

Overview of NOAA's Short-Range Model Forecast Systems (HRRR and RRFS)



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**Global Systems
Laboratory**

Motivation

- Biden Administration priorities:
 - 30 gigawatts of offshore wind generation installed by 2030
 - 45% of the electricity in the U.S. from solar generation by 2050
- Better weather forecasts make the electric grid more
 - Efficient, Resilient, and Prepared (for climate change)



- NOAA provides foundational weather forecasts for the RE community
- Need to improve treatment of:
 - Boundary layer (winds, turbulence, thermodynamics)
 - Clouds and wildfire smoke
 - Precipitation (esp. hail and graupel)

- ASRE is a multi-NOAA laboratory program that:
 - Conducts field campaigns and analysis
 - Improvements to NWP modeling systems
 - Transfers these improvements to the NWS every approx 2 y

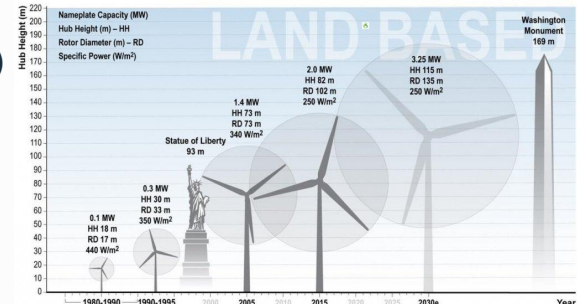


Figure 1. Expected Growth in Land-Based Turbine Size in North America

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

- **Chemical Sciences Lab**

- Alan Brewer
- Yelena Pichugina
- Bob Banta
- Sunil Baidar
- Graham Feingold
- Jake Gristey
- Edward Strobach
- Wayne Angevine

Renewable Energy Challenges

- Energy
- Converter/
- Inverter



Motivation

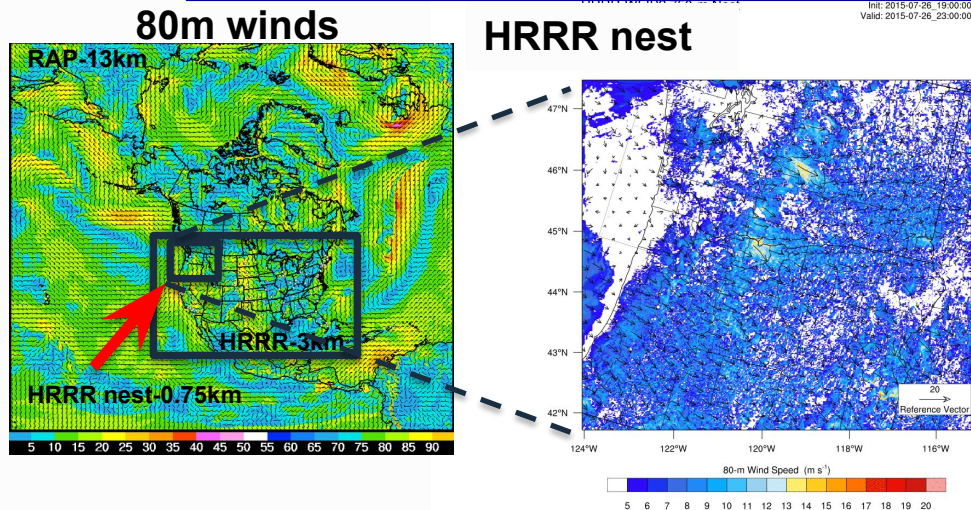
- Wind & solar are highly variable sources of energy; *accurate forecasts are needed* to integrate wind and solar energy into the electric grid

Benefits

- Reduce electricity costs (less penalties, less need for reserves)
- More stable electric grid (if forecasts are accurate)
- Reduction of CO₂ can mitigate climate change

Improving RAP/HRRR for Renewable Energy Applications

- Improve understanding of physical processes (e.g., clouds & turbulence) important for wind & solar energy.
- Improve representation of these processes in our models:
 - Improve model physical parameterization schemes
 - Improved coupling of schemes
 - Make schemes scale-aware
- Improve data assimilation of clouds, lower troposphere, PBL



