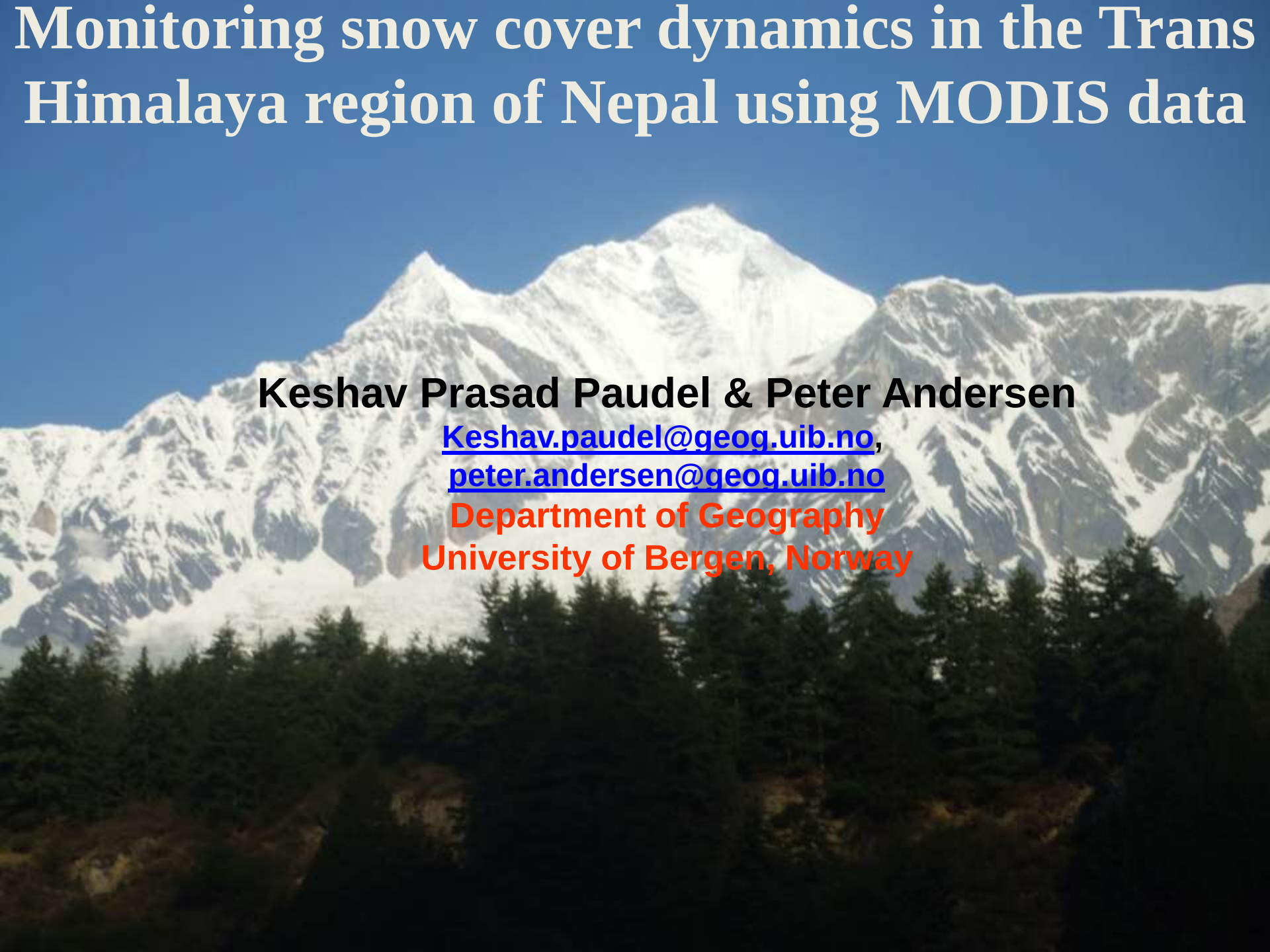
Monitoring snow cover dynamics in the Trans Himalaya region of Nepal using MODIS data



