OCEAN WEATHER SHIPS

SOME NAVIGATIONAL AND OCEANOGRAPHICAL ASPECTS

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Since 1954 there have been 9 ocean stations in the North Atlantic and it seems likely that these stations will be manned for many years to come. The North Atlantic Ocean Station Agreement, under which this scheme is operated, originated in 1947, when 13 ocean stations were established — primarily for the purpose of providing a permanent network of meteorological observations, surface and upper air, to supplement the observations provided voluntarily by merchant ships. The chief reason was to provide better meteorological facilities for trans-Atlantic aircraft, but it has been found in practice that the information provided by this network is also essential for general meteorological purposes. This is particularly true now that the electronic computer has made numerical forecasting possible; all weather forecasting nowadays is based upon a study of meteorological conditions in the upper air as well as at the surface.

In 1949, the number of stations was reduced to 10 for reasons of economy and in 1954 it was reduced to its present number of 9 (see Fig. 1 which also shows some of the main airline tracks across the North Atlantic).

The general principle of the North Atlantic Ocean Station Agreement, which operates under the auspices of the International Civil Aviation Organisation, is that all those countries which operate aircraft across the Atlantic contribute to the scheme, the amount of each contribution being based upon the number of scheduled flights across the ocean; some countries make their contribution by operating ships to man the stations, whereas the others contribute cash.

The 5 eastern stations A., I., J., K. and M. are operated jointly by European countries, two ships being needed to operate each station and two ships being provided by France, two by the Netherlands, two by Norway and Sweden and four by the United Kingdom. The British, French and Netherland ships operate in rotation at stations A., I., J. and K. and a Norwegian ship is normally at station M., but for six months every two years a Norwegian ship occupies station A. while the Netherlands take over station M., the British concentrate at I. and J. and the French at K. The four western stations B., C., D. and E. are occupied throughout the year by

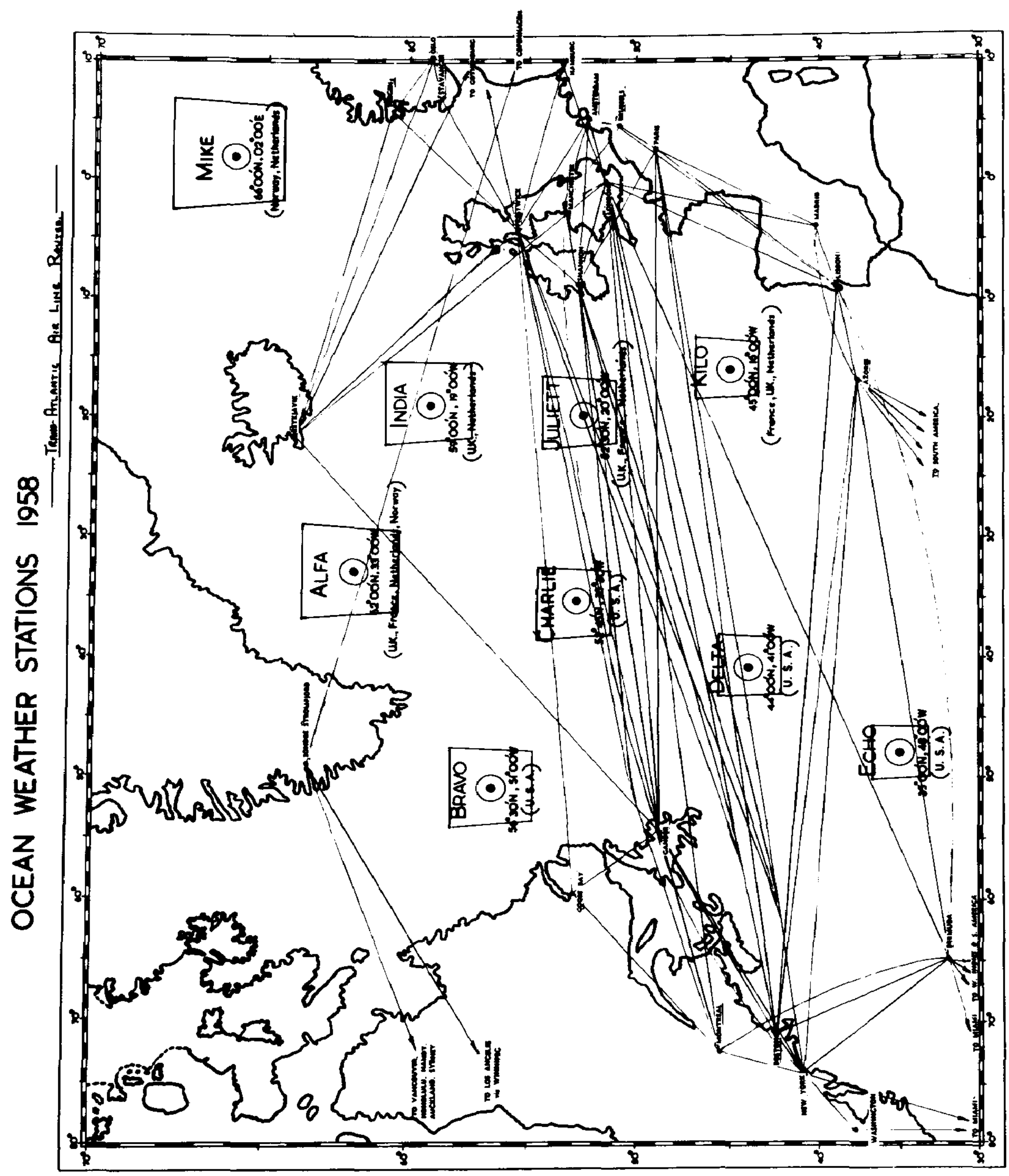
OCEAN WEATHER STATIONS 1958
Trans-Atlantic Air Line Routes
MIKE
66°00N, 02°00E
(Norway, Netherlands)
INDIA
59°00N, 19°00W
(UK, Netherlands)
ALFA
62°00N, 33°00W
(UK, France, Netherlands, Norway)
JULIETT
KILO
45°00N, 16°00W
(France, UK, Netherlands)
CHARLIE
(U.S.A.)
DELTA
44°00N, 41°00W
(U.S.A.)
ECHO
35°00N, 48°00W
(U.S.A.)
BRAVO
56°30N, 51°00W
(U.S.A.)
TO SOUTH AMERICA
NEW YORK
WASHINGTON
MONTREAL
GOOSE BAY
Feb. 1959

