GLOBAL VARIATION IN ATMOSPHERIC ELECTRIC FIELD ON THE SEA SURFACE

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Abstract

An analysis of the global nature of atmospheric electric field on the ocean is presented on the basis of measurement on the research vessel, Hakuho-Maru. The daily averages of electric field ranging 50 to 140 v/m give a latitude dependence, that they are higher as much as 25 % in high latitude than in low latitude, in spite of widely dispersed values. On the other hand, the diurnal course of electric field displays more or less a typical variation in phase with the thunderstorm activity integrated over the entire globe. Some changes in the hours that give the maximum field in daily courses, when they are averaged for every 10 degrees latitude section, seem to suggest the regional effect due to the distance from thunderstorm areas acting as the generator of global atmospheric electrical circuit.

1. Introduction

It is a well known observational result that the atmospheric electric field on the sea surface displays a diurnal variation almost in phase with the thunderstorm activity accumulated all over the world. From this fact the existence of a global electric current circuit has been assumed, which starts from thunderclouds mainly distributed in the tropical zone, passes through the upper conductive atmosphere and terminates at the fair weather ground and sea surface. Out of the hypothetical global circuit, we could easily bring two factors, which would have an effect on the intensities of fair weather atmospheric electric field in different locations on the earth ; first the geographical distribution of thunderstorms as the generators of global circuit, and second the latitude dependence of electric conductivity in the upper atmosphere related to the ionization by cosmic ray. In recent years we have confirmed the typical diurnal variation of the atmospheric electric field on the neighboring sea of Japan (Takagi and Kanada, 1969), and have had a further opportunity to measure it on the Mid- and South-Pacific Ocean. The present paper is to report an analysis of

