Improving the Representation of Physical Atmosphere in Air Quality Decision Support Systems Used for Emissions Control Strategy Development

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Collaborators

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5. **Texas Commission on Environmental Quality (TCEQ)**
6. **Georgia Environmental Protection Division (Georgia-EPD)**
7. **National Aeronautics and Space Administration (NASA)**
8. **Environmental Protection Agency (EPA)**
9. **National Oceanic and Atmospheric Administration (NOAA)**

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PROJECT INFORMATION

TOPIC: **Improving the Representation of Physical Atmosphere in Air Quality Decision Support Systems Used for Emissions Control Strategy Development**

POP: 6/24/1/2015 – 6/23/2018 (ROSES2013-A.44)
(Project Ended, NCE Till 6/23/2019)

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Co-Is: Dick McNider (UAH), Daniel Cohan (Rice)

Partners: California Air Resources Board (CARB), Bay Area Air Quality Management District (BAAQMD), USEPA, Texas Commission on Environmental Quality (TCEQ), Georgia Environmental Protection Division (GA-EPD), National Oceanic and Atmospheric Administration (NOAA)

NASA Assets: NASA's GOES Product Generation System (skin T, surface insolation and albedo, cloud top T, cloud albedo); MODIS products (Skin Temperature, surface insolation and albedo)

Objective: To employ NASA assets and satellite products to improve the air quality management Decision Support Tools (DSTs) used in defining emission control strategies for attainment of air quality standards.

Problem Statement

- Air quality regulatory agencies' mission is to maintain a healthy air by meeting the National Ambient Air Quality Standard (NAAQS) for criteria pollutants.

- Numerical air quality models are used to test the impact of different emissions reduction strategies in order to select the most efficient strategy for the State Implementation Plan (SIP).

- Therefore, the accuracy of these simulations is of outmost importance to decision makers as it impacts the decisions that are extremely costly.

- The retrospective model simulations often try to assimilate all available observations in order to replicate the observed atmospheric condition. However, there are still large uncertainties in model predictions using only surface observations. Due to sparseness of surface monitors, satellite observations offer an attractive complement to surface observations for assimilation.

Specific Objectives

In This Project NASA Assets and Satellite Data Will Be Used to Improve the Quality and Accuracy of Retrospective Baseline Simulation in Which Proposed SIP Emission Reductions Are Tested

Improving Emission Estimates in AQ Model

- **Utilization of Satellite Derived Photosynthetically Active Radiation (PAR) to Improve Biogenic Hydrocarbon Emissions:** This activity utilizes NASA's GOES Product Generation System (GPGS) to produce PAR (a new product) for use in AQ models.
- **Improving Soil NOx Emission Estimates:** By including the impact of satellite derived temperature and soil moisture.

Improving Physical Atmosphere

- **Improved Characterization of Surface Energy Budget:** Using satellite derived skin temperature to retrieve soil moisture and Improve Surface Evapotranspiration Performance in WRF.
- **Improving Boundary Layer Development in the Model:** By improving BL moisture and temperature structure.

SCHEDULE / MILESTONES

Major Tasks	FY16	FY17	FY18
Satellite skin temperature	evaluation and product selection	testing & evaluation	Reprocessed for case studies
Surface energy budget	Preparation and test simulations	implementation in P-X scheme, testing & evaluation	Case study completed
Satellite-based PAR retrieval	Algorithm devised, PAR produced & evaluated	Reprocessing GOES Imager data	Re-organizing the archives completed
Reprocessing satellite data	Updating retrieval code/scripts	Obtaining raw images for 2006-present	reprocessing completed
Improved biogenic emission estimates	Using satellite PAR in MEGAN	Using satellite-based PAR in BEIS	Satellite-based PAR generated/archived
Benchmarking (multiple activities)	Satellite PAR/BVOC emissions in CMAQ	Satellite Skin T for Texas case study	Skin-T Assimilation For Great Lakes
Transition (TCEQ, G-EPD, BAAQMD, …)		Started work with paertners for transition	Data/code provided to: EPA, Wisconsin DNR, LADCO, TCEQ
Impact analysis		BenMAP work started	First Report Prepared Assessment completed

Completed
Ongoing
Future

ARL PROGRESS

Use of Satellite-based PAR for BVOC Emission Estimates			
	FY16	**FY17**	**FY18**
Starting ARL	**1**	**4**	**5**
Ending ARL	**4**	**5**	**7**

ARL 7: Application Prototype in Partner's Decision Making (Functionality Demonstrated)

- 1) Prototype application system integrated into end-user's operational environment:
  a. Support was provided to partner organization to fully integrate the assimilation system for operational use.
  b. All technical difficulties related to software installation and data acquisition were addressed by UAH. Necessary modifications were made to codes/scripts to be compatible with the operational environment.
- 2) Prototype application functionality tested & demonstrated in decision making activity
  a. August 2013 simulations were performed by the partner organization and the results were evaluated against UAH results. The evaluations were satisfactory and indicated a successful transition.
  b. Further simulations for May-September 2012 episode resulted in comparable improvements.

