The NOAA Atmospheric Science for Renewable Energy Research Program

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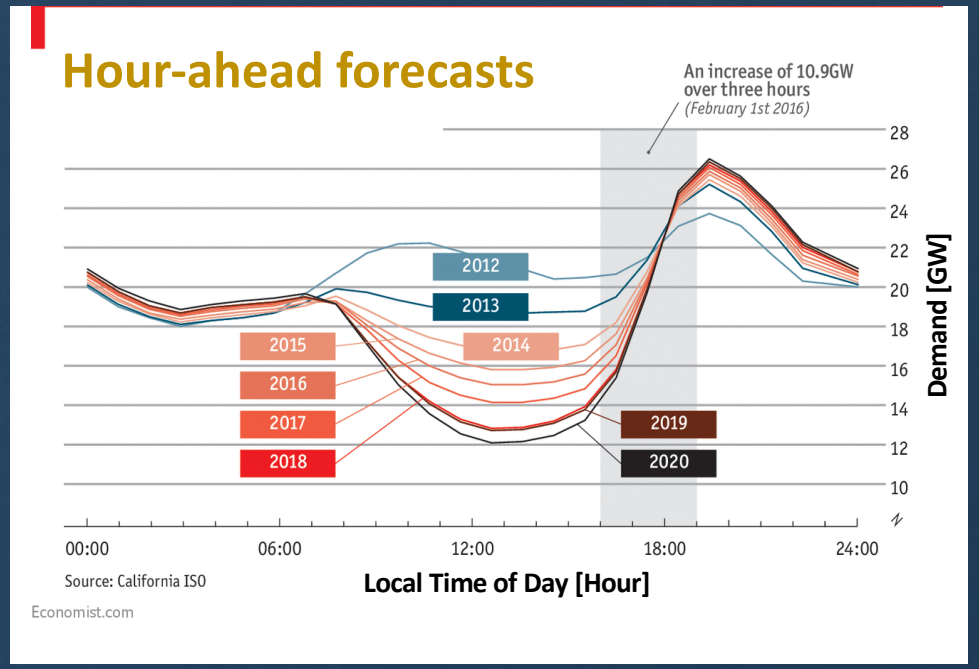
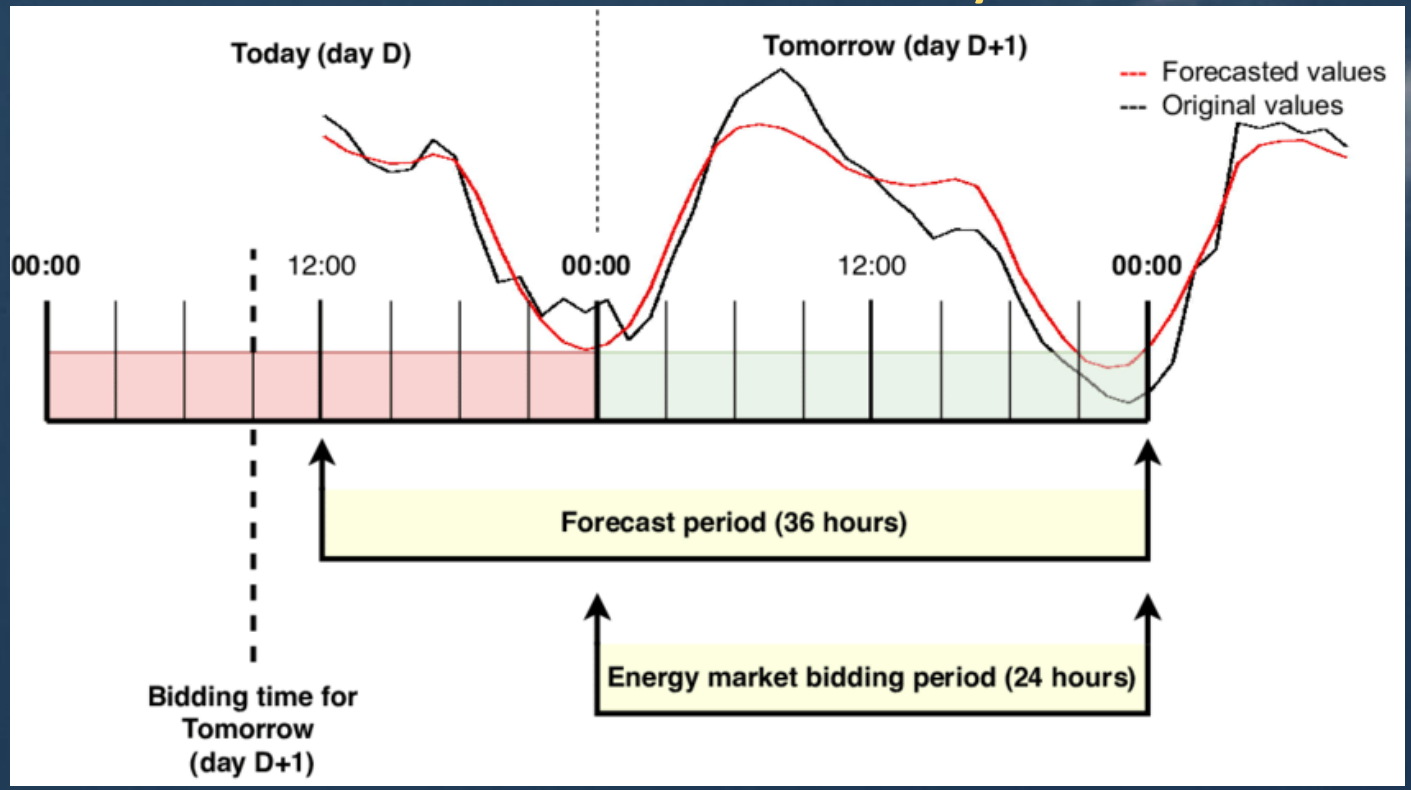
Weather Forecasts for Energy

- Renewable energy is cost competitive; generation capacity increasing yearly
- Wind and solar are highly variable energy sources
- Accurate weather forecasts are needed to better integrate wind and solar energy into the electric grid

