The 10.7-cm Solar Flux and the 26-Month Oscillation[1]

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ABSTRACT

The 10.7-cm solar radio flux is considered to be highly correlated with solar extreme ultraviolet radiation, thermospheric temperatures, sunspots, and the 27-day and 11-year solar cycles. To investigate the possibility of ultraviolet radiation being a cause of the quasi-biennial oscillation in tropical stratospheric winds and temperatures, the daily values of 10.7-cm flux were subjected to a non-linear, curve-fitting analysis to determine the major component sinusoidal frequencies of the time series. No evidence was found for a period near 26 months; hence, to the extent that extended ultraviolet 10-cm flux relationship is valid, ultraviolet insolation does not appear to vary with a quasi-biennial oscillation.

1. Introduction

Among the current hypotheses advanced for the cause of the quasi-biennial wave (QBW) in stratospheric temperature and wind in the tropics is one which requires direct heating of the upper atmosphere by ultraviolet absorption of ozone (Staley, 1963). The fact that biennial periods in equatorial ozone concentrations have been established (Funk and Garnham, 1962; Ramanathan, 1963; Rangarajan, 1964) naturally encourages this theory. Another hypothesis heats the atmosphere by reflection of ultraviolet radiation from average cloudiness in which either the average cloudiness or the incoming radiation itself is required to vary biennially (Lindzen, 1964). As the sun is the most likely source of direct heating, it is natural to attribute the needed variability to it, especially as a weak quasi-biennial cycle has been attributed to the equatorial geomagnetic field and to sunspots (Shapiro and Ward, 1962; Westcott, 1964).

As was shown by Das Gupta and Basu (1963), the solar radio flux at 2800 mc is very near that frequency (4000 mc) which has the maximum correlation with relative sunspot numbers at periods of high solar activity. The solar flux can be considered as composed of: 1) a fairly constant component (the quiet sun emission, of thermal origin); 2) highly variable components of different types (disturbed sun emission, non-thermal origin); 3) a distinct type of slowly varying radiation only near centimeter wavelengths from 470 mc to 29,000 mc and with a maximum correlation to relative sunspot number at 4000 mc. The flux at 2800 mc (10.7 cm) routinely measured at Ottawa is very near this frequency with highest correlation and has been used here.

[1] Paper presented at the Symposium on Solar-Terrestrial Relations at Boulder, Colo., on 29 July 1965.

Nicolet (1963) and Jacchia (1965) have shown that this 10.7-cm flux is highly correlated with the temperature and density of the thermopause (near 200 km). This region is heated by both far ultraviolet and corpuscular radiation which originate in the very active upper chromosphere and higher levels. As the 10-cm flux also has its source in the chromosphere, its correlation with sunspots and the temperature of the thermosphere appears reasonable, although Anderson (1965) finds that the latter relationship varies with the phase of the solar cycle. The longer ultraviolet wavelengths, above 2000 Å, which penetrate into the stratosphere where there is ozone absorption, originate in the photosphere where no variations have been found. Thus, the possibility of variations of 26 months, for example, at these longer ultraviolet wavelengths is very much less than at shorter ultraviolet wavelengths.

With these limitations in mind, the 10.7-cm flux was examined to see if any evidence of a fundamental period near 26 months could be found even at the most likely wavelengths. If found, there would be a possibility of such a periodicity at longer, and for our problem, more pertinent wavelengths. If not found, a quasi-biennial variation in ozone producing ultraviolet would be very unlikely.

2. Data and analysis method

The 18 years of available once-daily 10.7-cm flux data, extending from February 1947 to December 1964, were used. Occasionally missing observations in the early years were interpolated linearly to give a continuous time series of 6002 values. Figs. 1 and 2 show sample periods of record during high and low solar activity, respectively. Fig. 3 gives the mean monthly trend for the entire period of record.

