SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 111, NUMBER 7

Roebling Fund

MONTEZUMA SOLAR-CONSTANT VALUES AND THEIR PERIODIC SOLAR VARIATIONS

BY
C. G. ABBOT
Research Associate, Smithsonian Institution

(Publication 3981)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
APRIL 19, 1949

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

Roebling Fund

MONTEZUMA SOLAR-CONSTANT VALUES AND THEIR PERIODIC SOLAR VARIATIONS

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We are convinced that solar-constant values from the Mount Montezuma, Chile, station are more accurate than those of any other Smithsonian station. This results from the meteorological superiority of the location. In three recent papers[1] (treating respectively of the 6.6456-day period in the solar radiation and in weather, of the trigger action of depressions of solar radiation to set off West Indian hurricanes, and of the effect of ionic bombardment of the earth to diminish solar radiation received here at times of great sunspot activity) I used the daily solar-constant values of Montezuma exclusively. The inclusion with them of less accurate data from our other stations would have been injurious in these studies of very small solar changes.

In volumes 5 and 6 of Annals of the Smithsonian Astrophysical Observatory, and in my paper "A Revised Analysis of Solar Constant Values"[2] the 10-day and monthly mean solar-constant values from several Smithsonian stations were combined in researches on long periods in solar variation. It seemed advisable to me to make a new search for long solar periodicities, using Montezuma data alone. I wished especially to test my former conclusion that all the periodic variations are integral submultiples of 273 months.

I have prepared a table of 10-day and monthly mean solar-constant values for Montezuma alone, from September 1923 to December 1947. They are given in table 1.

In table 1 the year and month are given in column 1. In column 2 appear the 10-day and monthly mean values of the solar constant, from Montezuma observations alone. Column 3 gives the number of days entering into these mean values. Readers should note that values in column 2 are to be understood as prefixed by the figures 1.9

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[1] Smithsonian Misc. Coll., vol. 107, No. 4, 1947; vol. 110, Nos. 1 and 6, 1948.

[2] Smithsonian Misc. Coll., vol. 107, No. 10, 1947.

TABLE I.—*Ten-day and monthly means, Montezuma solar-constant values*

Values given assumed to be prefixed by 1.9. Thus, 1.9536, etc.

1923			1924			1926			1927			1928		
9 I	536	9	12 I	506	5	3 I	439	7	6 I	479	8	9 I	—	0
II	531	8	II	470	1	II	515	4	II	427	6	II	442	4
III	540	8	III	518	5	III	393	8	III	433	9	III	410	4
M	536	25	M	508	11	M	435	19	M	447	23	M	426	8
			1925											
10 I	446	9	1 I	442	5	4 I	317	10	7 I	445	6	10 I	452	9
II	410	7	II	490	2	II	396	10	II	440	8	II	487	6
III	452	6	III	360	1	III	398	9	III	451	11	III	390	7
M	436	22	M	444	8	M	369	29	M	446	25	M	442	22
11 I	392	5	2 I	—	0	5 I	394	8	8 I	415	10	11 I	427	6
II	451	7	II	600	2	II	405	4	II	412	8	II	453	3
III	490	4	III	573	3	III	407	7	III	442	11	III	461	8
M	443	16	M	584	5	M	401	19	M	424	29	M	448	17
12 I	420	3	3 I	537	3	6 I	388	4	9 I	414	8	12 I	500	4
II	445	6	II	492	6	II	434	9	II	428	10	II	446	7
III	291	8	III	542	8	III	456	5	III	471	7	III	463	3
M	368	17	M	524	17	M	430	18	M	436	25	M	465	14
1924												1929		
1 I	416	7	4 I	536	8	7 I	439	10	10 I	481	7	1 I	450	1
II	443	8	II	530	8	II	424	9	II	438	5	II	590	3
III	459	9	III	477	3	III	433	11	III	417	9	III	485	2
M	441	24	M	524	19	M	432	30	M	443	21	M	532	6
2 I	369	8	5 I	463	8	8 I	472	8	11 I	450	8	2 I	432	4
II	460	1	II	484	9	II	433	3	II	446	5	II	390	3
III	422	6	III	479	8	III	475	6	III	436	5	III	335	4
M	396	15	M	476	25	M	466	17	M	445	18	M	385	11
3 I	523	9	6 I	420	4	9 I	441	9	12 I	479	7	3 I	443	3
II	380	7	II	496	5	II	396	5	II	388	4	II	360	9
III	434	7	III	480	5	III	457	8	III	381	7	III	422	5
M	453	23	M	469	14	M	437	22	M	421	18	M	393	17
									1928					
4 I	392	5	7 I	510	2	10 I	373	9	1 I	442	6	4 I	370	10
II	416	7	II	510	6	II	423	10	II	374	5	II	492	9
III	432	9	III	436	8	III	374	8	III	476	5	III	442	10
M	417	21	M	473	16	M	392	27	M	431	16	M	435	29
5 I	467	9	8 I	477	9	11 I	359	8	2 I	480	6	5 I	420	6
II	493	7	II	442	6	II	357	6	II	433	7	II	430	5
III	506	10	III	431	8	III	405	2	III	470	1	III	436	10
M	489	26	M	452	23	M	364	16	M	456	14	M	430	21
6 I	554	7	9 I	524	8	12 I	333	3	3 I	464	7	6 I	395	6
II	492	5	II	470	10	II	359	8	II	464	5	II	344	5
III	522	6	III	471	8	III	370	1	III	468	6	III	413	7
M	526	18	M	487	26	M	353	12	M	466	18	M	388	18
						1927								
7 I	511	7	10 I	452	8	1 I	396	9	4 I	430	8	7 I	397	8
II	544	10	II	500	6	II	357	3	II	411	8	II	407	9
III	470	9	III	458	9	III	375	2	III	408	6	III	420	9
M	510	26	M	467	23	M	385	14	M	417	22	M	409	26
8 I	542	5	11 I	420	6	2 I	348	4	5 I	436	9	8 I	396	8
II	411	8	II	487	10	II	467	7	II	511	8	II	398	6
III	390	5	III	470	6	III	—	0	III	468	9	III	402	6
M	442	18	M	464	22	M	424	11	M	470	26	M	399	20
9 I	462	5	12 I	482	10	3 I	—	0	6 I	472	9	9 I	397	6
II	483	7	II	460	3	II	500	6	II	475	4	II	381	9
III	431	8	III	497	7	III	466	9	III	460	3	III	416	9
M	457	20	M	484	20	M	479	15	M	471	16	M	397	24
			1926											
10 I	536	5	1 I	473	7	4 I	446	5	7 I	446	10	10 I	413	7
II	524	8	II	499	7	II	472	9	II	435	6	II	442	4
III	528	11	III	390	5	III	414	8	III	413	6	III	370	3
M	528	24	M	461	19	M	445	22	M	434	22	M	412	14
11 I	557	9	2 I	405	2	5 I	426	8	8 I	444	5	11 I	419	9
II	494	8	II	410	5	II	426	5	II	449	7	II	422	5
III	498	6	III	400	1	III	420	11	III	440	6	III	480	8
M	520	23	M	408	8	M	423	24	M	444	18	M	442	22