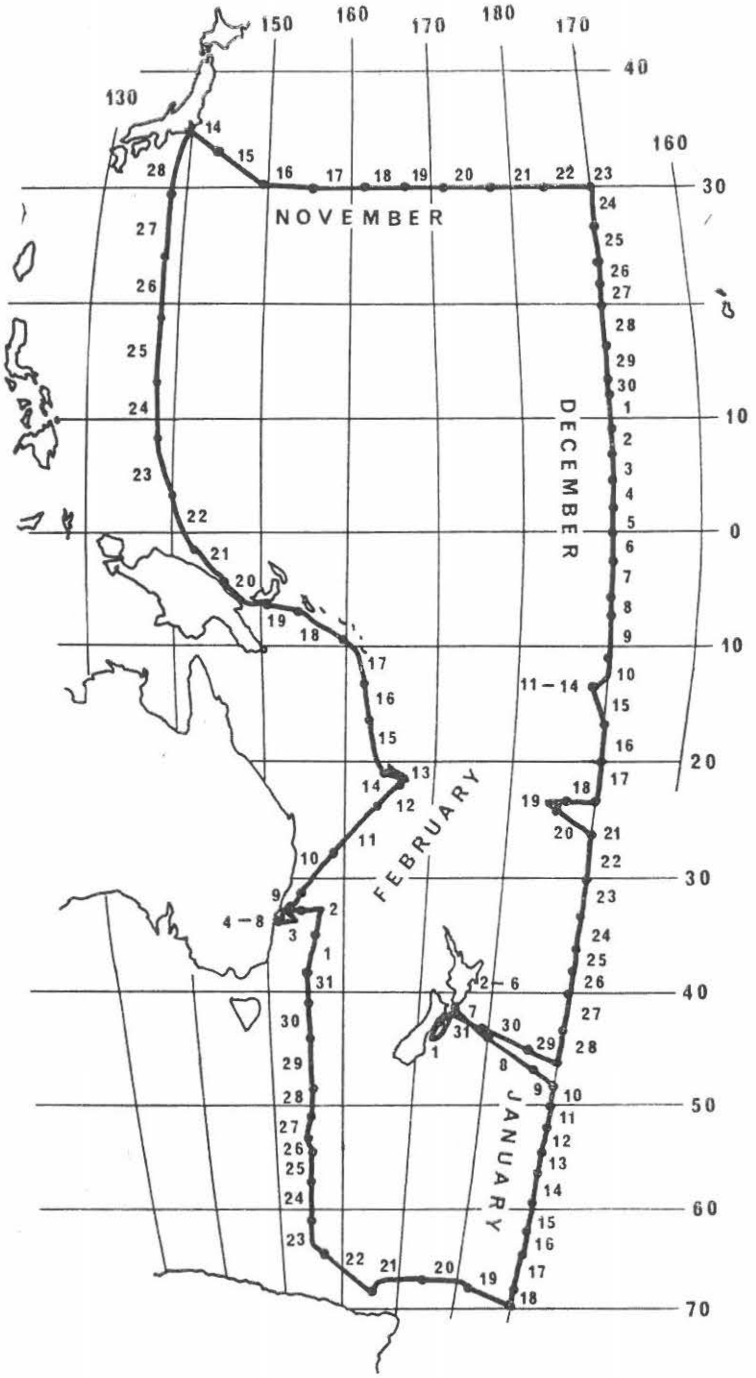

Fig. 1. Course of research vessel, Hakuho-Maru.
Numbers along the course indicate the dates,

the universal variation in atmospheric electric field on the basis of the measurement with a mill type field meter on the research vessel, Hakuho-Maru, of the Ocean Research Institute, University of Tokyo. The cruise reached to 70°S in the Antarctic Ocean as shown in the course map, Fig. 1. It was very suitable for investigating the latitude dependence of atmospheric electricity. The measurement on a vessel would be essential to know the natural properties of atmospheric electricity by minimizing the effect of land pollution, although it would involve difficult problems of space charge originating from the sea surface and of electrode effect (Blanchard, 1966; Mühleisen, 1961; Takagi and Kanada, 1969). To approach to the general elucidation of atmospheric electricity on the sea, several kinds of measurements have been done at the same time on Hakuho-Maru on air-earth current density, atmospheric electric conductivity and mobility spectrum of small ions in addition to atmospheric electric field. These measurements are still being processed and will be reported in a near future.

2. Latitude dependence of atmospheric electric field

The measurement of electric field was carried out over whole period of the cruise, which amounted to 110 days from November 14, 1968 through March 3, 1969. The cruise was generally favored by fair weather in its earlier half, when the vessel took almost all parts of the longitudinal route along 170°W. In the later half that coincided in part with the First Intensification Interval of the Atmospheric Electricity Ten-Year Program, the weather was not always desirable and the route that the vessel took was often too close to islands where atmosphere had a possibility to be affected by pollution from the land.

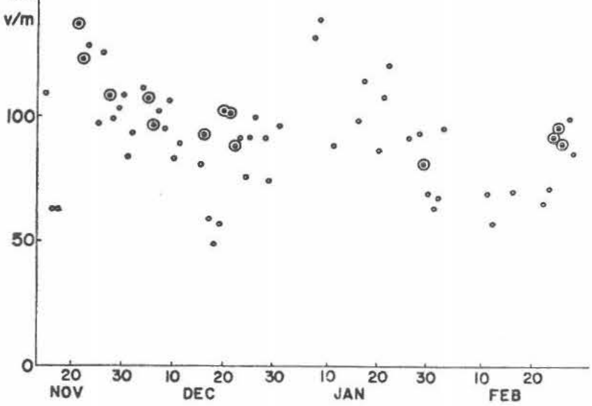

Fig. 2. Daily average of atmospheric electric field with the progress of cruise.

Fig. 2 illustrates how the daily averages of atmospheric electric field go with the progress of cruise. The values at such days were excluded from the figure, as the atmosphere seemed to be disturbed over more than 12 hours by meteorological reason such as precipitation as well as by land pollution. Double circles in the figure indicate the values in especially good weather, when the blue sky or partly cloudy sky had continued all day. Although Fig. 2, even only on double circles, shows much fluctuation day by day in the daily averages, the arrangement of daily averages in the whole are recognized as to take W-like pattern during the course. This might correspond to the location of the vessel moving from the northern hemisphere down to the southern high latitude and then coming back. Fig. 3 is the correspondence of the daily averages to the geographic latitude. There seems, in spite of considerable dispersion, to be a tendency that the daily averages in higher latitude are larger than those in lower latitude in both hemispheres. The mean values in every 10 degrees section are shown by connecting them with a dashed line. The difference of intensities amounts to 25 %. It gives the similar result to the rather old analyses by Rough (1941) and Gish (1942), excepting that the latitude giving the lowest field is not the equator but around 20°S.

