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	2014
Project Title:	Support Tool for HALO Missions
Computer Project Account:	SPDEHALO
Principal Investigator(s):	Dr. Andreas Dörnbrack Marc Rautenhaus Dr. Andreas Schäfler
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) HALO aircraft missions 2014

In the year 2014, two HALO research missions were supported by providing standardized forecasts on the web-site and by personnel providing met briefings at the campaign sites. The first HALO aircraft mission - called NARVAL[1] - took place in January 2014 and observed postfrontal mesoscale precipitation over the North Atlantic For this mission, the Mission Support System was used via the web site http://www.pa.op.dlr.de/missionsupport/classic/forecasts/ 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. During the ML-CIRRUS[2] campaign, a team of scientists from the DLR, ETH Zürich, the University of Mainz, and the Technical University of Munich provided detailed cirrus and contrail forecast for a period of more than three weeks in March 2014.

(2) DEEPWAVE-NZ aircraft mission 2014

The DLR Institute of Atmospheric Physics participated in the Deep Propagating Gravity Wave Experiment (DEEPWAVE) organized by various US American institutes (NCAR, Yale University, GATS, NRL, University of Utah, …) with airborne observations, radiosonde launches and ground-based lidar observations of the stratospheric and mesospheric temperature. Furthermore, detailed ECMWF IFS forecasts were provided to guide the aircraft operations of the DLR Falcon and the NSF/NCAR Gulfstream V over New

[1] https:/halo-db.pa.op.dlr.de/mission/6
[2] http://www.pa.op.dlr.de/ML-CIRRUS/

Zealand and the southern ocean. In a paper (accepted for publication in the Bull. Am. Meteorol. Soc.), the DEEPWAVE experiment is summarized as follows (Fritts et al., 2015):

“The DEEPWAVE experiment was designed to quantify gravity wave (GW) dynamics and effects from orographic and other sources to regions of dissipation at high altitudes. The core DEEPWAVE field phase took place from May through July 2014 using a comprehensive suite of airborne and ground-based instruments providing measurements from Earth’s surface to ~100 km. Austral winter was chosen to observe deep GW propagation to high altitudes. DEEPWAVE was based on South Island, New Zealand to provide access to the New Zealand and Tasmania “hotspots” of GW activity and additional GW sources over the Southern Ocean and Tasman Sea. To observe GWs up to ~100 km, DEEPWAVE utilized three new instruments built specifically for the NSF/NCAR Gulfstream V (GV): a Rayleigh lidar, a sodium resonance lidar, and an advanced mesosphere temperature mapper. These measurements were supplemented by in-situ probes, dropsondes, and a microwave temperature profiler on the GV and by in-situ probes and a Doppler lidar aboard the German DLR Falcon. Extensive ground-based instrumentation and radiosondes were deployed on South Island, Tasmania, and Southern Ocean islands. Deep orographic GWs were a primary target, but multiple flights also observed deep GWs arising from deep convection, jet streams, and frontal systems. Highlights include the following: 1) strong orographic GW forcing accompanying strong cross-mountain flows, 2) strong high-altitude responses even when orographic forcing was weak, 3) large-scale GWs at high altitudes arising from jet stream sources, and 4) significant flight-level energy fluxes and often very large momentum fluxes at high altitudes.”

