TSIS-1 SIM Version 10 Level 3 Data Product Release Notes (2023/05/31)

NASA's Total and Spectral Solar Irradiance Sensor -1 (TSIS-1) operates on the International Space Station (ISS). TSIS-1 obtains absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI). TSI and SSI are essential for scientific models of climate change and solar variability. TSIS-1 has two science instruments, the Total Irradiance Monitor (TIM), and the Spectral Irradiance Monitor (SIM).

This document describes Version 10 (V10) of the TSIS-1 SIM Level 3 (L3) data release. This document summarizes data processing and calibration changes that affect SIM L3 data and is not a complete list of changes affecting lower-level data products. Details of SIM L3 temporal and spectral data coverage can be found in §1. When referring to L3 data product columns, references are in ALL_CAPS.

SIM L3 data is released on 12-hour and 24-hour cadences. The DOIs for V10 are:

- 12-hour cadence: https://doi.org/10.5067/TSIS/SIM/DATA319
- 24-hour cadence: https://doi.org/10.5067/TSIS/SIM/DATA320

TSIS-1 SIM V10 L3 data appears in three locations, in the specified formats:

1) the LASP LISIRD website (ASCII, CSV, and NetCDF)
   - 12-hour: https://lasp.colorado.edu/lisird/data/tsis_ssi_12hr
   - 24-hour: https://lasp.colorado.edu/lisird/data/tsis_ssi_24hr
2) the LASP TSIS website (ASCII, IDL SAV file, and NetCDF)
   - https://lasp.colorado.edu/home/tsis/data/
3) the NASA DAAC (ASCII)
   - https://disc.gsfc.nasa.gov/datasets?page=1&source=TSIS-1%20SIM

Changes since the V09 TSIS-1 SIM data release include:

- ESR (> 740 nm) wavelength alignment using prism offset corrections from IR diode observations
- Temporal smoothing of diode and DSP temperatures
- NetCDF file enhancements
- Updated irradiance degradation corrections
  - Incorporate April 2023 Channel-C calibration scans
  - Updated algorithm for IR bandpass (950–1050 nm)
  - Extension of correction for entire IR bandpass (950–1620 nm)
  - Introduction of correction for ESR bandpass (1620–1845 nm)
- Updated MEASUREMENT_STABILITY uncertainties
- Updated baseline (filtering) spectrum

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1) Temporal and Spectral Coverage:

Table 1 gives the available time and spectral range for TSIS-1 SIM L3 data. Nominally, L3 irradiances have a latency of ~25 days to allow for processing and the application of instrument degradation corrections. Data latency is driven by the cadence of Channel-B observations, which are used in the degradation correction model. This delay may be extended due to delays in receiving telemetry and scheduling constraints such as ISS operations or periods of high beta angles.

Table 1: Time and spectral range of the dataset.

Time Range	Wavelength Range (nm)
2018/03/14 - present	200 – 2400

Temporal gaps are common in the TSIS-1 SIM data record due to factors such as ISS operational activities (e.g., orbit boost), anomalies (e.g., power outages), and obstructions at extreme beta angles. ISS obstructions can result in partial or complete loss of SIM spectra for a given day. Early in the mission, spectral gaps also occurred due to instrument planning and operations errors. Figure 1 shows the V10 L3 TSIS-1 SIM 24-hour data acquisition record. Nominal data are shown in green, data quality flag (QUALITY=0), red points show missing data (QUALITY=1), and blue points show data backfilled from the previous day (QUALITY=2). Backfilling is never done when temporal gaps exceed 1 day. Pink data were acquired during the High-rate Fine Sun Sensor-B (HFSS-B(OFF)) pointing period (QUALITY=512, see §5), and purple data are both backfilled and during the HFSS-B(OFF) period (QUALITY=514). Data during the HFSS-B(OFF) pointing period have a wavelength-dependent spectral correction applied, maintaining their usability as quality direct irradiance observations, but carry a slightly higher uncertainty as captured in the ADDITIONAL_UNCERTAINTY column (see §4 and §6).

