POWER-SPECTRUM ANALYSIS OF ATMOSPHERIC OZONE PARAMETERS[1]

By Arthur Adel and Edward S. Epstein[2]

Arizona State College

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ABSTRACT

Power spectra have been computed for three parameters of atmospheric ozone: ERTOR (effective radiation temperature of the ozone region), absorption of solar radiation by ozone in the 9.6-micron band, and total amount of ozone as measured with a Dobson spectrophotometer. Power spectra have been computed also for 700-mb middle-latitude zonal wind, geomagnetic planetary index, and Farthing's "net" index of solar coronal activity. All the spectra of the atmospheric variables exhibit spectral peaks in the vicinity of two and one-half week periods. Additional peaks in several of the ozone spectra suggest a high atmospheric level summertime variation in ozone densities with a period near one and one-half weeks.

1. Introduction

It has been well established that the existence of ozone in the atmosphere is due to solar radiation. Solar radiation of wave lengths shorter than about 2400A leads to the dissociation of oxygen molecules and thus to the formation of ozone in the atmosphere. In the neighborhood of 2600A, ozone exercises strong absorption, thereby shielding the earth's surface and at the same time producing the atmospheric warm layer near 50 km.

Apropos of the dominant role played by the sun in the formation and heating of the ozone, it has long been suspected that investigations of atmospheric ozone might reveal a mechanism whereby the lower regions of the earth's atmosphere respond to fluctuations in the solar output.

Since July 1953, the Atmospheric Research Observatory has been collecting data pertinent to the behavior of the ozone region. Three basic parameters are routinely observed. These are (1) ERTOR, the effective radiation temperature of the ozone region, influenced by vertical ozone distribution as well as by temperature structure throughout the first 50 km of the atmosphere; (2) the absorption of solar radiation by ozone via its intense band at 9.6 microns, dependent upon total amount of ozone and its distribution with pressure throughout the first 50 km; and, finally, (3) the total amount of ozone in a vertical column of the atmosphere. These three parameters enter importantly in the calculation of vertical ozone distribution by the method of VODARO [1; 2].

The parameters described above are integrated quantities, involving the ozone at all heights.

The two parameters of solar activity studies in the present analysis are (1) Farthing's "net" index of coronal activity, which is the ratio of the intensities of the green to the red coronal lines multiplied by the sum of their intensities, and (2) K_p, actually a measure of geomagnetic activity, but employed as an index of solar corpuscular radiations.

The statistical methods applied to the ozone and solar parameters are those of statistical power-spectrum analysis. These techniques were largely developed by John W. Tukey and were brought to the attention of the authors by Drs. Hans A. Panofsky and Franklin A. Gifford, Jr.

2. Spectrum analysis

One may refer to papers by Griffith, Panofsky, and Van der Hoven [3], Kahn [4], and Panofsky and McCormick [5], and also to the recent text by Panofsky and Brier [6]. The paper by Griffith *et al* is particularly relevant since it describes the technique employed here, that of overlapping spectra.

The principal advantage of this technique lies in the fact that it permits one to determine spectral curves over wide ranges of frequency with a minimum of computing. In accordance with this technique, different portions of the spectrum are estimated separately. The highest frequencies are analyzed in the standard manner, using the daily values of the observations and m (number of lags) $= 10$. Spectral estimates are thus obtained for periods between 2 and 20 days. Non-overlapping averages are then determined for some interval (for example, three-day periods), and its spectrum is analyzed, again with $m = 10$. This latter spectrum provides spectral estimates for periods between 6 and 60 days. In the present study, means of 3, 5, and 7 days are used.

The effect on the spectrum of averaging the data in

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[2] Present address: Pennsylvania State University.

this manner is to reduce the energy at high frequencies. $S_x(k)$, the original spectrum of x as a function of the frequency k, is related to $S_{\bar{x}}(k)$, the spectrum of $\bar{x}$, according to [3], by

$$S_{\bar{x}}(k) = S_x(k)[\sin(\pi n T_0)/\pi n T_0]^2.$$

There is one significant manner in which the data involved in the present study differ from those of most similar previous investigations. There are gaps in the sequences of ozone data since the necessary observations cannot be made with overcast skies. Thus, in computing mean lagged products (the first step in the spectrum computation), some of the data—namely, those with which there were no data available for pairing at the lag in question—could not be used. In the cases of spectra based on daily values, this presented no particular difficulty, but in the cases of spectra based on averaged data, the averages had to be recomputed for each lag.

The mean lagged products with which the calculation of a spectrum begins are actually approximations to the lag correlation coefficients multiplied by the total variance of all the data (or of all the means). Because of the selection process which was employed, it seemed possible that there might be considerable variations to the size of the variance of all the data used in computing a particular lag. In other words, it appeared that a spectrum based on actual lag correlation coefficients might differ from one based on the mean lagged products. A test, described in Appendix A, indicates that this is not the case. Spectra based on correlation coefficients and on mean lagged products are sufficiently similar so that the differences can be neglected without loss of information.

