An Evaluation of CONUS and Northern Hemispheric Retrospective WRF Simulations (2002-2019)

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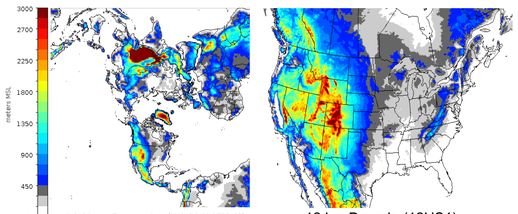
Motivation and Configuration

The US EPA's Air QUAlity TimE Series (EQUATES) project has developed a consistent set of modeled meteorology and emissions that have been used to produce multidecadal timeseries (2002-2017, with extension to 2019 expected) of air quality using the Community Multiscale Air Quality (CMAQ) model. This gridded CMAQ dataset will be leveraged for a diverse set of research and air quality management applications. The meteorology, emissions, and CMAQ output are being prepared for public distribution. To support this collective dataset and its broad distribution, we present an evaluation of the nearly twenty years of meteorology that was produced using the Weather Research and Forecasting model (WRF). In this poster, the simulated meteorology is examined using a broad range of observations including upper-air and near-surface temperature, moisture and winds. We also take advantage of shortwave radiation observations to examine the model's ability to represent clouds. And finally, the US-based PRISM (Parameter-elevation Regressions on Independent Slopes Model) precipitation dataset is compared with WRF estimates to understand how well seasonal and annual precipitation are characterized.



108km Domain (108NHEMI)

12 km Domain (12US1)

Key WRF Settings

Setting	WRF 108/12km
Microphysics	Morrison
Subgrid convection	Kain-Fritsch (w/trig 2)
Radiation	RRTMG
Boundary Layer	ACM2
Land-Surface	Pleim-Xiu
FDDA	OG+NAM/GFS
Soil Nudging	OG+NAM/GFS
Landuse dataset	MODIS

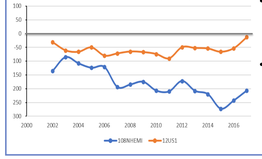
WRFv4.1.1 was ran continuously (no reinitialization) on Northern Hemisphere and CONtiguous United States (CONUS) domains for the 2002-2019 period. These domains have horizontal grid-spacing of 108 km (108NHEMI) and 12 km (12US1). The area extent of these domains and additional configuration settings are shown above using the topography of those grids. In general, the WRF configuration and model domains follow the standard U.S. EPA air quality modeling protocol used in research, application and policy-making at the agency and by collaborators. The Pleim-Xiu land-surface model is a key physics option because of its indirect soil nudging that reduces near-surface temperature and moisture errors. Both domains employed four-dimensional data assimilation (FDDA) using the National Center for Environmental Prediction (NCEP) analysis products: North American Model (NAM) and Global Forecast System (GFS). These background analyses were blended with upper-air and surface observations using the Obsgrid tool (OG) for refined soil and atmospheric nudging targets. All model evaluation was done using the Atmospheric Model Evaluation Tool (AMET).

Precipitation

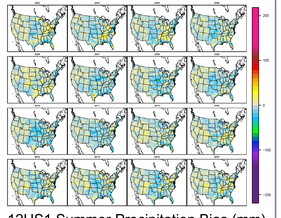
Annual Precipitation Statistics

	108NHEMI			12US1		
	MAE (mm)	BIAS (mm)	IOA	MAE (mm)	BIAS (mm)	IOA
2002	206	-135	0.88	172	-31	0.89
2003	185	-85	0.87	164	-61	0.91
2004	198	-108	0.84	172	-66	0.88
2005	202	-124	0.81	150	-50	0.89
2006	201	-121	0.82	160	0	0.89
2007	242	-194	0.84	159	-72	0.88
2008	252	-185	0.85	172	-65	0.9
2009	232	-175	0.9	163	-67	0.93
2010	268	-207	0.76	174	-74	0.86
2011	264	-210	0.87	162	-90	0.92
2012	233	-172	0.85	144	-49	0.91
2013	248	-208	0.89	148	-52	0.91
2014	270	-220	0.83	163	-54	0.88
2015	303	-273	0.88	180	-66	0.89
2016	284	-243	0.82	161	-53	0.89
2017	267	-207	0.85	152	-13	0.91

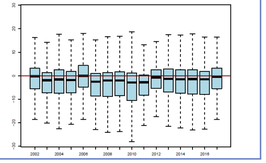
Annual Bias (mm)



- Monthly observed PRISM data was interpolated to WRF domains for grid-based statistics (upper-left).
- Mean Absolute Error (MAE, mm) indicates 12US1 domain has constantly lower error than the108NHEMI domain.
- Negative precipitation bias (lower-left) exists for both domains, but more pronounced on the 108NHEMI grid that grows in the last few years of the timeseries.
- Index Of Agreement (IOA) at ~0.90 suggests 12US1 matches observed precipitation well.
- 12US1 bias for summer months (upper-right) shows general low simulated precipitation in the eastern half of U.S. and this skews grid cell bias distribution (bottom-right) negative every summer.