ARL PROGRESS

Surface Energy Budget Improvement

	FY16	FY17	FY18
Starting ARL	2	3	3
Ending ARL	3	3	6

ARL 6: Demonstration in Relevant Environment (Potential Demonstrated)

- 1) Prototype application system beta-tested in a simulated operational environment:
  - The assimilation technique was implemented in WRF and tested for 2013 Discover-AQ case study. The setup for the simulation was chosen to mirror EPA's configuration. The code for processing satellite skin temperature retrievals were integrated into the WRF preprocessing system and was tested with few different configurations.
- 2) Projected improvements in performance of decision making activity demonstrated in simulated operational environment:
  - WRF simulations for the summer of 2013 were performed in semi-operational environment. The results from the simulations were extensively evaluated and demonstrated substantial improvements in several key meteorological parameters. The results are being published.

OVERALL ARL PROGRESS

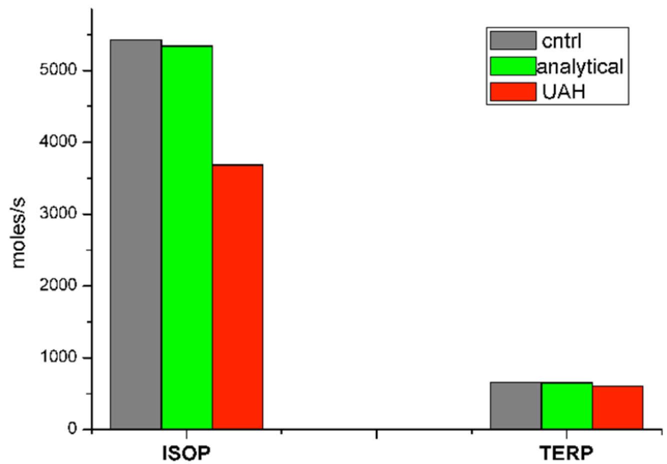
Overall ARL			
	FY16	FY17	FY18
Starting ARL	1-2	4	5
Ending ARL	4	5	7

RISKS & ISSUES

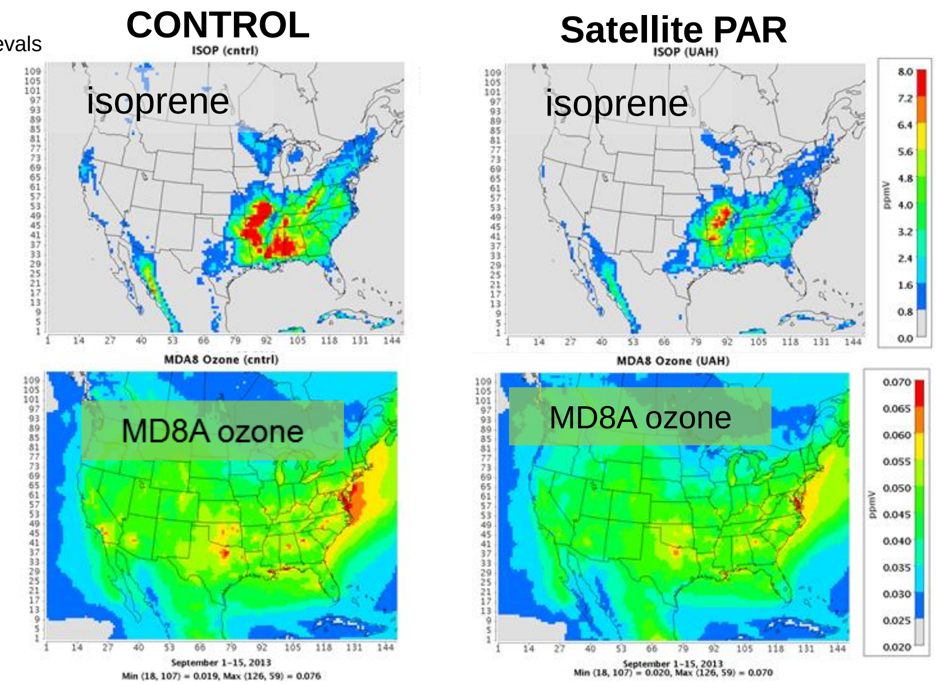
- GOES-13 was retired on January 8, 2018. GOES-16 is positioned as GOES-east with a significantly different data feed. The Geostationary Operational Environmental Satellite (GOES) Product Generation System (GPGS) does not function with the new data feed.
  - Working with the Short-term Prediction, Research, and Transition Center (SPoRT) to resolve this issue.
  - We are evaluating NOAA operational products for possible use. Due to the poor quality of NOAA products, GPGS products were used in the past.
- Skin temperature assimilation for the summer of 2012 not satisfactory.
- There seems to be a need for expert support after the end of the project in order to have a sustainable use of satellite data in the operational use of DST.
  - There have been frequent requests for support with respect to the data, tools for processing the data (EPA, DNR, TCEQ), issues during the operational use of DST (TCEQ).

Satellite-derived PAR substantially reduced isoprene emission estimates during DISCOVER-AQ period and improved ozone predictions

Zhang, Rui, Alexander Cohan, Arastoo Pour Biazar, Daniel S. Cohan, (2017): Source apportionment of biogenic contributions to ozone formation over the United States, Atmospheric Environment, Volume 164, 2017, Pages 8-19, ISSN 1352-2310, http://dx.doi.org/10.1016/j.atmosenv.2017.05.044. (http://www.sciencedirect.com/science/article/pii/S1352231017303564)
Zhang, Rui, Andrew White, Arastoo Pour Biazar, Richard T. Mcnider, and Daniel S. Cohan (2017): Incorporating GOES satellite photosynthetically active radiation (PAR) retrievals to improve biogenic emission estimates in Texas. (JGR Atmosphere, submitted)



Domain-wide sum of estimated isoprene (ISOP) and monoterpene (TERP) emission strength over Texas area using different PAR inputs in MEGAN during September 2013.



