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COZUV Third Annual Report

Coordinated Ozone and UV Project
Reporting period: 01.01.1999-15.12.2001

Geir O. Braathen

Norges forskningsråd
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Environment and Development
Research Programme on Climate and Climate Change

COZUV

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COZUV
Third Annual Report

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Progress of the project

1.0 Overall project progress

1.0.1 Introduction

The COZUV application that was submitted in June 1998 covered four years (1999-2002). Funding was granted for two years. We call these two first years (1999 and 2000) the first phase (or phase I) of COZUV. A new application for 2001 and 2002 was submitted in June 2000. These next two years are called the second phase (or phase II) of COZUV. This report covers the first three years of the COZUV project from 1.1.1999 until mid-December 2001.

The project consists of two main thematic parts: an ozone part and a UV part. The links between the UV part and the ozone part were somewhat limited during the first phase of COZUV. During the second phase this is remedied through a more extensive exchange of data and results between the ozone and UV tasks. Data from Task 1 on the long term development of the ozone column will be used in Task 9 for the calculation of UV maps.

The links between the various ozone tasks have been strong and observational data have been used both for empirical ozone studies and for validation of the models in tasks 1 and 2. One of the main goals of COZUV has been to develop a Norwegian 3-D chemical transport model (CTM) that can compete with the best models available internationally. During phase I and the first year of phase II of COZUV this work has had considerable progress. The model underestimates the ozone loss that has been observed, but several reasons for this have been found and it is expected that further improvements will be made during the last year of COZUV. Observational data obtained through tasks 3, 4, 5 and 6 have been very helpful in the assessment of the model data. During the first phase of COZUV the winter of 1995-96 was chosen as the study year. This winter was chosen because it was a very cold winter with extensive ozone loss. During the second phase of COZUV one will study three more winters, namely 1996-97, 1999-2000 and 2000-01. The first two of these also experienced large ozone loss and will therefore be well suited to test the model.

1.0.2 Organisation of the report

The report is divided into seven sections. Section 1 describes the progress of the project relative to the aims set out in the work plan. If there have been deviations from the project plans these are explained. Plans for the remaining year of the second phase are also given. This section should be read with the aid of the work plans for phase I and phase II of the project. These work plans are available via anonymous ftp on NILU’s ftp server:

ftp://ftp.nilu.no/pub/NILU/geir/cozuv/wp/cozuv.pdf and

ftp://ftp.nilu.no/pub/NILU/geir/cozuv/wp/cozuv-2.pdf

Section 2 describes the scientific results that have been achieved during the first three years of the project. Section 3 gives a comprehensive overview of publications, reports and presentations where COZUV results have been used. Section 4 gives an overview of international cooperation where COZUV partners participate. Section 5 gives details about the internal and external relations and the benefits of organising the research through coordinated projects. Section 6 contains ideas about areas of research that should be addressed during a possible phase III of COZUV. Section 7 contains an overview of how the resources have been spent.

1.0.3 Status of project progress

Task 1 has reached all its milestones except for the inclusion of a new particle scheme (see section 1.1).

Task 2 has reached all the milestones.

In task 3 there have been no ozonesonde launches from Kjeller. The ozonesonde activity at Ørland took a pause from early May 2001 until December 2001 due to operational problems, as described under Task 3 in section 1. Otherwise the milestones have been reached.

In task 4 all observations at Ny-Ålesund have been carried out as planned. At Andøya there have been some technical problems with the instruments that have led to gaps in the observation series with the two SYMOCS instruments.

In Task 5 all the milestones have been reached.

In Task 6, there was a change in the work relative to the work plan as it was decided to study the winter of 1995-96 rather than the winter of 1999-2000. The reason for this was the availability of necessary input data for the 3-D-CTM. Such data was available for 1995-96 and not for 1999-2000. 1995-96 was also a very cold winter and therefore well suited to test the performance of the model. Apart from this change of study year, all the milestones in Task 6 have been reached.

In Task 7 some of the milestones have not been reached. This is partly due to late delivery of vital components from a manufacturer and partly due to sick leave. Most of the delay has been caught up with during the last months of 2000 and during 2001, but certain milestones are deferred to the last year of COZUV. There is a good possibility that these aims will be fulfilled during 2002.

In Task 8 some of the milestones have been reached, but the balloon launches and data analysis were delayed due to instrumental problems with the NILU-CUBE. The instrument is a new development and such problems must always be envisaged. However, two flights with the new instrument have been carried out. The data analysis is under way and some results are presented in this report.

In Task 9 the plans of phase I had to be changed due to lack of data caused by instrumental problems. The goals for this task were therefore changed and the milestones defined for this task therefore became irrelevant. This work has been published (see section 3.1.9). During phase II task 9 is progressing well, but the order of the tasks has been modified as explained in section 1.9.2.

In Task 10 all the milestones have been reached.

1.0.4 Conclusion

The overall progress of the project is good and most of the tasks and activities are on schedule. Some activities have had problems, mainly due to late delivery of components or faulty components that had to be replaced. Such delays are part of all experimental work. In the modelling activities there have been some small changes in the choice of study years due to availability of meteorological data. An aim for 2002 is to catch up with these delays and since the problems causing them have been solved, there is a very good chance that all the activities will be completed.

1.1 Task 1: 3-D modelling of atmospheric chemistry

Responsible scientist: Ivar S.A. Isaksen

Co-workers: Michael Gauss
Bjørg Rognerud
Bojan Bojkov
(act. 1.5 until May 2001)
Geir Braathen
(act. 1.5 from May 2001)

1.1.1 Progress during Phase I

Activity 1.1: Development of a global 3-D CTM for stratospheric process studies

Development of a new 3-D CTM

A new 3-D CTM was developed. The model is an extension of the tropospheric Oslo CTM-2, including new stratospheric ozone chemistry. Meteorological data for 1996 were used during COZUV 1. A new photolysis module was included and a multi-year run (perpetual 1996) was performed to obtain equilibrium for slow processes.

Testing of the new 3-D CTM

The new 3-D CTM was tested extensively against observations. Data samples as a part of COZUV (lidar) as well as other data (in particular satellite data from GOME and SAGE) were used.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

The milestones have been reached.

Activity 1.2: Long term studies of stratospheric ozone depletion

Long term integrations with SCTM

The stratospheric 3-D model (SCTM-1) has been used to look at long term studies of future ozone changes over the next 1 to 2 decades. The model was run one year with a spin up time of 2 years for each of the following years, 1980, 2000 and 2015.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

The milestones have been reached.

Activity 1.3: Model improvements

Improvement of chemical scheme

The focus was on the bromine chemistry. Comparison between model calculations and observation showed that HBr is underestimated in the models, therefore the Oslo 2-D model was used to examine if this discrepancy could be reduced by assuming that a small fraction of the reaction $BrO+HO_2$ was producing HBr. The results of the study showed large differences of this assumption within the polar region. This shows that we have to be careful when new reactions are included in the model, in particular for polar night conditions.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

The milestones have been reached.

Activity 1.4: Model studies of ozone loss and changes

Process studies with SCTM-1

Oslo SCTM-1 has been used to look at the catalytic ozone loss in the stratosphere. Nine different loss cycles in the hydrogen, nitrogen, chlorine and bromine families have been analysed. In the upper and lower stratosphere almost all of the ozone loss is through the HO_x cycle, while at the edge of the polar night the Cl_x cycle is significant, up to 50% in the lower stratosphere.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

The milestones have been reached.

Activity 1.5: Provision of meteorological data

Provision of T_{106} data from ECMWF

Meteorological fields from ECMWF have been transferred on a daily basis via DNMI throughout the period. The data flow has been surveyed on a daily basis. In conjunction with the upgrades of the ECMWF model to 50 and 60 levels in March and October of 1999, respectively, the software at NILU was upgraded to handle the new number of levels. These data are available to all COZUV partners and also to stratospheric scientists in Europe.

Deviation from project plan

The milestones have been reached.

1.1.2 Progress during Phase II

Activity 1.1: Further development of a global 3-D CTM for stratospheric process studies

Development of a new scheme for particles in Oslo CTM-2:

The inclusion of an extensive scheme developed by N.Larsen at the Danish Meteorological Institute was thoroughly considered. In collaboration with I.Fløisand (NILU) this scheme was modified for inclusion in CTM-2. However, the scheme turned out to be too expensive for the global CTM even if the number of size bins could be reduced from 50 to 15 (N.Larsen, pers. comm.). As parallel processing is implemented, one of the main problems with CTM-2 i.e. the high CPU requirement will be alleviated and the detailed microphysics scheme of N.Larsen could be reconsidered. It appears more likely, however, to include a more simplified scheme used by the group of G.Brasseur (G.Brasseur, pers.comm.).

Extension of the vertical range of CTM-2 to 0.1 hPa:

Scheduled for 2002, depending on the quality and availability of ECMWF data for the years to be modelled.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

Although the existing parameterisation of heterogeneous chemistry in CTM-2 could be improved during COZUV 2 (see ‘Scientific results’), the inclusion of a detailed module for particle formation could not been achieved. However, the inclusion of a more simplified scheme for PSC formation is now under consideration (G.Brasseur, pers. comm.) and seems within reach. The module will be tested in the part of the second year of COZUV 2.

Activity 1.2: Long-term studies of stratospheric ozone depletion

Long-term integrations for the past (1970-2000) with SCTM-1

Model runs for 1970 and 1980 have been performed with the improved SCMT-1 and a run from 1981 through 2000 has been started. For the surface area of sulphate aerosols, SAGE II measurements have been used for the corresponding year.

Long-term integrations for future scenarios until 2050 with SCTM-1

SCTM-1 will be run for the following years 2010, 2015, 2020 and 2050. In order to study water vapour in the upper stratosphere/lower mesosphere the chemistry has to be calculated up to 70 km. A simplified mesospheric chemistry package has to be included in SCTM-1 in order to perform these studies.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

Due to problems with running SCTM-1 on the new computer (HP at University of Oslo) the model calculations from 1980 through 2000 are not finished. This will be done before the end of 2001.

Activity 1.3: Improvements of the stratospheric chemical transport model

The gas phase reaction in the three dimensional model (SCTM-1) has been updated JPL2000 (Sander et al., 2000) and a new code for calculation of photodissociation rates, called FAST-J (Wild et al., 2000), has been included. Updating the chemistry to JPL2000 (Sander et al., 2000) leads to changes in the chemical partitioning in the stratosphere. The largest changes in the column ozone is seen when $NO_2+O(^1D)$ is updated. The reaction has become faster and leads to more efficient ozone depletion through the nitrogen cycle.

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

The milestones have been reached.

Activity 1.4: Model studies of ozone loss processes

Analysis of changes of spring and summer ozone with CTM-2 for the years 1997,2000,2001

The vertical resolution in the tropopause region was improved by a factor of two by using 40-layer ECMWF data rather than 19-layer data. The effect of this improvement could not be assessed directly as there is only one set of data per year (1996: 19-layer data only, 1997: 40-layer data only). However, the agreement in the years where 40-layer data is available show a much better agreement with observations than was achieved with the 19-layer data for 1996. Validation efforts have been made using data from different sets of observations for the whole year of 1997 and the winter season 2000/2001 (see ‘Scientific results’). Spring and summer 2000 as well as summer 2001 have not been investigated yet, as meteorological input data for these periods have not been provided. This is scheduled for the second period of this activity (early 2002). In collaboration with Y.Orsolini the ozone chemistry of ozone was analysed for June 1997 (see task 2, activity 1).

Presentation of results

Results from this activity have been presented at COZUV project meetings.

Deviation from project plan

The milestones have been reached.

Activity 1.5: Provision of meteorological data

Provision of 6-hourly T_{106} data from ECMWF on a daily basis

Meteorological fields from ECMWF have been transferred on a daily basis via DNMI throughout the project period. The data flow has been surveyed on a daily basis. These data are available to all COZUV partners and also to stratospheric scientists in Europe.

Deviation from project plan

The milestones have been reached.

1.1.3 Plans for 2002

In the second phase of COZUV II, new study years will be considered, with particular focus on the record cold winter of 1999/2000. Data from numerous measurement campaigns will facilitate a detailed model validation. This will be particularly helpful during the inclusion and testing of a new particle scheme, which is scheduled for the first half of 2002. Also the horizontal and vertical resolutions will be further improved. Following the COZUV work plan the vertical domain of CTM-2 will be extended up to 0.1 hPa in order to get a more realistic simulation of the middle stratosphere. The success of this effort will depend on the quality and availability of ECMWF stratospheric data.

Thanks to the inclusion of an efficient scheme for the calculation of photodissociation values long-term integrations of SCTM-1 are now computationally affordable. In 2002 future scenarios until 2050 will be calculated with SCTM-1.

1.2 Task 2: Dynamical studies

Responsible scientist: Yvan Orsolini

Co-workers: Georg Hansen, Inga Fløisand, Ivar Isaksen, Michael Gauss, Bjørg Rognerud, Ulf-Peter Hoppe

1.2.1 Progress during Phase I

Activity 2.1: Polar/Mid-latitude exchange processes

Analysis of THESEO winter 97/98

The main objective was to develop a modelling approach to re-construct locally at Andøya, daily-varying ozone profiles and columns that bear strong resemblance to the ones observed. We made extensive use of meteorological analyses, lidar as well as global satellite observations collected during THESEO. This work was done in collaboration with Georg Hansen (NILU-Tromsø) and Ulf-Peter Hoppe (FFI), and is fully integrated with Task 5. An in-depth analysis of ozone transport for entire winter-spring period of 97/98 during the THESEO campaign has been realised.

Simulation for THESEO winter 98/99

As for the first THESEO winter, the model study aimed at a re-construction of high-latitude ozone lidar observations made at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) throughout winter and spring. Extensive use of satellite observations (UARS MLS) has been made.

Analysis of THESEO winter 98/99

Ozone profiles and variability at Andøya have been reconstructed in detail for February 1999 and 1998. Interannual variability of the ozone profiles in these two years with little ozone destruction has been examined, and further compared with February 1996, a year characterized by large ozone depletion in February.

Presentation of results

These results are described in an article to J Geophys Res., which has been published in the year 2001, and presented at several conferences.

Activity 2.2: Coupled dynamical and chemical modelling of filaments.

Modelling of chemical mixing in filaments

The objective has been the development and testing of a new

Lagrangian chemical/dynamical model, that can resolve chemical fields at high horizontal resolution. This work was done in collaboration with Inga Fløisand (NILU) and the atmospheric chemistry group at U of Oslo (I, Isaksen, M. Gauss, B. Rognerud) and is hence strongly coupled to TASK 1. Global maps of reactive stratospheric trace species were calculated using a domain-filling trajectory model, which incorporates a complete chemical integration along the ensemble of isentropic trajectories. The period of interests has been the mid-winter 1996, when strong ozone depletion was observed over the northern hemisphere high latitudes.

Presentation of results

These results have been presented at several conferences.

1.2.2 Progress during Phase II

Activity 2.1: Ozone chemistry in spring and summer

Model calculation of spring/summer 2000

The objective has been the further development of the new Lagrangian chemical/dynamical model, and its application to ozone chemistry in the summer polar stratosphere, an area with has received scant attention. Ozone loss processes have been diagnosed in several summer periods with the new model. This has involved strong collaboration with the U of Oslo (Task 1), where CTM simulation are needed to ensure proper initialisation. More focus has been devoted to Activity 2.2 in year 3 of the project (see below). Latest, state-of-the-art CTM simulations have proved to be needed to adequately initialise the Lagrangian model. Case studies for June-July 2000 are being pursued.

Study of vortex break-down and debris.

This activity is scheduled for year 4 of the project.

Presentation of results

These results have been presented at several conferences, including the ESA conference “15th European Rocket and Balloon Programmes and Related Research”.

Activities 2.2: Ozone minihole events

Interannual variability of miniholes during THESEO

The objective was to study some ozone minihole events over Europe in recent winter and spring periods with a particular emphasis on recent years, and to investigate the nature of interannual variability of ozone minihole occurrences. The North Atlantic Oscillation has been found to play a key role in governing this interannual variability.

Presentation of results

This task was mostly scheduled for the 4th year of the project, but has been completed in year 3. The topic of low-ozone episodes has raised considerable interest, with several articles appearing in the literature (i.e. Geophysical Research Letters) in recent months. This motivated us to complete our study and speed up publication in year 3. Our resulting publication in Geophysical Research Letters has been commented on in the journal Nature.

1.2.3 Plans for 2002

In year 4 of the project, we will continue our investigations of transport and chemistry of ozone in the spring and summer 2000. The study will be based on lagrangian trajectory calculations and the new summertime lidar ozone observations from ALOMAR. Ozone profiles and column variability at ALOMAR will be reconstructed for the June-July 2000 period. Ozone transport and loss processes will be diagnosed in the model. There will be a focus on the origin of low-ozone episodes and the fate of polar vortex debris in the spring to summer transition.

1.3 Task 3: Ozonesonde observations

Responsible scientist: Geir Braathen

Co-workers: Bojan Bojkov (until May 2001)
Thor Ofstad
Britt Ann K. Høiskar
(from May 2001)

1.3.1 Progress during Phase I

Activity 3.1: Climatological measurements

Regular ozonesonde launches from Kjeller and Ørland

The ozonesonde activity at Ørland was started in November 1994 as part of the Second European Stratospheric Arctic and Mid-latitude Experiment (SESAME). The activity at this station has continued since then, with bi-weekly soundings during the summer and autumn and more frequent soundings during the winter and spring periods. A summary of observations is given under Activity 3.2 below.

Presentation of results

Results from this activity have been presented at COZUV project meetings and they have been reported to the State Pollution Control Authority of Norway (Høiskar et al., 2000 and Høiskar et al., 2001; see section 3 for references). The data are also used in the studies reported in section 2 under Tasks 3 and 6.

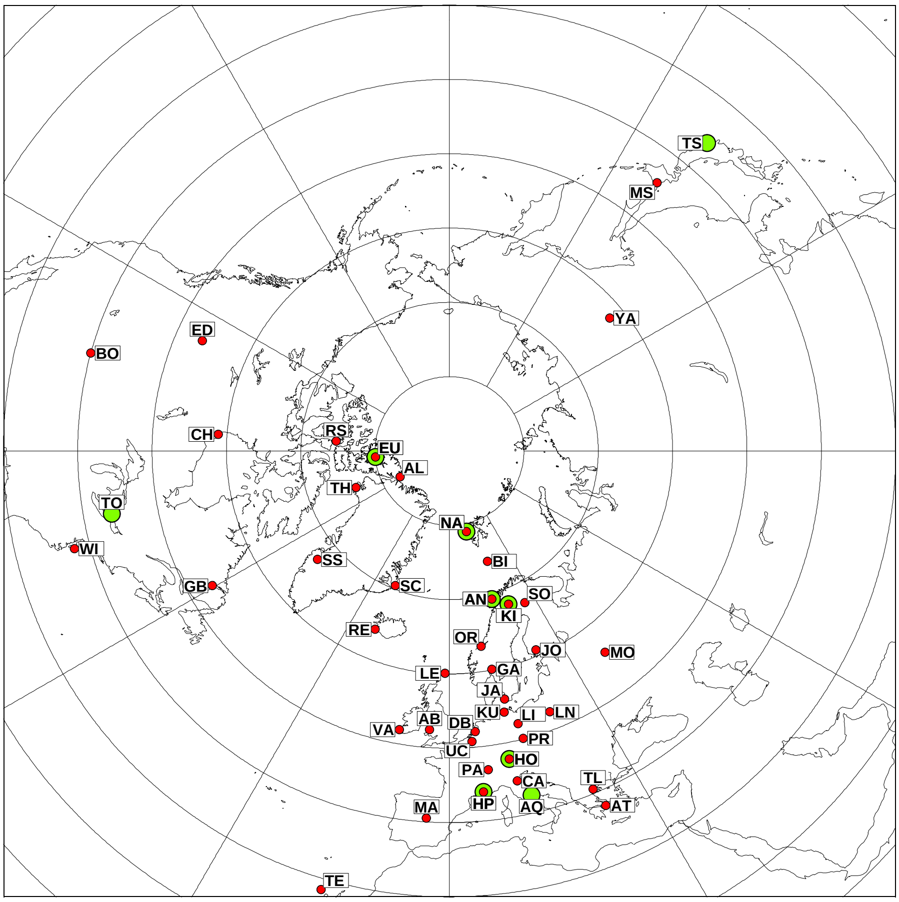
Activity 3.2: Participation in international ozonesonde programmes

2-3 weekly launches during Match campaigns and special meteorological conditions

Sonde launches have been carried out at Ørland and Andøya in coordination with launches at other stations in the international ozonesonde network. A map of this network is shown in Figure 1.3.1.1.

Activities in support of the EC-DGXII project THESEO-O_3Loss' MATCH winter campaign 1998/99 included additional soundings from Andøya in Northern-Norway and Ørland. In the period from December through March, launches at both stations were coordinated through NILU. Special attention was given to coincide Ørland's climatological measurements with MATCH measurements. During the winter 1999-2000 NILU took part in the Match campaign of the THESEO 2000 campaign. During 1999, 47 ozonesondes were launched from Ørland and 11 from Andøya. During 2000 (from 1.1 - 15.9), 47 sondes were launched from Ørland and 6 from Andøya.

Figure 1.3.1.1. *This map shows the complete network of stations participating in the European ozonesonde/lidar activities. The red dots indicate ozonesonde stations, and the green dots are lidar stations. Some stations have both sonde and a lidar facilities.*



A considerable effort was also given to the development of more efficient routines for the preparation and post-flight evaluation of the ozone profiles. The attention focused primarily on improving the quality of the ground procedures and also on the quality assurance and quality control (QA/QC) algorithms used in the derivation of the vertical ozone. Some laboratory experiments were performed in conjunction with quality aspects of the measurement so as to better quantify the instrument's limitations.

A summary of ozonesonde observations during phase I of COZUV is given in the table below.

Table 1.3.1.1.Number of ozonesonde launches from the Norwegian network in 1999 and 2000

Station/ Month	9812	9901	9902	9903	9904	9905	9906	9907	9908	9909	9910	9911	9912	0001	0002	0003	0004	0005	0006	0007	0008	0009	0010	0011	0012
Gardermoen														2	4	3									
Ørland	8	5	8	6	4	3	2	2	2	3	3	4	5	9	8	5	4	5	4	4	5	3	4	5	3
Andøya		3	4	4										5	1										

Presentation of results

The data are used in the studies reported in section 2 under Tasks 3 and 6.

Deviations from work plan

Sondes have never been launched from NILU's main office at Kjeller. This is due to the fact that the flight corridor to the Gardermoen airport passes over Kjeller. Instead some sondes have been launched from Gardermoen since the launching is easier from there.

1.3.2 Progress during Phase II

Activity 3.1: Climatological measurements

Regular ozonesonde launches from Kjeller and Ørland

Ozonesondes were launched from Ørland during the first four months of 2001, until the automatic launcher was put into operation in May (see below under "deviations from work plan"). An overview of ozonesonde flights is given under Activity 3.2 below.

Presentation of results

Results from this activity have been presented at the COZUV project meeting in November 2001. The data have been used in the studies described in section 2 under Tasks 3 and 6.

Activity 3.2: Participation in international ozonesonde programmes

2-3 weekly launches during Match campaigns and special meteorological conditions

NILU participated in the 2000-2001 Match campaign, which was organised by the Alfred Wegener Institute. The table below shows the number of launches from the Norwegian ozonesonde stations.

Table 1.3.2.1.Number of ozonesonde launches from the Norwegian network in 2001

	0101	0102	0103	0104	0105	0106	0107	0108	0109	0110	0111	0112
Gardermoen												
Ørland	5	4	3	4	1							2
Andøya								1				

Presentation of results

Data from the sonde launches at Ørland have been used in the studies described in section 2 under Tasks 3 and 6.

Deviations from work plan

The meteorological station at Ørland put an automatic radiosonde launching station into operation in May 2001. This made it difficult to launch ozonesondes with the equipment. The offer from DNMI was too costly for NILU. During the autumn of 2001 it was decided that the equipment that was purchased for launches from Kjeller be moved to Ørland. The first tests of this equipment was carried out on 3-4 December 2001, and two successful ozonesonde flights were carried out on these days. Normal operation will therefore resume in January 2002.

1.3.3 Plans for 2002

Activity 3.1: Climatological measurements

The regular bi-weekly launches will be restarted in January 2002.

Activity 3.2: Participation in international ozonesonde programmes

NILU will participate in the Match campaign which is planned for the winter of 2001-2002. This campaign is part of the EU project QUOBI, where NILU participates. During this campaign ozonesondes will be launched with a frequency of up to 2-3 soundings per week, depending on ozonesonde coincidences.

1.4 Task 4: DOAS measurements

Responsible scientist: **Bill Arlander**

Co-workers: **Britt Ann K. Høiskar**
Kjersti Karlsen Tørnkvist

1.4.1 Description of the experiments

The SAOZ instrument on the observation platform of the Norwegian Polar Institute research station in Ny-Ålesund, Spitsbergen. Photo: Ove Hermansen.

NILU has operated NILU has operated a SAOZ (Système D'Analyse par Observations Zénithales) instrument at Ny-Ålesund (78.9°N, 11.9°E) for the total column measurement of ozone and NO_2 since 1990. Due to the high latitude at Ny-Ålesund, the SAOZ measures from August until late October, and from February until late April. The SYMOCS (SYstem for Monitoring Compounds in the Stratosphere) instruments are standard DOAS (Differential Optical Absorption Spectroscopy) zenith-sky grating spectrometers built at NILU for measuring total column O_3 and NO_2 (SYMOCS-Vis) and differential slant column densities (DSCD) of BrO and OClO (SYMOCS-UV). Both the SAOZ and SYMOCS-Vis instruments participated in the NDSC (Network for Detection of Stratospheric Change) intercomparison campaign at Observatoire de Haute Provence in June 1996. The SYMOCS systems were installed at Andøya (69.3°N, 16.0°E) during the spring of 1998. SYMOCS spectra are analysed with the WinDOAS analysis package developed at IASB-BIRA, Belgium. The measurement periods at Andøya are from January until June, and from August until late November. The Andøya site is advantageous due to its proximity to the winter polar vortex, whereby the chemistry of the polar vortex edge could also be studied quite readily. This also enables improved latitudinal coverage that complements ongoing and planned European stratospheric ozone measurement programs. The construction of the SYMOCS-UV instrument in 1998 has yielded much improved spectral resolution in the UV region (for BrO and OClO) leading to a better characterisation of spectral features and a significant improvement in the retrieval of these compounds. The SYMOCS instruments complement the NILU-UV and the UV-Vis scanning spectrometer, both of which yield total ozone at solar zenith angles <80°, as well as the ozone LIDAR system operated by FFI, NILU and ARR. Instruments at this site co-operate in satellite validation studies currently in progress, or being planned. During this period, additional funding was obtained through the EU projects GODIVA (GOME Data Interpretation, Validation and Application), THESEO-Stratospheric-BrO, COSE (Compilation of atmospheric Observations in support of Satellite measurements over Europe) and QUILT (Quantification and Interpretation of Long-Term UV-Visible Observations of the Stratosphere).

1.4.2 Progress during Phase I

SAOZ Measurements in Ny-Ålesund

1999

SAOZ measurements of total column ozone and NO_2 were made during the standard measurement periods of February to the end of April and from August to the end of October.

2000

SAOZ measurements of total column ozone and NO_2 were started in March and continued to the end of April, and started again in August to the end of October.

SYMOCS-1(Vis) and SYMOCS-2(UV) Measurements at Andøya

1999

SYMOCS-Vis

Total column ozone and NO_2 were measured in the March to summer period. Detector problems prevented fall measurements. The detector was sent to the USA for repair.

SYMOCS-UV

Measurements of BrO and OClO were made during the standard period of January to the end of November with the exception of the maximum solar altitude period during the summer.

2000

SYMOCS-Vis

After receiving the detector system from repair, total column ozone and NO2 were measured in the March to summer period. Further detector problems prevented fall measurements.

SYMOCS-UV

Measurements of BrO and OClO were made during the standard period of January to the summer. Detector problems prevented fall measurements. The detector was sent to the USA for repair.

1.4.3 Progress during Phase II

SAOZ Measurements from Ny-Ålesund

SAOZ measurements of total column ozone and NO_2 were made during the standard measurement periods of February to April and from August to October.

SYMOCS-Vis and SYMOCS-UV Measurements at Andøya

SYMOCS-Vis measurements of total column ozone and NO_2 were performed for the entire year except for the summer period when the solar elevation is at a maximum. SYMOCS-UV measurements of slant column BrO and OClO commenced in early September after the detector had been returned from extensive repair in the USA.

Improved air mass factors for ozone and NO_2

Substantial work has been done for calculation of NO_2 air mass factors. Further work will include the calculation of NO_2 air mass factors at different latitudes, and will include ozone. The calculation of improved air mass factors for ozone and NO_2 will continue through 2002.

Airmass factors for OClO and BrO

This activity is, according to the project plan, scheduled for the first half of 2002.

Analysis of IO

This activity is, according to the project plan, scheduled for the latter half of 2002.

Deviations from project plan

1. The UV detector at Andøya was repaired during 2001, and put into operation again in August 2001. These detector problems have hindered measurement during some periods, therefore several gaps in the data record exist.
2. For the determination of NO_2 AMFs, calculated NO_2 profiles will, in addition to profiles from the Oslo CTM, also be acquired from the University of Leeds 3-D CTM, SLIMCAT. The calculation of improved air mass factors for ozone and NO_2 will continue throughout the project period.

1.4.4 Plans for 2002

All main Task 4 activities will be continued during the second years of phase II. In review, this is comprised of the following issues:

SAOZ Measurements in Ny-Ålesund

Measurements will commence in February and will be continued according to the standard procedure. Further spectral analysis will be performed, including reanalysis of total column ozone from Ny-Ålesund using the WinDOAS analysis package.

SYMOCS-Vis and SYMOCS-UV Measurements at Andøya

SYMOCS-UV/VIS measurements at Andøya will commence in January and will be continued according to the standard procedure. Further spectral analysis will be performed for total column ozone and NO_2 and slant column BrO and OClO.

Improved Air Mass Factors for NO_2 and ozone

Work will be continued on the improvement of NO_2 and ozone AMFs. This work will be based on calculated profiles from the University of Leeds 3-D CTM, Slimcat.

Air Mass Factors for OClO and BrO

The calculation of AMFs for OClO and BrO will based on vertical profiles of these compounds calculated from the Oslo CTM and from University of Leeds 3D-CTM, SLIMCAT. These AMFs will be used for the conversion of slant to vertical columns as measured by the SYMOCS-UV instrument.

Analysis of IO

During 2002, attempts will be made to retrieve slant column IO in the visible from the SYMOCS-Vis instrument.

The latter two activities will coincide with work planned in the EU funded QUILT project.

1.5 Task 5: Ozone lidar measurements

Responsible scientist: **Ulf-Peter Hoppe**

Co-worker: **Georg H. Hansen**

1.5.1 Progress during Phase I

The ALOMAR observatory at Andøya. Photo: Andøya Rocket Range.

Year-round measurements and analysis, special emphasis on winter/spring

According to the COZUV plan, an important contribution of the ALOMAR Ozone Lidar to the project is a number of stratospheric ozone profiles to be measured whenever conditions permit throughout the year. Such profiles are important input information - in some cases verification information - for contributions made by other COZUV partners, especially in the modelling field.

Since the laser refurbishment and re-installation at ALOMAR in June 1999, measurements were taken whenever the weather and personnel situation permitted. The data were analysed at NILU Tromsø and made available to the COZUV partners.

Table 1.5.1.1. Lidar Measurements 6/1999 - 12/2000

Month	Days
June 1999	28, 30
July 1999	1, 4, 5/6, 14
August 1999	--
September 1999	7, 8, 12, 14, 17, 24
October 1999	19
November 1999	16, 17, 30
December 1999	1, 6, 7, 8, 9, 10, 13, 14, 17, 21
January 2000	10, 21/22, 26, 27, 28, 29
February 2000	(6), 14, 15, 17, 21, 22
March 2000	2, 3
April 2000	4, 11, 12, 13, 14
May 2000	--
June 2000	21, 22, 28
July 2000	2, 7, 11, 13, 14, 15, 17, 18, 19, 21, 24, 25, 27, 31
August 2000	1, 2, 15
September 2000	6, 7, 13, 14, 21, 22, 23, 27
October 2000	2, 4, 5, 10, 11, 24
November 2000	19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30
December 2000	10, 11, 12, 13, 20

Presentation of results

The analysed data and their scientific interpretation were presented to the COZUV partners at the COZUV meetings. In addition, the results were presented at international conferences, see section 3 on Dissemination and Publications.

Deviations from project plan

Table 1.5.1.1 documents that we have observed with the ALOMAR Ozone Lidar whenever conditions permitted. Months with few or no measurements are due to persistent cloudy weather. This is known and expected. Therefore, there have been no deviations from the project plan.

1.5.2 Progress during Phase II

Year-round measurements and analysis, special emphasis on winter/spring

Lidar measurements continued as during phase I, year-round. The standard night time system was run until April, and again from the end of August. Measurements are listed in Table 1.5.2.1; they show a large variability from month to month in measurement frequency, which almost completely mirrors the very variable observation conditions due to weather.

Table 1.5.2.1.Lidar Measurements 1/2001 - 11/2001

Month	Days
January 2001	2, 3, 5, 9, 21, 23, 24, 25, 26, 30, 31
February 2001	1, 2, 3, 6, 11, 12, 22, 23, 24, 25, 27, 28
March 2001	1, 2, 7, 13, 14, 15, 16, 17, 22, 25, 27, 30
April 2001	25
May 2001	29
June 2001	19, 20, 21, 22
July 2001	23, 24, 25
August 2001	6, 9, 10, 17, 20/21
September 2001	10/11, 11, 12, 17, 22, 30
October 2001	3, 4, 5, 9, 10, 12, 19, 30
November 2001	12

As in phase I, the contribution of the ALOMAR Ozone Lidar to COZUV II is a number of stratospheric ozone profiles to be measured whenever conditions permit throughout the year. However, in phase II we promised to put even more emphasis on winter and spring. Table 1.5.1.2 documents that we have observed with the ALOMAR Ozone Lidar whenever conditions permitted.

