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SOME NOTES ON THE ACCURACY OF THE NAVY NAVIGATION SATELLITE SYSTEM

by Mark SZYMOŃSKI,
Institute of Marine Navigation, Gdynia, Poland

INTRODUCTION

This paper describes the evaluation of the accuracy of determinations of a ship's position by means of Navy Navigation Satellite System (NNSS) receivers. Using a dual channel receiver, type RSN-2, manufactured by the British firm Redifon Telecommunications Ltd., measurements were carried out in the following South American ports : Callao (Peru), Grytviken (South Georgia), Montevideo (Uruguay), Port William (Falkland Islands); and for the port of Gdynia (Poland) an American-made single channel receiver, Magnavox type MX-1102, was used. The results were compared with the geodetic positions on navigational charts and also with transformed coordinates in several geodetic systems obtained from the GEOCN (Geodetic Coordinate Conversion) computer program.

THE ACCURACY OF SATELLITE-DETERMINED POSITIONS

Problems connected with the analysis of the accuracies obtained with NNSS will be of interest to the ever-increasing number of users of this system, although there are already several well-known publications on the subject [1], [2], [3].

The problems described here concern the determination of a ship's position by means of the NNSS system and dual channel and single channel receiving equipments. The former equipment receives signals on frequencies of both 400 MHz and 150 MHz, and thus assures refraction corrections. The latter receives signals on 400 MHz only; it is equipped with a special micro-processor which controls the tuning of the receiver and chooses the best satellite passes.

The measurements were made at fixed points at which all satellite passes were registered. This rendered possible the following evaluation :

(a) value for the mean latitude φ of N fixes;

(b) value for the $(1\ \sigma)_\varphi$ latitude of all fixes;
(c) value for the expected error on the mean latitude (mean error : $M = 1\ \sigma/\sqrt{N}$);
(d) value for the mean longitude λ;
(e) value for the $(1\ \sigma)_\lambda$ longitude;
(f) value for the mean error in longitude;
(g) fixing the ship's position on the basis of (a) and (d) above;
(h) value for the $(1\ \sigma)$ position error;
(i) value for the expected error of the mean position;
(j) computing the latitude and longitude differences between satellite measurements and geodetic positions.

The results, taking into account all satellite passes, are given in table A. Those from satellite passes at elevations of from 10° to 80° are shown in table B. This enables evaluation, *inter alia*, of the influence of tropospheric refraction for the case of the satellite passing too low and also the effect of degrading accuracy for satellite passes at an elevation greater than 80°. The results obtained confirm earlier experiments of this kind in the case of a large majority of the measurements.

Ignoring the results from satellites passing too low or too high, obvious improvements in the accuracy of the positions can be noted and the total discrepancy is around 100 m which highlights the usefulness of the receivers employed, not only for ocean navigation but also in coastal areas. The fact that both receivers assure the same accuracy should be stressed. However, the need remains to choose the most suitable satellite passes, rendered possible with the single channel MX-1102 receiver.

Some important systematic position errors were observed, of the order of 200-500 metres. These errors were due, among other reasons, to the fact that for the NNSS the reference ellipsoid used differs from the geodetic ellipsoid on which the charts were constructed, to the fluctuations of the sea surface and to inaccurate height corrections for positions in the reference ellipsoid when taking into consideration the right shape of the globe.

Shown below are data for the various ellipsoids of reference used.

Ellipsoid of reference	Semi-major axis (metres)	Reciprocal flattening
APL 4.5	6 378 144	298.23
WGS-72	6 378 135	298.26
NWL-8D	6 378 145	298.25
SAO-C7	6 378 142	298.255

Figures 1 to 4 illustrate the dual-channel satellite fix results and figure 5 the single-channel results. Satellite passes at elevations lower than 10° and higher than 80° are denoted by an asterisk.

