5

WATER VAPOUR DISTRIBUTION AND TRANSPORT AT ANTARCTICA

5.1. Introduction :

The Antarctica, world's driest icy continent is surrounded by southern ocean. For most of the year, except for some brief periods during polar summer, the continent looses more heat than it gains from the sun. As the continent does not get progressively colder by this process it must acquire energy from elsewhere. The source of heat and the mechanism of heat distribution is still not clearly understood.

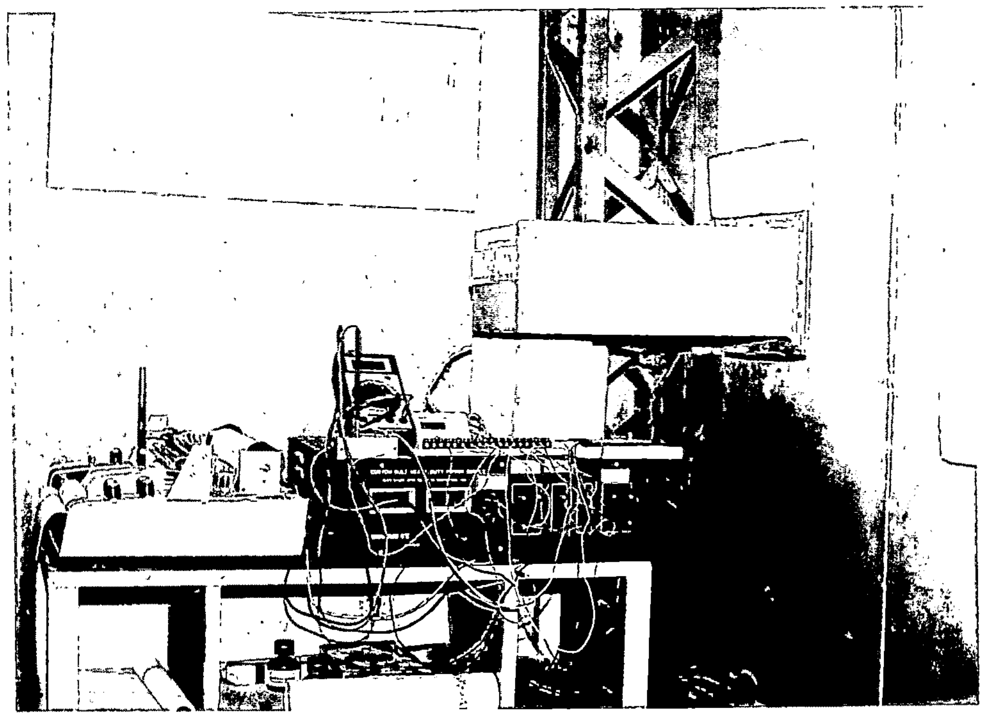
Weather at any region on the earth is not an isolated event. It is a global phenomena. To understand the climate, global weather pattern is to be studied. Incidentally, Antarctic weather plays a key role in setting the global weather pattern. But, unlike any other places Antarctic weather is guided by the motion of atmosphere and oceans which redistribute heat from heat surplus zone(tropics) to the heat deficit zone(poles). Antarctica is colder than Arctic because it is surrounded by southern ocean which prevents transport of heat from tropics to the poles. Water vapour, temperature and wind are three important elements of the weather since different combinations of the three characterize the regional climate. Different aspects of climatic changes have been studied by various authors which revealed that water vapour plays a crucial role in the heat distribution process guided by wind and cloud cover. A complex system combined with radiative cooling, slopping convection and weather pattern actually sets the weather pattern in the region. To understand the mechanism, a 22.235 GHz radiometer was taken to Antarctica and put into continuous operation during polar summer. Simultaneous measurements of pressure, temperature and relative humidity were also carried out to analyse the dynamic variations recorded by the radiometer. The main advantage of the microwave sensing is that, it can penetrate many types of aerosols and clouds and still permits accurate remote sensing from ground or space.

5.1.1 Choice of frequency :

Because 22.235 GHz line has a pressure dependence on line shape change, *Hogg et al.* [1982, 1983] suggested some offset frequency such as 21.0 or 24.4 GHz for water vapour measurement and which are ideal for their pressure independence. It has been observed by *Datta et al.* [1994]; with experimental data that 22.235 GHz radiometer is most appropriate for water vapour sensing at Antarctica and also equally good for other dry regions. For any offset frequency, the radiometer will operate in the less sensitive mode which is about 1/3 of the sensitivity as compared to 22.235 GHz radiometer. In addition, measurement with 22.235 GHz radiometer suffers occasional saturation problem in tropical regions like Calcutta when water vapour content in the atmosphere goes high especially during pre and post rain conditions. Since water vapour at Antarctica is remarkably low and rain is rare, the radiometer never saturates and even it can see through higher altitudes of the atmosphere. Thus, a 22.235 GHz radiometer is more appropriate for water vapour measurement at Antarctica.

