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Vertical cutoff rigidities for cosmic ray stations since 1955

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Abstract. We have computed vertical cutoff rigidities from 1955 to 1995, at five-year intervals, for neutron monitor stations. We have utilized the Definitive International Geomagnetic Reference Field as published by IAGA for five-year intervals from 1955 to 1990 and the Interim International Geomagnetic Reference Field for 1995. The results show that the changes in cutoff rigidity are not linear and vary with location over the world. We find that the vertical cutoff rigidity is relatively stable for European cosmic ray stations. However, there is a substantial reduction in the vertical cutoff rigidity at Latin American and Southern Africa stations. At the same time we have found a slow, but steady increase in the vertical cutoff rigidity values at cosmic ray stations located near the east coast of North America.

1 Introduction

With the advent of high-speed digital computers in the 1960s, it became viable to calculate the orbits of charged particle access through a model of the geomagnetic field. This trajectory-tracing procedure led to the determination of cutoff rigidities for selected cosmic ray stations with the first extensive tables published by Shea et al., (1965). These vertical cutoff rigidity values for cosmic ray stations were determined using the trajectory-tracing method through the Finch and Leaton (1957) 6th order geomagnetic field representation. Finch and Leaton utilized the British Admiralty charts for 1955.0 to derive their model. The charts were prepared from worldwide ground-based measurements of the geomagnetic field. Thus the initial vertical cutoff rigidity values calculated by Shea et al. (1965) were appropriate for Epoch 1955.0.

With an increase in spacecraft experiments in the mid 1960s, satellite instrumentation was employed to obtain geomagnetic field measurements in near-earth space. These measurements were incorporated in the development of subsequent mathematical representations of the geomagnetic field such as the IGRF model for Epoch 1965.0 (IAGA Commission 2, Working Group 4, 1969). Using these and other models, Shea and Smart (1970) found significant changes in some vertical cutoff rigidity values resulting from secular variations in the geomagnetic field. Shea (1971) predicted that the decrease in the cutoff rigidity at Huancayo, Peru would result in an apparent increase in the cosmic ray intensity as measured by a stable neutron monitor. Cooper and Simpson (1979) confirmed this prediction. In subsequent studies and utilizing latitude survey measurements by König and Stoker (1981), Shea and Smart (1990) found that the secular changes in the geomagnetic field were sufficiently large to be a significant factor in the use of these values to analyze precise cosmic ray measurements.

The Working Group on Geomagnetic Field Models of the International Association of Geomagnetism and Aeronomy (IAGA) has been responsible for the determination, evaluation and approval of mathematical models of the geomagnetic field. With extensive work, much of which is documented by Sabaka et al. (1997), this group derived Definitive Models of the Geomagnetic Reference Field every five years from 1940 through 1990. The coefficients for these models are available through World Data Center A for Solar-Terrestrial Physics.

Using these standardized and improved mathematical representations of the geomagnetic field, we have determined effective vertical cutoff rigidities for the known cosmic ray neutron monitors (Shea and Smart, 2000). These values, for selected neutron monitors, are given in Table 1. The stations are listed by decreasing latitude. At the present time only the IGRF (Interim) field model for Epoch 1995 is available. The DGRF Epoch 1995 model will be available when the geomagnetic field evolution from 1990 to 2000 is evaluated and incorporated into the final model.

2 Discussion

The values in Table 1 show that the vertical cutoff rigidities for stations in Latin America and Southern Africa have steadily decreased over this 40-year period. The cutoff rigidity at Mexico City has decreased from 9.45 GV

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to 8.02 GV. The cutoff rigidity at Huancayo has decreased from 13.44 GV to 12.63 GV. While cosmic ray observations terminated at Huancayo in 1992, the monitor at Haleakala, Hawaii, should provide continuity for the long-term measurement of the high-energy galactic cosmic radiation. Figure 1 shows that the cutoff rigidity for these two high altitude stations was about the same from 1975 to 1985 thus allowing for extrapolation and normalization of the data over that time period.

Of particular interest are locations where neutron monitors have been in operation for long time periods. The cutoff rigidity value at Jungfraujoch has remained essentially constant. However, the cutoff rigidity at Climax, shown in Figure 2, reflects the relative decrease of the geomagnetic field.

