Integrating Satellite Data into Air Quality Management

Experience from Colorado

by Sarah Witman, Tracey Holloway, and Patrick J. Reddy

A first-person perspective on the potential gains of applying satellite data to forecast air quality from Patrick J. Reddy, lead forecast meteorologist at Colorado's Department of Public Health and Environment.

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Air quality management has changed dramatically since 1990. Desktop computers were not yet commonplace back then, and the Internet was practically nonexistent. In those days, satellite data were also primitive: typically grainy, black-and-white images that were a challenge to decipher. Today, computers and access to online data are fundamental to air pollution analysis and regulation. However, despite the boom in satellite data quality and availability, many air quality managers have not yet tapped into these high-value resources.

The Colorado Department of Public Health and Environment has, however, been active in using space-based data. The agency has applied satellite data to forecast air quality; write up exceptional event reports on blowing dust and ozone intrusions; analyze specific air quality events, including wildfire smoke; and characterize relationships between meteorology, emissions, and air quality. The experience of Patrick Reddy, lead forecast meteorologist at the Department's Air Pollution Control Division, offers a first-person perspective in the potential gains from satellite data analysis.

Eyes in the Sky

Suspended tens of thousands of miles above Earth, satellites have a unique perspective on the atmosphere. Different chemicals absorb and emit specific wavelengths of radiation, allowing satellite detectors to "see" gases and aerosols, even some invisible to the human eye. With many satellites passing over Earth every day, we get a continuous record of key air quality information, from gases and particles in the air to fires on the ground.

In evaluating satellite data for air quality applications, there are some limitations. Satellite data reflect the full atmosphere, or a wide slab, versus "nose level" values; polar-orbiting satellites provide a once-a-day (or less frequent) snapshots; data reflect a footprint average (e.g., for NASA's Ozone Monitoring Instrument [OMI] instrument, a minimum area of 13 x 24 km^2), versus a single point; and, on cloudy days or over snow-cover, most satellite data products are unavailable.

Despite limitations, satellite data can fill important, policy-relevant data gaps. Above all, satellites provide more spatial data coverage than any other source. This big picture view allows air quality managers to track smoke plumes back to forest fires, or dust storms back to deserts. For air quality managers, satellite estimates of nitrogen dioxide (NO_2) can be particularly useful, as NO_2 is a criteria pollutant, as well as a precursor to ozone and nitrate aerosols. Because most tropospheric NO_2 originates from surface emissions, and NO_2 has a relatively short

lifetime (minutes to hours), the satellite retrievals of NO_2 may be directly linked back to regulated sources.

The primary satellite NO_2 instrument that an air quality manager might select is OMI onboard the NASA Aura satellite, complemented either by the coarser resolution Global Ozone Monitoring Experiment (GOME)/GOME-2 instruments, or the Scanning Imaging Absorption Chartography (SCIAMACHY) instrument, both onboard European satellites.

Martin[1] offers an overview of air quality monitoring data from space, including additional information on OMI, GOME, GOME-2, and SCIAMACHY. The primary issue determining data choice is usually spatial resolution, where OMI emerges as the strongest candidate because it can see features at the finest scale of any available NO_2 instrument. However, not all data are available for all years: OMI data are available from 2004 to present, GOME from 1996 to 2003, GOME-2 from 2007 to present, SCIAMACHY from 2002 to 2012.

Finally, time of day may affect a user's choice. The NASA Aura satellite, containing OMI, passes over a location in the early afternoon,[2] whereas The MetOp satellite from the European Space Agency, containing GOME-2, passes over in the morning. Using both data sets together provides two snapshots of the same location each day. Looking at satellite NO_2 informs the spatial distribution of the pollutant, day-to-day variability, and—if data from both detectors are used—even some level of diurnal variation.[3] These data, in turn, can be linked to emission trends, pollution events and weather patterns.

Beyond NO_2, satellite platforms provide information a wide range of gas-phase species, as well as particulate abundance and characteristics. Even in cases where the satellite does not measure the exact species of interest, sometimes space-based data may be used as proxies for other atmospheric characteristics. For example, satellites cannot detect

