

MONITORING OF SEASONAL SNOW COVER IN SIKKIM HIMALAYA USING REMOTE SENSING TECHNIQUES

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ABSTRACT

The study shows distribution of snow cover in the Teesta basin of Sikkim Himalayas for four years from 2004 to 2008. Snow cover of Sikkim state has been monitored using 200 imageries of Advanced WiFS data of RESOURCESAT- using Normalised Difference Snow Index (NDSI). Maximum extent was 50% in February. Two peaks in the snow accumulation were observed in October and February. Snow areal extent is comparatively high (35-40%) even in the summer months, indicating different snow accumulation and ablation pattern in Sikkim as compared to the Western Himalayas. Long Period Average (LPA) temperature and rainfall trends influence snow accumulation and ablation pattern.

KEYWORDS: *NDSI, Snow cover, LPA, Sikkim*



Noon evaporation observed in the mountain peaks near Rathong, West Sikkim.
The rugged de-glaciated and moraine laden valley lead to the glacier



Gurudongmar glacier, draining into the lake. Minimal snow cover seen during June, 2011

Most glaciers in mountainous regions of the world have receded during the last 100 years, in response to climatic variation (Hansen and Lebedeff 1978). Variation in glaciers and snow cover are also reported from many parts of the world (Dhobal et al. 1995; Ding and Haeberlie 1996; Kulkarni and Bahuguna 2002) During the peak of glaciation, the area covered by the glaciers was 46 million sq. km (Embleton and King 1975). At present total glaciated area on the earth is about 14.9 million sq. km. Out of this 12.5 million sq km is located in Antarctic and 1.7 million sq km in the Greenland ice sheet (Flint 1971). The remaining 0.7 million sq km area is distributed in the other parts of the world (Sugden and John 1976). In the Indian Himalayas, the glaciers cover almost 23,000 sq km. area, and large quantity of water is stored in the form of seasonal snow, ice and glaciers (Kulkarni and Buch 1991). Himalaya has one of the largest concentrations of glaciers outside the polar region and some estimates suggest that the number could be as high as five thousand (Kulkarni and Bahuguna 2001).

The earth has experienced repeated cycles of warm and cold climate. The warming and cooling periods affect the ocean current and planetary wind system, which influence snow accumulation and ablation patterns. Solid precipitation (snow and ice) forms the primary input of mass for glacier systems. In most areas this differs from the annual precipitation total, because in the warm season much precipitation may fall as rain, so that in the glaciological terms the most important factor is the effective precipitation (Benn and Evans 1998). Precipitation in the form of rain on icebody produces large amounts of energy. Therefore, freezing of rain-water or the condensation of water vapour on a glacier surface can yield large amounts of energy, part of which can raise the temperature of the surrounding ice and increase the likelihood of future ablation.



Moraines flank the edge near Changme Khangse, glacier in North Sikkim

STUDY AREA

The state of Sikkim in the midst of the Eastern Indian Himalayan Region is surrounded by snow-clad mountains of Nepal, China and Bhutan (Figure 1). Teesta basin of Sikkim has 84 glaciers covering 440.30 sq km, and 251.22 sq km of permanent snowfields (Bahuguna et al. 2001). Snow cover is crucial for glacier buildup and initialization of further glacierization. The Himalayan snow fed Teesta river almost entirely traverses the state from North to South while forming the state's catchment area.

