Observations of the North Atlantic jet stream from NAWDEX

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1. The NAWDEX field campaign

The North Atlantic Waveguide and Downstream Impacts Experiment (NAWDEX; Schäfler et al (2018)) explored the impact of diabatic processes on disturbances of the jet stream and their influence on downstream high-impact weather through the deployment of four research aircraft, including the UK FAAM BAe146 (see Fig 1).

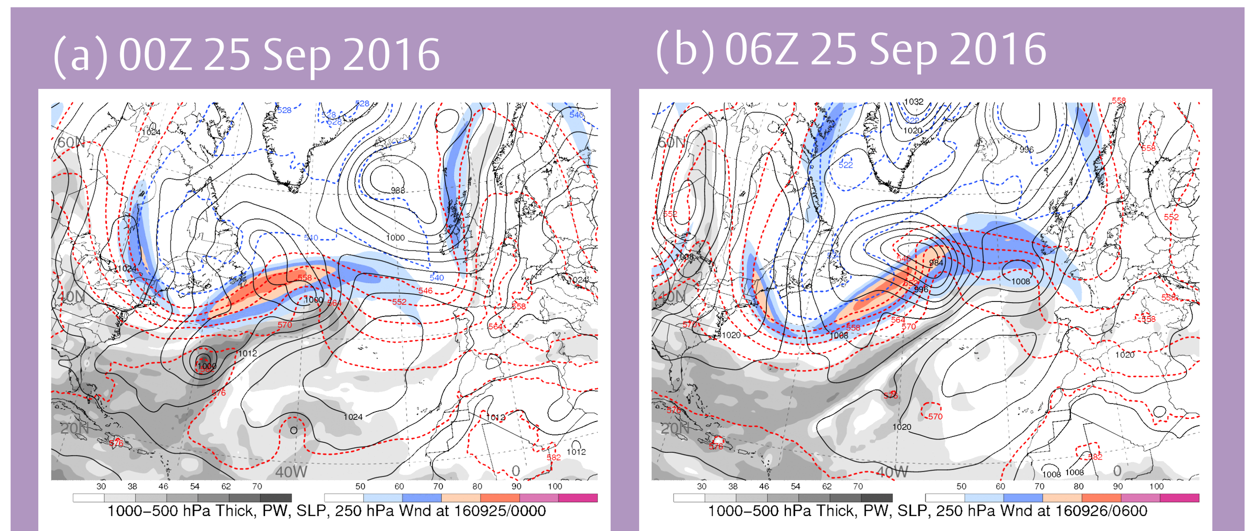
The observation period was from 17 Sep to 22 Oct 2016, which coincides with frequently occurring extratropical and tropical cyclones in the North Atlantic region, together with an active and variable North Atlantic jet stream.

In total, 49 research aircraft flights were performed out of Iceland and the UK, aimed at a broad range of research topics, including the characterization of water vapour transport in warm conveyor belt (WCB) inflow regions, measurement of cloud properties in WCB ascent and outflow, the modification of jet stream structure by the associated diabatic heating, and subsequent consequences on predictability of downstream high impact weather in Europe.

Fig 1: The research aircraft and academic partners involved in NAWDEX. Instrumentation carried includes:
HALO: temperature and lidar humidity profiles beneath aircraft; radar reflectivity; spectral radiances; lidar backscatter; dropsondes
DLR Falcon: Doppler lidar wind profiles; lidar backscatter
SAFIRE Falcon: Doppler radar wind profiles; lidar backscatter; dropsondes
FAAM Bae-146: in situ cloud particle size distributions; passive radiometer; dropsondes

2. Case study: Extratropical transition of Tropical Storm Karl

- Karl was a long-lived tropical storm which progressed northwards and interacted with the jet stream on 26 Sep 2016 (Fig 2a).
- It moved under a pre-existing jet streak whilst transitioning rapidly into an extratropical cyclone (Fig 2b).
- The jet streak was enhanced during the extratropical transition of Karl, with wind speeds up to 90 m/s passing to the North of Scotland on 27 Sep 2016 (Fig 2c).



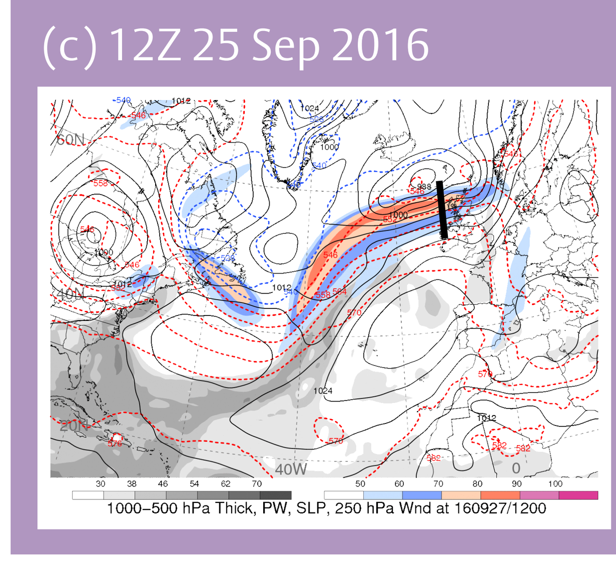


Fig 2: The synoptic evolution during 25-27 Sep 2016. Colours show the jet stream and grey is water content. The black line in (c) shows the flight track in Figs 3 & 4. Figures courtesy of www.atmos.albany.edu/student/heathera/

