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

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


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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.
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 Representation of 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.
<table>
<thead>
<tr>
<th>Major Tasks</th>
<th>FY19</th>
<th>FY20</th>
<th>FY21</th>
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<tbody>
<tr>
<td>Retooling retrieval software for GOES-16 Advanced Baseline Imager (ABI)</td>
<td>New insolation retrieval code completed</td>
<td>Testing &amp; evaluation</td>
<td>Reprocessing to fill the archive</td>
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<tr>
<td>GOES Skin-T retrieval (SPoRT)</td>
<td>Work has started, 2016 being priority</td>
<td>Testing &amp; evaluation</td>
<td>Reprocessing to fill the archive</td>
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<tr>
<td>New Cloud Assimilation System</td>
<td>Software were revised and tested</td>
<td>Performing simulation for the summer of 2016</td>
<td>Test and evaluation with GOES16 products</td>
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<tr>
<td>LNOx Emission Estimates Using GLM obs.</td>
<td>Lightning NOx (LNOx) algorithm development</td>
<td>Testing &amp; evaluation within AQ models</td>
<td>Realtime generation to be added to GPGS (Revised)</td>
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<tr>
<td>Testing skin-T assimilation over regions of interest</td>
<td>2016 simulations using moisture adjustment (California)</td>
<td>Impact of moisture adjustment for eastern U.S.</td>
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<td>Benchmarking (multiple activities)</td>
<td>Performing simulations for 2016, testing CAS</td>
<td>Performing simulations for 2016, testing LNOx emissions</td>
<td>Performing Benchmarking soil moisture adjustment</td>
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<td>Transition (LADCO, TCEQ, G-EPD, ...)</td>
<td>2016 SIP simulations</td>
<td>Coordinating with EPA and GAEPD</td>
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<td>Initial health and economic impact analysis</td>
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<td>Using BenMAP</td>
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Monthly meetings with our partner organizations have been useful.

Atlanta results generated interest. We were invited to make a presentation for other regulatory agencies.

Working with EPA to transition tools related to LNOx work.

Working with GAEPD to transition tools related to cloud assimilation work.

Have already provided data and relevant computer codes for model evaluation to LADCO.
Same as last year, the major challenges are due to the restricted working conditions under the pandemic. Our NASA partners at NSSTC are still working virtually.

Disparity in the definition of a “lightning flash” for GLM vs NLDN, combined with recent changes in NLDN classification of a cloud-to-ground flash, and GLM upgrades are introducing new challenges for validation efforts. This has delayed the benchmarking for LNOx work.

Availability and quality of insolation retrievals is still a concern. We are still examining the use of COD as a possible option to replace insolation in CAS. The preliminary results haven’t been satisfactory.
Overall Objective: To Reduce the Uncertainties in Regulatory Air Quality Simulations Through the Use of NASA Science and Satellite Data Products

In SIP modeling it is imperative to reproduce the observed atmosphere. Model uncertainties translates into uncertainties in emission control strategy which has significant economic consequences.

**Fundamental Approach in Air Quality Modeling Systems**

**Physical Atmosphere**
Models: e.g. WRF, Recreates the physical atmosphere (winds, temperature, precipitation, moisture, turbulence etc) during the design period

- Clouds and microphysical processes
- Atmospheric dynamics
- Boundary layer development
- Fluxes of heat and moisture
- LSM describing land-atmosphere interactions

**Chemical Atmosphere**
Models: CMAQ, CAMx
Recreates the chemical atmosphere

- Transport and transformation of pollutants
- Heterogeneous chemistry, aerosol
- Photochemistry and oxidant formation
- Natural and anthropogenic emissions, Surface removal

Winds, temperature, BL height, Radiation, moisture, surface properties, surface fluxes, precipitation
Cloud Assimilation System (CAS) for Weather Research and Forecasting (WRF) Model
Correcting Under-Prediction

- Lift a parcel to saturation using satellite info.
- Estimate the location and thickness of the observed cloud from GOES derived cloud top temperature and cloud albedo.
- Given the estimated cloud thickness, determine the minimum height a parcel at a given model location needs to be lifted to reach saturation.

**The displacement height is used to estimate vertical velocity.**

Correcting Over-Prediction

- Create subsidence within the model to evaporate cloud droplets.
- Determine the model layer with the maximum amount of cloud liquid water (CLW) and how far it has to move to completely evaporate.
Cloud Assimilation System (CAS) Was Further Improved
White et al. 2022 (NewCLD)

Mixed results for surface statistics for wind, temperature, humidity (some improve and some degrade). Overall, no significant change.


**Significant Improvement in Surface Radiation**

Model performance with respect to USCRN pyranometers observations. (left) Mean bias absolute difference and (right) the RMSE difference between the CNTRL and NewCLD (negative indicates a reduction in bias and error when cloud assimilation is performed).

Time series comparison of surface insolation between the observation (black) and WRF simulated: CNTRL (blue), CLD (red) and NewCLD (green) at the USCRN station located near Austin, TX.

Results discussed in White et al., 2022
Impact of Cloud Assimilation on 2016 Air Quality Simulations
Improvement in ozone BIAS and RMSE (June-September 2016)

**DAYTIME**

- **BIAS**
  - Cloud Assim. – Control
- **RMSE**
  - Cloud Assim. – Control

**NIGHTTIME**

- **BIAS**
  - Cloud Assim. – Control
- **RMSE**
  - Cloud Assim. – Control
2016 Simulations for Atlanta Performed Exceptionally Well for Ozone Exceedance Days
The improvement was due to wind correction by CAS

Surface Ozone Mixing Ratio (ppb) (2016-06-10 21:00:00)

Results discussed in Cheng et al., 2022
GLM-Derived LNOx
UAH LNOx model from GLM – based on Koshak 2014

\[ P = \sum_{k=1}^{N} P_k = \beta \frac{Y}{N_A} \sum_{k=1}^{N} q_k = N \bar{P} \]

\[ \beta = \frac{N_A N \bar{P}}{Y \sum_{k=1}^{N} q_k} \]

- **Uses both GLM16 and GLM 17 (options of either or both)**
- **\( \beta \) – model approach**
- **Default \( \beta \) over 2 years of CONUS average**
- **3D emissions (options of 2D or/and 3D emissions)**
- **Empirical IC/CG LNOx vertical distribution**
- **Z-ratio (IC to CG) options (default, empirical, or against NLDN CG)**
- **Works for various grid specifications (map projections)**
- **User output specifications**
- **Parallel processing**

With \( N \) being total number of GLM flashes for 2019-2020

Detection degrades as the viewing angle increases

\( P = 250 \) moles/flash

\( \bar{P} = 6.022 \times 10^{23} \) molecules/mol (Avogadro’s number)

\( q_k = \) flash optical energy detected by GLM

\( \beta = \) scaling factor (accounting for all the uncertainties)

\( Y = 10^{17} \) molecules/J (thermo-chemical yield of NOx)
Tool is Ready and Tested, But More Analysis is Needed
Daily vs hourly – August 2020 case
Animation 8/9/2020 00:00 UTC - 8/14/2020 23:00 UTC
Thank You