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Meteorological Studies Carried Out at Maitri During Winter Period of Tenth Indian Scientific Expedition to Antarctica

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Abstract

The Antarctic continent is the coldest, windiest, driest and least accessible of all the continents. It plays an active role in shaping the global climate and is significantly responsible for future climatic changes. Extensive meteorological observations, comprising surface and upper-air parameters, were taken on ship during voyage, from Goa to Antarctica and back, and at Maitri during 1991. In this report the studies carried out at Maitri are discussed.

The interesting features with respect to surface observations, total ozone and vertical profiles of ozone during the period 01.01.91 to 31.12.91 have been discussed. August was the coldest month with a lowest monthly mean air temperature of-17.0°C and extreme lowest air temperature of-30.6°C of the year was observed on 2nd August 1991. There were in all 15 blizzards spanned over 27 days during 1991. Warmer air temperatures were experienced during blizzards. The infrared (terrestrial) radiation disposition in the different layers of upper atmosphere have also been discussed.

Introduction

Meteorological programme of the Tenth Indian Antarctic Expedition (both summer and winter) was mainly the continuation of the long term programme of IMD introduced in earlier expeditions.

The Tenth Indian Antarctic Expedition left Goa from Marmugao port on 27.11.90 and reached Antarctic ice-shelf near Dakshin Gangotri station on 20.12.90. India Meteorological Department contingent consisted of two members for winter and one member for summer.

Objectives

(i) Recording of 3 hourly synoptic observations and to disseminate 6 hourly synoptic data to IMD, New Delhi for its global telecommunication network exchange on real-time basis.

(ii) To investigate ozone-hole phenomena during Austral spring over Antarctica.

(iii) To monitor surface ozone.

(iv) To measure infrared radiative fluxes in the upper atmosphere.

To accomplish the above objectives the following meteorological observations were planned:

(a) *Onward Cruise*

Surface observations at 3 hourly intervals of the parameters such as: surface pressure, wind speed, wind direction, visibility, air temperature, humidity, sea surface temperature, state of the sea etc. and transmission of main synoptic data to IMD, New Delhi on real-time basis.

Radiosonde ascents were taken at the rate of one ascent per clay preferably at 12 Z subject to the suitable surface wind below 30 kts.

(b)At Maitri

(i) Synoptic observation at 3 hourly intervals and transmission of main synoptic data to IMD, New Delhi on real-time basis.

(ii) Ozonesonde ascent, one per week, to study the upper-air profile witlh respect to temperature, humidity and ozone concentration. Ozonesonde data was exchanged with George Forster and Syowa station for comparing the data during ozone-hole period of Antarctica.

(iii) Radiometersonde: These were attempted before and after the blizzard at the rate of two ascents per month from March to November to study the infrared radiative fluxes in the upper atmosphere.

(iv) Weather forecast: Outlook of weather for 24 hours was provided for planning the daily activities and maintenance of the station and also during convoy from Maitri to Dakshin Gangotri and back.

In addition to these observations the atmospheric turbidity with sunphotometer on 440 and 640 mm wavelengths, surface ozone and day-to-day maintenance of all the autographic instruments used for continuous record of temperature, wind speed, wind direction, pressure, global solar radiation etc. were carried out.

Results and Discussions of Meteorological Data

A. *Mean Sea Level Pressure*

As seen from the graph of monthly mean sea level pressure for 1991 (Fig. 1 A), there is no systematic variation of monthly mean sea level pressure. There are significant variations from January to April and gradual variations are observed from April to October followed by steep rise thereafter till December.

The highest maximum mean sea level pressure during 1991 was 1010.5 hPa recorded on 27 December and extreme lowest M.S.L. pressure of 952.1 hPa was

