Advancements in ARM's Instrumentation and Measurement Strategies

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U.S. Department of Energy | Office of Science

Thank You to Organizers

- Laura Riihimaki
- Jennifer Comstock
- Olga Mayol-Bracero
- Manajit Sengupta
- Aron Habte
- Gary Hodges
- Hagen Telg

Goal

- Provide a forum for the ARM/ASR communities to engage in discussions about recent **successes**, ongoing **challenges**, and **future** directions for ARM's instrumentation.

Time (ET)	Talks	Presenter
10:45-10:50	Introduction	Adam Theisen
10:50-10:55	ECOR and SEBS Upgrades	Ryan Sullivan
10:55-11:00	SONDE Humidity Chamber and Ecosonde Testing	Evan Keeler
11:00-11:05	CSPHOT (Lunar mode, precip update)	Lynn Ma
11:05-11:10	All-Sky Imager	Donna Flynn
11:10-11:25	NSA Snow Measurements	Matthew Sturm/Jennifer Delamere
11:25-11:40	Discussion on Measurement Gaps and Community Needs	
11:40-11:45	Distributed aerosol sensors	Sarah Petters and Markus Petters
11:45-11:50	New Aerosol Node and Flux Capabilities	Ashish Singh
11:50-12:00	Radiometer quality-control for snowy environments	Daniel Feldman
12:00-12:10	Radiometer Upgrades	Aron Habte, Shawn Jaker, Manajit Sengupta
12:10-12:15	Cavity Update	Ibrahim Reda
12:15-12:25	New RadSys Radiometer Systems for SE Tower	Hagen Telg and Ben Sheffer
12:25-12:45	Discussion on Measurement Gaps and Community Needs	

6 MARCH - 2025 ARM/ASR PI MEETING
ADVANCEMENT IN ARM’S INSTRUMENTATION AND MEASUREMENT STRATEGIES

UPDATES TO THE ARM NEAR SURFACE TURBULENT FLUX SYSTEMS

Ryan Sullivan (rcsullivan@anl.gov)
Argonne National Laboratory

U.S. DEPARTMENT OF ENERGY
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Argonne NATIONAL LABORATORY

EBBR

Energy Balance Bowen Ratio system

1992 – 2024

ECOR -> ECORSF: ECOR WITH SMARTFLUX

- SGP in 2019, ENA/NSA/AMFs completed in 2024
- EddyPro corrected fluxes in near real time, no VAP needed
- Validation experiments:
  - ECORSF v ECOR-like system at FermiLab
  - Roving AmeriFlux PECS-like system v ECORSF at SGP

- QCECOR update: Fully corrected CO_2 fluxes at all ARM ECOR sites

SEBS UPGRADE

- AMF1 to CRG -> 4 SEBS; AMF3 to BNF -> 6 SEBS
- Stevens HydraProbes and HukseFlux heat flow plates replace REBS Inc.
  - Soil moisture in volumetric units
  - Soil temperature at 2.5 cm
- CNR4 net radiometer and Vaisala rain detector unchanged
- Replacing SGP, ENA, NSA, and AMF2 requested (ENG0004909)

Questions: rcsullivan@anl.gov

Mentor team:

Sujan Pal, Jenni Kyrouac, and Evan Keeler

Improvements to the ARM SONDE Network

EVAN KEELER

Argonne National Laboratory

RS-41SGPE “Eco-sonde” Characterization

- New eco-friendly line of radiosondes released by Vaisala
  - Same sensor package, new housing
  - 66% less non-biodegradable plastics
  - Biodegradable twine
- Evaluating/Characterizing 40 of these sondes at SGP and NSA
  - 10 dual flights with current sondes, point-to-point comparison
  - 25 flights in targeted weather conditions
  - 5 sondes placed at NSA to explore decomposition
- Note: This is not a full network switch to the eco-sondes, we just want to establish a level of DQ comfort for future use.

North Slope of Alaska Autosonde Upgrade

- Installed the Vaisala AS41 in Sept. 2022 to replace AS15
- Large improvements in reliability
  - AS41 uses mechanical actuators rather than pneumatic
  - Many updated designs to better combat the harsh environment in NSA
- Nearly triple the radiosonde capacity
- Upgraded MAWS

Sharing Data with GTS Partners

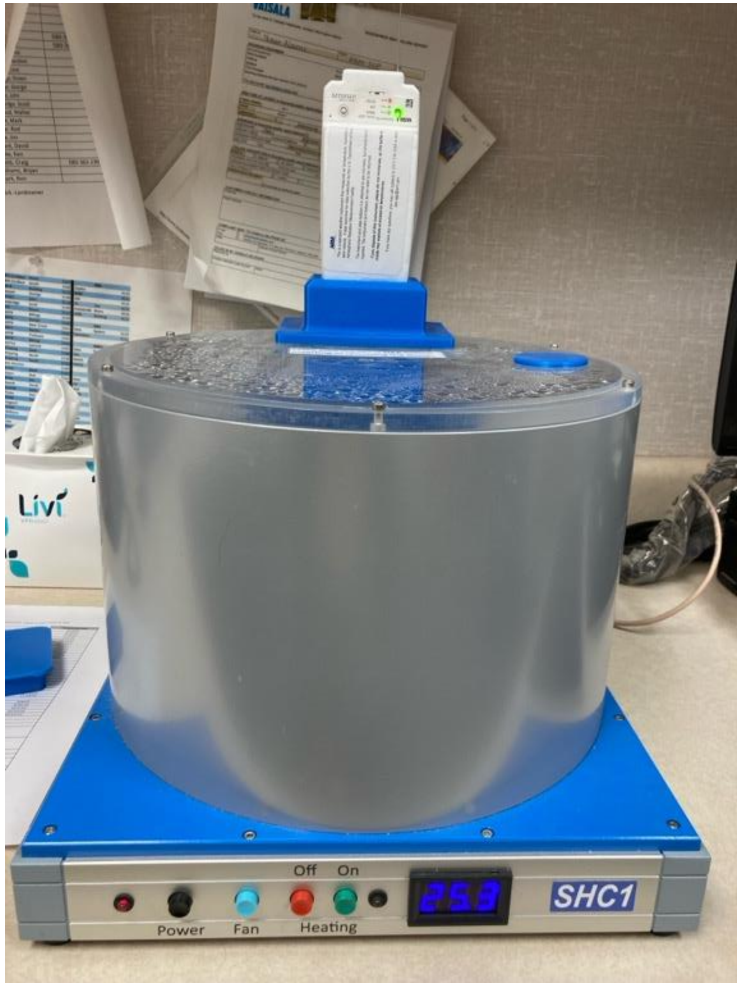
- Worked closely with NOAA partners to establish a data pipeline
  - Generating dedicated WMO IDs for our mobile facilities.
  - Methods for updating metadata when sites move
- Highly requested at most AMF campaigns
  - Operational Forecasting
  - NWP Research

- Current GTS products generated by ARM:
  - SGP C1 (WMO 74646)
  - NSA C1 (WMO 70026)
  - AMF2 CAPE-K M1 (WMO 95954)
  - AMF3 BNF M1 (WMO 72800)
- Future GTS products (coming very soon):
  - CRG M1 (WMO 72801)
  - CRG S2 (WMO 72802)

Thanks to the ARM Data Center for the massive assist with this project!

Standard Humidity Chamber (SHC)

- SGP, ENA, and NSA are GRUAN member stations
- Manufacturer independent ground check is a GRUAN certified site requirement
- ARM implemented SHC usage at SGP, ENA, and NSA manual launches in late 2024.
- Benefits
  - Additional level of ground check prior to launch > earlier systematic error detection
  - Improved uncertainty profiles within the GRUAN Data Products



ARM

CLIMATE RESEARCH FACILITY

Questions, comments, suggestions don’t hesitate to reach out!

ekeeler@anl.gov

Cimel Sun Photometer (CSPHOT)

Deployment of Triple-Mode Sun, Moon, and Sky Radiometers

- ARM has deployed the new triple-mode Sun, Moon, and Sky radiometers across all ARM sites since February 2021. This new model enhances atmospheric measurements, including:
  - Direct Sun Observations – Aerosol Optical Depth (AOD) and Precipitable Water Vapor (PWV).
  - Direct Night-time Moon Observations – AOD and PWV, improving nighttime atmospheric monitoring.
- Recent Improvements :
  - **Expanded Lunar AOD Measurements** – AOD data collection now extends from daytime to nighttime during the first and full moon phases, provided the sky is clear.
  - **Optimized Data Processing** – All Lunar AOD data have been reprocessed without the "provisional" designation using the latest algorithm, significantly improving data quality within AERONET.
  - **Complete Data Archival** – All ARM Lunar AOD data have been fully reprocessed and archived as of February 2025.
- These advancements ensure higher accuracy, extended measurement capabilities, and improved data reliability for atmospheric and climate research

Enhanced Optical Wet Sensor for Cimels

All Cimels are equipped with metal water sensors, which are susceptible to erosion under harsh weather conditions. The new optical wet sensor overcomes these challenges with the following key features:

- **Increased Sensitivity** – Detects moisture more accurately, from rain to mist.
- **Enhanced Durability** – A protective cover shields sensor components from environmental damage.
- **Cost-Effective Solution** – Reduced replacement costs improve long-term efficiency.

This upgrade ensures greater reliability and longevity for Cimel water sensors.

Original wet sensor

Optical wet sensor

All Sky Imager (ASI)

DONNA FLYNN

NSA Snow Measurements

STURM AND DELAMERE

Open Discussion on Instrument Gaps and Needs

Distributed Aerosol Sensors

SARAH PETTERS

Development of mini-AOS and Aerosol Flux System for AMF3 BNF: Expanding ARM's Multi-Scale Observations

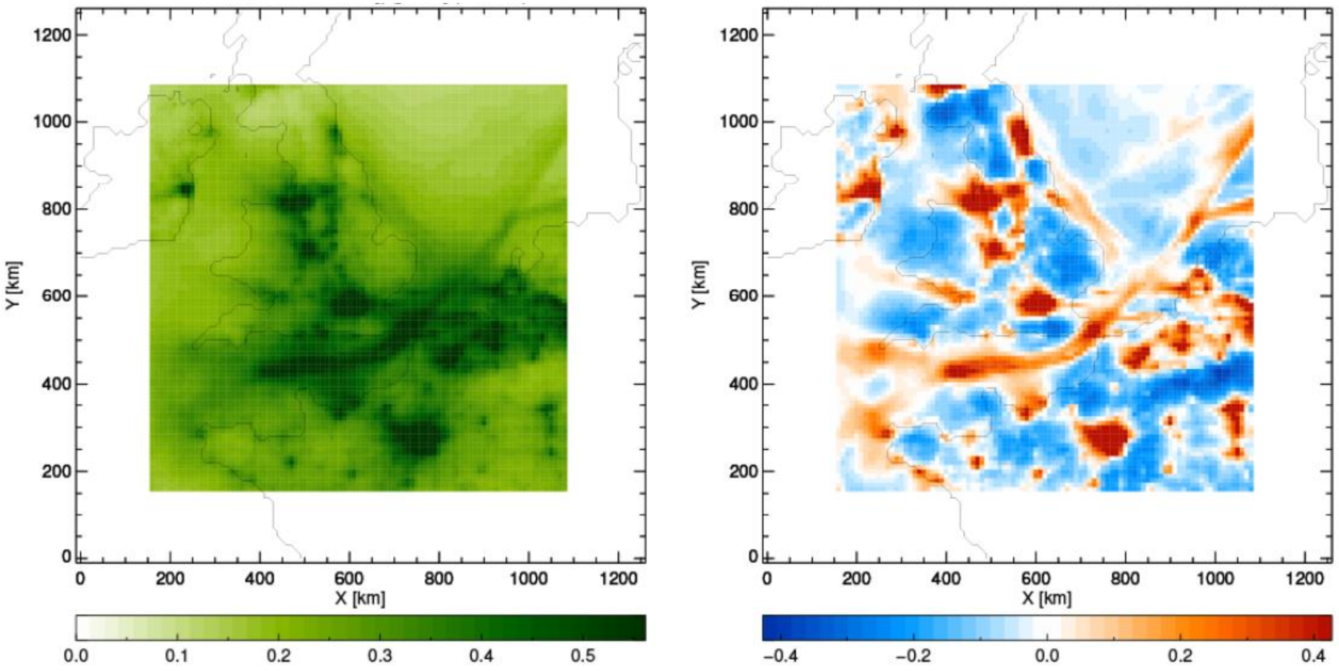
Ashish Singh, Scott Smith, Andrew McMahon, Chris Hayes, Delano De Oliveira

ARM-ASR, 2025/03/06

Motivation: Capturing Aerosol Spatial Heterogeneity and its Drivers

Multi-scale measurements are essential for resolving spatial heterogeneity.