Daylight Ozone DIAL measurements

Work on reaching full daylight capability has continued throughout the project time. At present, an ozone profile of similar quality can be measured with 1 hour of lidar data in darkness or with 4 hours of

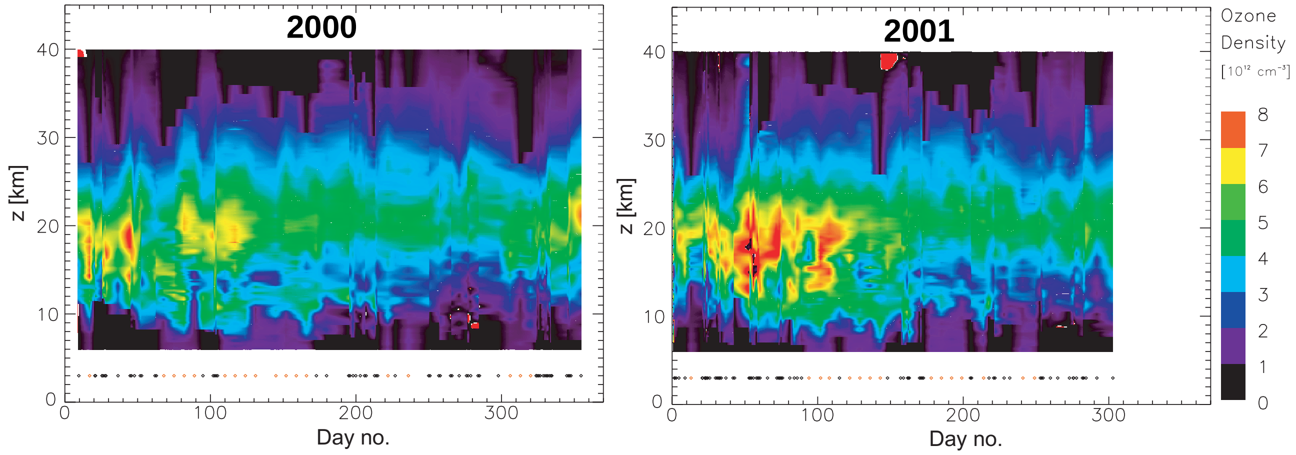


Figure 1.5.2.1. *The ozone distribution over ALOMAR as a function of altitude and day of the year. Data from 2000 are shown on the left and data from 2001 on the right. The black diamonds at the bottom of the plots show days with lidar measurements. The red diamonds represent days where data from ozonesondes launched in Sodankylä have been used because of lacking measurements at ALOMAR. Linear interpolation has been used between the data points.*

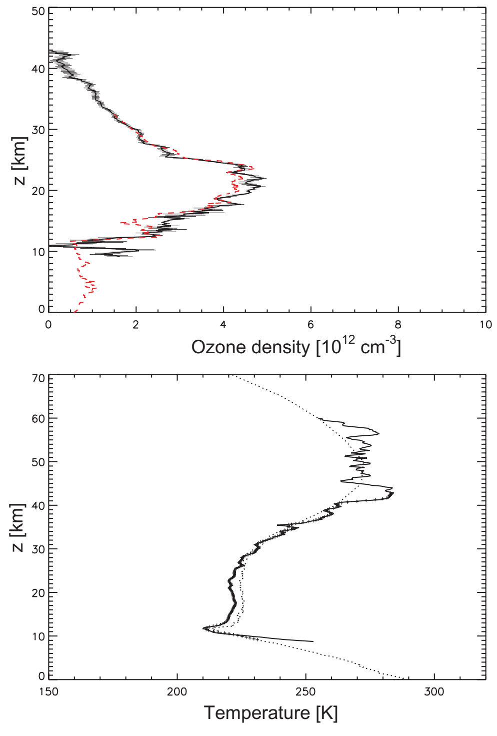


Figure 1.5.2.2. *Comparison of ozone density (upper panel) and temperature (lower panel) as measured with the ALOMAR ozone lidar and with an ozonesonde on the evening of August 20, 2001. Upper panel: solid line with error bars: ozone lidar; red dashed line: ozonesonde. Lower panel: solid line: ozone lidar; dotted line: ozonesonde (up to 33 km), CIRA 86 above 33 km. There was very little wind, so that the ozonesonde did not drift more than 20 km from ALOMAR at any height.*

lidar data in daylight. While this is much better than most other ozone lidars in the world, and the data is useful for scientific studies, we are working on improving the receiver alignment, so that more signal and less sky background is received.

Presentation of results

The analysed data and their scientific interpretation were presented to the COZUV partners at the COZUV meetings. In addition, the results were presented at international conferences, see section 3 (Dissemination and Publications).

The ozone layer in 1999/2000 and 2000/2001

The plots below show the distribution of ozone as a function of altitude and time of the year. These plots are made by combining all the ozone profiles measured during a year.

Comparison to ozonesonde data

Comparison of lidar profiles with ozonesonde measurements is a standard method to quality-control lidar data. This has been done a number of times at ALOMAR, both with sondes released from Andøya and from Sodankylä, Finland. The most recent local comparison was made on August 20, 2001. The result is depicted in Figure 1.5.2.2 with ozone in the upper and temperature in the lower panel. The sonde reached an altitude of about 33 km. With respect to ozone, the agreement is satisfactory throughout most of the altitude range above the tropopause, which on this day was at about 11.5 km. There are, however, also altitude ranges, e.g. 14 - 15.5 km, where systematic deviations occur. The temperature profiles show the same structure, especially with respect to the tropopause altitude, but lidar temperatures which are systematically 3-4 K lower than the sonde values below 26 km altitude. This is most probably

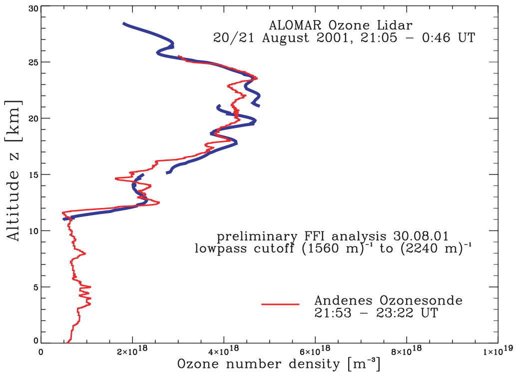


Figure 1.5.2.3. *Same data as in Figure 1.5.2.2 (upper panel), but using a different analysis algorithm. See text for details.*

due to a slight misalignment of the laser beam (which, however, has no impact on ozone density!).

Work on the analysis algorithms

The standard analysis of the DIAL data at NILU Tromsø is quality-checked by the NDSC methods and therefore of high quality. At FFI work has been done and is ongoing to improve the analysis algorithms. The improvements involve statistical methods for background subtraction and for the detection of interference, conscientious smoothing of the raw data (as much as necessary, as little as possible) using digital filtering, and an integral DIAL algorithm as opposed to a differential algorithm (Stelmaszczyk et al., 2000). The present status of this analysis is demonstrated in Figure 1.5.2.3. The three blue lines show the lidar's result from three sets of interleaved data files. We collect data from the highest altitudes without attenuation, from the intermediate altitudes with 10x attenuation, and from the lowest altitudes with 100x attenuation.

Attenuation is switched every 5 minutes. For this plot, no attempt was made to connect the three altitude ranges, e.g., by a weighted average. The apparent discontinuities therefore show the sum of the observation's uncertainty and the geophysical fluctuations. The red line shows the data from the ozonesonde for comparison.

References

Stelmaszczyk, K., A. Czyzewski, A. Szymanski, A. Pietruczuk, S. Chudzynski, K. Ernst, T. Stacewicz, New method of elaboration of the lidar signal, Appl. Phys. B 70, 295-299, 2000.

Deviations from project plan

Months with few measurements are due to persistent cloudy weather. This is known and expected. Therefore, there have been no deviations from the project plan. In Table 1.5.2.1 and in Figure 1.5.2.1, it can be seen that there are more measurements in the months January, February and March than in the other months, showing our emphasis on winter and spring. There are no deviations from the project plan.

1.5.3 Plans for 2002

Observation series of this kind are most useful if they are continued with similar quality for a long time. We intend to continue to measure ozone profiles with the ALOMAR Ozone Lidar, improving the daylight measuring capabilities, and making the data analysis more automatic and faster. This lends itself to the education of masters students, as they can improve the instrument in stages, contribute to measurement campaigns, and publish parts of the data.

1.6 Task 6: Analysis of ozone change

Responsible scientist: Frode Stordal

Co-workers: Georg Hansen (act. 6.1)
Geir Braathen (act. 6.2)

1.6.1 Progress during Phase I

Activity 6.1: Hemispheric data

The purpose of Activity 6.1 “Hemispheric data” is to provide additional data in addition to that gathered in the frame of COZUV in order to analyse ozone changes on a broad scale. In practice, the following support tasks were addressed during COZUV-1:

- Providing data files of ozone density at four altitude levels (16, 18, 21, 25 km) as well as total ozone on a hemispheric scale for the time period 13 - 23 February, 1996, from all sources available, in order to quantify ozone depletion in this period
- Providing hemispheric total ozone maps from every 1^{st} and 16^{th} of the month for the period January 1 to March 31, 1996, in order to validate the Oslo climatological model and accumulated ozone loss during the winter 1995/96.

The winter of 1996 was chosen, because ozone depletion was very large in this year, thus being a good test for coupled dynamical-chemical models in terms of stratospheric chemistry. The problem related to this winter was that there was no TOMS instrument operational and the GOME instrument still suffered from start-up problems. Concretely, the GOME data showed large deviations in total ozone from quality-checked measurements at solar zenith angles of more than 75º (which are found at high latitudes in the first three months of the year!). However, the deviation could be determined within 3% by comparison with ground-based data, and the GOME data were corrected accordingly (Hansen et al., 1999).

Another problem in the winter 1996 data was the frequent presence of strong polar stratospheric clouds (PSC), which affected space-borne measurements of ozone profiles, especially in January 1996.

The following data were gathered and provided as input to Task 1 and 6:

- GOME total ozone maps (corrected at large solar zenith angles) from January 1, 16, February 1, 13, 16, 23, March 1 and 16;
- TOVS total ozone maps for the same days
- POAM-II ozone density values at 16, 18, 21 and 25 km altitude for day 1 and 16 of January, February and March as well as the Period 13-23 February, 1996

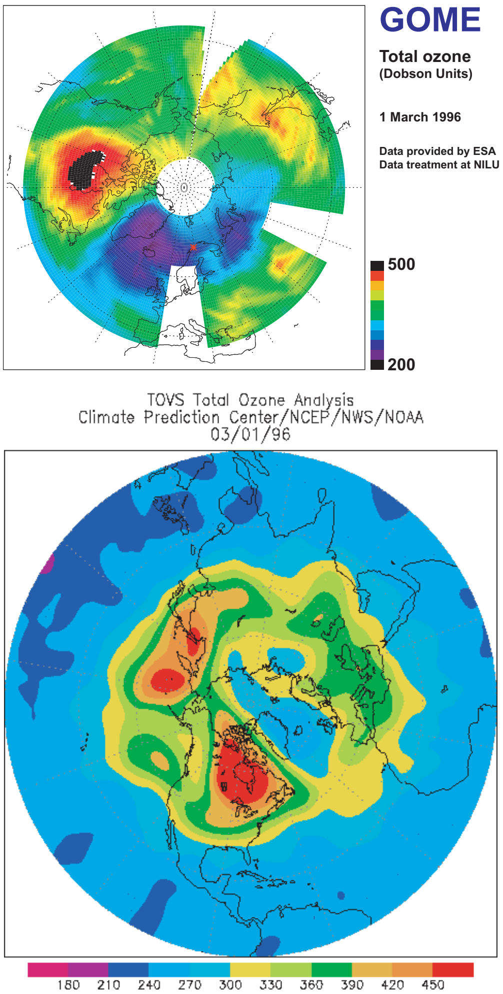


Figure 1.6.1.1. *Satellite maps of ozone on 1 March 1996. The upper panel shows ozone as measured by the Global Ozone Monitoring Experiment (GOME) on board the ERS-2 satellite. The lower panel shows ozone data from the Tiros Operational Vertical Sounder (TOVS).*

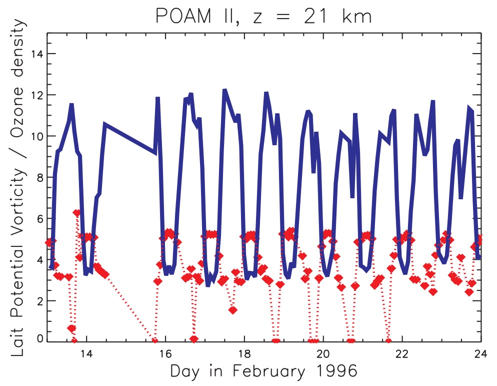


Figure 1.6.1.2. *POAM ozone densities (red dotted line) and Lait's potential vorticity (blue curve) at 21 km altitude. Data are given for the 13-23 February, 1996 time period.*

- SAGE II ozone density values at the same altitudes and on the same days as for POAM II.

Figure 1.6.1.1 shows a total ozone map from GOME (upper panel) on March 1, 1996. It reveals a large area of significantly reduced ozone over the North Atlantic and Northern Eurasia, and very high ozone values over North America. Figure 1.6.1.2 shows POAM II ozone densities (dotted line/diamonds) and Lait's potential vorticity (solid line) at 21 km altitude in the period February 13-23, 1996. The latitude of the single measurement points is about 67º through-out the period, while all longitudes are covered periodically (one orbit per day). The non-symmetric location of the polar strat-ospheric vortex then leads to the quasi-periodic variation of the potential vorticity and the anti-correlated variation of ozone density values. Points with significantly reduced (compared to other meas-urements with the same PV) or zero ozone values are affected by PSCs and must not be used.

Activity 6.2: Temporal development of the ozone mixing ratio on isentropic surfaces

Analysis of sonde data from the winter 99-00

Ozonesonde data from Norwegian and other stations in the network have been used to calculate the development of the ozone mixing ratio at the 475 K isentropic level (approx. 19 km) for the winter of 1999-2000. The effect of diabatic descent, which masks part of the chemical loss, has been taken into consideration.

Presentation of results

The results of this analysis have been presented at COZUV project meetings and at various conferences as detailed in Section 3.

Activity 6.3: Comparison between modelled and observed ozone loss

Results from two models in COZUV were used in this task; from the Oslo CTM2 (Activity 1.1) and the domain-filling trajectory model (Activity 2.2). Concentrations of activated chlorine and ozone depletion as calculated in the two models was compared with results derived from observations, namely satellite and ozone sonde data. The focus was changed from the years 1999 and 2000 to the year 1996. Otherwise, the milestones were reached.

We focused on the winter of 1996, for which the two models had been run at that stage in the COZUV project. In general, models have tended to underestimate the chlorine activation and the ozone depletion. This was the case also in the two models used here. A first attempt was also made to compare the ozone loss calculated in the two models with the ozone loss derived in Activity 6.2 based on ozone soundings.

Deviations from project plan

For Activity 6.1 the focus was changed from the years 1999 and

2000 to the year 1996. Otherwise, the milestones were reached.

The milestones of Activity 6.2 have been reached.

The milestones of Activity 6.3 have been reached.

1.6.2 Progress during Phase II

Activity 6.1: Hemispheric data

In COZUV-2, it was intended to both continue the provision of satellite and other data on a hemispheric scale to verify the modelling work at the University of Oslo for the years already studied in COZUV-1, and to provide new data sets for the winters of 2000-01 and 2001-02. It was assumed that for these winters the following satellite instruments would be available:

- Earth Probe TOMS
- GOME
- ENVISAT (from autumn 2001)
- POAM-III
- SAGE-III.

In addition, ground-based data from the NDSC data base and from the World Ozone Data Centre were to be included in the studies. However, since the start of COZUV-2, several important factors related to satellite data support occurred:

- Since autumn 2000, the Earth Probe TOMS instrument has suffered rapidly increasing degradation problems which have a significant influence on the data quality. The follow-up TOMS instrument was lost due to a failure during the satellite launch in autumn 2001.
- The launch of SAGE-III scheduled for spring 2000, took place in December 2001.
- The launch of ENVISAT has been postponed several times and is now scheduled for February 2002; data will not be available before summer 2002.

These circumstances severely limit the amount of satellite data with satisfactory data quality available for the recent two winters. The most important single data source is the GOME instrument. Severe efforts have been made, e.g. in the frame of the EU project GOA, to extend and improve the amount of data considerably, both total ozone, ozone vertical distribution and NO_2 total column. NILU participates in the GOA project, mainly in the validation of ozone profiles.

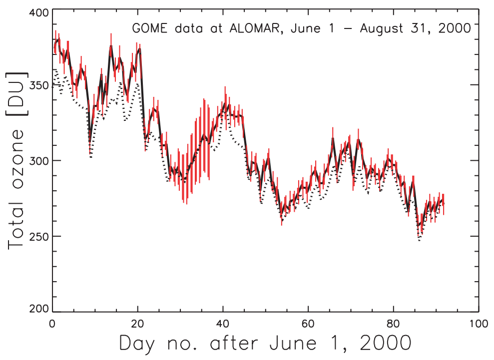


Figure 1.6.2.1. *Time series of GOME total ozone above the ALOMAR observatory. During periods of missing satellite data model data are introduced.*

GOME total ozone data are available for COZUV in several versions:

- In the official GDP 2.7 version since June 1996 on CD-ROM

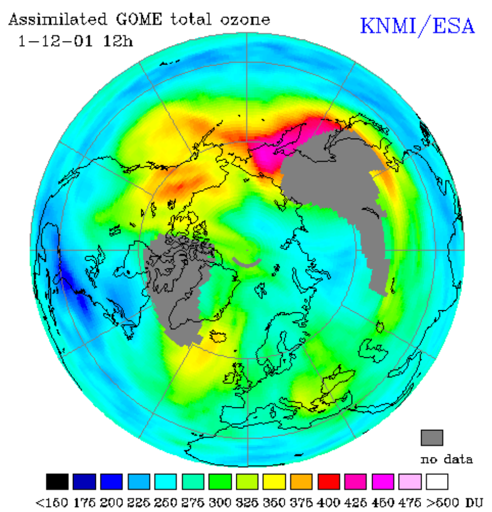


Figure 1.6.2.2. *Total ozone map for 1.12.2001 made by the KNMI (Royal Dutch Meteorological Institute). The map is based on ozone data from GOME aboard ERS-2 and wind data from the ECMWF.*

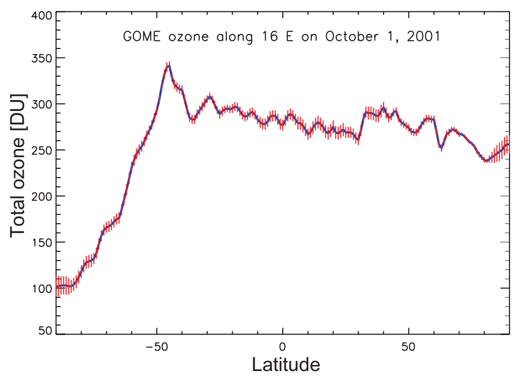


Figure 1.6.2.3. *Meridional cross section of total ozone along 16°E on 1 October 2001. The data are from the GOME instrument aboard ERS-2.*

- In the KNMI fast delivery version since January 1998 (on Internet, http://www.knmi.nl/gome_fd/)
- As assimilated daily ozone fields since November 1999 at KNMI (above web address)

Figure 1.6.2.2 shows an example of assimilated GOME total ozone from KNMI from December 1, 2001. Applying an assimilation model using meteorological analysis data helps to fill areas where direct measurements are not possible any more due to missing illumination conditions. Besides daily ASCII data files on a hemispheric (or global) scale, the KNMI server also provides data sequences from any geographical location over a chosen period of time (time resolution: 6 hours) or along a chosen longitude on selected days. Figure 1.6.2.1 shows total ozone above ALOMAR for the period June 1 to August 31, 2000. It reveals a satellite data series with the best time resolution available today, but also the weakness of the series, namely a daily cycle in the ozone data, which is caused by the solar zenith angle dependence of the GOME data. Values at 00 and 06 UT are typically 20 DU lower than noon/afternoon values. The period from day 31 to day 36 does not show this oscillation, but larger uncertainties. In fact, these data are purely model-based; no GOME data are available there. Figure 1.6.2.3 shows a cross section of total ozone from the equator to the north pole at 16° E on October 1, 2001. Both data sets, once validated properly, will be of great value in the model development at the University of Oslo.

A validation of the official GOME product (GDP 2.7) and the KNMI-based products, performed by IASB (Belgium) and NILU, showed that there is little difference in the deviations between the above products and ground-based measurements, i.e., both GOME data sets suffer from the problems described above. However, in the near future, a new version of the GOME total ozone algorithm will be released which hopefully will remove much of the problems at large solar zenith angles.

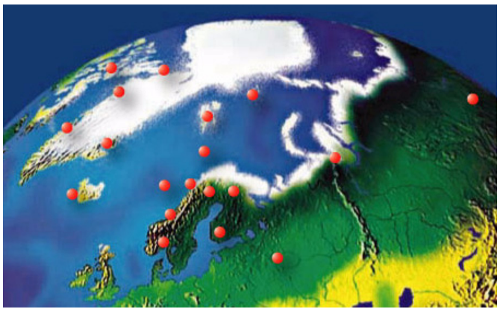
GOME-based ozone profiles on a global scale have been derived and are available via Internet (http://www.knmi.nl/gome_fd/prof/profile.html) since October 2000. The validation of these data only has started, so that they have to be regarded as preliminary so far.

Ground-based ozone profile data were acquired from the database of the Network for the Detection of Stratospheric Change (NDSC) and from the ozonesonde database at NILU. The former contain ozone lidar data from six stations on the northern hemisphere between 20 and 80° N. However, the coverage of the years 2000 and 2001 is still quite poor, mainly because of the rule in NDSC that data have to be submitted only within one year after measurement. The ozonesonde database at NADIR is very comprehensive, covering the complete 1990s as well as 2000 and 2001, but with a strong focus on Europe and the Euro-Atlantic Arctic.

Activity 6.2: Temporal development of the ozone mixing ratio on isentropic surfaces

Calculation of ozone loss for the winters 00-01 and 01-02 at 400, 450, 475, 500 and 550K

The ozone loss inside the north polar vortex at the isentropic level of 475K during the winter of 2000-2001 has been calculated as shown in section 2.6.2. The loss during winter 2001-2002 will of course have to wait until that winter is over. Data from several stations in the Arctic have been used for this study. The map to the left shows the location of the stations whose data have been used.



Map of Arctic ozonesonde stations. These stations are located inside the polar vortex for shorter or longer periods each winter,

Calculation of ozone loss for the winters 88-89 to 99-00 at 400, 450, 500 and 550K

The ozone loss at 475K has already been calculated for all these years. The ozone loss at 400, 450, 500 and 550K will, as outlined in the work plan, be calculated during the second year of COZUV-2.

Presentation of results

The ozone loss calculation for the 2000-2001 winter has been presented at the COZUV project meeting in Nov. 2001 and at three conferences (EGS, March 2001; NDSC Symposium, Sept. 2001; Climate Conference of the Research Council of Norway, Nov. 2001).

Activity 6.3: Comparison between modelled and observed ozone loss

A main goal of this activity is to quantify ozone loss due to chemical ozone depletion. A basic idea is that the models, which are developed as a part of COZUV can be used for this purpose. Some preliminary analyses have been made and are presented in Section 2.6.

Deviations from project plan

Problems encountered with the acquisition of various data sets are described above for Activity 6.1. Data from the remaining sources have been provided according to requests from modelling groups; i.e., there were no other deviations from the work plan.

In activity 6.2 the calculation of ozone loss at other levels than 475K has been delayed to 2002. These calculation will be done together with the analysis of the 2001-2002 winter.

In Activity 6.3 the work largely follows the planned schedule. It is important to notice that the work rests upon comparison between modelled and observed ozone. As model results on ozone changes over individual winters as well as over the last decades have just become available, only preliminary results have been obtained by now.

1.6.3 Plans for 2002

Activity 6.1: Hemispheric data

Besides the validation/quality assessment work described in 1.6.1 and 1.6.2, some of the tasks started in the previous years will be followed up. POAM-II data on polar stratospheric clouds from winter 1995/96 are currently worked up in order to assess to what degree CTM-2 produces PSCs in agreement with observations. Similar investigations will be performed with POAM-III data for winter 1999/2000.

Activity 6.2: Temporal development of the ozone mixing ratio on isentropic surfaces

Ozone loss at more levels will be calculated. Focus has been on the 475 K isentropic level, which usually is the level that displays the largest ozone loss in the Arctic vortex. During 2002 ozone loss for the years 1988-89 until 2001-2002 will be calculated at these levels: 400, 450, 500 and 550 K.

Activity 6.3: Comparison between modelled and observed ozone loss

In the final year of Phase II an assessment of ozone loss during the three winters 1997, 2000 and 2001 will be made. Results from Oslo CTM-2 will be compared to sonde data (Task 6.2), in particular with available MATCH data. For the year 2000 we will also focus on chemical ozone changes during spring and summer. Long term ozone changes calculated from Oslo SCTM-1 will be compared to observations by ozone sondes and satellite data, at least the SAGE data.

1.7 Task 7: Ground-based UV measurements

Responsible scientist: Berit Kjeldstad

Co-workers: **Phase I** Trond Morten Thorseth task 7.1-7.4.

Phase II Trond Morten Thorseth task 7.1-7.3

Arne Dahlback task 7.4

1.7.1 Organisation of task into activities

Phase I

Phase I included following four activities:

Table 1.7.1.1.Activities in Task 7 during Phase I

Activity #	Title	Major objective
7.1	New experimental developments	To establish a method to measure calibrated direct and global UV irradiance.
7.2	Development of radiance measurements	To measure polarised UV radiance under clear sky conditions. Comparison with available models.
7.3	Data quality control with emphasis on cosine correction procedures	To establish methods valid during all weather conditions, for correction of UV irradiance measurements performed by instrument with different instrument characterisation.
7.4	Effects of broken clouds on UV measurements	To retrieve instantaneous solar UV spectra under broken cloud conditions.

Phase II

In Phase II there are three tasks from phase I and one new task, 7.4.

Table 1.7.1.2.Activities in Task 7 during Phase II

Activity #	Title	Major objective
7.1	Direct and global UV measurements in Trondheim as part of a European network.	Measurements of global and direct UV in Trondheim as a part of a European network (EC funded project EDUCE).
7.2	UV radiance distribution in a sub-Arctic region	UV radiance distribution in a sub-Arctic region, seasonal variations.
7.3	Impact of broken clouds on ground based UV irradiance; measurements, analyses and validation	Impact of broken clouds on ground-based UV irradiance, measurements, analyses and validation
7.4	UV radiation on a vertical surface	Measurement and modelling of radiation on vertical surfaces

How tasks in phase I and phase II are related

Task 7.1 and 7.2 are the same in both phases. Task 7.3 and 7.4 from phase I were merged to 7.3 in phase II. Thorseth and Kjeldstad have been involved in the project. The new task 7.4 in phase II is run by Dahlback. An overview of tasks in both Phase I and II is shown in the table below.

Table 1.7.1.3. Structure of task 7, phase I and phase II

Phase #	Instrument development	Radiance distribution	Cosine correction	Effects of broken cloud	Vertical surfaces
Phase I	7.1	7.2	7.3	7.4	
Phase II	7.1	7.2	7.3	7.3	7.4 (new)

1.7.2 Progress during Phase I

Activity 7.1: Development of appropriate measurement techniques.

Responsible scientists: Berit Kjeldstad, NTNU

Test and calibration

Completely new software for controlling the system for measuring global and direct irradiance has been developed. Tests during phase I revealed that the original software did not meet the scientific demands for both direct and global irradiance. New software had to be designed for the purpose. A calibration of the global irradiance unit has been performed. The instrument worked satisfactorily at the Nordic Intercalibration in 2000. Test calibrations of the direct irradiance system has been made, but validation and intercomparison was moved to phase II. Humidity sensors have been installed.

Deviations from project plan

Instrument development has been delayed, especially during 1999, due to late delivery from the manufacturer and reduced manpower. Tests and calibration were postponed to 2000. The final intercomparison of both direct and global irradiance input optics with a similar instrument which has to be proposed for phase 2. This is planned for 2002.

Monitoring

Regular monitoring has been performed with the old spectroradiometer Optronic 752 for the entire period. The new instrument has only been used on a campaign basis. No regular monitoring was performed in phase I.

Deviation from project plan

Only campaign monitoring has been performed with the new spectroradiometer in phase I. But, spectral global irradiance data is available from Trondheim due to monitoring with the old instrument.

Deviation from project plan

The goals for the task have been achieved.

Activity 7.2: Development of radiance measurements

Responsible scientist: Trond Morten Thorseth, NTNU

Construction

The first version of the tracker system needed to perform both direct and radiance UV measurements was built in phase I. After that, modifications had to be done and we are currently measuring with a later version. Development of software for controlling the tracker is still on-going. The software for moving the tracker was almost finished in phase I, but was continued in phase 2.

Deviation from project plan

The milestone is reached.

Testing

The tracker was tested for radiance measurements. Basic functions work satisfactorily. There was still some need to improve the software for accurate positioning of the input optics according to the sun position.

Deviation from project plan

The milestone was nearly reached in phase 1. But due to the delayed instrument development described in task 7.1, the final version of the entire system was finished in the early part of phase II. The task was slightly behind schedule. Installation of polarisers in the input optics to perform measurements of polarized radiance distributions which was originally planned could not be fulfilled

Campaign measurements

The first radiance measurements was performed in October 2000, after further improvements new radiance measurements was performed in phase 2.

Deviation from project plan

Was delayed and postponed to phase 2.

Data analysis

No data on radiance measurements in Trondheim have been available at the moment for analysis. A model is under preparation for comparison with spectral measured data.

Deviation from project plan:

Delayed according to schedule. Will be proposed to continue in phase 2.

Activity 7.3: Data quality control with emphasis on cosine correction procedures

Responsible scientists: Trond Morten Thorseth, NTNU

Data analysis

Data analysis was been performed on measurements performed during the intercomparison campaign in Sweden June 2000.

Deviation from project plan

The milestones have been reached.

Activity 7.4: Effects on broken clouds on UV measurements

Responsible scientists: Trond Morten Thorseth, NTNU

Method Development

A method to detect rapid changes in cloud conditions during a spectral scan was developed using high frequency logging moderate bandwidth filter-radiometer in addition to a spectroradiometer. Results are published.

Deviation from project plan

The milestones have been reached.

Data analysis

Further tests of the method was done at NOGIC 2000 intercomparison where data from a GUV was sampled at a sampling rate of 2Hz synchronised with spectral measurement from 14 instruments during all weather conditions. Results are now under preparation.

Deviation from project plan

The milestones have been reached.

1.7.3 Progress during Phase II

Activity 7.1: Direct and global UV measurements in Trondheim as part of a European network.

Responsible scientists: Berit Kjeldstad NTNU

Improvement of input optic system for simultaneous direct and global.

Improvements has been performed and test measurements show that the existing solution is satisfactory.

Deviation from project plan

The milestones have been reached.

Measurements, quality control and submission of global irradiance data.

Submission of spectral UV data (performed with the old instrument as explained in phase I) to the European UV database is under preparation and will be performed in near future. Development of the database has also been delayed. Monitoring measurements of global solar irradiance with the new instrument have been delayed due to the software and hardware developments. The software has been under constant development to reach a level where automated measurements of both direct / radiance and global irradiance measurements can be performed.

Deviation from project plan

Submission of spectral data will be performed as scheduled.

Measurements, quality control of both direct and global UV.

Measurements on more regular basis than just testing are scheduled for spring 2002 as planned.

Deviation from project plan

There has been some delayed developments of both the software and hardware that has caused a delay in more regular measurements of global irradiance since the system has been located in the lab and has been under further developments. More regular measurements will be initiated in spring 2002.

Results from direct measurements, UV, aerosol and ozone.

Work on retrieval of aerosols from direct sun measurement was initiated before the scheduled plan of 2002. However, no algorithms have been developed yet. This task will proceed as planned.

Deviation from project plan

The milestones have been reached.

Presentation of results.

Deviation from project plan

Publication of the results has been delayed to spring 2002.

Activity 7.2: UV radiance distribution in a sub-Arctic region

Responsible scientists: Trond Morten Thorseth, NTNU

Improvement of tracker system for radiance measurements

Further improvements of the tracker system has been made. A new feedback system on directional control has been installed and test measurements have been made. Radiance distribution measurements shown later in this report, indicate that the prototype instrument and software has the potential to give reliable measurement as soon as weather conditions are suitable.

Deviation from project plan

The milestones have been reached.

Tests and measurements.

Test measurements of radiance distribution been performed in late October 2001 under variable cloud conditions. Software for automated operation is under development and will be applied in measurements during spring 2002 when the weather conditions allow.

Deviation from project plan.

The milestones have been reached.

Campaign at Andøya.

Deviation from project plan.

Due to the financial situation of the project this activity can not be performed as planned.

Presentation of results.

Deviation from project plan.

Publication of the results has been delayed to spring 2002.

Activity 7.3: Impact of broken clouds on ground based UV irradiance; measurements, analyses and validation

Responsible scientists: Trond Morten Thorseth, NTNU

Results on intercomparison of cosine error correction (cont. from phase 1).

This task of comparing different cosine error correction procedures has proceeded as planned and a paper on the comparison is in preparation. Results from the comparison has also been presented for the Nordic Ozone Group at the annual meeting in Trondheim April 2001.

Deviation from project plan

The milestones have been reached.

Measurements during broken cloud conditions, testing of algorithm.

A new algorithm for retrieval of data from the filter-instrument GUV-541 has been developed and tested.

Deviation from project plan

There has been no regular measurements of global irradiance with the new system and hence the algorithm to derive global irradiance spectra at ~1Hz has not been tested. This will be made when the measurements start in 2002.

Results of cosine correction during all weather conditions, including broken clouds

In phase II, the development of methods to perform measurements during broken cloud conditions has continued and an investigation of cosine corrections in cloudy conditions has been included in this task. One of the milestones of the project plan was to make direct measurements of the cosine error during broken cloud conditions. This experiment was performed but the results were not reliable enough to publish due to stray light problems that were later corrected. Preliminary results were presented at the European Society of Photobiology conference at Lillehammer 2001.

Deviation from project plan

The milestones have been partly reached.

Activity 7.4: Measurements of UV radiation on vertical surfaces

Two 6-channel NILU-UV radiometers were planned to be used in this sub-project. Unfortunately the instruments were not available before October 1, 2001, i.e. some months delayed. It was decided to install the instruments on the roof of the NILU building at Kjeller. At this site a third NILU-UV instrument is available. Thus, with this additional instrument UV radiation is measured with identical instruments in three directions: North (vertical), South (vertical) and upward looking (horizontal surface). The use of the third instrument will undoubtedly strengthen the measurement program.

1.7.4 Plans for 2002

In general emphasis will be put on measurements. Two masters students will be working on the project in addition to Thorseth.

Task 7.1 will be carried out in collaboration with the EC project EDUCE, developing an European database and continue for 2002.

Both direct and radiance distribution measurements in task 7.2 will start immediately next year when weather conditions are sufficient (solar zenith angle less than 75 degrees). Due to lack of manpower in the latter part of the project, it will be merged with the EC project INSPECTRO. Intercomparison of direct measurements will be performed. Algorithms for retrieving aerosols will be developed. Task 7.3 on broken clouds will be finished in April.

Direct measurements and radiance distribution measurements in task 7.1 and 7.2 will start in early spring as soon as conditions are suitable for these experiments.

The campaign at Andøya will be cancelled due to reduced budget for 2002. Results related to radiance distribution measurements and the measurement system will be presented in august.

Work related to broken cloud cover can, due to budget reductions, only be partly performed at late spring 2002 when the measurement conditions give conditions with higher solar zenith angles than winter measurements.

Measurements can be started in March 2002.

Measurements on a vertical surface in task 7.4 will continue during spring and summer 2002. Final results will be presented at the end of the period.

