SAND2023-02752C

Sandia National Laboratories

Changes in Arctic Summer Ice Albedo Measured from Global Positioning System (GPS) Satellites

CERES Science Team Meeting

NASA Langley Research Center, Hampton, VA

May 9-11, 2023

Philip L. Dreike, Ph.D., Amy Kaczmarowski & Erika L. Roesler, Ph.D.

dreikepl@sandia.gov

(505)844-5446

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

Sandia provides two 0.4-1.0 micron radiometers that ride on Global Positioning System (GPS) satellites

- 37% of the earth is visible from the 20,200 km altitude GPS orbit.
- One radiometer is pixelated so there is geographic resolution on the full visible disk of the earth

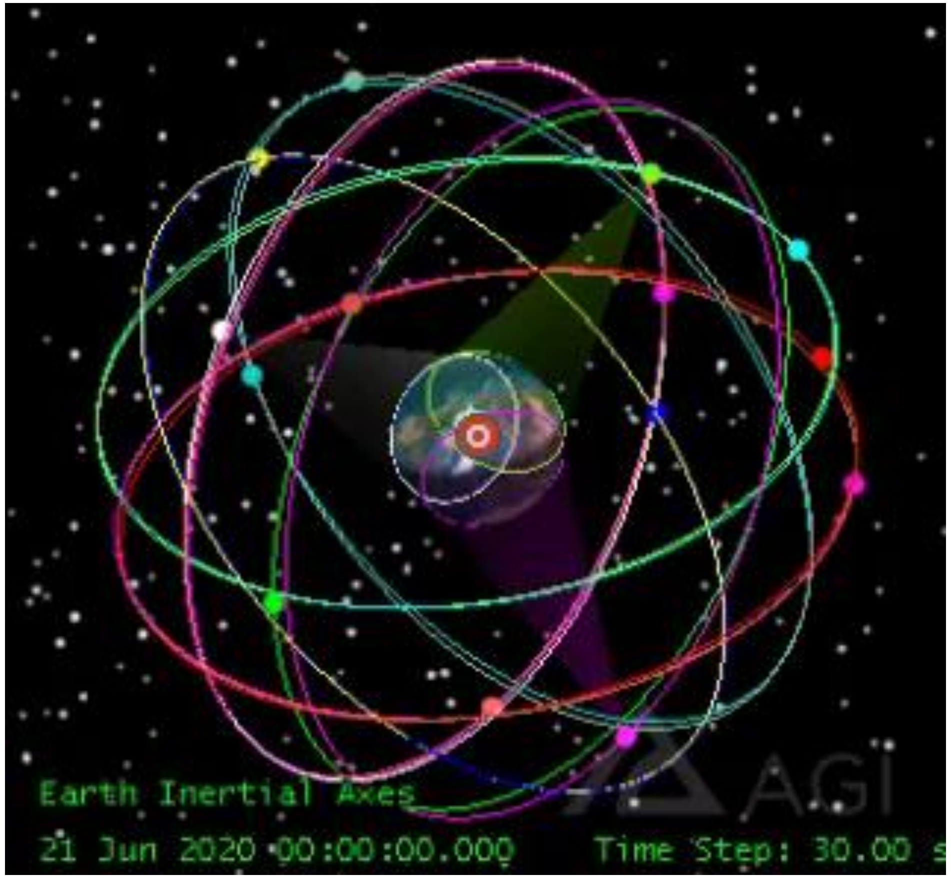
We are exploring use of these measurements for monitoring earth radiation balance

We compared measurements of Antarctic and Arctic reflectivity to get a sense of how to use and analyze the data that is collected

