Aerosol and Cirrus Measurements at Midlatitudes on the Southern Hemisphere- An Overview Based on the First INCA Experiment

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Funded by the European Union (Fifth Framework Programme)

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Abstract for Proceedings of
European Workshop on Aviation, Aerosols, Contrails, and Cirrus Clouds,
Seeheim, Germany
July 10-12, 2000
pp.211-214

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Abstract

The INCA project involves the first in-situ observations of cirrus clouds performed in the Southern Hemisphere midlatitudes. An extensive scientific payload to characterize aerosol-cloud interactions, cloud microphysical properties, and trace gases was deployed on the research aircraft Falcon. A second experiment in the Northern Hemisphere midlatitudes will be used to compare clean and polluted air masses in order to study if anthropogenic emissions have a measurable effect on cirrus cloud properties.

Introduction

The impact of anthropogenic emissions on climate change and on changes of the air composition, in particular ozone, was the topic of several recent assessments by the IPCC (1996, 1999) and the WMO/UNEP (1999). It is still the topic of the ongoing third IPCC Climate Assessment. The assessments have shown so far that cirrus clouds are important in influencing the radiative forcing and air chemistry. However, the estimated values of radiative forcing and ozone changes with a certain probability are within large ranges of potential best estimates, and one cannot exclude that future assessments will result in strongly different values because of yet incomplete scientific understanding. This is the case in particular for assessing the impact of aviation induced aerosols and contrails on cloud cover changes. In fact, the IPCC-Aviation report of 1999 states that the key uncertainty which has to be overcome in the future for better assessing the climate impact from aviation is the knowledge of contrail and aerosol impact on cirrus cloudiness.

The aim of the project INCA (Interhemispheric Differences in Cirrus Properties From Anthropogenic Emissions) is to study the aerosol and cirrus properties in the Southern and Northern hemispheres in order to understand the impact of aerosols on cirrus properties.

Project strategy

The measurements are performed using the DLR Falcon research aircraft, with support from ground-based LIDAR (AWI) and satellite products (NASA). The overall strategy is to compare observations made in one of the cleanest regions available (aircraft based in Punta Arenas, 53°S, Chile) to observations made in air strongly affected by anthropogenic emissions near the North Atlantic Flight Corridor (aircraft based in Prestwick, 54°N, Scotland). The measurement campaigns are performed in both hemispheres during the same year, at equivalent seasons, using the same measurement strategy and instrument payload. The aircraft payload can be divided into four groups:

1) Microphysical properties, mainly observed using PMS-probes. A Polar Nephelometer is used to measure the crystal phase function.
2) Trace gases, measurements of CO, O_3, NO, NO_y and H_2O to characterize the air mass. In addition NO_y contained in the crystals is measured by differentiation.
3) Ambient and interstitial aerosol properties are measured using several different techniques to characterize: number, size, thermal properties, morphology, chemistry, and light absorption.
4) Residual aerosol properties (particles remaining after evaporated crystals sampled by a CVI) are observed using an identical setup as for ambient or interstitial aerosols. In addition the water vapor evaporated from the crystals is measured using a Lyman-α hygrometer.

Outputs from chemical and meteorological forecast models provide an important basis for flight planning and data interpretation. Numerical process-models are used to simulate cases observed during the measurements. The models will be initialized using detailed aerosol properties and information about the state of the atmosphere and wind field. The agreement or disagreement between observed and simulated cirrus properties is a good test of our level of understanding.

Southern Hemisphere campaign

The first campaign took place from 13 March to 20 April 2000, with four weeks in Punta Arenas, Chile. Two shorter technical flights and 10 scientific mission flights, which typically lasted 3.5 hours, were conducted in various cloud conditions ranging from thin wispy clouds and frontal cirrus to intense lee-wave driven lenticular clouds. In addition almost 60 hours of measurements were also performed during the transfer flights to and from Punta Arenas. The instruments generally worked very well and showed excellent consistency where intercomparisons could be made. Due to the short time since the completion of the experiment we stress that the data presented below are very preliminary and may be adjusted after post flight calibrations.