The very dominant frequencies in the data are the

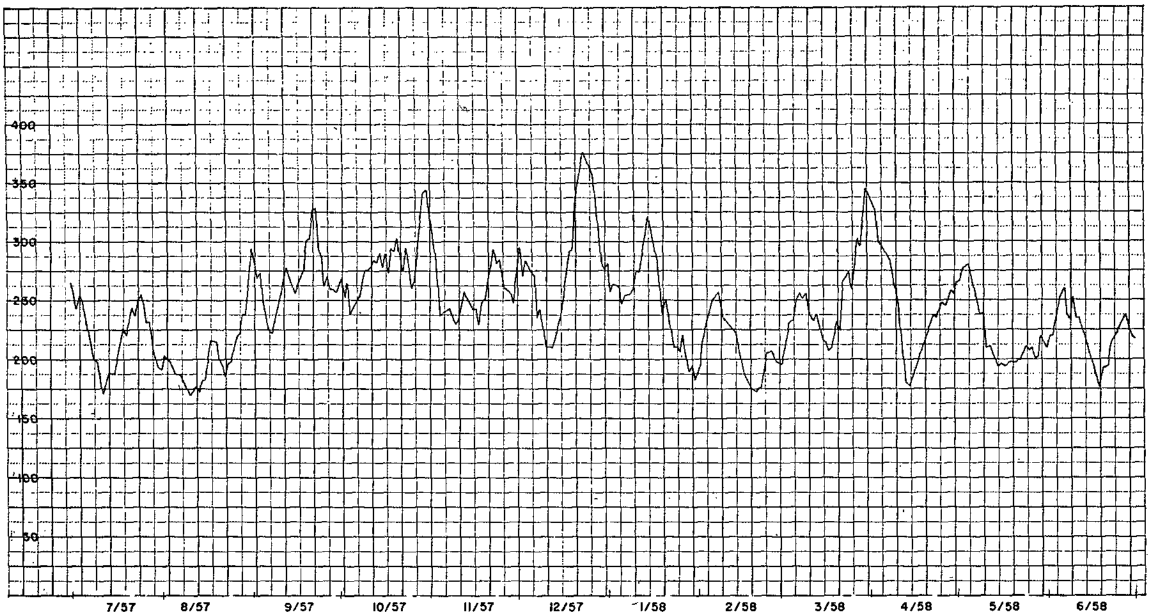

FIG. 1. Daily 10.7-cm solar flux data during high solar activity, July 1957 to July 1958. Unit $=10^{-22}$ watt m^{-2} (cps)$^{-1}$.

11-year and 27-day cycles. To avoid frequencies beyond the range of the biennial period, and to remove any high frequency noise background, the data were filtered with a band pass filter which has the response shown in Fig. 4. This effectively attenuates the amplitude of waves in the data whose periods are shorter than about 14 months, thus eliminating any possible seasonal or annual effects, and also all waves whose periods are longer than approximately 10 years, thus removing the 11-year cycle. The weighting system of the band pass filter results in shortening the series to 3000 completely filtered values. Fig. 5 shows the data of Fig. 1 after filtering.

To find the periods hidden in the smoothed data a newly developed method, described below, was applied. Power spectrum analysis, the usual tool, is not reliable because of subjective interpretation in the presence of truncation error.

Fig. 6 is the power spectrum of the complete unfiltered original data. The general logarithmic decrease of power with increasing frequency is due to truncation effects of the mean and the 11-year solar cycle. The irregularity of the spectrum is due both to truncation effect and component frequencies. As truncation effect and the component waves cannot be divorced in spectrum analysis, interpretation is therefore very difficult. Fig. 7 is the power spectrum of the filtered data. This shows a large peak near 5 years (1715 days), absolutely nothing at 26 months (780 days), and a peak near 19 months. The spectra in Figs. 6 and 7 were computed for integral multiples of $1/(2s)$ and $1/(6s)$, respectively, (where $s=4015$ days or one solar cycle), thus providing reasonably fine resolution to show major features.

A curve-fitting method was recently developed[2] and applied to this type of problem for the first time. This technique will find the mean, amplitude, and phase of any number of input data minus one, utilizing an over-determined system of equations. The program seeks to compute the minimum value of the error function representing the squared difference between the given data and the trial component waves whose variables are amplitude, phase, and frequency.

