Nitrogen Dioxide: Pollution precursor culprits revealed

NO_2 is a brownish gas that is corrosive and toxic and is also a precursor of ground-level small-sized particulate matter and of O_3 through a complex path of chemical reactions triggered by sunlight. In addition, NO_2 is part of the highly reactive family of gases, generically referred to as NO_x, that result from combustion at high temperatures. Its principal anthropogenic sources are motor vehicle exhaust and power plants. NO_2 is detectable from space because of its unique spectral signature that can be differentiated from other atmospheric constituents. However, the concentrations are small, sensitive to surface reflectivity, and highly variable, spatially and temporally. Therefore, remote sensing of NO_2 is a continuing challenge. The presentations on this topic focused on case studies, algorithm refinements, and the detection of ten-year trends.

A summary presentation described how NO_2 concentrations over the tar sands in Alberta, Canada are increasing at a rate of 10% per year—consistent with the increase in oil mining operations. Another important area of interest for OMI NO_2 data use is to improve *emission inventories*—a measure of pollutants discharged into the atmosphere from combined individual sources. In some cases, the data calculated from OMI observations agree reasonably well with standard inventories, but in others, they do not. One aid to resolve these discrepancies is the use of chemical transport models that help researchers understand the inconsistencies between observed OMI NO_2 trends and decreases in emissions.

Other studies are underway that attempt to use OMI data directly, without models. By analyzing the downwind patterns of NO_2 over megacities for different wind conditions, lifetimes and (subsequently) emissions amounts can be calculated. Several studies are underway to improve NO_2 algorithms by testing them with similar instruments on other satellites (e.g., GOME-2), and by developing algorithms with advanced capabilities for upcoming missions, as will be discussed below.

One technique, called *cloud slicing*, employs cloud top heights and yields layer NO_2 amounts in the *free troposphere* (the upper part of the troposphere above the boundary layer), produced by lightning and brought in via long-range transport. One analysis indicated that these amounts are independent of the NO_2 concentration in the lower troposphere, where the primary source is combustion. Another study relevant to future instruments demonstrated how data artifacts due to instrument peculiarities can be removed, which results in better consistency among observing spectral windows. Another presentation showed how cloud and aerosol corrections, spectral window selection, and air mass factors were dependent on increasing amounts of NO_2.

Ozone in the troposphere: The "hidden" ozone

Observing tropospheric O_3, particularly in the boundary layer, is a continuing challenge for space-based observations. O_3 is the primary component of polluted air at this level, but stratospheric O_3 concentrations are about 10 times larger than those observed in the lower troposphere, and current instruments struggle to distinguish the small amounts at lower levels from total column values. There are several ongoing efforts to more accurately retrieve O_3 in the troposphere, and in particular to be able to discriminate O_3 in the boundary layer and in the free troposphere, where O_3 becomes a greenhouse gas. One presentation on measuring O_3 above the boundary layer over OMI's 10-year lifetime described O_3 stratospheric–tropospheric exchange and correlations with tropical cycles, observations in deep convective clouds, and anthropogenic O_3 sources.

A complementary study showed a clear correlation of OMI-observed tropospheric O_3 over eastern China, presumably in the boundary layer, with increased amounts of CO measured by the Measurements of Pollution in the Troposphere (MOPITT) between the 0 and 3 km (0 and ~1.9 mi) altitude range, with strong evidence from aircraft measurements, of transboundary pollution to Korea and Japan—see **Figure 4**. The

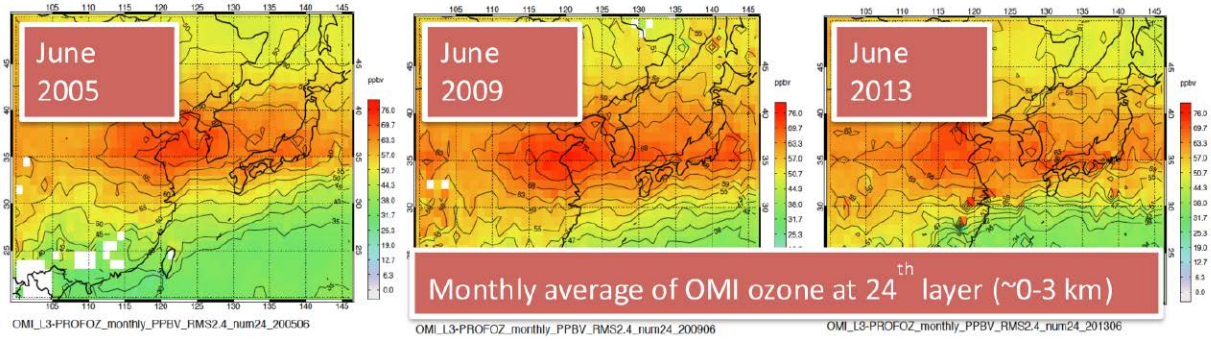

Figure 4. The maps show monthly averages of O_3 between 0 and 3 km (0 and ~1.9 mi) as measured by OMI for June 2005 [*left*], June 2009 [*middle*], and June 2013 [*right*]. Ozone builds up in the planetary boundary layer over eastern China; the prevailing westerlies in the free troposphere transport it into Korea and Japan. **Image credit:** Hayashida *et al.*, manuscript in preparation for *Geophysical Research Letters*, 2014

correlation of OMI and aircraft data at this altitude range was on the order of 0.9, indicating that OMI can measure tropospheric O_3 exiting the boundary layer and transported into the upper troposphere.

