NASA Air Quality Applied Sciences Team (AQAST)

Daniel J. Jacob, Harvard University
AQAST Leader

Funded by the NASA Applied Sciences Program
Lawrence Friedl and Doreen Neil, Program Managers

Earth Science  Air Quality Management
AQAST Membership: PIs and Co-Is

- Daniel Jacob (leader), Loretta Mickley (Harvard)
- Greg Carmichael (U. Iowa)
- Dan Cohan (Rice U.)
- Russ Dickerson (U. Maryland)
- Bryan Duncan, Yasuko Yoshida, Melanie Follette-Cook (NASA/GSFC); Jennifer Olson (NASA/LaRC)
- David Edwards (NCAR)
- Arlene Fiore (NOAA/GFDL); Meiyun Lin (Princeton)
- Jack Fishman, Ben de Foy (Saint Louis U.)
- Daven Henze, Jana Milford (U. Colorado)
- Tracey Holloway, Steve Ackerman (U. Wisconsin); Bart Sponseller (Wisconsin DRC)
- Edward Hyer, Jeff Reid, Doug Westphal, Kim Richardson (NRL)
- Pius Lee, Tianfeng Chai (NOAA/NESDIS)
- Yang Liu, Matthew Strickland (Emory U.), Bin Yu (UC Berkeley)
- Richard McNider, Arastoo Biazar (U. Alabama – Huntsville)
- Brad Pierce (NOAA/NESDIS)
- Ted Russell, Yongtao Hu, Talat Odman (Georgia Tech); Lorraine Remer (NASA/GSFC)
- David Streets (Argonne)
- Jim Szykman (EPA/ORD/NERL)
- Anne Thompson, William Ryan, Suellen Haupt (Penn State U.)
AQAST Mission Statement: To transfer Earth Science knowledge to serve the needs of US air quality management with focus on the use of NASA satellites, suborbital platforms, and models.

Earth science resources

- Satellites
- Suborbital platforms
- Models

Air Quality Management Needs

- Pollution monitoring
- Exposure assessment
- AQ forecasting
- Source attribution of events
- Quantifying emissions
- Assessment of natural and international influences
- Understanding of transport, chemistry, aerosol processes
- Understanding of climate-AQ interactions
AQAST has strong resources to serve AQ management needs…

• Team is constituted for 5 years with a budget of $3.5M/year
• Combined expertise in satellite observations, models, data assimilation, emission inventories
• Flexibility in allocating resources with priority on optimizing service
• Portfolio of short-term and long-term projects; ability to start projects with quick turn-around

…but we need your guidance on how best we can help!
Near-real-time fire activity and smoke emissions estimates for models

Air quality forecasting systems need fire data
• 100% automated
• Low latency: within 3 hours of observations
• Systematic, validated accounting for gaps/limitations of observations

Currently available: FLAMBE smoke emissions
• Hourly emissions at sat. resolution (<8 km)
• GOES WF_ABBA for Western Hemisphere, MODIS elsewhere
• Available online (2006-present)*
• Ref: Reid et al., JSTARS 2009

Planned upgrades/improvements
• Integrated GOES+MODIS fire activity product: “best of both”
• Integration with smoke monitoring tools like USFS BlueSky
• Improved accounting for fire detection efficiency
• Flexibility to adapt to changing satellite constellation

*Data available online: http://www.nrlmry.navy.mil/flambe

PIs: Jeff Reid and Edward Hyer, NRL
Using satellite retrievals to monitor rapidly changing emissions in China

42 new electricity generating units (16 GW) were installed in northern China between 2005 and 2007 in relatively remote areas (few other NO\textsubscript{x} emissions).

Their emissions are clearly seen in OMI NO\textsubscript{2} retrievals, and there is good agreement between GEOS-Chem modeled columns and OMI columns.

D. Streets, S. Wang (Argonne)
Combining trends analysis with emissions calculations offers the potential to determine plant compliance status.

This plant appears not to have installed flue-gas desulfurization (FGD) equipment in 2007, as was required (constant OMI SO$_2$ column, 2006-2008).

This plant does appear to have installed FGD in 2008, as was required (OMI SO$_2$ column decrease between 2007 and 2008).

