JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 94, NO. A12, PAGES 17,017–17,020, DECEMBER 1, 1989

Modeled Solar EUV Flux During the Equinox Transition Study: September 17–24, 1984

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A new empirical model of solar extreme ultraviolet (EUV) irradiance variability has been developed based on satellite and rocket EUV observations for all levels of solar activity. Its results for the Equinox Transition Study (ETS) period of September 17–24, 1984, have been calculated, and the tabulated results of photon and energy fluxes for each day of this period are presented. The model average total EUV full-disk energy flux for the spectral range between 1.9 and 105.0 nm for the ETS period is 2.9 ergs cm^{-2} s^{-1}, with a general secular increase in the total flux level between September 17 and September 24. This modeled rise corresponds to the increased EUV irradiance variability due to active region evolution and passage across the disk. The modeled EUV values in September 1984 near solar cycle 21 minimum conditions are higher than rocket- and satellite-measured EUV values near solar minimum conditions of cycle 20. However, the results are consistent with recent trends in the literature to revise the solar cycle 20 minimum flux values upward.

INTRODUCTION

Solar EUV heating is a fundamental energy input into the terrestrial thermosphere. The spectral range between the Lyman α emission at 121.6 nm and the X rays near 0.1 nm is the source of a substantial part of the energy needed to ionize the major and minor neutral constituents in the thermosphere. In particular, flux in this spectral range is responsible for the formation of the *D*, *E*, and *F* regions of the ionosphere. None of these emissions reach the surface of the Earth, since they are totally absorbed by the atmosphere.

Measurements of these solar EUV emissions are made above the atmosphere by rocket and satellite remote sensing instruments. The record of EUV measurements consists of sounding rocket observations reviewed by *Schmidtke* [1984] and *Feng et al.* [1989] and a number of satellite observations [*Neupert et al.*, 1964; *Timothy and Timothy*, 1970; *Hall and Hinteregger*, 1970; *Woodgate et al.*, 1973; *Schmidtke*, 1976; *Schmidtke et al.*, 1977; *Hinteregger*, 1977; *Hinteregger et al.*, 1977, 1981; *Schmidtke*, 1984]. Recently, the San Marco satellite observed EUV emissions in 1988, although the data are not yet available.

Since there are no continuous long-term observations of EUV irradiance variation on the time scale of a solar cycle and there are gaps between observations, modeling of this irradiance variation becomes important. EUV modeling has been reviewed by *Schmidtke* [1984], and two models applicable to solar cycle time scales presently exist [*Hinteregger et al.*, 1981; *Tobiska*, 1988; *Tobiska and Barth*, 1989]. Since there were no EUV irradiance observations made during the Equinox Transition Study (ETS) period in September 1984, the estimated solar energy input in the form of EUV radiation must be calculated by a model.

SOLAR EUV MODEL RESULTS

The model of solar EUV flux which has been developed for aeronomical use by *Tobiska and Barth* [1989] is used to