The interpretation of the spectra is based on an understanding of the sampling fluctuations of the spectral estimates. These estimates are distributed about their population mean in accordance with the distribution of χ^2/ν; ν is the number of degrees of freedom, $(2N - \frac{1}{2}m)/m$, where N is the total number of observations. Table 1 gives the limiting ratios of the variate to its population value for the 0.10, 0.05, and 0.01 levels of significance, for $m = 10$ and for various values of N.

These ratios are not strictly applicable to the ozone spectra presented below because of the missing observations. For these spectra, the total number of observations exceeds the number of observations upon which the mean lagged products are based, generally by a factor in the neighborhood of one-half. A complete list of the data employed in this study is given in [9], Appendix B. The numerical results, along with the numbers of days, or means, on which the various spectra are based, are given in Appendix B of this paper.

3. Drawing the spectral curve

The spectral curves which are shown in figs. 1 through 4 were drawn by inspection to fit the spectral estimates as well as possible. In drawing such curves, it is necessary to bear in mind several considerations. Of these, the two principal ones are the possible effects of aliasing and the differences in resolution at any given frequency of spectral estimates based on different means.

In general, the influence of aliasing on the spectral estimates becomes apparent immediately upon plotting the points. The effect of aliasing is to increase the variance at very high frequencies. Griffith *et al* [3] have shown empirically that the aliasing effect is practically eliminated by discarding the terminal 20 to 40 per cent of the spectral estimates. Thus, if high-frequency points of a particular spectrum appear to be elevated relative to the spectral estimates based on means of shorter duration, then these few elevated points should be ignored. It is quite apparent in figs. 2 and 4 which spectral estimates, affected by aliasing, have been ignored. On the other hand, in fig. 3, the spectra of the various ozone parameters, the points possibly subject to aliasing have not been plotted. Thus, the last four points of the 5-day and 3-day mean spectra, and the last three points of the daily spectra, have been omitted. This was done to avoid the possibility of drawing spurious features into the spectra. In other words, an effort was made to be especially conservative in analyzing the ozone spectra because of the uncertainties of the sampling errors which might possibly result from the missing data.

The second consideration can best be described by example. In the V-total spectrum of fig. 2, consider the spectral estimate based on daily values and plotted against a period of 10 days. It is apparent that the spectral curve has not been drawn to fit this point but has instead been drawn in conformity with the estimates based on the three-day means. This was done

Table 1. Limiting ratios of spectral estimates to their population values. (Computed for $m = 10$).

		Upper limit (per cent)			Lower limit (per cent)		
N	ν	1	2	10	10	5	1
25	4.5	3.15	2.28	1.89	0.297	0.206	0.095
50	9.5	2.36	1.85	1.61	0.475	0.382	0.245
60	11.5	2.21	1.77	1.56	0.517	0.426	0.288
70	13.5	2.10	1.71	1.51	0.549	0.462	0.325
80	15.5	2.02	1.65	1.48	0.576	0.491	0.356
100	19.5	1.89	1.58	1.43	0.618	0.538	0.407
150	29.5	1.70	1.46	1.34	0.684	0.614	0.495
200	39.5	1.58	1.39	1.29	0.721	0.654	0.535
250	49.5	1.51	1.35	1.26	0.751	0.689	0.579
500	99.5	1.35	1.24	1.18	0.822	0.776	0.693
750	149.5	1.28	1.19	1.15	0.854	0.816	0.745
1000	199.5	1.24	1.17	1.13	0.874	0.840	0.778

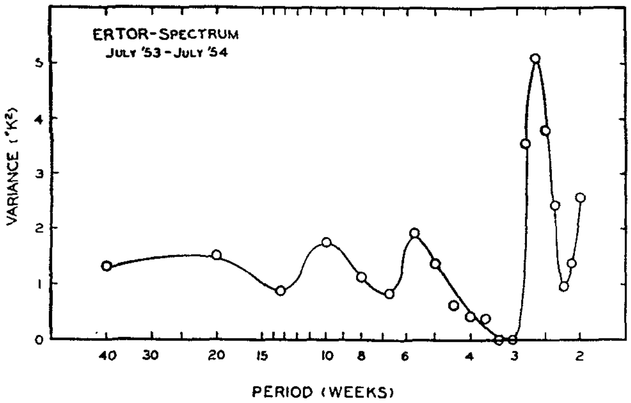

FIG. 1. Spectrum of first year's ERTOR data. Spectral estimates shown are based on weekly means.