1.8 Task 8: Airborne UV measurements

Responsible scientist: Arve Kylling, NILU

Co-worker: Tron Danielsen

The NILU-CUBE instrument hooked on to the flight train and ready for launch. on 30 June, 2000.

Photo: Arve Kylling.

1.8.1 Progress during Phase I

The main objectives of this task are to develop a data logging system for an existing NILU-CUBE UV instrument and fly the instrument on balloons to document and study the vertical distribution of UV radiation.

Due to instrumental problems outlined below, the task suffered a delay of one year. The task is now on schedule with successful flights and a reliable data analysis chain.

To measure UV radiation with high sensitivity and accuracy it is necessary to reject radiation outside the wavelength band of interest. To reject straylight is particularly challenging in the UVB (280-320 nm) part of the spectrum. The NILU-CUBE used for balloon flights has one channel centred at 312 nm and one centred at 340 nm. It was seen that the 312 channel had unacceptable amounts of out of band radiation, hence the custom made filters were not behaving as expected. After extensive testing and searching for possible errors it was clear that additional blocking filters were required. These filters were received an installed in July 1999.

Due to the above mentioned filter problems both the construction of the data logging system and the calibration of the instrument was delayed not enabling us to fly during 1999 as originally planned. The first flight was made from the airport of Gap-Tallard, France, on 30 June, 2000. Further details of the flight and the recorded and analysed data are provided in section 2.8.

As part of the EC funded ADMIRA project the NILU-CUBE took part in a surface-based measurement campaign in August 2000, Nea Michaniona, Greece. During that campaign the NILU-CUBE was calibrated against well-characterised spectroradiometers.

1.8.2 Progress during Phase II

The objectives for phase II were to continue with the balloon flights to study the behaviour of the vertical distribution of UV radiation.

During 2001 one flight was made from Gap-Tallard, France, on 11 June 2001. The balloon malfunctioned and never made it higher than approximately 13000 m.a.s.l.

The NILU-CUBE however, functioned well and recorded data during the entire flight. The data from the flight is currently being analysed.

1.8.3 Plans for 2002

Several flights are planned for 2002. One tropospheric-stratospheric flight is planned in June 2002 from Gap, France. A similar flight will be made in Nov.-Dec. (or possible Jan.-Feb., 2003) from Bauru, Brazil. The latter flight is dedicated to validation of ENVISAT and may be delayed if the launch of ENVISAT is further delayed. As part of the EU funded INSPECTRO project hot-air balloon flights are planned in East Anglia in September.

Tron Danielsen, NILU, in front of the balloon, which is being inflated. This photo was taken during the first NILU-CUBE experiment in Gap, 30 June 2000.

Photo: Arve Kylling.

1.9 Task 9: UV modelling

Responsible scientist: Phase I: Arve Kylling
Phase II: Ola Engelsen

Main objective of task

Phase I

The main objective of this task was to quantify the effects of cloud cover on UV radiation for selected sites in Norway. This include the sites in Tromsø, Andøya, Trondheim, and possibly data from several multi-channel narrow-band filter instruments.

Phase II

The main reason for our concern about the depletion of the ozone layer is the biological hazards of increased UV radiation. Thus task 9 form an important link between the COZUV project and end-users. We have initiated a scientific dialogue with biologists doing research on skin cancer and vitamin D in humans.

1.9.1 Progress during Phase I

It was envisaged that data would be taken during the project period. However, due to instrument malfunction in Tromsø no information was available from which aerosol and surface albedo could be derived. In Trondheim, delays in instrument delivery caused delays in data gathering. Hence, with the reduced data set it would be difficult to work for the above objectives. However, using data from 1997 a new study was performed of the effect of increasing snow line on UV irradiances using both measurements and 3-D radiative transfer simulations. The study was performed both for cloudless and cloudy skies. This work is described below. It has been published by Kylling and Mayer [2001]

1.9.2 Progress during Phase II

The objectives of task 9 are:

1. To homogenise satellite and model information for input to radiative transfer algorithms.
2. To generate present UV maps of Norway using satellite information.
3. To generate future UV maps of Norway using chemistry model ozone column information together with satellite information.
4. To compare the present UV maps at selected locations with measurements.

The work undertaken within this task is progressing well. Originally objectives 1 and 2 were scheduled for 2001 whereas objectives 3 and 4 would be completed in 2002. However, we have chosen to focus on objective 4 prior to completing objective 2 in order to ensure the quality of the UV maps.

1.9.3 Plans for 2002

Work for phase II of task 9 in 2002 comprises:

1. Completing the new version of the fast UV simulation tool suitable for UV maps.
2. Generating present UV maps of even better accuracy and spatial resolution.
3. Generating future UV maps based on the Oslo SCTM-2 model ozone data.

Regarding point 2, better spatial resolution will be facilitated by applying the fast simulation tool in point 1. Thus we anticipate that map generation will no longer be limited by computer speed. The spatial resolution will thus be mostly due to limitations of effective spatial resolution of input data, particularly in terms of clouds structures.

Improvements of accuracy in the UV maps we anticipate will be achieved by improvements of input data, particularly from new satellite data e.g. from MODIS and MISR.

Regarding point 3, future ozone data will be generated by the Oslo SCTM-2 model. Along with realistic climatological model input parameters, future UV maps will be generated.

We expect to establish closer collaboration with biologist doing research on the effect of UV on vitamin D production and malignant skin cancer in humans and cod larvae mortality, and feel this may offer exciting new prospectives for applications of our UV and ozone research.

1.10 Task 10: Coordination

Responsible scientist: Geir Braathen

Co-worker: Berit Modalen

1.10.0 Introduction

The planning and arrangement of project meetings has been one of the main activities of this task. The experience from the first three years of the project is that the arrangement of project meetings is quite an important factor for the progress of the project. Because of this all the meetings that were planned have been arranged. Some additional meetings have also been held.

A second important activity is the preparation of progress reports. For the current report it has been of great help to have the template provided by the programme committee.

1.10.1 Progress during Phase I

Project meetings

Kick-off meting

A kick-off meeting was held at NILU on 17-18 February 1999. Each research group presented their plans for work to be carried out in COZUV. It was pointed out at this meeting that COZUV consists of two separate parts; one on ozone and one on UV radiation. It was agreed that one should build a bridge between the two activities. It was agreed that one will aim at calculating global UV maps based on the ozone fields produced by the SCTM-1 model. This will give us an indication of future UV radiation levels. More details on the kick-off meeting can be found at
ftp://ftp.nilu.no/pub/NILU/geir/cozuv/minutes/kick-off_minutes.pdf

2nd Project meeting (plenary)

The second project meeting took place on 24. November 1999 near Oslo airport. At this meeting reports on the progress were presented by each group. It became apparent that there was a need for a separate meeting for discussion on model validation against observations.

3rd Project meeting

A small meeting, involving modellers only, was held on 10.12.1999 at the University of Oslo.

4th Project meeting

The fourth project meeting took place on 17. February 2000 in Oslo. At this meeting one discussed how one best could validate the

Oslo CTM-2 model. At this meeting modellers and experimentalists agreed on specific time periods and chemical species for model/ observation intercomparison.

5th Project meeting (plenary)

A plenary meeting was held on 10-11 April 2000 in Oslo. The first day was devoted to a discussion on the contents of the progress report. The second day was used to discuss the contents of a new COZUV proposal for 2001-2002. The minutes from this meeting can be found here:

ftp://ftp.nilu.no/pub/NILU/geir/cozuv/minutes/minutes_second_annual.pdf

Distribution of funds

The funds for COZUV is routed via NILU. Agreements have been obtained with NTNU and the University of Oslo for the employment and payment of salary for post-doctoral fellow Trond Morten Thorseth and doctoral student Michael Gauss.

Dissemination of information on COZUV

Web page

A web page to describe the project was first made in a preliminary version. Based on comments from the COZUV partners this web page was slightly modified and made available on NILU's ordinary web pages. The pages can be found here: http://www.nilu.no/projects/cozuv.

Information on the ozone layer problem for pupils has also been made, partly based on the material in the COZUV proposal. This information is available on NILU's regular web pages; http://www.nilu.no/avd/reg-glo/pupils/pupils.html.

1.10.2 Progress during Phase II

Project meetings

Kick-off (plenary)

The second phase of COZUV started formally on 1. January 2001. A kick-off meeting was held at NILU on 14-15 March 2001.

7th project meeting (plenary)

A plenary project meeting was arranged at the University of Oslo on 7-8 November. Bo Christiansen (DMI), who is member of the Climate Programme committee took part in the meeting. We had also invited two external experts to assess the project; Guy Brasseur of the Max Planck Institute in Hamburg and Neil Harris of the European Ozone Research Coordinating Unit in Cambridge.

Presentation of project

The COZUV project was presented at the Climate Conference of the Research Council of Norway that took place in Bergen on 27-29 November 2001.

1.10.3 Plans for 2002

Emphasis in 2002 will be on the validation of the CTM-2 model. For this there will be more frequent meetings than planned in Table 8-2 of the work plan.

Meeting in February 2002

A one-day plenary will meeting will be held in February 2002 in order to assess progress of the modelling development and validation.

Meeting in May 2002

A new plenary meeting will be held in early May. This meeting will have three main purposes:

1. To assess results from the winter of 2001-2002
2. To assess progress on model development and validation
3. To plan a proposal for a possible third phase of COZUV in case the programme committee decides they want a proposal for this.

Meeting in August 2002

A plenary meeting will be held in mid-August 2002 in order to finalise the proposal for a possible third phase of COZUV.

Meeting in November/December 2002

A final COZUV-II meeting will be held in November or December 2002. The purpose of this meeting will be to assess progress and summarise the results of COZUV-II. Possible publications will be discussed and the outline for the final report will be discussed.

Science colloquies

In order to improve collaboration and in order to distribute responsibilities several science colloquies will be held at NILU and at UiO. The various chapters of the 2001 EU ozone assessment will be subject to lectures given by the COZUV partners.

SECTION

2

Scientific achievements

2.1 Task 1: 3-D modelling of atmospheric chemistry

2.1.1 Activity 1.1: Development of a global 3-D CTM for stratospheric process studies

CTM-2 is a 3-dimensional chemical transport model for the troposphere and the lower stratosphere developed at the University of Oslo and extending from the surface up 10 hPa. The transport and physical parameters used in the model are taken from ECMWF forecast data. Advection is done using the Second Order Moment scheme (Prather, 1986), while convection is based on the Tiedtke mass flux scheme (Tiedtke, 1989). Surface emissions are based on GEIA and EDGAR for anthropogenic emissions, and Müller (1992) for natural emissions. Aircraft emissions are taken from the NASA inventory, while NO_x emissions from lightning are parameterised following Price et al. (1997a/b).

In the framework of COZUV 1, a new version of the model was developed including comprehensive chemistry for both the troposphere and the lower stratosphere. The tropospheric chemistry scheme is basically the same as in the OSLO CTM-1 model (Berntsen and Isaksen, 1997) and calculates 51 species including 86 thermal, 17 photolytic, and 2 heterogeneous reactions. The numerical scheme for stratospheric chemistry was taken from the chemical transport model for the stratosphere, SCTM-1 (Stordal et al., 1985, Rummukainen et al., 1999). 104 thermal and 47 photolytic reactions are integrated involving 64 species and families relevant for stratospheric chemistry. 7 heterogeneous reactions are simulated on sulphate aerosols and/or PSCs.

Both the tropospheric and the stratospheric modules apply the QSSA method for numerical integration (Hesstvedt et al., 1978). In total 98 components are handled, 76 of which are transported. The boundary condition at the model top is based mixing ratio data from the Oslo 2-D model.

During the inclusion of stratospheric chemistry much effort was made to improve the efficiency, flexibility, and transparency of the code. Another major progress was the inclusion of the highly efficient ‘Fast-J’ module for the calculation of photo-dissociation coefficients (Wild et al. 2000). 60 photo-dissociation rates are now calculated on-line once every hour. The J-values were found to be in good agreement with calculations reported in the scientific literature and results from the well-tested module of Kylling et al. (1995) that is used in SCTM-1. During COZUV 1 numerous simulations were performed for the year 1996 with T21 resolution and 19 layers from the surface up to 10 hPa. As was shown in previous reports, stratospheric ozone profiles and total ozone distributions compared well with satellite (GOME, POAM) and lidar (ALOMAR) observations, except for periods with very strong ozone depletion due to heterogeneous chemistry.

In the second year of COZUV 1 a new tropospheric version of CTM2 became available featuring improvements in surface emissions and various transport processes (boundary layer mixing, rainout, and improved transport in polar regions), and the combined tropospheric-stratospheric version had to be thoroughly revised accordingly. This effort greatly improved ozone levels in the upper troposphere, which were too high in the previous version (J.Sundet, personal communication).

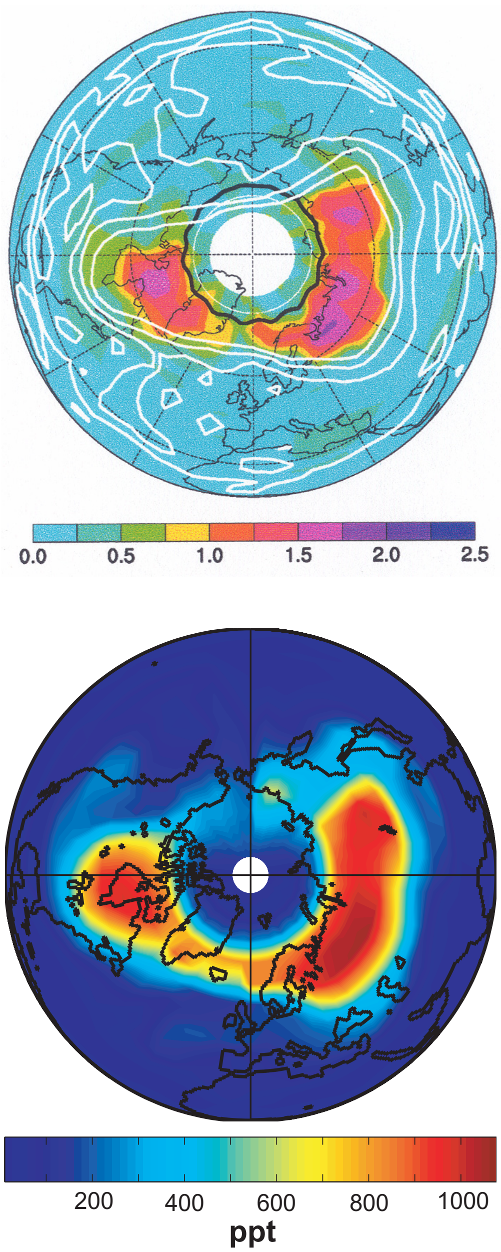


Figure 2.1.1.1 *ClO at 465 K on 30 January 1996, 12 local time. Upper: observed by UARS (MLS) [ppbv]. Lower: modelled by CTM-2 [pptv].*

However, the activation of ClO and depletion of ozone during winter and early spring remained too small compared with observations. Therefore it was decided to improve the heterogeneous chemistry parameterisation. The main step was to include a detailed microphysical scheme of Carslaw et al. (1995), which calculates the chemical composition of aerosols, the removal of HNO_3 and HCl from the gas phase, and rate coefficients for heterogeneous reactions. CTM-2 now includes the following heterogeneous reactions:

$ClONO_2(g) + HCl(s) \rightarrow Cl_2(g) + HNO_3(s)$ on liquid aerosols, NAT and SAT particles,

$ClONO_2(g) + H_2O(s) \rightarrow OHCl(g) + HNO_3(s)$ on liquid aerosols, NAT and SAT particles,

$N_2O_5 + HCl(s) \rightarrow ClNO_2(g) + HNO_3(s)$ on NAT particles,

$N_2O_5 + H_2O(s) \rightarrow 2\ HNO_3(s)$ on liquid aerosols, NAT and SAT particles,

$OHCl(g) + HCl(s) \rightarrow Cl_2(g) + H_2O(s)$ on liquid aerosols and NAT particles,

$BrONO_2 + H_2O \rightarrow OHBr + HNO_3$ on liquid aerosols, and

$OHBr + HCl \rightarrow H_2O + BrCl$ on liquid aerosols, where (s) indicates the species staying in the particles.

Rate coefficients for heterogeneous reactions on liquid aerosols and SAT particles are calculated by the scheme of Carslaw (1995) and based on the aerosol background, while gamma values for the reactions on NAT particles are taken from JPL (2000). The data base for sulphate aerosol densities was updated for CTM-2 based on SAGE satellite observations (1996 and 1997), and the distribution of PSCs is calculated pole-ward of 50 degrees assuming fixed temperature thresholds for PSC formation (<197 K at heights between 90 and 40 hPa, <193 K between 40 and 20 hPa). For NAT, a particle density of $10cm^{-3}$ is assumed with a mean particle radius of 1 micron. PSC type 2 particles (water ice) are not considered yet.

ClO activation is significantly enhanced by the new parameterisation. However, a comparison with MLS observations of extreme

ClO activation events in the Arctic winter of 1996 (Santee et al., 1996) revealed that modelled ClO during these periods is still some 30% lower than the measurements (see Figure 2.1.1.1). This can be due to too low activation through heterogeneous reactions and/or to too low Cl_y levels. A more comprehensive set of observations would be needed to settle this question, but an extensive set of sensitivity experiments has been performed investigating both possibilities:

- the chemical time step in the stratospheric chemistry code was reduced from 10 to 5 minutes
- an enhanced Cl_y/total chlorine ratio was applied at the top layer to increase chlorine available for activation
- temperatures in December 1995 were artificially reduced by 5 degrees
- complete denitrification was simulated (removal of all nitrogen that is taken up in particles)
- use of higher resolution for temperatures (ECMWF, T63 data)

In the latter experiment the lowest temperature among the 9 T63 boxes that comprise one T21 box was used throughout the T21 box. By this approach the temperature requirement for PSCs was met more frequently.

The achieved increases in ClO activation and ozone depletion were, however, almost negligible in all these experiments.

It now seems likely that the low concentrations of chlorine could be connected with problems in the downward transport of Cl_y. Also, the rather simplified parameterisation for PSC formation and size distribution should probably be improved. To this end, the option of implementing the microphysical model of N. Larsen (Larsen, 2000) was further investigated during the first year of COZUV 2. In order to model the different kinds of particles properly a minimum number of 15 size bins is needed (N. Larsen, personal communication). Although this approach would yield a rather accurate parameterisation of PSC occurrence, it turned out to be too expensive for realisation in CTM-2. Instead, an efficient scheme used by the group of G. Brasseur is now being considered for this purpose (G.Brasseur, personal communication).

During the first part of COZUV-2 new data from ECMWF became available with a higher vertical resolution. The vertical resolution of CTM-2 was improved accordingly resulting in 40 layers between the surface and 10 hPa. The height intervals in the UTLS region are between 800 and 1200 meters, which is about twice the resolution of the previous model. Extensive testing has been done for the year 1997 and the winter season 2000/2001. Figures 2.1.1.2-2.1.1.4 show comparisons with satellite, sonde, and LIDAR observations respectively. Apart from the overestimations in the lower stratosphere in January 1997 (2.1.1.3), which was characterized by very low temperatures and PSC formation, modelled ozone is in relatively good agreement with the observations.

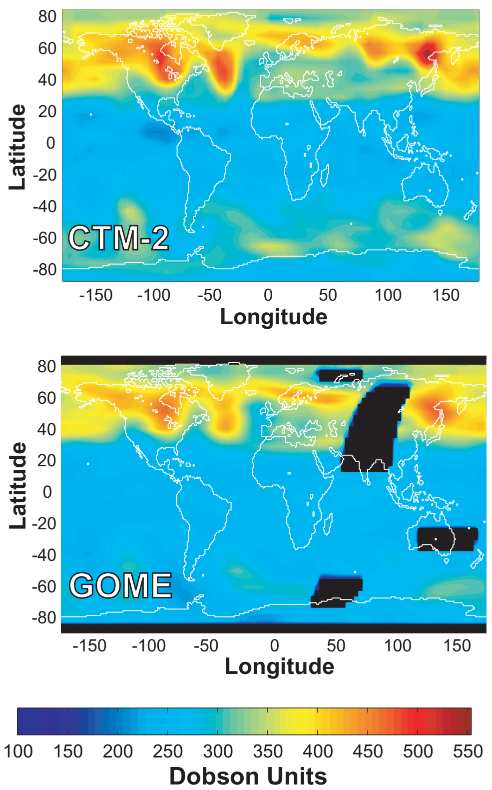


Figure 2.1.1.2 Total ozone on 15 March 1997 as modelled by CTM-2 (upper) and observed by GOME (lower). [DU]

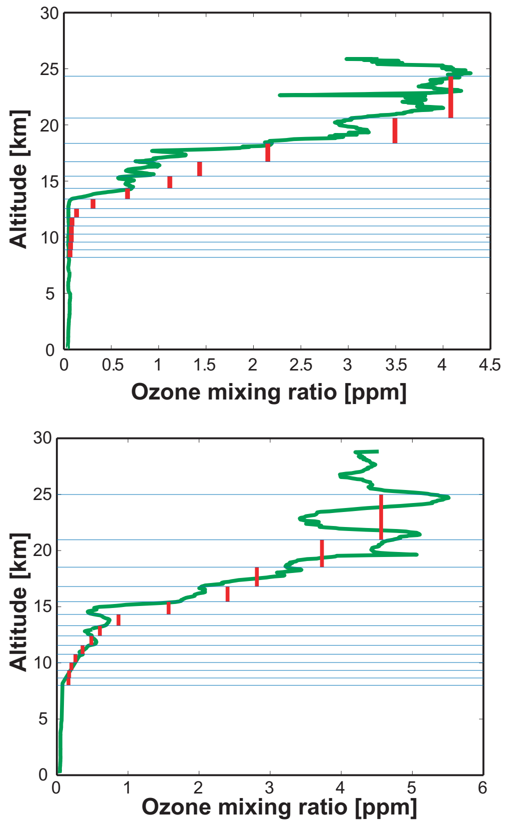


Figure 2.1.1.3 *Ozone mixing ratio (ppm) as a function of altitude (km) at Sodankylä on 13 January 2001 (upper) and 14 February 2001 (lower) modelled by CTM-2 (red lines) and measured by ozone sondes (green lines). The thin blue horizontal lines show the levels 27-39 of the Oslo CTM-2 model.*

ECMWF data for the cold winter of 1999/2000 are not available yet, but will be provided in the second year of COZUV 2. Similarly the extension of the model up to 0.1 hPa had to be postponed as the 60 layer reanalysis calculation of ECMWF has not reached the late 1990's yet.

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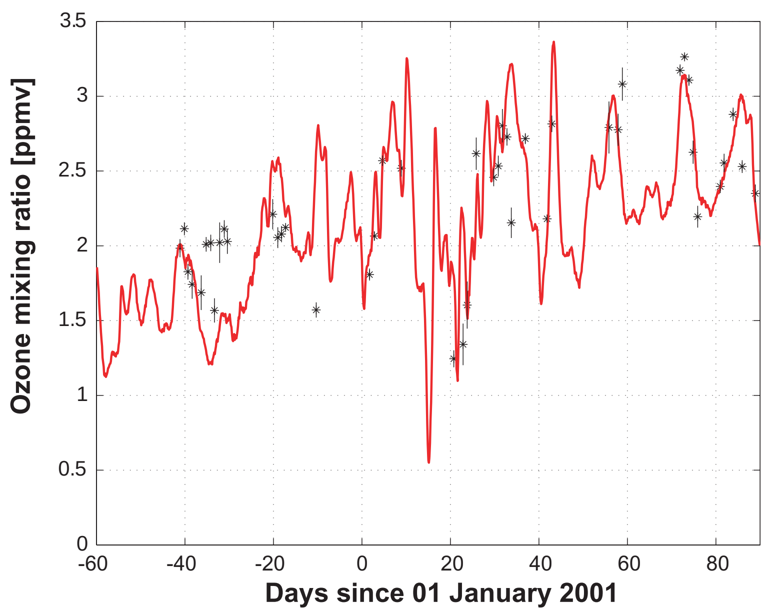

Figure 2.1.1.4 *Ozone mixing ratio [ppmv] at 18 km above Andenes measured by LIDAR (black asterisks) and modelled by CTM-2 (red solid line) during the winter season 2000/2001.*

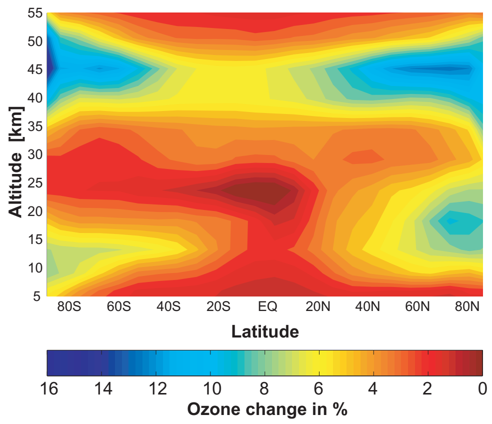

Figure 2.1.2.1 *Percentage changes in ozone between 1980 and 1970 for April 1. as a function of latitude and altitude.*

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2.1.2 Activity 1.2: Long term studies of stratospheric ozone depletion

The stratospheric 3-D model (SCTM-1) (Rummukainen et al., 1999) has been used for long-term studies for the past as well as the future. In phase I the model was run for each of the following years 1980, 2000 and 2015 with model calculations from the Oslo 2-D model (Stordal et al., 1985, Zerefos et al., 1997) as input. For phase II model runs for 1970 and 1980 have been performed with the improved SCMT-1 and also a run from 1981 through 2000. For the surface area of sulphate aerosols SAGE II measurements have been used for the corresponding year. Figure 2.1.2.1 shows the percentage changes of ozone between 1980 and 1970 for April 1 as zonal mean. A decrease of up to 12% is calculated at about 45km in the stratosphere.

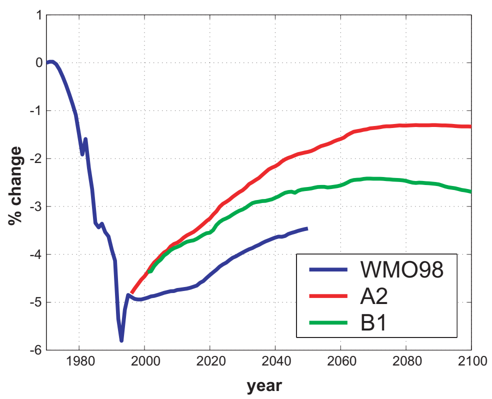

Figure 2.1.2.2 *Changes in global mean ozone column for 1970 through 2100 with 1970 as reference with the following emission scenarios, WMO 98, IPCC B1 and IPCC A2. WMO 98 is run for the period 1970 through 2050.*

Future changes in stratospheric ozone depend on the scenarios used for chlorine, bromine as well as nitrous oxides and methane emissions. The Oslo 2-D model has been used to study the long term ozone recovery (over the next 100 years). We have adopted historic emissions up to 2000 and the IPCC (2001) scenarios for the future CFCs, N_2O and CH_4 emissions. The WMO (1998) scenario is used for comparison studies. The future scenarios are connected with large uncertainties in N_2O and CH_4 emissions, particularly towards the end of the century. We have therefore adopted a high and a low scenario for the compounds to estimate the possible range in ozone recovery. The model used for these calculations are the Oslo 2-D model (Stordal et al., 1985, Zerefos et al., 1997). Shown in Figure 2.1.2.2 are the percentage changes in global mean ozone using the year 1970 as the reference. The calculations demonstrate clearly that ozone recovery depends strongly on the adopted scenario and the relative changes in methane and nitrous oxides. Ozone recovery will take place only when the IPCC A2 scenario is adopted. Due to updated reaction rates from the JPL 2000 compilation (Sander et al., 2000), N_2O becomes more important and the ozone recovery more dependent on N_2O growth than in previous estimate using earlier JPL compilations. The increased ozone loss by nitrogen reactions will to a large extent counteract the reduced ozone loss due to chlorine recovery. In particular, for the IPCC B1 scenario case total ozone development is dominated by the growth in N_2O after 2050.

2.1.3 Activity 1.3: Model improvement

In phase I focus was on the bromine chemistry. Comparison between model calculations and observation showed that HBr is underestimated in the model, therefore the Oslo 2-D model was used to examine if this discrepancy could be reduced by assuming that a small fraction of the reaction BrO + HO_2 was producing HBr. The results of the study showed large differences of this assumption within the polar region. This shows that we have to careful when new reactions are included in the model. The discrepancy we obtained between model and measurement are not unusual in models.

The gas phase reaction in the three dimensional model (SCTM-1) has been updated JPL2000 (Sander et al., 2000) and a new code for calculation of photo-dissociation rates, called FAST-J (Wild et al., 2000), has been included. Updating the chemistry to JPL2000 (Sander et al., 2000) leads to changes in the chemical partitioning in the stratosphere. The largest changes in the column ozone is seen when NO_2+O(^{1} D) is updated. The reaction has become faster and leads to more efficient ozone depletion through the nitrogen cycle.

2.1.4 Activity 1.4: Model studies of ozone loss and changes

Oslo SCTM-1 has been used to look at the catalytic ozone loss in the stratosphere. Nine different loss cycles in the hydrogen, nitrogen, chlorine and bromine families have been analysed. In the upper and lower stratosphere almost all of the ozone loss is through the HO_x cycle, while at the edge of the polar night the Cl_x cycle is significant up to 50% in the lower stratosphere.

2.2 Task 2: Dynamical studies

2.2.1 Activity 2.1 (Phase I): Polar/mid-latitude exchange processes

An in-depth analysis of ozone transport for entire winter-spring periods (97/98 and 98/99) during the THESEO campaign has been realised. Extensive use of satellite observations (UARS MLS) and lidar observations from Andøya has been made. The model study aimed at a re-construction of high-latitude ozone lidar observations made at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) throughout winter and spring. These results are described in a JGR article, which has been published in the year 2001. Ground-based ozone lidar measurements at ALOMAR on the island of Andøya (69.3°N;16°E) are now routinely used to investigate dynamical and chemical processes affecting the high latitude lower stratosphere. As Andøya is often located under the stratospheric polar vortex in winter, the observed ozone profile and column are hence strongly variable due to polar vortex displacements, and to fine- scale filamentation and lamination occurring near the vortex edge. Due to its location at the extremity of the Atlantic storm track, a strong lower stratospheric ozone variability is also induced by active weather systems and accompanying tropopause level fluctuations.

The large variability of column ozone in the Arctic is revealed by the several records of column ozone observations at Andøya or Tromsø (69.7°N, 19°E). There were very large fluctuations on day-to-day, or week-to-week time scales during the winter-spring 1997/98, as during any particular winter. Very low column ozone values were also observed throughout March 1998. Similarly, the strong variability in ozone lidar profiles is exhibited in Figure 2.2.1.1, which shows lidar profiles as a function of potential temperature on four neighbouring days in early March 1998 (thick black line). The lidar measurements are averaged in 6-hour time bins, centred on standard meteorological times. A large ozone-depleted lamina is seen to appear between March 2 and 3, near 400K. High resolution ozone profiles as well as column ozone, are reconstructed locally at ALOMAR, several times a day, regularly throughout the winter and spring. The approach consists of calculating a large number of back trajectories to determine the origin of air parcels above ALOMAR, and of using satellite observations to determine their ozone content. Hence, combining satellite observations with limited spatial and temporal coverage, and global gridded meteorological data, allows: i) a systematic comparison between re-constructed and observed ozone profiles and column, ii) a characterisation of modelled ozone profile and column covering the entire winter and spring, and in particular their day- to-day variability. The ozone initialisation requires the creation of an ozone “catalogue”, whereby coarse three-dimensional ozone fields can be looked up every 6 hours. The model uses ozone observations from the Microwave Limb Sounder

(MLS) instrument, mapped with respect to equivalent latitude. Referring back to Figure 2.2.1.1, the re-constructed ozone and equivalent latitude profiles are shown on March 1 (00Z), 2 (06Z), 3 (18Z), and 4 (00Z), along with the lidar profiles. The abrupt appearance of a prominent ozone-depleted lamina near 400K on March 3, is reproduced by the model, which further indicates that mid-latitude air (equivalent latitude near 50) was advected above Andøya in that layer. The overall shapes of the profiles, which change from day-to-day, are reproduced.

In addition to re-constructing the ozone profile, we have calculated the 6-hourly model column ozone. It was shown that the model reproduced the total ozone evolution throughout the winter and spring 1997/98: i.e. low values in early winter, high values in spring, and most remarkably, many fluctuations on day-to-day or week-to-week scales.

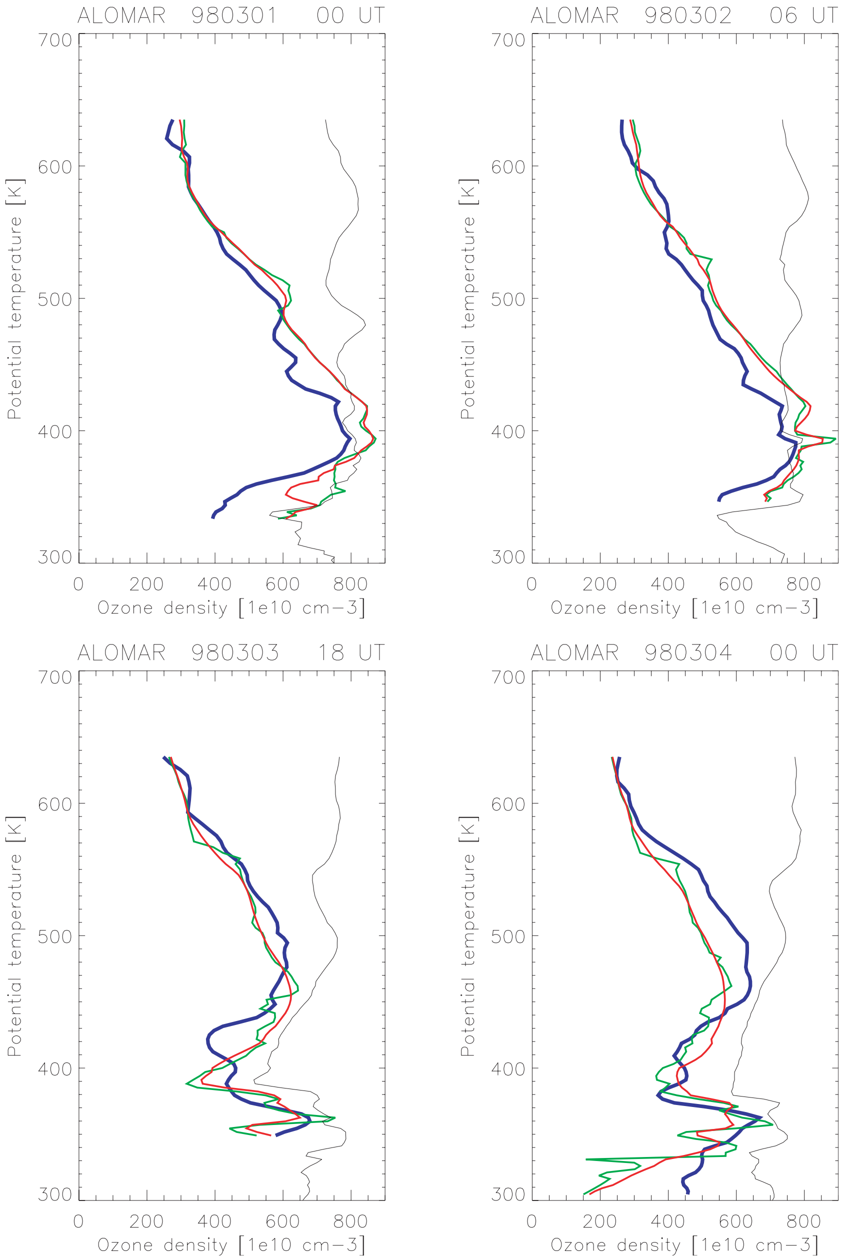

Figure 2.2.1.1 *Lidar and re-constructed ozone profiles on March 1 to 4, 1998 (lidar: thick blue line; model at Andøya: green line; model box averaged: red line). Re-constructed equivalent latitude profiles are also shown (equivalent latitude multiplied by 10: thin black line). Lidar profiles are averaged in 6-hour bins, centred on standard meteorological times (0Z, 6Z or 18Z).*

2.2.2 Activity 2.2 (Phase I)/Activity 2.1 (Phase II): Ozone transport and chemistry

Global maps of reactive stratospheric trace species were calculated using a domain-filling trajectory model, which incorporates a complete chemical integration along the ensemble of isentropic trajectories. Periods of interests have been the mid-winter 1996, when strong ozone depletion was observed over the northern hemisphere high latitudes, and also the spring-to-summer transition. The model development included the coupling of the dynamical module, which calculates the large ensemble of back-trajectories in a domain-filling mode, with a chemical module. The dynamical history of each trajectory (location, temperature,...) is hence used for a comprehensive box model calculation. The latter requires initialisation of the chemical fields, i.e. about 60 chemical compounds. This is performed by using a coarse resolution simulation provided by the University of Oslo.

