CERES Top-of-atmosphere and Surface fluxes in the Arctic: A comparison with ARISE and MOSAiC measurements

Patrick C. Taylor

NASA Langley Research Center

Acknowledgements: Yiyi Huang, Kyle Itterly, Brant Dodson, Joe Corbett, Sergio Sejas, Wenying Su, Dave Doelling, Seiji Kato, Anthony Bucholtz

Fall 2022 ERB Workshop

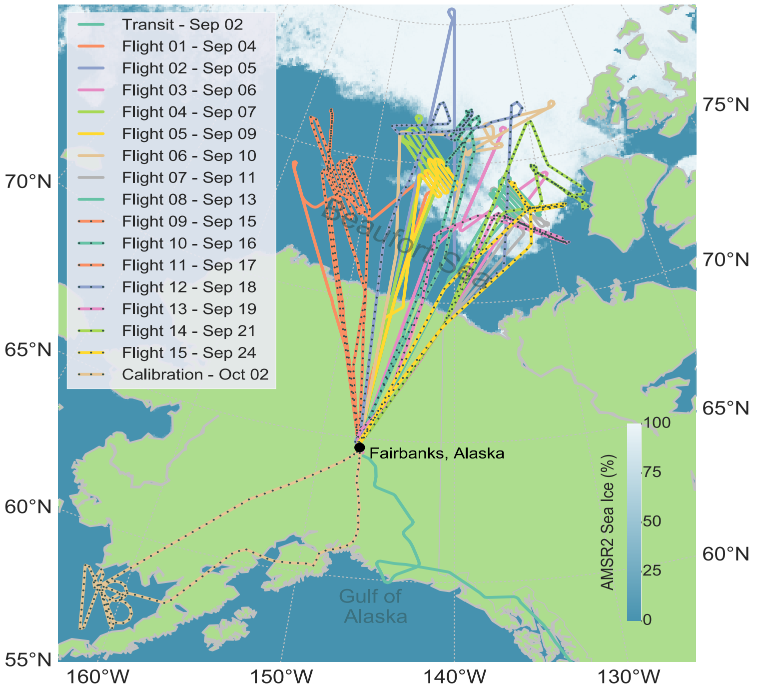
October 13, 2022

Overview

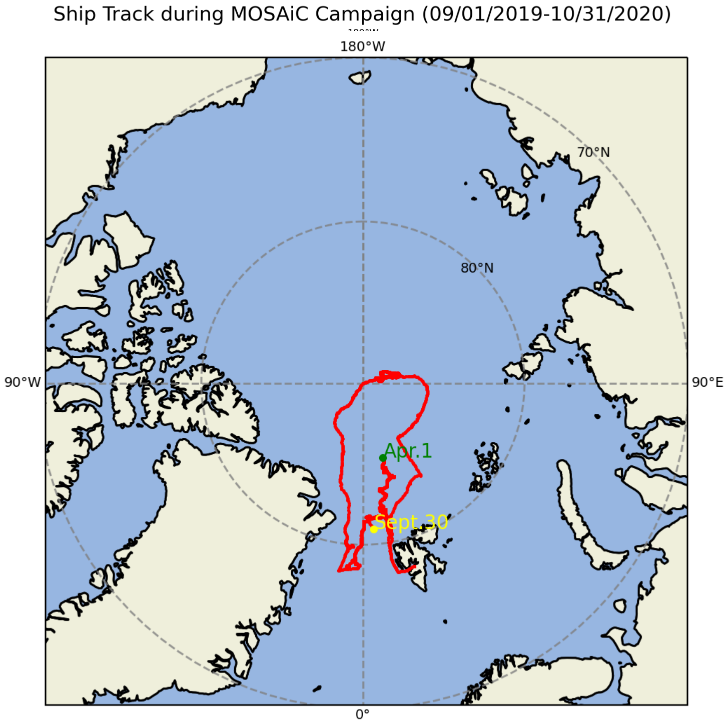
Motivation

- Uncertainty in CERES-derived irradiances is larger over sea ice than any other scene type

- Uncertainty in atmospheric temperature and humidity from reanalysis, heterogeneity in surface conditions, and difficulties in detecting and characterizing clouds over sea ice all contribute to the CERES irradiance uncertainty



ARISE (Sept. 2014)



MOSAiC (2019-2020)

Outline

- Taylor et al. (in revision): Comparison of CERES TOA fluxes during ARISE.
- Huang et al. (2022): Comparison between CERES SYN and MOSAiC during summer.
- Scott et al. (2022): Comparison between CERES CRS and MOSAiC and polar surface sites.
- Dodson et al. (in prep.) Comparison between CERES SYN1deg and MOSAiC during polar night

Arctic Radiation-IceBridge Sea ice Experiment (ARISE)

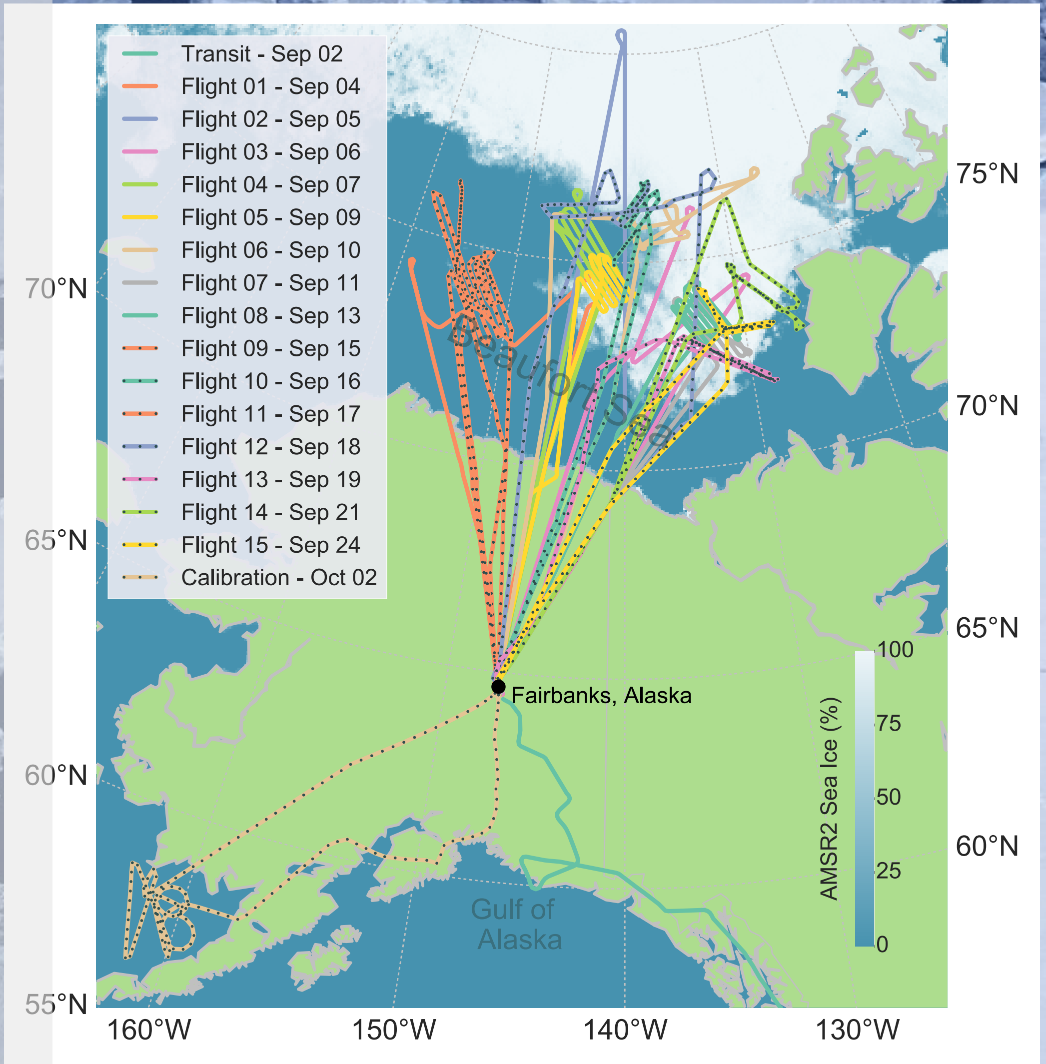
Based in Fairbanks, Alaska during September 2014

From the NASA C-130:

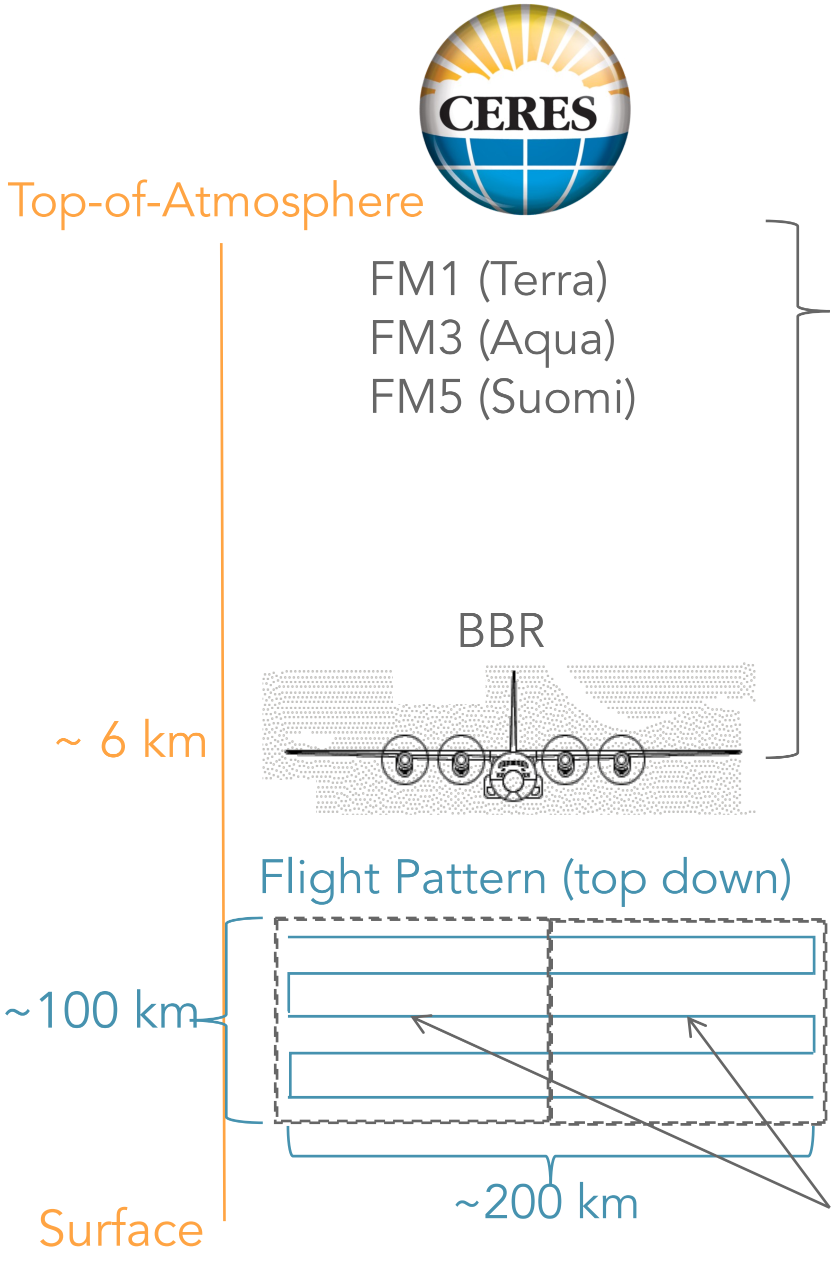
- Measure spectral and broadband radiative flux profiles
- Quantify surface characteristics, cloud properties, and other atmospheric state parameters under a variety of Arctic atmospheric and surface conditions
- Coincide with satellite overpasses as often as possible

