SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2009
Project Title:	Ice Supersaturation and Cirrus Clouds ………………………………………………………………
Computer Project Account:	SPDEISSR
Principal Investigator(s):	Dr. Klaus Gierens Dr. Peter Spichtinger (ETHZ)
Affiliation:	Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt Münchener Str. 20 D-82234 Wessling
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………………… ………………………………………………………………
Start date of the project:	April 2004
Expected end date:	2011

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	350000.0 (incl. additional res.)	228792.3 (12/01/08)	200000.00	95257.26 (06/15/09)
Data storage capacity	(Gbytes)	100	99	100	106

Summary of project objectives

(10 lines max)

Our project has two objectives. One is to evaluate the IFS forecasts of ice supersaturation and upper tropospheric humidity with help of other data (e.g. satellite data).

The second objective is to improve our understanding of ISSRs and their relation with cloudiness using our cloud-resolving model. We use it for simulations of cirrus clouds, and spreading contrails, embedded in their supersaturated environment. The model is used also for case-studies to help planning of measurement campaigns and interpretation of their data. Radiation is included, and its influence on the evolution of cirrus clouds and contrails is investigated.

Summary of problems encountered (if any)

(20 lines max)

None

Summary of results of the current year (from July of previous year to June of current year)

1. Contrails and Contrail Cirrus

Simon Unterstrasser has completed his thesis

Numerische Simulationen von Kondensstreifen und deren Übergang in Zirren
(Numerical Simulations of Condensation Trails and their Transition to Cirrus).

The contrail-to-cirrus transition is studied numerically and the evolution of contrail geometric, microphysical and optical properties is investigated. The contrail evolution was studied separately for the vortex phase and the dispersion phase. An existing LES-Code (EULAG) with an ice microphysics module (see below) was adapted in a way, that allowed an ample number of contrail simulations. Especially the so-called CC-tool was designed which ensures a realistic vortex decay during the vortex phase. During the latter a substantial fraction of the ice crystals in the primary wake can sublimate, depending most sensitively on relative humidity and temperature.

The contrail-to-cirrus transition was studied at static background conditions (i.e. no large-scale vertical motion). The contrail properties depend most sensitively on relative humidity. Further controlling factors are temperature, vertical wind shear and the radiation scenario. A substantial spreading of contrails is only visible for relative humidities above 120%. The optical depth is mostly below 0.5 and decreases with time. Sedimentation dehydrates the contrail core region and limits the lifespan of contrails to 4-6 hours. Under appropriate conditions radiation lifts the contrail which prolongs the lifespan due to a lowering of the saturation pressure and the corresponding crystal growth.

A first part of the thesis, namely the vortex phase simulations have already been published. The abstract of that paper reads as follows:

We investigate the evolution of contrails during the vortex phase using numerical simulations. Emphasis is placed on microphysical properties and on the vertical distribution of ice mass and number concentration at the end of the vortex phase. Instead of using a 3D model which would be preferable but computationally too costly, we use a 2D model equipped with a special tool for controlling vortex decay. We conduct a great number of sensitivity studies for one aircraft type. It turns out that atmospheric parameters, namely supersaturation, temperature, stability and turbulence level have the biggest impact on the number of ice crystals and on the ice mass that survives until vortex breakup and that therefore makes up the persistent contrail in supersaturated air. The initial ice crystal number density and its distribution in the vortex, are of minor importance.

2. Cirrus Model with Explicit Ice and Aerosol Microphysics

Ingo Sölch has completed his thesis

Ein Euler-Lagrange'sches Zirruswolken-Modell mit expliziter Aerosol- und Eismikrophysik: Studien zur Aggregation von Eispartikeln

(An Euler-Lagrangian cirrus cloud model with explicit aerosol and ice microphysics: Studies of the aggregation of ice crystals).

A cloud-resolving, multidimensional model complex (EULAG-LCM) for cirrus clouds is developed and implemented. Aerosol and ice microphysics are treated in detail. The model accounts for radiative transfer and internal dynamics in the cloud structures. The ice phase is treated by tracking the life cycle of a large number of simulation particles individually. Validation of the newly developed EULAG-LCM is threefold: Besides validation in a box model study, the EULAG-LCM took part in an international cirrus cloud model intercomparison project and was validated in the framework of a case study which has been set up in the thesis. An essential process distributing ice mass vertically (important for radiative transfer) and in the generation of precipitation-sized ice particles is the aggregation mechanism. In the thesis process-oriented algorithms for ice particle aggregation are developed based on the trajectories and sedimentation velocities of individual ice crystals. In the case study and associated sensitivity runs, which are built on comprehensive measurements in a mid-latitude cirrus cloud, the aggregation process and its modification with atmospheric parameters is studied in detail.

