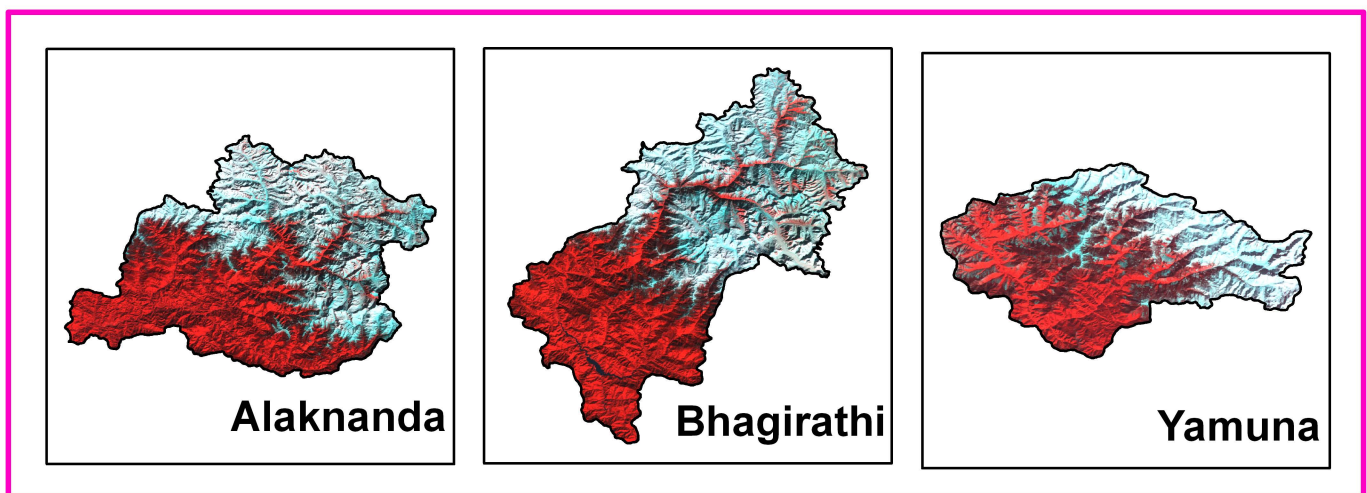# SNOW COVER ATLAS OF GANGA BASIN

Sub basins: Alaknanda, Bhagirathi and Yamuna

(A Joint Project of Indian Space Research Organisation and Ministry of Environment and Forests, Govt. of India)

Year : 2011-12

SNOW COVER ATLAS OF THE GANGA BASIN

Sub-basins: Alaknanda, Bhagirathi and Yamuna

**(A Joint Project of Indian Space Research Organization and
Ministry of Environment and Forests, Govt. of India)**

Year: 2011-12

**Uttarakhand Space application centre
Dehradun
and
Space Applications Centre (ISRO)
Ahmedabad-380015**

March 2013

SPACE APPLICATIONS CENTRE (ISRO), AHMEDABAD - 380015

DOCUMENT CONTROL AND DATA SHEET

Report Number	SAC/EPSA/MPSG/SGP/SN/ 87 /2013
Month and year of publication	March 2013
Title	Snow cover Atlas of the Ganga basin
Type of Report	Scientific Report
No. of pages	76
No. of figures, Charts & Tables	56, 9 & 6
Authors	Team members
No. of References	9
Originating Unit	Geo Sciences Division, Marine, Geo and Planetary Sciences Group, Earth, Ocean, Atmosphere, Planetary Sciences and Applications area, Space Applications Centre (ISRO), Ahmedabad-15
Abstract	This atlas gives subbasin-wise distribution of snow cover in the Ganga basin from October 2011 to June 2012. The subbasins included in this report are Alaknanda, Bhagirathi and Yamuna. The areal extent of snow cover was estimated in fully automatic mode using Normalized Difference Snow Index (NDSI) based algorithm. For this purpose AWiFS sensor of Resourcesat satellite was used. This atlas gives snow cover products, statistics and seasonal snow depletion curve. It is expected that this data will be useful for hydrological and climatological applications.
Key words	Snow cover, NDSI, AWiFS, depletion curve, Alaknanda, Bhagirathi and Yamuna basins.
Security Classification	Unrestricted
Distribution	Among concerned

Authors

Space Applications centre (ISRO), Ahmedabad

B. P. Rathore

S. K. Singh

I. Bahuguna

A. S. Rajawat

Ajai

Uttarakhand Space Application Centre, Dehradun

Asha Thapliyal

Anju Panwar

M. M. Kimothi

CONTENTS

1. **Introduction**

Snow covers almost 40 per cent of the Earth's land surface during Northern Hemisphere winter. This makes albedo and areal extent of snow as important component of the Earth's radiation balance (Foster and Chang, 1993). In addition, large areas in the Himalayas are also covered by snow during winter. Area of snow can change significantly during winter and spring. This can affect stream flow for rivers originating in the higher Himalayas. All the rivers originating from higher Himalayas receive almost 30-50 % of annual flow from snow and glacier melt run off (Agarwal et al., 1983). In addition, snow pack ablation is highly sensitive to climatic variation. Increase in atmospheric temperature can influence snowmelt and stream runoff pattern (Kulkarni et al., 2002). Therefore, mapping of the areal extent and reflectance of snow are important parameter for various climatological and hydrological applications. In addition, extent of snow cover can also be used as input for numerous other applications.

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. Snow cover monitoring using satellite images were started by using the TIROS-1 satellite from April 1960 (Singer and Popham 1963). Since then, the potential for operational satellite-based mapping has been enhanced by the development of higher temporal frequency and satellite sensors with higher spatial resolution. In addition, satellites with better radiometric resolutions, such as NOAA have been used successfully for snow mapping (Hall et al., 1995). This is possibly due to the distinct spectral reflectance characteristics of snow in visible and near infrared regions. India has launched series of Indian Remote Sensing satellite (IRS) to study the different earth resources. Previously launched satellites have flown with many sensors having different spatial, temporal and spectral resolutions. Recently launched RESOURCESAT-1 satellite has three different sensors namely LISS III, LISS IV & AWiFS with different spatial, temporal and spectral resolutions as desired for different applications. AWiFS (Advanced Wide Field Sensor) is an advanced version of earlier Indian satellite sensor WiFS (Wide Field Sensor) with improved spectral and spatial resolutions maintaining the same repetivity. There are a series of other polar orbiting satellites, like Landsat, NOAA and MODIS etc., which have provided information on different aspects of

snow. Geo-stationary satellites also proved their utility in mapping/monitoring the snow-covered regions. Information generated from satellite observations has been extensively used for snowmelt runoff modeling (Kulkarni et al., 1997).

2. Study Area:

This Atlas gives distribution of snow cover in three sub-basins of the Ganga basin. These are Alaknanda, Bhagirathi and Yamuna sub basins. Locations of these basins are shown in Figure 1.

3. Data used:

AWiFS data from October 2011 to June 2012 were used in this study.

4. Normalised Difference Snow Index (NDSI):

In general, the reflectance of snow is high at the red end of the visible spectrum. It tends to decline in the near-infrared region until 1090 nm, where slight gain in reflectance occurs and gives a minor peak at approximately 1090 to 1100 nm. One of the important difficulties in snow cover monitoring is the presence of cloud cover. Cloud has strong reflectivity in visible, NIR and SWIR regions while snow absorbs in SWIR, and this difference can be utilized for snow/cloud discrimination. Normalized Difference Snow Index (NDSI) utilize the normalized ratio of green and SWIR and is used as an automated approach for snow mapping addressing the shadow and cloud problems in snow bound areas.

Normalized Difference Snow Index was calculated using the ratio of green wavelength (band 2) and SWIR (band 5) of AWiFS sensor:

$$Normalized\ Difference\ Snow\ Index\ (NDSI) = (band\,2 - band\,5)/(band\,2 + band\,5) \qquad ..(1)$$

To estimate NDSI, DN numbers 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. Various parameters needed for estimating spectral reflectance are maximum and minimum radiances and mean solar exo-atmospheric spectral irradiances in the satellite sensor bands, satellite data acquisition time, solar declination, solar zenith and solar azimuth angles, mean Earth-Sun distance etc. (Markham and Barker, 1987; Srinivasulu and Kulkarni, 2004).

5. Snow cover monitoring algorithm

An algorithm is developed to provide changes in the areal extent of snow (Kulkarni et. al., 2006). Snow extent is estimated at an interval of 5-days and 10-days, depending upon availabilities of AWiFS data. In 5-daily product, snow extent is generated scene-wise. In this product, snow and cloud extents are given. Estimate of cloud is important because, at times, snow is covered by cloud and this may be classified as non-snow area, leading to erroneous conclusions. In 10-daily product, three scenes are analyzed, if available. For example, 10 March product data of 5, 10 and 15 March was used. If any pixel is identified as snow on any one date then this pixel will be classified as snow on final product. This provides snow cover at an interval of 10 days, an important requirement in hydrological applications. Therefore, this product is generated basin-wise. Since this product is using three scenes, probability becomes high that at least in one scene, pixel may be cloud-free and this helps in overcoming problem associated with snow under cloud cover. If three consecutive scenes are not available, then all available scenes in 10 days window was used in the analysis. Differentiation between water and snow is difficult using NDSI image. In addition, separation of snow and water pixels is also difficult based on reflectance due to mountain shadow. Therefore, in the present algorithm, water bodies are marked in pre-winter season and are masked in the final products during winter. Flow diagram of the algorithm is given in Figure 2.

6. Results and discussions

In this atlas, basin-wise snow cover statistics, maps, and seasonal depletion curves have been provided from October 2010 to June 2011. Snow ablation pattern varies from basin to basin, depending on area altitude distribution in the basins. There is not much snow fall was observed in all the basins from October to end of December. Maximum snow was observed in the month of January and minimum was in the month November end to mid of December. Ablation starts from middle of March for the three basins.

Acknowledgements

References

Agarwal, K. G., Kumar, V. and T. Das, 1983, Melt runoff for a subcatchment of Beas basin. In Proceedings of the First National Symposium on Seasonal Snow Cover, New Delhi, India, April 28-30, 43 p.

Foster, J. L. and Chang, A. T. C., 1993, Snow cover, in Atlas of satellite observations related to global change. R. J. Gurney, C.L. Parkinson and J. L. Foster (eds.), Cambridge University Press, Cambridge, pp. 361-370.

Hall, D. K., Riggs, G. A. and Salomonson, V. V., 1995, Development of methods for mapping global snow cover using moderate resolution Image Spectroradiometer data. Remote Sensing of Environment, 54, pp. 127-140.

Kulkarni, A. V., Mathur, P., Rathore, B. P., Alex, S., Thakur N. and Kumar, M. 2002, Effect of global warming on snow ablation pattern in the Himalayas. Current Science, 83(2), pp 120-123.

Kulkarni A. V., Singh, S. K., Mathur, P. and Mishra, V. D., 2006, Algorithm to monitor snow cover using AWiFS data of RESOURCESAT for the Himalayan region. International Journal of Remote Sensing, 27(12), pp 2449-2457.

Kulkarni, A. V., Randhawa, S. S. and Sood, R. K., 1997, A stream flow simulation model in snow covered areas to estimate hydro-power   potential: a case study of Malana nala, H.P. Proc. of the First international Conference on Renewable Energy- Small Hydro, Hyderabad, pp 761-770.

Markham, B. L. and Barker, J. L., 1987, Thematic Mapper bandpass solar exoatmospheric irradiances. International Journal of Remote Sensing, 8(3), pp 517-523.

Singer, F. S. and Popham, R. W., 1963. Non-meteorological observations from satellite. Astronautics and Aerospace Engineering 1(3), 89-92.

Srinivasulu, J. and Kulkarni, A. V., 2004, A satellite based spectral reflectance model for snow and glacier studies in the Himalayan terrain. Proceedings of the Indian Academy of Science (Earth and Planetary Science), 113 (1), pp. 117-128.
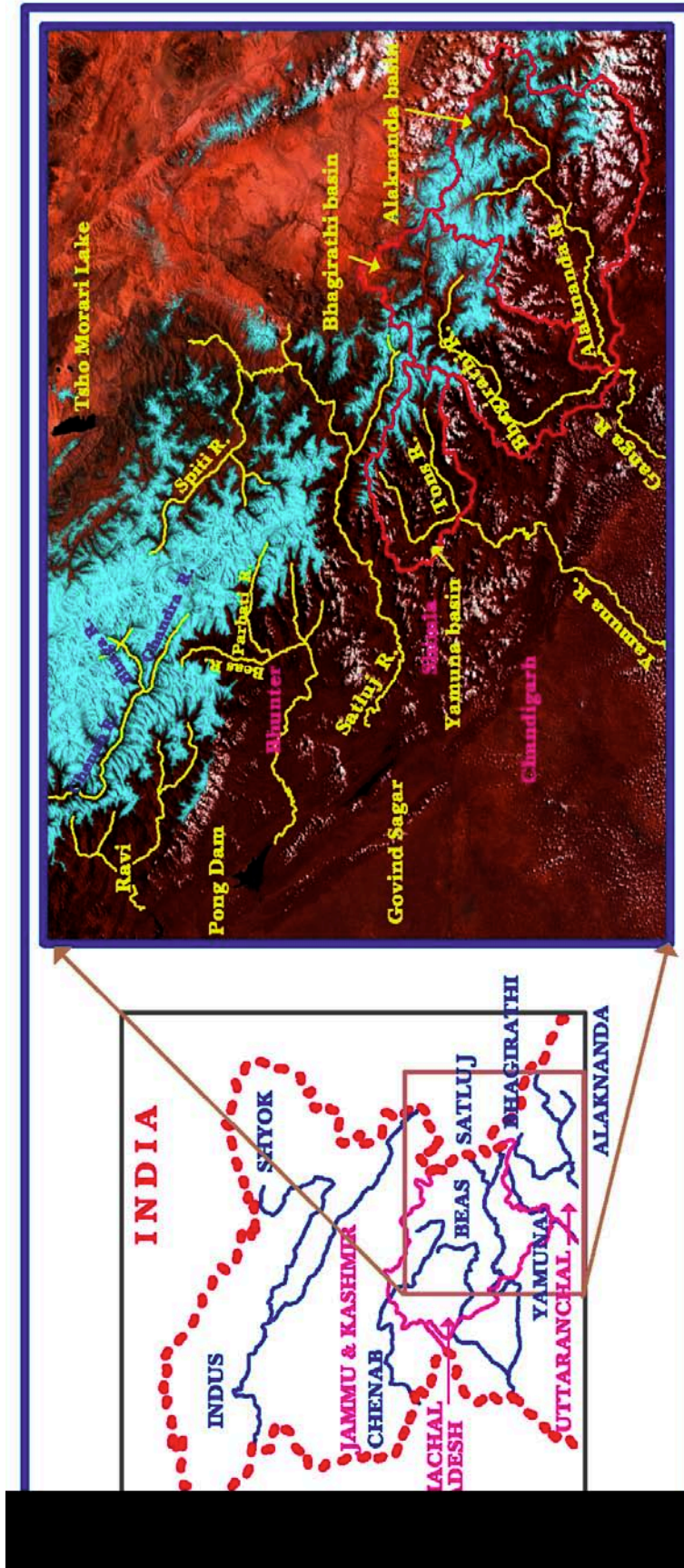
Figure 1: Location map of Alaknanda, Bhagirathi and Yamuna sub-basins (Part of Ganga basin)

```
┌──────────┐              ╭───────────────╮
│ AWiFS    │─────────────▶│  Reflectance  │
│ B2 AND B5│              │  image        │
└──────────┘              ╰───────────────╯
                                  │
                                  ▼
                          ╭───────────────╮
                          │  NDSI IMAGE   │
                          ╰───────────────╯
              ┌────────────┬───────┬──────────────┐
            > 0.4       < 0.4   >0              < 0
              │            │                      │
              ▼            ▼                      ▼
         ┌─────────┐  ┌─────────┐          ┌─────────┐
         │ Snow +  │  │ Cloud   │          │ Other   │
         │ Water   │  │ Pixel   │          │ Pixel   │
         └─────────┘  └─────────┘          └─────────┘
                                                │  N-5 days
                                                ▼
                                      ┌──────────────────┐
┌──────────┐                          │ AWiFS B2 and B5  │
│ AWiFS B4 │                          └──────────────────┘
└──────────┘                                   │
     │                                         ▼
     ▼                                 ╭──────────────────╮
╭──────────────╮                       │   NDSI IMAGE     │
│ Reflectance  │        ┌──────────┐   ╰──────────────────╯
│ Image        │        │ AWiFS B4 │─────▶│           │
╰──────────────╯        └──────────┘      ▼           ▼
     │                               ┌─────────┐  ┌─────────┐
     ▼                               │ Snow    │  │ Non-    │
┌─────────────┐                      └─────────┘  │ Snow    │
│ Water pixel │──────────▶                        └─────────┘
└─────────────┘                                        │ N+5 days
                                                       ▼
                   ┌─────────┐              ┌──────────────────┐
                   │ Snow    │              │ AWiFS B2 and B5  │
                   └─────────┘              └──────────────────┘
                        │        ┌──────────┐        │
                        ▼        │ AWiFS B4 │        ▼
         ┌────────────────────┐  └──────────┘  ╭──────────────────╮
         │ SNOW AND CLOUD MAP │   ┌─────────┐  │   NDSI IMAGE     │
         └────────────────────┘   │ Snow    │◀─╰──────────────────╯
              ┌─────────────┐     └─────────┘        │
              │ Basin Mask  │         │              ▼
              └─────────────┘         ▼        ┌─────────┐
┌────────────────────────────────────┐        │Non-Snow │
│ 10-DAILY BASIN-WISE MAXIMUM SNOW    │        └─────────┘
│ COVER                               │
└────────────────────────────────────┘
```
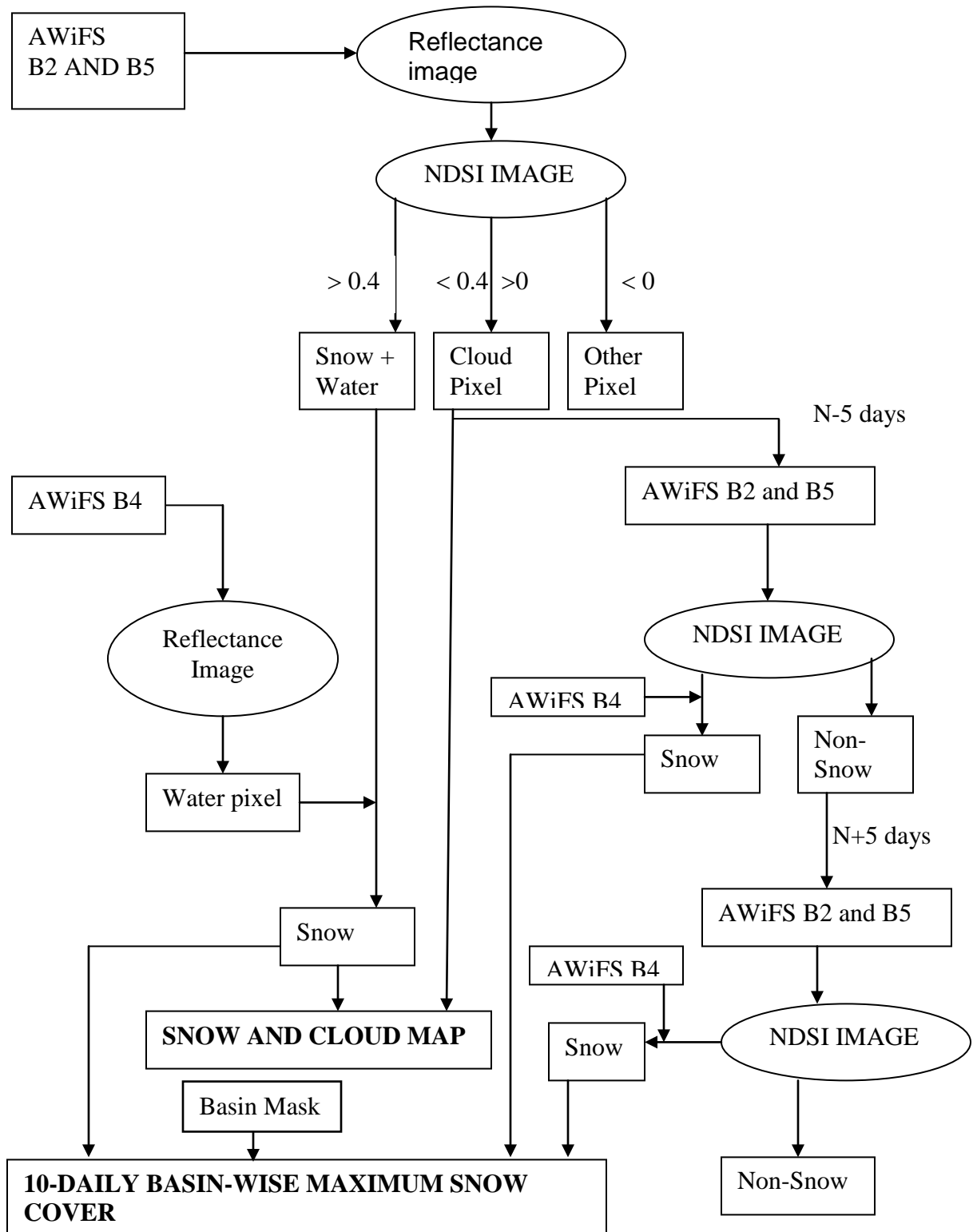
Figure 2: Algorithm for snow cover mapping using AWiFS data

ALAKNANDA BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: ALAKNANDA   **BASIN AREA: 11090 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
**October 2011**
1	03-Oct-2011	1243	11	5	15-Oct-2011	1946	18
2	04-Oct-2011	1222	11	6	25-Oct-2011	2552	23
3	09-Oct-2011	1618	15	7	27-Oct-2011	1731	16
4	10-Oct-2011	1016	9				
**November 2011**
1	02-Nov-2011	1373	12	5	18-Nov-2011	2053	19
2	03-Nov-2011	1420	13	6	20-Nov-2011	1039	9
3	08-Nov-2011	1912	17	7	21-Nov-2011	1118	10
4	13-Nov-2011	2155	19	8	27-Nov-2011	1040	9
**December 2011**
1	02-Dec-2011	2115	19	7	20-Dec-2011	846	7
2	10-Dec-2011	2072	19	8	22-Dec-2011	1198	11
3	14-Dec-2011	1234	11	9	27-Dec-2011	1255	11
4	15-Dec-2011	1929	17				
5	17-Dec-2011	1869	17				
6	19-Dec-2010	2596	23				
**January 2012**
1	02-Jan-2012	968	9	6	24-Jan-2011	7272	66
2	03-Jan-2012	2809	25	7	27-Jan-2011	6110	55
3	10-Jan-2012	7741	70	8	29-Jan-2011	6091	55
4	12-Jan-2012	8830	80	9	31-Jan-2011	4872	44
5	17-Jan-2011	6428	58				
**February 2012**
1	01-Feb-2012	5283	48	7	17-Feb-2012	6860	62
2	03-Feb-2012	6290	57	8	18-Feb-2012	5069	46
3	06-Feb-2012	5263	47	9	22-Feb-2012	6438	58
4	07-Feb-2012	3563	32	10	29-Feb-2012	5676	51
5	10-Feb-2012	6069	55				
6	12-Feb-2012	5829	53				
**March 2012**
1	03-Mar-2012	5528	50	13	19-Mar-2012	5302	48
2	03-Mar-2012	6271	57	14	20-Mar-2012	5182	47

8

3	03-Mar-2012	6215	56	**15**	22-Mar-2012	5324	48
4	07-Mar-2012	6271	57	**16**	24-Mar-2012	4907	44
5	08-Mar-2012	6110	63	**17**	25-Mar-2012	4200	38
6	12-Mar-2012	6220	55	**18**	27-Mar-2012	5363	48
7	12-Mar-2012	5912	53	**19**	29-Mar-2012	4694	42
8	15-Mar-2012	6382	58	**20**	31-Mar-2012	4951	45
9	19-Mar-2012	5302	48				
10	20-Mar-2012	5182	47				
11	22-Mar-2012	5324	48				
12	24-Mar-2012	4907	44				
April 2012							
1	03-April-2012	5033	45	**8**	18-April-2012	6215	56
2	05-April-2012	6595	59	**9**	19-April-2012	3497	32
3	06-April-2012	3833	35	**10**	20-April-2012	6317	57
4	07-April-2012	3055	28	**11**	24-April-2012	5198	47
5	08-April-2012	4332	39				
6	10-April-2012	7365	66				
7	15-April-2012	8164	74				
May 2012							
1	04-May-2012	5178	47	**7**	16-may-2012	4353	39
2	07-May-2012	4395	40	**8**	23-may-2012	3905	35
3	09-May-2012	4305	39	**9**	26-may-2013	3520	32
4	12-May-2012	3511	32	**10**	28-may-2013	3813	34
5	13-May-2012	4060	37	**11**	30-may-2013	3144	28
6	14-May-2012	4284	39	**12**	31-may-2013	2898	26
June 2012							
1	02-June-2011	3129	28	**7**	18-June-2011	2009	18
2	04-June-2011	2398	22	**8**	19-June-2011	2023	18
3	05-June-2011	2391	22	**9**	23-June-2011	1724	16
4	09-June-2011	1880	17				
5	09-June-2011	1880	17				
6	14-June-2011	1702	15				

AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: ALAKNANDA   **BASIN AREA: 11090 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2011							
1	05-Oct-2011	1219	11	3	25-Oct-2011	1774	16
2	15-Oct-2011	1993	18				
November 2011							
1	05-Nov-2011	1890	17	5	25-Nov-2011	1185	11
3	15-Nov-2011	2188	20				
December 2011							
1	05-Dec-2011	1664	15	6	25-Dec-2011	1304	12
3	15-Dec-2011	998	9				
January 2012							
1	10-Jan-2012	7920	71	3	25-Jan-2012	7319	66
February 2012							
1	07-Feb-2012	6099	55				
March 2012							
1	05-Mar-2012	6321	57	6	25-Mar-2012	5768	52
2	15-Mar-2012	6210	56				
April 2012							
1	05-Apr-2012	4880	44				
May 2012							
1	5-May-12	4395	40	2	25-May-12	3882	35
2	15-May-12	4246	38				
June 2012							
1	05-June-12	3105	28				

