II. POSITIONING BY NNSS AND OMEGA SYSTEM IN THE GH78-1 CRUISE

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Introduction

NNSS was used as a main navigational and positioning equipment throughout the cruise. Recalculated stational positions are listed in Table II-1. Recalculation procedure is similar to that of GH76-1 cruise (ISHIHARA and ISHIBASHI, 1977). Although satellite fixes are accurately determined with error of the order of 0.1 nautical mile, these stational positions are less precisely determined because in estimate of the error of a recalculated position the dead reckoning error, which becomes greater as the time to the closest satellite fix becomes greater, should be added to the satellite fix error. In this respect the situation in this cruise is not good. Generally speaking, a satellite fix is available only when one of the transit satellite passes over the vessel, typically every 1–2 hours. However, due to the satellite orbital configuration of this period, e.g. on January 29, there are data blanks of more than four hours, from 124 to 552 GMT and from 1258 to 1716 GMT, while in the other time span satellite fix data is available almost every hour (Table II-2). This situation occurred throughout the cruise. According to the result of GH76-1 cruise (ISHIHARA and ISHIBASHI, 1977) the estimated error of recalculated position exceeds 0.5 nautical mile in the worst case (e.g. estimated error for FG91-2 in Table II-1).

In this cruise we tried to use the Omega system as an auxiliary positioning equipment. The Omega system is a world wide positioning system like NNSS. Although each Omega fix is less precise than the satellite fix, we can obtain Omega fix data at desired time or periodically (in this cruise Omega reading data were outputted onto a paper tape every 5 minutes and Omega reading data given below were calculated by interpolation). We attempted the following analysis with the expectation that Omega fix data are sometimes more accurate than recalculated NNSS positions.

Calculation of standard Omega reading

To compute standard Omega reading we need formula for the distance from one station to the Omega receiver:

$$d = a(\sigma + \delta), \qquad (1)$$

where σ is the angular distance from the station to the Omega receiver, δ is the elliptical correctional factor and a is the earth equatorial radius.

σ and δ are calculated from the reduced latitude and the longitude of the station and the receiver, (λ_1, φ_1), (λ, φ):

$$\cos\sigma = \sin\lambda \sin\lambda_1 + \cos\lambda \cos\lambda_1 \cos(\varphi - \varphi_1) \qquad (2)$$

and $\delta = -f/4[(\sigma - 3\sin\sigma)(\sin\lambda + \sin\lambda_1)^2/(1+\cos\sigma)$

Table II-1 Results of recalculation of stationary positions

St. no.	Observ. no.	Date	GMT	Latitude	Longitude	Error
1036	G604	19	2011	8 0.30 N	176 57.28 E	0.27
	FG73-1	19	1810	8 0.10 N	176 57.04 E	0.21
	FG73-2	19	1815	8 0.10 N	176 56.71 E	0.22
1037	G605	20	543	9 4.23 N	176 58.01 E	0.19
	FG74-1	20	348	9 2.70 N	176 58.20 E	0.42
	FG74-2	20	352	9 2.92 N	176 58.09 E	0.41
1037-1	G605-1	20	914	8 59.86 N	176 58.16 E	0.12
1038	G606	20	2000	9 59.72 N	176 58.12 E	0.16
	FG75-1	20	1806	9 59.45 N	176 58.12 E	0.18
	FG75-2	20	1809	9 59.47 N	176 57.95 E	0.17
1039	G607	21	547	11 1.60 N	177 0.23 E	0.18
	FG76-1	21	337	10 59.80 N	176 59.97 E	0.55
	FG76-2	21	341	10 59.98 N	177 0.02 E	0.56
1040	G608	21	1950	11 57.37 N	176 57.51 E	0.15
	FG77-1	21	1759	11 57.23 N	176 57.84 E	0.19
	FG77-2	21	1802	11 57.25 N	176 57.64 E	0.20
1041	G609	22	606	12 58.92 N	177 0.13 E	0.28
	FG78-1	22	408	12 59.22 N	177 0.28 E	0.34
	FG78-2	22	411	12 59.35 N	177 0.34 E	0.33
1042	G610	22	2004	12 59.93 N	177 58.42 E	0.13
	FG79-1	22	1759	12 59.99 N	177 58.27 E	0.19
	FG79-2	22	1803	13 0.00 N	177 58.46 E	0.18
1043	G611	23	552	12 0.94 N	178 0.00 E	0.15
	FG80-1	23	337	12 0.91 N	177 59.42 E	0.63
	FG80-2	23	341	12 0.91 N	177 59.55 E	0.62
1044	G612	23	1949	11 0.20 N	178 1.06 E	0.19
	FG81-1	23	1800	11 0.54 N	178 0.67 E	0.21
	FG81-2	23	1803	11 0.50 N	178 0.82 E	0.22
1044-1	G612-1	23	2253	11 0.38 N	178 0.54 E	0.15
1045	G613	24	736	9 59.31 N	178 0.56 E	0.12
	FG82-1	24	552	9 59.60 N	178 0.30 E	0.25
	FG82-2	24	555	9 59.59 N	178 0.39 E	0.26
1046	G614	24	1949	9 1.02 N	177 59.93 E	0.17
	FG83-1	24	1801	9 1.41 N	178 0.23 E	0.17
	FG83-2	24	1807	9 1.45 N	178 0.43 E	0.15
1047	G615	25	603	7 59.15 N	178 1.67 E	0.12
	FG84-1	25	415	7 59.13 N	178 0.86 E	0.47
	FG84-2	25	418	7 59.13 N	178 0.96 E	0.46
1048	G616	25	2016	7 59.22 N	179 0.19 E	0.12
	FG85-1	25	1800	7 59.67 N	179 0.04 E	0.22
	FG85-2	25	1804	7 59.74 N	179 0.17 E	0.24
1048-1	G616-1	25	2331	7 59.72 N	179 0.26 E	0.15
1049	G617	26	2001	9 4.51 N	179 2.38 E	0.12
	FG86-1	26	1801	9 4.46 N	179 1.44 E	0.15
	FG86-2	26	1804	9 4.54 N	179 1.55 E	0.14
1050	G618	27	534	9 59.65 N	179 0.65 E	0.17
	FG87-1	27	346	9 59.22 N	179 0.14 E	0.50
	FG87-2	27	349	9 59.24 N	179 0.27 E	0.51
1051	G619	27	1957	10 59.21 N	179 1.10 E	0.22
	FG88-1	27	1806	10 59.54 N	179 1.10 E	0.26
	FG88-2	27	1809	10 59.56 N	179 1.18 E	0.27
1052	G620	28	612	12 0.27 N	179 1.46 E	0.22
	FG89-1	28	420	12 0.06 N	179 1.69 E	0.25

Table II-1 (Continued)

