PREFIRE Data User Guide

Level 3B Monthly Mean Spectral Surface Emissivity and its Standard Deviation Sorted by Surface Type (3-SFC-SORTED-ALLSKY)

Version R01
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1 Introduction

This user guide contains information for the PREFIRE data collections PREFIRE_SAT1_3-SFC-SORTED-ALLSKY and PREFIRE_SAT2_3-SFC-SORTED-ALLSKY – version R01 – which are archived by the Atmospheric Science Data Center (ASDC) at the NASA Langley Research Center. These collections contain gridded (1°×1° latitude/longitude) monthly averages and standard deviations of spectral surface emissivity collected by the PREFIRE Thermal Infrared Spectrometer (TIRS) instruments, sorted by surface type.

1.1 Mission Overview

The Science Mission Directorate (SMD) at NASA Headquarters selected the Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE) as an Earth System Science Pathfinder (ESSP) Earth Venture Instrument (EVI-4) class Mission of Opportunity. Through spectrally resolved observations of radiances spanning the radiatively significant portions of the Mid- and Far-InfraRed (MIR and FIR), PREFIRE addresses two complementary hypotheses:

1. Time-varying errors in both FIR surface emissivity and thermal radiation modulate estimates of energy exchanges between the surface and the atmosphere in the Arctic.
2. These terms are responsible for a large fraction of the spread in projected rates of change for Arctic surface, ocean, and atmosphere characteristics.

These hypotheses are addressed through five related objectives:

- O1.1 Quantify snow and ice FIR emissivity spectra and their variability on seasonal scales;
- O1.2 Quantify the FIR thermal radiation and its response to seasonal variations in cloud cover / water vapor;
- O1.3 Quantify variability in Arctic spectral surface emission and the thermal radiation across the FIR owing to transient cloud and water vapor and sub-daily surface phase-change processes;
- O2.2 Quantify thermal emission errors on projected rates of Arctic warming and sea ice loss;
- O2.3 Determine the impact of improved surface emissivity on modeled ice sheet dynamic processes on hourly scales.

PREFIRE uses broadband infrared (> 75% of surface emitted thermal radiation) radiance measurements made from the separate orbiting platforms (CubeSats) to address the science objectives. The PREFIRE payloads are two stand-alone instruments built at JPL using heritage from the Mars Climate Sounder and the Moon Mineralogy Mapper. The PREFIRE instruments are thermal infrared imaging spectro-radiometers with more than 50 spectral bands. Each PREFIRE instrument uses ambient temperature thermopile detectors and operates in a pushbroom mode with a point and stare mirror for viewing nadir (Earth), space, and a calibration target. PREFIRE data are calibrated with data from views of the internal calibration target and of space, which are viewed multiple times per orbit.

Soon after launch, the orbit altitude was approximately 531 km for both satellites. However, the PREFIRE CubeSats do not have station-keeping abilities and so their altitudes decrease with time. The current satellite altitude is recorded as *sat_altitude* (*Geometry* data group) in the file data.

The PREFIRE project delivers space-based measurements of radiative fluxes, cloud masks, spectrally variant surface emissivity (ε_λ), and column water vapor (CWV). These are science products with the precision, resolution, and coverage needed to improve our understanding of polar energy balances and Earth-system effects over diurnal and seasonal cycles at scales that capture surface and cloud variability.

During its approximately one-year baseline mission, PREFIRE will capture the natural variability in Arctic and Antarctic CWV and surface temperature. PREFIRE reduces uncertainties in the surface and atmospheric components of the polar energy budget.

1.2 Data Overview

The PREFIRE Level 3B Monthly Mean Spectral Surface Emissivity and its Standard Deviation Sorted by Surface Type data are contained in two collections: PREFIRE_SAT1_3-SFC-SORTED-ALLSKY and PREFIRE_SAT2_3-SFC-SORTED-ALLSKY. The data are provided in distinct data collections because the two PREFIRE-TIRS instruments each have different mission timeframes, characterizations, and known issues.

