Laboratory for Atmospheric and Space Physics

University of Colorado
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Earth Observing System
SOlar Radiation and Climate Experiment
(EOS SORCE)

Algorithm Theoretical Basis Document – Post Launch Update

Total Irradiance Monitor (TIM)

Document No. 164786 Date: 13 May 2021

Description/Summary/Contents:

In this document we describe the scientific basis of the Level-1 processor algorithms used for the Total Irradiance Monitor (TIM), flying on the SORCE platform. This document represents an update to the pre-launch ATBD that was reviewed and published April 2000 and applies specifically to the algorithms developed and/or refined to support post launch processing.

Prepared by Greg Kopp and Brandon Stone Date May 2021

Approved by Thomas Woods Date May 17, 2021

Approved by ____________________ Date ________

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Revisions				
Rev	Description of Change	By	Approved	Date

Outline

1 Introduction

1.1 Purpose of this Document

This supplemental Algorithm Theoretical Basis Document (ATBD) describes the algorithms used to produce total solar irradiance (TSI) data for the SORCE Total Irradiance Monitor (TIM) instrument. This document is a supplement to the full SORCE ATBD written at the start of the mission. It mainly includes changes since that time and does not attempt to redundantly replicate the descriptions in that document.

1.2 Scope

In conjunction with the original SORCE ATBD [15], this document describes those algorithms required to generate the TSI data sets from direct observations of the Sun from space. A summary of on-orbit calibrations is included here.

1.3 Applicable Documents

The initial SORCE ATBD [15] is the primary ATBD for this mission. This TIM-specific post-mission ATBD merely provides updates based on on-orbit changes.

1.4 Contributing Authors

Greg Kopp	TIM Instrument Scientist and SORCE Co-I
Brandon Stone	TIM Data-Systems Processing Specialist

2 Overview and Background Information

2.1 Introduction

A continuous space-based record of the TSI now exists for more than 41 years (see Figure 1). The individual TSI datasets in Figure 1 from 1978 to the present time include observations made by ERB on Nimbus-7; ACRIM1 on the SMM; ACRIM2 on the UARS; ERBS on the ERBE; VIRGO on the SoHO; ACRIM3 on the ACRIMSat; TIM on the SORCE, TCTE, and TSIS-1; and PREMOS on the Picard. Only the VIRGO and the TSIS-1 continue observations after the SORCE mission.

Evident in this combined record is an 11-year solar cycle with peak-to-peak amplitude of ~0.1 % and variations on weekly timescales that are a factor of 2 to 3 greater due to the passage of sunspots across the disk. TSI variability occurs over all timescales on which it has been observed [12].

The most prominent contribution of the SORCE/TIM to the TSI climate-data record is that it established the now-accepted value of 1361 W m^{-2} with an uncertainty of ±0.5 W m^{-2} for the total solar irradiance arriving at the top of the Earth's atmosphere [10,16]. This accomplishment also improved the SI-traceability of the World Radiometric Reference [3]. The SORCE/TIM is also the most intrinsically stable of any of the flight TSI instruments [11].

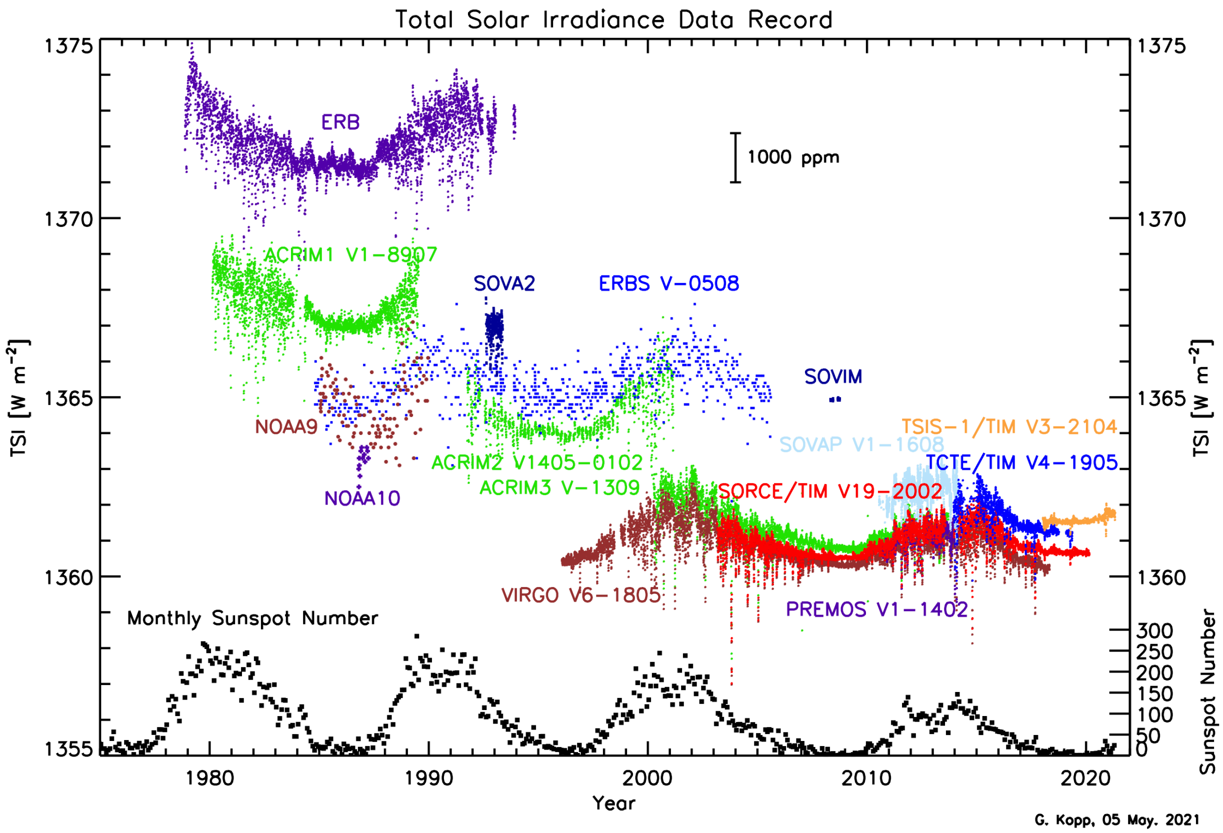

Figure 1: The SORCE/TIM (data shown in red) is one of the longest-duration instruments contributing to the uninterrupted 41-year record of space-based TSI measurements. This plot is updated regularly at http://spot.colorado.edu/~koppg/TSI.

2.2 TSI Science Goals and Objectives

The primary goal of the SORCE/TIM is the measurement of the TSI for Earth-climate studies, giving this time-varying value with high accuracy, precision, and stability. The TIM achieved these goals, demonstrating better accuracy [10], stability [11], and noise [11] than any other on-orbit TSI instrument previously flown. With climate studies as the principal objective, daily and 6-hourly averaged TSI values are the primary data products (see §7.2). Higher-cadence data are not a released product, but have been used for solar studies, such as flare detections [17,18,12,8] and planetary transits [12,13].

The SORCE/TIM measurement-accuracy goal was to determine the TSI with a combined standard uncertainty of ≤100 ppm (0.01%) (k=1). The instrument was intended to overlap prior and subsequent TSI instruments to maintain continuity of the space-borne TSI record. The measured TSI variability helps validate and understand the causes of solar variability, assess how the Sun affects the Earth's atmosphere and climate, and improve estimates of past and future solar behavior and climate response. To help achieve these goals, the SORCE/TIM measurements are compared with those of other instruments (see §6.2) and solar-irradiance models (§6.3).

2.3 Instrument Description

The TIM is a four-channel, ambient-temperature electrical-substitution radiometer (ESR). These are pairwise thermally balanced. The four channels provide redundancy and allow for solar-exposure-dependent degradation tracking via duty cycling. The design is unchanged from that described in the original SORCE ATBD [15]. A detailed description of the design and calibrations is given in [6] and [7].

3 Measurement Equation and Definition of Terms

The TIM measurement equation is unchanged from that in the original SORCE ATBD. The equation is reproduced as Eqn. 1 here (using slightly different nomenclature, with terms described below), but for a full description and background, reference [15].