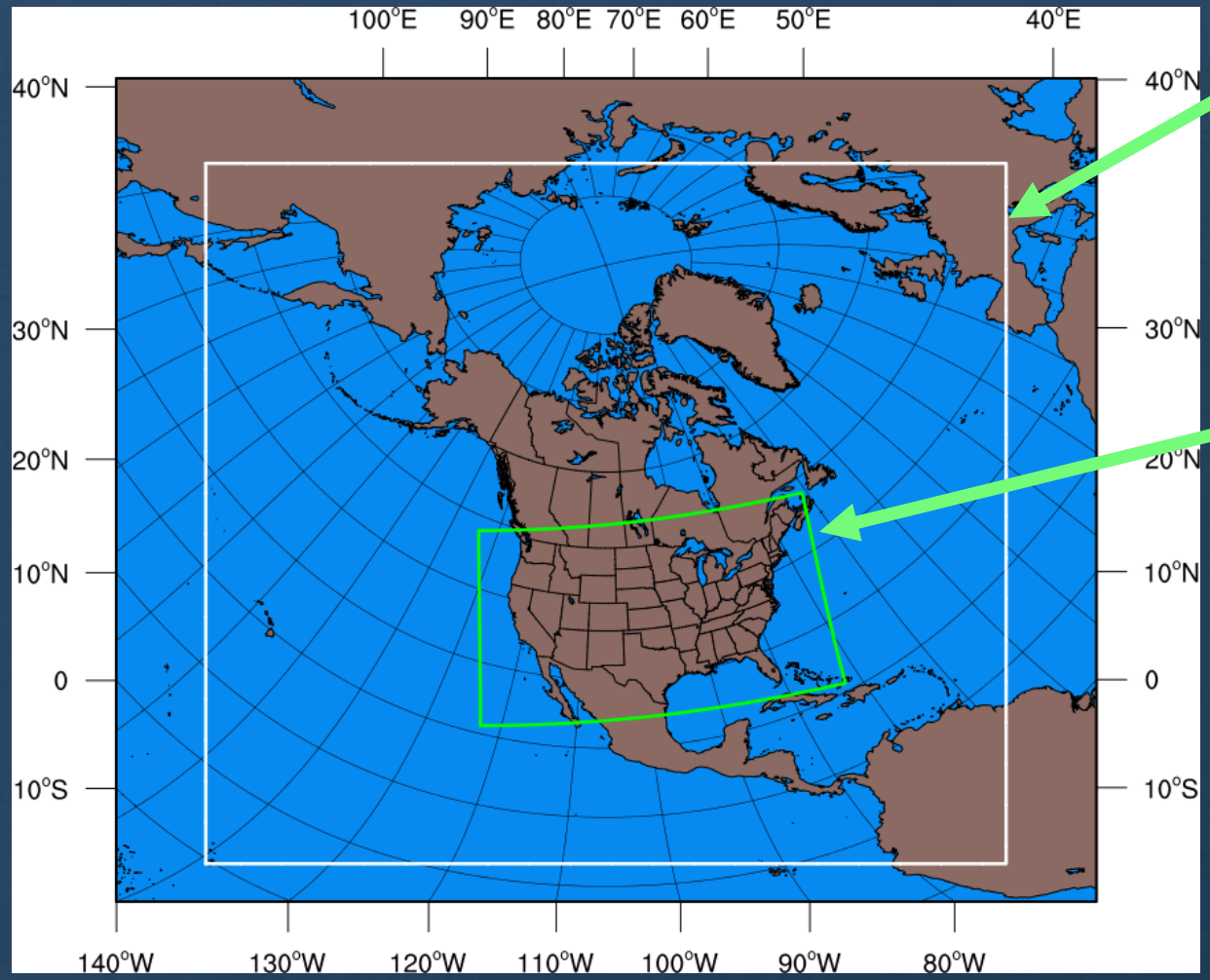


Day-ahead forecasts



- Hourly updates to Wx forecast very valuable

Rapid Refresh Forecast Model Suite



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

Initial & Lateral Boundary Conditions

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

- "Rapid Refresh" models designed for situational awareness
- Two resolutions provided (13 and 3 km)
- Restarts hourly to bring in latest observational data to get best "current" weather conditions

HRRR Users and Applications

Example: National Weather Service including Storm and Weather Prediction Centers (SPC and WPC)
Aviation Weather Center (AWC) and FAA Command Center
National Severe Storms Laboratory (NSSL) and Air Resources Laboratory (ARL)
National Centers for Atmospheric Research (NCAR) and Lincoln Laboratory (LL)

QPF / hydro	Heavy rainfall/snowfall watches, National Water Model	Heavy rainfall/snowfall Day 2 Outlooks
Renewable Energy (wind / solar) Same-Day Decision Support		Renewable Energy (wind / solar) Day-Ahead Decision Support
General Forecasting		
Severe Weather	Severe Weather -Watches, Convective Outlooks	Severe Weather Day 2 Outlooks
Aviation Tactical Planning	Aviation Strategic Planning	

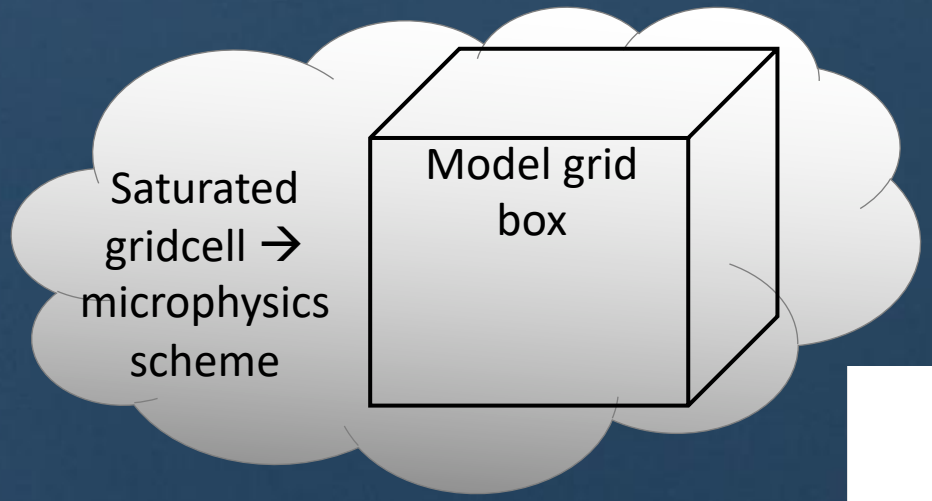
0–2 hr 2–8 hrs 8–15 hrs 15–24 hrs 24–48 hrs Forecast Length

Atmospheric Science for Renewable Energy (ASRE) Program

- Significant ESRL scientific program; crosses all four ESRL research divisions
- ASRE focus: "*To improve solar and wind renewable energy forecasts by improving the representation of boundary layer and other processes in numerical weather prediction models*", especially in the 1-48 hr forecast
- Improvements to the HRRR are transitioned to NCEP operations on 2-year cycles

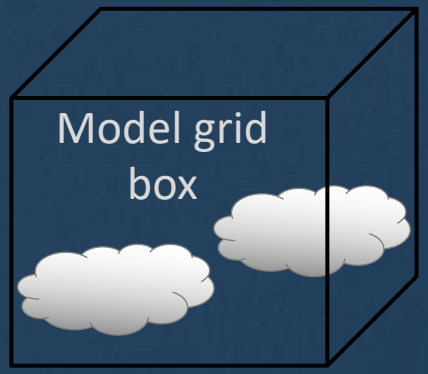
- Constraint: "Do no harm". For example, improving the wind forecast near the surface in complex terrain can not degrade the forecast in some other area or for another metric (e.g., precipitation). Thus an integrated approach is needed
- Major challenge: Improving representation of subgrid-scale processes

