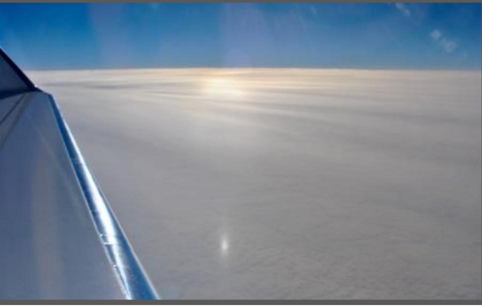

Observation of jet stream winds during NAWDEX and systematic meteorological analysis errors

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NAWDEX Workshop 2019

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Motivation for this project

Open question: to what extent are NWP analyses able to capture observed wind speeds and especially the sharpness of the wind gradients at the tropopause?

→ evaluation of errors and uncertainty in meteorological analyses and forecasts requires high resolution profile observations across the tropopause (→ NAWDEX)

→ 1990s and early 2000s: large biases 5-10% detected (Tenenbaum 1991, 1996, Rickard et al. 2001, Cardinali et al. 2003).

→ Since then: substantial improvement of winds: continuous increase of NWP resolution, continuous increase in quality, amount and resolution of aircraft and satellite wind observations and their improved application

→ Still average uncertainty of 2-3 $m\ s^{-1}$ expected over the NA Ocean Baker et al. (2014)

→ Clear need for vertically resolved wind data for improving NWP (→ ESA Aeolus satellite mission)

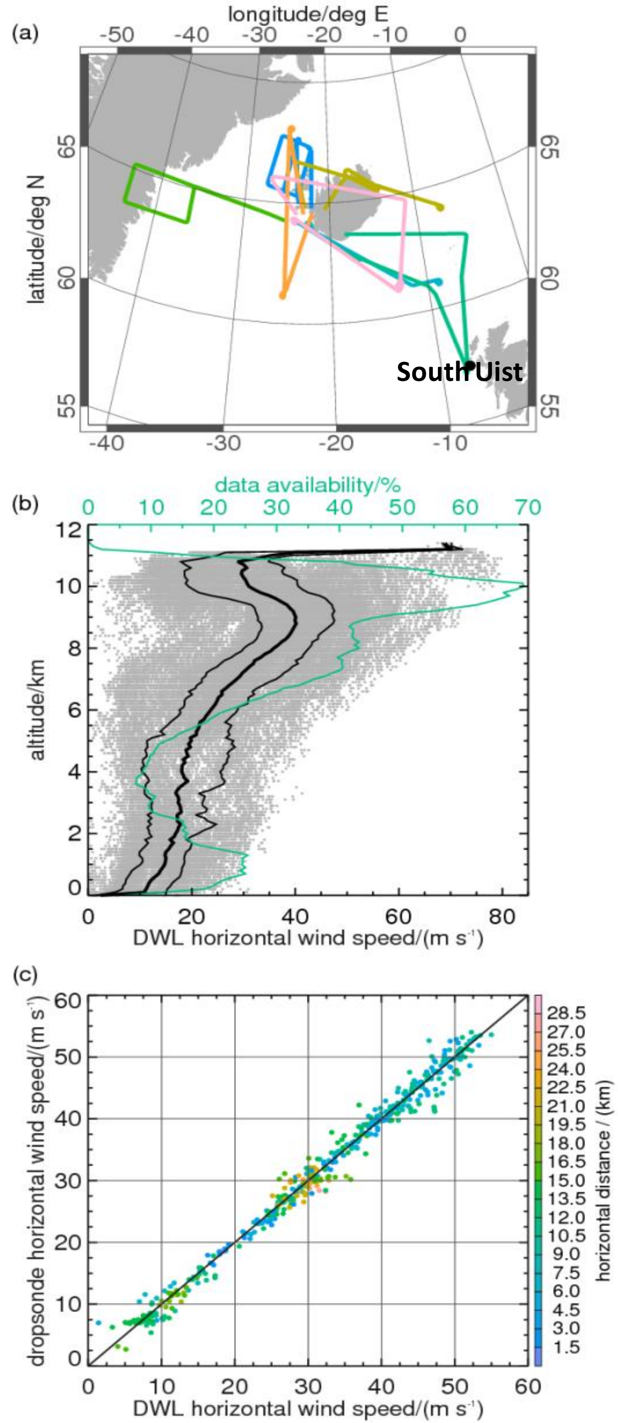
Wind observations during NAWDEX

Airborne observations of horizontal wind :

- 2-µm Doppler wind lidar (DWL) + in-situ and dropsonde (DSO) winds: **1885 profiles** (59443 wind vector observations) during **8 flights**
- max. in data availability at high wind speeds (8 -10 km)
- mean profile distance (depends on the speed of the aircraft) is ~**8.6 km**, vertical resolution **100m**
- winds up to 80 m s^{-1} were sampled → highest wind speeds that were observed by the DWL
- comparison of 420 DWL and DSO winds
  → good agreement: mean bias of 0.12 m s^{-1} and standard deviation is 1.58 m s^{-1}

Ground-based observations

- Wind profiler at South Uist, Scotland,
- Used wind profiles every 6h to match with analysis times



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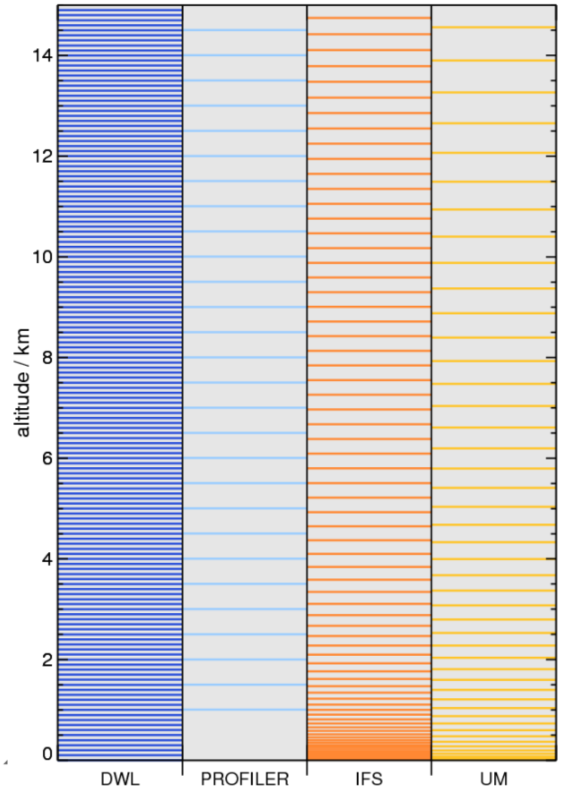
NWP Data

ECMWF:

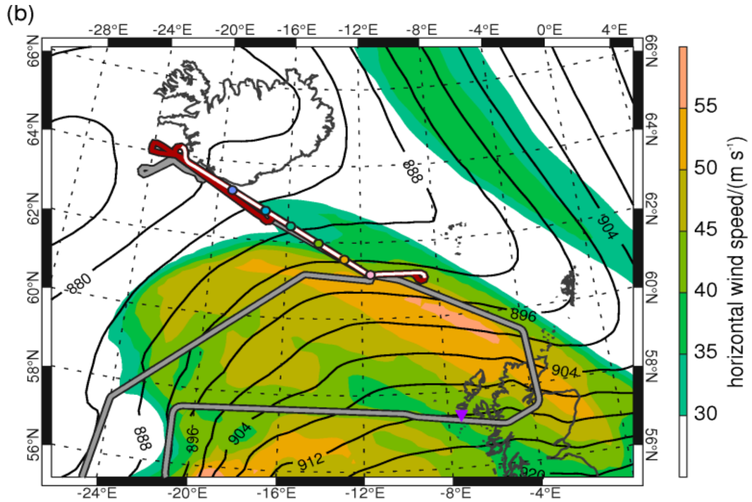
- IFS operational HRES AN and FC fields (cycle 41r2) with TCo1280 horizontal resolution
- interpolated to a Gaussian grid with a 0.125°/0.125° resolution (16 km), 137 ML
- 6-h AN fields (00, 06, 12 18 UTC) and 1-hourly FC initialized from 00 and 12 UTC

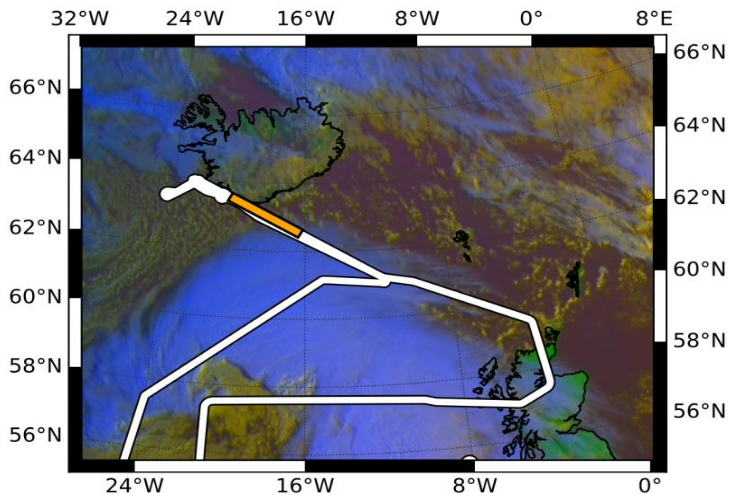
Met Office: Unified Model (UM) N768 (~17km) and 70 vertical levels, 6-h analysis fields (00, 06, 12 18 UTC) and 1-hourly FC initialized from 00, 06, 12 and 18 UTC



- **DSO/Profiler data** from HALO and SAFIRE aircraft were sent to GTS and **assimilated at ECMWF and Met Office**
- comparisons between obs and NWP performed at the vertical resolution of the DWL (100 m)
- between 8-14 km (across TP):
  - UM: 11 ML with a vert. separation of Δz ≈ 550 m
  - IFS: 19 ML, Δz ≈ 300 m
  - Wind Profiler Δz = 500 m

Case Study: Cyclone Vladiana (IOP 3)





- Cyclone Vladiana observed on 23 September 2013: (details were shown in Annika’s talk)
- DLR Falcon (0710–1020 UTC) and HALO (0736–1636 UTC)
- coordinated leg with HALO performing collocated dropsonde observations
- aircraft were separated by only 50 km horizontal distance
- sampling of jet stream winds in the upper-level outflow of the WCB
- relatively close to the wind profiler in South Uist, Scotland

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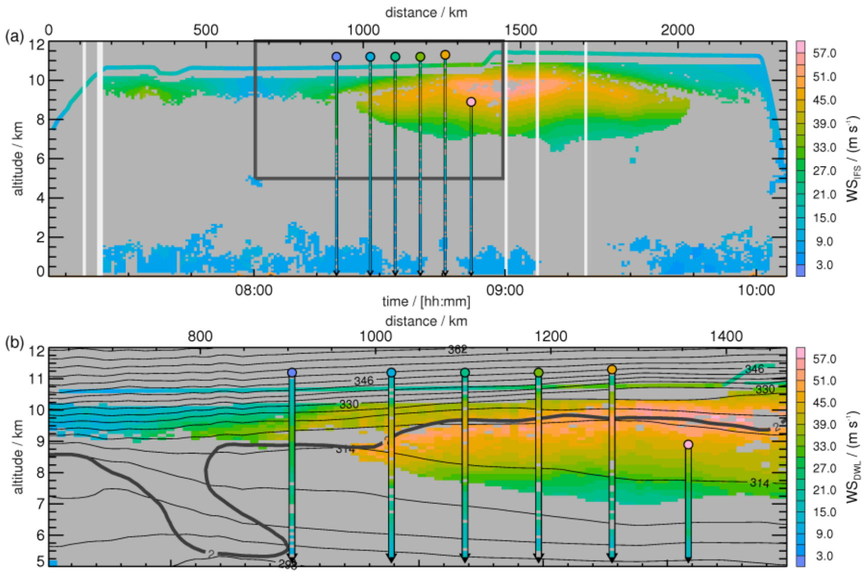
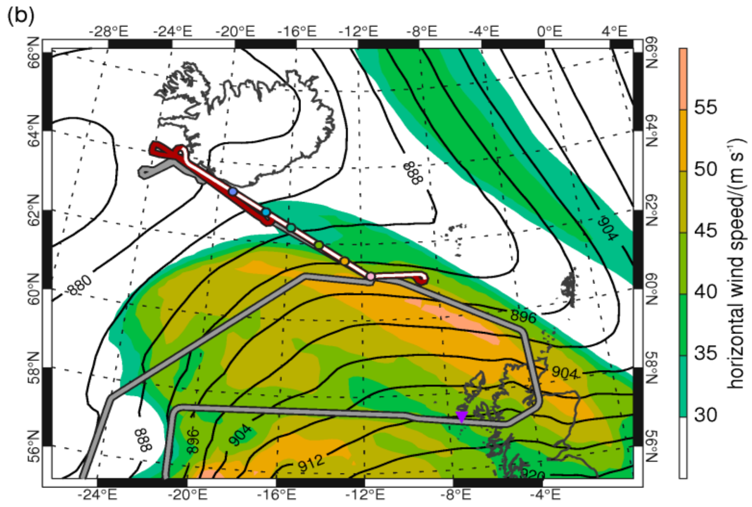
Case Study: Cyclone Vladiana (IOP 3)

