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Study of Snow-Met Parameters And Estimation of Surface Energy Budget Over Continental Shelf Through Ground Based Observations

Partap Singh Negi and Mahender Kumar
Snow & Avalanche Study Establishment, Manali

Objectives

To measure

- Snow-met parameters over continental shelf
- Albedo values over continental shelf

  Components of surface energy budget over continental shelf
- Estimation of net surface energy fluxes over the continental shelf

Microstructural Analysis of Different Snowllce Medium in Antarctica

Ice sample and study area : Near coastal blue-ice region

  Mean crystal size in the surface layer and their spatial distribution within the study area.
- Effect of slope variation on the mean crystal size
- Depth density profile and crystal size variation with depth in near surface ice core stratigraphy

To estimate the energy budget of continental ice, SASE has installed one AWS near the "Sankalp Point", that is approximately 6 km form Maitri station. This year the AWS was re-installed and renovated.

The following Sensors were mounted on the AWS :

1. Albedo meter
2. Anemometer
3. Dry bulb temperature
4. Wind direction
5. Relative humidity

6. Maximum temperature
7. Minimum temperature
8. Wind speed

Installation of Observatory Over Shelf-Ice Near Dakshin Gangotri

To estimate the energy budget of continental shelf SASE installs snow-met observatory near Dakshin Gangotri every year. This observatory is installed for the austral summer only because during winter no one stays at this location.

The various instrument required and installed for the observatory are:

1. Pyranometer
2. Hand held cup type anemometer
3. Dry bulb thermometer.
4. Dial gauge thermometer
5. EPR recorder.
6. Battery 12V 88AH
7. Digital Pressure displayer.

Snow Met Data Collection for Estimation of Energy Budget over Continental Shelf at Dakshin Gangotri

The following parameters were measured, from the observatory, set up near Dakshin Gangotri during the austral summer of 1999-2000:

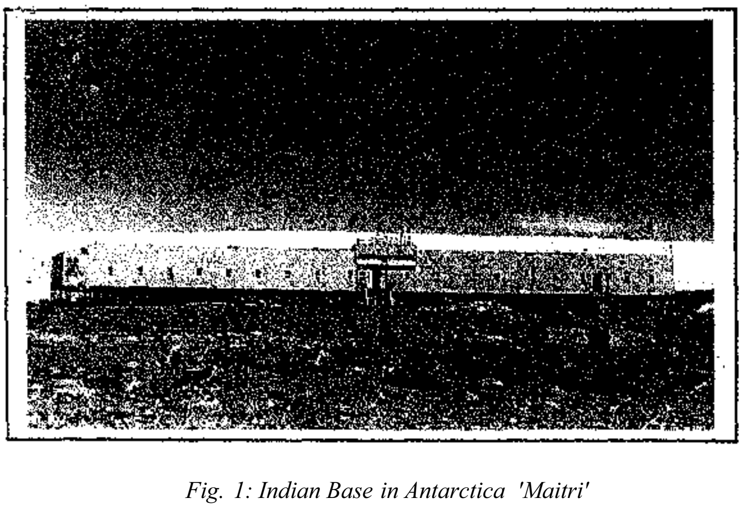


Fig. 1: Indian Base in Antarctica 'Maitri'

- Solar radiation
- Snow surface temp.
- Ambient temp.
- Wind speed
- Pressure
- Albedo

Measurements of snow-met data for estimation of surface energy budget includes net radiation, wind speed, air temperature, surface temperature and pressure. All the snow-met data were collected on hourly basis. The net radiation is sum of net short wave radiation and net long wave radiation. The net short wave radiation is the difference between the measured incoming solar radiation and the measured reflected solar radiation. The long wave radiation was calculated from the model. The incoming and reflected radiations were measured with two precision pyranometers, one facing upward and other downward. These instruments have a nominal sensitivity of 7-8 V/Wm^{-2}. They have a flint glass double dome with excellent transmission characteristic for solar radiation in the wave length range 0.3-3 m. This instrument was kept at a height of 1.5m above a flat snow/ice surface so that cosine error can be minimized. An EPR Recorder was used to record incoming and outgoing radiation on a thermal chart. The measurements of one-hour intervals were taken for the calculation of Albedo. Spot wind speed was measured with a hand held cup type anemometer. Atmospheric pressure was measured with a digital barometer. The Air temperature was measured with a dry bulb thermometer. The surface temperature was measured with dial gauge thermometer having a measuring range of -50°C + 50°C. Surface temperature has been found

Fig. 2: Ice class logistic vessel provided far XIX IAE

very important parameter for estimation of energy budget of snow/ice surface. Cloud amount and cloud types were observed every one hour interval during the observation period.

Fig. 3: AWS Continental ice

The surface energy balance:

The energy available on snow/ice surface is obtained from the following equation

$$Q = S_w + L_w + Q_h + Q_e + Q_m + Q_g \qquad \ldots(1)$$

Where Q is the net surface energy budget, S_w is the net short-wave radiation flux, L_w the net long wave radiation flux, Q_h and Q_e are the sensible and latent turbulent heat fluxes respectively. Q_m and Q_g are advected heat flow (mass transfer due to rain/snow) and heat exchange and snow-ground interface respectively. The last two terms on right hand side of the Equation. 1 are negligible components in daily energy balance of a surface when compared to the other terms.

