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Report of Tasks Completed By Snow and Avalanche Study Establishment (S.A.S.E.) during Winter - XXI IAE

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Snow and Avalanche Study Establishment

Introduction

Snow and Avalanche Study Establishment (SASE) is engaged to carry out studies on snow in different fields of science. Some of the important studies are; snow mechanics, snow dynamics, heat changes in snow pack, energy budget model based on reflectance, glaciological and meteorological parameters, snow metamorphism, accumulation and ablation pattern of snow cover, settlement rate of snow and glaciers, recording of snow and met parameters manually as well as using automatic weather stations. Studies on crevasse formation are also being carried out in world's highest battlefield (i.e. Siachen Glacier).

Based on above studies, the main aim of SASE is to minimize the avalanche hazard and to save the men and material. These avalanche hazards can be minimized using active and passive methods. Active methods are control of avalanches using different control structures and passive is avalanche-forecasting techniques based on current parameters and past experiences.

During this XXI Indian Antarctic Scientific Expedition following projects were included in Antarctic study program by SASE.

(a) Energy Budget Model Based on Reflectance (Albedo) and Glaciological, Meteorological parameters of Antarctic Ice Sheet through ground based observations, Automatic Weather Station data.

(b) Microstructural Analysis of different Snow and Ice medium in Antarctica; Grain size, Structure and Orientation Fabric in Glacier and Ice Sheet.

(c) Study of Crack propagation on Ice Sheet using GPS and Satellite Imagery.

Energy Budget Model Based on Reflectance (Albedo) and Glaciological, Meteorological parameters of Antarctic Ice Sheet through ground based observations, Automatic Weather Station data:

The reflectance, absorption and transmission of solar radiation from any glaciological surface controls the radiation energy budget and hence, the surface conditions. The radiation budget estimation of strongly reflecting surfaces of different snow and ice media in Antarctica (continental ice, shelf ice and drifted snow, etc.) makes the study of their optical properties in order to estimate the global energy balance and climate modeling. The knowledge of energy balance over a variety of terrain existing in Polar Regions could only be obtained by understanding reflectance and albedo characteristics of different snow and ice mediums. The heat budget of different types of terrain during winter remains similar. However during summer season, the melting process exposes the blue ice regions and causes wide variations in the reflectance and albedo.

In Indian Antarctic Program, this project was initiated by SASE in the 15^{th} expedition during summer with the albedo study of shelf ice at DG. Since then, the reflectance characteristics of different snow and ice media are being carried out in Antarctica by SASE scientists. The ultimate aim of the project is to develop the monogram, accounting for various snow and meteorological parameters controlling reflectance behavior.

Energy budget is estimated using various energy fluxes i.e. short wave radiation flux, long wave radiation flux, sensible heat flux and latent heat flux. Short wave radiation flux is the amount of total short wave energy absorbed by the snow surface. It depends on the albedo of the snow surface and the amount of insolation received by the surface. The insolation is estimated with the help of upper pyranometer or by using various physical models. The short wave radiation flux is in the wave length range of 0.3 to 3.0μ m. The long wave radiation flux are the electromagnetic radiation received from the atmosphere, clouds and snow surface, if the long wave radiation are responsible for cooling and heat of the surface. The night time cooling is because of the long wave radiation escaped from the snow surface. Latent heat flux is a phase change because of condensation and sublimation as gradient of water vapours between snow surface and atmosphere. If vapour pressure at snow surface is more than the atmosphere, there will be sublimation and if it is low, there will be condensation. The sensible heat flux is as a consequence of temperature gradient between snow surface and atmosphere. It will be positive if snow surface absorbed energy from the atmosphere and negative if, it transmits energy to the atmosphere. The total energy budget depends upon the sum of all these components.

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

$$Q = S_w + L_w + Q_h + Q_e + Q_m + Q_g$$

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

Therefore, neglecting the last two terms, the net energy storage at the snow/ice surface is given by:

$$Q = S_w + L_w + Q_h + Q_e$$

The sum of S_w and L_w gives net radiation components and sum of Q_h and Q_e gives energy fluxes. The terms are calculated in watt per square meter.

