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Evidences for a shift in barometric pressure, air temperature and rainfall patterns circa 1920, and its possible relation to solar activity

Evidencias de un cambio en los patrones de la presión atmosférica, la temperatura del aire y la precipitación pluvial alrededor de 1920 y su posible relación con la actividad solar

Norma Sánchez Santillán,
Alfonso Esquivel Herrera y
Rubén Sánchez-Trejo

Depto. El Hombre y su Ambiente. UAM-Xochimilco. e-mail: santilla@cueyatl.uam.mx

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ABSTRACT

A survey of 300 meteorological stations worldwide located showed that nearly half of the stations presented a pattern change in the correlations between the sunspot number and barometric pressure, air temperature and precipitation, around 1920. This change was mainly from a negative correlation to a positive correlation. Furthermore, we also found strong correlations between sunspots and pressure and precipitation in both tropical and extratropical latitudes; for the temperature the strong correlations appear mainly in extratropical zones.

Keywords: Climatic reversal, climatic variability, sunspots.

RESUMEN

Se analizan los registros de 300 estaciones meteorológicas distribuidas mundialmente, encontrando que en la mitad de éstas se presentaba un cambio en el patrón de las correlaciones entre el número de manchas solares y la presión barométrica, la temperatura y la precipitación pluvial, que se reportó alrededor de 1920. Este cambio consistió principalmente en un cambio en el signo de la correlación, de negativo a positivo. Además, encontramos fuertes correlaciones entre el número de manchas solares y la presión barométrica y la precipitación pluvial, tanto en latitudes tropicales como extratropicales; las correlaciones fuertes con la temperatura sólo se presentan en las zonas extratropicales.

Palabras clave: Rompimiento climático, variabilidad climática, manchas solares.

INTRODUCTION

Recently, Mendoza and Ramírez (1999) showed that during times of low solar activity sunspots dominate over bright features within the time scale of solar cycles and viceversa. They identified 4 periods: from circa 1530 to 1715, and from circa 1780 to 1915 the sunspots dominated over bright features, the associated cycle lengths were longer (L > 10.941) and the Earth's temperature was relatively low. From circa 1725 to 1789, and from circa 1920 up to the present time the solar cycle has been dominated by bright features, the cycle lengths are shorter (L < 10.94) and the temperatures have been relatively higher.

It is this last change of the Sun's behavior, which occurred around 1920, the one that has been obviously most documented. In fact several papers have reported that sign reversals in meteorological variables such as temperature, rainfall, water level, etc., occurred in various locations around 1920: Schuurmans (1975) and Kullmer (1943) observe this situation in 1922 for the barometric pressure, dominant winds and tropical storm frequency. Starr and Oort (1973), King (1973, 1975), Eddy (1976) and King *et al.* (1974) noticed this change in the temperature pattern during the period from 1921 to 1930. King *et al.* (1974), King (1975) and Cornish (1982) noticed a shift in precipitation patterns within the period from 1922 to 1925. Clayton (1934) observed a similar shift in the apparent dependence of water levels in Lake Victoria after 1920.

It is the purpose of the present paper to assess if the claimed change in patterns of the main meteorological variables, namely barometric pressure, temperature and precipitation, ocurred around 1920.

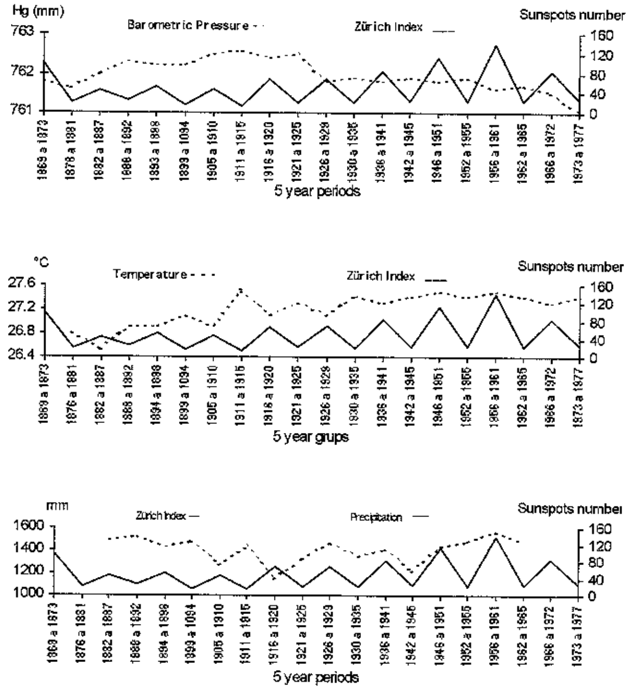

Figure 1. Zürich Index as compared to climatic variables: (a) Barometric Pressure in la Habana, Cuba; (b) Temperature in Bombay, India; (c) Rainfall in Curitiba, Brazil.

MATERIAL AND METHODS

We surveyed 300 meteorological stations worldwide located for barometric pressure, temperature and precipitation data (Clayton, 1927, 1934 and 1959). From these, a time series of five-year moving averages for each of the variables was computed; this was performed in order to smooth the original series. We plotted each of these smoothed series *versus* the R_z sunspot estimates time series, where R_z is Wolf's sunspot number, also known as Zurich's relative sunspot number (Herman & Goldberg, 1978). Fig. 1a shows an example for the barometric pressure in La Habana Cuba; Fig. 1b displays an example for the temperature in Bombay India; and Fig. 1c presents an example for precipitation in Curitiba, Brasil.

Linear correlations for the five-year averages -of each of the three meteorological variables considered- versus R_z were performed and the correlation coefficients were computed. These analysis were performed separately for the data from 1869 to 1925 and for those from 1926 to 1977. Histograms of the correlation coefficients that included data of the stations considered were plotted for each of the former periods and a non-parametric test (Kruskal-Wallis' ANOVA) was performed. This test was chosen because a prior assumption of normal distribution is not needed.

