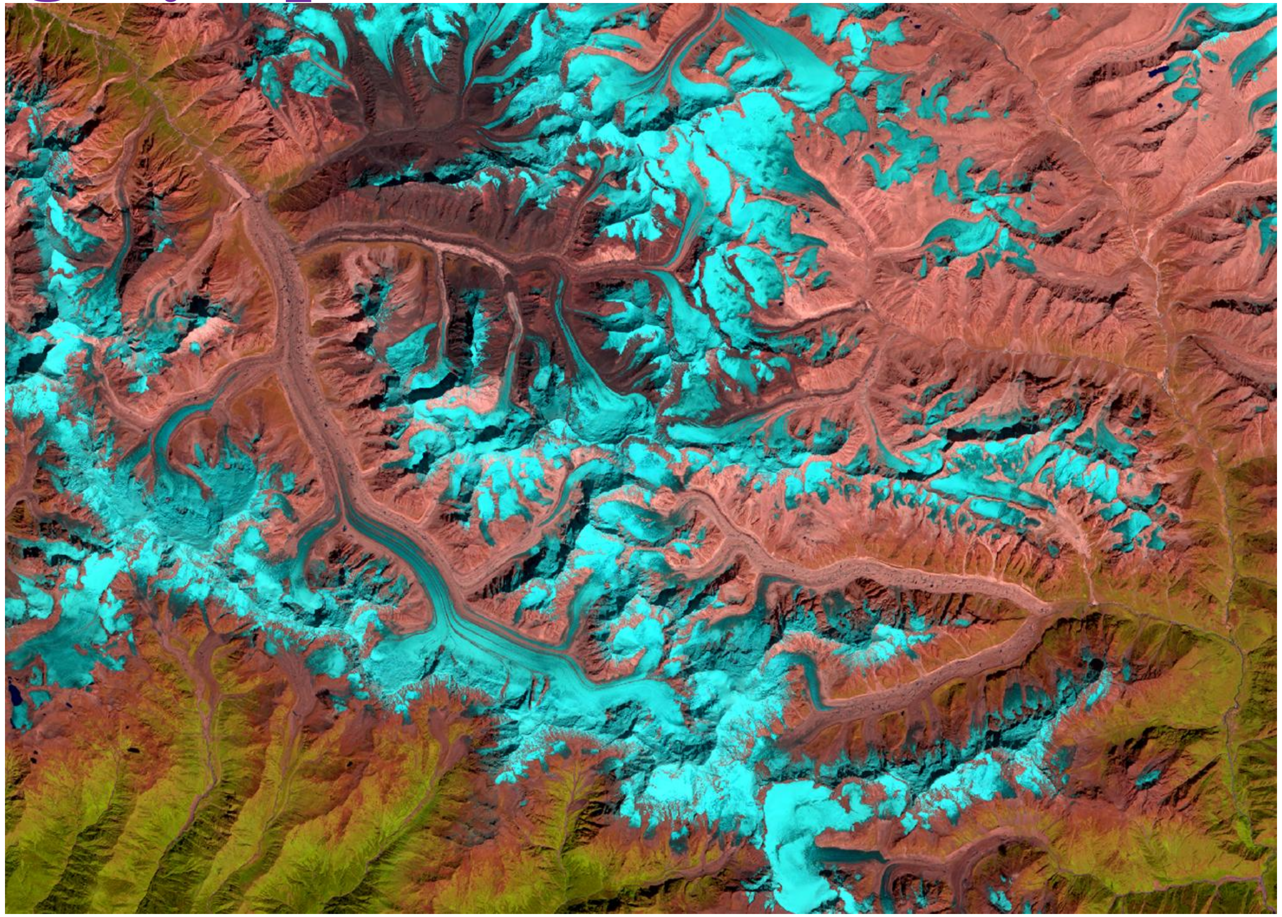
Role of EO data and process based models in monitoring cryosphere ECVs in North West Himalaya

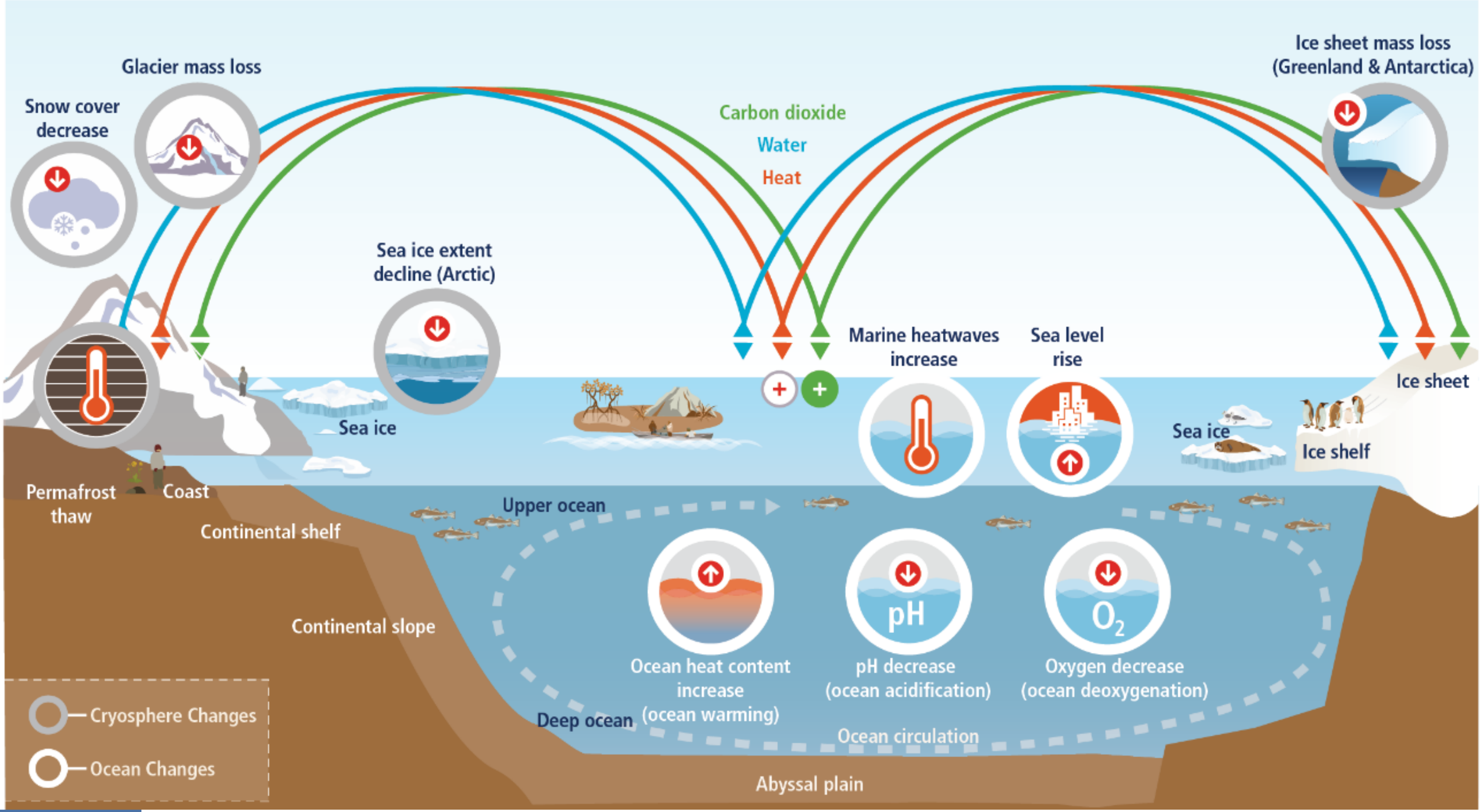


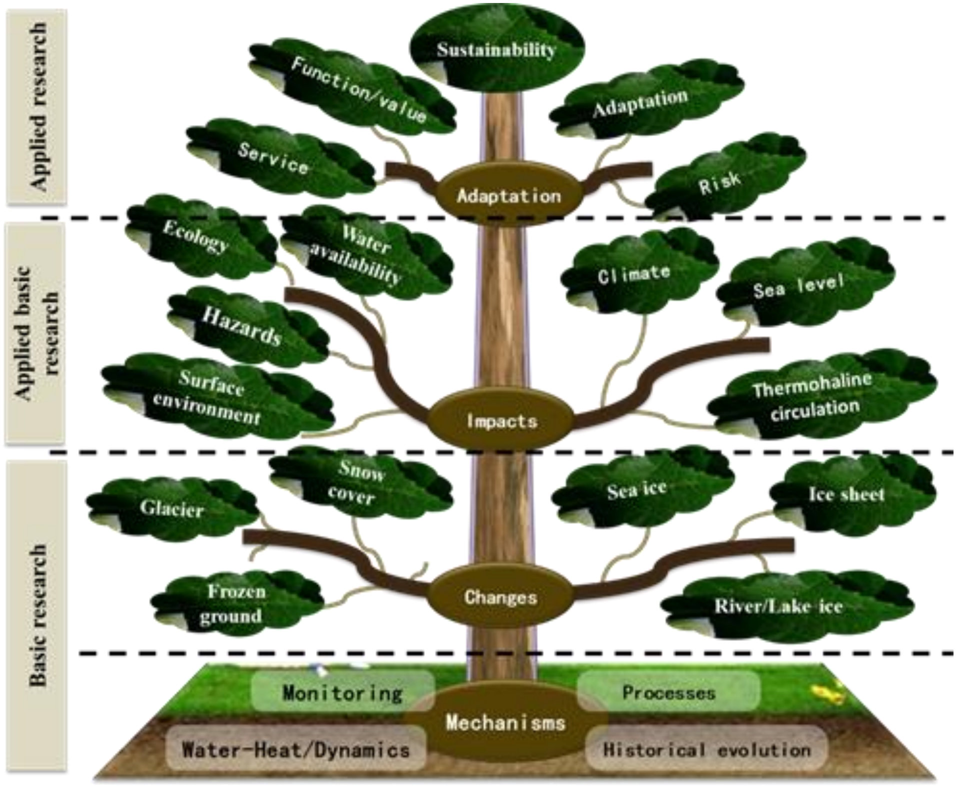
Dr. Praveen K. Thakur (praveen@iirs.gov.in), Sc./Eng. SG,
Head, Water Resources Department (WRD),
Indian Institute of Remote Sensing (IIRS), ISRO,
Department of Space, 4-Kalidas Road, Dehradun - Uttarakhand

