2011 NDACC Symposium

Network for the Detection of Atmospheric Composition Change

SESSION 2

POLAR CHEMISTRY AND OZONE LOSS

2011 NDACC Symposium
Network for the Detection of Atmospheric Composition Change

Oral Session

2-1 Monitoring and understanding polar stratospheric ozone: a short historical overview and results from the ongoing project RECONCILE

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Introduction

The continuous monitoring of our atmosphere with respect to its physical and chemical properties is a key to the detection of atmospheric change. Focused field campaigns and diagnostic modelling studies are the tools of choice to understand these changes, and to predict future trends – including possible impacts of abatement or mitigation strategies – in prognostic models. A prominent example of the synergetic use of these various approaches and tools has been the study of stratospheric ozone (O_3), and in particular the discovery, comprehension and successful remedy of the so called Ozone Hole.

The Story of the Ozone Hole

The ozone layer – situated between 15 and 50 km altitude in the stratosphere – started to form about 2 billion years ago, when oxygen (O_2) released by the first photosynthetic organisms accumulated in the atmosphere, and ever since, it has shielded the Earth's surface from UV radiation. An equilibrium between formation and destruction reactions, some of which involve naturally occurring hydrogen, nitrogen and halogen compounds as catalysts, kept the stratospheric ozone concentration relatively constant throughout Earth's history.

With the modern industrialisation that began around the turn of the 18th to the 19th century, trace gases released by human activities started to significantly alter the composition, chemistry and radiative balance of the atmosphere. At first, impact on the stratosphere was rather insignificant: reactive pollutants would decompose long before reaching high altitudes, and the atmospheric increase in the long lived greenhouse gases CO_2, CH_4 and N_2O was not yet significant enough to alter stratospheric chemistry[1]. However, in the middle of the 20th century, chloroflourocarbons (CFCs) were introduced as refrigerating agents and as propellants in spray cans. These compounds would not readily decompose in the lower atmosphere and thus be transported to the stratosphere. Several atmospheric scientists pointed out the CFCs' potential to release their chlorine upon UV irradiation, and by doing so supply a catalyst that could accelerate the rate of ozone decomposition (Cicerone et al., 1974; Molina and

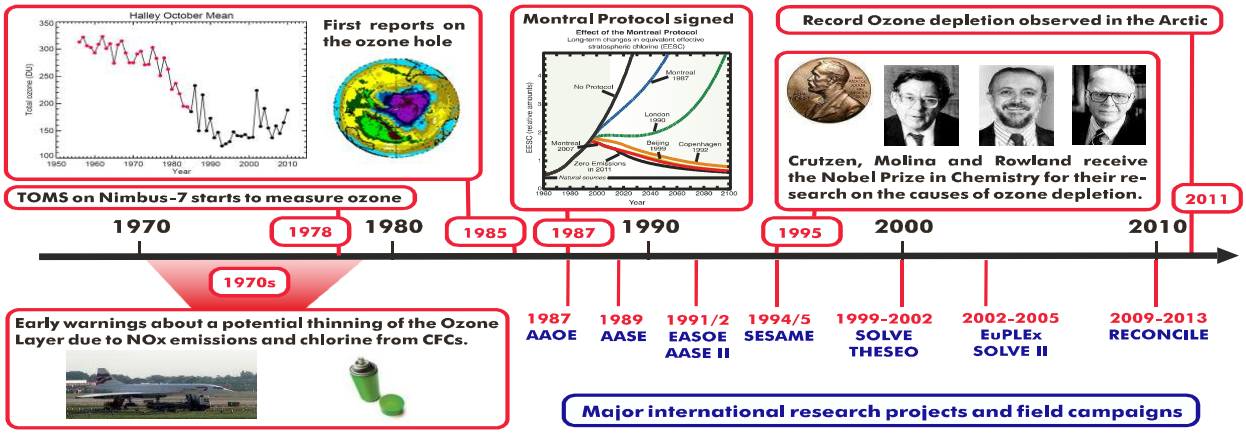

Figure 1 Timeline of ozone hole research

[1] Today, with CFC emissions being reduced to almost zero, N_2O is the dominant ozone depleting substance (ODP) released by humans (Ravishankara, 2009).

would have happened to the ozone layer and UV radiation intensity had the Montreal Protocol not been signed. In addition to their harmful effects on the stratospheric ozone layer, the CFC's tremendous greenhouse gas potential has been recognised over the past few years, and the Montreal Protocol is now recognised as the single most efficient policy measure to date limiting global warming (WMO, 2010).

But back in 1987, the ozone hole theory was far from being generally accepted, and a quantitative understanding of polar ozone loss was lacking. People also started to consider to what extent an ozone hole could form over the Arctic, where normally the polar vortex is less stable and temperatures are higher than in the Antarctic. Laboratories around the world started a quest to accurately determine the rates of the heterogeneous and catalytic processes leading to ozone depletion. Balloon- and airborne field missions were carried out to investigate the relevant physical and chemical processes in the atmosphere. They were supported by efforts to simulate observed ozone levels in diagnostic models. This research during the 1980s and 90s corroborated the theory developed in the mid-1980s.

