Reports of the Department of Geodetic Science
Report No. 228

THE OSU 275 SYSTEM OF SATELLITE TRACKING STATION COORDINATES

by
Ivan I. Mueller and Muneendra Kumar

Prepared for the
National Aeronautics and Space Administration
Washington, D.C.

Grant No. NGR 36-008-093
OSURF Project No. 2514

The Ohio State University
Research Foundation
Columbus, Ohio 43212

August, 1975

Reports of the Department of Geodetic Science

Report No. 228

THE OSU 275 SYSTEM OF SATELLITE TRACKING STATION COORDINATES

by

Ivan I. Mueller and Muneendra Kumar

Prepared for the

National Aeronautics and Space Administration
Washington, D.C.

Grant No. NGR 36-008-093
OSURF Project No. 2514

The Ohio State University
Research Foundation
Columbus, Ohio 43212

August 1975

PRE FACE

This project is under the supervision of Professor Ivan I. Mueller, Department of Geodetic Science, The Ohio State University and under the technical direction of Mr. James P. Murphy, Special Programs, Office of Applications, Code ES, NASA Headquarters, Washington, D.C. The contract is administered by the Office of University Affairs, NASA, Washington, D. C. 20546.

TABLE OF CONTENTS

1. INTRODUCTION

The most extensive purely geometric solutions completed to date were performed at the Department of Geodetic Science, The Ohio State University (OSU) [Mueller et al., 1973 and Mueller, 1974a]. The solutions included some 100,000 observations from 158 sites: 36 SECOR stations, 49 BC-4, 21 PC-1000, 16 MOTS, 23 SAO, 6 special camera stations and 6 C-Band radars.

Subsequent to the above solutions, it was felt necessary to extend the scope of the WN14 system for better worldwide coverage. At present, numerous world satellite systems are available to a geodetic analyst, but all of these systems have limited coverage with their own individual origin, scale and orientation. The most extensive effort to date is the Department of Defense World Geodetic System 1972 [Seppelin, 1974]. A brief review of the methods and data used in the OSU 275 system is given here along with the summary of results. The system consists of 275 tracking stations.

2. METHOD

It was decided to base the OSU 275 systems of tracking station coordinates on the previously published WN14 geometric solution for 158 stations and to add further stations either by direct survey connections or by transformation from other satellite systems.

A total of 117 new stations were added in this manner. The new stations connected by direct survey ties were designated by a subscript "C" and those obtained by transformation by "T" to distinguish them from the original WN14 stations.

The numbering system corresponds to the one in [NASA, 1973], where the stations are also described in detail. The first digit indicates the type of instrumentation at the site as follows: 1 — MOTS camera, 2 — Doppler site, 3 — PC-1000, 4 — C-Band radar, 5 — SECOR, 6 — BC-4 camera, 7 — special optical site, 8 — special camera and 9 — SAO optical/laser site.

3. DATA USED

3.1 Survey Information

Survey information regarding the stations included in OSU 275 is summarized in Table 3.1-1, including the sources which are listed in Table 3.1-2. For a list of geodetic datums, the reader is referred to Table 3.1-3 [Mueller et al., 1973].

Table 3.1-1

Survey Information of Observation Stations

STATION NO	STATION LOCATION	DATUM CODE	SURVEY COORDINATES[1] LATITUDE			LONGITUDE			ELL. H(M)	MSL[2] (M)	INSTR.[3] HEIGHT (M)	INSTR. TYPE	SOURCE[4] CODE
80	SAN FERNANDO	16	36	27	50.120	353	47	[illegible]	-9.6	25.40	*	MOTS 40	1
1021	BLOSSOM POINT	29	38	25	49.628	282	54	48.225	6.8	5.76	1.23	MOTS 40	1
1022	FORT MYERS	29	26	32	51.891	278	8	3.926	20.8	4.81	1.23	MOTS 40	1
1024	WOOMERA	6	-31	23	30.069	136	52	11.022	128.5	129.51	1.71	MOTS 40	1
1025	QUITO	41	- 0	37	20.621	281	25	17.939	3592.9	3568.60	1.21	MOTS 40	1
1028	SANTIAGO	41	-33	8	57.242	289	19	56.402	719.6	693.40	1.25	MOTS 40	1
1030	GOLDSTONE	29	35	19	48.088	243	6	2.730	907.1	929.10	1.71	MOTS 40	1
1031	JOHANNESBURG	3	-25	52	58.862	27	42	27.931	1530.3	1522.30	1.73	MOTS 40	1
1032	ST. JOHN'S	29	47	44	29.739	307	16	43.369	106.0	69.00	1.95	MOTS 40	1
1033	FAIRBANKS	29	64	52	19.721	212	9	47.169	164.7	162.70	2.18	MOTS 40	1
1034	E. GRAND FORKS	29	48	1	21.403	262	59	21.581	255.4	252.58	1.71	MOTS 40	1
1035	WINKFIELD	16	51	26	49.110	359	18	14.100	60.4	67.37	1.71	MOTS 40	1
1036	FAIRBANKS	29	64	58	38.600	212	28	40.899	291.6	289.55	1.50	MOTS 40	1
1037	ROSMAN	29	35	12	6.911	277	7	41.308	916.1	909.27	1.69	MOTS 40	1
1038	ORRORAL	6	-35	37	37.501	148	57	10.705	939.5	931.25	2.24	MOTS 40	1
1042	ROSMAN	29	35	12	6.926	277	7	41.008	916.1	909.40	1.69	MOTS 40	1
1043	TANANARIVE	45	-19	0	27.097	47	19	0.461	1377.9	1377.94	1.00	MOTS 40	1
1122	TANANARIVE	45	-19	1	3.320	47	19	9.450	1402.7	1402.70	*	S-BAND	1
1123	TANANARIVE	45	-19	1	9.330	47	18	12.560	1399.0	1399.00	*	S-BAND	1
1126	ROSMAN	29	35	11	45.051	277	7	26.230	880.3	873.90	10.10	S-BAND	1
1128	FAIRBANKS	29	64	58	20.896	212	29	22.415	348.6	346.60	6.55	S-BAND	1
1152	CARNARVON	6	-24	54	14.964	113	42	54.938	44.0	37.90	10.00	S-BAND	1
2002	AUSTIN	29	30	17	17.150	262	16	6.150	189.0	184.38	*	DOPPLER	2
2014	ANCHORAGE	29	61	17	1.980	210	10	37.460	61.8	60.00	*	DOPPLER	1
2017	TAFUNA	2	-14	20	7.950	188	17	7.870	6.7	6.67	*	DOPPLER	1
2018	THULE	29	76	32	18.615	291	13	46.641	80.7	48.70	*	DOPPLER	1
2019	MCMURDO	10	-77	50	56.720	166	40	3.400	38.2	38.20	3.90	DOPPLER	1
2020	MAHE	42	- 4	40	6.840	55	28	48.640	591.0	591.00	5.51	DOPPLER	1
2049	PUERTO RICO	29	18	27	14.070	293	47	9.000	9.0	1.37	*	DOPPLER	2
2092	AUSTIN	29	30	17	18.610	262	16	5.750	203.0	197.75	*	DOPPLER	2
2100	KAHIAWA	33	21	31	26.860	202	0	0.630	395.0	395.60	*	DOPPLER	1
2103	LAS CRUCES	29	32	16	43.750	253	14	48.250	1209.2	1212.30	*	DOPPLER	1
2106	LASHAM	16	51	11	12.320	358	58	30.210	193.3	190.30	*	DOPPLER	1
2111	HOWARD COUNTY	29	39	9	47.830	283	6	11.070	146.2	145.00	*	DOPPLER	1
2115	PRETORIA	3	-25	56	46.150	28	20	53.120	1588.0	1580.00	*	DOPPLER	1
2117	TAFUNA	2	-14	20	8.030	189	17	7.650	9.2	9.17	*	DOPPLER	1
2203	WALLOPS ISLAND	29	-37	51	51.314	284	29	31.414	11.6	13.59	*	DOPPLER	1
2707	DARWIN	6	-12	27	17.890	130	49	52.044	22.5	15.00	*	DOPPLER	2
2708	WAKE ISLAND	49	19	17	27.050	166	36	39.180	10.3	10.31	*	DOPPLER	1
2709	MUCHEA	6	-31	36	29.508	115	55	47.610	46.4	90.80	*	DOPPLER	1
2715	GUAM	19	13	27	58.220	144	43	20.420	189.0	189.00	*	DOPPLER	2
2717	MAHE	42	- 4	40	6.470	55	28	48.810	587.1	587.10	5.81	DOPPLER	1
2722	ASCENSION ISLAND	5	- 7	58	11.299	345	35	38.767	81.2	81.18	5.57	DOPPLER	1
2723	COCOS ISLANDS	*	-12	11	58.347	96	49	47.640	8.6	8.60	*	DOPPLER	1
2724	MIDWAY ISLAND	27	28	11	37.440	182	36	38.080	6.0	6.00	*	DOPPLER	2
2726	MANUS	6	- 2	3	7.030	147	21	34.460	57.2	57.29	*	DOPPLER	2
2727	TERCEIRA	17	38	45	38.420	332	54	19.000	56.2	56.23	*	DOPPLER	1
2735	FORT STEWART	29	32	0	3.760	278	50	43.010	23.5	18.50	*	DOPPLER	2
2738	MOSES LAKE	29	47	11	8.140	240	39	47.400	361.2	372.20	4.7	DOPPLER	1