TABLE 1.—*Continued*

1929 12	I	468	5	1931 3	I	390	4	1932 6	I	446	5	1933 9	I	473	7	1934 12	I	535	6
	II	477	8		II	468	9		II	500	6		II	450	9		II	522	8
	III	426	5		III	514	9		III	505	6		III	504	5		III	520	2
	M	461	18		M	472	22		M	486	17		M	470	21		M	527	16
1930 1	I	460	2	4	I	520	5	7	I	532	5	10	I	493	3	1935 1	I	482	9
	II	412	4		II	462	4		II	390	1		II	500	7		II	460	2
	III	395	2		III	432	5		III	435	10		III	499	7		III	467	4
	M	420	8		M	472	14		M	462	16		M	498	17		M	475	15
2	I	398	6	5	I	——	0	8	I	456	7	11	I	438	5	2	I	455	4
	II	460	1		II	520	1		II	412	5		II	509	8		II	430	1
	III	480	5		III	460	2		III	382	5		III	510	1		III	410	2
	M	437	12		M	480	3		M	421	17		M	484	14		M	439	7
3	I	450	7	6	I	473	7	9	I	432	5	12	I	512	5	3	I	437	4
	II	422	8		II	480	2		II	447	6		II	480	4		II	——	0
	III	443	10		III	432	5		III	456	5		III	505	10		III	492	6
	M	438	25		M	459	14		M	445	16		M	502	19		M	470	10
4	I	444	8	7	I	570	2	10	I	414	5	1934 1	I	504	5	4	I	437	9
	II	401	7		II	593	3		II	310	6		II	450	4		II	488	5
	III	443	6		III	505	4		III	346	5		III	515	2		III	475	6
	M	430	21		M	549	9		M	354	16		M	486	11		M	461	20
5	I	450	4	8	I	485	4	11	I	370	7	2	I	555	2	5	I	478	10
	II	490	4		II	512	6		II	342	8		II	455	2		II	451	9
	III	470	4		III	456	7		III	377	6		III	462	6		III	478	9
	M	470	12		M	482	17		M	361	21		M	477	10		M	469	28
6	I	463	3	9	I	502	6	12	I	373	3	3	I	430	3	6	I	463	9
	II	462	4		II	518	5		II	457	4		II	478	5		II	484	5
	III	483	3		III	537	7		III	387	3		III	543	6		III	455	6
	M	469	10		M	520	18		M	411	10		M	496	14		M	466	20
7	I	437	8	10	I	544	7	1933 1	I	510	1	4	I	503	3	7	I	453	9
	II	490	1		II	450	6		II	472	5		II	456	8		II	460	3
	III	517	3		III	452	8		III	485	2		III	435	8		III	430	1
	M	462	12		M	482	21		M	480	8		M	455	19		M	453	13
8	I	473	3	11	I	431	7	2	I	477	3	5	I	480	6	8	I	484	7
	II	490	4		II	452	8		II	480	4		II	466	5		II	514	10
	III	479	11		III	460	7		III	——	0		III	440	11		III	460	9
	M	481	18		M	448	22		M	479	7		M	457	22		M	483	26
9	I	456	10	12	I	444	8	3	I	450	3	6	I	518	6	9	I	420	3
	II	340	2		II	477	7		II	373	3		II	516	5		II	419	8
	III	422	4		III	——	0		III	407	4		III	460	2		III	405	2
	M	433	16		M	459	15		M	410	10		M	508	13		M	417	13
10	I	453	9	1932 1	I	462	4	4	I	410	8	7	I	524	7	10	I	407	3
	II	470	6		II	447	3		II	457	9		II	502	6		II	469	8
	III	462	8		III	465	2		III	370	10		III	477	7		III	449	7
	M	461	23		M	458	9		M	411	27		M	501	20		M	451	18
11	I	482	5	2	I	435	4	5	I	384	10	8	I	507	4	11	I	515	2
	II	475	8		II	492	4		II	401	9		II	497	6		II	539	8
	III	528	5		III	432	4		III	414	5		III	499	7		III	516	8
	M	492	18		M	453	12		M	397	24		M	500	17		M	526	18
12	I	540	9	3	I	363	3	6	I	421	8	9	I	474	10	12	I	415	4
	II	535	10		II	447	7		II	426	8		II	490	9		II	437	3
	III	550	4		III	444	7		III	412	9		III	466	7		III	400	2
	M	540	23		M	431	17		M	420	25		M	477	26		M	421	8
1931 1	I	430	1	4	I	497	4	7	I	415	4	10	I	495	8	1936 1	I	378	6
	II	497	6		II	441	9		II	471	8		II	497	7		II	340	2
	III	——	0		III	440	3		III	449	7		III	515	8		III	300	1
	M	484	7		M	455	16		M	451	19		M	503	23		M	361	9
2	I	485	2	5	I	452	4	8	I	——	0	11	I	530	9	2	I	500	5
	II	497	6		II	410	5		II	428	6		II	528	5		II	492	5
	III	458	5		III	——	0		III	420	9		III	504	8		III	440	2
	M	480	13		M	429	9		M	423	15		M	520	22		M	487	12