St. no.	Observ. no.	Date	GMT	Latitude	Longitude	Error
	FG89-2	28	423	12 0.11 N	179 1.79 E	0.24
1053	G621	28	1938	12 57.44 N	179 1.19 E	0.12
	FG90-1	28	1757	12 58.80 N	179 0.64 E	0.42
	FG90-2	28	1801	12 58.76 N	179 0.81 E	0.43
1054	G622	29	500	12 59.51 N	179 59.92 E	0.29
	FG91-1	29	330	12 59.51 N	179 59.46 E	0.55
	FG91-2	29	334	12 59.51 N	179 59.62 E	0.57
1060	G623	29	2001	12 59.08 N	178 59.46 W	0.31
	FG92-1	29	1800	12 59.39 N	179 0.11 W	0.26
	FG92-2	29	1809	12 59.47 N	179 0.14 W	0.29
1061	G624	30	608	11 59.82 N	179 2.60 W	0.22
	FG93-1	30	403	11 59.91 N	179 3.04 W	0.29
	FG93-2	30	406	11 59.89 N	179 2.88 W	0.28
1055	G625	30	2007	12 1.11 N	179 58.69 E	0.29
	FG94-1	30	1758	12 0.04 N	179 59.26 E	0.75
	FG94-2	30	1802	12 0.04 N	179 59.28 E	0.74
1056	G626	31	610	10 58.83 N	179 58.62 W	0.19
	FG95-1	31	410	10 58.47 N	179 58.99 W	0.44
	FG95-2	31	413	10 58.50 N	179 58.87 W	0.43
1057	G627	31	1951	9 59.62 N	179 59.86 W	0.28
	FG96-1	31	1754	9 59.85 N	179 59.95 E	0.24
	FG96-2	31	1757	9 59.85 N	179 59.96 W	0.25
1057-1	G627-1	31	2330	9 59.23 N	179 59.60 E	0.16
1057-2	G627-2	32	237	9 59.36 N	179 59.96 W	0.32
1058	G628	32	2033	9 1.08 N	179 59.80 W	0.22
	FG97-1	32	1803	9 1.47 N	179 59.86 W	0.10
	FG97-2	32	1808	9 1.60 N	179 59.77 W	0.12
1059	G629	33	619	7 59.60 N	179 59.41 W	0.23
	FG98-1	33	434	7 59.31 N	179 59.94 W	0.34
	FG98-2	33	437	7 59.31 N	179 59.83 W	0.33
1062	3.5K-1	36	2324	11 57.15 S	178 40.55 W	0.18
		37	032	11 57.41 S	178 40.76 W	0.41
1063	G630	46	2009	7 52.52 S	175 16.36 E	0.12
	FG99-1	46	1753	7 52.78 S	175 14.99 E	0.14
	FG99-2	46	1758	7 52.94 S	175 14.97 E	0.16
1064	G631	49	2013	7 33.08 N	179 29.90 E	0.15
	FG100-1	49	1828	7 33.16 N	179 29.96 E	0.11
	FG100-2	49	1831	7 33.20 N	179 30.12 E	0.12
1065	G632	50	548	8 32.06 N	179 28.51 E	0.15
	FG101-1	50	348	8 31.46 N	179 28.67 E	0.20
	FG101-2	50	350	8 31.55 N	179 28.71 E	0.19
1066	G633	50	2002	8 30.44 N	178 31.06 E	0.18
	FG102-1	50	1750	8 30.66 N	178 31.02 E	0.18
	FG102-2	50	1753	8 30.71 N	178 31.16 E	0.19
1067	G634	51	724	7 29.11 N	178 31.31 E	0.16
	FG103-1	51	433	7 29.21 N	178 30.59 E	0.22
	FG103-2	51	436	7 29.28 N	178 30.72 E	0.21
1068	C13	51	2008	7 29.49 N	177 30.77 E	0.16
		51	2145	7 29.54 N	177 30.41 E	0.13
	FG104-1	51	1751	7 29.63 N	177 30.39 E	0.31
	FG104-2	51	1755	7 29.64 N	177 30.57 E	0.30
1069	G635	52	740	8 30.65 N	177 29.48 E	0.42
1052	FG105-1	52	535	8 30.38 N	177 29.51 E	0.18

Table II-1 (Continued)

St. no.	Observ. no.	Date	GMT	Latitude	Longitude	Error
	FG105-2	52	537	8 30.46 N	177 29.65 E	0.18
1036-A	D261	52	2045	8 0.94 N	176 57.10 E	0.11
		52	2220	8 1.00 N	176 55.71 E	0.29
1070	G636	53	640	7 33.83 N	176 32.97 E	0.20
	FG106-1	53	500	7 33.40 N	176 33.28 E	0.11
	FG106-2	53	503	7 33.55 N	176 33.41 E	0.10
1071	G637	53	2027	8 30.50 N	176 30.39 E	0.18
	FG107-1	53	1752	8 29.44 N	176 30.14 E	0.19
	FG107-2	53	1756	8 29.54 N	176 30.34 E	0.18
1072	D262	54	435	8 30.10 N	176 59.40 E	0.19
		54	606	8 29.84 N	176 57.77 E	0.14
	FG108-1	54	140	8 29.75 N	177 0.82 E	0.49
	FG108-2	54	143	8 29.82 N	177 0.95 E	0.50
1073	FG109-1	54	1759	9 30.02 N	176 59.95 E	0.15
	FG109-2	54	1814	9 28.01 N	176 59.96 E	0.11
	FG109-3	54	1829	9 26.08 N	176 59.85 E	0.15
	FG109-4	54	1844	9 24.15 N	176 59.75 E	0.10
	FG109-5	54	1903	9 25.18 N	177 1.76 E	0.14
	FG109-6	54	1918	9 27.24 N	177 1.73 E	0.12
	FG109-7	54	1932	9 29.32 N	177 1.72 E	0.16
	FG109-8	54	1946	9 31.42 N	177 1.71 E	0.14
1074	G638	55	430	9 31.00 N	176 30.14 E	0.20
	FG110-1	55	232	9 30.67 N	176 30.45 E	0.25
	FG110-2	55	234	9 30.68 N	176 30.29 E	0.24
1075	G639	55	1915	9 0.17 N	177 30.09 E	0.13
	FG111-1	55	1748	9 0.04 N	177 29.89 E	0.19
	FG111-2	55	1751	9 0.11 N	177 30.04 E	0.18
1076	C14	56	300	9 28.64 N	177 30.03 E	0.33
		56	425	9 29.17 N	177 29.80 E	0.18
	FG112-1	56	119	9 28.60 N	177 30.09 E	0.52
	FG112-2	56	121	9 28.59 N	177 30.18 E	0.53
1038-A	G640	56	1943	10 0.22 N	176 59.26 E	0.18
	FG113-1	56	1744	9 59.79 N	176 59.48 E	0.20
	FG113-2	56	1747	9 59.88 N	176 59.55 E	0.21
1039-A	G641	57	426	11 0.38 N	176 59.63 E	0.21
	FG114-1	57	248	11 0.48 N	176 59.52 E	0.19
	FG114-2	57	250	11 0.52 N	176 59.62 E	0.18

$$+(\sigma+3\sin\sigma)(\sin\lambda-\sin\lambda_1)^2/(1-\cos\sigma)], \quad (3)$$

where f is the flattening coefficient. The relation between the reduced latitude λ and the geographic latitude λ′ is as follows:

$$\tan\lambda=(1-f)\tan\lambda.' \quad (4)$$

The standard omega reading ϕ_{AB}, which is obtained by adding 900 to the phase difference between the signals from A station and those from B station, is calculated using the above-mentioned distance formula:

$$\phi_{AB}=F/V(d_A-d_B)+900, \quad (5)$$

where F and V are Omega radio frequency and propagation velocity, and d_A and d_B are distance to the receiver from A station and from B station, respectively.

Table II-2 Satellite fix data of January 29, 1978

GMT	LATITUDE		LONGITUDE		ELEV	GEOM	SAT
124	12	59.83 N	179	40.21 E	19.9	S-W	30200
552	12	59.15 N	179	59.49 E	62.6	N-E	30120
712	13	0.24 N	179	55.06 W	10.3	S-E	30190
740	13	0.17 N	179	51.40 W	11.0	N-W	30120
858	13	0.26 N	179	41.00 W	73.8	S-W	30190
1004	13	0.03 N	179	32.31 W	66.8	S-E	30130
1050	13	0.17 N	179	25.95 W	7.9	S-W	30140
1114	12	59.86 N	179	22.75 W	22.1	N-E	30200
1154	12	59.91 N	179	17.31 W	9.7	S-W	30130
1258	12	59.63 N	179	8.86 W	26.3	N-W	30200
1716	13	1.78 N	179	1.41 W	31.1	S-E	30120
1902	12	58.94 N	178	59.74 W	23.8	S-W	30120
2044	12	58.38 N	179	0.78 W	88.5	N-E	30190
2148	12	58.99 N	178	59.48 W	50.3	N-E	30130
2232	12	57.29 N	178	59.78 W	13.3	N-W	30140
2336	12	45.96 N	179	0.36 W	15.0	N-W	30130

We use following values for constants:

$$
\begin{aligned}
a &= 6378.166 \text{ km}, \\
f &= 1/298.3, \\
F &= 10.2 \text{ kHz}, \\
V &= 300574 \text{km}/s.
\end{aligned} \qquad (6)
$$

As the Australian station G was not yet in operation, C-H and E-H station pairs were chosen for Omega positioning in this cruise (Fig. II-1). The R/V Hakurei-maru stayed at Majuro from January 15 till January 17. The reliable average position with 23 good satellite passes during her stay at Majuro coupled with positional data of C, E, H stations gives the standard Omega readings at Majuro (Table II-3).