Naval Research Laboratory Broadband Radiometers (BBR):

- SW up and down – modified Kipp and Zonen CM-22 pyranometers
- LW up and down – modified Kipp and Zonen CG-4 pyrgeometers
- estimated uncertainty ~ 3-5%



CERES-Aircraft Comparison Methodology:



Compare mean BBR TOA and mean CERES fluxes for each grid box

Need to account for:

LW - absorption

SW - scattering/absorption

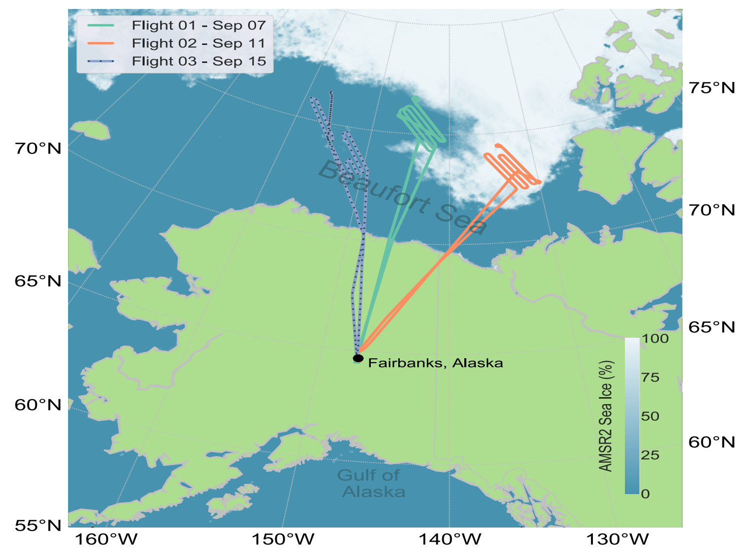
Langley Fu-Liou Radiative transfer model:

- Atmospheric state information from GEOS 5.4.1
- Cloud property information from MODIS (CERES cloud group)
- Surface information from the AMSR2 ASI 3.5km sea ice concentration dataset (Uni. Hamburg)

To convert BBR from 6 km to TOA:

$$\text{BBR TOA} = (F(\text{TOA})_{\text{model}}/F(6\text{km})_{\text{model}}) \times \text{BBR}$$

ARISE TOA gridbox experiments :



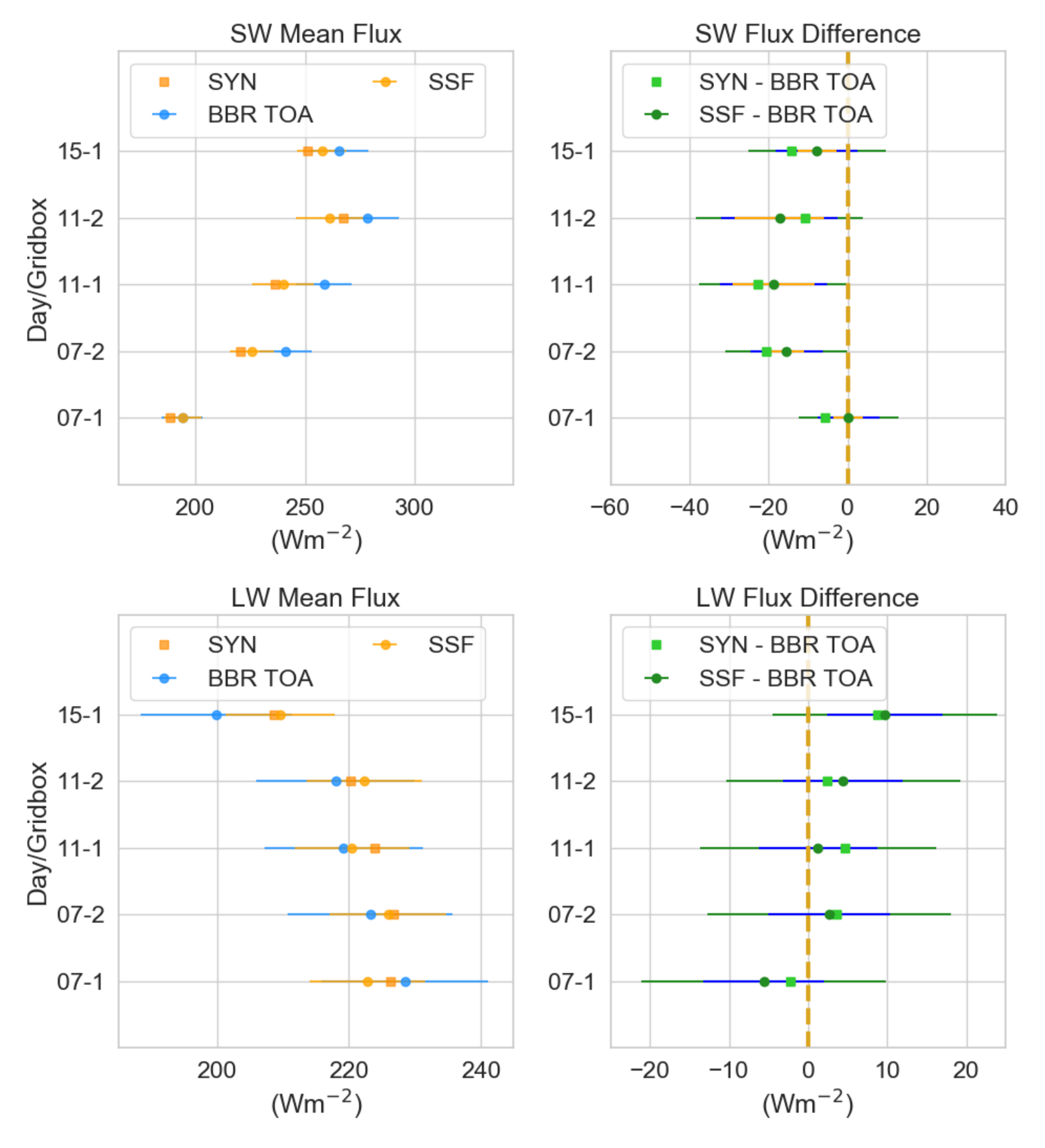
Overcast ocean

Partly cloudy sea ice

Overcast sea ice

Overcast MIZ

Overcast MIZ

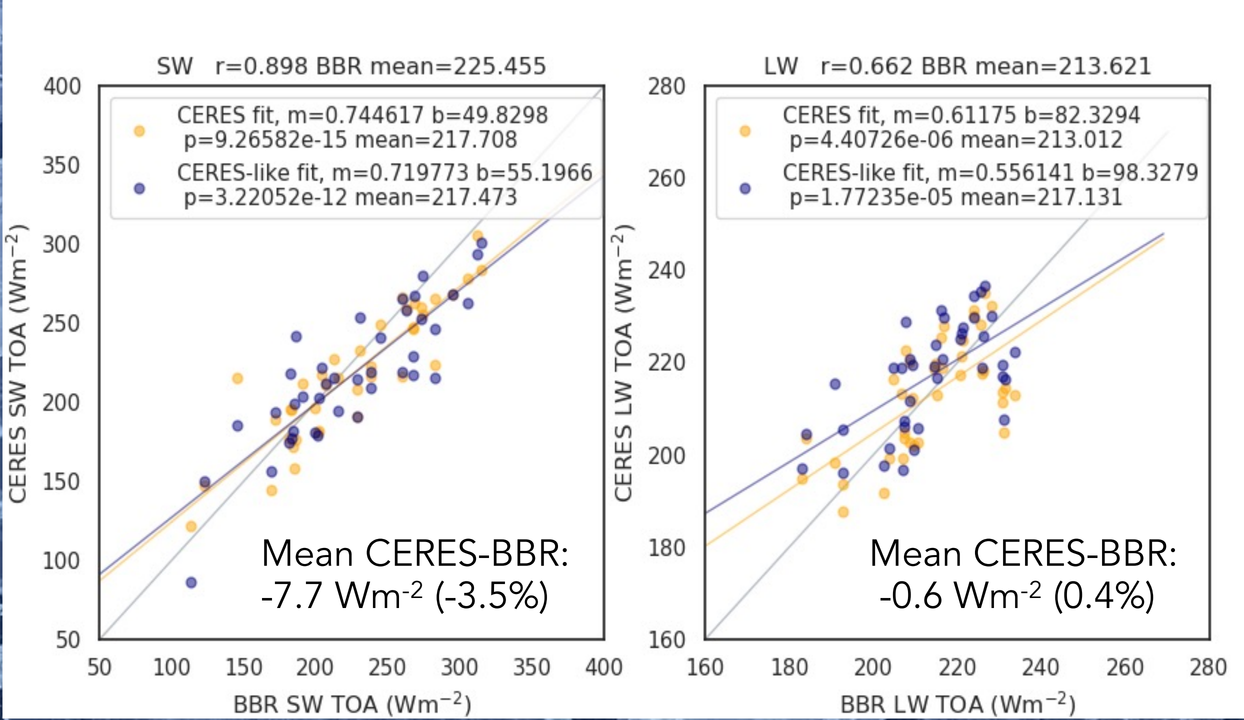


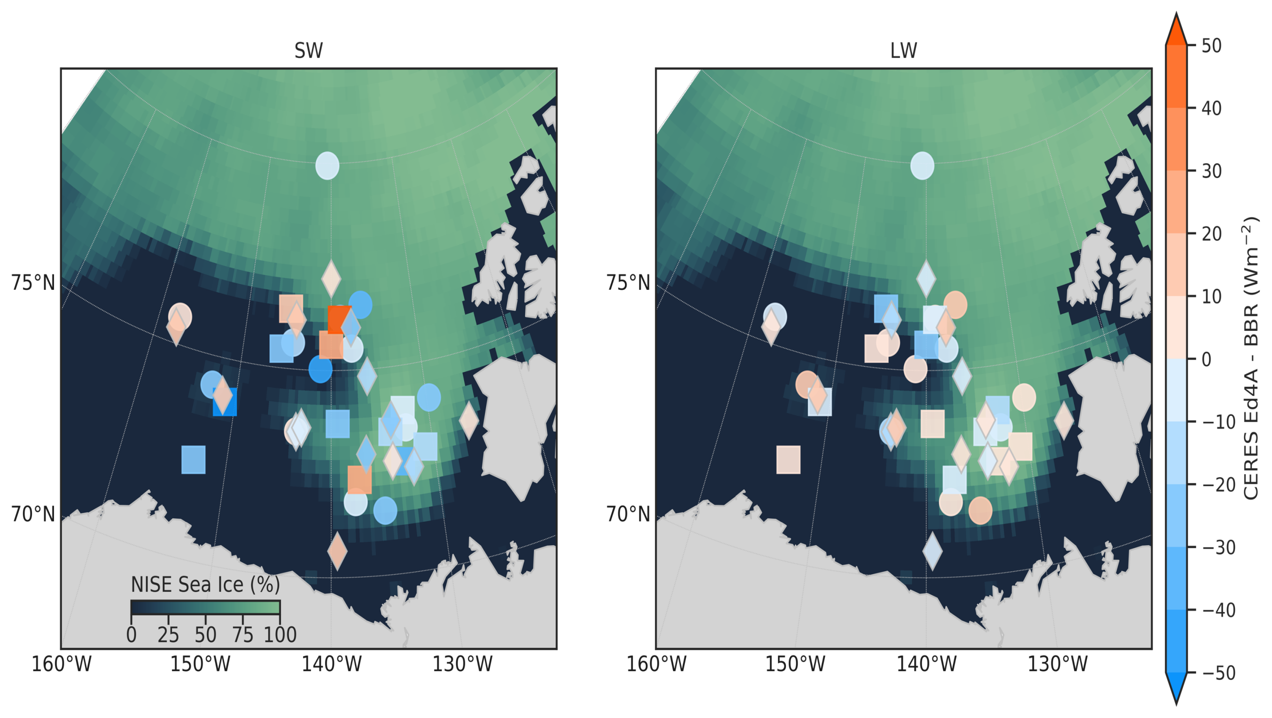
SW CERES-BBR mean difference: -13.0 Wm^{-2}
LW CERES-BBR mean difference: +2.5 Wm^{-2}

- LW shows good agreement for all grid-boxes (< +/- 2 Wm^{-2})
- SW shows agreement within uncertainty for 4/5 grid-boxes

Instantaneous comparisons: 39 matched FOVs

- An alternative to the gridbox experiments is to compare only the instantaneous matches between aircraft and CERES FOVs
- Time match: within 15 minutes
- Despite the small number of samples, the overall results matches the gridbox experiments.





