THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

SASKATOON CENTRE

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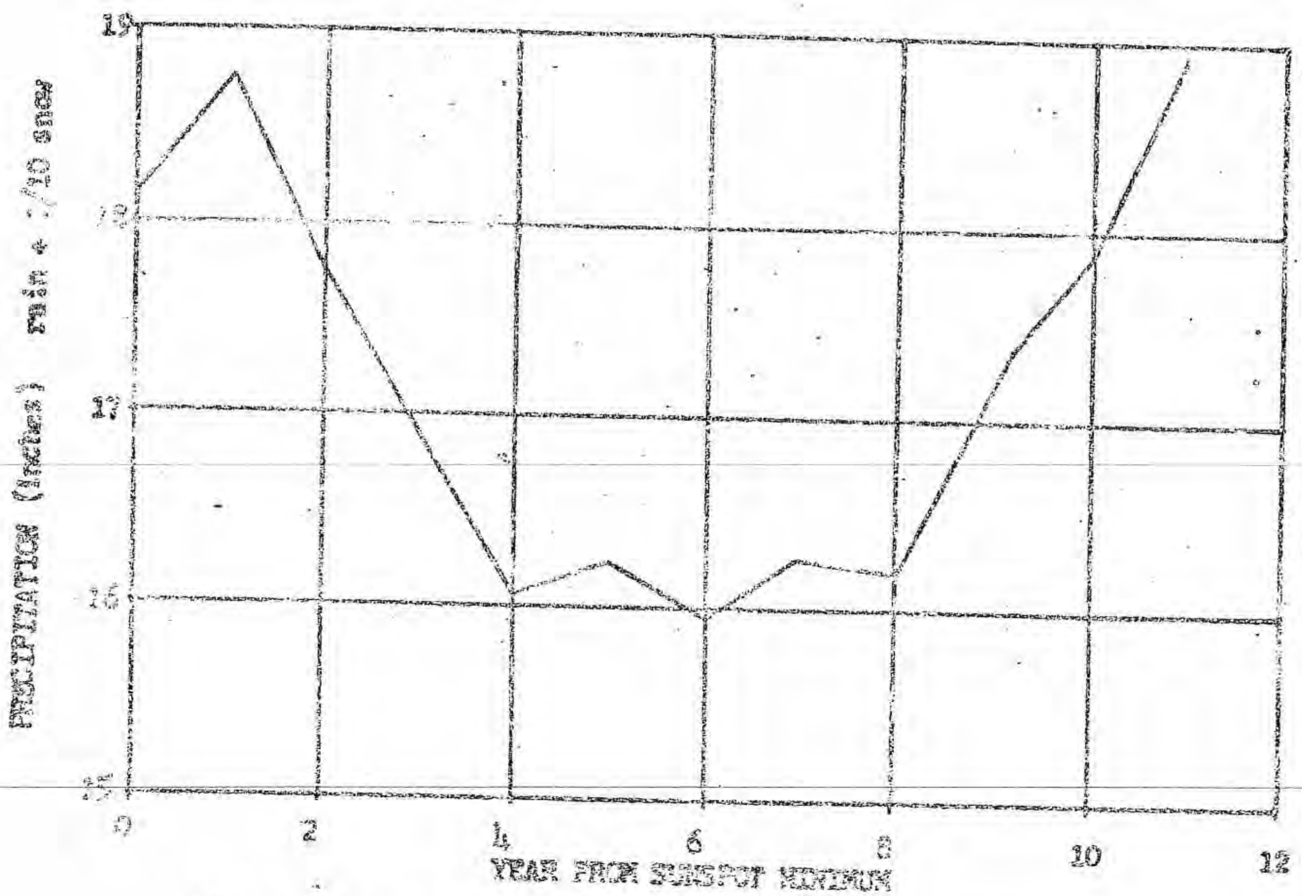
NEWSLETTER



MEAN ANNUAL PRECIPITATION

Calgary (1886-1974)
Edmonton (1882-1974)
Regina (1891-1974)
Saskatoon (1908-1974)
Winnipeg (1878-1974)

The Sun and Terrestrial Climate

Dr. B.W. Currie

Introduction

Not since the 1930s when the interior plains of North America experienced a succession of drouth years has so much attention been given in scientific journals, newspapers and the media generally to changes in our climates. This has resulted from the concern of the environmentalists about man-made factors which may affect climate, and by recent widespread drouths in northern parts of Africa and in the U.S.S.R. The former include additions to the atmosphere of carbon dioxide from auto exhausts, factories and so on, and gases in aersol sprays that may reduce the ozone content of the upper atmosphere. The latter have occurred over large areas in a relatively short period of time so that man-made factors are primarily not responsible for them. They are fluctuations characteristic of terrestrial climates at this time in the Earth's history.

