670 AIRBORNE DOPPLER WIND LIDAR MISSIONS IN THE ARCTIC: LOW LEVEL OBSERVATIONS AND COMPARISON WITH MODELS AND OTHER OBSERVING PLATFORMS

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1. INTRODUCTION

During Oct-Nov 2014 and May 2015, NASA sponsored two airborne missions designed to fly the Doppler Aerosol WiNd (DAWN) lidar to take wind measurements of the Arctic atmosphere, specifically over and off the coasts of Greenland. Campaign I was based in Kangerlussuaq, Greenland and flew DAWN on board the NASA King Air UC-12B aircraft while Campaign II was based in Keflavik, Iceland and utilized the NASA DC-8 aircraft to fly DAWN and Dropsondes over the Arctic.

Both Campaigns were designed to look at atmospheric circulations such as the Greenland Tip Jet, Barrier winds off the east coast of Greenland, katabatic flows near the coast lines and low level circulations over transitional ice zones and the Ice cap; as well as to practice underflying and validating measurements from existing satellites and sensors such as CALIPSO, MODIS (AQUA and TERRA), ASCAT (METOP-A/B) and others. In addition, much of Campaign II was planned in collaboration with ESA and DLR of Germany to conduct coordinated (with the DLR Falcon) underflights of a simulated Aeolus ADM (due to be launched in 2017) and using ADM scanning strategies to take measurements (lidar and Dropsondes) that would benefit future development planning and cal/val of ADM Aeolus.

This paper will focus mainly on the polar science objectives mentioned above and an overview of the measurements taken during Campaign II.

2. INSTRUMENTS AND WIND MEASUREMENTS

The focus instrument for the wind measurements over the Arctic was an airborne lidar. The lidar selected for both Campaigns I and II was DAWN, the most powerful airborne Doppler Wind Lidar available today. (Figures 1 and 2). The DAWN system parameters are given in Table 1 along with those of other existing airborne Doppler Wind Lidars. The DAWN has been flown on the NASA DC-8 during the 2010 Genesis and Rapid Intensification Processes (GRIP) campaign and on the NASA C-12 for wind field characterization off the coast of Virginia in support of future wind energy project design. While the laser and receiver portions of the system are fixed, the manner in which the laser beam is scanned can be altered to meet mission requirements. At this current time, only downward viewing is accommodated.

In additions to DAWN, we utilized the Dropsonde delivery system by Yankee Environmental Services to drop100 dropsondes during Campaign II in an attempt to get additional high-resolution vertical wind profiles during most missions. These dropsondes would also provide cal/validation for DAWN and for the numerical models. The Dropsonde Delivery system is shown on board the NASA DC-8 in Figure 3.

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3. NUMERICAL MODELING SUPPORT

Currently, the best source of routine wind data over the Arctic sea ice comes from reanalyses and model forecast data. Reanalyses data includes data sets such as ECMWF ERA-Interim, the NCEP CFSR reanalyses, or the new regional scale Arctic System Reanalysis (ASR). The ECMWF/NCEP data sets provide a reasonable characterization of the wind field over the Arctic at resolutions of up to 1/2 degree while the ASR provides the same on the mesoscale resolution of 10 km and 3 hours.

The WRF model (Skamarock et al., (2008)) and the Polar WRF (Bromwich et al., 2009; Hines et al., 2011) optimized for polar conditions by the Byrd Polar Research Center at OSU have also been used to investigate the low level circulations of the Arctic over various land surface type (ice sheet, water, land, transition zones) and provide "data" for reanalysis of the data-sparse arctic regions but mainly at horizontal grid scales greater than 10 km. The model run for this experiment was the WRF 3.6.1 with OSU BPRC polar optimizations (Polar WRF). Below are the main attributes of the model:

- 421 x 481 one-domain grid with 8 km spacing
- 48 terrain following layers: Lowest levels at 7 and 14 m; 9 layers at lowest 500 m; top at 10 hPA
- 40-sec time step; run with 20 tasks; 48-hr runs; output every 3 hrs.
- Radiative time step: every 30 min
- Morrison 2-moment microphysics
- RRTMG longwave and shortwave radiation
- Grell-3 cumulus parameterization
- MYJ Planetary boundary layer and surface boundary layer
- Noah Land surface model
- Fractional sea ice 1.5 m thick; albedo 0.82; 5 cm snow on sea ice

The domains of the model used during Campaign II is shown in Figure 4. The model was run twice a day at 00 & 12 UTC. The initial and boundary conditions are interpolated from the daily 00 and 12 UTC run of the Global Forecast System (GFS) issued by the National Centers for Environmental Prediction (NCEP).

