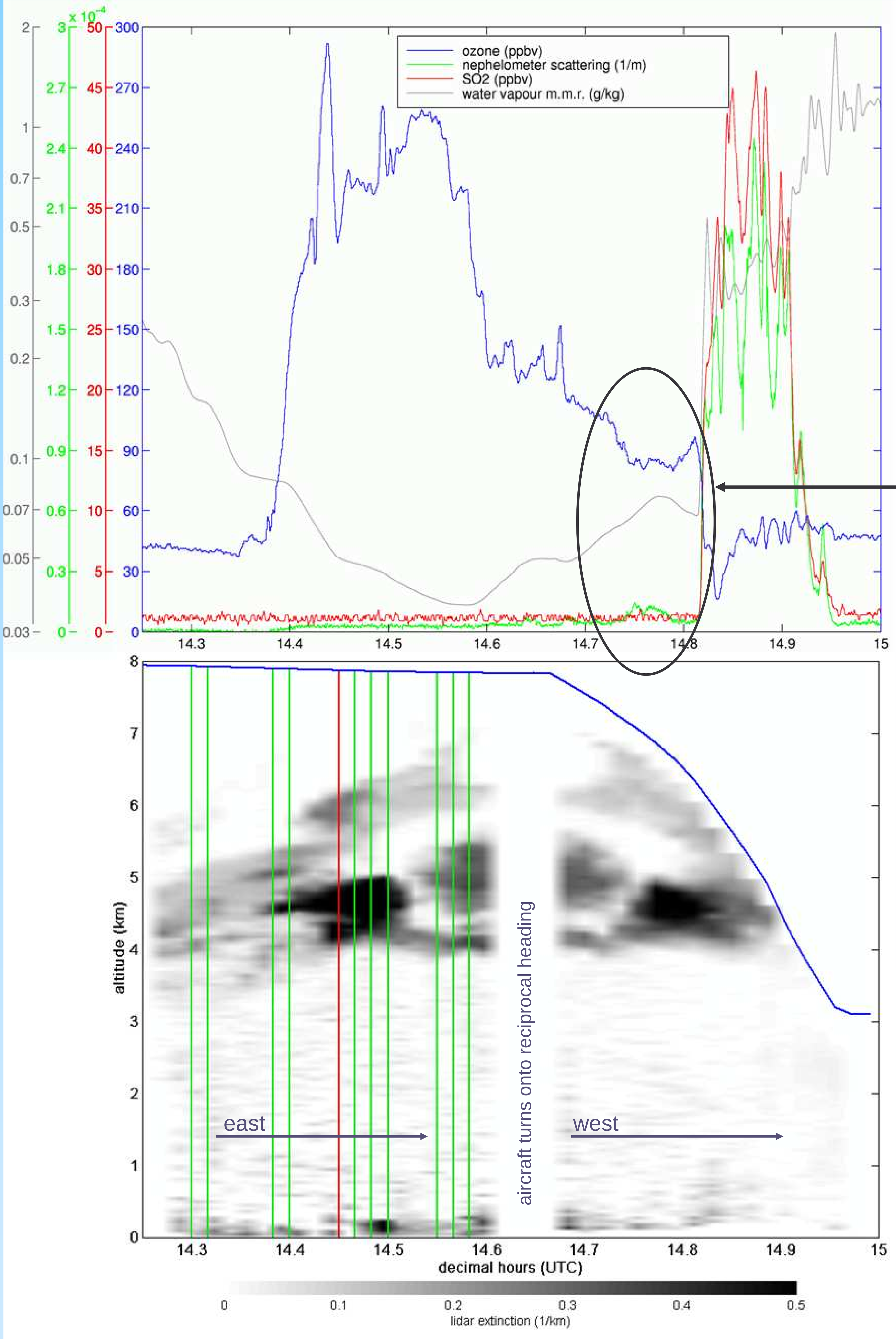
Stratosphere-Troposphere Exchange Involving the Eyjafjallajökull Volcanic Plume

A. Vance[1], A. Woolley[2], F. Marenco[1], S. Havemann[1], S. Milton[1], K. Turnbull[1], M. Bush[1]
[1] Met Office, United Kingdom
[2] F.A.A.M., United Kingdom