5.2. Experimental set-up :

The 22.235 GHz radiometer, a similar prototype of which was flown into Indian Remote Sensing Satellite Bhaskara I & II, was taken to Indian Antarctic Station Maitri for water vapour studies. The corrugated horn lens antenna along with radiometer assembly were placed inside a small temperature controlled room specially built for such purpose as shown on Fig.5.1. The antenna beam pointed horizontally through an aperture in the wall of the room to a flat aluminium reflector aligned at 45^0 to the zenith as shown in Fig.5.2. Emission noise of water vapour from the zenith is sensed by the radiometer after being reflected from the flat reflector. To from a low loss window to the microwave energy, the aperture on the wall was covered with two sheets of 'Mylar' each of 2 mil thick. Continuous observations were made during polar summer and the output was recorded on chart paper. The radiometer was calibrated with liquid nitrogen from time to time to ensure good measurement accuracy. The details of radiometer setup, reflector position and calibration technique are discussed in Chapter 2. Liquid nitrogen dewar and parabolic reflector were also taken to Anatarctica for performing calibrations time to time.



▲ **Fig.5.1.** The 22.235 GHz radiometer, power supply and chart recorder at Maitri, Antarctica with antenna looking outside a metallic reflector

▶ **Fig.5.2.** A flat metallic reflector placed 45^0 to the ground facing radiometer antenna that reflects sky emission noise for radiometric sensing.

5.3. Observation :

5.3.1. Radiometric sensing of water vapour at Antarctica :

The 22.235 GHz radiometer setup was operated in zenith looking mode round the clock at Indian Antarctic station Maitri for three months (Dec. 1991-Feb.1992) during polar summer. Simultaneous measurement of other surface meteorological parameters were also carried out. Fig.5.3 displays an one day (24-01-1992) time series of zenith brightness temperature(K) as recorded by 22.2235 GHz radiometer with corresponding variations in surface tempera-ture(^{o}C), relative humidity(%), pressure(mb), wind speed (M/s). Due to low temperature and high wind speed the absolute humidity remains very low in the continent while the relative humidity varies a lot. Sometimes it goes beyond 90% and even below 30% at times. Simultaneous measurement of surface temperature, pressure and humidity have revealed that the surface water vapour density is not correlated with integrated water vapour. Some interesting features of integrated water vapour profile are noticed. A typical brightness temperature profile is shown in Fig.5.4. The figure demonstrates a very fast change in integrated water vapour during polar summer near the Indian station 'Maitri', indicating more than 100% increase within a time scale of few minutes. Such an abrupt increase of water vapour content is due to the motion of water vapour from coastal zone to the inner plateau. These events were frequent during blizzards and were found to be associated with high wind speed. Formations of similar profile and motion of water vapour form coastal zone to the inner ice cover can be understood by a cold front model as explained below.