Discrepancies of this order in both the measured positions and the geodetic positions on navigational charts will not appreciably influence

Table A

Accuracy of the receiving equipment of NNSS
(All satellite passes)

	Port	Number of passes	Number of iterations min.	Number of iterations max.	Pass elevation (degrees) min.	Pass elevation (degrees) max.	Satellite position Geodetic position latitude φ	Satellite position Geodetic position longitude λ	$\Delta\varphi$ (in minutes and metres)	$\Delta\lambda$ (in minutes and metres)	Distance between geodetic and satellite positions (NM) (metres)	Azimuth between geodetic and satellite positions (degrees)	Latitude error (in minutes and metres) 1 σ	Latitude error M	Longitude error (in minutes and metres) 1 σ	Longitude error M	Position fix error (in metres) 1 σ	Position fix error M
REDIFON RSN-2	CALLAO (Peru) 23-26.05.1977	37	1	6	5	85	S 12°03.0107′ S 12°02.7750′	W 77°08.7129′ W 77°08.5350′	0.2357 437	0.1779 321	0.3 556	222.5	0.0548 101	0.0090 17	0.0518 94	0.0085 15	138	23
REDIFON RSN-2	MONTEVIDEO (Uruguay) 01-03.06.1977	16	2	11	8	88	S 34°54.1645′ S 34°54.2200′	W 56°12.6987′ W 56°12.6200′	−0.0555 103	0.0787 120	0.0875 162	311	0.0098 18	0.0025 5	0.0693 107	0.0173 27	109	27
REDIFON RSN-2	PORT WILLIAM (Falkland Is.) 27-28.01.1977	32	1	8	2	83	S 51°40.2646′ S 51°40.5700′	W 57°49.9401′ W 57°50.0000′	−0.3054 556	−0.0599 70	0.3100 574	4	0.0912 169	0.0161 30	0.1665 192	0.0294 34	256	45
REDIFON RSN-2	GRYTVIKEN (South Georgia) 15-16.03.1977	12	3	5	12	85	S 54°16.8736′ S 54°16.5000′ S 54°16.9000′ (plan) (chart)	W 36°30.4410′ W 36°30.3000′ W 36°30.3000′	0.3736 692 −0.0264 49	0.1410 165 0.1410 165	0.3825 708 0.0875 162	195 288	0.0186 35	0.0056 10	0.0597 69	0.0179 21	77	23
MX-1102	GDYNIA (Poland) 17.02-20.02.1978	76	1	6	4	81	N 54°31.0900′ N 54°31.1600′	E 18°33.2700′ E 18°33.6100′	−0.07 130	−0.34 367	0.212 393	249	0.06 111	0.007 13	0.08 86	0.009 10	112	16

Table B

Accuracy of the receiving equipment of NNSS
(Fixes from satellite passes between 10° and 80°)

	Port	Number of passes	Number of iterations min.	max.	Pass elevation (degrees) min.	max.	Satellite position Geodetic position latitude φ	longitude λ	$\Delta\varphi$ (in minutes and metres)	$\Delta\lambda$	Distance between geodetic and satellite positions (NM) (metres)	Azimuth (degrees)	Latitude error (in minutes and metres) 1 σ	M	Longitude error 1 σ	M	Position fix error (in metres) 1 σ	M
REDIFON RSN-2	CALLAO	29	1	6	10	74	S 12°02.9966′ S 12°02.7750′	W 77°08.7189′ W 77°08.5350	0.2216 410	0.1839 338	0.286 529	223	0.0330 61	0.0061 11	0.0447 81	0.0083 15	101	19
	MONTEVIDEO	14	2	6	30	77	S 34°54.1652′ S 34°54.2200′	W 56°12.7007′ W 56°12.6200′	−0.0548 101	0.0707 108	0.0863 160	309	0.0075 14	0.0019 4	0.0680 104	0.0181 28	105	28
	PORT WILLIAM	27	1	4	11	80	S 51°40.2748′ S 51°40.5700′	W 57°49.9368′ W 57°50.0000′	−0.2952 547	−0.0632 74	0.2976 552	8	0.0365 68	0.070 13	0.0703 81	0.0135 16	108	21
	GRYTVIKEN	11	3	5	12	60	S 54°16.8745′ S 54°16.5000′ (plan) S 54°16.9000′ (chart)	W 36°30.4323′ W 36°30.3000′ W 36°30.3000′	0.3745 694 −0.0255 47	0.1323 155 0.1323 155	0.3825 708 0.0798 148	191 289	0.0122 28	0.0045 8	0.0424 49	0.0122 14	56	16
MX-1102	GDYNIA	65	1	4	10	80	N 54°31.0800′ N 54°31.1600′	E 18°33.2700′ E 18°33.6100′	−0.08 148	−0.34 367	0.216 400	246	0.03 56	0.004 7	0.05 54	0.006 7	78	10

