A Satellite Constrained Meteorological Modeling Platform for LADCO States SIP Development

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Project Goals

• We will support the modeling needs of the Lake Michigan Air Directors Consortium (LADCO) through development, verification, and delivery of a satellite-constrained meteorological modeling platform that can be used for air quality assessments of ozone in the Lake Michigan region

- Ozone non-attainment events occur periodically, especially along the Lake Michigan shoreline, so those states are required by the Clean Air Act to demonstrate strategies to mitigate these ozone exceedance events
- Meteorological modeling is very challenging due to the influence of lake/land breeze circulations on the transport and chemistry along the Lake Michigan shoreline
- Complex interplay between generation of pollution along southern rim of Lake Michigan and its northward advection

Project Goals

- Modeling platform is based on the WRF model, with high-resolution (4- and 1.33-km) nests covering the LADCO states

    - Sensitivity experiments will be performed to determine the optimal configuration of the modeling platform

    - Examine the impact of using different model parameterization schemes and high-resolution input datasets such as MODIS/VIIRS vegetation data, NASA LIS soil moisture and soil temperature, and GLSEA sea surface temperatures

- End goal is to deliver a well-tested modeling platform to LADCO that leverages NASA satellite observations and land surface modeling and data assimilation capabilities

    - Will enhance their ability to address requirements of air quality assessment modeling along the Lake Michigan shoreline

Project Partners and End Users

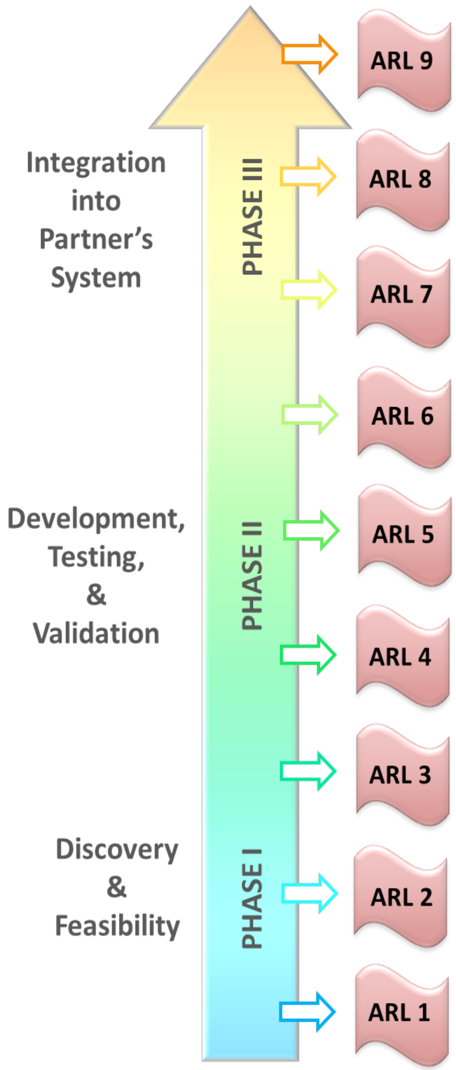
Role	Name	Affiliation Organization	Organization Type
Co-Investigator	Zac Adelman	Lake Michigan Air Director's Consortium (LADCO)	Non-profit multi-jurisdictional (end user / stakeholder)
Co-Investigator	Gail Good	Wisconsin Department of Natural Resources (WDNR)	State Government Agency (end user / stakeholder)
Co-Investigator	Chris Hain	NASA Marshall Space Flight Center	Federal Agency
Co-Investigator	Jonathan Case	ENSCO Inc., NASA SPoRT	Private Sector, under contract with NASA SPoRT
Co-Investigator	Monica Harkey	Univ. Wisconsin – Madison, SAGE	Academic Institution
Collaborator	Brad Pierce	Univ. Wisconsin – Madison, SSEC/CIMSS	Academic Institution
Collaborator	Andy Heidinger	NOAA Advanced Satellite Products Branch	Federal Agency
Collaborator	James Szykman	Environmental Protection Agency	Federal Agency