Global set of 10-day backward trajectories was calculated for the covering the latitude band 30ºN-90ºN. The horizontal resolution of the simulation is approximately 1 degree (i.e. 22000 trajectories per level). Chemical species maps at very high resolution were hence constructed for the 64 chemical fields of the chemical box model. An analysis of the spatial patterns of ozone loss is being done, including ozone loss in filamentary structures. Global maps of several key species (ClO, ozone, HNO_3) are being drawn.

Winter

Figure 2.2.2.1 shows maps of ClO and ozone loss along the trajectories. These simulations reveal a considerable amount of structure in the chemical fields (e.g. ClO), both inside and outside of the polar vortex. The figure shows a remarkable fine-scale filament of ClO, where ozone depletion has been enhanced, being exported to the mid-latitudes.

Spring/Summer

We have carried out a large ensemble of trajectory calculations for two case studies in spring/summer 1997 and 2000. Several ensembles of 22000 full chemical trajectories were calculated at levels near 20-30 km, for several consecutive periods in June 1997 and June 2000. These calculations provided high-resolution chemical fields and chemical loss estimates for these periods. Calculations for June 2000 made use of the recent 60-level version of the ECMWF re-analyses.

The partition of the ozone loss with respect to different cycles has been determined, and compared with observations from the POLARIS campaign. The NO_x cycle proved to be the dominant cycle in the polar cap, with a fractional contribution of 40% to 60%, depend-

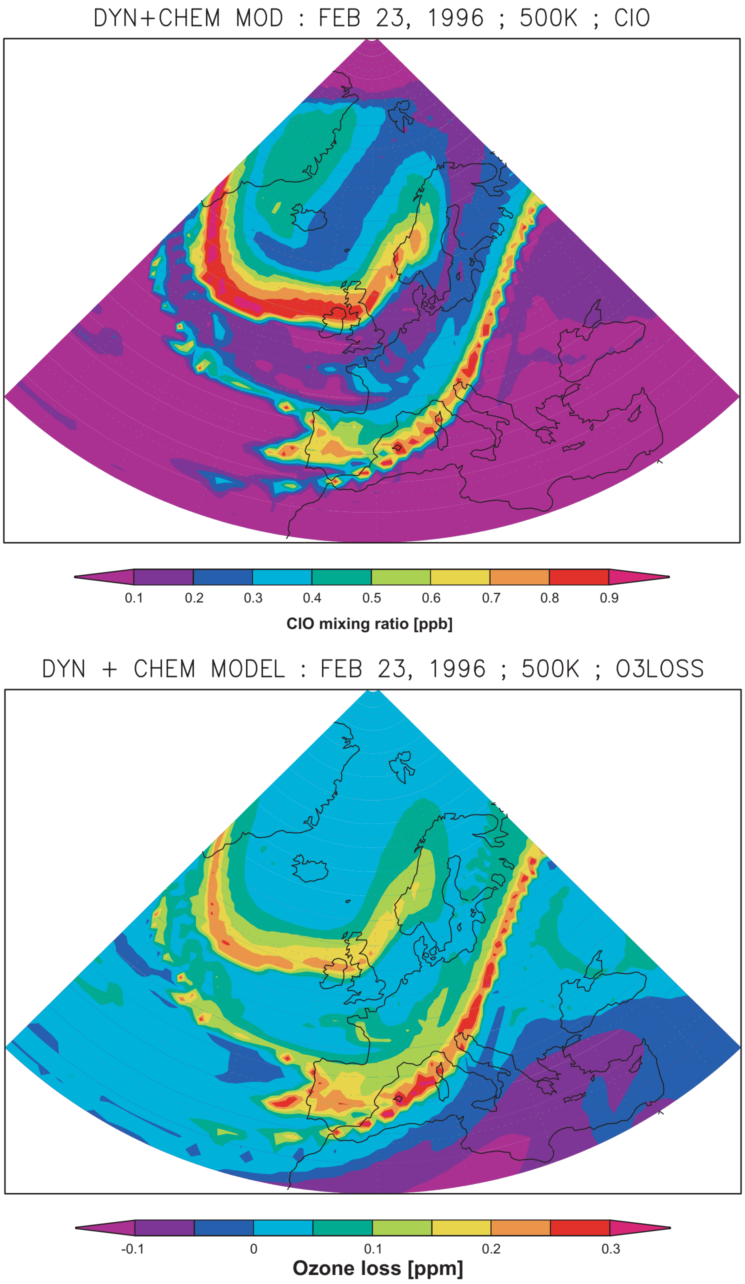

Figure 2.2.2.1 *Maps of ClO (top) and ozone loss (bottom) from the coupled dynamical-chemical trajectory model, without mixing, valid for 23 Feb. 1996 (12Z), at the 500K isentropic level. Note the filament enriched in ClO, exported from the polar vortex edge into the mid-latitudes, where ozone loss is enhanced. The ClO mixing ratio is given in ppb and the ozone loss is given in ppm, such that positive values denote ozone loss and negative values denote ozone gain.*

ing on the solar illumination. The ozone loss at 25 km in June 1997 was calculated to be of 0.4-1 %/day. The large sensitivity with respect to the initial conditions provided by several versions of the Oslo CTM is being examined.

2.2.3 Activity 2.2 (Phase II): Ozone mini-hole events

Very low ozone column values were observed in late November and early December 1999, over a large sector of the eastern North Atlantic and northern Europe. Over Oslo in southern Scandinavia, satellite and ground-based observations recorded values in the range of 160-180 DU, i.e. the lowest of the entire winter-spring period, despite the pronounced ozone depletion over the northern high latitudes in the spring 2000. In fact, the low values briefly observed near December 1, 1999 in southern Scandinavia were some of the lowest values ever observed in the northern hemisphere (NH) in the cold season.

Albeit such short-duration low ozone episodes occur in the extra-tropics of both hemispheres in winter, particularly strong, even extreme, events tend to occur over the north Atlantic. Such low-ozone episodes have been termed “miniholes” and are of particular interest as the low ozone column and anticyclonic conditions imply enhanced UV radiation reaching the ground. Preferred regions of ozone variability on synoptic time scales (2-10 days) lie in the storm track regions. Which factors govern interannual, or month-to-month variability in the occurrence of such ozone miniholes over the Atlantic and Europe?

The North Atlantic Oscillation (NAO) is the leading mode of year-to-year wintertime variability in the NH extratropics. It is linked to changes in the direction and intensity of the dominant westerly tropospheric jet stream over the Atlantic. The 20-year period of observations by TOMS Nimbus 7 (1979-93), Meteor (1993-94) and Earth-Probe (1996-2000) was segmented in monthly data sets. We band-pass filtered satellite observations of column ozone to retain only synoptic periods (2-10 days). Mean Absolute Deviation (M.A.D.) maps have been calculated for each month throughout the period. The monthly M.A.D. anomalies (i.e. departure from their monthly climatology) were locally regressed against the NAO index.

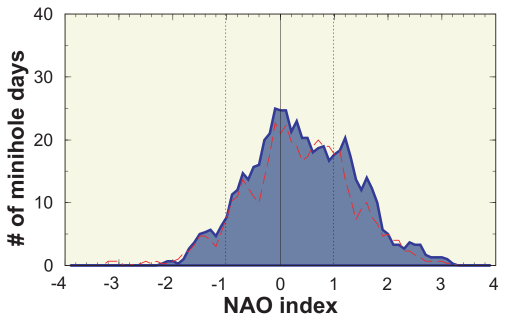

Figure 2.2.3.1 Histogram showing the number of days with miniholes as a function of the index of the North Atlantic Oscillation (NAO).

We further proceed by showing that not only synoptic fluctuations in general, but more specifically negative fluctuations and ozone miniholes, are strongly influenced by the NAO over the Atlantic. A measure of the daily magnitude of such fluctuations has been calculated. Daily time series of this Atlantic minihole index have been calculated for the 20-year period from November to April, along with the phase of the NAO for each month. We compared the daily minihole index time series with a daily NAO index. The results binned according the NAO index show an histogram skewed toward positive NAO. This is shown in Figure 2.2.3.1. Hence one finds a higher number of minihole days, hence more frequent minihole conditions, for positive NAO.

2.3 Task 3: Ozonesonde observations

In COZUV this task is planned as a support for the other tasks. However, the data obtained from Ørland and other stations are used in the international cooperation around the European and Arctic ozonesonde network. Data from Ørland were used in the EU projects THESEO-O_3LOSS and THESEO 2000 - EuroSOLVE. In particular the data have been used in the Match campaigns. There have been Match campaign with Ørland participation during all the years of the COZUV project.

2.4 Task 4: DOAS measurements

2.4.1 Measurement and Model Comparisons

A major effort within the COZUV project is the development of the Oslo 3-D CTM. A major objective of the ground-based measurements is to assist in the validation of such model calculations. Recent developments in the Oslo model have enabled us to begin comparisons of total column ozone from the NILU SAOZ instrument located at Ny-Ålesund. In addition, as part of European funded studies, we compare our measurements with another 3-D CTM, SLIMCAT, from the University of Leeds. From SLIMCAT, we also are able to compare DSCDs of BrO for the Andøya measurement series. Examples will be shown of measurement time series in combination with model comparisons.

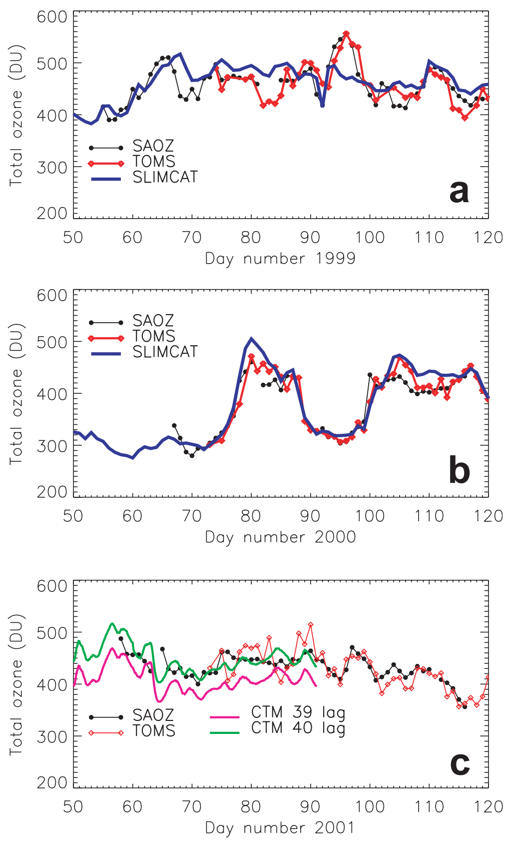

Figure 2.4.2.1
a) Spring 1999 SAOZ total column ozone from Ny-Ålesund and comparison with Earth Probe TOMS and SLIMCAT.
b) Spring 2000 SAOZ total column ozone from Ny-Ålesund and comparison with Earth Probe TOMS and SLIMCAT.
c) Spring 2001 SAOZ total column ozone from Ny-Ålesund and comparison with Earth Probe TOMS and Oslo 3-DCTM.

2.4.2 Measurement Results from Ny-Ålesund

As a main activity in Task 4, the entire measurement series of total column NO_2 and ozone from the SAOZ instrument at Ny-Ålesund is to be reanalysed with the WinDOAS analysis package from IASB-BIRA, Belgium. At present, the entire ozone time series has nearly been reanalysed and the reanalysis of the NO_2 time series will soon commence. The choice of the WinDOAS analysis package is based on the need to merge analysis routines for the SAOZ and SYMOCS systems. In the following, reanalysed total column ozone for the period 1999 to 2001 is shown. In addition, time series comparisons with the Oslo 3-D CTM are shown for the year 2001.

In Figure 2.4.2.1, total column ozone over Ny-Ålesund as measured by the NILU SAOZ and by Earth Probe TOMS is plotted for the spring periods 1999-2001. A comparison with the SLIMCAT model is also included. For Ny-Ålesund during 1999, the PV at the 475K level approached $40 \cdot 10^{-6}$ Km^2/kgs for the first few weeks of the measurement period, indicating vortex edge conditions. On day 65, PV decreased and remained low for the rest of the 1999 winter/spring period. Simultaneously, temperatures increased significantly and remained above 220K for the rest of the measurement period. Very low ozone loss was reported. During 2000, two periods of vortex conditions are noted at Ny-Ålesund during the usual measurement period: days 56-76, and days 89-99. Only the former period was characterised by sub-200K temperatures. During the first week of SAOZ measurements, temperatures were low enough for PSC formation. Total column ozone values showed much variability during 2000. This is mainly due to very active dynamics above Ny-Ålesund this year. Sudden increases in total column ozone, such as

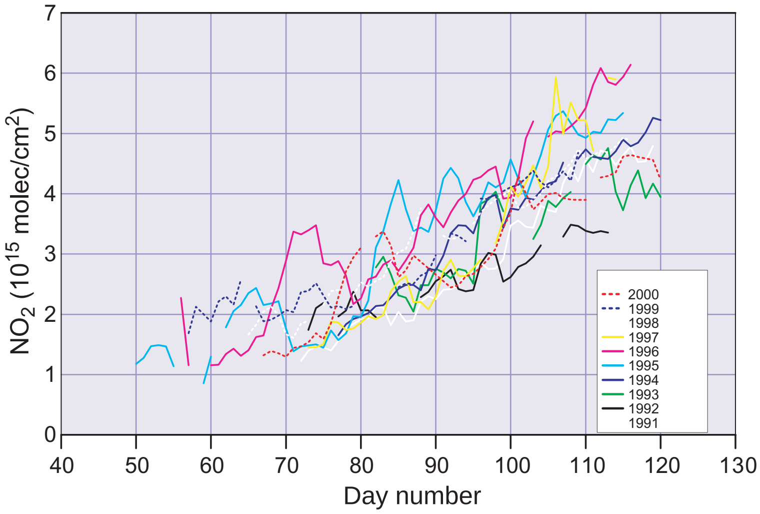

Figure 2.4.2.2 *Spring 1991-2000 evening SAOZ total column NO_2 from Ny-Ålesund.*

seen around day 78, can be attributed to mixing of ozone rich air from lower latitudes over Ny-Ålesund. Such large variations are often accompanied by sharp changes in PV and in temperature in the lower stratosphere. A secondary effect is due to variations in tropopause height. Tropopause height variations are a major cause of day-to-day total column variations during non-vortex back-ground conditions. During 2001, preliminary results indicate that the polar vortex was weaker than the previous year. This is also seen by the relatively flat time series. In this case, a comparison with the Oslo CTM shows good agreement with the measurements. The modelled results are given for 2 cases: within and without the top model layer, which includes the 27 to 43 km altitude region. The top layer is based on climatological 2-D data from the Oslo 2-D model. Total column evening NO_2 values for the spring from the years 1991 to 2000 are shown in Figure 2.4.2.2. As seen in previous years, minimum values are observed in the early winter, and the diurnal variation is seen to decrease as the number of sunlit hours increases during the course of the spring into the summer months. When the entire SAOZ record back to 1990 has been reanalysed, we will perform more exhaustive trend analyses and model compar-isons for both ozone and NO_2. These measurements are also com-pared with measurements from other sites around the world within the NDSC.

2.4.3 Measurement Results from Andøya

During 1999 at Andøya, two relatively short periods of elevated PV (at or above $40 \cdot 10^{-6}$ Km^2/kgs) and low temperatures (at or below 200K) were noted in mid-January and the second half of February. The SYMOCS-UV DSCD (differential slant column density) meas-urements of BrO during this period showed much variability. AM and PM measurements are reported for twilight taken twice a day at a solar zenith angle of 90°. BrO can therefore be observed nearly throughout the year at this site with this instrument. Maximum val-ues are generally observed during the coldest winter periods within

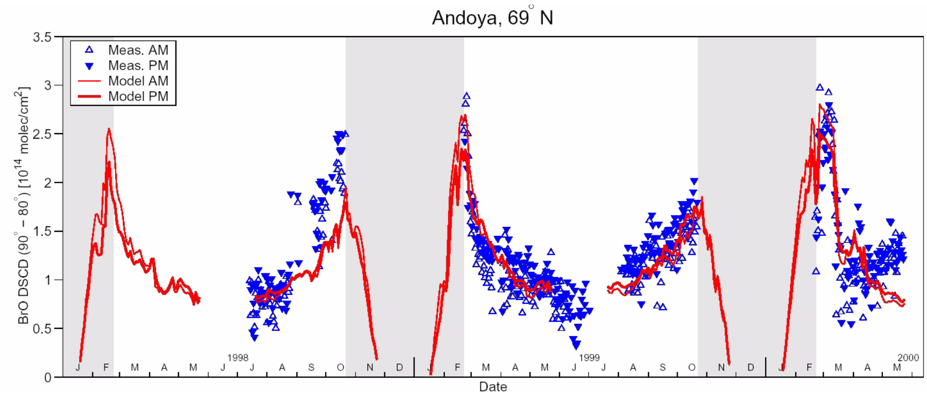

Figure 2.4.3.1 Comparison of SYMOCS-UV BrO DSCDs vs. SLIMCAT over Andøya for spring 1998 to spring 2000.

the vortex. The day-to-day variability is mainly dependent upon the vortex location and the inhomogeneity of chemical species within the vortex. These measurements have been compared with the 3-D chemical transport model (CTM) SLIMCAT from the University of Leeds, and results are shown in 2.4.3.1 for the spring 1998 to spring 2000 period. The comparison of observed BrO (90°-80°) DSCDs to modelled BrO yielded satisfactory agreement. The model reproduces the seasonal variation well. No clear systematic difference is seen except that the model underestimates the enhanced AM-BrO values inside the polar vortex around mid-February 1999. This could be corrected by increasing the rate constant for the reaction BrO+ClO -> BrCl+O_2 to the upper limit of current reaction rate recommendations (Sinnhuber et al., 2001). All of our observations indicate an enhancement of the morning BrO values compared to the evening BrO values when temperatures become sufficiently low within the polar vortex.

In general, our BrO measurements can be divided into two separate cases:

1. Unperturbed chemistry conditions, i.e. no chlorine activation, high NO_2

According to the model, $BrONO_2$ is then formed as the night-time reservoir, which is heterogeneously converted into HOBr during night. HOBr serves therefore as the major bromine reservoir in the morning. Since $BrONO_2$ photolyses faster than HOBr at high SZAs, there is slightly more BrO at PM than at AM.

2. Perturbed conditions with chlorine activation, and low NO_2

BrCl is then formed as the major night time reservoir at sunset through the reaction of BrO + ClO. Since BrCl photolyses more rapidly than $BrONO_2$ or HOBr, the BrO concentrations at high SZA are elevated during perturbed chemistry conditions compared to unperturbed conditions. This is in agreement with our observations. Modelled BrO concentrations during sunrise are slightly higher than during sunset. Since BrCl is not converted during night within the model, the most probable explanation as stated in Fish et al. (1997), is that ClO is slowly converted to Cl_2O_2 at sunset, and ClO abundances are larger than their steady-state value. When the sun rises, however, ClO is slowly released as Cl_2O_2 is photolysed, and ClO amounts are smaller than at the same SZA at sunset. At sunrise, BrO is released following BrCl photolysis, and the low ClO concentrations allow BrO to remain elevated. The distinction between sunrise and sunset BrO concentrations is also seen in our observations. The winter/spring measurement period at Andøya during 2000 was characterised by strong vortex activity from the middle of January to mid-March. Maximum PV values $40 \cdot 10^{-6}$ Km^2/kgs, and minimum temperatures of 189K at the 475K isentropic level were noted in this period. This was followed by intermittent episodes at the end of March and the beginning of April. PV and temperature recovered to background conditions by the middle of April. The BrO observations during 2000 follow a similar trend to previous years. The maximum BrO values are well correlated with maximum values of PV and low temperatures. Thus far it has been shown that the NILU BrO measurements at Andøya are in good agreement with both models and with other NDSC sites, such as in Kiruna, Sweden. Previous OClO measurements made by NILU at Ny-Ålesund during 1996 and 1997 have agreed favourably with other systems, and are in line with present knowledge of the chlorine chemistry of the Arctic stratosphere. Maximum values for DSCD OClO from Andøya for 1999 were around 50% of that seen during previous colder winters at Ny-Ålesund (COZUV Second Annual Report, 2001). In 1999, OClO was not detected until day 32. Compared to the colder winters of 1996 and 1997, the chlorine activation this winter was much less both in strength and duration. In light of the relatively high temperatures (above threshold temperatures for PSC formation), the existence of OClO indicates that heterogeneous chemistry on PSCs is not absolutely necessary for the formation of activated chlorine species as reported by Erle et al. (1998), and is confirmed by our measurements. Their findings provide evidence for possible OClO formation due to heterogeneous bromine chemistry on background aerosols. We report measurements of slant column OClO during periods of chlorine activation in the winter polar vortex. The formation of OClO is inversely proportional to NO_2 and temperature, and can be detected at temperatures around 10 K above PSC formation temperature and below. Further work is needed in determining the formation mechanisms and the stratospheric profile of this compound. There are a number of factors that make it difficult to use OClO as a quantitative indicator of chlorine activation. The ratio of sunset OClO to sunrise OClO depends strongly on the solar zenith angle as well as the ClO_x concentration (Sessler et al., 1996). From the model calculations the PM/AM ratio at 90 SZA is close to unity for ClO_x concentration between 0 and 5 ppbv. However, at 92 SZA the ratio varies from approximately 0.75-2.1 depending on the ClO_x concentration. The preliminary OClO data from 2000 show that the stratospheric conditions were very similar to those in Ny-Ålesund in 1996 and 1997. The maximum OClO values from 1996, 1997 and 2000 were very similar, and support other evidence that chlorine activation within the polar vortex in 2000 was very significant. The detection limit for these measurements was approximately $0.4 \cdot 10^{13}$ molecules/cm^2.

2.4.4 Air Mass Factor Calculations for NO_2

The ultimate quality of NO_2 total column data is highly dependent on the quality of the air mass factors (AMF) needed for the conversion from slant to vertical column densities. In turn, the determination of the AMFs depends on accurate knowledge of their atmospheric profiles, temperature and air pressure profiles, the surface albedo and aerosol profiles. Considerable work has been done for ozone, so the main emphasis in this project has been put on developing seasonally averaged AMFs for NO_2. NO_2 exhibits significant diurnal, latitudinal and seasonal variations that need to be accounted for in the AMF calculations (Høiskar et al., 1999). A major challenge thus far has been the determination of the vertical profile distributions. Work done thus far has been based on measured profiles available in the literature combined with the NILU box model (Fløisand, 1999) and radiative transfer modelling present in the COZUV project will be used for the calculation of the AMFs. The main conclusions thus far are included below:

- Including multiple scattering increases the calculated AMF with ~4% compared to single scattering case for SZA > 80°
- The sensitivity of the AMFs to surface albedo increases with decreasing SZA. The effect is negligible for SZA = 90°
- Including tropospheric NO_2 reduces the AMF (the effect increases with increasing SZA)

2.4.5 Deviations from project plan:

Activity 2). The UV detector at Andøya was repaired during 2001, and put into operation again in August 2001.

Activity 3). For the determination of NO_2 AMFs, calculated NO_2 profiles will also be acquired from the University of Leeds 3-D CTM, SLIMCAT.

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2.5 Task 5: Ozone lidar measurements

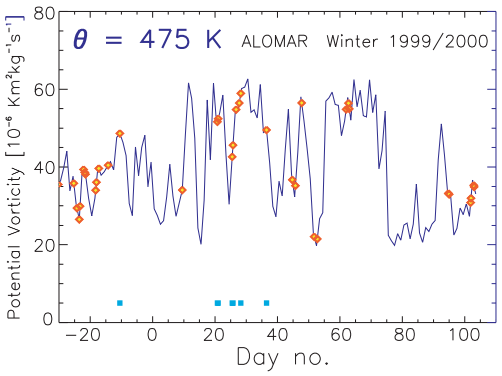

Figure 2.5.1.1 *Potential vorticity at the 475 K potential temperature level (about 19±1 km altitude) over ALOMAR during winter 1999/2000 (December 1, 1999 - April 20,2000). Occasions of ozone lidar measurements are marked with red diamonds, measurements containing polar stratospheric cloud signals are marked with blue squares.*

2.5.1 Ozone depletion in winter 1999/2000

Despite the adverse weather conditions in Northern Norway during the winter 1999/2000, the lidar was capable of monitoring the very interesting development of the Arctic ozone layer during the recent winter. The Arctic polar stratospheric vortex in 1999/2000 was very strong and cold until about mid-March 2000. ALOMAR was - as during previous winters - mostly located at the edge of the vortex, with two periods of more than ten days clearly inside the vortex and a number of episodes of up to 5 days outside the vortex. Figure 2.5.1.1 shows the development of the potential vorticity at ALOMAR for the period December 1, 1999, - April 20, 2000 at the 475 K level (approximately 19 km). Occasions with ozone lidar measurements are marked with red diamonds. They cover both periods where the location is deeply inside the vortex, e.g., in early March, episodes, when the station is outside the vortex (21-22 February), and - most frequently - times when the station is at the edge of the vortex, as around January 26 and April 4, 2000.

Figure 2.5.1.2 shows characteristic examples of vertical ozone density distribution under these different geophysical conditions. The January 10 profile is a vortex edge profile from the early phase of the vortex with an ozone maximum at 21 km. On January 29, when ALOMAR was deeply inside the vortex, the ozone maximum has moved down to 17 km, but there is still no signature of ozone depletion. On February 21, ALOMAR is outside the vortex, which is seen in the high ozone densities above 20 km. On March 3, inside the vortex, there is a clear indication of ozone depletion in the form of a bite-out in the profile between 17 and 21 km altitude. Finally, on April 4, the instrument probed air from the edge of a vortex fragment, which still has the typical vortex edge profile between 20 and 30 km altitude, but where the ozone depletion signature around 20 km is gone.

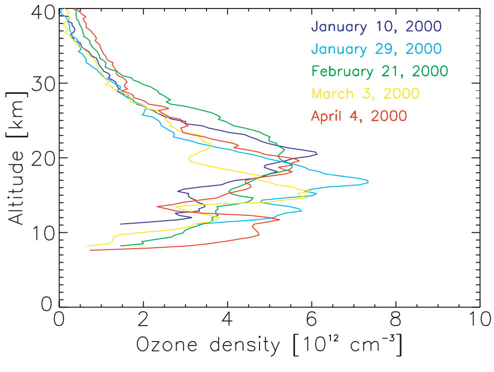

Figure 2.5.1.2 *Series of ozone density profiles measured with the ALOMAR ozone lidar in the course of the winter 1999/2000. Further explanation in the text.*

Chemical ozone depletion is seen more clearly if one depicts ozone mixing ratio as a function of potential temperature, i.e. ozone mixing ratio on isentropic levels. Figure 2.5.1.3 shows a series of these relations for days when the lidar clearly probed intra-vortex air. The December 17, 1999, profile is typical of the very early vortex with very low mixing ratios at high altitudes. The January 21 profile is a kind of reference profile at the starting point of chemical ozone depletion. The subsequent profiles show increasing ozone depletion, first around 500 K, then progressing down to 400 K. Part of this downward progression is due to diabatic descent of vortex air. The March 3 profile reveals significant ozone depletion (about 40%) at 475 K potential temperature. Furthermore, the depletion signature between 400 and 500 K very much resembles the situation

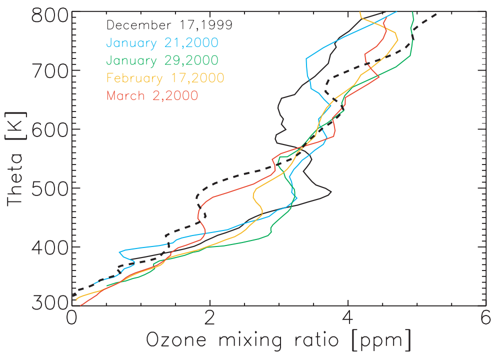

Figure 2.5.1.3 *Series of ozone mixing ratio profiles measured inside the polar stratospheric vortex in winter 1999/2000 at ALOMAR. Dashed line: ozone profile recorded on March 5, 1996, also inside the vortex.*

in March 1996, when the so far most severe ozone depletion in Northern Scandinavia was recorded. The dashed profile is a measurement with the same instrument on March 5, 1996. However, the depletion altitude range was shallower in 2000, leading to a less severe decrease of total ozone than in 1996.

2.5.2 PSC and stratospheric temperature observations

The ozone depletion as described above occurred because the Arctic polar stratospheric vortex in winter 1999/2000 was much stronger and colder than in the two winters before, especially the first COZUV winter 1998/1999. From early December to early March, temperatures were low enough to allow the formation of polar stratospheric clouds (PSCs) over large parts of the Arctic. PSCs become much stronger - and thus more effective for ozone depletion - than to be expected from a synoptical point of view, if the weather conditions are suitable to excite mountain lee-waves, for example at the Scandinavian mountain ridge. This was the case in 1997, and even more in the 1999/2000 winter with its almost continuous westerly wind situation in Scandinavia. Under such conditions, Kiruna is on the lee side, experiencing strong PSC displays, while ALOMAR is on the weather side, with much weaker PSCs (and poor measurement conditions).

PSCs were recorded at ALOMAR with both the ozone lidar and the Rayleigh-Mie-Raman lidar system, yielding backscatter ratios on 4 very different wavelengths: 1064 nm, 532 nm, 355/353 nm, and 308 nm, where the 1064 nm channel is most sensitive.

Table 2.5.2.1 lists all occasions with PSC observations in winter 1999/2000 with a 1064 nm backscatter ratio of > 1.3. These represent nearly all measurement periods in the period December 20, 1999, - March 5, 2000. In all cases with simultaneous measurements with both systems, when the 1064 nm backscatter ratio was larger than 2.0, also the ozone lidar detected a PSC signal; these occasions are also marked with blue squares in Figure 2.5.1.1. As to be expected, the backscatter ratios were generally 1 to 2 orders of magnitudes weaker than typical values in Kiruna and than PSC backscatter ratios in 1996 and 1997.

The strongest PSC detected with the ozone lidar is shown in Figure 2.5.2.1. The PSC was detected in the morning of January 29, 2000 and consisted of a double layer at 16 and 17.5 km with obviously different particle characteristics. The lower, strong layer with an Ångstrøm coefficient of about 3 consists of smaller particles than the upper and weaker layer, which has an Ångstrøm coefficient of about 1.

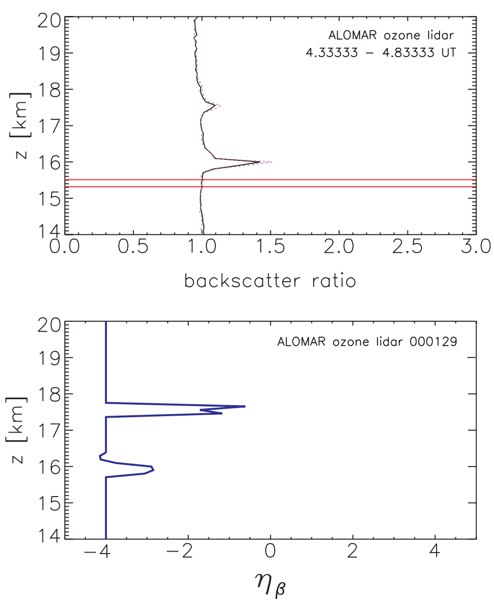

Figure 2.5.2.1 *PSC observations with the ALOMAR ozone lidar on January 29, 2000. Upper panel: Backscatter ratios at 308 nm (solid line) and 353 nm (dotted line); double line: reference altitude range ($R_{308,353}$ = 1.0). Lower panel: modified (308,353)-Ångstrøm coefficient (Rayleigh scattering: -4)*

Simultaneously recorded temperatures (outside the PSC) indicate that on the weather side of the Scandinavian mountain ridge, temperatures of less than 190 K are required for the occurrence of PSCs

Table 2.5.2.1.PSC observations at ALOMAR winter 1999/2000

		Maximum backscatter ratio				
Date	Time [UT]	1064 nm	532 nm	353 nm	308 nm	z [km]
991221	11:30-12:30	4.3	1.6	1.25	1.15	21.0
000121	16:10-16:40	3.0	1.3	1.15	1.10	18.5
	22:25-23:10	4.2	1.25	n.m.	n.m.	23.0
000122	01:20-01:50	7.5	1.7	1.15	1.10	22.5
	20:10-20:50	3.5	1.2	n.m.	n.m.	20.5
000126	13:10-13:25	5.0	1.7	n.m.	1.35	20.5
	17:45-19:30	1.7	1.1	<1.1	<1.1	19.0
000127	19:05-19:15	1.6	1.1	---	---	17.0
000129	04:30-05:45	n.m.	n.m.	1.6	1.47	16.0
000129	09:10-11:35	2.0	1.2	n.m.	n.m.	18.5
	14:30-16:15	1.7	1.1	n.m.	n.m.	17.0
000206	12:30-12:35	n.m.	n.m.	n.m.	1.40	19.5
000302	10:10-13:25	1.4	1.05	---	---	18.0
000303	09:35-11:05	1.4	1.08	---	---	17.0
n.m.= no measurement						

at about 20 km altitude. During most of the winter, the temperatures recorded at ALOMAR were close to this threshold value, and thus higher than in the two extreme winters of 1995/1996 and 1996/1997. This explains the generally marginal intensity of PSCs at ALOMAR. A detailed analysis of temperatures and their correlation to PSC observations at ALOMAR as well as co-ordinated PSC analyses with air-borne measurements and ground-based measurements in Kiruna is ongoing.

