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:	Influence of non-hydrostatic gravity waves on the stratospheric flow field above Scandianvia
Computer Project Account:	SPDESCAN
Principal Investigator(s):	Dr. Andreas Dörnbrack
Affiliation:	DLR Oberpfaffenhofen, Institut für Physik der Atmosphäre
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Nils Wedi
Start date of the project:	2008
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)	150 000	200 000	150 000	120 000
Data storage capacity	(Gbytes)	80	80	80	80

Summary of project objectives
(10 lines max)

The projects objectives are to study the mesoscale dynamics of Arctic flows, especially the mountain-wave induced disturbances in the troposphere and lower stratosphere. This special project consists of two work packages: First, analysis of ECMWF stratospheric temperature fields on the northern hemisphere. We want to find out if signatures of mountain waves in the analyses above Scandinavia or other mid-latitude mountain ranges exist. The next step is the investigation of their characteristics in terms of horizontal wavelengths, amplitude and meteorological conditions of appearance. These data will be used as input for upcoming field campaigns in the Arctic in winter 2009/2010. The second part comprises the multiscale numerical simulations of the three-dimensional flow over Arctic and mid-latitude mountain ranges by means of the code EULAG. This geophysical fluid solver allows a much more realistic resolution of the topography. Here, the influence of shorter, non-hydrostatic mountain waves will be studied and compared with independent observations of European and international field campaigns.

Summary of problems encountered (if any)
(20 lines max)

No problems encountered

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

Comparison of ECMWF's stratospheric temperatures with GPS occultation data

In the publication of de la Torres et al. (2009), we use global positioning system radio occultation (GPSRO) data from the Challenging Mini-Satellite Payload for Geophysical Research and Application (CHAMP) and Satelite de Applicaciones Cientificas-C (SAC-C) low Earth orbiting satellites to investigate the occurrence of air with temperatures cold enough to allow the formation of polar stratospheric clouds (PSCs) during four successive Arctic winters spanning 2001 to 2005. The GPSRO data are validated and compared with analysis data from the ECMWF using a series of criteria designed to eliminate faulty soundings but retain profiles which do not differ too strongly from the model data. We find that GPSRO is able to detect more PSC-prone temperature profiles during winters with disturbed conditions (in particular during December 2001 and 2003) than the analysis, but that the model fully captures the extent of PSC-prone air in winters with strong, cold vortices (in particular December 2002 and January 2005). Examination of detailed profiles for December 2001 shows that this difference is due to the ability of GPSRO to detect short-vertical wavelength features which may represent either localized gravity or global-scale planetary waves. Since the GPSRO data are now being directly assimilated into operational analysis systems, the benefits of the higher vertical resolution retrievals it provides should become evident in future observational studies of PSC formation and ozone loss, particularly under the disturbed conditions noted in several recent winters.

Support of field campaigns at the DLR Institute of Atmospheric Physics

During 2008, numerous field campaigns (EUCAARI, POLARCAT, CONCERT) were supported by the users of the special project. Essentially, the operational meteorological forecasts of the ECMWF as well as the GEMS forecasts of the aerosols particles constituted the basis of our flight planning.

Here, one example of an airborne field campaign measuring the distribution and characteristics of atmospheric trace gases and aerosols is presented.

The access to the ecgate server and the MARS archive provided forecast products which are essential to carry out an airborne field campaign. The forecast products were used for flight planning and creating reasonable flight tracks which were appropriate to satisfy the scientific goals. The major field campaign EUCAARI-LONGREX was conducted in May 2008. The EUCAARI-LONGREX aircraft experiment provided data on how aerosol properties change over Europe as a consequence of a many processes: particle formation and condensation onto existing particles from precursor gases originating from pollution and natural sources; uptake of primary aerosols from pollution and natural sources; exchange between polluted boundary layer and clean free troposphere; ageing of aerosol particles during transport. More information about EUCAARI and EUCAARI-LONGREX can be found on the internet at http://www.atm.helsinki.fi/eucaari/ and at the DLR project webpage http://www.pa.op.dlr.de/aerosol/eucaari2008/, respectively.