Therefore, neglecting the last two terms the net change in energy storage at the snow/ice interface is given as:

$$Q = S_w + L_w + Q_h + Q_e \qquad \ldots(2).$$

The surface of first two terms on the right hand side of the Equation 2 gives net radiation components and the sum of the last two terms gives the turbulent energy fluxes. All these terms are measured and calculated in Watt per square meter.

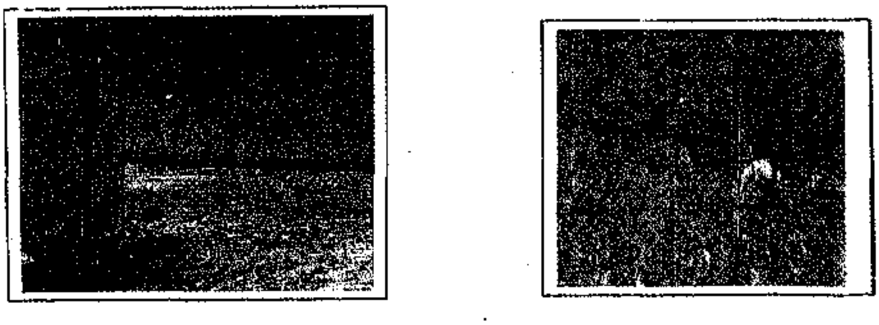


Fig. 4: Dakshin Gangotri Station and observatory on continental shelf

(a) Short-wave radiation flux:

The reflect short-wave radiation from the snow/ice surface $S_{w0}(t)$ depends on the amount of incident radiation S_{wi} (I) and the surface albedo a . The expression for the net short-wave radiation flux (S_w) absorbed by the snow/ice surface is calculated as:

$$S_w = S_{wi} (\downarrow) - S_{wo} (\uparrow)$$

$$S_w = S_{wi}(\downarrow) - (1 - ά) \qquad ...(3)$$

Where $ά = S_{w0} (\uparrow) / S_{wi} (\downarrow)$

(b) Long-wave radiation flux:

The Net long-wave radiation flux is the difference between the downward radiation from the atmosphere and emitted radiation from the snow/ice surface. The emitted long wave radiation L_{wo} (↑) from the snow/ice surfaces can be calculated from the Stefan-Boltzman law :

$$L_{W0}(\uparrow) = Є_s \sigma T_s^4$$

Where $Є_s$ is the emissivity of the snow. The value of $Є_s$ varies from 0.98 to 1. Here the value have been chosen as 1. T_s is the snow surface temperature (K) and σ is the Stefan-Boltzman constant (5.67 x 10^{-8} Wm^{-2} K^{-4}).

The downward long-wave radiation depends on the air temperature and composition of the overlying atmosphere. It is calculated form the model of Prata (1996), which computes emissivity of the atmosphere depending on precipitable water content (w) and performs well in the limit of a dry atmosphere :

$$L_{wi} = \{ 1 \quad (1+w)\exp(-(1.2 + 3.0w)^{1}/_{2})\}\sigma T_s^4$$

$$W = 46.5(e_a/T_a)$$

Here, T_a is the air temperature whereas, e_a is saturated vapour pressure of air. Clouds, being composed of water droplets, absorbs much more long-wave radiation than water vapour and have strong influence on long-wave radiation exchange because they act as near perfect black body. The most common approach to estimate the effect of clouds upon the net long-wave radiation is to modify the cloudless sky value by a non-linear cloud term. Thus, the net long wave radiation flux under cloudy skies is modified as :

$$L_{out} = \sigma [\{ 1 \quad (1+w) \exp (- (1.2 + 3.0w)^{½})\} T_s^4 - e_s a T_s^4][1-c^2] \qquad ... (4).$$

Where c is the decimal cloud cover (estimated in octa) (Oke, 1987).

(c) Turbulent energy exchanges between the snow/ice surface and the atmosphere:

Qh, Qe

The Sensible heat flux Q_h which is a direct transport of heat energy and Latent heat flux Q_h which is a transport of heat through the phase change of water play an important role in determining the rate of sublimation/melt from the snow/ice surface.

(i) Sensible heat flux:

The sensible heat flux calculation requires measurement of air temperature, surface temperature and wind speed. Following Ambach and Kirchlechner (1986) and Paterson (1994) :

$$Q_h=(C_p/P_0)D\ Pu(T_a\ \ T_s) \qquad \ldots(5)$$

$$D=k^2/[In(z_a/z_0)]^2 \qquad \ldots(6)$$

Where C_p is specific heat of air at constant pressure, P_0 is the density of air (1.29 Kg m-3) at the standard atmospheric pressure P_0 (101300 Pa), D is the transfer coefficient under neutral conditions (dimensionless), P is the mean atmospheric pressure at the measuring site, u and T_a are wind speed and air temperature at measurement level, z_a = 1.5 meter above the snow/ice surface, k is the von Karman constant (0.4) and z_0 is the aerodynamic roughness length, T_s is the snow surface temperature (K).