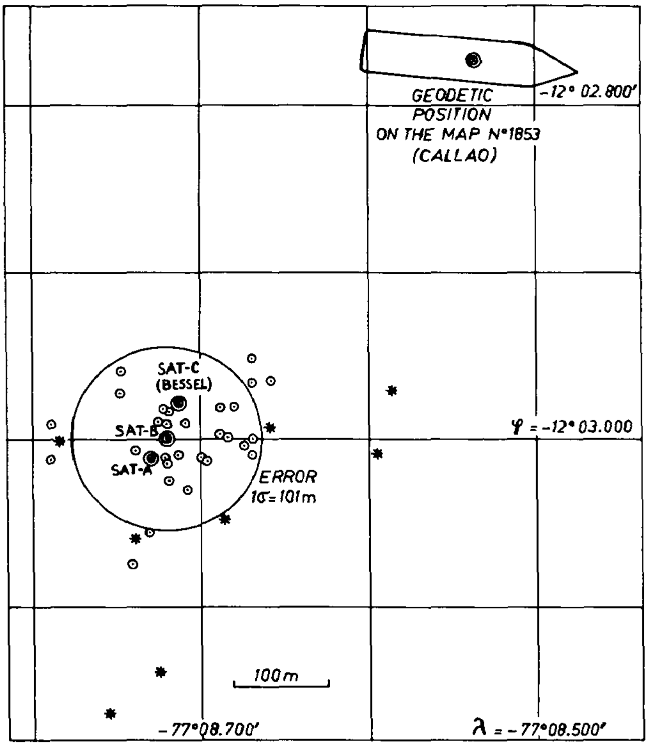

FIG. 1. — Satellite determined positions in Callao (dual-channel RSN-2 receiver).

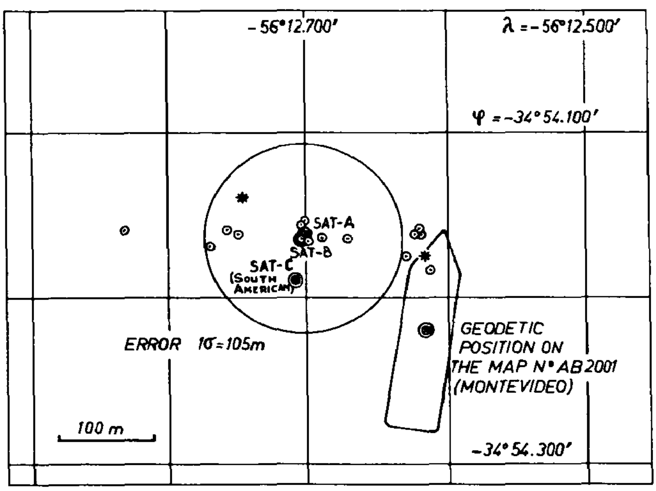

FIG. 2. — Satellite determined positions in Montevideo (dual-channel RSN-2 receiver).

the safety of navigation at sea, but in coastal navigation and in narrow waters they can have a significant effect.