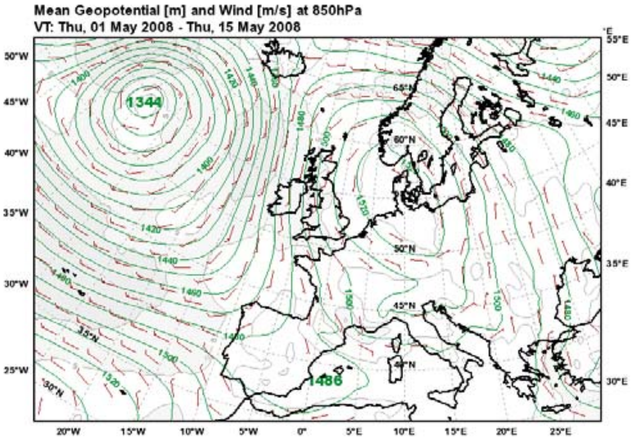

Fig. 1: Mean geopotential height and wind at 850hPa averaged for 01-15 May 2008.

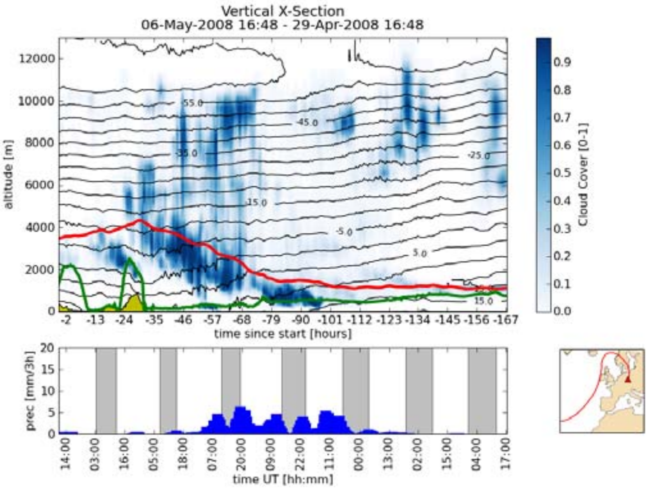

Fig. 2: Vertical cross section along a backward trajectory track (red) containing cloud cover (blue, upper panel), temperature, boundary layer height (green) and precipitation (blue, lower panel).

The meteorological data of the MARS operational archive provided fundamental information for the analysis of the measured data. The data is used for the detailed analysis of the synoptic conditions (see Fig. 1) as well as for modelling air mass transport. Backward trajectories are calculated for air parcels to get information about the meteorological history of air masses which were probed during the aircraft experiment and to determine the sources of measured emissions (see Fig. 2).

Analysis of the Arctic field campaigns ASTAR 2004 and ASTAR 2007

A series of publications appeared (Gayet et al., 2009, Lampert et al., 2009a) or has been submitted recently (Dörnbrack et al., 2009, Lambert et al., 2009b) to a Special Issue of the Atmospheric Chemistry and Physics dealing with the investigation of the Arctic Study of Tropospheric Aerosol, Clouds and Radiation (ASTAR) campaigns which were conducted in May 2004 and in March/April 2007.

In collaboration with the Alfred-Wegener Institut für Polarforschung in Potsdam, airborne lidar observations of the aerosol distribution around Svalbard under strong easterly winds (Dörnbrack et al., 2009) have been investigated.

