Evaluation of Three Numerical Weather Predictions Using the Weather Research and Forecasting Model

Benjamin Yang[1], Vikram Ravi[2], Joseph Vaughan[2], Brian Lamb[2], and Yunha Lee[2]
[1]Department of Meteorology and Atmospheric Science, Pennsylvania State University
[2]Laboratory for Atmospheric Research, Civil and Environmental Engineering, Washington State University

Motivation and Objectives

Motivation:

Air quality forecasts (e.g., AIRPACT; http://lar.wsu.edu/airpact/index.html) depend on pollutant emissions, atmospheric chemical processes, and predicted meteorology. In particular, wind speed and direction affect dilution, air temperature affects chemical reaction rates, and moisture affects aerosol dynamics. Reliable numerical weather predictions (NWP) are essential for air quality forecasting. Evaluation of NWP variables can show us where NWP and, thus, air quality prediction can be improved. The Weather Research and Forecasting Model (WRF) is a NWP system that has dynamical cores to solve the equations of motion. There are a range of physics options to represent atmospheric radiation, the surface and boundary layers, and cloud and precipitation processes.

Objectives:

- Determine which of the following factors play the most important role in WRF model performance: resolution, coupling, or physics options.
- Understand how model performance fluctuates over time during an intensive wildfire period.
- Recognize and explain any spatial patterns in model biases.

Methods

- Evaluated model output from 3 variants of the WRF model:
  1. University of Washington's (**UW**) WRF-GFS – *4-km resolution*
  2. Washington State University's (**WSU**) WRF-Chem – *18-km resolution*
  3. NOAA's High Resolution Rapid Refresh (**HRRR**) – *3-km resolution*

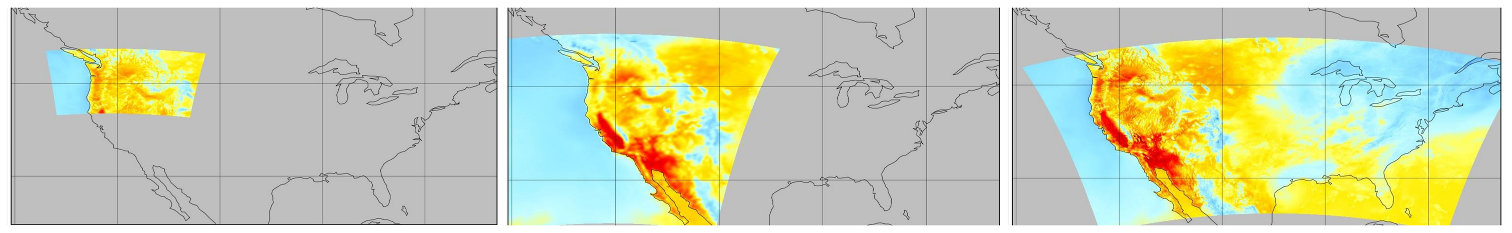

Figure 1. *Maps depicting model domains (left to right: UW WRF, WSU WRF, HRRR) and 2-m temperature (C°) for August 29, 2017 at 00 UTC.*

- WSU WRF is a coupled simulation, accounting for feedbacks between meteorology and chemistry, while both UW WRF and HRRR are uncoupled meteorology simulations without chemistry.
- Selected the 12-day evaluation period—00 UTC August 29 to 23 UTC September 9, 2017—for model comparison because of the high wildfire activity in the Pacific Northwest during this time.
- Obtained hourly MesoWest (https://synopticlabs.org/api/) observations for ASOS/AWOS stations (https://www.faa.gov/air_traffic/weather/asos/) in WA, OR, and ID that had available near-surface wind speed, temperature, wind direction, and relative humidity data for the entire period. Python scripts were used to compare these observations with the corresponding model variables, which produced:
  - Overall statistics (Table 1) with normalized mean bias (NMB), normalized mean error (NME), root mean square error (RMSE), and coefficient of determination (R^2).