* Whole Alaknanda basin is not covered

Snow cover depletion curve

ALAKNANDA BASIN (5 DAILY) : WITH CLOUDY DATA

ALAKANANDA BASIN (5 DAILY) : WITHOUT CLOUDY DATA

Snow cover depletion curve
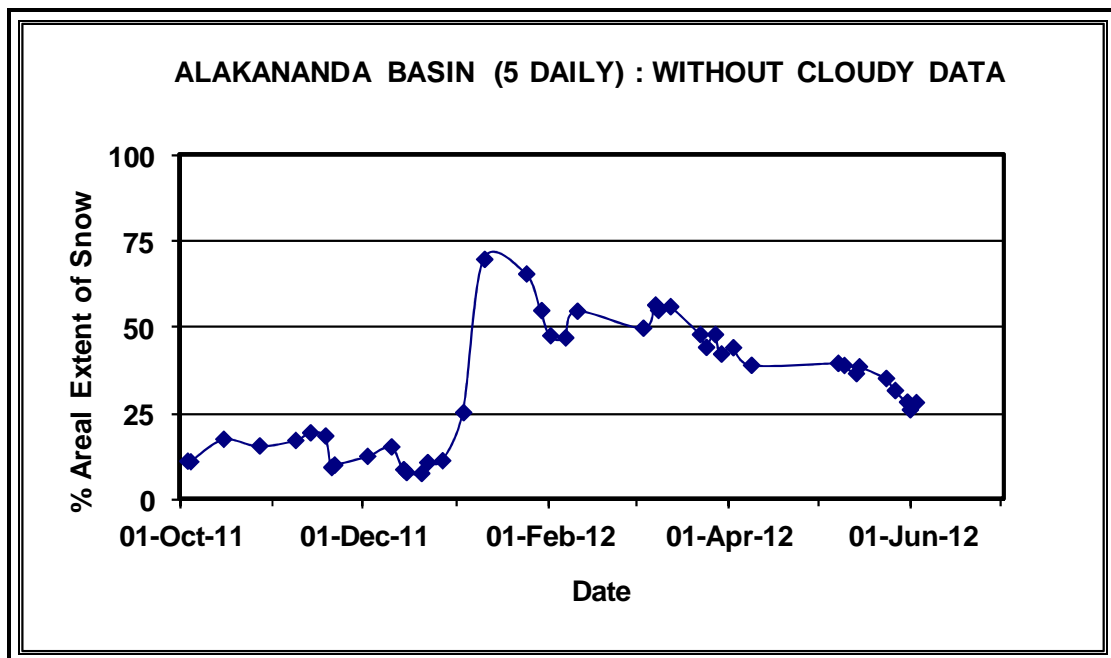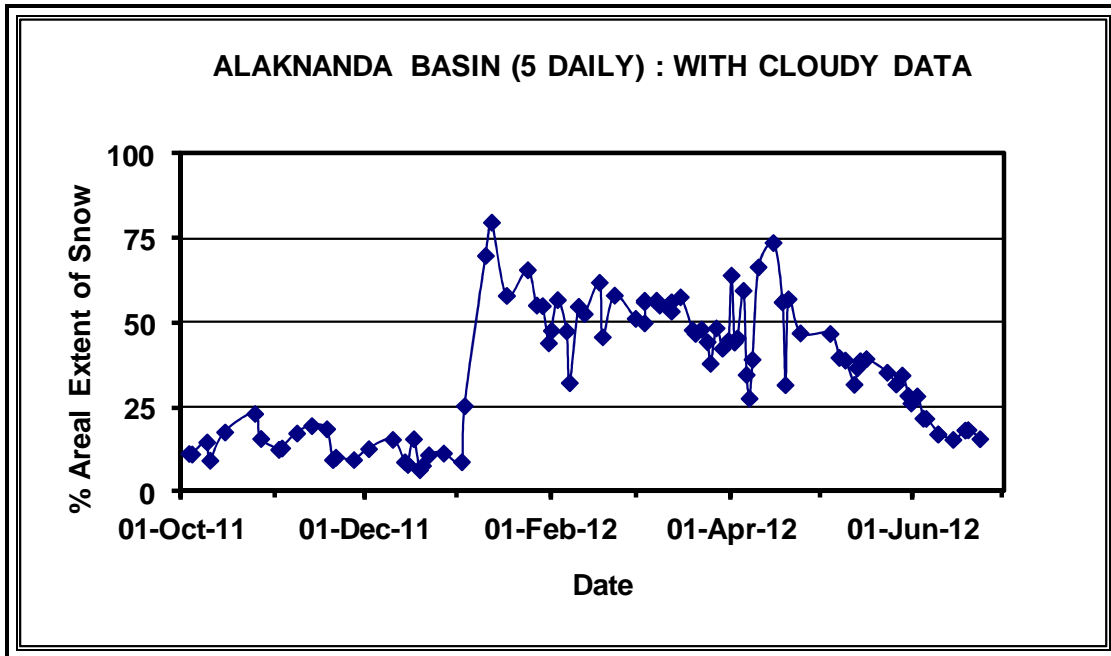
ALAKNANDA BASIN (10 DAILY)
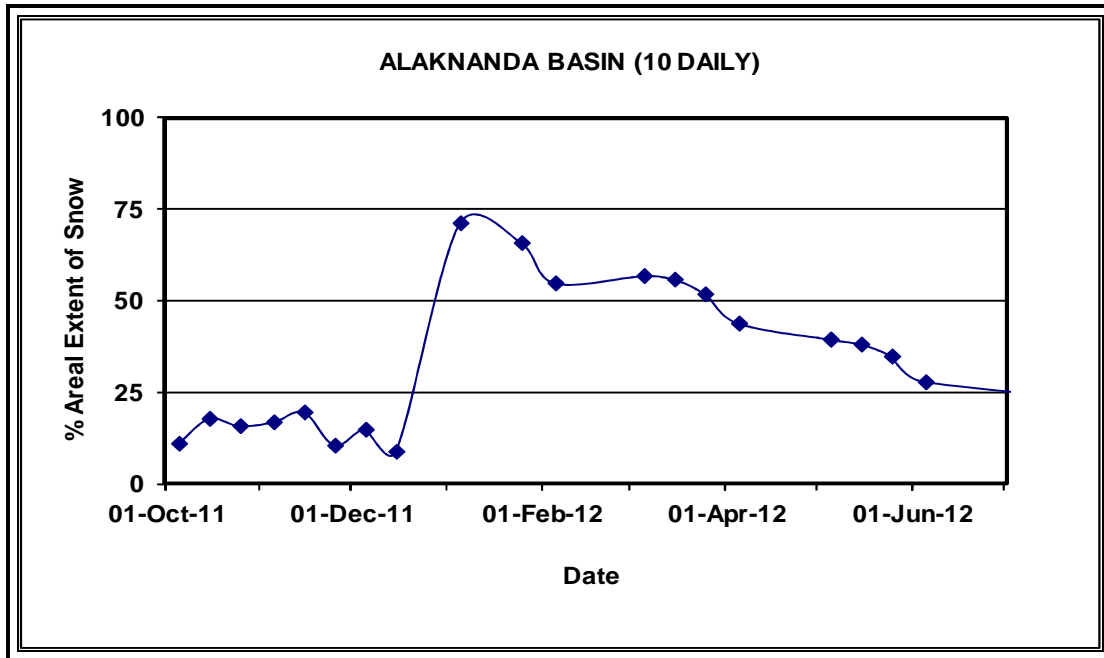
SNOW COVER MAP

SNOW COVER MAP : ALAKNANDA BASIN
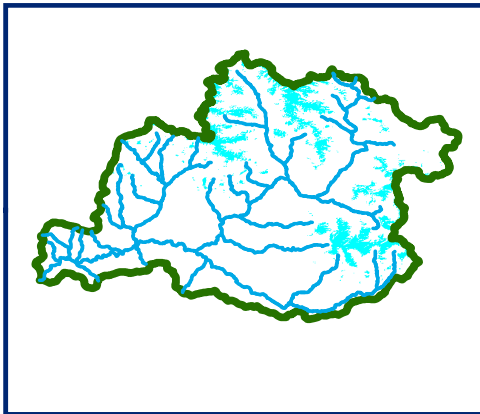
CLOUDY DATA

04 OCT 2011
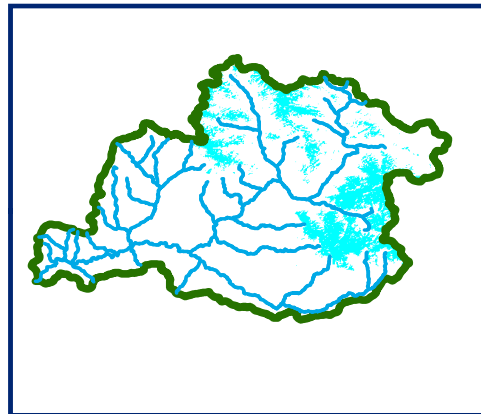
09 OCT 2011
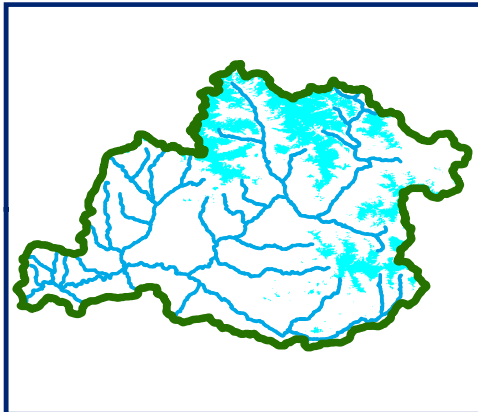
15 OCT 2011
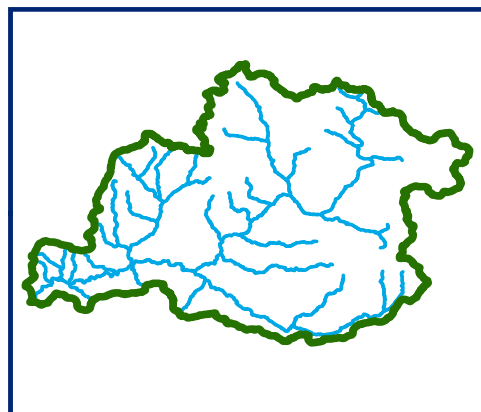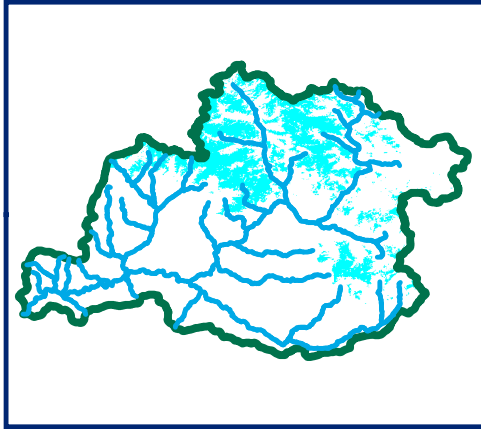
DATA NOT AVAILABLE
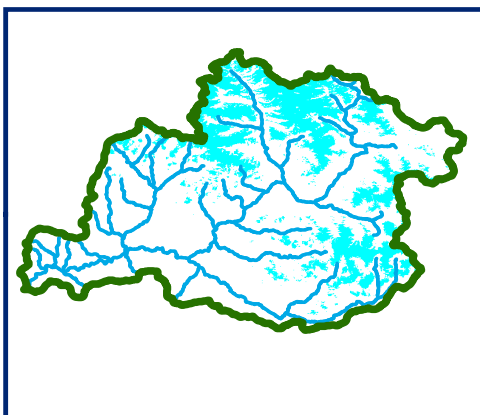
CLOUDY DATA

25 OCT 2011

27 OCT 2011

SNOW

0 20 40   80   120   160
Kilometers
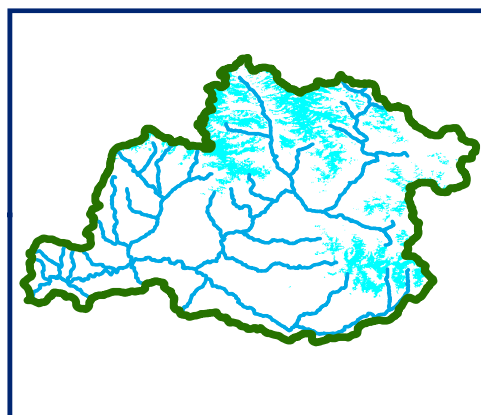
10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
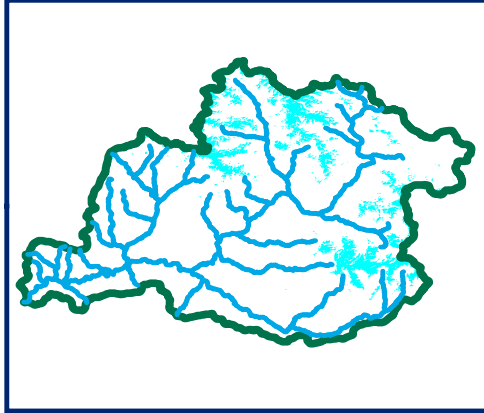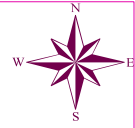
DATA USED

04 OCTOBER 2011
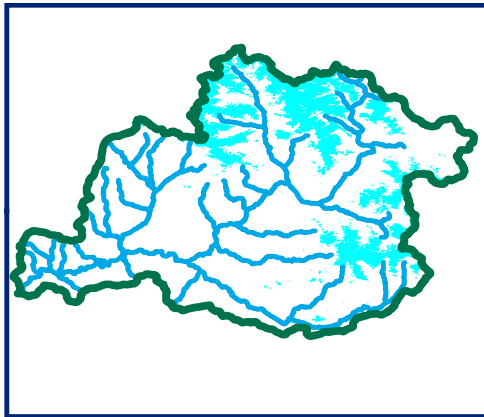
DATA USED
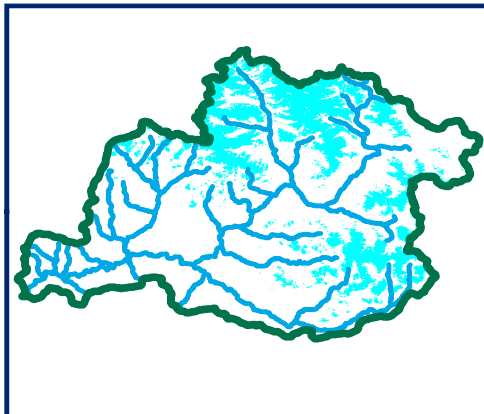
15 OCTOBER 2011

DATA USED

25 OCTOBER 2011

SNOW

0   20   40   80   120   160
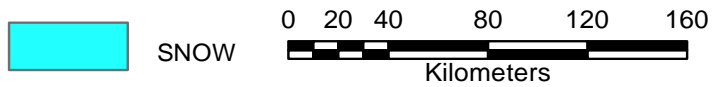
Kilometers

SNOW COVER MAP   :   ALAKNANDA BASIN

CLOUDY DATA
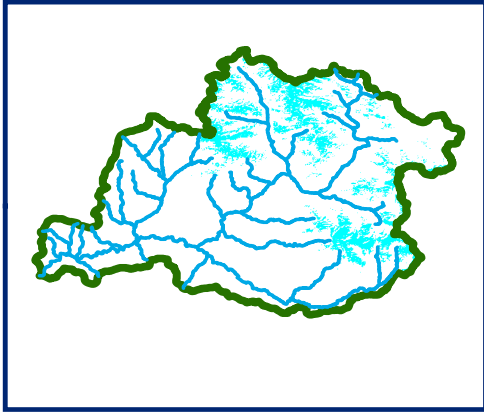
02 NOV 2011
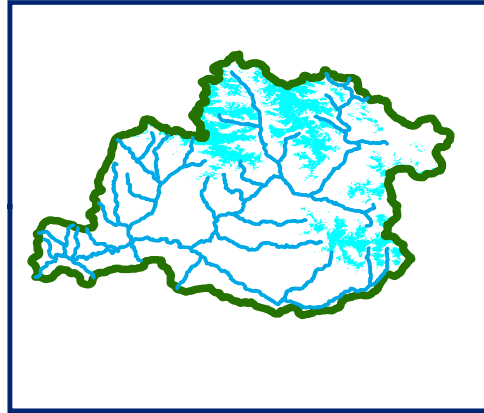
08 NOV 2011
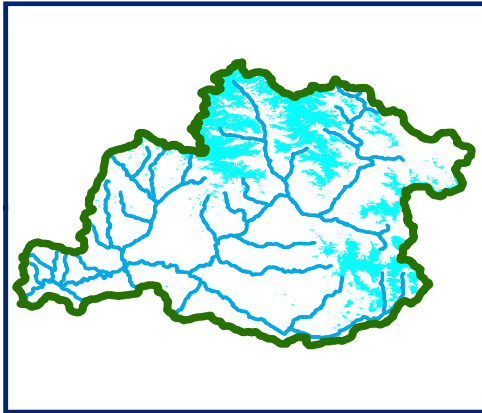
13 NOV 2011
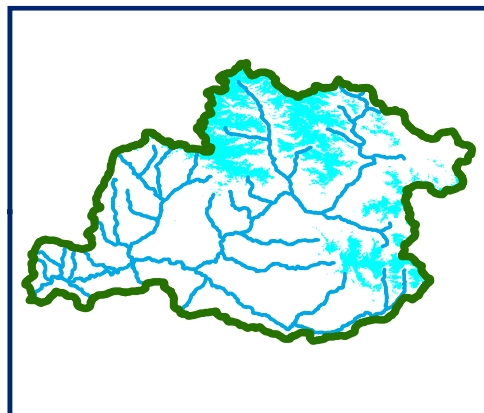
18 NOV 2011
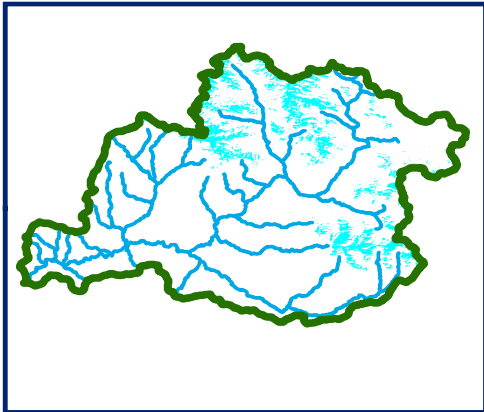
21 NOV 2011
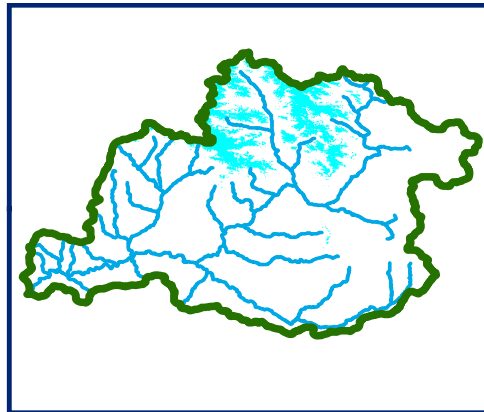
27 NOV 2011

SNOW

0 20 40   80   120   160
Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
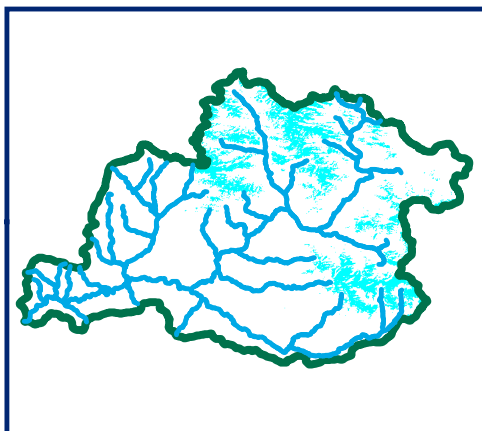
DATA USED
02 NOVEMBER 2011
03 NOVEMBER 2011
08 NOVEMBER 2011
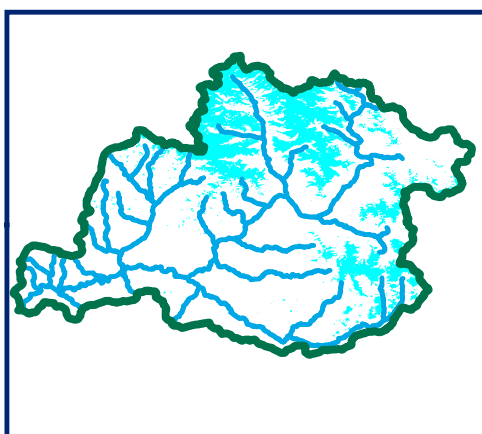
DATA USED
13 NOVEMBER 2011
18 NOVEMBER 2011

DATA USED
21 NOVEMBER 2011
27 NOVEMBER 2011

```
0   20  40      80      120     160
```
Kilometers
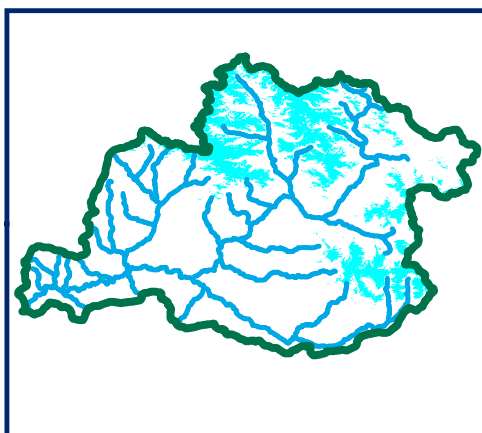
SNOW

SNOW COVER MAP   :   ALAKNANDA BASIN
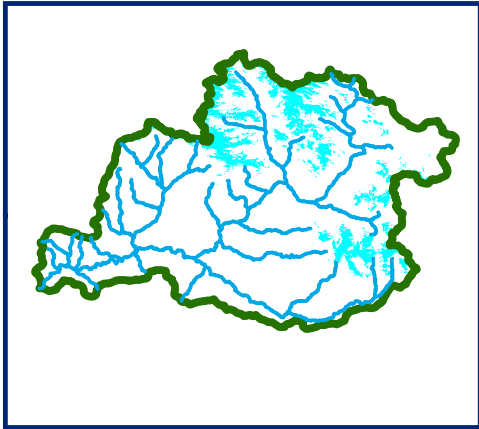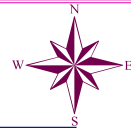
02 DEC 2011
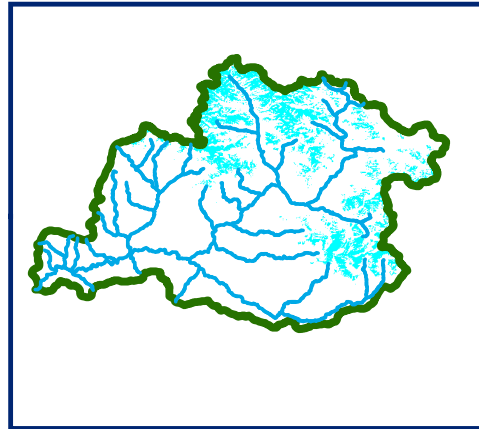
10 DEC 2011
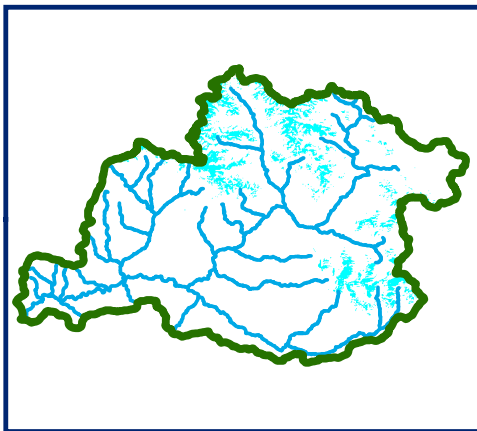
14 DEC 2011
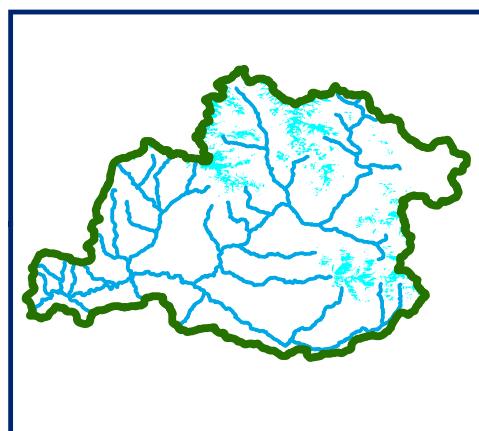
20 DEC 2011

22 DEC 2011

27 DEC 2011

SNOW

0 20 40   80   120   160
Kilometers
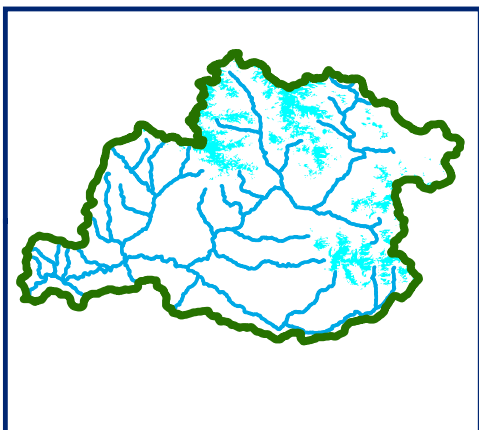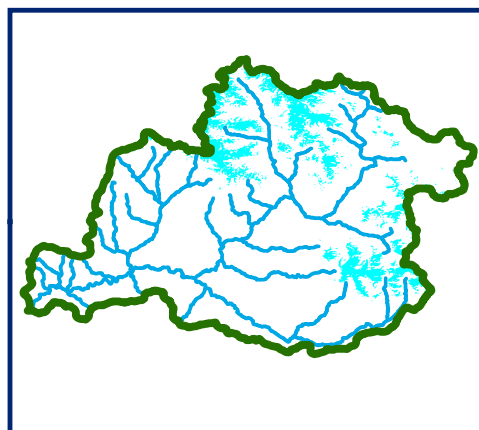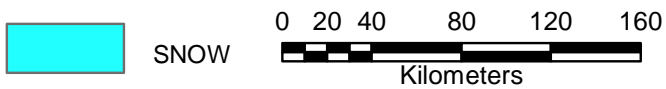
10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
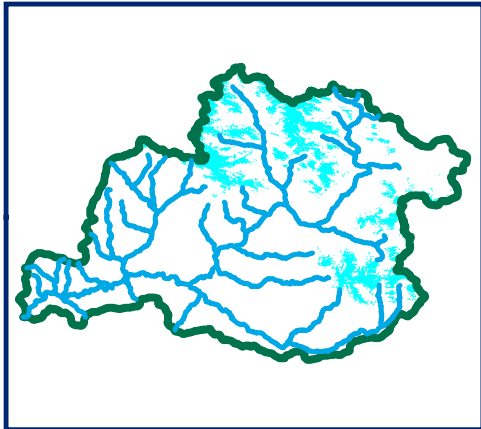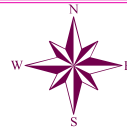
DATA USED
02 DECEMBER 2011
09 DECEMBER 2011
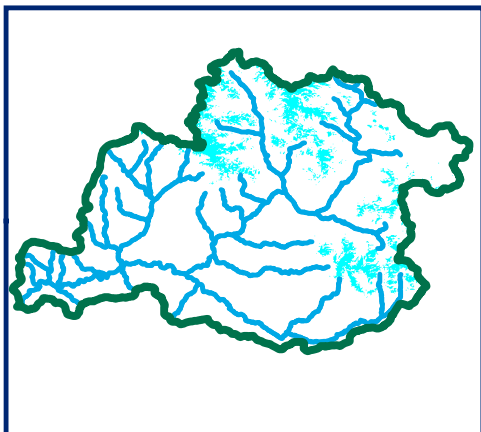
DATA USED

12 DECEMBER 2011

17 DECEMBER 2011

19 DECEMBER 2011

DATA USED

22 DECEMBER 2011
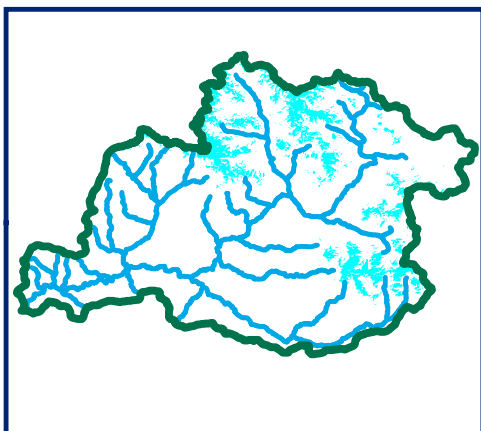
27 DECEMBER 2011

SNOW

0   20 40   80   120   160
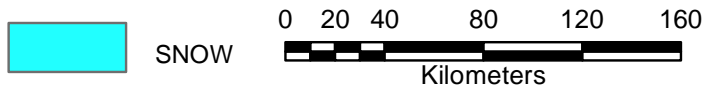
Kilometers

SNOW COVER MAP   :   ALAKNANDA BASIN
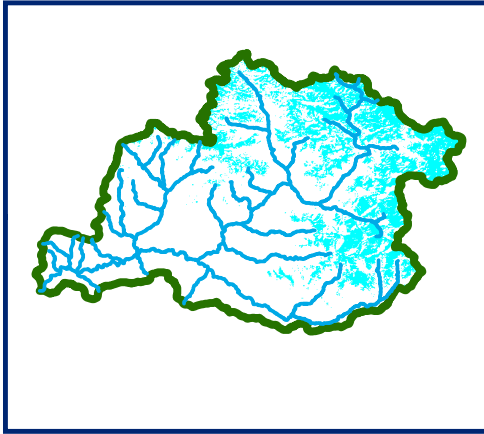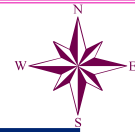
03 JAN 2012
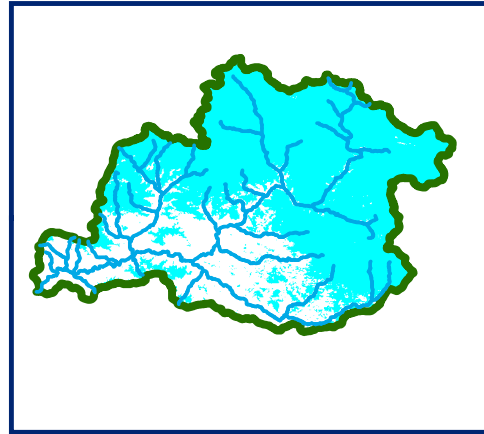
10 JAN 2012
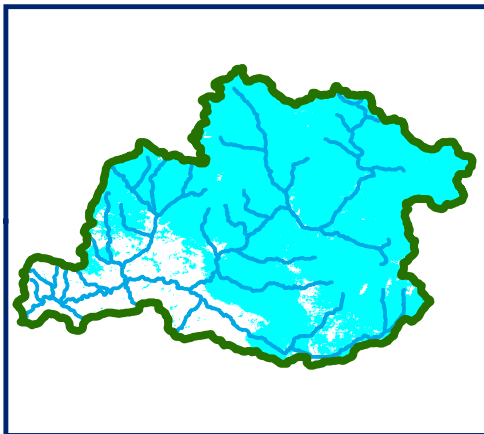
12 JAN 2012
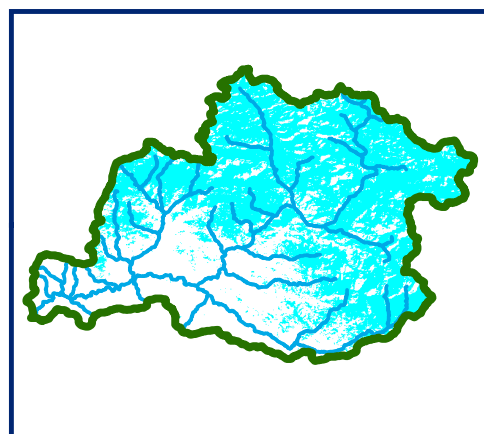
17 JAN 2012
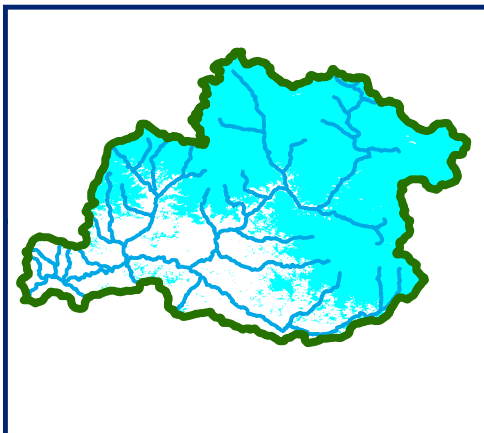
24 JAN 2012
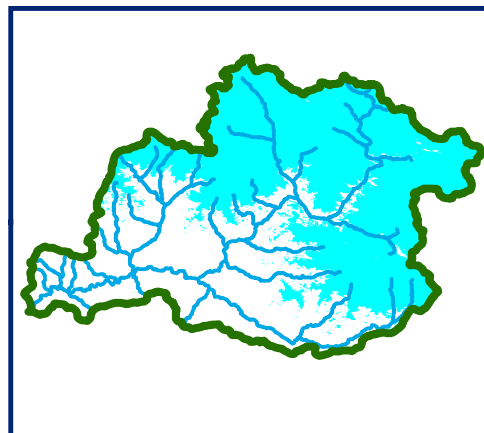
29 JAN 2012

