The Northern Hemisphere

Stratosphere

in the

2001/02 Winter

This short report was prepared by the European Ozone Research Coordinating Unit and is based on preliminary results provided by European and collaborating scientists working in projects in the European research cluster SOLO.

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Summary

Ozone loss over the Arctic has been one of the main objectives of stratospheric ozone research in Europe over the last ten years. This research has been conducted within several major field campaigns, most recently the Third European Stratospheric Experiment on Ozone (THESEO) in 1998-2000, and through long term observational programmes. Continuity of observation is important as a striking feature of Arctic ozone loss has been its large interannual variability. There was no large-scale observational campaign during the 2001/02 winter. However there are many on-going research projects which include studies of this winter's stratosphere. This research is coordinated through the European research cluster SOLO of EC and nationally funded projects.

The Arctic vortex developed during October and November 2001 and temperatures cooled from the seasonal average to below the long-term mean in November and December. On 28 November the temperature at 50 hPa was 192 K, the lowest recorded in November in 1979-2001, breaking the previous record by 2 K.

Polar stratospheric clouds (PSCs) were observed on most days during mid-December. The most striking feature was the high altitude at which these were observed. A strong warming of the vortex occurred in the second half of December which significantly weakened the vortex. PSC conditions were briefly re-established in early January, but a second strong warming then occurred and temperatures were subsequently not low enough for PSC formation. Despite a succession of minor warmings, a weak, warm vortex was present until mid-May when the summertime circulation was established.

The lack of sunlight during the period of activation limited the amount of chemical loss that took place to perhaps about 10% in the total ozone column in the Arctic vortex. In addition, the weak vortex was smaller than average. The impact of chemical ozone loss on overall ozone amounts was thus smaller than in some years. Averaged over the January-March period, ozone amounts at high latitudes were similar to those in other warm winters when relatively little loss occurred, while at mid-latitudes ozone was lower than recent years.

1 Background

A prime objective of stratospheric research in Europe over the last ten years or so has been to gain an improved understanding of the processes underlying the observed Arctic losses and of the influence on mid-latitudes. A number of pan-European campaigns have been mounted to investigate these processes:

- European Arctic Stratospheric Ozone Experiment (EASOE) in 1991/92;
- Second European Stratospheric Arctic and Mid-latitude Experiment (SESAME) in 1994/95;
- Third European Stratospheric Experiment on Ozone (THESEO) in 1998/99; and
- THESEO 2000, an extension of THESEO, through the 1999/2000 winter and spring.

Other field activities have taken place in other winters such as POLSTAR, APE, and the ILAS validation, which also involved balloons, aircraft, ozone sondes, ground-based measurements and satellite monitoring. In all these winters, the observational activities were complemented by modelling studies of the high latitude stratosphere.

No large-scale observational campaign was planned for the 2001/02 winter. However there have been a significant number of on-going research projects coordinated within the SOLO research cluster which have studied this winter's stratosphere. Details can be found in a planning document "European Research On Arctic Ozone in the 2001/02 Winter – Minimum Requirements and Planned Activities" available on the EORCU web site (http://www.ozone-sec.ch.cam.ac.uk). A brief description of the activities is given here in the Annex.

The on-going observation of ozone loss during successive Arctic winters is important as substantial losses can occur. A striking feature of Arctic ozone loss has been the large interannual variability of the ozone loss and its strong dependence on temperature. For example, there were losses of <10% in 1998/99 and >65% in 1999/2000 at around 18 km. Losses of 50% or more have been seen at the same altitudes in the Arctic in several winters since the early 1990s. A decrease in total ozone in the Arctic region has been observed since 1980, although there is considerable year-to-year variation in the observed values. This variability in the ozone loss is to be contrasted with the Antarctic where nearly complete ozone loss has taken place in all winters in the 1990s at altitudes between about 15 and 20 km.

In this document, the stratospheric evolution and some preliminary results from studies in the 2001/02 winter are presented. In Section 2, the meteorology is described, with the implications for and observations of PSC formation being discussed in Section 3. The chemical evolution, particularly the aspects important in rapid ozone loss, is considered in Section 4, and in Section 5 the ozone fields and chemical ozone loss are discussed.

2 The meteorology of the Arctic stratosphere in the 2001/02 winter

In September and October 2001 the conditions in the Arctic stratosphere were close to the long-term mean. There was a strong symmetrical vortex through most of November, with temperatures below the long-term mean in the second half of the month. On 28 November the temperature at 50 hPa was 192 K, the lowest recorded in November between 1979 and 2001, breaking the previous record by 2 K. Conditions were suitable for the formation of Polar Stratospheric Clouds (PSCs) over an altitude range of roughly 19-24 km. A minor warming began on 30 November, dying away by 8 December. PSC conditions were again established over Scandinavia from 70-20 hPa on 9, 10 and 11 December. A strong warming then ensued, continuing through the rest of the month, and subsiding in early January. PSC conditions were again established briefly from 70-20 hPa on 6-9 January, followed by another strong warming. This was the last occasion in the 2001/02 winter favouring PSC formation on a synoptic scale.