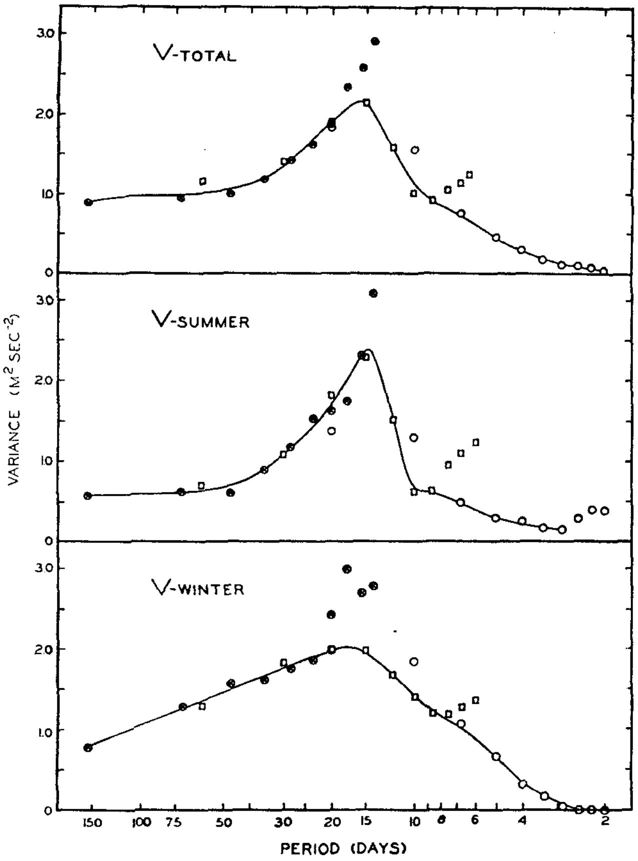

FIG. 2. Spectra of the 700-mb middle-latitude hemispheric zonal wind. Summer periods extend from May through October. 935 daily values were used in computing the total spectrum. The circled crosses represent spectral estimates based on weekly means; the squares, 3-day means; and the open circles, daily values.

because the point in question, although plotted at a frequency of 2 cycles per 20 days, actually represents an average spectral estimate for all frequencies between 1.5 and 2.5 cycles per 20 days—that is, between periods of 8 and 16.7 days. It is clear from the three-day spectrum that much of this interval may be as-

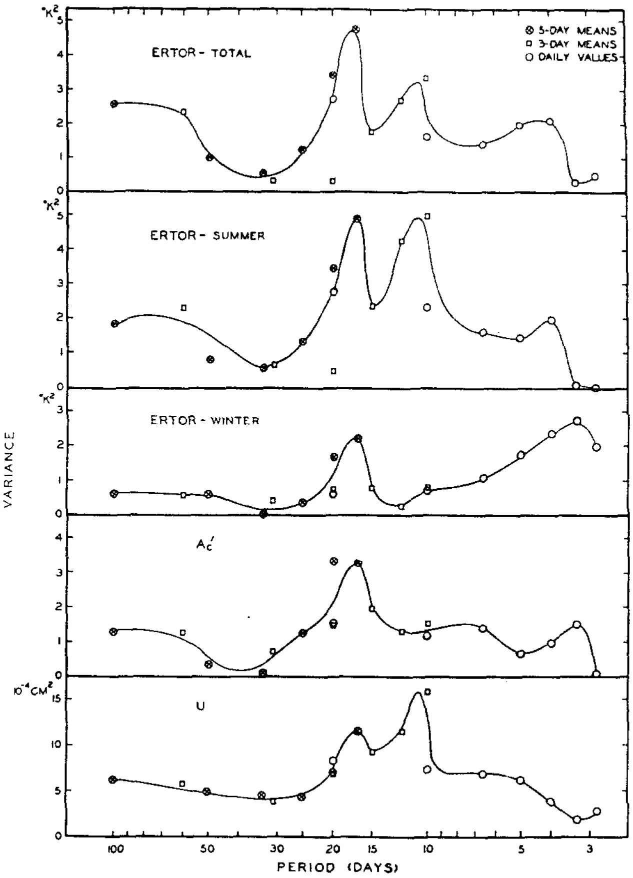

FIG. 3. Spectra of the ozone parameters. Total numbers of observations (days) upon which spectra are based are 310 for total ozone amount (u), 570 for infrared absorption (A_c'), and 557 for ERTOR. Summer periods extend from May through October.

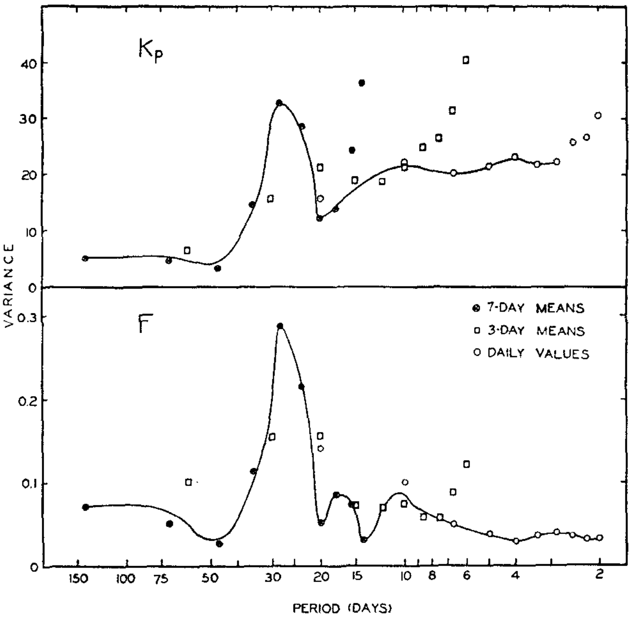

FIG. 4. Spectra of K_p, geomagnetic planetary index, and F, logarithm of Farthing's "net" coronal index. 876 and 426 daily values, respectively, were used in the reductions.

sociated with more variance, and some with less variance, than the particular central frequency. As a general rule, when there is a fairly large gradient of spectral intensities, one should not expect a point computed with little resolution to fall on a curve through points computed with greater resolution. Thus, in drawing the spectral curves, somewhat greater weight has been given to points with increased resolution, except where such points may be subject to aliasing.