Omega reading observation at Majuro

Two day long Omega reading data were obtained during our stay at Majuro.

Table II-3 Omega stations and Receiver

Station/Receiver	Latitude	Longitude	Distance in Wavelength from Majuro
C (Hawaii)	21°24.282′N	157°49.878′W	124.469
E (Reunion)	20°58.441′S	55°17.404′E	441.273
H (Japan)	34°36.888′N	129°27.208′E	178.392
M (Majuro)	7° 6.34′ N	171°22.31′ E	——
Standard Omega Reading at Majuro			
C-H	846.077		
E-H	1162.881		

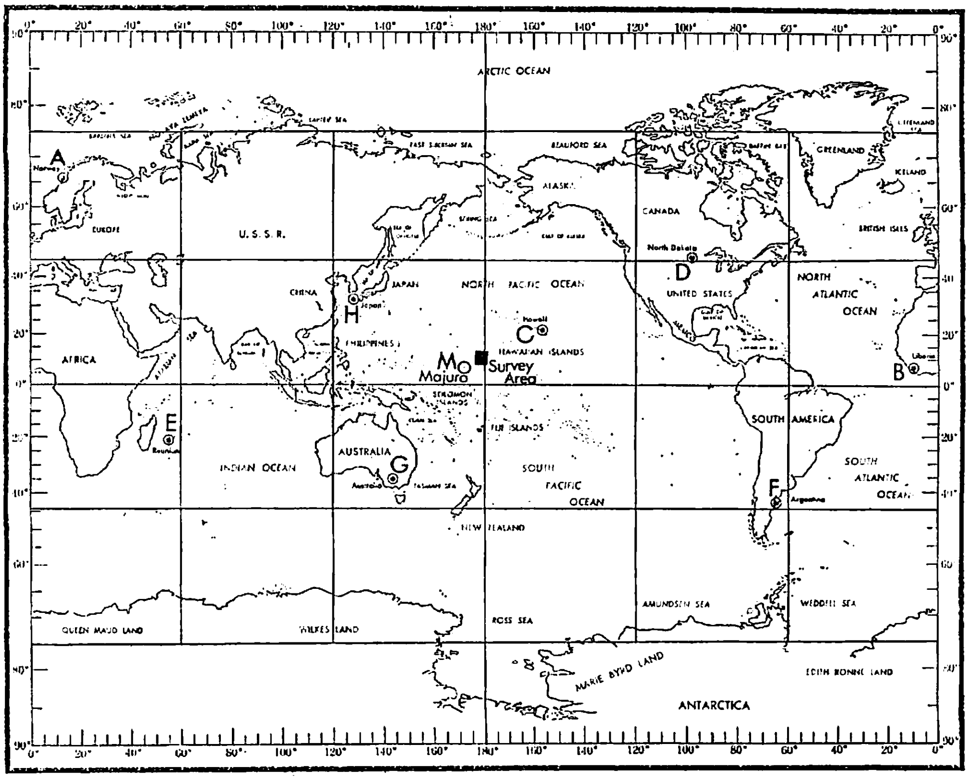


Fig. II-1 Omega stations, Majuro and the survey area.

In Fig. II-2 observational PPC values, which are calculated by subtraction of observational readings from the standard readings, are compared with theoretical PPC values for 8°N, 172°E (Defence Mapping Agency Hydrographic Center, 1976). General features of observational and theoretical PPC value curves agree well. Both of observational and theoretical E-H PPC values have their maximum at about 800 GMT and their minimum at about 1800 GMT, while C-H PPC values have their maximum at about 1900 GMT and their minimum at about 600 GMT. However, the difference of observational and theoretical PPC values reaches 0.1 to 0.2 for the greater part of a day. It is better to use the observational PPC values for more precise positioning.

Although we have only two days of observational data, it can be safely said that the observational PPC values in the local day time are stable and depend only on the local time and change very little day to day, while those in the local night time are unstable, especially PPC values of C-H station pair. Differences between PPC values of the same time on January 15 and on January 16 are 0.00–0.02 in the local day time (from 1900 to 600 GMT). So we will analyse Omega data only from 1900 to 600 GMT in the following paragraphs.

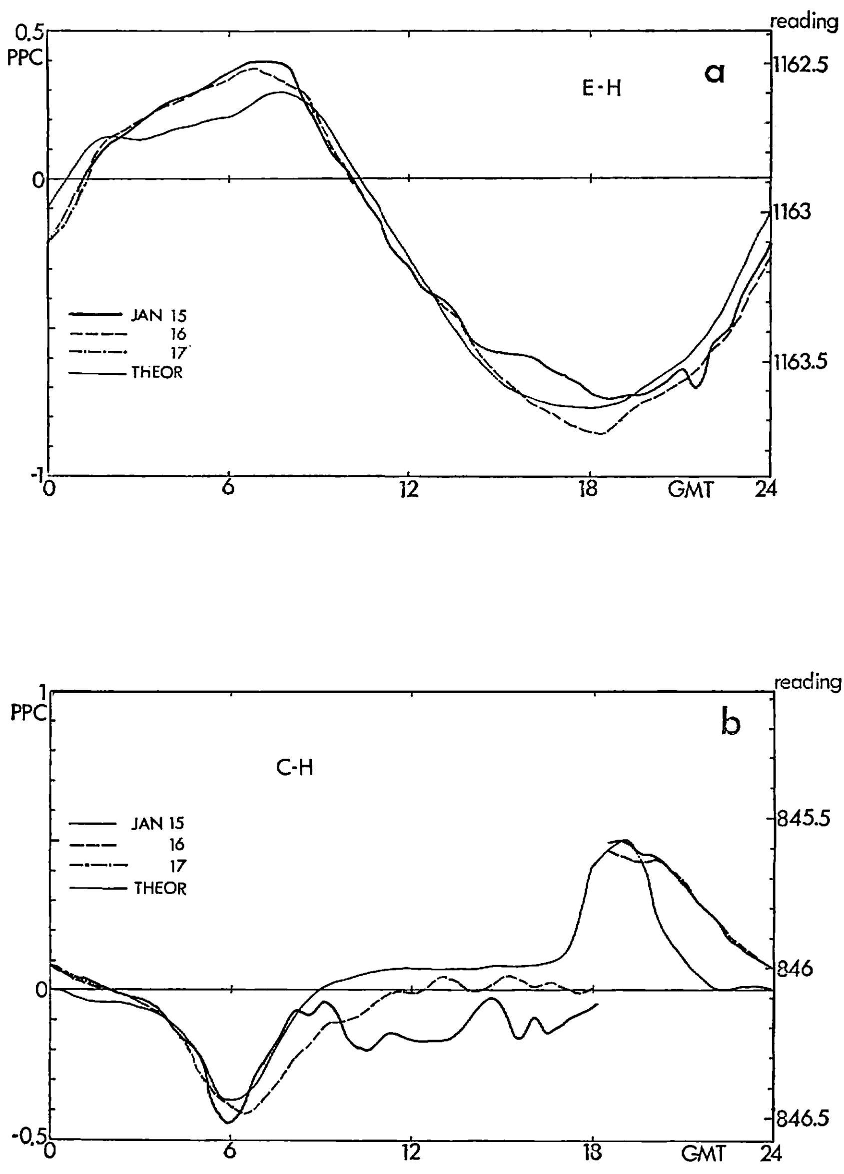


Fig.II-2 Omega observational readings (in heavy lines) and theoretical PPC values for 8°N, 172°E.