Monthly surface BC conc.   Relative spatial sampling error



Representativeness errors (spatial and temporal)

Sub-grid variability→ aerosol process controls

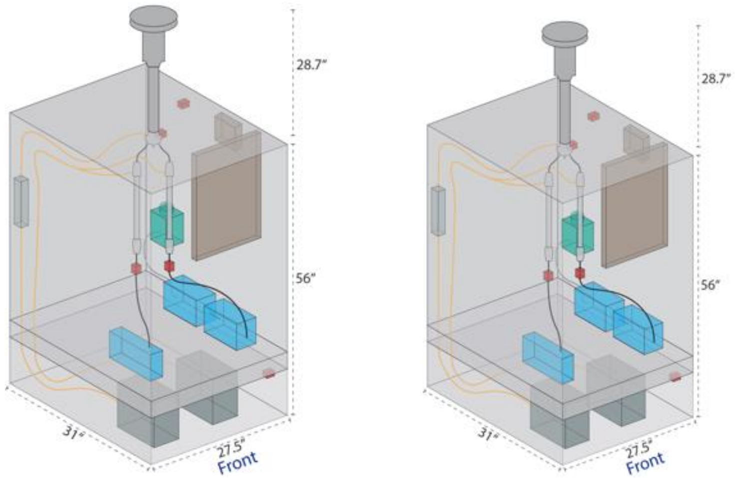
Model-Observation bias

Schutgens et al., 2016

Expanding Multi-Scale Observations at AMF3 BNF

Horizontal Domain

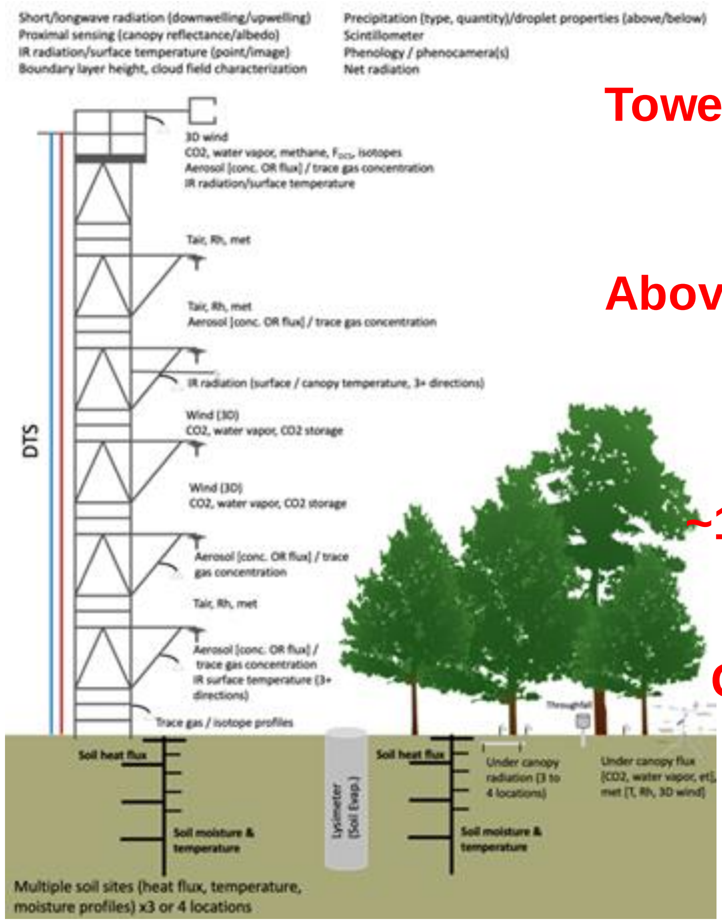
Distributed Sensor Node: Mini-Aerosol Obs. Sys. (mini-AOS)



2 nodes- for 2 supplementary sites

Vertical Domain

Aerosol Flux System (AFS)



Tower top

Above Canopy

~10 meters

Ground

Brookhaven National Laboratory

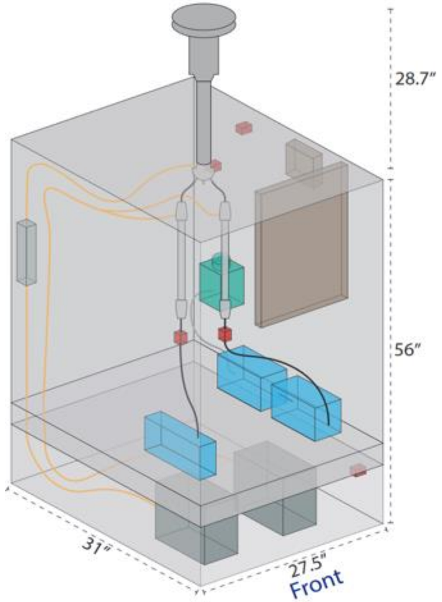
Mini-AOS is part of the Tiered Network of AOS

Tier 1: AOS

- Large footprint: 6 m x 3 m x 3 m
- Highest quality instrumentation
- 10-20 instruments
- Process studies

Intermediate Tier: “mini-AOS”

- Small footprint: 1 m x 1 m x 2 m
- Miniaturized instrumentation
- 4-5 instruments
- Budgets, spatio-temporal scaling



In development for AMF3 BNF

Baseline Tier: “micro-AOS”

- Very small footprint: 0.5 m x 0.5 m x 1 m
- Lower-complexity instrumentation
- 1-2 instruments
- Spatio-temporal scaling

SGP POPsNET
AMF1 POPsNET

BNF Mini-AOS: Aerosol Size Distribution (10 nm – 10 µm)

AOS vs Mini-AOS

First mini-AOS is currently in-dev.

Instrument & System Uncertainty: Mini-AOS & AOS Bias Assessment ??

Data Products Include:

- **Size Distribution** with transmission efficiency correction
- **Metadata:** Sampling configuration, calibration, and validation

Mini-AOS Operations:

- ARM Data Quality (DQ) Control, QA/QC
- Remote Access & Onsite Infrastructure Management

Brookhaven National Laboratory

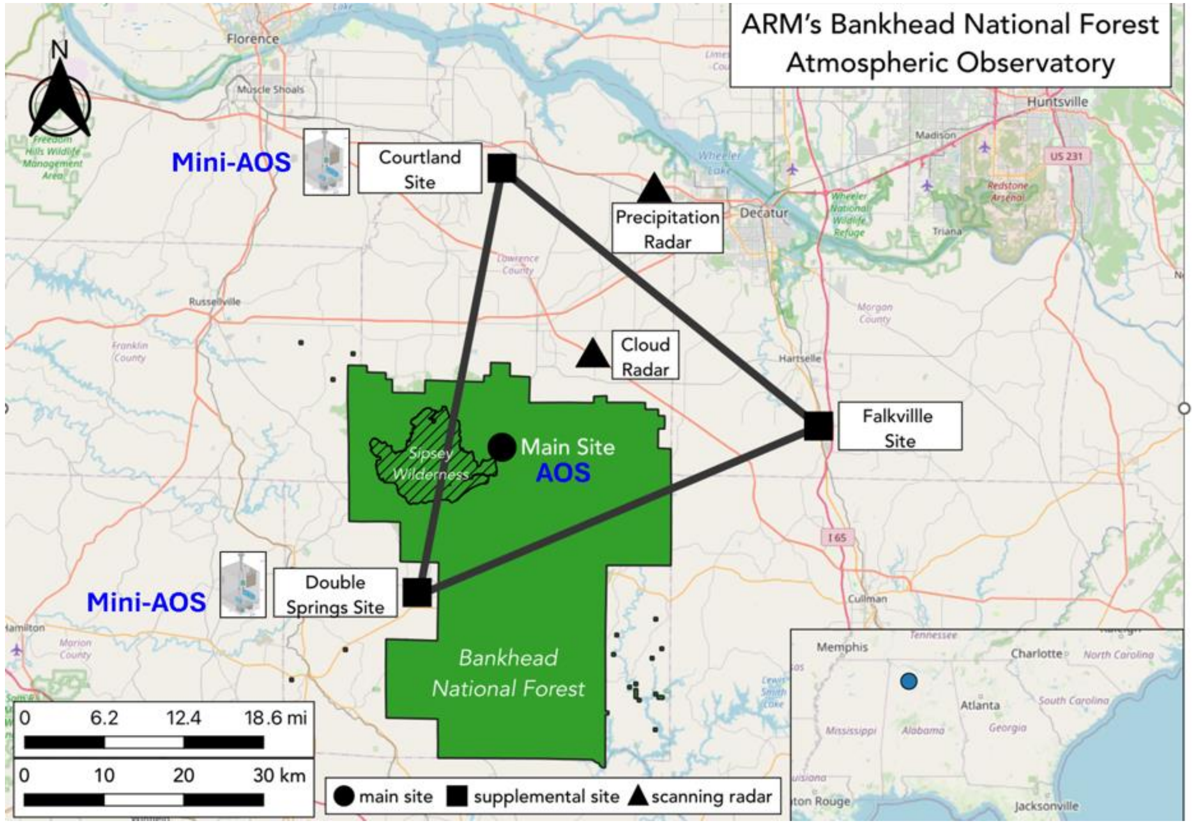
First mini-AOS: FY26 for field observations

Development time

- **FY24/25:**Develop & Test mini-AOS 1
- **FY 26:**Deploy mini-AOS1
- **FY26/27:**Develop & Test mini-AOS 2

Deployment plans?

- Two supplementary sites
- Continuous operation
- Data access/availability mirror AOS
- Calibration plan-TBD

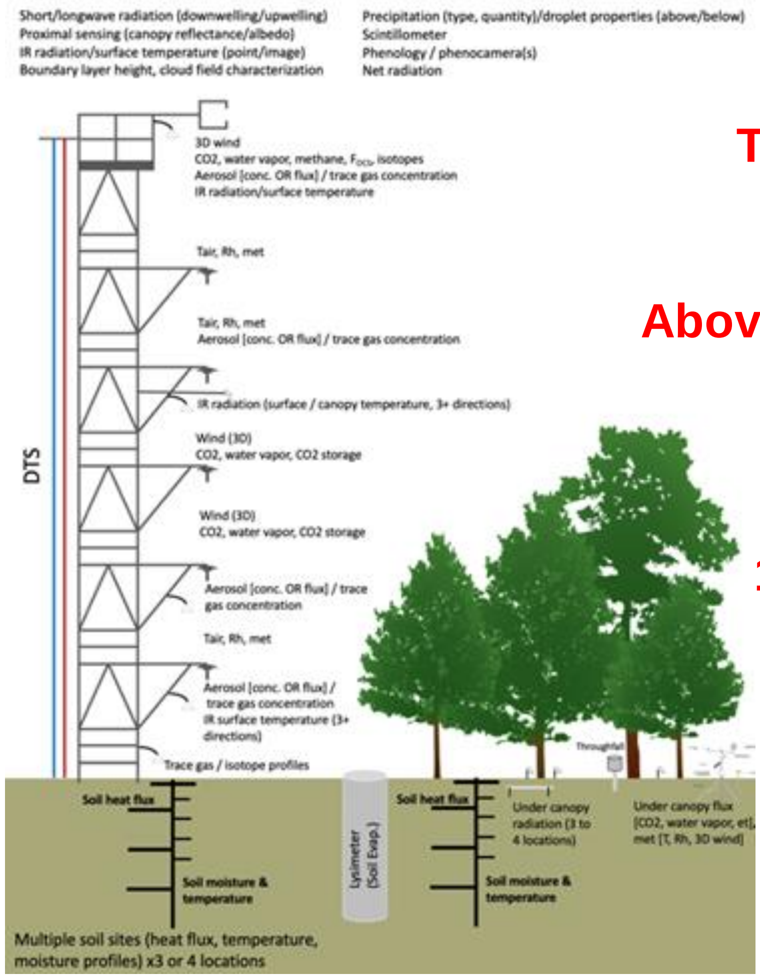


Beyond BNF?

Optical, filter-based, columnar-based, hygroscopic, trace gas

Developing an Aerosol Flux System (AFS)

AMF3 Flux Tower Plan



Tower top

Above Canopy

10 meters

Ground

Flux Measurement Methods
- Eddy Covariance (EC)
- Gradient Method (GM)

Target Aerosol Properties
- **Size distribution (0.25–10 µm)**: OPC-based flux measurement for size-resolved aerosol fluxes
- **Total number concentration (>2.5 nm)**:TBD

Development Timeline (FY25–FY27)
- **FY25**: Define design requirements
- **FY25/26**: Develop DAQ system
- **FY26/27**: System integration and testing

Brookhaven National Laboratory

Radiometer quality-control for snowy environments

2025 Joint ARM User Facility and ASR PI Meeting
March 6, 2025

Dan Feldman, drfeldman@lbl.gov
Lawrence Berkeley National Laboratory

Will Rudisill (LBNL), Chris Cox (NOAA), Marianne Cowherd (UC-Berkeley)
Laura Riihimaki (NOAA), Joseph Sedlar (NOAA), Emily Ammeraal (Oregon State), Felix Yu (Univ. Michigan)

This work was supported by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research and the Atmospheric System Research under U.S. Department of Energy Contract No. DE-AC02-05CH11231.

SAIL: The Surface Atmosphere Integrated Field Laboratory

- SAIL deployed the AMF2 to the East River Watershed near Crested Butte, Colorado from 09/2021 – 06/2023.
- SAIL collected a lot of datasets and partnered with NOAA SPLASH and NSF SOS.

From Feldman et al, BAMS, 2023

Excellence in Radiometry

- The ARM program has decades of experience in delivering accurate radiative flux estimates AND multiple simultaneous observations of the atmospheric and surface state.

Images courtesy of ARM Flickr Account

Lots of Data! Precipitation, Clouds, Winds, Aerosols, Radiation, Temperature, Humidity …

- The ARM program delivers accurate radiative flux estimates AND many other observations to help interpret them.