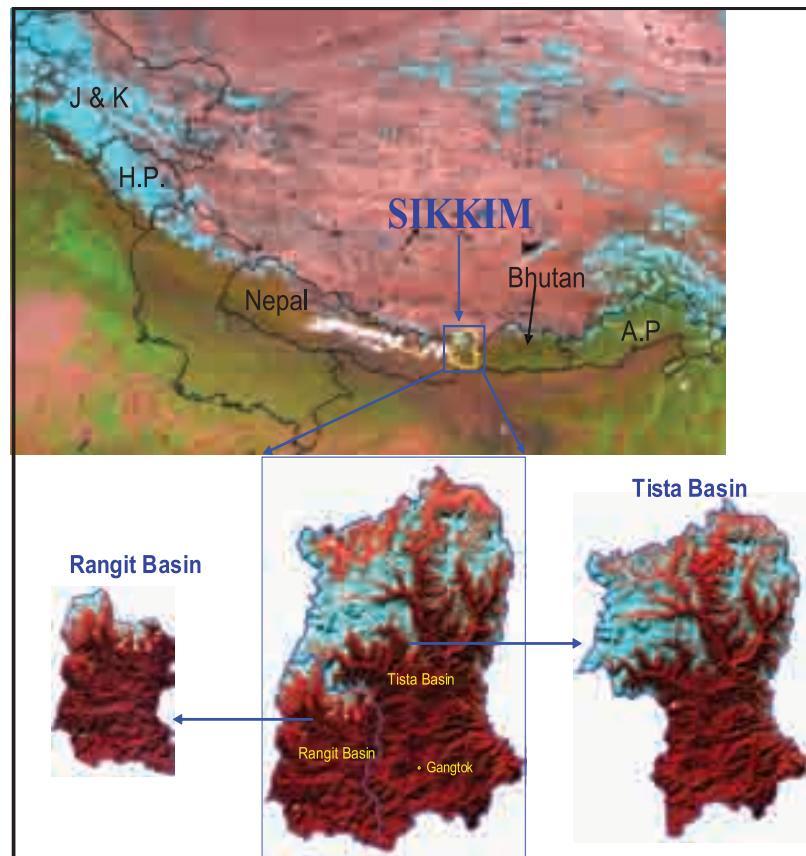


Figure 1: Location map of Sikkim and two sub-basins



Sebu stream draining out from seasonal snow in the month of May, 2008, North Sikkim



“U-shaped” valley on the way to Changme near Sebu. The valley represents de-glaciated area, now housing a wide range of alpine flowers and meadow



Seasonal snow near Changme Khangse. Lateral moraines seen at the bottom, North Sikkim

The river influences the life pattern and economy of the Sikkimese and others in Eastern India, parts of West Bengal and Bangladesh (Mukhopadhyay 1982). Irrigation, hydel power and adventure tourism depend highly on the meltdown from seasonal snow cover. Besides replenishing the streams that feed the perennial river system of the Brahmaputra, it represents a major storage of water, estimated as 140.05 cu km, which is released during the spring-melt period (Bahuguna et al. 2001). The rate of snowmelt is critical information for flood forecasting, agriculture and optimal management of water resources. However, information about snow cover accumulation and ablation for the Sikkim Himalaya is not available to the scientific community, significantly affecting planning strategies. In this paper results of snow cover monitoring are discussed for four years between 2004 to 2008.

METHODOLOGY AND DATA

The study gives distribution of snow cover in the Teesta basin of Sikkim, which includes Teesta and Rangit sub basins. Teesta basin occupies an area of 7096 sq km. AWIFS data covering an areal extent of 1,83,405 sq km at an interval of 5-days were used. Approximately 200 AWIFS scenes from October 2004 to June 2008 were analyzed in this investigation.

Initially master template was generated using control points from toposheet, and then basin boundaries were delineated using drainage map. The master template was used for registration of all satellite data. Then, algorithm based on normalized difference snow index (NDSI) was used to map snow cover (Kulkarni et al. 2006).

