Climate watchdog in space: Ten years of SCIAMACHY on ENVISAT

How did our ozone layer change in the last ten years? In what ways do trace gases such as nitrogen dioxide, carbon dioxide and methane affect our climate? How effective are environmental protection measures? These are the questions that have occupied the minds of European scientists since the launch of the European Environmental Satellite ENVISAT ten years ago when it took off into space with one of the first Ariane-5 rockets on 28 February 2002. On board the biggest Earth observation satellite that has ever been built was the German-Dutch-Belgian instrument SCIAMACHY, acronym for ‘Scanning Imaging Absorption Spectrometer for Atmospheric Chartography’, which was financed up to 50% by Germany’s Space Agency DLR (Deutsches Zentrum für Luft- und Raumfahrt). Head of the scientific team is Prof. John P. Burrows of the Institute of Environmental Physics at the University of Bremen. The data are systematically analysed and interpreted in the Institute in cooperation with the DLR in Oberpfaffenhofen. During the last century, these data have influenced our view of the world in a tremendous way.

Figure 1 ENVISAT in space (Source: ESA)

A map of the ozone layer

The ozone layer at a height of 15 to 50 kilometers (stratosphere) is the part of the atmosphere that protects our planet from short wave ultraviolet radiation. The sun’s high energy UV-radiation strikes oxygen molecules (O_2) and changes it into ozone (O_3). The UV-rays are absorbed by the high concentration of ozone in the stratosphere; in this process, ozone is changed back into ordinary oxygen – the so-called Ozone-Oxygen-Cycle. The ozone concentration is normally kept in balance. During the last century, however, this equilibrium has been greatly disturbed by manmade chemical substances, particularly by chlorofluorocarbons (CFC), which led to the formation of the ozone hole over the South Pole and to a general thinning of the ozone layer worldwide. Since 1996, a sequence of SCIAMACHY data and that of its predecessor GOME (on the satellite ERS-2) are being used to chart the ozone layer and the growth of the ozone hole continuously. Although the amount of ozone aggressive chemicals (CFCs, etc.) in the stratosphere has declined since their prohibition as a result of the Montreal Protocol 25 years ago, air currents and air flows have brought about surprising effects. One example is the formation of an ozone hole over the North Pole. However, this observation occurred only twice during the whole observation period: in winter 1996/1997 and in winter 2010/2011. Aside from the ozone concentration, SCIAMACHY also gathers data on Chlorine, Bromine and Nitrogen compounds worldwide since these substances also play a direct role in the ozone depletion.

