ARM CLIMATE RESEARCH FACILITY

DOE ARM Tethered Balloon System at AMF3 in Oliktok Point, Alaska

Darielle Dexheimer[1], Fan Mei[2], Lexie Goldberger[2], Casey Longbottom[1], Jasper Hardesty[1], Mark Ivey[1]
1. Sandia National Laboratories, Albuquerque, NM, United States.
2. Pacific Northwest National Laboratory, Richland, WA, United States.

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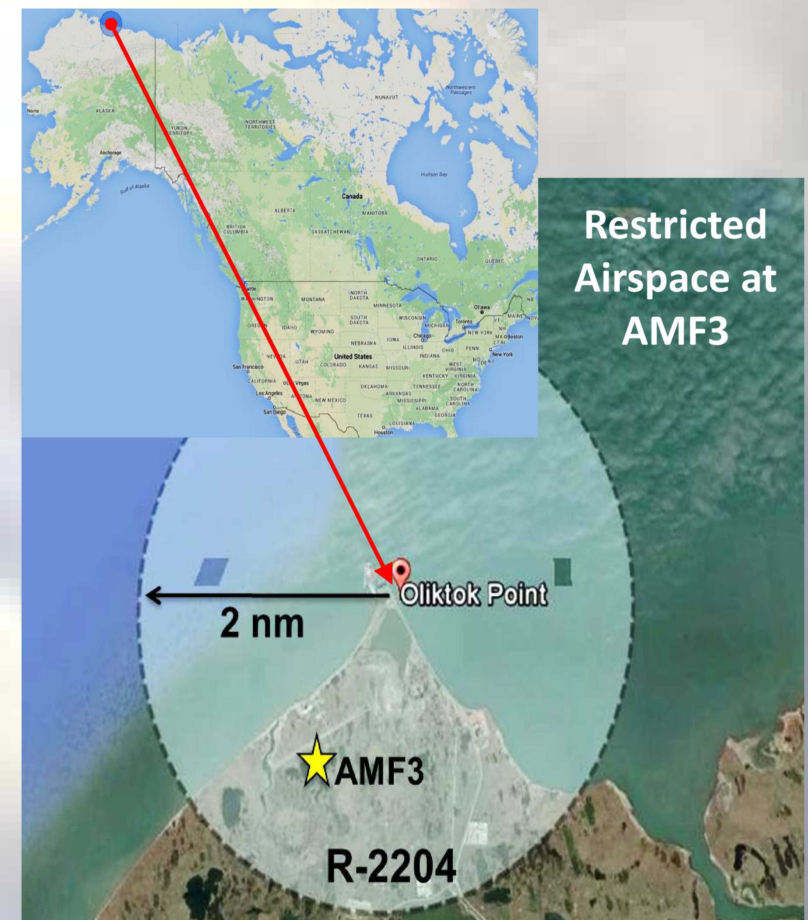
Introduction