The results of theses studies can be used for improved representation of cirrus and their interaction with the ambient aerosol in larger scale models, including weather prediction models. A publication in a peer-review journal is in preparation.

3. Cloud Resolving Cirrus Model and Applications

We have also developed a cloud resolving cirrus model with bulk microphysics which can be used to conduct a large number of simulations in relatively short time. The model and its validation are described in Spichtinger and Gierens (2009a). The abstract reads as follows:

A double-moment bulk microphysics scheme for modelling cirrus clouds including explicit impact of aerosols on different types of nucleation mechanism is described. Process rates are formulated in terms of generalised moments of the underlying a priori size distributions in order to allow simple switching between various distribution types. The scheme has been implemented into a simple box model and into the anelastic non-hydrostatic model EULAG. The new microphysics is validated against simulations with detailed microphysics for idealised process studies and for a well documented case of arctic cirrostratus. Additionally, the formation of ice crystals with realistic background aerosol concentration is modelled and the effect of ambient pressure on homogeneous nucleation is investigated in the box model. The model stands all tests and is thus suitable for cloud resolving simulations of cirrus clouds.

It might be mentioned here that this microphysics module was used for Simon Unterstraßer's contrail simulations.

The model has been used to study the effect of dynamics on the developing cloud structure (Spichtinger and Gierens, 2009b). The abstract reads as follows:

A recently developed and validated bulk microphysics scheme for modelling cirrus clouds (Spichtinger and Gierens, 2009), implemented into the anelastic nonhydrostatic model EULAG is used for investigation of the impact of dynamics on the evolution of an arctic cirrostratus. Sensitivity studies are performed, using variation of large-scale updraughts as well as addition of small-scale temperature fluctuations and wind shear. The results show the importance of sedimentation of ice crystals on cloud evolution. Due to non-linear processes like homogeneous nucleation situations can arise where small changes in the outer parameters have large effects on the resulting cloud structure. ***In-cloud ice supersaturation is a common feature of all our simulations, and we show that dynamics is as least as important for its appearance than is microphysics.***

Very interesting effects are caused by the competition of heterogeneous and homogeneous nucleation in combination with crystal sedimentation and cloud dynamics. This is described in Spichtinger and Gierens (2009c). The abstract reads as follows:
We study the competition of two different freezing mechanisms (homogeneous and heterogeneous freezing) in the same environment for cold cirrus clouds. To this goal we use the recently developed and validated ice microphysics scheme (Spichtinger and Gierens, 2009a) which distinguishes

between ice classes according to their formation process. We investigate cases with purely homogeneous ice formation and compare them with cases where background ice nuclei in varying concentration heterogeneously form ice prior to homogeneous nucleation. We perform additionally a couple of sensitivity studies regarding threshold humidity for heterogeneous freezing, uplift speed, and ambient temperature, and we study the influence of random motions induced by temperature fluctuations in the clouds. ***We find three types of cloud evolution, homogeneously dominated, heterogeneously dominated, and a mixed type where neither nucleation process dominates. The latter case is prone to long–lasting in–cloud ice supersaturation of the order 30% and more.***

We note that neither in-cloud supersaturation nor heterogeneous nucleation (at temperatures below the supercooling limit of pure water) is currently represented in the IFS cloud physics. In-cloud supersaturation is not only found in our simulations, but is also very often observed. A recent account of such observations has been published by Krämer et al. (ACP, 2009).

The model is currently used for investigations on convection in cirrus clouds and for interpretation of measurements:

While we usually assume cirrus clouds as homogeneous layer clouds, especially in investigations of cirrus from satellites, this is obviously not true as it can be seen from surface observations. In an ongoing study the possible impact of convective cells inside a cirrus layer on the structure and the microphysical properties of the cloud is investigated. Generally, convection in cirrus clouds is quite frequent and it can maintain high vertical velocities inside (thick) cirrus clouds in order to maintain in cloud ice supersaturation. A publication on this topic is currently prepared and will be submitted soon.

During aircraft campaigns high ice crystal number concentrations were observed frequently. There is an ongoing discussion in the community about the reliability of such measurements. However, we could show for a special case measured during the CIRRUS II campaign in November 2004 that high ice crystal number concentrations could be real while the cirrus cloud formation was driven by a strong Kelvin-Helmholtz instability. Thus, our model simulations could be used for interpretation of measurements. A publication on this topic is currently prepared and will be submitted soon.

