The 2014-2015 PolarWinds DAWN Airborne Campaigns; Instrument Performance, Data Collection and Advanced data Processing Algorithm Development

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NASA's PolarWinds and ESA's ADM Cal/Val

- Two airborne Doppler Wind Lidar campaigns:
  - Campaign 1 November 2014 on UC-12B based Kangerlussuaq, Greenland
  - Campaign 2 May 2015 on DC-8 based Keflavik, Iceland
- Purpose was to conduct basic polar science investigations and <u>demonstrate technology readiness for ADM Cal/Val</u>

PolarWinds Science and Instrument Team

- G. D. Emmitt (Simpson Weather Associates) , Principal Investigator
- M. Kavaya (NASA/LaRC), Technology Lead
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- R. Foster (University of Washington)
- M. Shapiro (NCAR)
- D. Winker (NASA/LaRC)

Preview of Major Results and Plans (1)

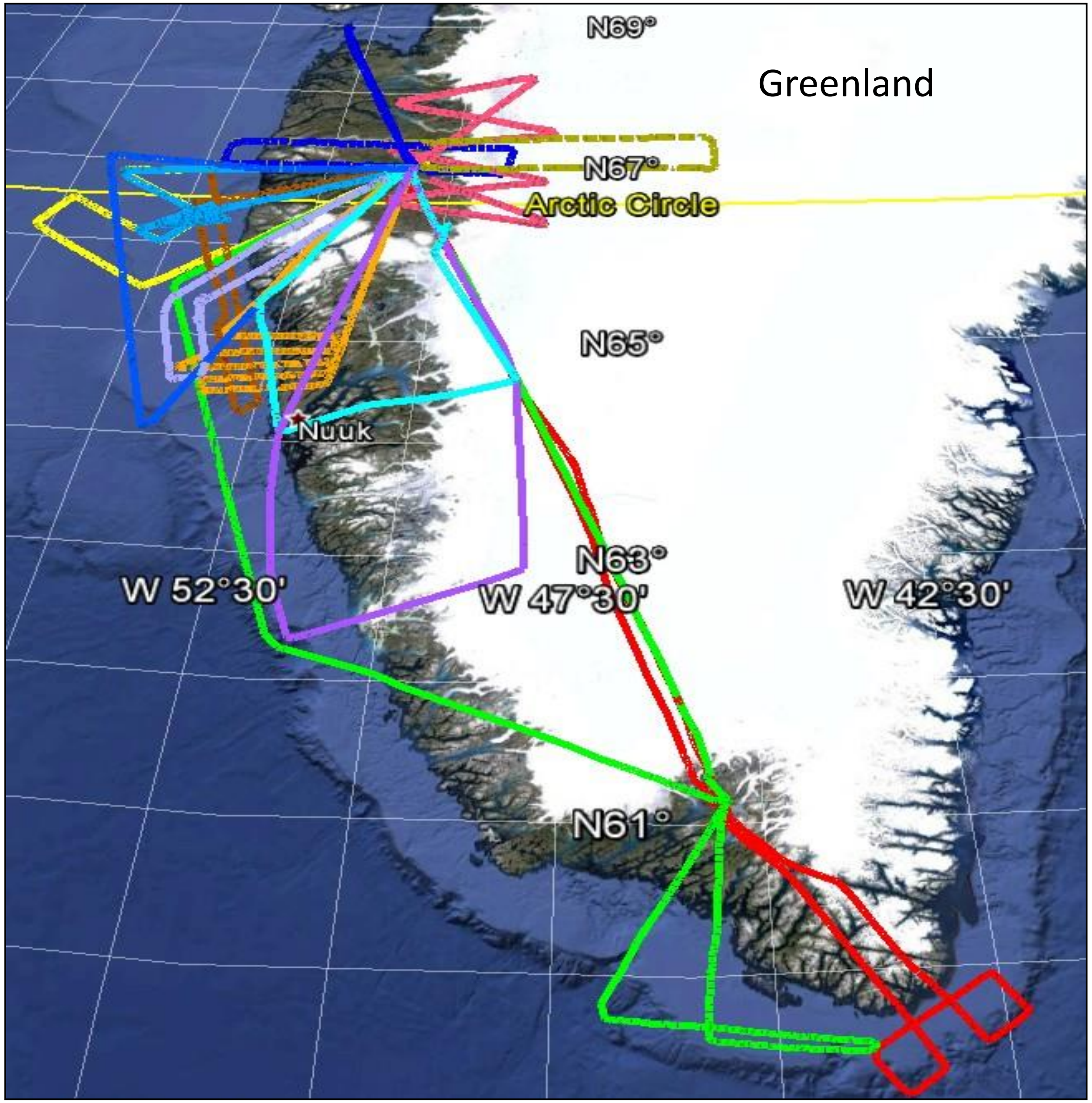
- More than 80 hours of DAWN research flights in 2014 and 2015 in the Arctic region near Greenland and Iceland. Most hours were related to PolarWinds science objectives. Six missions flown together with DLR Falcon. NASA provided ESA the requested dropsonde and wind profiling support. DAWN in final round of processing.
- DAWN/dropsonde comparisons demonstrated close agreement.
- While DAWN performed less than ideally due to misalignments, the DAWN profiles have provided quality data for numerical model (e.g. Polar WRF) validation. Since Campaign II, DAWN's performance has been improved by a factor ~ 22x by Beyond Photonics.
- **All PolarWinds and ADM Cal/Val objectives were met**.

Preview of Major Results and Plans (2)