---o--- OMI SO$_2$ column

---Δ--- OMI NO$_2$ column

Calculated SO$_2$ emissions (without FGD)

Calculated SO$_2$ emissions (with FGD)

C. Li (NASA GSFC), D. Streets (Argonne) and others
Evaluating AQ Impacts of Truck & Rail using OMI

(a) OMI Satellite NO$_2$ Measurements

(b) U.S. Population

(c) Freight Truck Volumes

(d) Freight Rail Densities

Tracey Holloway & Erica Bickford, UW-Madison
Near-real-time monitoring of isoprene emissions using formaldehyde observations from space

OMI HCHO columns, Jun-Aug 2006

Construct operational tool to monitor time-dependent isoprene emissions using HCHO from OMI, GOME-x and GEOS-Chem inverse model (25 km resolution); follow changes in ecosystem function and type

$E_{\text{isoprene}}(x, t)$

D. Jacob (Harvard), T. Pierce (EPA/ORD)
Investigate the utility of OMI HCHO/NO$_2$ as an Indicator of the instantaneous ozone production rate in the boundary layer.

OMI HCHO/NO$_2$

Southwest US

- Los Angeles
- San Francisco
- Central Valley
- Las Vegas

Northeast US

- Washington, DC
- Richmond
- Philadelphia
- New York City
- Boston

August 2006

Transition

VOC controls O$_3$ prod.

NO$_x$ controls O$_3$ production

B. Duncan, Y. Yoshida, M. Follette-Cook (NASA GSFC), J. Olson (NASA LaRC)
Products for Aerosol Data Assimilation from MODIS

Data assimilation systems have specific needs for data products:
- Highly conservative filtering: “a few good obs”
- Aggregation for noise reduction and to avoid assimilating subgrid features
- Quantitative error estimates for each observation

Currently available: NRL/UND 1-degree L3 AOD
- Filtered and corrected from MOD04_L2 data
- 1-degree global land and ocean
- Distributed via GODAE*

Planned upgrades/improvements:
- 0.5-degree version in testing
- Planned product at L2 resolution for mesoscale models
- Near-real-time distribution via LANCE
- Products in development from NOAA ACSPO AVHRR products (NPP-VIIRS after launch)

*Data available online: http://usgodae.org/cgi-bin/datalist.pl?Data_Type=ALL&Parameter=ALL&Provider=nrl&meta=Go#nrl_modis_l3

Pls: Jianglong Zhang, U. North Dakota; Jeff Reid, NRL; Edward Hyer, NRL

Aerosol Data Assimilation: Zhang et al., JGR 2008
Over-Ocean AOD for DA: Zhang and Reid, JGR 2006
Improvement of aerosol forecast skill by MODIS data assimilation

Global (2°x2°) aerosol forecasting experiments were conducted during the NOAA CalNex field mission using the Real-time Air Quality Modeling System (RAQMS) in support of Operational implementation of aerosol assimilation within the NCEP Global Forecasting System (GFS).

Northern Hemisphere 850mb Anomaly Correlations (AC)

Assimilation of Moderate Resolution Imaging Spectroradiometer (MODIS) Aerosol Optical Depth (AOD) results in significant improvements in 850mb smoke (BC+OC) and dust aerosol forecasts with useful forecast skill to 1.5 and 2.3 days, respectively.

Brad Pierce, NOAA
The Joint Center for Satellite Data Assimilation (JCSDA) is conducting data assimilation experiments to assess the impact of GOES TCO assimilation on NCEP Operational Air Quality Forecasts.

Results show a strong dependence on upper tropospheric/lower stratospheric ozone distributions and point to the need for improved lateral boundary conditions for use in operational AQ forecasting.
Understand the relationship between satellite-derived trace-gas measurements and surface observations

- Continue analyses that define when surface $O_3$ distribution is captured by satellite observations

- Use models to provide insight into when surface patterns are captured by satellite measurements
Improving Operational Regional Air Quality Forecasting Performance through Emissions Correction Using NASA Satellite Retreivals and Surface Measurements

PI: Armistead G. Russell1, Co-Is: Yongtao Hu1, M. Talat Odman1, Lorraine Remer2

1Georgia Institute of Technology, 2 NASA Goddard Space Flight Center

Bringing an emissions auto-correction system utilizing near real-time space and surface observations into an existing operational regional air quality forecasting system

Hi-Res Air Quality Forecasting System
Serving Metro-Atlanta Area since 2006
http://forecast.ce.gatech.edu

Daily Maximum Air Quality Index
At date below (4-km Resolution)

A byproducts will be estimated emission biases using inverse modeling linked to integral space and surface observations to adjust regional emissions estimates for decision-making activities