(ii) Latent heat flux:

The latent heat flux Q_e is calculated using:

$$Q_e = L_v\ (0.623\ P_O/P_O)\ D\ U\ (e_a - e_s) \quad \ldots(7)$$

Where L_v is the latent heat of vaporization, e_a is the vapour pressure at height z above the snow / ice surface and is the saturation vapour pressure at the snow/ice surface. Es is the function is the surface temperature and is 611 Pa for a melting surface (Paterson, 1994). e_s is calculated from the saturation vapour pressure over a plane surface of pure water using the goff-Gratch formulation (list, 1971) and the prevailing relative humidity. Es is assumed to be the same as the saturation vapour pressure over a plane surface of pure water at surface temperature Ts. The distinction between condensation and sublimation are made following Ambach and Kirchlecchner (1986), i.e. with latent heat L_v = 2.514 and 2.849 MJ Kg^{-1}, respectively. When (e_a - e_s) is positive and Ts = 0°C, water vapour condenses as liquid water on the melging snow/ice surface with $L_v = 2.514$ MJ Kg^{-1}. When $(e_a - e_s)$ is negative, there is sublimation with $L_v = 2.849$ MJ Kg^{-1}. Also when $(e_a - e_s)$ is positive and Ts<0°C, there is condensation from vapour to solid ice with $L_v = 2.849$ MJ Kg^{-1} .

The bulk transfer equations (5), (6) and (7) are valid only for neutral atmospheric conditions. However, if atmospheric conditions are not neutral than an appropriate stability correction can be applied for stability of atmosphere using the Richardson's number Ri (Price and Dunne, 1976).

$$T_I = gz \qquad (T_a - T_s)/T_a(U_z - U_s)^2 \qquad \text{...(8)}$$

Where g is the acceleration due to gravity (ms-1) and Us the wind velocity at the snow surface (ms-1)

For stable conditions ($R_I > 0$), transfer coefficient is given by :

$$Ds = D/(1+10R_i) \qquad \text{...(9)}$$

For unstable conditions ($R_i < 0$), the transfer coefficient can be modified by:

$$D_u = \qquad D(1-10R_i) \qquad \text{...(10)}$$

Elements at 1 -Hourly interval for calculation of surface energy budget are shown in Fig. 5. The incoming short wave radiation is a measure of the radiative energy coming down to the snow surface from the sun. The solar radiation is the main drive in the surface energy budget during summer, but as the winter starts the effect of solar radiation keeps on reducing. Measurement of the air temperature shows that it is more during summer and reduces gradually as the winter approaches. Wind speed also shows the seasonal effect. During initial observation the wind speed was found low but as the winter starts the variation in wind speed was more. The trend was increasing. The minimum and maximum wind speeds during observation we recorded as 0.02 m/s and 19.1 m/s. Pressure also shows an increasing trend as the winter commensurate. The pressure is very much dominated by the movement of the cloud system and the season. Generally overcast and cloudy days restrict pressure fluctuation. But when system moves in or moves out then fluctuation starts.

From the aggregate of data from Fig.5 it is evident that the summer at observation site is relatively warm with high air temperature, low wind speed, low pressure and high solar radiation. The trend in micro-climatological elements changes as summer approaches winter season. The air temperature and solar radiation show a decreasing trend whereas the wind speed and the pressure show an increasing trend.