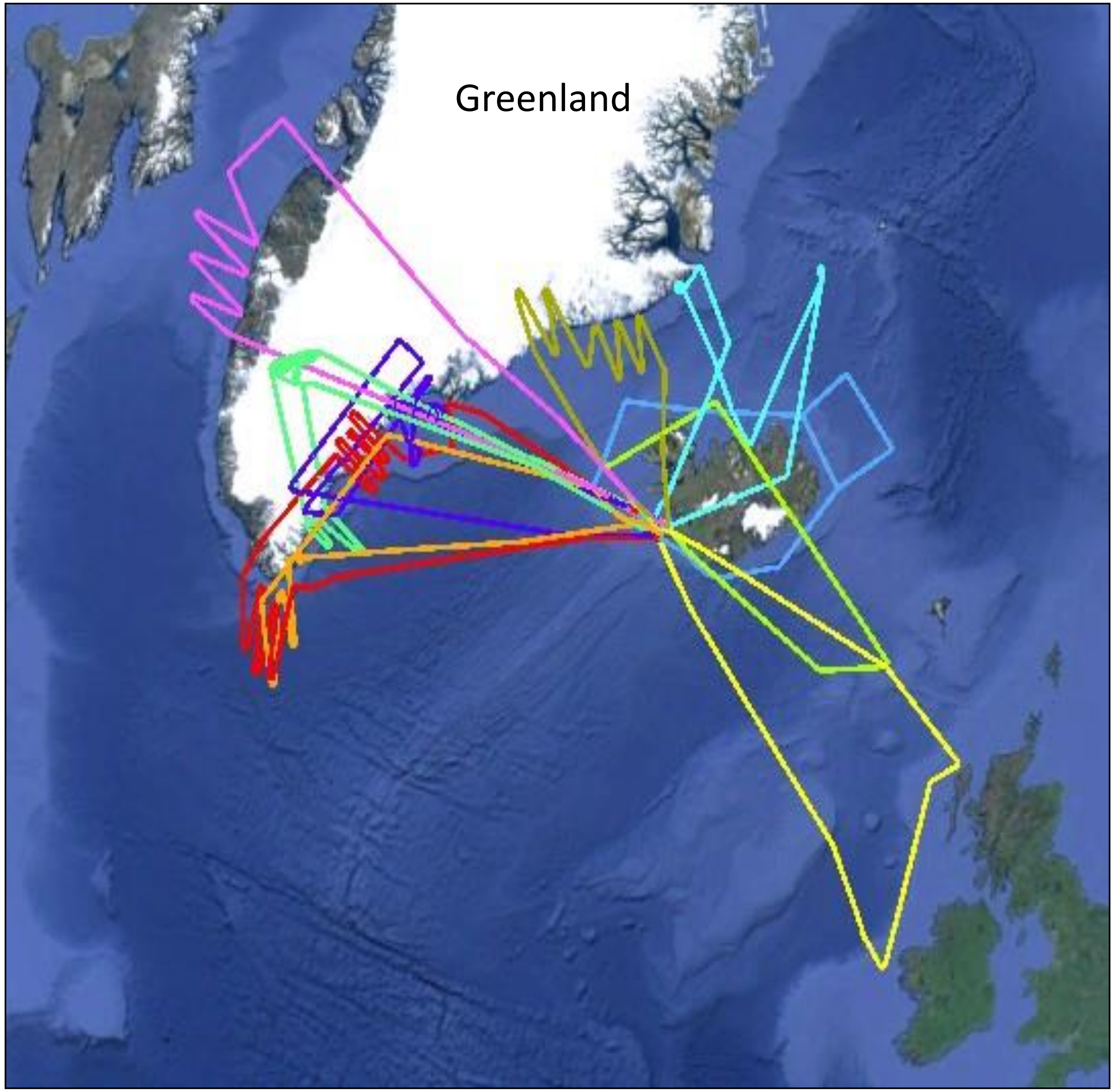
- Level 0 – 3 data and documentation to be archived at the LaRC DAAC (ASDC).
- More than 10 conference/workshop presentations. Two papers are being prepared for publication, one accepted in Monthly Weather Review. Three papers submitted to the 2017 AMS Annual Meeting.
- DAWN, with its precision and restored sensitivity, represents the most capable coherent airborne DWL available to atmospheric research (e.g. CPEX) and ADM Cal/Val after its launch in 2017.
- A DAWN-SP (Space Pathfinder) has been designed and proposed to the IIP to evolve the DAWN low PRF technology into a space-based DWL with a higher PRF better suited for wind profiling in the ubiquitous cloudy scenes.

PolarWinds Science Objectives

- Validate numerical model forecasts and reanalysis characterizations of airflow in the lower atmosphere over the open oceans, land, ice sheets and transition zones of the Arctic.
- Conduct detailed investigations into the importance of dynamic features such as Arctic low level jets, barrier winds and organized large eddies to the transport and fluxes of heat and energy.
- Characterize and study the wind regime of the lower atmosphere over marginal ice zones in the Arctic, where ice drift and other processes are largely controlled by the low-level winds.
- Provide wind/aerosol observations that can be used to validate or compare with existing remote sensing platforms. Three examples are CALIPSO aerosol measurements , MODIS Atmospheric Motion Vectors and ASCAT Ocean Vector Winds. Additional comparisons can be made with observing systems identified by ESA and the PolarWinds Science Team.