TABLE 1.—*Continued*

1936			
3	I	304	9
	II	340	8
	III	412	9
	M	352	26
4	I	417	4
	II	440	2
	III	496	8
	M	466	14
5	I	463	6
	II	442	6
	III	466	10
	M	459	22
6	I	495	6
	II	461	8
	III	498	5
	M	482	19
7	I	504	6
	II	441	7
	III	455	11
	M	463	24
8	I	420	4
	II	470	6
	III	455	8
	M	452	18
9	I	385	4
	II	430	10
	III	486	9
	M	444	23
10	I	426	5
	II	494	8
	III	486	5
	M	473	18
11	I	500	6
	II	506	7
	III	484	7
	M	496	20
12	I	525	4
	II	496	5
	III	—	0
	M	509	9
1937			
1	I	—	0
	II	450	1
	III	477	4
	M	472	5
2	I	513	9
	II	470	4
	III	516	5
	M	504	18
3	I	389	8
	II	403	6
	III	407	8
	M	400	22
4	I	372	9
	II	424	7
	III	431	7
	M	406	23
5	I	343	3
	II	469	7
	III	490	6
	M	453	16
1937			
6	I	472	8
	II	451	7
	III	443	3
	M	460	18
7	I	—	0
	II	456	8
	III	459	7
	M	457	15
8	I	491	9
	II	474	9
	III	484	7
	M	483	25
9	I	449	7
	II	487	9
	III	404	10
	M	445	26
10	I	419	8
	II	434	10
	III	540	5
	M	452	23
11	I	503	9
	II	457	6
	III	505	6
	M	490	21
12	I	518	5
	II	570	3
	III	541	8
	M	540	16
1938			
1	I	490	1
	II	534	8
	III	520	3
	M	527	12
2	I	—	0
	II	440	2
	III	—	0
	M	440	2
3	I	505	2
	II	456	5
	III	400	1
	M	461	8
4	I	445	8
	II	432	6
	III	462	6
	M	446	20
5	I	458	9
	II	430	5
	III	396	7
	M	430	21
6	I	420	6
	II	454	5
	III	460	4
	M	442	15
7	I	441	8
	II	445	8
	III	437	6
	M	441	22
8	I	462	5
	II	466	8
	III	458	6
	M	463	19
1938			
9	I	462	6
	II	448	8
	III	479	10
	M	464	24
10	I	470	8
	II	495	6
	III	522	9
	M	497	23
11	I	495	6
	II	532	10
	III	537	3
	M	521	19
12	I	514	5
	II	538	9
	III	493	10
	M	514	24
1939			
1	I	—	0
	II	—	0
	III	400	2
	M	400	2
2	I	424	7
	II	—	0
	III	463	6
	M	442	13
3	I	420	3
	II	442	5
	III	452	8
	M	443	16
4	I	427	8
	II	453	7
	III	427	3
	M	437	18
5	I	420	6
	II	383	6
	III	393	11
	M	397	23
6	I	393	7
	II	378	8
	III	402	9
	M	391	24
7	I	420	8
	II	388	9
	III	398	6
	M	402	23
8	I	373	8
	II	354	5
	III	417	8
	M	385	21
9	I	476	7
	II	447	6
	III	452	8
	M	459	21
10	I	447	6
	II	426	7
	III	352	10
	M	399	23
11	I	380	4
	II	399	9
	III	404	8
	M	397	21
1939			
12	I	375	6
	II	473	7
	III	445	9
	M	435	22
1940			
1	I	460	5
	II	450	3
	III	453	11
	M	454	19
2	I	437	7
	II	434	10
	III	385	4
	M	426	21
3	I	469	8
	II	362	10
	III	401	7
	M	407	25
4	I	435	2
	II	458	9
	III	544	7
	M	489	18
5	I	519	9
	II	486	8
	III	510	9
	M	506	26
6	I	486	10
	II	491	7
	III	516	7
	M	496	24
7	I	520	9
	II	493	6
	III	525	6
	M	514	21
8	I	508	6
	II	484	8
	III	508	5
	M	496	19
9	I	552	6
	II	564	7
	III	479	8
	M	528	21
10	I	450	2
	II	472	4
	III	486	7
	M	476	13
11	I	408	6
	II	447	9
	III	414	7
	M	426	22
12	I	429	7
	II	492	5
	III	507	4
	M	468	16
1941			
1	I	483	7
	II	533	8
	III	410	1
	M	504	16
2	I	525	4
	II	—	0
	III	590	6
	M	564	10
1941			
3	I	575	4
	II	545	4
	III	540	9
	M	549	17
4	I	500	9
	II	520	4
	III	525	2
	M	509	15
5	I	553	7
	II	—	0
	III	602	6
	M	575	13
6	I	590	5
	II	575	2
	III	557	4
	M	575	11
7	I	637	3
	II	560	9
	III	554	5
	M	572	17
8	I	566	7
	II	542	4
	III	480	6
	M	529	17
9	I	540	8
	II	509	7
	III	585	2
	M	532	17
10	I	525	8
	II	479	7
	III	511	7
	M	506	22
11	I	515	6
	II	472	6
	III	500	9
	M	496	21
12	I	525	8
	II	492	4
	III	548	9
	M	529	21
1942			
1	I	565	8
	II	536	5
	III	494	5
	M	537	18
2	I	496	7
	II	499	7
	III	460	6
	M	486	20
3	I	413	3
	II	409	10
	III	444	5
	M	419	18
4	I	424	5
	II	464	10
	III	426	7
	M	443	22
5	I	422	4
	II	490	7
	III	482	9
	M	473	20

