Seven Ways to Configure WRF for Simulating Land-Water Interfaces, and How to Pick Just One

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Motivation and Objectives

The Great Lakes create complex meteorological conditions that influence air quality throughout the region. Lake-breeze circulation, lake-induced low level jets, shoreline boundary layer processes, and photochemistry at the land-water interface affect the magnitude and timing of regional ground-level ozone and particulate matter episodes.

Meteorological model performance varies by location, month, hour, and grid resolution. There is a practical need at LADCO to develop diagnostic methods that indicate which Weather Research Forecast (WRF) model configuration provides the lowest error/bias for key variables. Such methods are needed to lend insight into the strengths and limitations of WRF applications to support regulatory air quality modeling in the Midwest.

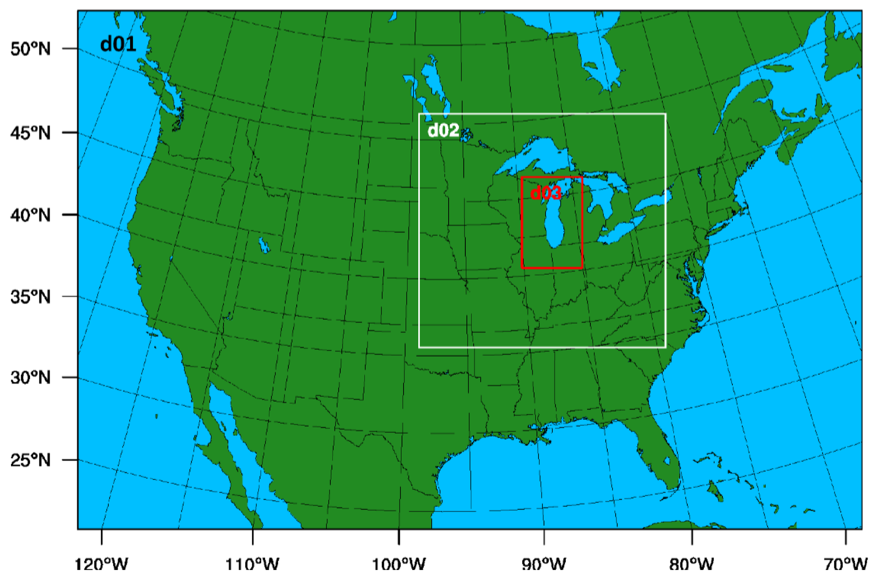

Figure 1. LADCO WRF simulation domains: (d01)12km CONUS, (d02) 4km Midwest, and (d03) 1.33km Lake Michigan

Methods

WRF version 3.9.1 simulated three nested domains (Figure 1) to test the best performing (i.e., lowest errors) configuration among various combinations of physical options, forcing data, sea surface temperature integration, and nudging options.

We developed a 'Best Config' diagnostics method that uses statistical significance testing for comparing different model configurations. The method is implemented in R using a significance testing algorithm adopted from the NOAA/NCEP Scorecard. The R script is integrated into the U.S. EPA's Atmospheric Model Evaluation Tool (AMETv1.3) and can be used to examine the model performance statistics of various sensitivity runs at individual monitors across different diurnal periods.

We tested the approach with WRF simulations of June 9-19, 2016, during which high surface ozone concentrations were observed in the Lake Michigan region. Here, we present our analysis results for a 4x4 km grid domain for the model configurations shown below.

CASE1 = LADCO2016_WRFv39_**APLX_NAM_g**da_**nd** (d02, d03)
- **A**CM2 PBL, **Pl**eim-**X**iu LSM, Morrison 2 moments microphysics, P-X surface layer option
- **NAM**218 (12km, 3hr FDDA); 3D grid nudging
- ICBC from US EPA's 12km WRF output (**ND**OWN)
- GHRSST (0.25° derived from NOAA/AVHRR, bias corrected with ship and buoy observations)

CASE2 = LADCO2016_WRFv39_**YNT_GFS_gs**da (d01-d03)
- **Y**SU PBL, Unified **N**oah LSM, **T**hompson's microphysics, MM5 Monin-Obukhov surface layer option
- **GFS** Grid4 (~25km, 6hr FDDA); 3D grid (d02 and d03) and obs nudging (d02)
- GLSEA SST over the Great Lakes (1.3-2.6 km res., daily)

CASE3 = LADCO2016_WRFv39_**YNT_NAM_gs**da (d01-d03)
- **Y**SU PBL , Unified **N**oah LSM, **T**hompson's microphysics, MM5 Monin-Obukhov surface layer option
- **NAM**218 (12km, 3hr FDDA); 3D **g**rid (d02 and d03) and **o**bs nudging (d02)
- GLSEA SST over the Great Lakes