Outline of the presentation

- Importance of Cryosphere and ECVs w.r.t climate change
- Remote Sensing based Snow ECVs
- Remote Sensing based Glacier ECVs
- Role of Process based models for in snow/glacier ECVs
- Key highlights
- Future EO Missions for Snow/Glacier studies

IPCC AR6: Impact on oceans and cryosphere





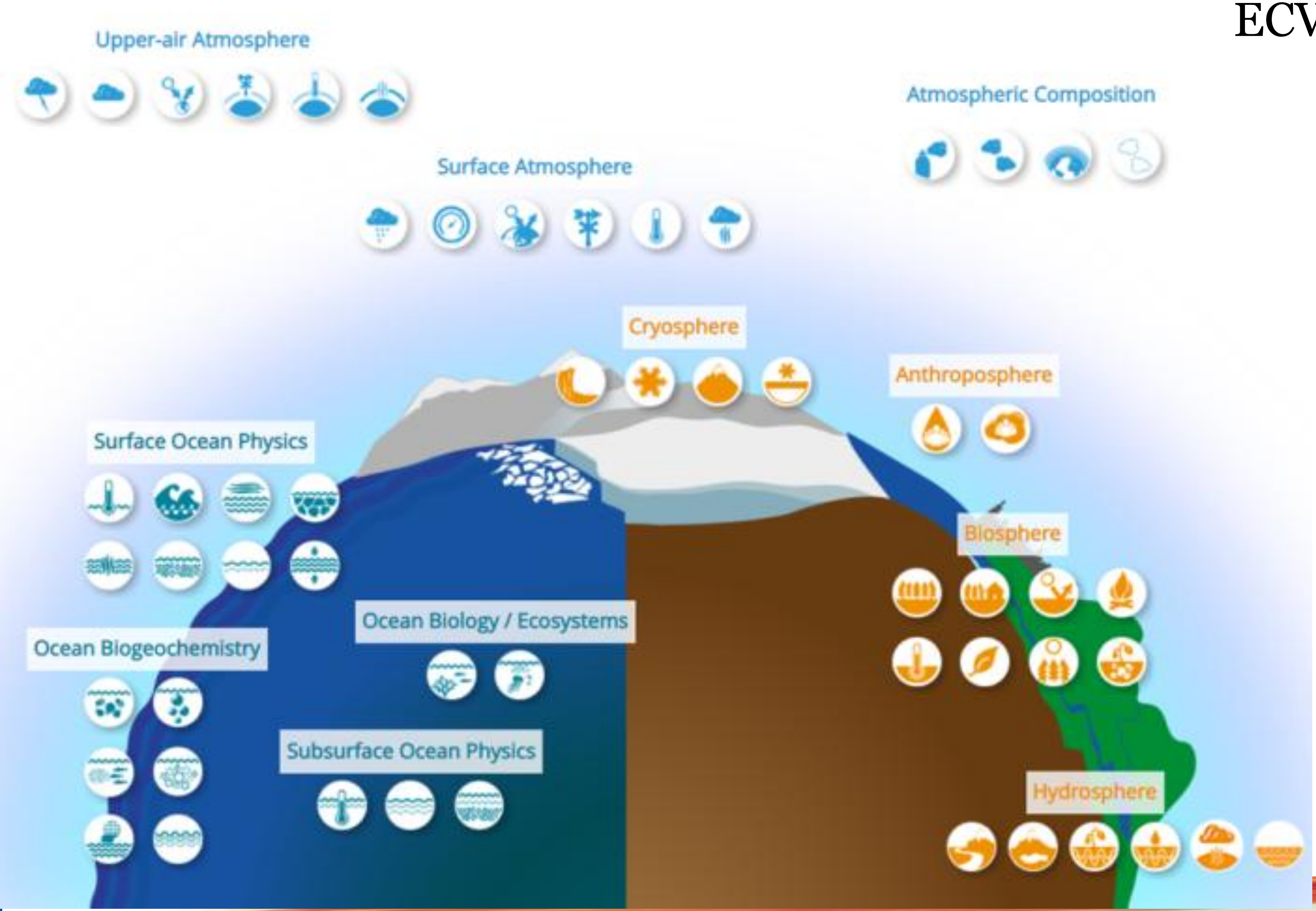
Long term field observations & Remote Sensing time series: Visible signs of climate change and climate attribution via "Essential Climate Variables" ECVs as defined by WMO

"Research tree of climate change"

An Essential Climate Variable (ECV) is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate. GCOS currently specifies 55 ECVs.

EO provides basic data for monitoring of Climate change indicators and its impacts

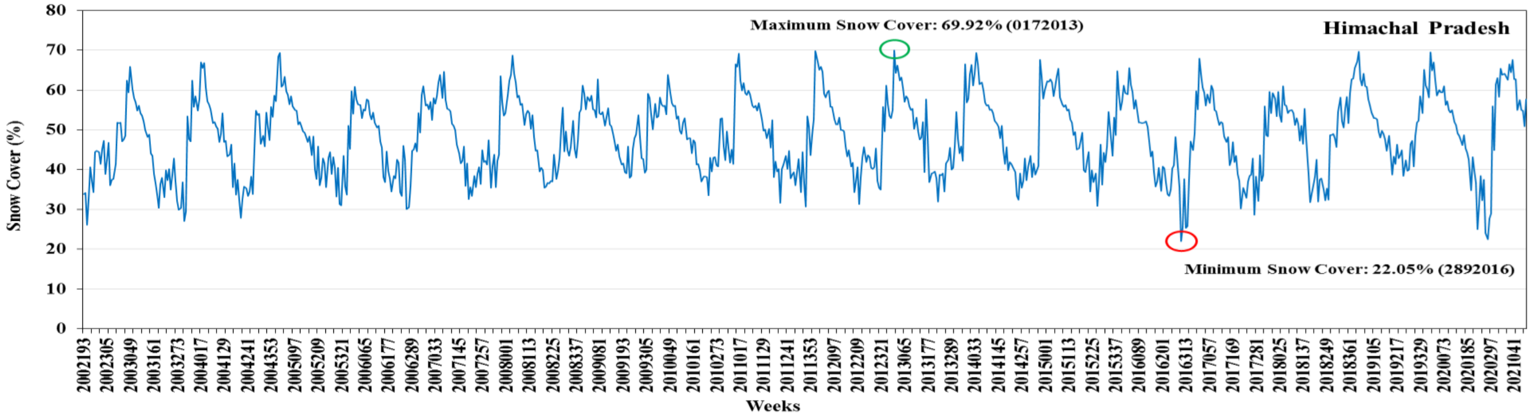
Global climate observing system (GCOS) supported ECVs



ECVs relevant for 3rd Pole

- Snow
- Glacier
- Permafrost
- Surface Atmosphere
- Hydrosphere

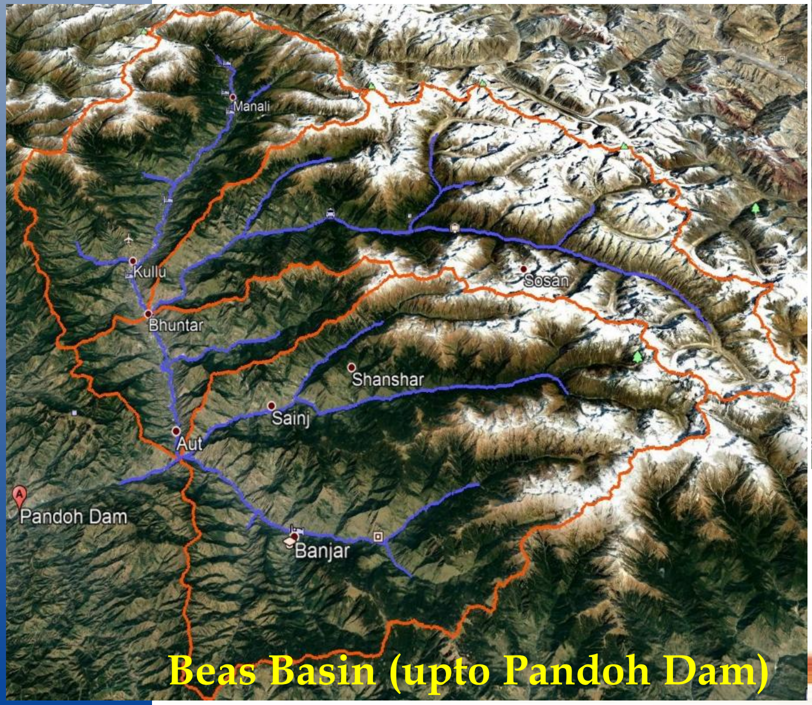
Snow cover and snowpack: A key indicator of climate change