The purpose of this paper is to review Sun-Earth relationships, some of which could lead to climatic changes over long periods of time, and others which may have short period effects which are not fully understood at this time. The former includes a change in the eccentricity of the Earth's orbit, a variation in the tilt of the Earth's axis of rotation relative to the plane of its orbit, and a precession of the Earth's orbit about the Sun. The latter involves the amount of energy from the Sun that is intercepted by the Earth. This is of two types, namely, the wave radiation of which the visible light is only a part, and the corpuscular radiation consisting mostly of electrons and protons and constituting the solar wind. The corpuscular radiation is only a small fraction of the total radiation, but the particles which penetrate to ionospheric levels (80 to 500 km) at the higher latitudes may "trigger" atmospheric processes affecting climate.

Changes in the Earth's Orbital Parameters Text-book illustrations of the Earth's orbit greatly exaggerate its ellipticity. The most correct representation for the scale on which they are drawn would be a circle with the Sun at its centre. For our purpose it is convenient to assume that the orbit varies from a circle to a greatly elongated ellipse with the sun at one of its foci. For the circle the speed of the Earth around it would be constant. The amount of wave radiation intercepted by the Earth per unit of time would also be constant. For the elliptical orbit the speed of Earth on the part of the orbit distant from the Sun would be slow; on the part close to the Sun, fast. The wave radiation intercepted by the Earth varies inversely as the square of the distance from the Sun. The climates for both the Northern and Southern Hemispheres would be cool, or even cold, and drawn out in time for the distant part of the orbit; warm, or even hot, and short for the close part of the orbit. One could anticipate that the snow and ice accumulated in the winter Hemisphere while the Earth was distant from the Sun might not be completely melted during the following summer when the Earth was close to the Sun. This could lead to an ice age. Just what would be the affect on the Earth's average temperature by change in the average distance of the Earth from the Sun is speculative. By one estimate, displacement of the Earth as little as 6 million miles closer to the Sun could generate a powerful greenhouse effect through carbon dioxide and water vapour evaporated into the atmosphere. Actually, the eccentricity varies by only a very small amount and over a period of about 80,000 years. Since glacial periods apparently have not varied with a constant period, one can safely assume that changes of eccentricity have not had a major affect on climate during geologic time. Still one should not assume that a change in eccentricity along with other factors peculiar to the Earth's surface and atmosphere did not contribute to the beginning of glacial ages.

The tilt in the rotation axis of the Earth is responsible for seasonal climates, summer in the Northern Hemisphere when it is winter in the Southern Hemisphere, and vice versa. The rotational inertia of the Earth tends to keep the rotation axis fixed in space. But for convenience assume that it varies from perpendicular to the plane of the orbit to parallel to the orbit. The inclination of the equatorial plane of the Earth to the plane of the ecliptic or orbit is about 23.5 degrees at the present time. For the perpendicular position and a nearly circular orbit there would be no seasonal changes of climate. Equatorial climates would be hot; polar climates cold throughout the year. For the parallel position, the hemisphere when away from the Sun would have a very cold season; six months later a hot season. Just what the effects would be on terrestrial climates is difficult to estimate. Large glacial sheets might develop over polar and subpolar latitudes, since ice and snow have a high reflectivity for wave radiation, and the heat of a hot summer would likely not completely melt the accumulations of ice and snow of the previous cold winter. Actually the variation has been very much smaller and also with a very long period. Studies of geologic climates have failed to disclose the effects of such a periodicity. Still one cannot discount the effects of the change in inclination in triggering both the formation of widespread glaciers and their subsequent melting. An extensive ice sheet formed in high latitudes and not removed by melting during the following summer will grow and spread toward lower latitudes.

The precession of the orbit about the Sun should have little effect on climates, provided the eccentricity of the orbit and the inclination of the rotation axis does not vary appreciably. Assuming a combination of eccentricity and inclination responsible for glaciation in one hemisphere and not in the other, one would expect the glaciation to increase and to decrease with a periodicity the same as that of the precession of the orbit. For an extreme situation one would expect glaciation in one hemisphere, followed by its melting and the formation of ice sheets in the other hemisphere. Paleoclimatologists generally agree that this has not occurred. Glacial ice sheets appear to have increased and decreased simultaneously in the two hemispheres. The periodicity of the precession is roughly 21,000 years.

While I would hesitate to argue that these changes have not been a factor in triggering changes in climate during geologic time, I think we can assume that they have had little effect during historic time, and will continue to have little effect for many generations of people yet to be born.