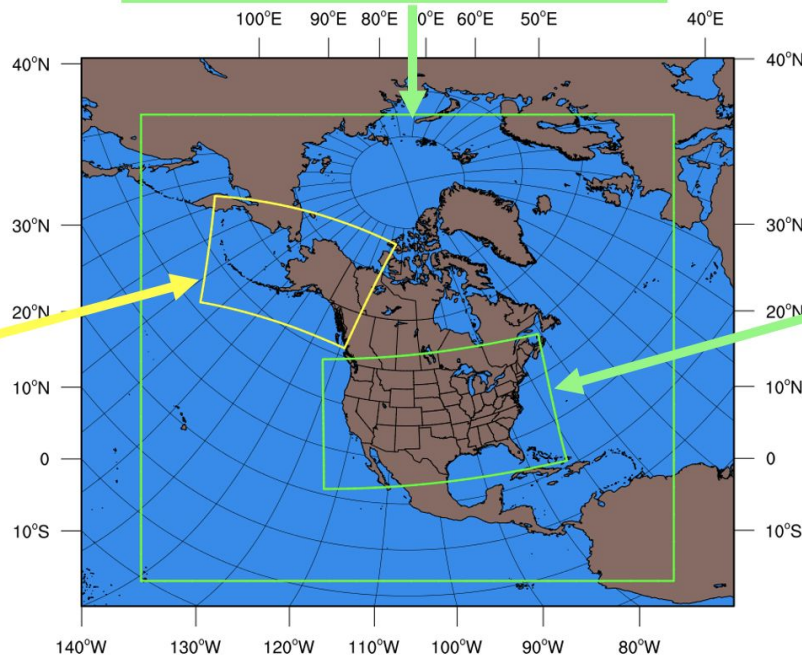
ASRE-related Model Improvement

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**

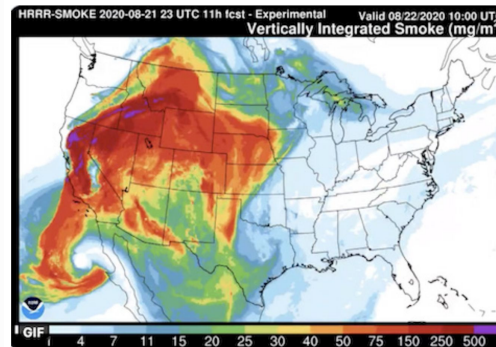
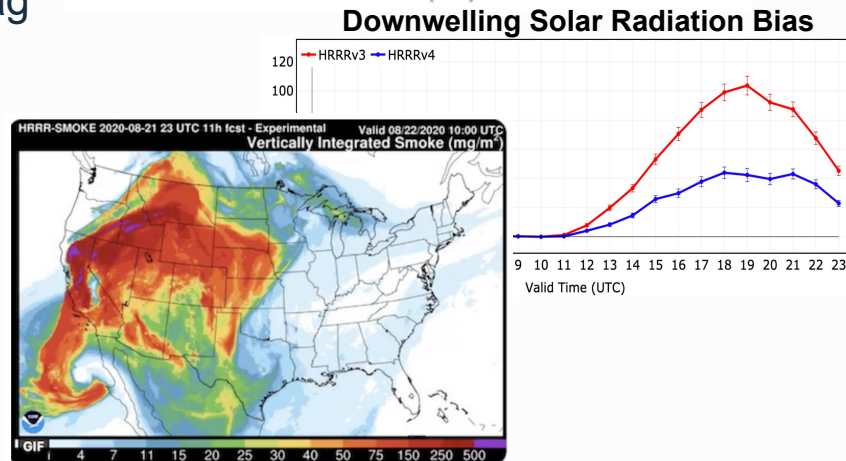
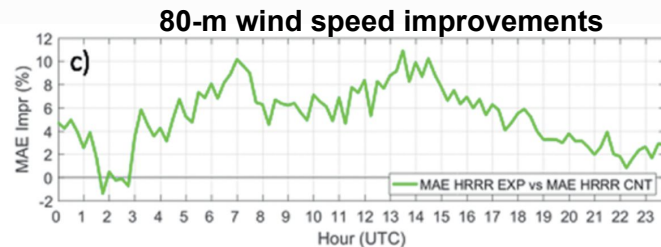