The spectral reflectance of snow, vegetation and rock is high in optical region of the electromagnetic spectrum and snow reflectance is lower in SWIR region (Joseph 2003). This characteristic difference has been used to

develop a normalized difference snow index (NDSI) for snow mapping. To estimate NDSI, Digital numbers (DN) were converted into reflectance. This involves conversion of digital numbers into the radiance values, known as sensor calibration, and then estimation of reflectance from these radiance values (Kulkarni et al. 2002). The normalized difference snow index (NDSI) is estimated using the following equation (Hall et al. 2002):

$$\text{NDSI} = \frac{(\text{Green reflectance (B2)} - \text{SWIR reflectance (B5)})}{(\text{Green reflectance (B2)} + \text{SWIR reflectance (B5)})}$$



Mt. Khangchengyao, 2011, enroute to Gurudongmar, North Sikkim



One year snow accumulation pack with layers in the snow profile indicating various interval of snow precipitation.
Near Tso Lhamu Lake. North Sikkim



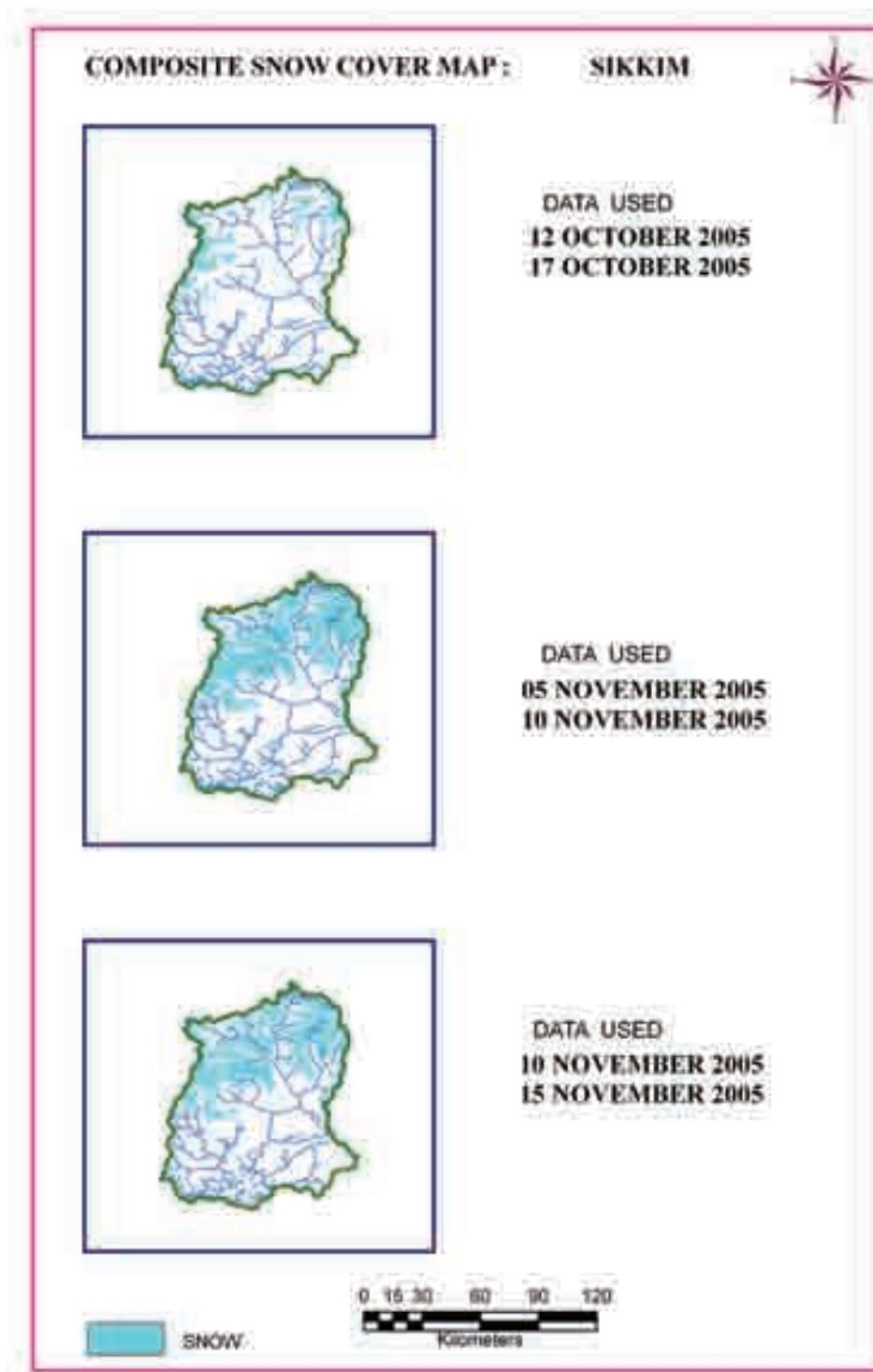
Permanent snow observed at the end of ablation (melting) season in the cold desert of North Sikkim. Snow pack ablation is highly sensitive to climatic variation



