Turbulence encounter by the research aircraft HALO above Iceland

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Introduction

- RF10 of HALO during NAWDEX on 13 October 2016
- Cruise at FL430 (about 13.8 km altitude) between Lang-Jökull and Hofs-Jökull
- Strong turbulence encounter leading to altitude variations of 100 ft
- Pilots switched off the automatic thrust control

Which physical processes caused this incident?

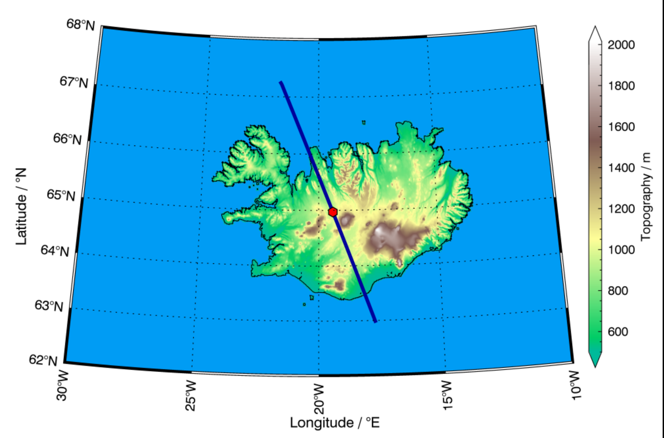

Fig. 1: HALO flight track above Iceland. Red dot shows the position of the turbulence encounter.

Pilot's Report

" So we were flying on our way across Iceland coming from north, I mean it was FL430! The turbulence was so strong that I had to turn off the automatic thrust control because it couldn't adjust to the rapid changes in speed. In part we would need full throttle to keep our speed (which is kind of dramatic in this altitude as the residual thrust is rather small). I left the autopilot up and running, but we experienced altitude variations of 100ft. …" S. Gemsa

Wind and turbulence forecasts for RF10

- Operational analyses of the ECMWF IFS show that HALO crossed a polar front jet (PFJ) with horizontal winds up to 50 ms^{-1} (Fig. 2b)
- Strong southerly surface winds with a maximum of 15 ms^{-1} provided good low-level forcing conditions for the generation of orographic gravity waves (Fig. 2a,c)
- Graphical Turbulence Guidance System (GTG) forecasted light to moderate turbulence above Iceland due to the PFJ and mountain waves (Fig. 3)

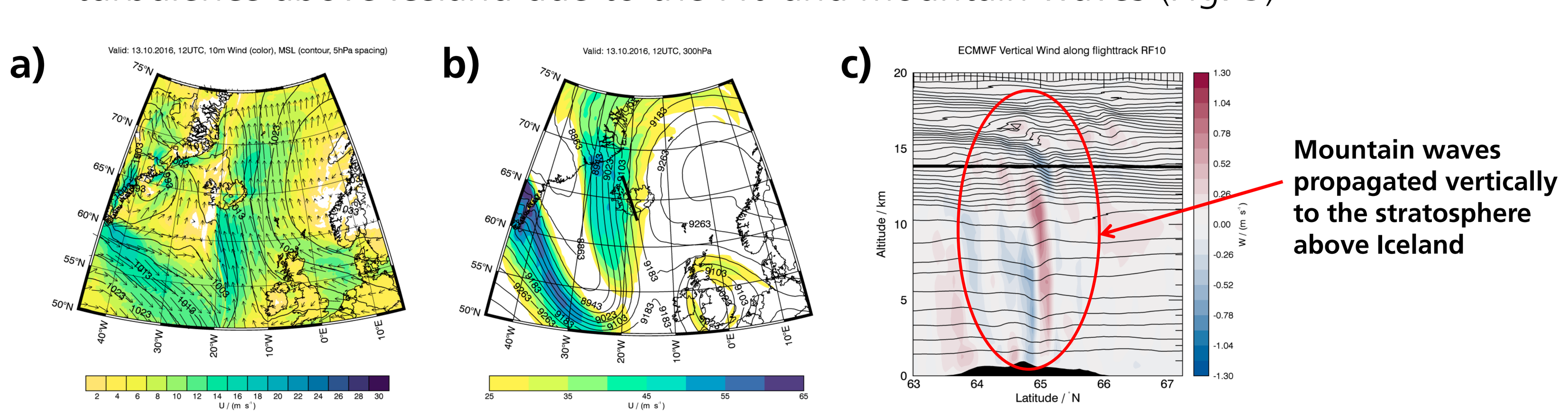

Fig. 2: **a)** 10 m horizontal wind (m s^{-1}) and mean sea level pressure (hPa); **b)** Horizontal wind (m s^{-1}) and geopotential height (m) at 300 hPa; **c)** Vertical cross section of the vertical wind along the HALO flight track