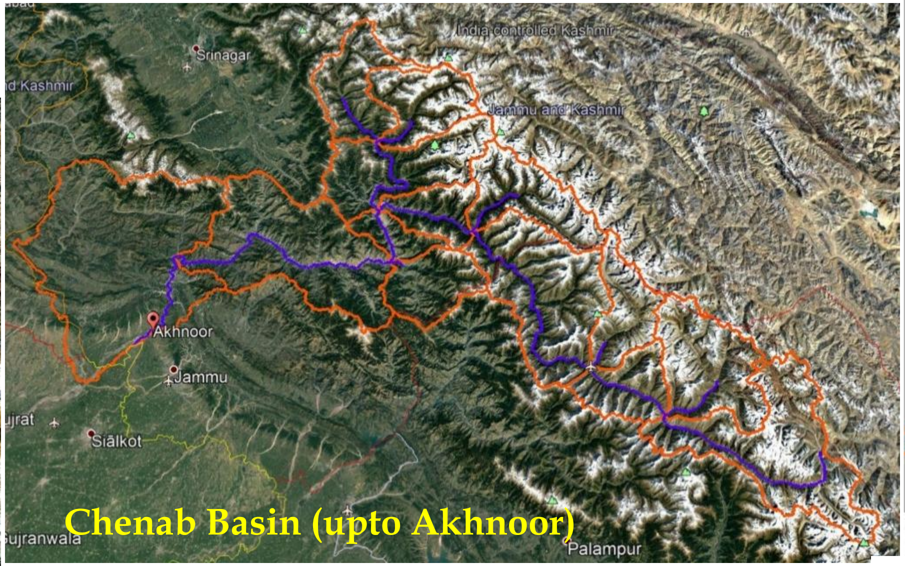
Satluj Basin (upto Bhakra Dam)

Total Area (km2)	Max SCA (km2)	Min SCA (km2)
22275	15125 (66.99%)	4025 (18.07%)

SCA used as direct input to snowmelt runoff models



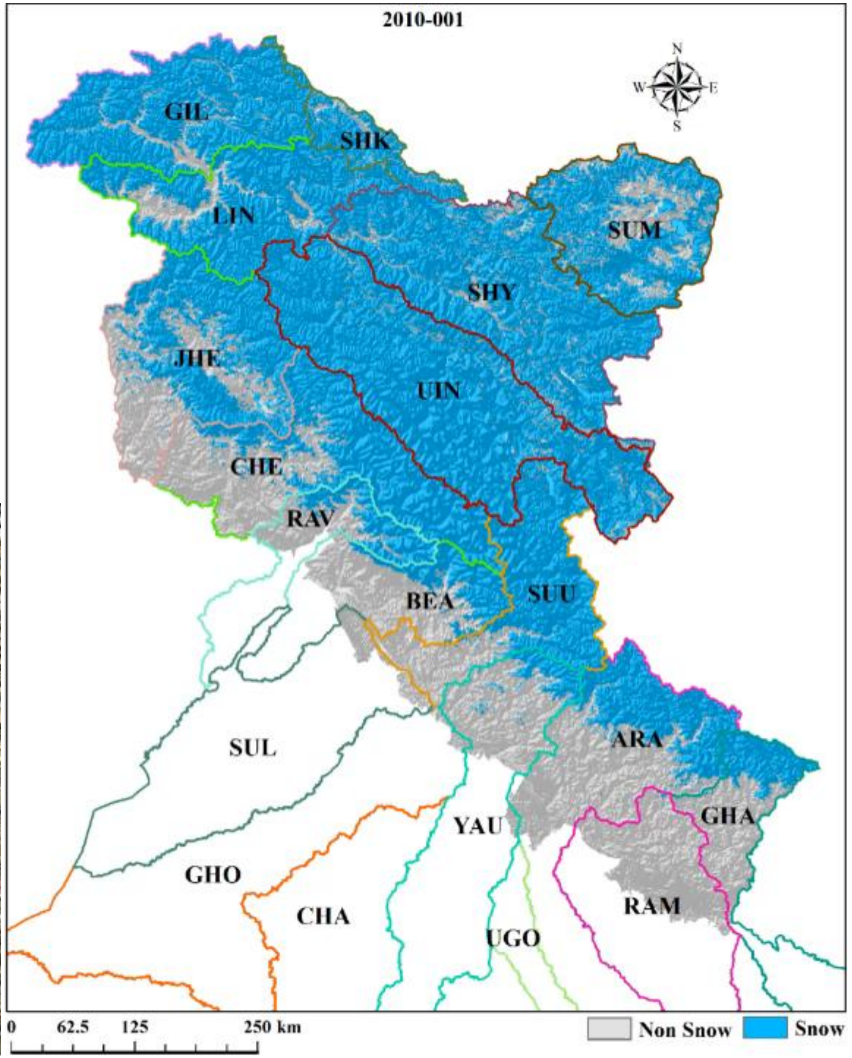
Beas Basin (upto Pandoh Dam)



Chenab Basin (upto Akhnoor)

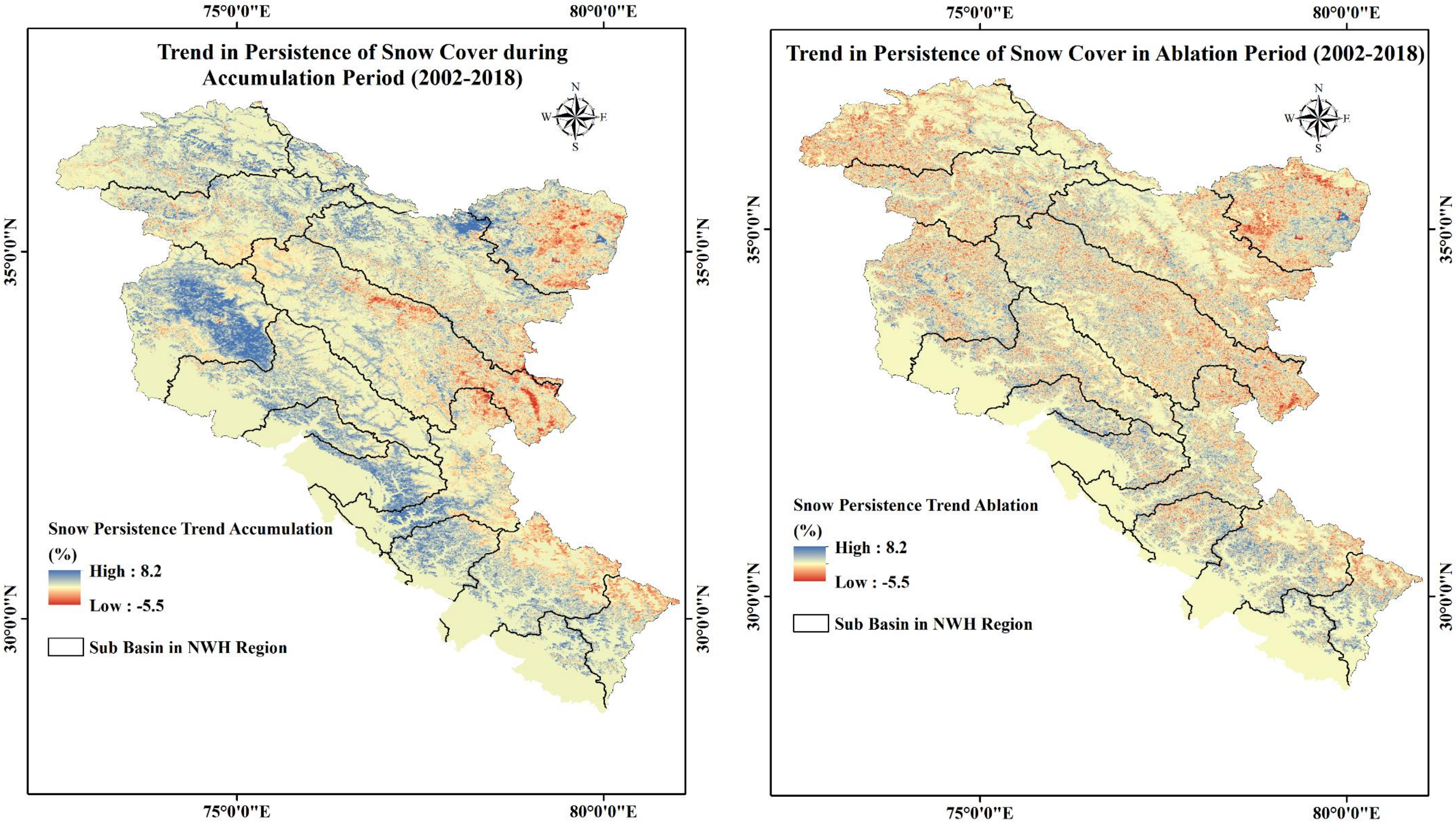
Total Area (km2)	Max SCA (km2)	Min SCA (km2)
22200	16415 (73.94%)	4590 (20.67%)

Total Area (km2)	Max SCA (km2)	Min SCA (km2)
5278	2825 (53.52%)	575 (10.89%)



IIRS has created long-term record (2000-onwards) of satellite based cloud free, snow cover for entire Himalaya, including NWH

Persistence of Snow Cover and Change in Persistence



- **Negative trend** is more dominant in **Ablation season**: Effect of **Increase in Temperature**
- **Negative trend in Accumulation**: **Decline in Precipitation** and **Increase in Temperature**

Remote Sensing and Modelling Approach to generate the High Resolution Snow ECV's Products in Himalayas

(Ongoing ISRO-NICES sponsored projects on generating Snow ECVs at IIRS)

Objective:

To derive the snow related essential climate variable products for North West Himalaya (NWH) using remote sensing data and modelling approach

- Snow Cover (30m, daily)
- Snow Depth (100 m, daily)
- Snow Water Equivalent (100 m, daily)

