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Temperature Variation and Apparent Thermal Diffusivity at Lilla Albo, Uppsala, Sweden

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Abstract

The surface temperature of the earth differs from place to place. These variations are also influenced by the cloud cover. Using the three months sampled temperature data the variations in temperature of Lilla Albo have been studied. This analysis is carried out to determine Apparent Thermal Diffusivity and Zero Curtain Effect which gives an idea and clear understanding about boundary layer interaction with the atmosphere and osmotic potential variation induced by freeze-thaw events at the soil surfaces.

Keyword: Boundary layer climate, Lilla Albo, Sweden, temperature variation, apparent thermal diffusivity.

Introduction

Temperatures sampled are as per the requirement for the study i.e., at two hours interval over three months period within soil and air at Lilla albo, Uppsala, Sweden[1]. The thermal records are used to calculate apparent thermal diffusivity at regularly spaced depths in the substrate. Thermal diffusivity is the key parameter which governs the soil surface temperature, where periodic temperature change is attenuated and delayed with depth[1]. Non conductive process plays an important role in heat transfer between soil and air surfaces. Phase change, water vapour transport, heat flux, water advection all can enhance or oppose the conductive tendency[2]. Spectral analysis of temperature-time series and calculation of apparent diffusivity from these series could play an important role in heat and moisture transport in the active layer[2]. Non conducting process plays an important part in the formation and maintenance of Zero Curtain effects. Zero Curtain effects is produced and maintained by vapour transport and internal distillation mechanism, driven by osmotic potential variation induced by freeze-thaw events at the soil surfaces[3]. Soil near the surface will frequently undergo freezing and thawing, convective heat transfer due to the water that is infiltered and due to the temporal variation in the Thermal properties. Thus, Zero Curtain effects are applicable only to active layer depth rather than permafrost. Zero Curtain effects depend upon characteristics of soil surfaces and its properties. Zero curtain effects is probably absent in dryer, coarse soil and clay soil with low hydraulic conductivity[4]. Analysis is carried out to determine apparent thermal diffusivity which gives an idea about boundary layer interaction.

Study Area: Lilla Albo as shown in figure-1, which is located 17 Km away from Uppsala in Sweden. It is located between Latitude 59°51’40’’ and Longitude 17°21’33’’. It is located in a jointed bed rock valley. It is an open field lined with forest cover. The type of soil present in this region is moraine clay with upper sandy layer. The active surface layer is covered by snow of about 5 cm thickness. The grass is about 0.4m high and it has dense cover up to 0.1 meter. Tiny Tag Data loggers were installed in November which has an accuracy of 0.2°C at a depth of -0.3 and -0.4 meter level and it has 0.1°C accuracy for all other depth and heights.

Methodology

Time series analysis: This analysis is carried out to know about the temperature variation over the three months time period (Nov. 2011 to Jan. 2012) and the interaction between the air and soil temperatures in the boundary layer. Here the boundary layer considered is between 0.5 meter below soil surface and up to 2 meter in air above the soil surface.

ATD calculation: Apparent thermal diffusivity is defined as the transfer of temperature between materials or grain particles. The impact of non conductive heat transfer process on the evolution of thermal profile within the refreezing active layer can be evaluated by calculating apparent thermal diffusivity from the temperature and time graphs[2].

ATD can be calculated by using the below formula:
$\alpha = T\,t / Tzz$

Where, T is temperature in °C, t is time period & z is the depth in m from the surface of the soil. Time and space derivatives can be approximated by[2]:

$Tt = Ti\ j+1 - Ti\ j-1 / 2\Delta t$
$Tzz = Ti-1\ j - 2Ti\ j + Ti+1\ j / (\Delta Z)\ 2$

Where Δt and ΔZ are the increments in time and space and the integers j and i refers to the temporal and depth positions of nodes in the time space mesh. In this study diffusivity is studies based on the temperature measurements carried out at -0.5,-0.4,-0.3,-0.2,-0.1, and 0.0 meter depth with a time interval of 2 hours.

Vertical temperature profile: The vertical temperature profile is analyzed using the data provided. The given temperature data is measured up to a depth of 0.5m and 2m above ground surface.