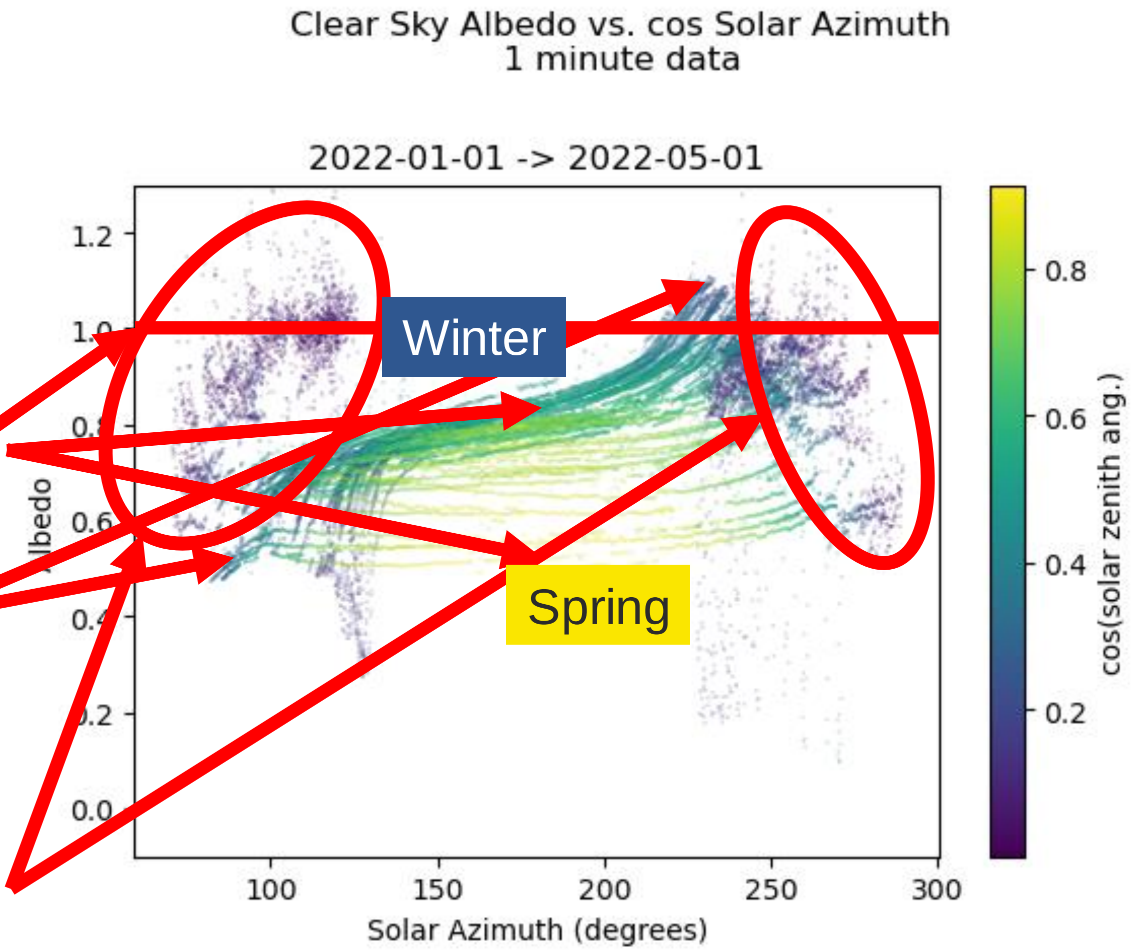




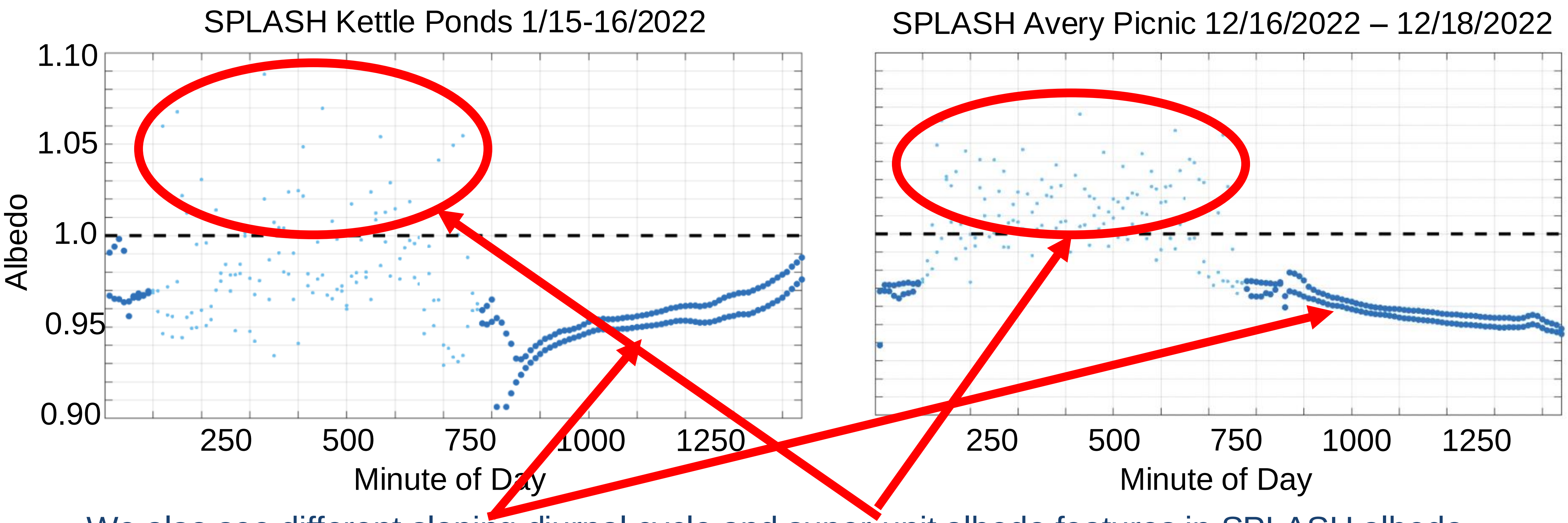
Images courtesy of ARM Flickr Account

Features in Snow Albedo Observations

- SAIL measured downwelling and, separately, upwelling shortwave radiation.
- SAIL qcrad albedo values from these observations (downwelling SW/ upwelling SW) are hard to explain.
- **Expected:** albedo is high when snow is present and goes down as snow recedes in spring.
- **Unexpected:** albedo has a sloping diurnal cycle.
- **Unexpected:** albedo exceeds 1.
- **Unexpected:** clusters of large albedo values close to sunrise and sunset.

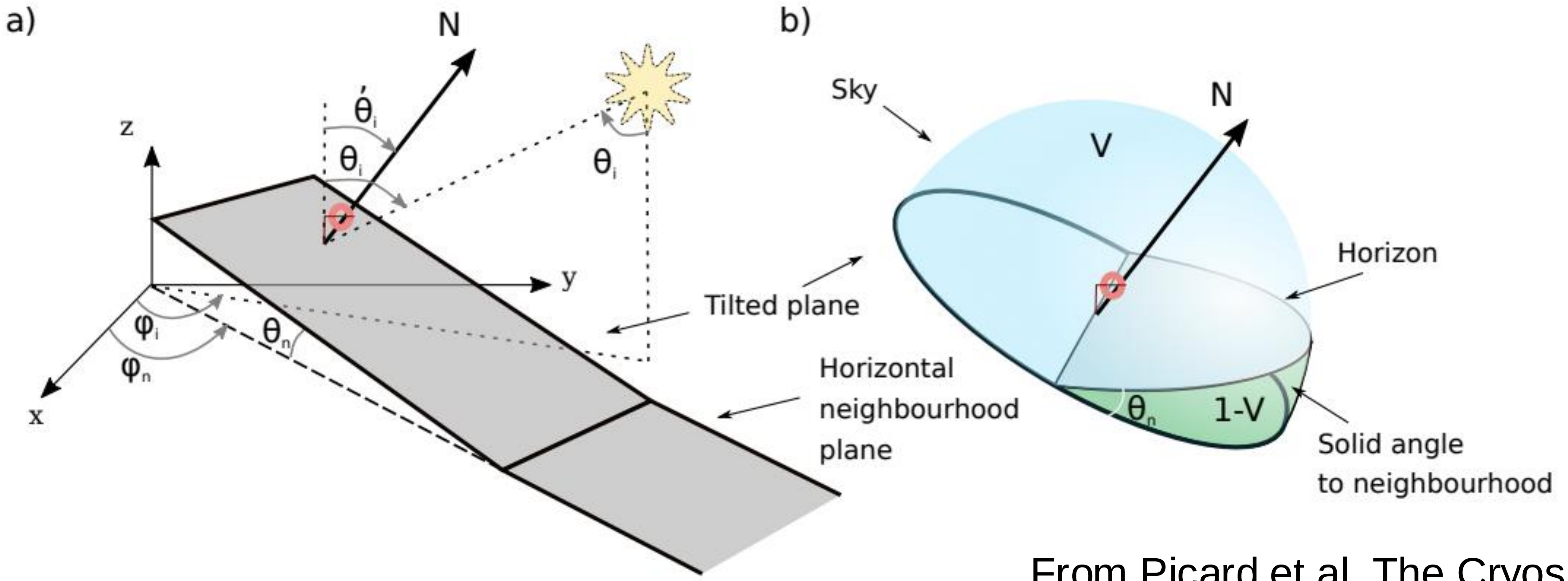


Diurnal Cycle and Super-Unit Albedo Also in SPLASH data



- We also see different sloping diurnal cycle and super-unit albedo features in SPLASH albedo measurements.
- What's going on?!?!

(1) Local Slope Effects Create an Albedo Diurnal Cycle

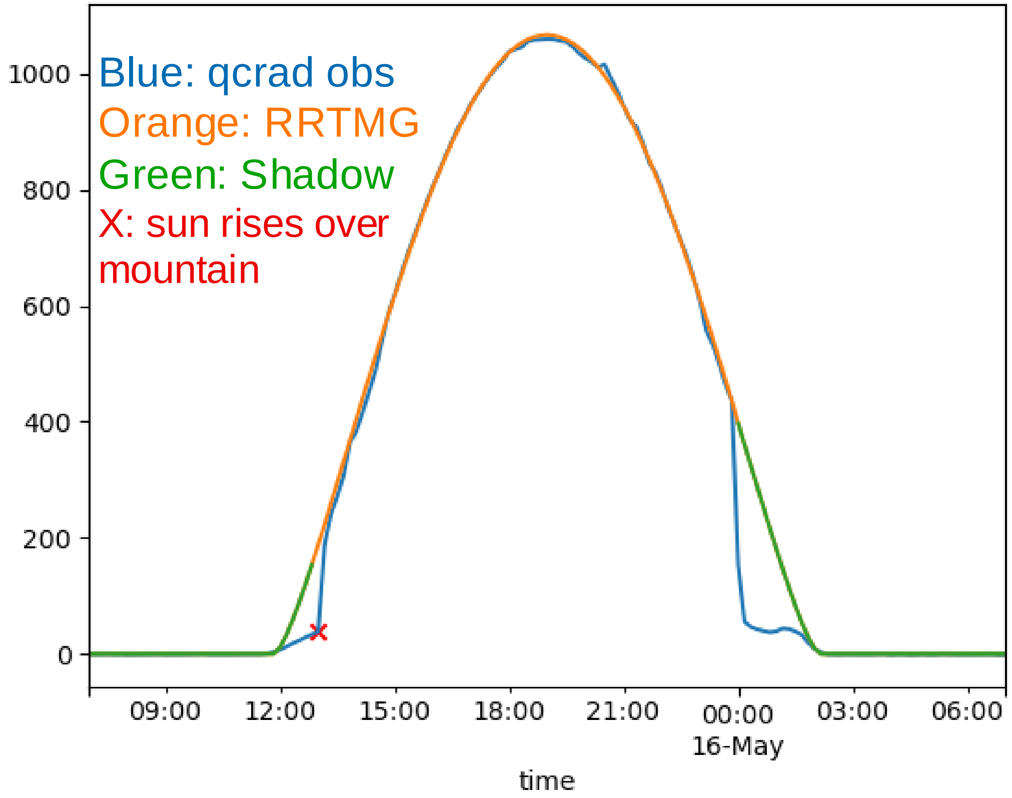


From Picard et al, The Cryosphere, 2020

- Measured upwelling SW ≠ Upwelling SW normal to the surface.
- The surface slope changes with snow accumulation/melt.
- Upwelling SW flux corrections required.

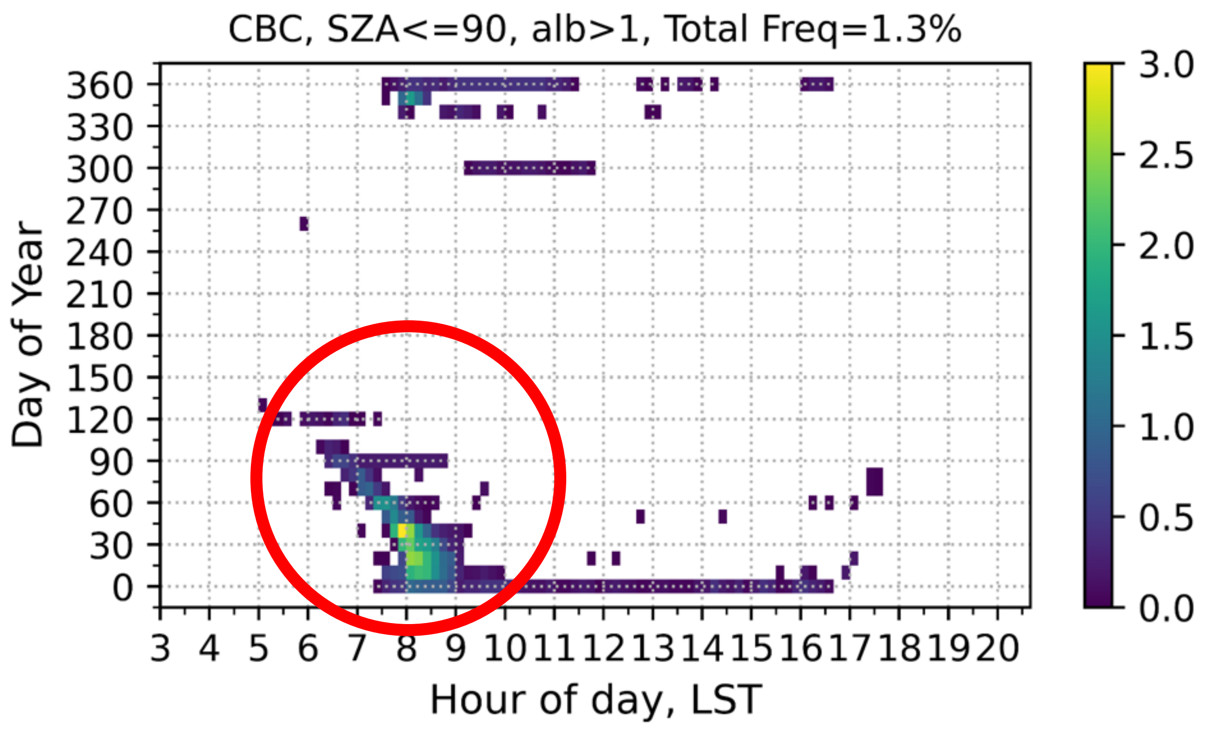
(2) Terrain Shadows Influence the Albedo Diurnal Cycle

Terrain shadow corrections are needed.
Solar geometry and a Digital Elevation Model enable these corrections.