SNOW

0 20 40   80   120   160
Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
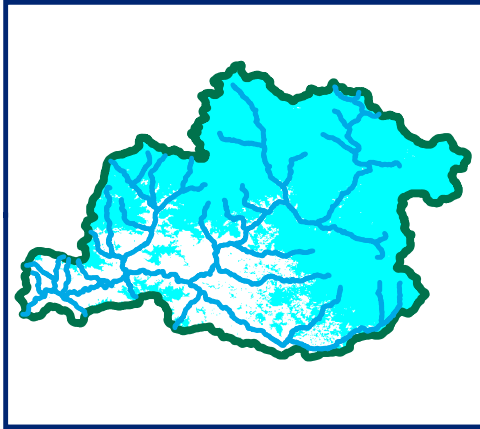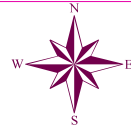
DATA USED

10 JANUARY 2012
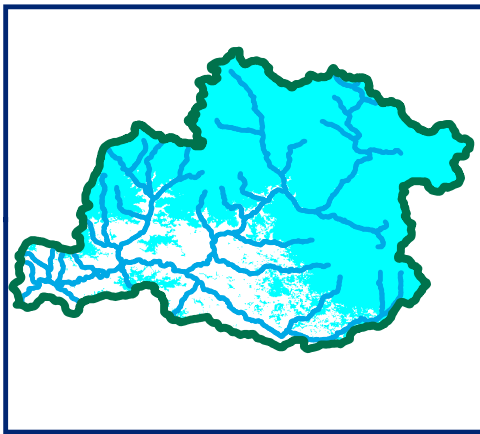
DATA USED

12 JANUARY 2012
14 JANUARY 2012
17 JANUARY 2012
19 JANUARY 2012
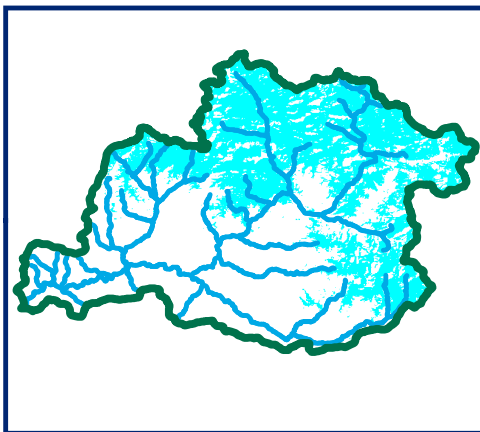
DATA USED

24 JANUARY 2012
27 JANUARY 2012
29 JANUARY 2012
31 JANUARY 2012

SNOW

0   20 40   80   120   160

Kilometers

20

SNOW COVER MAP : ALAKNANDA BASIN
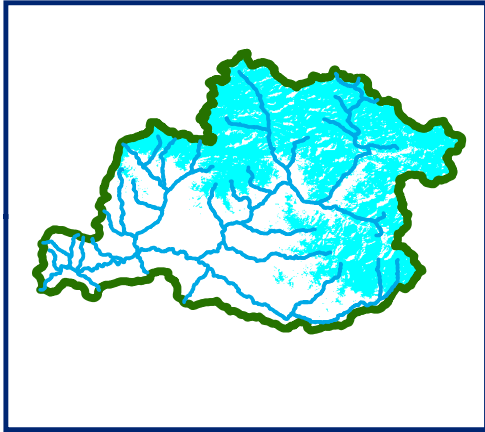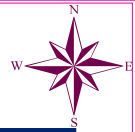
01 FEB 2012
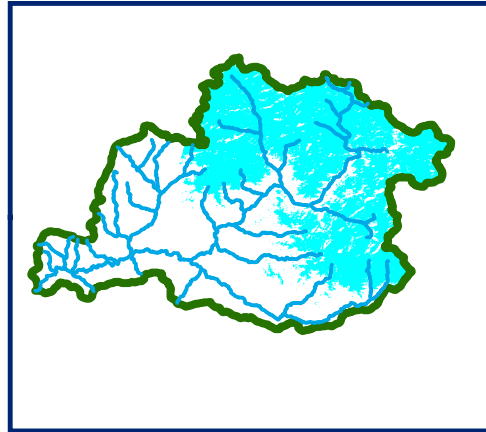
06 FEB 2012
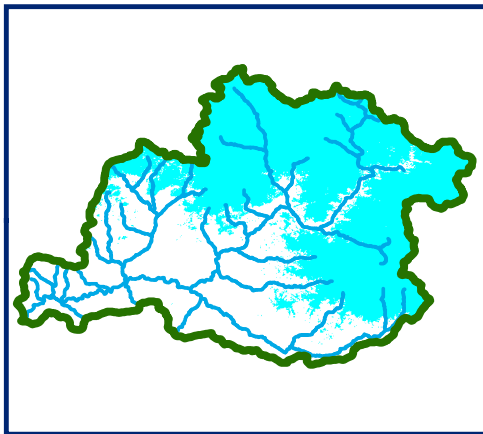
12 FEB 2012
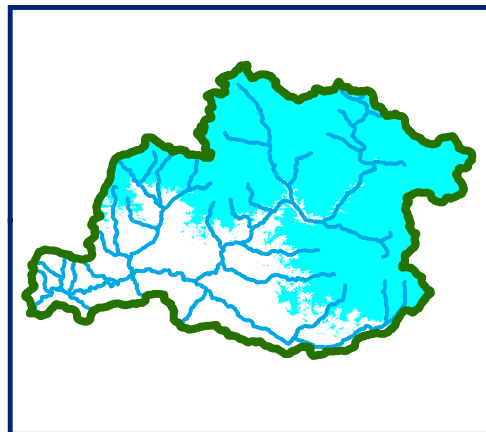
17 FEB 2012
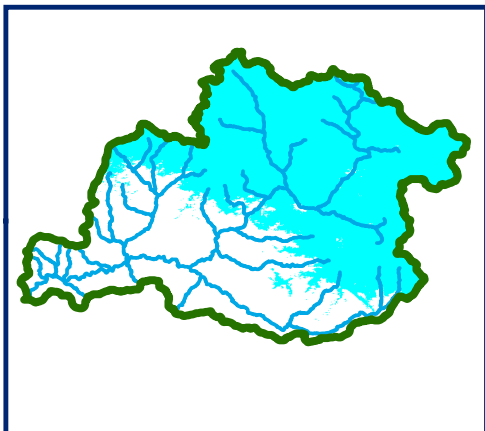
22 FEB 2012
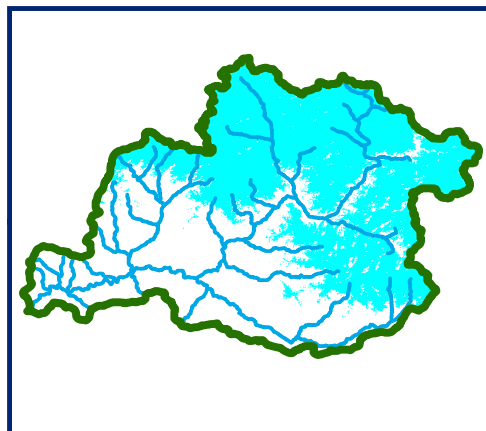
29 FEB 2012

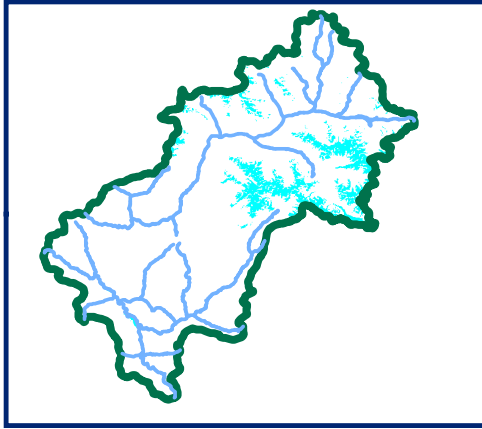SNOW

0 20 40   80   120   160
Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
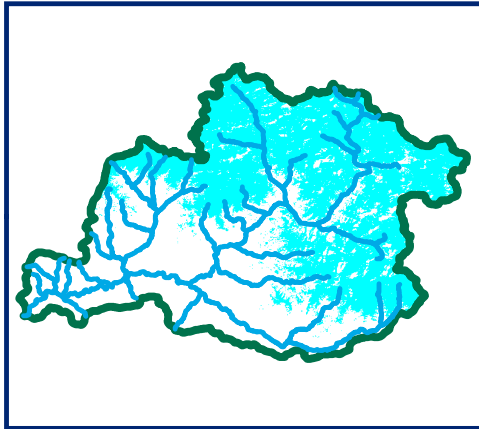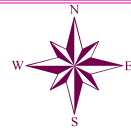
DATA USED

07 FEBRUARY 2012
10 FEBRUARY 2012
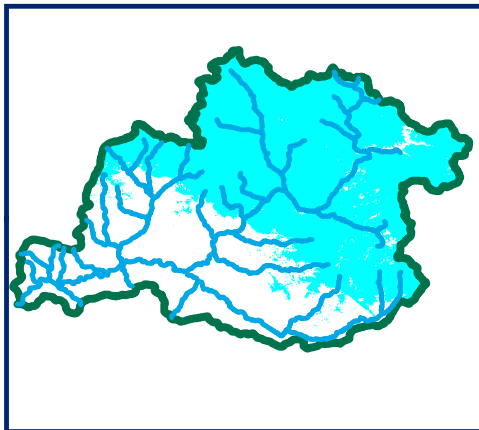
DATA USED

17 FEBRUARY 2012
20 FEBRUARY 2012

DATA USED

DATA NOT AVAILABLE

SNOW

0   20 40   80   120   160

Kilometers

22
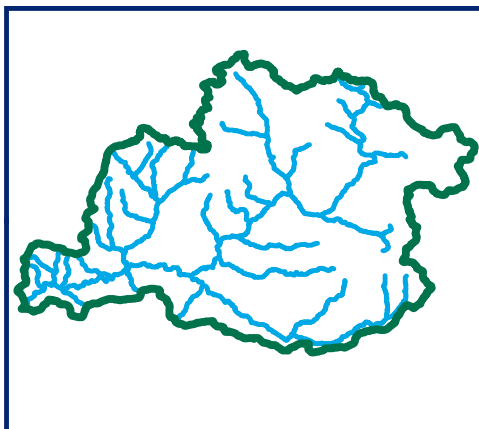
SNOW COVER MAP   :   ALAKNANDA BASIN
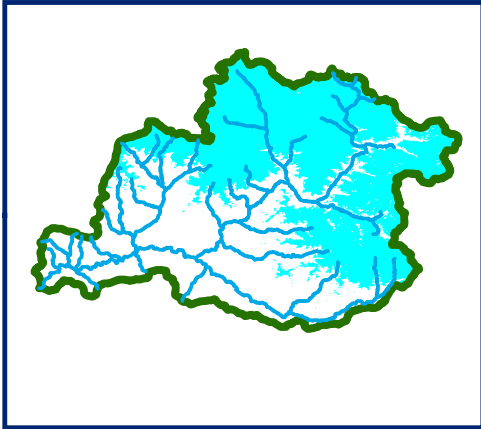
03 March 2012
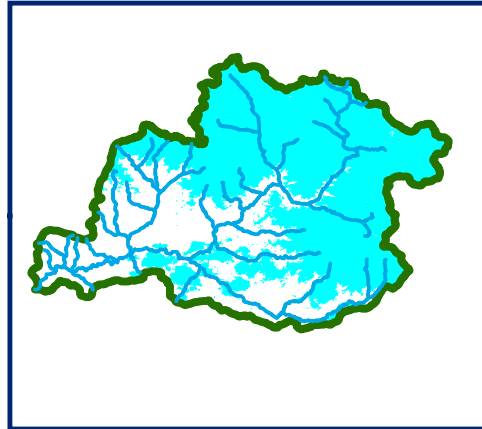
08 MARCH 2012
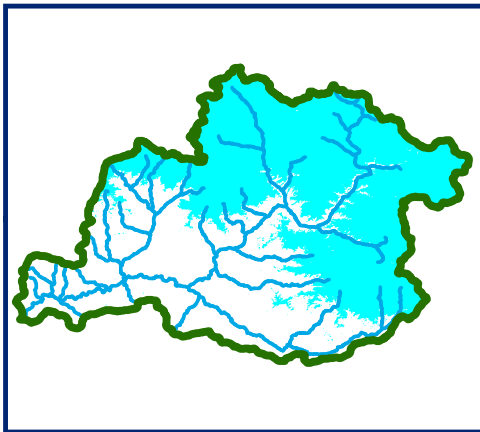
12 MARCH 2012
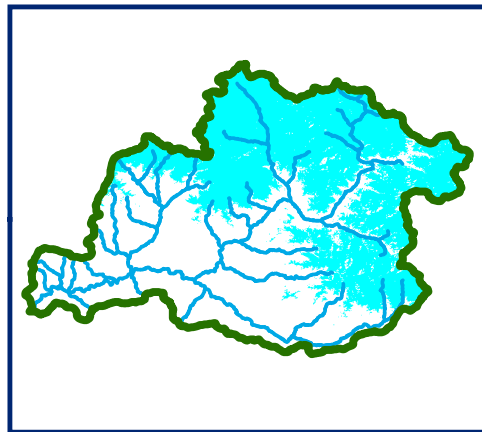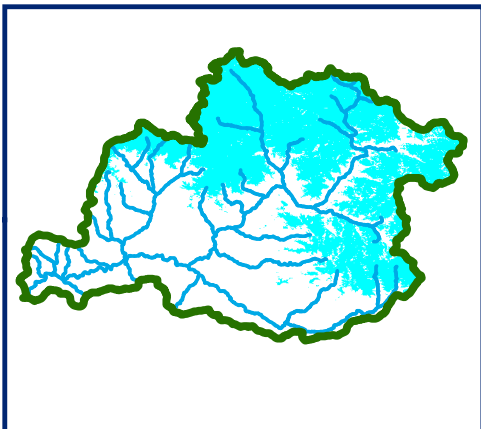
19 MARCH 2012

24 MARCH 2012
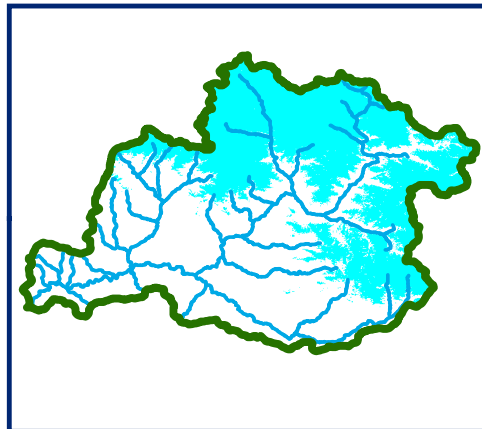
29 MARCH 2012

SNOW

0 20 40   80   120   160
Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
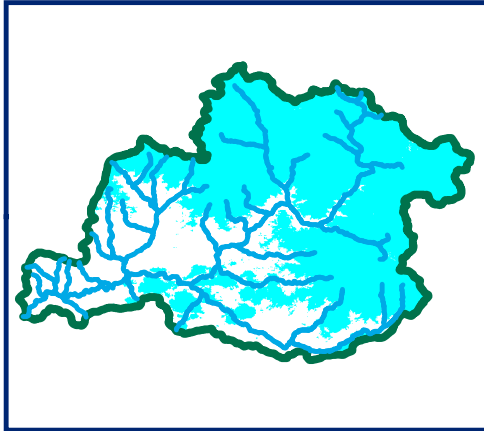
DATA USED
02 MARCH 2012
08 MARCH 2012
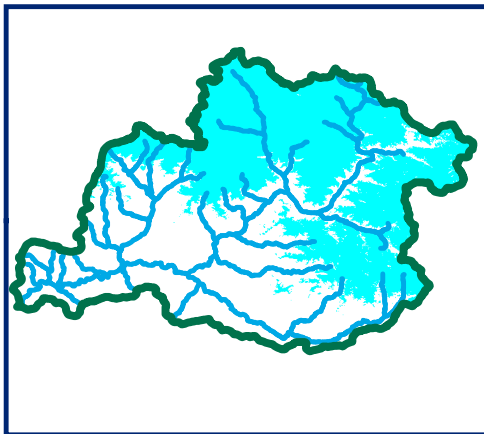
DATA USED

12 MARCH 2012
19 MARCH 2012
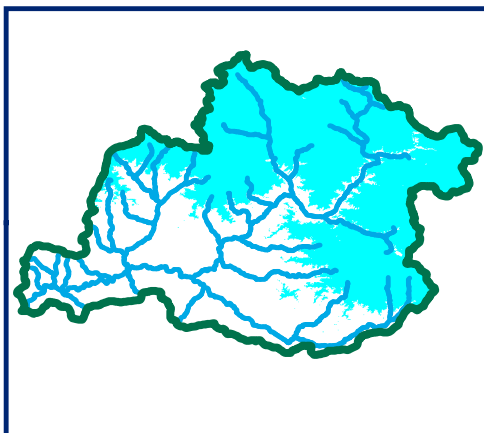
DATA USED

22 MARCH 2012

SNOW

0   20 40   80   120   160

Kilometers

24
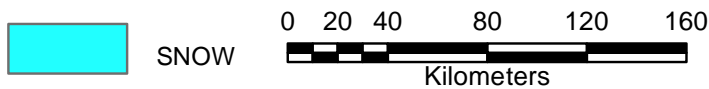
SNOW COVER MAP : ALAKNANDA BASIN
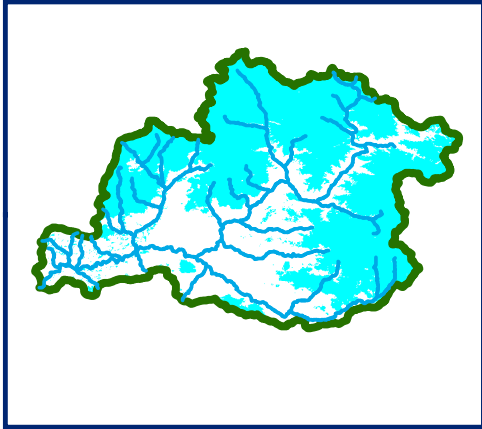
05 APRIL 2012
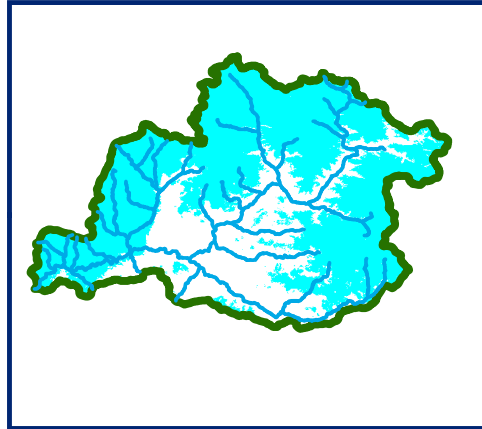
10 APRIL 2012
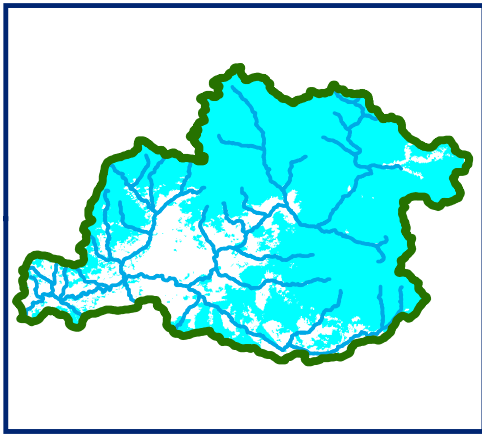
15 APRIL 2012
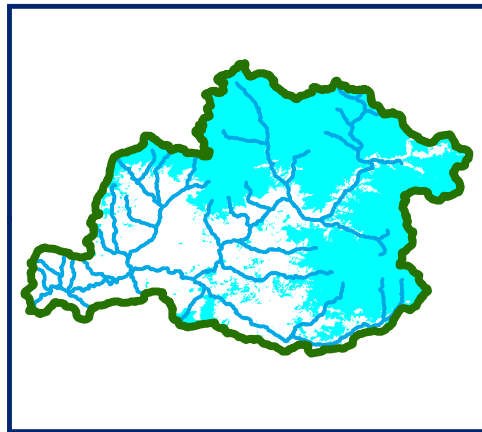
20 APRIL 2012
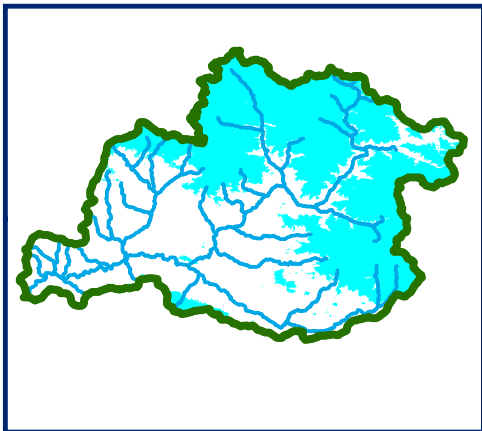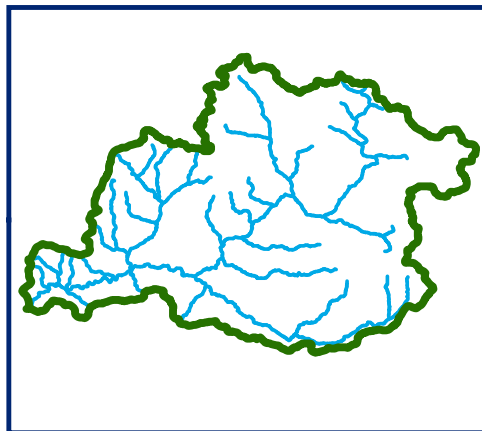
24 APRIL 2012

DATA NOT AVILABLE

SNOW

0 20 40   80   120   160
Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
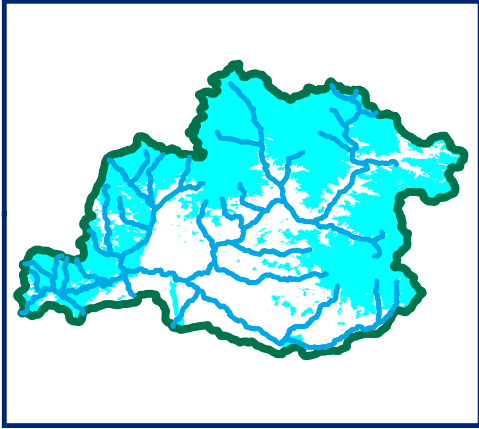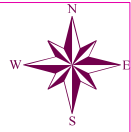
DATA USED

01 APRIL 2012
08 APRIL 2012
10 APRIL 2012
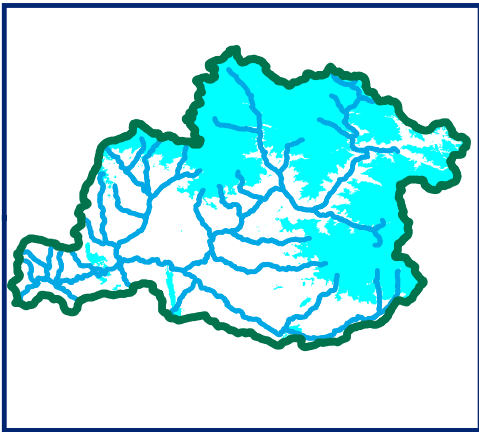
DATA USED

15 APRIL 2012
20 APRIL 2012
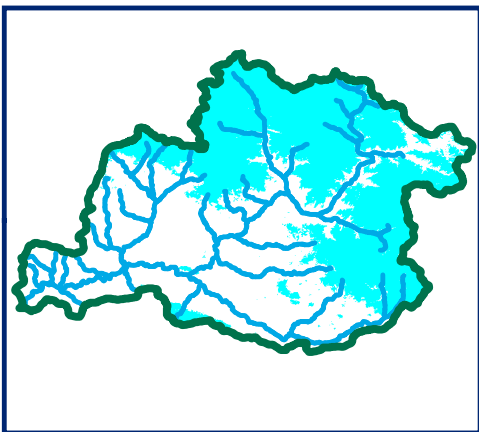
DATA USED

22 APRIL 2012
30 APRIL 2012

SNOW
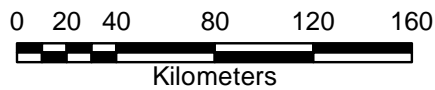
0   20 40   80   120   160

Kilometers

SNOW COVER MAP : ALAKNANDA BASIN
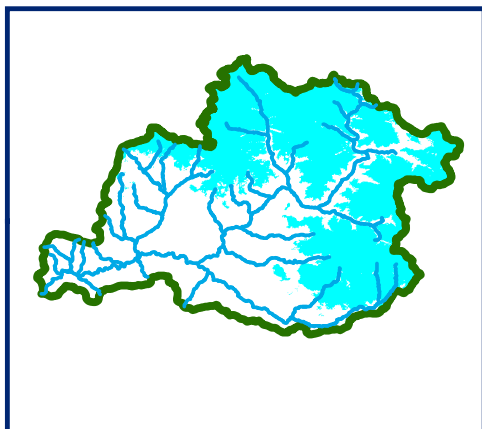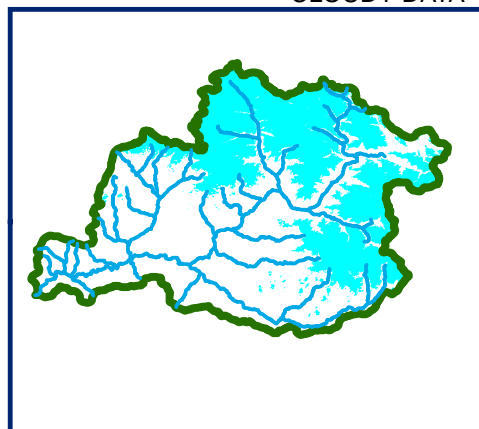
04 MAY 2012

09 MAY 2012
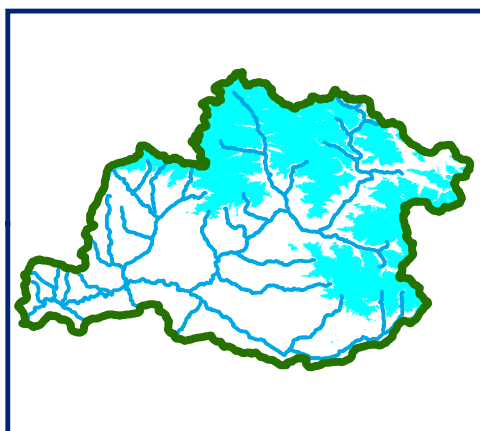
13 MAY 2012
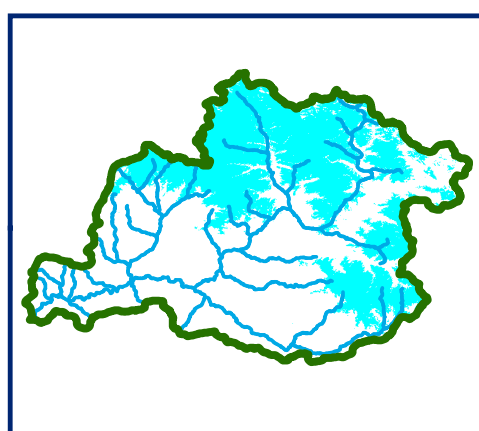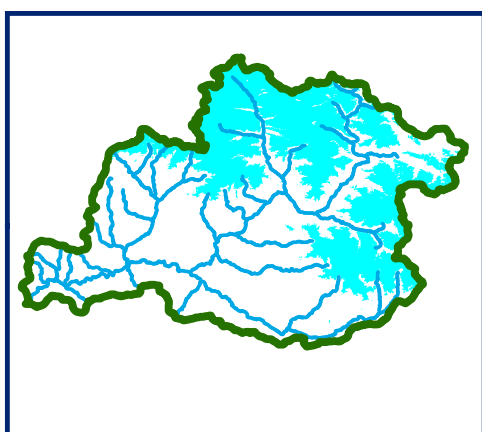
16 MAY 2012

