Geostationary satellite mission for air quality and coastal ecosystems

One of 15 missions recommended to NASA for the next decade by the U.S. National Research Council

Atmospheric GEO-CAPE Workshop at Columbia, MD
22 September 2009


Atmospheric Variability sub-team: Fishman & Newchurch Co-chairs, Al-Saadi, Chatfield, Crawford, Christopher, Duncan, Kawa, Pickering, Scheffe.
PURPOSE: Defining the spatial and temporal scale requirements for GEO-CAPE to
1) characterize emission patterns and
2) observe the spatio-temporal evolution of pollution processes.

The critical precursors and pollutants are: O3, CO, NO2, SO2, HCHO, H2O2, PAN, HNO3, HNO4, acetylene, HCN, glyoxol, and formic acid.
The critical processes are biomass burning, lightning, biogenic VOC emission, dust events, and surface carbon flux.
The critical time frames range from hourly to multi-day episodic.

Data Sources and analyses methods for Atmospheric Variability:
• Space-borne observations of columns and profiles (O3-, NO2, CO, HCHO, CHOCHO, aerosols)
• EPA and USDA nets (CO, O3, NO2, SO2, aerosols)
• Lidar observations (O3 and aerosols)
• McDermid/LeBlanc: mid- & upper-trop DIAL O3 at TMF
• Ozonesonde observations
• Nested resolution WRF-chem (define regions and dates)
• Global GEOS-chem
• Univariate statistical climatologies
• Calculated variability: data and models (variograms)
• Pattern recognition
• Production/Destruction rate calculations
• Horizontal Variability of Trace Gases over the Eastern United States
• Spatial autocorrelation (vertical, horizontal, cross species)
• Vertical Autocorrelations of O3 from the Ozonesonde Record
• EOF and SVD analyses
Aerosol backscatter (right) and ozone (left) profiles from a/c DIAL
13 September 2008
Huntsville, AL

C$_3$ DIAL Retrieval

Alt (km)

13 Sep. 2008
Time

ppbv

0 10 20 30 40 50 60 70 80 90 100 110 120
10 August 2008
Huntsville Ozone DIAL

WRF calculation, Pickering et al.
Diurnal processes

WRF calculation, Pickering et al.
Variability Statistics Based on CMAQ 1.5-km Horizontal Resolution Simulation

Ken Pickering, NASA/GSFC
Melanie Follette-Cook, UMBC/GEST
Yasuko Yoshida, UMBC/GEST
Chris Loughner, Univ. of MD
CMAQ 1.5 km run results

- 1.5 km domain covering the Baltimore/Washington area and upwind regions, nested within a 4.5 km domain, nested within a 13.5 km domain
- 30 levels in the vertical, up to 90 hPa
- Spatial analysis at 18 UTC to correspond with Aura overpass time. Temporal analysis from 13 -23 UTC.
- Data analyzed for a low pollution day – July 7th, 2007, and a high pollution day – July 9th, 2007
- All plots have two lines on them
  - Dashed line is $r = 0.7$ contour, indicating ~50% of variance explained by neighboring grid cell
  - Solid line is $r = 0.87$ contour, indicating ~75% explained variance
  - Also some results for $r = 0.95$, indicating ~90% explained variance
CMAQ 1.5 km domain – surface ozone
CMAQ 1.5 km domain – surface NO$_2$
CMAQ 1.5 km domain – surface CO
CMAQ 1.5 km domain – surface SO$_2$
Decay of horizontal autocorrelation of the tropospheric column

Horiz. res. needed
Chance of missing info.:
10%: Clean: ~12 km
  Polluted: ~8 km
25%: Clean: ~30 km
  Polluted: ~22 km

At 8 km horiz. res.:
Clean: ~30% chance of NOT missing info.
Polluted: ~18%

10%: Clean: ~4 km
  Polluted: ~4 km
25%: Clean: 11 km
  Polluted: 15 km

At 8 km horiz. res.:
Clean and Polluted: ~35% chance
Decay of horizontal autocorrelation as a function of pressure
$O_3$ and CO
Decay of horizontal autocorrelation as a function of pressure – NO$_2$ and SO$_2$. 
Decay of temporal correlation as a function of pressure $O_3$ and CO
Decay of temporal correlation as a function of pressure

NO$_2$ and SO$_2$
Decay of vertical correlation as a function of pressure – NO$_2$

Boundary layer NO$_2$ not very well mixed. Correlations decay rapidly.
Decay of vertical correlation as a function of pressure – CO

CO much better mixed in BL than NO2.
Correlation of surface ozone and tropospheric column ozone
INTEX-B Flight 3 20:30-22:13 UT

Primary Finding:
Overall tropospheric column increases during flight leg as plane approaches Houston, a result of larger scale structure in free troposphere even though values in pbl increase slightly as plane approaches metropolitan area.

Presented by Fishman

Browell et al. data
Signature of shipping lane South Africa – Indonesia becomes increasingly visible in GOME-2 data.