Best Performing WRF Configuration for Selected Variables in the Daytime and Nighttime

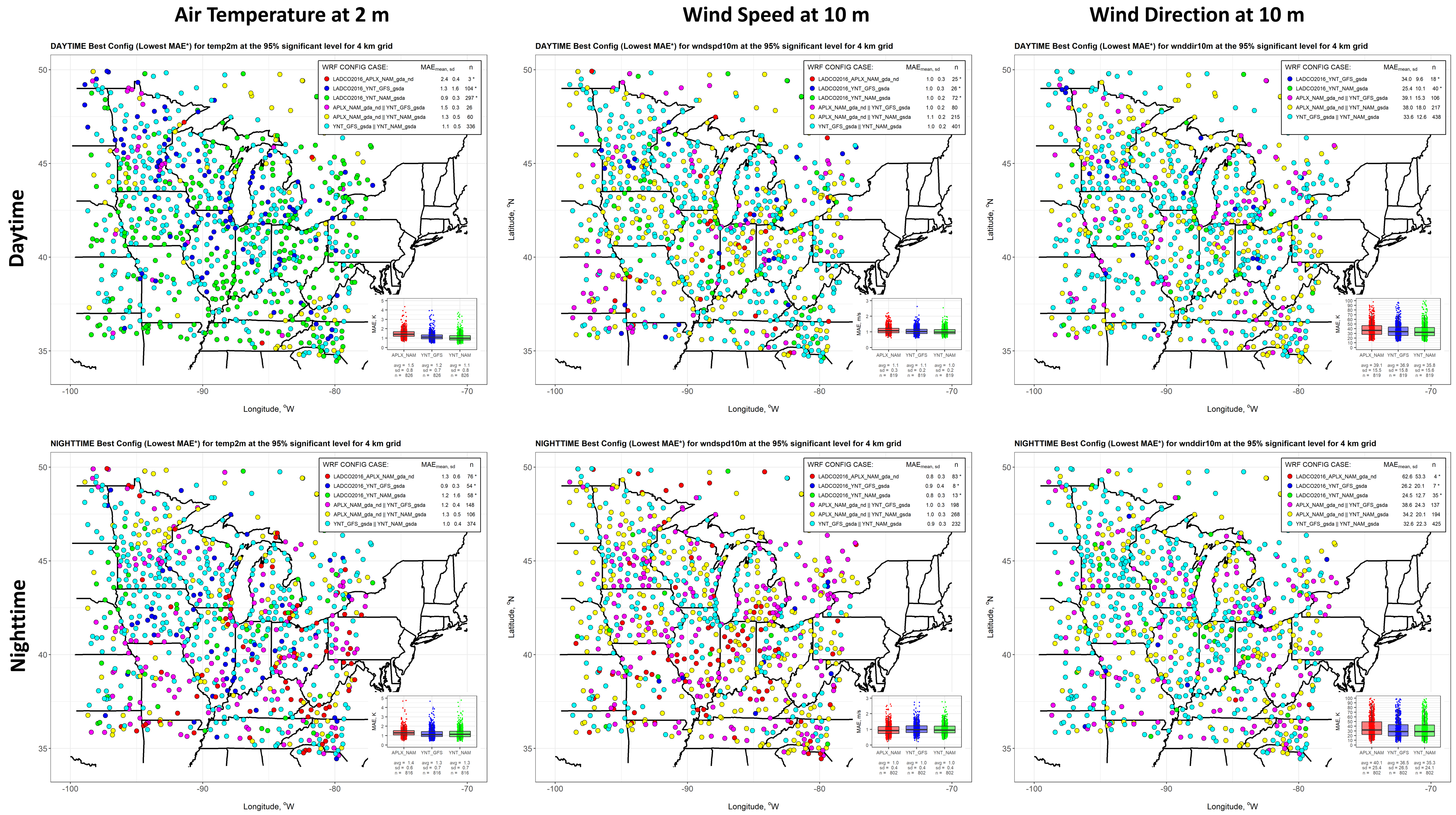

Figure 2. Best Performing Configuration for Temperature (left column), Wind Speed (middle column), and Wind Direction (right column) in the Daytime (top row) and Nighttime (bottom row). Dot colors indicate the WRF configuration that provides the lowest Mean Absolute Error (MAE) among other examined configurations. Plot legend summarizes MAE magnitude and total number of sites for each examined cases. A star (*) at the end of the number of sites indicates that particular configuration had lowest MAE than other cases at 95% significant level.

