

# SPECIAL PROJECT INTERIM REPORT

Interim 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** 2008

**Project Title:** Ice-supersaturation and cirrus clouds  
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**Computer Project Account:** SPDEISSR

**Principal Investigator(s):** Dr. Klaus Gierens

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**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
<b>High Performance Computing Facility</b>	(units)	181.000	148320.3	170.000 230.000 after additional request	123989.0 so far
<b>Data storage capacity</b>	(Gbytes)	100	88	100	99, currently

## 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 the problem of representation of orographic cirrus in large scale models is investigated.

## Summary of problems encountered (if any)

(20 lines max)

No problems.

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

### 1.) Comparison between ECMWF/IFS and AIRS and CALIPSO upper tropospheric humidities and cloudiness

A comparison of the upper tropospheric humidity from the European Centre of Medium--Range Weather Forecasts (ECMWF) Integrated Forecast System (IFS) with humidity retrievals from the

Atmospheric InfraRed Sounder (AIRS) and of the upper tropospheric cloudiness with data from CALIPSO has been performed. The spin-up analysis from the last year warned us to use only forecast steps from 12 hrs onwards, so we used 24 hrs forecasts. The analysis is made over one year between October 2006 and September 2007, that is when the new supersaturation feature of the IFS was already operational. The comparisons have been performed for data over Europe, and collocation was used. Aqua overflies at 01:30 AM and PM local time and the AIRS large swath (about 1700 km) makes it possible to find numerous events which are close in terms of time and location to ECMWF forecasts for 00:00 and 12:00 UTC. The geographical proximity is easily obtained and events from both datasets are associated when the centre-to-centre distance  $\sqrt{\{\Delta lat^2 + \Delta lon^2\}}$  is lower than  $0.25^\circ$ .

A layer-to-layer comparison with AIRS, distinguishing clear and cloudy situations from AIRS L2 cloud features, yielded the detection of two modes, a dry and a moist one. For situations where IFS predicts  $RHi < 80\%$  (i.e. mainly cloud free in IFS, the dry mode) we generally find small biases of the order percent (in RHi units) between AIRS and IFS upper tropospheric humidities (IFS is slightly moister than AIRS). The standard deviations of the differences are of the order 10 to 15%, that is, they are of the order of humidity measurement uncertainties that can be achieved in the UT. In the moist mode, that is mainly values around ice saturation in IFS, AIRS has a large spread of values ranging from about 50% up to and exceeding 150%. It may be noted that AIRS always detects clouds in these cases.

A layer-by-layer comparison of IFS humidities with the cloud products from CALIPSO showed a strong positive correlation between RHi and the probability that CALIPSO finds a cloud in the respective layer. The peak relative humidity from IFS is mostly located in the pressure layer where CALIPSO indeed finds a cloud. The CALIPSO cloud probability reaches 100% when the IFS humidity approximately reaches the threshold for homogeneous nucleation; the cloud probability at ice saturation is 65%. The comparison uncovers that occasionally CALIPSO finds clouds (of geometrical thickness exceeding 1 km) where IFS predicts dry air. These cases need further consideration.

Finally we tested the dependence of vertical resolution on the reported frequency of ice supersaturation. This is a problem in particular for nadir sounders, but also for the forecast and radiosonde data when only the standard pressure levels are retained. We compared the IFS data on the standard pressure levels with those of higher vertical resolution and high-resolution radiosonde data with layer averages obtained in the same way as upper tropospheric humidity is determined for AIRS. These exercises demonstrated that the true frequency of occurrence as a function of the low-resolution relative humidity follows a s-shaped function, that can be used for a correction algorithm. Application of such a correction yielded roughly a ratio of two between the true (high-resolution) and the apparent (low-resolution) frequency of ice supersaturated layers. To our opinion, the s-function correction should be further tested with more data.

## **2.) Numerical simulations of the contrail-to-cirrus transition**

The development of the EULAG-subversion enabling us to model contrails in the dispersion phase was completed. The radiation routine (Fu & Liou) was added to model. We used the results of the vortex phase simulation (see report of last year) as initial conditions for the dispersion phase simulation. We are able to model the contrail-to-cirrus transformation and we did a lot of simulations in order to cover the huge parameter space in which contrails can develop and spread out to eventually form a cirrus cloud.

We identified key parameters controlling the properties of these special cirrus clouds. The most relevant parameters are relative humidity, temperature and shear. Moreover, we studied the impact of radiation, stratification, turbulence and several more parameters.

The results will be part the thesis of Simon Unterstrasser (to be submitted by end of August 2008).