Survey Information of Observation Stations

STATION NO	STATION LOCATION	DATUM CODE	SURVEY COORDINATES[1] LATITUDE			LONGITUDE			ELL. H(M)	MSL[2] (M)	INSTR.[3] HEIGHT (M.)	INSTR. TYPE	SOURCE[4] CODE
2739	SHEMYA	29	52	43	1.520	174	6	51.430	-1.7	44.30	*	DOPPLER	1
2742	BELTSVILLE	29	39	1	39.460	283	10	27.250	51.0	49.80	*	DOPPLER	1
2744	THURSDAY ISLAND	6	-10	35	6.148	142	12	37.057	61.3	60.12	*	DOPPLER	1
2745	STONEVILLE	29	33	25	31.570	269	5	10.700	48.0	44.00	*	DOPPLER	1
2766	WAKE ISLAND	49	19	17	26.384	166	36	39.817	9.4	9.92	*	DOPPLER	1
2801	PALAU	*	7	20	30.360	134	29	52.820	72.0	72.10	*	DOPPLER	2
2803	ROTA	16	36	37	41.270	353	40	6.640	-21.0	14.39	*	DOPPLER	2
2805	CULGOORA	6	-30	18	39.612	149	33	36.724	215.8	215.13	*	DOPPLER	1
2809	INVERCARGILL	28	-46	24	49.239	168	18	13.127	6.4	6.45	6.45	DOPPLER	1
2811	MAUI	33	20	49	38.020	203	31	52.070	32.3	32.30	*	DOPPLER	1
2812	CATANIA	16	37	24	38.780	14	55	5.790	12.9	28.90	*	DOPPLER	1
2813	DAKAR	1	14	44	36.040	342	31	0.087	48.2	27.55	4.65	DOPPLER	1
2815	PARAMARIBO	41	5	26	54.360	304	47	42.990	12.9	21.45	*	DOPPLER	1
2817	MASHHAD	16	36	14	30.140	59	37	42.970	962.6	994.60	5.20	DOPPLER	1
2818	TROMSO	16	69	39	44.160	18	56	30.520	122.3	109.34	*	DOPPLER	1
2820	VILLA DOLORES	41	-31	56	34.680	294	53	39.524	624.0	610.96	*	DOPPLER	1
2821	ZAMBOANGA	26	6	55	26.850	122	4	3.770	14.5	14.51	*	DOPPLER	1
2822	FORT LAMY	1	12	7	50.885	15	2	5.764	321.9	298.35	*	DOPPLER	1
2823	CASEY	*	-66	16	45.120	110	32	4.610	18.0	18.00	*	DOPPLER	2
2825	PALMER STATION	51	-64	46	34.920	295	56	29.770	15.0	15.00	*	DOPPLER	1
2830	HOHENPEISSENBERG	16	47	48	8.390	11	1	30.310	942.8	943.14	*	DOPPLER	1
2831	SOCORRO ISLAND	23	18	43	43.680	249	2	40.500	26.3	26.30	*	DOPPLER	1
2832	SASSEO	46	33	4	46.650	129	42	43.640	20.0	40.90	*	DOPPLER	2
2837	NATAL	41	- 5	54	56.436	324	49	57.617	67.1	41.00	*	DOPPLER	1
2838	MAURITIUS	*	-20	13	41.719	57	25	7.427	140.5	140.50	*	DOPPLER	1
2840	ADDIS ABABA	1	8	46	9.563	38	59	49.284	1861.8	1890.80	5.80	DOPPLER	1
2844	QUITO	41	- 0	5	51.332	281	34	50.213	2710.6	2686.00	4.60	DOPPLER	1
2846	EASTER ISLAND	10	-27	10	38.024	250	34	18.457	233.9	233.90	4.60	DOPPLER	1
2847	CERRO SOMBRERO	39	-52	46	51.083	290	46	29.084	87.4	887.35	*	DOPPLER	1
2849	CHRISTMAS ISLAND	12	2	0	35.622	202	35	21.961	6.5	6.50	5.30	DOPPLER	1
2907	CYPRUS	16	35	9	52.320	33	19	38.080	173.0	182.91	*	DOPPLER	2
3106	ANTIGUA	29	17	8	52.685	298	12	37.552	7.9	1.90	*	PC-1000	1
3334	STONEVILLE	29	33	25	31.950	269	5	11.350	44.0	39.00	*	PC-1000	1
3460	COLORADO SPRINGS	29	39	0	22.440	255	7	1.010	2191.1	2184.10	*	PC-1000	1
3401	BEDFORD	29	42	27	17.530	288	43	35.033	89.0	83.00	1.32	PC-1000	1
3402	SEMMES	29	30	46	49.350	271	44	52.370	80.0	73.00	*	PC-1000	1
3404	SWAN ISLAND	*	17	24	16.570	276	3	29.870	40.4	40.40	*	PC-1000	1
3405	GRAND TURK	29	21	25	46.796	288	51	13.786	8.2	2.20	*	PC-1000	1
3406	CURACAO	41	12	5	26.843	291	9	45.803	-4.0	6.83	1.25	PC-1000	1
3407	TRINIDAD	41	10	44	35.844	298	23	25.652	236.7	254.80	1.25	PC-1000	1
3413	NATAL	41	- 5	54	56.253	324	49	57.605	63.0	36.90	*	PC-1000	1
3414	BRASILIA	41	-15	51	35.540	312	6	2.679	1058.7	1058.25	1.14	PC-1000	1
3431	ASUNCION	41	-25	18	56.192	302	25	15.376	161.5	149.74	1.65	PC-1000	1
3476	PARAMARIBO	41	5	26	54.292	304	47	43.744	9.8	18.27	1.25	PC-1000	1
3477	BOGOTA	41	4	49	2.379	285	55	35.482	2586.2	2557.90	1.25	PC-1000	1
3478	MANAUS	*	- 3	8	44.820	300	0	59.420	98.0	83.60	*	PC-1000	3
3499	QUITO	41	- 0	5	50.468	281	34	49.212	2706.4	2681.80	*	PC-1000	1
3648	HUNTER AFB	29	32	0	5.868	278	50	46.359	17.4	12.00	1.32	PC-1000	1
3657	ABERDEEN	29	39	28	18.971	283	55	44.780	5.8	5.50	1.32	PC-1000	1

Table 3.1-1 (Cont'd)

Survey Information of Observation Stations

STATION NO	STATION LOCATION	DATUM CODE	SURVEY COORDINATES[1] LATITUDE			LONGITUDE			ELL. H(M)	MSL[2] (M)	INSTR. HEIGHT[3] (M)	INSTR. TYPE	SOURCE[4] CODE
1861	HOMESTEAD	29	25	30	24.686	279	36	42.688	18.2	2.40	*	PC-1000	1
3902	CHEYENNE	29	41	7	59.200	255	8	2.650	1890.0	1882.20	*	PC-1000	4
3903	HERNDON	29	38	59	32.360	282	40	21.200	169.3	168.00	*	PC-1000	1
4050	PRETORIA	3	-25	56	35.336	28	21	29.948	1592.0	1584.00	*	MPS-25	1
4961	ANTIGUA	29	17	8	34.780	298	12	24.470	48.3	42.30	*	FPQ-6	1
4981	GRAND TURK	29	21	27	43.490	288	52	3.050	42.0	36.00	*	TPQ-18	1
4982	MERRITT ISLAND	29	28	25	27.930	279	20	7.380	21.2	11.25	*	TPQ-18	1
4260	VANDENBERG AFB	29	34	39	57.140	239	25	10.430	89.0	123.00	*	TPQ-18	1
4740	BERMUDA	7	32	20	48.070	295	20	44.320	19.9	19.86	*	FPS-16	1
4760	BERMUDA ISLAND	7	32	20	47.530	295	20	46.532	21.1	21.10	*	FPQ-6	1
4840	WALLOP ISLAND	29	37	50	28.393	284	30	52.378	10.4	12.39	*	FPS-16	1
4860	WALLOP ISLAND	29	37	51	36.509	284	29	25.236	13.[illegible]	14.95	*	FPQ-6	1
4946	WOOMERA	6	-30	49	11.002	136	50	13.120	123.2	124.71	*	FPS-16	1
5001	HERNDON	29	38	59	37.697	282	40	16.7[illegible]	1[illegible].0	127.80	9.39	SECOR	1
5201	MOSES LAKE	29	47	11	5.916	240	39	50.463	358.0	368.92	2.00	SECOR	1
5410	SAND ISLAND	27	28	12	32.061	182	37	49.531	6.1	6.10	4.13	SECOR	1
5648	FORT STEWART	29	31	55	18.405	278	26	0.260	34.1	27.82	3.90	SECOR	1
5712	PARAMARIBO	41	5	26	59.460	304	47	44.520	13.0	21.50	4.93	SECOR	1
5713	TERCEIRA	17	38	45	36.725	332	54	21.064	54.0	54.02	4.25	SECOR	1
5715	DAKAR	1	14	44	36.678	342	30	59.794	47.9	27.34	4.42	SECOR	1
5717	FORT LAMY	1	12	7	49.291	15	2	6.232	322.1	298.50	4.83	SECOR	1
5720	ADDIS ABABA	1	8	46	9.479	38	59	49.196	1860.4	1889.37	4.29	SECOR	1
5721	MASHHAD	16	36	14	30.404	59	37	40.105	962.4	994.41	4.[illegible]5	SECOR	1
5722	DIEGO GARCIA	*	- 7	20	57.440	72	28	31.570	6.7	6.70	4.60	SECOR	1
5723	CHIANG MAI	*	18	47		99	00		*	15.0	*	SECOR	1
5724	ZAMBOANGA	26	6	55	26.213	122	4	3.558	13.6	13.60	4.83	SECOR	1
5730	WAKE ISLAND	49	19	17	24.100	166	36	41.206	8.1	8.06	4.29	SECOR	1
5732	PAGO PAGO	*	-14	20	0.958	189	16	36.412	164.5	3.97	*	SECOR	7
5733	CHRISTMAS ISLAND	12	2	0	35.622	202	35	21.962	3.5	3.54	2.29	SECOR	1
5734	SHEMYA	29	52	42	54.894	174	7	37.870	-6.7	39.26	1.50	SECOR	1
5735	NATAL	41	- 5	54	56.253	324	49	57.605	65.6	39.52	*	SECOR	1
5736	ASCENSION ISLAND	5	- 7	58	15.220	345	35	32.385	74.0	74.03	4.32	SECOR	1
5739	TERCEIRA	17	38	45	36.311	332	54	19.684	56.1	56.08	4.25	SECOR	1
5744	CATANIA	16	37	26	40.831	15	2	44.955	-4.2	11.77	4.17	SECOR	1
5907	WORTHINGTON	29	43	38	57.913	264	25	18.167	482.5	477.92	*	SECOR	7
5911	BERMUDA	7	32	21	45.043	295	20	22.891	23.0	18.01	*	SECOR	7
5912	PANAMA	*	8	58	22.793	280	26	55.303	101.0	5.13	*	SECOR	7
5914	PUERTO RICO	29	18	29	38.210	292	50	50.520	49.0	64.41	*	SECOR	2
5915	AUSTIN	29	30	13	45.790	262	14	50.760	21.3	206.48	*	SECOR	2
5923	CYPRUS	16	35	11	24.090	33	15	51.460	154.0	163.84	*	SECOR	2
5924	ROTA	16	36	37	40.840	353	40	6.590	-22.0	12.74	*	SECOR	2
5925	ROBERTS FIELD	*	6	13	48.490	349	38	18.888	56.9	7.58	*	SECOR	7
5930	SINGAPORE	*	1	22	20.190	103	59	42.229	350.2	2.10	*	SECOR	7
5931	HONG KONG	*	22	11	53.707	114	12	59.094	418.1	157.40	*	SECOR	7
5933	DARWIN	6	-12	27	19.710	130	48	53.380	18.6	11.10	*	SECOR	2
5934	MANUS	6	- 2	2	25.080	147	21	36.680	3.6	5.60	*	SECOR	2
5935	GUAM	14	13	26	17.630	144	37	56.490	37.4	37.40	*	SECOR	2
5937	PALAU	*	7	20	29.840	134	29	53.060	67.7	67.70	*	SECOR	2
5938	GUADALCANAL	*	- 9	25	45.282	160	2	38.220	342.3	7.77	*	SECOR	7

Table 3.1-1 (Cont'd)

