

Large-scale monitoring of snow cover area and variability in Hindu Kush-Himalaya region.

Deo Raj Gurung
drgurung@icimod.org

International Centre for Integrated Mountain Development

Kathmandu, Nepal

ICIMOD

FOR MOUNTAINS AND PEOPLE



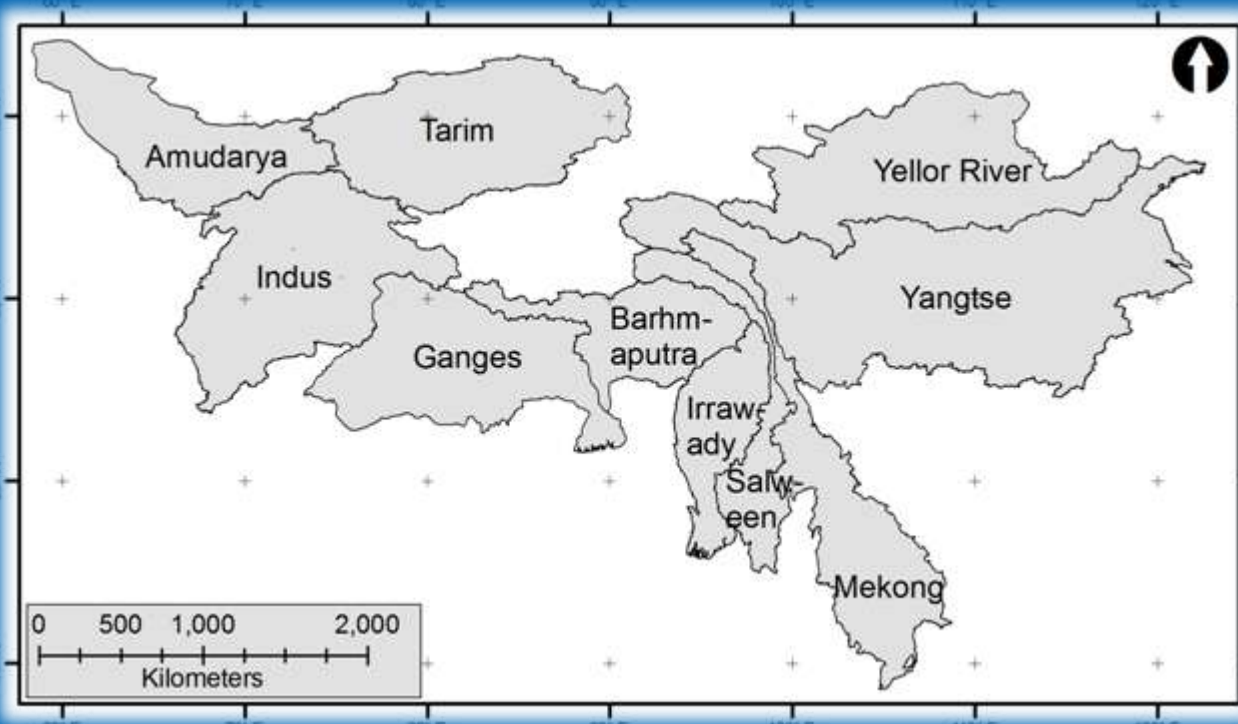
International Symposium
**Benefiting from
Earth Observation**
Bridging the Data Gap for Adaptation
to Climate Change in the HKH Region

Team members

- Dr. Giriraj Amarnath
- Mr. Khun San Aung
- Mr. Basanta Shrestha

Study scope

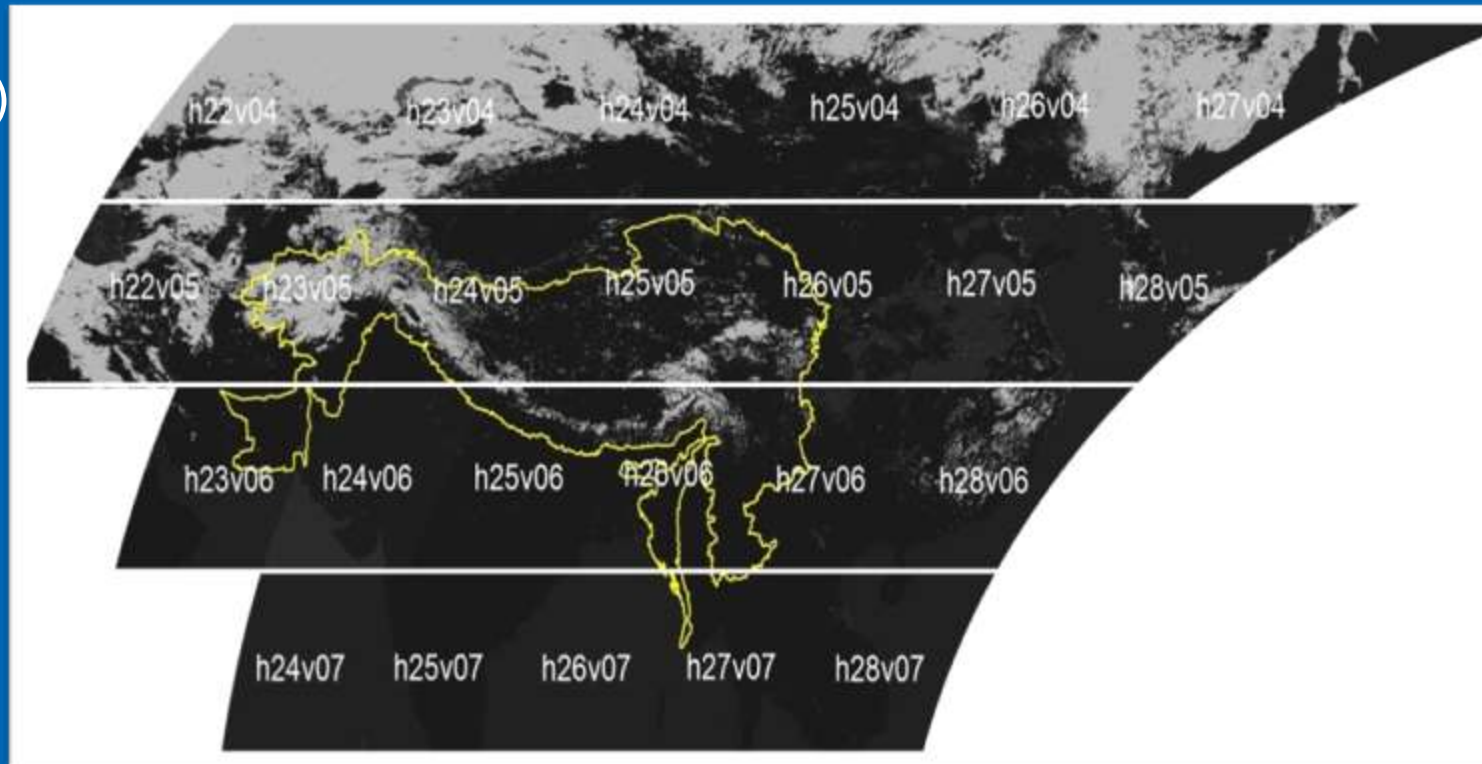
- Snow cover distribution pattern – aspect, altitude and slope.
- Intra-annual and inter-annual trend?
- Seasonal trend?