FIG. 1

United States Coastguard cutters, but as these stations are so remote from a base, more than two ships are needed to man each station. As a general rule, each ship spends 24 days on station at a time; an agreed International operating schedule is rigidly adhered to. The British ships, for example, are based at Greenock, operate at an economical speed of 9 knots, and their time on passage from and to station takes from 6 to 10 days (depending on the station) and their periods in harbour vary from 15 to 21 days. None of the ships have any lengthy overhaul period, all maintenance and repairs have to be done during the scheduled harbour period. The ships used for this job are :

United States. — Coastguard Cutters (length 250-330 feet).

France. — From 1947-1960 Frigates (length 300 feet); 1960 onwards diesel electric powered ships built specially for the job, having a length of 240 feet.

Netherlands. — Frigates (length 270 feet). The Netherlands has one new ship, specially designed for the job, under construction.

Norway and Sweden. — "Flower" class corvettes (length 205 feet).

United Kingdom. — 1947-1961 "Flower" class corvettes; 1961 onwards "Castle" class frigates (length 250 feet).

Under the terms of the Agreement, the duties of a weather ship station are :

(*a*) **Meteorological**

(1) Surface observations — wind, weather, visibility, pressure, air temperature and humidity, sea temperature, direction, period and height of waves and details about cloud formation — every three hours. (European ships and the U.S. ship at station B. now make hourly surface observations).

(2) Upper wind observations, by radar, to a height of about 60,000 feet, every 6 hours.

(3) Radio sonde observations (pressure, temperature and humidity), also to a height of about 60 000 feet, every 12 hours. These upper air observations involve the launching of a hydrogen-filled balloon, having a diameter of about 9 feet.

(*b*) **Search and rescue services**

For which the ships form part of the general search and rescue organisation. They carry special rescue equipment and their crews are expertly trained.

(*c*) **Communications services,** which include

(1) H. F. R/T for communicating with aircraft in flight and with air traffic control centres ashore.

(2) V.H.F. R/T and U.H.F. R/T for communication with aircraft in flight.

(3) M.F. W/T on the international maritime distress frequency.

(4) H.F. W/T for meteorological, administrative and operational traffic with the shore or for contact with shipping.

(*d*) **Radio navigational aids to aircraft,** which include

(1) Direction finding (V.H.F. and M.F.).

(2) M.F. radio beacon.

(3) Microwave search radar.

(*e*) **Incidental services,** which include

(1) Collection and re-transmission of radio weather messages from merchant ships.

(2) Supplementary air traffic control functions.

(3) Oceanographical and other scientific work.