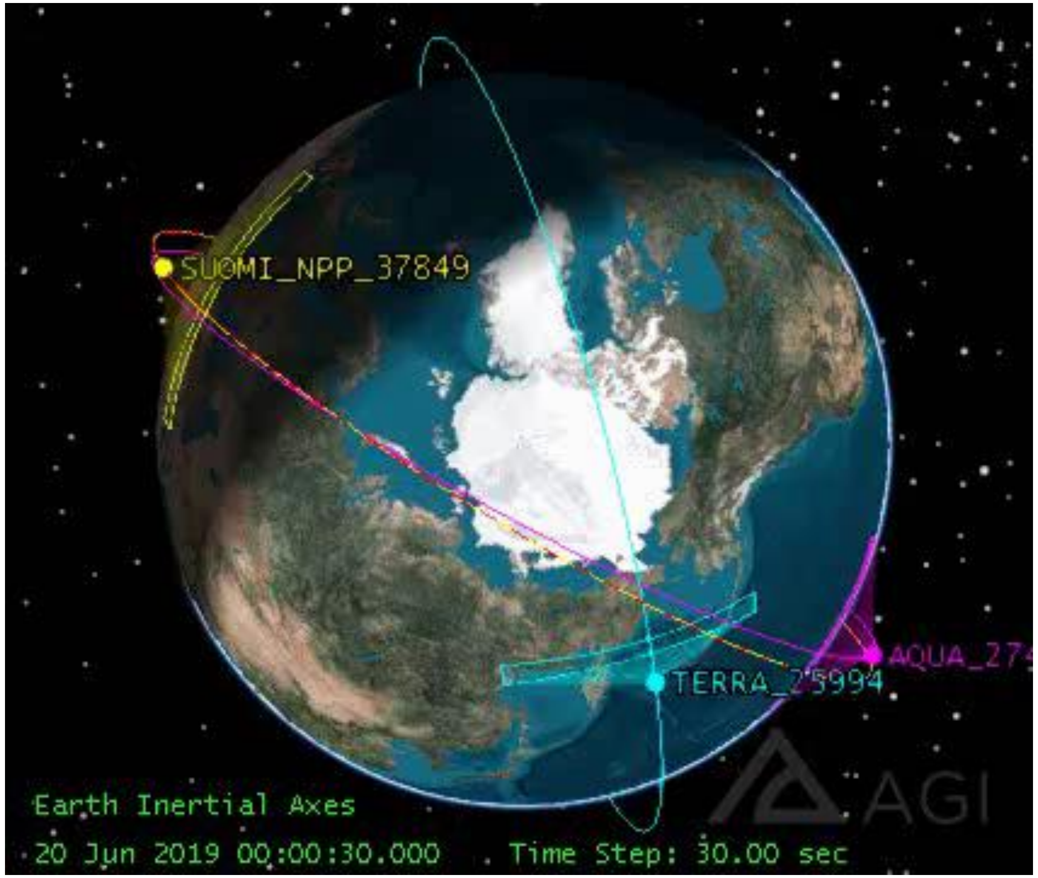
We are looking for ideas on how these measurements may complement the existing sensor suite

GPS Constellation Has An Unrivaled View of the Earth

24 GPS satellites in 20,200 km 12 hr orbits have large overlapping views of the earth. North Pole view shown with cones and circular fields of view on the earth.
(Play animation)



Polar Weather Satellites sweep the earth in ~850 km, 90 minute orbits. North Pole view.
(Play animation)



The Radiometers Provide Whole Earth Coverage and Might Be Used to Validate Interpolation and Extrapolation of Other Measurements to the Full Earth and Full Time Coverage

The pixelated measurements are available in ~15 minute intervals throughout the day since 2015 from some of the Block IIF and Block III satellites

The radiometers are based on nominally unfiltered silicon photodiodes so the measurements are much more closely related to optical flux reaching GPS than optical power reaching GPS

- Power can be inferred from the photodiode output current using the measured radiometer spectral responsivity (amps/watt) and
- An estimate of the incident light spectrum

Important Spectra for Albedo Analyses – Responsivity, Solar Spectrum, Ice-Snow Reflected Spectrum

