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Multi dimensional scaling of geomagnetic Sq (H) variations

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The dominant relationship in respect of geomagnetic solar quiet day variations (Sq) among the six Indian geomagnetic observatories is analysed by employing multidimensional scaling. This is a powerful technique for data analysis to identify the proximity and dominance relationship between data points of different classes.

Keywords: Multidimensional scaling, Proximity relationship, Geomagnetic solar quiet day (Sq) variation

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1 Introduction

The extent to which the high and low latitude ionosphere is interlinked electromagnetically during quiet geomagnetic conditions is a point of debate. This paper aims to give a quantitative estimation in terms of proximity distance of geomagnetic solar quiet day (Sq) variation ranges of the horizontal H component which is highly sensitive to the ionospheric dynamo current. The technique of multidimensional scaling (MDS) is applied to find the proximity relationship. Proximity relationship in MDS reveals the similarity or dissimilarity between the entities to which the indices differ. The superiority of MDS over the conventional correlation coefficient method to establish internal relationship of several data points of different classes has been proved by Sridharan & Ramasamy[1] for the analysis of geomagnetic storms and hence the same process is not repeated here. The aim of this technique is simplification and reduction of data structures and rescaling of original data into new and reduced space so that patterns and relationship of original objects can be conveniently examined in a two-dimensional plot. The daily variation in the magnetic field at the earth's surface during geomagnetic quiet periods (Sq) is known to be associated with the dynamo currents driven by winds and tidal motions in the E-region of the ionosphere known as atmospheric dynamo. Besides the atmospheric dynamo, other sources of electric field and currents at equatorial region contribute to Sq variations on different components of geomagnetic fields observed at the ground level[2]. Daily range of the geomagnetic field is an important parameter measuring the magnitude of diurnal variation. Being dependent on the daily maximum and minimum field values, the parameter fluctuates from day to day in accordance with the variability of both these values. Internationally declared geomagnetic quiet days data are considered for this analysis. For each day of a calendar month, every three hours, the order numbers (Kp) are assigned on the basis of the level of geomagnetic activity. Days with the five lowest mean order numbers are chosen as quiet days and those with five highest values as the excessively disturbed days of the month. On days not excessively disturbed, the daily maximum should be predominantly controlled by ionospheric dynamo Sq current intensity, so that the daily range and maximum values may be expected to fluctuate in unison. The unique configuration of the ionosphere over the equatorial region can contribute significantly in judging the nature of the effect[3]. The daily range of Sq (H) variation has been studied to reveal the annual variation and seasonal changes at Alibag[4]. Quantitative estimation of the contribution to the day to day variability of Sq current and equatorial electrojet has been studied by Alex *et al.*[5] Rangarajan *et al.*[6] found that disturbance dynamo caused by even moderate geomagnetic activity alters the shape and structure of the equatorial electrojet and Sq current system. Absence of equatorial enhancement in annual periodicity was observed in monthly ranges of Sq (H) variations by Yacob[7]. Simultaneous data of six Indian geomagnetic observatories during January 1996-

September 1999 are considered for this analysis. Analytical technique and the result of the analysis are presented in this paper.

2 Multidimensional scaling technique

Multidimensional scaling moves objects around the space defined by the requested number of dimensions, and checks how well the distances between objects can be reproduced by the new configuration. It uses a function minimization that evaluates different configurations with the goal of maximizing the goodness-of-fit or minimizing lack of fit. It is complementary with classical factor analysis. In factor analysis, the similarities or dissimilarities between objects are expressed in the correlation matrix. In MDS, one may analyze any kind of similarity or dissimilarity matrix, in addition to correlation matrices. The actual orientation of axes in the final solution is arbitrary; the dimensions of such a configuration can be freely translated, permuted, reflected, orthogonally rotated and uniformly rescaled to facilitate the interpretation. The final orientation of axes in the plane or space is mostly the result of a subjective decision by the researcher, who will choose an orientation that can be most easily explained.

One classical example of multi dimensional scaling is the judgment of efficiency of a particular dispensary or a hospital in a location based on the data of several treatments for a number of diseases by different physicians during different periods in comparison with similar data at various places in other locations. For a background of this technique, one may refer models and methods for multidimensional analysis of preferential choice by Carrol[8], Armitage & Cotton[9] and Thompson & Woodbury[10]. In this paper, multidimensional reduction technique[1] is applied to identify the proximity relationship of Indian observatories in respect of the variations in the horizontal (H) component of the geomagnetic field during international quiet days.

