Use of Remote Sensing Data to Improve Air Quality Decision Support Systems Used to Protect Public Health

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5. California Air Resources Board (CARB)
6. Texas Commission on Environmental Quality (TCEQ)
7. Georgia Environmental Protection Division (Georgia-EPD)
8. U.S. Environmental Protection Agency (USEPA)

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PROJECT INFORMATION

TOPIC: **Use of Remote Sensing Data to improve Air Quality Decision Support Systems Used to Protect Public Health**

POP: 8/24/2018 - 8/23/2021 (ROSES17-A.39)
(New Project – First Year Report)

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Partners: California Air Resources Board (CARB), USEPA, Texas Commission on Environmental Quality (TCEQ), Georgia Environmental Protection Division (GA-EPD), The Lake Michigan Air Directors Consortium (LADCO - representing states of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin).

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

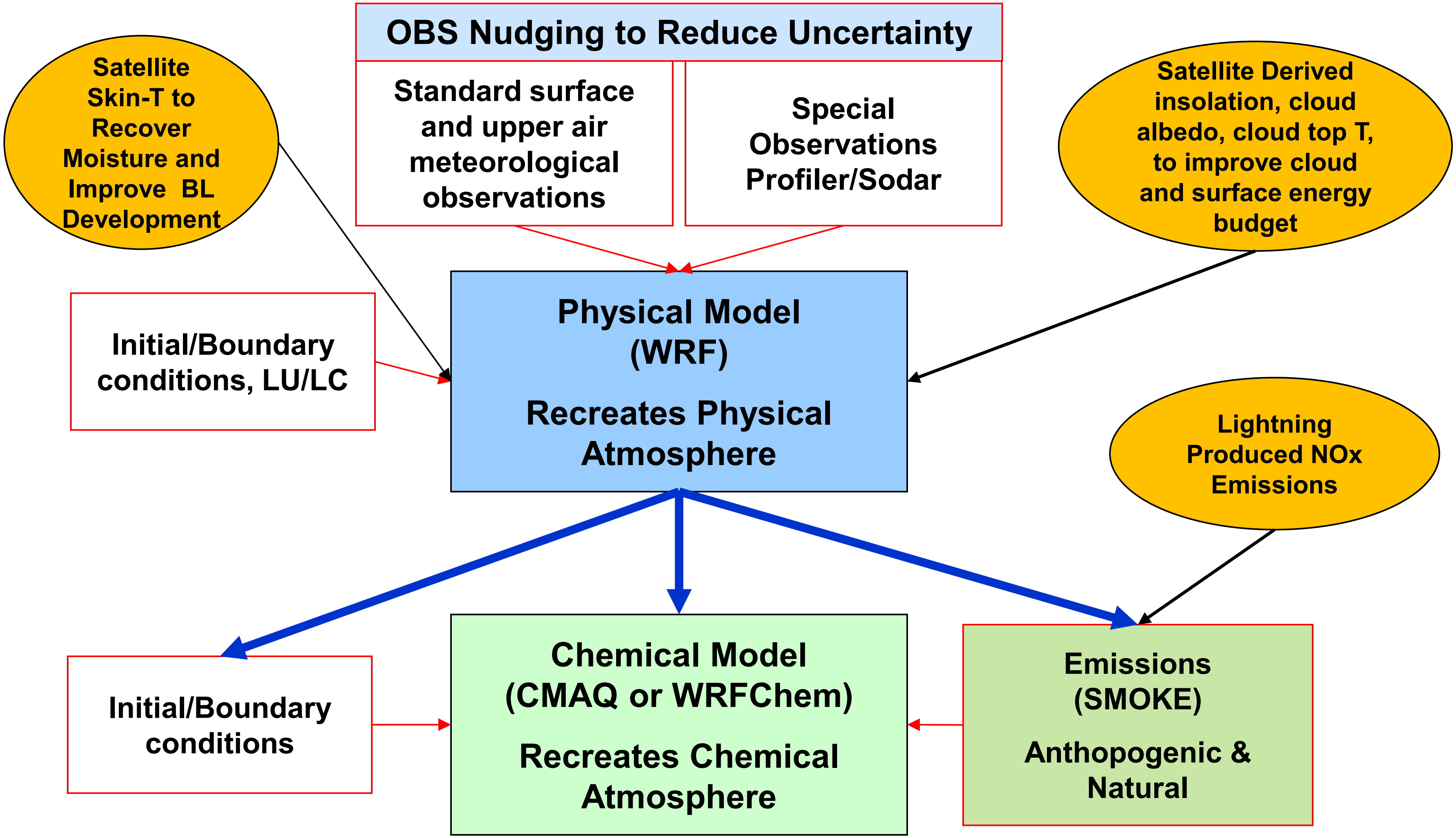
- Air quality regulatory agencies' mission is to maintain a healthy air by meeting the National Ambient Air Quality Standard (NAAQS) for criteria pollutants.