Heavy debris covered Zemu glacier, with thick mass of glacial ice beneath

NDSI values for rock and vegetation are negative, for cloud close to 0.2 and for snow and water above 0.4 (Kulkarni et al. 2002). Based on this, an algorithm has been run in a fully automatic mode to provide changes in the areal extent of snow. Snow extent is estimated at 5-day and 10-day intervals. In the 5-day product, snow extent is generated scene wise, and snow and cloud extent will be given. Cloud extent is important because at times, snow is covered by cloud, which could be classified as a non-snow area. In the 10-day product, three scenes are analyzed. For example 10-day March product will use the scene of 5, 10, 15 March. If any pixel is identified as snow on any one date, then this pixel will be classified as snow in the final product. This will provide a 10- day maximum extent of snow . But, due to un availability of cloud free data for Sikkim, the algorithm had to be modified (Kulkarni et al. 2006). Since three consecutive cloud free scenes were not available, two corresponding data scenes have been merged to analyze maximum snow cover. This gives a composite snow cover extent for the mean date. For instance, 14th October scene is the product of 12th and 17th October (Figure 2).

Figure 2: Composite snow cover map



RESULTS AND DISCUSSIONS

In this paper, composite snow cover data of 4 years (2004-2008) have been averaged to estimate mean monthly snow cover in Sikkim (Figure 3). Monthly snow cover distribution varies greatly from October to April. It has been observed that in October snow covers 17.5%, increases upto 25.74% in November. A slight dip is seen in the months of December and January. In February the depletion curve shows increase in snow cover up to 50%, with a gradual depletion upto April. Hence, the observation shows that snow cover is substantially higher in February than in the month of October, November. This suggests that Sikkim receives higher snow precipitation from Western Disturbances in the winter month of February, than from North East Retreating Monsoon.

Snow cover pattern has been analyzed with the Long Period Average (LPA) temperature and rainfall data. The Long Period Average gives an average of temperature and rainfall from 1979 to 2008 (Figure 4a and 4b). The LPA data obtained from ICAR Research Centre has been observed at Gangtok in Sikkim. The LPA rainfall data shows 170 mm precipitation in October and 37 mm in November. However, amount of snow cover is higher in November as compared to October, indicating more precipitation of snow than rain in the higher altitudes. This is possibly due to LPA temperature, which is 20 and 17 degree Celsius in October and November, respectively. Even though, amount of difference is only 3 degree, it has significantly influenced the nature of precipitation, suggesting sensitivity of snow to temperature change in the state of Sikkim.

Figure 3: Mean monthly and mean yearly snow cover distribution (2004-2008)

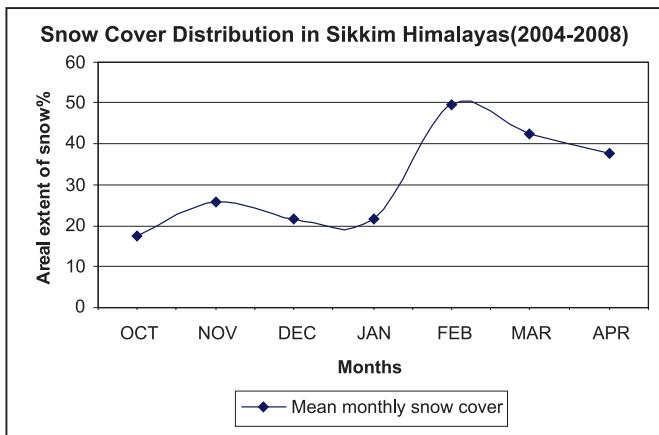


Figure 4a: Rainfall pattern in Sikkim (Gangtok)