The fundamental TIM measurement equation is

Eqn. 1
$$E_{meas} = \frac{V^2}{64000 \cdot R_{eff}} \cdot \frac{1}{A_p} \cdot \frac{1}{\alpha} \cdot Re\left\langle \frac{1}{\psi} \cdot \left[-DN_{meas}\left(1 + \frac{1}{G}\right) + DN_{FF} \cdot \frac{1}{G} \right] \cdot \frac{Z_H}{Z_R} \right\rangle$$

where

- E_{meas} is the measured irradiance,
- V is the applied voltage,
- R_{eff} is the cavity-heater resistance,
- A_p is the aperture area (including diffraction-loss, temperature, and pressure corrections),
- α is the cavity absorptivity,
- Ψ is the shutter waveform,
- *DN* is the data number value for the measurement (*meas*) or for the applied feedforward (*FF*), and is applied as a value digitized over 64000 steps (hence that value in the denominator in Eqn. 1)
- G is the servo-system gain,
- Z_H/Z_R is the non-equivalence of heater to radiative power absorbed.

The last four items in this list are represented as complex phasors. All terms physically are unique to each cavity, although, in implementation, the value for the non-equivalence is applied as a common value to all four cavities because it is estimated from a thermal model.

The value given by the instrument-intrinsic measurement in Eqn. 1 is corrected for thermal background (E_{dark}) and sensitivity degradation as well as external factors by

Eqn. 2
$$E_{Sun} = \frac{1}{f_{AU} f_{Doppler} f_{point} f_{degrade}} \cdot [E_{meas} - E_{dark}]$$

where

- f_{AU} is the correction for spacecraft distance to the Sun
- $f_{Doppler}$ is the correction for spacecraft velocity relative to the Sun
- f_{point} is the sensitivity of the instrument to incidence angle
- $f_{degrade}$ accounts for changes in instrument response with time through the mission

4 Instrument Calibrations and Characterizations

4.1 Calibration Overview

The TIM is a primary radiometer that achieved higher accuracy than any TSI instrument prior. As a primary instrument, no facility existed at the time of calibrations to perform end-to-end ("system-level") calibrations of the instrument. Even validations, such as made possible later by the TSI Radiometer Facility (TRF) [9], were not possible at nearly the desired uncertainty levels prior to launch. Instead, the instrument is thoroughly calibrated on the ground at the component level with select on-orbit calibrations acquired on orbit.

Planned underflights, as mentioned in [15], never occurred, even though the Hitchhiker TIM (aka "Traveler") was built for that purpose. These plans were put on hold about a week after the SORCE launch by the re-entry loss of the *Columbia* space shuttle and the resulting rescoping of the shuttle program.

4.2 PRE-FLIGHT CALIBRATIONS

4.2.1 Component-Level Calibrations

All pre-flight component-level calibrations are described in [15]. Updates after launch are provided in [7]. Subsequent lab-based aperture-scatter and -diffraction measurements are described by Harber *et al.* [4] and detailed uncertainty analyses of the cavity reflectance measurements are described by Heuerman *et al*. [5].

4.2.2 System-Level Calibrations

There were no full system-level irradiance calibrations for the TIM prior to launch. The TRF [9] did not exist at the time. System-level optical-power tests prior to launch were in-line with expectations, as presented at reviews then. Post-launch system-level optical-power comparisons in 2006 with the NIST POWR and the ground-based TIM Witness unit also demonstrated agreement, helping validate the SORCE/TIM instrument for optical power accuracy.

Ground-based pre-launch dark measurements gave signals higher than expected, leading to an aperture redesign implemented on all subsequent TIM instruments. Actual, on-orbit dark measurements with the SORCE/TIM nevertheless account for the instrument's background levels (see §4.3.1).

4.3 FLIGHT CALIBRATIONS

The in-flight calibrations for the TIM include dark (thermal background) measurements, servo-system gain calibrations, degradation tracking and corrections, and cavity-reflectance monitoring via photodiodes.

4.3.1 Dark Signal and Dark Model

The dark (thermal background) signal was measured during the eclipse portion of nearly every orbit when the instrument was powered on through eclipse. These dark measurements ceased with the start of instrument power cycling on 9 Nov. 2012.

The direct dark measurements were fitted to four instrument temperatures: the heat sink, shutter, pre-baffle, and shutter-housing temperatures. The pre-baffle and shutter temperatures are only used during the portion of the shutter cycle when these components are visible by the cavities. The temperature dependencies of the model then allow estimates of the dark-signal contributions during solar measurements despite the difference in instrument temperatures during these portions of the orbit. This dark model was a singular-value decomposition (SVD) model until V.17, when it was transitioned to using principal-component analysis (PCA) fits.

Figure 2 shows samples of the dark measurements and models from both types of fits. Note that the orbital variations are ~0.3 W m^{-2} (~200 ppm), indicating the importance of accounting for thermal-emission differences between the times of dark measurements (during the cooler, eclipse portion of an orbit) and the times of solar observations (on the sunlit side of each orbit, when the instrument is warmer). Despite this importance and the magnitude of the correction, *no prior TSI instrument had accounted for these orbital thermal variations*.

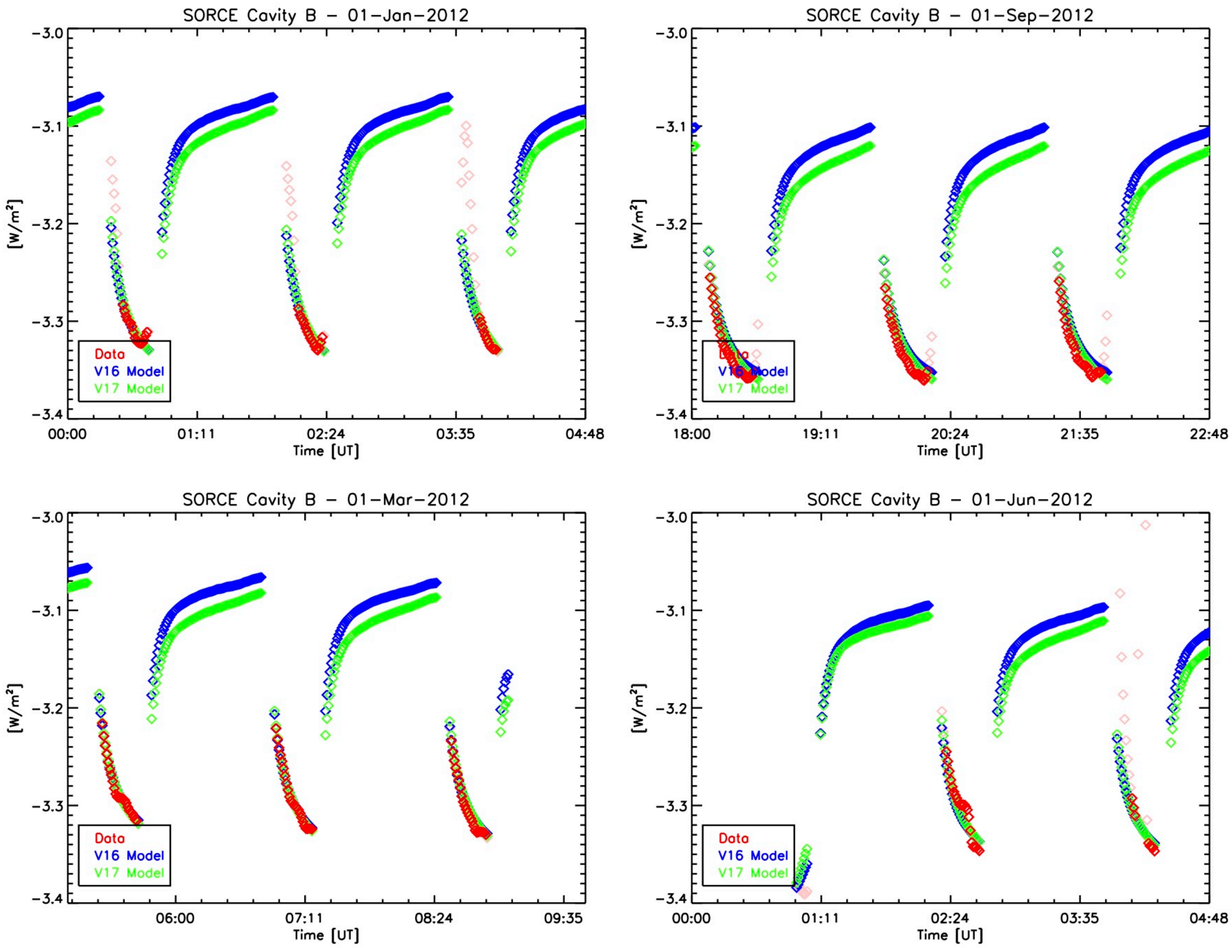

Figure 2: The three-eigenvector PCA model (green) used from V.17 onward matches the PreliminaryIrradiances (red) at least as well as the V.16 SVD-based model (blue). These four seasonal plots from the primary cavity (B) sample the extreme annual temperature variations due to Sun-Earth distance.