For the analysis of vertical temperature profile we have considered 4 days of different conditions such as, i. For a day without snow: 2012-01-29, ii. For a day with snow: 2012-01-31 (snowfall and snow cover), iii. For cloudy day: 2012-01-24, iv. For a day with clear sky: 2012-01-17.

We have considered 4 days from the same month, so that it will be easy to analyze the change in temperature over the period 17th Jan to 31st Jan.

Zero curtain effect: The zero curtain effect can be noticed mainly due to process of warming up of ice surface which induces freezing up at the isothermal region and hence cooling of evaporates during cold temperatures i.e., When the water changes its phase state to ice heat energy is released, but the process is slowdown due to the latent heat.

To analyze zero curtain effect the temperature-time series graph is used. From the temperature data obtained, zero curtain effect is noticeable only during certain time period so the temperature range between 21st Jan 2012 to 29th Jan 2012 is selected for this analysis.

Results and Discussion

Time Series Analysis of Air and Soil Temperatures: The Figure-2 explains the changes in temperature below the soil/ground surface up to a depth of 0.5 m. The overall temperature trend is smooth and much linear which indicates the reduction in temperature from November, 2011 to February, 2012 along the soil boundary layer. The maximum observed soil temperature is during November 2011 and February 2012 are 8°C and 1.5°C at a depth of 0.5 meters and the minimum temperature observed during November 2011 and February 2012 are -1°C and -6.2°C at the ground surface layer[5].

The figure-3 explains the changes in the air temperature. The air temperature increases from the ground surface abruptly in the vertical scale. The maximum temperatures during November 2011 and February 2012 are 12°C along 0.3m level and 7°C along 1.0m level, the minimum temperatures observed during November, 2011 and February, 2012 are -6°C along 0.1m level and -24°C along 0.3m level[5,6].

