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	2015
Project Title:	Support Tool for HALO Missions
Computer Project Account:	SPDEHALO
Principal Investigator(s):	Dr. Andreas Dörnbrack Dr. Marc Rautenhaus Dr. Andreas Schäfler Sonja Gisinger Martina Bramberger Benedikt Ehard
Affiliation:	DLR Oberpfaffenhofen, Institut für Physik der Atmosphäre
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Sylvie Malardel Nils Wedi
Start date of the project:	2015
Expected end date:	2018

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)	100000	50000	100000	0
Data storage capacity	(Gbytes)	80	80	80	0

Summary of project objectives

(10 lines max)

High-quality meteorological forecast and analysis products are essential for the successful planning and evaluation of airborne measurements. The novel and outstanding research possibilities offered by the German High Altitude and Long Range (HALO) research aircraft dedicated for atmospheric and geophysical research prompt the development of an innovative instrument in support of HALO missions. This special project is dedicated to access ECMWF's meteorological forecast and analysis products for developing and deploying such a mission support tool.

Summary of problems encountered

none

Summary of results of the current year

(1) Aircraft missions 2015

In the year 2015, no aircraft missions were actively supported by our institute applying the HALO mission support system. Instead, we concentrated on the publication of previous mission results (see Section 2), the further development and publication of Marc Rautenhaus MET.3D visualization of ensemble forecasts (see Section 3), and the preparation of the upcoming missions in 2016. These missions POLSTRACC/SALSA/GW-LCYCLE 2[1] and NAWDEX[2] are international field campaigns combining the two research aircraft HALO and the DLR Falcon together with ground-based and airborne instrumentations of a variety of partners. For both missions, so-called dry runs were conducted at our institute to test, modify, and customize the forecasts tools together with their application under quasi real conditions one normally encounters in a field campaign. For this purpose, the Mission Support System was used via the MSS-website[3] where standardized products of the IFS high-resolution prediction were displayed. Additionally, extensive use of the interactive Mission Support System was made to design optimal flight routes over the northern Atlantic for NAWDEX. Also, in cooperation with the Ludwig-Maximilians Universität in Munich, tutorials were offered how to use the interactive MSS and MET.3D most effectively.

(2) **Publications**

ECMWF IFS and ERA-Interim data were used in a couple of publications devoted to the deep vertical propagation of mountain waves over New Zealand during DEEPWAVE and during the GW-LCYCLE 1 mission over northern Scandinavia. The THE DEEP PROPAGATING GRAVITY WAVE EXPERIMENT (DEEPWAVE) was overviewed in a comprehensive Bull. Am. Met. Soc. article by Fritts et al. (2016). For an observational study, Bossert et al. (2015) used ECMWF profiles to determine the background wind

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[1] https://www.polstracc.kit.edu/polstracc/index.php/POLSTRACC
[2] http://www.pa.op.dlr.de/nawdex
[3] http://www.pa.op.dlr.de/missionsupport/classic/forecasts/

conditions during one research flight during DEEPWAVE. There, observations performed with a Rayleigh lidar and an Advanced Mesosphere Temperature Mapper aboard the NSF/NCAR Gulfstream V research aircraft on 13 July 2014 revealed a large-amplitude, multi-scale gravity wave (GW) environment extending from ~20-90 km on flight tracks over Mt. Cook, New Zealand. Data from four successive flight tracks were employed to assess the characteristics and variability of the larger- and smaller-scale GWs, including their spatial scales, amplitudes, phase speeds, and momentum fluxes. On each flight, a large-scale mountain wave (MW) having a horizontal wavelength ~200-300 km was observed. Smaller-scale GWs over the island appeared to correlate within the warmer phase of this large-scale MW. This analysis reveals that momentum fluxes accompanying small-scale MWs and propagating GWs significantly exceed those of the large-scale MW and the mean values typical for these altitudes, with maxima for the various small-scale events in the range ~20-105 m^2s^{-2}. This study and Ehard's recent paper in Monthly Weather Review (Ehard et al., 2016) investigating the stratospheric and mesospheric mountain waves over Scandinavia have sparked our interest to study the ability of the IFS to simulate internal gravity waves in this altitude region.