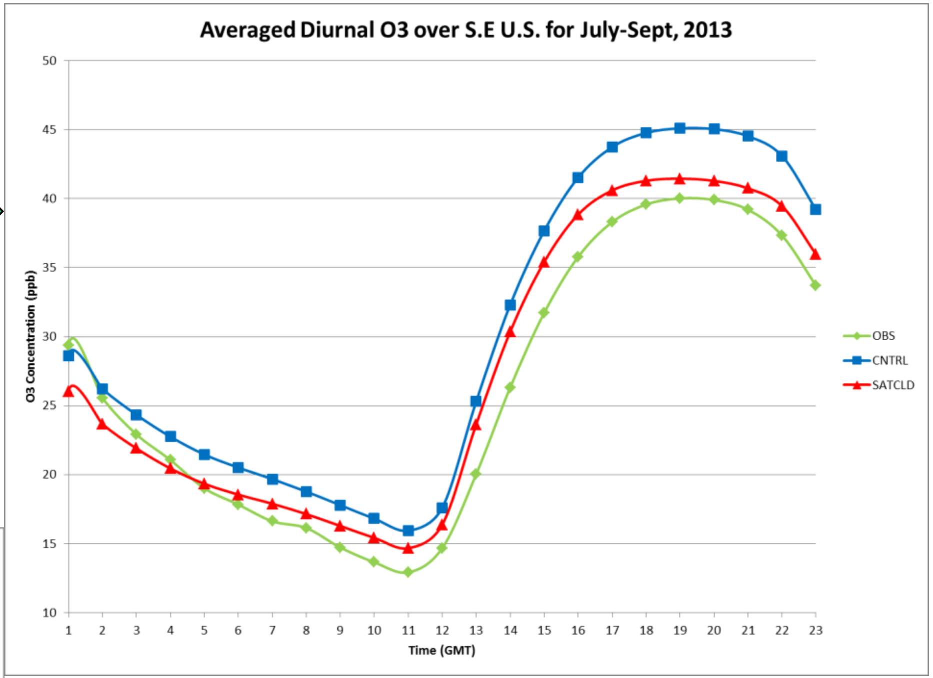
Comparison of the spatial pattern of estimated average isoprene and ozone concentrations for different PAR inputs during September 2013.

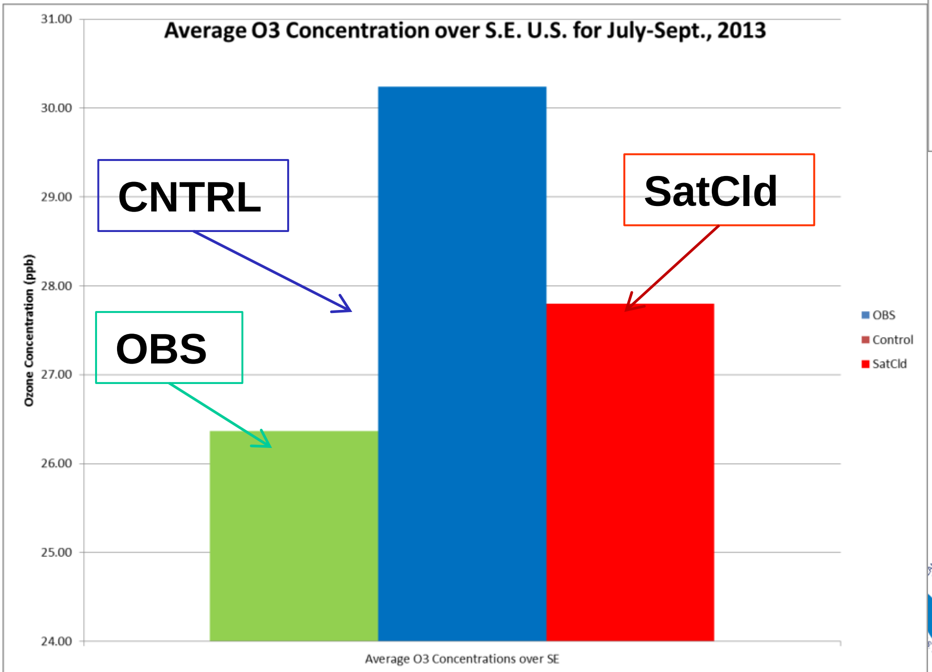
Case	OBS_AVE (ppbV)	SIM_AVE (ppbV)	IA	R	RMSE (ppbV)	MB (ppbV)	MAGE (ppbV)	NMB (%)	NME (%)
cntrl	0.23	0.59	0.37	0.36	0.69	0.39	0.49	292	326
analytical	0.23	0.61	0.37	0.37	0.72	0.42	0.51	311	342
UAHPAR	0.23	0.47	0.41	0.40	0.69	0.29	0.41	225	271

Statistics for model isoprene predictions for three cases over 18 TCEQ CAMS sites.

The Impact of Cloud assimilation is Comparable to the Use of Satellite-derived PAR

Significant daytime improvement for O3 over S.E. U.S. during summer of 2013.



