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Comprehensive Investigations of Polar stratospheric Aerosols

Energy, Environment and Sustainable Development Programme
Contract n° EVK2-CT-2000-00095

Final Report

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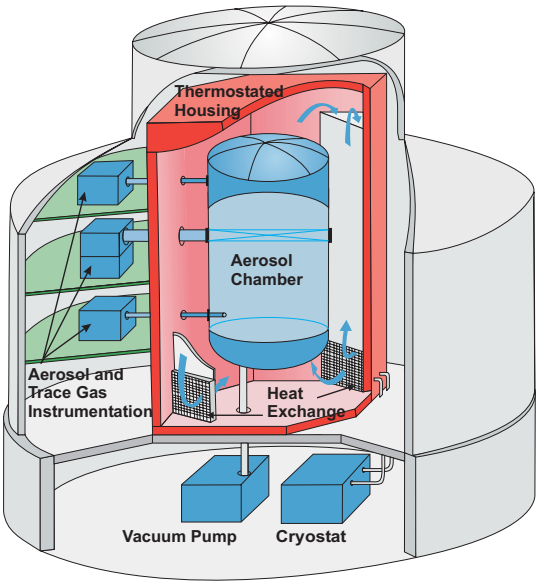
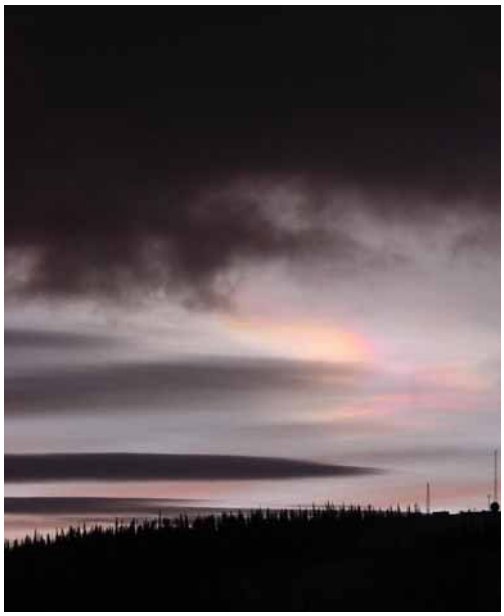
Comprehensive Investigations of Polar stratospheric Aerosols
CIPA.





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ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT PROGRAMME
KEY ACTION: 2.1.2 STRATOSPHERIC OZONE DEPLETION

Contract EVK2-CT-2000-00095

EXECUTIVE SUMMARY

Contract	EVK2-CT-2000-00095	Project duration	1 October 2000 – 30 June 2003
Title	Comprehensive Investigations of Polar stratospheric Aerosols (CIPA)		

Objectives:

- Cryo-chamber campaigns
- Balloon-borne field campaigns; experiments on aerosol composition and environmental measurements, aerosol optical measurements, meteorological support and analysis
- Optical and microphysical modelling
- Internet presentation

Scientific achievements:

The results of the cryo-chamber experiments on homogeneous ice freezing in binary sulphate solutions were used to test the validity of parameterisation of this process under close-to-atmospheric conditions. Extending the investigations of homogeneous ice nucleation to ternary solution droplets, a set of similar experiments was performed for the $HNO_3/H_2O/H_2SO_4$ aerosol system. In a second set of experiments, the formation of the solid hydrates NAT and NAD was forced by nucleation of water/nitric acid gas mixtures that were rapidly cooled to temperatures below 180 K. In order to investigate the possibility of induced nucleation by seeds other than ice particles, additional experiments were performed using soot and mineral dust. For these experiments, an aerosol of liquid particles containing binary solution of nitric acid and water was produced inside the AIDA chamber by mixing gas flows of HNO_3 and H_2O at a ratio around 1:3. In this series the mixing with soot was varied. Due to the experimental conditions the exact composition of the resulting solid particles is not known, i.e., whether they are the dihydrate or trihydrate of nitric acid. These experiments are the first to produce, in a large aerosol chamber, solid particles which contain nitric acid and water.

A CIPA gondola was launched on 9 December 2001. The gondola flew through PSC layers for nearly 3 hours in two up/down manoeuvres. The flight was very successful and at least three different types of PSC particles were measured in a wide temperature range in three distinct layers between 22 and 26 km, including the detection of particles with a very high concentration of nitric acid. Below 24.5 km liquid supercooled ternary solution (STS) droplets of water, nitric acid, and sulphuric acid, and a thin ice layer were observed. Above this layer the particles were primarily solid nitric acid trihydrate (NAT). Just above 26 km, at cloud top, there was a thin layer of solid particles, some of which were rich in nitric acid.

Two balloon-borne CIPA-gondolas were launched from Esrange on 4 Dec and 6 Dec, 2002 as part of the European VINTERSOL campaign. The last flight was performed in close coordination with a MIPAS balloon flight, launched a few hours after the CIPA balloon, and with airborne lidar measurements by the Falcon aircraft, probing air masses where the PSC particles could have formed. Four independent backscatter soundings were also performed.

In contrast to previous winters where the PSC-analysis experiments have been conducted from Esrange, the observations in early December 2002 were characterised by the absence of mountain leewaves, and the observed PSC particles were formed in huge synoptic-scale regions with low temperatures over the North Atlantic between Greenland and Scandinavia. The absence of mountain leewaves implies that the temperature histories of the observed particles, derived from meteorological analyses will be much more accurate, compared to a mountain leewave situation.

Correlations between backscatter measurements and integrated particle surfaces from optical particle counters have been used to establish an empirical rule to infer particle surface areas from optical measurements. Optical measurements and optical model calculations (T-matrix and Mie codes) have been applied to infer PSC particles refractive indices.

Socio-economic relevance and policy implications:

The proposed investigations have strengthened the scientific base, needed to implement the European Union's environmental policy in support of the Montreal Protocol, by contributing to improved understanding of some basic physical and chemical processes in the atmosphere, which have a strong influence on stratospheric ozone depletion. Thereby improvements have been made to European modelling tools, necessary as a base for scientific recommendations and political actions for protection of the atmospheric environment and for sustainable management of resources.

Conclusions:

Most of the cryo-chamber results on homogeneous ice freezing agree with an existing parameterization. All attempts to generate NAT aerosol in the AIDA chamber have resulted in the exclusive formation of NAD which could be unambiguously identified by FTIR spectrometry and aerosol chemical mass spectrometer analyses. Although the evaluation of the results must still be considered as preliminary, there are strong indications from several experiments that the NAD nucleation thresholds disagree significantly with parameterisations for surface-induced NAD nucleation.. The ease of forming NAD instead of NAT particles under simulated stratospheric conditions leads to the conclusion that other unknown (possibly heterogeneous) processes must be responsible for the presence of NAT and for denitrification events in the polar stratosphere.

The balloon measurements from December 2001 represent the most comprehensive *in situ* observations of all phases of polar stratospheric cloud particles so far, while the large particles at cloud top have not been previously observed, and may have implications for producing particles large enough to remove reactive nitrogen from the polar stratosphere. For the first time signals of hydrochloric acid were detected clearly above background noise in measurements from December 2002. The measured mass-spectrometer signals of mass 35 (^{35}Cl), 36 ($H^{35}Cl$), 37(^{37}Cl) and 38($H^{37}Cl$) show the right atmospheric isotopic ratio of chlorine as well as the well-known ratio for electron-beam ionization fragments for mass spectrometers. The derived mol percentage of dissolved hydrochloric acid in PSCs is in good agreement with theoretical calculations. In addition at the top of both clouds sampled, there was a layer of particles consisting of very few large solid particles and almost no smaller PSC particles. The large particles had radii >1-4 µm and concentrations of less than 10^{-3} cm^{-3}. The molar ratios from these particles varied between two and four. Because of the few detected particles, the statistical error was too large to distinguish NAD and NAT composition of these large particles. But it could be clearly shown that these strange large particles contain a large amount of nitric acid. The measurements can exclude that these particles consist only of pure ice. The existence and formation of these particles raises interesting questions about PSC evolution and denitrification.

In December 2002 it can be noted from the temperature histories, that the particles did not experience temperatures below the ice frost point. The particles spent several days at temperatures between the ice frost point T_{ice} and the nitric acid trihydrate condensation temperature T_{NAT}. The local temperature plays a major role for the appearance of liquid particles. The solid particles observed in December 2002 must have formed by a slow freezing process above the ice frost point, and given that the temperature histories are very similar, this is also reflected in the observed properties among the solid particles. Based on preliminary comparison with aerosol measurements from satellite (SAGE-III) and in-situ measurements of HNO_3 from MIPAS, there are indications that surface-induced freezing rates are too high. Further investigations are being continued including a broad range of satellite and in-situ measurements of particles and HNO_3 gas phase measurements from MIPAS, aiming at more accurate description of the freezing process above the ice frost point.

Keywords:

PSC, composition, size-distributions, microphysics, optical properties

DETAILED REPORT, RELATED TO THE OVERALL PROJECT DURATION.

1 Background

Increased concentrations of greenhouse gases and depletion of the ozone layer may cause lower temperatures in the stratosphere. Combined with increases in stratospheric water vapour concentrations this may lead to more widespread formation of polar stratospheric clouds (PSC), in particular in the Arctic regions. The formation of PSCs is a key-process for chemical ozone depletion, first because the surfaces of the particles serve as sites for heterogeneous chemical activation of halogen species which deplete ozone, second because sedimentation of the nitric acid holding cloud particles depletes the air from reactive nitrogen and thereby prolong the chemical ozone destruction, a process known as denitrification. This important process will only be induced by a few large PSC particles in the solid state. Details about the formation of these types of particles have so far been unknown.

2 Scientific/technological and socio-economic objective

The objective of the CIPA-project, funded by the European Commission within the 5th Framework Programme, has been to obtain a detailed knowledge of the pathways to formation of different types of PSCs. This has been accomplished by balloon-borne measurements of particle chemical composition, size distributions, phase, and optical properties in combination with large-scale cryo-chamber experiments. Results from the chemical and optical PSC analysis have provided several missing details about the particles which are required by atmospheric chemistry and microphysical models to calculate more reliable scenarios for the ozone layer in a future climate.

3 Applied methodology , scientific achievements and main deliverables

The investigations have combined three activities as an integrated research project:

- field measurements
- large-scale laboratory simulations
- microphysical and optical modelling.

Four balloon-borne experiments have been performed from Esrange, Kiruna in winters 2000/2001, 2001/2002, and 2002/2003 using multi-instrument payloads to measure the chemical and physical characteristics of PSC particles and their gas phase environment, cf. Figure 1.

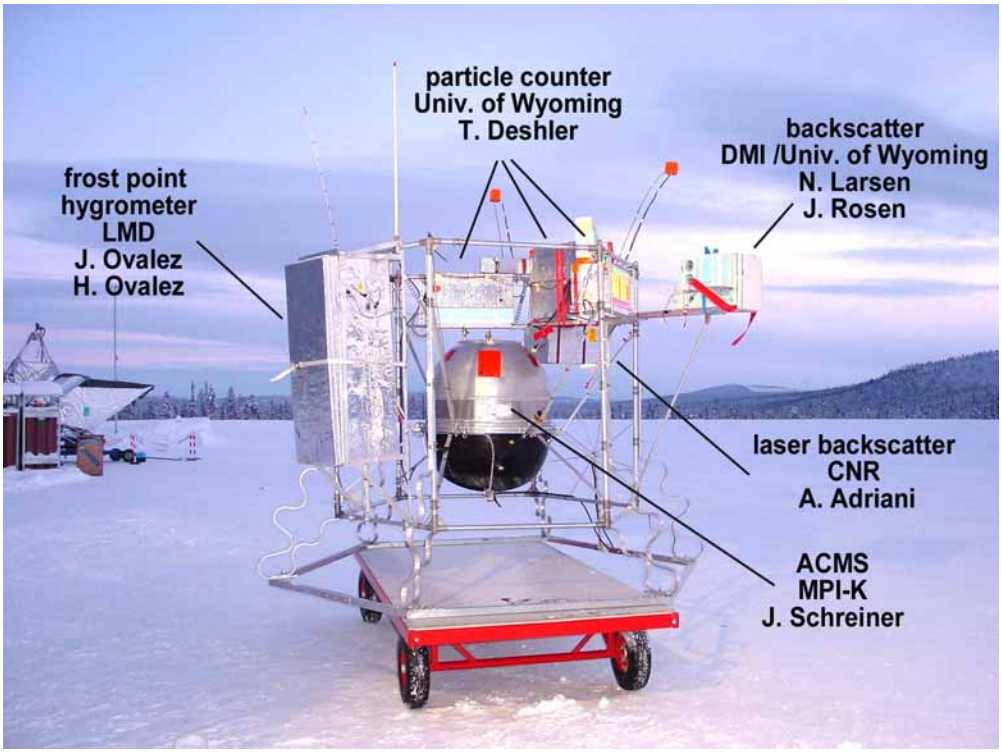

Figure 1. The CIPA gondola on the mounting trolley at Esrange. At the centre is located the aerosol chemical mass spectro-meter (ACMS) and to the left the frost point hygrometer. At the top, optical particle counters (size distributions) and two backscatter sondes.