Wind observations

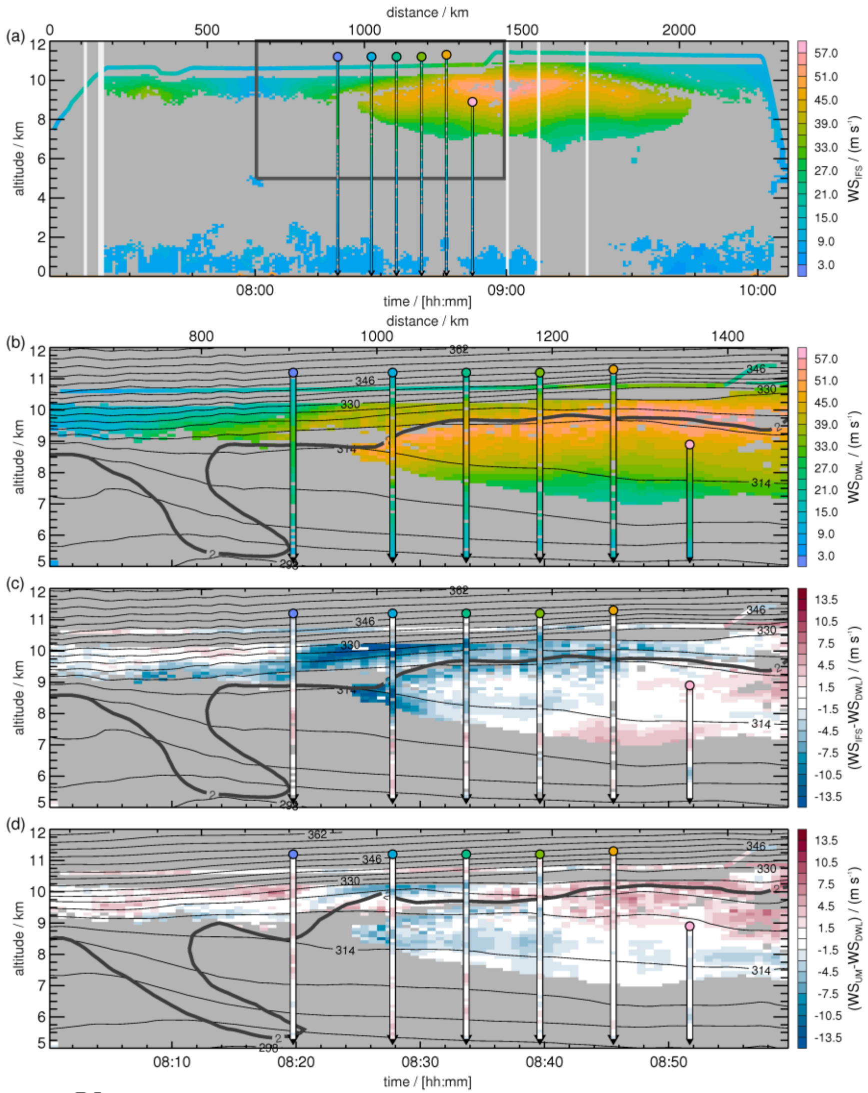


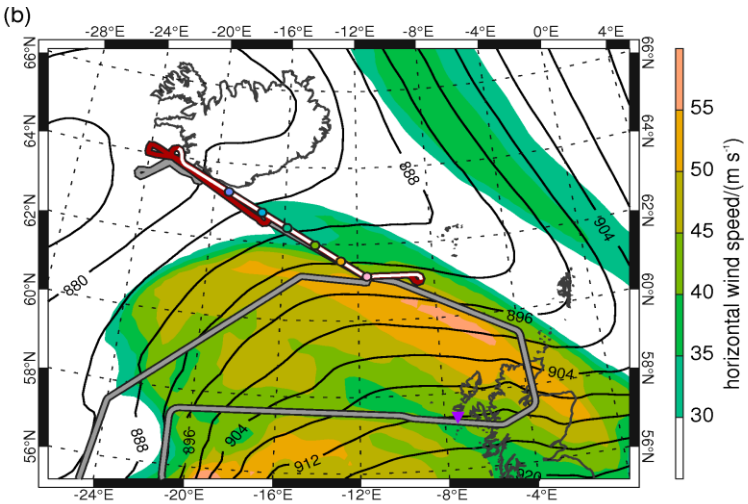


- low data coverage in clean and dry air
- data coverage and the observed wind speeds (up to 57 m s^{-1}) increase in the upper-level cirrus
- dropsonde winds show that DWL captured the whole vertical extent of the jet stream
- fold like structure results from ascending WCB air masses

Case Study: Cyclone Vladiana (IOP 3)

Differences NWP-OBS





- coherent areas of increased differences above and below the tropopause
- consistent difference fields for DWL, in-situ and dropsondes → underlines the reliability of the result
- the IFS and UM differences differ substantially but most negative differences occur at the same location

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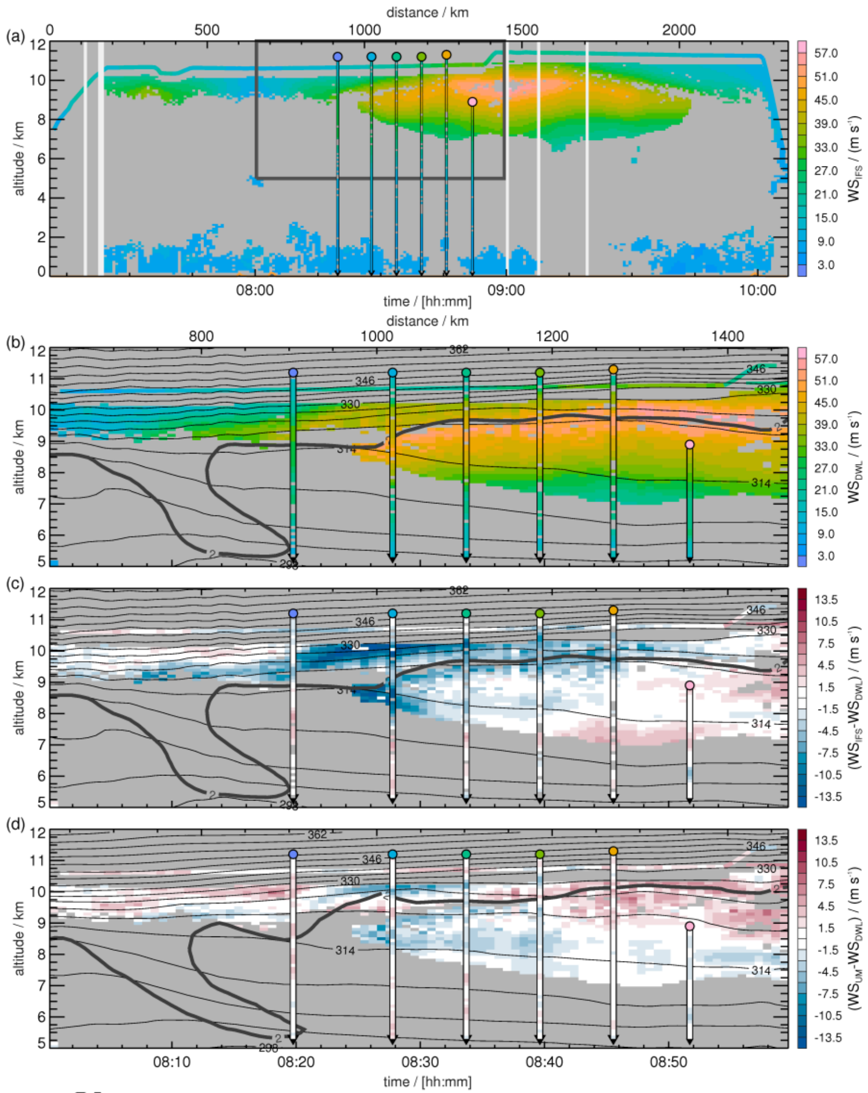
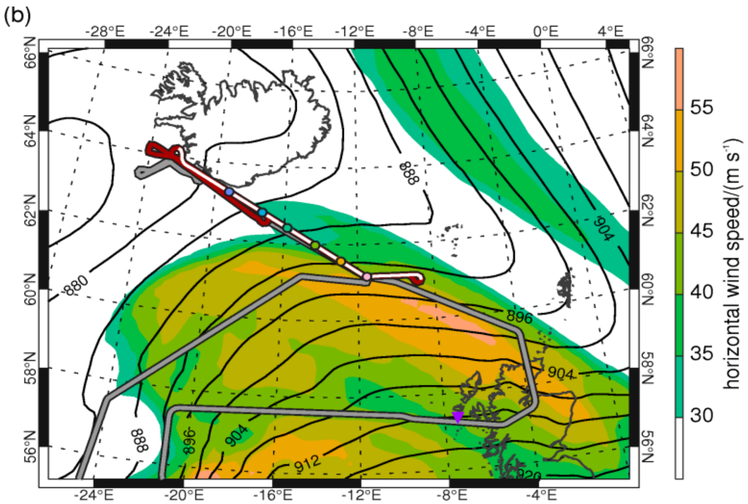
Case Study: Cyclone Vladiana (IOP 3)

