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ACRIM-gap and TSI trend issue resolved using a surface magnetic flux TSI proxy model

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[1] The ACRIM-gap (1989.5–1991.75) continuity dilemma for satellite TSI observations is resolved by bridging the satellite TSI monitoring gap between ACRIM1 and ACRIM2 results with TSI derived from Krivova et al.'s (2007) proxy model based on variations of the surface distribution of solar magnetic flux. 'Mixed' versions of ACRIM and PMOD TSI composites are constructed with their composites' original values except for the ACRIM gap, where Krivova modeled TSI is used to connect ACRIM1 and ACRIM2 results. Both 'mixed' composites demonstrate a significant TSI increase of 0.033 %/decade between the solar activity minima of 1986 and 1996, comparable to the 0.037 % found in the ACRIM composite. The finding supports the contention of Willson (1997) that the ERBS/ERBE results are flawed by uncorrected degradation during the ACRIM gap and refutes the Nimbus7/ERB ACRIM gap adjustment Fröhlich and Lean (1998) employed in constructing the PMOD.

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1. Introduction

[2] The contiguous ~30 year TSI database of satellite observations extends from late 1978 to the present includes the maxima and minima of three sunspot cycles. This database is comprised of the observations of seven independent experiments: Nimbus7/ERB [*Hoyt et al.*, 1992], SMM/ACRIM1 [*Willson and Hudson*, 1991], ERBS/ERBE [*Lee et al.*, 1995], UARS/ACRIM2 [*Willson*, 1997], SOHO/VIRGO [*Fröhlich et al.*, 1997], ACRIMSAT/ACRIM3 [*Willson and Mordvinov*, 2003] and SORCE/TIM [*Kopp et al.*, 2005] (see Figures S1–S3 of the auxiliary material).[1] None of these independent datasets covers the entire period of observation, thus a composite of the database is necessary to obtain a TSI time series.

[3] There are two principal TSI satellite composite datasets: the ACRIM [*Willson and Mordvinov*, 2003] and the PMOD [*Fröhlich and Lean*, 1998; *Fröhlich*, 2004, 2006] (Figures S4 and S5). Each is compiled using different combinations of the extant satellite TSI database and in the case of PMOD, TSI proxy models. The primary TSI results for these datasets are derived from the TSI monitoring experiments: ACRIM 1, 2 & 3, VIRGO and TIM. These are capable of highly precise observations by virtue of their design which includes self calibration of sensor degradation, frequent electronic self calibration, frequent observations and precise solar pointing. The Nimbus7/ERB and ERBS/ERBE were lower precision experiments designed to meet the less stringent requirements of Earth Radiation Budget modeling. They lacked effective sensor degradation calibration, were infrequently electrically self calibrated, had limited solar observational opportunities and were not solar pointed.

[4] The single greatest challenge in constructing multi-decadal TSI composites is providing continuity across the two year gap between ACRIM1 and ACRIM2 results (1989.5 to 1991.75) when no solar monitoring experiments were deployed (the so-called ACRIM-gap). ACRIM1 and ACRIM2 were intended to initiate a TSI monitoring overlap strategy designed to provide maximum relative precision and traceability through on-orbit comparisons. ACRIM2, launched as part of the UARS payload on the shuttle, was delayed by the Challenger disaster, and eventually deployed about two years after the last data from ACRIM1. The only satellite TSI data obtained during the ACRIM gap were from the lower precision Nimbus7/ERB and ERBS/ERBE experiments.

[5] Bridging the ACRIM-gap using Nimbus7/ERB and ERBS/ERBE is complicated both by their lower quality and because their results demonstrate very different trends during the gap. Nimbus7/ERB TSI increases during rising solar activity levels approaching the solar cycle 22 maximum in 1991, as one would expect from previous observations. ERBS/ERBE TSI decreases significantly during the gap [*Willson*, 1997], contrary to expectation. Consequently, the multi-decadal TSI composites resulting from use of the ERB and ERBE results to bridge the ACRIM gap show significantly different trends in the subsequent time series. Use of the ERB results shows an increase between successive solar minima during 1986–1996 while use of ERBE results show no net change [*Willson and Mordvinov*, 2003]. Resolution of this difference is important for understanding the relative significance of TSI variations and other forcings of climate change.

[6] The explanation for the ACRIM-gap dilemma must be either that ERB experienced an uncorrected sensitivity increase or ERBE experienced uncorrected degradation during the gap. The preponderance of evidence indicates ERBE results are affected by degradation both early in the mission and during the ACRIM-gap [*Willson and Mordvinov*, 2003] (see Figure S3).