3 Analytical technique

For the purpose of analysis of data, H field range of every month from January 1996 to September 1999 was represented as points in a multidimensional space of which one dimension was allocated for each of the six stations. It is not possible to visualize geometrically such a higher dimensional space for the purpose of understanding the concept of representation of Sq variations by means of points in that space. However, it may be mentioned that just as one can compute the distance between two points in a two-dimensional plane or in a three-dimensional space, the distance in an n-dimensional Euclidean space between two points with coordinates (X_{11}, X_{12}, .., X_{1n}) and (X_{21}, X_{22}, .., X_{2n}) can be calculated from the following well known formula:

$$D = \text{Square root of } [(X_{11}-X_{21})^2 + (X_{12}-X_{22})^2 + \ldots + (X_{1n}-X_{2n})^2] \quad \ldots (1)$$

This distance is a number, which tends to be small if the values of the corresponding coordinates of the two points are similar in magnitude and large if the points differ significantly in several coordinates. Therefore, the computed distance between two points can be used as a measure of similarity or dissimilarity between the Sq ranges of two months at two given points at a time. If a series of points represent the sequence of Sq variation of a single station in time, the path or trajectory connecting the point is indicative of the station's Sq variation.

Using Eq. (1), distances between one point and all other variable points in the n-dimensional space can be computed. Spanning distance of a month with respect to other 44 months is found. Next, the distances are ranked in ascending order. This enables one to find out which point is closest to which other point, the second closest point and so on. A minimum coverage algorithm is employed to connect each point to at least one nearest neighbour. This enables one to construct a branching network that ties together all the available points. Since a tree has no cycles, one has to avoid cycles in the construction of a network. If only points are connected which in some previous steps have not been connected to the same network; the final network will be a tree. It is not really possible to display accurately an n–dimensional network on a two dimensional plane. However, by stretching, bending and twisting the arcs connecting adjacent points, it is usually possible to locate the points on a plane, so that most of the near neighbours of each point are closer to it, while points which are not its neighbours tend to be farther away. The resulting "road map" provided is at best an approximation of the real situation but still it may contain a surprising amount of useful information in a highly compressed form.

4 Dimension reduction technique

The way in which points in n-dimensional space have been connected by a tree will be maintained for the further process.

Now, instead of n coordinates, choose any two coordinates and determine the distances between the points as restricted to these two coordinates. The sum of the distances is calculated. This sum gives the covering distance for all the points in the graph, in the two dimensional sense. This procedure is repeated for each pair of coordinates in the n-dimensional space. For each pair of coordinates, consider the tree structure and the corresponding covering distance in the two dimensional sense. One will have n(n-1)/2 values of such covering distances. The covering distances for all possible trees are put in ascending order. With the help of this ordering one can find out which two factors are approximately nearby compared to the remaining factors in the two dimensional sense. Nearness of two points in the two dimensional sense does not mean that they are geographically nearby. But it indicates that they possess almost similar characteristics with respect to a certain feature.

5 Data analysis

The geographic and dipole coordinates of the observatories are presented in Table 1. From 1996 to 1999, there were 240 international quiet days. Since Trivandrum observatory was closed in September 1999 due to technical reasons, simultaneous data for six observatories, viz. Alibag, Nagpur, Pondicherry, Trivandrum, Ujjain and Visakapatnam are considered for 225 international quiet days. The daily ranges, that is, the difference between daily maximum and minimum[11] are found and their monthly average is calculated and presented in Table 2.

Monthly mean values of geomagnetic Sq ranges, presented in Table 2, are used to find 990 proximity distances presented in Table 3. The distances are calculated by applying Eq. (1). Proximity relationship, in respect of 45 months from Jan 1996 to Sep 1999 derived from Table 3, is used to derive pair of months presented in Table 4. It is derived by taking only least 44 values among 990 values as described in the analytical technique.

The pair of months (period) presented in Table 4 are used to construct a tree structure provided in Fig. 1. Proximity distances between a pair of stations with respect to pair of months are again found using the Eq. (1) and is presented in Table 4. The sum of total covering distances described in Table 4 is applied to construct the tree described in Fig. 2. Only the highlighted minimum distances (sum) were taken for getting the tree structure as described in dimension reduction technique.