Short wave radiation flux

The reflected short wave radiation from the snow/ice surface $S_{wo}(\uparrow)$ depends upon the amount of incident radiation $S_{wi}(\downarrow)$ and the surface albedo (α). The expression for the net short wave radiation flux (S_w) absorbed by the snow/ice surface is calculated as:

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

$$S_w = S_{wi}(\downarrow)(1-\alpha)$$

Where $$\alpha = S_{wo}(\uparrow)/S_{wi}(\downarrow)$$

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 $L_{wo}(\uparrow)$ from the snow/ice surface can be calculated from the Stefan- Boltzman law:

$$L_{wo}(\uparrow) = \varepsilon_s \sigma T_s^4$$

Where ε_s is the emissivity of the snow. The value of ε_s varies from .98 to 1.0. Here the value have been chosen as 1.0. T_s is the snow surface temperature (K) and σ Stefan- Boltzman constant (5.67×10^{-8} Wm^{-2} K^{-4})

The downward long wave radiation depends upon the air temperature and composition of overlying atmosphere.It is calculated from the model

Prata (1996), which computes emissivity of the atmosphere depending upon water contents (W) and performs well in the limit of a dry atmosphere:

$$Lwi(\downarrow) = \{ 1 - (1+ w) \exp (-(1.2 + 3.0 w)^{0.5}) \}\sigma T_s^4$$

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

Here, T_a is the air temperature, whereas, e_a is the saturated vapour pressure of air. Clouds having water droplets, absorb much more long wave radiation than water vapour.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 the cloudy sky is modified as:

$$L = \sigma [\{ 1 - (1+ w) \exp (-(1.2 + 3.0 w)^{0.5})\} [T_s^4 - \varepsilon_s \sigma T_s^4] [1- kN/8]$$

Where k is constant and depends upon the height of clouds, N is no of okta.

$K = 0.76$ for low clouds
$= 0.52$ for medium clouds
$= 0.26$ for high clouds

Sensible heat flux

The sensible heat flux Q_h is a direct transport of heat and energy. Calculation of sensible heat flux requires measurement of air temperature, surface temperature and wind speed. As per Ambach and Kirchlechner(1986) and Paterson (1994):

$$Q_h = (C_p \rho_0/P_0) D P u(T_a -T_s)$$

$$D = k^2/[\ln (Z_a/Z_0)]^2$$

Where C_p is specific heat of air at constant pressure, ρ_0 is the density of the air (1.29 Kgm^{-3}) at standard atmospheric pressure P_0 (101300Pa), 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 Von Karman constant (0.4) and Z_0 is the aerodynamic roughness length. T_s is the snow surface temperature (K).

Latent heat flux

The latent heat flux is calculated using:

$$Q_e = L_v (0.623\rho_0/P_0) D u (e_a - e_s)$$

Where L_v is the latent heat of vaporization, e_a is the vapour pressure at height z above the snow/ice surface and e_s is the saturation vapour pressure at the snow/ice surface. e_s is the function of 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. e_s is assumed to be the same as the saturation vapour pressure over a plane surface of pure water at surface temperature T_s . 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 T_s - 0°C, water vapour condenses as liquid water on melting snow/ice surface with L_v = 2.514 MJ Kg"^{1}. When (e_a - e_s) is negtive, there is sublimation with L_v = 2.849 MJ Kg"^{1}. Also when (e_a - e_s) is positive and T_s < 0°C, there is condensation from vapour to solid ice with L_v = 2.849 MJ Kg^1.

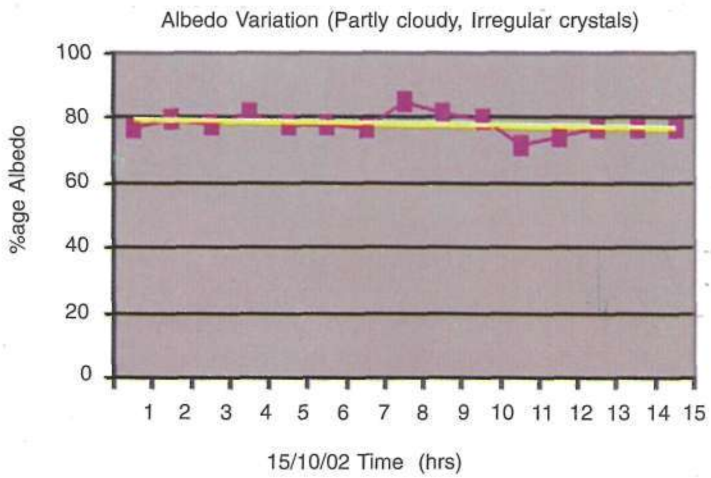
Aim of albedo studies:

The albedo studies were aimed with the following objectives:

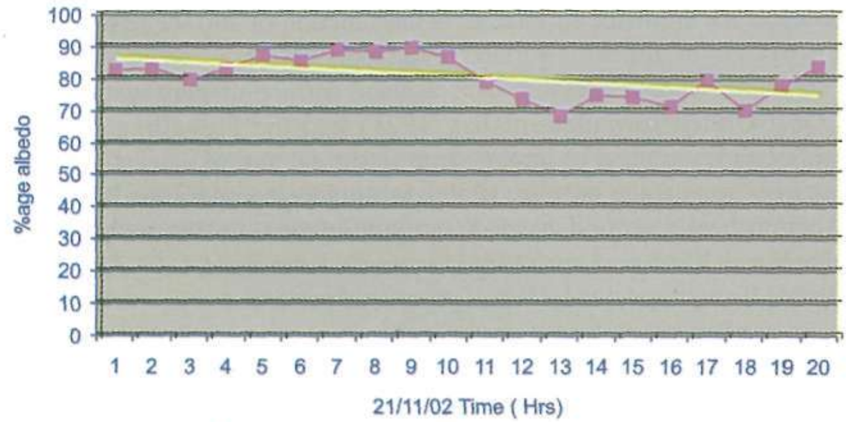
(a) To determine dependence of snow albedo on.the following parameters: Cloud amount and cloud type, Snow surface wetness, Solar elevation angle, Age of snow

(b) Determination of albedo distribution over various parts of ice shelf, continental ice & snow medium.

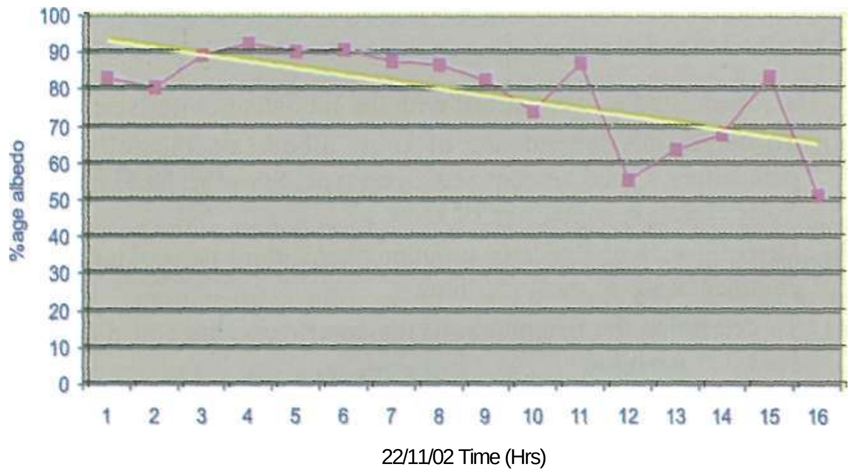
(c) To determine the magnitude of the energy exchange in different snow/ice medium.



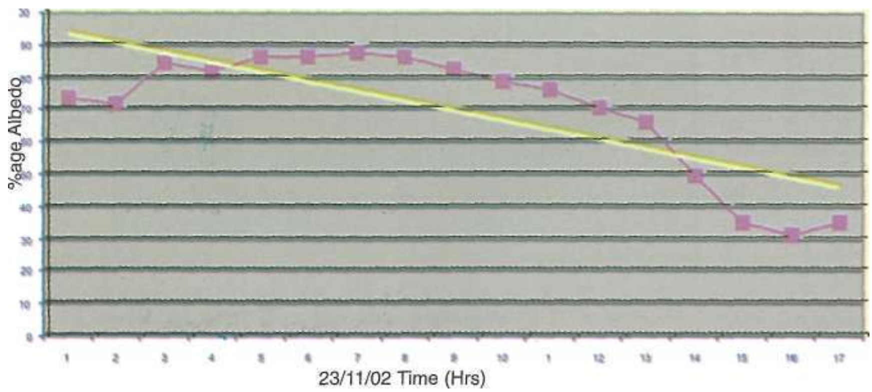
Albedo Variation (Partly cloudy, staller crystals)



Second day albedo decay (fair weather, crystals- felt like)