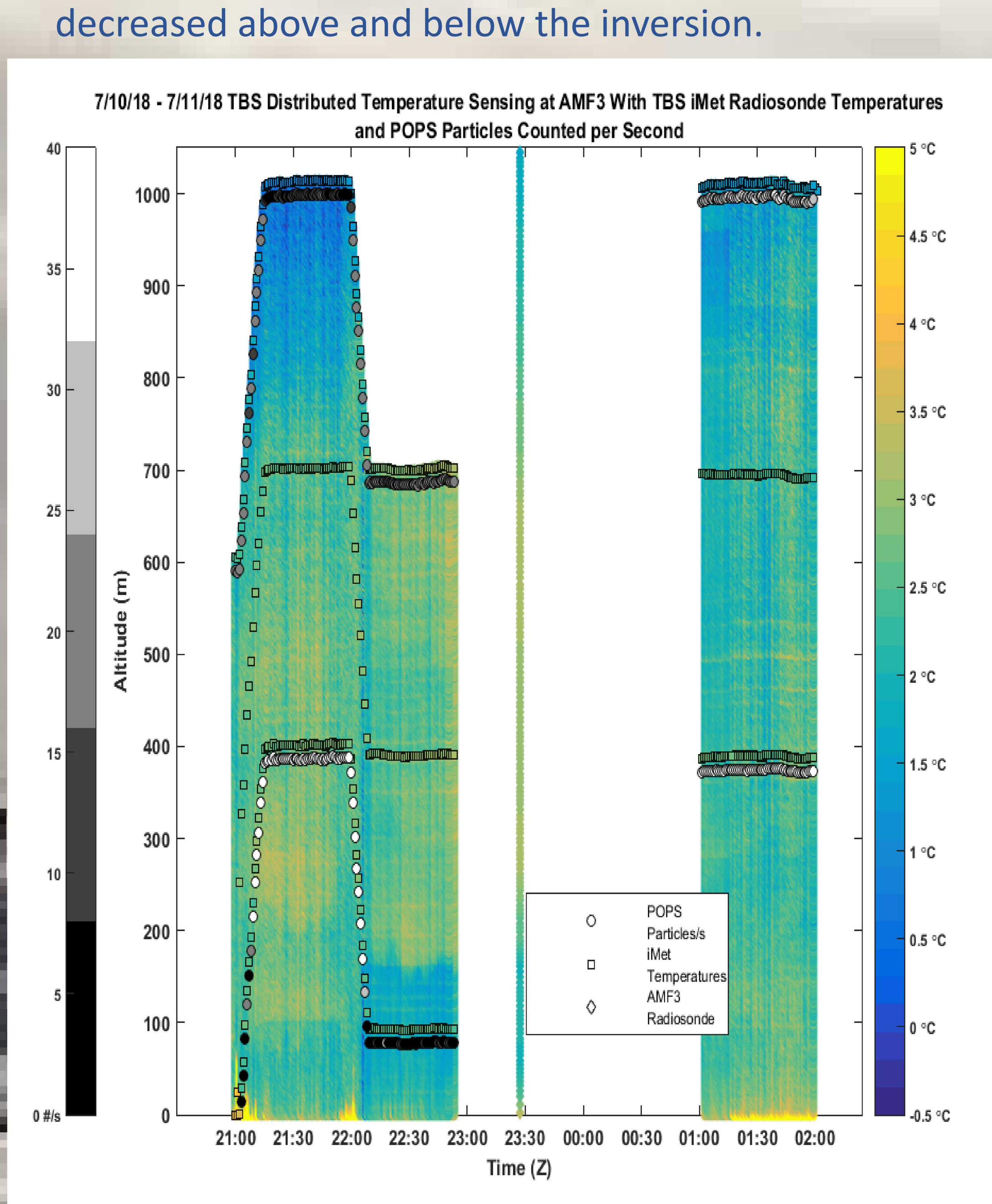
- ARM North Slope of Alaska (NSA) Science Mission is to collect high latitude atmospheric data to refine climate models as they relate to the Arctic.
- Sandia National Laboratories (SNL) manages the DOE ARM facilities in Alaska and has operated the ARM Mobile Facility #3 (AMF3) at Oliktok Point since 2013 on behalf of ARM.
- SNL operates Restricted Area R-2204 and Warning Area W-220 at AMF3, the only ARM site with restricted airspaces.
- SNL operates a tethered balloon system (TBS) on behalf of ARM up to 1.5 km in altitude within DOE's R-2204 Restricted Area at AMF3.
- Almost 135 hours of TBS flights and 63 hours of small UAS flights were conducted at the AMF3 from 7/1/18 – 9/30/18 as part of the POPEYE (Profiling at Oliktok Point to Enhance YOPP Measurements) ARM campaign.
- Sensors operated on the TBS during POPEYE included:
  - 2 Printed Optical Particle Spectrometers (POPS)
  - Condensation Particle Counter (CPC)
  - Supercooled Liquid Water Content sondes
  - iMet-1-RSB radiosondes
  - iMet XQ2 sensors
  - Two-channel fiber optic distributed temperature sensing
  - Anemometers