6 Results

It is observed from Fig. 2 that Alibag - Visakhapatnam observatories are very close to each other in terms of solar quiet (Sq) day variations and Alibag - Trivandrum observatories are at the extreme end. Trivandrum is close to the magnetic equator. The unique condition of orthogonality of electric field, magnetic field and plasma density gradient in the E-region over the magnetic equator makes this region very sensitive to the changes of electric fields. The normal eastward electric field during day time causes a strong eastward current-equatorial electrojet (EEJ). The abnormal features of Sq variations have been studied by scientists and the day-to-day changes in the electrojet strengths have been estimated by the difference field (ΔH) of daily variations of Alibag and Trivandrum[5]. The Sq variation at Pondicherry is similar to Nagpur and it is not influenced by EEJ effect, is confirmed by a dendogram on the analysis of fuzzy clustering to study geomagnetic coastal effects[12]. One can observe that the spanning distance between Pondicherry and Trivandrum is larger than Pondicherry and Nagpur. Though Pondicherry is geographically close to Trivandrum, the range of Sq (H) variation between the two places is larger, whereas geographically far away places at Nagpur and Pondicherry, Sq variation is similar. This confirms that Pondicherry is not influenced by the day time equatorial electrojet.

Table 1—Location of Observatories (geographic and dipole coordinates) and its abbreviations

S. No	Station	Geographic		Dipole	
		Latitude	Longitude	Latitude	Longitude
1	Alibag (ALB)	18° 37'N	72° 52'E	10.0° N	145.9°
2	Nagpur (NAG)	21° 09'N	79° 05'E	11.9°N	152.1°
3	Pondicherry (PON)	11° 55'N	79° 55'E	2.7°N	152.1°
4	Trivandrum (TRV)	08° 29'N	76° 58'E	07.8°N	155.5°
5	Ujjain (UJJ)	23° 11'N	75° 47'E	14.3°N	149.2°
6	Visakhapatnam (VIZ)	17° 41'N	83° 19'E	08.2°N	155.9°

Table 2—Monthly Sq (H) ranges from January 1996 to September 1999

S. No.	Month	ALI	NAG	PON	TRV	UJJ	VSK
1	Jan 1996	31.6	36.6	42.6	65.2	21	33.2
2	Feb 1996	41.8	50	49.4	63.4	33	44.8
3	Mar 1996	38	60	47.4	76	33.4	43.4
4	Apr 1996	41.8	51.4	65	99.8	34.2	51
5	May 1996	41.8	50.2	49	68.8	36.2	44.4
6	Jun 1996	42.8	48.4	45	72.6	37.6	42
7	Jul 1996	28.8	46.4	38.2	73.4	25.2	28.4
8	Aug 1996	24.6	47.4	40.2	80.8	25.6	24.6
9	Sep 1996	38.4	36.4	58.6	95.4	27.2	41.4
10	Oct 1996	40.4	53.2	53.2	84.2	35.6	45.6
11	Nov 1996	42.4	52.2	46.4	57	34.8	43.4
12	Dec 1996	28	46.8	35	58.8	21.6	29.2
13	Jan 1997	24.6	40.8	34.4	60.4	17.8	24.8
14	Feb 1997	36.4	46	43.4	62.4	27.8	37.2
15	Mar 1997	46.8	63.4	60.2	100.2	36	50.2
16	Apr 1997	32.2	54	51.4	92	24	34.8
17	May 1997	34.6	49.8	47.2	79.4	28	36.4
18	Jun 1997	38.6	53	49.2	80.2	28	42.6
19	Jul 1997	39	44.2	40	64	34	32.8
20	Aug 1997	39.8	62.8	48.4	82.4	34.8	39.6
21	Sep 1997	39	45.4	60.4	112.2	32.6	43.8
22	Oct 1997	34.2	45.2	60.4	110.4	23.6	41.8
23	Nov 1997	39.8	60.2	52.4	86.6	30.2	45.4
24	Dec 1997	21	28.8	32	54.4	16	23.4
25	Jan 1998	29.2	55.2	42.6	64.4	23.2	34.4
26	Feb 1998	35.6	49.8	46.6	81.4	28	39.4
27	Mar 1998	45.6	60.8	58.6	105.8	38.2	53
28	Apr 1998	52	53	76.6	140.2	45.2	59.6
29	May 1998	45	57.4	56	95.8	39.6	50.2
30	Jun 1998	42.2	62.4	42	65	37.6	43.6
31	Jul 1998	41.6	66.8	39.6	76.2	35	44.4
32	Aug 1998	50.2	65.4	49.8	83	40.6	49.2
33	Sep 1998	48.8	52.6	58.8	126.8	38.6	58
34	Oct 1998	44.2	60.4	68.6	119.4	28.8	53.4
35	Nov 1998	56.8	67	59	90	43.4	56.2
36	Dec 1998	29	45.6	39	90.8	17.4	31.4
37	Jan 1999	45.6	56.6	53.6	92.8	31.8	50
38	Feb 1999	43.4	54	55.8	98.8	29.4	48.4
39	Mar 1999	56.8	67	86.4	126.4	40.8	61.6
40	Apr 1999	53.2	71.6	62.6	113.8	41.6	58.2
41	May 1999	58.6	79.4	62.2	102.2	47	60.2
42	Jun 1999	72.4	79.4	69.2	85.8	56.8	69.8
43	Jul 1999	69.2	73.2	79.8	126.2	51.2	68.2
44	Aug 1999	58.8	68.4	65.6	109.4	45	60
45	Sep 1999	60.6	75.6	75.6	141.2	45.8	62

