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## New Directions: Infrared measurements of atmospheric pollution from space<sup>☆</sup>

Human activities generate emissions of pollutants that are changing the chemical composition of the Earth's atmosphere. Observation of how the planet system is responding to this anthropogenic perturbation is key to understanding the consequences of both natural and human induced modifications. On the short term and a local scale, an important concern is air quality, whereas on the longer term and a global scale, climate change is an issue to be addressed. Measurement from space is increasingly viewed as a means to measure atmospheric changes and to control the implementation of environmental policies.

There are two important advancements that have recently opened up challenging perspectives in tropospheric chemistry, as previously emphasized by H. Singh and D. Jacob (Future directions: Satellite observations of tropospheric chemistry, *Atmospheric Environment*, 34(25), 4399–4401, 2000), and P. Borrell et al. (New Directions: New Developments in Satellite Capabilities for Probing the Chemistry of the Troposphere, *Atmospheric Environment*, 37(18), 2567–2570, 2003). One of them is the operation of passive remote sensors using either the absorption, refraction or reflection properties of the atmosphere to probe the lower layers. In less than a decade, nadir-viewing space-borne instruments have provided satellite-derived global views of trace gases (GOME, IMG, MOPITT, SCIAMACHY) and aerosols (TOMS, POLDER, MODIS), on a long-term basis. The other major step forward is associated with the improved coupling of observation and modeling, especially through implementation of data assimilation for chemistry applications. Atmospheric models are now used to interpret the dynamical and chemical processes that are revealed by satellite monitoring, to estimate the source emissions of pollutants, and to provide chemical forecasts.

The observational capabilities of remote sensors that exploit the infrared (IR) long-wave Earth and atmospheric radiation to monitor the tropospheric composition are now well-established and were demonstrated by

IMG (1996–1997 on the Japanese ADEOS) and MOPITT (1999–now, onboard US TERRA). These instruments have already provided large amounts of observations that are being analyzed by different research teams, generating new insights in the study of the troposphere. Most molecules that play an important role in environmental issues have a spectral signature in the infrared, although the information is easier to extract for those combining high atmospheric variability with large infrared absorption. In this regard, water vapour (H<sub>2</sub>O), carbon monoxide (CO), and ozone (O<sub>3</sub>) are the more suitable molecules to be monitored using infrared techniques.

Carbon monoxide is a reactive toxic gas, mainly produced by the combustion of fossil fuels and vegetation burning. Fig. 1 illustrates the seasonal CO abundance distribution as measured by the MOPITT (Measurements Of Pollution In The Troposphere) instrument, averaged over four years of operation. High levels of pollution are found in both hemispheres, essentially above urban areas due to industry, motor vehicle traffic and domestic heating, and over areas where biomass fires occur, either natural, related to agriculture, or deforestation. Elevated CO amounts are found long distances from where the pollutants are released, as the atmospheric life time is long enough (from a few weeks to several months) that long-range transport can occur.

Ozone is a secondary pollutant, being produced photochemically from primary pollutants emitted from natural sources, industrial processes, vehicle exhaust, and other products of fossil fuel combustion through a complex series of chemical reactions. Summer ozone-related smog events are now observed over most cities in the world, particularly in developing countries. Satellite data also highlight how O<sub>3</sub> plumes are transported trans-boundary, affecting air quality in regions far from industrial and vegetation burning activity.

Last but not least, these two compounds, together with methane and other hydrocarbons, NO<sub>x</sub>, and water vapour, regulate the distribution of the hydroxyl radical (OH). Reaction with OH provides the dominant loss mechanism of most atmospheric pollutants. A change in the concentration of one of these species or in the UV radiation modifies the oxidation efficiency of the

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<sup>☆</sup>Something to say? Comments on this article, or suggestions for other topics, are welcome. Please contact: [new.directions@uea.ac.uk](mailto:new.directions@uea.ac.uk), or go to [www.uea.ac.uk/~e044/apex/newdir2.html](http://www.uea.ac.uk/~e044/apex/newdir2.html) for further details.

