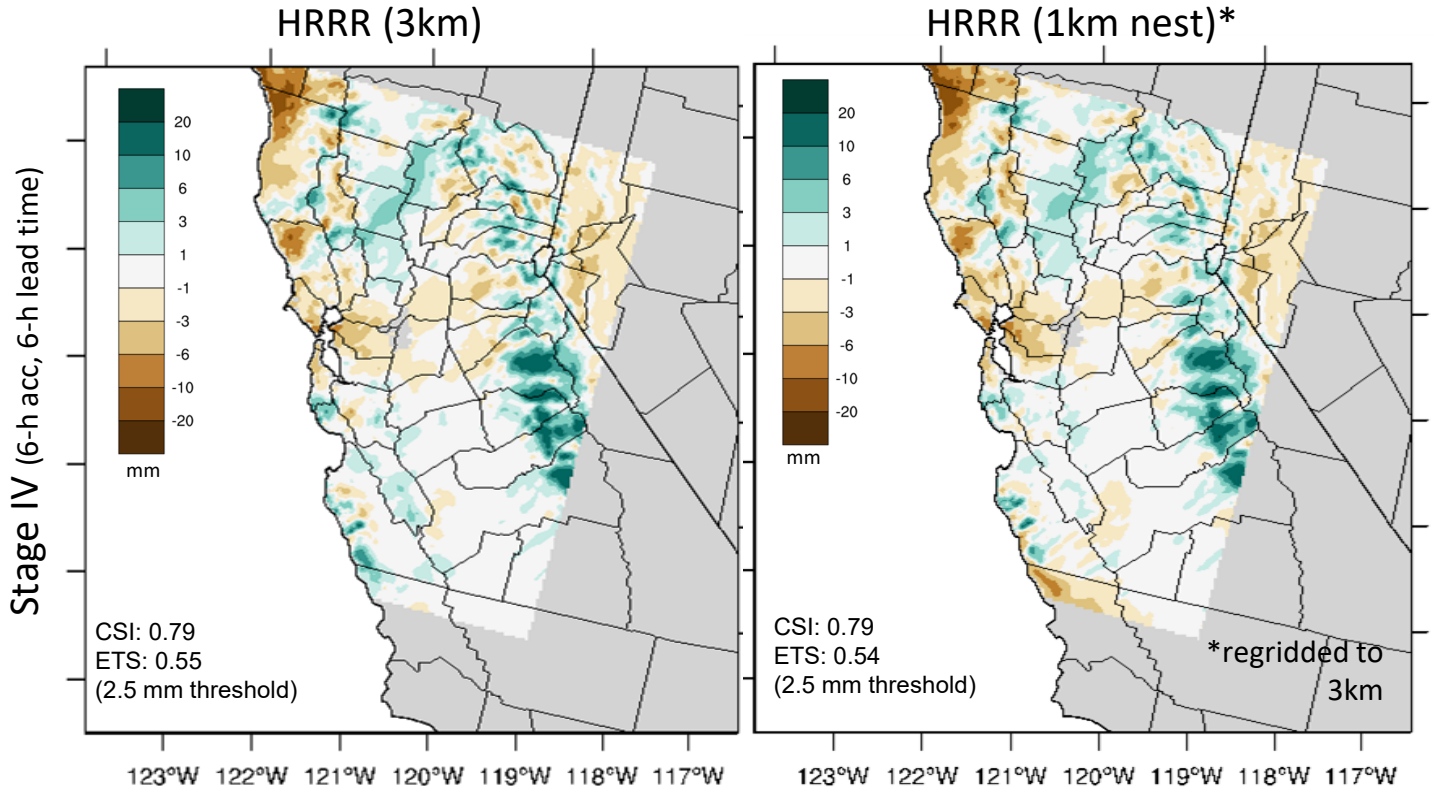



Improved timing of SFO fog burnoff for airport operations




Evaluation of QPF biases with finer orographic detail (English et al. 2021)