There are also changes along the Eastern Coast of North America, as shown in Figure 3. The vertical cutoff rigidity at Mt. Washington was originally determined to be 1.24 GV using the Finch and Leaton model for Epoch 1955.0. This value has been used consistently over the years since this station is well above the knee in the cosmic ray latitude curve. However, the cutoff rigidity values listed in Table 1 reveal an increase from 1.25 GV for 1955 to 1.58 GV for 1995. A similar effect is present at Deep River, Durham, and Newark. These changes in vertical cutoff rigidities are significant in the analyses of relativistic solar-cosmic ray events. The increase in cutoff rigidity along the East Coast of North America is the result of the “well-known western drift” of higher order moments in the North Atlantic.

3 Summary and Conclusions

Using the trajectory-tracing method, we have determined vertical cutoff rigidities for cosmic ray stations at five-year intervals from 1955 to 1995. These values have been derived using the appropriate Definitive Geomagnetic Reference Field coefficients in the trajectory-tracing program. Significant changes in the vertical cutoff rigidity values have been noted for stations in Latin America, southern Africa and near the east coast of North America. The effect of the secular changes in the geomagnetic field and the resulting changes in vertical cutoff rigidity values should be considered when using neutron monitor data for studies such as latitude surveys, long term modulation, and relativistic solar proton events.

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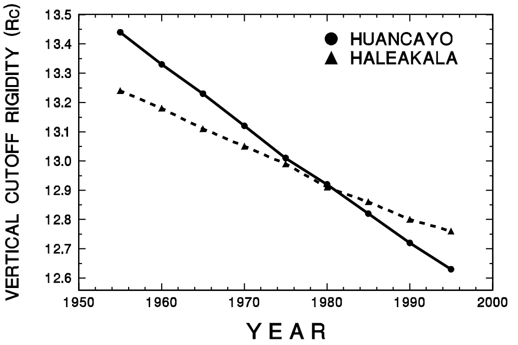

Fig.1. The changing cutoff rigidity at Hauncayo and Haleakala.

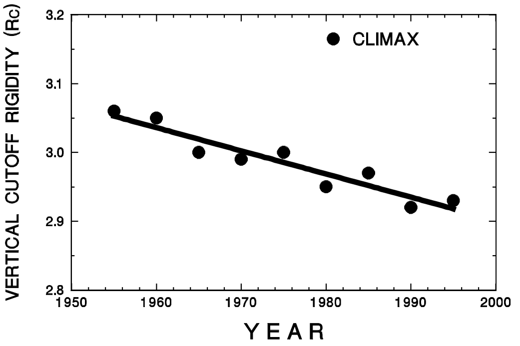

Fig.1. The cutoff rigidity for the Climax neutron monitor.

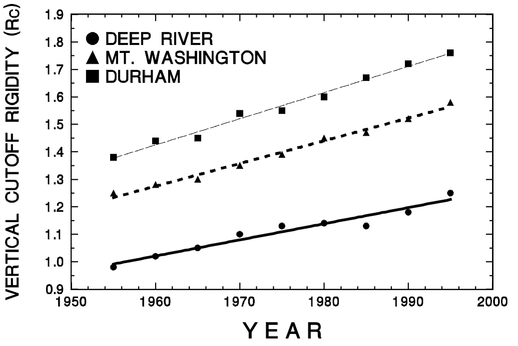

Fig.3. The change in cutoff rigidity for Deep River, Mt, Washington, and Durham.

Table 1. Effective vertical cutoff rigidities at various epochs for selected neutron monitors

