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CHARTED PORT POSITIONS IN THE PACIFIC AS DEFINED BY SATELLITE DETERMINED POSITIONS USING MULTIPLE OBSERVATIONS

by Valerie M. GODLEY
Hawaii Institute of Geophysics, University of Hawaii, Honolulu

FOREWORD

Valerie GODLEY's paper points out in a practical way how doppler satellite multiple observations can be used to determine more precise geographic positions. Of particular importance is the feasibility of relocating numerous oceanic islands and reefs which on current nautical charts can cause navigation problems when using the Navy Navigation Satellite System and in the future when the Global Positioning System (GPS) becomes operational.

The data in Table 3 shows the significant geographic differences between chart-scaled and satellite-derived positions for various ports in the Pacific. The range in position differences is most likely due to the various local, regional, or unknown geodetic datums used to orient the charts. Some 45 different sets of observations yield an average difference of 314 meters (latitude) and 409 meters (longitude). The maximum difference is in Ponape 843 meters (latitude) and 1748 meters (longitude).

It is clearly evident that an enormous effort is required in the near future to provide nautical charts accurately oriented to an earth-centered geodetic datum. Charts are used not only for navigation but also for other purposes such as providing a basis for the establishment of international boundaries and offshore economic zone limits.

Hydrographic offices and navigators generally are invited to collect and submit Doppler receiver data along with chart positioning discrepancies to the Defense Mapping Agency for analysis. Changes to charts resulting from these analyses will be reflected in the DMA Notices to Mariners and disseminated to the International Hydrographic Community.

ABSTRACT

Positions for 34 docks or anchorage sites in and around the Pacific basin were defined by multiple position determination using the Magnavox 702 Satellite Navigator as a fixed-point positioning device. A significant number of positions represent improvements of 15 seconds or more in the charted positions of islands, ports and harbors in the Pacific basin. This study will contribute to the safety of land-approach navigation by providing more modern and accurate positional information than can be obtained from current charts.

INTRODUCTION

The Navy Navigation Satellite System (NNSS), often referred to as the Transit system, has been used as a primary navigation system aboard the oceanographic research vessels of the Hawaii Institute of Geophysics (HIG) since 1970. A Magnavox 702 (MX/702/hp) Satellite Navigator was used aboard the R/V *Mahi* from April to December 1970, and the R/V *Kana Keoki* from December 1970 to July 1976. In a test program, the MX/702/hp system was used to make continuous observations at dock side in Honolulu over a period of 16 days. After analyzing the 79 satellite position determinations taken during this period, DAUGHERTY (1972) determined that, despite occasional erratic values, a remarkably precise mean position (standard deviation ± 1.63 sec of arc, standard deviation of the mean ± 0.185 sec of arc) could be determined by simple arithmetical averaging without editing of the data or *a posteriori* updating of the satellite orbital parameters. On the basis of this initial testing of the satellite navigation system at Honolulu, DAUGHERTY (1972) proposed using the system as a point-positioning device to improve charted positions for various ports about the Pacific visited by the Institute's research vessels. That there is considerable need for such information was brought out in World War II when charted positions of isolated islands in the South Pacific were reported as much as 20 miles in error. Results from an initial evaluation of the data taken at nine port docking sites in the Pacific basin were published as Part I of Report HIG-74-1 (DAUGHERTY, 1974).

The present study is a continuation of the work and an improvement, in that the data are edited as suggested by DAUGHERTY (1974). The coverage is expanded to include 22 additional ports, some of which were occupied at the same locations several times and also at different docking sites. The data were reduced by the arithmetic averaging procedure of DAUGHERTY (1972, 1974) in order to permit comparisons with his unedited results.

There are other methods of handling the data. For example, WOOLLARD and THOMPSON (1974) used a graphical approach for refining positions obtained with a Magnavox 706 satellite receiver system at land-based sites in South America. BERG (1975, 1976) showed that the double pass method of ANDERLE (1971) with antenna height corrections based on STANSELL (1970) can yield highly refined positions (approximately 8 m or better in position coordinates). However, the improvement in positions using these more sophisticated, time-consuming, and expensive methods is not sufficient to affect significantly the basic conclusions regarding errors in charted positions. For example, if a comparison is made of coordinates for Pier 18 in Honolulu Harbor as determined in this study with those determined by BERG (1975, 1976) using the double pass method for the same site and using the same data sets, the greatest discrepancy is 0.07 sec (approximately 2 m), and on average only 0.05 sec. As these differences are within the scaling error on the best charts, which seldom are on a scale of better than 1:10 000, the extra expense of these other methods was not justified for this study.

DATA UTILIZED

Only the information contained in the standard satellite fix output of the HP 2114 computer was used in this study. Two programs were used during the period of data accumulation, the MAPS-70065 program aboard the R/V *Mahi* in 1970, and the MAPS-70356 program aboard the R/V *Kana Keoki* thereafter. The satellite navigation program output was changed by deleting parameters relating to the movement of the receiver. The parameters retained are :

Input Data

1. — ***Date:*** The Julian Day Number, i.e. DATE 59 is 28 February.