A novel result that demonstrated synergy of Aura instruments used Aura's Tropospheric Emission Spectrometer (TES)-derived tropospheric O_3 and OMI NO_2 measurements, along with a chemical transport model for the period 2005 to 2010. Tropospheric O_3 was calculated from the model using derived OMI NO_2 emissions and then compared with the TES-derived O_3 amounts; the results showed good agreement. A byproduct of this study showed that the increased emissions of pollution over China increased the free tropospheric O_3 amount over the western U.S. by a factor of two due to the strong westerly transpacific winds during spring.

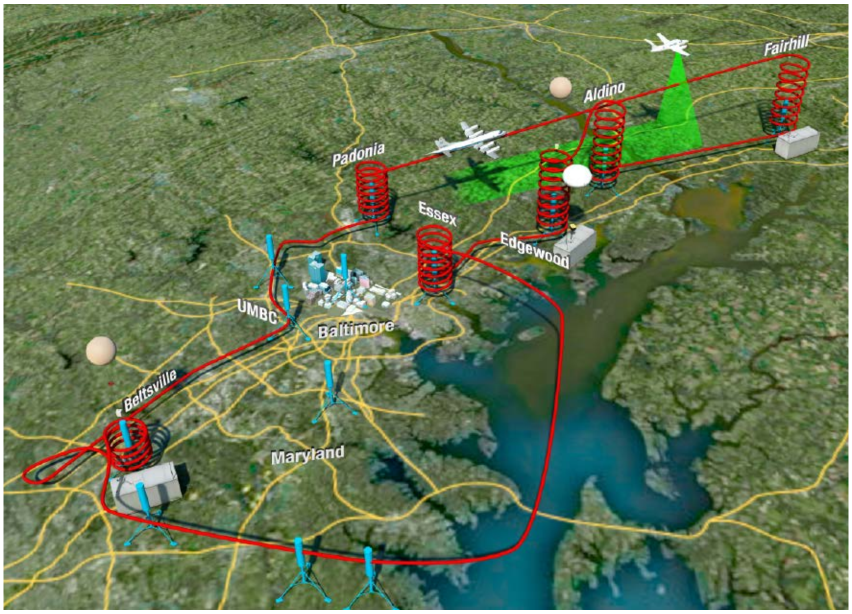

Figure 5. DISCOVER-AQ fourteen day observing strategy for July 2013 over the Baltimore, MD/Beltsville, MD/Washington, DC area. The aircraft ground track has been overlaid on a map of the region showing major roadways. The vertical spirals represent locations where aircraft made descents to measure atmospheric constituents at different levels—to construct profiles. Ground stations are indicated by the towers. **Image credit:** Timothy Marvel [NASA's Langley Research Center]

Using the OMI Algorithms on OMPS

Despite the fact that the priority for OMPS on Suomi NPP was to measure stratospheric O_3 only to meet NOAA requirements, OMI algorithms for measuring the array of atmospheric constituents discussed above have been put to use on OMPS data. For example, the application of the SO_2 algorithm to OMPS clearly showed SO_2 hot spots and their daily variations over the Ohio Valley, eastern China, and from most volcanic emissions, worldwide. The OMI NO_2 algorithm was also tested on OMPS, and also showed seasonal variations similar to those detected by OMI. Other results showed excellent agreement of monthly zonal averages between OMI and OMPS, thereby assuring the needed consistency between the two datasets to detect global trends in air quality across satellite missions.

Validation

Validation of OMI data products is an ongoing process, but significant progress already has been made. Uncertainties have been quantified and systematic effects characterized. Since 2011, 18 papers on validation results have been published; several more have been submitted or are in preparation. Gaps in validation results have been identified for almost all products. The main issues are with the latest versions of the KNMI cloud products, HCHO, bromine monoxide (BrO), and chlorine dioxide (ClO_2)—particularly over snow/ice and under partly cloudy conditions.

DISCOVER-AQ: A field campaign to validate OMI and other instruments

A major NASA aircraft-based field campaign is called *Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality* (DISCOVER-AQ[7]). It is designed to improve the use of satellites to monitor air quality for public health and environmental benefit. Specific regions in the U.S. were selected to measure the horizontal, vertical, and temporal variations of key air-polluting substances. Measurements were conducted using two NASA aircraft, several ground stations, and balloons, and then correlated with OMI and other instruments on the A-Train satellites. The key objectives of the four-mission campaign are to quantify the relationships between tropospheric columns amounts as measured by the satellites to ground-level amounts of air constituents of interest to the air quality data user, improve satellite retrievals, and advance regional air quality models and forecasts. The aircraft deployment strategy and location of ground stations are illustrated in **Figure 5**. Key findings from the

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[7] DISCOVER-AQ has been discussed previously, most recently in "NASA's Venture Continues: An Update on the EV-1 Investigations," *The Earth Observer*, July–August 2013 [**Volume 25**, **Issue 4**, pp. 19-32].