Initial & Lateral
Boundary Conditions

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

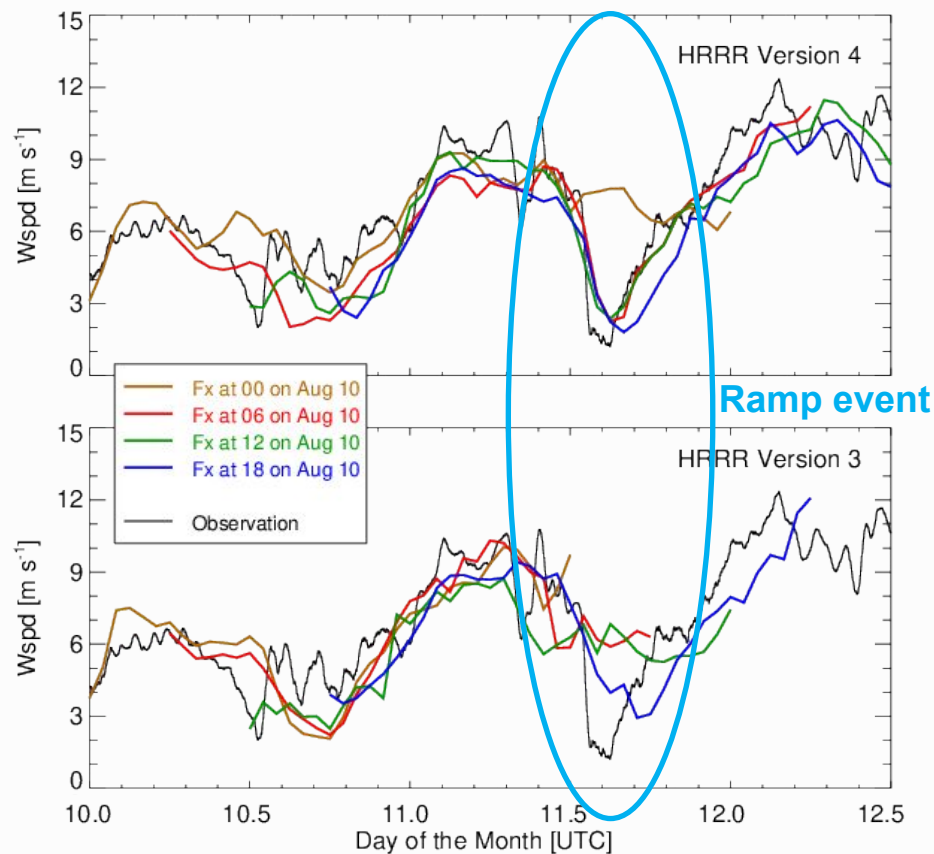
Major Recent Improvements to the HRRR

- 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 conversation 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*

Wind Ramp Improvements: Example



- Case Study on 10 – 12 August 2019
- ARM Southern Great Plains (SGP) Site
- Comparisons with 60 m tower

U.S. wind farms by wind design class and summer capacity (2018)