In winter 2000/01, the situation was very different from the year before, and rather comparable to 1998/99. The first strong warming occurred in early December 2000, followed by a continuous cooling in late December and most of January 2001. In mid-January, very low temperatures and strong PSCs were observed in Kiruna. At the same time, the weather was dominated by strong westerly winds and clouds in North Norway. Only at the end of the cold period, measurements could be performed at ALOMAR, showing a weak PSC on January 21. End of January, a new strong stratospheric warming took place, marking the end of the PSC and ozone depletion season in 2001 (the earliest termination since 1990).

2.5.3 No obvious ozone trend in the high stratosphere

According to long-term studies of the vertical distribution of the ozone layer based on satellite data (WMO,1999, p. 4.40 ff), the most significant negative trend at mid-latitudes is found between 35 and 45 km altitude. The average ozone density measured by the ALOMAR Ozone Lidar in the months January, February, and March each year from 1995 to 2001 has been investigated at eight

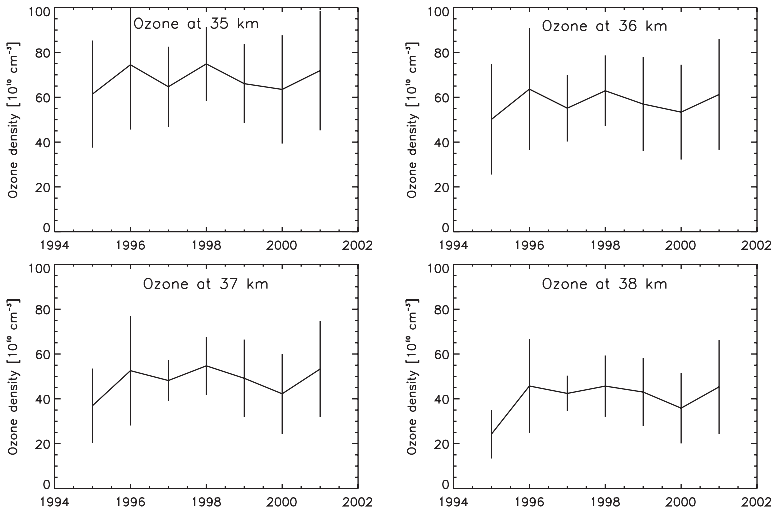

Figure 2.5.3.1 *Average ozone densities as measured with the ALOMAR ozone lidar for the period January-March of all years from 1995 to 2001 at 35 km (upper left), 36 km (upper right), 37 km (lower left) and 38 km (lower right) altitude. The vertical bars denote the variation of the single ozone density values, not their measurement uncertainty.*

high altitudes, from 24 to 39 km. The results for altitudes from 35-38 km are shown in Figure 2.5.3.1. The "error bars" in the figure show the scatter of the individual measurements (standard deviation), not the uncertainty of the mean, which is much smaller. Within this scatter, no decrease in ozone density is apparent. However, this first preliminary result, rather manifests the location of ALOMAR relative to the vortex, varying considerably from year to year. In the next step the study will be continued taking into consideration the position relative to the vortex.

2.5.4 Sudden stratospheric warming

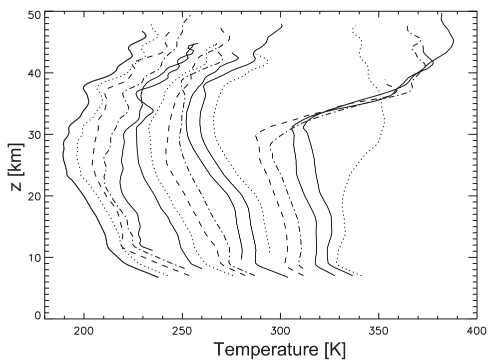

Figure 2.5.4.1 *Series of temperature profiles composed of lidar measurements (typically above 25 km altitude) and ECMWF temperatures close to ALOMAR (below 25 km) in the period 19-30 November, 10-13 December and 20 December, 2000. The x axis values are valid for the first profiles; the other profiles are offset by 7 K, respectively. The December 10-13 profiles show a strong stratospheric warming above 30 km; by December 20 the warming has progressed downward to about 20 km, while the warming above 30 km has faded. Note also the wavelike disturbance between 35 and 40 km altitude in the first 6 profiles which was due to the presence of an aerosol layer.*

The ability of the ozone lidar to measure atmospheric backscatter ratios up to 80 km altitude yields, as already mentioned, also temperature profiles to well above 60 km. The technique is thus suited to document one of the most characteristic features of the northern hemisphere winter, sudden stratospheric warmings. This phenomenon, which is manifests the strong planetary wave activity on the northern hemisphere, usually commences at around 50 km altitude and then propagates downwards on a typical time scale of 10 days. Depending on whether the zonal average zonal circulation north of 60°N reverses, one speaks of a minor or a major warming event (http://www.ffi.no/publikasjoner/hoppe-r-2001-02263.pdf page 11). Then latter class usually leads to the complete break-up of the polar vortex, while in the minor event case the vortex re-establishes. The temperature increases by up to 70 K, reaching more than 300 K at, say, 40 km altitude. In the 2nd COZUV winter (2000/01), two strong warming events occurred, one in the first half of December, and the second one end of January, leading to the break-up of the vortex. Figure 2.5.4.1 shows a series of temperatures profiles from end of November to mid-December, documenting the massive temperature increase in the upper stratosphere until 13 December, and the following warming in the middle stratosphere (down to about 20 km) until 20 December. Similar warmings were also registered in the winters of 1997/98 and 1998/99.

2.6 Task 6: Analysis of ozone change

Ozonesonde launch in the Arctic.
Photo: Thomas Seiler.

2.6.1 Activity 6.1: Hemispheric data

This activity is not a scientific activity, but rather acts as a support for the validation of the 3-D CTM (activity 1.1) and the assessment of ozone loss in activities 6.2 and 6.3. Some examples of data collected under this activity are shown in section 1.

2.6.2 Activity 6.2: Temporal development of the ozone mixing ratio on isentropic surfaces

Introduction

Several of the winters during the last decade have been characterised by heterogeneous processing and substantial chemical ozone loss. This has been shown with various techniques, such as satellite observations (Müller et al., 1997; Manney et al., 1997) and airborne experiments (Schoeberl et al., 1990). The ozonesonde network built in Europe, Canada and Russia since 1988 makes it possible to assess the degree of chemical ozone loss for almost every winter since 1988-89. Several studies based on the ozonesonde network have been carried out (Kyrö et al., 1992; Braathen et al., 1994; Rex et al., 1997; Knudsen et al., 1998). In this work the ozone loss at 475 K (approx. 18 km) is calculated by combining the observed ozone loss rates inside the vortex with the daily average diabatic subsidence inside the vortex. The loss rates are compared to the degree of potential processing inferred from temperature and wind data.

In an idealised polar vortex the ozone mixing ratio at any given isentropic level is constant. In "real life" there are three processes which can disturb this relationship: 1) Diabatic descent of air masses due to radiative heat loss to space, 2) lateral mixing with air masses at middle latitudes due to leakage through the vortex wall and 3) chemical depletion of ozone. The diabatic descent during the winter will cause the ozone mixing ratio at a given isentropic level to increase since the mixing ratio increases with altitude in the height region of interest for ozone destruction (14-25km). The degree of lateral mixing can be limited by studying data taken deep inside the vortex. The third process, chemical destruction of ozone, is the one we want to quantify. By studying the ozone mixing ratio, measured with ozonesondes launched from a large number of sites deep inside the vortex, as a function of time throughout the winter one will get a conservative estimate of the chemical depletion of ozone. By correcting for the diabatic descent that occurs during the winter one will obtain a quite precise estimate of the chemical depletion.

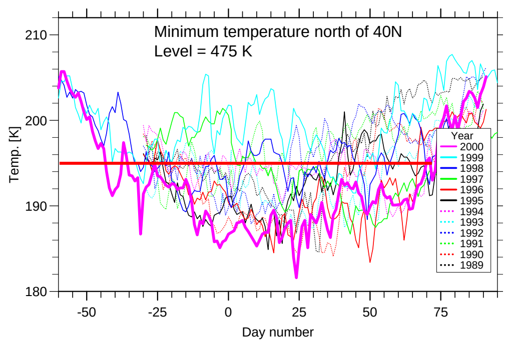

Figure 2.6.2.1 *Minimum temperature north of 40°N. This parameter is calculated by looking through the ECMWF temperature field north of 40°N and picking out the grid point with the lowest temperature. This is done for every day throughout the winter. The plot shows* T_{min} *for every day for the 12 winters from 1988/89 through 1999/00. The thick horizontal line shows the NAT threshold temperature at 475 K.*

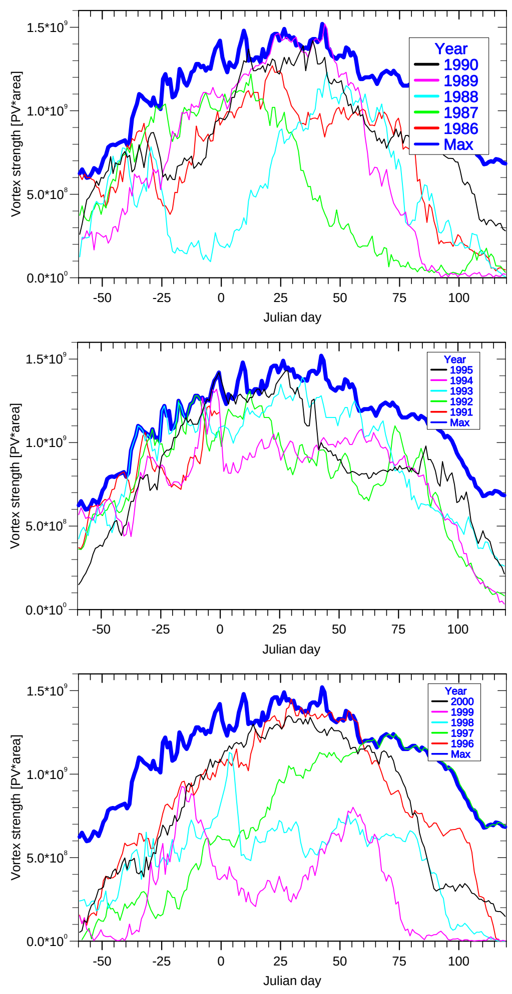

Figure 2.6.2.2 *Vortex strength. This parameter is PV•area ∀ grid cells where PV>42. The upper left panel shows the temporal development of this parameter for the five winters from 1985/86 until 1989/90, the upper right panel for 1990/91 to 1994/95 and the lower left panel for the winters 1995/96 to 1999/00. The thick blue curve represents the maximum vortex strength for each day during the 1979/80 - 1999/00 time period.*

Measurements

The ozonesonde is one of the best tools for measuring the vertical distribution of ozone in the polar vortex.It does not depend on the lighting conditions and it can be launched under almost any weather condition. Since 1988 several ozonesonde stations have been put into operation in the Arctic. Sonde data from these 19 stations have been used in the present study (latitude in parentheses): Alert (83), Heiss Island (82), Eureka (80), Ny-Ålesund (79), Thule (77), Bear Island (75), Scoresbysund (71), Egedesminde (69), Andøya (69), Kiruna (68), Salekhard (67), Sodankylä (67), W/S Polarfront (66), Keflavik (64), Ørland (63), Yakutsk (62), Gardermoen (60), Jokioinen (60), Moscow (56). The photo above shows an ozonesonde launch from Ny-Ålesund. The map shows the stations whose data have been included in the present study. All these stations use the ECC type ozone sensor (ECC-5A or ECC-6A from Science Pump Corp. or the ECC-1Z or ECC-2Z from ENSCI).

Meteorology and PSC incidence

Minimum temperatures

The lowest temperature anywhere north of a certain latitude is often used as a parameter to describe the temperature conditions in the polar vortex. The number of days when the minimum temperature drops below the NAT threshold gives a measure of the time period where PSCs can exist. Figure 2.6.2.1 shows the temporal development of the minimum temperature for the last twelve winters. It can be seen that the 1999/00 winter has been the coldest on many occasions compared to the other winters of the last 12 years.

Vortex strength

The temperature conditions and the longevity of the polar vortex has varied from one winter to the next during the twelve year period from 1989 to 2000. Figure 2.6.2.2 shows the longevity of the polar vortex for the 15 last winters from 1985-86 to 1999-00. One can see a tendency towards more long-lived vortices during the last years. This extends the possible period for ozone depletion, either through halogen chemistry if the temperature is low enough, or through NO_x chemistry if the vortex lasts well into spring (such as in 1997).

PSC area

The geographical area with temperatures low enough for PSC type I condensation is often used as a proxy for the degree of activation. In the present study this parameter has been calculated from ECMWF data and compared to the degree of ozone loss. The light blue shaded curves in Figure 2.6.2.5 show the temporal evolution of this area for the various winters.

Cooling rates

Some earlier studies have been based on the assumption that the ozone mixing ratio is conserved on isentropic surfaces as long as there is no chemical production/depletion (Kyrö et al., 1992;

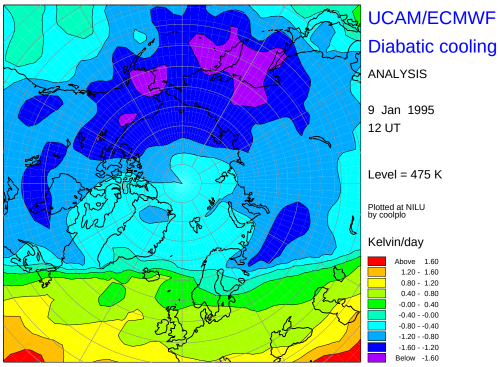

Figure 2.6.2.3 *A typical diabatic heating/cooling field. 9 January 1995 at 12 UT has been chosen as an example. Cooling rates have been calculated by the Atmospheric Chemistry Group at Cambridge University and the University of Leeds with the SLIMCAT 3-D chemical transport model.*

Braathen et al., 1994). Due to radiative processes (diabatic cooling/heating) an air mass will not keep its potential temperature for very long. Since the ozone mixing ratio profile displays a gradient at the level of interest here (475 K), we need to take the diabatic heating/cooling into account when calculating ozone loss rates. Data are available for most of the winters of the last decade. Figure 2.6.2.3 shows a typical cooling/heating field.

Chemical ozone loss analysis

The change of ozone on isentropic surfaces can be caused by either horizontal or vertical transport, or chemistry. A suitable mathematical description of this is given by the zonal mean system in Andrews et al. (1989). As e.g. Schoeberl et al. (1992) have indicated, horizontal transport across the vortex edge approximates to zero. On isentropic surfaces, vertical transport is caused by diabatic effects only. This results in the following expression for the temporal development of the ozone mixing ratio:

$$\left(\frac{\partial X_{O_3}}{\partial t}\right)_{chem} = \left(\frac{\partial X_{O_3}}{\partial t}\right)_{obs} + \frac{\partial X}{\partial \theta} \cdot \frac{\partial \theta}{\partial t} \qquad \text{(Eq. 1)}$$

where $\partial X/\partial\theta$ is the ozone gradient as a function of potential temperature and $\partial\theta/\partial t$ is the diabatic heating/cooling rate. The ozone gradient has been determined from monthly mean ozone profiles. An example of such a profile is shown in panel D of Figure 2.6.2.4. The diabatic heating/cooling rate has been calculated as a vortex average of four daily fields. An example of the temporal development of the heating/cooling rate is shown in panel C of Figure 2.6.2.4.

Time series of PV for each of the stations have been extracted from ECMWF data for each of the winters. Only ozone profiles where $PV > 42 \cdot 10^{-6} Km^2/kgs$ at 475 K have been included in the analysis. Two exceptions are the winters of 1990-91 and 1998-99, where this criterion was relaxed to $36 \cdot 10^{-6} Km^2/kgs$ in order to get enough data. The mixing ratio of ozone at various levels has been extracted from the sonde data. The temporal rate of change has been calculated from the mixing ratio time series.

The analysis is illustrated in Figure 2.6.2.4. The active period of ozone depletion has been identified from graphical presentations like the one shown panel B in Figure 2.6.2.4.

Results and discussion

Figure 2.6.2.5 shows combined plots of the area of air subject to sub-NAT temperatures and the temporal development of the ozone mixing ratio. The first impression is that every winter is different in terms of PSC incidence. Three winters stand out as particularly cold, namely 1994-95, 1995-96 and 1999-00. These three winters are characterised by large PSC areas in the early winter and also PSC activity late in the winter. Some winters also stand out as particularly mild, namely 1990-91, 1997-98 and 1998-99. The remaining six winters represent intermediate cases.

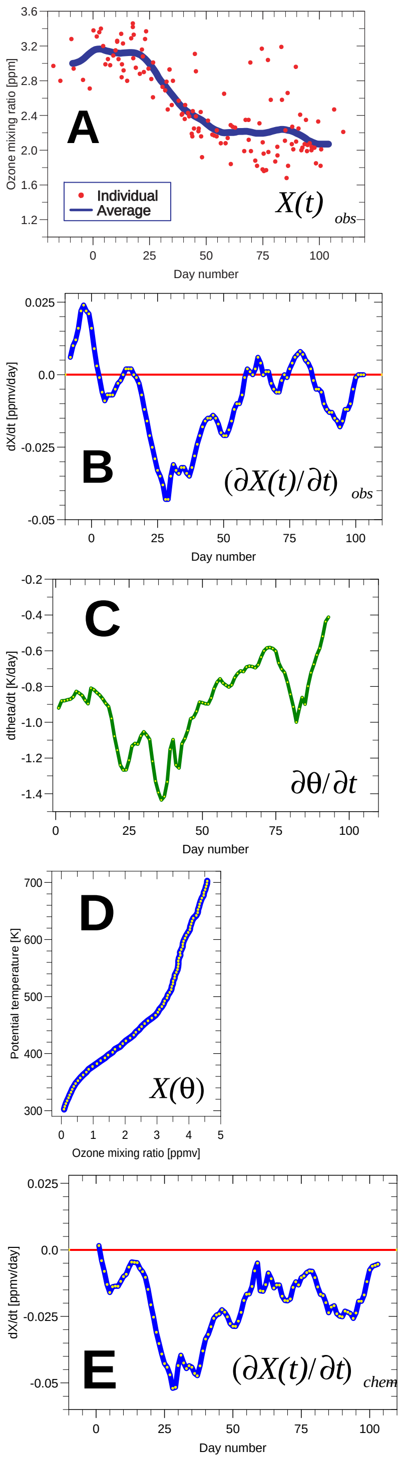

Figure 2.6.2.4 *Illustration of the analysis. Winter 1994-95 is chosen as an example. Panel A is the observed data set. Ozone mixing ratios at 475K are calculated from inside vortex soundings. Differentiation with respect to time gives the next plot (panel B). This data set is then added to the product of ∂θ/∂t and ∂X/∂θ. The first is shown in panel C, the latter is obtained by differentiating the ozone profile shown in panel D. The resulting rate of change is shown in panel E.*

The chemical ozone loss for all the winters with sufficient data has been carried out according to Eq. 1 and illustrated in Figure 2.6.2.4. The results of these calculations are shown in Table 2.6.2.1.

Eq. 1 holds under the assumption that there is no lateral mixing across the vortex boundary. Experimental evidence shows that this assumption is valid. Ozone mean profiles have been calculated for days 50-75 inside and outside the vortex in 1995. These profiles are shown in Figure 2.6.2.6. It can be seen from this figure that the ozone concentration is larger outside than inside the vortex. Mixing of air from mid-latitudes into the vortex would lead to an increase in the ozone concentration and thereby mask some of the chemical ozone depletion. This means that the estimates made here are conservative estimates of the chemical ozone loss. Tracer-tracer correlations, such as N_2O vs. CFC-11, can be used to detect intrusion of mid-latitude air into the vortex. Since these gases have different life-times in the stratosphere they exhibit different vertical profiles. Intrusion of mid-latitude air would lead to a change in the tracer-tracer correlation over time. Tracer measurements carried out in Kiruna in late January and early March 2000 show that there is no change in the N_2O vs. CFC-11 relationship. This is a clear indication that the vortex edge has been tight and that no mid-latitude air has entered the vortex (Müller, 2000).

From Figure 2.6.2.5 it is clearly seen that the ozone decline coincides in time with periods of PSC activity. Plotting of the ozone rate of change (Figure 2.6.2.4, panel E) together with the PSC area shows that the loss rate decreases immediately after the PSCs disappear. However, the ozone reduction continues for 10-20 days after the temperature rises above the PSC condensation temperature. Three winters stand out with regard to the amount of ozone loss, namely the winters 1994-95, 1995-96 and 1999-00. All these winters exhibit approx. 70% ozone loss at 475K. These three winters are the same as the three mentioned above as outstanding in terms of PSC area. These three winters have large PSC areas in the early winter, starting already in early December, and they also have PSC possibilities late in the winter. PSC temperatures in the early winter alone does not give rise to massive ozone loss, such as in 1989-90 and in 1992-93. Likewise, low temperatures late in winter alone is also not enough to cause the massive ozone loss of approx. 70% seen in 94-95, 95-96 and 99-00.

Typical winters with low temperatures at a late stage are 1993-94 and 1996-97. These winters experienced chemical ozone loss on the order of 40-50% at 475K.

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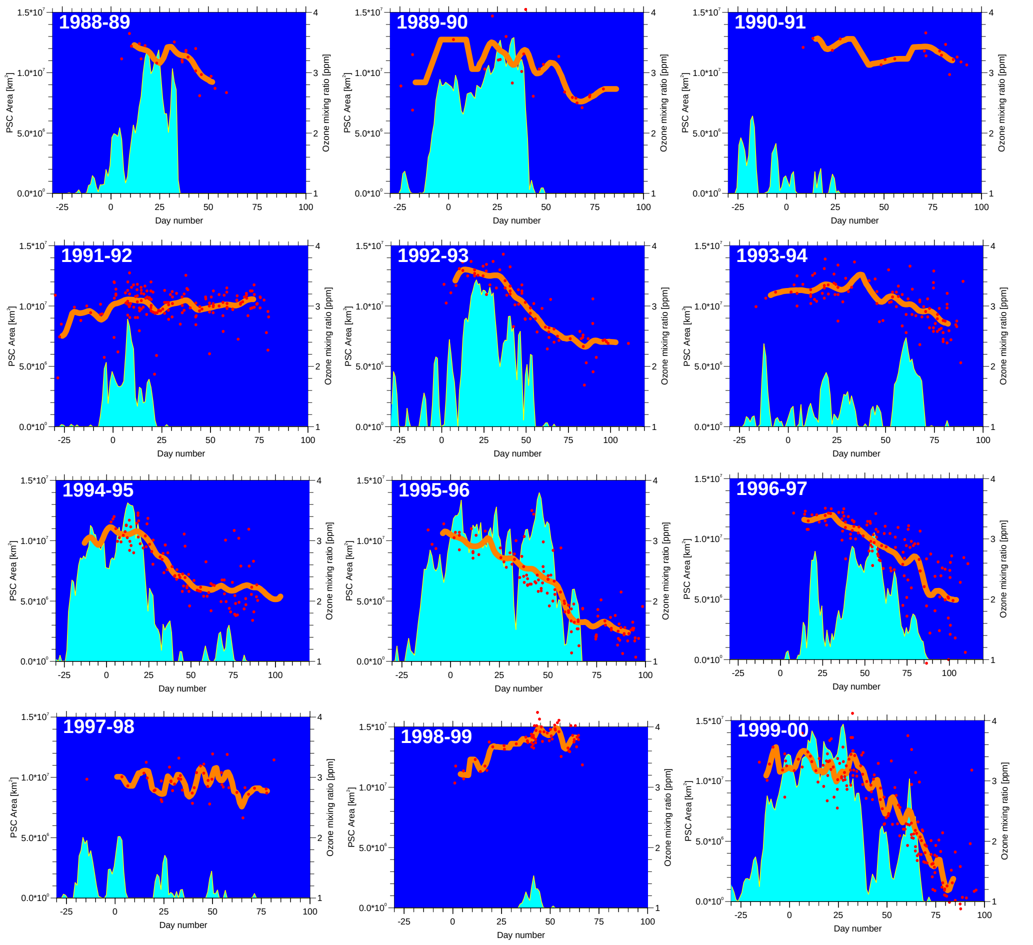

Figure 2.6.2.5 *Time series of the ozone mixing ratio at 475K for the winters between 1988-89 and 1999-00. The red dots represent individual soundings and the orange line is a 15-day Gaussian running average. The light blue shaded curve shows the geographical area subject to temperatures below the PSC type I condensation limit at the 475K level. All soundings were carried out inside the polar vortex (PV > 42·10^{-6} Km^2/kgs except for winters 1990-91 and 1998-99 where this criterion was relaxed to 36·10^{-6} Km^2/kgs).*

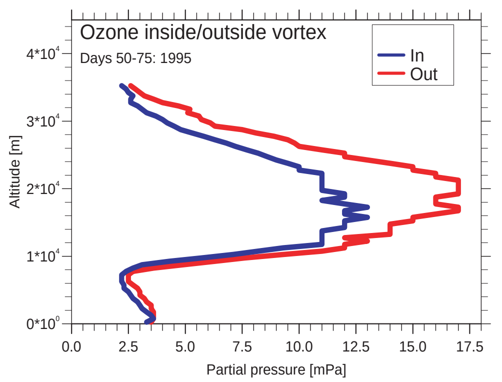

Figure 2.6.2.6 *Average ozone profiles for the time period between days 50 and 75 in 1995. The blue curve represents soundings taken inside the vortex and the red curve is the mean of profiles measured outside the vortex.*

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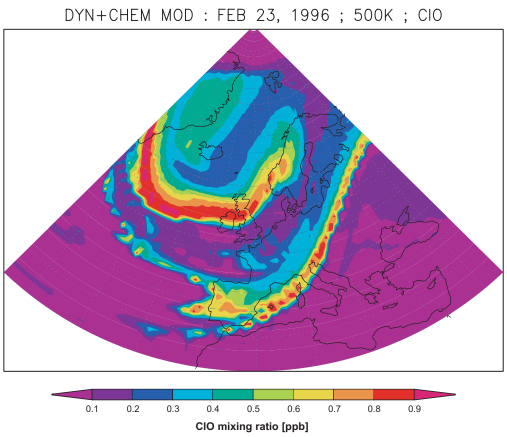

Figure 2.6.3.1 *ClO mixing ratio calculated by the domain-filling trajectory model at 500K for February 23rd, 1996. The red colour corresponds to 1ppb.*

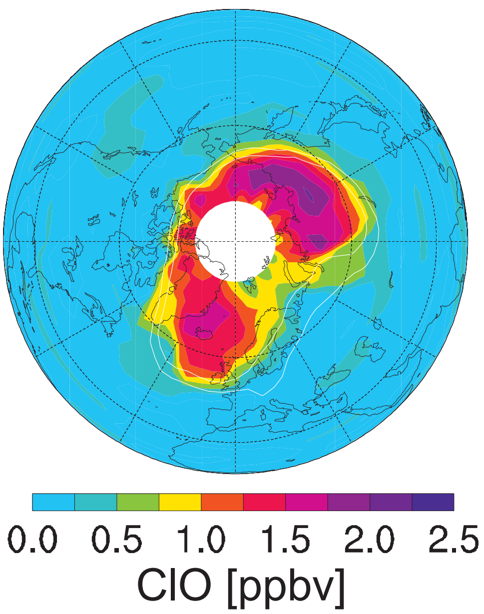

Figure 2.6.3.2 *ClO observed by the MLS instrument for 23 February 1996 at the 500K isentropic level.*

Table 2.6.2.1.: Summary of ozone loss data

Winter	# of sondes	Active ozone loss period (days)	Observed ΔO_3 (ppm)	Chemical ΔO_3 (ppm)	% change
1988-89	35	29-55	-0.58 ± 0.11	-0.69 ± 0.13	20 ± 4
1989-90	32	21-69	-0.86 ± 0.14	-1.18 ± 0.23	33 ± 6
1990-91	12	not enough ozonesonde data			
1991-92	208	10-25	-0.13 ± 0.07	-0.72 ± 0.31	23 ± 10
1992-93	93	16-84	-1.22 ± 0.10	-1.50 ± 0.17	43 ± 5
1993-94	112	35-85	-0.74 ± 0.07	-1.27 ± 0.31	38 ± 9
1994-95	156	1-100	-1.09 ± 0.06	-2.12 ± 0.58	67 ± 18
1995-96	140	1-94	-1.65 ± 0.07	-2.22 ± 0.33	72 ± 11
1996-97	143	24-104	-1.37 ± 0.10	-1.60 ± 0.17	47 ± 8
1997-98	46	13-68	-0.35 ± 0.11	-0.74 ± 0.25	24 ± 6
1998-99	70	24-58	0.13 ± 0.06	-0.49 ± 0.36	15 ± 11
1999-00	183	10-90	-2.27 ± 0.11	-2.53 ± 0.17	73 ± 5
2000-01	36	25-35	-0.32 ± 0.09	no cooling data	
The uncertainties are 1 σ					

2.6.3 Activity 6.3: Comparison between modelled and observed ozone loss

Phase I

Ozone loss in the domain-filling trajectory model

The domain-filling trajectory model was in Phase I run with ozone chemistry for a period of time in February 1996. We show ClO results for February 23rd for the 500 K potential temperature level in Figure 2.6.3.1. It is interesting to notice the fine structure of the ClO concentrations as computed by the model. There are zonal bands of relatively fine structure, with very fine structure along the zonal direction. The maximum ClO concentrations are estimated from the British Isles and northward. There is an interesting feature east of Iceland, with a secondary minimum in ClO. This secondary minimum cannot be seen in the MLS data, which are shown for the same potential temperature level and the same date in Figure 2.6.3.2. The extent of the minimum is of roughly the same magnitude as the horizontal resolution of the satellite observations (about 400 km), so that it cannot be ruled out that the model here resolves a

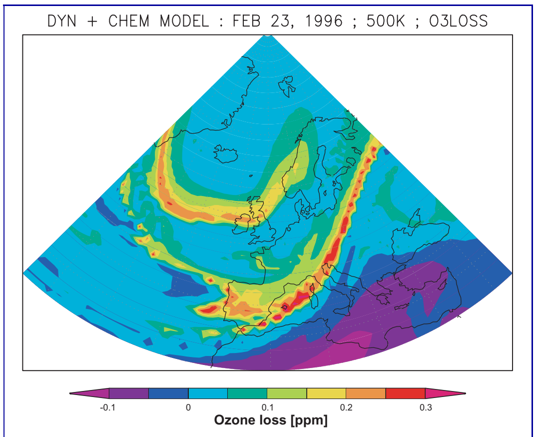

Figure 2.6.3.3 Chemical ozone loss (mixing ratio over 10 days) calculated with the domain-filling trajectory model at the 500K isentropic level for 23 February 1996.

feature, which cannot be seen in the satellite data. Very interestingly, a rather fine band of high ClO can be seen in the Mediterranean area at a scale that can not be resolved by the MLS observations. This is a fine-scale filament which has been exported from the polar vortex to mid latitudes. The ClO concentrations are similar to the ones in the maximum area near the edge of the polar vortex, namely almost 1 ppb. Fine structures of elevated ClO at mid-latitudes can be seen in the MLS observations as well, although not at the exact same location and with significantly lower values (only up to about 0.5-0.7 ppb). The ozone loss modelled is presented in Figure 2.6.3.3. The ozone depletion follows the same pattern as the ClO concentration. It is interesting also to notice that the ozone depletion in the band in southern Europe is somewhat stronger than in the area near the vortex edge. This is due to the higher levels of solar radiation to drive the ozone depletion chemistry further south.

Ozone loss from models and observations

We first compared the ozone loss in 1997 calculated by the Oslo CTM-2 model with the loss found from ozone soundings in the period for which the model had been run, namely 1 January to 1 February. The maximum ozone loss was about 100 ppb. This is little compared to the ozone loss found in the soundings, which amounts to about 400 ppb in the same period as an average for the vortex region. Next we compared the loss rate computed in the domain-filling trajectory model with the loss rate derived from the ozone soundings. The loss rate in the model for February 23rd is 0.3ppm over 10 days. This is significant and reflects an activated chlorine chemistry. The observed ozone loss (from the ozonesondes) in late February is between 0.2 and 0.4 ppm over a 5 day period, which for the observed ozone content of about 2 ppm corresponds to a lifetime of 10-20 days. The discrepancy between the model and the observations is not too large, but the ozone loss from the sondes represent an average for the entire polar vortex region.

Phase II

In this activity ozone loss as calculated by models will be compared to observations. Model results have only recently been available for this task, and the results obtained so far are therefore not very extensive and only preliminary. The following is status of the progress in Phase 2.

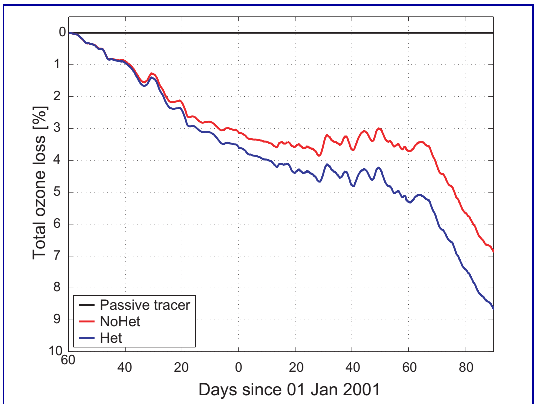

Figure 2.6.3.4 Chemical depletion of total ozone in the area north of 66°N deduced from runs with ozone vs passive ozone in the Oslo CTM-2. Two separate runs including ozone chemistry have been made, including and excluding heterogeneous chemistry.

Ozone loss during individual winters

Oslo CTM-2 has been run with the aim to quantify the chemical loss. For the winter 2000/01 an experiment was run with ozone as passive tracer. The difference between the standard run and the passive tracer run is interpreted as the chemical loss. This is a technique used earlier by the SLIMCAT (Chipperfield, 1999) as well as the REPROBUS (Goutail et al., 1999) models. The results from CTM-2 are shown in Figure 2.6.3.4, as total ozone north of 66°N. From December 1st to March 10th the ozone loss was about 4%.

This is in reasonable agreement with similar model results (Deniel et al., 2000 and updates from F.Goutail, private communication) from REPROBUS (about 5%, using ECMWF winds, as Oslo CTM-2), but somewhat lower than SLIMCAT (about 12%, using UKMO winds). The results obtained in COZUV also give a lower ozone loss than observed by a group of SAOZ instruments (F.Goutail, private communication). It is important to notice that in this preliminary comparison the results from SAOZ, SLIMCAT and REPROBUS are all averages in the polar vortex, whereas in the Oslo CTM-2 an area north of 66°N has been used. Vortex averages will be calculated in the near future.