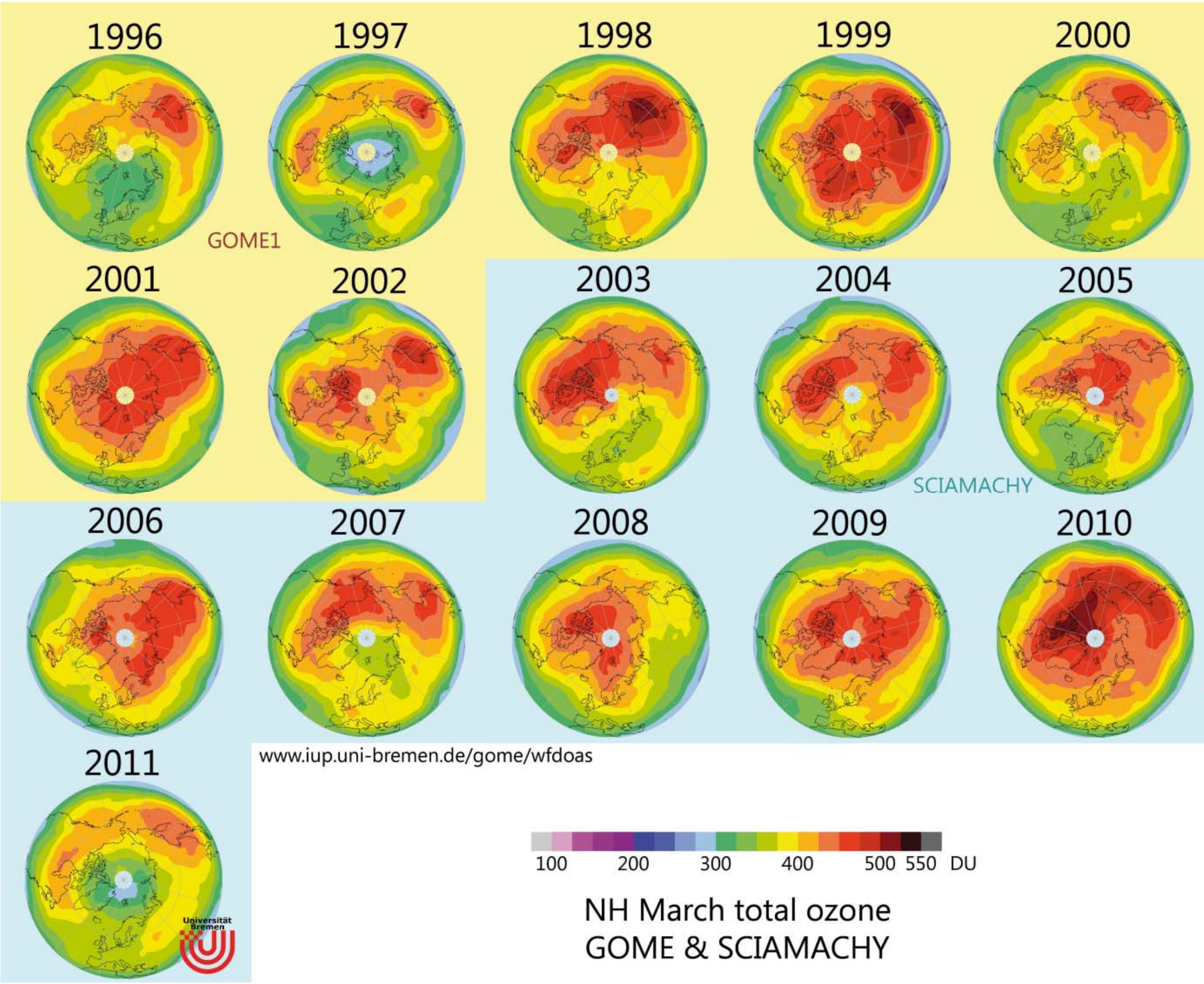

Figure 2 **Time series of the ozone layer above the North Pole in March from 1996 to 2011 (Source: M. Weber, Institute of Environmental Physics, University of Bremen)**

How effective are environmental protection measures?

Nitrogen dioxide is an air pollutant that arises from combustion processes, particularly in power plants or from motor vehicles. This oxidized form of nitrogen is responsible for the formation of smog in urban centers and poses a high risk to the human respiratory system, especially when combined with particulate matter such as dust. SCIAMACHY data show that environmental protection measures do work and this can be observed from space. For example, a team of German and American scientists was able to prove that between 1999 and 2006, the contamination level of nitrogen dioxide in certain areas of the Unites States declined up to 35%. This was the result of introducing anti-emission measures in three coal-fired power plants in the area. On the other hand, the scientists did not find any improvement in urban areas where the air is highly polluted with nitrogen oxides produced by motorized traffic. For a greater part of Europe, an improvement of the air quality as a result of environmental protection measures during the last 15 years could be shown.