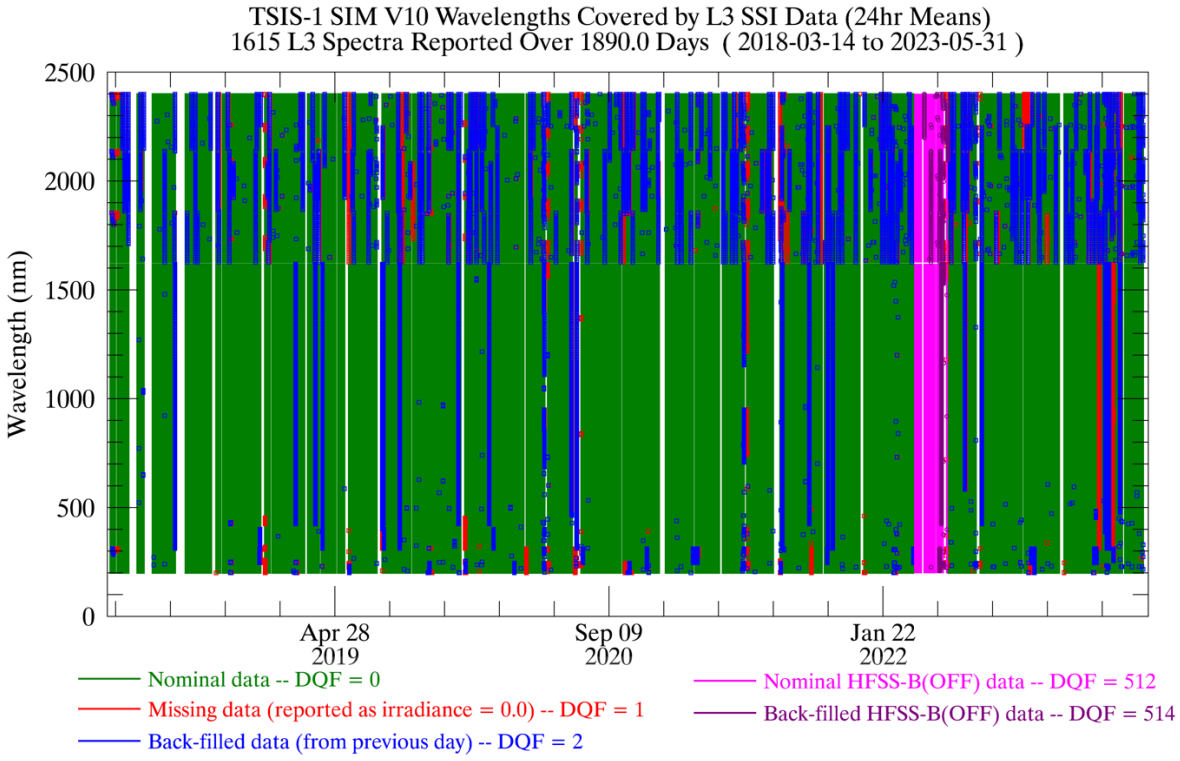

Figure 1: V10 TSIS-1 L3 SIM data acquisition record. As of 30 May 2023, the TSIS-1 L3 SIM data are available on 85.54% of days since the beginning of nominal operations on 14 March 2018.

2) Comparison to TSIS-1 TIM TSI:

Figure 2 compares the Total Solar Irradiance (TSI) measurements from the V03 data release of TSIS-1 TIM[1] with a TSI estimate (spectrally integrated SSI, iSSI) derived from the V10 TSIS-1 SIM L3 data release. The SIM iSSI was generated by integrating the daily L3 spectrum from 200–2400 nm and adding an offset to account for wavelength regions not measured by SIM. Only complete SIM L3 spectra, with no missing or backfilled values, were used in Figure 2.

