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NEW DIRECTIONS

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New Directions: New Developments in Satellite Capabilities for Probing the Chemistry of the Troposphere ☆

The successful launch in early 2002 of the SCanning ImAging spectroMeter for Atmospheric CHartographY (SCIAMACHY) instrument on the ESA ENVISAT satellite opened the second phase of a substantial European effort to study trace substances and pollutants in the troposphere with measurements from space. It was also the culmination of an idea, mooted first 15 years ago, which found its first expression in 1995 with the launch of the Global Ozone Monitoring Experiment (GOME) on the Earth Research Satellite 2 (ESA ERS-2).

SCIAMACHY is already producing good data, but the validation procedures must be completed before this is made generally available. However, a foretaste can be obtained from the excellent lower resolution results, which are being regularly provided by the GOME spectrometer operating in the visible and UV and by TOMS and by MOPITT. Data are available for the past few years on tropospheric O_3, NO_2, H_2O, BrO, SO_2, formaldehyde (HCHO), clouds and aerosol. These have been used to study a large and growing number of phenomena in the lower atmosphere. Biomass burning in Africa is accompanied by plumes of NO_2 and HCHO, part of which streams out into the Indian Ocean and part contributes to the large excess of tropospheric ozone seen over the southern Atlantic Ocean. Information can also be obtained on the contribution of lightning to tropospheric NO_2 production. The same images show the high concentrations of NO_2 produced by industrial activities in South Africa, and the burning of natural gas in the Middle East is clearly visible. Similarly NO_2 and HCHO from the 1997 fires and smog in South East Asia could readily be discerned, as could the aerosol and SO_2 from the eruption of Mount Etna (Sicily) in 2002. The large concentrations of BrO found around the Arctic and Antarctic continents in their respective spring seasons correlate well with the fall of boundary layer ozone to nearly zero in these regions at these times of the year. Nearer to home, one can readily discern the regions over north western Europe and the Po Valley that produce high concentrations of NO_2, and which give such problems to environmental policy developers with the highly non-linear response of ozone to the reduction of the precursors, NO_x and volatile organic compounds (VOCs). Likewise, it becomes obvious that there are extremely high SO_2 levels in China, and SO_2 is still noticeable in eastern Europe.

The accompanying figures illustrate the potential of satellite measurements for tropospheric measurements. They show the excellent resolution provided by SCIAMACHY in observing NO_2 over the Middle East (Fig. 1), the SO_2 from the erupting volcano, El Reventador in Ecuador (Fig. 2), probable production of NO_2 by lightning over Australia (Fig. 3), HCHO, NO_2 and O_3 from biomass burning over Africa (Fig. 4) and the production of BrO around the polar regions in the spring (Fig. 5).

The inherent difficulty with tropospheric satellite measurements is the retrieval of the tropospheric absorption from reflected sunlightshine, which is measured in a downward-looking (nadir) configuration from about 800 km through the stratosphere. Some trace gases of interest in the troposphere (e.g. O_3, NO_2) are also abundant in the stratosphere, while others (like SO_2 or HCHO) are not. In the former cases, various procedures have been developed to separate troposphere from the stratosphere. The comparison of signals from known NO_2-free regions with those from polluted tropospheric regions gives the NO_2 in the boundary layer; the difference between "on-" and "off-cloud" signals can give concentrations at levels depending on the cloud height, and one can take advantage of the differences in the spectroscopic features to obtain profiles of ozone in the troposphere. The development of algorithms is a difficult task and, at the moment, most of the data is the product of detailed skilled work on individual data sets. But, as experience grows, automation can be expected. Data are already available to those interested, subject to the proper recognition of those doing the retrieval work.