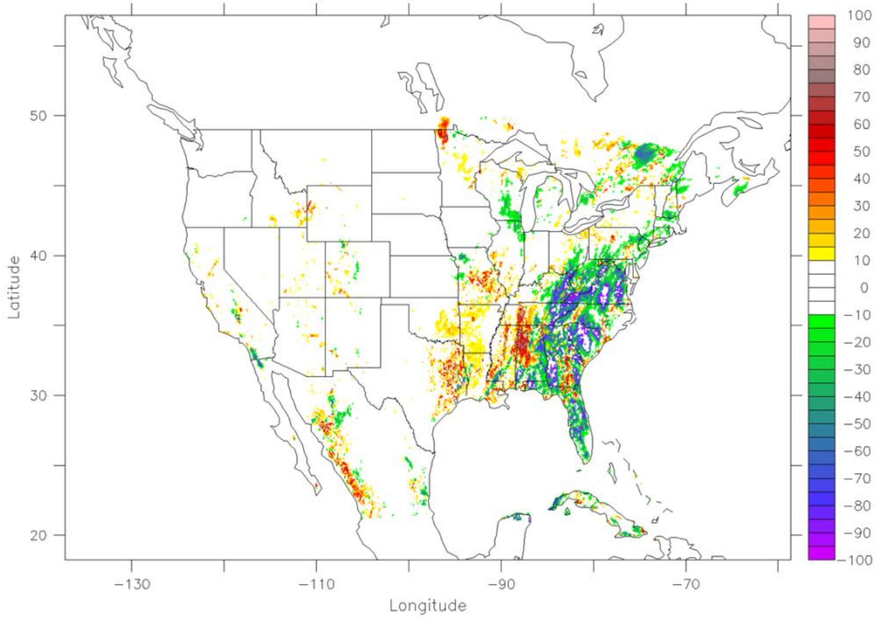


63% reduction in bias for ozone over the S.E.

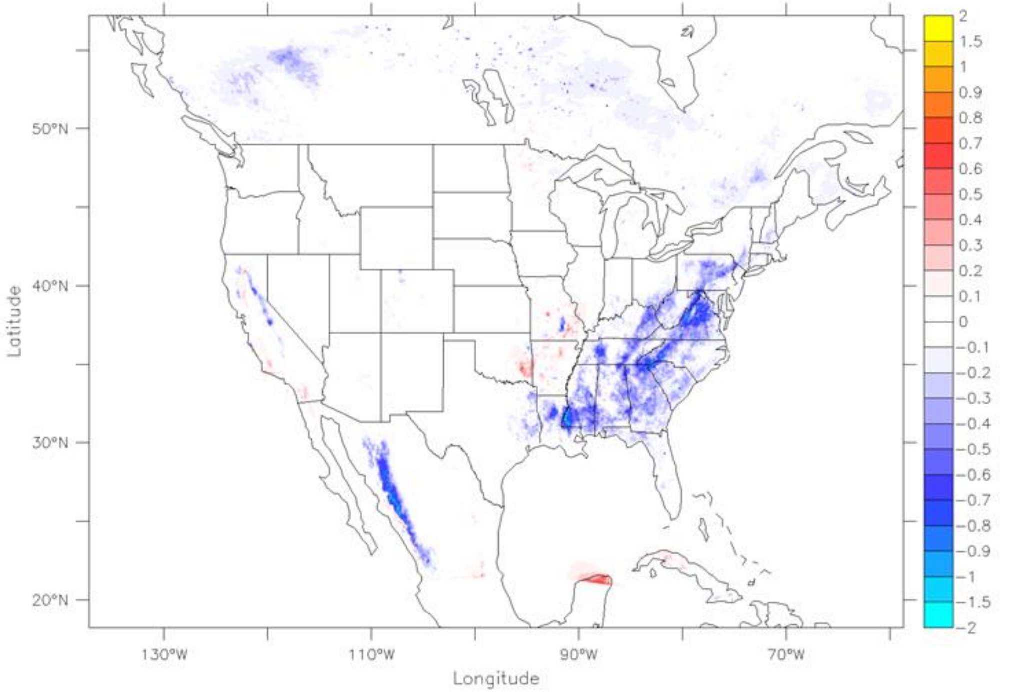
Impact on 2013 Photochemical Simulations

- Cloud-assimilation produces patterns similar to the simulations using Satellite-derived PAR.
- Reduced photolysis rates, as well as reduced isoprene emission is responsible for this improvement.
- Isoprene concentration over eastern U.S. by about .5-1 ppb (averaged over Jul-Aug-Sept)

Difference in Isoprene Emissions (g/s) at 20 GMT on July 4, 2013
(CldAssim - Control)



Difference in Isoprene Concentration (ppb)
Averaged over July-August-September, 2013
(CldAssim - Control)