	Lat.	E. Long.	1955.	1960.	1965.	1970.	1975.	1980.	1985.	1990.	1995.
ALERT, CANADA	82.50	297.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
THULE, GREENLAND	76.50	291.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RESOLUTE, CANADA	74.72	265.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TIXIE BAY, RUSSIA	71.58	128.92	0.48	0.48	0.47	0.47	0.47	0.48	0.44	0.44	0.43
NORILSK, RUSSIA	69.26	88.05	0.61	0.59	0.59	0.57	0.58	0.57	0.59	0.54	0.53
CAPE SCHMIDT, RUSSIA	68.92	180.53	0.58	0.53	0.55	0.55	0.56	0.57	0.55	0.51	0.52
INUVIK, CANADA	68.35	226.28	0.15	0.01	0.15	0.15	0.13	0.13	0.15	0.01	0.14
KIRUNA, SWEDEN	67.83	20.43	0.50	0.51	0.50	0.52	0.52	0.51	0.49	0.51	0.49
APATITY, RUSSIA	67.55	33.33	0.63	0.60	0.60	0.62	0.63	0.60	0.57	0.56	0.55
OULU, FINLAND	65.05	25.47	0.80	0.79	0.79	0.81	0.81	0.79	0.76	0.76	0.77
COLLEGE, USA	64.08	212.17	0.58	0.55	0.55	0.56	0.57	0.56	0.53	0.53	0.52
YAKUTSK, RUSSIA	62.03	129.73	1.61	1.65	1.65	1.63	1.65	1.62	1.62	1.57	1.55
OKTYEMTSY, RUSSIA	61.66	129.37	1.71	1.68	1.71	1.72	1.70	1.71	1.65	1.61	1.60
TURKU, FINLAND	60.40	22.60	1.38	1.40	1.32	1.35	1.34	1.35	1.32	1.35	1.35
MAGADAN, RUSSIA	60.12	151.02	2.04	2.10	2.08	2.09	2.04	2.07	2.03	2.01	1.99
FORT SMITH, CANADA	60.02	248.07	0.28	0.28	0.27	0.28	0.28	0.28	0.28	0.30	0.30
UPPSALA, SWEDEN	59.85	17.55	1.39	1.38	1.42	1.39	1.41	1.38	1.37	1.37	1.37
CHURCHILL, CANADA	58.75	265.91	0.18	0.19	0.20	0.18	0.19	0.20	0.18	0.21	0.22
SVERDLOVSK, RUSSIA	56.73	61.07	2.30	2.29	2.28	2.27	2.29	2.25	2.19	2.14	2.13
NAIN, CANADA	56.55	298.32	0.28	0.32	0.30	0.35	0.36	0.36	0.39	0.43	0.45
MOSCOW (IZMIRAN), RUSSIA	55.47	37.32	2.44	2.48	2.37	2.45	2.44	2.37	2.36	2.33	2.30
PEAWANUCK, CANADA	54.98	274.56	0.31	0.32	0.33	0.34	0.35	0.35	0.35	0.37	0.40
KUHLUNGSBORN, GERMANY	54.12	11.77	2.39	2.41	2.41	2.42	2.50	2.44	2.46	2.38	2.43
NOVOSIBIRSK, RUSSIA	54.80	83.00	2.86	2.89	2.84	2.87	2.89	2.86	2.75	2.74	2.69
KIEL, GERMANY	54.33	10.13	2.34	2.30	2.32	2.32	2.34	2.38	2.39	2.37	2.36
LEEDS, ENGLAND	53.83	358.42	2.15	2.16	2.16	2.16	2.18	2.22	2.25	2.29	2.27
GOOSE BAY, CANADA	53.27	299.60	0.51	0.52	0.56	0.57	0.60	0.64	0.66	0.71	0.74
IRKUTSK, RUSSIA	52.47	104.03	3.67	3.69	3.66	3.66	3.65	3.64	3.58	3.51	3.49
IRKUTSK-2, RUSSIA	52.37	100.55	3.64	3.60	3.61	3.65	3.67	3.59	3.56	3.48	3.46
NERA, THE NETHERLANDS	52.23	5.08	2.72	2.74	2.78	2.76	2.77	2.81	2.83	2.84	2.86