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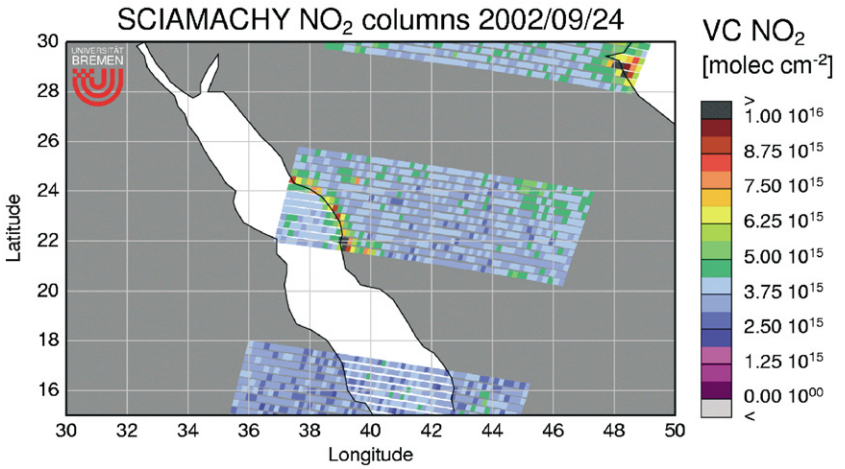

Fig. 1. NO_2 total columns derived from measurements of the new SCIAMACHY instrument on ENVISAT in September 2002. Pollution from individual cities such as Jeddah, Mecca, Medina and Kuwait City can clearly be identified in the otherwise clean region.

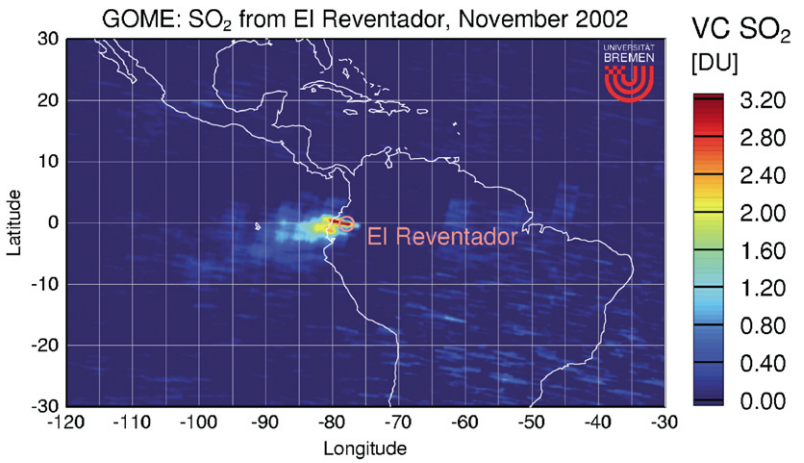

Fig. 2. Average SO_2 columns measured by GOME in November 2002 showing the huge cloud of SO_2 emitted by the volcano El Reventador in Ecuador.

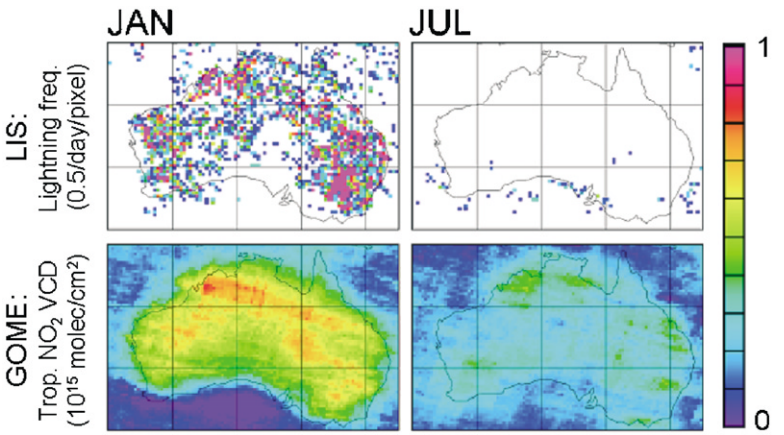

Fig. 3. Monthly means of the lightning frequency (from LIS) and tropospheric NO_2 vertical column density (from GOME) over Australia for selected months in 1999. High NO_2 values are only seen for strong lightning activity (S. Beirle, Uni-Heidelberg).