AQI forecasts based on 8hr $O_3$ and 24hr PM$_{2.5}$ predictions, in support of GA EPD’s panel forecasting for Georgia
Satellite observations applied to ozone attainment planning in Texas

1. Photolysis Rates assimilated using GOES data (A. Pour-Biazar, U. Alabama-Huntsville)

2. NO$_x$ Emissions inverted from OMI and TexAQS-II data

3. Model how revised inputs affect ozone responsiveness

4. Provide results to TCEQ and stakeholders for upcoming SIP attainment planning

Daniel Cohan (Rice U.)
Satellite Improved Photolysis Rates

Impact: Clouds have a major impact on photolysis rates which are a first order parameter in determining photochemical production rates in models. Baseline runs showed that incorporating the satellite data improved the photolysis rates and changed point ozone levels in the model by up to 70ppb.

RELEVANCE: When ozone levels exceed air quality standards states must adopt emission reductions to lower levels based on models. It may cost industry and the public billions to reduce ozone levels by 20-30ppb. Thus, the differences in modeled ozone levels (70 ppb) due to the satellite photolysis technique are huge relative to reductions needed.

Figure 1: Top figure shows the differences in ozone between two CMAQ runs with and without use of satellite derived photolysis fields. Note the maximum differences exceed 50 ppb. Bottom figure shows time series of ozone prediction from the model vs. observations at an EPA monitoring site in South Mississippi.
Utilizing Satellite Data to Improve Model Temperatures

Temperatures have an impact on:
- Chemical reaction rates
- Thermal decomposition of NOy species
- Biogenic and anthropogenic emissions
- Mixing heights
- Turbulence levels

Satellite data can improve temperature predictions in the models. Technique uses morning satellite skin temperature tendencies to adjust soil moisture and evening tendencies to adjust surface heat capacity.
Penn State/NCAR AQAST: “Optimizing AQ Forecasts with NASA Observations and Economic Data”

- Anne Thompson, PI, & Wm Ryan (PSU); Sue Ellen Haupt (NCAR)
- Right: AQAST goal - accurate prediction of Code Orange (100 AQI) threshold when Maryland-DC-No. VA Alerts lead to actions with economic consequences, eg free bus rides
  - Present Model Status given by comparison of NAQFC (Natl AQ Forecast Capability) on y-axis vs MD-DC-VA surface observations (x-axis), JJA 2005-2009 Bias
    - Forecast is 18% too high
    - RMS Error is ~30%
    - AQAST can select set of inputs to test as a group
    - Economic value is presently parameterized. Work w/ EPA to obtain actual costs of action, losses prevented

Quantifying the policy-relevant background (PRB) ozone for NAAQS setting and compliance

GEOS-Chem global CTM with 50 km nested resolution over North America

Sample MDA8 time series for 2006
Gothic, CO (39N, 107W, 2926m)

Measurement GEOS-Chem PRB

56.4 56.1 42.2

Acadia NP, ME (44N, 68W, 158m)

Ozone [ppbv]

4th highest MDA8 PRB value, 2006

Detailed PRB statistics provided to EPA/NCEA for risk assessment
Future work: model intercomparisons, satellite data assimilation, PRB forecasts

Daniel Jacob (Harvard), Arlene Fiore (NOAA), Brad Pierce (NOAA)
Developing space-based indicators for daily and inter-annual variations in components of policy-relevant background \(\text{O}_3\) (PRB)

Total and PRB \(\text{O}_3\) at 14 inter-mountain western U.S. CASTNet sites in spring (MAM)
GFDL AM3 model, nudged to NCEP U and V, \(~200\text{km horizontal resolution}\)

<table>
<thead>
<tr>
<th>Year</th>
<th>Model MDA8 O_3 (ppb)</th>
<th>Observed MDA8 O_3 (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quantify the role of specific components and how they change with climate:
- Fires (MOPITT, OMI, AIRS)
- Stratospheric \(\text{O}_3\) (MLS, OMI/MLS, OMPS?)
- Intercontinental transport (AIRS, OMI/MLS)
- Natural emissions (OMI)

Goals: Define exceptional event criteria, deliver multi-decade PRB estimates to EPA, scope potential for space-based indicators of “high PRB” days

Arlene Fiore (NOAA/GFDL), Meiyun Lin (Princeton)
Policy relevant science question: What are the spatial scales of PM and \( \text{O}_3 \)? CMAQ has \( \text{SO}_2 \) lifetime too long, (and \( \text{NO}_2 \) too short).
DISCOVER-AQ: NASA Venture Class Mission focused on improving air quality observation from space

Deployments in different US urban areas over 2011-2016

DISCOVER-AQ Deployment Strategy

Systematic and concurrent observation of column-integrated, surface, and vertically-resolved distributions of aerosols and trace gases relevant to air quality as they evolve throughout the day.

