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STUDY OF THE DISTRIBUTION OF SEA SURFACE TEMPERATURE IN THE REGION OF THE ANGRA DOS REIS NUCLEAR POWER PLANT-ANGRA-03 MISSION

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14. Abstract/Notes

The Angra-03 Mission was made during 22-25 March, 1983. Four experiments were completed, one each day, to collect data. Sea surface temperatures and wind measurements were obtained from a boat during each experiment, while visible and thermal infrared satellite data were collected at INPE receiving stations in São José dos Campos and Cachoeira Paulista. The INPE aircraft was able to fly over the Angra area only on 24 March and did not record any data. Vertical profiles of air and dew point temperature were obtained from radiosonde soundings made at Galeão International Airport on the same days. An evaluation of mission data showed that surface wind direction and speed were strongly affected by the local coastal terrain. The local winds were effective in advecting surface water in/out and around Piraquara de Fora Bay. During the 4-day period, the Angra power plant operated at about 25% of capacity and cooling water discharged into Piraquara de Fora Bay was about 4°C warmer than ambient temperatures. Vertical profiles of precipitable water vapor were computed and the vertically integrated values are also discussed.

15. Remarks

ACKNOWLEDGMENTS

Appreciation is expressed to the Comissão Nacional de Energia Nuclear (CNEN) for their support, through Contract Number 840.1.031.0/82. Thanks are also given to Dr. N.J. Parada, Director General of INPE for the fine support provided by INPE in resolving problems that occur during the planning and execution of such a field project. The Brazilian general contractor for the Angra dos Reis plant, FURNAS, generously provided the high speed boat with an extremely competent pilot. Mr. Luis Henrique, chief of the Radioecology Laboratory (FURNAS) at the power plant site, kindly made laboratory space available, so INPE personnel could make final field preparations for the Angra-03 experiments. Mr. Henrique also had the Laboratory vessel make one of its routine cruises in the two bays to be coincident with the 3rd field experiment of the Angra-03 Mission.

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1. INTRODUCTION

The primary objective of Project Angra is to conduct a series of field missions in which the sea surface temperature field is mapped in various ways, near Angra dos Reis (RJ) (Figure 1). These and other data are used to derive information about how the warm water discharged into Piraquara de Fora Bay, from the cooling system of the Angra-I power plant, affects the local sea surface temperature field.

In order to facilitate the evaluation of maps of surface water temperature in both the inlet Bay (Itaorna) and the outlet Bay (Piraquara de Fora), it is first necessary to obtain information on environmental conditions prior to the operation of the power plant. Field missions, Angra-01 and Angra-02, were made to obtain such background information (Stevenson et al., 1982, 1983a, 1983b).

The second phase of field research requires information on the horizontal thermal patterns produced when the heated water is *initially* discharged, that is when the plant initiates a testing phase. Following the start of discharge of heated water, a tongue of warm water is expected to extend outward from the discharge area and undergo changes due to the local interaction of surface winds and water currents. This report describes data and results from the Angra-03 Mission which was synchronized with such a testing phase of the power plant. Missions Angra-04 and -05 are planned to occur when the power plant is in normal and commercial operation, later in 1983.

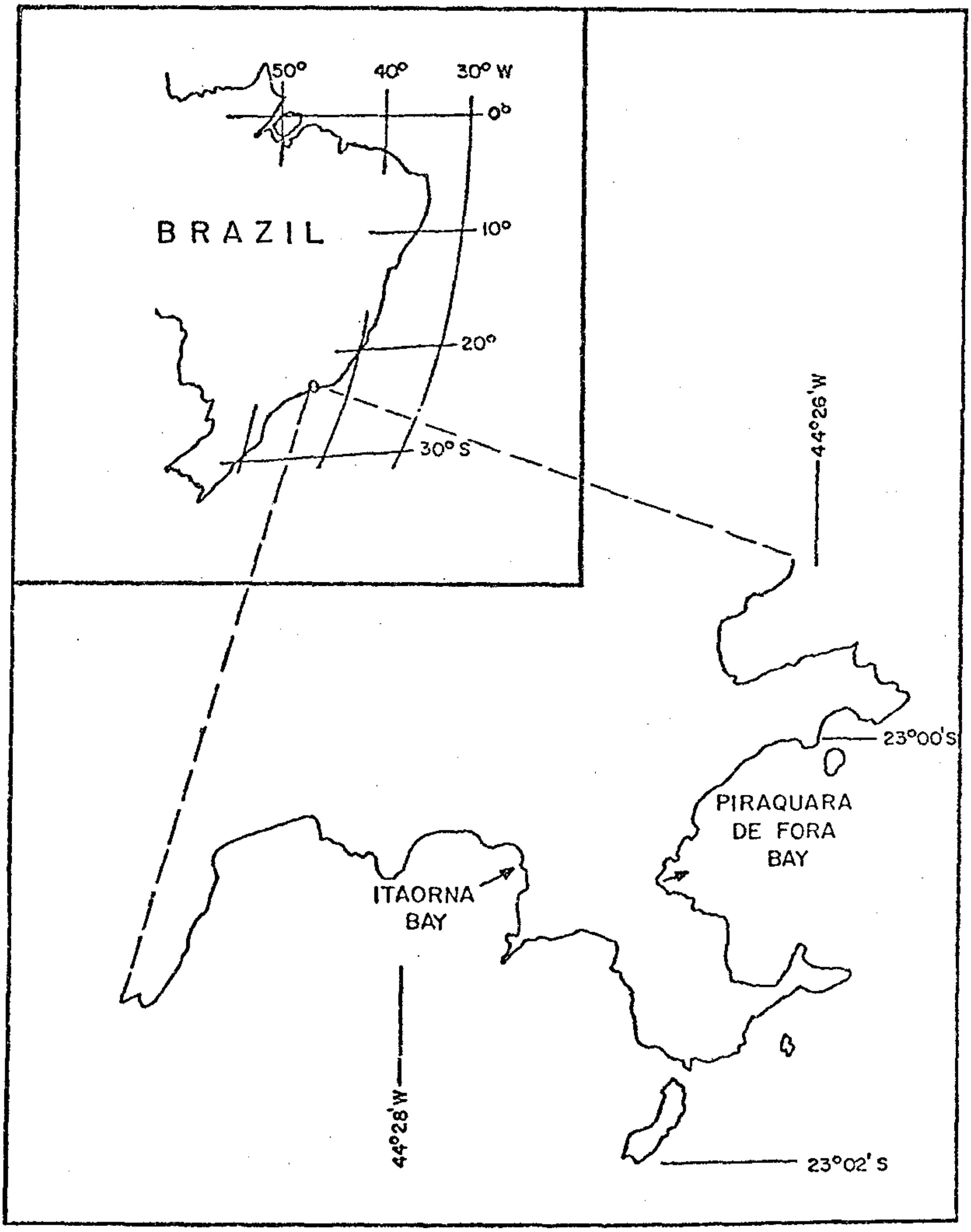

Fig. 1 - Location of PROJECT ANGRA.

Arrows indicate locations for inlet and outlet of water used to cool the power plant.

Angra-03 Mission was generally planned for March when the Angra-I plant was projected to be undergoing a testing cycle. Because of the necessity of strict coordination with the testing operations at the power plant, a number of telephone contacts were made between INPE (SJC), CNEN (RJ and Angra dos Reis) and FURNAS (Angra dos Reis), during the two week period prior to actualization of the mission. Although weather conditions were not good before the mission and poor or bad weather predicted for the following days, it was considered of primary importance to attempt to synchronize the field work in the best manner possible, with the test phase of the power plant. Information received at INPE suggested that testing cycles would be made in the latter part of the month of March at an output level sufficient for the detection of the thermal discharge. The final decision to travel to Angra was made on the morning of March 21, 1983, based on the activition of the power plant. During the period of 22-25 March, the Angra-I power plant was conducting a testing cycle and maintained an average power output of 25%. Actual power output fluctuated slightly about this average value during the 4-day period (Eng. R. Matsumura - CNEN, personal communication).

INPE personnel remained at Angra during 21-25 March, and in this time 4 experiments were conducted with the boat. Weather conditions prevented the aircraft from coming to the Angra area until Thursday, March 24, when the primary experiment was planned. Weather conditions at Angra on the morning of 24 March were reasonably good with scattered clouds present at the time of coordination with the aircraft coming from São José dos Campos (SJC). The aircraft arrived over the Angra area and after flying a flightline signaled the necessity to return to SJC due to air turbulence. The experiment continued using the boat measurements and satellite data.

Surface measurements were made with the boat on 22, 23, 24 and 25 March. Satellite data were also acquired on these days in support of the ground measurements. On 24 March the boat used by the Radioecological Laboratory of FURNAS also conducted a set of stations in order to increase the density of data coverage. Data collected by the FURNAS boat will be separately processed and published by the Radioecology Laboratory as part of its ongoing research program.

The fourth experiment was made on Friday, March 25. Weather conditions over the Angra area were excellent and cloud free at the time of the experiment. The aircraft did not participate during the Friday experiment due to poor visibility conditions at SJC. No aircraft data were collected during the Angra-03 Mission.

The following personnel assisted in the acquisition and processing of data from the boat, satellite and aircraft.

Merritt R. Stevenson - oceanographer

Hector M.V. Inostroza - oceanographer

Paulo C.G. de Albuquerque - cartographer

Antonio Oliveira - driver

Carlos A. Steffen - physicist

Carlos A. Intrieri - pilot aircraft

Vitor A.S. Oliveira - copilot aircraft

Celso A. Monteiro - photo-technician

Nelson Yokoyama - I-100 system

Leopoldo Parada - GOES receiving station (C.P.)

Eugenio Sper - technician

Pedro R.A. Carvalho - NOAA receiving station (SJC)

Antonio Doia - boat pilot (FURNAS)

Beate M. Eschebach - meteorologist (FURNAS)

2. DATA AND METHODOLOGY

Four experiments were conducted during the Angra-03 Mission. During each experiment, the boat occupied stations according to the general station pattern used on prior Angra Missions, as well as additional stations added to provide for improved areal coverage.

The first experiment was made on March 22, 1983 and the location of stations is shown in Figure 1. As in prior missions, surface water temperatures were measured with a precision mercurial thermometer read to the nearest 0.1^{o}C. Wind measurements were made at each station using a handheld anemometer. Wind speed was read from the dual-scale meter to the nearest 0.5 knot. Wind direction was obtained by referencing the anemometer to the bow of the boat and that in turn to the boat's compass. Directions were estimated to within $\pm 2^{o}$ and together with the boat's compass are considered good to within about $\pm 5^{o}$. Wind directions as given in this report are degrees magnetic in the direction *toward*, not from, in order to be more directly related to surface water movements. A motor driven psychrometer was used at frequent intervals during each experiment to obtain wet and dry bulb temperatures read to the nearest 0.5^{o}C from which relative humidity was subsequently extracted using standard tables (Handbook of Physics and Chemistry, 1954). The second, third and fourth experiments were similar to the first except that several additional stations were added to obtain better two-dimensional coverage of surface temperature and wind conditions. Surface measurements are given for each of the experiments in Tables 1, 2, 3 and 4, respectively. The location of the stations are shown in Figures 2, 3, 4 and 5 respectively, for the 4 experiments.

Radiosonde measurements were also utilized for this Mission and these data were obtained from soundings made at Galeão International Airport in Rio de Janeiro, and later digitized and transmitted via teletype to the Department of Meteorology and Oceanography at INPE (SJC). The 1200 GMT (0900 LT) soundings were selected for comparison with this study since this time occurred in the middle of both boat and satellite measurements.

TABLE 1

SHIP STATION DATA FOR 22 MARCH, 1983

ANGRA-03 MISSION								
SHIP STATION DATA								
EXPERIMENT Nº 1: DATE: 22 MARCH, 1983								
STATION	POSITION		TIME	BKT. TEMP.	AIR TEMP.		WIND (SPEED/DIR)	
Nº	o ' " S	o ' " W	LOCAL	(°C)	DRY (°C)	WET (°C)	(KNOTS)	(°MAGN)
01	23 00 52	44 26 26	1005	27.8	Intermittent rain during experiment		calm	-
02	23 00 46	44 26 16	1023	27.8			1	237
03	23 00 38	44 26 03	1027	27.4			2	250
04	23 00 30	44 25 48	1052	26.2			2	308
05	23 00 10	44 25 25	1057	25.8			2	307
06	22 59 52	44 24 48	1105	26.4			2	313
07	22 59 47	44 25 27	1109	25.5			1	315
08	23 00 05	44 25 26	1113	26.0			3.5	354
09	23 00 16	44 25 25	1117	26.0			2	30
10	23 00 27	44 25 23	1121	26.0			3.5	17
11	23 00 42	44 25 22	1125	26.2			5	65
12	23 00 56	44 25 19	1128	25.6			5.5	64
13	23 01 09	44 25 16	1133	26.6			4	79
14	23 02 02	44 27 20	1153	26.6			2	111
15	23 01 30	44 27 03	1203	26.1			1	132
16	23 01 13	44 27 22	1208	26.0			2.5	94
17	23 00 47	44 27 49	1216	26.0			1	31

TABLE 2

SHIP STATION DATA FOR 23 MARCH, 1983

ANGRA-03 MISSION									
SHIP STATION DATA									
EXPERIMENT Nº 2: DATE: 23 MARCH, 1983									
STATION	POSITION		TIME	BKT. TEMP.	AÍR TEMP.		REL. HUM.	WIND (SPEED/DIR)	
Nº	° ' "S	° ' "W	LOCAL	(°C)	DRY (°C)	WET (°C)	(%)	(KNOTS)	(°MAGN)
A	23 00 43	44 26 31	1013	29.5				2	151
C	23 00 37	44 26 45	1018	30.9				2	51
B	23 00 32	44 26 30	1023	28.6				3.5	64
01	23 00 52	44 26 26	1026	28.2				<1	321
02	23 00 46	44 26 16	1034	28.0				1	94
03	23 00 38	44 26 03	1037	27.9				2	37
04	23 00 30	44 25 48	1041	26.6	253	239	88	calm	-
05	23 00 10	44 25 25	1050	26.6				3	105
06	22 59 52	44 24 48	1056	27.2	254	229	81	4	41
07	22 59 47	44 25 27	1101	27.4				7.5	5
08	23 00 05	44 25 26	1106	27.0				11	21
09	23 00 16	44 25 25	1111	27.0				10	46
10	23 00 27	44 25 23	1115	26.8				7	68
11	23 00 42	44 25 22	1118	26.6				7	68
12	23 00 56	44 25 19	1121	26.3				7.5	71
13	23 01 14	44 25 16	1125	26.3	268	232	75	7	61
D	23 01 12	44 25 32	1134	27.1	236	228	92	6.5	35
E	23 01 09	44 25 47	1139	27.4				5	19
17	23 00 47	44 27 49	1151	25.8				2	70