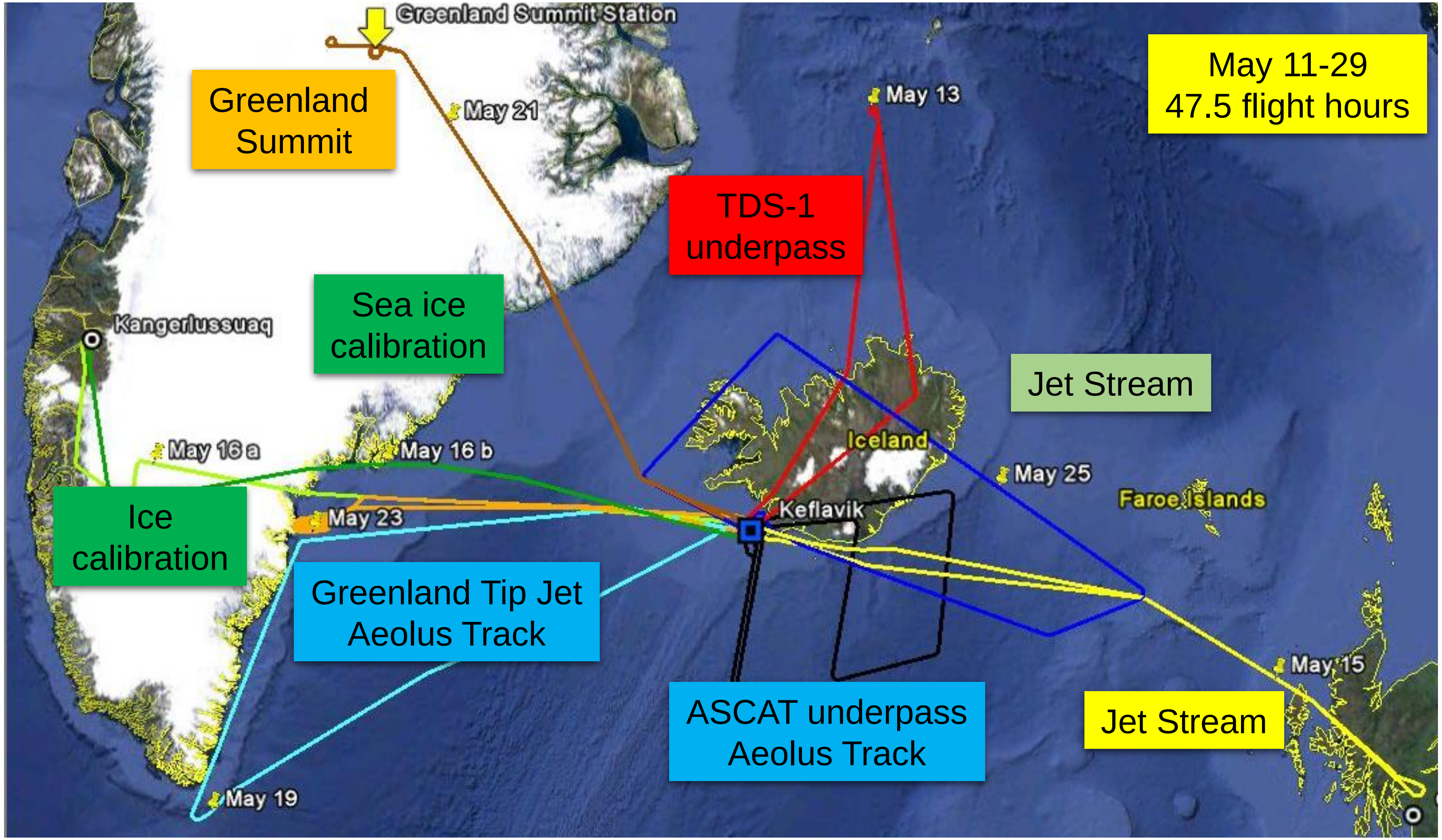


PolarWinds Campaign I Flight Tracks



PolarWinds Campaign II Flight Tracks

NASA DC-8*/DLR Falcon Flights in May 2015



*Exception: the DC-8 did not accompany the Falcon to the Greenland Summit

Mission Summary for Campaign II

(51 hours not including ferry hours)

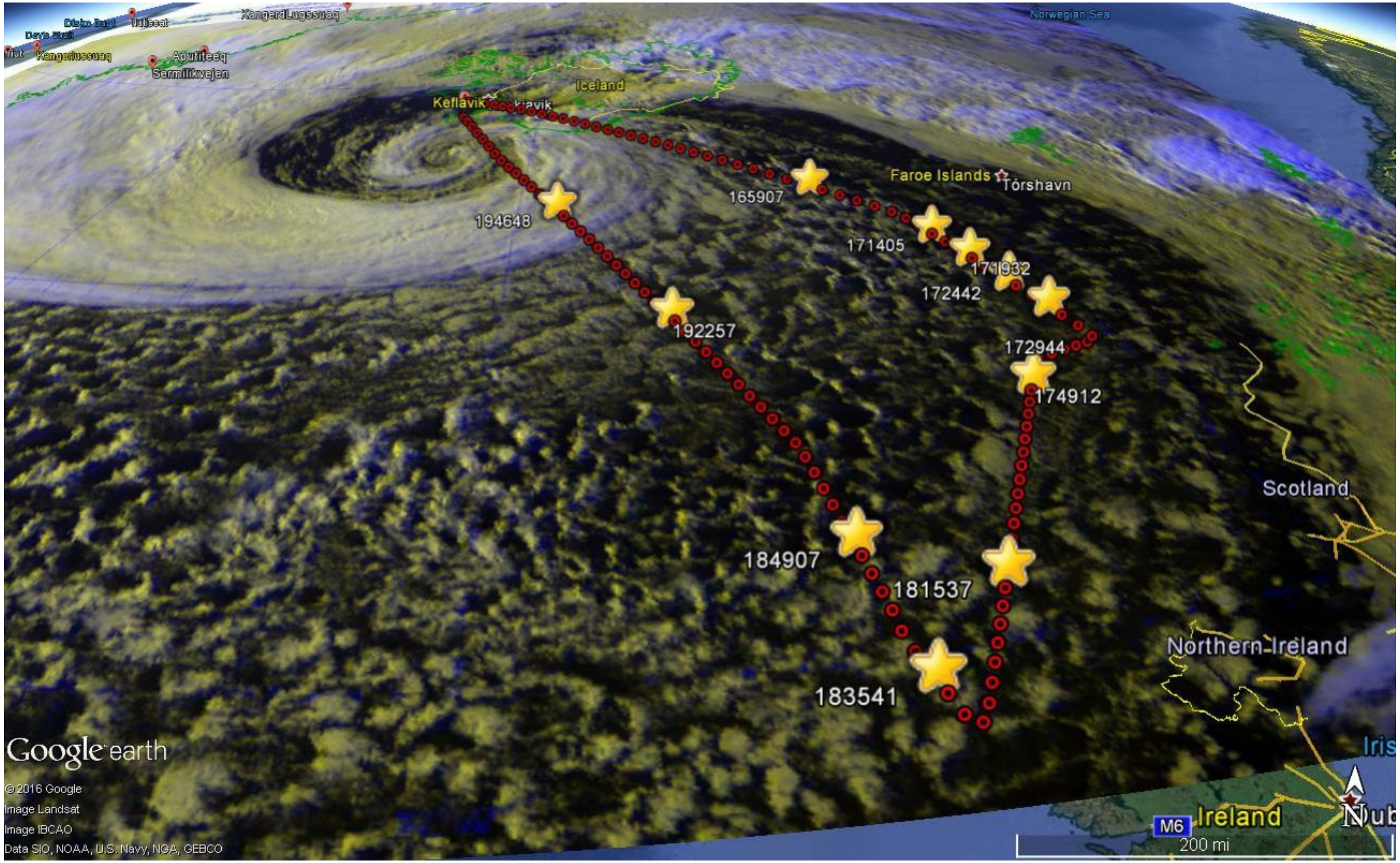
Date	Mission	DC-8	Falcon	Drops	DAWN	TWiLiTE
5/11	Iceland flow splitting with NE BL winds	x		3/5	x	x
5/13	TDS underflight(DLR/NASA) and Greenland CIZ (NASA)	x	x	5/6	x	x
5/15	Upper level jet between Iceland and Scotland	x	x	10/12	x	x
5/16	ADM cal/val over Greenland ice cap; CIZ and Kat-winds	x	x	8/10	x	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