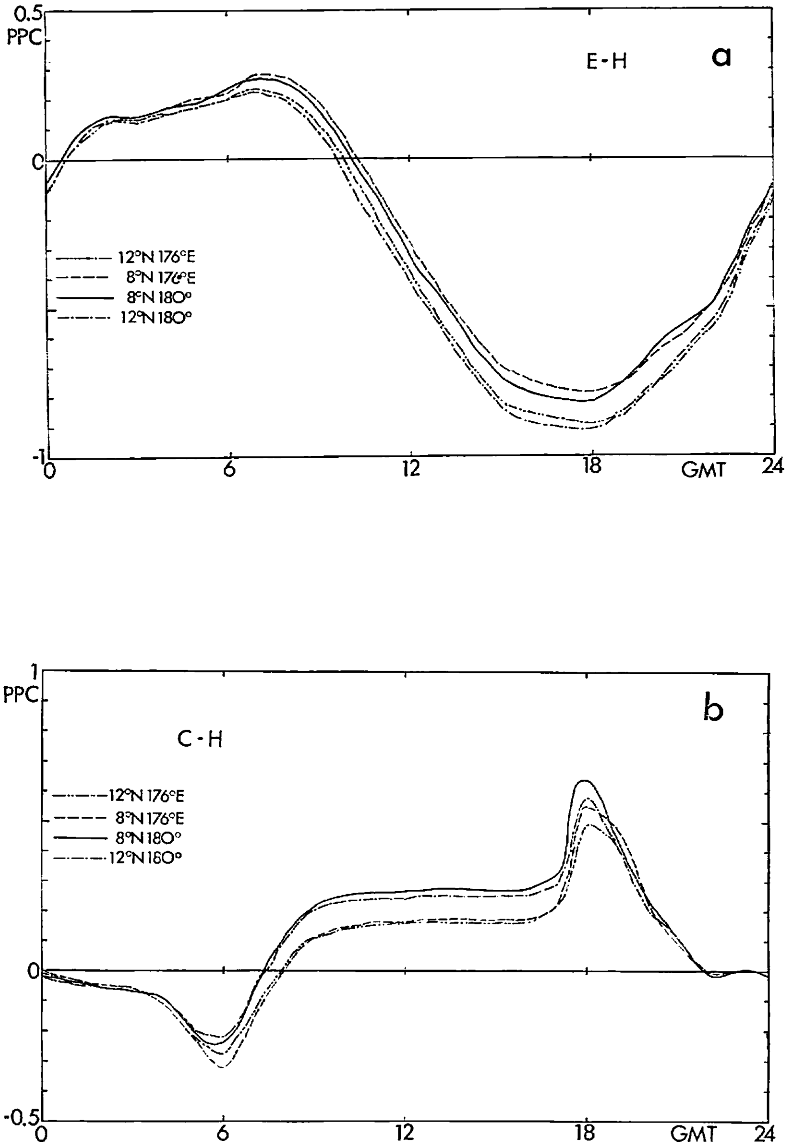


Fig. II-3 Regional change of theoretical PPC values.

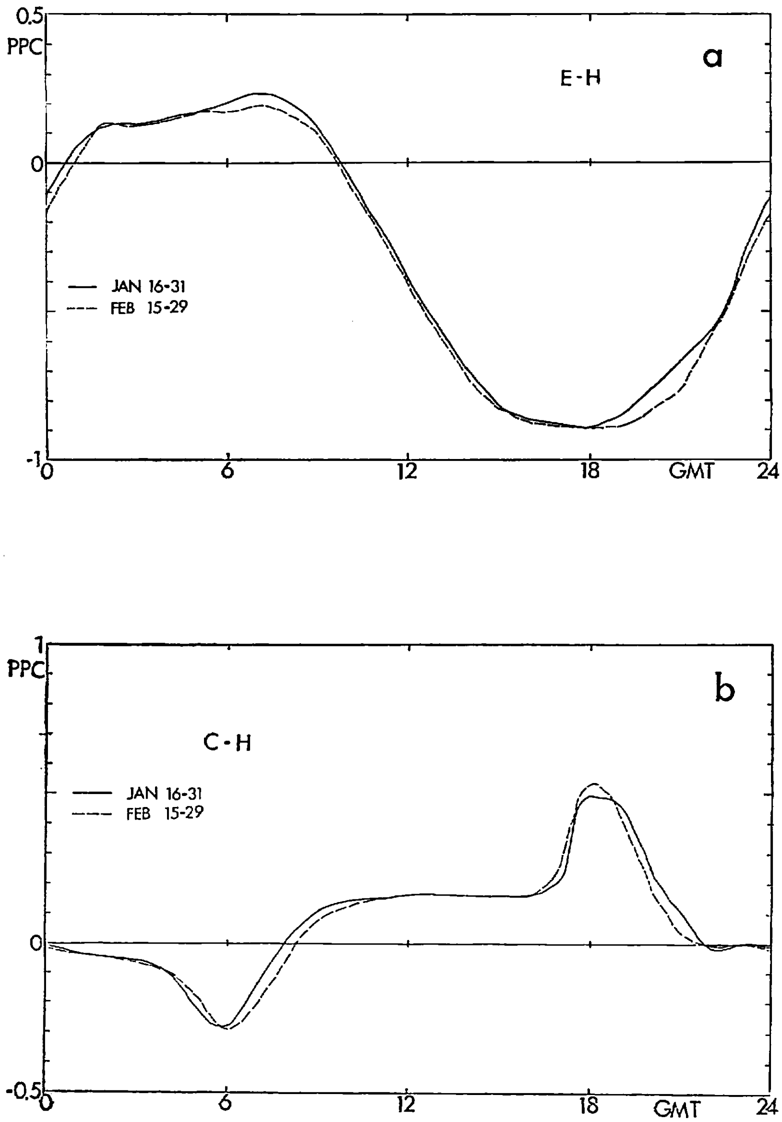


Fig. II-4 Seasonal change of PPC values for 12°N, 176°E.

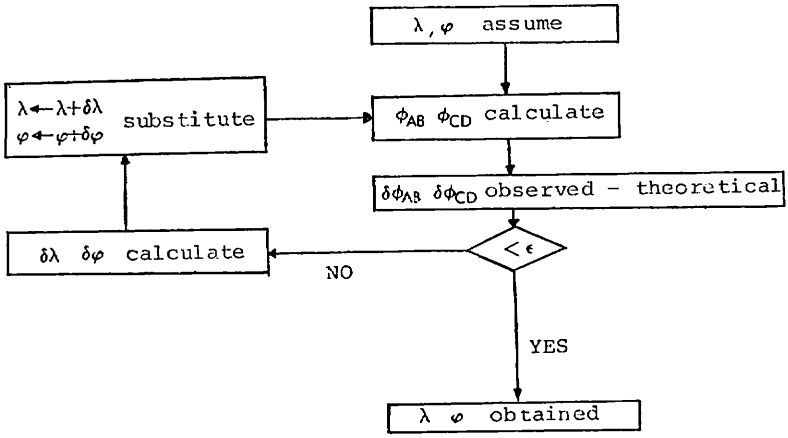


Fig. II-5 Position calculation flow for observed Omega readings.

PPC values in the survey area

Accuracy of an Omega fix is largely depend on how precisely PPC values are determined. In this study observational PPC values at Majuro, which is located not so far from the survey area, are used and the regional change of PPC values is also taken into account. Regional change of theoretical PPC values of C-H station pair is not significant in the time span of 1900–600 GMT, but PPC values of E-H pair for 8°N, 176°E and for 8°N, 180° are a little defferent from those for 12°N, 176°E and for 12°N, 180°, especially before 2200 GMT (Fig. II-3).

There is also a little seasonal change of PPC values, an example of which is shown in Fig. II-4, but we neglect this effect in the following calculation.

We divide the survey area into 4 parts (Table II-4), and the regional PPC values in the survey area is calculated by the following equation:

Regional PPC = Observational PPC at Majuro
− Theoretical PPC for 8°N, 172°E
+ Theoretical PPC at standard point. (7)

Calculation of position for observed Omega readings

The position for observed Omega readings is calculated iteratedly. The calculation flow is shown in Fig. II-5.