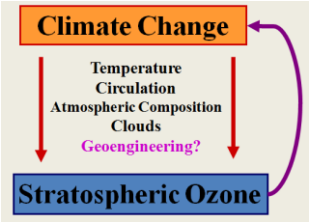

Figure 3 Ozone climate interactions

In the meantime, climate change was being recognized as another global environmental threat, and one of much greater scope and one much harder to mitigate. Questions were raised as to the possible interactions between stratospheric ozone and climate change (Figure 3), and by the late 1990s, the focus of stratospheric research shifted towards the question how climate change would affect stratospheric chemistry and in particular the recovery of the ozone layer. Efforts were made to develop and improve prognostic chemistry climate models (CCM). Today, these models and semi-empirical projections provide consistent estimates with respect to the so-called "recovery date". This is the time when the ozone layer is expected to return to its 1980 state and is currently projected to around the middle of the century (WMO, 2010).

RECONCILE

Some remaining ambiguities in the context of polar ozone depletion are being addressed by the EU funded research project RECONCILE, with the objective to *fully quantify* the rates of some of the most relevant physical and chemical processes. Key results from a dedicated Arctic field campaign in the winter 2009/10, novel laboratory experiments, and extensive modeling studies using state of the art chemical transport models include:

- Laboratory experiments and field data on the ClOOCl photolysis rate[4] and other kinetic parameters are shown to be consistent with an adequate degree of certainty.
- Heterogeneous NAT nucleation in the absence of ice has been unambiguously demonstrated, and a variety of possible "nuclei" was detected. This improves our understanding and model parameterization of PSC formation and denitrification via sedimenting particles.[5]
- Strong evidence has been found for significant chlorine activation not only on PSCs but also on cold binary aerosol (Drdla and Müller, 2010).
- Quantification of transport/mixing is not always correct in existing models.
- Uncertainties in trajectory calculations have been quantified in an active aircraft Match experiment. These uncertainties can influence the Match technique to determine ozone in an inhomogeneous vortex.
- One important issue that still needs to be addressed is the currently highly unpredictable year-to-year variability in Polar vortex stability in the Arctic. For example, in 2010/11, a particularly stable and compact vortex led to record ozone losses in the Arctic.

In an integrated approach (Figure 4), RECONCILE aims to directly improve a prognostic CCM (LMDZrepro), and to validate the CCM results against satellite data and other long term records using

[4] ClOOCl photolysis essentially governs the rate of catalytic ozone loss (von Hobe, 2007).

[5] The removal of $_x$ decelerates chlorine deactivation in late winter and thus influences the duration of the O_3 loss period.

data assimilation and detrended fluctuation analysis (e.g. Kiss et al., 2007). The emphasis is clearly placed on the correct and realistic representation of the various processes in CCMs, so that they may be used to predict stratospheric ozone levels in a stratosphere altered by climate change. The alterations include the physical conditions, atmospheric transport, or possible geoengineering endeavours to avert further climate change, e.g. the deliberate enhancement of stratospheric aerosol to reflect incoming solar radiation.

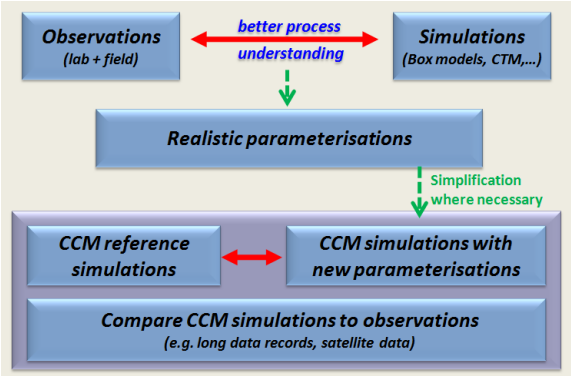

Figure 4 The RECONCILE integrated approach

Conclusion

The ozone story clearly demonstrates the value, yes even the necessity, to continuously monitor the state of our atmosphere by ground stations and satellite data. Without this monitoring, the ozone hole may have gone undetected for some time, with the consequence that the Montreal Protocol would not have been signed and we would indeed have been bound for the "World Avoided", in which life as we know it would not be possible. Furthermore, these time series are extremely valuable in testing prognostic models. The understanding of the physical and chemical processes in these models, however, is mainly gathered in dedicated and carefully planned experiments. Both approaches are warranted in our continuing efforts to cope with threats to the ozone layer and with global climate change.

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Oral Session

2-2 Arctic ozone profiles as seen by GOMOS

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Exceptionally low ozone concentrations were observed in Spring 2011 in the Arctic. The cold stratosphere and strong vortex that lasted till the end of March created meteorological conditions where the catalytic ozone loss took place. More than one third of the total ozone was destroyed. The stellar occultation instrument GOMOS with robust retrieval algorithm and good vertical resolution turned out to provide reliable measurements in the exceptional conditions. GOMOS measured the ozone profiles inside and outside the vortex and showed that more than 70 % of the ozone was destroyed at 20 km altitude. In this presentation we discuss the GOMOS measurements of Arctic ozone during the spring 2011. Comparisons with soundings and chemistry transport model are given. The GOMOS data quality, error characterization and the new version 6 data will be discussed.