Survey Information of Observation Stations

STATION NO	STATION LOCATION	DATUM CODE	SURVEY COORDINATES[1] LATITUDE	LONGITUDE	ELL. H(M)	MSL[2] (M)	INSTR. HEIGHT[3] (M)	INSTR. TYPE	SOURCE[4] CODE
5941	MAUI	33	20 50 6.304	203 31 50.409	34.7	34.73	2.27	SECOR	1
6001	THULE	29	76 30 3.411	291 27 51.887	238.0	206.00	1.50	BC-4	1
6002	BELTSVILLE	29	39 1 39.003	283 10 26.942	45.4	44.30	1.50	BC-4	1
6003	MOSES LAKE	29	47 11 7.132	240 39 48.118	357.8	368.74	1.50	BC-4A	1
6004	SHEMYA	29	52 42 54.890	174 7 37.870	-9.2	36.80	1.50	BC-4	1
6006	TROMSO	16	69 39 44.290	18 56 32.326	119.0	106.60	1.50	BC-4	1
6007	TERCEIRA	17	38 45 36.725	332 54 21.064	53.3	53.30	1.49	BC-4	1
6008	PARAMARIBO	41	5 26 54.970	304 47 42.350	9.9	18.38	1.49	BC-4	1
6009	QUITO	41	- 0 5 50.468	281 34 49.212	2706.7	2682.10	1.50	BC-4	1
6011	MAUI	33	20 42 38.561	203 44 28.529	3049.3	3049.27	1.50	BC-4	1
6012	WAKE ISLAND 1	49	19 17 23.227	166 36 39.780	3.5	3.50	1.50	BC-4	1
6013	KANOYA	46	31 23 30.140	130 52 24.860	46.9	65.90	1.50	BC-4	1
6015	MASHHAD	16	36 14 29.527	59 37 42.729	945.0	991.00	1.50	BC-4	1
6016	CATANIA	16	37 26 42.345	15 2 47.696	-6.8	9.24	1.50	BC-4A	1
6019	VILLA DOLORES	41	-31 56 33.954	294 53 41.342	621.2	608.18	1.50	BC-4	1
6020	EASTER ISLAND	15	-27 10 39.213	250 34 17.495	230.8	230.80	1.50	BC-4	1
6022	TUTUILA	2	-14 20 12.216	189 17 13.247	5.3	5.34	1.50	BC-4A	1
6023	THURSDAY ISLAND	6	-10 35 8.037	142 12 35.496	61.7	60.50	1.50	BC-4	1
6031	INVERCARGILL	28	-46 25 3.491	168 19 31.155	0.9	0.90	1.49	BC-4	1
6032	CAVERSHAM	6	-31 50 28.992	115 58 26.618	32.5	26.30	*	BC-4	1
6038	SOCORRO ISLAND	23	18 43 44.930	249 2 39.280	23.2	23.20	1.50	BC-4	1
6039	PITCAIRN ISLAND	36	-25 4 7.146	229 53 11.882	339.4	339.40	1.50	BC-4	1
6040	COCOS ISLAND	*	-12 11 57.910	96 49 47.080	4.4	4.40	*	BC-4	1
6042	ADDIS ABABA	1	8 46 8.501	38 59 49.164	1857.3	1886.46	1.52	BC-4	1
6043	CERRO SOMBRERO	39	-52 46 52.468	290 46 29.573	80.7	80.70	1.48	BC-4A	1
6044	HEARD ISLAND	20	-53 1 12.030	73 23 27.420	3.8	3.80	1.50	BC-4	1
6045	MAURITIUS	*	-20 13 50	57 25 15	*	149.40	*	BC-4	1
6047	ZAMBDANGA	26	6 55 26.132	122 4 4.838	9.4	9.39	1.50	BC-4	1
6050	PALMER STATION	51	-64 46 33.980	295 56 37.040	16.4	16.44	1.58	BC-4	1
6051	MAWSON STATION	*	-67 36 3.080	62 52 24.410	11.3	11.30	*	BC-4	1
6052	WILKES STATION	*	-66 16 45.120	110 32 4.610	18.9	18.00	1.50	BC-4	1
6053	MCMURDO STATION	10	-77 50 46.249	166 38 7.584	19.0	19.00	1.50	BC-4	1
6055	ASCENSION ISLAND	5	- 7 58 16.634	345 35 32.744	70.9	70.94	1.50	BC-4	1
6059	CHRISTMAS ISLAND	12	2 0 35.622	202 35 21.962	2.8	2.75	1.50	BC-4A	1
6060	CULGOORA	6	-30 18 39.418	149 33 36.892	211.8	211.08	*	BC-4	1
6061	SOUTH GEORGIA IS.	43	-54 16 39.515	323 30 42.531	4.2	4.20	1.49	BC-4A	1
6063	DAKAR	1	14 44 39.899	342 31 2.452	46.9	26.30	1.50	BC-4A	1
6064	FORT LAMY	1	12 7 51.741	15 2 6.234	319.0	295.40	1.50	BC-4A	1
6065	HOHENPEISSENBERG	16	47 48 7.009	11 1 28.574	942.6	943.20	*	BC-4A	1
6066	WAKE ISLAND II	49	19 17 24.100	166 36 41.206	5.3	5.30	1.51	BC-4	1
6067	NATAL	41	- 5 55 37.414	324 50 6.200	66.7	46.63	*	BC-4A	1
6068	JOHANNESBURG	3	-25 52 56.980	27 42 25.170	1531.8	1523.80	*	BC-4	1
6069	TRISTAN DA CUNHA	47	-37 3 26.257	347 40 53.555	24.8	24.80	*	BC-4	1
6072	CHIANG MAI	*	18 46 10	98 58 15	*	319.20	*	BC-4	1
6073	DIEGO GARCIA	*	- 7 20 58.527	72 28 32.156	3.9	3.90	1.50	BC-4	1
6075	MAHE	42	- 4 40 7.230	55 28 50.380	589.1	588.98	1.55	BC-4A	1
6078	PORT VILA	52	-17 41 46.956	168 17 57.921	15.2	15.20	1.50	BC-4	1
6111	WRIGHTWOOD 1	29	34 22 54.537	242 19 9.484	2259.3	2284.30	1.50	BC-4	1
6123	POINT BARROW	29	71 18 49.882	203 21 20.720	-6.0	8.30	*	BC-4	5

Table 3.1-1 (Cont'd)

Survey Information of Observation Stations

STATION NO	STATION LOCATION	DATUM CODE	SURVEY COORDINATES[1] LATITUDE			LONGITUDE			ELL. HGT (M)	MSL[2] (M)	INSTR. HEIGHT (M)	INSTR. TYPE	SOURCE[4] CODE
6134	WRIGHTWOOD-II	29	34	22	44.444	242	19	9.259	2173.4	2198.40	1.50	BC-4	1
7034	EAST GRAND FORKS	29	48	1	21.403	262	59	21.561	255.4	252.58	1.71	MOTS 40	1
7036	EDINBURG	29	26	22	45.443	261	40	9.033	66.7	59.59	1.11	MOTS 40	1
7037	COLUMBIA	29	38	53	36.068	267	47	42.120	273.4	272.68	1.11	MOTS 40	1
7039	BERMUDA	7	32	21	44.529	295	20	34.485	31.2	31.18	1.13	MOTS 40	1
7040	SAN JUAN	29	18	15	26.216	294	0	27.174	58.7	49.70	1.07	MOTS 40	1
7043	GREENBELT	29	39	1	15.014	283	10	19.034	54.6	53.46	0.64	PTH-100	1
7045	DENVER	29	39	38	48.026	255	23	41.194	1795.9	1789.63	1.11	MOTS 40	1
7050	GREENBELT	29	39	1	13.676	283	10	18.035	55.9	54.91	*	LASER	1
7052	WALLOPS ISLAND	29	37	51	35.432	284	29	23.336	6.6	5.56	*	LASER	1
7053	GREENBELT	29	39	1	15.323	283	10	18.871	55.5	54.45	*	LASER	5
7054	CARNARVON	6	-24	54	19.908	113	42	53.892	37.6	31.40	*	LASER	1
7071	JUPITER	29	27	1	12.769	279	53	12.312	25.4	14.64	1.13	MOTS 24	1
7072	JUPITER	29	27	1	13.168	279	53	12.485	25.6	14.19	1.10	MOTS 40	1
7073	JUPITER	29	27	1	13.107	279	53	12.722	25.0	13.56	0.64	PTH-100	1
7074	JUPITER	29	27	1	13.313	279	53	12.761	25.6	14.25	1.47	BC-4	1
7075	SUNBURY	29	46	27	20.918	279	3	10.354	281.3	281.60	1.17	MOTS 40	1
7076	KINGSTON	29	18	4	31.980	283	11	26.529	485.9	445.90	1.07	MOTS 40	1
7077	GREENBELT	29	38	59	56.770	283	9	37.310	51.8	50.85	1.11	MOTS 40	1
7078	WALLOPS ISLAND	29	37	51	46.779	284	29	26.940	5.6	7.56	0.63	PTH-100	1
7079	CARNARVON	6	-24	54	26.914	113	43	11.592	29.7	23.40	*	PTH-100	1
7809	HAUTE PROVENCE	16	43	56	0.190	5	42	48.788	649.4	657.82	*	LASER	6
7816	STEPHANION	16	37	45	17.043	22	49	43.313	788.7	803.11	*	LASER	6
7818	COLOMB-BECHAR	16	31	43	19.250	357	34	54.960	813.7	855.65	*	LASER	6
7912	MAUI	33	20	42	37.230	203	44	24.030	3026.1	3034.14	*	LASER	6
8009	WIPPOLDER	16	52	0	9.240	4	22	21.230	21.0	24.70	*	LOUWERS	1
8010	ZIMMERWALD	16	46	52	40.318	7	27	58.239	906.3	903.44	*	SCHM H	1
8011	MALVERN	16	52	8	39.130	358	1	59.470	108.6	113.20	*	SCHM A	1
8015	HAUTE PROVENCE	16	43	56	1.140	5	42	49.280	650.8	659.00	*	SCHM D	1
8019	NICE	16	43	43	36.496	7	18	3.309	349.4	377.42	*	AUTARES	1
8130	MEUDON	16	48	48	25.354	2	13	51.339	155.2	165.46	*	REFR A	1
8804	SAN FERNANDO	16	36	27	50.119	353	47	41.296	-9.7	25.40	*	LASER	1
8815	HAUTE PROVENCE	16	43	55	59.193	5	42	48.383	649.6	657.83	1.00	LASER	1
8820	DAKAR	1	14	46	0.548	342	35	29.321	44.1	28.48	*	LASER	1
9001	ORGAN PASS	29	32	25	24.560	253	26	51.170	1650.1	1651.33	*	B-N	1
9002	OLIFANTSFONTEIN	3	-25	57	33.850	28	14	53.910	1552.1	1544.10	*	B-N	1
9003	WOOMERA	6	-31	6	7.241	136	46	58.449	158.1	159.21	*	B-N	1
9004	SAN FERNANDO	16	36	27	51.370	353	47	42.009	-9.1	25.90	*	B-N	1
9005	TOKYO	44	35	40	11.078	139	32	28.922	59.8	59.77	*	B-N	1
9006	NAINI TAL	16	29	21	38.970	79	27	25.510	1927.0	1927.00	*	B-N	1
9007	AREQUIPA	41	-16	27	55.085	289	30	26.814	2486.1	2461.86	*	B-N	1
9008	SHIRAZ	16	29	38	18.117	52	31	11.445	1553.4	1597.40	*	B-N	1
9009	CURACAO	41	12	5	25.912	291	9	44.078	-2.1	8.70	*	B-N	1
9010	JUPITER	29	27	1	12.882	279	53	13.008	26.5	15.13	*	B-N	1
9011	VILLA DOLORES	41	-31	56	33.228	294	53	38.949	621.0	608.00	*	B-N	1
9012	MAUI	33	20	42	37.500	203	44	24.080	3034.1	3034.14	*	B-N	1
9021	MOUNT HOPKINS	29	31	41	2.670	249	7	21.350	2372.1	2383.10	*	B-N	1
9022	OLIFANTSFONTEIN	3	-25	57	33.820	28	14	54.350	1551.3	1543.90	*	B-N	1
9023	WOOMERA	6	-31	23	30.816	136	52	39.016	136.9	137.91	*	B-N	1

Table 3.1-1 (Cont'd)

Survey Information of Observation Stations

STATION NO	STATION LOCATION	DATUM CODE	SURVEY COORDINATES[1] LATITUDE			LONGITUDE			ELL. H(M)	MSL[2] (M)	INSTR.[3] HEIGHT (M)	INSTR. TYPE	SOURCE[4] CODE
9025	DODAIRA	46	36	0	8.606	139	11	43.159	855.9	855.89	*	B-N	1
9027	AREQUIPA	41	-16	27	54.365	288	30	26.578	2484.4	2450.23	*	B-N	1
9028	ADDIS ABABA	1	8	44	47.230	38	57	30.490	1896.2	1925.20	*	B-N	1
9029	NATAL	41	- 5	55	36.616	324	50	8.660	71.4	45.34	*	B-N	1
9031	COMODORO RIVADAVIA	41	-45	53	11.028	292	23	12.215	172.5	186.54	0.33	B-N	1
9039	NATAL	41	- 5	55	38.616	324	50	9.401	67.7	41.60	*	B-N	1
9049	JUPITER	29	27	1	12.726	279	53	12.634	24.2	12.93	*	GEO 36	1
9050	HARVARD	29	42	30	20.970	288	24	28.719	193.3	187.19	*	GEO 36	1
9051	ATHENS	16	37	58	40.310	23	46	42.890	180.9	187.90	*	GEO 36	1
9091	DIONYSOS	16	38	4	48.215	23	56	1.587	459.2	466.25	*	B-N	1
9424	COLD LAKE	29	54	44	33.858	249	57	26.389	701.7	704.60	6.90	B-N	1
9425	EDWARDS AFB	29	34	57	56.742	242	5	11.584	760.4	784.23	*	B-N	1
9426	MARESTUA	16	60	12	40.380	10	45	8.740	581.7	575.92	*	B-N	1
9427	JOHNSTON ISLAND	24	16	44	45.390	190	29	5.590	5.0	5.00	*	B-N	1
9431	RIGA	16	56	56	54.900	24	3	37.910	2.-	8.00	*	AFU 75	1
9432	UZHGOROD	*	48	38	4.560	22	17	57.880	*	189.00	*	AFU 75	1
9711	GOLDSTONE	29	35	23	22.346	243	9	5.262	1014.3	1036.30	11.80	BS* M-D	1
9712	GOLDSTONE	29	35	17	59.854	243	11	43.434	967.3	988.90	11.70	BS* M-D	1
9714	GOLDSTONE	29	35	25	33.340	243	6	40.950	1009.8	1031.80	15.50	210*A-E	1
9741	WOOMERA	6	-31	22	59.430	136	53	10.124	147.3	148.28	*	BS* M-D	1
9742	TIDBINBILLA	6	-35	24	8.042	148	58	48.191	664.1	655.78	15.08	BS* M-D	1
9751	JOHANNESBURG	3	-25	53	21.150	27	41	8.530	1399.0	1391.00	13.00	BS* M-D	1
9761	MADRID	16	40	25	47.717	355	45	8.278	766.4	788.40	14.60	BS* M-D	1
9762	MADRID	16	40	27	15-273	355	38	0.572	716.3	738.30	15.00	BS* M-D	1
9901	ORGAN PASS	29	32	25	24.360	253	26	51.130	1650.0	1651.00	*	LASER	1
9902	OLIFANTSFONTEIN	3	-25	57	33.850	28	14	53.910	1551.9	1549.90	*	LASER	1
9907	AREQUIPA	41	-16	27	55.0FC	238	30	26.910	2484.5	2452.30	*	LASER	1
9921	MOUNT HOPKINS	29	31	41	2.870	249	7	21.350	2372.1	2389.10	*	LASER	1
9929	NATAL	41	- 5	55	38.620	324	50	8.660	71.7	45.60	*	LASER	1
9930	DIONYSOS	16	38	4	46.150	23	55	59.990	465.4	472.40	*	LASER	1

