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An integrated platform for observing the radiation budget of sea ice at different spatial scales

Stephen R. Hudson *, Mats A. Granskog, Tor Ivan Karlsen, Kristen Fossan

Norwegian Polar Institute, Fram Centre, N-9296 Tromsø, Norway

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ABSTRACT

An integrated instrument package for measuring and understanding the surface radiation budget of sea ice is presented, along with results from its first deployment. The setup simultaneously measures broadband fluxes of upwelling and downwelling terrestrial and solar radiation (four components separately), spectral fluxes of incident and reflected solar radiation, and supporting data such as air temperature and humidity, surface temperature, and location (GPS), in addition to photographing the sky and observed surface during each measurement. The instruments are mounted on a small sled, allowing measurements of the radiation budget to be made at many locations in the study area to see the effect of small-scale surface processes on the large-scale radiation budget. Such observations have many applications, from calibration and validation of remote sensing products to improving our understanding of surface processes that affect atmosphere-snow-ice interactions and drive feedbacks, ultimately leading to the potential to improve climate modeling of ice-covered regions of the ocean. The photographs, spectral data, and other observations allow for improved analysis of the broadband data. An example of this is shown by using the observations made during a partly cloudy day, which show erratic variations due to passing clouds, and creating a careful estimate of what the radiation budget along the observed line would have been under uniform sky conditions, clear or overcast. Other data from the setup's first deployment, in June 2011 on fast ice near Point Barrow, Alaska, are also shown; these illustrate the rapid changes of the radiation budget during a cold period that led to refreezing and new snow well into the melt season.

1. Introduction

The radiation budget of sea ice, especially during the melt season, is affected by many processes that take place at small (order of 1 to 10 m) scales, such as the existence of melt ponds, the variation of their depth and color, and the variable distribution of snow or a surface scattering layer. Often data or models cannot resolve these small-scale features, but instead represent the combined effect of them on the scale of a satellite pixel or model grid cell. It is therefore useful to study these processes with measurements that capture the small scales and can be integrated over larger scales to see how the individual processes and surface types are combining to affect the overall energy budget of the ice.

Spatial variability of spectral and broadband albedo has been measured during multiple projects (e.g. Grenfell and Perovich, 1984, 2004; Perovich et al., 2002). Other relevant measurements, coincident in space and time, are often lacking from such spatial surveys, including observations of longwave radiation, sky and surface conditions, and surface and air temperatures. Here we present a sled-based instrument package that allows for the simultaneous collection of all components of the surface radiation budget along with various supporting data that allow for increased interpretation and extension of the observed radiation data. Earlier work with sled-based radiation measurements have largely focused on obtaining observations over very large areas by towing the sled behind a snowmobile (e.g. Maslanik et al., 1999; Schnell, 2004; Walden et al., 2006). That approach is useful for getting many data for statistics, but here we focus on a mobile platform that is moved between measurements, but allows the user to accurately level instruments and observe specific locations, providing high-quality, useful data for process studies. The goal of such a system is to be able to better exploit the observed radiation data, using the supporting data to account for variability not driven by surface properties, to understand the connection between the development of the large-scale energy budget and the small-scale processes driving that development, ultimately leading to the ability to evaluate model parameterizations and satellite algorithms.

2. Instrument setup

The setup, shown in Fig. 1, is based on a lightweight, modified wooden dog sled on skis. For the radiation measurements it uses a Kipp & Zonen CNR4 four-component net radiometer to observe broadband upwelling and downwelling shortwave (solar) and longwave (thermal terrestrial)

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* Corresponding author. Tel.: +47 77750553.
E-mail address: hudson@npolar.no (S.R. Hudson).

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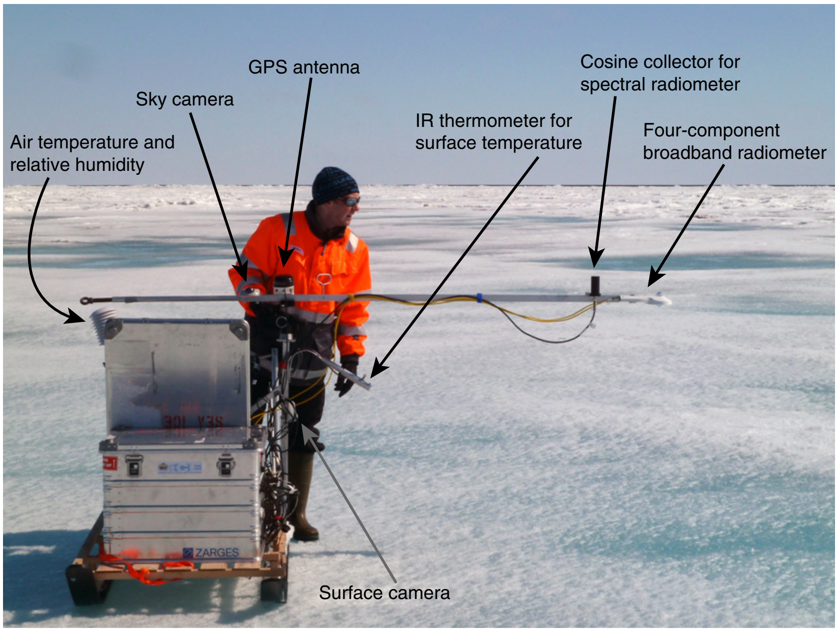