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Oral Session

2-3 Highlights of Atmospheric Composition Measurements at Canada's Polar Environment Atmospheric Research Laboratory

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The Polar Environment Atmospheric Research Laboratory (PEARL) is located in the Canadian High Arctic at Eureka, Nunavut (80N, 86W) and is operated by the Canadian Network for the Detection of Atmospheric Change (CANDAC). It has been equipped with a suite of instrumentation to investigate chemical and physical processes in the atmosphere from the ground to 100 km. One of the four research themes being pursued at PEARL is that of Arctic Middle Atmosphere Chemistry, whose overall goal is to improve our understanding of the processes controlling the Arctic stratospheric ozone budget and its future evolution. In the Arctic, ozone concentrations are tied to stratospheric dynamics and concentrations of other highly variable trace gases. Therefore, year-to-year and season-to-season, Arctic stratospheric ozone concentrations vary greatly. Anthropogenic halogen emissions and climate change complicate this system further. In order to understand this complex system, long-term measurements of the composition of the Arctic stratosphere are necessary. PEARL houses a number of NDACC instruments, including two UV-visible grating spectrometers (on site for spring campaigns since 1999, and year-round since 2006) and a Bruker 125HR Fourier transform infrared (FTIR) spectrometer (on site since 2006), which replaced the former Bomem DA8 FTIR spectrometer (operational from 1993-2008). This presentation will provide an overview of the measurements made by these instruments, including the long-term time series of ozone, NO2, OClO and BrO measured by the UV-visible spectrometers, and ozone, HCl, HF, NO, NO2, HNO3 and ClONO2 measured by the FTIR spectrometers. Four years of measurements of the nitrogen species and total reactive nitrogen (NOy) budget will be compared with ACE-FTS satellite data, and with the CMAM-DAS, GEM-BACH, and SLIMCAT models. In winter 2011, the polar vortex was mostly circular, cold and centered above the pole, with Eureka mostly inside the vortex from October 2010 until late March 2011. Unusually low ozone, HCl, and HNO3 total columns were observed in comparison to the previous 14 years. These measurements are consistent with the low temperatures measured by radiosondes launched twice daily at Eureka and with the polar stratospheric clouds observed by the CANDAC Rayleigh-Mie-Raman Lidar at Eureka. These results will be presented, along with calculations of the chemical ozone loss above Eureka using SLIMCAT passive ozone.

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2-4 Probing the Antarctic ozone hole with NDACC total ozone column observations in 1989-2010

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We present the ozone depletion analysis in the Antarctic using the ground-based total column measurements of the NDACC cluster. The analysis includes measurements from the historic stations Syowa, South Pole, Halley, and Faraday, in addition to Arrival Heights, Dumont d'Urville, Marambio, Belgrano, Zhongshan, San Martin and Dome Concordia, and it takes the available measurements from the respective stations in 1989-2010. We use the passive tracer method, in which a tracer simulated from a chemical transport model, REPROBUS, was subtracted from ozone measurements to calculate the chemical ozone loss within the Antarctic vortex. Since the stations cover most parts of the Antarctic, a complete evolution of the ozone loss processes in the region for each year can be derived. Unlike the Arctic, the inter-annual variation in the Antarctic meteorology rarely changes to extreme conditions, ozone depletion measured seldom shows extreme episodes. The analysis shows about a maximum of 35-40% loss of ozone in the late 1980s and early 1990s and got intensified due to increased halogen loading in the mid and late 1990s. Therefore, the maximum ozone loss increased to 50-55% during that period. Because of the loss saturation, the ozone depletion unabated and stayed around 55% in the last decade. The yearly difference in the maximum loss rests within 5% after 1995, which is well within the error bounds of the ozone loss computations. However, there was a major warming event in 2002, and hence the loss reduced to 40% due to a small and short-lived vortex. On the other hand, the winters 2003 and 2006 show the largest vortex area and highest loss of ozone in the last decade. The ozone loss estimated from satellite measurements agree well with those from the ground-based observations as well. Any sort of ozone recovery signals cannot be traced from the present analysis though there is evidence of reduction in stratospheric halogens. This implies that the ozone recovery is still a few decades away.

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2-5 In Situ Measurements of Polar Stratospheric Ozone from Long Duration Balloons during Concordiasi

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The discovery of an annual, austral spring decrease in column abundances of ozone over the Antarctic continent, now popularly known as the "ozone hole", served as a cautionary tale regarding the impact of anthropogenic emissions on the global atmosphere. While considerable progress on our understanding of the causes of polar stratospheric ozone loss has been made during the past two decades, model calculations are still limited by uncertainties in both chemical and dynamical factors. These uncertainties also affect predictions of the future state of stratospheric ozone, such as the point at which the Antarctic "ozone hole" recovers and the extent to which climate changes may impact ozone abundances.

The first quasi-Lagrangian measurements of polar stratospheric ozone were made from long duration stratospheric balloons, deployed from McMurdo station by CNES during the Concordiasi field campaign in the austral spring of 2010. The primary goal of the international Concordiasi project, which was an International Polar Year (IPY) effort, was to validate measurements made by the Infrared Atmospheric Sounding Interferometer (IASI) satellite instrument by comparing data obtained from radiosondes with observations made by dropsondes launched from long-duration balloons flying over Antarctica. These long-duration balloons additionally make excellent platforms from which to study the chemistry of Antarctic ozone depletion.