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Background

- Snow cover in the Himalaya
- @ local scale

….which have been generally ignored

Background

- Data and knowledge gap

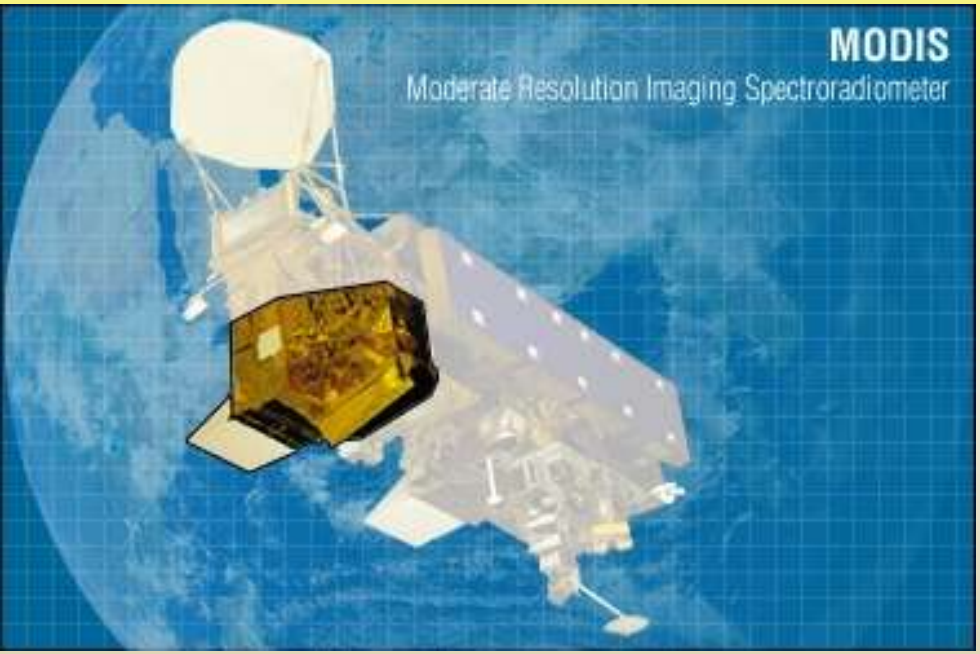
"...if the present rate continues, the likelihood of 'glacier in the Himalayan region' disappearing by the year 2035 … " IPCC (2007: 493)

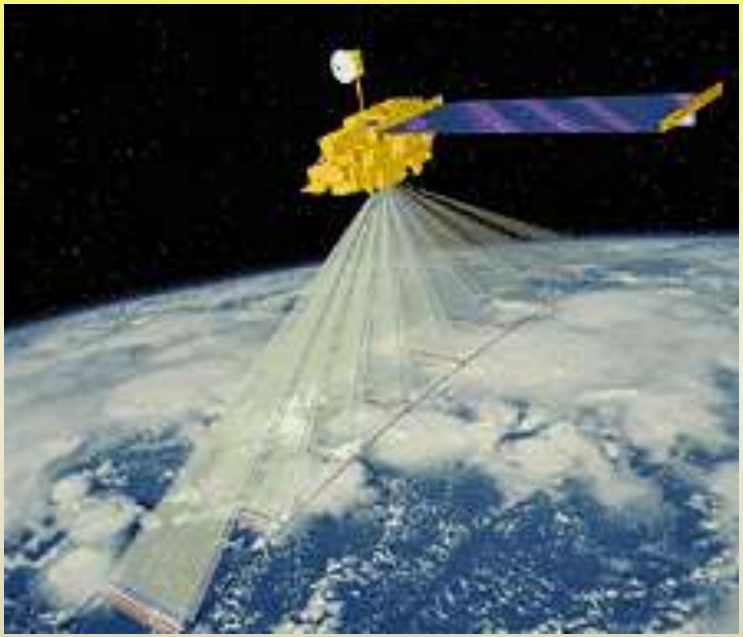
"…refers to poorly substantiated estimates of rate of recession and date for the disappearance of Himalayan glaciers…" **IPCC (2010 Jan 20)**

- No ground observation data available

MODIS snow cover data

- Freely available, 500 m resolution, daily
- Cloud obscuration – main limitation