Fig. 1. A labeled photograph of the radiation sled as it was used in Barrow in June 2011. The broadband radiometer is approximately 1.4 m from the sled and 1.2 m over the surface.

radiation and a single-channel ASD FieldSpec Pro spectroradiometer (Kindel et al., 2001), fitted with the Remote Cosine Receptor manufactured by ASD, to observe spectral albedo and calibrated solar fluxes at wavelengths from 350 to 2200 nm (signal loss in the 5-m fiber optic cable precludes the use of the data from 2200 to 2500 nm). The length of the sensor arm, from the sensor side of the sled to the broadband radiometer, was 1.4 m, and the height of the sensors was 1.2 m over the ice. Supporting data include surface and sky photos taken at the time of each observation, surface temperature observed with a Campbell IR-120 infrared thermometer, air temperature and humidity observed with a Vaisala HMP45 sensor, and time and location from GPS.

The observation sequence is carried out automatically by the controlling computer when, using a weatherized keyboard, a given command is entered in the LabView application that communicates with the sensors. Upon receiving the measurement command all data are recorded from all sensors and the sky and surface photographs are taken, a sequence that takes about 5 seconds. The only remaining task, a result of the single input to the spectroradiometer, is then to manually turn the cosine collector for the spectroradiometer 180°, so it is looking down rather than up, and press another key to initiate measurement of the upwelling spectral solar flux.

In its current configuration, a series of measurements made every 5 m along a 200-m line can be made in about 75 minutes. Before each measurement sequence begins, the radiation sensors (four-component radiometer and cosine collector for the spectroradiometer) must be leveled. They are mounted on the end of a long cross arm that is secured to a tripod head that allows for fine adjustments in three axes to ensure good leveling. These leveling adjustments can take a minute or two to get right, especially on deformed ice, and are the current limiting factor in the area covered in a given time.

Using the method described by Nicolaus et al. (2010, Section 4.3), which calculates the shadowing caused by a setup at a grid of points on the surface around the sub-sensor point and also the amount of light blocked by the setup between the surface and the downward facing sensor, an upper limit on the error in the observed albedo was calculated. It represents an upper limit because the shadowing calculation assumes all parts of the setup are perfectly black. The results indicate that shadowing by the sled and boxes reduces the observed reflected flux by up to 7.6% under a diffuse incident light field or 4.4% under perfectly direct light from an incident zenith angle of 50°, with the incident azimuth angle aligned with the sensor arm. In the results presented in Sections 3 and 4, no correction for this shadowing effect has been applied because, in practice, it is a difficult correction to accurately apply given that the incident light field is typically a mix of diffuse and direct light, with the fraction of each varying with wavelength. This calculation therefore serves more as an estimate of the largest source of uncertainty in the measurements presented here.

3. Data collection and results

The instrument setup was used for the first time on fast ice near Point Barrow, Alaska, USA in June 2011. The measurement area was centered at 71.36667° N, 156.5414° W, about 900 m from the shore on the north side of the narrow strip of land leading up to the point. On each day from 5 to 13 June, measurements were made every 5 m along the same 200-m line on a relatively level section of ice. Along most of this line, the surface was not disturbed by walking over it with the sled, but on snow-covered or other easily disturbed surfaces, care must be taken when trying to repeat a transect so that measurements are not affected by previous disturbances along the transect. Based on 2011 data from an ice mass balance installation at the site (Druckenmiller et al., 2009 http://seaice.alaska.edu/gi/data/barrow_massbalance), we know that surface temperatures first rose to the melting point in mid May and snow melt completed around 1 June; during the measurement period the surface was bare ice with a thin surface scattering layer and some melt ponds, shallow in the middle of the line and deep near the far end of the line. Air temperatures were often just below freezing during the period, with moderately strong winds coming from the east, leading to some refreezing of the surfaces; some very light snowfall on 10 and 11 June further brightened the surface. The changes in the surface at two locations along the measurement line are shown in Fig. 2. All data are published on PANGAEA (Hudson et al., 2012), making them freely available to the community.

The measurement sequences were carried out around solar noon each day, with solar zenith angles between 48° and 55°. On 5 June the measurements were made under mostly clear skies; on 12 and 13 June there was a fairly uniform thick overcast, and the other days had broken cloud cover. All measurements were made with the radiometers to the south of the sled, thus avoiding any shadowing of the direct radiation.