Differences NWP-OBS





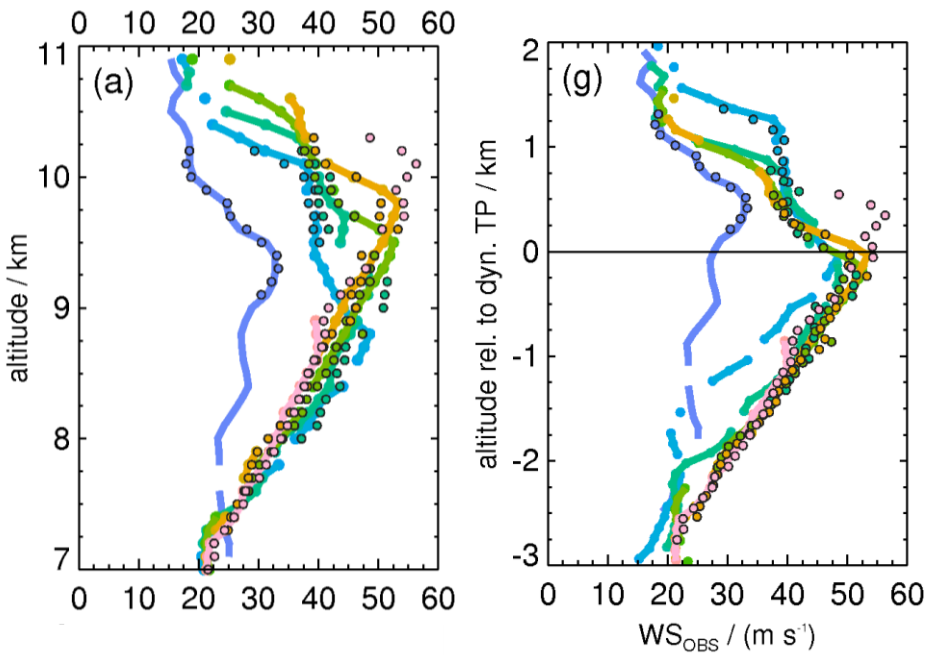
- IFS and UM tropopause altitude is different at the leading edge of the WCB outflow
  → influence of a correct representation of the tropopause altitude

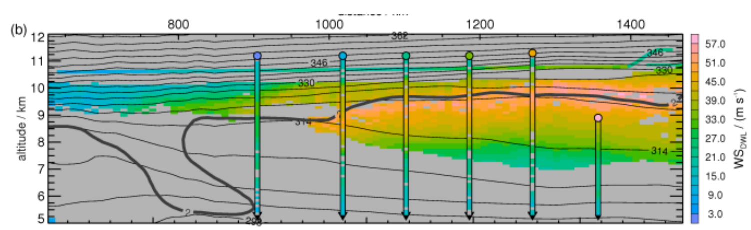
  → however, a simple vertical shift would show up as a dipole-like structure in the difference field

Case Study: Cyclone Vladiana (IOP 3)

Tropopause-relative profile comparisons

- DWL and dropsonde winds match well for the six profiles
- high variability in tropopause altitude and the height of the wind maximum along the flight (and between cases)
  → analysis of wind speeds and differences with respect to their vertical distance to the dynamical tropopause
- In tropopause-relative coordinates wind profiles nicely collapse on each other





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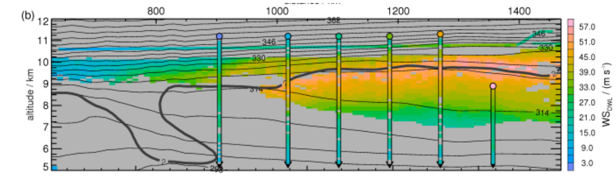
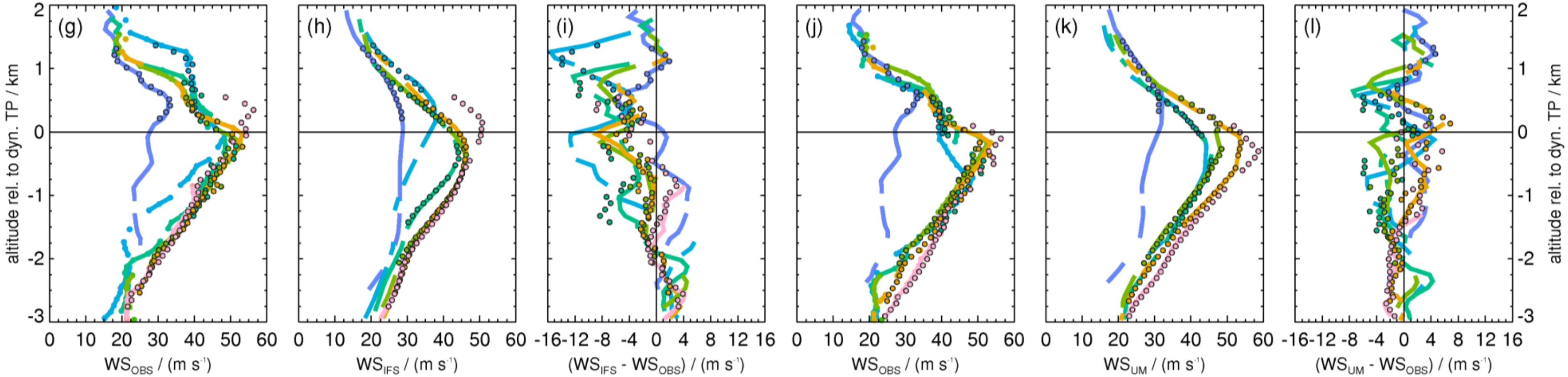
Case Study: Cyclone Vladiana (IOP 3)

Tropopause-relative profile comparisons





IFS:

- strength of the wind maximum and the vertical gradients are underestimated
- step-like reduction in wind speed at ~10 km altitude is not represented