Several specially designed ultraviolet photometers were built at the University of Colorado Boulder (UCOz) and at Laboratoire de Météorologie Dynamique (LMD, B-Bop) for this purpose to meet the requirements of long life and low power consumption. These instruments were flown on six Concordiasi balloons launched in September and October 2010 within the developing Antarctic "ozone hole". Because the balloon trajectories are nearly Lagrangian over a few days' time, the observations provide a detailed picture of ozone loss in individual air masses.

In this presentation, we will describe the Concordiasi balloon project and will present ozone data obtained from the long-duration flights. We will discuss efforts to compare ozone measurements from the Concordiasi balloons with those made from ozonesondes in a Match-style campaign involving Antarctic surface stations at Neumayer, Belgrano, Syowa, Davis, Dumont D'Urville, McMurdo and South Pole. Observations from the Concordiasi balloons will be compared with calculations of photochemical ozone loss from a sophisticated trajectory model, initialized with observed temperature, pressure and location. The in situ data and comparison to photochemical models will address long-standing questions about the chemical processes that cause stratospheric ozone depletion.

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2-6 Variation of chlorine species related to Antarctic ozone hole observed by ground-based FTIR at Syowa Station, Antarctica

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Chlorine species play important role in stratospheric polar ozone destruction. Active for of chlorine species, such as Cl or ClO, are formed by heterogeneous reactions on the surface of polar stratospheric clouds (PSCs) from chlorine reservoir species, such as HCl or ClONO2. However, temporal variation of these spices have never monitored from ground throughout the Antarctic winter/spring covering the whole ozone hole period yet. We have installed the Bruker IFS-120M FTIR with the resolution of 0.0035 cm-1 at Syowa Station, Antarctica in March, 2007. We have observed solar-absorption spectra with 6 NDACC filters covering from 750 to 4300 cm-1 mid-IR regions. We made 87 days of observations in 2007. Vertical profiles and/or column amounts of stratospheric minor species, such as O3, HNO3, N2O, HCl, HF, and ClONO2, were retrieved with fitting program called SFIT2. Retrieved profiles were validated by comparison with ozonesondes and satellite (Aura/MLS, ACE) data. The agreements were generally very good in all species. In addition to the above species measured by FTIR, we used ClO profile data measure by Aura/MLS for our analysis. First, we omitted the data outside of the polar vortex by looking at the potential vorticity calculated by the meteorological analysis. Then, time variations of O3, ClO, HCl, ClONO2, and HNO3 were investigated. When stratospheric temperature got cooler than PSC threshold temperature (T_NAT), PSCs started to form. Consequently, amount of HCl, HNO3, and ClONO2 started to decrease, by the heterogeneous reactions on the surface of PSCs. On the other hand, increase of ClO was observed by Aura/MLS data. After the arrival of sun light, ozone amount started to decrease from August. When the stratospheric temperature warmed up above T_NAT in mid September, enhanced ClO amount started to decrease, then became background value in early October. The chlorine from ClO has two ways to recover, HCl and ClONO2. Temporal build up of ClONO2 prior to HCl increase at 20 km in September 2007 was first confirmed from ground-based FTIR data. It is suggested that this preferable conversion into ClONO2 was caused because there were still some O3 available in this time period to keep high ClO/Cl ratio at this altitude.

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2-7 Total atmospheric bromine, chlorine, and fluorine trends and age of the air from the NOAA GMD Cooperating Network

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The Montreal Protocol on Substances that Deplete the Ozone Layer and its subsequent amendments has been successful in decreasing the total equivalent chlorine of man-made halocarbons in the atmosphere by 13% since its peak in 1994-5. The National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA/ESRL) maintains a global in situ and flask network for the measurement and analysis of halocarbons and other atmospheric trace gases that started in 1977. The purpose is this work is to study atmospheric trace gases that affect climate change, stratospheric ozone depletion, and air quality from observations at NOAA and cooperating stations. The analysis of flask samples and data are conducted within the Global Monitoring Division (GMD) in Boulder, Colorado, USA. Through collaborations with the National Aeronautics and Space Administration (NASA) and the National Science Foundation, NOAA/ESRL operates a number of in situ and flask collection instruments from manned and unmanned aircraft up to 21 km, and balloon platforms up to 32 km on airborne experiments that have spanned the globe that began in 1991. We measure over 40 trace gases in the atmosphere including nitrous oxide (N2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), methyl halides, numerous halocarbons, sulfur gases (COS, SF6, CS2), and selected hydrocarbons. This presentation will highlight our recent observations of halocarbons and other trace gases from the NSF and NOAA sponsored HIAPER Pole-to-Pole Observations over NDACC and NOAA stations from 2009 to 2011 and the NASA and NOAA sponsored Unmanned Aircraft Systems Missions. We will include comparisons with NDACC and satellite (ACE and AURA) observations. For more information see http://www.esrl.noaa.gov/gmd/hats and our data are available via anonymous ftp at ftp://ftp.cmdl.noaa.gov/hats.