All Level 1 through Level 3 PREFIRE data products are produced at the PREFIRE Science Data Processing System (SDPS), located at the University of Wisconsin-Madison. Level 0 data are ingested approximately four times per day for each satellite. Level 3B Monthly Mean Surface Emissivity and its Standard Deviation Sorted by Surface Type data products are nominally processed on a delay of at least five weeks from ingest of the Level 0 science data, allowing for data sent from the spacecraft out of chronological order to be incorporated, and for data for each calendar month to accumulate.

To provide monthly climatologies of spectral surface emissivity (sorted by surface type), data from all available/relevant PREFIRE Level 2B Spectral Surface Emissivity (2B-SFC) and Auxiliary Satellite Data (AUX-SAT) granules are utilized. In cases where an AUX-SAT granule is unavailable, surface type data are instead obtained from the associated PREFIRE Auxiliary Meteorology (AUX-MET) granule. It is helpful to consider the spatial and spectral characteristics of all these input data products. Abbreviated descriptions of those characteristics are provided in the following sections, but users are encouraged to review the PREFIRE Level 1B Radiance, Level 2B Surface Emissivity, Auxiliary Satellite Data, and Auxiliary Meteorology user guides for additional information.

1.2.1 Spatial characteristics of 2B-SFC, AUX-SAT, and AUX-MET input

The PREFIRE-TIRS instruments collect data continuously in a pushbroom mode, with an integration time of 0.7 seconds for each data frame. Each data frame contains a spectral measurement from each cross-track scene collected simultaneously. Within this continuous data collection, there are planned interruptions due to calibration cycles or data downlinks, and there are also occasional interruptions due to unplanned instrument operations changes or outages. Each calibration cycle takes ~18.7 seconds for PREFIRE-TIRS1 and ~9.7 seconds for PREFIRE-TIRS2, which implies a gap of approximately 27 and 14 data frames, respectively. Data downlinks create data gaps of up to 13 minutes, and the exact length varies.

Within the orbital swath there are eight distinct tracks of data associated with the eight separate spatial scenes for each PREFIRE-TIRS (e.g., Fig. 1-1). The approximate scene footprint sizes are 11.8 km × 34.8 km (cross-track × along-track), with gaps between each scene of approximately 24.2 km. The swath itself is ~264 km across. Note that the scene footprint and swath sizes quoted here are for the orbit altitude soon after launch. However, the footprint size will slowly become smaller as the orbit altitude decreases with time. Do not assume constant footprint or swath dimensions.

PREFIRE-TIRS spatial footprints overlap each other in the along-track dimension. Assuming that no data are missing, any given point along the orbit swath will be observed by up to about 7 overlapping footprints in the along-track direction. The number of footprints that overlap a given footprint will slowly become smaller during the mission, as the satellites' orbital altitudes decreases. Do not assume an integer number of overlapping footprints.

