# A Satellite Constrained Meteorological Modeling Platform for LADCO States SIP Development

**Jason Otkin**

**University of Wisconsin-Madison**
**Cooperative Institute for Meteorological Satellite Studies**

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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*

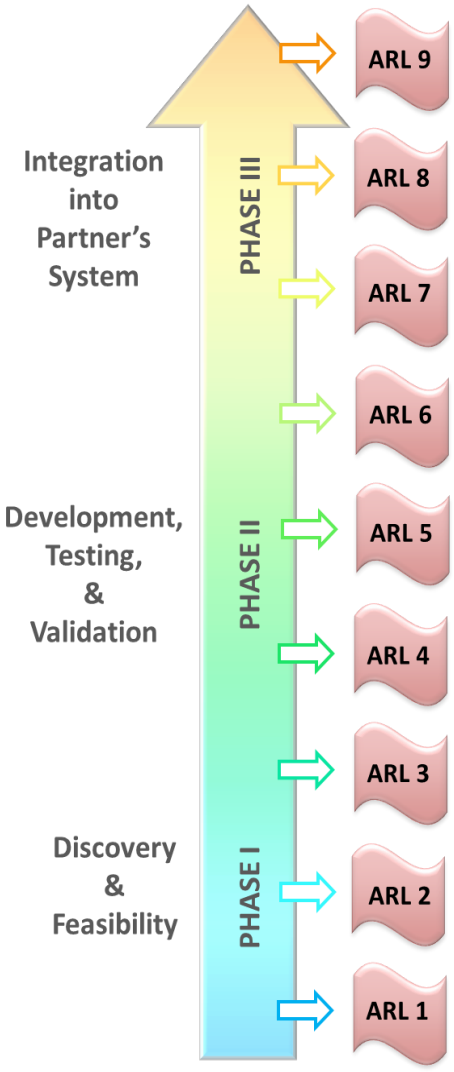
| Role | Name | Affiliation Organization | Organization Type |
|---|---|---|---|
| Co-Investigator | Zac Adelman | Lake Michigan Air Director's Consortium (LADCO) | Non-profit multi-jurisdictional (end user / stakeholder) |
| Co-Investigator | Gail Good | Wisconsin Department of Natural Resources (WDNR) | 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 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 are on pace to meet our Year 1 milestones by the end of September (Year 1, Q4) or shortly thereafter

# Project Application Readiness Level




- Start-of-Project ARL = #3 *(01 October 2018)*
- Goal ARL = #8
- Current ARL = #3 *(01 July 2019)*

At the start of this project, each of the components that we are 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 of ARL-3.

Model sensitivity experiments have been performed, which have provided useful guidance to LADCO. We are developing interfaces for integration of the model output into the LADCO modeling framework.

Final set of model sensitivity experiments are currently being run. Once these are complete we will increase the readiness level to ARL-4.