TABLE 1.—*Continued*

1942 6 I	483	7	1943 8 I	469	10	1944 10 I	468	10	1945 12 I	421	8	1947 2 I	360	1
II	475	6	II	485	4	II	432	6	II	409	7	II	410	3
III	464	7	III	512	11	III	364	8	III	391	8	III	420	4
M	474	20	M	490	25	M	420	24	M	407	23	M	409	8
7 I	494	7	9 I	470	9	11 I	455	8	1946 1 I	375	10	3 I	342	9
II	490	7	II	476	9	II	436	9	II	410	7	II	382	8
III	464	8	III	469	7	III	470	8	III	489	7	III	413	11
M	482	22	M	472	25	M	453	25	M	418	24	M	381	28
8 I	450	8	10 I	447	8	12 I	422	5	2 I	378	5	4 I	380	3
II	461	9	II	462	5	II	410	1	II	360	3	II	450	6
III	436	10	III	430	11	III	446	8	III	357	7	III	458	6
M	449	27	M	443	24	M	435	14	M	365	15	M	439	15
9 I	451	8	11 I	478	6	1945 1 I	420	2	3 I	381	7	5 I	450	2
II	443	3	II	390	1	II	413	7	II	363	8	II	443	7
III	450	8	III	410	2	III	440	1	III	393	7	III	411	7
M	449	19	M	453	9	M	417	10	M	378	22	M	430	16
10 I	443	8	12 I	450	1	2 I	503	9	4 I	492	9	6 I	384	9
II	440	5	II	415	4	II	435	6	II	488	5	II	470	8
III	456	9	III	502	10	III	480	2	III	370	5	III	454	9
M	447	22	M	475	15	M	477	17	M	459	19	M	435	26
11 I	439	8	1944 1 I	403	3	3 I	451	8	5 I	486	5	7 I	428	9
II	485	10	II	——	0	II	458	10	II	486	8	II	378	5
III	526	8	III	440	1	III	415	4	III	433	6	III	424	5
M	483	26	M	412	4	M	448	22	M	469	19	M	414	19
12 I	429	10	2 I	460	1	4 I	451	10	6 I	432	4	8 I	373	4
II	404	8	II	347	3	II	488	10	II	470	5	II	387	7
III	447	10	III	——	0	III	487	10	III	458	5	III	416	5
M	428	28	M	375	4	M	475	30	M	455	14	M	393	16
1943 1 I	404	9	3 I	377	6	5 I	469	10	7 I	484	5	9 I	422	6
II	419	9	II	377	4	II	453	10	II	495	6	II	432	5
III	390	6	III	368	8	III	481	8	III	406	8	III	395	4
M	406	24	M	373	18	M	467	28	M	455	19	M	418	15
2 I	465	2	4 I	373	6	6 I	466	9	8 I	409	8	10 I	429	9
II	486	8	II	434	8	II	436	10	II	396	7	II	433	7
III	443	6	III	427	6	III	418	6	III	420	2	III	479	7
M	467	16	M	413	20	M	442	25	M	405	17	M	445	23
3 I	425	4	5 I	457	8	7 I	464	8	9 I	444	7	11 I	479	8
II	501	8	II	442	5	II	472	9	II	450	6	II	454	8
III	439	8	III	431	8	III	475	6	III	415	4	III	438	4
M	461	20	M	443	21	M	470	23	M	439	17	M	460	20
4 I	427	10	6 I	441	9	8 I	421	7	10 I	388	5	12 I	433	4
II	443	9	II	430	10	II	417	7	II	421	7	II	454	5
III	459	7	III	443	10	III	243	6	III	428	7	III	435	4
M	441	26	M	438	29	M	366	20	M	415	19	M	442	13
5 I	463	7	7 I	400	5	9 1	398	6	11 I	437	4			
II	467	10	II	444	9	II	427	6	II	395	4			
III	465	4	III	393	7	III	417	7	III	270	1			
M	465	21	M	417	21	M	414	19	M	400	9			
6 I	503	6	8 I	452	8	10 I	441	7	12 I	300	1			
II	497	4	II	391	7	II	391	9	II	——	0			
III	498	5	III	363	6	III	324	7	III	398	5			
M	500	15	M	407	21	M	386	23	M	373	6			
7 I	484	7	9 I	395	10	11 I	486	5	1947 1 I	492	4			
II	443	7	II	347	3	II	409	9	II	450	1			
III	496	9	III	316	5	III	465	10	III	473	3			
M	476	23	M	365	18	M	448	24	M	480	8			

