# Wind Lidar Observations in the Lee of Greenland

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## Introduction

The Greenland tip jet is a narrow, low-level jet periodically developing in the lee of Cape Farewell. It has recently been identified as an important mesoscale meteorological element driving the thermohaline circulation in the Atlantic Ocean. Due to the heat loss by the enhanced turbulent transport over the sea the sporadically occurring "corner wind" initiates the deep sea convection in the Irminger Sea (Pickart et al. 2003). This area is considered to be an additional source of deep sea water (so called Labrador Sea Water) and the subject is strongly discussed among oceanographers (Dickson 2003). Doyle and Shapiro (1999) investigated the Greenland tip jet by means of real case and idealized model simulations. They explored the flow response to large-scale topography which is particularly difficult to predict (Ólafsson, 1998, Schär 2002).

Flow over and around Greenland is affected by the large and very steep elevation change between the ocean and the central plateau of about 3000 m, the roughness of the jagged mountains around the coastline, and the predominant katabatic flows from the plateau down the coast. Greenland may influence the atmospheric flow several thousand kilometers downstream (Scorer 1988). Vertically, the flow past Greenland induces disturbances up to stratospheric altitudes (e. g. Leutbecher and Volkert 2000).

Most of the recent papers study the influence of Greenland's topography on the impinging westerly flow and the lee cyclogenesis by numerical simulations (e.g. Kristjánsson and McInnes, 1999 Schwierz and Davis, 2003, Petersen et al. 2003). Observations of the flow field in the lee of Greenland are rare. Here, we present airborne Doppler wind lidar and dropsonde observations of a tip jet event on 24 November 2003. The observations took place during the Atlantic THORPEX Regional Campaign (ATReC), which was conducted from October to December 2003 under the lead of EUCOS with participation of NOAA, NCAR, UCAR, NASA, NRL, DLR, and Environment Canada. During that time the DLR research aircraft Falcon was based in Keflavik, Iceland. The goal of the DLR participation was to deliver targeted dropsonde and wind lidar observations.

## Instruments

Standard Väisälä GPS dropwindesondes RD93 with PTU sensors were used. Their vertical resolution amounts to 10 m and the accuracy of horizontal wind measurement is ± 0.5 m/s. Additional wind observations were performed with the DLR 2µm Doppler wind lidar system. A wedge-scanner provides a conical step-and stare scan around the vertical axis with 20° half cone angle. The stare time is 1 or 2 s, thus, 500 or 1000 shots are accumulated per position (see paper 7.1). The profiles of the horizontal wind were calculated with the velocity azimuth display technique (Browning and Wexler 1968) for one and four scanner revolutions. The resulting wind profiles have a horizontal resolution between 5 and 40 km.

A sine-fit algorithm and the MFAS algorithm (maximum of the function of accumulated spectra, Smalikho 2003) were used. Then the horizontal wind speed (u and v-component) was compared to 35 dropsonde profiles from the ATReC. The resulting bias was 0.1 m/s for the MFAS algorithm, and 0.2 m/s for the sine-fit algorithm. The standard deviation of lidar measurements was 0.5 - 1.5 m/s and is correlated with the quality indices of the two algorithms (the percentage of line-of-sight-values which can be used for the calculation of the horizontal wind).

## Observations

Figure 1 depicts the horizontal locations of the vertical profiles of the wind observations by the lidar along the flight path from Iceland toward the west, then toward the south and on the final northbound back to Keflavik. The positions are given for one and four scanner revolution averages, respectively. The flight path was chosen to maximize the aircraft endurance at FL 200 (approximately 6 km altitude). Due to strong surface winds and the turbulent mixing, the lower troposphere was loaded with sea salt aerosols. On the other hand, the MODIS imagery illustrates that the Irminger Sea east of Greenland was partly covered by cumulus clouds formed by convection in the cold air flowing over the warm sea surface (Fig. 1). There are only two extended cloud free regions. The one directly downwind of Cape Farewell is produced by the strong surface winds of ~35 m/s in the tip jet region.