TABLE 3

SHIP STATION DATA FOR 24 MARCH, 1983

ANGRA-03 MISSION									
SHIP STATION DATA									
EXPERIMENT Nº 3: DATE: 24 MARCH, 1983									
STATION	POSITION		TIME	BKT. TEMP.	AIR TEMP.		REL. HUM.	WIND (SPEED/DIR)	
Nº	o ' "S	o ' "W	LOCAL	(°C)	DRY(°C)	WET(°C)	(%)	(KNOTS)	(°MAGN)
R≠1	23 00 47	44 27 49	0733	24.4					
R≠2	23 00 30	44 25 48	0750	25.8					
R≠3	23 00 37	44 26 32	0755	27.0					
1	23 00 52	44 26 26	0833	26.5	22.2	19.7	80	1	25
2	23 00 46	44 26 16	0835	26.6				3.5	302
3	23 00 38	44 26 03	0840	26.4	22.8	19.9	76	2.5	287
4	23 00 30	44 25 48	0844	26.3				6.5	263
5	23 00 10	44 25 25	0849	25.6				5	226
6	22 59 52	44 24 48	0853	25.0				2	216
7	22 59 47	44 25 27	0857	24.3	21.6	19.0	80	3.5	229
8	23 00 05	44 25 26	0900	25.0				3	226
9	23 00 16	44 25 25	0902	25.4				4	218
10	23 00 27	44 25 23	0905	25.6	22.1	19.6	80	4	206
11	23 00 42	44 25 22	0908	25.4				5	225
12	23 00 56	44 25 19	0912	25.5				5	272
13	23 01 09	44 25 16	0917	25.3				3	231
D	23 01 13	44 25 37	0922	25.9	22.4	19.6	77	5	252
E	23 01 09	44 25 47	0925	26.0				4.5	285
14	23 02 02	44 27 20	0939	25.0				2.5	84

(continued)

Table 3 - Conclusion

ANGRA-03 MISSION									
SHIP STATION DATA									
EXPERIMENT Nº 3: DATE: 24 MARCH, 1983									
STATION	POSITION		TIME	BKT. TEMP.	AIR TEMP.		REL.HUM.	WIND (SPEED/DIR)	
Nº	° ' "S	° ' "W	LOCAL	(°C)	DRY (°C)	WET (°C)	(%)	(KNOTS)	(°MAGN)
15	23 01 30	44 27 03	0946	24.9				<1	-
16	23 01 13	44 27 22	0952	24.9	23.6	19.9	71	1	265
17	23 00 47	44 27 49	0957	24.8				3	20
A	23 00 43	44 26 31	1012	28.5				3	335
C	23 00 37	44 26 45	1017	29.9				1	238
B	23 00 32	44 26 30	1020	27.5				4	296

TABLE 4

SHIP STATION DATA FOR 25 MARCH, 1983

ANGRA-03 MISSION									
SHIP STATION DATA									
EXPERIMENT Nº 4: DATE: 25 MARCH 1983									
STATION	POSITION		TIME	BKT. TEMP.	AIR TEMP.		REL. HUM.	WIND (SPEED/DIR)	
Nº	o ' "S	o ' "W	LOCAL	(°C)	DRY (°C)	WET (°C)	(%)	(KNOTS)	(°MAGN)
C	23 00 37	44 26 45	0827	30.0	23.4	19.6	70	3	319
A	23 00 43	44 26 31	0833	29.2				3	338
B	23 00 32	44 26 30	0842	26.9				3.5	305
1	23 00 52	44 26 26	0847	27.4	23.8	19.7	69	1	295
2	23 00 46	44 26 16	0852	26.4				5	281
3	23 00 38	44 26 03	0855	26.9	23.8	20.1	70	6	260
4	23 00 30	44 25 48	0901	26.3				5.5	270
5	23 00 10	44 25 25	0907	25.7	23.4	20.0	73	4.5	209
6	22 59 52	44 24 48	0914	25.8				3	257
7	22 59 47	44 25 27	0919	25.1				5	183
8	23 00 05	44 25 26	0922	25.4				3.5	229
9	23 00 16	44 25 25	0926	25.8	24.2	20.8	73	3	204
F	23 00 21	44 25 46	0937	26.4				2.5	255
G	23 00 25	44 26 09	0945	26.8				3	289
10	23 00 27	44 25 23	0953	26.0				2	262
H	23 00 26	44 24 43	0958	26.4	25.4	21.1	69	1	270
11	23 00 42	44 25 22	1006	26.0				3	224
12	23 00 56	44 25 19	1010	26.3				2.5	216
13	23 01 18	44 25 15	1015	26.7				3.5	182

(continued)

Table 4 - Conclusion

ANGRA-03 MISSION									
SHIP STATION DATA									
	EXPERIMENT Nº 4: DATE: 25 MARCH,1983								
STATION	POSITION		TIME	BKT.TEMP.	AIR TEMP.		REL.HUM.	WIND (SPEED/DIR)	
Nº	o ' "S	o ' "W	LOCAL	(ºC)	DRY (ºC)	WET (ºC)	(%)	(KNOTS)	(ºMAGN)
D	23 01 12	44 25 32	1020	26.8	25.3	20.6	65	4	268
E	23 01 09	44 25 47	1025	26.6				2	240
14	23 02 03	44 27 26	1034	26.0				5	322
15	23 01 30	44 27 03	1044	26.1				4	349
16	23 01 13	44 27 22	1047	26.2				2	64
17	23 00 47	44 27 49	1051	26.2	25.8	21.2	67	3	50

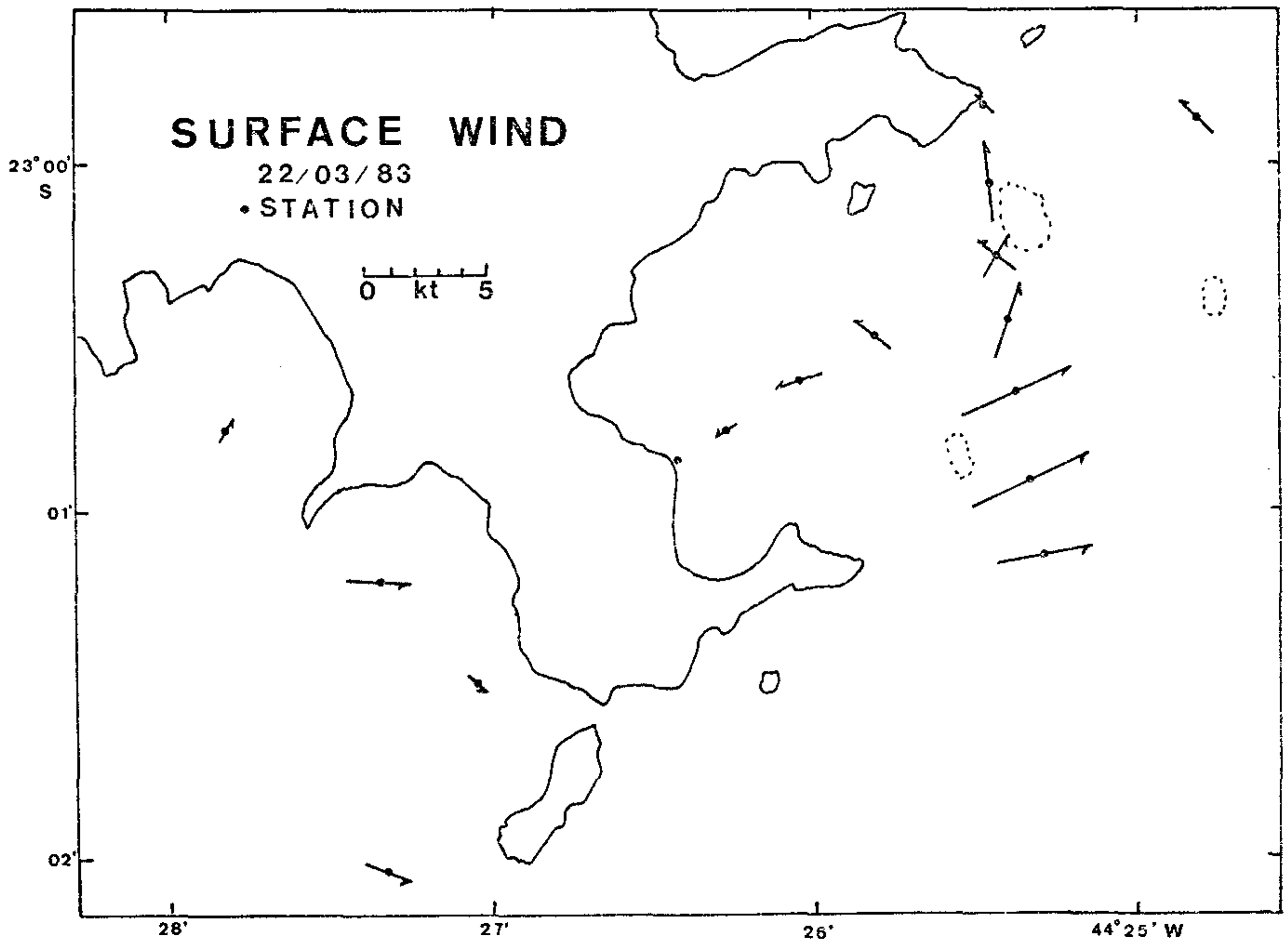

Fig. 2 - Surface wind measurements during the first experiment.

Wind arrows point in the direction of flow. Wind speed is obtained from the scale (in knots).

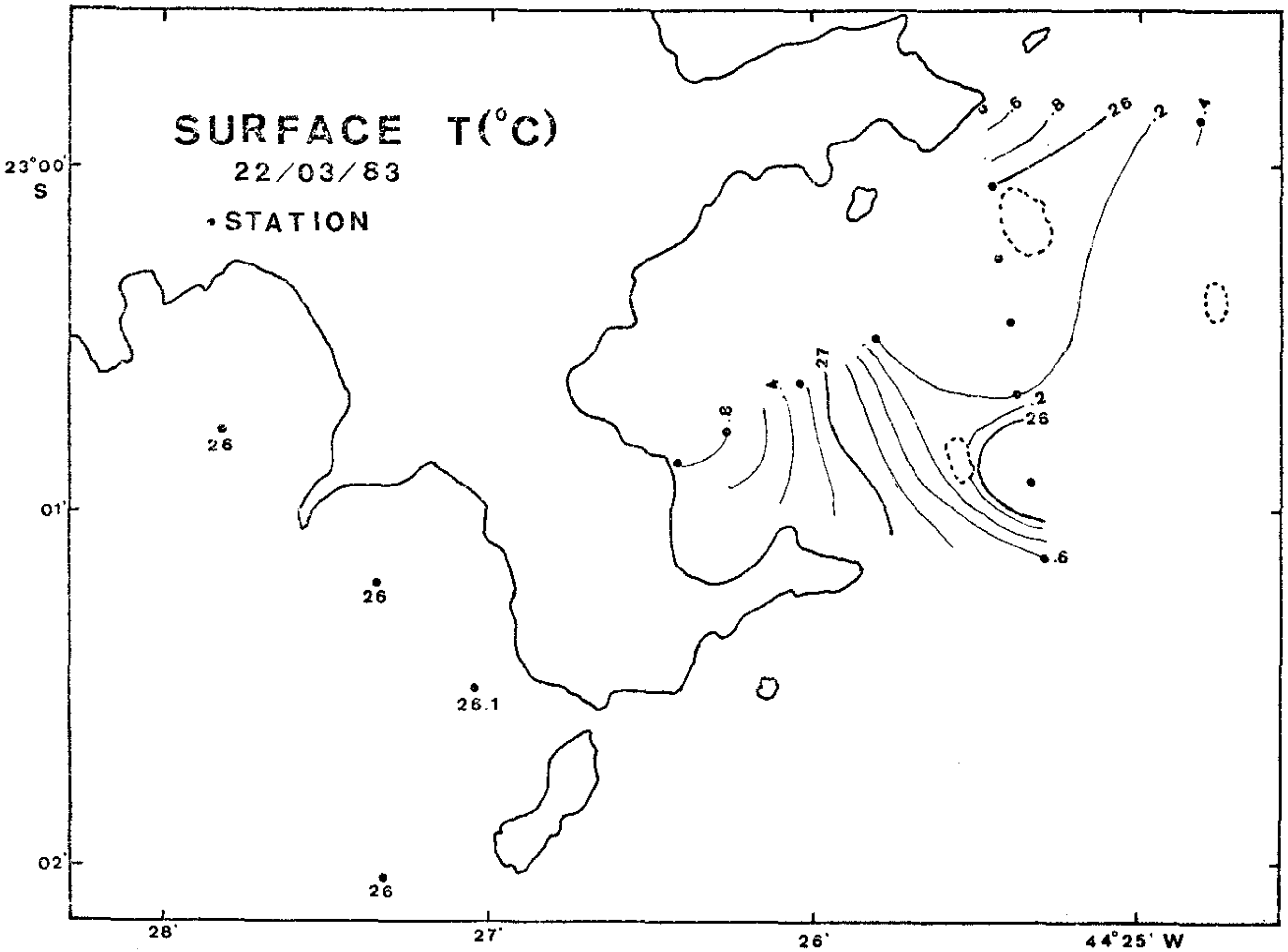

Fig. 3 - Surface temperature measurements during the first experiment.