23 MAY 2012
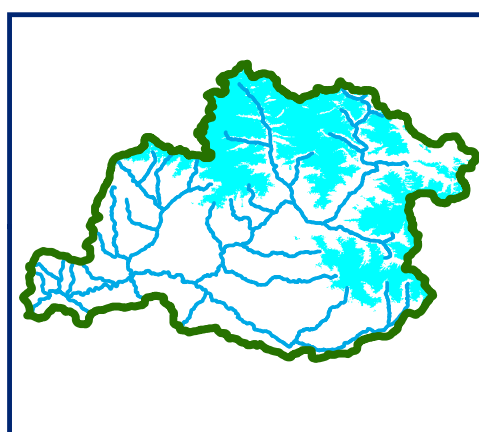
26 MAY 2012

SNOW

0 20 40 80 120 160

Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN
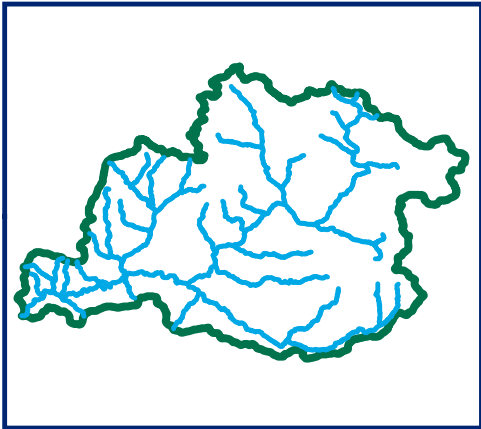
DATA USED

DATA NOT AVAILABLE
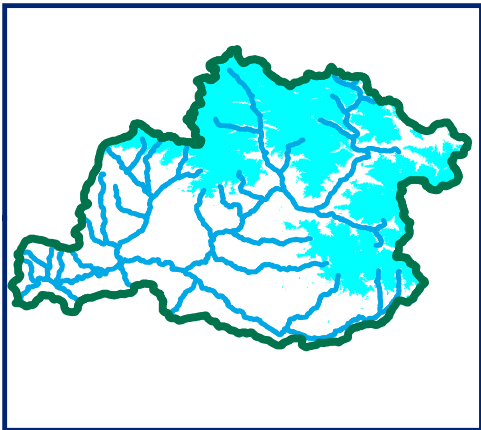
DATA USED

13 MAY 2012
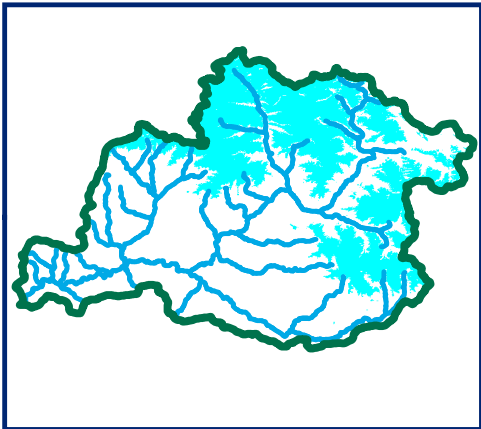
DATA USED

23 MAY 2012

26 MAY 2012

SNOW

0   20   40   80   120   160

Kilometers

28
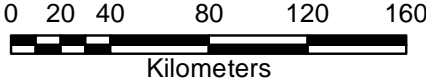
SNOW COVER MAP : ALAKNANDA BASIN
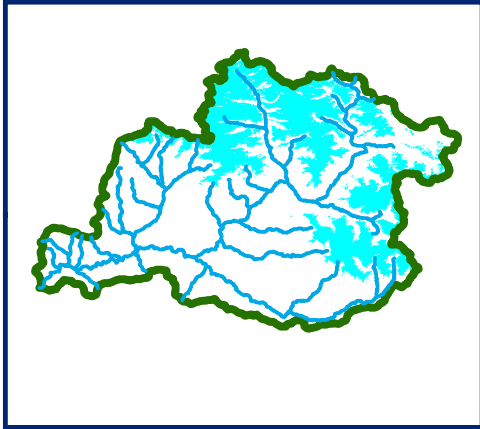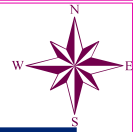
02 JUNE 2012
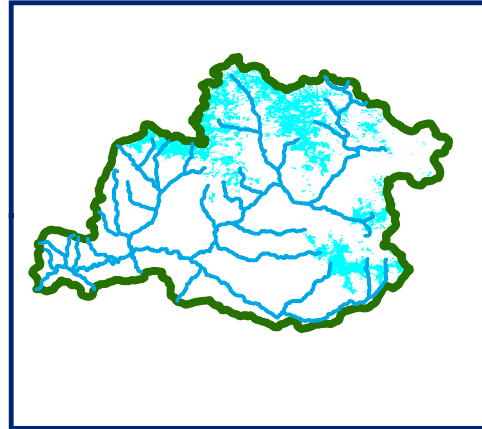
09 JUNE 2012
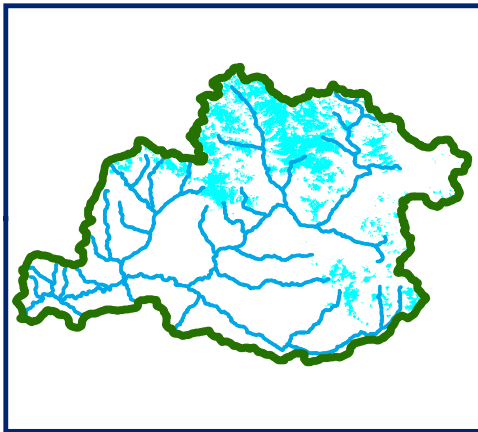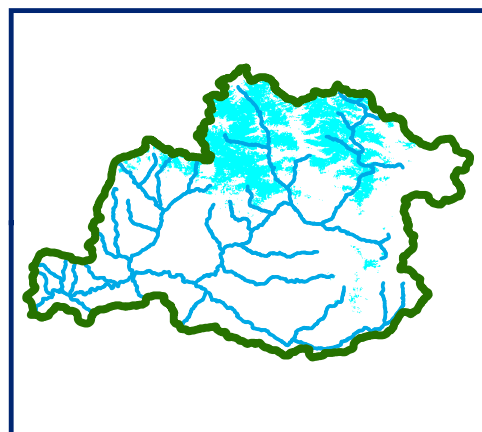
14 JUNE 2012
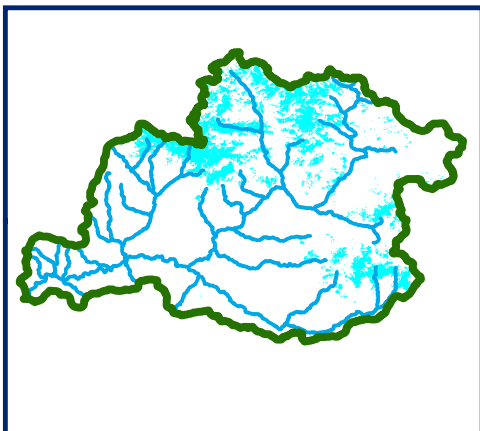
18 JUNE 2012

23 JUNE 2012
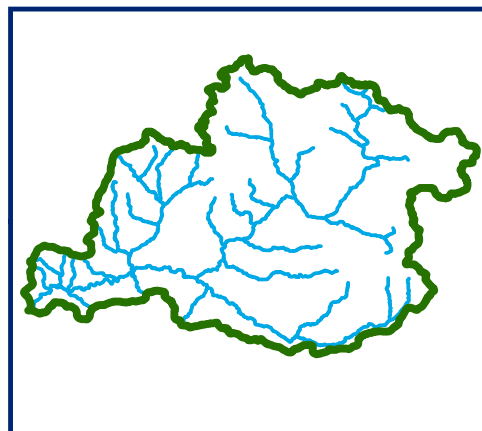
DATA NOT AVAILABLE

SNOW

0 20 40   80   120   160
Kilometers

10 DAILY SNOW COVER MAP: ALAKNANDA BASIN

DATA USED
04 June 2012

DATA USED

14 June 2012

DATA USED

DATA NOT AVAILABLE

SNOW

0   20 40   80   120   160

Kilometers
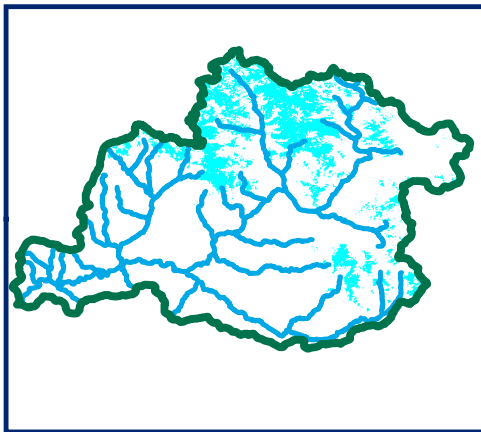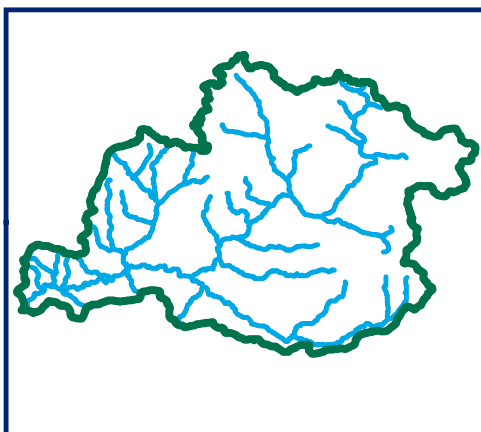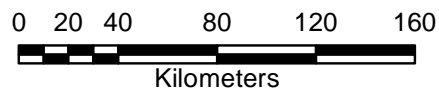
BHAGIRATHI BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: BHAGIRATHI   **BASIN AREA: 7438 Sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2011							
1	01-Oct-2011	1302	18	5	15-Oct-2011	1298	17
2	03-Oct-2011	900	12	5	25-Oct-2011	1562	21
3	04-Oct-2011	650	9	6	27-Oct-2011	1093	15
4	10-Oct-2011	1356	18	7	29-Oct-2011	1087	15
November 2011							
1	03-Nov-2011	1296	18	5	21-Nov-2011	797	11
2	13-Nov-2011	1427	19	6	22-Nov-2011	766	10
3	18-Nov-2011	1392	19	7	27-Nov-2011	892	12
4	20-Nov-2011	753	10				
December 2011							
1	02-Dec-2011	930	13	7	17-Dec-2011	1116	15
2	09-Dec-2011	965	13	8	19-Dec-2011	667	9
3	12-Dec-2011	1254	17	9	21-Dec-2011	1069	14
4	14-Dec-2011	813	11	10	22-Dec-2011	992	13
5	15-Dec-2011	825	11	11	27-Dec-2011	966	13
6	16-Dec-2011	846	11	12	28-Dec-2011	966	13
January 2012							
1	03-Jan-2012	935	13	6	21-Jan-2012	5784	78
2	10-Jan-2012	5892	79	7	27-Jan-2012	4214	57
3	12-Jan-2012	4361	59	8	29-Jan-2012	4206	57
4	14-Jan-2012	5784	78	9	31-Jan-2012	3922	53
5	17-Jan-2012	4685	63				
February 2012							
1	01-Feb-2012	3883	52	6	22-Feb-2012	4218	57
2	03-Feb-2012	4226	57	7	29-Feb-2012	4086	55
3	07-Feb-2012	4189	56	8			
4	10-Feb-2012	4292	58	9			
5	20-Feb-2012	4293	58				
March 2012							
1	03-March-012	3939	53	8	20-March-2012	3888	52
2	08-March-2012	4140	56	9	22-March-2012	3980	54
3	12-March-2012	4167	56	10	24-March-2012	3394	46
4	15-March-2012	4186	56	11	27-March-2012	5050	68
5	19-March-2012	3912	53	12	29-March-2012	3535	48

	April 2012						
1	01-April-2012	5810	78	**7**	15-April-2012	4454	60
2	02-April-2012	3353	45	**8**	19-April-2012	4208	57
3	03-April-2012	3543	48	**9**	20-April-2012	3890	52
4	07-April-2012	3235	43	**10**	22-April-2012	3160	42
5	08-April-2012	3085	41	**11**	24-April-2012	4052	54
6	10-April-2012	5151	69				
	May 2012						
1	02-May-2012	3216	43	**8**	19-May-2012	2642	36
2	04-May-2012	3429	46	**9**	23-May-2012	2587	35
3	06-May-2012	3183	43	**10**	25-May-2012	2555	34
4	07-May-2012	2971	40	**11**	26-May-2012	2323	31
5	13-May -2012	2996	40	**12**	28-May-2012	2441	33
6	16-May-2012	2801	38	**13**	30-May-2012	2262	31
7				**14**	31-May-2012	2160	29
	June 2012						
1	02-June-2012	2265	30	**7**	18-June-2012	1543	21
2	04-June-2012	1842	25	**8**	19-June-2012	1039	14
3	09-June-2012	1508	20	**9**	21-June-2012	1799	24
4	12-June-2012	1913	26	**10**	22-June-2012	1817	24
5	14-June-2012	1341	18	**11**			
6	16-June-2012	1825	25				

AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: BHAGIRATHI　　　　　　　　　　**BASIN AREA: 7438 Sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
			October 2011				
1	03-Oct-2011	1328	18	3	27-Oct-2011	1116	15
2	15-Oct-2011	1298	17				
			November 2011				
1	08-Nov-2011	1296	17	3	21-Nov-2011	892	12
2	18-Nov-2011	1392	19				
			December 2011				
1	02-Dec-2011	930	13	3	22-Dec-2011	1027	14
2	15-Dec-2011	1254	17				
			January 2012				
1	03-Jan-2012	5892	79	3	27-Jan-2012	5784	78
2	17-Jan-2012	5784	78				
			February 2012				
1	01-Feb-2012	4339	58	3	29-Feb-2012	4086	55
			March 2012				
1	03-March-2012	4086	55	3	24-March-2012	3980	54
2	15-March-2012	4205	57				
			April 2012				
1	03-April-2012	3353	45	3	22-April-2012	3160	42
			May 2012				
1	02-May-2012	3225	43	3	30-May-2012	2587	35
2	16-May-2012	2996	40				
			June 2012				
1	02-June-2012	2265	30	3	23-June-2012	1799	24
2	14-June-2012	1904	26				

Snow cover depletion curve

BHAGIRATHI BASIN (5 DAILY) : WITH CLOUDY DATA

BHAGIRATHI BASIN (5 DAILY) : WITH CLOUDY DATA
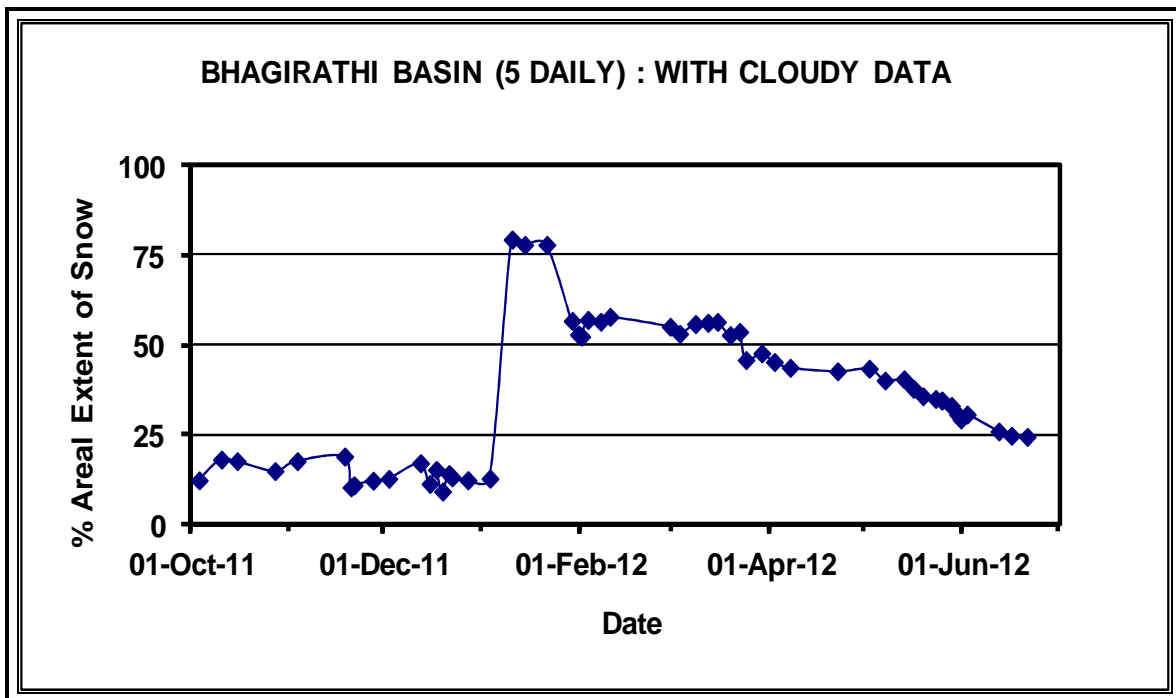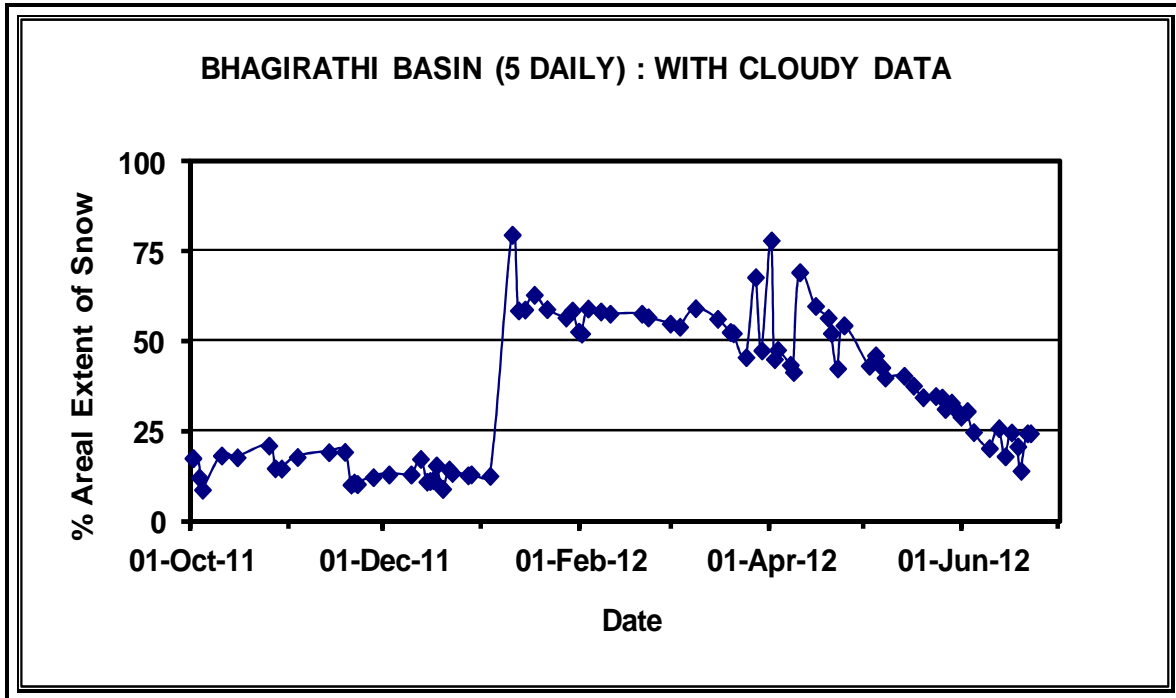
Snow cover depletion curve
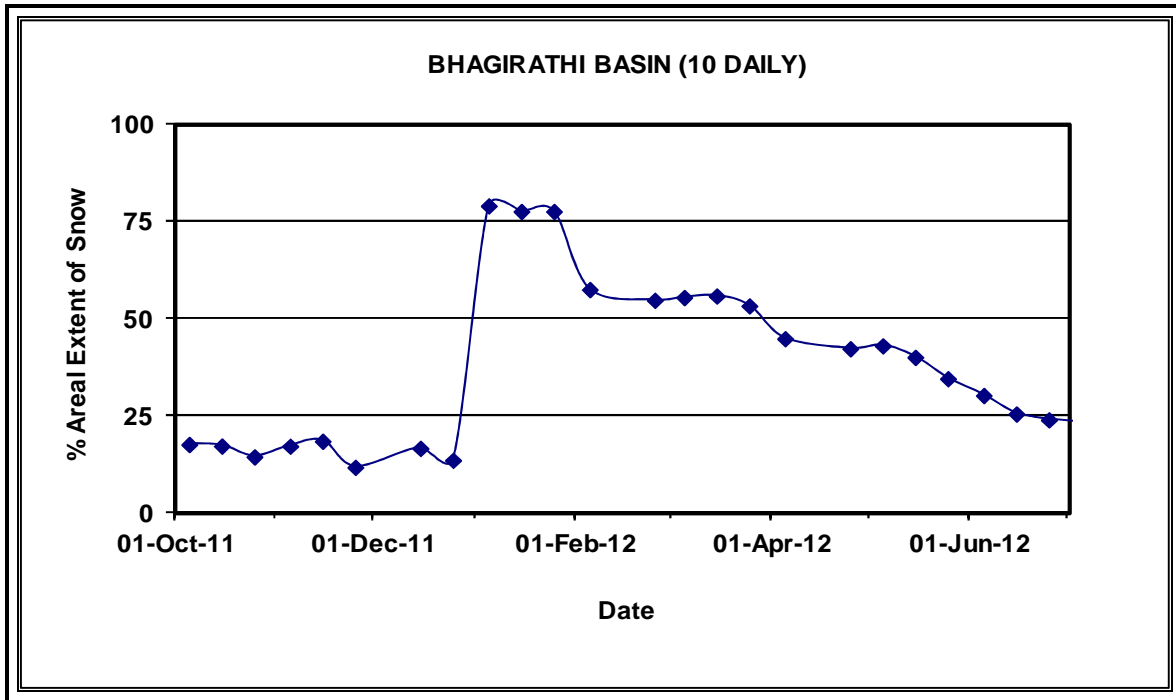
SNOW COVER MAP

SNOW COVER MAP : BHAGIRATHI BASIN

04 OCTOBER 2011

CLOUDY DATA

10 OCTOBER 2011

CLOUDY DATA
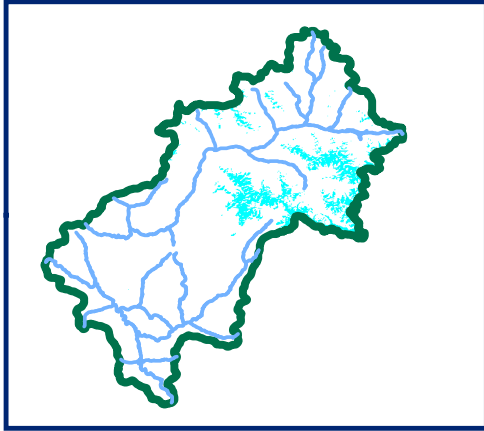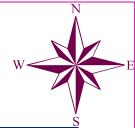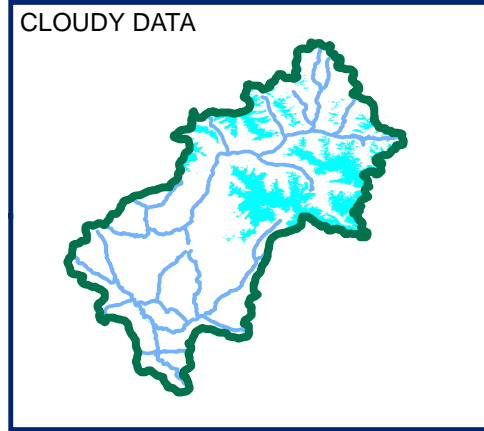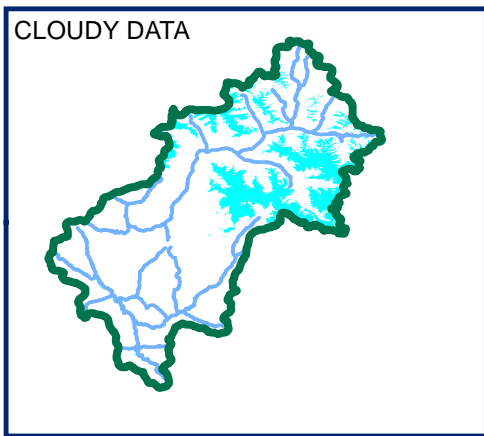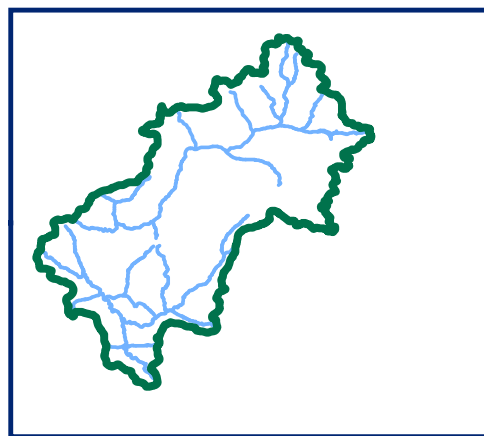
15 OCTOBER 2011

DATA NOT AVAILABLE

25 OCTOBER 2011

CLOUDY DATA
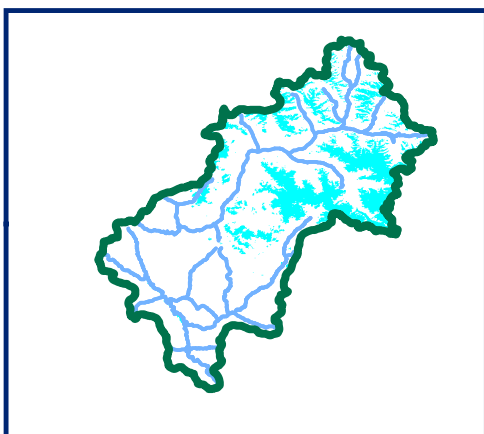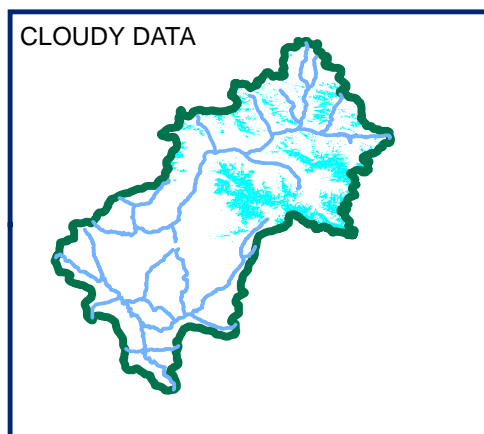
27 OCTOBER 2010

SNOW

0 20 40   80   120   160
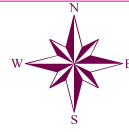
Kilometers

10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN

DATA USED
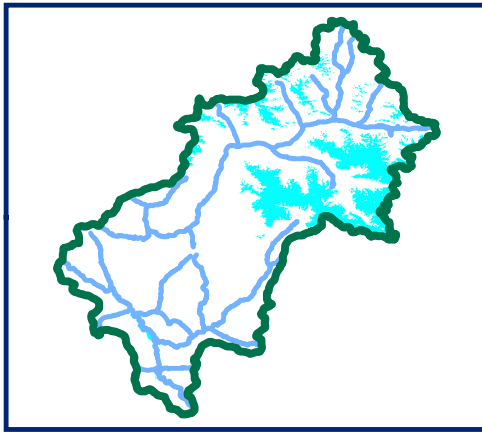
03 OCTOBER 2011

DATA USED
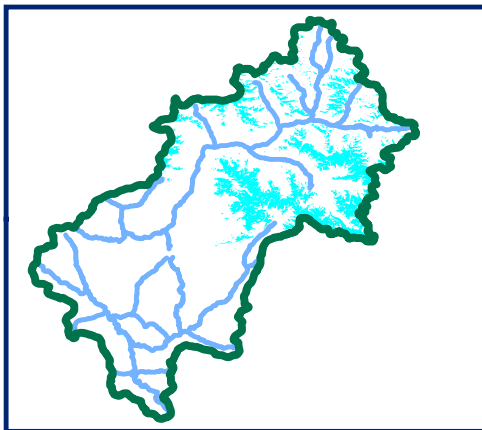
15 OCTOBER 2011

DATA USED

27 OCTOBER 2011

SNOW

0 20 40   80   120   160

Kilometers

SNOW COVER MAP : BHAGIRATHI BASIN
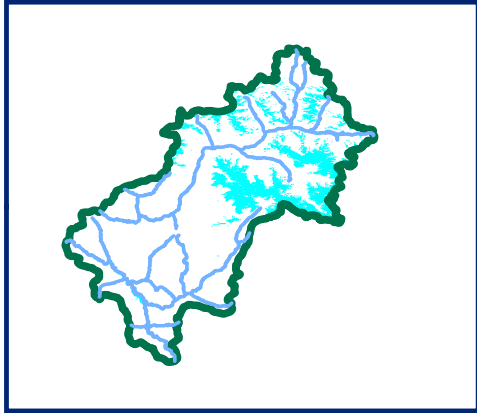
03-NOVEMBER-2011