- 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 (billions of dollars in cumulative costs).

- 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.

Contribution of This Project in Reducing Simulation Uncertainties



Satellite Skin-T to Recover Moisture and Improve BL Development

OBS Nudging to Reduce Uncertainty

Standard surface and upper air meteorological observations

Special Observations Profiler/Sodar

Satellite Derived insolation, cloud albedo, cloud top T, to improve cloud and surface energy budget

Initial/Boundary conditions, LU/LC

Physical Model (WRF)

Recreates Physical Atmosphere

Lightning Produced NOx Emissions

Initial/Boundary conditions

Chemical Model (CMAQ or WRFChem)

Recreates Chemical Atmosphere

Emissions (SMOKE)

Anthopogenic & Natural

TCEQ California Air Resources Board Georgia NASA LADCO NSSTC The University of Alabama in Huntsville

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

Upgrading Data Generation and Archiving System

- **Upgrading GOES Product Generation System (GPGS):** Collaborating with the NASA's the Short-term Prediction Research and Transition (SPoRT) Center, GPGS is being recoded to process GOES-16, 17, data.

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.
- **Improving Model Cloud Field:** Assimilating satellite observed clouds in WRF.

Improving Emission Estimates in AQ Model

- **Utilization of Satellite Derived Lightning Generated NO (LNOx) Emissions:** This activity utilizes newly available lightning optical energy from the Geostationary Lightning Mapper (GLM) to produce lightning-generated NO emissions input for air quality models.

ARL PROGRESS

Improving Physical Atmosphere			
	FY19	**FY20**	**FY21**
Starting ARL	**2**	**4**	
Ending ARL	**4**		

ARL 4: Initial Integration & Verification (Prototype/Plan)

- 1) Components of eventual application system brought together and technical integration issues worked out:

  The new Cloud Assimilation System (CAS) was integrated in WRF and tested for the summer of 2013 simulations. A preliminary simulation for our baseline period of 2016 were performed.

- 2) Organizational challenges and human process issues identified and managed

  We are holding monthly conference calls with our stakeholders to communicate our efforts and get their feedback as how this project is helping them in their SIP modeling activities. Each region faces a different challenge. However, summer of 2016 was identified as the period of interest. Modeling configurations were shared and the personnel for carrying out the simulations were identified.

ARL PROGRESS

Improving LNOx Emission Estimates

	FY19	FY20	FY21
Starting ARL	2	3	
Ending ARL	3		

ARL 3: PROOF OF APPLICATION CONCEPT (VIABILITY ESTABLISHED).

- 1) Components of your application have been tested & validated independently:
  - LNOx emissions based on GOES-16 lightning observations were estimated. The complete evaluation of this product requires estimating LNOx over a much longer period (e.g., 1 year). Such analysis may result in additional adjustment in the formulation used for the estimates. Since the data from GOES-16 is only available since 2018, and is more reliable for 2019, the full impact on air quality simulations requires additional air quality simulations for later dates. Thus, the impact of this component of research will be fully realized later in this project.
- 2) Detailed characterization of user decision-making process has been completed (e.g., pre-application baseline performance, mechanisms, and limitations):
  - Baseline performance for 2016 is being performed. WRFChem simulations for 2016 over-predicted ozone for most of the domain.
- 3) A convincing case for the viability of your application concept has been made.
  - Previous case studies demonstrated that inclusion of accurate LNOx emissions improved air quality simulations.