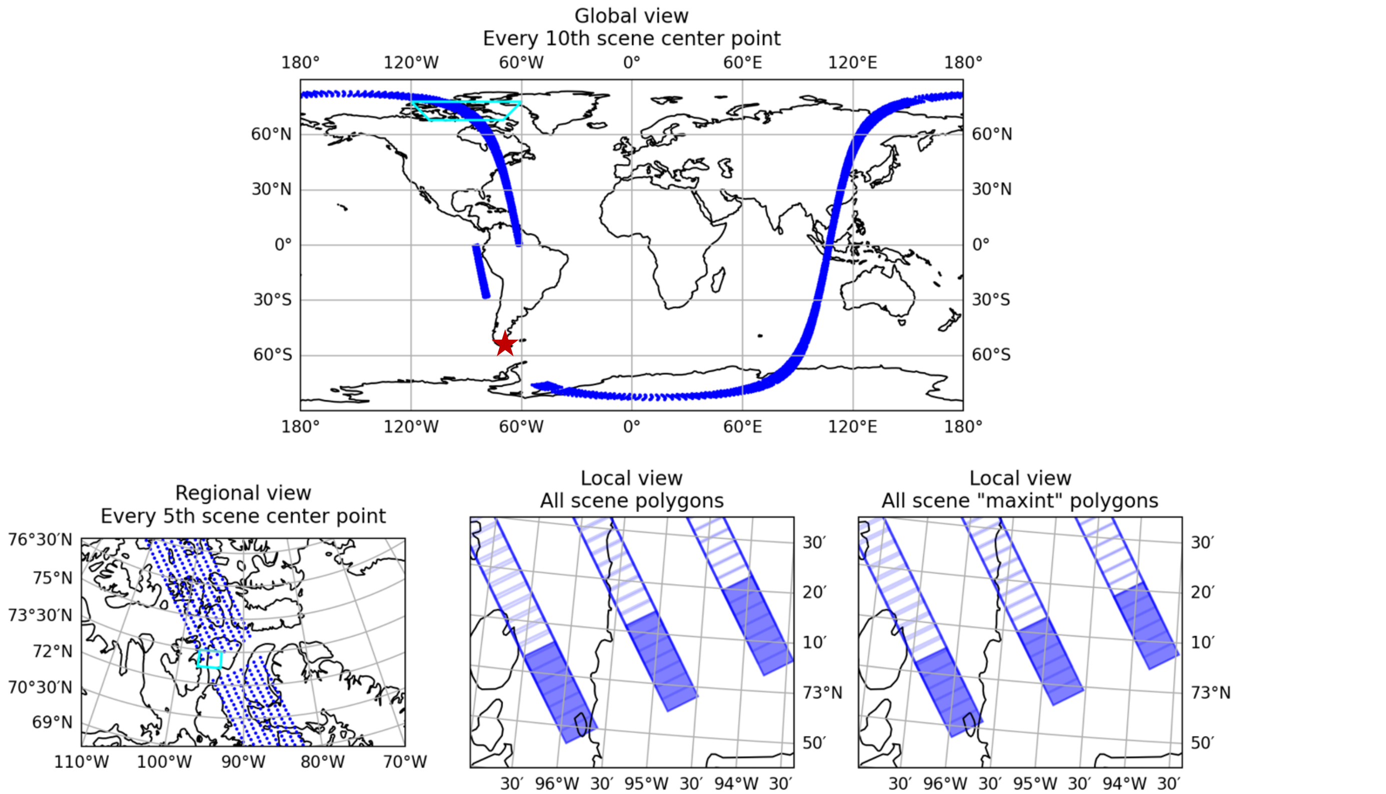

Figure 1-1: An example geolocated orbit (top panel) and focused regional and local plots (bottom panels). The global plot was selected to illustrate a data gap due to a data downlink at the Punta Arenas, Chile ground station, from approximately 70°S to 30°S on the ascending pass at the end of the granule. The zoomed in regional view (lower left) shows the data within the small cyan box in the global plot and illustrates a smaller data gap due to instrument calibration. The local views (lower middle and right) show the actual scene ground footprint polygons, for the cyan box denoted in the regional view. The first scene's polygon is filled blue, to illustrate the shape of the full field of view (FOV) for one data integration. During the 0.7 second integration time, the satellite moves along track slightly more than 5 km, which means the leading and trailing edges of the instantaneous FOV have translated forward by the same amount. The lower right plot shows the "max integration" footprint polygon, which includes the interior portion of the scene footprint that was within the sensor field of view for the entire integration period.

Note that the relevant surface type fields in AUX-SAT and/or AUX-MET granules are determined from a variety of datasets, each with different spatial characteristics – although they are interpolated to the PREFIRE-TIRS ground footprints/geometry.

1.2.2 Spectral characteristics of 2B-SFC input

Each PREFIRE-TIRS contains a Focal Plane Array (FPA) of thermal radiation detectors that collect measurements for 64 spectral "channels" (for each of 8 spatial "scenes"; see section

1.2.1). One channel (channel 0) measures total direct, undispersed light. The remaining 63 spectral channels collect dispersed light from the internal grating for distinct "idealized" wavelengths, which constitute the central wavelengths of the grating dispersion. In addition to the idealized wavelength, each channel can be described by its mean wavelength, which is a weighted average based on weights from the Spectral Response Function (SRF) for each channel. Pairs of masked channels at the edges of the four order-sorting filters (MIR-1, MIR-2, FIR-1, and FIR-2) and three masked channels at the beginning of the FPA result in a total of 54 potentially active channels per instrument. All 63 channels are retained during processing, but inactive and some particularly-problematic channels are masked.