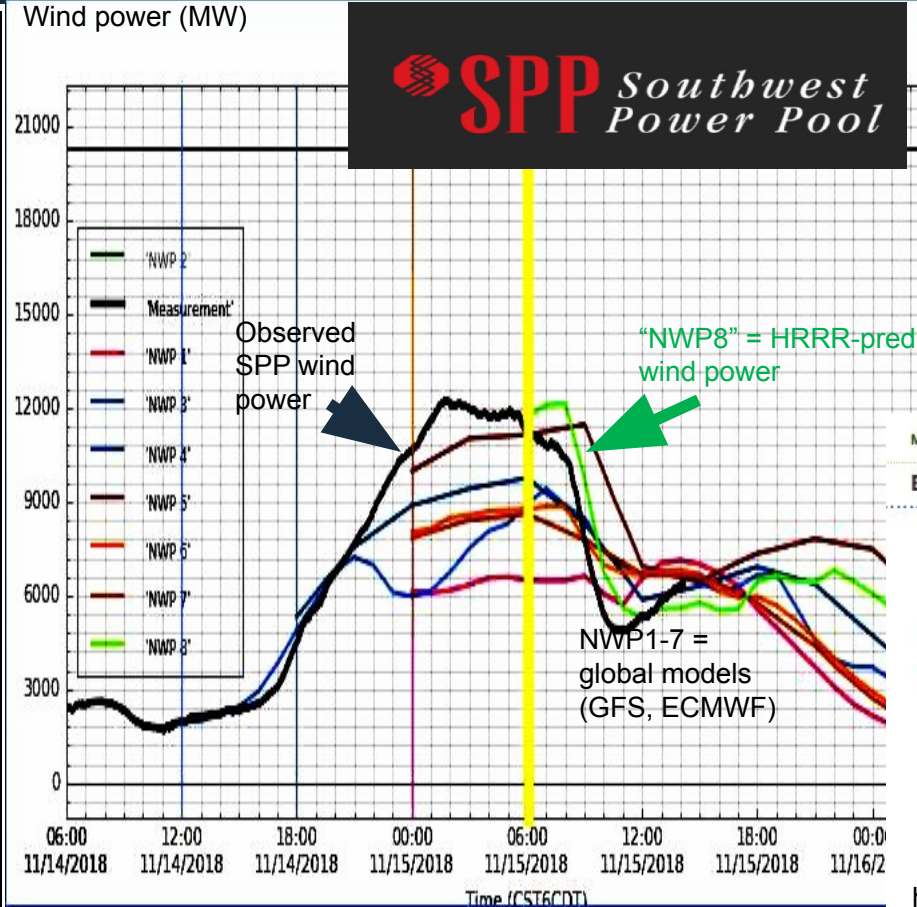


Source: U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report

- HRRRv4 identified down-ramp ~30 h before
- v3 hinted at ramp event at ~18 h before

HRRR for Wind Energy Decision Support

High-Impact Event Prediction



29 Nov 2018 –

"SPP/ERCOT/MISO/PJM switched short-term forecast to HRRR today."

It is now main weight for forecasting our 21,000MW of wind power in the Midwest! SPP went from not using HRRR in July 2018 to full weight implementation in 4 months because it performed so well, especially on AM/PM ramps. "

- Gunnar Shaffer – Southwest Power Pool, Little Rock, AR. 25

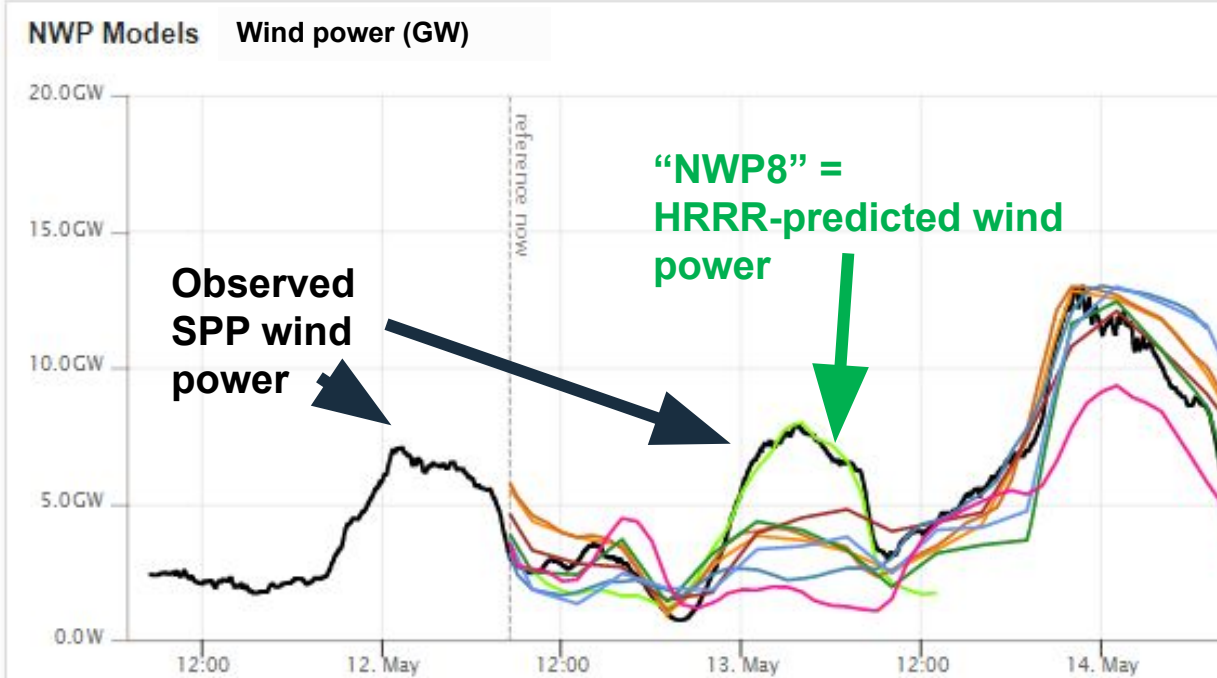
Market Oversight >> Electric Power Markets