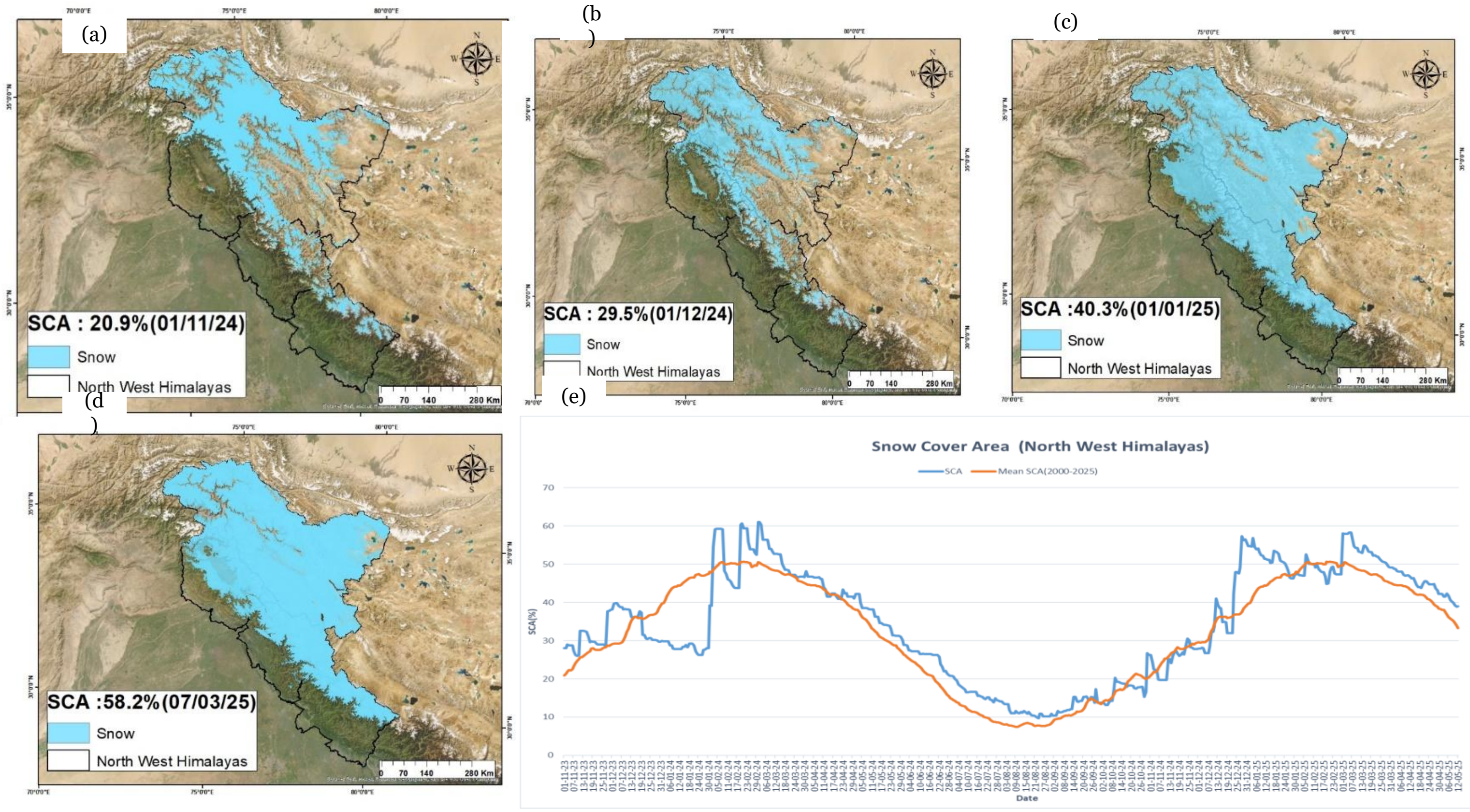


Figure 1.
(a) Snow cover Area on 01/11/24, (b) Snow cover Area on 01/12/24, (c) Snow cover Area on 01/01/25, (d) Snow cover Area on 07/03/25 , (e) Snow Cover Area in North West Himalayas (1Nov,2023-12May,2025)

Global Data Available for Snow Cover, Snow Depth and Snow Water Equivalent (SWE)

Parameter	Sensor Type	Product Name	Agency	Period	Resolution	Coverage	Access
1. Snow Cover	Optical	MODIS Terra/Aqua/ AWiFS	NASA/ ISRO	2000–present 2014-present	500 m, daily 5km, 15 days	Global (land) Regional	NSIDC Bhuvan-ISRO
		VIIRS S-NPP / NOAA-20 (VNP10A1)	NASA/NOAA	2012–present	375 m, daily	Global (land)	NSIDC
	Microwave	IMS Daily Snow Cover	NOAA/NCEP	1997–present	24 km	Global	NOAA IMS
	Reanalysis	ERA5 / ERA5-Land	ECMWF	1981–present	~9–31 km	Global	Copernicus CDS
2. Snow Depth	Microwave	AMSR2 Snow Depth (GCOM-W1)	JAXA/NASA	2012–present	~10 km	Global (land)	G-Portal
	Reanalysis	ERA5 / ERA5-Land	ECMWF	1981–present	~9–31 km	Global	Copernicus CDS
		MERRA-2	NASA GMAO	1980–present	~50 km	Global	GES DISC
		GLDAS (Noah)	NASA	2000–present	0.25°	Global	GES DISC
3. SWE	Microwave	GlobSnow SWE	ESA/NSIDC	1979–2018	25 km	Northern Hemisphere	NSIDC
		Copernicus SWE (H-SAF)	ECMWF/EUMETSAT	2000–present	~25 km	Global/NH	CDS/H-SAF
	Reanalysis	ERA5 / ERA5-Land SWE	ECMWF	1981–present	~9–31 km	Global	Copernicus CDS
		MERRA-2 SWE	NASA GMAO	1980–present	~50 km	Global	GES DISC
		GLDAS SWE	NASA	2000–present	0.25°	Global	GES DISC

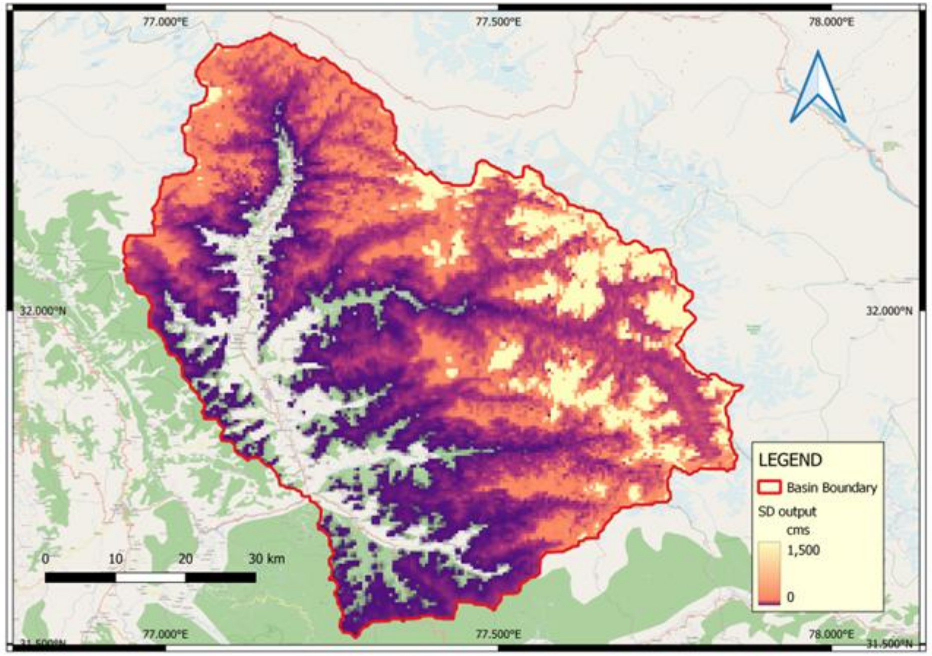
Multi-Sensor inputs, HMA data and machine learning based estimation of snow depth and SWE

