THE DE-ICING COMPARISON EXPERIMENT (D-ICE)

Christopher J. Cox[1,2], Sara M. Morris[1,2], and the D-ICE Team

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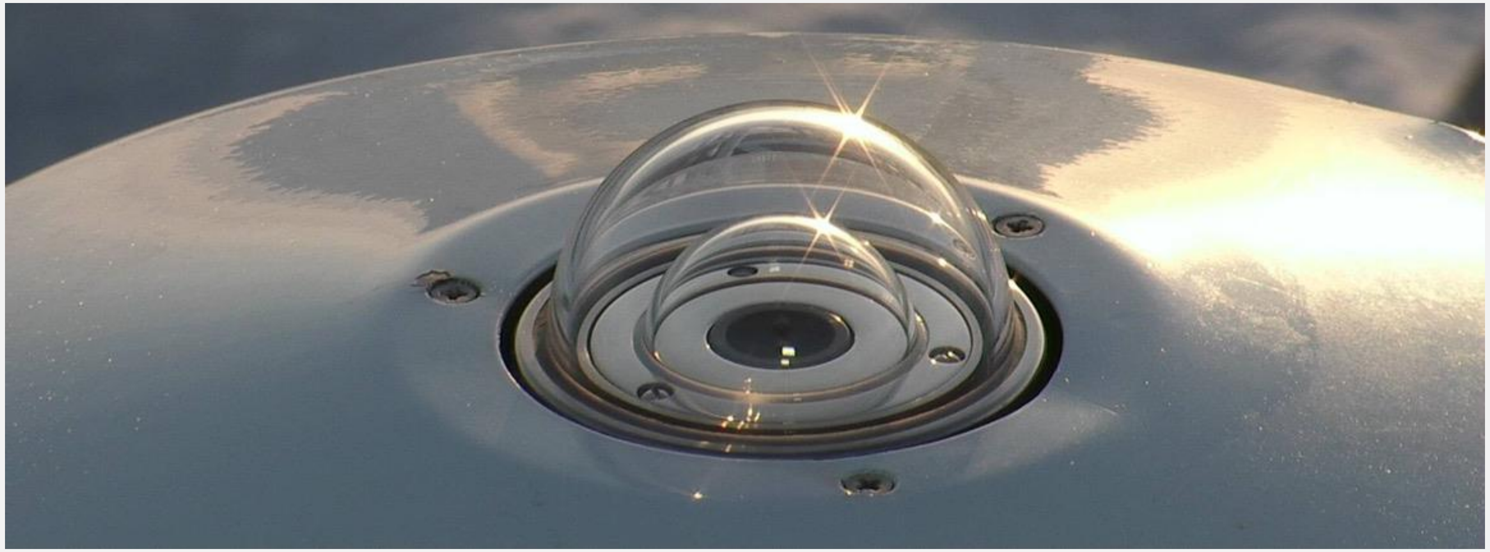
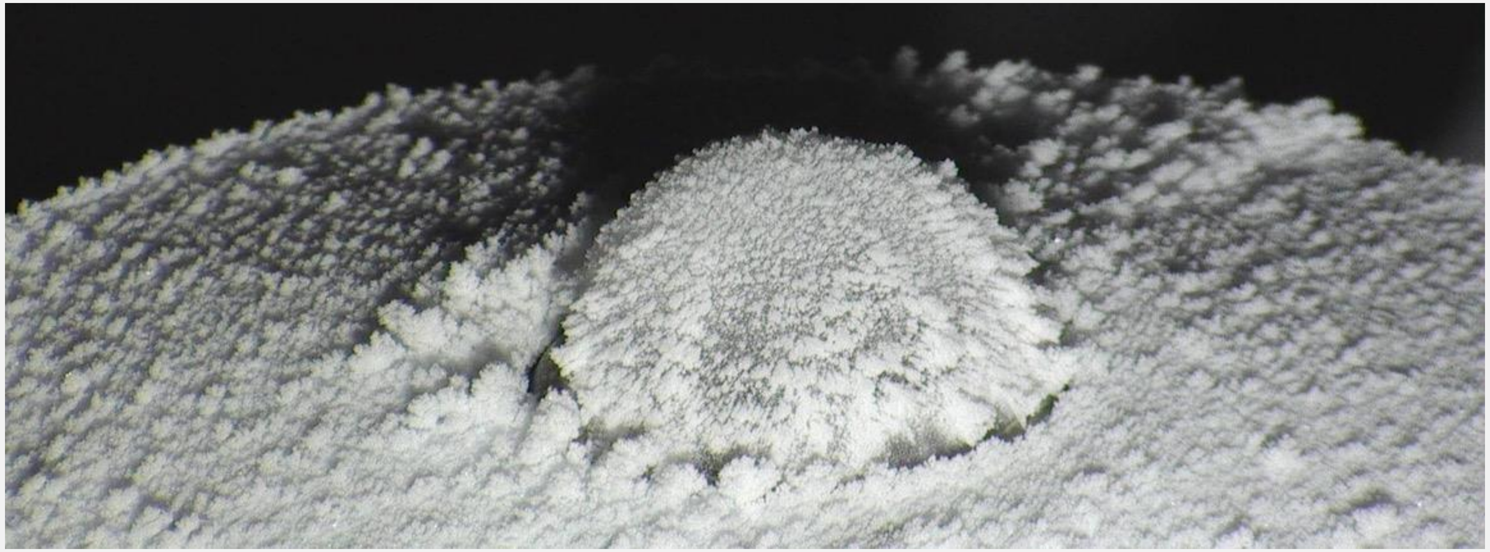
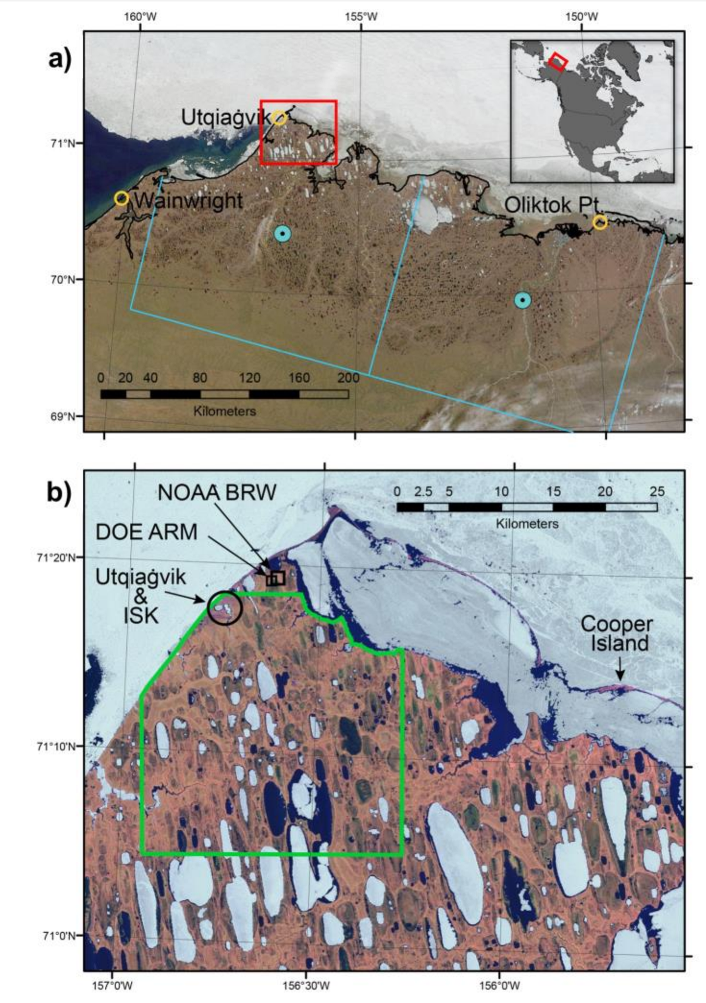
THE PROBLEM