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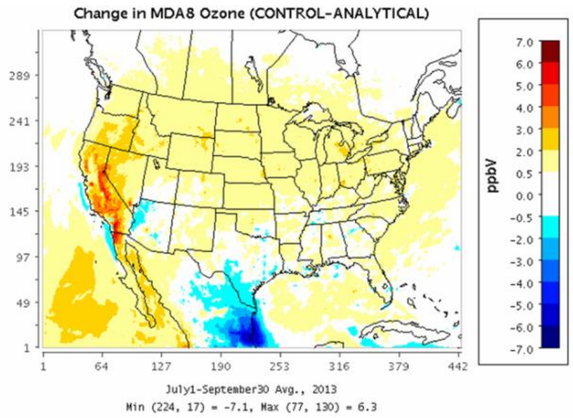
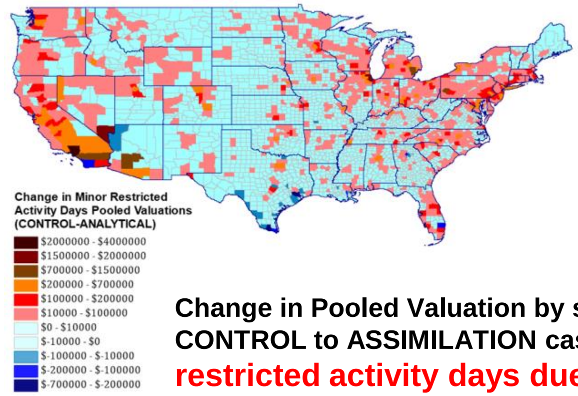
ECOINOMIC IMPACT ASSESSMENT: Valuation of Up to $110,000,000

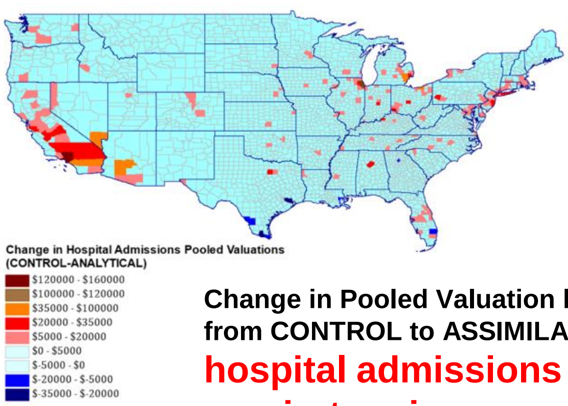
Given the fact that the baseline simulation represents the best AQ simulation used in a SIP study, the amount of improvement in baseline is the least expected reduction in uncertainty.



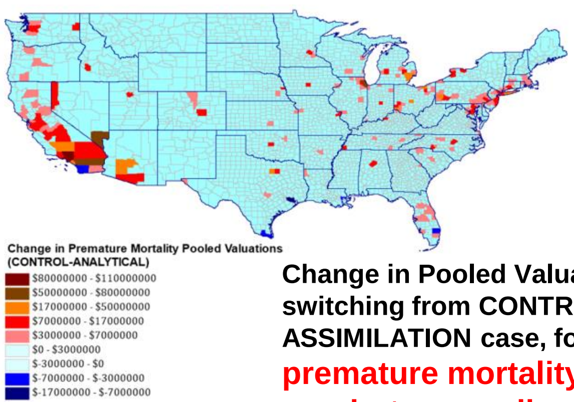
CONTROL-ASSIMILATION daily max 8 hourly ozone difference averaged over July-Sept., 2013



Change in Pooled Valuation by switching from CONTROL to ASSIMILATION case, for minor restricted activity days due to acute respiratory symptoms caused by MDA8 O_3 exposure



Change in Pooled Valuation by switching from CONTROL to ASSIMILATION case, for hospital admissions due to respiratory issues (including chronic lung ailments, Pneumonia and asthma) caused by MDA8 O_3 exposure



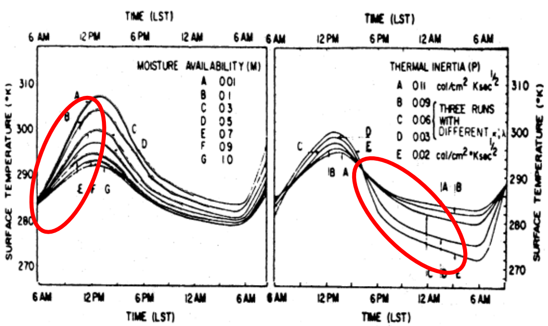
Change in Pooled Valuation by switching from CONTROL to ASSIMILATION case, for premature mortality due to respiratory cardio-pulmonary and cardio–vascular issues caused by MDA8 O_3 exposure

IMPROVING BOUNDARY LAYER REPRESENTATION

The main component of this part of the project was Satellite-derived skin-temperature assimilation

Employing a two-stream but still simple model based on the Pleim-Xiu scheme in WRF that uses satellite skin temperature to correct fundamental physical properties such as soil moisture and heat capacity.

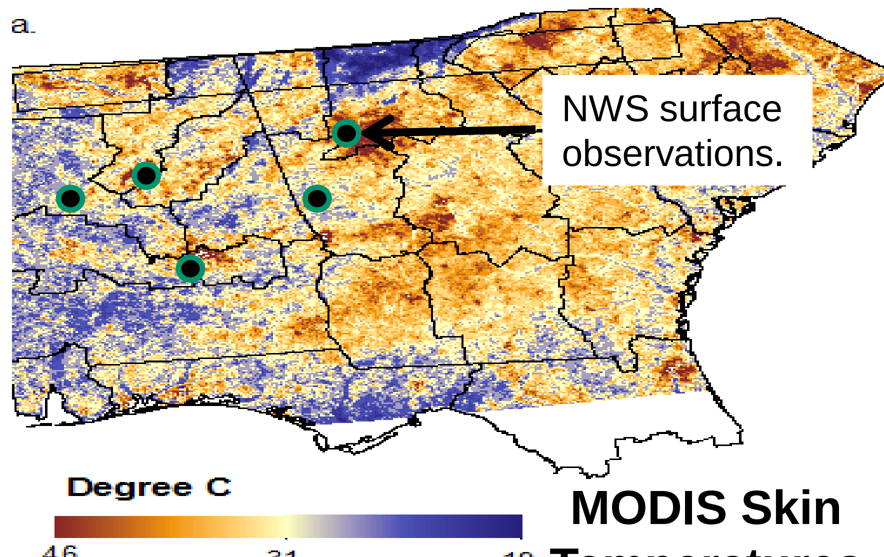
Moisture Availability



Thermal Inertia

Taken from Carlson (1986) to demonstrate the sensitivity of the surface energy budget model. Each panel represents the sensitivity of the simulated LST to uncertainty in a given parameter