[7] An independent test of the effects of the different ACRIM gap assumptions made by the ACRIM and PMOD TSI composite time series constructions can now be made using comparisons of ACRIM, ERB and ERBE data near

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the ACRIM gap with the TSI reconstruction of a new solar proxy model based on surface magnetic flux [*Krivova et al.*, 2007] (hereafter referred to as the KBS07 model).

2. ACRIM and PMOD TSI Composites and the KBS07 TSI Proxy

[8] The ACRIM team uses the Nimbus7/ERB data to 'bridge' the ACRIM gap, convinced it is superior to the ERBS/ERBE data in every respect. The resulting ACRIM TSI composite presents a significant upward trend between successive solar minima in 1986 and 1996 by 0.037 %/decade [*Willson and Mordvinov*, 2003].

[9] The PMOD team uses the sparse ERBS/ERBE database to 'bridge' the ACRIM gap, conforming the higher cadence Nimbus7/ERB data to it by making adjustments they contend are necessary due to sensor sensitivity increases during the gap. PMOD is strongly affected by selective alterations of published Nimbus7/ERB and ACRIM1 results made using Lean's TSI proxy model as a guide. No new instrument evaluations, algorithms or analysis of original data were conducted [*Fröhlich and Lean*, 1998; *Fröhlich*, 2004, 2006] by the PMOD team. The resulting PMOD composite shows no minima-to-minima trend and, not surprisingly, a high degree of conformity with Judith Lean's TSI proxy model.

[10] The large difference in TSI trend between ERB and ERBE during the ACRIM-gap and the corresponding trend difference between the ACRIM and PMOD composites is a compelling argument for invoking an independent method of resolving the controversy. Our approach to this is the creation of two 'mixed' TSI composites that bridge the gap using the KBS07 TSI proxy instead of the ERB or ERBE results. The predictions of this model during the ACRIM gap will then be compared with ERB results to test Fröhlich's PMOD assumption of an ERB sensitivity increase, and with ERBE results to test Willson's ACRIM contention that ERBE suffered uncorrected degradation.

[11] The lack of a trend between the solar minima of 1986 and 1996 in both the TSI proxy reconstruction by Solanki's team and the PMOD composite is widely viewed as evidence of their correct representations of proxy modeling and observations, respectively. This is not a valid conclusion, however, since the PMOD composite is also a theoretical reconstruction, relying heavily on a hypothetical Nimbus7/ERB sensitivity change and Lean's TSI proxy model.

[12] PMOD [*Fröhlich*, 2004] specifically claims Nimbus7/ERB experienced a step function sensitivity change of + 0.034 % on 09/29/89 followed by a gradual upward drift from October 1989 through mid 1992. During the ACRIM-gap this would produce a net sensitivity increase of +0.063 % which Fröhlich corrects by shifting the Nimbus7/ERB record downward to agree with the ERBE results (Figure S7).

[13] If Fröhlich's Nimbus7/ERB correction during the ACRIM-gap is contradicted by KBS07 it would imply that the minima trend agreement between PMOD and KBS07 is coincidental and that both TSI models are wrong on decadal time scales. Thus, instead of comparing KBS07 with PMOD as done by *Krivova et al.* [2007], where it is erroneously claimed to constitute a theory and observation comparison, we compare KBS07 directly with the true TSI satellite observations, that is, with ACRIM1, ACRIM2, Nimbus7/ERB and ERBS/ERBE.

3. ACRIM-KBS07 and PMOD-KBS07 "Mixed Mode" TSI Composites

[14] ACRIM-KBS07 and PMOD-KBS07 'mixed' TSI composites are formed by using original ACRIM and PMOD values outside the ACRIM gap and KBS07 to bridge the gap. KBS07 ACRIM gap data for the period 1988.5 to 1993.75 provides one year comparisons with ACRIM1 (1988.5–1989.5) and ACRIM2 (1992.75-1993.75). The overlaps for ACRIM1, ACRIM2 and KBS07 are shown in Figures 1a and 1b. The KBS07 model (gray curve) and the actual satellite data (black dots) match closely over these periods. The resulting ACRIM1-KBSO7-ACRIM2 composite from 1980 to 2002 shown in Figure 1c exhibits a TSI trend between successive minima of + 0.033 %/decade, just 0.004 less than the trend found by the ACRIM composite.

[15] The resulting 'mixed' TSI composites ACRIM-KBS07 and PMOD-KBS07 are shown as Figure 1d. A trend in TSI between successive minima of 0.033 (± 0.004) %/decade is found in both composites.