SW CERES-BBR mean difference: -7.7 Wm^{-2} (-3.5%)
LW CERES-BBR mean difference: -0.6 Wm^{-2} (0.4%)

Instantaneous comparisons: Stratifying by scene type

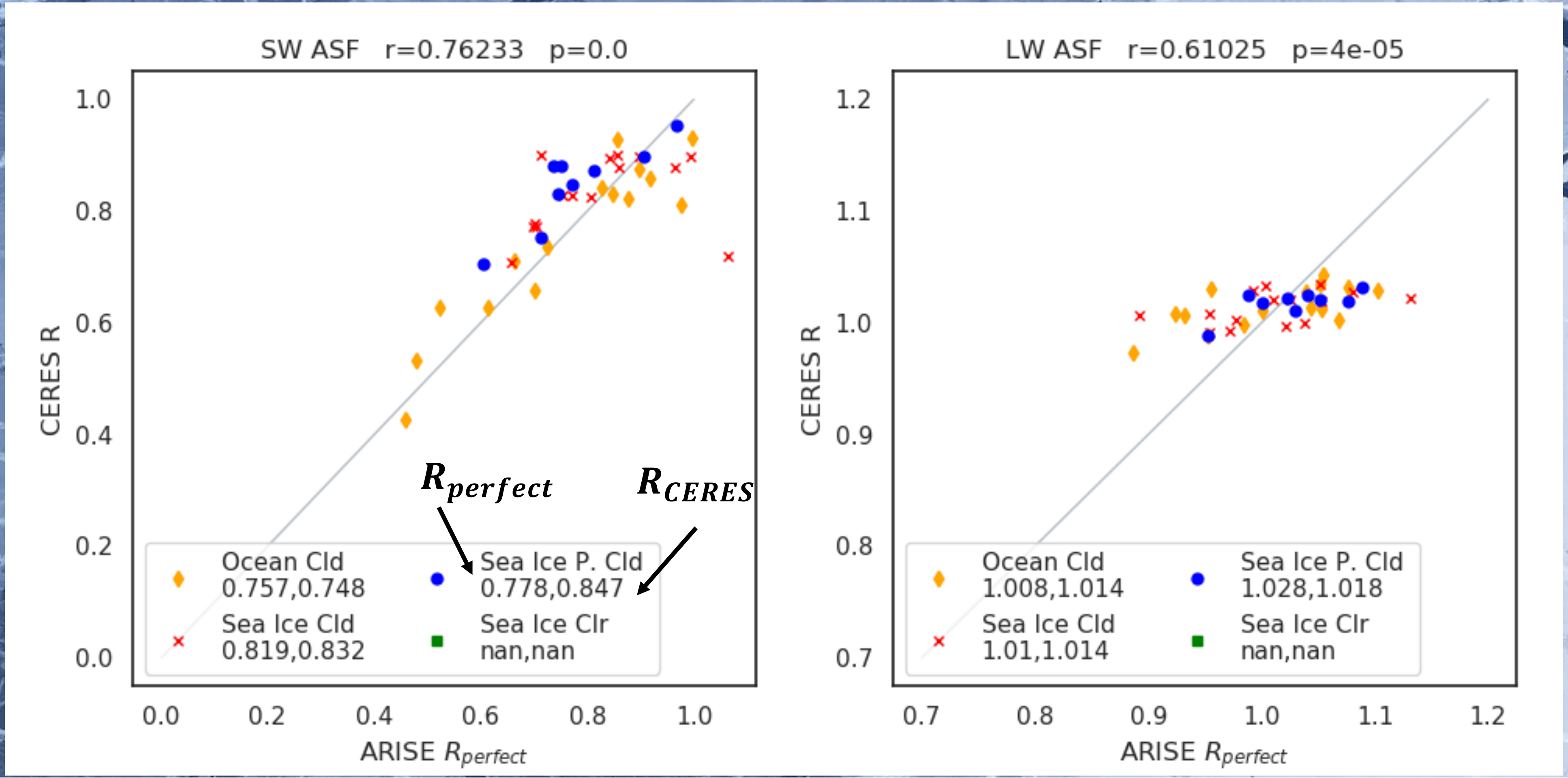
- An alternative to the gridbox experiments is to compare only the instantaneous matches between aircraft and CERES FOVs
- Time match: within 15 minutes
- Despite the small number of samples, the overall results matches the gridbox experiments.

ADM GROUP	N (count)	SSF-BBR SW Mean Difference (W m^{-2})	SW SSF STDEV (W m^{-2})	SSF NISE as imager –BBR Mean Difference (W m^{-2})	SW STDEV (W m^{-2})	CERES Ed4a LW Mean Difference (W m^{-2})	LW SSF STDEV (W m^{-2})
Ocean Cloudy	15	-0.8	17.6	-2.4 (12)	18.2	-1.9	11.2
Sea Ice Clear	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sea Ice Partly Cloudy	9	-17.1	13.6	+9.2 (12)	17.1	1.9	7.4
Sea Ice Overcast	15	-9.1	29.3	-9.1 (15)	29.3	-0.9	11.0

Largest difference are found in sea ice partly cloud scenes and the differences are sensitive to the choice of sea ice data set.

Influence of sea ice data set: Perfect Anisotropy (R)

$$R_{perfect} = \frac{\pi ICERES}{BBR_{TOA}}$$

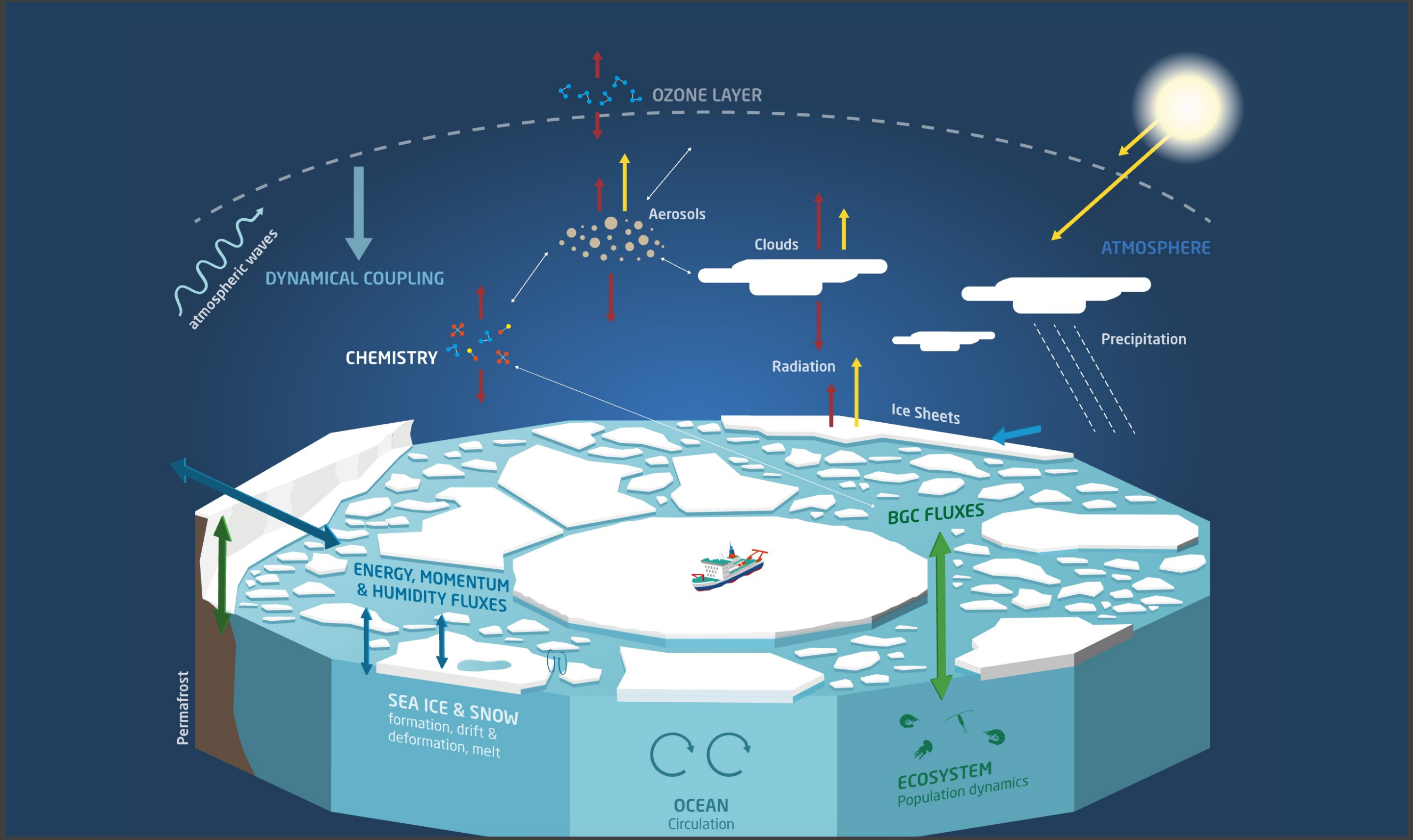


R_{CERES} is systematically ~0.07 larger than $R_{perfect}$ for the sea ice partly cloudy scenes indicating that the anisotropy differences contribute to the negative SSF-BBR flux differences. Using NISE as imager removes this difference.