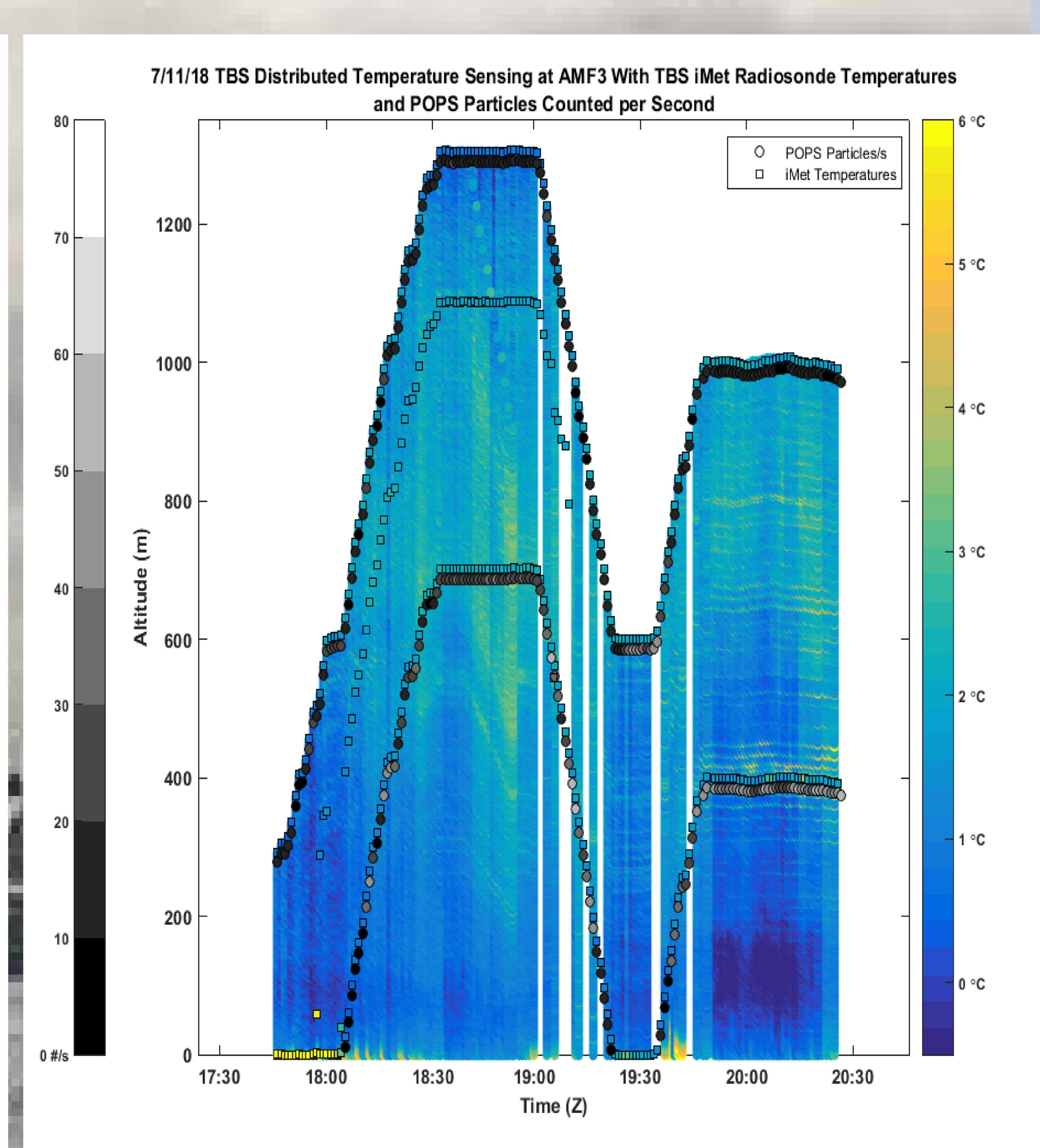
Aerosol Sensors		
	POPS	CPC
Detectable particle size range	140 nm – 3.0 µm	10 nm – >3.0 µm
Maximum particle concentration range with < 10% coincidence error	1,250 #/cm^3	100,000 #/cm3
Particle concentration accuracy	140 nm – 3.0 µm	+/- 20%
Sample flow rate	0.05 – 0.35 LPM	0.7 LPM
Operating temperature range	-40 °C to 35 °C	10 °C to 35 °C