[2] Ulstad, M. S., 1965. Approximation of numerical data using a set of optimized non-orthogonal functions. In preparation.

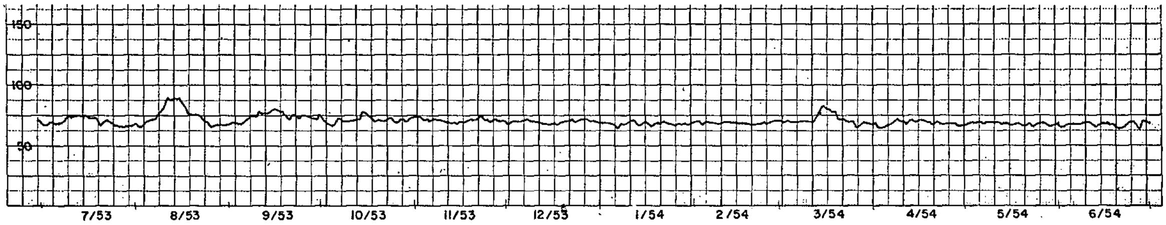

FIG. 2. Daily 10.7-cm solar flux data during low solar activity, July 1953 to July 1954. Unit $=10^{-22}$ watt m^{-2} (cps)$^{-1}$.

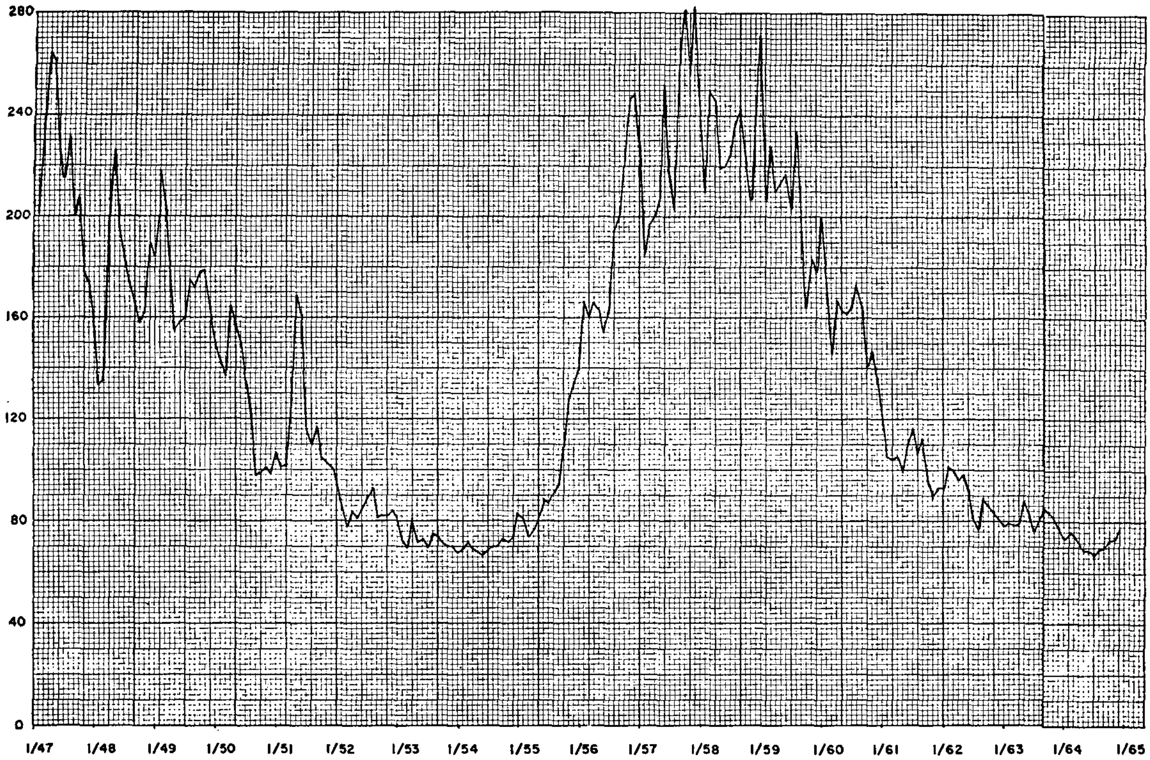

FIG. 3. Mean monthly 10.7-cm solar flux, 1947 to 1964. Unit $=10^{-22}$ watt m^{-2} (cps)$^{-1}$.