Every hour the ship on duty at stations A., I., J., K. and M. respectively broadcasts her surface observations by H.F. on a rigid "staggered" schedule. Thus the surface observations at station I. are always broadcast at H plus 06 minutes, station J. at H plus 02, etc. The upper air observations are similarly broadcast on the same H.F. frequency on schedule. The U.S. vessels broadcast their observation on a different schedule. All meteorological services can thus have instant access to all these observations.

Each ocean station is surrounded by a grid, 210 miles square and the grid is sub-divided into 10 mile squares. The purpose of the grid is to provide a device for indicating the ship's position on her M.F. beacon; as long as the ship is inside the grid, she is considered to be "on station". The M.F. beacon operates on a slightly different frequency at each station (e.g. 388 kc/s at India and 370 kc/s at Juliett) to avoid interference and transmits for five minutes at H + 05, 20, 35 and 50 but operation may be interrupted when radio sonde observations are being made from 1100 to 1200 and from 2300-2400. The beacon operates automatically and transmits the call sign of the station followed by two letters indicating the grid position of the ship. Thus at station J., if the ship is in the centre of the grid where she can, in fact, normally be expected to be, the beacon transmits YJOS. Merchant ships as well as aircraft can get D/F bearings on this beacon; most aircraft are fitted with a radio compass for this purpose.

M.F. D.F. is now only used for the weather ship's own navigational purposes, because it is rare for a modern aircraft to be fitted for transmission on M.F.; it can also be used for getting bearings on other ships and survival craft in emergency. V.H.F. D.F. is used primarily for obtaining positive identification of aircraft when providing them with a radar fix and it normally operates on a frequency of 121.5 or 126.7 mc/s.

The air search radar in all weather ships is used primarily for tracking the target attached to the balloon for upper wind finding, but is is also used for providing navigational fixes to aircraft. Aboard the British and

Norwegian ships, this is a 10 centimetre naval pattern radar, stabilised in azimuth and in one directional plane. Aboard the other ships the search radar operates on $1\frac{1}{2}$ metres but plans are afoot to supersede this by a more modern instrument. The Netherlands, for example, are planning to install in their ships a 3 centimetre Silenia search radar, stabilised in azimuth and in two directional planes.

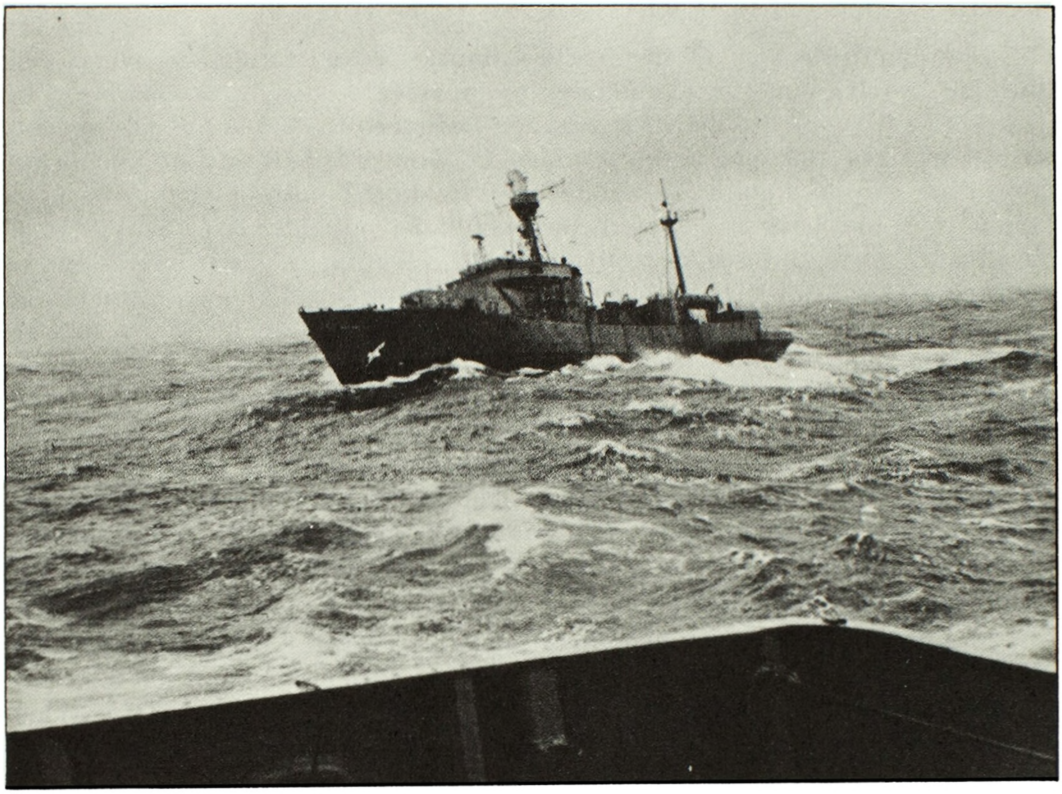

Fig. 2. — OWS *Weather Adviser.*

All the weather ships are also fitted with surface navigational radar, which is not only useful for conventional navigational purposes but may also prove very handy for close range air sea rescue work. The British weather ships have found that in thick weather they need to keep constant watch on this radar and their engines at immediate notice because of the unfortunate habit of certain merchant ships of approaching the weather ship too closely on bearing of her M.F. beacon.