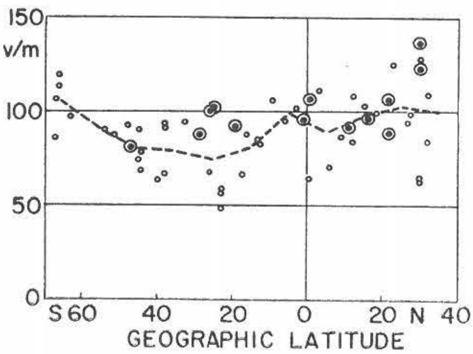

Fig. 3. Daily averages with geographic latitude.

The latitude effect of electric field has been explained by the difference in the conductivity of vertical column guiding electric current from the upper conducting layer to the earth surface. The ionization that makes atmosphere conductive is mainly attributed to cosmic ray not only in the upper atmosphere but also on the ocean surface, where no ionization would be expected from radioactive substance in the earth crust. Thus it would be more reasonable to plot the daily values with geomagnetic latitude as shown in Fig. 4. But the step does not seem to bring a significant improvement in the distribution. The latitude that gives the lowest field values is further shifted to around 25°S in geomagnetic. The disaccord of the latitude of lowest field with the equator may correlate to the annual variation of electric field

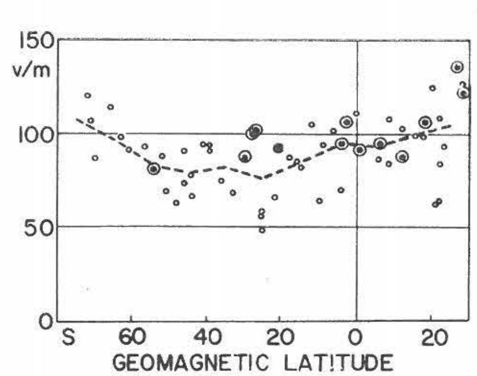

Fig. 4. Daily averages with geomagnetic latitude.

in the global scale. According to the statistical treatment of atmospheric electric field at number of stations in northern hemisphere as well as in southern hemisphere, the annual course of the field involves 16 % variation related to the alteration of warm and cold seasons, that is high in winter and low in summer (Paramonov, 1950). The annual effect undoubtedly moves the latitude giving the lowest level toward the south in the season of our observation.

3. Diurnal variation of atmospheric electric field

In Fig. 5 the diurnal variations averaged in every 10 degrees geographic latitude section and for whole period of cruise are illustrated. In the figure, dots are mean levels for every hour and the curve in solid line is calculated out from these dots by using the method of harmonic analysis as far as two components of diurnal and semi-diurnal variations are concerned. Table 1 also shows the results of calculation. The periods taken up as fair weather for the analysis are about 3 to 7 days in accumulation for each latitude section, which are found in the last column in Table 1.

The pattern of diurnal variations has the maximum around 14 to 19 UT and the minimum around 02 to 08 UT, which could be considered as representing a global characteristic. As well known, the pattern almost coincides with that of thunderstorm area integrated over the whole globe. In the season of our measurement, we could assume that the active regions of thunderstorm were roughly concentrated into three active centers around 10°S, 120°E in South-East Asia, 10°S, 30°E in South Africa and 10°S, 60°W in South America. Since the storms usually take the maximum in activity at 14 to 18 hours local time, the effects of the three active centers appear around 06 to 10, 12 to 16 and 18 to 22 UT, respectively. The three centers are arranged successively 90 degrees apart in longitude, and the effects of them appear with intervals of 6 hours. The daily course of atmospheric electric field would mainly be affected by the changes of the three centers. If the three centers would have the same magnitude of contribution to the electric field, the maximum in the diurnal variation would come out at 14 UT, the middle point of the three hourly periods of storm activity, and the two maximums for the semi-diurnal variation at 08 and 20 UT, coinciding with each center of the two activities on both sides. Usually the contribution from South-East Asia is smaller than the other two, so that the maximum in diurnal course would be shifted to later hours than 14 UT. For the semi-diurnal variation, South-East Asia and South America are in the same phase, while South Africa is in the inverse phase with the former two. So the maximums will come out at 08 and 20 UT or at 02 and 14 UT according to the magnitude of contribution from the three centers.

