Aura Chemical Reanalysis in support Air Quality Applications

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(NOAA/NESDIS)

Presented by
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Contributions from
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Solicitation – ROSES 2013 Aura Science Team

Project Summary

Utilize the Real-time Air Quality Modeling System (RAQMS) in conjunction with the NOAA Operational Gridpoint Statistical Interpolation (GSI) 3-dimensional variational data assimilation (DA) system to conduct a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements.

Project Objectives

1. Provide the air quality community with a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements.
2. Conduct regional chemical data assimilation experiments to quantify the influences in changes in NOx emissions on US air quality during the Aura period.
3. Provide global 3 dimensional O3, CH4, N2O production and loss rates for next generation NOAA global forecast system.
As of June 2, 2016

The uncosted FY15 amount due to costing/reporting from multiple entities – Cooperative Institute for Meteorological Satellite Studies (CIMSS), NESDIS Center for Satellite Applications and Research (STAR) Cooperative Research Program (CoRP)

FY16 funds were accepted by NESDIS on July 19, 2016 due to delays in MOU approval by NOAA legal but the funds will carry over until FY17. The CIMSS proposal to NESDIS has been submitted, so we should have our FY16 funding sometime in early FY17.

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As of July 16, 2015

Started at ARL 3 (Proof of Application Concept) with real-time RAQMS Data assimilation

Currently at ARL 4 (Initial Integration and Verification) based on successfully completing the RAQMS/GSI Data Denial experiments

Anticipate reaching ARL 5 (Validation in Relevant Environment) upon completion of 2010 RAQMS/GSI analysis by December 2016

Anticipate reaching ARL 6 (Demonstration in Relevant Environment) upon completion of full 2006-present RAQMS/GSI Reanalysis

Will reach ARL 7 by the end of the 3-year funding cycle with delivery of RAQMS Aura Reanalysis to DAAC.
Results and Milestones (Year 2)

- Developed approach to use RAQMS NOx emission sensitivity experiments and RAQMS/GSI OMI NO2 data assimilation adjust 2010 global Hemispheric Transport of Air Pollution (HTAP) monthly NO2 emissions
- Developed an approach to use the adjusted HTAP NO2 emissions and multiple linear regression of OMI urban NO2 trends to generate 2005-2015 global NO2 HTAP emissions
- Conducted July 2011 CMAQ NOx emissions sensitivity studies for generation of regional background error covariances and adjustment of NEI 2011 NOx emissions CMAQ/GSI OMI NO2 assimilation experiments
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Constraining 2010 HTAP NO2 emissions with RAQMS/GSI OMI NO2 data assimilation

Monthly mean \textit{NO2 Jacobians} (\(\beta=\text{normalized delta-Emissions/normalized delta-NO2}\)) are computed from the 2010 RAQMS NO2 emission perturbation experiment following (Lamsal, et al, 2012)

\[
\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.
\]

Monthly mean tropospheric **NO2 column assimilation increments** are computed from the 2010 RAQMS Aura Reanalysis OMI NO2 assimilation (used to define normalized delta-NO2)

\[
\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}
\]
Constraining 2010 HTAP NO2 emissions with RAQMS/GSI OMI NO2 data assimilation

delta-NO2 from OMI NO2 DA and Jacobian (β) from NO2 emissions perturbation experiment are used to adjust monthly HTAP NO2 emissions

\[
\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.
\]
Constraining 2010 HTAP NO2 emissions with RAQMS/GSI OMI NO2 data assimilation

Adjusted HTAP NO2 Emissions (10^{15} \text{ mol/cm}^2) January 2010
(Aura Reanalysis RAQMS/GSI OMI DA )

Adjustment leads to reductions in emissions in industrialized areas
(regions of large positive changes have low anthropogenic emissions)

\[
\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.
\]
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Multiple Linear Regression of OMI urban NO2 trends used to generate 2005-2015 global NO2 emissions (applied uniformly across each HTAP region)

Benjamin de Foy, B. et al. (2016), Impacts of control strategies, the Great Recession and weekday variations on NO2 columns above North American cities, http://dx.doi.org/10.1016/j.atmosenv.2016.04.038
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In support of the Lake Michigan Air Directors Consortium (LADCO) State Implementation Plan (SIP) modeling we are conducting July 2011 CMAQ simulations to investigate:

• how model bias in ozone precursors (NO2 and HCHO as proxies for total NOx and VOCs) is sensitive to model processes and emissions inputs

• how simulated ozone is sensitive to changes in precursors, via changing model processes and inputs