DATA NOT AVAILABLE

CLOUDY DATA
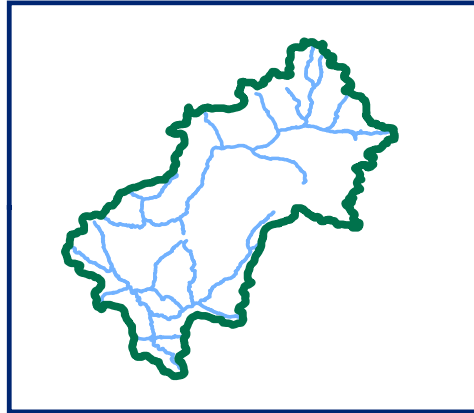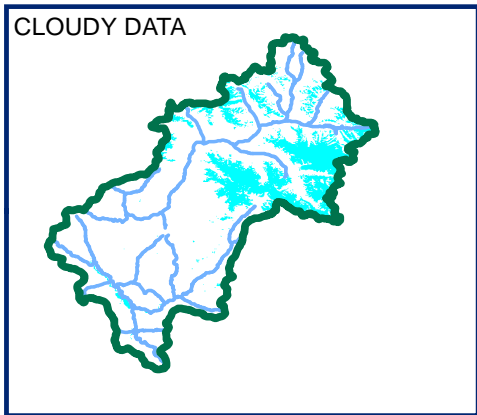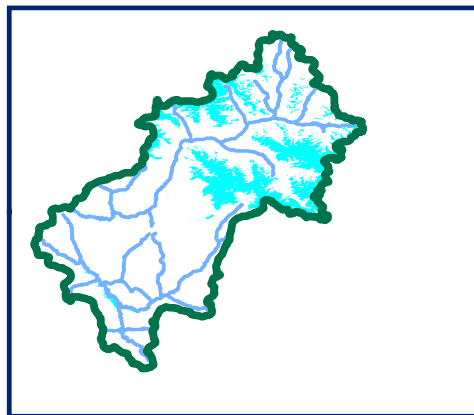
13-NOVEMBER-2011
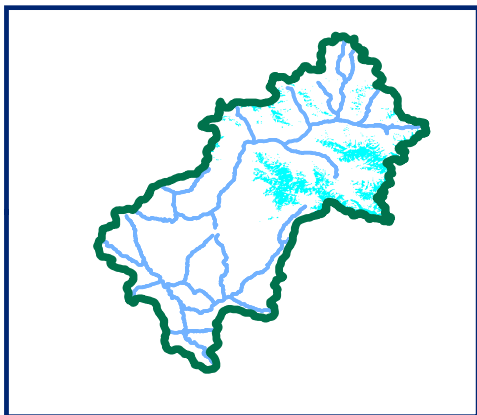
18 NOVEMBER 2011

21 NOVEMBER 2011
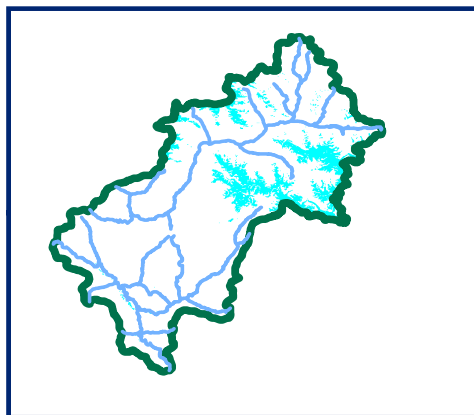
21 NOVEMBER 2011

SNOW

0 20 40   80   120   160

Kilometers

10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
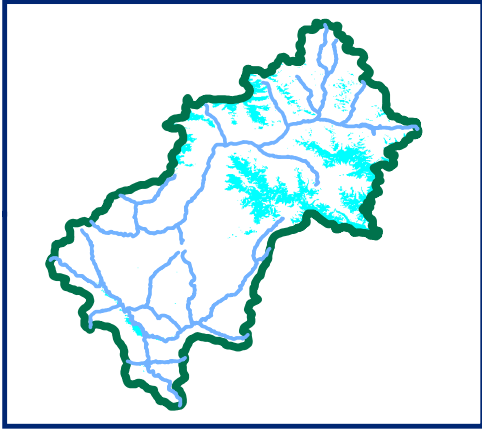
DATA USED
08 NOVEMBER 2011
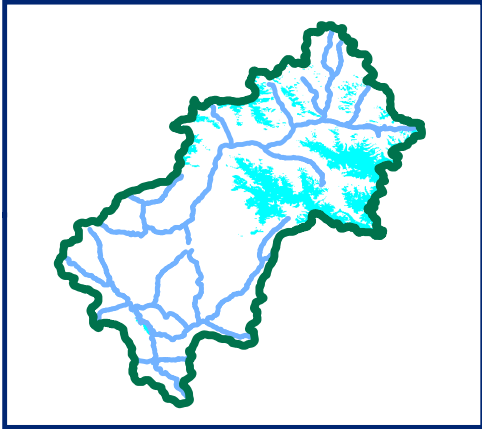
DATA USED

18 NOVEMBER 2011

DATA USED

21 NOVEMBER 2011

SNOW

0 20 40   80   120   160
Kilometers
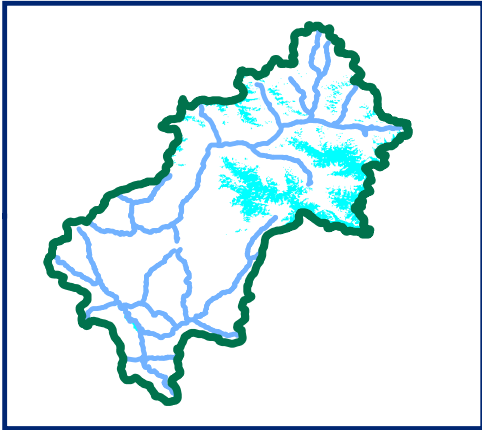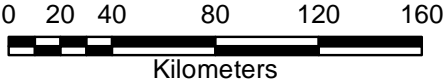
SNOW COVER MAP : BHAGIRATHI BASIN

02 DECEMBER 2011

09 DECEMBER 2011
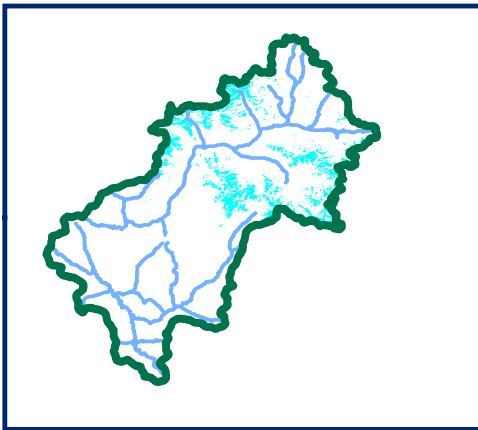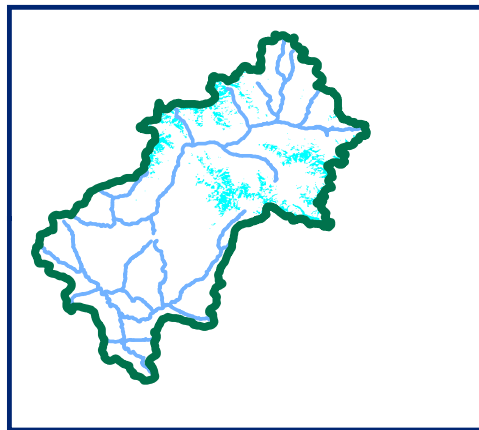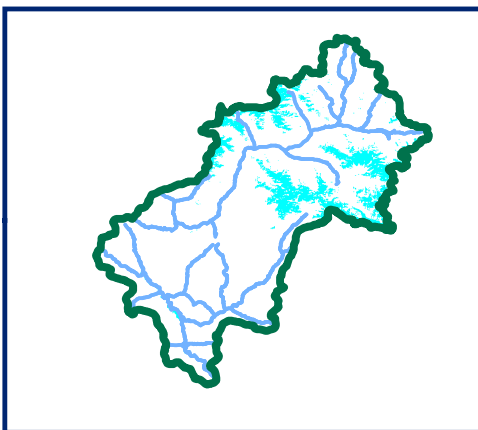
15 DECEMBER 2011

19 DECEMBER 2011

22 DECEMBER 2011

27 DECEMBER 2011

SNOW

0   20 40   80   120   160

Kilometers
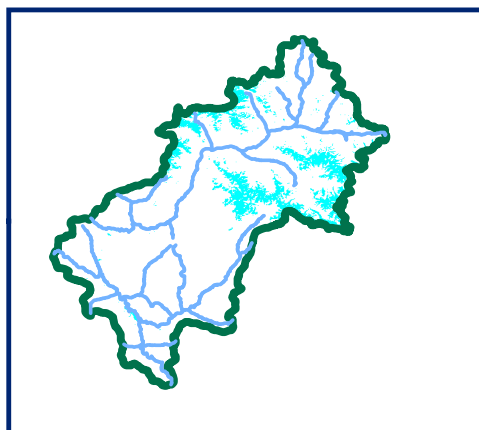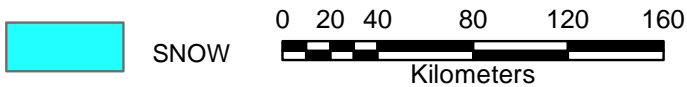
10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
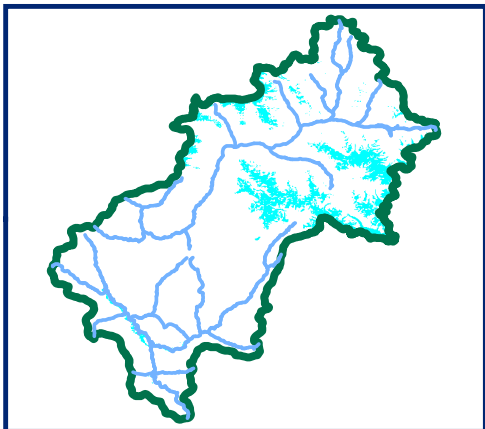
DATA USED
02 DECEMBER 2011
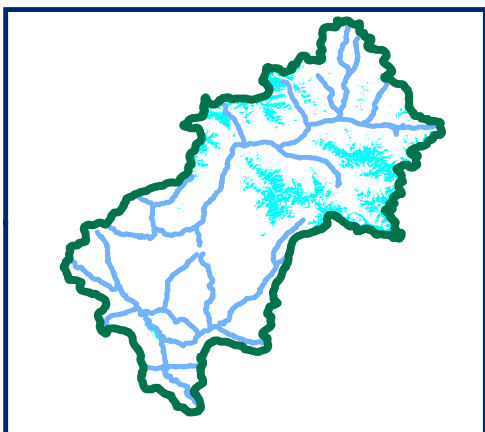
DATA USED
15 DECEMBER 2011

DATA USED
22 DECEMBER 2011

SNOW

0   20   40   80   120   160

Kilometers
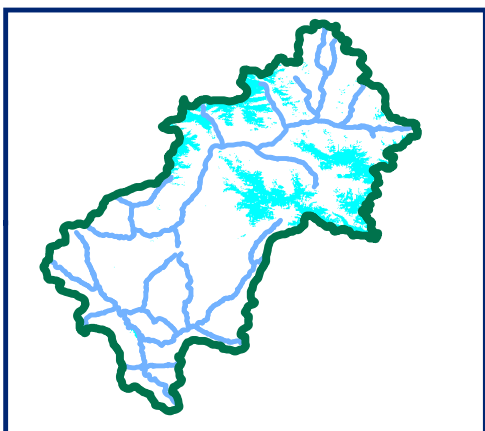
41
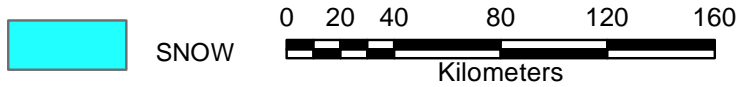
SNOW COVER MAP : BHAGIRATHI BASIN
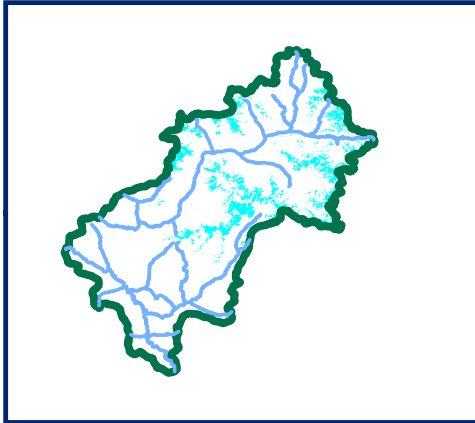
03 JANUARY 2012

10 JANUARY 2012

CLOUDY DATA

12 JANUARY 2012

CLOUDY DATA
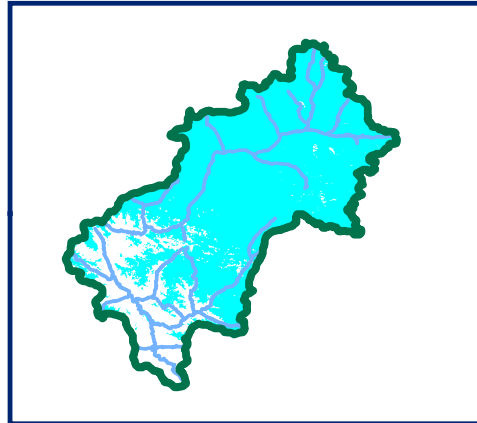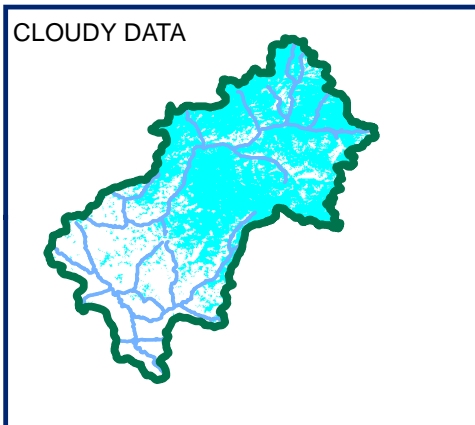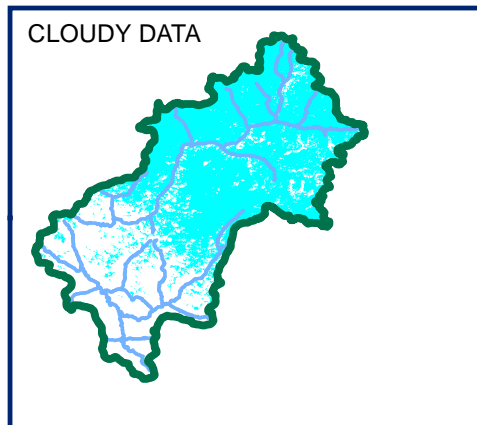
17 JANUARY 2012

21 JANUARY 2012
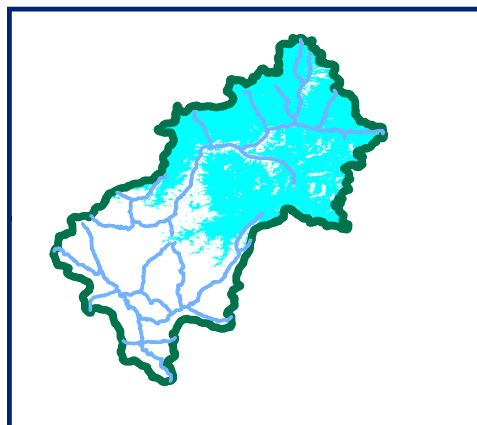
31 JANUARY 2012
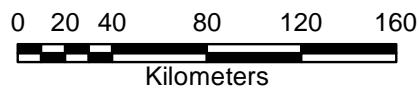
SNOW

0 20 40   80   120   160

Kilometers

42

# 10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
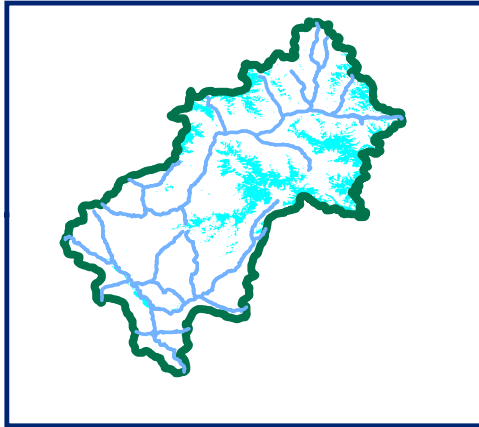
DATA USED
03 JANUARY 2012
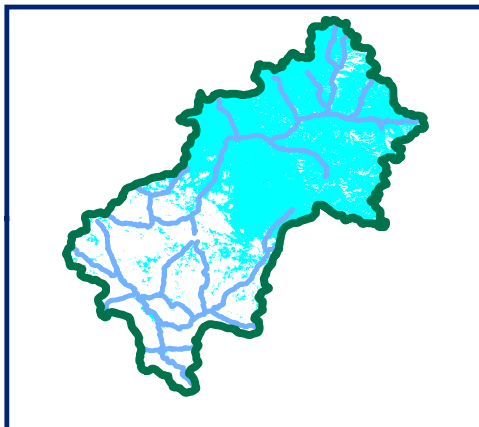
DATA USED
17 JANUARY 2012
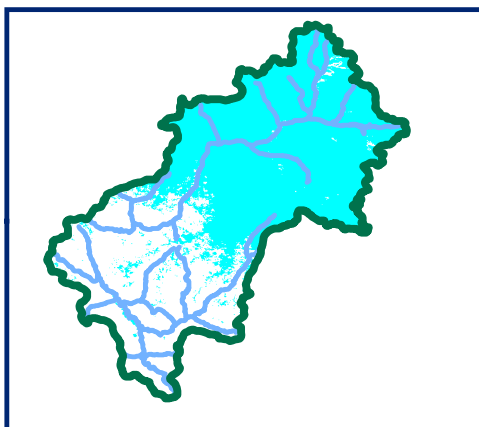
DATA USED

27 JANUARY 2012

SNOW

```
0  20  40      80       120      160
```
Kilometers

SNOW COVER MAP   :   BHAGIRATHI BASIN
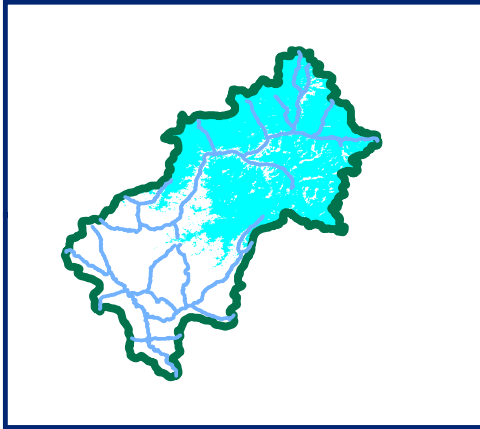
01 FEBRUARY 2012
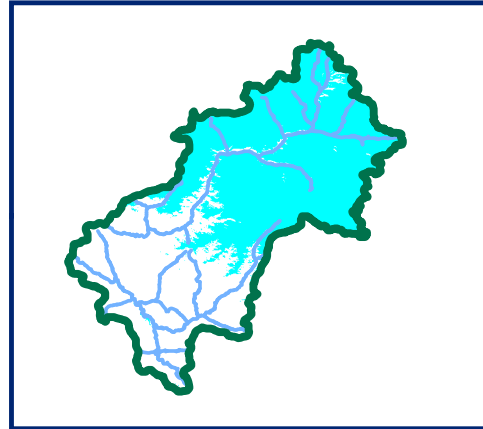
07 FEBRUARY 2012

DATA NOT AVAILABLE

CLOUDY DATA

20 FEBRUARY 2012

CLOUDY DATA
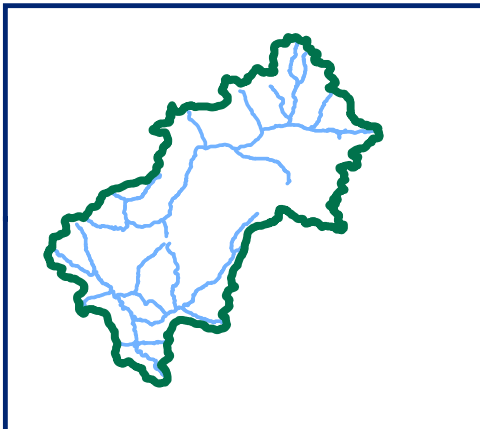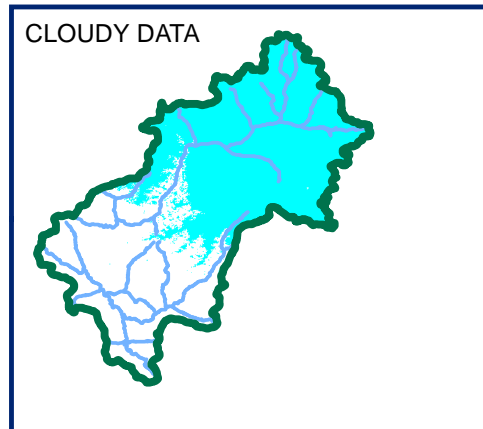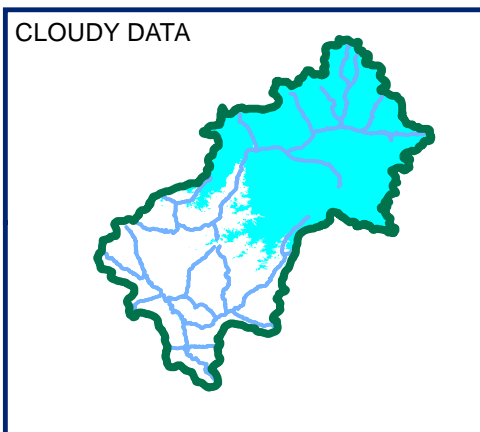
22 FEBRUARY 2012

29 FEBRUARY 2012

SNOW

0   20 40   80   120   160

Kilometers

44
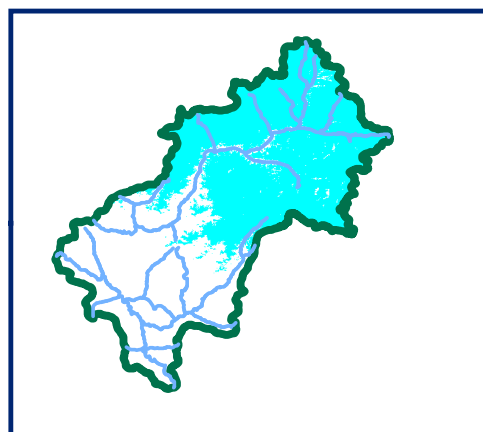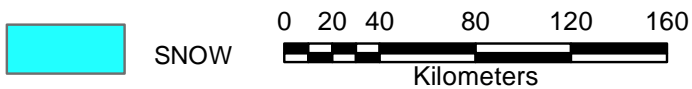
10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
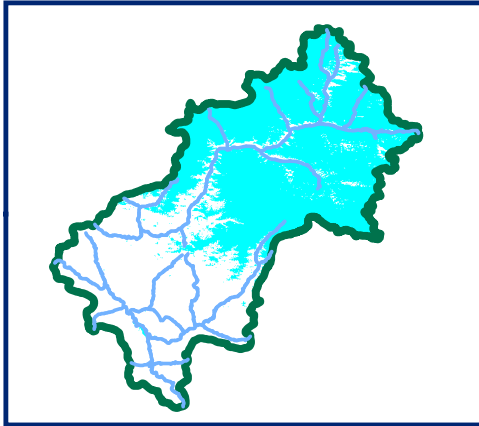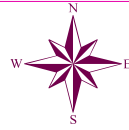
DATA USED
01 FEBRUARY 2012
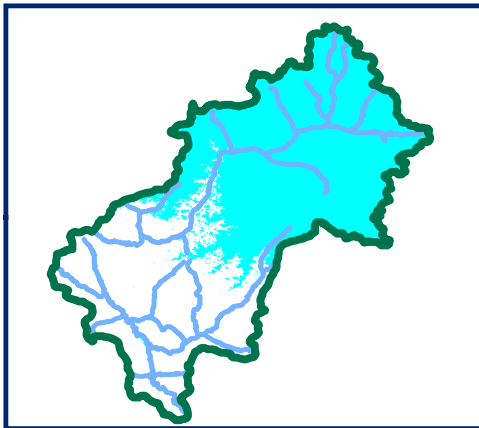
DATA USED

20 FEBRUARY 2012

DATA USED

29 FEBRUARY 2012

SNOW

0   20 40   80   120   160

Kilometers

45
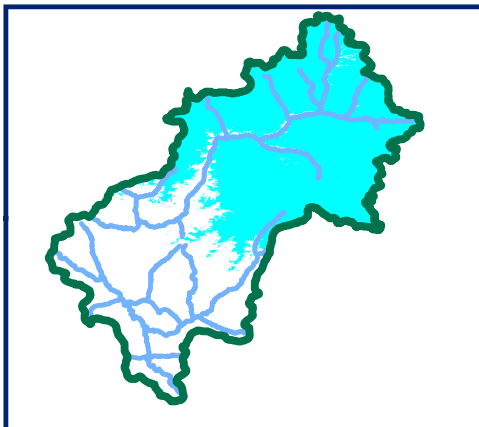
SNOW COVER MAP   :   BHAGIRATHI BASIN

03 MARCH 2012

CLOUDY DATA
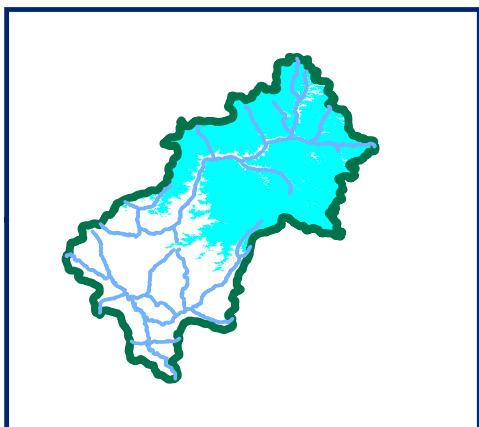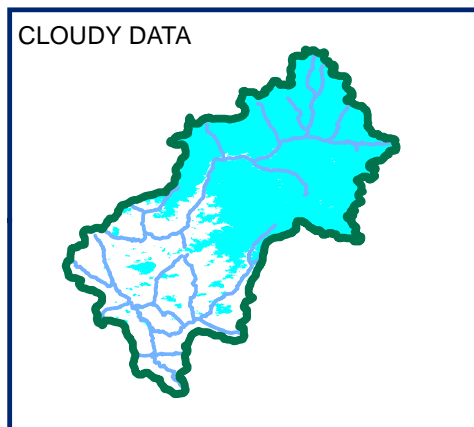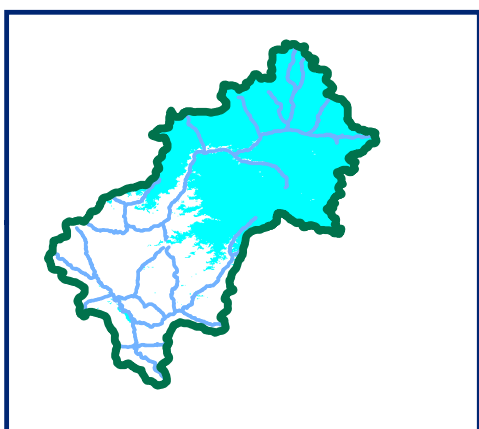
08 MARCH 2012
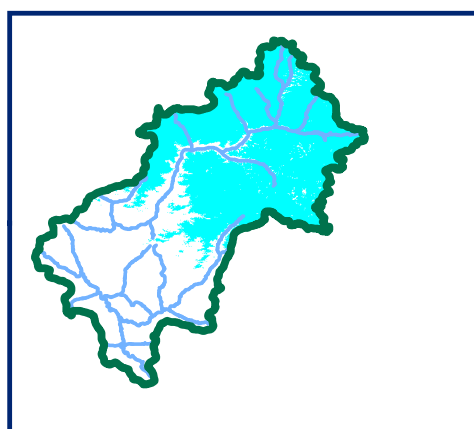
12 MARCH 2012
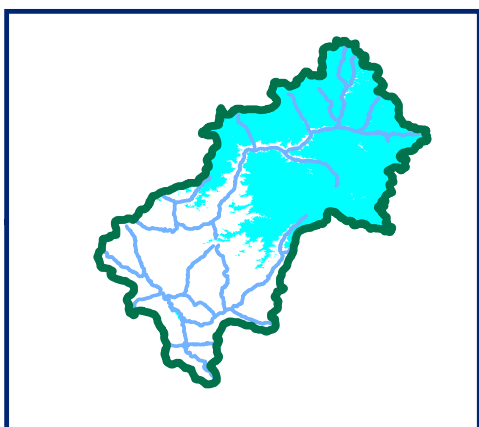
19 MARCH 2012