The positional inaccuracies differ in the various geographical regions. In Grytviken the discrepancy in the satellite-determined positions vis-à-vis

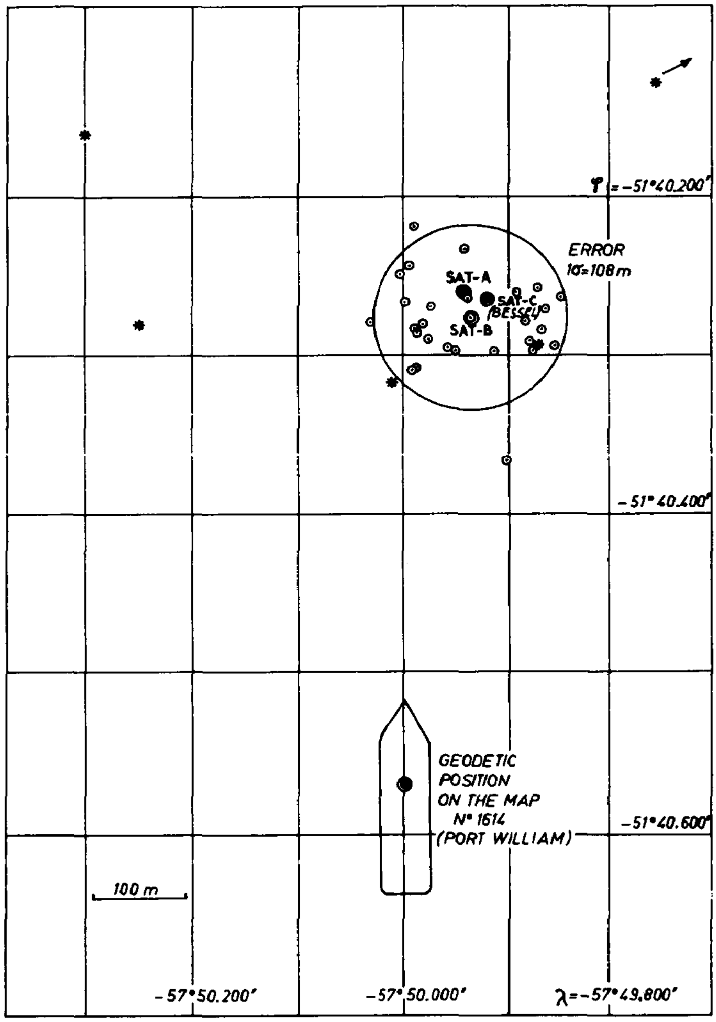

FIG. 3. — Satellite determined positions in Port William (dual-channel RSN-2 receiver).

the geodetic positions fixed on the British chart of the locality amounts to 148 metres (table B), and in Montevideo it amounts to 160 metres. Neither of these values exceeds the tolerance limit for such measurements. As regards Callao and Port William on British charts and for Gdynia on a Polish chart, the positional discrepancies are respectively 529 m, 552 m and 400 m (see table B).

THE RESULTS OF COORDINATE TRANSFORMATIONS

It is important to make clear to NNSS users the order of the discrepancies in satellite-determined positions obtained after correcting for differences for the reference ellipsoid used. The GEOCN program [4] was