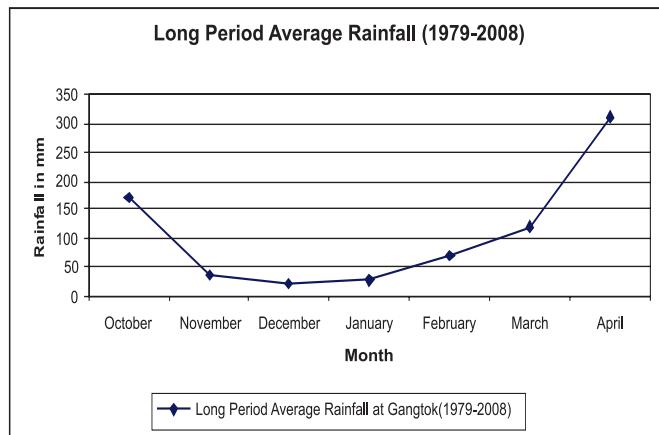


Figure 4b: Temperature trend in Sikkim (Gangtok)

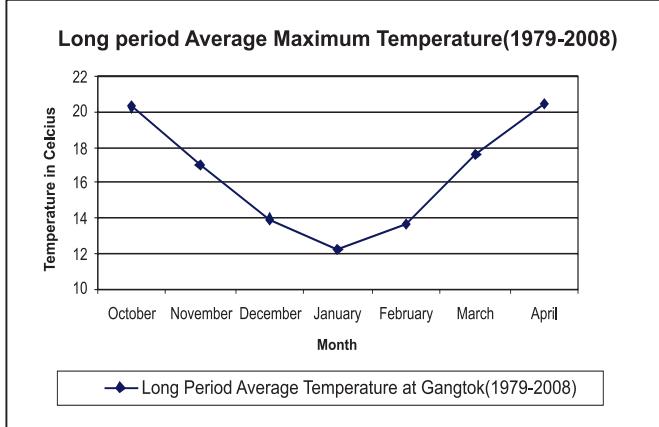
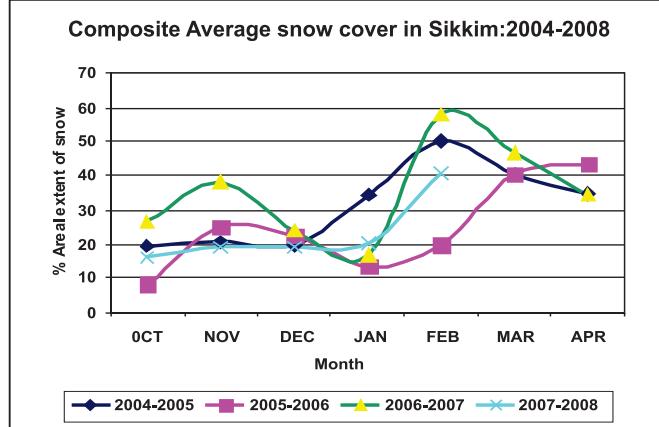


Figure 5: Composite monthly average snow cover in Sikkim. (2004-2008)



Note: Data not available from April onwards due to cloud cover



Snow sampling for snow contamination study in North Sikkim. Snow covers almost 40 per cent of the Earth's land surface during Northern Hemisphere winter. This makes albedo and areal extent of snow an important component of the Earth's radiation balance