$$NMB = \frac{\sum_1^n (P-O)}{\sum_1^n (O)} \cdot 100 \qquad RMSE = \sqrt{\frac{\sum_1^n (P-O)^2}{n}}$$

$$NME = \frac{\sum_1^n |P-O|}{\sum_1^n (O)} \cdot 100 \qquad r^2 = \left[\frac{\sum_1^n (P-\bar{P})(O-\bar{O})}{\sqrt{\sum_1^n (P-\bar{P})^2 \cdot \sum_1^n (O-\bar{O})^2}}\right]^2$$

P = predicted value,
O = observed value,
n = number of values

  - Time series plots (Figure 2) for 2 stations: Seattle-Tacoma International Airport (KSEA) and Pullman / Moscow Regional Airport (KPUW).
  - Maps of NMB (Figure 3).

Daily Weather Patterns

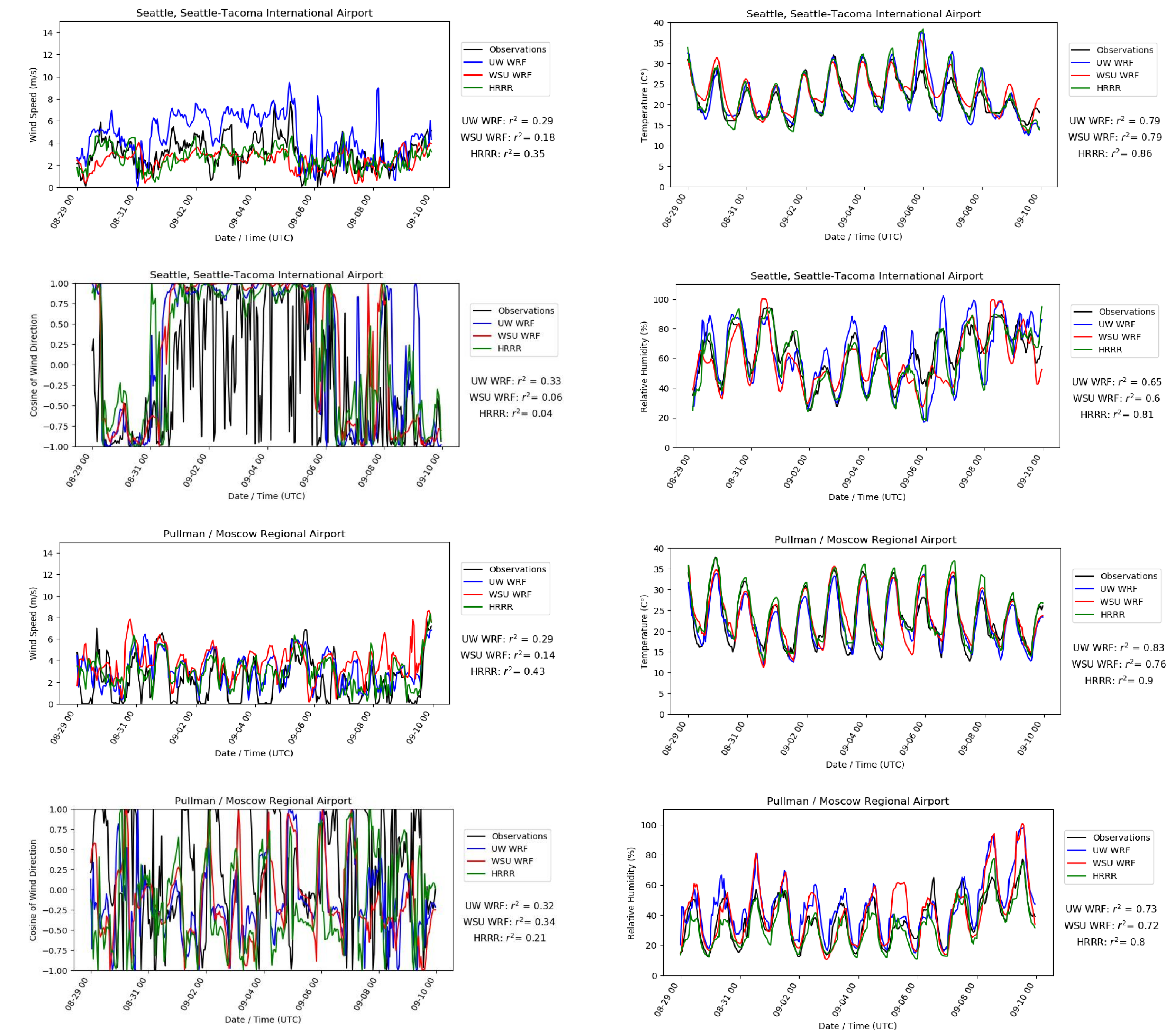

Figure 2. *Time series of wind speed, temperature, cosine of wind direction, and relative humidity for the entire period. KSEA and KPUW were chosen from distinct physiographic regions.*