The payloads consist of an aerodynamic focusing lens and a mass spectrometer for measurements of condensed H_2O and HNO_3, together with detection of dissolved trace gases (Max-Planck-Institut für Kernphysik, Heidelberg). Optical particle counters provide particle concentration and size distributions (University of Wyoming), and backscatter sondes measure the backscatter ratio at four wavelengths and depolarisation (University of Wyoming; Instituto di Fisica dell'Atmosfera, Rome; Danish Meteorological Institute, Copenhagen). Physical phase and refractive indices of the particles have been derived from these measurements. Finally, observations have been made of near-gondola environment, especially temperature and water vapour (Laboratoire de Météorologie Dynamique du CNRS, Paris).

Nearly identical instrumentation has been used within a large cryo-chamber to perform simulations of PSC particle formation over a wide temperature and gas phase range (Forschungszentrum Karlsruhe), cf Figure 2. Aerosol experiments are performed in a cylindrical aerosol vessel with a volume of 84 m^3. The vessel is located inside a thermal insulating box that can homogeneously be cooled to any temperature between room temperature and 183 K. Physical and chemical aerosol properties are characterised by various techniques including the molar concentration ratios of H_2O, HNO_3, and H_2SO_4 of the aerosol and number concentrations, size distributions and physical phase of aerosol particles.

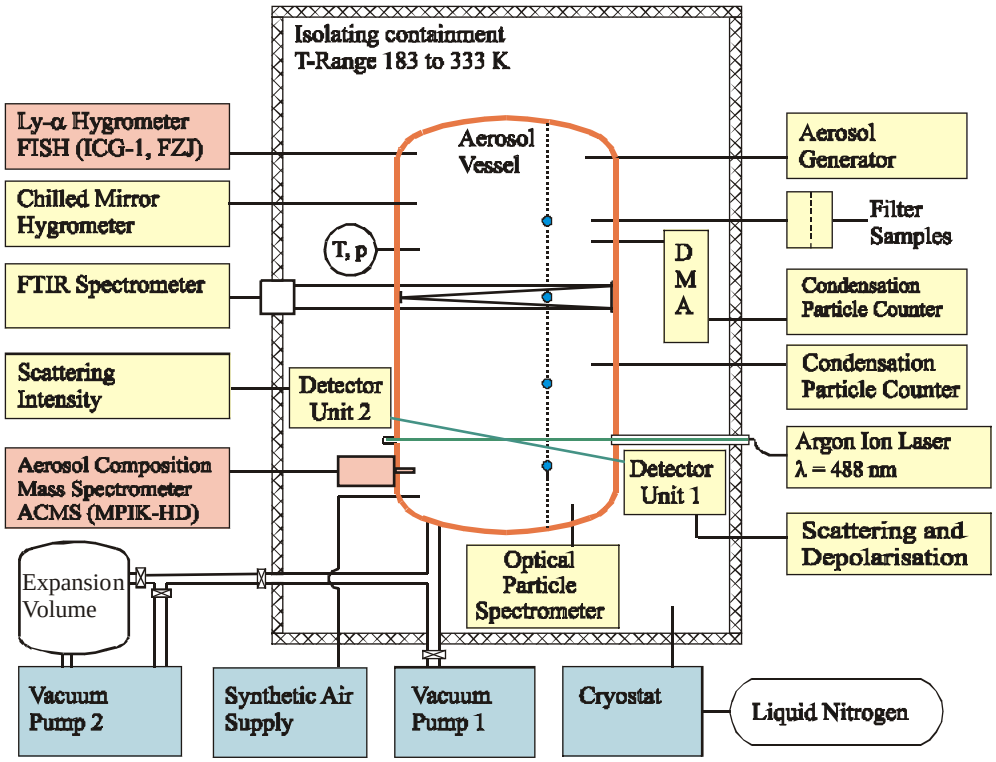

Figure 2. The 84 m^3 experimental 4-floor cryo chamber with the instrumentation for particle investigations at Forschungszentrum Karlsruhe.

The aerosol composition mass spectrometer (ACMS) of the Max Planck Institute for Nuclear Physics in Heidelberg allows quantitative measurements of the particle content of water, nitric acid, and sulphuric acid. The ACMS has been used both for the balloon-borne and cryo-chamber experiments. Aerodynamic lens, pumping system and mass spectrometer have been adapted to the special measurement conditions at the aerosol chamber or for the in-situ measurements. Particle-containing air enters the system through an aerodynamic lens which focuses particles into a very narrow aerosol beam. The lens samples gas and particles and nearly all gas molecules are removed by a first cryo-pump, while the aerosol particle beam penetrates through a small skimmer into the second chamber. Differential pumping results in a suppression of atmospheric gases over condensed species by five orders of magnitude. The separated, condensed phase is evaporated at 373 K in a heated gold sphere inside the second chamber and the resulting gas is analysed by a quadrupole mass spectrometer, while a second cryo-pump ensures low signal contributions from the remaining background gases. The ACMS delivers the bulk composition of the binary and ternary aerosol solution droplets and of solid nitric acid hydrate particles. Small numbers of larger solid particles, e.g. ice particles or nitric acid hydrates, can be recognized as spikes on the water and nitric acid mass signals, respectively, superimposed on the steady background signal arising from the much larger number of small supercooled liquid droplets.

The meteorological conditions in connection with the balloon-borne field measurements have been analysed by the Danish Meteorological Institute, providing temperature histories of the observed air parcels. Microphysical and optical models from DMI have been used to calculate

the chemical compositions, physical phase, size distributions, and optical properties of PSC particles, which have been compared directly to the field and laboratory measurements.

Balloonborne measurements

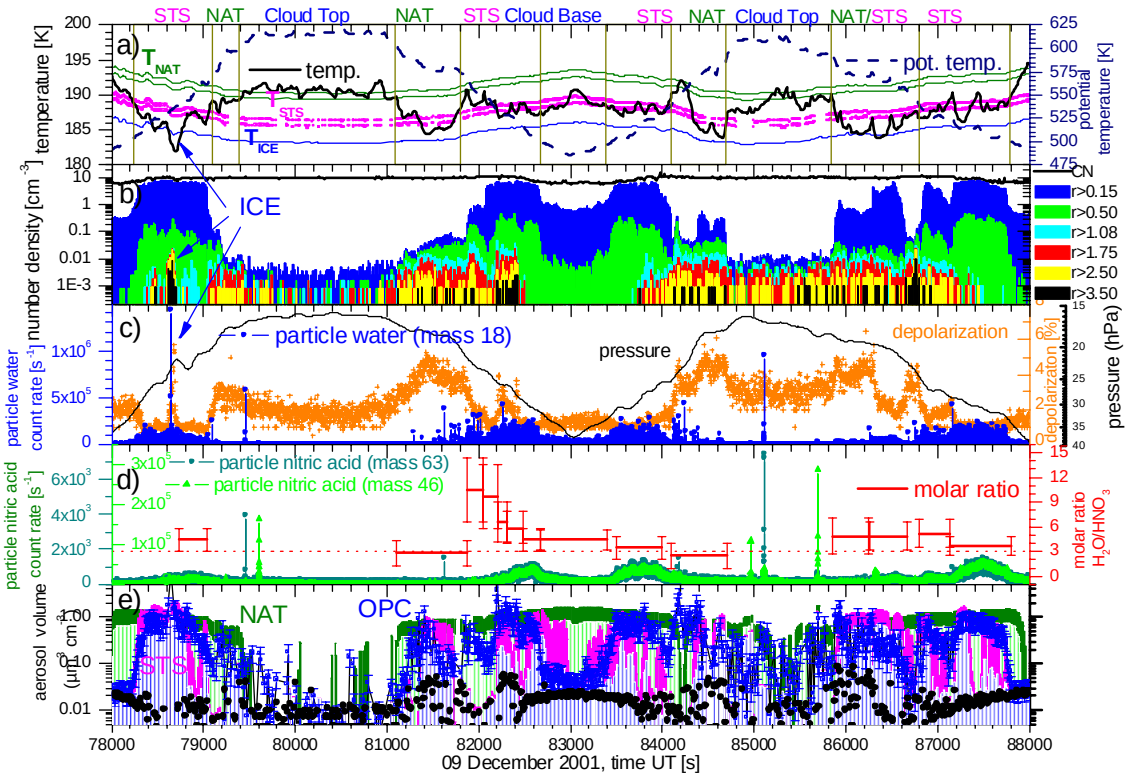

Figure 3. In situ measurements on 9 December 2001within a PSC during four transits from cloud base (potential temperature of 500 K, ~35 hPa, 22 km) to cloud top (625 K, ~15 hPa, 26.3 km). a) Potential temperature and measured temperature compared to measured T_{ICE} and estimates of T_{NAT} and T_{STS}, assuming 5 and 10 ppbv HNO_3. b) Aerosol concentration at radii > 0.01 - 3.50 μm. Particles > 10 μm, at a concentration 6 x 10-4 cm-3, could be measured. There were two observations of particles between 5 and 10 μm, in the ice cloud and in the NAT cloud on first descent. c) Number of water molecules counted per second, volume depolarization, and altitude. d) Number of nitric acid molecules counted per second and molar ratio with error bars. The mass 63 and 46 count rates are shown separately. e) Aerosol volume inferred from aerosol spectra measurements compared to a range of aerosol volumes expected for STS and NAT. Aerosol volume for particles passing though an inlet heated to 245 K are shown as black circles and represent the background sulphate aerosol. Cloud regions of predominantly a single particle type are labelled at the top with separation points indicated in a).

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ternary solution (STS) droplets of water, nitric acid, and sulfuric acid, and a thin ice layer were observed. Above this layer the particles were primarily solid nitric acid trihydrate (NAT). Just above 26 km, at cloud top, there was a thin layer of solid particles, some of which were rich in nitric acid. These *in situ* measurements represent the most comprehensive *in situ* observations of all phases of polar stratospheric cloud particles so far, while the large particles at cloud top have not been previously observed, and may have implications for producing particles large enough to remove reactive nitrogen from the polar stratosphere.

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For the first time signals of hydrochloric acid were detected clearly above background noise. The measured mass-spectrometer signals of mass 35 (^{35}Cl), 36 (H^{35}Cl), 37(^{37}Cl) and 38(H^{37}Cl) show the right atmospheric isotopic ratio of chlorine as well as the well-known ratio for electron-beam ionization fragments for mass spectrometers. Hydrochloric acid measurements inside liquid polar stratospheric cloud layers are shown in Figure 4.

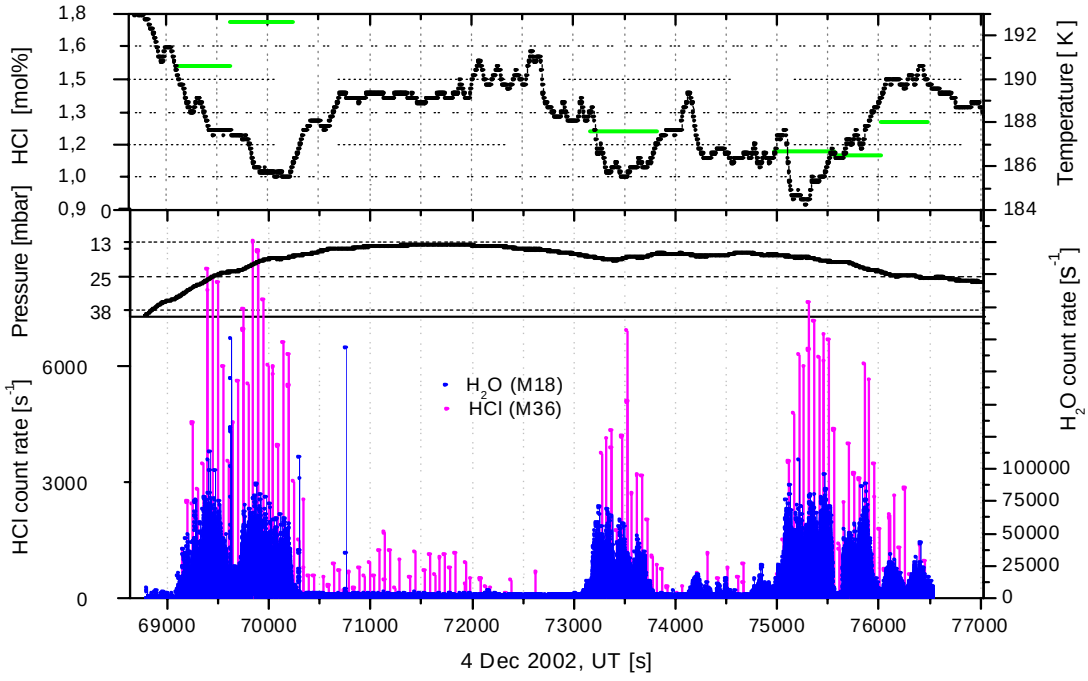

Figure 4: Measured signals of condensed water (blue) and condensed hydrochloric acid (purple) during the balloon flight of 4 December 2002. Additionally the outside pressure and temperature are shown. The mol percentage of hydrochloric acid dissolved in the PSCs derived from calibration is indicated in green.