NAWDEX observations of this case include a HALO flight across storm during extratropical transition (26/9), coordinated FAAM and DLR-Falcon flights across the jet streak to the North of Scotland (27/9) and a second HALO flight through the developing WCB upstream of the jet streak (27/9).

In addition to measurements made by the SHOUT mission in and around tropical storm Karl, this case provides the first ever direct observations of a storm from tropical phase and extra tropical transition through mid-latitude intensification, jet streak formation, ridge enhancement and subsequent high impact weather downstream (precipitation over Scandinavia in this case).

3. Observations of negative potential vorticity in the jet steak

FAAM flight B981 traversed the jet streak to the North of Scotland at 12Z on 27 Sep (Fig 2c), releasing a 'curtain' of dropsondes across the jet streak (see Fig 3).

- The jet streak at 58N lies above a strong baroclinic zone; strong shear is also present at 61N, but is more barotropic in nature (Figs 3a and 3c)
- Both features are associated with deep intrusions of dry stratospheric air (Fig 3b)
- Assuming the jet streak is linear, the potential vorticity (PV) can be computed from cross sections of u and θ:

$$\rho P = (f + u_y)\theta_z + u_z\theta_y$$

- The derived PV field (Fig 3d) consistently shows a PV filament structure with deep intrusions of high PV stratospheric air on either side
- Of interest is the presence of two regions of negative PV, at jet stream level on either side of the intrusion. These are a clear marker of diabatic modification of the jet stream by warm conveyor belt cloud – see next section.

