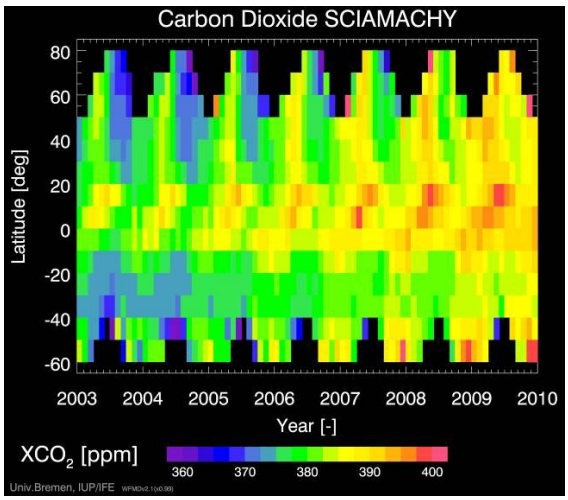
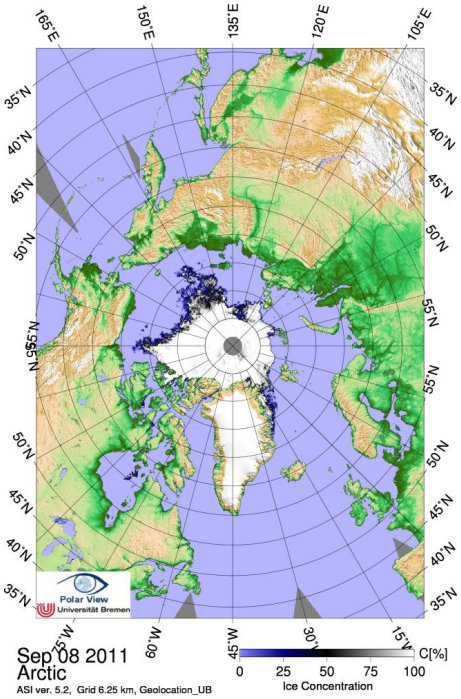
IUP Research Highlights 2010/2011

© IFM-GEOMAR





Institute of Environmental Physics (IUP)
Institute of Remote Sensing (IFE)
University of Bremen
Otto-Hahn-Allee 1, 28359 Bremen, Germany

Edited by: Christian von Savigny (IUP Bremen)

With contributions from: Maria-Dolores Andrés-Hernández, Astrid Bracher, John Burrows, Michael Buchwitz, Helmut Fischer, Dagmar Kieke, Annette Ladstätter-Weissenmayer, Christian Melsheimer, Stefan Noël, Justus Notholt, Mathias Palm, Monika Rhein, Andreas Richter, Christian von Savigny, Maren Walter, Thorsten Warneke, Mark Weber, Folkard Wittrock.

Bremen, March 15, 2012

Table of Content

1. Introduction 4

2. Remote sensing of the Earth System (Prof. Dr. Justus Notholt) 6
2.1. Ground-based remote sensing of greenhouse gases 7
2.2. Mercury pollution in Suriname 8
2.3. Mesosphere 9
2.3.1. Ground-based measurements of mesospheric properties above the Polar region 11
2.4. Sea Ice 13

3. Physics and Chemistry of the Atmosphere (Prof. Dr. John Burrows) 16
3.1. Phytooptics 16
3.2. Distribution of radical species in the lower layers of the troposphere 18
3.3. Carbon Dioxide and Methane from Satellite and Aircraft 19
3.4. Multi-Axis DOAS observations of tropospheric trace gases 22
3.5. Monitoring emission changes in Europe from space 24
3.6. Stratosphere 27
3.7. Stratospheric Methane Profiles from SCIAMACHY Solar Occultation Measurements 30
3.8. Noctilucent clouds – ice clouds at the frontier to space 33

4. Oceanography (Prof. Dr. Monika Rhein) 36
4.1. Rapid dispersal of a hydrothermal plume by turbulent mixing 36
4.2. Deep water formation, the subpolar gyre, and the meridional overturning circulation in the subpolar North Atlantic 39

5. Terrestrial Environmental Physics (Dr. Helmut Fischer) 40
About us 40
5.1. Routine and emergency program 40
5.2. Fukushima 40
5.3. Research 41
5.3.1. Dating of sediments using radioiso-topes 41
5.3.2. Nuclear and radiological security research 43

6. Teaching activities 46

1. Introduction

The mission statement of the Institute of Environmental Physics (IUP) is as follows:

"The overarching objective of the Institute of Environmental Physics is to understand the mechanisms controlling the Earth System and its response to change. This is achieved by using physical methods and research focuses on the sub systems atmosphere, ocean, cryosphere, and their interfaces. This requires the development and use of remote sensing techniques from the ground, from ships, aircraft and satellite platforms and in-situ measurements for process studies. The data are coupled with models to interpret the observations and improve the prediction of change."

The IUP comprises four departments: Remote Sensing, Physics and Chemistry of the Atmosphere, Oceanography, and Terrestrial Environmental Physics.

The ***Department of Remote Sensing*** employs passive remote sensing instrumentation such as Fourier transform interferometers and microwave radiometers taking measurements in the spectral region from the infrared to the microwave. The instruments are located at various ground based sites ranging from the high Arctic (Svalbard) to the tropics (Surinam), as well as aboard research vessels (R.V. Polarstern) and aircraft (Falcon). Furthermore, operational satellite instruments are used to monitor atmospheric and earth surface properties. Among them are sea ice coverage, water vapour and clouds. A further research focus is the investigation of stratospheric and mesospheric processes including solar effects on the terrestrial atmosphere. These activities are supported by atmospheric modelling.

The research activities carried out in the ***Department of Physics and Chemistry of the Atmosphere*** aim at improving the understanding of the complex physical chemical processes in the atmosphere and its interfaces to land, ocean, ice, and deep space. Emphasis is placed on the impact of climate change of either anthropogenic or natural origin on the composition of the troposphere, stratosphere, and mesosphere, including greenhouse gases, pollutants and reactive gases. A particular focus has been the scientific support and direction of the Global Ozone Monitoring Experiment (GOME) and Scanning Imaging Absorption spectroMeter for Atmospheric ChartograpHY (SCIAMACHY) missions. These satellite sensors allow characterizing the chemical composition of the atmosphere remotely by means of spectroscopy in the ultraviolet, visible and near-infrared spectral regions using grating spectrometers. Similar instruments are operated ground-based (NDSC stations, BREDOM network), on ships (R.V. Polarstern), planes and balloons. Remote sensing is complemented by in-situ experiments, laboratory work on spectroscopy and reaction kinetics, and modelling of physical and photochemical processes in the lower, middle and upper atmosphere.

The main research topics of the ***Department of Oceanography*** are the climate relevant processes in the Atlantic Ocean. The global meridional overturning circulation (MOC) plays an important role in the distribution of the heat received from the sun and thus for climate and climate change. Whether and how global warming will affect the circulation and how this will feed back on the climate is one of the central issues of marine research. The department studies – mainly with experimental methods – circulation, formation, and transformation changes in key regions of the Atlantic MOC, develops methods to infer the strength of the MOC, and improves and expands the tracer analysis techniques. Other interdisciplinary research themes are the role of vertical mixing in water mass transformation and at hydrothermal vents, the calculation of upwelling velocities at the equator and at the coast as well the dating of groundwater. The research is part of national and international programmes such as

CLIVAR (Climate Variability and Predictability) and CARBOOCEAN (EU Integrated Project).

The ***Department of Terrestrial Environmental Physics*** of the IUP investigates transport processes in porous systems and soils. It takes advantage of the excellent equipment available in the Bremen State Radioactivity Measurements Lab and of a unique Earth Field NMR apparatus.

The IUP is internationally well known for its participation in a number of advanced space-borne missions, like GOME and SCIAMACHY. Of particular importance is the Global Ozone Monitoring Experiment, GOME, which was the first satellite sensor to measure tropospheric trace constituents from space and has operated aboard ERS-2 for over 10 years. GOME is a smaller version of SCIAMACHY, which was launched successfully in 2002 and has now provided almost a decade of successful measurements. Both sensors, GOME and SCIAMACHY, were proposed by the IUP, and the IUP acts as Principal Investigator. The IUP is also involved in many international projects with space-borne instruments for remotely measuring the surface, such as sea ice, the Wadden sea and land use. In addition the IUP runs instrumentation at research measurement stations worldwide. It has participated in many international and national research campaigns using ships, aircraft and ground-based instruments. Members of the IUP are actively involved in the international scientific organisations like COSPAR, IGBP-IGAC, WCRP-SPARC, CACGP and WMO-IGACO.

More than 100 Ph.D. students and postdocs work at the IUP. Students in general physics have the possibility to specialize in environmental physics. A variety of courses is offered at the IUP, in cooperation with the colleagues from the Alfred-Wegener-Institut of Polar Research and Oceanography (AWI) in Bremerhaven. The aim of the environmental physics course is to provide a basic education in the areas of the ocean, the atmosphere and the solid Earth. Whereas other German universities cover parts of environmental physics, for example physical oceanography or meteorology as independent subjects, Bremen addresses all of them within the physics course fully integrated into the general physics. The students even have the opportunity to participate in exciting expeditions worldwide. To strengthen environmental physics as a course of study in its own right and also to motivate students from abroad to study in Bremen, a four-semester international course leading to a Master of Science (M.Sc.) in Environmental Physics and a two-semester postgraduate course for the Certificate in Environmental Physics have been offered since autumn 2000.

This document provides an overview of selected research highlights achieved by the members of the four IUP departments during the period 2010/2011.

Department Contacts:

Physics and Chemistry of the Atmosphere
Prof. Dr. John P. Burrows
+49-421-218 62100
burrows@iup.physik.uni-bremen.de

Remote Sensing
Prof. Dr. Justus Notholt
+49-421-218 62190
jnotholt@iup.physik.uni-bremen.de

Oceanography
Prof. Dr. Monika Rhein
+49-421 218 62160
mrhein@physik.uni-bremen.de

Terrestrial Environmental Physics
Dr. Helmut Fischer
+49-421-218 62761
hfischer@physik.uni-bremen.de

2. Remote sensing of the Earth System (Prof. Dr. Justus Notholt)

The department of Remote Sensing is one of the three departments at the Institute of Environmental Physics devoted to investigating the system Earth using physical methods. One focus of our department is the development and maintenance of ground-based remote sensing instruments and networks, mainly in the IR and microwave spectral ranges. A global network of measurement sites from the tropics to the high Arctic has been established, e.g., in Merida/Venezuela, Paramaribo/Suriname, Bremen/ Germany, Bialystok/Poland, Trainou/France and the Norwegian Island of Spitsbergen in the high Arctic. The observations at these specific sites are complemented by regular ship cruises. With these instruments, measurements of key atmospheric species are achieved, covering long periods of time, and detecting, e.g., tropospheric air pollution, the temporal development of greenhouse gas abundances, and the chemical composition of the middle atmosphere. Another focus of research is the application of satellite instrument data, e.g., to observe surface temperatures, sea ice cover, or the state of the middle and upper atmosphere. In this sense, in our department the atmosphere is sounded from the surface up to the edge of space. The observations are complemented by model studies, concentrating on process studies in the middle and upper atmosphere. Our research is funded mainly from external sources, like the DFG, BMBF and European programmes, but also by the senate of Bremen and the University.

Research Topics

Understanding on the one hand the impact of anthropogenic activities, and on the other hand, of extraterrestrial sources (e.g., solar variability or volcanic eruptions) onto the system Earth, is key to understanding present and future climate change. To separate between these two is a main task of climate research. In our department surface properties like the sea ice coverage, greenhouse gas concentrations, tropospheric pollutants, stratospheric composition as well as extraterrestrial impacts like meteoric metals or solar proton events, are detected and monitored. To interpret the observations, numerical models of the atmospheric composition are developed and maintained, in cooperation with the modelling group of the department of 'Physics and chemistry of the atmosphere' (Prof. Burrows).

Specific research topics include:

- monitoring tropospheric carbon dioxide and methane together with tropospheric pollutants using ground based FTIR measurements at different sites

- measuring stratospheric and mesospheric trace gases related to stratospheric ozone chemistry and the dynamics of the middle atmosphere using ground-based microwave and FTIR instruments

- using operational satellites in the microwave spectral region to study surface properties, like the sea ice coverage, or vegetation patterns, and water vapour and clouds on a global scale

- developing algorithms to derive mesospheric and lower thermospheric constituents from satellite emission measurements, in cooperation with the SCIAMACHY group in the department of 'Physics and chemistry of the atmosphere'

- development of three-dimensional chemistry and transport models from the tropopause to the lower thermosphere to investigate solar variability impacts into the middle atmosphere, the impact of anthropogenic emissions on the middle atmosphere, and the coupling between atmospheric layers

The following sections highlight selected research topics.

2.1. Ground-based remote sensing of greenhouse gases

Thorsten Warneke[1], Nicholas Deutscher, Christof Petri, and Justus Notholt

Mankind currently emits each year several gigatons of carbon into the atmosphere mostly as carbon dioxide (CO_2), mainly due to the burning of fossil fuel. Fortunately, only about 50% of the emitted CO_2 remains in the atmosphere and thus contributes to global warming. The other 50% are taken up by natural sinks - the terrestrial biosphere and the ocean. Methane (CH_4) is the second most important anthropogenic greenhouse gas after CO_2. It is emitted from highly variable and not well understood sources such as wetlands, rice fields and ruminants. Both CO_2 and CH_4 are regulated by the Kyoto Protocol.

In order to reliably predict the future climate of our planet a good understanding of the sources and sinks of CO_2 and CH_4 is mandatory. Unfortunately, there are large gaps in our understanding of the natural sources and sinks of these gases. Key questions to be answered are: Where are the natural and anthropogenic sources and sinks? How strong are they? What are their characteristics? How will they respond to a changing climate? Our group contributes to answering these questions by performing ground-based observations of greenhouse gases (GHGs) at a number of measurement stations around the globe, and by developing algorithms to retrieve GHG information from satellite and ground-based spectroscopic measurements.

Ground-based solar absorption FTIR-spectrometry is becoming a vital component in the global atmospheric observing system for greenhouse gases. It links in-situ measurements and remote sensing measurements. In-situ measurements are able to measure the surface amount of the greenhouse gases with high precision, but highly localized and without information about the vertical distribution of the gases. Remote sensing measurements provide a different quantity, the column integral, and satellites are able to provide global maps of the atmospheric greenhouse gas concentrations. The IUP started the first dedicated ground based remote sensing measurements of greenhouse gases in Europe in the high Arctic at Ny-Ålesund (Spitsbergen) and at Bremen (Germany) (Figure 2-1, Figure 2-2, Figure 2-3). Since the absolute calibration of the column measurements must be firmly tied to the existing in-situ network it is highly important to co-locate FTIR and vertically resolved in-situ measurements. For this reason the IUP has upgraded two of the existing main European sites for atmospheric greenhouse gas observations, Bialystok (Poland) and Orleans (France) with solar absorption FTIR-spectrometers. These two sites will form the backbone for the integration of the satellite data into the existing European atmospheric measurement systems for greenhouse gases.

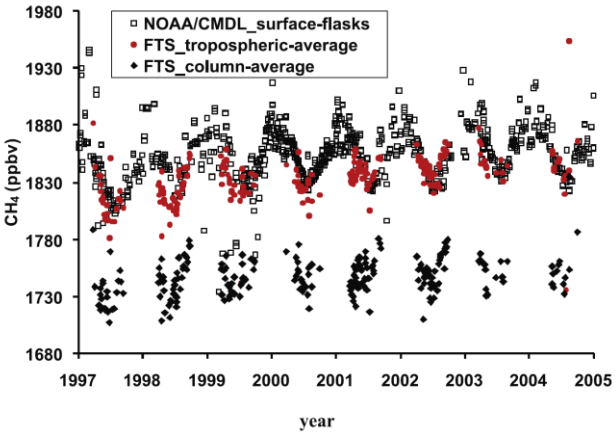


Figure 2-1: Ground-based Fourier Transform Spectroscopic (FTS) measurements of the column averaged Volume Mixing Ratio (VMR) of CH_4 (solid black diamonds) and tropospheric VMRs of CH_4 (red circles) compared with NOAA-ESRL surface in-situ sampling (open black squares) at Ny Alesund (Spitsbergen). The ground-based FTS measurements have a precision of better than 0.5%. The large difference between the tropospheric and column averaged VMRs is due to the decrease of CH_4 in the stratosphere.

[1] E-mail: warneke@iup.physik.uni-bremen.de

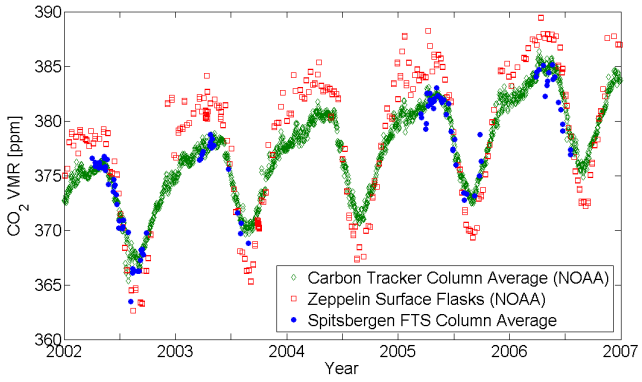


Figure 2-2: Seasonality of column averaged VMR of CO_2 measured by ground-based Fourier Transform Spectroscopy (blue circles) compared with model data (green diamonds) and surface CO_2 in-situ measurements (red squares).

Figure 2-3: FTIR-observatory at the University of Bremen

2.2. Mercury pollution in Suriname

Thorsten Warneke, Dennis Wip, Denise Müller and Justus Notholt

Mercury has a variety of documented, significantly adverse impacts on human health and the environment. In the Amazon region, large amounts of mercury are released in the environment as a result of small-scale and artisanal gold mining. It is estimated that in Suriname 20.000 kg/year are discharged into the environment. These amounts are one order of magnitude larger than other important mercury sources in Suriname, namely the bauxite refining industry and biomass burning. The mining activities take place in the greenstone belt in the southeast of Suriname, where miners are dispersed in an area of approximately 20.000 km^2 (Figure 2-4). The government is not present in this area, as it is difficult to access, and therefore there is almost no Government control of the mining operations. Artisanal gold mining in this region is still increasing, due to a lack of opportunities for unskilled people in the interior and due to migration of Brazilian gold miners to Suriname. Efficient gold-extraction methods are not known to most of the miners resulting in high amounts of mercury used. In many cases the whole ore is amalgamated, which could result in mercury losses of 3 times the amount of gold produced. The lack of knowledge about the danger of mercury vapors and a diet heavily relying on river fish results in high exposure of the miners and their families to mercury. The threats of mercury exposure are not limited to the interior. The gold miners sell the gold to gold shops in the City of Paramaribo. During the purchasing process, the gold is melted and the residual mercury is released. This results in mercury emissions that potentially represent a serious health hazard to the population of Paramaribo.

The IUP, in cooperation with the Anton de Kom University of Suriname, performs mercury measurements as well as capacity building related to mercury pollution monitoring and training of gold miners in environment-friendly and safe mining techniques (Figure 2-5 and Figure 2-6). These activities were partly funded by the United Nations Environment Programme (UNEP). The first measurements of elemental gaseous mercury in ambient air in Suriname at different sites demonstrate that the Hg^0 mean concentration level in clean air coming from the Atlantic is 1.4 ng/m^3. Emissions of mercury from gold-shops in the City of Paramaribo result in Hg^0 maximum concentrations of 109 ng/cm3 and a mean concentration level of about 6 ng/m^3 in the City of Paramaribo (Figure 2-6). These levels are comparable with world cities in Asia and North America and represent no risk for the general public. A survey inside and in the close vicinity of the gold-shops shows high mercury concentration levels that are above the minimal risk level.