Low temperatures at 20 hPa were again present from 5-19 February over Europe, but did not reach the PSC threshold at lower altitudes. Thereafter a succession of minor warmings kept minimum temperatures close to the long-term mean, well above the PSC threshold. The vortex was weaker than average from mid-January onwards. Starting on 22 March the vortex underwent rapid distortion, becoming long and narrow, and by 26 March had split into two distinct regions. These persisted until 11 April, when a tongue of very low vorticity air crossed the line between the centres and provoked distortion leading to rapid recombination of the regions of high potential vorticity. By 19 April the recombination was complete. The erosion in the course of recombination was considerable, and the residual vortex in late April was much weaker than that present in mid-March. Thereafter it weakened steadily, and by 13 May the anticyclonic, summertime circulation had been established over the pole at 20 hPa, and established down to 50 hPa shortly after.

3 Polar Stratospheric Clouds (PSCs)

The possible areas for PSC type I existence are shown in Figure 1 at 475 K and 550 K. As indicated above, temperatures were low enough for PSCs to form for much of November and December, but only on the odd occasion after that. Analysed temperatures were never low enough for PSC II (ice) formation.

The overall picture deduced from the temperature fields is confirmed by measurements. Observations by the POAM III instrument on the SPOT IV satellite indicated the presence of PSCs from 26-30 November and on each measurement day from 6-24 December. (POAM alternates daily between the NH and SH.) PSCs were again observed from 7-17 January, after which no further PSCs were detected. The most remarkable feature in the 2001/02 POAM observations was that some of the mid-December PSCs were very high, with a few having peak extinctions as high as 27 km. These findings were in general accord with lidar measurements at Esrange (68ºN, 21ºE) on 8 December and *in situ* backscatter measurements made on 10 December at Sodankylä (67ºN, 27ºE), where PSCs were detected between 21 and 26.5 km. This PSC layer was composed of mixtures and layers of different types of PSC particles: NAT, STS and ice. The highest backscatter ratio at 940 nm was over 40 at 26.5 km during ascent and over 130 at 25 km on descent through colder air. Local temperatures were below the ice point by up to 4 K. On 11 December PSCs were seen over a similar altitude range, but the measurements indicated that these were composed of mainly NAT. The occurrence of PSCs over Sodankylä from 1965-2002 inferred from radiosonde measurements is shown in Figure 2.