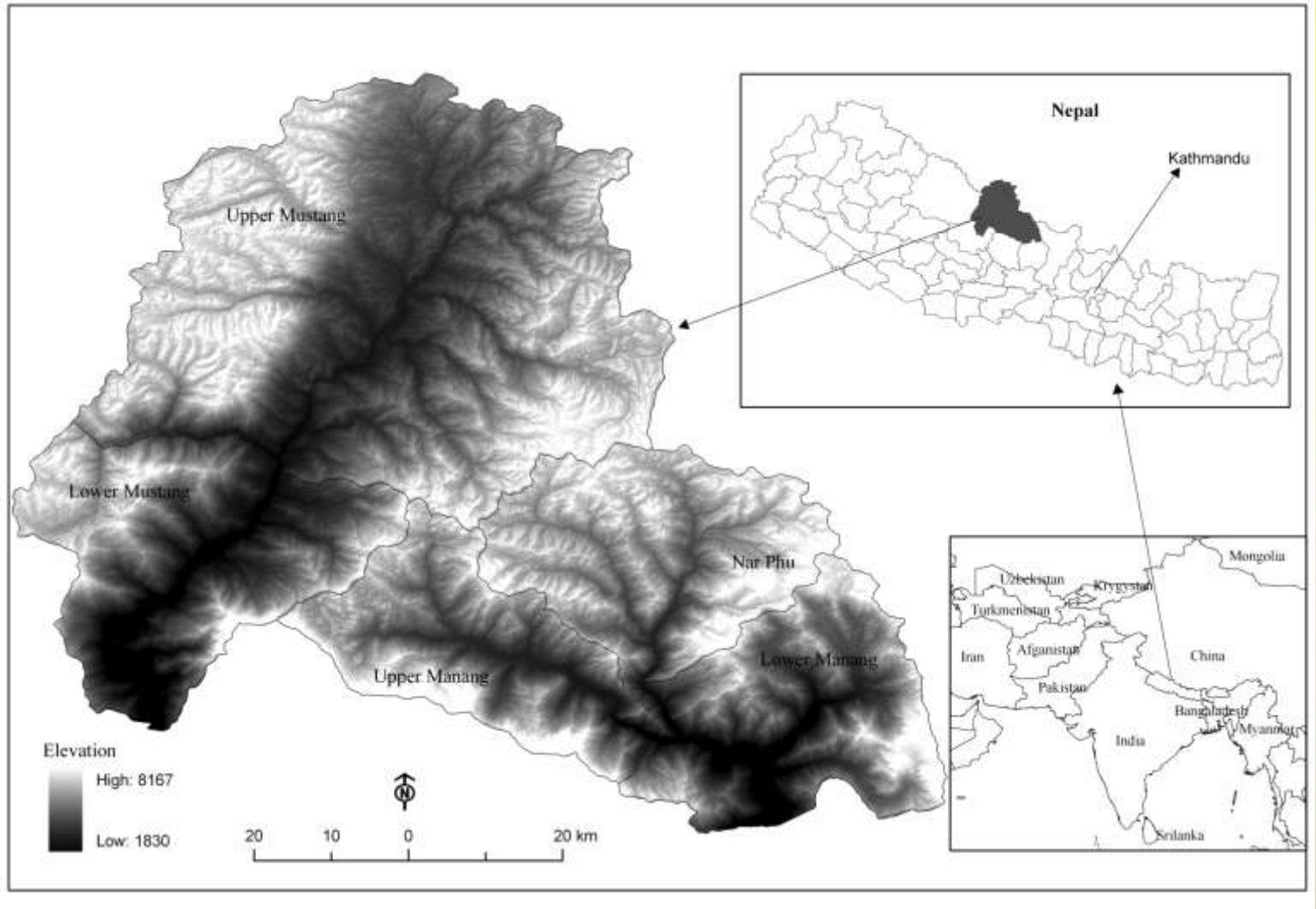


Objectives

- Improve and develop method to reduce cloud cover

- examine the spatial and temporal variability of snow cover

Study area


Upper Mustang
Lower Mustang
Nar Phu
Upper Manang
Lower Manang
Nepal
Kathmandu
Mongolia
Uzbekistan
Kyrgyzstan
Turkmenistan
Iran
Afganistan
China
Pakistan
Bangladesh
Myanmar
India
Srilanka
Elevation
High: 8167
Low: 1830
20
10
0
20 km

Method

Data

- MODIS Terra (MOD10A1) – Oct 1, 2000 – Apr 30, 2010
  2105 images (27 missing)
- MODIS Aqua (MYD10A1) – Oct 1, 2002 – Apr 30, 2010
  1707 images (1 missing)

- SRTM DEM 90 m resolution

- Landuse map 2000 (1:50,000), Survey Department/NG

- SPOT 4 (XI) image,20 m resolution, 16 Oct 2008

Cloud removal methodology

- snow = 200, no snow = 25, cloud = 1
- Python programming in ArcGIS
- Five subsequent steps

1. Terra – Aqua snow cover image composites

$$S_{(y,x,t)} = \max(S^{T}_{(y,x,t)}, S^{A}_{(y,x,t)}) \quad (1)$$

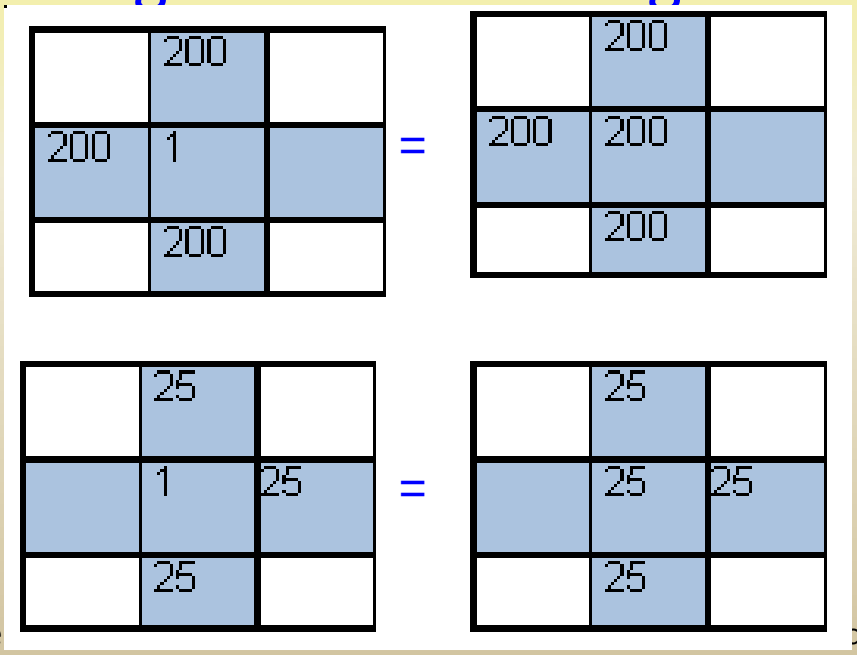
Cloud removal methodology

2. Adjacent temporal deduction

$$\text{if } (S_{(y,x,t-1)} = 200 \text{ and } S_{(y,x,t+1)} = 200),\ S^{c}_{(y,x,t)} = 200 \qquad (2)$$

$$\text{if } (S_{(y,x,t-1)} = 25 \text{ and } S_{(y,x,t+1)} = 25),\ S^{c}_{(y,x,t)} = 25 \qquad (3)$$