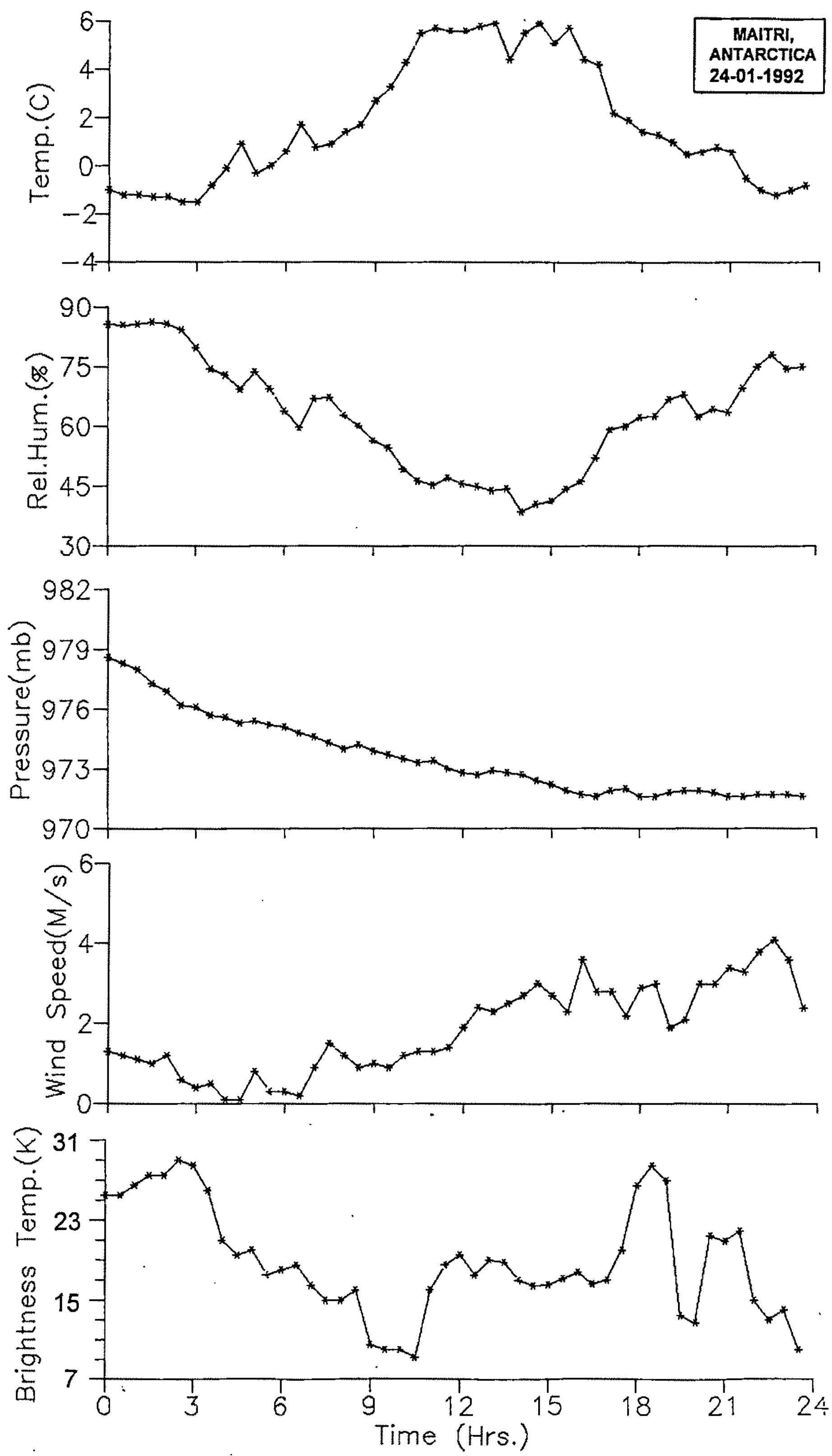


Figure 5.3 : One day time series of plot of temperature (C), relative humidity (%), pressure (mb), wind speed (M/s) and brightness temperature (K) on 24-01-1992.