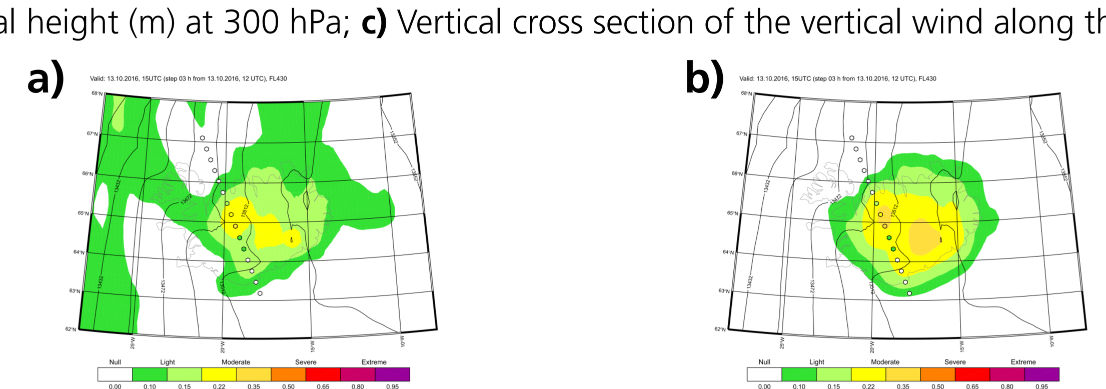

Fig. 3: GTG forecasts of **a)** Clear Air Turbulence (CAT) and **b)** Mountain Wave Turbulence (MWT); the dotted line shows the EDR values derived from HALO in-situ measurements

Mountain Wave - and Turbulence analysis of in-Situ Data

- In the area of the turbulence encounter strong gradients in all three wind components and the static temperature are measured