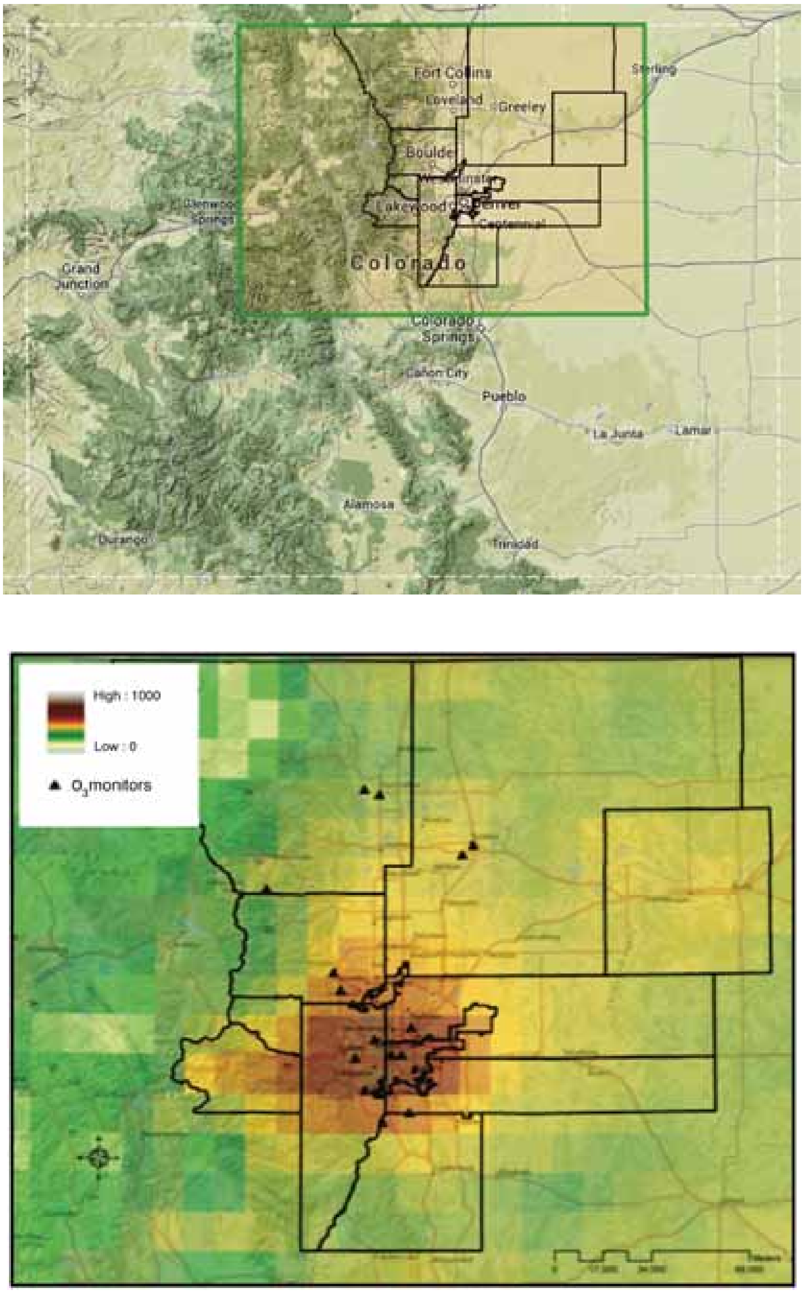

Figure 1. (a) Topographic map of Colorado, with Denver-area counties and sub-region marked for comparison with part (b) created with ZeeMaps.com; (b) 2009–2012 July mean tropospheric NO_2 (units of 10^{13} mol/cm^2) over the Denver, Colorado, area, as detected by the OMI instrument. Brown and yellow show emissions migrating from valley cool pool into higher terrain. Black lines represent county borders.

Figure presented by Patrick Reddy at the Fall 2012 Meeting of the American Geophysical Union. Full presentation available at: http://www.colorado.gov/airquality/repository/mmei_file.aspx?file=Patrick+Reddy+AGU+fall+2012d.pptx.

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 abundance.[4]

Tales from the Front Range

Colorado is part of the U.S. Environmental Protection Agency (EPA) Region 8, where the Rocky Mountains and other topographic features affect the NO_2 distribution in a way that would be nearly impossible to assess from ground-based data alone. Using space-based data, air quality managers can see detailed NO_2 distributions by month, or in some cases by day, across all of Colorado and neighboring states. Figure 1a provides an overview of this region's topography, and Figure 1b shows an example of satellite-detected NO_2 distributed throughout canyon areas.

In 2009, there was debate as to whether the Front Range region operated as a nitrogen oxides (NO_x)-sensitive regime, suggesting that NO_x controls would be effective in controlling ozone (O_3) levels.