Figure 1

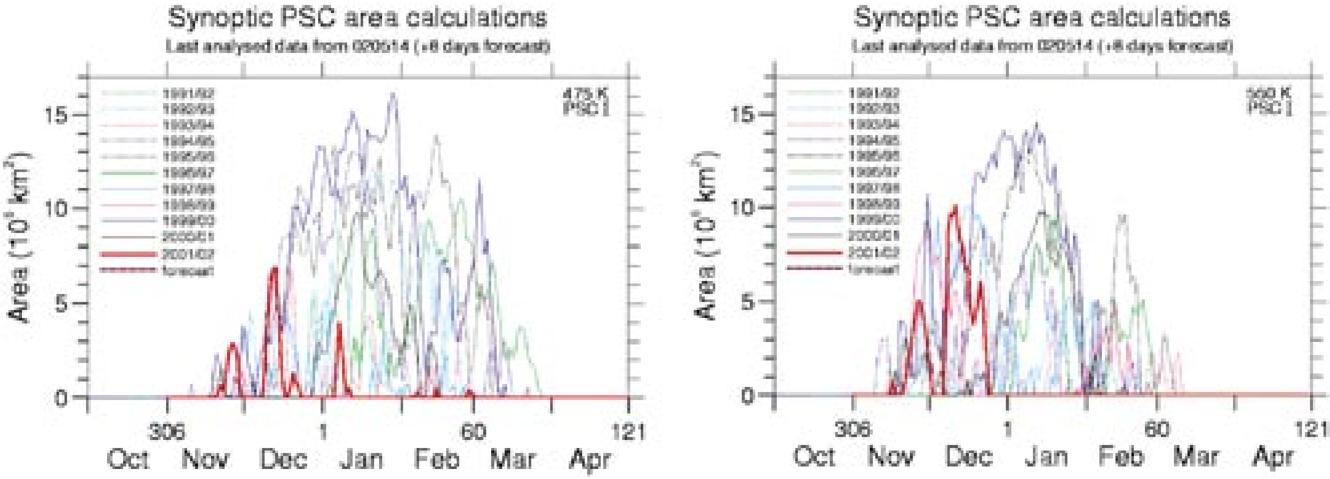
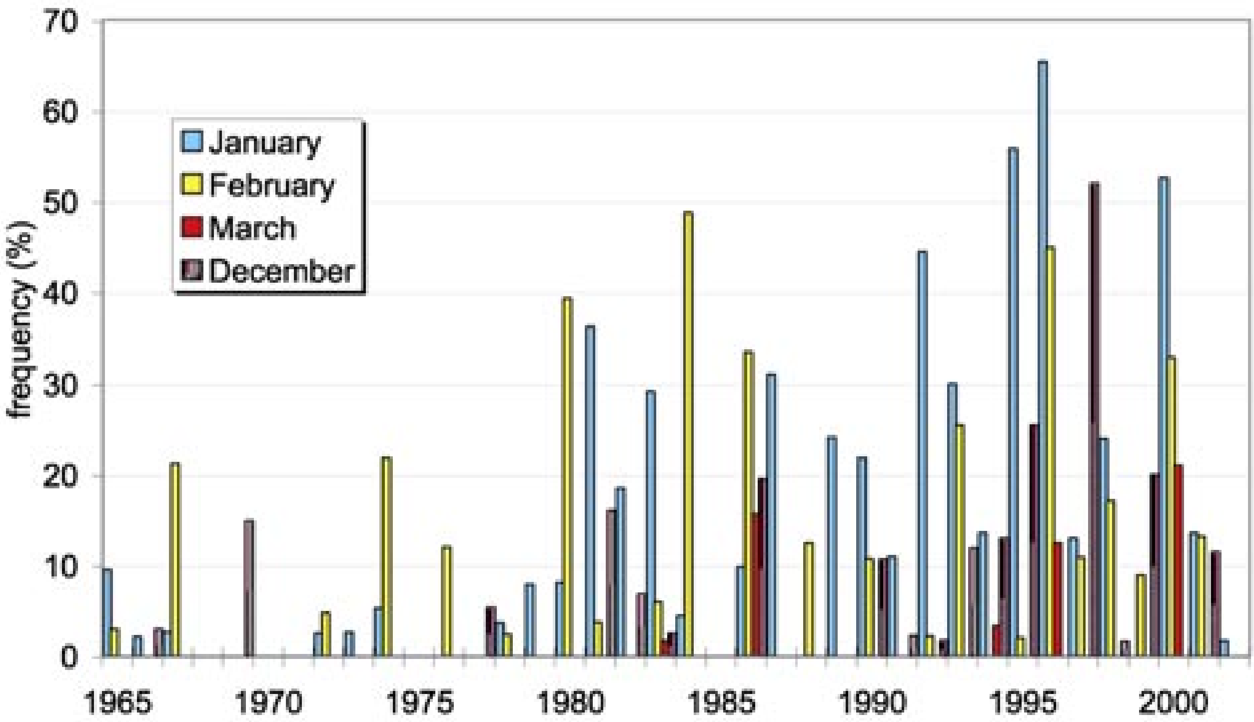


Figure 2



The PSC analysis balloon gondola was launched from Esrange, Sweden on the evening of 9 December 2001. The launch was made following reports of the first Arctic PSCs this winter observed by POAM and lidar observations with the U. Bonn lidar at Esrange combined with stratospheric temperature forecasts. A backscatter sounding in the afternoon confirmed the presence of PSCs downwind of Esrange. PSCs were observed between 23 and 26 km altitude (33 and 17 hPa). The lower part of the cloud showed very large backscatter ratios (>20 at 940 nm) with low colour indices whereas the upper part of the cloud had lower backscatter ratios and higher colour indices, indicating different types of particles throughout the PSC layer with highly detailed structure.

4 Chemistry

For the first time, the instruments on the ODIN satellite was operational during an Arctic winter. Preliminary analysis of the SMR measurements of ClO indicates that significant amounts of ClO were present in early January. The elevated ClO amounts were seen at 21 km altitude over northern Europe and Greenland on 7-8 January. The broad spatial features are in agreement with the ClO field seen in the Reprobus CTM. ODIN instruments measure at 0600 and 1800 local time and are used for atmospheric measurements every few days, so the representativeness of these preliminary data is not yet clear. The vortex was activated in December and January according to the SLIMCAT model. However the amount of ozone loss which resulted from this activation was not large as there was not much sunlight around to drive the photochemical ozone destruction cycles. At 475 K, SLIMCAT estimates that up to 10% loss occurred locally by 21 January towards the end of the ozone loss period.