RESULTS

In nearly half of the stations the plots showed a change in the patterns of the meteorological variables within the period 1920 to 1925; therefore the data were divided in two periods 1869 to 1925 and 1926 to 1977, and the correlations between the meteorological parameters and the sunspots numbers were computed separately for each period. The results appear in Tables 1, 2 and 3 for the barometric pressure, the temperature and the precipitation respectively. These tables contain the localities and countries, their geographical coordinates, their correlation coefficients for both periods and the number of five-year average data pairs considered for each locality. These tables show that the change of pattern occurs either as a sign reversal of the correlation coefficient -positive to negative or viceversa- or as a variation of

Table 1. Location of stations and their correlation coefficients of mean annual Barometric Pressure *vs* Sunspots.

Locality	Country	Latitude	Longitude	Correlation coefficient 1869-1925	Correlation coefficient 1926-1977	5 years groups
Aden	Arabia	12° 46' N	45° 03' E	-0.608	0.203	18
Bombay	India	18° 55' N	72° 54' E	-0.385	0.009	20
Bangalore	India	12° 58' N	77° 37' E	-0.074	0.112	19
Nagpur	India	21° 00' N	79° 09' E	-0.443	-0.138	20
Madras	India	13° 04' N	80° 15' E	-0.556	0.135	20
Jaipur	India	26° 55' N	75° 52' E	-0.403	-0.063	19
Puerto Blair	India	11° 41' N	92° 45' E	-0.275	0.260	20
Manila	Philipines	14° 35' N	120° 59' E	-0.684	0.550	17
Stykkysholm	Iceland	65° 05' N	22° 46' W	0.297	-0.038	20
Thornshavn	Hovijg	62° 03' N	06° 45' W	-0.025	-0.254	19
Gjesvar	Norway	71° 06' N	25° 22' E	-0.108	-0.291	19
Viena	Austria	48° 15' N	16° 22' E	-0.317	-0.141	20
Goya	Argentina	29° 09' S	59° 15' W	-0.243	-0.205	19
Córdoba	Argentina	31° 25' S	64° 12' W	0.479	0.288	20
Corrientes	Argentina	27° 27' S	58° 49' W		0.167	6
Punta Arenas	Argentina	53° 10' S	70° 54' W	-0.225	0.151	17
Buenos Aires	Argentina	34° 36' S	58° 22' W	0.352	-0.014	20
Greenwich	England	51° 20' N	0° 00'	0.796	0.160	20
Helsinsky	Finland	60° 10' N	24° 57' E	0.316	0.274	18
Madrid	Spain	40° 24' N	03° 41' W	0.160	0.010	20
Bismark	U.S.A.	46° 47' N	100° 38' W	-0.133	-0.136	18
El Paso, Texas	U.S.A.	31° 47' N	106° 30' W	-0.002	0.206	18
Red Bluff	U.S.A.	49° 10' N	122° 15' W		0.518	5
Portland	U.S.A.	45° 03' N	122° 40' W	0.445	-0.430	19
Cape Town	Islas Canarias	33° 56' S	18° 29' E	-0.396	0.043	19
Gibraltar	England	36° 06' N	05° 21' W	0.183	-0.026	20
Nikolaesky	C.I.S.	53° 08' N	140° 45' E	-0.927	0.103	17
Obdorsk	C.I.S.	66° 35' N	66° 35' E	0.666		5
Arcángel	C.I.S.	64° 35' N	40° 36' E	0.748	0.620	18
Sn Petesburgo	C.I.S.	59° 56' N	30° 16' W	0.977	-0.409	20
Turgai	C.I.S.	49° 38' N	63° 27' E	-0.131	0.601	19
Olerminsk	C.I.S.	60° 22' N	120° 26' E		0.191	11
Verkoyansk	C.I.S.	67° 03' N	133° 24' E	-0.057	0.039	14
Turukhansk	C.I.S.	65° 47' N	88° 04' E		-0.015	11
Irkust	C.I.S.	52° 16' N	104° 19' E	0.086	0.018	19
Quixeramobin	Brazil	05° 16' S	39° 15' W	-0.744	0.099	15
Turiacu	Brazil	01° 43' S	45° 24' W		-0.444	8
Fer. de Noroña	Brazil	03° 50' S	32° 25' W		-0.037	7
Olinda Recife	Brazil	08° 04' S	34° 53' W	-0.412	0.335	16
Salvador	Brazil	12° 57' S	38° 29' W		0.630	9
R. de Janeiro	Brazil	22° 54' S	43° 10' W	0.356	0.032	18
Curitiba	Brazil	25° 25' S	49° 17' W	-0.188	-0.097	18
Haparanda	Sweden	65° 50' N	24° 09' E	-0.466	0.668	20
Kano	Africa	12° 02' N	08° 32' E		-0.452	9
Freetown	S. Leona	08° 29' N	13° 09' W	-0.223	-0.555	18
Tunez	Africa	36° 48' N	10° 10' E		0.171	9
Mocamedes	Africa	15° 12' S	12° 09' E		-0.341	7
Calabar	Africa	04° 58' N	08° 19' E		-0.551	8
Pto. Sudan	Africa	19° 35' N	37° 13' E	0.235	0.275	10
L. Marquez	Africa	25° 58' N	32° 36' E	-0.608	0.207	14
Marruecos	Africa	31° 39' N	08° 01' W		0.125	11
Nouakchott	Mauritania	18° 07' N	15° 56' W		-0.275	8
Bulawayo	Rhodesia	20° 09' S	28° 40' W	-0.380	-0.002	16
Entebbe	Uganda	0° 05' N	32° 29' E	0.520	0.158	12
El Cairo	Egypt	30° 07' N	31° 21' E	-0.405	0.101	17
Tokio	Japan	35° 41' N	139° 45' E	-0.103	-0.022	19
Beirut	Lebanon	33° 54' N	35° 28' E	-0.347	0.120	17
Santiago	Chile	33° 27' S	70° 41' W	0.382	-0.374	17
Valdivia	Chile	38° 48' S	73° 14' W		0.409	7
Arequipa	Peru	16° 22' S	71° 33' W	-0.763		7
Calgary	Canada	51° 02' N	114° 02' W	0.768	-0.068	13
Eureka	Canada	80° 00' N	85° 56' W		0.414	3
Winnipeg	Canada	49° 53' N	97° 07' W	-0.315	0.04	17
Father Point	Canada	48° 31' N	68° 10' W	0.129	0.559	14
Barkerville	Canada	53° 02' N	121° 35' W	0.936		6
Anchorage	Alaska	61° 13' N	149° 51' W	0.525	-0.234	11
Roma	Italy	41° 54' N	12° 29' E	0.251	-0.050	20
Pto. Darwin	Australia	19° 28' S	130° 51' E	-0.534	-0.074	18
Perth	Australia	31° 57' S	115° 51' E	-0.195	0.027	18
Lord Howels	Australia	31° 31' S	159° 04' E		-0.367	8
Cairns	Australia	16° 53' S	145° 44' E	-0.608	-0.004	13
Hobart	Australia	42° 53' S	147° 30' E	-0.454	-0.148	16
Buschire	Persian	29° 00' N	49° 50' E	-0.643	-0.178	18
Upernivik	Greenland	72° 47' N	56° 07' W	0.999	0.275	18
Jacobshavn	Greenland	69° 13' N	51° 02' W	0.999	0.502	17
Ivigtut	Greenland	61° 12' N	48° 10' W	0.758	0.299	17
Batavia	Djarta	06° 11' S	106° 50' E	-0.683	-0.513	17
Antananarivo	Madagas.	18° 56' S	47° 32' W	-0.404	-0.973	10
Bogotá	Colombia	04° 36' N	74° 05' W		-0.039	4
San Cristóbal	Venezuela	07° 46' N	72° 14' W		0.002	6
Caracas	Venezuela	10° 28' N	67° 02' W		-0.212	7
Trinidad	Tobago	10° 40' N	61° 31' W	0.206	0.015	15
La Habana	Cuba	23° 08' N	82° 22' W	0.037	-0.033	20
San Juan	Pto. Rico	18° 27' N	66° 06' W	0.388	0.018	15
Jerusalem	Israel	31° 46' N	35° 14' E	0.035	-0.115	19
Jask	Iran	25° 45' N	57° 45' E	0.017	0.142	16