Milestones During the Entire Project

Project Steps by Project Year Quarter	***Year 1***				***Year 2***				***Year 3***			
	Q1	***Q2***	***Q3***	***Q4***	***Q1***	***Q2***	***Q3***	***Q4***	***Q1***	***Q2***	***Q3***	***Q4***
Generate SPoRT LIS soil moisture analyses												
Conduct WRF physics/satellite data sensitivity tests												
Generate 2017 CLAVR-x satellite cloud climatologies												
Conduct WRF/SPoRT-LIS nudging experiments												
Develop and test WRF cloud optical thickness bias correction methodology												
Develop 2017 NEI emissions surrogates												
Conduct preliminary 2017 SIP assessment modeling												
Conduct final 2017 SIP assessment modeling												
Evaluate 2017 SIP model simulations												
Generate 2016 meteorological fields												
Generate 2016 CLAVR-x satellite cloud climatologies												
Develop 2016 NEI emissions surrogates												
Generate 2016 cloud optical thickness bias corrections												
Perform 2016 SIP assessment modeling												
Evaluate 2016 SIP model simulations												
ARL Level	**3**			**4**		**5**		**6**		**7**		**8**

- We have completed some of our Year 2 tasks, and are making good progress on the remaining tasks

Project Application Readiness Level



- Start-of-Project ARL = #3 *(01 October 2018)*
- Goal ARL = #8
- Current ARL = #5 *(01 July 2020)*

At the start of this project, each of the components that we were planning to use to enhance the accuracy of the LADCO meteorological modeling platform had been tested and validated independently. This allowed us to place the initial readiness level at ARL-3.

The project readiness level is currently RL-5; however, we expect it to increase to RL-6 by the end of the year. We have made substantial progress evaluating the accuracy of the WRF model simulations and have started to run the 2017 CMAQ simulations. We also continue to work closely with our project collaborators, by providing recommendations on the model configuration.

Project Challenges and Risks

Rank	Type*	Risk	Mitigation Action
1	Techni cal	Proposed satellite-constrained modeling system is not more accurate than baseline configuration	We view this as a low-level risk because of the large number of potential optimizations (high-resolution soil moisture, vegetation, and sea surface temperature datasets; new model physics) that we will explore during this project. Sensitivity tests will allow us to robustly determine if any one of these potential changes leads to a poorer result, and if it does, it will not be included in the final version of the modeling system delivered to the end users.
2	Manag ement	Lack of engagement from the end of users	We also view this as a low-level risk because both end-user organizations (LADCO and Wisconsin DNR) have participated in the monthly and quarterly telecons.
3	Sched ule Risk	Delays performing/ evaluating model simulations	Researchers at the Wisconsin DNR are tasked with performing full-year model simulations during Years 2 and 3 of the project. It is possible that delays could occur due to lack of personnel or computing resources. This risk is mitigated by requesting (and receiving) an account on the NESDIS/STAR/SSEC S4 supercomputer to complete the simulations if necessary.