BSRN INITIATIVE: *COLD CLIMATE ISSUES WG*

- Recognition of icing as a problem for radiometric measurements and attempts to mitigate go back at least to the 1960s (e.g., Koerner et al. 1963)
- Within BSRN this came up at the 2012 (Potsdam), 2014 (Bologna) and 2016 (Canberra)
- And there has been previous work (DoE ARM NSA Radiometer Campaign, efforts by individual institutions and commercial firms) largely focused on ventilation/heating, though largely also independently and in parallel
- Chris/Taneil and CIRES/NOAA volunteered to lead a CCIWG effort
- After Canberra, in August 2016 an internal organizational meeting was held within CIRES/NOAA
  - Resources (personnel, funds), location (Barrow, AK), tentative dates (2017-2018)
- In November 2016, CCIWG, BSRN and others were contacted about participation



COLLABORATORS

Institutes

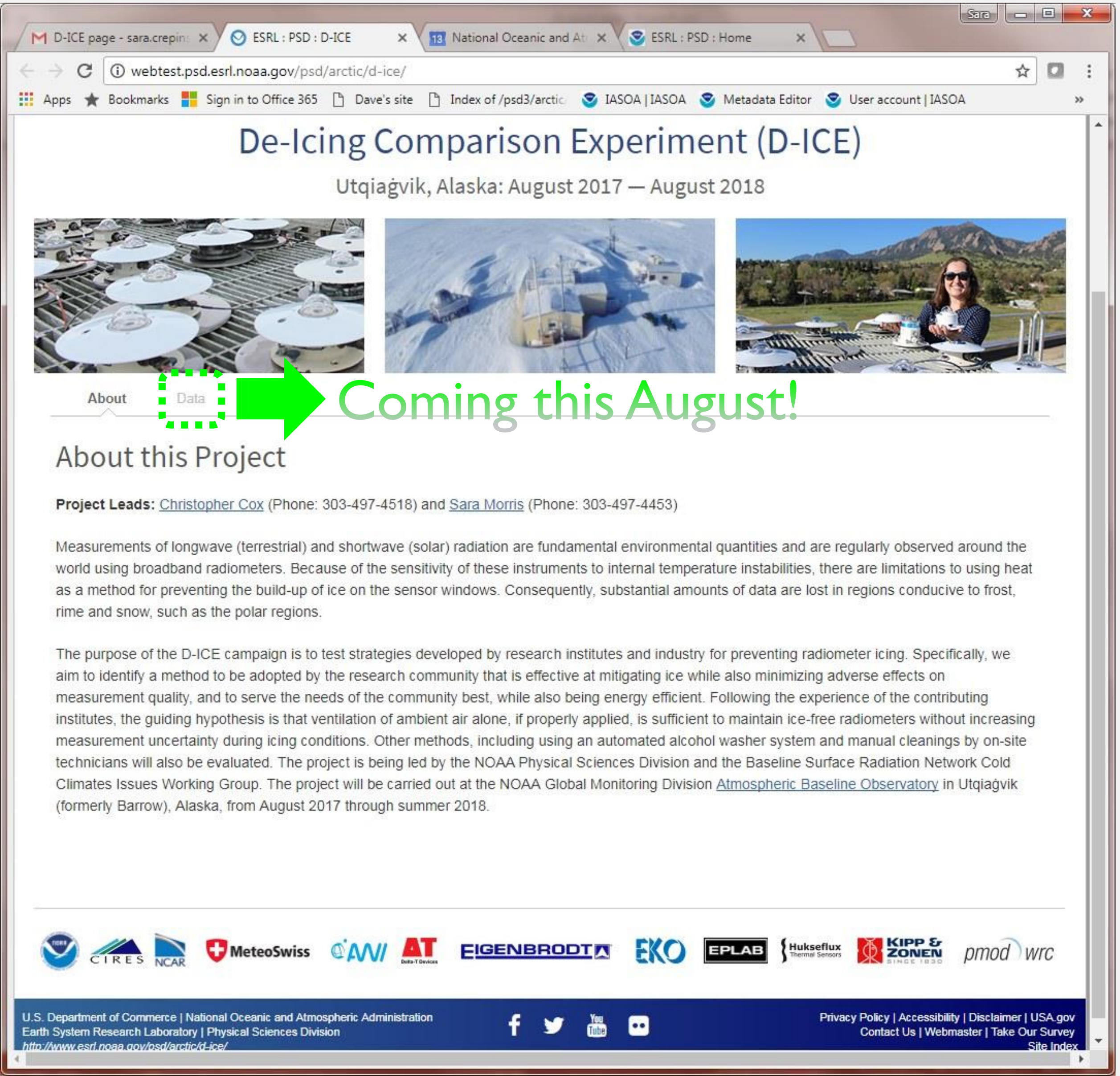
Alfred Wegener Institute (AWI), Hukseflux, MeteoSwiss, EKO Instruments, Eppley, Kipp and Zonen, Delta-T, U.S. DoE Atmospheric Radiation Measurement (ARM) Program, NCAR, NOAA PSD/POP, NOAA GMD/G-Rad, and PMOD-WRC.

People

Taneil Uttal (NOAA-PSD), Chuck Long (CIRES/NOAA-GMD), Allison McComiskey (NOAA-GMD), Jim Wendell (NOAA-GMD), Emiel Hall (CIRES/NOAA-GMD), Brian Vasel (NOAA-GMD), Christine Schultz (NOAA-GMD), Andy Clarke (NOAA-GMD), Robert Albee (NOAA-PSD), Ola Persson (NOAA-PSD), Bernd Loose (AWI), Gert König-Lango (AWI, retired), Holger Schmithüsen (AWI), Jörgen Konings (Hukseflux), Matt Martinsen (NOAA-GMD), Tom Kirk (Eppley), Julian Groebner (PMOD-WRC), Steven Semmer (NCAR), Steve Oncley (NCAR), Kurt Knudeson (NCAR), Victor Cassella (Kipp & Zonen), Dick Jenkins (Delta-T), Laurent Vuilleumier (MeteoSwiss), Matt Shupe (NOAA-PSD), Will Beuttell (EKO), Johan Booth (NOAA-GMD), Nick Lewis (Univ. Colorado), Meghan Helmberger (Univ. Colorado), Martin Stuefer (UAF), Fred Helsel (Sandia), David Oaks (Sandia), Ben Bishop (Sandia), Jim Mather (PNNL), Mark Ivey (Sandia), Walter Brower (ARM), Bryan Thomas (NOAA-GMD), Kevin Olivas (STC), Amanda Looze (NOAA), Ross Burgener (NOAA-GMD) and members of the BSRN Cold Climates Issues Working Group.