3. Spatial filtering based on orthogonal neighboring pixels



Cloud removal methodology

4. Zonal snow transition line approach

- landscape unit within a sub-basin further sub divided by combination of aspect and land cover classes

if $(H^{c}_{(y,x)} > \text{zonalmin}(H^{S}_{z}) > \text{zonalmax}(H^{NS}_{z})$ and $C_z < 75$ and $S < 60)$, $S^{c}_{(y,x,t)} = 200$

But

if $\text{zonalmin}(H^{S}_{z}) < \text{zonalmax}(H^{NS}_{z})$

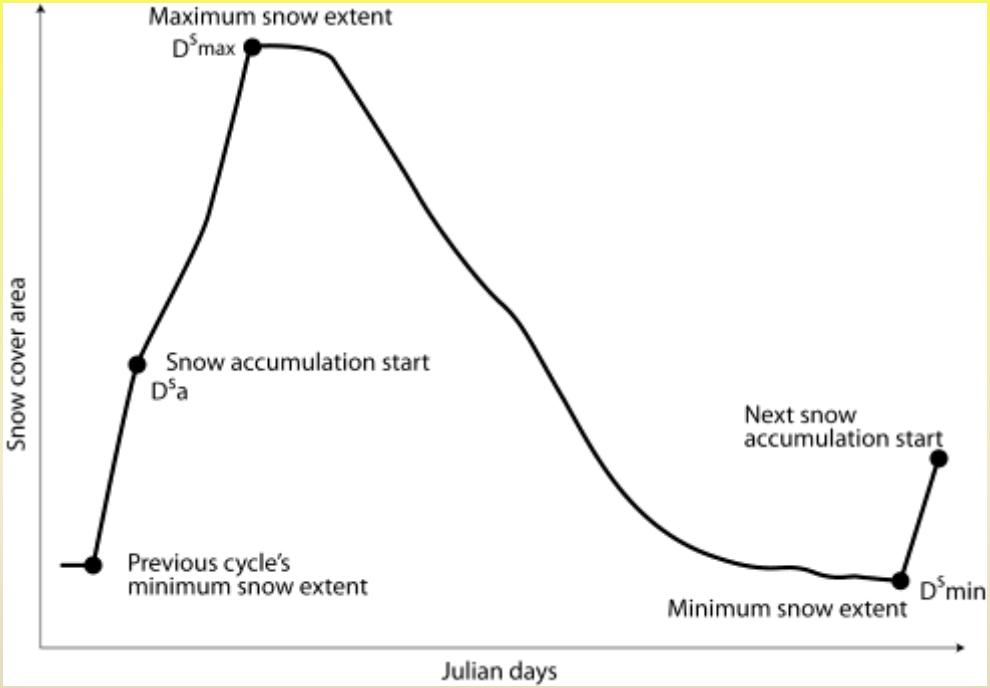
Then

if $(H^{c}_{(y,x)} > \text{zonalmean}(H^{S}_{z}) > \text{zonalmax}(H^{NS}_{z})$ and $C_z < 75$ and $S < 60)$, $S^{c}_{(y,x,t)} = 200$

if $(H^{c}_{(y,x)} < \text{zonalmean}(H^{NS}_{z}) < \text{zonalmin}(H^{S}_{z})$ and $C_z < 75)$, $S^{c}_{(y,x,t)} = 25$