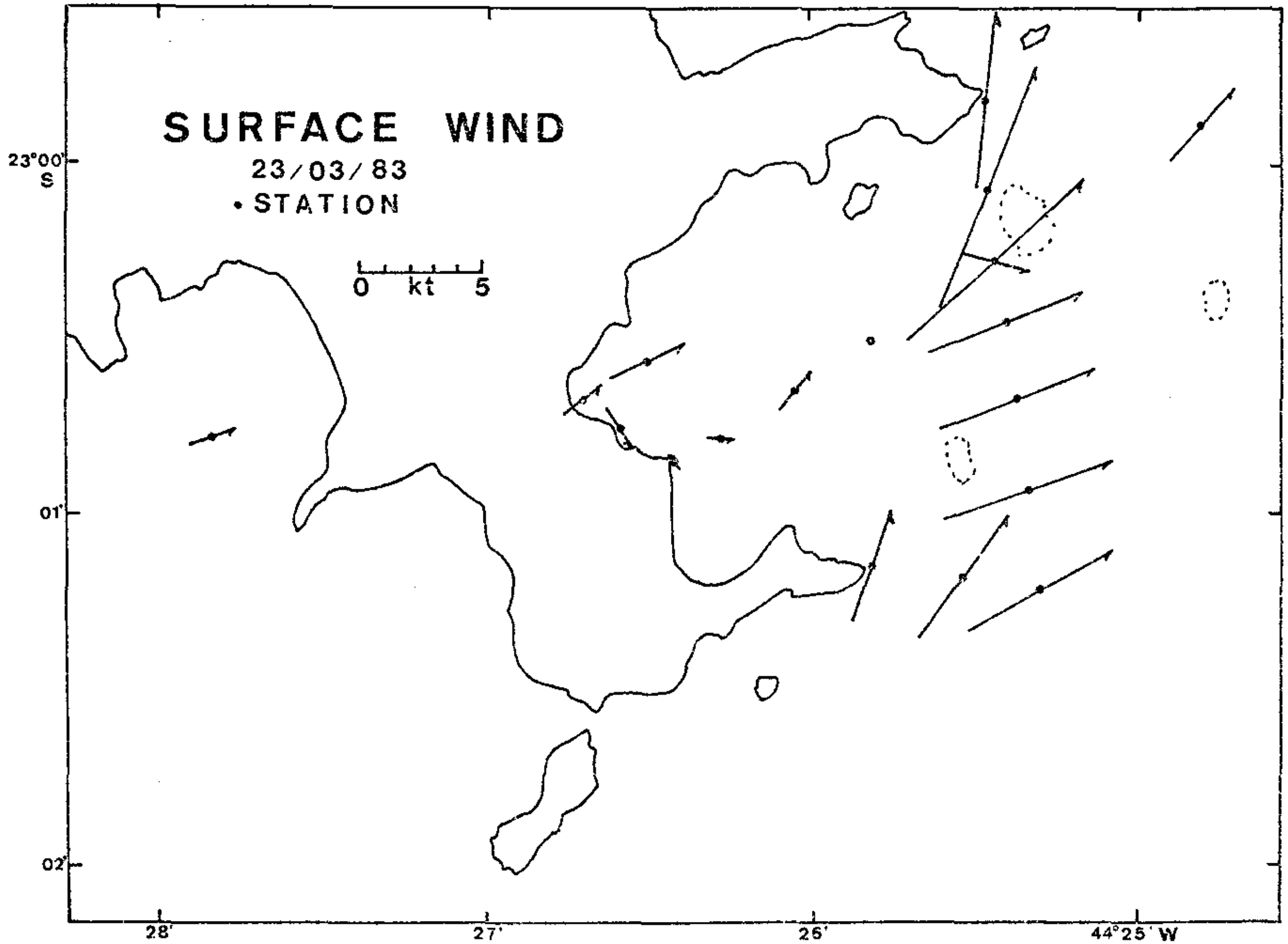

Fig. 4 - Surface wind measurements during the second experiment.

Wind arrows point in the direction of flow. Wind speed is obtained from the scale (in knots).

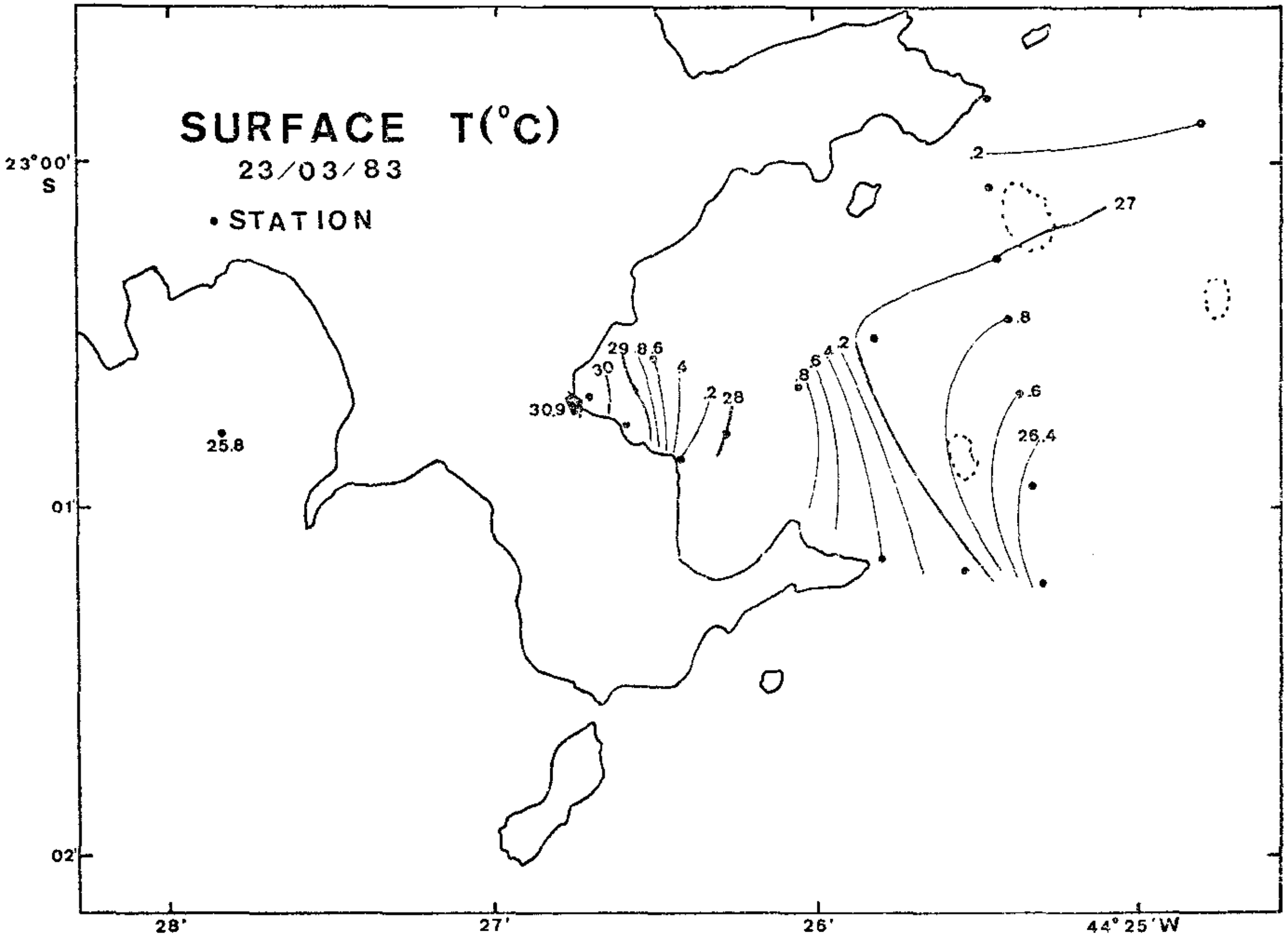

Fig. 5 - Surface temperature measurements during the second experiment.

The air temperature data were used to determine vertical (thermal) profiles in the lower atmosphere for each day of the Mission. The mixing ratio and precipitable water vapor in the air column from the surface up to 300 mb (~10,000 m) were also estimated from the air and dew point temperatures. The method used follows that described by Haltiner and Martin (1957).

Data were acquired from both the geostationary satellite GOES-5 using the INPE receiving station at Cachoeira Paulista and AVHRR data from the polar orbiting NOAA-7 satellite from the receiving station on INPE's campus at São José dos Campos. In the case of the GOES data, both old and new computer formats were used to acquire data. The old format corresponds to a global image in only the infrared channel, whereas the new format corresponds to a sectorized part of the image with both visible and infrared channels of data being recorded. The method and format of data tapes from the AVHRR instrument were unchanged from earlier missions. A summary listing of data acquired in support of the Angra-03 Mission is seen in Table 5. Due to a lack of data tapes and poor weather conditions at the start of the Mission, the tapes used to record the 20-23 March GOES images were reused to record the following days.

Following the mission, both the GOES-5 and NOAA-7 images were evaluated on the Image-100 interactive system at INPE (SJC) to determine which images contained less cloud cover and hence were the most usable for analysis. It was discovered in this evaluation process that the new data formatting at Cachoeira Paulista still contained some unforeseen software problems, with the result that the data tapes recorded in the new format were of very limited use. Consequently, emphasis was given to the single (IR) channel format and to the NOAA-7 coverage.

TABLE 5

SATELLITE DATA

DATE	SATELLITE	LOCAL TIME	TYPE OF DATA COLLECTED
20/3	NOAA-7	14:49	AVHRR - VIS/IR
21/3	NOAA-7	14:37	AVHRR - VIS/IR
24/3	GOES-5	09:00	VISSR - IR only
24/3	GOES-5	09:30	VISSR - VIS/IR sectorized
24/3	NOAA-7	15:40	AVHRR - VIS/IR
24/5	GOES-5	09:00	VISSR - IR only
25/3	GOES-5	09:30	VISSR - VI/IR sectorized
25/3	NOAA-7	15:28	AVHRR - VIS/IR
26/3	GOES-5	09:30	VISSR - VIS/IR sectorized
27/3	GOES-5	09:00	VISSR - IR only
27/3	GOES-5	09:30	VISSR - VIS/IR sectorized

3. RESULTS

Measurements of surface wind and water temperature were made at each station during the 4 experiments (see Figures 2-11) starting with the 22nd of March. On 22 March, surface winds were toward the NE in the outer part of Piraquara de Fora and Itaorna Bays (Figure 2). Although some variability in the wind direction and speed may have been time-related, orographic effects or "steering" of the wind around and over the peninsula is expected to be very important. Several mountain peaks dominate the peninsula and these peaks would be very effective in determining the direction and speed of air flow over the general area.

The wind measurements on the west side of the peninsula show the effects of such steering as well as the curvature of the wind field toward the SN in the inner part of Piraquara de Fora Bay. Although no measurement was made in the SW corner of the Piraquara de Fora entrance, the air flow appears to have been in the form of a counter clockwise eddy.

Surface water temperature in and adjacent to Itaorna Bay on 22 March was essentially isothermal at 26^{o}C (Figure 3). In and adjacent to Piraquara de Fora Bay, however, the temperature varied from 25.5^{o}C to 27.8^{o}C, with the coolest water found in the NE corner of the entrance to the Bay and the warmest at the inshore stations. A comparison of the water temperature and the surface wind patterns suggests a counter clockwise motion of the surface water in the southern part of Piraquara de Fora Bay.

Winds over the Angra area continued toward the NE on the 23rd but intensified (Figure 4). The wind pattern within the Piraquara de Fora Bay changed direction, with a strong flow apparently over the penninsula as evidenced by the intensity of the wind at the inshore stations closest to the discharge barrier of the power plant. Fairly strong alongshore winds were present for several hundreds of meters distance from the discharge area. The station showing calm or near calm wind conditions (station 4) is difficult to explain unless we consider the orographic influence of the peninsula to have produced such a localized effect.

Water temperatures for 23 March were 0.4-0.6^{o}C warmer in the northeastern part of the Bay entrance than for the preceeding day (Figure 5). The relatively isothermal water in that location was maintained in part by the momentum transfer of the wind stress over that area, which was able to readily advect warm water from the inner part of the Bay toward the entrance. A thermal front or interface was present between stations 3 and 4 and was apparently related to the strong change in wind strength. Temperatures across the entrance to Piraquara de Fora Bay were about 1^{o}C warmer than for 22 March and attest to the gradual warming of the surface water in the Bay. The innermost stations common to 22 and 23 March show the water to be 0.4^{o}C warmer on the 23rd of March. The 3 special inshore stations used on 23 March show the warmest water (30.9^{o}C) to decrease to 28.6^{o}C within 500 m of the discharge area. The warmest water was found along the south shore of the Bay and is consistent with the alongshore winds there.

Weather conditions improved between 23 and 24 March with a concurrent change in wind direction toward the Southwest, outside Piraquara de Fora Bay (Figure 6). Strong winds extending into the Bay also decreased and also changed direction before being orographically lifted over the peninsula. On the southwest wide of the peninsula there was a weak counterclockwise eddy in the air flow downwind of the peninsula.

Water temperatures on 24 March (Figure 7) in and adjacent to the southwest side of the peninsula were 24.9^{o}C, about 1^{o}C cooler than for the previous day. Coolest water in Piraquara de Fora Bay was found in the northeast corner of the entrance. The strong winds off the small cape at the location may have resulted in some upwelling of cooler water. The effect of changes in wind stress due to changes in local wind direction and intensity on the surface water in the Bay is apparent from the $2^{o}C$ cooling in the same area. There the wind direction is toward the southwest as opposed to being toward the northeast. The effect of the winds blowing toward the southwest is to advect cooler ocean water into the outer part of the bay and to resist the outflow of the warmer water. On the 24th the water temperatures were generally about $1^{o}C$ cooler than for the 23rd, including the temperatures closest to the discharge barrier.