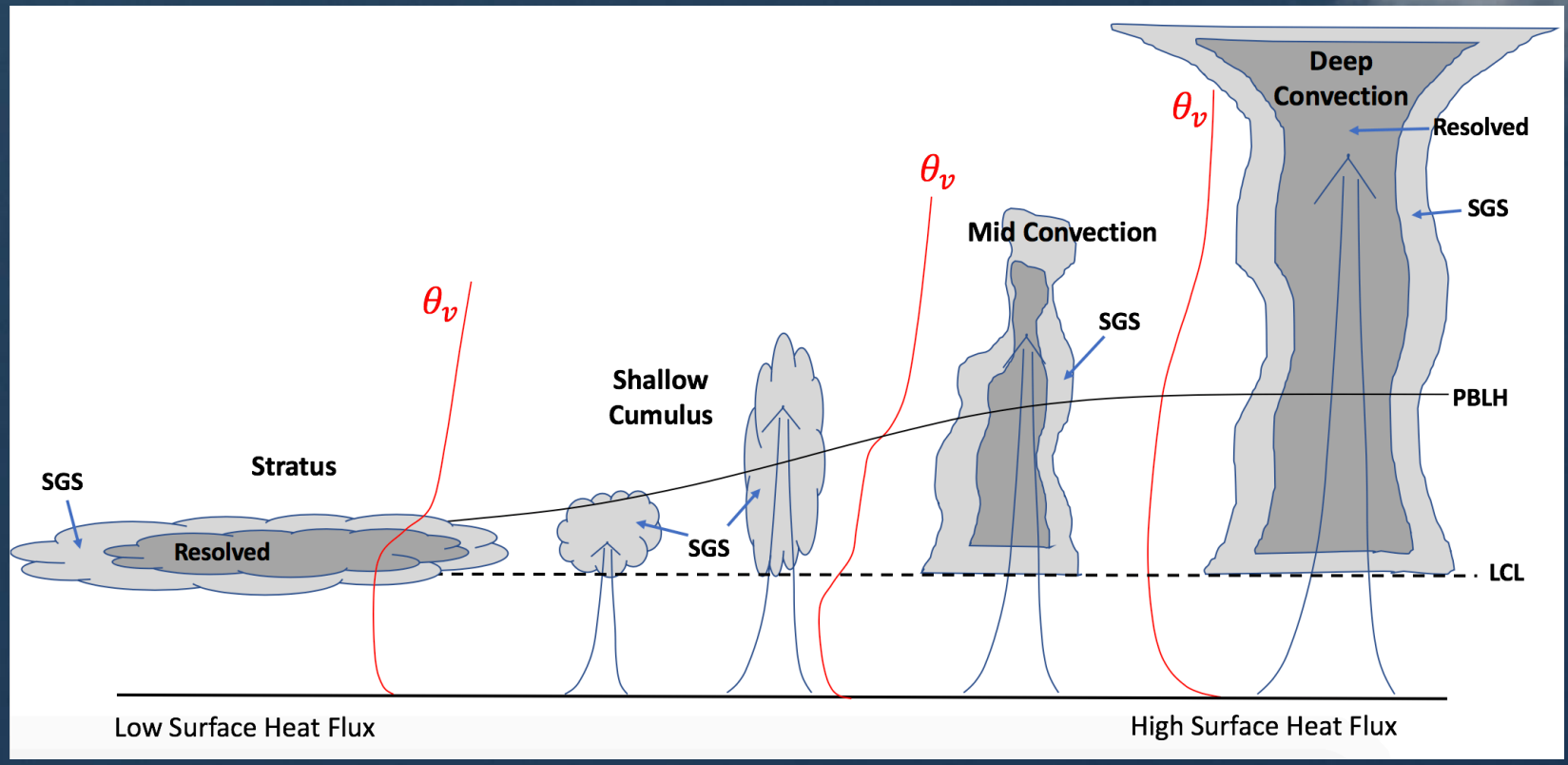
Resolved and Subgrid-scale Clouds



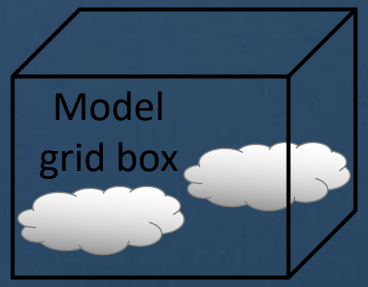
Representing clouds properly in weather and climate models is perhaps the most challenging problem facing meteorologists

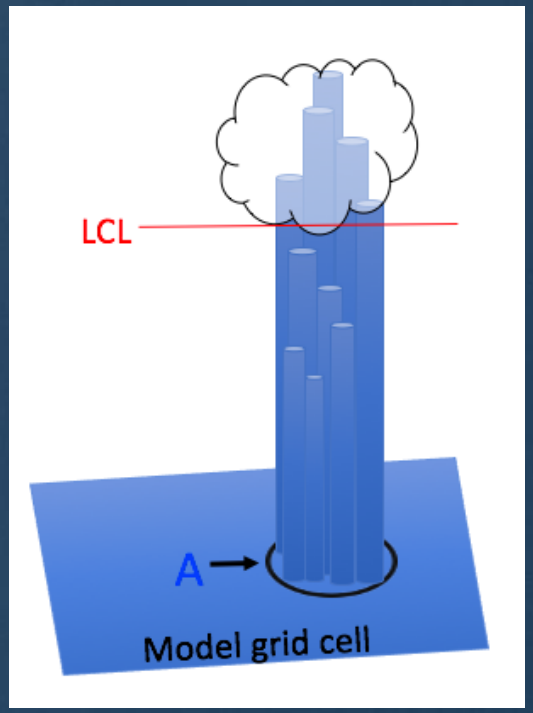
Subsaturated gridcell → subgrid-scale clouds

