Wisconsin from Space: How Satellites Can Support Air Quality Management

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with

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What is “Air Quality Management”?

- Operational efforts to reduce levels of health- and welfare-damaging air pollution
- Setting air quality and emission limits
- Designing and enforcing rules to meet federal, state, or local limits
- Federal EPA + 10 Regional Offices
- 50 U.S. States offices
- Multi-state “RPO”s
- Intra-state air districts (30+ in CA)
- County & city efforts
Data needs for AQMs (1 of 3)

- Emissions – what’s being released?
  - Trends over time
  - Spatial patterns, timing, sensitivities
  - Absolute levels
  - Chemical Speciation

Figure 2.1.1 2007 January diesel NO\textsubscript{2} emissions inventory comparison (in tons/day) between the WIFE freight + non-freight on-road diesel inventory and LADCO’s on-road diesel inventory, for the continental U.S. gridded to 36 x 36 km\textsuperscript{2}, and the upper Midwest gridded to 12 x 12 km\textsuperscript{2}.

Bickford, Holloway, et al., ES&T 2014
Data needs for AQMs (2 of 3)

- Ambient air quality – what’s in the air?
  - Trends over time
  - Spatial patterns, vulnerable populations,
  - Absolute levels & violations of NAAQS
  - Chemical environment and sensitivities
Data needs for AQMs (3 of 3)

• Models – what are cause-effect linkages?
  o Future projections under alternate scenarios
  o Ambient air quality where no monitors are present
  o Estimated violation of NAAQS under alternate scenarios
  o Chemistry, transport, and attribution

*Karambelas, Holloway, et al., in prep*
HELLO? CAN ANYBODY HEAR ME?

armedwithvisions.com/2013/01/21/ramon-when-a-tree-falls-in-the-forest/
Problems with the status quo

• Monitor data is only available in monitor locations (mostly urban areas)
• Lack of information about air quality away from monitors
• Lack of information about emission sources away from monitors
• Lack of information about model performance away from monitors
• Monitors are $$ to install and maintain
• Monitors cannot be moved easily
Satellite Data – the Upsides

• Continuous global coverage:
  \( \text{NO}_2, \text{SO}_2, \text{AOD} \sim \text{PM, CO, HCHO} \sim \text{VOCs, etc.} \)
• “See” pollutants where no monitors exist
• Inform day-to-day and multi-year trends
• Products on wildfires, climate, land cover, etc.
• Compelling images
• 2016 TROPOMI; 2018 TEMPO
Satellite Data – the Downsides

- No legal/policy framework
- Column vs. ground-level
- Limited suite of products comparable to criteria pollutants (NO$_2$ and AOD ~ PM most equivalent)
- Satellite data are available < 1 x per day (e.g. ~1:00 local time for Aura, not on cloudy days)
NASA Air Quality Applied Sciences Team
Earth Science Serving Air Quality Management Needs

Pollution monitoring
Exposure assessment
AQ forecasting
Source attribution
Quantifying emissions
Natural & foreign influences
AQ processes
Climate-AQ interactions

satellites
suborbital platforms
models

AQAST
AQAST members

- Daniel Jacob (leader), Loretta Mickley (Harvard)
- Tracey Holloway (deputy leader), Steve Ackerman (U. Wisconsin); Bart Sponseller (Wisconsin DNR)
- 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 (Columbia Univ.); Meiyun Lin (Princeton)
- Jack Fishman, Ben de Foy (Saint Louis U.)
- Daven Henze, Jana Milford (U. Colorado)
- 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.)
Connecting with AQAST

Connect with ARSET Training

Active

What do you need?

Research collaborations

NC Jan ‘16!

Advice

Basic

Case studies

Twitter @NASA_AQAST

www.aqast-media.org

Success stories

Tools and “How to”

Passive

Advanced

www.aqast.org

Publications
Connecting with AQAST

Active

Basic

Advanced
Eastern U.S. Episodes Tiger Team
Why is AQAST Unique?