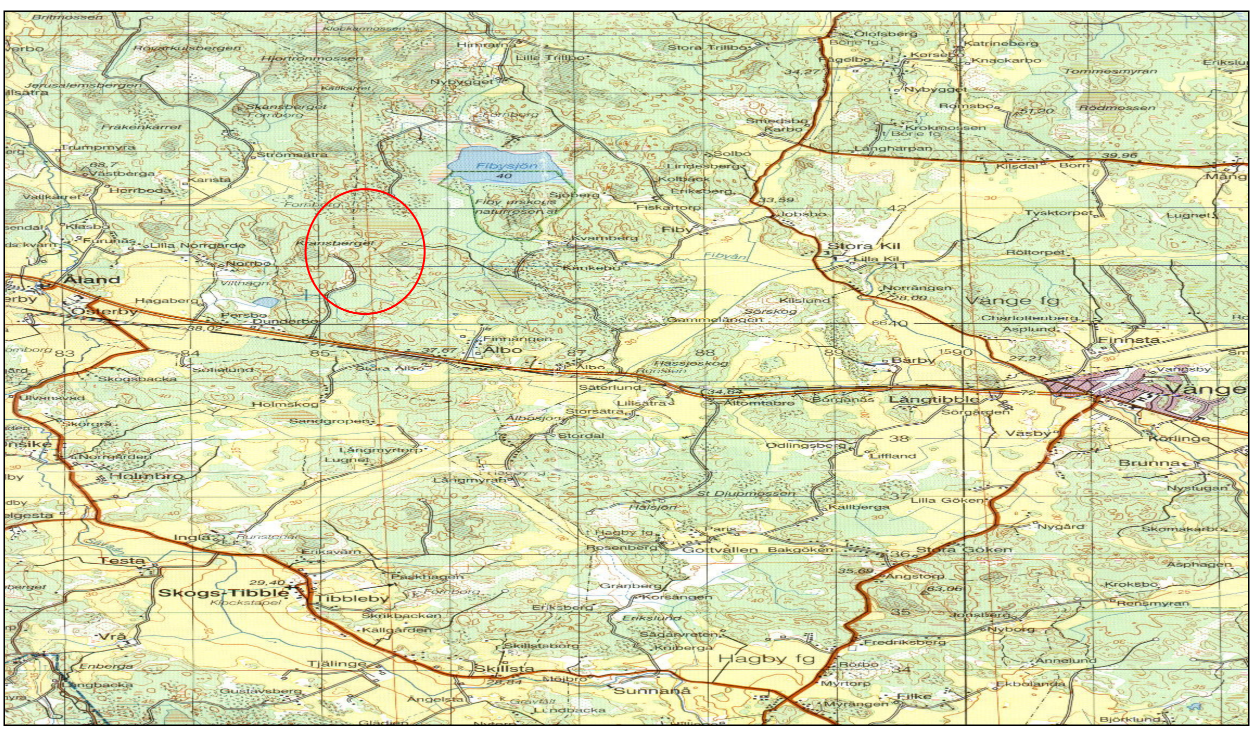

Figure-1
Location map of the Study Area (Lilla Albo)

