



# 1984-2003, Earth Radiation Budget Satellite (ERBS)/Earth Radiation Budget Experiment (ERBE) Total Solar Irradiance (TSI) measurements

**Robert B. Lee III<sup>a</sup> and Robert S. Wilson<sup>b</sup>**

**<sup>a</sup>Atmospheric Sciences, NASA Langley Research Center, Hampton, Virginia  
23681-0001**

**<sup>b</sup>Science Applications International Corporation (SAIC), One Enterprise  
Pkwy, Suite 300, Hampton, Virginia 23666**



# 1984-2003, Earth Radiation Budget Satellite (ERBS)/Earth Radiation Budget Experiment (ERBE) Total Solar Irradiance (TSI) measurements

- THE ERBS/ERBE SOLAR MONITOR IS OPERATING NOMINALLY, AND PRODUCING EXCELLENT TSI MEASUREMENTS.
- The ERBS SPACECRAFT & ERBE SOLAR MONITOR IS EXPECTED TO BE OPERATIONAL THROUGH 2009, SUNSPOT MAXIMUM.



# 1984-2003, Earth Radiation Budget Satellite (ERBS)/Earth Radiation Budget Experiment (ERBE) Total Solar Irradiance (TSI) measurements

HOWEVER, THE ERBS/ERBE  
SOLAR MONITOR TSI  
PROCESSING HAS BEEN  
STOPPED DUE TO THE LOST OF  
FUNDING.



# SUMMARY

**1365  $\text{Wm}^{-2}$  IS MEAN VALUE OF TSI DURING PERIODS OF MINIMUM SOLAR MAGNETIC ACTIVITY.**

**1.4  $\text{Wm}^{-2}$  [0.1 %] IS THE MAGNITUDE OF THE 11-YEAR SUNSPOT CYCLE], LONG-TERM TSI VARIABILITY COMPONENT.**



# OUTLINE

**TSI CHARACTERIZATIONS USING SOLAR  
MAGNETIC INDICES.**

**PRESENTATION OF LONG-TERM  
SPACECRAFT TSI DATA SETS.**

**ANALYSES OF TSI DATA SETS.**



# DATA REDUCTION

- LOW FREQUENCY OF ERBS/ERBE SOLAR MONITOR TOTAL SOLAR IRRADIANCE [TSI] MEASUREMENTS ARE IDEAL FOR LONG-TERM CLIMATE STUDIES BECAUSE OF THE ABSENCE OF LONG-TERM SENSOR DEGRADATION.
- EACH TOTAL SOLAR IRRADIANCE VALUE IS A 3 MINUTE AVERAGE OF 2-3 MEASUREMENTS.
- TSI MEASUREMENTS ARE OBTAINED AT LEAST EVERY 14 DAYS ON A WEDNESDAY.