At first the latitude λ and the longitude φ is supposed (we suppose them to be the recalculated NNSS position) and the standard Omega readings for the assumed position are calculated by the equation (5). The subtraction of these

Table II-4 Regions for PPC calculation

Region	Latitude	Longitude	standard point
A	≥ 10°N	≤ 178°E	12°N 176°E
B	< 10°N	≤ 178°E	8°N 176°E
C	< 10°N	> 178°E	8°N 180°
D	≥ 10°N	> 178°E	12°N 180°

values from the corresponding observed Omega readings corrected by the regional PPC values (7) yields the observational and theoretical difference ($\delta\phi_{AB}$, $\delta\phi_{CD}$ when A-B and C-D station pairs are used) and when both of the absolute values of $\delta\phi_{AB}$ and $\delta\phi_{CD}$ are smaller than some threshold ε (we set it 0.001), then we let λ and φ to be the Omega fix. When not, then we compute the amount of latitudinal and longitudinal correction, $\delta\lambda$, $\delta\varphi$ by solving the following equations, which are derived from the differentiation of (5):

$$\delta\phi_{AB} = \Lambda_{AB}\delta\lambda + \Phi_{AB}\delta\varphi,$$
$$\delta\phi_{CD} = \Lambda_{CD}\delta\lambda + \Phi_{CD}\delta\varphi. \qquad (8)$$

Neglecting small term δ of (1), we obtain,

$$\Lambda_{AB} = aF/V\{\sin\lambda\,[\cos\lambda_A\cos(\varphi-\varphi_A)/\sin\sigma_A - \cos\lambda_B\cos(\varphi-\varphi_B)/\sin\sigma_B]$$
$$-\cos\lambda(\sin\lambda_A/\sin\sigma_A - \sin\lambda_B/\sin\sigma_B)\}, \qquad (9)$$
$$\Phi_{AB} = aF/V[\cos\lambda_A\sin(\varphi-\varphi_A)/\sin\sigma_A - \cos\lambda_B\sin(\varphi-\varphi_B)/\sin\sigma_B].$$

Λ_{CD}, Φ_{CD} are in the same form as (9) except the subscripts.

Solving (8), we obtain:

$$\delta\lambda = (\Phi_{CD}\delta\phi_{AB} - \Phi_{AB}\delta\phi_{CD})D^{-1},$$
$$\delta\varphi = (\Lambda_{AB}\delta\phi_{CD} - \Lambda_{CD}\delta\phi_{AB})D^{-1}, \qquad (10)$$
$$D = \Lambda_{AB}\Phi_{CD} - \Lambda_{CD}\Phi_{AB}.$$

We substitute $\lambda + \delta\lambda$ for λ and $\varphi + \delta\varphi$ for φ and go to the first step with the new estimated position.

Accuracy of Omega fix in the survey area

For the estimate of Omega fix Omega and satellite fixes are compared in Table II-5. As concerned satellite fixes their error is estimated to reach to about 0.1 nautical mile, so when Omega and satellite fixes differ more than 0.1 nautical mile, it means to be due to the Omega fix errors.

To clarify the effectiveness of our method, errors of Omega fixes using the regional PPC values for region A calculated by the equation (7) and the conventional theoretical PPC values for 12°N, 176°E are compared in Fig. II-6. Difference of standard deviation is significant (Fig. II-6a, 0.25; 6b, 0.28).

Table II-5 and Figs. II-6–9 show that we can get considerably precise longitudinal information with standard deviation of 0.25–0.62 in normal state from 1900 to 600 GMT if we shift 0.32–0.39 nautical mile east from the original Omega fix data obtained through our method, while for latitudinal information it has standard deviation of 0.86–1.41 nautical mile. Omega fixes sometimes differ from satellite fixes by 4 nautical miles or more and we exclude them from the computation of mean and standard deviation of differences between both of fixes. It is suspected that those large errors of Omega fixes are due to disturbed state of ionosphere where Omega VLF radio propagates.

Table II-5 Comparison between Omega and Satellite Fix Data

No.[1]	Date	GMT	Corrected C-H	Reading[2] E-H	ITR[3]	Omega fix Latitude		Omega fix Longitude		Satellite fix Latitude		Satellite fix Longitude		Difference[4] Latitude	Difference[4] Longitude
Region	A														
4	20	2016	813.20	1176.81	2	10	0.07N	176	57.74E	9	59.80N	176	58.10E	0.27	-0.35
5	20	2052	813.22	1176.84	2	10	0.51N	176	57.57E	9	59.73N	176	58.04E	0.78	-0.46
6	20	2120	813.25	1176.80	2	9	59.96N	176	57.23E	10	0.40N	176	57.70E	-0.44	-0.46
7	20	2202	813.01	1176.81	2	9	59.65N	176	59.55E	9	59.55N	177	0.07E	0.10	-0.52
8	20	2308	813.05	1177.41	2	10	10.18N	177	0.03E	10	10.63N	177	0.54E	-0.46	-0.50
9	20	2346	813.13	1177.87	2	10	18.20N	176	59.92E	10	18.00N	177	0.19E	0.20	-0.26
10	21	132	813.37	1179.05	2	10	39.13N	176	59.34E	10	38.51N	176	59.59E	0.63	-0.25
11	21	1918	814.40	1183.49	2	11	58.96N	176	56.99E	11	57.26N	176	57.64E	1.70	-0.63
12	21	2004	814.44	1183.54	3	12	0.05N	176	56.71E	11	57.38N	176	57.40E	2.67	-0.68
13	21	2032	814.45	1183.55	3	12	0.20N	176	56.60E	11	57.81N	176	57.45E	2.39	-0.83
14*	21	2150	814.49	1183.64	3	12	1.92N	176	56.41E	11	57.79N	176	56.53E	4.13	-0.12
15*	21	2216	814.46	1183.74	3	12	3.67N	176	56.90E	11	58.33N	176	57.55E	5.34	-0.64
16*	22	024	814.48	1185.01	3	12	26.50N	176	59.09E	12	20.36N	176	59.16E	6.14	-0.08
17*	22	210	814.59	1185.96	3	12	44.04N	176	59.85E	12	39.77N	177	0.00E	4.27	-0.15
18*	22	516	814.96	1187.07	3	13	4.89N	176	58.70E	13	0.19N	177	0.21E	4.70	-1.48
19	22	2012	808.57	1187.33	2	13	0.21N	177	57.97E	12	59.91N	177	58.40E	0.30	-0.42
20	22	2100	808.62	1187.35	2	13	0.74N	177	57.53E	12	59.78N	177	58.11E	0.97	-0.56
21	22	2124	808.61	1187.31	2	12	59.96N	177	57.55E	12	59.99N	177	57.76E	-0.03	-0.21
22	22	2210	808.34	1187.28	2	12	59.04N	177	59.98E	12	57.83N	178	0.65E	1.21	-0.65
23	22	2312	808.28	1186.64	2	12	47.08N	177	59.33E	12	45.54N	178	0.05E	1.54	-0.71
24	22	2358	808.18	1186.13	2	12	37.62N	177	59.34E	12	36.28N	177	59.75E	1.34	-0.40
25	23	102	808.08	1185.57	2	12	27.27N	177	59.26E	12	25.83N	177	59.72E	1.43	-0.45
26	23	1918	807.05	1180.81	2	11	0.32N	178	1.34E	11	0.24N	178	1.21E	0.08	0.12
27	23	2014	807.11	1180.88	2	11	1.69N	178	0.88E	11	0.16N	178	0.91E	1.53	-0.03
28	23	2036	807.15	1180.89	3	11	1.90N	178	0.51E	10	59.98N	178	0.98E	1.92	-0.46
29	23	2124	807.18	1180.81	2	11	0.57N	178	0.10E	11	0.36N	178	0.55E	0.21	-0.44
30	23	2200	807.16	1180.80	2	11	0.40N	178	0.28E	11	0.49N	178	0.64E	-0.09	-0.35
31	23	2218	807.17	1180.80	2	11	0.34N	178	0.24E	11	0.39N	178	0.60E	-0.05	-0.36
32	23	2306	807.12	1180.78	2	10	59.89N	178	0.67E	11	0.36N	178	0.51E	-0.47	0.15
33	23	2356	807.15	1180.80	2	11	0.36N	178	0.37E	11	0.04N	178	0.36E	0.33	0.01