Paper number 89JA02948.
0148-0227/89/89JA-02948$05.00

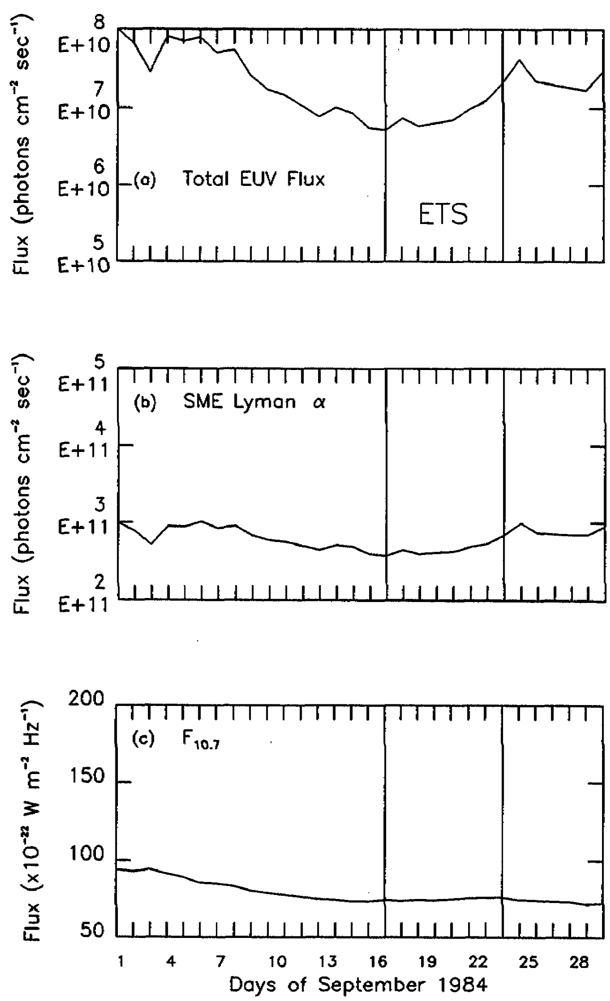

Fig. 1. (*a*) The model's total integrated EUV flux between 1.9 and 105.0 nm. (*b*) The SME-measured solar Lyman α. (*c*) The $F_{10.7}$ for the month of September 1984. The Equinox Transition Study period is demarcated by vertical lines between the abscissa day ticks of September 17 and 24.

TABLE 1. Model EUV Photon Flux

Wavelength, Å	Day of 1984							
	261	262	263	264	265	266	267	268
19–30	36	35	36	35	36	37	37	37
30–49	72	73	73	72	74	76	77	79
51–100	572	595	580	585	591	614	629	663
101–148	177	184	179	181	182	188	192	202
150–199	3,343	3,525	3,404	3,448	3,492	3,669	3,784	4,054
200–249	2,479	2,508	2,496	2,494	2,533	2,604	2,641	2,719
256–256	239	242	240	241	241	243	245	249
284–284	223	206	223	213	233	250	254	256
251–300	3,040	3,038	3,051	3,037	3,090	3,158	3,189	3,243
303–303	448	435	448	440	456	469	472	474
304–304	5,165	5,207	5,178	5,189	5,193	5,226	5,249	5,304
303–350	1,731	1,699	1,731	1,711	1,750	1,782	1,790	1,794
368–368	483	483	483	483	483	483	483	483
356–400	406	396	407	400	415	429	433	437
401–437	545	559	550	553	556	569	577	597
465–465	189	188	189	189	190	191	191	191
453–499	202	217	208	211	217	234	244	268
500–550	1,017	1,064	1,032	1,044	1,051	1,090	1,117	1,181
554–554	660	667	662	664	664	670	673	683
584–584	894	920	902	909	911	932	946	981
554–600	670	685	675	679	680	692	699	719
610–610	199	197	199	198	201	203	203	204
630–630	1,275	1,290	1,280	1,284	1,285	1,297	1,305	1,324
610–644	877	939	897	913	925	982	1,019	1,109
650–700	398	410	401	405	406	416	422	438
703–703	375	379	376	378	378	382	384	390
701–750	398	409	402	405	406	415	421	436
765–765	424	434	427	430	431	439	445	459
770–770	406	402	406	403	408	412	413	413
788–788	1,596	1,640	1,609	1,621	1,626	1,661	1,685	1,744
750–800	511	511	511	511	511	511	511	511
801–850	3,476	3,570	3,505	3,531	3,540	3,615	3,666	3,791
851–900	7,154	7,371	7,220	7,280	7,302	7,474	7,593	7,882
901–950	6,502	6,690	6,559	6,611	6,630	6,779	6,882	7,132
977–977	6,142	6,257	6,177	6,209	6,220	6,311	6,374	6,527
951–1000	1,838	1,879	1,851	1,862	1,866	1,899	1,921	1,976
1026–1026	4,932	5,081	4,977	5,018	5,033	5,151	5,233	5,431
1032–1032	6,999	7,216	7,065	7,125	7,147	7,319	7,438	7,727
1001–1050	1,082	1,087	1,084	1,085	1,085	1,089	1,091	1,097
Total flux	67,177	68,687	67,691	68,047	68,443	69,958	70,930	73,204

Flux in units of $\times 10^6$ photons cm^{-2} s^{-1}.

calculate the irradiance variations for the ETS period. The model uses two daily measured solar emissions, the Lyman α line and the 10.7-cm radio flux $F_{10.7}$, as indices for full-disk solar EUV chromospheric emissions and transition region-coronal emissions, respectively. The model wavelength equation coefficients and spectral weighting functions allow the determination of flux for 39 wavelength groups or discrete lines from 1.9 to 105.0 nm. The model satisfies two general constraints which require (1) spectral matches with rocket-observed solar EUV emissions and (2) a temporal variation which produces thermospheric densities similar to satellite-derived densities when the model solar flux is used as an energy input in a thermospheric density model.