1.2.3 Level 3B binning and sorting characteristics

For each PREFIRE CubeSat, each calendar month's retrieved spectral surface emissivity values for each of the 8 cross-track scenes and surface type are binned using a regular 1°×1° latitude/longitude grid. This results in data product arrays which have five dimensions ({cross-track, surface type, latitude, longitude, spectral}; see section 2.2.3 for more detail). The surface classifications in Table 1-1 are used to sort the surface emissivity data. Note that the coastal surface type includes many sorts of mixed land/water surface areas within a PREFIRE-TIRS ground footprint, including inland lake and river edges. See section 2.1for more detail.

Table 1-1: Surface classifications used in the PREFIRE 3-SFC-SORTED-ALLSKY data product

3-SFC-SORTED-ALLSKY surface types
[1] open water
[2] sea ice
[3] partial sea ice
[4] permanent land ice
[5] Antarctic ice shelf
[6] snow-covered land
[7] partial snow-covered land
[8] snow-free land
[9] coastal

In addition to gridded averaged spectral surface emissivity and standard deviations sorted by surface type, the 3-SFC-SORTED-ALLSKY data product also contains the corresponding counts, summation of spectral surface emissivity, and summation of squared spectral surface emissivity to empower users who wish to compute emissivity statistics independently. All variables are provided as full granule, ascending-pass-only, and descending-pass-only versions. An example of 3-SFC-SORTED-ALLSKY counts, mean emissivity, and standard deviations for four Antarctic surface types is given in Figure 1-2.