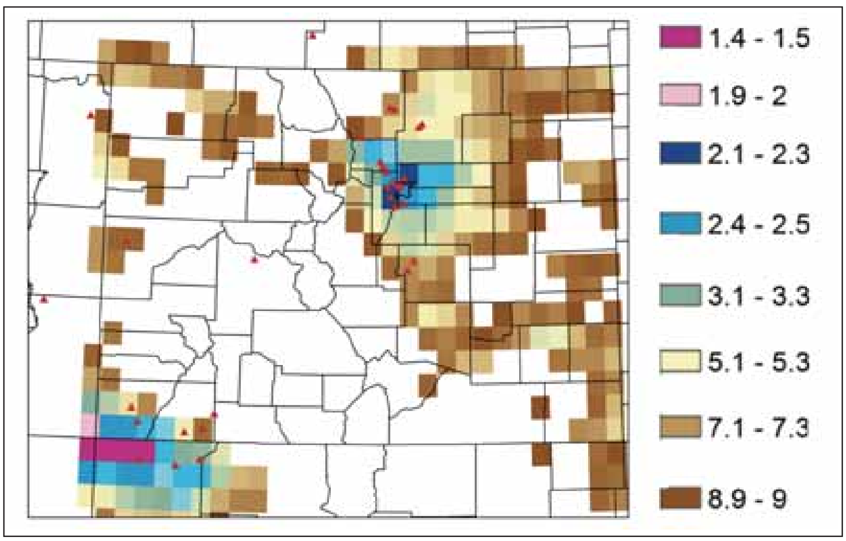

Figure 2. Ratio of tropospheric HCHO to tropospheric NO_2 over the Colorado Front Range area, derived from mean $GOME_2$ satellite measurements for July 2007 and 2008. A ratio of above 1.0 may indicate a NO_x-sensitive ozone production regime. All ratios in this region show ratios are above 1.0. Gridded data from KNMI TEMIS (http://www.temis.nl/airpollution/no2.html).

Figure courtesy of Patrick Reddy, from presentation "2009 Ozone Season Review: Briefing to the Colorado Air Quality Control Commission," September 17, 2009 (Figure legend adjusted for clarity). Full presentation available at http://www.colorado.gov/airquality/repository/mmei_file.aspx?file=OZ+2009+AQCC+Presentation+Sept+Els+without+xtras.ppt.

The Rocky Mountains and other topographic features affect the NO_2 distribution in a way that would be nearly impossible to assess from ground-based data alone.

O_3 is not directly emitted, but forms in the atmosphere from chemistry between NO_x (NO_2 + NO) and VOCs. High O_3 pollution may be produced with high NO_x relative to VOCs (a so-called VOC-sensitive O_3 regime) or with high VOCs relative to NO_x (a NO_x-sensitive regime). Characterizing the O_3 regime is essential for effective control policies, otherwise expensive regulations may not have the intended effect. At the time, NO_x controls were contentious. Some participants in the policy stakeholder process argued that reducing NO_x would *increase* O_3, typical of a VOC-sensitive regime. Thus, whether NO_x controls would be effective or detrimental depended on one issue: whether the region was in a NO_x-sensitive or VOC-sensitive O_3 regime.

Around this same time, Bryan Duncan, a scientist at the NASA Goddard Space Flight Center in Maryland and now a member of the NASA Air Quality Applied Sciences Team (AQAST), showed how the ratio of OMI HCHO to OMI NO_2 could be a powerful way to determine the O_3 regime over a wide spatial area.[5] This approach, known as "indicator ratios," was first applied to ground-based measurements,[6] and earlier applied to satellites using GOME data.[7]

Inspired by Duncan's work, Reddy gave a presentation to the Colorado Air Quality Control Commission, introducing satellite data to show that on average the Front-Range was NO_x-sensitive (as shown in Figure 2, taken from his 2009 presentation). NO_x controls were eventually passed by the Commission, although it is hard to characterize the specific role of satellite-based analysis in the policy process. In general, this type of analysis can complement ground-based measurements, modeling, and other weight-of-evidence approaches, in the broader context of decision-making on emission controls.

Signals Transmitted and Received

Satellite data analysis in Colorado highlights how space-based platforms, and new ways of using atmospheric data, can support air quality management. Reddy's own involvement in satellite applications, following his use of indicator ratios to Front Range O_3 control, has been supported in part by new collaborations with members of NASA AQAST. NASA AQAST encourages air quality managers from across the United States to partner in their activities by contacting team members, attending biannual meetings, or following updates on team web sites (www.aqast.org and www.aqast-media.org) and Twitter (@NASA_AQAST).

Although many states have begun to use satellite data for air quality management, a range of factors can influence the time devoted to learning and using spaced-based data products. In-person workshops and online webinars provided by the NASA Applied Remote SEnsing Training (ARSET; http://airquality.gsfc.nasa.gov) program can help agencies build capacity and facilitate the use of satellite data for air quality applications.

For resources and instructions for calculating O_3 indicator ratios, please visit *www.sage.wisc.edu/airquality_ratios*. **em**

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