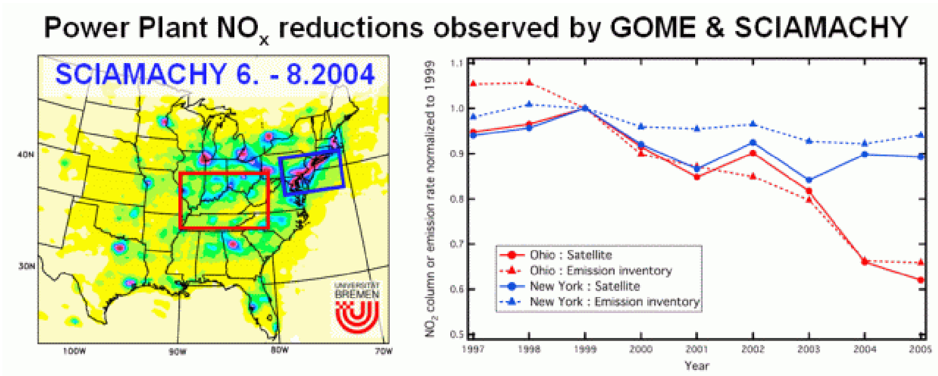

Figure 3 Evidence of the reduced concentration levels of nitrogen dioxide in the US between 1999 and 2006 as a result of improved waste gas purification measures in coal-fired power plants. Shown are the data from four locations of coal-fired power plants. (Source: Kim, S.-W., A. Heckel, S. A. McKeen, G. J. Frost, E.-Y. Hsie, M. K. Trainer, A. Richter, J. P. Burrows, S. E. Peckham, and G. A. Grell (2006), Satellite observed U.S. power plant NOx emission reductions and their impact on air quality, Geophys. Res. Lett., 33, L22812, doi:10.1029/2006GL027749).**

Rapid economic growth = rapid ecological problems?

SCIAMACHY has observed a rapid increase of nitrogen oxides in countries and areas where the economy is growing at a fast rate, most particularly in China. Sulfur dioxide, a gas which is also produced by oil and coal burning, behaves differently than nitrogen dioxide. While the concentration levels of nitrogen dioxide showed a temporary decline during the economic crisis of 2008 and as result of the anti-air pollution measures taken during the Olympic games of the same year, it is now slowly on the rise again. Sulfur dioxide concentration levels, however, have declined considerably since 2007. The reason behind this is that China is now becoming environmentally conscious, too. They have started to establish and install desulfurization systems in many coal-fired power plants.

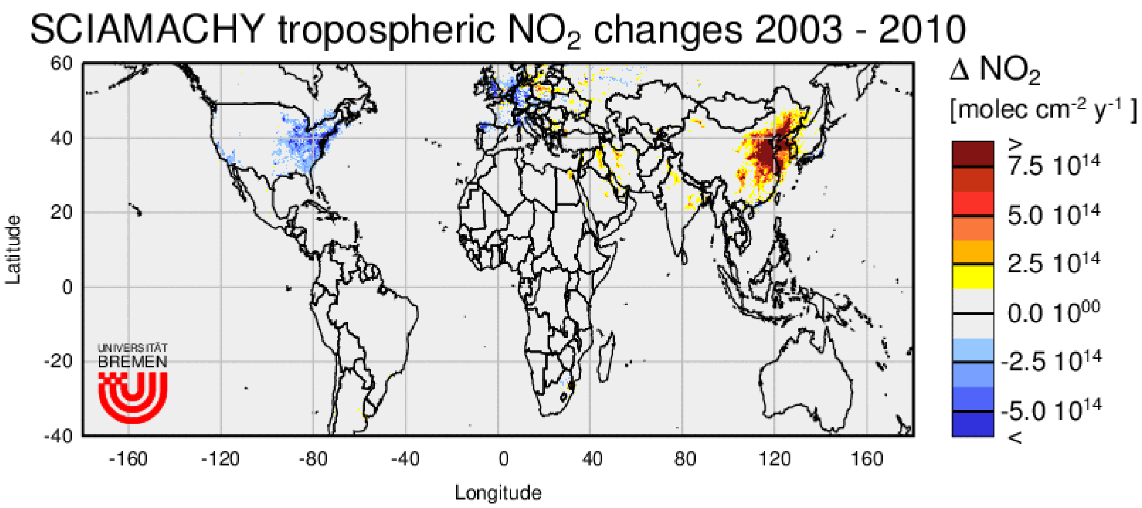

Figure 4 **Changes in the NO_2-concentraion levels between 2003 and 2010 worldwide. While a considerable decline can be observed in large areas of the US and Europe, a considerable increase is**

