ACRIM Observations and Variations of Total Solar Irradiance During the Past 25 Years

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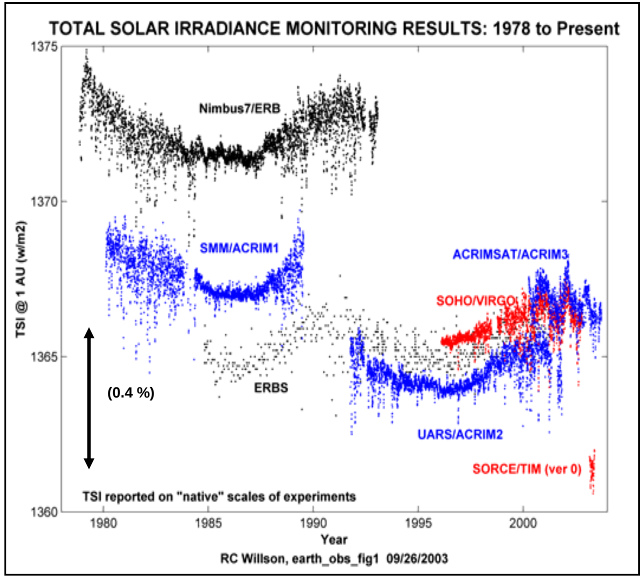
The Total Solar Irradiance (TSI) Observational Database

TSI monitoring has been conducted continuously since 1978 by redundant, overlapping, satellite experiments. Monitoring with highest precision and traceability has been accomplished by satellite experiments employing three-fold sensor redundancy. Three-fold redundancy facilitates self-calibration of the monitoring sensor's degradation with maximum traceability. The series of ACRIM experiments (SMM/ACRIM1, UARS/ACRIM2 and ACRIMSAT/ACRIM3) have this capability. The ACRIM's have been monitoring almost continuously since 1980. Traceability of the results has ranged from < 5 ppm/yr. for ACRIM1 to < 3 ppm/yr. for ACRIM3. The recently launched (2003) SORCE/TIM experiment also employs three-fold sensor redundancy and should provide comparable traceability. The SOHO/VIRGO experiment (1996 to present) has two TSI monitoring instruments (DIARAD and PMO6V) with a total of three sensors of two different types. While this provides some degree of redundancy the different rates of degradation of the two sensor types reduces VIRGO's self-calibration capability and provides less traceability than the three-fold redundant experiments. The VIRGO instruments have experienced some other difficulties that impact their results including permanent calibration changes from an over-range 'cold soak' during the first of two SOHO operational crises (1998) and shutter failure and excessive degradation of PMO6V's monitoring sensor during the mission. The Nimbus7/ERB experiment (1978 to 1993) monitored with moderate precision and traceability, limited by infrequent electrical self-calibration and a lack of sensor redundancy for self-calibration of degradation. Nimbus7/ERB's limited solar observing opportunities (an average of an hour per day) appear to have resulted in minimal degradation of its single sensor. The ERBS's ERBE experiment (1984 – 2000) monitored with limited precision and traceability. ERBS's results exhibit significant uncorrected sensor degradation throughout the record even though its solar observation duty cycle was smaller than Nimbus7/ERB's. The uncertainty of all the experiments to date, in the international system of units (SI), varies amongst them but none has demonstrated a capability significantly smaller than ± 0.1 %.

Critical Characteristics of TSI Monitoring Experiments

Experiment	PI Mode	Observing Frequency	Shutter Calibration Frequency	Electrical Calibration Frequency	Sensor Degradation Calibration	Solar Pointed
Nimbus7/ERB 1978 – 1993	Quasi	3 of 4 days 5 min/LEO orbit	None	2 weeks	None No redundant sensors	No
SMM/ACRIM1 1980 - 1989	Yes	55 min/LEO orbit	1 min. cycle	Continuous	3-fold redundant Monthly Calibration	Yes
ERBS 1984 - 2000	No	5 min. every 14 days	30 sec. cycle	2 weeks	None No redundant sensors	No
UARS/ACRIM2 1991 →	Yes	35 min/LEO orbit	1 min. cycle	Continuous	3-fold redundant Monthly Calibration	Yes
SOHO/VIRGO 1996 →	Yes	Continuous L1 Point Orbit	Occasional using instrument door	Continuous	2-fold redundant SOHO Hiatus issues Degradation Rate issues	Yes
ACRIMSAT/ACRIM3 2000 - 2005	Yes	62 min/LEO orbit	1 min. cycle	Continuous	3-fold redundant Monthly Calibration	Yes
SORCE/TIM 2003 - 2008	Yes	~ 55 min/LEO orbit	100 sec. cycle	Continuous	3-fold redundant Periodic Calibration	Yes