4.3.2 Degradation Corrections

Almost all flight TSI instruments include multiple, nearly identical cavities to track solar-exposure-dependent degradation in the primary solar-viewing cavity via duty cycling the lesser-used ones to acquire simultaneous measurements of the TSI from channels having different net-exposure levels. The pre-launch plan described in [15] was to operate the four TIM cavities with duty cycles of Channel A 100% of the time, B 1%, C 0.1 %, and D annually. Higher cadences were actually used on-orbit: Channel B (primary) 99.5%, A 1%, C 0.05%, and D 0.025%. These are apportioned as Channel A for one orbit per week, C for one orbit every two weeks, and D for one orbit every four weeks. The net exposure of all cavities to date is shown in Figure 3.

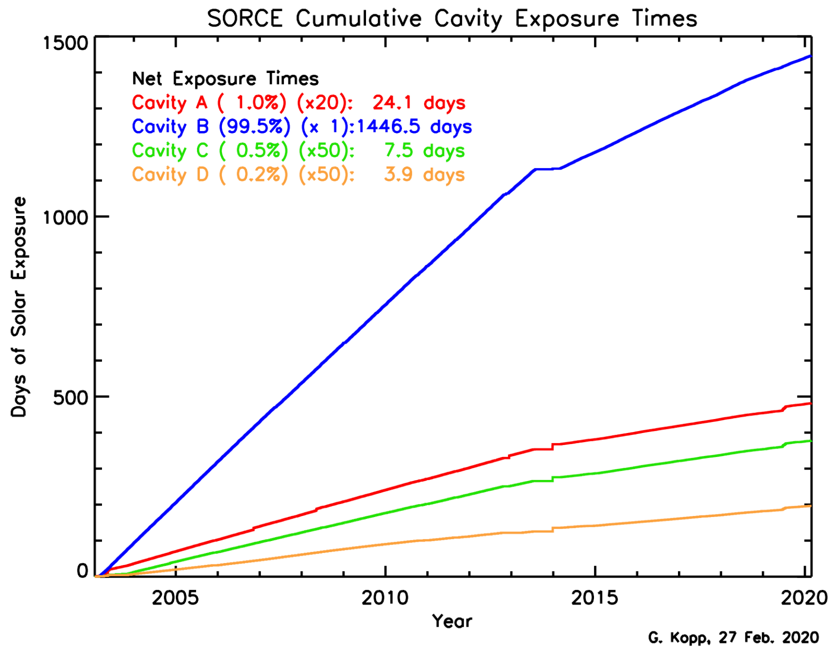

Figure 3: Net exposure of all SORCE/TIM cavities is plotted as a function of time. Degradation corrections are based on accumulated exposure time rather than chronological time.

Figure 4 shows the relative differences between all paired cavities in the degradation experiments. The degradation of the primary cavity (B) is determined primarily by comparisons with the secondary (Cavity A). An upward linear trend in the CA inter-comparisons is added to the downward degradation trend in the AB comparisons, assuming that this trend is a gradually increasing signal in Cavity A. This assumption is consistent with the DB inter-comparisons in the pre-jump portion of those.

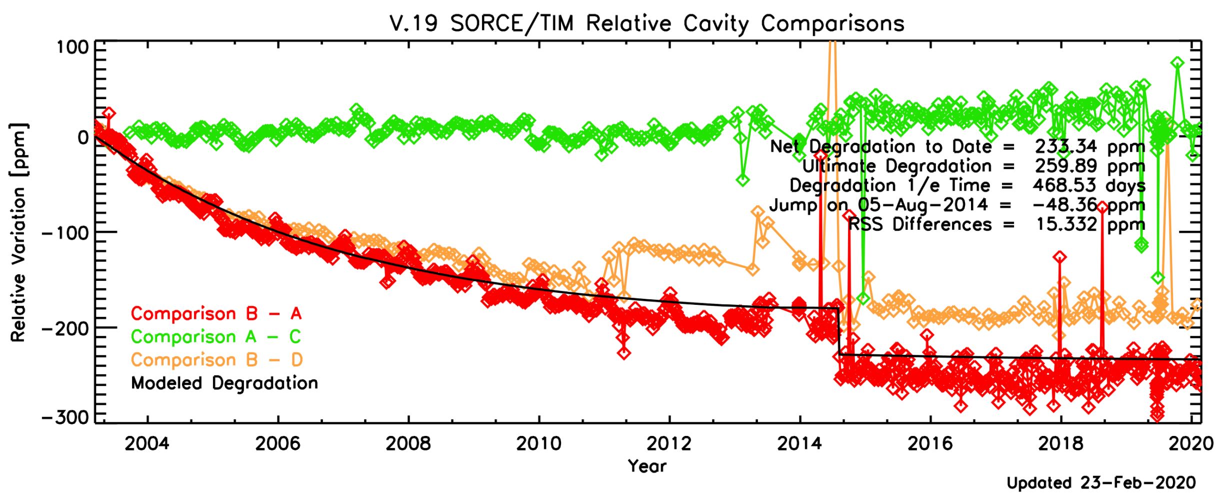

Figure 4: The primary cavity (B) has degraded by ~225 ppm over the duration of the mission.

The Cavity B degradation is fitted to an exponential with a single Heavyside (step) function to allow for the discontinuity (of unknown cause) in early August 2014. The CA inter-comparisons show a linear upward trend that indicates either Cavity A is measuring slightly higher signals with time or Cavity C lower (or a combination summing to this difference). The DB inter-comparisons are fitted to an exponential and two step functions to allow for the increase in the differences between those two near 28 Dec. 2010 and that in Cavity B in early August 2014.

This fitted degradation is applied to the 'TIMCorrectedIrradiances' in data processing. The degradation of the primary cavity is 3 to 20 times lower than that of prior TSI instruments on orbit, giving the SORCE/TIM *the best intrinsic stability of any flight TSI instrument*.

4.3.3 Gain Calibrations

The servo-system gain is calibrated in flight (and on the ground) with a special program of the instrument's DSP that injects a test square wave into the servo loop and observes the resulting response. This is done with no sunlight entering the instrument. Gains for Channels A and B were performed monthly and those for C and D every other month. To achieve the elevated temperatures needed for these calibrations, each was done for four orbits, or 6 hours, during which time no solar observations were acquired. Because of the needed durations, no gain calibrations were acquired after instrument power cycling began on 9 Nov. 2012.

The gains are applied in data processing as time-dependent values based on the nearest gain calibrations. Those calibrations for the primary channel (B) are shown in Figure 5.

Because of the applied feedforward, the instrument is relatively insensitive to the servo-system gain, as the servo system does not deviate significantly from thermal balance.