5 Ozone and ozone loss

5.1 Evolution of the ozone field in the winter 2001/2002

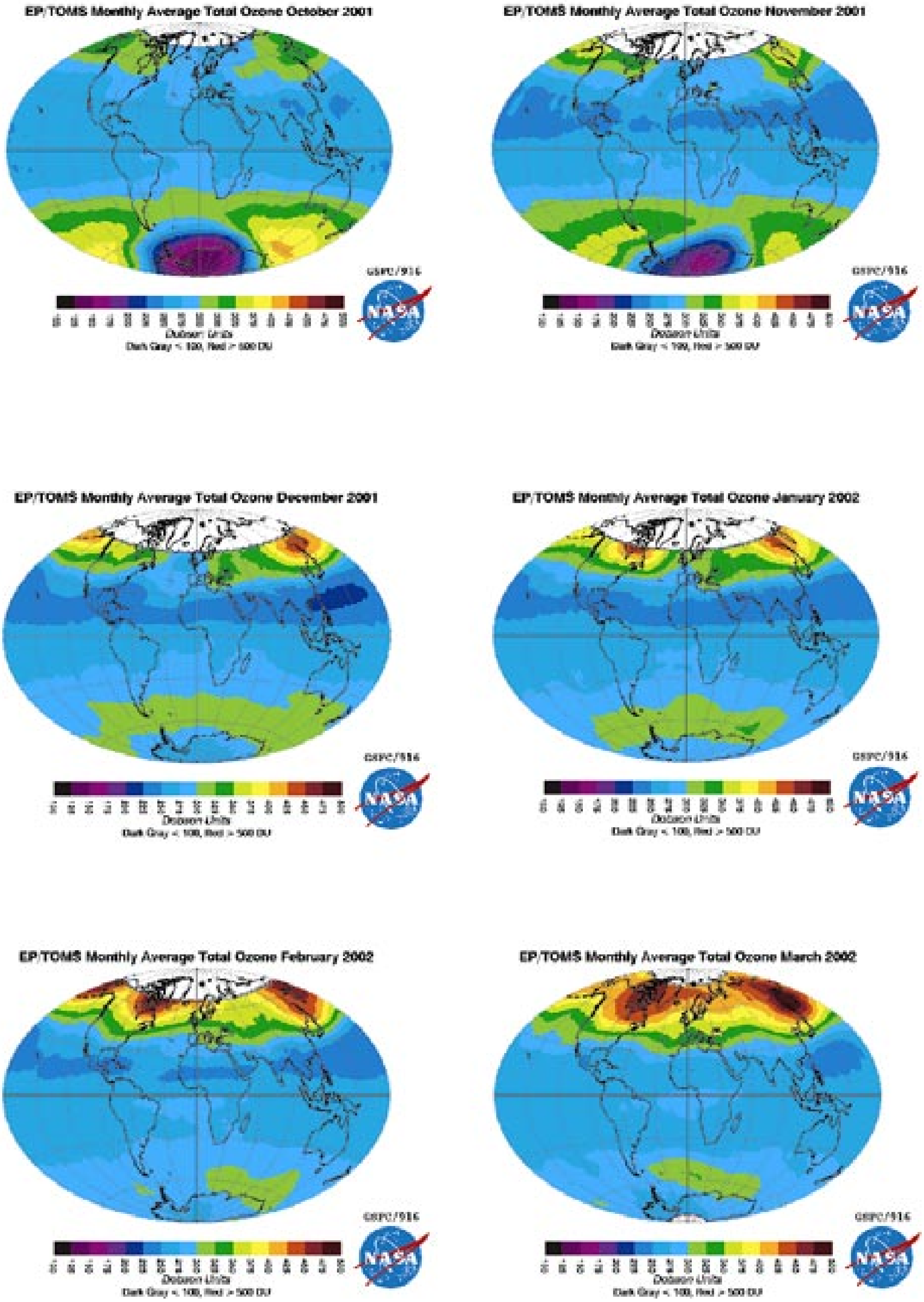
EP/TOMS monthly average total ozone maps for October 2001 to March 2002 are shown in Figure 3. In the northern hemisphere in October the ozone field has weak gradients, with a single high, about 350 DU, centred over Kamchatka. The sector 0-30°E is notable for the virtual absence of a south to north ozone gradient, with ozone values between 250 and 275 DU. In November the pattern is similar, but the maximum from 50-60°N has intensified, and there is a pronounced minimum in the northern sub-tropics. The lowest ozone values at mid-latitudes are over the western Atlantic, and the ozone field is almost featureless over Europe and much of northern Asia. The pattern has changed little by December, the ozone high is more pronounced, and a distinct low has appeared over the western sub-tropical Pacific. Low ozone persists over the Atlantic and western Europe.

