Documentation file for Solar Spectral Flux Radiometer (SSFR) during CAMP^{2}Ex 2019

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Instrument package information
The instrument package provided by this team consisted of the following sub-systems:

- SSFR radiometer: down- (zenith) and upwelling (nadir) spectral irradiance 350-2100 nm
- ALP (active leveling platform) to level the SSFR zenith light collector up to angles of 6°
- SPN-S for global/diffuse downwelling spectral irradiance from 350-800 nm
- Nadir hemispherical RGB imager (ALCOR Alphea 6.0WC)

Only the instruments in black (primary/funded instruments) are contained in the data package and described in this document. The instruments in grey are distributed and described separately.

Instrument Description
1. External components (light collectors and leveling platform) and related processing
The radiation signal is collected by integrating spheres made of Spectralon® or Fluorilon® as described by Kindel (2010), and transmitted into an optical fiber at the sphere base. The circular inlet on top of the sphere serves as an aperture that provides the weighting of the incoming radiance with the cosine of the incidence (polar) angle, as required for irradiance measurements. The integrating sphere is enclosed in a housing and mounted either to ALP (P-3 zenith light collector) or to the aircraft fuselage.

New light collectors based on improvements from Kindel (2010) were built at CU. They mainly improved the response with regard to the polar incidence angle of the solar radiation (so-called "cosine response"). In addition, the azimuthal response was also improved in the process. However, despite these changes, the response is still not ideal. Therefore, post-flight corrections need to be applied. They are referred to as "cosine correction". These corrections are performed separately for the diffuse and direct portions of the global (total) downwelling irradiance, whereas the upwelling irradiance only requires a diffuse correction. The first step is to measure the angular response in the laboratory. Then, the measured downwelling irradiance is separated into the diffuse and direct components. This separation is done based on the SPN-S, which measures the direct and diffuse irradiance separately. In the final step, the direct irradiance is corrected according to the laboratory spectral angular response at the current solar zenith angle, whereas the diffuse component is corrected using the spectral angular response integrated over the cosine of the incidence angle (which means that one assumes an isotropic distribution of the diffuse radiation). At the end, diffuse and direct irradiance are re-combined. For the nadir (upwelling) irradiance, only a diffuse correction is applied.

As mentioned above, the zenith light collector was mounted on the ALP system, which unfortunately didn't work very well (or at all) during CAMP2Ex, due to early water intrusion into the system (the hatch had not been properly sealed). Therefore, aircraft attitude corrections were mainly done in software. See Chen et al. (2019) for details how data from BBR (PI: Bucholtz), SPN, and SSFR will be combined in a future data compilation that should be more accurate than the data from the individual instruments while providing more information.

2. Internal components (radiometer unit) and related processing

Two fiber optic cables connect the externally mounted zenith and nadir light collectors to a rack-mounted radiometer unit, which also houses the control electronics for ALP and records the data. Each fiber optic cable is connected to a pair of spectrometers, one covering the near-UV, visible, and very-near infrared (350-1000 nm), the other the very-near infrared to the shortwave infrared (900-2150 nm). Both spectrometers are based on monolithic enclosures that encapsulate a grating and subsequent linear detector array with an overlaid order-sorting filter. The substrate for the linear detector array is Silicon (Si) and Indium-Gallium-Arsenide (InGaAs) for the short and long portion of the spectrum, respectively. The InGaAs detector is actively cooled to -10C, whereas the temperature of the Silicon detector is passively monitored. The signals from the four spectrometers (Si/InGaAs pairs for nadir and zenith) are subsequently read out and written in the binary format. The sampling frequency is 1 Hz. The distance between individual spectrometer wavelengths (spectral sampling) is 4 nm (6 nm) for the Si (InGaAs) spectrometer. The spectral resolution is about twice these values (8 and 12 nm), and it corresponds to the instrument line shape (ILS). It is obtained by measuring the width of the spectrum of monochromatic source (e.g., a gas lamp) for a number of wavelengths. At the same time, it is the basis for the wavelength registration of the instrument that is used to convert channel numbers (256 for each spectrometer) to wavelength. The Si and InGaAs spectra are joined at 940 nm to provide the full spectral range. Since dark currents change with the temperature in the spectrometer box, four mechanical shutters are included in the optical flow, and they are closed periodically (typically every 6 minutes for 30 seconds) to record dark spectra. In the processing, these are first subtracted from the raw counts, and later converted into spectral irradiance by dividing by the spectral radiometric response function. Whereas the Si spectrometer has a linear response with respect to the signal integration time (ranging from 100-500ms), the InGaAs spectrometer has a non-linear response with respect to the integration time (between 200 and 350ms). Therefore, radiometric calibrations are done separately for different sets of integration times.

3. Calibration, quality control and data processing

Before and after each campaign, absolute radiometric calibrations were performed with a standard, NIST-traceable lamp. These primary lamps come with a calibration data sheet, which specifies the irradiance at a distance of 50cm with an uncertainty of about 3%. The primary spectral response function for each spectrometer is obtained by sampling a lamp and a dark spectrum, subtracting dark counts from the lamp spectrum, and dividing that by the irradiance from the data sheet. In addition, the primary calibration is transferred to a field standard. During the deployment, multiple secondary radiometric calibrations are performed to track the stability and any degradations over time since the throughput from the light collector to the spectrometer unit often changes over the course of the installation process. For example, fiber bends introduce spectrally dependent changes. After the field experiment, the primary and secondary (field) calibrations are analyzed to establish which calibration is applicable for every flight and spectrometer. A preliminary quality control parameter is the extent to which spectra agree at the joinder wavelength. Before the installation of the system on the aircraft, side-by-side measurements of the zenith and nadir light collector (both looking upward) are conducted at the surface under clear-sky and cloudy-sky conditions. Later in the quality control process, radiative transfer is used to ensure that the downwelling and upwelling irradiance spectra are consistent with the calculations, both in terms of the magnitude of the transmitted and reflected irradiance, and in terms of the spectral shape.

Instrument output data description

At this point, we uploaded both “ICT” ascii files (partial data data) and “H5” (HDF-5) files (full data set). The traditional ICT file is organized as follows:

1) General information/header (PI, Instrument, date), including some details about the processing such as radiometric response function, angular response functions etc.
2) Data: Time_Start; downwelling irradiance at selected channels; upwelling irradiance at selected channels; altitude; pitch; roll; heading; solar zenith angle

The H5 files contain complete spectra of upwelling and downwelling irradiance, rather than selected channels only. They are organized as follows:

- CAMP2EX-SSFR_P3B_20190925_R...
  - altitude
  - info
  - latitude
  - longitude
  - nad_flux
  - nad_wvl
  - utc
  - zen_flux
  - zen_wvl

The variable “info” contains some case-specific information on a flight, including the information that is provided in the ICT header (such as the applied response function, see (1) above). “nad_flux” and “zen_flux” are two-dimensional data arrays, where the first dimension is time (as in “utc”) and the second dimension is wavelength (as in “nad_wvl” and “zen_wvl”). Each variable has attributes such as units or an explanation to facilitate its use. We recommend using the H5 file instead of the ICT files.

Future data products

In the future, we will merge mutually complementary data from SSFR (spectral, but non-ideal angular response), BBR (broadband, but better angular response), and SPN (separating global and diffuse radiation) and provide those as a new, additional, product.

We will also provide camera imagery and calibrated data from the nadir hemispherical RGB imager.

Appendix: References

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