Measurements

During research flights in May 2010 investigating the ash plume emanating from the Eyjafjallajökull eruption, the BAe 146 aircraft, operated by the Facility for Airborne Atmospheric Measurement (FAAM), encountered what appears to have been a stratospheric intrusion over the southern North Sea. During a straight and level run at 8 km, *in situ* instrumentation on the aircraft measured very dry, ozone rich air. Dry, ozone-rich air was measured by the aircraft as low as 6.3 km, and dropsonde released during the high level run also recorded very dry conditions in the upper troposphere. This run was made in an easterly direction above a region of dense volcanic ash, measured with a lidar onboard the aircraft, while the upwelling infrared radiation was measured with the ARIES interferometer.



Nephelometer data shows aerosol in stratospheric intrusion - reduced ozone and elevated humidity suggests volcanic origin (very little SO_2 was emitted in first phase of summit eruption).

Time series of *in situ* ozone, SO_2, humidity and aerosol measurements (top) and (bottom) lidar measurement of aerosol extinction made on high level run, overlaid with the aircraft flight altitude (horizontal run due east followed by descending profile due west) in blue, a dropsonde profile in red (marked at launch time) and ARIES observations in green.

Instrumentation

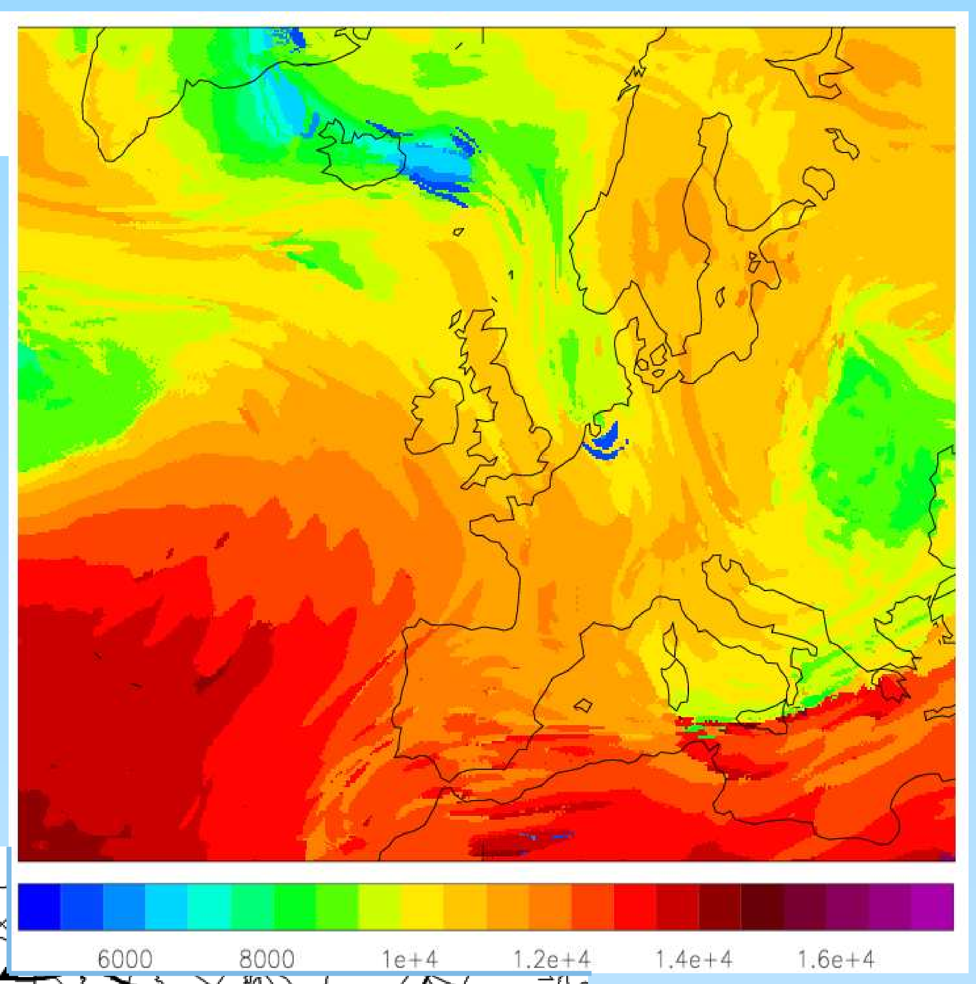
The FAAM BAe 146 aircraft carries a comprehensive suite of *in situ* and remote sensing instruments including:

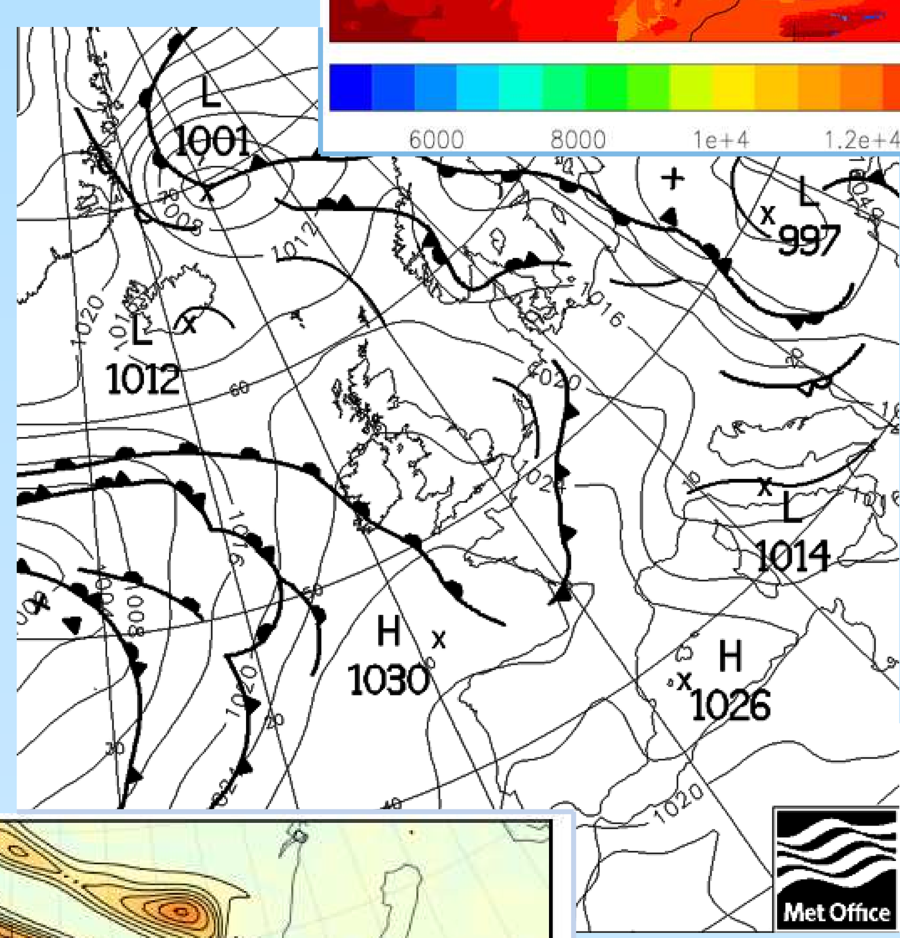
- TECO 49C (ozone)
- TECO 43 (sulphur dioxide)
- General Eastern chilled mirror hygrometer
- Buck CR2 chilled mirror hygrometer
- Leosphere ALS450 elastic backscatter lidar
- ARIES (thermal infrared Fourier transform interferometer)
- Vaisala RD93 dropsondes (pressure temperature humidity, wind)
- TSI 3563 three wavelength nephelometer (aerosol scattering)