Stakeholder Involvement/Interaction

- Holding monthly web meeting with stakeholders to update them about the progress of our efforts, get feedback, and learn about their issues that can be addressed by remote sensing data.
- Participants are: The Lake Michigan Air Directors Consortium (LADCO) representing states of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin; California Air Resources Board (CARB), USEPA, Texas Commission on Environmental Quality (TCEQ), Georgia Environmental Protection Division (GA-EPD).
- All the participants expressed interest in modeling the summer of 2016. California also interested in other years.
- Since they are using different model configurations, it was decided for UAH to use USEPA's configuration.
- UAH was asked to test the impact of different configurations on the CAS and surface flux adjustment performance.

LNOx Calculation Directly from Flash Optical Energy

$\mathrm{LNO_x}$ Production P in moles:

In collaboration with Bill Koshak

$$P = \left[\frac{Y}{N_A}\right] E = \left[\frac{Y}{\beta N_A}\right] Q\ , \qquad Q \text{ in Joules}$$

$Y \sim 10^{17}\ molecules\ J^{-1}$ (Thermochemical Yield)

$N_A = 6.022 \times 10^{23}\ molecules\ mol^{-1}$ (Avogadro's Number)

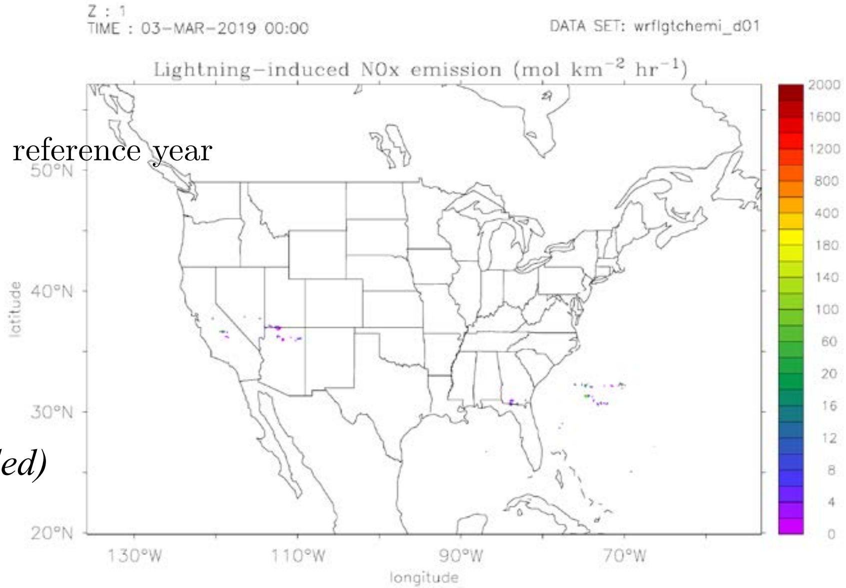
$\beta \sim 1.35997 \times 10^{-22} \Rightarrow$ ave $P = 250$ moles/flash over 1st 10 mo of 2018 reference year

Flash Energy E when $P = 250$ moles is:

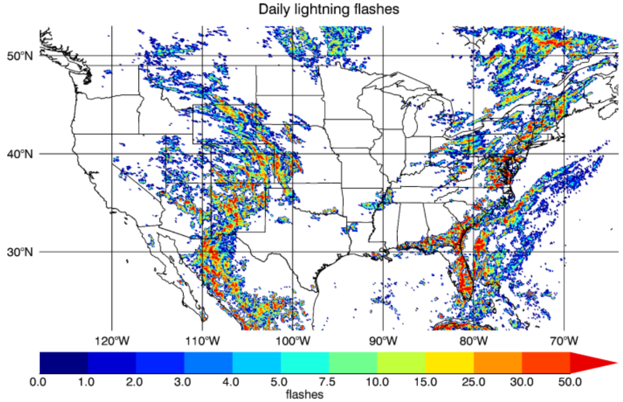
$$E = \frac{N_A P}{Y} = 1,505,500,000\ J \sim 1.5\ GJ$$