Following Table 1 the time of maximum in diurnal variation is later in northern

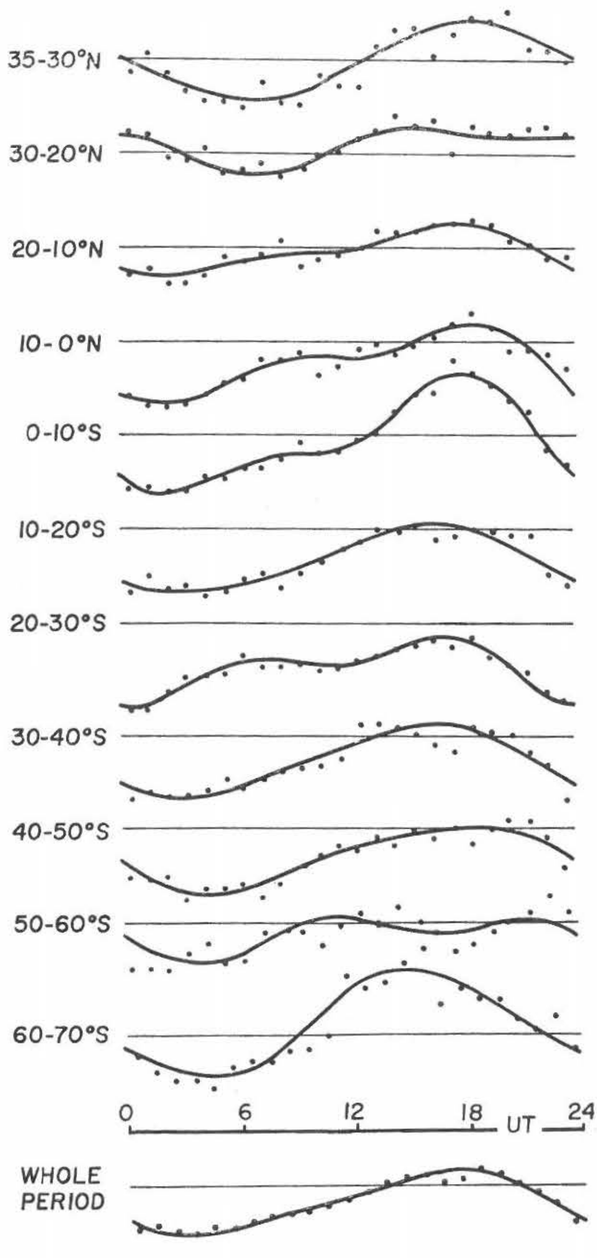

Fig. 5. Diurnal variation of atmospheric electric field in every 10 degrees latitude section and for whole period of measurement. Straight horizontal line in every section is the level of 100 v/m, and intervals of successive levels are equivalent to 50 v/m.

Table 1. Daily course of atmospheric electric field in every 10 degrees latitude section and for whole period of measurement.

Geographic latitude	Daily average v/m	Diurnal variation		Semi-diurnal variation		No. of fair-weather days
		Amplitude v/m	Time of max. h UT	Amplitude v/m	Time of max. h UT	
35-30 N	99.1	20.2	18.7	1.4	4.9, 16.9	5.3
30-20 N	104.1	10.7	18.8	4.9	1.4, 13.4	5.6
20-10 N	98.3	12.0	16.2	5.0	6.8, 18.8	5.7
10-0 N	89.0	16.6	16.3	8.4	7.7, 19.7	4.3
0-10 S	97.5	27.0	16.9	11.0	6.7, 18.7	4.1
10-20 S	84.0	17.6	16.1	1.6	6.0, 18.0	4.3
20-30 S	76.2	12.6	14.1	8.5	6.0, 18.0	6.6
30-40 S	86.6	19.5	15.5	2.2	6.1, 18.1	7.2
40-50 S	84.5	17.2	17.4	3.7	8.9, 20.9	6.0
50-60 S	92.9	8.5	15.9	6.7	9.9, 21.9	2.7
60-70 S	104.4	28.0	15.7	4.2	10.4, 22.4	4.5
Whole period	90.3	15.6	16.4	3.0	7.0, 19.0	56.4