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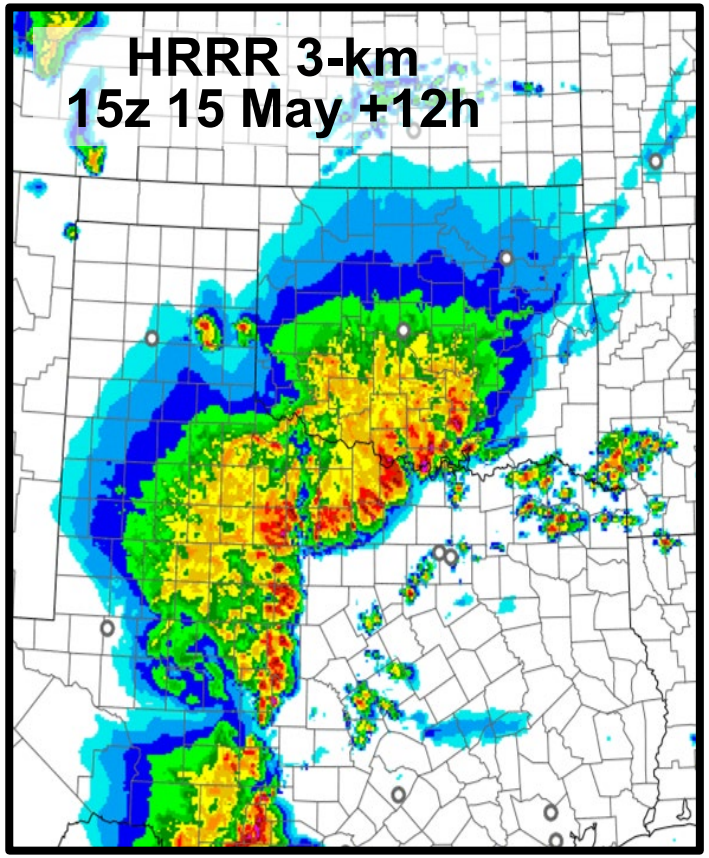