During flight the balloon crossed several times liquid particle layers. Inside the PSCs the water signal (blue) and simultaneously the hydrochloric acid signal (purple) increased. The derived mol percentage of dissolved hydrochloric acid in PSCs (green) is in good agreement with theoretical calculations. In addition at the top of both clouds sampled, there was a layer of particles consisting of very few large solid particles and almost no smaller PSC particles. The large particles had radii >1-4 µm and concentrations of less than 10^{-3} cm^{-3}. The aerosol mass spectrometer detected some of these large particles as strong simultaneously increasing signals of water and nitric acid during their evaporation within a time scale of 200-2000 ms. The molar ratios from these particles varied between two and four. Because of the few detected particles, the statistical error was too large to distinguish NAD and NAT composition of these large particles. But it could be clearly shown that these strange large particles contain a large amount of nitric acid. The measurements can exclude that these particles consist only of pure ice. The existence and formation of these particles raises interesting questions about PSC evolution and denitrification.

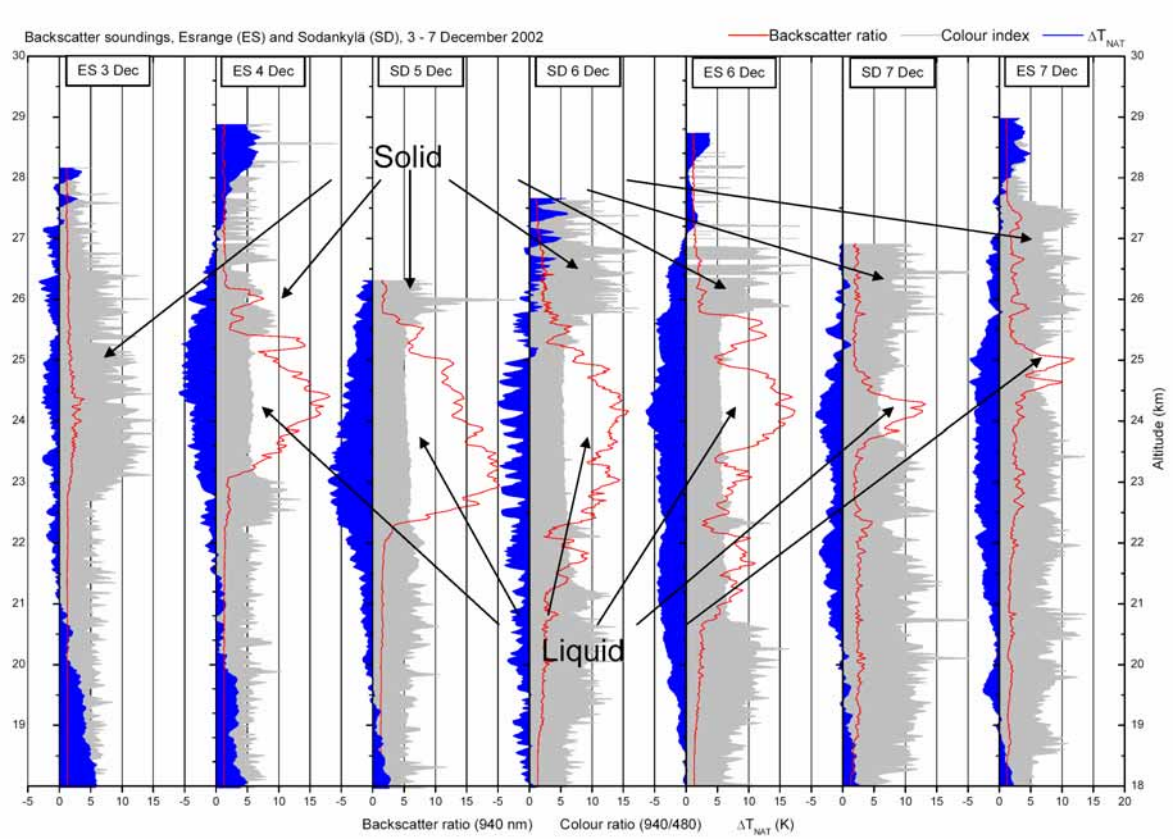

Figure 5. A sequence of vertical profiles of backscatter ratio at 940 nm (red), colour index (940/480 nm) (grey), and temperature depression below the threshold for existence of nitric acid trihydrate (blue). Measurements obtained between 3 Dec and 7 December 2002 from Esrange (ES) or Sodankylä (SD). Low and nearly constant colour indices indicate the existence of liquid particles, higher indices solid particles. The liquid particles are only observed at the lowest temperatures in the middle of the profile, giving rise to the development of a "sandwich structure" in the middle of the period, characterised by liquid particles surrounded by solid particles at the bottom and top of the profile.
Sodankylä measurements: courtesy of Rigel Kivi, Finnish Meteorological Institute.

The balloon-borne PSC measurements from December 2002 were outstanding in the sense that the observations were made early in the winter, shortly after the development of large re-

gions of synoptic scale with very low temperatures. The balloon-borne measurements this year were not influenced by local mountain leewaves over the Scandinavian mountains as in previous winters. A sequence of measurements during a 5-days period (supplemented by backscatter soundings by the Finnish Meteorological Institute at Sodankylä, Finland) shows a gradual change between liquid and solid type PSCs with the development of a well-known "sandwich structure" of liquid between solid PSCs, cf. Figure 5.

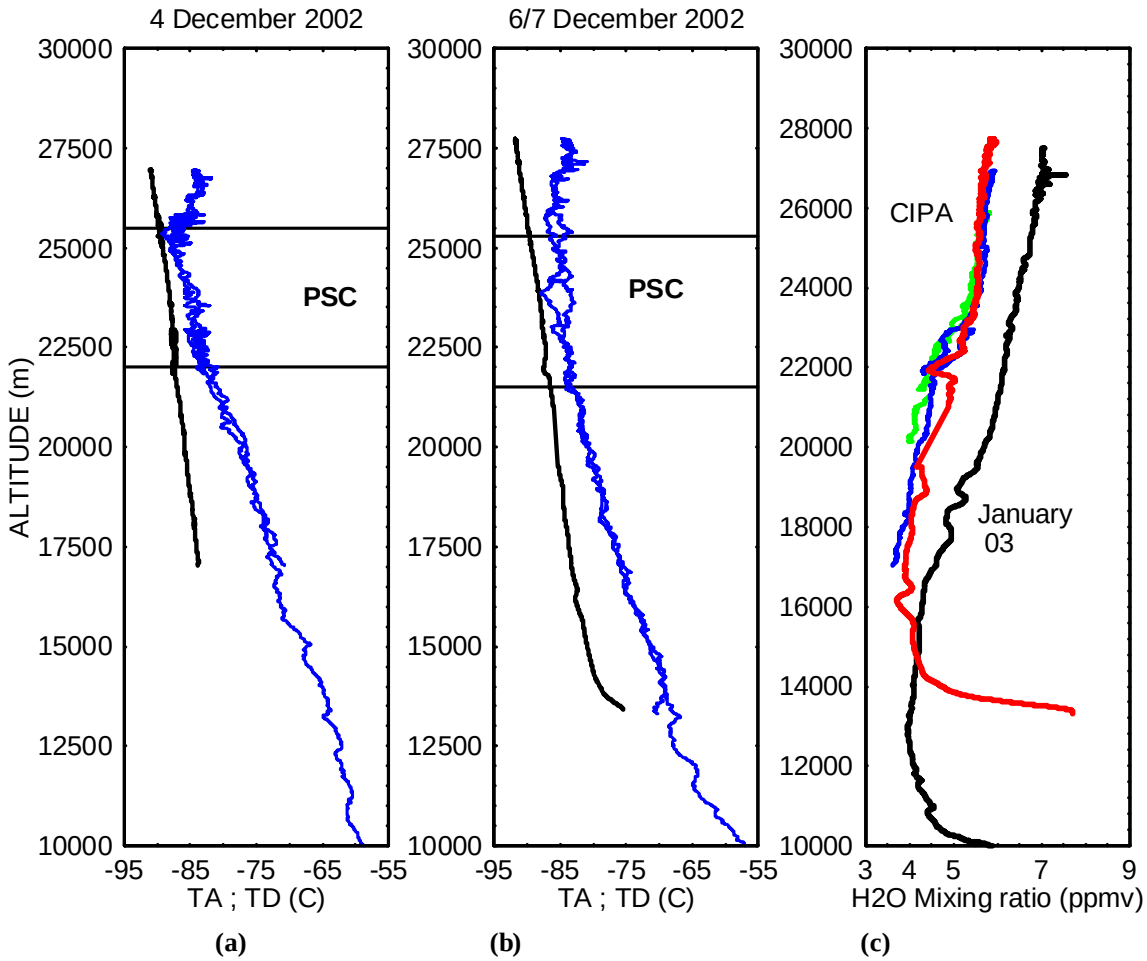

Figure 6: The figures (a) and (b) show the air and frost-point temperature profiles for the two flights of the 2002-2003 CIPA campaign, together with the range where the particles from the PSCs were detected: it is seen that on 4 December the thin layer where saturation (air temperature ≅ frost- point temperature) is detected is at the top of the PSC. On 6/7 December the saturated layer is in the middle of the PSC. On figure (c) it is seen that the water vapour mixing ratio profiles are similar for the 2 CIPA campaigns, both performed in December: the green line is for December 2001; the blue and red lines are respectively for 4 and 6/7 December 2002. The black line is for a flight performed on mid January 2003 during a campaign devoted to the validation of the ENVISAT satellite instruments.

On the Figure 6c the water vapour mixing ratio profiles for the 3 flights of the CIPA campaign are displayed together with a profile measured with the frost-point hygrometer from LMD during January 2003. The four profiles, on Figure 6c, have been measured with the same water vapour instrument. The January profile has been measured from Kiruna during the ESABC –ENVISAT Stratospheric Aircraft and Balloon Campaign, devoted to the validation

of the instruments onboard the ENVISAT platform (Bureau et al, 2003). That flight occurred inside the vortex, but without the presence of PSCs.

During December 2001 and 2002, the three water vapour profiles from CIPA are quite similar together, so that the differences in the observations in the number, sizes and composition of the particles inside the PSCs are essentially due to the differences in the local air temperature profile and temperature history of the air masses probed. However in mid January, in the altitude range where the PSCs are generally observed, the water vapour mixing ratio is higher by 1 ppmv compared to December, due to the diabatic descent of the air masses inside the vortex.

In order to provide easy-to-use lookup tables to convert optical parameters retrieved by LIDARs to aerosol particles and volumes, correlations between backscatter measurements and integrated particle surfaces from optical particle counters have been used to establish an empirical rule. A linear relationship between aerosol backscatter coefficient B_a as measured by backscattersondes and lidars, and total particle surface area SA, as measured by OPC, has been assumed. The relationships at 480, 532, 680, 940 nm have been tested in case studies taken from 5 flights performed respectively on the 19 and 25 January 2000, 9 December 2001, and 4 and 6 December 2002.

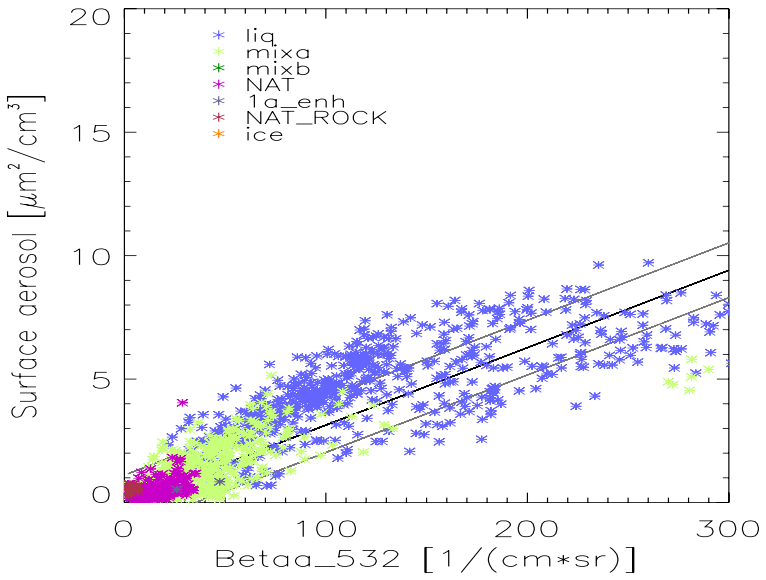

Figure 7

Example of relationship between surface area (SA) and aerosol backscatter coefficient (B_a) at 532 nm.