UM:

- more realistic representation of the peak wind speeds
- strong vertical gradients and step-like wind speed decrease is not represented correctly

- Differences are result of a complex interplay of uncertainties related to the wind speed (maximum) representation, the strength of vertical wind gradients and a misrepresentation of complex vertical wind structure and uncertainty in tropopause altitude

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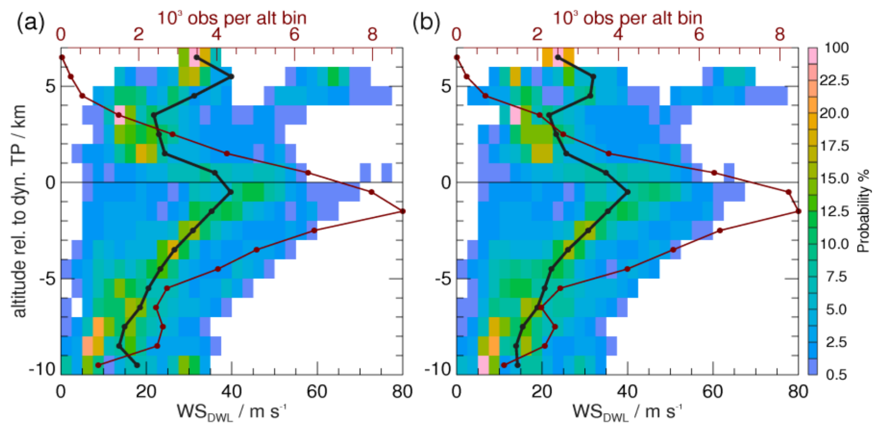
Campaign statistics

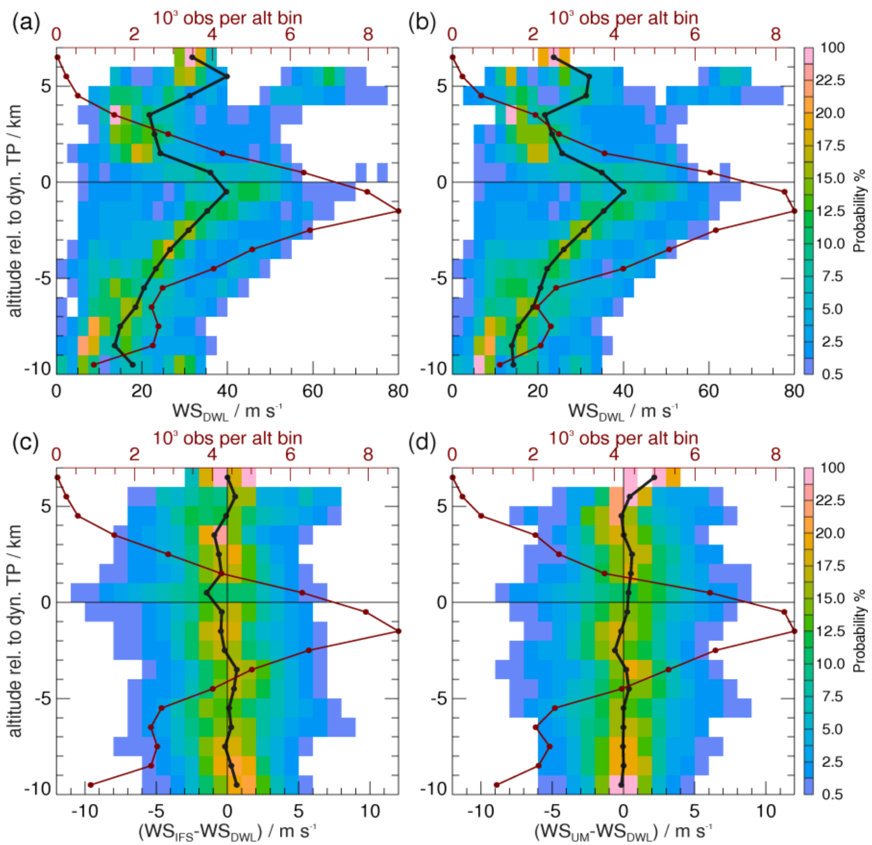
Frequency distributions for all lidar data



- highest average winds peak around the tropopause (maximum average wind of ~40 m s^{-1})
- Highest number of observations around the tropopause

Campaign statistics

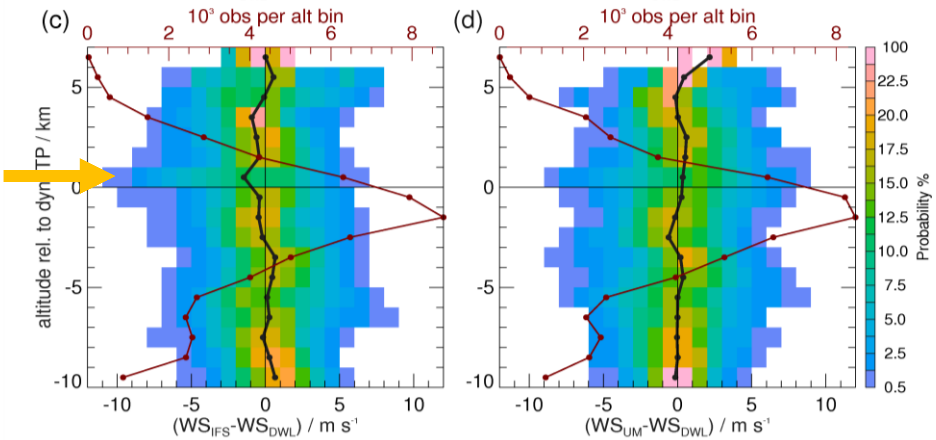
Frequency distributions for all lidar data

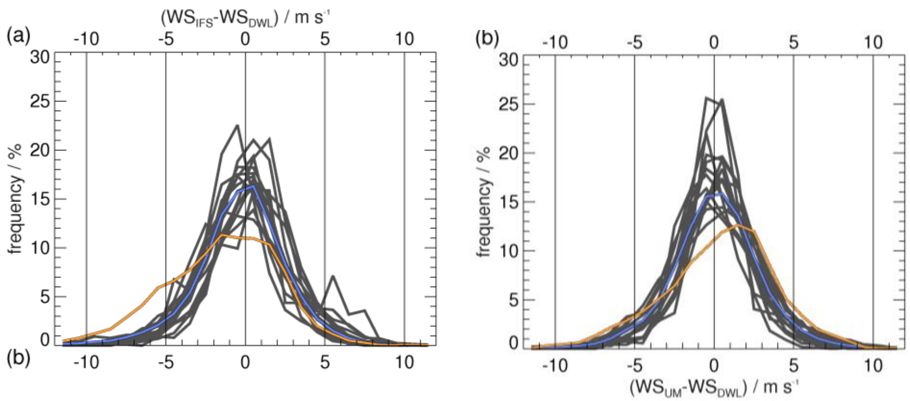


- mean bias of the models is small:
  - -0.27 m s^{-1} for the IFS
  - 0.09 m s^{-1} for the UM
- biases are small in all height bins
  - -1.46 m s^{-1} to 0.66 m s^{-1} for the IFS
  - -0.59 m s^{-1} to 0.60 m s^{-1} for the UM
- highest variability in the differences in the altitude bin directly above the tropopause in both models
  → increased uncertainty in the representation of the wind fields