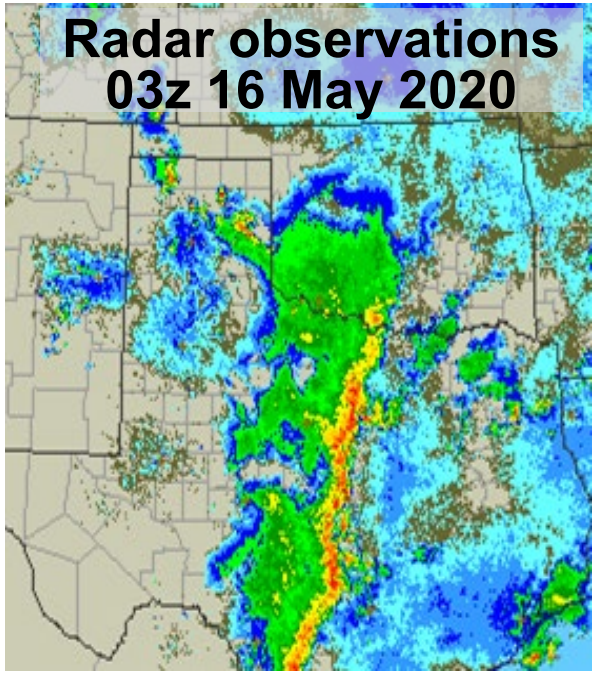
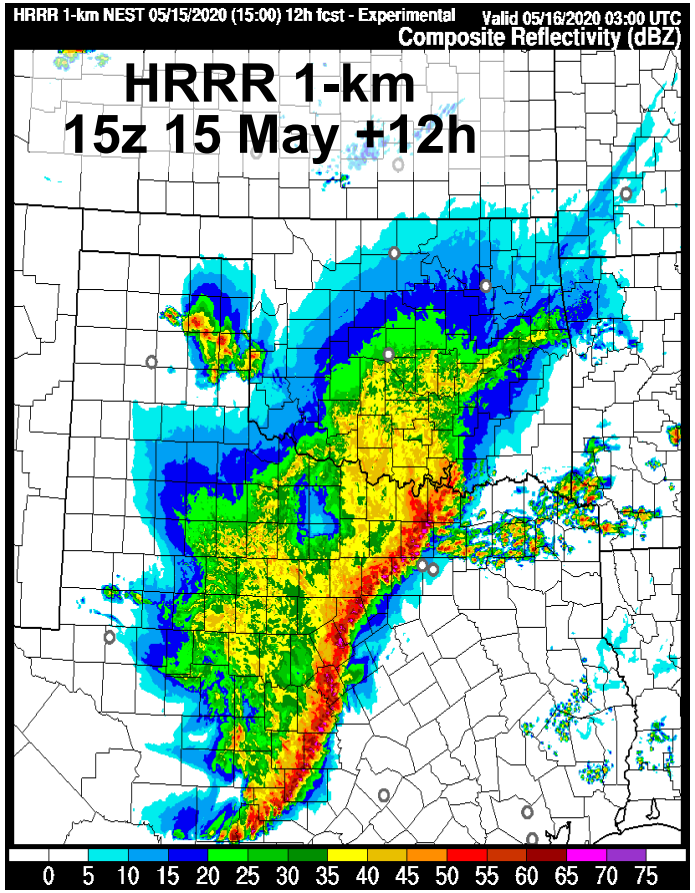
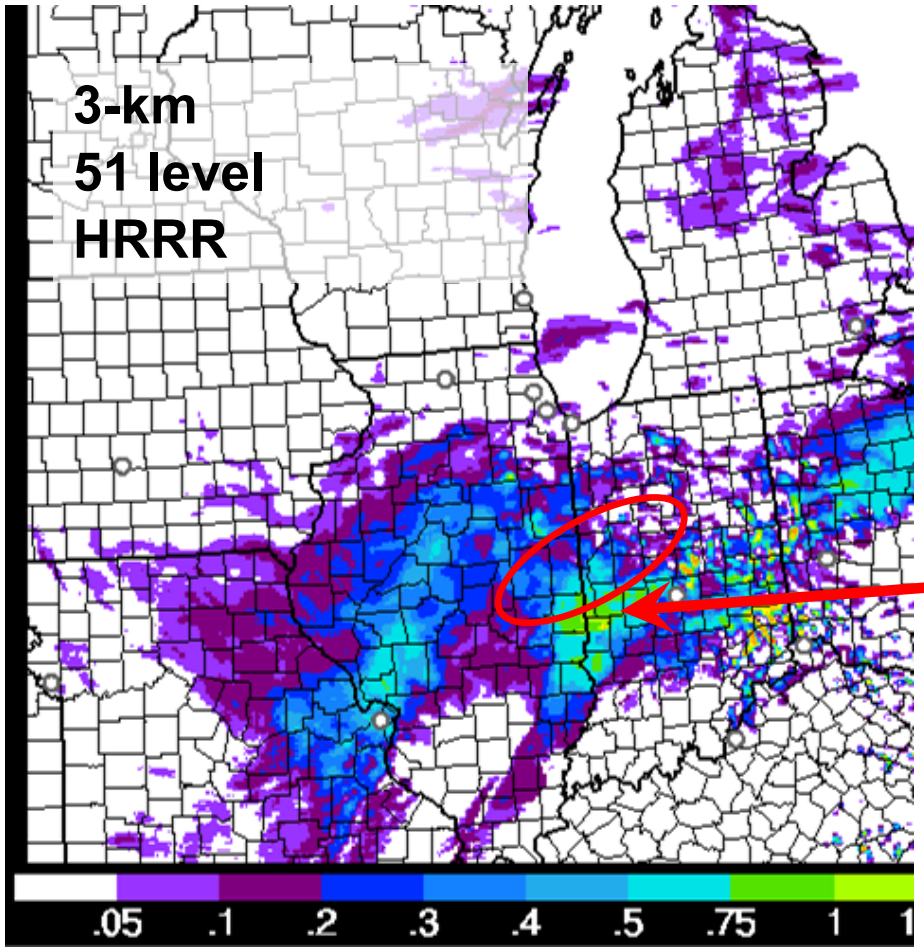