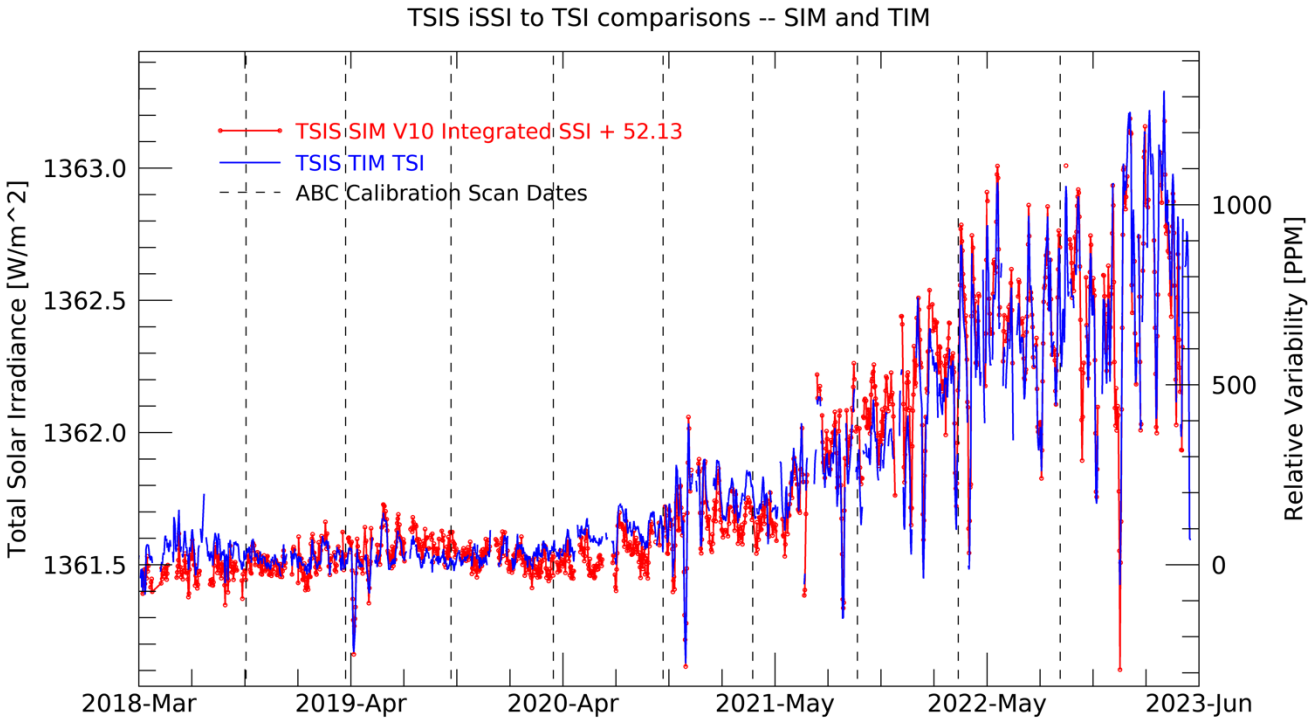

Figure 2: Comparison of V03 data release of TSIS-1 TIM (blue) Total Solar Irradiance (TSI) to the spectrally integrated Solar Spectral Irradiance (iSSI) from the V10 data release of TSIS-1 SIM (red). An offset of +52.1334 W m^{-2} has been added to the iSSI to account for wavelength regions not measured by SIM.

Figure 2 highlights the quality of the long-term SIM corrections by comparing the iSSI against the TSIS-1 TIM TSI, which has a reported stability correction uncertainty of ~10 ppm/year. This plot should not be used to evaluate the TSIS-1 SIM absolute calibrations, as the offset (+52.1334 W m^{-2}) was chosen to match TIM as closely as possible over the mission. However, this value is close to the theoretically expected value of ~4% of the TSI that falls outside of the SIM instrument's spectral range.