In January the ozone high has developed two centres, one west of Kamchatka, and another, slightly stronger over Hudson Bay. Ozone remains relatively low over Europe, but there is now a moderate south-north gradient of ozone over the Atlantic. The sub-tropical belt of minimum ozone shows much less structure than in December. Overall January 2002 was most notable for the apparent absence of poleward transport of ozone. In contrast ozone values north of 40°N increased considerably from January to February, but with little change to the overall pattern. The highs remain over Kamchatka and Hudson Bay, with central values over 450 DU. The sub-tropical belt of minimum ozone has begun to fragment. By March only the western sub-tropical Pacific has ozone values below 250 DU. The 300 DU contour is everywhere close to 30°N. On average the 400 DU contour is at about 50°N, and the centres of high ozone have remained more or less stationary.

Of course monthly mean maps conceal much of the fine structure of ozone distribution. The map for 12 March shows the quasi-stationary ozone highs over Kamchatka and Hudson Bay (greater than 500 DU, actually off-scale!), but also a mobile tongue of high ozone over the western Atlantic, with values greater than 500 DU at 35°N. On the following day ozone values were greater than 500 DU across all of Scandinavia. In April the distribution of was much more variable than in February and March. Values greater than 500 DU are still present, however the filamentation and mixing that eventually produce a flat summer field seem to be well under way.

Based on the analysis of preliminary near-to-real time ground based total ozone data and EP-TOMS total ozone, during October 2001, the total ozone values were within 5% of their 1978-1988 average. In November 2001 relative low ozone values (-10%) were observed over N. Canada, N. Atlantic and East Siberia. The situation was different during December 2001 when total ozone was 15% lower than the long-term average over the East coast of the U.S. and Canada and about 10% lower over the UK and Scandinavia, while transport of subtropical air masses poor in ozone towards these areas was observed.

Figure 3


EP/TOMS Monthly Average Total Ozone October 2001
Dobson Units
Dark Gray < 100, Red > 500 DU
EP/TOMS Monthly Average Total Ozone November 2001
Dobson Units
Dark Gray < 100, Red > 500 DU
EP/TOMS Monthly Average Total Ozone December 2001
Dobson Units
Dark Gray < 100, Red > 500 DU
EP/TOMS Monthly Average Total Ozone January 2002
Dobson Units
Dark Gray < 100, Red > 500 DU
EP/TOMS Monthly Average Total Ozone February 2002
Dobson Units
Dark Gray < 100, Red > 500 DU
EP/TOMS Monthly Average Total Ozone March 2002
Dobson Units
Dark Gray < 100, Red > 500 DU

Over Alaska and Kamchatka total ozone values were 15% higher from their normal values. The ozone field during January 2002 was 5-10% below normal over the entire middle latitudes, while in February a more complex situation was observed. High ozone values up to 20% from normal were observed over N. Atlantic and N. Scandinavia, while over Central Siberia ozone values were 20% lower than average. Centers of –10% were also observed over Europe and N. America. During March 2002 the low ozone values persisted over Central Siberia and low values (–20%) were observed over NE Pacific and NW Atlantic. Very high values (+20%) were observed NE of Iceland, while over Europe ozone ranged from –5 to –10% relative to normal. The ozone anomalies during April 2002 were similar to March but much weaker and as a result total ozone was within 5% of the long-term mean over most of the Northern latitudes. The long-term evolution wintertime TOMS / GOME total ozone is shown in Figure 4. The evolution for the 2001/02 winter for the region north of 55°N is shown in Figure 5.

Figure 4

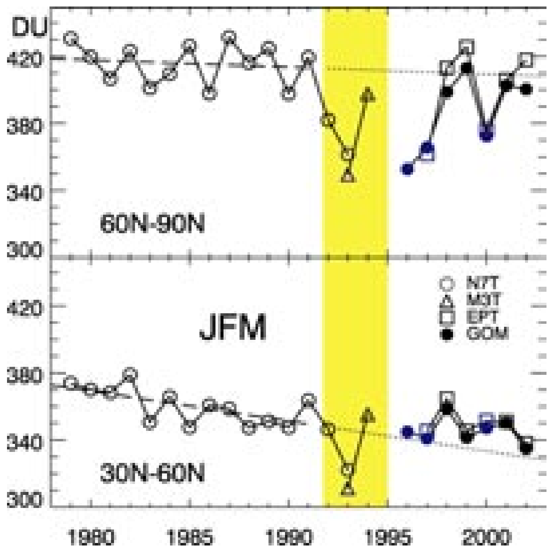
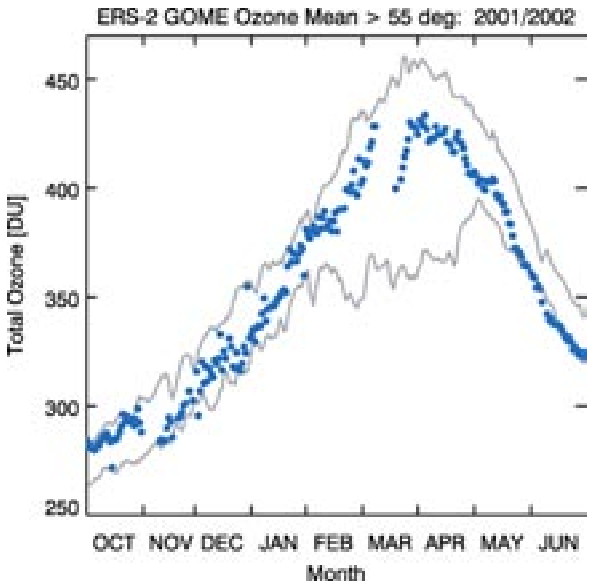