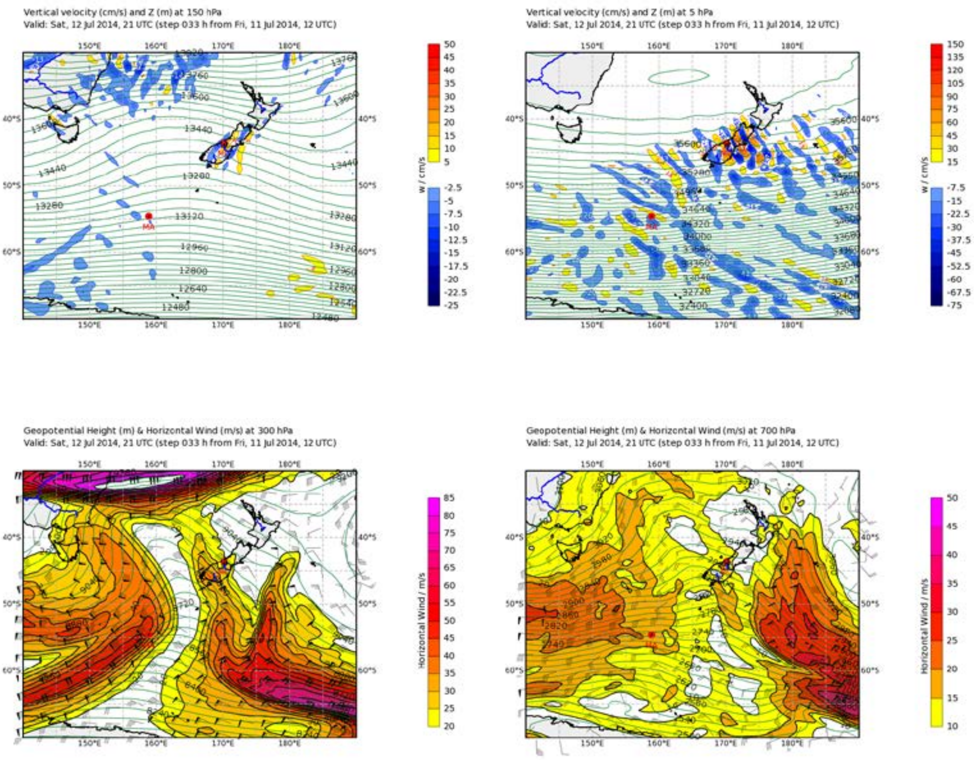

Fig.1: Forecasts charts showing the horizontal wind at 700 hPa and 300 hPa (lower panels) and the vertical velocity at 150 hPa and 5 hPa (upper panels) valid for 13 July 2014 21 UTC. The green contour lines are the geopotential heights.

Altogether, the ECMWF IFS forecasts were extremely useful in guiding the aircraft operations. Especially, the occurrence of upper stratospheric gravity waves over the southern island and over the southern oceans with varying phase orientations made the forecasts challenging. Fig. 1 shows an example where the phase lines in the lower stratosphere (150 hPa) are oriented parallel to the mountain ridge whereas at higher levels (5 hPa) the wave fronts are oriented perpendicular to the ridges. Fig. 2 illustrates that the predicted deep wave propagation was a consistent feature of the three subsequent forecasts runs of the IFS.