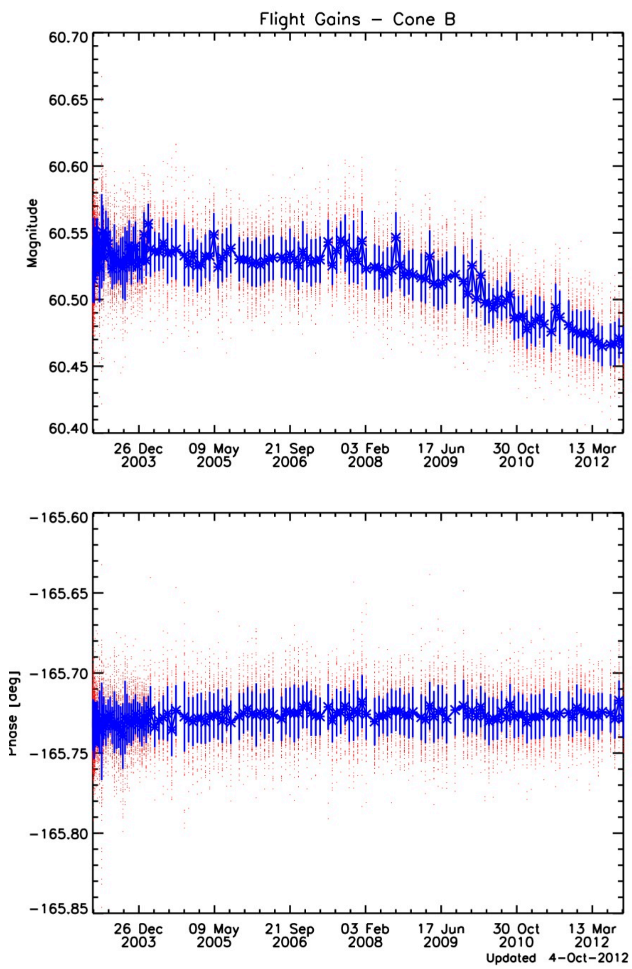

Figure 5: Gain calibrations of the primary channels were acquired monthly and are plotted here. Changes are insignificant but are nevertheless included in data processing.

4.3.4 Photodiode Monitors

Four photodiodes, each mounted near the front of the heat sink to face into each cavity, monitor relative changes in cavity reflectance. The photodiodes can monitor changes in reflectance with a sensitivity of a few ppm, but they do not sample the cavity interiors uniformly, so are not used as degradation corrections.

Figure 6 shows the changes seen during the SORCE mission after corrections for radiation-induced degradation. These are consistent with the degradation changes based on the cavity inter-comparisons.

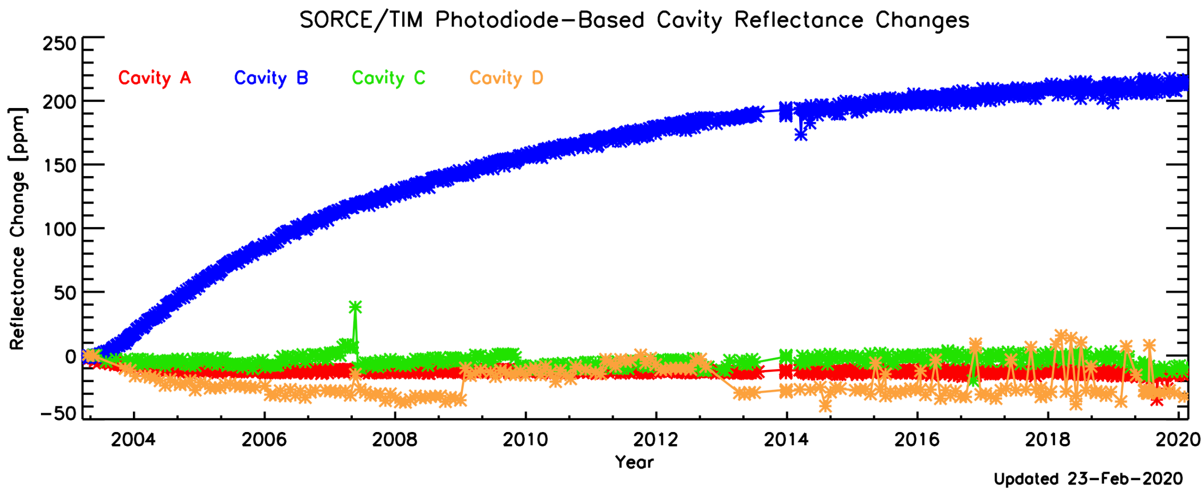

Figure 6: Relative photodiode-based reflectance changes are shown after corrections for radiation-induced degradation.

4.4 Operational Changes from Original ATBD

4.4.1 Non-Linearity Calibrations

After launch, a severe non-linearity was discovered in the pulse-width modulation (PWM) circuit of the TIM's detector-head board. These non-linearities were subsequently measured on the two ground-based TIMs and the average of the eight circuits measured became the non-linearity correction for all four of the flight instrument's cavities (see Figure 7). Uncertainties for the flight instrument's non-linearities are based on the variations in the eight ground-based channel measurements with increases to account for their applicability to the actual (but unmeasured) flight non-linearities. This correction is a dominant uncertainty source in the SORCE/TIM's accuracy, giving at-launch uncertainties estimated at ~350 ppm.

On-orbit tests of adjusting the reference cavity's PWM value to span the PWM operational range helped validate that the applied non-linearity corrections are reasonable.

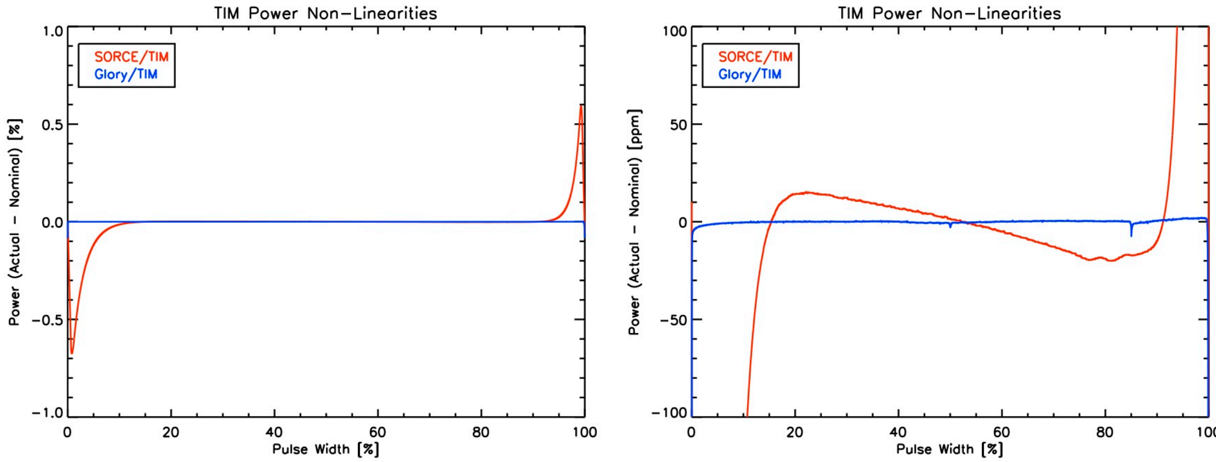

Figure 7: Non-linearity corrections are estimated from two ground-based SORCE/TIM units and applied to the flight unit. The average of the non-linearities of all four channels in each of the two ground-based units tested are plotted in red. Uncertainties for the SORCE flight unit for this correction are based on the variations in all channels of the two ground-based units. Non-linearities for the Glory/TIM, which implemented modified electronics to resolve this issue, are plotted in blue for comparison. (The data are the same in both plots. Only the vertical scales differ.)

Had it not been for the existence and availability of the ground-based TIM instruments, no such corrections would have been possible, and the SORCE/TIM's accuracy uncertainty would have been ~2000 ppm.

4.4.2 In-Flight Anomalies

Cavity B became the primary cavity after the post-launch realization that the cavity pair containing the intended primary cavity, A, had a miswiring in its electrical amplifier. The PID coefficients for that cavity pair were changed to compensate for the resulting gain, but the alternate cavity pair was used instead in case of subsequent failure of the mis-wired pair and the potential ensuing lack of measurement consistency that could result. (No such changes to this mis-wired pair have been observed on orbit.)