observed in China. Different urban areas in Eastern Europe, the Middle East and India also show increased levels. (Source: A. Richter, IUP University of Bremen).

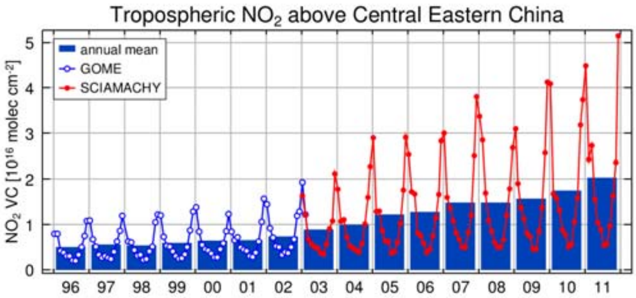

Figure 5 Increase of NO_2-columns over Central China from 1996 to 2011. The data for 1996-2002 are from GOME on ERS-2, the subsequent data are from SCIAMACHY. The annual fluctuations are caused by the seasonal changes in the atmospheric life of NO_2 as well as changes in the energy consumption of humans (Source: A. Richter, IUP University of Bremen).

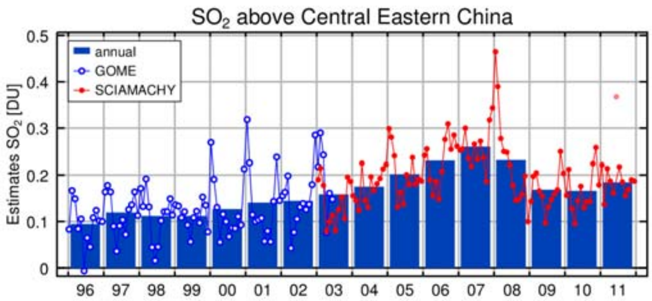

Figure 6 Variation of SO_2-columns over Central China from 1996 to 2011. The data for 1996-2002 are from GOME on ERS-2, the subsequent data are from SCIAMACHY. The annual fluctuations could be a result of the seasonal changes in the energy consumption of humans. The increased values in June 2011 were caused by a SO_2-cloud of volcanic origin (Source: A. Richter, IUP University of Bremen).

Impact of carbon dioxide and methane on climate change

With SCIAMACHY, it was possible to chart the worldwide distribution of the major greenhouse gases such as carbon dioxide (CO_2) and methane from space for the first time. This helps us to have a better understanding of the natural and ‘manmade’ sources and sinks of these greenhouse gases. How potent are these sources and sinks? What is their impact on climate change? Can major sinks such as expanse forested areas which presently absorb a huge bulk of CO_2 emissions possibly turn into sources and speed-up the global warming process in the future? Will rising temperatures in wetlands aggravate the levels of methane emissions?

Systematic observations with SCIAMACHY have contributed to improving the determination and detection of methane in wetlands and to a better understanding of the carbon budget of boreal forests, thereby helping to find answers to major questions concerning climate change and working out effective corrective measures.