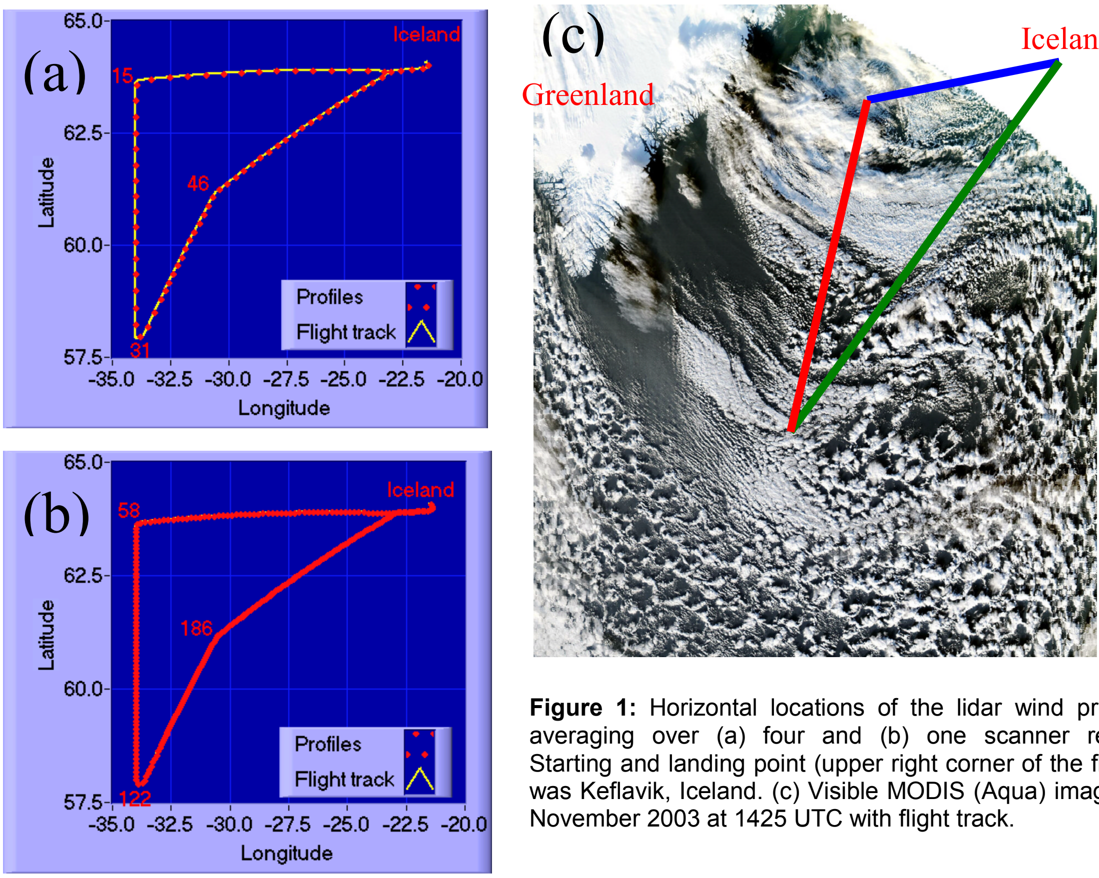


**Figure 1:** Horizontal locations of the lidar wind profiles with averaging over (a) four and (b) one scanner revolutions. Starting and landing point (upper right corner of the flight track) was Keflavik, Iceland. (c) Visible MODIS (Aqua) imagery on 24 November 2003 at 1425 UTC with flight track.

Further downstream, where the wind is deceased cloud streets and convective cells are formed. Further north of the tip jet, tropospheric gravity wave breaking along Greenland's east coast and the associated adiabatic warming of the descending air masses prevent cloud formation. However, cloud form fairly quickly over the sea when the flow propagates further downstream.

Figure 2 presents the airborne lidar observations of the horizontal wind speed averaged over one and four scanner revolutions, respectively. Missing data points are kept black. These missing values are either due to the extinction of the laser pulse in clouds, or to very clear air without backscattering aerosols. The lidar observations reveal three dominant wind systems in the lee of Greenland:

(1) after a segment of weak south/southwesterly winds in the first part of the flight, a wind maximum is seen between profile #58 and #80 in Fig. 2a; strongest winds of up to 30m/s were measured at ~1000 m MSL; above this maximum the wind speed decreases with height. The whole jet extends up to ~ 4000 m altitude; on the northbound leg the same wind system has been sampled between profiles #230 and #260, however, the horizontal wind speed is weaker and the jet spreads over a wider horizontal range; we will call this jet katabatic jet as will be discussed below

(2) the Greenland tip jet itself could only be sampled by a couple of profiles around profile #121; unfortunately, cloud streets of cumulus with cloud tops between 2000 and 3000 m altitude blocked the laser beam. However, it was possible to retrieve at least one reliable profile with a maximum of 42 m/s at the surface and at about 1000 m altitude (Fig.3).

(3) south of the katabatic jet and north of the tip jet, the lidar observations reveal a region of variable wind speeds; we loosely refer to this region as turbulent wake. It extends from profile #85 to #118 on the southbound and from profile #128 to #190 on the northbound in Fig. 2a. Below ~2500 m altitude the wind speed ranges from 15 to 25 m/s. The wind is strongest in a few narrow (~40 km wide) bands (compare the four scanner revolution averages in Fig 2c). Above this wake region, there exist a pronounced wind minimum between 2500 and 3500 m (profiles #83...87 and #180...210). Most remarkable, there is a jet with a maximum wind speed of ~30 m/s sitting on the top of wake region; the dominating wind direction in this area is west although exceptions occur in the turbulent wake.