The SORCE's three generic channel interfaces (GCIs), each of which directly controls an instrument (with one GCI specific for the TIM), were inadvertently mis-wired, causing radiation-induced on-orbit lockups that prevented further commands from reaching the instrument until a power cycle was initiated. This led to occasional data gaps, incorrect operational states, and higher uncertainties in the state of the instrument's shutter position. The latter in turn caused higher uncertainties in the knowledge of the actual acquired cavity exposure due to ram and solar radiation. Checks for this lockup condition were implemented for each orbit-terminator crossing, limiting the duration of operating in an unknown state to no more than about half of an orbit period.

5 Uncertainty Estimates

5.1 Absolute Accuracy

The SORCE/TIM, with its at-launch quoted uncertainty of 350 ppm, provided approximately a 10x improvement in absolute accuracy over prior TSI instruments (see §6.2.1). Kopp et al. [7] tabulate some of the effects contributing to the TIM's estimated on-orbit uncertainties, with an unmeasured non-linearity in the TIM's PWM electronic circuit being a dominant contributor (see §4.4.1).

The instrument's uncertainty increases monotonically with time after the initial measurements, as on-orbit degradation and unknown space-environment effects can decrease the certainty of the ground-based calibrations with time. Examples include drifts in the instrument's two voltage or four heater-resistance references, cavity degradation with exposure to unfiltered UV and x-rays from the Sun, radiation damage from high-energy electrons and protons, contamination due to spacecraft or instrument materials, and changing emissivities of instrument surfaces. Stability estimates of 10 ppm yr^{-1} are summed in quadrature with the initial uncertainty to indicate the time-dependent uncertainty in the TIM's measurements. (This is likely an overestimate of the uncertainty growth with time, as suggested by a 1/*f* dependence described by [2].) Operational changes contribute additional uncertainties associated with those events, as described in §5.3.

The individual and net effects of these uncertainty contributions are plotted in Figures 8 and 9 and reported in the released Level 3 data products.

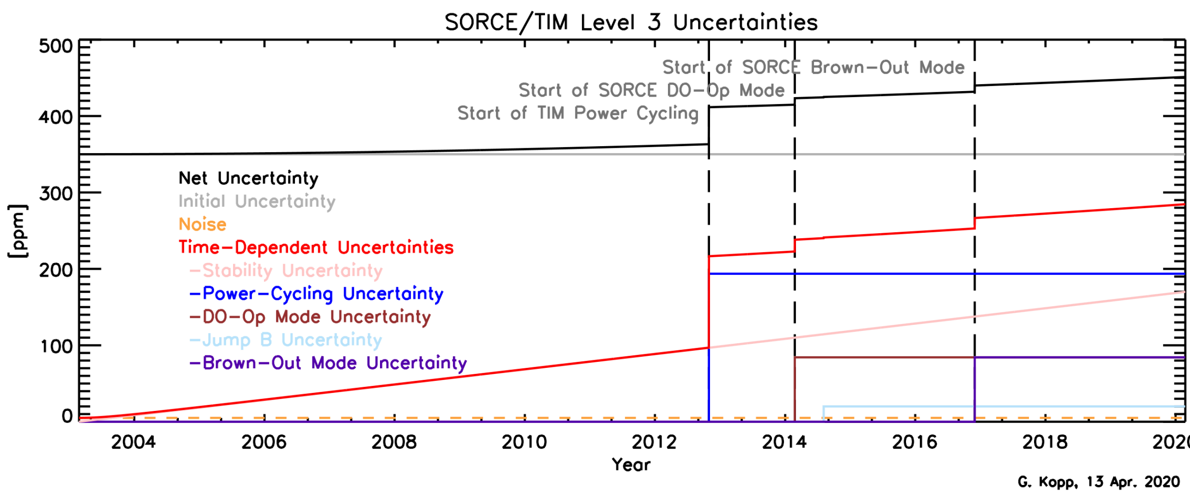

Figure 8: Uncertainties are time dependent to reflect gradual degradation and abrupt operational changes with time.

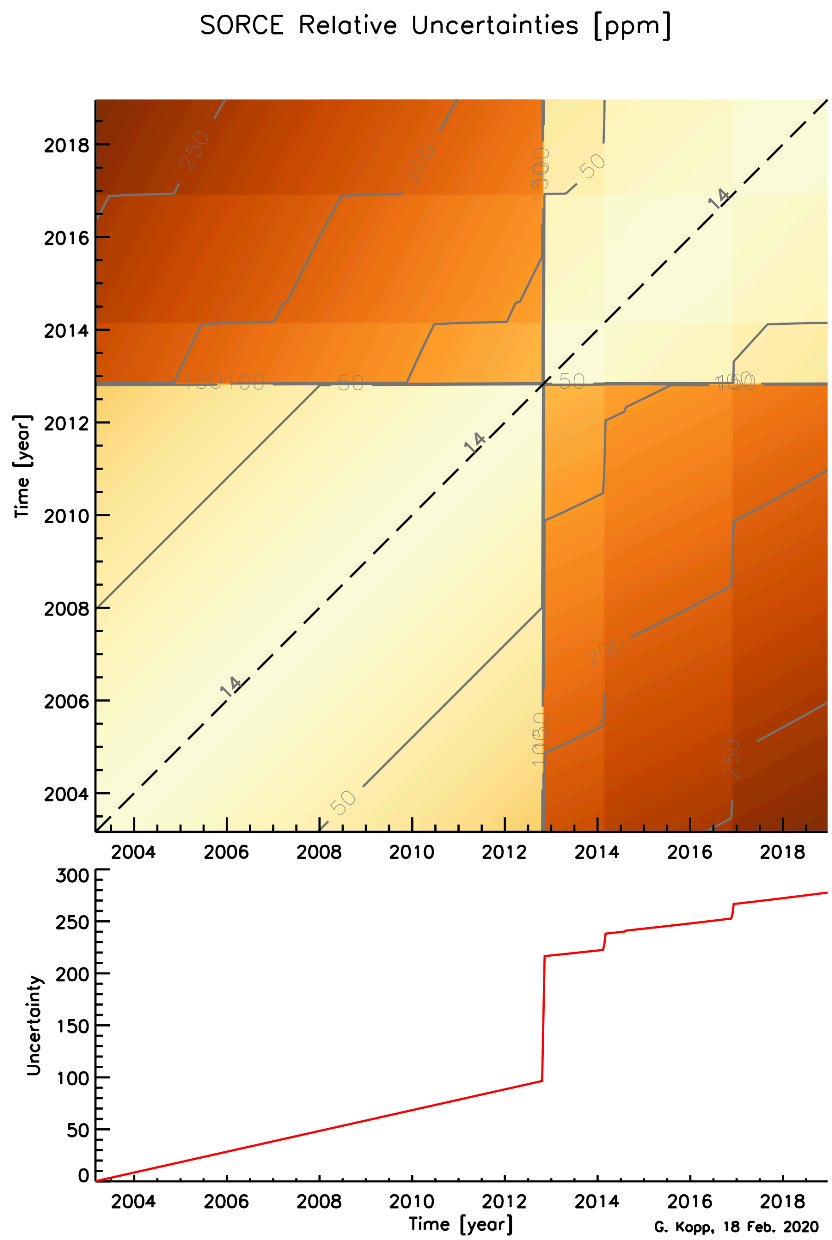

Figure 9: Uncertainties are better represented in two dimensions in order to more easily visualize the relative differences between any two times.

5.2 Measurement Precision

The TIM measurement precision is ~4 ppm based on laboratory and on-orbit noise measurements [7]. This precision, which is better than that of any prior TSI instrument, is achieved by the instrument's phase-sensitive-detection (PSD) algorithms and digital PID-controlled servo-system.

On-orbit measurements near solar minimum give an upper bound on the TIM's precision of 17 ppm [11]. Comparisons with the VIRGO and ACRIM3 from the same time range show those instruments having noise levels a factor of two or more higher.

5.3 STABILITY

Figure 4 shows the net degradation of the TIM's primary cavity with time. This degradation of ~225 ppm is as much as 20x lower than that of any other flight instrument. The plotted degradation, which is fitted to ~15 ppm RMS, as detailed in §4.3.2, is corrected in ground-based data processing.