Table 3—Spanning distances of 45 months from January 1996 to September 1999

	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	611.6	986	2513	699.4	678.2	231.2	509.9	1320	1193	736.2	232.1	237.7	182.1	2998	1110
2		279.3	1610	39.76	136.6	737.2	1153	1350	466.7	60.4	802.5	1246	167	1714	1111
3			1023	173.7	194.5	653.2	827.5	1101	162.5	444.2	1065	1550	469.3	891.5	503.9
4				1266	1242	2201	2059	438	418.9	2237	3427	3852	2155	196.1	711.2
5					42.4	698.2	1030	1092	267.6	153.3	942.2	1391	241.5	1344	891.6
6						585.6	869.3	976.7	247.5	269.7	931.9	1338	272.4	1304	797.8
7							92	1265	926.4	872	237.8	300	290.2	2407	632
8								1148	1005	1383	560.1	554.2	653.6	2289	458.8
9									529	1951	2293	2384	1434	980	465.4
10										7965	1636	2073	770.5	471.3	383.1
11											745.6	1237	200	2249	1548
12												84.3	257	3626	1478
13													505	4230	1658
14														2358	1042
15															827.4

	17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1	465.3	723.9	289.9	1315	2905	2521	1412	523.2	358.6	556.1	3374	8748	2363	1162	1464
2	408.3	331.4	275.2	560.1	2533	2508	663.5	2013	437.2	424.5	2108	7119	1231	233.8	546.3
3	205.3	100	562.1	69.4	1694	1684	154.9	2669	443.1	184.7	1187	5621	606.4	191.2	123.6
4	1039	755.6	2298	842.6	273.2	426.7	461.8	5187	2325	891.1	199.8	2068	173	1928	1484
5	298.8	218.5	287.3	373.1	2058	2109	469.4	2236	513.1	295.4	1666	6284	885.3	215	420.2
6	243.8	206.7	228.6	337.5	1857	1946	465.3	2172	569.3	232.7	1570	6042	816.3	265.7	394.6
7	234	516.3	297.3	792.6	2395	2075	1001	879.7	218	321	2730	7892	1885	905.4	941.8
8	301.7	638.5	637.7	847.6	2023	1681	1031	1217	458.5	393	2549	7245	1842	1293	1167
9	605.6	597	1513	1033	401.7	336.4	709.3	3199	1721	532	1011	3447	722.7	2003	1734
10	246.6	102	831.6	155.4	911	999.2	85	3186	913	182.2	642	4106	218.3	590	437.2
11	664.2	608	278.5	783	3306	3292	1008	1973	468	710	2718	8298	1701	195	629.7
12	718.6	1031	346.5	1414	3954	3512	1731	466.4	190.7	857.1	4114	10452	2976	996	1320
13	944.4	1376	589.7	1903	4168	3610	2196	204	433	1109	4699	11010	3532	1601	1922
14	322	433.5	82	774	2843	2637	953	1057	170	391	2776	8252	1787	448.3	768
15	1190	818.2	2455	619.2	581.4	818.4	361.7	5874	2382	1029	55	2177	89.2	1639	1074
16	218.4	263	1160	376	764.2	550	277.2	2745	850.4	201.8	1001	4416	691.5	1250	854
17		69.3	389	263	1365	1205	300	1795	332	14.4	1449	5708	837	595	519
18			557	158	1230	1138	117.2	2370	476.7	37.7	1066	5115	542.2	477.4	359.8
19				802.6	2864	2782	1094	1130	343.2	468.8	2838	8236	1812	476.1	802
20					1358	1399	95.2	3178	689.4	237.2	880.4	4889	428.9	373.5	158.2
21						111.3	947.4	5439	2971	1211	440.9	1682	558.3	2891	2200
22							943.3	4782	2613	1080	736.3	2312	824.5	2959	2260
23								3478	896.2	227.3	562.8	4086	243.9	643.3	342.8
24									1149	1996	6348	13061	4959	2665	3203
25										423.2	2841	8545	1939	513.5	675.8
26											1249	5341	693	602.2	475
27												1702	128.5	2043	1373
28													2584	7350	6099
29														1225	807.8
30															158.3