# *Project Challenges and Risks*

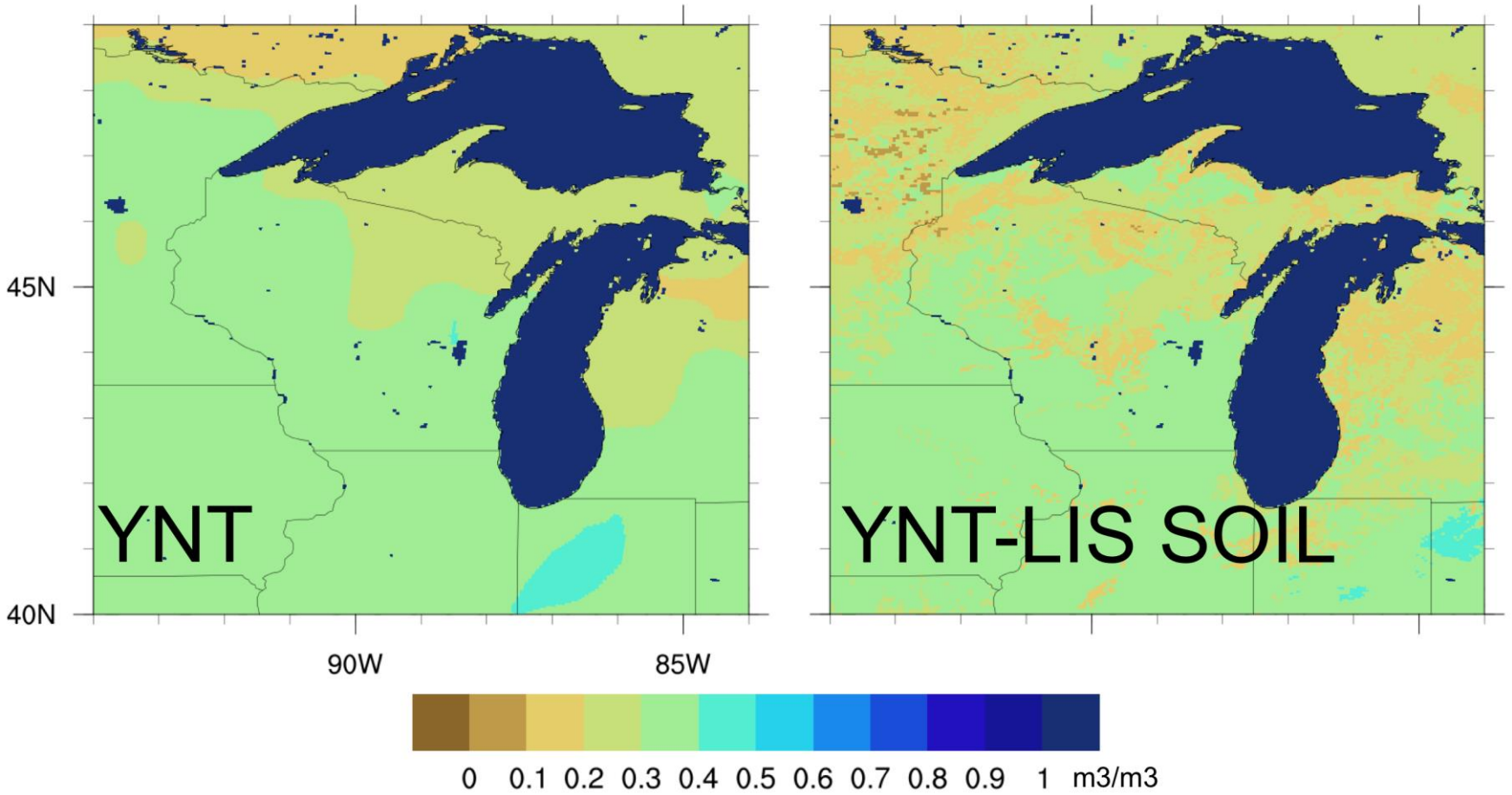
| Rank | Type* | Risk | Mitigation Action |
|---|---|---|---|
| *1* | Technical | Proposed satellite-constrained modeling system is not more accurate than baseline configuration | We view this as a low-level risk because of the large number of potential optimizations (high-resolution soil moisture, vegetation, 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* | Management | 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* | Schedule 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. Regular interactions will minimize the potential for delays. |

# Model Sensitivity Simulations

| EXPERIMENT | GLSEA SST | LAI | SOIL | IC/BC | status |
|---|---|---|---|---|---|
| 1) EPA | -- | -- | -- | GFS | **complete** |
| 2) EPA-SST | ✔ | -- | -- | GFS | **complete** |
| 3) YNT | -- | -- | -- | GFS | **complete** |
| 4) YNT-NAM | -- | -- | -- | NAM | **complete** |
| 5) YNT-SST | ✔ | -- | -- | GFS | **complete** |
| 6) YNT-SST-nudge2km | ✔ | -- | -- | GFS | **complete** |
| 7) YNT-SST-SOIL | ✔ | -- | ✔ | GFS | **ongoing** |