# ERBS/ERBE SOLAR MONITOR RAW TSI DATA

CALENDAR	TIME	TSI	TSI	TSI	TSI	TSI	TSI	ANGLE	BAFFLE	BAFFLE
YEAR/ MONTH/ DAY	HOURS/ MINUTES/ SECONDS	MEASUREMENT SUN	SUN SHUTTER OPENED	MEASUREMENT BEFORE REFERENCE SHUTTER CLOSED	MEASUREMENT BEFORE REFERENCE SHUTTER CLOSED	MEASUREMENT AFTER REFERENCE SHUTTER CLOSED	MEASUREMENT AFTER REFERENCE SHUTTER CLOSED	BETWEEN SUN & ACR OPTICAL AXIS	TEMP CELSIUS	TEMP CELSIUS
YY:MM:DD	HH:MM:SS		STD		STD		STD			
Y/M/D	H:MI:S	COUNTS	COUNTS	COUNTS	COUNTS	COUNTS	COUNTS	DEGREES	DEGREES	DEGREES
Y/M/D	H:MI:S	CX	SDCX	RC1	SDRC1	RC2	SDRC2	AGO	TB	TA
841101	84312	4319.6	3	7268.6	2.8	7263.4	2.9	3.3	19.79	19.6
841105	61944	4304.2	3	7265.2	2.4	7266	1.2	2.33	19.93	20.11
841228	83512	4236.4	3	7265	1.6	7263.2	2.9	1.93	19.44	19.67
850123	16656	4247.2	1.5	7266.6	0.9	7266.8	1.3	1.14	19.45	19.62
850206	13214	4261.2	2.8	7267.4	1.5	7266.4	2.6	1.08	19.25	19.48
850220	13328	4108.4	4.3	7161.8	3.2	7162	3.6	2.75	29.26	29.38
850220	13536	4102.4	4	7161.8	3.1	7161.2	2.4	0.86	29.28	29.4
850220	13744	4110.4	2.9	7160.6	3.8	7161.2	3.3	3.76	29.31	29.42
850306	111024	4301.8	1.6	7261.2	1.8	7259.8	0.8	1.11	19.74	19.94
850320	12574	4339.2	1.9	7265.2	2.6	7266.2	1.3	0.8	19.47	19.64
850403	173008	4318.6	2.3	7231.8	1.9	7232	1.4	2.28	22.68	22.79
850403	173216	4317.8	1.8	7232	1.4	7231.6	1.5	2.06	22.69	22.8
850417	135648	4416.2	3.7	7274.4	3.6	7274.8	1.8	0.46	18.61	18.81
850051	12494	4421	1.9	7260	1.2	7258.8	1.1	1.25	19.94	20.14
850058	12400	4428	1.9	7257.8	1.6	7255.6	1.5	0.89	20.21	20.4
850529	123928	4479.6	2.7	7267	1.7	7267.2	1.5	1.74	19.41	19.58
850618	120936	4427	3.2	7222.2	2	7222.2	2	3.23	23.54	23.64
850618	121144	4421.2	1.5	7223	1.2	7221.8	1.5	1.02	23.56	23.64
850626	121040	4495.4	4	7265.6	2.8	7266	1.2	1.87	19.48	19.65
850710	123543	4498.2	1.5	7265	1.4	7263.8	1.3	2.2	19.45	19.65
850724	121455	4483.2	1.9	7261.4	1.5	7261	1.2	1.62	19.77	19.97
850807	140447	4491.6	2.9	7271.2	3.3	7271.2	2.9	3.7	19	19.19
850821	115823	4341.6	2.7	7189	1.9	7187.8	1.9	4.72	26.83	26.94
850821	120031	4331.8	2.6	7188.6	1.5	7188	1.2	1.54	26.86	26.97
850821	120239	4331.2	2.3	7187.4	2.7	7187.2	1.5	1.91	26.89	26.99
850904	133007	4431.2	3.5	7261.8	2.8	7262.8	1.5	2.04	19.71	19.88
850918	121735	4409.8	1.9	7264.6	2.5	7263.6	1.5	2.97	19.64	19.83
851002	133943	4316	1.9	7223.8	1.1	7224.2	1.3	3.89	23.34	23.46
851002	134151	4306	2.1	7224	2	7223	1.9	0.83	23.37	23.51
851016	131543	4353.6	2.3	7267.4	2.1	7267.6	1.5	2.88	19.19	19.4
851020	175751	4361.6	3.9	7278.2	3	7277.2	2.4	3.29	18.35	18.56
851031	120447	4305.8	3.2	7260	3.1	7261.2	1.5	2.78	20.06	20.21
851113	130951	4291	3.4	7263.6	3	7263.6	2.9	3.66	19.67	19.83
851127	133527	4264.2	1.5	7262.4	1.5	7263	1.9	2.33	19.71	19.89
851218	114711	4171.4	2.2	7218.8	1.5	7217.6	1.7	4.05	23.87	23.97
851218	114919	4159.2	2.3	7218.4	1.5	7217.4	1.1	0.53	23.91	24
851225	144415	4231	2	7261	1.6	7260.2	1.3	1.72	19.93	20.11
860108	114119	4244	3.5	7267.2	3.5	7268	3.1	2.88	19.44	19.61
860122	125631	4242.8	4	7262.8	3.7	7262.8	3.2	2.67	19.82	19.98
860215	121039	4228.6	1.8	7234.6	1.8	7234	1.2	3.7	22.54	22.67
860215	121247	4219.6	1.8	7233.8	1.8	7232.4	1.8	0.95	22.57	22.7
860305	124831	4310.4	2.5	7261	1.6	7260.2	1.5	4.37	19.96	20.14
860305	125039	4299.8	1.9	7259.2	1.5	7258.2	2.8	2.54	20.01	20.2
860402	123927	4310.6	1.8	7227.2	1.9	7227.6	1.3	3.55	23.29	23.37
860402	124239	4308.4	1.8	7226.4	1.5	7227.4	1.7	2.79	23.31	23.39
860430	124831	4416	2.1	7259.2	2.2	7258	1.9	0.8	20.14	20.32
860514	122639	4457.8	2.9	7264	1.4	7262.6	0.9	4.09	19.74	19.94
860528	123647	4487	3.7	7267	2.3	7266.4	3.6	4.94	19.48	19.65
860528	123855	4477.6	1.7	7266.2	1.5	7266.2	1.3	2.32	19.5	19.66
860604	121839	4437.2	2.3	7235.8	1.8	7236.8	1.1	3.05	22.47	22.57
860604	122047	4434	1.9	7236	1.4	7235.8	1.8	1.49	22.48	22.58
860619	123159	4460.2	2.2	7238	2.2	7237	1.9	5.14	22.23	22.34



# SENSOR-LEVEL, ACTIVE CAVITY RADIOMETER DATA REDUCTION EQUATION

$$T_{SI}_{ins} = (r_{E-S})^2 \{ (R)(\alpha)(A_{PA}) \}^{-1} \times \\ \{ (V_C^2 - V_O^2) + \sigma(CF)(T_C^4 - T_O^4) + \Sigma P_i \}$$

WHERE:

$r_{E-S}$  = EARTH-SUN DISTANCE, AU

$R$  = ACTIVE CAVITY HEATER RESISTANCE, OHMS

$\alpha$  = ACTIVE CAVITY ABSORPTANCE

$A_{PA}$  = PRIMARY APERTURE (PA) AREA

$V_C$  = ACTIVE CAVITY HEATER VOLTAGE, CLOSED SHUTTER

$V_O$  = ACTIVE CAVITY HEATER VOLTAGE, OPENED SHUTTER

$\sigma$  =  $5.6697 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-1}$

$CF$  = PA TO SECONDARY APERTURE CONFIG. FACTOR

$T_C$  = PRIMARY CAVITY TEMPERATURE, CLOSED SHUTTER

$T_O$  = PRIMARY CAVITY TEMPERATURE, OPENED SHUTTER

$P_i$  = POWER EXCHANGES OF CAVITY WITH SURROUNDINGS





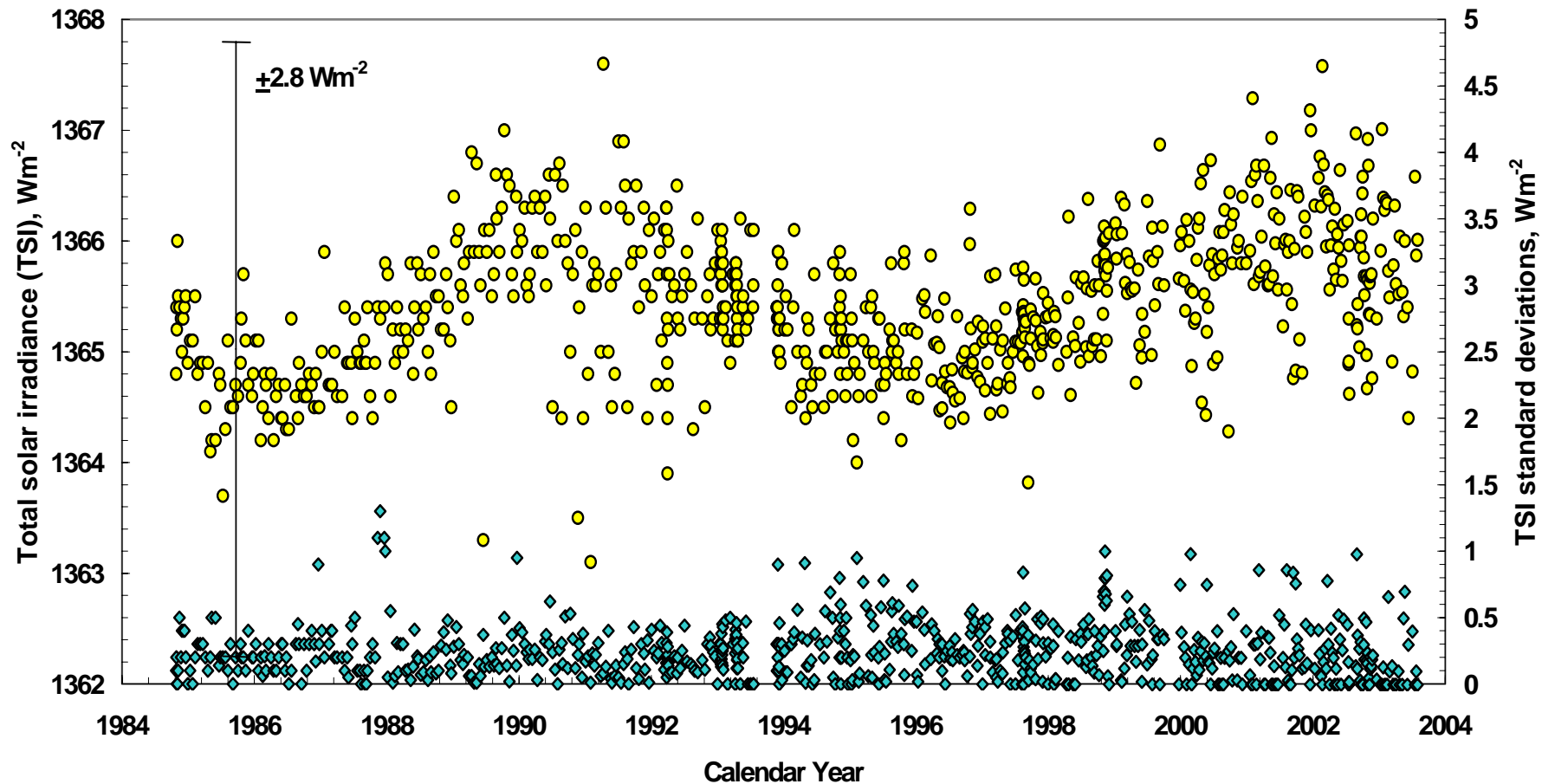
# PRIMARY TSI CORRECTIONS

- NOMALIZATION TO MEAN EARTH-SUN DISTANCE [1AU],  $\pm 3.34\%$ .
- LW FLUX LOSSES OUT OF SECONDARY APERTURE WHEN SHUTTER IS OPENED, 0.44%.
- $\Sigma P_i$ ; ;  $\pm 0.02\%$ .



# ERBE SOLAR MONITOR TOTAL SOLAR IRRADIANCE (TSI) MEASUREMENTS FROM THE ERBS SPACECRAFT

● Measurements ◆ Meas. Std. Dev.





**1365 Wm<sup>-2</sup> APPEARS  
TO BE THE BEST  
VALUE OF TSI  
DURING PERIODS OF  
MINIMUM SOLAR  
MAGNETIC ACTIVITY.**



**- 1.4 Wm<sup>-2</sup> [0.1 %] IS THE  
MAGNITUDE OF THE 11-YEAR  
SUNSPOT CYCLE], LONG-  
TERM TSI VARIABILITY  
COMPONENT.**



# ERBS/ERBE SOLAR MONITOR TSI DATA SET

- AFTER 1<sup>ST</sup> 6 MONTHS IN ORBIT, NO INSTRUMENT DRIFTS OR SHIFTS.
- LONGEST CONTINUOUS TSI DATA SET [19 YEARS, 2 COMPLETE SUNSPOT CYCLES] AVAILABLE FOR LONG-TERM TSI VARIABILITY STUDIES.
- ONLY DATA SET THAT CAN BE USED TO IDENTIFY TSI VARIABILITY COMPONENTS WITH PERIODS LONGER THAN 11 YEARS.
- ONLY DATA SET THAT DID NOT REQUIRE CORRECTIONS FOR LONG-TERM INSTRUMENT DEGRADATION.