*B_a =0.031*SA*

Number of data points=2108

Determination coefficient=0.89

Points within 1-sigma =74.5%

In Figure 7 is shown an example of the linear regression at the typical lidar wavelength 532 nm. SA is displayed against B_a, together with the linearly regressed equation which has been used. In the Figure legend, determination coefficients and percentage of experimental data within the 1-sigma dispersion are also indicated, showing the overall satisfactory the statistical approach. Different colours in experimental data refer to different microphysical phases, derived from a statistical analysis of 10 years LIDAR measurements in Antarctica.

The T-Matrix algorithm by Mishenko and Travis (1998) has been used to compute the optical parameters - aerosol depolarization and aerosol backscatter coefficient for the aspherical particles - for time-averaged measured PSC particle concentrations and size distributions to be compared to aerosol depolarization and aerosol backscatter coefficients measured by a laser backscatter-sonde. The calculations have been performed by varying particle's refractive indices between 1.30 and 1.60 and aspect ratios between 0.5 and 2.0. The aim of the comparison was the determination of the refractive index and aspect ratios giving the best accordance between calculated and measured quantities.

The results of the study are shown in Figure 8 where refractive index as a function of aerosol depolarization, colour coded in terms of PSC particle type. Three different zones can be discerned: The first with high depolarisation and low refractive index can be associated to ice PSC (S-II). The second with high-moderate depolarisation and intermediate refractive index would correspond to NAT PSC (S-I,S-II). The third region is characterised by very low depolarisation and high refractive indices and represents liquid STS PSC (L-I, L-II).

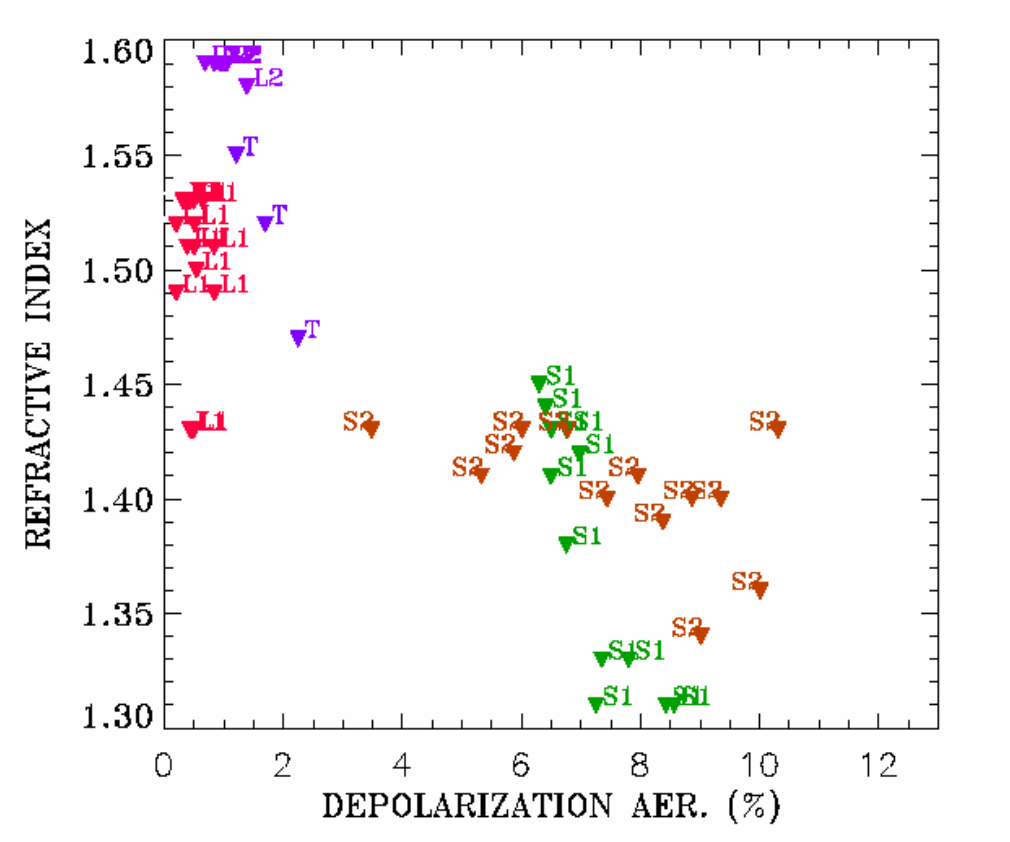

Figure. 8. Refractive index as a function of aerosol depolarization, colour coded in terms of PSC particle type.

AIDA-experiments

The large cryogenic aerosol chamber AIDA of Forschungszentrum Karlsruhe was used to simulate PSC conditions over a wide range of temperature, relative humidity, and gas phase composition (Möhler et al., 2003). In four experimental campaigns during November 2000 (CIPA-1), July 2001 (CIPA-2), November/December 2001 (CIPA-3), and May/June 2003 (CIPA-4) three series of experiments were performed (1) to investigate the homogeneous freezing of sulphuric acid, nitric acid, and super cooled ternary solution (STS) particles, (2) to generate and comprehensively characterise nitric acid hydrate particles, and (3) to investigate the effect of homogeneous and heterogeneous nucleation on the formation of nitric acid dihydrate (NAD) and trihydrate (NAT) particles. The latter two campaigns CIPA-3 and CIPA-4 have also been part of the POSTA project funded within the German research program AFO2000.

Homogeneous freezing of supercooled liquid aerosols is thought to be one of the key steps in the formation of cirrus clouds in the upper troposphere and of solid polar stratospheric clouds in the lower stratosphere. Therefore, in the aerosol chamber a set of experiments was performed to investigate the homogeneous ice nucleation in liquid supercooled H_2SO_4/H_2O solution droplets at temperatures as low as 183 K. Cloud cooling rates were simulated dynamically in the chamber by adiabatic gas expansion. Due to the cooling rate, the freezing thresholds were exceeded after expansion time periods in the range of minutes. The onset of ice nucleation can be very accurately measured with 3 independent detection methods: backscattered intensity and depolarization measurements, single large-particle counting (PCS), and chemical composition measurements of particles with the ACMS. Koop et al. (2000) found that the ice nucleation rate in solutions of different chemical composition and solute concentrations was almost the same for solutions of the same water activity at a given temperature. As a result, a parameterization yields the saturation ratio in solution droplets as a function of the temperature. The measured saturation ratio at the onset of freezing versus the freezing temperature is shown in Figure 9.

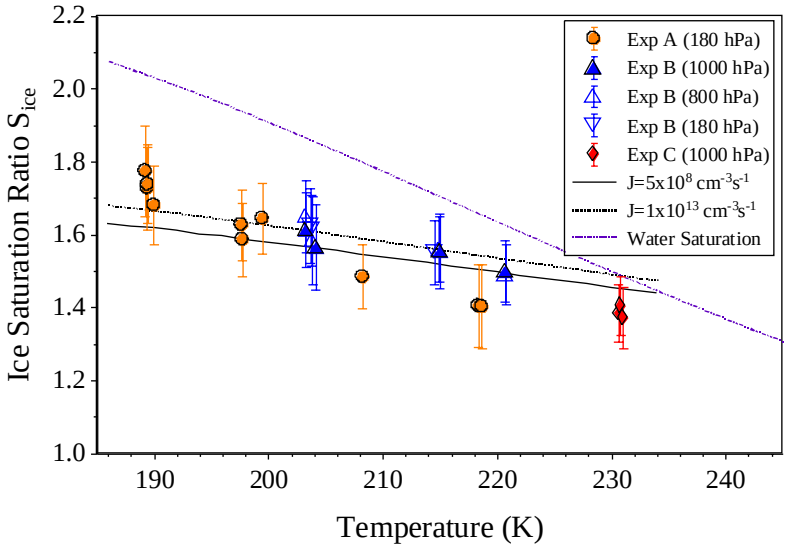

Figure 9: Temperature dependent freezing onset ice saturation ratios measured for homogeneous IN in supercooled sulphuric acid droplets compared to the water activity based parameterisation given by Koop et al. (2000), calculated for two different nucleation rates that are typical for the AIDA experiments.

The results of the AIDA experiments are in good agreement with the parameterization based on the water activity (Koop et al., 2000). Extending the investigations of homogeneous ice nucleation to ternary solution droplets, a set of similar experiments was performed for the $HNO_3/H_2O/H_2SO_4$ aerosol system. The evaluation of the data is still in progress.

In a second set of experiments, the formation of the solid hydrates NAT and NAD was forced by nucleation of water/nitric acid gas mixtures that were rapidly cooled to temperatures below 180 K. The nucleated particles were added to the chamber under well controlled conditions at t = 0 sec and analyzed by the ACMS and FTIR extinction measurements. As shown in Figure 10, the estimated molar ratio H_2O/HNO_3 = 2 suggests the presence of the solid hydrate NAD in the chamber (Budz, 2003).

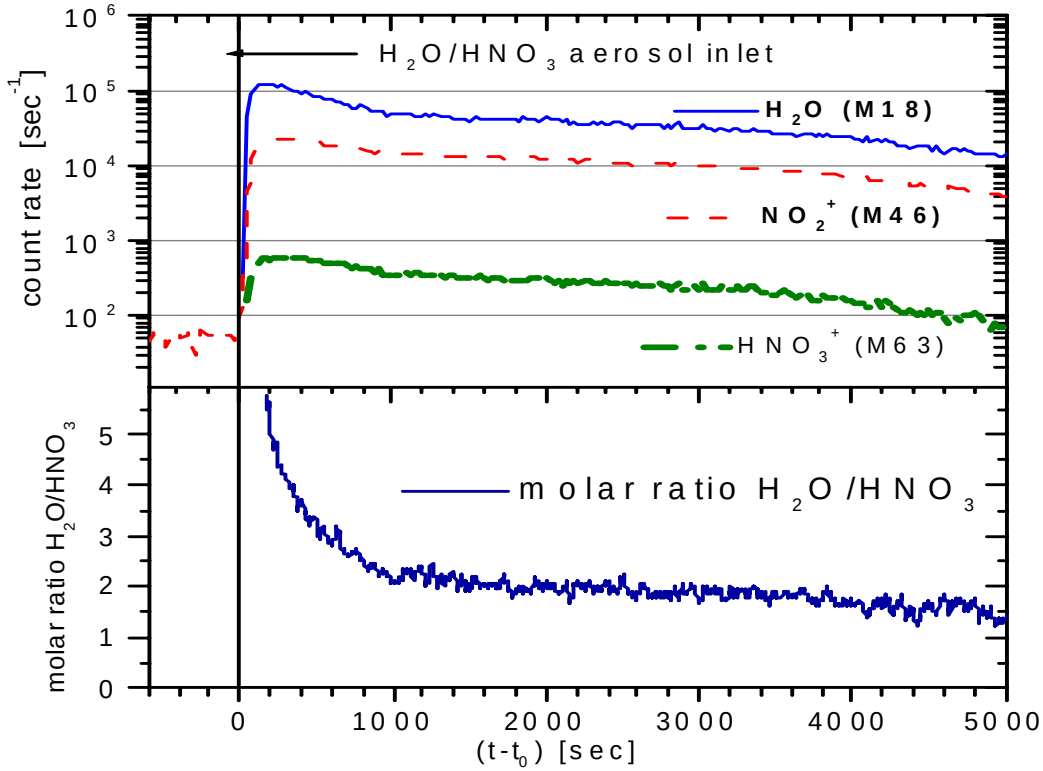

Figure 10: ACMS measurement of a binary H_2O/HNO_3 aerosol system. M46 and M63 are both a measure of HNO_3. From the count rates (upper panel) a molar ratio H_2O/HNO_3 (lower panel) can be derived for the given temperature of 193 K and pressure of 180 mbar.

All attempts to generate NAT aerosol in the AIDA chamber have resulted in the exclusive formation of NAD which could be unambiguously identified by FTIR spectrometry and ACMS. NAD nucleates homogeneously in supercooled liquid binary nitric acid-water particles and in ternary solution particles. The retrieved critical supersaturations are in conflict with the surface-induced NAD nucleation hypothesis of Tabazadeh et al. (2002).

