STUDIES ON DISTRIBUTION OF OXYGEN IN THE NORTH ARABIAN SEA DURING THE POST MONSOON PERIOD

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Study on distribution of dissolved oxygen is important from the point of view of productivity and structure of water masses. Water samples at about 60 stations spread over the Northern Arabian Sea were collected and their oxygen conten estimated. The study reveals fairly high oxygen content in Surface waters off the Bombay coast and along latitude 15°N. Progressive lowering in depth of oxygen minimum zone from 24°N Southwards is also noticed. Subsurface upwelling around 60°E, 20°N seems to be in progreess.

Study of distribution of dissolved oxygen in the ocean is important from the point of view of productivity of water masses. It also helps in elucidating the structure of water masses. Earlier work in this field which is of special interest is of Thomsen[1]; Seiwell[2]; Richard[3]; and Myake and Saruhashi[4]. Observations recorded by the Dana and the Swedish Deep Sea Expedition[5] regarding oxygen minimum were made in the Southern part of the Arabian Sea. In the recent years important contributions, however, have been made by Jayaraman and Gogate[6], Jayaraman[7], Carruthers *et al.*[8] and Ramamirtham and Jayaraman[9]. But their investigations have been mostly in the coastal waters of the Arabian Sea. Thus information available so far is for limited regions only and not based on systematic study. With this object in view an intensive Oceanographic Research programme in the Indian Ocean under the name—'International Indian Ocean Expedition' was started in 1961 by the International Council of Scientific Unions and UNESCO. The programme of the Indian participation in this joint venture was developed by the Indian National Committee on Oceanic Research (INCOR). Active participation by India commenced in the year 1962 when one of our research vessels INS KISTNA made her first four cruises in the Arabian Sea during post monsoon period. On the basis of observations made at about 60 stations spread over the Northern Arabian Sea certain tentative conclusions have been drawn and presented herein.

AREA UNDER INVESTIGATION

The part of the Arabian Sea which is in the North of latitude 15°N and bounded by longitudes 60° and 72·5°E was covered by a net work of 60 observation stations. The distance between two successive stations was approximately 60 miles. Details regarding positions of stations, dates and timings of collection of water samples are given in Appendix 'A'.

ANALYTICAL TECHNIQUE

The classical Winkler procedure[10] has been adopted throughout for the determination of dissolved oxygen in the sea water samples. Tight fit ground glass stoppered bottles of 300 ml capacity were made use of for collection of water samples. Water samples were "pickled" immediately after collection and placed in the dark. Time gap between the first and second stages, pickling and titration, was usually between 6 — 12 hours. An automatic burette graduated to 0·02 ml was used. All the apparatus were calibrated before the start of the cruise.

RESULTS AND DISCUSSION

In order to facilitate the interpretation of observed data all the observation stations were grouped into eight sections as shown in Fig. 1. Oxygen concentration (ml/L) of water samples collected at stations that come under one section were plotted against the corrected depths of sampling and the isopleths were drawn. Thus a section-wise study regarding the structure of water masses in the northern Arabian Sea has become more convenient and feasible.

Section No. 1—(*Stations* 1—9 *along the Gujarat Coast*)

This section mainly represents conditions that existed over the continental shelf off the Gujarat coast. The average depth in this region was about 88 metres. Being the first portion of the maiden cruise of INS KISTNA, very few water samples were collected and analysed. Results of the analysis are presented in Table 1.

The data in Table 1 are inadequate for drawing the oxygen isopleths for the region. Thus a detailed study regarding oxygen distribution in this region in the present state is not possible. However, a look at the data suggests that water from surface down to 30 m. in che coastal region North of Bombay upto latitude 22°N is well mixed up and rich in oxygen tontent (5 — 6 ml/litre). The oxygen distribution suggests that thermocline does not