After corrections, the SORCE/TIM has an estimated stability of 10 ppm yr^{-1}. For comparison, the VIRGO, PREMOS, and ACRIM3 range from ~30 to 60 ppm yr^{-1} [11].

Changes in on-orbit operations caused associated increases in uncertainties. The most dominant are:

1. Power cycling the instrument during each eclipse – Power cycling mandated by spacecraft battery issues commenced on 30 Oct. 2012 and caused ~7°C orbital variations in the Heat Sink temperature (as opposed to the ~0.2°C changes prior). Characterized as a thermally controlled instrument, such temperature changes caused operations outside of the nominal ranges.
2. Day-Only Operation (DO-Op) – The DO-Op mode, which began in early March 2014, caused inconsistent start-up times on each orbit and inconsistent and limited data acquisition, which relied on TDRSS or end-of-orbit ground-station passes. The lower data availability meant less-consistent sampling of solar variability and a higher sensitivity to instrument noise while the irregular power-on times meant lower thermal stability.
3. Brown-out conditions – SORCE brown-outs caused further reductions in measurement times due to more irregular start-up times on each orbit, further lowering data availability and thermal stability.

Applied uncertainty increases due to these primary three operational changes are shown in Figure 8.

6 Validation

6.1 VALIDATION PHILOSOPHY

The TIM is a primary radiometer. It is not cross-calibrated from any other TSI instrument on-orbit. To maintain independence between all TSI instruments, the SORCE/TIM data products do not rely on any other instrument.

This has not been the case with some other TSI instruments. Such cross-calibrations, however, can cause measurement consistency between separate instruments, which can erroneously be considered as validations of each. This has particularly been an issue with the SoHO/VIRGO, which formerly relied on other on-orbit instruments to determine how to allocate internal degradation corrections.

The SORCE/TIM data maintain complete independence from other instruments.

6.2 COMPARISONS WITH OTHER SOLAR MEASUREMENTS

The SORCE/TIM demonstrated better absolute accuracy (by ~10x) and better on-orbit intrinsic stability (by 3 to 20x) than any prior TSI instrument.

6.2.1 Lower TSI value

Initial comparisons after launch between the SORCE/TIM TSI values and other spaceflight data showed the TIM measuring ~0.35 % lower than other instruments. This value turned out to be the more accurate [10], indicating an uncertainty of this magnitude in the accuracies of other instruments. This is a much larger error than those instruments had quoted as their uncertainties and is ~10x higher than the at-launch SORCE/TIM uncertainties.

Concurrent instruments subsequently lowered their values to the SORCE-established value of 1361 W m^{-2}, with the ACRIM3 being the first to do so (in 2011, or eight years after the SORCE launch) and the VIRGO being the most recent (in late 2014). The PREMOS and TCTE instruments helped validate this new, lower value by performing pre-launch end-to-end ground tests on the TSI Radiometer Facility [9]. It is these adjusted values from the pre-SORCE-era VIRGO and ACRIM3 instruments that are plotted in Figure 1.

6.2.2 Comparisons with Other TIM Instruments

The SORCE/TIM overlapped temporally (and temporarily) with the successor TIMs on the TCTE and TSIS-1, as shown in Figure 10. The short-term variations in this plot are due to actual solar-irradiance variations, and, as should be expected, are therefore common-mode between the three instruments despite their different spacecraft platforms and slightly different observing times. The scale differences between the three are small, as indicated in ppm on the right-hand vertical axis, and the three agree within their stated uncertainties. Achieving this level of agreement is a necessary but not sufficient condition of the three independently calibrated instruments' stated uncertainties being realistic and of these values reflecting the actual TSI level at these times.

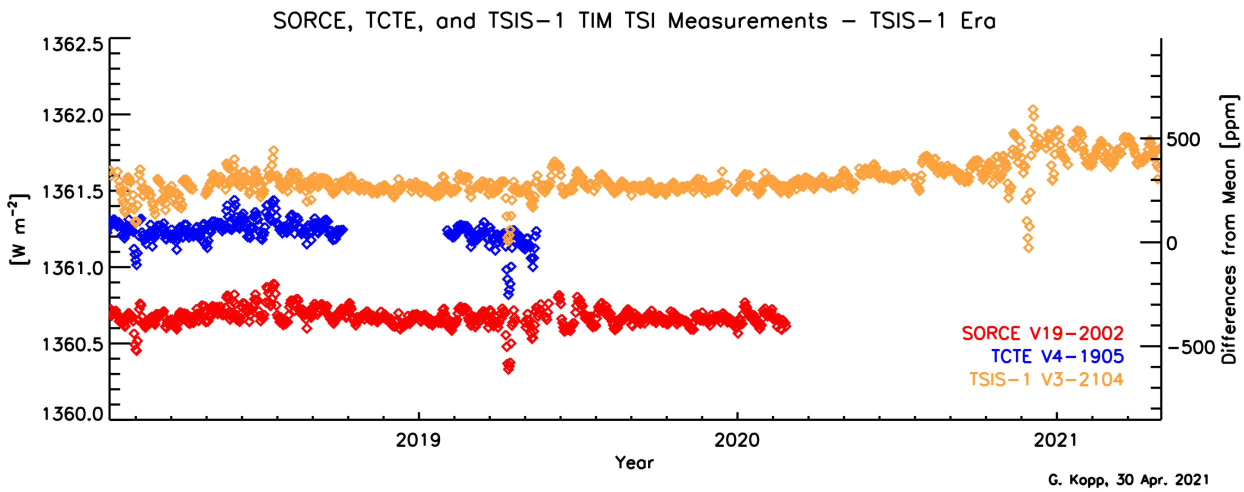

Figure 10: The SORCE, TCTE, and TSIS-1 TIMs overlapped near the end of the SORCE mission. Shown here are the overlapping values during the TSIS-1 era up until the end of the SORCE mission. Each instrument shows similar short-term changes, which are due to variations in solar activity. On an absolute scale, the three instruments agree within their stated uncertainties. These Level-3 data from the three TIMs are not adjusted in any way to each other.

6.2.3 Trends Relative to ACRIM3 and VIRGO

There are nearly linear trends between the SORCE/TIM and the ACRIM3 and VIRGO data, with both decreasing with time relative to the TIM (see Figure 11). The cause of these drifts is not known, as no on-orbit source provides a stability reference at this level.

The SORCE/TIM helped discern artifacts in both the ACRIM3 and the VIRGO TSI instruments. The ACRIM3 showed annual oscillations that were in-phase with the Sun-Earth distance. These were identified during TRF testing of an ACRIM engineering unit as being due to a neglected instrument-temperature correction. Oscillations having time-varying low-frequency periods still exist in the released ACRIM3 data (see [11] and Figure 11). Comparisons of the SORCE/TIM and the VIRGO data show regular 90-day spikes, which are also apparent in Figure 11. These were identified as being due to telemetry issues and subsequent data-processing temperature-correction problems at the times of the 90-day SoHO orbital maneuvers. Kopp [11] also uses comparisons between these three instruments during the 2008 solar minimum, when the TSI had very little variability, to infer estimated noise in the daily values from each instrument. The SORCE/TIM demonstrated approximately 2x lower noise than the VIRGO and ACRIM3 and post-correction stabilities that are estimated to be 3x better than VIRGO and 6x better than ACRIM3.