[16] The trend agreement of these 'mixed' composites disagrees with the absence of a minima trend in the KBS07 model and the PMOD composite. It implies: (1) that the ACRIM gap re-calibration of Nimbus7/ERB by the PMOD is incorrect; (2) that the PMOD TSI trend is incorrect; (3) that TSI proxies are not reliable on decadal and longer time scales.

4. Comparison of Nimbus7/ERB and ERBS/ERBE With KBS07 During the ACRIM Gap

[17] Comparisons of the Nimbus7/ERB and ERBS/ERBE TSI satellite records with KBS07 during the same 1988.5 to 1993.75 ACRIM gap and overlap periods are shown as Figure 2. This comparison is important because it provides independent evaluations of (1) the 'sensitivity drift' corrections applied by Fröhlich to the Nimbus7/ERB data in constructing the PMOD composite and (2) the ERBS/ERBE 'uncorrected degradation' used by Willson as the rationale for using the Nimbus7/ERB ACRIM gap results for the ACRIM composite.

[18] The relative difference between Nimbus7/ERB and KBS07 during the ACRIM gap (Figure 2a) changed by 0.023 % (+0.31 W/m^2) across the gap, significantly less than the 0.063 % (0.86 W/m^2) assessed by Fröhlich in the PMOD composite. Additionally there is a virtually insignificant ERB-KBS07 TSI difference of 0.006 % (+0.08 W/m^2) for the one year intervals before and after the 29th of September 1989, the date of Fröhlich's proposed Nimbus7/ERB 'glitch'. Clearly Fröhlich's step function sensitivity shift of 0.034 % (±0.47 W/m^2) that day is not supported by the KBS07 proxy model.

[19] We can apply the KBS07 model as an independent test of ERBS/ERBE uncorrected degradation during the ACRIM gap [*Willson*, 1997; *Willson and Mordvinov*, 2003]. The ERBE-KBS07 ratio changes by −0.034 % (−0.47 W/m^2) between the pre- and post ACRIM gap comparisons (Figure 2b). This is approximately equal to

