

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: INFLUENCE OF NON-HYDROSTATIC GRAVITY WAVES ON THE STRATOSPHERIC FLOW FIELD ABOVE SCANDINAVIA

Computer Project Account: SPDESCAN

Principal Investigator(s): Andreas Dörnbrack
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Affiliation: DLR Oberpfaffenhofen

Name of ECMWF scientist(s) collaborating to the project (if applicable) Dr. Nils Wedi

Start date of the project: 2001

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)	150000	150000	136000	45800 (29.6)
Data storage capacity	(Gbytes)	80	15	80	?

Summary of project objectives

(10 lines max)

This special project consists of two work packages:

First, we want to analyse the ECMWF stratospheric temperature fields on the northern hemisphere. For this purpose, we use the analyses with the recently increased horizontal and vertical resolution. We want to find out if signatures of mountain waves in the analyses above Scandinavia exist. The next step is the investigation of their characteristics in terms of horizontal wavelengths, amplitude and meteorological conditions of appearance. Subsequently, this analysis will be expanded to other mountain ranges as the Ural, Novjia Semljia, Greenland etc.

The second part comprises the multiscale numerical simulations of the three-dimensional flow over the Scandinavian mountain range by means of the code EULAG by Piotr K Smolarkiewicz. This code allows a much more realistic resolution of the Scandinavian 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)

This report gives an overview of selected results achieved during the recent period from July 2007 till June 2008. I've picked those results where the access to the resources at ECMWF was most beneficial. First, this relates to computer time of the high-performance computer facility for extensive numerical calculations with the geophysical fluid solver EULAG as performed for the papers by Craig and Dörnbrack (2008) and Smolarkiewicz and Dörnbrack (2008). Second, we appreciate the reliable access to the high-quality forecast and analyses data. Those data were both used for the planning of airborne observations during the international field campaigns as COPS 2007, IPY-THORPEX 2008 and POLARCAT 2008 as well as for the analyses of the observations in relation to the overall meteorological situation. In the study about mixed-phase clouds in the Arctic we attempt to understand the significant differences in the predicted and observed liquid and ice water content of the tropospheric clouds.

Mixed-Phase Clouds in the Arctic: A Synopsis of Airborne Lidar, *In-Situ*, and Albedometer Observations, Complemented by Meteorological Analyses (A. Lampert, J.-F. Gayet, G. Mioche, A. Ehrlich, and A. Dörnbrack, 2008)

During the Airborne Study of Tropospheric Aerosol, Clouds and Radiation (ASTAR 2007) campaign, airborne cloud observations were performed over the Arctic Ocean around Svalbard in the period from March till April 2007. On board of the AWI (Alfred Wegener Institute) Polar-2 aircraft, lidar remote sensing, *in-situ* cloud and albedometer solar radiation measurements were combined to investigate the properties of tropospheric clouds in the Arctic. On April 8th, a mixed-phase cloud formation was observed in a cold-air outbreak over open water. On April 9th, mixed-phase clouds were probed in two different air masses, see Fig. 1. First we observed remnants of the northerly cold-air outbreak which was gradually replaced by warmer air originating from the South. In the mixing zone between both air masses, the cloud consisted of pure ice.