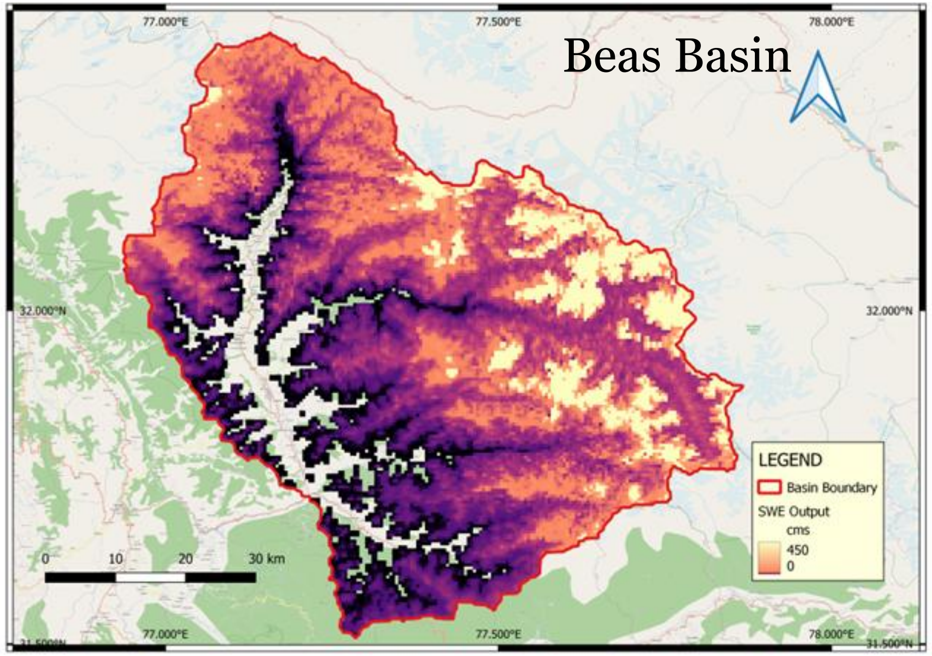
SD

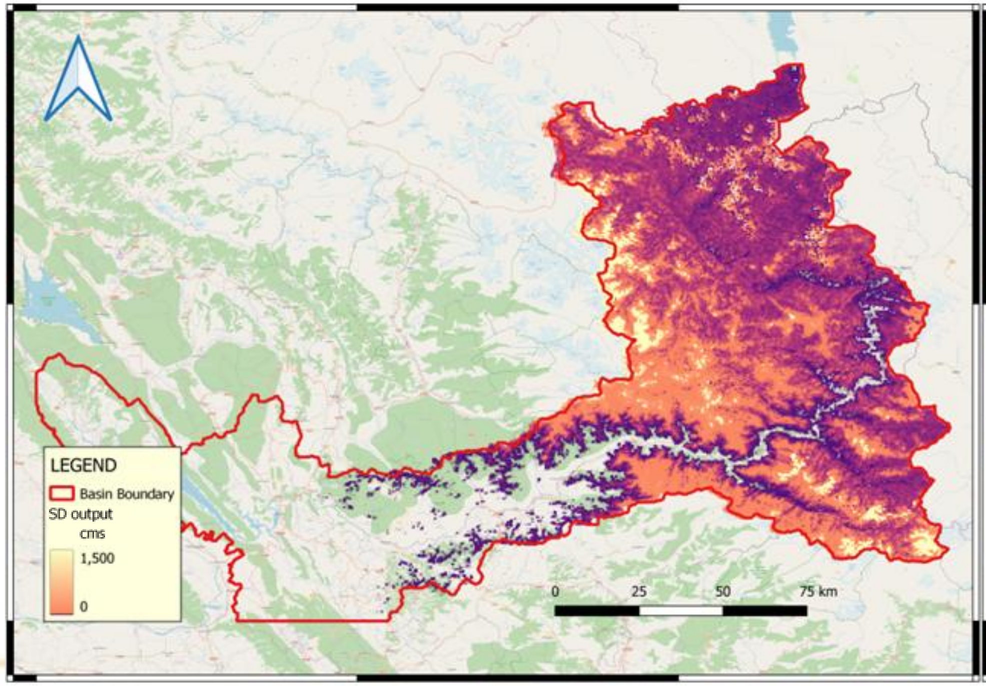
R²	0.811
MAE	7.447
RMSE	13.940

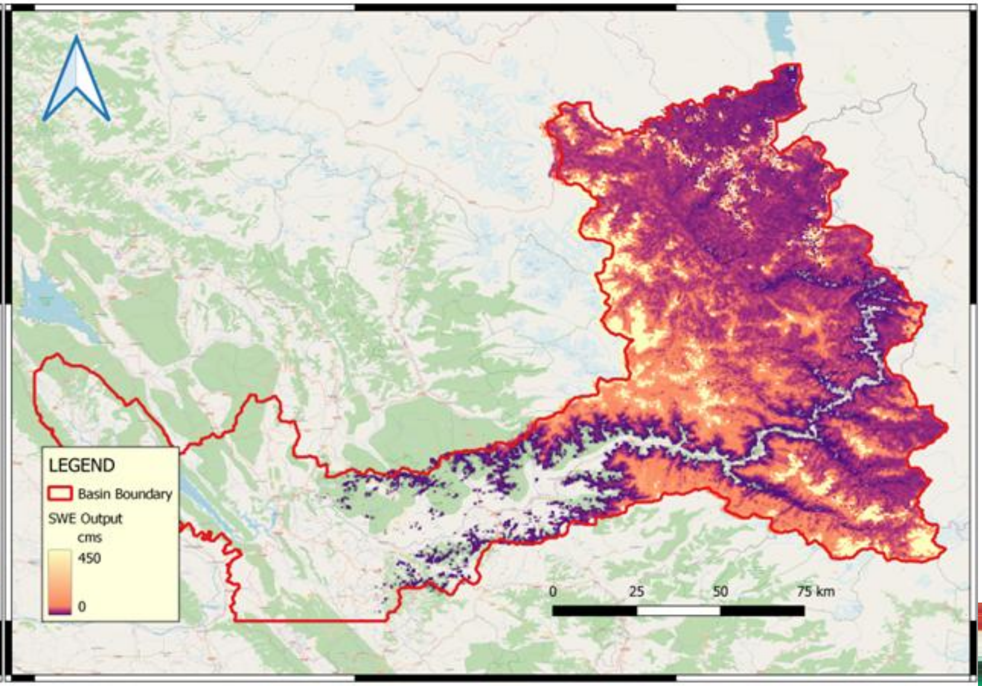
Beas Basin

Feb 2017





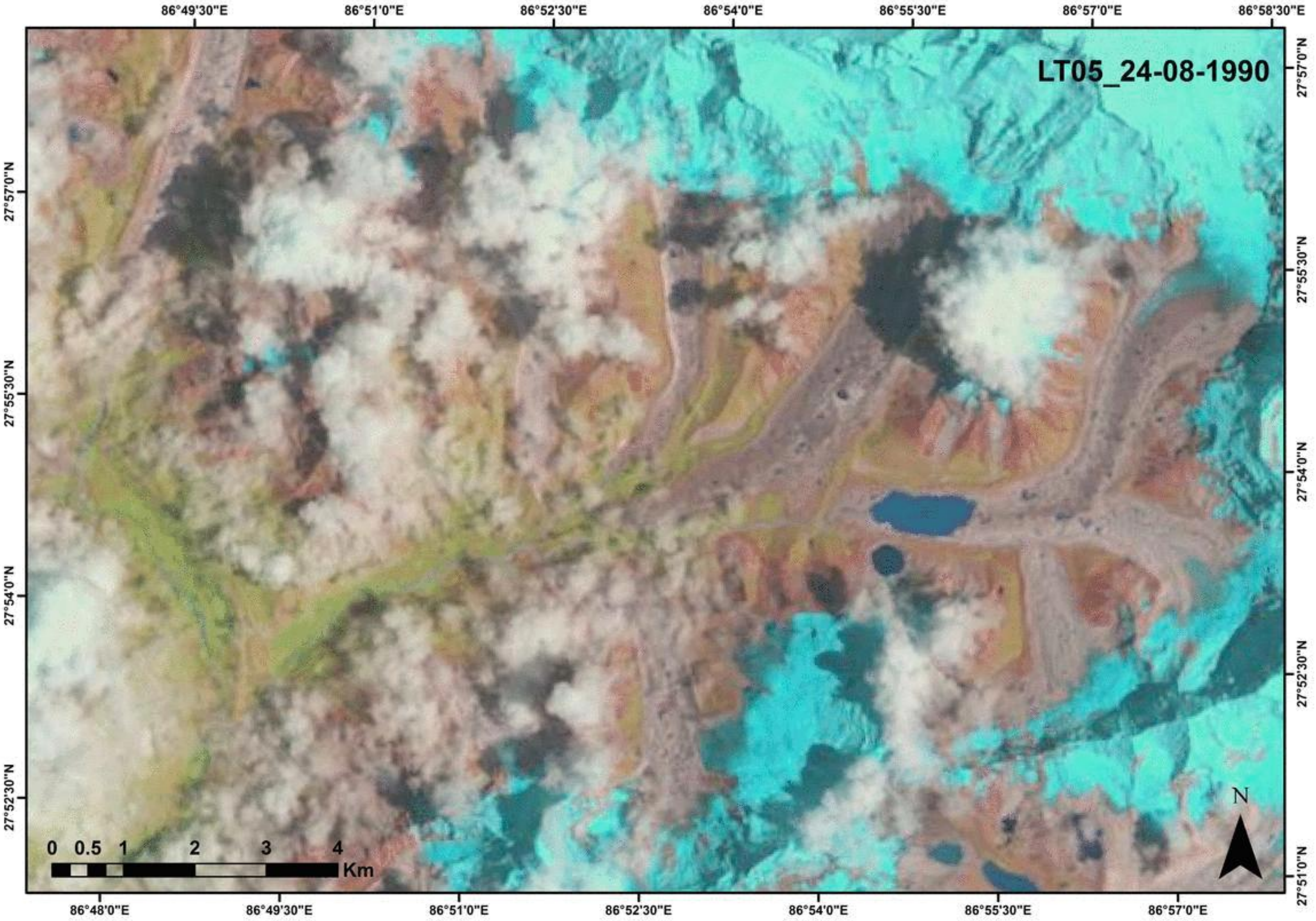


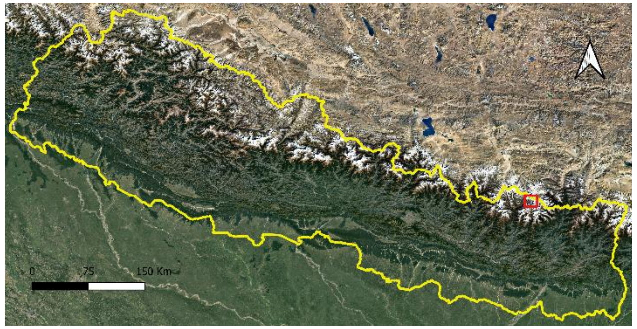


SWE

R²	0.7080
MAE	2.750
RMSE	5.407

Imja group of glaciers, Dudh Kosi basin, East Nepal, increasing GLOF risk





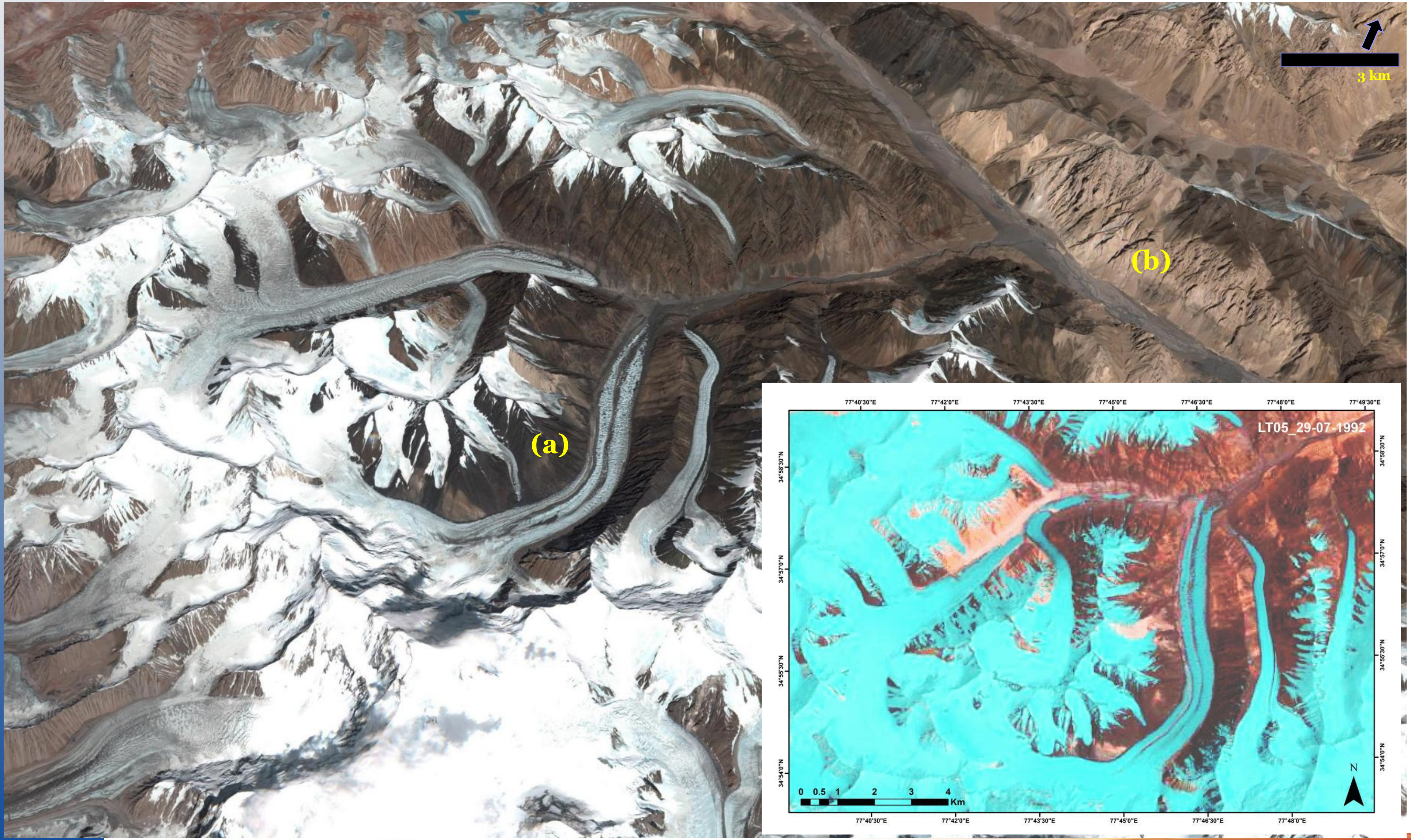
Total increase of glacier lake Length and area since 1990

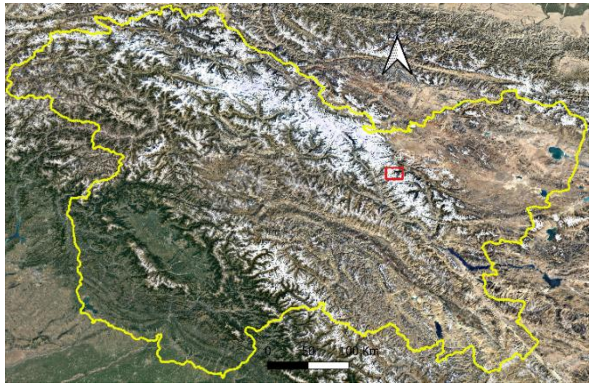
Length: 1.08 Km.
Area: 0.84 km²

Mean surface velocity of glacier for year 2017
23.15 m/year

Since 1960, a supra glacier lakes combined to form big single lake and has increased to 2.5km in length & Area of 1.44 km² and 150 metres deep. Increased GLOF risk due to such glacier lakes in Himalaya