to give the complete solar constant in calories per square centimeter per minute.

Figure 1 shows graphically in curve A the march of the monthly mean values given in table 1. Curve B, on the same scale, gives departures from 1.945 calories remaining after 14 periodicities specified in table 2, below, have been removed from the original data given in column 2, table 1.

Table 2 also gives the yearly mean values, and numbers of days entering into them. It gives also smoothed-curve values derived from these yearly data, after plotting them as shown in figure 2. In the statistical search for periodic variations reported below, the smoothed-curve yearly mean values of table 2 were first to be removed by subtraction from the original monthly means. In order to do this the smoothed yearly means were first expanded graphically into a plot of smoothed monthly means. I do not take space to publish these smoothed monthly means, as their simple derivation will be easily understood, and as it makes no appreciable errors in the periodicities, to be given in table 2, whether these smoothed monthly means for eliminating yearly changes of the solar constant are the best that could be found or not; for these periodicities are found as means from statistical tables including many repetitions of the periods, and local errors are smoothed out.

In previous analysis of solar-constant values [3] numerous periodicities in solar variation were found to proceed simultaneously, all being approximately integral submultiples of 273 months in length. I did not wish to adopt this master period of 273 months in this present research without independently confirming it from Montezuma data alone. Figure 2, however, itself seems to indicate that a period of about this length would fit the yearly variations of the solar constant. There are researches of other authors which support the validity of a period approximating two 11-year sunspot cycles, as being in evidence in various solar and terrestrial phenomena. Thus G. E. Hale discovered that magnetism in sunspots reverses its polarity in a remarkable way with each successive sunspot cycle of 11 years, so that the sun's magnetic condition is restored only after two 11-year cycles pass, or about 22$\frac{2}{3}$ years. A. E. Douglass has remarked a 23-year period in tree-ring widths. Various meteorologists have found it in terrestrial data. I myself pointed out that Wild's meteorological studies of the Russian Empire, when supplemented by later data, showed very clearly a 23-year cycle in weather at St. Petersburg.

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[3] Ann. Astrophys. Obs., vol. 6, p. 181, 1942; Smithsonian Misc. Coll., vol. 107, No. 10, 1947.


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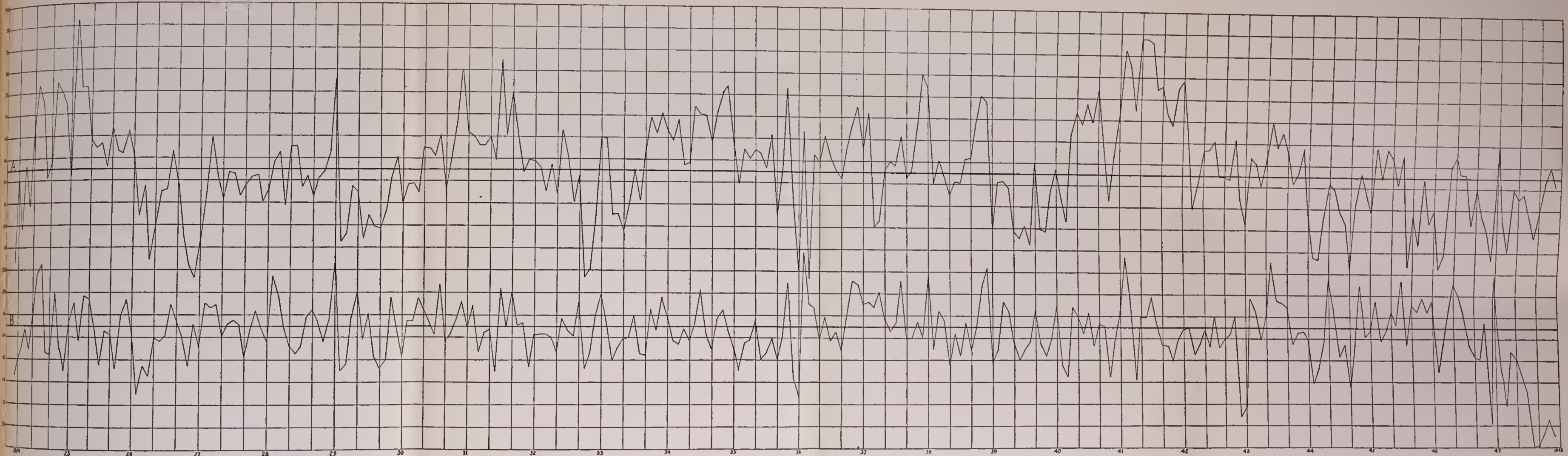

FIG. 1.—A, monthly mean march of solar constant, December 1923–December 1947, Montezuma station; B, residuals after periodic fluctuations removed.