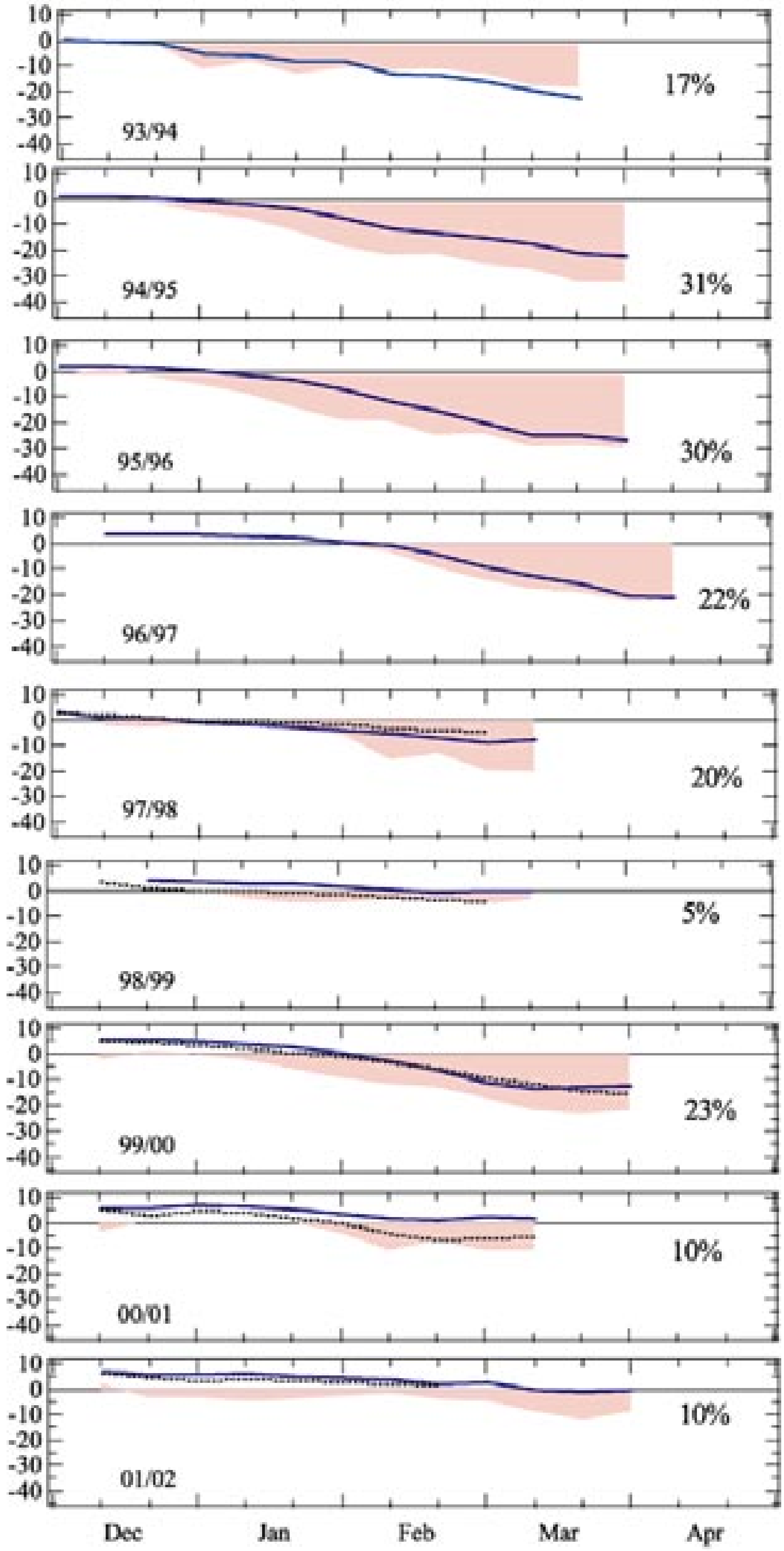
Figure 5



5.2 Ozone loss

The cold period occurred in mid-winter during Arctic night, and the lack of sunlight limited the amount of photochemical ozone loss that could take place. Accordingly no Match campaign was run. The principal ozone loss estimate is derived by comparing the SAOZ total ozone observations with 'passive' ozone from the Reprobus model. In 2001/02 total column loss of 10% is found, as shown in Figure 6. Results from earlier years are also shown and the loss in this winter with early cold temperatures is at the low end of the range observed over the last ten years.