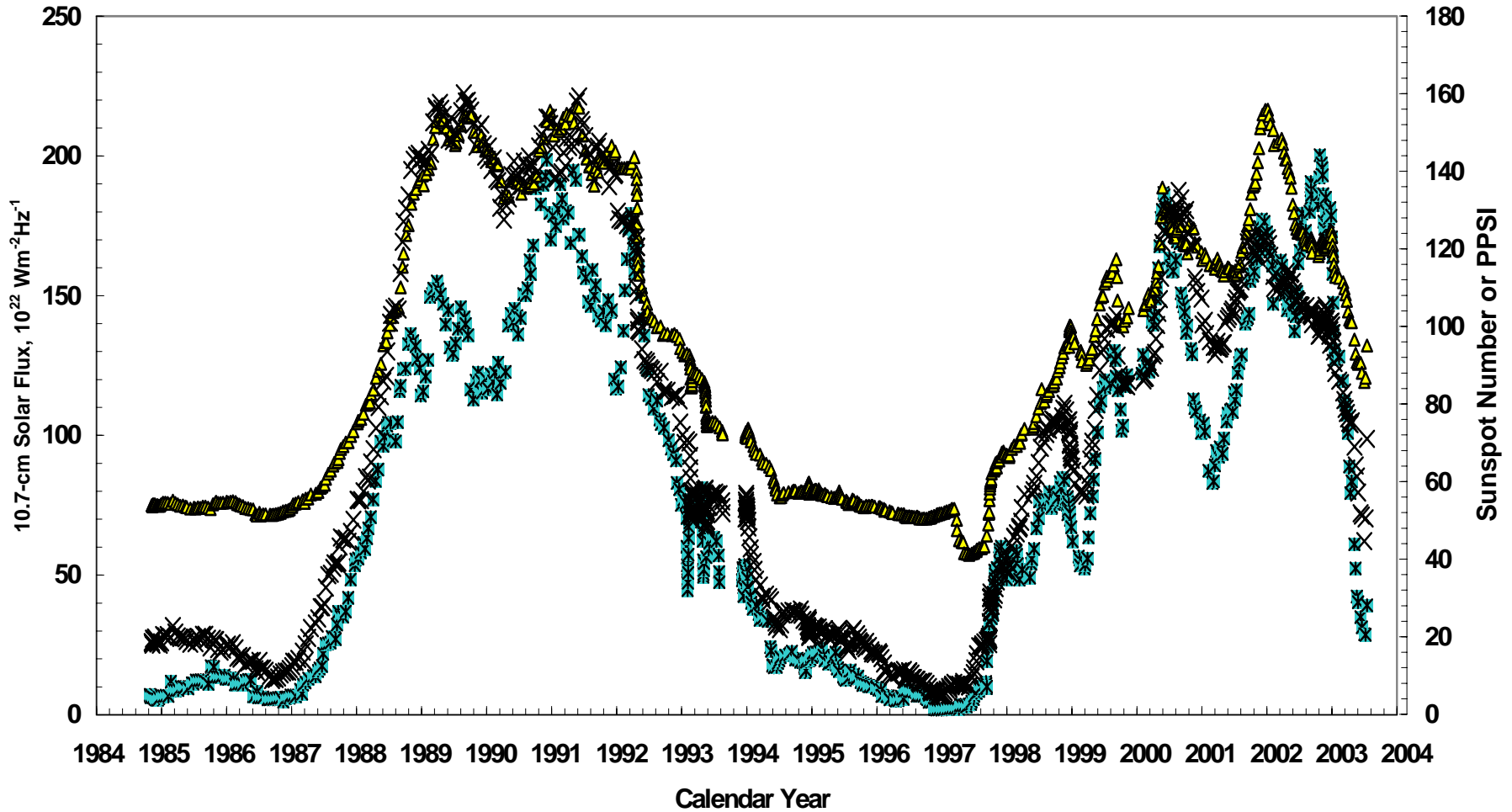
**LONG-TERM, TSI BRIGHTENING  
IS ATTRIBUTED TO FACULAE.**

**SHORT-TERM, TSI DARKENING  
IS ASSOCIATED WITH  
SUNSPOTS.**



# INDICES OF SOLAR MAGNETIC ACTIVITY

✱ Prompt Photometric Sunspot Index (PPSI) ▲ F10.7-cm Solar Flux ✕ Sunspot Number





# REGRESSION FIT MODEL

THE MODEL IS DERIVED FROM MULTI-REGRESSION ANALYSIS OF THE MARCH 1985 TO AUGUST 1989 ERBS IRRADIANCE MEASUREMENTS, THE CORRESPONDING PHOTOMETRIC SUNSPOT INDEX (PSI, SUNSPOT DARKENING), AND THE 10.7-CM SOLAR RADIO FLUX (F10,FACULAE BRIGHTENING) VALUES. THE RESULTING IRRADIANCE REGRESSION FIT  $I^*$ , ARE

$$I_{ERBS} = 1362.9 - (705.3 \times PPSI) + [0.02953 \times 10^{22} (F10)] - [0.00005 \times 10^{44}(F10)^2]$$

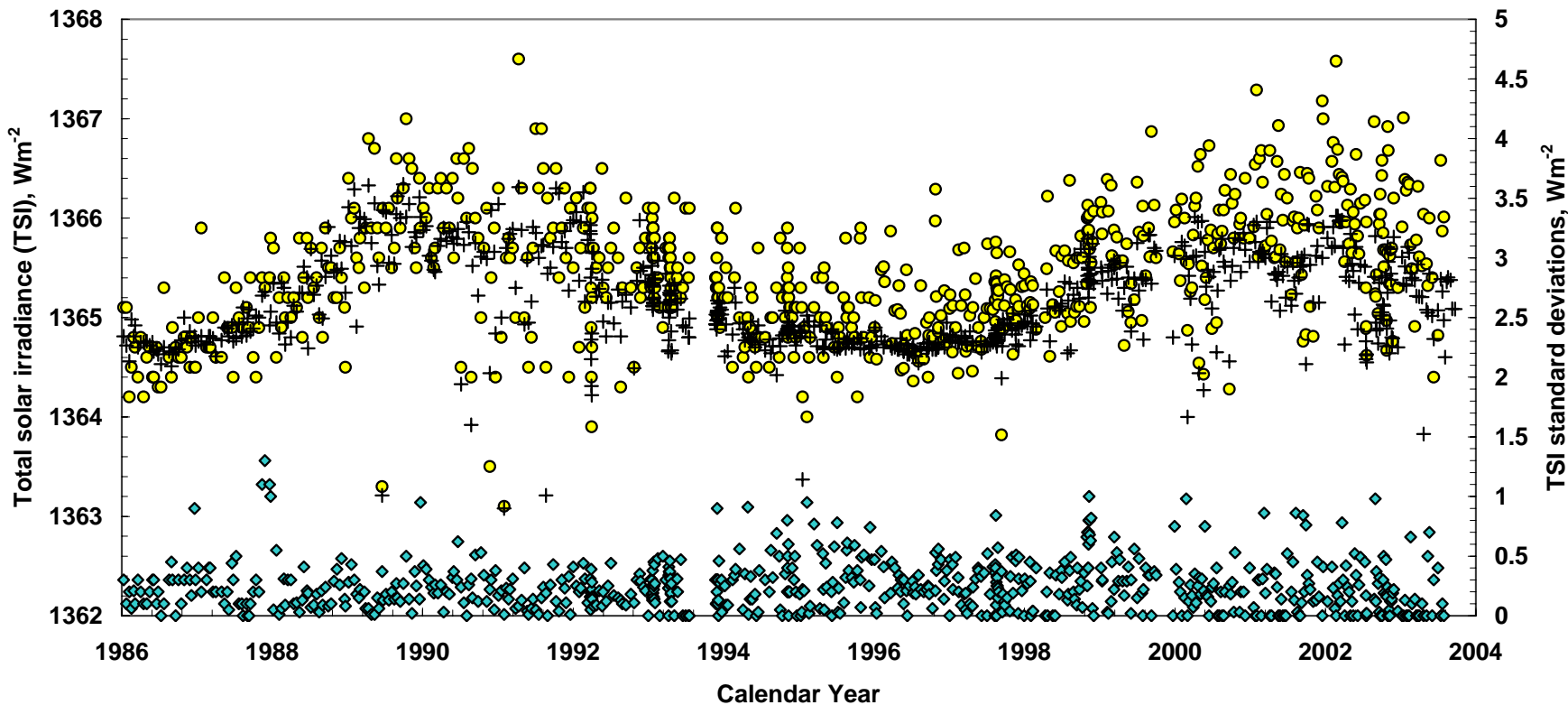
WHERE F10 IS EXPRESSED IN SOLAR FLUX UNITS (1 sfu= $10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$ ) AND PPSI IS EXPRESSED IN UNITS OF  $10^{-5} \text{ Wm}^{-2}$ .