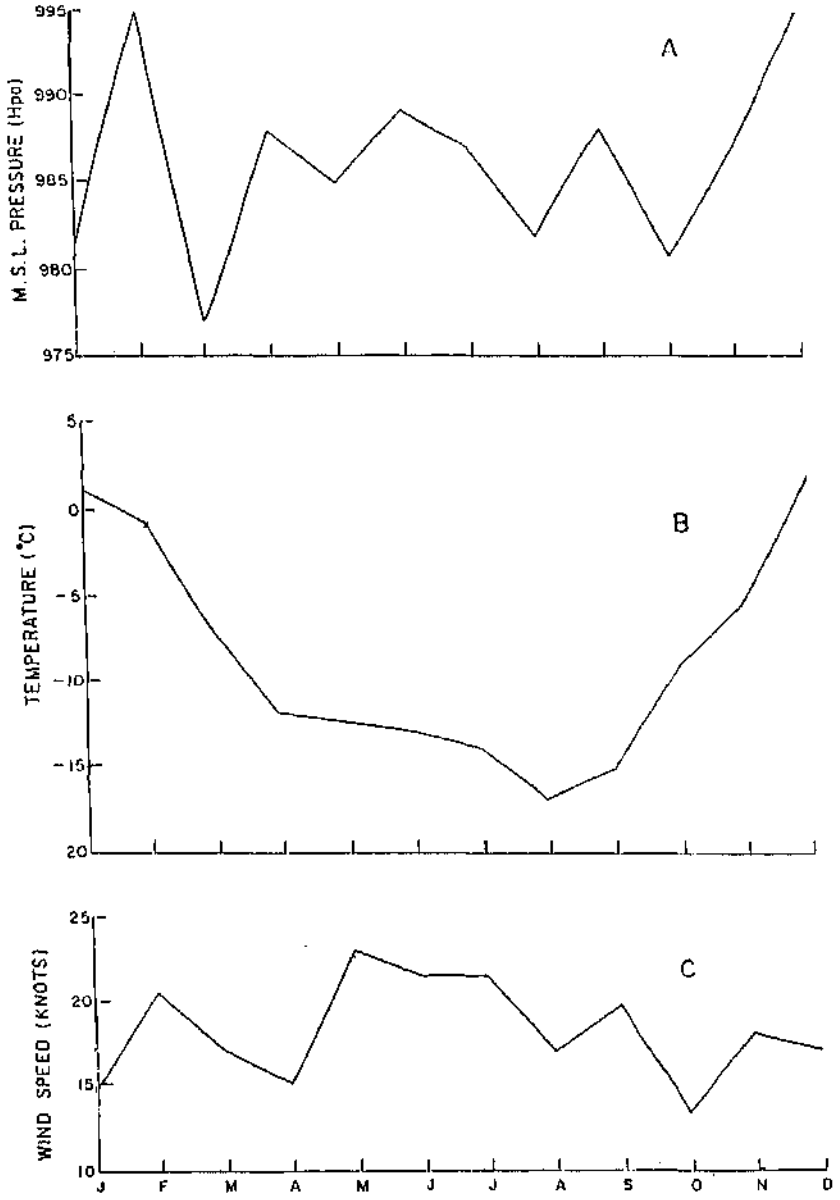

Fig. J. Mean monthly variations of (A) mean sea level pressure (B) surface air temperature and (C) wind speed.

recorded on July 7. The highest mean monthly M.S.L. pressure of 995.1 hPa was attained in December and lowest mean monthly M.S.L. pressure of 977.7 hPa in March. In majority of cases decrease of pressure was associated with bad weather or strong wind speed.

B. *Surface Air Temperature*

The monthly mean air temperature during 1991 decreased gradually from +0.9°C to - 0.9°C from January to February (Fig. 1B). Further decrease is steep due to onset of winter till April. From April onwards, the decrease in mean monthly temperature is gradual upto August due to the increased activities of low pressure systems moving West to East encircling Antarctic coast along polar low pressure belt fluctuating north-south. These systems are associated with cyclonic circulation incursing warm and moist air mass from lower latitudes towards polar regions and thereby raising the temperature. The gradual decrease in temperature is also caused by obscured and overcast skies causing obstruction to out-going radiation.

Highest temperature of the year (10.3°C) was recorded on December 28, 1991 during overcast skies alongwith light winds. The lowest temperature (-30.6°C) was attained on August 2 during calm wind and cloud free sky.

The monthly mean, highest maximum and lowest minimum have been compared with those of previous year (1990) recorded at Maitri and Dakshin Gangotri respectively. It is found that the year 1991 was warmer than 1990. The temperature was warmer at Maitri when compared to Dakshin Gangotri by about 10°C to 15°C for all the months. This is due to the orographic feature of the Maitri station.

C. *Surface Winds*

Wind speed is very important weather parameter in planning day-to-day outdoor activities of the station. There was no systematic variation of the wind speed during 1991.

Highest wind speed recorded during 1991 was 82 kts on September 30 during strong blizzard. The highest monthly mean wind speed of 22.9 kts was attained in the month of May followed by June and July (Fig. 1C). May, June and July were the windiest months during 1991 owing to 10 blizzards spanned over 17 days. There were in all 27 days covered by blizzardic weather. This number is significantly less compared to Dakshin Gangotri station.

October was the best weather month during the year with monthly mean wind speed of 13.4 kts and with only one blizzard lasting for 8 hours duration.

The most predominant wind direction observed during blizzardic weather was SE and ESE al Maitri.

D. *Clouds*

During blizzardic weather sky remained obscured due to blowing snow. Cloud amounts at Maitri are highly variable in nature from day-to-day. Mainly stratus, strato-cumulus, altostratus, altocumulus, cirrus and cirrocumulus clouds are observed at Maitri. Cumulus with little vertical extent is observed in the northern portion of the horizon. Increase or decrease of cloud amounts is mainly associated with the approach of sub-polar lows and passage of the same.

E. *Precipitation*

In Antarctica, precipitation in the form of rain or drizzle is a very rare phenomenon. In almost all cases it is in the form of snowfall. During 1991, Maitri experienced 86 days snowfall. It is generally observed before and after the commencement of blizzard or strong winds. As seen from the monthly weather summary for 1991, the month of June experienced 16 days of snowfall followed by December with 12 days. On January 17, 1991 Maitri experienced light rain and drizzle around 1930 to 2030 hours.

Table 1 gives the monthly weather summary during January '91 to December '91 and Table 2 pertains to climatological features observed during 1991.

Upper-air Studies

The standard isobaric height temperatures and humidity have been worked out on the basis of 45 successful ozonesonde ascents taken during 1991. These are summarized in Tables 3 to 6. The following annual variations at almost all pressure levels have been observed.

(i) The monthly mean heights of all standard pressure levels decrease gradually from middle of summer to the end of the Antarctic autumn months. The standard isobaric heights start increasing from September onward till December. The increase is quite steep.

(ii) Air temperatures at all standard isobaric levels are maximum in summer and minimum in spring season.

(iii) The monthly mean heights of tropopause show decrease upto March and increase thereafter till May. It shows gradual decrease thereafter till August (Fig. 2). The annual mean tropopause is at 256 hPa and the corresponding geopotentiometric height of 9449 gpm with annual tropopause temperature - 63.4°C. The tropopause is warmer in summer compared to winter by about 15°C. The monthly mean tropopause temperature shows steep decrease upto May and exhibits an increasing trend with the onset of summer.