Model Data

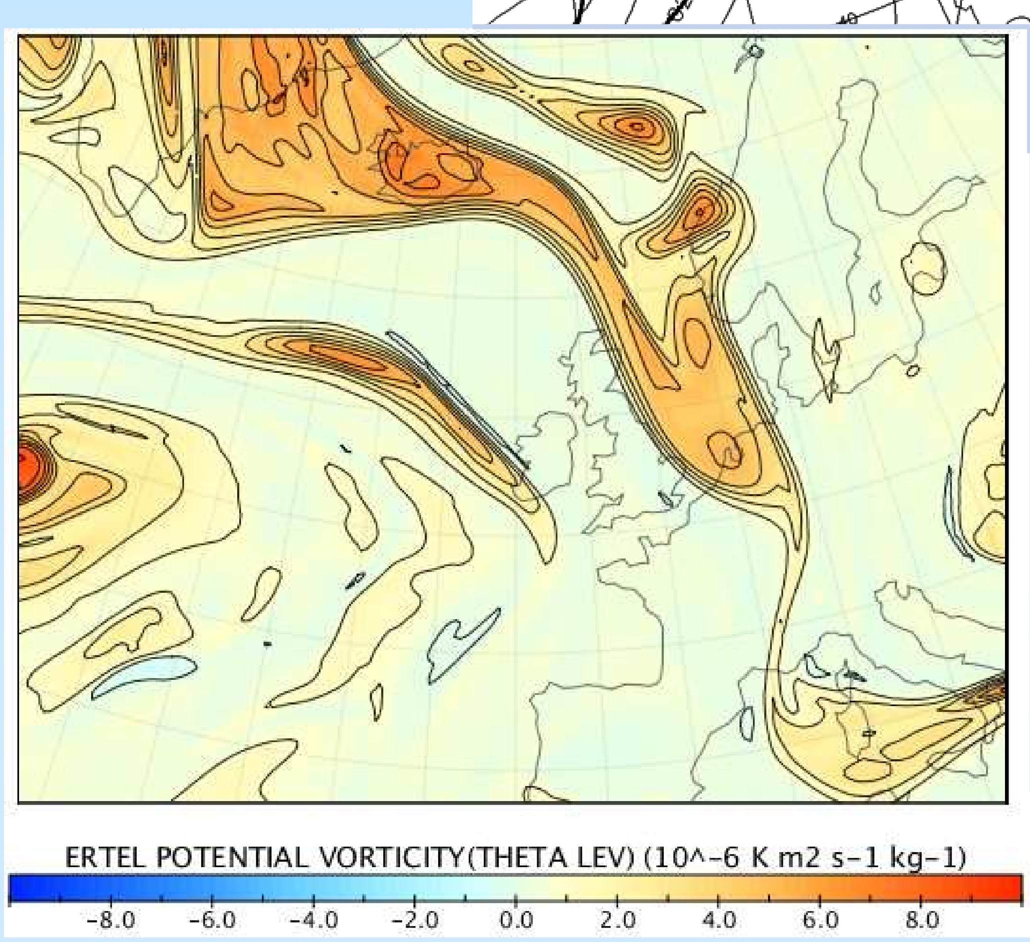
Met Office Unified Model fields for 1200 UTC on this day show a tongue of low tropopause and high Ertel potential vorticity (PV) extending south over the North Sea, behind a cold front, trough and occlusion. Note that the lowest tropopause and highest PV values in this feature are located near and over Iceland.

model tropopause height





synoptic chart



potential vorticity

Met Office FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom
Tel: 01392 885083
Email: alan.vance@metoffice.gov.uk