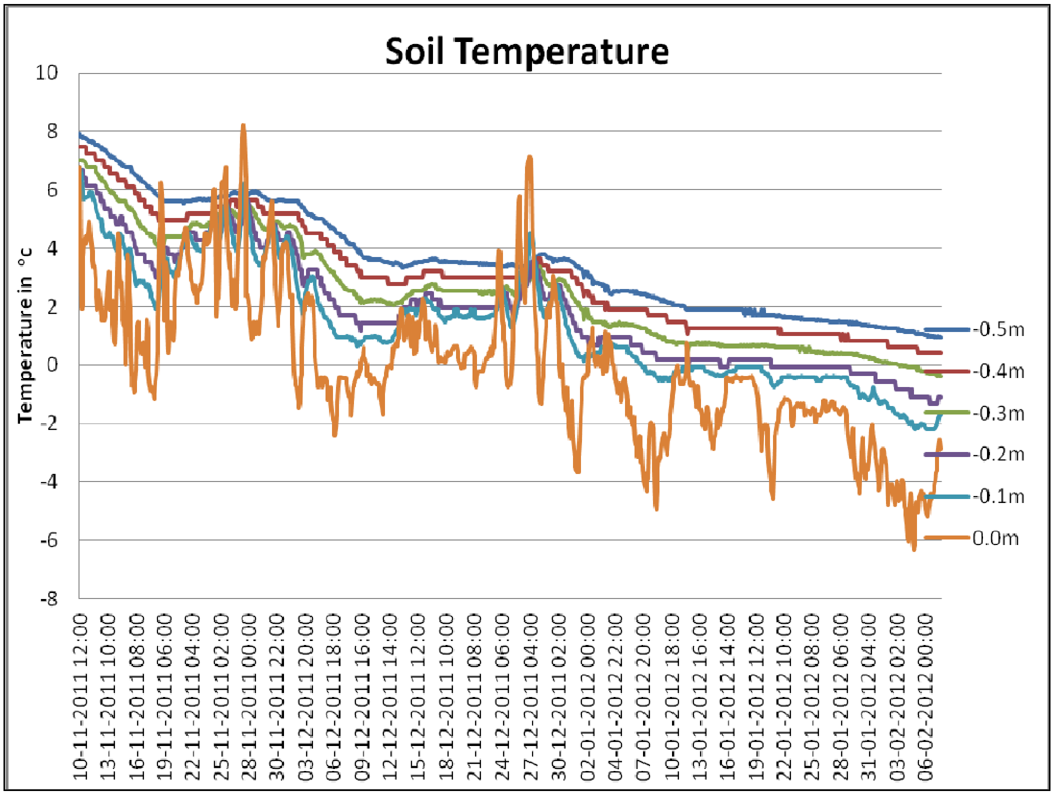

Figure-2
Time Series Graph for Soil Temperature

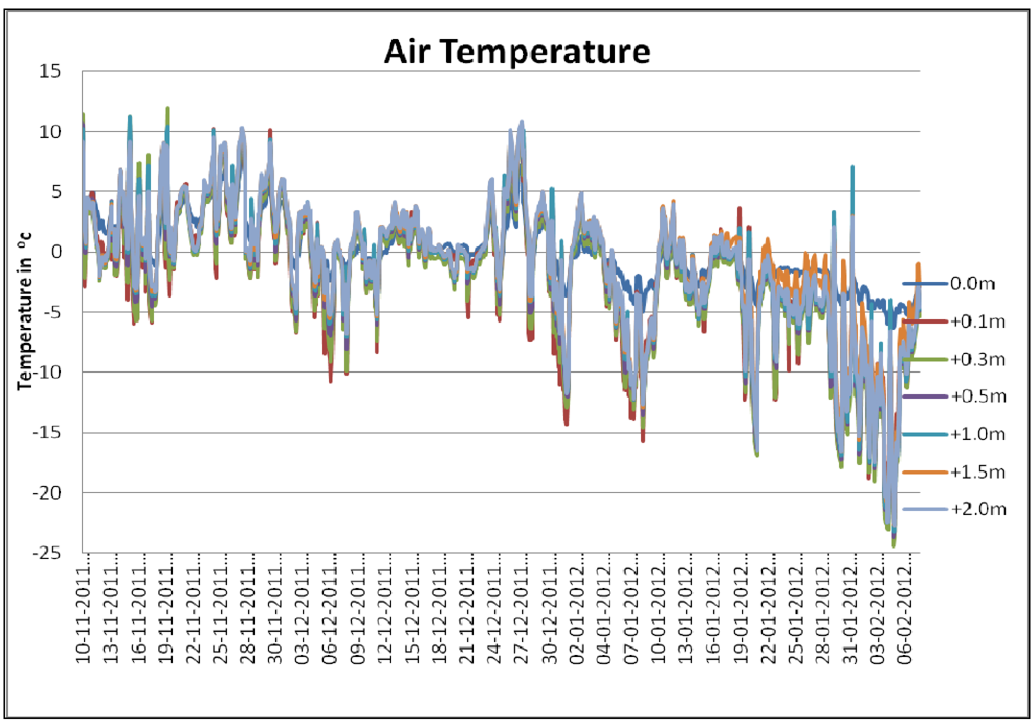

Figure-3
Time Series Graph for Air Temperature

Analysis of Temporal Trends in ATD at Surface and Deep Soil: The figure-4 to figure-8 explains the transfer of/changes in temperature from surface with condensed snow up to 0.5m depth of sandy soil grains and to the clay particles lying below. The Graph obtained for ATD values at various depths (-0.1m,-0.2m,-.3m,-0.4m) indicates diffusion values during the months of November, December and starting of January and more converging towards zero when the diffusion is less during January to February. The diffusion rate at 0.4m depth is obtained as 0.0514x10^-7 m2/s during the end of November and reduces to zero during the end of January, similarly at the depth of 0.3m the diffusion rate is higher as 0.068x10^-7 m2/s during December and 0.004 during February. At the depth of 0.2m the diffusion rate of 0.18x10^-7 m2/s and 0.08x10^-7 m2/s is notable during November and sometime during January which is higher than the values obtained in the depths below. The diffusion rates 0.028x10^-7 m2/s and 0.029x10^-7 m2/s during November and January can be clearly seen with higher diffusion points in 0.1m depth. The surface diffusion rate is much high as 0.17x10^-7 m2/s which is as seen in the -0.2m level.

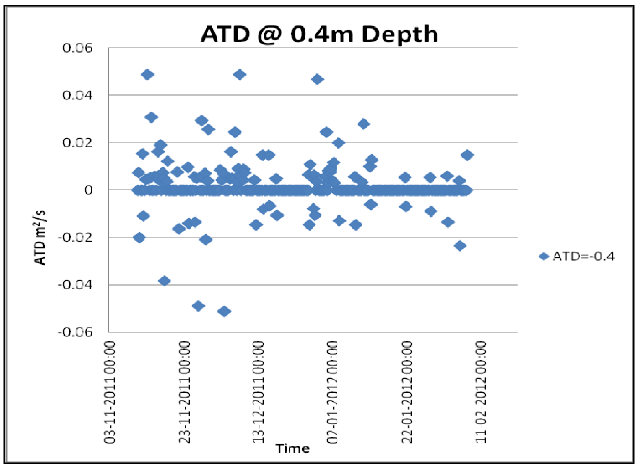

Figure-4
ATD Calculation for 6hrs Time Span in Soil at 0.4m depth

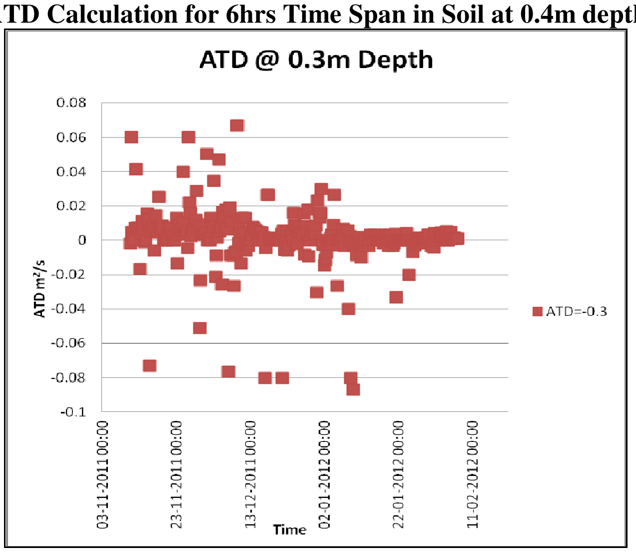

Figure-5
ATD Calculation for 6hrs Time Span in Soil at 0.3m depth

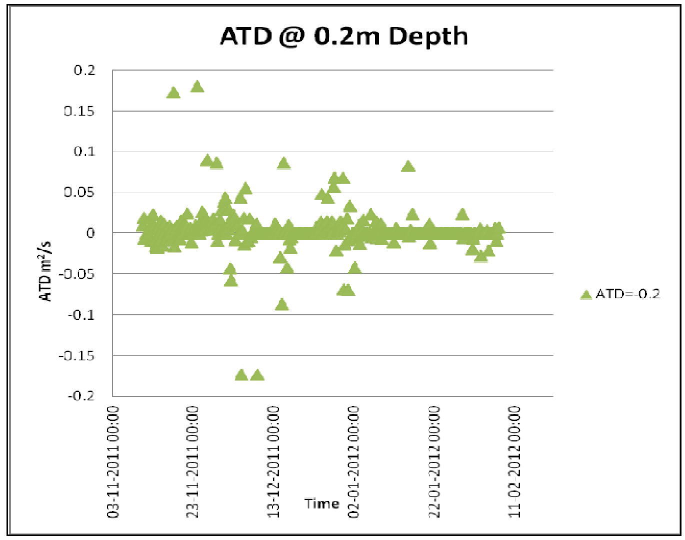

Figure-6
ATD Calculation for 6hrs Time Span in Soil at 0.2m depth

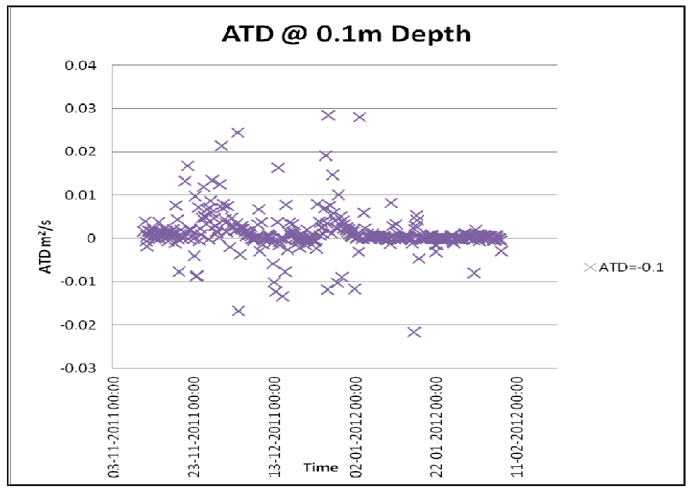

Figure-7
ATD Calculation for 6hrs Time Span in Soil at 0.1m depth

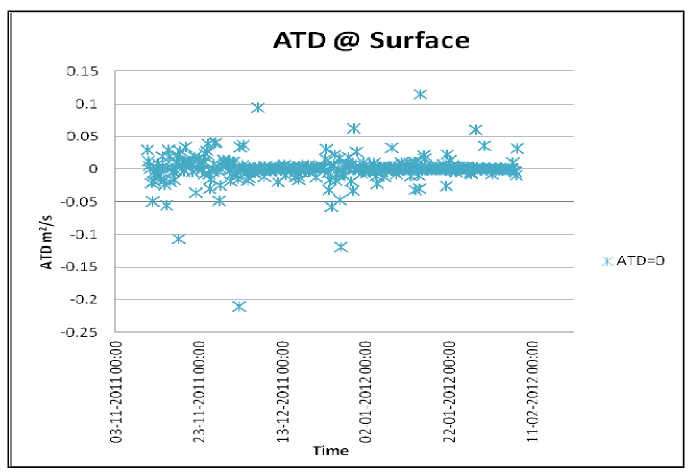

Figure-8
ATD Calculation for 6hrs Time Span in Soil at Surface

Analysis of Vertical Temperature Profile: i. For the analysis of vertical temperature profile following days are selected, ii. For a day without snow: 2012-01-29 (figure-9), iii. For a day with snow: 2012-01-31: (figure-10), iv. For cloudy day: 2012-01-24: (figure-11), v. For a day with clear sky: 2012-01-17: (figure-12).

