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	2011
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	150 000	150 000	0
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 encounter

Summary of results of the current year (from July 2010 to June 2011)

There are three highlights of research relevant for this Special Project during its last phase. First of all, we participated in a model intercomparison between 11 different non-hydrostatic numerical models. A basic benchmark and five other test cases were simulated in a two-dimensional framework using the same initial state, which is based on conditions during Intensive Observation Period (IOP) 6 of the Terrain-Induced Rotor Experiment (T-REX). All of the models used an identical horizontal resolution of 1 km and the same vertical resolution. The 6 simulated test cases used various terrain heights: a 100-m bell-shaped hill, a 1000-m idealized ridge that is steeper on the lee slope, a 2500-m ridge with a similar terrain shape, and a cross-Sierra terrain profile. The models were tested with both free-slip and no-slip lower boundary conditions. The results indicate a surprisingly diverse spectrum of simulated mountain-wave characteristics including lee waves, hydraulic-like jump features, and gravity wave breaking. The vertical velocity standard deviation is over a factor of 2 larger in the free-slip experiments relative to the no-slip simulations. Nevertheless, the no-slip simulations also exhibit considerable variations in the wave characteristics. The vertical flux of horizontal momentum profiles vary significantly among the models, particularly for the case with realistic Sierra terrain.

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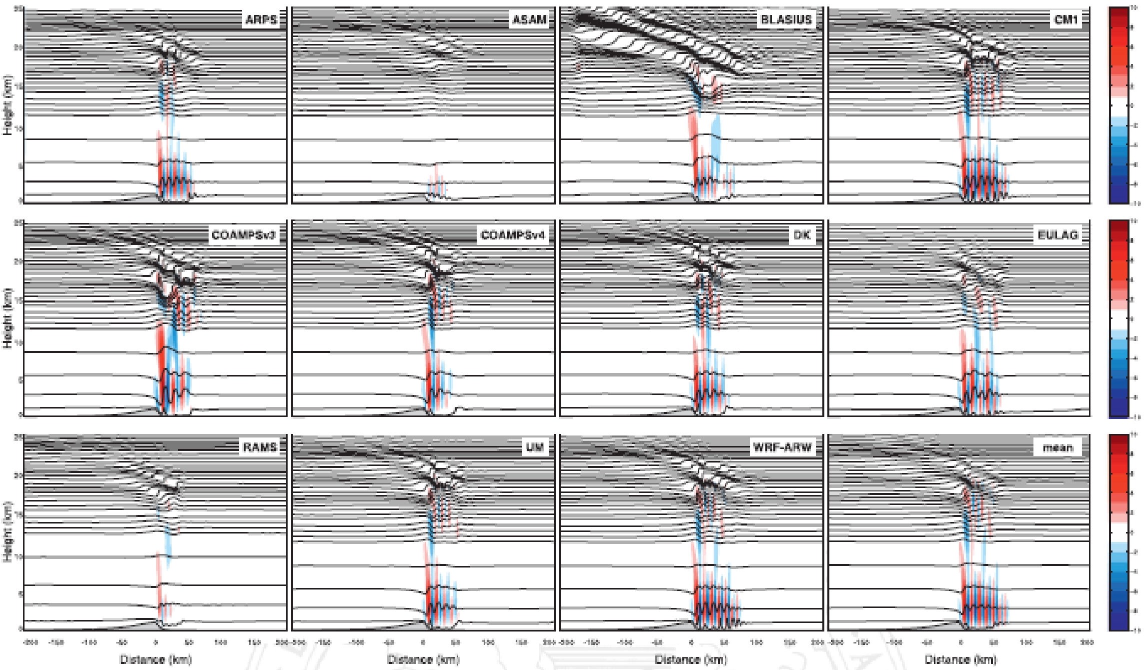

FIG. 4. Vertical velocity (color, interval 1 m s^{-1}) and potential temperature (black contours, interval 10 K) for Ex1000_fs case at the final time (4 h) for all models and (bottom right) the mean.

The results imply relatively low predictability of key characteristics of topographically forced flows such as the strength of downslope winds and stratospheric wave breaking. The vertical flux of horizontal momentum, which is a domain-integrated quantity, exhibits considerable spread among the models, particularly for the experiments with the 2500-m ridge and Sierra terrain. The differences among the various model simulations, all initialized with identical initial states, suggests that model dynamical cores may be an important component of diversity for the design of mesoscale ensemble systems for topographically forced flows. The intermodel differences are significantly larger than sensitivity experiments within a single modelling system.