Electric Power Markets: National Overview

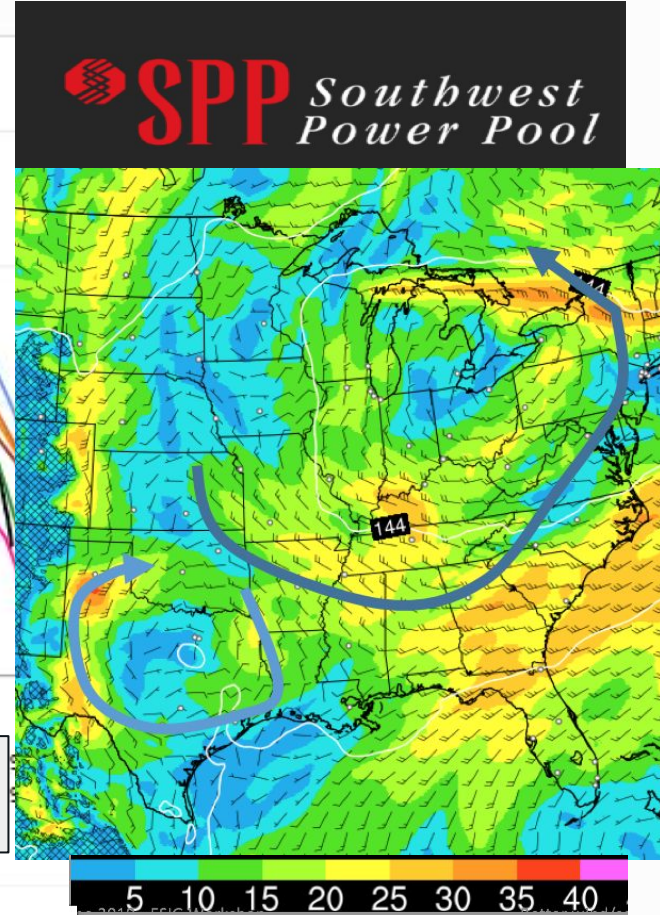


<https://www.ferc.gov/market-oversight/mkt-electric/overview.asp>

Another case – 12 May 2019

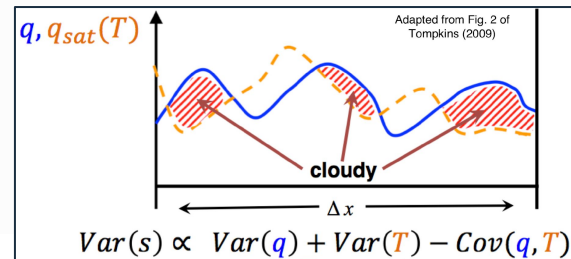


E&M now using HRRR for SPP, MISO, ERCOT, PJM



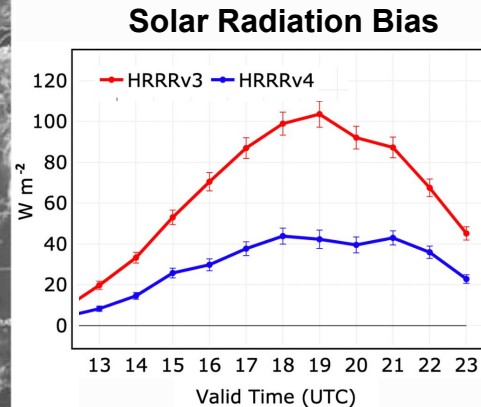
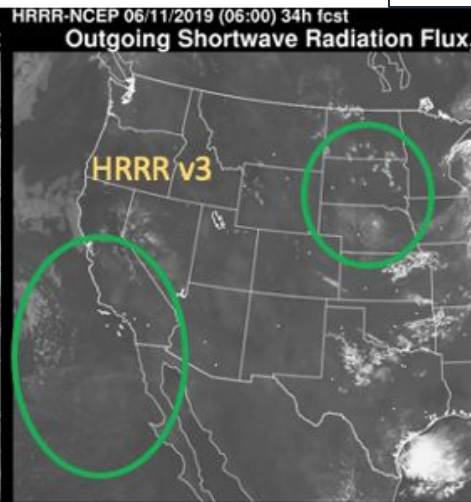
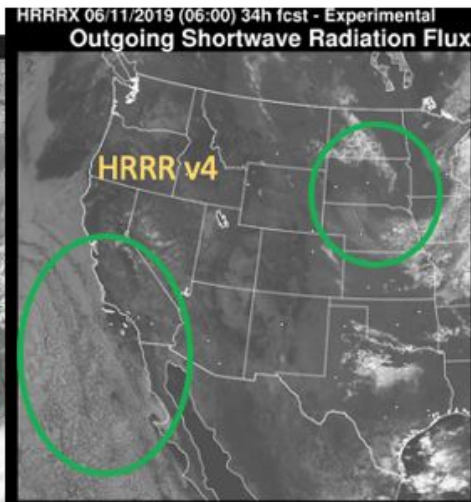
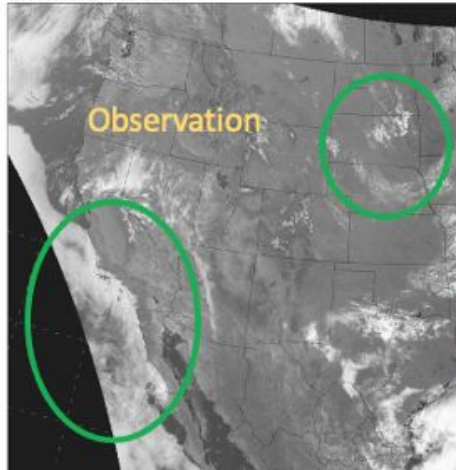
Improving Subgrid-scale Clouds