Ozone trends

The SCTM-1 will be run from 1970 to 2000 in Phase II. At the moment, results up to 1989 have just been completed. In the following a preliminary analysis of the results obtained is made. Figure 2.6.3.5 shows the ozone changes in the periods 1970-1980 and 1980-1989. The results are given for April conditions. It is interesting to notice that although the main pattern is similar between the two periods, there are significant quantitative differences. In the upper stratosphere the ozone loss was larger in the former than in the latter period, with 6% and 3% reductions at the Equator, respectively, increasing to 12% and 6%, respectively, at high latitudes in the Northern Hemisphere. The situation is reversed in the lower stratosphere, where the maximum ozone reduction was weaker in the former than in the latter period, namely 8% and 15% during the two time periods, respectively. In order to interpret these results additional experiments will be run to identify the changes which are due to methane, nitrous oxide and halogenated source gases.

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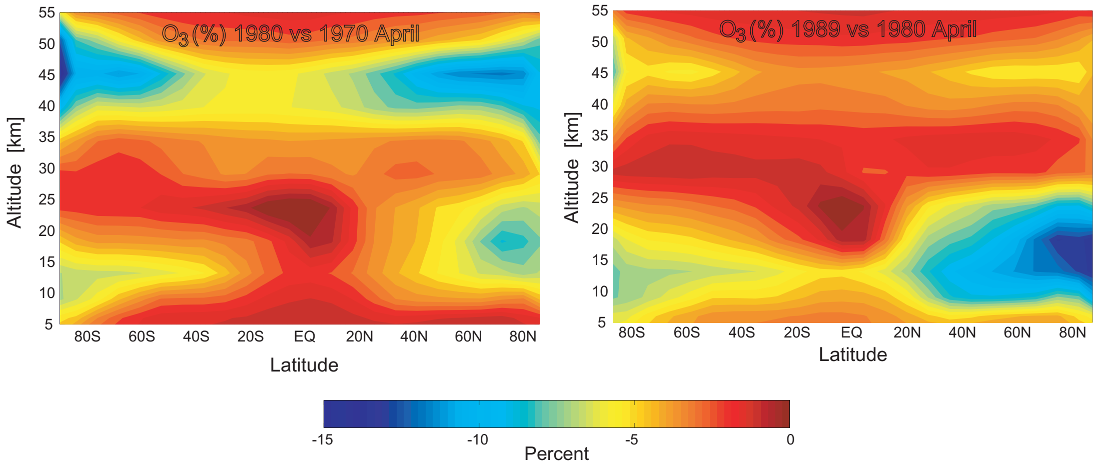
Figure 2.6.3.5 *Meridional distribution of zonally averaged ozone changes in the two periods 1970-1980 (left panel) and 1980-1989 (right panel) as calculated in SCTM-1.*



2.7 Task 7: Ground-based UV measurements

2.7.1 Activity 7.1: Direct and global UV measurements in Trondheim as part of a European network

Figure 2.7.1.1 *The tracker pointing the telescope measuring in zenith direction and the global irradiance cosine head (J1002) in the background to the right.*

A spectroradiometer system has been developed with a sun tracker system to make it possible to do direct sun and sky radiance measurements. The kernel of the spectrometers system is a modified Bentham DM150 with two optical inputs to the monochromator. Each of the optical inputs has a 4m long quartz fibre. One fibre was mounted on a cosine head of type J1002 with an entrance optics which has close to ideal angular response (see Figure 2.7.1.1). This new cosine head, which is built into a housing with heating to prevent frost and ice, replaced the original flat transmission diffuser and the cosine error was reduced to an insignificant problem. Estimates of the cosine error with this new cosine head have been made and a paper showing the results is in preparation [Thorseth et. al. 2002].

The other fibre bundle was connected to a telescope mounted on a sun tracker for direct or radiance measurements (see Figure 2.7.1.1).

No commercial tracker system with a flexible software to be integrated with a spectroradiometer system existed and the tracker system had to be designed. The complete system is weather proof and has the freedom of performing sky radiance distribution measurements at any desired direction. The need to alternate between global and direct scans, being able to put time stamps on each measurement event down to a time resolution of less than one Hz, to include temperature and relative humidity readings of the monochromator environment as part of the quality control, called for new software developments in addition to the tracker system developments. The tracker system design has been improved through several modifications of the initially designed prototype and has been tested recently.

Information from a multi-channel filter radiometer (Biospherical GUV-541) with high sampling rate was used in addition to the spectroradiometer. A method to apply filter instrument data to monitor stability of the spectroradiometer absolute calibration on a short term range, between regular calibrations has been developed [Thorseth and Kjeldstad 1999].

A significant part of the quality control (QC) of the measurements are calibrations of the wavelength scale and the absolute scale. A procedure for calibrating the wavelength scale has been developed in phase I and an algorithm for continuous monitoring of the wavelength scale of the solar global irradiance spectra was improved.

Calibration of the global irradiance measurements has been performed without problems and calibrated measurements have been done. Our absolute calibration standard and measurement system with setup to reproduce the absolute standard has been verified through an international co-operation [Gröbner et. al. 2002].

A method for QC on global irradiance absolute scale has been developed, based on comparison of the measurements with ancillary data (filter instrument data).

2.7.2 Activity 7.2: UV radiance distribution in a sub-Arctic region

The spectroradiometer system described in Activity 7.1 will be used for radiance distribution measurements. The system is working and some preliminary tests have been performed. Results from the first measurements are shown in Figure 2.7.2.1. A complete check of the reliability of the radiance measurements will be done as soon as some clear sky days appear and the Sun is higher.

Test measurements done under partly cloudy and complete overcast conditions showed that the signal is a factor 100 above noise level. At complete overcast conditions there was typically a signal to noise ratio of 5-7. At these conditions noise becomes a problem for wavelengths below 320 nm under cloudy conditions. For clear sky measurements where the signal is stronger, the throughput of the telescope and the direct entrance optics seams to satisfactory. Calibrated radiance distribution measurements can be performed after the calibration procedure has been established for direct and radiance measurements. Instrument characterisation of the tracker system has to be performed before a lamp calibration of the system can be done correctly.

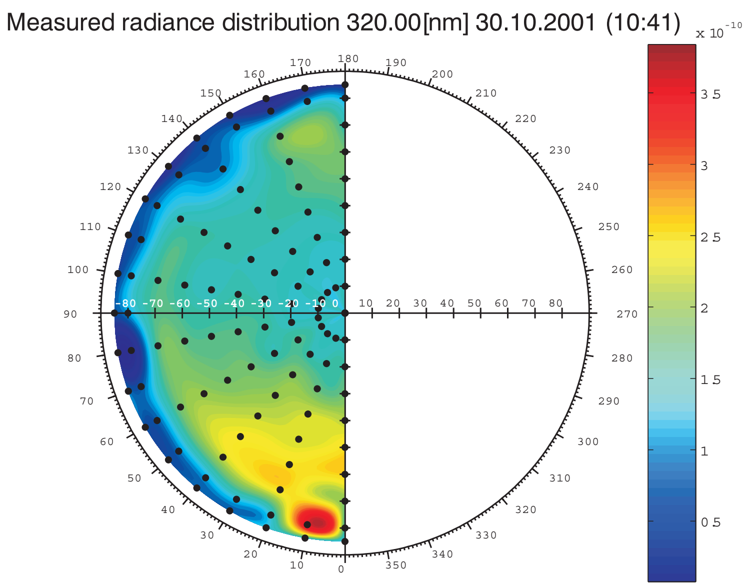


Figure 2.7.2.1 *Radiance distribution measurement at 320 nm made on 30 Oct. 2001 under fractional variable cloud cover, s.z.a 77.3°. The Sun was located at an azimuth angle of ~0 and partly covered by clouds. The irradiance scale is relative, red denotes high signal, blue denotes low signal. Red areas, indicating strong radiance, are not located directly towards the sun but are indirectly reflected from clouds or is shown as circumsolar radiation passing through openings in the cloud cover.*

Algorithms for direct sun measurements are still under development, thus calibration of the direct input optics has been postponed. Thus the scale in Figure 2.7.2.1 is relative.

2.7.3 Activity 7.3: Impact of broken clouds on ground based UV irradiance; measurements, analyses and validation

Measurements at variable cloud conditions are based on spectral measurements in combination with a multi-channel filter instrument detecting rapid changes. The two sets of data can be combined to gain spectra at an effective sampling rate of ~0.5.Hz in the paper published as part of COZUV I.

In order to meet the objectives of measuring radiation under variable cloud conditions a software system has been given several features to help meet the measurement problem. Timing of each measurement event is essential in combining measurements with data from other instruments. By applying time stamps on each measurement event in both systems the measurements can easily be joined together for several purposes.

Figure 2.7.3.1 shows how combined filter instrument data measured simultaneously can be used to derive spectral irradiance at a new sampling rate, providing data that can be used to study cloud effects in a new way.

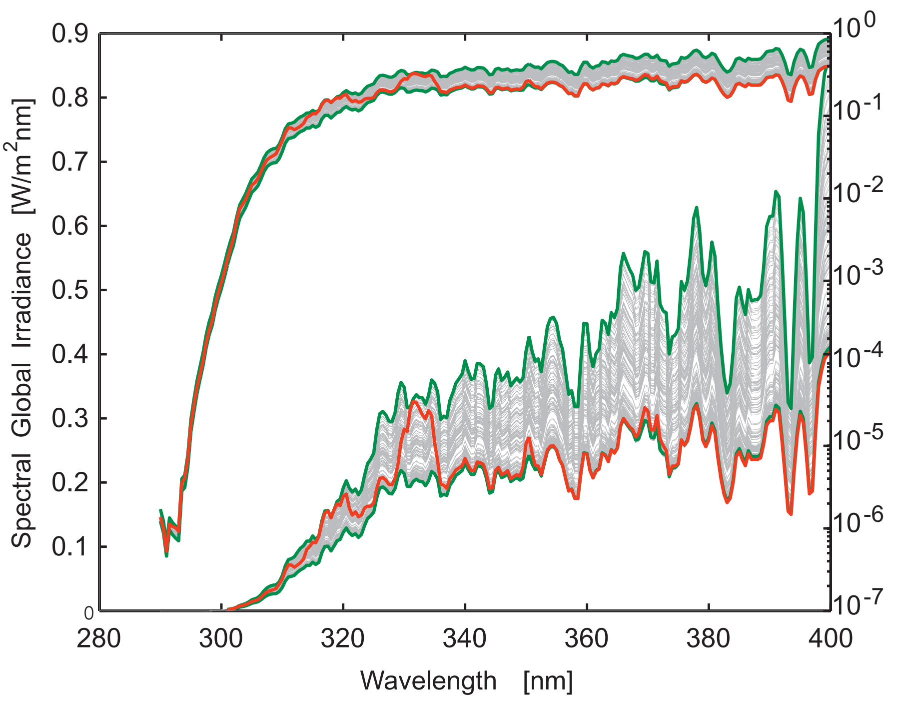


Figure 2.7.3.1 *Global irradiance spectra at 0.5Hz (grey curves) derived from spectral global scan and filter radiometer data at 0.5Hz at five channels. Note both logarithmic and linear scale. The red lines show the original solar scan and the green thick lines show max and min irradiance level during spectral scan time.*

Cosine error corrections

Cosine error caused by an imperfect irradiance cosine head has been one of the main problems and concerns for intercalibration of global irradiance measurements. The error will depend on the radiance distribution in addition to instrumental factors, and thus depends on atmospheric conditions. Corrections of cosine error can be done at clear sky conditions when the radiance distribution is known. The radiance distribution and its dynamical features during variable cloud conditions remain unmapped, thus making corrections at cloudy conditions is more difficult. The 1-D radiative transfer model Libradtran, from A. Kylling and B. Meyer, has been applied to estimate cosine error for clear sky measurements knowing the angular response of the instrument. A comparison of different cosine correction methods was performed at an intercalibration in Sweden June 2000. A complete comparison of our initial correction method and the correction method applied by five other groups was performed on the same instrument, a Brewer spectroradiometer, with known angular response [Thorseth et. al. 2002]. The comparison is under preparation for the NOGIC-2000 intercomparison report. Filter instrument data at 3Hz from the NTNU group were applied to help analysing both the cosine error comparison and the spectral sky measurements [Kjeldstad et. al. 2002].

Figure 2.7.3.2 and 2.7.3.3 show cosine correction factors for one instrument retrieved from 5 different methods.

At clear sky conditions (Figure 2.7.3.2) factors range between 1.04 and 1.09 at 300 nm to 1.04-1.12 at 360 nm. The dynamical variation is biggest for the NTNU algorithm since it applies a modelled radiance distribution and is not assuming isotropic diffuse radiance distribution as all the others. At cloudy conditions less diurnal variability will be observed and the corrections that apply cloud input tend to indicate a constant correction factor. There is a signifi-

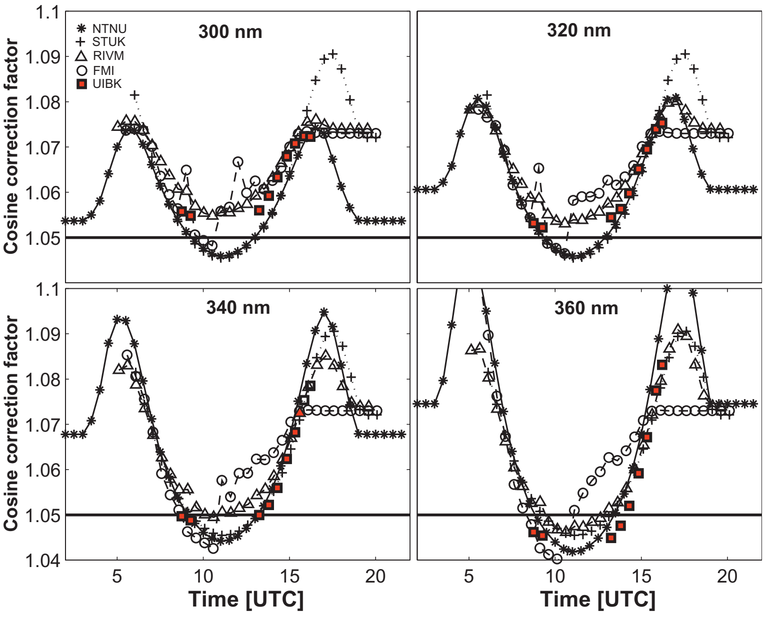


Figure 2.7.3.2 *Cosine correction factors for the Brewer #128, estimated for a close to clear sky day showing results from four wavelengths 300 (top left), 320 (top right), 340 (bottom left), and 360 nm (down right).*

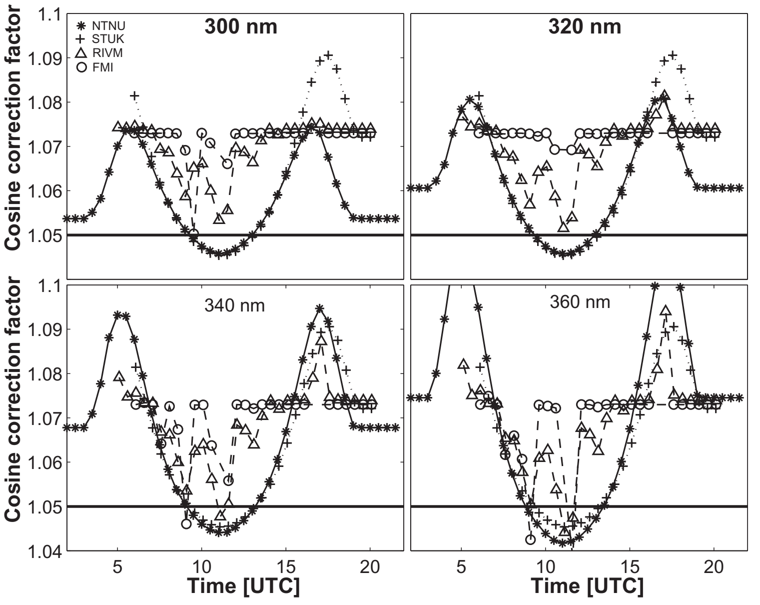


Figure 2.7.3.3 *Cosine correction factors for the Brewer #128, estimated for a day with complete cloud coverage for four wavelengths 300 (top left), 320 (top right), 340 (bottom left), and 360 nm (down right).*

cant variability in the results from the different algorithms, that gets more pronounced during cloudy conditions. The different algorithms used are homogenous. At cloudy conditions less diurnal variability will be observed. However, there is a larger variability between the different algorithms. The two algorithms that apply cloud corrections show a correction factor that is constant with time but this level is constant with wavelength and also with cloud optical thickness. There are indications that those algorithms that include clouds in their correction procedures have a too strong sensitivity to clouds. Small clouds or thin cloud layers cause the correction to be made as if the sky was completely covered. The overall conclusion from the study is that we have no knowledge about the true cosine error when there are clouds present on the sky.

Since the intercomparison of cosine error correction procedures revealed a complete lack of knowledge about the cosine error under variable fractional and complete overcast sky, the NTNU measurement system was modified to perform a direct test measurement of the cosine error. This approach of directly measuring the cosine error can be further applied to develop cosine error correction procedures that has a known error for all kind of weather conditions. The results of this preliminary cosine error measurement campaign were presented at the ESP meeting at Lillehammer, September 2001 by Thorseth. Also here the 3Hz filter instrument data played a significant role in correcting the data for rapid dynamic changes.

Preliminary results show that there are large dynamical changes in the real cosine error that were strongly dependent on whether clouds were covering the sun or not. This cloud effect on cosine error is wavelength-dependent. Before these effects can be modelled correctly and ancillary data at 3Hz exist in parallel with the measurements only rough estimates of the cosine error can be performed. However the data was measured with the stray light problem and has hence a large portion of noise. In order to get a publication out of this work, the measurements have to be repeated with better characterisation of both entrance optics and spectral resolution. This can not be done until the sun trajectory is higher on the sky.

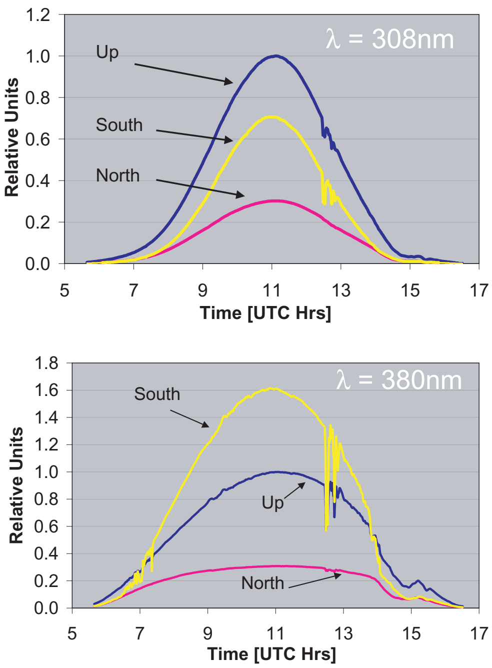


Figure 2.7.4.1 *Measurements on a clear day (5 Oct. 2001). The upper graph shows the result for a UV-B channel (308nm) and the lower graph shows the result for a UV-A channel (380nm)*

2.7.4 Activity 7.4: Measurements of UV radiation on vertical surfaces

Due to the late start of the measurement programme the results are limited. During the project the collected data will represent highly variable conditions with respect to solar elevation, surface albedo, cloudiness and atmospheric ozone amount. Figure 2.7.4.1 shows results from October 5, 2001, a day which represents a clear sky. This figure illustrates the daily variations in the UV-B and the UV-A regions. Relative units are used where 1 is the maximum value obtained during the day by the upward looking instrument (horizontal surface). The sun was quite low in the sky even at noon, approximately 25 degrees above the horizon. In the upper panel (305nm channel) the irradiance in the upward looking instruments is highest and lowest in the north pointing instrument. The lower panel (380nm channel) reveals a different behaviour between the three instruments. Here the south pointing instrument receives the highest irradiance most of the day. But the north pointing instrument still receives the lowest irradiance. The different behaviour in the UV-B and the UV-A is probably due to stronger scattering by air molecules in the UV-B compared to what is the case in the UV-A. On a cloudy day the wavelength dependent result seen on the clear day was not present. This is also expected because the radiation is strongly scattered by clouds and the direct component of the radiation is absent. On the cloudy day the irradiance in the north and south pointing instrument are comparable and about half of what was measured in the upward looking instrument.

2.8 Task 8: Airborne UV measurements

The NILU-CUBE instrument is a twelve channel narrow-band filter instrument with six input optic heads, each mounted on the face of a cubical frame. Each head measures the irradiance in two channels. The channels are centred at 312 and 340 nm and have a full width at half maximum (FWHM) of approximately 10 nm. In order to keep the weight and power consumption low, the instrument is not temperature stabilized. However, the instrument is very well insulated and the temperature is recorded for each of the six heads. Data are recorded every five seconds and stored in a separate logging unit.

To measure UV radiation with high sensitivity and accuracy it is necessary to reject radiation outside the wavelength band of interest. To reject straylight is particularly challenging in the UVB (280-320 nm) part of the spectrum. The NILU-CUBE has one channel centred at 312 nm and one centred at 340 nm. It was experienced that the 312 channel had unacceptable amounts of out of band radiation, hence the custom made filters were not behaving as expected. After extensive testing and searching for possible errors it was clear that additional blocking filters were required to make the instrument behave as planned. These filters were received in July 1999.

Due to the above mentioned filter problems both the construction of the data logging system and the calibration of the instrument was delayed not enabling us to fly during 1999 as originally planned. The filter problems was finally resolved and the first flight was made from the airport of Gap-Tallard (44.457°N, 6.034°E, 618 m.a.s.l.), France, on 30 June, 2000. The flight started at 174850 UTC. It took about 90 min. to reach the float altitude of approximately 30450 m.a.s.l. The balloon stayed at the float altitude for 28 min. The NILU-CUBE was mounted such that one head pointed straight up and the opposite head down. Altitude information was taken from GPS receivers.

To check the NILU-CUBE before and after flying a NILU-UV instrument was used. The NILU-UV is a six channel moderate bandwidth filter instrument. It measures the total (direct plus diffuse) downward irradiance at 305, 312, 320, 340, and 380 nm with a FWHM of 10 nm. In addition it has a channel covering photosynthetic active radiation (PAR) between 400-700 nm. The 312 and 340 nm channels are identical on the NILU-UV and the NILU-CUBE except for the shape of the teflon diffusors on the respective instruments. The NILU-UV is temperature stabilized. It reported data every second to a computer. Comparison between the NILU-CUBE and the NILU-UV before and after flight revealed no detectable changes in the NILU-CUBE.

In addition to being used to check the stability of the NILU-CUBE before and after flying, the NILU-UV was used during the flight to monitor the radiation field at the surface. The clocks of the NILU-CUBE and the NILU-UV where synchronized using Global Position System (GPS) receivers prior to the flight.

The NILU-CUBE was absolutely calibrated against a Bentham DM300 scanning spectroradiometer after the flight using the procedure described by Dahlback [1996].

The measurements represented as the sum of the calibrated signal from all heads for each channel are shown in Fig. 8.1 as blue (312 nm) and red (340 nm) lines as a function of solar zenith angle. The green line indicates the altitude of the instrument.

The measurements were simulated by the UVSPEC model from the libRadtran package (www.libradtran.org). The radiative transfer equation was solved by the discrete ordinate algorithm of Stamnes et al. [1988] operating in 16 streams mode with spherical correction as described by Dahlback and Stamnes [1991]. The radiative transfer model has earlier shown good agreement with surface UV-measurements (Mayer et al., 1997, Kylling et al. 1998).

Ozone and temperature profiles were taken from an ozone sonde launched from Observatoire Haute Provence, (OHP), 100 km to the south of Gap-Tallard, on 28 June. The ozone column estimate from the sonde data was 303 DU. Data from EP-TOMS between the 28-30 June indicates that the ozone field was relatively stable during this period. Hence, the profile from the 28th is expected to be representative for the conditions on 30 June as well. The ozone cross section was taken from Bass and Paur [1985]. The ground albedo was set to 0.05 which is representative for the type of surfaces around Gap-Tallard (Feister and Grewe, 1995).

The NILU-CUBE reports data values every 5 s which corresponds to an altitude resolution of about 50 m. For each altitude an actinic flux spectrum was calculated and convolved with the spectral response for each channel. The resulting simulated actinic fluxes are shown as black lines in Figure 2.8.1.

The agreement between the simulations and the measurements is excellent. The simulations may thus be used as basis for the calculation of actinic flux spectra which subsequently may be used to estimate various photo-dissociation rates. An example is provided in Figure 2.8.2 which shows $J(NO_2)$ (blue line) as estimated from the NILU-CUBE simulations. The black lines are the $J(NO_2)$ for fixed solar zenith angles of 75 and 90°.

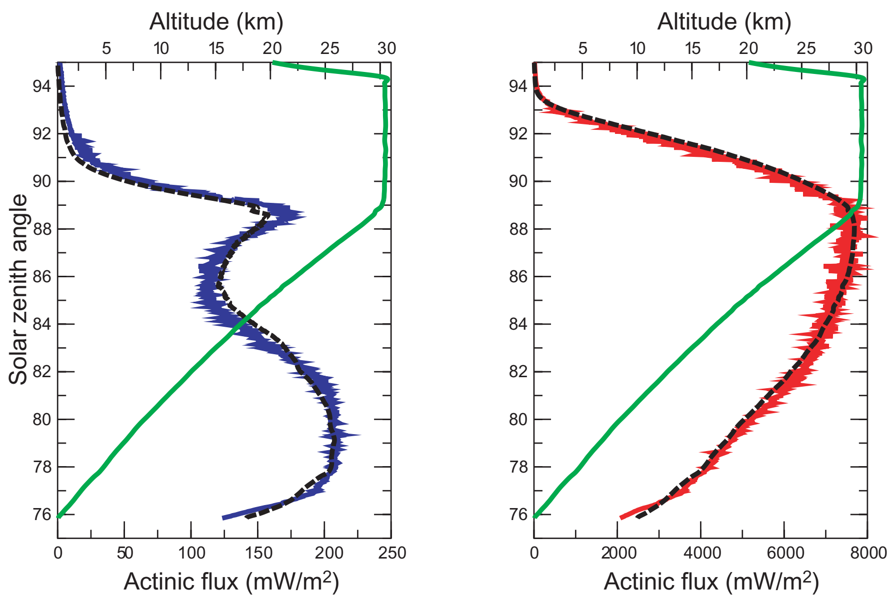


Figure 2.8.1 *The sum of the signal from all heads for each channel as a function of the solar zenith angle (blue line: 312 nm, red line: 340 nm). The green line is the altitude of the instrument. The black lines are model simulations of the measurements.*

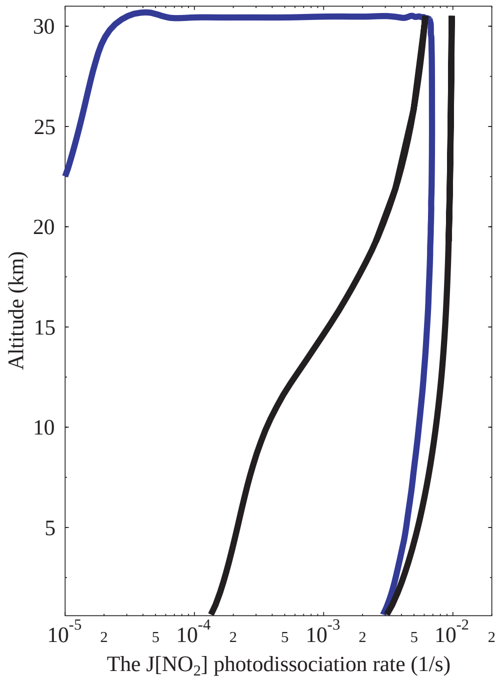


Figure 2.8.2 *(Blue line) The $J(NO_2)$ photo-dissociation rate as estimated from the NILU-CUBE measurements. (Black lines) The same photo-dissociation rate, but for constant solar zenith angles of 75° (right black lines) and 90° (left black lines).}*

2.9 Task 9: UV modelling

2.9.1 Results from Phase I

The Earth's surface makes up a complex lower boundary for atmospheric radiative transfer. Its optical properties vary with altitude and season and is highly inhomogeneous. To quantify the effects of realistic surface albedo on radiation poses a challenging problem for both experimentalists and modellers.

Degunther et al. [1998] and Degunther and Meerkötter [2000] performed 3-D radiative transfer calculations for various idealized snow distributions under cloudless and cloudy conditions respectively. The UV irradiance over dark regions is less influenced by bright surrounding surfaces than vice versa. The presence of clouds decrease the area of importance and increase the albedo effect on the surface UV irradiance. These general results agree with the site specific studies performed for Palmer Station [Ricchiazzi and Gautier, 1998] and McMurdo [Podgorny and Lubin 1998]. Smolskaia et al. [1999] experimentally investigated the effect of the step function like behaviour of the surface albedo for Davis Station and reported a smaller effect than anticipated. Mayer and DeGunther [2000] simulated the situation and concluded that the measurements needed to be taken both further offshore and inland to see the full effect.

Here the first 3-D radiative transfer simulations for an increasing snow line are presented. The simulations are compared with measurements for both cloudless and cloudy situations.

For a non-zero surface albedo a fraction of the down-welling radiation will be scattered upwards. Part of the upward scattered radiation will be scattered downward again increasing the global downwelling irradiance at the surface compared to a surface with zero surface albedo. For a plane-parallel situation neither the atmospheric nor the surface properties vary with x and y and the albedo enhancement can simply be calculated by evaluating a geometric series, e.g. Kylling et al. [2000a]. However, for a realistic atmosphere 3-D radiative transfer simulations are required.

The enhancement in the UV radiation due to the presence of snow is a function of the surface area covered by snow. At high latitudes the snow cover may last into early summer and then rapidly decline. Here the UV radiation field for Tromsø (69.65°N, 18.95°E) is simulated as the snow line moves upwards during springtime snowmelting. The surroundings of Tromsø form a complex mixture of surfaces with open fiords surrounded by high mountains. Furthermore, snow is persistent into the early summer and UV measurements are available against which the model simulations will be compared below.

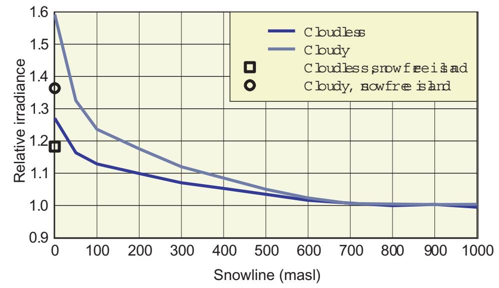


Figure 2.9.1.1 *The global irradiance at 340 nm relative to the global irradiance for a snow free domain, as a function of snow line. Cloudless (solid line) and overcast (dashed line) ratios are shown for the island of Tromsø. The box and circle are the relative enhancements when the island of Tromsø is snow free, but otherwise all land is snow covered*

The simulations are performed for a 201 times 201 km² domain with a resolution of 1 km. Tromsø is located in the centre of the domain. Elevation information is taken from the GTOPO30 data set (Global 30 Arc Second Elevation data set, available at http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html) and regridded to 1×1 km² resolution using the Generic Mapping Tools (GMT) [Wessel and Smith, 1991, 1995]. The snow line is moved from 0 m.a.s.l. to 1000 m.a.s.l, in steps of 100 m. The ocean and fiords are assumed to be ice free which is in general true for all but the deepest fiords within the domain. For the simulations an albedo of 0.07 is used for the snow free areas including the ocean and an albedo of 0.8 for the snow covered areas. The simulations are performed for a solar zenith angle of 60 degrees with the sun in the south. The sub-Arctic winter atmosphere model of Anderson et al. [1986] is used with the total ozone column scaled to 340 DU. No aerosols are included. For the cloudy simulations a homogeneous cloud located between 2-3 km is introduced. The optical depth of the cloud is 10, the asymmetry factor 0.75 and the single scattering albedo 1.0. A Heyney-Greenstein phase function is assumed.

For the pixel covering the measurement site in Tromsø the ratio of the down-welling global (direct + diffuse) for the various snow lines to the global irradiance for snow free conditions is shown in Figure 2.9.1.1. As expected from the studies mentioned above, the enhancement is larger under cloudy conditions, dashed line Figure 2.9.1.1.

At the Auroral Observatory, Tromsø, Norway, measurements were routinely made by a GUV narrow bandwidth multi-channel instrument. It measured the UV irradiance in five channels centred at 305, 313, 320, 340, and 380 nm with a bandwidth of approximately 10~nm at FWHM and is part of the Norwegian UV monitoring network that was established in 1995. For comparison with the above 3-D radiative transfer simulations cloudless and cloudy subsets of the measurement series for the year 1997 were selected. Cloudless time periods were identified by visual examination of the daily variation in the irradiance values.

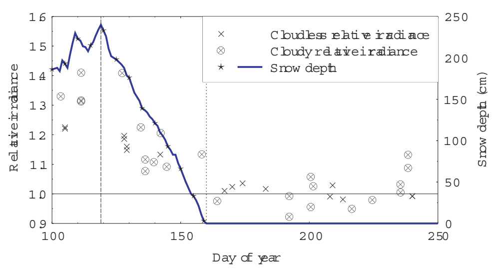


Figure 2.9.1.2 *The global irradiance at 340 nm relative to the global irradiance for snow free conditions for the island of Drams. The irradiance values are from a GUV instrument for a solar zenith angle of 60. Days to the left of the dashed vertical line is believed to have a snow line of 0 m.a.s.l. The dotted vertical line indicates the estimated day for when the snow line is 100 m.a.s.l. The snow depth (solid line with stars) is measured at 65 m.a.s.l.*

The crosses in Figure 2.9.1.2 are the 340~nm global irradiances for cloudless days relative to the cloudless average days 177-240 which is representative for snow free conditions.

Overcast situations were selected from the data set presented by Kylling et al. [2000a]. To facilitate comparison with the 3-D simulations, irradiance values at 340 nm for which the effective cloud optical depth was 10+-1 and the solar zenith angle 60 +-1, were selected. By effective cloud optical depth is meant the optical depth that when used in a one-dimensional model best reproduces the measurements [Dahlback, 1996]. These irradiances are shown in Figure 2.9.1.2 as encircled crosses. Due to the allowed variations in the effective cloud optical depth and the solar zenith angle, and the inherent uncertainty present for overcast situations, the scatter in Figure 2.9.1.2is larger for the cloudy data points. A clear enhancement in UV radiation is seen with snow on the ground and the enhancement is larger than for a cloudless sky, as predicted by theory.

For cloudless sky, simulations and observations agree reasonably well. The simulated radiation enhancement of 1.27 is slightly larger than the observed maximum, 1.23. With the snow line at 100~m.a.s.l. the simulations predicts 1.13 while the measurements indicate about 1.09. As the snow gradually disappears between days 160-180, the enhancement goes away. The cloudy simulations give a larger enhancement than the cloudless simulations which is in qualitative agreement with the observations. While the simulations predict an enhancement of 1.59 for completely snow covered land, the measurements give a maximum enhancement of 1.42.

To fully understand the UV radiation environment in regions with complex surface characteristics, 3-D radiative transfer simulations are required. Further improvements include methods to determine the effective surface albedo of individuals pixels, and methods to allow more realistic handling of clouds.

2.9.2 Results from Phase II

The objectives of task 9 are:

1. To homogenise satellite and model information for input to radiative transfer algorithms.
2. To generate present UV maps of Norway using satellite information.
3. To generate future UV maps of Norway using chemistry model ozone column information together with satellite information.
4. To compare the present UV maps at selected locations with measurements.