Figure 6



F. Goutail

Figure captions

Figure 1 Areas of PSC existence calculated from ECMWF analysed temperatures from 1991/92 to 2001/02 for (a) 475 K (about 19 km altitude) and (b) 550 K (about 22 km). (Courtesy of P. von der Gathen, AWI.)

Figure 2 Observed occurrence of temperatures at 50 hPa which allow PSC formation according to radiosonde data from Sodankylä between January 1965 and March 2002. (Courtesy of R. Kivi and E. Kyrö, FMI.)

Figure 3 EP/TOMS monthly average total ozone maps for October 2001 to March 2002. (Courtesy of NASA Goddard.)

Figure 4 Mid-latitude (30-60°N) and polar (60-90°N) winter ozone mean between 1979 and 2002 for January-March. The various symbols show the TOMS (N7T: Nimbus 7, M3T: Meteor-3, EPT: EP-Toms) and GOME data. Regression line shows the linear fit to the Pre-Pinatubo data (before 1991). Shaded regions indicate a period with enhanced stratospheric aerosol loading. Blue symbols show the values representative for cold Arctic winters (update from EU Commission Report- Scientific Assessment of European Stratospheric Research 1996-2000. (Courtesy of M. Weber and K-U. Eichmann, IUP Bremen.)

Figure 5 Time series of daily mean total ozone north of 55°N. The two grey lines indicate the maximum and minimum total ozone mean measured by GOME between 1995/96 and 2000/01. (Courtesy of K-U. Eichmann and M. Weber, IUP Bremen.)

Figure 6 Chemical depletion of ozone in the Arctic vortex deduced from (i) comparing SAOZ measurements with the Reprobus passive ozone (red hatched area); and (ii) the Reprobus CTM chemical loss calculation (blue line) and the SLIMCAT chemical loss calculation (dotted line). (Courtesy of F. Goutail, CNRS-SA.)

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Annex Field activities

European research activities on ozone loss in the Arctic is coordinated within the EU research cluster SOLO which covers research on long term ozone changes. More information can be found at the web site of the European Ozone Research Coordinating Unit (http://www.ozone-sec.ch.cam.ac.uk/).

The following activities were carried out in the 2001/02 winter. Analysis of the results continues.

QUILT

Quantification and Interpretation of Long-Term UV-Vis Observations of the Stratosphere (QUILT) is a three-year EU project devoted to the improvement and development of GOME data products, UV-Vis ground-based and balloon-borne data, 3-D CTM and RTM optimisation and internet-based near real-time (NRT) data dissemination. QUILT aims to improve our understanding of global concentrations and trends of stratospheric ozone and related trace gas species (NO_2, BrO, OClO, IO). The entire data record of the global NDSC UV-Vis network and balloon-borne measurements are being reanalysed with the purpose of determining ozone loss in the past, monitoring its development in the present and investigating its relation to active halogen and nitrogen species. During the 2001/02 winter, near real-time GOME measurements were produced (see below). Real-time information from the ground-based SAOZ network was used by CNRS-SA to estimate ozone loss. More information can be found on the QUILT project website at http://nadir.nilu.no/quilt/index.php/

GOME

Observations by the ESA GOME instrument on the ERS-2 satellite were made in a near-real-time mode through combined support from the QUILT project, ESA and DLR. The observations show the evolution of ozone and other trace species in the sunlit portions of the atmosphere during winter. More information is available at the GOME near real-time data website at http://www.iup.physik.uni-bremen.de/gomenrt2002/

ODIN

The ODIN satellite, launched in February 2001, is a Swedish-led small satellite project for astronomical and atmospheric research which is operated in conjunction with Canadian, Finnish and French partners. Between them, ODIN's UV-Vis spectrometer (OSIRIS) and submillimeter radiometer (SMR) supply valuable atmospheric measurements of a number of species, including ClO, O_3, NO_2, N_2O, H_2O, and HNO_3. Instrument observation time is split between atmospheric and astronomic users, with atmospheric measurements made routinely every three days. The measurements made during the 2001/02 winter are preliminary.