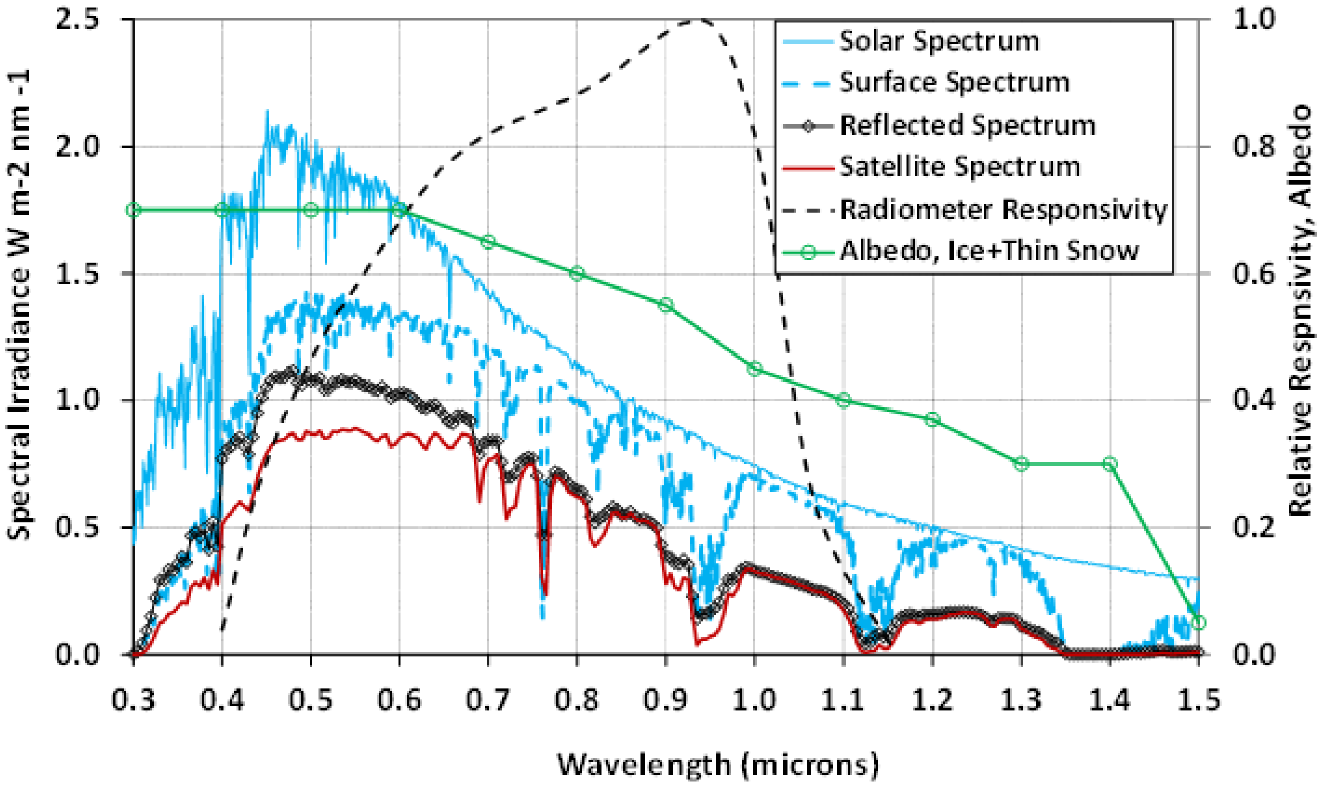
To convert radiometer current to received power we use a measured responsivity and educated assumptions about the received spectrum.

Start with the incident Top of Atmosphere (ToA) solar spectrum.

Propagate the ToA spectrum to the ground using atmospheric transmission.

Reflect the ground spectrum using a measured spectral albedo for thin snow covered ice.