Figure 2-4: Gold mining area in the Surinamese rain forest

Figure 2-5: Training of miners in the field

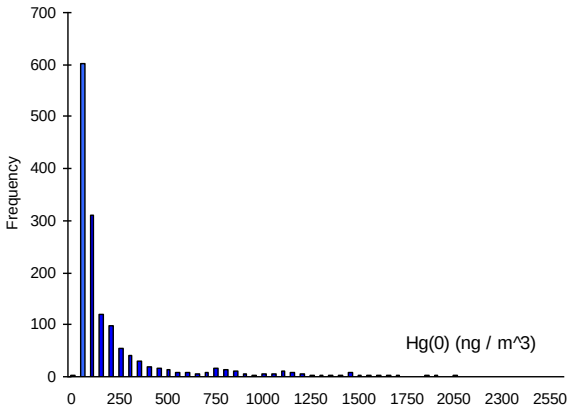


Figure 2-6: Typical distribution of mercury concentrations measured in the City of Paramaribo. High concentrations are due to emissions from shops that buy the gold from the miners and evaporate off the residual mercury.

2.3. Mesosphere

Mathias Palm[2], Christoph Hoffmann, Stefan Kowalewski, Miriam Sinnhuber, Nadine Wieters, Holger Winkler, and Justus Notholt

The mesosphere, the altitude region between about 50 - 90 km acts as a transition region between what is commonly referred to as 'space', and the atmosphere. It is affected both by processes propagating up from the Earth's surface and by extraterrestrial impacts. Greenhouse gases which are stable in the lower atmosphere are transported up to the mesosphere or even lower thermosphere, where they are destroyed photolytically. Gravity waves, which are excited at the surface, can under certain conditions propagate up to the mesopause, where they break, transferring energy from the surface to the upper atmosphere. On the other hand, meteors propagating into the Earth system start to evaporate around 105 km altitude, and ablate metals into the mesosphere and lower thermosphere which are the precursors for meteoric smoke particles. Highly energetic protons and electrons from solar eruptions or the radiation belts of the Earth leave most of their energy in the mesosphere, changing the chemical composition and possibly also the dynamics of this region. There is increasing evidence that air from the mesosphere or even from the lower thermosphere can be transported down to the stratosphere, thus coupling processes in the mesosphere (or lower thermosphere) to the lower atmosphere. In a paper from the year 2000, the mesosphere was nicknamed the 'ignorosphere' because of the lack of measurements in this region. Since then, the situation has improved with the start of several satellite missions which can observe the mesosphere and lower thermosphere, but it is still the atmospheric region which we know least about.

At the Institute of Environmental Physics, we use measurements from different platforms together with

[2] E-mail: mathias@iup.physik.uni-bremen.de

numerical models of the chemistry and dynamics of the stratosphere and mesosphere to test our understanding of processes in the mesosphere, and their relation to the lower atmosphere.

Several ground-based microwave instruments have been developed and are maintained at different research stations, in Bremen, in Ny-Ålesund, Spitsbergen (78°N, see Figure 2-7), and in Merida, Venezuela (8°N). Microwave radiometers can obtain altitude information of atmospheric constituents up to the mid-mesosphere (~60 – 70 km altitude) due to the effect of pressure on the line shape of the rotational transitions emitting in the microwave or submillimeter-wave region. As the method is independent of external light sources, measurements can also be obtained during night-time and during polar night. Thus, the diurnal variation of the observed species can be studied, which is quite useful to test our understanding of the photochemistry driving this variation. The high latitudes during winter provide a very important link between the upper and lower atmosphere, as only during this time, large-scale downwelling of air is possible. However, most satellite measurements do not cover very high latitudes due to the satellite orbit, and rely on solar light for measurements, thus can not measure during polar night. Therefore, the ground-based microwave measurements at Ny-Ålesund provide a unique data set of measurements during polar night. At the moment, measured substances are ozone and water vapour. However, the instrument is currently being extended to target a rotational transition of CO, the thermospheric end-product of CO_2, which is transported down into the lower atmosphere during polar winter, and can be used as a marker for downwelling of air from the thermosphere into the lower atmosphere.

A focus of our work is the investigation of the impact of energetic particle precipitation - protons, electrons and heavier ions from solar wind, solar eruptions and the trapping regions of the magnetosphere - on the atmosphere. Large solar particle events originating from solar flares or solar coronal mass ejections (see Figure 2-8) are known sources of reactive nitrogen and hydrogen compounds in the mesosphere and stratosphere, both of which contribute to ozone loss there. To test our understanding of these events, and to quantify their impact on stratospheric ozone and the lower atmosphere, we have developed global chemistry, radiation and transport models of the stratosphere and mesosphere which consider atmospheric ionisation. Model studies show a long-lasting impact of these events on the total amount of ozone, which, however, is small compared to the dynamical variability of total ozone, or compared to the anthropogenic 'ozone hole'. New studies using data from the HALOE / UARS satellite instrument show that energetic particles from the radiation belts – electrons that are accelerated by geomagnetic substorms – can also have a quite significant impact on stratospheric ozone, although the direct impact of these events on the chemical composition of the stratosphere and mesosphere is still highly uncertain, because of a lack of direct measurements.

Figure 2-7: The high-latitude research station in Ny Alesund, Spitsbergen, photographed from the air. In the small picture on the left, the observatory containing our microwave radiometers is shown, which can also be made out in the middle of the larger picture. Pictures by M. Palm (IUP Bremen).

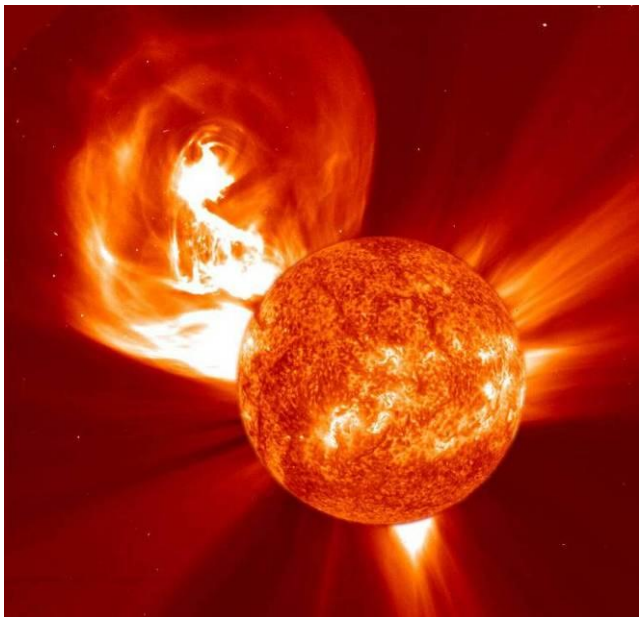


Figure 2-8: A snapshot of the sun, courtesy of the EIT / C2 / SOHO consortium, from January 2002. SOHO is a project of international cooperation between ESA and NASA. In the upper left of the picture, a large solar coronal mass ejection can be identified, a massive eruption from a very active region on the sun's surface (Courtesy of SOHO consortium. SOHO is a project of international cooperation between ESA and NASA).

2.3.1. Ground-based measurements of mesospheric properties above the Polar region

The IUP operates two ground-based instruments to measure properties of the polar mesosphere: The microwave radiometer OZORAM (Palm, 2010) has been designed for measuring an ozone emission line in the millimeterwave region up to the lower mesosphere (see Figure 2-9). The FTIR (Fourier Transform InfraRed spectrometer) in Ny Ålesund is used to measure mesopause temperatures at around 87 km altitude. Additionally, a data set measured in Kiruna by the IRF Kiruna in cooperation with the KIT Karlsruhe is used for the study of mesospheric dynamics in the Arctic mesosphere.

The high latitudes during winter provide a very important link between the upper and lower atmosphere, as only during this time large-scale down-welling of air is possible. However, most satellite measurements do not cover very high latitudes due to the satellite orbit, and rely on solar light for measurements, thus can not measure during polar night. Therefore, the ground-based microwave measurements at Ny Ålesund provide a unique data set of measurements during polar night.

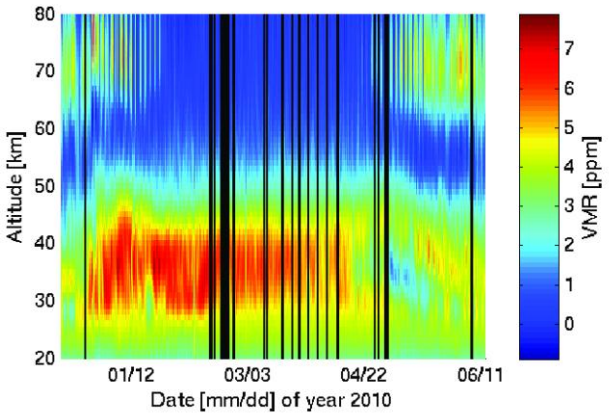


Figure 2-9: Time series of ozone throughout the year 2010 measured by the millimeterwave radiometer OZORAM.

Measurements of high altitude ozone above the Arctic

The millimeterwave radiometer OZORAM is designed to measure the thermally excited rotational transition of ozone at 142 GHz. Figure 2-9 shows the development of ozone above the Arctic during the year 2010.

The mesospheric ozone maximum in polar winter and during twilight conditions between September and April can be observed. This maximum is caused by the equilibrium reaction

$$O_3 + h\nu \longleftrightarrow O_2 + O$$

which is almost completely on the side of O_3 in the absence of light.

While the diurnal variation of mesospheric ozone is well known, it also exhibits a distinct diurnal dependency during polar day in the middle stratosphere as can be observed in Figure 2-10. The

reason for this diurnal change is the attenuation of solar light which depends on the elevation of the sun.

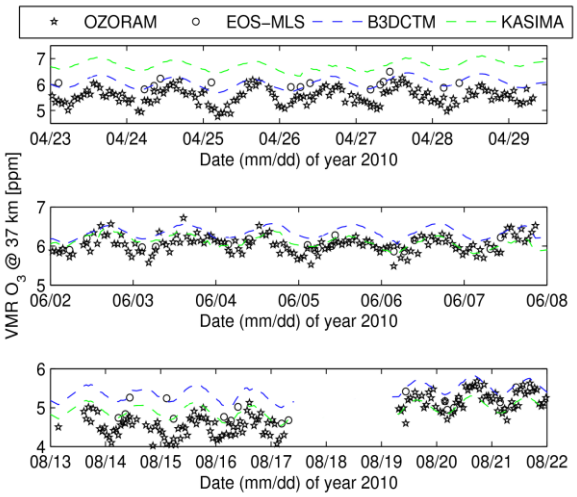


Figure 2-10: The diurnal variation of ozone at 37 km altitude above the Arctic during polar day 2010 as measured by the OZORAM and the satellite-borne MLS instrument and as modelled by two state-of-the-art atmospheric models (B3DCTM and KASIMA).

The major circulation patterns can well be observed in Figure 2-9. The down-welling of air above the winter pole can be observed starting in the end of August. Because ozone is dynamically controlled in the polar winter, the mixing ratio is preserved. This can very well be observed in the autumn of 2010, where the stratospheric maximum is transported from 37 km altitude to little more than 30 km altitude within two months time.

Measurements of CO above Kiruna

The KIMRA instrument in Kiruna, Sweden is operated by the IRF Kiruna. It is designed to measure the thermally excited rotational line of CO at 230 GHz. Because of the unique features of CO in the middle atmosphere, it can be used to track air-masses above the polar regions.

In Figure 2-11 a time series of CO above northern Sweden during the winter 2009/10 is plotted. At the beginning of September the air above the pole starts to descend, thus creating the so called polar vortex, an enclosed airmass above the pole.

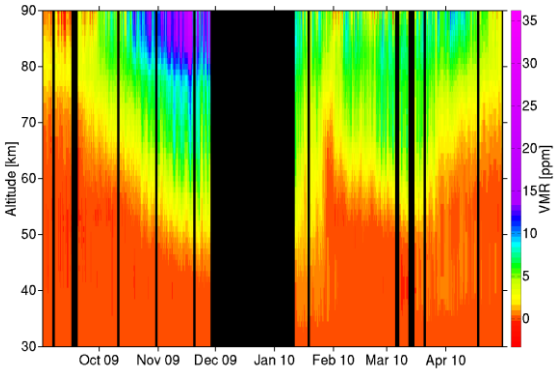


Figure 2-11: Time series of CO measured by the millimeterwave radiometer KIMRA above Northern Sweden. Blackened areas correspond to times without measurements.

This descent is disrupted in the middle of January 2010 when a major disturbance of the polar vortex took place, a so-called sudden stratospheric warming. What actually happens to the air above the pole is still a topic of research but it is likely that CO poor air from the mid-latitudes is inserted into the polar stratosphere and vertical uplifting occurs. Both effects combined create the impression in Figure 2-11 that the air is rapidly moving up. After the event, the polar vortex reforms and the air starts descending again until the polar vortex breaks up in middle of March during the change from the winter to the summer circulation pattern of above the Arctic.

Measurement of mesopause temperature above Spitsbergen using FTIR-spectroscopy

Exploiting a unique feature of the mesosphere, a thin layer of chemically excited OH at about 87 km altitude it is possible to derive the temperature of this region by analysing the spectrum of the de-excitation of OH (compare Figure 2-12).

Because of the circulation patterns in the atmosphere, the temperature in this region is very

sensitive to changes in the circulation which can be caused elsewhere in the atmosphere.

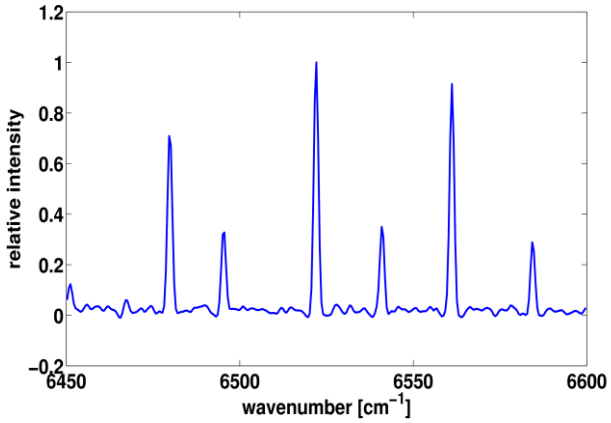


Figure 2-12: OH spectrum measured on 28th of January 2011 corresponding to a temperature of 227 K. Shown are the rotational transitions of the de-excitation of vibrational state 3 to vibrational state 1. Those transitions are commonly used for temperature retrieval of the mesopause region.

References

Palm, M., et. al., The ground-based MW radiometer OZORAM on Spitsbergen – description and status of stratospheric and mesospheric O_3-measurements, Atmos. Meas. Tech., 3, 1533 – 1545, 2010.

2.4. Sea Ice

Christian Melsheimer[3], Georg Heygster

The inaccessible polar regions belong to the regions of the world of which the least information on weather and climate is available. In the Arctic, regular (daily) measurements of, e.g., temperature, air pressure, wind, clouds and precipitation can only be made by weather stations surrounding the Arctic Ocean, on the northern coasts of Eurasia and America. In the Antarctic, such measurements can only be made at a handful of research stations on the Antarctic continent, most of which are near its coast. Observations of the sea ice on the polar seas from ships are equally sparse and cannot cover the entire polar regions. Satellite remote sensing, i.e., observing and measuring from satellites, is therefore essential for monitoring weather and climate in the polar regions. But here as well, these regions pose a challenge as many established remote sensing methods that have been developed for earth observation do not work in polar conditions: Clouds, e.g., may be hard to distinguish from snow or sea ice. In addition, the surface and the atmosphere in polar regions cannot be observed separately: In order to look at the atmosphere (e.g., temperature, humidity, clouds), it is essential to know about the surface, but the sea ice cover of the polar oceans can change within hours to days because of ice drift, freezing and thawing. Likewise, in order to look at the surface (e.g., snow/ice cover, temperature) it is essential to know about the atmosphere.

A major research topic is therefore the Arctic and Antarctic sea ice. From microwave data of AMSR-E (Advanced Microwave Scanning Radiometer - Earth Observing System, on NASA satellite Aqua), the PHAROS group at the IUP produces daily or twice daily maps of global sea ice cover, at a resolution of 6.25 km. The sea ice cover is measured in per cent, i.e., the percentage of surface in each resolution cell (e.g., 6.25 by 6.25 km) that is ice-covered. This percentage is usually called sea ice concentration. For about 20 special regions (e.g., Baltic Sea, Bering Strait, Ross Sea), additional sea ice maps are produced at an even higher resolution of 3.125 km. Such sea ice charts have a number of routine users, such as research vessels, which use them for planning their route. The daily sea ice maps clearly show the seasonal variation of the ice cover. It reaches its maximum in early spring of the respective hemisphere, i.e., in March in the Arctic and in September in the Antarctic, and reaches its minimum in early autumn, i.e., September (Arctic) and March (Antarctic). A common measure for the areal extent of the sea ice is the total area with an ice concentration above 15%. The period for which we have daily sea ice maps reaches back to 2002 which allows looking for changes. The time series of the total Arctic ice extent clearly shows the dramatic and

[3] E-mail: melsheimer@uni-bremen.de

unprecedented sea ice minimum in the Arctic in September 2007, which undercut the previous "record" from 2005 by more than 20% (see Figure 2-13 and Figure 2-14). The Arctic sea ice minimum in September 2011 was very close to the 2007 minimum, and the three minima in 2008, 2009, and 2010 were well below all previous minima before 2007. In other words, the five consecutive Arctic sea ice mimima from 2007 to 2011 are the lowest on record (there have been satellite observations of global sea ice since the early 1970s). Sea ice maps from August and September 2008 show another unusual feature: For the first time in many years, both the Northwest passage (seaway north of America) and the Northeast passage (seaway north of Eurasia) were ice-free.

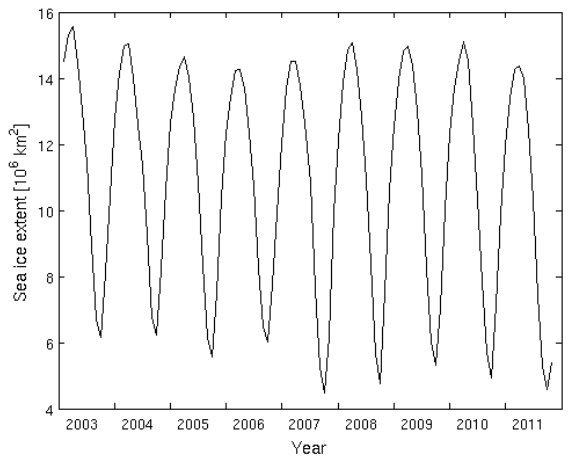


Figure 2-13: Monthly Arctic sea ice extent 2003-2011.

While the 2011 minimum hinted at the fact that the 2007 minimum was not one singular outlier, it remains to be seen in the years to come if the sea ice decline continues at a quicker pace or if it will revert to the somewhat slower rate already observed since the 1980s. Note that in the Antarctic, there is no clear trend of the sea ice extent. The direct causes of the extreme Arctic sea ice minima of the last five years are still being investigated – rather than just attributing them to global warming, one wants to know which of the following processes are most relevant for the sea ice decline: (1) changes in the ocean currents, (2) changes in the prevailing winds, (3) changed cloudiness, or (4) increased air temperature. In order to understand and predict how the sea ice will react to ongoing change, knowledge of the sea ice thickness and the snow cover on the sea ice are essential. In addition, the so-called albedo matters, i.e., the ability of the sea ice surface to reflect sunlight (albedo literally means "whiteness") – the less bright the ice, the more sunlight it absorbs and the more rapidly it might melt. The albedo of the Arctic sea ice can indeed be significantly altered by dust and soot transported by the winds over large distances into the Arctic. At the IUP a new method has been tested and implemented which derives the snow grain size and the soot concentration of snow from optical and infrared data of the MODIS instrument (Moderate Resolution Imaging Spectroradiometer on the European research satellite ENVISAT).

