Report to the COST Office on the

COST 723 Workshop on

Cirrus Clouds and their Supersaturated Environment

(11/12 Oct. 2004, DLR Oberpfaffenhofen, Weßling, Germany)

On 11/12 Oct. 2004 about 50 scientists from many COST signature countries, and from Canada, India, and the United States met at DLR Oberpfaffenhofen in order to discuss how to unify the so far distinct research topics of Cirrus Clouds and Ice-Supersaturated Regions. The workshop was organised by Dr. Klaus Gierens as an activity of Working Group 3 (WG3) of the COST Action 723 (Data Exploitation and Modelling for the Upper Troposphere and Lower Stratosphere; http://www.cost723.org/). The workshop saw the presentation of 15 talks and several posters. There was a splinter session with two working group and, simultaneously, a meeting of the Action's Management Committee.

The workshop was opened by Bernard Legras, leader of WG3, who introduced the participants, and the goals of the Action, in particular those of WG3.

Klaus Gierens gave an overview of the problems that arise in the relationship of cirrus and climate as a consequence of the fact that cirrus clouds have only a weak relationship with ice saturation, because (1) they form at high supersaturation and (2) their tendency to approach equilibrium (i.e., saturation) after ice formation is not very strong. He pointed out also that it is extremely difficult to correctly predict cirrus cloudiness in a future climate, since changing background conditions affect the probability to surpass the required high nucleation thresholds more strongly than they affect the mean state.

The first session saw talks about recent field measurements by Bob Herman, Andy Heymsfield, and Cornelius Schiller, and about ground radar and lidar measurements by Y Jaya Rao. Bob Herman reported on measurements of relative humidity inside and outside of cirrus clouds and contrails. In a 20 to 40 min old low temperature contrail (–76°C) there was residual supersaturation of about 30%, which could have been Gao's Δ-ice. Also, in clear air they sometimes measured supersaturation exceeding 80%, where the threshold for homogeneous nucleation was about 60%. Andy Heymsfield discussed measurements and modelling of a wave cloud event during NASA MidCiX. It was impressive to see how such a cloud forms within one second: the RHi drops down from 140% to saturation while a huge number of ice crystals are formed. Interestingly, this burst of cloud formation took place when the vertical velocity in the wave was still low. The observations gave indications of a strong heterogeneous mode of ice formation (concentration 1/L), while the model results showed that use of the Koop formulation for homogeneous nucleation yielded good agreement between observations and modelling at the temperature of the event, –55°C. Y Jaya Rao presented combined lidar and VHF radar measurements of cirrus and aerosol from Gadanki, India. This is a very useful combination of instruments, since the radar is able to measure vertical velocities in the tropopause region with a velocity resolution of 10 cm/s and range resolution of 150 m. Together, these instruments can be used to estimate diabatic heating rates and ice mass fluxes in tropopause cirrus clouds. Such monitoring is of great value for studies of STE. Cornelius Schiller reported on results of the APE-THESEO campaign over the Indian Ocean. In particular, he showed that the cirrus clouds in the TTL can be divided into two classes: (i) barely visible cirrus, and (ii) sub-visible cirrus. Barely visible cirrus clouds probably originate from convective towers, and are surrounded by subsaturated air, i.e., this air is not the parent region of the embedded clouds. These clouds are in moisture equilibrium, i.e., RHi inside these clouds is 100%. Sub-visible cirrus clouds, however, are always embedded in humid (sometimes supersaturated) air, and the supersaturation within these clouds reaches 70%. They are probably formed in situ, for instance by gravity wave activity.