Propagate the reflected spectrum back up through the atmosphere

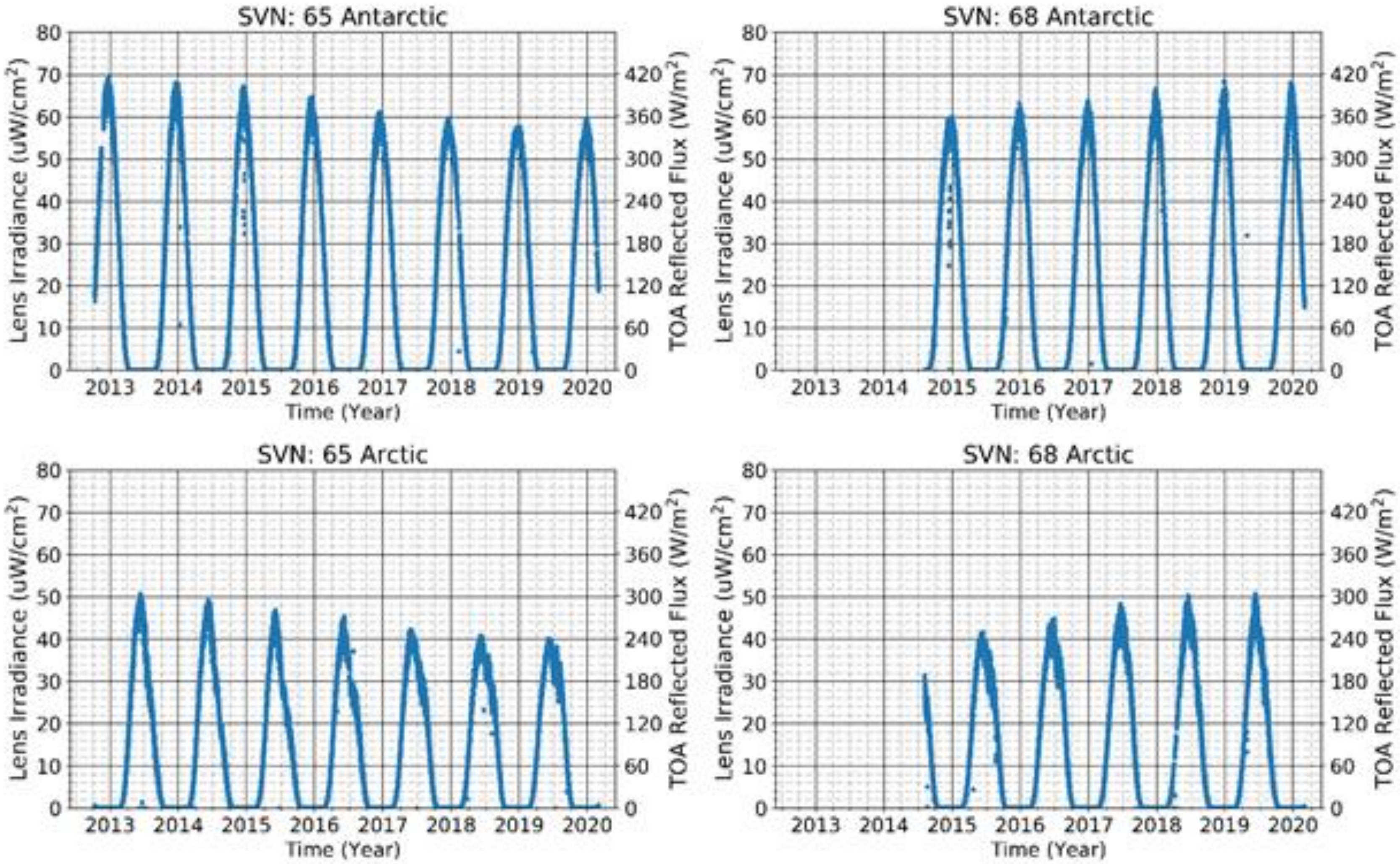


Pixelated Radiometer Measurements of Central Antarctic and Central Arctic Show Brighter Reflections from the Antarctic than the Arctic

Here we plot the twice-daily aggregated pixel measurements for pixels viewing below 80°S and above 80°N when the satellites were at their southernmost and northernmost orbital extremes.

Year-to-year variations are due to slow drift of the orbits.

The Antarctic is brighter than the Arctic



Pixelated Radiometer Measurements Reveal Striking Differences in Antarctic and Arctic Reflectivity