Website: https://www.esrl.noaa.gov/psd/arctic/d-ice/

Data Management Plan



De-Icing Comparison Experiment (D-ICE)

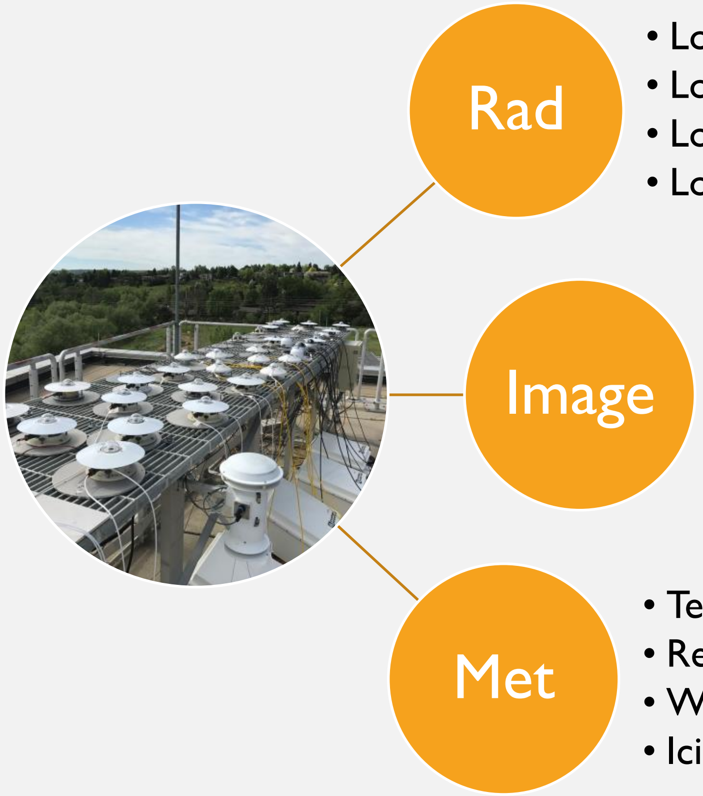
Utqiaġvik, Alaska: August 2017 — August 2018

About this Project

Project Leads: Christopher Cox (Phone: 303-497-4518) and Sara Morris (Phone: 303-497-4453)

Measurements of longwave (terrestrial) and shortwave (solar) radiation are fundamental environmental quantities and are regularly observed around the world using broadband radiometers. Because of the sensitivity of these instruments to internal temperature instabilities, there are limitations to using heat as a method for preventing the build-up of ice on the sensor windows. Consequently, substantial amounts of data are lost in regions conducive to frost, rime and snow, such as the polar regions.

The purpose of the D-ICE campaign is to test strategies developed by research institutes and industry for preventing radiometer icing. Specifically, we aim to identify a method to be adopted by the research community that is effective at mitigating ice while also minimizing adverse effects on measurement quality, and to serve the needs of the community best, while also being energy efficient. Following the experience of the contributing institutes, the guiding hypothesis is that ventilation of ambient air alone, if properly applied, is sufficient to maintain ice-free radiometers without increasing measurement uncertainty during icing conditions. Other methods, including using an automated alcohol washer system and manual cleanings by on-site technicians will also be evaluated. The project is being led by the NOAA Physical Sciences Division and the Baseline Surface Radiation Network Cold Climates Issues Working Group. The project will be carried out at the NOAA Global Monitoring Division Atmospheric Baseline Observatory in Utqiaġvik (formerly Barrow), Alaska, from August 2017 through summer 2018.



- Logger #4
- Logger #5
- Logger #6
- Logger #7

- CAM#1: NW of table
- CAM#2: SE of table
- CAM #3: tracker

- Temperature
- Relative Humidity
- Wind Spd/Dir
- Icing Probe??

- ➢ "Field" computer located in Boulder
- ➢ All data types (raw, product, etc.) publically available
- ➢ Raw data/images transferred daily to webpage
- ➢ Product (cal/QC) data transferred monthly to webpage
- ➢ DICE Datagrams (metadata) available on webpage
- ➢ Archive data/images to NCEI at end of campaign

NOAA Global Monitoring Division (GMD)
Barrow Atmospheric Baseline Observatory

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research

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D-ICE De-Icing Comparison Experiment

About | Science Objectives | Experimental Design | Details | Data | Data Browser | Webcam

About this Project

August 2017—August 2018 | Utqiaġvik, Alaska

Measurements of longwave (terrestrial) and shortwave (solar) radiation are fundamental environmental quantities and are regularly observed around the world using broadband radiometers. Because of the sensitivity of these instruments to internal temperature instabilities, there are limitations to using heat as a method for preventing the build-up of ice on the sensor windows. Consequently, substantial amounts of data are lost in regions conducive to frost, rime and snow, such as the polar regions.