Data and sources

- MODIS 8-day products (MOD10A2 and MYD10A2) – NSIDC

24 tiles
(120km x 120km)



- SRTM DEM v4

- Elevation;
- Aspect;
- Slope

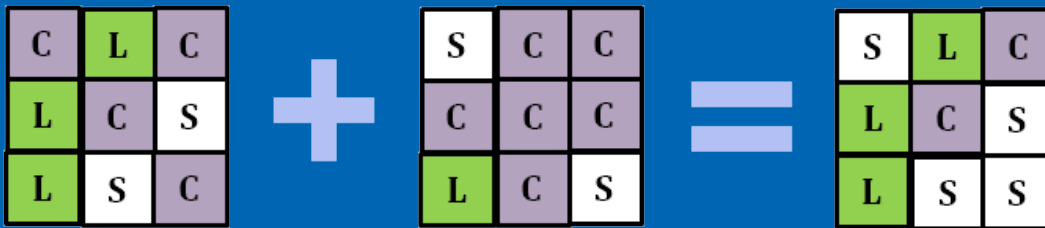
- Boundary data:

- HKH boundary file - ICIMOD;
- Basin boundary – Generated from SRTM DEM

Methodology

1. Cloud removal techniques

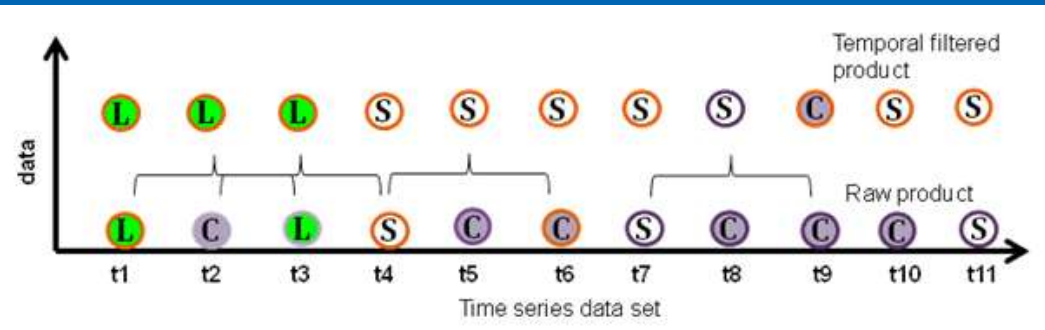
1.1 Combining Terra and Aqua



$$S(x, y, t) = \max (S^A(x, y, t), S^T(x, y, t))$$

y: index for row (vertical);
x: index for column (horizontal);
t: index for day of pixel **S**.
S^A and **S^T**: Aqua and Terra pixels

1.2 Temporal filtering



S-8, S and S+8: three consecutive set of 8-day products
1: corresponds to snow cover
0: for land cover

$$S(x, y, t) = 1 \text{ if } (S(x, y, t - 8) = 1 \text{ OR } S(x, y, t + 8) = 1$$

Methodology

1. Cloud removal techniques

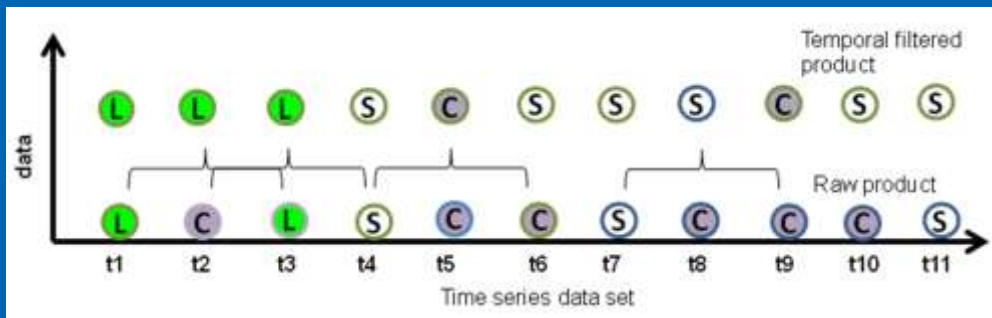
1.3 Spatial filtering



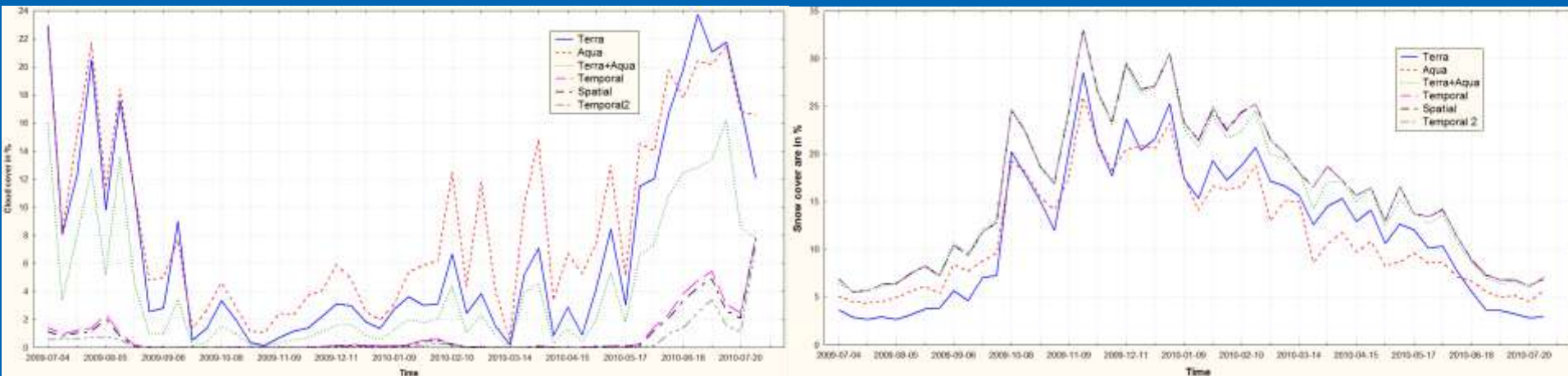
1.4 Altitude based filtering

Zone	Elevation	Latitude	Longitude		Baseline	Purpose
			From	To		
Pakistan, India, Bangladesh, Myanmar	< 2000 m	< 26°N	70°E 58°E?	98°E	Lowest snow line (Ground information)	Need DEM for S. India
Thailand, Laos, Vietnam, Hainan, Taiwan, Philippine	< 2000 m	< 21°N	98°E	123°E	Ground Information (Mt. Guanshan, 3668m, Taiwan)	Need DEM for Taiwan. If to Include Taiwan on map.

1.5 Temporal filtering (2nd)



2. Sensitivity analysis of different filtering steps



Cloud profile

Snow profile

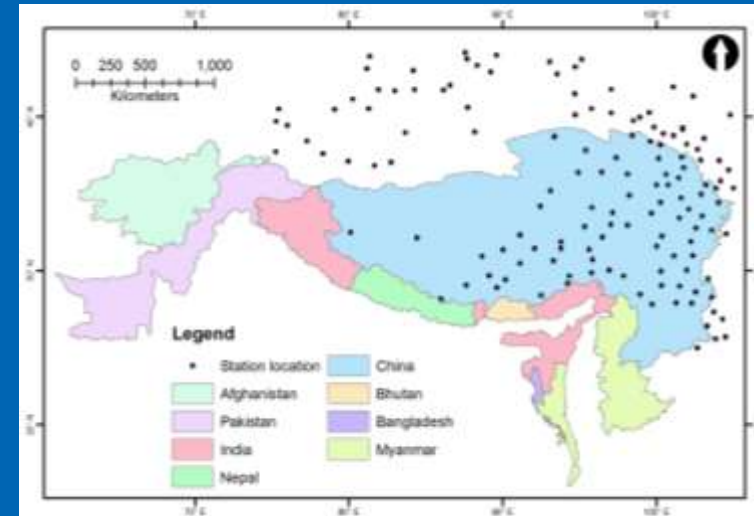
Accuracy assessment

1. Absolute accuracy – based on in situ data

In situ data from 168 stations

(courtesy Dr. Lingmei Jiang, Beijing Normal University (BNU).