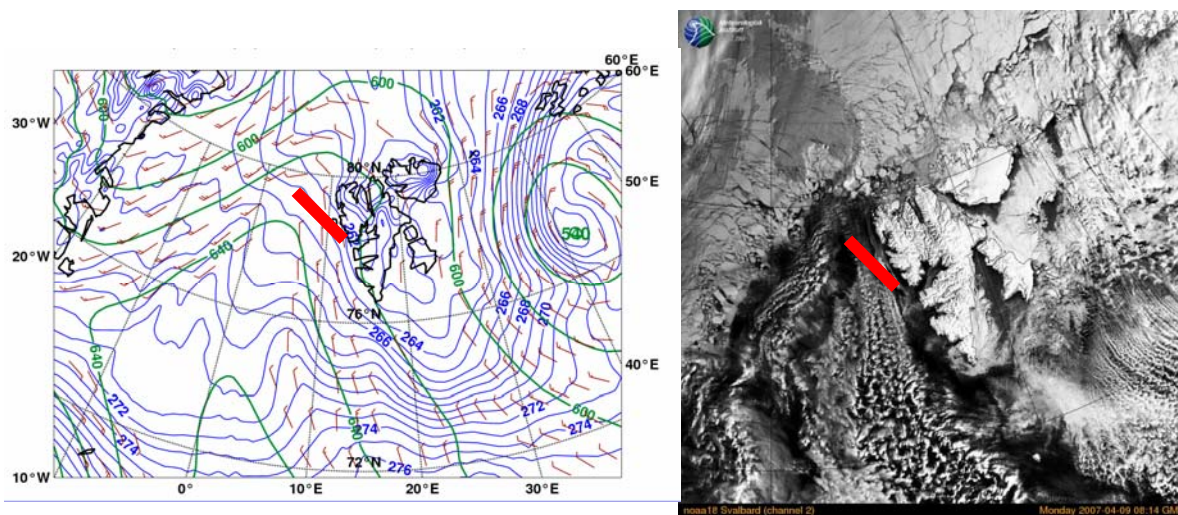


FIG. 1. Geopotential height (m, green lines), equivalent potential temperature (K, blue lines) and wind speed (ms^{-1} , barbs) at 850 hPa on 9 April 2007 at 06 UTC (left). NOAA visible satellite imagery valid at 0814 UTC on 9 April 2007 (right). The approximate locations of the flight paths are indicated by red lines. Meteorological data are taken from operational ECMWF analyses.

The following figure from Lampert *et al.* (2008) shows the backscatter observations with superimposed ECMWF analyses of potential temperature. The overall structure of the air mass boundary is pretty accurately analysed by the IFS. In Fig. 2, we additionally show the liquid water content interpolated and space and time on the flight path where the *in-situ* observations were performed (thick black line in Fig. 2, left). The virtual flight through the ECMWF fields revealed

the result which is shown in Fig. 2, right. A significant difference between the observed and analysed liquid and ice water content of the Arctic mixed-phase clouds occurs. Currently, we are

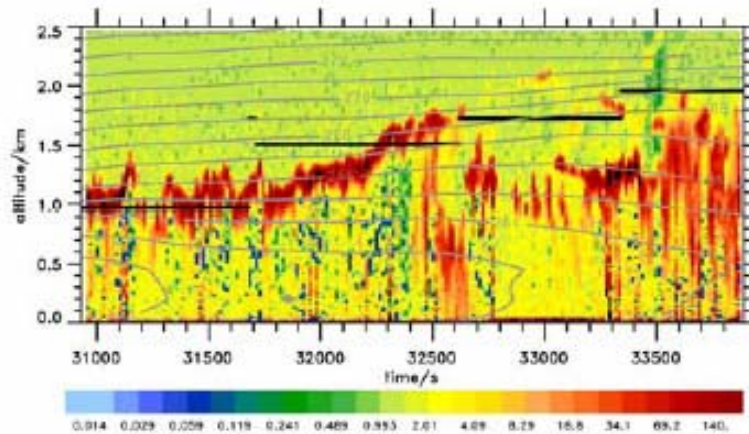


Figure 5: Lidar backscatter ratio (color shaded) along the flight track toward NW on 9th April. Potential temperature (K, grey lines) interpolated in time and space on the flight track. The straight black lines indicate the boundary layer height (see text). Meteorological data are taken from operational ECMWF analyses.

checking the data and prepare a quantitative comparison between both sets of data.

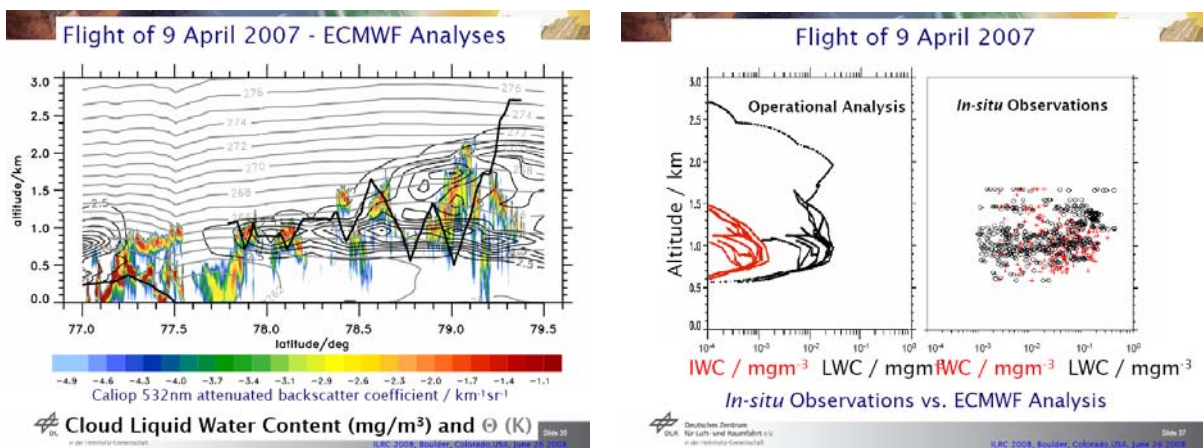


FIG. 2. Comparison of the ice and liquid water content analyzed by the ECMWF IFS and interpolated on the flight track (as shown by the black line on the lhs) in space and time and the in-situ observations during a ASTAR 2007 measurement flight (right panel).