CIZ (Coastal Ice Zone); Kat (Katabatic); BL (Boundary Layer)
Dropsonde numbers indicate good/total dropped

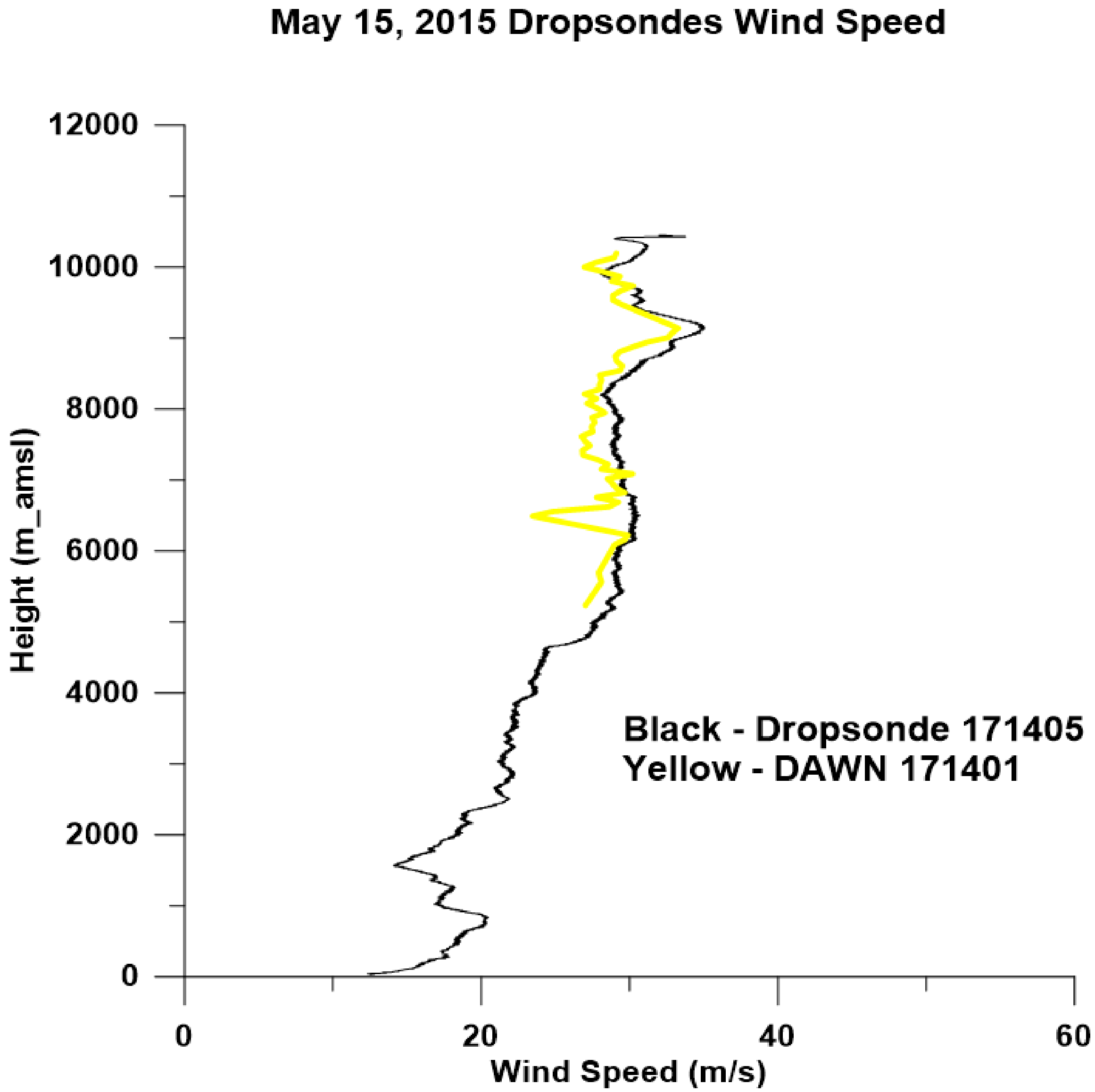
Joint NASA/DLR Wind Shear Mission: 5/15/15