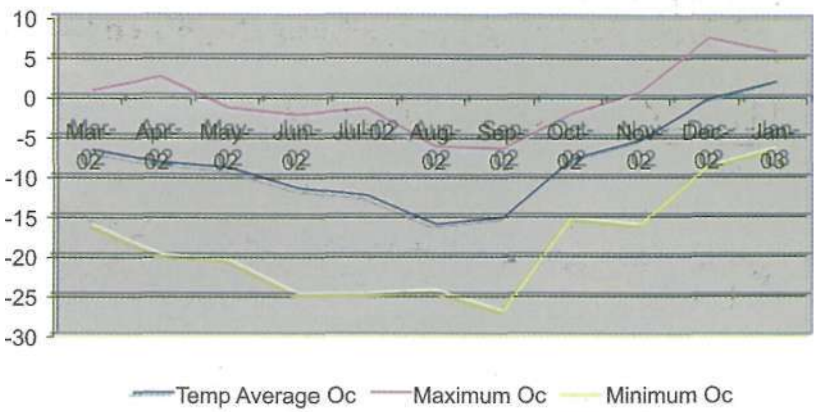


Third day albedo decay (Fair weather, crystals-felt like)

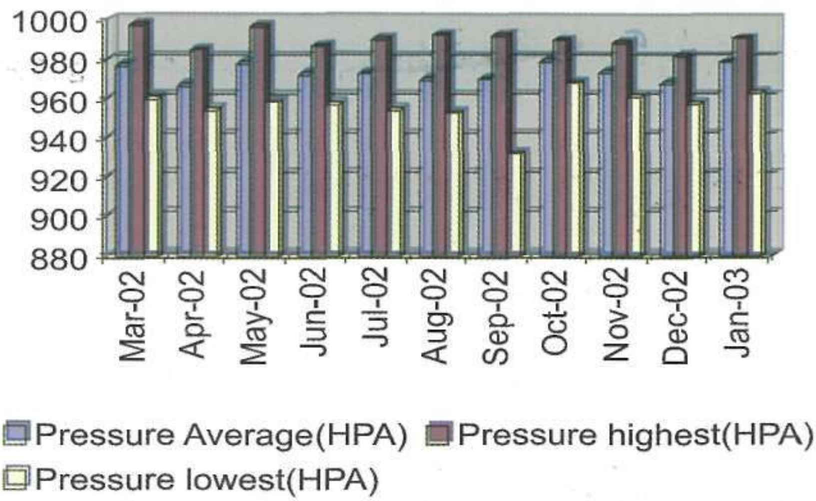


Instrumentation and Location of Measurement sites:

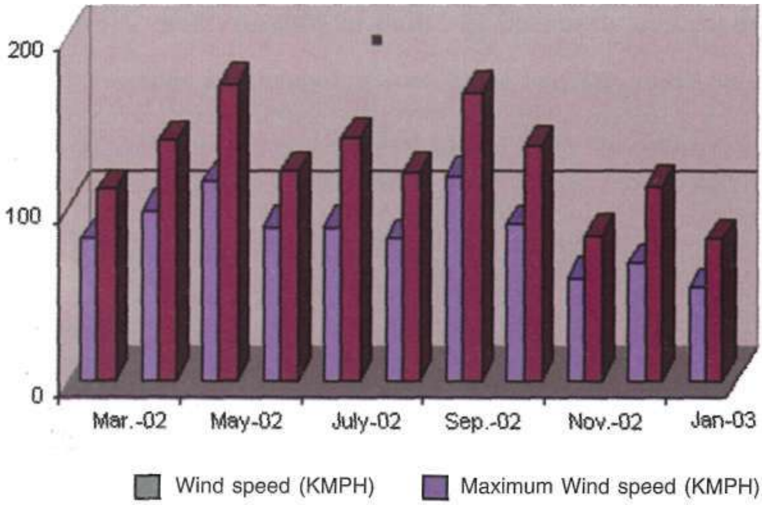
For recording the continuous meteorological and radiation data, an automatic weather station was installed during XXI expedition to Antrarctica. It was set up at 70° 45' 32" (S) and 11° 40'23" (E) over the continental ice.AWS did not work after Mar 2002, therefore manual observations have been collected. Some of the important results of temperature pattern, wind speed and blizzard record are as follow:



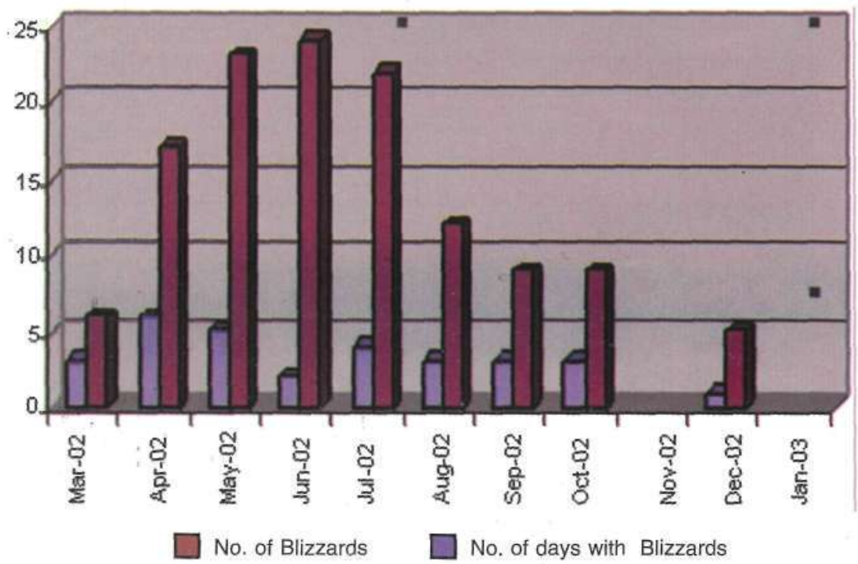
Maximum, Minimum and average temperature



Average highest and lowest atmospheric pressure



Average and maximum wind speed



No. of blizzards and no. of days with blizzards

Microstructural Studies of Different Snow and Ice Media

Ice is a solid state form of water. The formation of ice results from densification process of snow. Mainly we consider three stages of densification in snow.During the first stage, the densification of snow is mainly of structural rearrangements of snow grains.Sintering process is driven by the temperature gradient in the top few meters and by surface tension. Transport mechanism such as evaporation, condensation and surface diffusion contributes to rounding the grains and inters granular bonding. The critical density reached in this process is 550kg/m^3.

The second stage occurs due to the seasonal variation of snow surface temperature, which disappear below 10 meters. The densification within this pack can be considered as isothermal. The end of this stage is characterized by the growth of pore space fraction verses depth under the increasing overburden pressure.

Pancake Ice

During the final stage, the atmospheric air is trapped in the formation of cylindrical and spherical pores, and further densification of bubbly ice is driven by the pressure lag between the ice matrix and the air in bubbles.

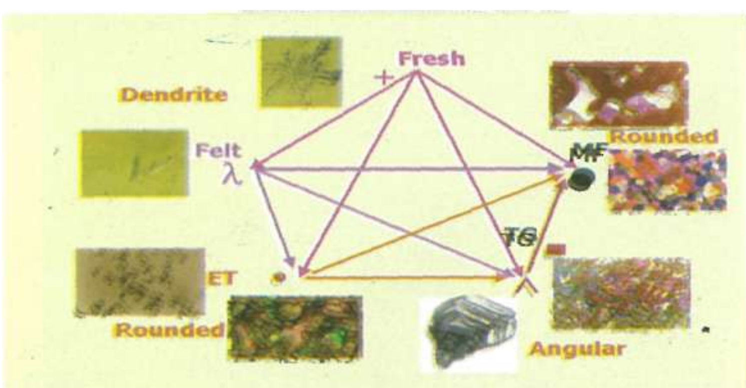
Floating pieces of pack Ice

The potential significance of density profiles and crystal size for glaciological studies have been discussed by many researchers. For example, during snow to consolidated snow, the air inside the pores becomes progressively isolated from the atmosphere prevailing at the surface of the ice sheets,the air content in ice is directly related to the porosity, temperature and pressure at the time corresponding to this transition; The crystal size record within an ice-core can be interpreted in terms of palaeoclimate and in relation to the flow properties of ice.

The main objective of this type of study is to determine mean crystal size and possible correlation with the reflectance properties of the surface.

Thin section of continental Ice

During calm conditions when there is no wind, stellar type of crystals have been observed. Sometime needle shaped crystals has also been noticed. When there is a strong blizzard , the crystals form irregular shapes due to collision with each other. The metamorphic changes in snow take place is shown below.



Cycle of Metamorphism

Study of Crack propagation on Ice Sheet using GPS:

Failure of ice shelf in Antarctica governs the formation of icebergs in Antarctic Ocean. The Antarctic ice cap is made up of ice-shelf and continental ice cap.The ice shelf extends hundreds of kilometers in sea.These ice shelves break off from the main mass to form iceburgs.This is happening because of temperature variation and other interactions between the ocean and ice.The unstable ice structure of the shelf is quite dangerous for the berthing of the ships and loading/ unloading point of view.At present many weaknesses and cracks have been identified in the ice shelf near India way.