# ERBE SOLAR MONITOR TOTAL SOLAR IRRADIANCE (TSI) MEASUREMENTS FROM THE ERBS SPACECRAFT

● Measurements + Empirical fit model    ◆ Meas. Std. Dev.





# **PRESENTATIONS OF LONG-TERM SPACECRAFT TSI DATA SETS.**



# TABLE 1

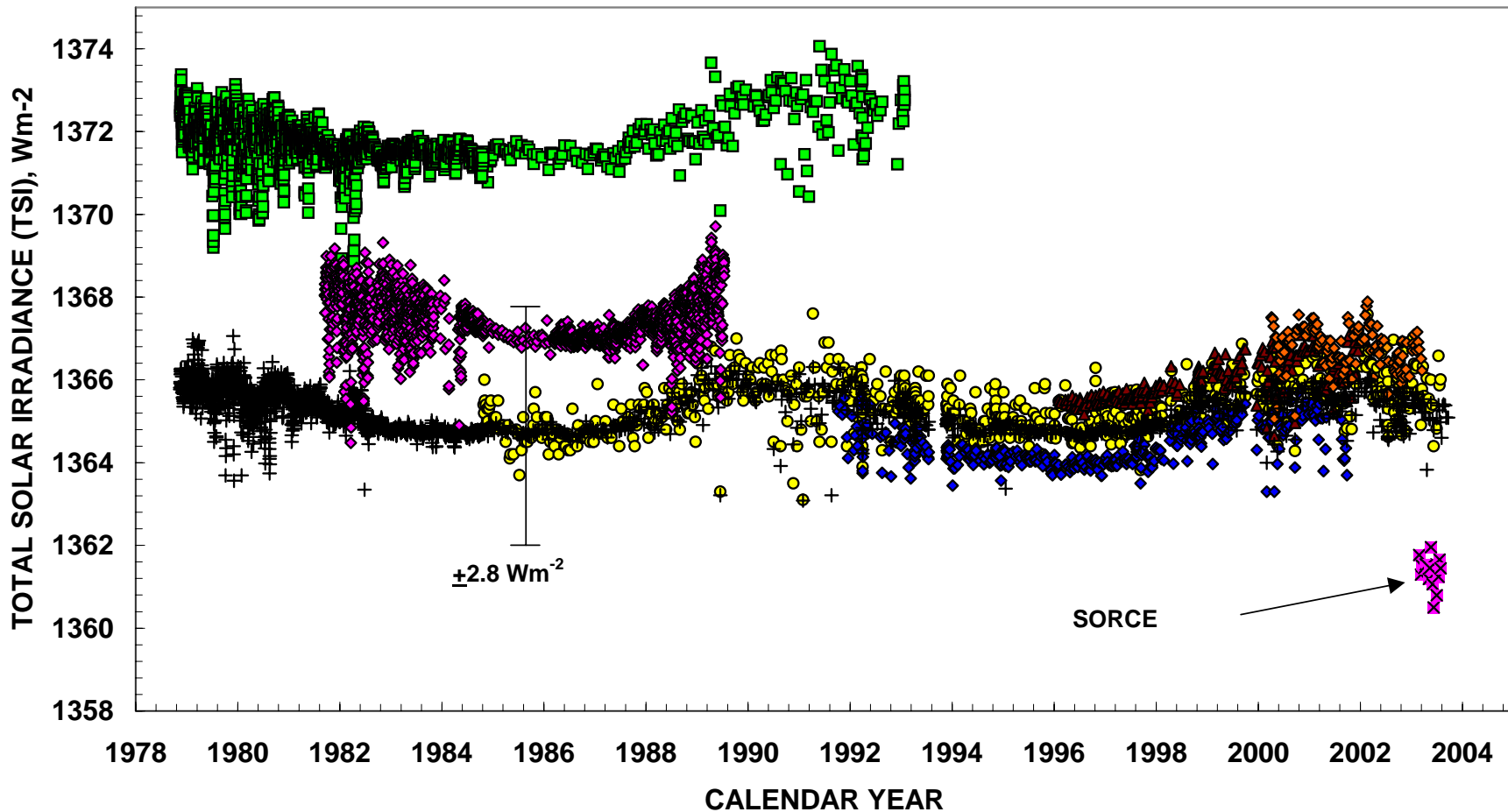
## TOTAL SOLAR IRRADIANCE [TSI] SPACECRAFT MEASUREMENTS

SPACECRAFT	TSI ( $\text{Wm}^{-2}$ )
1969 MARINER VI	1352.5 $\pm$ ???
1969 MARINER VII	1354.5 $\pm$ ???
1975-1977, NIMBUS-6	1392 $\pm$ ???
1978-1993, NIMBUS-7	1372.1 $\pm$ 0.7
1978-1993, SOLAR MAXIMUM MISSION (SMM)/ACRIM I	1367.51 $\pm$ 0.65
<b>1984-2003, EARTH RADIATION BUDGET SATELLITE (ERBS)</b>	<b>1365.4<math>\pm</math>0.6</b>
1991-2001, UPPER ATMOSPHERE RESEARCH SATELLITE ( UARS )/ACRIM II	1364.44 $\pm$ 0.5
1992,1993,1994,1996,1997,1998, ATLAS / SOLAR CONSTANT (SOLCON)	1366.4