Glaciers - Large Reserves of Fresh Water & key indicator of change





Maximum Surge (km)

1: 1.36 (2010-2011)

Total Surge since 1991

1: 2.76 km

Mean surface velocity

1: 39.57 m/year (2014)

The glacier and river seen in this image **a) Chamsen, b) Shyok River**.

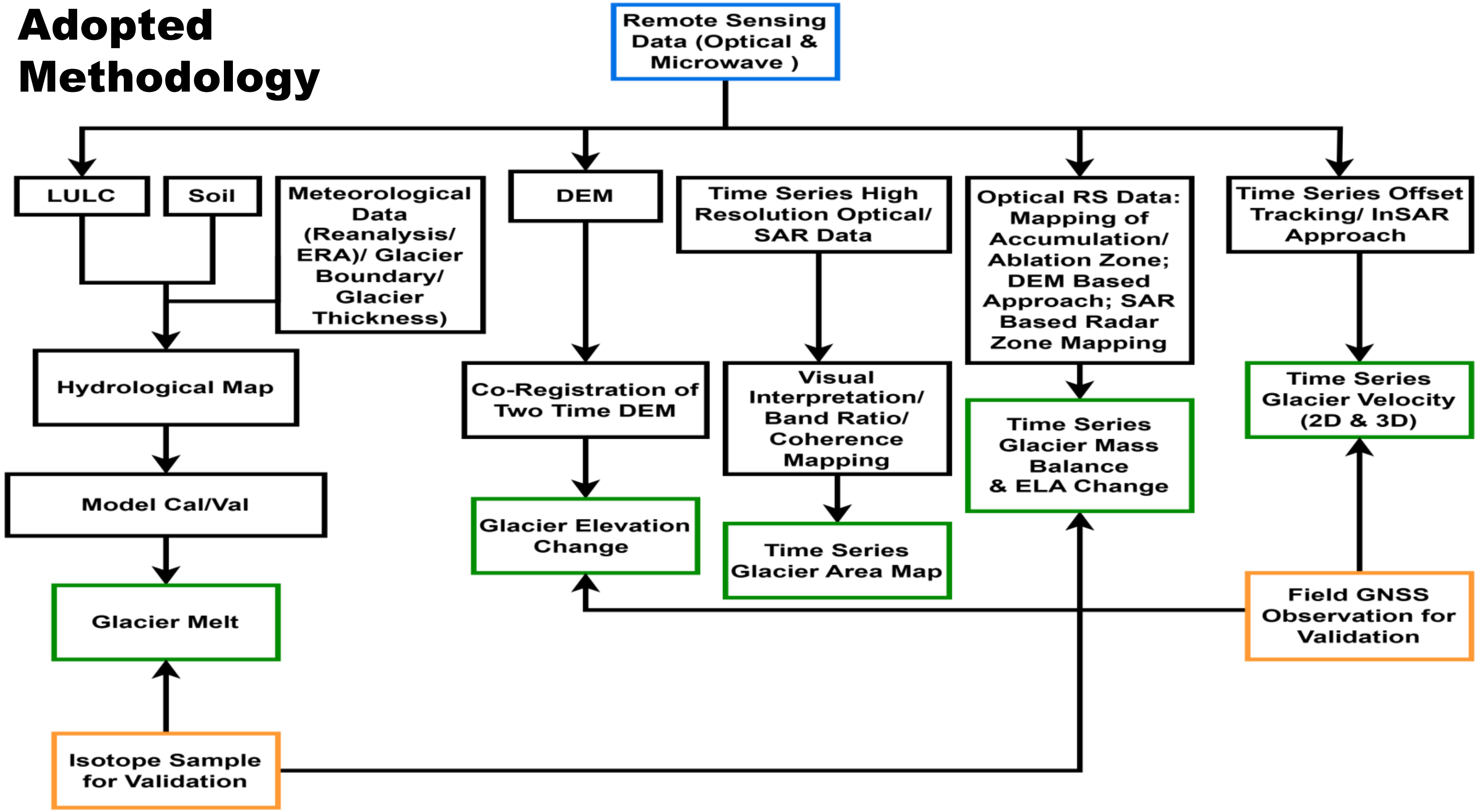
Multi Satellite And Multi Sensor Approach To Generate The High Resolution Glacier Related Essential Climate Variables Product In Himalaya (2024-2028): (Ongoing ISRO-NICES sponsored projects on generating Glacier ECVs at IIRS)

Objectives

To derive glacier related essential climate variables products for North West Himalaya (NWH) using remote sensing data and modelling approach such as:

- Glacier area
- Accumulation/Ablation zones
- Glacier mass change
- Glacier elevation change
- Glacier Velocity