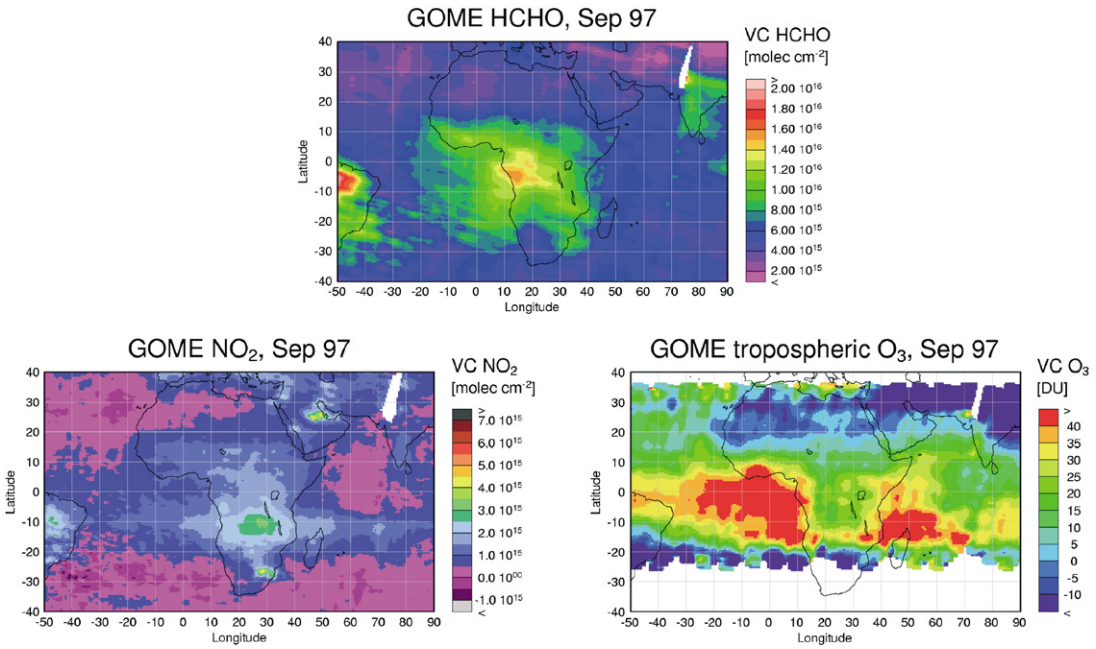

Fig. 4. Results obtained for formaldehyde (HCHO), NO_2 and O_3 over Africa, India and western Brazil. The large amounts of HCHO and NO_2 over Africa and western Brazil can be attributed to biomass burning. Persistently high concentrations of NO_2 are observed over the industrial region of South Africa and the oil-producing states of the Persian Gulf. The large O_3 signal over the Atlantic Ocean was first observed in TOMS data.