* INSUFFICIENT DATA

1 GEODETIC COORDINATES OF THE INSTRUMENTAL REFERENCE POINT (OPTICAL/ELECTRONIC CENTER,ETC.) ON THE LOCAL GEODETIC DATUM

2 MEAN SEA LEVEL HEIGHT OF THE INSTRUMENTAL REFERENCE POINT

3 HEIGHT OF INSTRUMENTAL REFERENCE POINT ABOVE SURVEY MONUMENT

4 REFER TO TABLE 3.1-2.

NOTE : ZERO IN THE LAST DIGIT MAY INDICATE THAT THE DIGIT IS UNKNOWN.

COORDINATES OF STATION NO. 2823 ARE APPROXIMATE.

Table 3.1-2

Summary of Source Information

Code	Source
1	[NASA, 1973]
2	[Anderle, 1972]
3	[Huber, 1971]
4	[NASA, 1969]
5	[CSC, 1972 and 1973]
6	[AGU, (in press)]
7	[DMA, 1972]

3.2 Survey Ties

An extensive effort was made to locate and select proper survey connections for use in OSU 275. In a number of cases two or more values were available from different sources in respect to survey ties. The criteria for retention/selection for any tie were:

(i) When two or more sources agree in value, and/or

(ii) When the new coordinates so generated did not give unusually large residuals in subsequent use in a coordinate transformation, vis-a-vis any other satellite system.

In some cases no direct survey tie was available from the WN14 station, but only a secondary connection existed, i.e., a new tie could be generated to another station which has already been tied to the WN14 station. A total of 78 new stations under category "C" could thus be included in the OSU 275 system and the survey ties are listed in Table 3.2-1 together with their respective sources.

Table 3.2-1

Relative Position Survey Ties

STATIONS	RELATIVE SURVEY TIES			SOURCE CODE[1]
	Δu(m)	Δv(m)	Δw(m)	
80 - 9004	20.21	-22.23	-31.29	1
1024 - 4946	21763.16	-24681.10	-54300.15	1
1024 - 9023	502.17	543.25	24.09	1
1025 - 6009	-17214.40	-4054.65	-58089.50	1
1031 - 6068	-59.33	55.68	-51.46	1
1034 - 7034	0.00	0.00	0.00	1
1037 - 1042	7.55	0.76	-0.44	1
1037 - 1126	333.98	403.74	571.14	1
1038 - 6060	304146.82	-114911.72	-494901.06	1
1152 - 6032	47149.23	424142.27	676055.49	1
1152 - 7054	-54.98	52.16	135.29	1
2002 - 5915	2441.48	2991.52	5613.76	2
2017 - 2117	3.15	-6.16	1.81	1
2018 - 6001	-7191.06	1607.24	824.36	2
2019 - 6053	130.41	-808.60	-87.04	1
2100 - 6011	-38134.78	180270.31	83073.90	1
2115 - 4050	355.44	-972.88	-297.56	1
2117 - 6022	-62.16	159.84	123.63	2
2203 - 7052	116.96	336.56	389.65	1
2707 - 5933	31.52	48.33	54.25	2
2708 - 6012	36.07	10.98	113.58	2
2715 - 5935	-5167.26	-8280.54	3041.46	2
2717 - 6075	41.80	-28.54	25.01	2
2722 - 6055	78.13	172.06	160.56	2
2723 - 6040	-16.96	-0.71	-13.80	1
2724 - 5410	-889.08	1909.29	-1479.49	2
2726 - 5934	31.84	60.20	-1289.25	2
2727 - 5713	-52.29	-30.85	40.82	2

Table 3.2-1 (cont'd)

Relative Position Survey Ties

STATIONS	RELATIVE SURVEY TIES			SOURCE CODE[1]
	Δu(m)	Δv(m)	Δw(m)	
2735 - 5648	37794.23	10456.14	7451.23	2
2738 - 6003	-4.04	23.66	22.05	2
2739 - 6004	246.56	850.01	129.87	2
2742 - 6002	6.17	6.09	14.48	2
2744 - 6023	-35.68	-29.80	55.25	2
2803 - 5924	-5.82	1.55	10.78	2
2805 - 6060	3.08	6.56	-6.92	2
2809 - 6031	22.84	1695.26	297.85	2
2811 - 6011	-1998.22	23015.42	10996.24	2
2812 - 6016	5189.47	-10355.63	-3019.82	2
2815 - 6008	17.38	6.38	-16.93	2
2817 - 6015	-7.84	-4.15	16.22	2
2818 - 6006	8.86	-12.78	1.63	2
2822 - 6064	12.07	-13.64	-23.78	2
2830 - 6065	-36.29	28.62	27.32	2
2831 - 6038	27.86	-27.23	-35.34	2
2837 - 6067	-45.57	-290.84	1252.04	1
2847 - 6043	3.13	-38.26	19.67	2
2849 - 5733	-1.50	-4.24	0.11	2
2907 - 5923	-1624.56	5793.71	-2552.70	2
4760 - 7039	683.19	-706.64	-1488.55	1
4840 - 4860	2384.72	-712.15	-1659.94	1
4840 - 7052	2425.94	-685.65	-1629.78	1
6002 - 7050	94.58	535.35	600.04	1
6060 - 9741	-772918.65	-932773.88	102026.67	1
7043 - 7052	-130836.44	50256.18	100969.44	1

Table 3.2-1 (cont'd)

Relative Position Survey Ties

STATIONS	RELATIVE SURVEY TIES			SOURCE CODE [1]
	Δu(m)	Δv(m)	Δw(m)	
7043 - 7077	652.96	1711.12	1877.55	1
7043 - 7078	-130867.81	50025.49	100693.86	1
7054 - 7079	415.40	289.40	192.03	1
7071 - 7072	-3.77	-6.14	-11.03	1
7071 - 7073	-10.26	-6.95	-9.09	1
7071 - 7074	-10.87	-9.72	-15.55	1
7072 - 0049	-4.96	4.23	12.71	1
8015 - 8815	-42.91	15.88	44.40	1
8804 - 9004	20.21	-22.23	-31.29	1
9002 - 9751	-29320.41	48263.28	-7062.21	1
9002 - 9902	0.16	0.09	-0.09	1
9003 - 9023	-6011.77	17986.68	27467.31	1
9003 - 9741	-5076.20	18236.52	26647.26	1
9004 - 9761	256350.70	-194931.26	-345204.51	1
9005 - 9025	-56256.10	-10061.87	-39387.14	1
9007 - 9907	-0.15	0.45	-0.18	1
9021 - 9921	-1.15	-3.02	-5.24	1
9029 - 9929	-0.24	0.17	0.03	1
9091 - 9930	-56.26	17.70	46.42	1
9425 - 9714	-96368.01	16918.75	-42019.65	1
9711 - 9714	2192.21	-3736.79	-3288.55	1
9712 - 9714	3178.70	-10636.74	-11423.51	1
9741 - 9742	482265.64	1042434.19	372405.59	1
9761 - 9762	2542.26	9918.38	-2023.26	1

3.3 Transformation

The transformation parameters used in obtaining satellite station coordinates in the OSU 275 system are given in Table 3.3-1.

Table 3.3-1

Transformation Parameters between various Satellite Systems and OSU 275 System

(OSU 275 - Satellite System)

System / Tr. Parameter	NWL-9D	SE-III	GSFC 73	GEM6
Δu	-18.49	-12.36	-15.48	-15.42
Δv	-7.67	-13.82	-20.42	-12.09
Δw	3.53	13.07	-0.67	-5.57
Δ ($*10^6$)	-0.28	-0.93	-1.09	-0.95

A total of 39 points were transformed using the above parameters in OSU 275. The distribution of these points in the respective satellite system from where they were transformed is given in Table 3.3-2.

Table 3.3-2

Distribution of Transformed Stations

System	Stations Numbers	Total
NWL-9D	2020, 2049, 2092, 2709, 2765 2766, 2801, 2813, 2820, 2821 2823, 2825, 2832, 2838, 2840 2844	16
SE III	7816, 7817, 7912, 9022, 9027 9039. 9901	7
GSFC 73	1035, 1036, 7809, 8820, 9050	5
GEM 6	1028, 1043, 1122, 1123, 1128, 2014, 2103, 2106, 2111 2745, 7053	11

4. OSU 275 PARAMETERS, ORIGIN AND ORIENTATION

4.1 OSU 275 Geodetic and Geophysical Parameters

In view of its basic dependence on the OSU geometric solution WN 14 [Mueller et al., 1973], the suggested geodetic and geophysical parameters are given in Table 4.1-1.

Table 4.1-1
Geodetic and Geophysical Parameters

Parameters	Notation	Magnitude
Gravitational constant	$K^2 M$	$3.98600922 \times 10^{14} m^3 sec^{-2}$
Second degree zonal harmonic	J_2	1082.6863×10^{-6}
Angular velocity	ω	$0.72921151467 \times 10^{-4}$ rad sec^{-1}
Flattening	f	1/298.25
Equatorial normal gravity	γ_e	978.03226 cm sec^{-2}
Geopotential on the geoid	W_0	6263688.00 kgal m
Equatorial semi-diamter	a	6378142 m

4.2 Origin and Orientation

The OSU 275 system is oriented towards the Zero Meridian (u axis) and the Conventional International Origin (w axis), both as defined by the Bureau International de l'Heure. The v axis forms a right handed system with the u and w, and together with the u axis defines the average geodetic equator.

It should be remembered that the origin of the system is arbitrary, but its position with respect to the geocenter has been estimated from the comparison between the coordinates of collocated stations in OSU 275 and in the dynamic solutions. The suggested coordinates of the origin with respect to the geocenter are $u_0 = 16$ m, $v_0 = 12$ m and $w_0 = -2$ m.

In a height analysis when the geoid undulation (geodetic minus mean sea level heights) were compared with gravimetrically determined ones, the rms residual was 0.44m for OSU 275.

5. CARTESIAN COORDINATES

The Cartesian coordinates resulting from the survey ties and transformations based on the WN 14 solution are given in Table 5.1.

Standard deviations of basic stations are retained from the WN 14 solution, while for "C" and "T" stations these have been estimated and rounded to the nearest meter.