22 MARCH 2012
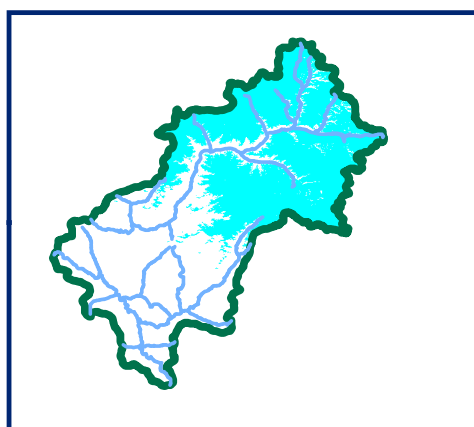
29 MARCH 2012

SNOW

0 20 40   80   120   160

Kilometers

10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
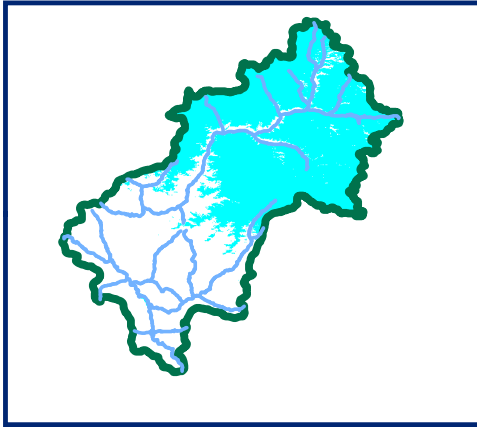
DATA USED
03 MARCH 2012
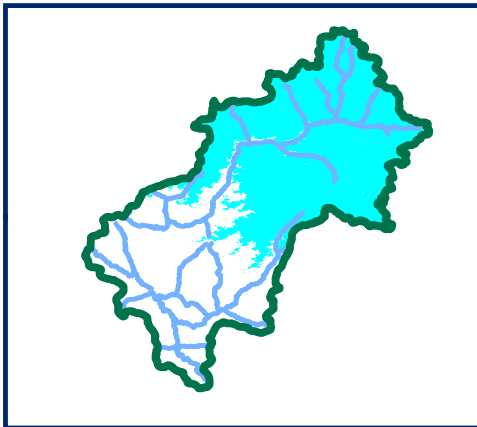
DATA USED
15 MARCH 2012
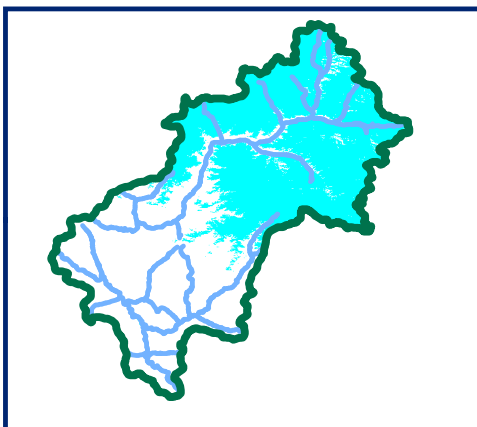
DATA USED
24 MARCH 2012

SNOW
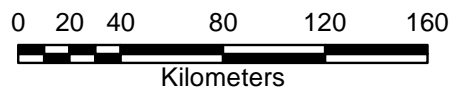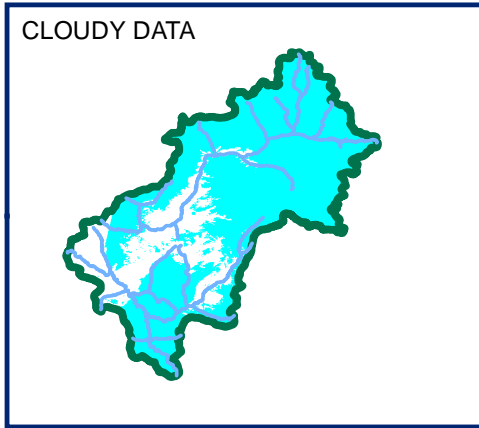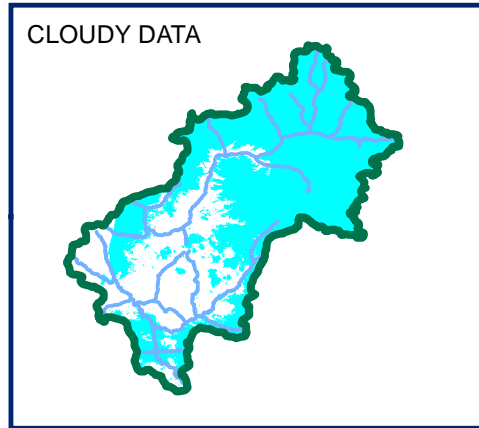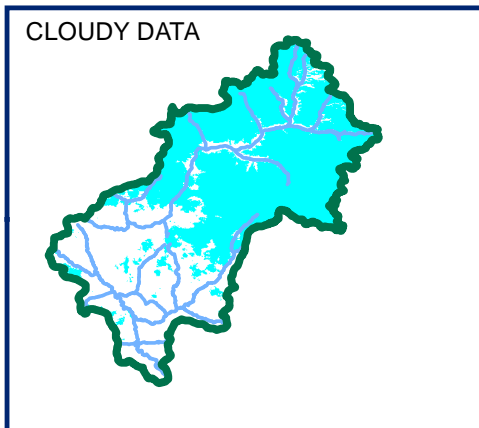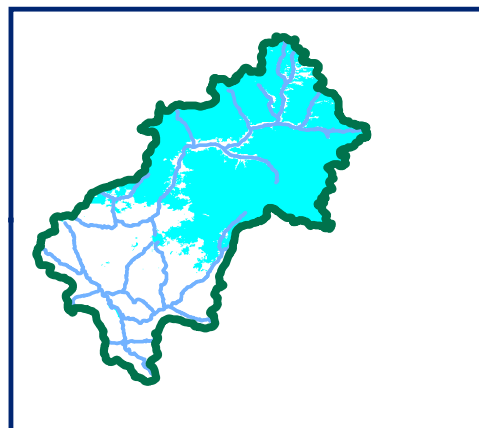
0	20	40	80	120	160

Kilometers

47

SNOW COVER MAP : BHAGIRATHI BASIN

CLOUDY DATA

01 APRIL 2012

CLOUDY DATA

10 APRIL 2012

CLOUDY DATA

15 APRIL 2012

CLOUDY DATA

19 APRIL 2012

CLOUDY DATA

22 APRIL 2012

DATA NOT AVAILABLE

SNOW

0 20 40   80   120   160
Kilometers
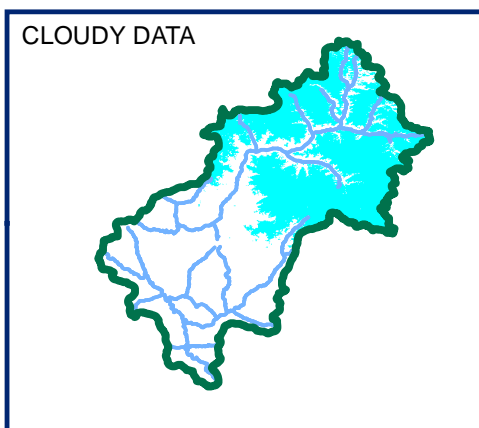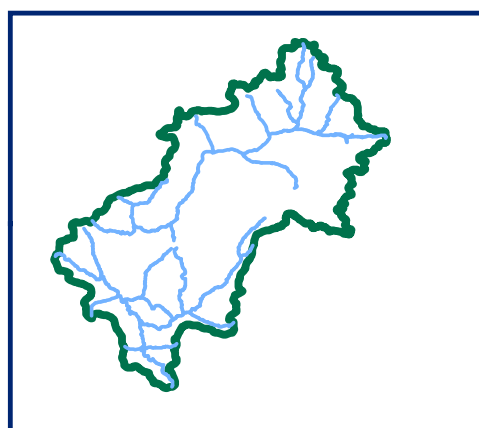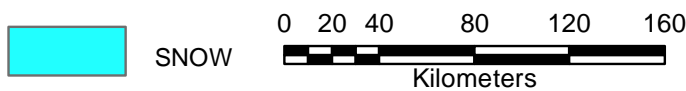
10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
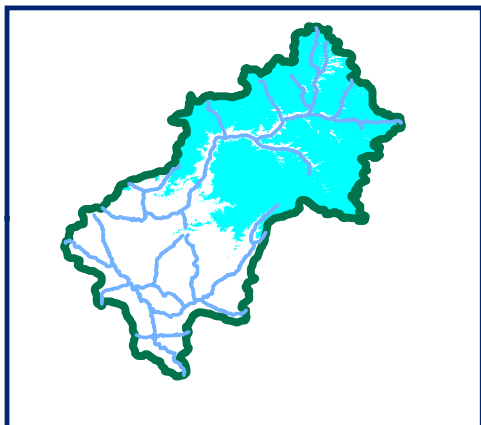
DATA USED
03 APRIL 2012

DATA USED
15 APRIL 2012

DATA USED
22 APRIL 2012

SNOW

0   20 40   80   120   160

Kilometers
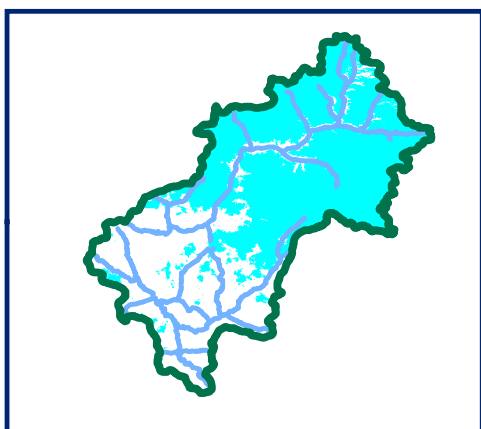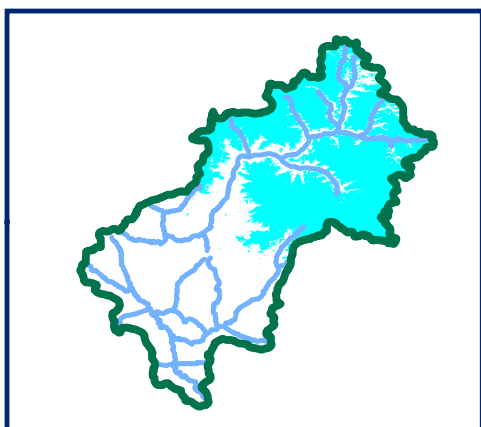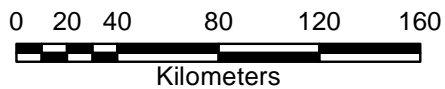
SNOW COVER MAP : BHAGIRATHI BASIN
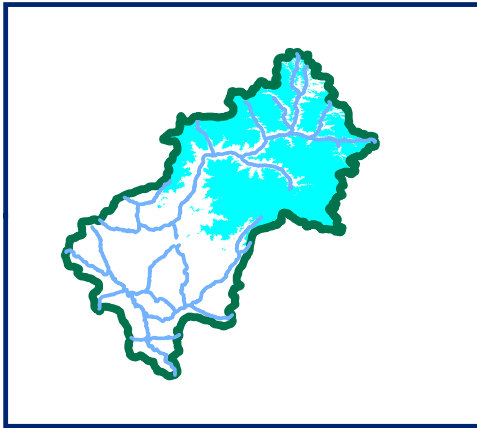
02 MAY 2012
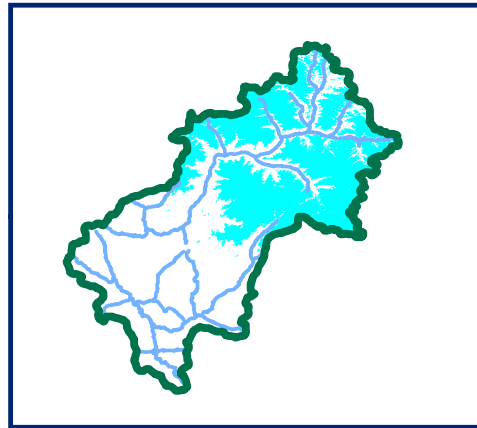
07 MAY 2012
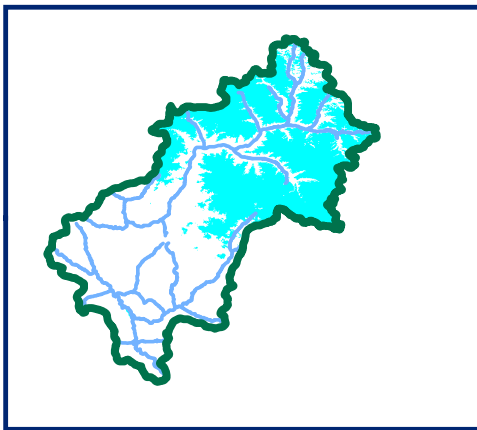
13 MAY 2012
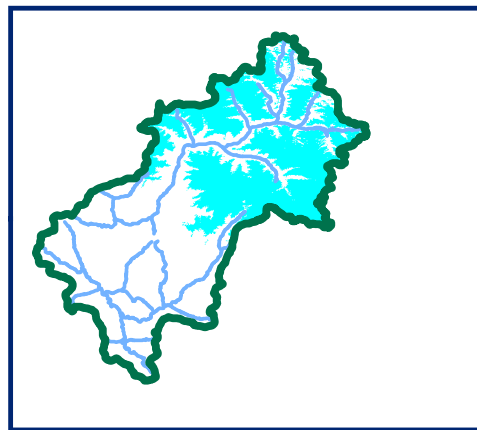
16 MAY 2012

25 MAY 2012

28 MAY 2012

SNOW

0 20 40   80   120   160

Kilometers
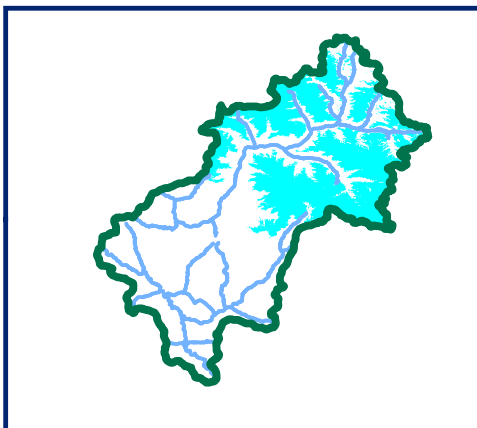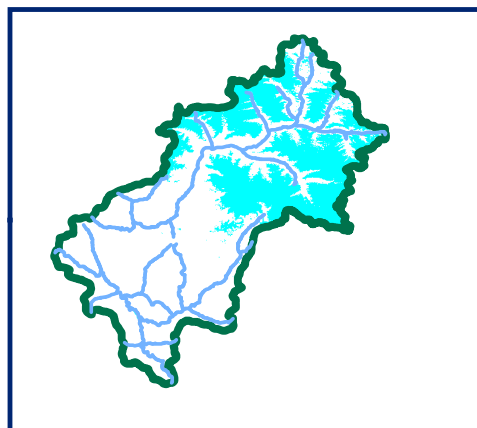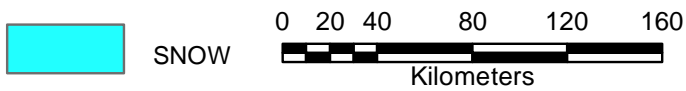
10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
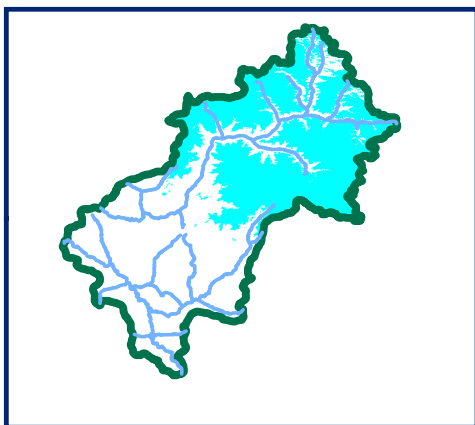
DATA USED
02 MAY 2012
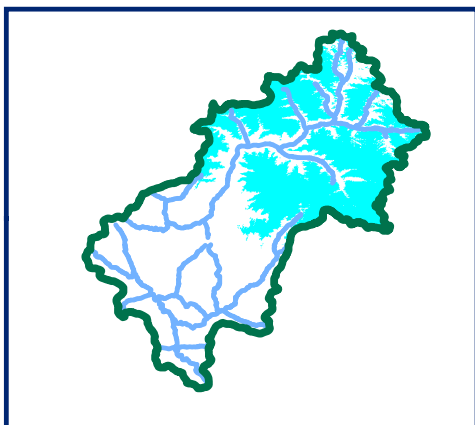
DATA USED
16 MAY 2012
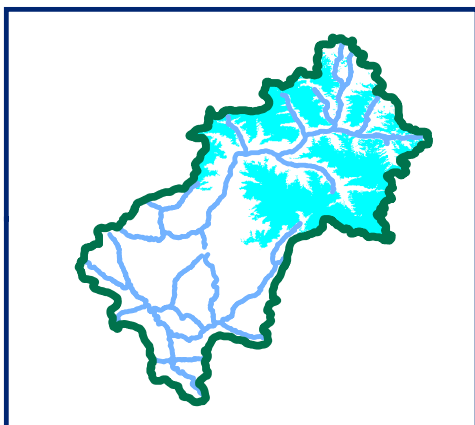
DATA USED
30 MAY 2012

SNOW

| 0 | 20 | 40 | | 80 | | 120 | | 160 |
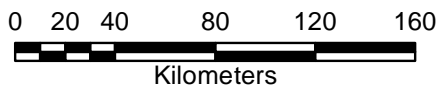
Kilometers

SNOW COVER MAP　　　: BHAGIRATHI BASIN
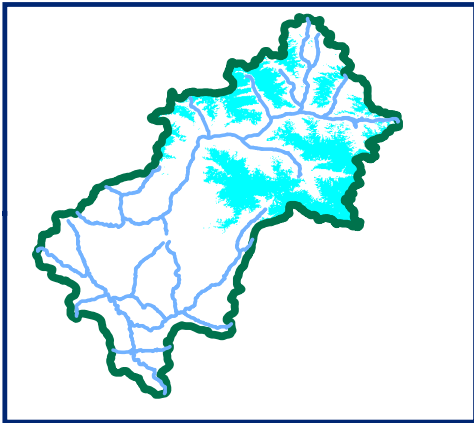
04 JUNE 2012
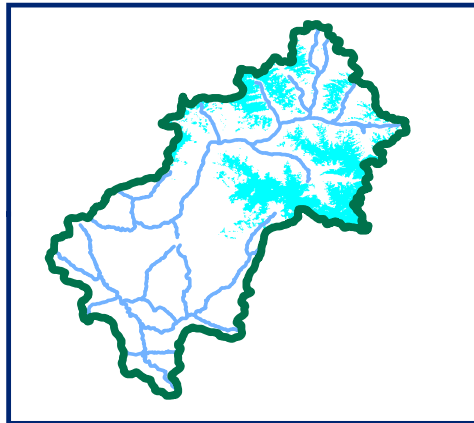
09 JUNE 2012
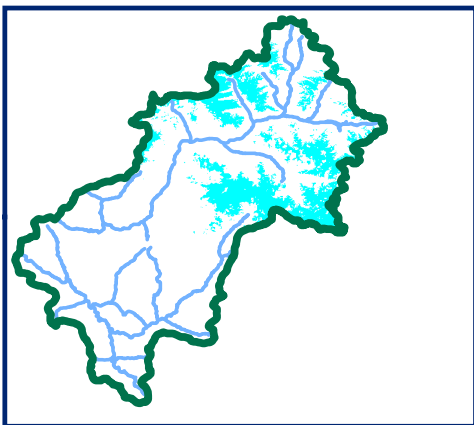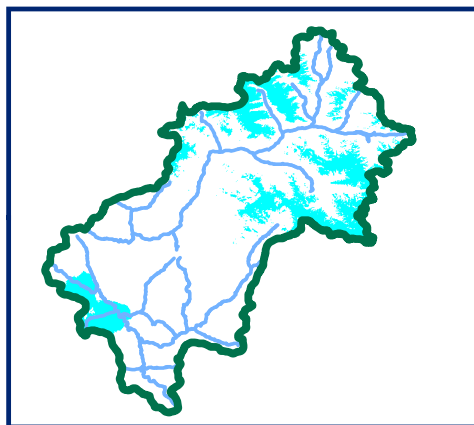
14 JUNE 2012
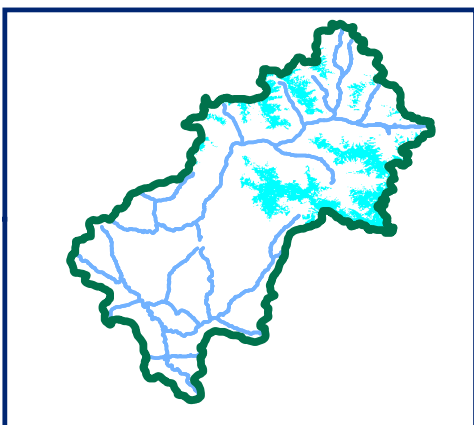
18 JUNE 2012

24 JUNE 2012
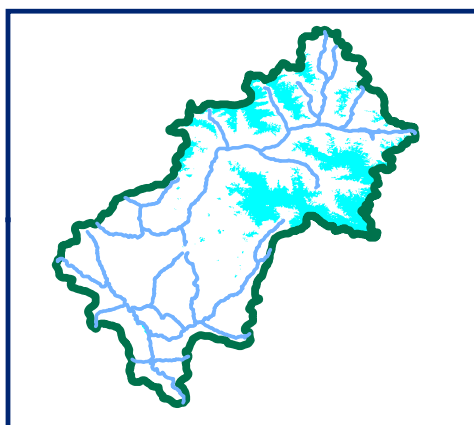
30 JUNE 2012

SNOW

0　20　40　　80　　120　　160

Kilometers

10 DAILY SNOW COVER MAP: BHAGIRATHI BASIN
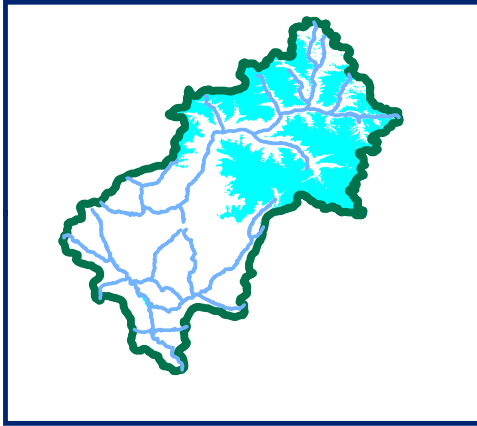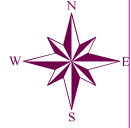
DATA USED
02 JUNE 2012
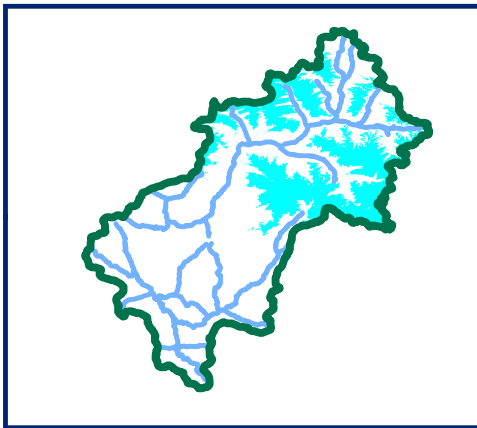
DATA USED
14 JUNE 2012
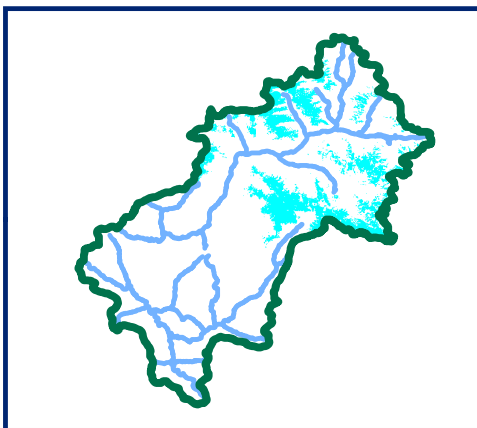
DATA USED
23 JUNE 2012

SNOW

0   20 40   80   120   160

Kilometers

YAMUNA BASIN

AREAL EXTENT OF SNOW (5 DAILY)

BASIN NAME: YAMUNA   **BASIN AREA: 3527 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2011							
1	01-Oct-2011	340	10	5	25-Oct-2011	321	9
2	03-Oct-2011	180	5	6	27-Oct-2011	308	9
3	10-Oct-2011	459	13	7	29-Oct-2011	359	10
4	15-Oct-2011	385	11				
November 2011							
1	03-Nov-2011	356	10	5	20-Nov-2011	190	5
2	8-Nov-2011	294	8	6	21-Nov-2011	186	5
3	13-Nov-2011	283	8	7	22-Nov-2011	281	8
4	18-Nov-2011	294	8	8	27-Nov-2011	254	7
December 2011							
1	02-Dec-2011	232	7	7	19-dec-11	384	11
2	4-Dec-2011	140	4	8	21-Dec-11	639	18
3	9-Dec-2011	471	13	9	22-Dec-11	602	17
4	12-Dec-2011	832	24	10	28-dec-11	327	9
5	15-Dec-2011	743	21				
6	16-dec-2011	735	21				
January 2012							
1	3-Jan-12	391	11	6	21-Jan-12	2412	68
2	10-Jan-12	2721	77	7	27-Jan-12	2319	66
3	12-Jan-12	3070	87	8	29-Jan-12	2476	70
4	14-Jan-12	3049	86	9	31-Jan-12	1880	53
5	17-Jan-12	2781	79				
February 2012							
1	1-Feb-12	830	24	6	20-Feb-12	2148	61
2	2-Feb-12	2328	66	7	22-Feb-12	1645	47
3	3-Feb-12	1778	50	8	26-Feb-12	1813	51
4	7-Feb-12	1895	54	9	29-Feb-12	1629	46
5	10-Feb-12	2228	63				
March 2011							
1	2-Mar-12	1713	49	8	22-Mar-12	1423	40
2	3-Mar-12	1584	45	9	24-Mar-12	1320	37
3	8-Mar-12	1521	43	10	27-Mar-12	1567	44
4	12-Mar-12	1346	38	11	29-Mar-12	1240	35
5	15-Mar-12	1358	38	12	31-Mar-12	1469	42

54

6	19-Mar-12	1408	40				
7	20-Mar-12	1414	40				
April 2012							
1	2-Apr-12	1113	32	6	15-Apr-12	1563	44
2	3-Apr-12	1294	37	7	19-Apr-12	1360	39
3	5-Apr-12	1858	53	8	20-Apr-12	1372	39
4	7-Apr-12	1257	36	9	22-Apr-12	972	28
5	8-Apr-12	1017	29	10	24-Apr-12	1341	38
May 2012							
1	2-May-12	1117	32	8	16-May-12	885	25
2	4-May-12	1194	34	9	19-May-12	917	26
3	6-May-12	1147	33	10	23-May-12	803	23
4	7-May-12	1158	33	11	25-May-12	817	23
5	9-May-12	1108	31	12	28-May-12	781	22
6	13-May-12	944	27	13	30-May-12	729	21
7	14-May-12	923	26				
June 2012							
1	2-June-12	738	21		18-June-12	290	8
2	4-June-12	662	19	7	19-June-12	412	12
3	9-June-12	487	14	8	21-June-12	457	13
4	12-June-12	297	8	9	23-June-12	265	8
5	14-June-12	431	12	10	24-June-12	232	7
6	16-June-12	564	16	11	30-June-12	441	12

AREAL EXTENT OF SNOW (10 DAILY)

BASIN NAME: YAMUNA   **BASIN AREA: 3527 sq km**

S No	Date	Snow cover (sq km)	Snow cover (%)	S No	Date	Snow cover (sq km)	Snow cover (%)
October 2011							
1	5-Oct-11	459	13	2	15-Oct-11	388	11
3	25-Oct-11	339	10				
November 2011							
1	5-Nov-11	353	10	2	15- Nov-11	294	8
3	25-Nov-11	273	8				
December 2011							
1	5-Dec-11	295	8	2	15-Dec-11	846	24
3	25-Dec-11	635	18				
January 2012							
1	5-Jan-12	2716	77	2	15-Jan-12	3068	87
3	25-Jan-12	2469	70				
February 2012							
1	3-Feb-12	2222	63				
2	25-Feb-12	1799	51				
March 2012							
1	5-Mar-12	1728	49	3	25-Mar-12	1481	42
April 2012							
1	15-Apr-12	1376	39				
May 2012							
1	5-May-12	1058	32	3	15- May-12	949	27
2	25-May-12	817	24				
June 2012							
1	5-June-12	741	21	2	15-June-12	564	16
3	25-June-12	459	13				