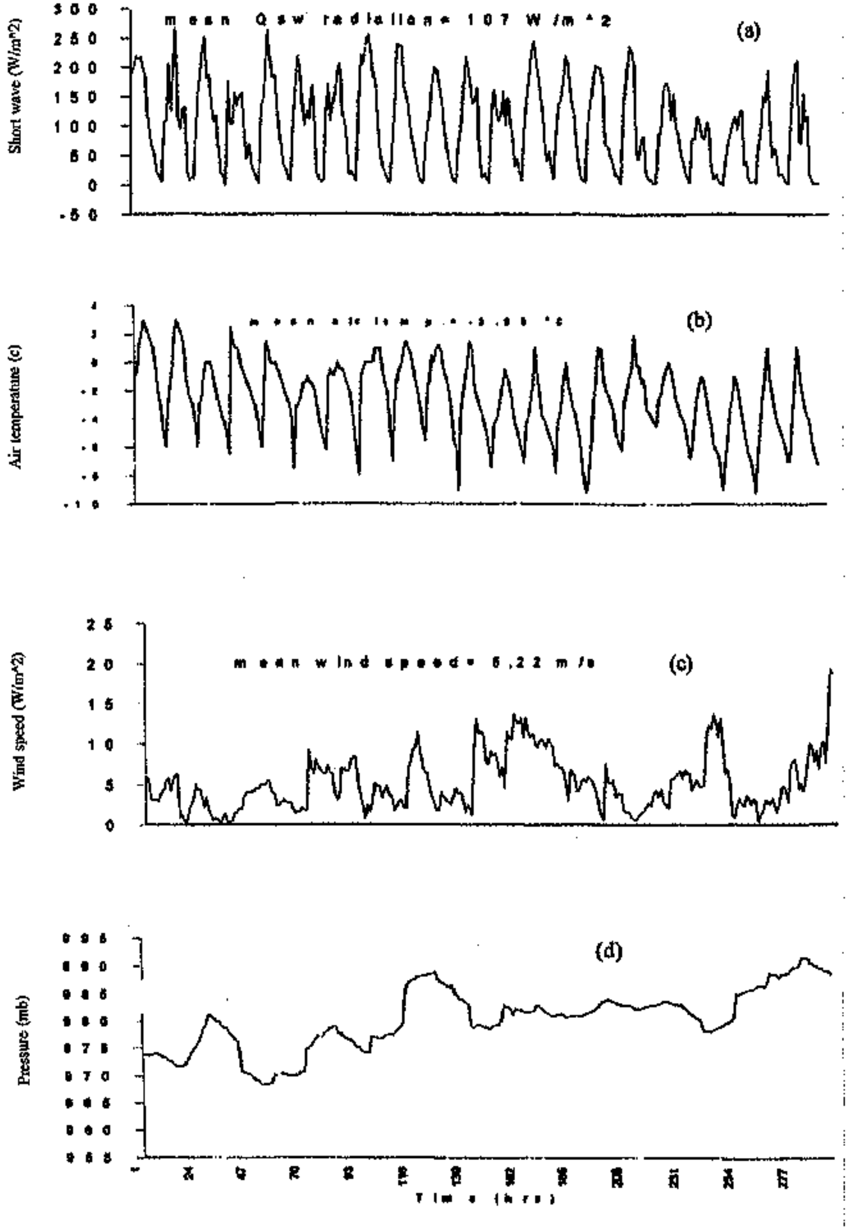


Fig. 5: Time series of hourly meteorological data measured at the study site between 11 Jan and 31 Jan 2000: (a) Incoming shortwave radiation, (b) air temp (c) wind speed and (d) pressure

Albedo Variation on Continental Shelf

The daily average and daily hourly Albedo variation of continental shelf is shown in Fig. 6 and Fig. 6a. The average Albedo value varies from 72 to 81 percent. During light snowfall the Albedo increases. The decrease in Albedo value may be attributed to melting of surface snow and recrystallization due to solar radiation and wind drift. The density of continental shelf was found 450-500 K/m^3, which is quite high. It has been reported many times that the Albedo values decreases as density increases. It is believed that as crystal size increases, the Albedo decreases. The dependence of Albedo observed on the density might actually be a dependence on grain size, since large density attributes to low pore space and less volumetric scattering, which reduces Albedo. Surface scattering is more for higher density as compared to lower density. From Fig. 5 it is clear that temperature is close to 2.6°C which is very high temperature as far as metamorphism is concerned. So definitely thermal metamorphism

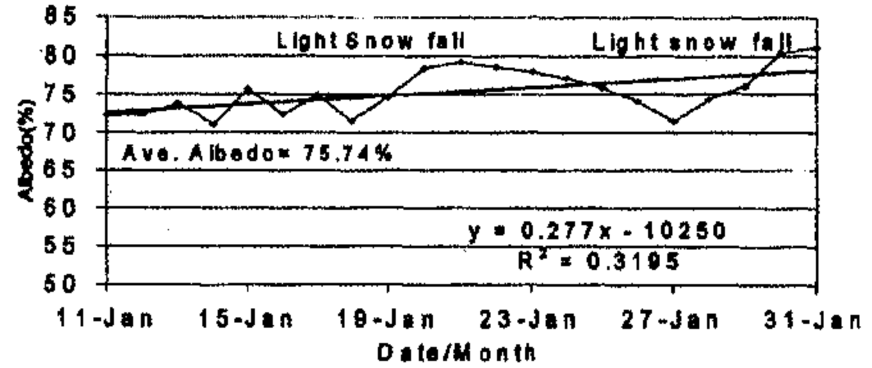


Fig. 6: Daily average value of albedo on continental shelf

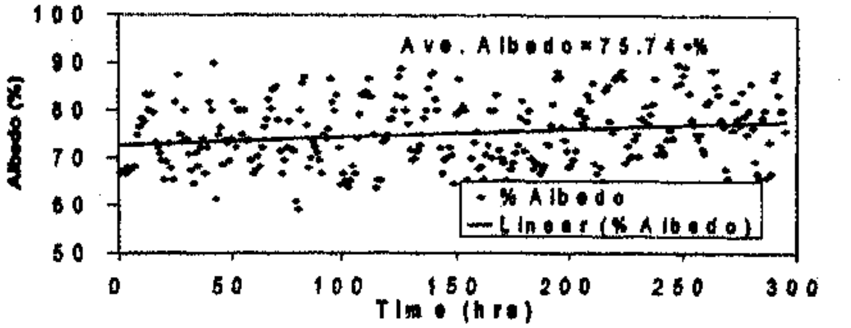


Fig. 6(a): Daily hourly value of albedo on continental shelf will play a role in further densification apart from direct short wave radiation and wind compaction. Wind drift plays an important role in recrystallisation of snow grain at the snow surface. Process of melt-freeze on snow surface reduces the Albedo value. However, these types of grains were observed during initial days of the observation when solar radiations were more intense.

