If you don't display discrepancies (and this is about the only use for them), roughly sketch to see that the lines are all towards or all away. In this case the fix is good, though there is some sort of systematic error (sextant index correction probably). If the sights were not evenly distributed and **S** is small, the fix will probably be okay (it depends on the spread in azimuth) but it is advisable to sketch and interpret the lines. If **S** is large where the sights were not evenly distributed, the least squares fix is poor; sketch the lines and do your best.

It should be clear how valuable it is to have stars evenly distributed around the horizon. The discrepancies are not all that useful; they hardly show anything that the intercepts don't.

The above is the procedure for computer celestial navigation. It has been standard on the top-selling navigation computers since the mid-to late-eighties. (These computers are not on sale in Britain.) To my knowledge, no one sells the above described spreadsheet program. If the war which knocks out all the GPS systems occurs in 20 or more years' time, ship officers would need to be taught sextant navigation. They might have to be taught how to draw lines.

All the above was predicated on the assumption that a world war will knock down the GPS satellites. It is not necessarily 'idle to speculate'. On the contrary, prevention would be better than cure and discussion makes democracy. It appears that democracies don't make war on one another, which means we are okay if powerful countries are democracies. If it is also true that to get rich nowadays (and hence powerful) it is necessary to be a democracy, then we've got the game sewn up. No more war. The various squabbles which do go on are not going to bring down the GPS satellites.

GPS is part of the human race forever. The USA will soon release the full accuracy. Europe will sometime launch a parallel system and there will be a dense network of differential stations. Isn't it marvellous? The million-year problem of navigation and the ten-thousand-year problem of war both solved while we weren't looking. In a few years, children will carry or wear a 'phone/GPS. In a few more years you won't step outside without one.

Where does the sextant fit in? In the same place as the horse and buggy – as a hobby.

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KEY WORDS

1. Astro navigation. 2. Errors and accuracy. 3. Computers.

Observed Effect of Air-Sea Temperature Differences on Marine Sextant Altitudes

Mark Dixon

1. INTRODUCTION. While at anchor off the island of Waiheke in the Hauraki Gulf, North Island, New Zealand, the author was, by chance, able to observe the effect

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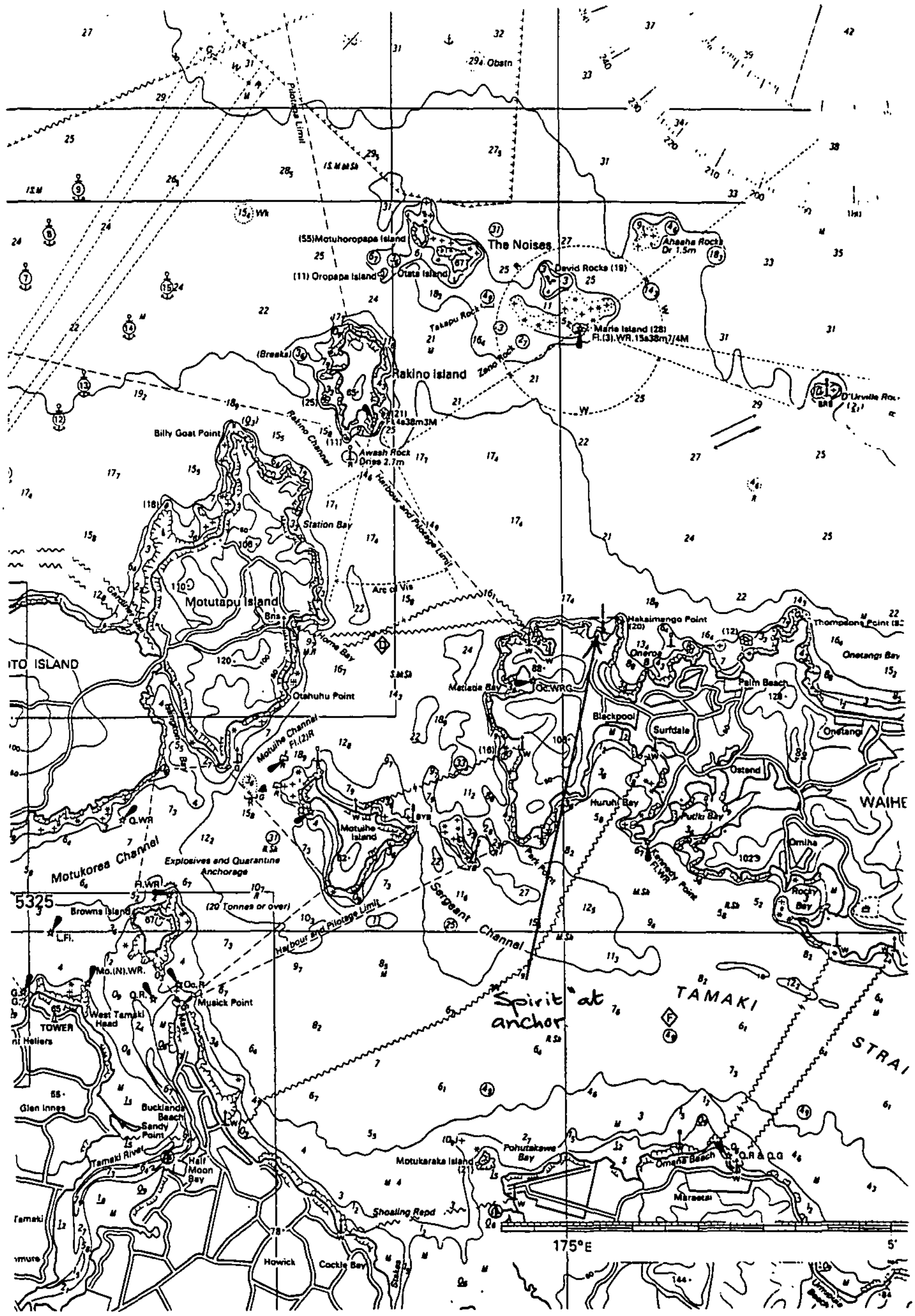

Fig. 1 Part of chart NZ532. Reproduced by permission of the Hydrographer, RNZN.