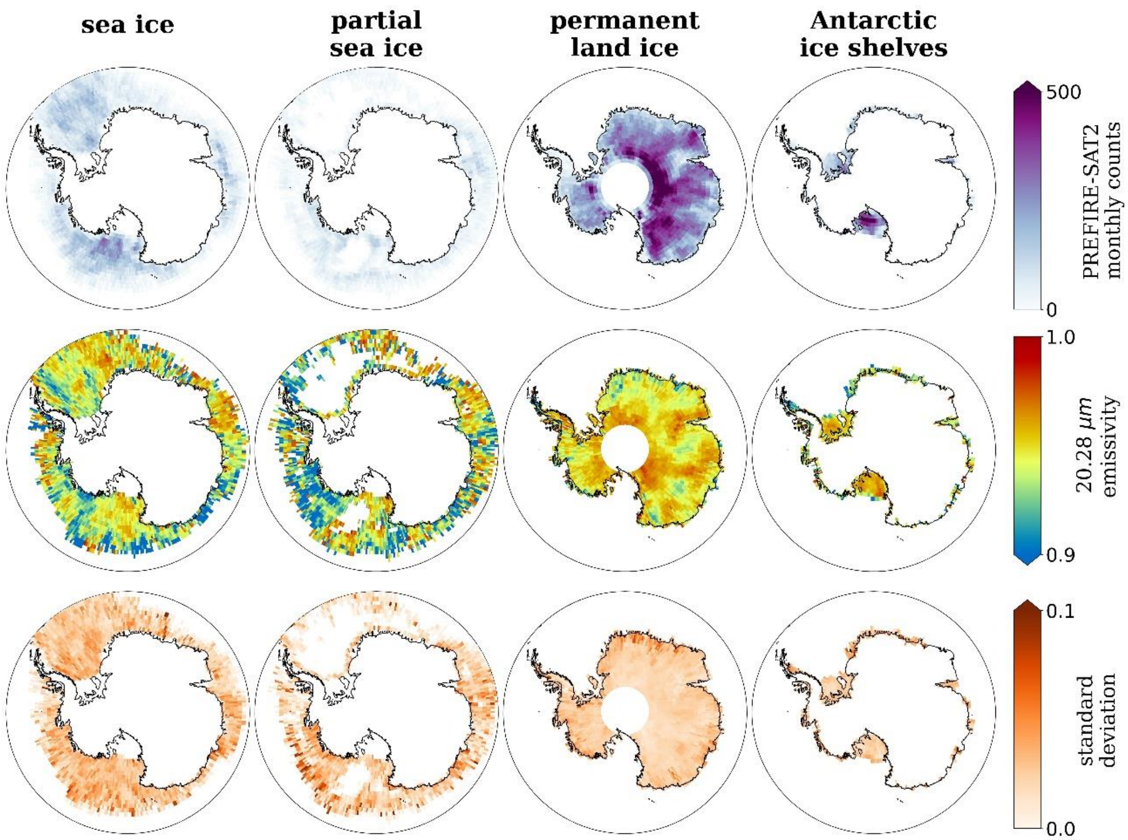

Figure 1-2: A sample of preliminary 3-SFC-SORTED-ALLSKY output for July 2024 showing PREFIRE-SAT2 channel 22 (20.28 µm) gridded monthly counts (top), average surface emissivity (middle), and standard deviation of surface emissivity (bottom) for four Antarctic surface types. Data shown are for full granules and the average and standard deviation are taken with respect to the combination of all 8 cross-track scenes.

Data files are in the NetCDF4 format. These data collections are archived at the ASDC DAAC and can be found at https://asdc.larc.nasa.gov/project/PREFIRE/PREFIRE_SAT1_3-SFC-SORTED-ALLSKY_R01 and https://asdc.larc.nasa.gov/project/PREFIRE/PREFIRE_SAT2_3-SFC-SORTED-ALLSKY_R01.

1.3 Purpose

The PREFIRE 3-SFC-SORTED-ALLSKY data product provides monthly climatologies of MIR and FIR spectral emissivities for common polar surfaces. This data product includes gridded, time-averaged spectral surface emissivity sorted by surface type as well as gridded standard deviations of time-averaged spectral surface emissivity sorted by surface type. This product provides full-orbit climatologies in addition to subsets containing only the ascending and descending orbit passes to account for diurnal variability and viewing geometry changes.

2 Product Description

2.1 Algorithm description

The 3-SFC-SORTED-ALLSKY data product is created by a Level 3 algorithm that generates time-averaged output for any PREFIRE variable sorted by a selected metric. To achieve monthly Level 3 output for spectral surface emissivity sorted by surface type, the program begins by retrieving granules completed in whole or in part during the time interval defining a calendar month (UTC) and selecting the along-track frames that occurred over the interval. The sample is audited to remove any granules for which Auxiliary data are unavailable. For the remaining granules, surface type information is ingested from AUX-SAT or, if unavailable, AUX-MET. Currently, the surface classification in AUX-SAT/AUX-MET includes surface types [1] through [8] in Table 1-1. The Level 3 algorithm performs a simple surface type adjustment to reclassify ground footprints near coastlines. The adjustment reclassifies observations as coastal [9] under two sets of conditions dependent on latitude: Ground footprints that sample latitudes north of 60°N are reclassified as coastal if the observed land fraction is greater than 10% and less than 90%; similarly, ground footprints located at or south of 60°S are reclassified as coastal if the sum of the observed land fraction and Antarctic ice shelf fraction is greater than 10% and less than 90%. Figure 2-1 summarizes the flow used to designate the surface types in 3-SFC-SORTED-ALLSKY.

