Mapping of Spatio-Temporal Variations of Snow-Cover in Western Tibetan Plateau Using Time Series of Modis Satellite Imageries

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Abstract

Snow clad western Tibetan plateau is the source region of the Indus-Sutlej river system. Reports of global warming impacting higher elevation areas have raised concerns about early melt of snow cover feeding river systems in pre monsoon months. The fluctuations of snow-cover in this area were studied using MODIS satellite imageries for first three years of present century. Interpretation of maximum monthly snow extent maps clearly reflects the seasonal rhythm of snow accumulation and depletion and also the year to year huge variations in the onset of snow accumulation. However, any signs of early snow melt were not detected.

Keywords: Tibetan Plateau, Temperature Rise, Snow Cover Accumulation, Snow Cover Depletion, MODIS Imagery

Introduction

As the roof of the world, the Tibetan Plateau is a gigantic tectonic geomorphologic region on the earth, with an average elevation greater than 5,000 m. It is the source of snowmelt runoff, supplying water resources to users in India, China and other surrounding areas. A significant warming trend, occurring at a faster rate than over low-elevation regions, have reported that over high-elevation Tibetan Plateau (Braeuning and Mantwill, 2004; Diaz and Bradley, 1997; Ding et al, 2007; Liu and Chen, 2000). However, due to lack of detailed long-term and densely distributed spatial observations of temperature and snow cover researchers have not been able to determine the mechanisms influencing the observed rapid climate change and their impacts at this high-elevation region.

Recent warming trends on the plateau directly influence the permafrost and snow melting and will impact not only impact on local climate and environment, but also have important hydrological implications for the rivers like the Indus and Sutlej, which originates in the western Tibetan Plateau complex. (Cheng and Wu 2007; Jiming et al., 2010). Sutlej river waters provide a very large part of north western India with domestic and irrigation supplies. Ground based data collection at high spatial resolution is impossible for the catchment of Sutlej or Indus due to highly rugged terrain and extreme climatic conditions in this Trans-Himalayan region. Remote sensing offers a very cost effective alternative for obtaining snow cover information for inaccessible areas.

Objective of the Study

The objective addressed in this paper is to visualize and quantify the spatial variations in the snow-cover in the upper catchment of Sutlej river, situated in western Tibetan plateau, at a monthly time step for a total period of three years so as to identify the trends of snow-cover accumulation and snow-cover depletion.

Study Area

Sutlej originates from Rakastal and Mansarovar lakes near mount Kailash and traverses throught the rugged nari Kharosam province of western Tibet. It enters India near Shipki La pass and meets, Spiti river at Khab (Figure 1). A shape file of the upper catchment of Sutlej river was used to extract the spatio-temporally varying snowcover from the mosacied MODIS 8 Day Maximum Snow Extent images.