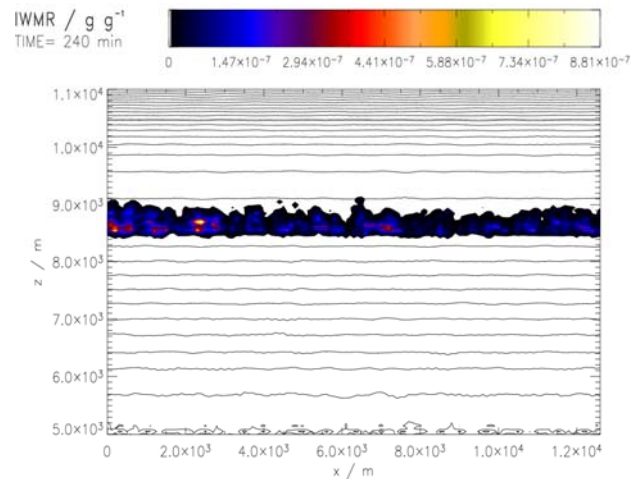
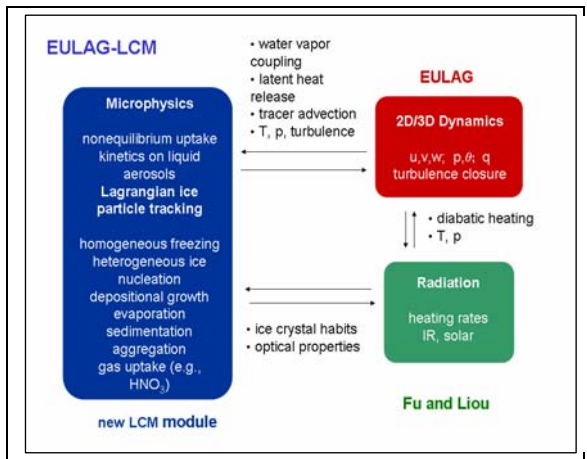
## **3.) Cirrus cloud formation processes: Application of a single-particle microphysics code**

In the last year a novel 2D / 3D cirrus clouds microphysics code, based on the multiscale flow model EULAG, has been set up. The EULAG-LCM considers non-equilibrium aerosol processes, homogeneous and heterogeneous ice nucleation, depositional growth of ice crystals, sedimentation, gas uptake (e.g. HNO<sub>3</sub>) and aggregation. Additionally an efficient 1D radiation module (Fu and Liou) has been coupled. A summary of the comprised processes is given in the left figure. The EULAG-LCM captures the important microphysical processes during cirrus cloud development and their interaction with turbulence and radiation. A novel Lagrangian particle tracking method allows for detailed analysis of cloud formation processes.

The model participated in the GEWEX GCSS WG2 cirrus model inter-comparison study. First results of this inter-comparison study show that modeled ice water content, ice crystal number concentrations and effective radii are in agreement with other cloud-resolving models participating. Results were presented at the 4th Pan-GCSS Meeting on "Advances on Modelling and Observing Clouds and Convection".

The panel on the right-hand side shows an example of the resulting 2D ice water mixing ratio field of the cirrus considered in the inter-comparison study, that is evaluated against detailed measurements.

In an additional study the further development of the cirrus field is considered. Detailed analysis of the simulations show the importance of the aggregation process in the formation of the observed ice crystal size-distribution. This work is part of a PhD thesis in progress.



#### 4.) Cloud-resolving modelling of cirrus clouds and ice supersaturation:

##### 4.1 Synoptically driven cirrus clouds:

During the last year we have validated the newly developed ice microphysics scheme (Spichtinger and Gierens, 2008a). After the test phase, the model was used for investigations on the impact of small-scale dynamics on the formation and evolution of cirrus clouds, originally triggered by large-scale updraughts (Spichtinger and Gierens, 2008b). Additionally, several studies on the competition of different nucleation mechanisms (i.e. homogeneous freezing of solution droplets vs. heterogeneous nucleation) within slowly ascending air masses were carried out (Spichtinger and Gierens, 2008c). These studies on properties of cirrus clouds driven by large-scale motions give important insights into the structure:

It could be shown that for slowly ascending air masses the sedimentation of ice crystals formed in the nucleation zones at the cloud top has a crucial impact on the structure of the cloud by suppressing in cloud nucleation events. Additionally, in 2D simulations (in contrast to the usual 1D or box model simulations) it could be shown that even small scale dynamics triggering small eddies can influence the structure of cirrus clouds critically. The competition of different nucleation mechanisms also changes the structure of synoptically driven cirrus clouds. In all simulations, high ice supersaturation inside cirrus could be observed; this is also an important result in terms of the ongoing discussion in the community about this topic (see e.g. Peter et al., 2006).

##### 4.2 Internal dynamics of cirrus clouds

The model was also used for first investigations and interpretations of field measurements during the CIRRUS II campaign (November 2004, Dr. M. Krämer, FZ Jülich). It could be shown, that internal dynamics of cirrus clouds could lead to high internal variability, which could trigger the formation of very high ice crystal number densities (Spichtinger et al., in prep.). The simulations for interpretation of the real measurements lead to a series of idealized simulations on the internal dynamics of cirrus clouds (Spichtinger, in prep.) and will be extended in future.