Cloud removal methodology

5. Zonal snow cycle



For $D^s_{\min} \geq t > D^s_{\max}$

$$if\,(S_{(y,x,t)} = 200), S^c_{(y,x,t-1)} = 200$$

For $D^s_{\min} < t \leq D^s_{\max}$

$$if\,(S_{(y,x,t)} = 25), S^c_{(y,x,t+1)} = 25$$

For $D^s_a < t \leq D^s_{\max}$

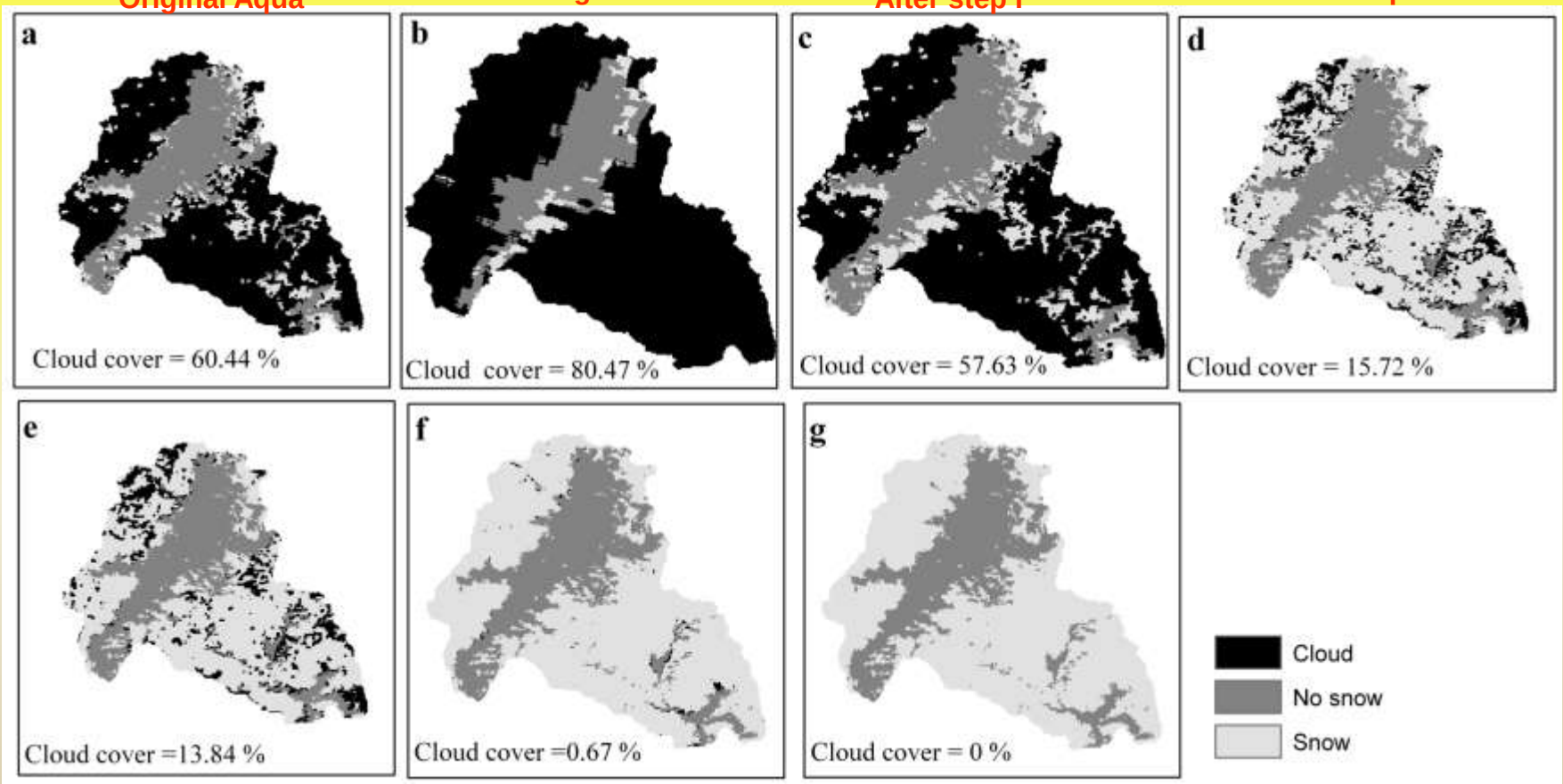
$$if\,(S_{(y,x,t)} = 25), S^c_{(y,x,t-1)} = 25$$

For $D^s_a \geq t > D^s_{\max}$

$$if\,(S_{(y,x,t)} = 200), S^c_{(y,x,t+1)} = 200$$

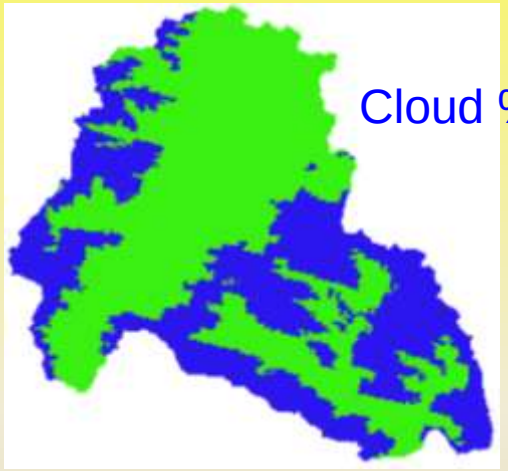
Results

Cloud cover in original images and after implementation of each steps (20 Feb 2005)



Accuracy assessment

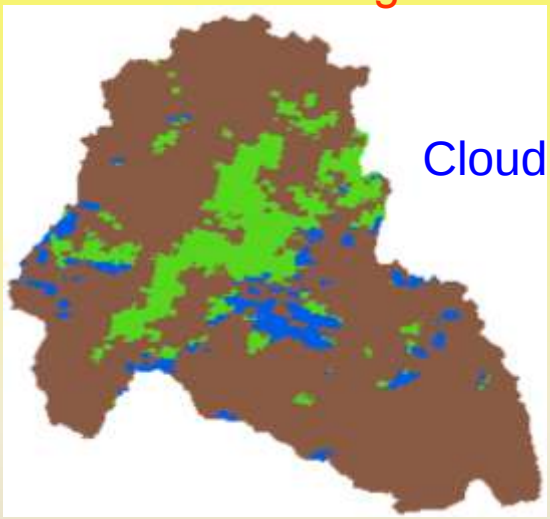
Ground truth



Cloud % = 0.002

Original MODIS Terra
30 Apr 2006

"observed image"