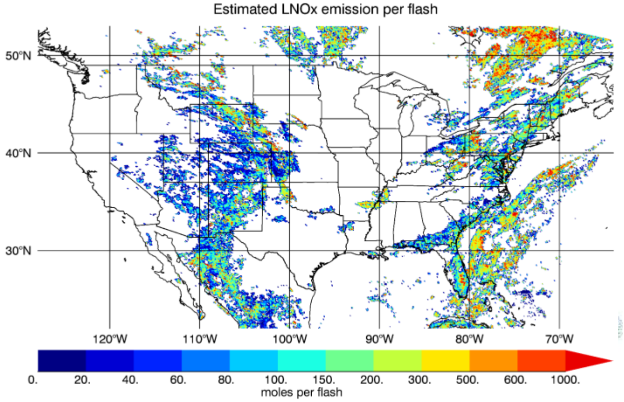
$Q_{ave} = 300\ fJ = 3\text{x}10^{-13}\ J$ *(what satellite measures)*

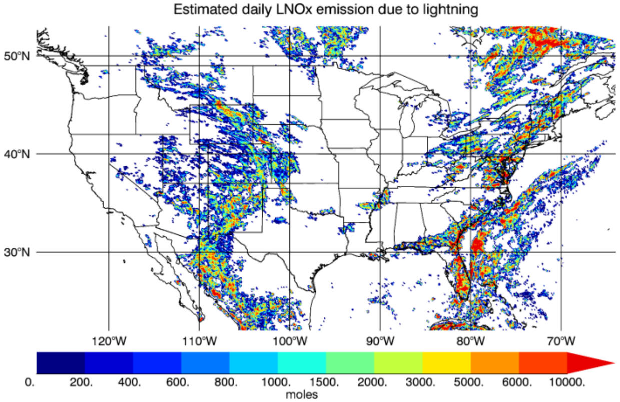
$E/Q = (1.5\text{x}10^{9})/(3\text{x}10^{-13}) = 0.5\text{x}10^{22}$ *(magnitude of scaling needed)*



β=2.68577×10^{-22} *(based on average 250 moles/flash was used in the following estimates)*