In agreement with increasing AMVER ship numbers.

http://www.amver.com/density.asp
GOME-2 HCHO and CHOCHO

- Glyoxal and formaldehyde fields are very similar
- Good agreement with SCIAMACHY data
- Ratio CHOCHO / HCHO depends on sources

Vrekoussis et al., GOME-2 observations of oVOCs: What can we learn from the ratio CHOCHO to HCHO on a global scale, *paper in preparation*, 2009
TES Observations of Tropospheric Ammonia

Karen E. Cady-Pereira, Mark W. Shephard, Vivienne H. Payne
AER, Inc.

Ming Luo, Reinhard Beer, + JPL TES Science Team
JPL

Daven Henze
University of Colorado

Robert W. Pinder, John Walker
US EPA-ORD

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NASA Langley

Lieven Clarisse
Universite Libre de Bruxelles

AURA, Sept 14-18, 2009, Leiden, The Netherlands
Why Measure Ammonia from Space?

Lack of direct NH$_3$ obs. to help with large uncertainties in modeled emissions

- *In situ* (mostly surface) measurements are sparse
- Uncertainty in the *seasonal* and *spatial* variability
  - CMAQ (regional) : peak emissions during *fertilization* application in *spring* (April)
  - GEOS-Chem (global) : peak emissions with *high temperatures* in *summer* (July)

Satellite measurements have potential to constrain the NH$_3$ emissions

US EPA Monitoring Network

(Gary Lear)
How sensitive are TES measurements to changes in NH$_3$ emissions?

- Map shows the sensitivity of TES measurements (marked by X) to NH$_3$ emissions from any model grid box (from up to a week prior)
  - relative to the influence of the NH$_3$ directly underneath the TES track

Sensitivity of TES obs in the track to NH$_3$ emissions from the week prior

TES Obs are most sensitive to NH$_3$ emissions directly underneath the track (X)

TES is sensitive to NH$_3$ emissions away from obs.

- e.g. TES is ~40% as sensitive to emissions here compared with directly beneath (X)

NH$_3$ lifetime increased:

- NH$_3$ (gas) $\rightarrow$ NH$_4$ (aerosol-phase)
- Bi-directional flux (biosphere and atmosphere)
Spatial Gradients and Seasonal Variability: San Joaquin Valley - 2008

TES captures spatial gradient
• High values (40 ppbv): much greater than GEOS-Chem

Seasonal variability
• Peaks in April and September
  • Typical of farming with fertilizer application?
  • Will compare with in situ datasets where available
TES NH3 Validation Example: Transects over North Carolina USA

- Started in early February 2009
- Will run at least through Dec. 2009
- CAMNet NH₃ monitoring sites match-up with TES overpass
- Will allow detection of spatial variability and seasonal trends
Observing the troposphere with IASI: Emission, chemistry and transport

Pierre Coheur, SPECAT/ULB and CNRS/LATMOS team
Tropospheric sources

Ammonia

The link to agriculture


Inland empire
High Plains Aquifer
Ebro valley
Nile Delta
Global Modelling of NH$_3$ and the first comparison with satellite observations

Frank Dentener
Lieven Clarisse
Comparison of NH₃ on global, country and urban scale

Sutton et al, 2008
NH$_3$ from IASI: 2008 average

Po Valley
Snake river Valley
Fergana Valley

Clarisse et al, [2009]
Some new uses of OMI NO$_2$ observations

- Spatial Resolution
- Fires
- Farms

R.C. Cohen
UC Berkeley

$$ NASA$$
11/21/2004: Unbinned 3km wide pixels
The Sensitivity of U.S. Surface Ozone Formation to NO\textsubscript{x} and VOCs as Viewed from Space

Bryan Duncan\textsuperscript{1}, Yasuko Yoshida\textsuperscript{1}, Jennifer Olson\textsuperscript{2}, Sandy Sillman\textsuperscript{3}, Christian Retscher\textsuperscript{1}, Ken Pickering\textsuperscript{1}, Randall Martin\textsuperscript{4}, Ed Celarier\textsuperscript{1}, Jim Crawford\textsuperscript{2}

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\textsuperscript{4}Dalhousie University

September 16, 2009 Leiden, Netherlands
VOC controls $O_3$ production. NO$_x$ controls $O_3$ production.

OMI captures gradient from downtown to suburbs to rural areas!
WRF-Chem: July 9th: 3 pm: Surface

HCHO/NO$_2$  Ozone (ppbv)
OMI HCHO as Proxy for Variability of Isoprene Emissions

Above Normal Rainfall

Major player in AQ!
~22% Variation

Serious Drought

Historic Drought
Testing and improving OMI NO\textsubscript{2} using DANDELIONS and INTEX-B data

J. Hains, K.F. Boersma, M. Kroon, and many others

Evaluating TM4 a priori profile shapes

- TM4 at 3˚x2˚
- Good agreement for a, c, f, g
- Too little mixing at Cabauw
The Cabauw Intercomparison campaign of Nitrogen Dioxide measuring Instruments