Cloud % = 80.1%

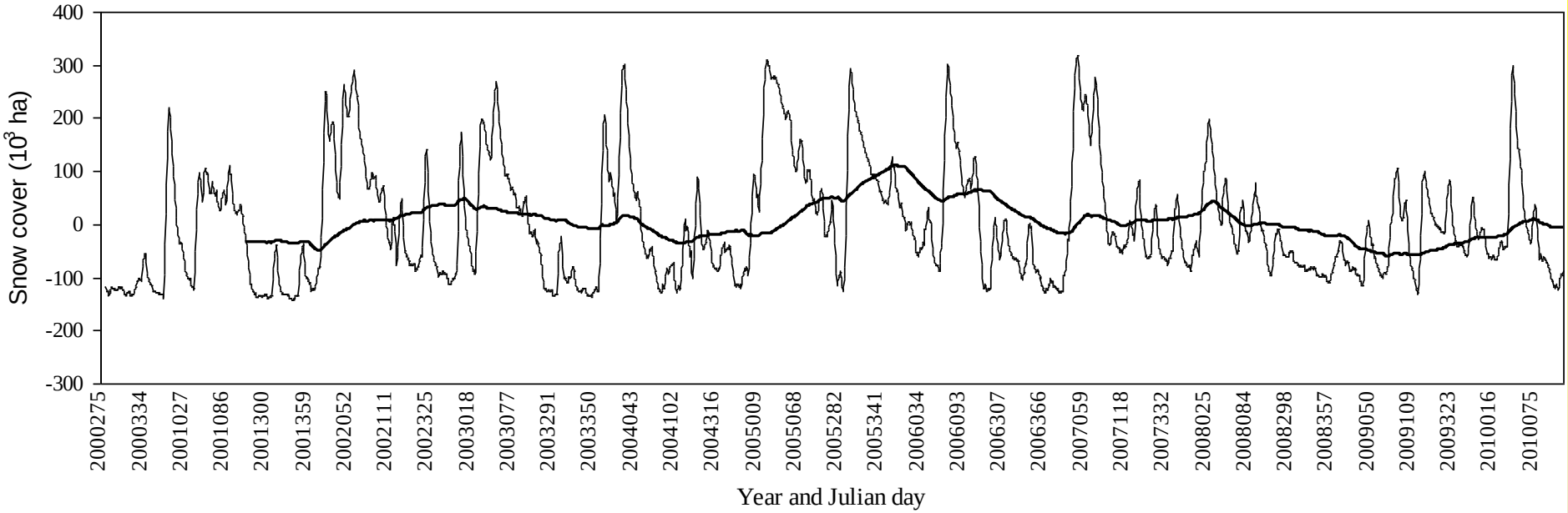
Cloud filled by
2 March 2007

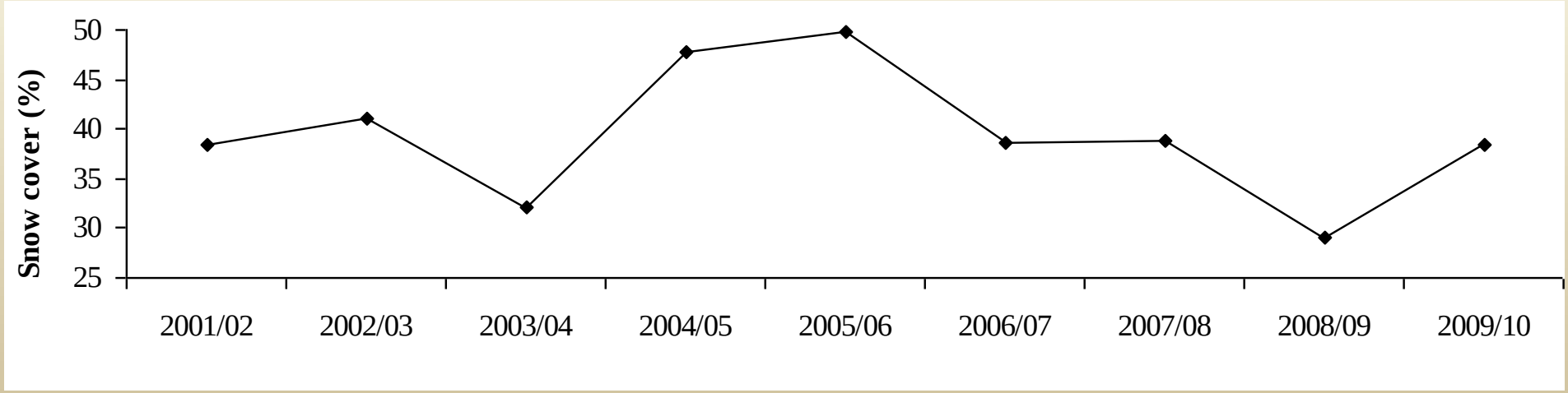
Accuracy assessment

Validation test day	Steps	Total cloud elimination	Agreement			Disagreement		
			Snow	No snow	Total	UE	OE	Total
	2	52.28	29.11	21.35	50.46	1.15	0.67	1.82
	3	1.44	0.88	0.45	1.33	0.06	0.05	0.11
	4	28.95	20.00	4.42	24.42	2.62	1.91	4.53
	5	16.71	8.06	7.91	15.97	0.30	0.44	0.74
2005 March 14	Total	99.38	58.05	34.13	92.18	4.13	3.07	7.20
	2	72.35	23.51	44.37	67.88	4.14	0.32	4.47
	3	1.90	0.78	1.00	1.79	0.07	0.04	0.11
	4	16.03	9.98	4.52	14.50	0.33	1.20	1.53
	5	8.96	6.28	1.46	7.74	0.11	1.11	1.22
2006 April 30	Total	99.24	40.55	51.35	91.90	4.65	2.68	7.33
	2	60.05	17.33	39.22	56.55	2.39	1.11	3.51
	3	0.84	0.51	0.26	0.77	0.01	0.05	0.07
	4	20.59	16.73	0.03	16.76	0.13	3.70	3.83
	5	18.28	5.61	11.51	17.12	0.37	0.79	1.16
2007 March 29	Total	99.76	40.19	51.01	91.20	2.90	5.66	8.56