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Project Leads

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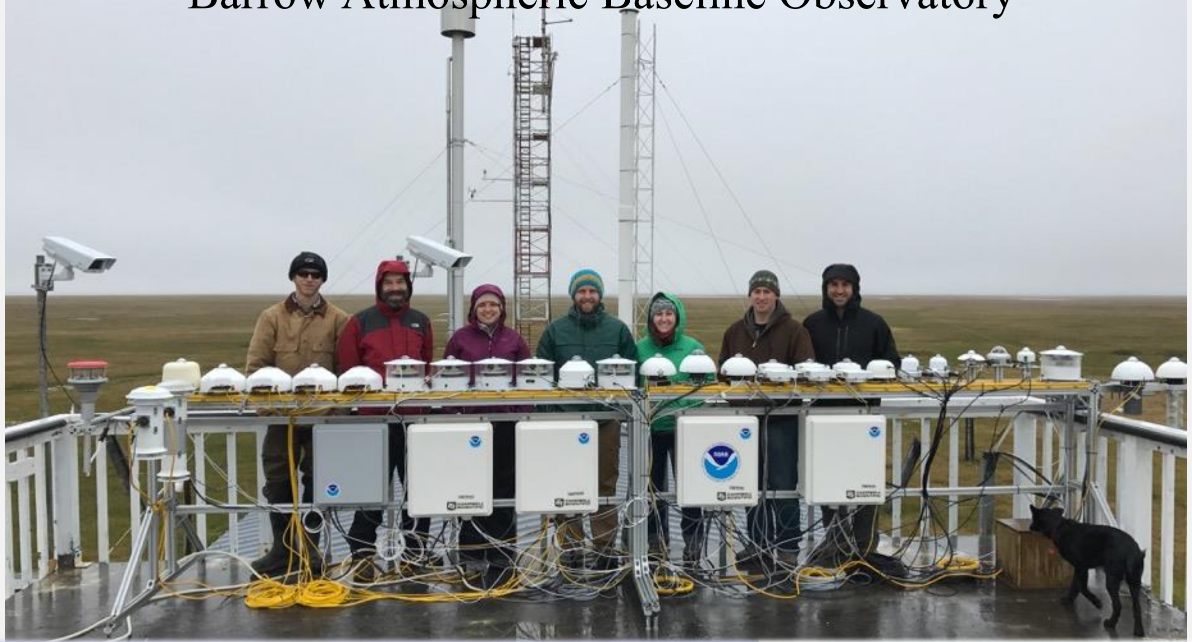
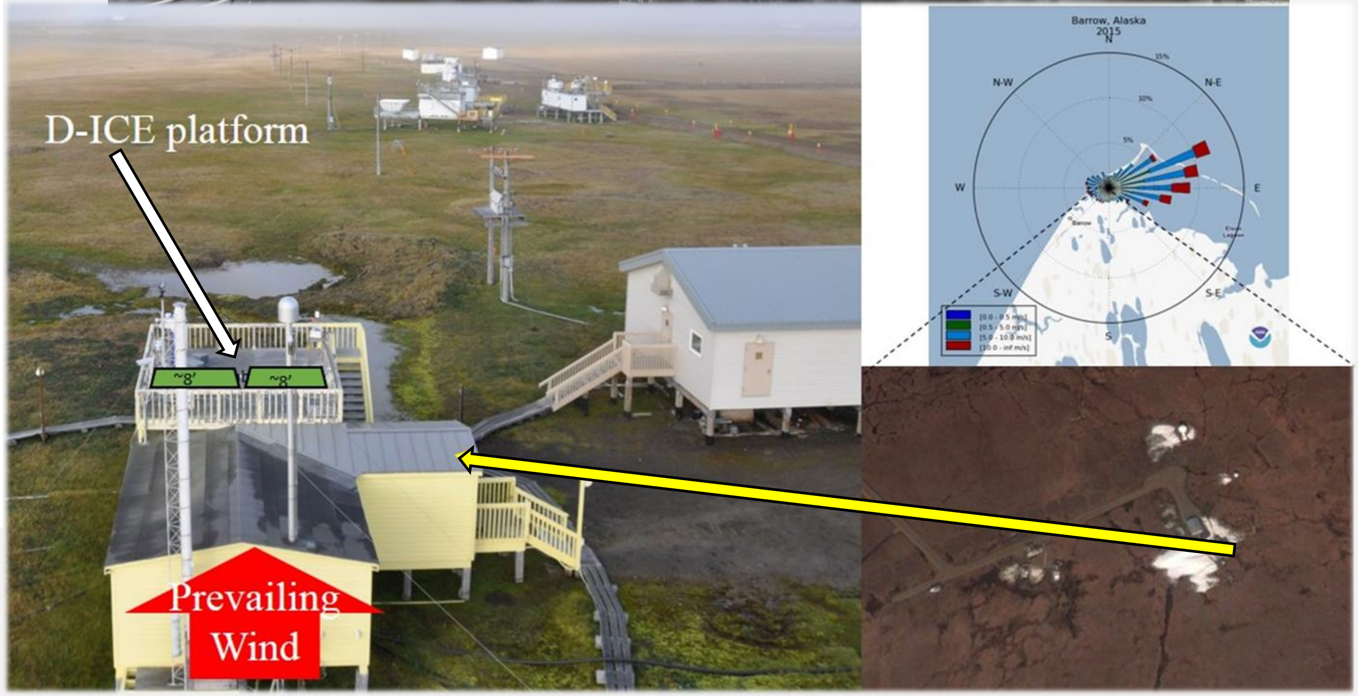
Follow our Blog at CIRES

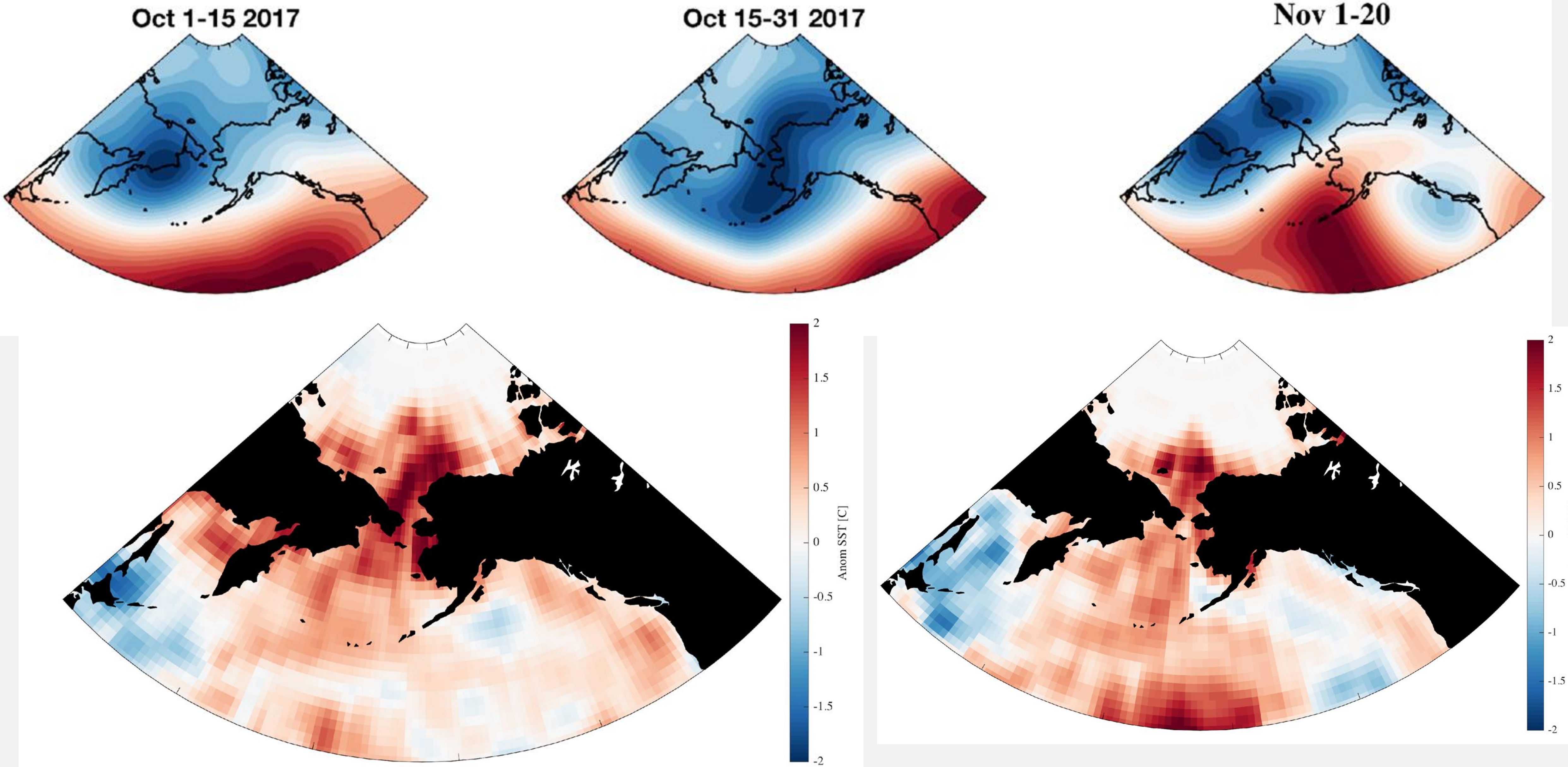




D-ICE Webpage: https://www.esrl.noaa.gov/psd/arctic/d-ice/

WELCOME TO D-ICE

Photo: Bryan Thomas (NOAA)