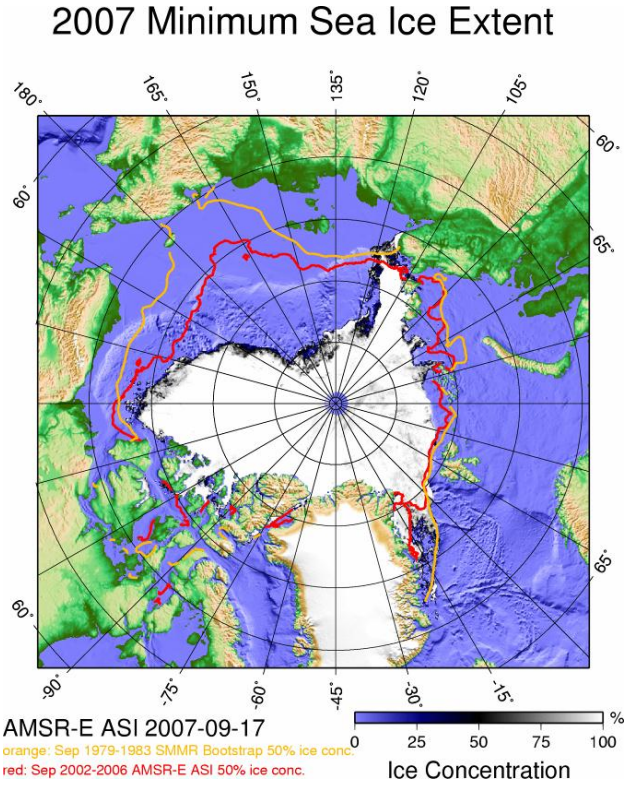


Figure 2-14: Map of the Arctic sea ice cover during the record minimum in September 2007, compared to the average minima in 2002-2006 (orange contour), and 1979-1983 (red contour).

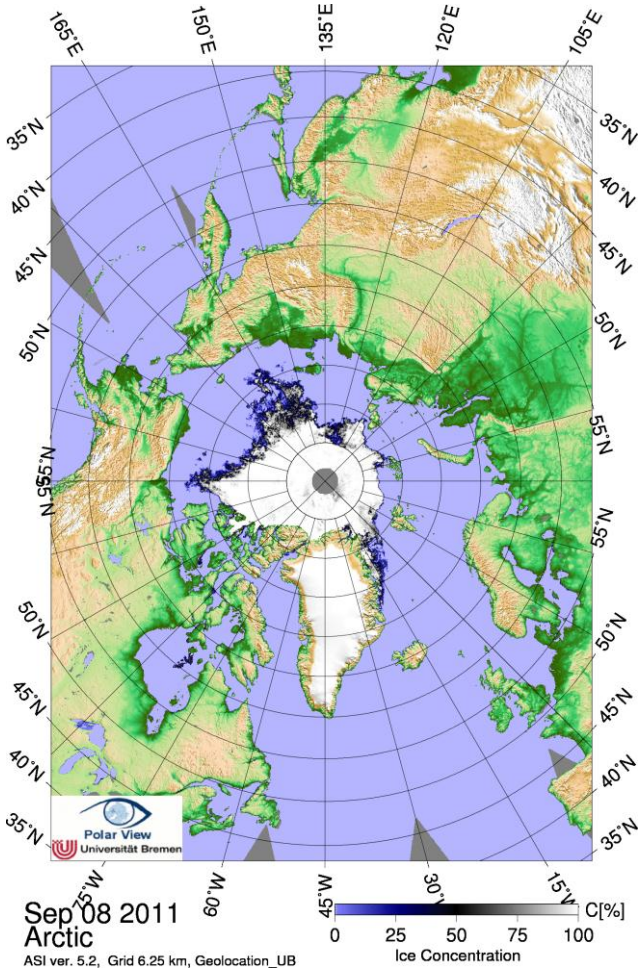


Figure 2-15: Map of the Arctic sea ice on 8 September 2011, during the 2011 minimum.

3. Physics and Chemistry of the Atmosphere (Prof. Dr. John Burrows)

3.1. Phytooptics

Astrid Bracher[4], Tilman Dinter, Alireza Sadeghi, Bettina Taylor, Marco Vountas

Marine phytoplankton represents the basis of the marine food web and plays an important role as a biological pump within the global carbon cycle. The Helmholtz Young Investigators Group PHYTOOPTICS, a cooperation between the Alfred-Wegener-Institute for Polar and Marine Research (AWI, Climate Sciences) and the Institute of Environmental Physics at the University of Bremen (IUP) aims at improving estimates of marine primary production by retrieving new biooptical information from the European satellite SCIAMACHY in addition to using the data of the common ocean colour sensors. The methods include working on remote sensing retrievals, measuring in-situ biooptical and biogeochemical parameters of phytoplankton and light conditions during various cruises with the research vessels “Polarstern“ , “Maria S. Merian“, “Poseidon“ and “Sonne“ (See Figure 3-1), and developing models to calculate radiative transfer and primary production. Through a better knowledge of the sinks and sources of CO_2 in the ocean a contribution will be made to a better understanding of changes in the world's climate as well as to the understanding of the marine food web. The last two years focused on the development of the PhytoDOAS method. This retrieval technique applied to data of the satellite instrument SCIAMACHY enables us to determine not only the general global distribution of phytoplankton, but also its composition in terms of different functional groups of phytoplankton. These temporally highly resolved global maps enable to derive how much CO_2 is fixed as organic carbon, and how much oxygen and food is produced by marine microalgae. Since different algae groups have different functions within the marine ecosystem and carbon cycle, the maps enable to observe their temporal changes and to improve estimates on the effect of climate change.

In order to understand the marine phytoplankton’s role in the global marine ecosystem as well as biogeochemical cycles it is necessary to derive global information on the distribution of its biomass and primary production, in particular the distribution of major phytoplankton functional types (PFT) in the world oceans. Using “common” ocean color sensors like SeaWiFS or MERIS, only the overall phytoplankton biomass or the dominant phytoplankton group can be derived. In order to get a global quantitative estimate of different PFTs in the oceans, we adapted the technique of Differential Optical Absorption Spectroscopy (DOAS), which has been established for the retrieval of atmospheric components, for the retrieval of the absorption and biomass of two major phytoplankton groups (PhytoDOAS) from data of the Scanning Imaging Absorption spectroMeter for Atmospheric CHartography (SCIAMACHY) satellite sensor. SCIAMACHY measures back-scattered solar radiation in the UV-Vis-NIR spectral regions with a high spectral resolution (0.2 to 1.5 nm). In order to identify phytoplankton absorption characteristics in SCIAMACHY data in the spectral range of 430 to 500 nm, phytoplankton absorption spectra measured in-situ during two different RV (research vessel) “Polarstern” expeditions were used. The two spectra have been measured in different ocean regions where different phytoplankton groups (cyanobacteria and diatoms) dominated the phytoplankton composition. Results show clearly distinct absorption characteristics of the two phytoplankton groups in the SCIAMACHY spectra. Using these results in addition to calculations of the light penetration depth derived from DOAS retrievals of the inelastic scattering, globally distributed pigment concentrations for these characteristic phytoplankton groups for monthly periods were determined. This satellite information

[4] E-mail: bracher@uni-bremen.de

on cyanobacteria and diatom distributions matches well the concentrations based on high pressure liquid chromatography (HPLC) pigment analysis of collocated water samples and concentrations derived from a global model analysis with the NASA Ocean Biogeochemical Model (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.modelDay.shtml). This method has been improved for detecting four different types of PFTs by using simultaneous fitting of the differential specific absorption spectrum of each PFT to the satellite measurement. These PFTs are diatoms, cyanobacteria, dinoflagellates and coccolithophores. The whole SCIAMACHY data set has been analysed retrieving phytoplankton biomass (2002 until today). An example is shown in Figure 3-2. The quantitative assessment of the distribution of key phytoplankton groups from space enables various biogeochemical provinces to be distinguished and has already been used for improving regional and global modeling of marine ecosystem and biogeochemical cycles which enables to assess the impact of climate change in the oceanic biosphere. Temporal variations of coccolithophore blooms using the PhytoDOAS technique are investigated in three selected regions characterized by frequent occurrence of large coccolithophore blooms.

Figure 3-1: Radiometric measurements of radiances and irradiances onboard research vessel "Polarstern" to validate ocean color data of satellite sensors MERIS, MODIS and SeaWiFS. Photo: Anja Bernhardt, AWI.

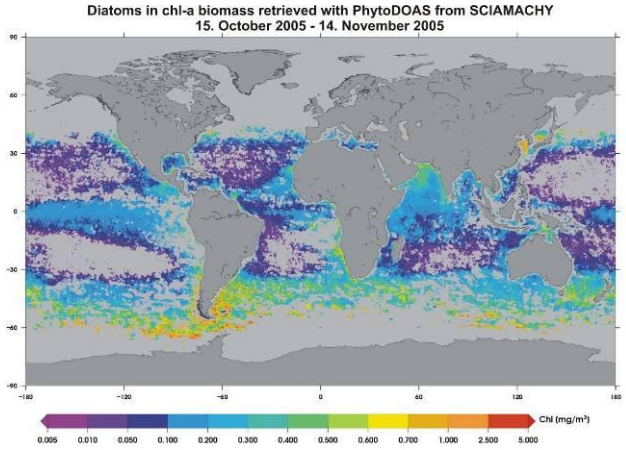


Figure 3-2: Monthly average (October 15 to Nov 15, 2005) global distribution in chl-a concentration of diatoms determined by using the PhytoDOAS with SCIAMACHY data (Figure from Bracher et al. (2009)).

References

Bracher A., Vountas M., Dinter T., Burrows J. P., Röttgers R., Peeken I., Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data, Biogeosciences, 6, 751 – 764, 2009.

Sadeghi, A., Dinter, T., Vountas, M., Taylor, B., Peeken, I., and Bracher, A., Improvements to the PhytoDOAS method for identification of major phytoplankton groups using hyper-spectral satellite data, Ocean Sci. Discuss., 8, 2271 – 2311, 2011.

Sadeghi A., Dinter T., Vountas M., Taylor B., Altenburg Soppa M., Bracher A., Remote sensing of coccolithophore blooms in selected oceanic regions using the PhytoDOAS method applied to hyper-spectral satellite data, Biogeosciences Discuss., 8, 11725 – 11765, 2011.

Taylor B., Torrecilla E., Bernhardt A., Taylor M. H., Peeken I., Röttgers R., Piera J., Bracher A.: Bio-optical provinces in the eastern Atlantic Ocean, Biogeosciences, 8, 3609 – 3629, 2011.

Vountas M., Dinter T., Bracher A., Burrows J. P., Sierk B., Spectral studies of ocean water with space-borne sensor SCIAMACHY using Differential Optical Absorption Spectroscopy (DOAS), Ocean Science, 3, 429 – 440, 2007.

3.2. Distribution of radical species in the lower layers of the troposphere

Maria-Dolores Andrés-Hernández[5], Markus Horstjann, Deniz Kartal and John Burrows

The IUP-Bremen has a long-term experience with measurements of peroxy radicals, very reactive species playing a crucial role in the formation and depletion mechanisms of O_3 in the troposphere. Simultaneous and accurate measurements of these radicals, their precursors and the products of their reactions in polluted and remote environments are required to test our understanding of the processes determining the chemical behavior of the troposphere. Although radical chemistry in the troposphere has been subject of intensive research in the past three decades, very little is still known about the vertical distribution of peroxy radicals. Airborne observations are scarce in spite of being especially important to improve the understanding of tropospheric chemistry and the oxidative capacity of the atmosphere at different altitudes.

Recent measurements within convective episodes have raised considerable scientific interest, as the injection of organic radical precursors has been traced up to 12 km altitude. In the presence of enough NO from lightning, biomass burning and aircraft emissions, these precursors can actively promote the O_3 production in the upper layers via radical formation, which can have a global impact presently underestimated in model calculations. Similarly, airborne measurements in the boundary layer have shown the crucial influence of vegetation in the prevailing chemistry at the tropospheric layers close to the ground.

The IUP-Bremen investigates the link between the variability of the oxidative capacity of the lower layers of the troposphere and the vertical and horizontal distribution of peroxy radicals and their precursors by analysing airborne and ground based measurements over sites with different vegetation cover and precursor patterns. Field measurements were carried out in summer 2010 on board of the INTA (Instituto Nacional de Técnicas Aeroespaciales) C212 aircraft in the frame of the EUFAR project VERDRILLT **(VER**tical **D**istribution of **R**adicals **I**n the **L**ower **L**ayers of the **T**roposphere) and in cooperation with the DLR (Deutsches Zentrum für Luft- und Raumfahrt), the University of Wuppertal, the CEAM (Centro de Estudios Ambientales del Mediterráneo) and the UPV-EHU University in Bilbao. The results are presently being evaluated.

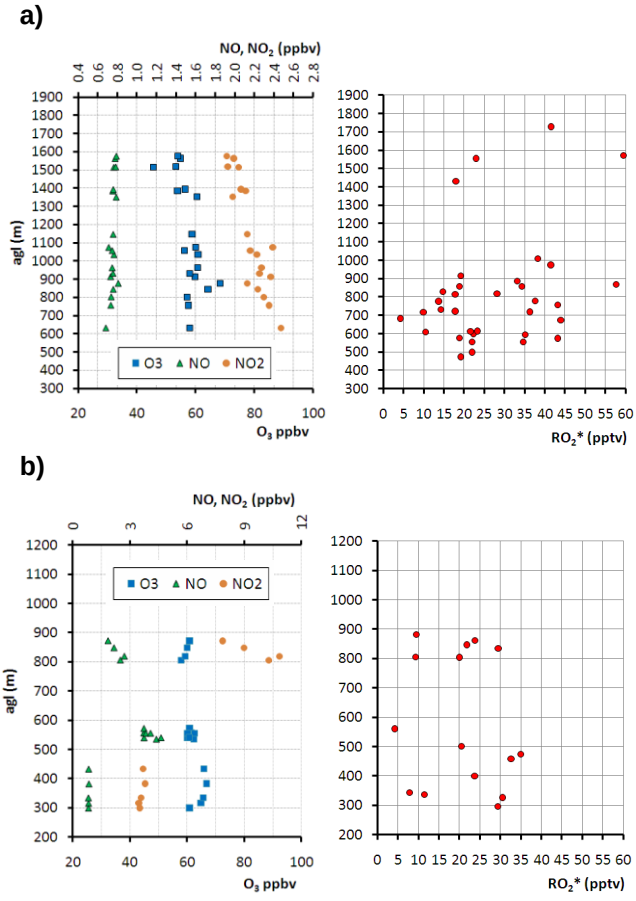


Figure 3-3: Example of vertical profiles of trace gases measured during VERDRILLT over a) a semi-rural coastal area, b) an urban area. The flight track is shown in the top panel in red. agl = altitude above ground level.

[5] E-mail: lola@iup.physik.uni-bremen.de

3.3. Carbon Dioxide and Methane from Satellite and Aircraft

Michael Buchwitz[6], Heinrich Bovensmann, Konstantin Gerilowski, and John Burrows

Carbon dioxide (CO_2) and methane (CH_4) are the two most important man-made („anthropogenic“) greenhouse gases (GHG) contributing to global climate change via their global warming potential. Despite their importance our understanding of their variable natural and anthropogenic surface sources and sinks has large gaps. This limits the reliability of the prediction of the future climate of our planet.

Most of our knowledge about CO_2 and CH_4 sources and sinks stems from accurate but sparse networks of surface observations performing local point measurements. Satellite observations of greenhouse gases can add important information due to their global coverage. This however requires high measurement sensitivity to CO_2 and CH_4 concentration changes close to the Earth's surface, where the source/sink signals are largest.

At present only two satellite instruments are in orbit, which fulfil these requirements: The IUP-Bremen led SCIAMACHY instrument on ENVISAT and the recently launched Japanese GOSAT satellite. Because of the relatively large footprint size of the satellite data, small scale (~100 m) surface fluxes cannot be resolved. In order to measure greenhouse gases also on this scale, the Methane Airborne Mapper (MAMAP) instrument has been developed at IUP-Bremen in collaboration with the Geoforschungszentrum (GFZ) Potsdam in Germany. In the following selected results from the two instruments SCIAMACHY and MAMAP will be presented.

Results from satellites derived from SCIAMACHY on ENVISAT

The IUP-Bremen is one of the leading institutes in the world in the new area of satellite remote sensing of greenhouse gases (GHG). IUP-Bremen is leading the GHG-CCI project of ESA's Climate Change Initiative (CCI) which will deliver the European "Essential Climate Variable" (ECV) Greenhouse Gases (http://www.esa-ghg-cci.org/). At IUP retrieval algorithms are being developed and continuously improved to convert the spectra of reflected solar radiation as measured by SCIAMACHY into atmospheric CO_2 and CH_4 concentrations ("column-averaged mixing ratios"). Among the highlights in 2010/11 were major results which have been obtained by analyzing the SCIAMACHY global GHG time series now covering more than 7 years as shown in Figure 3-4 to Figure 3-6. For example, the analysis of the SCIAMACHY data suggests larger CO_2 uptake by terrestrial vegetation during the vegetation growing season by the Canadian boreal forests compared to Siberia than a state-of-the-art model (Schneising et al., 2011). A major highlight was also the successful first application of the new advanced SCIAMACHY CO_2 retrieval algorithm BESD (Reuter et al., 2010, 2011) to real SCIAMACHY data (Figure 3-7).

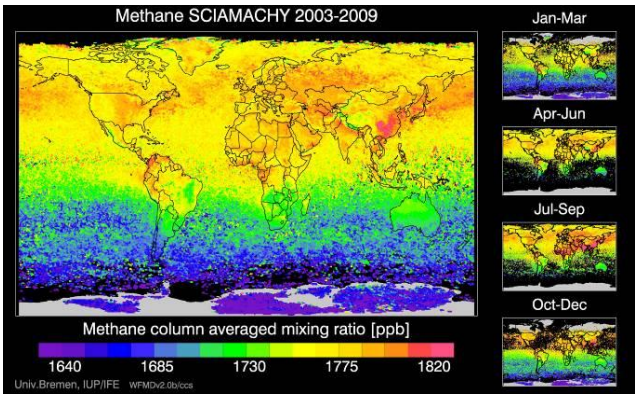


Figure 3-4: Global maps of column-averaged mixing ratios of methane as retrieved from SCIAMACHY/ENVISAT during 2003-2009. Major source regions of methane can be clearly identified such as China and India (methane emissions from rice fields, wetlands, ruminants and other sources).

Carbon Monitoring Satellite (CarbonSat)

To continue the global satellite derived GHG time series, which started with SCIAMACHY in 2002, the IUP has proposed the "Carbon Monitoring Satellite" (CarbonSat) to ESA (Bovensmann et al., 2010). In November 2010 CarbonSat has been selected by

[6] E-mail: buch@iup.physik.uni-bremen.de

ESA to be one of two candidate missions for Earth Explorer 8 (EE-8) to be launched around 2019 (http://www.iup.uni-bremen.de/carbonsat/). This success was a major highlight in 2010.

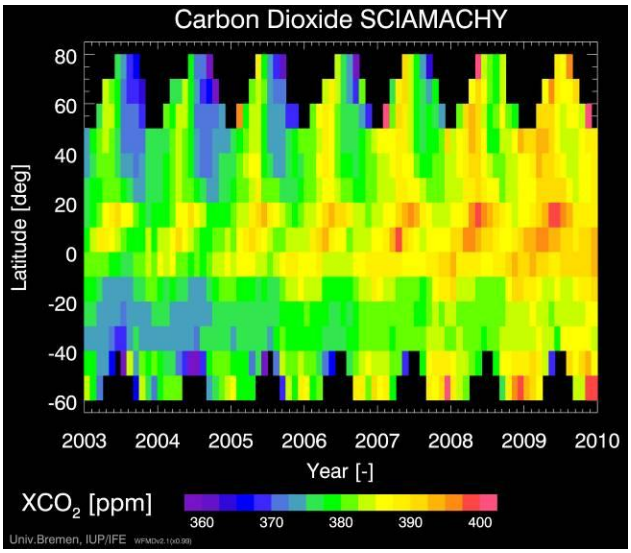


Figure 3-5: Time series of zonally averaged column-averaged mixing ratios of CO_2 as retrieved from SCIAMACHY/ENVISAT during 2003-2009. Clearly visible is the steady increase of atmospheric CO_2 of approximately 2 ppm/year and the CO_2 seasonal cycle.