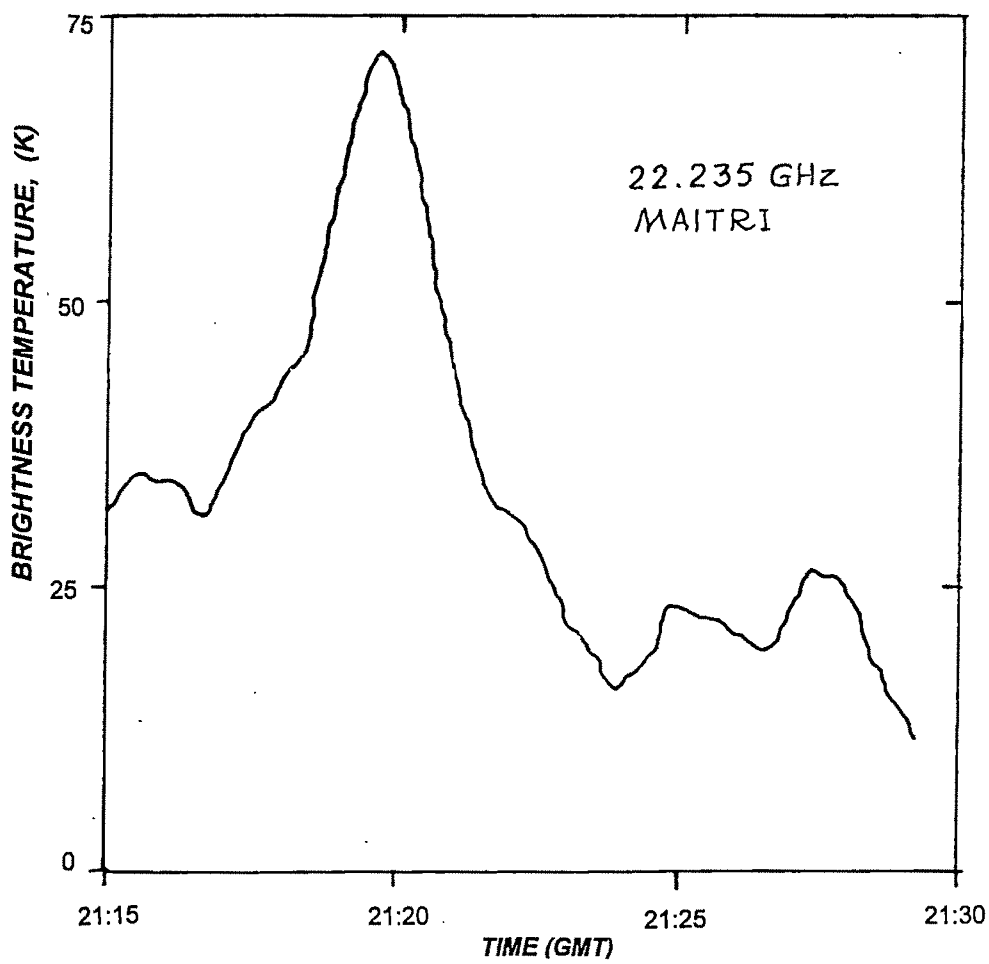


Fig.5.4 : A Plot showing fast change in brightness temperature (K) within short interval of time.

5.3.2. Cold front model :

Several cold front passages were reflected on the chart paper of radiometer output out of which a few clear air observations were selected for detail analysis. The motion of the wave front and the direction was found out from the radiometric data and surface meteorological parameters. Fig.5.5 shows a model of a cold front showing features observed by microwave radiometer. Such a comparison between radiometric observation and cold front model may be justified because at Antarctica, 22.235 GHz zenith looking radiometric observation is better correlated with water vapour density aloft. A composite picture of the cold-front passage was thus assembled, using the inferred values of surface water vapour density, cloud thickness and cloud density as functions of time. The picture agrees well with typical frontal characteristics, although scattering effects were neglected because scattering contribution is not available from radiometric measurements. Since rain is sparse in the continent, such approximation would not induce much error. The key features of radiometric observations are summarized below,

- water vapour cloud system extends far into warm air ahead of the front at the ground.
- high westerly wind caused sudden increase in water vapour cloud thickness.
- Cold front precipitation resulted in snow fall of short interval.
- The tail of frontal system may be extended long behind.
- Shortest spell of cold front was noted to be 4-5 mins and largest of 2-3 hours duration.

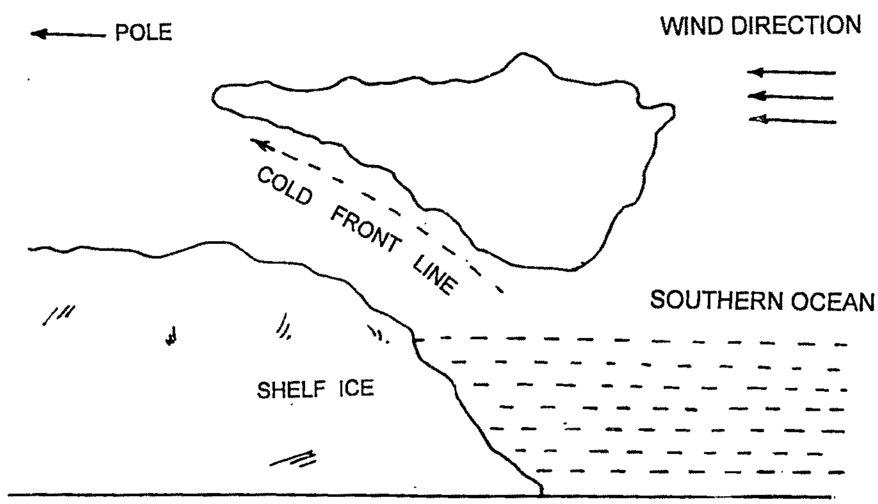


Fig.5.5 : A composed picture of cold-front passage and its movement as extracted from radiometric output.