Table II-5 (Continued)

No.[1]	Date	GMT	Corrected Reading[2] C-H	E-H	ITR[3]		Omega fix Latitude	Longitude			Satellite fix Latitude	Longitude		Difference[4] Latitude	Longitude
34	24	142	807.12	1180.05	3	10	47.12N	177	59.61E	10	45.14N	177	59.93E	1.98	-0.31
35	24	510	806.73	1177.86	2	10	8.24N	178	0.48E	10	6.80N	178	0.55E	1.45	-0.07
											Mean			0.80	-0.37
											Standard Deviation			0.91	0.25
	Region	B													
1	19	1924	812.43	1169.80	2	8	0.53N	176	56.79E	8	0.18N	176	56.73E	0.36	0.06
2	19	2254	812.24	1170.25	2	8	7.71N	176	59.07E	8	8.92N	176	58.95E	-1.22	0.12
3	20	038	812.30	1171.52	2	8	28.99N	176	59.88E	8	28.45N	177	0.38E	0.54	-0.50
36	24	2130	806.46	1173.97	2	9	1.04N	177	58.70E	9	1.26N	177	58.70E	-0.22	-0.00
37	24	2218	806.34	1173.81	2	8	58.21N	177	59.67E	8	57.17N	178	0.28E	1.04	-0.60
38*	25	006	806.34	1172.90	3	8	42.88N	177	58.76E	8	39.16N	177	59.12E	3.72	-0.36
39	25	558	805.75	1170.41	2	8	0.12N	178	2.22E	7	59.15N	178	1.64E	0.98	0.58
78	51	1932	808.83	1168.24	2	7	29.03N	177	30.35E	7	29.47N	177	30.68E	-0.44	-0.32
79	51	1952	808.83	1168.21	2	7	28.53N	177	30.36E	7	29.45N	177	30.73E	-0.92	-0.37
80	51	2038	808.89	1168.22	2	7	28.79N	177	29.80E	7	29.54N	177	30.84E	-0.75	-1.03
81	51	2138	808.91	1168.20	2	7	28.56N	177	29.54E	7	29.56N	177	30.47E	-1.00	-0.92
82	51	2236	808.90	1168.30	2	7	30.12N	177	29.70E	7	29.15N	177	30.20E	0.97	-0.49
											Mean			-0.06	-0.32
											Standard Deviation			0.81	0.47
	Region	C													
40	25	1912	799.80	1170.90	2	7	59.08N	179	0.78E	7	59.33N	179	0.42E	-0.24	0.36
41	25	2020	799.89	1170.99	2	8	0.77N	178	59.95E	7	59.21N	179	0.17E	1.57	-0.22
42	25	2040	799.93	1170.99	2	8	0.80N	178	59.59E	7	59.26N	179	0.15E	1.55	-0.56
43	25	2130	799.91	1170.93	2	7	59.70N	178	59.73E	8	0.13N	179	0.06E	-0.42	-0.33
44	25	2208	799.76	1170.91	2	7	59.28N	179	1.20E	7	59.90N	179	0.06E	-0.62	1.13

Table II-5 (Continued)

No.[1]	Date	GMT	Corrected Reading[2] C-H	Corrected Reading[2] E-H	ITR[3]	Omega fix Latitude		Omega fix Longitude		Satellite fix Latitude		Satellite fix Longitude		Difference[4] Latitude	Difference[4] Longitude
45	25	2226	799.78	1170.91	2	7	59.32N	179	0.96E	7	59.96N	176	0.09E	-0.64	0.86
46	25	2316	799.90	1170.88	2	7	59.00N	178	59.73E	7	59.77N	179	0.25E	-0.77	-0.51
47	26	114	799.80	1171.16	3	8	3.41N	179	0.90E	8	0.81N	179	1.43E	2.60	-0.52
48*	26	504	799.97	1173.62	3	8	45.15N	179	1.08E	8	36.71N	179	1.71E	8.43	-0.63
49	27	006	800.31	1175.94	3	9	25.47N	178	59.73E	9	23.00N	179	0.38E	2.47	-0.64
50	27	154	800.48	1177.10	3	9	45.69N	178	59.20E	9	42.46N	178	59.42E	3.23	-0.22
65	49	1928	796.81	1169.67	2	7	34.02N	179	29.44E	7	33.07N	179	29.99E	0.95	-0.54
66	49	2028	796.87	1169.77	3	7	35.79N	179	28.95E	7	33.09N	179	29.87E	2.70	-0.91
67	49	2116	796.88	1169.76	3	7	35.54N	179	28.85E	7	32.98N	179	29.97E	2.56	-1.11
68	49	2304	796.92	1170.08	2	7	40.94N	179	28.61E	7	40.95N	179	29.43E	-0.01	-0.81
69	50	416	797.10	1173.28	3	8	35.17N	179	28.71E	8	31.94N	179	28.60E	3.23	0.11
70	50	1938	802.99	1172.57	2	8	32.04N	178	30.90E	8	30.48N	178	31.42E	1.56	-0.51
71	50	2024	803.06	1172.56	2	8	31.96N	178	30.23E	8	30.38N	178	31.37E	1.58	-1.13
72	50	2046	803.06	1172.55	2	8	31.82N	178	30.22E	8	30.25N	178	31.38E	1.58	-1.15
73	50	2156	803.01	1172.52	2	8	31.26N	178	30.66E	8	29.93N	178	31.68E	1.34	-1.01
74	50	2230	803.08	1172.53	2	8	31.54N	178	29.97E	8	30.06N	178	30.74E	1.48	-0.76
75	50	2342	803.09	1171.95	3	8	21.72N	178	29.40E	8	19.00N	178	30.06E	2.72	-0.65
76	51	322	802.92	1169.71	3	7	44.00N	178	29.33E	7	40.35N	178	29.75E	3.65	-0.41
77	51	506	802.67	1169.04	3	7	32.53N	178	31.36E	7	29.30N	178	30.82E	3.23	0.53
											Mean			1.53	-0.39
											Standard Deviation			1.40	0.62
Region D															
51*	27	554	800.64	1178.12	3	10	3.69N	178	58.76E	9	59.75N	179	0.73E	3.94	-1.95
52	27	1908	800.75	1181.20	2	10	57.91N	179	1.25E	10	59.34N	179	1.36E	-1.44	-0.11
53	27	2030	800.86	1181.28	2	10	59.44N	179	0.31E	10	59.00N	179	0.83E	0.44	-0.51
54	27	2138	800.84	1181.33	2	11	0.35N	179	0.54E	11	0.01N	179	1.44E	0.34	-0.89
55	27	2220	800.97	1181.38	2	11	1.41N	178	59.35E	11	0.29N	178	59.86E	1.12	-0.50
56	27	2302	801.03	1181.87	3	11	10.31N	178	59.44E	11	7.81N	178	59.86E	2.50	-0.41
57	27	2328	801.08	1182.15	3	11	15.34N	178	59.34E	11	12.43N	178	59.96E	2.90	-0.61

Table II-5 (Continued)

No.[1]	Date	GMT	Corrected C-H	Reading[2] E-H	ITR[3]	Omega fix Latitude		Longitude		Satellite fix Latitude		Longitude		Difference[4] Latitude	Longitude
58*	28	046	801.20	1183.02	3	11	31.15N	178	59.41E	11	26.48N	178	59.66E	4.68	-0.24
59	28	502	801.15	1184.75	2	12	2.31N	179	2.31E	12	0.47N	179	1.80E	1.84	0.51
60	28	1944	801.79	1187.85	2	13	0.21N	179	1.44E	12	58.72N	179	1.21E	1.49	0.23
61	28	2130	801.97	1187.85	2	13	0.32N	178	59.80E	13	0.13N	179	0.38E	0.19	-0.57
62*	28	2338	799.84	1188.29	3	13	5.45N	179	20.25E	13	0.20N	179	22.13E	5.25	-1.84
63*	29	124	797.84	1188.36	3	13	3.93N	179	38.85E	12	59.83N	179	40.21E	4.10	-1.33
64	29	552	795.66	1188.43	3	13	2.23N	179	59.13E	12	59.15N	179	59.89E	3.07	-0.74
													Mean	1.25	-0.36
													Standard Deviation	1.41	0.44

* excluded from calculation of mean and standard deviation.
[1] Time sequential number.
[2] Omega reading corrected with PPC values calculated by (7).
[3] Number of iterations required for Omega fix calculation.
[4] In nautical mile. A latitudinal difference is positive, when an Omega fix is north of the satellite fix. A longitudinal difference is positive when an Omega fix is on the eastern side.