In order to obtain more sea truth data on the planned day of the aircraft overflight, the Radioecology Laboratory (FURNAS) planned and made its usual set of temperature measurements at the same time as our 3rd experiment. While their measurements will be reported separately by FURNAS scientists, data from the 6 stations positioned along the axis of the discharge water are also included in this report (Figure 8). Measurements of temperature were made at 0.5, 2 and 4 m depth at these stations. The higher resolution possible with these closely spaced stations found the warmest water temperature ($30^{o}C$) within 50 m of the discharge barrier. Comparison of the surface temperatures of Figure 8 with Figure 7 shows the two sets of temperature measurements to be in good agreement. An important aspect of the warm water discharge, is to have an estimate of the thickness of the newly formed surface layer. A vertical temperature section along the axis of the discharge water is seen in Figure 9 and also uses the FURNAS Radioecology Laboratory data. Within 100 m of the discharge barrier, the horizontal and vertical thermal gradients were intense: $\delta t/\delta x = 2^{o}C/50m$ and $\delta t/\delta z = 2^{o}C/3.5m$, respectively. By the time the warm water had moved 200 m away from the discharge barrier, the warm water had formed a buoyant surface layer 1-2 m in thickness. Because the temperature differential between the warm layer and the surrounding water determines the buoyancy of the warm layer, this layer will remain until the excess heat is dissipated through air/sea processes, turbulent mixing and local currents.

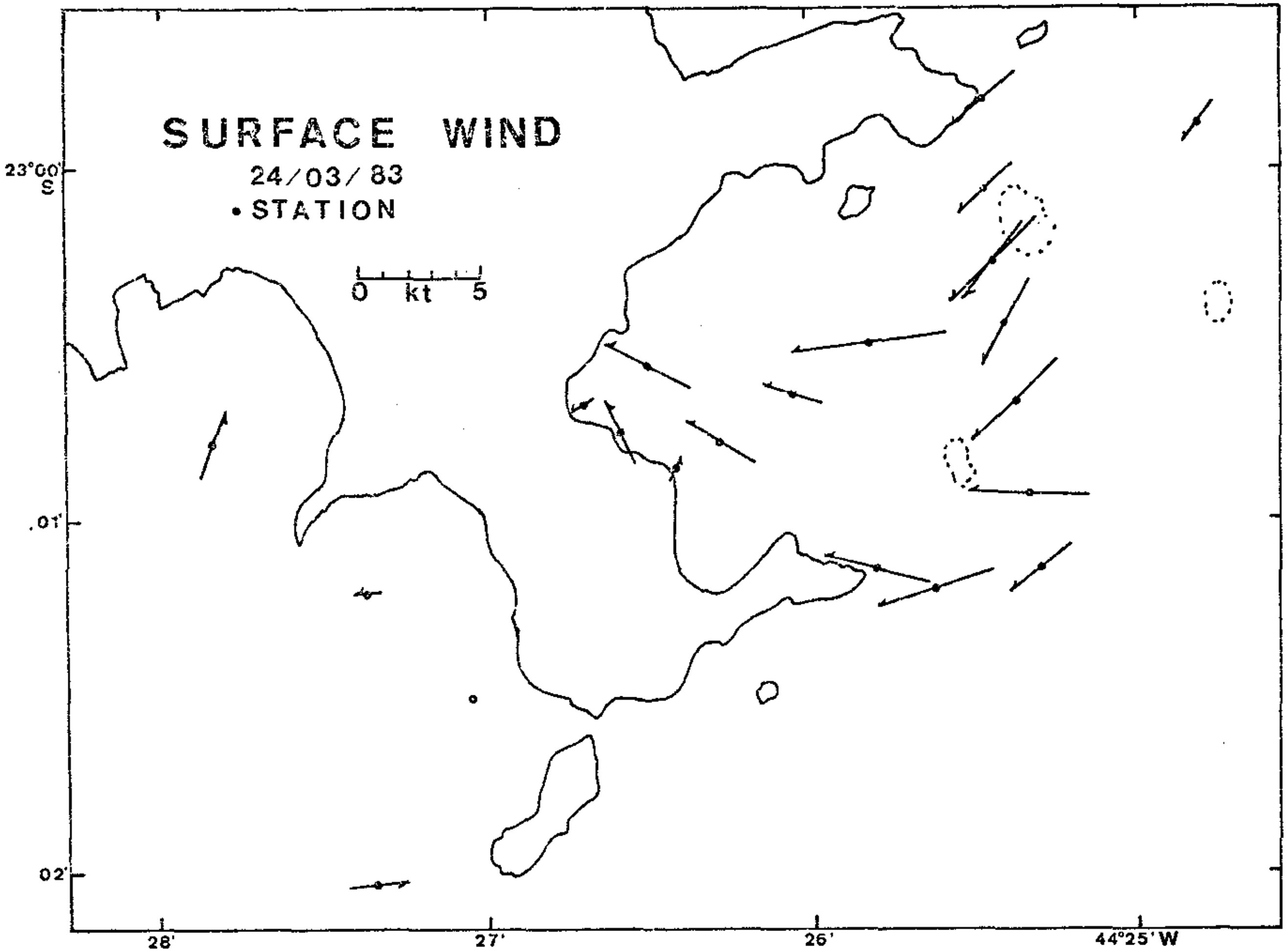

Fig. 6 - Surface wind measurements during the third experiment.

Wind arrows point in the direction of flow. Wind speed is obtained from the scale (in knots).

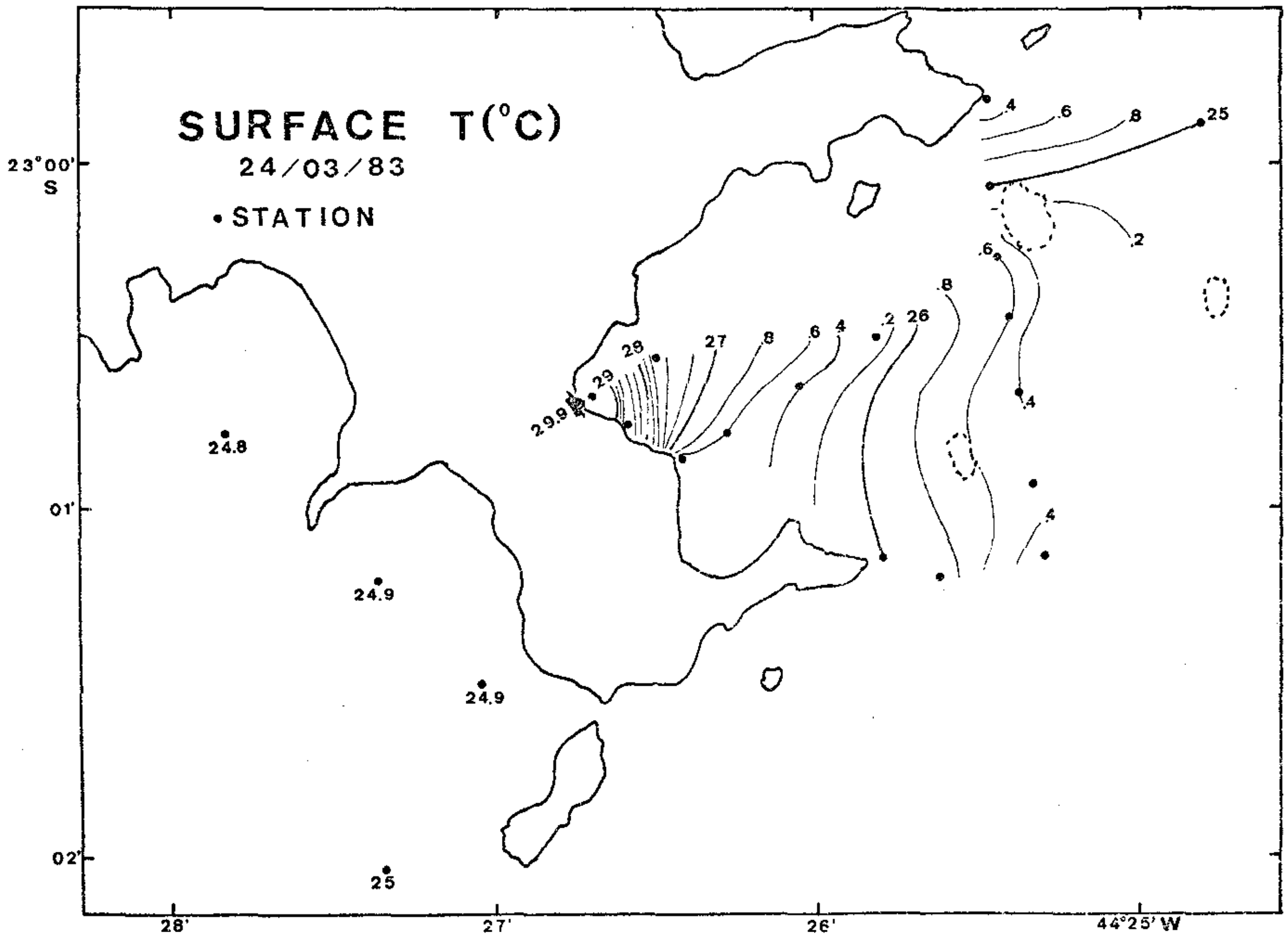

Fig. 7 - Surface temperature measurements during the third experiment.

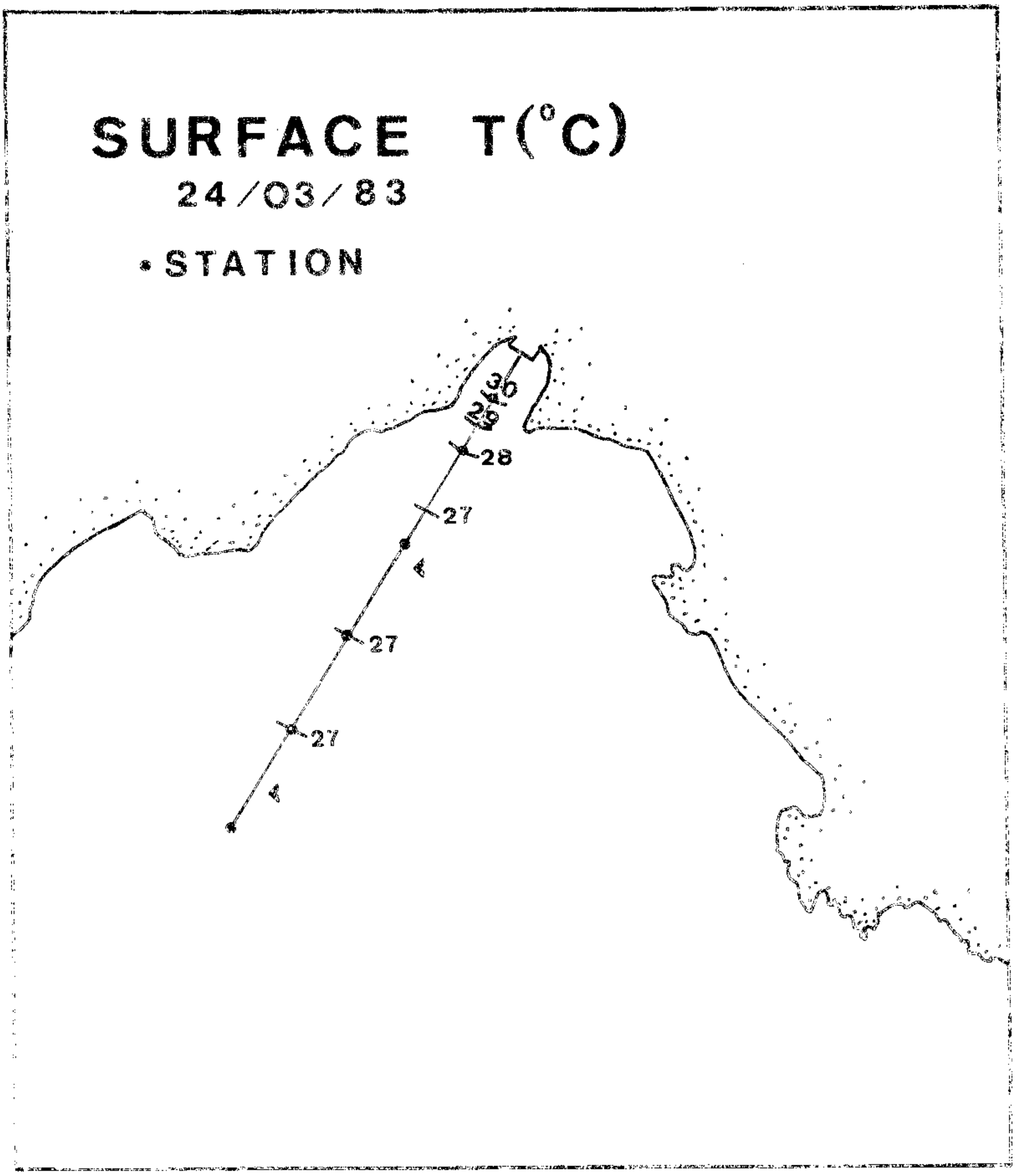

Fig. 8 - Surface temperature (0.5 m depth) along the discharge axis, near the discharge barrier in Piraquara de Fora Bay (Data courtesy of the Radioecology Laboratory, FURNAS).