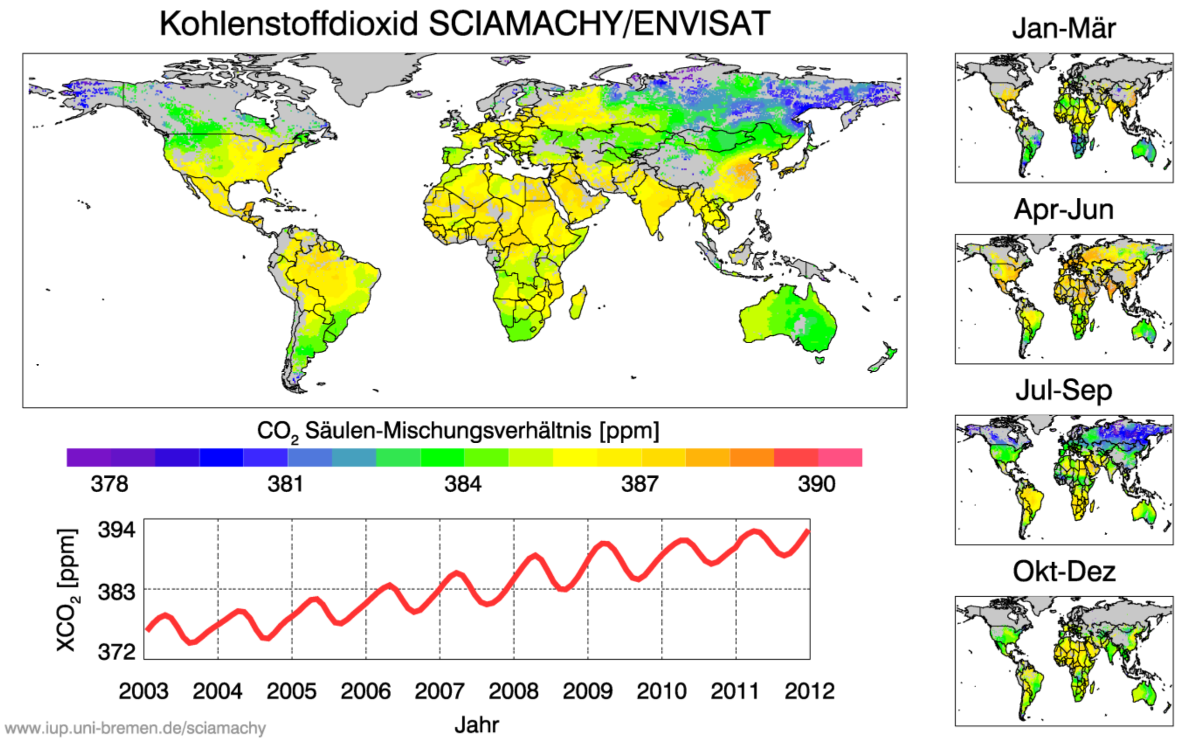

Figure 7 Map showing the worldwide distribution of carbon dioxide over land, the seasonal variations and the average increase in the years 2003 – 2011 (Source: M. Buchwitz, IUP University of Bremen).