Greenhouse gas observations from aircraft: Methane Airborne Mapper (MAMAP)

The Methane Airborne MAPper (MAMAP) instrument is a spectrometer similar as SCIAMACHY which has been built at IUP in collaboration with the Geoforschungszentrum (GFZ) in Potsdam mainly to investigate small scale (~100 m) methane surface fluxes from aircraft (Gerilowski et al., 2011). MAMAP also covers absorption bands of CO_2. This permits the retrieval of atmospheric CO_2 concentrations. Figure 3-8 shows MAMAP CO_2 retrievals over two CO_2 emitting power plants in Germany, which have been used to derive the power plant's CO_2 emissions (Krings et al., 2011). This is a new and important application relevant for CO_2 emission monitoring in the context of the Kyoto Protocol and its follow-on agreements and has also stimulated the development of CarbonSat.

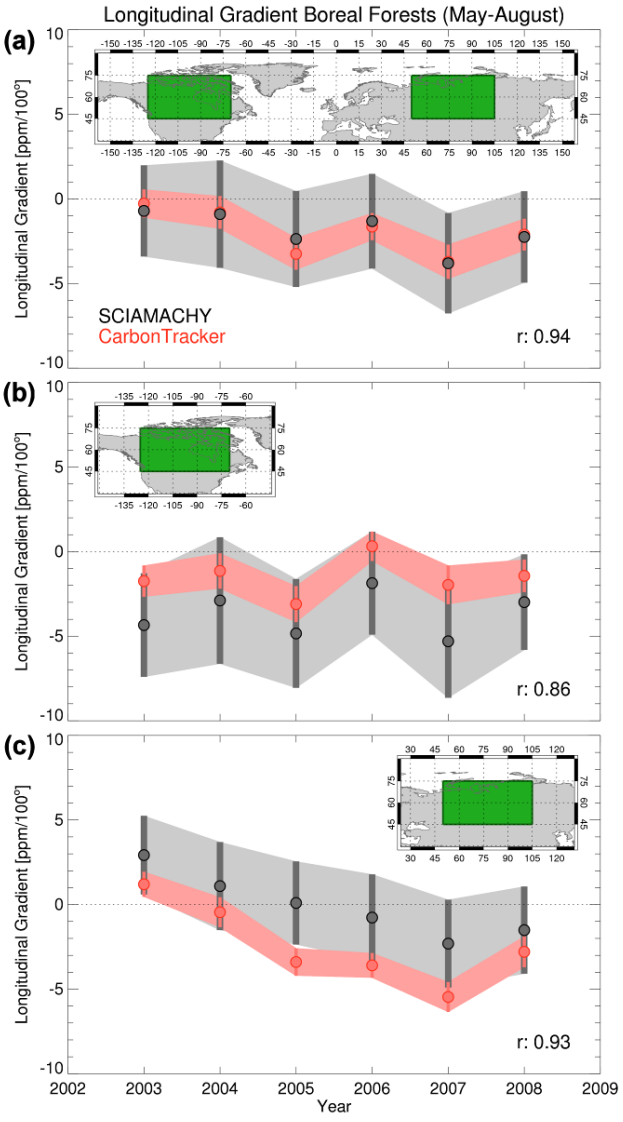


Figure 3-6: Longitudinal gradients of XCO_2 (in ppm/100 degrees longitude) over boral America (b), boral Eurasia (c) and both regions combined (a) derived from SCIAMACHY/ENVISAT (black) and NOAA's CO_2 assimilation system CarbonTracker (red) for the years 2003-2008. As can be seen, there is nearly perfect overall agreement between SCIAMACHY and CarbonTracker (a). However, SCIAMACHY shows a larger (more negative) gradient over Canada and a smaller (more positive) gradient over Russia compared to CarbonTracker. Assuming that the gradient is proportional to CO_2 uptake over the corresponding region, the satellite data suggest a larger CO_2 uptake during the terrestrial vegetation growing season by the Canadian boreal forests and a weaker uptake by Russian boral forests as assumed in CarbonTracker (from Schneising et al., 2011).

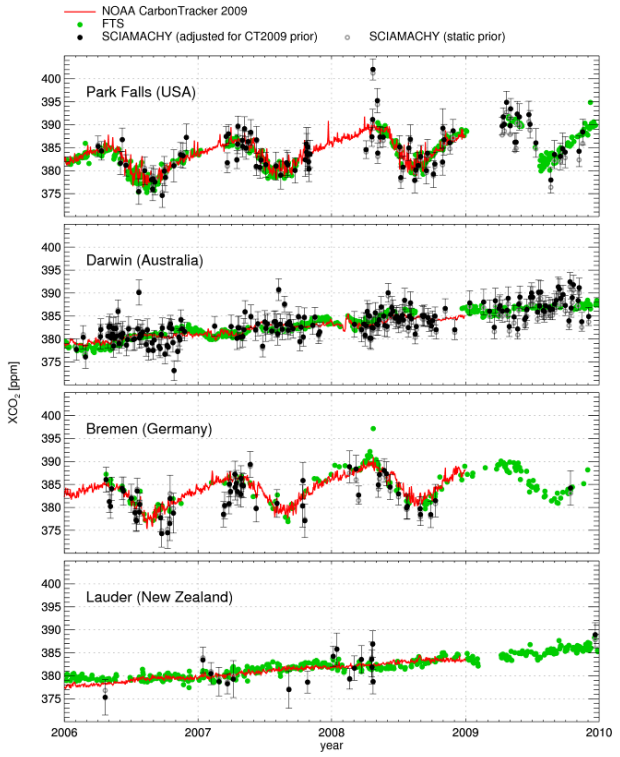


Figure 3-7: First results from the application of the advanced SCIAMACHY CO_2 algorithm "BESD" (black) to real SCIAMACHY data. The results are compared to ground-based Fourier-Transform-Spectroscopy (FTS) observations (green) and CarbonTracker model output (red) (from Reuter et al., 2011).

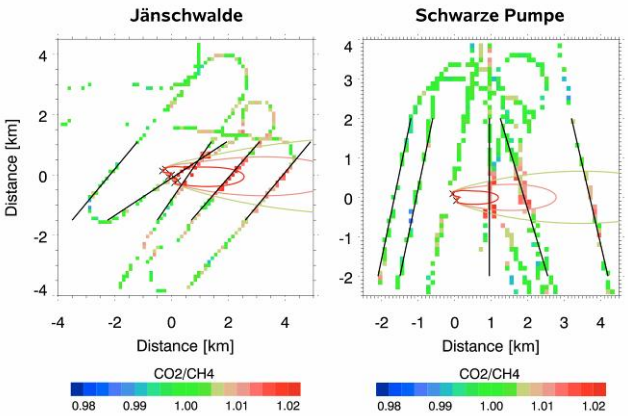


Figure 3-8: CO_2 to CH_4 column ratios as proxy for relative CO_2 column-averaged mixing ratios retrieved from MAMAP aircraft observations over two CO_2 emitting power plants (left: Jänschwalde, right Schwarze Pumpe, both located in Germany near Berlin). Clearly visible is the elevated CO_2 (shown in red) downwind (to the right) of the power plants (the positions of the individual stacks are indicated as black crosses). From these observations the power plant CO_2 emissions can be derived using inverse modelling (from Krings et al., 2011).

References

Bovensmann, H., M. Buchwitz, J. P. Burrows, M. Reuter, T. Krings, K. Gerilowski, O. Schneising, J. Heymann, A. Tretner, and J. Erzinger, A remote sensing technique for global monitoring of power plant CO_2 emissions from space and related applications, Atmos. Meas. Tech., 3, 781 – 811, 2010.

Gerilowski, K., Tretner, A., Krings, T., Buchwitz, M., Bertagnolio, P. P., Belemezov, F., Erzinger, J., Burrows, J. P., and Bovensmann, H., MAMAP - a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: instrument description and performance assessment, Atmos. Meas. Tech., 4, 215 – 243, 2011.

Krings, T., Gerilowski, K., Buchwitz, M., Reuter, M., Tretner, A., Erzinger, J., Heinze, D., Pflüger, U., Burrows, J. P., and Bovensmann, H.: MAMAP – a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: retrieval algorithm and first inversions for point source emission rates, Atmos. Meas. Tech., 4, 1735 – 1758, 2011.

Reuter, M., Bovensmann, H., Buchwitz, M., et al., Retrieval of atmospheric CO_2 with enhanced accuracy and precision from SCIAMACHY: Validation with FTS measurements and comparison with model results, J. Geophys. Res., 116, D04301, doi:10.1029/2010JD015047., 2011.

Reuter, M., Buchwitz, M., Schneising, O., Heymann, J., Bovensmann, H., and Burrows, J. P., A method for improved SCIAMACHY CO_2 retrieval in the presence of optically thin clouds, Atmos. Meas. Tech., 3, 209 – 232, 2010.

Schneising, O., Buchwitz, M., Reuter, M., Heymann, J., Bovensmann, H., Burrows, J. P., Long-term analysis of carbon dioxide and methane column-averaged mole fractions retrieved from SCIAMACHY, Atmos. Chem. Phys., 11, 2881 – 2892, 2011.

3.4. Multi-Axis DOAS observations of tropospheric trace gases

Folkard Wittrock[7], Andreas Richter, Enno Peters, Anja Schönhardt, Mihalis Vrekoussis

Measurements of scattered sun-light from the ground have been used as a technique for the determination of atmospheric concentrations of trace gases using absorption spectroscopy for many years. Originally, the instruments were pointed at the zenith which results in a high sensitivity for stratospheric species, in particular at twilight. More recently, the measurement geometry was extended by also pointing the instrument to the horizon at different elevation angles (Multi Axis Differential Optical Absorption Spectroscopy, MAX-DOAS). In this configuration, columns and coarse vertical profiles of tropospheric constituents can be derived. These quantities are particularly relevant for the validation of satellite observations.

The accuracy of the retrieved tropospheric quantities is determined by the accuracy and precision of the measurements, the consistency of the observations in different viewing directions and the quality of the retrievals of the oxygen dimer O_4, which is used to correct for the effects of aerosols on the radiative transfer in the atmosphere. In order to assess the quality of current MAX-DOAS measurements, CINDI, a semi-blind intercomparison campaign, was organised in Cabauw, The Netherlands in June 2009. In total, 22 MAX-DOAS instruments from 14 institutes participated and a number of correlative measurements of NO_2, aerosols and meteorological parameters were performed in parallel.

As an example of the results, an overview on the linear fits of the observations from all instruments to a set of reference instruments is shown in Figure 3-9 for NO_2 and O_4. Ideally, the slope should be 1 for all viewing directions, the error small and the intercept 0. As can be seen, the overall agreement is good (within 5% for most instruments) and the results of the instrument from IUP Bremen are excellent. Similar results were obtained for HCHO in spite of the smaller signals. An additional focus of the campaign was the comparison of the retrieved profiles of NO_2, and these results are currently being prepared for publication.

[7] E-mail: folkard@iup.physik.uni-bremen.de

References

Roscoe, H. K., van Roozendael, M., Fayt, C., du Piesanie, A., Abuhassan, N., Adams, C., Akrami, M., Cede, A., Chong, J., Clémer, K., Friess, U., Gil Ojeda, M., Goutail, F., Graves, R., Griesfeller, A., Grossmann, K., Hemerijckx, G., Hendrick, F., Herman, J., Hermans, C., Irie, H., Johnston, P. V., Kanaya, Y., Kreher, K., Leigh, R., Merlaud, A., Mount, G. H., Navarro, M., Oetjen, H., Pazmino, A., Perez-Camacho, M., Peters, E., Pinardi, G., Puentedura, O., Richter, A., Schönhardt, A., Shaiganfar, R., Spinei, E., Strong, K., Takashima, H., Vlemmix, T., Vrekoussis, M., Wagner, T., Wittrock, F., Yela, M., Yilmaz, S., Boersma, F., Hains, J., Kroon, M., and Piters, A.: Intercomparison of slant column measurements of NO2 and O4 by MAX-DOAS and zenith-sky UV and visible spectrometers, Atmos. Meas. Tech., 3, 1629 – 1646, doi:10.5194/amt-3-1629-2010, 2010.

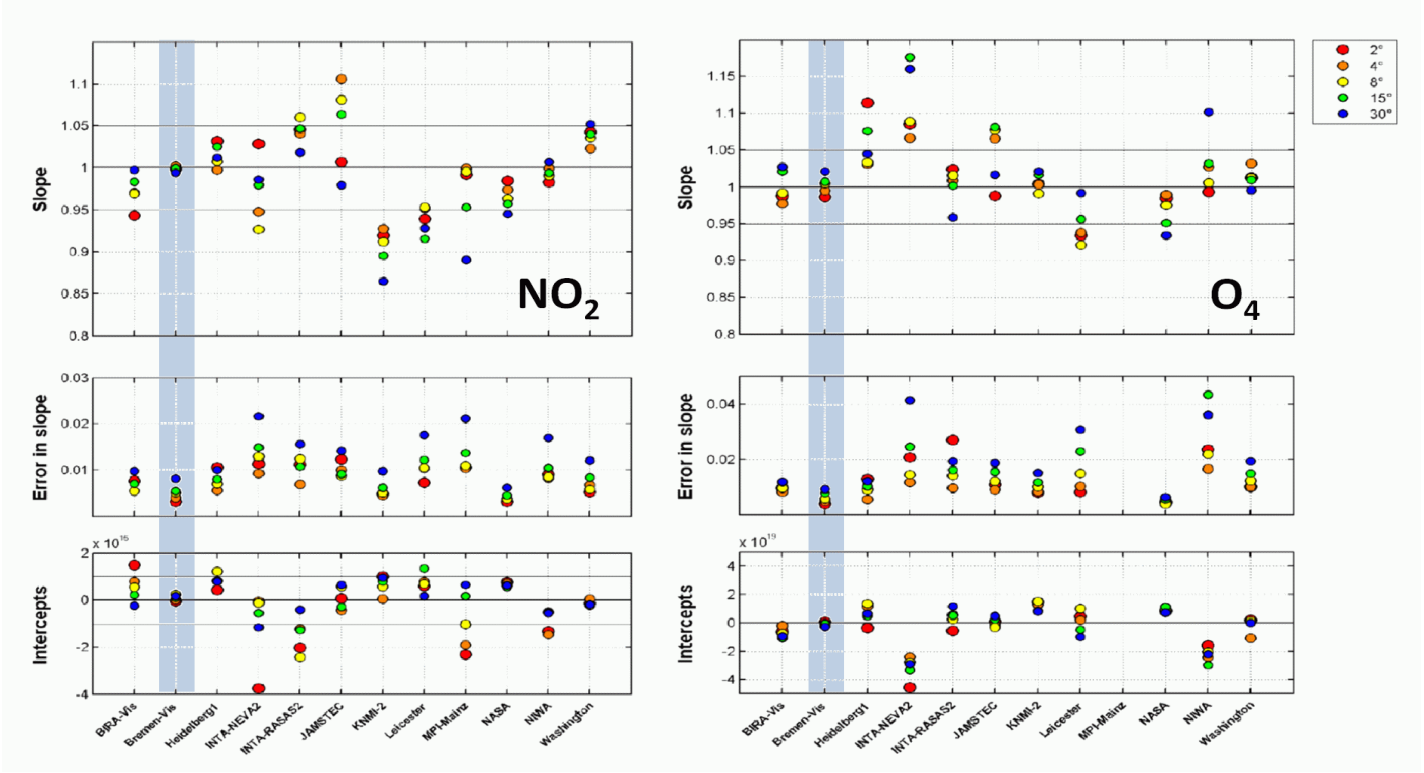


Figure 3-9: Results from the CINDI intercomparison campaign of MAX-DOAS instruments in Cabauw, June 2008. Shown are the straight line slopes, errors and intercepts for all instruments relative to a set of reference instruments for NO_2 (left) and O_4 (right). Colours identify the different elevation angles. The blue bar highlights the results for the Bremen instrument. Figure adapted from Roscoe et al., 2010.

3.5. Monitoring emission changes in Europe from space

Andreas Richter[8], Folkard Wittrock, Michalis Vrekoussis, Katsuyuki Nogushi, Andreas Hilboll, Joana Leitao

In any combustion process, nitrogen oxides are produced and emitted into the atmosphere. This happens in wild fires as well as when using fossil fuels for heating, energy production or transportation. Although natural sources of nitrogen oxides such as lightning or microbial activity in soils also exist, anthropogenic sources dominate in the industrialised regions of the world. At enhanced concentrations, nitrogen oxides are harmful to human health. In addition, they are one of the key ingredients needed for the formation of ozone during summer smog, still one of the most important pollution problems in industrialised countries. Therefore, their atmospheric levels are regulated by national and international laws.

To reduce the impact of nitrogen oxides on health and atmosphere, measures have been taken in many countries to decrease their emissions, e.g., through the use of catalytic converters in cars and implementation of filter techniques in power plants. As some time is needed until new technology is fully applied, a continuous decrease in emission is expected after each change in legislation as long as improvements in emissions are not offset by increased overall fuel consumption. Using reported numbers on fossil fuel consumption in combination with assumptions on technology, the total amount of nitrogen oxides emitted to the atmosphere can be assessed from bottom up. This type of emission inventories is very useful as it provides detailed information on the contributions of different sectors. However, it is based on many assumptions and relies on numbers reported by industry and governments and therefore is subject to some uncertainty.

An alternative approach for estimating emissions is to use satellite data of the total nitrogen oxide amounts as shown in Figure 3-10 and to link them to the emissions. As the atmospheric concentrations of nitrogen oxides not only depend on the magnitude of the emissions but also on the time it takes to remove them from the air, e.g., through chemical reactions or by transport, atmospheric models are needed to infer emissions from the satellite measurements.

The main advantage of this approach is that it is not based on reports and statistical data, but rather on atmospheric measurements. Even though the satellite data have relatively large uncertainties, they do provide a sensitive measure of changes from year to year, and therefore are well suited to monitor the effect of air quality measures. An example of such an analysis is shown in Figure 3-11 where changes in nitrogen oxide emissions derived from two European satellite instruments, GOME and SCIAMACHY, are shown for several countries in the European Union. The values are compared to bottom-up estimates from EMAP for the same regions. As one can see from the figure, the two methods do agree well for some countries, showing a systematic decline in nitrogen oxide emissions over the time period studied. However, for some countries discrepancies are found, indicating shortcomings in the bottom-up inventories. One possible reason for the differences observed are the emissions from ships, which have been rapidly increasing over the last years but are not included in the bottom-up inventories. Therefore, satellite data for countries with heavy ship traffic along their coasts may show less reduction than those estimates that are using land-based sources only. Both, the excellent agreement for some regions and the differences for others demonstrate the value and accuracy of current satellite based emission estimates on a country-by-country level.

[8] E-mail: richter@iup.physik.uni-bremen.de

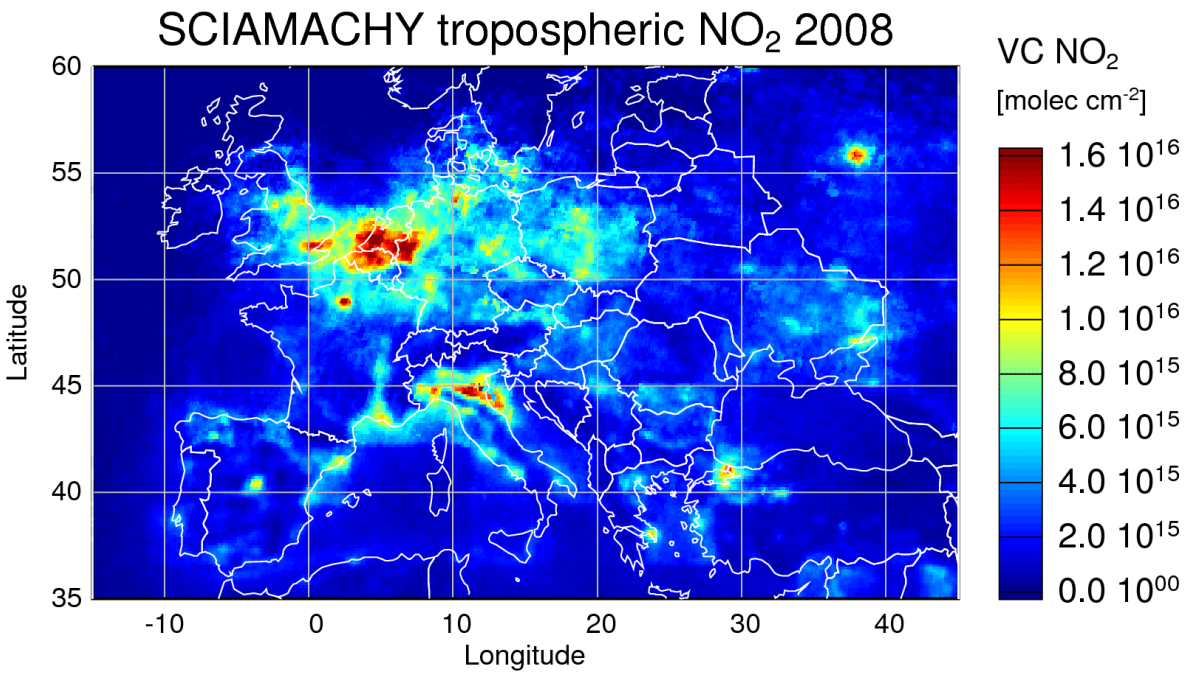


Figure 3-10: Tropospheric NO2 columns over Europe in 2008 as retrieved from SCIAMACHY observations.