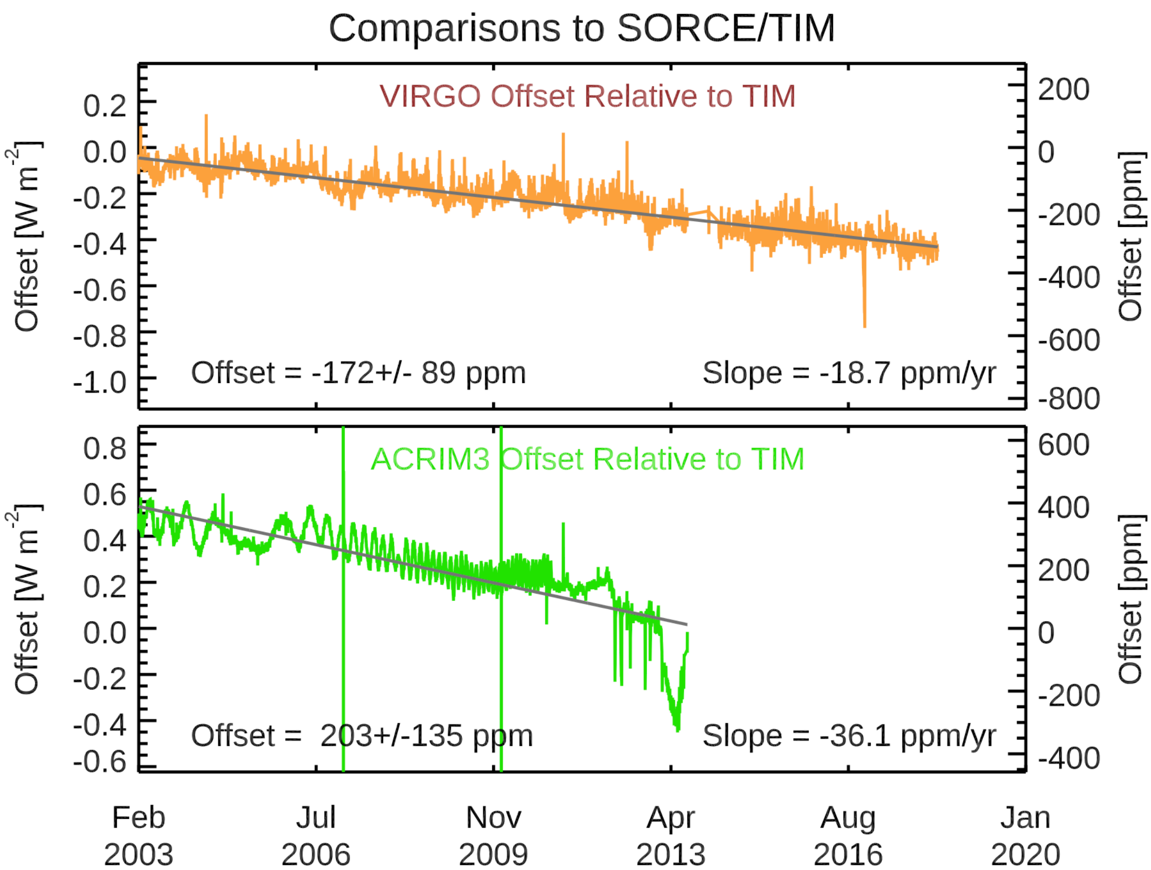

Figure 11: Nearly linear drifts with time between the SORCE/TIM and the ACRIM3 and the VIRGO are not understood.

6.3 COMPARISONS WITH MODELS OF TOTAL SOLAR IRRADIANCE

The two most prominent TSI models are the NRLTSI [1] and the SATIRE model [14]. Comparisons of the TIM data with these two models are shown in Figure 12.

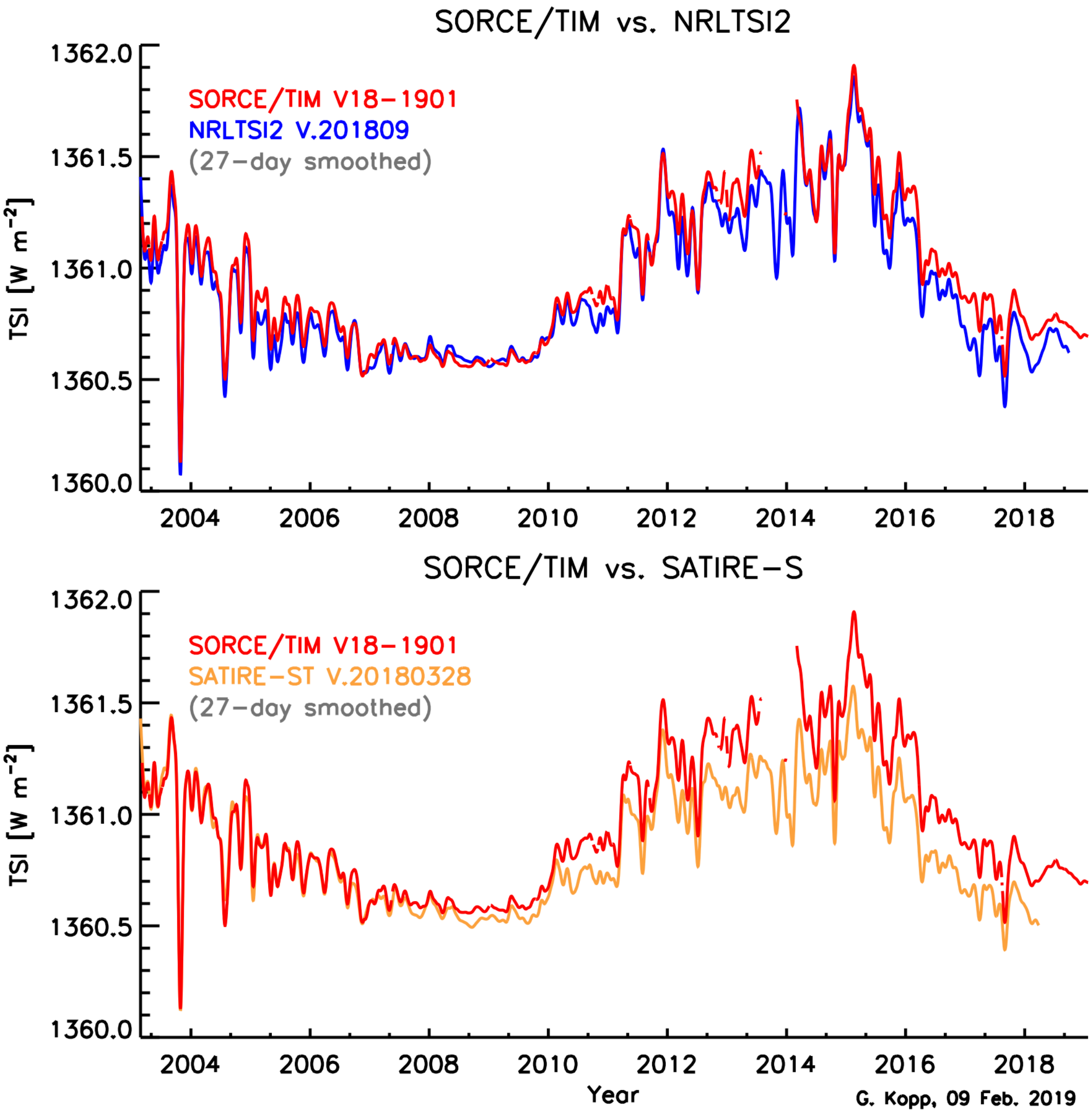

Figure 12: The SORCE/TIM agrees well with both the NRLTSI and the SATIRE irradiance models. The NRLTSI model best matches the TIM long-term trends, whereas the SATIRE model more closely follows the downward VIRGO trend.

7 Data Product Description

7.1 Overview

The SORCE project uses the data-level definitions that are consistent with NASA Earth Science conventions as described in the *Earth Science Reference Handbook – A Guide to NASA's Earth Science Program and Earth Observing Satellite Missions* [available via *http://eospso.nasa.gov/publications/56*]. Data products are archived and made available to the public at the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC).

7.2 DATA-LEVEL DEFINITIONS

The results from the various processing levels are stored in separate database tables. The data from the lower levels are used as inputs when processing the higher data levels. Table 1 provides information about each level for the SORCE/TIM instrument, as defined by the NASA GES DISC (https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels).

Table 1: SORCE/TIM Data Products

Level	Time Cadence	Spectral Resolution	Spectral Coverage	Format
Level 0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g. synchronization frames, communications headers, duplicate data) removed			CCSDS
Level 1	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g. platform ephemeris) computed and appended but not applied to Level 0 data. A portion of Level 1 data is processed to sensor units.			zip-netCDF
Level 2	Derived geophysical variables at the same resolution and location as Level 1 source data			zip-netCDF
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.			ASCII

Only the fully-calibrated Level 3 data product is made available to the scientific community and general public. Lower-level data products (e.g. Level 2) have limited scientific value due to data gaps and instrument artifacts and therefore are not made publicly available. All levels, however, are archived at the NASA GES DISC and can be made available upon special request.