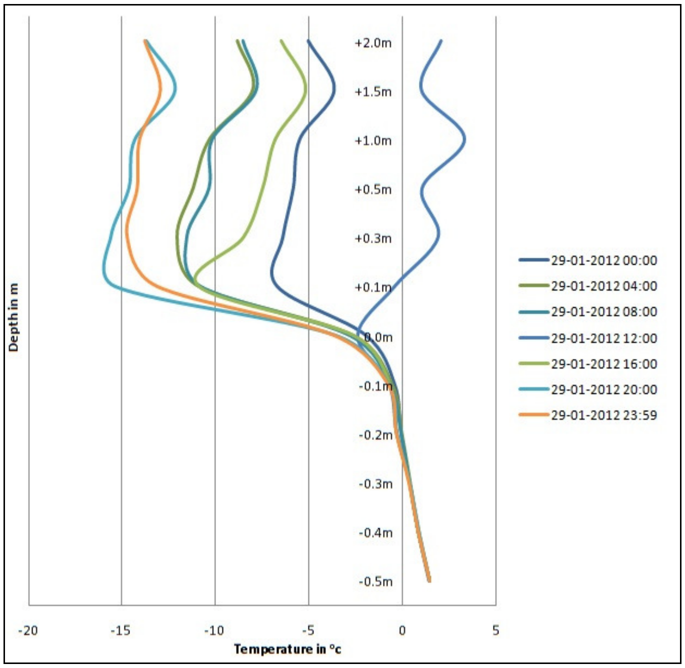

Figure-9
Vertical Temperature Profile for a Day without Snow 2012-01-29

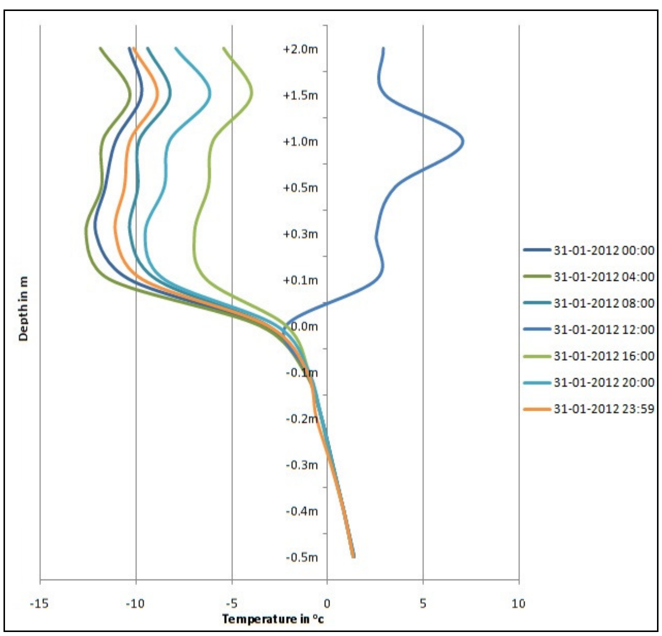

Figure-10
Vertical Temperature Profile for a Day with Snow: 2012-01-31

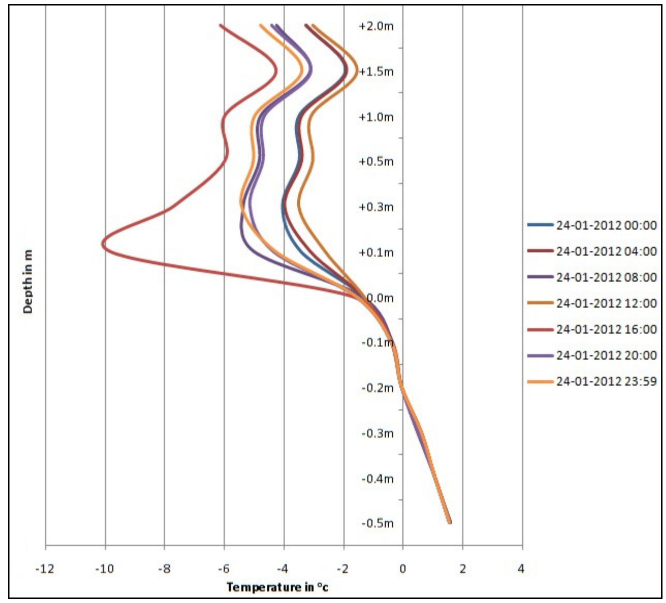

Figure-11
Vertical Temperature Profile for a Cloudy Day: 2012-01-24

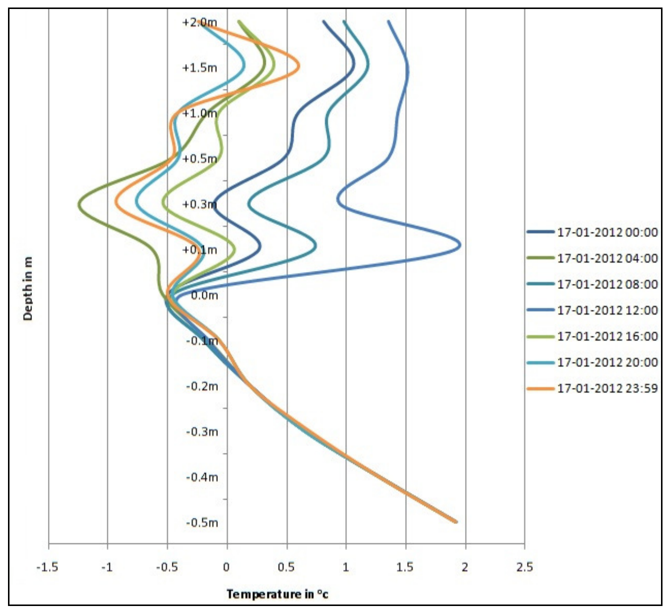

Figure-12
Vertical Temperature Profile for a Day with Clear Sky 2012-01-17

Zero Curtain Effect: The figure-13 doesn't provide any information about freezing soil. But the soil at -0.2m level starts freezing during 23rd -30th January2012 and shows zero curtain effect. **Figure-13, 14** explains the zero curtain effect during 23rd till 30th Jan 2012. At -0.1m the freezing soil remains at -0.4 °C temperature. At -0.2m, the freezing soil remains at -0.1 °C temperature.

The soil temperature decreases and hasn't reached a stable temperature after 29th Jan till observed time.