Table 5.1

Cartesian Coordinates for OSU 275 Stations

STATION NO		LOCATION	STATION COORDINATES : OSU275 U	V	W	σ_u	σ_v	σ_w
80	C	SAN FERNANDO	5105601.7	-555293.7	3769644.7	5.0	12.0	6.0
1021		BLOSSOM POINT	1118023.1	-4876323.4	3942963.9	2.8	2.6	2.8
1022		FORT MYERS	807851.9	-5651989.6	2833500.2	2.2	1.9	2.3
1024	C	WOMERA	-3977293.6	3725625.1	-3302986.6	8.0	8.0	8.0
1025	C	QUITO	1263619.8	-6254990.6	-68890.1	5.0	5.0	6.0
1028	T	SANTIAGO	1769701.1	-5044622.9	-3468259.5	26.0	26.0	26.0
1030		GOLDSTONE	-2357242.9	-4646338.5	3668306.8	5.6	3.3	3.2
1031	C	JOHANNESBURG	5084771.1	2670396.9	-2768146.7	5.0	5.0	6.0
1032		ST. JOHN'S	2602688.6	-3419228.9	4697637.3	39.3	46.7	13.8
1033		FAIRBANKS	-2299282.6	-1445693.7	5751811.6	6.9	9.7	5.7
1034		E. GRAND FORKS	-521704.5	-4242064.3	4718716.8	3.1	3.0	2.7
1035	T	WINKFIELD	3903098.8	-48514.0	4964714.0	8.0	8.0	11.0
1036	T	FAIRBANKS	-2282362.1	-1452662.9	5756892.0	8.0	8.0	11.0
1037	C	ROSMAN	647505.0	-5177934.9	3656705.5	4.0	4.0	5.0
1038	C	ORRORAL	-4447503.1	2677146.4	-3695065.0	8.0	5.0	5.0
1042		ROSMAN	647497.5	-5177935.6	3656705.9	2.8	2.4	2.8
1043	T	TANANARIVE	4091856.4	4434279.4	-2064728.7	9.0	9.0	9.0
1122	T	TANANARIVE	4091206.0	4434257.1	-2066017.2	9.0	9.0	9.0
1123	T	TANANARIVE	4091326.3	4434221.3	-2065973.7	9.0	9.0	9.0
1126	T	ROSMAN	647171.1	-5178338.6	3656134.3	5.0	5.0	6.0
1128	T	FAIRBANKS	-2282517.6	-1453391.1	5756698.7	15.0	15.0	15.0
1152	C	CARNARVON	-2328271.4	5299689.0	-2669355.6	5.0	11.0	16.0
2002	C	AUSTIN	-741649.6	-5462247.2	3198081.2	6.0	6.0	7.0
2014	T	ANCHORAGE	-2656190.3	-1544375.0	5570644.0	15.0	15.0	15.0
2017	C	TAFUNA	-6100020.7	-997208.5	-1568460.0	6.0	6.0	7.0
2018	C	THULE	539377.6	-1388386.5	6181061.0	4.0	4.0	5.0
2019	C	MCMURDO STATION	-1310721.9	310448.9	-6213363.5	6.0	6.0	6.0
2020	T	MAHE	3602861.9	5238204.1	-515934.4	7.0	6.0	7.0
2049	T	PUERTO RICO	2440932.8	-5531065.9	2006220.8	5.0	5.0	5.0
2092	T	AUSTIN	-741659.3	-5462215.8	3198133.2	5.0	5.0	5.0
2100	C	WAHIAWA	-5504153.4	-2224161.2	2325298.3	5.0	6.0	5.0
2103	T	LAS CRUCES	-1556231.4	-5169428.4	3387248.7	15.0	15.0	15.0
2106	T	LASHAM	4005420.1	-71762.3	4946709.4	15.0	15.0	15.0
2111	T	HOWARD COUNTY	1122633.1	-4823045.4	4006469.0	6.0	6.0	6.0
2115	C	PRETORIA	5051963.2	2725632.7	-2774463.8	5.0	5.0	6.0

Table 5.1 (Cont'd)

Cartesian Coordinates for OSU 275 Stations

2117	C	TAFUNA	-6100023.8	-997202.3	-1568461.9	5.0	5.0	6.0
2203	C	WALLOPS ISLAND	1261662.0	-4881250.9	3893555.7	5.0	4.0	5.0
2707	C	DARWIN	-4071536.8	4714301.7	-1366474.1	5.0	5.0	6.0
2708	C	WAKE ISLAND	-5858533.2	1394519.7	2093933.9	4.0	4.0	5.0
2709	T	MUCHEA	-2377598.6	4889656.1	-3323432.3	34.0	28.0	36.0
2715	C	GUAM	-5064993.0	3582905.4	1475804.0	5.0	5.0	5.0
2717	C	MAHE	3602862.4	5238212.1	-515923.3	6.0	5.0	6.0
2722	C	ASCENSION ISLAND	6118417.3	-1571576.3	-878436.0	4.0	4.0	5.0
2723	C	COCOS ISLAND	-741998.7	6190792.2	-1338560.1	6.0	5.0	6.0
2724	C	MIDWAY ISLAND	-5619643.2	-256328.2	2995770.7	5.0	5.0	6.0
2726	C	MANUS	-5367631.3	3437930.1	-226705.2	5.0	5.0	5.0
2727	C	TERCEIRA	4433585.5	-2268184.1	3971697.6	4.0	5.0	5.0
2735	C	FORT STEWARD	832485.3	-5349594.9	3360533.6	6.0	5.0	6.0
2738	C	MOSES LAKE	-2127836.2	-3785839.3	4656059.3	4.0	4.0	4.0
2739	C	SHEMYA	-3851550.9	397259.4	5051470.4	5.0	5.0	6.0
2742	C	BELTSVILLE	1130771.0	-4830825.8	3994718.5	4.0	4.0	4.0
2744	C	THURSDAY ISLAND	-4955422.5	3842218.0	-1163792.2	5.0	5.0	6.0
2745	T	STONEVILLE	-85010.6	-5327963.0	3493447.7	6.0	6.0	6.0
2765	T	CHIANG MAI	-941675.7	5967443.3	2039341.4	35.0	28.0	37.0
2766	T	WAKE ISLAND	-5858540.6	1394520.9	2093920.5	34.0	28.0	36.0
2801	T	PALAU	-4433465.2	4512966.3	810002.7	35.0	28.0	37.0
2803	C	ROTA	5093550.4	-565320.7	3784279.1	4.0	5.0	5.0
2805	C	CULGOORA	-4751646.9	2792064.7	-3200170.9	5.0	5.0	5.0
2809	C	INVERCARGILL	-4313802.5	893029.2	-4596968.0	5.0	6.0	6.0
2811	C	MAUI	-5468016.8	-2381416.1	2253220.6	5.0	5.0	5.0
2812	C	CATANIA	4901577.8	1305816.5	3853648.4	4.0	4.0	4.0
2813	T	DAKAR	5684479.5	-1853566.1	1612735.8	5.0	5.0	5.0
2815	C	PARAMARIBO	3623258.4	-5214227.4	601519.1	4.0	4.0	5.0
2817	C	MASHHAD	2604345.4	4444161.8	3750336.7	4.0	4.0	4.0
2818	C	TROMSO	2102936.3	721655.7	5958182.4	4.0	5.0	5.0
2820	T	VILLA DOLORES	2280571.4	-4914564.8	-3355440.7	8.0	8.0	8.0
2821	T	ZAMBOANGA	-3361919.5	5365834.0	763659.0	7.0	6.0	7.0
2822	C	FORT LAMY	6023398.7	1617918.2	1331709.4	5.0	4.0	5.0
2823	T	CASEY	-902608.3	2409529.7	-5816541.2	7.0	6.0	7.0
2825	T	PALMER STATION	1192559.3	-2451018.0	-5747057.2	7.0	6.0	7.0
2830	C	HOHENPEISSENBERG	4213528.3	820858.6	4702811.7	4.0	4.0	4.0
2831	C	SOCORRO ISLAND	-2160953.0	-5642737.8	2035332.5	4.0	5.0	6.0
2832	T	SASEBO	-3417816.6	4115338.4	3461705.6	35.0	28.0	37.0
2837	C	NATAL	5186351.6	-3654224.1	-653024.9	4.0	4.0	4.0
2838	T	MAURITIUS	3223444.2	5045328.7	-2191792.0	7.0	6.0	7.0
2840	T	ADDIS ABABA	4900753.9	3968227.8	966356.7	5.0	5.0	5.0
2844	T	QUITO	1280851.8	-6250961.6	-10839.8	5.0	5.0	5.0
2847	C	CERRO SOMBRERO	1371379.0	-3614788.6	-5055908.2	5.0	6.0	6.0
2849	C	CHRISTMAS ISLAND	-5885335.4	-2448384.7	221670.8	5.0	5.0	6.0
2907	C	CYPRUS	4361707.6	2868048.6	3652828.0	4.0	5.0	5.0
3106		ANTIGUA	2881838.3	-5372164.6	1868538.6	3.7	3.3	4.3
3334		STONEVILLE	-84963.8	-5327974.9	3493428.3	13.6	6.8	9.6
3400		COLORADO SPRINGS	-1275207.7	-4798029.3	3994208.3	9.1	5.1	5.7
3401		BEDFORD	1513136.1	-4463576.8	4283055.8	3.2	3.4	3.0
3402		SEMMES	167259.7	-5481971.0	3245037.0	3.9	2.8	3.5
3404		SWAN ISLAND	642491.4	-6052940.3	1895688.6	4.7	3.7	4.9
3405		GRAND TURK	1919482.9	-5621088.1	2315775.3	3.3	3.5	4.0
3406		CURACAO	2251800.2	-5816912.9	1327191.1	2.4	2.1	3.4
3407		TRINIDAD	2979891.1	-5513530.9	1181129.3	4.7	3.4	5.3
3413		NATAL	5186348.4	-3654222.4	-653018.9	2.1	2.2	2.7
3414		BRASILIA	4114977.8	-4554142.5	-1732154.0	7.7	6.1	7.2
3431		ASUNCION	3093045.4	-4870081.7	-2710823.0	7.6	6.5	10.8
3476		PARAMARIBO	3623277.3	-5214210.7	601515.3	2.2	2.0	3.0
3477		BOGOTA	1744650.2	-6114286.7	532208.6	10.2	6.6	9.6
3478		MANAUS	3185777.0	-5514585.9	-347703.2	18.7	14.5	35.1

Table 5.1 (Cont'd)