Simulation of satellite water vapour lidar measurements: Performance assessment under real atmospheric conditions (P. Di Girolamo, A. Behrendt, C. Kiemle, V. Wulfmeyer, H. Bauer, D. Summa, A. Dörnbrack, and G. Ehret, 2008)

A lidar simulator has been developed and applied to assess the performances of a satellite water vapour differential absorption lidar (DIAL) system. Measurements performed by the airborne Deutsches Zentrum für Luft-und Raumfahrt (DLR) water vapour DIAL on 15 May 2002 during ESA's Water Vapour Lidar Experiment (WALEX), in combination with ECMWF and PSU/NCAR Mesoscale Model (MM5) output, were used to obtain backscatter and water vapour fields with high resolution and accuracy. These data and model output serve as input for the simulator, allowing for the performance of satellite DIAL under highly-inhomogeneous atmospheric conditions including clouds to be assessed. The airborne measurements show an intrusion of stratospheric air into the troposphere, and MM5 data used above the DLR Falcon airplane flight altitude are characterized by very high upper tropospheric humidity levels, comparable to those associated with strong mid-latitude transport events from the troposphere to the lowermost stratosphere. Results of the simulator reveal that the maximum systematic error does not exceed 5% up to 16 km, except in the presence of thick cirrus and mid level clouds with an optical thickness up to 2 and, occasionally, inside the dry stratospheric intrusion, while the random error is less than 20% up to 16 km when spatial measurement resolutions are applied that follow the World Meteorological Organization (WMO) threshold observational requirements for numerical weather prediction (NWP). The bias is even smaller if a drier upper troposphere/lower stratosphere (UTLS) region from a reference atmosphere is considered. The results confirm the capability of satellite water vapour DIAL systems to retrieve thin structures of the tropospheric water vapour and particle backscatter fields, as well as its capability to provide low bias and random error measurements even in the presence of clouds.

Entrainment in Cumulus Clouds: What Resolution is Cloud-Resolving? (Craig and Dörnbrack, 2008)

Systematic numerical experiments to determine the spatial resolution required to resolve a moist thermal show convergence at a scale proportional to the smaller of the initial thermal diameter D_0 and a buoyancy length scale L_{buoy} . The buoyancy length scale $L_{buoy} = \Delta T_0 / \Delta \Gamma$ (ΔT_0 is the initial buoyancy excess of the thermal and $\Delta \Gamma$ is the ambient stratification) describes the maximum vertical displacement that can be induced against the stratification in the environment by buoyancy-driven pressure perturbations in the cloud, and thus the maximum scale of eddies that cross the cloud boundary. For typical atmospheric conditions where the cloud size D_0 is larger than L_{buoy} , numerical simulations of the mixing processes in cumulus clouds must resolve L_{buoy} .

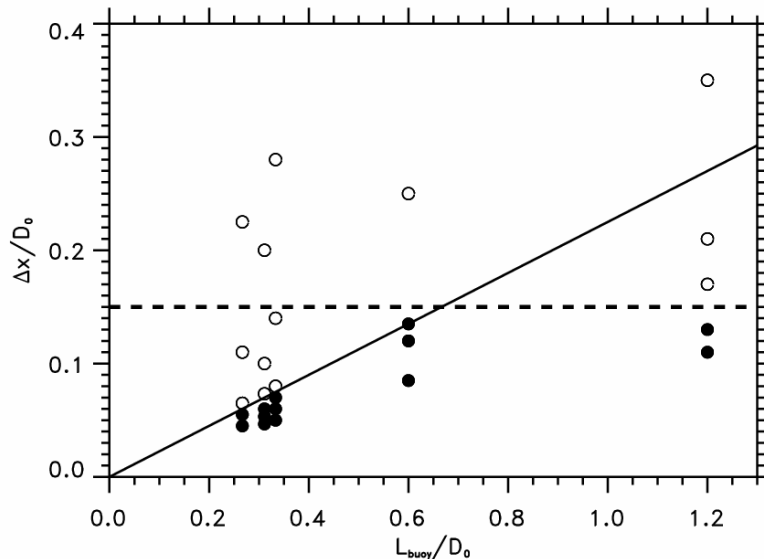


FIG. 3. Scatter plot showing the dimensionless resolution $\Delta x/D_0$ as function of L_{buoy}/D_0 for all experiments, with open circles to indicate lack of convergence and solid dots for convergence according to the criterion defined in the text. The solid and dashed lines correspond to $\Delta x = 0.2L_{buoy}$ and $\Delta x = 0.15D_0$, respectively.