The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) field campaign

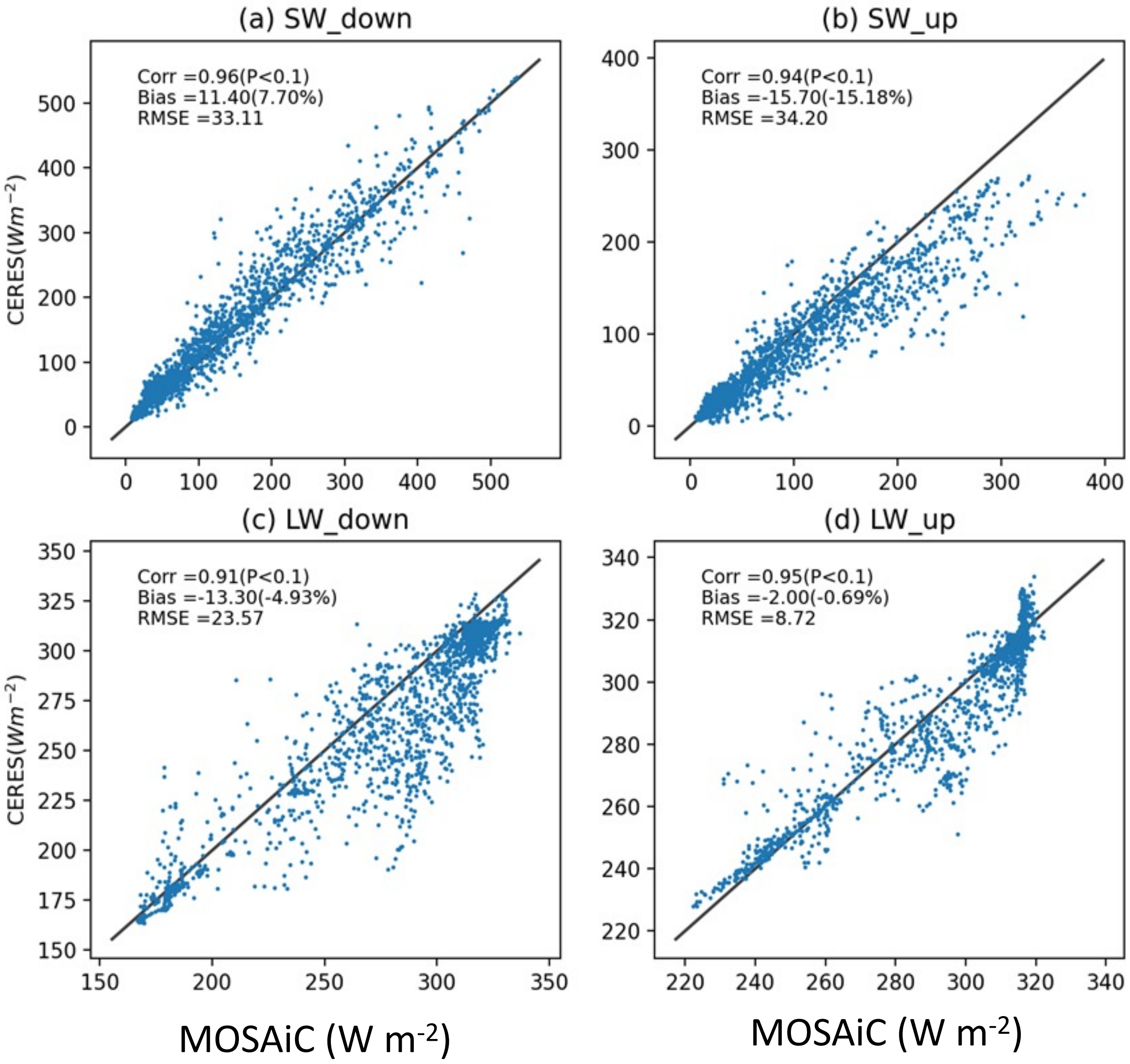
September 2019 - October 2020

- The largest polar expedition in history; the first time in polar winter
- The goal of the MOSAiC expedition was to take the closest look ever at the Arctic as the epicenter of global warming and to gain fundamental insights that are key to better understand global climate change



https://mosaic-expedition.org/

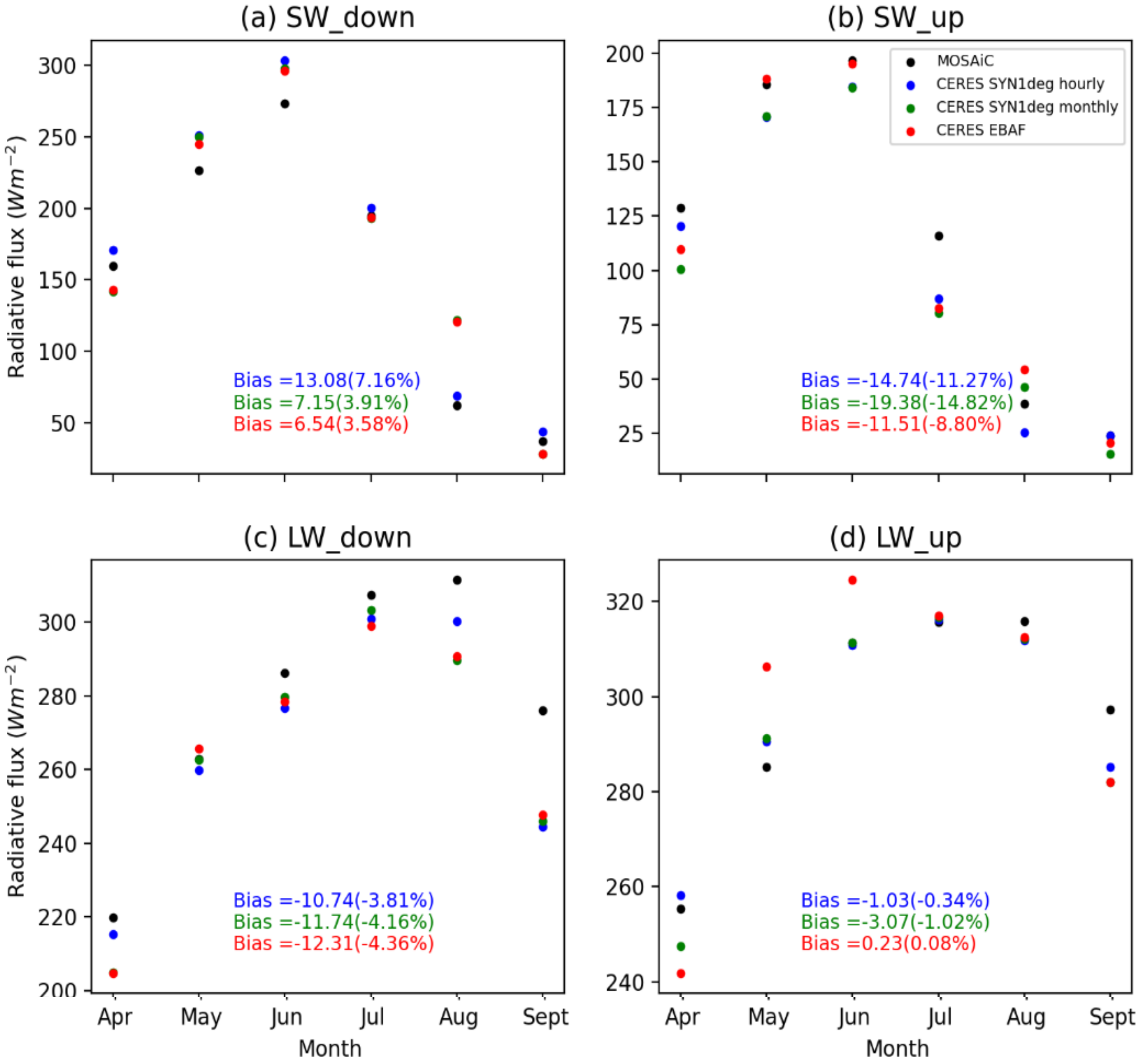
Radiative fluxes at the surface: MOSAiC and CERES SYN1deg



- The SYN1deg tends to overestimate SW_down flux, but underestimate SW_up and LW_down fluxes at the surface during summertime
- The SW_up flux is the most uncertain quantity
- Larger uncertainty in LW_up flux (~320W/m^2) occurs when the surface reaches melting point

Huang et al. (2022; Elementa)

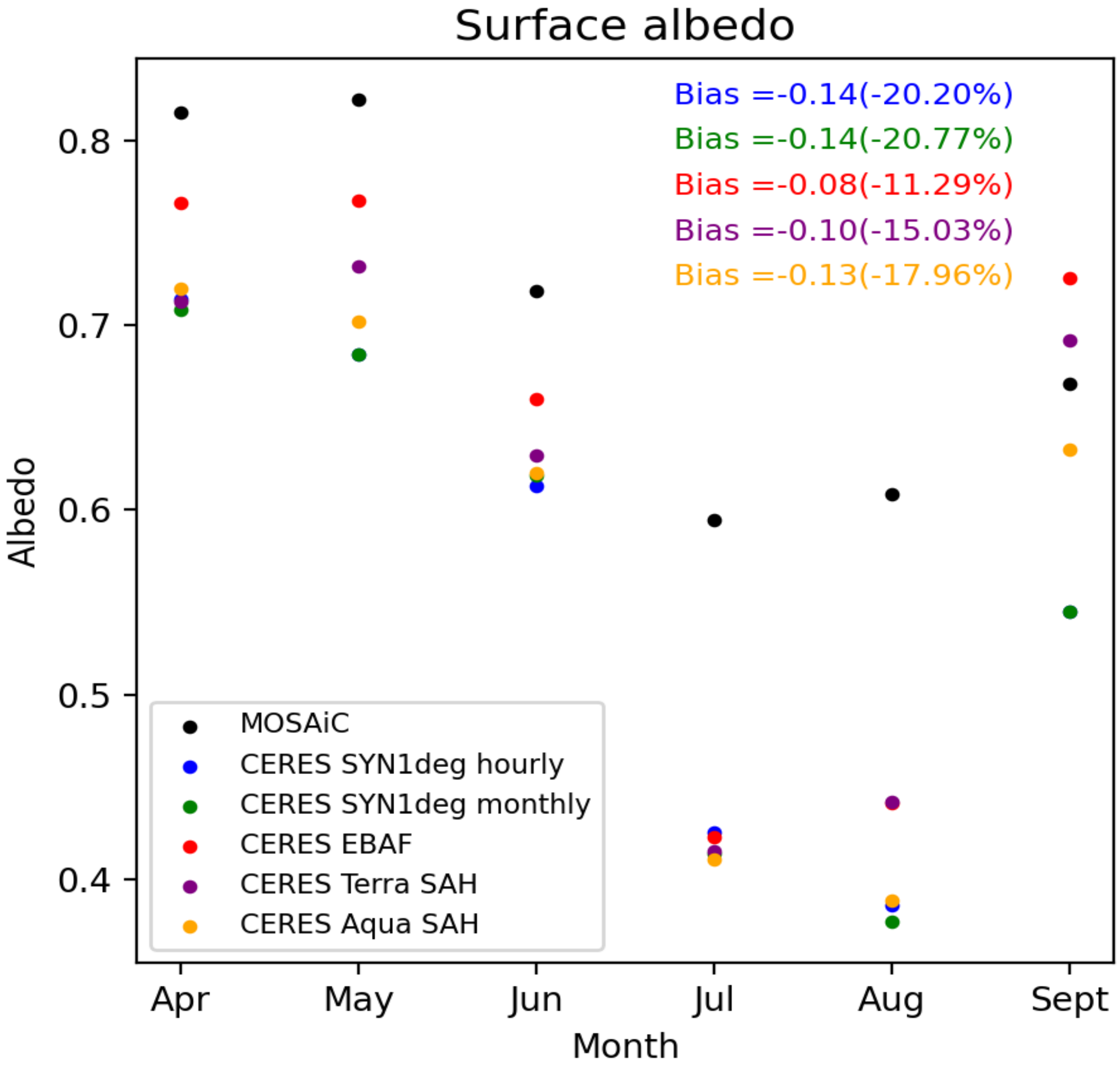
Monthly Radiative Mean fluxes : MOSAiC and CERES SYN1deg



- Monthly mean CERES-MOSAiC fluxes differ between for CERES products (e.g., SYN 1deg and EBAF).
- SFC EBAF represents the smallest biases over the 6-month period but is not always the most accurate for an individual month.