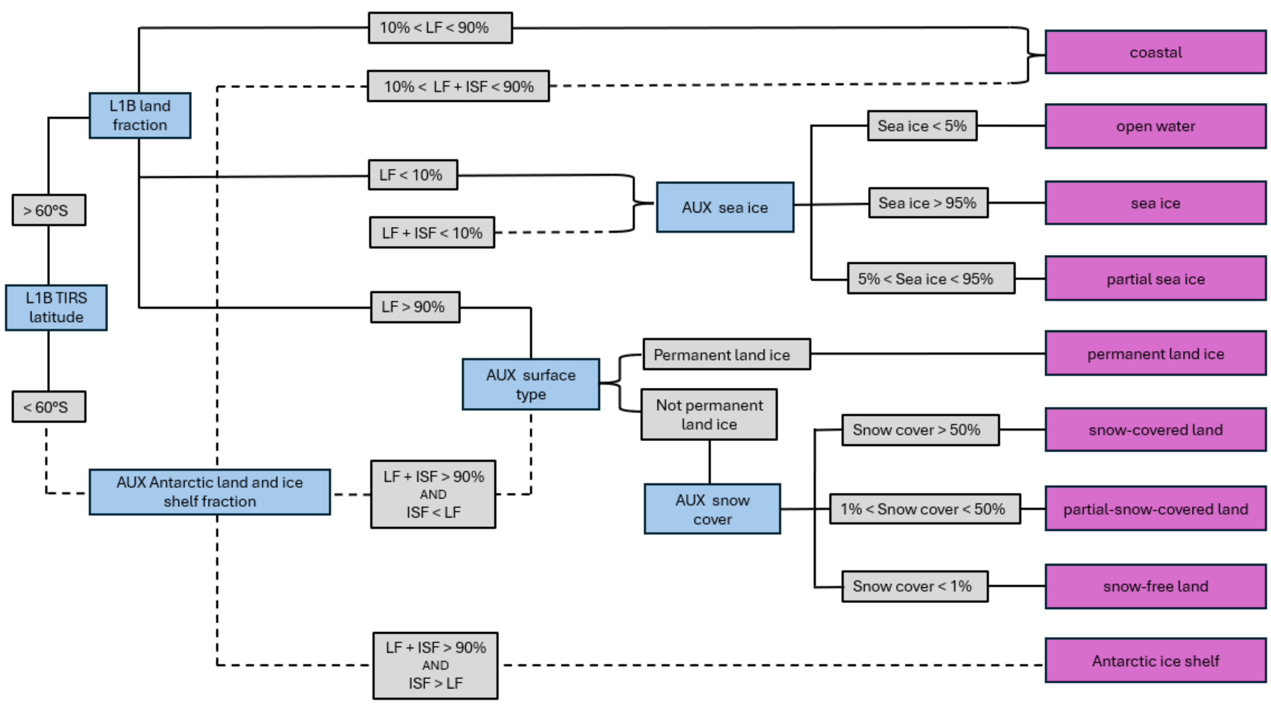

Figure 2-1: A flow chart summarizing the surface type designation used in the 3-SFC-SORTED-ALLSKY algorithm. **LF** and **ISF** denote land fraction and ice shelf fraction, respectively. **AUX** denotes PREFIRE Auxiliary data (AUX-SAT or, if unavailable, AUX-MET). The dashed lines represent the flow specific to observations at latitudes equal to or south of 60°S.

The corresponding 2B-SFC Surface Emissivity for the monthly sample are also ingested. The Surface Emissivity product contains two quality flags, valid [0] and valid [1]. Both quality flags are associated with scenes for which the PREFIRE cloud mask cloud probability is less than 0.4; however, valid [1] contains some spectral emissivity values greater than unity. Conservatively, the 3-SFC-SORTED-ALLSKY algorithm selects only observations with quality flag valid [0]. Note that preliminary testing showed that the sample size was not drastically reduced when observations with quality flag valid [1] were excluded.

For every observation in the monthly sample, the program retrieves cross-track scene and surface type as well as the surface emissivity for up to 63 spectral channels measured by the PREFIRE-TIRS. Additionally, latitude and longitude are extracted to determine the appropriate latitude and longitude bin (i). The current version bins observations using a regular 1° latitude by 1° longitude grid. The cross-track scene, surface type, latitude bin, longitude bin and spectral channel indices are used to modify the associated element in the output arrays. One array holds the number of monthly observations per grid box, or counts (N_i), sorted by surface type; another holds the sum of spectral emissivity per channel per grid box ($\sum \varepsilon_i$) sorted by surface type; and a third holds the sum of squared spectral emissivity per channel per grid box ($\sum \varepsilon_i^2$) sorted by surface type. The counts, sum and squared sum for each cross-track scene are represented separately. Ascending-pass- and descending-pass-only subsets are also stored in separate arrays. Gridded time-averaged spectral emissivities per surface type ($\bar{\varepsilon}_i$) are then computed by dividing $\sum \varepsilon_i$ by N_i. Finally, gridded standard deviations ($\sigma_{\varepsilon,i}$) are computed via Equation (1).