Adopted Methodology

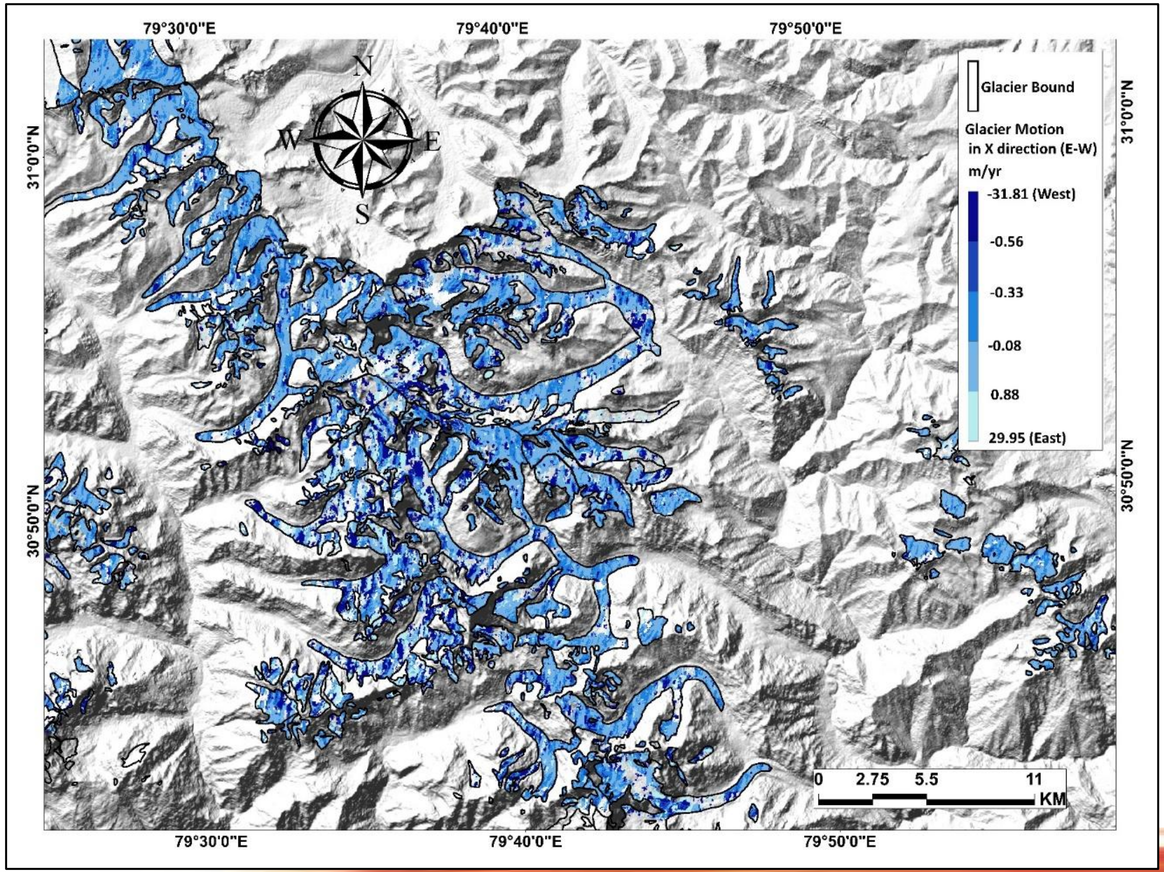


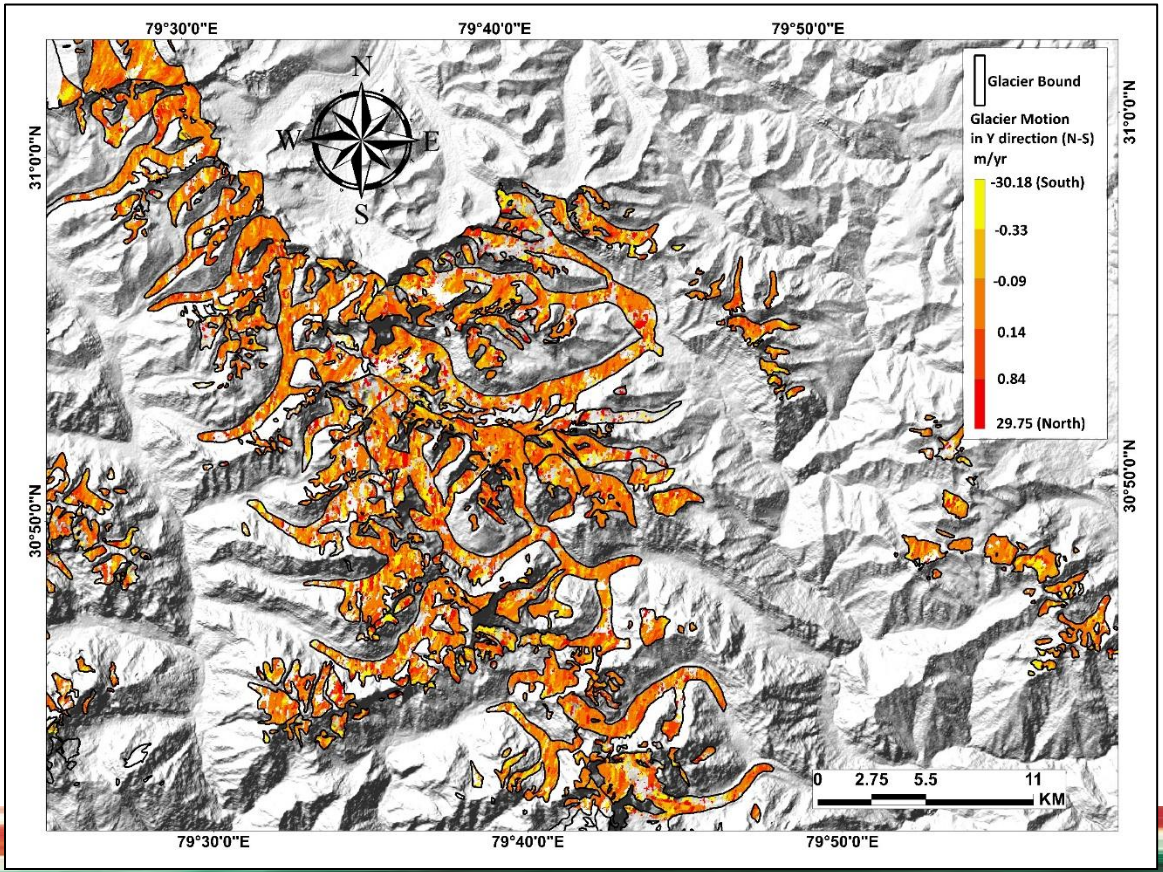
Global Spatial Datasets for Glacier monitoring

Category	Satellite / Dataset	Sensor	Spatial Resolution	Temporal Resolution	Agency
Optical	IRS Series (e.g., Resourcesat-1, 2, 2A)	LISS III, LISS IV	5–56 m (depending on sensor)	5–24 days	ISRO
	Landsat Series (Landsat 8/9)	OLI, TIRS	30 m (MS, TIR)	16/8 days	NASA / USGS
	Sentinel-2A/2B	MSI	10 m (VIS/NIR	5 days (combined)	ESA
Radar	Sentinel-1A/1B/1C	C-band SAR (IW, EW, SM)	5–20 m	6–12 days	ESA
	RISAT-1/2/2B	C-band SAR	3–50 m (depending on mode)	~25 days	ISRO
	NISAR (Upcoming)	L- and S-band SAR	~3–10 m (planned)	12 days (global coverage)	NASA & ISRO
Readymade	NASA ITS_LIVE Velocity Product	Derived from optical (Landsat) imagery	120 m (velocity grids)	Annual to seasonal composites	NASA

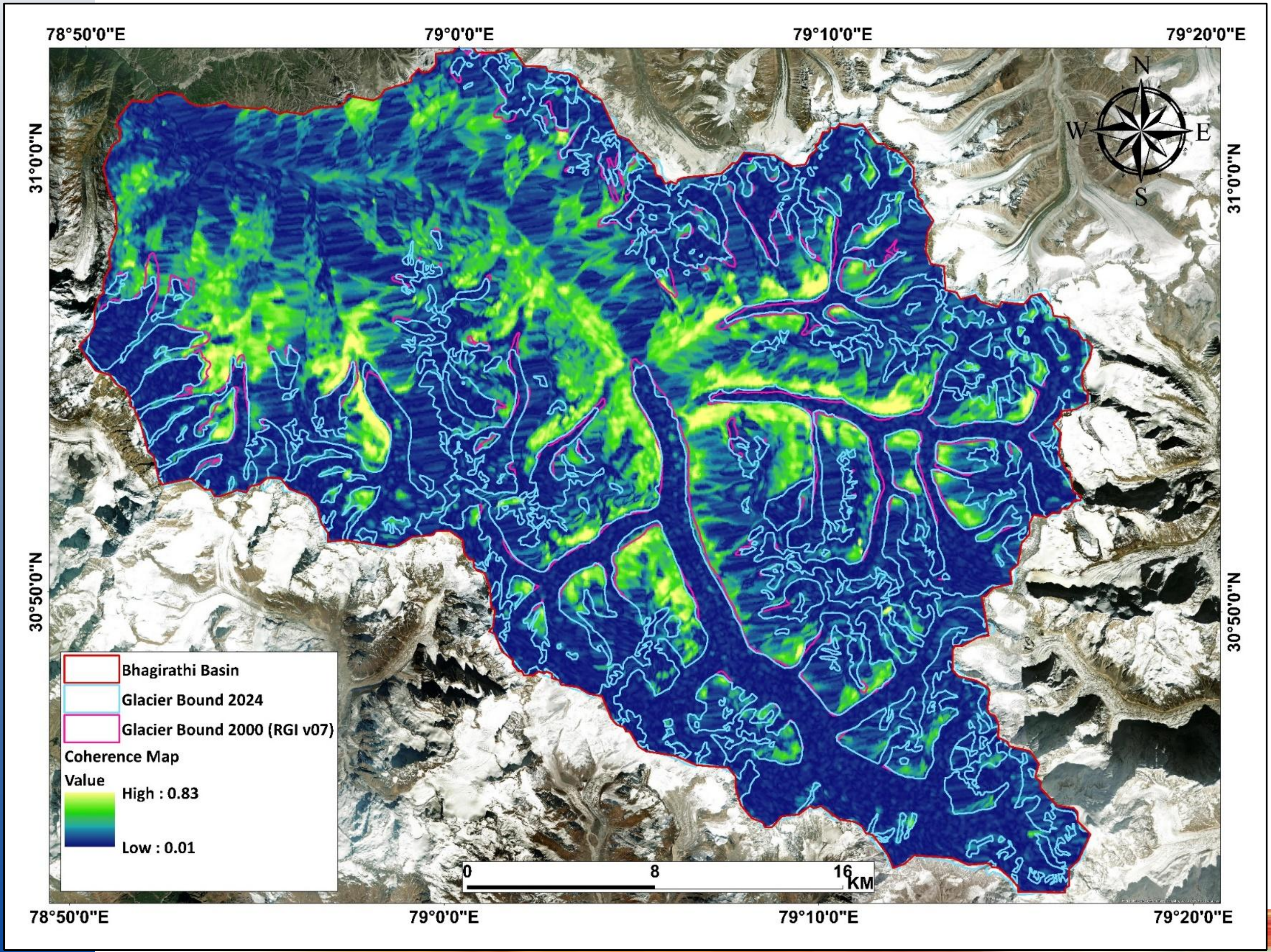
Glacier Velocity

- The Glacier velocity is being derived using the Offset Tracking & InSAR based approach using Sentinel 1A &1B (Sentinel 1c and NISAR data in future).
- A python based algorithm ISCE 2 is being utilised for time series SLC SAR data stacking and InSAR based velocity estimation.
- The shown 2D velocity maps (developing stage) are generated using Offset Tracking approach based on a python based methodology combining ISCE 2, ISCE 3 and AutoRIFT in a Linux environment .