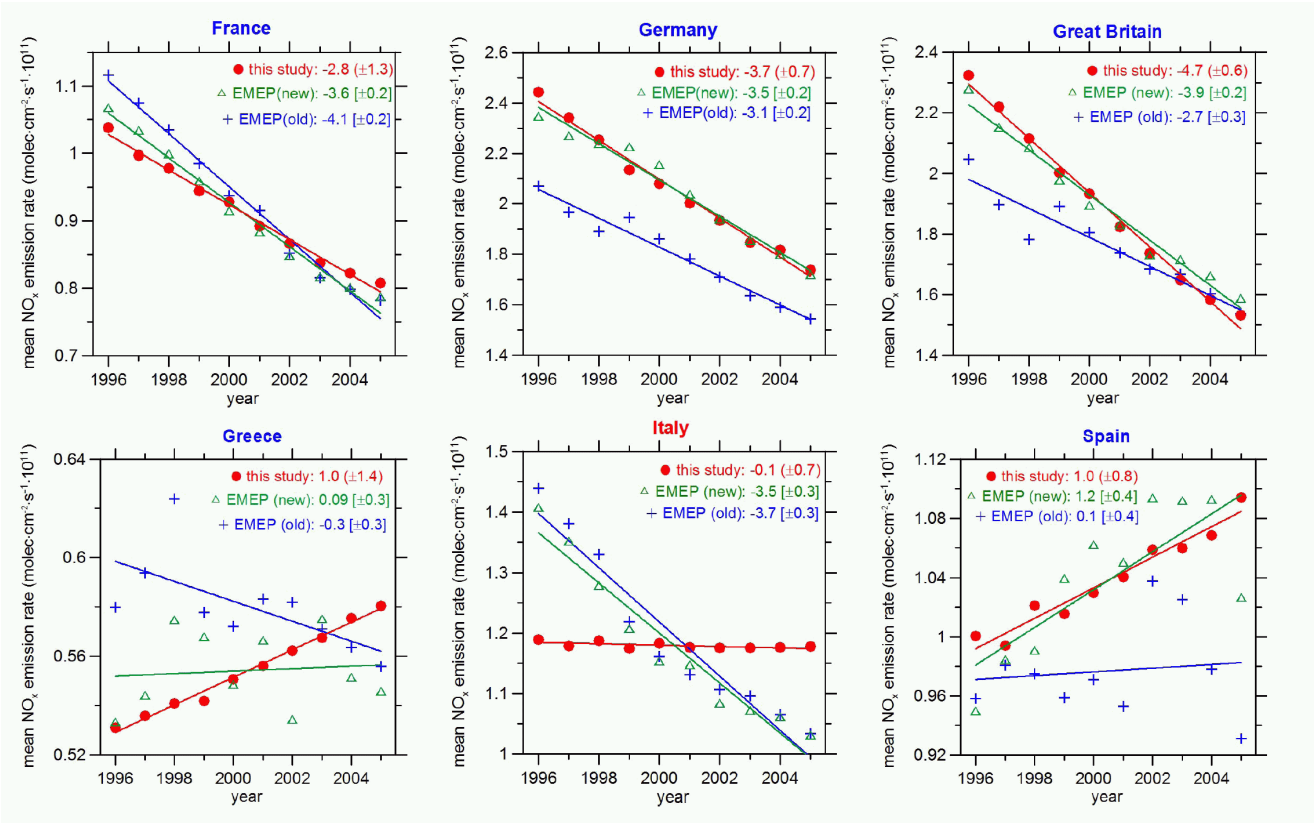


Figure 3-11: Changes in NOx emission rates as determined from satellite observations (red) and two bottom-up emission inventories (blue and green). Figure taken from Konovalov et al., 2008.

Observations of VOCs from space

Volatile organic compounds (VOCs) play many important roles in the atmosphere. Together with nitrogen oxides, they are involved in photochemical ozone production. They are linked to the formation of secondary aerosols, and at large concentrations they also adversely affect human health.

Satellite measurements of backscattered sunlight can be used to determine the tropospheric amounts of two VOCs, formaldehyde (HCHO) and glyoxal (CHOCHO). Both are mainly secondary products of the oxygenation of other larger VOCs such as isoprenes or terpenes. The resulting maps of HCHO and glyoxal clearly highlight the importance of biogenic precursors for both species on a global scale, as the largest values are found over tropical rain forests. In addition to these natural emissions, biomass burning and anthropogenic emissions also contribute to the overall budget of HCHO and glyoxal, and here simultaneous measurements of both species can provide additional information.

This is illustrated in Figure 3-12 , where the ratio of glyoxal to formaldehyde R_{GF} is shown as a function of NO_2 for a number of large cities. Interestingly, a compact correlation is found with smaller R_{GF} at higher NO_2. This is surprising as neither HCHO, nor glyoxal amounts show clear correlation to NO_2 levels, and the emission patterns for NO_2 and VOCs are expected to be very different in cities such as New York and Beijing. Possible explanations for this behaviour are that either HCHO emissions are closely linked to NOx emissions or that at high NOx levels, HCHO yield is larger than that of glyoxal. This illustrates that the ratio R_{GF} can be used to characterise different regions according to their emission sources such as biogenic, pyrogenic or anthropogenic.

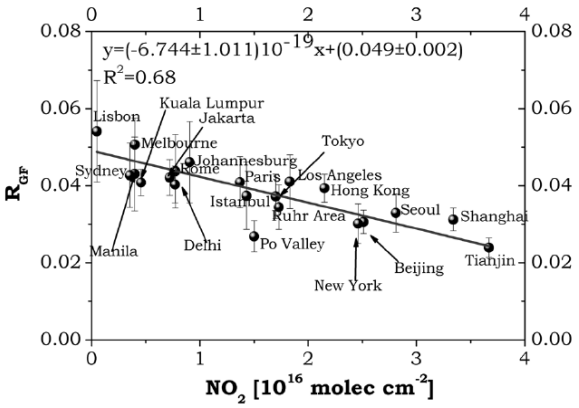


Figure 3-12: Dependency of the ratio of glyoxal to formaldehyde on NO_2 levels in large cities. Measurements from the GOME-2 instrument in 2007 and 2008 were used for all three species. Figure from Vrekoussis et al., 2010.

References

Konovalov, I., Beekmann, M., Burrows, J. P., Richter, A., Satellite measurement based estimates of decadal changes in European nitrogen oxides emissions, Atmos. Chem. Phys., 8, 2623 – 2641, 2008.

Vrekoussis, M., Wittrock, F., Richter, A., and Burrows, J. P.: GOME-2 observations of oxygenated VOCs: what can we learn from the ratio glyoxal to formaldehyde on a global scale?, Atmos. Chem. Phys., 10, 10145 – 10160, doi:10.5194/acp-10-10145-2010, 2010.

3.6. Stratosphere

Mark Weber[9], Jan Aschmann, Gregor Kiesewetter, Alexei Rozanov, Björn-Martin Sinnhuber, Thiranan Sonkaew, Christian von Savigny, and John Burrows

Stratospheric ozone protects the biosphere from harmful UV radiation. In the early 1970s Sherwood Rowland and Mario Molina discovered, that a set of artificially produced chlorine (Cl) compounds (CFCs or chlorofluorocarbons) is capable of severely damaging the stratospheric ozone layer. CFCs were widely used for different purposes, e.g., as cooling agents in refrigerators and air conditioners, or as aerosols in spray cans. Due to their chemical inertness they were considered harmless. CFCs actually pose no threat in the lowermost atmospheric layer – the troposphere – but they can be transported upwards into the stratosphere by slow atmospheric motions. In the stratosphere the intensity of energetic solar radiation is higher than near the surface, and the CFC molecules can be split into their constituents. The resulting chlorine then acts as a catalyst in the destruction of ozone molecules.

In order to mitigate the ozone depletion caused by the halogen compounds (CFCs and bromine containing species (halons)) the Montreal protocol "on substances that deplete the ozone layer" was adopted in 1987. The Montreal protocol was complemented by a series of amendments in the following years (London 1990, Copenhagen 1992, Vienna 1995, Montreal 1997, und Bejing 1999) in order to extend the list of regulated chemical species. The Montreal protocol and its amendments have been ratified by more than 190 countries.

Until the end of the 1990s ozone levels have declined on a global scale. Above Antarctica the spring ozone hole reached its maximum extent and more sporadically large spring ozone losses were observed above the Arctic. Measurements revealed that the stratospheric halogens started to slowly decline since the mid 1990s as a consequence of this regulation and stratospheric ozone is therefore expected to recover. Observations from SCIAMACHY and other satellite instruments show at least a leveling off of ozone from the long-term decline in the upper stratosphere (Jones et al., 2009, Steinbrecht et al., 2009). In the lowermost stratosphere the picture is less clear since natural variability of other processes, such as solar variability (11-year solar cycle), circulation patterns (atmospheric dynamics, Brewer-Dobson circulation), and major volcanic eruptions also contribute to ozone changes. Figure 3-13 shows the long-term change in total ozone (representative for lower stratospheric ozone) on a global scale (60°S-60°N) as well as for middle latitudes (30°-60°) and in the tropics (Weber et al., 2011a). In the middle latitudes the long-term decline until end of the 1990s is evident. In the northern hemisphere a rapid increase until 2000 and leveling-off after is observed while in the southern hemisphere the long-term decline was stopped after 2000. The total ozone record from the GOME1, SCIAMACHY, and GOME-2 satellite instruments were retrieved using a state-of-the art retrieval algorithm developed in this institute.

The speed of ozone recovery in the future strongly depends on the interaction of ozone with climate change and vice versa. Many climate models predict an enhancement in the Brewer-Dobson circulation meaning that more ozone will be transported into middle and high latitudes (speeding up recovery). On the other hand a global warming in the troposphere will result in a cooler stratosphere so that more lower stratospheric ozone can be depleted in polar spring despite falling halogen levels (slowing down of recovery). However, in the upper stratosphere a cooling will result in faster gas-phase production of ozone ("super recovery").

Important scientific contributions from this institute to stratospheric ozone science are:

- From SCIAMACHY BrO observations and from estimates from the total bromine (Br_y) the importance of very short lived substances (VSLS), contributing about 25% of the total bromine was found (Sinnhuber et al., 2005).

[9] E-mail: weber@uni-bremen.de

Bromine is less abundant than chlorine but more effective in ozone depletion as expressed by the alpha factor (α~60). VSLS may play a larger role in ozone depletion under conditions of high stratospheric aerosols following major volcanic eruptions like the 1992 Pinatubo event (Sinnhuber et al., 2009). Transport mechanisms of bromine into the stratosphere were investigated as well (Aschmann et al., 2009).

- The role of the Brewer-Dobson circulation on ozone variability from seasonal to decadal time scales have been studied using observations and results from two different chemistry climate models (Weber et al., 2011b). The extremely high annual mean ozone in the northern hemisphere as observed in 2010 and the Antarctic ozone hole anomaly in 2002 are the results of a very strong winter Brewer-Dobson circulation in the respective winter hemisphere.
- Attribution of various factors to long-term global ozone trends and inter-annual variability in polar ozone have been studied using a results from Chemical-Transport-Model (CTM) calculations (Kiesewetter et al., 2011a) and a novel assimilated SBUV ozone profile data set (Kiesewetter et al., 2010b), respectively.
- Chemical ozone losses above Antarctica and the Arctic during polar spring were derived from SCIAMACHY limb ozone profiles for the years 2002 to 2009 (Sonkaew et al., 2011). The variable Arctic ozone loss correlates well with the QBO (quasi-biennial oscillation) again demonstrating the impact of atmospheric dynamics on ozone chemistry.

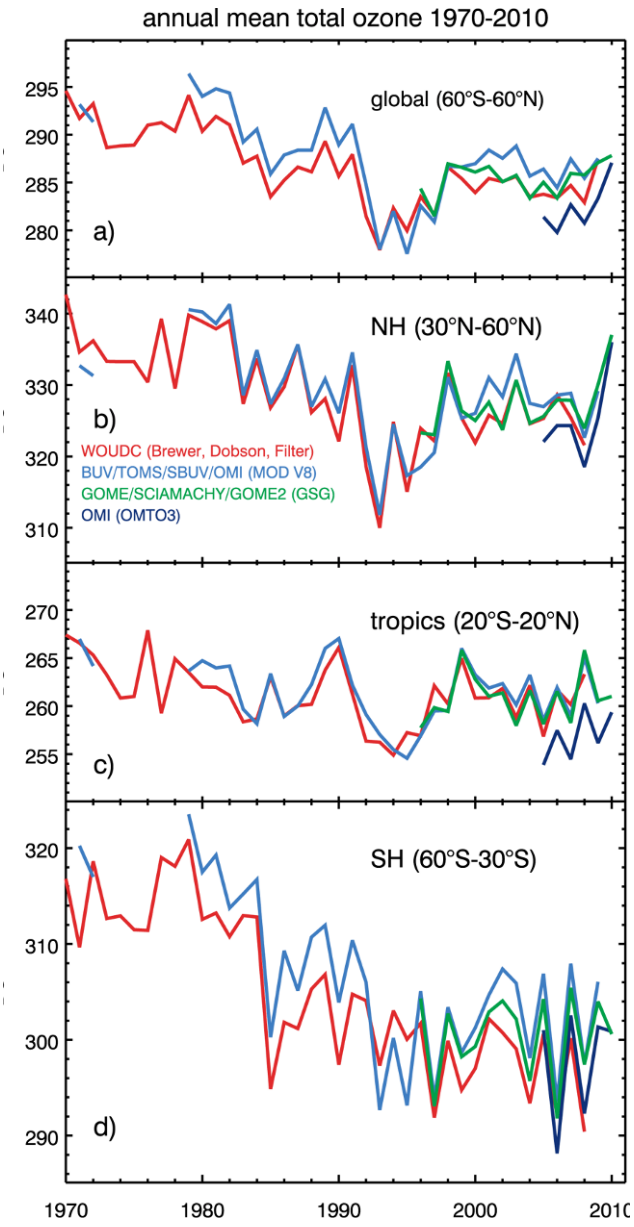


Figure 3-13: Annual mean total ozone time series of ground-based measurements combining Brewer, Dobson, and filter spectrometer, the merged BUV/SBUV/TOMS/OMI MOD V8, and GOME1/SCIAMACHY/GOME2 GSG, and OMI OMTO3 (OMI-TOMS) satellite data in the a) 60°N-60°N (global), b) 30°N-60°N (NH), c) 20°S-20°N (tropics), and d) 30°S-60°S (SH) zonal bands (Weber et al., 2011a).

References

Aschmann, J., B.-M. Sinnhuber, E. L. Atlas, and S. M. Schauffler, Modeling the transport of very shortlived substances into the tropical upper troposphere and lower stratosphere, Atmos. Chem. Phys., 9, 9237 – 9247, doi: 10.5194/acp-9-9237-2009, 2009.

Jones, A., J. Urban, D. P. Murtagh, S. Brohede, C. Haley, D. Degenstein, C. von Savigny, T. Sonkaew, A. Rozanov, H. Bovensmann, J. P. Burrows, L. Froidevaux, and A. Lambert, Evolution of stratospheric ozone and water vapour time series studied with satellite measurements, Atmos. Chem. Phys., 9, 6055 – 6075, 2009.

Kiesewetter, G., B.-M. Sinnhuber, M. Weber, and J. P. Burrows, Attribution of stratospheric ozone trends to chemistry and transport: a modelling study, Atmos. Chem. Phys., 10, 12073 – 12089, doi:10.5194/acp-10-12073-2010, 2010.

Kiesewetter, G., B.-M. Sinnhuber, M. Vountas, M. Weber, and J. P. Burrows, A long-term stratospheric ozone data set from assimilation of satellite observations: High-latitude ozone anomalies, J. Geophys. Res., 115, D10307, doi:10.1029/2009JD013362, 2010.

Sinnhuber, B.-M., A. Rozanov, N. Sheode, O. T. Afe, A. Richter, M. Sinnhuber, F. Wittrock, J. P. Burrows, G. P. Stiller, T. von Clarmann, and A. Linden, Global observations of stratospheric bromine monoxide from SCIAMACHY, Geophys. Res. Lett., 32, L20810, doi: 10.1029/2005GL023839, 2005.

Sinnhuber, B.-M., N. Sheode, M. Sinnhuber, M. P. Chipperfield, and W. Feng, The contribution of anthropogenic bromine emissions to past stratospheric ozone trends: A modelling study, Atmos. Chem. Phys., 9, 2863 – 2871, doi: 10.5194/acp-9-2863-2009, 2009.

Sonkaew, T., C. von Savigny, K.-U. Eichmann, M. Weber, A. Rozanov, H. Bovensmann, and J. P. Burrows, Chemical ozone loss in Arctic and Antarctic polar winter/spring season derived from SCIAMACHY limb measurements 2002-2009, Atmos. Chem. Phys. Disc., 11, 6555 – 6599, 2011.

Steinbrecht, W., Claude, H., Schönenborn, F., McDermid, I. S., Leblanc, T., Godin-Beekmann, S., Keckhut, P., Hauchecorne, A., Gijsel, J. A. E. V., Swart, D. P. J., Bodeker, G. E., Parrish, A., Boyd, I. S., Kämpfer, N., Hocke, K., Stolarski, R. S., Frith, S. M.,Thomason, L. W., Remsberg, E. E., Savigny, C. v., Rozanov, A., and Burrows, J. P., Ozone and temperature trends in the upper stratosphere at five stations of the Network for the Detection of Atmospheric Composition Change, Int. J. Remote Sens., 30, 3875 – 3886, 2009.

Weber, M., W. Steinbrecht, R. J. van der A, P. K. Barthia, V. E. Fioletov, R. McPeters, and R. S. Stolarski, [Global Climate] Stratospheric Ozone [in State of the Climate in 2010], Bull. Amer. Meteor. Soc., 92, S67 – S68, 2011a.

Weber, M., S. Dikty, J. P. Burrows, H. Garny, M. Dameris, A. Kubin, J. Abalichin, and U. Langematz, The Brewer-Dobson circulation and total ozone from seasonal to decadal time scales, Atmos. Chem. Phys., 11, 11221-11235, doi:10.5194/acp-11-11221-2011, 2011.

3.7. Stratospheric Methane Profiles from SCIAMACHY Solar Occultation Measurements

Stefan Noël[10], Klaus Bramstedt, Alexei Rozanov, Heinrich Bovensmann and John Burrows

Atmospheric methane (CH_4) is after water vapour and CO_2 the most important greenhouse gas. CH_4 is released into the troposphere by both natural processes and anthropogenic activity. Because of its long tropospheric chemical lifetime of about 8 to 10 years, CH_4 can be transported into the stratosphere where it is the major source of water vapour and HCl. As a result CH_4 plays a significant role in stratospheric chemistry. In the lower stratosphere loss reactions are however sufficiently slow and CH_4 can be also used as a dynamical tracer. The coupling between stratospheric CH_4 and water vapour (and their trends) is of relevance for atmospheric chemistry and climate change.

Several space-borne instruments measured stratospheric CH_4 data in the past, but only few of them are still operating. Currently stratospheric CH_4 profiles are, e.g., provided by the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) on SCISAT, launched in 2003, and the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on ESA's environmental satellite ENVISAT.

The SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) is also part of the atmospheric chemistry payload of ENVISAT, which was launched in 2002. Originally designed for only a 5 years mission, ENVISAT and its instruments, including SCIAMACHY, are still operational. An extension of the ENVISAT mission to at least 2014 and hopefully beyond is planned.
SCIAMACHY makes measurements of the electromagnetic radiation leaving the top of the atmosphere in nadir, limb and both solar and lunar viewing geometries from about 240 to 2400 nm. Appropriate mathematical inversion of these data yields the amounts and distributions of various atmospheric trace gases, cloud and aerosol parameters.

A new retrieval method has been developed to derive stratospheric CH_4 profiles from SCIAMACHY solar occultation measurements in the spectral region around 1.6 µm (Noël et al., 2011). The method is based on a combination of an onion peeling approach with a weighting function DOAS (Differential Optical Absorption Spectroscopy) fit. This is an extension of the Onion Peeling DOAS (ONPD) method which has already been successfully applied to water vapour (Noël et al., 2010). Currently, reasonable CH_4 profiles are obtained between 20 and 40 km altitude with a vertical resolution of 4.1 km; a potential application to lower altitudes is under investigation.

SCIAMACHY performs solar occultation measurements every orbit at Northern latitudes between about 50° and 70°. Although these measurements are limited in latitude range the signal-to-noise ratio of the occultation measurements is high and they are less sensitive to calibration issues, yielding high precision data products. The long duration of SCIAMACHY of already now more than 9 years provides a unique set of decadal data about the atmospheric composition at mid to high latitudes in the Northern Hemisphere.

Up to now, the ONPD method has been applied to all SCIAMACHY solar occultation measurements from August 2002 until end of 2010. Up to 13 CH_4 profiles are obtained per day at almost the same latitude but different longitudes. Figure 3-14a) shows a time series of daily averaged CH_4 number densities derived with the ONPD method. In Figure 3-14b) the same data set is shown, but converted to volume mixing ratios (VMRs) using temperature and pressure profiles provided by ECMWF (European Centre for Medium Range Weather Forecasts).

[10] E-mail: noel@iup.physik.uni-bremen.de

As can be seen from Figure 3-14 there is a pronounced seasonal variation visible in the CH_4 time series. This variation is mainly related to the specific observational geometry. Because of the sun-fixed ENVISAT orbit, there is a one-to-one relationship between the latitude of the tangent point and time, as can be seen from the top parts of each sub-panel. At low altitudes, this variation follows roughly the variation of the tropopause height (calculated from collocated ECMWF data and shown as a black line in the lower part of the sub-figures). This systematic coupling of observational time and space complicates the interpretation of the SCIAMACHY solar occultation time series.

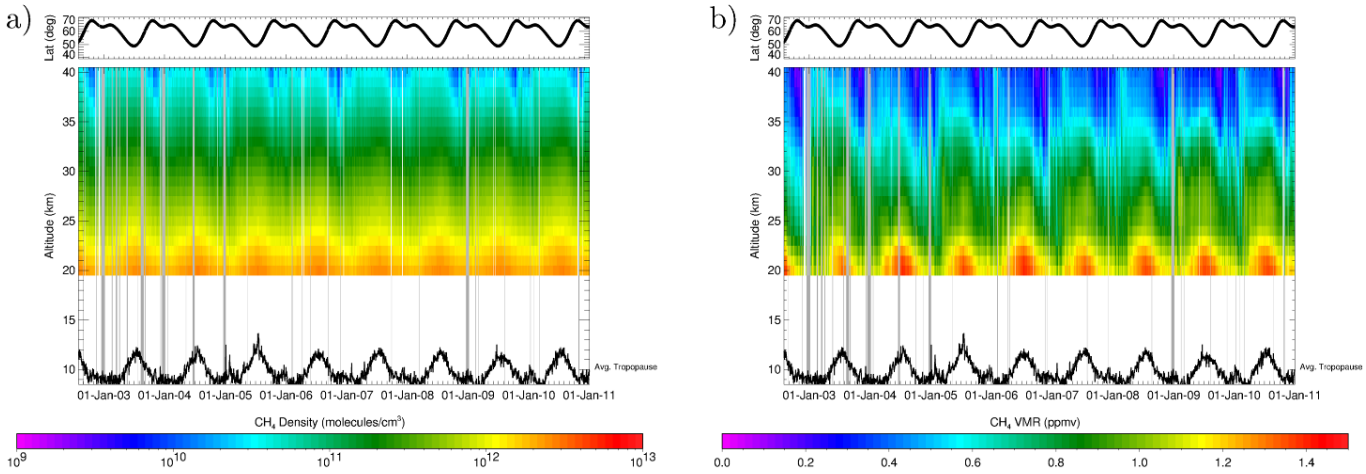


Figure 3-14: Time series of daily averaged CH_4 profiles August 2002 – December 2010. a) Retrieved number densities. b) Volume mixing ratios (VMRs) derived from combination with ECMWF pressure and temperature data. The vertical grey bars mask out periods of reduced SCIAMACHY data quality (e.g. due to instrument switch-offs or decontamination periods). Figure taken from Noël et al., 2011.

To assess the quality of the derived SCIAMACHY CH_4 profiles, they have been compared with about 900 collocated profiles derived from the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS). ACE-FTS is the main payload of the Canadian SCISAT satellite launched in August 2003. The ACE-FTS instrument also performs solar occultation measurements, but in the infrared wavelength range (2.2 to 13.3 µm). The comparisons have been performed based on ACE-FTS CH_4 data V2.2, which have been intensively validated by various comparisons with ground-based, balloon-borne and satellite-based measurements (De Mazière et al., 2008). The results of the inter-comparison between SCIAMACHY and ACE-FTS CH_4 profiles are shown in Figure 3-15.

As can be seen, the SCIAMACHY and ACE-FTS CH_4 VMRs agree within about 10%, which is in line with the expected accuracy of the ACE-FTS V2.2 data product.

The estimated mean error of the SCIAMACHY CH_4 profiles lies between 10 and 20% below 30 km and strongly increases for higher altitudes, reaching more than 100% at 40 km. The agreement with ACE-FTS at these altitudes is however still good. This is probably because the given SCIAMACHY errors are essentially random errors which have been quite conservatively estimated solely from the fit residuals and therefore can be considered as upper estimates.

The correlation between the SCIAMACHY and ACE-FTS CH_4 VMRs is very good (0.8 – 0.95). This indicates that CH_4 variations seen by ACE-FTS are also seen by SCIAMACHY.

All in all, the first stratospheric CH_4 profiles derived from SCIAMACHY solar occultation data look very promising. The analysis of time series and preliminary validation results show that the SCIAMACHY data set can provide unique information about CH_4 changes in the stratosphere at mid to high latitudes.

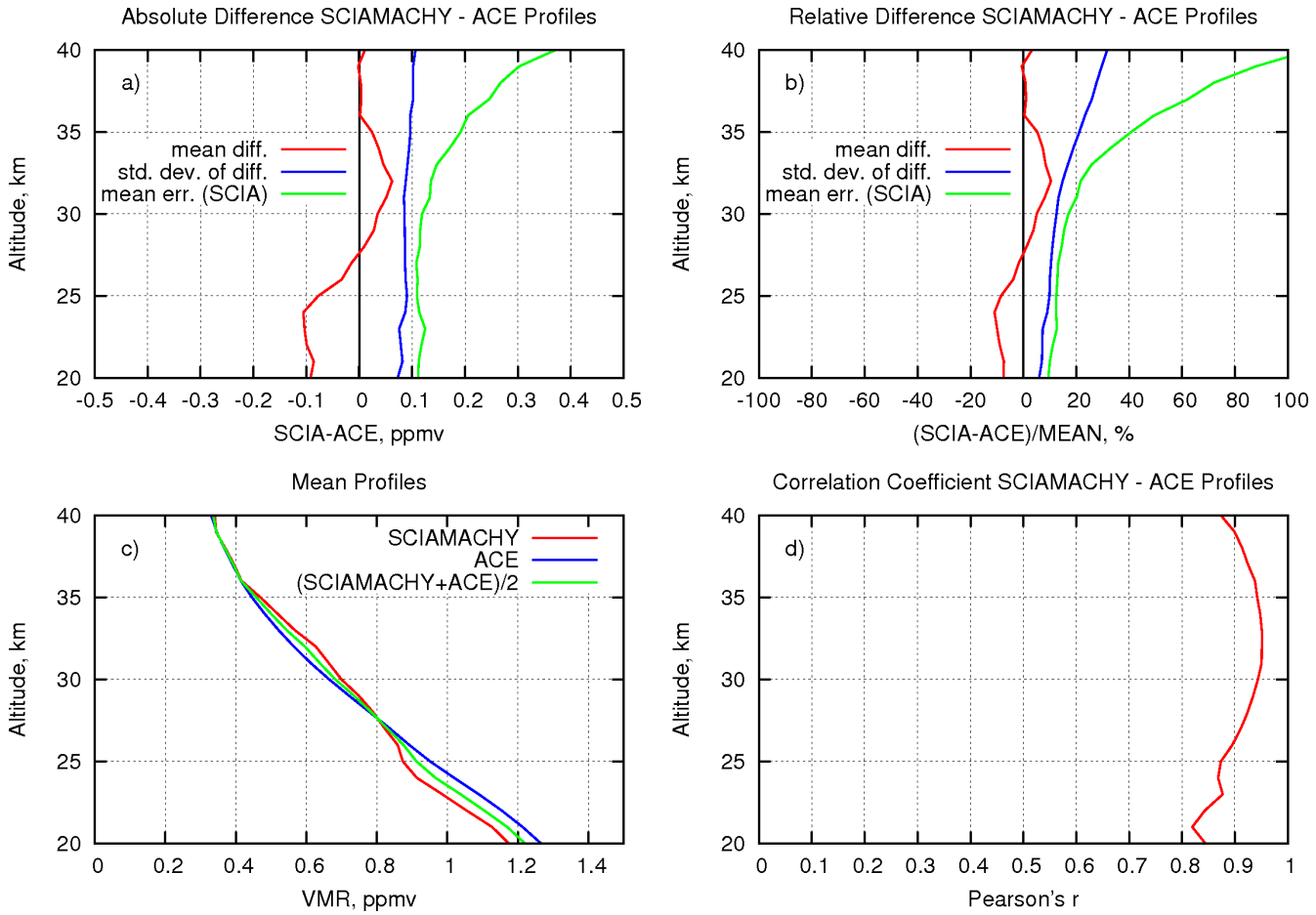


Figure 3-15: Comparison of retrieved SCIAMACHY methane profiles (ONPD V3.3.6) with ACE-FTS data (V2.2).a) Mean absolute difference (red) and its standard deviation (blue); mean absolute error of SCIAMACHY data (green). b) Mean relative difference (red) and its standard deviation (blue); mean relative error of SCIAMACHY data (green). c) Mean profiles (red: SCIAMACHY, blue: ACE-FTS, green: average of both). d) Correlation between SCIAMACHY and ACE-FTS data. Figure taken from Noël et al., 2011.

References

De Mazière et. al., Validation of ACE-FTS v2.2 methane profiles from the upper troposphere to the lower mesosphere, Atmos. Chem. Phys., 8, 2421 – 2435, doi:10.5194/acp-8-2421-2008, http://www.atmos-chem-phys.net/8/2421/2008/, 2008.

Noël et al., Water vapour profiles from SCIAMACHY solar occultation measurements derived with an onion peeling approach, Atmos. Meas. Tech., 3, 523 – 535, http://www.atmos-meas-tech.net/3/523/2010/, 2010.

Noël, S., Bramstedt, K., Rozanov, A., Bovensmann, H., and Burrows, J. P.: Stratospheric methane profiles from SCIAMACHY solar occultation measurements derived with onion peeling DOAS, Atmos. Meas. Tech., 4, 2567 – 2577, doi:10.5194/amt-4-2567-2011, 2011.

3.8. Noctilucent clouds – ice clouds at the frontier to space

Christian von Savigny[11], Nabiz Rahpoe, Charles Robert, Lena Brinkhoff and John Burrows

Noctilucent clouds (NLCs), also known as polar mesospheric clouds (PMCs) are the highest clouds in the terrestrial atmosphere. They occur at altitudes of around 83 km at mid and high latitudes during a 3 month period around summer solstice in the summer hemisphere. The clouds consist of tiny water ice particles with typical radii of several tens of nm. NLCs can be seen from the Earth surface, when the sun is slightly below the horizon, and the lower atmosphere is not directly illuminated any more. Figure 3-16 shows a photograph of a noctilucent cloud above the Baltic Sea, and displays the large variability of the cloud structure over a wide range of spatial scales. Noctilucent clouds have become an intensely studied topic during recent decades, because they react very sensitively to small changes in ambient conditions (temperature and water vapour), and may be indicators of global change. The basic motivation behind NLC research is the conviction that the role of NLCs as indicators of global change can only be established if all processes driving variability of NLCs are fully understood. The NLC research group at IUP Bremen was able to make some interesting and relevant contributions to current research on NLC and the mesopause region in recent years, including:

- First observation of a depletion of NLCs during a solar proton event (von Savigny et al., 2007a). The chemo-dynamical mechamisms leading to the NLC depletion were recently identified by Becker and von Savigny (2010).
- First evidence for a solar-driven 27-day signature in NLCs (Robert et al., 2010)
- Experimental evidence, that the quasi 5-day wave signatures in NLCs are caused by similar planetary wave signatures in the mesopause temperature field (von Savigny et al., 2007b)
- First evidence for a QBO (Quasi-Biennial-Oscillation) signature in NLCs (von Savigny et al., 2011, in preparation)
- Determination of the fractal perimeter dimension of NLCs (von Savigny et al., 2011)

Two of the topics just mentioned will be discussed in more detail in the following: the effects of solar proton events and of the 27-day solar cycle on NLCs. Solar proton events are caused by solar coronal mass ejections (CMEs) and are associated with the precipitation of highly energetic solar protons in the Earth's polar cap regions. In terms of solar proton events we were able to show for the first time, that they affect the occurrence of NLCs [von Savigny et al., 2007a]. Figure 3-17 shows the occurrence frequency of NLCs as observed with SCIAMACHY (Scanning Imaging Absorption spectrometer for Atmospheric CHartographY) on Envisat during the January 2005 solar proton event for different latitude ranges (grey and blue lines) together with the rate of ionization due to the proton precipitation (red line). The solar proton event apparently coincides with a severe reduction in the occurrence frequency of NLCs. Simultaneous observations of the temperature at NLC altitude revealed that the immediate cause of the NLC depletion is a strong increase in mesopause temperature. When this effect was discovered, the processes leading to the strong temperature increase were not understood at all. Further research in this direction showed that a complicated dynamical response of the entire polar middle atmosphere – which is mainly driven by the catalytic ozone depletion during the solar proton event – eventually leads to an increase of the temperature at the polar summer mesopause. This mechanism was recently confirmed using model simulations by Becker and von Savigny (2010).

Regarding the 27-day solar cycle a 27-day signature in NLC occurrence rates was identified, which appears to be anti-correlated with solar activity

[11] E-mail: csavigny@iup.physik.uni-bremen.de

proxies such as the Lyman-α irradiance [Robert et al., 2009b]. The 27-day cycle in solar UV radiance is directly caused by the effective 27-day rotation of the sun, in combination with electromagnetic flux anomalies associated with the darker sun spots and the surrounding and brighter faculae. The 27-day variation of solar UV irradiance is expected to cause variability in many atmospheric parameters such as the abundance of chemical species, atmospheric temperature and possibly also atmospheric dynamics. Figure 3-18 shows anomalies – times series minus the times series smoothed with a 35-day running mean filter – of NLC occurrence rate and the Lyman-α irradiance for different northern hemisphere NLC seasons. In particular for the seasons 2004 and 2005 a negative correlation between the time series is quite obvious. Comparisons between Lyman-α irradiance and mesospheric temperature as observed with MLS (Microwave Limb Sounder) on the Aura satellite are shown in Figure 3-19. The significant positive correlations between solar activity and mesopause temperature show that the 27-day signature in NLCs is most likely driven by a temperature variation with the same period.

The current NLC research activities pursued at the institute of environmental physics at the University of Bremen concentrate on improving the understanding of the effects of solar proton events, as well as planetary wave perturbations on NLCs, and to establish whether the variability observed in NLCs from satellites can be explained by the known drivers for variability. Only if all of these aspects are well understood we will be able to judge, whether NLCs may be considered indicators of global change.

Figure 3-16: Photograph of a NLC taken from Kühlungsborn in north-east Germany (kindly provided by Dr. Gerd Baumgarten, Institute of Atmospheric Physics, Kühlungsborn).

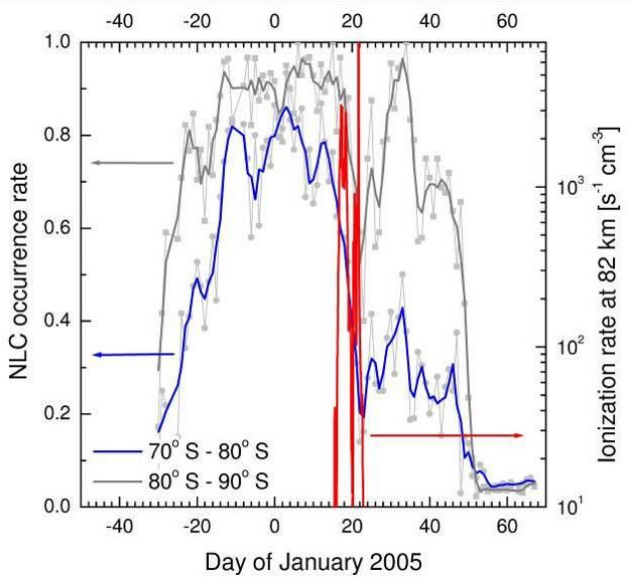


Figure 3-17: NLC occurrence frequency for different latitude ranges together with the ionization rate at NLC altitude during the 2004/2005 NLC season (adapted from von Savigny et al., 2007a).

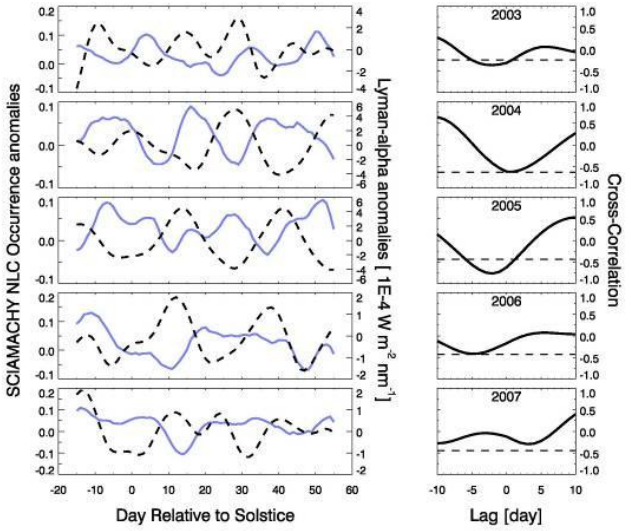


Figure 3-18: NLC occurrence rate anomalies (blue solid lines) and Lyman-α irradiance anomalies (black dashed lines) for the northern hemisphere NLC seasons 2003 – 2007. Also shown are the cross-correlations between these anomalies. The seasons 2004 to 2006 in particular show strong negative correlations between the Lyman-α and the NLC anomalies obtained (Figures taken from Robert et al., 2010).

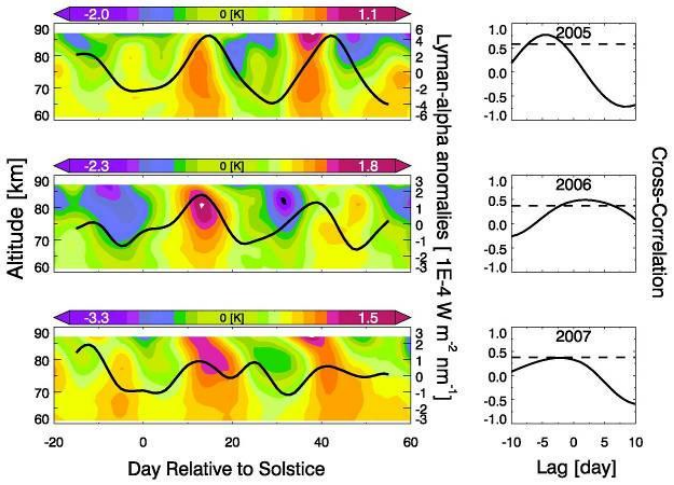


Figure 3-19: Middle atmospheric temperature anomalies (colour contour plot) and Lyman-α anomalies (black solid line) for the northern NLC seasons 2005 to 2007. For 2005 and 2006 positive correlations – significant at the 90% level – were obtained (Figures taken from Robert et al., 2010).