UTRECHT, THE NETHERLANDS	52.10	5.12	2.76	2.76	2.84	2.78	2.81	2.86	2.89	2.80	2.87
LINDAU/HARZ, GERMANY	51.60	10.10	2.92	3.05	2.98	3.02	3.06	3.06	3.05	3.00	3.03
LONDON, ENGLAND	51.53	359.90	2.73	2.78	2.78	2.77	2.91	2.85	2.87	2.86	2.87
HALLE, GERMANY	51.48	11.97	3.07	3.01	3.04	3.08	3.12	3.06	3.09	3.05	3.07
IRKUTSK-3, RUSSIA	51.29	100.55	4.04	4.00	4.03	4.02	4.06	3.97	3.89	3.85	3.82
SULPHUR MT., CANADA	51.20	244.40	1.12	1.12	1.11	1.11	1.14	1.12	1.13	1.12	1.13
CALGARY, CANADA	51.08	245.87	1.10	1.09	1.06	1.10	1.11	1.10	1.07	1.07	1.09
HERSTMONCEUX, ENGLAND	50.88	0.33	2.89	3.00	2.99	2.95	3.00	3.04	3.04	2.99	3.06
KIEV, UKRAINE	50.72	30.30	3.58	3.61	3.54	3.65	3.64	3.50	3.49	3.42	3.39
DOURBES, BELGIUM	50.10	4.60	3.27	3.27	3.27	3.30	3.26	3.30	3.36	3.34	3.33
PRAGUE, CZECH REPUBLIC	50.07	14.43	3.51	3.51	3.61	3.53	3.53	3.55	3.50	3.51	3.49
LOMNICKY STIT, SLOVAKIA	49.20	20.22	3.94	3.98	3.96	4.04	4.00	3.99	3.95	3.94	3.88
KHABAROVSK, RUSSIA	48.50	135.20	5.40	5.43	5.45	5.43	5.41	5.39	5.42	5.35	5.33
VICTORIA, CANADA	48.42	236.68	1.86	1.86	1.85	1.84	1.88	1.79	1.79	1.80	1.81
MUNICH, GERMANY	48.20	11.60	4.10	4.09	4.12	4.11	4.17	4.14	4.14	4.16	4.14
SCHAUINSLAND, GERMANY	47.92	7.75	4.13	4.13	4.12	4.16	4.17	4.18	4.16	4.20	4.20
PREDIGTSTUHL, GERMANY	47.70	12.88	4.33	4.20	4.29	4.33	4.34	4.35	4.33	4.29	4.31
ZUGSPITZE, GERMANY	47.42	10.98	4.33	4.32	4.36	4.34	4.33	4.34	4.38	4.36	4.38
HAFELEKAR, AUSTRIA	47.32	11.38	4.32	4.28	4.27	4.41	4.40	4.36	4.31	4.40	4.35
BERN, SWITZERLAND	46.95	7.98	4.30	4.46	4.42	4.41	4.44	4.44	4.48	4.40	4.42
JUNGFRAUJOCH, SWITZERLAND	46.55	7.98	4.53	4.50	4.51	4.58	4.58	4.62	4.62	4.64	4.59
DEEP RIVER, CANADA	46.10	282.50	0.98	1.02	1.05	1.10	1.13	1.14	1.13	1.18	1.25
OTTAWA, CANADA	45.44	289.32	1.08	1.10	1.11	1.13	1.20	1.19	1.31	1.26	1.30
SIMFEROPOL, UKRAINE	44.73	34.00	5.53	5.46	5.53	5.58	5.51	5.41	5.39	5.40	5.31
MT. WASHINGTON, USA	44.30	288.70	1.25	1.28	1.30	1.35	1.39	1.45	1.47	1.52	1.58
ALMA ATA-U, KAZAKHSTAN	43.25	76.92	6.73	6.80	6.72	6.76	6.69	6.60	6.55	6.49	6.45
DURHAM, USA	43.10	289.17	1.38	1.44	1.45	1.54	1.55	1.60	1.67	1.72	1.76
BAGNERES, FRANCE	43.08	0.15	5.29	5.41	5.42	5.46	5.54	5.52	5.59	5.57	5.62
PIC DU MIDI, FRANCE	42.93	0.25	5.39	5.43	5.44	5.48	5.60	5.62	5.66	5.70	5.67
MUSSALA, BULGARIA	42.18	25.58	6.39	6.39	6.41	6.39	6.34	6.29	6.28	6.22	6.20