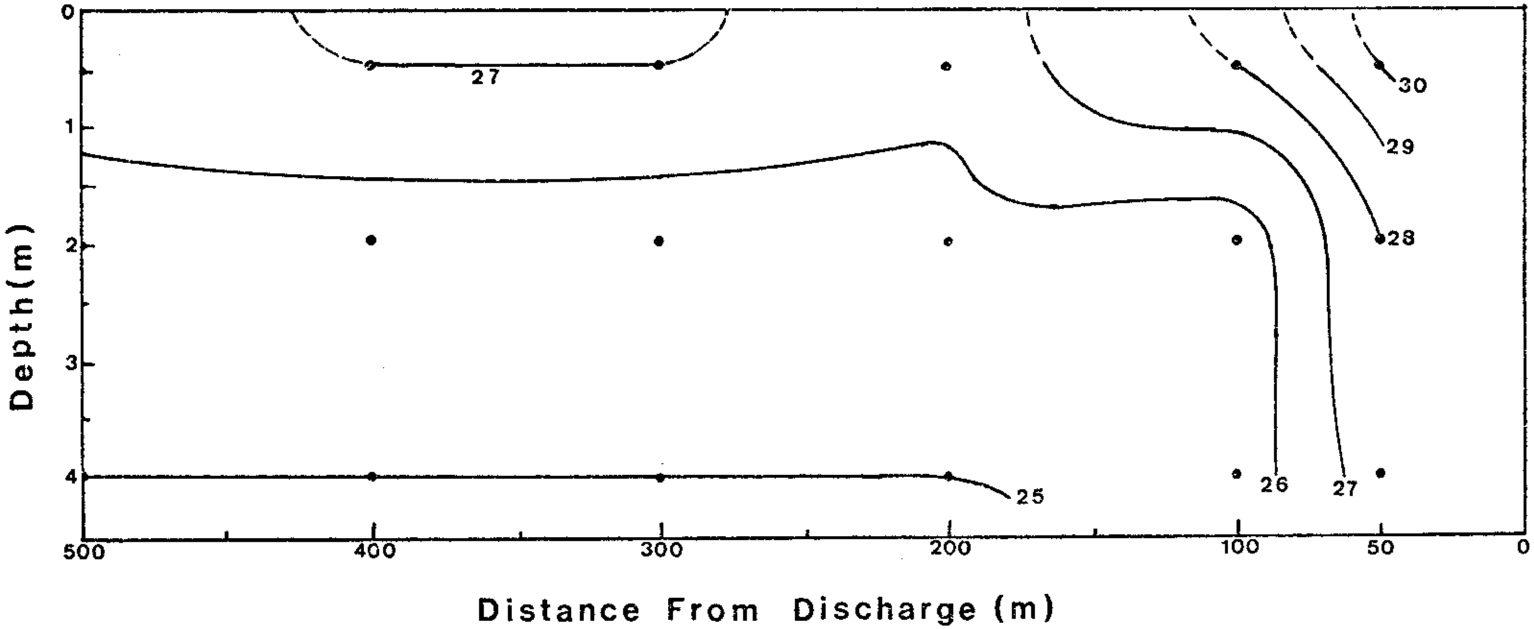

Fig. 9 - Vertical section of temperature (^{o}C) along the discharge axis shown in Figure 8 (Data courtesy of the Radioecology Laboratory, FURNAS).

Locally, weather conditions continued to improve on 25 March (Figure 10), the 4th and final day of the experiment. Winds were toward the southwest outside the Piraquara de Fora Bay but curved westward upon entering the Bay. Winds remained strong even at the most inshore station where the air flow apparently was up and over the peninsula Winds in and adjacent to Itaorna Bay were generally toward the north.

The surface temperature field in and near Itaorna Bay (Figure 11) was about 1.2^{o}C warmer than on the previous day. Surface temperatures on the northeast side of the Piraquara de Fora Bay entrance remained essentially unchanged. The effect of the nearshore winds was to move surface water into the bay, in opposition to the outflowing warm water, thereby causing an accumulation of warm water in the innermost part of the bay. A local thermal front was present near the innermost stations and may have been the result of the balance between the wind stress on the surface of the water and the outflowing warm water. When the wind changes its direction or weakens, the accumulated warm water would be expected to flow more rapidly into the outer part of the Bay.

At the present time some uncertainty still exists as to how the circulation in Piraquara de Fora and Itaorna Bays is related to the circulation in Ilha Grande Bay. Various studies of the circulation and dynamics in Ilha Grande Bay are available (for example, Ikeda and Stevenson, 1980; Signorini, 1980; Ikeda and Stevenson, 1982) but these studies do not provide a detailed analysis of conditions adjacent to Piraquara de Fora and Itaorna Bays.

Although information on relative humidity was not available from the aircraft for Angra-03, surface measurements were frequently made with a psychrometer on the 23rd, 24th and 25th of March from the boat. There was intermittent rain during 22 March and no psychrometric measurements were made. For 23 March, weather conditions were slightly improved and the relative humidity was 84%. On the 24th and 25th, the relative humidity was 77% and 70%, respectively.

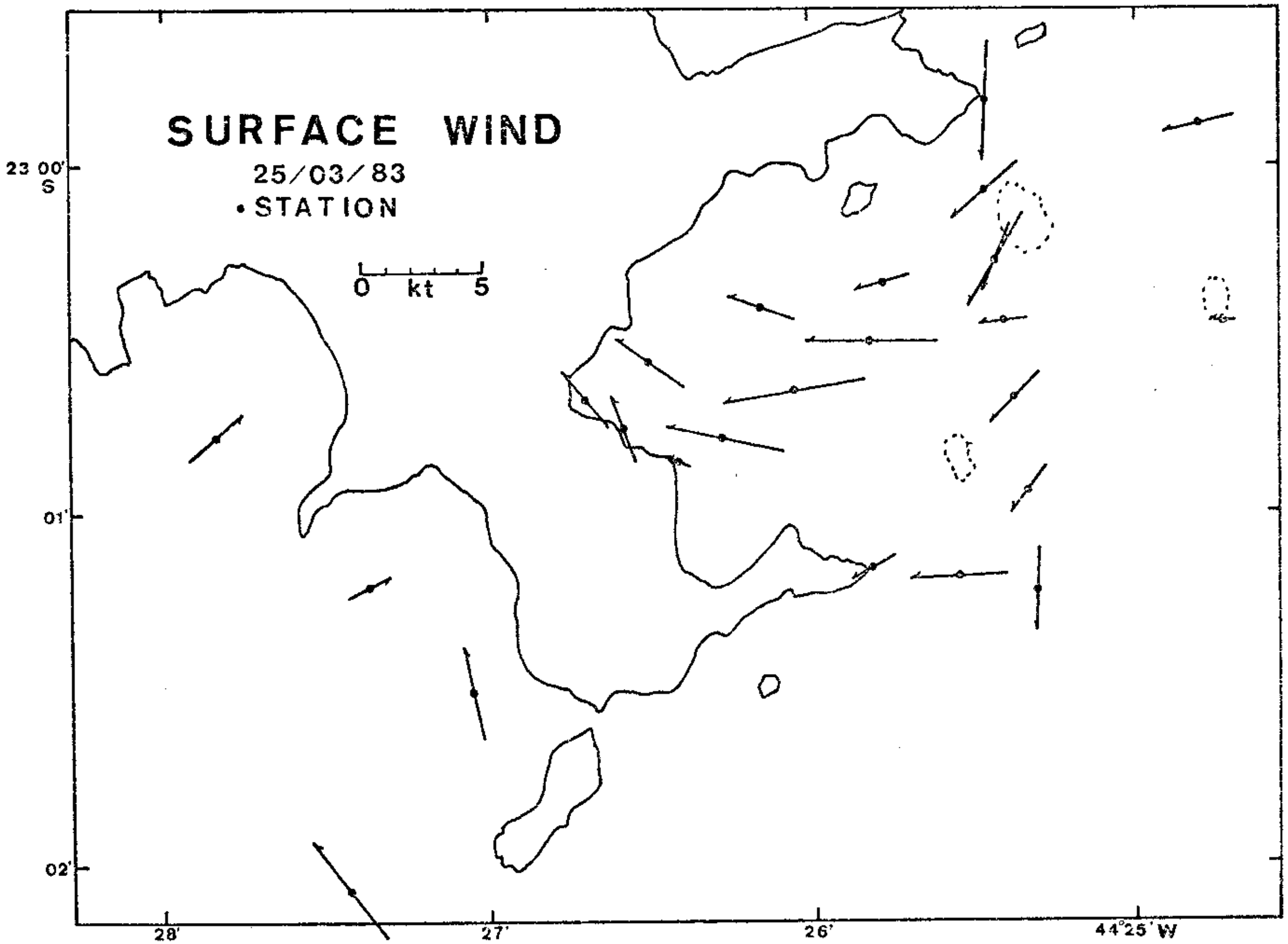

Fig. 10 - Surface wind measurements during the fourth experiment. Wind arrows point in direction of flow. Wind speed is obtained from the scale (in knots).

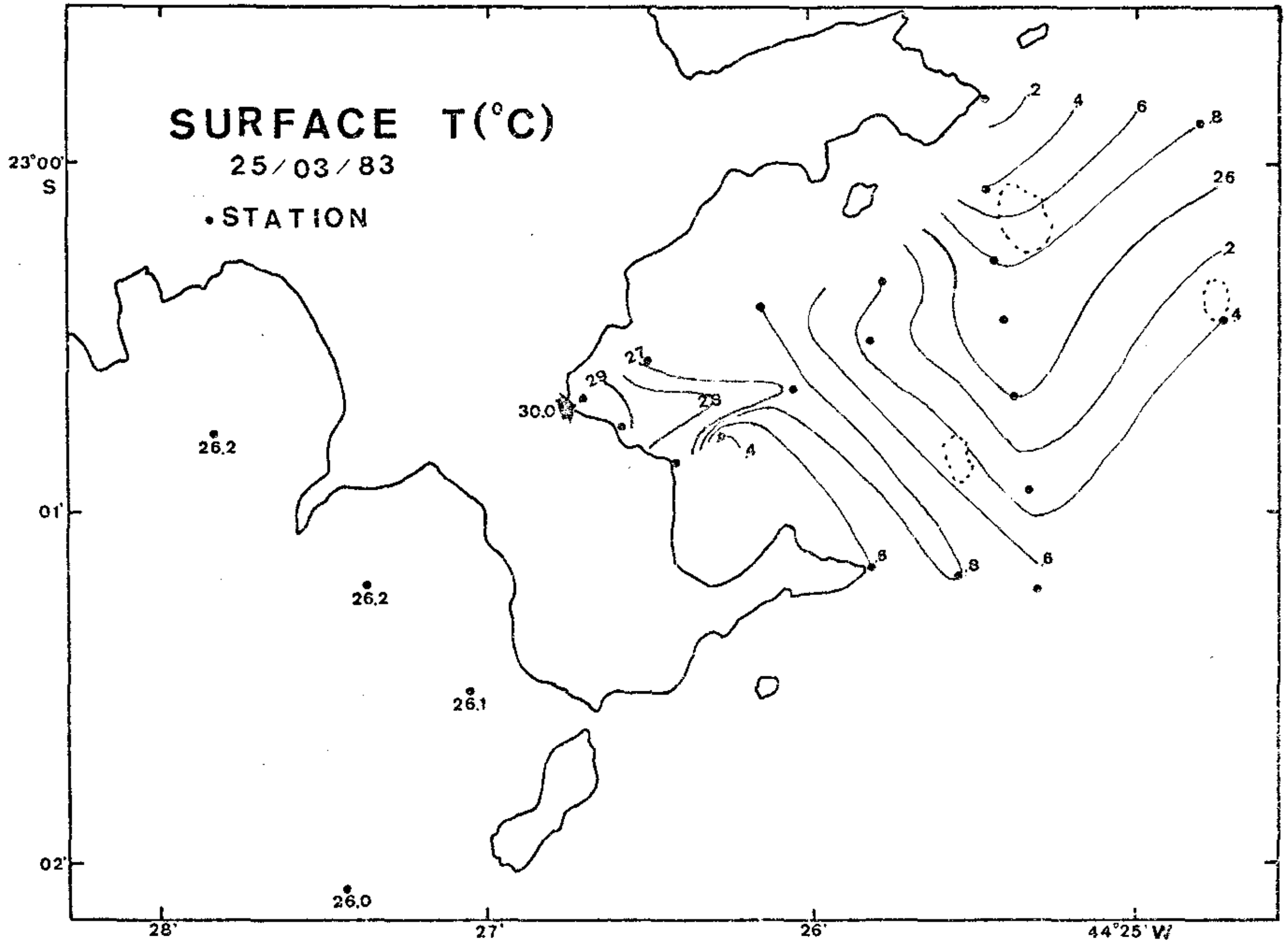

Fig. 11 - Surface temperature measurements during the fourth experiment.

For the Angra-03 Mission, radiosonde data obtained from the Galeão Airport in Rio de Janeiro (about 150 km distant) were also used. Previous results from the Angra-02 Mission suggest that it is sometimes reasonable to use observations from the Galeão location, if weather conditions are similar in both locations.

Wind profiles for the winds over Galeão Airport are shown as vertical profiles in Figures 12 and 13. The upper winds (e.g. altitude > 5000 m) did not differ much during the 4 day period and were toward the SE-SW. Intermediate level (1500-3000 m altitude) were toward the SW before changing toward the NW-NE on the 23rd and 24th of March. Winds in the lowest 100 m were toward the NE on 22 March but began to change toward the SE on 23 March and intensified further on the 24th and 25th.

Air temperature and dew point temperature data from the radiosondes for 22, 23, 24 and 25 March were also obtained and used to construct the temperature profiles shown in Figures 14 to 17. The temperature profiles for the 22nd (Figure 14) show the air above Galeão Airport to have been relatively moist and with notable inversions. Corresponding profiles for the 23rd (Figure 15) appear very similar to the 22nd. The change from the 23rd to the 24th (Figure 16) is more pronounced with a much drier air mass present between 1500 m and 5000 m altitude. The lowest 100 m of air was much warmer, however, than during the preceding 2 days. On the 25th (Figure 17) the air above Galeão was generally much drier than the first 2 days. Although the intermediate level air was not as dry as on the 24th, the air was more consistently dry with increase in altitude than on the 24th.