Contd.

Table 3—Spanning distances of 45 months from January 1996 to September 1999—*Contd.*

	32	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
1	2184	5534	4808	3474	772.3	1878	2047	8422	5503	5719	7250	9995	5528	10672
2	769.2	4369	3710	1552	1465	968.5	1339	6195	3564	3249	3886	7036	3381	8208
3	318.2	3122	2493	996.8	978	436.1	696.5	4849	2312	2173	3376	5649	2360	6300
4	824	886.4	518.8	712.1	1621	227.2	124.8	1790	846.4	1328	2798	2727	868.2	3021
5	546.3	3706	3190	1248	1291	703.3	1026	5541	3018	2791	3556	6315	2865	7350
6	535.8	3439	3101	1276	1086	654.7	943	5545	2932	2802	3739	6267	2813	7166
7	1716	4770	4111	3021	374	1510	1644	7686	4615	4869	6817	9129	4821	9413
8	1907	4359	3689	3175	237.5	1533	1545	7235	4379	4847	7191	8840	4703	8799
9	1452	1762	1432	1786	774.3	586.7	408	3602	2302	3062	4892	4995	2348	5186
10	296	2080	1650	700	965.8	146.5	276	3626	1662	1766	3004	4455	1654	5034
11	990	5295	4593	1912	1867	1416	1894	7210	4245	3726	4170	7948	4025	9288
12	2405	6775	5886	3992	1065	2444	2751	9868	6278	6229	7820	11341	6408	11992
13	3124	7264	10358	4846	1031	2940	3152	10667	7095	7272	9177	12429	7285	12901
14	1340	5131	4416	2467	1023	1405	1720	7567	4580	4444	5529	8720	4521	9647
15	441.7	898	517	309.2	1871	163.7	168	1639	394.3	624.2	2017	2213	460	2493
16	1020	2295	1601	1670	291	484	405	4183	2209	2737	4917	5569	2495	5495
17	829	3170	2552	1670	384	587.2	691.4	5333	2902	3124	4775	6547	3016	6940
18	498.8	2717	216.4	1141	601.1	309.3	449.2	4570	2296	2421	3840	5590	2359	6106
19	1344	5120	4628	2510	1099	1512	1841	7759	4646	4495	5571	8755	4555	9672
20	243	2618	2029	826.3	941.4	324.4	520.7	4207	1837	1785	3179	4964	1937	5417
21	1584	601.2	477.7	1549	1401	630.7	325.4	2045	1184	2120	4308	3199	1372	2956
22	1871	1027	640.9	2004	1016	750.4	395	2606	1667	2722	5198	4094	1961	3702
23	277.5	2025	1424	681.2	886.8	110.2	221.4	3450	1447	1563	3017	4313	1555	4708
24	4598	9007	8165	6564	1786	4276	4479	12959	9200	9486	11390	14981	9332	15572
25	1465	5341	4345	2709	844.7	1516	1795	7713	4590	4495	6000	9054	4735	9662
26	724.1	2850	2311	1492	383.7	452	548.8	5011	2629	2875	4514	6154	2743	6535
27	659.8	543.7	375.6	451	2015	261.6	206.5	1442	293	670.2	2205	1976	389.2	2125
28	4276	553	919.6	3064	6006	3101	2597	528.9	1255	2396	4366	1020	1353	592.8
29	295.3	1068	852.2	324.5	1556	76.6	130.4	2223	704.4	903.1	2189	2784	713.7	3198
30	498.2	4449	3848	1341	1688	1027	1495	6310	3241	2714	3429	6810	3164	7854
31	280.6	3380	2874	1008	1301	633.2	987.6	5271	2334	2028	3196	5748	2420	6386
32		2247	1896	236.6	1874	287.2	587.9	3423	1242	950.9	1760	3661	1166	4456
33			350	1652	3286	1320	1001	1051	572.8	1506	3535	1545	743.6	1226
34				1380	2758	969.5	655.2	779.4	460.7	1283	3339	1681	692.2	1387
35					2923	443.6	693.1	2112	620.7	345	883.3	2140	442.9	3025
36						1167	1057	6205	3652	4392	6990	7792	4041	7521
37							60.8	2654	968	1186	2548	3342	1007	3753
38								2351	921.9	1378	3043	3228	1031	3406
39									771.5	1369	2665	387.5	747.8	449.2
40										257.9	1623	900.3	84.7	1023
41											696.6	1118	188.5	1724
42												1827	1111	3446
43													720.8	390
44														1171