Forecasts for various aircraft campaigns

The deterministic forecasts of the IFS have been used in several international field campaign to guide the aircraft operations on the Cape Verdes (SAMUM 2, Jan. 2008), from Oberpfaffenhofen in middle Europe (COPS July/August 2007, EUCAARI, April 2008), from Andoya in Norway (IPY-THORPEX, Feb/Mar 2008) and, currently from Kangerlussuaq, Greenland for POLARCAT 2008. For this purpose, the web-based presentations using ECMWF's METVIEW have been improved gradually; see the campaign webpages:

<http://www.pa.op.dlr.de/cops>,

http://www.pa.op.dlr.de/ipy_thorpex,

<http://www.pa.op.dlr.de/aerosol/eucaari2008>, and

<http://www.pa.op.dlr.de/polarcat>.

The experimentalists from all participating nations (England, France, Norway, USA, Island, Germany, Austria) appreciated the high quality and reliability of the ECMWF forecast products to achieve their mission's goals.

Further Activities

In a Diploma thesis "Tropospheric Water Vapor Transport in a Pre-convective Environment - as determined from Airborne LIDAR Measurements and ECMWF Model Simulations", Andreas Schäfler investigated the tropospheric water vapor transport in a pre-convective environment by means of high resolution lidar measurements and model simulations. Wind and water vapor observations from two state-of-the-art airborne lidar instruments and short term forecasts from the June 2008

ECMWF's IFS are applied to analyze the humidity transport in the vicinity of a developing cyclone. Additionally, Lagrangian backward trajectories were calculated to determine the parcel's pathways and the origin of the observed air masses. The measurements of water vapor and wind velocity were used to evaluate the global model forecasts. The observations were made during the Convective and Orographically-induced Precipitation Study COPS 2007. In the course of this international field campaign, the DLR research aircraft Falcon performed 14 measurement flights. In his Diploma Thesis, Andreas Schäfler focuses on a special event where upstream as well as local observations of the developing convection were possible.

On 1 August 2007 a strong cyclogenesis took place at the leading edge of a trough. The evolution of the dynamic structure of this system was investigated by three consecutive flights. The first two flights covered the beginning of the cyclogenesis. The third flight took place in the warm sector ahead of the arriving cold front that initiated strong convection over France. The trajectory analysis shows a large-scale transport of warm and moist air from the south-west towards Central Europe. Calculations of the water vapor transport highlight the large-scale transport and show enhanced values at smaller scales in the valleys. The comparison of model forecasts and lidar observations shows a model wet bias in the short-term ($t_0 + 6h$) humidity forecast of 21.82 %, 17.75 % and 9.46 % for the three flights. In general the model forecast is too wet in the lower troposphere. Dry layers and strong humidity gradients show maximum deviations. In case of the wind lidar, differences are lower with a bias of -4.86 % and -2.48 %. The largest deviations are found for low level winds in the valleys which are not resolved by the model.

List of publications/reports from the project with complete references

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

Di Girolamo *et al.*, 2008: Simulation of satellite water vapour lidar measurements: Performance assessment under real atmospheric conditions, *Remote Sensing of Environment* **112**, 1552–1568.

Lampert, A., Gayet, J.-F., Mioche, G., Ehrlich, A., and A. Dörnbrack, 2008: Mixed-Phase Clouds in the Arctic A Synopsis of Airborne Lidar, In-Situ, and Albedometer Observations, Complemented by Meteorological Analyses, *Proc. of the 24th International Laser Radar Conference*, Boulder, CO, 881-884.

Schäfler, A., 2008: Tropospheric Water Vapor Transport in a Pre-convective Environment - as determined from Airborne LIDAR Measurements and ECMWF Model Simulations, Diploma Thesis, Universität Innsbruck, 106 pp.

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

Summary of plans for the continuation of the project

(10 lines max)

1. participation in field campaigns in the framework of THORPEX, i.e. support in the planning and performance of targeted observations during national and international field campaigns; e. g. T-PARC 2008
2. the remote LIDAR data (tropospheric wind and water vapour profiles) gathered during the field campaigns COPS 2007, IPY-THORPEX 2008 and T-PARC 2008 will be used to perform impact studies with the ECMWF's IFS in close collaboration with Dr. Martin Weissmann
3. preparation of the HALO Demo-Mission POLSTRACC in Kiruna, Sweden 2010: in this demonstration mission the original goal of the current Special Project (mountain waves above Scandinavia) will be addressed by extensive in-situ and remote-sensing observations with the new German airborne research platform HALO and with the high-altitude research aircraft Geofysika
4. extensive numerical modelling with EULAG (case studies of flows over Scandinavia, Island, Svalbard and Greenland) and comparison with results from international field campaigns
5. publication of results