Energy balance over Snow and Ice

The thermal energy moves in the climate system from one form to another. Thermal energy or heat can move from one place to another in three different forms in a climate system. The three forms of the thermal energy transfer are briefly described in the following sections:

1. **Radiation**

Radiation is the transfer of energy through ***electromagnetic waves***. This form of energy transfer does not require the presence of matter to occur. In this form of energy, energy can travel through empty space from the Sun to the Earth. Radiation also occurs within the climate system between the earth's surface and the atmosphere, and within the atmosphere and ocean.

2. **Advection/convection**

The spreading of heat in fluids and gases through the ***flow of matter*** from one place to another. Advection occurs in the horizontal plane and convection in the vertical.

3. **Conduction**

The spreading of heat through ***molecular vibrations*** is known as conduction. This form of heat transfer requires the presence of matter and can occur in solids, liquids, and gases. In the climate system conduction occurs mainly over small distances. In the atmosphere and oceans it is taken over by advection and convection.

Characteristics of Snow and ice

The estimation of energy balance over snow and ice need consideration is different from any other system as snow and ice has certain special characteristics. The special characteristics of snow and ice are as follows:

I. Surface temperature snow and ice

Ice and snow melt at 0°C, but this does not necessarily mean that melting will occur with an air temperature > 0°C or that there is no melting at an air temperature < 0 °C. In fact, the energy balance at the snow/glacier-atmosphere interface determines snow and glacier melt, for which air temperature is only an index. The energy balance over snow and Ice is controlled by the ***meteorological conditions*** above the snow/glacier surface, the ***physical properties*** of snow/glacier surface.The components of energy balance show *large spatial heterogeneity*, typically in steeply sided terrain. In short the surface temperature of snow and ice behaves as:

- The surface temperature over snow and ice cannot exceed **0 °C:**
- ***strong temperature gradients*** can develop in the air immediately above the surface.
- temperature gradients may reach more than **5 °C/m** within the first 2 m above the surface.
- during melt season the **air** is generally **stably stratified,** i.e. strong **temperature inversion** close to the surface.
- without wind, the stable layer does not break up and ***turbulent fluxes*** become ***minimal***.

Furthermore, during winter and cold nights the snow or ice ***surface*** can be ***warmer than air hence*** energy losses from the surface to the air, due to evaporation consequently there is significant reduction of the energy available for melt.

II. Vapour pressure over snow and ice

The vapour pressure over snow and ice cannot exceed **6.11 hPa.** This relatively low value favours vapour pressure gradients towards the surface **condensation.** Since the latent heat of evaporation is **7.5** times larger than the latent heat of fusion, condensation can be an important energy source for melt.

III. Reflectance (Albedo)

Albedo is another important of energy balance. Shortwave radiation is normally the main energy input for a snow cover.So albedo is one of the most important parameters driving snow energy balance Albedo of Snow is generally higher than albedo of ice. The **Albedo of fresh snow** varies roughly between **0.7 and 0.9 while as the Albedo of ice** varies roughly between **0.3 and 0.5.**

The reflectance of Snow is strongly dependent on wavelength:

- ***highest* in the *visible spectrum* (shortwave)**
- ***very low* in the *longwave region***

Snow reflectance decreases as the snow grain size (r) increases

IV. Emissivity

In the infrared part of the spectrum snow and ice behave as almost perfect black-bodies and the emissivity of land surface varies as:

- Snow: 0.98 -0.99
- Ice: ~0.97
- Soil: 0.95-0.97

V. Transmission

Snow and ice allow some transmission of shortwave radiation. Only about *1-2%* of global radiation penetrates into a snow cover. Shortwave radiation penetrates ice and snow to a depth of about 10 m and 1 m. The transmission of radiation *declines exponentially with increasing depth*. Most of the energy is absorbed in the first few cm below a snow surface and at the depth of *snow cover > 20 cm the transmission* is *negligible*.

Measurement of energy balance components over snow and Ice

The measurement of components of energy balance need sophisticated instrumentation. The components of energy balance and the instrument required. Ground measurements of solar radiations: Radiation measuring instruments can be classified according to their use. The generic term for all radiation measuring instruments is the radiometer. Following is a brief over view of radiometers used for measuring energy balance components over snow and Ice.