	Lat.	E. Long.	1955.	1960.	1965.	1970.	1975.	1980.	1985.	1990.	1995.
ROME, ITALY	41.86	12.47	6.27	6.27	6.26	6.33	6.35	6.36	6.36	6.33	6.27
CHICAGO, USA	41.83	272.33	1.71	1.74	1.73	1.77	1.73	1.80	1.82	1.82	1.85
TBILISI, GEORGIA	41.72	44.80	6.86	6.88	6.91	6.88	6.83	6.72	6.63	6.59	6.55
TASHKENT, UZBEKISTAN	41.33	69.62	7.69	7.61	7.67	7.66	7.61	7.53	7.37	7.31	7.23
LINCOLN, USA	40.82	263.32	2.21	2.23	2.20	2.23	2.21	2.20	2.14	2.23	2.21
EREVAN, ARMENIA	40.17	44.25	7.81	7.75	7.78	7.73	7.65	7.56	7.51	7.46	7.36
SWARTHMORE, USA	39.90	284.65	1.88	1.91	1.93	1.96	1.99	2.09	2.06	2.12	2.21
MORIOKA, JAPAN	39.70	141.13	10.13	10.08	10.15	10.20	10.18	10.24	10.19	10.08	9.98
NEWARK, USA	39.68	284.25	1.87	1.93	1.95	2.06	2.07	2.09	2.16	2.13	2.21
DENVER, USA	39.67	255.03	2.90	2.89	2.95	2.88	2.93	2.86	2.80	2.84	2.85
SAMARKAND, UZBEKISTAN	39.60	66.90	8.70	8.72	8.74	8.69	8.70	8.59	8.43	8.32	8.29
CLIMAX, USA	39.37	253.82	3.06	3.05	3.00	2.99	3.00	2.95	2.97	2.92	2.93
BEIJING, CHINA	39.08	116.27	10.05	10.04	10.10	10.09	10.13	10.08	10.06	9.92	10.22
ATHENS, GREECE	37.97	23.72	8.75	8.72	8.69	8.72	8.65	8.69	8.57	8.56	8.53
BERKELEY, USA	37.86	237.70	4.55	4.55	4.57	4.57	4.55	4.47	4.47	4.45	4.41
FUKUSHIMA, JAPAN	37.75	140.48	10.50	10.48	10.53	10.57	10.56	10.60	10.55	10.49	10.40
SEOUL, KOREA	37.50	127.00	10.69	10.75	10.77	10.78	10.77	10.79	10.78	10.68	10.67
MT. NORIKURA, JAPAN	36.11	137.55	11.35	11.38	11.41	11.40	11.46	11.48	11.45	11.36	11.25
TOKYO-ITABASHI, JAPAN	35.75	139.72	11.49	11.49	11.58	11.57	11.56	11.63	11.59	11.50	11.40
TEHRAN, IRAN	35.67	51.43	10.58	10.50	10.58	10.59	10.51	10.43	10.32	10.23	10.20
GULMARG, INDIA	34.07	74.42	11.78	11.75	11.78	11.74	11.69	11.59	11.49	11.45	11.39
MT. HERMON, ISRAEL	33.30	35.79	10.78	10.80	10.78	10.81	10.76	10.65	10.59	10.47	10.41
DALLAS, USA	32.98	263.27	4.30	4.26	4.27	4.19	4.14	4.14	4.06	4.01	4.00
SACRAMENTO PEAK, USA	32.72	254.25	5.10	5.07	4.95	4.90	4.93	4.83	4.80	4.70	4.69
YANGBAJING, TIBET	30.11	90.53	14.34	14.31	14.34	14.30	14.23	14.20	14.12	14.03	13.99
ALIGARH, INDIA	27.91	78.07	14.79	14.77	14.81	14.77	14.72	14.67	14.57	14.52	14.47
REWA, INDIA	24.32	81.24	15.85	15.84	15.87	15.83	15.77	15.72	15.65	15.59	15.55
AHMEDABAD, INDIA	23.01	72.61	15.90	15.90	15.92	15.89	15.84	15.79	15.71	15.67	15.63
MAKAPUU POINT, USA	21.30	202.35	13.17	13.11	13.05	12.99	12.92	12.85	12.79	12.75	12.70
KULA, USA	20.73	203.67	13.24	13.18	13.11	13.05	12.99	12.91	12.85	12.80	12.76
HALEAKALA, USA	20.72	203.73	13.24	13.18	13.11	13.05	12.99	12.91	12.86	12.80	12.76