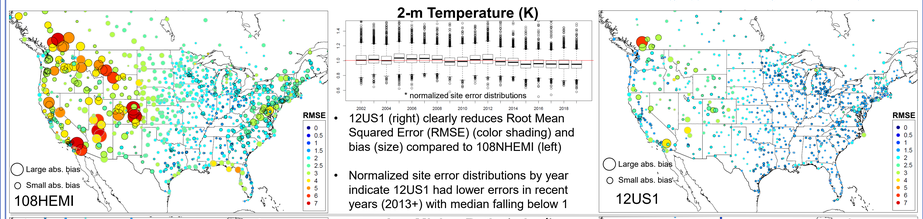
12US1 Summer Precipitation Bias (mm)



Surface Meteorology

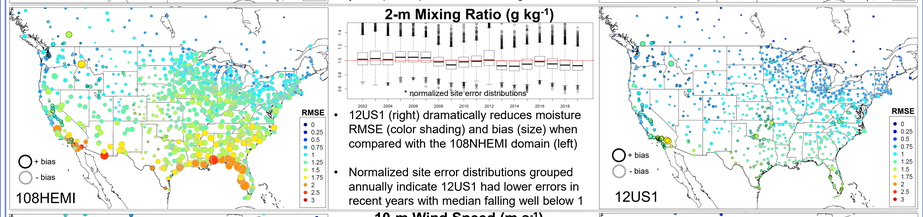
Spatial statistics plots (surface and upper-air analysis): Plots includes error (RMSE or MAE) and bias for the modeling period using color shading for error and circle size/outline for bias. The absolute bias is proportional to circle size and circles outlined in black (gray) indicate negative (positive) bias.

2-m Temperature (K)



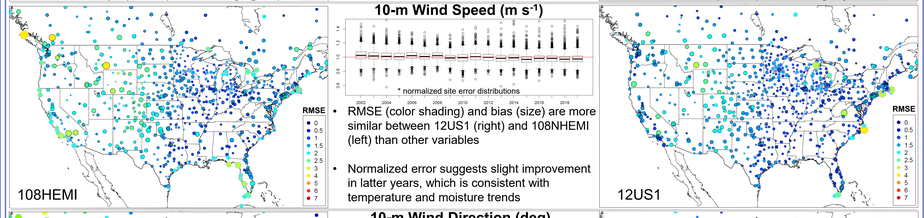
- 12US1 (right) clearly reduces Root Mean Squared Error (RMSE) (color shading) and bias (size) compared to 108NHEMI (left)
- Normalized site error distributions by year indicate 12US1 had lower errors in recent years (2013+) with median falling below 1

2-m Mixing Ratio (g kg^{-1})



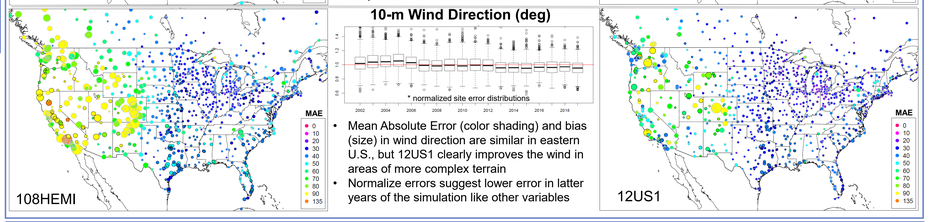
- 12US1 (right) dramatically reduces moisture RMSE (color shading) and bias (size) when compared with the 108NHEMI domain (left)
- Normalized site error distributions grouped annually indicate 12US1 had lower errors in recent years with median falling well below 1

10-m Wind Speed (m s^{-1})



- RMSE (color shading) and bias (size) are more similar between 12US1 (right) and 108NHEMI (left) than other variables
- Normalized error suggests slight improvement in latter years, which is consistent with temperature and moisture trends

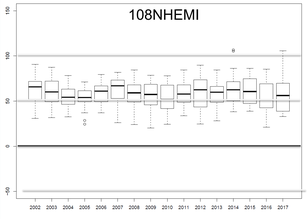
10-m Wind Direction (deg)



- Mean Absolute Error (color shading) and bias (size) in wind direction are similar in eastern U.S., but 12US1 clearly improves the wind in areas of more complex terrain
- Normalize errors suggest lower error in latter years of the simulation like other variables