Table 4—Spanning distances of 45 months in two dimensional sense

Period (Sl. Nos)	ALB-NAG	ALB-PON	ALB-TRV	ALB-UJJ	ALB-VSK	NAG-PON	NAG-TRV	NAG-UJJ	NAG-VSK	PON-TRV	PON-UJJ	PON-VSK	TRV-UJJ	TRV-VSK	UJJ-VSK
17.26	1	1.17	2.24	1	3.16	0.6	2	0	3	2.09	0.6	3.06	2	3.61	3
26.16	5.4	5.88	11.13	5.25	5.72	6.38	11.4	5.8	6.23	11.64	6.25	6.65	11.33	11.56	6.1
26.18	4.39	3.97	3.23	3	4.39	4.12	3.42	3.2	4.53	2.86	2.6	4.12	1.2	3.42	3.2
18.34	9.28	20.19	39.6	14.71	12.17	20.76	39.89	7.44	13.09	43.74	19.42	22.2	39.21	40.66	10.83
34.33	9.06	10.83	8.71	10.83	6.51	12.53	10.75	12.53	9.06	12.28	13.86	10.83	12.28	8.71	10.83
33.45	25.85	20.53	18.62	13.82	12.46	28.48	27.14	24.1	23.35	22.13	18.28	17.27	16.1	14.95	8.24
45.4	9.4	14.96	28.38	8.51	8.32	13.6	27.69	5.8	5.52	30.33	13.66	13.54	27.54	27.66	5.66
40.44	6.45	6.35	7.12	6.55	5.88	4.39	5.44	4.67	3.67	5.33	4.53	3.5	5.56	4.75	3.85
44.41	11	3.41	7.2	2.01	0.28	11.51	13.15	11.18	11	7.96	3.94	3.41	7.47	7.2	2.01
41.42	13.8	15.47	21.43	16.93	16.81	7	16.4	9.8	9.6	17.83	12.04	11.88	19.1	19	13.72
45.43	8.93	9.57	17.29	10.15	10.6	4.84	15.19	5.91	6.65	15.58	6.84	7.49	15.94	16.23	8.22
45.36	43.58	48.35	59.49	42.49	43.99	47.32	58.65	41.31	42.85	62.29	46.33	47.71	57.85	58.96	41.75
39.28	14.8	10.91	14.61	6.51	5.2	17.09	19.66	14.68	14.14	16.93	10.74	10	14.48	13.94	4.83
18.1	1.81	4.39	4.39	7.81	3.5	4	4	7.6	3.01	5.66	8.59	5	8.59	5	8.17
10.23	7.03	1	2.47	5.43	0.63	7.05	7.4	8.84	7	2.53	5.46	0.82	5.91	2.41	5.4
23.37	6.83	5.92	8.49	6.02	7.4	3.79	7.17	3.94	5.84	6.32	2	4.75	6.4	7.72	4.87
37.38	3.41	3.11	6.39	3.26	2.72	3.41	6.54	3.54	3.05	6.39	3.26	2.72	6.46	6.21	2.88
38.04	3.05	9.34	1.89	5.06	3.05	9.56	2.79	5.46	3.68	9.25	10.38	9.56	4.9	2.79	5.46
38.09	18.3	5.73	6.05	5.46	8.6	17.82	17.93	17.74	18.94	4.4	3.56	7.54	4.05	7.78	7.34
9.22	9.75	4.57	15.58	5.53	4.22	8.98	17.39	9.51	8.81	15.11	4.02	1.84	15.43	15.01	3.62
22.21	4.8	4.8	5.13	10.2	5.2	0.2	1.81	9	2.01	1.8	9	2	9.18	2.69	9.22