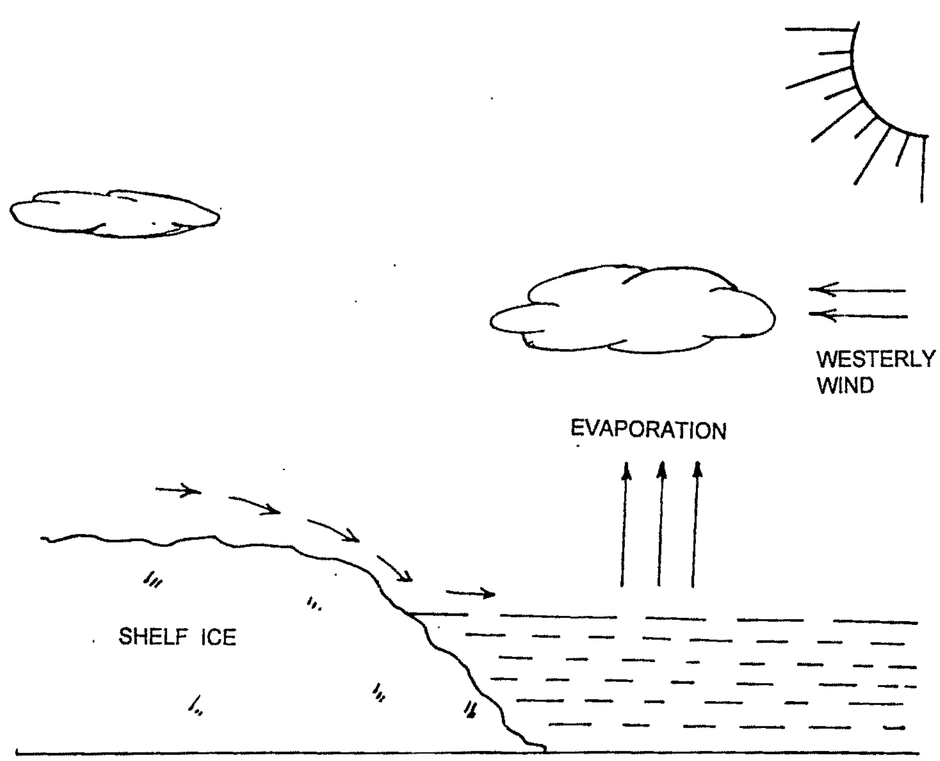


Figure 5.6 : Water vapour evaporation and transportation near the coastal region of Antarctica.

5.4. Analysis :

5.4.1. Water vapour transport mechanism :

During polar summer the Antarctic continent comes closest to the sun and receives maximum solar radiation than it receives any other time of the year. But, the continent's perpetual snow cover is efficient in reflecting almost 70%-80% of the incident radiation back into the atmosphere, thereby further cooling the surface. As a result, air above the surface remains dry, colder and heavy. On the other hand, the incident solar radiation is much absorbed by the sea water and it gets evaporated. The air above the sea surface becomes warmer and moistened and tends to go high whereas air above the cold ice surface tends to slide down the sea under the influence of gravity. A pressure gradient is set up and wind blows from coastal zone to the pole. This wind flow gets stronger by the circumpolar wind which flows around the mid latitudes. The wind is extended through the entire tropo-sphere and gives birth to occasional depressions. These weather systems which lasts from few days to weeks usually move polewards across the ocean and is guided by the upper part of the troposphere. The wind carries warmer and humid air from over the ocean and while going towards the pole it releases the latent heat into the atmosphere and turned into water vapour and sometimes falls as snow over the inner plateau. The evaporation and flow of wind can be understood by Fig.5.6. In polar summer, the solar radiation remains for 24 hours with maximum intensity and due to the exchange of water vapour latent heat, low pressure centers are developed and wind speed gets stronger at an average speed of 80-120 km/hr with occasional gusts exceeding 250 km/hr. This is known as 'katabatic' wind which is guided by the shape of ice cover rather than atmospheric pressure as observed in other parts on the earth. The wind tends to flow at lower altitude under the influence of gravity with warmer air above. Thus the coastal region becomes the breeding zone of many depressions that is generally developed during polar summer and experiences very high wind speed at times. These depressions decays with the exchange of latent heat towards the pole.

Southern ocean remains cloudy for most of the year. The coastal region also remains cloudy. But there is less cloud towards the pole. The low, thick, stratocumulus cloud is usually seen over the ocean at times. In summer, cumulus clouds are often seen near the coastal zone. These are basically ice crystal clouds which bear almost no water on its surface. The ice crystal clouds sometimes form spectacular hanging objects in the sky after being reflected and refracted by sun beam which are called 'haloes'.