Table 1: Monthly Weather Summary of Maitri for the Period Jan.1991 to Dec. 1991
station-Maitri (895514) 70 45 11 44 03 E Elevation: 117 Mtrs

Month	M.S.L.pressure (mb)			Air temperature (°C)			Wind speed (kts)		No. of oyc - days	No. of SKC days	No. of PPTN days	Blizzards		Remarks
	highest	lowest	mean	highest	lowest	mean	max	mean				No.	Days	
JAN	994.6	960.0	981.8	+8.2	-5.6	+0.9	62	14.8	6	2	8	0	0	Rain and Drizzle on 17th Jan.
FEB	999.3	963.3	994.9	+7.6	-8.5	-0.9	68	20.7	16	2	10	0	0	
MAR	997.2	961.3	977.7	+ 1.5	-20.7	-6.9	72	17.1	8	2	10	1	3	
APR	1001.3	975.6	988.2	-4.2	-21.8	-12.1	53	15.1	4	0	2	1	2	
MAY	1001.0	967.0	985.2	-2.8	-24.6	-12.5	74	22.9	13	1	7	4	8	
JUN	1010.4	967.6	989.7	-3.0	-27.9	-12.9	72	21.5	10	0	16	4	5	
JUL	1004.3	952.1	987.5	-4.2	-29.6	-14.2	68	21.5	12	0	10	2	4	
AUG	994.7	963.6	982.2	-4.7	-30.6	-17.0	64	17.0	7	0	2	0	0	Fog on 2 Aug.
SEP	1008.1	969.0	988.0	-1.4	-28.2	-15.2	82	19.7	8	0	7	2	4	
OCT	1006.3	965.1	981.1	-1.4	-22.6	-9.2	67	13.4	6	2	1	1	1	
NOV	998.5	975.5	987.5	+4.8	-13.5	-5.4	64	18.2	6	0	1	0	0	
DEC	1010.5	985.3	995.1	+10.3	-4.3	+2.0	54	17.1	7	0	12	0	0	Fog on 15, 16 and 17 Dec.

Table 2: Climatological Features Observed during 1991

S.N.	Phenomena	Value	Date
1)	Highest Maximum Temperature	10.3°C	28 Dec.
2)	Lowest Minimum Temperature	-30.6°C	02 Aug.
3)	Maximum MSL Pressure	1010.5 hPa	27 Dec.
4)	Minimum MSL Pressure	952.1 hPa	07 July
5)	Maximum Wind Speed	82kts	30 Sep.
6)	Warmest month of the year	December with mean temp. of 2.0°C.	
7)	Coldest month of the year	August with mean temp. of-17.0°C.	
8)	Windiest month of the year	May with mean wind speed of 23 kts.	
9)	Windiest day of the year	30 Sep. with mean wind speed of 51 kts.	
10)	Mean temperature of the year	-8.6-C.	
11)	Mean MSL Pressure of the year	986.6 hPa.	
12)	Mean wind speed of the year	18.3 kts.	
13)	Light rain and drizzle		17 Jan. 1991
14)	Warmest day of the year	28 Dec. with mean temp. of 2.0°C.	
15)	Coldest day of the year	02 Aug. with mean temp. -27.0°C.	
16)	Total number of blizzards	15 with longest blizzard of 70 hrs duration in March 91	
17)	Blizzardous month	May and June with 4 blizzards in each month.	

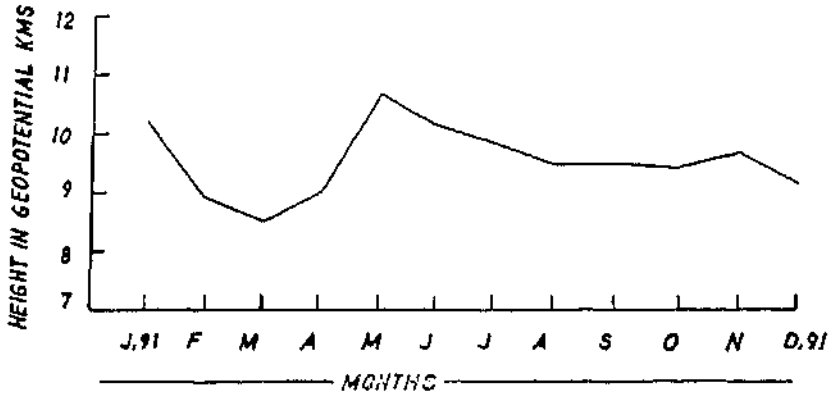

Fig. 2. Antarctic tropopause height variation.

Table 3:Mean Monthly Upper-air Temperature over Maitri for Standard Isobaric Levels (Station : Maitri, Year: 1991)

Month	850	700	600	500	400	300	250	200	150	100	70	50	30	20	15	10	07	05	03
JAN	4.3	13.9	18.7	24.9	34.4	45.6	49.9	45.8	43.7	41.2	38.8	36.3	33.3	31.4	30.4	28.9	—	24.8	13.9
FEB	10.0	16.6	22.5	30.3	40.4	49.4	49.8	47.2	46.5	45.8	44.2	44.0	42.1	40.3	40.1	37.2	34.6	30.6	—
MAR	14.2	23.1	29.2	34.9	43.8	54.5	51.0	46.9	46.7	48.0	47.7	49.0	49.0	49.4	48.5	50.9	—	—	—
APR	17.9	24.9	30.4	36.6	46.9	58.9	59.8	55.8	54.9	58.9	62.2	64.8	62.2	61.9	63.6	—	—	_	_
MAY	14.9	17.5	27.4	36.3	46.3	58.9	62.7	65.2	67.0	68.6	73.6	73.5	76.1	75.2	74.3	69.2	—	—	—
JUN	18.5	24.6	31.0	37.9	47.0	54.6	62.1	65.1	67.0	70.7	73.3	76.5	78.3	78.4	78.4	—	—	—	__
JUL	19.9	26.9	33.8	40.0	49.5	60.9	69.2	72.4	75.1	7.7.3	82.3	85.5	86.4	82.1	79.4	78.6	76.8	77.4	—
AUG	18.5	23.6	26.2	37.2	49.7	63.0	67.9	71.5	74.9	77.0	76.1	76.9	76.1	73.9	73.2	65.3	64.3	67.2	—
SEP	19.9	28.9	34.5	41.1	51.5	64.9	70.5	75.6	79.1	82.6	83.6	81.6	79.5	72.7	74.6	69.5	65.8	61.4	73.8
OCT	18.4	21.5	27.3	36.3	46.9	60.6	65.9	69.1	70.6	70.2	67.8	59.2	52 0						
NOV	11.8	21.7	28.9	38.4	47.8	59.4	62.9	65.0	65.5	65.9	59.3	50.3	35.8	25.7	19.3	15.8	15.3	15.2	21.5
DEC	7.4	14.1	20.0	28.3	38.1	51.9	50.9	47.3	44.9	41.8	38.7	35.6	31.4	28.7	29.1	28.1	28.2	28.9	—