Albedo Variation with Cloud Amount

The observation of Albedo variation with cloud amount is shown in Fig. 7. The Albedo value also varies with cloud thickness and increases with increasing cloud thickness. This increase in Albedo values are due to the fact that clouds absorb more radiation in near infra red region than in visible region. Therefore, under cloudy conditions a larger part of visible radiation reaches the snow surface. The snow Albedo in visible range was found high (> 0.90) compared to the near-infrared Albedo (~ 0.50), an increase in surface Albedo is to be expected during overcast weather (Warren 1982, Graanger and others, 1981). From the Fig. 7 it is clear that the average values of the Albedo are showing an excellent correlation with cloud amount. The average Albedo values increases from 70 to 80 percent with the increase in the cloud amount (from clear to overcast condition).

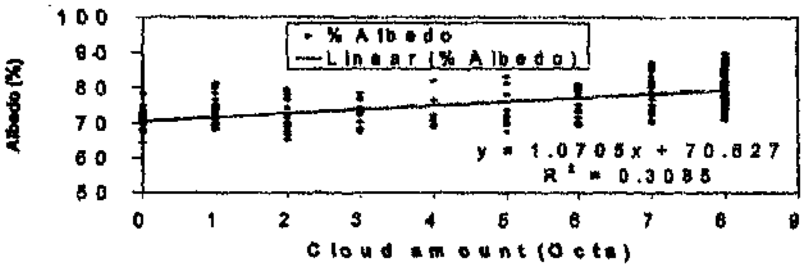


Fig. 7: Albedo variation with cloud amount

Comparison of Diurnal Albedo Value for Cloudy and Clear Day

To study the dependence of Albedo values on cloud amount, observations were taken both for clear and cloudy days. A comparative study of Albedo value for cloudy day and clear day is shown in Fig. 8. It is clear from Fig. 8 that the Albedo value is higher for cloudy days and fluctuates with the cloud amount and cloud type. Whereas for the clear day the Albedo value initially decreases with increasing solar angle and again increases with decreasing solar angle without any fluctuations.

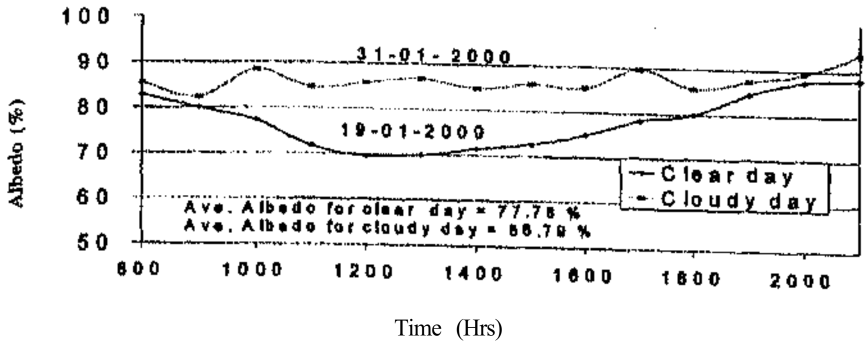


Fig. 8: Comparison of diurnal albedo value for clear and cloudy day

Energy Budget

A simple model using the data presented above has been used to calculate surface energy budget. The radiation balance, sensible heat flux, latent heat flux and snow temperature is considered for surface energy budget. The net radiation balance, the sum of net solar radiation and net long wave radiation are presented in Fig.9a in this study both incoming and out going solar radiation were measured and the long wave radiation were calculated from the model. During summer, the solar radiation clearly dominates the radiation. Due to low solar angel in summer nights the nighttime radiation is controlled by the long wave radiation, while in the daytime it is dominated by the short wave radiation. During winter net radiation loss is due to the long wave radiation, The net turbulent heat exchange is sum of sensible and latent heats. The sensible heat flux represents energy transfer across the snow/ice interface due to differences in air and snow temperature and wind activity. The sensible heat flux is shown in Fig. 9b. The positive value of sensible heat flux represents the energy gain by the snow surfaces. It can have both positive and negative value through out the year on an hourly or daily basis, in general during summer it warms the surface and cools the surface in the winter. Both short-wave and sensible heat fluxes act as a source for the snow surface. The latent heat flux represents energy transfer with advection cooling and sublimation / condensation at the snow surface. The net latent heat exchange, due to water vapor transfer and sublimation or condensation is depicted in Fig.9c. The latent heat flux value is negative. Due to low temperature of both air and snow surface the saturated vapor pressure of air over snow-ice surface as well as saturated vapor pressure of the snow ice surface both are low. In general latent heat flux is positive when saturated vapor pressure of air over snow-ice surface is more as compared to the saturated.