Table 2. Location of stations and their correlation coefficients of mean annual Temperature vs Sunspots.

Locality	Country	Latitude	Longitude	Correlation coefficient 1869-1925	Correlation coefficient 1926-1977	5 years groups	Locality	Country	Latitude	Longitude	Correlation coefficient 1869-1925	Correlation coefficient 1926-1977	5 years groups
Nikolaesky	C.I.S.	53° 08' N	140° 45' E	0.992	0.225	19	Bangalore	India	12° 58' N	77° 37' E	-0.506	0.085	19
Obdorsk	C.I.S.	66° 31' N	66° 35' E	0.765		6	Pto. Blair	India	11° 41' N	92° 45' E	-0.333	0.615	20
Olerminsk	C.I.S.	60° 22' N	120° 26' E	-0.060	-0.546	15	Bombay	India	18° 55' N	72° 54' E	-0.447	0.314	19
Arcangel	C.I.S.	64° 35' N	40° 36' E	0.834	0.050	19	Madras	India	13° 04' N	80° 15' E	-0.085	0.491	19
Tomsk	C.I.S.	56° 30' N	84° 58' E	-0.987	-0.412	19	Moulmein	India	16° 30' N	96° 38' E	-0.727	1.000	12
Turgai	C.I.S.	49° 38' N	63° 27' E	-0.992	-0.575	15	Bushire	Persian	29° 00' N	49° 50' E	-0.118	-0.484	19
Astracan	C.I.S.	46° 21' N	48° 02' E	-0.895	-0.148	19	Winnipeg	Canada	49° 53' N	97° 07' W	-0.217	-0.770	19
Irkust	C.I.S.	52° 16' N	104° 19' E	-0.176	-0.370	18	Barkerville	Canada	53° 02' N	121° 35' W	-0.437	0.263	16
Turukhansk	C.I.S.	65° 47' N	88° 04' E	-0.919	0.090	19	Father Point	Canada	48° 31' N	68° 10' W	0.151	0.277	14
Verkoyansk	C.I.S.	67° 03' N	133° 24' E	0.921	-0.225	17	Calgary	Canada	51° 02' N	114° 02' W	-0.184	-0.371	15
Sn Petesburgo	C.I.S.	59° 56' N	30° 16' W	0.954	-0.163	20	Eureka	Canada	80° 00' N	85° 56' W		0.133	5
Novakchott	Africa	18° 07' N	15° 56' W		0.265	8	Upernivik	Greenland	72° 47' N	56° 07' W	-0.393	-0.219	20
Helsinsky	Finland	60° 10' N	24° 57' E	0.062	0.286	20	Jacobshavn	Greenland	69° 13' N	51° 02' W	-0.838	0.545	20
Haparanda	Swiss	65° 50' N	24° 09' E	0.998	0.082	20	Ivigtut	Greenland	61° 12' N	48° 10' W	-0.860	-0.013	17
Gjesvar	Norway	71° 06' N	25° 22' E	0.998	-0.044	19	El Paso, Texas	U.S.A.	31° 47' N	106° 30' W	0.150	-0.495	18
Viena	Austria	48° 15' N	16° 22' E	-0.998	0.337	20	Bismark	U.S.A.	46° 47' N	100° 38' W	-0.427	0.273	18
Madrid	Spain	40° 24' N	03° 41' W	-0.446	0.130	20	Red Bluff	U.S.A.	40° 10' N	122° 15' W	-0.298	-0.267	14
D. F.	Mexico	19° 26' N	99° 08' W	-0.923	0.150	19	Portland	U.S.A.	45° 32' N	122° 41' W	-0.349	0.493	19
Mazatlan	Mexico	23° 12' N	106° 25' W	-0.230	0.542	18	Atenas	Greece	37° 58' N	23° 43' E	0.611	0.026	20
Veracruz	Mexico	19° 12' N	96° 08' W	0.921	0.057	11	Arequipa	Peru	16° 22' S	71° 33' W	0.215	-0.357	11
Quixeramobin	Brazil	05° 16' S	39° 15' W	0.834	0.056	15	Anchorage	Alaska	61° 13' N	149° 51' W	-0.358	-0.282	13
Gibraltar	Ingland	36° 06' N	05° 06' N	0.385	-0.031	20	Roma	Italy	41° 54' N	12° 29' E	-0.055	0.716	20