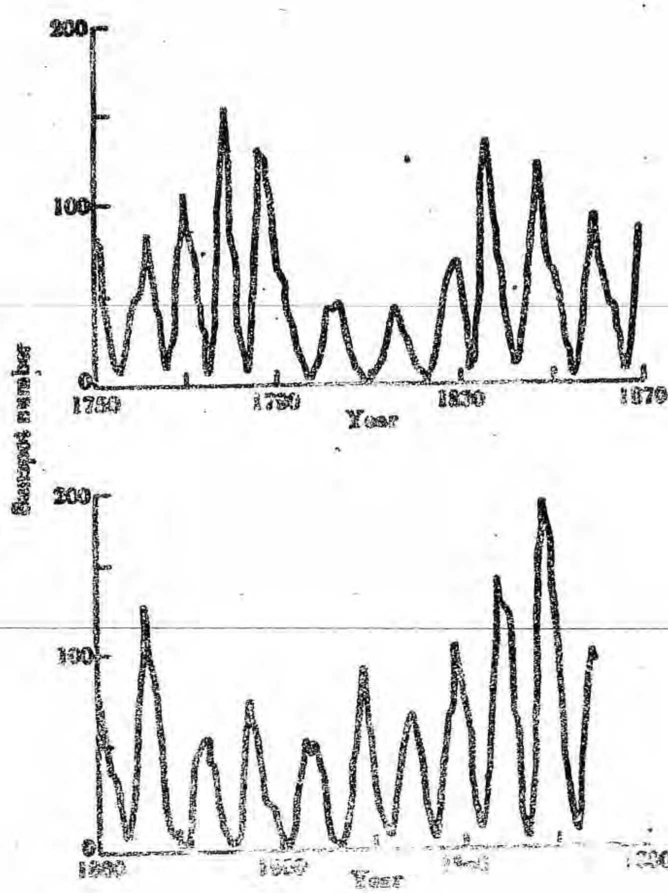
Wave Radiation From the Sun Measurements of the wave energy intercepted by the Earth is generally assumed to be a constant. In fact the more accurate the measurements the more certain becomes this assumption. The quantity of wave energy that passes through an area of one square centimetre in a minute, the square perpendicular to the rays of the Sun and at the outer limits of the Earth's atmosphere at the average distance of the Earth from the Sun is 1.96 calories, more specifically $1.96/cm^2/min$. This quantity should not be confused with the quantity of energy that would reach the Earth's surface for a square centimetre placed parallel to its spherical surface and the Earth without an atmosphere. The amount decreases poleward because of the inclination of the square centimetre to the Sun's rays. For example during the summer half-year the total radiation incident upon the surface of the Earth under a completely transparent atmosphere is 160.5 kilocalories/cm^2 at the Equator and 1.33 kilocalories/cm^2 at the Pole. For the winter half-year the quantities are respectively 160.5 and 0.

The measurement of the solar constant is complex, requiring certain adjustments. A device called a pyroheliometer is used. The sensor is a black surface which is a perfect absorber of the incident wave radiation. It is backed by a copper coil through which water is circulated so as to keep it at a constant temperature. From the heat added to the water, the solar constant is computed. Since the measurements cannot be made yet at the limits of the atmosphere an adjustment must be made for the loss of heat in passing through the atmosphere. This is done by keeping the pyroheliometer pointed at the Sun from close to the horizon up to the maximum altitude of the Sun. From the measurements made at various solar altitudes it is possible to deduce the quantity of incident energy for zero atmosphere and with the Sun at the zenith. Still another adjustment must be made. This is for the very short or ultraviolet wave energy which never reaches the Earth's surface. This is absorbed in the upper atmosphere, - mostly notably by ozone. This adjustment is made by assuming the Sun radiates as a black body at a known temperature. The temperature is deduced from observations of the incident energy at wave lengths within the visible or detectable part of the solar spectrum. It is then possible to compute the energy which should be incident on the atmosphere by all wavelengths from a source at the deduced black-body temperature. The adjustment is small.

It is possible that the effective black-body temperature of the Sun has varied during geologic time. However, there is no known physical explanation for such a variation. Measurements of the solar constant during the past hundred years have failed to detect such a variation; if it does exist. However, we do know that there are great disturbances on the Sun during which large fluxes of solar corpuscles (mostly electrons and protons) are ejected into space. The most visible example is a large solar flare. Very short ultraviolet and x-rays are also radiated into space from these flares. The most convenient indicator of these disturbances are the sunspots which have an average periodicity of 11.5 and 23.0 years. While the wave radiation may be essentially constant, and have no effect on weather and climate, it is possible that the corpuscular radiation may do so.