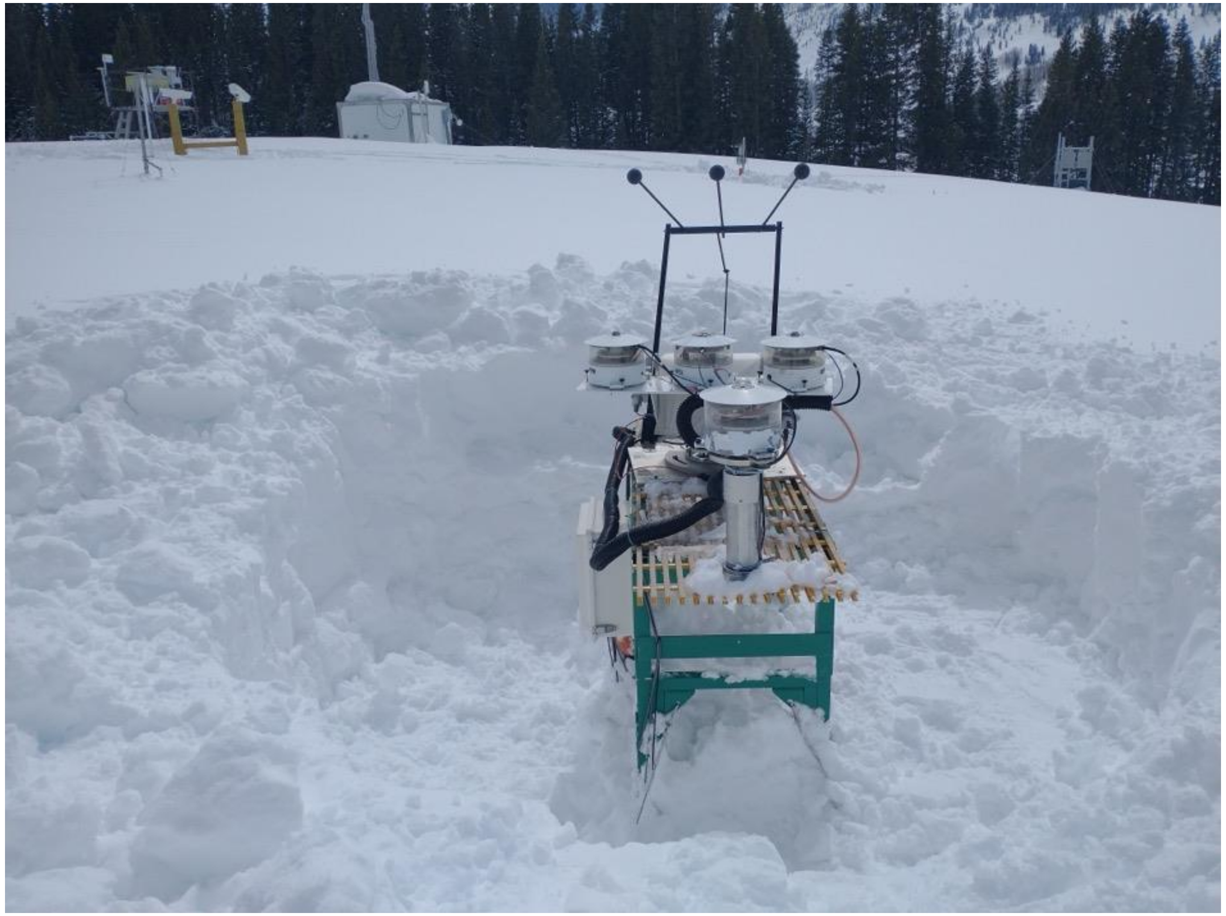
(3) Snow Surface Bi-Directional Reflectance

Snow does not reflect sunlight isotropically.
Upwelling radiometer receives non-local sunlight, so albedo can be > 1



(4) Snow Covers Radiometers

- Total or partial snow cover impacts downwelling radiometers measurements.



Images courtesy of ARM Flickr Account

The Importance of Videography

We can see exactly when radiometers were partially and fully covered in snow and when they are snow-free

A Brief Word on the Problem With (Snow) Donuts

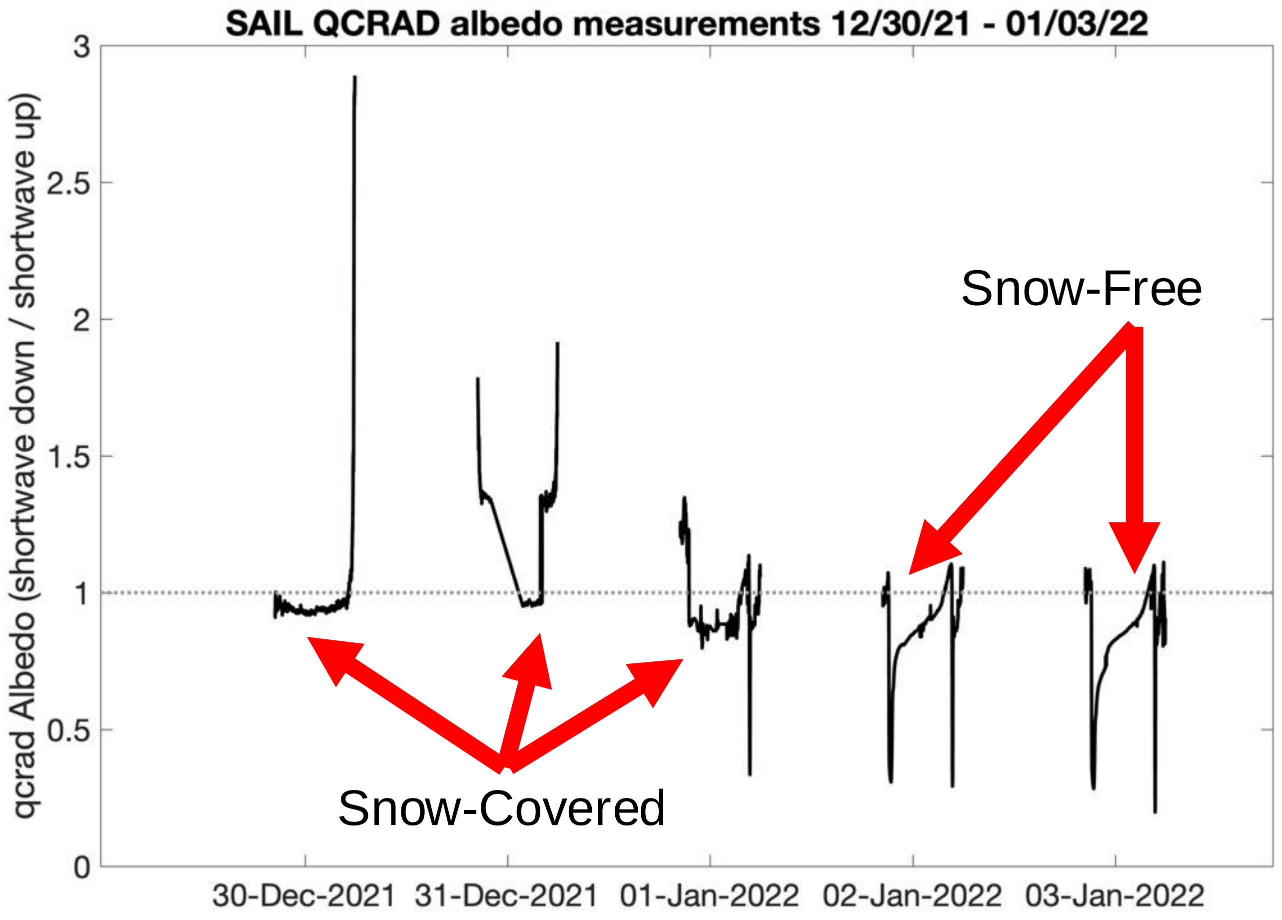
SAIL technicians noted that the radiometer field-of-view can be partially obscured by snow. These “snow donuts” are very significant for radiometry.

Image courtesy of ARM Flickr Account

We Can QC Albedo Data with Videography

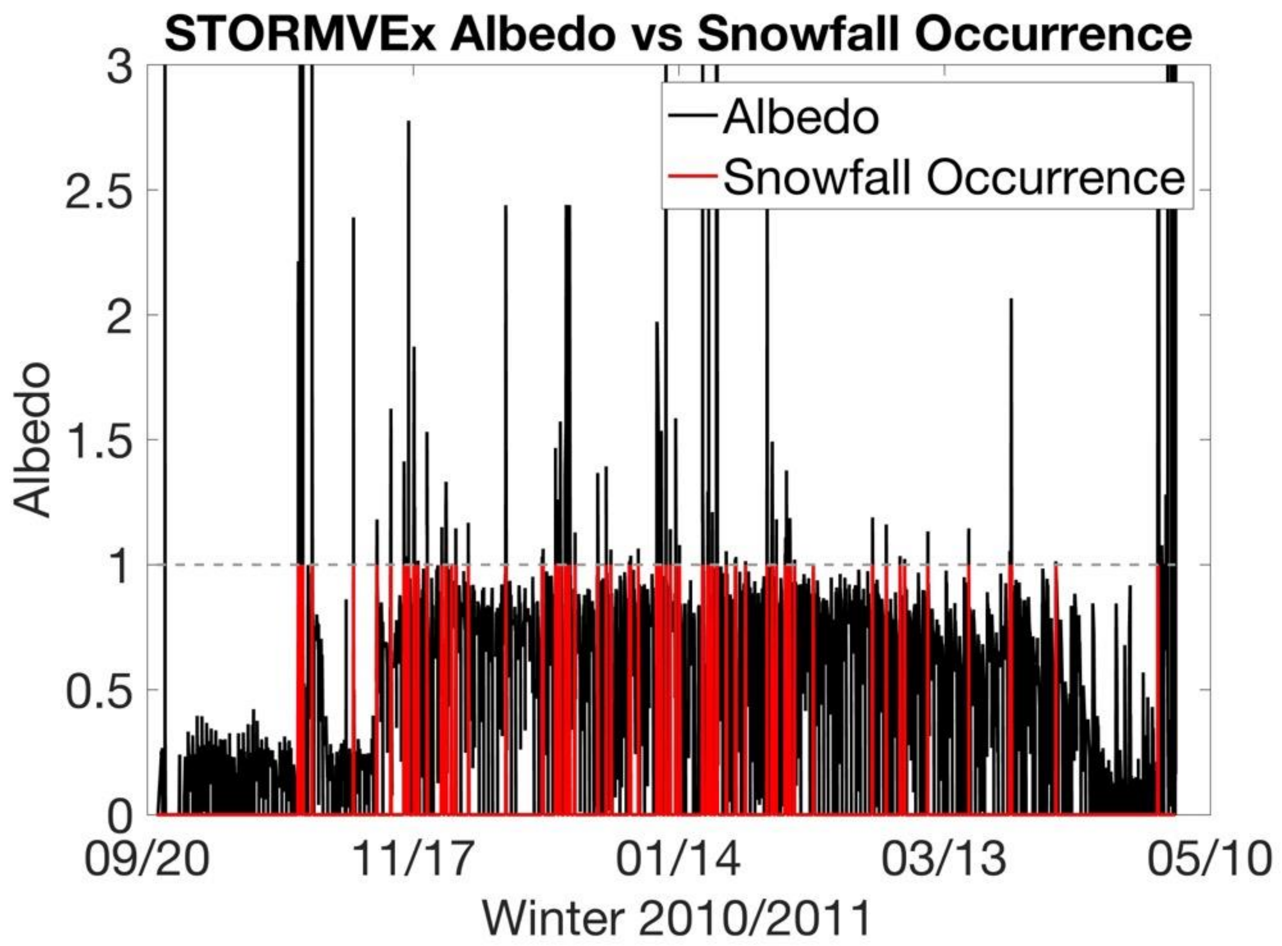
We have built up a library of albedo data where radiometers are snow-free:

https://tinyurl.com/bdazyk5w



We Can Extend Findings to Other Field Campaigns

- Other field campaigns encounter super-unit albedo.
- Rules-of-thumb from SAIL can be used to QC data from other field campaigns.
- For example, 99% of STORMVEx super-unit albedo values occur within 1 day after a snowfall.



Conclusions: Why Does this Matter?

SAIL Surface Atmosphere Integrated Field Laboratory

- Models of snow must account for surface albedo.
- We need observations to test models, but lots of gotcha's in measuring albedo, including:
  - Local slope effects
  - Surrounding terrain effects
  - Surface anisotropic reflectance effects
  - Snow contamination
- Videography helps QC radiometry data
- SAIL/SPLASH findings are relevant for QC-ing other field campaign albedo measurements.

NREL
Transforming ENERGY

Progress Report on the Radiometer Enhancement for the Atmospheric Radiation Measurement (ARM)

Presenter: Aron Habte

Manajit Sengupta (PI) , Aron Habte, Shawn Jaker , Afshin Andreas, Ibrahim Reda, Jaemo Yang, Yu Xie

2025 Joint ARM User Facility and ASR PI Meeting

1 Background

2 Engineering Changes (ENGs)

3 Characterization of new radiometers

4 Projects in the Works at NREL relevant to ARM

Background

- ENG0004176 Change Surface Broadband Radiometer replacements
- ENG0004406 Change Split SIRS into SKYRAD and GNDRAD
- ENG0004788 Change Solar Trackers (Sun Tracker) Replacement
- ENG0004843 Change New design of Pyranometer and Pyrheliometer base foot and brackets for proper alignment
- ENG0004849 Change Plan to retire old Eppley Radiometers
- ENG0004752 Change 20-second data collection to 1-second for SIRS, SKYRAD and GNDRAD

ENG0004176 - Change Surface Broadband Radiometer replacements

Upgrade Status

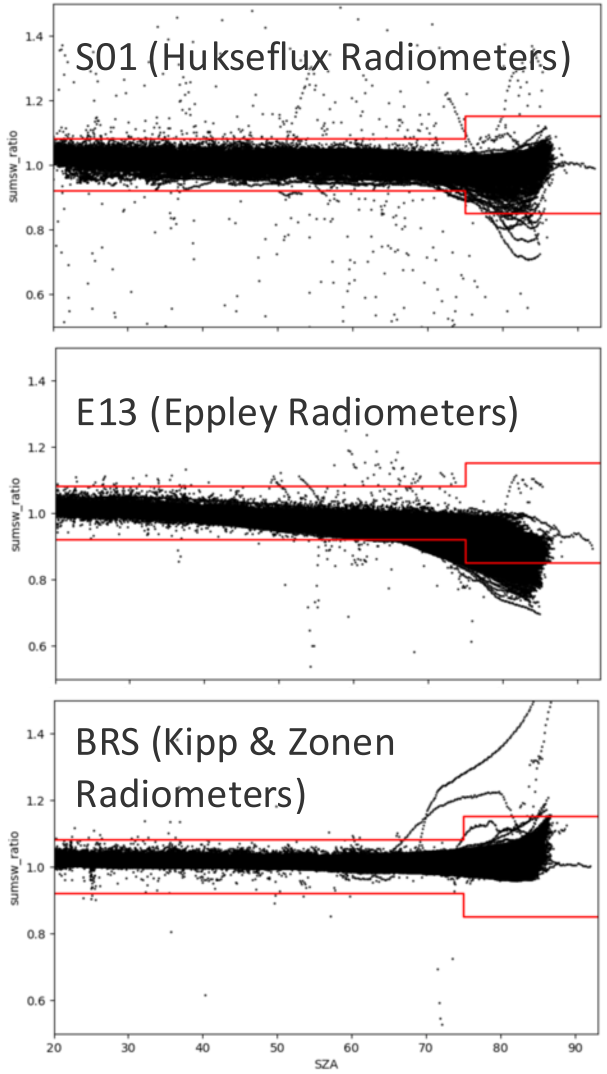
- The Eppley radiometers (NIP, 8-48, PSP) are in the process of being replaced by Hukseflux radiometers. This ENG is to track the requirements, testing, procurements and deployment of the new radiometers.