- Snow depth (SD)
- Snow water equivalent (SWE)



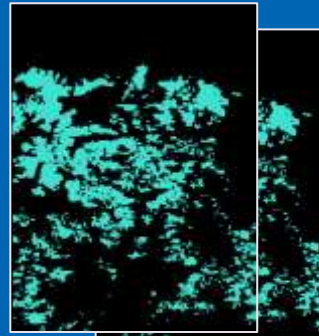
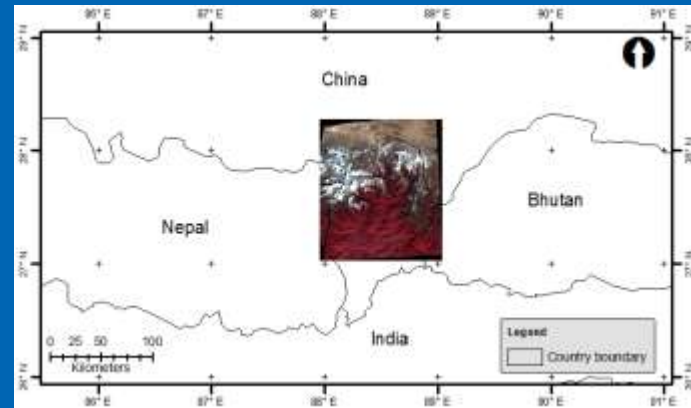
Sl. No.	Product Date	No. of points	Over all accuracy	Kappa Statistics
1.	17.11.2003	28	46.15%	0.1034
2.	01.12.2003	41	97.30%	0.9165
3.	15.01.2004	95	54.95%	0.2196
4.	15.02.2004	71	73.53%	0.4383
5.	16.03.2004	68	92.19%	0.4161

Lower accuracy according to Ault et al., 2006 is related to presence of thin (<10 mm depth) traces of snow.

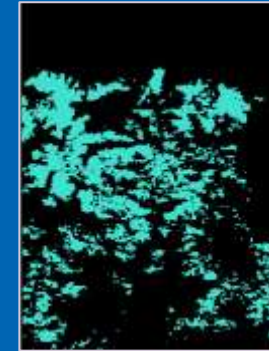
Accuracy assessment

1. Relative accuracy – based on high resolution snow product

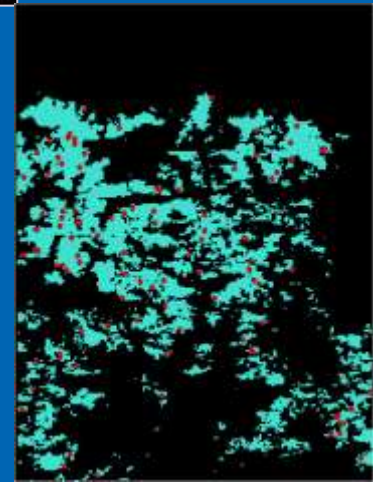
AWiFS (58m res.) – 16 Jan and 21 Jan 2006 *(courtesy Dr. Anil Kulkarni)*



16 and 21 Jan
AWiFS products



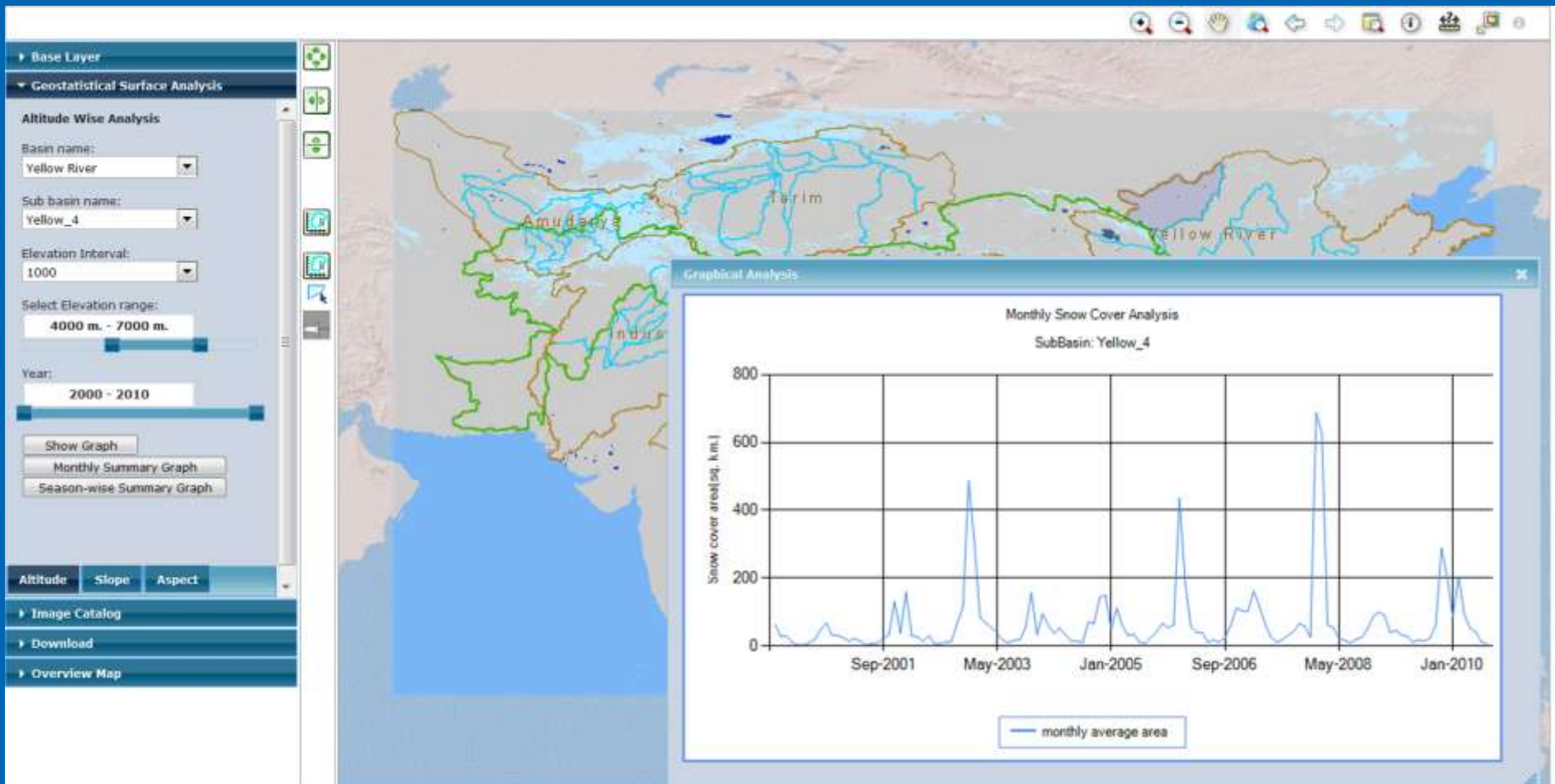
AWiFS 5-day
composite



Over all accuracy = 93.00 %

Cryosphere portal

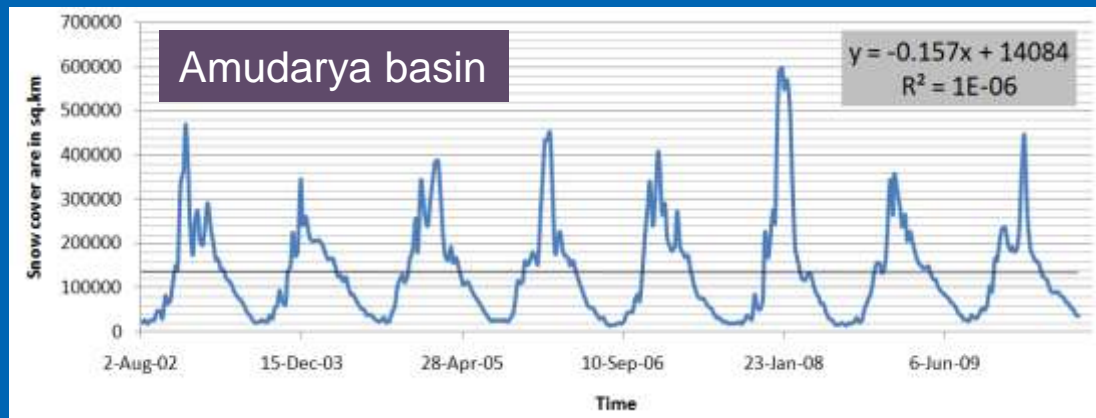
Present data base: 8-day product (March 2000 to upto date)