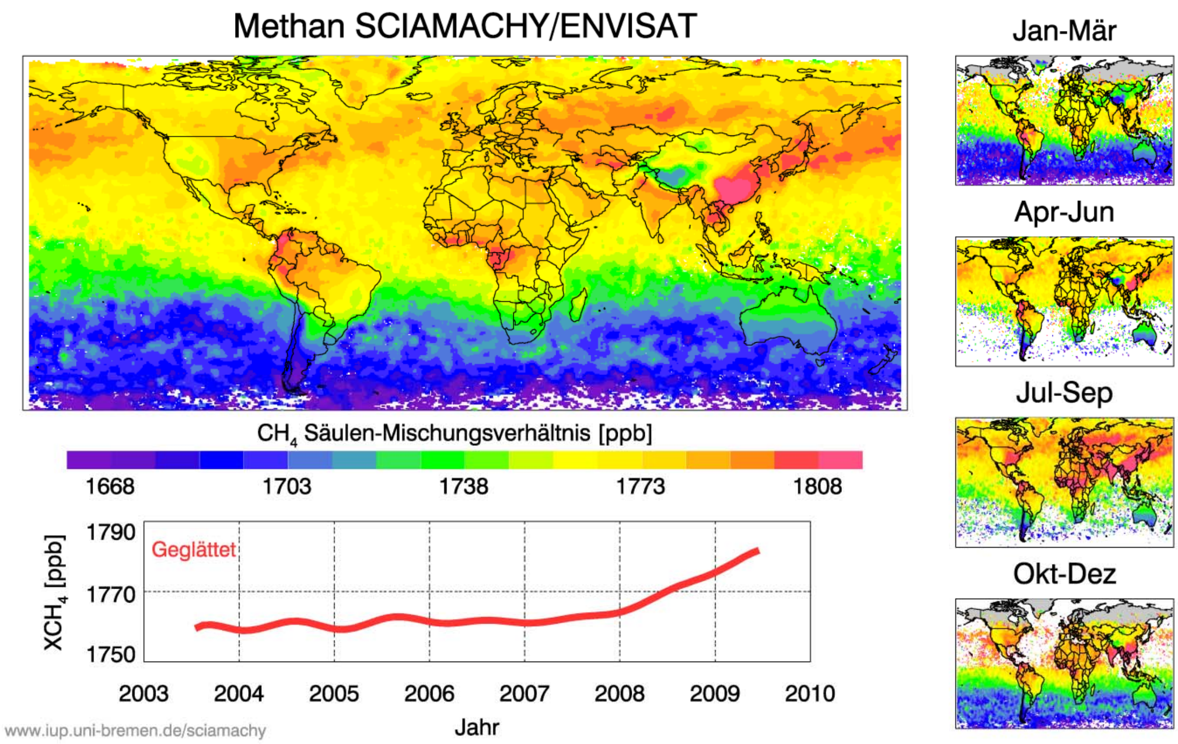

Figure 8 Map showing the worldwide distribution of methane, the seasonal variation and the average increase for the years 2003 – 2009 (Source: M. Buchwitz, IUP University of Bremen).

After ENVISAT, what next?

Presently, SCIAMACHY and ENVISAT are functioning perfectly and are expected to be operational until 2014 at the least. However, the fuel supply is slowly running short. The European Space Agency, in cooperation with the European Union and the weather satellite operator EUMETSAT, is currently planning new missions – the so-called 'Sentinel Missions' S4, S5 and S5P, which are to take place after SCIAMACHY. S5P und S5 shall make use of knowledge and findings that have been gained from SCIAMACHY, and Sentinel-4, originally conceptualized as GeoSCIA by the IUP in University of Bremen, shall transpose the measurement principle on the geostationary orbit. Almost all running data series shall be continued in these satellite missions, with one major exemption: it is no longer possible to observe and chart carbon dioxide, the most important manmade greenhouse gas. This is a great gap which is not easy to breach without ENVISAT. In 2010, a team of international scientists headed by the Institute of Environmental Physics, University of Bremen, has submitted a proposal to ESA, suggesting CarbonSat as a satellite mission specializing on CO_2 and methane. CarbonSat was then selected by ESA for a Phase A/B1 study and could be launched as 'Earth Explorer Mission' in 2019. Will SCIAMACHY on ENVISAT remain operational until then? Only time can tell.

Contact:
University of Bremen, FB 1, Institute of Environmental Physics
Prof. John P. Burrows
Telephone: 0421-218 62100
Fax: 0421 – 218 4555
E-Mail: burrows@iup.physik.uni-bremen.de

Dr. Stefan Noël
Telephone: 0421-218 62090
Fax: 0421 – 218 4555
E-Mail: stefan.noel@iup.physik.uni-bremen.de

Dr. Heinrich Bovensmann
Telephone: 0421-218 62102
Fax: 0421 – 218 4555
E-Mail: heinrich.bovensmann@iup.physik.uni-bremen.de

Web links:
www.iup.uni-bremen.de
www.dlr.de
www.esa.int