[1] See https://lasp.colorado.edu/home/tsis/data/tsi-data/

3) Details of TSIS-1 SIM V10 Changes:

1. ESR data (> 740 nm) now implements a wavelength alignment algorithm using prism offset corrections derived from IR diode observations:
    a. In V06, a scan-to-scan wavelength alignment algorithm was introduced for all diode irradiance measurements. The same algorithm cannot be used to derive corrections for the ESR wavelength alignment due to shorter scan bandpasses, fewer spectral features, and the lower signal-to-noise of the ESR measurements.
    b. However, analysis has shown that the prism offset corrections trend similarly in time for all detectors on a given channel. Applying the IR diode corrections to ESR data results in improved wavelength alignment of the ESR scans. In V10, the IR diode prism-offset corrections are applied to all ESR data longer than 740 nm.
2. Temporal smoothing of SIM diode and Digital Signal Processor (DSP) temperatures:
    a. In V09, a 30-second temporal smoothing of the prism thermistor temperature data was introduced to reduce noise in the irradiances of SIM data.
    b. In V10, temporal smoothing for diode temperatures and those of the DSP board was introduced. The diode smoothing uses the same 30-second smoothing as the prism temperature smoothing, while the DSP uses a 15-second smoothing window as its temperature changes more rapidly.
3. NetCDF file enhancements:
    a. The CALENDAR attribute of the TIME variable was misspelled (‘calender’). This prevented utilities, such as ***ncdump***, from properly interpreting the TIME variable, which is in Julian Date (JD).
    b. Two NetCDF attributes have been added to the QUALITY variable to better describe the L3 data quality flags. Previously, the attribute description was limited to the COMMENTS attribute, which is still the main source of information on QUALITY.
        i. With these changes, the FILE_FORMAT_VERSION is now V05.
        ii. The new attributes are:
            1. FLAG_VALUES: Integer array of the L3 QUALITY flag values, ([0,1,2,512]).
            2. FLAG_MEANINGS: String array of the L3 QUALITY flag meanings, (['nominal ', 'missing ', ' backfilled’, 'HFSSB_corrected_pointing']).
4. Updated prism degradation corrections:
    a. V10 degradation models were generated using data through April 2023 (including April 2023 Channel-C scans), while the V09 models only included data up until October 2023.
    b. Updated degradation correction for IR bandpass (950–1050 nm)
        i. Degradation corrections from 950–1050 nm now use a linear fit, instead of a two-term exponential fit, due to the degradation appearing more linear over time.
    c. Extension of degradation correction for the entire IR bandpass (950–1620 nm)
        i. V10 adds IR diode prism degradation corrections longward of 1050 nm, updating and extending the correction to 1620 nm.
        ii. V10 IR corrections use a linear fit across the entire IR bandpass, 950–1620 nm.
    d. Introduction of prism degradation correction for ESR bandpass (1620–1845 nm)

   i. A correction is now applied to part, 1620–1845 nm, of the ESR bandpass to address a local (1620–1780 nm), Channel-A only, degradation of up to 0.2%.
   ii. V10 uses Channel-B ESR data for this correction due to sparse Channel-C data.
   iii. Given the unexpected nature of prism degradations at these wavelengths, this degradation's cause is still being investigated.
5. Updated MEASUREMENT_STABILITY Uncertainties
   a. MEASUREMENT_STABILITY includes estimated uncertainties related to the prism degradation corrections, which are updated for each version.
   b. As V10 extends degradation corrections longward of 1050 nm, to 1845 nm, the MEASUREMENT_STABILITY values at these wavelengths are now non-zero.
6. Updated baseline (filtering) spectrum
   a. Changes to the V10 degradation corrections have improved the data in the period assigned to our baseline (filtering) spectrum, March 18, 2021, to March 18, 2022. In response, the baseline (filtering) spectrum was recreated for V10.

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4) Definition of Uncertainties:

Four types of uncertainties are reported in the TSIS-1 SIM L3 data release, these are:

INSTRUMENT_UNCERTAINTY (W m^{-2} nm^{-1}) is a pre-launch measure of instrument spectral irradiance uncertainty with contributions from component, and unit-level, instrument laboratory characterizations, and calibrations with the final end-to-end full spectrum validation of the measured irradiances against a NIST-traceable cryogenic radiometer performed in LASP's Spectral Radiometer Facility. Reported uncertainties represent an upper limit to the irradiance accuracy for each wavelength.