Ankie Piters, KNMI and CINDI Organisation Team
NO2 gradients <200m measured by lidar

- c) Measuring from a distance towards the tower to validate with the in-situ sensors at different latitude levels

courtesy: D. Swart, RIVM
NO2 surface gradients exceed satellite resolution

courtesy: T. wagner, MPI Mainz
Molybdenum converter

courtesy: D. Swart, RIVM
Aerosol comparisons

courtesy: U. Friess, IUP Heidelberg

aerosol extinction profiles
Use of OMI Data in Monitoring Air Quality Changes Resulting from NO\textsubscript{x} Emission Regulations over the United States

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\textsuperscript{4} University of Maryland, College Park
\textsuperscript{5} GEST/Univ. of MD Baltimore County
Lightning NO\textsubscript{x} Source Being Added to CMAQ

Lightning flash rates predicted for times and locations of convective precipitation in meteorological model.

Flash rates scaled on a monthly basis to the NLDN + IC estimate from Boccippio IC/CG climatology

Vertical distribution of LNO\textsubscript{x} production based on observed climatology and direct function of pressure. Production/flash = 500 moles NO

Comparison of CMAQ with INTEX-A aircraft data is good up to ~7 km. Aircraft emissions still needed in CMAQ.
Method

Airborne field data are statistically evaluated using a modified variogram technique to examine their spatial variability.

Classical Variogram Definition (Matheron, 1962)

\[ 2\gamma(h) \equiv \frac{1}{N(h)} \sum_{N(h)} (Z(s_i) - Z(s_j))^2 \]

Where \( N \) is the number of data pairs separated by distance \( h \); \( Z(s) \) is the variable of interest at a given location \( s \); and locations \( s_i \) and \( s_j \) denote location pairs separated by distance \( h \).

Variogram Definition used for this analysis (also called a semimadogram)

\[ \gamma(h) \equiv \frac{1}{N(h)} \sum_{N(h)} |Z(s_i) - Z(s_j)| \]

Simply stated, it is the average difference for the variable of interest over a given distance. Future plans may include calculating other statistics (e.g., median and percentiles).
Distribution of Flight Data Collected in the Boundary Layer (below 2 km)

TEXAQS 2000 NOAA P-3 (16 Aug – 13 Sep)

ICARTT NOAA P-3 (5 Jul – 15 Aug)

TEXAQS 2006 NOAA P-3 (31 Aug - 13 Oct)

ARCTAS CARB NASA DC-8 (18-24 June)
**NO2 Variograms:** Basic behavior is similar for all four campaigns, although magnitudes differ. Interpreting magnitude is difficult since it is influenced by both the magnitude of pollution encountered and the fraction of flight time in urban/polluted versus remote areas.
Normalized NO2 Variograms: Here, variograms have been calculated for the fractional difference in NO2 for values in excess of 1 ppbv. The similarity in these curves suggests that despite the differences in magnitude for the campaign-specific variograms, the variability in proximity to pollution plumes is consistent across campaigns.
The 2008-2009 cluster of North Pacific volcanic eruptions: A-Train observations and OMI validation

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8. Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA
9. JCET, UMBC, Baltimore, MD, USA
Okmok: \( \text{SO}_2 \) validation with WSU MF-DOAS

Spinei et al., JGR Special Issue on 2008 Okmok-Kasatochi eruptions, submitted, 2009

MLDP0 model data courtesy of Environment Canada, Montreal
Backup
Conclusions

• Multiple species exhibit significant variation in time and space at increasingly finer scales.
• Autocorrelations and cross correlations are strong functions of species, altitude, horizontal distance, and time separation.
26 June 2009
Huntsville, AL

O$_3$ DIAL Retrieval

26 Jun, 2009
Time [GMT]
Ozone and CO 4 days in Atlanta July
The nugget represents a minimum variance. For this analysis, the nugget is likely dominated by the measurement uncertainty.

The contribution (sometimes called the “sill”) represents the average variance of points at such a distance away from the point in question that these is no correlation between the points.

The range represents the distance at which there is no longer a correlation between the points.

For the airborne data analysis presented here, the distance \( (h) \) is considered to represent satellite resolution and the variogram \( (\gamma(h) = \text{average difference}) \) to be an indication of expected sub-grid variability for a given resolution.
**Data filtering and assumptions:**

Data assessed for all pairs below 2 km.

Data pairs with distances of up to 100 km included.

Data pairs must span less than 30 minutes which minimizes differences that may be attributed to chemistry (especially for NO2) and transport.

Assessed variables are measured at 1 hz (roughly 100 m resolution for NOAA P-3 and 150 m for NASA DC-8).

Data pairs are restricted to daylight conditions as defined by solar zenith angles of 70 degrees or less.

Data are assumed to be isotropic (i.e., vector direction between data pairs is not important).

Data are assumed to represent a well-mixed boundary layer (i.e., vertical separation between data pairs is not used as a discriminator).
Normalized NO2 Distributions: CARB data shows the broadest distribution which helps corroborate the larger relative NO2 differences observed on the previous slide.