- Variability of turbulence, moisture, and clouds within the model grid cell must be parameterized
- Huge challenges for all atmospheric modeling systems
- Improved how these SGS clouds are represented



GOES-16 combined (ch1, 2, 3) visible albedo

16:03:06 12 Jun 2019

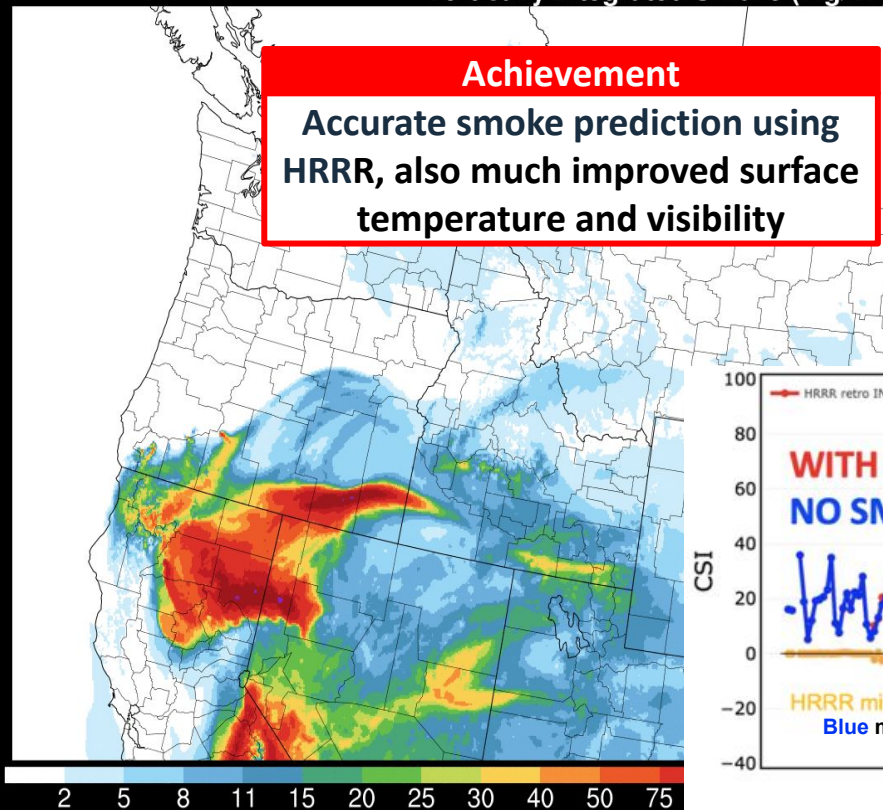


Smoke Forecasts from the HRRR

HRRR-SMOKE 2018-07-27 00 UTC 6h fcst - EXPERIMENTAL Valid 07/27/2018 06:00 UTC
Vertically Integrated Smoke (mg/m²)