Corpuscular Radiation From the Sun. The corpuscular radiation constitutes the solar wind. Because they are electrically charged the Earth's magnetic field is a barrier to their direct penetration deep into the atmosphere. The Earth's magnetic field is distorted by the solar wind, - compressed toward the Earth on the side toward the Sun and drawn out into a long tail on the side away from the Sun. Apparently only a small fraction of the particles penetrate to ionospheric levels (80 to 500 km), and these mostly over the polar caps and subpolar latitudes. The most visible evidence of this penetration is the aurora. The assumption that the corpuscular radiation may have an effect on weather and climate comes from numerous studies (many in the past decade) of the variations in precipitation and temperature with respect to the sunspot cycle. I have been concerned with these variations for the Prairie Provinces. The simplest comparison is to compute the average temperature or precipitation for several weather stations for a year at sunspot minimum, for one year after the minimum, two years after the minimum and so on until the next sunspot minimum, and then plot these averages against the corresponding averages of the sunspot numbers. Figure 1 and Figure 2 are the resulting graphs for 5 weather stations (Edmonton, Calgary, Regina, Saskatoon and Winnipeg) for roughly the past 70 years. On an average basis, both precipitation and temperature are above normal for sunspot minimum and below normal for a sunspot maximum. Figure 3 shows plots by Xanthakpis according to the average precipitation for selected ranges of latitudes - 70-80°N, 60-70°N and 50-60°N. Figure 4 is a graph of annual precipitation versus sunspot cycle for Adelaide, Australia. Figure 5 is a graph for the variation in atmospheric pressure for a range of latitudes between sunspot minimum and sunspot maximum. The largest change is at latitudes centered about latitude 60°N, and this is the region of the maximum occurrence of auroras and, hence, where the greatest penetration of solar corpuscular radiation occurs. The zone of maximum auroral occurrence crosses Canada by way of Churchill, Yellowknife and Dawson. In fact, Canada is the only country where the zone for either Hemisphere extends so far equatorward. If the variation of precipitation with sunspot cycle is real, we would have a method of predicting agricultural productivity for several years into the future.

The amount of energy brought into the atmosphere by solar corpuscles is very small and how it is used up in ionization and heating processes is still a matter of much research. The physical processes by which they affect weather may be resolved by studies now in progress as part of the International Magnetospheric Study, 1976-78. This study has been described in our Newsletter circulated several months ago. If the processes are resolved we may then have a reliable method of predicting agricultural productivity everywhere, and to take the necessary steps to minimize the effects of severe drouths in various regions. It is possible that the sunspot-related variations of weather and climate are due not to the solar corpuscles but to the very short ultraviolet radiation and x-rays radiated from solar flares. These vary roughly in intensity with the sunspot cycle. The x-rays in particular penetrate deep into the atmosphere and can be detected by using high-flying balloons (100,000 to 130,000 ft.). The ultraviolet radiation from solar flares may be much larger than is estimated in determining the solar constant. Once the Space lab is in operation it will be possible to measure both the ultraviolet and x-radiation continuously and to get a much better idea of the energy involved and of its effect on weather as the radiation penetrates into the lower layers of the atmosphere.