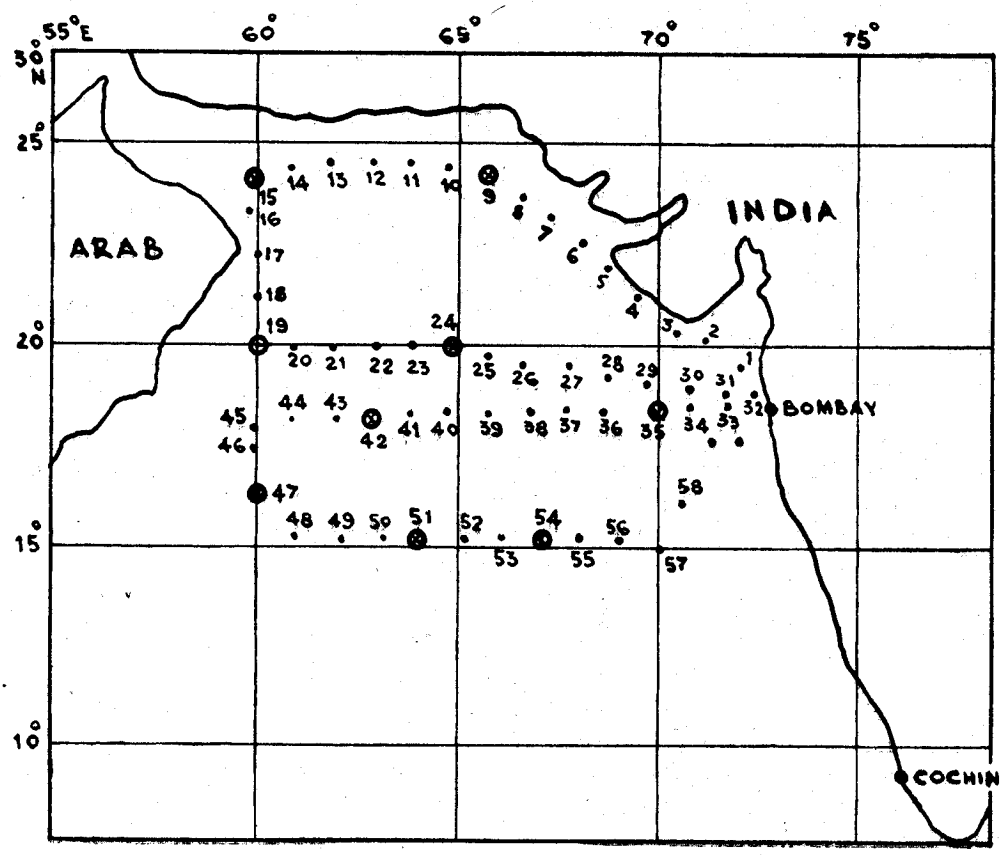

FIG. 1

TABLE 1

OXYGEN CONCENTRATION (Ml/litre)

Depth in m.	Stn. 1	Stn. 3	Stn. 4	Stn. 5	Stn. 7	Stn. 8	Stn. 9
0	6·2	5·5	..	..	..	..	..
10	3·6	4·9	..	..	5·03	4·38	4·2
20	1·8	5·0	4·4	6·0	4·86	..	..
30	..	5·18	3·4	1·94	..	2·11	2·27
50	..	..	..	..	..	1·30	1·62

seem to be clearly developed here but further North the surface water is com aratively poor in oxygen content and marked fall below 30 m. is noticed. This hints that the thermocline in this region is clearly developed. Such a feature of the thermocline along this coast was also reported by Menon and Kurup[11] and Ramam *et al.*[12].