Oct 1-15 2017
Oct 15-31 2017
Nov 1-20
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Anom SST [C]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Anom SST [C]

CAM#1: JANUARY 28, 12 UTC

CAM#2: JANUARY 28, 12 UTC

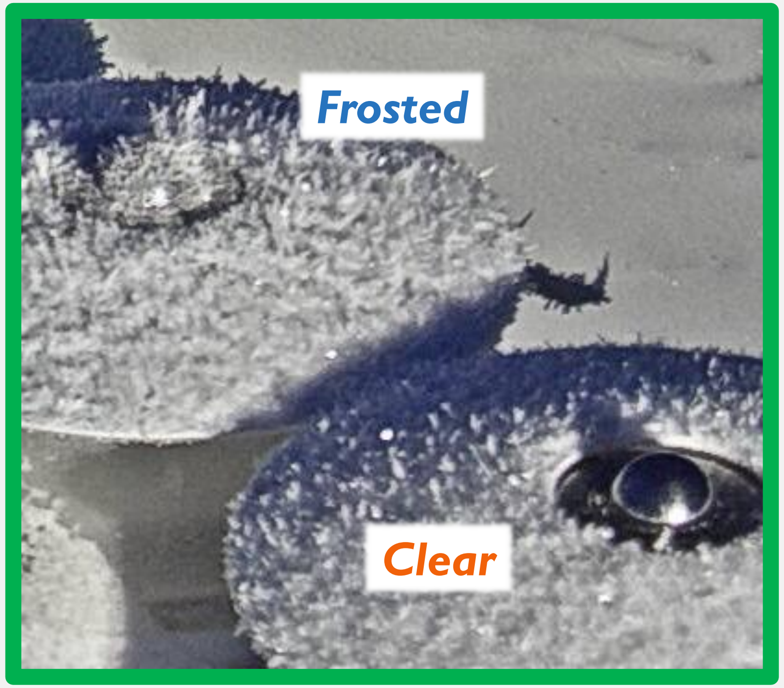
CAM#3: JANUARY 28, 12 UTC

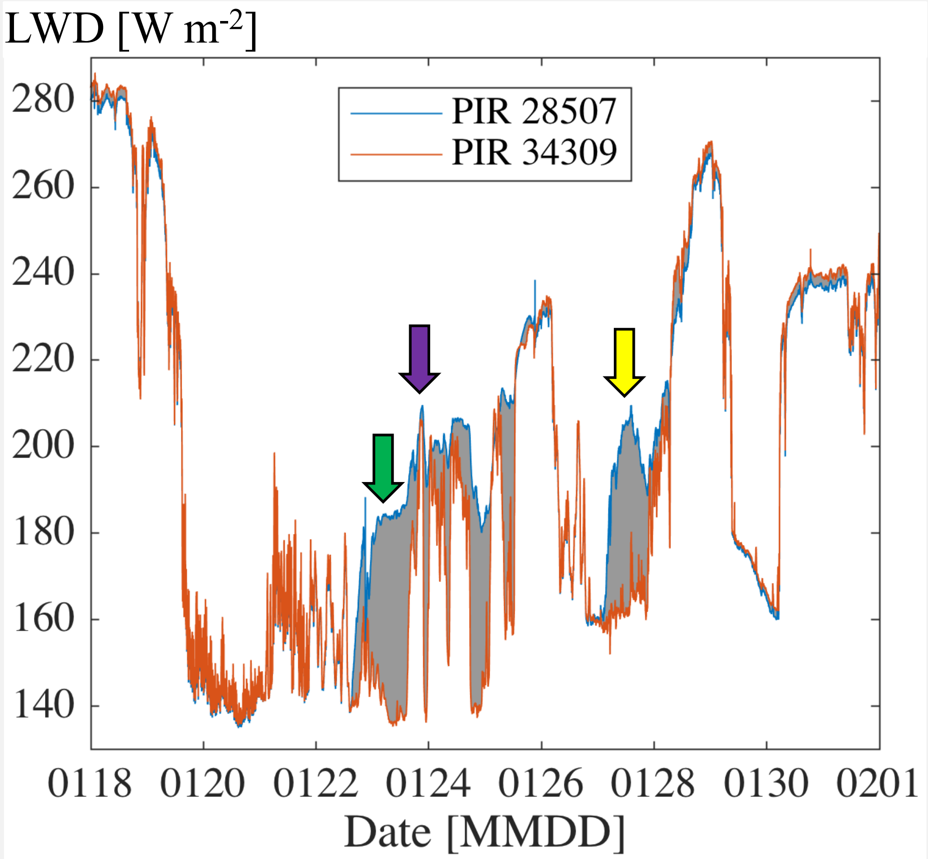
IMPACT OF VENTILATION

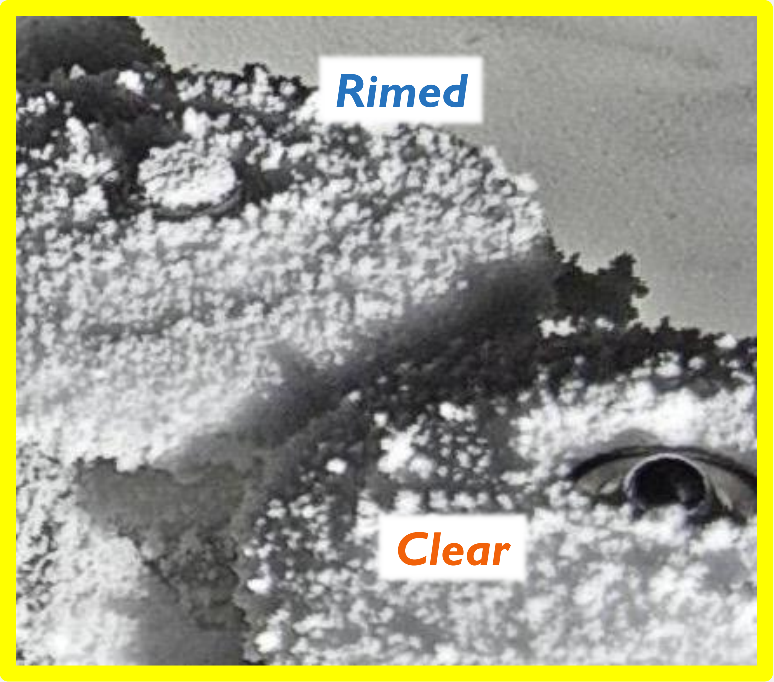
Ventilators Turned Off

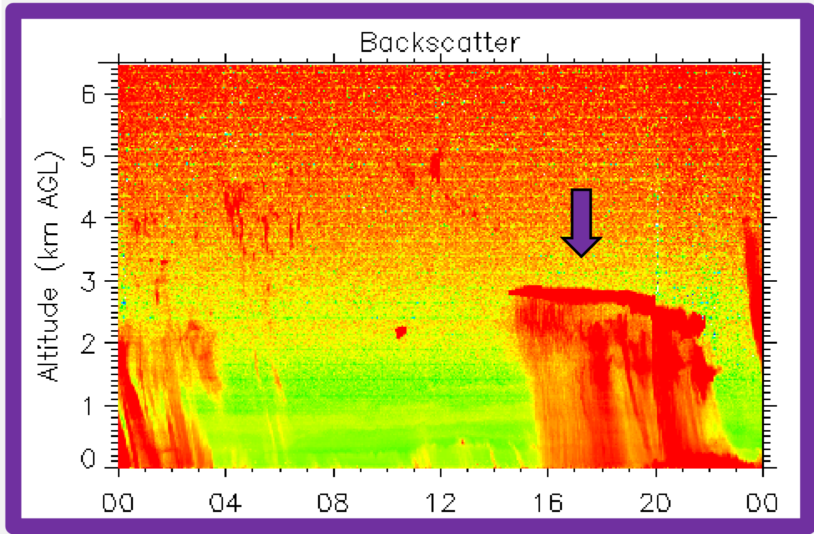
Ventilators Turned On (+8 hrs)