Preliminary analysis & results

Inter-annual and seasonal trend

Inter-annual trend: data used August 2002 – July 2010



Sl. No.	Basin	Trend	Sl. No.	Basin	Trend
1	Amudarya	+0.0098	6	Irrawaddy	-0.0021
2	Tarim	-0.0022	7	Salween	-0.012
3	Indus	+0.0197	8	Mekong	-0.0004
4	Ganges	-0.0097	9	Yangtze	+0.001
5	Barhmaputra	-0.0367	10	Yellow River	-0.008

Summary of inter-annual & seasonal trend

Immerzeel et al. 2009
Jain et al. 2006

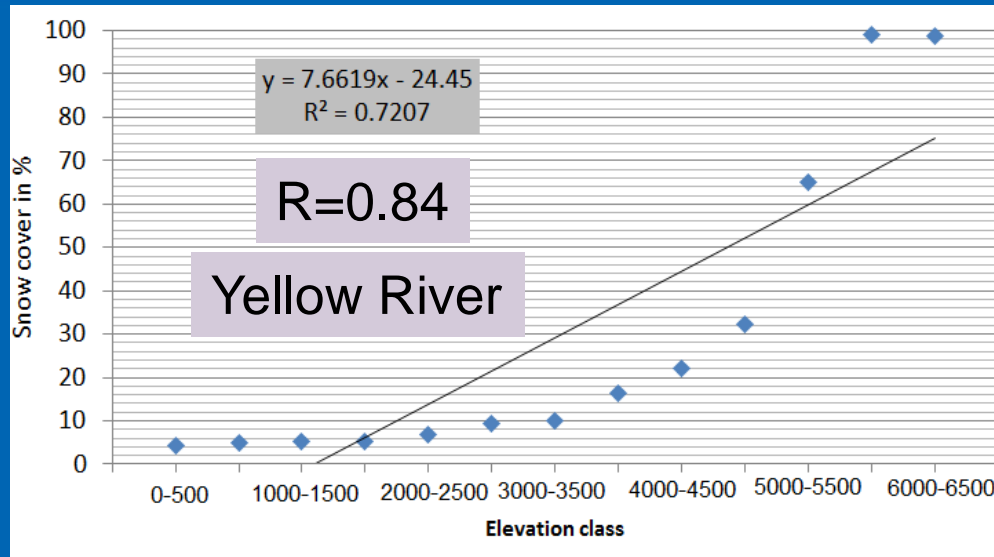
Season	Months
Winter	Dec - March
Spring	April - June
Summer	July – Sept
Autumn	Oct - Nov

Sl. No.	Basin	Trend	Winter	Summer
1	Amudarya	+0.0098	+0.002	+0.266
2	Tarim	-0.0022	-0.159	-3.708
3	Indus	+0.0197	+0.099	+0.213
4	Ganges	-0.0097	-0.174	-0.069
5	Barhmaputra	-0.0367	-0.612	-0.395
6	Irrawady	-0.0021	-0.038	-0.017
7	Salween	-0.012	+0.652	+0.040
8	Mekong	-0.0004	+0.002	+0.209
9	Yangtse	+0.001	-0.208	-0.104
10	Yellow River	-0.008	-0.0381	-0.0957

Elevation wise snow cover trend

	Amudarya	Tarim	Indus	Ganges	Brahmapu	Irrawady	Salween	Mekong	Yangtse	Yellow R.
0-500	0.816								-1.464	-0.932
500-1000	0.085	-0.87	0	-0.000004					-0.831	-0.713
1000-1500	-0.172	-1.445	-0.013	-0.047	-0.04	-0.032	-0.012	-0.011	-0.08	-2.691
1500-2000	-0.27	-1.277	-0.077	-0.193	-0.109	-0.07	-0.037	-0.032	-0.312	-0.419
2000-2500	-0.237	-0.531	-0.082	-0.272	-0.146	-0.086	-0.047	-0.021	-0.327	0.186
2500-3000	-0.258	-0.315	0.089	-0.292	-0.179	-0.084	-0.08	-0.046	-0.306	-0.147
3000-3500	-0.28	-0.335	0.145	-0.306	-0.214	-0.067	-0.12	-0.093	-0.48	-0.329
3500-4000	0.002	-0.088	0.398	-0.298	-0.3	-0.037	-0.065	-0.022	-0.592	-0.52
4000-4500	0.011	-0.163	0.879	-0.285	-0.606	-0.022	-0.054	0.072	-0.39	0.516
4500-5000	0.157	0.904	1.037	-0.26	-2.041	-0.013	-0.936	-0.111	1.425	0.422
5000-5500	-0.002	0.847	1.093	-0.309	-3.307	0	-0.666	-0.138	0.3	0.00007
5500-6000	-0.006	-0.135	0.411	-0.135	-0.853		-0.014	0	-0.018	0.00008
6000-6500	-0.001	-0.005	0.003	-0.008	-0.011		0.000005	-0.000008	0.00002	0.0000007
6500-7000	0.00004	-0.001	-0.001	0	0		-0.000002		0.00001	
7000-7500	-0.000007	0	0	0.00003	-0.00003				0.235	
7500-8000	-0.008	-0.00005	0.00003	0.00009	0.000003					
8000-8500	0	0	0.00003	0.00002						

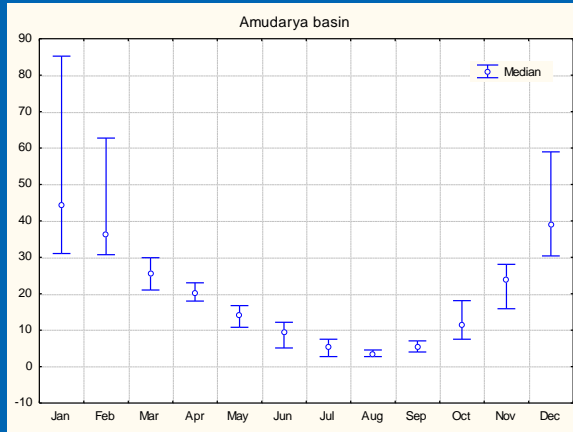
Relationship between elevation and snow distribution



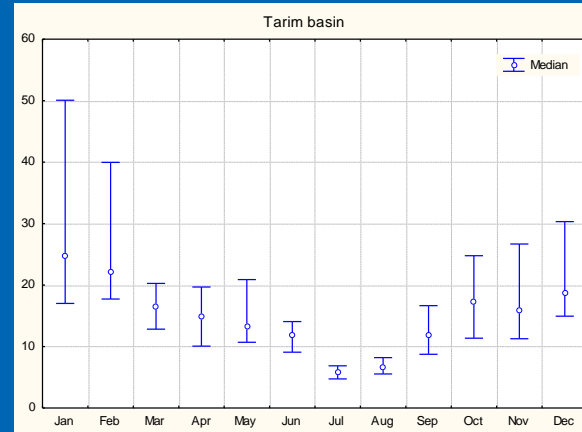
Average snow cover area in % over Aug 2002 to July 2010 plotted Vs. elevation classes (500 m)