Pyrheliometer (PHM)

The Pyrheliometer (PHM) mmeasures direct beam solar radiation. The general design of PHMs is a metal tube with a small opening at one end for the solar radiation. PHMs are *oriented toward the Sun* so the receptor surfaces are perpendicular to the incident solar beam. The PHMs have an aperture with an *acceptance angle of 2.5°-5°* to limit the view to the solar disk. A PHM has to be attached to a mounting that permits it to follow the Sun. PHMs are the most accurate of all radiation instruments.

- *MS-56 First Class Pyrheliometer* has a *response time < 1s* and an excellent temperature stability (-40 °C to 80 °C**)**

PHMs are commonly used as calibration standards for working instruments

Such type of instruments are usually found only at research station or laboratories because of their *need to track the Sun and are relatively expensive.*

Pyranometer

The Pyranomete is an instrument used for measuring global radiation (direct and diffuse shortwave radiation), onto a plane surface . A horizontally mounted pyranometer detects radiation from all parts of the sky. While as an inverted pyranometer measures reflected solar radiation. The most popular instruments are based on *thermopiles* that measure the thermal difference between a black and a white surface. The thermopiles are protected by one ore two *hemispherical glass domes,* which provide isolation from the longwave radiation.

Albedometer

An albedometer is a combination of two pyranometers, one facing upward and one facing downward. The upward facing pyranometer measures global radiation (diffuse and direct solar radiation), while the downward facing pyranometer measures reflected solar radiation. The Albedo is the fraction of incident solar radiation reflected by a surface.It can be calculated from the output data of an albedometer . Short-wave net radiation can also be calculated using Albedometer.

Pyrgeometer

Pyrgeometer is used for measuring longwave radiation. A pyrgeometer resembles a pyranometer, but instead of a glass dome - it has a *polyethylene* or *silicon dome* with good transmittance for the spectral domain of thermal IR in the range of 3.0 to 50 μm. Polyethylene or silicon *domes filter out unwanted* shortwave *solar radiation.* The reliability of a pyrgeometer is closely related to the transmittance of the dome, which must be *cleaned daily*. Polyethylene domes must be replaced frequently.

Pyrradiometer (Net Radiometer)

Net pyrradiometers measure the net total radiation flux (shortwave and longwave) downward and upward through a horizontal surface. *Two* black, radiation absorbing plates act as *sensors,* one facing upward and one facing downward. Pyrradiometer has two separately working receivers. Each blackened disk has an internal thermopile, and the temperature difference between the two sensors is proportional to net radiation. Most pyrradiometers use *polyethylene domes,* because it is transparent to both shortwave and longwave radiation (0.3 to 100 μm).

Energy balance over snow and Ice

Melting can be modelled through calculating the energy balance, i.e. the energy that is available for melting. The energy balance of a temperate glacier can be calculated with the help of the following meteorological data at one level (e.g. 2 m) on the glacier:

- net radiation

- air temperature (used to compute the sensible heat flux)
- air humidity (used to compute the latent heat flux)
- wind speed (used to compute the sensible and latent heat fluxes).

Energy Balance Equation

The energy balance over Snow and Ice is measured using the energy balnce equation given bellow.

$$\frac{dU_I}{dt} = \sum Q_{in} - \sum Q_{out}$$

$$Q_I = Q_{NR} + Q_S + Q_L + Q_R + Q_G + Q_M$$

Where

U_I	snowpack internal sensible and latent heat storage
Q_{NR}	net radiant energy exchange
Q_S	sensible heat exchange with the atmosphere
Q_L	latent heat exchange of vaporization and sublimation with the atmosphere
Q_R	heat provided by rain
Q_G	heat from conduction in the ground
Q_I	change in snowpack internal sensible and latent heat storage
Q_M	Loss of latent heat of fusion due to meltwater leaving the snowpack

The energy balance components (if not measured directly) can be approximated with the help of appropriate parameterizations, i.e. as functions of variables that control the component and that can be measured simply. This usually includes a simplification of the physical processes. Instead of net radiation, the different radiation components can be measured separately. In practice, parameterizations are most often used because radiation measurements are expensive and difficult to obtain under the difficult conditions that typically prevail on a glacier. So incoming longwave radiation can, for example, be parameterized with the help of air temperature, humidity, and cloud data. A large number of the parameterizations for the different components of the energy balance have been developed and applied for energy balance over snow and Ice.