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Poster Session

2P-1 Winter to winter variability of chlorine activation and ozone loss as observed by ground-based FTIR measurements at Kiruna since winter 1993/94

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In the framework of the NDACC (Network for the Detection of Atmospheric Composition Change) a ground-based FTIR (Fourier Transform Infrared) spectrometer is operated in Kiruna (Sweden). From winter 1989/90 to 1995/96 measurements at Kiruna have been performed on a campaign basis. Since March 1996 a FTIR spectrometer is operated continuously in collaboration with the IRF Kiruna and the University Nagoya (J). From individual absorption lines column abundances of several trace gases like O3, H2O, N2O, CH4, HF, HCl, ClONO2, NO, NO2, and HNO3 can be derived. Furthermore, using the altitude dependent pressure broadening of absorption lines useful height information can be retrieved for some species. This paper will focus on observations made when Kiruna was inside or at the edge of the vortex. Kiruna is quite often inside the vortex and the polar night is rather short. This allows us to start solar measurements as early as mid-January: More than 100 days of solar observations could be made in the polar vortex since winter 1993/94. Column amounts of HF are used as a dynamical tracer. Using the ratios of column amounts of HCl and ClONO2 to HF the degree of chlorine activation is determined. During most of the winters significant chlorine activation is observed. Similarly, the ratio of O3 to HF is used in order to investigate ozone depletion. These ratios will be discussed in terms of chlorine activation and deactivation and ozone loss in the polar vortex with respect to stratospheric temperatures during the different winters.

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Poster Session

2P-2 Measurements of the winter stratospheric structure and composition from the NDACC station at Thule, Greenland: long-term evolution and the exceptional winters of 2008-2009 and 2010-2011

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The station of Thule Air Base (76.5°N, 68.8°W), loc ated in the North Western coast of Greenland, is part of the Network for the Detection of Atmospheric Composition Change. A lidar was installed at Thule in 1990 for the observation of the upper tropospheric and lower stratospheric aerosols, and the measurement of the middle atmospheric temperature (T) profiles. In 2009 the system was upgraded to measure also lower tropospheric (from about 200 m) aerosols. The lidar has been operational during many of the last twenty years, particularly during the winter season. A ground-based millimeter-wave spectrometer (GBMS) was installed at Thule in 2001, and has been operational during the winter seasons of 2001-2002, 2002-2003, 2008-2009, 2009-2010, and 2010-2011. The GBMS allows the retrieval of atmospheric concentration profiles of different chemical species, such as O3, CO, N2O, and HNO3, between about 15 and 80 km at a resolution of ~ 8 km. The Arctic winter stratosphere is characterized by a high variability. The evolution of the vortex and the temperature in the lower stratosphere has a large impact on formation of Polar Stratospheric Clouds (PSC) and on the stratospheric chemical evolution. A summary of the measurements of the thermal and chemical stratospheric structure obtained at Thule Air Base between 1990 and 2011 is presented. Cold winters were those of 1997 and 2011. Two intensive measurement campaigns were conducted at Thule Air Base, during winters 2008-2009 and 2010-2011. These two winters have been consistently different in their thermal, dynamical and chemical evolution. The 2008-2009 Arctic winter has been characterized by the most intense Sudden Stratospheric Warming (SSW) event ever observed. The maximum of this warming was detected over Greenland, and the ground-based observations obtained at the station of Thule Air Base have permitted to show the evolution of the phenomenon and its interactions with the dynamical structure of the polar vortex in the region of maximum warming. On the contrary, the 2010-2011 has been a very cold winter, and polar stratospheric clouds have been detected by lidar from mid-February to mid-March. This very cold winter, together with the massive formation of PSCs, has caused the record stratospheric ozone loss in spring 2011 in the Arctic.

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Poster Session

2P-3 Atmospheric Research at Eureka in Canada's High Arctic

James Drummond Dalhousie University

Measurements in the High Arctic are always extremely difficult. There are a limited number of locations where measurements are possible and the costs are high. In the time frame of International Polar Year (IPY), Canada has built up its High Arctic measurement capability with the Polar Environment Atmospheric Research Laboratory (PEARL) at Eureka, Nunavut (80N, 86W). PEARL is now home to over 25 atmospheric instruments including several contributing to the the NDACC database. Automated operation is encouraged, but on-site technical support is available when automation fails. Communications is provided by one of the most northerly internet connections to a geostationary satellite in the world. The PEARL research domain is currently the atmosphere from the ground to 100km altitude, but the success of PEARL has encouraged other science activity in the Eureka area and this can only make things easier. This talk will discuss the atmospheric equipment and measurements at PEARL and also look into the future as Canada prepares to build its Canadian High Arctic Research Station (CHARS) at Cambridge Bay (69N, 105W) and considers a new major project, the Canadian Advanced Polar Science Network (CAPSNet) to advance the full gamut of science activities in the Canadian High Arctic. This research was supported by the Canadian Foundation for Innovation; the Ontario Innovation Trust; the Ontario Research Fund; the Nova Scotia Research and Innovation Trust; the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS); the Natural Sciences and Engineering Council (NSERC); Environment Canada; Polar Continental Shelf Project (PCSP); Canadian International Polar Year Program; Canadian Space Agency (CSA); Arctic Research Infrastructure Program; and the Study Of Environmental Arctic Change (SEARCH).

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Poster Session

2P-4 Stratospheric ozone observations at Sodankylä

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Sodankylä in northern Finland (67.4°N, 26.6°E) i s one of the ozonesonde stations in the NDACC network. Continuous data record from the station starts in year 1989 (Figure 1). Regular sounding program involves a weekly ozonesonde during all seasons. In addition campaign activities have increased sounding frequency especially during winter and spring. Location of the station allows frequent sampling of air inside the Arctic stratospheric vortex, in average in January, February and March more than half of the sondes have sampled air inside the vortex. We have flown ECC (electrochemical concentration cell) type of ozonesondes throughout the data record. The ECC sensors are known to provide high precision and accuracy of the stratospheric ozone profile measurements. Prior to calculating trends we investigated sources of possible inconsistency, which include changes in sonde type, sensing solution, thermistor placement inside the ozone box, pump efficiency corrections, background current correction method. Both EN-SCI and SPC manufactured ozonesondes have been used in the past. Therefore we have investigated the relative differences between these two sonde subtypes by performing dual soundings and by applying both 0.5 % and 1 % KI sensing solutions. A traditional method to evaluate sonde performance is based on estimation of the total column from sonde measurements and then comparing the total column measurements with other instruments. In Sodankylä total column measurements by Brewer spectrophotometer have been used. In addition, in order to fill the data gaps, we constructed a reference data set combining total ozone measurements by Total Ozone Mapping Spectrometer (TOMS) aboard Nimbus-7, Meteor-3, Earth Probe; Ozone Monitoring Instrument (OMI) aboard NASA's EOS-Aura; and the Global Ozone Monitoring Experiment (GOME) aboard ESA's ERS-2 satellite. Profile data since 2004 were also compared to the coincident Microwave Limb Sounder (MLS) stratospheric observations aboard the EOS-Aura satellite. We found that relative difference MLS-sonde at the altitude from 20 to 30 km was less than 2%, while above 30 km there was an altitude dependent positive bias. Finally, the quality controlled ozonesonde data set was used in trend analysis. The January to April ozone trends were -1.97 +/- 0.95 %/year in layer 150-30 hPa and -3.13 +/- 0.92 %/year in layer 30-10 hPa regarding time period 1989-1997. For the years 1989-2009 we found significant trends in layer between tropopause and 150 hPa (1.04 +- 0.45 %/year). We applied a statistical model to simulate the observed inter-annual and longer term variability, it included proxies accounting for the dynamical and chemical variability. Model suggested that large part of the winter/springtime lower stratospheric ozone changes from late 1990s until 2009 can be explained by dynamical variables. Other variables, such as Arctic EESC (Arctic Effective Equivalent Stratospheric Chlorine), VPSC (Volume of Polar Stratospheric clouds) and Volcanic Aerosol were found to improve the model (Figure 2).

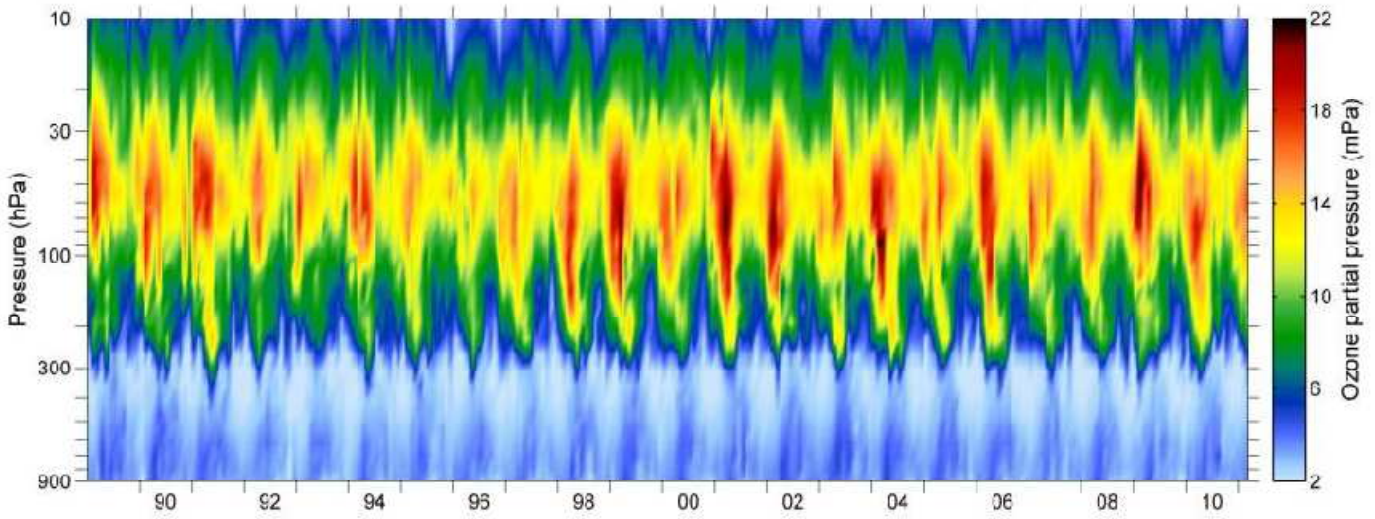

Figure 1. Ozonesonde profiles at Sodankylä since 1989.

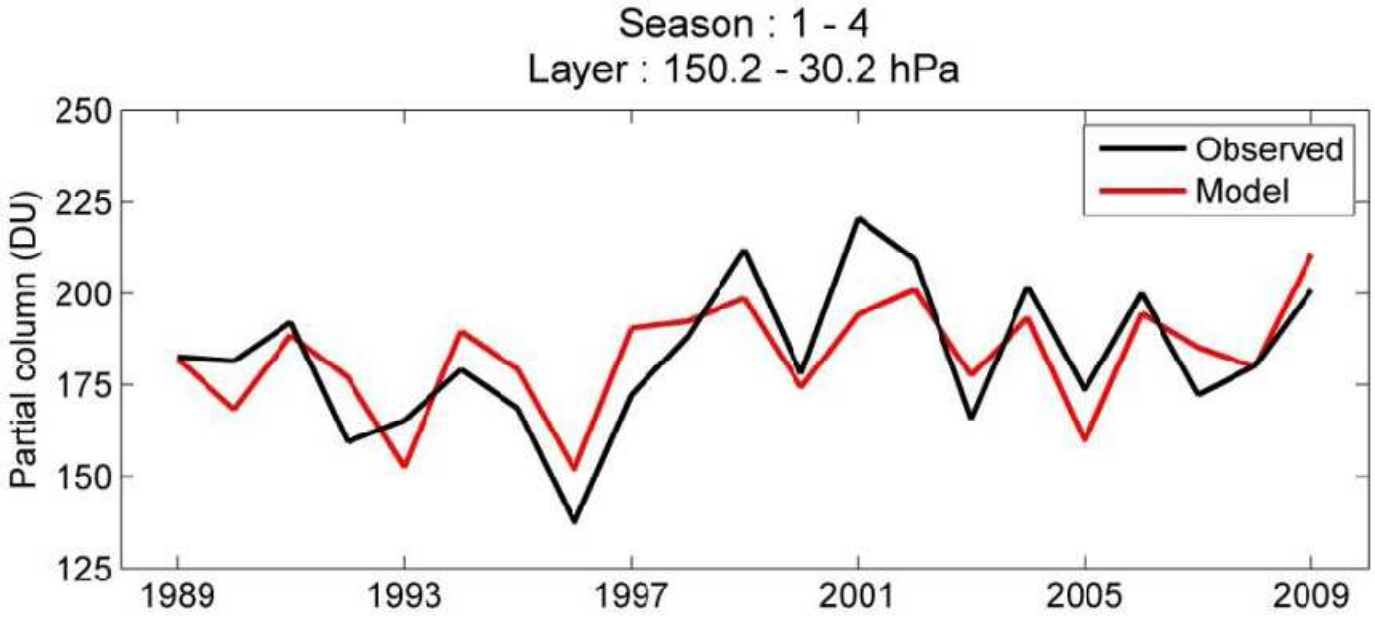

Figure 2. Observed and modeled ozone partial columns at 150-30 hPa over Sodankylä during January to April season from 1989 until 2009.

References:

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2P-5 Balloon observations of water vapor and aerosols in the arctic polar stratosphere in summer 2009 and springs 2010 and 2011

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We present here observations of stratospheric water vapor and aerosol size distributions from three balloon campaigns conducted from Kiruna (Sweden) in summer 2009, spring 2010 and winter-spring 2011 and operated by the French National Space Agency (CNES). In situ vertical profiles of stratospheric water vapor were observed by a frost-point hygrometer and an infrared spectrometer. The size distributions of stratospheric aerosols were obtained at various altitude levels by two aerosol counters/sizers implemented onboard various balloon gondolas, with one these instruments newly developed and first flown in 2011. The first scientific objective was to study the variations of the stratospheric water vapor vertical content and aerosol vertical distribution with respect to dynamical conditions. The second scientific focus was to compare simultaneously the observations of both water vapor instruments associated in the same balloon flight chain. The summer 2009 campaign, conducted in the frame of the International Polar Year STRAPOLETE project, have particularly revealed a high-variability in the aerosol content in the upper stratosphere. The exceptionally large liquid aerosol concentrations measured in the lower stratosphere are attributed to the Sarychev volcano emissions of SO2 as also shown by NDACC Lidar observations. The balloon campaigns of spring 2010 and winter-spring 2011, having occurred in the frame of the AEROWAVE (AEROsols, WAter Vapor and Electricity) national project, have shown lower aerosol contents in the lower stratosphere with still significant vertical variability higher up in altitude, both apparent in the two aerosol counter data. No systematic dependence of this variability on the presence of the polar vortex can be highlighted. Conversely, the profiles of water vapor show vertical behaviors well-correlated with the presence of the polar vortex with higher amounts inside. This typical feature is both seen in the two balloon water vapor instruments. Comparisons with other data sets are also investigated.

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2P-6 Interannual variability of ozone loss in the Arctic and Antarctic polar vortex using 20 years of NDACC ozone measurements

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Since 1990, stratospheric chemical ozone losses in the Arctic have been reported, but the large activity of planetary waves in the northern hemisphere makes the evaluation of photochemical destruction far more difficult than in the southern hemisphere. To overcome the difficulty, several methods for removing the contribution of transport have been suggested. Among those is the transport model approach. With this method, chemical ozone reduction is derived by comparison between ground based total ozone measurements and 3D model simulations in which ozone is considered as a passive tracer. Using this method, the total ozone reduction in the Arctic vortex was derived each winter since winter 1994 by comparing the SAOZ/NDACC measurements to two 3D CTM, Reprobus and Slimcat. The method allows determining the period of ozone destruction, the daily rate and the amplitude of the cumulative loss. The amplitude of the ozone loss is very sensitive to stratospheric temperature history during the winter and thus highly variable from one winter to another. In general, strongest ozone losses of 25-30 % are occurring during coldest winters while very little 0-10% could be observed during the warmest. There is an exception for the winter 2011 when a record low value of 39% has been measured. This 39% loss is close to the depletion reported in the Antarctic regions using the same method and SAOZ measurements together with other ground-based observations such as Dobson or other UV-visible DOAS/NDACC instruments, where during the last 23 years of available measurements the ozone loss is reaching 50-52%, except in 2002 when it was limited to 40%.