Campaign statistics

Frequency distributions for all lidar data



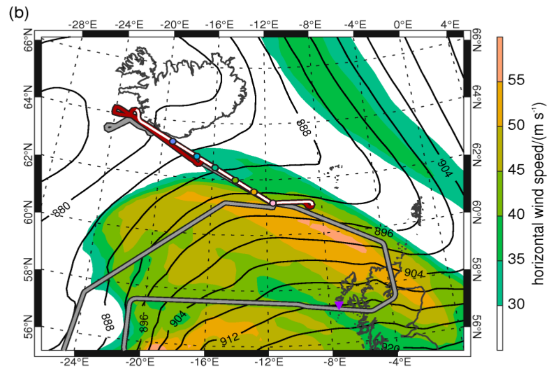


Standard deviation (Layer on top of TP/MEAN)

- IFS: 3.52 m s^{-1} / 2.85 m s^{-1}
- UM: 3.49 m s^{-1} / 2.82 m s^{-1}

Campaign statistics

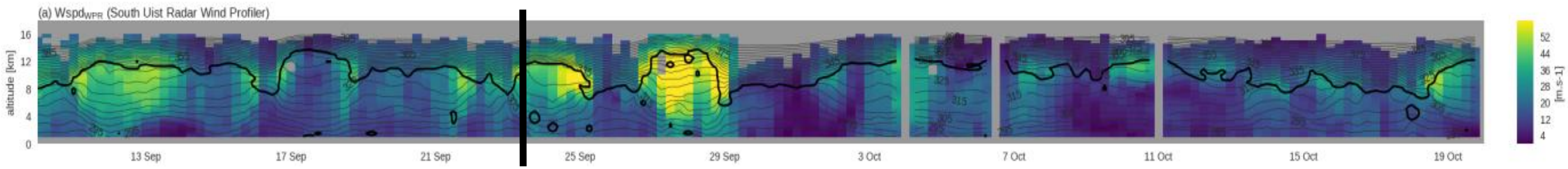
South Uist wind profiler



Observed winds

Case Study
Vladiana

figs/plot_winds/TS_03023_006.png



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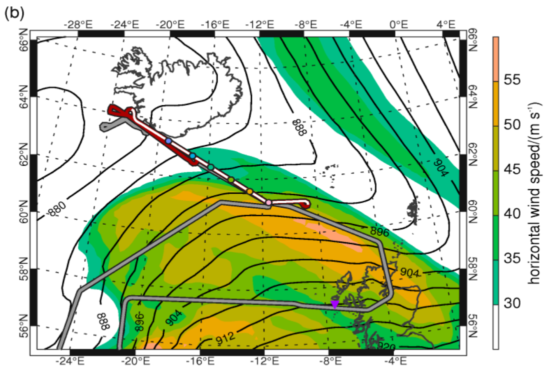
Campaign statistics

South Uist wind profiler



Observed winds

Case Study
Vladiana

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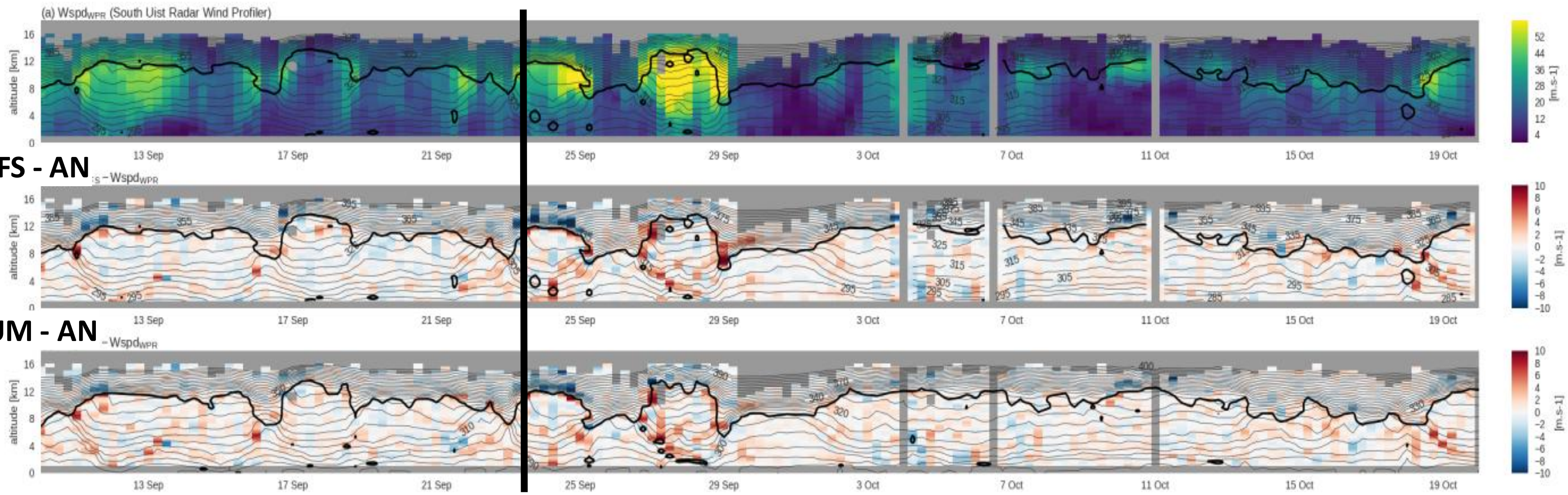

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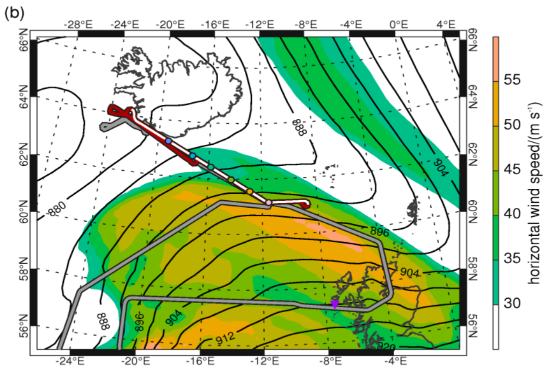
Campaign statistics