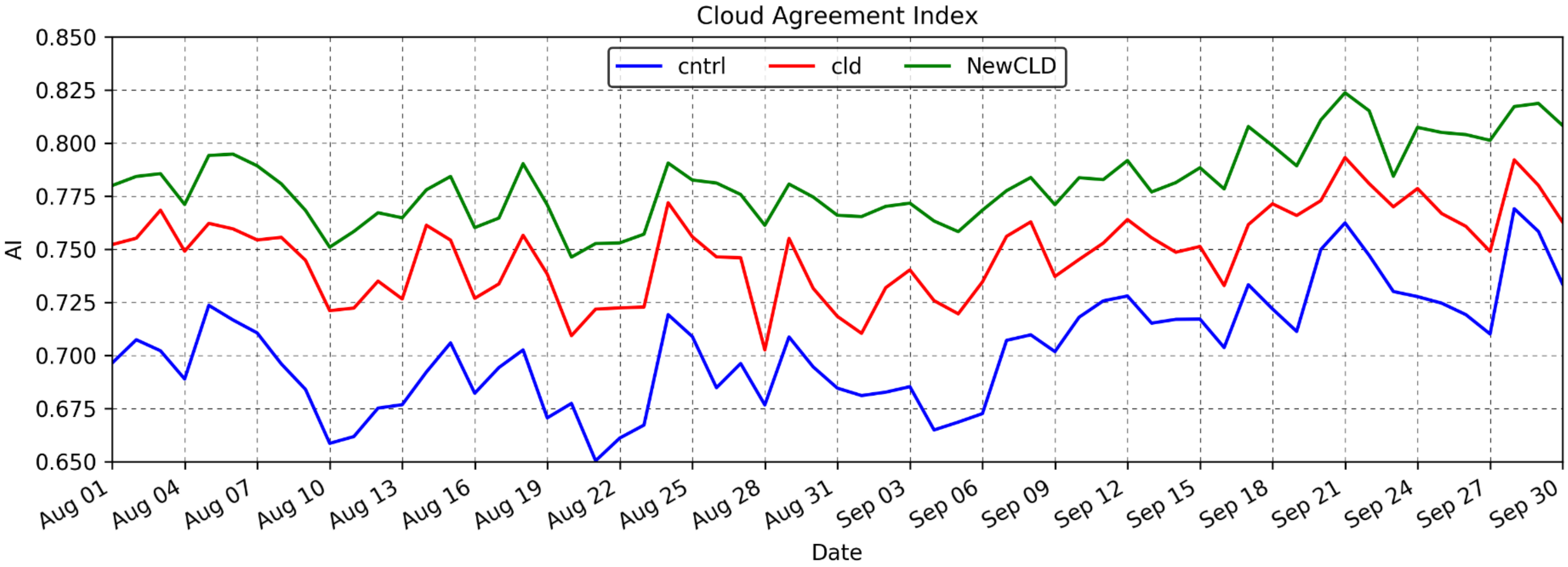

Daily lightning flashes


Estimated LNOx emission per flash


Estimated daily LNOx emission due to lightning

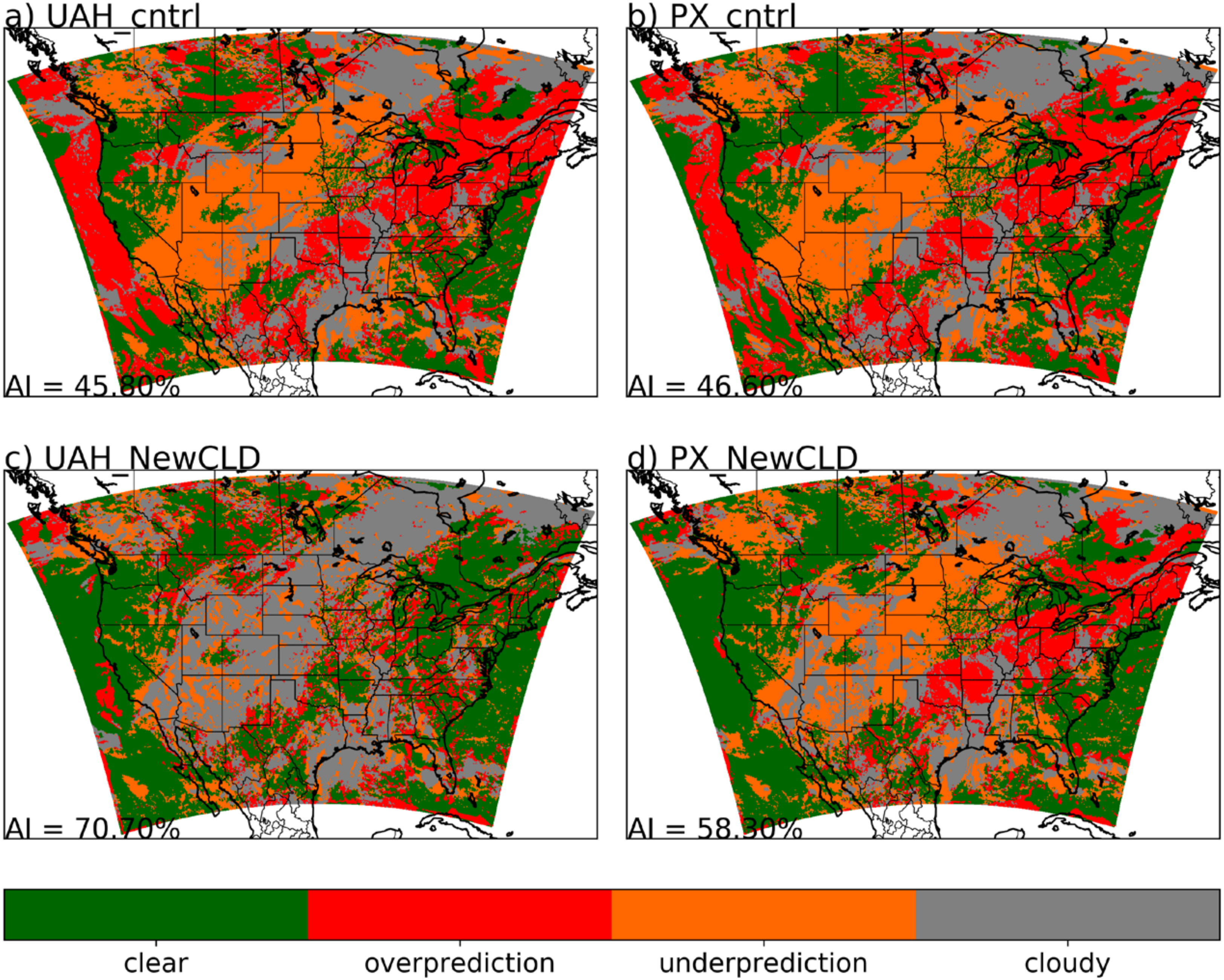
Improved Cloud Assimilation System (CAS)