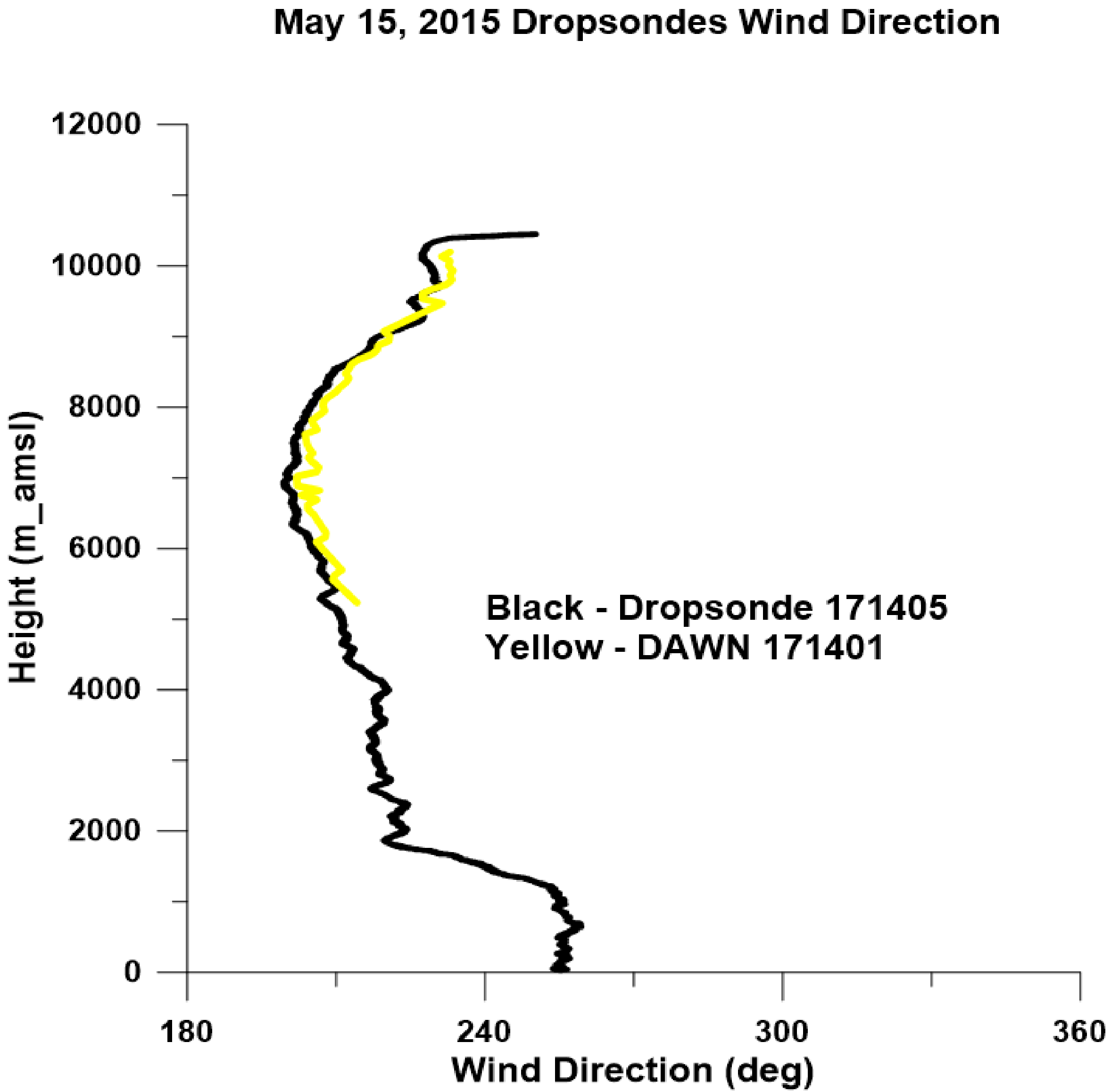
Red circles:
DAWN profiles

Yellow stars:
Dropsondes



DAWN and dropsondes compare very well in a region of an upper level jet


May 15, 2015 Dropsondes Wind Speed
12000
10000
8000
6000
4000
2000
0
Height (m_amsl)
0
20
40
60
Wind Speed (m/s)
Black - Dropsonde 171405
Yellow - DAWN 171401


May 15, 2015 Dropsondes Wind Direction
12000
10000
8000
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4000
2000
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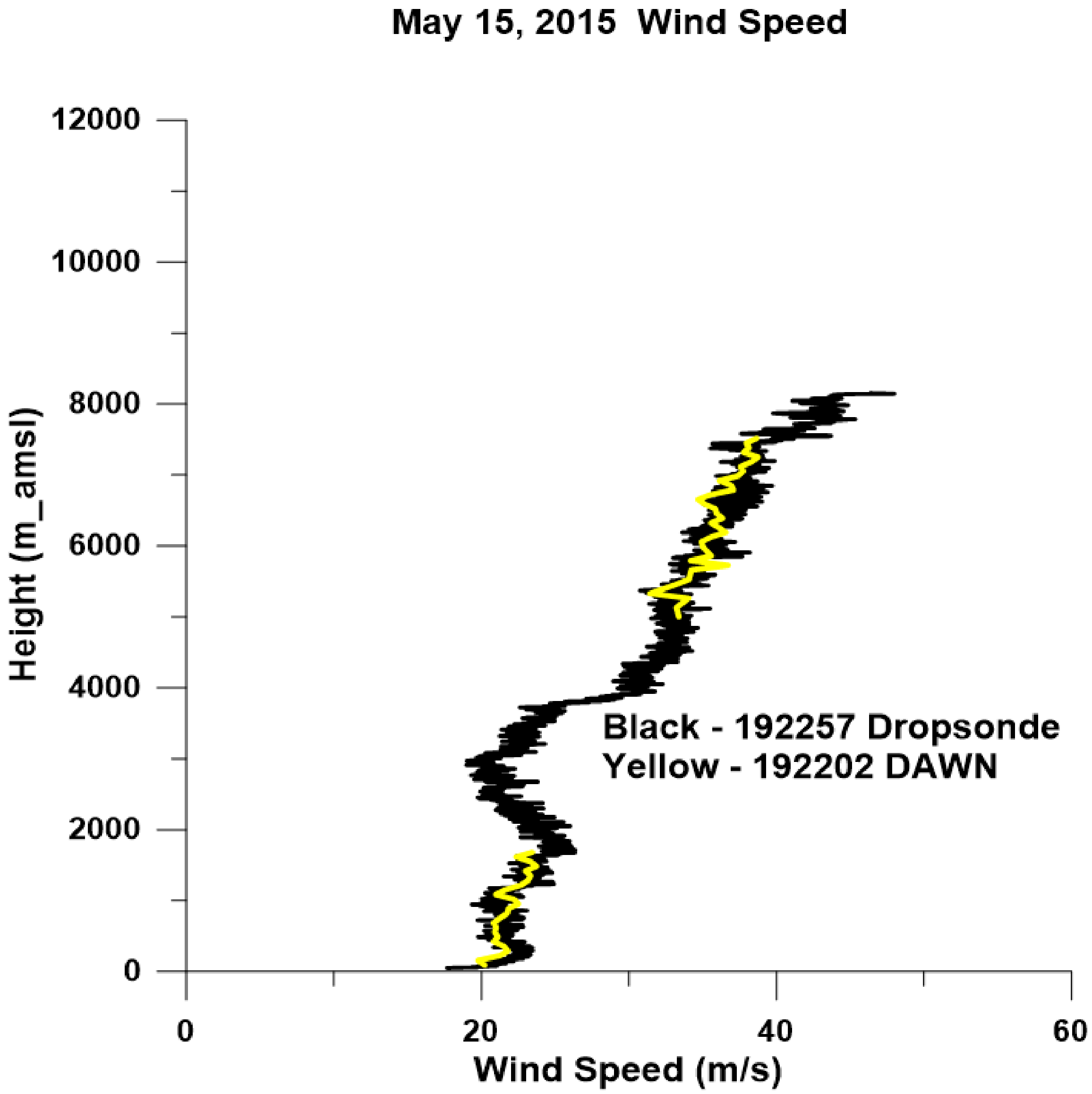
Height (m_amsl)
180
240
300
360
Wind Direction (deg)
Black - Dropsonde 171405
Yellow - DAWN 171401