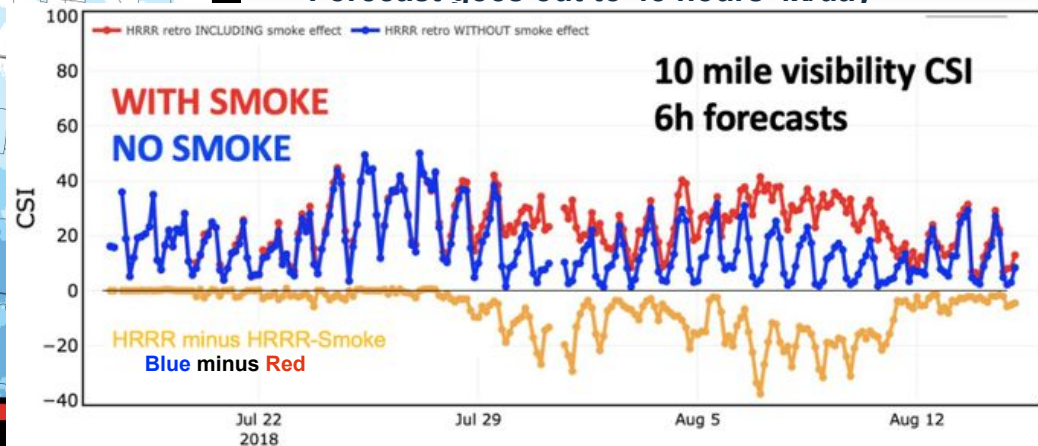
Achievement

Accurate smoke prediction using
HRRR, also much improved surface
temperature and visibility



The HRRR-Smoke modeling system

- Single tracer (smoke) (minimal CPU cost)
- Merged within HRRRv4 @NCE – Dec2020
- Full coupling between meteorology and smoke; feedback of smoke on predicted radiation, clouds, and precipitation
- Biomass-burning emissions and inline plume rise parameterization based on satellite FRP
- Forecast goes out to 48 hours 4x/day



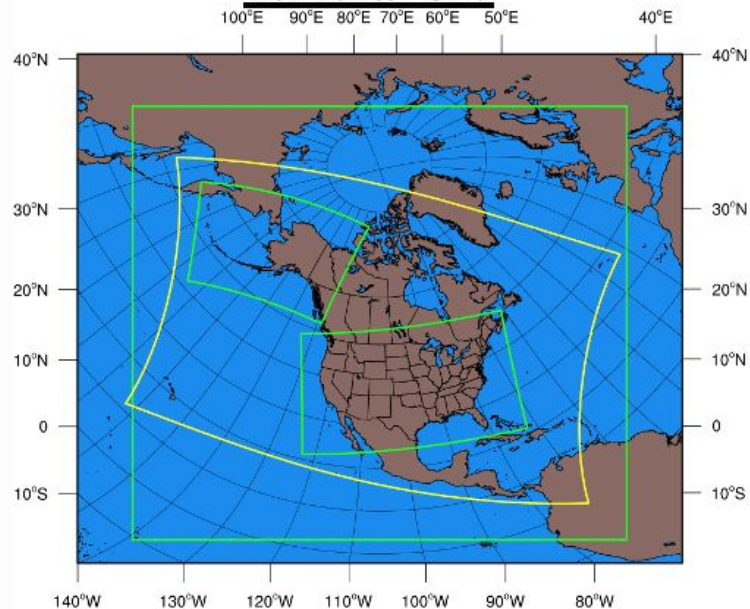
NOAA's Future Storm-scale Operational Model

- Moving towards a Unified Forecast System (UFS)
 - Common dynamic core used in all models (FV3 adopted)
 - Codes are open to the community
- Global Forecast System already using FV3 (operational 2019)
- Rapid Refresh Forecast System (RRFS) being developed to replace the HRRR

NPS Modeling System	Current Version	Q4 FY 21	Q4FY21-Q3FY22 Moratorium	Q4 FY 22	Q1 FY 23	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	Q1 FY 25	Q2 FY25	Q3 FY25	Q4 FY 25	Q1 FY 26	Q2 FY26	Q3 FY26	UFS Application			
Global Weather, Waves & Global Analysis	GFS/ GDASv16.2											GFSv17/ GEFSv13	Seasonal Reforecast Production								GFSv18/ GEFSv14/ SFSv1	UFS Medium Range & Sub-Seasonal	
Global Weather and Wave Ensembles, Aerosols	GEFSv12			Coupled Reanalysis and SubX Reforecast Production																			
Short-Range Regional Ensembles	SREFv7																						
Global Ocean & Sea-Ice	RTOFSv2			RTOFSv3																			
Global Ocean Analysis	GODASv2			GODASv3																UFS Marine & Cryosphere			
Seasonal Climate	CDAS/ CFSv2																				UFS Seasonal		
Regional Hurricane 1	HWRFv13																						
Regional Hurricane 2	HMONv3			HAFSv1								HAFSv2		HAFSv3						HAFSv4	UFS Hurricane		
Regional High Resolution CAM 1	HiRes Window v8											RRFSv1		RRFSv2								RRFSv3/ WoFSv1	UFS Short-Range Regional HiRes CAM & Regional Air Quality
Regional High Resolution CAM 2	NAM nests/ Fire Wxv4																						
Regional High Resolution CAM 3	RAPv5/ HRRRv4																						
Regional HiRes CAM Ensemble	HREFv3																						
Regional Mesoscale Weather	NAMv4																						
Regional Air Quality	AQMv6	AQMv6																					
Regional Surface Weather Analysis	RTMA/ URMA v2.8											3DRTMA/ URMAv3		3DRTMA/ URMA v4						3DRTMA/ URMA v5			