The failure of ice shelf is not a frequent process and its prediction is not so easy. Therefore, formation of crack propagation and dislocation of ice shelf requires continuous monitoring.

The project has the following aim:

To monitor the surface crack formation and propagation over ice shelf near India way. After having with the adequate data available, to prepare model for weakness prediction of ice shelf.

Fig. Crack near Indian Bay

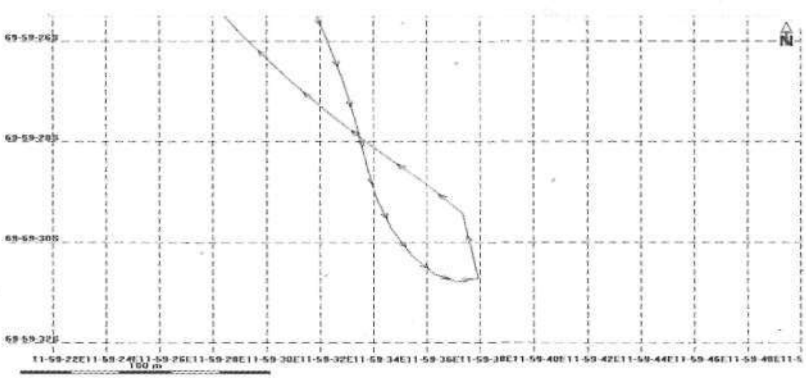


Fig. GPS data of Crack

Work carried out during the Reporting Period

(a) Installation of Automatic Weather Station at Sankalp Point:

Immediately after reaching at Maitri station, a general recce of area was carried out. It was observed that aws mast installed by previous expedition members at Sankalp point was fell down and embedded with the continental ice. This job, to dig it out from frozen continental ice was a challenging one. Myself and Mr R K Das(summer member) tried to dig it out with all possible efforts for continuous two days working, but, unfortunately all efforts ended with no use. Finally, a team alongwith Maj RK Sharma and DEAL scientists helped a lot and achieved the goal to dig out the aws for further installation. Sensors namely, wind speed and wind direction, relative humidity, air temperature, atmospheric pressure; snow depth and albedometer sensors were integrated with the automatic weather data logger. The sensors were logged to record the data on hourly basis. The charging of battery for data logger is through solar panel.

AWS and Wind Electric generator at Sankalp point

/(b) Installation of Wind Electric Generator:

Since, there is no sunshine during polar nights over Antarctica and . solar panel does not provide any charge to battery. Therefore, an alternate source for charging up of battery was installed adjoining to aws.

(c) Setting up of a Lab for Microstructural Studies:

There is no such cabin/hut which is enmarked to SASE for setting up of laboratory. Therefore, every time instruments are being installed and re-installed and are transported from one place to another, wherever space is available. This time, it was established at Satpura. \

Installation of Albedometer :

An albebometer was installed nearby area of Maitri to carry out the reflectance studies on drifted snow.

The whole system was dismantled in first week of Dec, because after that water channels and crevasses opening get started and vehicles movement is risky one during this period.

Microstructural Studies:

Almost hundred samples were collected from continental ice, glacier ice and even of frozen Priyadarshini Lake. To prepare thin section of ice sample is quite challenging and needs patience. A method known as hot plate technique was adopted to prepare the thin section of ice. Adequate number of photographs has been taken at different time exposure. The detailed results can only be discussed after development of film.

Downloading Data from AWS installed on continental Ice:

Data from aws was transferred in PCMCIA card on fortnightly basis. During polar nights, complete loss of data have been noticed, when battery get discharged and wind electric generator damaged due to strong winds. In the month of August, it was again brought to working conditions when polar nights were over and sunshine started for few hours. Since SASE has to withdraw its all projects in coming near future, therefore,

Crack Propagation Studies:

The study area for cracks propagation has been identified and its observations have been carried out.

Acknowledgement

I sincerely thank the Director SASE (Retd. Maj Gen SS Sharma, KC, VSM) for recommending me in IASE, Col P Mathur Deputy Director and Sh N K Thakur Technical Officer 'B', who boosted my morale to participate in Antarctic Scientific program. I also want to thank Dr PC Pandey, Director NCAOR, who finally selected me in this Antarctic Program and Sh R P Lai leader 21st IASE, who provided all necessary helps: