The Northern Hemisphere Stratosphere in the Winter of 1998/99

This report was prepared by the European Ozone Research Coordinating Unit and is based on preliminary results of studies of the 1998/99 winter provided by THESEO scientists and project coordinators.

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Background

A long-term decrease in stratospheric ozone has occurred at mid-latitudes in both hemispheres. The decrease is larger in winter and spring (5-6% since 1979) than in summer and autumn (2-3% since 1979). The most dramatic changes have been seen at high latitudes in the vortices that form each winter over the Arctic and Antarctic. Analyses of measurements of ozone at the end of the Arctic winters of 1994/95, 1995/96 and 1996/97 have shown chemical ozone losses of up to 50% at some altitudes. In the warmer 1997/98 winter, the chemical loss was smaller, 25-30% at some altitudes. Over Antarctica local losses in excess of 99% have been seen. Chemicals resulting from the breakdown of CFCs and other ozone-depleting compounds are clearly involved at both high and mid-latitudes.

The Third European Stratospheric Experiment on Ozone (THESEO) was organised to investigate the long-term loss over mid-latitudes during 1998 and 1999. The processes studied are those which occur over mid-latitudes and those resulting from the exchange of air between the mid-latitude stratosphere and the neighbouring parts of the atmosphere. Measurements were most intensive between July 1998 and June 1999, and the 1998/99 winter was thus closely monitored.

Summary

The 1998/99 winter was warmer than those in the mid 1990s. The area of possible PSCs was the smallest since 1984/85. There were two periods when temperatures were low enough for PSCs to be able to form. The first of these was at the beginning of December 1998 when PSCs were observed over northern Scandinavia. This relatively short cold period was followed by a major mid-winter warming and the vortex was disturbed for several weeks from around the middle of December. This major midwinter warming was the first since 1990/91. The previous longest gap between such events in the 41 year record of the Free University of Berlin was 4 years.

The stratosphere settled down during January and the vortex remained weaker and smaller than during January in recent years. The vortex gradually cooled and there was a second cold period in the first half of February when temperatures were just below the PSC existence level. There were no reports of PSCs in this period, the most likely locations being only sparsely observed. A second major warming (the final one) started in the upper

stratosphere in the second half of February and decreased slowly throughout March.

These meteorological conditions led to a relatively high abundance of ozone at high latitudes throughout the winter. Ozone mixing ratios inside the vortex were higher than for any other winter in the 10 year record. Over northern mid-latitudes however, ozone amounts were on average slightly below the long term (1978-1988) average. In December they were close to the average, and in January and February values over middle latitudes were 5-10% below the long term mean. In March they were once again within 5% of the long term mean.

The ozone loss in the vortex this winter was relatively small as the low temperatures occurred over a limited altitude range, and the two cold periods were both brief. Results from measurements and models indicate a total column loss of about 5% over the winter with losses of up to 25% at altitudes around 20 km.

In the next section of this report, the evolution of the Northern hemisphere stratosphere in the 1998/99 winter is described in more detail. In the third and final section, preliminary accounts are given of the research undertaken in THESEO projects.

1 Stratospheric evolution

1.1 Stratospheric meteorology

The stratospheric winter 1998/99 started cold with a strong polar vortex well established in November. At the beginning of December, the centre of the vortex was located over the Siberian Arctic and the cold air covered western Siberia and northern Europe (Figure 1). The minimum temperatures at 50 and 30 hPa were low enough for the formation of PSCs by 26 November. Around mid-December, further PSC formation was prevented when a strong upper stratospheric warming penetrated downwards and polewards. In the second half of December, warm air covered the polar region throughout the stratosphere and the cold air was displaced far to midlatitudes (Figure 1). An anticyclone was established over the North Pole in the upper stratosphere and a wave number 2 circulation pattern developed in the lower stratosphere: one anticyclone over the Bering Sea, another one over the northern Atlantic region, the main vortex centre over central Siberia, and a secondary, weaker

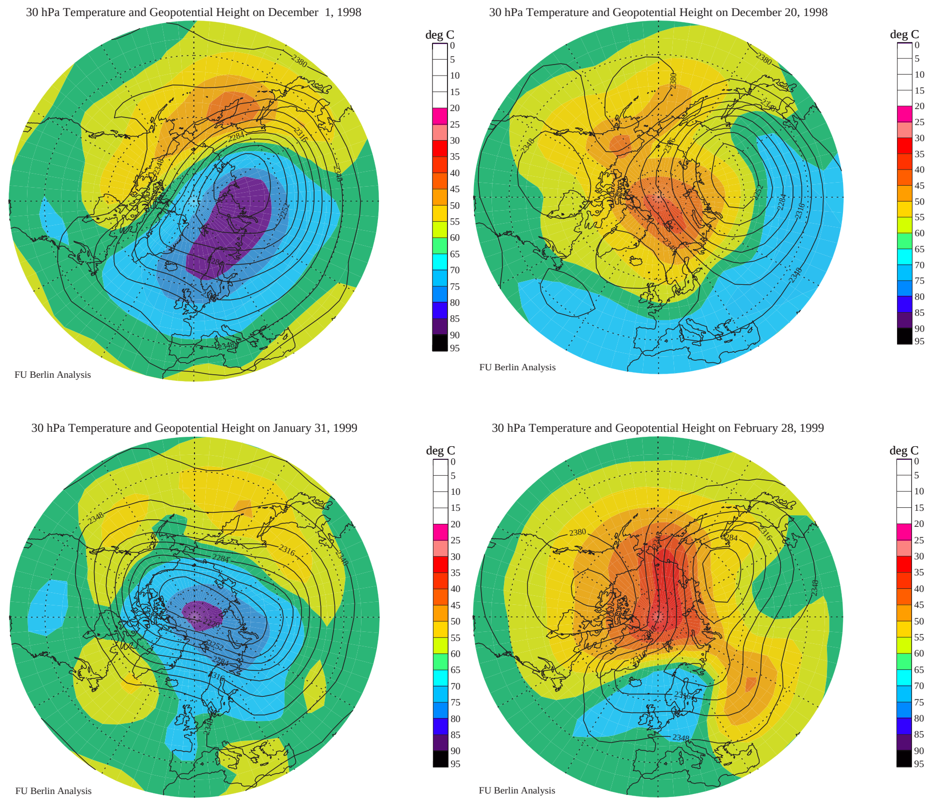

Figure 1: Temperature and geopotential height at 30 hPa level on 01/12/98, 20/12/98, 31/01/99 and 28/02/99. Courtesy of B. Naujokat.

vortex over the American continent. At the end of December, the Siberian vortex centre had considerably weakened while the main centre had developed over Canada/Greenland. This was only the second major warming event within the Berlin 41-year data series to occur early in December (the other was in December 1987).

During January, temperatures in the lower and middle stratosphere slowly decreased but the temperature and circulation pattern remained disturbed for a long time. Weak cold centres returned to the polar region around mid-January but the minimum temperatures were far above any PSC threshold. The vortex slowly deepened but exhibited two centres until 22 January. It was not before the end of January that a re-established, cold vortex was found again over the polar region (Figure 1). This was the beginning of the second period of this winter when minimum temperatures were near or slightly below the threshold for NAT PSCs.

Around mid-February, a second upper stratospheric warming rapidly penetrated downwards and polewards. At the end of February (Figure 1), the warm air covered the polar region, and the rest of the cold air was displaced to northern Europe. The temperature gradient between 60° and the North Pole was reversed throughout the stratosphere since 24 February. The vortex had elongated and moved southwards to central Siberia, while an anticyclone over Canada had moved northwards. At the beginning of March, this anticyclone reached the North Pole, and an easterly flow was established over high latitudes. The two centres of the split vortex were shifted further southwards over central Siberia and the northern Atlantic region, respectively. The final springtime warming started rather early at the end of February, continuing into March, although a weak cyclonic circulation was re-established at the end of the month. This was the warmest winter in the stratosphere since 1984/85, as indicated by the smallness of the area where PSCs could have formed. Figure 2 shows the possible PSC I area versus the potential temperature throughout the winter (as determined from ECMWF data). A pronounced feature during February and March was the persistence of temperatures below 195K in the lower stratosphere in the northern sub-tropics, from Africa to China, at latitudes up to 30°N, encroaching more on the middle latitudes than usually observed. TOMS ozone maps show that the low temperatures were associated with a belt of low ozone columns, which in fact constituted the minimum of the global distribution.

1.2 Temperature, PSC and chlorine species observations

The main features of the general evolution of the stratosphere can be illustrated by several observations in the Northern hemisphere.

The temperature measurements by radiosondes at several stations in Northern Scandinavia showed that temperatures necessary for PSC formation were observed in December 1998 only during a single event at the beginning of the month, while in February 1999 there were several occasions (altogether 9 percent of all radiosonde launches) when PSC temperatures were reached at the 50 hPa level. The occurrence of low stratospheric temperatures at Sodankylä (67°N, 27°E) was less frequent during this winter than during the previous decade, as shown in Figure 3. The minimum temperatures at several pressure levels over Sodankylä for January between 1990 and 1999 are shown in Figure 4. At all stratospheric levels, the minimum temperature was

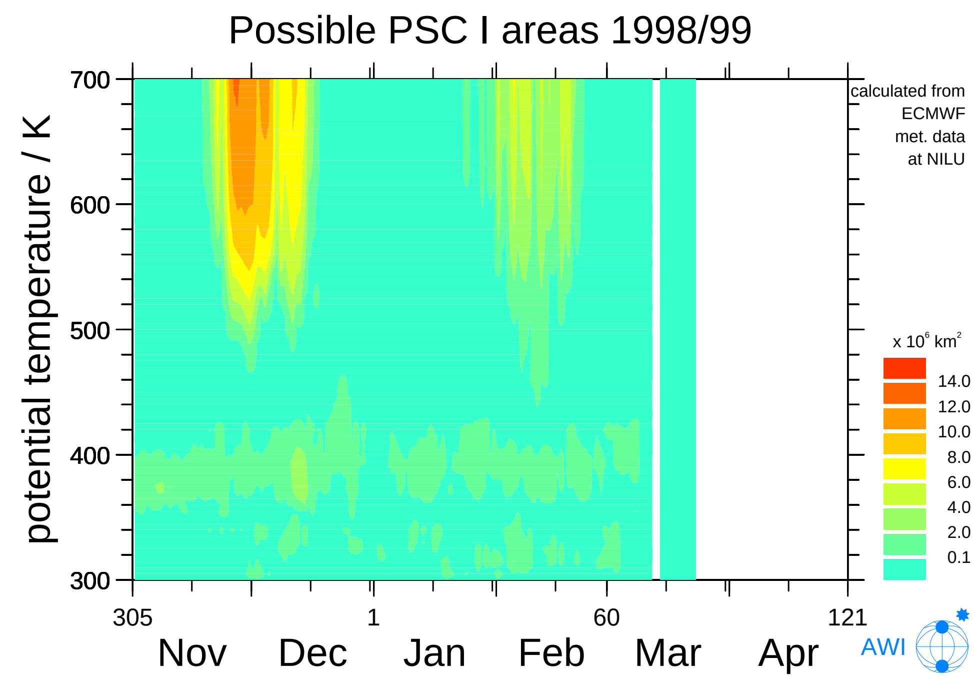

Figure 2: Possible PSC I areas versus potential temperature during the winter as determined from the old ECMWF model analysis. Care should be taken in interpreting the results at altitude levels higher than 600 K. Courtesy of P. von der Gathen.

highest in 1999.

Observations of PSC and background aerosols were also performed at the Scandinavian stations. PSCs were detected only on December 2, 1998 in the altitude range 23.8 km-25 km by a groundbased multiwavelength aerosol lidar located at FMI Sodankylä (project EU/SAONAS). PSCs were also observed visually above Kiruna between 1-3 December. In January balloon-borne backscatter sondes measured low background aerosol content inside the polar vortex. No PSCs were observed by lidar in January-February 1999 over northern Finland, despite the almost continuous lidar operation in the absence of thick tropospheric clouds. No PSCs were observed by balloon-borne backscatter sondes launched from Kiruna in early February even though temperatures below PSC existence temperatures were encountered.

Except for a brief period in mid-December, POAM III made regular observations in the latitude band 64°N-67°N throughout the winter. The only

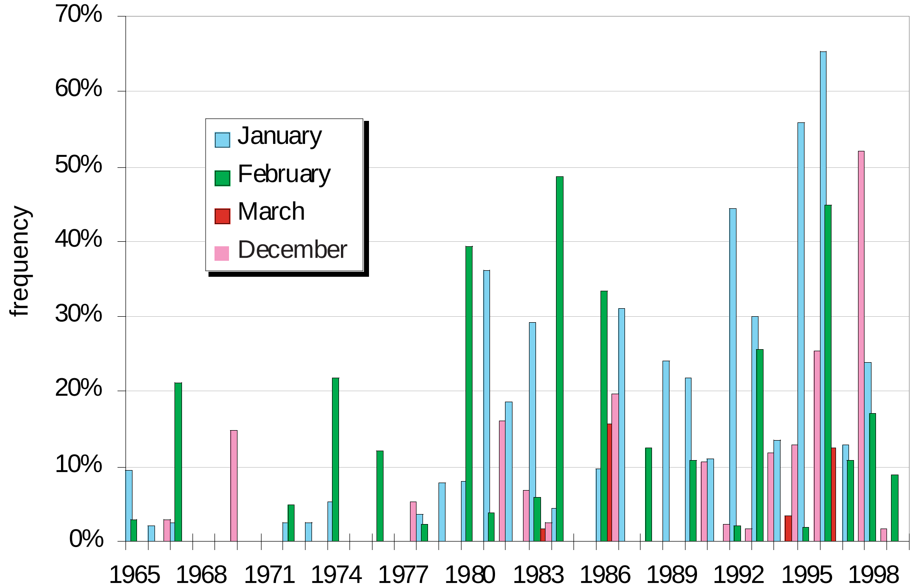

Figure 3: Frequency of temperatures low enough for PSC formation at Sodankylä (67°N, 27°E) between 1965 and 1999. Courtesy of R. Kivi and E. Kyrö.

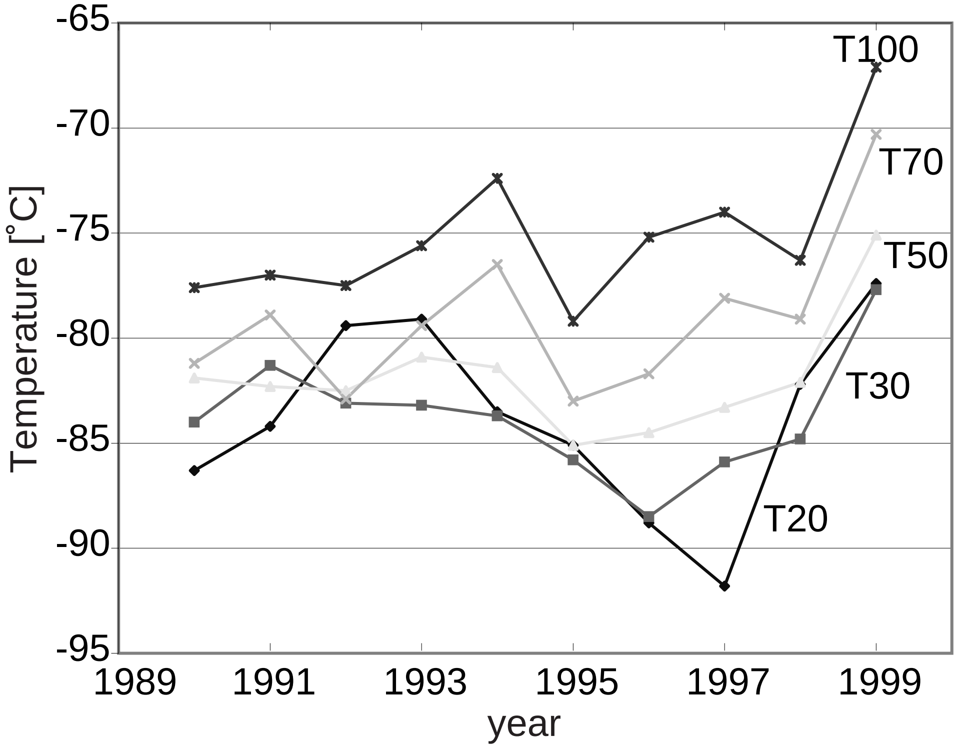

Figure 4: Minimum temperatures at several pressure levels over Sodankylä (67°N, 27°E) for January between 1990 and 1999. Courtesy of R. Kivi and E. Kyrö.

unambiguous PSCs occurred between 1 - 3 December, 1998 and were sighted near Scandinavia, centered in the altitude range 24 km-25 km. From February 8-13 there were a few observations of enhanced aerosol between longitudes 30 and 40°E. The small amount of enhancement makes it questionable whether these were PSCs, but the enhancement did occur at the altitude (approximately 20 km) where temperatures were at or below the NAT existence point.

Measurements by the ASUR instrument onboard the DLR aircraft Falcon for the HIMSPEC-THESEO project were made between January 22 and February 8 over the Scandinavian regions. A weak but significant chlorine activation was detected at altitudes between 18 km and 26 km inside or across the edge of the polar vortex on several occasions, although temperatures inside the polar vortex had been too high for PSC formation since the middle of December 1998. The highest chlorine activation of about 300 pptv to 400 pptv was observed on January 22 (Figures 5 and 6). Those high values of ClO at the beginning of the measurement period could be attributed to the persistence of the chlorine activation of early December. The ClO/BrO monitor operated by the Forschungszentrum Jülich on the TRIPLE payload launched from Kiruna on February 6 measured ClO and BrO in-situ inside the vortex (HALOMAX-THESEO project). The ClO descent profile shows mixing ratios linearly increasing from 100 pptv to 200 pptv from the 460 K to the 650 K level with no structures exceeding the 20 pptv level. This points to the absence of any recent activation in agreement with the temperature history of the observed air masses. A float of the balloon occurred around the 450 K (65 hPa) level where the ClO sunset evolution was monitored. The ClO mixing ratio decreased linearly with solar zenith angle from 100 pptv at 90° to around 30 pptv at 95°, which is in quite good agreement with ER2 measurements performed at mid-latitudes.

Also for HALOMAX-THESEO project, the French/German LPMA-DOAS payload operated by the Universities of Paris 6 and Heidelberg was launched from Kiruna on February 10. Although prior to the balloon flight the lower stratospheric temperatures were well above the threshold for synoptic PSC formation, OClO, a molecule that indicates chlorine activation of the probed air masses was surprisingly detected. This finding is in agreement with the observation by GOME (Global Ozone Experiment; Figures 7 and 8) showing sizeable amounts of OClO being present within the vortex throughout the arctic winter 1999. The observation of OClO has to be interpreted as either chlorine activation on lee-wave induced PSCs, or as activation that had already taken place on the cold sulphuric acid stratospheric background

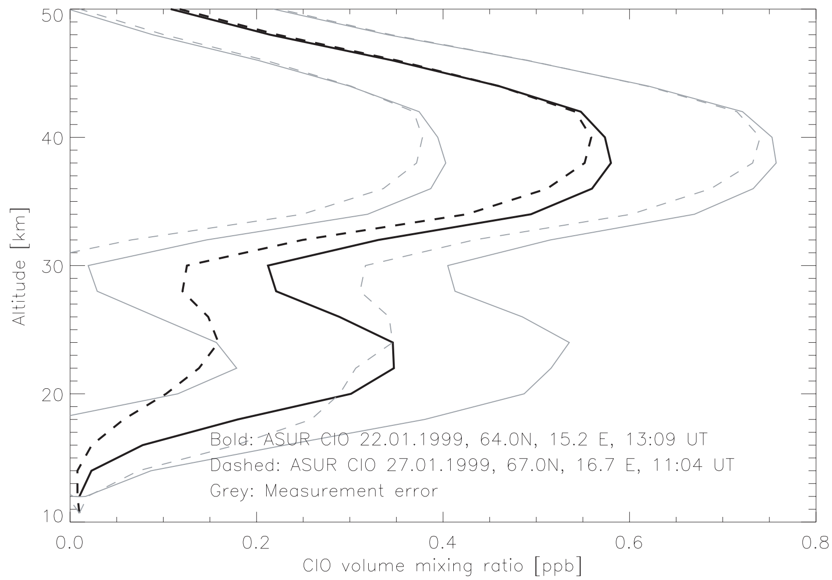

Figure 5: Vertical profiles of ClO mixing ratio measured by the ASUR instrument on board the Falcon on 22/01/1999 and 27/01/1999. Locations of the measurements are given in the Figure. Courtesy of M. von Koenig, H. Kuellmann and H. Oelhaf.

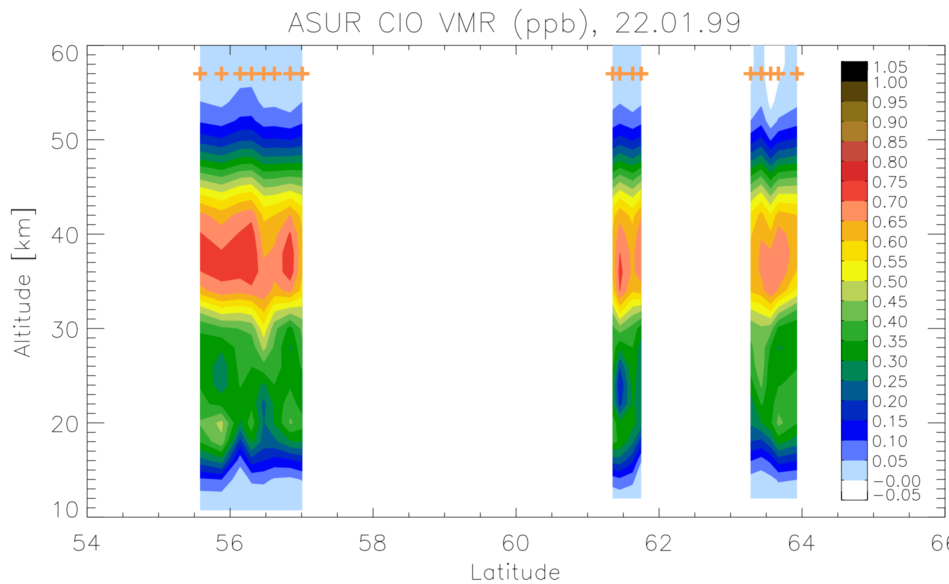

Figure 6: ClO mixing ratio versus altitude and latitude measured by the airborne ASUR instrument on 22/01/1999. Courtesy of M. von Koenig, H. Kuellmann and H. Oelhaf.

aerosol. The simultaneous detection of BrO together with 1D box-model calculations will allow to decide on either possibility in an ongoing post-flight data analysis. Spectra from the FTIR measurements of the LPMA instrument seem to indicate less $ClONO_2$ than during SESAME. A preliminary analysis of the measurements from AMON (HALOMAX-THESEO project), launched from Kiruna on February 11 shows that a large amount of OClO was present also on this date, correlated with small amounts of NO_2 and NO_3.

1.3 Ozone measurements

Consistently with the relatively high temperatures in the stratosphere during this winter, the measurements showed high ozone values at high latitudes compared to the previous winters (Figures 9 and 10). For instance, the ozonesondes and the ground-based measurements by SAOZ and Brewer instruments at Sodankylä showed generally higher values than the climatological mean for this season. More specifically, the ozone profiles measured at Ny-Ålesund and averaged throughout each winter for the last 11 years (Figure 10) showed that the ozone mixing ratio values were the highest for the winter 1998/99 between roughly 450 K and 750 K. These measurements are representative of the vortex, even though Ny-Ålesund was outside the vortex more often during this winter than during the previous ones.

On January 27, a flight of the DLR-Falcon (HIMSPEC-THESEO project) was conducted from Kiruna to study the vortex edge region since mixing processes might be of major interest in the recent winter. The main part of this flight was under the vortex. However, shortly before the turning point of the flight (61°N, 0°E) the vortex edge was reached. Figure 11 shows the two dimensional distribution of ozone mixing ratio as function of flight distance and potential temperature as measured by the ozone lidar OLEX on board the Falcon. The turning point was at a distance of approximately 1050 km. Following the isentrope of 475 K it can be seen that the ozone mixing decreases from inside the vortex to outside the vortex by about the half. The contours of potential vorticity are also plotted. The ozone mixing ratio under the PV-contour of 40 is clearly correlated to the potential vorticity. This situation is typical for a chemically undisturbed ozone distribution in the lower stratosphere.

Based on the analysis of the ground-based measurements collected by LAP total ozone over the middle latitudes during December 1998 was close to the mean values of the period 1978-1988. Total ozone over Canada was 15%

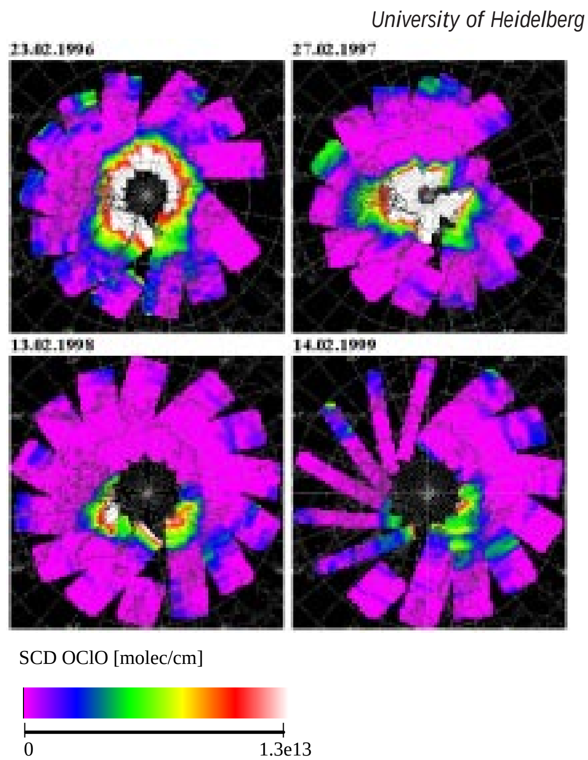

Figure 7: GOME OClO maps for days of the maximum SCDs observed in the northern hemisphere for different years. The magnitude of the OClO SCDs and the area enhanced values are significantly larger in the two first winters compared to the two following ones. Courtesy of T. Wagner, C. Leue and K. Pfeilsticker.

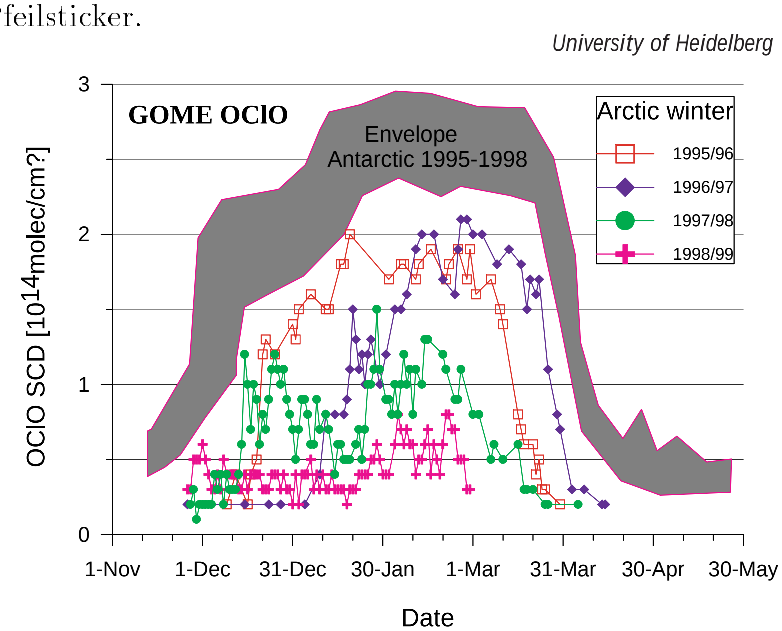

Figure 8: Time series for the daily maximum OClO SCDs (maximum values for SZA=90°) for both hemispheres in the winters 1995 to 1998. The OClO SCDs measured in the Antarctic winters are shifted by 6 months. Courtesy of T. Wagner and K. Pfeilsticker.

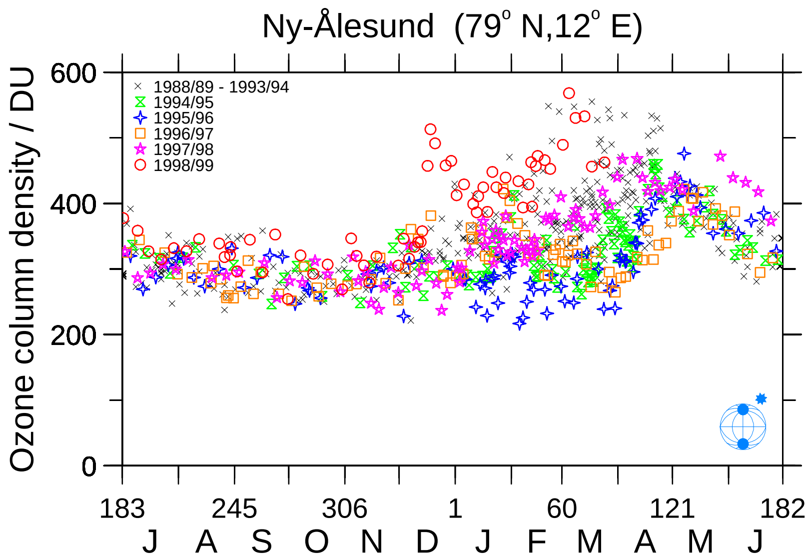

Figure 9: Ozone column values (DU) from ozonesondes measurements at Ny-Ålesund (79°N, 12°E) during the last 5 years and compared to the 1988/89-1993/94 average values. Courtesy of P. von der Gathen.

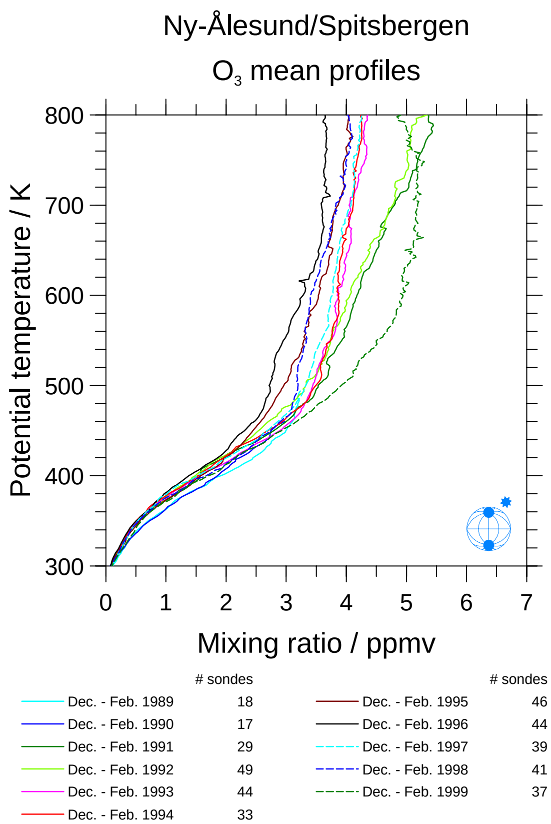

Figure 10: Mean ozone vertical profiles versus potential temperature measured by ozonesondes at Ny-Ålesund (79°N, 12°E) during the last 11 Arctic winters. Courtesy of P. von der Gathen.

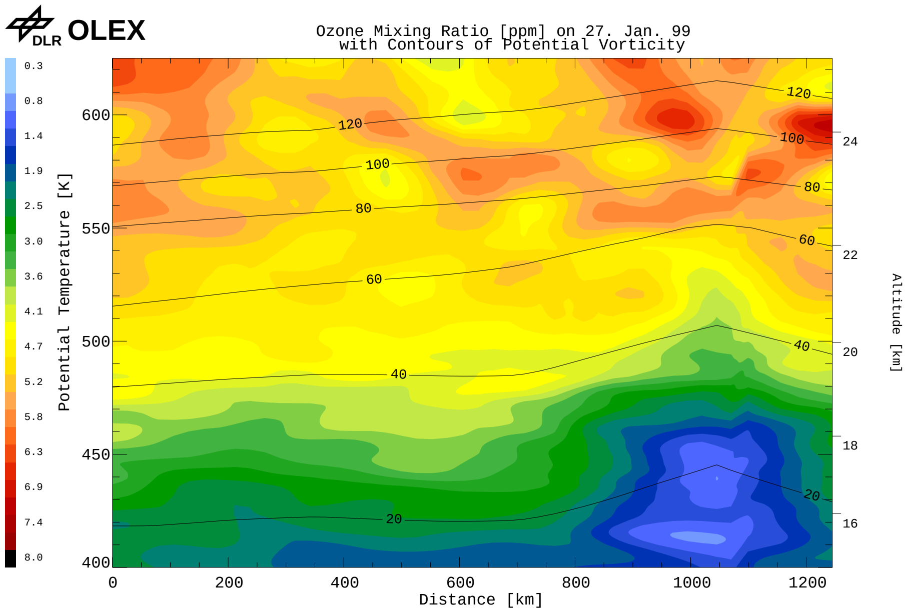

Figure 11: Ozone mixing ratio values versus flight distance measured on 27/01/99 by OLEX instrument on board the Falcon. Also plotted are the PV contours (black line). Courtesy of V. Weiss.

higher than the normal values, persistently throughout the month. During the last ten days of December relatively high ozone values (10% above the mean) were observed over the North Atlantic and the European part of Northern Russia. During January total ozone was 5% below the long-term mean values over the entire middle latitudes. Values 5-10% above the normal were observed over the Arctic Canada and Scandinavia. During February total ozone continued to be 10% lower than the climatological mean over the middle latitudes of North America and Siberia. Over Central Europe, Scandinavia and Alaska, ozone values up to +10% above the long-term mean were observed. Finally during March 1999 over the entire middle and middle to high latitudes, total ozone values were within 5% of their long-term values, while the +10% values over North Scandinavia persisted. Figure 12 shows the difference between the January-March average for 1999 and the January-March average for 1979-1988. The sub-tropical belt of minimum ozone column was located further north than usual in February and March, most markedly over India and China. As noted in the Section on Meteorology, there was a strong association between low temperatures in the lower stratosphere, and low ozone columns. In area-weighted mean ozone from 20°N to 60°N, the low sub-tropical values outweigh the high values recorded in the sub-Arctic in these months.

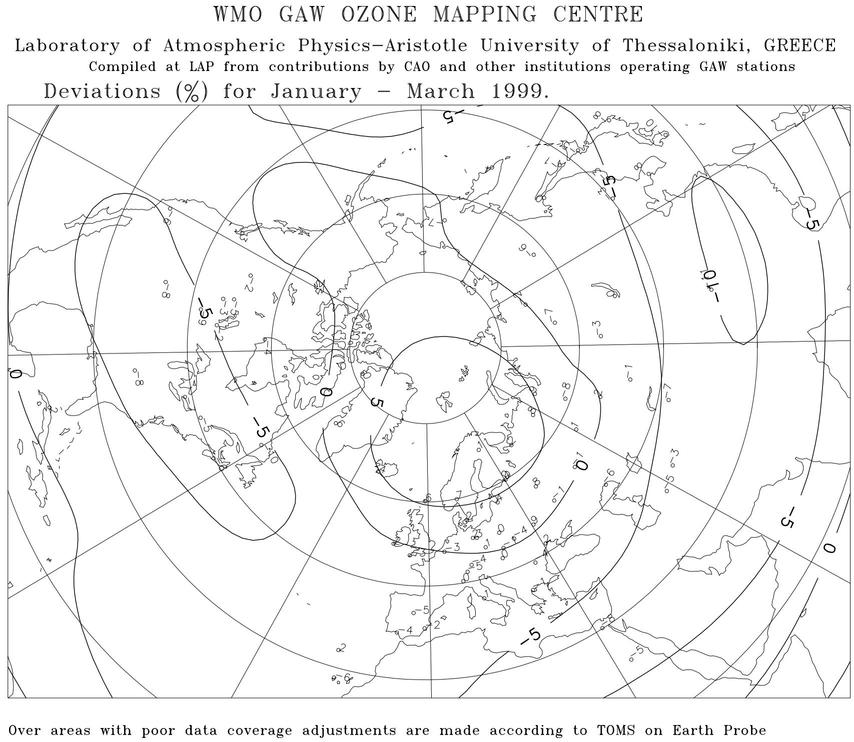

Figure 12: Deviations in % of the January-March 1999 average ozone value compared to the January-March average for 1979-1988 in the Northern hemisphere. Courtesy of D. Balis.

1.4 Ozone depletion

As for previous winters, several techniques have been used to estimate ozone depletion. The Match campaign started at the end of November and lasted until the first half of March. The preliminary values of the ozone depletion rate estimated by the Match technique inside the vortex in the 465K-485K altitude range are shown on Figure 13. Apart from the negative values lower than -5% at the end of December and the first half of January, the ozone depletion rate is low and almost zero at the end of the winter, compatible with no ozone loss at 475 K inside the vortex. No estimates are available at the higher altitudes where the lowest temperatures occurred.

Three-dimensional models have been used to interpret the observations made during THESEO, and to assess the extent of polar ozone depletion. Preliminary model studies, performed in near real time, show that there were two periods of chlorine activation in early December and early February. The

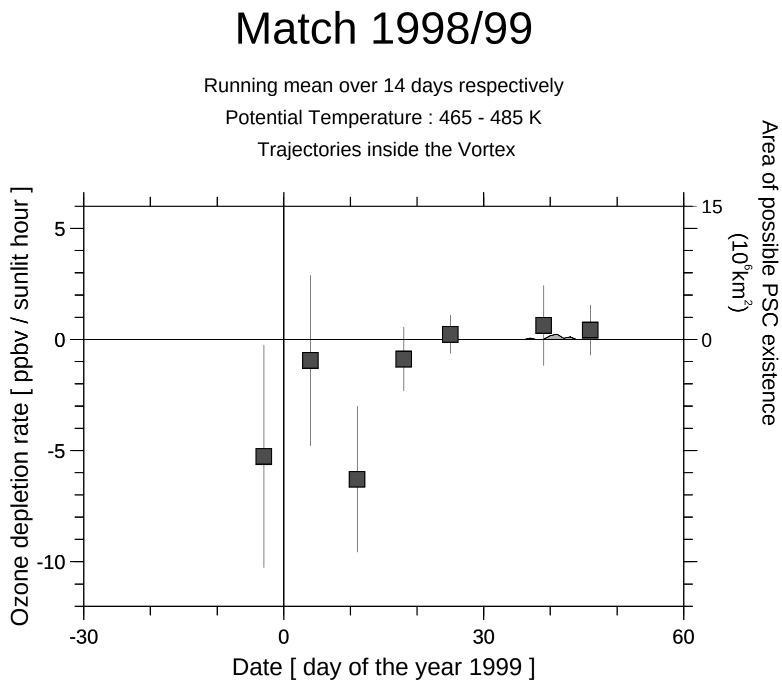

Figure 13: Ozone depletion rate and area of possible PSC existence inside the vortex in the 465K-485K altitude range during the winter 1998-1999 as determined by the Match method. Courtesy of P. von der Gathen.

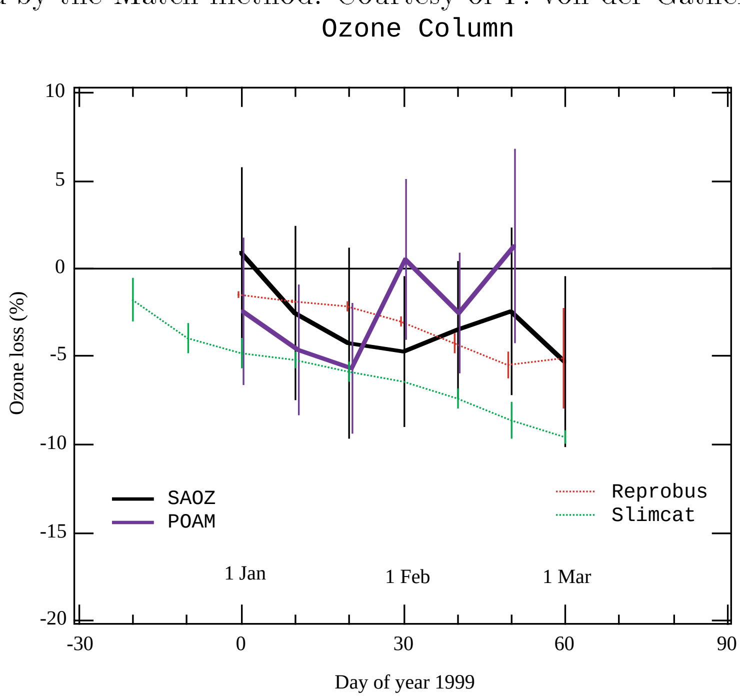

Figure 14: Ozone loss in % during the winter 1998/99 over 7 Arctic stations determined from SAOZ measurements, POAM III measurements, and from the 3D models Reprobus (10-1000 hPa) and Slimcat (above 380 K). Courtesy of J.P. Pommereau and F. Goutail.

meteorological analyses produced by the ECMWF and UK Met. Office indicate differences in temperatures (of a few K) in the polar lower stratosphere. This, in turn, affects the calculated chemical evolution in different models which use these different analyses. The SLIMCAT 3D model, which uses UK Met. Office analyses, shows that the initial period of chlorine activation led to loss of 10% of the O_3 north of 75°N at 480 K by late December. This loss increased to 25% by late February following the second period of PSC temperatures. Interestingly, in spite of the very different meteorological conditions in winter 1998/99, the model-calculated loss was similar to the loss at the same stage of previous, colder winters. An analysis based on ozone column measurements by SAOZ instruments above 7 Arctic stations, partial ozone column measurements (380K-700K) by POAM III, and simulations by Reprobus (10-1000 hPa) and SLIMCAT (above 380K) models estimated an average column ozone loss in the vortex of about 5 +/- 4% (Figure 14). The Reprobus model simulations did not begin until December 20, after the activation period of early December, so the losses calculated using Reprobus results could be underestimated. The large dispersion could be because the fragments of the vortex have different compositions. For example, it is possible that when the vortex is cut into two parts, one is activated and the other is not. The cumulative column reduction estimated from SAOZ measurements and Reprobus results for the winter 1998-1999 is lower than during the previous years (Figure 15).

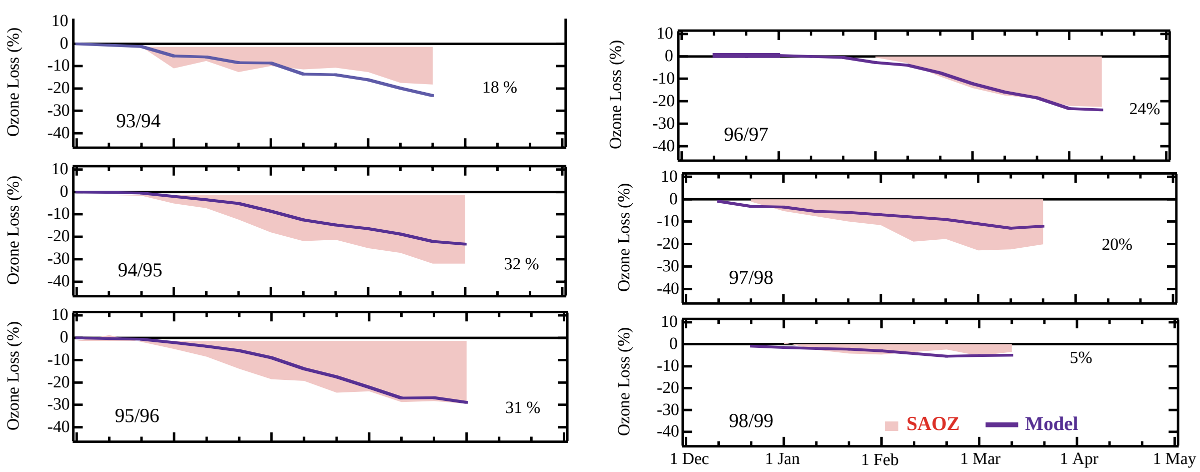

Figure 15: Ozone loss in % as determined from SAOZ measurements and Reprobus calculations during the last 6 winters. Courtesy of J.P. Pommereau and F. Goutail.

2 THESEO activities

Overview of field activities at Kiruna and in Northern Scandinavia

The most intensive Arctic phase of THESEO took place at SSC Esrange, Kiruna (67.9°N, 21.1°E), Sweden, between 15/01/99 and 23/02/99. During this period, 7 large balloons, 4 small balloons and 5 long duration balloons carrying scientific payloads were launched successfully from the base, and have provided preliminary measurements. Aircraft measurements (by the DLR Falcon, the CNRS ARAT and the Swiss Air Force Learjet) and simultaneous ground-based activities (ALOMAR, Kiruna, Ny-Ålesund, Sodankylä) provided complementary measurements in the general Scandinavian region, often along the balloon flight path. On-site meteorological support was provided by the FU-Berlin. Chemical transport modelling (UCAM) for support and comparison with the balloon and other measurements was done at Esrange during the whole period of activities. Supplementary measurements were made available through GOME and POAM data.

Mountain wave experiment

The DLR MM5 mesoscale model was used to forecast mountain waves in the Scandinavian region, and the results were used during the Arctic campaign at Kiruna to help balloon and aircraft measurement planning and to trigger additional radiosondes at Esrange and other nearby stations. Simultaneous launches at different stations upstream (Andoya), above (Abisko) and in the lee (Kiruna, Sodankylä) of the Scandinavian mountains were coordinated. Furthermore, at Sodankylä, multiple launches of radiosondes with different ascent rates should give information about the horizontal and vertical gravity wave structure. Multiple soundings were done several times in January and February. High resolution data from the several routine radiosonde stations run by European meteorological agencies were stored on the Nadir database. Eight periods of mountain-wave activity occurred during the winter, with four of these during January and February. PSCs were not observed over North Scandinavia after December, although temperatures did drop just below T_{NAT} in early February. All these events are now being looked at as case studies of wind and temperature deviations resulting from mountain waves.

THESEO projects activities

HIMSPEC

The objectives of the HIMSPEC-THESEO project are to study the chemistry and dynamics of ozone depletion in the lower and middle stratosphere from high northern latitudes down to sub-tropical latitudes by means of coordinated series of balloon and aircraft measurements at two characteristic seasons.

The first of two HIMSPEC-THESEO campaigns took place between January 22 and February 10. Within this period five flights were conducted with the German research aircraft Falcon which was equipped with the Airborne Submm-SIS-Radiometer (ASUR) and the 4-wavelength Lidar system OLEX. On two occasions the Falcon flights were coordinated with balloon flights to use the synergy of simultaneous aircraft and balloon measurements. On January 27, 1999 the aircraft flight and a balloon flight of the limb emission spectrometers MIPAS-B and SFINX were coordinated such that the same airmasses were measured at the same time (see Figure 16). The balloon launch had to be conducted under record low temperatures of -43°C on the launch pad. Spectra of a large number of species have been measured, including some of the key species of stratospheric ozone chemistry like ClO, HCl, $ClONO_2$, BrO, HNO_3, N_2O_5 and ozone itself as well as dynamical tracers like N_2O, CH_4 and CH_3Cl. All flights have been conducted inside or across the edge of the polar vortex. A second campaign dedicated to study spring conditions at mid-and low latitudes took place at the end of April/beginning of May.

HALOMAX

Three successful balloon flights have been performed in the frame of the HALOMAX-THESEO project.

As the first flight of HALOMAX the TRIPLE payload was launched on February 6. The payload consists of a cryogenic whole air sampler (University of Frankfurt), a ClO/BrO monitor, a Hygrometer, a photometer (all Forschungszentrum Jülich) and an aerosol counter (LMD). The whole flight took place inside the polar vortex at temperatures which were several degrees above the NAT existence threshold. The LPMA/DOAS payload (University of Paris 6/University of Heidelberg) was successfully flown from Kiruna on February 10 1999 and both instruments performed well. AMON (University of Orléans) was launched from Kiruna on February 11 1999.

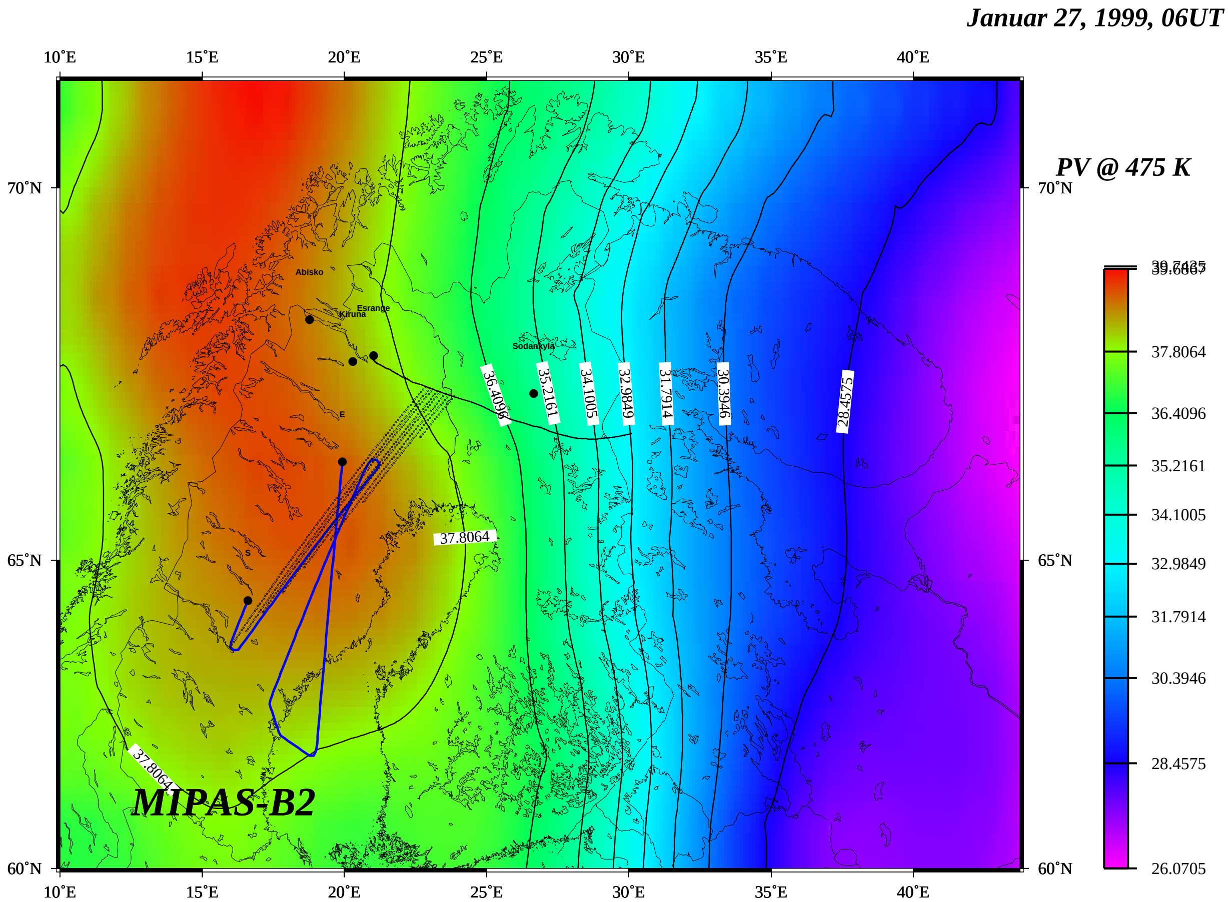

Figure 16: Tracks of the Falcon aircraft and balloon flights operated for HIM-SPEC (continuous lines) on 27/01/99 in North Scandinavia. Also plotted are some of the MIPAS measurement lines of sight and the PV contours at 475 K. Courtesy of M. Stowasser and H. Oelhaf.

PSC-Analysis

The cold conditions required for a successful flight of the PSC-Analysis payload never occurred as the temperatures in the stratosphere were too high after December. Much was learnt from a technical and operational point of view which should help successful flights to be made in the future.

Lagrangian

Five long-duration balloons were launched for the Lagrangian Experiment-THESEO project, 2 of them having flown more than 1 week, 1 of them flew during 17 days. This latter was an Infra-Red Montgolfier launched from Kiruna on the 19th of February deep inside a small piece of vortex (Figure 17). After a short turn around Svalbard, the balloon moved with the

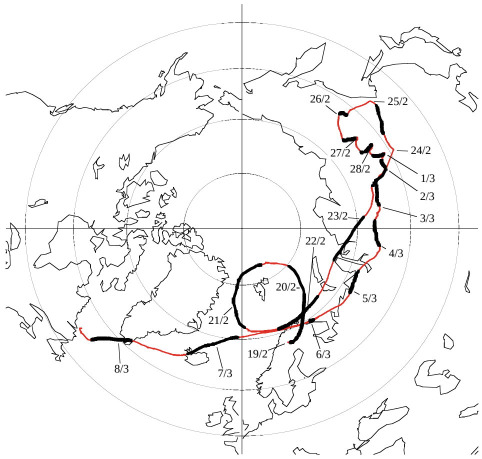

Figure 17: Trajectory of the Mir balloon launched from Esrange on 19/02/99 for the Lagrangian project. The bold fractions correspond to the night-time displacements. Courtesy of J.P. Pommereau.

weakening vortex toward Siberia where it remained for a few days. It then drifted back to the West after the reversal of the wind direction related to the progress of the final warming of the stratosphere. When reaching 55°N near the Labrador coast, the balloon was automatically cut down for air traffic security reasons.

O3-Loss

The project from which the first evaluation of Ozone Loss in the Arctic previously quoted was derived, continued during the second winter of THESEO activities. The measurements include: i) daily column ozone at the nine SAOZ stations in the Arctic; ii) profiles from the new POAM III instrument of the Naval Research Laboratory onboard the CNES SPOT IV satellite in orbit since March 1998; and iii) ozone and tracers profiles by flying together on small balloons a SAOZ UV-vis spectrometer, the UCAM Descartes air sampler for CFC 11 and 113, in situ ozone semi-conductor sensor and the new TDL for CH_4 or CH_4/ H_2O developed respectively at the National Physical Laboratory and Service d'Aéronomie. Overall 8 balloon flights have been carried out in 1998 and another 8 in 1999 which will be continued until June. The ozone reduction is derived by two methods: the comparison of the measurements with ozone profiles and columns simulated by the Reprobus CTM model of Service d'Aéronomie where ozone is assumed a pure tracer, and correlation between simultaneous ozone and tracers profiles. Both methods indicate little (5%) loss in 1999 in the Arctic vortex. The second one will be used extensively for determining if an ozone reduction could be seen at mid-latitudes in spring. Coordinated ozonesondes launches have been made as a Match campaign, looking at high and middle latitudes.

METRO

The two stratospheric warmings occurring this winter and the consequently disturbed vortex were associated with an intense mixing of air between the polar and the mid-latitude airmasses throughout the winter, which is the main interest of the METRO-THESEO project. Several polar and sub-tropical alerts were sent to the METRO-THESEO ground-based network requesting lidar, radar and ozonesondes measurements for the observation of filaments. Airborne measurements by the ALTO lidar experiment on board the French Falcon were also achieved during several flights around mid-February and after 15 March. Six days of flights for polar filaments and two days for subtropical intrusions have been performed to date.

More subtropical flights are scheduled until 16 April. As expected from a vortex with a low ozone depletion, preliminary results of ALTO flights indicate a good correlation between the observation of high (low) ozone mixing ratios and the forecast of filaments with high (low PV). This is illustrated in Figures 18 and 19. Figure 18 shows the preliminary ozone time-height section observed during a circular flight above France with a sub-tropical intrusion at 380K (around 14 km). Figure 19 shows the potential vorticity map at 380K obtained with the high resolution advection model of Service d'Aéronomie with the indication of the airplane track (arrows). The two areas with high ozone mixing ratios between 13 km and 14 km corresponds to the two regions of high PV at the west and east edge of the intrusion.

TRACAS

The second field campaign of the TRACAS-THESEO project started on 1 February 1999 and continued until 24 April 1999. The main objective of this campaign is to document the ozone distribution near the subtropical jet (STJ) in the 5°W-15°W and 20°E- 30°E longitude bands. This corresponds to an area where the STJ accelerates and interacts strongly with mid-latitude cyclones. One then expects an intensification of the meridional circulation at the tropopause altitude leading to the exchange of tropospheric and stratospheric air across the subtropical tropopause break.

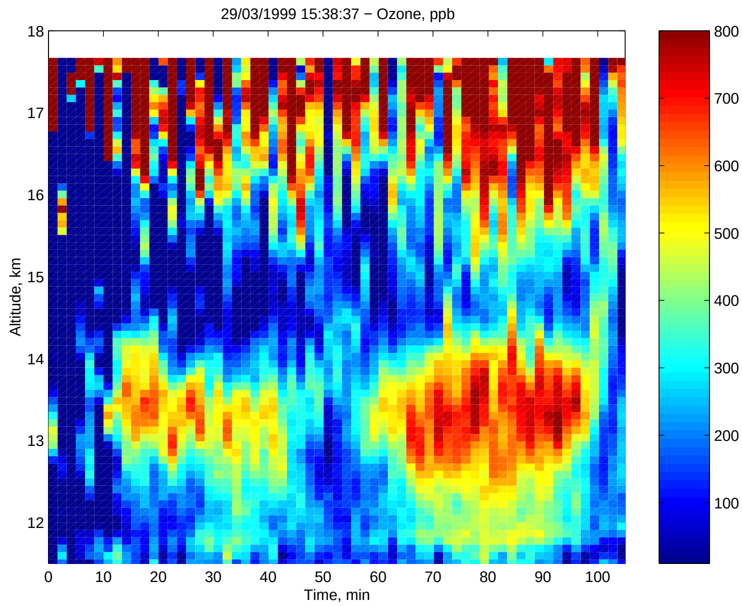

Figure 18: Ozone mixing ratio values measured by the ALTO lidar on board the Mystère 20 aircraft on 29/03/99 for the METRO project. Courtesy of A. Hauchecorne, S. Godin and B. Heese.

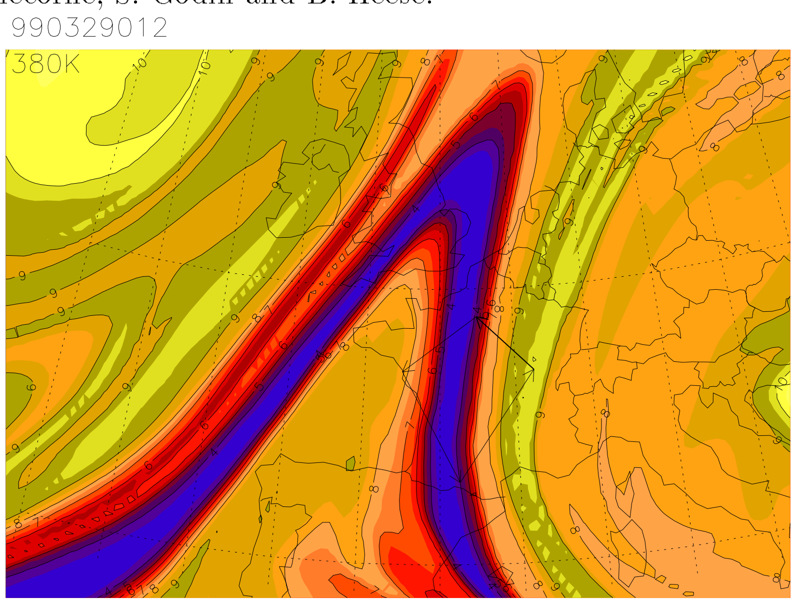

Figure 19: PV values at 380K from the model of Service d'Aéronomie-CNRS and track of the flight of the Mystère 20 aircraft (arrows) on 29/03/99 (METRO project). Courtesy of A. Hauchecorne, S. Godin and B. Heese.

The Mystère 20 aircraft flew from Paris to Mauritania on March 26-27 and from Paris to Egypt on April 21-23 with on board the ozone lidar ALTO (Service d'Aéronomie) measuring in the 9-16 km altitude range. MOZAIC aircraft carrying O_3 and H_2O in situ instruments flew regularly near the 200 hPa level in the 5°W-15°W area and the aircraft schedule is provided by the Laboratoire d'Aérologie, Toulouse.

ECC ozonesondes have been launched at two ground based stations of the Instituto Nacional de Meteorologia (Spain): Tenerife (28°N, 16°W) and Huelva/El Arenosillo (37°N, 7°W). The sondes are launched on a basis alert given by CNRS-Service dAéronomie using the KNMI web site which provides daily forecasts of the potential vorticity distribution and of the STJ position. Sondes were launched several times per day during the aircraft flights (ALTO on March 26-27 and on April 21-23; MOZAIC on March 13), allowing improved temporal evolution of ALTO airborne measurements and vertical descriptions of the MOZAIC measurements.

Preliminary results show large ozone layering in the ozone soundings above the tropopause suggesting significant horizontal meridional transport across the tropopause break. Moreover, the measurements during the aircraft campaign showed a layer of low ozone air (80-100 ppb) on the top of a stratospheric ozone layer (400 ppb). This is directly linked to an intrusion of subtropical air in the lowermost stratosphere. This campaign also allowed the characterization of the smooth ozone vertical profile on the equatorial side of the STJ. Indications of a leaky tropopause at this latitude were highlighted. Finally during the flight to Egypt, a midlatitude trough developed over central Europe and interaction with the STJ led to significant meridional transport in the lowermost stratosphere. Modelling of these events is under way.

APE-THESEO

APE-THESEO took place from Mahe International Airport in the Seychelles (S4°42', E55°30'), from 15 February to 17 March 1999. The mission comprised 7 sorties of 4-6 hours duration. With one exception, the sorties were flown by both the Geophysica and the DLR Falcon, with the Falcon acting as pathfinder for the Geophysica. The Geophysica payload consisted of instruments for measuring aerosols, radiative fluxes, and trace gases. The Falcon payload consisted of the OLEX ozone and aerosol lidar and radiative flux instruments. Meteorological support was provided by the Seychelles Met. Bureau, the UK Met. Office, and a Meteosat 5 receiving station specially set-up for the mission. Flight dates and 1-line summaries are given in the

Sortie	Date	Profile
1	19/2/99	NW-SE at tropopause. Dive to 12 km at 5°N
2	24/2/99	Interception of mesoscale convective system
3	27/2/99	Quasi-Lagrangian flight in thin cirrus
4	4/3/99	'Box' pattern in stratosphere over Mahe
5	6/3/99	Long meridional transect at maximum height, due south
6	9/3/99	Interception of cyclone Davina
7	11/3/99	Long meridional transect across ITCZ

Table above. Overall, tropopause temperatures were surprisingly cold (-90°C and above). Water vapour concentrations were concomitantly low. A number of thin cirrus decks were intercepted at altitudes of 16-17 km. Some of these cannot be easily connected to nearby convective systems. So, either they had travelled very large distances from intense convection far to the east, or they were produced in situ and without convection. The OLEX lidar detected one example of a haze layer (just visible to the lidar) appearing to form an ice cloud when disturbed by a wave. There were two close encounters with vigorous convective systems: one with a mesoscale convective system, and one with a cyclone. Unfortunately, FSSP and CVI data will not be available for those flights. The only instruments to produce no data were the two condensation particle counters (CVI-COPAS and Mini-COPAS) both of which had heat dissipation problems. The temperature and humidity gradients between ground and tropopause did prove to be a substantial problem, but on-ground overheating was minimised by flying early in the morning. The Falcon-Geophysica air-air communication, directed by a haupt-experimentator on the Falcon, went extremely well.

WAVE

During the WAVE-THESEO campaign in winter 1998/99, three ground-based microwave instruments have carried out stratospheric water vapour observations at the Ny-Ålesund station (Spitzbergen), ALOMAR station (Norway), Onsala Space Observatory (Sweden). Two instruments could not be used for technical reasons at Jungfraujoch and Bordeaux stations. The groups are now currently working on data reduction. Data will be included in the THESEO data bank at NILU.

Ground-based microwave instruments to observe stratospheric ozone and ClO profiles were also operated at Ny-Ålesund, ALOMAR, Onsala, Bern, Plateau de Bure and Bordeaux. Balloon flights of the ELHYSA (LMD/CNRS) and FISH (Forschungzentrum Jülich) payloads were performed at Kiruna, Sweden, in February 1999. Water vapour, aerosols, hydrogen compounds and air temperature profiles were measured in the lower and mid stratosphere. Data measured during those flights are analysed and will also be included into the NADIR/THESEO data base as soon as possible. Measurements are compared with model calculations of the hydrogen distribution as well as data provided by satellites. After a successful test aircraft flight in August 1998 by the University of Bern group, the microwave radiometer to observe a water vapour spectral line around 183 GHz was again installed onboard the Swiss Air Force Learjet and flown in February from the tropics to the pole. Two databases of climatological stratospheric water vapour profiles have been set up, a comparison of models and measurements is done as well as a study of the water vapour isotopic ratio.

STRATOSPHERIC BrO

In the framework of the STRATOSPHERIC BrO-THESEO project, UV-visible spectrometers of BrO have been successfully operated at all 7 stations of the projects network, including Calo Alto in Southern Spain. The amount of data collected varied from one site to another depending on logistical and/or technical constraints: some stations being able to provide BrO column measurements over a full annual cycle in 1998, others having been operated on a campaign basis only (e.g. Calo Alto). All instruments performed nominally during the winter 1998/1999 period. Six flights of the SAOZ-BrO balloon instrument have been carried out by CNRS, covering winter and summer conditions at high-latitudes and winter conditions at mid-latitudes. During this winter period, the SAOZ-BrO was launched twice from Kiruna, in parallel to several other payloads. Global fields of BrO total columns are retrieved from the GOME instrument on a continuous basis by IFE-Bremen, and a complementary GOME BrO product is currently developed at IASB-BIRA.

Altogether, the data accumulated so far should enable us to significantly improve the characterisation of stratospheric BrO behaviour at northen high and mid-latitudes. Possible interhemispheric differences will also be addressed thanks to the collaboration established with NIWA. Currently, the global consistency of the available BrO measurements is being investigated by gathering together data from the different instruments operated during the first part of the project (e .g. work is now in progress to study the consistency between integrated balloon profiles of BrO performed in 1998, and available co-located GOME and ground-based column data). As to model activities, preliminary comparisons of BrO measurements with 3-D chemical-transport model calculations (SLIMCAT) have been started for balloon data and some ground-based stations, and will be actively continued in the next few months. Model studies also include box-model simulations of the changing BrO at twilight above ground-based stations or along particular trajectories. This kind of studies have been used to investigate, for example, the role of heterogeneous bromine reactions on the background aerosol outside the vortex.

COSE

The aim of the COSE project is to provide a validated and consistent data set of stratospheric species by coordination of ground-based observations at existing high-latitude and mid-latitude stations in Europe. The COSE project started in October 1998.

Nearly all instruments performed nominally, apart from EMCOR at the Jungfraujoch and the SYMOCS (VIS) at Andoya, which made no measurements because of technical problems; EMCOR is designed for ClO profile measurements, the SYMOCS (VIS) for O_3 and NO_2 column measurements. The SAOZ measurements of O_3 and NO_2 at the Jungfraujoch started only by mid-December. It must be noted that several stations reported bad weather conditions during the period considered, especially in January and February, which reduced the number of observations where the experiments depended on weather conditions (e.g., FTIR at Jungfraujoch and Zugspitze, microwave at Pl. De Bure, Dobson at Bordeaux, etc.).

Because of the warm stratospheric conditions last winter, only one backscatter sonde was launched at Ny-Ålesund, and none at Thule. On the dates of observations, no PSCs were detected, either by the sondes or the lidar; nor were any PSCs observed over Kiruna. But ClO observing conditions at Ny-Ålesund were good for approximately 20% of the time.

In many cases, the data analysis has not been performed yet, so most scientific conclusions are expected in the second half of 1999. For example, OClO spectra have been recorded at Harestua and Andoya, but they have not been analysed yet for OClO events.

Data archiving in the cose subdirectory of theseo at NADIR/NILU will start by June 1999.

GODIVA

GODIVA (GOME Data Interpretation, Validation and Application) is a European Community pilot project funded through Theme 3 (Space Techniques Applied to Environmental Monitoring and Research). The main aims include the improvement of the accuracy of existing GOME data products, i.e. radiances, ozone and NO_2 vertical columns, and to develop new advanced GOME data products such as ozone profiles, OClO, BrO, HCHO and SO_2 columns. A maximum of ten out of the 14 daily GOME orbits are transmitted to Kiruna. After each completed orbit, the data was sent via ftp from Kiruna to the NADIR data base during February and March of 1999. The level 1 GOME data was processed daily and the data products were made available from websites at NILU and at the University of Bremen. The data provided included slant column OClO, ozone profiles and total column BrO from NRT GOME data.
A very strong correlation between high OClO and low temperatures (sub-200 Kelvin) with coinciding high potential vorticity at the 475 K and 550 K isentropic levels was observed for several periods during February. A reanalysis of the CD-ROM level 1 data has shown the same behaviour for OClO. The ozone profiles over northern Europe were derived using the Bremen FURM retrieval algorithm. This inversion scheme uses the radiative transfer code GOMETRAN++ as the forward model to derive ozone profiles from the UV spectral region. 24-hour forecasts for temperature and pressure profiles were provided by ECMWF for use in the NRT evaluations. In the future, a similar processing chain could be envisaged for other satellite instruments such as SCIAMACHY, and for producing input for atmospheric chemistry transport and numerical weather prediction models. Assistance from DLR, ESA and SSC was highly appreciated.

CASSIS

LAP operated during the winter spring season of 1998-99 the WMO Ozone Mapping Centre providing total ozone maps for the northern hemisphere every two days. A new web site was developed for the dissemination of the maps. LAP also continued the routine total ozone and spectral UV measurements at Thessaloniki and participated in this winter's Match campaign. Meteorologists from FU-Berlin were present at Kiruna during January and February 1999 and have provided weekly descriptions on the dynamic evolution of the stratosphere in addition to the daily analyses. The Nadir database at NILU is acting as the main data centre and, with DMI, has made available high quality meteorological products such as those from ECMWF. Members of the Coordinating Unit were present at Kiruna during January and February.

Web sites

European Ozone Research Coordinating Unit:
http://www.ozone-sec.ch.cam.ac.uk
APE-THESEO project:
http://ape.iroe.fi.cnr.it
CASSIS project (maps of total ozone in the Northern Hemisphere by the WMO Ozone Mapping Centre):
http://lap.physics.auth.gr/ozonemaps
COSE project:
http://www.nilu.no/projects/nadir/cose/cose.html
GODIVA project (GOME slant column OClO plots):
http://www.nilu.no/projects/nadir/index.html
HALOMAX project:
http://www.rz.uni-frankfurt.de/IMGF/meteor/halomax/halomax.html
HIMSPEC project:
http://www-imk.fzk.de:8080/imk2/mipas-b/himspec.htm
Lagrangian:
http://www.aero.jussieu.fr/experience/THESEO/Lagrangian.html
METRO:
http://www.aero.jussieu.fr/experience/THESEO/METRO.html
O3-Loss:
http://www.aero.jussieu.fr/experience/THESEO/O3Losss.html

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