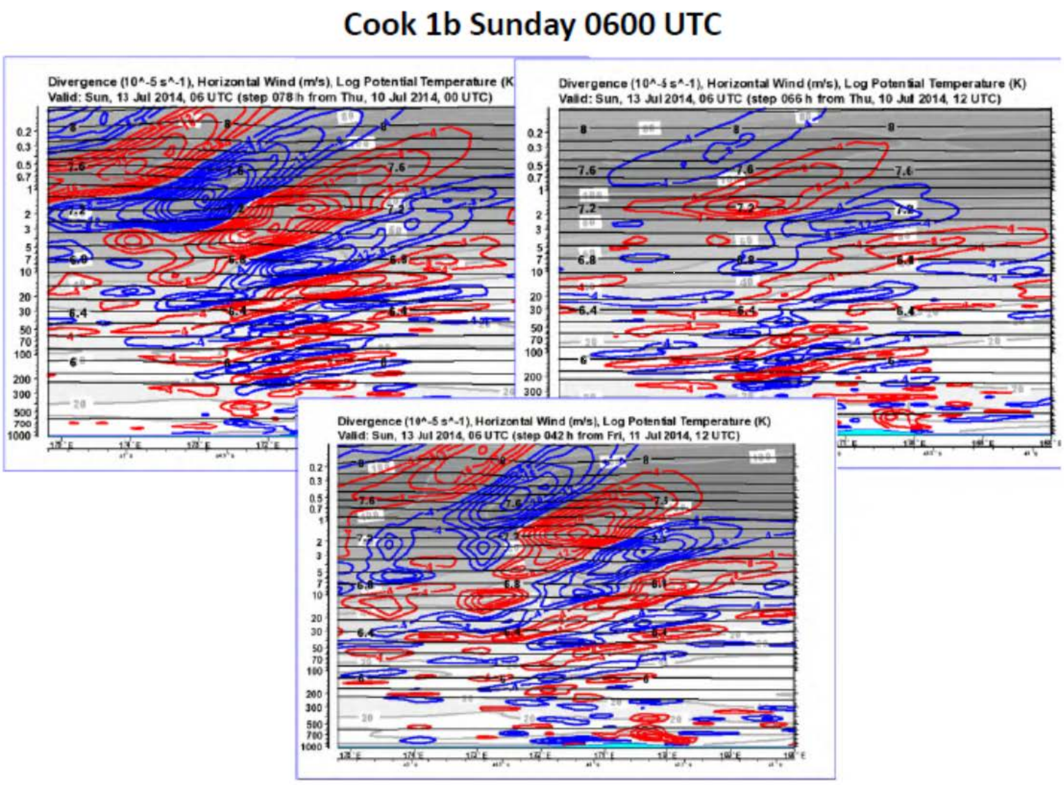

Fig.2: Horizontal divergence (red/blue contour lines), potential temperature (black lines), and horizontal wind (grey shadings) along the planned flight track "Cook 1b" for three subsequent forecast runs valid on 13 July 2014 at 06 UTC.

A short flight with the NSF/NCAR GV was designed to investigate deep gravity-wave packets predicted to occur at flight time (06-09 UTC on 13 July 2014) over the South Island of New Zealand during a period of progressive weakening in surface orographic forcing during the day. Surface forcing over the South Island earlier in the day generated orographic gravity waves at lower altitudes that were sampled by two daytime DLR Falcon flights. The GV research flight RF22 took place after this daytime phase of stronger orographic forcing had abated, and was designed to observe high altitude waves still evident in the forecasts, that pose interesting scientific questions. Are these deep gravity waves the final signatures of the orographic gravity waves forced earlier in the day that take ~12-24 hours to propagate their energy to higher altitudes of the atmosphere? Or are these waves generated instead from an entirely different source? On the latter hypothesis, possible non-orographic sources include spontaneous emission from the strong stratopause jet over Christchurch, and/or jet instabilities in the troposphere possibly associated with an approaching cold front. Another possibility is these deep waves in the forecasts they are simply artifacts (errors) of the model.

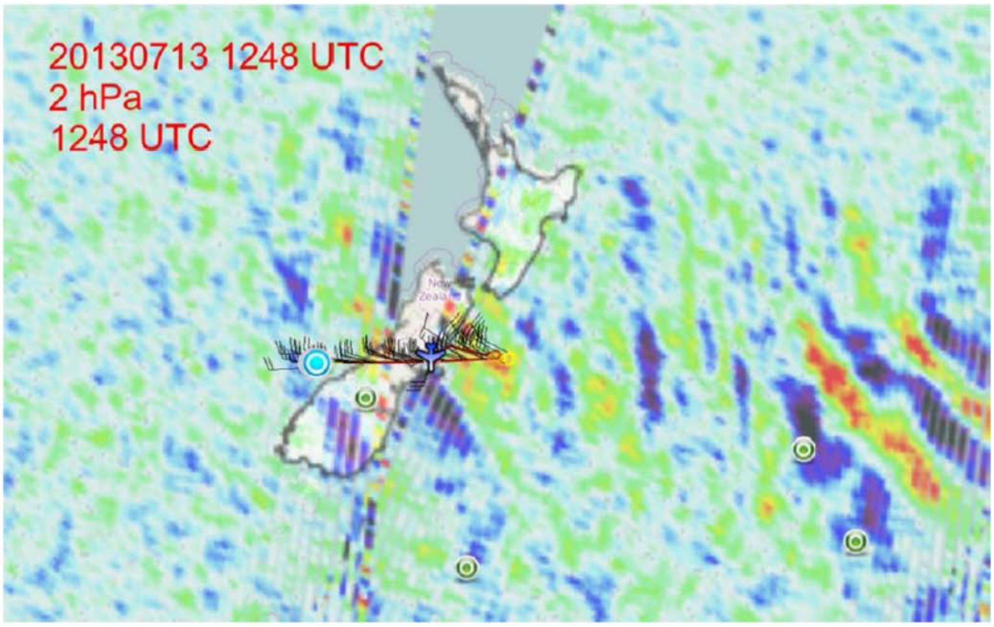

Figure 16: AIRS 2 hPa imagery at 1248 UTC on 13 July 2014, with flight track overlayed. This corresponds to about 3 hours after landing.