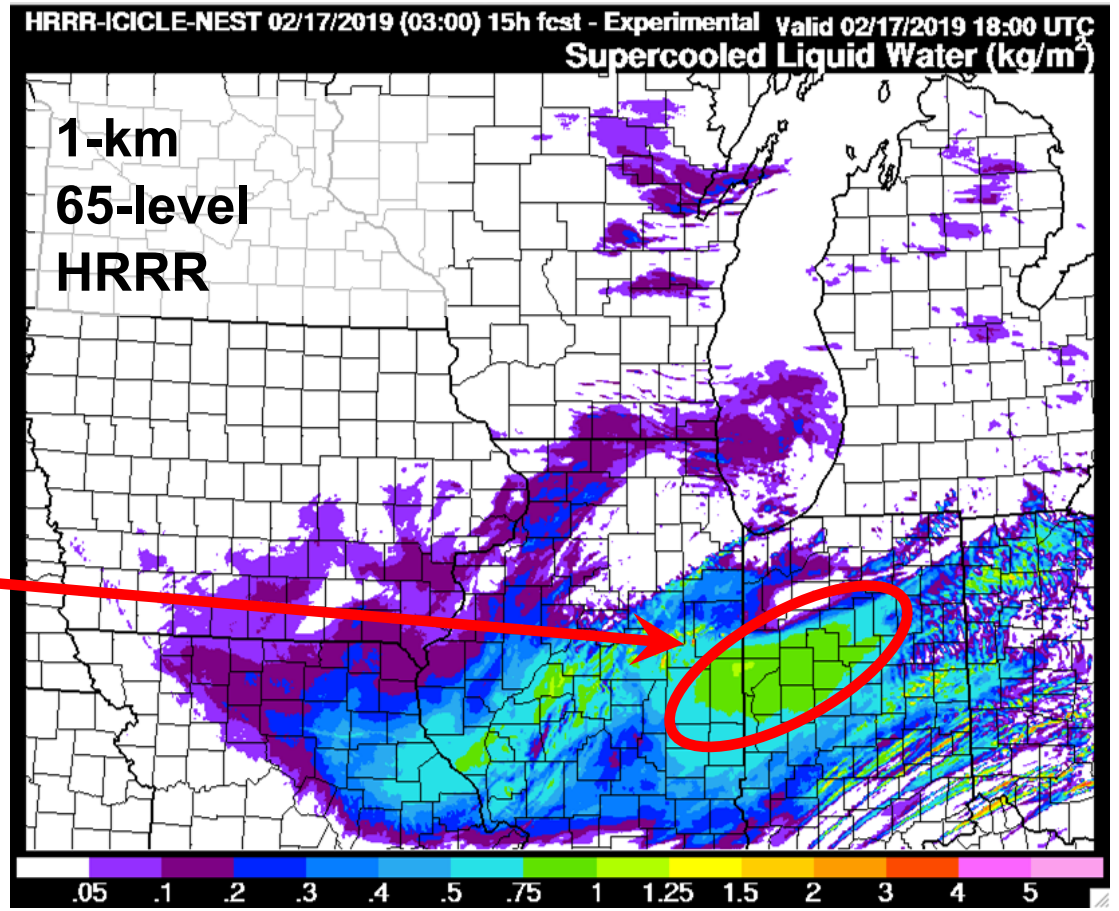




Convection impacts including more accurate initiation and system evolution at 1 km