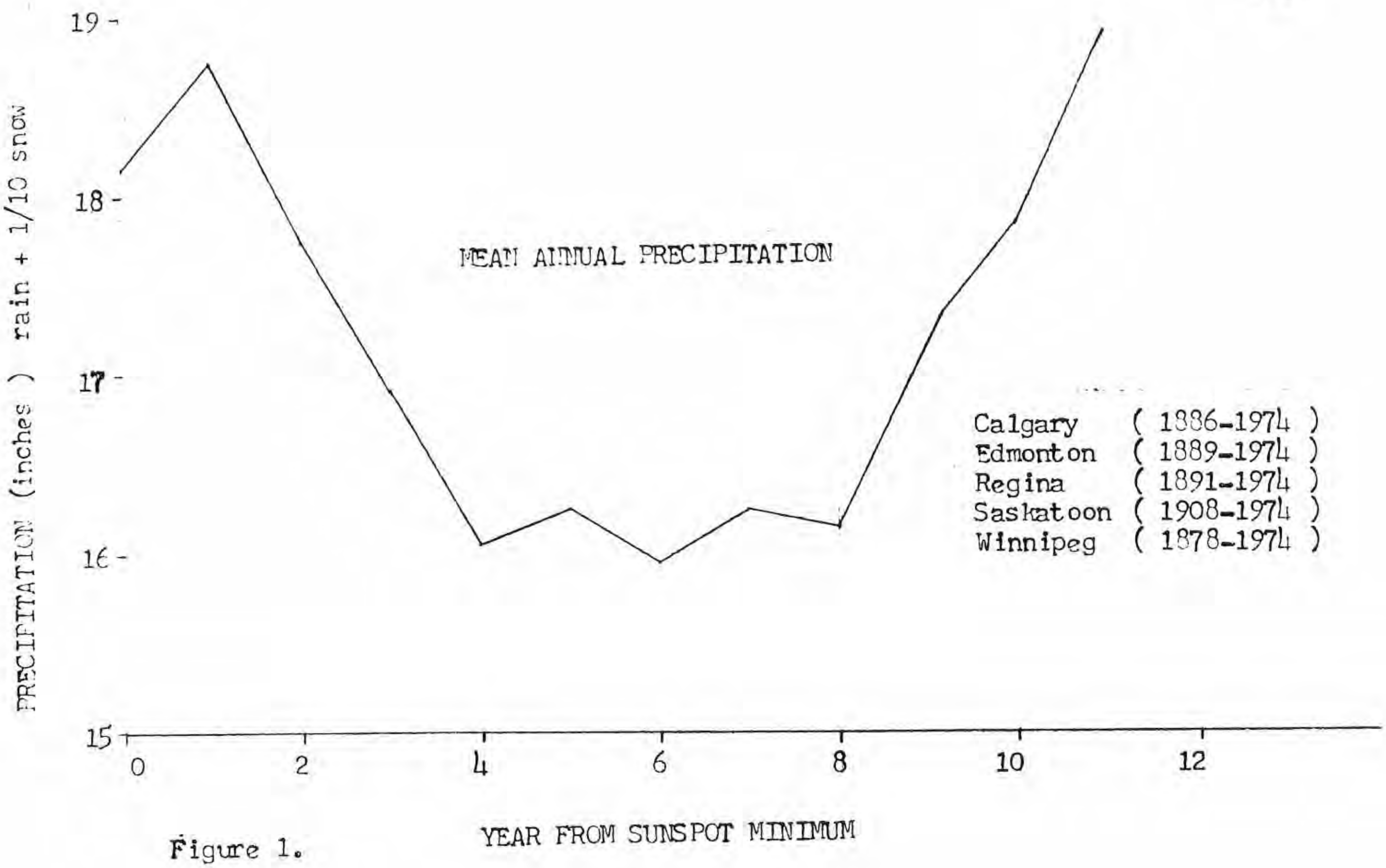


Figure 1.

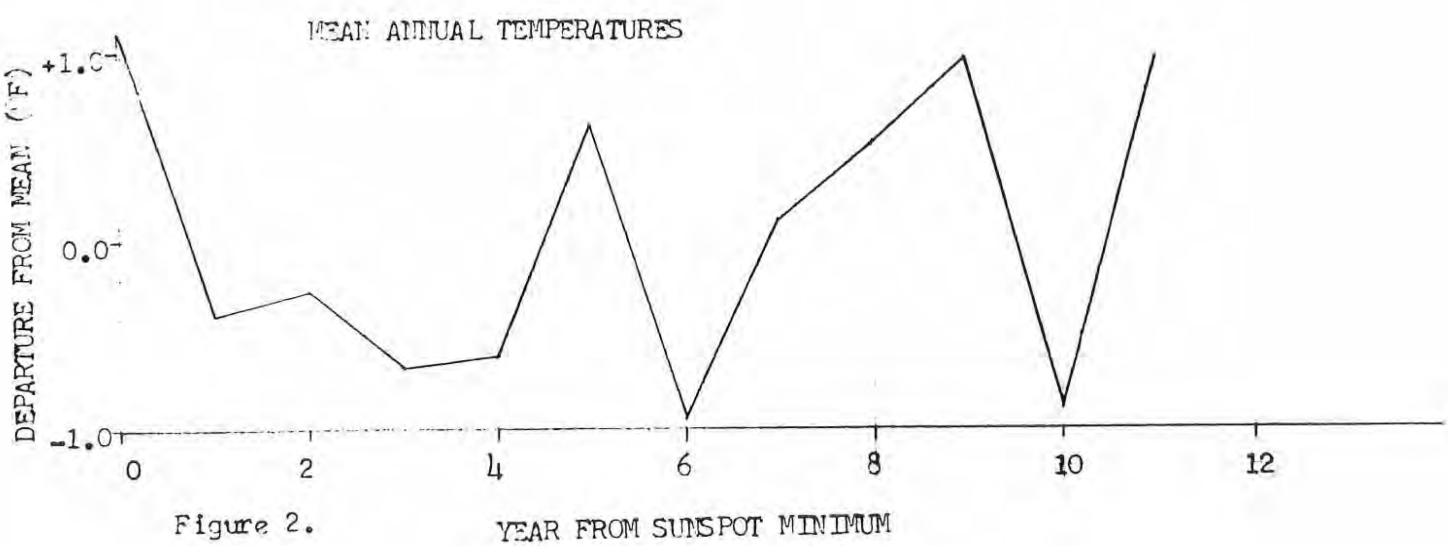


Figure 2.