Moraine dam lake near Rathong Glacier, West Sikkim. These lakes are formed when the flow of water is constrained by moraines. Overtime, a breach can cause Glacial Lake Outburst Flood (GLOF), which can disrupt landform, settlement and cause natural calamity



Hanging glacier seen across from the de-glaciated meadows towards HMI base camp, East Sikkim. All the rivers originating from higher Himalayas receive almost 30-50 % of annual flow from snow and glacier melt runoff



Thick patch of snow seen on the peaks enroute Gurudongmar, North Sikkim. Mapping and monitoring of seasonal snow cover using field methods are normally very difficult in a mountainous terrain, like the Himalayas. Therefore, remote sensing techniques have been extensively used for snow cover monitoring

The composite snow cover for each year has been tabulated by averaging two corresponding data scenes, to analyze maximum snow cover (Figure 5) (Table 1). All the years show a uniform trend in the snow depletion curves, with peaks in October and February. The months of March, April and May too receive heavy snow precipitation with snow cover higher than the average. This suggests, continuous snow precipitation pattern in the higher altitudes from February till the end of May, unlike Western Himalayas where snow areal extent show a declining trend from March onward (Kulkarni et al. 2010). This suggests different snow accumulation and ablation (melt) pattern in Sikkim Himalayas, as compared to Western Himalayas. Snow cover could not be mapped from April onwards, due to heavy cloud cover.

Table No.1. Monthly composite snow cover in Sikkim shown as percentage areal extent

	OCT	NOV	DEC	JAN	FEB	MAR	APR
2004-2005	19.39	20.66	19.77	34.43	50.09	40.5	34.86
2005-2006	(C) 8.15	25.12	22.44	13.38	(C) 19.69	40.36	43.41
2006-2007	26.67	38.28	24.02	17.03	58.12	46.92	34.57
2007-2008	15.91	18.91	18.93	20.4	40.75	114.9	

C: Cloudy Data

Table 2. Maximum, minimum snow cover extent in Sikkim (2004-2008)

Hydrological Year	% Areal extent of snow cover in Sikkim	
	Max	Min
Oct 2004-April 2005	50.90 (Feb)	15 (Dec)
Oct 2005-May 2006	46.43 (April)	8.15 (Oct) (C)
Oct 2006-April 2007	58 (Feb)	14 (Jan)
Oct 2007-Feb 2008	40 (Feb)	12 (Jan)



Alpine meadow along the valley leading towards East Rathong Glacier, West Sikkim

The yearly hydrological snow cover (2004-2005, 2005-2006, 2006-2007, 2007-2008) has been estimated by taking the arithmetic mean of composite mean monthly snow cover. Four years analysis of snow cover extent shows that almost 30% of Sikkim is snow covered, with maximum snow cover in 2004-2005 and least snow cover of 23% during 2006-2007.

CONCLUSION

In Sikkim, the maximum extent of snow cover is 50% i.e almost 3548 sq km of land is snow covered in February, contributing significantly in lowering the earth's global temperature and balancing the earth's radiation. The early increase in snow cover and continuous depletion of snow cover up to January end suggest an influence of monsoon snow fall in the Sikkim Himalayas. Maximum snow precipitation in February suggests that Sikkim receives higher snow precipitation in winter months from Western disturbances than North East Monsoon. Due to the advantageous location of Sikkim, the summer months of March, April and May receive comparatively higher snow precipitation than Western Himalayas (Kulkarni et al. 2010), which provide better input for the glaciers during the summer months. This also suggests different snow accumulation and ablation pattern in Sikkim. It has been observed that rainfall, air temperature and snow precipitation are very closely interrelated and a slight trigger in any one could drastically influence the pattern of snow accumulation. Due to heavy cloud cover, data was not available for May, June and July. With development of newer microwave technique, RISAT data would be of prime importance for thorough month wise analysis for snow monitoring. There is also a need for a better algorithm to monitor the areal extent of snow under canopy and vegetation in Sikkim.

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