2. — ***Time:*** The Greenwich Mean Time of the position fix in hours and minutes.

3. — ***Satellite*** : Six near-polar orbit navigation satellites were used to measure these data samples. A two-digit numbering code for the satellites, related to the semi-major axis in kilometers, was adopted. The correspondence to the Satellite Number is listed below :

Satellite	Semi-major axis	Satellite No.
42	7 442	30 120
54	7 455	30 140
63	7 463	30 180
64	7 464	30 130
65	7 465	30 190
67	7 399	30 200

4. — ***Elevation angle:*** Vertical angle, measured in degrees, of the satellite above the horizon at closest approach to the observing station.

5. — ***Antenna height*** : Geoid height, taken from the geoidal map in the Magnavox manual, added algebraically to the ship's antenna height above sea level.

6. — ***Iterations*** : Number of iterations required for the program to converge on a fix.

7. — ***Doppler counts*** : Number of counts received and used in the computation of the individual fix.

8. — ***Doppler count sequence*** : Number of balanced (symmetric) 24-sec counts about the point of closest approach.

Derived Quantities:

1. — ***Latitude*** : Latitude of observed points measured from the equator to the station in degrees, minutes, and seconds of arc.

2. — ***Longitude*** : Longitude of observation points measured from the Greenwich Meridian to the station in degrees, minutes, and seconds of arc.

Figure 1 shows the geographic distribution of the sites.

SOURCES OF ERROR IN THE MEASUREMENTS AND SELECTION CRITERIA USED

Each satellite fix may be influenced by several factors : the elevation angle, the antenna height assumed, the number of Doppler counts, and the symmetry of the Doppler count sequence. The latter two values indicate the quantity and quality of the Doppler data received—quantity is indicated by the number of Doppler counts, quality by the number of balanced (symmetric) Doppler counts about the point of closest approach.

NEWTON (1967) indicated that the elevation angle affects the positional accuracy of satellite fixes in several ways. A significant cross-track effect may be created by the increasing effects of refraction that can be quite serious for low elevation passes. The high elevation passes, which do not suffer from data loss, are increasingly sensitive to errors in the cross-track direction since the elevation angle usually enters these error factors as a tangent of the angle, thus approaching infinity at an elevation angle of 90°. For this reason NEWTON advocated deleting all passes below 15° and above 75° elevation angles. Similarly, STANSELL (1970) pointed out the importance of the antenna height used and the effect on the tangent of the satellite elevation angle and tropospheric effect, particularly in defining longitude positions for East and West passing satellites. BERG (1975, 1976), even after applying these corrections, found that certain data sets were of such variance from the rest, that the values should be rejected in deriving a final solution.

To define the arithmetical mean position of each site in this investigation, the following editing or rejection criteria were adopted. First, data for elevation angles less than 15° and greater than 75° were not used in the computations for reasons stated above.

A second rejection criterion—that there be no more than five program iterations required for convergence on a solution—was a quick means of eliminating from computation the mean data lacking in quality or quantity or both. Inspection of the data showed that the number of iterations is closely correlated with the information content and distribution.

The final automatic rejection criterion was based on first making a trial arithmetic solution and then inspecting all data for deviation against the trial mean. All passes having deviations of greater than 10 sec of arc in either latitude or longitude were not included in the final computation of the arithmetic mean. Inspection of the data showed that passes with large deviations are generally those with low or high elevation angles, a low number of Doppler counts or a poor count sequence, or a combination of these. Although it can be argued that this is not a valid procedure since it represents in some cases an "overkill" and in other cases the incorporation of data that would have been rejected on the basis of probability theory, it does put all the data on a uniform numerical standard defined statistically for acceptance or rejection.