37.29	1	2.47	3.06	7.82	0.63	2.53	3.1	7.84	0.82	3.84	8.16	2.41	8.36	3.01	7.8
29.15	6.26	4.57	4.75	4.02	1.8	7.32	7.44	7	6	6.08	5.53	4.2	5.69	4.4	3.6
15.27	2.86	2	5.73	2.51	3.05	3.05	6.17	3.41	3.82	5.82	2.72	3.22	6.02	6.26	3.56
23.2	2.6	4	4.2	4.6	5.8	4.77	4.94	5.28	6.36	5.8	6.1	7.05	6.23	7.16	7.4
23.32	11.63	10.72	11.01	14.71	11.07	5.81	6.32	11.63	6.44	16.49	10.72	4.6	11.01	5.23	11.07
32.35	6.79	11.32	9.62	7.17	9.62	9.34	7.18	3.22	7.18	11.56	9.62	11.56	7.54	9.9	7.54
20.03	3.33	2.06	6.65	2.28	4.2	2.97	6.99	3.13	4.72	6.48	1.72	3.93	6.55	7.44	4.05
3.05	10.51	4.12	8.14	4.72	3.93	9.93	12.16	10.19	9.85	7.38	3.22	1.89	7.73	7.27	2.97
5.06	2.06	4.12	3.93	1.72	2.6	4.39	4.2	2.28	3	5.52	4.24	4.66	4.05	4.49	2.78
5.02	0.2	0.4	5.4	3.2	0.4	0.45	5.4	3.21	0.45	5.41	3.22	0.57	6.28	5.41	3.22
2.11	2.28	3.06	6.43	1.9	1.52	3.72	6.77	2.84	2.61	7.07	3.5	3.31	6.65	6.55	2.28
2.14	6.72	8.07	5.49	7.5	9.32	7.21	4.12	6.56	8.59	6.08	7.94	9.68	5.3	7.67	9.21
14.01	10.55	4.87	5.56	8.32	6.25	9.43	9.81	11.6	10.22	2.91	6.85	4.08	7.35	4.88	7.89
14.19	3.16	4.28	3.05	6.72	5.11	3.85	2.41	6.46	4.75	3.76	7.07	5.56	6.4	4.68	7.6
14.25	11.68	7.24	7.47	8.54	7.73	9.23	9.41	10.29	9.62	2.15	4.67	2.91	5.02	3.44	5.39
25.12	8.49	7.69	5.73	2	5.34	11.33	10.1	8.55	9.88	9.44	7.77	9.21	13.76	7.64	5.44
12.13	6.9	3.45	3.76	5.1	5.56	12.61	6.21	7.1	7.44	1.71	3.85	4.44	4.12	4.68	5.81
13.24	12.53	4.33	7	4.02	3.86	12.24	13.42	12.13	12.08	6.46	3	2.78	6.26	6.16	2.28
25.07	8.81	4.42	9.01	2.04	6.01	9.84	12.59	9.02	10.65	10.02	4.83	7.96	9.22	10.82	6.32
7.08	4.32	4.65	8.51	4.22	5.66	2.24	7.47	1.08	3.93	7.67	2.04	4.29	7.41	8.32	3.82
8.36	4.75	4.56	10.93	9.31	8.1	2.16	10.16	8.4	7.03	10.07	8.29	6.91	12.93	12.09	10.65
3.31	7.69	8.59	3.61	3.94	3.74	10.35	6.8	6.99	6.87	7.8	7.96	7.86	1.61	1.02	1.89
31.3	4.44	2.47	11.22	2.67	1	5.01	12.03	5.11	4.47	11.45	3.54	2.53	11.5	11.23	2.72
SUM:	242.27	234.21	318.19	224.19	**193.16**	256.91	343.78	247.21	**228.47**	340.48	238.59	**217.37**	328.29	**306.32**	**202.63**