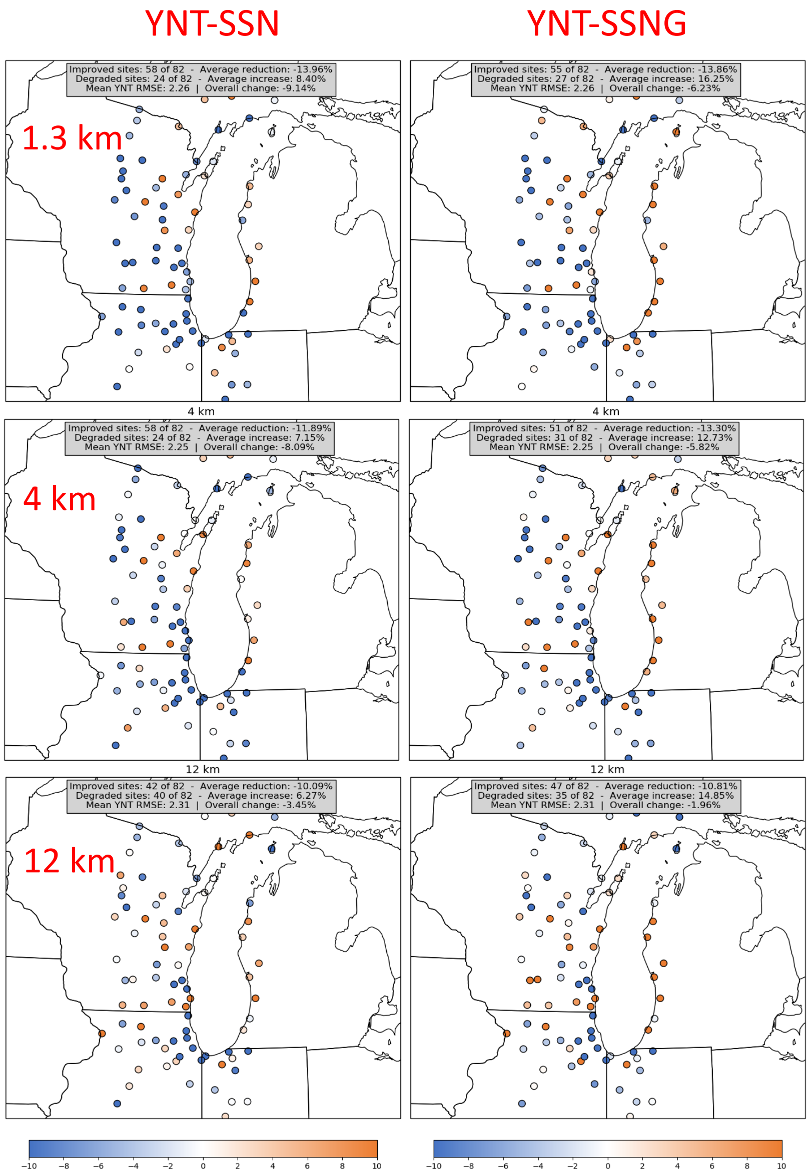
WRF Model Sensitivity Simulations

EXPERIMENT	SST	GVF	SOIL	Nudging
EPA	--	--	--	--
YNT	--	--	--	--
YNT-SST	✓	--	--	--
YNT-GVF	--	✓	--	--
YNT-SOIL	--	--	✓	--
YNT-N2KM	--	--	--	✓
YNT-SST-SOIL	✓	--	✓	--
YNT-GVF-SST	✓	✓	--	--
YNT-GVF-SOIL	--	✓	✓	--
YNT-GVF-SOIL-SST	✓	✓	✓	--
YNT-SSN	✓	--	✓	✓
YNT-SSNG	✓	✓	✓	✓

All simulations cover a seven-week period during 2017

- "EPA" simulations follow the EPA operational forecasting model configuration, including the Pleim-Xu land surface model (LSM), Morrison 2-moment cloud microphysics, and ACM2 PBL parameterization schemes
- "YNT" simulations use the YSU PBL, Noah LSM, and Thompson microphysics, respectively
- "SST" refers to the high-resolution, real-time GLSEA SST dataset
- "SOIL" refers to high-resolution soil moisture/temperature analyses provided by NASA SPoRT
- "GVF" refers to the high-resolution VIIRS green vegetation fraction dataset
- "N2KM" refers to nudging temperature, moisture, and horizontal winds above 2 km

Changes in 2-m Temperature RMSE and Bias



RMSE % Reduction

Simulation	12 km	4 km	1.3 km
YNT	*2.305*	*2.254*	*2.260*
YNT-SST	-0.494	-0.539	-0.569
YNT-SOIL	-1.012	-5.432	-7.315
YNT-GVF	-0.443	-2.690	-4.046
YNT-N2KM	-0.522	-0.617	0.703
YNT-SSN	-3.450	-8.094	-9.137
YNT-SSNG	-1.962	-5.820	-6.226

