Analysis and Applications of Satellite Remote Sensing Measurements by the Smithsonian Astrophysical Observatory

August 2, 2010

Summary

We will use U.S. Aura satellite observations, as well as selected measurements from the European ERS-2, Envisat, and MetOp satellites to (1) improve the suite of available global air quality indicators and (2) perform scientific studies using multiple products to address ongoing issues in atmospheric chemistry and air quality. We will:

- Develop H_2O measurements as an OMI scientific product using the 440-450 nm vibrational 7*v* polyad.

In terms of the solicitation goals, our research:

- *Develops new Level 2 data*: CHOCHO (operational), H_2O (science product).

2 Proposed research

2.3 Multi-species studies of biomass burning and air quality

Substantial enhancements in H_2O, HCHO, CO, SO_2, O_3, and a wide range of other trace constituents have been measured by aircraft in biomass burning plumes from African savanna and Yucatan forest and crop fires [Yokelson *et al*., 2003, 2009], and OSIRIS satellite measurements of the smoke plume over Australian wildfires in 2009 (S. Petelina, private communication, 2010). The plume chemistry is generally complex, with post-emission chemistry determining much of the atmospheric impact of smoke from fires: Emission ratios of HCHO relative to CO, for example, have been observed to increase by 50% or more in 1 hour-old plumes downwind of the source [Yokelson *et al*., 2003]. Laboratory studies of the photochemistry in smoke plumes [Grieshop *et al*., 2009a, b] find that photochemical oxidation in aged plumes produces a substantial amount of organic aerosol (OA), more than doubling the OA mass after a few hours of aging under typical summertime conditions [Grieshop *et al*., 2009b], yet less than 20% of OA production are explained by state-of-the-art organic secondary organic aerosol (SOA) models and the measured decay of traditional SOA precursors [Grieshop *et al*., 2009a]. Studies of the impact of seed effects from aqueous-phase organic aerosol photochemistry on SOA formation found evidence for the importance of CHOCHO and H_2O in SOA formation: SOA yields increased linearly with liquid water content and were not limited to clouds (and cloud droplets), pointing to the importance of water-soluble organic carbon photochemistry in SOA formation [Volkamer *et al.*, 2009].

OA is a significant source of absorption predominantly in the near-UV ("brown carbon" absorption), In addition to black carbon. Barnard *et al*. [2008] have shown that the organic aerosol component of the Mass Absorption Cross section over Mexico City falls off rapidly at UV wavelengths, predominantly from absorption by brown carbon aerosols. CHOCHO in fire plumes (**Figure 3**) suggests the substantial presence of brown carbon absorption. We will investigate whether any link between CHOCHO and AAI can be determined.

With the extending range of products observed by OMI, we can study biomass burning events and urban air quality related photochemistry on a global scale in more detail than ever before. OMI routinely observes HCHO, NO_2, total column SO_2, and Absorbing Aerosol Index

(AAI), all standard data products that are publicly available (HCHO is produced by the SAO BOREAS algorithm). In this study, we will extend the range of observations to CHOCHO (to be made a standard data product, see **Section 2.1**), tropospheric O_3 (proposed as an operational product separately by Dr. Xiong Liu), and H_2O (to be produced at SAO from the vibrational 7*v* polyad as a science data product, see **Section 2.6**, with data made available through the SAO atmospheric website www.cfa.harvard.edu/atmosphere. (Another reason to measure H_2O in the plume is that it affects the OH and O_3 and some of the other gas-phase chemistry branching ratios, and also provides a readily detectable signature of stratosphere-troposphere exchange.) Improvements to SO_2 observations are also planned as part of this work (**Section 2.5**). Collaborators will have important roles in various aspects of the proposed work: Randall Martin is involved in the improvement of NO_2 air mass factors for the standard product; Omar Torres is the developer of the AAI standard product; and Rainer Volkamer will provide support with his expertise on CHOCHO ground-based measurements and organic photochemistry.

As an example of the potential of OMI air quality and biomass burning studies, and as a demonstration of the feasibility of the proposed work, we show in **Figure 3** four key elements of observed and derived quantities for the case of an Alaskan forest fire in August 2005. From top to bottom, the four panels in **Figure 3** show (a) HCHO total columns from the standard data product, with an empirical background correction applied; (b) CHOCHO total columns from the science product glyoxal retrieval algorithm; (c) H_2O geometrical total columns from a first version of the water vapor retrieval algorithm; and finally (d) a "Smoke Index", derived from the product of HCHO total columns and AAI, normalized to a (so far) arbitrary value. The images clearly demonstrate the potential and feasibility of multi-species studies of biomass burning,