A second highlight is the case study of Wagner etal. (2011) who studied the mesoscale structure of a mature polar low on the basis of high resolution airborne measurements and numerical modelling. The polar low was measured by light detection and ranging (lidar) and dropsonde observations over the Norwegian Sea on 3 and 4 March 2008. Lidar observations provided cross sections of water vapour mixing ratio, backscatter ratio and horizontal wind speed around the polar low and through its centre. Mesoscale structures, such as shallow convection in a cold air outbreak, a dry intrusion in the eye-like centre of the cyclone and deep convection surrounding it could be identified. Numerical simulations were performed both with the ECMWF IFS and a high resolution, polar version of the WRF model. WRF simulations reproduced these structures and showed that the polar low had a warm, upper-level core with descending motions. The eye-like centre had a diameter of about 100-150 km and was characterised by rather stable stratification, horizontally constant potential temperatures and calm winds. Beyond the centre wind speeds increased rapidly. The observed radial wind and temperature profiles support previous idealised simulations. Several WRF sensitivity tests showed the influence of the initialisation time and sensible and latent heat fluxes from the surface on the simulated polar low development. The polar low simulations were more accurate in runs starting at the mature stage. Heat fluxes from the surface were important for the polar low energetic especially at final stages.

The third highlight is the analysis of the Arctic field campaign RECONCILE. There, ECMWF operational analyses have been used to interpret the CALIPSO data of observations of polar stratospheric clouds (see Pitts et al., 2011). Spaceborne lidar measurements from CALIPSO (Cloud-

Aerosol Lidar and Infrared Pathfinder Satellite Observations) are used to provide a vortex-wide perspective of the 2009-2010 Arctic PSC (polar stratospheric cloud) season to complement more focused measurements from the European Union RECONCILE (reconciliation of essential process parameters for an enhanced predictability of Arctic stratospheric ozone loss and its climate interactions) field campaign. The 2009-2010 Arctic winter was unusually cold at stratospheric levels, especially from mid-December 2009 until the end of January 2010, and was one of only a few winters from the past 52 years with synoptic-scale regions of temperatures below the frost point. More PSCs were observed by CALIPSO during the 2009-2010 Arctic winter than in the previous three Arctic seasons combined. In particular, there were significantly more observations of high number density NAT (nitric acid trihydrate) mixtures (referred to as Mix 2-enh) and ice PSCs.

We found that the 2009-2010 season could roughly be divided into four periods with distinctly different PSC optical characteristics and ECMWF's stratospheric temperature. The early season (15-30 December 2009) was characterized by patchy, tenuous PSCs, primarily low number density liquid/NAT mixtures. No ice clouds were observed by CALIPSO during this early phase, suggesting that these early season NAT clouds were formed through a non-ice nucleation mechanism. The second phase of the season (31 December 2009 – 14 January 2010) was characterized by frequent mountain wave ice clouds that nucleated widespread NAT particles throughout the vortex, including Mix 2-enh. The third phase of the season (15-21 January 2010) was characterized by synoptic-scale temperatures in the stratosphere as retrieved from ECMWF operational analyses below the frost point which led to a rare outbreak of widespread ice clouds. The fourth phase of the season (22-28 January) was characterized by a major stratospheric warming that distorted the vortex, displacing the cold pool from the vortex center. This final phase was dominated by STS (supercooled ternary solution) PSCs, although NAT particles may have been present in low number densities, but were masked by the more abundant STS droplets at colder temperatures.

List of publications/reports from the project with complete references

1. Doyle, J. D., S. Gaberšek, Q. Jiang, L. Bernardet, J. M. Brown, A. Dörnbrack, E. Filaus, V. Grubišić, D. Kirshbaum, O. Knoth, S. Koch, J. Schmidli, I. Stiperski, S. Vosper, S. Zhong, 2010: An intercomparison of T-REX mountain wave simulations and implications for mesoscale predictability, revised version submitted to *Mon. Wea. Rev*. (25 Feb 2011), accepted 22 March 2011, in press.

2. Wagner, J. S., A. Gohm, A. Dörnbrack, A. Schäfler, 2010: The mesoscale structure of a mature polar low: Simulations and airborne measurements, submitted to *Q. J. Roy. Met. Soc.,* accepted May 2011, in press.

3. Pitts, M. C., L. R. Poole, A. Dörnbrack, and L. W. Thomason, 2011: The 2009-2010 Arctic Polar Stratospheric Cloud Season: A CALIPSO Perspective, *Atmos. Chem. Phys.*, **11**, 2161-2177.

Summary of plans for the continuation of the project

(10 lines max)

Studies in this project are completed.