Huang et al. (2022; Elementa)

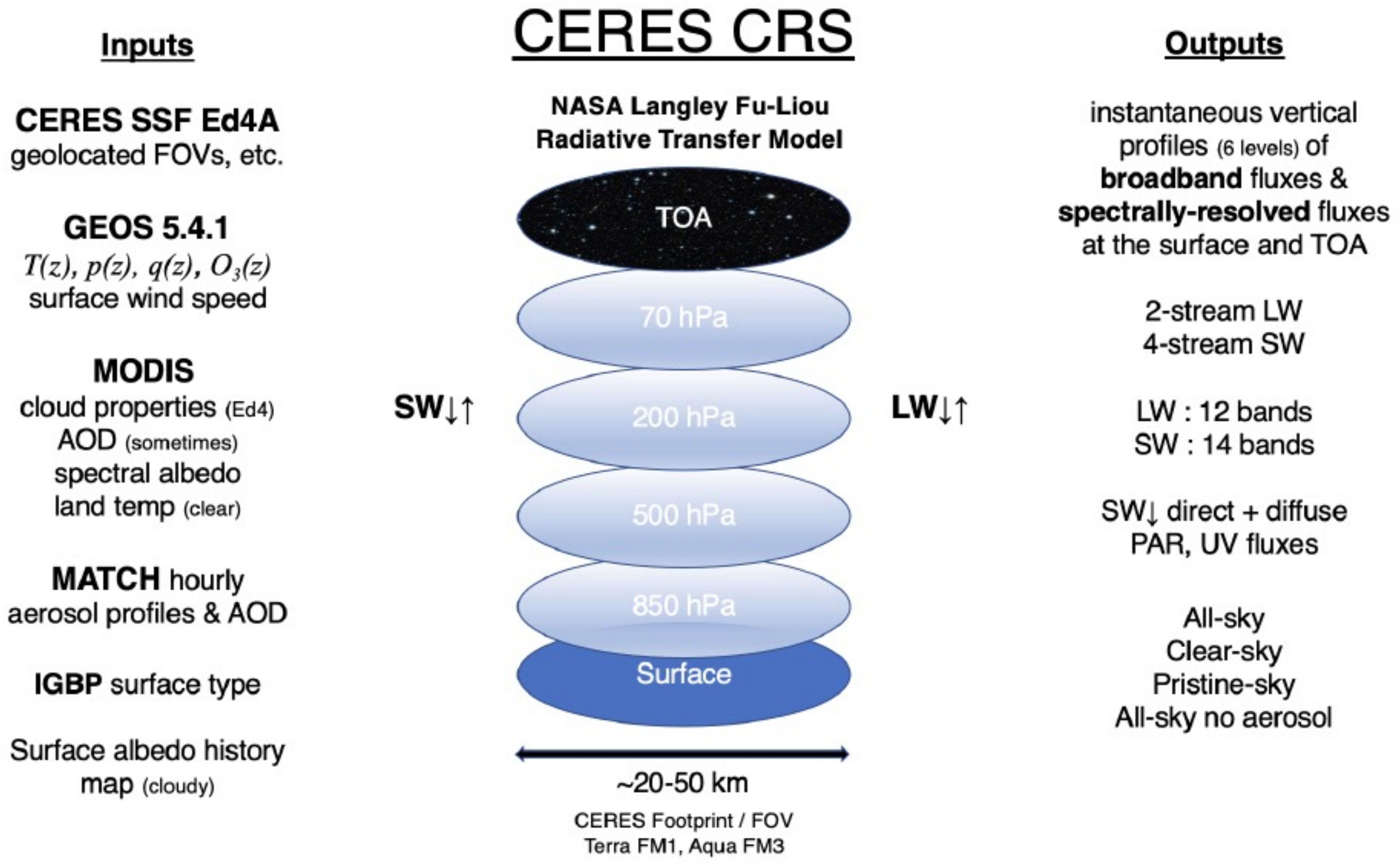
Monthly Surface Albedo: MOSAiC and CERES SYN1deg



- This comparison shows the monthly mean surface albedo values over the MOSAiC domain for different CERES products and observations.
- Differences are found between the different CERES produces (e.g., SYN-1deg and EBAF)
- SFC EBAF again represents the smallest bias over the 6-month period but is not always the most accurate for an individual month.

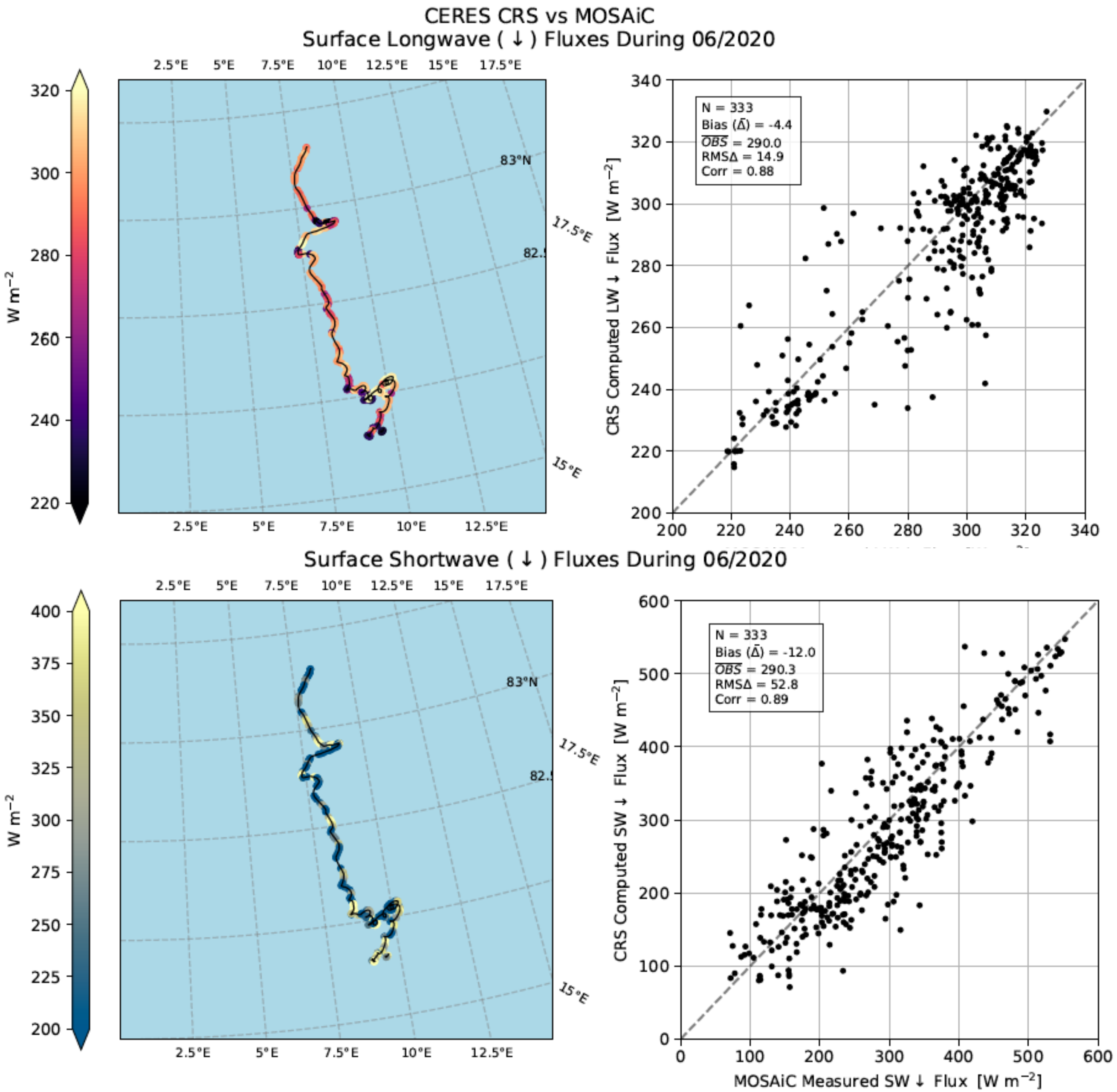
Huang et al. (2022; Elementa)

CERES SSF/CRS vs. MOSAiC and Polar surface sites



Scott et al. (2022; J. Climate)

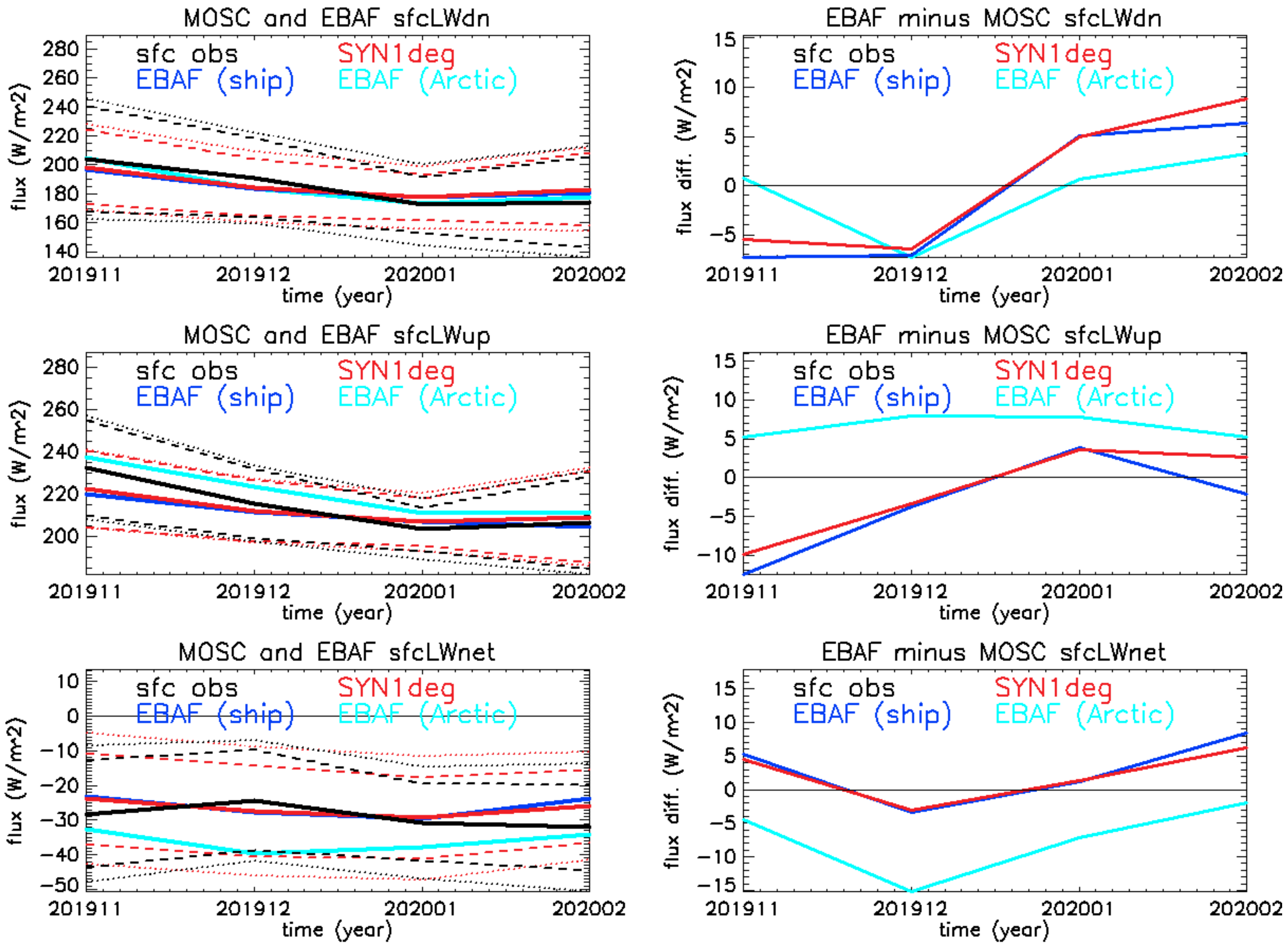
CERES SSF/CRS vs. MOSAiC and Polar surface sites