4. SCIENCE OBJECTIVES AND MISSIONS

During Campaigns I and II, we conducted a series of Polar Winds science experiments including the measurement and analyses of lower tropospheric winds associated with:

- Boundary layer rolls and organized large eddies (OLEs)
- The Greenland Tip Jet
- Ice Cap and Katabatic flows
- Barrier Winds
- Circulation around the Icelandic land mass
- Transitional Ice zone

In addition, every mission was seen as a model validation experiment and we attempted to generate a data base of 3-D wind information from both DAWN and the Dropsondes to be used for validation of the Polar WRF model (described in section 3) run specifically for the campaign.

4.1 Campaign I Flights

During Campaign I, missions were flown over a variety of conditions and attempted to meet all the satellite underflight and arctic science objectives. A summary is given below:

- 14 flights on 13 days
- ~ 45.5 science flight hours
- 22 ADM simulation segments
- 3 CALIPSO segments
- ~ 10 MODIS segments
- 2 "Tip Jet" missions
- Numerous missions overflying the Ice Cap, the coastal waters and regions of rolls/waves.

4.2 Campaign II Flights

During Campaign II, we examined all the science objectives mentioned above including ADM simulations, satellite underflights, Upper level jets, Barrier winds, Tip Jets, katabatic flow near the coast, rolls/OLES, flow over transitional ice zones, and the circulations around and over Iceland. A breakdown of the individual flights is provided (Figure 5) along with a composite of all the flight tracks (Figure 6).

4.3 Case Study – Barrier Winds off The East Coast of Greenland

The region off the southern and central eastern coast of Greenland is an area noted for strong low-level Barrier winds as strong low pressure systems move eastward towards and past Iceland and the northerly/northeasterly flow is blocked and channeled by the Greenland land mas resulting in strong low level winds. May 15, 2015 was a prime example of this scenario as forecasted by the models (Polar WRF, ECMWF) and is shown in Figure 7 (Polar WRF). A mission was flown to gather high-resolution DAWN and Dropsonde wind data for this case and to compare against each other and the Polar WRF model. The satellite image and flight track/drop location is shown in Figure 8.

Some of the wind speed and wind direction comparisons made between the model and observed data for the May 21 case are shown (Figures 9-12). During 1940-1950 LT the DC-8 was flying at 6 km but clouds around 2 km prevented the DAWN signal from reaching down to the boundary layer and surface. Later, between 2020 and 2100, the DC-8 was flown around 2.5 km and enabled total DAWN coverage of the boundary layer and down to the surface. Between the two sets of DAWN profiles, the entire atmosphere below 5 km was measured.

5. SUMMARY AND FUTURE WORK

As shown in this paper, initial comparisons between wind profiles taken from DAWN, the Dropsondes and the Polar WRF Model output is very promising in regards to both diagnostic studies and model validation.

Even more promising is that we are still working on techniques to improve the efficiency of DAWN and, more importantly, to improve the sensitivity in the processing of the raw lidar data which will enable fuller vertical wind profiles in the presence of weaker aerosols which often occurs in the arctic regions near Greenland. This improved processing will aid us in further documenting the structure of the Tip Jet, Barrier winds, katabatic flows and other low level circulations of the region.

6. REFERENCES

Bromwich, D. H., K. M. Hines, and L.-S. Bai, 2009: Development and testing of Polar WRF: 2. Arctic Ocean. *J. Geophys. Res.*, 114, D08122, doi: 10.1029/2008JD010300

Hines, K.M., D.H. Bromwich, L.-S. Bai, M. Barlage, and A.G. Slater, 2011: Development and testing of Polar WRF. Part III. Arctic land.*J. Climate*, 24, 26-48, doi: 10.1175/2010JCLI3460.1

Skamarock, W.C., J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, M.G. Duda, X.Y. Huang, W. Wang and J.G. Powers, 2008: A Description of the Advanced Research WRF Version 3, NCAR technical Note, NCAR/TN-475+STR, June 2008.

Figure 1: DAWN on board the NASA King Air in November 2014

Figure 2: DAWN on board the NASA DC-8 in May 2015

Parameter	DAWN	TODWL	P3DWL	Comments
Wavelength (microns)	2.05	2.05	1.67	
Energy per pulse (mJ)	250	1	2	
Pulse rate(Hz)	10	500	500	
Pulse length(m)	~100	90	90	Range resolution
Telescope diameter(m)	.15	.10	.10	
Detection type	Coherent	Coherent	Coherent	.5 m/s LOS precision
Weight(kg)	Varies	300	275	
Power(watts)	Varies	700	550	

Table 1 ADWL system parameter summary, including DAWN.