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2P-7 Analysis of the Antarctic ozone holes from 2003 to 2011 using data from NDACC and GAW

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Although the Antarctic ozone hole is an annual recurrent phenomenon there are large interannual variations in its geographical extent and in the minimum ozone values measured at the ground based stations. WMO issues biweekly Antarctic Ozone Bulletins that are based on a collection of data from ground-based stations in the WMO/GAW and NDACC networks. These data are analysed with the help of satellite data and meteorological data from NOAA and ECMWF. After the very special ozone hole in 2002, when the vortex split in two parts and ozone depletion came to an end at a much earlier date than usual, there have been annually recurring Antarctic ozone holes. However, the geographical extent of the ozone hole (area where total ozone is less than 220 DU) and the ozone mass deficit (the mass of ozone that has to be added in order to reach 220 DU in those regions where ozone is less than 220 DU) vary significantly from year to year. Figure 1 shows the ozone mass deficit averaged over the time period from 19 July to 1 December. It can be seen that 2006 had the largest ozone hole on record according to this particular metric. It can also be seen that in addition to 2002 also 2004 and 2010 were characterised by relatively small ozone holes. Figure 2 shows a map of ground based stations that provide rapid delivery data for the WMO Antarctic Ozone Bulletins. Figure 3 shows total ozone time series for the UK station Rothera based on data acquired with a SAOZ spectrometer. It can be seen that the total ozone values in 2010 were well above the minimum values observed since the measurements started in 1996. The lowest total ozone column measured at Rothera is 92.4 DU, measured on 21 September 2000. As long as there is enough chlorine and bromine in the stratosphere to cause total destruction of ozone in certain altitude intervals, the degree of ozone loss will to a large degree depend on the meteorological conditions. The Antarctic stratosphere was in 2010 characterised by a series of sudden warmings, the most important of which happened in July. Figure 4 shows the 10 hPa temperature averaged over the south polar cap from 60-90°S. Over the course of eighteen days the temperature rose by 20 K. Although the temperature rise was less dramatic lower down in the stratosphere it still led to a sudden decrease in the extent of polar stratospheric clouds (PSCs). This decrease in the occurrence of PSCs caused the degree of ozone loss to be less serious than in most other years of the last decade. With the exception of 2002 and 2004 one has to go back to 1991 in order to find a year with less ozone mass deficit over the 19 July to 1 December time period. In the present study more examples of ground-based and balloon-based data will be shown and interpreted in light of the meteorological conditions. Preliminary data from the 2011 ozone hole will also be presented.

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2P-8 First Ozonesonde measurements at Kerguelen Island (49.2°S 70.1°E 29masl) Radiosondages Ozone Complementaires aux Kerguelen ROCK campaign 2008-2009 (Polar International Year - IPEV)

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The Kerguelen archipelago (49.2°S, 70.1°E) has been selected in the frame of the Polar International Year because of its interesting geographical location: in the Southern Indian Ocean, nearby La Reunion Island and on the privileged transport routes of South-African and South American biomass burning products. Two measurement campaigns have been performed during the austral winter and summer (18 radiosoundings). The objectives of the ROCK project are linked to the study of processes like isentropic horizontal transport and general circulation, climatology and long term monitoring. This communication focuses on the measurement site and the context. Are also presented the first study of the annual variability and the analysis of two special events: air masses transport of enriched ozone from polar and tropical regions in the stratosphere and in the troposphere enhancement of ozone concentration due to a stratospheric tropospheric exchange linked to the influence of the polar jet stream over Kerguelen

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2P-9 Arctic ozone hole 2011: Ozone measurements from Greenland.

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The Arctic stratospheric vortex was unusual strong and long lasting during winter spring 2010/2011 with temperatures low enough for the formation of polar stratospheric clouds for long periods. These conditions favour strong chemical ozone depletion. During winter and early spring, Greenland was often located inside the polar vortex, and the NDACC stations at Pituffik (Thule), Kangerlussuaq (Sondre Stromfjord) and Illoqqortoormiut (Scoresbysund) were ideal sites for measurements of the ozone depletion. Groundbased and balloon borne ozone measurements from the three stations are presented together with analyses of the stratospheric meteorological conditions. Total ozone measurements from Pituffik during March on days central inside the vortex are roughly 40% lower than climatologically mean values. February and March monthly mean values are among the 5 lowest values recorded so far at Pituffik. Similarly, total ozone at Kangerlussuaq, when inside the vortex, was roughly 40% lower than normal values, but this site experienced shorter periods inside the vortex, and spring time mean values do not show significant departures from previous years. Ozone soundings from Illoqqortoormiut between the beginning of February and mid March indicate ozone losses of more than 1.5 ppmv in a broad altitude range between 15 and 21 km inside the vortex.