TSIS-1 SIM Version 11 Level 3 Data Product Release Notes (V2: 2024/01/30)

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 11 (V11) of the TSIS-1 SIM Level 3 (L3) data release. V11 is an 'off-cycle' release due to two unrelated issues with the V10 prism degradation corrections (see §3). The more important issue relates to increased prism degradation, due to increased solar activity during the Solar Cycle 25 maximum, that is not able to be corrected using the current degradation models. As explained in §3.2, V11 uses the actual measured degradations, instead of fits to the measured degradations at wavelengths shorter than 800 nm for data acquired on, or after, 21 Jan. 2023. The next data release, V12, will be an on-cycle release that provides an improved solution to the issue of changing prism degradation rates.

On 03 Sept. 2023, less than a week after the initial release of V11, the TSIS-1 SIM Digital Signal Processor (DSP) encountered an anomaly which prevented SIM science data from being obtained from 03 Sept. 2023 until 21 Oct. 2023. In the process of recovering from the DSP anomaly, a separate issue with the ESRs was discovered. The DSP+ESR anomaly is preventing the publication of L3 data longward of 1620 nm taken after 03 Sept 2023. Efforts are ongoing to develop corrections for the affected ESR data. These corrections will be available no earlier than TSIS-1 SIM L3 V13 (see §9 for details).

Publication of ESR data not affected by the anomalies is expected to resume in V12 (Feb 2024), however, V12 will have temporal and wavelength gaps where data does not yet meet accuracy standards.

SIM L3 data is released on 12-hour and 24-hour cadences. The DOIs for V11 are:

- 12-hour cadence: https://doi.org/10.5067/TSIS/SIM/DATA321
- 24-hour cadence: https://doi.org/10.5067/TSIS/SIM/DATA322

TSIS-1 SIM V11 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 V10 TSIS-1 SIM L3 data release include:

- April 2023 Channel C (ChC) measurements have been updated, using the correct ChC degradation rates.
- Measured prism degradations are applied for $\lambda < 800$ nm data acquired on, or after, 21 Jan. 2023.
- ESRIR data (1620–2400 nm) acquired after 03 Sept. 2023 are not available in V11 (see §9).

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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 (ChB) 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 L3 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 V11 L3 TSIS-1 SIM 24-hour data acquisition record. Nominal data are shown in green, data quality flag (QUALITY[1]=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 §6), 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 §5).

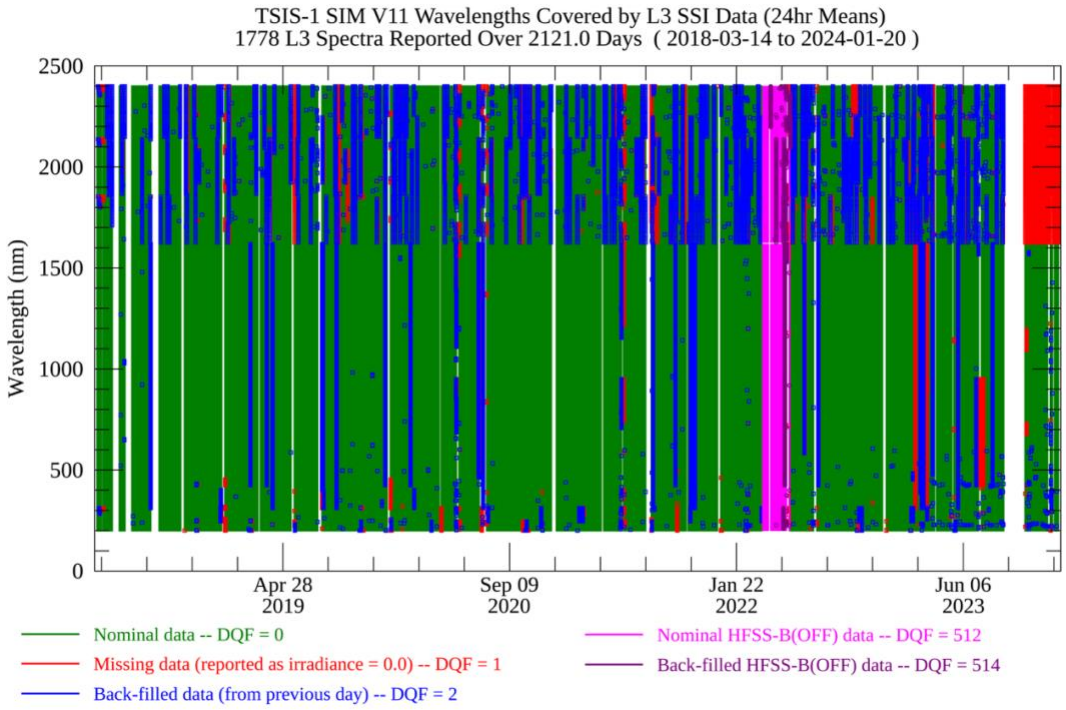

Figure 1: V11 TSIS-1 L3 SIM data acquisition record. As 01 Jan 2024, data are available 84% of days since the beginning of nominal operations on 14 March 2018. Note the missing ESRIR data (1620–2400 nm) after 21 Oct. 2023 due to the DSP and ESR anomalies as discussed in §9.