- Comparison shows the CRS footprints matches in space and time with the MOSAiC drift track for June 2020.
- Mean differences CRS minus MOSAiC:
  - LWDN: -4.4 Wm^{-2}
  - SWDN: -12.0 Wm^{-2}
- Mean all-sky differences between CRS and Polar surface sites:
  - LWDN (day): -3.1 Wm^{-2}
  - LWDN (night): 0.6 Wm^{-2}
  - SWDN: -18.0 Wm^{-2}

Scott et al. (2022; J. Climate)

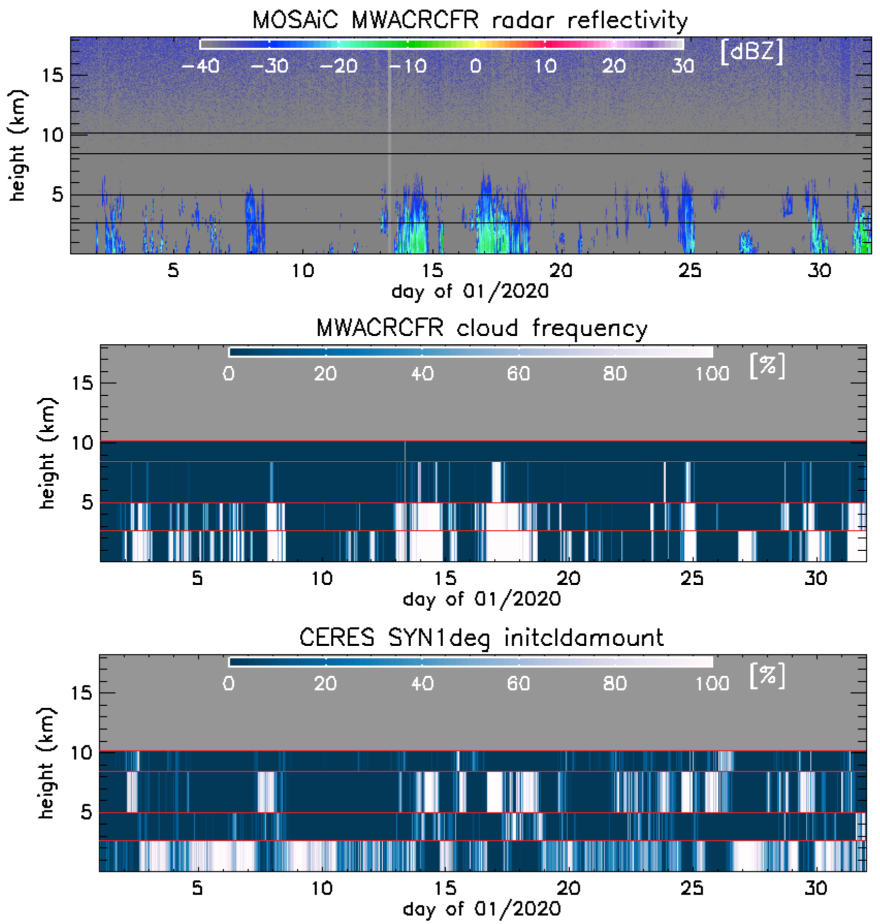
CERES SYN and EBAF vs. MOSAiC during polar night



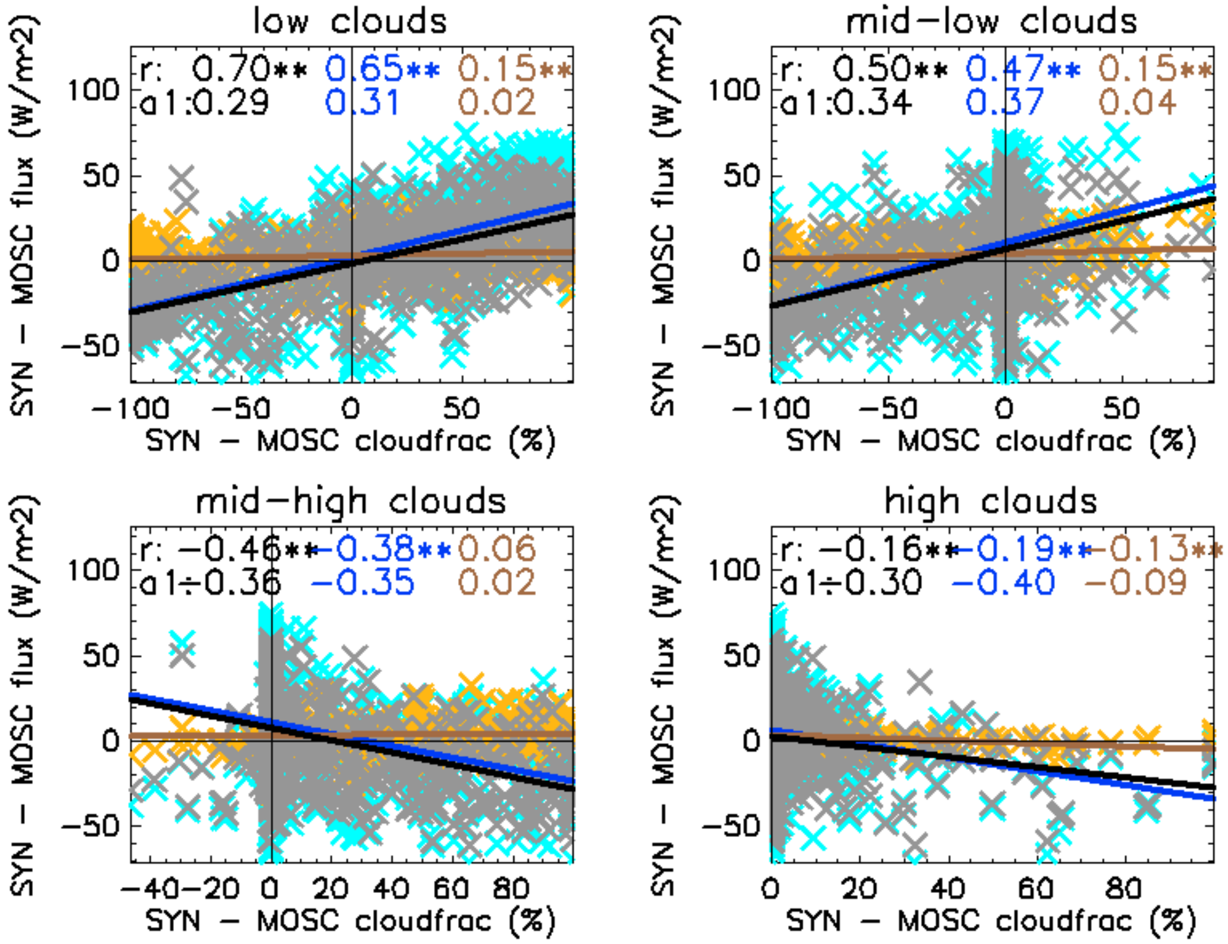
Dodson et al. (in prep.)

CERES SYN vs. MOSAiC during polar night: Role of clouds

Case study from January 2020



CERES SYN1deg cloud amount agrees well with in situ radar observations, but misses low clouds obscured by high clouds.

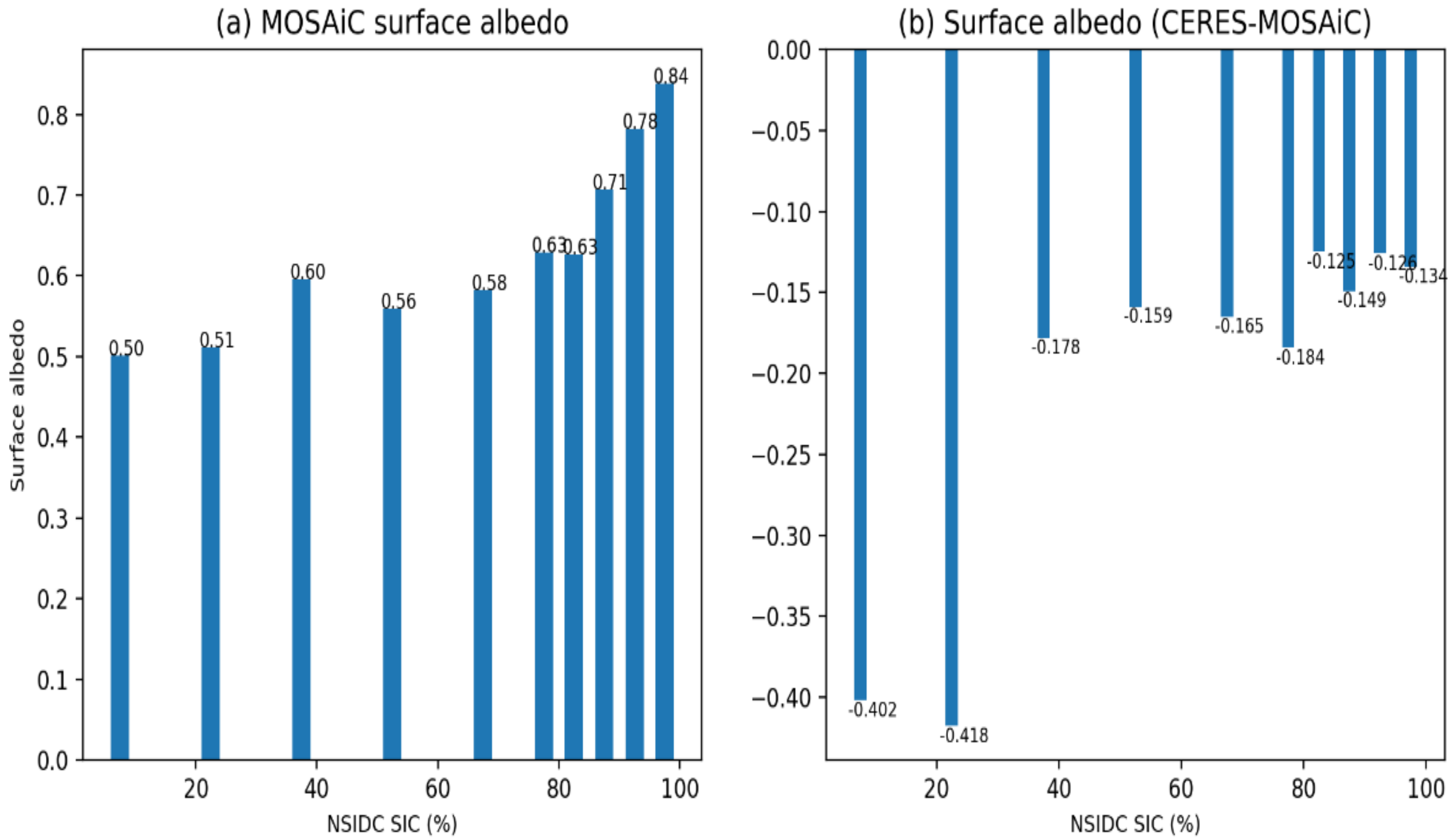


CERES SYN1deg-Radar cloud amount differences correlate strongly with differences in LW_down flux differences.