Towards objective 1 we have prepared computer programs to read updated satellite information on ozone columns (TOMS) and cloud fractions (AVHRR). Realistic input data for surface albedo and aerosols have been collected, but we consider applying quantities from satellite instruments such as MODIS and MISR. Surface topography have been accounted for by a 1 km resolution digital elevation map from US Geological Survey. With additional funding from the EU project EDUCE, we devise a fast simulation tool (fastrt) for UV radiation at the terrestrial surface. The program have been made freely available on the internet on http://zardoz.nilu.no/~olaeng/fastrt/fastrt.html. An updated version particularly suitable for generation of UV maps will be made available in early 2002.

Towards objective 2 we have generated a prototype example of a UV map (Figure 2.9.2.1). When the fastrt model is ready, UV maps will be produced with better spatial resolution and with a more comprehensive set of input data.

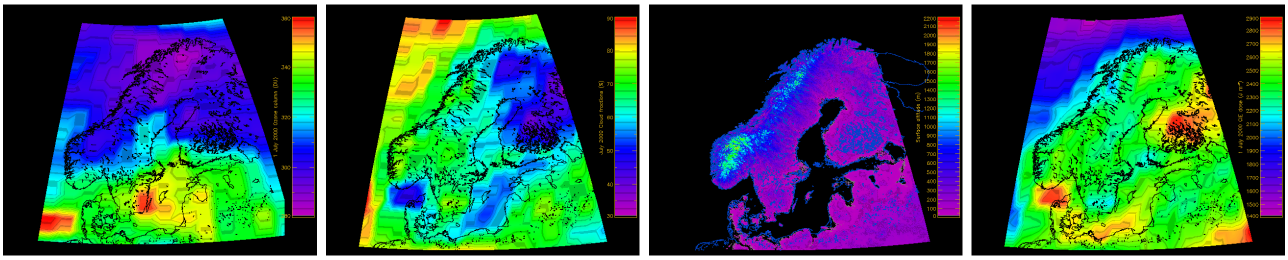


Figure 2.9.2.1 From left to right: TOMS total ozone for 1 July 2000, cloud fractions for July 2000, topography and the resulting UV dose map.

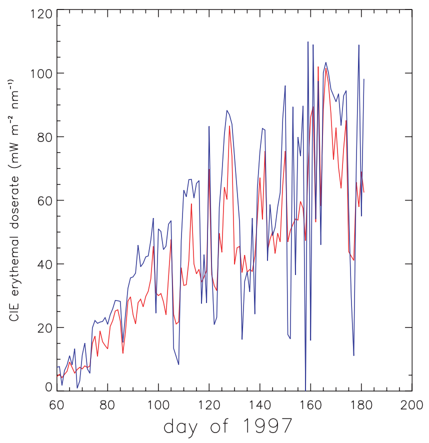


Figure 2.9.2.2 GUV measurements (blue) and corresponding modelled CIE erythemal UV doses (red) for Tromsø during spring 1997. Ratios of daily measurements vs. model are 1.03±0.42. Ratios of monthly integrated values are 1.11±0.14. Accuracies for UV reconstructions for the pre-satellite age where only ozone measurements are available and climatological values must be used for other model input data.

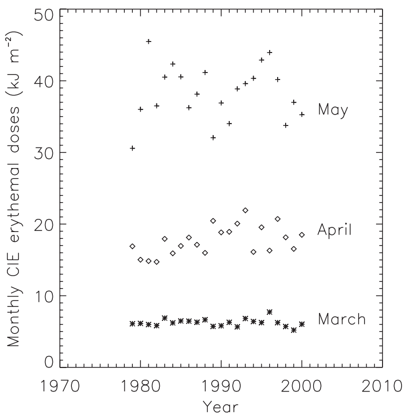


Figure 2.9.2.3 Reconstructed monthly CIE erythemal doses for Skrova in Lofoten, Norway. This information is used in a EU funded project to study of the impact of UV radiation on cod larvae.

Regarding objective 3 we have initiated talks on how to best use the Oslo SCTM model to produce UV maps for the future.

Towards objective 4 we have compared UV irradiances (313nm) and doses (CIE erythema) with those measured by a GUV surface instrument in Tromsø through spring 1997 (Figure 2.9.2.2). Monthly and annual averages are in fact preferable when longer time series of UV doses are investigated (e.g. Figure 2.9.2.3). The main uncertainty for modelling is the assumptions on droplet densities and properties within clouds, since these are temporally variable and difficult to measure accurately from satellite. Additionally, the GUV data were sometimes corrupted by snow on the instrument. However, monthly averages of measured and modelled data agreed quite well supposedly because occasional instrumental errors and the effect of deviations in cloud properties from their climatological mean diminish after the temporal integration process.

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SECTION

3

Publications and dissemination

3.1 Peer reviewed publications

3.1.1 Task 1

A detailed documentation of CTM-2 together with a model validation and first results of the process studies is now under preparation. Submission to J. Geophys. Res. is scheduled for early 2002.

Rummukainen, M., Isaksen, I.S.A., Rognerud, B., and Stordal, F. A global model tool for three-dimensional multiyear stratospheric chemistry simulations: Model description and first results. J. Geophys. Res., 104, p.26437-26456, 1999.

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3.1.2 Task 2

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Orsolini, Y.J. and V. Limpasuvan, “The North Atlantic Oscillation and occurrences of ozone miniholes”, Geophys. Res. Letters, 29, 4099-4102, 2001.

3.1.3 Task 3

Rex, M., von der Gathen, P., Braathen, G.O., Harris, NRP, Reimer, E, Beck, A, Alfier, R, Krüger-Carstensen, R, Chipperfield, M, de Backer, H, Balis, D, O’Connor, F, Dier, H, Dorokhov, V, Fast, H, Gamma, A, Gil, M, Kyrö, E, Litynska, Z, Mikkelsen, S, Molyneux, M, Murphy, G, Reid, SJ, Rummukainen, M, Zerefos, C, Chemical ozone loss in the Arctic winter 1994/95 as determined by the Match technique, J. Atm. Chem., 32, 35-59, 1999.

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3.1.4 Task 4

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Goutail, F., Pommereau, J.-P., Phillips, C., Deniel, C., Sarkissian, A., Lefèvre, F., Kyrö, E., Rummukainen, M., Eriksen, P., Andersen, S.B., Kåstad Høiskar, B.A., Braathen, G., Dorokhov, V., Khattatov, V.U., Depletion of column ozone in the Arctic during the winters of 1993-94 and 1994-95, J. Atm. Chem., 32, 1-34, 1999.

3.1.5 Task 5

Orsolini, Y.J., Hansen, G., Manney, G.L., Livesy, N., Hoppe, U.-P., Lagrangian reconstruction of ozone column and profile at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) throughout the winter and spring 1997-98, Jour.Geophys.Res., 106, D9, 10.011-10,0121, 2001.

3.1.6 Task 6

Activity 6.1

Activity 6.1 is not an independent research activity. The purpose of the activity is to provide additional input to model development in the frame of task 1 and ozone depletion analysis in the frame of task 6, activity 6.3. Publications will be envisaged as soon as the task 1 and activities 6.2 and 6.3 have progressed sufficiently.

Activity 6.2

A paper on the study in Activity 6.2 is in preparation and will be submitted to Atm. Chem. and Phys. in the middle of 2002.

Activity 6.3

The results from the comparison between modelled and observed ozone and other parameters will be submitted for publication towards the end of 2002. More model results are needed before a systematic comparison and validation can take place.

3.1.7 Task 7

Thorseth T. M. and Kjeldstad B, *All-weather ultraviolet solar spectra retrieved at 0.5 Hz sampling rate*, Applied Optics, **38**(30):6247-6252,1999

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3.1.8 Task 8

Kylling, A., Danielsen, T., Blumthaler, Schreder, J. and Johnsen, B., Tropospheric and stratospheric photodissociation rates derived from balloon borne radiation measurements, Atmos. Chem. Phys., To be submitted in December 2001.

3.1.9 Task 9

Kylling, A, and B. Mayer, `Ultraviolet radiation in partly snow covered terrain: Observations and three-dimension simulations', Geophysical Research Letters, 28, 3665-3668, 2001.

3.2 Published conference presentations

3.2.1 Task 1

Gauss, M., and Isaksen, I.S.A., 3-D CTM model calculations of chemical and dynamical processes in the lower stratosphere, Extended abstract in SPARC CD No.1:.:", Published by SPARC Office, 2000. Can be found at: http://www.aero.jussieu.fr/~sparc/SPARC2000_new/OralSess1/Session1_1/Gauss/Exabst_MGauss.htm#Anchor-49575

Oral presentation during SPARC 2nd General Assembly, Mar del Plata, November 6-10, 2000: "Gauss, M.: 3-D CTM model calculations of chemical and dynamical processes in the lower stratosphere"

Poster presentation at EGS, 26th General Assembly, Nice, 25-30 March, 2001: "Gauss, M., and Isaksen, I.S.A.: 3-D CTM model calculations of chemical and dynamical processes in the lower stratosphere"

Poster presentation at NFR programkonferanse, Bergen, 27.-29. november 2001: "Gauss, M., and Isaksen, I.S.A.: COZUV Task 1, 3-D Atmospheric Chemistry Modelling"

Rognerud, B. and Ivar S.A. Isaksen, Model calculations of the stratospheric ozone recovery, poster presented at the NDSC symposium, Arcachon, 24-27.september, 2001

Demoulin, Ph., E. Mahieu, R Zander B. Rognerud, I. Isaksen M. De Mazière The NO_y budget above the Jungfraujoch: long-term evolution, family partition and model comparison, poster presented at the NDSC symposium, Arcachon, 24-27.september

Mahieu, E., R. Zander, F. Mélen, P. Demoulin, P. Duchatelet, C. Servais B. Rognerud, I. Isaksen C.P. Rinsland and D.B. Considine FTIR observations and model calculations of the evolution of inorganic chlorine and fluorine above Jungfraujoch, poster presented at the NDSC symposium, Arcachon, 24-27.September

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Harris, N.R.P., M. Guirlet, G.T. Amanatidis, G. Ancellet, G. Braathen, A. Bregman et al., Overview of results of THESEO 1998-1999, Proceedings of Fifth European Workshop on Stratospheric Ozone, St. Jean de Luz, France, 27 Sept.-1 October, 1999, European Commission, Air pollution research report 73, Brussels, 2000. ISBN 92-827-5672-6.

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3.2.4 Task 4

Høiskar, B.A.K., I. Fløisand, K.K., Tørnkvist, K. K., and D.W. Arlander, Seasonal Variations in Airmass Factors for NO_2, Fifth European Workshop on Stratospheric Ozone, St. Jean de Luz, France, 27 Sept.-1 October, 1999.

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Braathen, G.O., et al., The Coordinated Ozone and UV project (COZUV), Oral presentation at the Climate and Ozone Programme Conference, Bergen 27-29 November 2001. NILU OR 66/2001. ISBN: 82-425-1319-8.

3.3 Other reports and presentations

3.3.1 Task 1

Rognerud, B. and I. S.A. Isaksen, 2001: Studies of the long term recovery of the ozone layer. Oral presentations and extended abstract Taiwan/China/Norway/US collaboration.

3.3.2 Task 2

Orsolini, Y. and V. Limpasuvan, “The North Atlantic Oscillation and occurrences of ozone miniholes”, poster presented at the American Meteorological Society Conference on Atmospheric and Oceanic Fluid Dynamics in Breckenridge (Colorado).

Orsolini, Y. and V. Limpasuvan, Occurrences of ozone miniholes in winter 1999-2000 and interannual variability, poster presented at the General Assembly of the European Geophysical Society, Nice, April 2001.

Orsolini, Y. and V. Limpasuvan, Occurrences of ozone miniholes in winter 1999-2000 and interannual variability, poster presented at the SOLVE/THESEO scientific workshop, Palermo (Italy), September 2000.

Orsolini, Y., Ozone transport and chemistry in the summer polar stratosphere, poster presented at the 15th ESA Symposium on European Rocket and Balloon programmes, Biarritz (France), May 2001.

3.3.3 Task 3

Høiskar, B.A.K., G.O. Braathen, A. Dahlback, B.R. Bojkov, T. Svenøe, K. Edvardsen and G.H. Hansen, 2000: Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report 1999. NILU OR 26/2000. ISBN 82-425-1180-2.

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3.3.4 Task 5

Baarstad, Ivar: Optisk System for Overvåking av Strålegeometri ved ALOMAR Ozon-lidar, Hovedoppgave for Sivilingeniørutdanning, NTNU, Jan 2000

Hoppe, Ulf-Peter: Stratospheric Warmings - the Quasi-biennial Oscillation; Ozone hole in the Antarctic but not in the Arctic - Correlations between the Solar Cycle, Polar Temperatures, and an Equatorial Oscillation, FFI/RAPPORT-2001/02263, ISBN 82-464-0503-9

Hoppe, Ulf-Peter, Hansen, Georg, and Gausa, Michael: Stratosphären-Ozonprofile aus 70° N von 1994-2001: Mittelwerte und Varianz im Jahreslauf und mit

der Höhe, Conference Presentation, DACH Meteorologentagung 2001, Wien, 20.09.01

Hoppe, Ulf-Peter, Studies of the mesosphere and stratosphere by rockets and ground-based instruments, 2 timer forelesning for Space Camp 2001, NAROM, Andenes, 12.08.01

Hoppe, Ulf-Peter, Hansen, Georg, Gausa, Michael, Stratospheric ozone profiles measured by the ALOMAR Ozone lidar in daylight, Conference Presentation at 15th ESA Symposium on European Rocket and Balloon Programmes and Related Research, Biarritz, France, 31.05.01

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Hansen, G., Y. Orsolini and E. Kyrö, Observation of total ozone and ozone profiles in winter, spring and summer 2000 in Northern Scandinavia, Poster at the SOLVE/THESEO 2000 Symposium, Palermo, September 2000.

Hansen, G., and J. Fiedler, Lidar observations of polar stratospheric clouds on the weatherside of the Scandinavian mountain ridge, Poster at the SOLVE/THESEO 2000 Symposium, Palermo, September 2000.

Hansen, G., Long-term and in depth studies of Arctic ozone in Northern Norway, Oral pres. at the 7th Circumpolar Univ. Coop. Conf., Tromsø, Norway, August 2001.

Hansen, G., R. Neuber, P. von der Gathen, P. Wall, B.-M. Sinnhuber, and M.P. Chipperfield, All-winter ozone in the mid- and upper stratosphere: Arctic lidar measurements vs. SLIMCAT model data, Poster on the European Ozone Symposium, Arcachon, France, September 2001.

Hoppe, Ulf-Peter, The Greenhouse Effect, 2 hours lecture for Høyskolen i Narvik at NAROM / Andenes, 25.01.99

Hoppe, Ulf-Peter, The polar middle atmosphere: Sudden stratospheric warming and the QBO, 6 hours lecture at UNIS, Longyearbyen, 13.-16.11.00

Hoppe, Ulf-Peter, The polar middle atmosphere: Sudden stratospheric warming and the QBO, 6 hours lecture at UNIS, Longyearbyen, 1.-5.10.01

Hoppe, Ulf-Peter, Examples of ALOMAR science, presentation at DNMI, Blindern, 14.09.00

Hoppe, Ulf-Peter and Sagsveen, Mona, A new algorithm for the analysis of Differential Absorption Lidar data, Conference presentation at the 27th Annual Meeting on Atmospheric Studies by Optical Methods, Stockholm, 23.08.00

Hoppe, Ulf-Peter, Die Bildung dünner Schichten in der mittleren Atmosphäre, presentation at Institut für Geophysik, Astrophysik und Meteorologie, Universität Graz, Austria, 07.12.01.

Lindhom, Bjørn Petter: Trender og Strukturer i Ozonprofilet ALOMAR Ozonlidar, Hovedoppgave i fysikk, UiO, Des 1999.

Lindhom, B.P. and Hoppe, U.-P.: Ozone laminae and filaments observed with the ALOMAR Ozone lidar, Conference presentation, EGS, Nice, 28.04.00

Sagsveen, Mona: Development and Demonstration of a new Algorithm for DIAL data analysis, Hovedoppgave i fysikk, Sept 2000.

3.3.5 Task 7

Kjeldstad, B., T.M. Thorseth, and B. Johnsen, *Benefits from making synchronous spectral and broad band solar UV measurements at all weather conditions.* European geophysical society conference, Nice, France 2000.

Thorseth, T.M., *Rapid scans at 0.5 Hz development of a new tracker system for the Bentham 150,* Nordic Ozone Group annual meeting Helsingør, Denmark April 2000.

Thorseth, T.M., *Comparison of cosine error correction factors*, Nordic Ozone Group, Annual meeting, Trondheim, Norway, 20-21 April 2001.

Thorseth T. M., M. Blumthaler ESP. Measurements if the cosine error in solar global irradiance measurements The 9th ESP Congress in Lillehammer, Norway, September 3-8, 2001.

3.4 User-oriented and popular dissemination

3.4.1 Popular science articles

Kjeldstad, B., Himmelen er blå og ultrafiolett. Naturen 3, 2000., s. 123-127.

3.4.2 Newspaper articles

Aftenposten, 13.04.99, Ozon forsvinner i nord-områdene.

Aftenposten, 10.09.99 Norske forskere frykter økning i skadelig UV-stråling

Aftenposten 8.2.01, Verdens nye miljøvaktbikkje i rommet

Aftenposten, 18.01.00, Plast kan bli redningen.

Aftenposten, 5.4.00, Stadig større ozonhull over Arktis

Aftenposten, 06.04.01, Rasfare truer idyllen i fjellet

Aftenposten, 2.7.01, Solen er farlig nå.

Aftenposten, 3.7.01, Don't underestimate Norway sun.

Braathen, Dagsavisen, Des. 1999

Dagladet, 06.07.2001, Varsler UV-stråling på nettet

Dagbladet, 03.07.2001, Pass deg for sola

VG, 5.4.00, Rekordtynt ozonlag over Arktis

VG, 5.10.00, Rekordstort ozonhull over Sørpolen

VG, 6.4.01, Værvinnere i påske

VG, 6.7.01, Varsler farlig UV-stråling på nettet

VG, 7.7.01, 15 minutters soling kan gi skader

Los miniagujeros de la capa de ozono en el Atlantico Norte dependen del pulso climatico, El Pais, October 31, 2001, Madrid (Spain).

The GRL article on ozone mini-holes by Orsolini and Limpasuvan has been commented by the journal Nature in its electronic NATURE NEWS (see NILU web page). An article for the general public has been published in the leading Spanish daily newspaper "El Pais" (October 31, 2001), based on the NATURE NEWS reviews.

In December 2000 Norwegian stratosphere research and ALOMAR was made known in Aftenposten and a large number of Norwegian regional newspapers in connection with a sudden stratospheric warming observed with the ALOMAR Ozone Lidar.

3.4.3 Radio and TV presentations

Braathen, G.: Interview on "O_4 in the atmosphere" in "Verdt å vite". Nov. 2001

Isaksen, I. interview on "Delayed ozone recovery" in "Verdt å vite", 22. Oct. 2001.

3.4.4 Web presentations

The COZUV project is presented on the web with this URL:

http://www.nilu.no/projects/cozuv

Popular information for pupils and other interested laymen on the ozone layer problem can be found here:

http://www.nilu.no/avd/reg-glo/pupils/pupils.html

http://www.nilu.no/niluweb/index.cfm?lang=1&id=1211&type=3&senter=234

http://www.nilu.no/niluweb/index.cfm?lang=1&id=1182&type=3&senter=234

Several other projects within the field of stratospheric ozone and UV are presented on the web.

http://www.nilu.no/projects/theseo2000

http://www.nilu.no/projects/nadir

http://www.nilu.no/projects/nadir/cose/cose.html

http://www.nilu.no/projects/ndsc

http://www.nilu.no/projects/mauve

http://www.nilu.no/projects/arctic2001

http://www.nilu.no/projects/nadir/o3hole

http://www.nilu.no/niluweb/services/admira

http://phaeocystis.nfh.uit.no/UVAC/

http://www.rocketrange.no/alomar/about/frameset.html

Engelsen O (2001): "Fast simulations of downward UV irradiances at the Earth's surface for clear sky conditions", http://zardoz.nilu.no/~olaeng/fastrt/fastrt.html.

The radiative transfer model used for tasks 8 and 9 is presented and made available at http://www.libradtran.org

3.4.5 Other

Rognerud, B.: Visit by 5 middle school pupils.

SECTION

4

International cooperation and recruitment

4.1 Introduction

The COZUV participants are engaged in extensive international cooperation, both through EU projects and otherwise. As will be shown below, the funding obtained through COZUV, and before 1999 through individual projects funded by the Research Council, is essential for Norway's ability to participate in international research.

4.2 Stay abroad

During September to December 2000 Trond Morten Thorseth stayed at Institute for Medical Physics, at University of Innsbruck. This group of Dr. Mario Blumthaler is one of the leading experimental groups on ultraviolet radiation measurements. This group is one of few that actually do direct sun and radiance distribution measurements. Hence all practical knowledge about direct sun calibration procedures was learned here. The knowledge in the group also contributed significantly to the developments of the tracker system as it is today. A part of the time was spent on working with cosine error correction procedures. The idea of actually measuring the cosine error the way it was done with the NTNU system originated from co-operative activity.

4.3 Collaborating institutions

The list below gives a list of institutions that the COZUV partners collaborate with.

Alfred Wegener Institute for Marine and Polar Research, Potsdam, Germany
Aristotle University of Thessaloniki, Laboratory of Atmospheric Physics, Greece
Belgian Institute for Space Aeronomy, Uccle, Belgium
British Aerospace Airbus, UK
Chalmers University of Technology, Gothenburg, Sweden
Colorado Research Associates (CoRA, NWRA), Boulder, Colorado, USA
DaimlerChrysler Aerospace Airbus GmbH, Germany
Danish Meteorological Institute, Copenhagen, Denmark
Deutsche Luft und Raumfahrt, Oberpfaffenhofen, Germany
European Centre for Medium-range Weather Forecasts, Reading, UK
Finnish Meteorological Institute, Finland
Forschungszentrum Jülich, Germany
Forschungszentrum Karlsruhe, Germany
Fraunhofer Institute for Atmospheric Research, Garmisch Partenkirchen, Germany.
Freie Universität Berlin, Institut für Meteorologie, Berlin, Germany
Institute for Meteorology and Climatology, University of Hannover, Germany
Institute of Atmospheric and Oceanic Sciences, Bologna, Italy
Institute of Atmospheric Physics, CNR, Rome, Italy.
Institute of Environmental Physics, University of Bremen, Germany
Institute of Environmental Physics, University of Heidelberg, Germany
Instituto Nacional de Técnica Aerospacial, Torrejón de Ardoz, Spain

Joint Center for Earth Systems Technology, University of Maryland, USA
Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece
Max-Planck-Institut für Meteorologie, Germany
Météo-France, Toulouse, France
NASA Goddard Space Flight Center, Maryland, USA
NASA Jet Propulsion Laboratory, Pasadena, California, USA
National Academy of Meteorological Sciences, Beijing, China
National Institute of Public Health and the Environment, The Netherlands
National Institute of Water and Atmospheric Research, Lauder, New Zealand
NERC-British Antarctic Survey, Cambridge, UK
Norwegian Radiation Protection Authority, Norway
QinetiQ, UK
Royal Belgian Meteorological Institute, Uccle, Belgium
Royal Dutch Meteorological Institute, De Bilt, Netherlands
Service d'Aéronomie du CNRS, Verrières-le-Buisson, France
Space Research Organization of the Netherlands, Utrecht, The Netherlands
State University of New York, Albany, USA
Stevens Institute of Technology, Hoboken, New Jersey
Swedish Meteorological and Hydrological Institute, Sweden
Swiss Federal Institute of Technology, Switzerland
Taiwan National University, Taiwan
Università Degli Studi L'Aquila, Italy
Universidad de Austral, Department of Physics, Valdivia, Chile
Universidad de Chile, Geophysical Institute, Santiago de Chile
Universität für Bodenkultur, Vienna, Austria
Universität Rostock, Institut für Atmosphärenphysik, Kühlungsborn, Germany
Université de Liège, Belgium
Université Joseph Fourier, Grenoble, France
University of Bristol, UK
University of California, Irvine, USA
University of Cambridge, Dept. of Chemistry, Cambridge, UK
University of Fairbanks, Geophysical Institute, Alaska, USA.
University of Frankfurt, Institute for Meteorology and Geophysics, Germany
University of Innsbruck, Institute of Medial Physics, Austria
University of Leeds, School of the Environment, United Kingdom
University of Leicester, Earth Observation Science Group
University of Manchester Institute of Science & Technology, U.K.
University of Washington, Seattle, Washington, USA

4.4 EU projects

During the duration of the two phases of COZUV the partners have participated or still participate in a number of EU projects related to stratospheric ozone and UV research. The table below lists these projects.

Several of these projects (THESEO-O3LOSS, THESEO 2000 - EuroSOLVE,

Table 4.4.1. EU projects with COZUV partners

Acronym	Title
ADMIRA	Actinic flux Determination from Measurements of Irradiance (2000 - 2002)
CANDIDOZ	Chemical and Dynamical Influences on Decadal Ozone Change (2002-2005)
COSE	Compilation of atmospheric Observations in support of Satellite measurements over Europe (1998-2000)
CRUSOE	Concerted Action for Scientific Strategy in the Stratosphere
EDUCE	European Database for UV climatology and Evaluation (2000 - 2003)
EUPLEX	European Polar Stratospheric Cloud and Lee Wave Experiment (2002 - 2005)
GOA	Global Ozone Assimilation (2001 - 2003)
GODIVA	GOME Data Interpretation, Validation and Application (1997 - 2000)
HIBISCUS	Impact of tropical convection on the upper troposphere and lower stratosphere at global scale (2002 - 2004)
INSPECTRO	Influence of clouds on the spectral actinic flux in the lower troposphere (2002-2005)
Leewave-PSC	Study of polar stratospheric clouds formed in lee-waves
MAPSCORE	Mapping of Polar Stratospheric Clouds and Ozone Levels Relevant to the Region of Europe (2001-2004)
MOZAIC II	Measurement of ozone by Airbus in-service aircraft
PAUR II	Photochemical activity and solar ultraviolet radiation (1998 - 2000)
POET	Precursors of Ozone and Their Effects in the Troposphere (2000 - 2003)
PVC	Polar Vortex Change (1997 - 2000)
QUILT	Quantification and Interpretation of Long-Term UV-Vis Observations of the Stratosphere (2000 - 2002)
QUOBI	Quantitative Understanding of Ozone losses by Bipolar Investigations (2002 - 2004)
SAMMOA	Spring to Autumn Modelling and Measurements of Ozone and Active species (2000 - 2002)
SOGE	System for observation of halogenated greenhouse gases in Europe (2000 - 2002)
SOLICE	Solar influences on climate and the environment (2000 - 2003)
SUVDAMA	Scientific UV DAta MAnagement (1997-1999)
TRADEOFF	Aircraft emissions: Contributions of various climate compounds to changes in composition and radiative forcing-tradeoff to reduce atmospheric impact. (2000 - 2003)
THESEO - O3LOSS	Third European Stratospheric Experiment on Ozone – Ozone Loss in the Arctic and at Mid-Latitudes (1998 - 2000)
THESEO-Stratospheric-BrO	Ground-based, GOME/ERS-2 and balloon measurement and modelling study of stratospheric BrO (1997-2000).
THESEO 2000 - Euro-SOLVE	Improved understanding of stratospheric ozone loss by measurements and modelling contributing to THESEO 2000 and SOLVE (2000)
TOPOZ II	Towards the prediction of stratospheric ozone - II (1998-2000)

Table 4.4.1. EU projects with COZUV partners

Acronym	Title
TOPOZ III	Towards the prediction of stratospheric ozone - III (2002-2005)
UVAC	The influence of UV radiation and climate conditions on fish stocks - A case study of the Northeast Arctic cod
UVRAPPF	UltraViolet Radiation in the Arctic: Past, Present and Future

QUILT, UVAC, SAMMOA, SOGE and TRADEOFF) are coordinated by COZUV participants.

4.5 Other international collaboration

Nordic collaboration

Several COZUV partners participate in the Nordic collaboration through the Nordic Ozone and UV Group (NOG), which involves ozone scientists from Scandinavia, Finland, Iceland and the Baltic states. NTNU participated in a Nordic intercomparison (Sweden June 2000) organised by the Nordic Ozone and UV Group with the new instrument.

NDSC

The Network for the Detection of Stratospheric Change (NDSC) is an international network that consists of high-quality measurements of ozone, UV and other parameters pertinent to the development of the ozone layer. NILU participates with SAOZ measurements from Ny-Ålesund, with SYMOCS measurements from Andøya and with ozone lidar measurements from Andøya. NILU is also involved in the operation of the Harestua site where Belgians and Swedes carry out NDSC measurements. Geir Braathen, NILU, is member of the NDSC Steering Committee. More information on NDSC can be found here: http://www.ndsc.ws and http://www.nilu.no/projects/ndsc.

Other international collaboration

In addition to the organised collaboration through EU projects and international networks there is also collaboration on a bi-lateral level between COZUV partners and research groups abroad. One example of such bi-lateral agreement is described here:

Intense international collaboration has been done in the context of programming with the University of California, Irvine (UCI). Essential parts such as the transport scheme and the photolysis scheme were adopted from UCI. Michael Gauss (UiO) spent one week in Irvine for exchange of scientific and modelling expertise. Contact has also been established with the Danish Meteorological Institute (DMI) regarding microphysics, including a short visit at DMI in early 1999.

Various European projects have profited from the development of the Oslo CTM-2 model. In particular, detailed model calculations were performed for GOA (GOME Assimilated and Validated Ozone and NO_2 Fields for Scientific Users and for Model Validation, web site: http://www.knmi.nl/goa). Another important model validation has been performed within the TRADEOFF project (aircraft emissions: contribution of different climate components to radiative forcing – trade-off to reduce atmospheric impact, web site: http://www.lapeth.ethz.ch/~dominik/tradeoff). Results of the validation against different sets of measurement data and an intercomparison between different transport models will be shown by D. Brunner (ETHZ, Switzerland) on the AGU meeting in San Francisco in December 2001. Tracer runs addressing H_2O emissions from aircraft have been performed with an increased horizontal resolution for the European 'CRYOPLANE' project (web site: http://europa.eu.int/comm/research/growth/gcc/projects/in-action-cryoplane.html). Experience from these high-resolution simulations will be valuable for COZUV as well, when high resolution is an option also for full chemistry runs. As parallel programming is proceeding such runs are likely to be possible in early 2002 – at least simulations covering one season only.

4.6 Importance of national funding

Several COZUV partners have expressed the importance of national funding for participation in international projects. For example, Berit Kjeldstad, NTNU writes the following:

COZUV has been of extreme importance for our group being able to participate in international collaboration. None of the EU projects have brought sufficient funding for personnel to cover a full position. Without funding from COZUV we would have had great difficulties participating in the EU projects.

Says Arve Kylling, NILU:

The balloon flights have been made in collaboration with the French group headed by Dr. J.-P. Pommereau. Without their support we would not have been able to perform the flights. We are currently participating in an EC-project named HIBISCUS which is coordinated by Prof. J.-P. Pommereau. HIBISCUS aims to study the tropic troposphere-stratosphere region by instruments on balloons. Our involvement in that project would not have been possible without the COZUV project which made it feasible for us to start this activity.

Ola Engelsen, NILU, writes this:

COZUV assists in expanding our expertise within UV and ozone research, and thus makes us more attractive partners in EU project proposals. In particular, the COZUV work (task 9) prepares the way collaboration with biologists and medical researchers, and thus opens up funding opportunities from other research programs than those aimed directly at stratospheric ozone loss and UV.

The same arguments can be used for most of the activities in COZUV: National funding ensures activities at a level that is sufficient to remain at the frontier of research and that makes us attractive partners in international projects and activities. COZUV has been invaluable in this respect.

4.7 Recruitment

Doctoral level

Three persons have been recruited with funding from COZUV:

1. Trond Morten Thorseth (NTNU) started out with a doctoral stipend in phase I of COZUV. He passed his doctoral exam in April 2000. Since his doctoral exam he has been employed as post doctoral fellow at NTNU.
2. Michael Gauss (Dept. of Geophysics, UiO) has been employed as doctoral student since April 1999. He plans to pass the exam towards the end of 2002.
3. Kjersti Karlsen Tørnkvist passed her doctoral exam in May 2000. 14% of the funding for her doctoral work came from COZUV.

Masters degree level

Ivar Baarstad, a civil engineering student from the University of Trondheim completed his thesis on a UV camera to monitor the lidar's geometry in January 2000. He subsequently worked at FFI during his military service, helping to improve the lidar instrument. Also in January 2000, Bjørn Petter Lindhom, a physics student from the University of Oslo completed his masters thesis on the trends and (laminae) structures in the ozone layer above ALOMAR. Mona Sagsveen, another physics student, finished her thesis about a new ozone analysis algorithm in November 2000. The latter three students have been working at FFI. All students mentioned have contributed significantly to observations (85 measurement nights, or potential measurement nights, in 1999) and several of them to instrumental improvements.

SECTION

5

Internal and external relations

5.1 Synergies

The various Norwegian groups that are active within ozone and UV research of course had knowledge of each other before the start of COZUV. But, apart from a few couplings, there was no close collaboration between these groups. The establishment of COZUV has led these groups into a much closer collaboration than before. Through the establishment of contact between various Norwegian research institutes COZUV has also paved the way for future scientific collaboration beyond COZUV. Especially in Norway where relatively small research units are spread over a large area, increased collaboration through a coordinated project appears indispensable.Several synergies can be identified:

- Large coordinated projects create a suitable discussion forum for scientists doing UV and ozone research in Norway and undoubtedly promotes collaboration.
- Valuable links have been established between the University of Oslo and NILU (Kjeller and Tromsø). Exchange of measurement data, model results, and scientific expertise has been made to a degree that could not have been achieved without the framework of COZUV
- Data from the experimental tasks (3, 4 and 5) are used for validation of the new Oslo CTM-2 model, which is still under development, and which needs experimental data in order to identify model problems.
- The dynamical modelling group at NILU and the atmospheric chemistry group at the University of Oslo have established a close collaboration and members of the two groups meet weekly.
- There are UV groups both at NILU and at NTNU. Through COZUV these groups have obtained a closer collaboration than before.
- The UV modelling group at NILU has established a link to the atmospheric chemistry modellers since ozone data is necessary for the calculation of UV maps of the future.
- Through meetings and collaboration arranged within COZUV the research carried out in the various groups is better known. This broadens the knowledge base and act as an inspiration for further research. It is inspiring and rewarding to see ones own results being used by other research groups.

As a whole the COZUV project has had a very positive effect on the Norwegian ozone and UV community and the project has contributed to the strengthening of the Norwegian ozone and UV community. It should be noted, however, that it takes time to build such relations and the group feels that the benefits of cooperation have become evident during phase II of COZUV.