Nevertheless, I began this present research without assuming a 273-month master period. First of all I removed the yearly variation from the values in column 2, table 1, as noted above. I then plotted the residual values and found that by far the most prominent periodic variation displayed in a large-scale plot of the residuals was of about 39 months. Seeking to fix its length as accurately as possible, by careful inspection of the large-scale plot, I finally decided on 39½ months. I am not sure that the period may not be 39 months, which is exactly 1/7 of 273 months; for the presence in the data of many other periodicities, and of accidental errors of observation, makes fixing of the exact length of a long period doubtful. Nevertheless, a table was prepared of seven columns, alternately of 39 and of 40 months in length. The mean of these columns is plotted in figure 3, *c*. As the reader will see, the march of this 39½-month periodicity is nearly a regular sine curve, and its amplitude is 0.0069 calorie, more than one-third of 1 percent of the solar constant.

The 39½-month periodicity was removed by subtraction to give a second list of monthly residuals. These also were plotted on a very large scale. There showed then a periodicity of considerable amplitude, approximately 91 months in length. A table 91 months long of three columns was made from the second residuals. With so few columns entering into the mean it seemed best to smooth the mean values by 5-month running means of them. The smoothed values being plotted, the 91-month periodicity appeared plainly, but superposed thereon there appeared a period of $\frac{1}{6}$ of 91 months. As it would be preferable to determine this curve of about 15 months by itself at a later stage, a smooth curve was drawn of 91-months period, cutting symmetrically through the 15-month superposed excrescences. The 91-month periodicity had the amplitude 0.0054 calorie. It is not of sine form, but rises rapidly to maximum, and falls slowly to minimum, like the well-known sunspot frequency curve of 11 years. This 91-month periodicity was removed from the data, leaving a third list of residuals, which were plotted on a large scale.

The third list, when plotted, showed clearly a strong periodic fluctuation of about 68 months. This was determined by forming a table of four columns, taking their mean, smoothing it by 5-month running means, and plotting the smoothed means in a curve given in figure 3, *b*. Very clearly there is a period of 1/7 of 68 months superposed on the principal curve. Not wishing to evaluate a 9¾-month periodicity until a later stage, I drew a smoothed curve as shown in figure 3, *b*. It is nearly of sine form, and has an amplitude of 0.0053 calorie, slightly under one-third of 1 percent of the solar constant.

It was now apparent from the behavior of the yearly variation of the solar constant, the excellence of the 39½-, 91-, and 68-month periodic curves, and the superposition of curves of 91/6 and 68/7 months, as noted above, that it is quite justified to regard 273 months as a master cycle in solar variation, and that many periodicities, nearly or exactly integral submultiples of 273 months, exist simultaneously therein. In all my subsequent search for periodicities in solar variation, as displayed in Montezuma solar-constant values, I accepted the 273-month master period, and sought for integral submultiples of it.

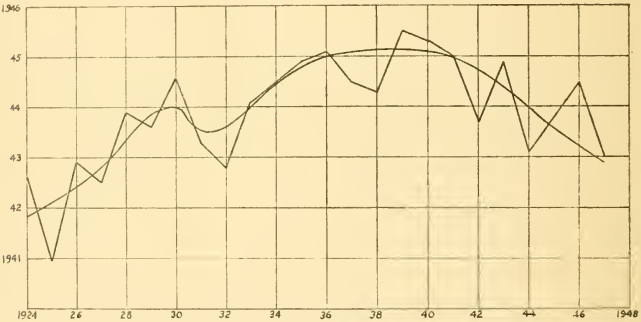

FIG. 2.—Yearly march of solar constant, 1924-1947.

Proceeding by the methods explained above, the periodicity of 54½ months was next sought, found, and determined. Its amplitude is 0.0020 calorie, its form, like that of 91 months, comprises a rapid rise and slow fall. The curve, though smoothed by 5-month running means, has excrescences indicating the encroachment of a period approximating 8 months. Study of it was postponed, like those found with the 91- and 68-month periodicities, for later determination.

Attempts were then made to determine periodicities of 45½, 34, and 30⅓ months. But these proved so far dominated and obscured by variations of shorter periods that they were all passed over for the time. However the curve drawn when seeking a periodicity of 30⅓ months clearly indicated a periodicity of half that length, of fairly large amplitude. So the next search made concerned 15⅙ months. It will be noted that solar variations of 273, 91, 68, and 54½ months period had now been extracted from the monthly data, and that the fourth list of residuals was now being used.

A period of $15\frac{1}{6}$ months is 1/18 of 273 months. It was now practicable to divide the data into three groups, and tabulate them in 6-line tables of 15 columns.[4] In this way it could be decided if the supposed $15\frac{1}{6}$-month period continued in all three sections of the interval of 273 months. Figure 3, *a*, gives the mean curves for the three tabulations and the general mean. The three group means show no certain secular displacement of maxima and minima, have nearly similar forms, and nearly equal amplitudes. Hence their mean was taken as shown in figure 3, *a*, and is regarded as a very well-determined periodicity of solar variation with an amplitude of 0.0030 calorie. This mean curve, being well supported in detail by the group means, is used unsmoothed, and the departures of it from