4. The spectra

ERTOR: the first year's data. At an earlier date, one of the authors [7] reported on a power-spectrum of the ERTOR observations made in the year beginning July 1953. This spectrum, fig. 1, has provided much of the impetus for the present investigation. The spectrum was calculated for weekly means with $m = 20$. Because the length of record was only one year, the number of degrees of freedom associated with the spectrum is less than five, and thus the spectral estimates have large sampling errors. Nevertheless, there can be no doubt as to the reality of the spectral peak corresponding to a period of about 19 days. The lesser peaks at periods in the neighborhood of 10 weeks and 6 weeks have less statistical significance, although they would certainly warrant further investigation. However, although the length of record available for the present study is two and one-half times that of the earlier spectrum, it did not seem possible to achieve both sufficient resolution and enough degrees of freedom at these lower frequencies to justify further study at this time. Rather, the analysis was limited to periods less than about four weeks.

V, the 700-mb temperate-zonal wind, latitude 35N to 55N, longitude 175E to 5W, western hemisphere. The temperate-zonal wind was originally investigated because of a finding by J. M. Mitchell, Jr. (private communication) of preferred periodicities in that parameter of about $2\frac{1}{2}$ weeks and 9 to 10 weeks. We were informed of this finding shortly after the appearance of a small note by one of us [8] describing similar periods in the ERTOR data for the first year. Mitchell's results followed from his analysis of a lengthy series of data. The results of our subsequent analysis of this zonal wind for the period 8 July 1953 to 29 January 1956 appear in fig. 2. Three spectra were computed: winter, summer, and total. The winter periods extend from November through April.

The three spectra differ only slightly among themselves. The major feature, a maximum in the spectrum centered at periods near $2\frac{1}{2}$ weeks, is prominent in all three. The principal difference between the summer and winter spectra is one of degree; the spectral maximum is considerably sharper in the summer than in the winter.

ERTOR: all data. Three ERTOR spectra, based on data collected between 14 July 1953 and 18 January 1956 are shown in fig. 3. The breakdown between summer and winter is identical with that for the V-spectra.

In contrast to the V-spectra, there is an appreciable difference between the summer and winter spectra. In the winter, relatively large amounts of variance are associated with high frequencies, and the peak in the spectrum near $2\frac{1}{2}$ weeks, while undeniably present, contains less variance than the corresponding peak in the summer spectrum. Furthermore, in the summer spectrum, in addition to the peak at $2\frac{1}{2}$ weeks, there is another peak of approximately equal magnitude centered near $1\frac{1}{2}$ weeks. This second peak is completely absent in the winter.

A_c', absorption by ozone in the 9.6-micron band. The spectrum of A_c', fig. 3, is quite similar to the winter ERTOR spectrum. Here again the peak in the spectrum at $2\frac{1}{2}$ weeks is the one prominent singularity. The A_c'-spectrum differs from that of ERTOR in the winter primarily in the lack of rise in the spectrum toward high frequencies. The data upon which this spectrum is based extend from 24 July 1955 to 5 March 1956.

u, total ozone amount. In contrast to the single maximum of the A_c'-spectrum (infrared absorption by ozone), the u-spectrum (ultraviolet absorption by ozone), also shown in fig. 3, has a double maximum with peaks centered near $2\frac{1}{2}$ weeks and $1\frac{1}{2}$ weeks. In this respect, the u-spectrum is quite similar to the summer ERTOR spectrum, the principal difference being the relative intensities of the peaks at $1\frac{1}{2}$ and $2\frac{1}{2}$ weeks.

The data on which the u-spectra are based extend from 24 August 1954 to 5 March 1956.

K_p, geomagnetic planetary index. The one singularity in the spectrum of K_p, fig. 4, is a strong peak at a period of 4 weeks, the period of the solar rotation. At periods shorter than that of the solar rotation, there exists an appreciable amount of variance, but in the absence of any outstanding features this is attributed to noise. The noisiness may be due in part to the nature of the solar corpuscular emissions and in part to atmospheric circulation in the ionosphere, which disturbs the earth's magnetic field.

The daily sums of the 3-hr planetary K-indices from 8 July 1953 through 30 November 1955 have been used in the computations.

F, the logarithm of Farthing's "net" index of solar coronal activity. As expected, the most prominent feature of the F-spectrum, fig. 4, is the concentration of variance at frequencies corresponding to the period of the solar rotation. The slight peaks at $1\frac{1}{2}$ and $2\frac{1}{2}$

weeks are not significant according to the usual statistical tests.

The coronal indices upon which the F-spectrum is based extend from 2 November 1954 through 14 January 1956. A simple calculation has indicated that in order for the two small peaks at $1\frac{1}{2}$ and $2\frac{1}{2}$ weeks to be significant at the 0.05 significance level, assuming the population spectrum is as indicated in the computed spectrum, approximately three years' data would be required.