Cape Town	I. Canarias	33° 56' S	18° 29' E	-0.249	-0.098	20	Budapest	Hungary	47° 17' N	19° 01' E	0.645	0.569	20
Tokio	Japan	35° 41' N	139° 45' E	-0.136	0.229	19	Aden	Arabia	12° 46' N	45° 03' E	-0.253	0.190	17
Beirut	Lebanon	33° 54' N	35° 28' E	-0.126	-0.160	19	Manila	Philippines	14° 35' N	120° 59' E	-0.210	0.491	17
Jerusalem	Israel	31° 46' N	35° 14' E	-0.504	-0.049	19	Thornshavn	Hovijg	62° 03' N	06° 45' W	-0.229	0.030	19
Jask	Iran	25° 45' N	57° 45' E	-0.854	-0.456	16	Greenwich	England	51° 28' N	0° 00'	-0.162	-0.222	20
Estocolmo	Iceland	65° 05' N	22° 46' W	-0.669	-0.052	20	Batavia	Djarta	06° 11' S	106° 50' E	-0.517	0.086	17
Santiago	Chile	33° 27' S	70° 41' W	0.048	0.152	20	Antananarivo	Madagasc.	18° 55' S	47° 32' W	-0.994	0.728	10
Valdivia	Chile	38° 48' S	73° 14' W		-1.000	6	Bogotá	Colombia	04° 36' N	74° 05' W		0.049	8
Buenos Aires	Argentina	34° 36' S	58° 22' W	-0.308	-0.037	20	San Cristóbal	Venezuela	07° 46' N	72° 14' W		-0.316	7
Punta Arenas	Argentina	53° 10' S	70° 54' W	0.229	0.150	17	Caracas	Venezuela	10° 28' N	67° 02' W		0.530	8
Cordoba	Argentina	31° 25' S	64° 12' W	-0.025	0.344	20	Trinidad	Tobago	10° 40' N	61° 31' W	-0.466	-0.181	20
Corrientes	Argentina	27° 27' S	58° 49' W		-0.556	6	La Habana	Cuba	23° 08' N	82° 22' W	-0.384	-0.303	20
Goya	Argentina	29° 09' S	59° 15' W	0.807	0.358	19	San Juan	Pto. Rico	18° 27' N	66° 06' W	-0.979	-0.084	15
Curitiba	Brazil	25° 25' S	49° 17' W	-0.829	-0.135	18	Lord Howe	Australia	31° 31' S	159° 04' E	-0.235	-0.586	13
Caetite	Brazil	14° 03' S	42° 37' W	0.221	-0.604	11	Entebbe	Uganda	0° 05' N	32° 29' E	0.227	-0.211	15
Turiacu	Brazil	01° 43' S	45° 24' W		-0.502	8	Calabar	Africa	04° 58' N	08° 19' E	-0.489	-0.177	14
F. de Norhona	Brazil	03° 50' S	32° 25' W		0.085	7	Freetown	S. Leona	08° 29' N	13° 09' W	-0.196	-0.020	18
Olinda Recife	Brazil	08° 04' S	34° 53' W		0.162	8	Kano	Africa	12° 02' N	08° 32' E	-0.903	-0.406	14
Salvador	Brazil	12° 57' S	38° 29' W		-0.193	9	El Cairo	Egypt	30° 07' N	31° 21' E	0.153	0.130	20
Perth	Australia	31° 57' S	115° 51' E	-1.000	-0.178	12	Bulawayo	Rodhesia	20° 09' S	28° 40' W	-0.844	0.386	16
Alice Spring	Australia	23° 38' S	133° 37' E	-0.339	-0.043	19	Marruecos	Africa	31° 39' N	08° 01' W		-0.188	11
Cairns	Australia	16° 53' S	145| 44' E	0.275	0.208	14	L. Marquéz	Africa	25° 58' N	32° 36' E	-0.348	-0.148	14
Hobart	Australia	42° 53' S	147° 30' E	-0.416	0.044	19	Port Sudán	Africa	19° 35' N	37° 13' E	-0.381	-0.035	10
Pto. Darwin	Australia	19° 28' S	130° 51' E	0.098	-0.058	18	Tunez	Africa	36° 48' N	10° 10' E	-0.689	-0.209	17
Jaipur	India	26° 55' N	75° 52' E	-0.162	0.123	19	Mocamedes	Africa	15° 12' S	12° 09' E		-0.124	7

Table 3. Location of stations and their correlation coefficients of annual Precipitation *vs* Sunspots.