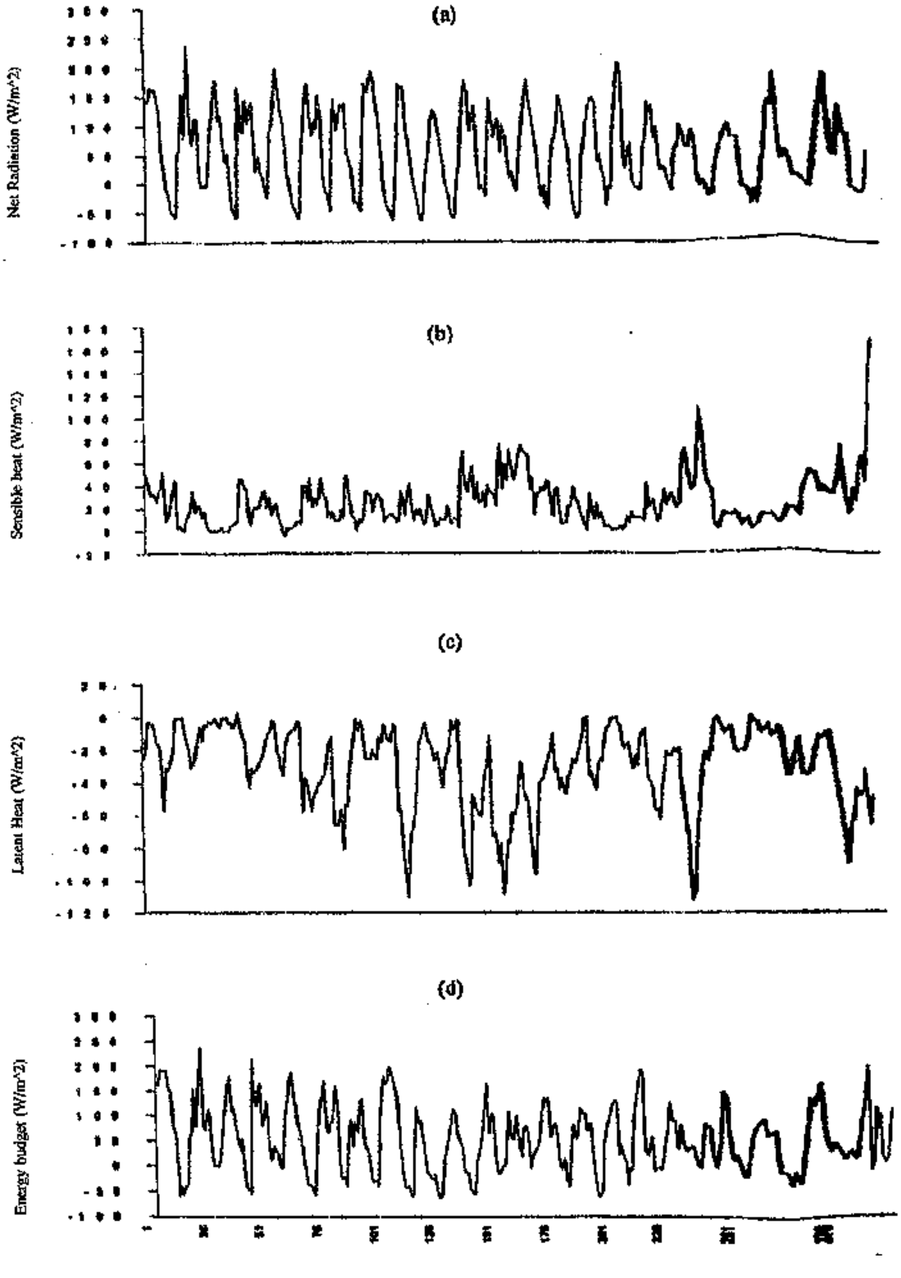


Fig. 9; Components of the radiation energy budget: (a) net radiation (sum of net solar radiation and net longwave radiation), (b) calculated sensible heat flux at the snow surface, (c) calculated latent heat flux at the snow surface, (d) net energy budget on shel

Vapour pressure of the snow-ice surface and snow temperature Ts = 0°C. When saturated vapour pressure of snow-ice surface is more than the saturated vapour pressure of air, sublimation takes place. When the difference of saturated vapour pressure of air and snow-ice is positive and snow surface temp. Ts < 0°C, condensation from vapour to solid takes place.

Table 1: Calculated total values (Wm^{-2}) of energy balance components at Princess Astrid coast, Dronning Maud Land Antarctica, 11 Jan and 31 Jan 2000

Components	Wm^{-2}
Net radiation	58.19
Sensible heat	24.85
Latent heat	- 30.66
Total energy flux	52.38

The energy budget is more in the daytime and is positive most of the time indicating that the snow surface is receiving energy. The net energy budget is positive because the data has been taken from 0800 hrs. to 2100 hrs. Data is not available from 2100 hrs to 0800 hrs next day. The net energy budget will be low if complete diurnal variation is considered. The present data represents most of the daytime measurement. The solar radiation is very low in the evening and in the early morning. Also the net long wave radiation loose more energy from the snow surface during night time, which would further reduce the net radiation.

Fig. 10: Cold lab setup for microstructural studies

Microstructure Studies of Continental Ice Using Polariscope and Hot Plate Technique

First time in Indian Antarctic expeditions, SASE has carried out microstructural studies by making thin sections of ice samples of the continental ice using Polariscope. SASE has designed and developed a polariscope in consultation with NBRC, Canada. The various techniques involved in preparation of thin section of ice sample for microstructural studies were discussed and learnt before going to Antarctica. Also a hot plate was designed for making thin section of ice samples. Both these equipments were carried to Antarctica for microstructural studies of continental ice.