Snow cover depletion curve

YAMUNA BASIN (5 DAILY) : WITH CLOUDY DATA

YAMUNA BASIN (5 DAILY) : WITHOUT CLOUDY DATA

Snow cover depletion curve

BHAGIRATHI BASIN (10 DAILY)
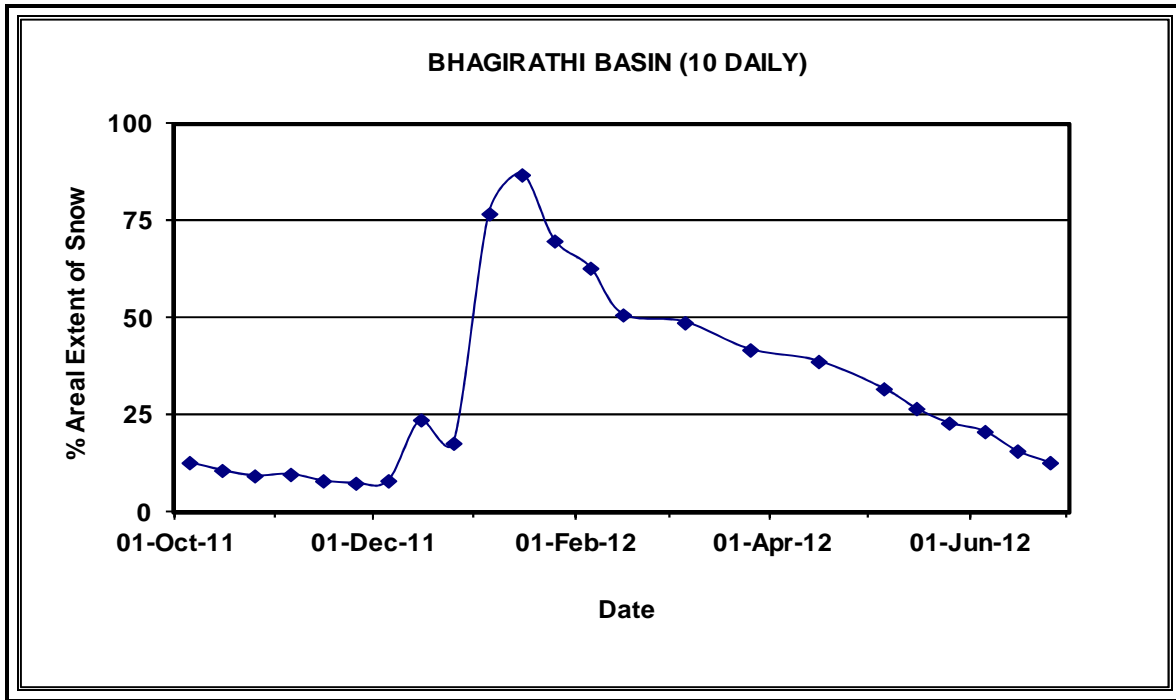
SNOW COVER MAP

SNOW COVER MAP   :   YAMUNA BASIN

CLOUDY DATA
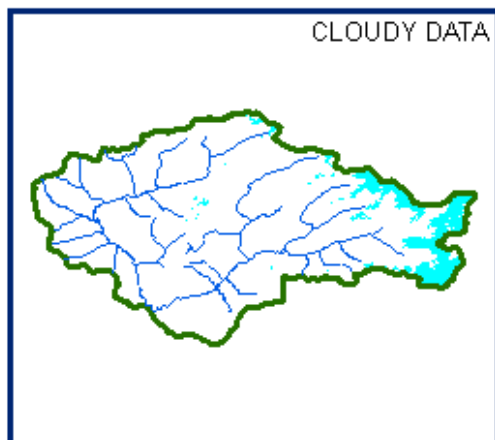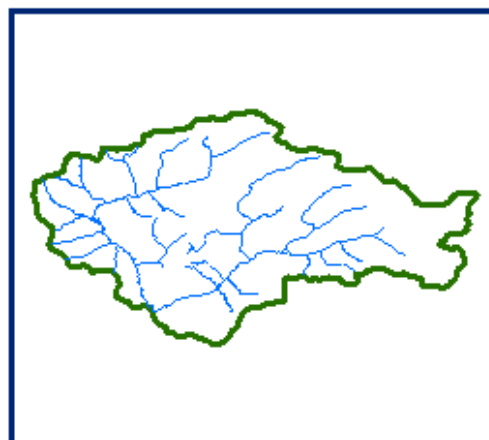
01 OCTOBER 2011

DATA NOT AVAILABLE
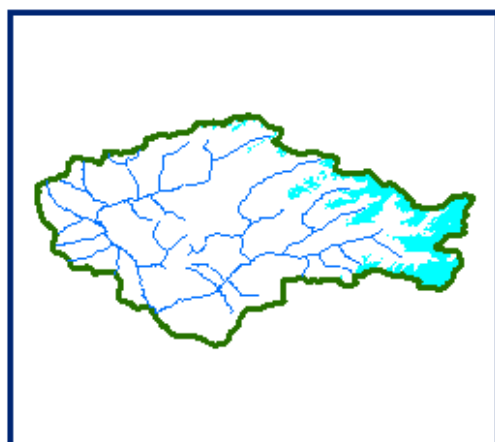
10 OCTOBER 2011

15 OCTOBER 2011

CLOUDY DATA

CLOUDY DATA
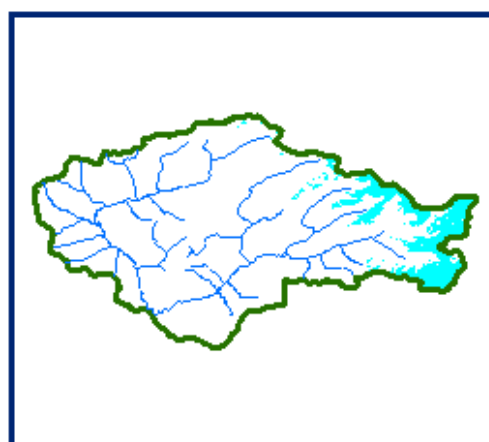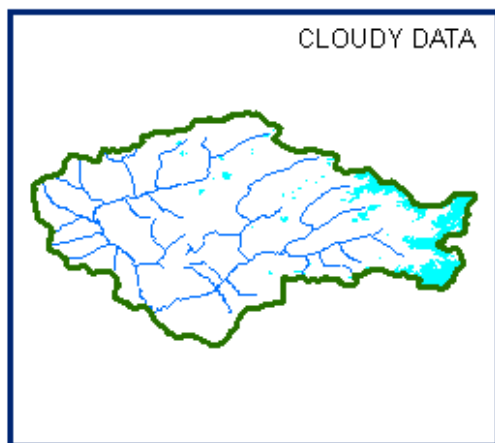
25 OCTOBER 2011

29 OCTOBER 2011
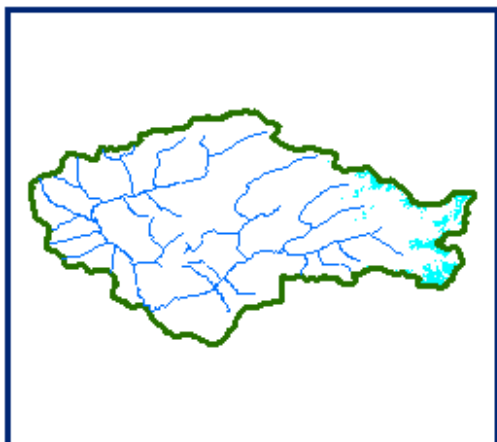
0 12.5 25   50   75   100

SNOW

Kilometers

10 DAILY SNOW COVER MAP: **YAMUNA BASIN**

DATA USED
03 OCTOBER 2011

DATA USED
15 OCTOBER 2011

DATA USED
27 OCTOBER 2011

SNOW

0 12.5 25   50   75   100

Kilometers
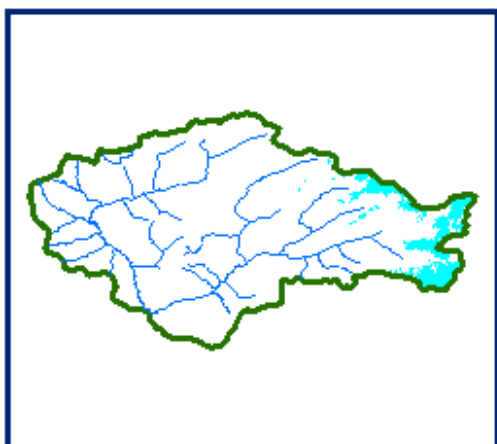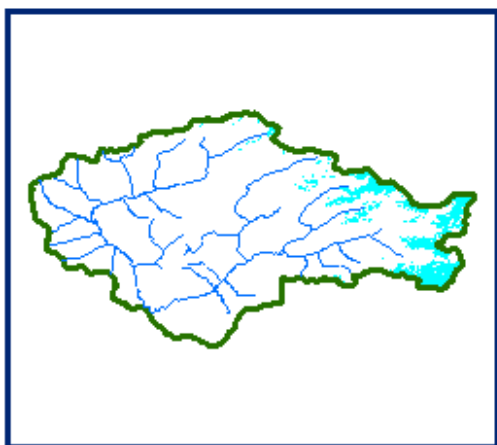
SNOW COVER MAP   :   YAMUNA BASIN

03 NOVEMBER 2011

08 NOVEMBER 2011

CLOUDY DATA
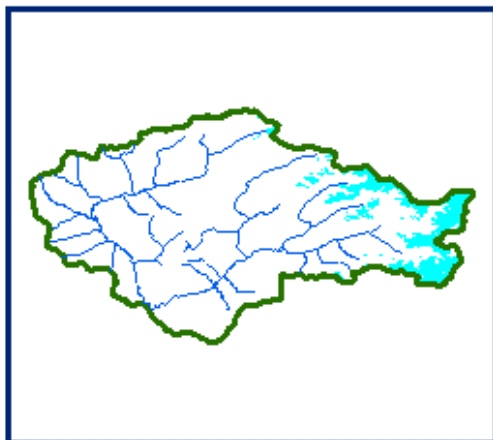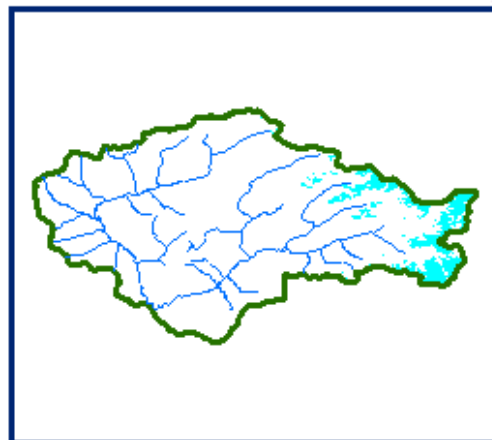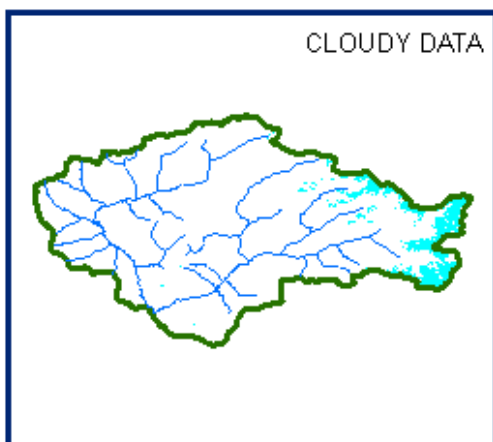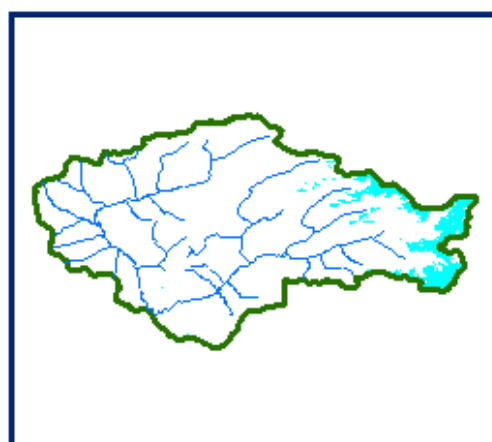
13 NOVEMBER 2011

18 NOVEMBER 2011

22 NOVEMBER 2011

27 NOVEMBER 2011

SNOW

0 12.5 25   50   75   100

Kilometers
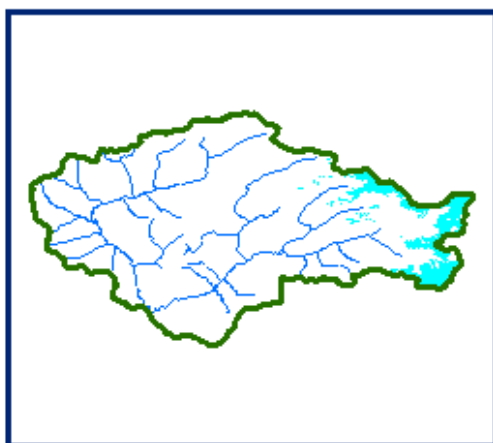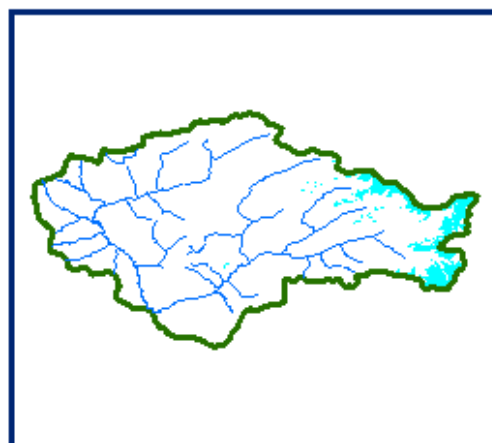
10 DAILY SNOW COVER MAP: **YAMUNA BASIN**
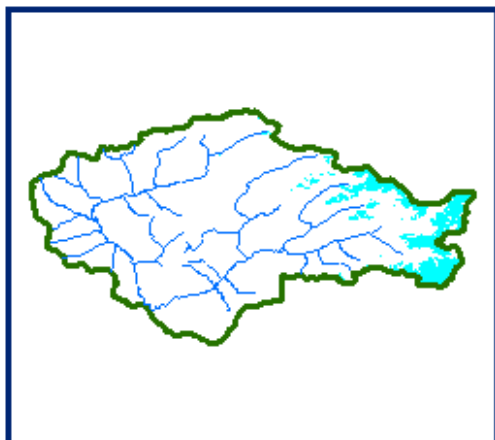
DATA USED
03 NOVEMBER 2011
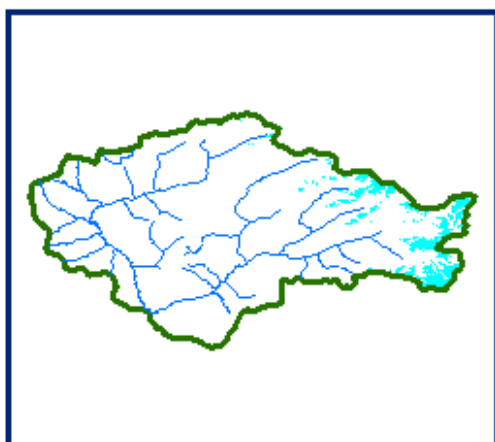
DATA USED
20 NOVEMBER 2011
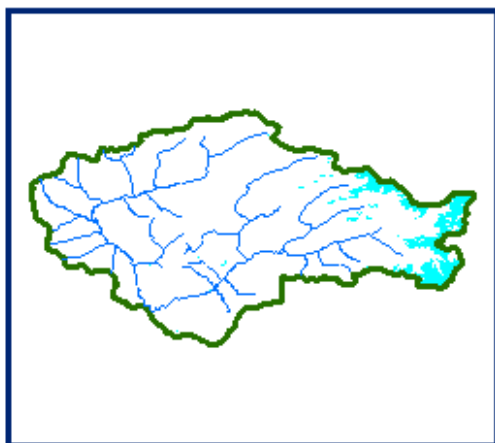
DATA USED
27 NOVEMBER 2011

SNOW

0 12.5 25 50 75 100
Kilometers

SNOW COVER MAP : YAMUNA BASIN
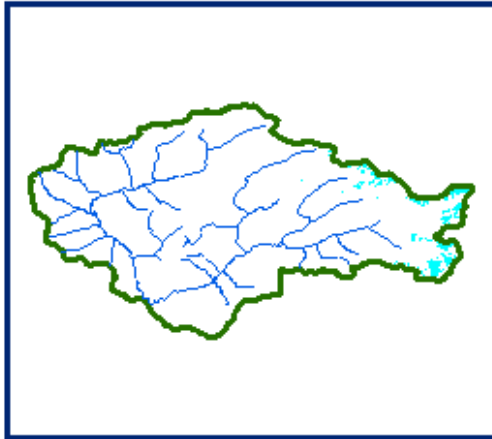
04 DECEMBER 2011
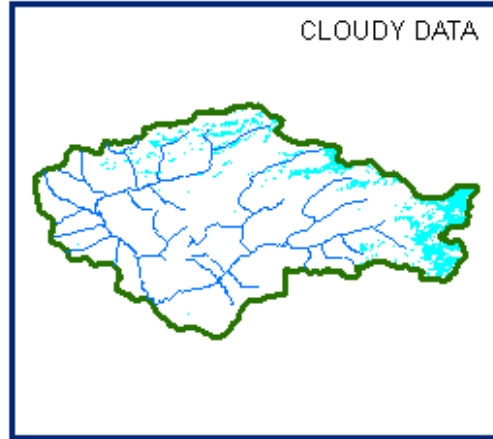
09 DECEMBER 2011
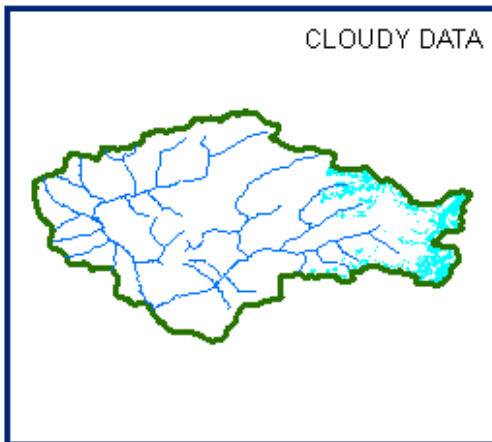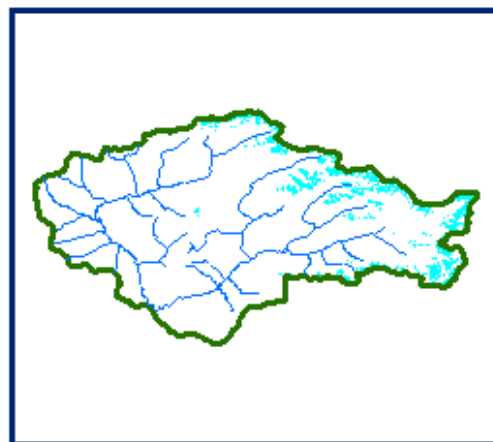
15 DECEMBER 2011
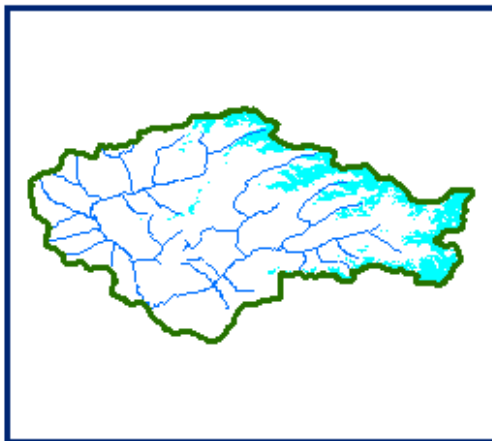
19 DECEMBER 2011

22 DECEMBER 2011

28 DECEMBER 2011

CLOUDY DATA

SNOW

0 12.5 25 50 75 100
Kilometers

63
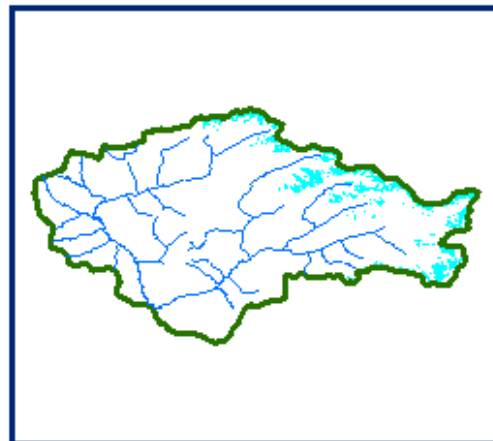
10 DAILY SNOW COVER MAP: YAMUNA BASIN
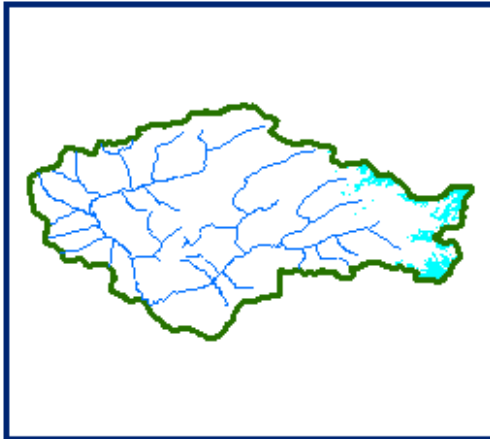
DATA USED

04 DECEMBER 2011
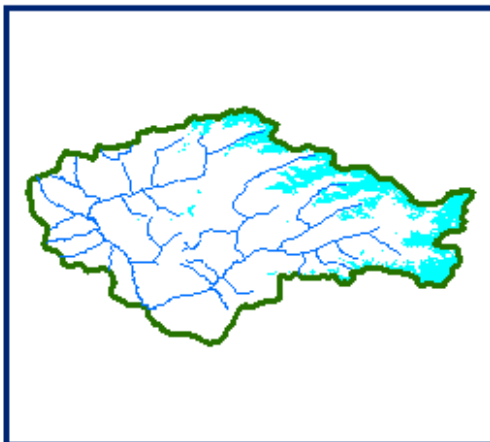
DATA USED

17 DECEMBER 2011

DATA USED

22 DECEMBER 2011

SNOW

0 12.5 25   50   75   100

Kilometers

SNOW COVER MAP : YAMUNA BASIN

CLOUDY DATA

03 JANUARY 2012

CLOUDY DATA
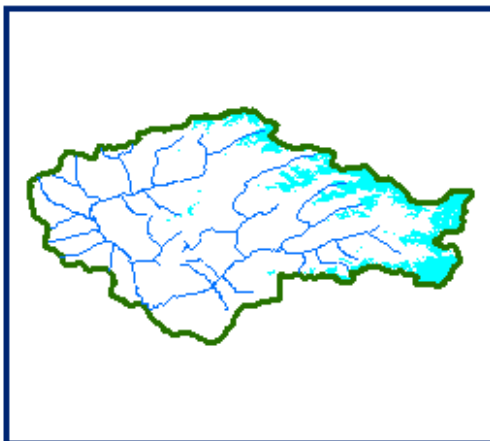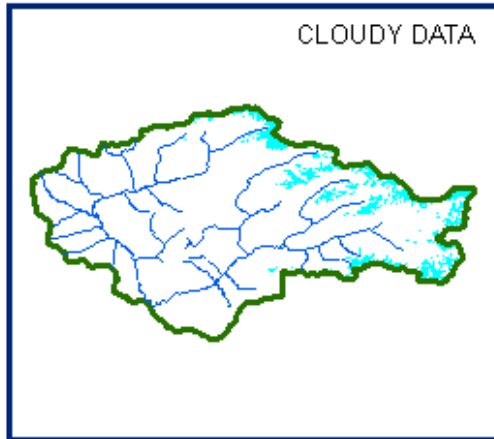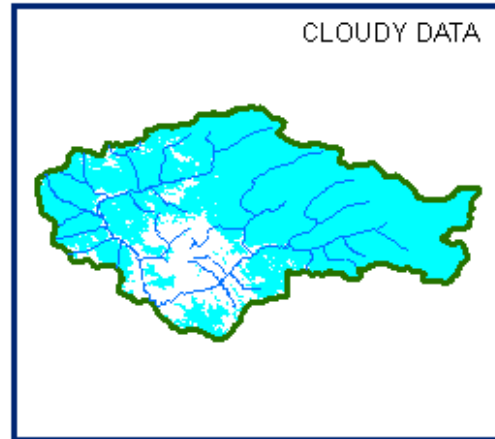
10 JANUARY 2012

14 JANUARY 2012

21 JANUARY 2012
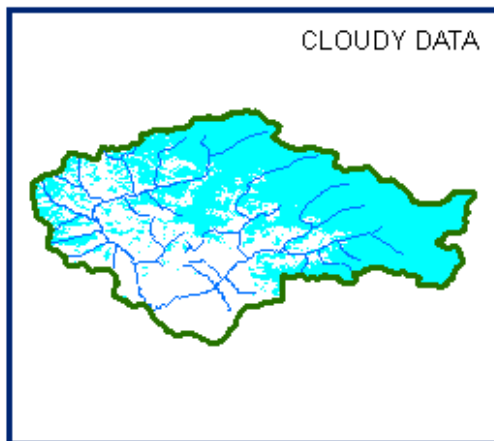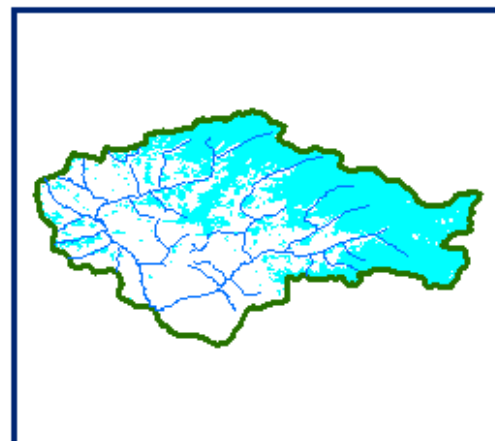
CLOUDY DATA

27 JANUARY 2012

31 JANUARY 2012
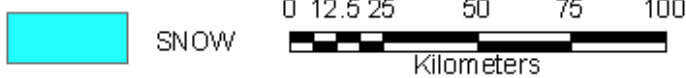
SNOW

0 12.5 25   50   75   100
Kilometers

10 DAILY SNOW COVER MAP: YAMUNA BASIN
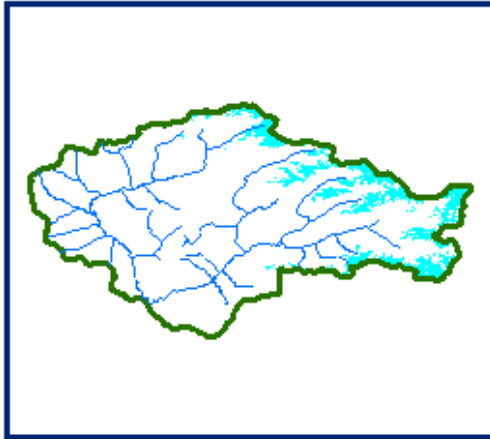
DATA USED
03 JANUARY 2012
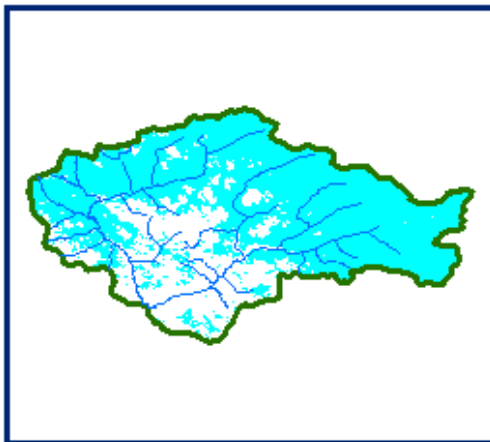
DATA USED
17 JANUARY 2012
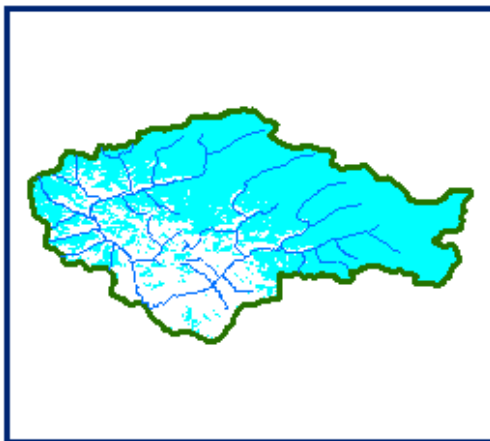
DATA USED
29 JANUARY 2012