The sessions about observations were continued by talks from Peter Spichtinger, Claudia Stubenrauch, Johannes Nielsen, and Markus Quante. Peter Spichtinger presented two case studies of Ice-Supersaturated Regions (ISSRs), one formed in a slow synoptic uplift that was accompanied by a warm conveyor belt; in this case the supersaturation were formed by the adiabatic cooling of the air masses, and the ISSR lasted for more than a day, probably without forming a cirrus cloud. The other ISSR was formed by quick upward motion induced by the superposition of two groups of internal gravity waves of different origin (jet stream and mountain overflow); within this ISSR a cirrus cloud formed and grew quickly, the lifetime of this system was less than 12 hrs. Claudia Stubenrauch presented a study of the evolution of persistent contrails using TOVS data of upper tropospheric humidity and effective high cloud amount. She showed there is a positive trend of contrails in regions with air traffic and that the trend is stronger in winter and spring than in other seasons. She also showed how to extract UTHi information from the TOVS data for the 100-300 hPa layer, and that there is often supersaturation in this layer, both in clear air and in thin cirrus. The supersaturation yields higher values in the thin cirrus than in clear air. Johannes Nielsen discussed whether humidity fluctuations (reaching far into the supersaturated regime even when there is a large crystal surface area density) observed in cirrus clouds could be explained within the current understanding of crystal growth theory. He tested several hypotheses without much success; the only mechanism that worked (i.e., that led to a long relaxation time for supersaturation in presence of large ice crystal surface area density) was to assume a very low deposition coefficient. The values required to reproduce the observations were much lower than what is usually assumed (although not excluded from microphysical theory); hence this issue is still open. Markus Quante then reviewed observations of turbulence in midlatitude cirrus clouds. Turbulence in cirrus is generally weak (with exceptions) and occurs intermittently. It may act as a trigger for nucleation of ice crystals in a supersaturated environment.

In the next session (talks by Andy Gettelman and Bernd Kärcher) the workshop turned to model-related questions. Andy Gettelman investigated the impact of a modification of the bulk nucleation formulation in the NCAR global modelling system, such that supersaturation is allowed. This modification affects the water vapour field, the cirrus fractional coverage, and the radiation flow through the atmosphere and chemistry. The threshold supersaturation also affects the water abundance in the stratosphere. He also showed that the new sensor AIRS measures ice supersaturation in the tropics at 200 hPa about 2% of the time. Bernd Kärcher presented results from domain-filling trajectory calculations of cirrus properties. The process simulations have led to the following conclusions. Synoptic cold pools define the overall thermodynamic conditions in which the formation of ice clouds takes place, but cloud properties are determined by mesoscale processes. The physical processes that determine the frequency of occurrence of cirrus (e.g., cloud cover) and the cloud microphysical properties (i.e., radiative forcing) depend on each other. Changes in upper tropospheric cooling rates and freezing aerosols can lead to changes in global cirrus cover comparable in magnitude to observed decadal trends.

The session about model-related questions was continued after the Tuesday morning break-out sessions with talks by William Lahoz, Adrian Tompkins, Herman Smit (replacing Chuansen Ren, who could not come), and Johannes Quaas. William Lahoz talked about assimilation of water vapour in the Met Office’s Unified Model. He stated that assimilation of water vapour in the UTLS is desirable because of the many important roles water vapour plays in radiation, dynamics, and chemistry; but unfortunately it is difficult for a number of reasons. New approaches are being tested at DARC/MetOffice, ECMWF and perhaps elsewhere. Data assimilation of water vapour can provide added value to the Earth Observation and modelling communities. Adrian Tompkins investigated the effect of simple homogeneous ice nucleation on the ECMWF model, i.e., he used simple extensions of the operational cloud scheme that allow supersaturation and looked at the consequences. He showed that one has either to assume that RHi in clouds relaxes instantaneously to saturation or one has to introduce a new prognostic equation. Herman Smit reported on MOZAIC data for upper tropospheric humidity. He stated that, over the North Atlantic, more than 35% of the MOZAIC data show ice supersaturation, but only less than one percent show liquid supersaturation. Median horizontal sizes of ISSRs are about 70 km, which is consistent with mean pathlengths of about 150 km determined by other work. Vertical thicknesses are mostly smaller than 1 km, consistent with results from radiosonde data. Backward trajectory calculations for tropical humidity data showed how a unimodal humidity distribution centred at saturation near convective outflows develops within a couple of days into a bimodal distribution, with one dry mode at about 25% RHi and one supersaturated mode. At present, it is not clear what keeps the air supersaturated over this period. Johannes Quaas, giving the final talk, showed how he evaluated the microphysical scheme in two GCMs using satellite data. He could, for instance, use satellite data to tune model parameters. Several model deficiencies were identified; hence the use of satellite data was stated useful for improving GCMs.