1992-1993,EURECA / SOLAR VARIATIONS (SOVA-1)	1365.1
1996-2002, SOHO / VARIATIONS OF SOLAR IRRADIANCE AND GRAVITY OSCILLATIONS (VIRGO)	1366.0 $\pm$ 0.5
2000-2002, ACRIMSAT/ACRIM III	1366.7 $\pm$ 0.5
<b>2003, Solar Radiation and Climate Experiment (SORCE)</b>	<b>1361.3<math>\pm</math>0.4</b>



# LONG-TERM SPACECRAFT TOTAL SOLAR IRRADIANCE (TSI) MEASURING MISSIONS

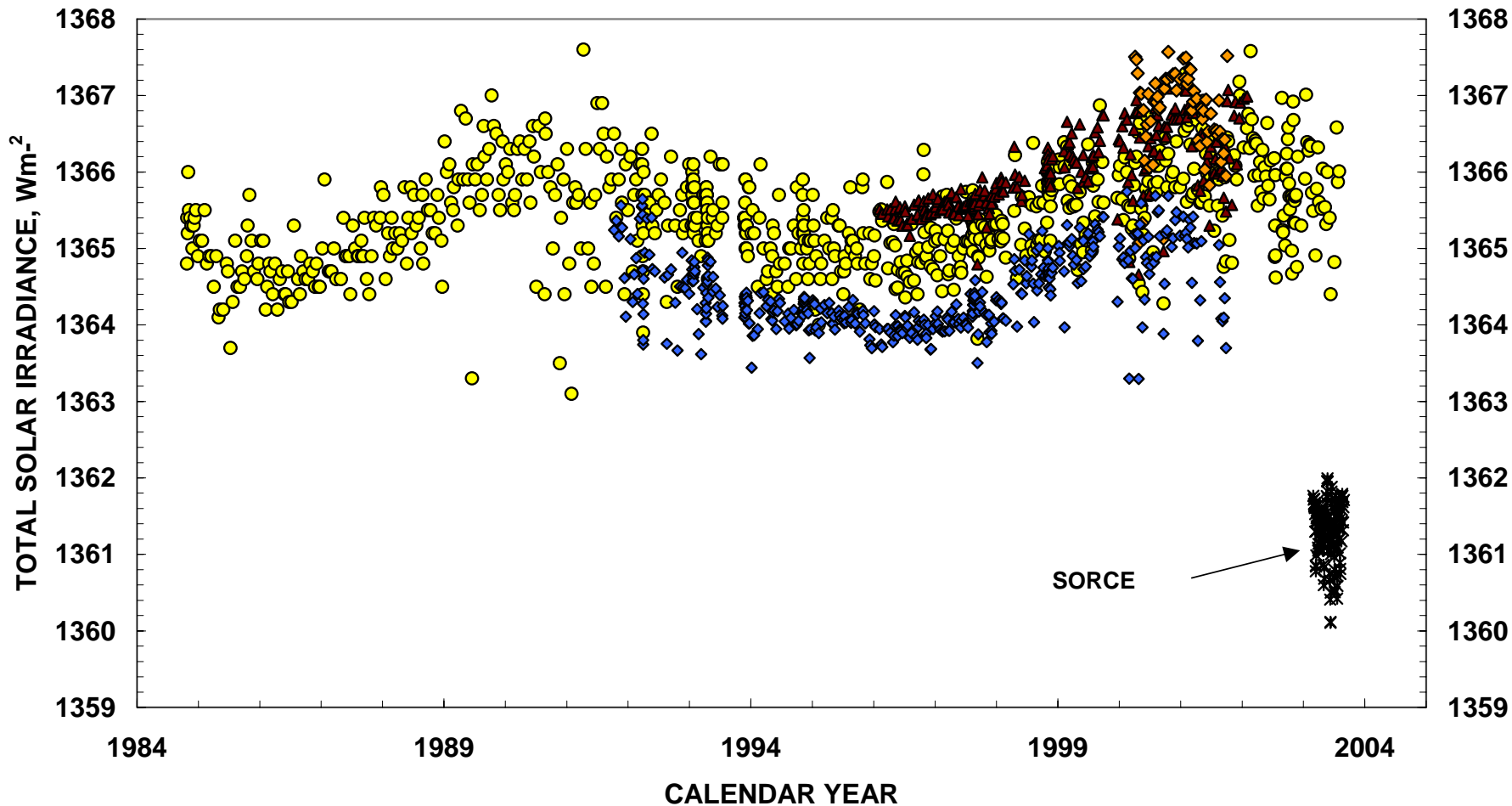
● ERBS ◆ UARS ▲ VIRGO ◆ ACRIMSAT ■ NIMBUS 7 + EMPIRICAL FIT ◆ SMM × SORCE





# ERBS/ERBE SOLAR MONITOR TOTAL SOLAR IRRADIANCE (TSI) MEASUREMENTS COMPARED WITH THOSE FROM POST-1984 SPACECRAFT MISSIONS

● ERBE SOLAR MONITOR ▲ SOHO/VIRGO ◆ ACRIMSAT/ACRIM III × SORCE ◆ UARS/ACRIM





**1365 Wm<sup>-2</sup> APPEARS  
TO BE THE BEST  
VALUE OF TSI  
DURING PERIODS OF  
MINIMUM SOLAR  
MAGNETIC ACTIVITY.**