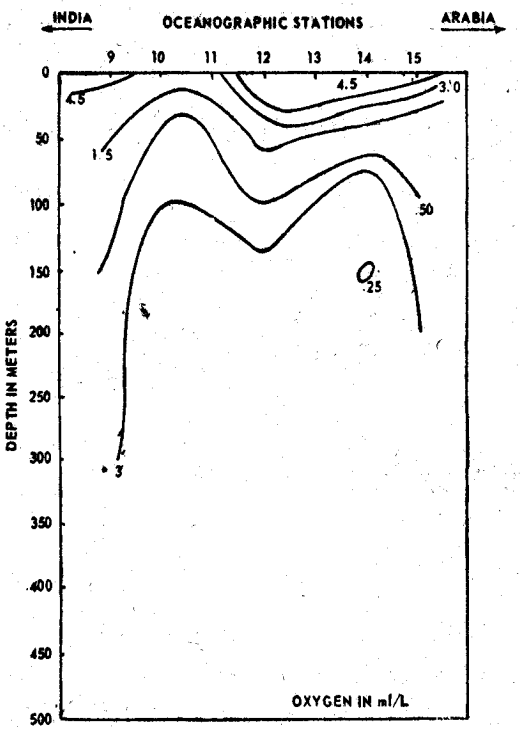

FIG. 2

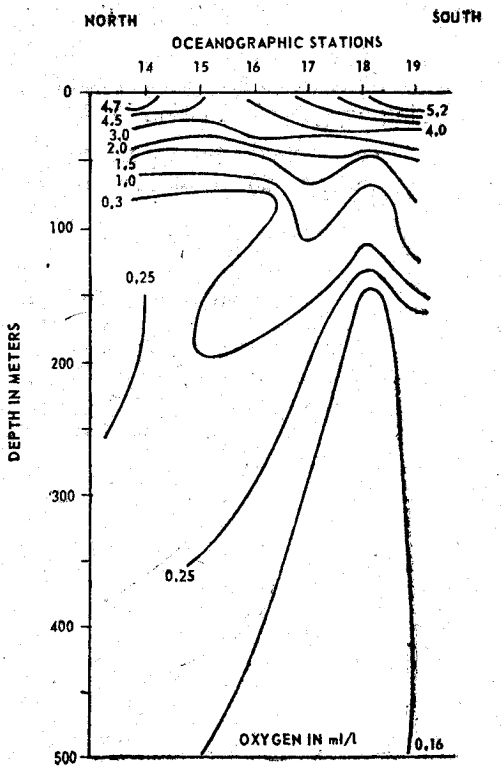

FIG. 3

Section No. 2 (*Stations* 9—14 *along latitude* 24°*N*)

The oxygen isopleths as shown in Fig. 2 indicate that maximum oxygen (4·5 ml/litre) exists in the surface waters at most of the stations except near station Nos. 10 and 11. The 1·5 ml/litre isopleth shows a ridge between station Nos. 10 and 11 and a trough at Station No. 12, west of which it rises towards the surface following the isopleths of higher values in the upper levels. The isopleths at deeper levels show ridges at Station No. 10 and 14 with a trough at station No. 12. Here regular sinking of the isopleths with rise on either side of Station No. 12 below 50 m. depth is maintained. Similar feature is indicated in the thermal structure presented by Menon and Kurup (op. cit.). A water mass with minimum oxygen content (0·25 ml/litre) seems to be localised only near station No. 14 at a depth of about 150 m.

Section No. 3 (*Stations* 15—19 *along longitude* 60°*E*)

This is a meridianal section along 60°E presenting the hydrographic conditions off the Arabian coast. This section was covered in all by 5 observation stations. The oxygen isopleths which are shown in Fig. 3 indicate that oxygen distribution at the surface shows an increase towards South from about 4·5 ml/litre at Station No. 16 to more than 5·2 ml/litre at station No. 19. At all the stations the oxygen concentration decreases with depth indicating a concentration of 2·0 ml/litre at depths of about 40 to 50 m. Below 50 m. the isopleths show appreciable sinking near Station No. 17. Isopleth with minimum oxygen content (0·16 ml/litre) seems to start below 500 m. at station No. 17 and shoots to 150 m. at station No. 18.

Section No. 4 (*Stations* 19—30 *along latitude* 20°*N*)

This section comprises 14 observation stations along latitude 20°N and extends between 60°E to 70°E. Oxygen isopleths as shown in Fig. 4 mark the following features regarding oxygen distribution in this region.