South Uist wind profiler



figs/plot_winds/TS_03023_006.png

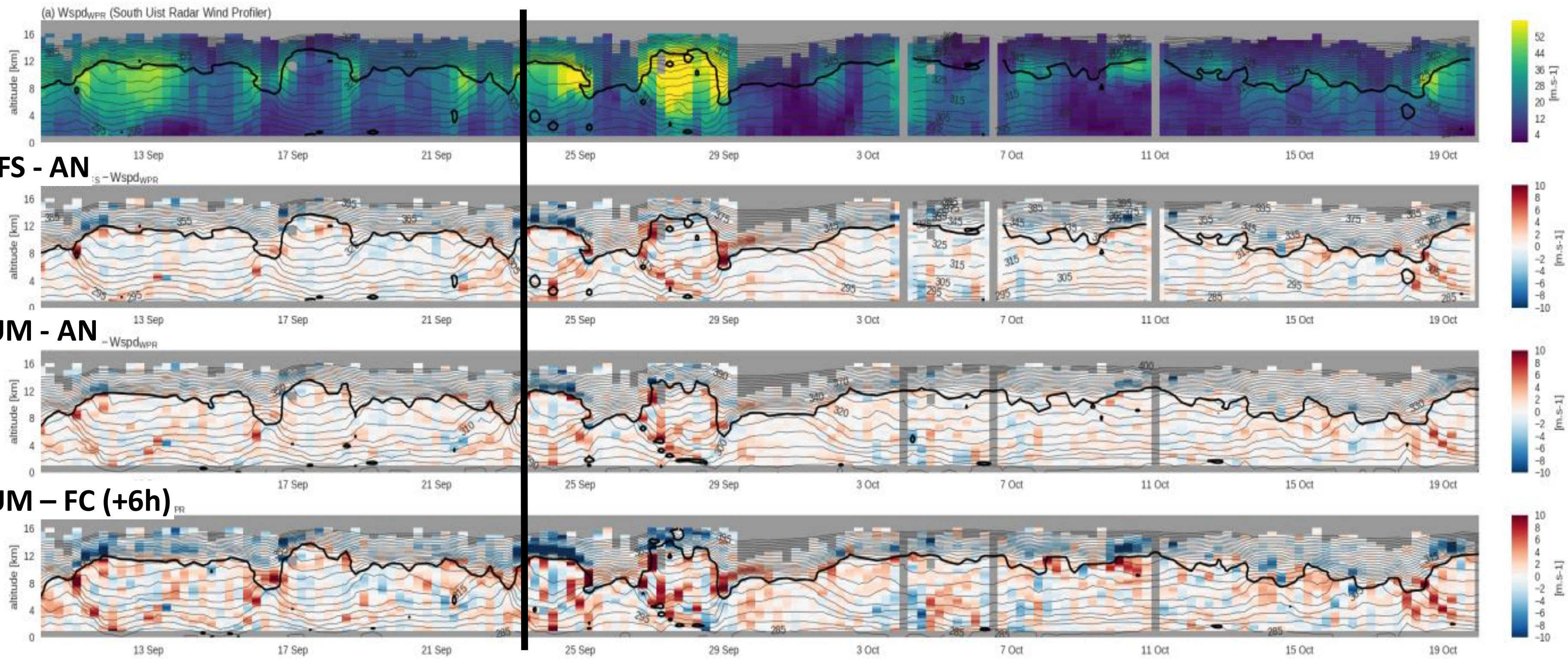
Case Study
Vladiana

Observed winds

IFS - AN

UM - AN

UM – FC (+6h)



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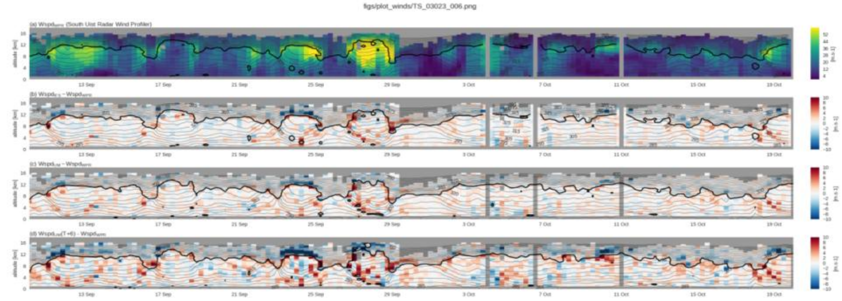
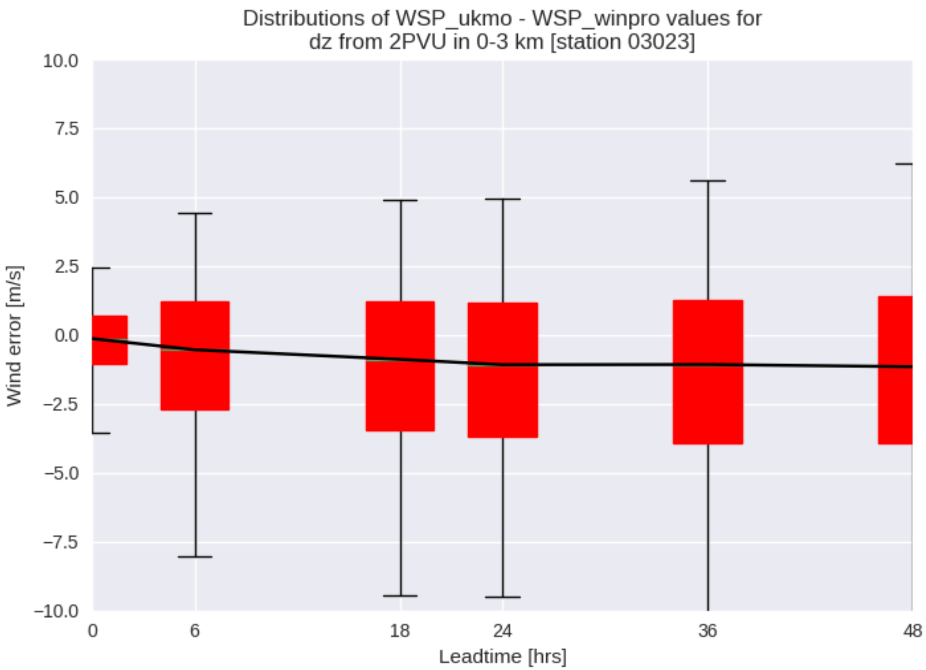
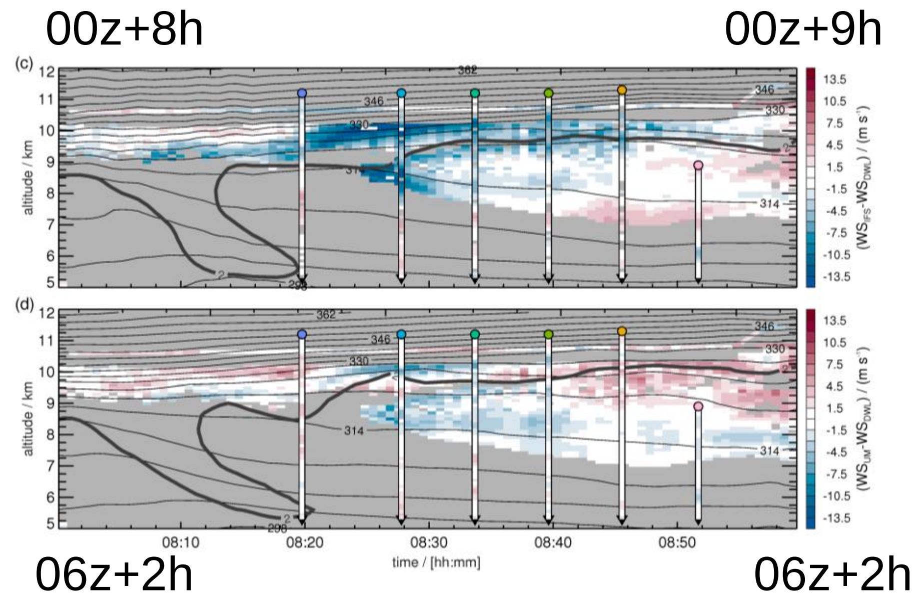
Campaign statistics







Conclusion

General

- NAWDEX Wind observations offered an **unprecedented data set to validate** the representation of jet stream winds across the tropopause in **two independent NWP models**
- DWL **data is independent** (not assimilated) data set offers required horizontally vertically resolved wind profiles
- Comparison of dropsondes and DWL wind profiles has **proven the accuracy demands** for model validation studies.