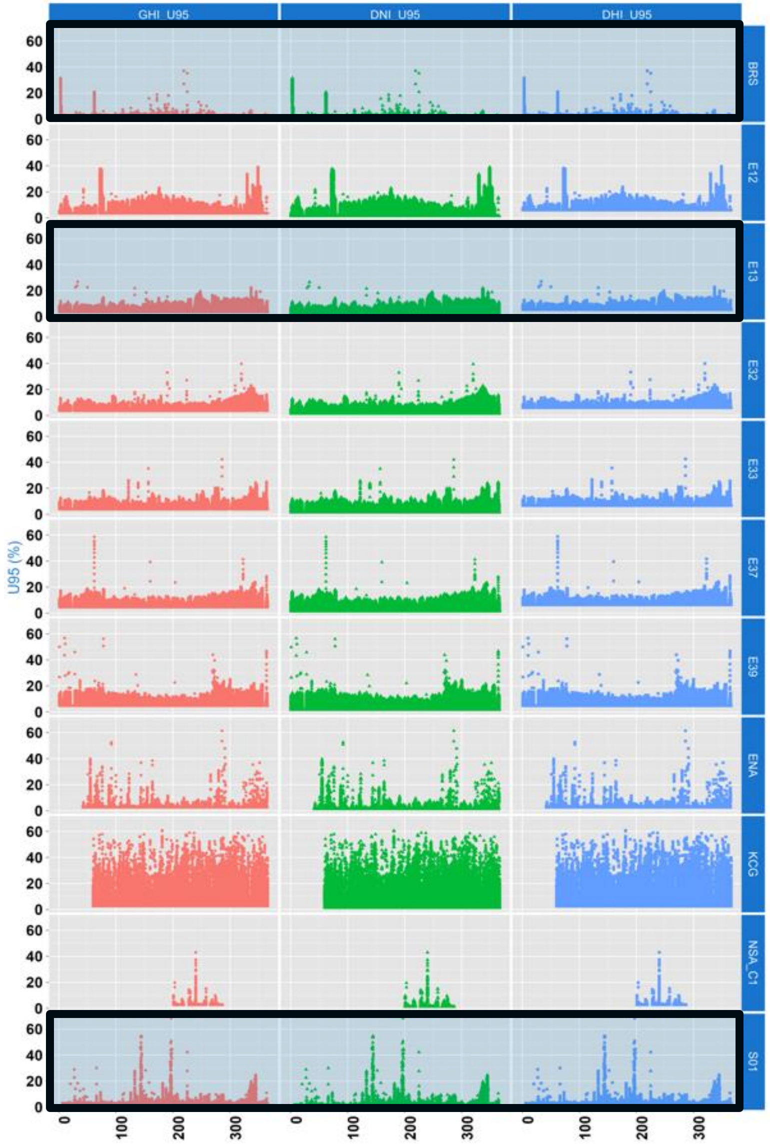
Table showing upgrade status

FACILITY NAME	SITE CODE	FACILITY CODE	Schedule for deployment
Pawhuska, OK (Extended)	SGP	E12	TBD
Lamont, OK (Extended and Co-located with C1)	SGP	E13	TBD
Medford, OK (Extended)	SGP	E32	TBD
Newkirk, OK (Extended)	SGP	E33	TBD
Waukomis, OK (Extended)	SGP	E37	TBD
Morrison, OK (Extended)	SGP	E39	TBD
Supplemental 1, Lamont, OK	SGP	S01	Upgraded
Central Facility, Barrow AK	NSA	C1	Upgraded
Graciosa Island, Azores, Portugal	ENA	C1	Upgraded
Bankhead National Forest, AL, AMF3	BNF	M1,S20,S30,S40	Upgraded
kennaook / Cape Grim, Tasmania, Australia; AMF2 (main site for CAPE-k)	KCG	M1	Upgraded
COURAGE	COU	M1,S2,S3	Upgraded

Comparison results

Component sum (derived) vs. measured GHI - 2024 data





Stations	Statistical Metrics			Instrument Manufacturer
	U_R GHI (Instrument Uncertainty)	U_{95} GHI (Instrument Uncertainty + Operational Uncertainty)	U_{95}GHI Exceeds U_RGHI (%)	
BRS	2.4	2.43	1.6	Kipp & Zonen
E13	3.7	4.24	32	Eppley
S01	2.9	2.98	4.7	Hukseflux
E12	3.7	4.35	21	Eppley
E32	3.7	4.37	37.8	Eppley
E33	4	4.52	28.6	Eppley
E37	4.7	5.28	25.9	Eppley
E39	4.9	5.67	32.7	Eppley
ENA	2.7	2.83	8	Hukseflux
KCG	2.8	10.86	76.7	Hukseflux
NSA C1	2.8	3	9.6	Hukseflux

- The KCG station contains the new Hukseflux radiometers; however, the location has difficult environmental/ meteorological conditions. These conditions are responsible for the higher uncertainty depicted in Table and middle plot.
- The BRS site is equipped with Kipp & Zonen radiometers. Relatively, it shows the lowest uncertainty.

Poster: Application of the Solar Uncertainty Integrator (SUNI) Software to the ARM Solar Radiation Measurements.

ENG0004406 Change Split SIRS into SKYRAD and GNDRAD

Upgrade Status

- Splitting SKYRAD and GNDRAD was carried out at some sites. SGP EFs will be upgraded this summer.

FACILITY NAME	SITE CODE	FACILITY CODE	Schedule for deployment
Pawhuska, OK (Extended)	SGP	E12	TBD
Lamont, OK (Extended and Co-located with C1)	SGP	E13	TBD
Medford, OK (Extended)	SGP	E32	TBD
Newkirk, OK (Extended)	SGP	E33	TBD
Waukomis, OK (Extended)	SGP	E37	TBD
Morrison, OK (Extended)	SGP	E39	TBD
Supplemental 1, Lamont, OK	SGP	S01	Upgraded
Central Facility, Barrow AK	NSA	C1	Upgraded
Graciosa Island, Azores, Portugal	ENA	C1	Upgraded
Bankhead National Forest, AL, AMF3	BNF	M1,S20,S30,S40	Upgraded
kennaook / Cape Grim, Tasmania, Australia; AMF2 (main site for CAPE-k)	KCG	M1	Upgraded
COURAGE	COU	M1,S2,S3	Upgraded

Other ENGs

- ENG0004788 Solar Trackers (Sun Tracker) Replacement
- ENG0004843 New design of Pyranometer and Pyrheliometer base foot and brackets for proper alignment
- ENG0004849 Plan to retire old Eppley Radiometers
- ENG0004752 Change 20-second data collection to 1-second for SIRS, SKYRAD and GNDRAD

Upgrade Status

- ENG0004788: Procurement process in place. Last year 5 of Soly GD trackers were ordered and they will be used for SGP RCF.
- ENG0004843: The DR20 mounts has been deployed at few sites and the SR20 feet are under testing. The latter will be deployed in all sites summer 2025.
- ENG0004849: Retiring of olde Eppley's radiometers in process.

Characterization of New Radiometers

Characterization of New Radiometers

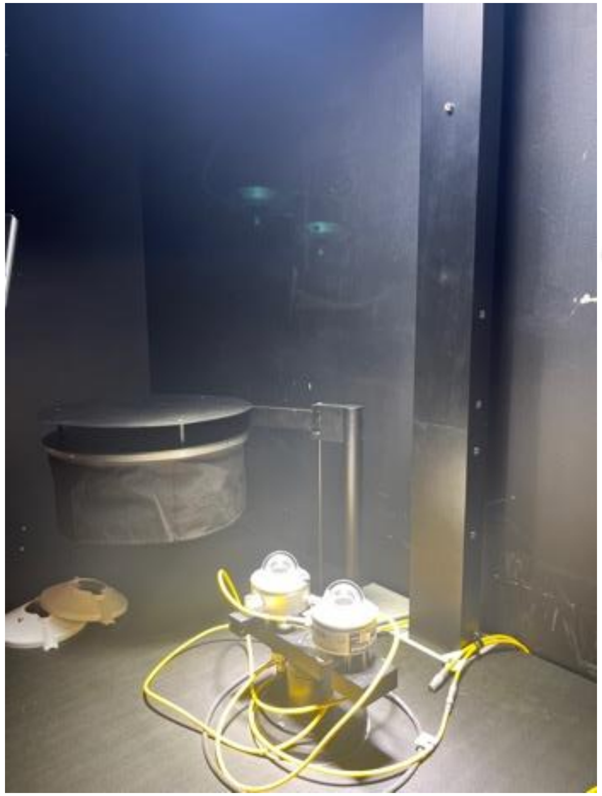
- IR loss correction
- Temperature response
- Directional response

SGP S01 and NSA S01 will be used for concurrent comparison.

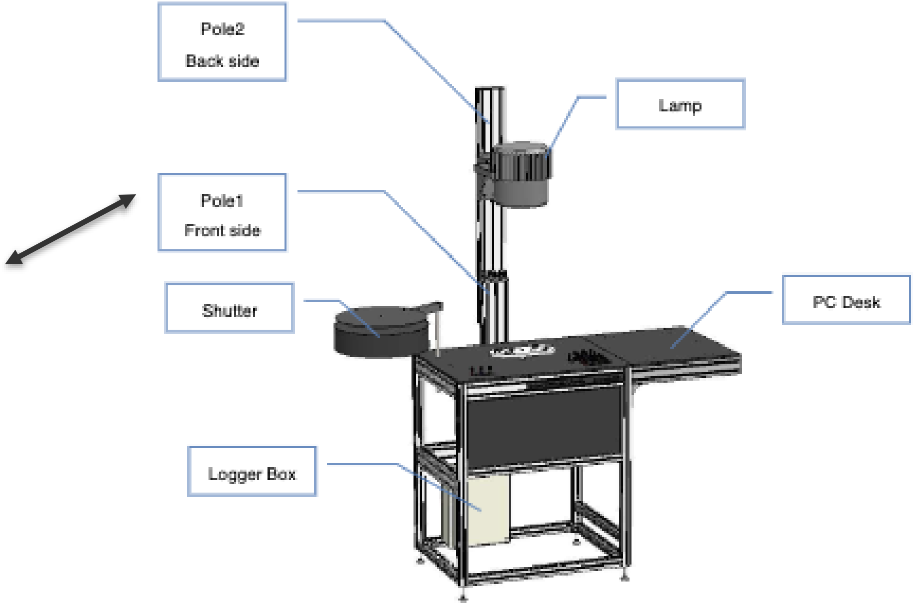
Projects in the Works at NREL relevant to ARM

Projects in the Works at NREL relevant to ARM

Broadband Indoor Radiometer Calibration (BIRCAL)



Indoor Calibration Setup



- Outdoor calibration using sun as a light source, is performed under unpredictable environmental condition and limited to certain sky condition and season.
- Indoor calibration is performed under controlled environment and uses a stable artificial light source.
- Manufacturers primarily use indoor calibrations.
  - Year-round calibration
  - Better uncertainty quantification
  - Standards for outdoor and indoor calibration (to provide leadership in advancing standards)
  - Independent validation of manufacturer specification

Projects in the Works at NREL relevant to ARM

Procuring solar simulator and temperature chamber

- As stated in the ISO 9060 (https://www.iso.org/obp/ui/en/#iso:std:iso:9060:ed-2:v1:en), for the classification of a pyranometer in the highest class, individual tests such as temperature response and directional response are required. It is essential to have capability of performing these individual tests to understand the characteristics of radiometers.
    - NREL is procuring a solar simulator from Newport, known to fulfill the specifications. This simulator features a stable light source with beam uniformity of >98% and ensures the necessary distance of parallel light (about 12 in.) to properly reach the unit under test.

Projects in the Works at NREL relevant to ARM

Procuring solar simulator and temperature chamber

- NREL is procuring a temperature chamber from EsPEC which satisfies the specific requirements.
- One of the key features of the ESPEC chamber is the option to install a custom port with a window on top, facilitating the passage of light from the solar simulator to the unit under test, independent of temperature variations.
- The temperature range of the temperature chamber covers at least −70°C to +180°C, and the temperature fluctuation of the temperature chamber should meet ±0.5°C, while temperature uniformity should meet 1.5°C below 100°C. The temperature chamber should have a capability to keep it dry, and with no fog, frost or dew on the test area and on the window glass throughout the temperature range.