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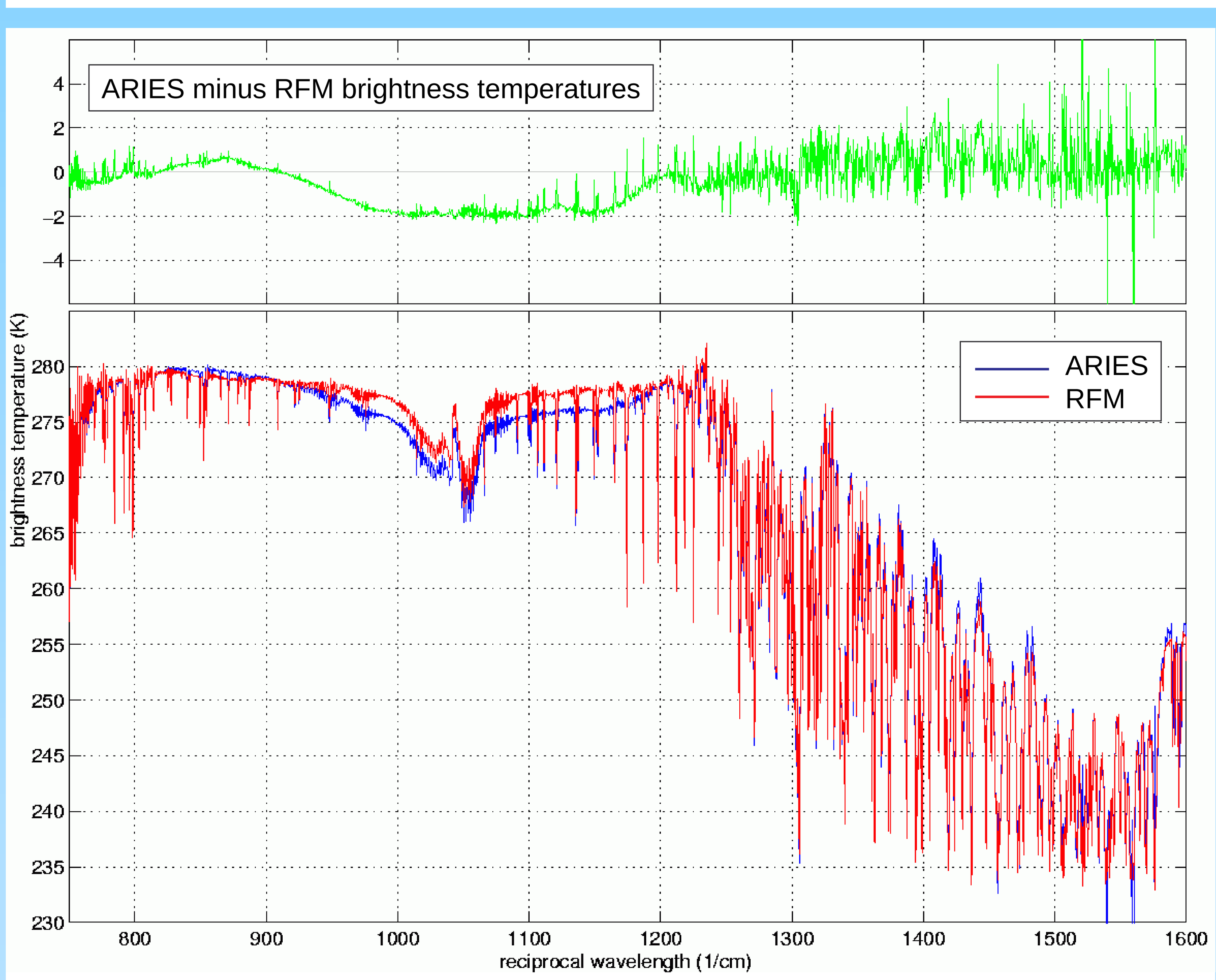
Part 2