In order to investigate the possibility of induced nucleation by seeds other than ice particles, additional experiments were performed using soot and mineral dust. In all these experiments binary systems of HNO_3 and H_2O were let into the chamber.

For these experiments, an aerosol of liquid particles containing nitric acid and water was produced inside the AIDA chamber by mixing gas flows of HNO_3 and H_2O at a ratio around 1:3. This ratio was controlled by the vapor pressure of the two liquids which were held in different reservoirs upstream of the inlet outside the cryo chamber. In this series the mixing with soot was varied. In the successful experiment presented here, soot was introduced before the aerosol into the AIDA chamber allowing the soot to fill the vessel homogeneously at a number concentration of 15000/cm^3 and decreasing afterwards.

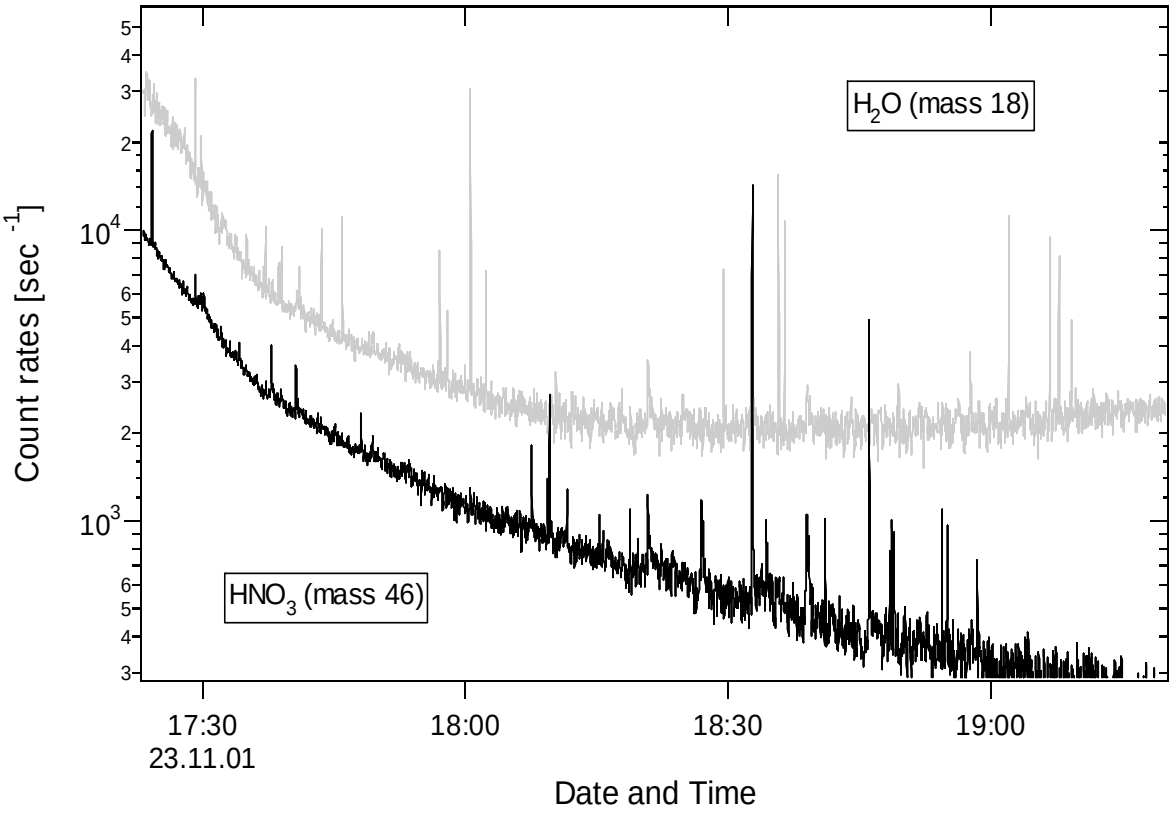

Figure 11: Results obtained from the aerosol composition mass spectrometer ACMS for a heterogeneous experiment with soot and HNO_3/H_2O aerosol on Nov 23, 2001. The temperature during this experiment was 192 K, the pressure inside the chamber 182 mbar.

Figure 11 shows the results obtained by the aerosol composition mass spectrometer. The count rates on mass 18 (water) and on mass 46 (nitric acid) show the development of a large number of small particles between 15:00 and 18:00, with a ratio H_2O:HNO_3 of 2.3. They are assumed to be liquid. Later single particles, identified by the 'spikes' in H_2O and HNO_3 arise out of this "bulk phase" which are larger and exist much longer than the particles which are formed first. Therefore these latter particles, which contain also nitric acid and water, should be solid. PCS measurements which give the size distributions for the aerosol particles in the

chamber support this scenario. Due to the experimental conditions the exact composition of these solid particles is not known, i.e., whether they are the dihydrate or trihydrate of nitric acid. We hope to solve this question with an improved setup in future experiments. However, these experiments are the first to produce, in a large aerosol chamber, solid particles which contain nitric acid and water.

The ease of forming NAD instead of NAT particles under simulated stratospheric conditions leads to the conclusion that other unknown (possibly heterogeneous) processes must be responsible for the presence of NAT and for denitrification events in the polar stratosphere.

Microphysical modelling

The measurements in winter 2001/2002 were strongly influenced by mountain leewaves. Temperature histories of the observed PSCs on 9 December 2001 have been obtained by combination of trajectory calculations with the RAMS non-hydrostatic model and from ECMWF analyses.

As mentioned above, nitric acid-rich particles were observed at high attitudes around 600 K potential temperature whereas NAT particles were observed below around 575 K potential temperature. The microphysical model from the Danish Meteorological Institute has been used, aiming at investigating possible reasons for the different solid type PSC compositions.

Comparing trajectories at 600 K (near the top layer where observations were made of solid nitric rich particles) with trajectories around 575 K (where the observations show more 'usual' NAT particles), one common feature in the two sets of temperature histories is the strong cooling/heating rates (4-6 K/hour). These strong temperature perturbations will cause strong non-equilibrium conditions, and smaller STS particles may obtain HNO_3 weight fractions larger than 50 %. These rich HNO_3 compositions may favour a freezing into NAD. However, in the lower trajectory at 575 K the temperature drops 3-4 K below T_{ice}, whereas the upper trajectory only drops slightly below T_{ice}. Therefore it has been suggested that in the lower airparcel, we see formation of ice particles during cooling and subsequent release of NAT, but no ice particle formation at the temperature minimum in the higher airparcel, but rather non-equilibrium NAD formation in the smaller particles in the subsequent strong heating.

In the winter 2002/2003 the PSC were observed during synoptic cooling and were not influenced by mountain leewaves. It appears that most of these observations show the presence of a background population of solid particles, occasionally mixed in with more dominating liquid PSC particles. Low number concentrations of solid type PSC particles were observed at very high altitude, clearly distinct from lower altitude liquid PSC layers. The measurements have been compared with results from the microphysical and optical model simulation of the formation processes. An example of such calculations appears in Figure 12.

Apparently the background solid particles are controlled by the synoptic temperature history while the presence of liquid particles is controlled by the local temperatures at the time of observation. The particles did spend several days at temperatures between the ice frost point T_{ice} and the nitric acid trihydrate condensation temperature T_{NAT}. The temperature histories indicate that the solid particles are slowly nucleated above the ice frost point, and a freezing mechanism for this is included in the model. Thereby the model is able to simulate the ob-

served particle size distributions, provided that a bimodal size distribution of sulphate aerosol is assumed cf. Figure 13.

Preliminary investigations have been initiated in comparing calculated optical properties of the observed PSC particles with satellite measurements from SAGE-III, applying the developed optical T-matrix database. The first preliminary results show good correspondence between measured and modelled aerosol extinctions. However, from these preliminary studies, also including in-situ measurements of HNO_3 from MIPAS, there are indications that the freezing rates, given by Tabazadeh et al. (2002), are too high.

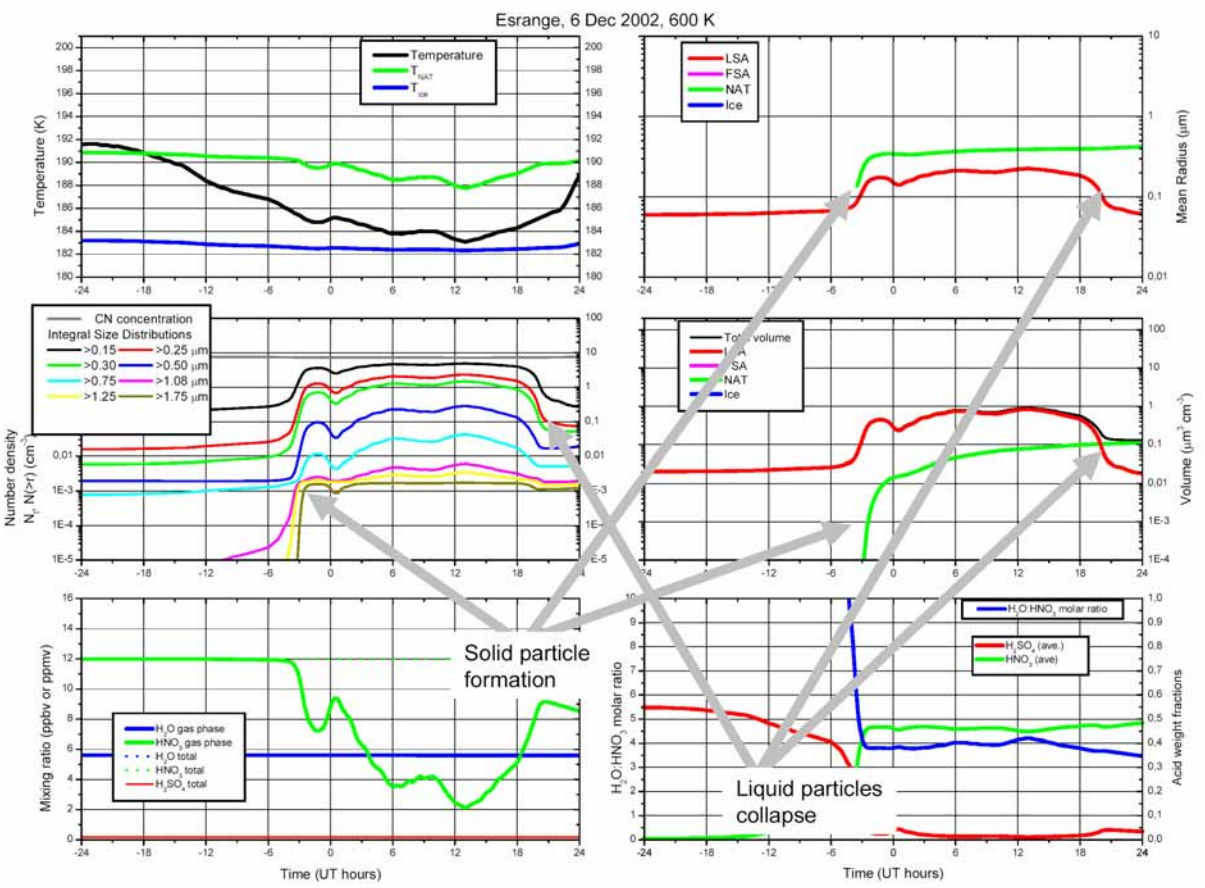

Figure 12. Simulation of the particle evolution at 600 K potential temperature on 6 December 2002. Upper left the temperature history, compared to T_{NAT} and the ice frost point Upper and middle right the mean radius and volume of liquid and solid particles. Middle left the size distribution which can be directly compared with the measurements. Lower panels the gas phase concentrations of HNO_3 and H_2O (left) and the particle chemical composition (right).