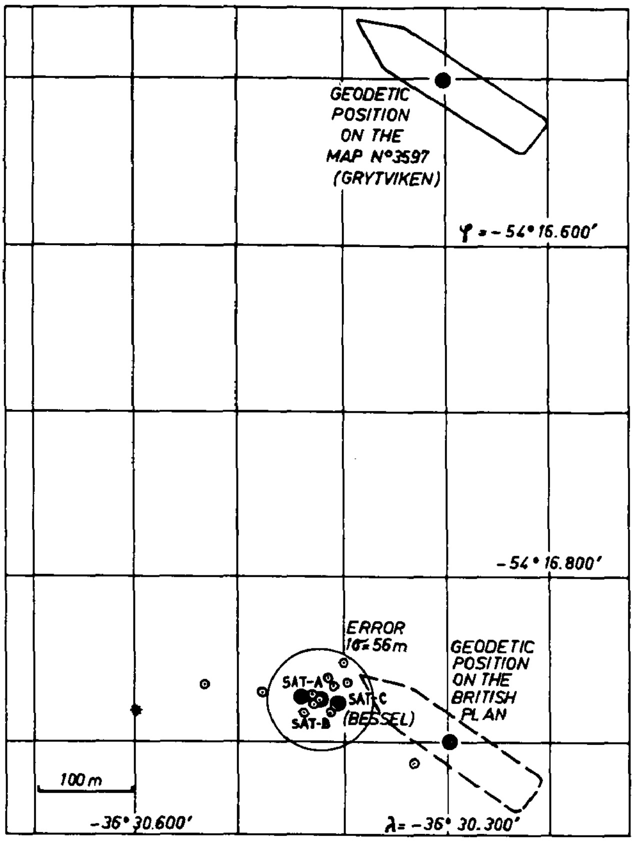

Fig. 4. — Satellite determined positions in Grytviken (dual-channel RSN-2 receiver).

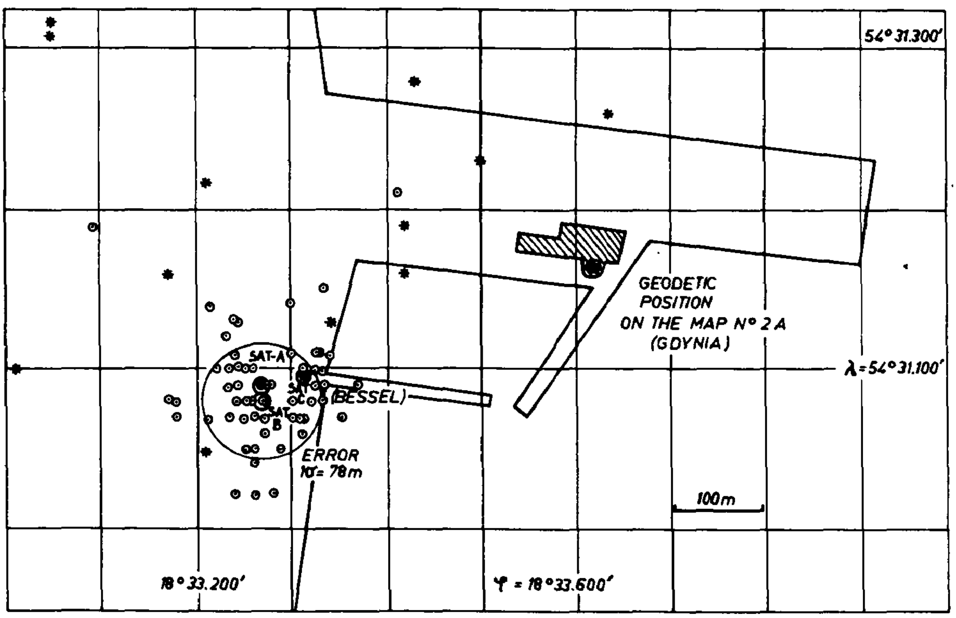

Fig. 5. — Satellite determined positions in Gdynia (single-channel MX-1102 receiver).

Table C

Geodetic coordinate transformation results
(Transformed datum : NWL-8D)