All AQAST projects **connect** Earth Science and air quality management:
- Pursue science to support air quality management
- Collaborate with partners in air quality management
- Expand relationships through meetings, online tools, newsletters

AQAST has **flexibility** in how it allocates its resources:
- Members can adjust work plans to meet evolving air quality needs
- Multi-member “Tiger Teams” compete for funding to address strategic problems requiring coordinated activity
- AQAST is self-organizing and can respond **quickly** to demands

AQAST supports two types of projects:
- **Investigator Projects** – core funding to individual members
- **Tiger Team Projects** – collaborations between AQAST members with supplementary funding to address urgent air quality management needs

Quick, collaborative, flexible, responsive to the needs of the AQ community

www.aqast.org
Highlights from the 4th biannual AQAST meeting (November 2012)
How can satellite data support AQM questions?

- Build on successes
  - trends and patterns in areas without monitors
  - ozone production regimes
  - Dust and smoke transport
- Model Evaluation
- Public outreach and education
- Identify technical versus legal barriers
- Normalize and facilitate new data sources
AIR QUALITY FROM SPACE

Welcome to NASA's Air Quality from space website! Currently, this website focuses on nitrogen dioxide (NO₂) observations from Aura's Ozone Monitoring Instrument (OMI). NO₂ is unhealthy to breathe and is also a necessary ingredient for the formation of unhealthy levels of surface ozone. The content on this site is created for US air quality managers, but there are many other applications and audiences that could benefit from this content.

Explore this site for:

1. Explore capabilities of OMI NO₂ data for major US cities and for individual power plants.
"Bright spots"

Story on Patrick Reddy from Colorado, and his use of satellite indicator ratios

Total volatile organic compounds (VOCs), but the OMI instrument does detect formaldehyde (HCHO). Past studies have shown how satellite HCHO can be used to estimate VOC abundances.

Tales from the Front Range
Colorado is part of the U.S. Environmental Protection Agency's (EPA) Region 8, where the Rocky Mountains and other topographical features affect the NOx distribution in a way that would be nearly impossible to assess from ground-based data alone. Using space-based data, air quality managers can use detailed NOx distributions by satellite, as in some cases by day, across all of Colorado and neighboring states. Figure 1a provides an overview of the region's topography, and Figure 1b shows an example of satellite-detected NOx distributed throughout canyon areas.

In 2009 there was debate as to whether the Front Range region operated in a nitrogen dioxide (NO2)-sensitive regime, suggesting that NOx controls would be effective in controlling ozone (O3) levels.

Above and Left:
Witman, Holloway and Reddy, EM 2014;
Building on past successes

- “Recipes” for useful satellite data analyses
- Research applying methods in new ways
- Insights into ozone production in areas without widespread monitoring

http://www.sage.wisc.edu/airquality_ratios/index.html
FIGURE 6-1 Typical ozone isopleths used in EPA’s EKMA. The NOx-limited region is typical of locations downwind of urban and suburban areas, whereas the VOC-limited region is typical of highly polluted urban areas. Source: Adapted from Dodge, 1977.
2005-2013 average, based on OMI satellite data

Jin and Holloway, 2015
HCHO > NOx $\rightarrow$ NOx-limited

HCHO < NOx $\rightarrow$ VOC-limited

FNR = HCHO/NO2

FNR < 1 then VOC-limited
FNR > 2 NOx-limited

Duncan et al., 2010

2005-2013 average, based on OMI satellite data

Jin and Holloway, 2015
Regime Classification in China

Jin and Holloway, 2015
Figure 5: Predicted or observed year when ozone photochemistry transitioned to VOC-limited regime in a) July and b) September. We assume the earliest year is 2005. Grid cells with less than 95% confidence level are masked.

Jin and Holloway 2015
How can satellite data support AQM questions?