1. Zone of maximum oxygen concentration occurs in surface waters and extends down to 20 m. at most of the stations.

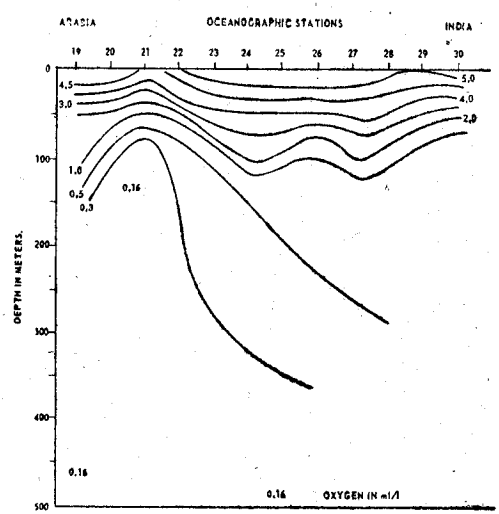

FIG. 4

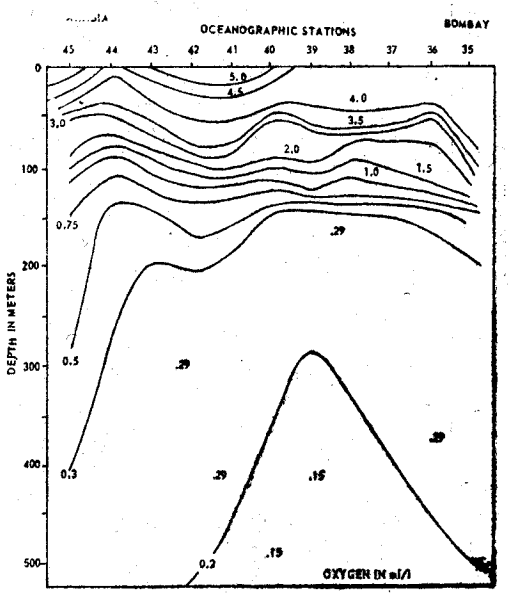

FIG. 5

2. The surface and sub-surface waters at Station No. 21 are comparatively poor in oxygen concentration. Marked 'dooming' of isopleths at these levels near this station is quite noticeable.

3. Area of oxygen minimum (0·3 ml/litre) is well developed between 150 m. to 500 m. in the Western part of the section.

Section No. 5 (*Stations* 35—45 *along latitude* 18°*N*)

Along this section there were only 11 observation stations spread along latitude 18°N; longitudinal limits of this section are 60°E and 70°E. Fig. 5 presents the vertical distribution of oxygen in this region. Study of these isopleths indicates that a zone of maximum oxygen concentration (4·5—5·0 ml/litre) from surface to 30 m. is confined to the Western flank of the section. At station 44, the isopleths from the surface layers show marked doming, a pattern similar to that near Station No. 21 along 20°N. Existence of almost uniform zone of oxygen minimum (0·15—0·20 ml/litre) is observed at 300 m. and this extends down to 500 m. or more at most of the stations.

Section No. 6 (*Stations* 45—47 *along longitude* 60°*E*)

It is a short meridianal section along 60°E. Latitudes 18°N and 16°N are the upper and lower limits of this section. The section was covered by 3 observation stations. The distribution pattern as shown by the disposition of oxygen isopleths (Fig. 6) indicates that water layers from surface down to 40 m. contains maximum oxygen content. Below50 m. the isopleths show oscillatory behaviour. Appreciable depression in the 0·75 ml/litre isopleth to a depth of about 250 m. near Station No. 45 from a depth of about 160 m. at Station No. 47 is observed. A limited zone of water mass with minimum oxygen content (0·29 ml/litre) is noticed near Station No. 45 at a depth of about 420m.

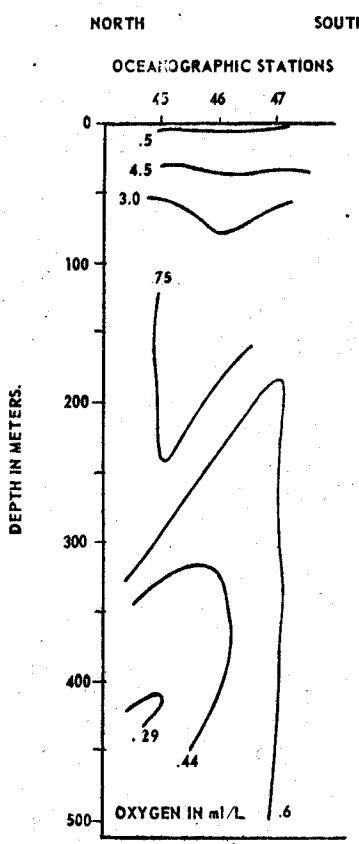

FIG. 6

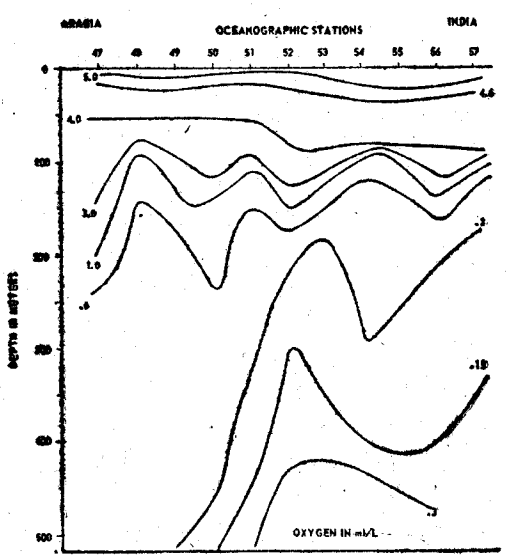

FIG. 7

Section No. 7 (*Stations* 47-57 *along latitude* 15°*N*)