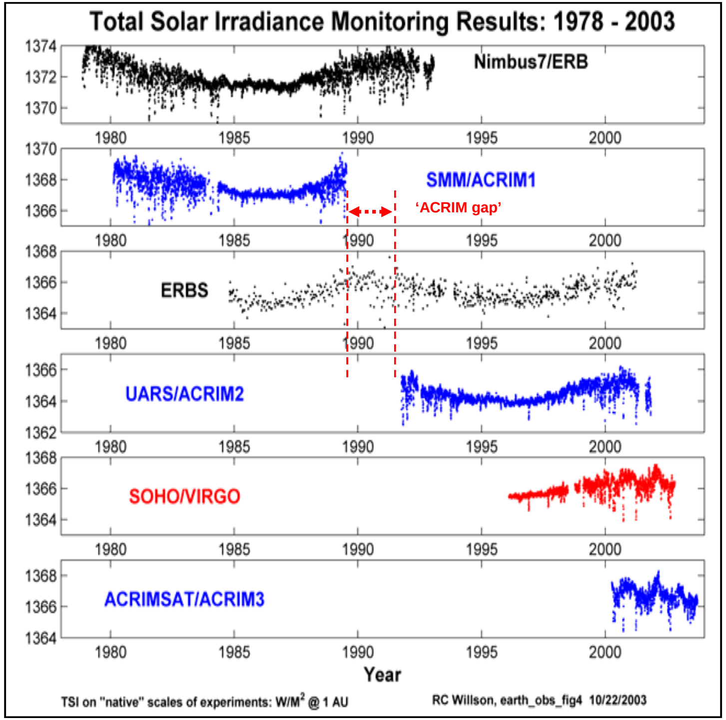
Color	(red)	(yellow)	(cyan)	(blue)
Impact on Observations	Degrading	Sub-optimal	Optimal	Optimum



TSI variability detected during solar cycles 21-23

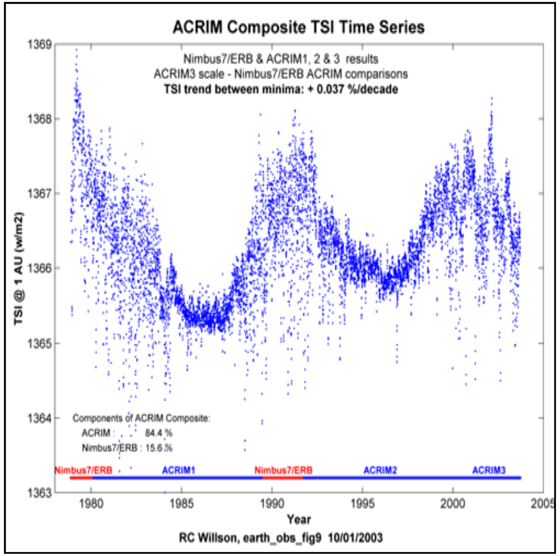
Solar Event	Period	Solar Feature	TSI impact
Solar Rotation	~ 28 days	Sunspots	< 0.3 %
Solar Rotation	~ 28 days	Faculae	< 0.05 %
Sunspot Cycle	~ 11 years	Active Regions & Bright Network	~ 0.1 % (peak-to-peak)
Solar Magnetic Cycle	~ 22 years	Minima-to-minima trend	+ 0.04 %/decade