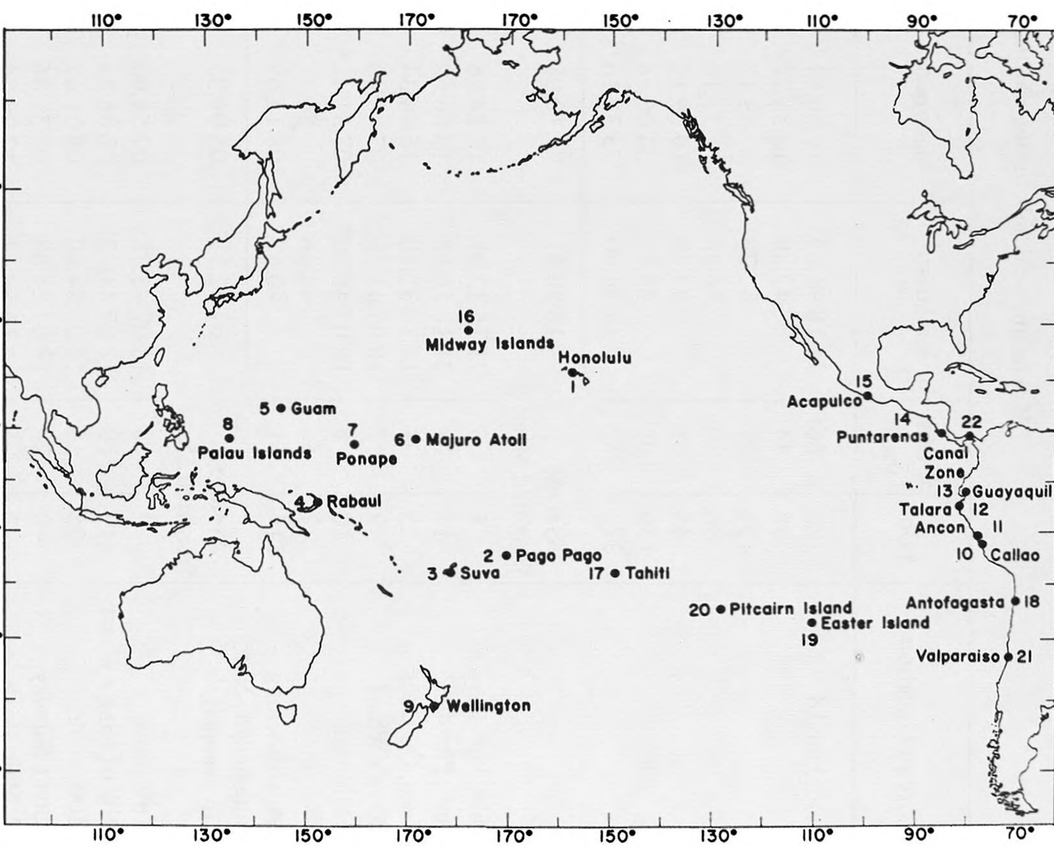

FIG. 1. — Chart of the Pacific showing harbor sites.

TABLE 1

Maximum and minimum values for latitude and longitude

Port and location	#Obs.	# Obs. used	Minimum ° ′ ″	Maximum ′ ″	Arithmetic mean ′ ″	Minimum ° ′ ″	Maximum ′ ″	Arithmetic mean ′ ″
Honolulu, Pier 18	86	66	21 18 44.22	19 00.84	18 48.21	157 45 39.66	52 05.34	52 01.53
	68	44	42.30	18 55.22	48.42	51 59.76	04.26	01.30
	37	29	32.28	53.10	49.92	55.14	07.14	00.90
	36	30	46.28	53.16	48.34	58.56	07.20	01.48
	45	31	33.24	19 09.12	48.70	52.26	11.94	01.70
	139	102	24.72	33 06.96	48.17	48 04.32	53 31.38	01.56
	377	252	17 54.60	23 38.16	48.19	51 42.18	55 22.92	01.48
	Average		18 30.81	21 10.08	18 48.56	50 27.41	52 47.17	52 01.56
	Weighted Mean :				18 48.28			52 01.52
Honolulu, Pier 10	8	5	21 18 13.98	18 28.26	18 27.82	157 51 54.36	52 02.82	51 58.99
Honolulu, Pier 40	17	11	21 18 56.58	19 06.60	19 04.31	157 52 37.20	53 34.02	52 54.09
Pago Pago, Oil Dock	25	21	14 16 32.10	16 44.34	16 34.91	170 40 51.78	40 58.38	40 55.32
Suva, King's Wharf	9	7	18 07 41.76	07 48.48	07 47.36	178 25 30.90	25 35.94	25 34.10
Suva, Dolphins	10	8	18 07 46.20*	07 51.42*	07 49.00*	178 25 35.10*	25 42.36*	25 37.55*
	77	56	44.46	54.72	46.79	24.96	36.18	32.27
*Values with wrong antenna height. Not used in averages.	114	81	40.62	08 13.68	46.76	24 01.14	45.30	32.20
	Average :		07 42.59	08 04.25	07 46.77	24 42.55	25 40.74	25 32.24
	Weighted Mean :				07 46.76			25 32.23
Suva, Dry Dock	9	8	18 07 45.98	07 54.90	07 49.60	178 25 34.08	25 40.92	25 37.40
Suva, NW of King's Wharf	19	10	18 07 41.22	08 06.36	07 56.27	178 25 12.66	25 36.42	25 26.68
Suva, 500' mark	25	15	18 07 54.60	08 01.62	07 59.91	178 25 00.90	25 48.06	25 25.28
Suva, Gov't Slipway	40	28	18 07 25.38	07 51.06	07 46.65	178 25 26.64	26 12.00	25 32.45
Rabaul, Main Dock	7	5	4 11 58.14	12 03.24	12 01.43	152 10 14.52	10 20.16	10 17.98
Guam, Dillingham Pier	21	13	13 27 19.62	27 56.10	27 42.63	144 39 08.76	39 59.52	39 52.61
	7	6	27 39.96	27 44.46	42.20	51.78	55.62	53.22