In order to carry out their meteorological and radio function all the weather ships need to carry a relatively large technical complement. For example, the British weather ships include 7 meteorologists and 11 radio/radar staff in the ship's company of 57. The arrangements are similar aboard the weather ships of the other nations.

Nearly all trans-Atlantic aircraft, when in radio contact with the weather ship, request navigational aids (usually a radar fix) and the latest information about upper winds at certain heights, sometimes upper air temperature and usually information about surface wind and weather and surface pressure. An average of about 50 aircraft a day regularly contact the weather ship on duty at Stations"J" for example. Obviously the upper wind information can be a maximum of 6 hours old and temperatures 12 hours old. The weather ships also act as relay stations at times between aircraft and their control stations ashore. On request, particularly when radio propagation conditions are bad, which is not infrequent (particularly at station Alpha), they relay weather bulletins and ice information to merchant ships and to trawlers.

The depth at each of the North Atlantic ocean stations is over 1,000 fathoms, so it is not economically practicable to anchor the ship or to provide a ' permanent ' buoy for position fixing, so the ships have to depend on astral fixes and long range radio aids. The practicability of anchoring a weather ship to a clump associated with a short length of chain and long nylon rope has been considered and would be possible, but the practical disadvantages of this seem to outweigh the advantages. Experiments made by the U.S.A. authorities with automatic meteorological reporting buoys in the Caribbean have shown that a more or less ' permanent ' buoy can be moored in about 1 200 fathoms, but the expense of laying such a buoy merely for position fixing purposes at an ocean station in the North Atlantic, and the risk of the buoy breaking away in heavy weather is so great it seems hardly worthwhile. But it does seem that there would be advantages in having a buoy at (say) selected ocean stations for a relatively short period in order to assist in the making of detailed studies of surface currents, and surface water temperatures, and for micro-meteorological studies. This possibility is being actively studied.

If a buoy could be fitted with a long mast, useful raingauge observations for example might be made, (it is very difficult to find satisfactory exposure for a raingauge aboard a ship, but comparative readings at various sites aboard the ship associated with readings made at a buoy, might lead the way to finding a suitable site in the ship). A Dan buoy attached to a piano wire is a possibility, but its life in mid-Atlantic, except in exceptionally good weather, would be rather too short, so some more sophisticated form of ' pillar buoy ' associated with a nylon rope and short chain mooring seems a desirable compromise. Such a buoy might stay in position for several months. But unless the buoy were of very light weight it wouldn't be practicable for a weather ship to lay it herself (perhaps a cable ship on passage across the Atlantic might do it). In order to ' home ' on a buoy in mid-ocean, even fitted with a reflector, radar would be of limited value, unless the ship stayed within about 5 miles range, but it seems that it would be fairly easy to fit a simple transistor radio transmitter to the buoy so that the weather ship could approach it on D.F. bearings until it came into radar range. With the aid of such a buoy the ship might be able to make some very useful checks on the accuracy of Loran, Consol and other electronic aids.

For practical purposes, the Master of a weather ship does not need to know the ship's position to any prescribed accuracy, but obviously the greater the accuracy he can achieve, the better, whether it be for providing navigational aids to aircraft, for meteorological purposes, or for air sea rescue.