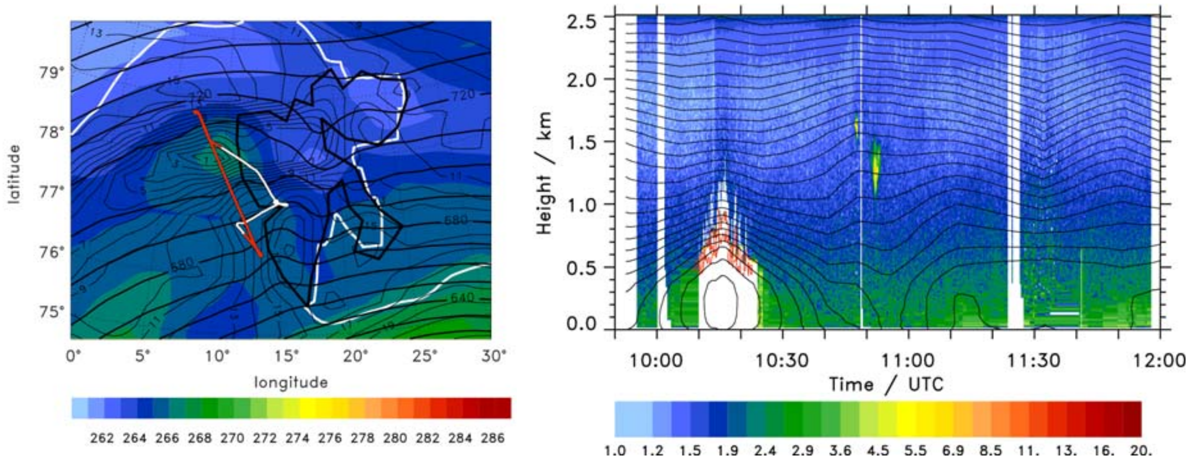

Fig. 3: Left: Temperature (colour shaded, K) and geopotential height (thick black lines, m) and horizontal wind speed (thin black lines, m/s) at the 925 hPa pressure surface on 19 May 2004 at 12 UTC (ECMWF operational analyses). The thick white line is the edge of the pack ice and the red segment represents the flight track where the backscatter observations are taken (right panel): Backscatter ratio $R_{532\ \mathrm{nm}}$ (colour-shaded) and range corrected signal strength $S = Ph^2 = 2$ and $4 \cdot 10^{-9}$ (red contour lines) along the flight track on 19 May 2004. Black contour lines mark the potential temperature Θ with $\Delta\Theta = 0.5$ K interpolated onto the flight path.

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A unique weather situation facilitated the observation of the aerosol concentration under strongly forced atmospheric conditions (see Fig. 3, left). The vigorous easterly winds distorted the flow past Svalbard in such a way that unique mesoscale features were visible in the remote-sensing observations (see Fig. 3, right). Mesoscale numerical modelling with the geophysical fluid solver EULAG was applied to identify the sources of the aerosol plumes and to explain the observed patterns (see Fig. 4).

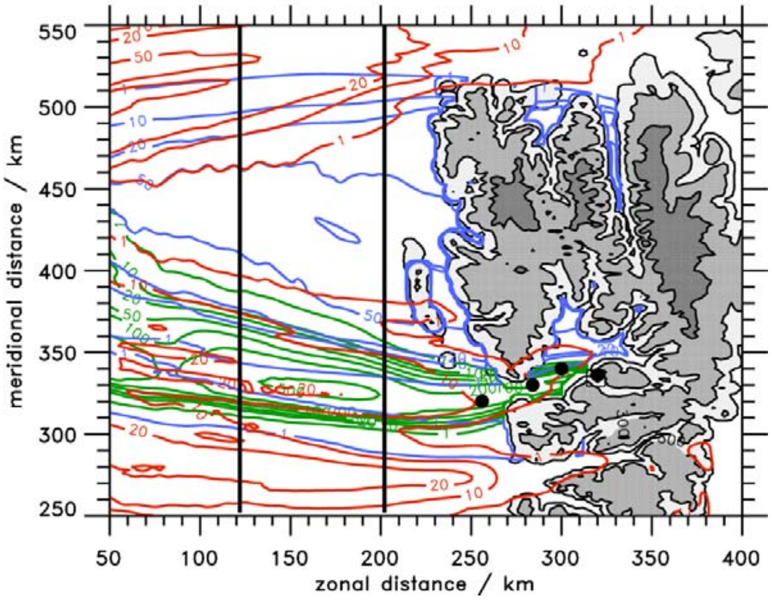

Fig. 4: Horizontal aerosol distribution at 300m after 18 h simulation time. The colors of the contour lines denote the different aerosol species: red - sea salt aerosol, green - dust, and blue snow and ice crystals.

Further ASTAR papers by Gayet et al. (2009) and Lampert et al. (2009a, b) deal with cloud observations in the Arctic. Especially, the results of Gayet et al. (2009) are interesting as they show that ECMWF's diagnostic partitioning between the liquid and solid phase of the water condensates might lead to large deviations to the observations of mixed phase clouds in the Arctic (Fig. 5).