Max Reduction 0 Max Increase

Bias

Simulation	12 km	4 km	1.3 km
YNT	0.175	0.495	0.581
YNT-SST	0.186	0.508	0.595
YNT-SOIL	-0.389	-0.178	-0.212
YNT-GVF	-0.276	-0.006	-0.019
YNT-N2KM	0.255	0.607	0.699
YNT-SSN	-0.287	-0.058	-0.087
YNT-SSNG	-0.564	-0.315	-0.380

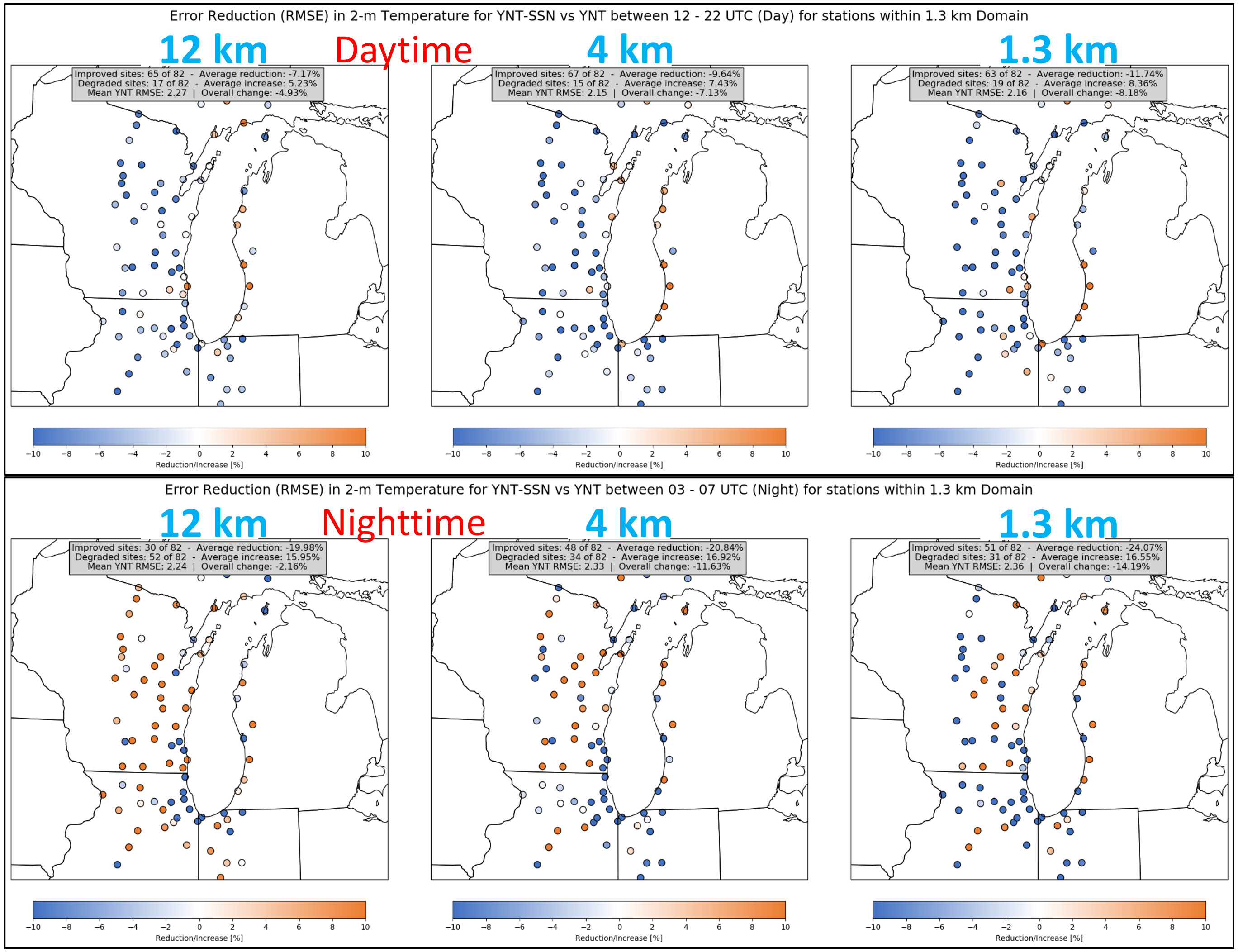
Min Bias 0 Max Bias

RMSE – blue is good

Bias is absolute (not % based)

- Figure shows the RMSE % changes in 2-m temperature for the YNT-SSN and YNT-SSNG configurations relative to the YNT baseline configuration for each of the three domains; Tables show the RMSE and bias statistics for all model configurations
- RMSE error reductions are largest within our study area along the western shoreline of Lake Michigan
- Left table shows that high-resolution surface datasets led to smaller RMSE (negative values)
- Soil moisture (YNT-SOIL) is the most important individual input dataset
- Impact of VIIRS GVF data (YNT-GVF) was mixed
- For bias, the high-resolution SSTs and nudging led to warmer solutions on average while soil moisture and GVF led to cooling

Changes in 2-m Temperature RMSE and Bias



- Large differences in RMSE percent changes between the daytime and nighttime
- YNT-SSN has larger error reductions during the day, but larger errors at night
- Error reductions are large during both daytime and nighttime in our region of interest along the western shoreline of Lake Michigan

- Percent change for 2-m temperature RMSE on each domain for the YNT-SSN configuration compared to the baseline YNT configuration (blue is good, orange is bad)

Summary and Future Plans

- When assessed over all variables, time periods, and domains:
  - High-resolution soil moisture and temperature analyses from NASA SPoRT had the largest positive impact in study region
  - GLSEA SST and analysis nudging above 2 km generally positive
  - Impact of VIIRS vegetation data was mixed, but we expect it to have the largest impact during the CMAQ simulations
- During the next few months, we plan to:
  - Incorporate the cloud-dependent bias correction method into the CMAQ modeling infrastructure
  - Run CMAQ simulations on the 12-km, 4-km, and hopefully 1.3-km resolution domains