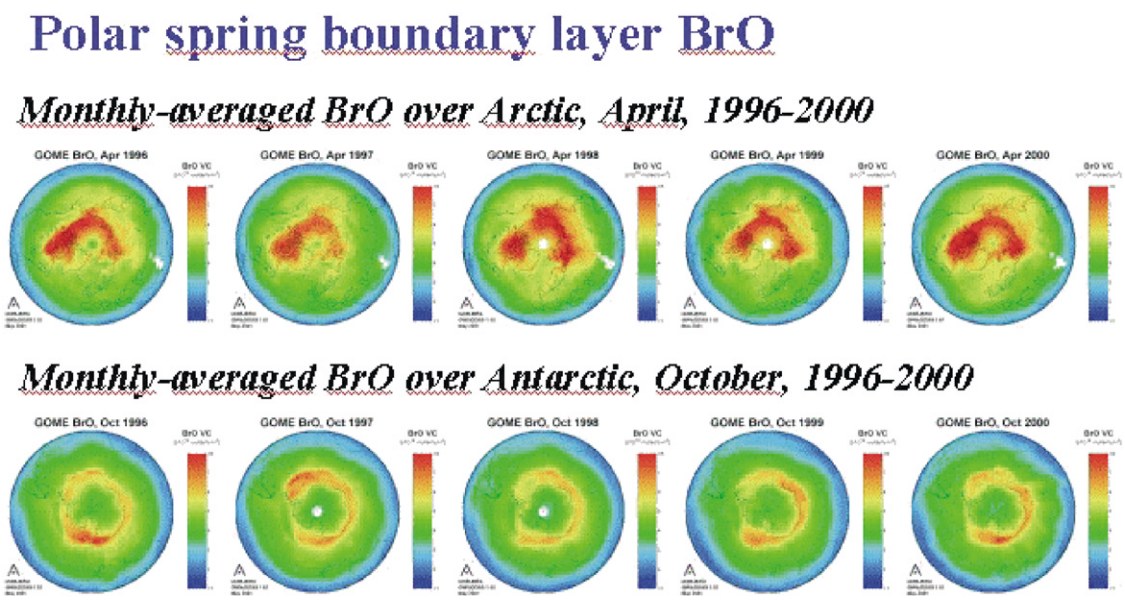

Fig. 5. Observations of the large tropospheric clouds of BrO formed above sea ice at high latitudes around the Arctic and Antarctic Oceans in the spring of each year. It coincides with very low levels of O_3 in these regions in spring. The source of the BrO is still not clear but is presumed to be released from sea salt or biogenic organo-bromine species (figure kindly supplied by Michel van Roozendael, BISA).

The new instrument, SCIAMACHY, will simplify the task of retrieving the tropospheric contribution. It is capable of making measurements looking at the horizon (limb) as well as nadir observations, and the comparison of these two will yield directly tropospheric trace gas concentration without resorting to any other

assumptions or favourable conditions. Also, the increased spatial resolution of SCIAMACHY is a great advantage for the retrieval of tropospheric trace gases from space, because of the higher probability of finding cloud-free ground pixels. SCIAMACHY extends the spectroscopic range into the infrared and is thus capable of providing tropospheric data on O_2, O_3, $(O_2)_2$, NO_2, N_2O, BrO, H_2O, SO_2, HCHO, CO, CO_2, CH_4, clouds and aerosols. ENVISAT is also carrying three other instruments, MIPAS, GOMOS, and MERIS that will determine O_3, NO_x, N_2O_5, $ClONO_2$, CH_4, CFCs in the upper troposphere, and water vapour, clouds and aerosol in the troposphere.

What opportunities do these new data offer to atmospheric chemists? The simple scrutiny of the concentration maps on global and regional scales should provide confirmation of, or provoke questions about what was not observable before. The data will provide a direct comparison with the output from chemical transport models (CTM) on global and regional scales and will be used for realistic validation and sensitivity work to improve substantially the accuracy and reliability of CTMs. Satellite measurements should also be useful in providing real boundary conditions for operational models. In addition, source strengths of trace gases can be derived. For field campaigns, the knowledge of the actual concentrations of appropriate species in the vicinity of the campaign area will be available. In short, satellite data will soon be an essential adjunct to the major activities of the field in the future.

And what of the future? The present satellites are sun-synchronous with orbits which interlace to give a global picture, and thus provide a snapshot of individual areas (of for example 320 km × 40 km in the case of GOME) at the same time every two or three days (depending on latitude), however always at the same local time (10:30 in the case of GOME). A major advance would be a geo-synchronous platform that remains stationary above the equator and observes continuously. Despite the increased distance (36,000 instead of 800 km) and the oblique angle subtended by the mid-latitude regions, integration means that a high-resolution picture could be obtained (about 15 km × 15 km) every 30 min. It would then be possible to make time-dependent studies to examine the development of concentration fields during the day; thus another large and yet more useful area would be opened up for model verification and process studies. Such a geostationary instrument is presently under consideration by the ESA. In addition, the low earth orbit satellite instruments will continue to evolve towards higher spatial resolution. While SCIAMACHY already offers a ground pixel size about 6% of that of GOME, future instruments (beginning with GOME-2 or OMI) will be able to observe the trace gas concentration at yet higher spatial resolution. Regional studies from space will thus become possible.

The utility of the present satellites is capable of being extended by combining the data with that from other means (surface stations, balloon sondes, regular aircraft measurements and so on) using data assimilation based on a good CTM. It is likely that such a system might well provide the initial basis for an Earth-observation system which, when proved, would go a long way to meeting the requirements of the Kyoto and other international treaties for the monitoring of the environment.

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