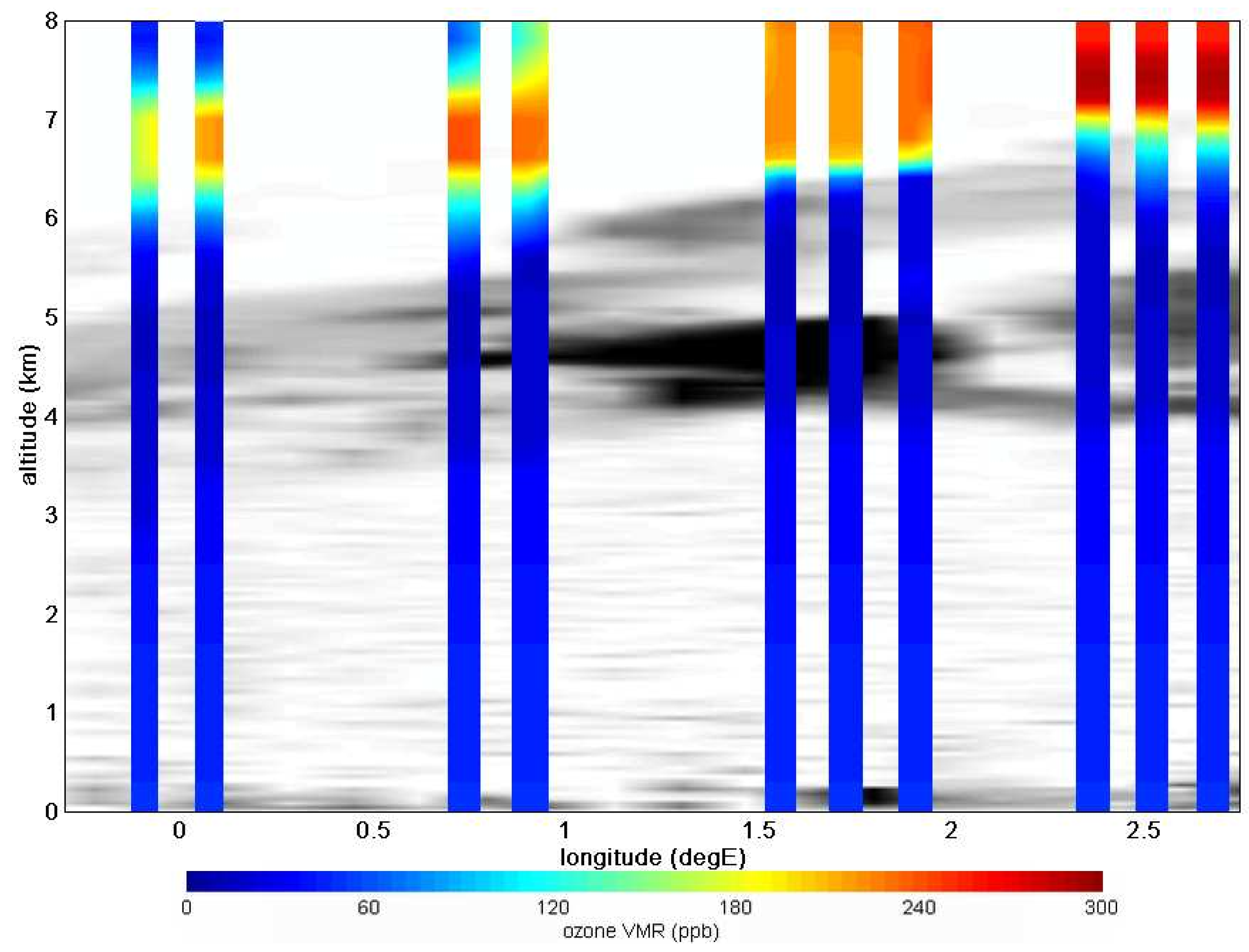
Retrieval of UTLS structure

ARIES nadir spectra showed clear signs of increasing ozone below the aircraft prior to it entering the stratospheric intrusion and so attempts were made to retrieve vertical profiles of water vapour and ozone from ARIES data using a Met Office developed optimal estimation retrieval scheme (Havemann, 2006, Thelen, 2009) which has proved successful in other situations but these were not successful here. It is believed that the main cause of failure was that the ECMWF error covariance matrix used in the retrievals prevented the reproduction of a low, folded tropopause, although the lack of accurate optical properties for the volcanic ash is also a problem.