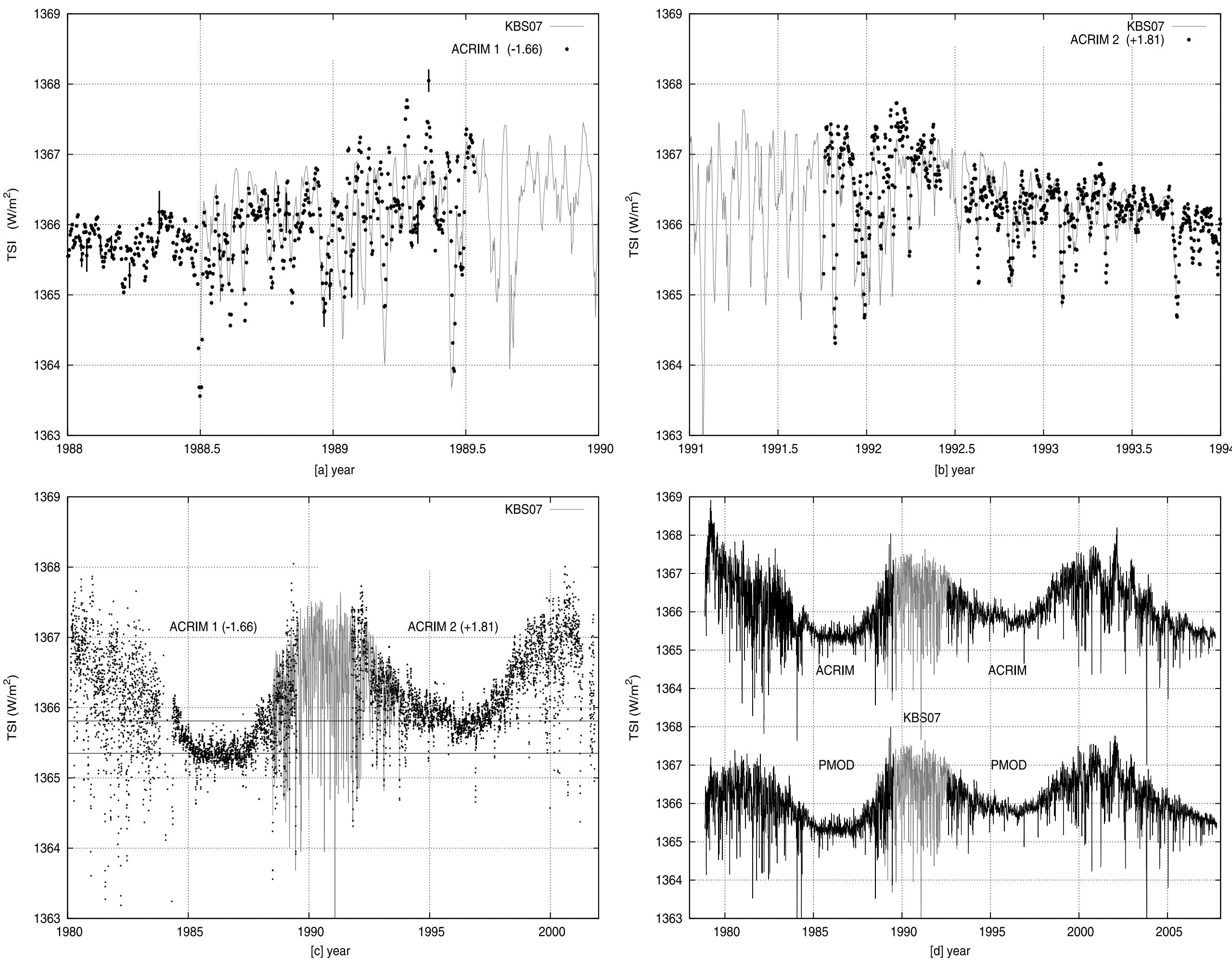

Figure 1. Composite of (a) ACRIM1, (b)ACRIM2 (black dots) and the TSI proxy model (gray lines). (c) Figures 1a and 1b are expanded views during the overlapping periods. (d) 'Mixed' TSI composites ACRIM-KBS07 and PMOD-KBS07 formed using KBS07 (gray line) to fill the ACRIM-gap period. A TSI trend between successive minima of +0.033 (±0.004)%/decade is found for both mixed composites.

the trend difference between ACRIM and PMOD composites during solar cycles 21–23, within computational certainty, and clearly supports the contention of uncorrected ERBE degradation during the ACRIM gap.

[20] The ERB and ERBE comparisons with KBS07 provide strong, independent evidence contradicting the claims of *Lee et al.* [1995], *Fröhlich* [2004, 2006] and *Fröhlich and Lean* [1998] that (1) ERBS/ERBE is the most reliable comparison database during the ACRIM gap; (2) that Nimbus7/ERB experienced a large increase of sensitivity during the ACRIM-Gap and (3) that Lean's proxy reconstruction can faithfully reconstruct the TSI.

5. Conclusions

[21] An independent evaluation of the ACRIM-gap problem has been made using the recently published TSI proxy model of *Krivova et al.* [2007]. Within the uncertainty of the model we have concluded that the data support the view that TSI increased significantly (by about 0.033 %) between the successive solar minima of 1986 and 1996, confirming the trend found by the ACRIM TSI composite and contradicting the absence of a TSI trend in the PMOD and the KBS07 proxy model.

[22] The corrections made by Fröhlich to the Nimbus7/ERB results during the ACRIM-gap for the PMOD composite are clearly not supported. It should be pointed out that the Nimbus7/ERB science team did not detect Fröhlich's proposed sensitivity changes during a thorough re-evaluation of the experiment near the end of its mission [*Hoyt et al.*, 1992] and have recently rejected them explicitly (D. V. Hoyt, personal communication, 2008).

[23] On a decadal scale, outside the ACRIM-gap period, KBS07 fails to reproduce the satellite data pattern and trend. A direct comparison with ACRIM1 and ACRIM2 shows that KBS07 underestimates the amplitude of the solar cycle 21–22 and overestimates the amplitude of the solar cycle 22–23 (Figure S8). A direct comparison of both the PMOD composite and the ACRIM2 record with KBS07 from 1992.5 to 2001 show significant upward trends with slopes of 0.078 and 0.11 Wm^{-2}/yr, respectively, confirming an upward trend that is missing in the KBS07 proxy record (Figure S9). Both findings suggest that on a decadal scale KBS07 should be significantly corrected downward during