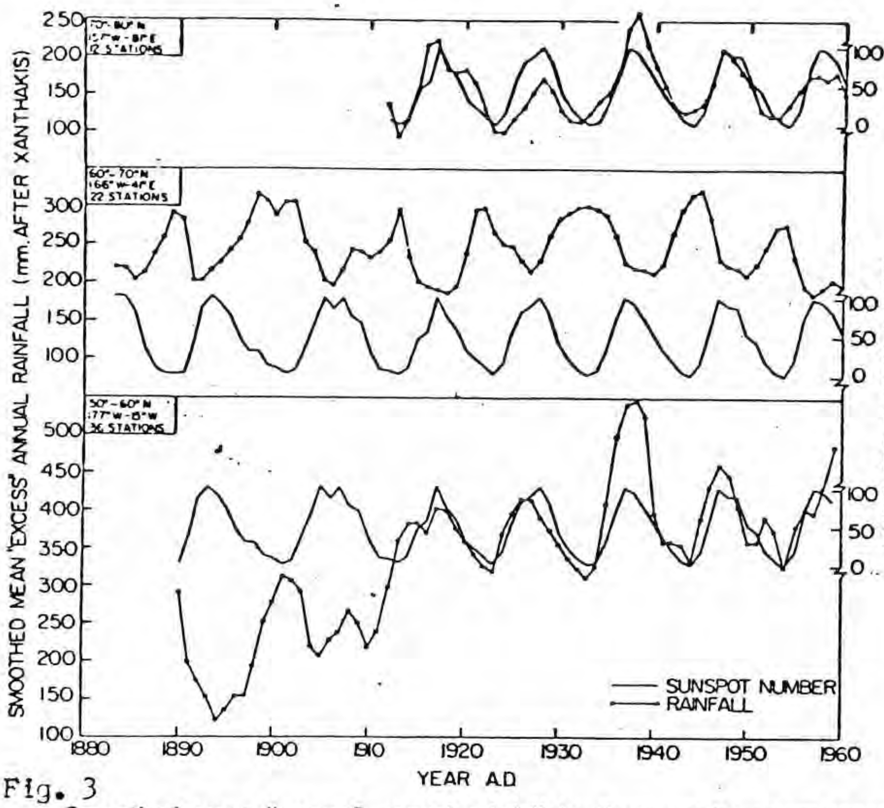


Fig. 3

Smoothed mean "excess" annual rainfall in three northern-hemisphere zones (after Xanthakis, 1973) compared with the corresponding "normalized" annual sunspot numbers. The normalized sunspot number for a particular year is given by $100\,(N_Y-N_N)/(N_X-N_N)$ where N_Y is the annual mean sunspot number for the year concerned and N_X and N_N are respectively the annual mean sunspot numbers for the maximum and minimum years between which the particular year falls. It should be noted that data from the American, European and Asian sectors have been analysed, but that, in the 50°-60°N zone, data from only the American sector are shown; the rainfall in the European and Asian sectors of this zone behaved differently.