NB: ALL temperature values are minus centigrade

Table 4: Mean Monthly Partial Pressure of Ozone over Maitri for Standard Isobaric Levels

Month	850	700	600	500	400	300	250	200	150	100	070	050	030	020	010	005	003
JAN	11.6	12.3	10.7	9.3	10.6	9.0	11.1	36.3	38.1	58.0	82.3	95.0	106.7	118.6	86.2	64.3	—
FEB	21.5	11.5	16.8	15.2	17.1	30.1	44.1	52.6	54.2	81.0	80.9	136.8	132.3	116.1	80.4	28.3	—
MAR	14.2	14.1	12.8	14.4	12.2	21.5	41.9	51.6	57.9	78.4	106.9	113.7	98.2	64.3	35.6	—	—
APR	23.1	20.7	20.4	19.7	21.6	26.7	49.2	61.0	60.8	79.6	97.2	123.0	94.7	69.5	58.3	—	—
MAY	25.3	23.0	20.6	19.0	17.4	16.4	27.6	35.0	47.0	98.7	135.0	135.1	81.3	65.1	21.1	—	—
JUN	29.3	24.3	22.9	19.3	20.0	20.4	30.5	51.1	62.1	129.8	136.6	88.2	112.4	82.3	—	—	—
JUL	38.8	31.4	29.1	27.4	23.8	19.5	24.5	40.2	73.8	116.4	130.3	113.5	82.9	46.1	19.3	16.0	—
AUG	22.2	16.8	16.1	15.8	11.8	11.9	14.5	24.9	41.4	85.1	120.9	88.7	60.4	50.6	27.1	16.4	—
SEPT	23.5	19.2	15.9	15.6	14.1	14.9	22.0	30.3	48.9	61.9	68.8	56.3	46.9	51.3	37.1	23.3	—
OCT	17.4	16.1	14.4	12.3	12.0	12.1	17.9	26.7	29.5	30.2	34.7	67.7	38.0	68.0	40.5	37.5	—
NOV	12.5	9.2	8.9	8.2	6.7	12.5	16.4	21.3	27.1	19.4	38.2	49.5	54.3	46.9	48.8	43.4	—
DEC	23.9	18.1	15.6	13.0	13.3	12.5	29.8	40.3	20.3	26.8	101.3	124.4	125.1	119.1	48.4	88.4	—

NB: All values of partial pressure of ozone are in μmb.

It is found that ground inversions ranging from 2^0C to 8^0C arc observed from March to September. The inversion is feeble in November and February and disappears in summer period clue to the onset of 24 hours day light.

In most of the ascents from March to October a very feeble inversion in the layer between 750 to 650 hPa was also observed.

Total Ozone

Table 5 gives the daily mean values of total ozone obtained from George burster station about 4 km from Maitri. The following variations have been observed in daily mean total ozone and monthly mean total ozone.

(i) There are gradual variations in daily mean total ozone from January to April, The tendency of variations are random during most part of the year except in the austral spring wherein a pronounced reduction in total columnar ozone is clearly observed. The lowest daily total ozone values are obtained in decreasing mode and highest values are obtained in increasing mode. The highest daily mean total ozone during 1991 of 358 DU was recorded on November 22 and lowest amount of 158 DU was obtained on September 16 during ozone-hole period.

(ii) The monthly mean total ozone values have been worked out and summarized in Table 5. These show negligible variation during January, February and March. Large decreasing variations are observed in April, August and September. From October onward the monthly mean total ozone shows increasimg trend. The lowest monthly mean total ozone of 196 DU is attained in September and highest value of 312 DU is attained in December,

(iii) There are three spells of ozone depletion followed by temporary revival of daily total ozone values, There is no systematic variations during the depletion and revival period of "ozone-hole" phenomenon.

(iv) The daily total ozone values during 1991 are comparable with those of 1987, 1989 and 1990 except the severity of reduction is less marked.

Ozonesonde Studies

The monthly mean values of partial pressure of ozone have been worked out for standard.isobaric levels (Table 4). The following variations are noticed.

(i) The partial pressure of ozone decreases with height and attains minimum value just before tropopause.

(ii) In almost all ozonesonde ascents partial pressure of ozone increases with height after tropopause.

Table 5: Daily Mean Total Ozone Measurements at George Forster Station
(Period: Jan. 1991 to Jan. 1992)

DATE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN
1		312	283	258	—	———		—	244	165	172	308	285
2		288	274	248	—	———		—	184	163	175	313	278
3		277	272	250	—	———		—	177	180	169	314	275
4	282	271	275	249	—	———		—	193	225	168	310	277
5	296	274	274	263	—	———		—	196	246	161	335	289
6	295	296	295	265	—	———		—	209	261	168	308	294
7		286	303	299	—	———		—	226	314	176	298	301
8	306	280	279	256	—	———		—	231	329	169	315	300
9	309	285	286	237	—	———		—	219	324	168	338	296
10	295	284	274	263	—				223	324	175	325	299
11	292	282	295	262	—				219	300	191	329	292
12	258	290	269	271	—					243	197	319	296
13	276	302	294	277	—				185	225	246	326	299
14	280	298	307	287	—				212	207	221	318	317
15	288	282	292	291	—				172	205	202	323	299
16	283	279	279	275	—			233	158	206	210	318	308

(Contd.)