The two working groups discussed the relation between cirrus and ISSRs from the measurement and observation perspective (Chair: Andy Heymsfield, Rapporteur: Martina Krämer) and from the modelling perspective (Chair: Adrian Tompkins, Rapporteur: Peter Spichtinger). The observation group asked the question: “What can we do to get a good representation between cirrus microphysics/dynamics and ice supersaturation?”. The following items were discussed: ice nucleation, measurement issues, ice growth rates and equilibrium (residual) supersaturation, cloud dynamics and radiation, anthropogenic effects, and satellite remote sensing. The group developed ideas for new measurement strategies and campaigns. The modelling group discussed possibilities for a more physically based representation of cirrus clouds and ISSRs in large-scale models. The following items were discussed: Relative roles of heterogeneous and homogeneous nucleation, whether they should be treated differently in different synoptic situations, role of gravity wave induced effects, necessity to describe ice supersaturation within clouds, what kind of pdfs to describe subgrid scale processes, sedimentation schemes, and whether one should describe vertical subgrid variations.

Resumee of the Workshop

I believe that this was a successful workshop, and comments of various participants after the workshop do confirm this. In particular, I see that the community is now aware of a problem that seemed to be not so obvious before, namely that cirrus clouds do not form at ice-saturation. Up to now, no operational weather prediction or climate model could represent the ice-supersaturated air masses that are the parent regions of non-convective cirrus. But the situation is beginning to change. The workshop has clarified the need to represent cirrus formation more correctly and, therefore, to include ice supersaturation in models. Ways to this end have been discussed, and the first numerical experiments in this direction have been presented. Experimenters have widened their view on cirrus clouds: not only the cirrus itself should be in their focus but also their environment and, in particular, the spectra and probability distribution of vertical wind speeds in cirrus altitudes have been seen as an important, but difficult to measure, parameter. On the other hand, there is hope that instruments like the radar antenna array in Gadanki, India, will help to establish the desired databases on vertical wind speeds. The workshop also discussed the relative relevance of heterogeneous vs. homogeneous nucleation mechanisms, and the significance of high residual supersaturation in some cirrus clouds, in particular at very low temperatures (T~200K). Additionally, in situ measurements of clear air with more than 100% supersaturation have been shown; however, their significance is unclear at the moment. Evidently, the solution of the last two issues needs better knowledge of nucleation modes and of possible mechanisms impeding crystal formation and growth. Work on these problems will form a natural bridge between these microphysical effects and the macrophysical properties of the clouds and the humidity inside and outside of them.

The workshop also made two suggestions to WMO and satellite data producers:

1. WMO should abandon the practice to report relative humidities with respect to liquid water at T<–40°C. As there is no bulk liquid water at these temperatures, the reported data are based on uncertain mathematical extrapolations of the saturation curve. Recent measurements by Fukuta and Gramada (2003) place considerable doubt on the accuracy of these formulations, including the standard one by Goff and Gratch. Relative humidities at T<–40°C should be reported with respect to ice.
2. Satellite data products of upper tropospheric humidity are mostly constrained to values up to ice saturation. There may be reasons for this practice, but it is against current knowledge, hence it should be abandoned.

It is hoped that the COST Action will lobby these suggestions in favour of better data in the UTLS.

Oberpfaffenhofen, 20 Oct 2004

Klaus Gierens