# Very High Resolution (≤ 1 km) Nesting Research



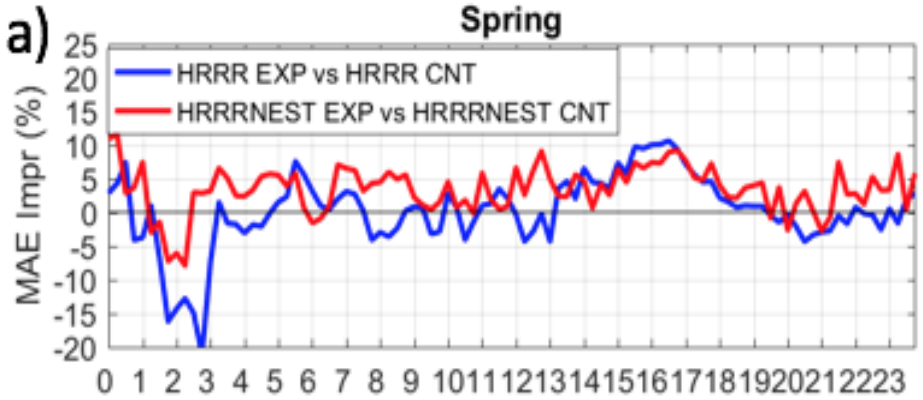

SLW
*Improved county-scale location of SLW from 1-km 65-level HRRR run*

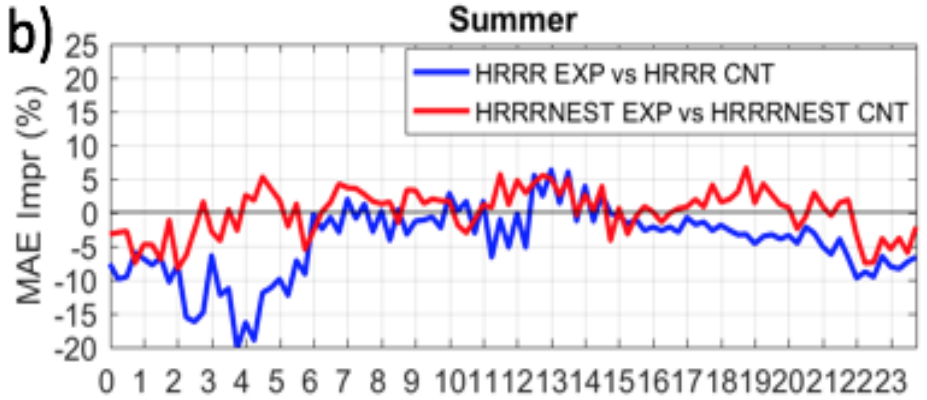


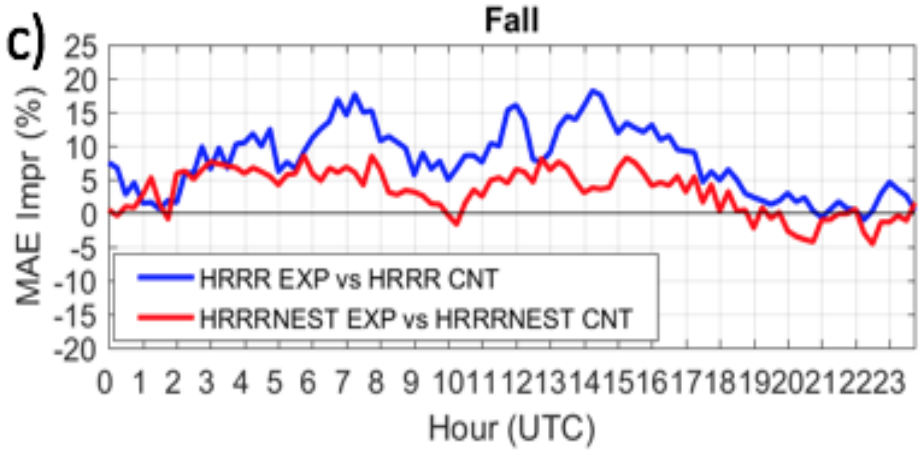

In-flight icing potential from increased supercooled liquid water (SLW)/banding at 1 km

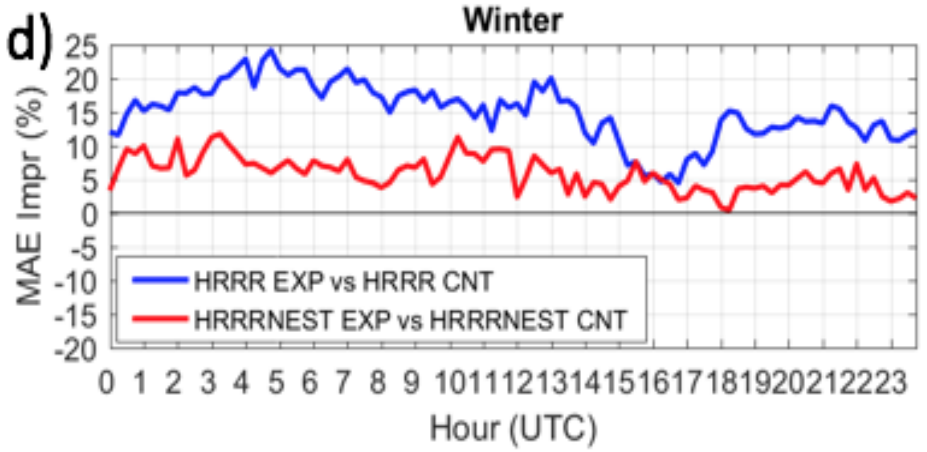
# Very High Resolution (≤ 1 km) Nesting Research

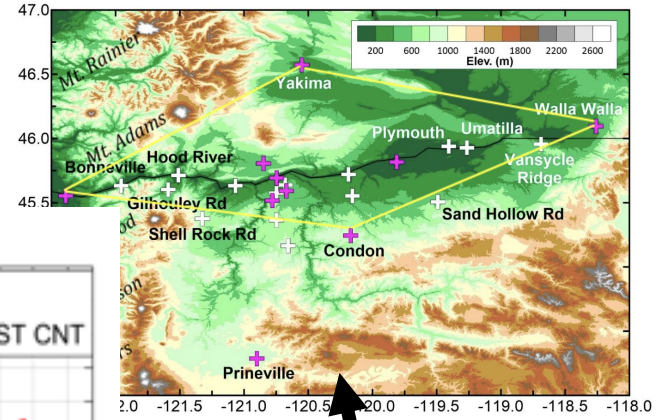
Seasonal dependence of 80-m wind speed validation in Columbia River Gorge with 750 m HRRR nest accuracy (red)