Shortwave Radiation

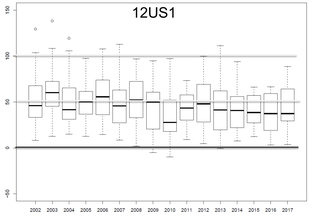
108NHEMI



Annual Distribution of Bias (W m^{-2})

- Annual distribution of shortwave radiation bias for the 2002-2017 modeling period that includes six SurfRad sites distributed across the CONUS
- 108NHEMI domain has a larger overestimation of SW radiation than the finer 12US1 domain
- Positive radiation bias suggests a lack of cloud cover and/or lack of attenuation of radiation by cloud water and ice
- 12US1 domain trends towards lower bias in latter period that is consistent with improved surface and upper-air meteorology

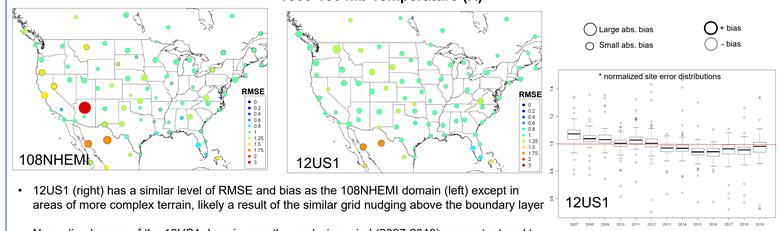
12US1



Upper-Air Meteorology

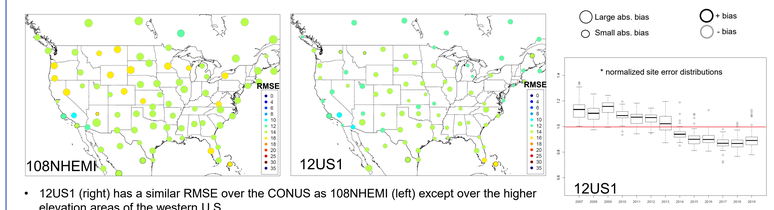
***Normalized site errors distribution (surface and upper-air analysis)**: These are grouped in annual distributions to examine the trends in model performance. Normalized error values in these distributions consider each observation site's annual-specific seasonal error that is normalized by the mean seasonal error over the modeling period. The purpose is to identify temporal trends in errors at each observation site. For upper-air, observations only covered the 2007-2019 modeling period whereas the surface analysis includes the entire 2002-2019 period.

1000-100 mb Temperature (K)



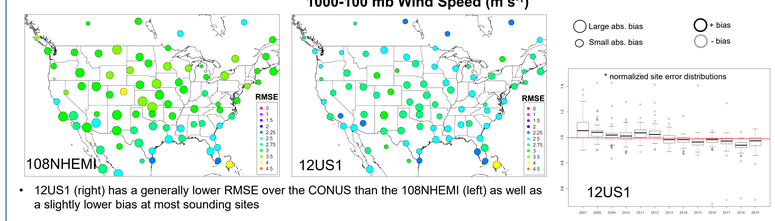
- 12US1 (right) has a similar level of RMSE and bias as the 108NHEMI domain (left) except in areas of more complex terrain, likely a result of the similar grid nudging above the boundary layer
- Normalized errors of the 12US1 domain over the analysis period (2007-2019) suggest a trend to lower model error of tropospheric temperature starting in 2013

1000-100 mb Relative Humidity (%)



- 12US1 (right) has a similar RMSE over the CONUS as 108NHEMI (left) except over the higher elevation areas of the western U.S.
- Model bias of the 12US1 domain is lower at most sites
- Normalized errors of the 12US1 domain over the modeling period suggest a clear trend to lower model error starting in 2014

1000-100 mb Wind Speed (m s^{-1})



- 12US1 (right) has a generally lower RMSE over the CONUS than the 108NHEMI (left) as well as a slightly lower bias at most sounding sites
- Normalized errors of the 12US1 domain over the 2007-2019 period suggest a slight trend to lower model error starting in 2013

Summary and Future Work

- Normalized errors suggest a clear reduction in model error from 2013 onward, but the attribution is not clear. Possibilities include the increasing use of satellite-based or remote-sensed observations in NCEP analysis methods, or some change in the settings like constraints on the error minimization in 3-Dimensional VARiational (3DVAR) data assimilation systems.
- While the evaluation here show general trends, mean statistics and annual summaries of a state-of-science retrospective simulation, a more detailed analysis of seasonal and diurnal statistics will be needed as the air quality modeling is examined and linked to meteorology.
- We are in the process of preparing the meteorology dataset for broad distribution that will be detailed in a journal article.