hemisphere than in southern hemisphere, and is the earliest around 20 to 30°S. On the other hand, the time of maximums in semi-diurnal variation is earlier in northern hemisphere, whereas excluding high latitude in northern hemisphere it is the earliest around 20 to 30°S then goes later toward both higher latitudes. The tendency is similar to that in the diurnal variation. As a possibility to explain the tendency, we could consider the distance from the three centers. In a recent paper, Anderson (1969) reported that the effect of thunderstorms as a generator of global atmospheric electricity might not perfectly be propagated to the opposite hemisphere. The tendency found in the time of maximums in Table 1 just seems to suggest the effect of distance to South-East Asia, because the bigger contribution from South-East Asia would give the earlier time of maximum. In the present cruise, the distance to South-East Asia from the vessel was ranged 20 to 80 degrees (2200 to 9000 km), and the measurements were done always in the same hemisphere as South-East Asia. Fig. 6 shows the correlation between the distance and the ratio of the mean level during 06 to 10 UT, when the effects of storms in South-East Asia would appear, to the daily average. Dots in the figure are so widely scattered that we cannot say any definite conclusion in this respect. The other two storm centers in South Africa and South America were ranged 100 to 160 degrees, and 90 to 160 degrees, respectively, being always in opposite hemisphere. We again find no reliable effect of distance in these two storm centers. To make the point clear, it would be desirable to compare the measurements done in other districts on the globe on the same day. We would expect to take a step to compare our results to the data obtained in the Antarctica and the Atlantic Ocean during the First Intensification Interval of Atmospheric Electricity Ten-Year Program.

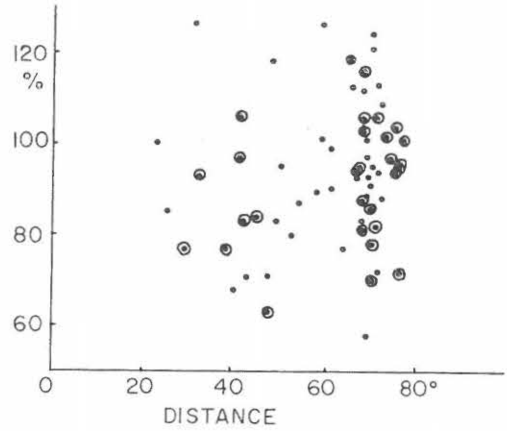

Fig. 6. Correlation between the distance to South-East Asia and the mean level during 06 to 10 UT. The mean level is represented by the ratio to the daily average to minimize the latitude effect.

Acknowledgement —— We wish to express our thanks to Prof. S. Horibe and the staffs of the Ocean Research Institute, University of Tokyo for giving us an opportunity to make our measurements possible on the research vessel, Hakuho-Maru.

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Appendix

Atmospheric Electricity Surface Observations

Hourly Means of Electric Field

Expressed in Volts/meter

Station : Research Vessel, Hakuho-Maru on the Mid- and South-Pacific Ocean

Period : November 14, 1968 to March 3, 1969

HOUR UT DATE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	DAILY AVERAGE	LOCATION AT NOON
NOV 1968																										
14														190	200	205										35N 140E
15	70	75	80	85	105	105	75	105			165	145			150	145									109	32 146
16				60	55	55				60	65	65	65	60	65	65	65	65	70	65	65	70	65	60	63	30 152
17	60	55	50	55	45	50	55	55	55	55	55	60	65	65	75	65	75	75	85	85	75	70	65	65	63	30 158
18	55	85	75	75	75	80	65																			30 165
19												35	35	40	35	40	45									30 168
20																								110		30 175
21	110	105	105	105	100	90	95	100	95	95	95	105	115	140	140	165	185	200	225	220	230	155	175	145	137	30N 179W
22	175	195	155	115	95	85	85	90	85	95	115	115	130	130	135	125	130	135	135	140	135	130	115	115	123	30 173
23	110	125	125	125	120	120	120	120	130	120	120	125	135	135	145	150	145								128	30 170
24											110	100														28 170
25			90	85	85	85	90	105	85	95	90	90	100	90	100	100	100	90	110	95	90	90	100	90	93	26 170
26	95	105	105	105	110	110	110	120	120	125	130	130	135	145	140	140	145	140	135	140	140	135	120	115	125	23 170
27	110	95	90	105	95	90	105	100	100	95	105	110	125	130	140	130	130	110	110	110	105	100	100	90	107	21 170
28	80	80	75	85	95	100	95	110	110	95	90	100	100	110	100	105	110	110	110	105	105				99	18 170
29	95	90	90	90	105	95	95	90	120	95	100	100	110	120	105	110	110	110	115	110	110	110	105	100	103	15 170
30	85	90	90	85	85	105	105	110	110	110	110	110	115	125	130	115	120	125	125	130	115	110	90	90	108	12 170