Cartesian Coordinates for OSU275 Stations

3499		QUITO	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1
3648		HUNTER AFB	832566.2	-5349540.7	3360585.3	3.6	2.5	3.6
3657		ABERDEEN	1186787.1	-4785193.1	4032882.3	3.1	3.0	3.0
3861		HOMESTEAD	961767.9	-5679156.6	2729883.5	3.0	2.3	2.6
3902		CHEYENNE	-1234720.7	-4651242.8	4174758.6	8.6	6.3	6.3
3903		HERNDON	1088989.7	-4843005.4	3991776.6	12.1	8.5	8.9
4050		PRETORIA	5051608.1	2726603.3	-2774166.8	3.2	3.2	4.4
4061		ANTIGUA	2881592.3	-5372523.9	1868024.4	3.8	3.5	4.3
4081		GRAND TURK	1920410.9	-5619417.8	2319128.5	3.3	3.6	4.0
4082		MERRITT ISLAND	910567.2	-5539113.2	3017965.3	2.6	2.4	2.8
4280		VANDENBERG AFB	-2671873.8	-4521210.5	3607490.4	3.8	3.3	3.6
4740		NBER 34	2308887.3	-4874298.2	3393082.1	3.3	3.1	3.8
4760	C	BERMUDA	2308896.6	-4874304.9	3393069.9	5.0	5.0	5.0
4840	C	WALLOPS ISLAND	1263971.0	-4882273.1	3891536.3	5.0	4.0	5.0
4860	C	WALLOPS ISLAND	1261586.3	-4881561.0	3893196.2	6.0	5.0	6.0
4946	C	WOOMERA	-3999056.7	3750306.2	-3248686.4	9.0	9.0	10.0
5001		HERNDON	1088849.4	-4842948.7	3991840.2	3.6	3.0	3.7
5201		MOSES LAKE	-2177802.2	-3785911.5	4656012.1	2.3	2.2	2.4
5410		MIDWAY ISLANDS	-5618754.1	-258237.5	2097250.2	2.3	2.8	3.6
5648		FORT STEWART	794691.0	-5360051.1	3353082.4	3.6	2.5	3.6
5712		PARAMARIBO	3623289.8	-5214188.0	601673.2	2.1	2.0	2.9
5713		TERCEIRA	4433637.8	-2268153.2	3971656.8	2.0	2.2	2.5
5715		DAKAR	5884468.8	-1853580.1	1612760.1	1.6	2.0	2.3
5717		FORT LAMY	6023410.7	1617946.5	1331655.8	2.0	2.0	2.7
5720		ADDIS ABABA	4900749.1	3968253.0	966354.7	2.0	2.1	2.9
5721		MASHHAD	2604404.8	4444122.3	3750344.3	2.1	2.1	2.7
5722		DIEGO GARCIA	1905127.0	6032287.5	-810716.2	3.5	4.1	4.3
5723		CHIANG MAI	-941709.4	5967445.0	2039322.9	2.5	2.3	3.5
5726		ZAMBOANGA	-3361946.8	5365837.0	763627.8	2.3	2.2	3.2
5730		WAKE ISLAND	-5858574.6	1394467.2	2093847.4	2.1	2.5	3.1
5732		PAGO PAGO	-6099970.5	-997355.3	-1568570.9	3.6	3.5	4.1
5733		CHRISTMAS ISLAND	-5885333.9	-2448380.4	221670.7	2.7	2.9	3.9
5734		SHEMYA	-3851799.0	396409.3	5051342.0	2.7	3.3	3.9
5735		NATAL	5186350.6	-3654223.7	-653018.9	2.0	2.1	2.5
5736		ASCENSION ISLAND	6118340.3	-1571761.9	-878553.6	2.3	2.2	2.7
5739		TERCEIRA	4433629.3	-2268186.2	3971647.0	2.0	2.2	2.5
5744		CATANIA	4896437.7	1316125.0	3856626.2	1.8	2.2	2.3
5907		WORTHINGTON	-449417.5	-4600905.5	4380288.1	4.2	3.2	4.5
5911		BERMUDA	2307991.2	-4873773.2	3394463.4	2.6	2.3	3.0
5912		PANAMA	1142644.5	-6196109.1	988336.6	3.1	3.4	4.1
5914		PUERTO RICO	2349456.9	-5576027.1	2010342.6	10.5	7.0	6.4
5915		AUSTIN	-744093.1	-5465238.7	3192467.4	3.8	3.8	4.7
5923		CYPRUS	4363332.2	2862254.9	3655380.7	1.9	2.1	2.4
5924		ROTA	5093556.2	-565322.3	3784768.3	1.9	2.6	2.9
5925		ROBERTS FIELD	6237366.3	-1140241.5	687740.2	2.3	2.6	3.0
5930		SINGAPORE	-1542549.4	6186956.7	151833.8	2.6	2.7	3.4
5931		HONG KONG	-2423914.9	5388250.3	2394869.2	2.5	2.5	3.6
5933		DARWIN	-4071568.4	4714253.3	-1366528.3	3.2	3.2	3.7
5934		MANUS	-5367663.1	3437869.9	-225416.0	2.5	2.5	3.3
5935		GUAM	-5059825.7	3591186.0	1472762.5	2.1	2.2	2.8
5937		PALAU	-4433463.6	4512930.3	809958.7	2.2	2.2	3.2
5938		GUADALCANAL	-5915096.5	2146860.8	-1037909.5	3.0	3.0	3.5
5941		MAUI	-5467757.3	-2381246.7	2254033.8	2.5	2.8	3.8
6001		THULE	546568.7	-1389993.7	6180236.7	2.6	2.4	3.4
6002		BELTSVILLE	1130764.9	-4830831.9	3994704.0	2.0	1.7	1.9
6003		MOSES LAKE	-2127832.1	-3785863.9	4656037.2	2.1	2.0	2.3
6004		SHEMYA	-3851797.5	396409.4	5051340.5	2.7	3.3	3.9
6006		TROMSO	2102927.4	721668.5	5958180.8	2.4	2.9	2.9
6007		TERCEIRA	4433637.3	-2268151.4	3971655.0	2.0	2.2	2.5
6008		PARAMARIBO	3623241.0	-5214233.7	601536.1	2.1	2.0	2.9

Table 5.1 (Cont'd)

Cartesian Coordinates for OSU 275 Stations

6009		QUITO	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1
6011		MAUI	-5466018.6	-2404431.5	2242224.4	3.0	2.9	3.3
6012		WAKE ISLAND I	-5858569.3	1394508.7	2093820.3	2.1	2.6	3.2
6013		KANOYA	-3565892.8	4120713.6	3303428.3	3.3	4.4	4.9
6015		MASHHAD	2604353.3	4444166.0	3750320.5	2.1	2.2	2.6
6016		CATANIA	4896388.3	1316172.1	3856668.2	1.8	2.2	2.2
6019		VILLA DOLORES	2280627.1	-4914543.2	-3355402.8	2.4	2.7	3.7
6020		EASTER ISLAND	-1888614.3	-5354894.4	-2895749.0	5.4	4.5	5.5
6022		TUTUILA	-6099961.7	-997362.2	-1568585.5	3.4	3.6	4.7
6023		THURSDAY ISLAND	-4955386.8	3842247.8	-1163847.4	3.2	3.0	4.0
6031		INVERCARGILL	-4313825.3	891333.9	-4597265.8	3.4	3.9	3.8
6032		CAVERSHAM	-2375420.6	4875546.7	-3345411.1	3.3	3.2	3.9
6038		SOCORRO ISLAND	-2160980.9	-5642710.5	2035367.8	2.5	2.8	3.8
6039		PITCAIRN ISLAND	-3724765.9	-4421237.6	-2686084.7	6.2	5.4	5.5
6040		COCOS ISLAND	-741981.7	6190792.9	-1338546.3	4.5	3.7	4.2
6042		ADDIS ABABA	4900750.7	3968252.7	966325.3	2.0	2.1	2.9
6043		CERRO SOMBRERO	1371375.9	-3614750.3	-5055927.8	3.3	3.8	4.8
6044		HEARD ISLAND	1098897.9	3684606.6	-5071873.1	6.8	6.2	7.8
6045		MAURITIUS	3223432.0	5045336.3	-2191805.7	3.2	3.1	3.9
6047		ZAMBOANGA	-3361976.9	5365811.9	763624.7	2.4	2.3	3.2
6050		PALMER STATION	1192678.8	-2451015.6	-5747034.2	4.9	6.1	6.1
6051		MAWSON STATION	1111336.1	2169262.7	-5874334.1	4.9	3.7	4.4
6052		[illegible]KES STATION	-902608.8	2409522.1	-5816551.8	4.4	4.0	5.4
6053		MCMURDO STATION	-1310852.3	311257.5	-6213276.5	4.6	4.5	4.3
6055		ASCENSION ISLAND	6118334.2	-1571748.3	-878596.5	2.3	2.3	2.8
6059		CHRISTMAS ISLAND	-5885333.5	-2448379.0	221671.1	2.7	2.9	3.8
6060		CULGOORA	-4751650.0	2792058.1	-3200164.0	3.3	3.3	3.7
4061		SOUTH GEORGIA IS.	2999915.6	-2210369.3	-5155246.0	3.7	5.7	5.3
6063		DAKAR	5844467.4	-1853495.8	1612855.1	1.7	2.1	2.5
6064		FORT LAMY	6023386.7	1617931.9	1331733.2	2.7	2.6	3.2
6065		HOHENPEISSENBERG	4213564.6	820830.0	4702784.4	2.0	2.4	2.3
6066		WAKE ISLAND II	-5858571.2	1394466.4	2093846.0	2.1	2.6	3.2
6067		NATAL	5186397.1	-3653933.3	-654276.9	2.1	2.2	2.6
6068		JOHANNESBURG	5084830.4	2670341.2	-2768095.2	3.0	2.9	4.2
6069		TRISTAN DA CUNHA	4978421.7	-1086874.0	-3823167.8	6.5	6.4	8.1
6072		CHIANG MAI	-941702.1	5967455.1	2039311.6	5.7	4.0	4.3
6073		DIEGO GARCIA	1905134.1	6032282.4	-810732.7	3.4	3.7	4.2
6075		MAHE	3602820.6	5238240.7	-515948.3	3.8	3.6	4.0
6078		PORT VILA	-5952303.4	1231904.9	-1925972.5	9.7	8.0	12.4
6111		WRIGHTWOOD I	-2448853.3	-4667985.8	3582754.9	2.6	2.1	2.4
6123		POINT BARROW	-1881799.4	-812439.0	6019590.7	4.6	4.4	4.5
6134		WRIGHTWOOD II	-2448907.0	-4668075.9	3582449.6	2.6	2.1	2.4
7034	C	EAST GRAND FORKS	-521704.5	-4242064.3	4718716.8	5.0	5.0	4.0
7036		EDINBURG	-828487.0	-5657471.3	2816814.0	3.5	2.4	2.9
7037		COLUMBIA	-191291.0	-4967293.9	3983252.6	2.9	2.2	2.4
7039		BERMUDA	2308213.4	-4873598.3	3394558.5	3.3	3.1	3.6
7040		SAN JUAN	2465049.5	-5534930.0	1985513.1	3.7	3.2	4.0
7043		GREENBELT	1130708.6	-4831331.3	3994135.5	2.0	1.7	1.9
7045		DENVER	-1240470.2	-4760242.1	4048985.3	4.2	2.8	2.9
7050	C	GREENBELT	1130670.3	-4831367.2	3994104.0	4.0	3.0	4.0
7052	C	WALLOPS ISLAND	1261545.1	-4881587.5	3893166.1	4.0	3.0	4.0
7053	T	GREENBELT	1130638.1	-4831360.6	3994149.6	6.0	6.0	6.0
7054	C	CARNARVON	-2328216.4	5299636.8	-2669490.9	6.0	12.0	17.0
7071	C	JUPITER	976257.5	-5601406.0	2880230.9	4.0	4.0	4.0
7072		JUPITER	976261.3	-5601399.9	2880241.9	2.2	1.8	2.3
7073	C	JUPITER	976267.8	-5601399.1	2880240.0	5.0	5.0	5.0
7074	C	JUPITER	976268.4	-5601396.3	2880246.4	5.0	5.0	5.0
7075		SUDBURY	692620.7	-4347076.5	4600475.4	3.7	3.8	3.4
7076		KINGSTON	1384158.7	-5905662.0	1966545.7	4.1	4.4	5.3
7077	C	GREENBELT	1130055.7	-4833042.4	3992258.0	4.0	3.0	4.0

Table 5.1 (Cont'd)