[1] When referring to L3 data product columns, references are in ALL_CAPS.

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[2] with a TSI estimate (spectrally integrated SSI, iSSI) derived from the V11 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.

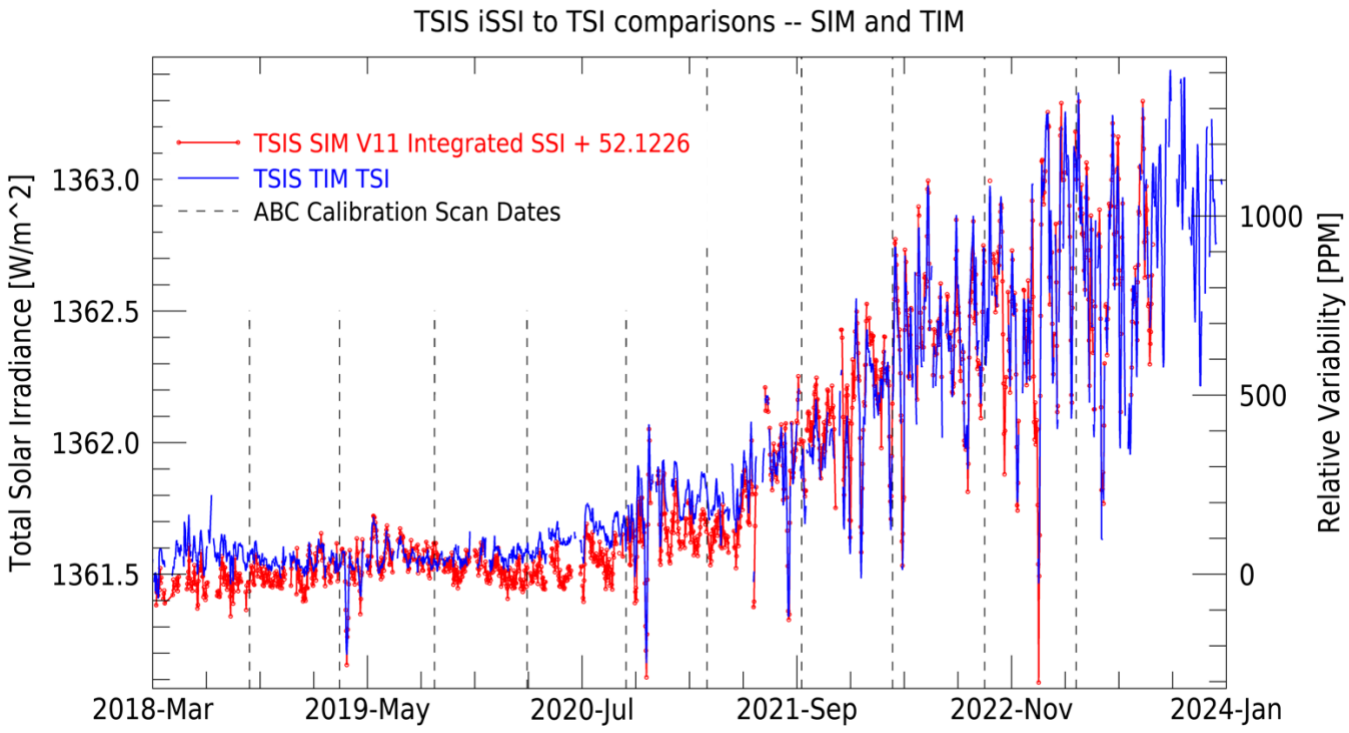

Figure 2: Comparison of V04 data release of TSIS-1 TIM (blue) Total Solar Irradiance (TSI) to the spectrally integrated Solar Spectral Irradiance (iSSI) from the V11 data release of TSIS-1 SIM (red). An offset of +52.1226 W m^{-2} has been added to the iSSI to account for wavelength regions not measured by SIM. Note that V11 iSSI is not included in this plot after 03 Sept. 2023, as V11 data longward of 1600 nm is not available.