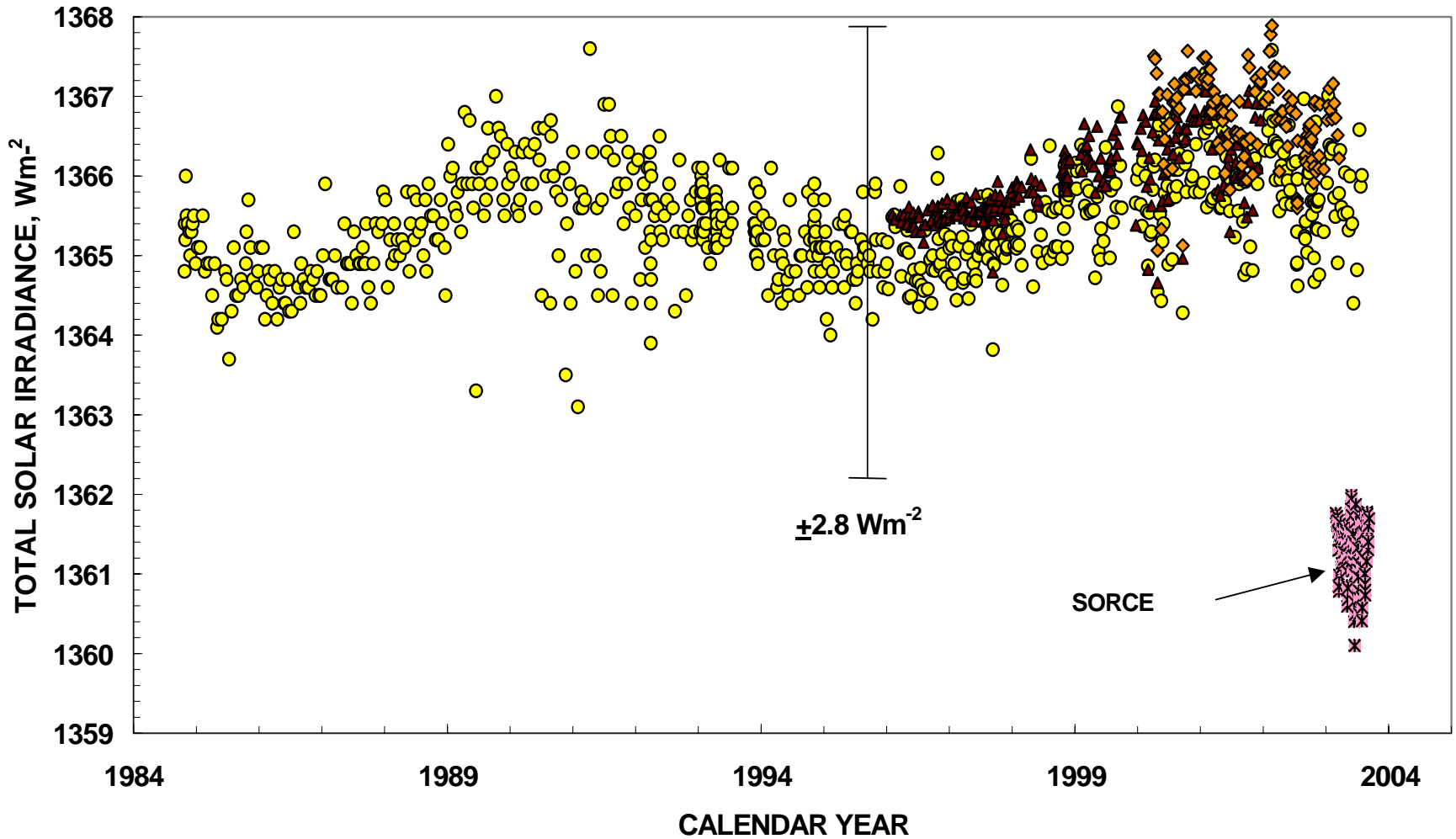
# ERBS/ERBE SOLAR MONITOR TSI DATA SET

- AFTER 1<sup>ST</sup> 6 MONTHS IN ORBIT, NO INSTRUMENT DRIFTS OR SHIFTS.
- LONGEST CONTINUOUS TSI DATA SET [19 YEARS, 2 COMPLETE SUNSPOT CYCLES] AVAILABLE FOR LONG-TERM TSI VARIABILITY STUDIES.
- ONLY DATA SET THAT CAN IDENTIFY TSI VARIABILITY COMPONENTS WITH PERIODS LONGER THAN 11 YEARS.
- ONLY DATA SET THAT DID NOT REQUIRE CORRECTIONS FOR LONG-TERM INSTRUMENT DEGRADATION.



# ACTIVE SPACECRAFT TOTAL SOLAR IRRADIANCE MISSIONS

● ERBE SOLAR MONITOR ▲ SOHO/VIRGO ◆ ACRIMSAT/ACRIM III ✖ SORCE







# 1984-2003, Earth Radiation Budget Satellite (ERBS)/Earth Radiation Budget Experiment (ERBE) Total Solar Irradiance (TSI) measurements