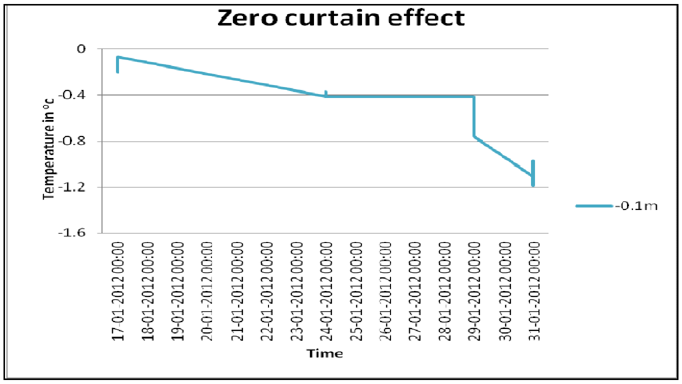

Figure-13
Zero Curtain Effect (23rd -30th Jan 2012) at 0.1m depth

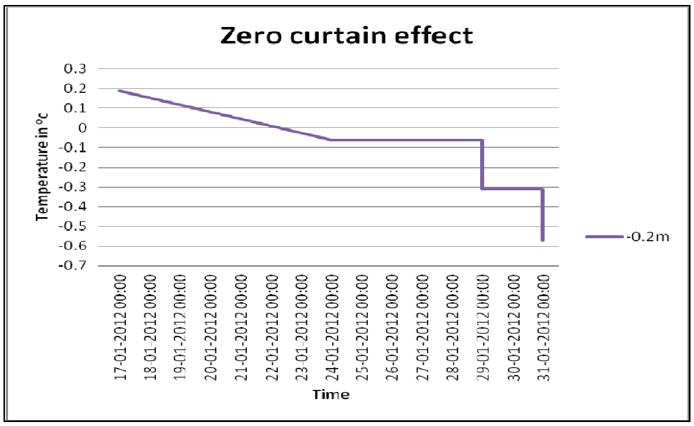

Figure-14
Zero Curtain Effect (23rd -30th Jan 2012) at 0.2m depth

Discussion: From the temperature-time series graphs of soil temperature, the peak values at 0.0m/ground surface indicates that there is more interaction between the soil and air layers. The temperature is increasing along the deeper layer of the soil. For example: during November2011 the increase in temperature between -0.1 to -0.5 m level was about 5.8°C to 8°C (2.2°) and at the end of January2012 the change in temperature was about -2.2°C to +1.6°C (3.8°). The increase in temperature between layers that is observed from the decreasing trend of the overall temperature graph could because of the presence of snow layer, which acts as an insulating layer which doesn't allow much colder temperature to transfer below the soil surface.

From the temperature-time series graph of air temperature, there is a decrease in the air temperature from November2011 to February2012 but still they are changing abruptly between 0.1m, 0.3m, 0.5m, 1m, 2m levels in shorter time spans. This could be because of increase or decrease in wind speed and albedo. The change in 0.0m level is not so random and abrupt this might be because of the laminar wind flow along the surface layer or because of the presence of snow layer.

The Apparent thermal diffusivity graph explains the diffusion rate of temperature at measured depths. The diffusion values can be commonly seen during November and January which means the temperature variation is high during this period of time. The values converging towards zero indicates temperature variation along time and depth is too low, the reason could be because of the presence of snow layer over the surface or because of lower air temperatures. The positive ATD values and negative ATD values indicate that the non conductive process plays an important role. Unusual higher diffusivity rate in 0.2m depth can be the because of the presence of frozen layer of soil (since ice has higher diffusivity rate).

Figure -9, the vertical temperature profile is as expected. But the temperature increases during 12:00, this could be because of the albedo. Figure -10, when there was snow cover. The temperature at 12:00 is little higher than that of Figure -9. This could be because of the increase in albedo due to higher reflection from snow cover, and hence temperature rapidly decreases over time increments on the same day. Figure-11 we can easily infer from the graph that the temperature is uniformly increasing and decreasing but the variation is still lesser than 0°C. This could be because of the absence of sunlight (albedo). Figure-12, this graph is a best example to indicate the changes in temperature on a day with clear sky. There is abrupt changes in temperature along the vertical profile in variation with time, indicating increase in temperature (>0°C) during day time which is influenced by albedo.

During Zero curtain effect the temperature remains unchanged for some period of time, this can be between days to weeks. But from the graph the zero curtain effect can be noticed only for a week of time at 0.1m depth and 0.2m depth. The temperature decreases after a week, this change depends on various factors such as soil uniformity and other soil parameters such as porosity etc., so the change could be because of the non uniform fractured bedrock soil and clay layers. At this time the ATD values will be much towards zero during zero curtain periods and thus the ATD values reveal the same.

Conclusion

From the results the soil near the ground surface and up to 0.2m depth is more active in freezing, thawing and infiltrated water resulting to convective heat transfer. Lower temperatures and absence of snow cover during December helps in controlling ground temperature. The ATD values were found too low during end of January and February during which coincide with zero curtain period.

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