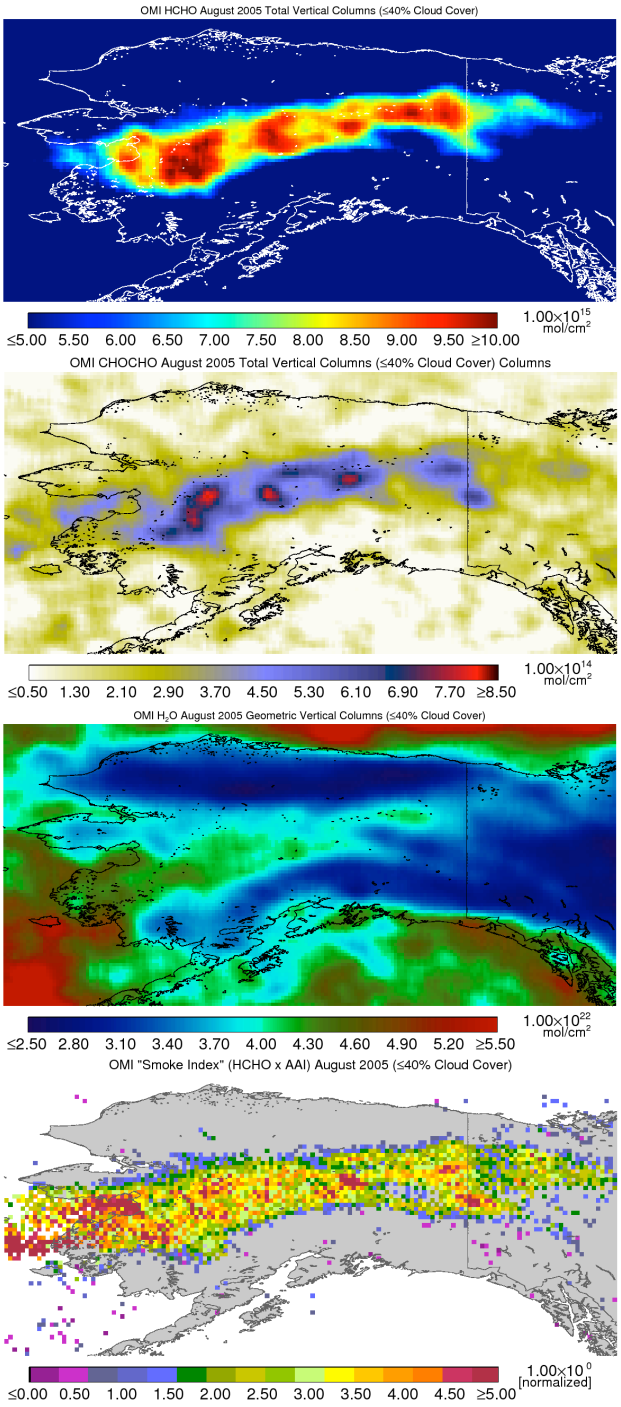

Figure 3. OMI observations of an Alaskan forest fire in August 2005. From top to bottom: HCHO total columns, CHOCHO total columns, H_2O geometric columns, and a Smoke Index (the product of AAI and HCHO, arbitrarily normalized). All values shown are monthly averages for 08/2005.

combining observations of VOCs, water vapor, and aerosol information. Air quality studies in megacities will pose a greater challenge than biomass burning events, due to the generally smaller column amounts observed in all quantities. Nevertheless, the combination particularly of VOCs and water vapor (as an indicator of relative humidity) is expected to yield new insights into air-quality related photochemistry and SOA formation in urban environments.

The Smoke Index is an as yet experimental indicator that will be developed into a more sophisticated tool to identify biomass burning events (see also proposal by D. Jacob). It will be improved in several respects, including optimizing the definition beyond a simple VOC-aerosol product, and screening for biogenic VOC production. In addition to the Smoke Index from OMI HCHO and aerosol, we will continue to investigate whether an index derived from addition of the longer-lived carbon monoxide (CO) provides additional information on plume characteristics, improving the extent of measurements (this area has been initiated by collaborator O. Torres).

OMI NO_2 observations are also closely linked to nitrate formation. Lin *et al*. [2010] use trends in MODIS and OMI NO_2 and aerosol columns to argue that despite reductions in SO_2 emissions, fine aerosol formation over China is increasing due to increases in other sources of fine aerosol. Coupling of OMI NO_2 measurements with aerosols and improved SO_2 will thus also potentially provide air quality diagnostics for anthropogenic pollution.

2.6 H_2O scientific data products

Very recent experience, discussed in **Section 2.3** and shown by example in **Figure 3**, suggests that H_2O is an important additional data product associated with fires. H_2O products from UV/visible/NIR satellites including SCIAMACHY and the GOME instruments have been developed using longer wavelengths, *e.g.*, from SRON, U. Bremen, U. Heidelberg, and KNMI. To our knowledge, H_2O products have not yet been developed from OMI spectra. However, the vibrational 7*v* polyad region, especially from 440-450 nm, is a very attractive candidate for H_2O measurements. The absorption is fairly weak (peak absorption optical depth about 0.05 for moderate humidity (10 g kg^{-1}) and typical satellite measurement geometry: the absorption is optically thin, so that interpretation as H_2O columns is simplified, yet the absorption is still substantially stronger than that of most trace gases measured by OMI. The fitting region is reasonably clean, and the wavelength window is long enough so that lower tropospheric measurements are not compromised. **Section 2.3** gave an example of H_2O in the plume from Alaskan wildfires. We will continue to develop the H_2O fitting for use in scientific studies.