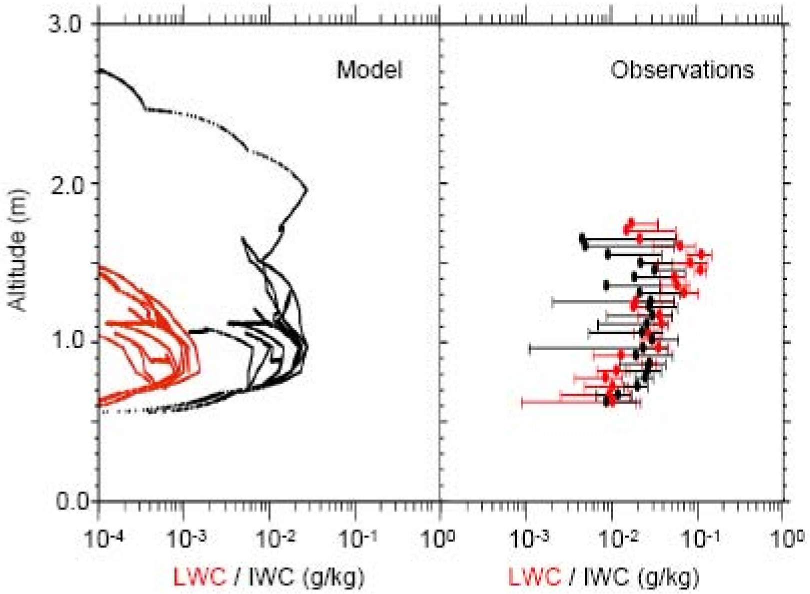

Figure 5: Vertical profiles of the modelled and observed liquid water content (red symbols). The black symbols represent the modelled and observed ice water content.

Airborne measurements in Arctic boundary-layer stratocumulus were carried out near Spitsbergen on 9 April 2007 during the ASTAR 2007 campaign. A unique set of co-located observations is used to describe the cloud properties, including detailed in-situ cloud microphysical and radiation measurements along with airborne and co-located space-borne remote sensing data (CALIPSO lidar and CloudSat radar). CALIPSO profiles indicate cloud top levels at temperature between -24°C and -21°C. In situ measurements confirm that the cloud-top lidar attenuated backscatter signal long the aircraft trajectory is linked with the presence of liquid water, a common feature observed in Arctic mixed-phase stratocumulus clouds. A low concentration of large ice crystals is also observed up to the cloud top resulting in significant CloudSat radar echoes. Since the ratio of the extinction of liquid water droplets to ice crystals is high, broadband radiative effects near the cloud top are mostly dominated by water droplets. CloudSat observations and in situ measurements reveal high reflectivity factors (up to 15 dBZ) and precipitation rates (1 mm h^{-1}). This feature results from efficient ice growth processes. About 25% of the theoretically available liquid water is converted into ice water with large precipitating ice crystals. Using an estimate of mean cloud cover, a considerable value of 10^6 m^3 h^{-1} of fresh water could be settled over the Greenland sea pool. ECMWF's operational analyses reproduce the boundary layer height variation along the flight track. However, small-scale features in the observed cloud field cannot be resolved by ECMWF analysis. Furthermore, ECMWF's diagnostic partitioning of the condensed water into ice and liquid reveals serious shortcomings for Arctic mixed-phased clouds. Too much ice is modelled.

Terrain-induced Rotor Experiment (T-REX)

For the T-REX a couple of analyses and high-resolution numerical simulations have been performed. Our project contributed to the papers by Drechsel et al. (2009), Weissmann et al. (2009) and Doyle et al. (2009). An own publication is in preparation. In the paper by Doyle et al. we focus on the documentation of small-scale intense vortices in the lee of steep topography: High-resolution observations from scanning Doppler and aerosol lidars, wind profiler radars, as well as surface and aircraft measurements during T-REX provide the first comprehensive documentation of small-scale intense vortices associated with atmospheric rotors that form in the lee of mountainous terrain. Although rotors are already recognized as potential hazards for aircraft, it is proposed that these small-scale vortices, or subrotors, are the most dangerous features because of strong wind shear and the transient nature of the vortices. A life cycle of a subrotor event is captured by scanning Doppler and aerosol lidars over a 5-min period. The lidars depict an amplifying vortex, with a characteristic length scale of 500–1000 m, that overturns and intensifies to a maximum spanwise vorticity greater than 0.2 s^{-1}. Radar wind profiler observations document a series of vortices, characterized by updraft/downdraft couplets and regions of enhanced reversed flow, that are generated in a layer of strong vertical wind shear and subcritical Richardson number. The observations and numerical simulations reveal that turbulent subrotors occur most frequently along the leading edge of an elevated sheet of horizontal vorticity that is a manifestation of boundary layer shear and separation along the lee slopes. As the subrotors break from the vortex sheet, intensification occurs through vortex stretching and in some cases tilting processes related to three-dimensional turbulent mixing. The subrotors and ambient vortex sheet are shown to intensify through a modest increase in the upstream inversion strength, which illustrates the predictability challenges for the turbulent characterization of rotors.