Cartesian Coordinates for OSU275 Stations

7078	C	WALLOPS ISLAND	1261576.5	-4881356.8	3893441.7	4.0	3.0	4.0
7079	C	CARNARVON	-2328631.8	5299347.4	-2669682.9	7.0	13.0	18.0
7809	T	HAUTE PROVENCE	4578327.5	457964.9	4403174.3	8.0	8.0	11.0
7816	T	STEPHANION	4654320.2	1959163.4	3884368.0	13.0	13.0	13.0
7818	T	COLOMB-"ECHAR	5426310.7	-229340.2	3334616.4	13.0	13.0	13.0
7912	T	MAUI	-5466070.3	-2404290.3	2242183.7	10.0	10.0	10.0
8009		WIPPOLDER	3923397.4	299869.4	5002975.5	8.5	10.1	6.9
8010		ZIMMERWALD	4331307.0	567490.8	4633108.3	5.7	8.3	5.4
8011		MALVERN	3920153.5	-134804.5	5012734.8	8.9	14.3	6.9
8015		HAUTE PROVENCE	4578322.1	457936.5	4403195.3	4.2	8.0	4.4
8019		NICE	4579463.2	586573.5	4386419.2	4.1	7.9	4.3
8030		MEUDON	4205626.9	163683.4	4776540.6	6.5	9.7	5.8
8804	C	SAN FERNANDO	5105601.7	-555293.7	3769644.7	5.0	12.0	6.0
8815	C	HAUTE PROVENCE	4578365.0	457920.7	4403150.9	6.0	10.0	6.0
8820	T	DAKAR	5886248.2	-1845660.0	1615260.7	12.0	14.0	16.0
9001		ORGAN PASS	-1535750.7	-5167014.4	3401039.4	4.2	2.8	2.7
9002		OLIFANTSFONTEIN	5056108.4	2716508.7	-2775768.8	3.0	3.0	4.2
9003	C	WOOMERA	-3983807.5	3743068.5	-3275543.4	6.0	6.0	7.0
9004		SAN FERNANDO	5105581.5	-555271.5	3769676.0	3.4	10.0	4.0
9005		TOKYO	-3946730.5	3366286.1	3698822.9	9.2	9.0	7.5
9006		NAINI IAL	1018164.5	5471108.7	3109625.6	12.4	5.5	6.0
9007		AREQUIPA	1942760.9	-5804088.2	-1796900.9	2.5	2.9	4.4
9008		SHIRAZ	3376875.2	4403976.2	3136257.3	6.8	6.1	6.1
9009		CURACAO	2251810.7	-5816917.6	1327163.4	2.4	2.1	3.4
9010		JUPITER	976276.2	-5601402.2	2880234.5	2.1	1.8	2.3
9011		VILLA DOLORES	2280575.3	-4914580.2	-3355383.7	2.4	2.7	3.7
9012		MAUI	-5466067.8	-2404312.7	2242188.4	3.0	2.9	3.3
9021		MOUNT HOPKINS	-1936789.3	-5077714.7	3331922.7	7.1	5.3	5.3
9022	T	OLIFANTSFONTEIN	5056103.6	2716508.0	-2775771.3	7.0	7.0	7.0
9023	C	WOOMERA	-3977795.7	3725081.8	-3303010.7	7.0	7.0	8.0
9025	C	DODAIRA	-3910474.4	3376348.0	3729210.1	11.0	11.0	9.0
9027	T	AREQUIPA	1942757.6	-5804104.5	-1796894.7	6.0	6.0	6.0
9028		ADDIS ABABA	4903726.6	3965206.3	963859.6	2.1	2.1	2.9
9029		NATAL	5186441.4	-3653871.9	-654314.1	2.1	2.2	2.7
9031		COMODORO R'DAVIA	1693797.3	-4112353.1	-4556622.0	8.3	8.8	11.2
9039	T	NATAL	5186452.6	-3653855.6	-654320.7	9.0	9.0	9.0
9049	C	JUPITER	976266.3	-5601404.1	2880229.2	4.0	4.0	4.0
9050	T	HARVARD	1489733.9	-4467483.4	4287304.9	12.0	11.0	15.0
9051		ATHENS	4606861.5	2029692.2	3903562.2	4.2	10.3	4.4
9091		DIONYSOS	4595158.9	2039417.6	3912670.6	4.2	10.3	4.4
9424		COLD LAKE	-1264831.9	-3466915.4	5185450.9	4.7	5.5	4.3
9425		EDWARDS AFB	-2450012.7	-4624431.6	3635036.6	2.6	2.2	2.4
9426		HARESTUA	3121261.3	592605.7	5512723.0	8.6	9.4	5.8
9427		JOHNSTON ISLAND	-6007428.7	-1111852.5	1825733.9	8.9	19.8	8.6
9431		RIGA	3183897.6	1421426.7	5322814.7	12.3	9.4	7.0
9432		UZHGOROD	3907419.2	1602378.6	4763922.1	7.9	10.4	5.9
9711	C	GOLDSTONE	-2351452.4	-4645087.1	3673767.7	5.0	5.0	5.0
9712	C	GOLDSTONE	-2350465.9	-4651987.1	3665632.7	5.0	5.0	5.0
9714	C	GOLDSTONE	-2353644.6	-4641350.3	3677056.2	4.0	4.0	4.0
9741	C	WOOMERA	-3978731.3	3724832.0	-3302190.6	5.0	5.0	6.0
9742	C	TIDBINBILLA	-4460996.9	2682397.8	-3674596.2	12.0	23.0	10.0
9751	C	JOHANNESBURG	5085428.9	2668245.4	-2768706.6	5.0	5.0	6.0
9761	C	MADRID	4849230.8	-360340.2	4114880.5	8.0	12.0	6.0
9762	C	MADRID	4846688.5	-370258.6	4116903.7	9.0	13.0	7.0
9901	T	ORGAN PASS	-1535779.5	-5166998.0	3401052.4	8.0	8.0	8.0
9902	C	OLIFANTSFONTEIN	5056108.3	2716508.6	-2775768.7	5.0	5.0	6.0
9903	C	AREQUIPA	1942761.1	-5804088.7	-1796900.7	4.0	5.0	6.0
9921	C	MOUNT HOPKINS	-1936788.2	-5077711.7	3331927.9	9.0	7.0	7.0
9929	C	NATAL	5186441.7	-3653872.0	-654314.2	4.0	4.0	4.0
9930	C	DIONYSOS	4595215.1	2039399.9	3912624.2	6.0	12.0	6.0

ALL UNITS IN METRES

T = TRANSFORMED COORDINATES

C = CONNECTED THROUGH SURVEY COORDINATES

NOTE : STANDARD DEVIATIONS FOR THE T AND C STATIONS ARE ESTIMATED AND ROUNDED TO THE NEAREST METRE

6. SYSTEMATIC DIFFERENCES WITH GLOBAL AND NON-GLOBAL GEODETIC SYSTEMS/DATUMS

The mathematical model developed earlier [Kumar, 1972] deals primarily with the case when the two systems involved have "global" coverage [Badekas, 1969; Bursa, 1965 and Wolf, 1963] and is known after Bursa. However, if one of the systems involved in the coordinate transformation is "non-global" in coverage, e.g., a national datum, then a slightly different approach [Badekas, 1969] is necessary to obtain more realistic parameter estimates.

The above distinction is essential as the rotations in a "non-global" case are to be considered about the origin (initial point) on the geodetic datum, rather than about the origin of the Cartesian coordinates, thus avoiding certain numerical and geometric problems [Mueller, 1975]. These rotations may be about axes parallel to the Cartesian axes u, v, w (Molodensky's model) or about the axes pointing South, East and the ellipsoidal normal upwards at the initial point (Veis's model). It is also possible, in certain modes, to orient the geodetic datum through only one rotation (Vanicek and Wells' model) about the ellipsoidal normal upwards.

6.1 Transformation Parameters in Non-global Systems

6.1.1 Molodensky's Model

If U_0 , V_0 , W_0 are the rectangular coordinates of the initial point of the geodetic datum UVW, then the transformation is given as [Badekas, 1969]:

$$\begin{bmatrix}\varphi_1\\ \varphi_2\\ \varphi_3\end{bmatrix} \equiv \begin{bmatrix}x\\ y\\ z\end{bmatrix}_t - \begin{bmatrix}U\\ V\\ W\end{bmatrix}_t - \begin{bmatrix}DU\\ DV\\ DW\end{bmatrix} - \begin{bmatrix}0 & \omega & -\psi\\ -\omega & 0 & \epsilon\\ \psi & -\epsilon & 0\end{bmatrix} \begin{bmatrix}U - U_0\\ V - V_0\\ W_0 - W_0\end{bmatrix}_t$$

$$- DL \begin{bmatrix}U - U_0\\ V - V_0\\ W - W_0\end{bmatrix} = 0 . \qquad (1)$$

The rotations here are about a set of parallel axes to that of Bursa's Model and considered at the initial point. Further, the above equation shows that for a global system (when $U_0 = V_0 = W_0 = 0$), Molodensky's Model would become identical to Bursa's.

6.1.2 Veis's Model

A somewhat more practical and realistic approach in the case of a non-global system is to consider the positive directions of axes along South, East and ellipsoidal normal upwards at the initial point. The transformation here is given as [Badekas, 1969]:

$$\begin{bmatrix}\varphi_1\\ \varphi_2\\ \varphi_3\end{bmatrix} \equiv \begin{bmatrix}X\\ Y\\ Z\end{bmatrix}_t - \begin{bmatrix}U\\ V\\ W\end{bmatrix}_t - \begin{bmatrix}DU\\ DV\\ DW\end{bmatrix} - M \begin{bmatrix}U - U_0\\ V - V_0\\ W_0 - W_0\end{bmatrix} - DL \begin{bmatrix}U - U_0\\ V - V_0\\ W - W_0\end{bmatrix} = 0. \qquad (2)$$

The matrix M in the above equations is defined as:

$$M = \begin{bmatrix} 0 & \sin\varphi_0\alpha - \cos\varphi_0\eta & -\cos\varphi_0 \sin\lambda_0\alpha - \cos\lambda_0\xi - \sin\varphi_0 \sin\lambda_0\eta \\ -\sin\varphi_0\alpha + \cos\varphi_0\eta & 0 & \cos\varphi_0 \cos\lambda_0\alpha - \sin\lambda_0\xi + \sin\varphi_0\cos\lambda_0\eta \\ \cos\varphi_0 \sin\lambda_0\alpha + \cos\lambda_0\xi + \sin\varphi_0\sin\lambda_0\eta & -\cos\varphi_0\cos\lambda_0\alpha + \sin\lambda_0\xi - \sin\varphi_0\cos\lambda_0\eta & 0 \end{bmatrix}$$

where $(\varphi_0, \lambda_0, h_0)$ are the geodetic coordinates of the initial point and η, ξ, α are the respective rotations about the above three axes.

Further, the three rotations η, ξ, α are related to the rotations ϵ, ψ and ω of Bursa's and Molodensky's models as

$$\begin{bmatrix} \alpha \\ \xi \\ \eta \end{bmatrix} = \begin{bmatrix} \sin\varphi_0 & \cos\varphi_0 \sin\lambda_0 & \cos\lambda_0 \\ 0 & \cos\lambda_0 & -\sin\lambda_0 \\ -\cos\varphi_0 & \sin\varphi_0 \sin\lambda_0 & \cos\lambda_0 \end{bmatrix} \begin{bmatrix} \omega \\ \psi \\ \epsilon \end{bmatrix} \qquad (3)$$

Also, if $\Sigma_{\alpha\xi\eta}$ and $\Sigma_{\omega\psi\epsilon}$ are the variance-covariance matrices in the two cases, then the principle of propagation of errors gives

$$\Sigma_{\alpha\xi\eta} = G\Sigma_{\omega\psi\epsilon} G' \qquad (4)$$

where

$$G = \begin{bmatrix} \sin\varphi_0 & \cos\varphi_0 \sin\lambda_0 & \cos\lambda_0 \\ 0 & \cos\lambda_0 & -\sin\lambda_0 \\ -\cos\varphi_0 & \sin\varphi_0 \sin\lambda_0 & \cos\lambda_0 \end{bmatrix}$$

The above relations (3) and (4) would then supply independent rotational constraints in Veis's model.

6.2 Transformation Results

The results of the seven parameter transformations for global and non-global systems are in the following tables.

6.2.1 Global Reference Systems

The worldwide reference systems considered in this paper are: NWL9D [Anderle, 1974a and 1974b], SEIII [Gaposchkin, 1974], GEM6 [Lerch, et al., 1974], GSFC [Marsh, et al., 1974b], NGS [Schmid, 1974] and WSG72 [Seppelin, 1974]. The transformation results using Bursa's model are given in Table 6.2.1-1.

6.2.2 Non-global Geodetic Datum

Only four major geodetic datums (Australian National, European 1950, North American 1927 and South American 1969, [NASA, 1973]) are available with sufficient suitable common points for parametric transformations.

Tables 6.2.2-1 and 6.2.2-2 give the transformation parameters for the above four datums, respectively, in the case of Molodensky's and Veis's models.