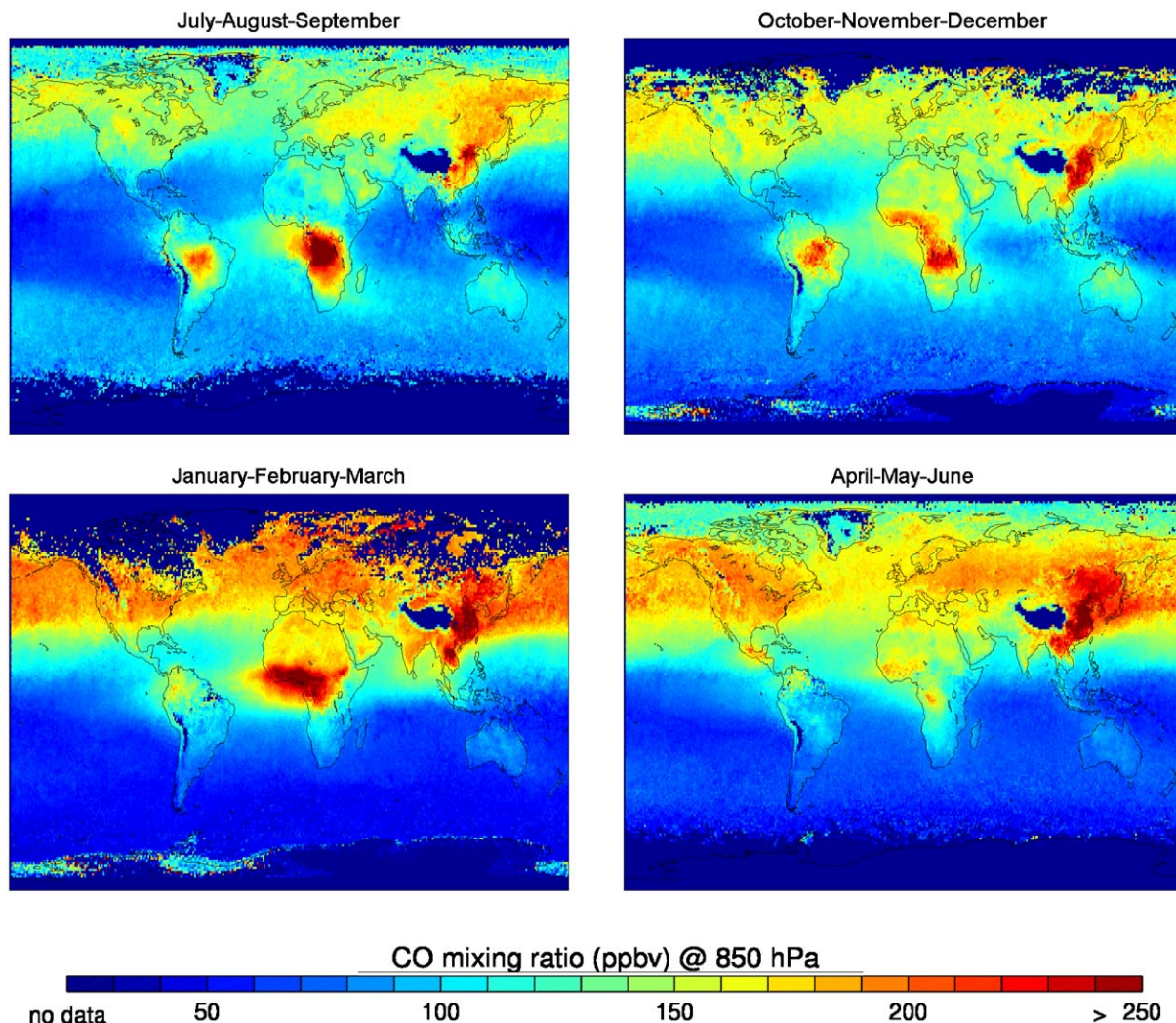


Fig. 1. These composite images depict CO measurements at an altitude of 850 hPa. The seasonal plots show the observations (high CO values are in red) averaged over 4 years (March 2000–February 2004) of MOPITT operation. In the Northern Hemisphere, most of the pollution is associated with urban activity, with persistent high values above China and elevated levels over US, Europe and Asia in spring and winter. In the tropics and Southern Hemisphere, most of the CO is emitted where biomass burning occurs, such as in Africa, Central and South America (following the seasonal shift in the Inter-Tropical Convergence Zone). The CO pollution plumes emitted locally spread from regional to global scales, depending on meteorological conditions and photochemistry.

troposphere (its self-cleaning capacity). This effect is clearly depicted in Fig. 1: CO levels are lower in the Northern hemisphere during summer, when sunlight induces high OH levels which activate faster chemistry.

Space-borne thermal IR instruments can measure during day and night, but the observations may be affected by the presence of clouds in the field-of-view. The cloud contamination, along with information on temperature, determines the reliability of the measurement. Advanced sounders onboard of operational weather satellites will open new areas of research as they combine the measurement of meteorological

variables (wind, clouds, temperature, and water vapour content) with CO and ozone. The AIRS instrument (launched in 2002 onboard US-AQUA) and the forthcoming IASI missions (to be part of the EU- METOP1, 2 and 3 weather satellites) are examples of such hyperspectral remote sensors. The synergy between UV-visible and IR instruments should allow measurements of all the main atmospheric gas pollutants (CO, O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>), as will be demonstrated soon by TES (IR) and OMI (UV-VIS) onboard AURA (2004), and IASI (IR) and GOME2 (UV-VIS) onboard the METOP series.

Finally, tracking air pollution requires high temporal coverage. All the above-mentioned instruments are limited to twice daily observations as they operate from polar-orbiting satellites. Projects are ongoing to define missions and sensors to fly on geostationary orbits for 2012 and onward. The next generation of operational weather satellites in preparation both in US (NOAA/GEOS-R) and EUROPE (EUMETSAT/MTG) includes high resolution infrared sounders designed to measure meteorological and chemical variables in four dimensions, with accuracies and spatial resolutions never achieved before. NASA is supporting studies for a prototype IR sounding instrument to fly in geostationary orbit (the GIFTS concept).

Significant efforts have been made to cope with air pollution, especially in urban areas, through strategies that essentially include emission controls and changes in fuel use. The integrated analysis of satellite monitoring from geo and polar orbits (to maximize the spatial and

temporal coverage), complemented with ground based data and regional measurements (to capture local changes with higher accuracy), and combined with advanced global and regional models, will revolutionize our ability to understand our environment and its fragile equilibrium.

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