Takeaways

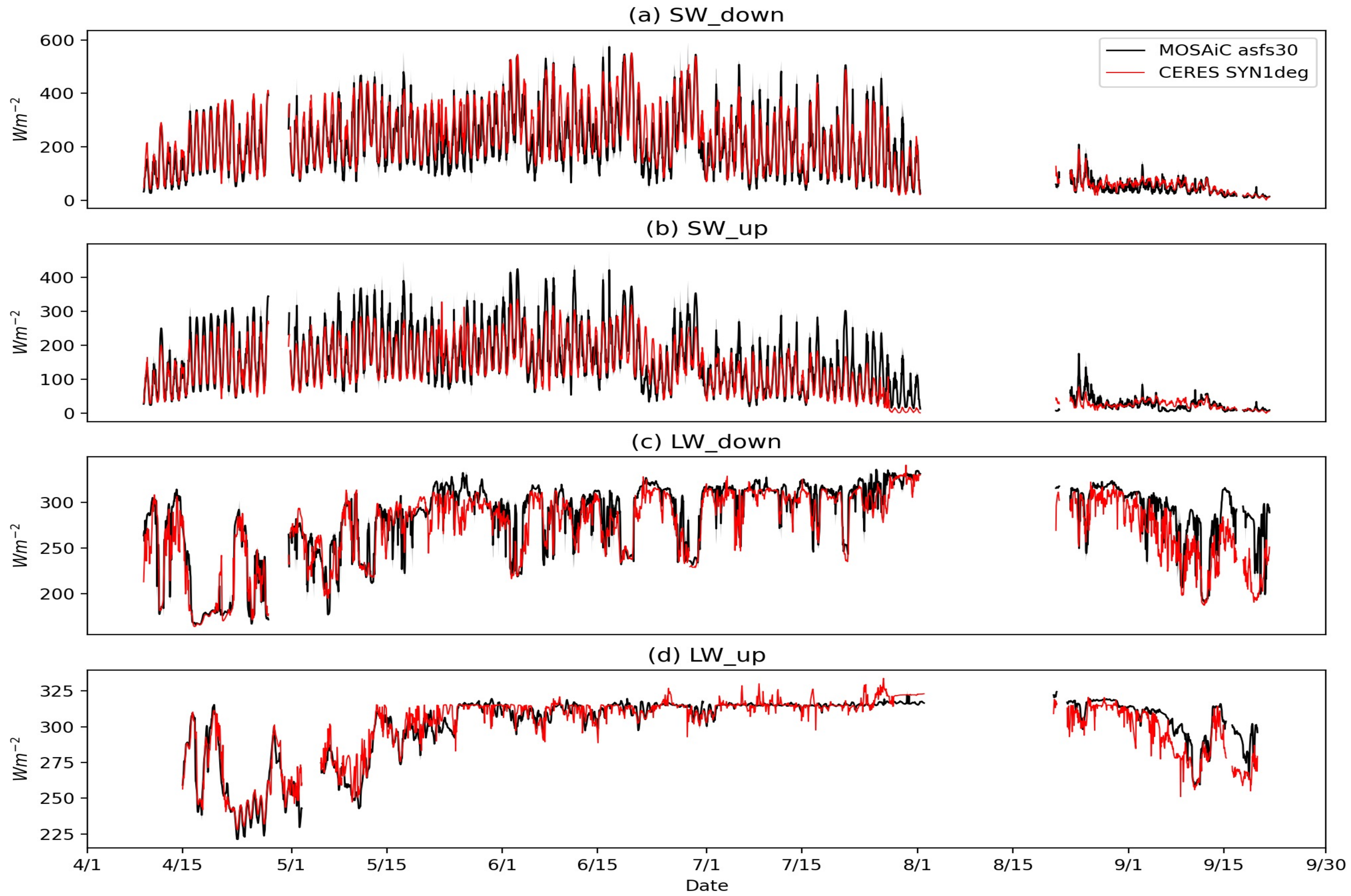
- **CERES-ARISE Comparison:**
  - CERES RSW fluxes are sensitive to the sea ice data set;
  - Points to errors in anisotropy over sea ice partly cloud scenes;
  - An ARISE-like approach can only to verify CERES TOA fluxes to the 7% level.
- **CERES-MOSAiC Comparison:**
  - Negative Polar Night LWDN differences with MOSAiC due to missing low clouds
  - CERES SYN and CRS LWDN all-sky is lower than MOSAiC and polar surface sites.
  - CERES SYN SWUP is lower than MOSAiC resulting from too low surface albedo: need to evaluate the use of the surface albedo history map.
  - CERES SYN and CRS SWDN comparisons with MOSAiC show conflicting results
    - CERES SYN SWDN is greater than MOSAiC
    - CERES CRS SWDN is less than MOSAiC
- **Possible next steps:**
  - Investigate sea ice partly cloud anisotropy: Use FM2 RAPS data during MOSAiC
  - Evaluate the radiative effect cloud handling approaches in CRS and SYN
  - Investigate the low cloud retrieval errors during polar night and their impacts on radiation.

Sea ice concentration dependent albedo differences: MOSAiC and CERES SYN1deg



- CERES-MOSAiC differences in surface albedo are sea ice concentration dependent.
- Differences at lower sea ice concentrations is attributed to the smaller scale of the MOSAiC observations (~6 m^2 area), such that they only represent the sea ice portions of the CERES gridbox.

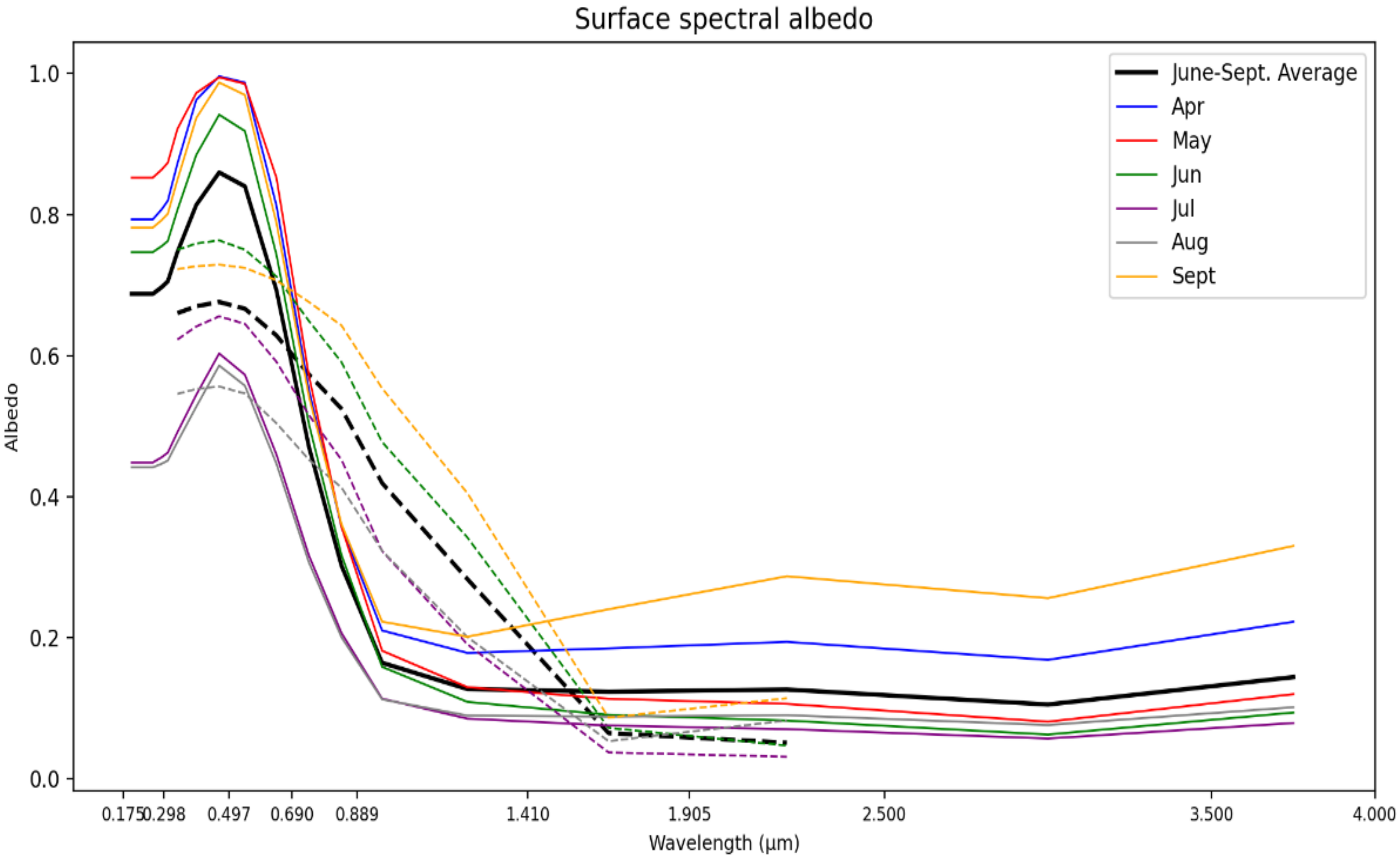
Radiative fluxes at the surface: MOSAiC asfs30 and CERES SYN1deg