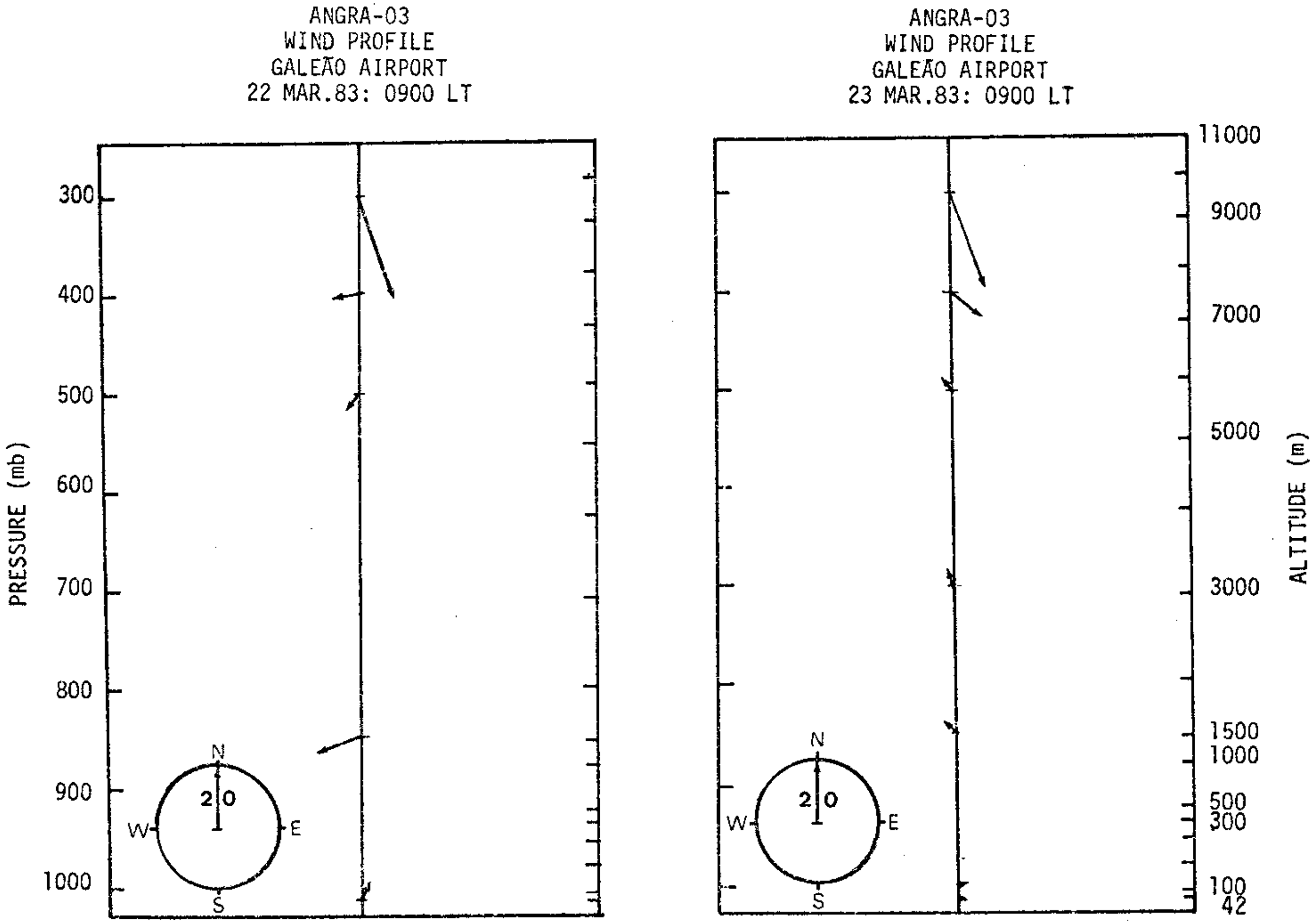

Fig. 12 - Vertical profile of winds over Galeão International Airport (RJ) during first and second experiments at Angra.

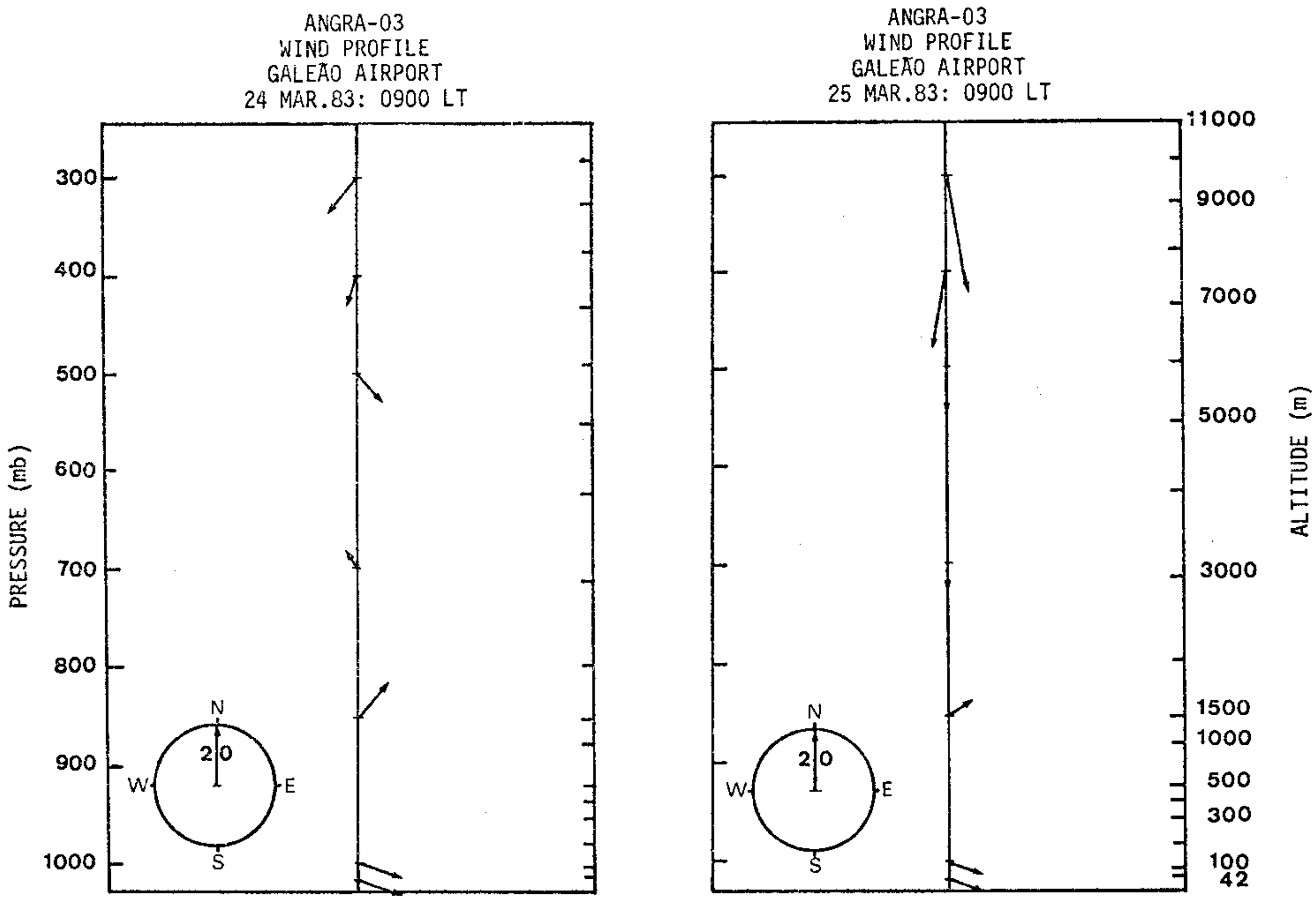

Fig. 13 - Vertical profiles of winds over Galeão International Airport (RJ) during the third and the fourth experiments of Angra.

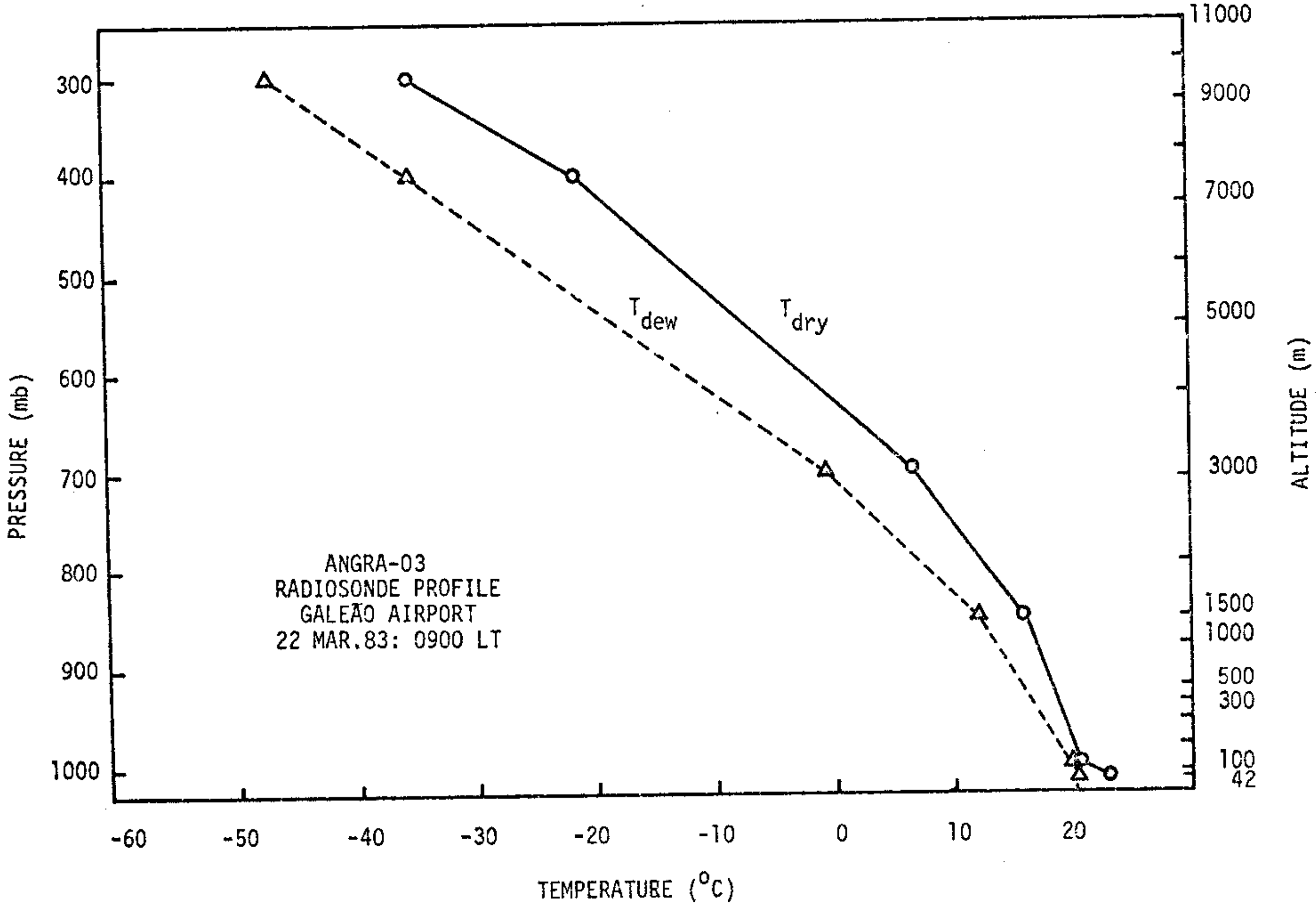

Fig. 14 - Vertical profiles of dry bulb and dew point temperatures from radiosondes at Galeão Airport on 22 March, 1983.

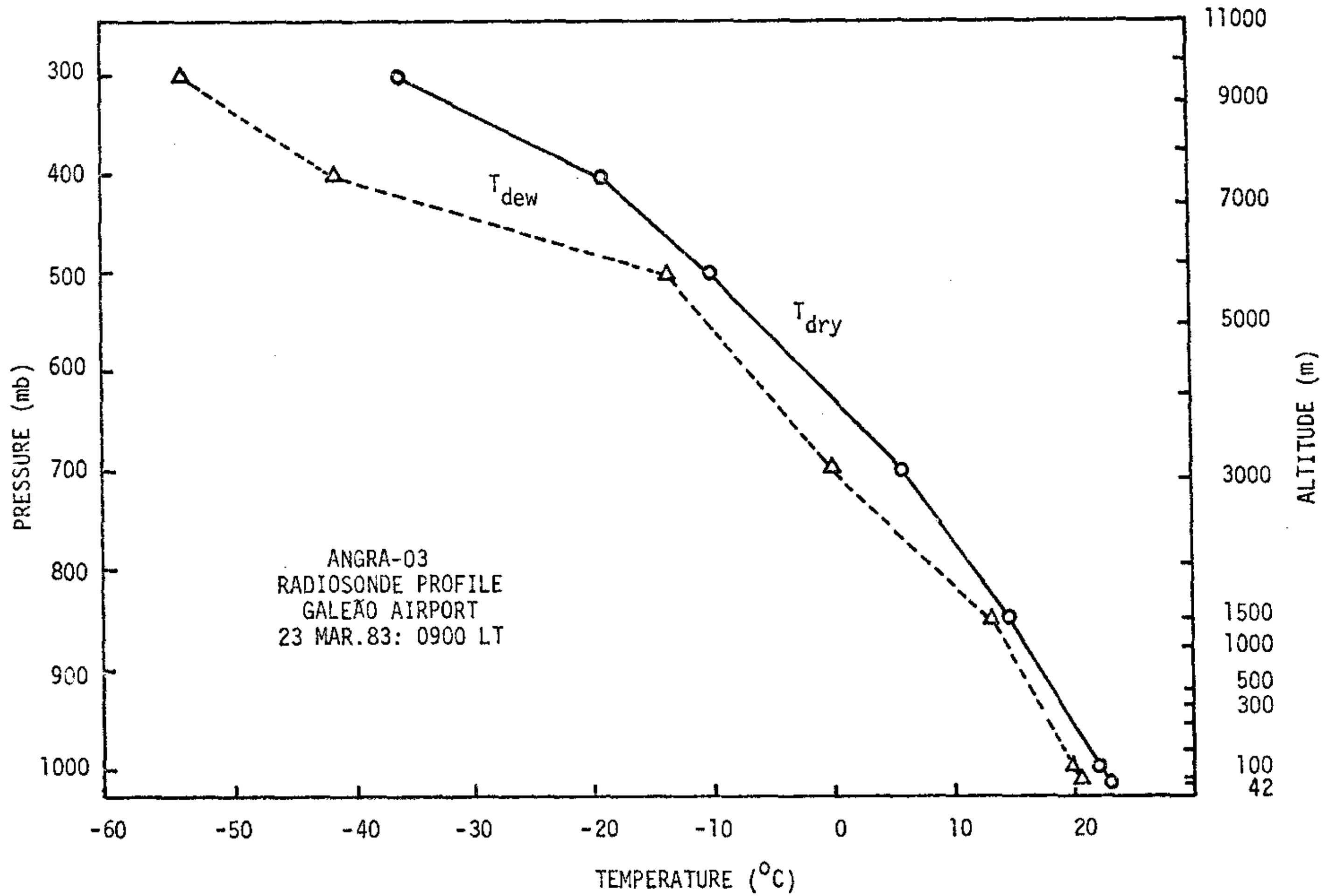

Fig. 15 - Vertical profiles of dry bulb and dew point temperatures from radiosondes at Galeão Airport on 23 March, 1983.