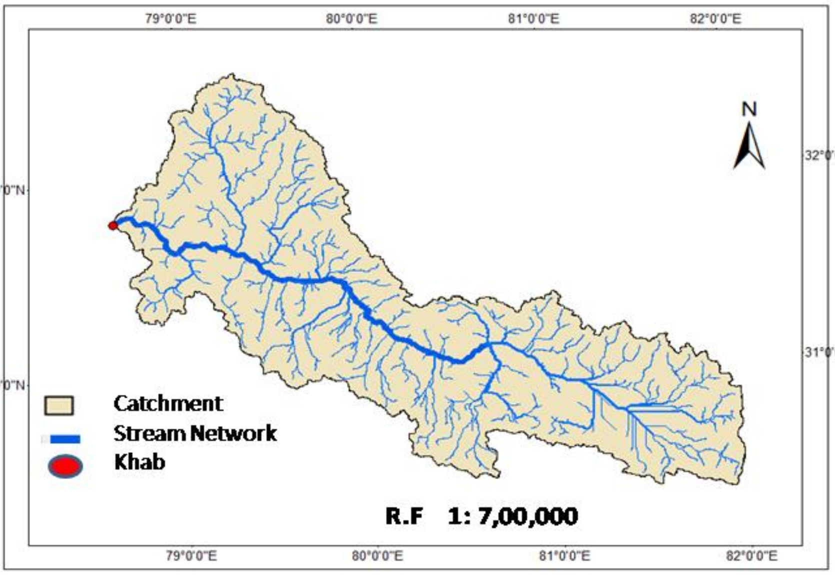


Figure 1: Study Area

Material and Methods

Though many different sensors onboard satellites provide continuous information about the earth's actual state, MODIS (Moderate Resolution Imaging Spectro-radiometer) sensor is considered most useful for mapping snow-cover. This sensor is on board both TERRA and AQUA satellites and views the entire Earth every day. MODIS sensor has 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm, this includes visible light, near infrared, short, mid, and long wave infrared. Automated algorithm for mapping snow-cover uses satellite reflectance in MODIS bands 4 (0.545–0.565 µm) and 6 (1.628–1.652 µm) to calculate the normalised difference snow index (NDSI) (Hall et al. 2002). The 8-Day L5 global 500 m grid, an 8-day composite product from Terra (MOD10A2) sensor with morning overpasses is being used for this study. This MODIS derived snow product has two types of information, fractional snow cover and maximum snow extent. The information on maximum snow extent gives the total maximum area of snow cover over 8 days and is generated by stacking 8 days of daily snow maps together. Thus for each year, 46 MOD10A2 products are generated for both Terra as well as AQUA sensors. The format of data is HDF-EOS format, a standard archive format for products from the Earth Observation Satellite data information system (EOSDIS). This information has been used for snowcover mapping and monitoring for this study.

Re-projection and Re-formatting of native MODIS Format Data Tiles

The MODIS data from NSDIC are available in the sinusoidal map projections and HDF format. These data tiles were re-projected from Sinusoidal Projection to Universal Transverse Mercator Projection with 44 N zone and converted to the GeoTIFF format using batch processing routines in the Modis Re-projection Tool software.

Mosaicing of MOD10A Tile h24 and MOD10A tile h25

The spatial extent of Sutlej river's Tibetan catchment is 78^0 36' to 82^0 1' longitudes and 30^0 19'; to 36^0 18' latitudes. Most of the catchment is covered by the h24 tiles (Figure 1). However, the upper catchment, near the origin of Sutlej at the Rakastal and Mansarovar lakes is mapped by the h25 tiles (Figure 2). Hence snow-cover tiles generated for both of these path/row granule locations need to be downloaded and mosaiced or stitched together for mapping the entire catchment of Sutlej in Tibet.

Forty six MOD10A2 snow-product data tiles are generated for every location each year. For the period commencing from March 2000 to February 2003, about 138 MOD10A2 h24 and 138 MOD10A2h25 tiles were downloaded from the NSDIS Earth Data site. Downloading details for tile 24 and tile 25 are given below for reference:

https://n5eil01u.ecs.nsidc.org/DP5/MOST/MOD10A2.005/2003.02.18/MOD10A2.A2003049.h25v05.005.2007283121220.hdf

https://n5eil01u.ecs.nsidc.org/DP5/MOST/MOD10A2.005/2003.02.18/MOD10A2.A2003049.h24v05.005.2007283120523.hdf

Figure 2: Sutlej Catchment (red outline) in MODIS10A2 Tile h 24.