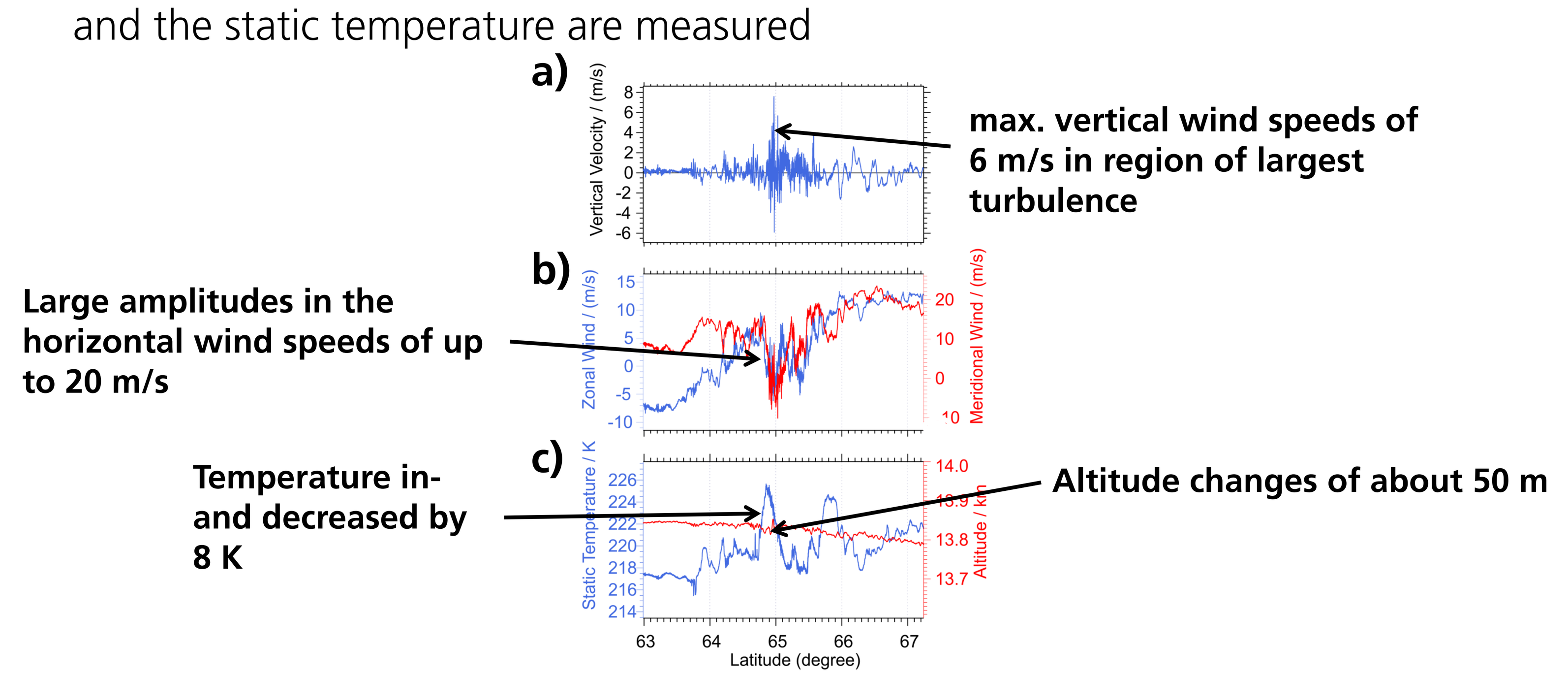

Fig. 4: In-situ measured meteorological parameters. **a)** vertical wind, **b)** zonal and meridional wind components and **c)** static air temperature and GPS altitude

- Along the flight leg, moderate mountain wave activity with energy fluxes up to 2 Wm^{-2} is observed. Most of the energy is contained in smaller scales, $\lambda_h \lesssim$ 5 km

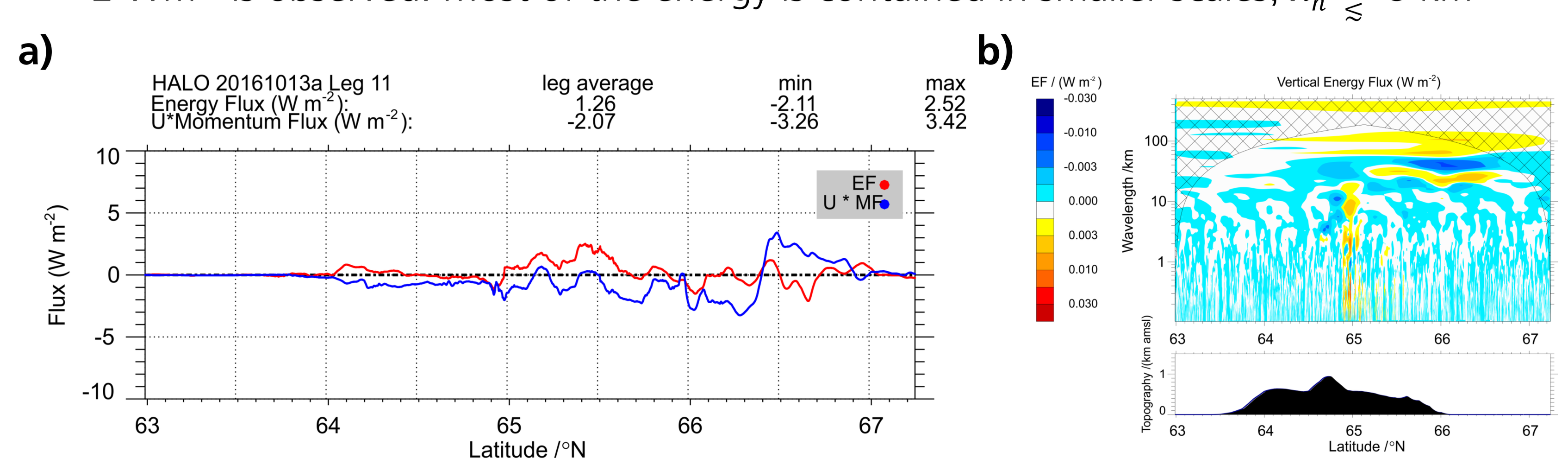

Fig. 5: **a)** Vertical energy- and horizontal momentum fluxes along the flight track
b) Co-spectrum of the vertical energy flux