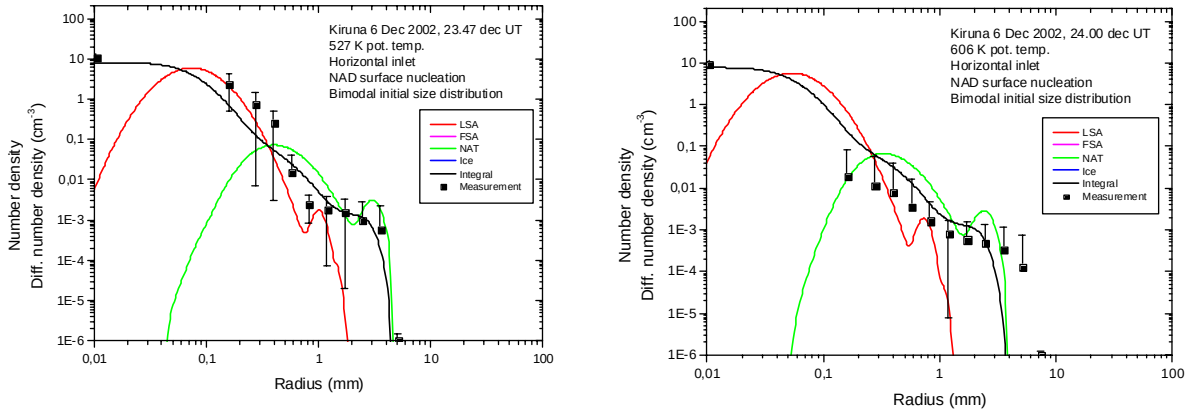

Figure 13 Measured (dots) and calculated integral PSC size distributions (black), composed of mixtures of liquid (red) and solid (green curves) type PSCs on 6 December at 527 K (left) and 606 K pot. temperature (right). By assuming a bimodal size distribution of the background sulphate aerosol (which serve as condensation nuclei for the PSC) is it possible to represent the measurements.

Summary of scientific achievements

The balloon flights for in-situ analysis of PSC particles started in January 1998 from Esrange with the launch of the ACMS instrument from MPI-Heidelberg in combination with just one backscattersonde from DMI/U.Wyoming. This flight resulted in the first direct measurement of the chemical composition of liquid type PSC particles composed of supercooled ternary solution (STS). These observations were first reported in the journal, *Science*. This experiment was the background for proposing to launch more of these gondolas, now equipped with a more comprehensive set of instrumentation to characterise the chemical and physical/optical properties of PSC particles and the atmospheric environment. This proposal was funded by the European commission as the PSC-analysis project ("In-situ analysis of aerosols and gases in the polar stratosphere - A contribution to THESEO", Contract n°: ENV4-CT97-0523). The main achievement within this project was the first identification of nitric acid trihydrate (NAT) PSC particles in the stratosphere. Again this result was first published in *Science*. Finally the CIPA project (Contract n°: ENK2-CT-2000-00095) has resulted in the measurements of 3-4 different particle type under very different temperature conditions within one single flight, the first identification of large nitric acid rich particles, measurements of dissolved HCl in the PSC particles, and measurements of PSC particles under synoptic PSC temperature conditions. The cryo-chamber experiments have been performed under conditions resembling the stratospheric environment. Critical supersaturations leading to homogeneous ice nucleation in supercooled binary sulphuric acid aerosols agree within error limits with previously published water activity parameterisation of the nucleation rate. All attempts to generate NAT aerosol in the AIDA chamber have resulted in the exclusive formation of NAD. The formation of very few large and extremely persistent NAX particles (either NAT or NAD) in a large excess of supercooled nitric acid/water particles was observed in the presence of soot aerosol. In conclusion, a wealth of data to characterise the complicated nature of

PSC particles have been obtained and a long record of scientific results and publications has emerged from these experiments.

The excellent results from these experiments, obtained in the CIPA-project and its predecessor, have been emphasised by a separate bullet in the Executive Summary of the recent published Scientific Assessment of Ozone Depletion 2002 (WMO, 2003), stating that "the chemical composition of liquid and solid polar stratospheric clouds has been measured directly for the first time. Most of the measured compositions are in agreement with model calculations for liquid and nitric acid trihydrate, which have been used in stratospheric models for many years. These measurements improve confidence in particle types used in microphysical models that are central to simulations of polar ozone loss".

4 Conclusion including socio-economic relevance, strategic aspects and policy implications

Socio-economic relevance
The stratospheric ozone layer protects the biological life on the surface of the Earth from harmful ultraviolet radiation from the Sun. It is well documented that increased atmospheric concentrations of man-made halogen compounds are responsible for the severe depletion of the ozone layer over mid-latitudes and the polar regions, including Europe and many inhabited regions in the Arctic, which have been observed during past 2-3 decades. Based on scientific results from atmospheric research, political decisions have been taken imposing restrictions and phase out of the most harmful of these pollutants as described in the Montreal Protocol and later amendments. Among the provisions to the Protocol is the requirement that the Parties to the Protocol base their future decisions on the available scientific, environmental, technical, and economic information from world wide expertise. This project has contributed to preserving and enhancing the environment through detailed and necessary information about key processes in the stratosphere, which affect the ozone layer.

In order, also in the future, to facilitate policy decisions regarding measures to protect the ozone layer and actions for mitigation, due to increased levels of UV-radiation, the state of the ozone layer must be monitored and basic atmospheric chemical and physical processes must be know in detail. State-of-the-art atmospheric chemistry models constitute the most comprehensive tools for predicting the future development and changes to the stratospheric ozone layer.

This project has set out for detailed investigations of basic processes, which are strongly connected to changing stratospheric temperature conditions and consequences for chemical ozone depletion, namely in-depth investigations on the nature of polar stratospheric clouds. By improving our knowledge about particles in the stratosphere, we have contributed to a better understanding of future scenarios for the state of the ozone layer.

Strategic aspects
It is of strategic importance to European Community to possess the ability, at a scientific level, to understand and predict the consequences of lower stratospheric temperatures for the ozone layer in a future climate. The project has addressed aspects of the global environmental

problem of climate changes, stratospheric cooling, and in particular the implications for stratospheric ozone depletion.

In order to be able to predict the consequences of future lower stratospheric temperatures on the arctic ozone layer, details about the PSC formation and chemical compositions must be known. The heterogeneous activation of halogen species depends on the chemical composition and physical phase of the particles. The occurrences of denitrification require the formation of solid phase PSC particles. Results from the chemical and optical PSC analysis in the present project have provided many missing details about the particles which can be used by atmospheric chemistry and microphysical models to calculate more reliable scenarios for the ozone layer in a future climate characterised by lower stratospheric temperatures.

Policy implications
The CIPA-investigations have strengthen the scientific base, needed to implement the European Union's environmental policy in support of the Montreal Protocol, by contributing to improved understanding of some basic physical and chemical processes in the atmosphere which have a strong influence on stratospheric ozone depletion. Thereby improvements have been made to European modelling tools, necessary as a base for scientific recommendations and political actions for protection of the atmospheric environment and for sustainable management of resources.

Restrictions on the usage and release of CFC and HALON gases to the environment, as laid down by the Montreal Protocol at its later amendments, have been demonstrated to decrease the concentrations of these gases in the troposphere. This is a major demonstration to the public of the usefulness of concerted international environmental policy efforts, based on an updated scientific knowledge. It is important for the Community to sustain the ability to predict the future implications for the global climate due to anticipated levels of the ozone depleting substances. Reliable atmospheric chemistry models comprehend all available knowledge of the basic atmospheric processes, and the complicated interaction between ozone depletion and global climate. Thereby, results from the models constitute the most important available tool for a transfer of scientific conclusions to be used by the Community as a guideline for actions in European politics to protect the atmospheric environment.

The collaboration between European and US research groups in this project has been in line with the intentions as laid down in the 5-year 1997-2002 EC/US Science and Technology Cooperation Agreement, concerning the cross-Atlantic support to joint research projects and studies, exchange or sharing of equipment, scientific personnel, and information within environmental and climate research.

The later cryo-chamber campaigns and balloon flights have been part of the POSTA project funded within the German research program AFO2000. The balloon flights have also been supported by other national funded research projects, including the support from the US National Science Foundation

5 Dissemination and exploitation of results

Scientific results from the CIPA-project have been published in refereed journals and presented at international meetings such as the Sixth European Symposium on Stratospheric Ozone, September 2002, Göteborg, Sweden, the EGS-AGU-EUG Joint Assembly, April 2003, Nice France, and the MAPSCORE/CIPA workshop, October 2001, Rome, Italy. Further results are submitted for presentation at the SOLVE II / VINTERSOL Joint Science Meeting, October 2003, Kissimmee, Florida, USA.

Results of chemical composition and physical properties of the cryo-aerosols have been available for internal usage in the project in final form within 6 months. Results have been disseminated to a wide scientific community interested in polar stratospheric cloud modelling and ozone predictions approximately within 1 year of the balloon flights for their use through European databases (NILU data center), as it has been the practice in previous European campaigns.

Results from the project has been synthesised through the microphysical model from DMI which as been distributed to a number of scientific institutions, including the University of Cambridge, UK, Laboratoire de Physique et Chimie de l'Environment, CNRS, Orleans, France, University of Nagoya, Japan, Belgian Institute for Space Aeronomy, Brussels, Belgium, and Forschungzentrum Karlsruhe, Germany.

Both the scientific community and the interested public have been kept informed about the CIPA research project by means of a special CIPA webpage, with links to the homepages of the participating institutions. The CIPA webpage contains - in addition to the Project Description – an updated project workplan, the most recent information about dates of campaigns, workshops and other relevant news, as well as short interim reports. A significant part of the information has been presented in a form, which is comprehensible to the non-specialist, explaining why the research is necessary, what the objectives are, and what has been learnt.

References:

Budz, P. PhD, Uni-Heidelberg, 2003

Carslaw, K. S., S. L. Clegg, and P. Brimblecombe, A thermodynamic model of the system HCl-HNO_3-H_2SO_4-H_2O including solubilities of HBr from <200 K to 328 K, *J. Phys. Chem. 99*, 11557-11574, 1995.

Clegg, S.L., P. Brimbleconbe, and A.S. Wexler, Thermodynamic model of the system H^+-NH_4^+-SO_4^{2-}-NO_3^--H_2O at tropospheric temperatures, *J. Phys. Chem., 102*, 2137-2154, 1998.

Koop, T., B. Luo, A. Tsias, and T. Peter, Water activity as the determinant for homogeneous ice nucleation in aqueous solutions, *Nature, 406*, 611-614, 2000.

Mishchenko, M.I., and L. Travis, Capabilities and limitations of a current Fortran implementation of the T-matrix method for ranmomly oriented, rotationally symmetric scatterers, J. Quant. Spectrosc. Radiat. Transfer 60, 309-324, 1998.

Niedziela, R.F., R.E. Miller, and D.R. Worsnop, Temperature- and frequency-dependent optical constants for nitric acid dihydrate from aerosol spectroscopy, *J. Phys. Chem. A, 102*, 6477-6484, 1998.

Prenni et al., J. Geophys. Res., 106,3037, 2001

Tabazadeh, A., Y.S. Djikaev, P. Hamill, and H. Reiss, Laboratory evidence for surface nucleation of solid polar stratospheric cloud particles, *J. Phys. Chem. A, 106*, 10238-10246, 2002.

World Meteorological Organisation, Scientific Assessment of Ozone Depletion: 2002, Global Ozone Research and Monitoring Project-Report No. 47, WMO, 2003.

Zöger, M., A. Afchine, N. Eicke, M.-T. Gerhards, E. Klein, D.S. McKenna, U. Mörschel, U. Schmidt, V. Tan, F. Tuitjer, T. Woyke, and C. Schiller, Fast in situ stratospheric hygrometers: A new family of balloon-borne and airborne Lyman photofragment fluorescence hygrometers, *Journal of Geophysical Research, 104* (D1), 1807-1816, 1999.

6 Main literature produced.

Authors	Date	Title	Journal	Ref.
Schreiner J., C. Voigt, P. Zink, A. Kohlmann, D. Knopf, C. Weisser, P. Budz, and K. Mauersberger	2002	A Mass Spectrometer System for Analysis of Polar Stratospheric Aerosols	Rev. Sci. Instrum.	73, 446-352 (2002).
Schreiner J., C. Voigt, A. Kohlmann, K.Mauersberger, T. Deshler, C. Kröger, N. Larsen, A. Adriani, F. Cairo, G. Di Donfrancesco, J. Ovarlez, H. Ovarlez, A. Dörnbrack, J. Rosen, and N. Kjome	2002	Chemical, microphysical and optical properties of polar stratospheric clouds	J. Geophys. Res	107, 10.1029/2001 JD000825 (2002).
N. Larsen, S. Høyer Svendsen, B. M. Knudsen, C. Voigt, A. Kohlmann, J. Schreiner, K. Mauersberger, T. Deshler, C. Kröger, J. M. Rosen, N. T. Kjome, A. Adriani, F. Cairo, G. Di Donfrancesco, J. Ovarlez, H. Ovarlez, A. Dörnbrack and T. Birner	2002	Microphysical mesoscale simulations of polar stratospheric cloud formation constrained by in-situ measurements of chemical and optical cloud properties	J. Geophys. Res.	107,D20,10.1029/ 2001JD000999, 2002
C. Voigt, N. Larsen, B.M. Knudsen, T. Deshler, C. Kröger, J. Schreiner, K. Mauersberger, A. Dörnbrack, A. Adriani, F. Francesco, G. Di Donfrancesco, J. Ovarlez, and H. Ovarlez.	2003	Impact of large-scale low temperatures on mountain waves polar stratospheric clouds	J. Geophys. Res.	108, (D5) 10.1029/2001JD001185, 2003.
Miklós Szakáll, Zoltán Bozóki, Martina Krämer, Nicole Spelten, Ottmar Möhler, and Ulrich Schurath	2001	Evaluation of a photoacoustic detector for water vapor measurements under simulated tropospheric/lower stratospheric conditions	Environ. Sci. & Technol.	35, 4881-4885 (2001)
Zink P, D. Knopf, J. Schreiner, K. Mauersberger, O. Möhler, H.Saathof, M.Seifert, R. Tiede, and U. Schurath	2002	Cryo-chamber simulation of stratospheric H_2SO_4/H_2O particles: Composition analysis and model comparison	Geophys. Res. Lett.	29, 10.1029/2001 GL013296 (2002)
Haag, W., B. Kärcher, S. Schaefers, O. Stetzer, O. Möhler, U. Schurath, M. Krämer, C. Schiller	2003	Numerical simulations of homogeneous freezing processes in the aerosol chamber AIDA	Atmos. Chem. Phys.,	*3*, 195-210, 2003.