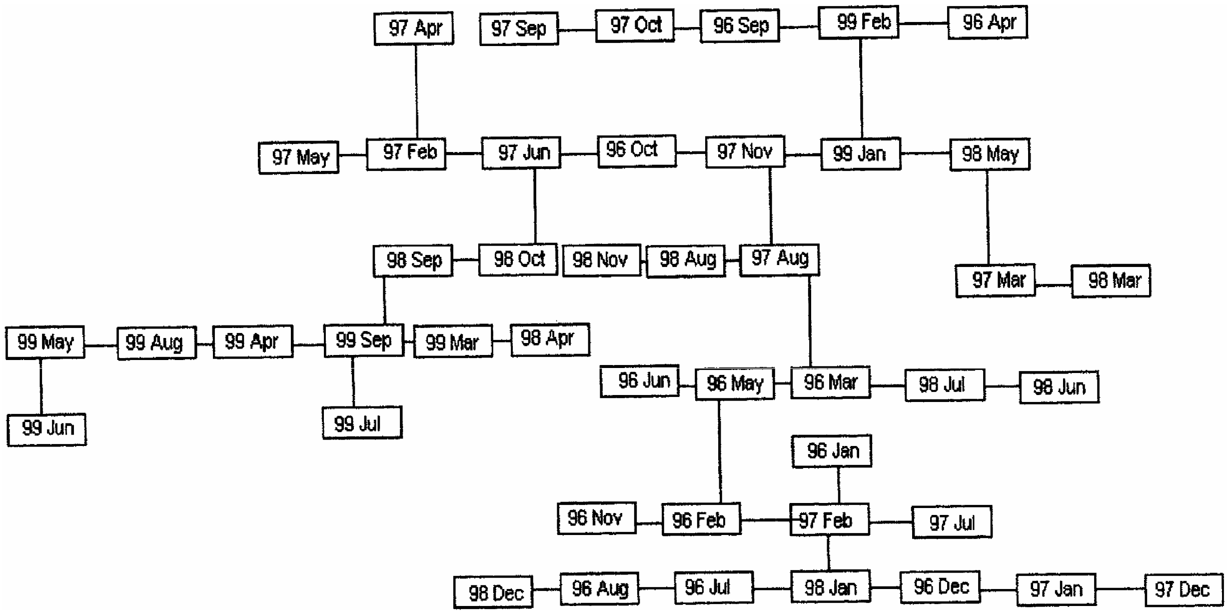

Fig. 1—Network with minimum covering connections in 6-dimensional space

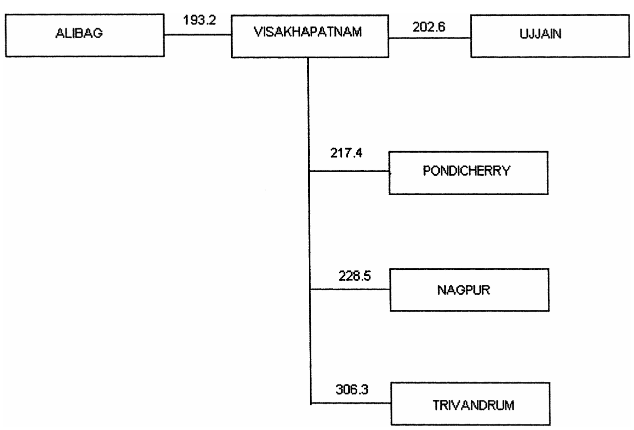

Fig. 2—Tree with minimum covering distance in two-dimensional sense

7 Conclusions

In classical univariate or multivariate statistics, individual measurements are lost sight of in favour of estimated means and variances of samples of population. In multidimensional scaling, the identity of each point, each observation vector and its relationship to all other points are preserved and are central to the analysis. This provides a powerful tool for examining interrelationship among the individual observatories. There is a procedure for comparing the data of ground geomagnetic surveys with corresponding data of the nearest permanent observatory during geomagnetic quiet days. This is to correct the measurement range of instruments and to eliminate abnormal values in the survey data. As a result of this study, it is expected that accurate determination of the solar quiet day field variation in terms of spanning distance can be used as a measure: to establish the interrelationship of measurements at one observatory to those at the others; to establish baselines from which magnetospheric disturbances are quantified; and for estimating the local anomalies while conducting ground geomagnetic surveys.

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