Table 6.2.2-3 lists the transformation parameters (Molodensky's model) in each case for other geodetic datums. A special mention may be necessary here regarding transformation parameters for the Indian Datum. It became possible for the first time to trace back a second station at CHIANG MAI (Thailand) on the Everest ellipsoid [DMA, 1975] and thereby making it possible also to gain some feeling about the reliability of transformation parameters obtained earlier [Mueller, et al., 1973]. In addition to the results in Table 6.2.2-3, a four parameter solution for the Indian Datum gave the following results:

DU	=	- 141.5 ± 13.0
DV	=	- 741.1 ± 5.0
DW	=	- 258.2 ± 6.0
DL ($\times 10^6$)	=	3.40 ± 6.40.

Table 6.2.1-1

Transformation Parameters
(Satellite Geodetic System - OSU 275 System)

	No of Stations	DU (m)	DV (m)	DW (m)	ω ($''$)	ψ ($''$)	ϵ ($''$)	D L ($*10^6$)
NGS (DYNAMIC)	45	18.8± 0.9	9.2± 0.9	-3.2± 1.0	0.08± 0.04	-0.06± 0.04	-0.07± 0.04	-2.33± 0.15
NWL-9D	50	19.8± 1.0	9.2± 0.9	-2.5± 1.1	0.44± 0.04	-0.12± 0.04	-0.13± 0.05	0.09± 0.14
GSFC 1973	67	13.7± 1.5	16.7± 1.5	-2.8± 1.9	-0.39± 0.06	0.20± 0.07	0.19± 0.07	1.19± 0.24
STD. EARTH III	101	15.0± 1.1	15.0± 1.1	-13.7± 1.2	0.30± 0.06	0.06± 0.05	0.03± 0.05	0.91± 0.17
WGS 1972	124	18.3± 0.6	9.6± 0.6	-13.5± 0.6	0.02± 0.06	-0.13± 0.06	-0.14± 0.07	-0.97± 0.03
GEM 6	134	18.3± 0.8	12.2± 0.8	4.7± 0.9	0.16± 0.03	0.09± 0.04	0.04± 0.04	0.95± 0.14

ω, ψ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

Table 6.2.2-1

Relationships between various Geodetic Datums
and the OSU 275 System (Datum - OSU 275)

(Molodensky's Model)

Datum No	Datum Name	No of Stations	DU (m)	DV (m)	DW (m)	ω ($''$)	ψ ($''$)	ϵ ($''$)	DL ($*10^{-6}$)
6	Australian National	16	156.2± 3.8	58.8± 3.8	-131.1± 3.2				0.63± 0.94
			155.0± 0.8	59.9± 0.9	-131.0± 1.1	1.17± 0.06	0.64± 0.07	-0.41± 0.07	-0.27± 0.55
16	European Datum 1950	31	125.5± 7.4	139.0± 4.0	151.2± 8.0				-6.41± 1.67
			101.5± 3.5	129.9± 3.5	117.2± 3.3	-0.46± 0.30	0.13± 0.55	-1.00± 0.30	-6.44± 1.62
29	North American 1927	71	35.4± 1.4	-164.0± 3.1	-164.1± 2.7				-2.86± 0.61
			36.7± 1.5	-150.4± 1.4	-177.9± 1.6	0.21± 0.15	0.37± 0.15	-0.83± 0.20	-2.86± 0.60
41	South American 1969	28	71.3± 2.6	31.0± 3.7	40.1± 1.5				5.44± 0.67
			94.2± 1.9	9.5± 2.1	30.0± 1.9	-0.36± 0.16	0.28± 0.15	-0.18± 0.15	5.43± 0.67

ω, ψ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

IF (DATUM-GEOCENTER) IS SOUGHT ADD TO THE TABULATED VALUES OF DU, DV, DW, THE RESPECTIVE QUANTITIES -16m, -12m AND +2m.

Table 6.2.2-2

Relationships between various Geodetic Datums
and the OSU 275 System (Datum - OSU 275)

(Veis's Model)

Datum Name	No. of Stations	DU (m)	DV (m)	DW (m)	α ($''$)	ξ ($''$)	η ($''$)	DL ($*10^{-6}$)
Australian National	16	155.0± 0.8	59.9± 0.9	-130.9± 1.1	0.16± 0.13	-0.14± 0.20	-1.38± 0.15	-0.27± 0.56
European Datum 1950	31	101.5± 3.6	129.9± 3.5	117.2± 3.4	-0.94± 0.35	0.35± 0.63	-0.47± 0.38	-6.44± 1.62
North American 1927	71	36.7± 1.5	-150.4± 1.4	-177.9± 1.6	0.05± 0.13	-0.87± 0.25	-0.32± 0.18	-2.86± 0.30
South American 1969	28	94.9± 1.9	9.5± 2.0	30.0± 1.9	-0.19± 0.13	0.05± 0.18	0.45± 0.18	5.43± 0.64

α, ξ, η, when positive, represent counterclockwise rotations about axes pointing up, east and south at the origin of the datum, as viewed from the end of the positive axis.

IF (DATUM-GEOCENTER) IS SOUGHT ADD TO THE TABULATED VALUES OF DU, DV, DW, THE RESPECTIVE QUANTITIES -16m, -12m AND +2m.

Table 6.2.2-3

Relationships between various Geodetic Systems or Datums and the OSU 275 System (Datum - OSU 275)

DATUM NO.	DATUM NAME	NO. OF STATIONS	DU(M)	DV(M)	DW(M)
1	ADINDAN (ETHIOPIA)	11	167.1± 2.9	21.0± 2.9	-210.1± 3.1
2	AMERICAN SAMOA 1962	3	119.2± 4.2	-105.7± 2.8	-423.3± 4.7
3	ARC CAPE (SOUTH AFRICA)	8	151.7± 4.2	126.7± 2.8	298.1± 4.7
5	ASCENSION ISLAND	3	227.1± 3.5	-93.1± 4.1	-58.3± 3.7
10	CAMP AREA ASTRO 1961/62(USGS)	1	111.0± 6.0	148.0± 9.0	-238.0± 6.0
12	CHRISTMAS ISLAND ASTRO 1967	3	-115.8± 5.5	-721.8± 9.1	529.7± 7.7
15	EASTER ISLAND ASTRO 1967	1	-181.9± 7.5	-137.4± 5.1	-128.2± 8.7
17	GRACIOSA ISLAND (AZORES)	4	124.5± 3.5	-146.3± 2.8	37.3± 4.7
20	HEARD ASTRO 1969	1	181.5± 7.5	56.0± 5.1	-114.3± 8.7
22	INDIAN DATUM	2	-145.0±12.0	-728.0± 8.0	-252.0± 9.0
23	ISLA SOCORO ASTRO	2	-133.6± 7.5	-205.8± 5.1	-503.6± 8.7
24	JOHNSTON ISLAND 1961	1	-160.8± 3.5	50.7± 4.1	217.2± 3.7
26	LUZON 1911 (PHILIPPINES)	3	143.4± 5.9	50.5± 5.8	108.0± 6.2
27	MIDWAY ASTRO 1961	1	-377.4± 7.5	84.1± 5.1	-278.5± 8.7
28	NEW ZEALAND 1949	2	-61.8± 5.5	41.9± 9.1	-191.7± 7.7
33	OLD HAWAIIN	5	-50.4± 3.5	298.0± 4.1	185.2± 3.7
36	PITCAIRN ISLAND ASTRO	1	-167.1± 5.5	-168.6± 9.1	-59.9± 7.7
39	PROVISIONAL S. CHILE 1963	2	0.9± 7.5	-196.0± 9.1	-92.1± 7.7
42	SOUTHEAST ISLAND (MAHE)	3	50.0± 3.1	189.4± 2.9	270.9± 3.1
43	SOUTH GEORGIA ASTRO	1	820.3± 7.5	-101.0± 6.8	290.3± 5.7
45	TANANARIVE	2	191.9± 3.1	253.5± 3.1	122.2± 3.1
46	TOKYO DATUM	3	180.2± 5.5	-508.4± 9.1	-679.0± 7.7
47	TRISTAN ASTRO 1968	1	653.7± 3.4	-420.3± 3.7	622.3± 3.6
49	WAKE ISLAND ASTRO 1952	5	-259.7± 7.5	66.5± 6.8	-140.6± 5.7
51	PALMER ASTRO 1969	2	-208.0± 8.3	-16.5± 8.4	-220.3± 8.4
52	EFATE (NEW HEBRIDES)	1	139.5± 7.5	791.5± 6.8	-452.8± 5.7
53	LE POUCI ASTRO	1	755.1± 7.5	-155.8± 6.8	506.6± 5.7
54	DIEGO GARCIA ASTRO 1969	2	-185.8± 8.8	438.5± 9.2	238.0± 9.5

REFERENCES

American Geophysical Union, (in press). The National Geodetic Satellite Program, NASA Special Publication, U.S. Government Printing Office, Washington, D.C.

Anderle, R.J., 1972. Private correspondence.

Anderle, R.J., 1974a. "Transformation of Terrestrial Survey Data to Doppler Satellite Datum," J. Geophys. Res., 79, 5319-5331.

Anderle, R. J., 1974b. "Role of Artificial Earth Satellite in Redefinition of the North American Datum," Canadian Surveyor, 28, 590-597.

Badekas, J., 1969. "Investigations Related to the Establishment of a World Geodetic System," Reports of the Department of Geodetic Science No. 124, The Ohio State University, Columbus, Ohio.

Bursa, M., 1966. "Fundamentals of the Theory of Geometric Satellite Geodesy, Travaux de l'Institut Geophysique l'Academie Tchecoslovaque des Sciences, No. 241, Czechosovakia.

Computer Science Corporation, 1972/1973. Correction Sheets to NASA Directory of Observation Station Locations, Vols. 1 and 2, Falls Church, Virginia.

Defense Mapping Agency, 1972. "Report of the DoD Geoceiver Test Program," DMA Rep. 0001, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland.

Defense Mapping Agency, 1975. Private correspondence.

Gaposchkin, E.M., 1974. "Earth's Gravity Field to the Eighteenth Degree and Geocentric Coordinates for 104 Stations from Satellite Terrestrial Data, J. Geophys. Res., 79, 5377-5411.

Huber, D. N., 1971. "Densification of the World Satellite Triangulation Network in South America with the PC-1000 Camera (Geometric Triangulation)," ACIC Tech. Rep. No. 72-3, U.S. Airforce, Aeronautical Chart and Information Center, St. Louis, Missouri.

Kumar, M., 1972. "Coordinate Transformation by Minimizing Correlations between Parameters," Reports of the Department of Geodetic Science No. 184, The Ohio State University, Columbus, Ohio.

Lerch, F. J., C. A. Wagner, J. A. Richardson and J.F. Brownd, 1974. "Goddard Earth Models (5 and 6)," GSFC Doc. No. X-921-74-145, Goddard Space Flight Center, Greenbelt, Maryland.

Marsh, J.G., B.C. Douglas and S.M. Klosko, 1974b. "A Global Station Coordinates Solution Based upon Camera and Laser Data - GSFC1973," The Use of Artificial Satellites for Geodesy and Geodynamics, edited by G. Veis, National Technical University of Athens, Greece.

Mueller, I.I., M. Kumar, J.P. Reilly, N. Saxena and T. Soler, 1973. "Global Satellite Triangulation for the National Geodetic Satellite Program (Solutions WN 12, 14 and 16)," Reports of the Department of Geodetic Science No. 199, The Ohio State University, Columbus, Ohio.

Mueller, I. I., 1974. "Global Satellite Triangulation and Trilateration Results," J. Geophys. Res., 79, 5333-5347.

NASA, 1969. Geodetic Satellite Observation Station Directory, Washington, D. C.

NASA, 1973. Directory of Observation Station Locations, Goddard Space Flight Center, Greenbelt, Maryland.

Schmid, H.H., 1974. "Worldwide Geometric Satellite Triangulation," J. Geophys. Res.,79, 5349-5376.

Seppelin, T.O., 1974. "The Department of Defense World Geodetic System," Canadian Surveyor, 28, 496-506.

Vanicek, P. and D.E. Wells, 1974. "Positioning Horizontal Geodetic Datums," Canadian Surveyor, 28, 531-538.

Wolf, H., 1963. "Geometric Connection and Re-orientation of Three-dimensional Triangulation Nets," Bulletin Geodesique, 68, 165-169.