Table 5 : *Contd*

DATE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN
17	286	284	273	255	–			214	167	194	227	307	297
18	277		261	248	–			223	198	171	290	318	296
19	278	283	270	249	–			224	202	176	305	333	291
20	273	275	277	246	–			199	211	238	297	315	290
21	262	285	280	236	–			208	188	232	331	321	302
22	266	296	298	222	–			223	212	208	358	320	290
23	265	298	335	215	–			224	223	212	319	319	303
24	276	298	313	211	–			234	205	232	309	311	289
25	287	271		206	–			229	179	252	312	319	286
26	283			218	–			225	183	235	310	308	286
27	285	280	306	222	–			198	177	247	305	287	292
28	278	295	267	237	–			229	165	222	291	280	300
29	30!		253	230	–			202	162	198	310	278	277
30	306		263		–			220	——	172	323	283	278
31	289		259		–			244	——	181		289	278
Mean	284	287	283	250	–			221	196	229	242	312	292

All values in Dobson units. From 30 Apr. to 15 Aug. no measurements possible (polar night)

Table 6: Mean Height of Standard Isobaric Levels in Geopotential Meters
(Station : Maitri; Year : 1991)

Month	850	700	600	500	400	300	250	200	150	100	70	50	30	20	15	10	5
JAN	1160	2652	3818	5163	6757	8724	9921	11373	13293	16031	18463	20781	24342	27197	29233	32122	37042
FEB	1223	2532	3845	5164	6723	8641	9836	11297	13207	15863	18252	20517	23968	26725	28685	31455	36428
MAR	1099	2546	3664	4954	6481	8359	9533	10999	12901	15579	17936	20127	23471	26092	28057	30710	
APR	1123	2555	3659	4945	6459	8315	9454	10860	12797	15243	17460	19517	22766	25264	27042	—	—
MAY	1155	2601	3724	5014	6529	8389	9525	10894	12635	15075	17155	19053	22128	24471	26141	28524	—
JUN	1183	2615	3720	5028	6535	8395	9532	10867	12630	15056	17157	19228	22143	24451	26089	—	—
JUL	1133	2550	3649	4911	6402	8233	9333	10654	12345	14660	16705	18535	21357	23535	25154	27456	—
AUG	1091	2523	3643	4917	6420	8249	9358	10687	12371	14709	16806	18731	21667	24018	25703	28251	31952
SEPT	1117	2530	3621	4878	6364	8174	9273	10577	12279	14557	16538	18409	21281	23674	25206	27586	31809
OCT	1105	2550	3671	4966	6483	8332	9412	10796	12473	14875	17045	19098	22629				
NOV	1159	2618	3740	5021	6526	8378	9512	10878	12625	15087	17325	19421	22863	25743	27754	30854	36578
DEC	1272	2705	3923	5254	6825	8756	9919	11411	13311	16037	18502	20796	24365	27075	29161	32059	36966

(iii) The variations in partial pressure of ozone are gradual or negligible upto tropopause compared to those in the ozone maxima layer.

(iv) Maximum ozone concentration is observed in a layer ranging between 18 to 25 km height,

(v) The height of ozone maxima decreases steeply from 25 km in January to 16 km in June. Further variations in the height of ozone maxima are gradual upto August and steep increase thereafter till December. This indicates that during polar nights the ozone maximas are attained at a lower height compared to summer, autumn and spring.

(vi) The monthly mean temperatures at ozone maximas have been worked out for 1991. These show steep decrease upto July and remain low till September followed by steep increase during November and December.

(vii) During ozone-hole period the depletion occurs in the maximum ozone layer, stretching it vertically upward establishing double maxima, one at 16-18 km and other in 22-25 km layer. This is illustrated in Fig. 3.

(viii) Fig. 4 shows the ozone profiles during maximum ozone period (May), depletion period (September) and building up period (December). The ozone depletion commenced in the first week of September and reduced to 40% by third week of September. During the second week of November ozone concentration started building up and got fully revived by December.

Radiometersonde Studies

The thermal radiant energy received from the sun by earth and its atmosphere provides the necessary driving force for the general atmospheric circulation. The actual radiation processes in the atmosphere are extremely complex in nature. The radiance from adjoining layers undergoes complex changes due to the selective absorption mostly by the minor atmospheric gaseous constituents and the result of such interactions is what we measure as the ambient temperature.

The solar energy received by earth and its atmosphere is first converted into potential energy and then to kinetic energy. The phenomena involving circulation of the atmospheric evolution and the existence of fossil fuels are totally dependent on solar energy.