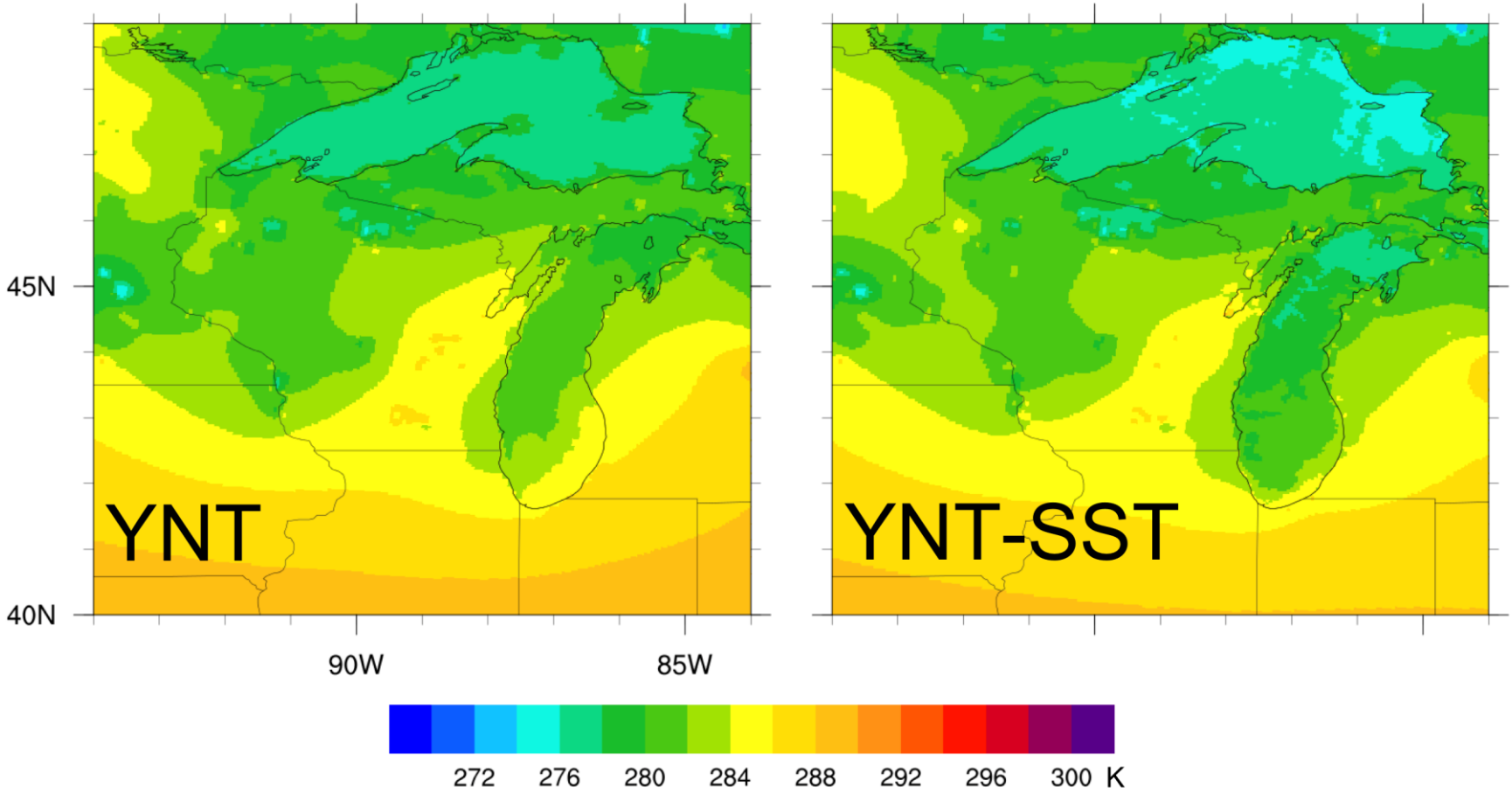
1) The "EPA" simulation follows the WRF model configuration used by the EPA in their operational forecasting model, except with analysis nudging toward GFS analyses instead of NAM analyses. It employs the Pleim-Xu land surface model (LSM), Pleim-Xu surface layer physics, Morrison 2-moment cloud microphysics, and the ACM2 (Pleim) planetary boundary layer (PBL) parameterization schemes.
2) The "EPA-SST" simulation is the same as 1, except for replacing the coarse-resolution SST initialization dataset with the high-resolution, real-time GLSEA SST dataset.
3) The "YNT" simulation is the same as 1, except for replacing the LSM, surface layer physics, cloud microphysics, and PBL parameterization schemes with the Noah LSM, Monin-Obukhov surface layer physics, Thompson microphysics, and YSU PBL, respectively.
4) The "YNT-NAM" simulation is the same as 4, except that the NAM analyses are used for the lateral boundary and initial conditions instead of GFS.
5) The "YNT-SST" simulation is the same as 4, except for replacing the coarse-resolution SST initialization dataset with the high-resolution, real-time GLSEA SST dataset.
6) The "YNT-SST-nudge2km" simulation is the same as 6 (previous slide), except for nudging temperature, moisture, and horizontal winds above 2 km (model level) instead of above the boundary layer
7) The "YNT-SST-SOIL" simulation will be the same as 6 (previous slide), except for replacing soil temperature and moisture with high-resolution analyses provided by SPoRT-LIS.