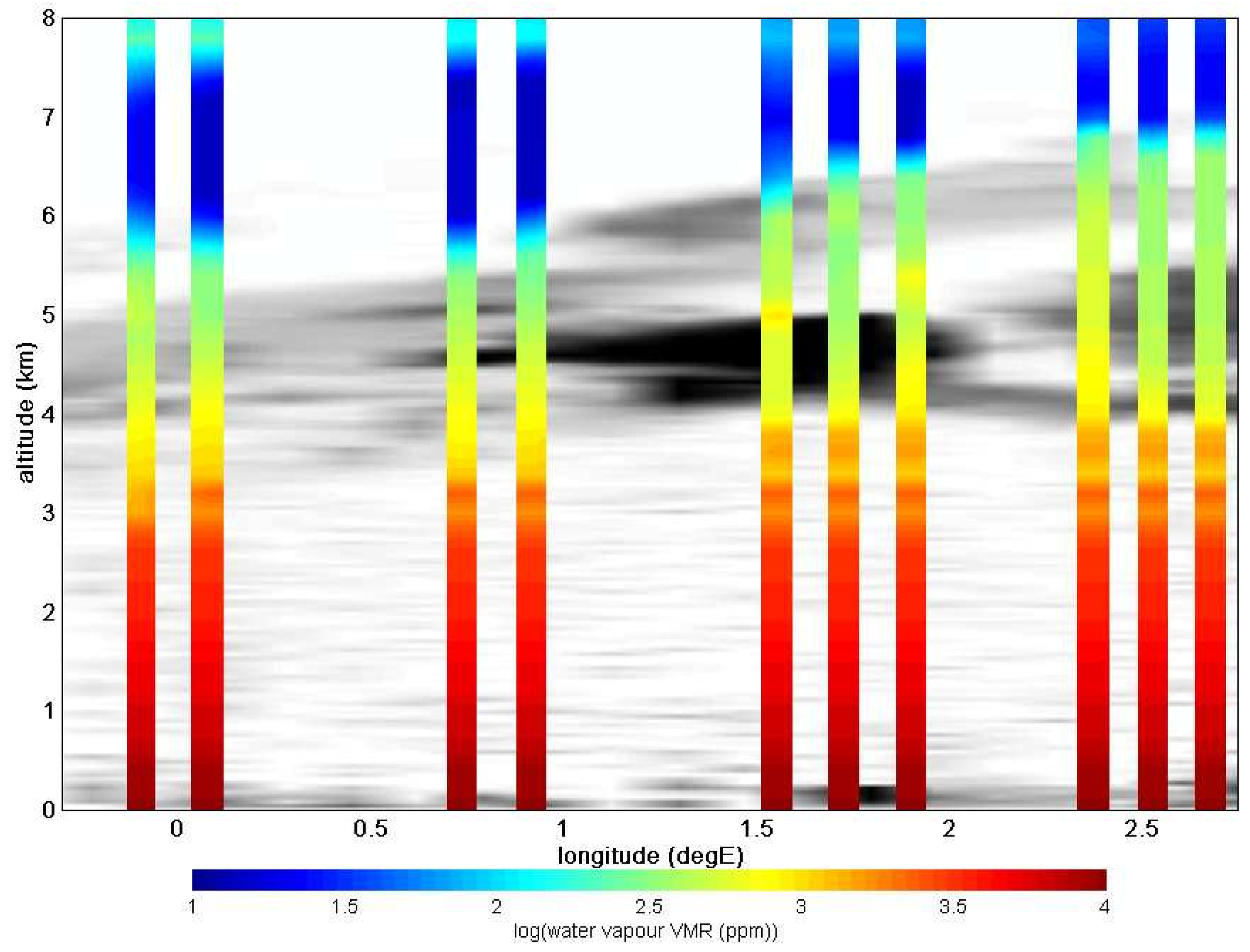
Simulations were then carried out using the Reference Forward Model (RFM, http://www.atm.ox.ac.uk/RFM/). Input profiles were constructed with ECMWF model analyses and a standard atmosphere, modified using *in situ* and lidar data. It was assumed that, within the volcanic plume the water vapour and ozone mixing rations might be reduced by up to 20% and 30%, respectively, based on previous observations and modelling (Vance et al., 2010, von Glasow, 2010); below the ash layer humidity and temperature were taken from the dropsonde and ozone from the ECMWF analysis. In order to match the observed radiances it is necessary to increase the ozone and decrease the water vapour between the aircraft and the ash plume. It is, however, assumed that more extreme conditions cannot exist within the intrusion than were sampled by the aircraft during the high level run.



Comparison of ARIES spectrum and RFM simulation showing good agreement in the water and ozone bands but also a substantial residual difference in the 800-1200 cm^{-1} window region resulting from the use of incorrect aerosol optical properties (Saharan dust).



Retrievals of ozone (above) and water vapour (below). Stratospheric intrusion, containing traces of aerosol, can be seen extending west below tropospheric air.



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Conclusions

A stratospheric intrusion was measured by the FAAM aircraft on 17th May 2010 in the vicinity of the volcanic plume. *In situ* and lidar data show a very rapid transition from stratospheric to tropospheric air bearing substantial ash. Retrievals carried out using thermal infrared data suggest that intrusion sampled was the open end of a tropopause fold containing volcanic ash from the first phase of the summit eruption. The proximity of heavy ash to the intrusion suggests that further ash and active bromine species may have been introduced to the lowermost stratosphere as a result of this folding event.

Met Office FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom
Tel: 01392 885083
Email: alan.vance@metoffice.gov.uk