The model was run for the 8 days of the ETS period beginning September 17, 1984 (day 261). Figure 1*a* shows the total integrated full-disk EUV flux between 1.9 and 105.0 nm modeled for the month of September 1984, where the ETS period is demarcated by vertical lines. Day-of-month ticks mark the abscissa. The largest calculated flux was 7.3×10^{10} photons cm^{-2} s^{-1} (3.0 ergs cm^{-2} s^{-1}) on day 268, while the lowest flux was 6.7×10^{10} photons cm^{-2} s^{-1} (2.8 ergs cm^{-2} s^{-1}) on day 261. Figures 1*b* and 1*c* show the Solar Mesosphere Explorer (SME) Lyman α [*Rottman et al.*, 1982; *Rottman*, 1987] and the Ottawa $F_{10.7}$ emissions, respectively, for September 1984, which were used as indices in the model.

Table 1 lists the modeled photon flux during the ETS period by 39 wavelength groups or discrete lines in the format of *Torr et al.* [1979] and *Torr and Torr* [1985]. Two additional intervals in the soft X rays (1.9–3.0 nm and 3.0–4.9 nm) have been added to the 37 wavelengths described by these two references. The first column lists the wavelength interval or discrete line in angstroms, and the other columns list the flux value at a wavelength for the ETS date. The bottom row lists the daily total photon emissions. Table 2 lists the energy flux for the ETS period in the same format as Table 1. The daily values of Lyman α and $F_{10.7}$ are also shown at the end of Table 2.

DISCUSSION

The period of September 1984 reflects approximate solar cycle 21 minimum conditions, even though the absolute cycle minimum in $F_{10.7}$ occurred nearly 2 years later in

TABLE 2. Model EUV Energy Flux

Wavelength, Å	Day of 1984							
	261	262	263	264	265	266	267	268
19–30	30	29	30	29	30	30	31	31
30–49	36	36	36	36	37	38	39	40
51–100	151	157	153	154	156	162	166	175
101–148	28	29	29	29	29	30	31	32
150–199	381	402	388	393	398	418	431	462
200–249	219	222	221	221	224	230	234	241
256–256	19	19	19	19	19	19	19	19
284–284	16	14	16	15	16	17	18	18
251–300	219	219	220	219	223	228	230	234
303–303	29	28	29	29	30	31	31	31
304–304	338	341	339	339	340	342	343	347
303–350	105	103	105	104	106	108	109	109
368–368	26	26	26	26	26	26	26	26
356–400	21	21	21	21	22	23	23	23
401–437	26	27	26	26	26	27	27	28
465–465	8	8	8	8	8	8	8	8
453–499	8	9	9	9	9	10	10	11
500–550	38	40	39	40	40	41	42	45
554–554	24	24	24	24	24	24	24	24
584–584	30	31	31	31	31	32	32	33
554–600	23	24	23	23	23	24	24	25
610–610	6	6	6	6	7	7	7	7
630–630	40	41	40	41	41	41	41	42
610–644	28	30	28	29	29	31	32	35
650–700	12	12	12	12	12	12	12	13
703–703	11	11	11	11	11	11	11	11
701–750	11	11	11	11	11	11	12	12
765–765	11	11	11	11	11	11	12	12
770–770	10	10	10	10	11	11	11	11
788–788	40	41	41	41	41	42	43	44
750–800	13	13	13	13	13	13	13	13
801–850	84	86	84	85	85	87	88	91
851–900	162	167	164	165	166	170	172	179
901–950	140	144	141	142	142	146	148	153
977–977	125	127	126	126	126	128	130	133
951–1000	37	38	38	38	38	39	39	40
1026–1026	96	98	96	97	97	100	101	105
1032–1032	135	139	136	137	138	141	143	149
1001–1050	21	21	21	21	21	21	21	21
Total flux	2,758	2,817	2,781	2,792	2,817	2,890	2,933	3,033
Lyman α*	258	266	260	262	263	269	274	284
$F_{10.7}$†	75	74	75	74	75	76	76	76

Flux in units of $\times 10^{-3}$ ergs cm^{-2} s^{-1}, except as noted.
*Flux in units of $\times 10^{9}$ photons cm^{-2} s^{-1}.
†Flux in units of $\times 10^{-22}$ W m^{-2} Hz^{-1}.

September 1986. $F_{10.7}$ values for the ETS period ranged from a low of 74 to a high of 76 (+3%), indicating a relatively stable period of full-disk $F_{10.7}$ activity during the 8 days. Figure 1*c* shows a relatively flat $F_{10.7}$ level during ETS. This index primarily represents the activity of the solar transition region and corona.