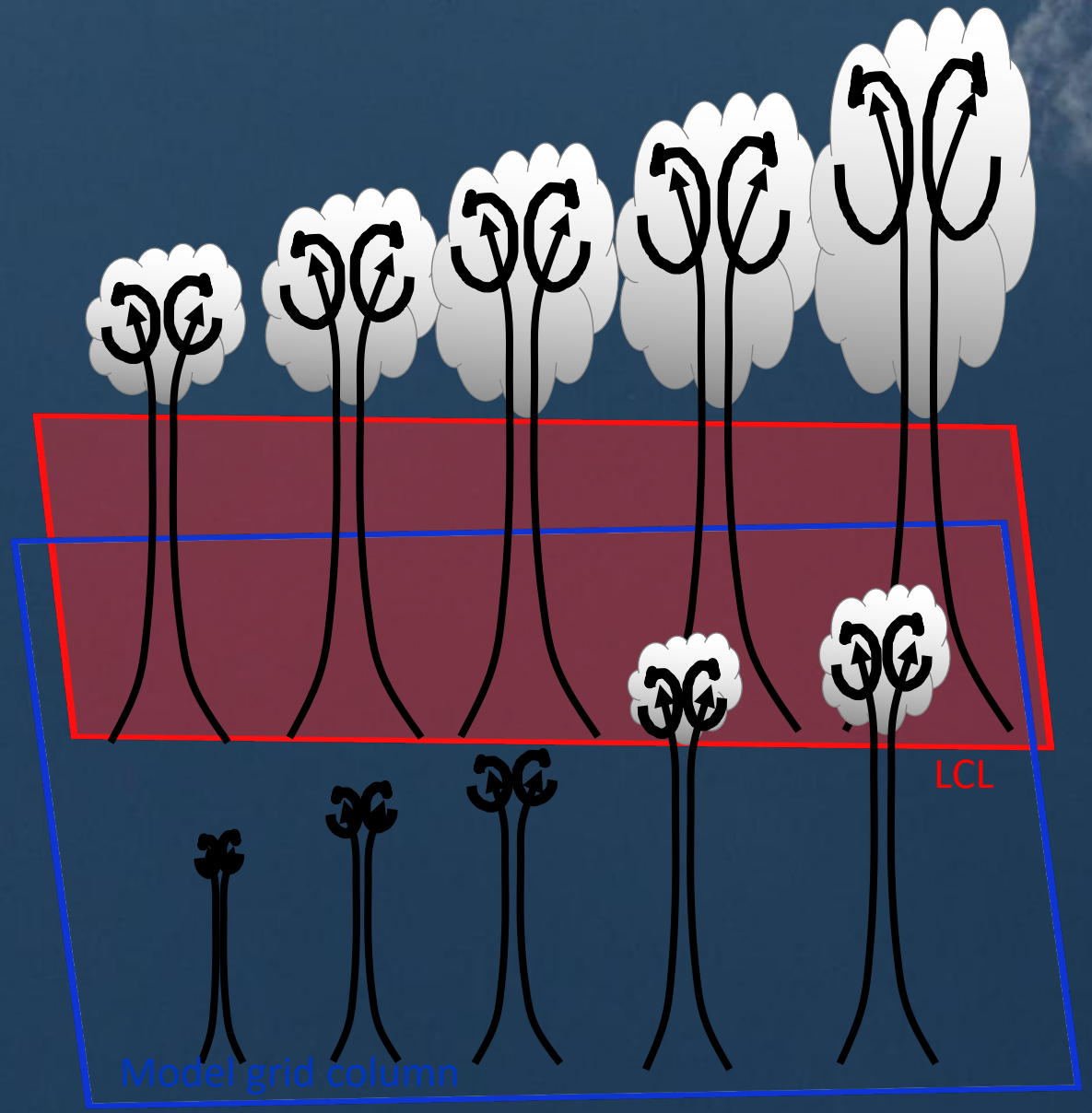




Example Chain of Processes with Subgrid-scale Clouds



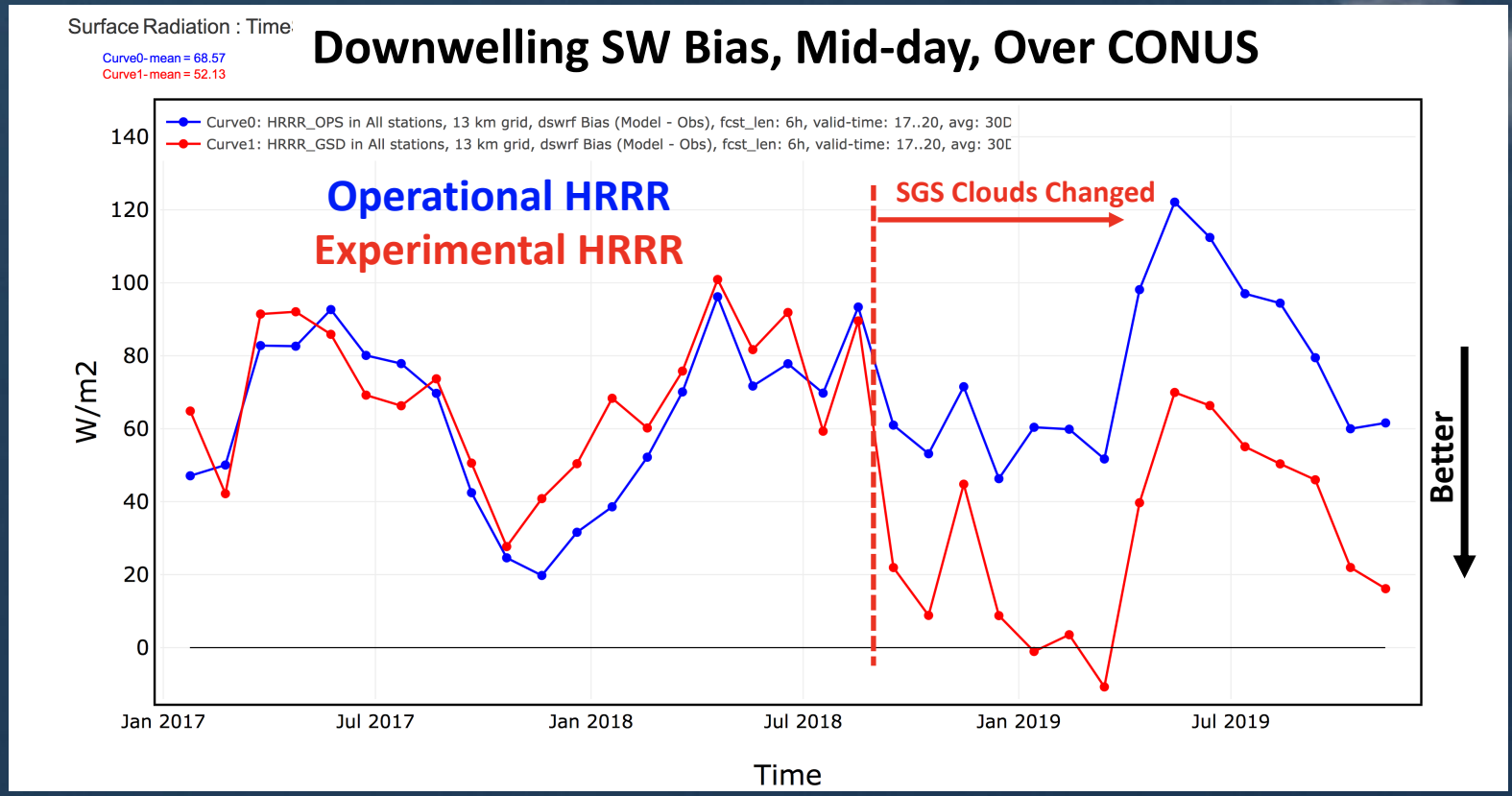




The Downwelling SW Bias in the HRRR

- Virtually all weather and climate models have difficulties modeling clouds
- Generally underpredict cloud coverage and thickness, leading to too much shortwave (SW = solar) radiation at the surface and hence a warm bias

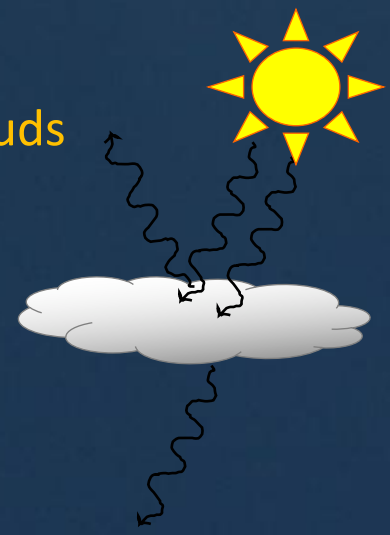
- HRRR is no different; downwelling SW bias has existed for years
- High-quality radiation measurements made by NOAA used to quantify this bias
- Improved the treatment of subgrid-scale clouds



Modifications to the SGS Cloud Components

Important subgrid-scale (SGS) microphysical/macrophysical quantities for interaction with the radiation scheme (notable changes in v4):

- SGS Mixing ratio (q_c *and* q_i):
  - Non-convective q_x: Chaboureau and Bechtold (2002) (removed constraints) ← stratiform
  - Mass-flux scheme: stronger mass-flux → deeper penetration → better areal coverage ← convective
- SGS Cloud fraction (A_{cf}):
  - Non-convective: Chaboureau and Bechtold (2002) (reduced, except for high RH)
  - Convective: Chaboureau and Bechtold (2005)
  - No longer use Xu-Randall (1996) cloud fraction (icloud = 1) – only use MYNN SGS clouds
- SGS cloud water/ice effective radii (r_e):
  - Water: Turner et al. (2007, BAMS)
  - Ice: Mishra et al. (2014, JGR)