Figure 4 shows the simulated wind and temperature field at 925 hPa. The numerical simulations are performed with the NCAR/PSU mesoscale model MM5. Three domains with 30 km, 10 km, and 3.33 km horizontal resolutions have been used. Altogether 173 vertical levels cover the vertical extent up to 10 hPa. The vertical grid spacing is ~100 m up to 3000 m altitude and ~200 m above. The simulations predict the locations of the observed jets fairly well. Cold temperatures of 262 K are associated with the tip jet. The katabatic jet is located directly at the air mass boundary of cold air in the north and the much warmer air (~275 K) in the turbulent wake of Greenland.

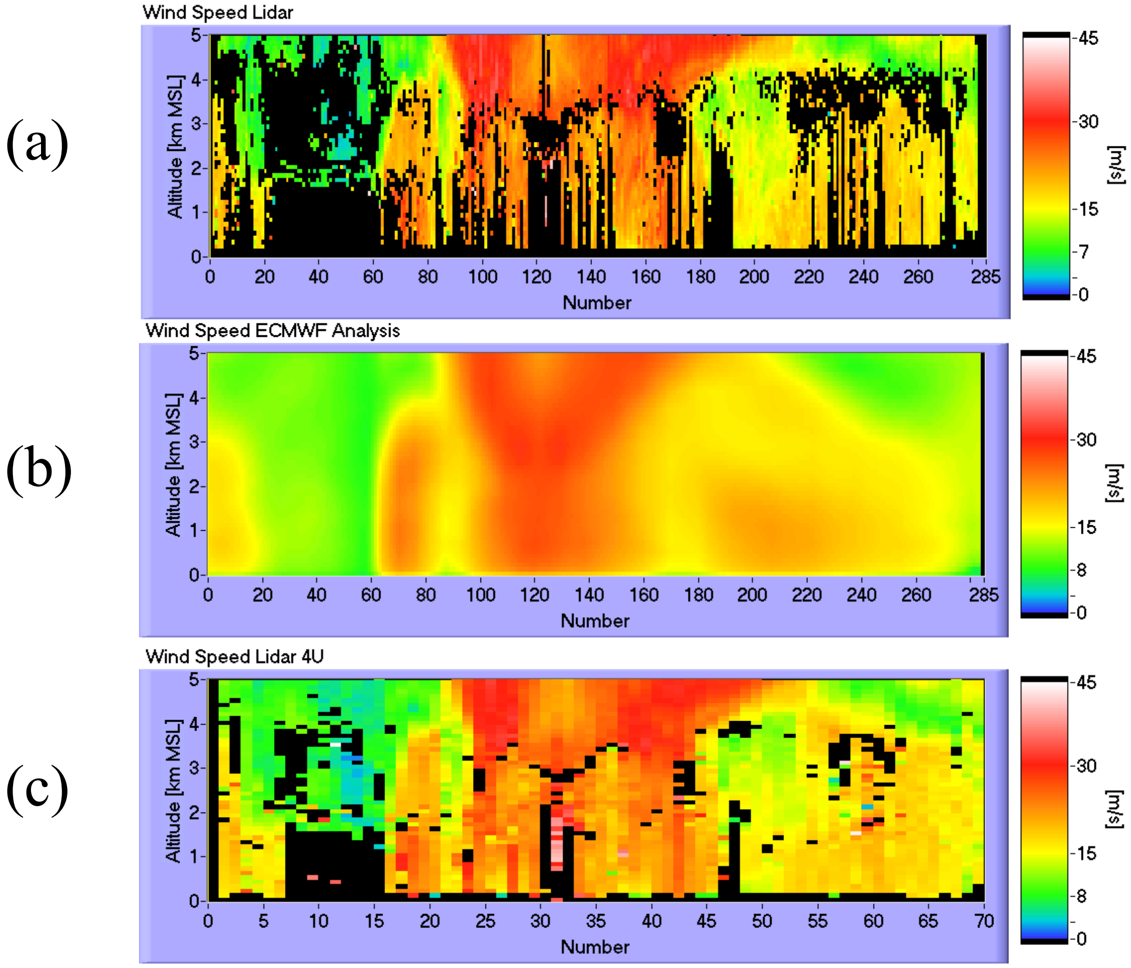


**Figure 2:** Vertical profiles of the horizontal wind speed (m/s) along the flight track as shown in Fig.1. Wind profiles derived from one (a) and four scanner revolutions (b), respectively. (c) ECMWF operational T511/L60 analyses interpolated in time and space onto the flight legs.