List of publications/reports from the project with complete references

1. Dörnbrack, A., I. S. Stachlewska, C. Ritter, and R. Neuber, 2009: Aerosol distribution around Svalbard during intense easterly winds, submitted to *Atmos. Chem. Phys. Discuss*.

2. Weissmann, M., A. Dörnbrack and J. D. Doyle, 2009: Vorticity from line-of-sight lidar velocity scans, submitted to *J. Atmos. Oceanic Techn*..

3. Lampert, A., C. Ritter, A. Hoffmann, J.-F. Gayet, G. Mioche, A. Ehrlich, A. Dörnbrack, M. Wendisch, and M. Shiobara, 2009b: Observations of Boundary Layer, Mixed-Phase and Multi-Layer Arctic Clouds with different lidar systems during ASTAR 2007, submitted to *Atmos. Chem. Phys. Discuss.*

4. Gayet, J.-F., G. Mioche, A. Dörnbrack, A. Ehrlich, A. Lampert, and M. Wendisch, 2009: Microphysical and optical properties of Arctic mixed-phase clouds – the 9 April 2007 case study. *Atmos. Chem. Phys. Discuss.*, **9**, 11333–11366.

5. Lampert, A., A. Ehrlich, A. Dörnbrack, O. Jourdan, J.-F. Gayet, G. Mioche, V. Shcherbakov, C. Ritter, and M. Wendisch, 2009a: Microphysical and radiative characterization of a subvisible midlevel Arctic ice cloud by airborne observations – a case study, *Atmos. Chem. Phys*., **9**, 2647–2661.

6. Doyle, J. D., V. Grubišić, W. O. J. Brown, S. F. J. De Wekker, A. Dörnbrack, Q. Jiang, S. D. Mayor, and M. Weissmann, 2009: Observations and Numerical Simulations of Subrotor Vortices during T-REX. *J. Atmos. Sci.*, **66**, 1229–1249.

7. de la Torre Juárez, M., S. Marcus, A. Dörnbrack, T. M. Schrøder, R. Kivi, B. A. Iijima, G. A. Hajj, and A. J. Mannucci, 2009: Detection of temperatures conducive to Arctic polar stratospheric clouds using CHAMP and SAC-C radio occultation data, *J. Geophys. Res.*, **114**, D07112, doi:10.1029/2008JD011261.

8. Drechsel, S., M. Chong, G. J. Mayr, M. Weissmann, R. Calhoun, and A. Dörnbrack , 2009: Three-Dimensional Wind Retrieval: Application of MUSCAT to Dual-Doppler Lidar, *J. Atmos. Oceanic Techn*., **26**, 635–646.

9. Craig, G. C. and A. Dörnbrack, 2008: Entrainment in Cumulus Clouds: What Resolution is Cloud-Resolving? *J. Atmos. Sci.*, **65**, 3978–3988.

10. Smolarkiewicz, P. K. and A. Dörnbrack, 2008: Conservative Integrals of Adiabatic Durran's Equations, *Int. J. Numerical Meth. Fluids*, **56**, 1513–1519.

11. di Girolamo, P., A. Behrendt, C. Kiemle, V. Wulfmeyer, H. Bauer, D. Summa, A. Dörnbrack, and G. Ehret, 2008: Simulation of satellite water vapour lidar measurements: Performance assessment under real atmospheric conditions, *Remote Sensing of Environment,* **112,** 1552–1568.

Summary of plans for the continuation of the project

(10 lines max)

- publication of further results of T-REX including ECMWF analyses and EULAG numerical simulations

- preparation of RECONCILE (Reconciliation of essential process parameters for an enhanced predictability of arctic stratospheric ozone loss and its climate interactions), an airborne field campaign in Northern Scandinavia which aims at stratospheric regions susceptible for PSC formation; the campaign will take place in January/March 2010

- numerical simulations with EULAG of the interaction of breaking Rossby waves and vertically propagating mountains waves