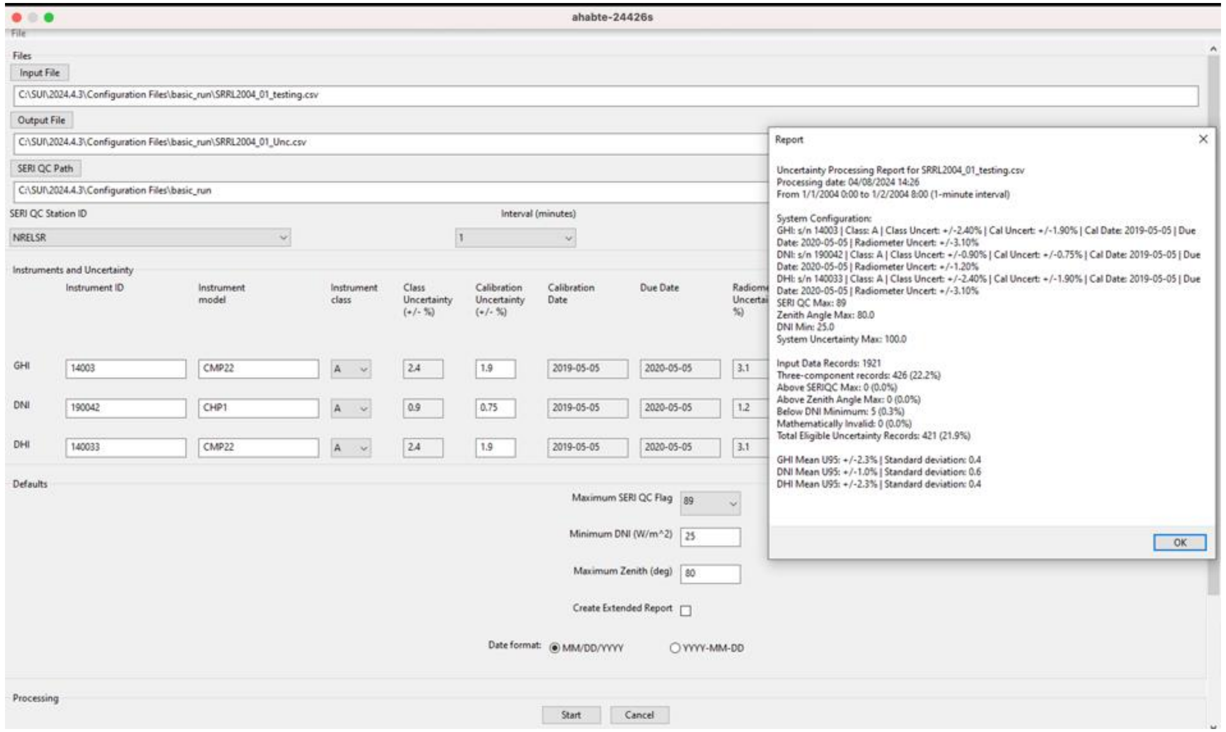
Example image on how the temperature chamber will be used to characterize radiometers

NREL's Solar Uncertainty Integrator (SUNI)

- Developed an *Integrated Solar Resource Uncertainty Software Package* that provides a method to assign expanded uncertainty estimates to three-component measured solar radiation data.

- The system merges static uncertainty information about radiometer performance with the dynamic operational uncertainty information extracted from data quality assessment.

Input: location and instrument information



[Poster: Application of Solar Uncertainty Integrator (SUNI) Software to ARM Solar Radiation Measurements.]

Thank You!

www.nrel.gov

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Latest Development to Establish the World Reference with Traceability to SI units for Measuring the Atmospheric Shortwave and Longwave Irradiance

2025 Joint ARM User Facility an ASR PI Meeting

Ibrahim Reda

Photo from iStock-627281636

Background and Objective

- To date, Interim world reference for atmospheric longwave irradiance is the World Infrared Standard Group (WISG), and shortwave irradiance is the World Standard Group (WSG); each are ~~ 3-6 W/m^2 > International system of Units (SI).

- Plan forward: Attend the World Meteorological Organization's (WMO) ET-RR expert team meeting on March 18, 2025 at PMOD/WRC to discuss/develop road map to establish a world reference traceable to SI for atmospheric longwave and shortwave irradiance.

ACP/IRIS Historical Results

Original Method

Comparison Dates	ACP95F3-IRIS W/m^2	Standard Deviation , W/m^2	U_{95}, W/m^2
PMOD February 2013	0.1	0.83	1.66
PMOD IPgC-II October 2015	-0.57	0.31	0.85
SGP phase 1 October 2017	0.86	0.78	1.79
SGP phase 2 November 2017	-1.05	0.85	2
PMOD July 2019*	0.75	1.11	2.34
PMOD IPgC-III October 2021**	0.1	1.2	2.4
NPC-2022/ACP95F3&IRIS 5***	0.2	1.78	3.57
NPC-2023 ACP95F3&IRIS 9	0.04	1.04	2.08
NPC-2024 ACP95F3&CG4 FT005(IRIS Traceable)****	0.08	1.26	2.52
Average Red color excluded	-0.12	0.76	1.68

*Thermopile voltage (Vtp) > -800 uVolt, Vtp must be < -900 uV for clearer sky conditions

**Thermopile voltage (Vtp) > -900 uVolt, Vtp must be < -900 uV for clearer sky conditions

***IRIS arrived late and limited data set with unfavorable atmospheric conditions

****might be spectral due to pyrgeometer dome

https://www.sciencedirect.com/science/article/pii/S1364682611003440?via%3Dihub

ACP/IRIS Historical Results

Proposed Method			
Comparison Date	ACP95F3-Radiometers W/m^2	Standard Deviation , W/m^2	U_{95}, W/m^2
NPC-2023 ACP95F3-ACP96F3	-2.84	1.75	4.50
NPC-2023 IRIS9-ACP96F3	-2.40	1.09	3.24
NPC-2024 ACP95F3-ACP10F3	0.88	2.32	4.72
NPC-2024 ACP95F3-ACP57F3	0.07	2.74	5.49
NPC-2024 ACP95F3-ACP96F3	-0.15	2.52	5.05
Average	-0.89	2.09	4.60

Summary: U_{95} = 1.68 W/m^2 & 4.60 W/m^2 Using original & proposed methods. Proposed method is using New Absolute Cavity Pyrgeometer equation by application of Kirchhoff's law and adding a convection term. https://research-hub.nrel.gov/en/publications/new-absolute-cavity-pyrgeometer-equation-by-application-of-kirchh-2

IPgC-IV Protocol to Establish World Reference Traceable to SI Units in 2026

1. ACP95F3 will arrive in PMOD by end of August 2025 to start outdoor data collection using NREL Laptop/software/original method (Measurand is atmospheric longwave irradiance).

2. For ACPs10F3, 57F3, and 96F3 using /laptops/software/proposed method (Measurand is PMOD Blackbody).

3. Once IPgC-IV starts all ACPs will be using NREL laptop/software/original method.

4. Results of the two methods would be evaluated, then decision would be made to establish the reference in 2026.

Developing the New-Generation Absolute Cavity Radiometer

- Developing the New-Generation Absolute Cavity Radiometer to maintain Solar Measurement Accuracy and Traceability which is critical to NREL's capability to conduct its ISO accredited Broadband Outdoor Calibration (BORCAL) process that is used to calibrate all NREL and DOE-ARM sites radiometers annually.

- Provide accurate solar radiation measurement for resource assessment, e.g., DOE-ARM sites.

IPC-XIV Protocol to Establish World Reference Traceable to SI Units in 2026

1. In collaboration between NREL, NIST, and Eppley Laboratory two prototype Absolute Cavity Radiometers (ACRs) model N2EHF will be assembled and characterized at NIST for traceability to SI units then shipped to NREL for a comparison using NREL's four reference cavities traceable to WSG through IPCs for verification by mid 2025.
2. The prototype cavities participate during IPC-XIV and compared with PMOD's Cryogenic Solar Absolute Radiometer (CSAR) .
3. More than one final cavities will be shipped to PMOD by April 2026 for a final comparison with CSAR.
4. Results are evaluated, then decision would be made to establish the reference in 2026.

Thanks to Laurent since his email to USA Department of Energy (DOE) helped in reviving the AHF

Consultative Committee for Thermometry of CCT recommendations in 2017 to establish SI traceability

1. These CCT recommendations are approved by CCT and approved by the CGPM which is the governing body of the Bureau International des Poids et Mesures (BIPM). These recommendations are taken quite seriously by the National Metrology Institutes (NMIs) for guidance.

2. Examples:

- The redefinition of the kelvin, at least three or two in our case independent measurement methods with sufficient uncertainties were needed for a new Boltzmann constant.
- WRR average of 13 ACRs different manufacturer and measurement method.

3. ACP/IRIS: for ACP the measurand is atmospheric longwave irradiance original method; for IRIS and ACP proposed method Blackbody is the measurand.

4. For ACR: CSAR is widowed and field of view > 5°and N2EHF is self calibrating without window and filed of view 5° consistent with WSG.

From NIST affiliate Dr. Howard Yoon *document available for review*

NPC-2023&24 Solar Irradiance < 700 W/m2 Results

One of WMO guidelines for IPCs states that the solar irradiance during the comparisons would be > 700 W/m^2; based on discussions within the ACR community it was suggested that irradiance data would be collected during NPC-2023&24 to change this criterion. During the two comparisons ~31 Absolute Cavity Radiometers (ACRs) participated and the WRR average difference between the >700 W/m^2 and <300 W/m^2 was < 0.04%.

Hopefully this will be resolved for world locations that doesn't meet this criteria

Acknowledgement

We are grateful to the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office (SETO) and to the ARM program where support for NREL is provided by Argonne National Laboratory MPO No.2T-30084.

Specifically, we acknowledge Dr. Tassos Golnas (SETO) , Dr. Jim Mather (PNNL), Dr. Adam Theisen (Argonne) and Dr. Lindsay Spritzer (NREL) for providing support, encouragement and funds to develop the new Absolute Cavities.

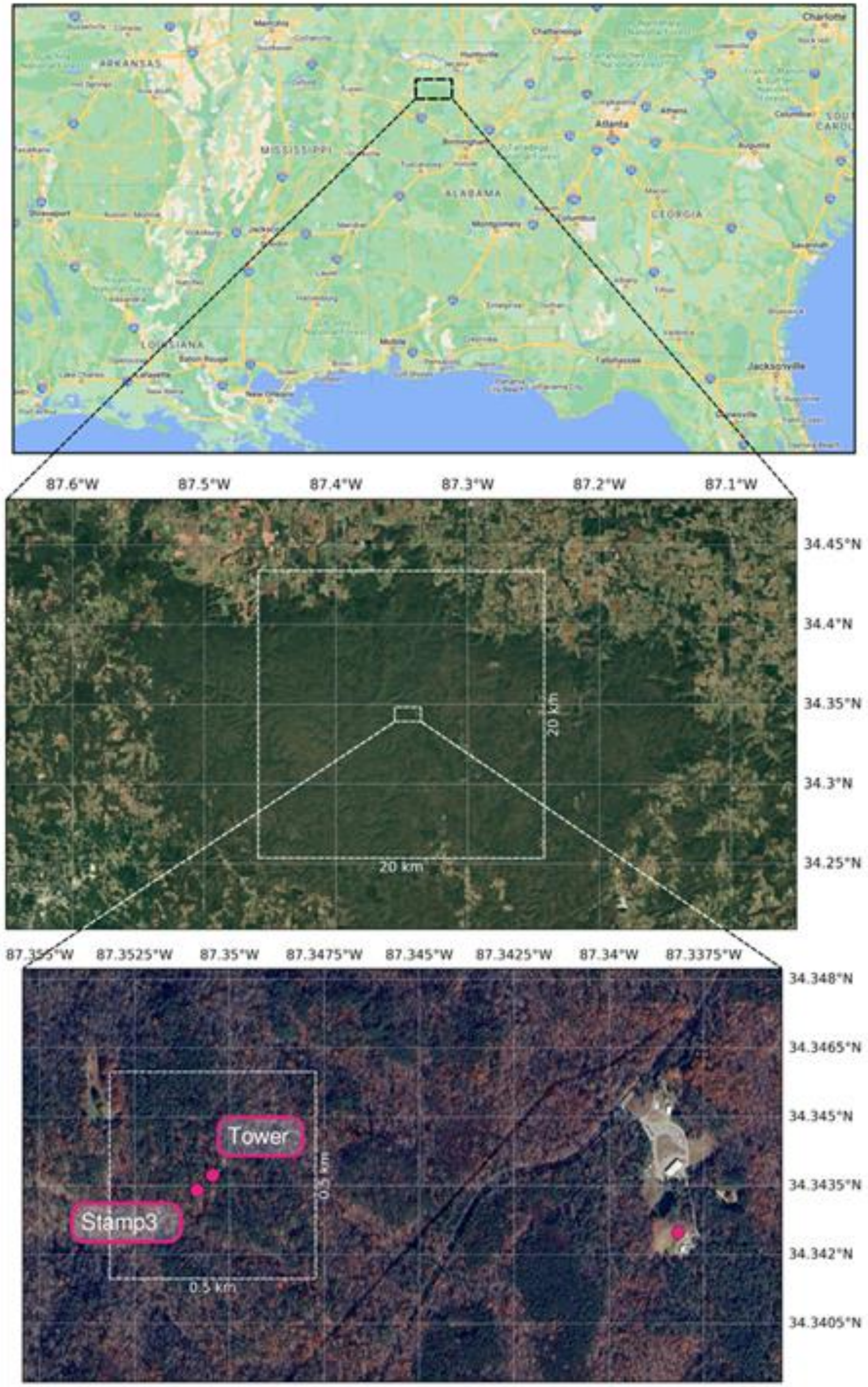
RadSys at Bankhead National Forest

Benjamin Sheffer, Hagen Telg, Laura Riihimaki, Mark Kutchenreiter, Gary Hodges, Allen Jordan

ARM's new BNF site

ARM is establishing a long-term mobile observatory in Bankhead National Forest (BNF), Alabama to study