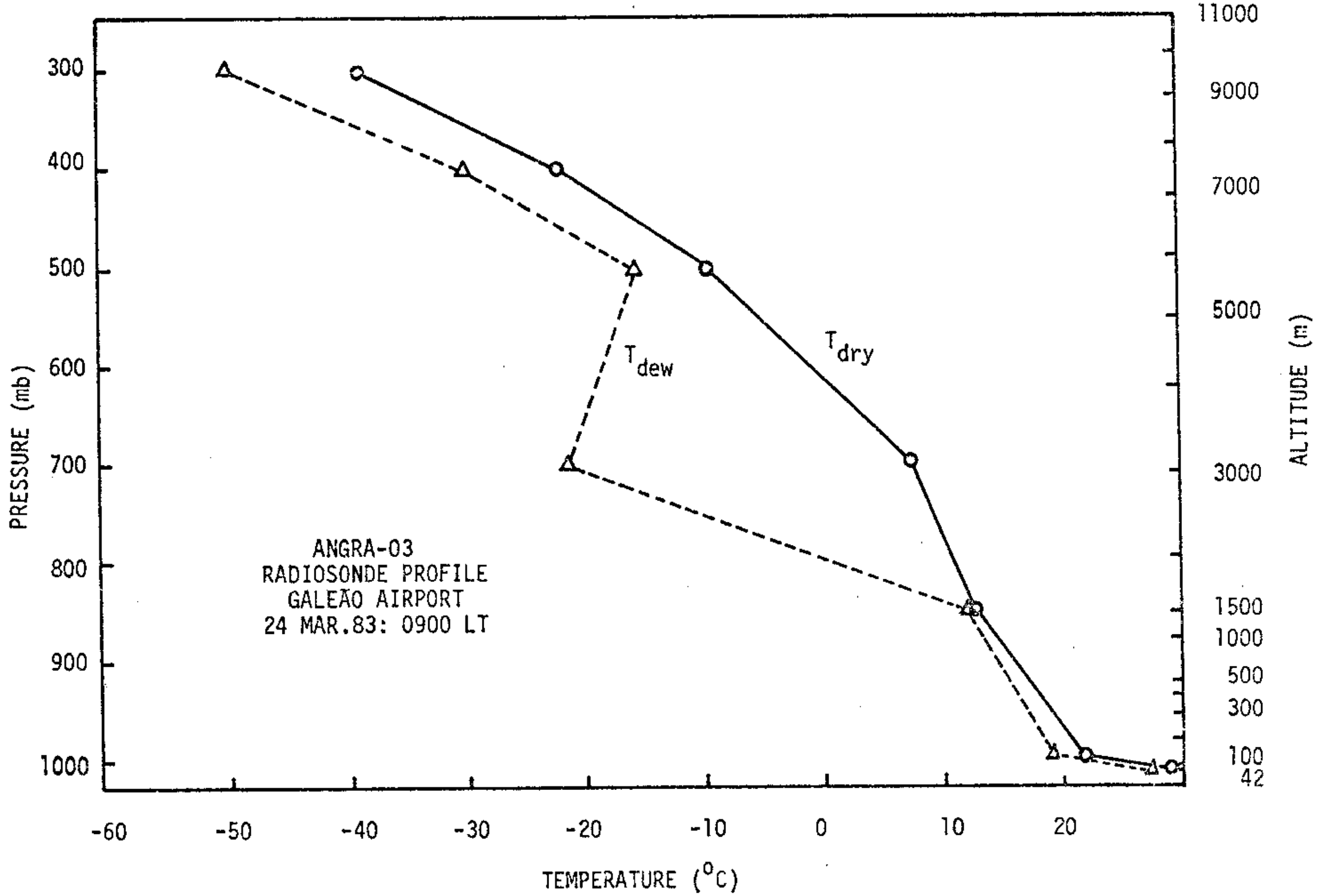

Fig. 16 - Vertical profiles of dry bulb and dew point temperatures from radiosondes at Galeão Airport on 24 March, 1983.

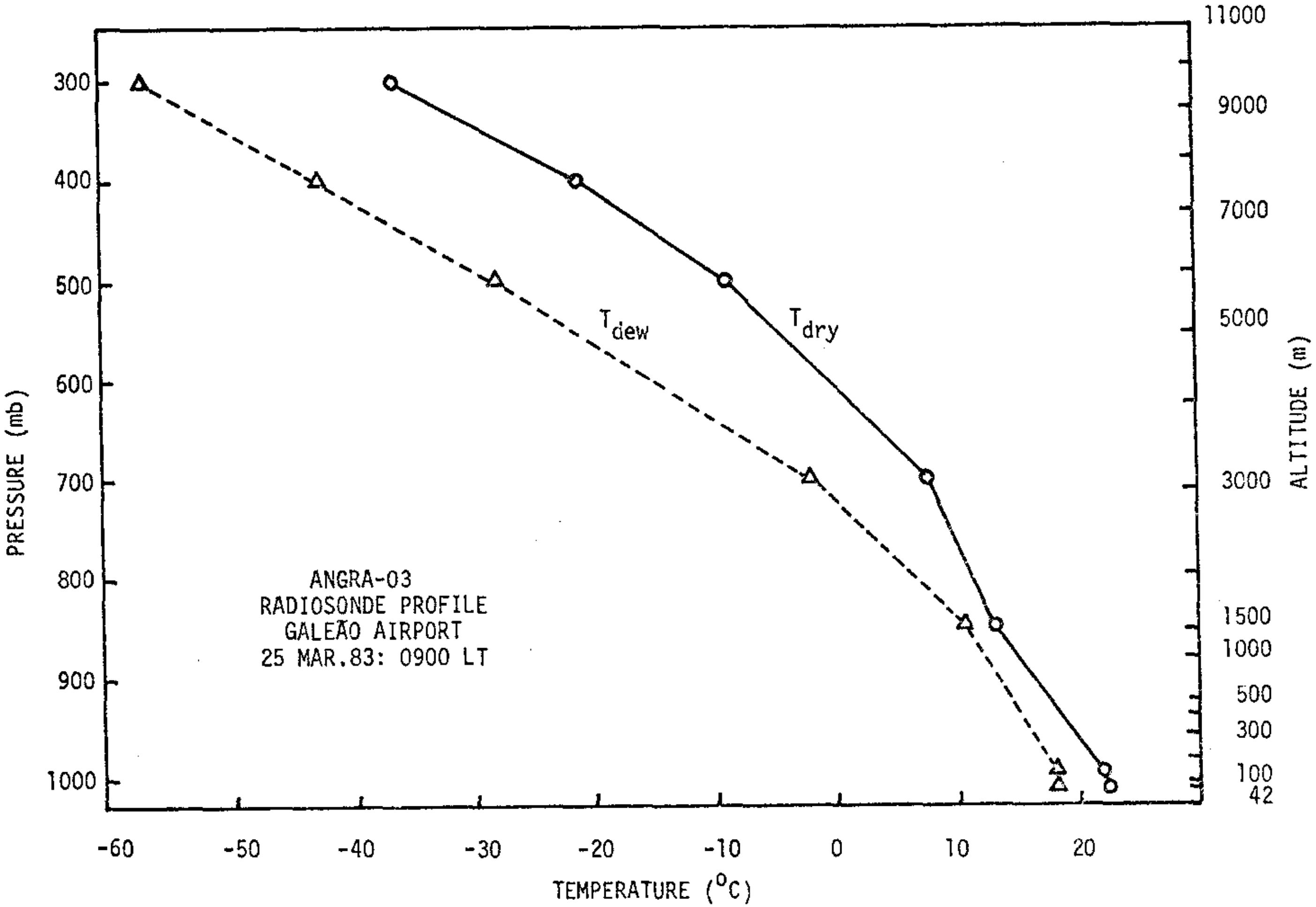

Fig. 17 - Vertical profiles of dry bulb and dew point temperatures from radiosondes at Galeão Airport on 25 March, 1983.

Vertical profiles of mixing ratios (estimates of moisture present in the air) and the integrated precipitable water vapor ($\sum H_2O$) were computed and are plotted in Figures 18 to 21. From these 4 figures it is apparent that the 4 days can be readily grouped into two periods: the 22nd and 23rd which were a high moisture content period with attendant rain: and the 24th and 25th which were low moisture days with clear or only partly cloudy skies (at the time of the measurements and experiments). Precipitable water vapor was found to be 3.2 cm on the 22nd and 3.4 cm on the 23rd. By contrast,the water vapor content was only 2.6 cm on the 24th and 25th of March. Cloud cover was heavy on the 22nd and 23rd, but such a water vapor content associated with cloud-free skies would still require a much larger radiometric correction for water vapor absorption and reemmision than for the 24th and 25th, which contained about 21% less water vapor than the first 2 days of experiments (Maul and Sidran, 1973).

For several reasons, including technical problems in evaluating satellite images on the I-100 system, processed satellite images for the Angra-02 Mission are not included here. They will, however, be included in the Final Report.

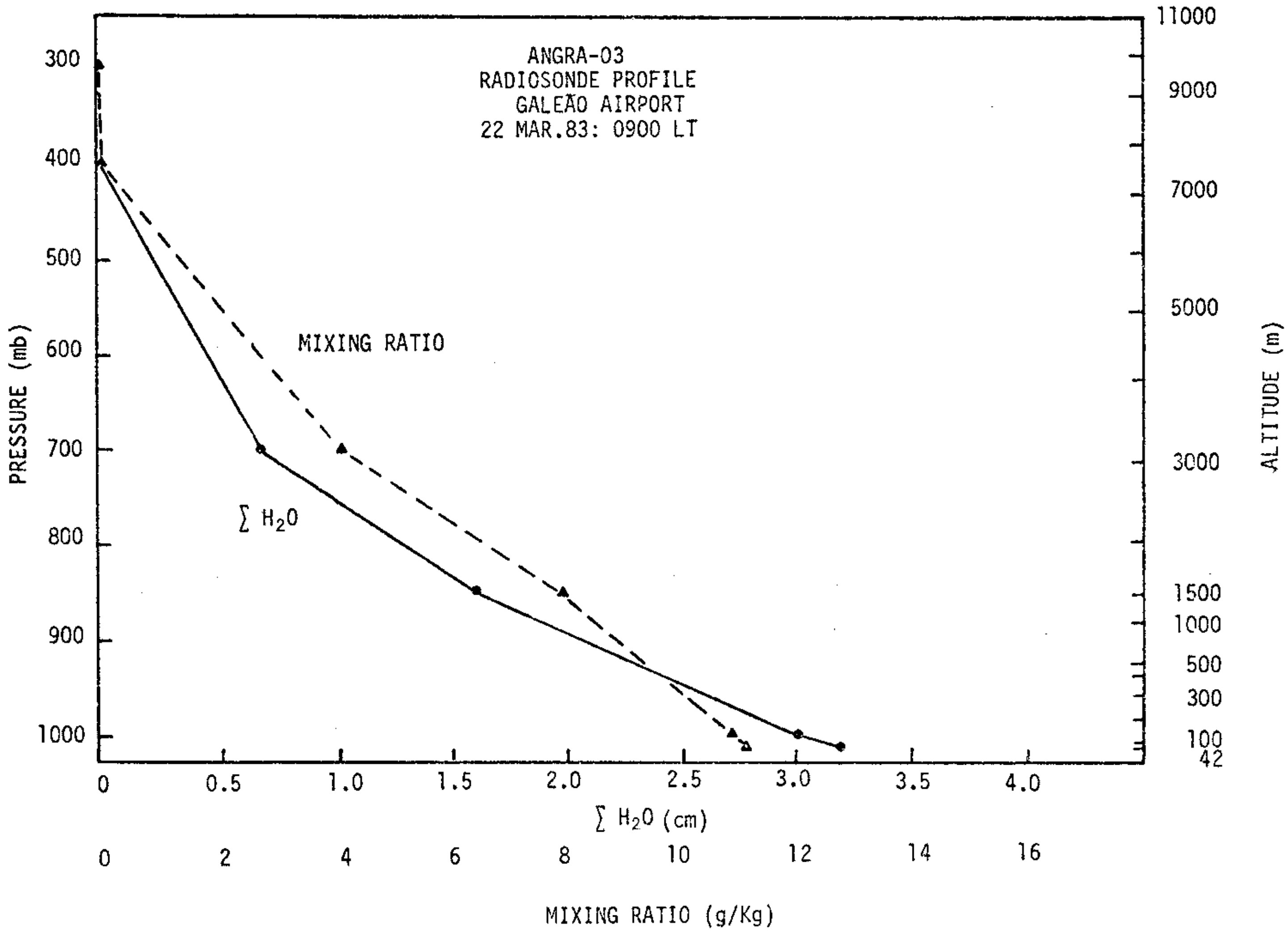

Fig. 18 - Vertical profiles of mixing ratios and precipitable water vapor determined from radiosonde data for 22 March.