An initial guess is made of the component frequencies present in the data and the error is determined. Then the initial frequency approximation of the first wave is adjusted slightly, once toward higher frequencies and once toward lower frequencies, and the residual error is computed for each instance using the initial estimates of the remaining waves. For this first component wave three points have now been found on the error versus frequency curve. These three points are fitted with a parabola and the minimum of the parabola marks the location of the next estimated frequency at which a residual error is calculated. Nearby values are again examined on each side of this frequency and the procedure repeated. As the residual error decreases, the frequency shifting approximation interval decreases and vice versa. In this manner the program "walks down" the error versus frequency curve to a minimum.

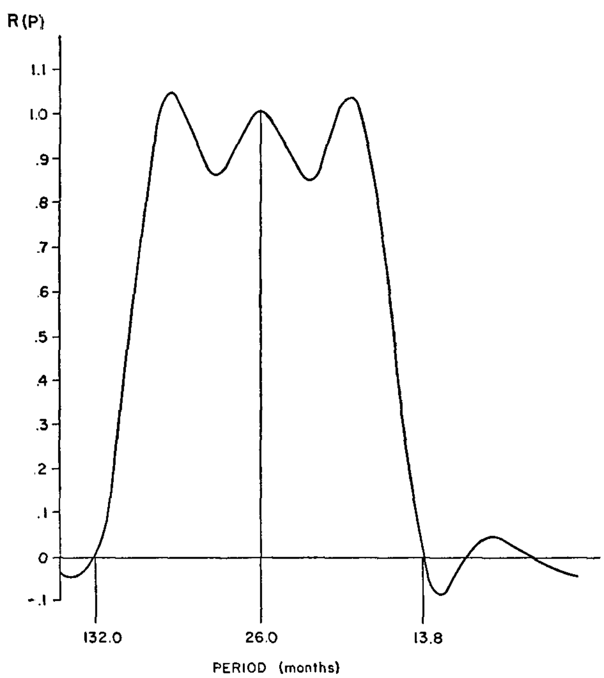

FIG. 4. Response of band-pass filter.

Once this has been established for the first wave, the program goes to the original frequency guess of the second component wave and repeats the entire operation. After all the original frequencies have "walked down" the error versus frequency curve, the entire procedure can be repeated as many times as needed, with the terminal values of frequency, due to the "walking down" procedure, becoming the new frequency guesses. The program can be terminated by finally reaching a threshold error or by setting a lower limit on the change in residual error after all "walking down" procedures have been completed for all frequencies. The usual difficulty in similar methods is the failure to avoid local relative minima. Dr. Ulstad's method provides a novel yet simple technique of locating the deepest minimum.

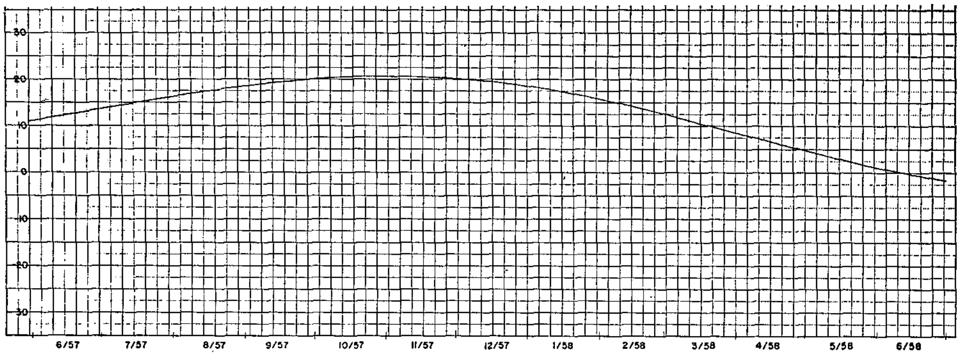

Fig. 5. Same data as in Fig. 1 after filtering.