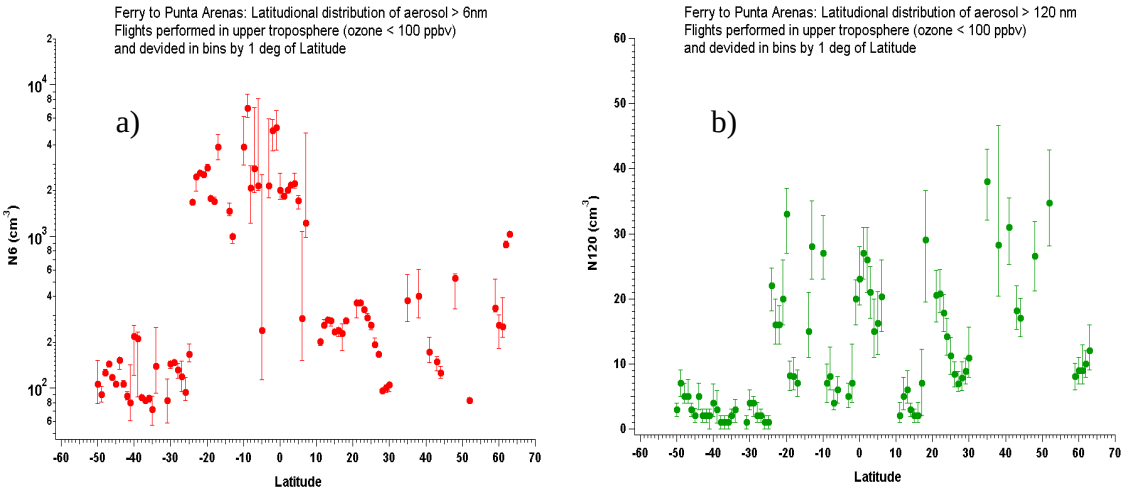

Figure 1. Number densities of particles a function of latitude during the outbound transfer flight to Punta Arenas, Chile. a) Particles larger than 6 nm diameter b) Particles larger than 120nm diameter. (Note difference in scale between Figures 1a and 1b)

The transfer flights gave a very clear picture of the differences in aerosol concentration between the two hemispheres. Figure 1a shows the number density of particles larger than 6 nm diameter during the outbound transfer flight. In the Northern Hemisphere (NH) the number densities seem to center around approximately 200 to 300 cm^{-3}. The ITCZ (Inter Tropical Convergence Zone) is very evident with a sudden increase in small particles reaching 10^4 cm^{-3} averaged over 1 degree of latitude. South of the ITCZ the number density drops down again and centers around approximately 100 cm^{-3}. The difference between the hemispheres is perhaps even more evident when comparing accumulation-mode particles (diameters grater than 120 nm) presented in Figure 1b. The ITCZ and NH do not differ significantly. The number density shows large scatter between 10 and 30 cm^{-3}. The SH, on the other hand, shows much less scatter and generally much lower number densities, typically less than 5 cm^{-3}. This is a significant finding since the cloud formation is strongly related to the composition and size of the aerosol. The same feature was observed during the inbound ferry flight one month later. The clean SH was also evident in the trace gas measurements. Typically, NO_y was around 0.1 ppbv, tropospheric ozone between 20 to 40 ppbv and CO between 50 and 60 ppbv.

Despite the low NO_y concentrations in the air, an uptake of NO_y by the crystals could be observed. By differentiating the NO_y signal from a forward facing and rearward facing inlet, the uptake of NO_y by cold clouds can be inferred. The enhancement of crystals in the sample line of the forward facing inlet (caused by the non-isokinetic sampling) gives the possibility to observe even small quantities of NO_y in the crystals. Preliminary NO_y data suggest a temperature dependence in the uptake over the observed temperature range from about –25° to –65°C. Humidity measurements performed by a cryogenic frostpoint mirror suggest that most of the clouds investigated were still developing. Besides one exception, the clouds were supersaturated with respect to ice and hence not in equilibrium with the ambient water vapor. Occasions were also observed where the air was above ice saturation but no clouds were detected. This indicates that the air is lacking sufficient heterogeneous ice nuclei.

Filter samples of residual particles and ambient aerosol were collected on substrates. These are currently awaiting analysis, but measurements of size distributions and thermal properties were performed in situ. By using a combination of different techniques, the size distribution is characterized for ambient air aerosols larger than 3 nm diameter, and for crystal residuals between 5 nm and 3.5 μm diameter. The smallest particles below 25 nm are characterized by differentiating integral number densities measured by several CPC's (Condensation Nuclei Counters). A DMA (Differential Mobility Analyzer) is used to measure the size distribution between 25 nm and 125 nm. For particles larger than approximately 120 nm, several optical probes are used both inside the aircraft as well as mounted on the wing.