Spectral Surface Albedo: MOSAiC and CERES SYN1deg

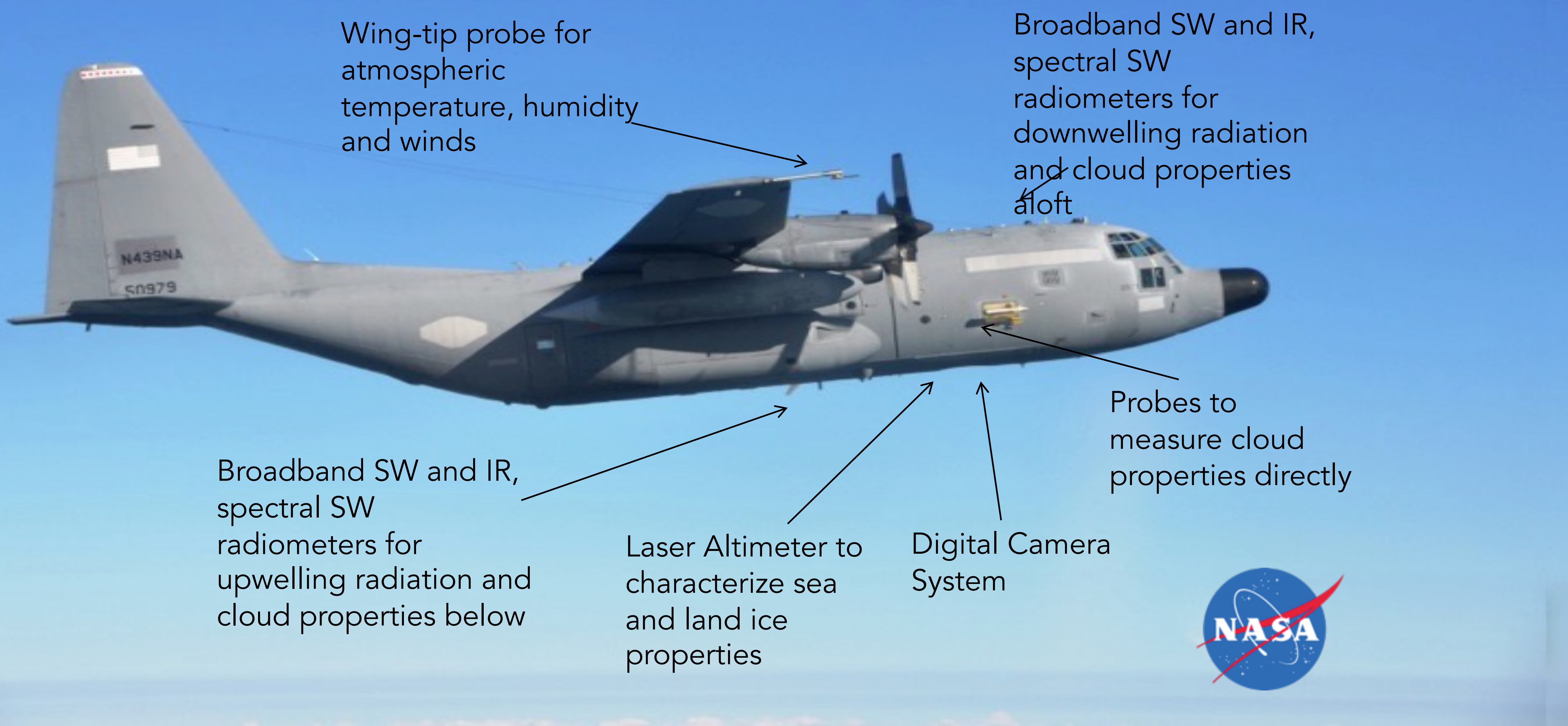
Solid—CERES (Jin 2004; LUT)

Dashed—MOSAiC observations (Perovich et al. 2021)



- Comparison reveals differences in the CERES surface spectral albedo shape model and the MOSAiC observations.

NASA C-130: An airborne radiometer (thermometer) with in-situ probes and a laser altimeter to characterize the surface, atmosphere and radiative effects of sea-ice and clouds

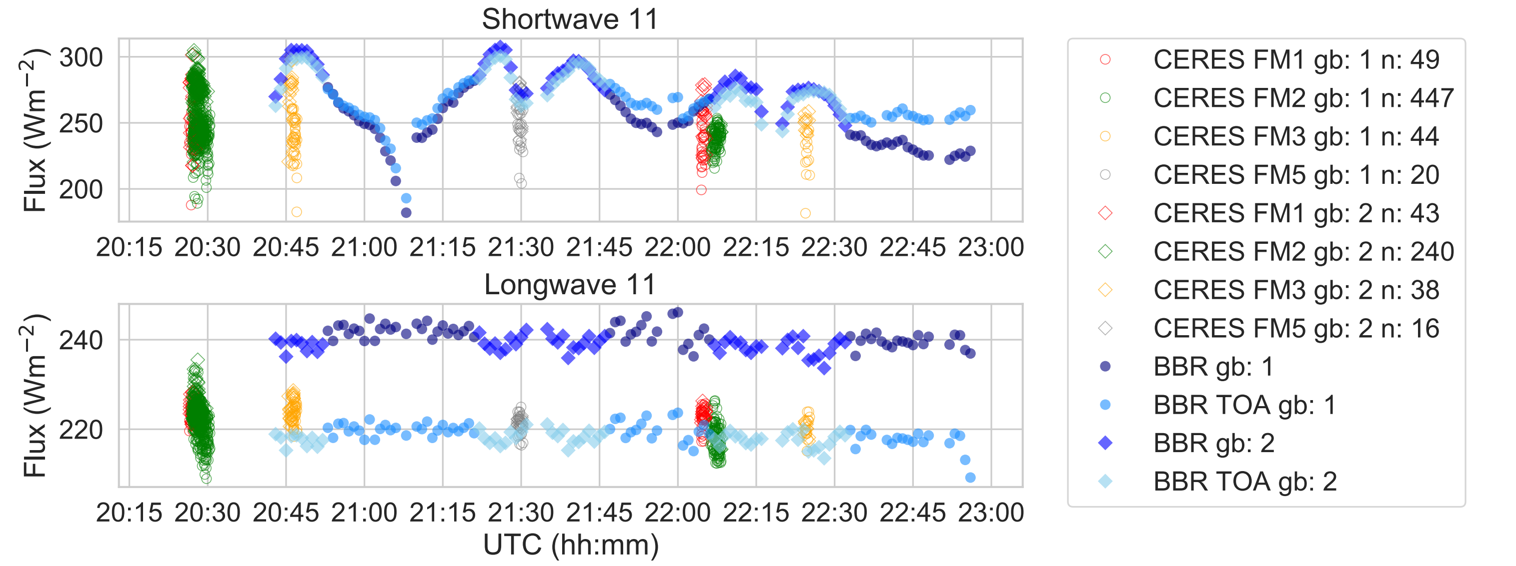


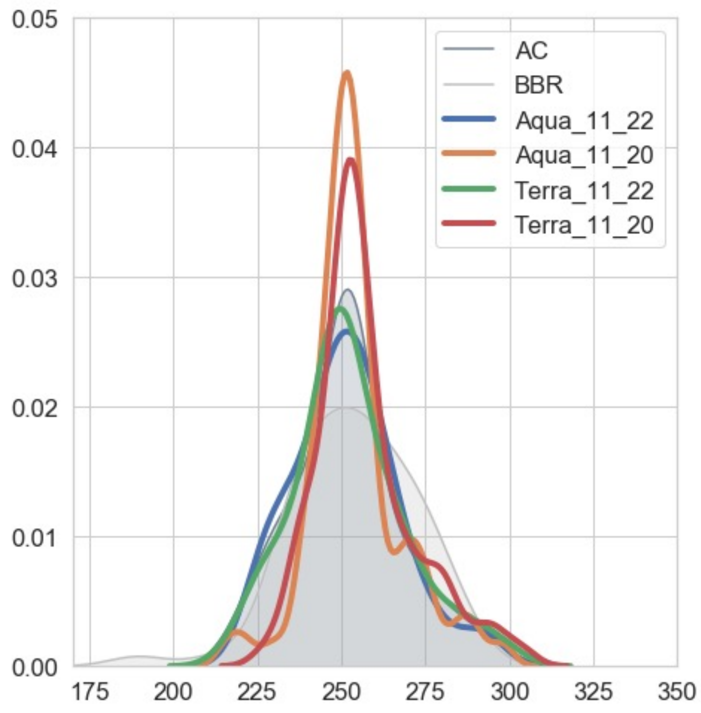
Sampling Uncertainty

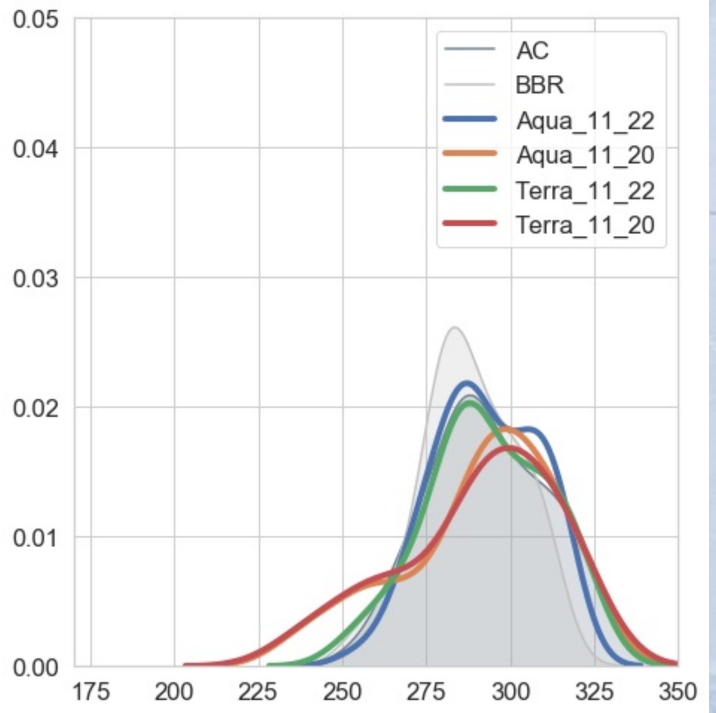
Satellite sampling: grid box averages are computed from 3-4 near-instantaneous snapshots

Aircraft sampling: grid box average are computed from 2-hour continuous sampling of the grid box.

- These sampling differences could influence the CERES-BBR differences since the scenes are not static.







Results indicate a 1.8% and 1.7% sampling uncertainty for SW and LW, respectively.

Summary

- The gridbox sampling/validation approach proved successful during ARISE
  - LW TOA shows good agreement – all differences within the uncertainty.
  - SW TOA not quite as good – 4/5 within the uncertainty.
  - Consistent negative CERES SW difference relative to Aircraft Observations.
- Instantaneous CERES FOV and Aircraft comparison provide similar results.
- Why the negative SW bias?
  - Not Sampling differences (~1.7-1.8%)
  - Scene ID…we find substantial sensitivity of the differences to the sea ice data set
  - ADMs…evidence that sea ice partly cloud scene anisotropy could contribute
- Five data points is not enough to make strong claims about any biases – more experiments needed (in the future, leverage MOSAiC)

- Switching from imager-based to passive microwave-based sea ice data in the CERES inversion process reduces the differences in the grid box average fluxes and in the sea ice partly cloudy scene anisotropy in the instantaneously-matched footprints.

- Our analysis indicates that calibration and sampling uncertainty limit the ability to place strong constraints (<±7%) on CERES TOA fluxes with aircraft measurements.

NASA C-130 PAYLOAD

Instruments	Measurement	Characteristics	Products
Broadband Radiometers (BBR) A. Bucholtz, NRL	SW and LW fluxes (↑, ↓) SW total, direct & diffuse (↓)	SW: modified K&Z CM-22 (0.2-3.6 μm) LW: modified K&Z CG-4 (4.5-45 μm) TDDR: Delta-Devices SPN-1 (0.4-2.7 μm)	Net SW, LW Irradiance, direct/diffuse SW partitioning, absorption, heating rates Surface albedo, cloud albedo
Spectral Solar Flux Radiometer (SSFR) S. Schmidt, U. of Colo.	Spectral SW fluxes (↑, ↓)	370-2170 nm, Resolution: 8-12 nm	Spectral fluxes, albedo Cloud properties
Spectral Sun-photometer 4STAR J. Redemann, NASA ARC	Spectral radiances (↓) Modes: direct beam, sky scanning, zenith	380-1700 nm	aerosols, gases, cloud properties above aircraft
Heitronics KT-19 D. Van Gilst, NSERC/UND A. Bucholtz, NRL	IR window radiance (↑, ↓)	9.6-11.5 μm	Skin temperature, sky and cloud temperature
Land, Vegetation, and Ice Sensor (LVIS) B. Blair, M. Hofton, GSFC	Geo-located waveform vector	1064 nm Scanning: 20-minute footprint, 2 km swath from 10 km, Full waveform recorded	Surface elevation, Sea-ice freeboard, Melt-pond distribution Cloud top height