MAPSCORE

The EU project Mapping of Polar Stratospheric Clouds and Ozone levels relevant to the Region of Europe (MAPSCORE) is investigating the role of PSCs in ozone destruction. Stratospheric ozone levels over the region of Europe are profoundly influenced by lower stratospheric temperatures and the stability of the polar vortex, as ozone loss is sensitive to the threshold nature of polar stratospheric cloud (PSC) formation and denitrification. This coupling is important for the evolution of climate over the next fifty years. In the EU MAPSCORE project, European scientists are exploiting existing data sets from field and satellite campaigns by providing maps of PSC properties, maps of denitrification, new observations of PSCs, and fields from chemical data assimilation for entire winter/spring periods.

CIPA and POSTA

CIPA is an EU project whose objective is to measure and understand the composition of polar stratospheric cloud (PSC) particles. Simultaneous balloon-borne observations are made of the chemical and physical properties of PSC particles and condensation nuclei, including size distributions, aerosol backscatter ratios and depolarisation, along with the gas phase water vapour concentrations and temperature. The CIPA web site is http://www.dmi.dk/pub/CIPA/.

The German BMBF support the POSTA project, which complements the research in CIPA through complementary field measurements with aircraft and balloons and through laboratory studies. The POSTA web site is http://imk-aida.fzk.de/posta/index_en.html.

Within these projects, a flight of the CIPA balloon payload took place from Esrange, Sweden, in the evening of 9 December 2001. The flight was very successful. Due to highly skilled manoeuvring of the balloon by the CNES team, it was possible to fly nearly continuously inside PSCs for more than 2.5 hours where the balloon passed the same PSC layers 4 times. The scientific instrumentation on the gondola consisted of the aerosol chemical mass spectrometer from MPI; optical and CN counters from U. Wyoming; backscatter sondes from CNR-IFA and U. Wyoming; and frostpoint hygrometer from LMD together with several temperature and pressure sensors. All instruments worked without problems during the whole flight.

A technical flight of the MIPAS-B balloon payload was made on 12 February 2002. The instrument worked well and the measurements are currently being analysed. Because of the warm conditions, the scientific aim of the flight was to study the diurnal variations around sunset, in particular with respect to the nitrogen chemistry using the improved sensitivity of the MIPAS instrument in the shortwave channels (i.e. for NO_2 and NO) by a factor of 2 to 5.

NDSC-FTIR

The FTIR spectrometers in place at the primary NDSC sites in Europe have been further operated to gather series of solar observations to derive vertical column abundances of a wide range of chemical species, including the key stratospheric compounds of the nitrogen-, chlorine- and fluorine families.

F.U. Berlin

F.U. Berlin monitored the stratospheric winter-time circulation and prepared the daily STRATALERT messages mandated by the WMO. This alert programme helps to coordinate research projects all over the world during interesting stratospheric events. F.U. Berlin also provided guidance on the likely stratospheric evolution to interested measurement groups. See http://strat-www.met.fu-berlin.de/ for more information. A paper "The early major warming in December 2001 – exceptional?" by Naujokat et al. is in press in Geophys. Res. Lett.

U. Thessaloniki

During the last winter-spring season the World Ozone Mapping Centre, hosted by the Laboratory of Atmospheric Physics at the University of Thessaloniki, Greece in collaboration with WOUDC, operated in near real-time. Fields of total ozone based on TOMS and ground-based data from stations in the WMO Global Atmospheric Watch ozone monitoring network, as well as daily deviations maps from the long-term mean for the Northern Hemisphere, were provided on a daily basis. Preliminary results are presented in section 5.1 (Ozone Evolution). Combined GB and GOME total ozone maps are prepared within the EU STREAMER project (http://lap.physics.auth.gr/ozonemaps and http://lap.physics.auth.gr/streamer).

U. Leeds

Calculations were performed for winter 2001/02 with the SLIMCAT 3-D chemical transport model in the same configuration as for winters 1999/2000 and 2000/01 [e.g., Sinnhuber et al., GRL, 27, 3473, 2000]. As for winter 1999/2000, the model was driven by temperatures and wind fields from the U.K. Met. Office (UKMO) analyses. Results from the model run have been made available online in near real time and can be found on http://www.env.leeds.ac.uk/slimcat.

AWI

At the NDSC station in Ny-Ålesund, AWI performed regular measurements during the winter months with ozone sondes and lidar, aerosol lidar and FTIR spectrometry, using the moon as light source once per month. A microwave radiometer for O_3 and ClO was operated together with Univ. Bremen. The PSC observations by lidar are part of the EU project MAPSCORE.

DLR

Forecasts and other information about mountain wave events and associated PSC formation were provided in the context of the general meteorological evolution of the stratosphere.

NILU

The NADIR database continued to be operated. Ozone was measured at Andøya, by a lidar and a UV filter instrument.