Pleim-Xiu scheme uses a nudging strategy only where NWS or surface observations exist. Thus, it may miss some temperature changes due to land surface variation.

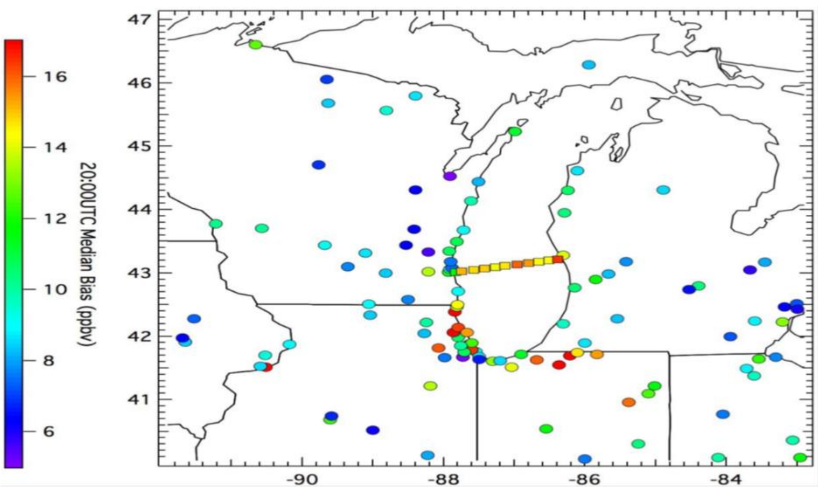


MODIS Skin Temperatures

USING SATELLITE-DERIVED Skin-T in Pleim-Xiu SCHEME

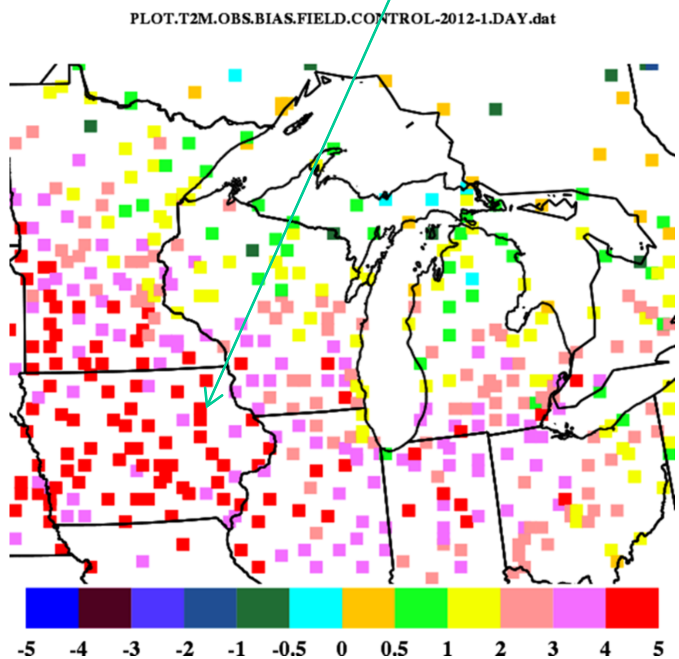
The technique was tested in simulations for summers of 2009, 2012, and 2013

Cleary et al., 2009, showed that NOAA air quality forecasts greatly overestimate ozone over Lake Michigan



Spatial plot of NOAA CMAQ bias in the Lake Michigan region showing over-prediction along the ferry plot (from Cleary et al. 2015) compared to land sites.

Note warm bias in temperature especially in Corn Belt (summer 2012)