HOUR UT / DATE	0 - 1	- 2	- 3	- 4	- 5	- 6	- 7	- 8	- 9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	-21	-22	-23	-24	DAILY AVERAGE	LOCATION AT NOON
DEC 1968																										
1	85	95	75	65	65	85	85	85	90	80	85	75	75	85	85	90	95	90	95	90	85	85	85		84	12N 170W
2		60	60			80			100	90	90	90	85	90	90	85				105	85	95	95	90	87	9 170
3																										6 170
4					70	85	105	115	130	120	105	115	120	130	120	125	110	110	120	120	120	110	105	90	111	3 170
5	80	95	85	85	90	100	85	80	85	100	85	90	95	110	110	115	130	150	155	150	120	135	120	110	107	1 170
6	95	90	90	90	100	100	85	80	75	90	85	80	90	95	100	105	110	135	130	115	110	105	75	65	96	1S 170
7	75	70	65	70	85	80	80	80	80	80	85	95	105	115	125	140	135	145	150	140	125	120	105	100	102	3 170
8	85	80	85	90	85	80	80	85	90	90	105								120	125	120	110	95	90	95	6 170
9	85	105	100	90	105	105	115	135	135	125	90	100	100	95	100			100	100	110	115	130	105	90	106	9 170
10	75	70	65	70			85	90	80	80	85	90	100	105			90	90	100	75			85	65	83	12 171
11	65	70	65	70	70	65	70			90	105	105	105	100	110	110									86	13S 172W
12																										APIA
13																										
14																										
15										70	70	80	85	100	100	105	100	110	105	100	85	70	70	70	88	16 171
16	65	65	70	80	80	75	75	75	65	85	90	95	110	125	130	130	125	120	125	110	90	90	80	65	93	19 170
17				85	75	75	80	70	65	50	50	50	60	70	70	60	65	65	55	50	45	40	30	25	59	23 170
18	30	30	35	45	50	50	55	45	40	45	45	40	45	45	45	45	50	60	65	60	70	60	65	65	49	23 173
19	50	45	55	60	60	60	70	65	65	70	50	65	55	65	65						50	50	45	40	57	23 176
20	50	55	70	80	90	90	90	95	100	110	110	110	110	110	125	135	145	135	130	130	135	105	80	70	103	25 173
21	65	85	85	85	85	75	105	105	100	105	105	115	110	115	125	125	120	110	110	105	105	105	95	85	101	26S 170W
22	80	70	75	70	80	85	95	90	90	95	95	105	100	100	90	85	90	90	105	85	85	90	80	70	88	29 170
23	80	90	90	95	100	105	110	120	105	90	70	90	80	90	100	90	80	90	95	90	105	80	70	70	91	32 170
24	65	60	65	65	70	70	75	70	80	85	80	75	85	85	85	75	75	70	80	85	85	80	80	65	75	35 170
25	70	75	70	70	70	80	70	70	85	95	115	90	135	135	100	105	100	75	110	110	105	95	90	70	91	38 170
26	55	65	65	75	70	70	60	80	85	85	105	100	105	120	120	125	115	125	135	120	95	105	115	70	94	38 170
27	65	80	85	70																						42 170
28					70	70	70	75	75	105	90				110	105	105	110	100	95	105	90	90	75	91	45 170
29	70	70	70	55	65	65	65	65	65	70	75	80	75	85	75	100	100								74	46 172
30				65	70	65	70						85	75	85	105	85	95				65		65	78	44 178
31	55	50	45	30	55				80	85	85	90	85													42S 176E