$$\sigma_{\varepsilon,i} = \sqrt{\frac{\sum \varepsilon_i^2}{N_i} - \frac{2\bar{\varepsilon}_i \sum \varepsilon_i}{N_i} + \bar{\varepsilon}_i^{\,2}} \tag{1}$$

where $\boldsymbol{\sigma_{\varepsilon,i}}$ is the standard deviation of average spectral surface emissivity per grid box sorted by surface type, $\mathbf{N_i}$ is the monthly counts per grid box sorted by surface type, $\boldsymbol{\bar{\varepsilon}_i}$ is the average spectral surface emissivity per grid box sorted by surface type, $\sum \boldsymbol{\varepsilon_i}$ is the sum of spectral emissivity per grid box sorted by surface type, and $\sum \boldsymbol{\varepsilon_i^2}$ is the sum of squared spectral emissivity per grid box sorted by surface type.

2.2 File Specifications

A single data file or granule consists of a climatology for one calendar month of data. Data files commonly range in size from 50 MB to 130 MB in size.

2.2.1 File naming convention

File names for this collection follow the following convention:

PREFIRE_SAT<*satID*>_<*productID*>_<*collectionVersion*>_<*internalProductVersion*>_<*startYYYYMMDDhhmmss*>_<*endYYYYMMDDhhmmss*>.nc

For example, a representative Level 3B Monthly Mean Spectral Surface Emissivity and its Standard Deviation Sorted by Surface Type (3-SFC-SORTED-ALLSKY) data product file generated from PREFIRE-SAT2 observations that occurred between 2024-08-01 00:00:00.000 UTC and 2024-08-31 23:59:59.999 UTC would have the following filename:

PREFIRE_SAT2_3-SFC-SORTED-ALLSKY_R01_P00_20240801000000_20240831235959.nc

2.2.2 File format

PREFIRE 3-SFC-SORTED-ALLSKY data product files are created in NetCDF4 format with standard metadata. These files can be read with standard NetCDF libraries available in all popular scripting languages and many data visualization programs.

2.2.3 Variable dimensions

A summary of all array dimensions is given in Table 2-1. The cross-track dimension is equal to the number of cross-track scenes (8, for both instruments); the surface type dimension is equal to the number of surface types recognized by Level 3B (9, as shown in Table 1-1); the latitude dimension is equal to the number of 1° latitude bins with edges between -84°N and 84°N, the approximate latitudinal sampling range of PREFIRE-TIRS (168 latitude bins); the longitude dimension is equal to the number of 1° longitude bins with edges between -180°E and 180°E (360 longitude bins) and the spectral dimension is equal to the number of possible spectral channels (63 for both instruments).

Table 2-1-: All dimensions of 3-SFC-SORTED-ALLSKY variables

Dimension	**Abbreviation**
cross-track	*xtrack*
surface type	*sfc_type*
latitude	*lat*
longitude	*lon*
spectral	*spectral*
Dimension label	**Definition (C-order)**
1D	(*sfc_type*)
2D	(*xtrack, spectral*)
2Dg	(*lat, lon*)
5D	(*xtrack, sfc_type, lat, lon, spectral*)

2.2.4 *Sfc-Sorted* group

The *Sfc-Sorted* group consists of all spatial, spectral and statistical variables in the 3-SFC-SORTED-ALLSKY data product. They are detailed in Table 2-2.

Table 2-2-: Variables within PREFIRE 3-SFC-SORTED-ALLSKY

Variable Name	**Type**	**Dimen-sion**	**Units**	**Description**
wavelength	float32	2D	microns	center wavelength of each spectral channel, given by the SRF-weighted mean over wavelength