- Previous 2006 and 2013 simulations were based on performing 1) a control simulation for the entire period; 2) identifying model cloud errors for the entire period; and 3) estimating the correction needed to the wind field and adjust the model dynamics accordingly.
- New improvements to the technique considers model response to cloud correction when identifying model cloud errors.



Cloud Agreement Index August-September 2013

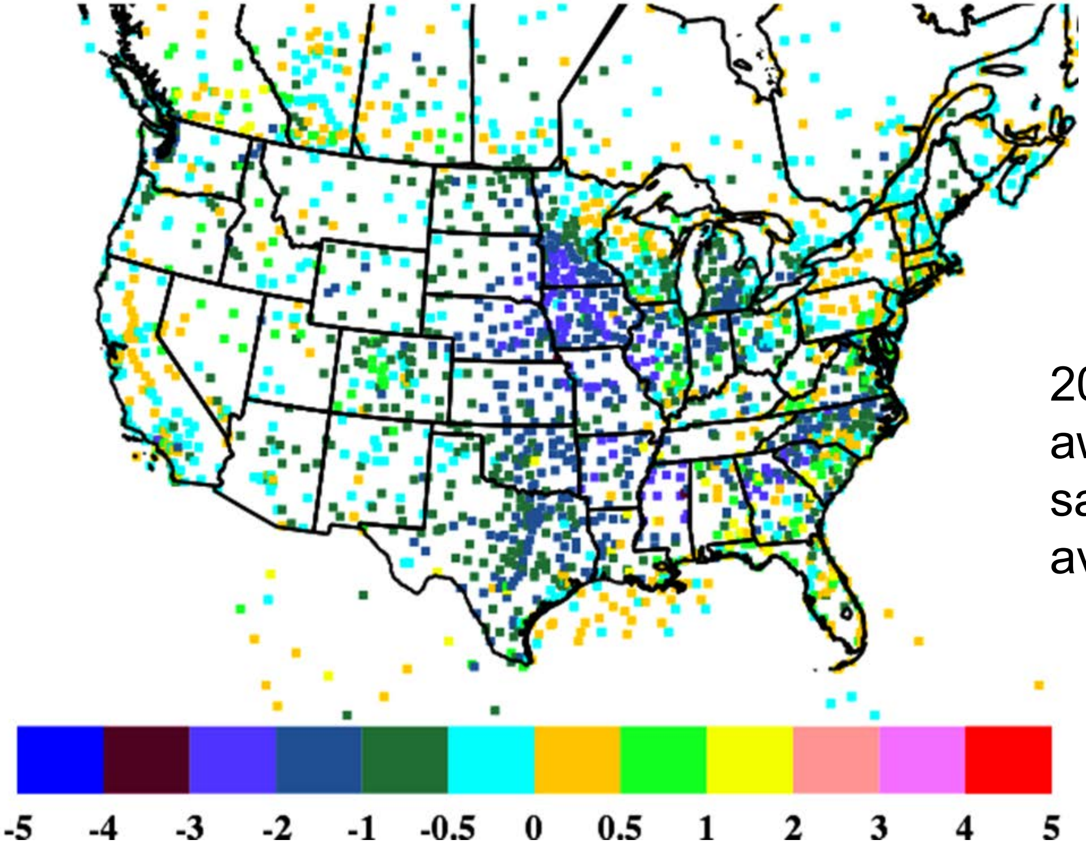
Snapshot For August 14, 2016, at 20:00 GMT



Skin Temperature Assimilation (Surface Moisture Adjustment)

- The technique uses satellite observed surface temperature changes in the morning to improve surface moisture (and thus estimates of evapotranspiration) and temperature changes in the afternoon to improve surface heat capacity and thus surface thermal inertia.