Figure 2 highlights the quality of the long-term SIM corrections by comparing the V11 iSSI against the TSIS-1 TIM TSI V04, which has a reported stability correction uncertainty of ~10 PPM (Parts-Per-Million)/year. This plot should not be used to evaluate the TSIS-1 SIM absolute calibrations, as the offset (+52.1226 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.

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

3) Details of TSIS-1 SIM V11 Changes:

1) April 2023 Channel C (ChC) degradation corrections have been updated:
    i. In V10, the degradation rates applied to the April 2023 ChC measurements were erroneously not updated from the Oct 2022 values, leading to outdated degradation corrections being applied.
    ii. This has been corrected for V11, resulting in relatively small irradiance changes, ranging from < 10 PPM to ~100 PPM varying with time and wavelength.

2) Direct measurements of prism degradations are now used for data with wavelengths shorter than 800 nm acquired on, or after, 21 Jan. 2023:
    i. V10, and previous versions since V06, used exponential decay models to fit measured degradation rates. These models have worked well, but with increasing solar activity our measured degradation has increased and started to deviate significantly from the exponential models over the past few months.
    ii. V11 reverts to the piece-wise linear degradation correction models for data acquired on, or after, 21 Jan. 2023 with wavelengths < 800 nm. This method was used exclusively in the first two years of the mission and is still used for 800–950 nm. This model
        1. corrects ChB to ChC by taking the ratio between the channels and linearly interpolating that ratio, in time, between ChC measurements to generate a correction for ChB,
        2. repeats to correct ChA to the corrected ChB, interpolating between ChB measurements.
    iii. The piece-wise linear correction is less susceptible to prism degradation rate changes as there is no fit or assumption of a degradation model. It simply corrects directly to the secondary channels. However, it is more susceptible to short term noise as a single ChB scan with above average noise levels could lead to slightly noisier L3 data for the approximately three-week period affected by that measurement.
    iv. Figure 3 shows the prism degradations measured at 306.5 nm for the UV diode for ChA (uncorrected) ÷ ChB (corrected) as explained in ii) above. The dashed orange line shows the V10 degradation model at 306.5 nm. On or about Jan. 21, 2023, the actual prism degradation deviates from the model, and illustrates the need for switching to the piece-wise linear model after this date.