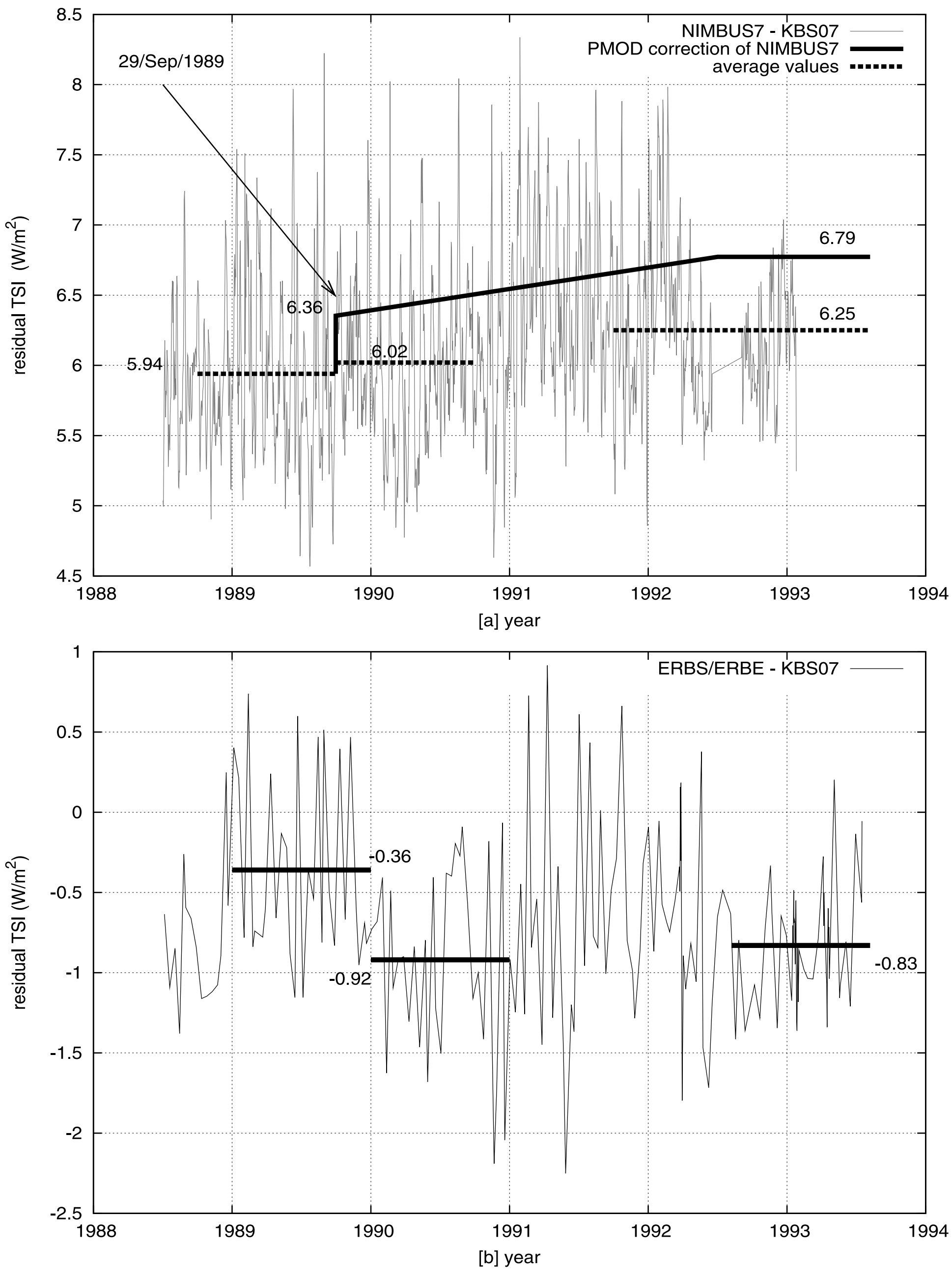

Figure 2. (a) TSI difference between NIMBUS7/ERB and the KBS07 proxy during the ACRIM gap. Dashed lines are averages of the difference. The black line shows Fröhlich's proposed corrections to Nimbus7/ERB results. (b) TSI difference between ERBS/ERBE and the KBS07 proxy during the ACRIM gap. Black lines are averages of the difference.

the solar cycle 21–22 minimum and upward during solar cycle 22–23, to make it compatible with the unquestioned TSI observations. Consequently, a corrected KBS07 proxy model is expected to reproduce the upward trend of the ACRIM TSI composite between the 1986 and 1996 TSI minima.

[24] This finding has evident repercussions for climate change and solar physics. Increasing TSI between 1980 and 2000 could have contributed significantly to global warming during the last three decades [*Scafetta and West*, 2007, 2008]. Current climate models [*Intergovernmental Panel on Climate Change*, 2007] have assumed that the TSI did not vary significantly during the last 30 years and have therefore underestimated the solar contribution and overestimated the anthropogenic contribution to global warming.

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