In comparison with spectral analysis, the curve-fitting program has the distinctive advantage of being able to determine with much higher resolution the properties of component waves in short time series and also of avoiding truncation peaks due to finite length records.

3. Results

Fig. 8 shows graphically, and Table 1 numerically, the results of nine different trials with the new method, compared to the usual power spectrum results in the upper left corner (repeated from Fig. 7 for easier comparison). Table 1 lists, for each trial, the waves which most reduce the variance of the original data, depending on the number of waves which were requested with or without a mean. The periods are given in days. The amplitude F is based on the filtered data and is hence attenuated. It has been restored to the true value, Amp (R), by applying the appropriate filter response factor. The rms error, in original data units, is the residual in the filtered data after the given waves have been subtracted. R is the ratio of the residual rms error to that of the filtered data, thus giving a measure of how well the solutions fit. As the trials were experimental, details of the method varied from one to another, partly accounting for the variations in results. Results also varied because of insufficient number of cycles in the period of record, especially at lowest frequencies, relative to the noise content of the data. Improvement of the fit will be possible with greater understanding of some of the characteristics of the method. Meanwhile, the resultant error may serve to select the best fitting group of waves. From these first results, it can be concluded that:

1. In no instance is there any response near 26 months (780 days).
2. There is a very consistent response near 19 months (570 days).
3. There appears to be large energy at a period near 5 years (1825 days), but there are insufficient

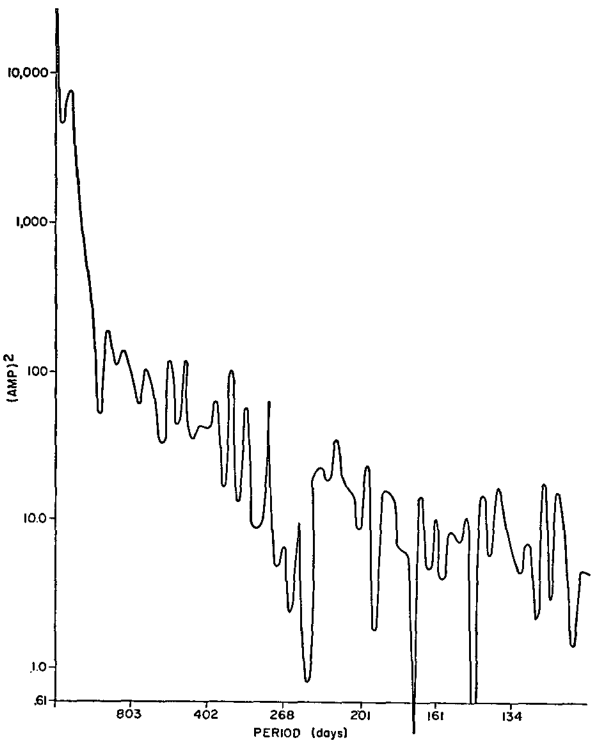

Fig. 6. Power spectrum of the original, unfiltered daily data.

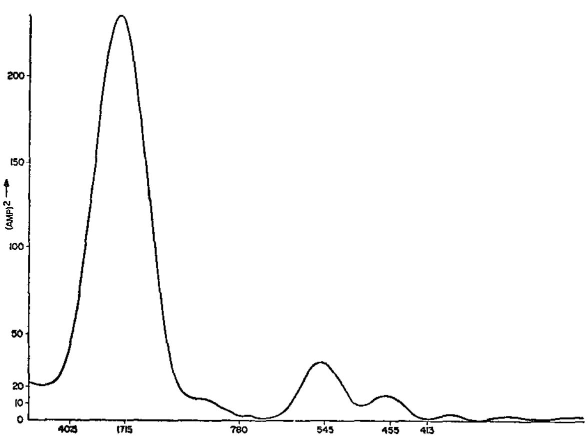

Fig. 7. Power spectrum of filtered data.

cycles to resolve its frequency or indeed to even know if it is the resultant of several other frequencies. Hence, the low frequencies drift from trial to trial, although the high frequencies are relatively fixed. All the combinations at low frequencies are equally good solutions.