Meteorological Sensors				
	iMet Radiosonde			
	Resolution	Accuracy	Range	Response Time
Pressure (hPa)	< 0.01	+/- 0.5	2 - 1070	< 1 s
Temperature (°C)	< 0.01	+/- 0.2	-95 to 50	2 s
Relative Humidity (%)	< 0.1	+/- 5	0 - 100	2 s @ 25 °C 60 s @ -35 °C
GPS Altitude		+/- 15 m	0 – 30+ km	
GPS Wind Velocity		+/- 1 m/s		
GPS Position		+/- 10 m		
	iMet XQ2			
	Resolution	Accuracy	Range	Response Time
Pressure (hPa)	0.01	+/- 1.5	10 - 1200	10 ms
Temperature (°C)	0.01	+/- 0.3	-90 to 50	1 s @ 5 m/s flow
Relative Humidity (%)	0.1	+/- 5	0 - 100	0.6 s @ 25 °C 5.2 s @ 5 °C 10.9 s @ -10 °C
GPS		+/- 12 m vertically		
	Distributed Temperature Sensing			
Temperature (°C)	sampling, 25 cm temperature 0.1 °C	+/- 0.08	-40 to 65	>= 5s

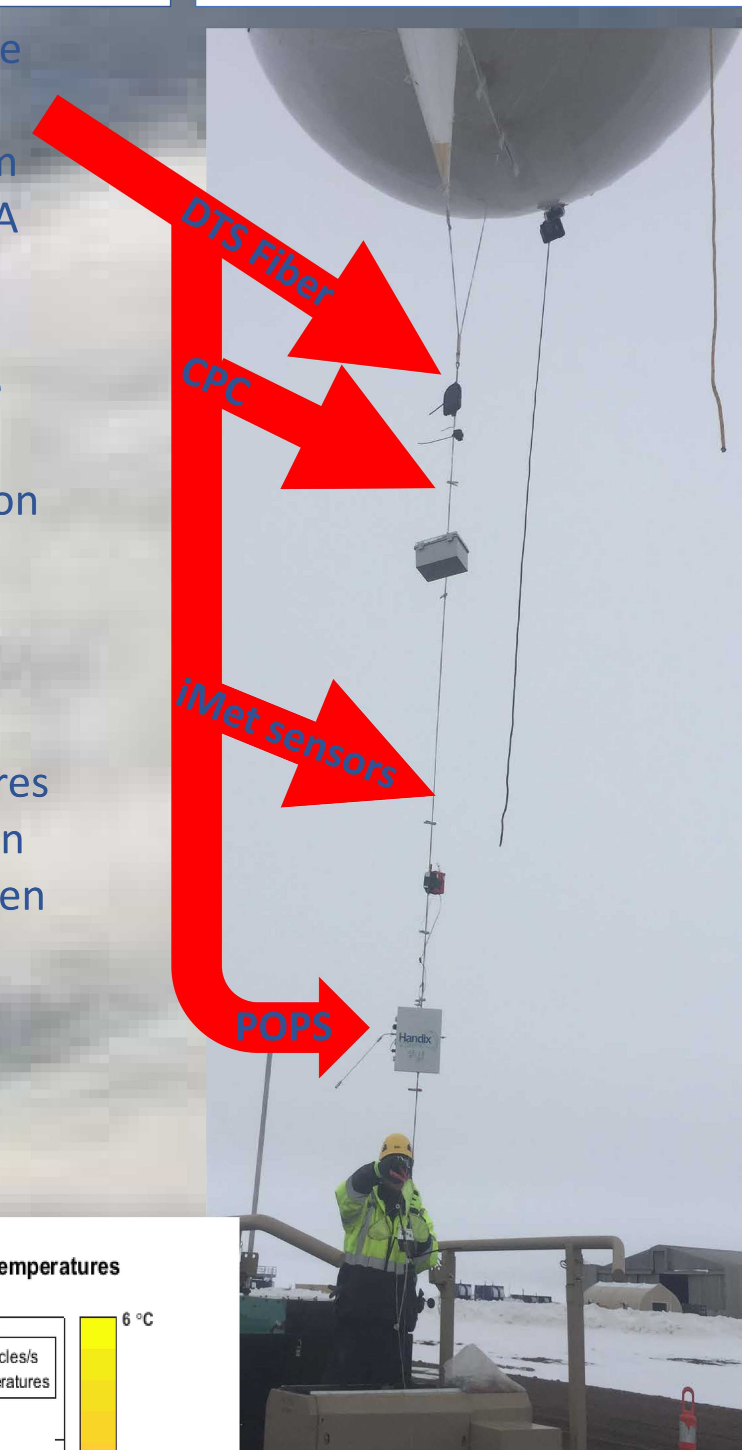
Distributed Temperature Sensing (DTS), POPS, iMet Radiosondes