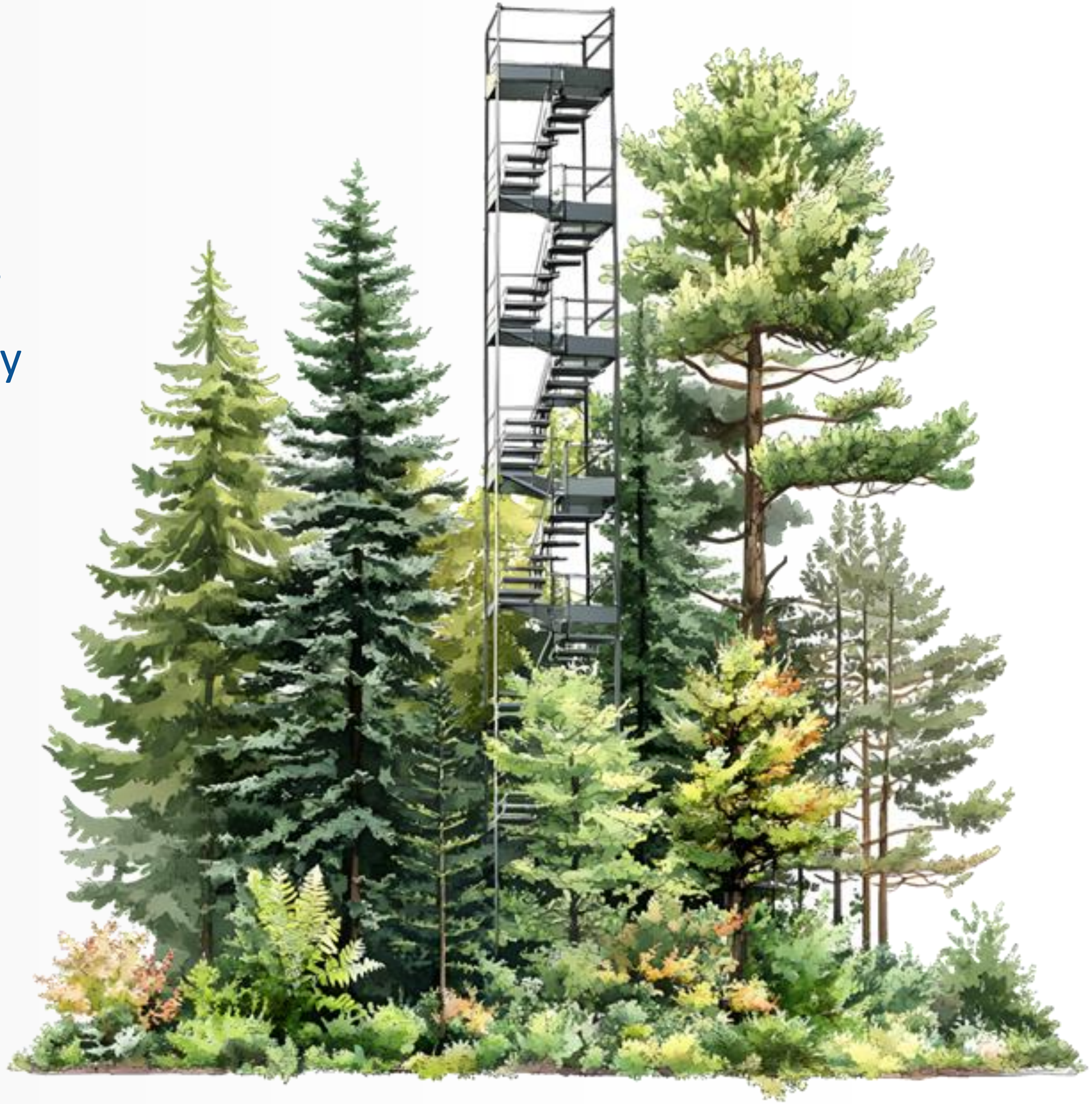
- biosphere-atmosphere interactions
- surface-vegetation coupling
- energy fluxes and planetary boundary layer evolution.



BNF Tower

Key feature of BNF site is a 140 feet (42.7 meter) tower.

⇒ Observations from the ground throughout the canopy (~30 m) and above.



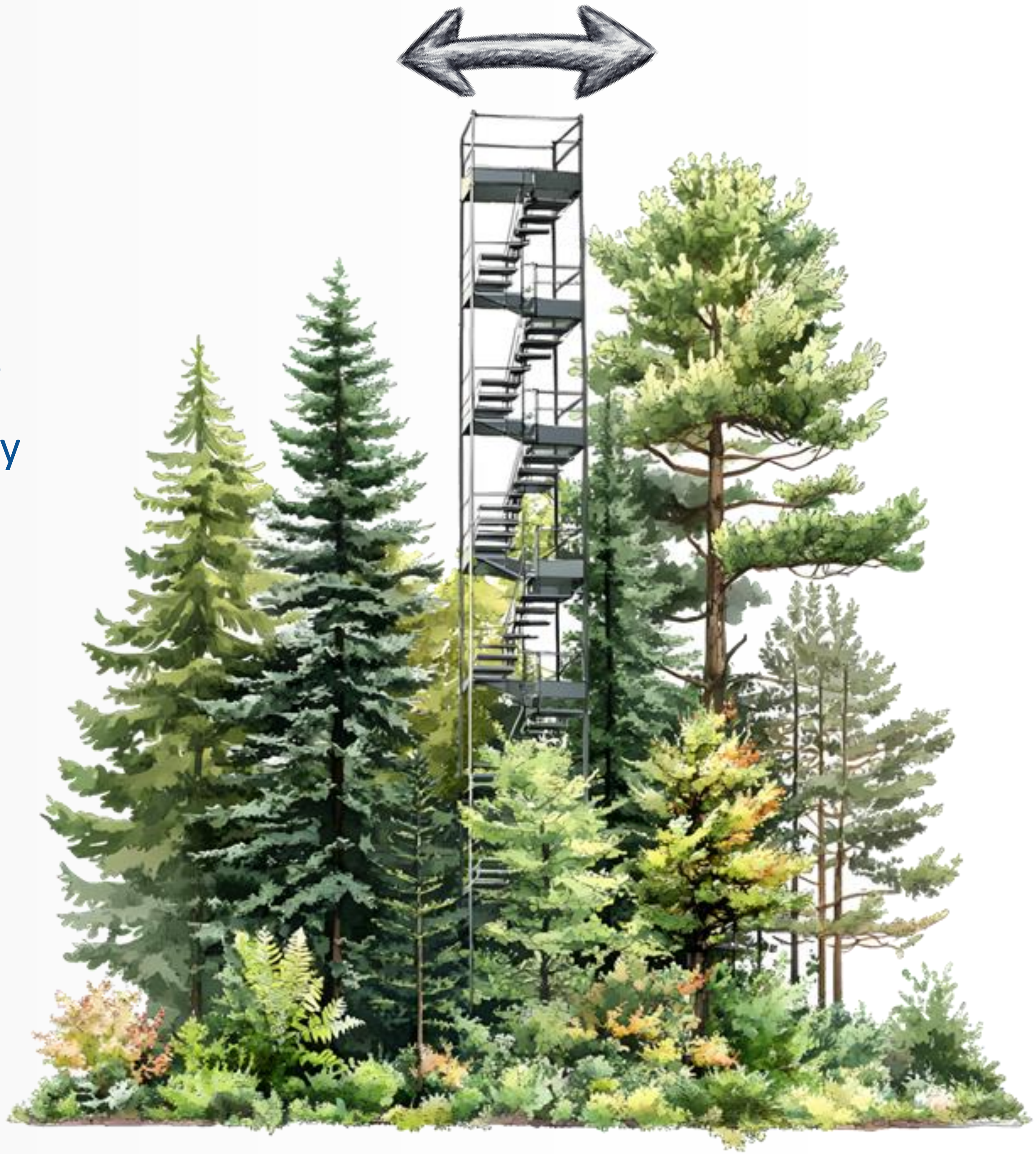
BNF Tower

Key feature of BNF site is a 140 feet (42.7 meter) tower.

⇒ Observations from the ground throughout the canopy (~30 m) and above.

Solar radiation observation face problem:

The tower is swaying



Solar radiation obs. from moving platforms

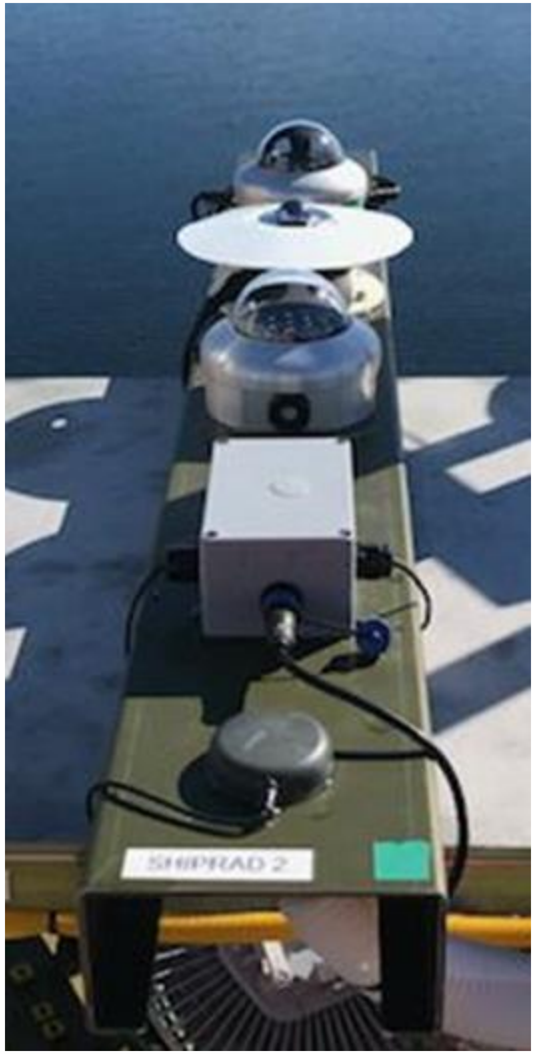
Typical ARM observations (SkyRad) use **trackers** to separate **global, diffuse, and direct** components of solar radiation.

Not practical on moving platforms

RadSYS I

Radiation system (RadSy) comprehensive suite of radiometric measurements, including:

- Shortwave radiation: downwelling global, diffuse, and direct components
- Longwave downwelling radiation



RadSYS I

Shadow mask pyranometer, Delta-T **SPN1**

Downwelling global and diffuse hemispheric shortwave irradiance

⇒ Works on moving platforms – when considering pitch and roll

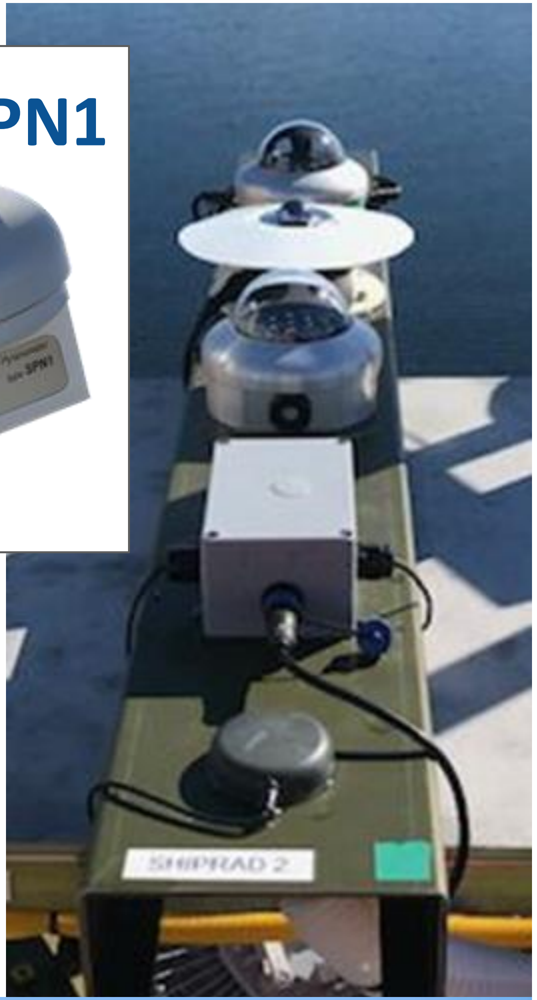
SPN1 has increased uncertainty

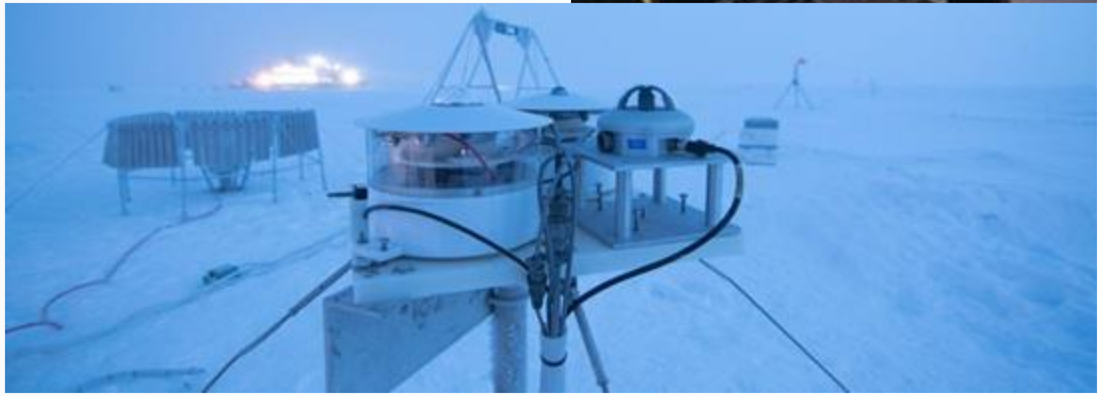
⇒ additional high-quality global observation compensate uncertainty

RadSYS I

Has minimum set of observations to run the **RADFLUX** algorithm ⇒ **cloud properties**.

Compact design allows for quick installation and versatile use in complex environments.

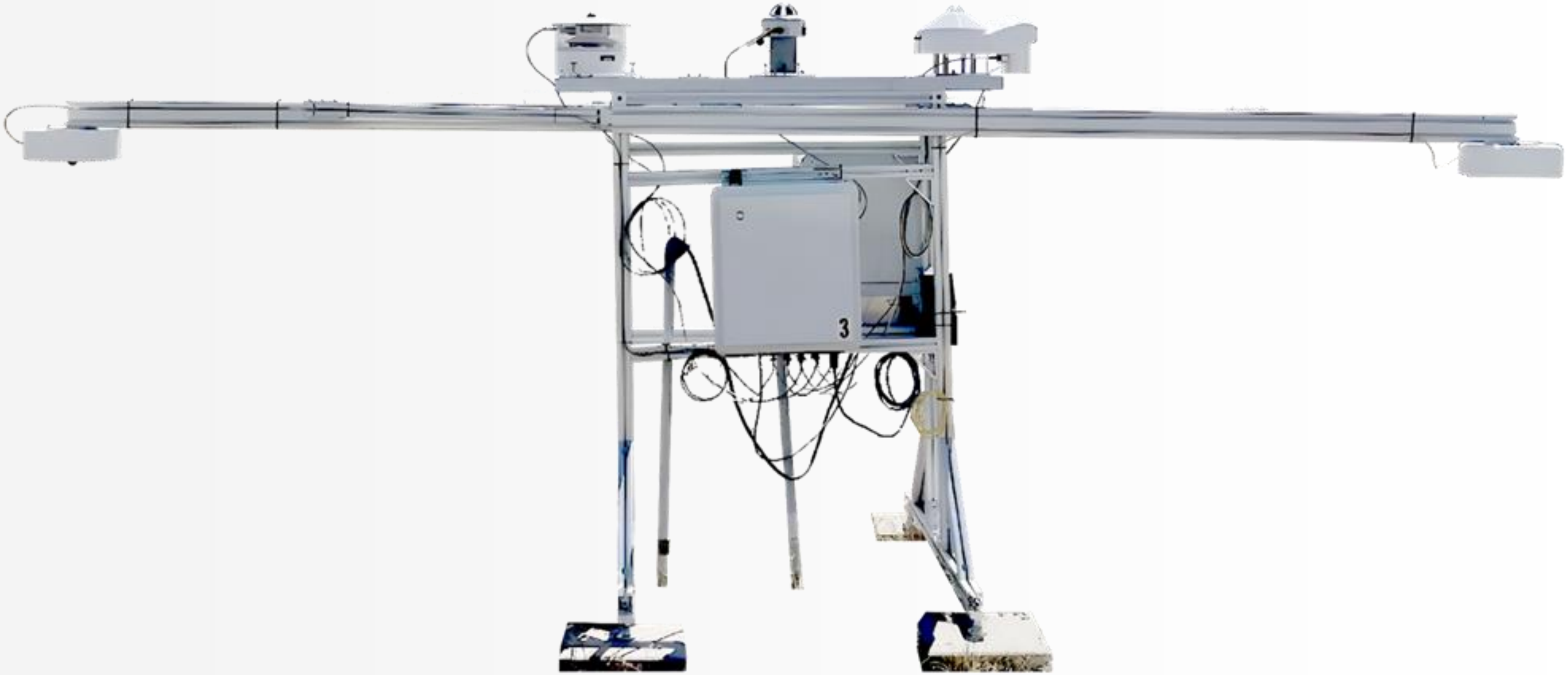




RadSys 2.x

Next generation RadSys: **Upwelling long and shortwave**.