If one relied only on the power spectrum, a single frequency would generally be ascribed to the peak near 1715 days. An advantage of the present analysis method is that such peaks can be resolved into numerous other possible combinations of frequencies, thus helping one to realize that the single frequency peak is highly misleading.

It should be borne in mind that the natural, irregular variability of the sun probably cannot be described accurately by any method such as spectral analysis or this one which assumes some combination of constant and regular sine waves. Lacking definite knowledge of other possible periodic functions, however, it is customary to attempt sinusoidal frequency analysis. The method outlined here does permit the use of other functions and exploration with some of them is planned.

The results show there is no fundamental average sinusoidal period near 26 months, nor any resultant period near there caused by other waves within the range passed by the filter. Thus, it appears unlikely that there is any fundamental solar variation with a period near 26 months, and the postulated variations

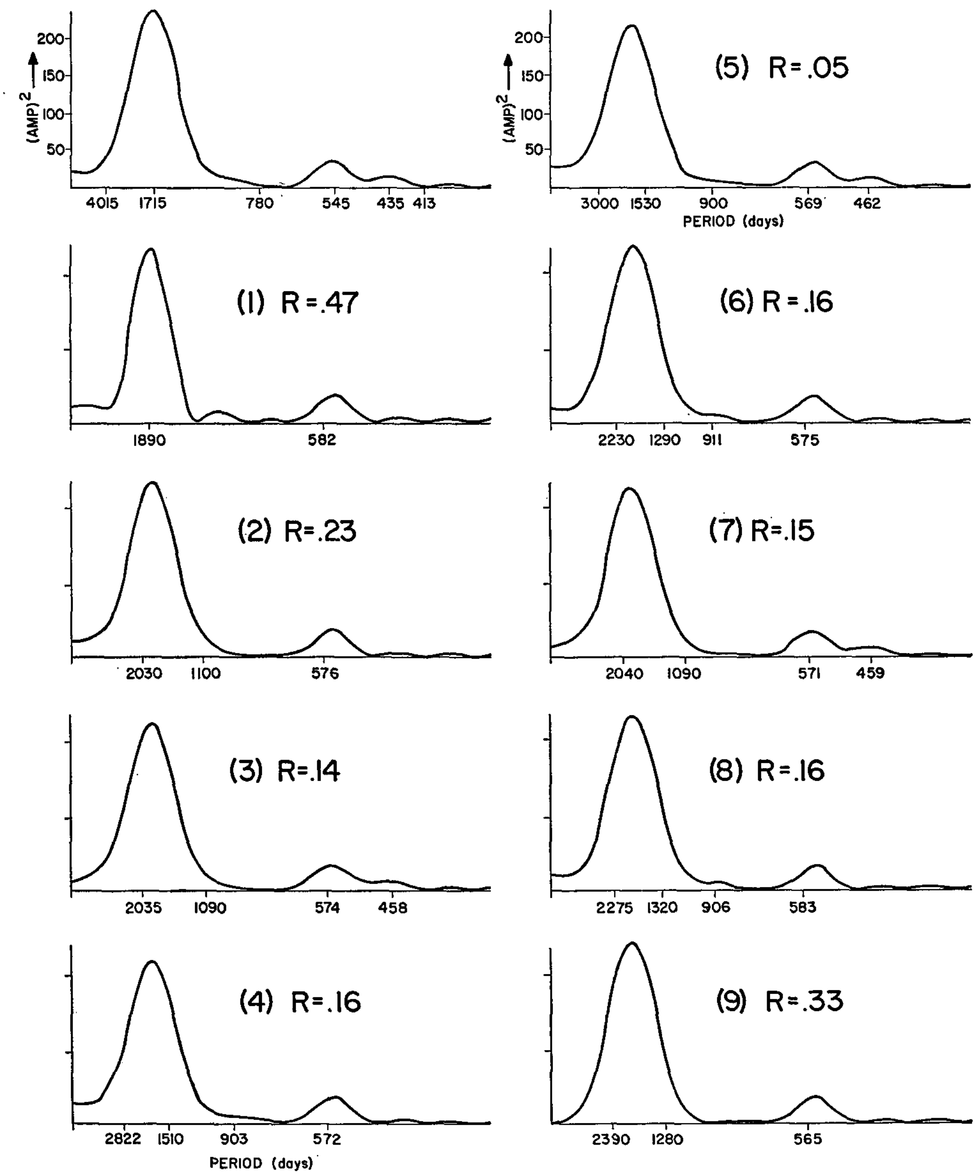

FIG. 8. Amplitude (in original data units) of frequency response by nine different trials using the Ulstad method, compared to usual power spectrum (upper left). R is the percentage of the rms error of the filtered data which remains when using the indicated solutions.

TABLE 1. Results of nine trials of frequency analysis (see text for explanation).

Approximation	No. of waves or mean	Frequency	Period Days	Period Months	Amp (F)	Amp (R)	rms error	$R=\frac{\text{rms error}}{\text{rms data}}$
1	2+M	3.316×10^{-3}	1890	63.0	15.5	21.6	6.12	0.47