The CMAQ NOx emission sensitivity studies, along with CMAQ/GSI OMI NO2 DA, will be used to adjust NEI 2011 NOx emission inventories following the procedure outlined for the RAQMS Aura Reanalysis
July 2011 CMAQ NOx emissions sensitivity studies: Ozone Response

July 2011 MDA8 ozone

(b) CMAQ, MEGAN

(d) CMAQ, MEGAN, 15% NO2 reduction

(e) CMAQ, MEGAN, 15% NOx reduction

Eastern US

<table>
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<th>RMSE</th>
<th>Mean Error</th>
<th>Mean Fractional Error</th>
<th>Mean Bias</th>
<th>Mean Fractional Bias</th>
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<td>CMAQ, MEGAN</td>
<td>6.56</td>
<td>5.8</td>
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<td>CMAQ, MEGAN, 15% NO2 reduction</td>
<td>6.52</td>
<td>5.77</td>
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<td>6.08</td>
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<td>15.38</td>
<td>1.2</td>
<td>1.94</td>
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Western US

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<tr>
<td>CMAQ, MEGAN</td>
<td>4.96</td>
<td>4.08</td>
<td>11.69</td>
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<tr>
<td>CMAQ, MEGAN, 15% NOx reduction</td>
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<td>4.18</td>
<td>12.06</td>
<td>-3.34</td>
<td>-9.53</td>
<td>0.6</td>
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Uniform 15% NOx reductions improves agreement between CMAQ and observed July 2011 MDA8 ozone in the Eastern US but worsens the agreement in the Western US.
The July 2010 emissions adjustments from the RAQMS/GSI OMI NO2 DA experiments show reductions in emissions in the North East and Mid West and increases in emissions in the intermountain West.

If the July 2011 CMAQ/GSI OMI NO2 DA experiments show similar responses, then we anticipate improved prediction of MDA8 ozone in CMAQ.
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Ongoing activities

- Collaboration with Wisconsin Department of Natural Resources (WDNR) and Lake Michigan Air Directors Consortium (LADCO) on influence of Chicago NO2 emissions on ozone exceedances at Sheboygan, WI (exceeded limit for the 2013-15 design value in 2015)
  - Lead effort to coordinate 2017 Lake Michigan Ozone Study (LMOS 2017) to use NASA satellite data and aircraft measurements to understand the reasons for the ozone exceedances along the Western Shore of Lake Michigan.

- PI is member of Aerosol and Atmospheric Composition Task Force for development of NOAA’s Next Generation Global Prediction System (NGGPS)

- NOAA Research Transition Acceleration Program (RTAP) proposal for implementation of reduced troposphere/stratosphere chemistry algorithms into NGGPS accepted for FY17 funding.
Acknowledgements

Thanks to Randall Martin (Dalhousie University) for guidance on the use of OMI NO2 columns to constrain NOx emissions

Thanks to Benjamin de Foy (Saint Louis University) for providing multiple regression based OMI NO2 trends for major world cities
Extra Slides
The AIRS CO observation operator\(^1\), was implemented within GSI and assimilation experiments were conducted to optimize the AIRS CO profile assimilation.

\(^1\)Applies AIRS CO averaging kernels and apriori profiles to the RAQMS CO predictions, tangent linear observation operator implemented within GSI inner loop. *Based on GMAO MOPITT DA*
The NSF HIAPER Pole-to-Pole Observations (HIPPO) III measured pole-to-pole cross sections of atmospheric concentrations from the surface to the tropopause across the mid-Pacific ocean.

HIPPO III measurements provide an opportunity to assess the impact of AIRS CO assimilation on carbon monoxide within the Aura Reanalysis over the mid-Pacific (upwind from North America).
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MODIS AOD July 2010 Assimilation Studies

Two MODIS AOD DA Experiments:
- One using the CRTM computed AOD and Jacobians
- One using the RAQMS computed AOD and Jacobians

Major differences:
- RAQMS Sea-salt AOD uses two bins (fine and coarse mode) and limits sea-salt aerosol size to 10 microns in hydroscopic growth
- CRTM Sea-salt AOD uses all 4 sea-salt bins and doesn’t limit hydroscopic growth
CRTM AOD and Jacobians

$r=0.854$

$\text{bias}=-0.009$
RAQMS AOD and Jacobians

\[ r = 0.862 \]
\[ \text{bias} = -0.015 \]
July 2010 Aeronet verification  CRTM AOD

July 2010 RAQMS vs Aeronet 550nm AOD (CRTM AOD+Jacobian)

- $r=0.719960$
- mod-obs=0.0088257
- rms=0.12924

July 2010 550nm AOD Histogram
- Aeronet (Black) RAQMS (Red)

Frequency

AOD
July 2010 Aeronet verification RAQMS AOD

Improved agreement for AOD>0.2