EXAMPLE FROM JANUARY 2018



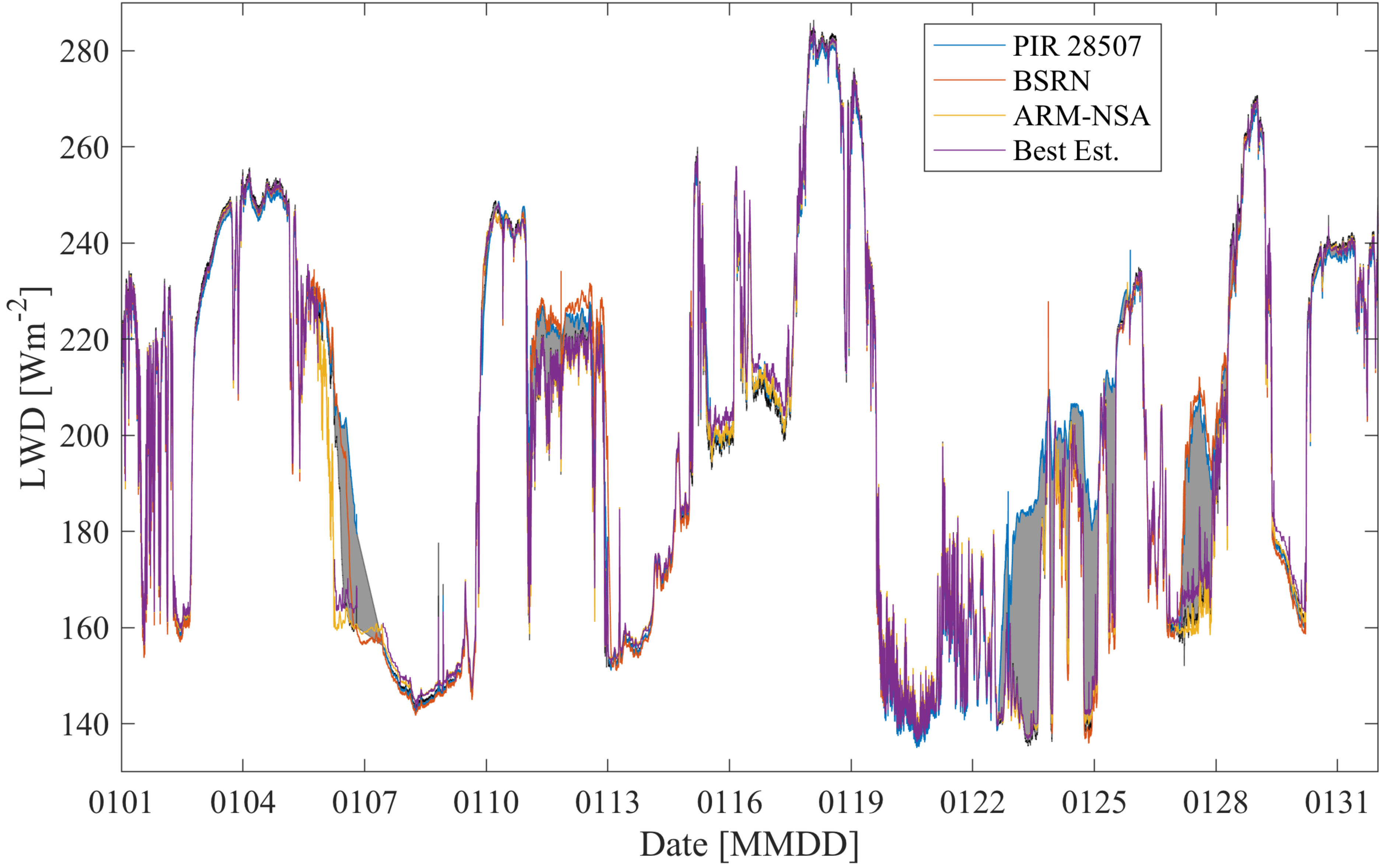






- Small modification to Eppley VEN significantly increases ice mitigation efficiency
- Biases for frosted or rimed pyrgeometers ~ **+50 W m^{-2}**
- Reduces to near 0 W m^{-2} under optically thick clouds (FCC ~63% during this period)

LWD icing biases: Smaller than expected!