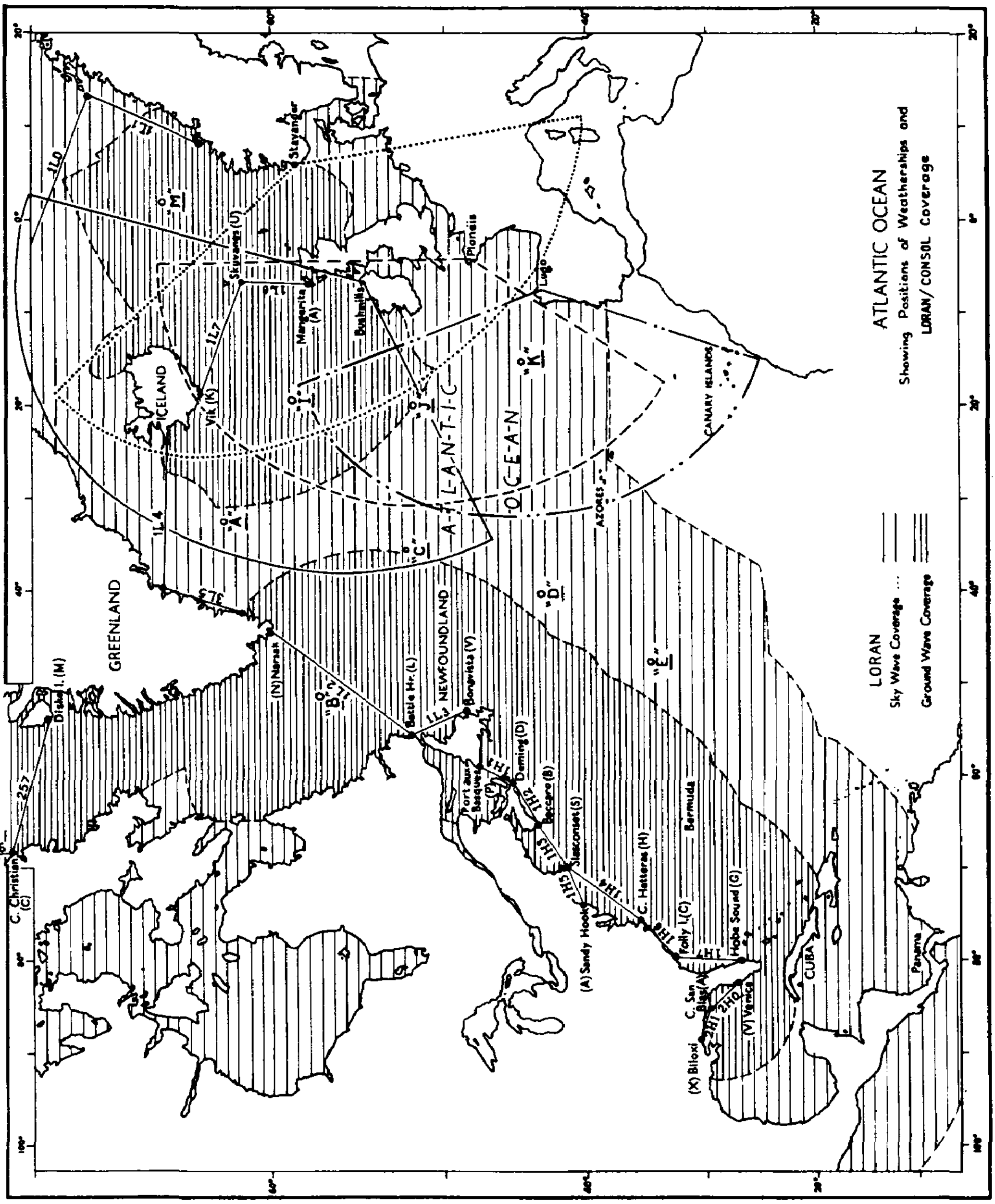
ATLANTIC OCEAN
Showing Positions of Weatherships and
LORAN/CONSOL Coverage
LORAN
Sky Wave Coverage
Ground Wave Coverage
GREENLAND
ICELAND
NEWFOUNDLAND
CUBA
Bermuda
Panama
AZORES
CANARY ISLANDS
A-T-L-A-N-T-I-C
O-C-E-A-N
Stavanger
Skuvanes (U)
Vik (K)
Margarita (A)
Bushmills
Lugo
Plonéis
(N) Narsak
Battle Hr. (L)
Bonavista (V)
Port aux Basques (P)
Deming (D)
Baccaro (B)
Siasconset (S)
(A) Sandy Hook
C. Hatteras (H)
Folly I. (C)
Hobe Sound (G)
C. San Blas (A)
(X) Biloxi
(V) Venice
C. Christian (C)
Dickel I. (M)

FIG. 3

All the North Atlantic weather ships are fitted with Loran 'A' receivers and can also receive Consol signals. In the British ships, the Loran and Consol receiver are both fitted in the chart room so that the deck officer on watch can get his own observations direct. Figure 3 illustrates the Loran and Consol coverage in the North Atlantic together with the positions of the ocean stations. It shows that only ocean stations A., I., B. and M. are in the ground wave coverage for Loran and this implies reasonably consistent accuracy with this aid at those ocean stations. Reports from the masters of various weather ships infer that in good propagation conditions Loran gives a fix with an accuracy of 2-3 miles at these 4 ocean stations. The only practicable method, at present, of checking the accuracy of a long range radio aid, is by comparison with astral observations and it is by this means that these figures were derived.

It was not until 1962 that the opening of Loran stations I.L.4 and I.L.5 (Greenland) made accurate electronic fixes possible at station A; this was very welcome for this is not normally a particularly good station for astronomical observations. In August 1962, however, horizon and cloud were favourable for sights and the following checks were made aboard the British weather ship 'Weather Monitor' : —

August 24th, astral observation	61 56 N, 32 57 W.	Loran 61 56 N, 32 58 W.
August 25th, astral observation	61 58 N, 32 20 W.	Loran 61 58 N, 32 27 W.
August 26th, astral observation	62 05 N, 32 12 W.	Loran 62 04 N, 32 14 W.
August 27th, astral observation	62 09 N, 32 04 W.	Loran 62 10 N, 32 03 W.
August 28th, astral observation	62 01 N, 32 53 W.	Loran 62 01 N, 32 56 W.

The Master goes on to say in his report, 'this close comparison (between astral and Loran fixes) was maintained throughout the period of duty on the station'. The other ocean stations in the North Atlantic come outside the present ground wave coverage and Loran observations there are nothing more than a guide as to the ship's probable position, when crossed with an astro position line or with a Consol observation. At ocean station K., for example, an observation from Loran station 7 can sometimes be used for a longitude check. At ocean station J., which is the busiest of the European stations for aircraft contacts, reports show that Loran is generally unreliable but occasionally provides a rough check on longitude. The Loran signals there are reported as being often weak to the point of being unreadable, also the angle of intersection is so acute as to detract further from accuracy. Consol is not normally needed at the ocean stations where Loran observations are good, but it proves to be useful at times at ocean station J. and reports indicate that bearings of Bushmills in particular give an accuracy there to within 5 or 6 miles in good propagation conditions. At ocean station K., Consol bearings from Ploneis and Lugo give bearings with an accuracy of 3 to 10 miles and recent reports suggest that Loran results there are slightly better than at ocean station J. A recent report also showed that at J., bearings from the 'new' Loran stations 4 and 5 can be sometimes 'crossed' with bearings from Loran stations 6 and 7. At ocean station I., a comparison of Loran fixes with positions of the ship by astral observations during 27 voyages (169 observations) proved that the mean Loran position was 044° 1.3 miles from the astral position. At ocean station J., a similar series of observations showed that the mean Loran position was 063° 3.8 miles from the mean of the astral positions. The general opinion of the masters of the ships is that Consol is not very accurate, but that it gives useful approximations at ocean stations J. and K., particularly at K. where good latitude position lines are obtainable from Lugo. Both Loran and Consol bearings are crossed wherever possible by astral position lines.

The frequency with which astral observations are obtainable at an ocean station obviously depends on meteorological conditions, for which the North Atlantic has rather a bad reputation ! The European ocean stations A., I., J. and K. are fortunate in experiencing little fog. In a five year period, at ocean stations I. and J. respectively the percentage frequency of occasions when visibility was 5 miles or less from November to April was 18 % and 15.7 % and from May to October it was 16.4 % and 20.5 % ; the figures for whole year were 17.2 % and 20.5 %. This infers the horizon would be good enough for an astral sight on about 80 % of occasions. At stations I. and J. visibility of 1 mile or less only occurred on 2.4 % and 3.2 % of occasions respectively. At the United States station B., at the mouth of the Davis Strait, visibility of 5 miles or less occurs on about 50 % of occasions throughout the year and a visibility of 1 mile or less is experienced on 26 % of occasions (7 days per month). But station B. is well served for Loran observations, so perhaps the lack of ' sights ' is not so serious there. During the same 5 year period, totally overcast sky (8th cloud cover) at noon ship time was recorded on 25 % of occasions at station I. and 30 % at station J. — this infers that a latitude by sun would be unobtainable on the same percentage of occasions. An examination of deck logs of British weather ships shows that noon sights were obtained on an average of 80 % of occasions, at these two stations, which seems to fit in broadly with these statistics.

Reports from the Masters of various North Atlantic weather ships indicate that a navigational fix by more or less simultaneous observations of 2 or more heavenly bodies is generally obtainable on about 60 % of the days the weather ship is on duty at a ' station '. The Master of one British weather ship stated that it is rare that the ship is more than 48 hours without a sight.

A study made by the British Institute of Navigation in 1957 inferred that in favourable conditions one could expect a fix from simultaneous observations of two heavenly bodies by an average observer to be accurate to about 0.75 miles. It seems reasonable to assume that the mean of a 'good' Astral fix and a 'good' (Ground wave) Loran observation would give a pretty accurate position.

In very general terms it can be said that at stations A. and I., under average conditions the Master of the weather ship on duty would know his position within two miles and it seems that there would be a somewhat similar answer at stations B. and M. At J. and K. he would generally know his position to within about 5 miles but at these two stations if a sight has not been obtainable for about 48 hours and there has been generally stormy weather he might not know his position closer than 7 or 8 miles. At station K., there is an indication that astronomical observations are more readily obtainable than at the other stations and in consequence less reliance needs to be placed on position finding by electronic means.

No exact details are available about ocean stations C., D. and E., but it seems probable that results at C. and D. would be similar to those at J. and K. respectively, whereas E., would be a bit better, because of more favourable meteorological conditions there.

Obviously, at any of these ocean stations, under favourable conditions, the accuracy will be greater than these figures suggest. There seems to be no way at present of proving whether a good sight or a good Loran observation is the more accurate fix. As the simultaneous astronomical observation is the more tangible and more easily verified, it seems reasonable to take this as the yard stick and assume plus or minus 0.75 miles as the most accurate position to be expected and to look upon Loran, Consol (and Dectra) for the present as being very valuable aids.

There is evidence that in average conditions the accuracy of the radar fix that a weather ship can expect to provide to a transatlantic aircraft at a slant range of 50 miles is about 7 miles and at a slant range of 100 miles the accuracy would be about 10 miles, taking into account the instrumental accuracy of the radars in use.

It is obvious that the accuracy with which the Master of a weather ship knows his dead reckoning position depends upon wind, waves and surface current. As the weather ships spend a large portion of their time lying stopped, the uncertainties due to course and speed (bad steering, slip, etc.) which are suffered by a ship when steaming are eliminated and the master should, as a result of experience, be able to form an accurate estimate of the ship's drift to leeward, in various conditions of trim and with various wind conditions. For example, experiments with a Dan buoy with a steel plate attached at such a depth that it was unaffected by surface current showed that the British 'Flower' class vessels set to leeward at about 1.4 knots with a force 8 wind. It has been found from experience that the British weather ships nearly always lie with the wind on the quarter and they can lie quite comfortably stopped with winds up to about force 9 Beaufort. Incidentally, these experiments also indicated that a heavy swell had the effect of setting the ship to leeward, irrespective of the current.

During a five year period, at station I., force 10 winds were experienced on five days a month and force 8 winds on 12 days a month from November to April; at station J. force 10 winds and over occurred on 2 days a month, and force 8 winds and over on 10 days a month. From May to October no force 10 winds were recorded at either station and force 8 winds occurred on 3 and 6 days per month respectively.

The surface currents at the various North Atlantic ocean stations are fairly well known to the Masters of the weather ships, both as a result of a long series of personal observations and from a study of the ocean current atlases issued by various authorities; like almost all ocean currents they have their periods of variability, and are apt to be affected by long-period or strong winds. At stations I. and J. the mean resultant current is found to be setting about 080° 4 ¾ miles per day.

At stations I. and J., during the year 1960, the result of the prevailing wind and current combining to set the ship to the eastward was that the British weather ships had to steam an average daily distance of about 25 miles to regain the centre of the station. Although a weather ship is technically 'on station' anywhere within the 210 mile grid encircling that station, for various practical reasons she should endeavour to keep in the vicinity of the centre. The Master is given discretion as to how he achieves this; weather maps based upon analyses issued by radio are plotted daily aboard weather ships and most of the masters do some form of 'meteorological navigation'. Whenever an upper wind observation is made, the ship has to be headed into the wind in any case, to facilitate launching the balloon.

Much has been written recently about the effect that sea and swell waves have upon a ship's progress through the water, stressing that this effect is greater than the wind effect; the 'weather routeing' technique which seems to have been satisfactorily carried out by the U.S. and Netherlands authorities is based upon this theory. But sea waves are obviously related to the wind and in general terms one can assume that when a ship in mid ocean is under the influence of (say) a force 8 wind, then the fetch will normally be such that she will experience the sea waves created by force 8 wind, as per the sea equivalents of the modern version of the Beaufort scale of wind force. But the height of the sea is affected also by the length of time that the wind had been blowing from a certain direction, and by the relative temperature of sea and air and by the complication of swell. So that the amount a stationary ship is set to windward (irrespective of surface current) is dependent upon a combination of wind, sea waves and swell waves. The possibility of using some kind of sea anchor to lessen the drift of a weather ship to leeward has been considered, and the ships are perhaps not too large for this, but any such device that would be effective would be bulky and cumbersome to handle at best and its practical value would be questionable. Economy of fuel is obviously important to a weather ship, but the amount of fuel used to regain the ocean station centre at slow speed isn't really very great.

The possibility of 'fixing' the weather ship's position by bottom soundings has been considered and in fact a study of the chart indicates that there are some helpful bottom contours at some of the ocean stations, but a provision of suitable deep echo sounding apparatus is somewhat expensive, and as the accuracy of such a method for navigational purposes is doubtful, it hasn't been tried out yet. But it seems that a detailed study of the bottom contours at each of the ocean stations, and on passage from and to station might serve a useful hydrographic purpose, and this added reason for the observations might justify the expense.

The possibility of using long range M.F. D.F. bearings as another means of checking the weather ship's position has been considered, but all the ocean stations are too far from the shore D.F. stations for such bearings to be accurate enough to be of practical value.

Aboard the British weather ships a series of experiments were carried out with Dectra apparatus, as this seemed to hold promise of greater long range accuracy than Loran, at station J. But, although Dectra has proved to be suitable for aircraft, it has not yet been perfected for use aboard ship, but when this does occur it is expected that further tests will be carried out aboard the British weather ships.

Weather ships provide an useful platform for experiments and tests to be carried out with various kinds of position-fixing devices and the authorities responsible for operating these ships are always willing to make facilities available aboard them for this kind of work to be done.

It has been mentioned earlier, that all the weather ships make hourly observations of direction, period and height of waves; the highest wave so far recorded by a British weather ship was one of 67 feet at station J. in 1961 with a force 12 wind.

If the wind force exceeds force 10, the masters of the British weather ships find they need to steam at slow speed; the decision as to whether to run or get the wind on one bow or other depends on circumstances — but usually it seems preferable to hold the wind on one bow so as not to interrupt the balloon launching programme. The meteorologists pride themselves in being able to launch a balloon in a force 11 wind ! There have been two occasions, during the 14 years that the weather ships have been in operation, when very prolonged storm conditions forced the ship outside the limits of her station grid !

The North Atlantic ocean stations provide unique opportunities for long term geophysical observations to be made at a fixed point in the ocean, and as stated earlier, the International Agreement specifies that operating authorities should give encouragement for work of this nature to be carried out aboard the weather ships. Magnetic variation observations, for example, are simple to make aboard ship and don't need any special instruments. Under arrangements made by the British Hydrographic Office, all the European weather ships make at least one swing for this purpose per voyage, and send the resulting observations to London. All the weather ships make oceanographic observations of one kind or another. The following programme is carried out, for example, aboard the British weather ships at present : —

(*a*) Deep soundings for temperature and salinity are made weekly on station to a depth of 1 800 metres maximum, readings being made at fixed depths beginning at 300 metres.

(*b*) Twice daily, except when weather conditions are too severe, a bathythermograph sounding is made to a depth of 450 feet.

(*c*) On station and on passage, hourly sea temperature observations are made with the aid of an insulated bucket — at the surface.

(*d*) Throughout the voyage a continuous record of sea temperature at a depth of 12 to 15 feet is made by means of a platinum resistance thermometer mounted in the ship's condenser intake — the thermometer being 5 feet from the ship's side — and operating a distant reading indicator in the ship's meteorological office.

(*e*) On passage, both outward and homeward, observations are made with a hardy continuous Plankton recorder.

(*f*) On station, portable hauls are made weekly, from a depth of 100 metres, with a 4 centimetre coarse mesh Plankton net for zoo-plankton.

(*h*) When at station Alpha, successful attempts have been made to catch redfish for biological research purposes.

(*j*) Drift bottles are dropped at every even degree of longitude during outward and homeward passage and once a week on station.

Aboard all the ocean weather ships, surface current observations are made whenever possible by taking the difference between the ships D.R. position by astronomical observations.

Aboard the British weather ships, regular observations are being made of solar radiation, using a solarimeter, and of total radiation by means of a flux metre mounted at the end of a boom (one each side of the ship); a continuous record of these observations is made on a distant reading recorder in the ship's meteorological office.

Other scientific work aboard these ships has included seismic observations (using explosive charges) to determine the nature of the sea bottom; various micro observations with Dan buoys and aboard the ship to study the sea and air temperature near the sea surface; and special observations of visibility and wind force. Aboard one of the British weather ships, some extensive 'ship motion trials' were made involving the use of a roll and pitch recorder, an accelerometer, and a wave recorder both aboard the ship and mounted on a buoy.

REFERENCES

[1] *Journal of the Institute of Navigation,* Vol. X, July 1957, 'The Accuracy of Astronomical Observations at sea'.