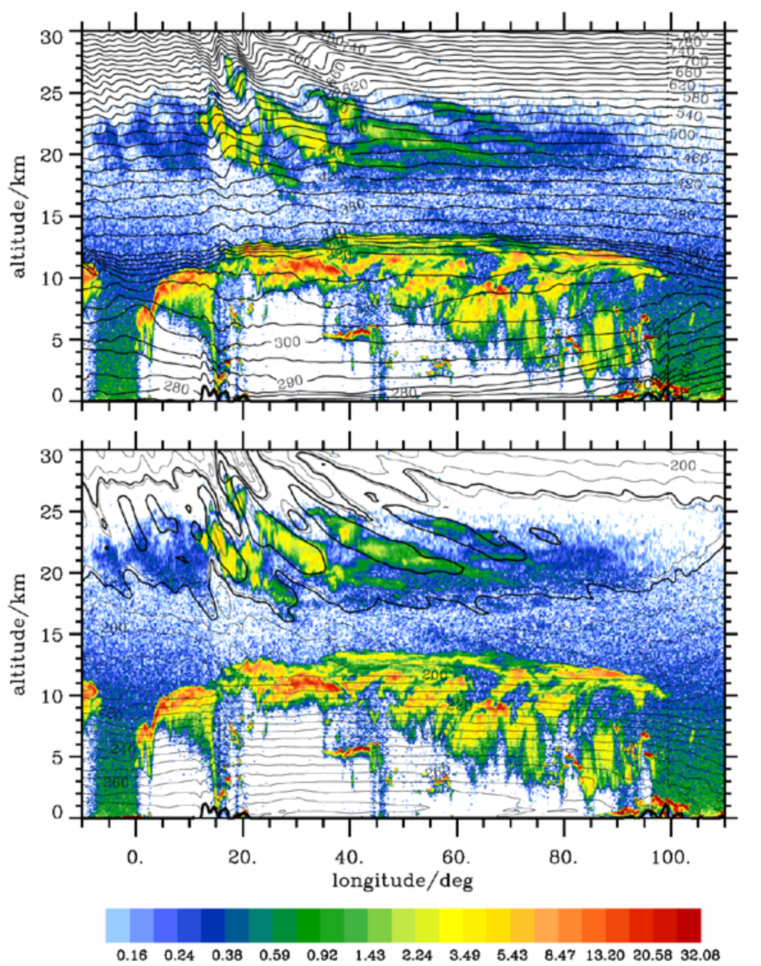

Figure 1: Composite of 532 nm total attenuated backscatter (10^{-3} km^{-1} sr^{-1}, color shaded) and ECMWF potential temperature (top, K, solid black lines) and absolute temperature (bottom, K, thin black lines every 5 K and thick black lines at 185 K and 191 K) valid on 30 December 2015 at 04 UTC (+ 4 h lead time from the 00 UTC high res IFS forecast of cycle 41r2.

In a short, recently submitted contribution to the "picture of the month" of Monthly Weather Review, we documented an interesting case observed at the end of December 2015. The presented picture of the month is a kind of collage, a superposition of space-borne lidar observations and high-resolution temperature fields of the ECMWF IFS. Fig. 1 displays complex tropospheric and stratospheric clouds over Svalbard at 30 December 2015. On this day, the unusual northeastward propagation of warm and humid subtropical air masses as far north as 80°N lifted the tropopause by more than 3 km in 24 h and cooled the stratosphere on a large scale. A widespread formation of thick cirrus clouds near the tropopause and of synoptic-scale polar stratospheric clouds occurred as the temperature dropped below the thresholds for the existence of ice cloud particles. Additionally, mountain waves were excited by the strong flow at the western edge of the ridge across Svalbard, leading to the formation of mesoscale PSCs. Two different IFS cycles using horizontal resolutions of 16 km and 8 km globally reproduce the large-scale and mesoscale flow features well whereby the higher resolution IFS cycle produces larger mountain wave amplitudes.

Recently, we analysed the Arctic stratospheric winter 2015/2015 using the operational IFS analyses and ERA-Interim data (Matthias et al., 2016). The Arctic polar vortex in the early winter 2015/16 was the strongest and coldest of the last 68 years. Using global reanalysis, satellite observations, and mesospheric radar wind measurements over northern Scandinavia we investigated the characteristics of the early stage polar vortex and related them to previous winters. We found a correlation between the planetary wave (PW) activity and the strength and temperature of the northern polar vortex in the stratosphere and mesosphere. In Nov/Dec 2015, a reduced PW generation in the troposphere and a stronger PW filtering in the troposphere and stratosphere, caused by stronger middle latitudes zonal winds, resulted in a stronger polar vortex. This effect was strengthened by the more equatorward shift of PWs due to the strong zonal wind at polar latitudes resulting in a southward shift of the Eliassen-Palm flux divergence and hence inducing a decreased deceleration of the polar vortex by PWs.

(3) Met.3D - Visualization of Ensemble Weather Predictions

Marc Rautenhaus defended his PhD thesis on the visualization of ECMWF ensemble weather predictions at the Technical University of Munich in September 2015. Two publications from this work appeared recently (Rautenhaus et al.. 2016 a, b) and his MET.3D tool will be extensively used during the upcoming NAWDEX field campaign which is embedded in the Transregional Collaborative Research Center "Waves to Weather" at the LMU Munich[4].

List of publications/reports from the project with complete references

Members of the Special Project are highlighted in the author's lists.

1. Bossert, K., D. C. Fritts, P.-D. Pautet, B. P. Williams, M. J. Taylor, B. Kaifler, **A. Dörnbrack**, I. M. Reid, D. J. Murphy, A. J. Spargo, et al. (2015), Momentum flux estimates accompanying multiscale gravity waves over Mount Cook, New Zealand, on 13 July 2014 during the DEEPWAVE campaign, *J. Geophys. Res. Atmos*., **120**, 9323–9337, doi:10.1002/2015JD023197.