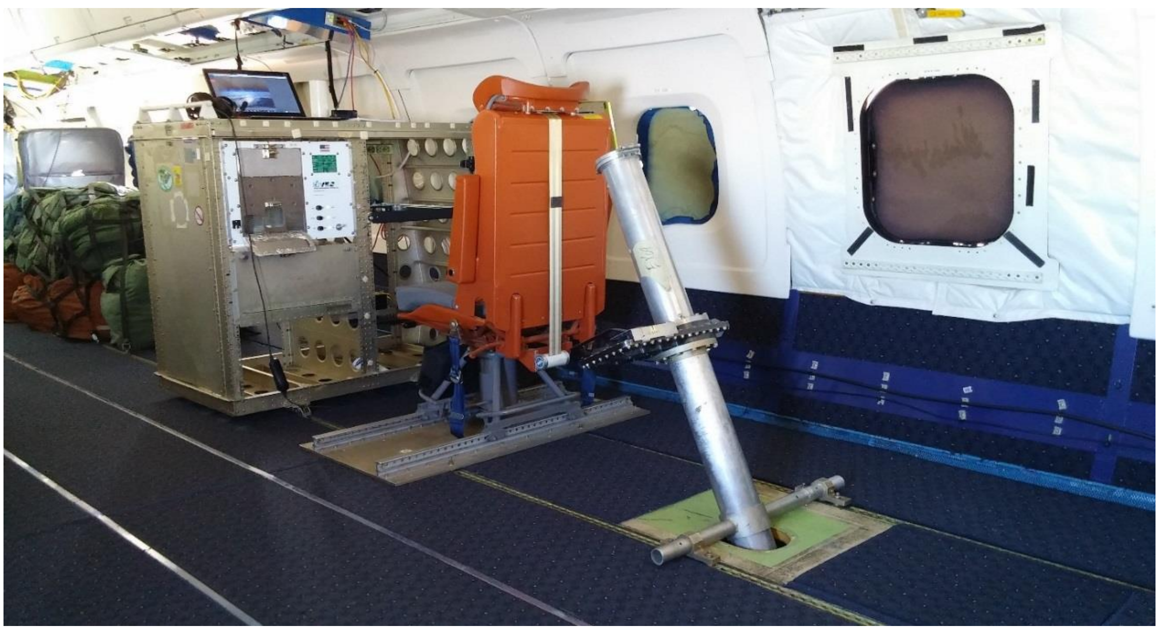

Figure 3: Yankee Dropsonde System on board the NASA DC-8 in May 2015

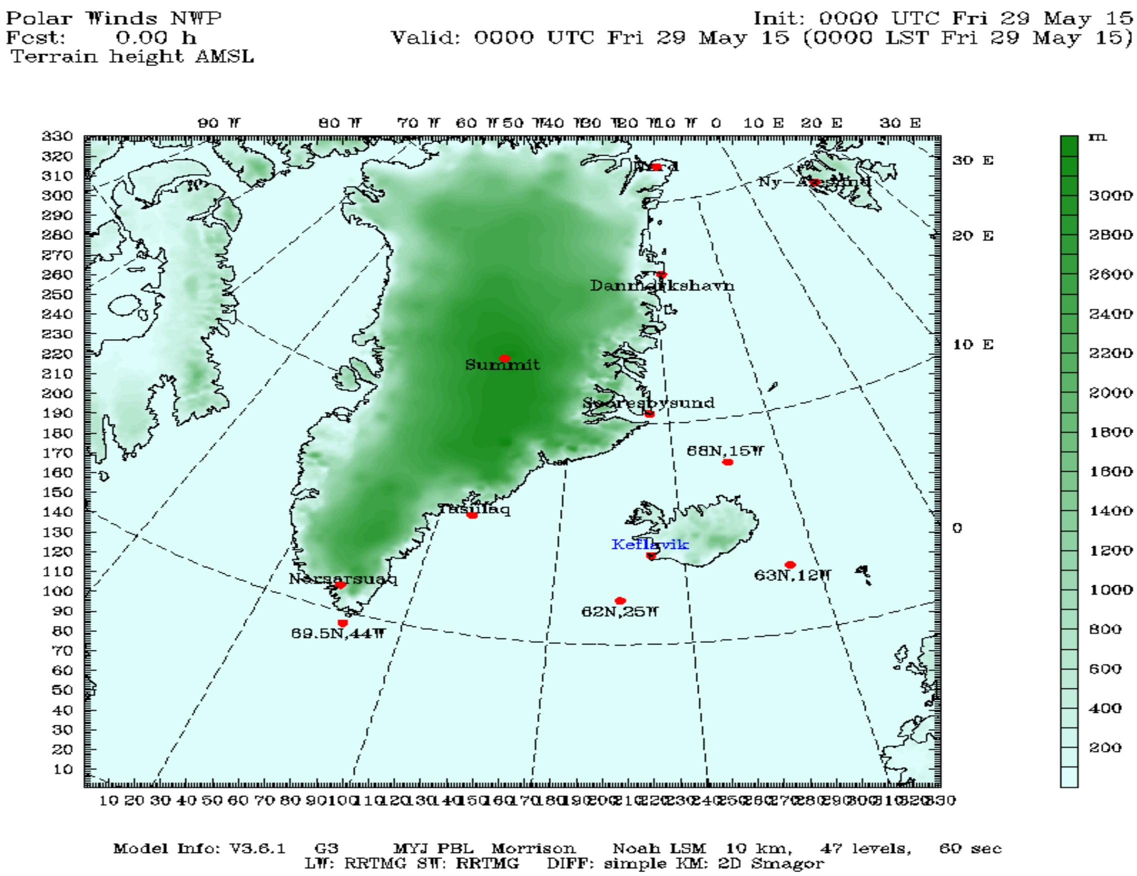

Figure 4: Campaign II Polar WRF Model Domain

Date	Mission	DC-8	Falcon	Drops	DAWN	TWiLiTE
5/11	Iceland flow splitting with NE BL winds	x		3/5	x	x
5/13	TDS underflight(DLR/NASA) and Greenland CIZ (NASA)	x	x	5/6	X	X
5/15	Upper level jet between Iceland and Scotland	x	x	10/12	X	X
5/16	ADM cal/val over Greenland ice cap; CIZ and Kat-winds	x	x	8/10	X	x
5/17	CALIPSO, MODIS, ASCAT underflights; CIZ;Tip jet	x		8/9	X	X
5/19	Upper level jet over southern Greenland; Tip jet	x	x	7/8	X	X
5/21	Barrier jet	x		7/11	X	X
5/23	Katabatic flows off Greenland east coast; ADM cal/val CIZ	x	x	15/19	X	
5/24	Baffin Strait ice edge west coast of Greenland; rolls	x		11/12	X	
5/25	Upper level jet south of Iceland	x	x	5/6	X	X