HOUR UT DATE	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 -10	-10 -11	-11 -12	-12 -13	-13 -14	-14 -15	-15 -16	-16 -17	-17 -18	-18 -19	-19 -20	-20 -21	-21 -22	-22 -23	-23 -24	DAILY AVERAGE	LOCATION AT NOON
JAN 1969																										
1																										43S 174E
2																										WELL-
3																										INGTON
4																										
5																										
6																										
7											110	100	105	105	110	110	105					155	150	145		42S 177E
8	145	130	135	130	135	135	155																			45S 177W
9																										48 170
10																	85	85	70				80	65		49 170
11	60	65	55	65	70	75	80	85	85	90	90	105	125	105	105	90	85	90	100	95	100	105	95	100	88	52S 170W
12	90	85	105	110	140			135	140	130								80	75							54 170
13		75	80	85	85	75	75																			56 170
14			65	70	70	85	85																			58 170
15			65						85	90	90	105	105						105	100	95	85	105			60 170
16		75	70	85	70			70	70	70	90			110	130	120	115	145	125	125					98	63 170
17								90	110	100	100	115	125	125			100	120	140	140	115	105	120	105	114	66 170
18	95	110	105	95	95	100	100	95	105	105	80															69 170
19																										69 172
20		60	55	50	45	55	65	65	45	65			125	135	140	130	125	105	100	105	95			70	86	67 180
21	80	70	70	70	65	65	65		90	90	110	150	150	145	150	190	125	130							107	66S 170E
22						110	110	110	125	130	125	135						125	130	125	125	120	105	105	120	66 162
23	95	90	85	85	90	90	95	90	90	90	95															63 155
24																										60 155
25																										56 155
26					75	80	80	65	70	75	85	85	85	95	110	110	105						130	110	91	54 155
27																										51 155
28								105	110	115	95	130	115	105	70	65	75						65	60	93	48 155
29	30	30	40	50	50	40	45	45	50	65	110	110	115	120	110	110	110	110	105	105	105	105	90	85	81	47 155
30	85	75	70	70	65	65	50	50	70	65	70	70	70	85	85									60	69	44 155
31	70			30	35	40	40	45	50	45	50	60	65	70	80	85	85	80	80	80	80	75	70	65	63	40 155

HOUR UT / DATE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	DAILY AVERAGE	LOCATION AT NOON
FEB 1969																										
1			60	60	65	75	70	70	75	70	75	65											60	55	67	38S 155E
2	65	60	55	50	55	60	60	60	60	80	65	115	130	140	145	130	125	120	130	130	135	115	120	65	95	33 156
3																										33 152
4																										SYDNEY
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8																										
9																										33S 152E
10														70	85	80				70	70			55		29 156
11	50	50										75	85	85	85	85	75	70			70	65	50	50	68	26S 161E
12	50	50										55														23 166
13																										NOUMEA
14																										
15																										21S 165E
16		110	85	65	65	65	65	65	65	65	65	70	70	70	55	65	65	65	70				40	60	67	17 162
17		65	65	65	55																					11 161
18																								30		8 157
19	40	35	30	35	45	50	65	55	55																	6 151
20																										6 148
21																							70	60		3S 144E
22	50	50	50	50	50	55	65	65	65	65	65	70	85	80	75	75	70	70	70	70	65	65	65	65	65	1N 141E
23	60	50	50	50	60	60	60				65	70		85	75	90	100			90	85	80	80	70	71	6 139
24	70	60	65	65	65	65	70	75	70	70	80	85	90	105	115	125	120	130	130	130	115	105	105	105	92	11 138
25	90	90	85	90	85	90	85	90	90	90	100	105	105	110	110	105	105	105	110	105	95	95	90	85	96	16 138
26	80	80	70	70	80	70	70	70	65	65	65	65	70	90	85	90	95	105	105	100	105	130	135	180	89	22 138
27	165	145	110		140	110	90	85	70		80	85	85	85	110	85	95	55						80	99	27 138
28	80	80	70	65	65	50	60	65	55	60	65	80	105	125	130	125	110	95	100	90					84	32 138
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