Key Statements from Stakeholders

- From the Wisconsin Department of Natural Resources:

"This collaborative project has helped further refine the technical modeling efforts supporting Wisconsin's SIP requirements. Ozone policy activities rely on meteorological and photochemical models and these models have long-standing and well documented issues representing ozone around Lake Michigan, given the complexities of lake breeze circulation patterns and pollutant transport. This project is digging deeply into how the models represent the meteorology of this area by refining multiple sets of model inputs and assumptions using satellite data. This work is also testing updated model configurations and evaluating their accuracy, all of which should lead to significantly improved modeling to inform DNR's ozone policy decisions. With the PIs now evaluating the impacts of these model updates on the photochemical modeling, the results of this NASA-funded project should continue to improve SIP modeling into the future."

- From LADCO:

"During the second year of this project, LADCO continued to benefit from collaborations with the project team. To support our work developing an improved regional ozone modeling platform, we used tools and data provided by the project team to create a nested WRF modeling application that used the GLSEA lake surface temperature and SPoRT LIS soil moisture data to add value to our WRF simulations. LADCO will apply the 2016 WRF simulations in regional haze and ozone planning decision support tools that we are developing for member states. In year 2 of this project, LADCO built off the relationships developed with the project team during the first year. The familiarity and trust between the project team and LADCO staff created a partnership that has become vital to supporting LADCO's goal of deploying state-of-the-science modeling approaches to inform the air quality planning process in our region. This project underscores the need for multi-year applied science programs that connect NASA-funded researchers with stakeholders that utilize atmospheric science data to improve public health and the environment."