7.3 PRACTICAL ALGORITHM CONSIDERATIONS

The SORCE data processing system accesses calibration data through look-up tables for most needs instead of running the full instrument model. This approach considerably improves ease in analysis and increases the processing speed without affecting the accuracy of the processed data. The individual calibration data look-up tables are stored in separate database tables. Additionally, SORCE instruments and spacecraft telemetry metadata as well as the planning and scheduling data are also stored in database tables. All of these tables are archived at the NASA GES DISC.

7.4 DATA FILTERING

A list of data filtered during processing is shown below. Spacecraft and instrument telemetry are used to determine when data should be flagged or discarded during Level 2 and 3 processing.

Level 2

- DNs from irregular shutter cycling are excluded from further processing

Level 3

- DNs high/low saturated or out of range
- Heater high/low saturated (*allowed after 2012-10-30*)
- Telemetry data gaps
- Spacecraft not closely tracking the Sun
- Spacecraft slewing
- Earth in the field of view
- Moon occulting the Sun
- Gain calibration mode
- Eclipse mode (*used to build the dark model*)
- Manually excluded time period (due to spacecraft or other anomaly)
- Relay Cone set as Active Cone
- Orbit propagated
- TEMP_BC, PCB-1, or PCB-2 thermistor out of range
- Science telemetry repaired
- Unexpected data rate
- Shutter not cycling

Version release notes available on the SORCE website (see Table 1) include more information on spacecraft events that led to filters being applied.

8 Production of Science Data

8.1 Overview

All science data production and management activities are provided by the LASP SORCE Science Data System, which resides at LASP in Boulder, Colorado. The SORCE Science Data System consists of both the hardware and software components necessary to capture, manage, process, analyze, validate, and distribute all science data products.

The Science Data System consists of software applications, running on dedicated processing hardware, which read data from the database, compute scientific results, and write them back to the database. They are then made available to the scientific community through the LASP website and the GES-DISC archive (see Table 2).

Table 2: Data access locations

Location	Role	URL	Content
SORCE Website	Primary	http://lasp.colorado.edu/home/sorce/data/tsi-data/	Full product documentation, release notes and direct downloads
LISIRD Website	Alternative	http://lasp.colorado.edu/lisird/	Solar irradiance data from SORCE and other missions via interactive tools and common interfaces
GES DISC	Archive	https://disc.gsfc.nasa.gov/datasets?project=SORCE	Archived L0 and science products

8.2 DATA MANAGEMENT

All project data are managed within a commercial relational database management system (DBMS). This system maintains and applies version control to all raw instrument and spacecraft data, engineering data products, science data products, calibration data necessary to produce science products, operations plans, and ancillary data. Data security is maintained using standard firewall and system security techniques, while integrity is guaranteed by employing backup/recovery capabilities.

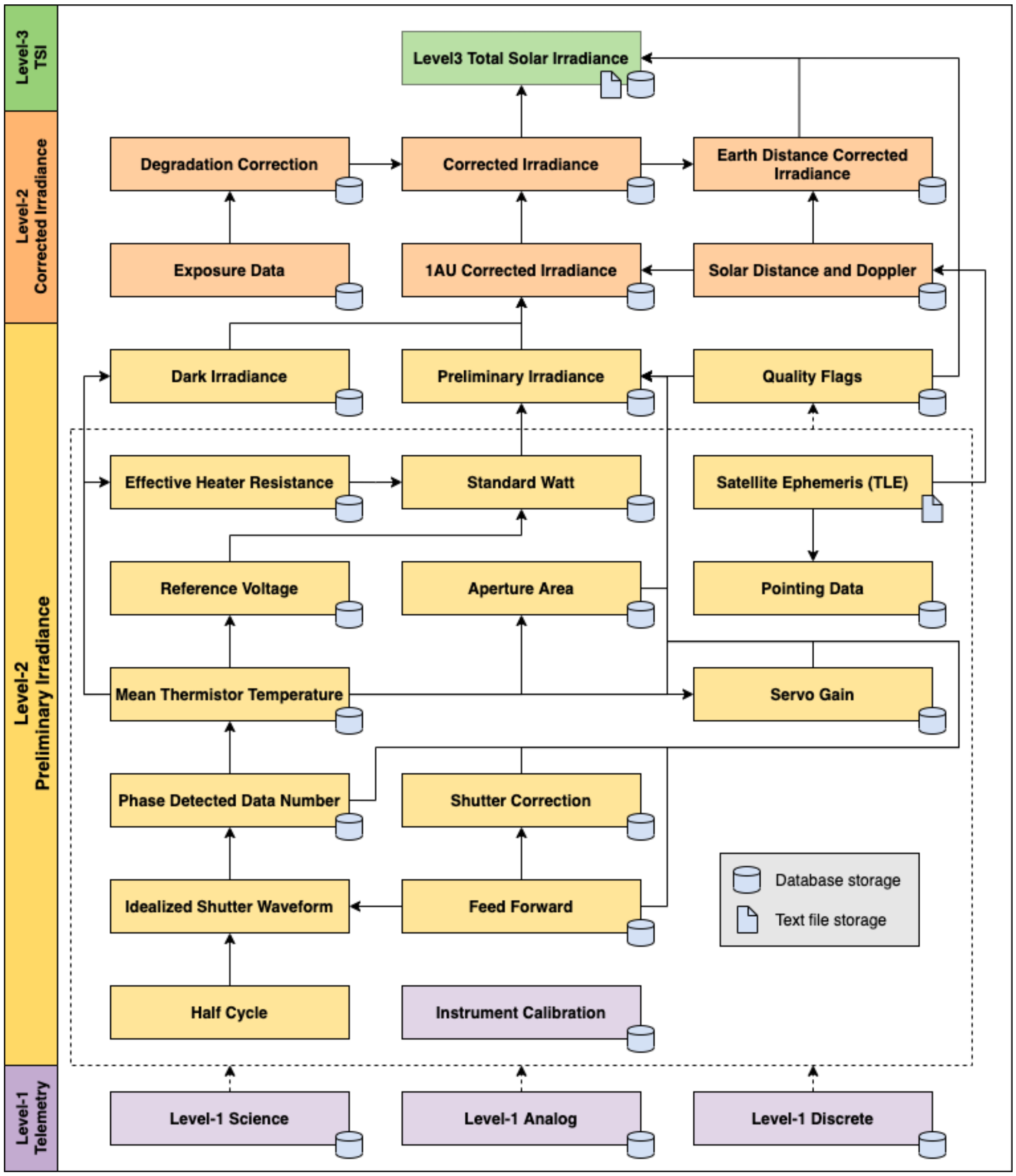

Figure 13: SORCE/TIM data flow for Level-1 through Level-3 calculations

8.3 DATA PROCESSING AND DATA FLOW

The processing of the SORCE/TIM data is based on the measurement equation described in §3. The production of the calibrated TSI from TIM raw data takes the following processing steps:

1. Telemetry unpacking into L1S tables
2. Calculate Preliminary Irradiance (Level 2)
3. Calculate Corrected 1AU & True-Earth Irradiance (Level 2)
4. Calculate Total Solar Irradiance on a fixed cadence (Level 3)

The processing of the ESR uses a phase-detection algorithm to obtain the initial data numbers at a 50-second cadence (half the nominal shutter period). The data flow diagram is shown in Figure 13.

8.4 DATA STRUCTURE

The SORCE Science Data System uses a relational database system in which all telemetry, calibration data, scientific data products, and ancillary information are stored. All data are stored in the database as individual time-referenced points to provide direct and rapid access to each datum received from the spacecraft or instruments or subsequently processed.

The Level-3 TSI data products in the released ascii files are delivered with the format described in the header of those files.

8.5 SOFTWARE CONFIGURATION

The SORCE Science Data System processing code is maintained and archived in a version-controlled code repository. The code selected for SORCE/TIM data production undergoes peer code-reviews using collaborative and iterative code-review software tools, unit testing, and continuous integration testing as part of a systematic production code release process.

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