- Build on successes
  - trends and patterns in areas without monitors
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- Model Evaluation
- Public outreach and education
- Identify technical versus legal barriers
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WHIPS
Wisconsin Horizontal Interpolation Program

- Create custom "Level-3" gridded satellite data
- Select grid resolution and projection for easier comparison with regional models
- NO2 (KNMI & NASA), HCHO, CO (MOPITT), MODIS

Above: January 2007; 12 km x 12 km NO$_2$. Units of $10^{15}$ molecules/cm$^2$

Students:
Jacob Oberman, Xiaomeng Wang, Erica Scotty, Alex Karambelas, Ryan Kladar, Andy Wentland & Keith Maki

http://www.sage.wisc.edu/download/WHIPS/WHIPS.html
Aligning Satellite & Model Data

Allows comparison across satellites, from satellite to model, satellite to ground-based measurements, etc.

*Jacob Oberman*
Standard Level-3 Grid

0.25° x 0.25° lat/lon grid

Only available on the single grid specified for that product.

WHIPS Output Grids

12 km x 12 km example grid

Average Tropospheric VCD from 07–01–05 through 07–31–05

Flexible in resolution/projection; (Lambert Conic Conformal)

Visualization on this slide was produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.
User-choice for interpolation method

Method 1: nearest neighbor

Method 2: regional intersection
OMI NO₂ (July)

CMAQ NO₂ (Base)

Harkey, Holloway, Scotty et al., in prep
Figure 1 vertical sum of lightning NO emissions in moles/hr for a) Lightning A and b) Lightning B.

Figure 1: Vertically averaged lightning NO emissions in mol/hr for Lightning A and B.
OMI NO$_2$ (July)

CMAQ NO$_2$ (Base)

CMAQ NO$_2$ (Lightning A)

CMAQ NO$_2$ (Lightning B)

Harkey, Holloway, Scotty et al., in prep
Harkey et al., in prep
Harkey et al., in prep
Milwaukee Summer
Weekday NO

Milwaukee Summer
Weekday NO₂

Milwaukee Summer
Weekday Ozone

Milwaukee Summer
Weekend NO

Milwaukee Summer
Weekend NO₂

Milwaukee Summer
Weekend Ozone

CASX

AQS
Figure 2-4: Eastern US Cities selected for study based on 1) CSAPR jurisdiction, 2) NAAQS ozone non-attainment, 3) High HDDV NOx contribution, 4) Geographic diversity, and 5) Expert opinion

Frost, Kopecky, Meier, Harkey, Holloway
Vehicle Engine Performance

VMT

Speed

Emissions

Ambient NO$_2$

etc.

Atmospheric Processing
Figure 2-1: Adherence of S/L/T agencies to EPA guidelines in preparing CDBs for 2011

NEI\(^7\) where color indicates method used and height indicates the number of states using each method

Figure 2-2: Level of detail provided by S/L/T agencies in hourly VMT.
2011 NED® ranging from least detail (blue) to most detail (red)

Zubrow 2013 (see next slide)
Figure 2-3: Map of data sources used in temporal allocation of VMT for 2011 NEI

* Taken from a presentation entitled “Car Time: Updating curcad temporal profiles” given by Alexis Zubrow (EPA) at the 2013 Community Modeling and Analysis System conference. This presentation can be found at: https://www.cmascen.tar.org/conference/2013/agenda.cfm
MOVES

- VMT
- Speed
- Emissions
- Ambient NO₂ etc.
- CMAQ
Potential Monitoring Site Purposes

1. To Determine Compliance with National Ambient Air Quality Standards (NAAQS)

2. To Develop Regional Pollution Trends in Urban and Rural Areas

3. To Evaluate the Effects of Population, Land Use and Transportation on Air Quality

4. To Evaluate Air Dispersion Models

5. To Provide Air Quality Information to the Public

A Role for Remote Sensing?

No (not yet?)

Yes

Yes

Yes

Yes

Adapted from a slide of Bart Sponseller, WI DNR (remote sensing added)
Want to know more?

- 2015 Article “What’s Next for Air Quality in the United States?”
  Google “UGEC Holloway” or https://ugec.org/tag/tracey-holloway/
- NASA AQAST Websites aqast.org and aqast-media.org and (soon!) aqast.wisc.edu
- NASA airquality.gsfc.nasa.gov
- 2015 Energy Summit videos (online soon! https://energy.wisc.edu/events/2015-energy-summit)
Thank you!

www.aqast-media.org & www.aqast.org