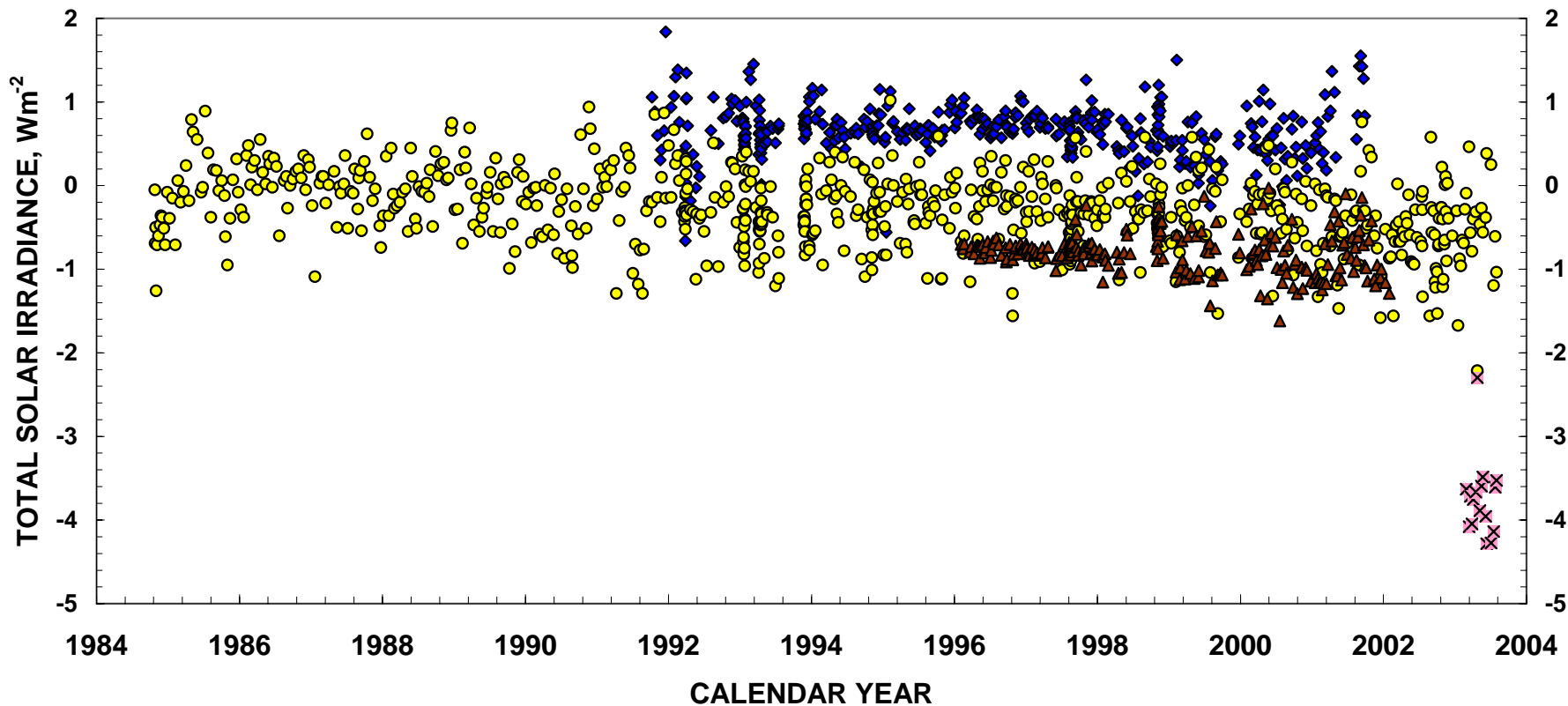
- THE ERBS/ERBE SOLAR MONITOR IS OPERATING NOMINALLY, AND PRODUCING EXCELLENT TSI MEASUREMENTS.
- The ERBS SPACECRAFT & ERBE SOLAR MONITOR IS EXPECTED TO BE OPERATIONAL THROUGH 2009, SUNSPOT MAXIMUM.
- HOWEVER, THE ERBS/ERBE SOLAR MONITOR TSI PROCESSING HAS BEEN STOPPED DUE TO THE LOST OF FUNDING.



# ACTIVE CAVITY RADIOMETER [ACR]: DIFFERENCES BETWEEN TOTAL SOLAR IRRADIANCE [TSI] EMPIRICAL MODEL FIT AND LONG-TERM SPACECRAFT MEASUREMENTS

## DIFERENCES BETWEEN EMPIRICAL MODEL FIT AND SPACECRAFT TOTAL SOLAR IRRADIANCE (TSI) MEASUREMENTS

◆ MODEL-UARS   ● MODEL-ERBS   × MODEL-SORCE   ▲ MODEL-SOHO





# TOTAL SOLAR IRRADIANCE (TSI) VARIABILITY: 1978-2002

## RESULTS

**1365  $\text{Wm}^{-2}$  IS MEAN VALUE OF TSI DURING PERIODS OF  
MINIMUM SOLAR MAGNETIC ACTIVITY.**

**1.4  $\text{Wm}^{-2}$  [0.1 %] IS THE MAGNITUDE OF THE 11-YEAR  
SUNSPOT CYCLE], LONG-TERM TSI VARIABILITY  
COMPONENT.**



# Data Source References

**1. ERBS:** The 1984-2003 measurements can be obtained from the Langley Distributed Active Archive Center [DAAC] by telnet [eosdis.larc.nasa.gov](telnet://eosdis.larc.nasa.gov), login name: `ims`, password: `larcims` or by NCSA Mosaic using the URL address <http://eosdis.larc.nasa.gov>

**2. UARS, SMM:** The 1981-2001 measurements can be obtained from the ACRMSAT web page [acrim.com](http://acrim.com) or the Langley Distributed Active Archive Center [DAAC] by telnet [eosdis.larc.nasa.gov](telnet://eosdis.larc.nasa.gov), login name: `ims`, password: `larcims` or by NCSA Mosaic using the URL address <http://eosdis.larc.nasa.gov>

**3. NIMBUS 7** The 1980-1993 measurements can be obtained from the Goddard Distributed Active Archive Center [DAAC] using the URL address <http://daac.gsfc.nasa.gov>

**5. SOLCON/ SOVA 1/VIRGO:** Dominique Crommelynck ,Royal Meteorological Institute of Belgium Avenue Circulaire, 3,1180 Bruxelles, Phone Number: (32 2) 3730600, Fax Number : (32 2) 3746788 E-Mail: [dcr@radio.oma.be](mailto:dcr@radio.oma.be)



# ERBE SOLAR MONITOR MEASUREMENT OF TSI DECREASES DUE SUNSPOT DARKENING: MARCH 23 THRU APRIL 3, 1992

● TSI MEASUREMENT + TSI EMPIRICAL FIT \* MEASUREMENT SIGMAS