# NASA LIS Soil Moisture and Soil Temperature



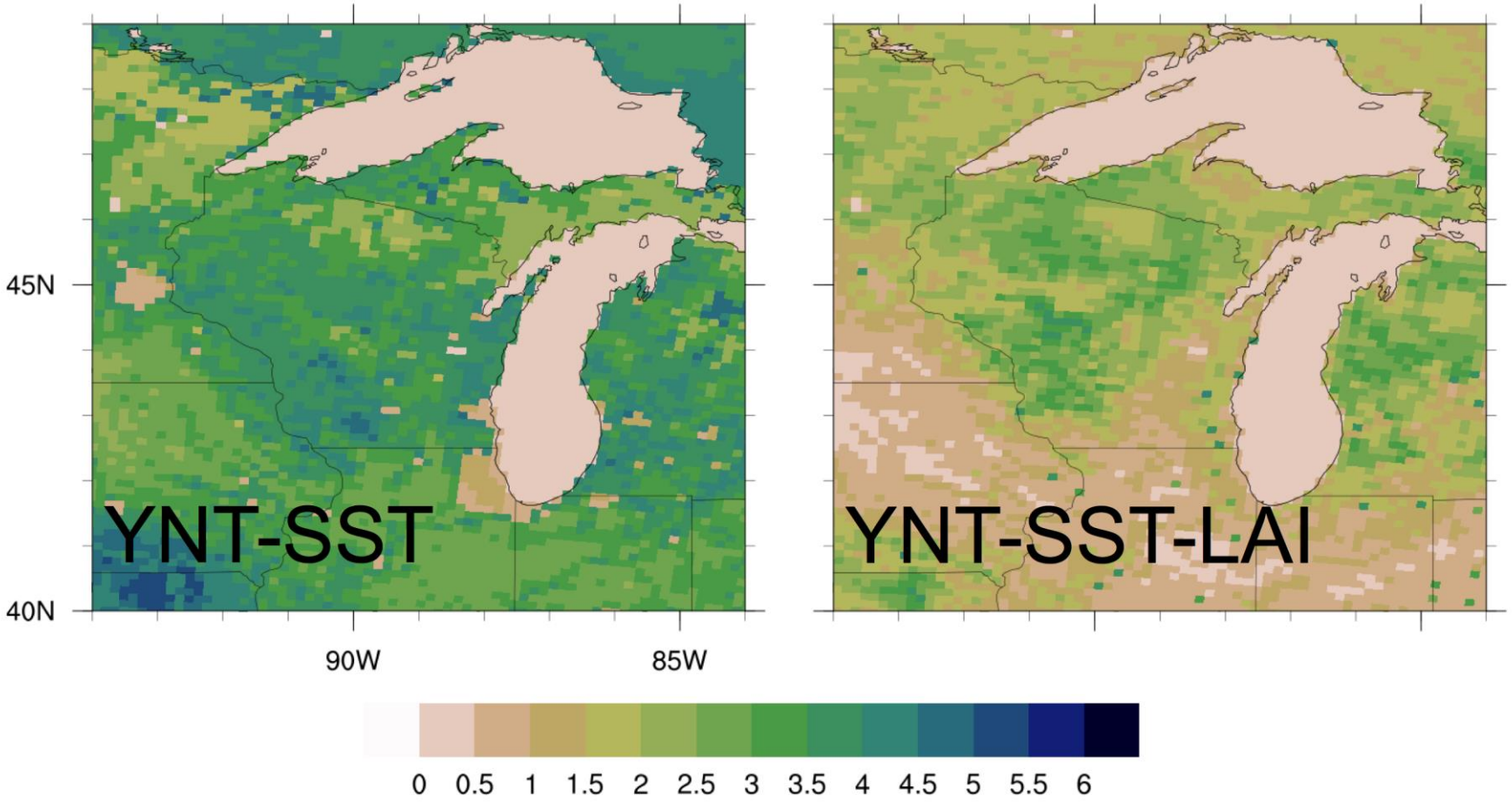

- NASA Land Information System (LIS) used to generate observations-driven land surface fields on ~1-km resolution grid for input to WRF model
- Much finer spatial detail evident in the 0-10 cm soil moisture content in the YNT-SOIL simulation

# GLSEA Sea Surface Temperatures




- Default SST on left, with 1.8-km resolution GLSEA SST on right
- Lake temperatures are generally cooler when the GLSEA SST is used, also have more fine-scale spatial structure