The occurrence of spring time depletion in total ozone amount in Antarctica due to infra-red radiational cooling of the upper atmosphere below -80°C, facilitates the formation of polar stratospheric clouds (PSCs). The effect of the PSCs is two fold. Firstly, they extract nitric acid ($HN0_3$) from air, thereby removing the check over chloric oxide (ClO) cycle. Secondly, chlorine nitrate can react with HCl on the surface of the cloud particles much more faster and effectively than in the air to form

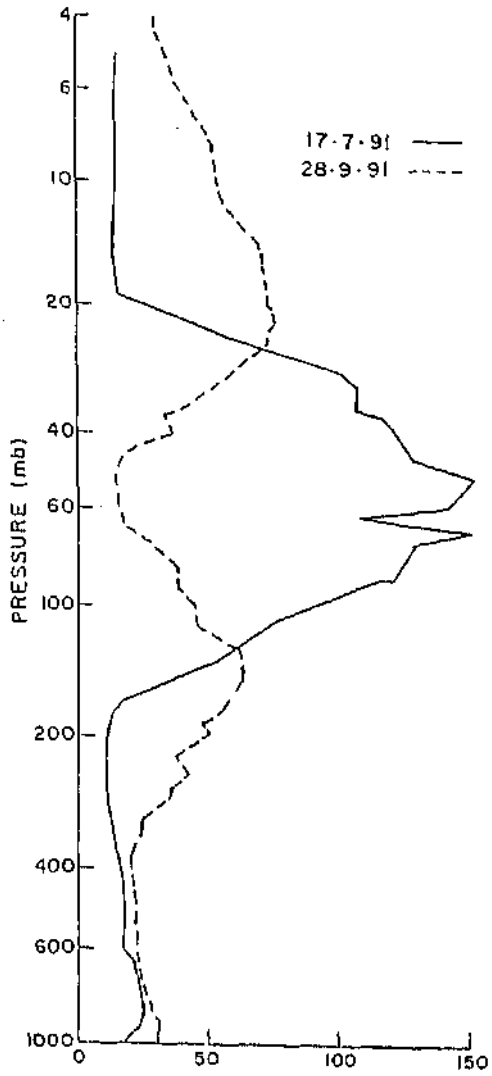

Fig. 3. Partial pressure of ozone during ozone hole period and maximum ozone period.

Cl2 and HNO3, This releases chlorine gas which can accumulate and survive in polar dark period until the sun returns in the spring when the sunlight breaks it into chlorine atoms which are ready to destroy ozone, Taking all these into account, the measurement of infra-red radiative fluxes in the upper reaches of the atmosphere are very important, However, this particular parameter has not been given due importance.

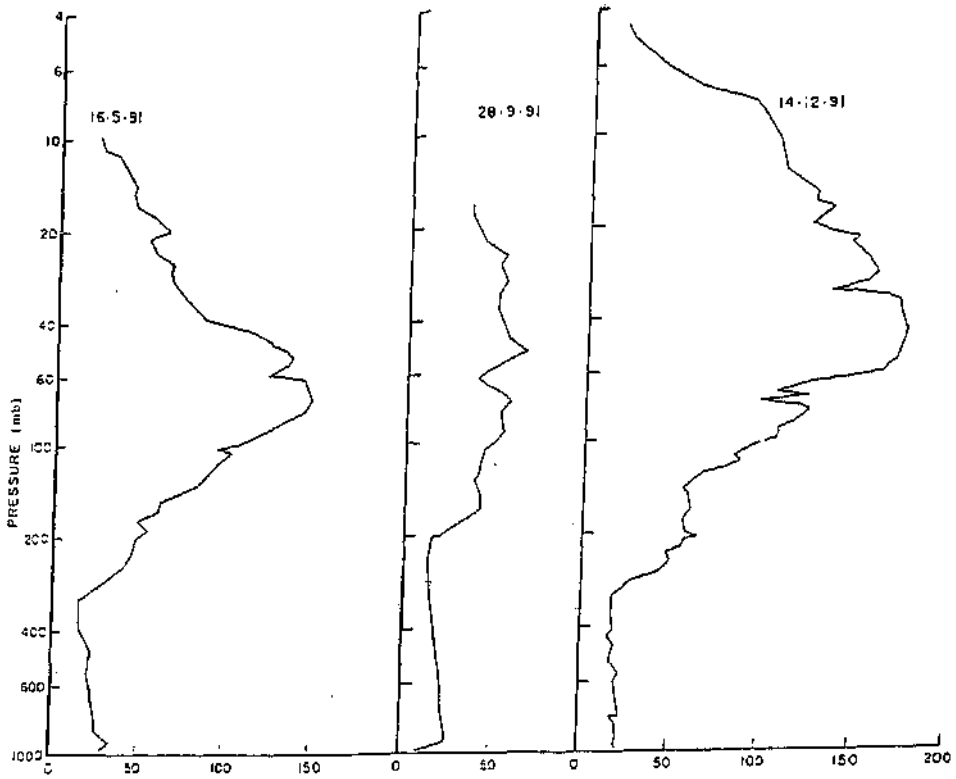

Fig. 4. Partial pressure of ozone for three different months.

During 1991, 14 successful radiometersonde ascents have been attempted from April onward to November and monthly, seasonal and annual values have been presented in Tables 7,8 and 9. The following variations have been observed:

(i) In the troposphere the water vapour present in various concentrations and cloud layers of stratiform or high cirrus type have a overshadowing role in the modification of the radiation field, at any given instances.

(ii) The upward terrestrial radiation and downward terrestrial radiation increase with height to varying degrees. The net terrestrial radiation decreases with height.

(iii) The vertical profile of the upward radiation shows decrease near the tropopause level. The field is nearly steady in the lower stratosphere due to its near isothermal temperature profile.

(iv) The decreasing tendency of the upward radiative fluxes is arrested in the lower stratosphere and the upward radiation starts increasing thereafter.

(v) The net radiation at the surface is centered around 40 Wm^{-2}.