Results from Implementation in WRF using Pleim-Xu Option

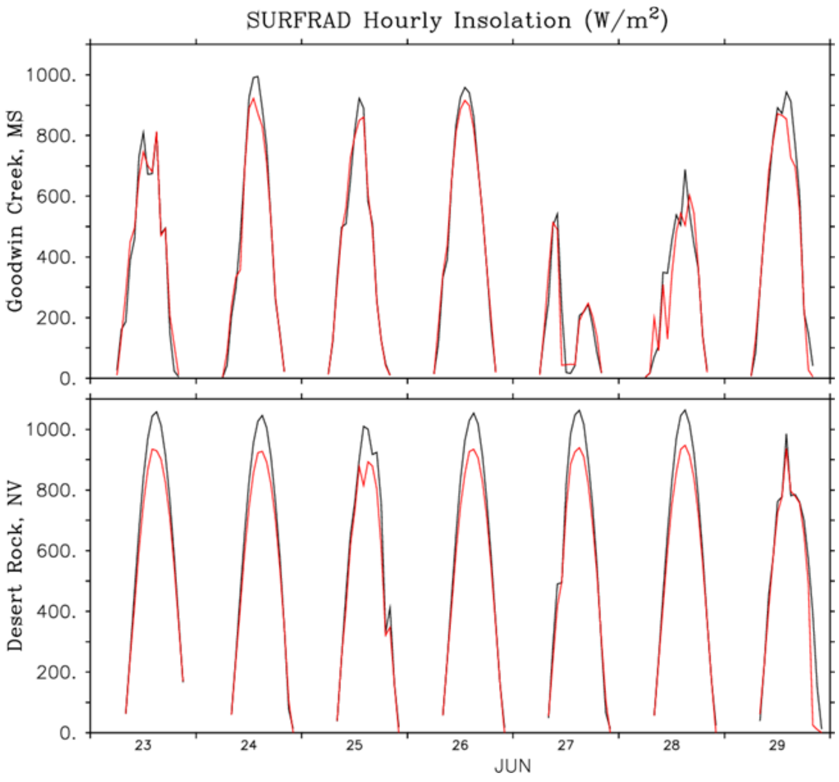


2016 simulation awaiting satellite data availability.

Difference in the magnitudes of bias values (units of degrees K) of 2-m temperatures for the period 1-30 September 2013 for daytime conditions between the simulation with satellite-skin_T assimilation and CNTRL. ***Negative values indicate improvement.***