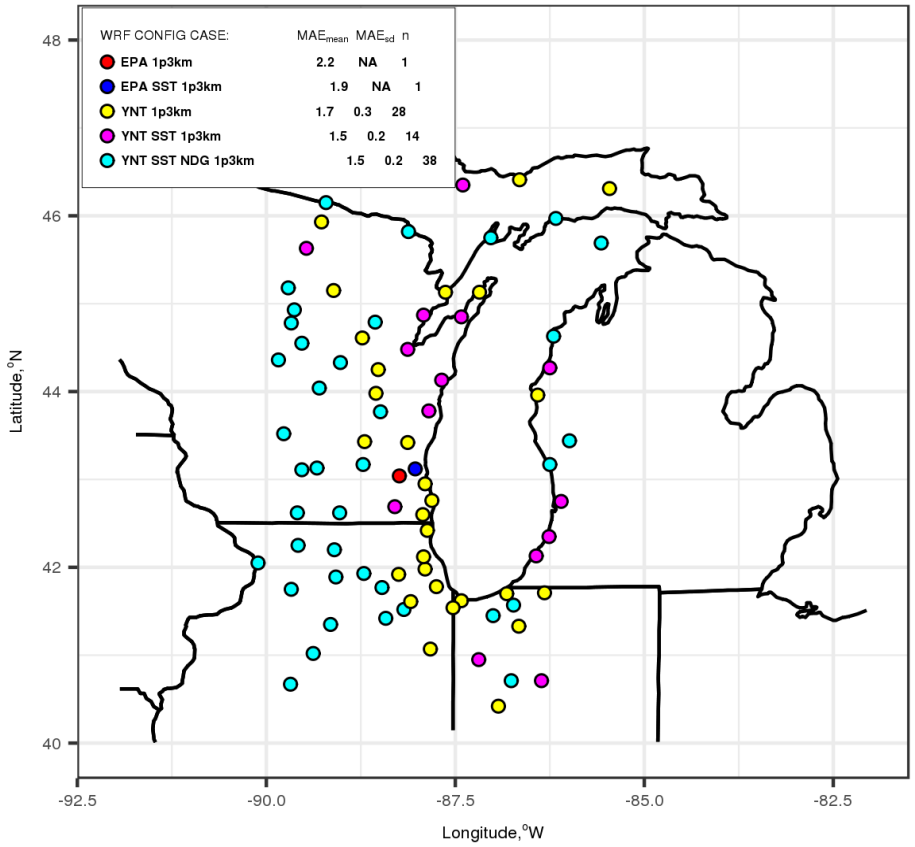
# MODIS Leaf Area Index




- Climatological leaf area index on left, with real-time MODIS on the right
- Much lower values in the real-time dataset that are more consistent with the cold spring in 2017 and delayed green-up of the vegetation

# 2-m Temperature Statistics (1.33-km Domain)

## Best Performing Model Configuration




## Statistical Summary

| Model Configuration | MAE Mean | MAE Standard Deviation | Number of Stations |
|---|---|---|---|
| EPA | 2.2 | NA | 1 |
| EPA-SST | 1.9 | NA | 1 |
| YNT | 1.7 | 0.3 | 28 |
| YNT-SST | 1.5 | 0.2 | 14 |
| YNT-SST-nudge2km | 1.5 | 0.2 | 38 |

- On the highest resolution domain, the YNT configurations greatly outperform the EPA baseline simulations
- Clear geographic separation with YNT-SST-nudge2km being the most accurate at western inland locations
- YNT and YNT-SST configurations provide superior results along the Lake Michigan shoreline

# *Key Statements from Stakeholders*

- From the Wisconsin Department of Natural Resources:
  - "This collaborative project has been very helpful in strengthening the technical modeling efforts being completed in support of Wisconsin's state implementation plan (SIP) requirements. The satellite constrained meteorological modeling results developed to date have informed the team's understanding as to how sensitive the models are to various satellite data sets; this has allowed the team to identify the modeling configuration most likely to replicate the complex lake breeze circulation along the Lake Michigan shoreline. These results are already being presented and evaluated in multi-state ozone policy and planning discussions and will be used to support Wisconsin's ozone-related SIP submittals in the coming year."
- From LADCO:
  - "In collaboration with the NASA HAQ project team, LADCO created a new diagnostic approach for identifying the best performing WRF model configuration. The approach uses statistical significance testing for comparing multiple WRF model simulations for different periods in the diurnal cycle. Ideas for this approach provided by the project team, such as statistical testing and model performance at specific diurnal periods, were indispensable for developing the approach. We are using this approach in the project team to compare multiple WRF configurations, and to find the best configuration for use in air quality modeling. Active and on-going collaboration between the NASA HAQ project team and LADCO is helping to streamline and improve the use of satellite data for air quality planning in the Great Lakes region."