Wellington, Glascow Wharf	58	43	41 16 35.10	18 03.60	16 54.19	174 45 37.44	47 23.34	46 57.55
Callao, Berth 9-D	104	70	12 02 55.86	03 33.18	03 19.62	77 07 00.30	09 30.72	08 58.97
Callao, Berth 4-A	84	54	12 01 40.80	08 05.88	02 50.43	77 08 12.24	15 22.68	08 44.97
Ancon, Anchored	11	8	11 44 25.62	45 14.76	44 31.51	77 10 17.40	19 35.46	10 24.73
Talara, Anchored	25	11	04 33 30.96	34 03.78	33 44.51	81 17.14.76	17 34.26	17 20.44
Guayaquil, Berth #2	110	73	2 16 43.98	20 12.18	16 59.84	79 51 43.02	54 38.10	54 20.35
	64	45	16 47.28	25.32	59.76	53.16	38.10	20.46
* Omitted in averages.	22	12	37.50*	17 17.76*	58.11*	54 09.48*	33.18*	23.65*
	Average :		16 45.63	19 18.75	16 59.80	52 48.09	54 38.10	54 20.41
	Weighted Mean :				16 59.81			54 20.39
Guayaquil, Berth #6	4	3	2 16 43.62	16 46.38	16 43.86	79 54 43.44	54 46.50	54 44.60
Puntarenas, Anchored	19	11	9 57 47.40	57 54.90	57 51.33	84 49 19.32	49 29.28	49 26.30
Acapulco, Main Dock	20	12	16 50 41.76	51 05.76	50 53.76	99 54 04.74	54 39.84	54 15.86
	6	5	30.78	50 54.66	53.84	51 11.88	20.22	17.23
	Average :		50 36.27	51 00.21	50 53.80	52 38.31	54 30.03	54 16.55
	Weighted Mean :				50 53.78			54 16.47
Acapulco, W of Main Dock	47	26	16 50 44.28	51 15.48	50 54.65	99 53 19.38	59 11.76	54 19.16
Midway, Main Pier	18	13	28 12 47.52	13 01.98	12 50.37	177 21 43.08	21 53.76	21 48.40
Papeete, Main Wharf	7	7	17 31 59.58	32 03.90	32 01.50	149 34 20.70	34 22.74	34 21.80
Papeete, Fuel Dock	15	11	17 31 57.30	32 20.16	32 14.22	149 34 09.06	35 30.66	34 10.69
Antofagasta, Sitio #2	52	36	23 39 09.96	39 42.12	39 13.70	70 24 00.78	24 35.64	24 20.40
Easter Is., Anchored	14	12	27 08 20.70	08 33.18	08 30.42	109 26 16.26	26 28.86	26 18.43
Pitcairn Is., Anchored	6	6	25 03 51.24	03 53.88	03 52.02	130 05 33.72	05 38.58	05 36.17
Valparaiso, Berth #4	38	25	33 01 45.12	02 07.32	02 00.48	71 37 30.24	38 37.68	37 36.72
Balboa, Pier #2	81	55	8 52 04.80	57 17.10	57 06.86	79 30 22.02	35 06.90	34 22.90

STATISTICAL TEST OF RELIABILITY ADOPTED

The initial statistic calculated on all samples was the most obvious one, the arithmetic mean (table 1). The statistical parameters used as a measure of precision of the positional data were the standard deviation of a single observation :

$$s_x = \pm \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

and the standard deviation of the mean :

$$s_{\bar{x}} = \pm \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n(n-1)}}$$

where n is the number of observations and $\bar{x}$ is the mean.

DISCUSSION OF SATELLITE RESULTS

Table 1 shows the maximum and minimum values for latitude and longitude, the site, and the number of observations accepted in each case after editing for computation of the arithmetic mean values of latitude and longitude. Also shown is the spread in maximum and minimum values of latitude and longitude recorded for each series of measurements.

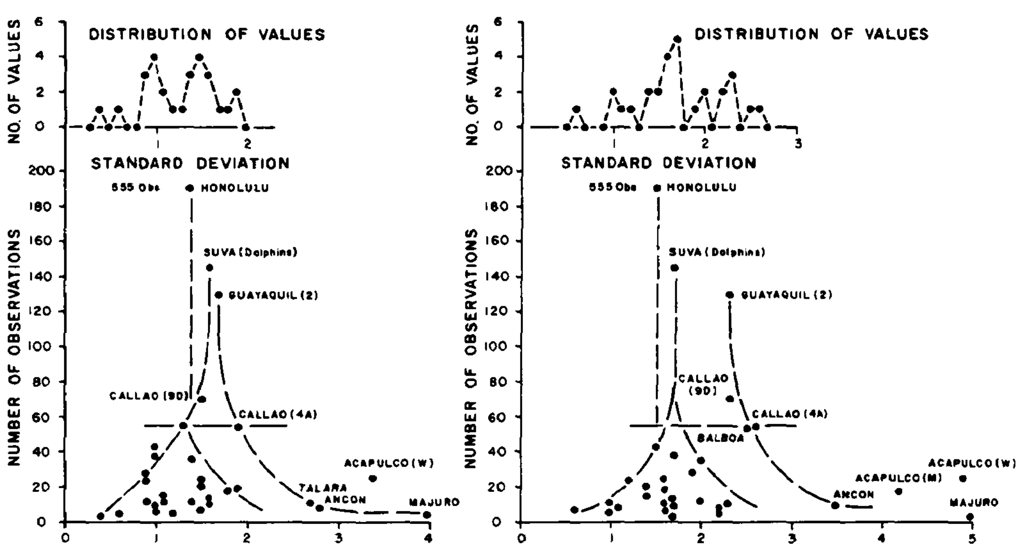

FIG. 2. — Relationship of standard deviation to number of observations.