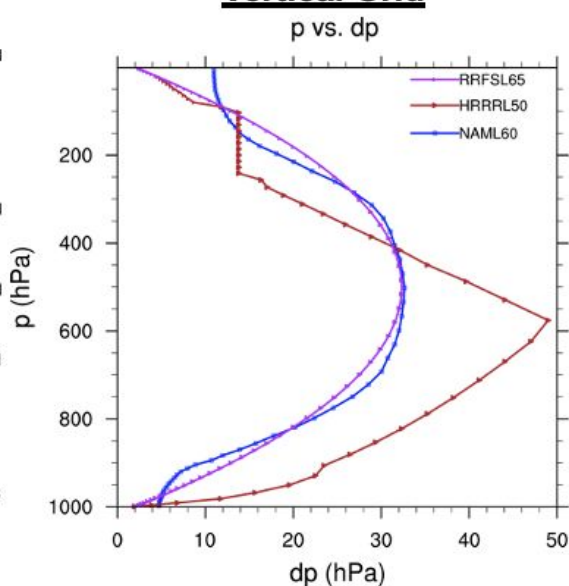
RRFS Design Elements

Horizontal Grid



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

Vertical Grid



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

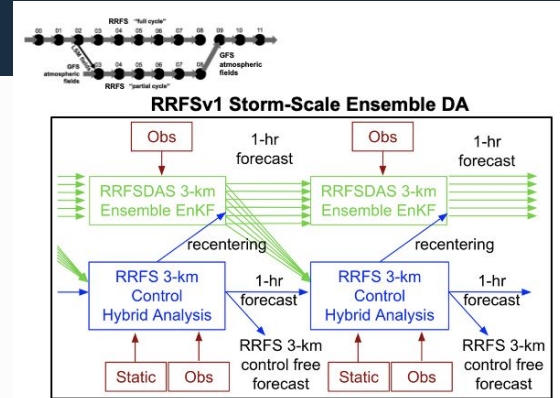
Model Physics

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)

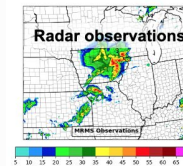
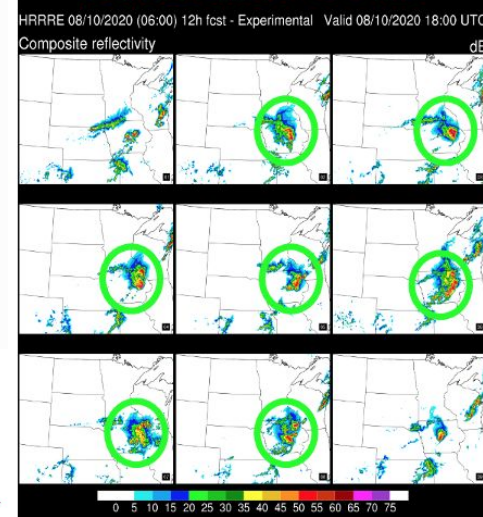
- Origin largely in HRRR physics
- Adopting CCPP interface

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
 - Will be evaluating these for wind/solar energy Fx



12-h lead-time: 7 of 9 hits



Summary

- Version 4 of the HRRR became operational Dec 2020
 - Longer forecasts, marked improvements to DA and physics
- Working on RRFS now, which will tentatively replace HRRR in Q2 of FY24
- Research focus continues on the entire atmosphere-surface system (holistic approach)
- Field campaigns
 - Continuing to analyze WFIP-2 in complex terrain
 - Continuing to analyze solar radiation / cloud datasets
 - Planning WFIP-3, a major offshore wind energy experiment
- Analyzing HRRR forecasts for Dynamic Line Rating applications
- Large number of papers published / in press right now on the HRRR and its components, evaluation, economic impact, and more