- Energy dissipation rate (EDR = $\sqrt[3]{\epsilon}$) calculated from wind measurements reveals moderate to severe turbulence

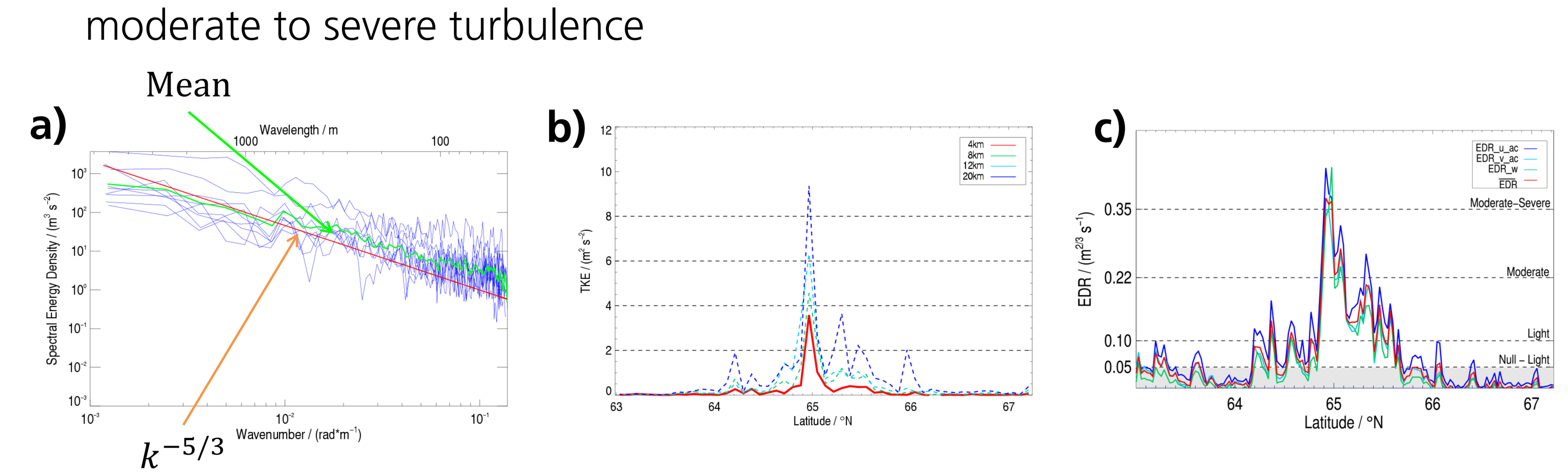

Fig. 6: **a)** Spectral energy density derived from vertical wind
b) Turbulent kinetic energy (TKE) for subleg lengths between 4 and 20 km.
c) Eddy dissipation rate derived from the u_{ac} ,v_{ac} , w wind components on 4 km sublegs

Process studies of atmospheric dynamics with EULAG

- HALO's flight track was located above a valley between two mountains (Lang-Jökull and Hofs-Jökull)
- To simulate HALO`s turbulence encounter, a setup with simplified topography consisting of two witches of Agnesi was used:

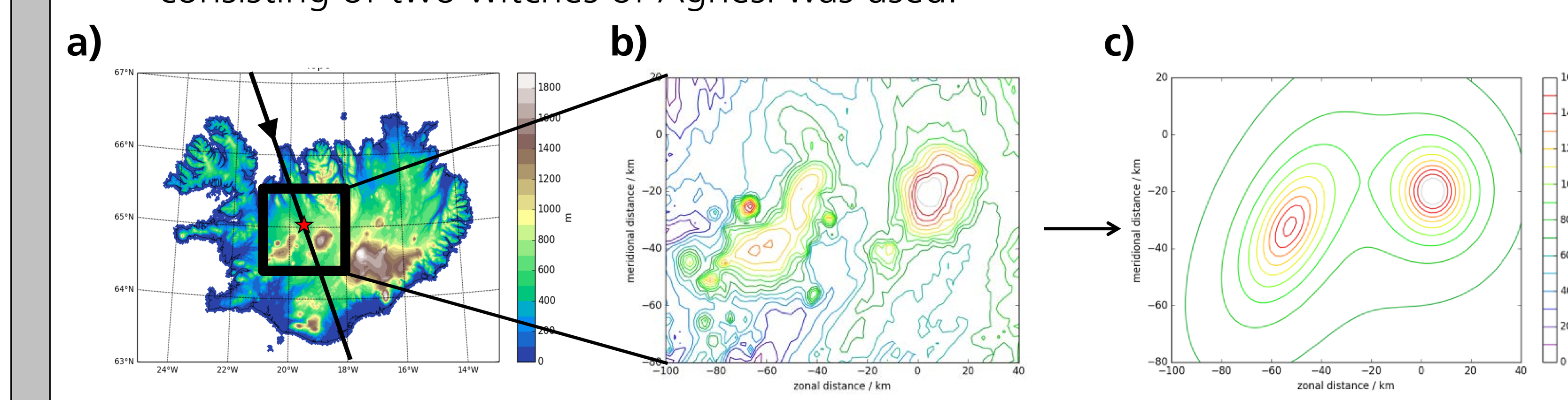

Fig. 7: **a)** Complete topography of Iceland, red star denotes the location of the strong turbulence event
b) Zoom into the area of the turbulence encounter with two dominating mountains
c) Resulting simplified topography used to analyse the generation process of the observed turbulence

- Simulations reveal a turbulent region downstream and in between the two mountains
- Turbulence due to superposition of mountain waves excited by the two mountains and their subsequent breaking

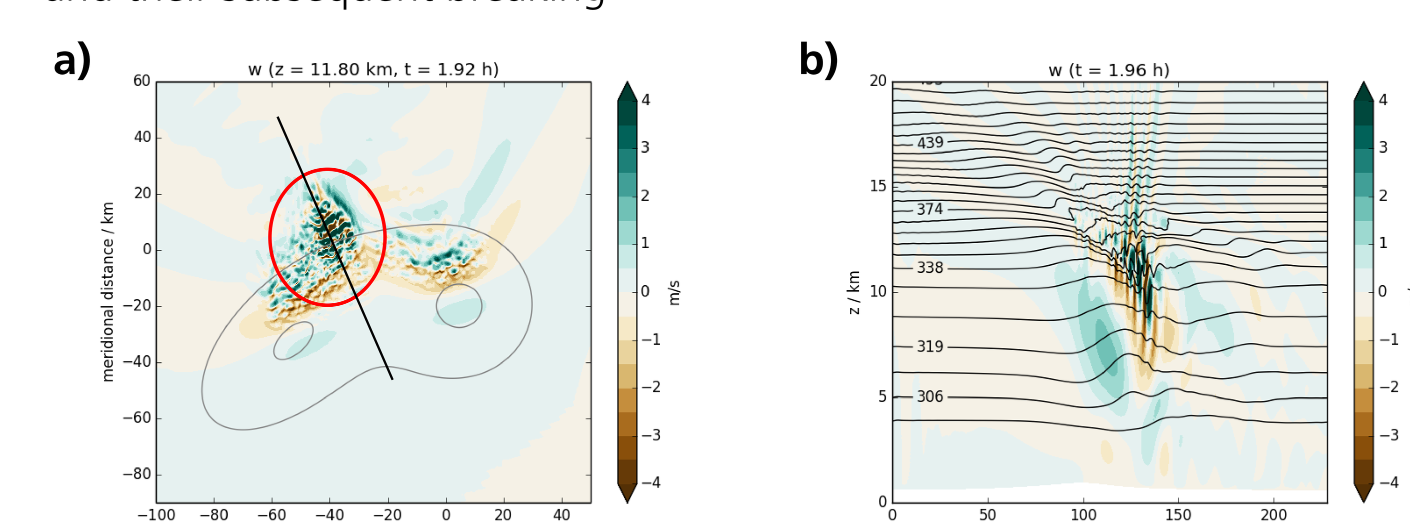

Fig. 8: **a)** Horizontal cross-section of the vertical wind speed; the red circle highlights the turbulent region due to breaking mountain waves
b) Vertical cross-section of vertical wind speed along black line in Fig. 8a

Summary

- Case study reveals that the superposition of two mountain waves caused wave breaking above a valley between two mountains
- HALO entered this unstable area from north and encountered moderate to severe turbulence, which was well predicted by GTG
- Programmed autopilot reactions were not capable to deal with the rapid changes in wind speed and the pilot had to switch off the auto-throttle system of HALO

⇨ Not only the vertical but also horizontal propagation of mountain waves needs to be considered for the forecast of mountain wave turbulence

⇨ Open question remains regarding the role of latent heat release for this event