Möhler, O., O. Stetzer, S. Schaefers, C. Linke, M. Schnaiter, R. Tiede, H. Saathoff, M. Krämer, A. Mangold, P. Budz, P. Zink, J. Schreiner, K. Mauersberger, W. Haag, B. Kärcher, and U. Schurath, ,	2003	Experimental investigation of homogeneous freezing of sulphuric acid particles in the aerosol chamber AIDA	Atmos. Chem. Phys.,	*3*, 211-223, 2003.
Brogniez, C., N. Huret, S. Eckermann, E.D. Rivière, M. Pirre, M. Herman, J.-Y. Balois, C. Verwaerde, N. Larsen, B. Knudsen	2003	Polar Stratospheric Cloud microphysical properties measured by microRADIBAL instrument on January 25, 2000 above Esrange and modeling interpretation	J. Geophys. Res.	108,D6, 8332, doi: 10.1029/2001JD00107, 2003
Schiller, C., R. Bauer, J. Beuermann, F. Cairo, T. Deshler, A. Dörnbrack, J. Elkins, A. Engel, H. Flentje, N. Larsen, I. Levin, M. Müller, S. Oltmans, H. Ovarlez, J. Ovarlez, C. Poss, F. Stroh, H. Vömel, T. Wetter	2002	Dehydration in the Arctic stratosphere during the SOLVE/THESEO-2000 campaigns	J. Geophys. Res	107, (D20), 1029/2001JD000463, 2002
R. Wagner, A. Mangold, O. Möhler, H. Saathoff, M. Schnaiter, U. Schurath	2003	A quantitative test of infrared optical constants for supercooled sulphuric and nitric acid aerosols	Atms. Chem. Phys.	3, 1147-1164 (2003)
H. Bunz, M. Koyro and G. Scheurig	2002	Numerical simulation of the conditioning of volatile particles in laminar flow tube reactors	Aerosol Sci. Technol.	36 (2002) 934-940
Deshler, T., N. Larsen, C. Weisser, J. Schreiner, K. Mauersberger, F. Cairo, A. Adriani, G. Di Donfrancesco, J. Ovarlez, H. Ovarlez, U. Blum, K.H. Fricke and A. Dörnbrack	2003	Large nitric acid particles at the top of an Arctic stratospheric cloud	J. Geophys. Res.	accepted
C. Weisser, K. Mauersberger, J. Schreiner, N. Larsen, F. Cairo, J. Ovarlez, and T. Deshler	2004	Composition analysis of liquid particles in the Arctic stratosphere	Atmospheric Chemistry and Physics	submitted
N. Larsen, B.M Knudsen, S.H. Svendsen,T. Deshler, J. M. Rosen, R. Kivi, C. Weisser, J. Schreiner, K. Mauerberger, F. Cairo, J. Ovarlez, H. Oelhaf, and A. Schmidt	2004	Formation of solid particles in synoptic-scale Arctic PSCs in early winter 2002/2003	Atmospheric Chemistry and Physics	submitted

Claudio Scarchilli, Alberto Adriani, Francesco Cairo, Terry Deshler, Guido Di Donfrancesco, Niels Larsen, Beiping Luo, Konrad Mauersberger, Joelle Ovarlez, Jim Rosen, and Jochen Schreiner	2003	Determination of PSC Particle Refractive Indexes using In Situ Optical Measurements and T-Matrix Calculations	Applied Optics	to be submitted
Maria Luisa Moriconi, Alberto Adriani, Francesco Cairo, Terry Deshler, Guido Di Donfrancesco, Niels Larsen, Konrad Mauersberger, Joelle Ovarlez, Jim Rosen, and Jochen Schreiner	2003	Determination of polar stratospheric clouds physical parameters by optical measurements using multi-instrumental in situ observations	Applied Optics	to be submitted

Non refereed literature:

Deshler Terry, Niels Larsen, Christoph Weisser, Jochen Schreiner, Konrad Mausberger, Francisco Cairo, Guido Di Francesco, Alberto Adriani, Joëlle Ovarlez, Henri Ovarlez, Ulrich Blum and K.H. Fricke, Andreas Dörnback, James Rosen, Large nitric acid particles above an Arctic stratospheric cloud, Invited talk and Poster presentation, Sixth European Symposium on Stratospheric Ozone, Göteborg, Sweden, 2 to 6 September 2002.

Stetzer O., Budz P., Krämer M., Mangold A., Möhler O., Schäfers, S., Schurath U., Aerosol chamber experiments on ice nucleation in supercooled droplets, 27th Genaral Assembly of the European Geophysical Society, Nice 2002.

Budz P., Möhler O., Indris, O., Mangold A., Schreiner J., Stetzer O., Wagner R., Schurath U., Mauersberger, K. Experiments on the formation and chemical composition of HNO_3 containing particles at simulated stratospheric conditions, 27th Genaral Assembly of the European Geophysical Society, Nice, 2002.

Indris O., Budz P., Schreiner J., Mauersberger K., Möhler O., Linke C., Saathoof H., Schaefers S., Schnaiter M., Stetzer O., Wagner R., Schurath U., Mangold A., Krämer M., Heterogeneous nucleation of nitric acid containing particles studied in an aerosol chamber using an aerosol composition, 27th Genaral Assembly of the European Geophysical Society, Nice 2002.

Möhler O., O. Indris, P. Budz, O. Stetzer , R. Wagner , K. Mauersberger , and U. Schurath, New chamber experiments on the formation of nitric acid hydrate aerosols, Sixth European Symposium on Stratospheric Ozone, Göteborg 2002.

Ovarlez J, A. Adriani, F. Cairo,T.Deshler, J.F Gayet, N. Larsen, K.Mauersberger, A. Minikin, H. Ovarlez, A. Petzoltd, J. Schreiner, U. Schumann, J. Ström and C. Weisser, Water Vapour measurements inside ice clouds in the upper troposphere and in the middle stratosphere, Proceedings of the Sixth European Symposium on Stratospheric Ozone, Göteborg, Sweden, 2 to 6 September 2002.

Bureau J., J. Ovarlez, J.B. Renard, G. Durry, and P. Wursteisen, Validation of GOMOS water vapour, temperature and ozone products with balloon-borne instruments during the Kiruna winter campaign 2002-2003, Proceedings of 16th ESA symp. on European rockets and balloon programmes and related research, St Gallen, 2-5 Juin 2003

Möhler, O. U. Schurath, M. Krämer, and C. Schiller, , Möhler, O., O. Indris, P. Budz, O. Stetzer, R. Wagner, K. Mauersberger, and U. Schurath, Aerosol chamber experiments on the formation of nitric acid hydrate aerosols, in *Sixth European Symposium on Stratospheric Ozone*, Göteborg, Sweden, 2002.

Stetzer, O., P. Budz, M. Krämer, A. Mangold, O. Möhler, S. Schaefers, and U. Schurath, Aerosol chamber experiments on ice nucleation in the temperature range 185 - 255 K, in *6th European symposium on stratospheric ozone*, Gothenburg, Sweden, 2002.

Deshler, Terry, Niels Larsen, Christoph Weisser, Jochen Schreiner, Konrad Mauersberger, Francesco Cairo, Alberto Adriani, Guido Di Donfrancesco, Joelle Ovarlez, Henri Ovarlez, and James M. Rosen, Large nitric acid particles above Arctic stratospheric clouds EGS, Nice, april 2003.

Larsen, N., B.M Knudsen, T. Deshler, J. M. Rosen, R. Kivi, C. Weisser, J. Schreiner, K. Mauersberger, F. Cairo, J. Ovarlez, Formation of Arctic solid type PSC particles in early winter 2002/2003, EGS, Nice, April 2003

R. Wagner, FTIR studies of aerosols contained in Polar Stratospheric Clouds. CER C3 Young Chemists Workshop on Atmospherick Chemistry and Particulate Matters, HelsingøDenmark, June 3-6, 2002

R. Wagner, S. Büttner, C. Linke, O. Möhler, H. Saathoff, M. Schnaiter, O. Stetzer, W. Schöck and U. Schurath, Einsatz der FTIR-Spektroskopie bei Simulationsexperimenten in der Aerosol- und Wolkenkammer AIDA. Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hannover, 24. – 18.03.2003-08-21

C. Giesemann, H. Teichert, V. Ebert, H. Saathoff, U. Schurath, Fiber-coupled near infrared dide laser based in situ hygrometer for the detection of water traces in cryogenic aerosols. 4th International Conf on Tunable Diode Laser Spectroscopy, Zermatt (CH), Juliy 14-18, 2003

H. Saathoff, S. Büttner, P. Budz, O. Indris, O. Möhler, M. Schnaiter, O. Stetzer, R. Wagner and U. Schurath, FTIR study of PSC-like aerosol particles in a large simulation chamber. EGS, Nice, April 2003

O. Möhler, O. Indris, A. Mangold, O. Stetzer, R. Wagner, H. Bunz, U. Schurath and K. Mauersberger, Evidence of nitric acid hydrate formation by heterogeneous nucleation. EGS, Nice, April 2003

C. Scarchilli, A. Adriani, F. Cairo, G. Di Donfrancesco, M. Moriconi, T.Deshler, N. Larsen, B. Luo, K. Mauersberger, J. Ovarlez, J. Schreiner, and P.Massoli, Determination of psc particle refractive indexes using optical measurements and t-matrix calculations, EGS, Nice, April 2003.

Appendix

ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT PROGRAMME

KEY ACTION: 2.1.2
STRATOSPHERIC OZONE DEPLETION

FINAL REPORT

Contract n°: EVK2-CT-2000-00095

Title: Comprehensive Investigations of Polar stratospheric Aerosols (CIPA).

Scientific coordinator: Danish Meteorological Institute,
Research and Development Department,
Middle Atmosphere Research Division (DMI)

Contractor(s):

C1: Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.,
Institut für Kernphysik (MPI)

C2: Forschungzentrum Karlsruhe GmbH
Technik und Umwelt (FZK)

C3: Consiglio Nazionale delle Ricerche, Instituto di Fisica dell' Atmosfera (CNR-IFA)

C4: Centre National de la Recherche Scientifique,
Laboratoroire de Météorologie Dynamique (CNRS-LMD)

Assistant contractor:

AC1: Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA)

Collaboration: University of Wyoming, Dept. of Atmospheric Science (UW-AS)
University of Wyoming, Dept. of Physics and Astronomy (UW-PA)

Key words: PSC, composition, size-distributions, microphysics, optical properties

Reporting period: 1 October 2002 – 30 June 2003.