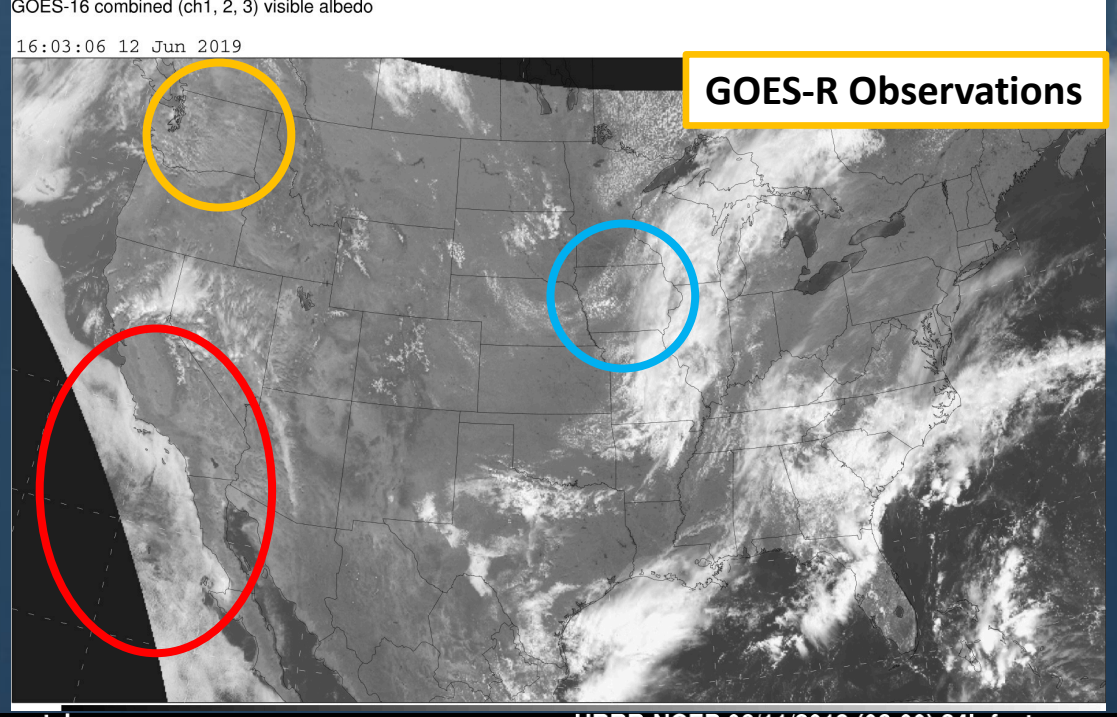


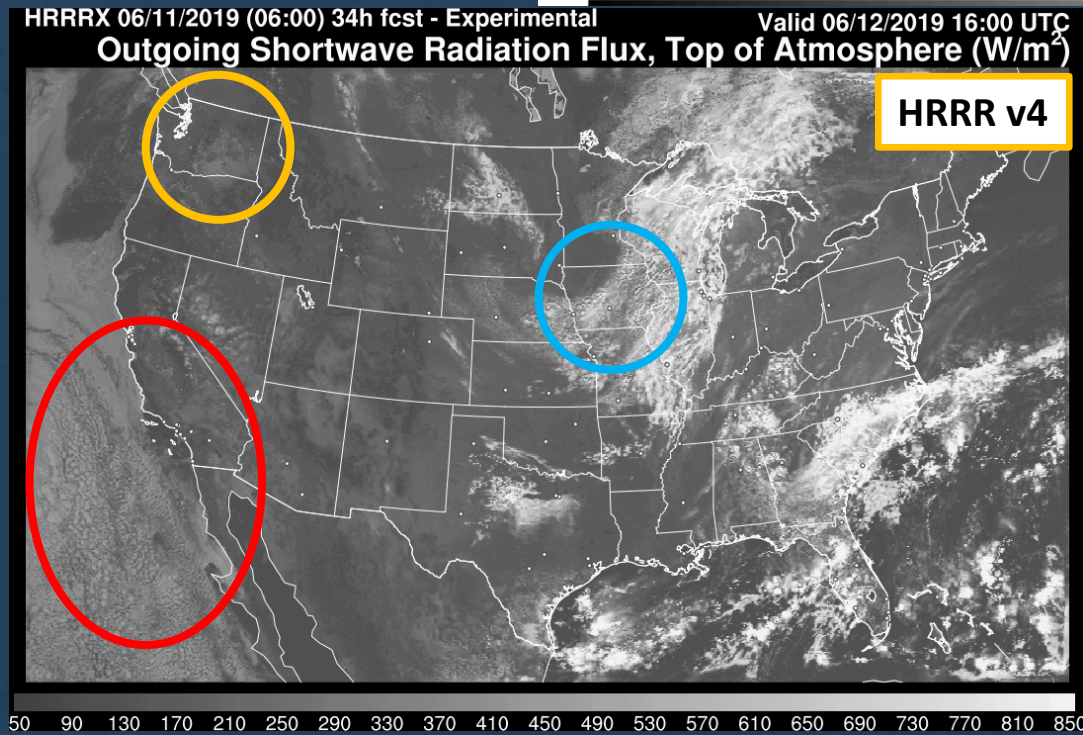
Improved Clouds

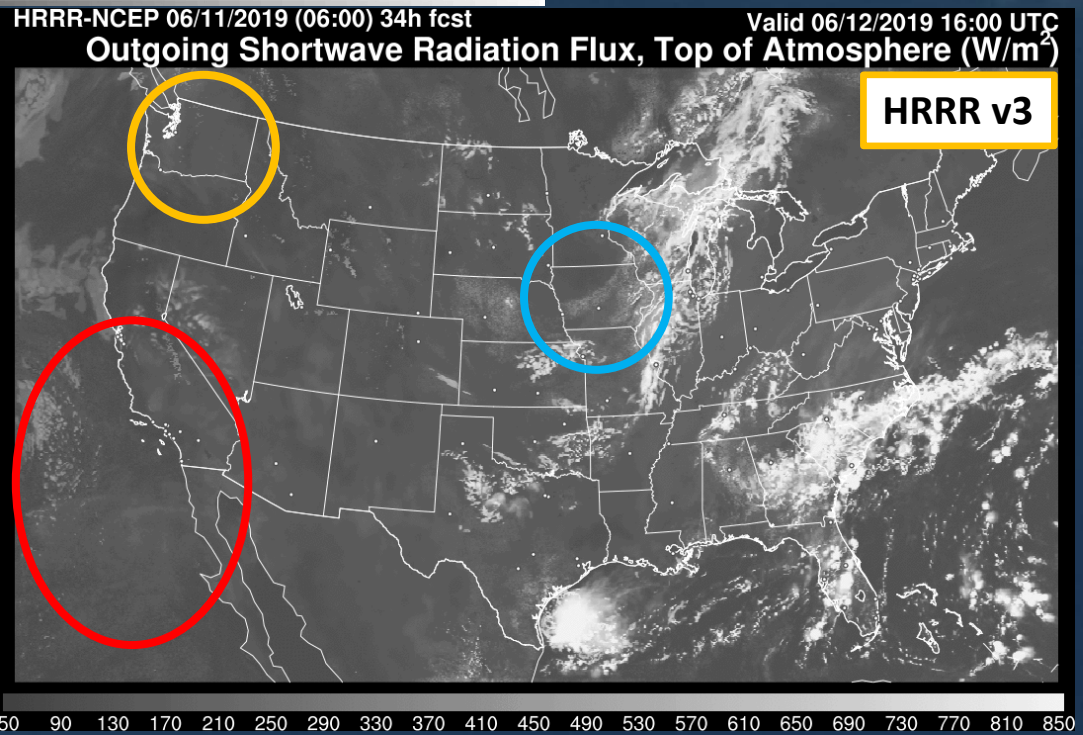
Comparison of SW-up at TOA

Valid: 16 UTC 12 June 2019

Initialized 06 UTC 11 June
(Forecast hour 34)