Locality	Country	Latitude	Longitude	Correlation coefficient 1869-1925	Correlation coefficient 1926-1977	5 years groups	Locality	Country	Latitude	Longitude	Correlation coefficient 1869-1925	Correlation coefficient 1926-1977	5 years groups
Bombay	India	18° 55′ N	72° 54′ E	0.226	-0.140	20	Jask	Iran	25° 45′ N	57° 45′ E	0.907	-0.018	16
Bangalore	India	12° 58′ N	77° 37′ E	0.789	0.124	20	Haparanda	Sweden	65° 50′ N	24° 09′ W	-0.072	-0.030	19
Madras	India	13° 04′ N	80° 15′ E	0.522	-0.362	20	Gjesvar	Norway	71° 06′ N	25° 22′ E	0.330	-0.302	16
Puerto Blair	India	11° 41′ N	92° 45′ E	0.430	0.449	20	Viena	Austria	48° 15′ N	16° 22′ E	0.208	0.278	20
Moulmein	India	16° 30′ N	97° 38′ E	0.542	-0.156	15	Madrid	Spain	40° 24′ N	03° 41′ W	0.007	0.423	20
Jaipur	India	26° 55′ N	75° 52′ E	-0.178	0.193	20	D.F.	Mexico	19° 26′ N	99° 08′ W	-0.667	0.252	19
Manila	Philippines	14° 35′ N	120° 59′ E	0.492	0.225	19	Mazatlan	Mexico	23° 11′ N	106° 25′ W	-0.312	-0.217	19
Batavia	Djarta	06° 11′ S	106° 50′ E	0.387	0.390	20	Veracruz	Mexico	19° 00′ N	96° 08′ W	-0.078	0.109	11
Pto. Darwin	Australia	12° 28′ S	130° 51′ E	0.921	-0.066	20	Quixeramobin	Brazil	05° 16′ S	39° 15′ W	-0.059	-0.240	15
Hobart	Australia	42° 53′ S	147° 30′ E	0.657	0.516	18	Estocolmo	Iceland	65° 05′ N	22° 46′ W	-0.258	-0.379	19
Perth	Australia	31° 57′ S	115° 51′ E	0.388	-0.294	19	Gibraltar	England	36° 06′ N	05° 21′ E	-0.174	-0.199	20
Cairns	Australia	16° 53′ S	145° 44′ E	-0.056	-0.385	18	Entebbe	Africa	0° 05′ N	32° 29′ E	-0.991	0.387	15
Alice Spring	Australia	23° 38′ S	133° 37′ E	0.780	0.181	19	Kano	Africa	12° 02′ N	08° 32′ E	-0.961	-0.539	14
Antananarivo	Madagas.	18° 55′ S	47° 32′ E	0.619	0.613	10	Freetown	Africa	08° 29′ N	13° 09′ W	-0.050	-0.792	18
Medan	East Indias	03° 35′ N	98° 41′ W	0.868	-0.189	18	Túnez	Africa	36° 48′ N	10° 10′ E	0.452	0.172	17
Menado	East Indias	01° 30′ S	124° 50′ E	0.423	-0.005	18	L. Marquez	Africa	25° 58′ S	32° 36′ E	0.770	-0.280	14
Amboina	East Indias	03° 42′ S	128° 10′ E	0.892	-0.951	18	Puerto Sudan	Africa	19° 35′ N	37° 13′ E	0.199	0.575	10
Kupang	East Indias	10° 10′ S	123° 34′ E	0.823	0.945	16	Mocamedes	Africa	15° 12′ S	12° 09′ E		0.748	7
Goya	Argentina	29° 09′ S	59° 15′ W	-0.078	0.371	19	Marruecos	Africa	31° 39′ N	08° 01′ W	-0.335	0.863	12
Córdoba	Argentina	31° 25′ S	64° 12′ W	-0.399	-0.135	19	Bulawayo	Rhodesia	20° 09′ S	28° 40′ E	0.010	-0.324	16
Buenos Aires	Argentina	34° 36′ S	58° 22′ W	-0.771	-0.017	20	Calabar	Africa	04° 58′ N	08° 19′ E	-0.107	0.035	15
Ajo Gral Lav.	Argentina	36° 31′ S	56° 46′ W	-0.734	-0.530	20	El Cairo	Egypt	30° 07′ N	31° 21′ E	0.540	0.332	16
Corrientes	Argentina	27° 27′ S	58° 49′ W	-0.715	0.247	19	Cape Town	Africa	33° 56′ S	18° 29′ E	-0.635	-0.148	20
Punta Arenas	Argentina	53° 10′ S	70° 54′ W	-0.257	0.408	17	Beirut	Lebanon	33° 54′ N	35° 28′ E	0.268	-0.296	16