At the European level the COZUV project is considered one of the most important national project within the field of ozone and UV research. For example, there is a link to the COZUV web page from the European Ozone Research Coordinating Unit in Cambridge (see http://www.ozone-sec.ch.cam.ac.uk/projects/project.html).

5.2 Links to other coordinated projects

There has, so far, been only limited contact between COZUV and the other coordinated projects of the Climate research programme, except for the contact that has been at the seminars/conferences. However, there is a link between the modelling activities of COZUV and the ChemClim research group.

One could envisage a closer collaboration between RegClim and COZUV. The future development of the ozone layer will depend on the changes in the climate. International ozone research will in the future change its focus from “what effect will changes in the halogen loading have?” to “what is the effect of climate change on the stratosphere”? These questions imply new directions in atmospheric research, which include a stronger emphasis on the coupling between the lower stratosphere and the upper troposphere and the interaction between ozone depletion, global pollution and climate change. This means that a possible third phase of COZUV should increase the emphasis on the links between climate change and stratospheric ozone, and in this case it would be of interest to establish links between COZUV and RegClim.

Ultraviolet radiation depend on many factors and ozone is one. In cases where modelling of UV has been performed, ozone becomes an important input factor and collaboration has been important within COZUV. For measurements preformed at cloudy conditions modelling these situations is still a challenge. There is no relevant part of COZUV discussing clouds.

5.3 Organisational benefits

From an organisational viewpoint it is much more efficient to organise the research through one or a few larger coordinated projects instead of creating a multitude of smaller project. Both for the Research Council and for the individual scientists there is less work spent on administration and reporting.

5.4 International projects and relations

The combination of national projects such as COZUV and international projects, such as EU funded projects and the Network for the Detection of Stratospheric Change, is necessary for both building national competence and for keeping updated with new developments in other countries.

The fact that Norway has a large coordinated project within the field of stratospheric ozone and UV increases the visibility of this research abroad to a larger extent than if the research had been organised in several smaller projects.

SECTION

6

The way ahead

6.1 Introduction

In the following we will point to important scientific issues within ozone and UV research that need to be solved and where the COZUV partners can contribute. Next we will discuss the methodologies that we envisage to put to use for answering these questions. We will also discuss couplings to other relevant projects, both national and international.

6.2 Scientific issues

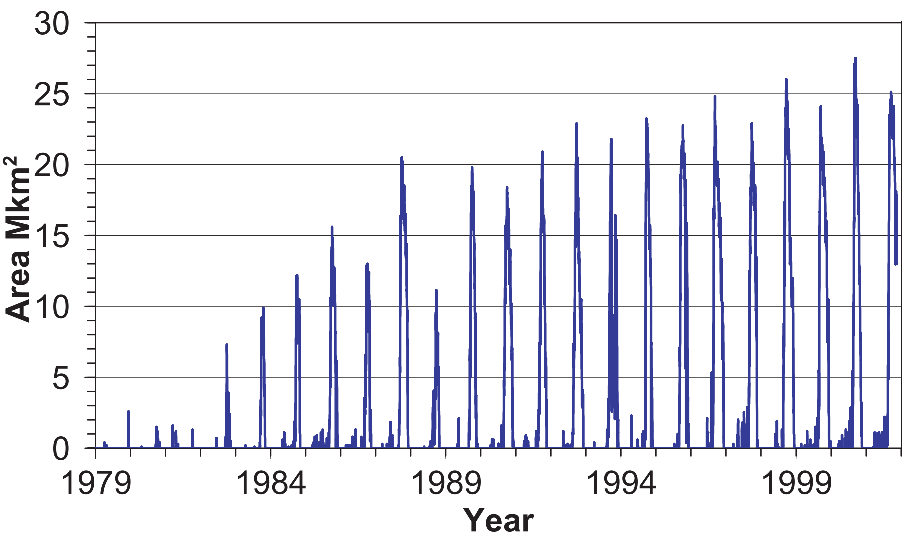
Ozone recovery

After the Montreal Protocol and its amendments were put in place during the 1980s and 1990s one tends to believe that the ozone layer will be repaired within a reasonable time frame. Realistic scenarios for compliance with the Montreal protocol indicates that the halogen loading will be back to pre-1980 levels by the middle of the 21st century. Assuming that the atmosphere does not otherwise change, complete recovery of the ozone layer would be expected by 2050. Observations show that some of the ozone depleting substances have reached their maximum concentrations and that the concentration curve starts to point downwards. However, some compounds, such as methyl bromide and other brominated compounds, are still on an increase and there are uncertainties as to how the abundances of these compounds will change in the future.

So far, the ozone layer shows no signs of recovery. The size of the Antarctic ozone hole continues to grow from one year to the next as shown in Figure 6.2.1. See figure legend for more details. The Arctic vortex has also undergone substantial ozone loss during several winters of the last decade, but the interannual variability is much larger than in the south.

Within the Network for the Detection of Stratospheric Change (NDSC) Norwegian COZUV participants contribute with various measurements. The detection of ozone recovery is one of the issues addressed by this network. It behooves Norway, with its strategic location close to the Arctic, to participate in the long-term monitoring of stratospheric ozone and other substances and parameters that

Figure 6.2.1. *The area where Antarctic total ozone is less than 220 DU. Using this definition of an ozone hole one can see that the first severe ozone hole occurred in Oct. 1982. The first few years the area grew bigger from one year to the next. Later (from 1986 onward) one can see the influence of the Quasi-Biennial Oscillation that causes an alternation between a larger and smaller ozone holes. The largest ozone hole was observed in 2000, but one can also see that the ozone hole of 2001 is larger than any previous hole that took place during the same phase of the QBO. Data from V. Fioletov.*



influence ozone and to participate in the further development of modelling and observational tools that can be used to assess the state of the ozone layer and the UV radiation that reaches the ground.

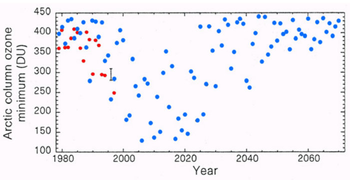


Figure 6.2.2. *March minimum total ozone north of 60°N from 1980 to 2080. The chemical reactions responsible for stratospheric ozone depletion are extremely sensitive to temperature. Greenhouse gases warm the Earth's surface but cool the stratosphere radiatively and therefore affect ozone depletion. Shindell et al. investigated the interplay between projected future emissions of greenhouse gases and levels of ozone-depleting halogen species using a global climate model that incorporates simplified ozone-depletion chemistry. Temperature and wind changes induced by the increasing greenhouse-gas concentrations alter planetary-wave propagation in the model, reducing the frequency of sudden stratospheric warmings in the Northern Hemisphere. This results in a more stable Arctic polar vortex, with significantly colder temperatures in the lower stratosphere and concomitantly increased ozone depletion. Increased concentrations of greenhouse gases might therefore be at least partly responsible for the very large Arctic ozone losses observed in recent winters. Arctic losses reach a maximum in the decade 2010 to 2019 in the model, roughly a decade after the maximum in stratospheric chlorine abundance. The mean losses are about the same as those over the Antarctic during the early 1990s, with geographically localized losses of up to two-thirds of the Arctic ozone column in the worst years. The severity and the duration of the Antarctic ozone hole are also predicted to increase because of greenhouse-gas-induced stratospheric cooling over the coming decades.*

Ozone/climate interactions

The ozone depletion over the polar regions is clearly caused by chemical destruction by chlorine and bromine compounds. These are strongly implicated in the ozone decline over mid-latitudes as well. However, recent modelling work has also demonstrated the possible contribution of long term changes in atmospheric dynamics to the ozone decline. An improved quantitative knowledge of these mechanisms based on experimental observations is clearly required. Research on the underlying chemical and dynamical processes is required to improve the understanding of the ozone depletion above Europe at mid- and high latitudes.

The main focus of stratospheric ozone research has been to study the effect of halogens on the ozone layer. One can now witness a change in focus to also include the effects of climate change and changes in dynamics on the ozone layer.

During the Climate and Ozone Programme Conference in Bergen in Nov. 2001 it became apparent that the North Atlantic Oscillation (NAO) is a common denominator for most, if not all, of the coordinated project funded by the Programme on Climate and Climate Change. As shown in section 2.2 of this report the occurrence of ozone mini-holes is correlated with he NAO index. This shows that the long-term (decadal) variability of ozone is linked to dynamical phenomena. Other tele-connections that can influence the ozone layer are the Arctic Oscillation, the El Niño Southern Oscillation and the Quasi-Biennial Oscillation (QBO).

It will be of interest to study the processes that allow the QBO, a strictly equatorial phenomenon, to modulate stratospheric ozone at high latitudes. The amount of ozone depletion each winter is clearly modulated by the QBO, but we do not know how. Also, the 30 hPa winter temperatures over the North Pole correlate with the solar cycle, but only if the temperatures are ordered by the phase of the QBO. It is not known how such a correlation should come about. The results from such research might help to explain how much of the observed temperature increase in the troposphere is due to an anthropogenic increase of the greenhouse effect, and how much is due to solar variation.

The increasing concentrations of greenhouse gases will almost certainly lead to a cooling of the lower stratosphere. A colder Arctic stratosphere will give rise to a more frequent occurrence of polar stratospheric clouds and this will lead to more activation of reservoir halogen species and hence increased ozone depletion. A study by Shindell et al. (1998) shows that the decade from 2010 - 2020 will be critical with respect to Arctic ozone loss. Figure 6.2.2 shows this in more detail.

Stratospheric water vapour

The observed cooling of the lower stratosphere over the last two decades has been attributed, in previous studies, largely to a combination of stratospheric ozone loss and carbon dioxide increase, and as such it is meant to provide one of the best pieces of evidence for an anthropogenic cause to climate change. A recent study [Forster and Shine, 1999] shows how increases in stratospheric water vapour, inferred from available observations, may be capable of causing as much of the observed cooling as ozone loss does; as the reasons for the stratospheric water vapour increase are neither fully understood nor well characterized, it shows that it remains uncertain whether the cooling of the lower stratosphere can yet be fully attributable to human influences. In addition, the changes in stratospheric water vapour may have contributed, since 1980, a radiative forcing which enhances that due to carbon dioxide alone by 40%. Besides, implications of an increase of water vapour for stratospheric ozone chemistry need to be explored. The AIRES in ERA report [European Commission, 2001] states that water vapour is probably the second most important chemical component of the stratosphere after ozone.

Exchange processes in the Arctic UTLS region

At the recent NDSC Anniversary meeting the UTLS region was identified as a region where much more research is needed in the future. Also in the EC Air Pollution report no. 76 “A global strategy for atmospheric interdisciplinary research in the European research area, AIRES in ERA”, UTLS studies are devoted ample of space, with focus on effects of surface pollution, aviation and natural factors on the chemical, radiative and dynamic processes in the UTLS region. In the last decade, most of UTLS research was focused on studies at mid-latitudes and in the tropics, while Arctic research was more or less absent. Only in the recent years, a few papers on the Arctic tropopause region have been published. The build-up of a troposphere lidar at ALOMAR (see below) combined with already existing infrastructure both there and at NY-Ålesund, and the already well-established co-operation with the Alfred Wegener Institute and the Finnish Meteorological Institute at Sodankylä offer an excellent starting point to intensify the research on this area with potentially large impact both on climate factors (ozone as a greenhouse gas) and long-term stratospheric ozone trends.

References

European Commission, A Global Strategy for Atmospheric Interdisciplinary Research in the European Research Area, AIRES in ERA, EUROPEAN COMMISSION, Research Directorate General, Environment and Sustainable Development Programme, Air pollution research report No 76, 2001.

Forster, P.M.D. and K.P. Shine, Stratospheric water vapour changes as a possible contributor to observed stratospheric cooling, Geophys Res. Lett., 26, 3309-3312, 1999.

Shindell, D.T., D. Rind and P. Lonergan, Increased polar stratospheric ozone losses and delayed eventual recovery owing to increasing greenhouse-gas concentrations, Nature, 392, 589-592, 1998

6.3 Methodologies

Models

Models for process studies

Focus needs to be on models describing individual processes on one hand and on integration of all the various processes on the other hand. The work here will be complementary. 3-D CTM models are needed for process studies and should build on what is done up to now. Two aspects are important: Improved model formulation: heterogeneous chemistry, extension of the model to higher altitudes to include the whole stratosphere, extension of meteorological data to include data for at least two decades (ERA-40). This will enable us to study how dynamical changes and changes in the meteorology affects stratospheric distributions. The main focus in the CTM studies is on comparisons and validation of observation results, and on process studies (effects of specific dynamical and chemical processes).

Another process type model is the Lagrangian chemical/dynamical model first developed during COZUV. It should be used for further studies on stratospheric transport and chemistry. In the coming years, a wealth of new satellite observations of the middle atmosphere will become available. Satellite validation campaigns are likely to be carried out at high northern latitudes. Such a model is suited for the analysis and interpretation of satellite, ground-based and airborne data, esp. at fine horizontal scales. In addition, the model will be used to assimilate in a lagrangian way chemical satellite observations.

Integrated model

GCM modelling is needed for integrated studies. Only a GCM can simulate the climate chemistry interactions fully. We suggest GCM modelling using the CCM-3 model as this model has already been used by COZUV participants. Implementation of a chemical scheme for tropospheric ozone and sulphur compounds have already been done as a collaboration with professor Wang and his group at SUNY, Albany (partly as contribution to RegClim). The chemical scheme will be extended to include stratospheric ozone chemistry. The first test of the chemical performance of the CCM-3 for the troposphere has been performed with good results. Similar tests for the stratosphere of the distribution of ozone and its precursors are expected to be performed during 2002. The coupled model will particularly be used to study ozone recovery over the next decades.

UV modelling

Clouds have a large impact on the UV radiation field. Independent information on cloud optical properties together with high quality measurements and careful modelling are required to further study and understand the effect of clouds.

The generation of UV maps are dependent on the availability of input parameters at sufficient spatial and temporal resolution and accuracy. A main source of such data are satellite instruments with suitable high level data products with adequate accuracy. In the future, it may be beneficial to link COZUV with other research and development programs in the EU system comprising satellite remote sensing. Unfortunately NFR still do not currently have a research program focused on satellite remote sensing of the atmosphere.

Observations

Long time series of observations have been acquired with several instruments. Such data are very valuable both for model validation and also for assessing the state of the ozone layer. Continued observation is therefore imperative in future stratospheric research.

Ozone lidar

Ozone lidar measurements from ALOMAR will be of benefit to several studies such as 1) the effect of the QBO and the solar cycle on polar ozone and 2) mixing and transport processes near the edge of the polar vortex. The results from such research might help to explain how much of the observed temperature increase in the troposphere is due to an anthropogenic increase of the greenhouse effect, and how much is due to solar variation.

Another field of research will be studies of the UTLS region, including stratosphere-troposphere exchange processes. For this purpose, the present lidar system will be of limited use due to its technical design. However, a separate troposphere lidar system is currently planned, which will give information on both tropospheric ozone, aerosols and water vapour. These data can be combined with (continuously recorded) radar data from ALOMAR to provide a powerful data set on the upper troposphere.

DOAS instruments

The DOAS instruments in Ny-Ålesund and at ALOMAR participate in the Network for the Detection of Stratospheric Change and thus provide valuable data for the international community. These instruments also form a strong basis for Norwegian participation in EU projects and thus represent an important and strategic activity.

Future development/improvement include the observation of the elusive compound IO and the improvement of air mass factors for NO_2 and other chemically active species

UV Spectroradiometers and UV filter instruments

UV radiation measurements in the troposphere and stratosphere are rare, compared with other climatological parameters. Such measurements are needed to document the radiation field, to verify models and to study the effect of various factors that affect the radiation field. Furthermore is accurate knowledge of the radiation field needed to understand the photochemistry of the atmosphere. Development of new flexible instrumentation and software to be able to measure as many atmospheric parameters as possible will be of importance to understand radiative transfer at different meteorological conditions.

Climatological changes of aerosols, clouds, different chemical components will all effect UV climatology in future. Clouds causes the largest variability in UV transmittance and mechanisms for radiative transfer in clouds in general is very limited. Thus a challenging topic for the future is the influence of clouds on the radiation field. There is a large potential for improving the representation of clouds in photochemical models. Such improvements must be based on well performed experiments and careful analysis of the results.

The generation of UV maps are dependent on the availability of input parameters at sufficient spatial and temporal resolution and accuracy. A main source of such data are satellite instruments with suitable high level data products with adequate accuracy.

It will be of importance for future projects on UV climatology to be closely connected to the parts in KlimaProg working on cloud climatology as well as ozone and aerosols. A fruitful collaboration with biologists is foreseen. A stronger scientific dialogue is necessary in order to understand their data needs, and will extend the exploitation of the results from the UV and ozone research within the COZUV project.

Sondes

Participation in international ozonesonde programmes requires that we continue our observations at Ørland. At present, measurements of stratospheric water vapour are carried out from only one site in the world; Boulder, Colorado. Otherwise, water vapour is only measured sporadically during campaigns. The SPARC assessment of upper tropospheric and stratospheric water vapour identifies a large need for more measurements of stratospheric water vapour. It would therefore be of interest to start up measurements of water vapour in the Arctic and one possible site would be Ny-Ålesund, where this could be done in collaboration with the Alfred Wegener Institute.

Satellite observations

After the second phase of COZUV we suggest to put more emphasis on the use of satellite data in order to gain a better understanding of the processes that lead to ozone change.

Several new instruments that observe the atmosphere have either been launched recently or will be launched in the near future. The ODIN satellite was launched in February 2002 and carries two instruments that both are of interest to atmospheric science: The Sub Millimetre Receiver (SMR) and an optical instrument called OSIRIS (Optical Spectrometer and InfraRed Imaging System). Together these instruments can measure ozone, HNO_3, ClO, NO_2, N_2O, H_2O and HO_2.

The SAGE III satellite was launched on 10 December 2001 and will provide data on aerosol extinction, water vapour, NO_2, NO_3, ozone, OClO and cloud presence.

The ENVISAT satellite carries several instrument of great interest to atmospheric scientists: GOMOS, MIPAS and SCIAMACHY. ENVISAT will probably be launched during the first half of 2002 and will provide atmospheric column and profile data on a wide range gases. The observations obtained will in general be used to study the chemical composition, dynamics, and radiation budget of the atmosphere. More particularly they can be used to investigate a wide range of phenomena which influence atmospheric chemistry such as biomass burning, pollution, and arctic haze in the troposphere; and ozone chemistry, volcanic events and solar proton events in the stratosphere.

The GOME instrument on ERS-2 will hopefully continue to deliver data on ozone, NO_2, OClO and BrO. These data will also be valuable.

6.4 Couplings to other projects

National projects

It is quite important that the individual tasks in a possible continued project be tied together in order to achieve a common goal. Other large national projects could possibly be tied to this project. Adequate resources would need to be allocated for defining common areas of interest between projects and performing the work. Collaboration with other research projects within the broad field of global change science could prove to be both successful and cost effective.

It has been mentioned above that clouds have a large impact on UV radiation and that in order to predict future UV levels we have to know both the development of the ozone layer and the development of the cloud cover. This implies that the relation to RegClim needs to be discussed. This applies also to the study of long-term (decadal) variability linked the NAO and for future changes in atmospheric chemistry and transport.

EU projects

The COZUV partners participate in several EU projects that will start in late 2001 or in 2002. In these projects we will carry out research which is related to both existing COZUV activities and new activities that should be included in a possible new COZUV project. It should also be pointed out that support through COZUV ensures activities and methodologies that are necessary in order to be regarded as interesting partners and that enables us to participate in such projects. Below follows a table of up-coming EU projects.

Table 6.4.1. Up-coming EU projects where COZUV partners participate

Acronym	Title
CANDIDOZ	Chemical and Dynamical Influences on Decadal Ozone Change (2002-2005)
HIBISCUS	Impact of tropical convection on the upper troposphere and lower stratosphere at global scale (2002 - 2004)
QUOBI	Quantitative Understanding of Ozone losses by Bipolar Investigations (2002 - 2004)
SCENIC	Scenario of aircraft emissions and impact studies on chemistry and climate (2002 - 2005)
TOPOZ-III	Towards the prediction of stratospheric ozone - III (2002 - 2005)

SECTION

7

Use of resources

COZUV 1999				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
Task 1	***1999***	***Institusjon 1***					
		UiO	UiO - Michael Gauss	277000,00		100 prosent	
		UiO	UiO - Bjørg Rognerud	82000,00	329000,00	20 prosent	20 prosent
		UiO	UiO – Driftsmidler	18000,00			
Task 1	***1999***	***Institusjon 2***					
		NILU	B. Bojkov - 84 timer á 700	58800,00			
Task 2	***1999***	***Institusjon 1***					
		NILU	Y. Orsolini - 222 timer á 700	155400,00			
		NILU	Y. Orsolini - 127 timer á 524	66580,00			
		NILU	Y. Orsolini - reise France 26-9	12767,50			
		NILU	Y. Orsolini - reise Gardermoen 24.11.	212,00			
		NILU	I. Fløisand - 71,50 timer á 700	50050,00			
		NILU	I. Fløisand - 214 timer á 700	149800,00			
		NILU	I. Fløisand reise Gardermoen 24.11.	120,00			
Task 3	***1999***	***Institusjon 1***					
		NILU	Arbeid ozonsondeslipp mars	8852,30			
		NILU	Sensor interface unit	7284,00			
		NILU	mva Vaisala, radiosonde	371,00			
		NILU	mva Vaisala, sensor interface	1675,00			
		NILU	mva inst. Meteolaborag	5457,00			
		NILU	Snow White	23641,28			
		NILU	Arb.ozon utslipp	5702,00			
		NILU	B. Bojkov reise Gardermoen 229	289,80			

COZUV 1999				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
Task 3	***1999***	***Institusjon 1***					
		NILU	Frakt utstyr	778,42			
		NILU	Mva inst en sci	9608,00			
		NILU	MV Vaisala	4148,00			
		NILU	MV Vaisala	6414,00			
		NILU	MV Vaisala	4276,00			
		NILU	Slipp av ozonsonder	16912,50			
Task 3	***1999***	***Institusjon 2***					
		DNMI	DNMI arb. Ozonsondeslipp apr	4360,00			
		DNMI	DNMI ozonsondeslipp juni	4739,88			
Task 4	***1999***	***Institusjon 1***					
		NILU	B. Arlander - 102,5 timer á 700	71750,00			
		NILU	B. Arlander - 4 timer á 700	2800,00			
		NILU	K. Törnkvist - 100 timer á 700	70000,00			
		NILU	K. Törnkvist - 191 timer ´700	133700,00			
		NILU	Instrumentleie spectrometer	20000,00			
Task 5	***1999***	***Institusjon 1***					
		NILU	G. Hansen - 81 timer á 700	56700,00			
		NILU	G. Hansen - reise Kjeller	6339,00			
		NILU	G. Hansen - reise Gardermoen 24.11	5056,00			
		NILU	Instr.leie ozonlidar	20000,00			

COZUV 1999				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
Task 5	***1999***	***Institusjon 2***					
		FFI	Ulf-Peter Hoppe				70 prosent
		FFI	Driftsmidler	133333,00			
Task 6	***1999***	***Institusjon 1***					
		NILU	G. Hansen - 27.5 timer á 700	19250,00			
		NILU	G. Braathen - 48 timer á 700	33600,00			
		NILU	F. Stordal - 97 timer á 700	67900,00			
		NILU	F. Stordal - reise Gardermoen 24.11	448,00			
Task 7	***1999***	***Institusjon 1***					
		NTNU	Trond Morten Thorseth	324000,00		100 prosent	
		NTNU	Berit Kjeldstad				7 prosent
		NTNU	Driftsmidler/o.h./utstyr	68000,00			
Task 8	***1999***	***Institusjon 1***					
		NILU	T. Danielsen - 79,5 timer á 560	44520,00			
Task 9	***1999***	***Institusjon 1***					
		NILU	A. Kylling - 52.5 timer á 700	36750,00			
			A. Kylling - reise Kjeller (8-1267)	3381,00			
Task 10	***1999***	***Institusjon 1***					
		NILU	G. Braathen - 141,5 timer á 700	99050,00			
			Møteutgifter	3650,00			

COZUV 2000				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
Task 1	***2000***	***Institusjon 1***					
		UiO	Michael Gauss	380000,00		100 prosent	
		UiO	Bjørg Rognerud	83000,00	395000,00	18 prosent	82 prosent
		UiO	Driftsmidler	33000,00			
Task 1	***2000***	***Institusjon 2***					
		NILU	Utlegg BRB	682,22			
Task 2	***2000***	***Institusjon 1***					
		NILU	Y. Orsolini, 72,5 timer á 715	51870,00			
		NILU	Y. Orsolini, 249 timer á 720	179280,00			
		NILU	I. Fløisand, 3 timer á 720	2160,00			
		NILU	I. Fløisand, 283 timer á 719	203520,00			
		NILU	Y.Orsolini reise Nice	13815,00			
		NILU	tungregning unik	1171,48			
Task 3	***2000***	***Institusjon 1***					
		NILU	T. Ofstad, 100 timer á 390	39000,00			
		NILU	B. Bojkov, reise Gardermoen 7-12-2-3	901,30			
		NILU	Div. Utlegg ozon gjøremål	332,00			
		NILU	Stoppur	249,00			
		NILU	Toll vaisala	3816,00			
		NILU	Kabler til ozon lab	1413,27			
		NILU	Frakt ozonsonder 3-6325	2117,52			
Task 3	***2000***	***Institusjon 1***					
		NILU	Frakt ozonkalibrator 3-6400	350,00			
		NILU	Utlegg porto 6-679	391,00			
		NILU	Div. Utlegg BRB	81,00			
		NILU	B. Bojkov reise Gardermoen (8-3228)	373,20			

COZUV 2000				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
		NILU	Utlegg v/O. Jenssen	68,00			
		NILU	Porto	1648,00			
Task 4	***2000***	***Institusjon 1***					
		NILU	B. Høiskar - 36,5 timer á 720	26280,00			
		NILU	B. Høiskar - Timer	490,00			
		NILU	B. Arlander - 208,5 timer á 719	150020,00			
		NILU	B. Arlander - losji	900,00			
		NILU	Losji 15.4-18.4	990,00			
		NILU	B. Arlander reise Andenes (7-753)	1742,00			
Task 5	***2000***	***Institusjon 1***					
		NILU	G. Hansen - 161,5 timer á 720	116280,00			
		NILU	K. Edvardsen - 33 timer á 729	24072,00			
		NILU	G. Hansen, reise Oslo 10-4	5672,50			
		NILU	G. Hansen reise Oslo (8-3180)	979,25			
Task 5	***2000***	**Institusjon 2**					
		FFI	**Ulf-Peter Hoppe**				**70 prosent**
		FFI	**Driftsmidler**	**219000,00**			
Task 6	***2000***	***Institusjon 1***					
		NILU	G. Hansen - 42,5 timer á 720	30600,00			
		NILU	G. Hansen - 18 timer á 720	12960,00			
		NILU	B. Høiskar - 14,5 timer á 720	10440,00			
		NILU	F. Stordal - 52 timer á 720	37440,00			
Task 7	***2000***	***Institusjon 1***					
		NTNU	Trond Morten Thorseth	378000,00		100 prosent	
		NTNU	Berit Kjeldstad				7 prosent
		NTNU	Driftsmidler/o.h./utstyr	172000,00			
Task 8	***2000***	***Institusjon 1***					

COZUV 2000				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
		NILU	S. Larsen 10 timer á 390	3900,00			
		NILU	T. Danielsen 450 timer á 572	257400,00			
		NILU	T. Nilsen 2 timer á 572	1144,00			
		NILU	V. Dahl 1 time	572,00			
		NILU	T. Hansen 121 timer á 390	47190,00			
		NILU	Printkort til kube	4400,94			
		NILU	Deler til kube	2107,95			
		NILU	Batterilader	465,00			
		NILU	Gebyr Carnet	1900,00			
		NILU	Bilder	172,20			
		NILU	T. Danielsen, reise GAP 21-6	36181,00			
Task 8	***2000***	***Institusjon 1***					
		NILU	A. Kylling reise GAP 21-6	19240,00			
		NILU	Filmfremkalling	184,00			
		NILU	Wire m/mer	714,00			
Task 9	***2000***	***Institusjon 1***					
		NILU	A. Kylling 169,5 timer á 720	122040,00			
		NILU	A. Kylling - Mobil tlf.	299,19			
		NILU	A. Kylling - Mobil tlf.	498,76			
		NILU	A. Kylling - reise Oslo (8-3365)	2190,00			
Task 10	***2000***	***Institusjon 1***					
		NILU	G. Braathen 138 timer á 720	99360,00			
		NILU	K. Gram 1 time	390,00			
		NILU	G. Braathen reise Lysebu	6829,00			
		NILU	G. Braathen konf.pakke Soria Moria	29940,00			
		NILU	Garder konf.senter (3-4465)	7590,00			
		NILU	G. Braathen reise Oslo (8-3394)	530,00			

COZUV 2000				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
		NILU	Carnet (7-678)	25,00			

COZUV **Prognose 2001**				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
Task 1	***2001***	***Institusjon 1***					
		UiO	Michael Gauss	397000,00		100 prosent	
		UiO	Bjørg Rognerud	100000,00	397000,00	20 prosent	80 prosent
		UiO	Driftsmidler	80000,00			
Task 1	***2001***	***Institusjon 2***					
		NILU	G. Braathen - 118 timer á 826	97468,00			
		NILU	DNMI Overf. Data	15600,00			
		NILU	Overføring av data	16900,00			
		NILU	Servering	2089,00			
		NILU	Overf. Met.data	18200,00			
		NILU	ECMWF-data fra DMI	39900,00			
Task 2	***2001***	***Institusjon 1***					
		NILU	Y. Orsolini - 181 timer á 808	146326,00			
		NILU	Y. Orsolini - 23,5 timer á 826	19411,00			
		NILU	I. Fløisand - 133 timer á 826	109858,00			
		NILU	Y. Orsolini - Konferanse	1500,00			
		NILU	Y. Orsolini - Blindern 3-24.10.	360,00			
		NILU	Y. Orsolini - Biarritz	12209,00			
Task 3	***2001***	***Institusjon 1***					
		NILU	G. Braathen - 101 timer á 826	83426,00			
		NILU	B. Bojkov - 22,5 timer á 826	18585,00			
		NILU	T. Ofstad - 143 timer á 404	57772,00			
Task 4	***2001***	***Institusjon 1***					
		NILU	B. Høiskar - 77,90 timer á 826	64345,00			
		NILU	B. Arlander - 109 timer á 826	90034,00			
		NILU	K. Tørnkvist - 34,5 timer á 772	26634,00			

COZUV Prognose 2001				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
		NILU	B. Arlander - Andenes 3-8.7.	7332,00			
Task 5	***2001***	***Institusjon 1***					
		NILU	G. Hansen - 139,5 timer á 826	115227,00			
		NILU	K. Edvardsen - 46 timer á 772	35512,00			
		NILU	G. Hansen, Arcachon 24-27.9.	5006,55			
		NILU	G. Hansen Oslo 8-9.11.	3871,25			
		NILU	K. Edvardsen Kjellder	4171,50			
		NILU	ALOMAR, Utgifter til observasjoner	36000,00			
Task 5	***2001***	***Institusjon 2***					
		FFI	Ulf-Peter Hoppe				70 prosent
		FFI	Ivar Baarstad			70 prosent	
		FFI	Driftsmidler	120000,00			
Task 6	***2001***	***Institusjon 1***					
		NILU	G. Hansen - 30 timer á 826	24780,00			
		NILU	K. Edvardsen - 23 timer á 772	17756,00			
		NILU	K. Edvardsen - 19 timer á 772	14668,00			
		NILU	G. Braathen - 18 timer á 826	14868,00			
		NILU	F. Stordal - 52 timer á 826	42952,00			
		NILU	G. Braathen Nice 24.31.3.	17113,00			
Task 6	***2001***	***Institusjon 1***					
		NILU	G. Braathen Konf.avg. Nice 24.3.	1620,00			
		NILU	Poster Arcachon	1370,00			
		NILU	G. Hansen Oslo 8-9.11.	3871,25			
Task 7	***2001***	***Institusjon 1***					
		NTNU	Trond Morten Thorseth	289000,00		100 prosent	
		NTNU	Berit Kjeldstad				7 prosent
		NTNU	Driftsmidler/o.h./utstyr	131000,00			

COZUV **Prognose 2001**				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
Task 7	***2001***	***Institusjon 2***					
		UiO	Arne Dahlback, Driftsmidler	10000,00			
Task 8	***2001***	***Institusjon 1***					
		NILU	A. Kylling - 91 timer á 826	75166,00			
		NILU	A. Kylling - 60,5 timer á 826	49973,00			
		NILU	T. Danielsen - 149 timer á 592	88208,00			
		NILU	Gebyr Carnet 01-0598/0	2025,00			
		NILU	Film	50,00			
		NILU	T. Danielsen Frankrike 9-13.6.	25293,00			
		NILU	Mobil ILAB	805,76			
		NILU	Mobil ILAB	305,65			
		NILU	A. Kylling - Berlin 15.18.10.	1530,00			
		NILU	A. Kylling - Oslo 8-9.11.	5599,00			
		NILU	A. Kylling - Kjeller (8-4680)	5159,00			
		NILU	A. Kylling - Kjeller (7-1138)	80,00			
Task 8	***2001***	***Institusjon 1***					
		NILU	A. Kylling - Kjeller (8-4459)	6057,00			
		NILU	A. Kylling - Publisering	5340,00			
Task 9	***2001***	***Institusjon 1***					
		NILU	G. Hansen - 9 timer á 826	7434,00			
		NILU	O. Engelsen - 127 timer á 772	98044,00			
		NILU	O. Engelsen Blindern 7-10.11.	6528,00			
Task 10	***2001***	***Institusjon 1***					
		NILU	G. Braathen - 207 timer á 826	170982,00			
		NILU	Medl.kon. NFFF	100			
		NILU	Servering (3-1804)	1665,00			
		NILU	Servering 3-1805)	1723,00			

COZUV **Prognose 2001**				Ressurser (knok)		Stillinger (Stillingsprosent på prosjektet)	
				Finansiering fra programmet	Egen/annen-finansiering	Finansiert av programmet	Faste stillinger/ finansiert med andre midler
		NILU	Servering (3-2589)	1865,00			
		NILU	EMS forsendelse (3-1092)	331,20			

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ABSTRACT
This report summarises the results from the first three years of the Norwegian Coordinated Ozone and UV project (COZUV). Results are reported on the following topics:
1. 3-dimensional atmospheric chemistry modelling
2. Dynamical modelling and ozone mini-hole climatology
3. Ozonesonde observations
4. DOAS observations of ozone and other stratospheric gases
5. Ozone lidar measurements
6. Analysis of ozone loss
7. Instrument development and measurements of UV radiation
8. Development of an instrument for measurements of actinic flux in the troposphere and stratosphere
9. UV modelling

NORWEGIAN TITLE
Rapport for de første tre årene av COZUV-prosjektet

KEYWORDS		
Stratospheric ozone	Ultraviolet radiation	Atmospheric measurements and modelling

ABSTRACT (in Norwegian)
Denne rapporten summerer resultatene fra de tre første årene av COZUV-prosjektet.

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