References

Becker, E., and C. von Savigny, Dynamical heating of the polar summer mesopause induced by solar proton events, J. Geophys. Res., 115, D00I18, doi:10.1029/ 2009JD012561, 2010.

Rahpoe, N., C. von Savigny, C. E. Robert, M. T. DeLand, and J. P. Burrows, Impact of Solar Proton Events on Noctilucent clouds, J. Atmos. Sol.-Terr. Phys., 73(14–15), 2073 – 2081, 2011.

Robert, C., C. von Savigny, and J. P. Burrows, A 6-year climatology of noctilucent cloud occurrence and particle size from SCIAMACHY/Envisat, J. Atmos. Sol.-Terr. Phys., 71, 408 – 423, 2009.

Robert, C. E., C. von Savigny, N. Rahpoe, J. P. Burrows, and M. T. DeLand, Evidence of a 27-day signature in noctilucent cloud occurrence frequency, J. Geophys. Res., 115, D00I12, doi:10.1029/2009JD012359, 2010.

von Savigny, C., M. Sinnhuber, H. Bovensmann, J. P. Burrows, M.-B. Kallenrode, and M. J. Schwartz, On the disappearance of noctilucent clouds during the January 2005 solar proton events, Geophys. Res. Lett., 34, L02805, doi:10.1029/2006GL028106, 2007a.

von Savigny, C., C. Robert, H. Bovensmann, J. P. Burrows, and M. J. Schwartz, Satellite observations of the quasi 5-day wave in noctilucent clouds and mesopause temperatures, Geophys. Res. Lett., 34, L24808, doi:10.1029/2007GL, 2007b.

von Savigny, C., L. Brinkhoff, S. M. Bailey, C. E. Randall, and J. M. Russell III, First determination of the fractal perimeter dimension of Noctilucent clouds, Geophys. Res. Lett., 38, L02806, 2011.

4. Oceanography (Prof. Dr. Monika Rhein)

4.1. Rapid dispersal of a hydrothermal plume by turbulent mixing

Maren Walter[12], Christian Mertens, Jürgen Sültenfuß, Uwe Stöber und Monika Rhein

Hydrothermal systems act as a bridge from the earths' mantle to the ocean, cooling the mantle by supplying heat from the earth's interior to the deep ocean, transferring chemical species like metals or gases from the crust to the water column, and, by allocating energy in the form of sulphur, methane or hydrogen molecules, they sustain oases of life for a variety of deep-sea chemosynthetic life forms from bacteria to mussels and shrimps. The export of matter from hydrothermal systems into the ocean takes place in form of the plume, a trail of hydrothermal products carried by a mixture of hydrothermal fluids and ambient sea water.

The recently discovered Nibelungen hydrothermal vent field in the South Atlantic (Koschinsky et al., 2006; Keir et al., 2008; Melchert et al., 2008) is located on the slow spreading Mid-Atlantic Ridge (MAR) between the Ascension and Bode Verde Fracture Zones (Figure 4-1). The field is mainly extinct, with only one known active hot smoker, the "Drachenschlund" ("Dragon Throat") that is surrounded by several inactive chimney structures (Figure *4-2*). Nibelungen is an off-axis ultramafic-hosted system, located south of a non-transform offset between two adjacent 2nd-order ridge-segments, a setting characterized by rugged topography with lots of scarps, fault blocks and topographic steps. The smoker Drachenschlund has not a typical chimney structure, but is a smoking hole of approximately 0.5 m diameter, situated at the bottom of a four meter deep and six meter wide crater at the eastern scarp of a fault block, approximately 80 m below the crest.

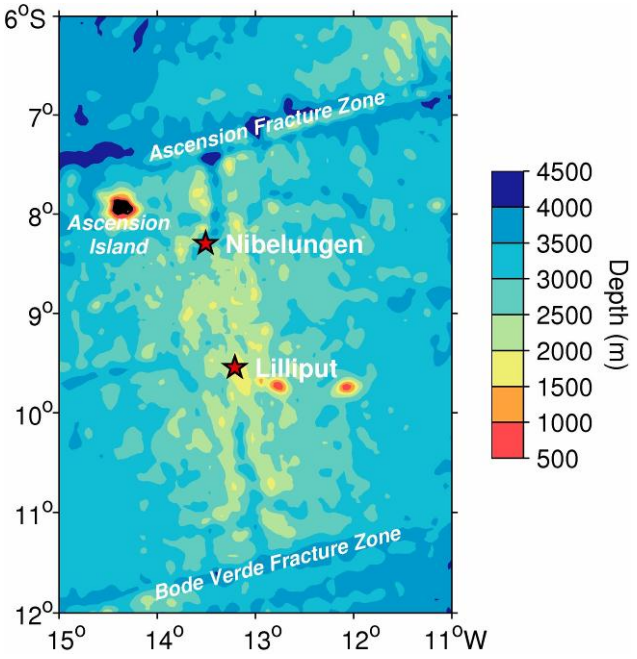


Figure 4-1: Overview of the South Atlantic with the location of the Nibelungen field; also marked is the low-temperature field Lilliput south of Nibelungen.

The hydrothermal plume of the Nibelungen field (Figure 4-3) was first discovered and sampled in 2004 during the *Meteor* cruise M62/5. The actual site of the Drachenschlund was discovered in 2006 during cruise M68/1 in a water depth of 2915 m at 8° 17.87' S, 13° 30.45' W by the autonomous underwater vehicle *ABE*, and the Bremen ROV *Quest*. The discovery of the source was delayed by the variability of the plume; the largest anomalies were repeatedly observed about half a mile southwest of the Drachenschlund, but these observations were interspersed with a recession to background values, and linked to a seemingly erratic flow field.

[12] E-mail: mwalter@physik.uni-bremen.de

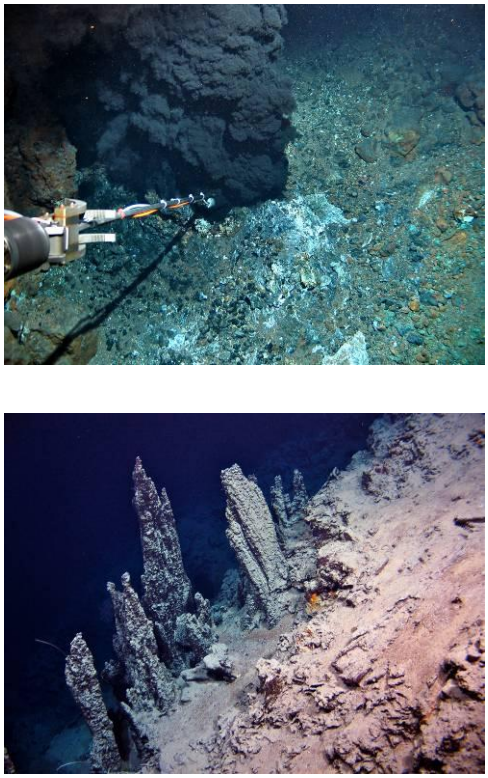


Figure 4-2: The Nibelungen hydrothermal field: Temperature measurements at smoking crater Drachenschlund (top), and extinct structures (bottom). (Photos taken during Meteor cruise M78/2, April 2009; copyright IfM-GEOMAR, Univ. Kiel.)

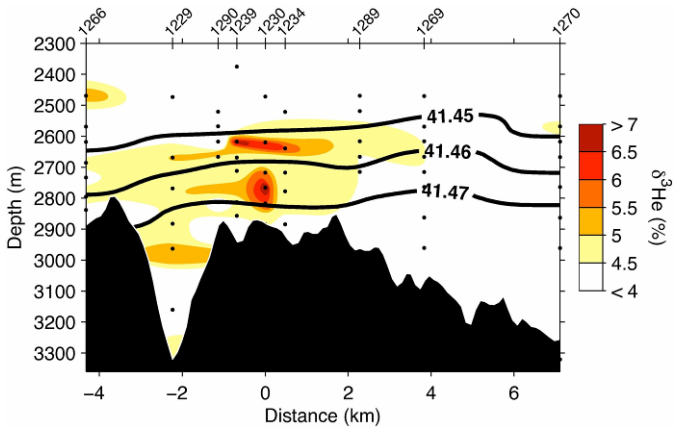


Figure 4-3: Interpolated δ^3He (relative difference of ^{3}He/^{4}He ratio from atmospheric air in %) transect across the vent site (SW to NE, cast 1234 is closest to the Drachenschlund); data points are indicated by the black dots. Also shown are the isopycnals σ_3 = 41.45, 41.46, and 41.47 kg m^{-3}, which confine the plume in the vertical.

We have used towed transects and vertical profiles of stratification, turbidity, and direct current measurements to investigate the strength of turbulent mixing in the vicinity of the vent site and the adjacent rift valley, and its temporal and spatial variability in relation to the plume dispersal. Turbulent diffusivities K_ρ were calculated from temperature inversions via Thorpe scales. Heightened mixing (compared to open ocean values) was observed in the whole rift valley within an order of K_ρ around 10^{-3} m^2 s^{-1} (Figure 4-4). The mixing close to the vent site was even more elevated, with an average of $K_\rho = 4 \times 10^{-2}$ m^2 s^{-1}. The average turbulent diffusivity is essential for modeling the dispersal of the particle plume of a hydrothermal site and its constituents. Keir et al. (2008) modeled the dispersal of the Drachenschlund plume with a Gaussian plume model, and found a vertical mixing rate K_v between 9×10^{-3} m^2 s^{-1} and 8×10^{-2} m^2 s^{-1} necessary to produce the observed distribution of CH_4 and δ^3He. Our estimates derived from the temperature finestructure analysis of the towed transects fall well within these brackets. The strength of the mixing follows a tidal cycle, with high turbulent diffusivities dominantly occurring during ebb flow, likely caused by the stronger currents interacting with the topography, and higher velocity shear. The magnitude of the observed mixing intensity is similar to observations at comparable locations on slow spreading ridges in the North Atlantic and Indian Ocean. In contrast to the fast spreading ridges in the Pacific, these are characterized by a steeper, more rugged bathymetry, favourable for an enhanced level of internal wave generation by interaction of currents with topography.

We find the tidally modulated strong mixing at the Nibelungen site is consistent with several aspects of the observed plume dispersal, namely the rapid mixing resulting in a patchy plume with a high degree of variability, the bifurcation of the plume, and the local generation of internal waves of near-buoyancy frequency by non-linear effects. These high frequency waves can add to rapid mixing of the plume by their local dissipation.

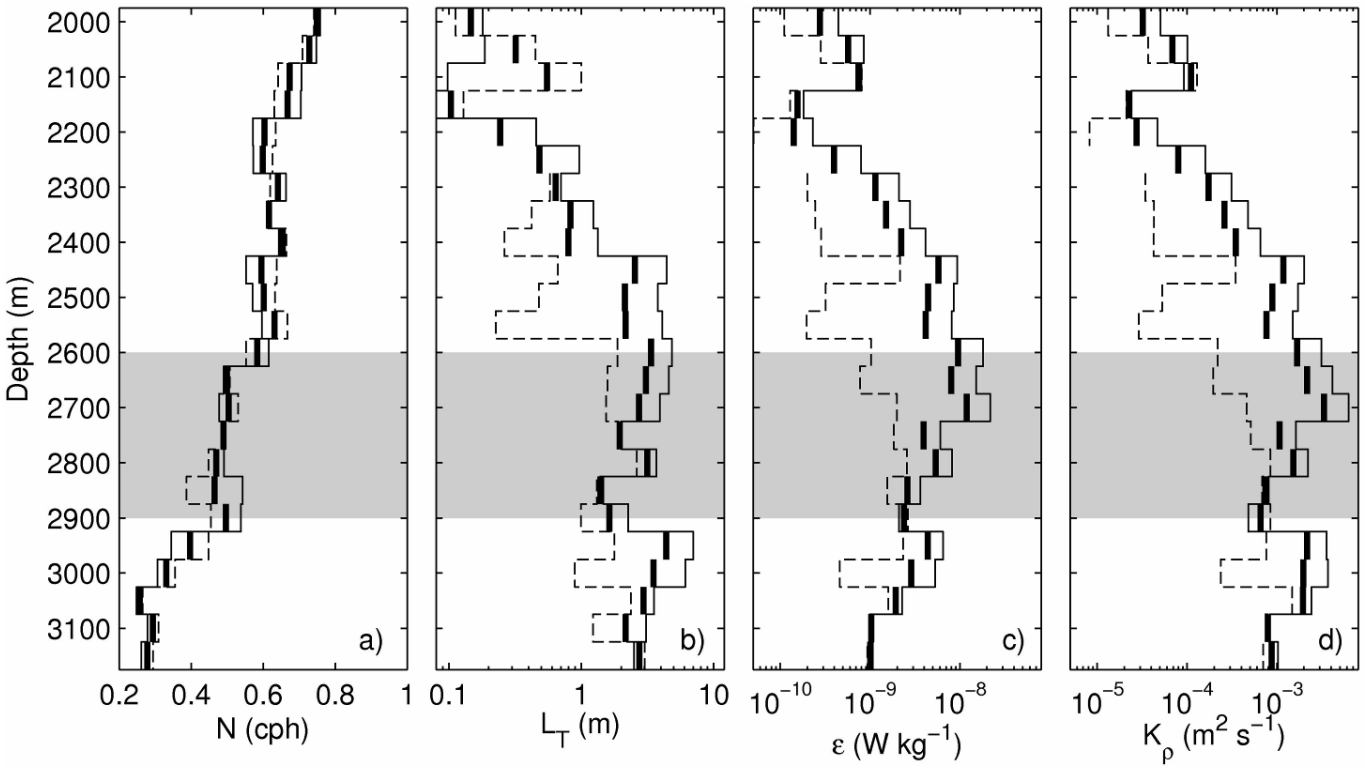


Figure 4-4: Stratification (a), average Thorpe scale (b), average dissipation rate (c), and turbulent diffusivity (d) for all CTD casts in the vicinity of Nibelungen (solid bold), during flood (thin dashed, 16 profiles) and ebb (thin solid, 17 profiles) flow. The depth range of the plume is shaded in grey.

References

Keir, R., O. Schmale, M. Walter, J. Sültenfuß, R. Seifert, and M. Rhein, Flux and dispersion of gases from the "Drachenschlund" hydrothermal vent at 8°18'S, 13°30'W on the Mid-Atlantic Ridge, Earth Planet. Sci. Lett., 270, 338 – 348, 2008.

Koschinsky, A., A. Billings, C. Devey, N. Dubilier, A. Duester, D. Edge, D. Garbe-Schönberg, C. German, O. Giere, R. Keir, K. Lackschewitz, H.A. Mai, H. Marbler, J. Mawick, B. Melchert, C. Mertens, M. Peters, S. Sander, O. Schmale, W. Schmidt, R. Seifert, C. Seiter, U. Stöber, I. Suck, M. Walter, S. Weber, D. Yoerger, M. Zarrouk, F. Zielinski, Discovery of new hydrothermal vents on the Southern Midatlantic Ridge, 4°S-10°S, during cruise M68/1. InterRidge News, 15, 9 – 14, 2006.

Melchert, B., C. W. Devey, C. R. German, K. S. Laschkewitz, R. Seifert, M. Walter, C. Mertens, D. R. Yoerger, E. T. Baker, H. Paulick, and K. Nakamura, First evidence for high-temperature off-axis venting of deep crustal/mantle heat: The Nibelungen hydrothermal field, southern Mid-Atlantic Ridge. Earth Planet. Sci. Lett., 275(1-2), 61 – 69, 2008.

Walter, M., C. Mertens, U. Stöber, C. R. German, D. R. Yoerger, J. Sültenfuß, M. Rhein, B. Melchert, and E. T. Baker, Rapid dispersal of a hydrothermal plume by turbulent mixing. Deep-Sea Res. I, 57(8), 931 – 945, 2010.

4.2. Deep water formation, the subpolar gyre, and the meridional overturning circulation in the subpolar North Atlantic

Monika Rhein[13], Dagmar Kieke, Sabine Hüttl-Kabus, Achim Rößler, Christian Mertens and Robert Meissner

In the subpolar North Atlantic, the transformation from warm, saline surface water from the subtropics into cold fresh deep water is the major process to maintain the oceanic meridional heat transport, which is important for the climate in Europe. The transformation is governed by air-sea interaction and thus especially vulnerable to climate change. Model simulations suggest a strong relationship between this transformation and the strength of the main circulation elements, i.e., the Atlantic meridional overturning circulation (AMOC) and the subpolar gyre. Whether this is valid can only be confirmed by continuous, long observational time series. Since 1997, we infer the biennial deep water formation rate by CFC inventory changes. The transport time series of the subpolar gyre was established in 2006, and the continuous measurement of transport and water masses of the main deep water export pathway, the Deep Western Boundary Current (DWBC) started in 2009. Up to now, the time series are too short to separate natural variability from trends. Our longest time series, the formation rate of Labrador Sea Water (Figure 4-5b) shows decadal variations, which are mainly caused by an atmospheric mode, the North Atlantic Oscillation (NAO) (Figure 4-5a). The baroclinic transport index is a measure for the strength of the subpolar and the subtropical gyre, the transport of the subpolar gyre is only measured until 2006 (not shown here).

An array to measure continuously the total AMOC volume and heat transport in the subpolar North Atlantic is still missing. In measuring the spatial and temporal variability of the temperature, salinity, and velocity fields, and combining the observations with outputs from a high resolution ocean model, Rhein et al. (2011) proposed a design for a sustainable AMOC array at 47°N.

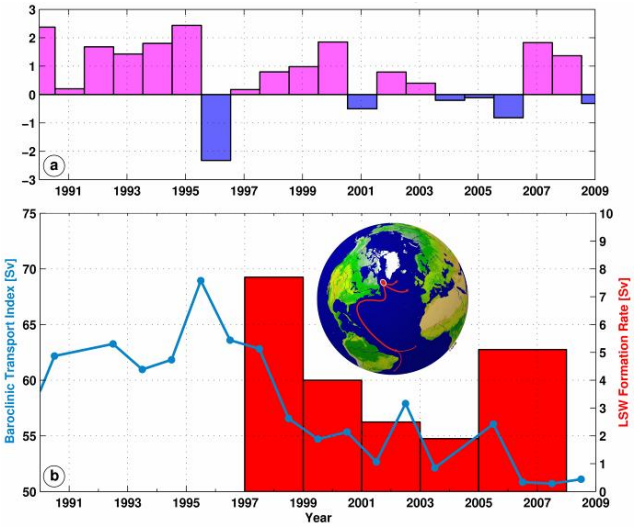


Figure 4-5: (a) Annual wintertime index of the North Atlantic Oscillation (NAO) for the years 1990-2009. (b) Baroclinic volume transport (blue line) between Bermuda and the Labrador Sea for the upper. The scale on the right indicates the formation rate of LSW [Sv] shown as red bars each covering 2 years from summer 1997 to summer 2005. The inset map shows the main circulation pathway for that water mass.

In order to obtain basin wide the velocity field, about 30 so-called C-PIES are needed in the ocean interior, and on three locations sensors measuring directly the velocity and temperature in the DWBC need to be deployed, and two moorings for the Flemish Pass. The moorings are already in place since 2009 and 2010, respectively. The C-PIES are deployed at the ocean floor and measure the acoustic travel time through the water column, the bottom pressure, and the velocity above the bottom. With sufficient spatial resolution, the instruments gain the full velocity field, and would allow calculating the volume and heat transport across 47°N in the ocean's interior.