Different from NH midlatitudes, situations with numerous small particles indicative of recent nucleation were not common during the SH campaign. This reflects the lack of sufficient condensable species near the tropopause in the measurement area. This is consistent with the lower particle number densities observed in the SH and that the mode in the particle distribution was shifted toward smaller particles. The lack of condensable vapors not only inhibits new particle formation but also limits growth by condensation.

The shift towards smaller aerosol particles in the ambient air was also reflected in the size distribution of the crystal residual particles (CRP). The mode in the CRP distribution was located in the Aitken mode around 30 to 80 nm diameter. Previous measurements over Germany (Ström et al, 1997) show that the mode was shifted towards larger sizes and located around 100 nm diameter in the more polluted environment. One explanation for this can be the very low number density of aerosol particles present in the free troposphere in the SH midlatitudes. In the NH, where the aerosol particles are more abundant, ice nucleation is quenched before the small particles have a chance to be activated.

Measurements of the amount of absorbing material contained in ice crystals show a clear difference between the Southern and Northern Hemisphere. Compared to previous measurements over central Europe (Ström et al., 1998) the crystals in the NH contain at least 100 times more absorbing material by mass. A simple but very effective way to gain more insight into the composition of the aerosol is to use thermal denuders. The sample air is divided into three parts and number densities are compared after warming the air to cabin temperature, 125ºC, and 255ºC, respectively. The particles evaporating after heating the air to 125ºC is termed volatile. The particles evaporating after heating the air to 255ºC

is termed semi-volatile, and the particles remaining after heating the air to 255ºC is termed non-volatile.

Measurements performed during the ferry flights to and from Punta Arenas show that the ITCZ contains the largest amount of non-volatile particles in absolute and relative terms. Fractions above 50% were observed in the ITCZ. In the NH the fraction was typically between 20% and 30% and in the SH between 10% and 20%. The fraction for CRP was between 20% and 30%. This represents enrichment of the non-volatile fraction in CRP of about a factor of two compared to ambient fractions. If this will be the case also during the upcoming NH campaign, the non-volatile particles could be a pathway through which cirrus clouds can be affected. Moreover, the non-volatile particles appear to be associated mainly with particles in the accumulation mode or larger.

If one assumes a one-to-one correspondence between the CRP and crystals, the CRP number density can be viewed as the crystal number density. A comparison between the CRP number density and the crystal number density observed by the PMS FSSP-300 probe shows excellent agreement. This gives confidence in the crystal number densities observed in the cloud, which typically ranged between 0.5 cm^{-3} and 2 cm^{-3}. A majority of the crystals were smaller than 30 μm diameter. Numerous small crystals in the cirrus clouds were also confirmed by scattering properties observed by a Polar Nephelometer.

Comparing the extinction coefficient observed by the Polar Nephelometer and the calculated extinction coefficient, inferred from size distributions by the PMS FSSP-300 and the PMS 2DC probes, shows that small crystals need to be included in order to explain the optical properties of the cirrus cloud. Asymmetry factors derived from the Polar Nephelometer indicate a reduction in this parameter with altitude. Close to the top of cold cirrus the distribution of values is very narrow and around 0.79, which suggests quasi-spherical ice particles of sizes less than about 25 μm diameter. Deeper down into the cirrus cloud the distribution of asymmetry factors broadens due to the inhomogeneities in the microphysical properties. Values down to 0.75 indicates irregular shaped particles that probably grew rapidly in the ice-supersaturated air. We know that the particles are really ice because the shape of the scattering phase function very effectively detects liquid water. No evidence of liquid water below –30ºC was observed.

Conclusion

The first experiment of the INCA project conducted in the Southern Hemisphere midlatitudes really gave what we had hoped for. The observations were performed in the cleanest environment that can be found, and the ambient conditions extend over a wide range in temperature and synoptic situations. This truly unique data set will be compared with observations performed during the second campaign in the Northern Hemisphere, which is planed for September/October 2000 in Prestwick, Scotland.

Acknowledgements

The INCA team acknowledges the funding support by the European Union and by the institutes of the associated partners.

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