- A Silixa XT **DTS** system was operated on the TBS using 50 micron multimode **optical fiber** suspended along the tether. Temperature measurements were collected every 30 – 60 s with a spatial resolution of 0.65 cm.
- Two **POPS** and one **CPC** were suspended along the tether. A CPC and POPS were typically operated in tandem just below the balloon in order to reach the maximum possible altitude, which was ideally above cloud top. A second POPS was generally operated lower on the tether near cloud base.
- Up to 3 **iMet-1 RSB radiosondes** and 3 iMet XQ2 sensors were spaced at least 100m apart along the tether.
- Example TBS datasets from the POPEYE campaign from 7/10/18 and 7/11/18 are shown below. On 7/10, the continuous DTS temperature profiles and iMet radiosonde temperatures reveal a cool layer at the surface below 100m with a 3-4 °C warmer layer between 150 and 800m, then another cooler layer above the inversion from 800m to 1 km. The AMF3 radiosonde launch at 23:30 measured a similar profile. The particle concentration per second measured by the POPS demonstrates increased concentration within the temperature inversion, with fewer particles above the inversion and in the surface-cooled layer. The surface layer warmed in the afternoon and the height of the inversion layer increased with time.
- On 7/11 the surface layer below 200 m was roughly 2 °C cooler than on the previous day, as were temperatures in the inversion layer between 200m and 1.2 km. POPS particle concentration per second within the inversion was approximately double that observed on the day prior. The height of the inversion layer decreases between 18:30 and 19:30, and a shallow ~50m deep inversion layer is isolated around 400m after 19:30 with a 200m deep cooler layer above. An iMet radiosonde on the tether corroborated this shallow inversion layer demonstrated by the DTS temperature profiles. POPS particle concentrations were elevated within this shallow warm layer and exhibited increased variability. Similar to the day prior, POPS particle concentrations decreased above and below the inversion.