Figure 5: List of missions flown during Campaign II

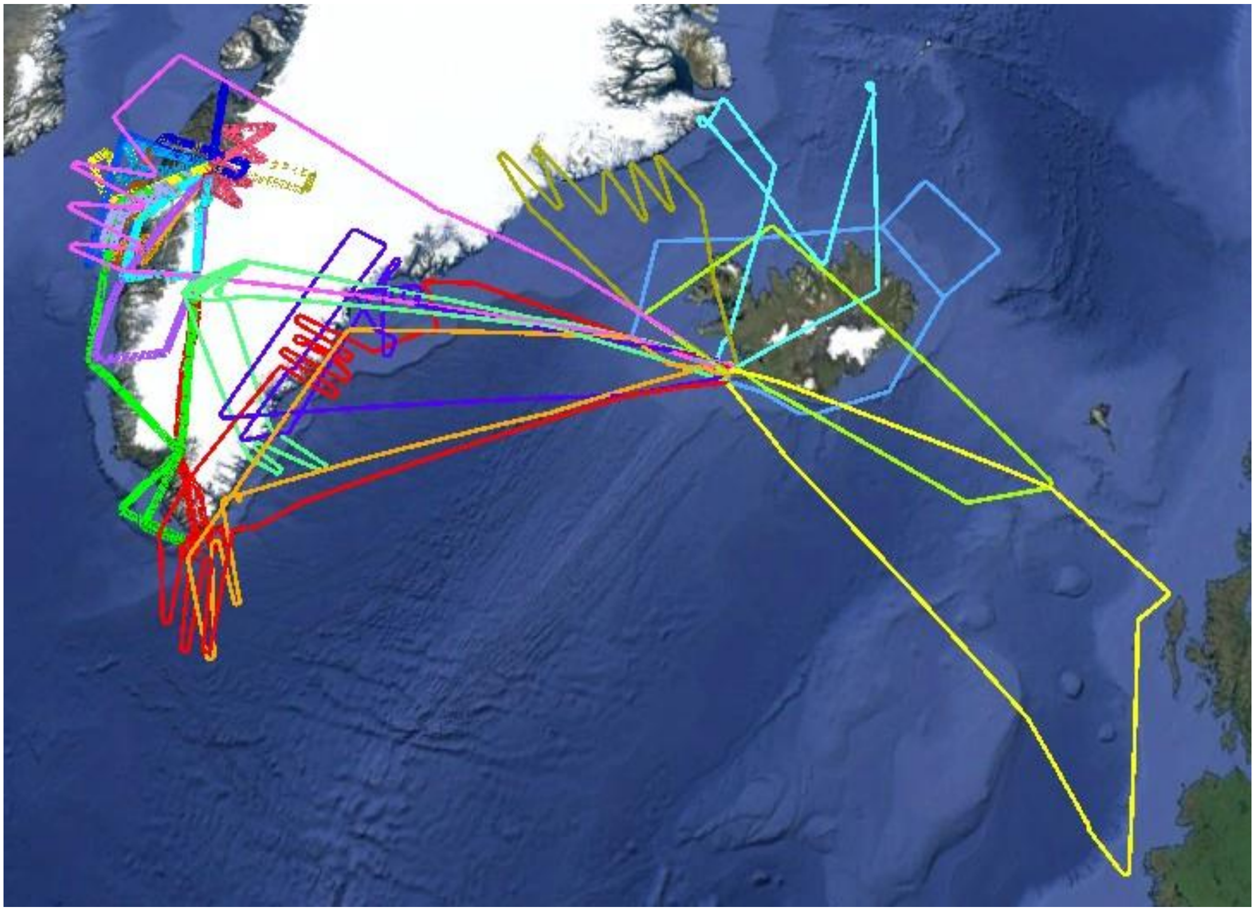

Figure 6: Campaign II Flight Tracks

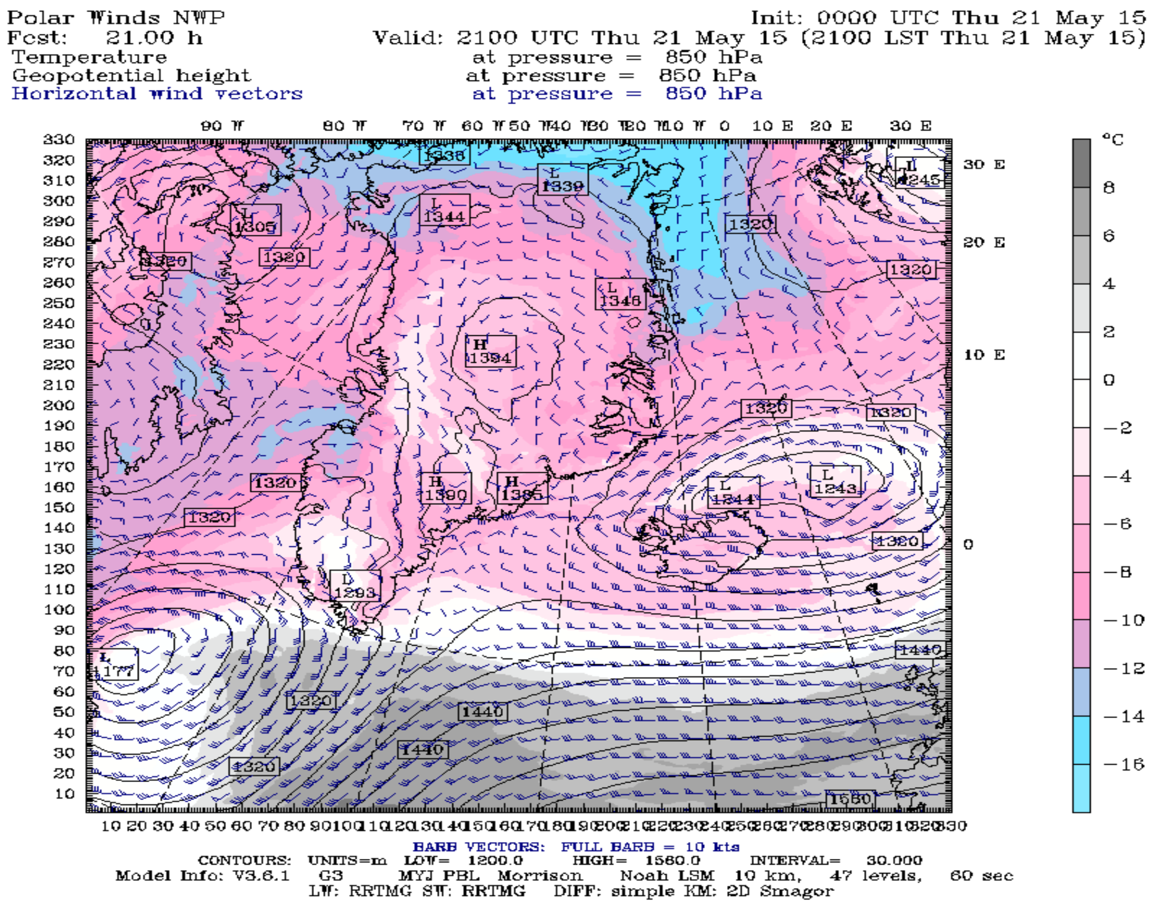