4. Comparison of ECMWF humidity (supersaturation) and cloudiness forecasts with AIRS and CALIPSO data

The novel feature of ice supersaturation in the IFS (Tompkins et al., QJRMS, 2007) has undergone some first validation tests in that paper. Now we have conducted further comparisons with AIRS and CALIPSO data. The results of this study are described by Lamquin et al. (2009). The abstract of that paper reads as follows:

An evaluation of the upper tropospheric humidity from the European Centre of Medium-Range Weather Forecasts (ECMWF) Integrated Forecast System (IFS) is presented. We first make an analysis of the spinup behaviour of ice supersaturation in weather forecasts. It shows that a spinup period of at least 12 h is necessary before using forecast humidity data from the upper troposphere. We compare the forecasted upper tropospheric humidity with coincident relative humidity fields retrieved from the Atmospheric InfraRed Sounder (AIRS) and with cloud vertical profiles from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). The analysis is made over one year, from October 2006 to September 2007, and we discuss how relative humidity and cloud features appear both in the IFS and in the observations. The comparison with AIRS is made difficult because of the vertical resolution of the sounder and the impossibility to retrieve humidity for high cloudiness. ***Clear sky relative humidities show a rather good correlation*** *whereas cloudy situations reflect more the effect of a dry bias for AIRS increasing with the relative humidity. The comparison with CALIPSO shows that* ***the IFS predicts high relative humidity where CALIPSO finds high clouds, which supports the good quality of the ECMWF upper tropospheric cloud forecast****. In a last part, we investigate the presence of ice supersaturation within low vertical resolution* *pressure layers by comparing the IFS outputs for high resolution and low-resolution humidity profiles and by simulating the interpolation of humidity over radiosonde data. A new correction method is proposed and tested with these data.*

Although the abstract emphasizes the positive aspects of the IFS cloud scheme, there are also occasions where the model seems to be grossly in error; for instance, situations where CALIPSO detects a thick cloud in the upper troposphere while IFS forecasts a dry situation with relative humidity of , say, 20%. Such situations occur nevertheless rarely. Another aspect to improve the IFS is the obvious inconsistency between the analysis model which does ignore ice supersaturation and the forecast model which explicitly treats it.

List of publications/reports from the project with complete references

Lamquin, N., K. Gierens, C.J. Stubenrauch, R. Chatterjee, 2009: Evaluation of Upper Tropospheric Humidity forecasts from ECMWF using AIRS and CALIPSO data. Atmos. Chem. Phys., 9, 1779-1793. (http://www.atmos-chem-phys.net/9/1779/2009/acp-9-1779-2009.pdf)

Sölch, Ingo, 2009: *Ein Euler-Lagrange'sches Zirruswolken-Modell mit expliziter Aerosol- und Eismikrophysik: Studien zur Aggregation von Eispartikeln.* Doctoral Thesis, LMU München.

Spichtinger, P., K. Gierens, 2009: Modelling of cirrus clouds - Part 1a: Model description and validation. Atmos. Chem. Phys., 9, 685-706. (http://www.atmos-chem-phys.net/9/685/2009/acp-9-685-2009.pdf)

Spichtinger, P., K. Gierens, 2009: Modelling of cirrus clouds - Part 1b: Structuring cirrus clouds by dynamics. Atmos. Chem. Phys., 9, 707-719. (http://www.atmos-chem-phys.net/9/707/2009/acp-9-707-2009.pdf)

Spichtinger, P., K. Gierens, 2009: Modelling of cirrus clouds - Part 2: Competition of different nucleation mechanisms. Atmos. Chem. Phys., 9, 2319-2334. (http://www.atmos-chem-phys.net/9/2319/2009/acp-9-2319-2009.pdf)

Unterstraßer, Simon, 2008: *Numerische Simulationen von Kondensstreifen und deren Übergang in Zirren.* Doctoral Thesis, LMU München.

Unterstraßer, S., K. Gierens, P. Spichtinger, 2008: The evolution of contrail microphysics in the vortex phase. Meteorol. Z., 17, 145-156.

Summary of plans for the continuation of the project

We are currently combining the vortex phase dynamics with the Lagrangian tracking microphysics in order to test our bulk microphysics results of contrail evolution during the vortex phase. The Lagrangian tracking will later be used for contrail-to-cirrus simulations as well. We plan to extend the contrail-to-cirrus simulations in two respects: 1) inclusion of synoptic changes during contrail lifetime, 2) simulation of contrail clusters. The internal dynamics of cirrus clouds will be investigated during the next year. Within the framework of a PhD project, starting in 2009, 3D inhomogeneity of cirrus clouds will be simulated using idealized setups as well as meteorological analyses as initial conditions. We focus on cirrus cloud convection and mesoscale instabilities. Forecast data from the MARS archive will be analysed further with respect to the representation of ice supersaturated regions and their development in the IFS.