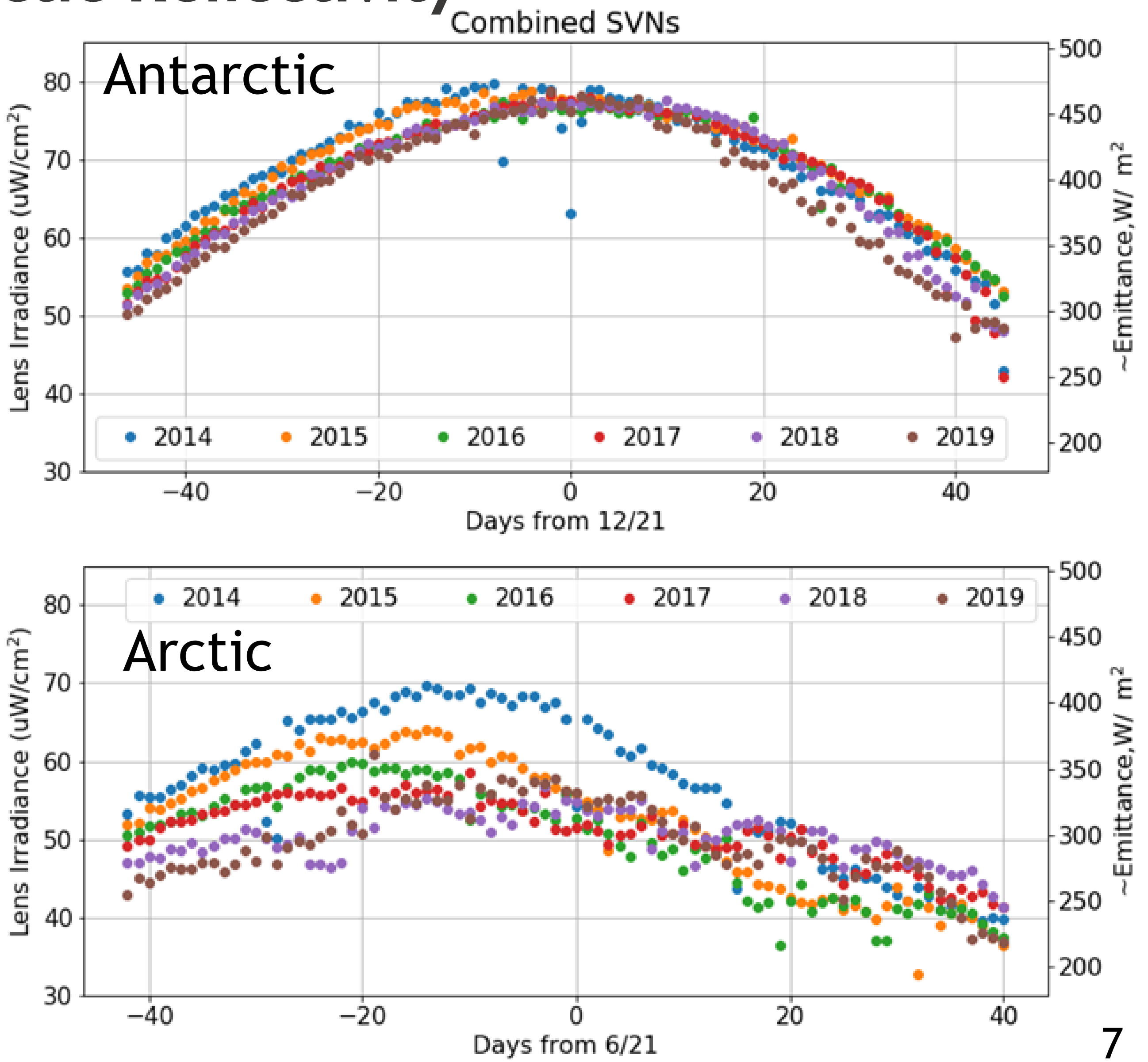
Summed pixel measurements of light reflected from central polar regions for pixels >80N or <-80S

Antarctic reflectance has high symmetry around solstice with good year-to-year consistency, presumably due to solid snow-covered glacier

Arctic reflectance peaks before the solstice, is asymmetric around the solstice and varies from year-to-year, presumably due to seasonal and year-to-year variations snow-ice-pack surface coverage and morphology in summer