Case study

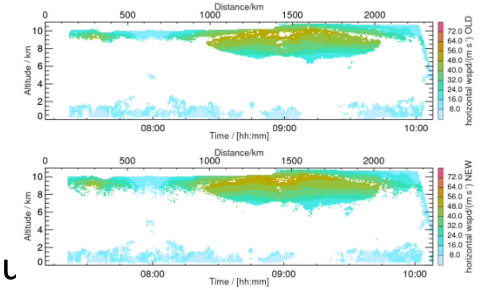
- Differences between of UM and IFS and observations show **consistent errors** when using **DWL**, **dropsondes and in-situ observations** which underlines the reliability of these results
- Diagnosed **coherent, large error structures** with increased differences at the tropopause for all three data types
- Complexity of the difference fields and the inter-model differences are a consequence of **complex interplay of uncertainties** related to the wind speed (maximum) representation, the strength of vertical wind gradients and a misrepresentation of complex vertical wind structure and uncertainty in tropopause altitude.

Summary

Statistical comparison

- The considerable improvement in the representations of the wind field during the last years is visible from **low mean differences**
- But, even **nowadays** wind errors reach values **up to $\pm$10 m s^{-1}** and those errors occur in extended areas around the jet stream.
- **increased uncertainty** in analyses and short-forecasts was found in the range bin **directly above the tropopause** (could be confirmed by WindVAL observations in 2015 over the NA in low wind situations)
- despite the differences in the data assimilation systems the results in terms of winds and **differences in UKMO and IFS look pretty similar**.
- Comparison with South Uist wind profiler has confirmed that **analysis errors are increased in situations of elevated tropopauses** related to ridges downstream of cyclones providing particularly strong wind gradients
- a comparison of the observations with FC data indicates a **systematic short-term forecast error** to represent winds correctly (resolution issue?)
- **data assimilation** of dropsonde data pushes **background fc towards the observations** (but maybe not enough)

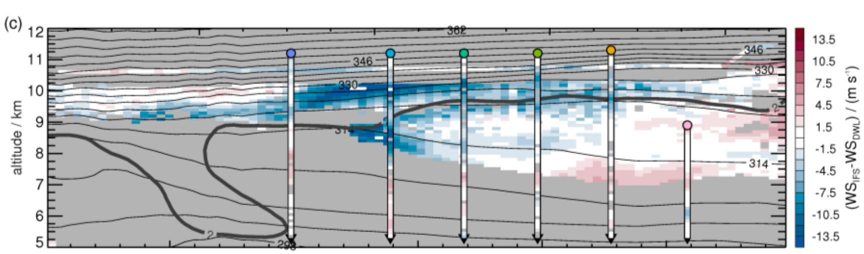
Outlook

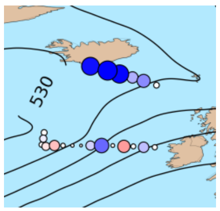


- Repeat all figures with improved DLW data set
- In earlier cases we observed high uncertainty of moisture at the tropopau
  → *Use NAWDEX dropsonde, radiosonde and WALES DIAL observations to quantify moisture errors and how they relate to wind/temperature errors*
- Investigate how the observations are able to modify tropopause sharpness in the model
  - Schindler et al. (2019) demonstrated an overall positive impact of additional radiosonde and dropsonde observations on the mid-tropospheric flow
  - Pilch Kedzierski et al. (2016) show a sharpening effect without looking at individual cases and individual parameters

→ *investigate effect of NAWDEX data on tropopause structure based on output of ECMWF's data assimilation system and sensitivity experiments*

→ *test how well the uncertainties in the ensemble of analyses cover the magnitude of the diagnosed errors*

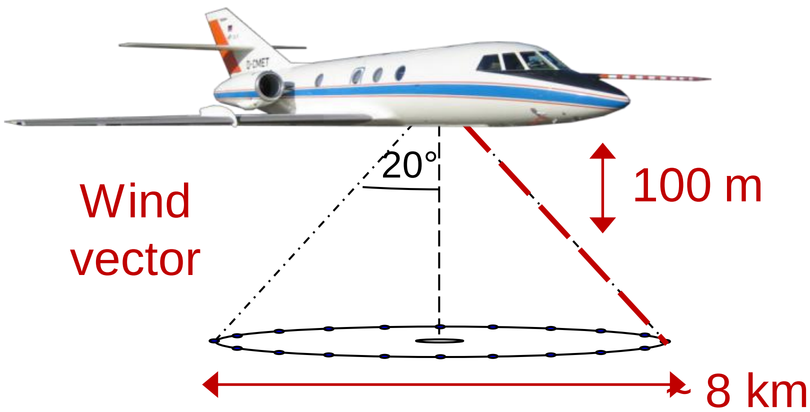




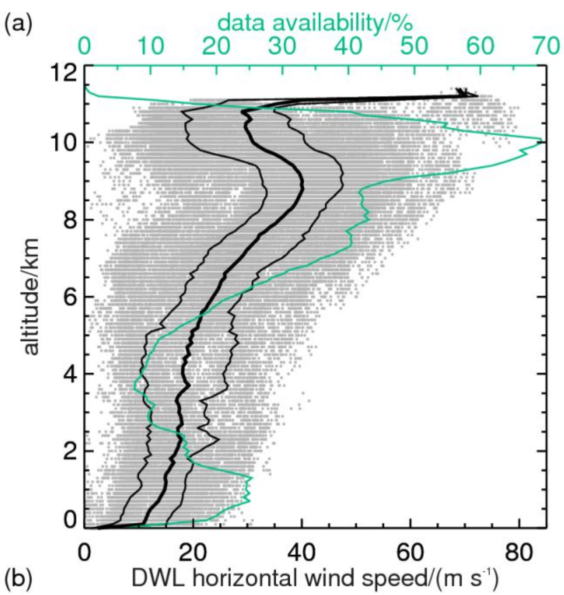
Selected highlights

Jet stream winds in NWP analyses during NAWDEX

Observations of winds with the 2 micron wind lidar onboard the German Falcon



- Scanning Doppler Windlidar: detects frequency shift between the emitted and received signals (2022 nm), which is proportional to the LOS wind velocity
- number of LOS measurements → three dimensional wind vector
- Random error: ~ 1 m/s, ~3.6°, Systematic error: < 0.3 m/s



- 1885 profiles from 7 flights
- 58657 observation points
- 8.5 km (42 s) horizontal resolution
- 100 m vertical resolution
- 26% data availability
- maximum data availability in 10 km at highest wind speeds and strong vertical gradients

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