Santiago	Chile	33° 27′ S	70° 42′ W	0.484	-0.305	20	Arequipa	Peru	16° 22′ S	71° 33′ W	0.173	-0.745	15
Valdivia	Chile	38° 48′ S	73° 14′ W	-0.551	0.210	17	Calgary	Canada	51° 02′ N	114° 02′ W	-0.722	-0.199	14
Caetite	Brazil	14° 03′ S	42° 37′ W	-0.141	-0.097	15	Eureka	Canada	80° 00′ N	85° 56′ W		-0.804	5
Turiacu	Brazil	01° 43′ S	45° 24′ W		-0.273	8	Barkerville	Canada	53° 02′ N	121° 35′ W	-0.026	0.293	16
F. de Norhona	Brazil	03° 50′ S	32° 25′ W	-0.466	-0.351	19	Winnipeg	Canada	49° 53′ N	97° 07′ W	0.601	-0.656	17
Olinda Recife	Brazil	08° 00′ S	34° 51′ W	-0.388	0.002	19	Anchorage	Alaska	61° 13′ N	149° 51′ W	0.245	0.104	13
Salvador	Brazil	12° 57′ W	38° 29′ W		0.252	9	Roma	Italia	41° 54′ N	12° 29′ E	0.523	0.890	20
Curituba	Brazil	25° 25′ S	49° 17′ W	-0.987	0.456	18	Lord Howe	Island	31° 31′ S	159° 04′ E	0.362	-0.370	18
Ivigtut	Greenland	61° 12′ N	48° 10′ W	-0.635	-0.249	19	Atenas	Greece	37° 58′ N	23° 43′ E	0.611	-0.545	16
Father Point	U.S.A.	48° 03′ N	68° 10′ W	-0.464	-0.341	17	Buschire	Persia	20° 00′ N	50° 50′ E	0.900	0.104	18
Bismark	U.S.A.	46° 47′ N	100° 38′ W	-0.823	-0.610	18	Upernivik	Greenland	72° 47′ N	56° 07′ W	0.625	-0.408	18
Portland	U.S.A.	45° 03′ N	122° 40′ W	-0.123	-0.045	18	Jacobshavn	Greenland	69° 12′ N	50° 02′ W	0.588	0.248	19
Red Bluff	U.S.A.	40° 10′ N	122° 15′ W	-0.983	0.146	18	Tokio	Japan	35° 41′ N	139° 46′ E	-0.440	0.341	19
El Paso, Texas	U.S.A.	31° 47′ N	106° 30′ W	-0.265	0.773	16	Anchorage	Alaska	61° 13′ N	149° 51′ W	0.245	0.104	13
Archangel	C.I.S.	64° 35′ N	40° 36′ E	-0.372	0.477	20	Roma	Italy	41° 54′ N	12° 29′ E	0.523	0.890	20
Tomsk	C.I.S.	56° 30′ N	84° 58′ E	-0.417	0.158	11	Aden	Arabia	12° 46′ N	45° 03′ E	0.684	0.104	18
Turgai	C.I.S.	49° 38′ N	63° 27′ E	0.165	0.122	13	Thornshavn	Hovjig	62° 03′ N	06° 45′ W	0.053	-0.080	19
Astracan	C.I.S.	46° 21′ N	48° 02′ E	-0.509	0.329	19	Groenlandia	England	51° 20′ N	0° 00′	0.054	0.225	20
Irkust	C.I.S.	52° 16′ N	104° 19′ E	-0.510	-0.200	11	Bogota	Colombia	04° 36′ N	74° 05′ W	0.489	-0.249	20
Turukhansk	C.I.S.	65° 47′ N	87° 57′ E	0.278	-0.107	11	San Cristóbal	Venezuela	07° 46′ N	72° 14′ W	1.000	-0.704	12
Verkoyansk	C.I.S.	67° 33′ N	133° 24′ E		0.364	10	Caracas	Venezuela	10° 30′ N	66° 55′ W	-0.178	-0.440	17
Olerminsk	C.I.S.	60° 22′ N	120° 26′ E		0.299	10	Trinidad	Tobago	10° 40′ N	61° 31′ W	0.720	-0.034	20
Sn Petesburgo	C.I.S.	59° 56′ N	30° 16′ E	-0.194	0.058	19	La Habana	Cuba	23° 08′ N	82° 21′ W	-0.844	-0.108	20
Lord Howe	Island	31° 31′ S	159° 04′ E	0.362	-0.370	18	San Juan	Pto. Rico	18° 29′ N	66° 07′ W	-0.565	0.451	15
Helsinski	Finland	60° 10′ N	24° 57′ E	-0.071	0.068	20	Jerusalem	Israel	31° 46′ N	35° 14′ E	0.850	-0.065	20
Jerusalem	Israel	31° 46′ N	35° 14′ E	0.850	-0.065	20	Jask	Iran	25° 45′ N	57° 45′ E	0.907	-0.018	16