Fig.3: Upper stratospheric temperature fluctuations over New Zeal and the southern ocean as measured by AIRS about 3 h after a research flight with the NSF/NCAR GV (courtesy S. E. Eckermann, NRL Washington, DC).

Figure 3 answers at least the question that the predicted wave were real and no numerical artifacts of the IFS as the Atmospheric Infrared Sounder, AIRS, aboard NASA's Aqua satellite observed them shortly after the research flight. The final investigation of the source mechanisms is ongoing.

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

Marc Rautenhaus completed and submitted his PhD thesis on the visualization of ECMWF ensemble weather predictions. Here, an abstract about his work (from https://wwwcg.in.tum.de/research/research/projects/met3d.html). In the context of weather forecasting during aircraft-based field campaigns, the Technical University of Munich's Chair for Computer Graphics and Visualization is, in collaboration with the DLR (German Aerospace Centre) Institute of Atmospheric Physics, developing a GPU powered 3D weather forecasting tool for ECMWF ensemble forecasts. In our project, we are interested in how we can exploit the computational power of GPUs to create interactive 3D visualizations of ensemble predictions that enable the forecaster to (a) quickly identify atmospheric features of interest to a campaign and (b) assess the features' uncertainty. This includes technical issues as well as the question of how the forecast meteorological fields and the uncertainty information derived from the ensemble can best be presented in three dimensions.

List of publications/reports from the project with complete references

Fritts, D. C, R. B. Smith, M. J. Taylor, J. Doyle, S. Eckermann, A. Dörnbrack, M. Rapp, B. P. Williams, P.-D. Pautet, K. Bossert, N. Criddle, C. Reynolds, A. Reinecke;. M. Uddstrom, M. Revell, R. Turner, B. Kaifler, J. Wagner; T. Mixa, C. Kruse, A. Nugent, C. Watson, S. Gisinger, S. Smith. J. Moore, W. Brown, J. Haggerty, A. Rockwell, G.Stossmeister, S. Williams, G. Hernandez, D. J. Murphy, A. Klekociuk, I. M. Reid, Jun Ma, R. S. Lieberman, B. Laughman, 2015: 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*., April 2015, accepted

Rautenhaus, M., A. Schäfler, C. M. Grams, and R. Westermann, 2014: GPU based interactive 3D visualization of ECMWF ensemble forecasts, ECMWF Newsletter **No. 138** – Winter 2013/2014, 34-38.

Schäfler, A., Boettcher, M., Grams, C. M., Rautenhaus, M., Sodemann, H. and Wernli, H., 2014: Planning aircraft measurements within a warm conveyor belt. Weather, 69: 161–166. doi: 10.1002/wea.2245

Schäfler, A. and Harnisch, F.,2015: Impact of the inflow moisture on the evolution of a warm conveyor belt. Q.J.R. Meteorol. Soc., 141: 299–310. doi: 10.1002/qj.2360

Summary of plans for the continuation of the project

We will accompany the upcoming combined HALO and DLR Falcon aircraft mission POLSTRACC/GW-LCYCLE in December 2015 and January 2016.

Further research on the MSS will consider investigating visualisation and data mining questions, with the objective of making the process of exploring the large amounts of prediction data that have to be handled during a campaign more efficient. It would be interesting, for example, to automatically track features of interest to the flight planner or to visualise information about prediction uncertainty. With the on-going development of the WMS standard within the OGC and upcoming related developments, interoperability to third-party providers will improve in the future.

Additionally, advanced functionality may be added to the MSS with little effort. The WMS approach will also be well suited to make new forecast and observation data accessible on-board the HALO aircraft. This will be useful to provide updated information to the aircraft crew during long-range flights.