Figure 7: Polar WRF wind forecast valid at 21Z on 5/21/15 at 850mb

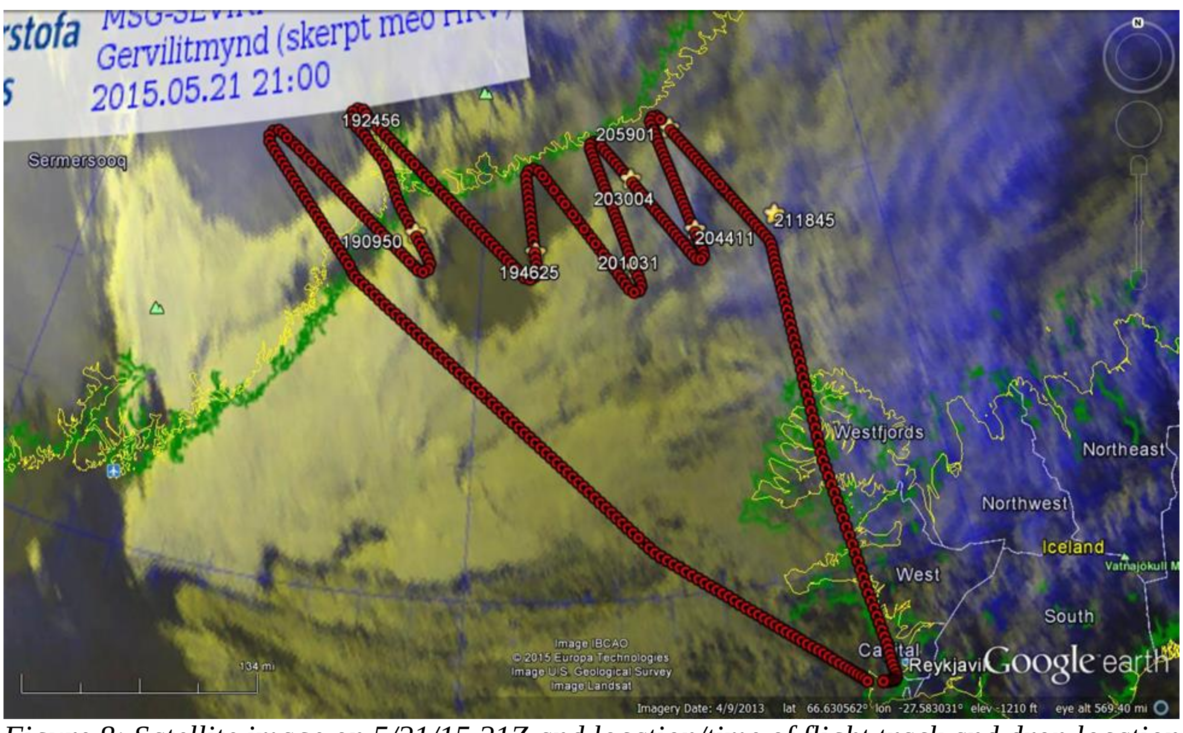

Figure 8: Satellite image on 5/21/15 21Z and location/time of flight track and drop location.