SNOW

0 12.5 25   50   75   100

Kilometers
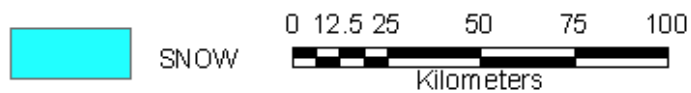
SNOW COVER MAP   :   YAMUNA BASIN
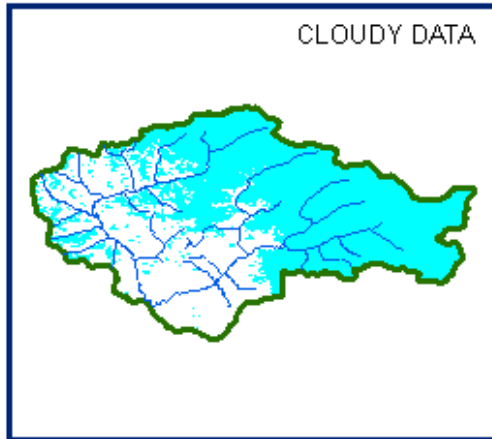
02 FEBRUARY 2012
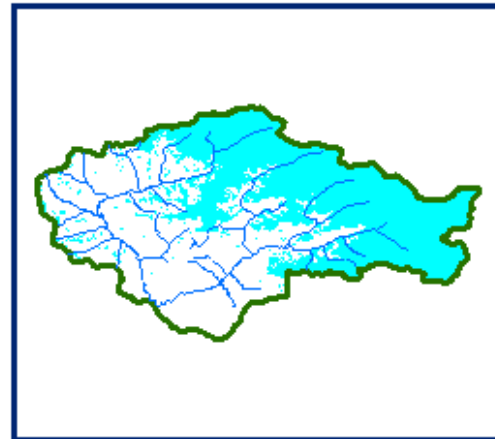
7 FEBRUARY 2012
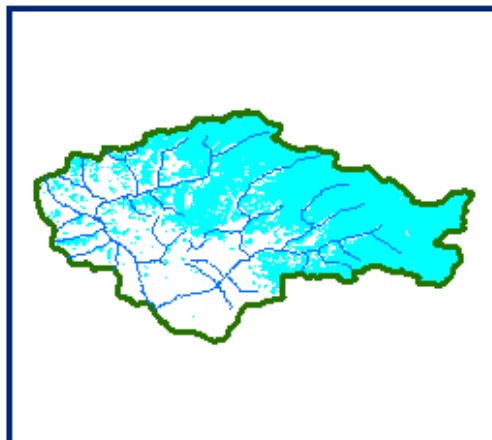
10 FEBRUARY 2012
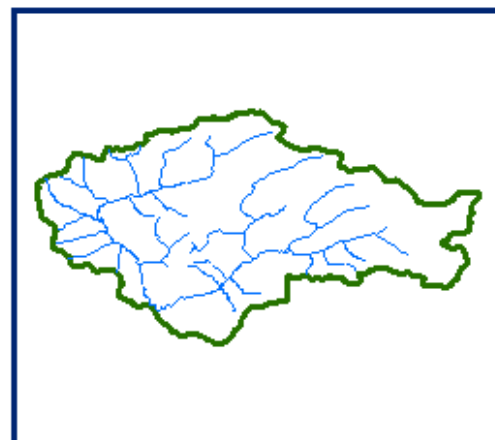
DATA NOT AVAILABLE
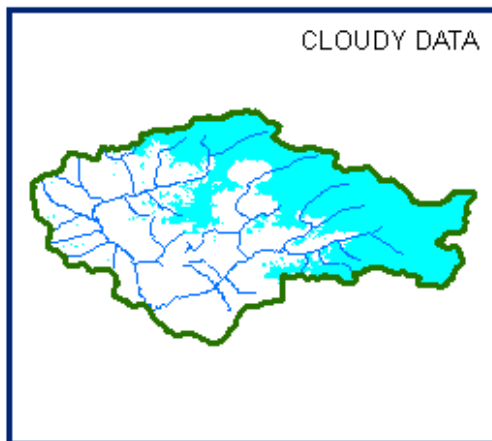
22 FEBRUARY 2012

26 FEBRUARY 2012

SNOW

0 12.5 25   50   75   100
Kilometers
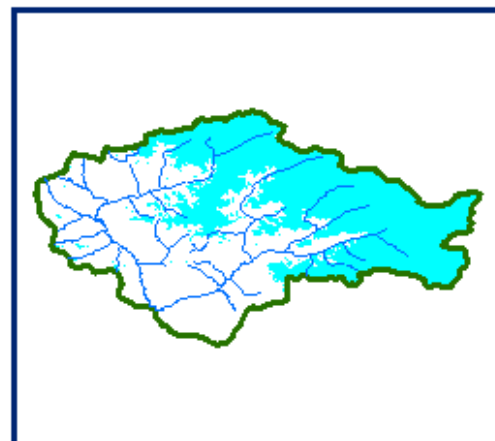
10 DAILY SNOW COVER MAP: YAMUNA BASIN
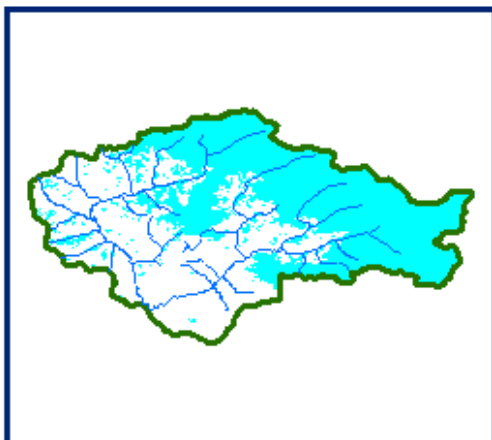
DATA USED
03 FEBRUARY 2012
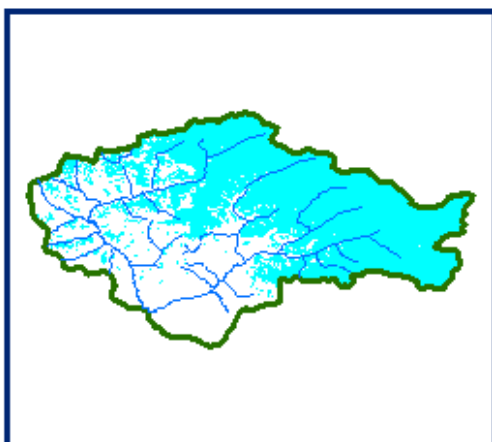
DATA USED
20 FEBRUARY 2012

DATA USED
29 FEBRUARY 2012

SNOW

0 12.5 25   50   75   100
Kilometers

SNOW COVER MAP : YAMUNA BASIN

CLOUDY DATA
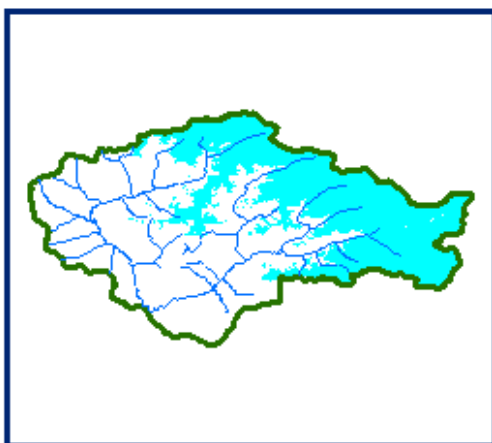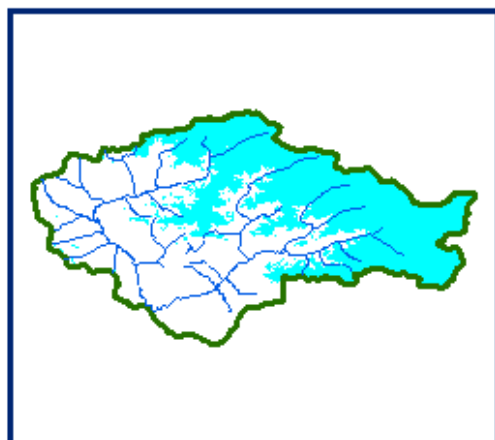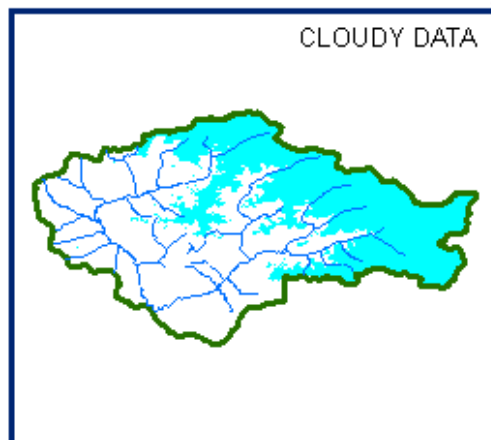
02 MARCH 2012
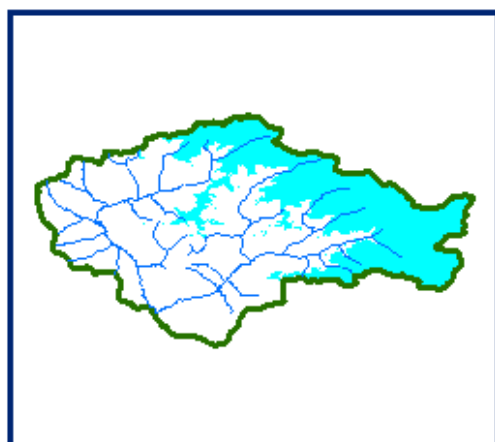
08 MARCH 2012

15 MARCH 2012
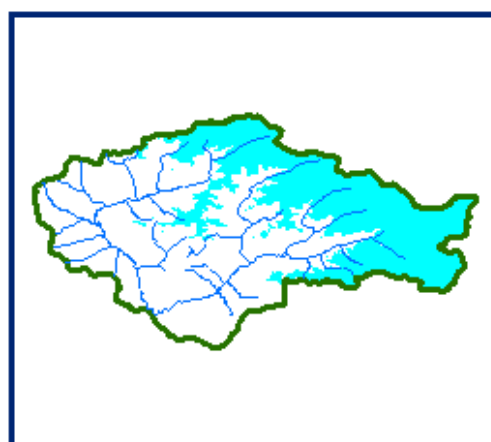
20 MARCH 2012
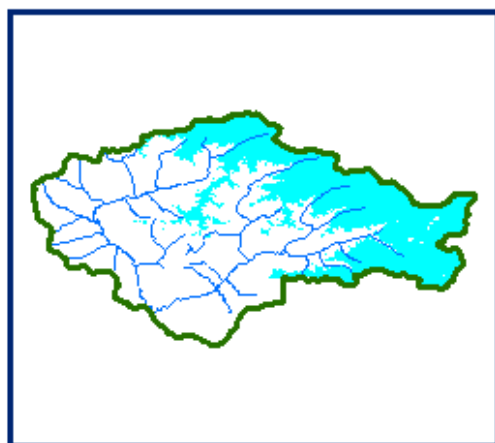
24 MARCH 2012
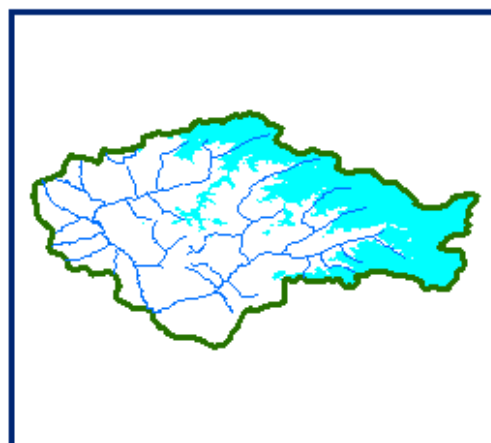
29 MARCH 2012

SNOW

0 12.5 25   50   75   100
Kilometers

10 DAILY SNOW COVER MAP: YAMUNA BASIN
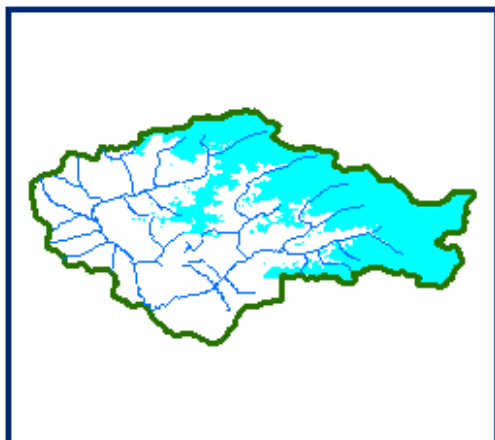
DATA USED
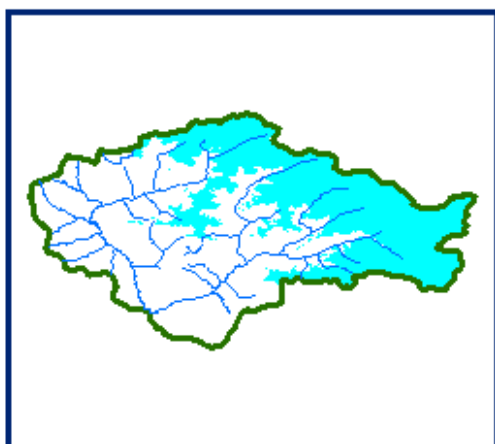
03 MARCH 2012

DATA USED
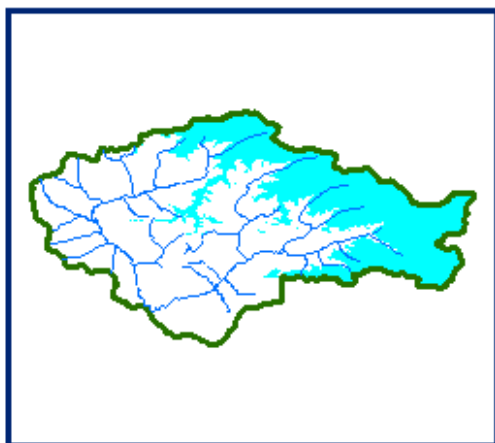
15 MARCH 2012

DATA USED

29 MARCH 2012

SNOW
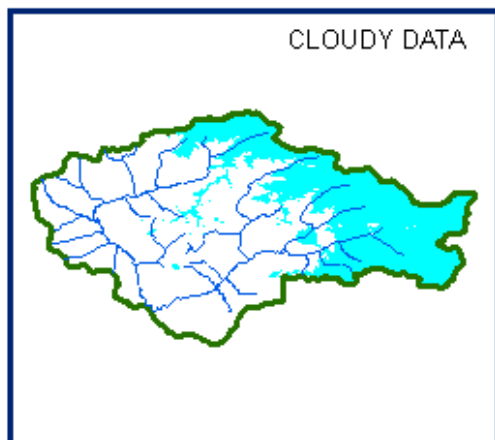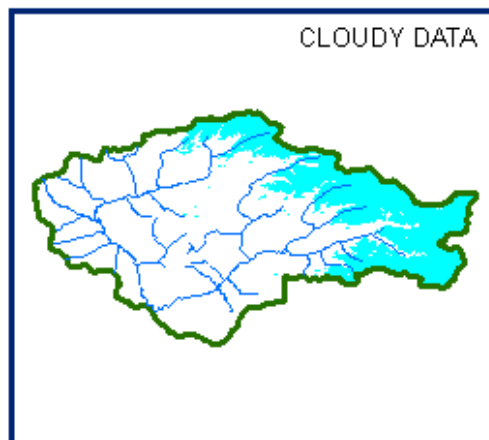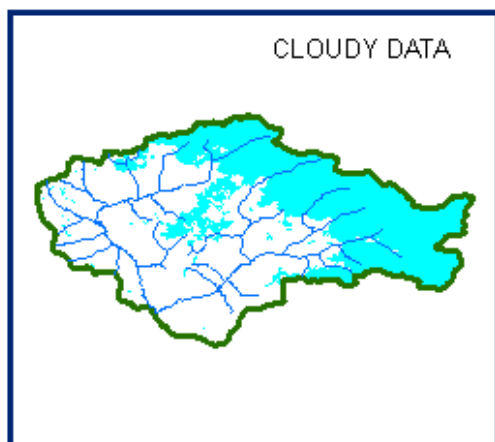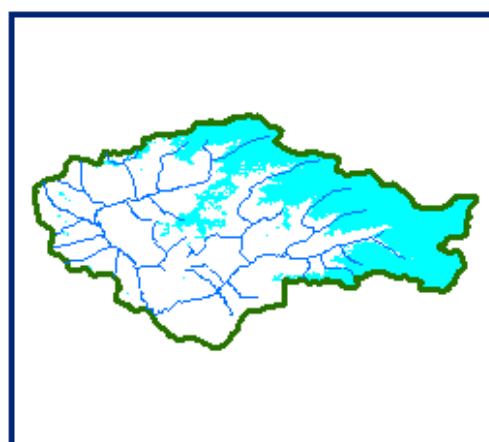
0 12.5 25   50   75   100

Kilometers

SNOW COVER MAP : YAMUNA BASIN

CLOUDY DATA

03 APRIL 2012

CLOUDY DATA

08 APRIL 2012

CLOUDY DATA

15 APRIL 2012

20 APRIL 2012

24 APRIL 2012

DATA NOT AVAILABLE

SNOW

0 12.5 25   50   75   100
Kilometers
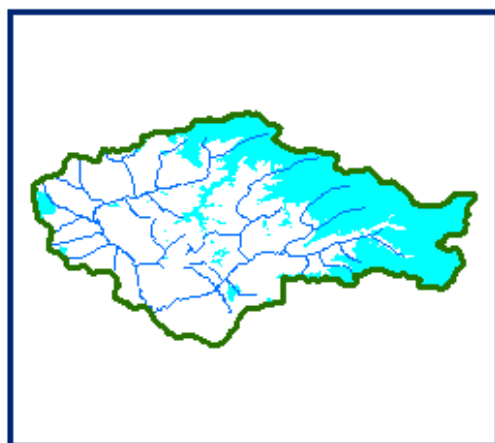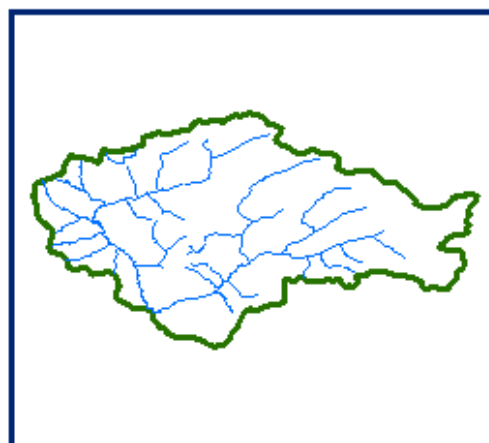
10 DAILY SNOW COVER MAP: YAMUNA BASIN
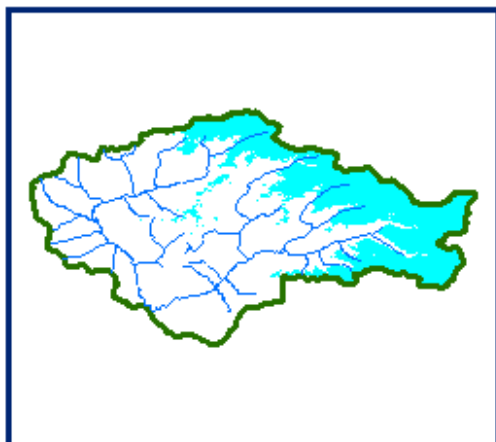
DATA USED

02 APRIL 2012
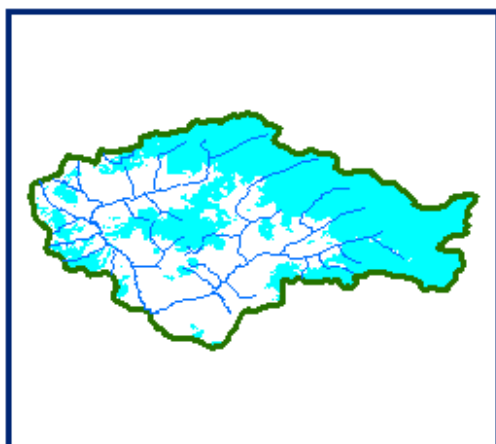
DATA USED
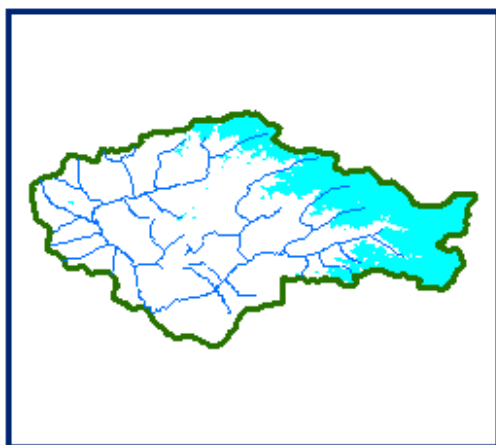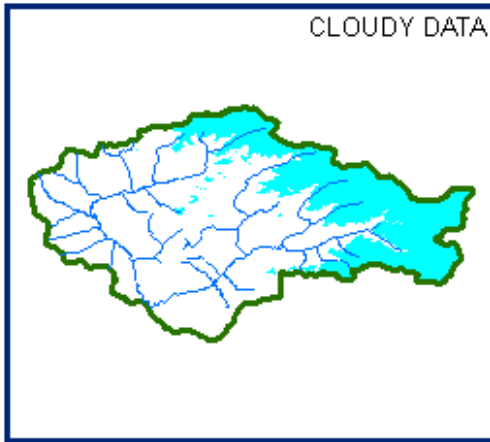
15 APRIL 2012

DATA USED

22 APRIL 2012

SNOW

0 12.5 25   50   75   100

Kilometers

72

SNOW COVER MAP : YAMUNA BASIN

CLOUDY DATA

02 MAY 2012

CLOUDY DATA

06 MAY 2012

CLOUDY DATA

13 MAY 2012

DATA NOT AVAILABLE

CLOUDY DATA

25 MAY 2012

CLOUDY DATA

30 MAY 2012

SNOW

0 12.5 25   50   75   100
Kilometers
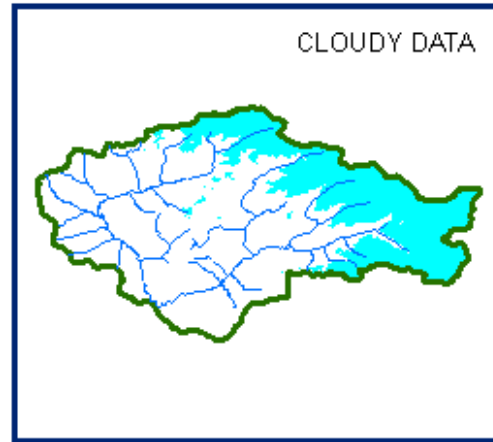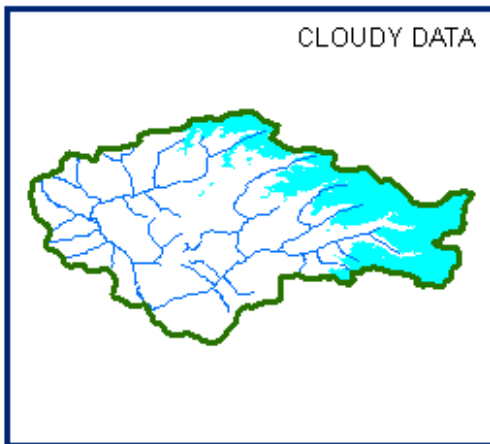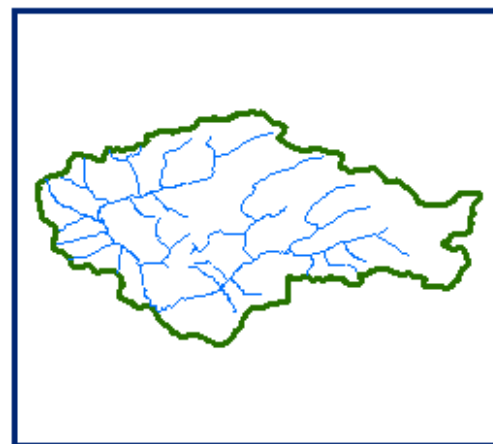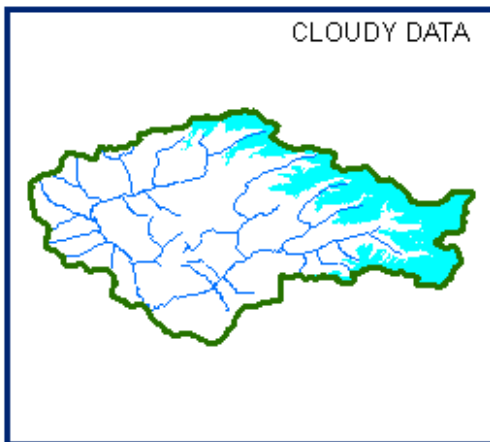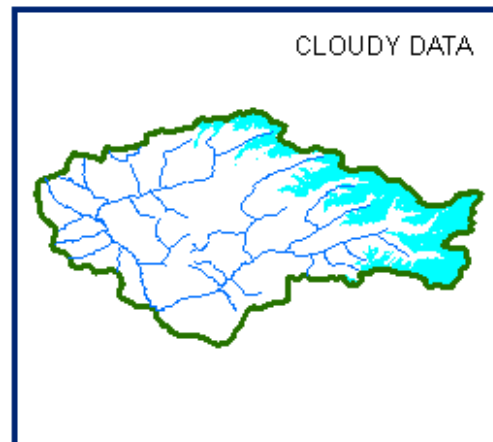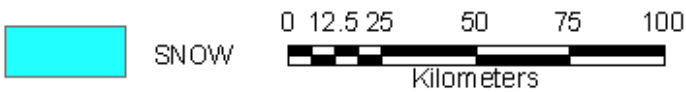
10 DAILY SNOW COVER MAP: YAMUNA BASIN
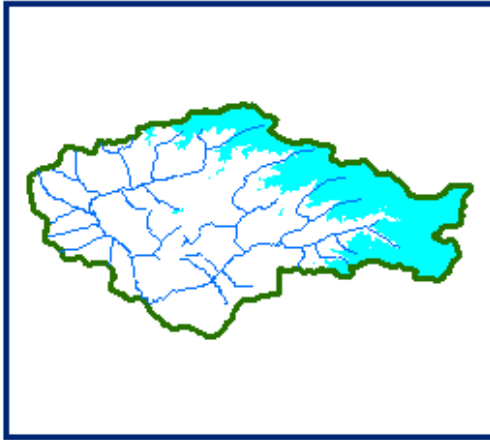
DATA USED

06 MAY 2012

DATA USED

16 MAY 2012

DATA USED

25 MAY 2012

SNOW

0   12.5 25   50   75   100

Kilometers

SNOW COVER MAP   :   YAMUNA BASIN

CLOUDY DATA

04 JUNE 2012

CLOUDY DATA

09 JUNE 2012

CLOUDY DATA

14 JUNE 2012

CLOUDY DATA

19 JUNE 2012

CLOUDY DATA

24 JUNE 2012

CLOUDY DATA

30 JUNE 2012
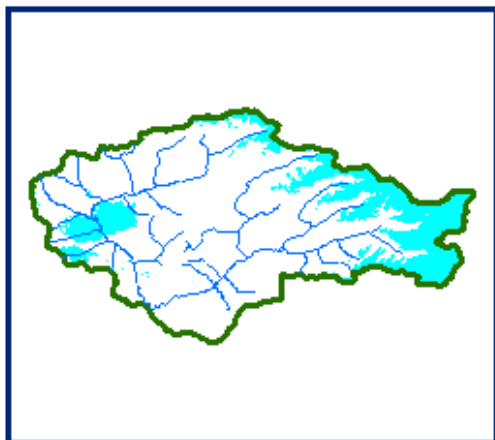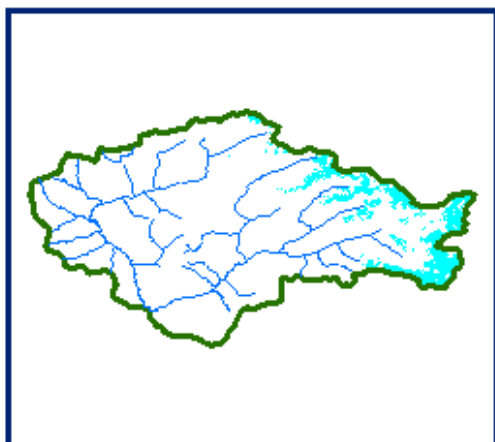
SNOW

0 12.5 25   50   75   100
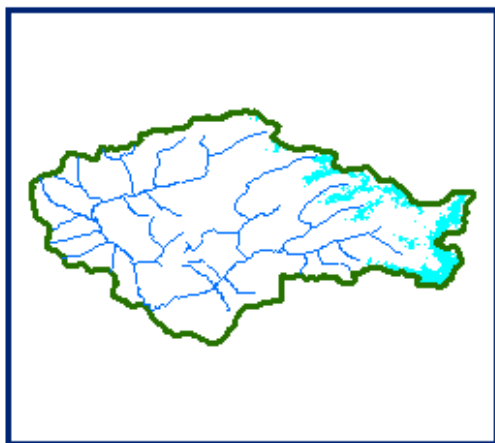Kilometers

10 DAILY SNOW COVER MAP: YAMUNA BASIN

DATA USED
02 JUNE 2012

DATA USED
14 JUNE 2012

DATA USED
23 JUNE 2012

SNOW

0 12.5 25   50   75   100
Kilometers