Extra space and ports for guest instruments



RadSys at BNF

1

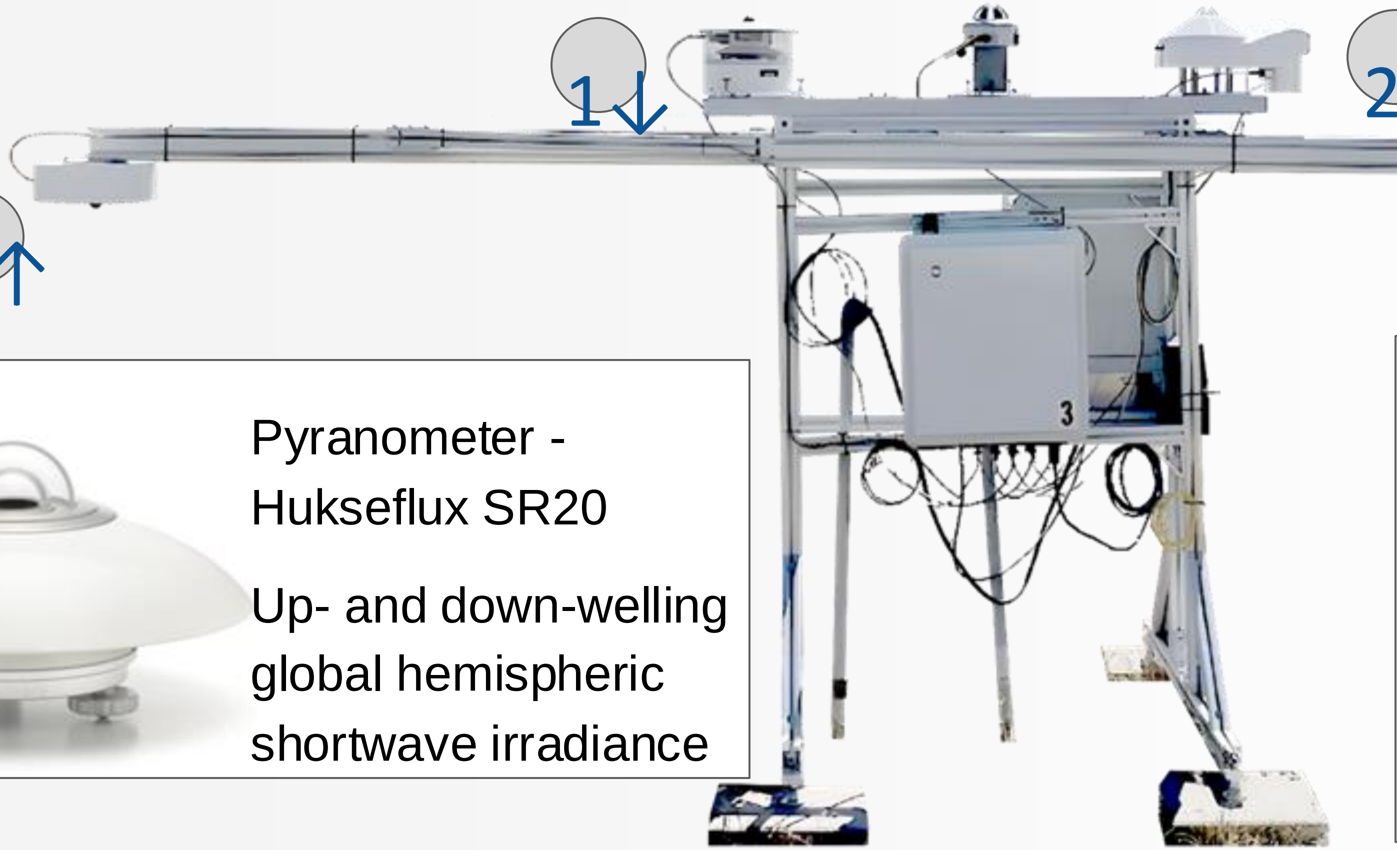
Pyrgeometer –
Eppley PIR

Up- and down-welling
global hemispheric
longwave irradiance

3

Shadow mask
pyranometer – Delta-T SPN1

Downwelling global and
diffuse hemispheric
shortwave irradiance.



2

Pyranometer -
Hukseflux SR20

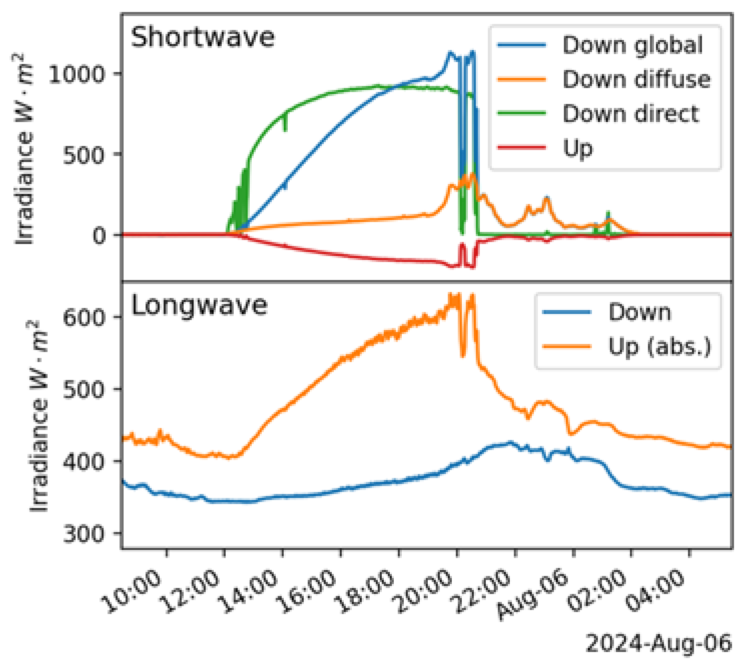
Up- and down-welling
global hemispheric
shortwave irradiance

+

Temperature & relative humidity -
Vaisala HMP60

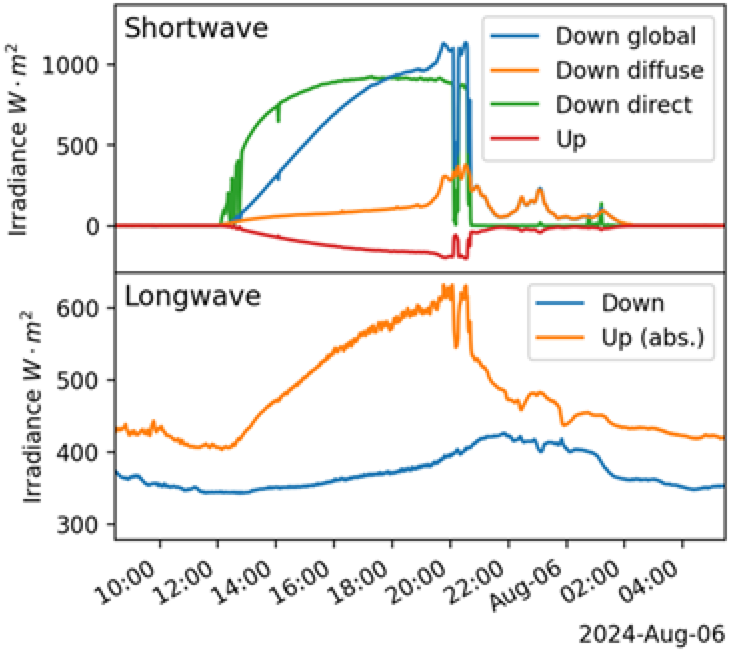
RadSys retrievals at BNF

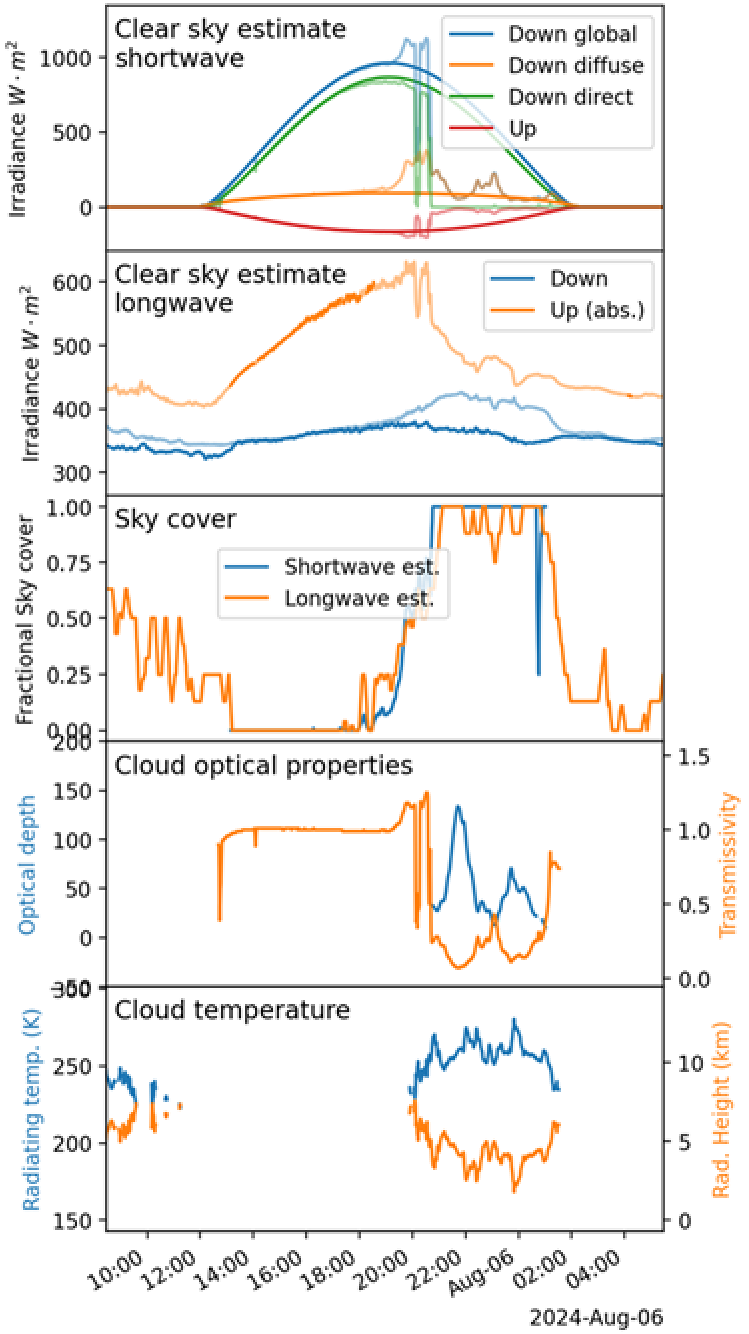
Primary observations	Instrument
Shortwave, downwelling, total	Pyranometer – Hukseflux SR20
Shortwave, downwelling, diffuse	Shadow mask pyranometer – Delta-T SPN1
Shortwave, downwelling, direct	Shadow mask pyranometer – Delta-T SPN1
Shortwave, upwelling	Pyranometer – Hukseflux SR20 (no fan)
Longwave, downwelling	Pyrgeometer – Eppley PIR
Longwave, upwelling	Pyrgeometer – Eppley PIR (no fan)



RadSys retrievals at BNF

Primary observations	Instrument
Shortwave, downwelling, total	Pyranometer – Hukseflux SR20
Shortwave, downwelling, diffuse	Shadow mask pyranometer – Delta-T SPN1
Shortwave, downwelling, direct	Shadow mask pyranometer – Delta-T SPN1
Shortwave, upwelling	Pyranometer – Hukseflux SR20 (no fan)
Longwave, downwelling	Pyrgeometer – Eppley PIR
Longwave, upwelling	Pyrgeometer – Eppley PIR (no fan)





RADFLUX retrievals	Reference
Clear-sky, shortwave, up/down, total, direct diffuse	Long & Ackerman, 2000, JGR; Long, 2005, ARM
Clear-sky, longwave, up/down	Long & Turner, 2008, JGR
Total sky Cover, shortwave, longwave	Long et al., 2006, JGR; Long & Turner, 2008, JGR; Durr & Philipona, 2004, JGR
Cloud optical depth (visible), transmissivity	Barnard & Long, 2004, JAM; Barnard et al., 2008, TOASJ; Long & Ackerman, 2000, JGR
Sky brightness temp., cloud radiating temp., cloud radiative height	Long et al., 2004, ARM
Clear-sky longwave emissivity	Marty & Philipona, 2000, GRL; Long et al., 2004, ARM

RadSys at BNF

Two RadSys will be install in Week of March 10th.

One at the top of the tower

- downwelling at 42.7 meters
- upwelling at 36 meters

On the forest floor 170 feet SW of tower.

Conclusions

- RadSys at BNF to study biosphere-atmosphere interactions.
- RadSys can handle moving platforms, here the swaying tower.
- One unit above the canopy and one on the floor to study
  - radiative fluxes through the canopy.
  - effects of biosphere on PBL and clouds above canopy.