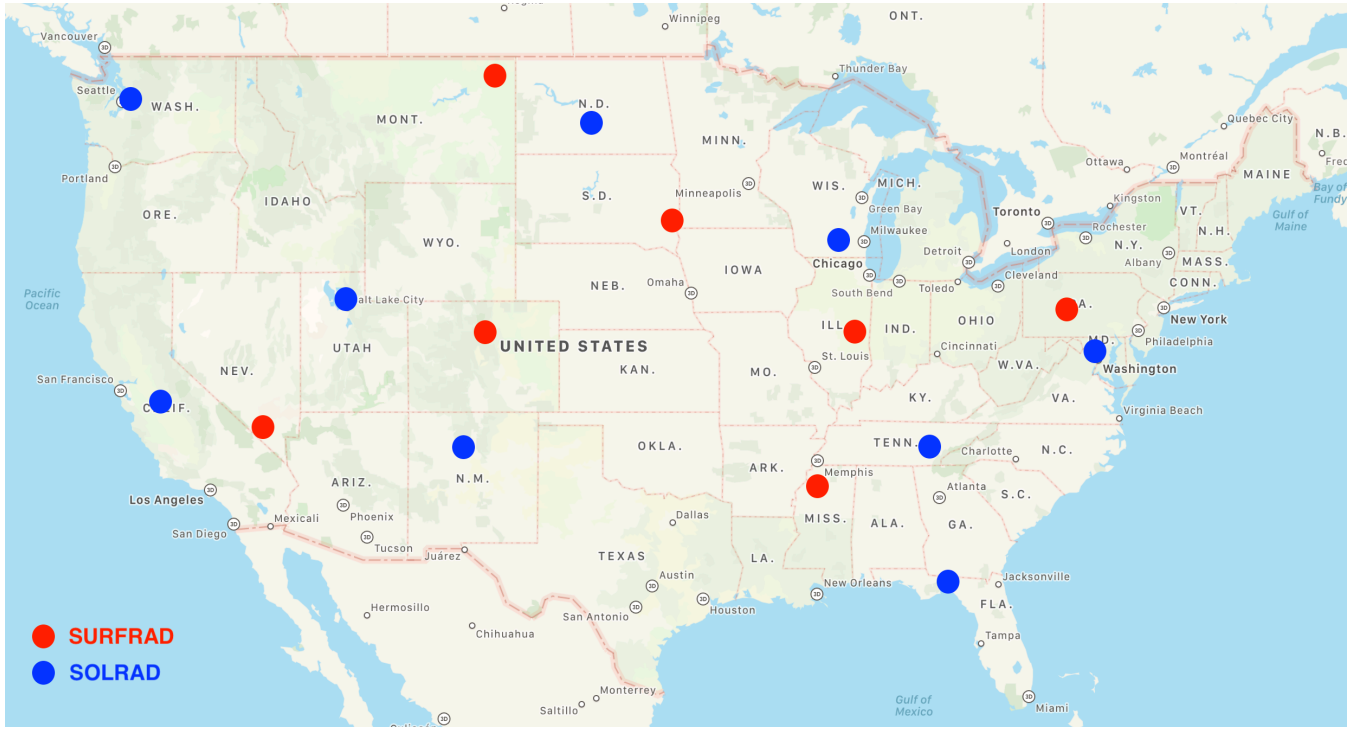


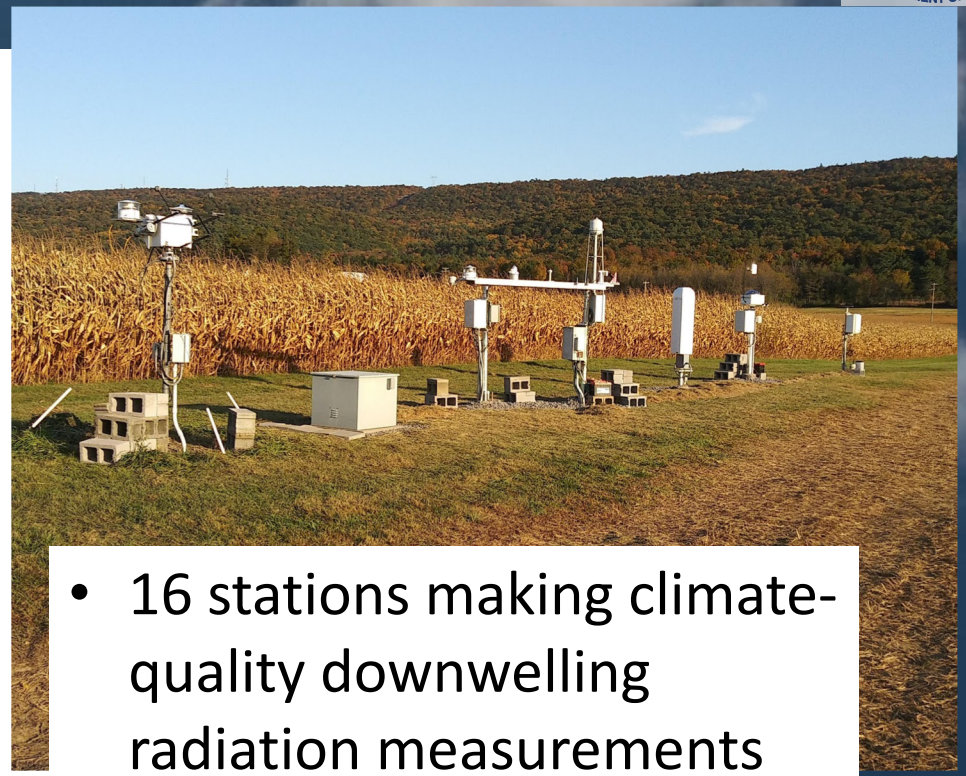




Statistical Improvements in Downwelling SW Radiation

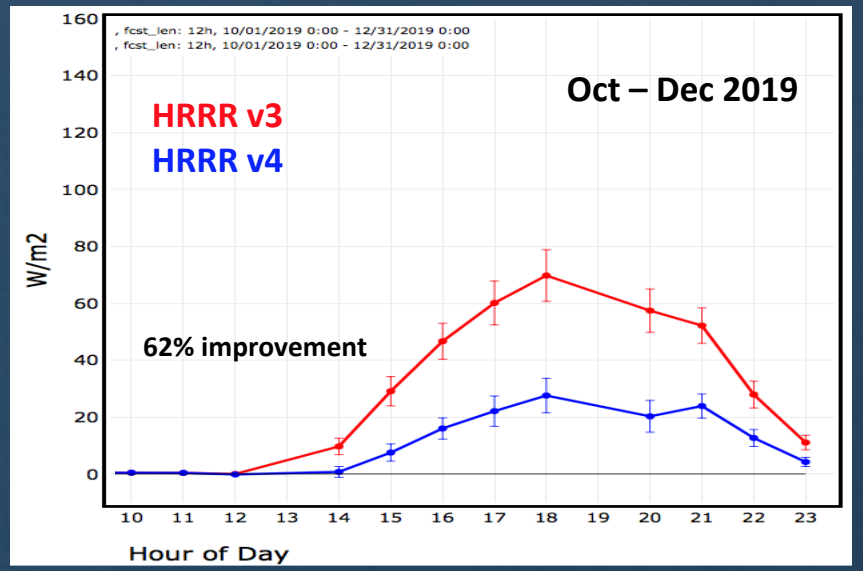
Verification Locations

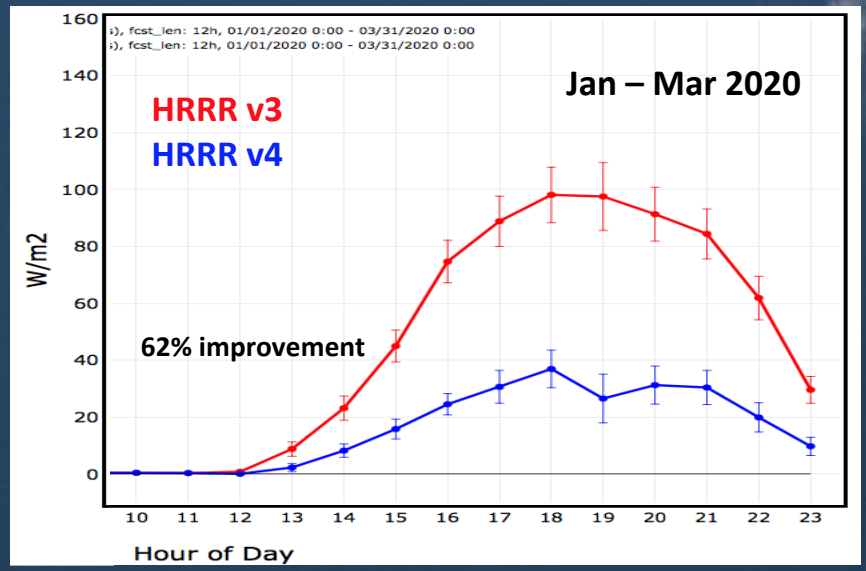


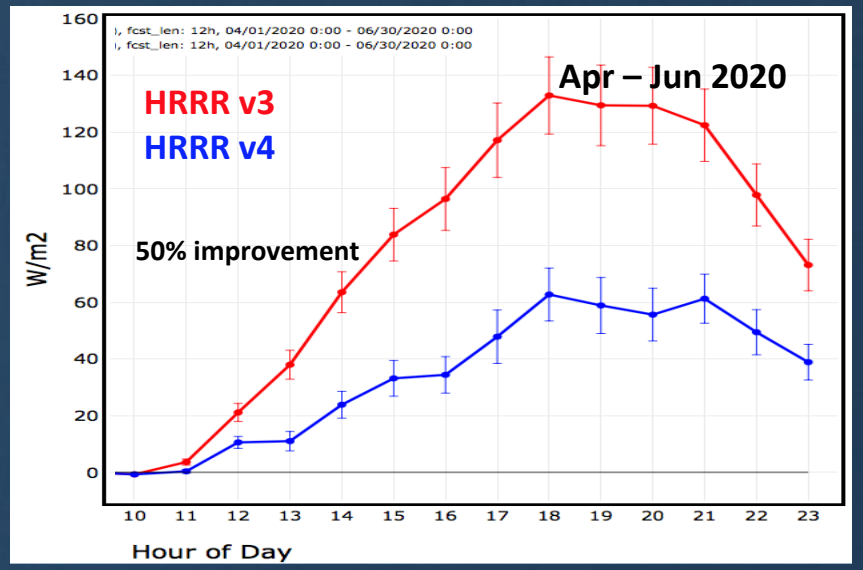


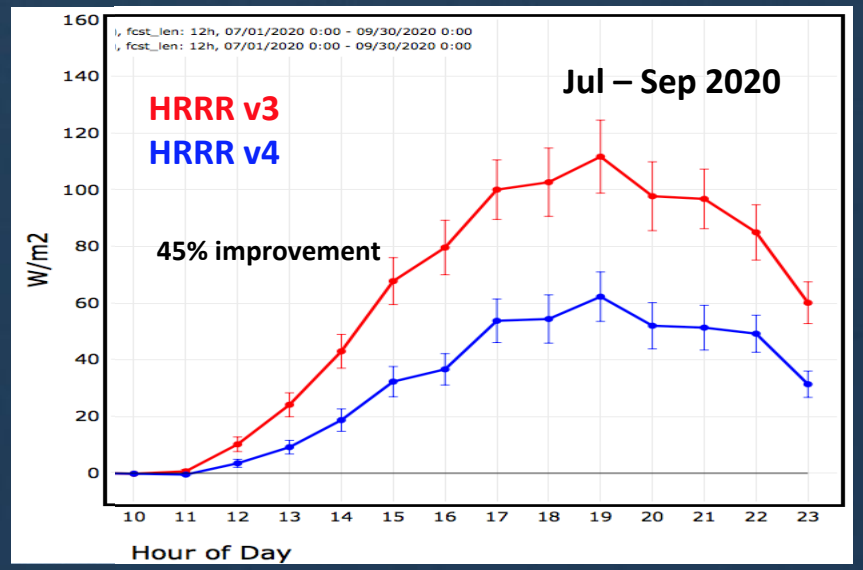
- 16 stations making climate-quality downwelling radiation measurements
- Extract downwelling SW from HRRR; compare to observations statistically

Statistical Improvements in Downwelling SW Radiation









Seasonal Bias Statistics by time-of-day

Adding Smoke to the HRRR

- Wildfires increasing both in frequency and number of acres burned
- Smoke has significant impacts on downstream air quality, visibility, impacts on weather, and solar energy production