A small setup consisting of Microtome machine, Optical microscope, Hot plate and Polariscope for microstructural studies of glacier ice was established inside the deep freezer.

Methodology

The ice samples were collected from the ice cap about 6 km from the station Maitri. A chain saw was used to cut the ice blocks from all corners and iron rod was used to take out the ice block from the ice cap. The samples were cut in small pieces and were kept in plastic bags. These samples were then brought to Maitri station. There these samples were kept inside the deep-freezer. A cold lab was set up in the deep-freezer where the equipment likes microscope, polariscope, heater, hack-saw and glass plates were kept for microstructural studies.

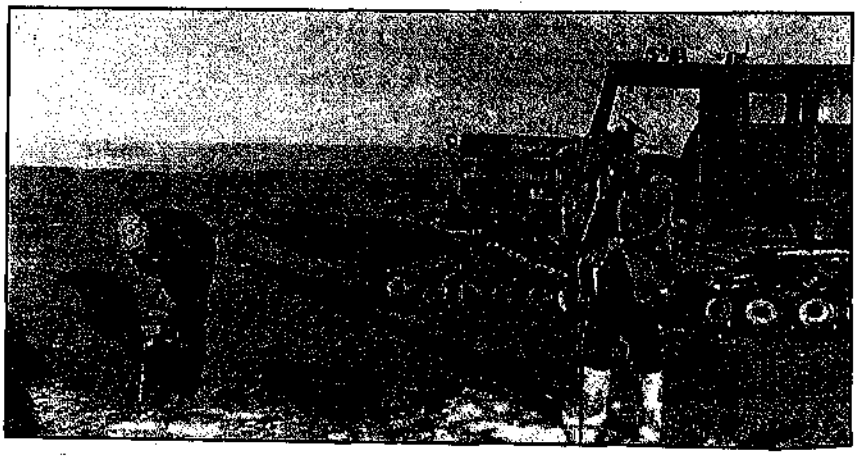
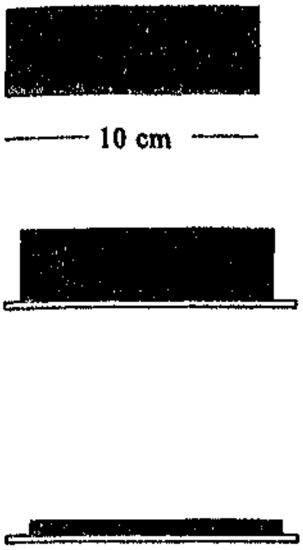


Fig. 11: Ice core for microstructural study being collected from the ice cap



Cut a thick section of size 3x10x12 cm from the ice sample

Rub the flat surface on the heater

Place the rubbed face on a clear glass slide for bonding

Perform successive shaves by rubbing on heater and gently removing the melt water from the flat surface

Prepare thin section of required size(.5 to .7 mm)

Place in between the Polarizing sheet for viewing and analysis of the ice sample

Fig. 12: Preparation of thin section of ice sample

Ice samples bought from the field were then cut into small blocks of 2-3cm with hack saw blade. These samples were cut in flats both vertically as well as horizontally. After sawing off a small block of required size from the ice samples first the flat surface was put on the heater plate for melting and then the same melted face was bonded to a clean glass slide. A thin section of 0.5-0.7mm was prepared by successive rubbing the other face of the ice sample on the heater plate and gently removing the melt water from the sample surface with a clean tissue paper.

This thin section bonded to a clean glass slide was then placed between the Polarizing sheets of the polariscope. A diffused transmitted light was illuminated from the bottom of the lower polarizing sheet for viewing and analysis. The mountings of polaride sheets were rotateable about vertical and horizontal. The method for observation is given in Fig. 13.

Each crystal had a different brightness and usually a different colour than the neighboring region depending upon crystal orientation and boundaries in the direction of transmission of the polarized light. Thus