In this section observations were made at 11 stations spread along latitude 15·5°N. Meridional limits of the section are 60°E and 69°E. Study of oxygen isopleths, as shown in Fig. 7, reveals that oxygen distribution from surface down to 40 m. is fairly uniform at all the stations. However, thickness of the well mixed surface waters is slightly reduced in the West. It is also observed that isopleths below 80 m. show wavy trend while the gradients within the layers increase towards the East. This structure within the layer is similar to that of thermocline along this section as indicated by Menon and Kurup[11].

Section No. 8 (*Stations* 57-60)

It is a diagonal section that runs about 15°N and 70°E in the North-East direction to wards Bombay. The section comprises of 4 observation stations. A close study of the isopleths as shown in Fig. 8 reveals that surface water down to 50 m. contains maximum oxygen 4·27 ml/litre isopleth seems to start from 90 m. depth near Station No. 57 and ascends to 20 m. level near Station No. 60. A sharp decrease in oxygen content in water layers below the said isopleths is noticed. 'Depression' in 0·3 ml/litre isopleth near Station No. 58 at a depth of about 300 m. is quite noticeable. In the same area another isopleth from a depth of about 500 m. shows marked doming but in the reverse order.

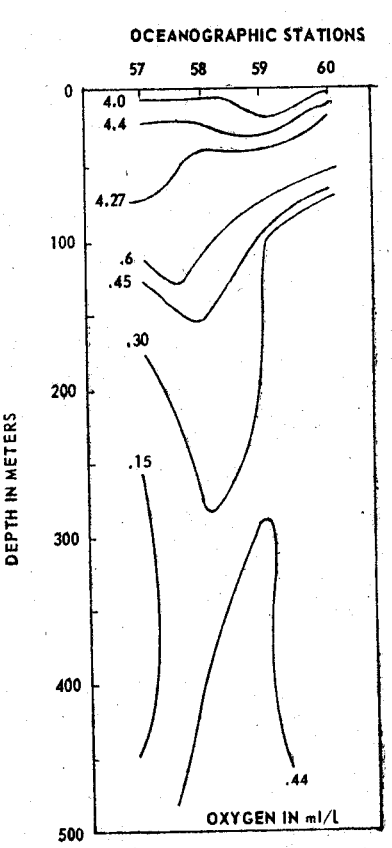

FIG. 8

CONCLUSION

On the basis of observations notice in the preceeding sections following conclusions regarding oxygen distribution in relation to water mass characteristics can be arrived at.

Existence of higher concentration of dissolved oxygen in the surface and sub-surface waters off the Bombay coast (along 20°N upto 22°N) and along latitude 15°N suggests the possibility of higher concentration of phytoplankton in these regions. Upwelling, which was reported to have occurred in the former region[6,8] and record of high temperature values in the surface layer in the latter region[12], are perhaps the main reasons for it.

Zone of low oxygen (0·3 ml/litre) is well developed along latitude 15°N at a depth of about 200 m. and extend down to 500 m. westwards; whereas the same exists at less than 100 m. along 18°N (eastwards only; Stn. No. 60). For want of other biochemical data the existence of low oxygen concentrations at variable depths could not be explained at present.

In the vicinity of meridians 62°E and 63°E along the latitude 24°N the waters of higher density from the Gulf of Oman flow into the Northern Arabian Sea. This water mass of

higher density partially mixes with the surface waters and sinks down partially. Existence of zone of oxygen minimum at a depth of 100—150 m. and relatively higher salinity values provide additional support to this deduction.

It is observed that conditions in the Northern Arabian Sea upto latitude 20°N are somewhat less stable in the early post monsoon period. But further down along latitude 15°N the conditions are fairly stable. Whether this can be the cause of progressive lowering in depth of the oxygen miminum zone needs further studies. Menon and Kurup[11] have reported existence of thick isothermal layers and increase vertical stability in the southern part of the Arabian Sea in the month of November.

Near longitude 60°E along latitude 20°N the existence of oxygen minimum zone at a depth less than 100 m. indicates that upwelling to certain extent in the sub-surface layers was in progress at the time of observations. The temperature structure presented by Menon and Kurup[11] suggests an anticlockwise circulation of the water mass. Perhaps this circulation is responsible for divergence and associated upwelling.