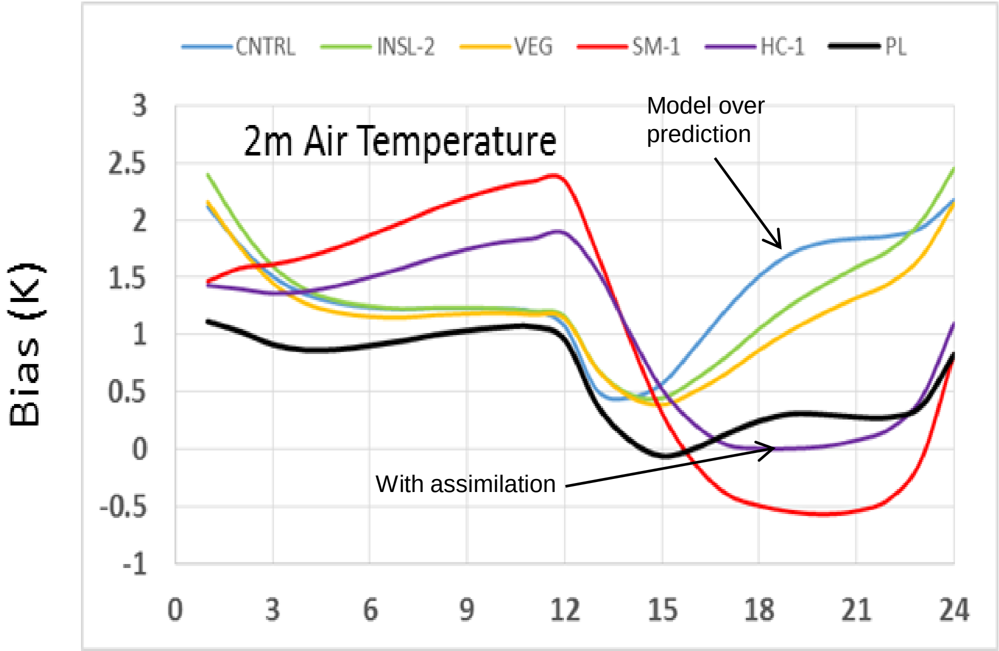
Spatial plot of control 2m temperature bias (Control – Observations) for August 2012 daytime hours. Note large warm bias across most of the region, especially the Corn Belt.

USING SATELLITE-DERIVED Skin-T in Pleim-Xiu SCHEME

Daytime temperature is critical in air quality. Higher temperatures can produce longer chemical chain lengths producing steeper ozone/NOy curves through thermal decomposition of nitrogen species.

Temperatures also impact both biogenic and evaporative emissions.

In the Midwest in 2012 and 2013 during drought conditions land use schemes produced soil moisture values that were far too dry. This led to temperatures that were too warm and a model atmosphere with too few clouds. It appears that current land use schemes perform well as long as they are forced by precipitation but become far too dry during drought conditions (Ukkola, 2016 Env. Res. Letters).



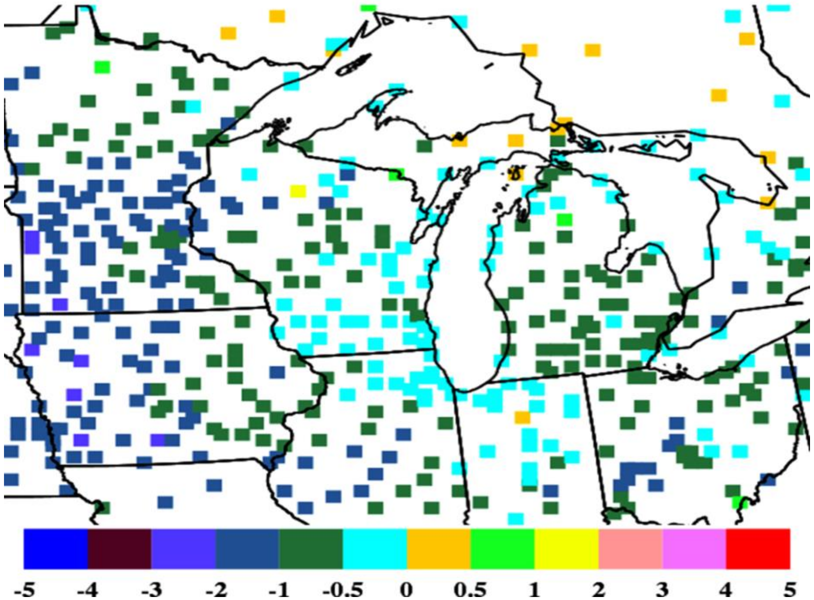
Successive cumulative levels of satellite data (insolation (INSL-1), vegetation (VEG), soil moisture (SM-1) and heat capacity adjustment HC-1) reduce daytime temperature bias for September 2013. The Pleim-Xiu scheme with moisture nudging (PL) also reduces bias.

In summary the satellite technique HC-1 (McNider et al.) or surface nudging PL (Pleim-Xiu) are needed to control temperature error in the Midwest

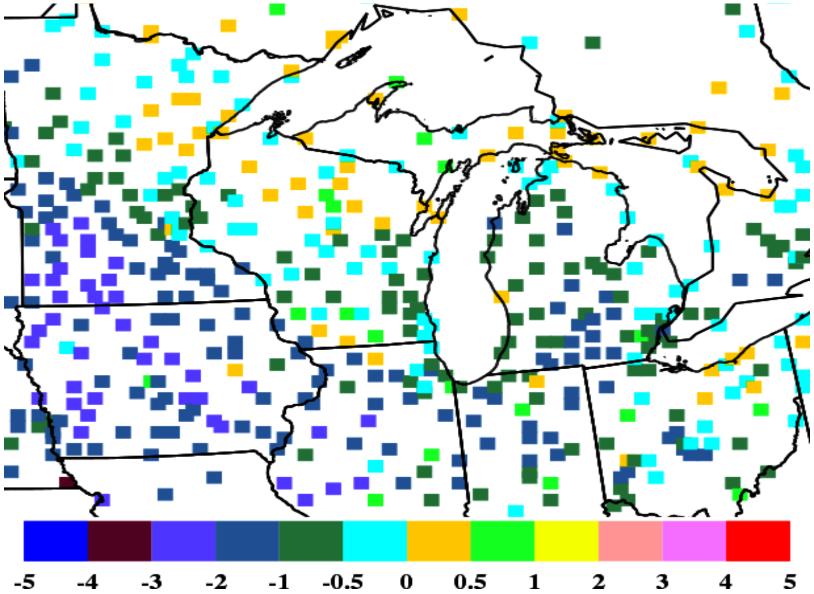
USING SATELLITE-DERIVED Skin-T in Pleim-Xiu SCHEME

Improvement in temperature bias:
Negative values indicate improvement.