Key Messages:
- Temperature: The YNT_NAM_gsda configuration has *significantly better* performance during the daytime; the APLX_NAM_gda_nd configuration works better at night.
- Wind Speed & Direction: No WRF configuration significantly outperforms another. However, YNT_NAM_gsda predicts daytime wind speed & direction slightly better than other cases. While APLX_NAM_gda_nd better simulates the nighttime wind speeds, it does not capture the wind direction.

Model Performances at Shoreline Sites of the Lake Michigan

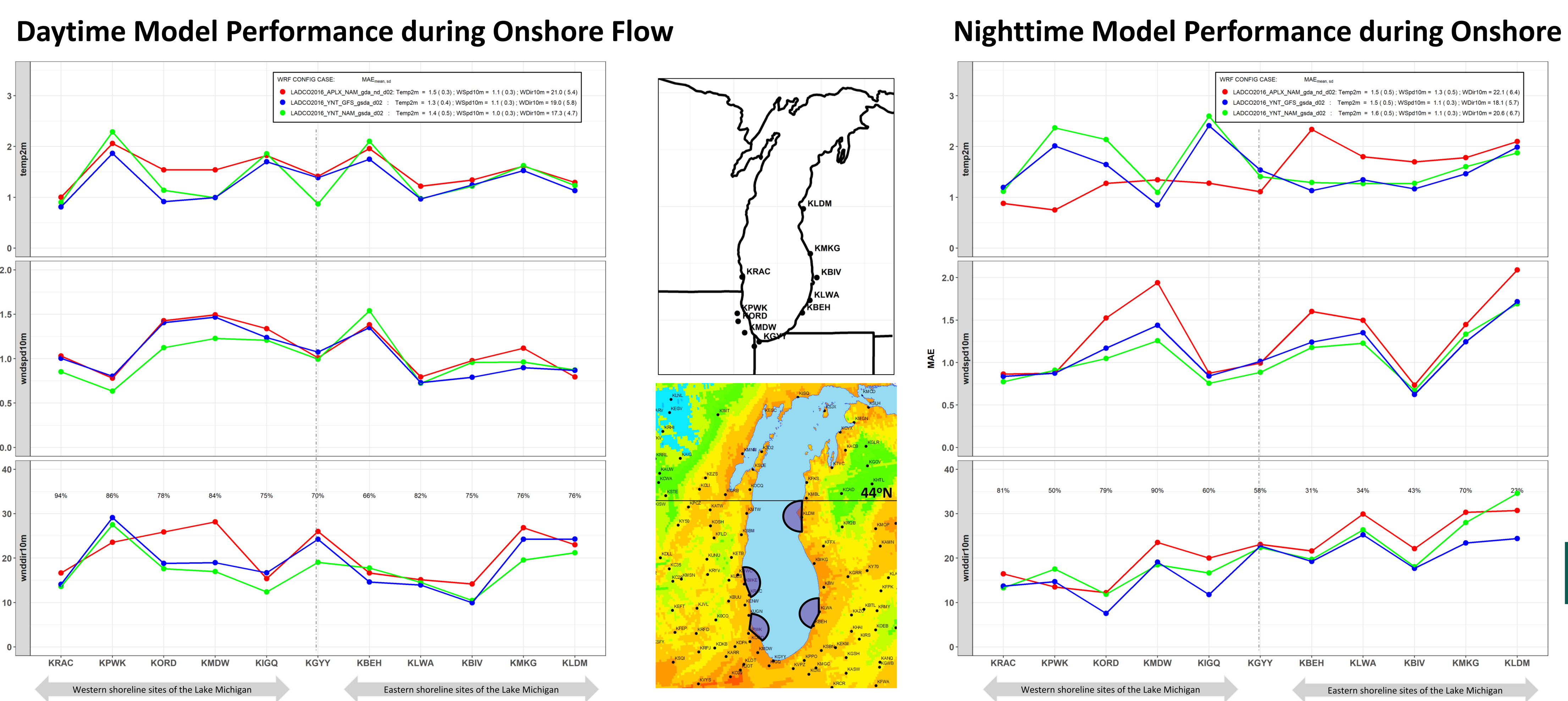

Figure 3. Model Mean Absolute Errors for Temperature and Wind Speed & Direction at shoreline sites of the Lake Michigan during the Daytime Onshore (left) and Nighttime Onshore Flow (right). The sites located south of 44°N latitude and elevated less than 200 m a.s.l. within the lake basin were examined for this study. Completeness of wind observation are shown by percent values in the bottom plots.