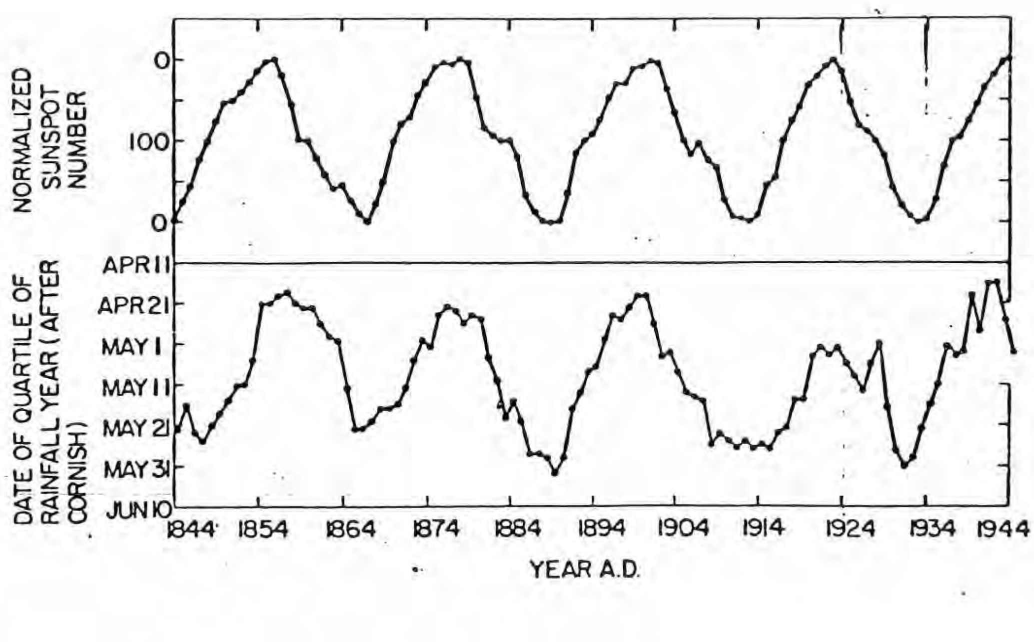
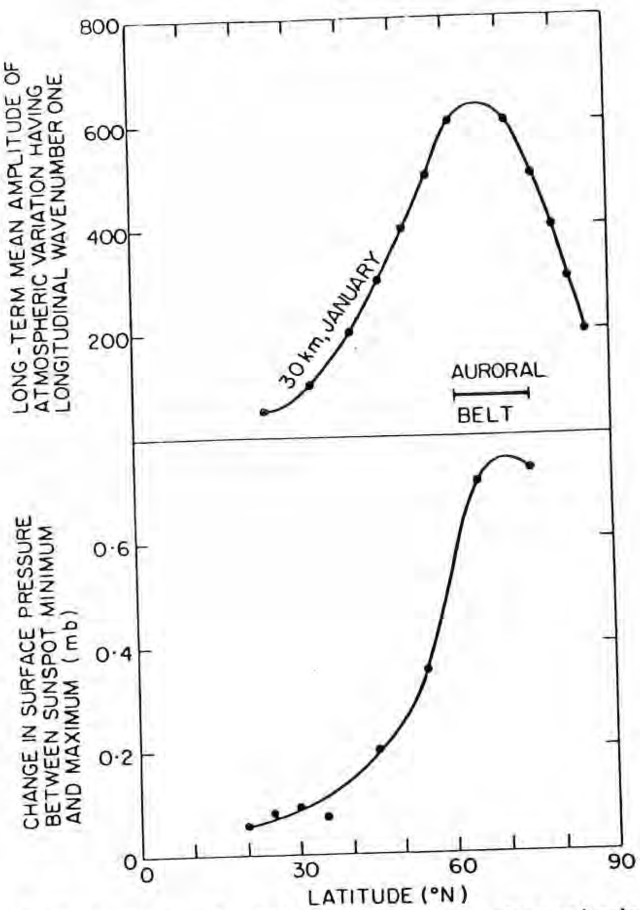
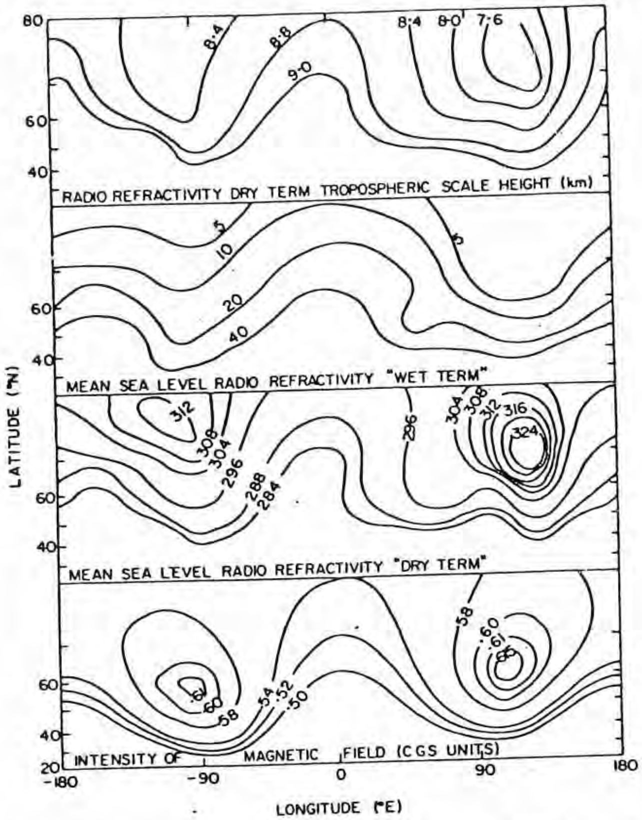


Fig. 4

Ten-year smoothed means (lower curve) of the annual rainfall "quartile" (the date by which one quarter of the annual rainfall had occurred) for Adelaide, Australia. After Cornish (1954). The date fluctuates by about six weeks in phase with the double sunspot cycle plotted in the form shown in the upper curve. The Cornish data points are slightly displaced because he used smoothed means for an even number of years.