5. Interpretation of the spectra

Inasmuch as the spectra of the ozone parameters and the zonal wind all display a strong peak near a period of $2\frac{1}{2}$ weeks, one may conclude either that the entire atmosphere has a period of resonance of about $2\frac{1}{2}$ weeks or that some extraterrestrial influence is enforcing this period on the atmosphere. The spectral peak at $1\frac{1}{2}$ weeks does not appear in the zonal wind, which refers to a rather low level of the atmosphere (about 3 km), but is prominent in the ozone spectra, which refer to integrated atmospheric phenomena ranging from the surface to approximately 50 km. Moreover, inter-comparisons of the several ozone spectra strengthen this suggestion that the spectral energy near $1\frac{1}{2}$ weeks may be due to events which occur at very high levels.

A comparison of the u- and A_c'-spectra, fig. 3, shows at once that the large amount of energy resident near $1\frac{1}{2}$ weeks in the spectrum of the total ozone amount (ultraviolet absorption) has no counterpart in the spectrum of A_c' (infrared absorption). These two parameters are very closely related physically, the essential difference between them being a significant pressure dependence of the infrared absorption. It is thus possible for u to vary without similar variations occurring in A_c' only if the variations occur in regions of low pressure—that is, in the neighborhood of 30 to 50 km.

If, now, a comparison is made between the summer and winter ERTOR-spectra, it is further seen that the variations of the ozone which give rise to the peak near $1\frac{1}{2}$ weeks and which, as we have just seen, must occur at high levels is intense in the summer months (high sun) but weak or absent in the winter (low sun).

It is possible to summarize the information relating to the spectral region near $1\frac{1}{2}$ weeks in the following concise manner. In the summer, at very high levels of the atmosphere, it would appear that variations occur which tend to repeat with a period near $1\frac{1}{2}$ weeks. This periodicity is absent at other times of the year and in lower regions of the atmosphere.

The spectral peak near $2\frac{1}{2}$ weeks appears to be present at all levels of the atmosphere, or at least to heights of 50 km, but it, too, is stronger in the summer than in the winter, again as indicated by a comparison of the summer and winter ERTOR-spectra.

The implication of the relative widths of the peaks in the ozone and zonal-wind spectra would seem to be that the variations which cause the peaks filter down from the ozone to the lower atmosphere.

The analysis of the interrelations among the various parameters would be greatly expedited through performance of a cross-spectrum analysis [5; 6]. Such an analysis would yield the degree of coherence among the several variables as a function of frequency and also the lags of each relative to the others. However, statistical uncertainties of cross-spectra are large. In the present application, ambiguous results were obtained because of limited data. See [9] for details.

It seems reasonable to suppose, however, that periodic changes in ozone density could lead to like changes in ERTOR. Similarly, periodic temperature fluctuations in the upper stratosphere could be expected to influence ozone density corresponding, because of the appreciable temperature coefficient associated with the photochemical formation of ozone [10].

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APPENDIX A

Test of assumption applied in case of missing data

The principal complication encountered in computing spectra for the several ozone parameters is that presented by the existence of missing data. Because of this, there was a selection of data, some being omitted in computing one mean lagged product, while other data were omitted in computing other mean lagged products. The spectra, as computed, were based on these mean lagged products, which are approximations to the lag correlation coefficients multiplied by the variance of all the data. When there are no missing data, this approximation is quite good, inasmuch as the same data (except those at the very end and very beginning of the series) are used in computing all the mean lagged products. The approximation would be unacceptable if the variances of the data actually used in the calculations were to vary severely from lag to lag.

As a test of the validity of the approximations of the present study, 7- and 3-day mean spectra of A_c', based on lag correlation coefficients, were determined and may be compared with the spectra based on the mean lagged products. These results are tabulated below.

It is apparent that there are quantitative differences between the corresponding spectral estimates. It should be equally apparent that there are no major qualitative differences. The essential features of the spectra remain unchanged. Thus, it is felt that the assumptions, and the resulting major reduction in the calculations, are justified.

7-day means

k	r_k'	r_k	$kS'(k)$	$kS(k)$
0	1.0000	1.0000	0.0000	0.0000
1	0.6698	0.5937	1.2851	1.1830
2	0.6475	0.5933	0.6727	0.6639
3	0.6318	0.5724	0.5471	0.6866
4	0.5978	0.5405	0.8686	0.9759
5	0.5440	0.4999	1.0143	1.1111
6	0.5682	0.5435	1.4993	1.8350
7	0.4070	0.4149	2.2191	2.6076
8	0.4488	0.3906	2.0642	2.7374
9	0.3304	0.3127	2.1197	3.2488
10	0.1826	0.1622	3.4533	4.6648
		3-day means		
0	1.0000	1.0000	0.0000	0.0000
1	0.6617	0.6689	1.2638	1.3069
2	0.5432	0.5459	0.7255	0.7501
3	0.5280	0.5357	1.4559	1.3237
4	0.5082	0.5398	1.9286	1.8818
5	0.6358	0.6070	1.3685	1.5487
6	0.6268	0.6042	1.4973	1.6858
7	0.5373	0.5136	2.6051	2.3538
8	0.4904	0.4544	3.1147	2.5834
9	0.4488	0.4672	2.4492	2.5174
10	0.4130	0.3920	2.1412	2.8278

r_k' is the kth mean lagged product divided by the variance of all the 7- or 3-day means.

r_k is the kth mean lagged product divided by the root mean square of the variances of the two columns used in forming the products.