Continuous lidar mapping of aerosols with HSRL on board B-200

Continuous mapping of trace gas columns with ACAM on board B-200

In situ profiling over surface measurement sites with P-3B

Continuous monitoring of trace gases and aerosols at surface sites to include both in situ and column-integrated quantities

Surface lidar and balloon soundings
Systems for modeling air quality & climate change

Ensembles of future scenarios: population, economy, land use, technology & policy

Atmosphere-Ocean General Circulation Model
GISS ModelE & others with online chemistry & aerosols

WRF regional meteorology

Assessments
human health, water resources, ecosystem impacts

target scenario

Atmosphere-Ocean General Circulation Model
GISS ModelE & others with online chemistry & aerosols

global impacts
Δ climate
2x2.5° horiz scale

WRF-CMAQ with online chemistry & aerosols

WRF regional meteorology

rapid screening & feedback

MARKAL Energy systems model: scenario -> Δemission of SLCF

GEOS-Chem adj / TES / LIDORT: Δemission of SLCF -> ΔRF

Daven Henze (CU) with Pinder, Akhtar, Loughlin (US EPA)
GLIMPSE: a rapid screening tool for assessing interactions between specific policy actions and climate impacts from SLCFs

- Use models and satellite data to estimate radiative forcing from specific emissions sectors and locations:

- Clear sky aerosol direct radiative forcing (DRF) aggregated according to EPA’s 9 energy regions considered by MARKAL:
  
  From BC:

  From SO₂:

  Daven Henze (CU) with Pinder, Akhtar, Loughlin (US EPA)
Application of Principal Component analysis to identify dominant meteorological regimes that drive PM$_{2.5}$ variability

PC decomposition of 8 meteorological variables ($x_k$):

$$PC_j = \sum_{k=1}^{8} \alpha_{kj} \frac{x_k - \bar{X}_k}{\sigma_{xk}}$$

Dominant PC in Midwest and Northeast is anticorrelated with PM$_{2.5}$ and associated with eastward-propagating mid-latitude cyclones: low Ts, low but rising pressures, and strong northwesterlies.

**Approach for AQAST:** Identify trends in dominant meteorological regimes in AR4 archive to assess consequences of climate change on pollution meteorology across United States.

Tai et al., 2011
NASA GEO-CAPE satellite mission: geostationary observation of US air quality

Atmosphere Science Questions:

1. What are the temporal and spatial variations of emissions of gases and aerosols important for air quality and climate?
2. How do physical, chemical, and dynamical processes determine tropospheric composition and air quality over scales ranging from urban to continental, diurnal to seasonal?
3. How does air pollution drive climate forcing and how does climate change affect air quality on a continental scale?
4. How do we improve air quality forecasts and assessments for societal benefit?
5. How does intercontinental transport affect air quality?
6. How do episodic events such as wild fires, dust outbreaks, and volcanic eruptions affect atmospheric composition and air quality?

Hourly observation of $O_3$, $CO$, AOD, $NO_2$, $SO_2$, $CH_4$, HCHO, CHOCHO, $NH_3$, AAOD, AOCH with 1x1-4x4 km$^2$ resolution

Active interaction between NASA and AQ agencies is critical for success of GEO-CAPE
IN CONCLUSION…

- AQAST represents a major new NASA resource to serve air quality management through the exploitation of Earth Science data and tools
  - Five-year financial commitment
  - Flexibility to act quickly and deliver on short-term projects

- AQAST has a diversity of expertise:
  - Use of top-down information from space to improve emission inventories
  - Assimilation of satellite data to improve AQ forecasting
  - Integration of satellite and suborbital data to improve process understanding and guide SIP modeling
  - Modeling of chemistry-climate interactions
  - Modeling of global influences on AQ

We need guidance from you on how to serve you best!
Secondary Objectives:

• Apply relationship between pollution and crop yield to improve agricultural productivity

• Increase public awareness of the relationship between air quality and the biosphere through the concept of the “ozone bio-indicator garden”