MEASUREMENT_PRECISION (W m^{-2} nm^{-1}) is a wavelength-dependent measure of the on-orbit variance in the scan-to-scan repeatability of the observed spectral irradiances during solar minimum. MEASUREMENT_PRECISION is wavelength dependent, but not time dependent.

MEASUREMENT_STABILITY (W m^{-2} nm^{-1}) is a relative metric of the on-orbit degradation correction uncertainties. It has contributions from uncertainties due to the post-processing of data (including instrument degradation correction) and differences between the observed irradiances of the three separate SIM channels. Measurement stability is given as 0.0 at wavelengths > 1845 nm, where the degradation corrections are currently not calculated, and for all data that arrives after the last bi-annual Channel-C calibration scans. The bi-annual Channel-C scans trigger a new data release version, so generally, there will be at least six months of measurement stability values that are 0.0 until they are determined during the creation of the next data release.

ADDITIONAL_UNCERTAINTY (W m^{-2} nm^{-1}) is a composite irradiance uncertainty pertaining to anomalous periods and the associated corrections in the data record, as indicated by the QUALITY data column. This uncertainty is applied to data where, due to atypical circumstances, the data have a higher uncertainty than nominal measurements.

Notes:

- Beginning with the V08 release, MEASUREMENT_PRECISION is no longer a term in the MEASUREMENT_STABILITY uncertainty.
- As of V10 the only type of ADDITIONAL_UNCERTAINTY is related to the HFSS-B(OFF) pointing anomaly in March-May of 2022 (QUALITY=512). Channel and wavelength-specific spectral corrections were needed during this period that introduced an additional irradiance uncertainty.
- V10 extends prism degradation corrections longward of 1050 nm to 1845 nm. MEASUREMENT_STABILITY uncertainties in this bandpass now include degradation uncertainty estimates.

For deriving a TSIS-1 SIM absolute irradiance uncertainties, it is recommended that V10 users add in quadrature all four uncertainty values. For a relative irradiance uncertainty, reflecting the uncertainty in the irradiances between two time periods, use MEASUREMENT_PRECISION, MEASUREMENT_STABILITY, and ADDITIONAL_UNCERTAINTY, added in quadrature.

5) Data Quality Flags (DQFs):

Each TSIS-1 SIM L3 spectral irradiance measurement includes an associated bit-wise integer data quality flag (DQF) in the QUALITY data product column. A QUALITY value of 0 indicates nominal data that has no associated DQFs. If a spectral irradiance measurement has multiple DQF flags set, the values of each flag are summed to create the final QUALITY value. For example, a QUALITY value of 514 indicates backfilled data that was obtained during the HFSS-B(OFF) pointing anomaly. A table of all TSIS-1 SIM L3 DQFs is shown below (Table 2).

Table 2: TSIS-1 SIM L3 data quality flags (DQFs). Note that a QUALITY value of 0 (zero) indicates that no DQF is associated with a particular spectral irradiance measurement and that data should be considered nominal.

Flag Value	Data Quality Flag Name	Description
1	MISSING_VALUE_FLAG	Indicates missing data items
2	FILL_VALUE_FLAG	Indicates data items that have been backfilled from previous measurements within one day.
512	BAD_HFSSB_POINTING	Indicates irradiance measurements for which a wavelength-dependent correction was applied to account for the HFSS-B(OFF) pointing anomaly that affected data obtained from 19 March to 19 May 2022.

6) Spectral Corrections and Uncertainties During HFSS-B(OFF) Pointing:

As previously reported in the V08 and V09 release notes, during two months from 19 March – 19 May 2022, TSIS-1 SIM observations were offset in pointing by ~1 arcmin due to surface contamination of the HFSS-B (High-rate Fine Sun Sensor-B). In this document, this is referred to as the HFSS-B(OFF) pointing period. On 19 May 2022, pointing was switched to the redundant sun sensor, HFSS-A, unaffected by surface contamination.