There is no apparent systematic relationship between the standard deviation values and the number of observations, indicating that some factor having greater weight than size of sample is involved in determining the reliability of a fix. The above is a general situation, as seen in table 2 showing the spread between minimum and maximum deviations from the mean for latitude and longitude along with the average standard deviation values for each site.

TABLE 2

Difference from the mean in latitude and longitude

Port and location	# obs. used	Series	Difference from the mean		Std dev.(*)	Difference from the mean		Std dev.(*)
			Minimum ′ ″	Maximum ′ ″		Minimum ′ ″	Maximum ′ ″	
Honolulu, Pier 18	555	6	− 17.47	+ 2 21.80	1.4	− 1 34.11	+ 45.65	1.5
Honolulu, Pier 10	5	1	− 13.84	+ 0.44	0.6	− 4.63	+ 3.83	1.0
Honolulu, Pier 40	11	1	− 7.73	+ 2.29	1.4	− 16.89	+ 20.07	1.7
Pago Pago, Oil Dock	21	1	− 2.81	+ 9.43	1.5	− 3.54	+ 3.06	1.4
Suva, King's Wharf	7	1	− 5.60	+ 1.12	1.0	− 3.20	+ 1.84	1.1
Suva, Dolphins	137	2	− 4.17	+ 17.49	1.6	− 49.68	+ 8.51	1.7
Suva, Dry Dock	8	1	− 3.62	+ 5.30	2.8	− 3.32	+ 3.52	2.2
Suva, NW of King's Wharf	10	1	− 15.05	+ 10.09	1.0	− 14.02	+ 9.74	1.7
Suva, 500' mark	15	1	− 5.31	+ 1.71	1.1	− 24.38	+ 22.78	1.4
Suva, Gov't Slipway	28	1	− 21.27	+ 4.41	0.9	− 5.81	+ 39.55	1.9
Rabaul, Main Dock	5	1	− 3.29	+ 1.81	1.2	− 3.46	+ 2.18	2.2
Guam, Dillingham Pier	19	2	− 12.70	+ 7.79	1.9	− 22.65	+ 4.65	1.6
Majuro, "T" Wharf	4	1	− 5.97	+ 6.21	4.0	− 7.33	+ 6.65	5.0
Ponape, Main Dock	24	1	− 4.72	+ 30.44	0.9	− 7.31	+ 1 17.17	1.2
Palau, Main Dock	37	1	− 15.14	+ 23.62	1.0	− 17.55	+ 28.29	1.7
Wellington, Glasgow Wharf	43	1	− 19.09	+ 1 09.41	1.0	− 1 20.11	+ 25.79	1.5
Callao, Berth 9-D	70	1	− 23.76	+ 13.56	1.5	− 1 58.67	+ 31.75	2.3
Callao, Berth 4-A	54	1	− 1 09.63	+ 5 15.45	1.9	− 32.73	+ 37.71	2.5
Ancon, Anchored	8	1	− 5.89	+ 43.25	2.8	− 7.33	+ 9 10.73	3.5
Talara, Anchored	11	1	− 13.55	+ 19.27	2.7	− 5.68	+ 13.82	2.3
Guayaquil, Berth #2	130	2	− 16.32	+ 2 19.18	1.7	− 1 46.27	+ 14.97	2.3
Guayaquil, Berth #6	3	1	− 0.24	+ 2.52	0.4	− 1.16	+ 1.90	1.7
Puntarenas, Anchored	11	1	− 3.93	+ 3.57	1.1	− 6.98	+ 2.98	1.6
Acapulco, Main Dock	17	2	− 17.53	+ 6.41	1.8	− 1 38.24	+ 13.48	4.2
Acapulco, W of Main Dock	26	1	− 10.37	+ 20.83	3.4	− 59.78	+ 4 52.60	4.9
Midway, Main Pier	13	1	− 2.85	+ 11.61	1.6	− 5.32	+ 5.36	2.0
Papeete, Main Wharf	7	1	− 1.92	+ 2.40	1.5	− 1.10	+ 0.94	0.6
Papeete, Fuel Dock	11	1	− 16.92	+ 5.94	0.9	− 1.63	+ 1 29.97	1.0
Antofagasta, Sitio #2	36	1	− 3.74	+ 28.42	1.4	− 19.62	+ 15.24	2.0
Easter Is., Anchored	12	1	− 9.72	+ 2.76	1.6	− 2.17	+ 10.43	1.7
Pitcairn Is., Anchored	6	1	− 0.78	+ 1.86	1.0	− 2.45	+ 2.41	1.6
Valparaiso, Berth #4	25	1	− 15.36	+ 6.84	1.5	− 6.48	+ 1 00.96	1.6
Balboa, Pier #2	55	1	− 4 49.76	+ 10.24	1.3	− 4 00.88	+ 44.00	1.6