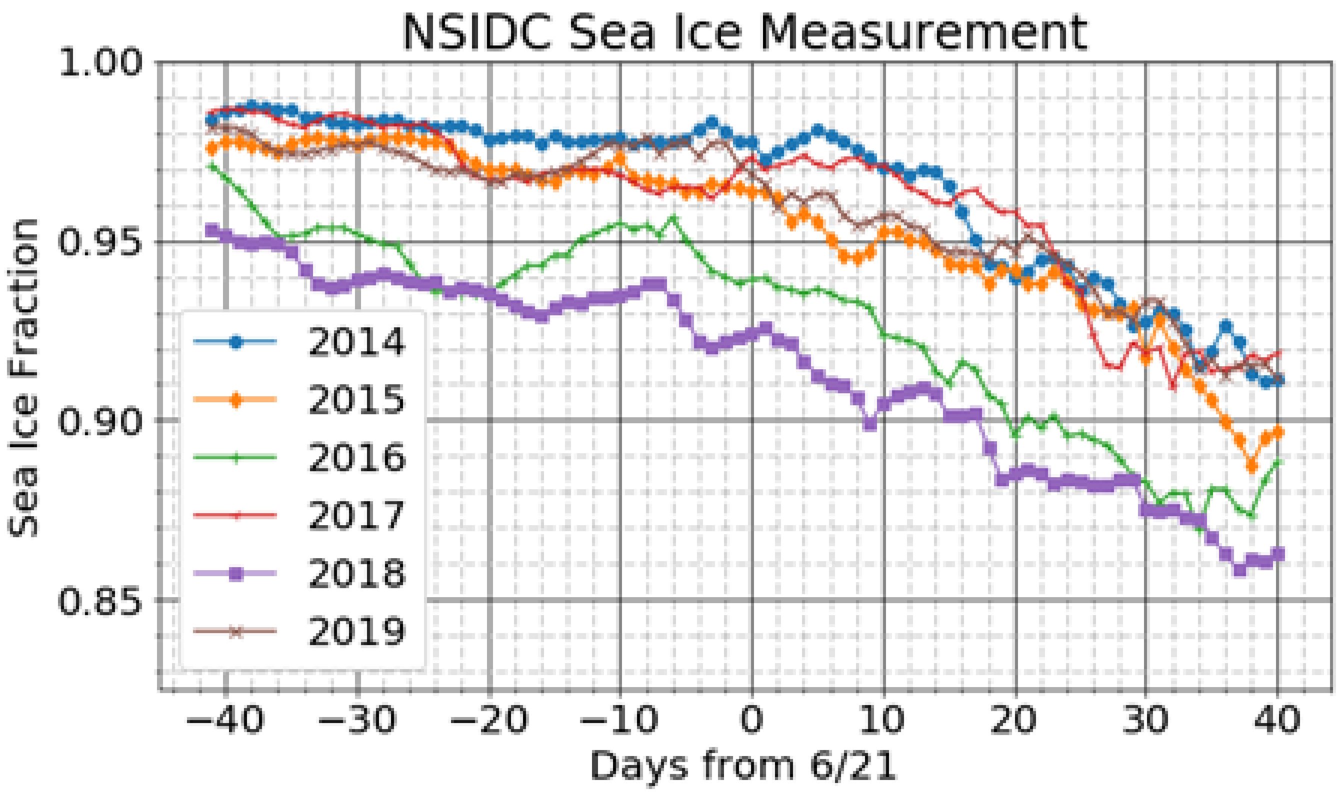
GPS satellite orbits and observation positions shift slowly during the summer and more from year-to-year

We use the Antarctic data to remove the effect of solar incidence angle from the Arctic data to determine relative reflectivity of sea ice



Radar-Measured Arctic Sea Ice Coverage Declines Through the Summers and Varies from Year-to-Year

Arctic sea ice coverage as measured with radar varies from year-to-year and decreases by 5-10% during 80 days around the summer solstice



(Original data from the National Snow and Ice Data Center)