$kS'(k)$ is the logarithmic spectra estimate (k cycles per 140 (60) days) computed from the r_k'.

$kS(k)$ is the logarithmic spectral estimate (k cycles per 140 (60) days) computed from the r_k.

APPENDIX B

Numerical results

ERTOR: July 1953 to July 1954

Weekly means

k	N	$\overline{T_iT_j} - \overline{T}_i\overline{T}_j$	$kS(k)$
0	52	5.0562	0.0000
1	49	3.3218	1.3295
2	47	2.7269	1.5187
3	49	2.0129	0.8791
4	48	1.0738	1.7504
5	45	1.8623	1.1121
6	46	1.2017	0.8306
7	43	0.5753	1.9010
8	44	1.0738	1.3721
9	41	0.4017	0.6139
10	42	0.6270	0.4132
11	41	0.9128	0.3881
12	40	−0.2704	−0.4312
13	38	−1.5623	−0.1216
14	35	−1.8385	3.5378
15	34	−2.9386	5.0956
16	36	−2.6383	3.7899
17	34	−1.0851	2.4281
18	31	−1.1021	0.9589
19	33	−0.8679	1.3844
20	30	−1.8948	2.5647

		V—All data			V—Winter			V—Summer		
	k	N	$\overline{V_iV_j} - \bar{V}_i\bar{V}_j$	$kS(k)$	N	$\overline{V_iV_j} - \bar{V}_i\bar{V}_j$	$kS(k)$	N	$\overline{V_iV_j} - \bar{V}_i\bar{V}_j$	$kS(k)$
7-day means	0	133	4.3115	0.0000	65	4.5023	0.0000	68	2.8376	0.0000
	1	132	2.3808	0.8994	67	2.1039	0.7949	65	1.2151	0.5755
	2	131	1.8358	0.9531	64	1.2272	1.2982	67	0.9289	0.6265
	3	130	1.6496	1.0051	66	0.9018	1.5814	64	0.8850	0.6169
	4	129	1.4944	1.1997	63	0.6315	1.6282	66	0.8614	0.8995
	5	128	1.3731	1.4367	65	0.7505	1.7667	63	0.5567	1.1851
	6	127	1.1987	1.6293	62	0.6687	1.8652	65	0.5527	1.5380
	7	126	1.1730	1.8813	64	0.7098	2.4332	62	0.3414	1.6330
	8	125	1.1085	2.3572	61	1.1434	2.9925	64	0.0995	1.7519
	9	124	0.9140	2.5930	63	0.8245	2.6929	61	0.0792	2.3216
	10	123	0.4997	2.9267	60	0.6417	2.7950	63	−0.3021	3.0900
3-day means	0	310	5.3878	0.0000	150	5.5234	0.0000	160	3.9116	0.0000
	1	309	3.7953	1.1609	152	3.7742	1.2938	157	2.4617	0.7183
	2	308	2.2446	1.4203	149	2.1206	1.8371	159	1.0320	1.0781
	3	307	1.5916	1.9251	151	1.4228	1.9996	156	0.3769	1.8296
	4	306	1.7519	2.1574	148	1.2269	1.9737	158	0.8584	2.2964
	5	305	2.0050	1.5980	150	1.1482	1.6722	155	1.3674	1.5228
	6	304	1.8853	1.0273	147	1.0348	1.4143	157	1.1943	0.6313
	7	303	1.6209	0.9315	149	0.9457	1.2022	154	0.7604	0.6420
	8	302	1.4344	1.0636	146	0.7003	1.1924	156	0.6622	0.9550
	9	301	1.4661	1.1473	148	0.7025	1.2763	153	0.7676	1.0934
	10	300	1.4797	1.2471	145	0.5551	1.3684	155	1.0149	1.2234
Daily values	0	935	5.8985	0.0000	451	6.2550	0.0000	484	4.1877	0.0000
	1	934	5.3867	1.8449	453	5.8812	1.9788	481	3.5869	1.3828
	2	933	4.5297	1.5718	450	4.5668	1.8558	483	3.1181	1.3128
	3	932	3.7597	0.7707	452	3.7546	1.0698	480	2.3919	0.5002
	4	931	3.1282	0.4682	449	2.9872	0.6670	482	1.8941	0.2960
	5	930	2.6138	0.3028	451	2.5264	0.3611	479	1.3249	0.2506
	6	929	2.8133	0.1927	448	2.1387	0.1978	481	0.8620	0.1770
	7	928	1.8905	0.1218	450	1.8002	0.0588	478	0.5892	0.1525
	8	927	1.6497	0.1046	447	1.5438	−0.1600	480	0.3694	0.2926
	9	926	1.5252	0.0767	449	1.3667	−0.3440	477	0.2705	0.4000
	10	925	1.5609	0.0412	446	1.2627	−0.4050	479	0.4416	0.3992