January 2018

Unattended

D-ICE 28507: 203.5 Wm^{-2}

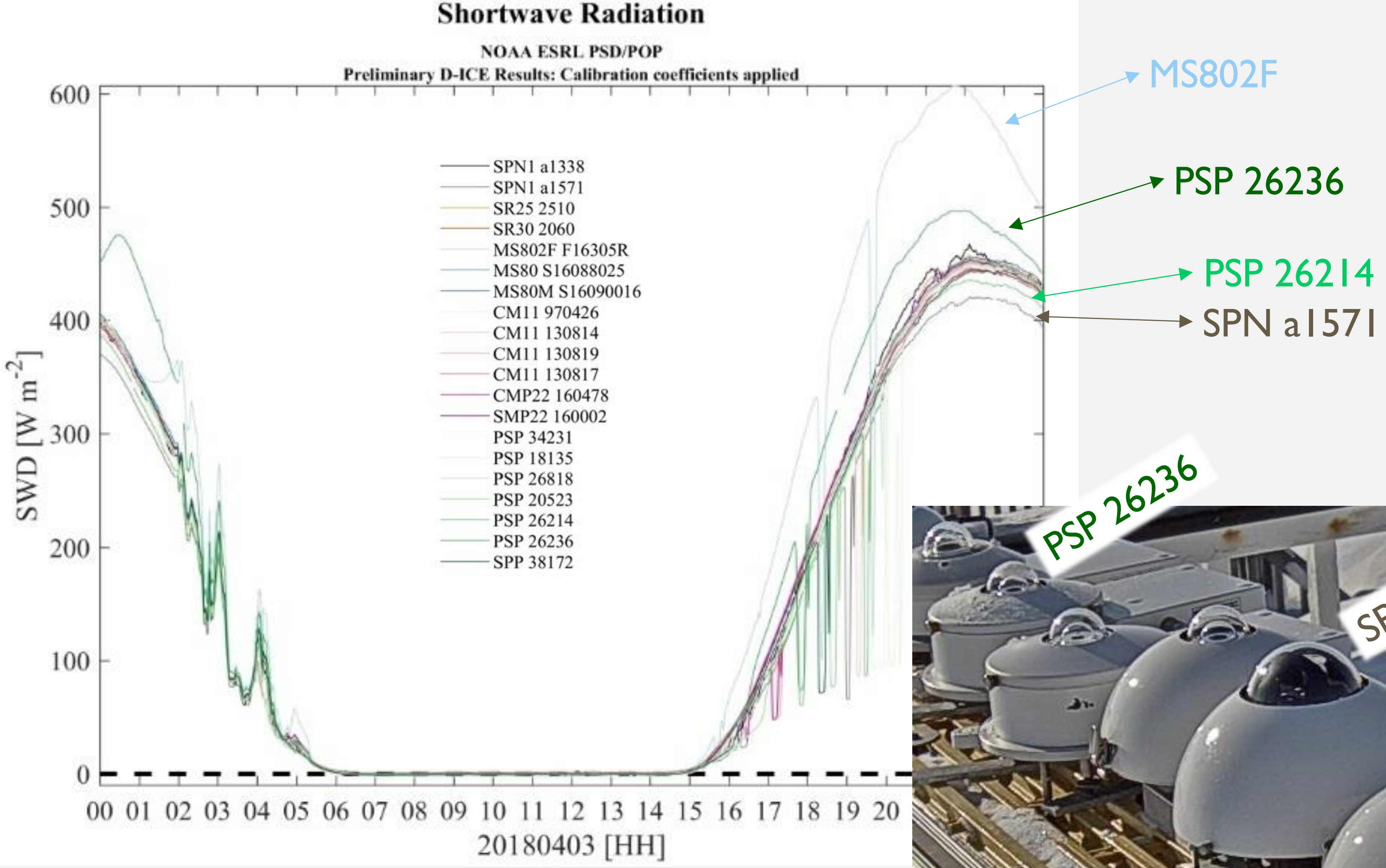
Operational

BSRN: 202.0 Wm^{-2}

ARM-NSA: 199.5 Wm^{-2}

Best Estimate Ice-Free

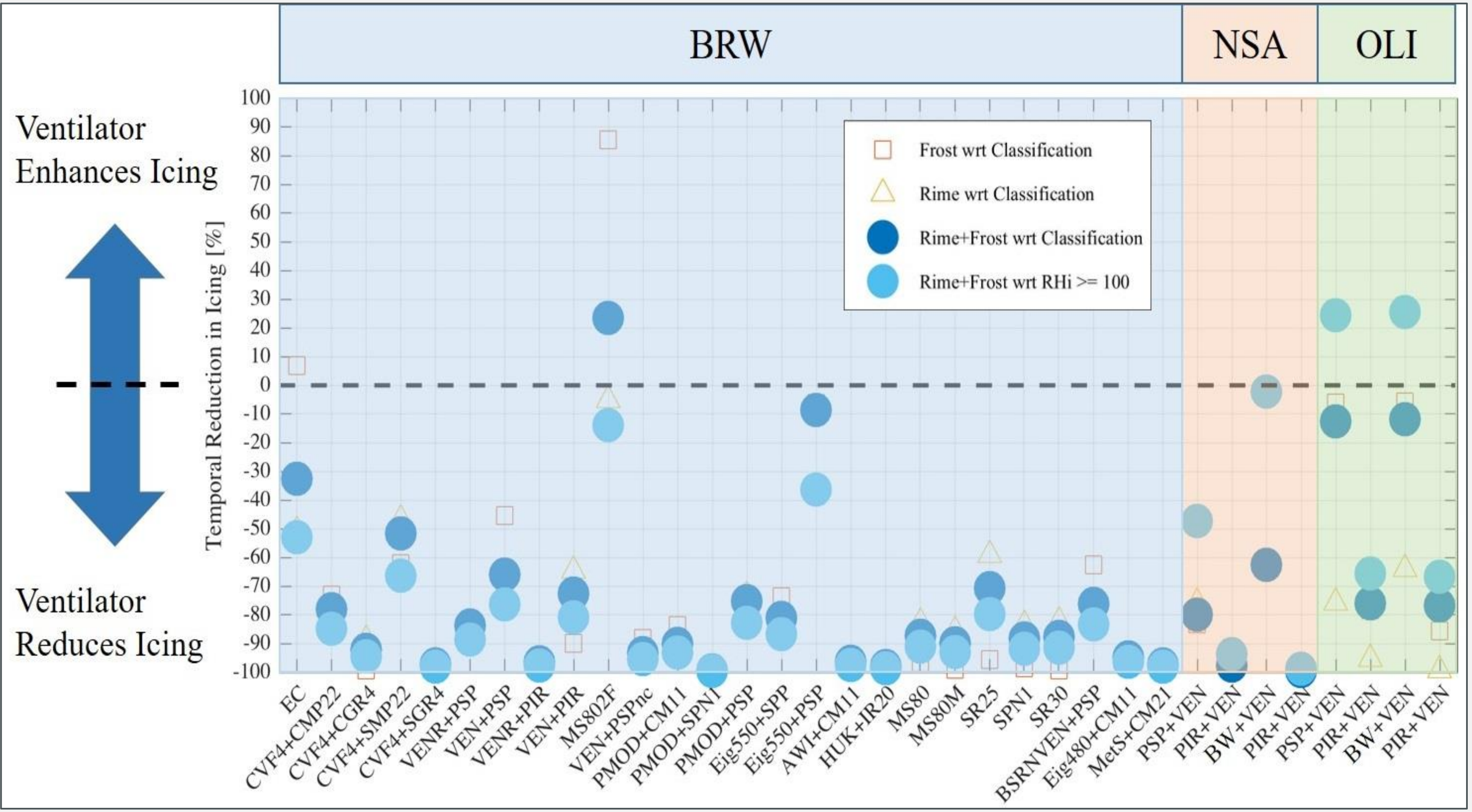
all D-ICE: 200.1 Wm^{-2}



APRIL 3RD, 2018

PRELIMINARY SWD RESULTS

VISUAL SCREENING



$$● = \left[\frac{t_{i\_iced}}{t_{exp\_iced}}\right] - 1$$

$\boldsymbol{t_{i\_iced}}$ is the time radiometer ***i*** was iced

$\boldsymbol{t_{exp\_iced}}$ is the time the natural icing condition was flagged either by classification or RH_i

<u>Dates analyzed: *Nov 2017 – Feb 2018*</u>

~ 288,000 radiometer images at D-ICE

~ 53,000 radiometer images at NSA

~ 54,000 radiometer images at OLI

<u>Visual Screening</u>

- Better at identifying ice on domes than classifying it (rime, frost …) or when icing conditions occurred
- t_{i_iced} is pretty good estimate
- t_{exp_iced} more uncertain (but applied uniformly to all *i* <u>at each site</u>)

PRELIMINARY RESULTS

- Aspiration of ambient air using a ventilator is a viable option for ice mitigation
  - Average improvement against rime/frost was 73 ± 31% amongst all systems
  - Need to identify the attributes of ventilators yield high performance
    - e.g., geometry: Better performance for pyrgeometers than pyranometers
  - Need to explain the physical mechanism
  - Additional heating is not likely necessary, though it is effective
- Instantaneous biases from ice of ~+50 Wm^{-2} observed in LWD and ~+150 Wm^{-2} in SWD
  - For LW, the bias in operational systems is small when averaged over time *at BRW*, in part because of high cloud cover
  - For SW??? TBD
- Cameras can provide useful real-time documentation of station status