Table 7: Mean Monthly, Seasonal and Annual Values of Net Terrestrial Radiation (Wm^{-2}) for Standard Isobaric Surfaces (Station: Maitri; Year : 1991)

Mbs/ Months	APR	MAY	JUN	IUL	AUG	SEPT	OCT	NOV	AUTUMN	WINTER	SPRING	ANNUAL
SURFACE	39.9	46.7	67.1	30.8	8.5	16.4	64.2	50.0	43.3	41.5	36.7	40.7
950	24.4	37.3	56.7	32.0	32.7	40.7	22.0	75.9	30.9	44.6	44.8	40.7
900	50.9	74.5	59.4	20.9	49.1	38.9	84.0	115.4	62.7	49.5	69.3	59.0
850	42.9	55.7	62.6	27.3	49.9	59.7	118.3	84.1	49.3	52.4	80.5	59.5
800	69.2	54.5	67.9	22.1	56.5	39.5	100.6	69.7	61.9	56.5	62.3	59.7
750	89.1	95.2	72.4	43.0	63.1	65.1	95.0	124.9	92.2	64.4	87.5	78.9
700	91.9	111.2	88.9	110.0	69.3	87.9	113.5	117.8	101.7	85.9	101.8	94.9
650	105.3	116.6	97.9	116.1	87.2	81.9	120.2	123.6	110.9	94.9	101.9	101.5
600	113.2	138.4	100.9	132.3	91.5	93.9	123.0	123.9	125.8	103.0	110.7	111.7
550	129.3	157.9	113.0	123.9	97.3	107.7	145.9	1325	143.5	109.6	123.5	123.2
500	135.1	158.3	118.9	126.7	105.7	103.4	140.3	145.1	146.7	115.4	125.5	127.2
450	132.5	156.1	118.2	145.2	114.5	105.9	154.0	149.1	144.3	121.5	128.7	130.1
400	136.1	151.2	143.9	147.7	116.7	121.9	164.1	141.2	143.7	135.5	137.3	138.3
350	127.8	151.5	123.7	153.7	123.1	124.9	176.1	153.5	139.6	145.2	144.8	143.5
300	137.0	159.3	160.4	155.8	120.7	115.8	173.0	165.3	148.1	146.1	142.5	145.7
250	'124.5	172.2	139.5	173.2	104.6	99.5	182.1	145.5	148.4	133.5	131.7	137.2
200	142.4	174.7	139.5	120.5	98.3	89.2	154.6	155.6	158.6	122.6	122.1	132.7
175	146.8	176.5	139.4	125.9	104.7	94.3	150.5	160.2	161.6	125.6	124.8	135.7
150	139.3	178.5	133.0	124.6	120.9	101.5	182.2	170.4	158.9	117.3	138.9	135.3
125	139.9	174.1	128.7	112.3	94.2	111.7	177.5	178.2	157.0	114.5	144.8	135.3
100	151.9	167.3	156.9	87.8	106.7	93.3	153.3	167.7	159.6	128.6	126.9	137.0
75	144.6	162.3	159.8	___	134.3	92.7	163.3	170.0	156.6	149.6	129.7	144.7
50	141.0	170.8	156.1	___	142.3	142.2	153.7	195.1	160.9	150.6	163.7	156.9
25	170.6	187.8	199.8	___	___	___	___	___	182.1	199.8	___	186.5

Table 8: Mean Monthly, Seasonal and Annual Values of Upward Terrestrial Radiation (Wm^{-2}) for Standard Isobaric Surfaces
(Station: Maitri; Year: 1991}

Mbs/ Months	**APR**	**MAY**	**JUN**	**JUL**	AUG	SEPT	OCT	NOV	AUTUMN	WINTER	SPRING	ANNUAL
SURFACE	311.8	307.1	310.5	345.8	258.2	320.8	390.8	478.3	309.1	299.0	377.7	324.5
950	197.0	265.5	286.1	301.4	240.5	263.1	273.4	370.1	231.2	273.4	292.5	266.8
900	289.3	267.7	275.3	274.4	221.1	226.7	265.8	353.4	278.5	257.0	268.2	266.4
850	280.7	250.7	262.3	275.9	212.9	225.7	267.1	311.8	265.8	248.1	257.6	255.9
800	277.9	243.1	256.1	257.4	206.4	194.8	250.4	300.2	260.5	240.0	235.1	244.3
750	272.3	240.3	248.8	248.7	201.4	189.3	228.3	289,5	256.3	233.0	224.1	237.1
700	260.9	236.4	245.1	237.6	195.7	202.5	232.5	285.4	248.7	227.4	230.9	234.5
650	264.9	230.8	245.3	228.6	195.1	175.4	238.0	273.3	247.9	226.3	215.5	229.4
600	255.5	227.9	241.7	222.2	192.1	185.6	227.4	266.9	241.7	221.9	216.4	226.0
550	251.3	229.4	236.2	213.0	186.9	182.5	227.6	250.4	240.3	215.8	210.8	221.2
500	234.5	218.1	227.7	207.2	183.8	172.9	215.4	249.5	226.3	210.0	202.7	212.4
450	222.0	217.5	217.7	208.5	180.3	156.7	212.0	241.5	217.5	203.7	191.7	204.2
400	206.7	202.3	215.3	195.7	170.5	164.2	202.5	223.9	204.5	197.1	188.7	196.8
350	192.3	198.1	200.3	189.9	171.2	153.7	201.7	206.8	195.2	188.9	178.9	187.9
300	191.8	201.6	195.7	185.3	159.6	145.9	185.8	206.4	196.7	181.9	171.0	183.0
250	183.0	213.2	176.3	170.9	148.3	141.5	176.0	183.4	198.3	165.9	160.6	173.7
200	193.9	208.0	174.1	135.9	138.1	119.7	145.8	184.7	200.9	150.7	142.5	164.9
175	190.5	209.5	171.3	141.3	133.8	117.8	150.3	192.7	200.0	153.8	144.7	164.4
150	179.3	209.1	165.4	143.3	127.7	119.7	156.3	204.0	194.2	149.2	149.9	162.3
125	182.5	204.7	164.1	136.3	127.6	118.8	155.9	244.8	193.6	147.3	159.6	164.0
100	183.1	191.7	176.1	136.3	129.6	115.4	151.5	273.0	187.4	157.5	163.8	166.3
75	154.1	187.5	183.4		141.2	123.0	158.8	290.7	176.4	166.5	176.4	172.3
50	153.1	191.5	172.9		144.0	143.1	157.8		178.7	161.4	150.5	164.3
25	164.0	199.5	202.8						187.6	202.8		