idealized_wavelength	float32	2D	microns	center wavelength of each spectral channel, in the idealized spectrometer grid
surface_type_for_sorting	int8	1D		merged surface type using coastline data, met analysis, and, where applicable, satellite observations of sea ice and snow cover
latitude	float32	2Dg	degrees_ north	latitude of grid box center
longitude	float32	2Dg	degrees_ east	longitude of grid box center
count	int32	5D		count of surface emissivity observations per grid box, cross-track scene, and spectral channel, sorted by surface type
asc_count	int32	5D		count of surface emissivity observations per grid box, cross-track scene, and spectral channel, sorted by surface type for ascending orbit pass only
desc_count	int32	5D		count of surface emissivity observations per grid box, cross-track scene, and spectral channel, sorted by surface type for descending orbit pass only
emis_mean	float32	5D		mean spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type
asc_emis_mean	float32	5D		mean spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for ascending orbit pass only
desc_emis_mean	float32	5D		mean spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for descending orbit pass only
emis_stdev	float32	5D		standard deviation of spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type
asc_emis_stdev	float32	5D		standard deviation of spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for ascending orbit pass only
desc_emis_stdev	float32	5D		standard deviation of spectral surface emissivity per grid box,

				cross-track scene, and spectral channel, sorted by surface type for descending orbit pass only
emis_sum	float32	5D		sum of spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type
asc_emis_sum	float32	5D		sum of spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for ascending orbit pass only
desc_emis_sum	float32	5D		sum of spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for descending orbit pass only
emis_sumsquares	float32	5D		sum of squared spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type
asc_emis_sumsquares	float32	5D		sum of squared spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for ascending orbit pass only
desc_emis_sumsquares	float32	5D		sum of squared spectral surface emissivity per grid box, cross-track scene, and spectral channel, sorted by surface type for ascending orbit pass only

Users may opt to combine the eight spatial scenes to achieve greater sampling size and reduced noise; however, we caution users that averaging over the scene dimension will not necessarily produce the true average of the collective sample. Instead, we encourage users to collapse the scene dimension by first summing the *count*, *emis_sum* and *emis_sumsquares* arrays over the *xtrack* dimension and then manually re-calculating the mean by dividing the modified *emis_sum* array by the modified *count* array. The standard deviation can then be re-calculated using Equation (1) with respect to the modified arrays. If Python is used, some care should be taken to minimize floating point rounding errors by converting non-zero values less than or equal to a sufficiently small threshold (i.e., 10^{-12}) to zero before taking the square root.

3 Updates Since Previous Version

None – this is the initial version.

4 Known Issues

Since 3-SFC-SORTED-ALLSKY uses data from upstream PREFIRE data products, issues impacting PREFIRE Level 1, 2, and Auxiliary products could result in Level 3 data product errors. Users are encouraged to review the user guides for PREFIRE 2B-SFC, AUX-SAT, and AUX-MET to learn about the specific issues impacting PREFIRE emissivity retrievals and auxiliary datasets. In particular, along-track geolocation errors of up to 50 km have been identified and are subject to ongoing corrections. Such errors may impact the performance of the emissivity retrievals and surface type identification, which will in turn introduce errors in the monthly means and standard deviations of spectral surface emissivity in the 3-SFC-SORTED-ALLSKY data product. Improvements in geolocation of the PREFIRE instruments will reduce errors in 2B-SFC and should therefore reduce errors, as yet unquantified, in Level 3 granules. Additionally, cloud contamination in the PREFIRE FOVs may introduce regional biases in 2B-SFC spectral surface emissivity that appear in 3-SFC-SORTED-ALLSKY statistical output. This remains under review.

The counts, mean, sum and squared sum arrays empower users to compile further spectral surface emissivity statistics at their discretion. We caution that the standard deviation calculation given by Equation (1) may be sensitive to precision and was found to achieve the greatest accuracy in Python when the arrays have a 64-bit floating-point data type (float64); however, it was operationally preferable to reduce the Level 3 arrays to data type float32 to reduce the overall size of the output files. Consequently, floating point rounding errors in Python could have a marginal impact on users' ability to replicate the standard deviations within 3-SFC-SORTED-ALLSKY granules.

5 Resources

For more information, please contact Erin Hokanson Wagner at prefire-sdps.admin@office365.wisc.edu.

6 References

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Citation

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- PREFIRE_SAT1_3-SFC-SORTED-ALLSKY_R01: 10.5067/PREFIRE-SAT1/PREFIRE/SFC-SORTED-ALLSKY_L3.R01