		1.087×10^{-2}	582	19.4	5.8	6.3		
		0			−3.7	85.0		
2	3+M	3.090×10^{-3}	2030	67.7	17.2	30.2		
		1.093×10^{-2}	576	19.2	5.8	6.3	3.01	0.23
		5.716×10^{-3}	1100	36.7	7.8	8.4		
		0			−3.6	82.6		
3	4+M	5.755×10^{-3}	1090	36.3	7.5	8.2		
		1.369×10^{-2}	458	15.3	3.2	8.4		
		1.095×10^{-2}	574	19.1	5.2	5.6	1.91	0.14
		3.087×10^{-3}	2035	67.8	17.5	31.2		
		0			−3.5	80.5		
4	4+M	6.963×10^{-3}	903	30.1	4.8	5.3		
		4.148×10^{-3}	1510	50.3	13.0	13.6		
		1.095×10^{-2}	572	19.1	6.2	6.7	2.15	0.16
		2.222×10^{-3}	2822	94.1	10.1	46.1		
		0			−2.6	59.6		
5	5+M	1.104×10^{-2}	569	18.9	5.5	5.8		
		4.100×10^{-3}	1530	51.0	13.4	14.0		
		1.364×10^{-2}	462	15.4	3.0	6.8	0.64	0.05
		6.984×10^{-3}	900	30.0	4.5	5.0		
		2.100×10^{-3}	3000	100.0	9.6	56.4		
		0			−2.4	55.0		
6	4+M	1.090×10^{-2}	575	19.2	6.0	6.4		
		4.873×10^{-3}	1290	43.0	8.3	8.2	2.16	0.16
		6.911×10^{-3}	911	30.4	3.9	4.3		
		2.824×10^{-3}	2230	74.3	15.1	30.2		
		0			−3.0	68.0		
7	4+M	1.372×10^{-2}	459	15.3	3.3	8.7		
		1.101×10^{-2}	571	19.0	5.5	5.9		
		$5{,}743\times10^{-3}$	1090	36.3	7.7	8.4	2.04	0.15
		3.079×10^{-3}	2040	68.0	17.4	31.1		
		0			−3.5	80.5		
8	4+M	2.769×10^{-3}	2275	75.8	14.5	29.6		
		4.761×10^{-3}	1320	44.0	9.2	8.9	2.15	0.16
		6.941×10^{-3}	906	30.2	3.8	4.2		
		1.089×10^{-2}	583	19.4	6.0	6.4		
		0			−2.9	66.5		
9	3	2.737×10^{-3}	2390	79.7	14.9	35.5		
		1.110×10^{-2}	565	18.8	6.0	6.4	4.38	0.33
		4.884×10^{-3}	1280	42.7	9.8	9.7		

of upper atmospheric heating, if they exist at all, must be caused by other, probably very indirect effects.

The method used here for the first time will be developed further and applied to other series of geophysical data possibly bearing on the quasi-biennial cycle.

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