Spatial plot of impact on 2m temperature at NWS sites due to satellite assimilation. Plot shows the difference in magnitude of the bias between the control run and the assimilation run for daytime hours.



2012 assimilation case: soil moisture nudging run (SM) for daytime hours.



2013 assimilation case: heat capacity run (HC) for daytime hours.

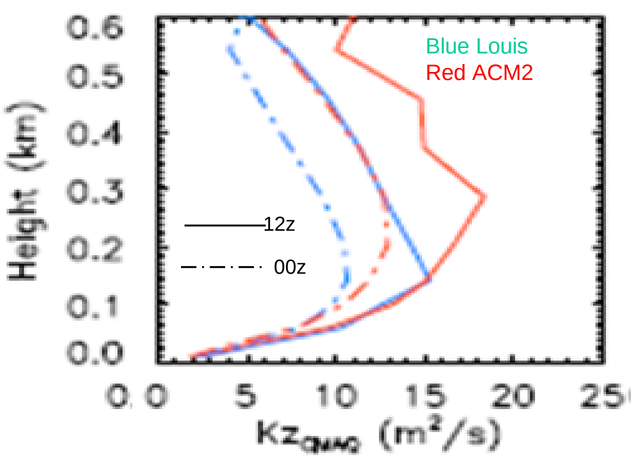
Note the HC case includes insolation, vegetation and soil moisture and heat capacity adjustments. Values truncated to the range ± 5 K.

CONCLUSION FROM GREAT LAKE STUDY

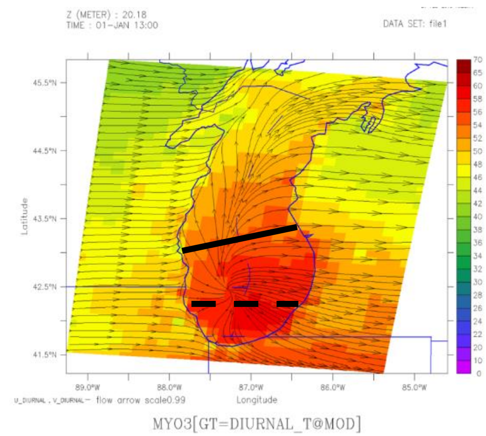
Hypothesis: The Over-prediction of Ozone in CMAQ Compared to Ferry Data Was Due to Too Much Mixing in the Meteorological Model

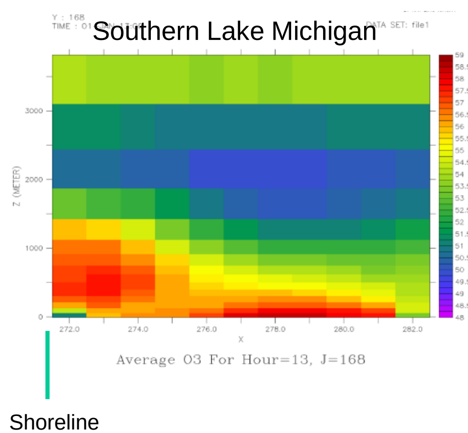
The original thinking that too much mixing in CMAQ transported elevated ozone aloft to the lake surface was incorrect. CMAQ sensitivity simulations indicated that **too much mixing** in the meteorological model causes **less mixing** in CMAQ. Since in the CMAQ model the mixing coefficients are re-diagnosed from the wind, temperature profiles, and friction velocities passed from the meteorological model, reducing vertical gradients as the result of mixing in the meteorological model, reduces the recalculated mixing coefficients.

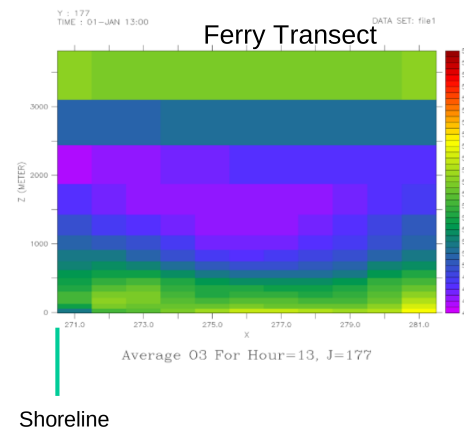
The re-diagnosed mixing coefficients in CMAQ were smaller for the Louis run than in the ACM2/Control.



The over-prediction in NAM/CMAQ 2009 was likely partly due to too much mixing in NAM which, ironically, led to too little mixing in CMAQ







Surprising results of this study have important implications on how mixing is carried out in offline chemical models.

ACRONYMS

ALEXI	THE ATMOSPHERE-LAND EXCHANGE INVERSE MODEL
CMAQ	EPA's Community Multiscale Air Quality (CMAQ) Model
CMAS	Community Modeling and Analysis System
EPA	Environmental Protection Agency
LNOx	Lightning Generated Nitrogen Oxides
MEGAN	Model of Emissions of Gases and Aerosols from Nature
NAAQS	National Ambient Air Quality Standard
NASA	National Aeronautics and Space Administration
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality

Thank You