MEXICO CITY, MEXICO	19.33	260.80	9.45	9.33	9.15	8.97	8.87	8.61	8.40	8.21	8.02
KODAIKANAL, INDIA	10.23	77.48	17.47	17.47	17.47	17.43	17.38	17.37	17.34	17.33	17.33
MAKERERE, UGANDA	0.34	32.56	15.08	15.07	15.04	15.00	14.93	14.89	14.84	14.82	14.79
HUANCAYO, PERU	-12.03	284.67	13.44	13.33	13.23	13.12	13.01	12.92	12.82	12.72	12.63
DARWIN, AUSTRALIA	-12.42	130.87	14.40	14.37	14.30	14.23	14.16	14.09	14.06	14.06	14.07
CHACALTAYA, BOLIVIA	-16.31	291.85	13.08	12.96	12.86	12.74	12.63	12.53	12.42	12.31	12.20
TSUMEB, NAMIBIA	-19.20	17.58	9.65	9.62	9.53	9.45	9.31	9.22	9.17	9.12	9.06
RIO DE JANEIRO, BRAZIL	-22.95	316.83	11.71	11.53	11.37	11.18	10.99	10.78	10.58	10.37	10.19
MINA AGUILAR, ARGENTINA	-23.10	294.30	12.49	12.33	12.22	12.09	11.94	11.83	11.69	11.56	11.44
POTCHEFSTROOM, S. AFRICA	-26.68	27.10	7.24	7.20	7.19	7.10	6.97	6.99	7.00	6.99	6.85
BRISBANE, AUSTRALIA	-27.42	153.12	7.40	7.34	7.28	7.17	7.10	7.08	6.95	7.01	7.08
CORDOBA, ARGENTINA	-31.42	295.80	11.43	11.25	11.10	10.92	10.78	10.58	10.39	10.22	10.05
HERMANUS, SOUTH AFRICA	-34.42	19.22	4.84	4.82	4.75	4.65	4.62	4.62	4.56	4.44	4.45
BUENOS AIRES, ARGENTINA	-34.60	301.52	10.63	10.44	10.29	10.06	9.93	9.72	9.46	9.32	9.09
HOBART, AUSTRALIA	-42.90	147.33	1.99	1.90	1.92	1.83	1.86	1.84	1.84	1.83	1.83
MT. WELLINGTON, AUSTRALIA	-42.92	147.23	1.93	1.91	1.89	1.88	1.85	1.81	1.85	1.79	1.83
KINGSTON, AUSTRALIA	-42.99	147.29	1.90	1.91	1.87	1.87	1.82	1.80	1.83	1.81	1.82
KERGUELEN ISLAND	-49.35	70.25	1.20	1.16	1.15	1.17	1.17	1.14	1.18	1.10	1.14
USHUAIA, ARGENTINA	-54.80	291.68	5.76	5.66	5.59	5.45	5.30	5.21	5.05	4.93	4.84
LARC, ANTARCTICA	-62.20	301.04	3.77	3.70	3.63	3.54	3.42	3.37	3.17	3.10	3.01
MIRNY, ANTARCTICA	-66.55	93.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TERRE ADELIE, ANTARCTICA	-66.65	140.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAWSON, ANTARCTICA	-67.60	62.88	0.20	0.19	0.17	0.17	0.17	0.16	0.16	0.20	0.15
SYOWA, ANTARCTICA	-69.00	39.60	0.38	0.39	0.39	0.39	0.39	0.42	0.39	0.38	0.36
SANAE, ANTARCTICA	-71.67	357.15	0.89	0.89	0.89	0.87	0.83	0.80	0.78	0.71	0.75
ELLSWORTH, ANTARCTICA	-77.72	318.87	0.75	0.74	0.73	0.74	0.71	0.68	0.67	0.65	0.63
MCMURDO, ANTARCTICA	-77.85	166.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GEN. BELGRANO, ANTARCTICA	-77.97	321.20	0.73	0.72	0.71	0.67	0.66	0.65	0.62	0.63	0.61
VOSTOK, ANTARCTICA	-78.47	106.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH POLE, ANTARCTICA	-90.00	0.00	0.06	0.05	0.07	0.07	0.01	0.06	0.05	0.01	0.05