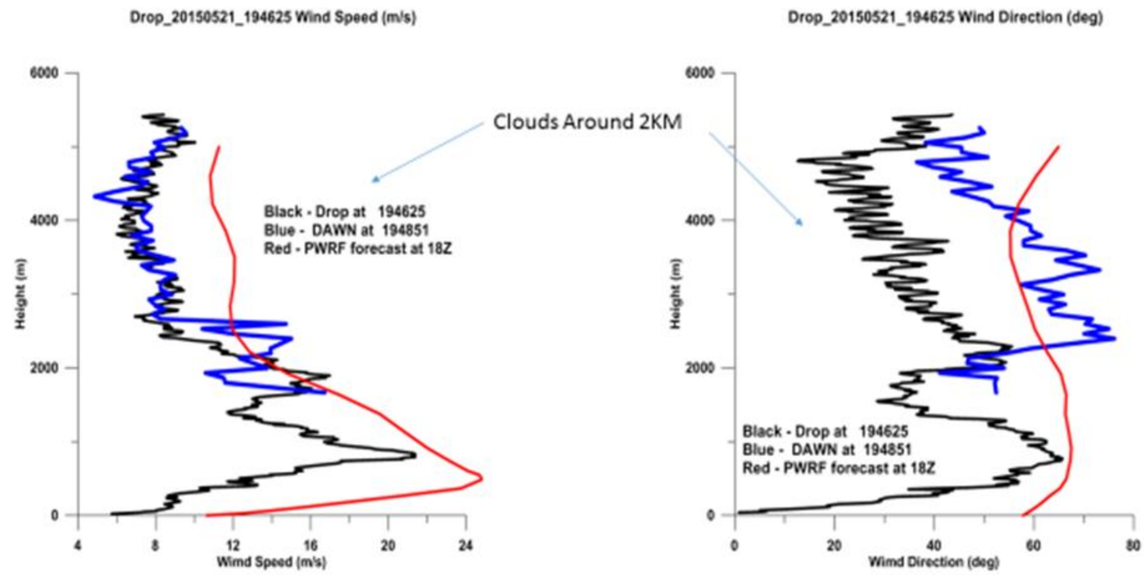

Figure 9: Vertical wind profiles as measured by DAWN and Dropsondes at around 1948Z on 05/21/15 along with Polar WRF forecast.

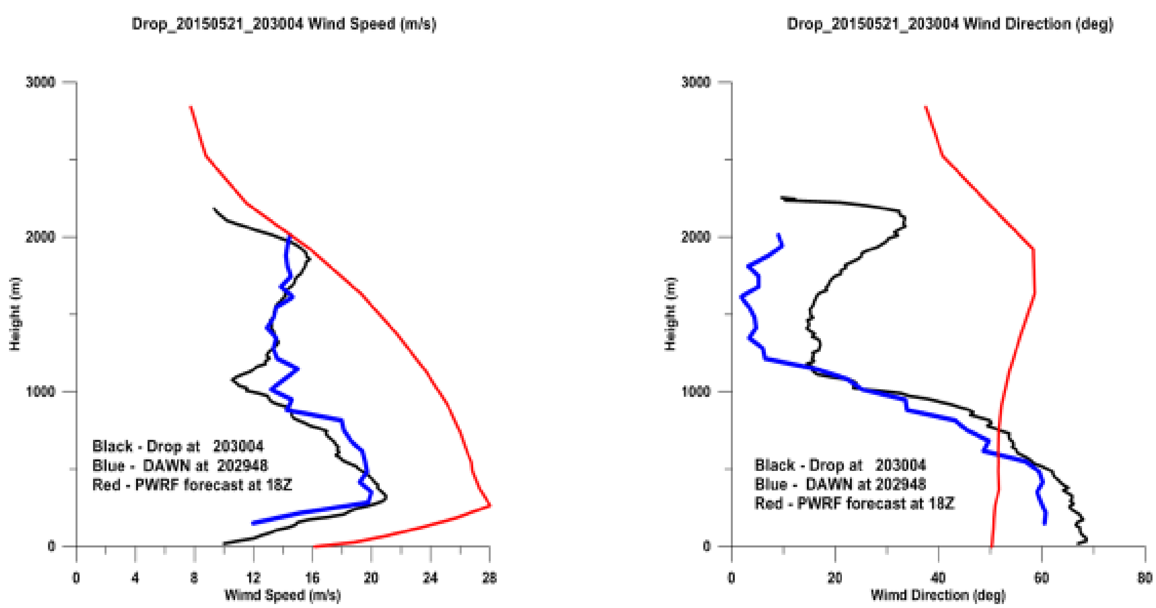

Figure 10: Vertical wind profiles as measured by DAWN and Dropsondes at around 2030Z on 05/21/15 along with Polar WRF forecast.