May 15, 2015 Wind Speed
12000
10000
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6000
4000
2000
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Height (m_amsl)
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20
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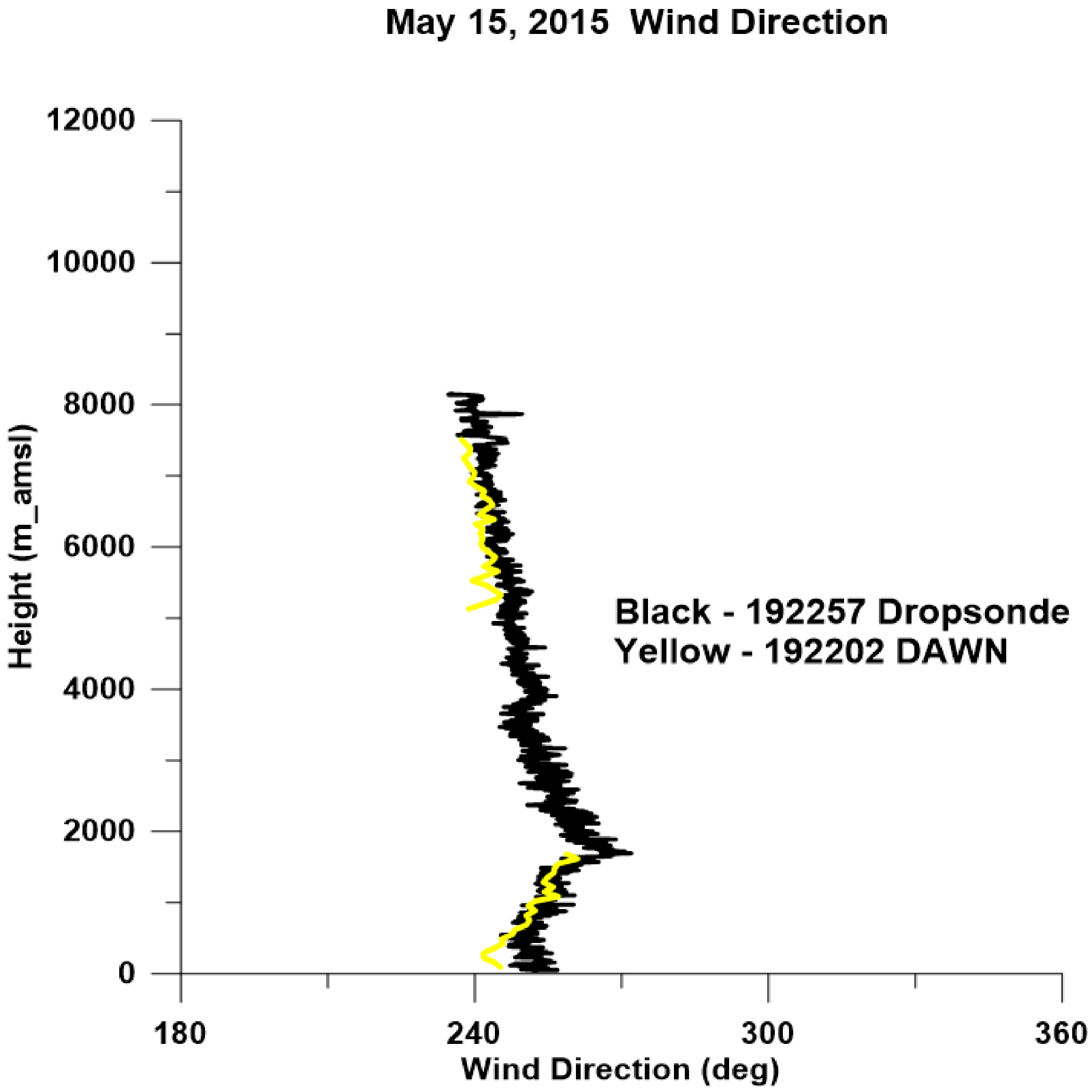
Wind Speed (m/s)
Black - 192257 Dropsonde
Yellow - 192202 DAWN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12000
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Height (m_amsl)
180
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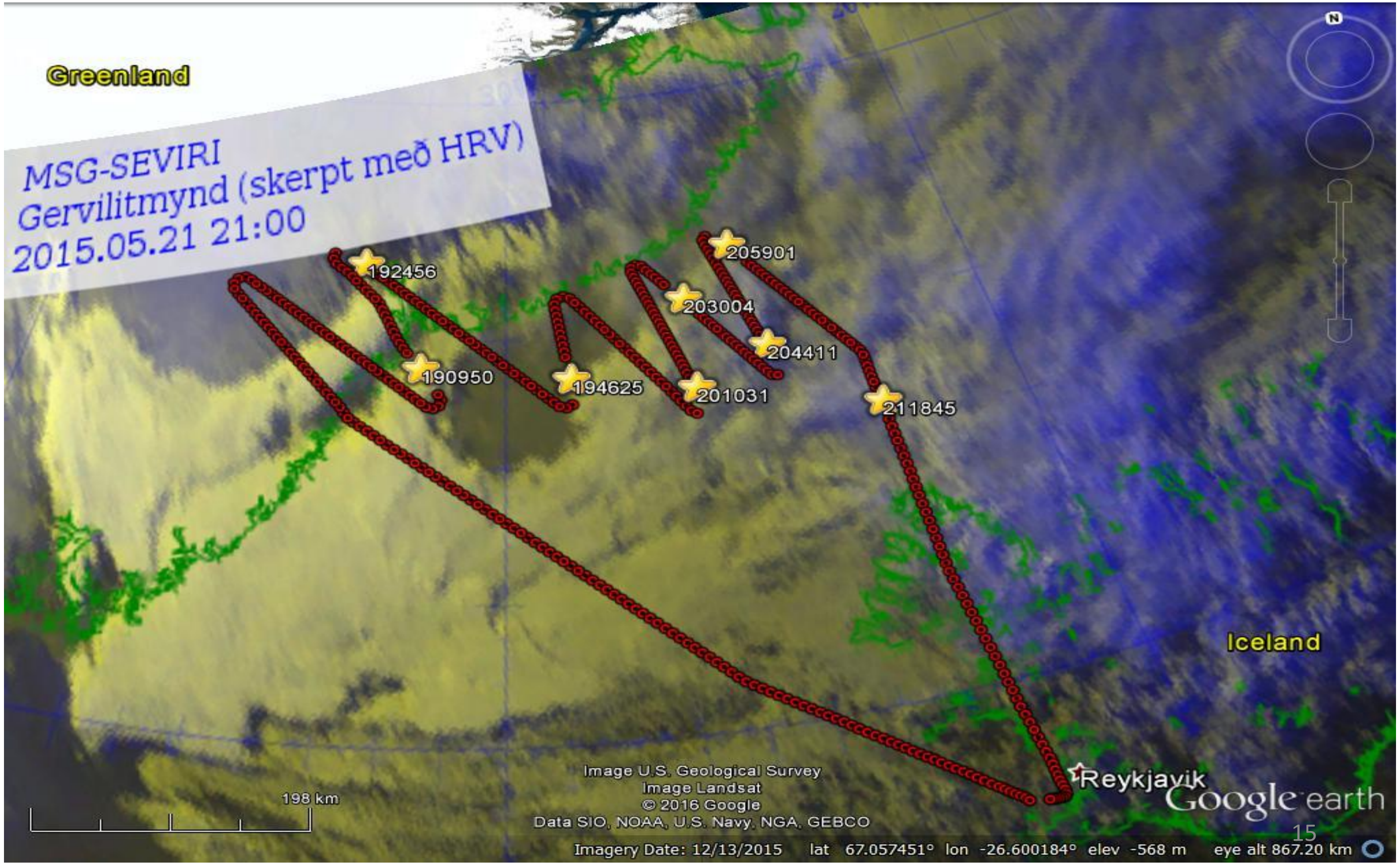
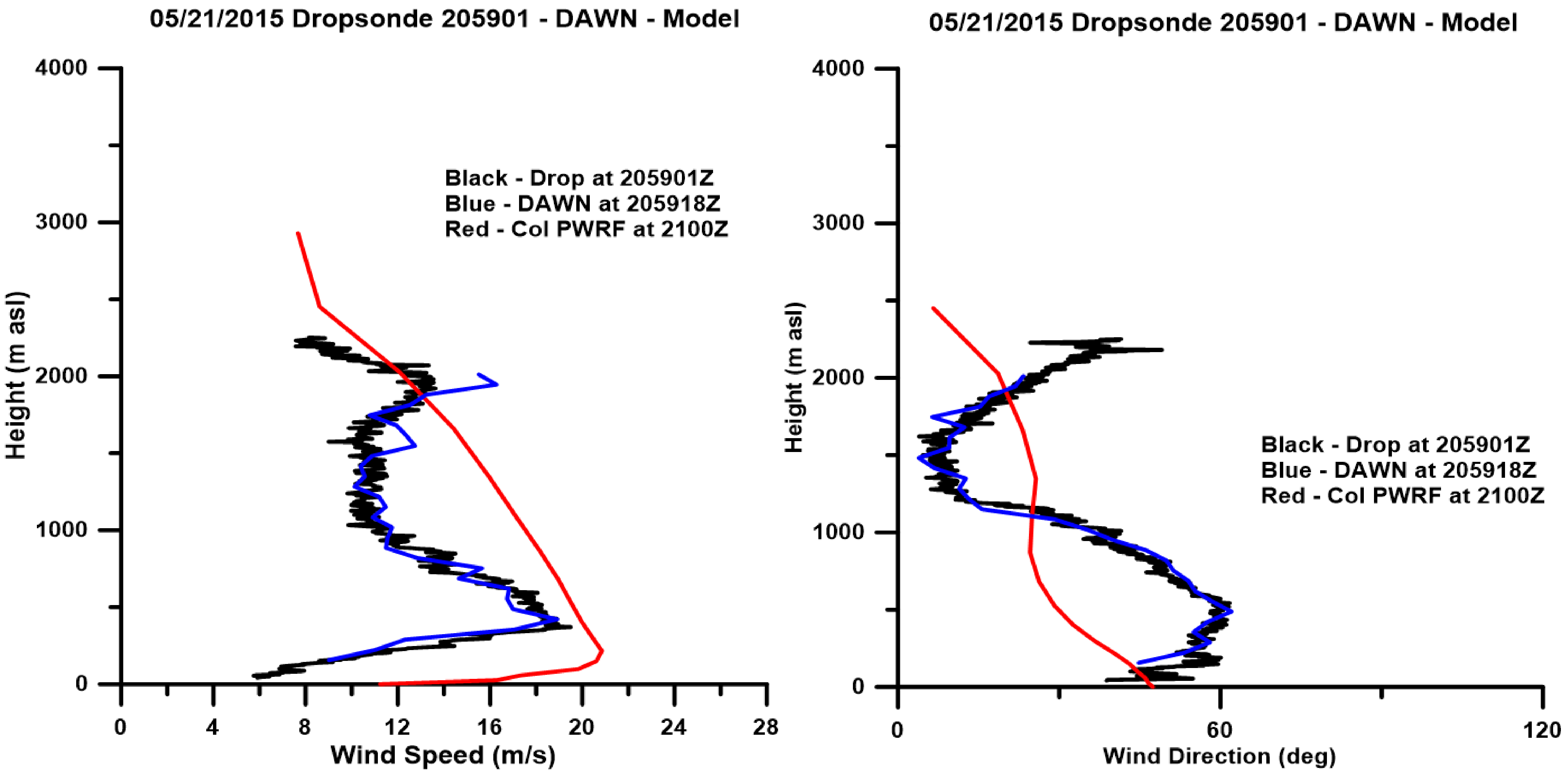
Wind Direction (deg)
Black - 192257 Dropsonde
Yellow - 192202 DAWN