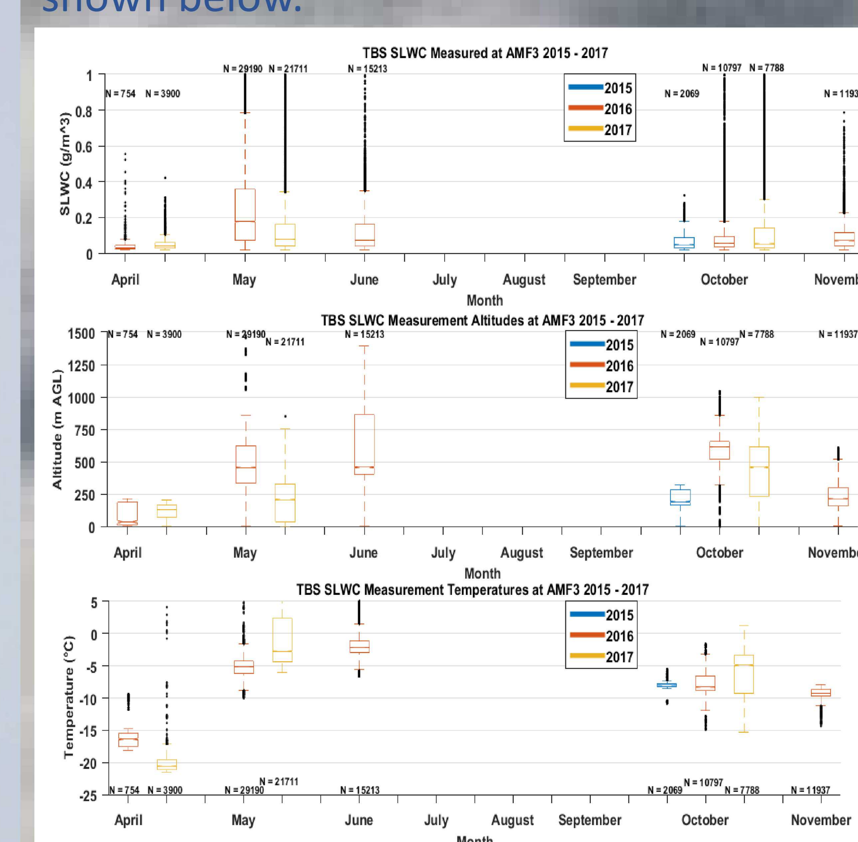


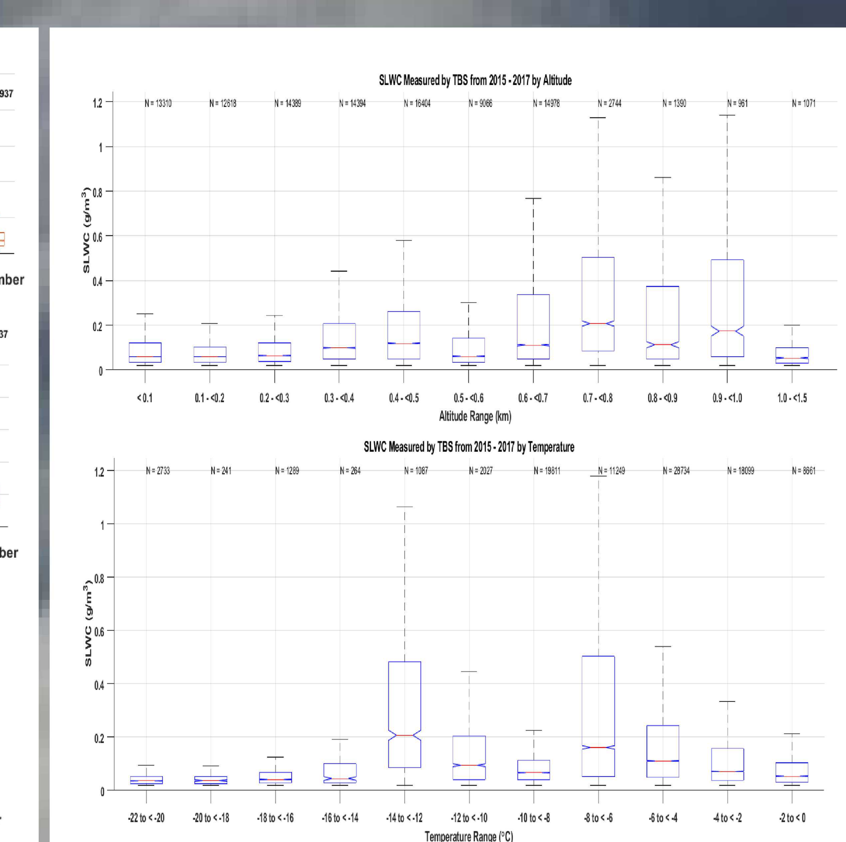
Supercooled Liquid Water Content (SLWC) Sondes



SLWC sondes were flown on the TBS from 2015 – 2017 and SLWC measurement altitudes and temperatures by month are shown below.