[4] http://www.w2w.meteo.physik.uni-muenchen.de

2. **Dörnbrack, A., S. Gisinger**, M. C. Pitts, L. R. Poole, and M. Maturilli, 2016: Multilevel cloud structure over Svalbard, *Mon. Wea. Rev*. , submitted 18 June 2016

3. **Ehard, B.,** P. Achtert, **A. Dörnbrack**, **S. Gisinger**, J. Gumbel, M. Khaplanov, M. Rapp, and J. Wagner, 2016: Combination of lidar and model data for studying deep gravity wave propagation, Combination of Lidar and Model Data for Studying Deep Gravity Wave Propagation. *Mon. Wea. Rev.*, **144**, 77–98. doi: http://dx.doi.org/10.1175/MWR-D-14-00405.1

4. **Ehard, B**., B. Kaifler, **A. Dörnbrack**, P. Preusse, S. D. Eckermann, M. Bramberger, S. Gisinger, N. Kaifler, B. Liley, J. Wagner, and M. Rapp, 2016: Vertical propagation of large amplitude mountain waves in the vicinity of the polar night jet, J. Geophys. Res., submitted 6 July 2016

5. Fritts, D. C., R. B. Smith, M. J. Taylor, J. D. Doyle, S. D. Eckermann, **A. Dörnbrack**, M. Rapp, B. P. Williams, P.-D. Pautet, K. Bossert, N. R. Criddle, C. A. Reynolds, P. A. Reinecke, M. Uddstrom, M. J. Revell, R. Turner, B. Kaifler, J. S. Wagner, T. Mixa, C. G. Kruse, A. D. Nugent, C. D. Watson, S. Gisinger, S. M. Smith, R. S. Lieberman, B. Laughman, J. J. Moore, W. O. Brown, J. A. Haggerty, A. Rockwell, G. J. Stossmeister, S. F. Williams, G. Hernandez, D. J. Murphy, A. R. Klekociuk, I. M. Reid, and J. Ma, 2016: The Deep Propagating Gravity Wave Experiment (DEEPWAVE): An Airborne and Ground-Based Exploration of Gravity Wave Propagation and Effects from their Sources throughout the Lower and Middle Atmosphere, *Bull. Am. Meteorol. Soc*., **97**, 425–453 doi:10.1175/BAMS-D-14-00269.1.

6. Giez, A., Mallaun, C., Zöger, M., **Dörnbrack, A**., and Schumann, U., 2016: Comparison of Static Pressure from Aircraft Trailing Cone Measurements and Numerical Weather Prediction Analysis, 32nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference, Washington DC, June 13-17, AIAA-2016-3273, 2016.

7. Kaifler, B., N. Kaifler, **B. Ehard**, **A. Dörnbrack**, M. Rapp, and D. C. Fritts, 2015: Influences of source conditions on mountain wave penetration into the stratosphere and mesosphere, *Geophys. Res. Lett.*, 42, doi:10.1002/2015GL066465.

8. Matthias, V., **A. Dörnbrack**, and G. Stober, 2016: The extraordinarily strong and cold polar vortex in the early northern winter 2015/16, *Geophys. Res. Lett.*, revised version submitted 4 July 2016.

9. **Rautenhaus, M**., M. Kern, **A. Schäfler**, and R. Westermann, 2015: Three-dimensional visualization of ensemble weather forecasts – Part 1: The visualization tool Met.3D (version 1.0), *Geoscientific Model Development*, **8**, 2329-2353.

10. **Rautenhaus, M**., C. M. Grams, **A. Schäfler**, and R. Westermann, 2015: Three-dimensional visualization of ensemble weather forecasts – Part 2: Forecasting warm conveyor belt situations for aircraft-based field campaigns *Geoscientific Model Development*, **8**, 2355-2377.

11. Smith, R. B., A. D. Nugent, C. G. Kruse, D. C. Fritts, J. D. Doyle, S. D. Eckermann, M. J. Taylor, **A. Dörnbrack**, M. Uddstrom , W. Cooper, P. Romashkin, J. Jensen, S. Beaton, 2016: Stratospheric Gravity Wave Fluxes and Scales during DEEPWAVE, *J. Atmos. Sci*., **73**, 2851–2869, DOI: http://dx.doi.org/10.1175/JAS-D-15-0324.1

Summary of plans for the continuation of the project

Full concentration further goes to the publication of the results of the previous campaigns. We will add a new diagnostic tool to the Mission Support System which forecasts clear-air turbulence using the Graphical Turbulence Guidance System developed by Bob Sharman, NCAR (Sharman, R. D., C. Tebaldi, G. Wiener, and J. Wolff, 2006: An integrated approach to mid- and upper-level turbulence forecasting. Wea. Forecasting, 21, 268–287, doi:10.1175/WAF924.1.).