DAWN/dropsonde comparisons in highly varying coastal region: **Greenland East Coast Barrier Wind Case**

Red circles:
DAWN profiles

Yellow stars:
Dropsondes





Col PWRF: University of Colorado Boulder's Polar Weather Research Forecast model

DAWN-Dropsonde Comparison for May 21, 2015 mission including 8 dropsondes

Height Layer	Number of Comparisons	Δz (m)	DAWN –Drop (m/sec) Mean ΔWS	DAWN – Drop (m/sec) Mean ABS(ΔWS)	DAWN – Drop (deg) Mean ΔWD	DAWN – Drop (deg) Mean ABS(ΔWD)	RMSE DAWN -Drop ΔWS
ALL	468	1.97	-0.004	1.15	-1.75	9.11	2.28
5200 – 4000 m	87	2.28	0.13	1.06	-7.80	13.81	1.87
4-3000 m	92	2.21	0.26	1.28	0.8	13.28	2.94
3-2000 m	92	1.92	-0.005	0.92	-1.95	11.33	1.32
2-1000 m	133	1.74	0.108	1.14	-0.27	4.70	2.03
1000m – sfc	64	1.73	-0.815	1.52	0.084	2.67	3.81

Notes: DAWN and dropsonde data averaged over 150m layers;
DAWN sounding with 5 look angles takes 25 seconds to complete (~ 5.5 km DC-8 flight segment;
Dropsondes took ~ 4 minutes to contact surface (~ 2.5 km drift)