		ERTOR—All data			ERTOR—Winter			ERTOR—Summer		
	k	N	$\overline{T_iT_j} - \bar{T}_i\bar{T}_j$	$kS(k)$	N	$\overline{T_iT_j} - \bar{T}_i\bar{T}_j$	$kS(k)$	N	$\overline{T_iT_j} - \bar{T}_i\bar{T}_j$	$kS(k)$
7-day means	0	129	11.7727	0.0000	61	2.4776	0.0000	68	12.1533	0.0000
	1	120	8.7153	3.2460	57	0.8404	0.5625	63	7.5811	3.2036
	2	115	8.6245	1.8166	53	1.3745	0.0438	62	7.1530	2.4788
	3	120	8.1757	0.9705	59	2.0048	−0.3652	61	6.0838	2.0324
	4	120	6.5049	1.2697	56	1.4536	0.0654	64	4.6775	2.6226
	5	116	7.0388	0.7773	56	1.3393	0.9322	60	5.2651	1.3770
	6	117	5.9586	1.7980	54	0.8121	1.6456	63	4.7664	2.5554
	7	114	4.6141	4.4879	55	0.6025	0.6525	59	2.1096	5.9236
	8	119	3.6238	6.1216	56	0.9373	3.3578	63	0.9985	7.2451
	9	116	2.1457	4.3835	56	−0.6025	1.9294	60	−1.1057	5.8567
	10	115	2.0318	2.9726	54	−0.0672	1.0527	61	−0.4475	5.9472
5-day means	0	178	10.8034	0.0000	89	2.7528	0.0000	89	8.4876	0.0000
	1	152	7.9312	2.5525	71	0.9493	0.6304	81	4.9511	1.8517
	2	145	6.9416	0.9993	63	0.8486	0.6041	82	4.5064	0.8344
	3	152	8.0462	0.5571	69	1.2256	0.0346	83	5.2779	0.5892
	4	153	7.9809	1.2437	73	1.2231	0.3858	80	5.5995	1.3599
	5	148	6.2006	3.4537	71	0.0220	1.6937	77	3.7915	3.4605
	6	152	6.1000	4.7875	73	−0.0903	2.2464	79	3.8033	4.9094
	7	156	6.8927	2.8819	77	−0.0841	1.7854	79	4.6500	3.0489
	8	153	5.6477	2.0577	75	0.2439	1.6500	78	3.0103	3.0969
	9	147	4.7722	2.9030	73	−0.3778	2.2764	74	1.7320	5.0876
	10	151	4.3944	3.3618	70	−0.4211	3.4751	81	1.7156	6.2400
3-day means	0	280	10.8649	0.0000	130	3.4365	0.0000	150	10.6720	0.0000
	1	227	7.3339	2.3551	95	1.3405	0.5768	132	6.7504	2.3295
	2	213	7.4936	0.3370	91	2.0308	0.4277	122	6.0069	0.6468
	3	210	7.9166	0.3583	94	1.0268	0.7734	116	7.0114	0.5389
	4	214	8.4464	1.7704	94	1.5089	0.7957	120	7.8431	2.3652
	5	208	7.7914	2.7016	84	1.2878	0.2886	124	6.3325	4.2918
	6	215	7.3465	3.3563	87	2.1098	0.8204	128	5.6102	4.9550
	7	226	6.7949	3.4546	97	1.2940	1.5867	129	5.7269	3.2918
	8	222	5.7196	4.2568	99	0.9809	2.2787	123	4.0039	3.5154
	9	203	6.4708	6.3015	83	1.4598	5.1536	120	3.8705	5.4415
	10	211	6.3617	7.8987	95	0.5590	8.5898	116	4.7047	6.2412
Daily values	0	557	11.8690	0.0000	238	3.8990	0.0000	319	11.7181	0.0000
	1	370	9.1001	2.7491	141	2.0788	0.6012	229	8.4501	2.7756
	2	350	8.3772	1.6291	133	0.1173	0.6831	217	8.3466	2.3394
	3	345	7.1051	1.4108	135	1.4967	1.0696	210	5.8693	1.6486
	4	338	7.6680	1.9988	128	1.4353	1.7370	210	6.5751	1.4528
	5	346	7.8811	2.1241	138	0.7634	2.3748	208	5.9890	1.9765
	6	353	5.7375	0.3066	131	1.4860	2.7402	222	3.7818	0.0835
	7	384	6.3077	0.5222	147	0.6620	1.9972	237	5.6506	−0.1824
	8	366	7.6478	2.5642	137	1.1035	−0.0458	229	7.0177	2.9958
	9	350	6.9960	2.5740	143	0.9456	−1.0017	207	5.7259	4.0997
	10	342	6.4608	2.0236	130	1.5307	−0.7416	212	5.2037	3.7244