Port	Chart number	Correction (in minutes and metres)			Reference position in original datum Reference position in transformed datum			Distance between geodetic and satellite positions	Azimuth between geodetic and satellite positions	Original datum
		$\Delta\varphi$	$\Delta\lambda$	ΔH	φ (in degrees)	λ (in degrees)	H (in metres)	(NM) (metres)	(degrees)	
CALLAO	1853	0.0282 52.2	−0.0014 2.5	−1423.8	S 12°03.0107′ S 12°02.9825′	W 77°08.7129′ W 77°08.7143′	58 −1365.8	0.266 493	220	Bessel
MONTEVIDEO	AB 2001	−0.0260 48.1	−0.0113 17.2	43.9	S 34°54.1645′ S 34°54.1905′	W 56°12.6987′ W 56°12.7103′	35 78.9	0.079 146	291	South American
PORT WILLIAM	1614	−0.0030 5.6	0.0137 15.8	−1567.2	S 51°40.2646′ S 51°40.2677′	W 57°49.9401′ W 57°49.9264′	35 −1532.2	0.298 552	9	Bessel
GRYTVIKEN	3597	−0.0009 1.7	0.0312 33.9	−1509.4	S 54°16.8736′ S 54°16.8746′	W 36°30.4410′ W 36°30.4098′	40 1469.4	0.381 706	189	Bessel
GRYTVIKEN	plan	−0.0038 7.0	0.0003 0.3	44.2	S 54°16.8736′ S 54°16.8774′	W 36°30.4410′ W 36°30.4407′	40 84.2	0.068 125	289	Argentine
GDYNIA	2A	0.0231 42.8	0.0509 57.8	−139.8	N 54°31.0900′ N 54°31.0931′	E 18°33.2700′ E 18°33.3109′	55 −84.8	0.188 348	247	Bessel

utilized for the transformation of the coordinates of the positions fixed. These results are shown in table C. They permit evaluation of the influence of the various regional surveys referred to a local datum on the NNSS measurements. It should be noted that the GEOCN program takes into consideration the range of the semi-major axis of the spheroids and of the flattening as well as of the shift of the centers of the two spheroids.

Some small changes had to be made on charts as a result of these transformations of satellite positions, but even so it is noted that fairly large discrepancies do still occur. It seems that the considerable differences in the height of fixed point positions obtained using different spheroids could be the explanation why so many errors occur. However, even using the traditional method of correcting the height above mean sea level by means of geoid-corrected but sadly inaccurate charts, this particular error is not avoided.

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A SEAGOING NATURALIST

In the spring of 1841 the Captain of H.M.S. *Beacon*, Thomas Graves, was in England. Like Fitzroy ten years before, though for different reasons, he conceived the idea of inviting a naturalist to join the ship and advertised that 'an officer of the surveying squadron in the Mediterranean... was anxious before returning to the East to make the acquaintance of a naturalist,, who would be content to share a sailor's fare for a year or two in the Levant.'

Of Forbes' work in *Beacon* Captain Graves wrote :

> "Forbes employed himself, and likewise not a few of his naval comrades, botanizing, zoologizing, and geologizing in turn. The few weeks of his intercourse with the officers and crew had sufficed to enlist all their sympathy and assistance. The first lieutenant, though anxious, as all first lieutenants are, to keep the decks clean, never objected to the contents of the dredge being spread out, but almost became a convert. The captain's cabin was turned into a kind of museum, laboratory, and store-room where the various animals brought up from the deep were dissected, drawn, or stored away in bottles, the captain himself lending every assistance, and eliciting many a quiet clinical lecture from the 'oyster-dredger', as sailors term a naturalist.
>
> It was quite amusing to see how Forbes gained the good opinion of the sailors of the *Beacon*, and how they all endeavoured to add to his collection. If a boat returned from surveying, there were always some shells for Mr. Forbes. If the seine was hauled at night, a lanthorn was always at hand when the fish were taken out, to look for *curios* (as Jack termed them) for their friend, and whether additions or not, the donor always received an encouraging answer, his present was accepted, the sailor felt gratified, and was only too anxious to search after other treasures of the deep.
>
> With a whole crew of assistants, and the accumulating results of his own explorations, there was, of course, ample scope for the microscope and the pencil in the evenings. And pleasant evenings they were when, the surveys and dredgings of the day over, the officers met in the cabin around Forbes, who, with the microscope at his eye, and a pencil in his hand, sketched the anatomy of the organisms that had been caught during the day, chatting the while in his own simple, impressive way, about the forms and habits of the creatures before them, and enlivening the description with many touches of quiet humour. Hours thus spent passed quickly away, and when at last the microscope was put up, it was only necessary to place a few scraps of paper before Forbes, to open up another inexhaustible source of amusement. He would draw groups in which we were all included as connected with our common pursuit during the day, placing himself conspicuous if anything ridiculous had occured."

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