Basin	R
Amudarya	0.98
Tarim	0.69
Indus	0.96
Ganges	0.96
Barhmaputra	0.91
Irrawady	0.99
Salween	0.93
Mekong	0.88
Yangtse	0.89
Yellow River	0.84

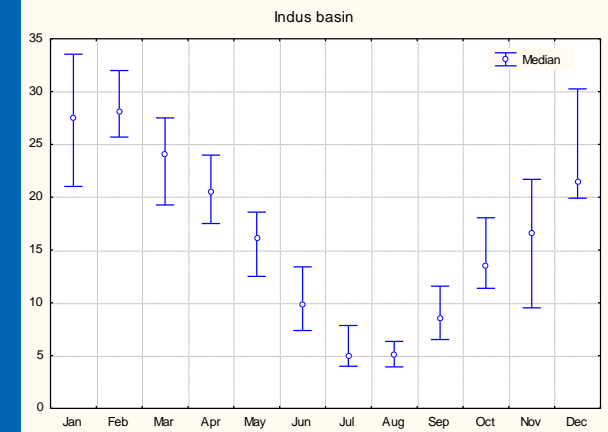
Monthly variation of snow cover area



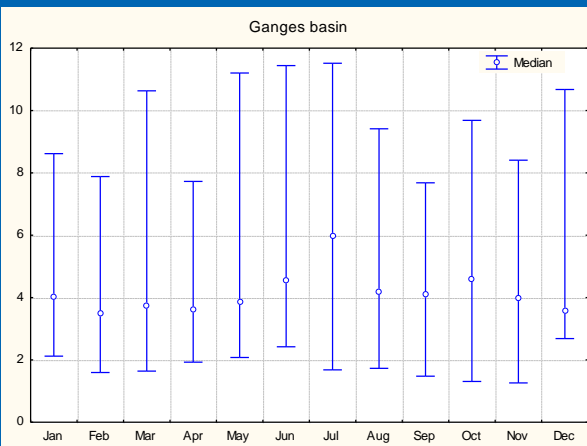
Amudarya



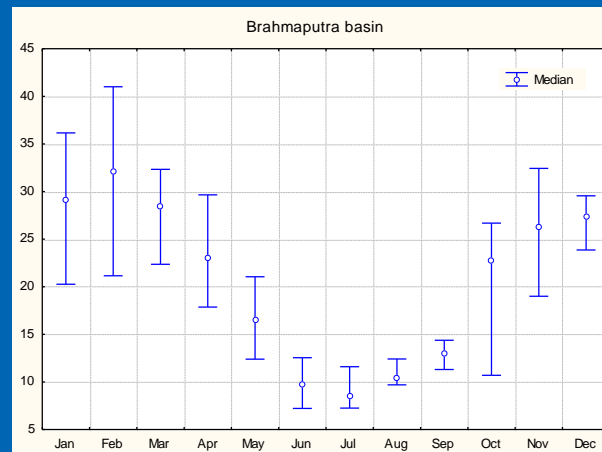
Tarim



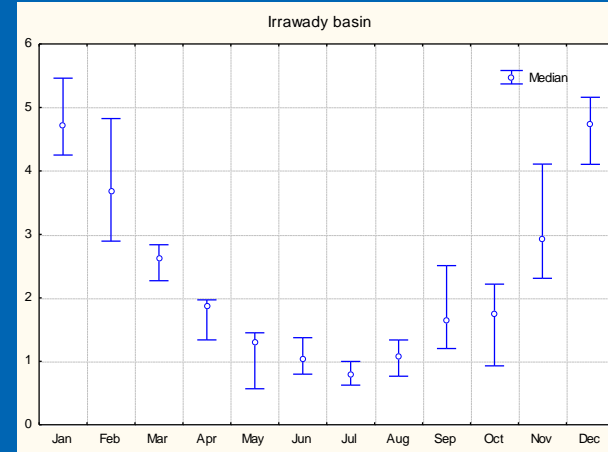
Indus



Ganges

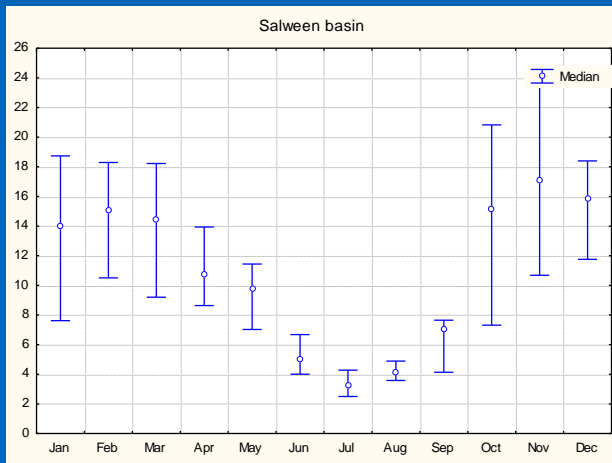


Barhmaputra

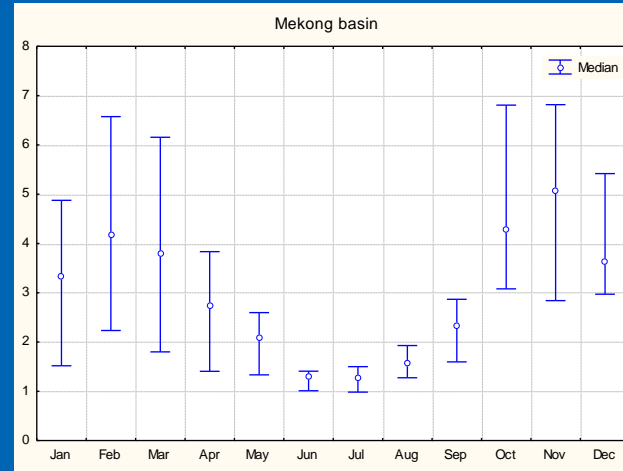


Irrawady

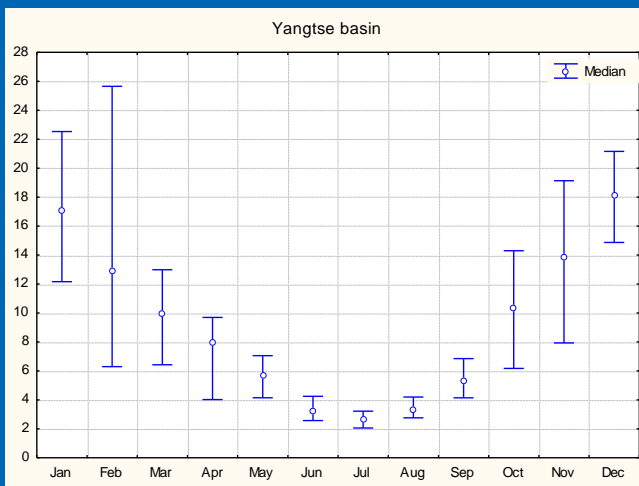
Monthly variation of snow cover area



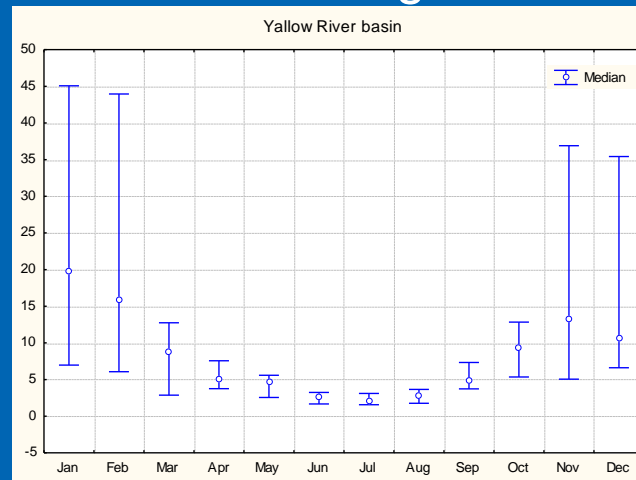
Salween



Mekong

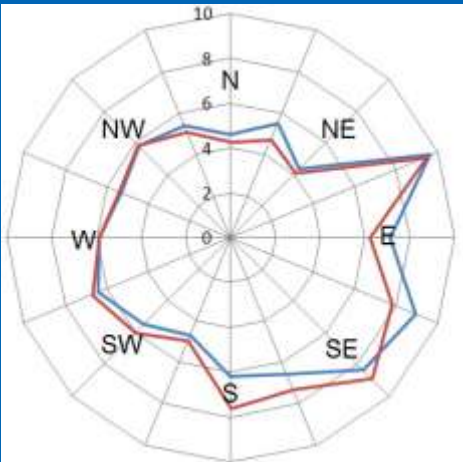
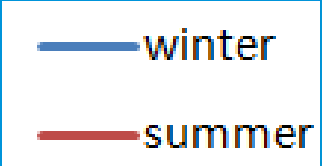