##### 4.3 Orographic cirrus clouds and turbulence

The model was used in order to investigate the formation and evolution of cirrus clouds triggered by vertically propagating waves. These waves could create turbulence after breaking. The impact of the waves and the generated turbulence is investigated and will be extended in future (Spichtinger and Smolarkiewicz, 2008).

##### 4.4 Process studies of sublimation for model improvement

Sublimation has been studied analytically and numerically in order to check the currently employed parametrisation of that process. It turned out that although the parametrisation hardly follows the mathematics of the process, there is not much potential for an improvement in the framework of a two-moment bulk microphysics model. A model artifact that occurs within mature clouds when the relative humidity fluctuates

slightly around saturation could be uncovered. A remedy for this artifact could be recommended (Gierens and Bretl, in prep.).

### **List of publications/reports from the project with complete references**

Gierens, K., S. Bretl, 2008: Analytical treatment of sublimation and test of sublimation parameterisations in two-moment ice microphysics models. In prep.

Lamquin, N., K. Gierens, R. Chatterjee, C. Stubenrauch, 2008: Comparison of Upper Tropospheric Humidity forecasts from ECMWF using AIRS and CALIPSO data. In preparation for ACPD.

Peter, T., C. Marcolli, P. Spichtinger, T. Corti, M. Baker, T. Koop, 2006: The high supersaturation puzzle. *Science*, 5804 (314), 1399-1402.

Spichtinger, P., 2007: Internal dynamics of cirrus clouds - some sensitivity studies. *Geophysical Research Abstracts*, Vol. 9, 07668.

Spichtinger, P.: Cirrus cloud dynamics - a source for ice supersaturation. *Tellus A*, in prep.

Spichtinger, P. and K. Gierens, 2008a: Modelling Cirrus Clouds. Part 1a: Model description and validation. *Atmos. Chem. Phys.*, revised version.

Spichtinger, P. and K. Gierens, 2008b: Modelling Cirrus Clouds. Part 1b: Structuring cirrus clouds by dynamics. *Atmos. Chem. Phys.*, revised version

Spichtinger, P. and K. Gierens, 2008c: Modelling Cirrus Clouds. Part 2: Competition of different nucleation mechanisms. *Atmos. Chem. Phys. Diss.*, 8, 9061–9098.

Spichtinger, P., M. Krämer, M. DeReus, S. Schlicht: High ice crystal number densities in stratiform cirrus clouds. *J. Geophys. Res.*, in prep.

Spichtinger, P., Gierens, K., Lohmann, U., 2006: Importance of a proper treatment of ice crystal sedimentation for cirrus clouds in large-scale models. 12th AMS Conference on Cloud Physics, Madison, USA, 10-14 July 2006. (extended abstract).

Spichtinger, P., Dörnbrack, A., 2006: Microphysical modeling of orographic cirrus clouds. 12th AMS Conference on Cloud Physics, Madison, USA, 10-14 July 2006. (extended abstract).

Spichtinger, P. and P. K. Smolarkiewicz, 2008: Turbulence in cirrus clouds. 15th Conference on Clouds and Precipitation. Cancun, Mexico. 7-11 July 2008. (extended abstract).

Tompkins, A.M., K. Gierens, G. Rädcl, 2007: Ice supersaturation in the ECMWF Integrated Forecast System. *Q. J. R. Meteorol. Soc.*, 133, 53-63.

Unterstrasser, S.; Gierens, K.; Spichtinger, P., 2006: Simulation of contrails in the vortex regime - Examination of the microphysical properties. In: 2005 Oxford TAC Conference, International Conference on Transport, Atmosphere and Climate TAC, Oxford, UK

Unterstrasser S., K. Gierens, P. Spichtinger, 2006: The evolution of contrail microphysics and structure in the vortex phase, *Meteorol. Z.*, 17, 145-156..

Weidle, F., M. Krämer, N. Spelten, P. Spichtinger, H. Wernli, H., 2007: The Cirrus III Campaign: Comparison of Observations with Model Simulations. *Geophysical Research Abstracts*, Vol. 9, 06574.

## **Summary of plans for the continuation of the project**

(10 lines max)

- GEWEX GCSS WG2 inter-comparison study Part2, further studies
- Comparison of forecast data from experiment evci with satellite and air-traffic data for contrail forecast experiments
- Evaluations of IFS forecasts of ice supersaturation and upper tropospheric humidity
- Contrail-to-cirrus transformation: completion of thesis
- Cirrus trajectory parcel model studies: completion of thesis
- Further numerical studies of orographic cirrus
- Numerical studies of the internal dynamics of cirrus clouds
- Numerical studies of contrail-cirrus and contrail clusters