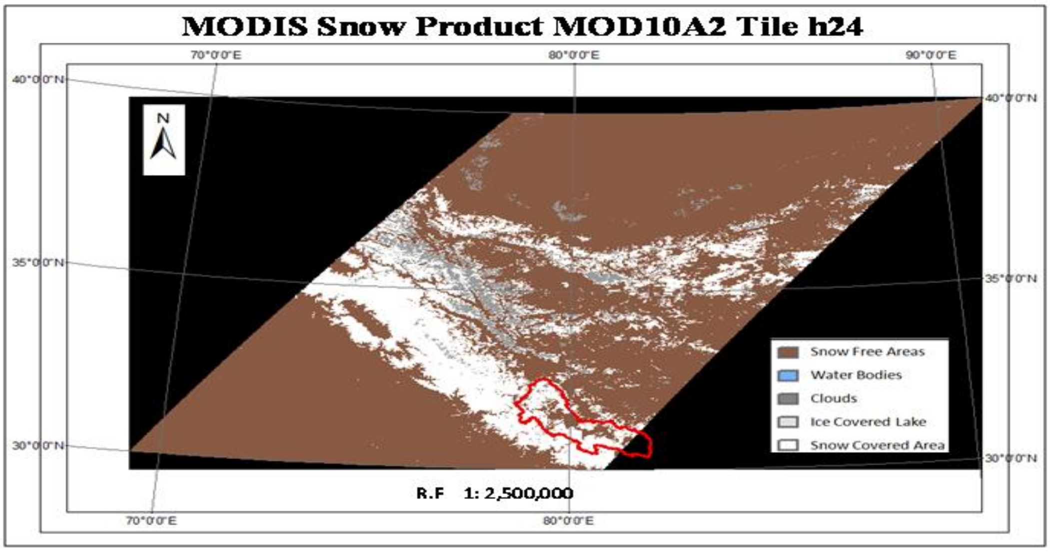
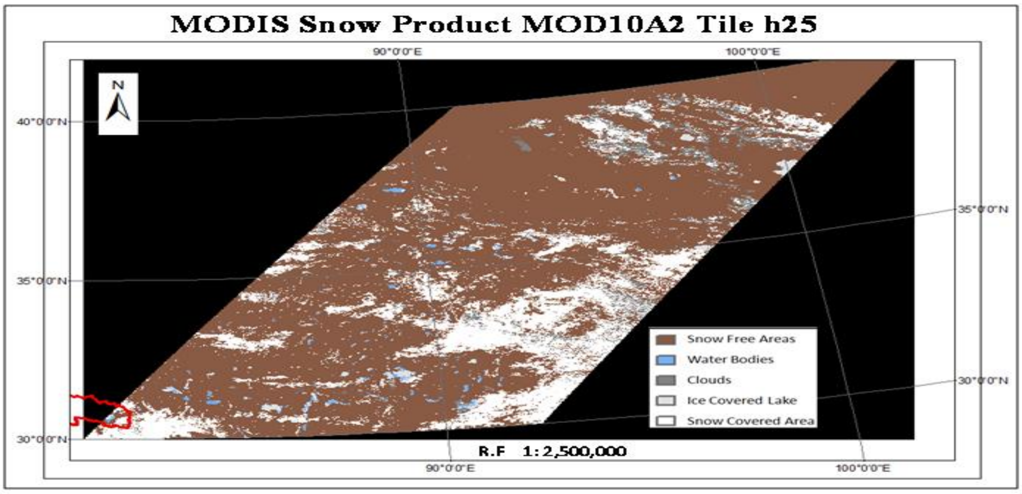
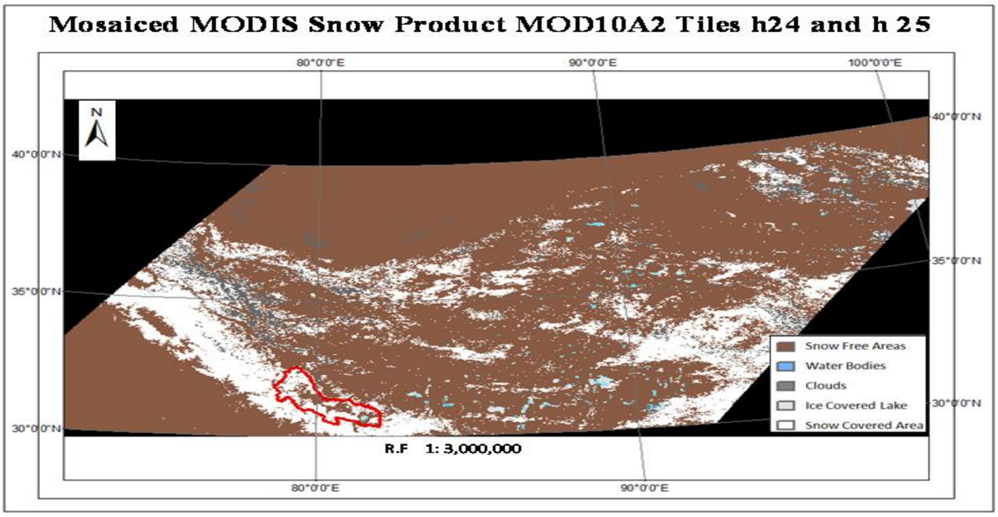


Figure 3: Sutlej Catchment (red outline) in MODIS10A2 Tile h 25.



The MRT output MOD10A2 h 24 and h25 tiles in GeoTiff format and UTM projection were stitched together or mosaiced in the ArcGIS environment (Figure 4).

Figure 4: Sutlej Catchment (red outline) in mosaiced MODIS10A2 Tile h 24 and h 25.



Results and Discussion

The study area boundary shape file (Figure 1), was used for masking out the area of interest from each of the mosaiced MOD10A2 Tiles. The major landcover features displayed in MOD10A2 product are snow, lake ice, clouds, and water bodies. The MOD10A2 derived snow area extent maps were compared for the years 2000-01, 2001-2002, and 2002-2003 at a monthly time step in order to find out if the snow cover is declining due to increased warming reported in recent climate change related scientific publications. Snow-cover depletion begins from the month of March.