Results

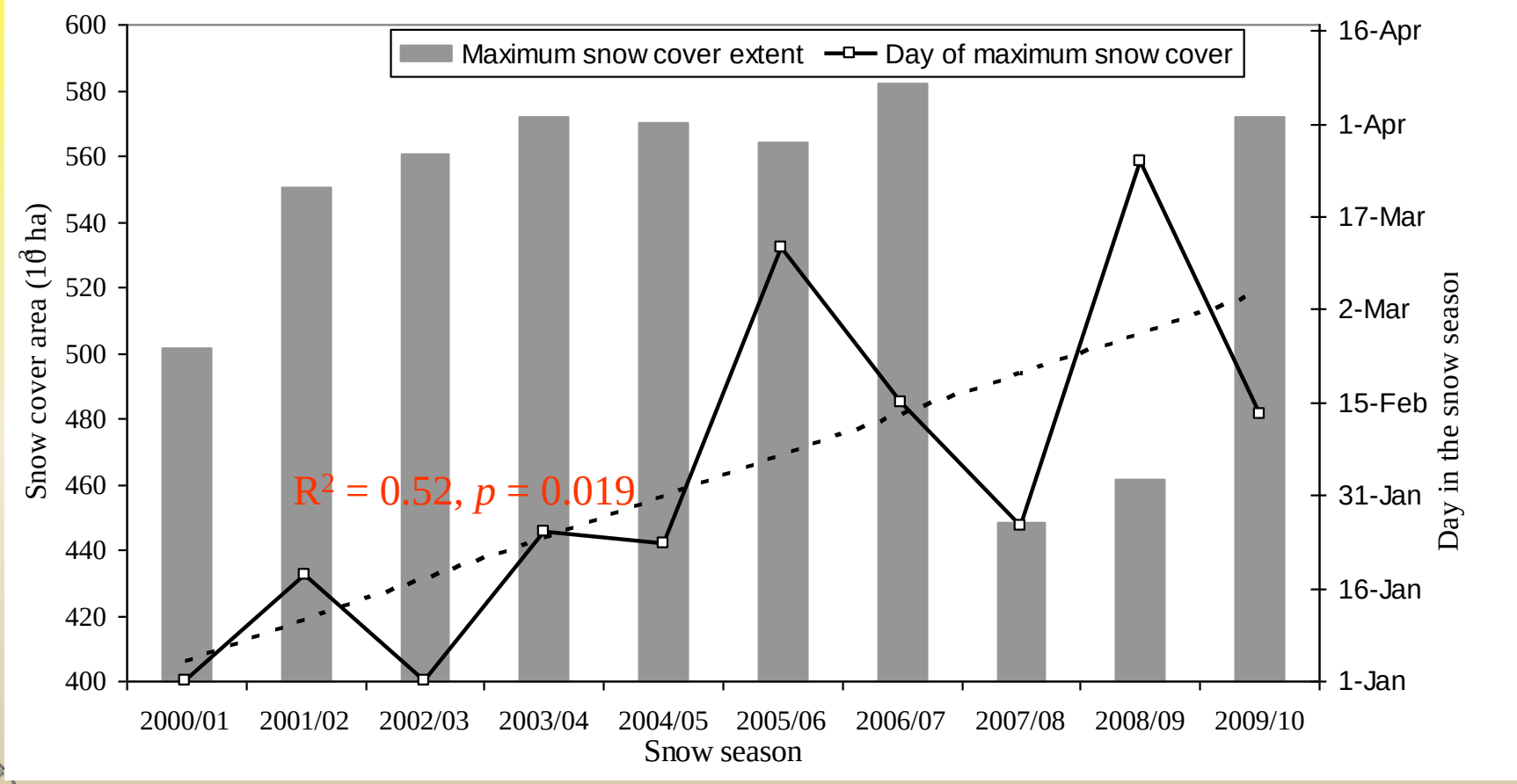
- Snow cover variability and trend





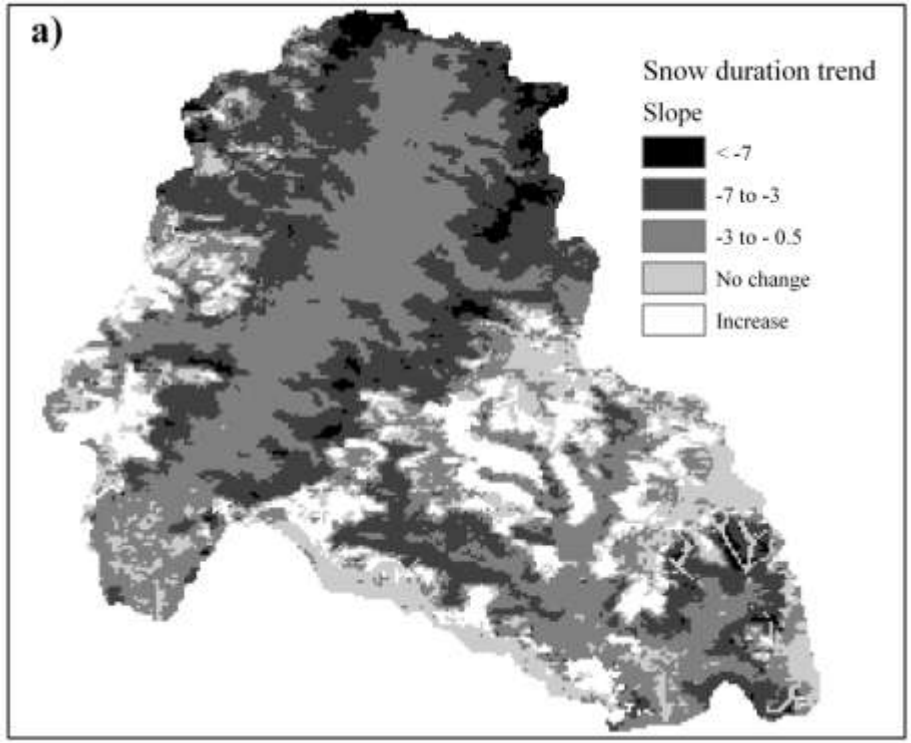
Results

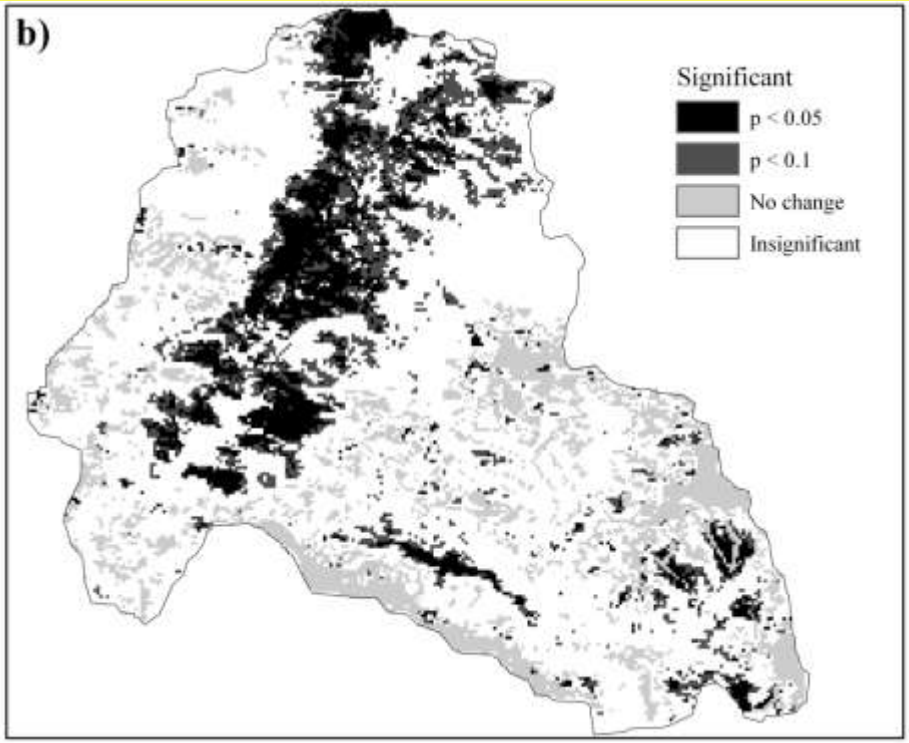
- Maximum snow cover extent and day of maximum snow cover



Results

- Snow cover duration trend





Conclusion

- Five steps approach presents a robust technique
- High interannual and intra-seasonal variability
- Peak snow day shifted forward by 6.7 days yr^{-1}
- Feb/March are main snow months
- Declining trend of snow cover duration in agropastoral areas