		A_c'—All data			u—All data		
	k	N	$\overline{A_iA_j} - \bar{A}_i\bar{A}_j$	$kS(k)$	N	$\overline{u_iu_j} - \bar{u}_i\bar{u}_j$ $(\times 10^4)$	$kS(k)$
7-day means	0	136	5.4066	0.0000	80	2.8968	0.0000
	1	125	3.7071	1.2977	72	1.4923	0.6615
	2	121	3.5007	0.7000	67	1.6190	0.3426
	3	124	3.4160	0.5823	71	1.7635	0.1084
	4	123	3.2320	0.8888	68	1.7041	0.3454
	5	119	2.9512	1.0146	64	1.0844	0.9227
	6	119	3.0723	1.4642	64	1.2106	1.6090
	7	116	2.2265	2.1026	65	1.0089	1.5718
	8	123	2.4264	1.8783	67	0.7028	1.4881
	9	120	1.7865	1.8883	65	0.4740	2.1699
	10	118	0.9873	3.1514	63	0.3785	3.1233
5-day means	0	182	5.8771	0.0000	107	2.799	0.0000
	1	153	3.6798	1.2510	85	1.854	0.6246
	2	146	3.0060	0.3690	82	1.498	0.4980
	3	154	3.9077	0.1146	83	1.698	0.4541
	4	157	4.6776	1.2620	84	1.277	0.4361
	5	152	3.1332	3.3325	85	1.212	0.7033
	6	154	2.6317	3.2831	86	1.284	1.1515
	7	157	2.9820	1.5801	83	1.158	1.5068
	8	153	3.4572	1.2409	85	1.399	1.2385
	9	150	1.7938	1.5137	86	0.710	0.1667
	10	147	2.2317	2.2623	79	0.857	−0.3313
3-day means	0	286	6.4665	0.0000	161	3.129	0.000
	1	226	4.2792	1.2572	117	1.980	0.576
	2	216	3.5126	0.7091	110	1.294	0.379
	3	211	3.4141	1.4815	116	1.758	0.680
	4	215	3.2865	1.9425	113	1.500	0.919
	5	210	4.1114	1.3079	110	1.683	1.159
	6	218	4.1951	1.5220	118	1.632	1.591
	7	224	3.4746	2.6896	126	1.832	1.615
	8	223	3.1711	3.0038	115	1.342	1.438
	9	207	2.9019	2.3280	117	1.395	0.774
	10	212	2.6709	2.2083	112	1.415	−0.099
Daily values	0	570	6.7358	0.0000	310	3.367	0.0000
	1	380	5.3646	1.5196	198	2.704	0.8277
	2	354	4.3902	1.1639	176	2.169	0.7317
	3	353	4.0479	1.4071	174	1.795	0.6965
	4	351	3.7836	0.6582	177	1.579	0.6149
	5	352	3.4483	0.9711	176	1.780	0.3870
	6	362	3.4862	1.5286	183	1.437	0.1942
	7	390	5.9390	0.0913	199	1.570	0.2858
	8	367	3.1650	0.8181	184	1.344	0.5665
	9	352	3.0661	1.6452	178	1.712	0.5333
	10	349	3.1818	0.7446	177	1.420	0.2898

		F—All data			K_p—All data		
	k	N	$\overline{F_iF_j} - \bar{F}_i\bar{F}_j$	$kS(k)$	N	$\overline{K_iK_j} - \bar{K}_i\bar{K}_j$	$kS(k)$
7-day means	0	61	0.3413	0.0000	124	30.521	0.000
	1	60	0.2011	0.0720	123	8.142	5.030
	2	59	0.1012	0.0524	122	1.298	4.619
	3	58	0.1684	0.0275	121	7.015	3.232
	4	57	0.2240	0.1170	120	16.441	14.644
	5	56	0.1271	0.2866	119	2.885	32.797
	6	55	0.0227	0.2173	118	−3.546	28.717
	7	54	0.1084	0.0560	117	0.924	12.200
	8	53	0.1624	0.0861	116	5.473	13.917
	9	52	0.0526	0.0734	115	−5.924	24.138
	10	51	0.0228	0.0318	114	−10.341	36.080
3-day means	0	147	0.4597	0.0000	290	46.124	0.000
	1	146	0.3613	0.1020	289	19.864	6.688
	2	145	0.2589	0.1547	288	8.277	15.596
	3	144	0.1807	0.1564	287	2.818	21.070
	4	143	0.1350	0.0733	286	0.982	18.950
	5	142	0.1133	0.0718	285	1.433	18.900
	6	141	0.1465	0.0756	284	5.694	21.395
	7	140	0.2092	0.0581	283	7.364	24.929
	8	139	0.2594	0.0575	282	11.265	26.394
	9	138	0.3027	0.0876	281	17.416	31.345
	10	137	0.2753	0.1216	280	13.459	40.352
Daily values	0	426	0.4772	0.0000	876	67.077	0.000
	1	425	0.4119	0.1411	875	40.217	15.889
	2	424	0.3643	0.1007	874	25.083	22.070
	3	423	0.3219	0.0504	873	17.904	20.091
	4	422	0.2769	0.0392	872	14.482	21.296
	5	421	0.2445	0.0294	871	10.067	23.097
	6	420	0.2198	0.0356	870	6.165	21.777
	7	419	0.1853	0.0400	869	4.251	22.166
	8	418	0.1576	0.0357	868	5.545	25.794
	9	417	0.1372	0.0318	867	2.093	26.690
	10	416	0.1097	0.0328	866	1.721	30.446