Bias Maps

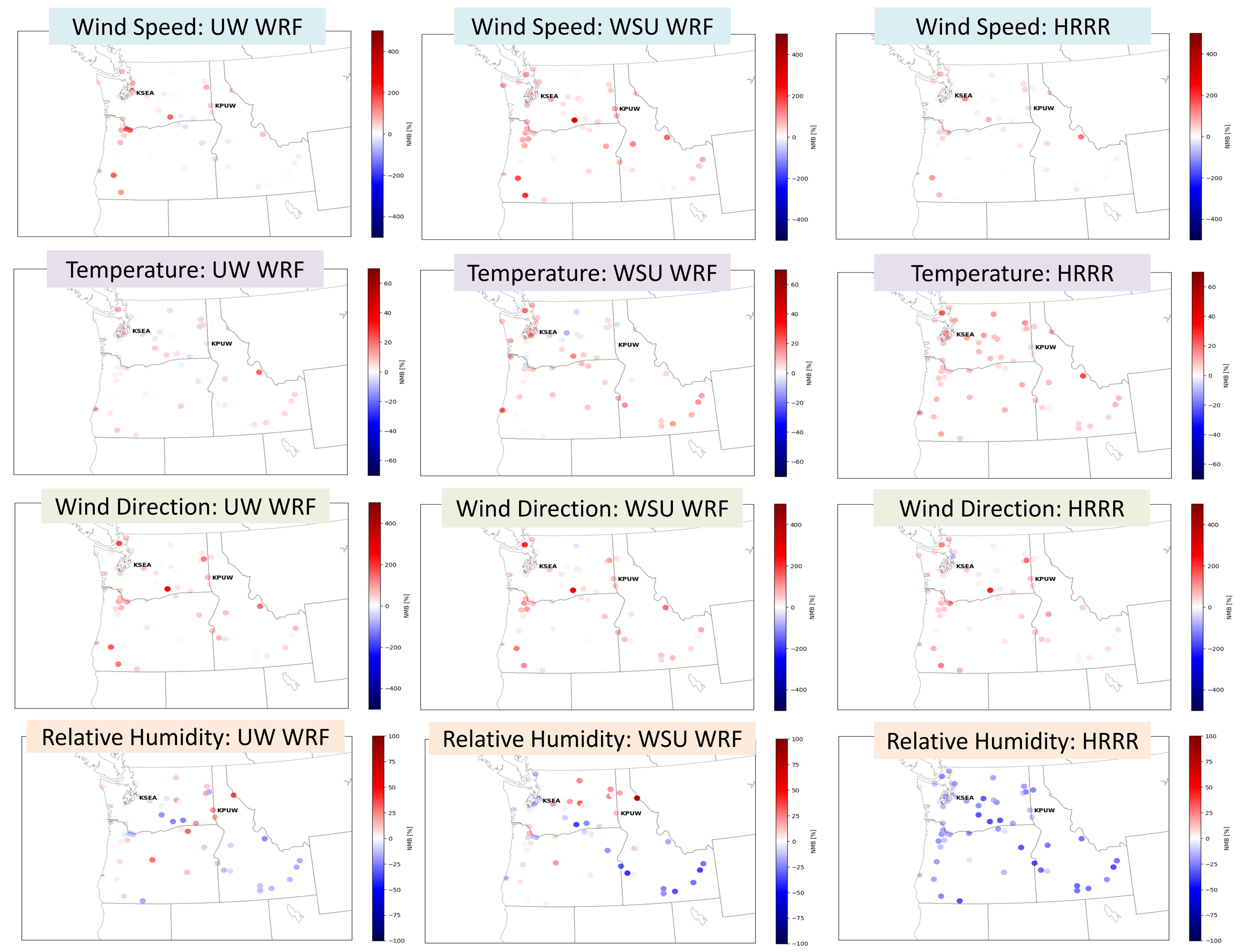

Figure 3. *Maps of NMB calculated at each site for the entire period. Red indicates a positive bias, while blue indicates a negative bias.*

Overall Statistics Table

Variables	OBS Mean	Model	Mean	NMB [%]	NME [%]	RMSE	R^2
Wind Speed (m/s)	2.2	UW WRF	2.7	20	58	1	0.26
		WSU WRF	3.1	40	72	1	0.15
		HRRR	2.5	10	50	1	0.36
Temperature (C°)	21.7	UW WRF	22.3	3	10	1	0.83
		WSU WRF	22.8	5	12	2	0.74
		HRRR	23.4	7	10	1	0.88
Wind Direction (°)	149	UW WRF	198	33	63	59	0.11
		WSU WRF	194	30	68	61	0.06
		HRRR	193	30	65	60	0.09
Relative Humidity (%)	54	UW WRF	54	-1	18	6	0.74
		WSU WRF	52	-4	23	7	0.58
		HRRR	45	-17	20	7	0.77

Table 1. *Statistics for all stations compared with each model for the entire period.*

Discussion and Conclusions

- The overall statistics (Table 1) show that the WSU WRF consistently has greater NME and RMSE values and smaller R^2 values, compared with those of the UW WRF and HRRR. This reveals that a high resolution might be more important for NWP.
- All the statistics agree that the HRRR predicted wind speed more accurately than the other two models. Considering that wind speed can vary dramatically from one location to another, smaller grid spacing was an advantage for the HRRR.
- For temperature and relative humidity, the R^2 values are slightly greater with the HRRR than with the UW WRF, suggesting that the HRRR fit the observed data better. However, the other statistics indicate that the UW WRF performed better. Both of these models performed rather similarly, whereas the WSU WRF clearly underperformed.
- None of the models predicted wind direction very well, although the UW WRF was slightly better than the other models. Since the UW WRF's domain covers just the Pacific Northwest, it used physics options that may have better represented air flow across terrains in this region.
- There does not appear to be significant similarities between KSEA and KPUW with respect to model performance fluctuation over time. If we were to focus on a group of stations in a smaller region, the variation in performance might be easier to discern.
- Most of the stations, as illustrated in the bias maps (Fig. 3), show a positive bias for temperature, wind direction, and wind speed and a negative bias for relative humidity. At several stations in and near the Cascade Mountains in WA, the WSU WRF had cold biases, possibly due to exaggerating the cooling effect of wildfire smoke in that area. The HRRR's ubiquitous warm bias and negative humidity bias were two of its weaknesses.

Future Study:

- Investigate additional variables relevant for air quality, such as precipitation and planetary boundary layer height.
- Assess model performance for urban, suburban, and rural areas to see if land type plays a role.
- Compare models using different wildfire periods and physiographic regions.

References

Skamarock, W. C., and Coauthors, 2008: *A Description of the Advanced Research WRF Version 3*. NCAR Technical Note NCAR/TN-475+STR, doi:10.5065/D68S4MVH.

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