Yangtse

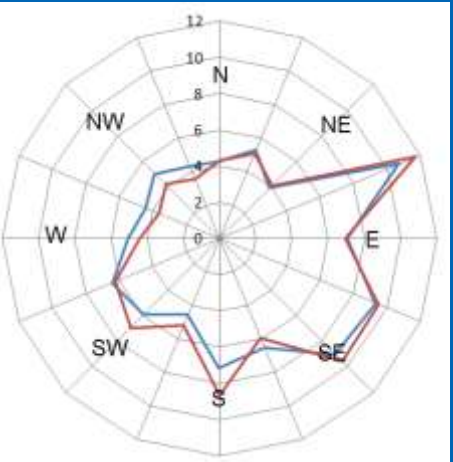


Yellow River

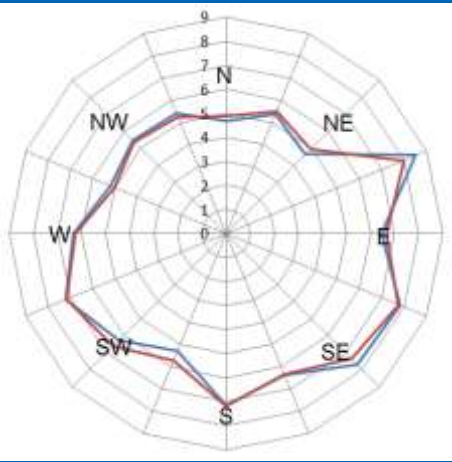
Snow distribution based on aspect



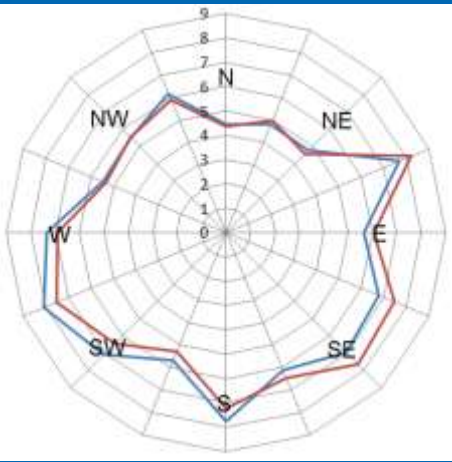
Amudarya



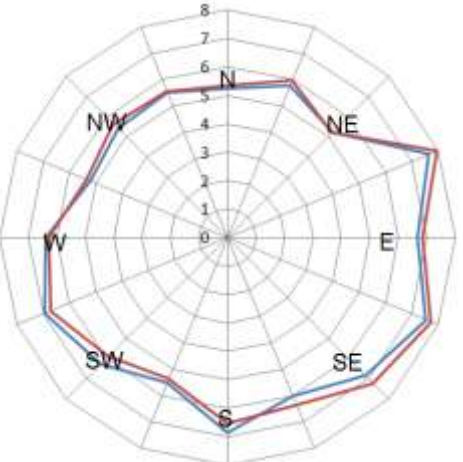
Tarim



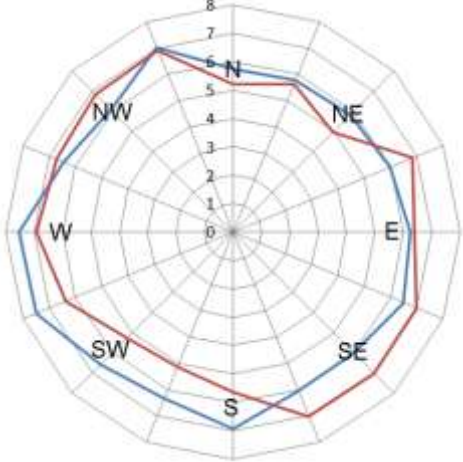
Indus



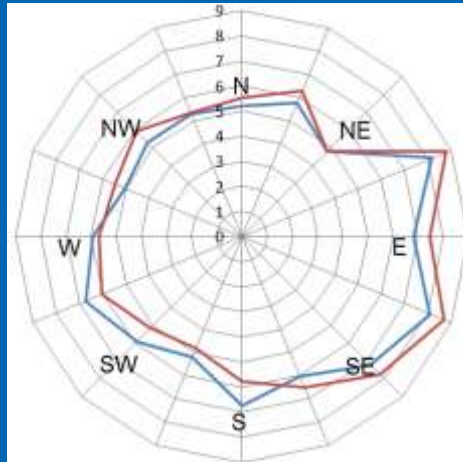
Ganges



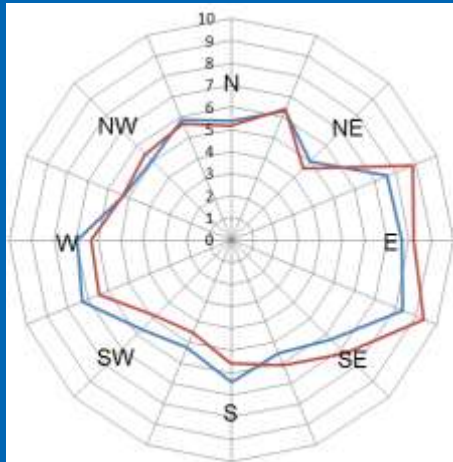
Barhmaputra



Irrawady

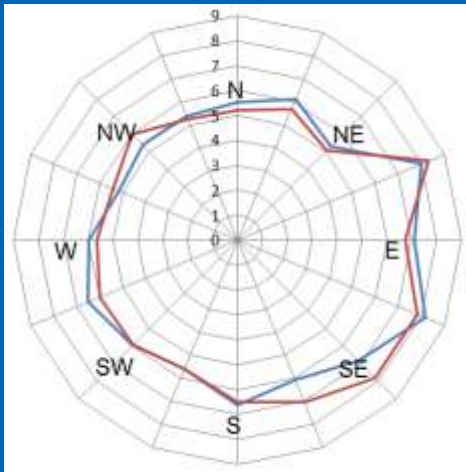


Salween

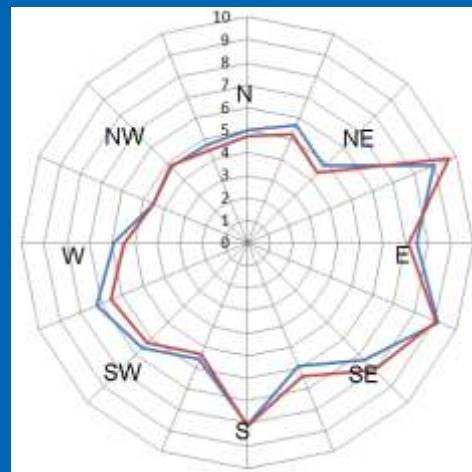


Mekong

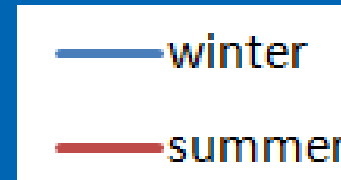
Snow distribution based on aspect