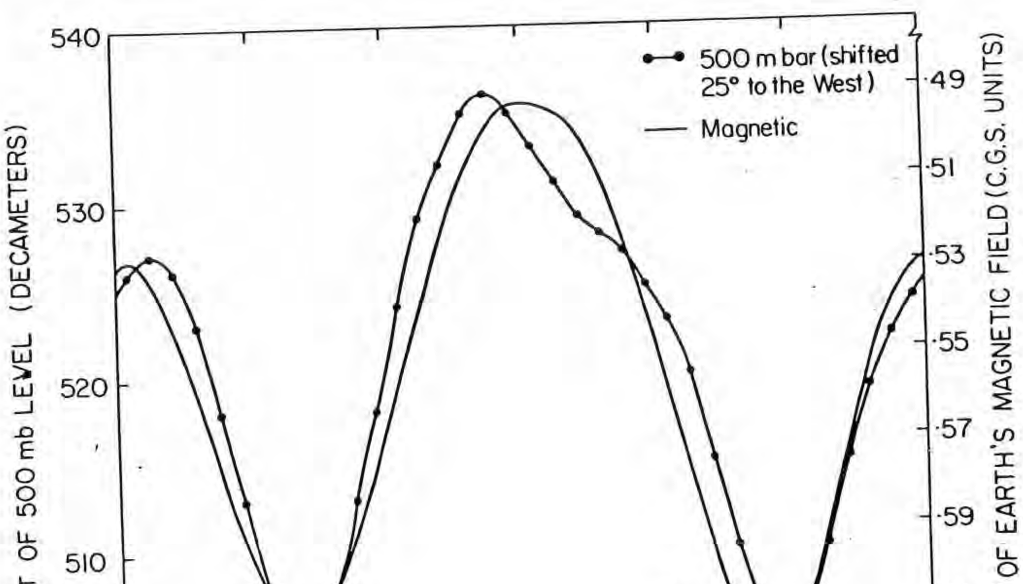


F-10 Latitudinal variations of two atmospheric parameters showing particularly large effects in the auroral belt. The values in the upper and lower curves were calculated from data published by Van Loon et al (1973) and Miles (1974) respectively.



F-11 Spatial variations of three different meteorological parameters compared with the intensity of the geomagnetic field (after King, 1974b). The upper three boxes contain maps, published by Bean et al (1966), that indicate how average tropospheric temperature, surface humidity and surface pressure vary over most of the northern hemisphere in November. The lowest box contains a map of the intensity of Earth's magnetic field.

Fig. 5



F-12 Longitudinal variations at 60-deg N of the average height of the 500-mb level for January (after Palmen and Newton, 1969) shifted 25 deg to the west and the intensity of the geomagnetic field.

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SASKATOON CENTRE

MEETING NOTICE

Place Rm. B110, Health Science Bldg., U of S.

Date Tuesday, May 18, 1976

Time 8:00 p.m.

Purpose May General Meeting

Report on Observatory Alterations

and on Centre participation at Calgary

POWER NEEDED TO SPLIT DOUBLE STARS

ANGULAR SEPARATION "	FOR APPARENT SEPARATION OF 4"	6"	8"	20"	25"	ANGULAR SEPARATION "	FOR APPARENT SEPARATION OF 4"	6"	8"	20"	25"	ANGULAR SEPARATION "	FOR APPARENT SEPARATION OF 4"	6"	8"	20"	25"
1	240	360	480	1200	1500	8.5	28	42	56	141	176	24	10	15	20	50	62
1.2	200	300	400	1000	1250	9	27	40	54	133	166	25	10	14	20	48	60
1.5	160	240	320	800	1000	9.5	26	39	52	126	156	30	8	12	16	40	50
1.7	140	210	280	700	882	10	24	36	48	120	150	35	7	10	14	34	43
2	120	180	240	600	750	11	22	33	44	109	136	40	6	9	12	30	37
2.5	96	144	192	480	600	12	20	30	40	100	125	45	6	8	12	27	33
3	80	120	160	400	500	13	18	28	36	91	115	50	5	8	10	24	30
3.5	68	102	136	343	428	14	17	26	34	86	107	55	5	7	10	22	27
4	60	90	120	300	375	15	16	24	32	80	100	60	4	6	8	20	25
4.5	54	80	108	266	332	16	15	22	30	75	94	65	4	6	8	19	23
5	48	72	96	240	300	17	14	21	28	70	88	70	4	6	8	17	21
5.5	44	66	88	218	272	18	13	20	26	67	83	75	4	5	8	16	20
6	40	60	80	200	250	19	12	19	24	63	78	80	3	5	6	15	18
6.5	36	54	72	184	230	20	12	18	24	60	75	85	3	5	6	14	18
7	34	51	68	171	214	21	12	17	24	57	71	90	3	4	6	14	17
7.5	32	48	64	160	200	22	11	16	22	55	68	95	3	4	6	13	16
8	30	45	60	150	188	23	10	16	20	52	65	100	3	4	6	12	15

MINUTES: Due to the lack of an April General Meeting and Executive meeting, there are no April minutes to publish. Regular meetings will resume this month and the May minutes will be published.