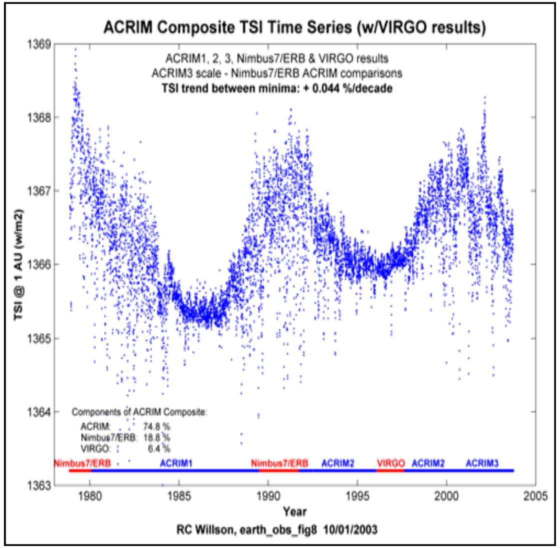
ACRIM Composite TSI



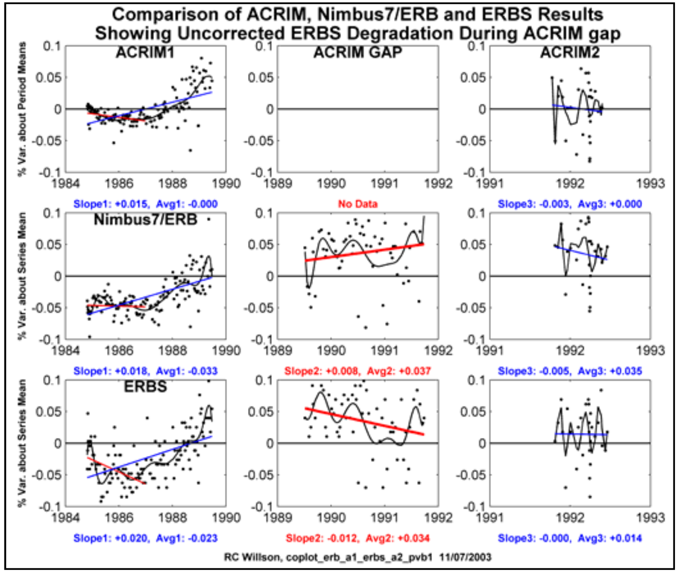
Construction of Composite TSI Time Series from Available TSI Results

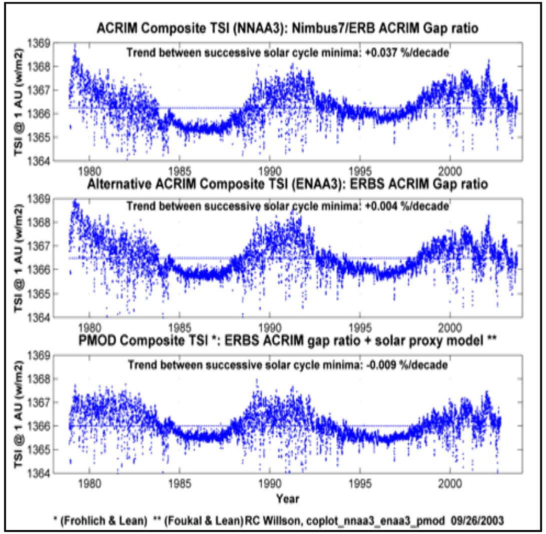
- ACRIM composites use results from Nimbus7/ERB, SMM/ACRIM1, UARS/ACRIM2, ACRIMSAT/ACRIM3 and SOHO/VIRGO experiments
- TSI results from the experiments are related using overlapping comparisons and reported on the 'native scale' of ACRIM3
- Key to constructing solar cycle 21 - 23 time series is relating non-overlapping ACRIM1 and ACRIM2 results across the 'ACRIM gap'
- Nimbus7/ERB and ERBS data overlap the 'gap' and can be used to relate ACRIM1 and ACRIM2 results
- The TSI trend between minima of Solar cycles 21-23 depends on choice of Nimbus7/ERB or ERBS for 'ACRIM gap' relationship
- Nimbus7/ERB comparisons provide the most precise 'ACRIM gap' ratio and yield a + 0.04 %/decade TSI trend between minima
- ERBS comparisons provide a less precise 'ACRIM gap' ratio and yield a negligible trend between minima





The Composite TSI Trend dilemma: Relate ACRIM1 and ACRIM2 results using Nimbus7/ERB or ERBS comparisons ?