The basin wide snow-cover fluctuations statistics, derived using ArcGIS spatial Analyst tools are given in Table 1.

Table 1: Monthly maximum snow cover extent in study area (2000-01 to 2002-03).

	2000-01	**2001-02**	**2002-03**
March	14397	9042	27886
April	10971	10900	15598
May	7053	4170	7981
June	6767	1166	1602
July	470	767	419
August	537	699	545
September	917	550	5140
October	609	608	4760
November	5919	924	7593
December	11647	12297	20713
January	16718	18762	22106
February	19393	25450	16967

Two important conclusions could be drawn from these numbers:

(a) There exists a seasonal rhythm of snow accumulation and depletion;

(b) Tibetan Plateau, situated in the rain shadow zone of the higher Himalayan mountain ranges receives little monsoon rainfall;

It is known for long that western Tibet is a cold desert, devoid of year round vegetation. But it is the source region of two most important river systems providing water to a huge chunk of the billion plus population of India: Indus-Sutlej and Sangpo-Bhramputra. These areas depend upon winter precipitation brought in by the western disturbance to sustain them. Meteorological data collection centers are very few in this rugged and inhospitable terrain. MODIS imagery derived data set are a tool to fill the gap.

Visual interpretation of available data sets was carried out for arriving at a preliminary spatially distributed understanding of precipitation regime in study area. These maps provide a synoptic view of the changing snow-cover extent at a time-step from March 2000 to February 2003 (Figure 5 to Figure 16). Maps of same month in above mentioned months have been placed side by side to allow visual interpretation of changes in snow-cover extent.