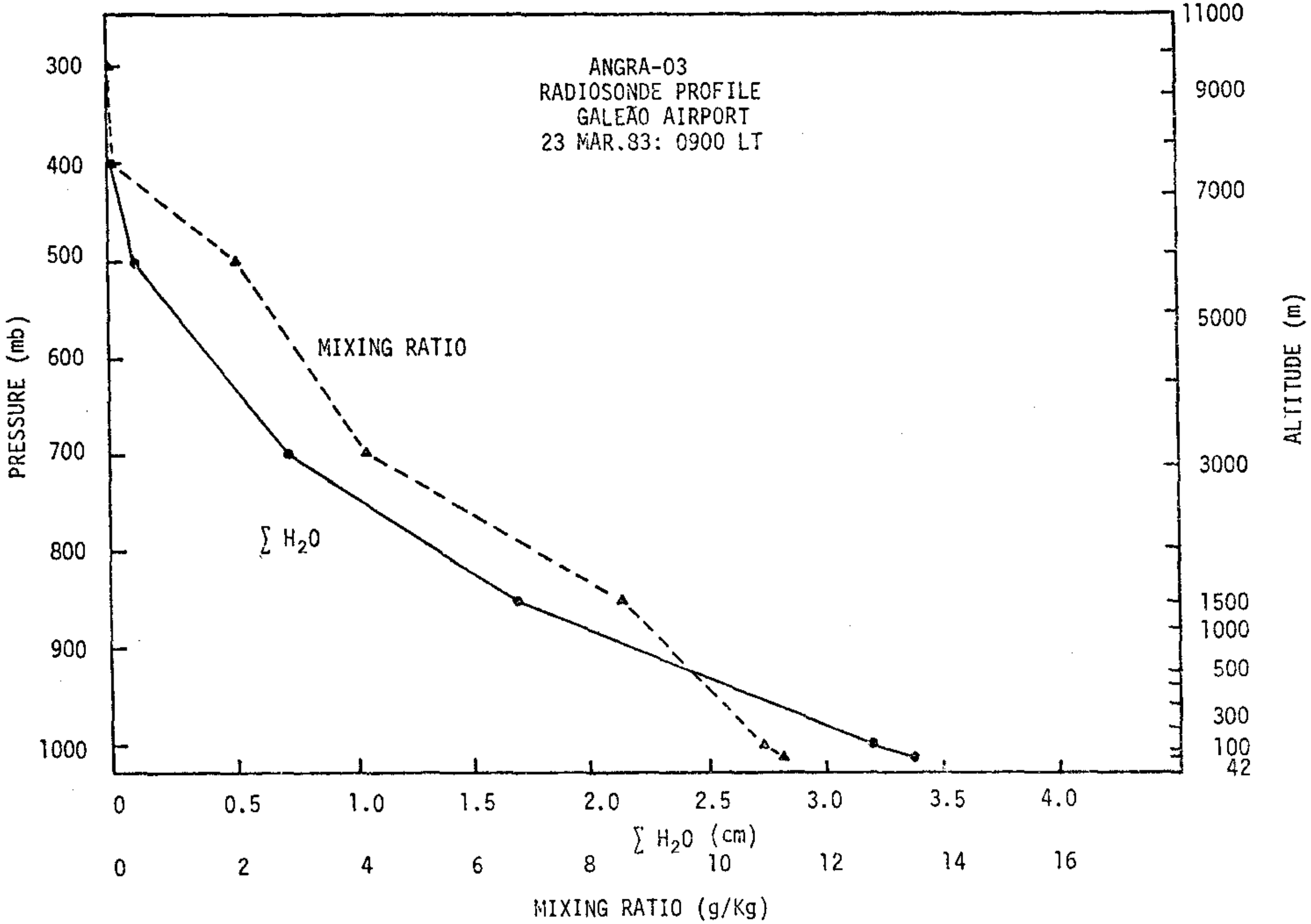

Fig. 19 - Vertical profiles of mixing ratios and precipitable water vapor determined from radiosonde data for 23 March.

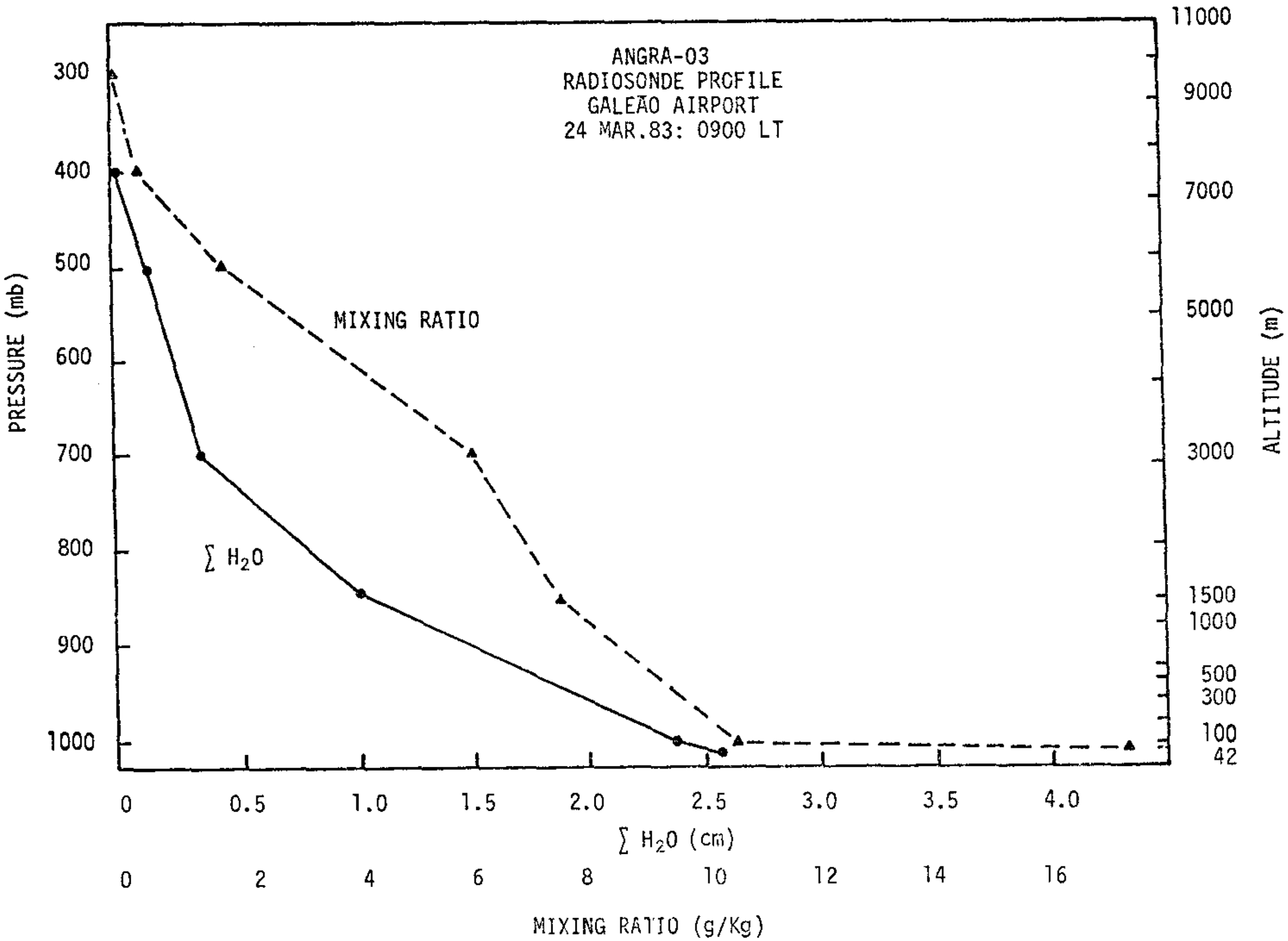

Fig. 20 - Vertical profiles of mixing ratios and precipitable water vapor determined from radiosonde data for 24 March.

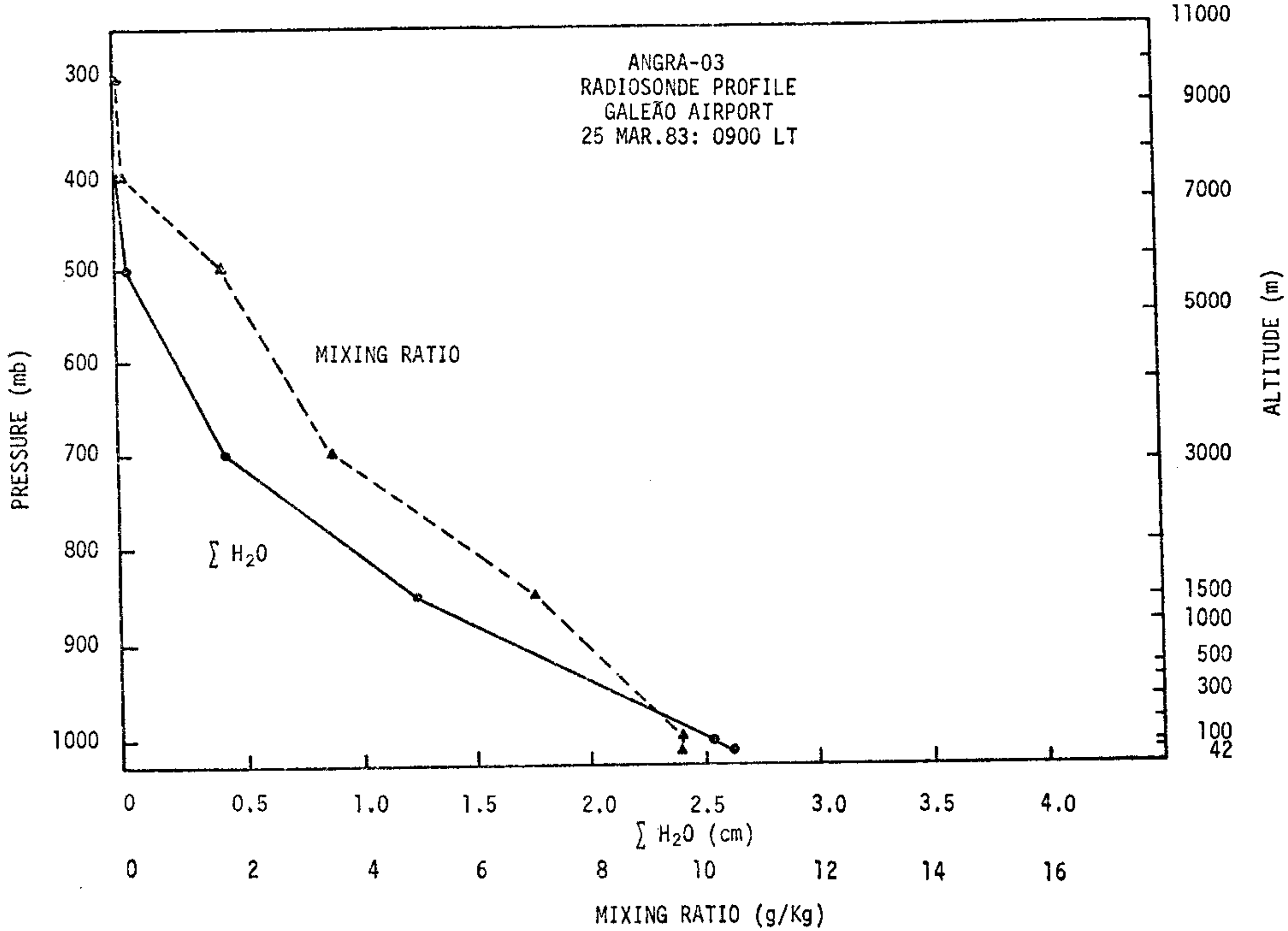

Fig. 21 - Vertical profiles of mixing ratios and precipitable water vapor determined from radiosonde data for 25 March.

4. CONCLUSIONS

The following conclusions are based on data and observations made during the Angra-03 Mission.

1. During the 4 experiments, the local wind direction and intensity was found to vary over the Angra area. The most reasonable explanation is that the local changes in the wind occur as the air is forced to flow around and over the rugged terrain.

2. Surface temperature in both Itaorna and Piraquara de Fora Bays may change as a result of the direction and intensity of local winds. This is considered to be due to a combination of wind mixing of the surface water layer as well as cloud cover changes over the area which affects the amount of insolation reaching the surface water. A secondary effect capable of changing water temperature is (local) upwelling, dependent upon wind direction and intensity, for example near the northeast corner of the entrance to Piraquara de Fora Bay.

3. The minimum and maximum water temperatures in Piraquara de Fora Bay during the 4 experiments were:

   22 March: $25.5^{o} \leqq T \leqq 27.8^{o}C$ (no temperatures near discharge barrier)

   23 March: $26.3^{o} \leqq T \leqq 30.9^{o}C$

   24 March: $24.3^{o} \leqq T \leqq 29.9^{o}C$

   25 March: $25.1^{o} \leqq T \leqq 30.0^{o}C$

   Temperatures were $26.0^{o}C$, $25.8^{o}C$, $24.8^{o}C$ and $26.2^{o}C$ respectively, on 22, 23, 24 and 25 March in Itaorna Bay.

4. During the Mission, the power plant operated at about 25% of capacity. Some fluctuations occurred in power output, however, and these slight increases or decreases were readily observed as slight increases or decreases in temperature, i.e., ~ $\pm 1^{o}C$.

5. Winds toward the northeast advected warm discharge water out of Piraquara de Fora Bay, along the Northeastern part of the entrance to the Bay. Winds toward the southwest appeared to oppose the movement of the warm water out of the Bay and in particular the moment of water away from the immediate area of water discharge.

6. Warm water discharged from the plant outlet in Piraquara de Fora Bay, underwent intense horizontal and vertical mixing between 50 and 100 m of the discharge barrier as evidenced by the gradients, $\delta t/\delta x = 2^{o}C/50m$ and $\delta t/\delta z = 2^{o}C/3.5m$. From 100m to 200 m distance from the discharge barrier, additional mixing further reduced the temperature of the surface water to 26.5-27.0^{o}C. Beyond 200 m distance from the barrier, the buoyant warm water formed a surface layer $\leq$ 2 m thick. It is this surface layer that must remove the remaining excess heat from the discharge area by a combination of advection and air/sea interaction.

7. Weather conditions during the Angra-03 Mission can be divided into two groups: rainy or heavily overcast conditions (22 and 23 March) and scattered clouds or clear sky conditions (24 and 25 March). Water vapor content during the overcast conditions was 3.2-3.4 cm of precipitable water vapor. Water vapor intent decreased to 2.6 cm on the 24th and 25th of March.

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