Project home page: www.dmi.dk/pub/CIPA

Participant information

No.	Institution/Organisation	Street name and number	Post code	Town	Country code	Title	Family name	First name	Telephone No.	Fan No.	E-mail
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3	Forschungszentrum Karlsruhe IMK 3, Atmosphaerische Aerosol-forschung, Bau 326	Postfach 3640	D-76021	Karlsruhe	DE	Prof.	Schurath	Ulrich	+49(0)7247-82-2659	+49(0)7247-82-4332	schurath@imk.fzk.de
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5	Laboratoire de Météorologie Dynamique du CNRS Ecole Polytechnique	Route de Saclay	91128 Cedex	Palaiseau	F	Dr.	Ovarlez	Joëlle	+33-6933-4800	+33-6933-3005	ovarlez@lmd.polytechnique.fr
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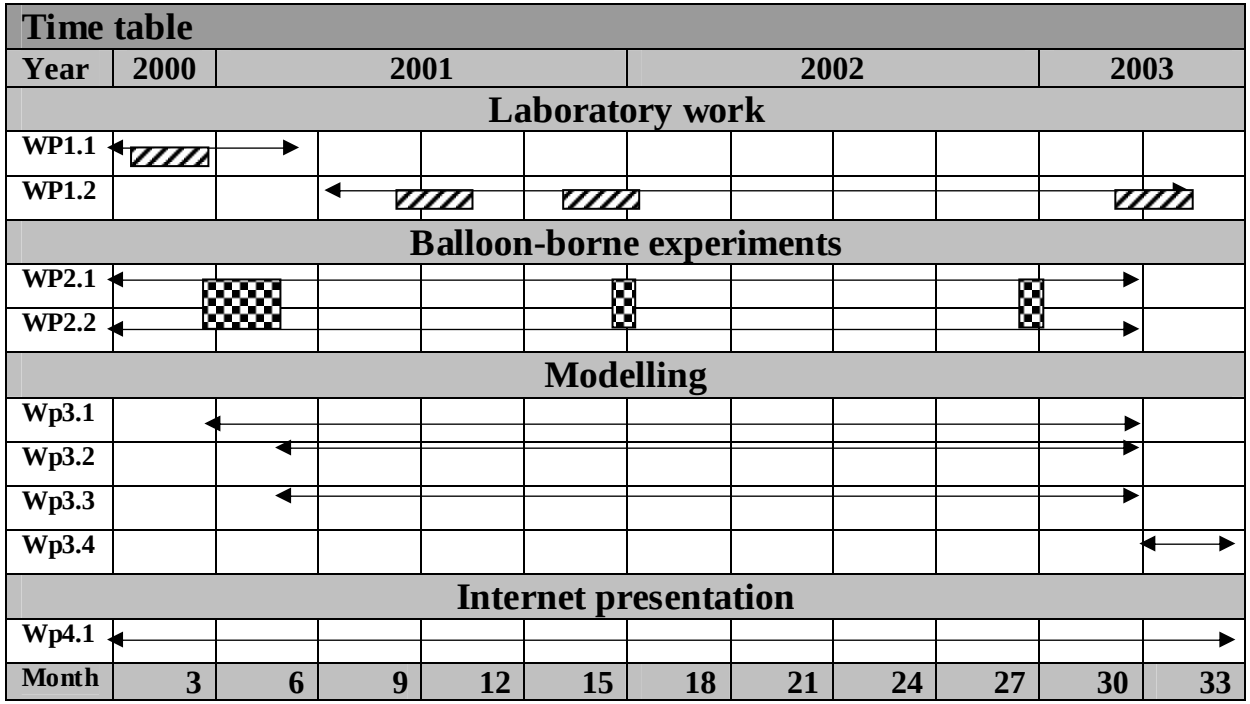

WP 1.1 and 1.2: Shaded blocks denote cryo-campaigns during which times the chamber is run at stratospheric temperatures.
WP 2.1 and 2.2: Dotted blocks denote balloon-borne field campaign at Kiruna in winters 2000/2001, 2001/2002, and 2002/2003.

CIPA											
Budget	Euro										
Parter no.	Name	Labour	Consum	Travel	Other	Subcont	Overhead	Total	CostBasis	%	EU-Req
1	DMI	79.595	4.600	11.600		0	19.159	114.954	AC	100	114.954
2	MPI	112.830	47.633	38.810	28.000	260.000	22.727	510.000	AC	100	510.000
3	FZK	199.450	16.500	6.000			37.868	259.818	FC	50	129.909
4	CNR-IFA	109.374	17.120	16.000			87.499	229.993	FF	50	114.997
5	ENEA	28.634	0	8.460			22.906	60.000	FF	50	30.000
6	CNRS-LMD	93.120	13.000	19.500			74.400	200.020	FC	50	100.010
								0			0
	Total-EU	623.003	98.853	100.370		260.000	264.559	1.374.785			999.870
7	UW-AS	60.000	18.000	14.000			18.400	110.400			
8	UW-PA	10.000	10.000	6.000			5.200	31.200		0	0
	Total US	70.000	28.000	20.000		0	23.600	141.600			
	Total	693.003	126.853	120.370		260.000	288.159	1.516.385			
CNES subcontractor to MPI, performing balloon launch, recovery, providing balloons, gas etc. ; site rental											
Partners 7 and 8 from US - no financial support requested from EU.											

CIPA											
Used	1 October 2002 - 30 June 2003				Euro						
Parter no.	Name	Labour	Consum	Travel	Other	Subcont	Overhead	Total	CostBasis	%	EU-Req
1	DMI			2835			567	3402	AC	100	3402
2	MPI	27900			208	166252	3	194362	FC	50	194362
3	FZK	23408	495	1270			7336	32510	FF	50	16255
4	CNR-IFA	14995		6787			11834	33615	FF	50	16808
5	ENEA	9065		1273				10337	FF	50	8795
6	CNRS-LMD	35032	6934	6319			28022	76315	FF	50	38157
											0
	Total-EU	110400	7429	18484	208	166252	47762	398303			277779

Deliverables list

Deliverable No[1]	Deliverable title	Delivery date[2]	Nature[3]	Dissemination level[4]
	Laboratory work			
D1.1.1	Additional optical detector-system for depolarisation measurements in backscatter geometry in the chamber.	3	Eq	RE
D1.1.2	Data set on particle composition and freezing, to improve extrapolated thermodynamic data and bulk nucleation rates.	9	Da	RE
D1.2.1	Composition and phase of particles under simulated balloon flight conditions, as function of p(HNO_3).	30	Da Re	RE PU
	Balloon-borne experiments			
D2.1.1	Chemical aerosol composition H_2O/HNO_3	30	Da	RE; PU
D2.1.2	Upper limits on dissolved gases HCl/H_2SO_4/HBr..	30	Da	RE; PU
D2.1.3	Frost-point temperature, water vapour, rel. humidity.	30	Da	RE; PU
D2.1.4	Temperature and pressure.	30	Da	RE; PU
D2.2.1	Aerosol total concentrations, size distributions.	30	Da	RE; PU
D2.2.2	Backscattering coeff. at 480, 532, 685 and 940 nm.	30	Da	RE; PU
D2.2.3	Depolarisation ratios at 532 nm.	30	Da	RE; PU
D2.2.4	Colour ratios 532/685 and 940/480 .	30	Da	RE; PU
	Modelling			
D3.1.1	Stratospheric forecast temperatures and polar vortex position for field campaign planning.	26	Da	RE
D3.1.2	Meteorological meso- and microscale analysis in connection with balloon-borne experiments.	30	Da Re	RE PU
D3.2.1	Parameterisations of PSCs as a function of composition, particle concentration and size distributions.	33	Da	RE PU
D3.2.2	Constraints for microphysical models.	33	Da	RE PU
D3.3.1	Microphysical simulations and "best fit" results, comparing each laboratory and balloon-borne experiment with model output	33	Da Si	RE PU
D3.3.2	Design strategy for laboratory experiments, based on analysis of balloon-borne experiments	9	Si Me	RE
D3.4.1	Recommendations for improved PSC microphysical and optical modelling	33	Th Re	PU
	Internet presentation			
D4.1.1	Updated WWW home pages	on-going	O	PU

[1] Deliverable numbers in order of delivery dates: D I.a.1 – DI.a.n. In addition periodic progress reports will be submitted to the Commission Services.

[2] Month in which the deliverables will be available. Month 0 mark the start of the project, and all delivery dates are relative to this start date.

[3] The nature of the deliverable using one of the following codes:

Re = Report **Da** = Data set **Eq** = Equipment
Pr = Prototype **Si** = Simulation **Th** = Theory
De = Demonstrator **Me** = Methodology **O** = other (describe in annex)

[4] The dissemination level using one of the following codes:

PU = Public (final version data)
RE = Restricted to a group specified by the consortium (including the Commission Services).
CO = Confidential, only for members of the consortium (including the Commission Services).

Milestones and deliverables obtained

WP1.1 completed:

D1.1.1: Additional optical detector-system for depolarization measurements in back-scatter geometry in the AIDA- chamber accomplished

D1.1.2: Data sets of particle composition on adiabatic cooling and HNO_3 uptake available.

WP1.2 completed.

D1.2.1: Data sets of particle composition and phase under simulated balloon flight conditions available.

WP2.1 completed:

D2.1.1: Data set of chemical aerosol composition from the balloon-borne flights 9 December 2001, 4 and 6 December 2002 available.

D2.1.2: Dissolved gases from the balloon-borne flight 4 December 2002 available.

D2.1.3: Data set of frost point temperature and humidity from the balloon-borne flights 9 December 2001, 4 and 6 December 2002 available.

D2.1.4: Data set of temperature and pressure from the balloon-borne flights12 January 2001, 9 December 2001, 4 and 6 December 2002 available.

WP2.2 completed:

D2.2.1: Data set of aerosol concentrations and size distributions from optical particle counters on the balloon-borne flights 12 January 2001, 9 December 2001, 4 and 6 December 2002 available.

D2.2.2: Data set of aerosol backscatter coefficients at 480 and 940 from balloon flight 12 January 2001, and at 480, 532, 685 and 940 nm from the balloon-borne flights 9 December 2001, 4 and 6 December 2002 available.

D2.2.3: Data set of aerosol depolarisation from the balloon-borne flights 9 December 2001, 4 and 6 December 2002 available.

D2.2.4: Data set of aerosol color index at 940/480 nm from balloon flight 12 January 2001 and at 940/480 and 685/532 nm from the balloon-borne flights 9 December 2001, 4 and 6 December 2002 available.

WP3.1 completed:

D3.1.1: Stratospheric forecast temperatures and polar vortex positions were reported during the field campaigns.

D3.1.2: Meteorological analyses in connection with the balloon-borne flights on 12 January 2001, 9 December 2001, 4 and 6 December 2002 have been performed.

WP3.2 completed:

D3.2.1 and D3.2.2: Correlations between backscatter measurements and integrated particle surfaces from optical particle counters have been used to establish an empirical rule to infer particle surface areas from optical measurements. A major computational effort has been completed in collaboration with partners from the MAPSCORE project to construct a database of optical parameters for non-spherical PSC particles, based on T-matrix calculations. The database has

been utilized for retrieval of refractive indices and other optical properties of PSC particles.

WP3.3 completed:

D3.3.1: Microphysical simulations of data obtained from Kiruna, 12 January 2001, 9 December 2001, 4 and 6 December 2002, with the CIPA-gondolas has been performed.

D3.3.2: A design strategy for laboratory studies has been accomplished.

WP3.4 completed:

D3.4.1: Recommendations for improved PSC microphysical and optical modeling has been delivered as conclusion of laboratory studies and the microphysical simulations performed in the project.

WP 4.1 completed:

D4.1.1: A CIPA project web site has been set up (http://www.dmi.dk/pub/CIPA) containing information on project news, publications, documents and information on partners in the project. Links to the CIPA web site have also been setup at the European Ozone Research Coordinating Unit's web site.

Deviations from the work plan or/and time schedule and their impact to the project

None

Co-ordination of the information between partners and communication activities (e.g. organised meetings, conference attendance, co-operation with other projects/networks).

The second ordinary CIPA project meeting was held in Rome 11 October 2001, mainly devoted into planning of the 2001/2002 winter campaign from Esrange.

In connection with the CIPA and MAPSCORE regular project meetings in Rome, a joint PSC-workshop was organised in Rome 9-10 October 2001 with participants from both projects and invited guests with whom the two projects have been collaborating (cf. progress report no.1).

A two-day project meeting was held in Heidelberg on 7-8 November 2001 for discussions on measurements on nitric rich particles in the 25 January 2000 balloon flight.

A three-day project meeting was held in Heidelberg on 16-18 April 2002 for discussions on measurements on the 9 December 2001 balloon flight.

A two-day project meeting was held in Heidelberg on 1-2 July 2002 for discussions on publication on measurements in the 9 December 2001 balloon flight.

The third ordinary CIPA project meeting was held in connection with the 6th ozone symposium in Gothenburg (2-6 September 2001), mainly devoted into planning of the winter 2001/2002 winter campaign from Esrange.

Results from the 9 December 2001 balloon flight and the AIDA experiments were presented at 27th General Assembly of the European Geophysical Society, Nice 2002, and at the 6th ozone symposium in Gothenburg (2-6 September 2001).

A two-day project meeting was held in Heidelberg on 3-4 April 2003 for discussions on publication of measurements in the 4-6 December 2002 balloon flights.

Results from the 4-6 December 2002 balloon flights and the AIDA experiments were presented at 28th General Assembly of the European Geophysical Society, Nice, April 2003

Difficulties encountered at management and coordination level and proposed/applied solutions.

None**.**

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OIST-4 Proceedings. 4'th Oersted International Science Team Conference. Copenhagen 23-27 September 2002

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