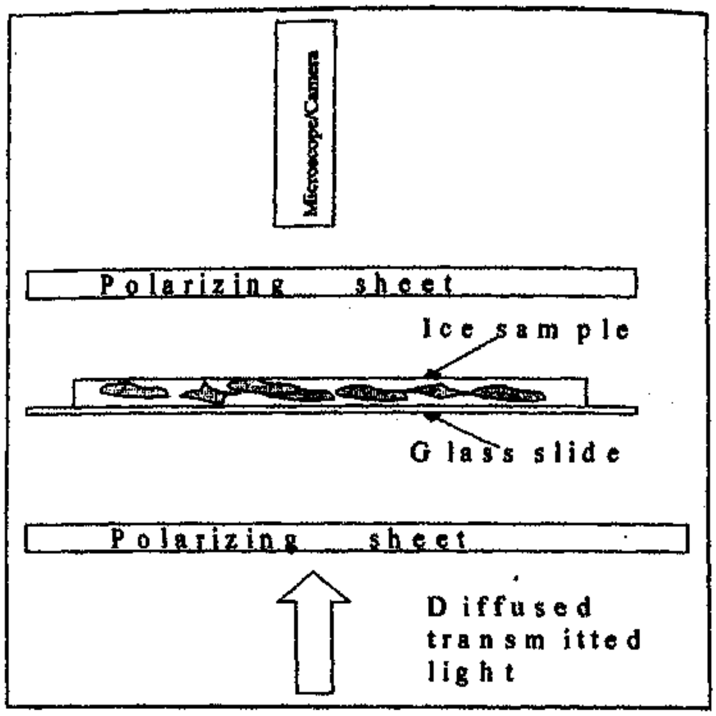


Fig. 13: Methodfor microscopic observation of 'ice sample. The image can be captured with a still of video camera.

each crystal can be distinguished as each transmits a different amount of light according to its orientation. The grain structure of the crystal in a particular plane of the section was easily seen and photographed with a still camera as well as with a video camera. Some of the results of the samples are shown in the figures.

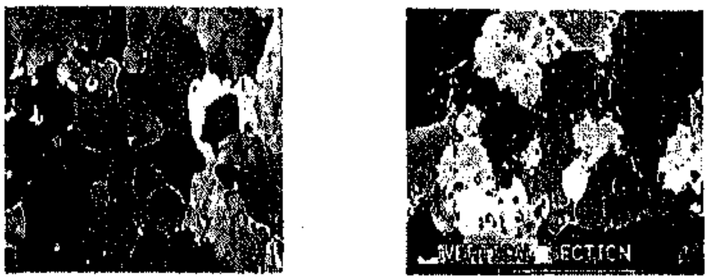
Results

Ice samples collected were of 75cm thick which was cut with chain saw and iron rod. Due to lack of facility we could not collect sample from more depth. The ice grain structure variation in top layer is not much. The ice sample collected' were from old glaciers which are coming to surface because of the negative mass balance. The grains are big. Even significant air bubbles are observed in the ice surface. The chemical analysis of the air bubble and size of air bubble convey a lot about the old climatic conditions and overburden pressure during that period.

Conclusion

The hourly measurements of microclimatological data obtained during the summer expedition in January 2000 are presented in this paper. These microclimatological data are used to calculate surface energy budget using a simple energy balance model. The measurement of air temperature at 2m height and solar radiation show a decreasing trend. The net radiation and net energy budget have distinct signature that show decreasing trend as winter approaches. Sensible heat flux shows an increase towards positive. The latent heat shows increase and decrease with a negative value. The

Vertical Section



Horizontal section

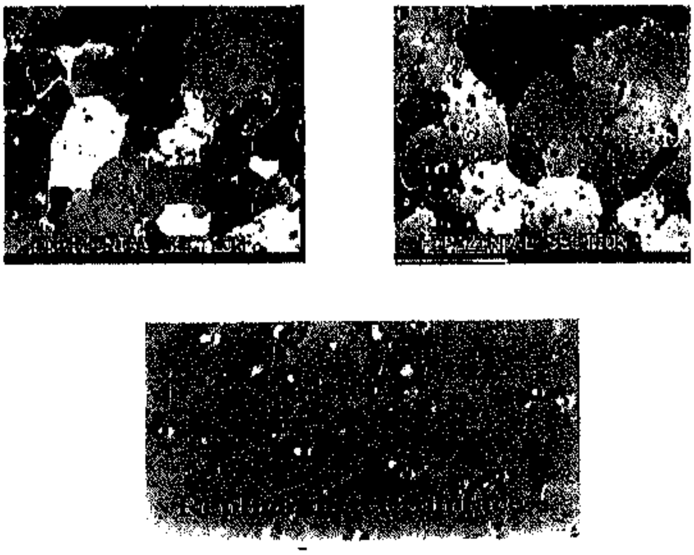


Fig14: Horizontal and vertical thin ice section and replica of continental ice

Fig. 9 depicts that the net radiation and the sensible heat fluxes are the two main energy source, while there is net loss of latent heat from the snow cover through sublimation and warming of the snow during the study period. The mean surface energy fluxes calculated for the study period are given in Table 1. The average Albedo value shows an increasing trend. The daily average value varies from 72 to 81 percent. The increase in Albedo value may be attributed to light snowfall as winter was approaching.

SASE carried out the microstructure study of continental ice cap by making thin section and using polariscope for first time. Due to lack of facility ice samples could not be collected from the more depth. We could collect ice samples up to 75cm below the snow surface. Both vertical and horizontal sections of these samples were prepared and results are shown in this report.

Further Scope

Energy balance studies should be used for mass balance calculation. Therefore, for mass balance studies marked poll should be placed in different location at continental ice as well as continental shelf. Energy balance studies clubbed with mass balance will definitely give the rate at which ablation/accumulation is taking place.

For microstructure studies we should have cold lab and deep core drill so that ice samples from more depth can be collected and their microstructure studies can be carried out. Also some icebox can be made available to keep ice sample. Temperature profile of continental ice should also should also carried out so that the microstructure of ice can be correlated with temperature.