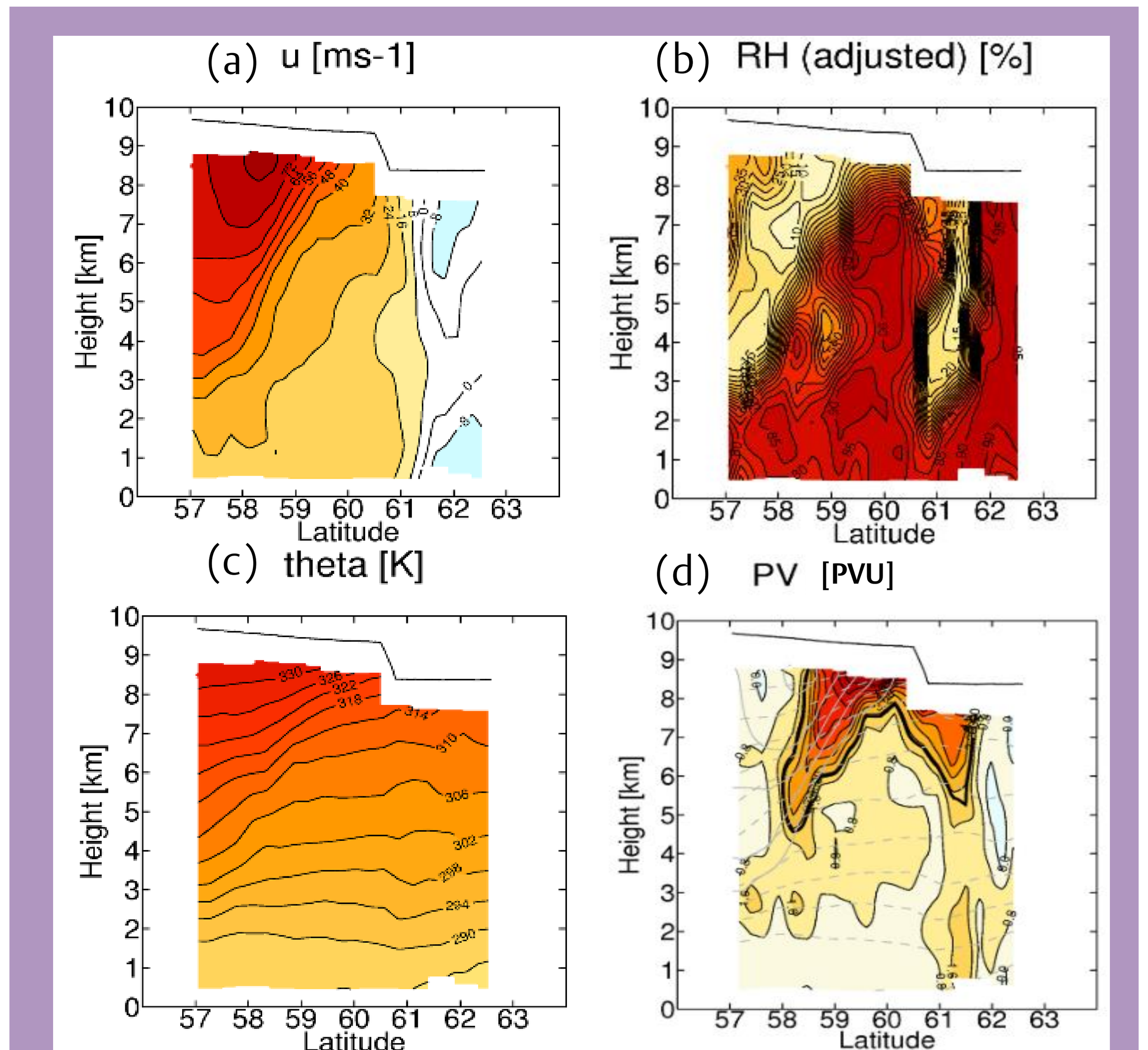


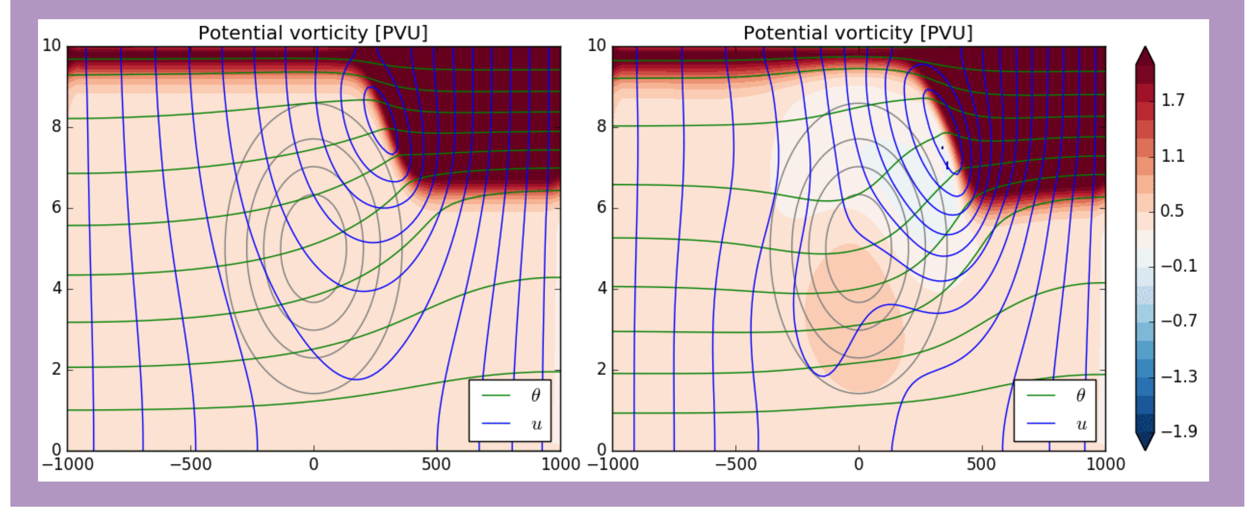
Fig 3: Dropsonde curtain along the N→S line at 7W. Plots are constructed from 22 dropsondes spaced 25 km apart (approx. ¼ deg latitude). A 500m vertical smoothing filter has been applied to the profiles.

4. Understanding the mechanism of negative PV generation in WCBs

On large scales, diabatic heating reduces PV above the heating maximum. However, this mechanism cannot by itself change the sign of PV. On small scales, diabatic heating in the presence of vertical wind shear is known to produce strong horizontal dipoles of PV, with no constraint on the sign.

WCB heating typically lies between these two scales. To reconcile the two aspects of diabatic modification of PV, we use a simple 2-d balanced model (Fig 4). Theoretical considerations show how the 'dilution' of PV on large scales transitions to an 'along-isentropic flux' of PV at small scales.

Fig 4: An illustration of the diabatic modification of PV in a WCB from the simple 2-d balanced model. The two panels show times t=0 and t=6hr. Shading shows PV (red=stratosphere), contours are wind speed (blue) and potential temperature (green). Grey contours show the region of heating. The heating causes a dilution of PV values above, but negative values occur next to the jet stream.



Future plans

NAWDEX was a remarkably successful field campaign thanks to the fortunate timing of numerous well-positioned weather events during the campaign period. NAWDEX is also a large collaboration between numerous international partners (see Fig 1). The work presented here is only one small part of the ongoing effort to utilise the large observational dataset in order to improve understanding of each of the research topics discussed in Section 1.

For further info on NAWDEX and ongoing work, see:

- http://nawdex.ethz.ch/
- Schäfler et al (2018), The North Atlantic Waveguide and Downstream Impact Experiment, BAMS *(in review)*