Table 9: Mean Monthly, Seasonal and Annual Values of Downward Terrestrial Radiation (Wm^{-2}) for Standard Isobaric Surfaces

Mbs/ Month	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	AUTUMN	WINTER	SPRING	ANNUAL
SURFACE	271.9	260.5	243.5	315.0	249.6	291.2	326.7	228.3	266.2	257.5	341.1	283.9
950	172.6	228.1	229.4	269.4	207.7	222.5	251.4	294.3	200.3	228.8	247.7	226.1
900	238.5	193.1	215.9	253.5	171.7	187.9	181.8	237.9	215.8	207.5	198.9	207.4
850	228.8	195.3	199.7	248.6	163.1	166.1	148.8	227.7	216.5	195.7	177.2	196.5
800	208.7	178.7	188.2	235.3	149.9	155.3	149.8	230.5	193.7	183.3	172.7	183.2
750	183.2	145.1	176.4	205.7	138.3	124.1	133.2	164.6	164.2	168.6	136.5	158.2
700	169.0	125.1	156.3	127.6	126.3	114.9	119.0	167.6	147.1	141.5	129.1	139.6
650	159.7	114.3	152.2	112.5	109.3	92.5	117.9	149.7	136.9	131.4	113.1	127.8
600	142.3	89-5	140.8	89.8	100.6	91.7	104.4	135.0	115.9	118.9	105.1	114.3
550	122.1	71.6	123.2	89.1	89.5	74.9	81.8	117.9	96.8	106.3	87.3	98.2
500	99.5	56.9	109.6	80.6	78.1	64.5	75.1	104.4	79.7	94.3	77.1	85.2
450	89.5	55.9	92.8	63.3	65.7	50.9	58.0	92.5	73.2	78.9	63.1	72.7
400	70.5	51.1	71.3	51.0	53.8	42.3	38.4	82.7	60.8	62.1	51.4	58.7
350	64.5	46.7	43.3	36.2	48.1	28.7	25.6	53.3	55.6	43.9	34.1	44.3
300	54.7	42.3	35.4	29.5	39.7	25.1	12.8	41.2	48.5	35.8	26.1	36.7
250	58.8	40.9	36.6	2.3	43.6	42.0	6.1	37.9	49.9	32.6	28.9	36.4
200	51.3	33.3	34.6	15.4	39.9	30.5	8.8	29.2	42.4	33.1	20.3	32.1
175	43.7	32.9	31.9	15.4	29.1	23.5	0.2	32.5	38.3	28.2	19.8	28.7
150	39.9	30.7	32.4	18.9	37.7	17.7	25.9	33.6	35.3	31.8	10.8	26.8
125	42.5	30.7	35.3	24.0	33.7	7.1	21.6	66.6	36.6	32.9	14.8	28.8
100	31.4	24.5	19.2	48.4	22.9	22.1	1.8	105.2	27.9	25.3	36.7	29.4
75	9.7	24.9	23.5		7.9	35.4	4.5	120.6	19.8	16.9	20.6	27.5
50	12.2	20.7	16.3		1.7	0.9	4.1		17.8	10.8	2.5	11.2
25	6.6	11.7	3.0		6.2				10.0	4.6		5.2

(vi) The upward radiative fluxes are highest in autumn and lowest in spring.

(vii) The net terrestrial radiation generally increases with height but the rate of increase reduces just below the tropopause and increases in the stratosphere.

(viii) The downward terrestrial radiation at the tropopause is very small compared to upward terrestrial radiation and net terrestrial radiation.

(ix) The lowest temperatures attained due to radiational cooling below -80°C during austral spring in the higher reaches of the atmosphere, facilitates the formation of polar stratospheric clouds which provide surfaces to undergo heterogeneous chemical reactions resulting in the production of chlorine gas; which survives in the cold dark period of polar nights.

This chlorine gas molecules get dissociated with the return of the sun in spring into chlorine atoms ready to destroy ozone catalytically.

Conclusions

1. At Maitri, August was the coldest month during 1991. Both lowest monthly mean air temperature (-17,0°C) and extreme lowest air temperature (-30.6°C) were recorded in August.
2. Highest mean sea level pressure attained in 1991 was 1010.5 hPa in December and the lowest 952.1 hPa in July.
3. Ozone-hole at Maitri started developing in the second week of September and got revived by first week of November. The lowest daily mean total ozone recorded at George Forster station, 4 km from Maitri, was 158 DU on September 16. The corresponding depletion in the partial pressure of ozone was around the level of maxima in the stratosphere found in the ozonesonde ascent attempted on September 17 of 58.2 NBar and 57.0 NBar on November 2, 1991.
4. The height of almost all standard isobaric levels was highest in summer (December, January and February) and lowest in spring (September, October and November). The annual mean tropopause was at 256 hPa level at the height of 9449 gpm and -63.9°C air temperature. Temperature of tropopause was highest in summer and lowest in winter.
5. Maximum ozone concentration was attained at a much lower height in winter than summer. Similarly, temperature at ozone maxima was lowest in winter than summer.
6. Based on total ozone observations at George Forster station, total ozone varies in amount hour to hour, day to day, month to month and season to season.

7. Longest duration blizzard of the year of about 3 days spanned over 70 hours was experienced in March. Highest maximum wind speed of the year 82 kts was experienced in September during strong blizzard. May had maximum number of blizzard days and January, February, August, November and December were the months having no blizzardic activity.
8. The mean temperature, the extreme highest and lowest temperatures of the year 1991 have been compared with those of 1990. It is observed that the year 1991 was warmer than 1990.

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