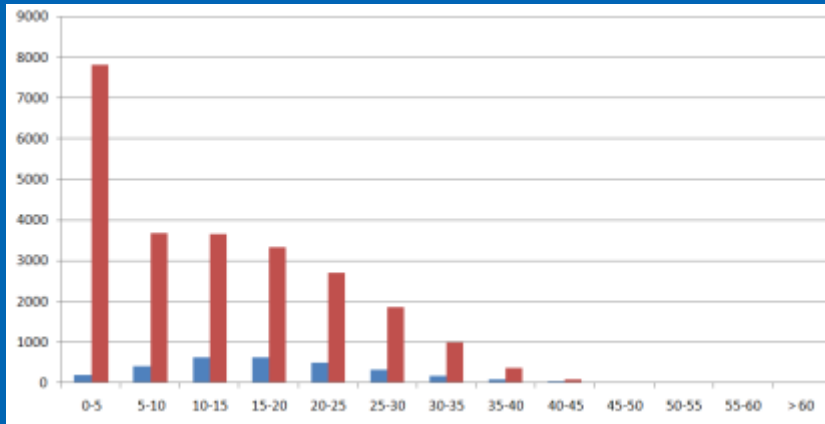
Yangtse



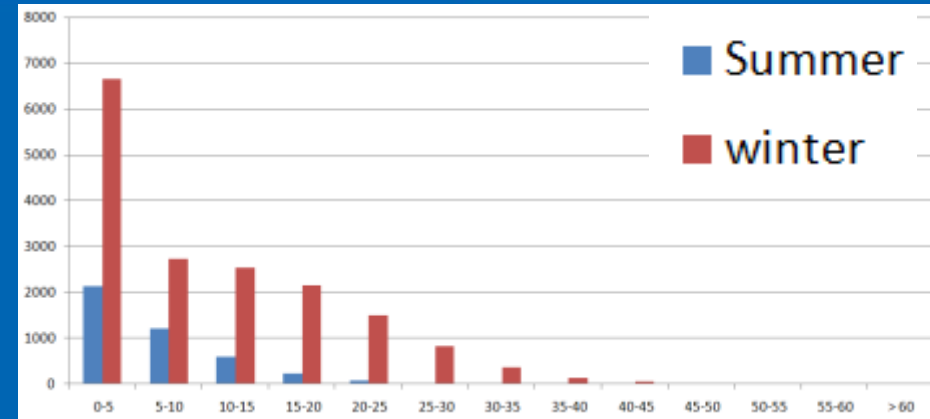
Yellow River



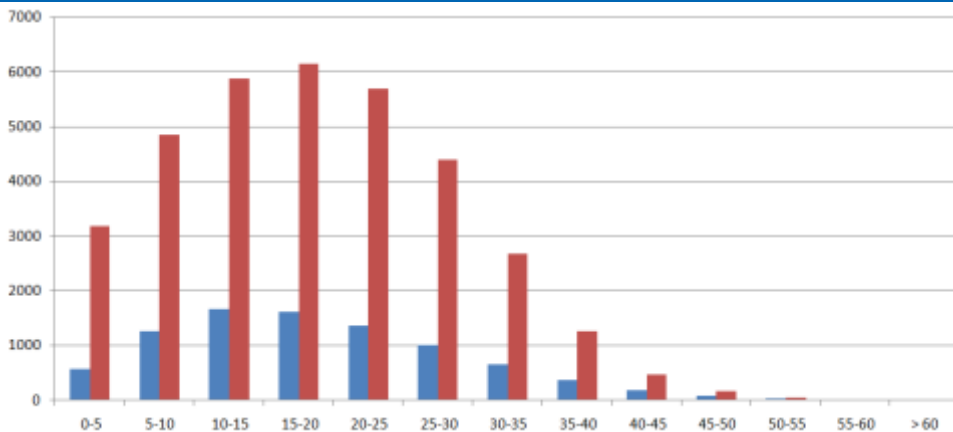
Snow distribution based on slope



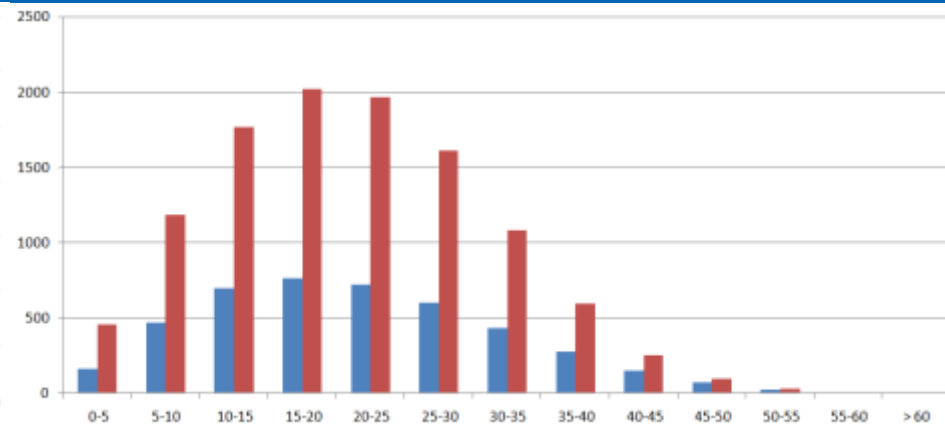
Amudarya



Tarim

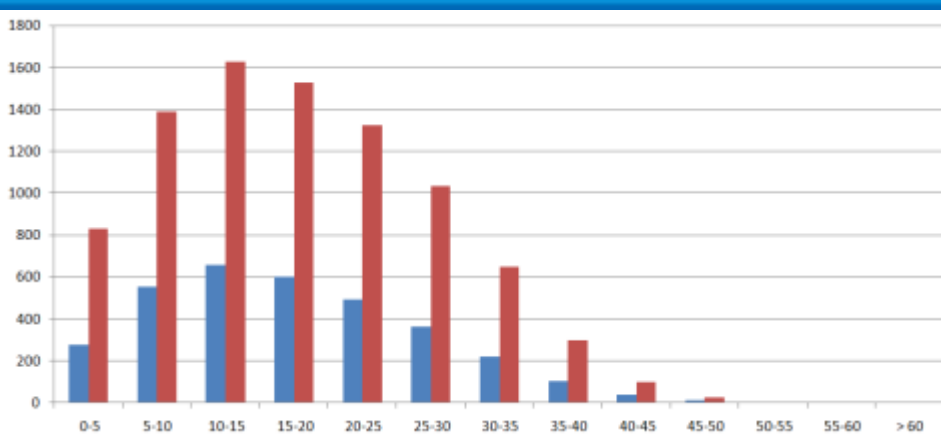


Indus

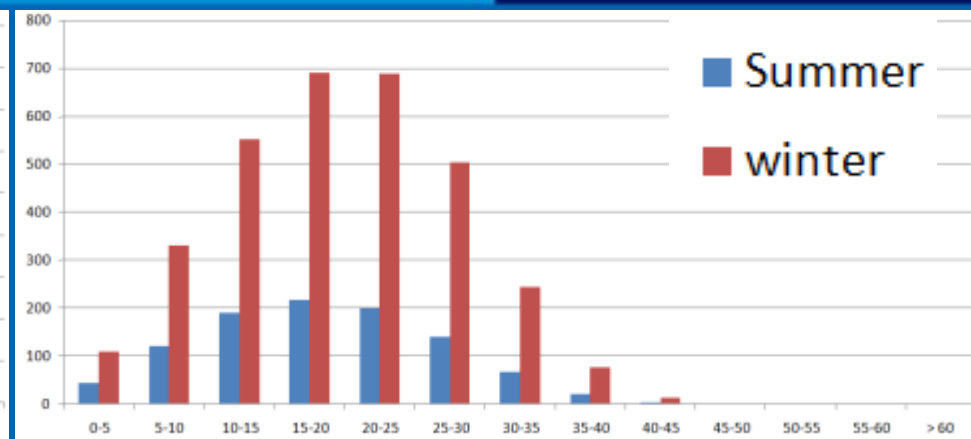


Ganges

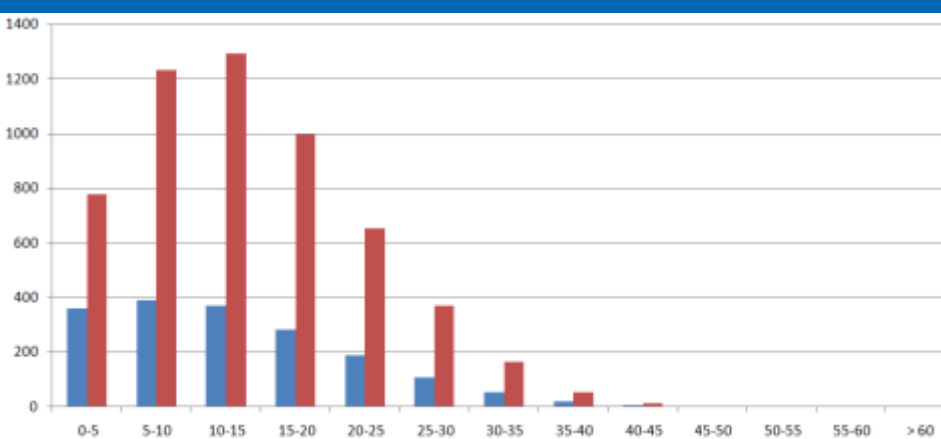
Snow distribution based on slope



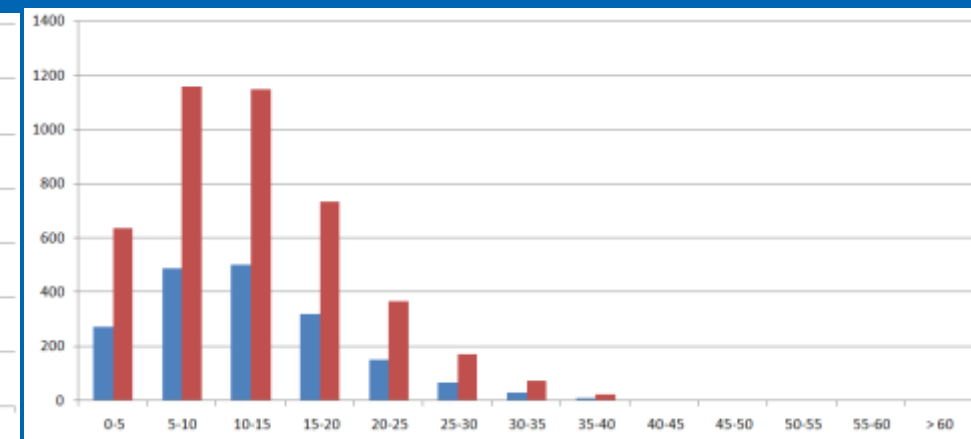
Barhmaputra



Irrawady

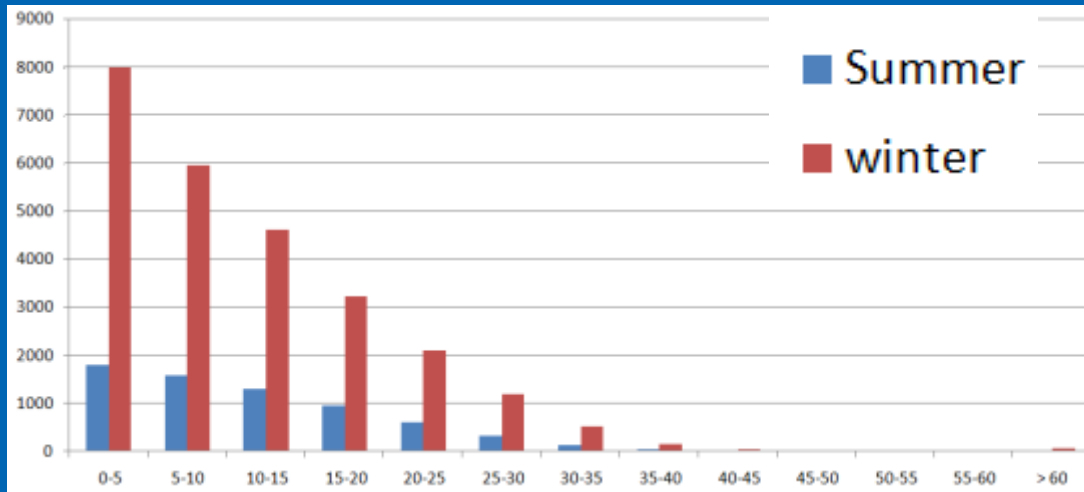


Salween

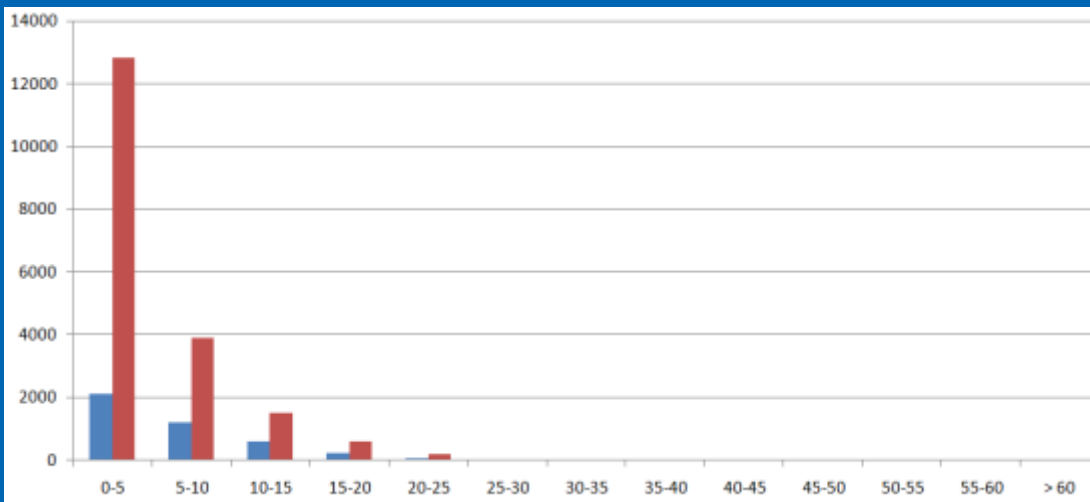


Mekong

Snow distribution based on slope



Yangtse



Yellow River

Conclusion

1. Cloud removal methods successful in removing clouds significantly and improving the products.
2. Snow cover area in agreement with the trend. It is depleting except in Amudarya, Indus and Yangtse basins.
 - Depletion rate is highest in Barhmaputra basin and accumulation is highest in Indus basin.
2. Strong linear regression relation is observed between percent snow cover and elevation in all basins except in Tarim basin ($R=69$).
3. Jan, Feb, Mar, Oct, Nov, Dec indicate maximum monthly variation in snow cover area.