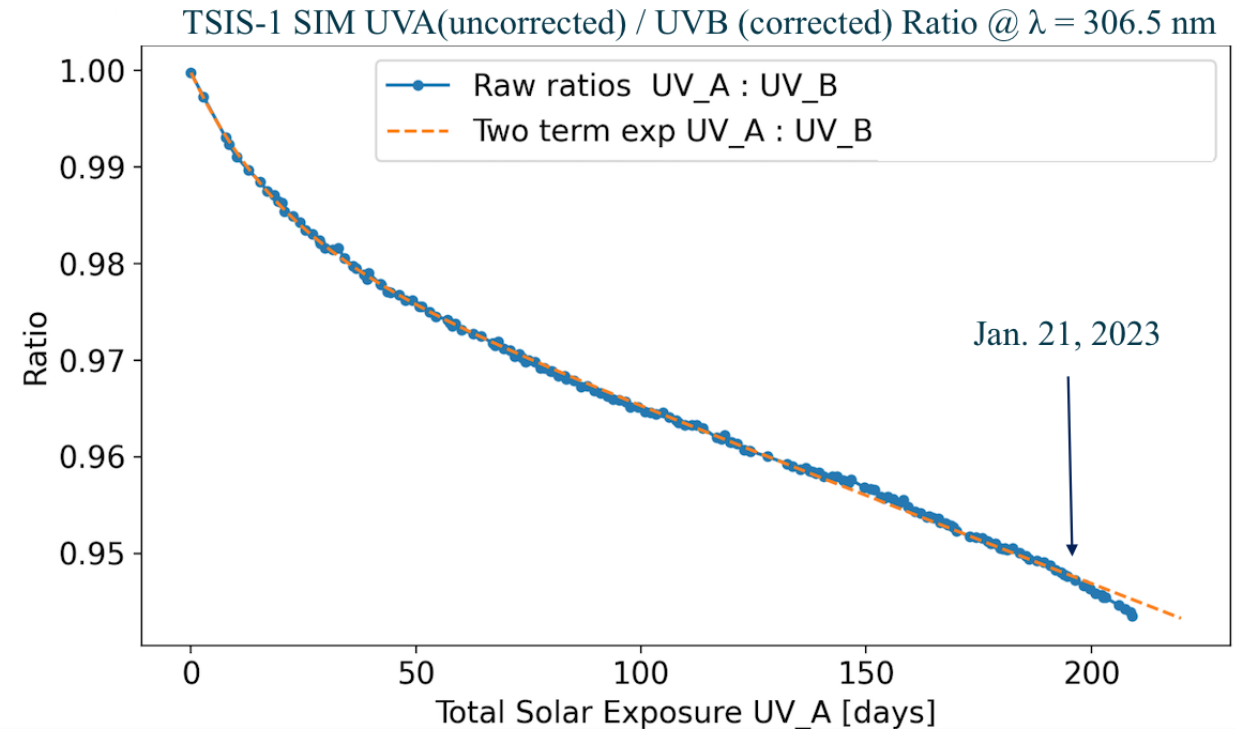

Figure 3: TSIS-1 SIM Channel A (ChA) prism degradation versus the V10 model (orange). On or after Jan. 21, 2023, the actual ChA (uncorrected) to ChB (corrected) ratio deviates from our model (two-term exponential) by enough to warrant for a change to a piece-wise linear degradation model.

4) Truncation of the V10 L3 datasets:

On 14 Aug. 2023, the V10 TSIS-1 SIM L3 datasets on the DAAC, LISIRD, and the LASP website were replaced with versions that only include data up to 07 March 2023. This date represents the approximate date where the incorrect V10 prism degradation corrections could result in up to a ~1000 PPM SSI offset at a single wavelength. This value is ½ of our baseline total accuracy requirement of 0.2%.

Even though the prism degradation issue only affects TSIS-1 SIM data at wavelengths shorter than 800 nm, all users are encouraged to immediately replace any use of TSIS-1 SIM V10 data with V11. Furthermore, use of previously released V10 data after 07 March 2023 is very strongly discouraged.

5) 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 V11, 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 extended prism degradation corrections longward of 1050 nm to 1845 nm. MEASUREMENT_STABILITY uncertainties in this bandpass now include degradation uncertainty estimates.
- For V11, the MEASUREMENT_STABILITY uncertainties reported after 20 Jan. 2023, and before the April 2023 ChC scans, were derived using the outdated V10 degradation models, and not the piece-wise linear degradations outlined in §3. As discussed in §7.3, the actual MEASUREMENT_STABILITY values reported during these time periods are likely to be slight underestimates.

For deriving a TSIS-1 SIM absolute irradiance uncertainties, it is recommended that V11 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.

6) 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.

7) Impacts of V11 changes:

1) The use of piece-wise linear degradation corrections will result in some additional delays in delivering L3 data updates. To deliver updated L3 measurements, we need full spectral coverage on Channel B (ChB) from 200–800 nm, which usually takes a couple of weeks. However, if any ChB scans are scheduled, but not executed, we may need to wait an additional 2 weeks to be able to publish new L3 daily spectra.
2) The use of piece-wise linear degradation models for prism degradation will result in slightly higher uncertainty than previous models. We are actively quantifying this additional uncertainty, and it will be included in future data releases.
3) Data in the V11 data record, with exposure times between 20 Jan. 2023 and early April 2023, currently report the MEASUREMENT_STABILITY uncertainty appropriate for the model degradation fits used for these times in V10. This is likely a slight underestimate of the actual MEASUREMENT_STABILITY, but not more than ~100 PPM. Consistent with previous data releases, no MEASUREMENT_STABILITY values are reported for any data taken after the latest ChC scans (early April 2023).

8) Additional Notes:

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

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

3) Known V11 data issues that are under further investigation include:
   a. Annual oscillations: There are annual oscillations in the SSI time series of some wavelengths, particularly longer than ~700 nm.
   b. 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 V10, are archived on CU-Scholar.

5) Note for Python users using the NetCDF files:
   a. 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.
   b. 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) DSP and ESR Anomalies of Sept/Oct 2023

On 03 Sept. 2023, the SIM Digital Signal Processor (DSP) stopped responding to ground commands. DSP command and control was restored on 21 Oct. 2023. However, the post-anomaly checkout showed issues with the electric substitution radiometers (ESRs) in certain configurations.

A workaround for the ESRs is being developed, however, ESR L3 data ($\lambda > 1620$ nm) taken after 21 Oct. 2023 do not currently meet the TSIS-1 SIM accuracy standards and are not published at this time. All affected ESR data have been flagged, and do not affect any published L3 data for any wavelength. If possible, a spectral correction for the anomalous ESR data will be developed, and the existing data gaps removed. However, this will occur no earlier than the V13 data release (Spring/Summer 2024). We expect that additional ESR data will be available in V12 (Feb. 2023), but details of the temporal and wavelength availability are yet to be determined.

10) V11 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*
2.0: – Steven Penton, Michael Chambliss, Keira Brooks, Luke Charbonneau, and Courtney Peck– *V11.1 update (DSP+ESR Anomalies)*