5.4.2. Air drying mechanism :

Antarctica is colder than the Arctic because it is surrounded by Southern Ocean, making it harder for ocean currents to transport heat to polar latitudes. Sloping convection accounts for the extra dryness behind cold fronts at Antarctica, which was confirmed by *McMurdie et al.* [1991] from satellite microwave data. This mechanism of drying air by sloping convection is explained by *Ludlam* [1980]. During cyclogenesis sloping convection dries the poleward moving air thereby providing a sink mechanism for water vapour, it is therefore crucial to the supply of water vapour in the upper troposphere, and hence to both cloud formation and the radiative balance. Such behaviour is consistent with the observation (*Peixoto*, 1970) and there is an excess of evaporation over precipitation at all latitudes except the sub-tropics. The subtropics are thus source of water vapour for the troposphere, atmosphere dynamics convey moisture to middle and subpolar latitudes where it is precipitated, Antarctica is more effective dry air factory than the Arctic, resulting in the observed inter-hemispheric wintertime asymmetry. From airborne measurement of total water vapour and ice crystal during winter of 1987 in the southern hemisphere and of 1988-89 in the northern hemisphere, it has been found that the upper troposphere is 2-4 times drier during austral winter than boreal winter, *Kelly et al* [1991]. In addition to this, a complex interplay between radiative cooling, sloping convection, and the water vapour content which sets the regional climate. Accurate simulation of these interactions through modeling is a severe test with current knowledge on circulation models.

5.5. Results :

Radiometric observation have shown the following characteristics of water vapour distribution at Antarctica.

- Integrated water vapour content remains at its lowest (one fourth as compared to Calcutta) as compared to any other parts in the world.
- Unlike tropical region, surface water vapour density is not correlated with the water vapour density aloft. The correlation coefficient is only 0.34.

- Sharp changes in integrated water vapour is found which resembles flow of small water vapour packets across the antenna beam looking zenith.
- A stepwise increase in water vapour is observed which remains for long time at higher value and falls back to its initial value. These may be treated as passage of large weather systems across the antenna main beam.
- During blizzards, a number of events with sudden shoot up in integrated water vapour were observed. This resembles passage of water vapor under the influence of wind from coastal zone to inner plateau.
- Carriage of water vapour from coastal zone to inner plateau can be well understood from the trend of radiometric output profile with due consideration of wind speed and wind direction.

5.6. Discussion :

Water vapour distribution in the atmosphere is the key factor of global heat budget and climatological change. Non uniform mixing ratio along the altitude makes it difficult to profile. At Antarctica, it is more complicated due to high wind speed and low temperature. It was the purpose of this study to track the water vapour transport from the ocean and how thermal energy is supplied to the pole so that there is no unlimited accumulation of ice in the Antarctica. Measurement of emission spectrum of atmospheric water vapour allowed us to determine water vapour at Indian Antarctic station Maitri. Simultaneous measurement of surface water vapour density, temperature, pressure helped to analyse the dynamic variation of integrated water vapour as recorded by 22.235 GHz radiometer. Some radiosonde values were also available to analyse the radiometric absorption in more detail. Due to low temperature and low humidity, rain is almost rare in the continent. Therefore, cloud liquid water contribution may be neglected in the retrieval of water vapour from radiometric measurements as ice crystal cloud of cumulus congestus is only found in the region. Also, it was relatively easy to estimate water vapour content in clear weather condition since scattering effects had only to be neglected in absence of rain. Of the many observations recorded by 22.235 GHz radiometer, a particular 4 hr. period corresponding to a cold-front passage was chosen for detailed study. Fig.5.4 agrees with typical frontal characteristics that have been described, thoroughly demonstrating the ability of this procedure to yield water vapour content with better/reasonable accuracy.

Another radiometer operating at 183 GHz would have been helpful for studies of lower atmospheric water vapour variation in more detail since at Antarctica lower 3 Km of height contributes almost 70-80% of total water vapour attenuation. With 183 Ghz radiometer very accurate water vapour profiling of lower atmosphere is possible which would obviously be helpful to understand water vapour distribution and transport at Antarctica.

It has been confirmed by many investigators that passive radiometric sensing can provide reasonably good predictions of water vapour. Therefore, multifrequency radiometers are gaining fast popularity and continue to rule the studies of terrestrial atmosphere in future.