Fight the Limb Gap: Need for High-Resolution Limb-Emission Measurements

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A key question in Earth system science is how climate change interacts with middle atmospheric circulation and composition. Another key issue is the monitoring of stratospheric ozone recovery and its feedback onto atmospheric processes. Limb emission measurements and limb measurement of scattered or attenuated sun- moon- or starlight provides vertically resolved information (profiles) with good global coverage of temperature and many atmospheric constituents over the altitude range of approximately 5–140 km, depending on instrument and species. A golden age of middle atmospheric observations has come to an end. ENVISAT and its instruments were lost in April 2012 and the remaining missions (Odin with OSIRIS and SMR, SCISAT-1 with ACE and MAESTRO, Aura with MLS and OMI, and TIMED with SABER) are beyond their expected lifetimes. The NASA OMPS and SAGE-III missions are short-duration missions, and provide information on a limited set of species. SAGE-III will be hosted by the ISS and thus will not cover the poles. Facing this limb gap, a limb mission with global coverage, providing information about as many as relevant atmospheric species as possible is overdue to monitor and understand the middle and upper atmosphere's interaction with climate change.

Evidence of changing stratospheric circulation has been found by analysis of altitude and latitude resolved trends of stratospheric SF_6 (Stiller et al., 2012). The exact patterns of these changes are still not fully explained, and thus no reliable prediction of the circulation of the stratosphere is possible yet. Linked to these circulation issues is the exchange of upper atmospheric air with the stratosphere. Huge amounts of mesospheric and thermospheric air intrude into the polar winter stratosphere and interact with stratospheric chemistry. The intensity of such events is coupled with stratospheric circulation and thus with climate change. Monitoring of such events requires continuous global altitude-resolved measurements of involved chemical reactants and suitable tracers.

Due to its role as the primary greenhouse gas, the temporal evolution of water vapour in the upper troposphere and lower stratosphere is of particular importance. The stratospheric water vapour budget is controlled by import from the troposphere, freeze-drying, dehydration, methane oxidation and stratospheric circulation. To diagnose these processes, highly altitude-resolved continuous measurements of H_2O, CH_4, temperature, and, if possible, also HDO are needed.

Another crucial stratospheric climate driver is aerosol. Volcanoes can both directly inject particle matter into the stratosphere or SO_2, of which aerosols are a secondary product. To better understand this natural component of climate change requires a better understanding of the stratospheric sulphur cycle. Besides their primary relevance in the context of the Earth's radiative budget, aerosols are important also as surfaces where heterogeneous reactions occur.

While some information on ozone will be available from OMPS and SAGE-III, no polar night measurements will be available. For the unambiguous detection of the recovery of stratospheric ozone, continuous vertically resolved long-term global data records, covering the whole globe and particularly polar winter in both hemispheres are needed. Dense spatial and temporal sampling is required to distinguish chemical from dynamical effects and to avoid sampling artefacts.

Attribution of ozone changes to its causes requires knowledge of dynamical tracers. Measurement of species like CFCs, N_2O, CH_4, CFCs, CO SF_6 or NOy allows analysis of vertical and horizontal transport and mixing processes (Glatthor et al., 2005; Funke et al., 2009; Stiller et al., 2012). Measurement of reactive species (ClO_x, NO_x and HO_x) along with their reservoirs (HNO_3, $ClONO_2$ and N_2O_5) is essential for the understanding of ozone chemistry in a changing climate.

Solar atmospheric interactions are particularly important for ozone chemistry (López-Puertas et al., 2005), and also for the atmospheric water vapour budget (Schieferdecker et al., 2015). Evidence of atmospheric perturbations due to precipitating solar protons, energetic electrons, and radiative effects, both locally in the stratosphere or via subsidence of processed air from the mesosphere and thermosphere has been found (e.g. Funke et al., 2011, 2014). Since the Golden Age of Earth Observation lasted only for about one solar cycle, a large part of our knowledge on solar-terrestrial interaction is still uncertain. Particularly the knowledge on processes related to the 11-year solar cycle is of poor statistical significance. Extension of altitudinally and latitudinally resolved time series of involved species is badly needed. To understand the effect of increasing tropospheric CO_2 onto the stratosphere, monitoring of upper atmospheric CO_2 and temperature are crucial. Two recent studies have shown that the increase rate of CO2 in the middle/upper atmosphere is larger than in the troposphere (Emmert et al., 2012; Yue et al., 2015) and then might affect the upper atmosphere density and planning spacecraft flight paths (Emmert et al., 2010). Similarly, to meaure the NO cooling of the thermosphere is fundamental for understanding the evolution of the upper atmosphere density (Mlynczak et al., 2010).

The interaction of the key processes described above require a holistic research approach which involves measurement of multiple species. The ideal instrument measures ozone, water vapour and its isotopes, the reactants NO_x, ClO_x, and HO_x, their reservoirs, dynamical tracers (CH_2, N_2O, CFCs, CO, SF_6), sulphur compounds, and organic species which help to better quantify the import of tropospheric air into the stratosphere. Continuous global measurements are needed, which cover the upper troposphere, the stratosphere, the mesosphere and the thermosphere. These requirements are best fulfilled by a limb emission sounder or limb imager on a polar orbit. Since the required gases have bands in the mid infrared but can be detected only at sufficiently high spectral resolution, a Fourier transform spectrometer is the instrument of choice. Optimally, it would be complemented by a microwave limb spectrometer. Past space missions have demonstrated the adequacy of suggested techniques, technological readines (MIPAS, MLS etc), and the technical readiness of improved methods (e.g. limb imaging instead of limb scanning) has been highlighted by airborne demonstrator missions (GLORIA (Friedl-Vallon et al., 2014)).

The research communities involved cover the scientists investigating climate change, atmospheric chemistry and dynamics, stratospheric ozone, monitoring of trace gases, solar terrestrial connection, aerosol, radiative budget, stratospheric radiative transfer, data assimilation, inverse modelling, retrieval, interferometry, spectroscopy, and many more. Both experimental (AGAGE, NDACC etc) and theoretical (modelling) communities would be involved.

The societal benefits are those of climate research in general and thus do not need any additional discussion.

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