Technology Lessons Learned: DAWN

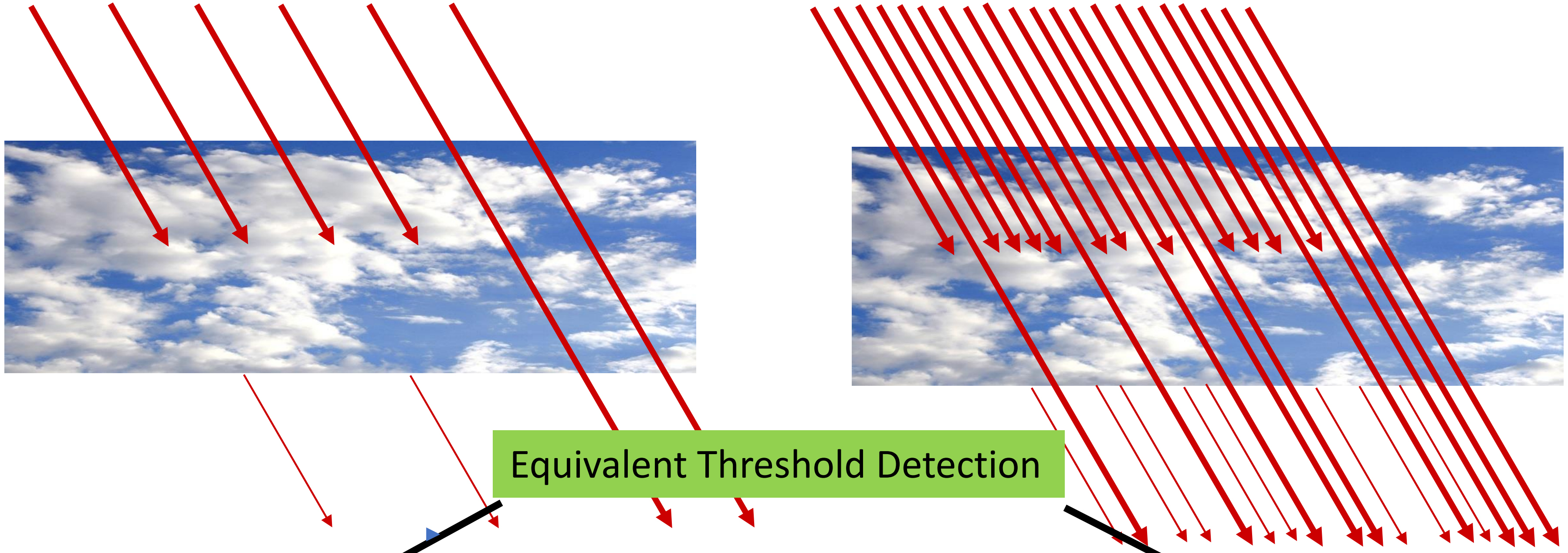
- Dropsondes
  - Experience with “spiral vs. wobble” DC-8 drops led to YES improvements in the aerodynamic design of the dropsondes. Significant reduction of the wobble mode was demonstrated in recent WB-57 drops.
- DAWN
  - Precision of wind measurements was found to be ~ 1.5m/s RMSE initially (ice returns)
    - Reduced to ~ 0.8 m/s RMSE with software improvements funded through PolarWinds
  - Threshold sensitivity during campaigns was less than ideal due to misalignment
    - SWA evaluated DAWN’s sensitivity using comparisons with DLR 2 um DWL (when in formation flight)
      - DAWN’s sensitivity during PolarWinds was equal to or better than the DLR 2 um system
      - However, DAWN’s sensitivity was ~ 25dB (350x) below its design threshold
  - Evaluation of DAWN post flight revealed significant losses due to misalignment
    - Need better pre-campaign end-to-end performance characterization

DAWN Repair and Upgrade Activities

- Hardware
  - Post campaign engineering has reported > 22x performance improvement measured on 29 July 2016. Additional 10x improvement is feasible (includes large optics). Recent lidar efficiency evaluation <u>suggests</u> ~100x improvement
- Flight Software
  - While very robust (99.99% available), the DAWN flight software will benefit from several low risk modifications.
- Post flight software
  - LaRC has invested in advanced signal processing and wind profile generation to optimize low signal strength retrievals
    - Adaptive Integration Algorithm
    - Supervised Search Algorithm
    - Multi-LOS Accumulation Algorithm

Looking ahead: near term airborne science

- NASA has awarded funding for CPEX (May-June, 2017) which will feature DAWN, dropsondes, APR and HAMSR. Base of operations still under discussion.
- Building upon DAWN I, NASA/LaRC is developing a lower energy per pulse/higher pulse frequency coherent lidar that will serve as the next generation airborne DWL for NASA research as well as providing a path to space. The design parameters optimize the probabilities of high quality wind observations in partly cloudy situations which are the norm over 80km dwell segments.



Existing DAWN-1 Airborne Wind Lidar		Proposed Improved Airborne Wind Lidar
250 mJ, 5 Hz laser	Laser Pulses	32 mJ, 300 Hz
Equal	Aerosol Sensitivity (Laser Figure of Merit)	Equal
Less	Cloud Wind Measurements	Up to 60x more
Less	Laser Shots Through Cloud Holes	Up to 60x more
Less	Wind Measurements Below Clouds	Up to 60x more
Higher	NWP Assimilation Representativeness Error	Much Lower
Good	Fractional Laser Efficiency	Higher
Good	Laser Beam Quality	Good
Low at 2 microns	Risk of Contamination Optics Damage	~8x lower

Conclusions

- DAWN was the right instrument for PolarWinds conducted from the high altitude and long range DC-8.
- DAWN, with its intrinsic precision and spatial resolution, is the appropriate airborne technology for ADM Cal/Val.
- DAWN’s less than ideal sensitivity during Campaigns I and II has been diagnosed and is being restored.
- DAWN represents the most powerful coherent DWL available to the atmospheric research community going forward (e.g. CPEX, YOPP)
- DAWN-SP (space pathfinder) evolves from the airborne DAWN by trading the demonstrated exceptionally high energy per pulse for a higher, cloud penetrating PRF, while maintaining the DAWN designed equivalent high sensitivity.
- The combination of molecular and aerosol DWLs is a logical follow-on.

Acknowledgements

The authors acknowledge the contributions of NASA headquarters in funding PolarWinds, the aircraft crews who made many mid-air corrections to adjust to cloud conditions and the many who supported the field campaign with inputs from models, imagery and Arctic field experience.