Radiometer Reflectivity Decrease is Larger than Ice Extent Decrease

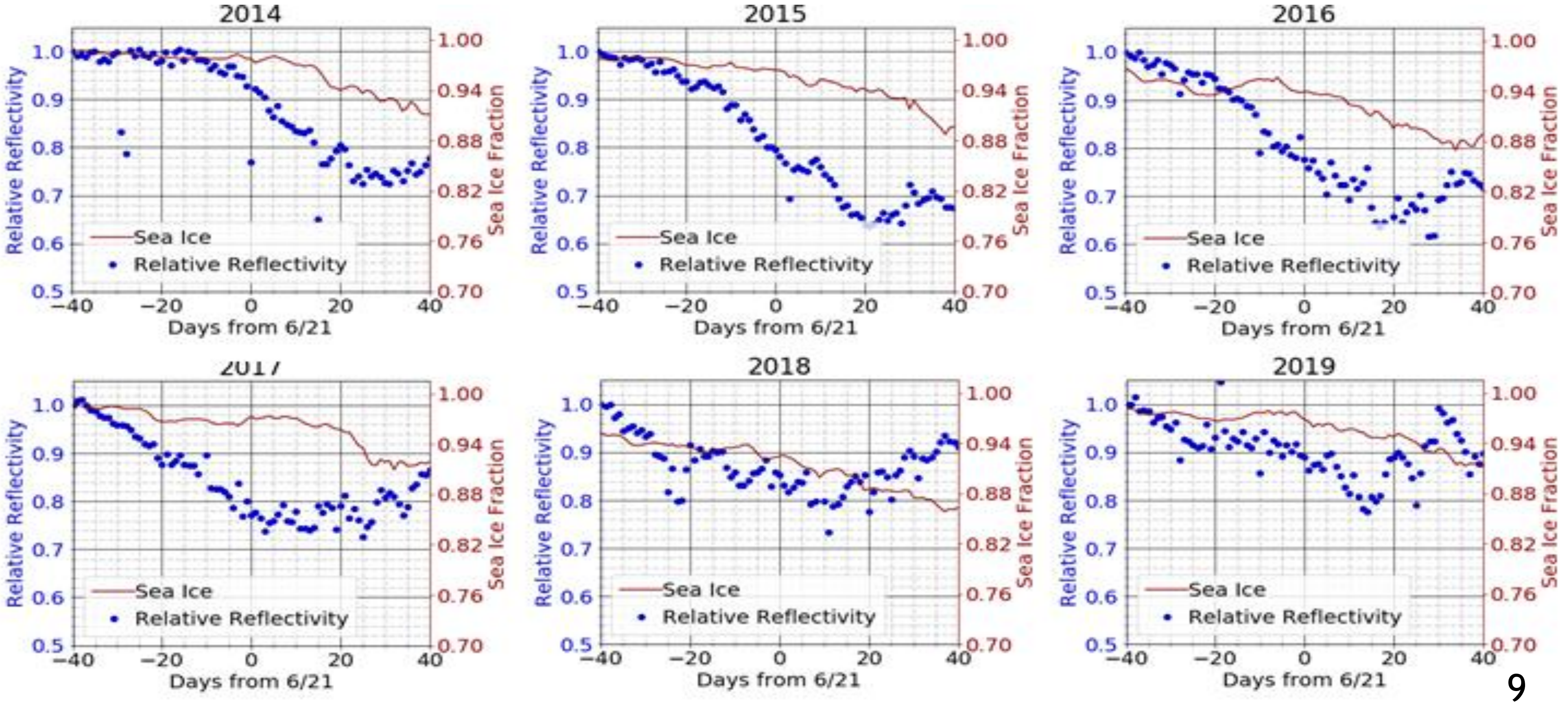
Radiometer currents for the Antarctic and Arctic are converted to Top of Atmosphere power flux.

The Arctic TOA is normalized to remove solar incidence angle effects using the Antarctic TOA

Reflectance measurements follow sea ice extent, but -

- Small changes in sea ice extent are accompanied by much larger reflectance changes.

Reflectance changes are probably due to partial melting of snow & ice (think water puddling on the ice) changing the local albedo



The Albedo Change Melts a Lot of Arctic Ice and Snow

20 days after the solstice, the average Arctic reflected ToA is about 195 W/m^2 compared with an Antarctic reflected ToA of 330 W/m^2.

- The heat of fusion of ice is about 330 J/g.

The 135 W/m^2 difference can melt 1.5 mm/hr of ice or about 1 meter/week of medium density (0.16 g/cm^3) snow.

The relatively low albedo of arctic sea-ice and the decrease of albedo during the summer have positive feedback on melt, probably playing a significant role in accelerating the Arctic sea-ice recession

Summary and Plans

Sandia provides radiometers that ride on GPS satellites making continuous measurements of earth reflected sunlight from the 37% of the earth visible from the 20,200 km high GPS orbit.

We are exploring how to use these uniquely synoptic measurements to contribute to earth radiation balance determination.

We noticed significantly smaller reflectivity from the central Arctic sea ice than the central Antarctic glacier and determined that the greater light absorption can account for melting up to 1 meter per week of snow

The broad spectral band radiometers measure photon flux accurately but inferring optical power has large uncertainty for the radiation balance problem because of uncertainty about the spectrum of the reflected sunlight.

Nevertheless, we hope to take advantage of these measurements that are geographically and temporally synoptic to *validate* less synoptic measurements made using instruments with narrow spectral bands and narrow fields of view by extrapolating photon *fluxes* to the GPS orbits and comparing synthetic broadband signals to the GPS-measured broadband signals.

Could these measurements play a role in calibrating or validating computer models of Arctic ice?

Thank You

We would really like to take your questions and hear comments or discussion about the usefulness of this work.