Table 4. Percentage of stations presenting a change of patterns around 1920.

Change	Pressure %	Temperature %	Precipitation %
- → +	31	34	30
+ → -	22	12	25
increasing or decrease	47		
no change		54	45

the amplitude of the correlation coefficients, *i.e.* their absolute value.

These results are summarized in Table 4 as percentages of the stations where changes occurred. For barometric pressure almost half of the stations (47%) show a change in the amplitude of the correlation, of the remaining half, a larger number of stations (31%) presented a shift from negative correlation to a positive correlation, those with the opposite trend were a mere 22%.

For temperature around half of the stations did not present a significant change (54%), most of the rest presented a change from a negative to a positive correlation (34%) and the inverse trend accounted only 12%. Finally, for the precipitation about half of the stations (45%) did not change, 30% presented sign reversals from positive to negative and 25% shifted from negative to positive.

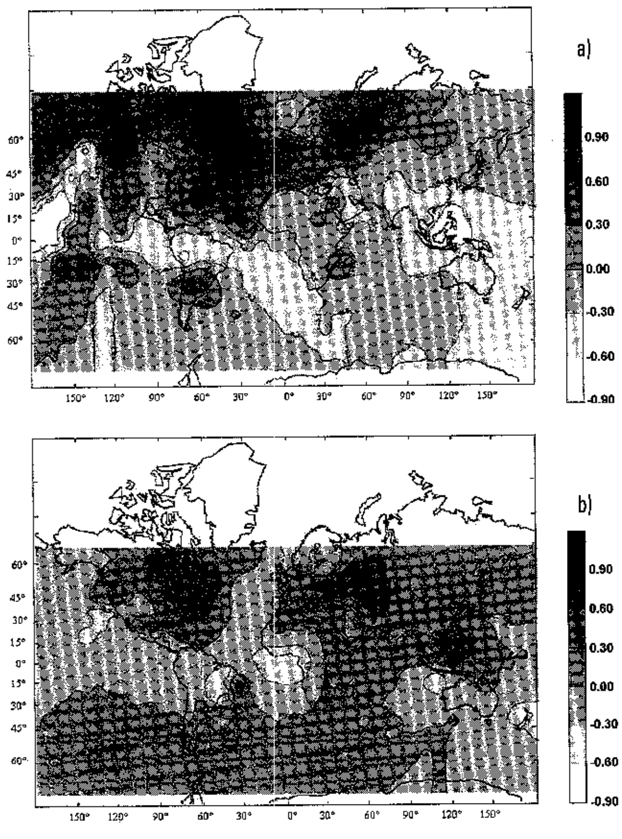

Figure 2. Isocorrelates of 5-year barometric pressure means *vs* sunspot number: (a) 1869-1925 (b) 1926-1977.

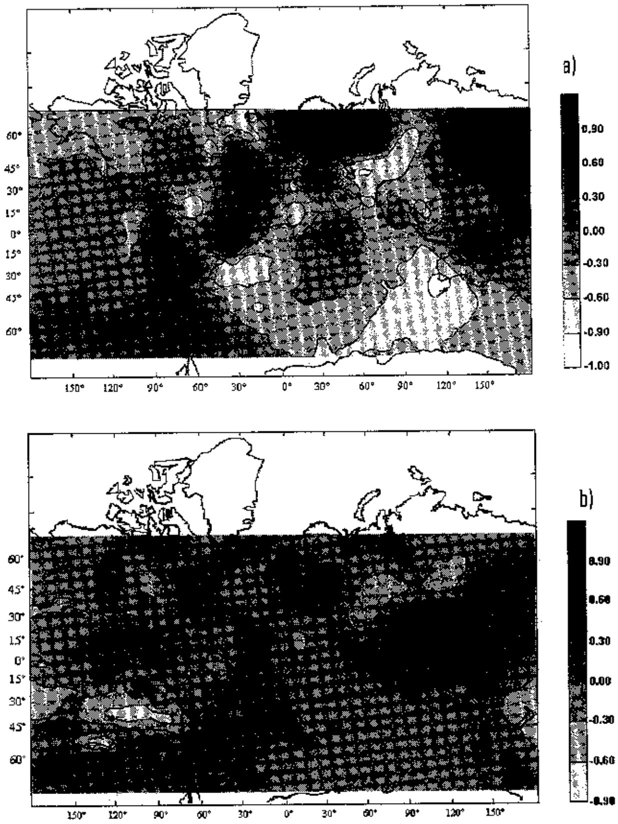

Figure 3. Isocorrelates of 5-year temperature means vs sunspot number: (a) 1869-1925 (b) 1926-1977.

The results of tables 1, 2 and 3 are also depicted in Figs, 2, 3 and 4 respectively, and a summary is presented in Table 5 which contains the sign of the correlation coefficients -either positive or negative- between the meteorological parameter and the sunspot numbers for two periods (I from 1869 to 1925 and II from 1926 to 1977). The results -converted to percentual correlation coefficents- were divided into intervals for each

Table 5. Percentages of correlation coefficients signs for the periods I and II.

Correlation		Pressure			Temperature			Precipitation		
		30-60	60	60-90	30-60	60	60-90	30-60	60	60-90
I	-	2S	1				2N, 2S			2S,2N
	+			2N			2N		1	
II	-	1			2N		2S			2N, 1
	+	2N				1				

I = period 1869-1925; II = period 1926-1977. N: northern; S: southern.
1 = tropical zone (-30° - 30° in latitude); 2 = extratropical zone

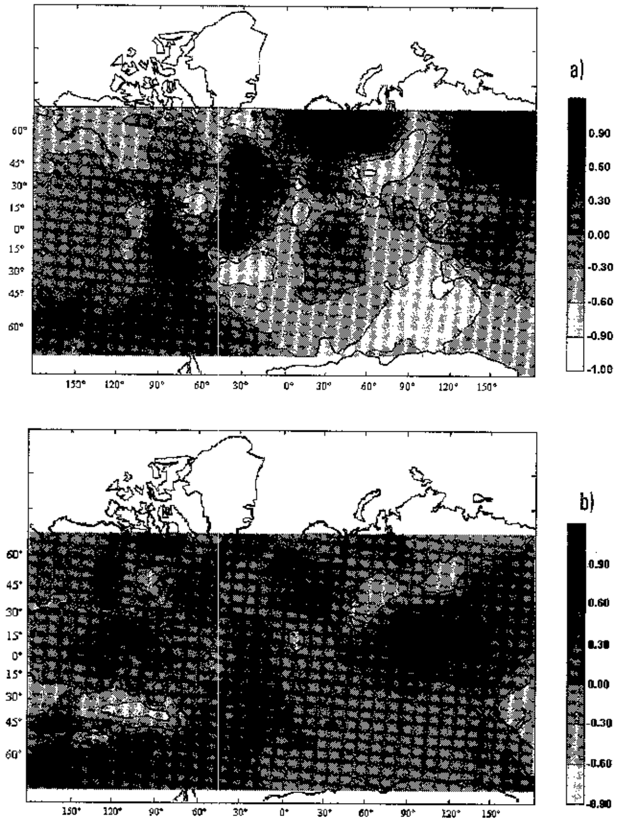

Figure 4. Isocorrelates of 5-year raifall averages vs sunspot number: (a) 1869-1925 (b) 1926-1977.

of the three meteorological variables and a code was employed in order to show whether the values ocurred within the tropical zone or in northern or southern extratropical locations. Also in agreement with Figs. 2, 3, and 4, the intervals of the correlation coefficients appear as percentages.