Comparison of Nimbus7/ERB, ACRIM and ERBS
(Simultaneous Daily Mean results)

- Avg. slopes of ACRIM, Nimbus7/ERB and ERBS comparable during ACRIM1 and ACRIM2 periods of measurement overlap
- Avg. slopes of Nimbus7/ERB and ERBS are significantly different during the gap in ACRIM observations (1989 – 1991)
- An upward trend in Nimbus7/ERB results during the ACRIM gap is compatible with rising TSI in solar cycle 22
- A downward trend of ERBS results during ACRIM gap is incompatible with rising TSI in solar cycle 22
- ERBS downward trend during ACRIM gap is likely uncorrected sensor degradation and equals the TSI trend difference between Nimbus7/ERB and ERBS-based composite TSI time series

Comparison of ACRIM TSI Composites
using both Nimbus7/ERB and ERBS ACRIM gap ratios
and the PMOD TSI Composite

- The ACRIM composite, based on the Nimbus7/ERB ACRIM gap ratio, yields a + 0.04 %/decade trend between solar cycles 21 – 23 minima
- An alternative ACRIM composite, using the ERBS ACRIM gap ratio, yields a negligible trend between solar cycles 21 – 23 minima
- The PMOD composite, based on the ERBS ACRIM gap ratio, also yields a negligible trend between solar cycles 21 – 23 minima
- The PMOD composite has lower TSI levels at solar maxima

Composite TSI Summary

Comparison of ACRIM and PMOD Composite TSI Approaches		
Composite TSI Time Series	**ACRIM**	**PMOD**
Published results used	**Nimbus7/ERB** **ACRIM1,2 & 3**	**Nimbus7/ERB** **ACRIM1 & 2** **VIRGO**
Modification of published results	**None**	**• Degrades Nimbus7/ERB and ACRIM1 to conform to TSI proxy model during solar cycle 21** **• Decreases Nimbus7/ERB during ACRIM gap to conform to ERBS** **• Uses ACRIM2 results to relate VIRGO data before and after SOHO hiatus in 1998**
Derivation of ACRIM1/ACRIM2 ratio across 'ACRIM gap'	**Nimbus7/ERB comparisons**	**ERBS comparisons**
TSI trend during solar cycle 21-23	**+ 0.04 %/decade**	**No significant trend**

Composite TSI Trend Conclusions

ACRIM composite's + 0.04 %/decade trend results from best use of available TSI data

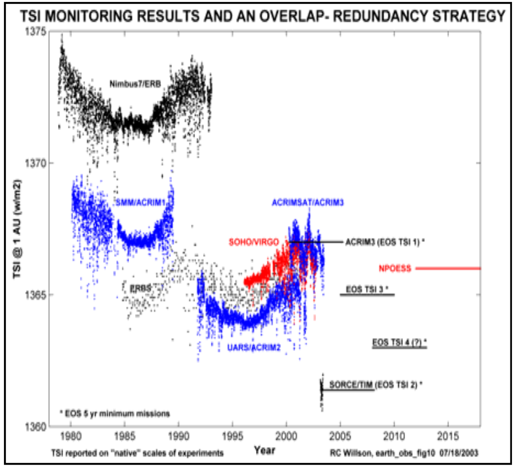
Fewest assumptions
Doesn't rely on predictions of TSI proxy models

PMOD composite's lack of a trend is an artifact of ERBS degradation during the 'ACRIM Gap'

Lower PMOD composite TSI during solar cycle 21 maximum is an artifact of degradation of published ACRIM1 and Nimbus7/ERB results to conform to TSI proxy models

Lower PMOD composite TSI during maxima of solar cycles 22 and 23 is an artifact of degradation of Nimbus7/ERB published results during the ACRIM gap

TSI Monitoring Requirements



TSI Monitoring for a Climate Database: Requirements and Strategy

TSI database to date depends on a redundant overlap strategy with ~ 100 ppm net traceability

TSI observational traceability goal for climate change: ~ 300 ppm on a centennial time scale

Traceability achievable with a redundant overlap strategy and current instrumentation: ~ 3 ppm/yr

SI uncertainty achieved by current satellite instrumentation: not demonstrably less than 1000 ppm

SI uncertainty required for paradigm change in TSI observational strategy: 100 ppm

Overlap Strategy required to provide adequate TSI database traceability with available technology

Redundant satellite experiments required to prevent single point failure in the Overlap Strategy