CLEANING TECHNIQUES

Instrument Details

Table	Table Position	Radiometer Logger Box #	Radiometer Serial #	Ventilator Logger Box #	Ventilator Model or Serial #	Radiometer Measurement	Radiometer Manufacturer	Radiometer Model	*Radiometer Calibrations for D-ICE [μV/W/m²]*	Previous Factory Calibration (μV/W/m²)	Ventilation Manufacturer	Ventilation Quality / Quantity	Ventilation Frequency	Heat Applied (y/n)	Heat Quantity (Watts)	Heat Frequency
1	1	7	34231F3	6	ALERT	Shortwave	Eppley	PSP	***8.397***	8.41	EC, Alert	DC / 80 [cfs]	continuous	no	n/a	n/a
1	2	6	160478	6	171842	Shortwave	Kipp&Zonen	CMP22	***9.697***	9.74	Kipp&Zonen	DC / 4400 [rpm]	continuous	yes	5.5 [W]	continuous
1	3	6	160183	6	171840	Longwave	Kipp&Zonen	CGR4	***C1 = 9.545 C2 = 0.998***	9.4	Kipp&Zonen	DC / 4400 [rpm]	continuous	yes	5.5 [W]	continuous
1	4	6	160002	6	171843	Shortwave	Kipp&Zonen	SMP22	***original cal***	10.07	Kipp&Zonen	DC / 4400 [rpm]	continuous	yes	5.5 [W]	continuous
1	5	6	160008	6	171841	Longwave	Kipp&Zonen	SGR4	***original cal***	11.03	Kipp&Zonen	DC / 4400 [rpm]	continuous	yes	5.5 [W]	continuous
1	6	7	26818F3	7	V6 909-12, washers/dome lift	Shortwave	Eppley	PSP	***8.449***	8.57	Eppley	DC / 80 [cfs]	continuous	no	n/a	n/a
1	7	7	18135F3	7	V6 809	Shortwave	Eppley	PSP	***8.556***	8.65	Eppley	DC / 80 [cfs]	continuous	no	n/a	n/a
1	8	5	34309F3	7	V6 808, washers/dome lift	Longwave	Eppley, PSD	PIR	***C1 = 3.39 K = 3.78***	3.54	Eppley	DC / 80 [cfs]	continuous	no	n/a	n/a
1	9	5	28507F3	7	V6 689	Longwave	Eppley	PIR	***C1 = 3.68 K = 3.567***	3.76	Eppley	DC / 80 [cfs]	continuous	no	n/a	n/a
1	10	4	F16305R	4	MS-401FU	Shortwave	EKO	MS-802F	***7.056***	7.01	EKO	DC / 3000 [rpm]	continuous	no	n/a	n/a
1	11, do NOT clean	7	26214	5	V6 910	Shortwave	Eppley, NCAR	PSP	***8.13***	8.52	Eppley, lift shield	DC / 80 [cfs]	continuous	no	n/a	n/a
2	12	6	130814	5	PMOD	Shortwave	Kipp&Zonen, GMD	CM11	***8.327***	8.31	PMOD	DC / 4200 [rpm]	continuous	yes	8.16 [W]	continuous
2	13	5	A1571		GMD PMOD	Total, Diffuse	Delta-T, GMD	SPN	***factory set***	factory set	GMD, PMOD	DC / 80 [cfs]	continuous	via instrument	20 [W]	continuous
2	14	7	20523F3	5	PMOD	Shortwave	Eppley	PSP	***9.433***	9.67	PMOD	DC / 4200 [rpm]	continuous	yes	8.16 [W]	continuous
2	15	7	38172F3	4	0932153	Shortwave	Eppley	SPP	***7.756***	8.05	Eigenbrodt 550	DC / 2500 [rpm]	continuous	yes	14 [W]	n/a
2	16	7	26236	4	0931190	Shortwave	Eppley, NCAR	PSP	***8.627***	9.07	Eigenbrodt 550	DC / 2500 [rpm]	continuous	no	n/a	n/a
2	17	6	130819	4	0932088	Shortwave	Kipp&Zonen, GMD	CM11	***8.681***	8.7	Eigenbrodt 550 modified	DC / 2500 [rpm]	continuous	yes	14 [W]	continuous
2	18	4	4037	5	VU01	Longwave	Hukseflux	IR20-T1	***C1 = 10.144 C2 = 0.995***	10.13	Hukseflux	DC / 50 [m³/hr]	continuous	no	5-10 [W]	optional
2	19	4	S16088025	5	MV0117004	Shortwave	EKO	MS-80	***10.616***	10.64	EKO	DC / 3000 [rpm]	continuous	yes	7 [W]	continuous
2	20	6	S16090016	5	MV0117003	Shortwave	EKO	MS-80M	***10.772***	10.76	EKO	DC / 3000 [rpm]	continuous	yes	7 [W]	continuous
2	21	4	2510	none	none	Shortwave	Hukseflux	SR25-T1	***14.804***	14.87	none	n/a	n/a	no	n/a	n/a
2	22	4	A1338	none	none	Total, Diffuse	Delta-T	SPN	***factory set***	factory set	none	n/a	n/a	via instrument	20 [W]	continuous
2	23	6	2060	none	none	Shortwave	Hukseflux	SR30-D1	***original cal***	10.29	none	n/a	n/a	no	n/a	n/a
2	24, GMD BSRN	none		none		Shortwave	Eppley	PSP			Eppley					
2	25	6	130617	4	0932152	Shortwave	Kipp&Zonen, GMD	CM11	***8.741***	8.79	Eigenbrodt 480	DC / 3300 [rpm]	continuous	yes	25 [W]	continuous
2	26	5	970426	5 = fan 4 = heat	METEOSWISS	Shortwave	Meteo-Swiss	CM21	***19.808***	19.74	METEOSWISS	DC / 3450 [rpm]	continuous	yes	20 [W]	continuous
n/a	none	5	Icing Probe	none	Icing Probe	Ice accretion	Anasphere									
n/a	none		9297	none	none	Direct	Hukseflux	DR02-T1-10	***original cal***	16.5	none	n/a	n/a	no	n/a	n/a
n/a	*none*	*7*	*26226*		*SPARE*	*Shortwave*	*Eppley, NCAR*	*PSP*	***8.053***	*8.46*	*none*	*n/a*	*n/a*	*no*	*n/a*	*n/a*
n/a	none		999991		none	Direct	Kipp&Zonen	CHP1	***original cal***	7.25	none	n/a	n/a	no	n/a	optional
n/a	none		999992		none	Direct	Kipp&Zonen	CHP1	***original cal***	7.52	none	n/a	n/a	yes	5.5 [W]	continuous

PARTICIPANTS

EPLAB
BSRN
Delta-T Devices
EIGENBRODT
NOAA — National Oceanic and Atmospheric Administration, U.S. Department of Commerce
EKO Beyond Accuracy
Kipp & Zonen since 1830
pmod wrc
CIRES
Hukseflux Thermal Sensors
AWI
MeteoSwiss
ARM Climate Research Facility
Environment Canada
NCAR National Center for Atmospheric Research