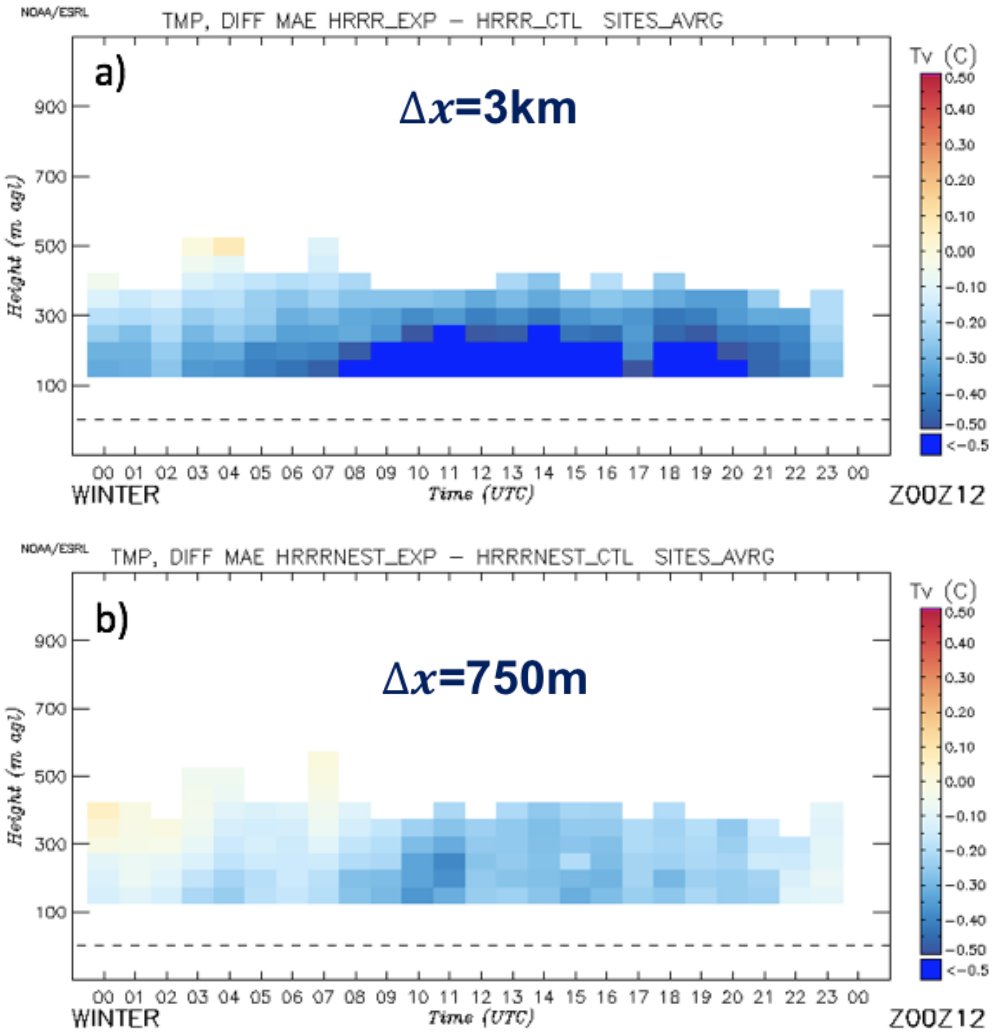




Validation against 19 sodars (white and pink crosses)