An on-orbit calibration campaign to derive channel and wavelength-dependent spectral correction factors for Channels A & B during the HFSS-B(OFF) pointing period was undertaken in June 2022. To limit solar exposure, especially at off-1AU locations, Channel-C calibration scans were not included. This campaign consisted of two sets of calibration observations, taken two weeks apart. In each set of calibration observations, irradiance data were alternately acquired for each detector and channel combination using the contaminated HFSS-B(OFF) and the uncontaminated HFSS-A. To reduce the impact of a changing Sun, every effort was made to minimize the time between identical scans taken with different pointing (sun sensors).

These spectral pointing corrections, applied in V08 and later data releases, bring irradiance data during the HFSS-B(OFF) period in line with nominal measurements, albeit with slightly higher uncertainty. This added uncertainty reflects the uncertainty in the off-pointing corrections, given the solar variability in the observed irradiances during the special calibration experiments. These uncertainties are reported in the column labeled ADDITIONAL_UNCERTAINTY in all V10 L3 data products.

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7) SSI Impacts of IR band degradation changes:

V10 updates to the IR and ESR degradation corrections, in conjunction with other changes, have resulted in SSI changes between 950 and 1845 nm. Specifically, three V10 changes affected the SSI/spectrally integrated SSI:

1. The V09 prism degradation correction at 950–1050 nm used an exponential degradation model. V10 uses a linear degradation model that now covers the entire IR diode bandpass of 950–1620 nm. The linear model more closely models the prism degradation effect, particularly at the bandpass edges. The ESR detector is used as the absolute irradiance calibration for this correction. This improvement has two related but distinct effects:
    - The relative trending over time is improved, especially at wavelengths longer than 1050 nm where no degradation correction was previously applied. This results in about +0.1 W m^{-2} to the integrated SSI in the IR bandpass (950–1620 nm) from the beginning of the mission to May 2023.
    - The absolute irradiance is decreased over most of this wavelength range despite the improved trending due to using the ESR as the absolute irradiance reference. This results in a change of about -0.25 W m^{-2} from 950–1620 nm.
2. The introduction of a prism degradation correction in the ESR bandpass of 1620–1845 nm restores about +0.05 W m^{-2} to the integrated SSI (as of May 2023).
3. As discussed in §3.1, ESR data now uses the IR diode prism offset, improving its wavelength alignment accuracy for longward of 740 nm. This directly affects ESR SSI, and, as outlined above. the ESR wavelength alignment improvement affects IR diode SSI.

Together, these combine to reduce the total spectrally integrated SSI of V10 by ~ -0.1 W m^{-2} compared to V09.

8) Additional Notes:

1. SIM line spread function (LSF) details are available on the TSIS-1 website:
    - https://lasp.colorado.edu/home/tsis/data/ssi-data/

2. An IDL (Interactive Data Language) reader for the ASCII formatted data is available at:
    - https://lasp.colorado.edu/data/tsis/file_readers/read_lasp_ascii_file.pro

3. Known V10 data issues that are under further investigation include:
    - Annual oscillations: There are annual oscillations in the SSI time series of some wavelengths, particularly longer than ~700 nm.
    - Residual temperature dependencies: The diode and ESR temperature corrections are less accurate during excursions from nominal operating temperatures. This is particularly true near the edges of the detector bandpasses.

4. Previous TSIS-1 SIM L3 data releases, including V09, are archived on CU-Scholar.

5. Note for Python users using the NetCDF files:
    - The `**xarray**` package (2022.3.0) does not properly decode Julian dates (JD) into datetimes. Users should include the `**decode_times=False**` in the `**xarray.open_dataset**` call to keep times in JD.
    - When using `**netCDF4.num2date**` (1.5.8) or `**cftime.num2date**` (1.6.0) to convert the time column, users should provide the flag `**has_year_zero=True**` to properly convert JD to datetimes.

9) V10 Release Notes Revision History:

1.0: – Michael Chambliss, Stéphane Béland, Keira Brooks, Luke Charbonneau, Odele Coddington, Courtney Peck, Steven Penton, and Erik Richard - *Initial Release*