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Furthermore the mesoscale simulations show:

- on the upwind westerly side the flow is partly blocked and develops into a well defined wind-jet propagating parallel to the coastline and speeding up markedly in the tip jet region; the air flow separates at the southern tip of Greenland where there is a sharp change in the direction of the coastline,
- there are sharp horizontal velocity gradients along the edges of the wake region and parallel to the coastline with highest velocities in the wind-jets,
- katabatic wind blows over Greenlands ice sheet, predominantly in an easterly/south-easterly direction, which is channeled into the katabatic jet
- very strong northerly winds are generated west of the Icelandic Low (>40 m/s) which appear in Fig. 4 as barrier jet propagating south parallel to the coastline
- as the flow continues downwind of Greenland, its velocity decreases gradually down to about 15 m/s over a distance of about 1000 km.

The ECMWF T511/L60 operational analyses interpolated onto the flight path reproduce the observed wind structure rather well (Fig. 2b). However, there are significant differences (up to 12 m/s) of the observed and analyzed wind. For instance, the jet on top of the wake region is about 10 m/s weaker in the analysis.

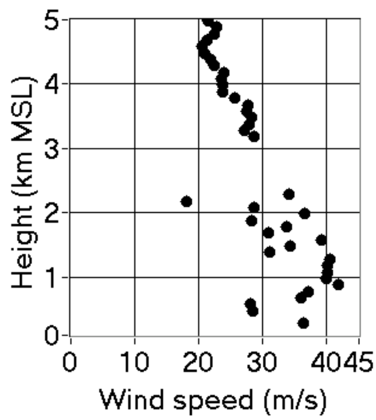


**Figure 3:** Vertical profile of lidar wind speed at the southern tip of the flight (#123)..

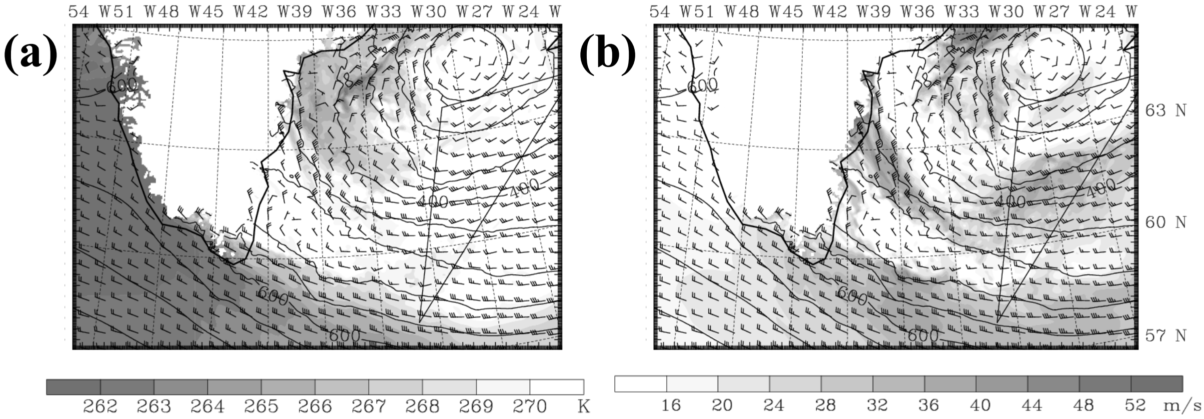


**Figure 4: (a)** Temperature (shaded, K) and **(b)** wind speed (shaded, m/s) at 925 hPa valid at 24 November 2003 1300 UTC. Superimposed are wind vectors (a half barb represents 5 m/s and a full barb 10 m/s). Results of the mesoscale numerical simulation from the innermost domain with 3.33 km horizontal resolution. The straight solid lines are the flight track of the DLR Falcon.

#### Concluding Remarks

For the first time an airborne wind lidar was used for targeted observations during ATReC. The 2µm Doppler wind lidar system proofed to be capable to measure wind profiles with a horizontal resolution of 10 km in clear air and partly cloudy conditions. After a statistical comparison of the lidar and dropsonde data, an individual standard deviation could be assigned to every lidar wind measurement.

The lidar data of 24 November 2003 (280 wind profiles) provide a new insight into the complex structure of the Greenland tip jet event with two different branches of low level jets, a turbulent wake in between, and a vertically extended jet close to the southern tip of Greenland. MM5 mesoscale model calculations simulate a turbulent wake as produced by gravity wave breaking, by turbulent convection as well as by horizontal mixing due to the strong meridional shear. Further studies will compare the observed wind data with ECMWF analyses and MM5 simulations. European weather centers will be using the wind lidar data for sensitivity experiments to investigate the impact of targeted observations on the forecast skill in the framework of THORPEX (http://www.wmo.int/thorpex).

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