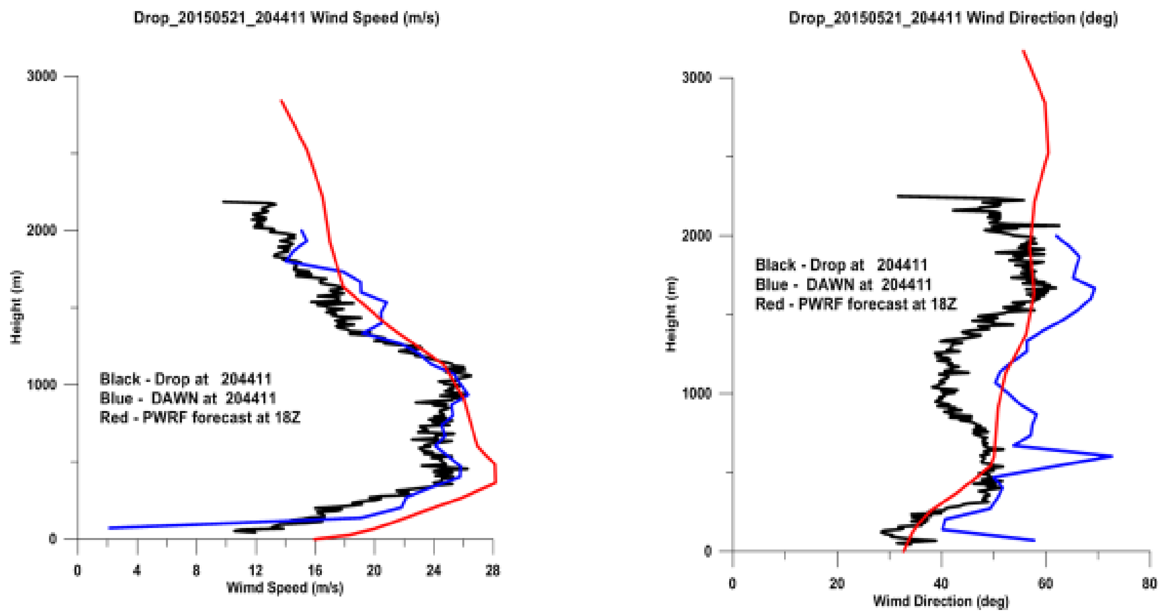

Figure 11: Vertical wind profiles as measured by DAWN and Dropsondes at around 2044Z on 05/21/15 along with Polar WRF forecast.

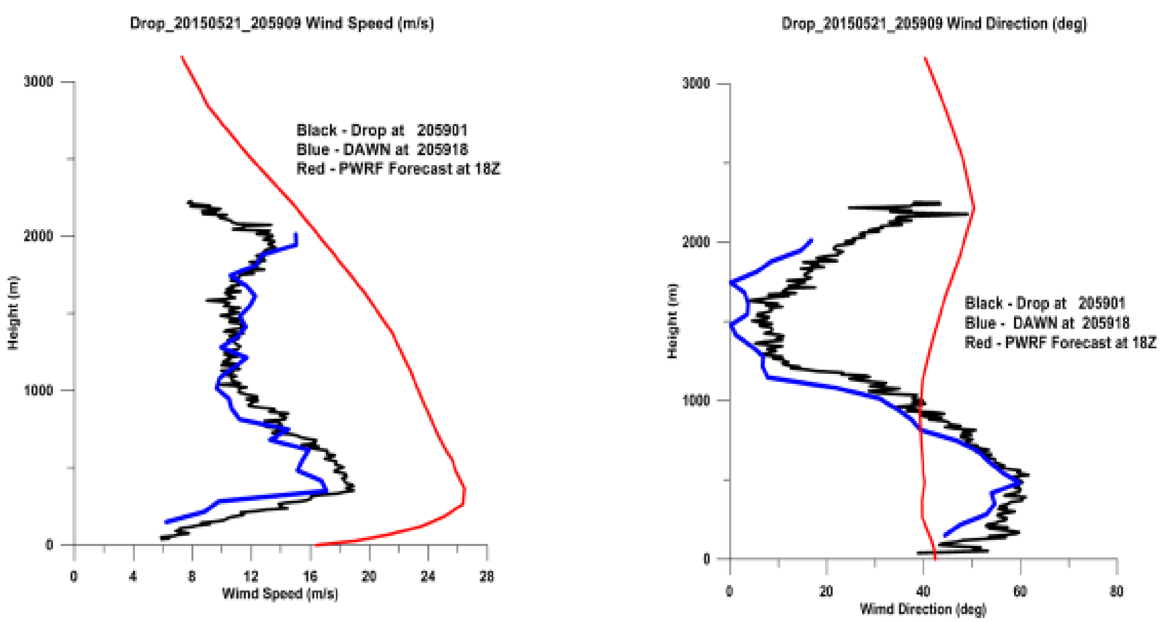

Figure 12: Vertical wind profiles as measured by DAWN and Dropsondes at around 2059Z on 05/21/15 along with Polar WRF forecast.