However, when the chromospheric Lyman α emission is reviewed for the ETS period, there is much more interesting detail. Day 261 (September 17, 1984) falls exactly at the minimum of a 27-day solar rotational feature, while day 268 shows a 10% increase in the chromospheric emission level over the day 261 value. Day 268 is near the peak flux of that particular solar rotation feature. The enhanced chromospheric emissions result from the combined effects of a small active region's evolution and its rotation across the solar disk beginning day 264. This can be seen in the data from the World Data Center for the calcium plage region 19463 (Solar-Geophysical Data Prompt and Comprehensive Reports, 1984, 1985), which achieved a maximum area between days 268 and 271. The model's sensitivity to the Lyman α chromospheric index leads to an increase in the total EUV flux between days 261 and 268.

Modeled solar irradiance of chromospheric origination, such as the H Lyman continuum (70.0–91.2 nm) and H Lyman β (102.6 nm), also shows an approximately 10% increase in activity. However, modeled coronal soft X rays in the 1.9- to 3.0-nm range show no relative increase in this same period. Modeled wavelength ranges which include a mix of chromospheric, transition region, and coronal irradiance variations between 3.0 and 20.0 nm show increased levels. Thus the net result is a modeled average total integrated EUV full-disk flux, from 1.9 to 105.0 nm, which is 69.3×10^{9} photons cm^{-2} s^{-1} and is dominated by the behavior of the chromospheric emission index. The average total EUV energy flux for this period is 2.9 ergs cm^{-2} s^{-1}.

Total EUV flux for solar minimum conditions was measured by a rocket flight near the minimum of solar cycle 20. *Hinteregger* [1976] discusses the April 23, 1974, rocket flight, which measured EUV emissions between 28.0 and 102.7 nm of 38.3×10^9 photons cm^{-2} s^{-1} with an uncertainty of ±30% [*Heroux and Hinteregger*, 1978]. The Atmosphere Explorer C (AE-C) satellite data between 14.0 and 102.7 nm for the same date were 46.0×10^9 photons cm^{-2} s^{-1} with an uncertainty of ±20–40% [*Hinteregger et al.*, 1977]. This satellite was calibrated with the April 23, 1974, rocket flight measurements. $F_{10.7}$ was 73 on April 23, 1974. For comparison, where $F_{10.7}$ averages 75 for the ETS period, the model's average total EUV flux is 52.6×10^9 photons cm^{-2} s^{-1} between 28.0 and 102.7 nm and 60.7×10^9 photons cm^{-2} s^{-1} between 14.0 and 102.7 nm. Thus the model results are 37% higher than the measured rocket data (outside the error bars) and 32% higher than the satellite data (inside the error bars). The difference is accounted for by the slightly higher solar activity during ETS, especially when the chromospheric emissions are considered, and by the possibility that the rocket measurements, and hence the AE-C data during low solar activity, are too low. This latter topic has been addressed in the literature by *Richards and Torr* [1984], *Ogawa and Judge* [1986], and *Link et al.* [1988]. These authors would increase the solar minimum EUV below 25.0 nm by factors of 2.0, 2.0, and 1.5, respectively. The *Tobiska and Barth* [1989] model increases the 15.0- to 25.0-nm range by 1.6 as compared with the April 23, 1974, spectrum (F74113) and generally agrees with these authors.

The uncertainty in the model results is not quantified. However, *Tobiska and Barth* [1989] generally assess the uncertainty in the model by comparing its results to many rocket observations reviewed by *Feng et al.* [1989]. For the 2.0- to 10.0-nm range the integrated model irradiance values fall within the error bars of 13 out of 14 rocket observations, and for the 5.0- to 57.5-nm range the integrated model irradiance values fall within the error bars of 9 out of 14 rocket observations.

It should be noted that F74113 was also used to calibrate the AE-E satellite EUV measurements [*Hinteregger et al.*, 1981]. AE-E data provided the basis for linear regression coefficients in the *Tobiska and Barth* [1989] model. Thus the EUV model and the F74113 spectrum are not entirely independent, although they are dissimilar because of the added effect of spectral weighting functions in the model, which were developed using independent rocket data.

CONCLUSIONS

Model EUV irradiance variations show a secular increase between September 17 and September 24, 1984. This is a result of increased chromospheric flux from active region evolution and rotation across the solar disk. The model EUV flux is dominated by the chromospheric emission contribution. An average total EUV full-disk energy flux for the ETS period is 2.9 ergs cm^{-2} s^{-1}. This value is higher than rocket- and satellite-measured total EUV flux near solar minimum conditions in cycle 20. The difference is attributed to a combination of slightly higher solar activity and possible uncertainty in rocket and satellite measurements from the solar cycle 20 minimum period.

Acknowledgments. The Editor thanks J. Lean and another referee for their assistance in evaluating this paper.

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(Received July 17, 1989;
revised September 14, 1989;
accepted September 15, 1989.)