We notice that for the barometric pressure during period I the strongest negative correlation occurred in the tropical zone (zone I) and a weak correlation exists in the southern extratropical zone (2S), while the strongest positive correlation occurred in the northern extratropical zone (2N). For the period II both correlations hold in the same zones but they have weakened.

For the temperature in period I the strongest negative correlation is found in both southern and northern extratropical zones, while the strongest positive correlations are found in the northern extratropical zones. For period II the strongest negative correlations occurred in the southern extratropical zone, and a weak correlation is in the northern extratropical zone, while a positive correlation is found in the tropical zone.

For precipitation, during the period I the negative correlation is strongest in both northern and southern extratropical zones and there is a weaker positive correlation in the tropical zone. For period II the strongest negative correlations are found in the tropical and northern extratropical regions.

For the three variables here considered, correlation coefficient histograms (Figs. 5a, 5b and 5c) show significant differences between both periods, where those for the second period (1926 to 1977) show a fairly good fit to a normal distribution with the mean close to 0.0. On the other hand, the histograms for the first period are close to a rectangular distribution and so higher frequencies of high correlations -in absolute values- occurred during this period.

Even though histograms point to differences in correlation coefficient distributions during both periods, Kruskal-Wallis' results for correlation coefficients only show significant

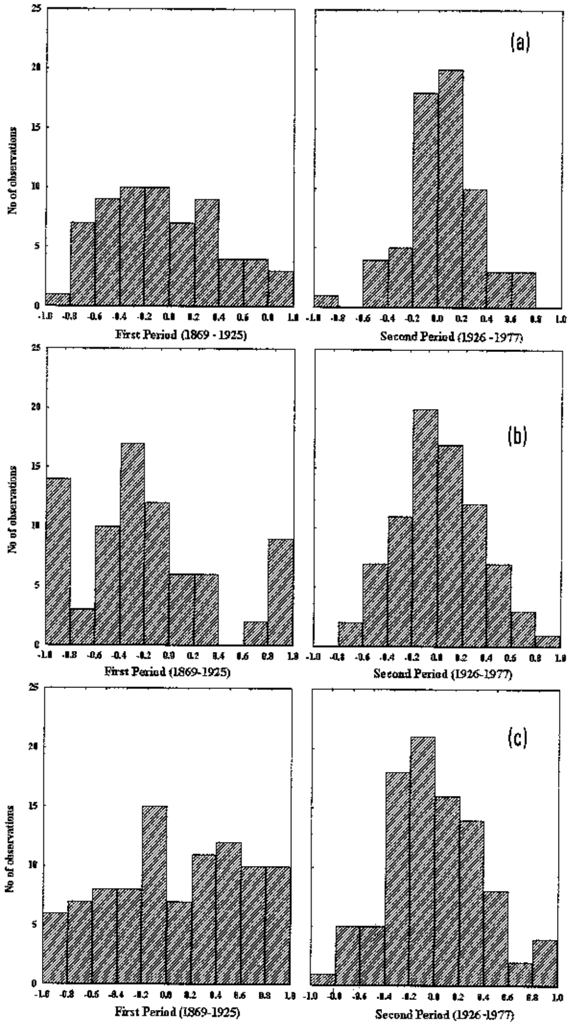

Figure 5. Frequency distribution of the correlation coefficient of sunspot number vs climatic variables for the periods 1869-1925 and 1926-1977: (a) Barometric pressure; (b) Air temperature; (c) Rainfall.

Table 6. Kruskal-Wallis ANOVA by ranks for the correlation coefficients of meteorological variables *vs* Sunspot Index comparing between the periods 1869-1925 and 1926-1977.

Meteorological Variable	H(1, N=188)	p
Temperature	13.1227	0.0003
Barometric Pressure	2.2679	0.1321
Precipitation	1.3379	0.2474

differences between both periods for the temperature series (p=0.003) (Table 6). Thus, according to this latter test, the claimed change in climate variables only holds for the correlation coefficients of air temperature *vs* sunspot numbers.

DISCUSSION

For most of the stations that presented a change of pattern around 1920 (see Table 4), the change was from negative to positive; this effect is particularly noticeable in temperature. It should be remembered that several authors have reported regional changes of pattern from positive to negative around 1920 in various meteorological variables (King, 1973; 1974; King *et al.*, 1974). Furthermore in a global context it has also been shown that a change of pattern from positive to negative should have occurred around 1920 (Mendoza and Ramírez, 1999).

It has been suggested that only in the equatorial regions there is a significant correlation between the sunspot cycle and the meteorological variables, specially the temperature, while from subtropical to polar latitudes the magnetic cycle masks the sunspot cycle (Willett, 1974). Table 5 indicates that the strongest correlations -either positive or negative- are present in both extratropical and tropical zones for pressure; are found mainly in the extratropical zones for temperature, and also appear in both extratropical regions for precipitation. In the present study the correlations for temperature found in the tropical zones are weak and this trend is opposite to the results of previous works (Schostakowitsch, 1933). However, both for barometric pressure and for precipitation the correlations with the sunspots cycle are very strong in the tropical zone even though the regions which present such correlations are less extensive in longitude and latitude than the areas with strong correlations in the extratropical latitudes.

CONCLUSIONS

- Around 1920 we found a change of pattern in the correlation between sunspots and pressure, temperature and precipitation.
- Most of the stations that presented a change did it from negative to positive correlation.
- We also found strong correlations between sunspots and pressure and precipitation in both tropical and extratropical latitudes. For the temperature the strong correlations appear mainly in extratropical zones.

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