References

Rhein, M., D. Kieke, S. Hüttl-Kabus, A. Roessler, C. Mertens, R. Meissner, B. Klein, C. W. Böning and I. Yashayaev, Deep-water formation, the subpolar gyre, and the meridional overturning circulation in the subpolar North Atlantic, *Deep-Sea Res. II*, 58(17 – 18), 1819 – 1832, 2011.

[13] mrhein@physik.uni-bremen.de

5. Terrestrial Environmental Physics (Dr. Helmut Fischer[14])

About us

The main fields of interest of our small group (5 scientists and 2 technicians) are transport of radioactive materials in soil and water, estimation of age of sediments using radioisotopes and duties in the realm of the Bremen State Radioactivity Measurements Laboratory.

5.1. Routine and emergency program

The Bremen State Radioactivity Measurements Laboratory has emerged from a radioecological laboratory at the physics department of Bremen University – founded in the early 1970s – after the Chernobyl NPP accident in 1986. It is a part of IMIS, a nationwide integrated measurement and information network run by the Federal Office of Radiation Protection (BfS).

The duties consist in surveying the level of natural and man-made radioisotopes in a wide variety of environmental media, ranging from groundwater and surface water to constituents of human diet. Several advanced analytical methods are used, including high-resolution, low-background gamma and alpha spectroscopy, in some cases after chemical extraction in a dedicated chemical laboratory. A portable gamma spectrometer is used for determining nuclide-specific dose rate values in the field. The quality of the data is proven by mandatory participation in nationwide laboratory intercomparison exercises organized by the BfS.

Apart from this routine program the laboratory is prepared for a quick-response emergency program which could be invoked by state or federal bodies in case of a nuclear emergency. In such a case, members of the group would act as advisors of the state authorities. The system is tested at regular intervals by invoking a fictitious emergency without prior announcement.

Figure 5-1: Left: Field gamma-spectroscopy during the routine monitoring program. Right: Chemical extraction of radionuclides for alpha spectroscopy.

5.2. Fukushima

The catastrophic radioactive releases from the nuclear reactors at Fukushima Daiichi, caused by the combination of the impacts of an extremely powerful earthquake and a subsequent Tsunami, led to all kinds of activities in the international and German nuclear emergency response systems. The whole group was involved in radiometric surveillance of ships, imported goods and the regional environment. Many questions from the public and the media had to be answered, and members of the laboratory had several appearances in regional newspapers and on TV.

Surprisingly at the beginning, but logical after evaluation of the atmospheric data, radioactive releases from Fukushima (isotopes ^{131}I, ^{134}Cs and ^{137}Cs) could be identified by gamma spectroscopy in various local environmental media, from rain water to milk. Fortunately, the levels were extremely small, only detectable due to the high sensitivity of the applied instruments. However, the data were useful to test radioecological models built for the prediction of contamination levels after nuclear releases, which proved to be quite reliable. The group was one of the first worldwide to publish results of long-range Fukushima effects.

[14] hfischer@physik.uni-bremen.de

References

Pittauerová, D., B. Hettwig, H. W. Fischer, Fukushima fallout in Northwest German environmental media. Journal of Environmental Radioactivity 102, 9, 877 – 880, 2011.

Fischer H. W., Medizinische Radioisotope im Abwasser – Umweltproblem oder Umwelttracer? Strahlenschutzpraxis 16, 64 – 68, 2011.

5.3. Research

Besides the routine and official tasks, the members of the group deal with a wide range of research topics:

Environmental research	Transport of radioactive materials in soil and water
Environmental protection	
Climate research Environmental research	Dating of sediments using radioisotopes
Radiation research	Radiation protection in medicine
Radiation emergency preparedness	Safety and security of radioactive sources used in medicine and industry
Material research	Application of Earth field Nuclear Magnetic Resonance (NMR) in porous and heterogeneous systems

The following sections describe selected research topics in more detail.

5.3.1. Dating of sediments using radioisotopes

Daniela Pittauerová[15], Helmut Fischer

Sediments in the bottom of lakes, seas and oceans serve as a unique archive of climate and environmental data. They are collected and studied by variety of geophysical and geochemical methods in order to obtain proxies of different parameters of water reservoirs and the climate in the past times. Upon these indicators scientists can reconstruct past conditions and compare them to the present situation.

Estimation of the age profile of sediment cores is an important part of the climate and environmental research, because often the data are worthless without information about the age of a specific sample. A well-known example of a method used for dating sediment cores is ^{14}C chronology.

For short-lived isotopes, having a higher specific activity, the radiometric methods used in our laboratory are ideally suited. Natural ^{210}Pb with a radioactive half-life of 22.3 years can cover a time span of about 100 to 150 years and is thus well suited for dating the uppermost part of sediment cores. This time range covers the most important recent climate and environmental changes connected with human industrial activities. Additionally, the artificial isotope ^{137}Cs, a product of atmospheric nuclear bomb testing and Chernobyl accident releases, omnipresent in all kinds of environmental samples, is used as a complementary and absolute time marker.

Figure 5-2: Taking sediment samples in the Gulf of Eilat.

[15] pittauerova@iup.physik.uni-bremen.de

^{210}Pb and ^{137}Cs dating method

^{210}Pb forms part of the natural ^{238}U decay chain, ^{226}Ra being the nearest long-lived parent isotope. In old, sealed samples the decay chain from ^{226}Ra to ^{210}Pb is in equilibrium, rendering identical specific activities ("supported" ^{210}Pb). Emanation of gaseous ^{222}Rn from soil in the atmosphere leads to production of ^{210}Pb in air without the parent ^{226}Ra ("unsupported" ^{210}Pb). In the catchment area of water bodies, the unsupported ^{210}Pb is transported to the sediment and can be discriminated from the supported portion due to the lack of the radioactive parent isotopes. It is thus often called "excess" ^{210}Pb. Assuming constant supply of this excess lead and a constant sedimentation rate, its specific activity will only be caused by radioactive decay and thus is a direct measure of relative age.

High-resolution, low-background gamma spectroscopy allows simultaneous detection of ^{210}Pb, ^{214}Bi/^{214}Pb and ^{137}Cs. When the samples under investigation are kept in a gas-tight container for at least two weeks before measurement, the short-lived ^{222}Rn daughters ^{214}Bi and ^{214}Pb are in equilibrium with ^{226}Ra and thus represent supported lead, to be subtracted from the total ^{210}Pb signal to obtain the unsupported fraction. Compared to otherwise popular radiochemical techniques, the method used in our laboratory is non-destructive and makes it possible to further investigate the samples by other methods. The disadvantage is the elaborate estimation of the self-absorption of the weak gamma radiation of ^{210}Pb in the sample itself and applying corrections to this effect.

Recent projects

In cooperation with national and international partners, we provide core dating in the frame of different climate and environmental research projects.

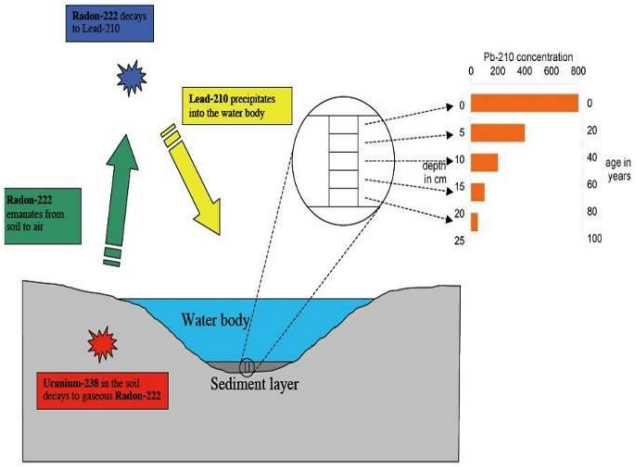


Figure 5-3: A schematic diagram of the environmental pathway of excess ^{210}Pb.

Holocene climate variability in the semiarid Sahel Belt

(cooperation: MARUM, University Bremen)

Water availability in this part of tropical North Africa, which is essential for life in the area, is affected by shifts to more arid climate. High resolution sediment cores off Senegal offer the opportunity to study the history of the Sahel drought and to assess its imprint on the composition of terrestrial materials deposited at the sea floor. The recent dry periods in the early 1970s and 1980s with partial recovery during the late 1990s are used as an image of such changes in the sediment record and enable to look for similar events in the past.

Anthropogenic input of particulate Phosphorus in the Gulf of Eilat, Israel

(cooperation: University of Kiel; Israel Oceanographic and Limnological Research, Haifa, Israel)

In this project a possible connection of eutrophication of the gulf and consequential environmental changes with industrial pollution caused by phosphorus ore mining and processing and transporting of fertilizers is studied. For the first time, sedimentation rates in this region could be quantified and a strong contribution of erosion processes to sediment formation was identified.

Figure 5-4: A dust cloud in Akaba, east coast of the Gulf of Eilat.

References

Mulitza, S., D. Heslop, D. Pittauerova, H. W. Fischer, I. Meyer, J.-B. Stuut, M. Zabel, G. Mollenhauer, J. A. Collins, H. Kuhnert, M. Schulz, Increase in African dust flux at the onset of commercial agriculture in the Sahel region, Nature, 466, 226 – 228, 2010.

Pittauerová D., B. Hettwig and H. W. Fischer, Pb-210 sediment chronology: Focused on supported lead. Radioprotection, 46, S277 – S282, 2011.

5.3.2. Nuclear and radiological security research

Tom Bielefeld[16]

Illicit trafficking of nuclear and radioactive materials is a phenomenon which has emerged in the early 1990s, facilitated by the collapse of the Soviet Union and the ensuing under-funding of control and security in its vast nuclear infrastructure. Since that time, hundreds of incidents of thefts and smuggling attempts of such materials all over the world have been recorded in the International Atomic Energy Agency's illicit trafficking database.

Moreover, in recent years, terrorist plots involving the use of radioactive sources in so-called "dirty bombs" were uncovered and foiled (notably in Great Britain in 2004 and in Germany in 2005). These incidents, as well as continuing threats by terrorist groups to use radiological and nuclear means of attack, underscore the urgency to improve the security of these materials in every country and in all facilities in which they are used and stored. These incidents also call for the competent authorities in potential target countries to improve radiological attack and emergency preparedness and response measures on a local and national level.

The issues of nuclear and radiological trafficking as well as attack preparedness and response are directly related to the Radioactivity Measurements Laboratory's task list and its responsibilities. Radioactive sources of unknown origin are found on a regular basis by local authorities and businesses, requiring the Laboratory's staff to provide assistance by identifying the material and evaluating radiological hazards. The Laboratory also plays an important role in the State of Bremen's response plan for radiological contingencies, being responsible for the implementation of an emergency measurements campaign and for providing rapid assessments of contamination levels.

In support of its responsibilities in the area of nuclear and radiological security, the Laboratory maintains a comprehensive research program, ranging from studies to improve the technical and organizational means of emergency response to those aimed at strengthening regulations for the physical security of radioactive materials:

Modelling radiological weapons attacks to improve attack preparedness and response

In this project, simulations of different conceivable "dirty bomb"-attack scenarios are used to better understand the effects of radiological weapons and to help improving operational guidelines for first responders (police, fire fighters, paramedics). The simulations use physics models to describe the explosive dispersal of various radioactive materials, such as ^{137}Cs and ^{60}Co. While in most scenarios the resulting contamination comprises a large area and requires a costly clean-up, high radiation doses are only expected for victims in the immediate vicinity of the attack and insufficiently protected first responders. The latter can be avoided with improved response procedures, training and equipment,

[16] Tom_Bielefeld@hks.harvard.edu

suggestions for which are being worked out as part of this research. For instance, early detection of the presence of a radioactive substance is an important factor in limiting the number of casualties and permits effective evacuation strategies and quick initiation of decontamination measures. Hence, one central recommendation of the project has been to include in responder's guidelines the requirement of the use of a radiation detector in every suspicious explosion or fire. Also, different radioactive materials may behave very differently when used in a terrorist attack, depending on their physical and chemical properties and the way they are dispersed. This has a number of implications both for the response in the immediate aftermath of an attack and for its long-term socio-economic impact. The project's insights will lead to a set of recommendations in the ongoing discussion about a new IAEA document on security classifications for radioactive sources.

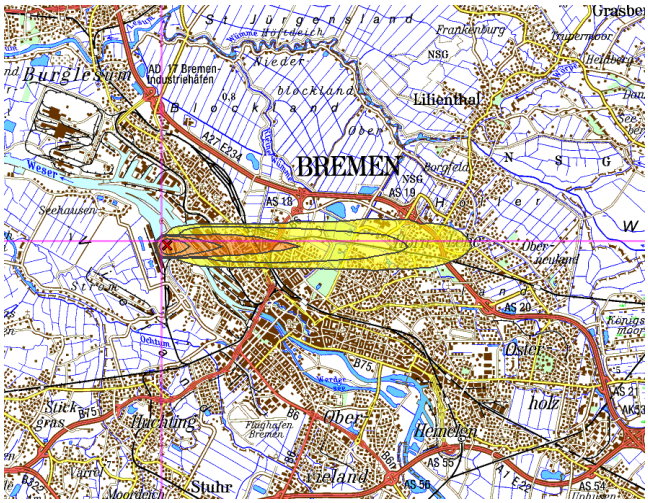


Figure 5-5: A prediction of contamination levels in Bremen after a radiological attack in the harbour region, in a west wind situation.

In the course of this project, the Laboratory co-organized a workshop together with the Bremen Fire Department and benefited greatly from the exchange with the State's first responders. Members of the group also contributed to two table-top exercises, organized by the Federal Office for Radiation Protection (BfS).

Assessing methods for the internal decontamination of persons who have ingested, inhaled or otherwise incorporated radioactive substances

This project, commissioned by the BfS, compiles and evaluates methods to treat internal radioactive contamination. It includes commonly used radionuclides, such as ^{137}Cs and ^{60}Co, as well as nuclides which could be released during a nuclear reactor accident, e.g., ^{90}Sr. It also takes into account more exotic materials of concern, such as ^{210}Po, which was used in the murder of former Russian secret agent Alexander Litvinenko in London in 2006.

Improving security for radioactive sources in medical and industrial facilities

Most of the recent terrorist plots in Europe were planned to a large extent by groups within the target country. This observation provided the motivation for this project, which analyses the security of radioactive materials in facilities in Germany. Like other western countries, Germany relies on comprehensive, but safety-centred regulations and functioning government oversight to protect materials of concern. However, the project's analysis, which is the only open study of its kind with empirical data, found that existing regulations and daily work procedures in most of the inspected facilities do not provide sufficient security against locally acting terrorist groups. The security assessments were conducted using an established physical protection systems methodology and included the development of plausible theft scenarios and technical analyses of the instruments holding the sources. The project also identified obstacles which make stealing and handling of radioactive sources difficult and found a significant risk for potential perpetrators to receive lethal doses in some relevant scenarios. However, since this may be acceptable for some of today's terrorist groups, even highly radioactive sources must no longer be considered "self-protecting". Hence the project recommends a number of mandatory technical and organizational measures to be

introduced in those medical and industrial facilities with sources of greatest concern. These comprise intrusion detection systems and technical measures to delay the access to the instrument which holds the material and to the actual radioactive source within an instrument. They also include access control for employees and the introduction of a 2-person-rule of access. Training and education for source owners and users is recommended to increase security awareness at their facilities.

In its various projects, the Laboratory maintains collaborations with researchers and practitioners from government agencies and universities such as Harvard University's Kennedy School of Government. Results are presented at national and international conferences and published in peer-reviewed journals. Members of the group have also been invited to present their findings at high-ranking panels at international workshops on nuclear materials security.

References

Bielefeld, T., H. W. Fischer, Security and Damage Potential of Commercial Radioactive Sources. Journal of Nuclear Materials Management 35, no. 2,14 – 17, 2007.

Hormann, V., H. W. Fischer, Materialsammlung zur internen Radiodekontamination von Personen, Studie im Auftrag des BfS. Salzgitter, BfS-RESFOR-18/09, 2009.

Fischer, H. W., T. Bielefeld, B., Hettwig, Krypton Gas Cylinders as a Source of Radiation, Health Physics 99, 58 – 65, 2010.

6. Teaching activities

Annette Ladstätter-Weißenmayer, Christian von Savigny, Anna Serdychenko, Anja Gatzka und Lars Jeschke

Today's graduate and postgraduate education in the field of Earth System and Environmental Science is a highly interdisciplinary and inter-institutional challenge. The existing research infrastructure at the University of Bremen (UB) and the Alfred Wegner Institute Bremerhaven (AWI) offers a unique research environment in north-western Germany to study past, present and future changes of the climate system. The education and qualification of Master and PhD students is carried out on an internationally competitive level.

Since 2000 the international Master program „Postgraduate Program Environmental Physics" (PEP) accredited by the German Accreditation Council is running in collaboration with the Alfred Wegener Institute (AWI) Bremerhaven and 58 students successfully passed this program with a Master degree, 10 with a Certificate. The foci of this program are on the Atmosphere, Ocean, Land and Climate as well as Remote Sensing and Dynamics.

In the winter terms 2007/08 until 2010/11, 40 students started this study-program at the University of Bremen (UB). The students came from Pakistan, Romania, Nepal, Nigeria, Germany, India, Iran, Indonesia, China, Azerbaijan, Ghana, USA, Iraq, Taiwan, Spain, Greece and Thailand.

In 2006 a very successful collaboration between the University of Bremen and the Ocean University of Qingdao of China (OUC) started with the aim to offer master double degrees of both universities. That means Chinese students start their studies in China, participate one year in the PEP program and then complete their studies at OUC. The German students start with one year of the PEP program and then study one year at OUC.

Following this double degree program, in addition to the "normal" PEP students, 19 pre-selected excellent students came in the winter terms 2007/08 until 2010/11 from the OUC to study one year in the PEP program to get a certificate. After finishing their master program at the partner university in China (OUC) they get a double degree from both universities (OUC and UB). From 2007 up to 2010 19 students finished successfully with a Certificate, 15 students with their master double degree. 5 of these students already started with a PhD thesis at IUP or AWI Bremerhaven.

In 2006 in the context of the excellence initiative the Bremen International Graduate School for Marine Sciences GLOMAR was launched and funded by the Deutsche Forschungsgemeinschaft (DFG). This Graduate School is carried out with the following partners: University of Bremen, DFG Research Center Ocean Margin (RCOM), Center for Marine Environmental Science (MARUM), Research Center for Sustainability Studies (ARTEC), AWI, German Maritime Museum (DMS), Max Planck Institute for Marine Microbiology, Center for Tropical Marine Ecology (ZMT). For excellent PhD students GLOMAR provides an optimal student research environment and fosters excellence in education and research. In general the Graduate School's educational concept allows the PhD students to develop into excellent interdisciplinary researchers, with international contacts and a publication record in peer-reviewed international journals, skills in conducting research and in communication (on disciplinary and interdisciplinary levels to both experts and students as well as to the public), and in project management.

Since 2008 the University of Bremen, AWI, and Jacobs University Bremen offers a new Helmholtz-PhD programme named ESSReS (Earth System Science Research School) and in 2009 a second one named POLMAR (Polar and Marine Research). The Helmholtz Graduate School POLMAR is carried out with the following partners: AWI (host institution), University of Bremen, Jacobs University Bremen, Max Planck Institute Bremen, University of Potsdam,

Institute for Marine Resources (IMARE), and Hochschule Bremerhaven.

These programs enable PhD students from a variety of disciplines to cooperate and exchange views on the common theme of linking ‘data and modelling’, leading to a better understanding of local processes within a global context. It provides a structured framework for education and qualification for excellent PhD students dealing with the challenging questions in Earth System Science and Polar and Marine Research. Developing all categories of skills needed for analysing complex climate and environmental systems and the development of integrated solutions in a supportive network of collaborating research institutions fosters outstanding career options. Structured training and supervision supported by a broad range of soft skill courses is indicative for the entire concept.

In 2008 12 internal and 12 external students started and the same number of students started in fall 2011 within the ESSReS program and up to now more than 100 PhD students are within POLMAR.

The IUP Bremen regularly welcomes high school students from high schools in Bremen carrying out practical exercises. That means that the students have the possibility to work in different research groups together with scientists for a time period of 2 weeks to get a first impression of research work.

In addition the members of IUP are very active and involved in the “Day of Physics” and “Saturday Morning Physics” to give an overview about scientific work at IUP.