Key Messages:
- In the daytime, all three configurations give comparable MAEs for temperature, wind speed and direction.
- At night, YNT and APLX physics options produce different patterns for temperature MAE at the western and eastern shoreline sites.
- At night, wind direction MAEs tend to be higher at the eastern shoreline sites than for the western shoreline sites.

Summary and Future Work

LADCO conducted multiple WRF simulations to identify the best performing model configuration for driving air quality simulations for the Great Lakes region.

We developed an approach for selecting the best performing WRF configuration that uses significance testing to compare model errors across multiple sensitivity runs. This approach is being developed to work alongside cloud and precipitation agreement indices, and model performance evaluation metrics for land-lake breeze events.

The YNT physical options better simulate daytime temperatures across the domain. The APLX options better simulate nighttime temperatures (Figure 2 and below).

WRF Config	Daytime T MAE	Nighttime T MAE
YNT_NAM_gsda	1.1±0.8 K	1.3±0.7 K
APLX_NAM_gda_nd	1.5±0.8 K	1.4±0.6 K

YNT_NAM_gsda case predicts wind speed & direction slightly better than the other cases, with MAEs of 1.0±0.2 m/s and 36±16 deg in the daytime, and MAEs of 1.0±0.4 m/s and 35±24 deg in the nighttime.

We explored model errors during the onshore flow from the Lake Michigan to shoreline sites (Figure 3) where key ozone non-attainment areas located. The YNT_GFS_gsda case produces smaller MAEs for daytime temperature during the onshore air flow, however, the errors aren't significantly different than other cases.

The YNT and APLX physics options produce different patterns for nighttime temperature errors at the western and eastern shoreline sites of the Lake Michigan. Wind direction errors tend to be higher at the eastern shore than those in the western shore of the Lake Michigan.

***Table 1**. Selecting Best Performing WRF configuration*

DECISION MAKER TOOL 1.0

FR - Feature importance rating. If the FR= 1 then not important, FR = 5 then needed but not critical and FR = 10 then absolutely critical
SR - Specification rating. If SR = 1 then awful, if SR = 5 acceptable and if SR = 10 then outstanding

Decision Making (June 9-19, 2016): Selecting the Best Performing WRF Configuration for the Midwest — Date: 12/04/2019

	Feature	FR (1-10)	Option 1 APLX_NAM_gda_nd Performance Statistics	SR (1-10)	Option 2 YNT_GFS_gsda Performance Statistics	SR (1-10)	Option 3 YNT_NAM_gsda Performance Statistics	SR (1-10)
1	Domain Daytime Temperature	10	MAE = 1.5±0.8	7	MAE = 1.2±0.7	8	MAE = 1.1±0.8	8
2	Domain Nighttime Temperature	8	MAE = 1.4±0.6	6	MAE = 1.3±0.7	6	MAE = 1.3±0.7	6
3	Domain Daytime Wind Speed and Direction	8	MAE = 1.1±0.3 MAE = 39±16	5	MAE = 1.1±0.2 MAE = 37±16	6	MAE = 1.0±0.2 MAE = 36±16	7
4	Domain Nightime Wind Speed and Direction	7	MAE = 1.0±0.4 MAE = 40±25	5	MAE = 1.0±0.4 MAE = 36±27	6	MAE = 1.0±0.4 MAE = 35±24	7
5	Cloud Agreement Index	8	?	5	?	5	?	5
6	Onshore Flow: Daytime Temperature	7	MAE = 1.5±0.3	5	MAE = 1.3±0.4	7	MAE = 1.4±0.5	6
7	Onshore Flow: Nighttime Temperature	6	MAE = 1.5±0.5	4	MAE = 1.5±0.5	4	MAE = 1.6±0.5	3
8	Onshore Flow: Daytime Wind	7	MAE = 1.1±0.3 MAE = 21±5	5	MAE = 1.1±0.3 MAE = 19±6	6	MAE = 1.0±0.3 MAE = 17±5	7
9	Onshore Flow: Nightime Wind	6	MAE = 1.3±0.5 MAE = 22±6	5	MAE = 1.1±0.3 MAE = 18±6	7	MAE = 1.1±0.3 MAE = 21±7	6
10	Daily Precipitation Totals	8	?	5	?	5	?	5
	SUM	67		397		455		458
			Score	5.93	Score	6.79	Score	6.84

Our results indicate that the YNT_NAM_gsda configuration provides better overall performance than other configurations for temperature and wind fields (Table 1). We are in the process of assessing model runs for Cloud Agreement Index using GOES satellite products and daily precipitation totals using PRISM precipitation estimates.

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Acknowledgements

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