Since data on nutrients and plankton density are not available at present, it is emphasised that conclusions drawn should be considered essentially preliminary in character. However, it may be seen that a fairly generalised picture regarding oxygen distribution and structure of water masses in the Northern Arabian Sea during the post monsoon seasons has been obtained.

Rechford[13] has convincingly shown the intrusion of Persian Gulf waters into the Indian Ocean through the Northern Arabian Sea from his study of the salinity maximum in the North Indian Ocean. However, his data (from Vityaz 1960) did not extend North of 20°N. It will be interesting to correlate the results of this present study with a more rigorous study of the hydrographic conditions in this part of the Arabian Sea.

A water mass with characterised poor oxygen content appears to be spreading approximately South-East wards from the region of Gulf of Oman where it appears at a depth of about 120 m. and sinks to a greater depth (300 m.) at its South-Eastern limits.

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APPENDIX 'A'

Station No.	Position		Date	Time (1st)
	Lat.°N	Long.°E		
1	19°25′	72°00′	25-9-62	0050
2	20°02′	71°13′	25-9-62	0720
3	20°15′	70°30·5′	25·9-62	1350
4	21°11′	69°46·5′	25-9-62	2020
5	21°46′	69°02·5′	26-9-62	0312
6	22°20′	68°15·5′	26-9-62	0920
7	22°58′	67°27′	26-9-62	2015
8	23°27′	66°41′	27-9-62	2015
9	24°15′	65°45′	27-9-62	1145
10	24°18′	65°00′	27-9-62	2015
11	24°18′	64°00°	28-9-62	0405
12	24°18′	63°00′	28-9-62	1230
13	24°15′	61°58′	28-9-62	1825
14	24°12′	60°58′	29-9-62	0110
15	24°00′	60°00′	29-9-62	0740
16	23°05′	60°00′	29-9-62	2135
17	22°12′	60°11′	30-9-62	0430
18	21°15′	60°00′	30-9-62	1135
19	20°00′	60°00′	30-9-62	1900
20	20°00′	61°00′	1-10-62	0330
21	20°00′	61°59′	1-10-62	0915
22	20°00′	63°00′	1-10-62	1435
23	20°00′	63°55′	1-10-62	2030
24	20°00′	65°00′	2-10-62	0334
25	19°51′	65°57′	2-10-62	1430
26	19°45′	66°50′	2-10-62	2020
27	19°33′	67°42′	3-10-62	0200
28	19°24′	68°50′	3-10-62	0900
29	19°11′	69°50′	3-10-62	1430
30	19°03′	70°44′	3-10-62	2110

Station No.	Position		Date	Time (Ist)
	Lat. °N	Long. °E		
31	18°55′	71°45′	4-10-62	0128
32	18°52′	72°27′	4-10-62	0540
33	18°45′	71°45′	13-10-62	1745
34	18°45′	70°40′	14-10-62	0016
35	18°46′	70°05′	14-10-62	0430
36	18°36′	68°57′	14-10-62	1315
37	18°35′	67°54′	14-10-62	2030
38	18°31′	66°52′	15-10-62	0305
39	18°27·25′	65°52′	15-10-62	0445
40	18°25′	64°47′	15-10-62	1620
41	18°31′	63°55′	15-10-62	2320
42	18°15′	62°52′	16-10-62	0445
43	18°12′	62°00′	16-10-62	1235
44	18°08′	60°56′	16-10-62	1920
45	17°40′	60°00′	17-10-62	0155
46	16°35′	60°00′	17-10-62	0845
47	15°30′	60°00′	17-10-62	1615
48	15°31′	61°00′	18-10-62	0100
49	15°30′	62°00′	18-10-62	0745
50	15°30′	63°00′	18-10-62	1400
51	15°30′	64°00′	18-10-62	2030
52	15°30′	65°00′	19-10-62	0305
53	15°29′	66°00′	19-10-62	0945
54	15°30′	67°00′	19-10-62	1620
55	15°30′	68°00′	20-10-62	0052
56	15°30′	69°00′	20-10-62	0740
57	15°13′	70°00′	20-10-62	1345
58	16°18′	70°28′	20-10-62	1930
59	17°04′	71°17′	21-10-62	0030
60	17°50′	71°55′	21-10-62	0531