San Francisco skyline during Camp Fire, Nov 2018

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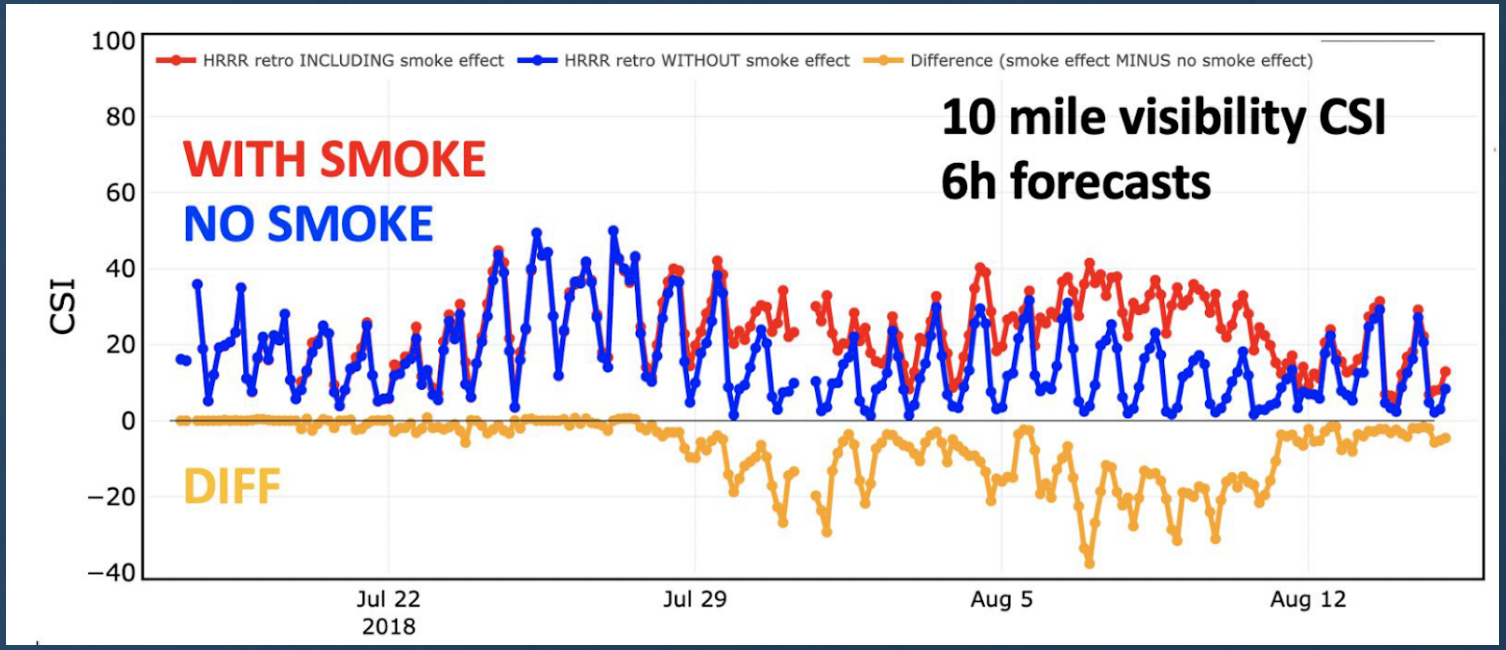
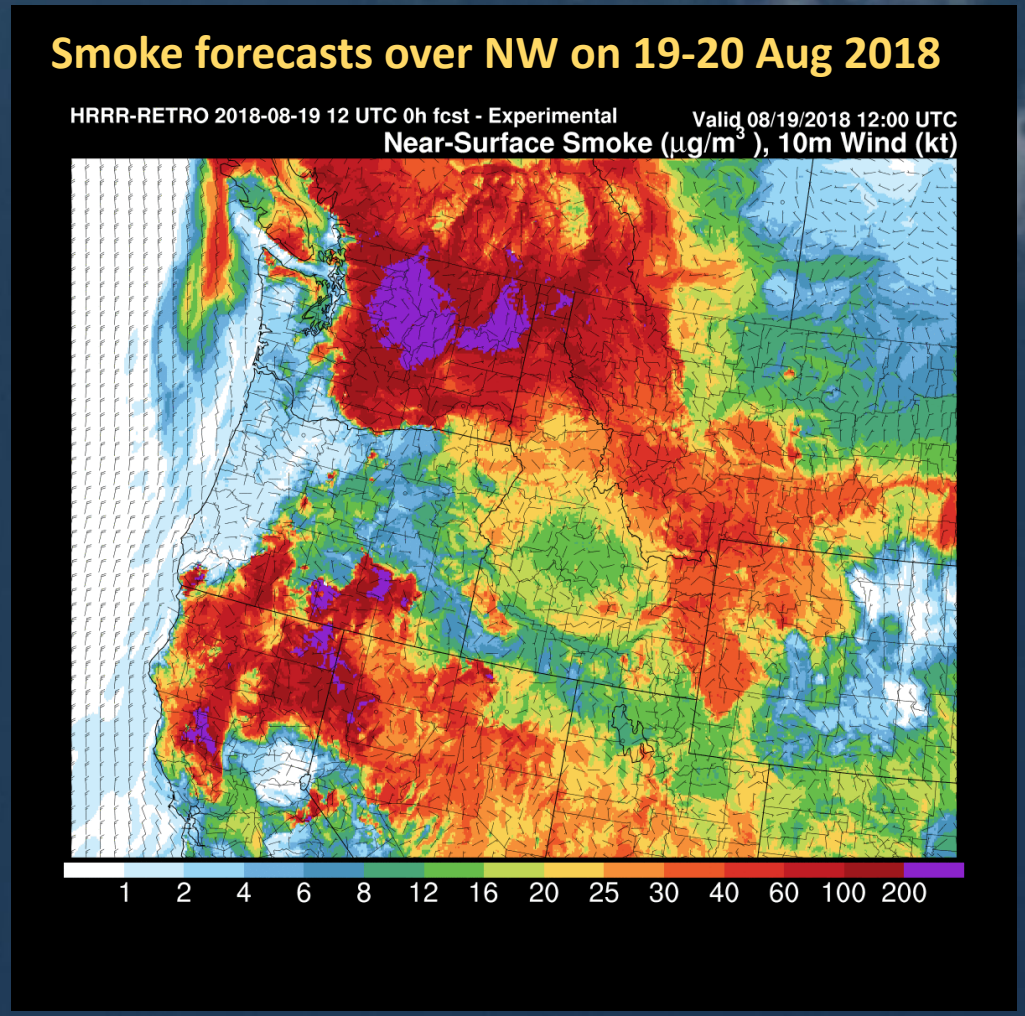
Adding Smoke to the HRRR

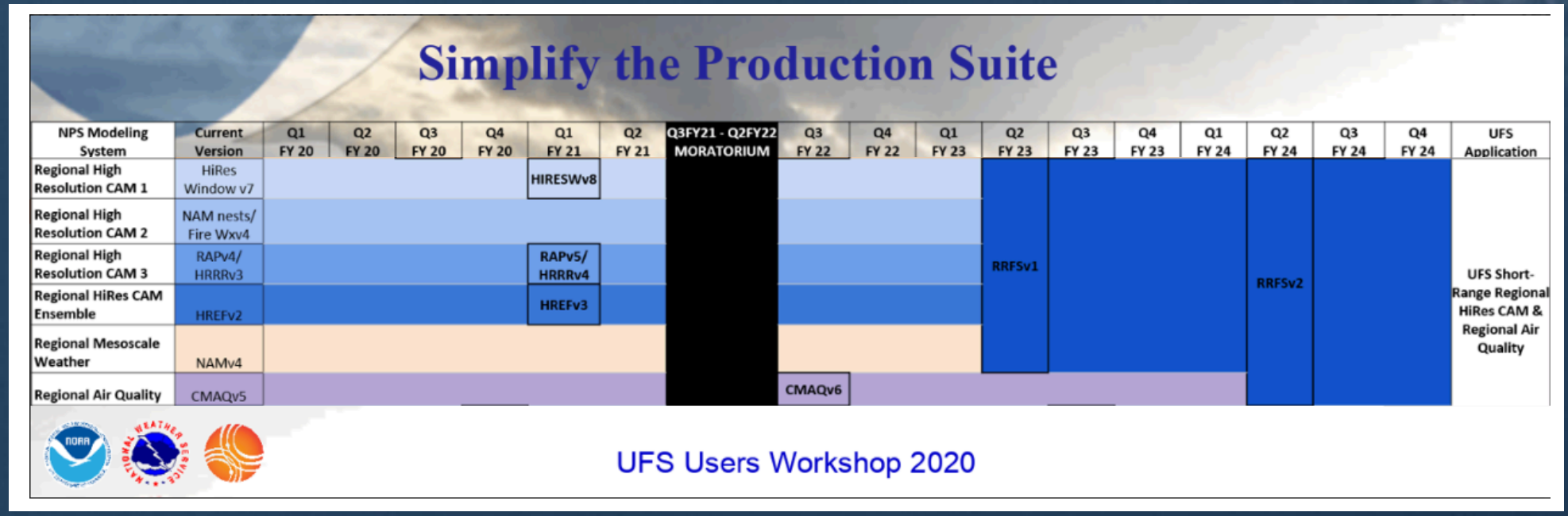
- Wildfires increasing both in frequency and number of acres burned
- Smoke has significant impacts on downstream air quality, visibility, impacts on weather, and solar energy production
- Incorporated smoke forecasts into HRRR v4
- First US model to include interactive aerosols and their impact on radiation and visibility





ASRE is a Basic and Applied Research Program

- NOAA is moving to a unified weather forecasting system (UFS)
- Current suite of models is too complex to maintain



- Latest release of HRRR (v4, which is a WRF-ARW codebase) became operational in December 2020
- Next release will use new dynamic core; working to use integrated physics schemes at all scales
- “Rapid Refresh Forecast System” (RRFS); will be available to the community
- ASRE will need to focus attention on this transition to make sure RE-related forecasts don’t regress

Looking Forward

- The renewable energy community is a new customer for the rapid refresh models
  - Traditionally the main customers have been Severe Weather and Aviation
  - Economic impact study at Colorado State Univ shows improved versions of HRRR save wind energy community $Ms (paper currently under review at *BAMS*)

- NOAA is moving towards a unified NWP modeling system
  - NWS currently runs multiple models over range of domains/forecast lengths
  - New RRFS needs thorough evaluation over range of applications / conditions
  - There are several “energy metrics” included for future CAM evaluation

- Looking to continue ASRE’s collaboration with DOE
  - Lots of natural collaboration opportunities between NOAA and DOE’s Energy Efficiency and Renewable Energy (EERE) and Office of Science
  - Working to build / strengthen the relationships with DOE

- ASRE is an example research spanning the research-to-operations (R2O) pipeline