SLWC measured by sondes flown on the TBS by altitude and temperature from 2015 – 2017.





The **highest SLWC values were measured in the late spring** during May and June, with **lower values being measured in fall and early spring**. Measured **SLWC** values **increased** at flight altitudes **between 400 m and 1 km AGL and were lower below 400 m**. The **highest measured SLWC** values **occurred at temperatures above -14 °C and below -2 °C**. In respect to interannual variability of SLWC, the **mean SLWC** values in **three sequential Octobers** were **0.06, 0.10, and 0.14 g/m^3**, in **sequential Aprils** were **0.05 g/m^3**, and **sequential Mays** were **0.26 and 0.14 g/m^3**, respectively.

DTS Temperature Calibration Source & Rotary Joint Impact on Accuracy

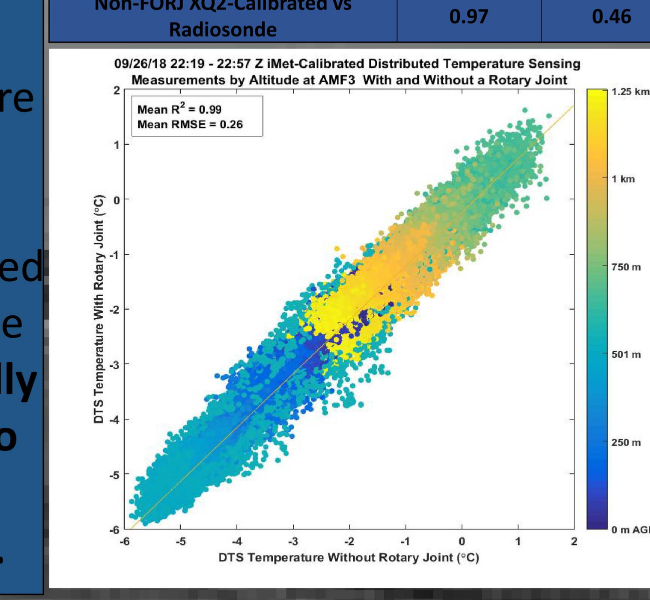
The DTS collected over 300 hours of 30s measurements with two fibers during the POPEYE campaign. One fiber did not include a rotary joint and was in use only when the balloon was not ascending or descending. The other fiber was installed with a fiber optic rotary joint (FORJ) and measured continuously.

The DTS measurements must be calibrated with a reference temperature sensor installed on the tether at the ends of the fibers. An iMet-1-RSB radiosonde and iMet XQ2 were both used to provide reference temperatures.

The DTS temperatures were averaged vertically over 5 meters in order to compare with temperatures from simultaneous radiosonde profiles.

The average correlation coefficients and RMSEs between the DTS fiber measurements calibrated with the iMet-1-RSB radiosonde or XQ2 sensor, collected with or without a FORJ, and free-flight radiosonde temperatures are shown in the table to the right. **The iMet-1-RSB and XQ2 sensors performed almost identically as reference temperatures. The FORJ and non-FORJ temperatures correlated to each other at .74 and had an RMSE of 0.5 °C. Both the FORJ and non-FORJ measurements correlated to radiosondes at 0.97 with RMSEs from 0.4 – 0.6 °C.**

	Correlation	RMSE (°C)
Average iMet-Calibrated to XQ2-Calibrated	0.76	0.49
Average iMet-Calibrated FORJ to Non-FORJ	0.74	0.51
Average XQ2-Calibrated FORJ to Non-FORJ	0.74	0.50
FORJ iMet-Calibrated vs Radiosonde	0.97	0.49
FORJ XQ2-Calibrated vs Radiosonde	0.97	0.60
Non-FORJ iMet-Calibrated vs Radiosonde	0.97	0.43
Non-FORJ XQ2-Calibrated vs Radiosonde	0.97	0.46



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