(*) As in shown in table 1, not all observations were used for calculations of standard deviation (for reasons explained in the text) ; consequently the maximum and minimum values were not included

As seen from figure 2, (1) the standard deviation values suggest a bimodal rather than a Gaussian (normal) distribution, although there were not really sufficient samples to define this adequately; (2) there is no direct relationship between standard deviation values and number of observations taken; and (3) certain sites are consistently subject to significant error in both latitude and longitude. This last is indicated by the values for these sites lying outside the envelope defining a convergence in values toward the most probable standard deviation. The standard deviation values are not significantly improved by taking more than 55 observations at a given site, and because of the bimodal distribution in values found, one should not expect better than a standard deviation of 1.3 sec of arc for latitude and 1.7 sec of arc for longitude. The values that fall outside the envelope enclosing most of the data points appear at first glance to be a function of geographic location, and for the most part are restricted to the West Coast of Central and South America. This is not consistently true, however, and it can only be concluded that the large standard deviations of these observations and the bimodal distribution pattern shown are functions of the satellites involved. A possible explanation could be errors in the ephemeris values, since certain satellites have been noted by BERG (1975) to give positions significantly at variance from all other satellites observed over the same time period and similarly reduced using the double pass method. These data were also edited to eliminate values apt to be suspect because of elevation angle values and number of iterations needed. On the basis of BERG's study, which involved some of the data here reported, a standard deviation that departed significantly ($>$ 10′ of arc) from the mean was used as an additional criterion for rejection in defining a position.

RESULTS ON CHARTED POSITIONS VERSUS SATELLITE DEFINED POSITIONS

All of the charts used for defining position were the most recent available, and except for the one for Ancon, Peru (1923) and the one for Rabaul (1966), they are all post-1972 editions. As seen from table 3, the scales of these charts range from 1:5 000 to 1:36 481; most scales are 1:10 000 and 1:12 500 (11 charts) or 1:25 000 and 1:35 000 (8 charts). If an average reliability of 1 mm is assumed for the ship's plotted positions at a dock or anchorage, on a chart of 1:10 000 scale uncertainty would be of about 10 m or 0.3 sec in position. For charts on a scale of 1:25 000 or 1:35 000, the uncertainty is proportionally greater. The uncertainty in scaling coordinates for these charted positions, on the other hand, is based on the spread in values obtained for the positions which were scaled twice by two different observers. This was on the order of ± 0.2 mm.

Table 3 lists the chart measured coordinates, the satellite derived coordinates and compares the chart and satellite defined positions. Seven series of observations were taken over a four-year period for Pier 18 in Honolulu Harbor and the latitude error indicated is + 11.54 ± 0.21 sec and for longitude + 9.23 ± 0.20 sec.

The final position determined by BERG (1976) for Pier 18, using the double pass method and additional rejection criteria, gives the following "best" coordinates : lat 21° 18.8140′ (18′ 48.48″); long 157° 52.0230′ (52′ 01.38″). The position derived in this study is lat 21° 18′ 48.56″ and

TABLE 3

Differences between chart measured and satellite derived coordinates: chart information

Chart evaluation and satellite coordinates						Charts used for position comparisons				
Location	# Obs. used	Chart evaluation of docking sites	Satellite coordinates	Difference (sec of arc)	Difference (m)	Chart No.	Scale	Datum	Source	Year
Acapulco, Main Dock	12	16°50′47.0″ 99°54′10.0″	16°50′53.76″ N 99°54′15.86″ W	− 6.8(1) − 5.9	210 174	21 401	1:25 000	North American - 1927	DMA-HC (2)	1974
Acapulco, Main Dock	5	16°50′47.0″ 99°54′12.0″	16°50′54.65″ N 99°54′19.16″ W	− 7.7 − 7.2	210 213					
Acapulco, W of Main Dock	26	16°50′47.0″ 99°54′10.0″	16°50′53.84″ N 99°54′17.23″ W	− 6.8 − 7.2	238 213					
Ancon, Anchored	8	11°44′30.0″ 77°10′30.0″	11°44′31.51″ S 77°10′24.73″ W	− 1.5 + 5.3	46 160	22 171	1:36 481	Not available	USN-HO (3)	1923
Antofagasta, Sitio #2	36	23°39′11.0″ 70°25′19.0″	23°39′13.70″ S 70°24′20.40″ W	− 2.7 + 58.6	83 1 658	22 221	1:12 500	Not available	DMA-HC	1976
Callao, 9-D	70	12°03′29.0″ 77°09′44.5″	12°03′19.62″ S 77°08′58.97″ W	+ 9.4 + 45.5	290 1 375	22 172	1:10 000	Not available	DMA-HC	1972
Callao, 4-A	54	12°03′24.0″ 77°09′38.0″	12°02′50.43″ S 77°08′44.97″ W	+ 33.6 + 53.0	1 038 1 601					
Easter Island, Anchored	12	27°08′00.0″ 109°26′30.0″	27°08′30.42″ S 109°26′18.43″ W	− 30.4 + 11.6	939 319	22 451	1:23 173	Not available	USN-HO	1975
Guam, Dillingham Pier	13	13°27′35.3″ 144°39′43.0″	13°27′42.20″ N 144°39′53.22″ E	− 6.7 − 10.2	207 306	81 048	1:10 000	Not available	NOAA (4)	1975
Guam, Dillingham Pier	6	13°27′35.5″ 144°39′43.0″	13°27′42.63″ N 144°39′52.61″ E	− 7.1 − 9.6	219 288					
Guayaquil, #2	73	2°16′47.0″ 79°54′13.5″	2°16′59.84″ S 79°54′20.35″ W	− 12.8 − 6.9	395 211	22 113	1:10 000	South American - 1956	DMA-HC	1973
Guayaquil, #2	45	2°16′47.0″ 79°54′13.5″	2°16′59.76″ S 79°54′20.46″ W	− 12.8 − 7.0	395 215					
Guayaquil, Tiuna	12	2°16′47.0″ 79°54′13.5″	2°16′58.11″ S 79°54′23.65″ W	− 11.1 − 10.2	343 313	22 113	1:10 000	South American - 1956	DMA-HC	1973
Guayaquil, #6	3	2°16′33.5″ 79°54′33.5″	2°16′43.86″ S 79°54′44.60″ W	− 10.4 − 11.1	321 340					

Chart evaluation and satellite coordinates						Charts used for position comparisons				
Location	# Obs. used	Chart evaluation of docking sites	Satellite coordinates	Difference (sec of arc)	Difference (m)	Chart No.	Scale	Datum	Source	Year
Honolulu, Pier 18	66	21°19'00.0" 157°52'10.6"	21°18'48.20" N 157°52'01.53" W	+ 11.8 + 9.1	364 262	19 367	1:5 000	Old Hawaiian	NOAA	1974
Honolulu, Pier 18	44	21°19'00.0" 157°52'10.6"	21°18'48.41" N 157°52'01.30" W	+ 11.6 + 9.3	358 268					
Honolulu, Pier 18	29	21°19'00.0" 157°52'10.5"	21°18'49.92" N 157°52'00.90" W	+ 11.1 + 9.6	343 276					
Honolulu, Pier 18	30	21°19'00.0" 157°52'10.6"	21°18'48.34" N 157°52'01.48" W	+ 11.7 + 9.1	361 262					
Honolulu, Pier 18	31	21°19'00.0" 157°52'10.6"	21°18'48.70" N 157°52'01.70" W	+ 11.3 + 8.9	349 256					
Honolulu, Pier 18	102	21°19'00.0" 157°52'10.6"	21°18'48.48" N 157°52'01.14" W	+ 11.5 + 9.5	355 273					
Honolulu, Pier 18	252	21°19'00.0" 157°52'10.6"	21°18'48.19" N 157°52'01.47" W	+ 11.8 + 9.1	364 262					
Honolulu, Pier 10	5	21°18'38.5" 157°52'08.8"	21°18'27.81" N 157°51'58.99" W	+ 10.7 + 9.8	331 282					
Honolulu, Pier 40	11	21°19'14.3" 157°53'03.3"	21°19'04.31" N 157°52'54.09" W	+ 10.0 + 9.2	309 265					
Majuro, "T" Wharf	4	7°06'24.0" 171°22'18.0"	7°06'18.99" N 171°22'16.59" E	+ 5.0 + 1.4	154 43	81 782	1:35 000	Local	DMA-HC	1974
Midway, Main Pier	13	28°12'36.0" 177°21'46.0"	28°12'50.37" N 177°21'48.40" W	− 14.4 − 2.4	445 65	19 481	1:32 500	Bosun Astro - 1941(Field)	NOAA	1973
Pago Pago, Oil Dock	21	14°16'45.0" 170°41'09.5"	14°16'34.91" S 170°40'55.32" W	+ 10.1 + 14.2	312 425	83 484	1:15 000	North American - 1927	NOAA	1975
Palau, Main Dock	37	7°19'39.0" 134°27'50.0"	7°19'49.34" N 134°27'23.49" E	+ 10.3 + 26.5	318 812	81 155	1:10 000	BAB South Astro	DMA-HC	1972

Panama, Balboa, Berth #2	55	8°57'12.0" 79°34'32.5"	8°57'06.86" N 79°34'22.90" W	+ 5.1 + 9.6	158 293	21 604	1:12 500	Not available	DMA-HC	1976
Pitcairn Island, Anchored	6	25°03'41.0" 130°05'35.0"	25°03'52.02" S 130°05'36.17" W	− 11.0 − 1.2	340 34	83 225	1:24 079	Not available	DMA-HC	1972
Ponape, Main Dock	24	6°59'12.0" 158°12'59.0"	6°58'44.74" N 158°12'01.97" E	+ 27.3 + 57.0	843 1 748	81 435	1:36 115	Ponape Astro - 1962	DMA-HC	1975
Puntarenas, Anchored	11	9°57'54.0" 84°49'28.5"	9°57'51.33" N 84°49'26.39" W	+ 2.7 + 2.1	83 64	21 546	1:12 500	North American - 1927	DMA-HC	1976
Rabaul, Main Dock	5	4°12'10.0" 152°10'08.0"	4°12'01.43" S 152°10'17.98" E	+ 8.6 − 10.0	266 308	82 192	1:25 000	Not available	USN-HO	1966
Suva, King's Wharf	7	18°08'00.5" 178°25'42.5"	18°07'47.36" S 178°25'34.10" E	+ 13.1 + 8.4	405 247	83 605	1:12 150	Not available	DMA-HC	1975
Suva, Dry Dock	8	18°07'55.8" 178°25'47.0"	18°07'49.60" S 178°25'37.40" E	+ 6.2 + 9.6	192 282					
Suva, Dolphins	8	18°07'53.5" 178°25'45.0"	18°07'49.00" S 178°25'37.55" E	+ 4.5 + 7.5	139 220	83 605	1:12 150	Not available	DMA-HC	1975
Suva, Dolphins	56	18°07'53.5" 178°25'45.0"	18°07'46.79" S 178°25'32.27" E	+ 7.6 + 12.7	235 373					
Suva, Dolphins	81	18°07'53.5" 178°25'45.0"	18°07'46.74" S 178°25'32.20" E	+ 6.8 + 12.8	210 376					
Suva, NW of King's Wharf	10	18°08'00.0" 178°25'39.5"	18°07'56.27" S 178°25'26.68" E	+ 4.2 + 12.8	130 376					
Suva, 500' King's Wharf	15	18°08'05.0" 178°25'38.5"	18°07'59.91" S 178°25'25.28" E	+ 5.1 + 13.2	158 387					
Suva, Gov't Slipway	28	18°07'52.5" 178°25'46.4"	18°07'46.65" S 178°25'32.45" E	+ 5.6 + 13.9	173 408					
Talara, Anchored	11	4°34'00.0" 81°18'00.0"	4°33'44.51" S 81°17'20.44" W	− 15.5 − 39.6	479 1 219	22 121	1:10 000	Not available	DMA-HC	1976
Valparaiso, Berth #4	25	33°01'55.0" 71°37'54.0"	33°02'00.48" S 71°37'36.72" W	− 5.5 + 17.3	170 448	22 259	1:8 000	Not available	DMA-HC	1976
Wellington, Glascow Dock	43	41°17'00.0" 174°46'58.0"	41°16'54.19" S 174°46'57.54" E	+ 5.8 + 0.5	179 12	76 071	1:12 000	New Zealand - 1949	DMA-HC	1975

(1) + values of latitude are North of satellite position ; + values of longitude are West of satellite position
(2) Defense Mapping Agency – Hydrographic Center, now Defense Mapping Agency Hydrographic/ Topographic Center (since 1978)
(3) United States Navy – Hydrographic Office
(4) National Oceanic and Atmospheric Administration

long 157° 52′ 01.56″. The difference in latitude is 0.08″ (2.5 m) and the difference in longitude is 0.18″ (4.5 m). Although this degree of agreement is undoubtedly fortuitous, it does support the initial assumption of this study, namely that the method of analysis adopted is adequate for evaluating the reliability of published chart positions.

CONCLUSIONS

Several unanticipated results concerning the reliability of satellite defined positions, although outside the primary objective of the study, are significant because to my knowledge they are not alluded to in previously published papers. These findings can be summarized as follows : (1) the standard deviation in satellite-defined values of position of latitude and longitude using all satellite passes is not improved with multiple observation samples in excess of 55 observations; (2) the distribution of values of standard deviation for a series of multiple passes converges as the number of passes increases toward an intermediate value between a minimum and maximum value, which is not the same for both latitude and longitude; (3) the distribution of values of standard deviation for multiple observations does not define a Gaussian (normal) distribution, but suggests a bimodal distribution that is most pronounced in the latitude observations.

Satellite-derived docking positions can contribute significantly toward improvement in charted positions by providing good approximate shifts from the local charting datum to the World Geodetic System (WGS).

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NAVIGATORS AND SOCIETY

"However, the most sophisticated equipment needs to be employed by those well trained in its use and capable of interpreting the output correctly if the ship is to be safely conducted along well planned tracks through coastal waters. I am therefore drawn inevitably to the conclusion that the weak link in the marine navigational chain is the lack of properly trained and certified personnel on the bridges of a number of the world's merchant ships. It is when this weak link breaks that a deep rift between our profession and society appears as the black tide flows in upon the long coastlines."

From an address "Navigation and Society" delivered by Rear Admiral G.S. RITCHIE to the International Congress of the Institutes of Navigation held at Falmer, Sussex, England, in September 1979.