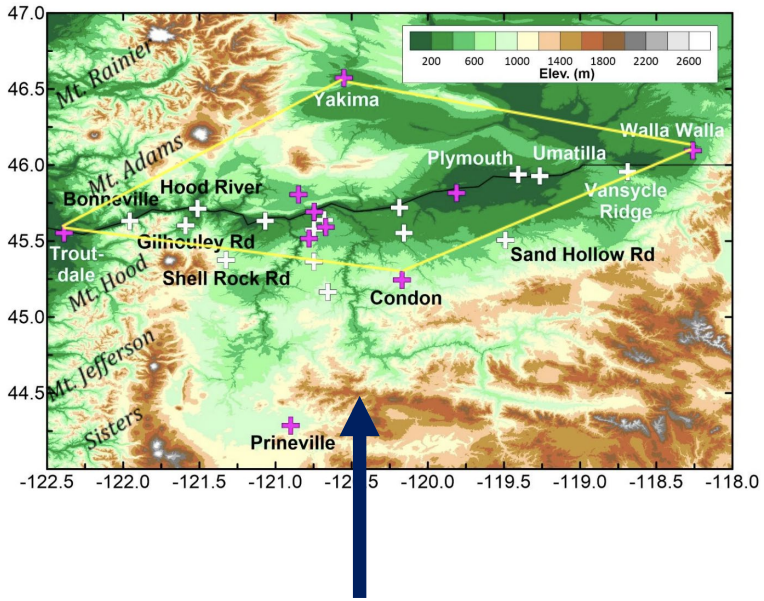
Olson et al 2019 BAMS

# Very High Resolution (≤ 1 km) Nesting Research




**Blue** = reduced MAE temp

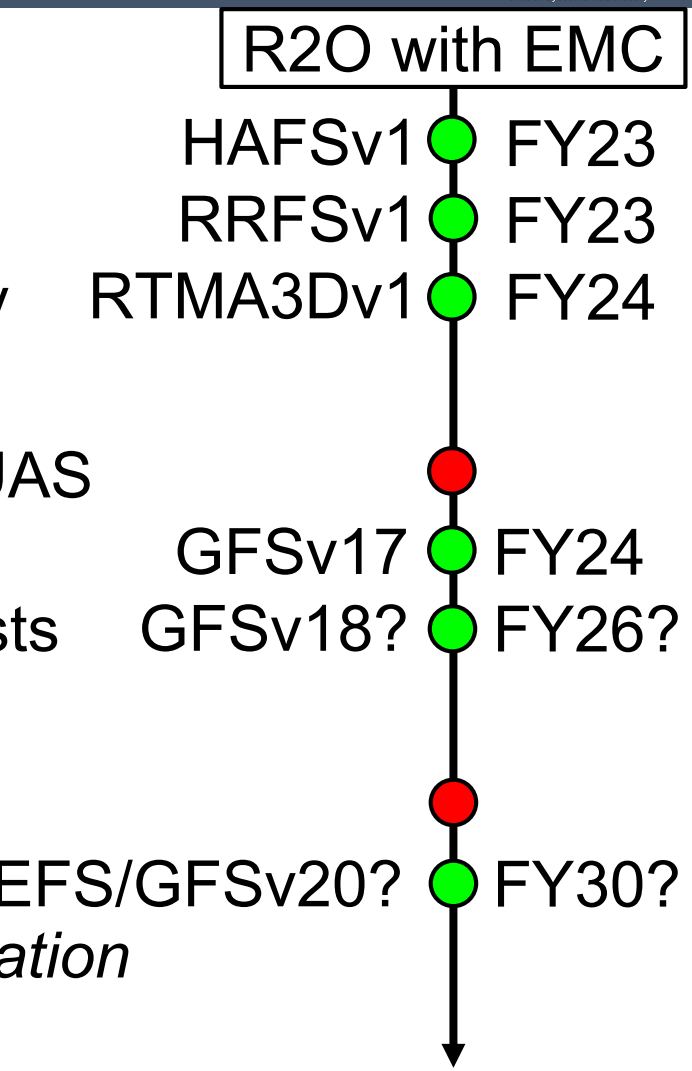
**Red** = increased MAE temp




**Validation against 9 RASS (pink crosses)**

# Future Direction Earth System Predictions

- Now (0-2 years)
  - Complete evolution to FV3LAM, JEDI and CCPP
  - Develop synergistic deterministic and ensemble CAM
  - Develop storm-scale 3D analysis-of-record and uncertainty
- Now and Next (0-5 years)
  - Research with very high-resolution LAM (≤ 1 km grid) for UAS
  - Develop global 13 km rapid refresh (hourly-cycled DA)
  - Develop global high-resolution (3 km) rapid refresh forecasts
- Now, Next and Later (0-10+ years)
  - Research into complex physical process understandings
  - Develop towards a global high-resolution ensemble
  - *Grand challenge: Provide actionable environmental information through the delivery of global storm-scale predictions and innovative decision support capabilities to serve society.*



# Thank you!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