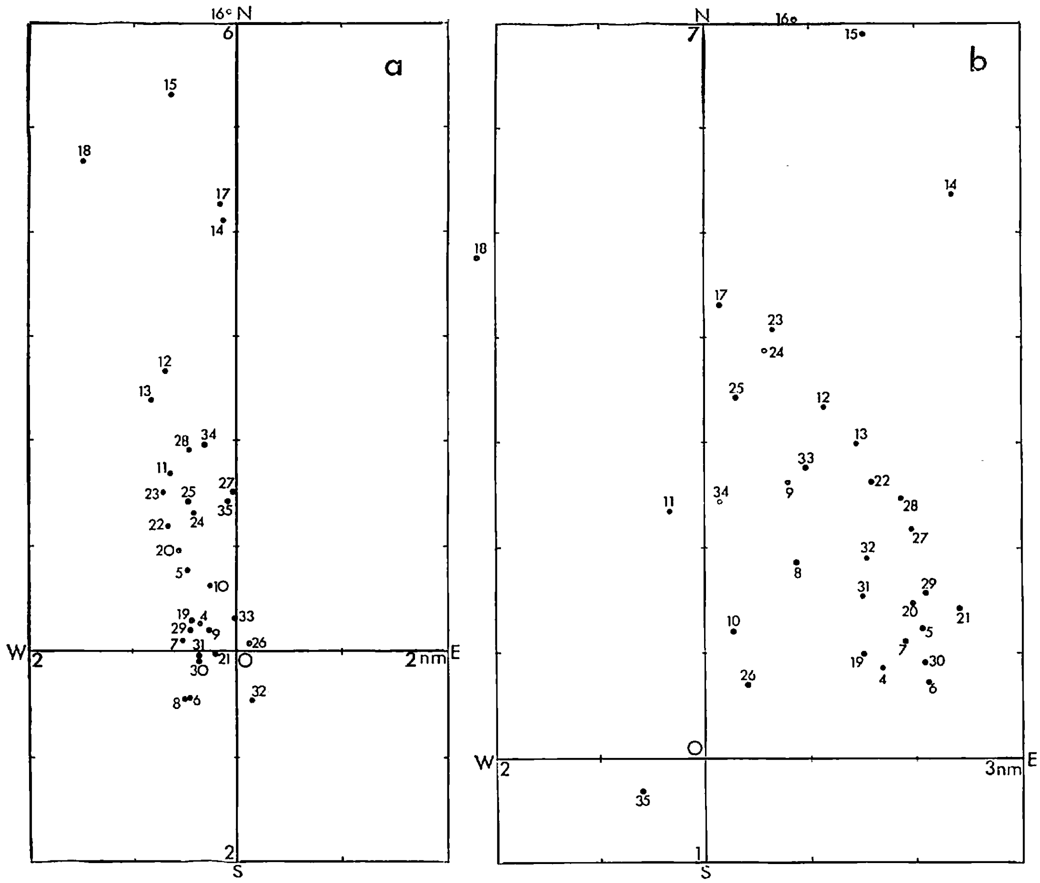


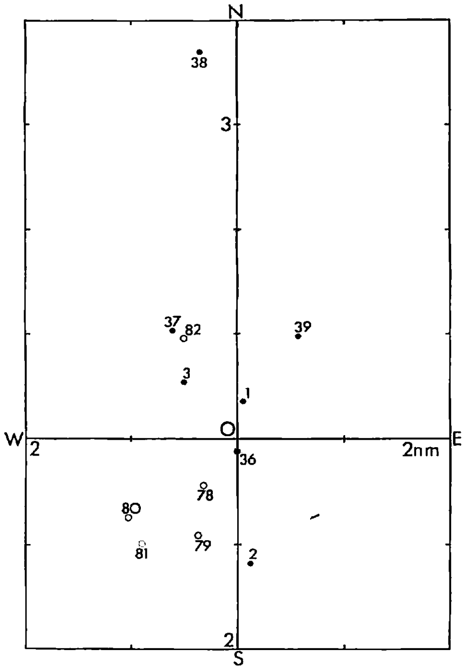
Fig. II-6 Differences of Omega fixes from satellite fixes in region A. Omega fixes using the regional PPC values (7) and those using the theoretical PPC values for 12°N, 176°E are shown in Fig. a and b, respectively. Figures correspond to "NO" in Table II-5.

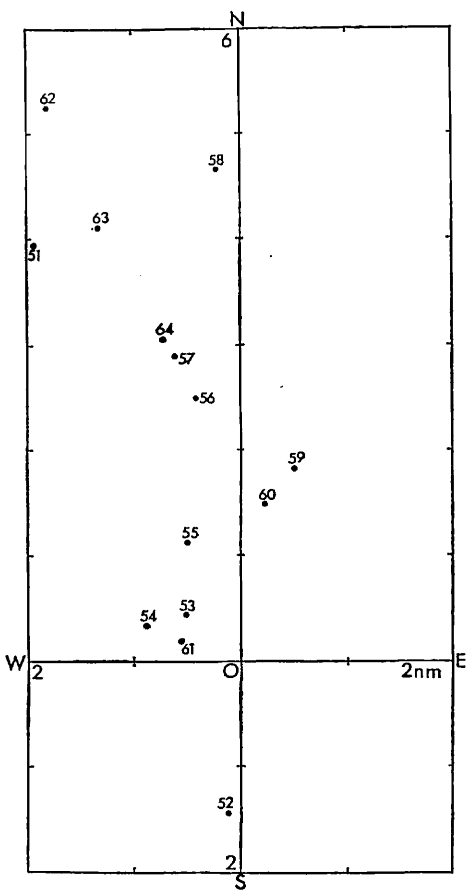
Omega and compound fixes of stational observations

Omega fixes for stational observations are computed when Omega reading data are available in the time span of 1900–600 GMT and when neighboring Omega fix data in Table II-5 are not far off the corresponding satellite fixed (Table II-6). The computation is carried out using the regional PPC values (7) and the latitudinal and longitudinal shifts which are equivalent to the mean values in Table II-5 with reverse sign. In addition to the Omega fixes, compound fixes of stational observations are calculated and listed in Table II-6, which *mean* the optimal positions considering both of Omega and recalculated NNSS fixes. The latitude of a compound fix λ_c is calculated as follows:

$$\lambda_C = (\lambda_N S_O + \lambda_O S_N)/(S_N + S_O) \quad (11)$$

where λ_N, λ_c are the latitude of the recalculated NNSS and Omega fix, respec-





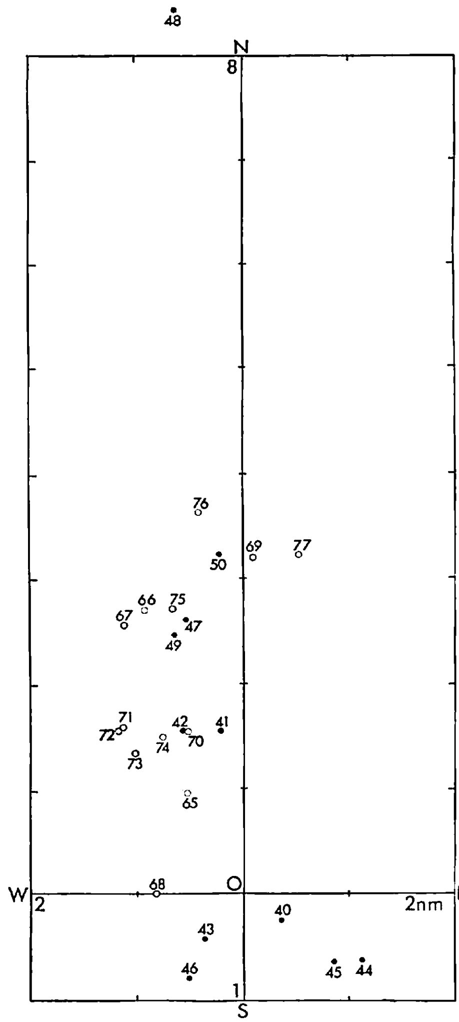


Fig. II-7 Differences of Omega fixes using regional PPC values (7) from satellite fixes in region B. Figures correspond to "NO" in Table II-5 and open circles means observations in February.

Fig. II-8 Differences of Omega fixes using regional PPC values (7) from satellite fixes in region C. Figures correspond to "NO" in Table II-5 and open circles means observations in February.

Fig. II-9 Differences of Omega fixes using regional PPC values (7) from satellite fixes in region D. Figures correspond to "NO" in Table II-5.

Table II-6 Omega and compound fixes of stationary observations

St. No.	Obs. no.	Date	GMT	Omega fix Latitude		Longitude		Compound fix Latitude		Longitude	
1036	G604	19	2011	8	0.47N	176	56.66E	8	0.33N	176	57.10E
1037	G605	20	543	9	4.94N	176	58.34E	9	4.33E	176	58.08E
	F G74-1	20	348	9	4.31N	176	59.24E	9	3.11N	176	58.60E
	F G74-2	20	352	9	4.54N	176	59.07E	9	3.33N	176	58.46E
1038	G606	20	2000	9	58.80N	176	58.16E	9	59.62N	176	58.13E
1039	G607	21	547	11	2.00N	177	0.55E	11	1.71N	177	0.34E
	F G76-1	21	337	11	1.52N	177	0.51E	11	0.31N	177	0.30E
	F G76-2	21	341	11	1.70N	177	0.68E	11	0.50N	177	0.42E
1040	G608	21	1950	11	59.04N	176	57.29E	11	57.54N	176	57.44E
1042	G610	22	2004	12	59.34N	177	58.42E	12	59.88N	177	58.42E
1044	G612	23	1949	11	0.54N	178	1.44E	11	0.24N	178	1.19E
1044-1	G612-1	23	2253	10	59.26N	178	0.64E	11	0.26N	178	0.57E
1045	F G82-1	24	552	9	59.06N	178	1.01E	9	59.51N	178	0.59E
	F G82-2	24	555	9	58.92N	178	1.19E	9	59.48N	178	0.73E
1046	G614	24	1949	9	3.05N	177	59.51E	9	1.27N	177	59.84E
1048	G616	25	2016	7	59.32N	179	0.33E	7	59.23N	179	0.21E
1048-1	G616-1	25	2331	7	57.56N	179	0.10E	7	59.57N	179	0.24E
1049	G617	26	2001	9	2.71N	179	2.53E	9	4.41N	179	2.40E
1050	F G87-1	27	346	9	59.49N	178	59.62E	9	59.27N	178	59.91E
	F G87-2	27	349	9	59.63N	178	59.96E	9	59.32N	179	0.13E
1051	G619	27	1957	10	57.69N	179	1.19E	10	59.06N	179	1.12E
1053	G621	28	1938	12	58.60N	179	2.09E	12	57.51N	179	1.34E
1054	G622	29	500	13	0.39N	179	59.24W	12	59.62N	179	59.81W
	F G91-1	29	330	13	1.02N	179	59.74E	12	59.84N	179	59.59E
	F G91-2	29	334	13	1.00N	179	59.93W	12	59.84N	179	59.84E
1064	G631	49	2013	7	34.23N	179	29.52E	7	33.16N	179	29.84E
1065	G632	50	548	8	33.88N	179	27.89E	8	32.19N	179	28.42E
	F G101-1	50	348	8	33.25N	179	28.74E	8	31.62N	179	28.68E
	F G101-2	50	350	8	33.26N	179	28.87E	8	31.70N	179	28.74E
1066	G633	50	2002	8	30.38N	178	30.97E	8	30.43N	178	31.04E
1067	F G103-1	51	433	7	30.88N	178	30.96E	7	29.38N	178	30.66E
	F G103-2	51	436	7	31.05N	178	31.12E	7	29.45N	178	30.80E
1068	C13	51	2008	7	28.59N	177	30.32E	7	29.39N	177	30.68E
		51	2145	7	28.99N	177	29.81E	7	29.49N	177	30.31E

tively, S_N is the standard deviation of recalculated NNSS fix, which is estimated to be $1/\sqrt{2}$ of the error in Table II-1, and S_0 is the standard deviation of latitude of Omega fix in Table II-4. Compound longitudes are calculated just in the same manner as described above.

Discussion

According to above mentioned result the latitudinal error of an Omega fix is twice or more as great as the longitudinal one. This fact is partly explained by the directions and the intervals of lines of position for C-H pair and for E-H pair. In Fig. II-10 lines of position for C-H pair are approximately parallel to meridian lines, while those for E-H pair are almost perpendicular to them. So, in a first approximation change of C-H reading corresponds to longitudinal change and change of E-H reading corresponds to latitudinal change. According

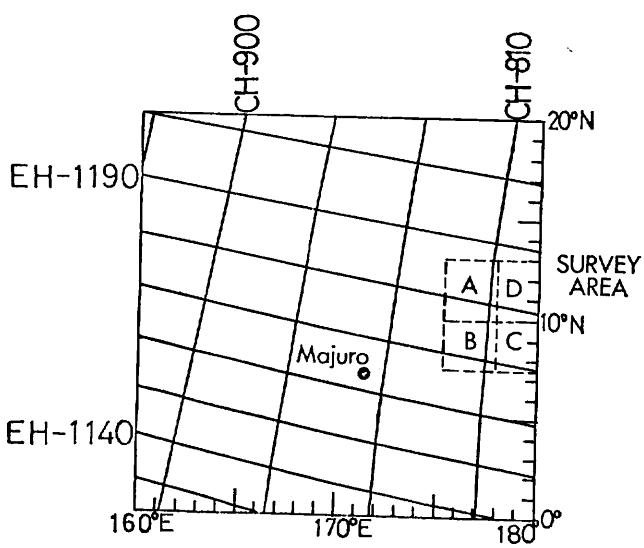


Fig. II-10 Lines of position for C-H pair and for E-H pair around the survey area.

to Omega tables in the survey area one C-H reading change corresponds to longitudinal change of 9.3–10.0 nautical miles, while one E-H reading change corresponds to latitudinal change of 16.5–18.7 nautical miles. In terms of Omega reading it can be said that errors of reading for E-H pair are about one and a half times as great and not twice or more as those for C-H pair: C-H readings have errors of the order of 0.05–0.09.

In addition to the lane interval problem it is quite plausible that due to the large distance between E station and survey area Omega VLF radio from E station tends to suffer from the effect of ionospheric disturbance than radio from C or H station and this tendency increases errors of E-H readings, or in other words, latitudinal errors of Omega fixes. It seems that this supposition is supported by the fact that in abnormal state, which we consider to be due to the effect of ionospheric disturbance, latitudinal errors of Omega fixes are as great as 4 nautical miles or more but longitudinal errors are almost as great as in normal state.

This problem will be probably greatly improved when G station in Australia is in operation. Latitudinal error of Omega fix in that case will be as great as longitudinal error and the radial error of Omega fix will be of the order of 0.5 nautical mile when PPC values are calculated through our method.

References

Defence Mapping Agency Hydrographic Center (1976) Omega propagation correction tables for 10.2 kHz.

Ishihara, T. and Ishibashi, K. (1977) Recalculation of positions by NNSS. *In* Mizuno, A. and Moritani, T. (*eds.*), *Geol. Surv. Japan Cruise Rept.*, no. 8, p. 21–30.