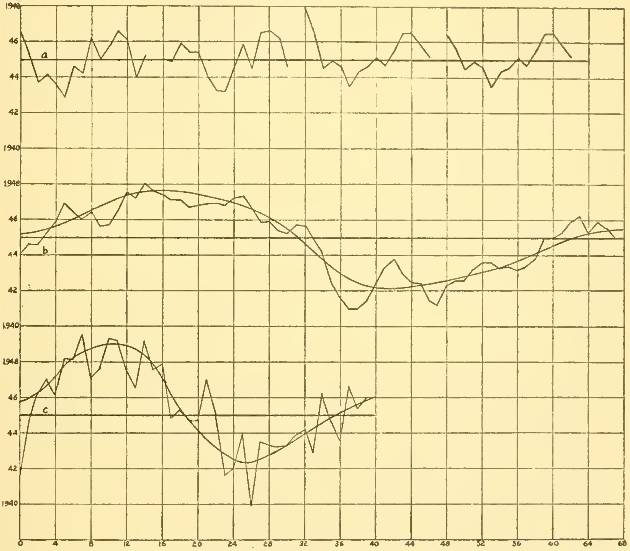

FIG. 3.—Examples of solar periodic fluctuations. *a*, $15\frac{1}{6}$ months. Observations 1924-31; 1932-39; 1940-47; and 1924-47; *b*, 68 months. 1924-47; *c*, $39\frac{1}{2}$ months. 1924-47.

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[4] Whenever a periodicity not of exact months is determined, values or columns are omitted occasionally in tabulations, so that the mean values of columns fit the exact length of the periodicity.

1.945 calories were subtracted from the fourth list, giving a fifth list of residuals.

Though convinced of the validity of the assumption of a 273-month master cycle, I have passed over any discussion of the sunspot cycle of 11⅓ years, approximating one-half of the master period. I now take up its consideration before noting the discovery of several other periodicities. Figure 2, which displays the variation of the yearly means of Montezuma solar-constant values, does, indeed, show depressions at the years 1925, 1931-32, 1937-38, and 1944. These may indicate a sunspot-cycle influence, but might better be attributed to the 68-month cycle which has already been discussed. Moreover, these depressions appearing in figure 2 are very small, with amplitudes only about 1/12 of 1 percent of the solar constant, yet the 68-month curve, when specifically determined as given above, has an amplitude approaching ⅓ of 1 percent.

Meteorologists recognize that the 11-year sunspot cycle is reflected in temperature, precipitation, and barometric pressure. Aldrich, also, has shown [5] by the study of individual daily values of the sunspot numbers, and of solar-constant values, that there is a complex correlation between these phenomena. But my residual plots of monthly solar-constant values do not show any 136-month periodicity of appreciable amplitude. This is not really in contradiction to the findings of meteorologists. It is well known that the sunspot areas bombard the earth with electric ions. These, by acting as centers of condensation for water vapor and dust in the earth's atmosphere, may very well be competent to produce meteorological changes. Besides this, the ozone contents of the atmosphere may be affected by them in a way to influence meteorological phenomena. So we may recognize two kinds of solar influences on meteorology. One depends on variations of the solar radiation, the other on variations of ionic bombardment.

Having discovered and evaluated periodicities of 273, 91, 68, 54½, 39½, and 15⅙ months in the variation of solar radiation, as evidenced by monthly mean solar-constant values of Montezuma, I next used the original 10-day mean values to seek for periodicities of less than 12 months. For such short periods the longer ones hitherto discussed produce no sensible interference. It would be tedious to recite all these trials. The method was always the same. By means of a long paper scale divided at regular intervals to represent a suspected period, I tested on the long plot of 10-day means whether such a

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[5] Smithsonian Misc. Coll., vol. 104, No. 12, 1945.

period seemed to be likely. If it seemed so, I arranged the 10-day mean values in groups of tables, each comprising about one-fourth of the total interval 1924-1947. They were never less than six lines long, and with as many columns as there were 10-day intervals in the proposed period. Where periods were not exact multiples of 10 days, values were omitted, or columns were omitted, occasionally, to bring the average lengths of the lines to that of the proposed period. The criterion of a true period was always that the several group tables agreed substantially in their means, as to phases and amplitudes of the suggested period, throughout the whole 273 months. Such good agreement is shown for the $15\frac{1}{6}$-month period in figure 3, *a*. In several cases proposed periods failed to meet this test, and were rejected. Sometimes the phases shifted regularly from group to group through the 273-month interval. In such cases the period was shortened or lengthened to give unchanging phases.

As a result of this branch of the investigation, periodicities of 5 2/15, 8.035, $9\frac{3}{4}$, $11\frac{1}{3}$, 11 15/16 months were recognized as true, according to the above criterion. Being incommensurable in length, there was no need to subtract them one by one from the data. They could not materially influence each other. After determining them in the 10-day mean data, they were transformed into monthly means. Then their marches were tabulated throughout the 273 months, their amplitudes added algebraically at each month, and the algebraic total per month was subtracted from the fifth residual list, remaining after removing the longer periodicities named above. This left a sixth list of monthly residuals for further exploration.