Figure 5: Snow cover extant in March

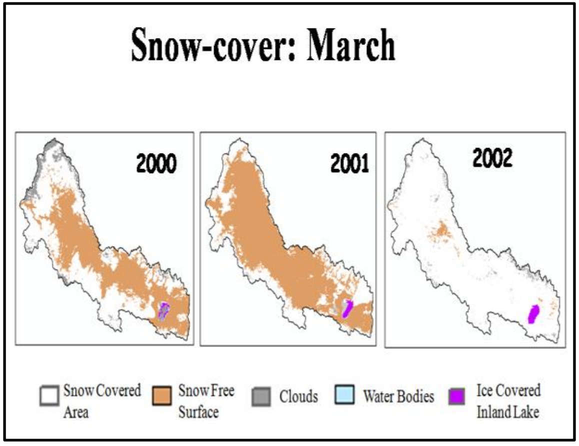


Figure 6: Snow cover extant in April

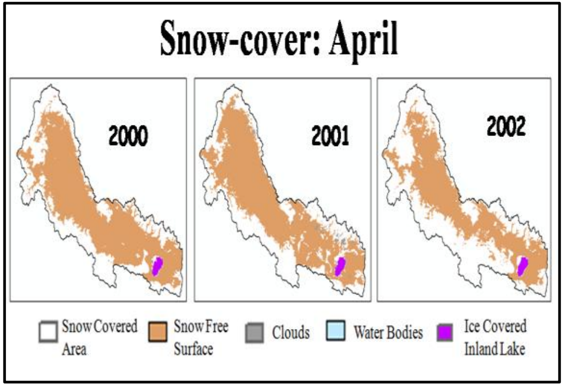


Figure 7: Snow cover extant in May

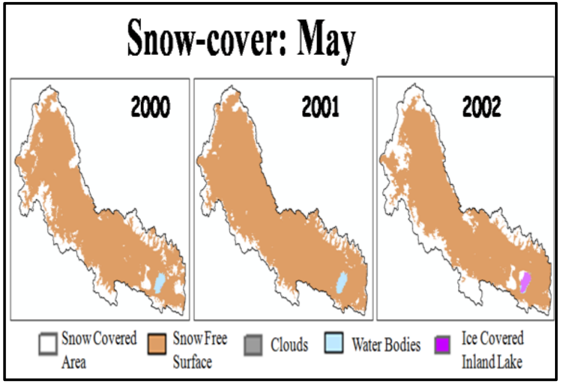


Figure 8: Snow cover extant in June

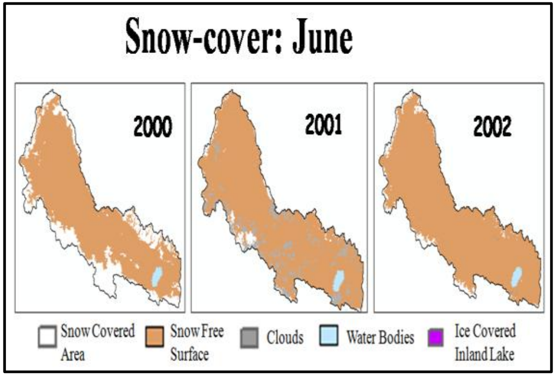


Figure 9: Snow cover extant in July

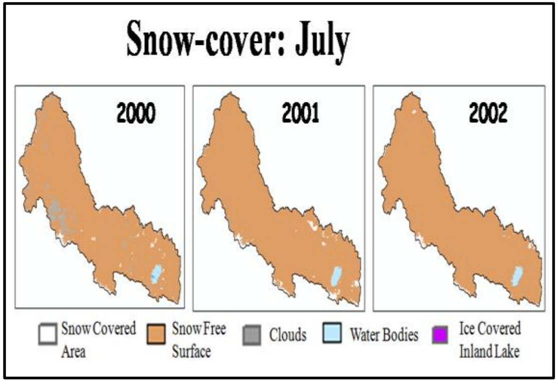


Figure 10: Snow cover extant in August

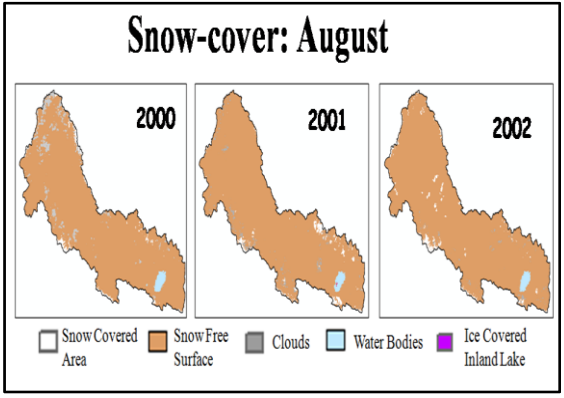


Figure 11: Snow cover extant in September

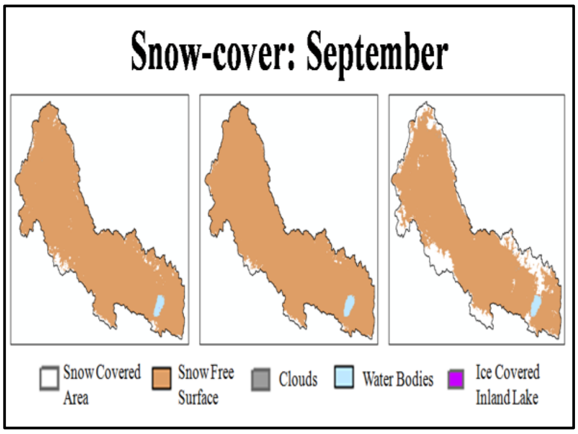


Figure 12: Snow cover extant in October

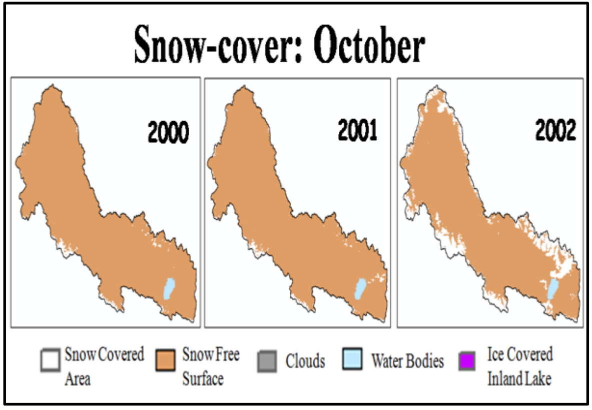


Figure 13: Snow cover extant in November

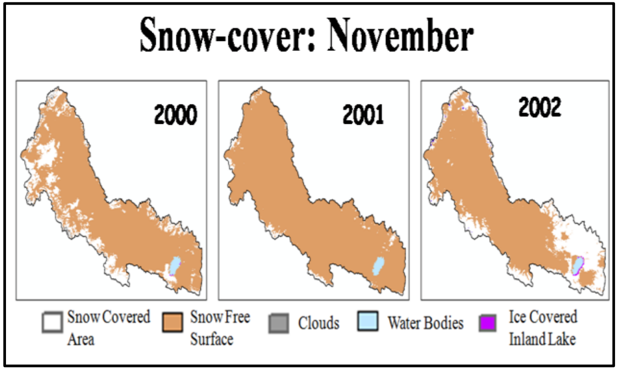


Figure 14: Snow cover extant in December

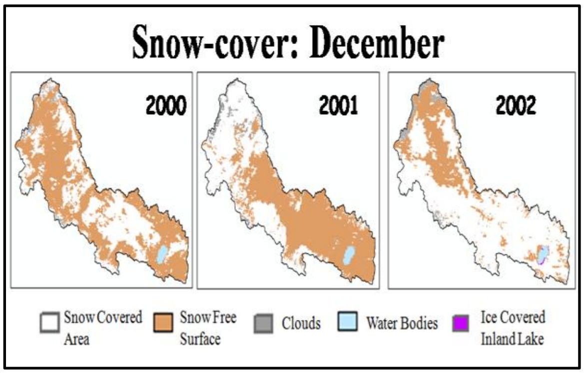


Figure 15: Snow cover extant in January

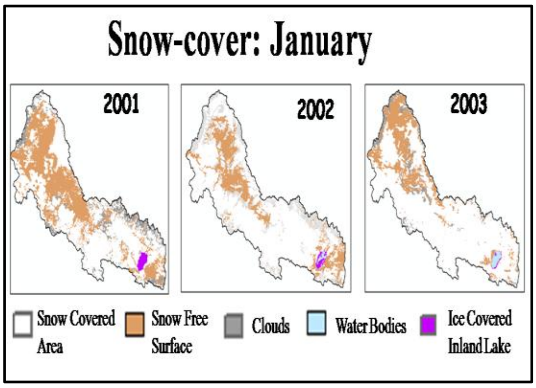
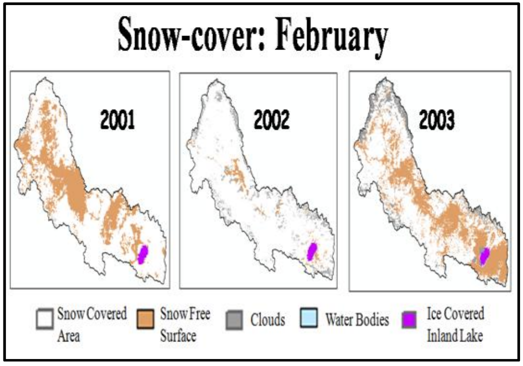


Figure 16: Snow cover extant in February



Most of precipitation on the western Tibetan plateau occurs during the winter months in form of snow-fall, brought in by the western disturbances which operate at altitudes higher than what monsoon system does and are able to move into the heart of

Tibetan Plateau. However, these disturbances originate in and around the Mediterranean and Caspian sea and their paths and intensity fluctuates very high year to year. This winter westerly precipitation is part of mid/upper tropospheric low-pressure systems, known as Western Disturbances, In contrast to the monsoonal air masses, winter westerly moisture is transported at higher tropospheric levels.

The Tibetan Plateau is very dry and arid due to the Himalayan mountain ranges preventing moisture reaching inland. Monsoonal air masses, are transported at lower tropospheric levels. The high mountains act as a barrier. The Himalayas forces the moist monsoonal air masses to ascend, which enhances condensation and cloud formation and precipitation on the southern side of the mountain chain. It typically prevents the migration of moist monsoonal air masses leeward of the orographic barrier and creates a rain shadow in the northern leeward interior.

Conclusions

Visual interpretation of above displayed maps indicate that the snow-cover begin to accumulate from the month of November onwards. Gradually the extent grows and by middle of March almost about 70% of the catchment area is covered with snow. The maximum snow-cover extent in catchment is reached either in February or in the month of March. Snowmelt season begins either in the middle of March or towards the third week of March. Extent of snow covered area begins to declines very quickly April onwards in extent and most of the snow is melted by July. Nevertheless there is some snow in the mountainous areas above 5500 m and most of that is also melted by mid August. Analysis of three year maximum monthly snow cover data does not indicate any pattern of impact of warming on the snow cover of western Tibet. It requires a minimum of 30 years data set to arrive some realistic understanding about the ‘climatic conditions’ prevailing in some region. MODIS data sets have become available since the year 2000.

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