Fig. 1

of air–sea temperature differences on lines of position obtained from evening stars using a marine sextant. The results are interesting because of the large size of the effect – about 9 n.m., and the fact that sights in an adjacent quadrant were largely unaffected.

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2. OBSERVATIONS. Evening stars were taken on 25 Jan 1996 off Haikamango Point (see Fig. 1) in position 36 46′.1 S 175 00′.6 E confirmed by radar and GPS. Height of eye on the quarterdeck of the Barquentine *Spirit of New Zealand* was 15 feet. Index error was negligible. The sights listed in table 1 were taken towards the open horizon to the NE.

TABLE 1. SUMMARY OF RESULTS OF OBSERVATIONS

Body	UTC	Sextant altitude	Intercept	Azimuth
Rigel	07.58.36	56 22	8·8T	037
Rigel	07.59.27	56 29	9·6T	037
Rigel	08.01.44	56 44	8·2T	036
Sirius	08.03.27	48 35	9·6T	073
Sirius	08.04.45	48 50	9·7T	072
Sirius	08.05.43	49 01	9·6T	072
Betelg.	08.07.09	38 51	8·9T	037
Betelg.	08.08.53	39 03	8·6T	036
Betelg.	08.10.41	39 17	9·9T	036

With respect to the radar/GPS position, they gave a mean intercept of 9·21 n.m. Towards, with standard deviation ± 0·56. Other sights taken towards the NW gave mean intercepts within 1 n.m. of the charted position.

3. METEOROLOGICAL CONDITIONS. The sea was slight with no swell and visibility was good. A cool SSE offshore breeze of about 5–10 kt had recently sprung up after a hot calm afternoon in the Gulf. This breeze would freshen later that night with the approach of a sub-tropical depression to the NE of North Island. Air and sea temperatures for the time of observation, 2000 hours (Zone-12) are estimated as follows:

Sea temperature (°C)	21·5a ± 0·5 °C
Air temperature (°C)	14a ± 1 °C
Difference (°C)	7·5a ± 1·5 °C

These figures were obtained from uncalibrated instruments onboard and maximum and minimum readings courtesy of the University of Auckland Leigh Marine Laboratory situated on Goat Island at the entrance to Hauraki Gulf.

4. EFFECT OF AIR–SEA TEMPERATURE DIFFERENCE. Significant sub-refraction was produced with the visible horizon being depressed between 8 and 10 minutes of arc by a temperature difference of about 6–9 degrees C, an effect of roughly 1′ arc error in the angle of dip per degree C temperature difference.

Sights towards the NW were not affected, probably because of the slightly higher surface windspeeds round the western end of Waiheke Island itself. These may have created sufficient turbulence to mix the lowest layers of the atmosphere and inhibit subrefraction. Investigations into mirage phenomena have shown that the detail of the temperature profile of the lowest few metres of the atmosphere is critical to abnormal refraction.[1]

5. PRACTICAL CONSIDERATIONS. Anomalous dip constitutes one of the largest errors in marine sextant work. Air–sea temperature differences of 14–17 degrees C are apparently not uncommon in certain sea areas[2] and, if the above observations are representative, may produce position line errors of 15 to 20 n.m. Similarly, air–sea temperature differences of only 2 to 3 degrees C may produce significant errors in

position. However, wind at Beaufort force 3 may produce sufficient mixing to eliminate the surface layers of air needed to promote abnormal refraction.

The author hopes that these figures will lend credence to the larger values of anomalous dip quoted in modern textbooks,[3] but not apparently observed in studies conducted earlier this century by the Carnegie Institution and the Japanese Hydrographic Office.

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KEY WORDS

1. Astronomical navigation. 2. Refraction. 3. Errors and Accuracy.

'A Voyage of Navigational Investigation'

Michael Richey *responds*

I appreciate the comments by Dr. Randles[1] on my original paper,[2] and I readily accept that the historian has to rely on documentation. But it seems reasonable to assume that manuscript or hand-copies of early navigating manuals preceded the printed versions which have come down to us; and no doubt, since it is a craft, many of the practices of navigation will have been imparted from master to apprentice without getting written down at all. It is the balance of probabilities as to what these practices were that has to be weighed up.

Jester's voyage of investigation could prove very little. But in saying there was nothing to show that I might not have reached the (English) Channel without altitude observations, Randles seems to have missed what point there was to the investigation. The key passage was the windward leg from Porto Santo to Sta Maria. When the wind heads under sail the navigator seeks to put his vessel on that board which makes up best for the destination; and the less weatherly the vessel, the more important this becomes. Knowing the latitude of Sta Maria I tacked *Jester* when the altitude of the North Star indicated that the port tack would be the more favourable one for reaching the required latitude. It is, of course, conjecture that the early navigator would have done the same thing. But, without any form of position line (from soundings or altitudes) to help him, it is difficult to see how otherwise he could have made the same landfall with the consistency we know he did.

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KEY WORDS

1. History. 2. Astro navigation.