To shorten a tedious story, the methods explained above, when applied to the sixth list of residuals, discovered additional periodicities of $14\frac{1}{3}$, $19\frac{1}{2}$, and $24\frac{1}{2}$ months. When all had been removed from the data, no other periodicities seemed worth investigation in the residual plot remaining. It is plotted as curve B of figure 1.[6] The mean of the departures from 1.945 calories in curve B is 0.00189 calorie, or 0.097 percent of the solar constant. Many of the larger departures, which materially raise the mean as just given, occur in

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[6] One disturbing feature will be noted in figure 1, B. Though the year 1947 shows no remarkable eccentricity in curve A, it gives a great slump of $\frac{1}{2}$ percent in curve B. This is strange, for all the periodicities seem to fit the last year's data, including 1946, as well as the earlier years, as we see from figure 1, B. One notes, however, that curve A of figure 1 is almost entirely below 1.945 calories in 1947. It may be that the Montezuma values of 1947 are subject to a yet undiscovered error. Further observations of future years will decide.

TABLE 2.—*Detailed periodicities*

From Montezuma solar-constant observations

Based on December 1923

Period in months	Amplitude 0.00	Denominator of approximate fraction of 273	March of departures from 1.945 calories in units of $\frac{1}{10,000}$ calorie.																	
$5\frac{2}{15}$	11	53	−6	−1	0	5	3													
8.035	19	34	−1	−5	−9	2	−7	5	10	0										
$9\frac{3}{4}$	16	28	3	0	10	−5	−5	−2	6	−2	−6	2								
$11\frac{1}{3}$	27	24	−10	−4	2	3	3	3	8	17	16	12	8							
$11\frac{15}{16}$	29	23	4	12	−2	1	−17	−3	1	3	4	−1	0	−2						
$14\frac{2}{5}$	25	19	−1	−8	−4	−2	0	3	3	10	0	6	15	17	4	−8				
$15\frac{1}{6}$	30	18	14	6	−5	−1	−4	−15	−7	−4	1	−3	5	15	15	9	2			
$19\frac{1}{2}$	27	14	4	1	6	9	6	12	16	0	2	−11	2	−2	−6	−4	3	−4	−4	−1
			10																	
$24\frac{1}{2}$	38	11	0	5	−5	−10	−23	2	6	8	9	13	13	12	10	2	0	2	7	5
			0	−25	−10	−7	−7	−7	(−2)											
$39\frac{1}{2}$	69	7	10	11	13	15	22	28	33	37	40	42	43	42	41	40	36	30	21	10
			3	0	−6	−11	−15	−22	−25	−26	−25	−24	−20	−18	−16	−14	−11	−8	−4	1
			3	6	9															
$54\frac{1}{2}$	20	5	−2	−1	−1	0	1	2	3	5	6	7	8	10	11	12	13	13	13	13
			12	10	8	5	3	2	0	0	−1	−2	−3	−4	−5	−6	−6	−7	−7	−7
			−7	−7	−7	−7	−6	−6	−5	−5	−5	−4	−4	−3	−3	−3	−2	−2	−2	−2
68	53	4	4	5	6	7	8	9	10	12	14	17	20	21	23	25	25	24	23	22
			21	21	20	20	20	19	18	17	16	14	12	9	6	2	−2	−6	−10	−15
			−20	−23	−25	−26	−27	−28	−28	−28	−28	−27	−26	−25	−24	−23	−23	−21	−20	−19
			−17	−15	−13	−10	−8	−6	−4	−2	0	1	[illegible]	3	4	4				
91	54	3	−2	−2	−2	−1	0	1	2	3	5	6	8	11	13	15	18	21	23	25
			27	28	28	29	29	30	30	29	28	28	26	24	21	18	15	13	11	10
			7	5	4	3	1	0	−1	−2	−2	−2	−3	−3	−4	−4	−4	−4	−5	−5
			−5	−5	−5	−6	−7	−8	−9	−10	−12	−13	−15	−17	−18	−20	−21	−22	−23	−24
			−24	−24	−24	−24	−23	−23	−22	−20	−19	−17	−15	−13	−11	−10	−8	−6	−4	−3
			−2																	
23 year	46	1	−19	−36	−16	−20	−6	−9	+1	−12	−17	−4	0	+4	+6	0	−2	+10	+8	+5
			−8	+4	−14	−7	0													
23 year smooth			−27	−24	−21	−17	−12	−7	−5	−10	−9	−5	−1	+3	+5	+6	+6	+6	+6	+5
			+3	−1	−5	−9	−12													
Year			1924	5	6	7	8	9	1930	1	2	3	4	5	6	7	8	9	1940	1
No. of days obs.			249	218	236	245	213	226	198	175	176	206	213	196	214	228	209	227	245	197
Year			1942	3	4	5	6	1947												
No. of days obs.			262	245	219	264	200	207												

the months December to February, when the atmospheric conditions at Montezuma are less favorable, and when many days are lost to observation. It cannot be claimed that the periodicities removed are perfectly correct in forms. Hence the final residuals are larger than they should be on this account also. We may conclude that of the variations of solar radiation indicated in figure 1,A, and which exceed 1 percent in range, accidental error of observation contributes less than 2/10 percent, and the periodic variations nearly 1 percent of the total range.

In table 2 I gave the details of the 14 periodicities in the variation of solar radiation which have been discovered. There may be others of less than 5-months period, some of minor amplitude, and still others exceeding 273 months in period, which our observations have not yet continued long enough to discover. Indeed the large fluctuations of Great Lakes levels occurring at intervals of about 45 and 91 years seem to indicate that the double and quadruple of the master period of 273 months are of very great importance in meteorology. There is also the noted Bruckner period, of about three sunspot cycles, which may also be found eventually in solar-constant values if they continue to be observed for some years longer.