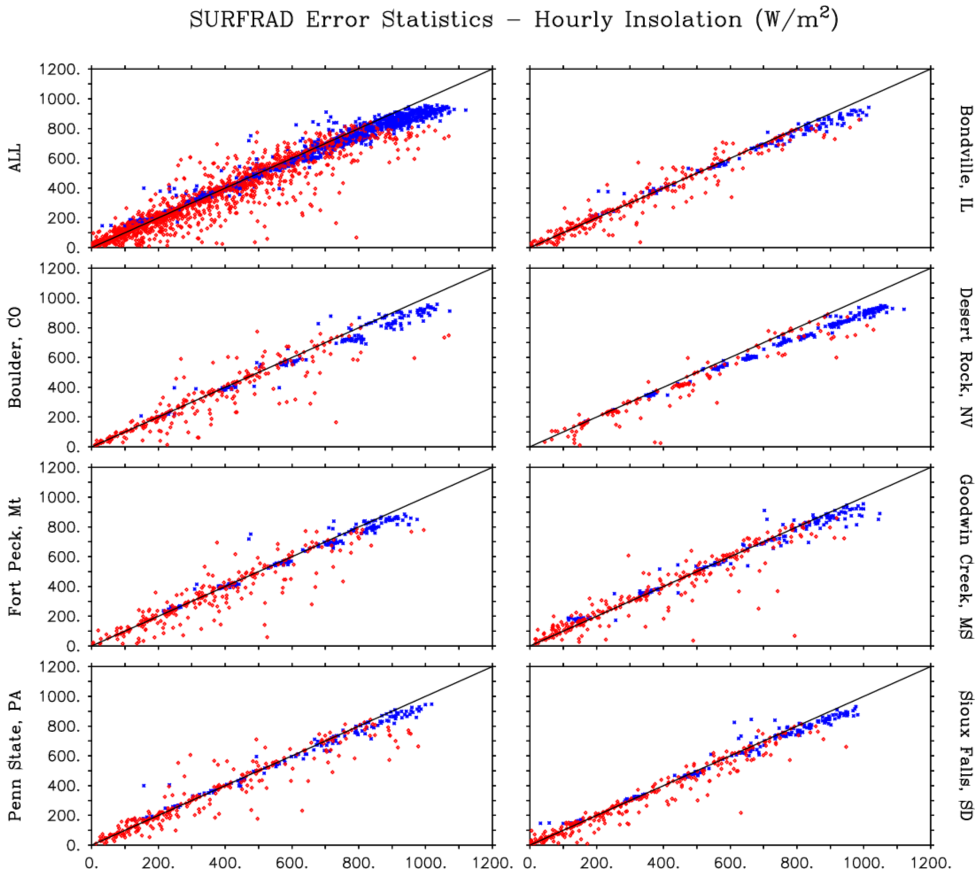
GOES-16 Insolation Product Against SURFRAD Observations

Compared to all 7 SURFRAD pyranometer observations insolation retrievals are underestimated near solar noon. BLUE is for clear sky and RED for cloudy.



SURFRAD Hourly Insolation (W/m^2)

SURFRAD and GOES insolation at MS and NV stations. Underestimation is smaller in the east and larger at west.



SURFRAD Error Statistics – Hourly Insolation (W/m^2)

SCHEDULE / MILESTONES

Major Tasks	FY19	FY20	FY21
Retooling retrieval software for GOES-16 Advanced Baseline Imager (ABI)	🟩 New insolation retrieval code completed	🟨 Testing & evaluation	🟥 Reprocessing to fill the archive
GOES Skin-T retrieval (SPoRT)	🟨 Work has started, 2016 being priority	🟥 Testing & evaluation	🟥 Reprocessing to fill the archive
New Cloud Assimilation System	🟩 Software were revised and tested	🟨 Performing simulation for the summer of 2016	🟥 Test and evaluation with GOES16 products
LNOx Emission Estimates Using GLM obs.	🟩 Lightning NOx (LNOx) algorithm development	🟨 Testing & evaluation within AQ models	🟥 Realtime generation to be added to GPGS
Testing skin-T assimilation over regions of interest		🟥 2016 simulations using moisture adjustment (California)	🟥 Impact of moisture adjustment for eastern U.S.
Benchmarking (multiple activities)	🟩 Performing simulations for 2016, testing CAS	🟥 Performing simulations for 2016, testing LNOx emissions	🟥 Performing Benchmarking soil moisture adjustment
Transition (LADCO, TCEQ, G-EPD, …)		🟥 2016 SIP simulations	🟥
Initial health and economic impact analysis		🟥 Using BenMAP	🟥

Completed 🟩

Ongoing 🟨

Future 🟥

RISKS & CHALLENGES

- Partner organizations have different priorities and expectations from this project.
    - We are trying to adjust our priorities, so that we can deliver and satisfy their immediate concerns. E.g., focusing on CAS to address the issues in the east (less important in California).
- There are issues with GLM data (stripes in flash energy) that are being pursued by the science team.
    - LNOx will not be of immediate use to our partner organizations and we will be able to address this issue in the following years.
- CAS does not perform as well with PX/ACM2 option (that is of interest to USEPA).
    - UAH was able to resolve part of the compatibility problem that was due to land/water mask, but still investigating other aspects.
- The data from new insolation retrieval system is not satisfactory.
    - We are still investigating the cause of noontime underestimation and sunrise/sunset overestimation.

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

THE UNIVERSITY OF
ALABAMA IN HUNTSVILLE