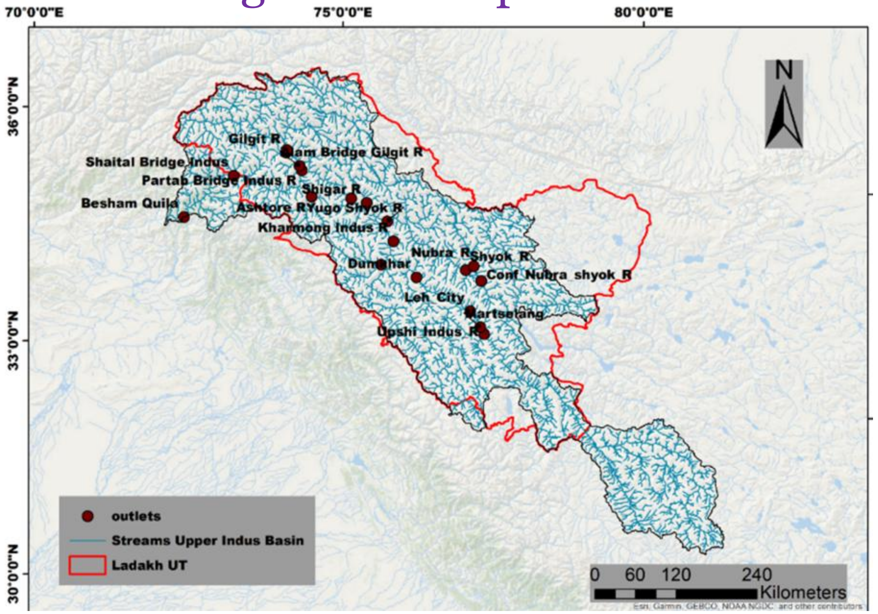


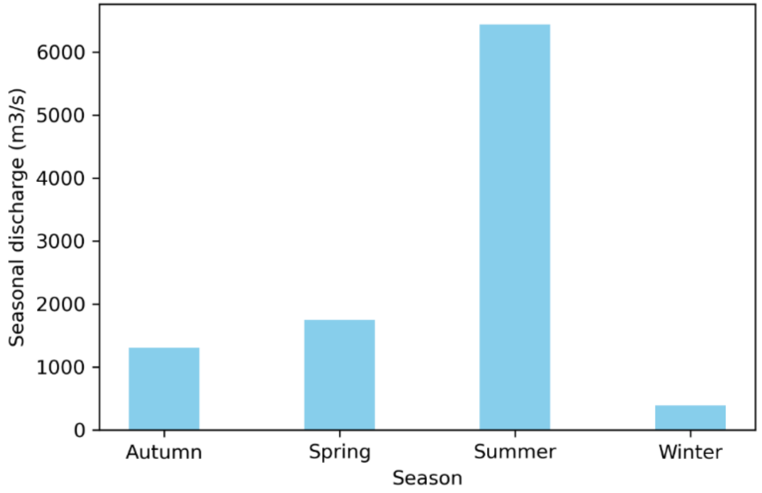
Glacier Area Mapping: Bhagirathi basin



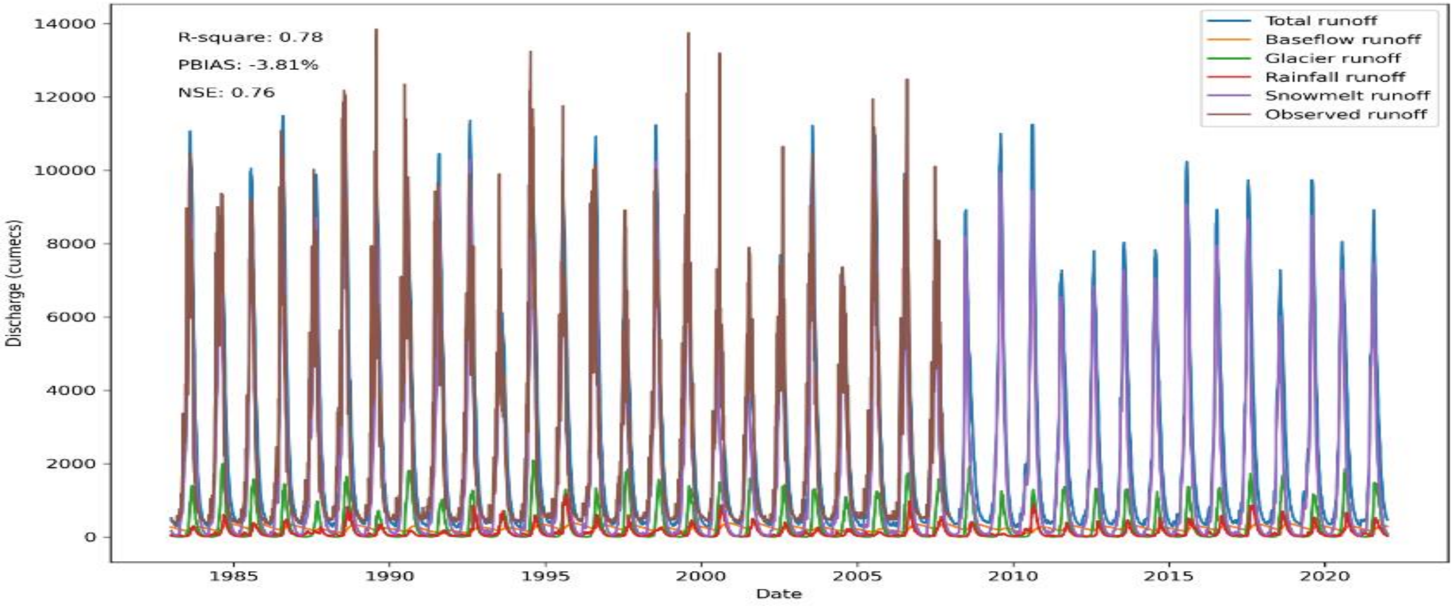
- The glacier area has been updated for the year 2024 using the combined approach using high resolution optical as well as SAR data.
- The coherence map was derived using Sentinel 1A SLC SAR data using InSAR approach, indicating coherence loss on dynamic glacier bodies, which was carefully utilised to map the glacier boundaries.
- The high resolution Liss-IV/S2 optical images were utilised to insure an accurate mapping of glacier boundaries specially near snout.
- The total glacier area, which was 107.25 km² in 2000 according to the RGI, has decreased to 102.20 km² in 2024 for identified 118 glacier in study area

Water resources availability upper Indus basin is highly influenced by solid precipitation, and climate change can have significant impact on water availability: Results from process based hydro-glaciological models





The snowmelt runoff contributes to the 69% of the total runoff, while the Glacier melt was observed to be 17% of the total runoff, the base flow contribution was 9% and the rainfall runoff was observed to be the 5% of the total discharge.

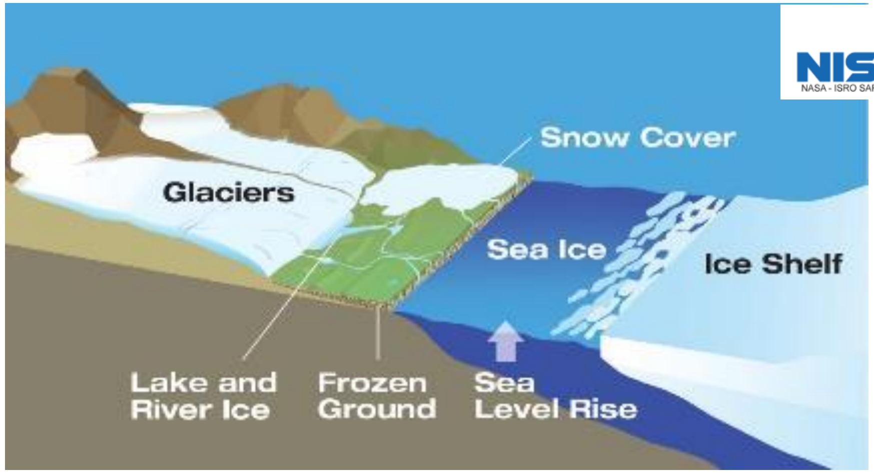


Long term monthly mean shows the average discharge of ~8000 cumecs is available at the Besham Quila gauging station

Key Highlights

- Third Pole contains largest reserves of fresh water ice outside the polar regions
- Climate and anthropogenic changes affects this ice reserve negatively
- EO data provides key inputs for systematic monitoring of Himalayan cryosphere
- High relief and complex topography provides challenge to achieve the targeted goals of required ECVs and good quality hydro-meteorological data in Himalaya
- ISRO working on R&D to solve such challenges with academic partners to provide relevant ECVs for Himalaya

Future EO Missions for Cryosphere Studies



Dual freq. SAR SAR, L-band and S-band SAR, for Soild earth and , biomass and cryosphere studies

Other Missions

ISRO RS 3/3A, RS Sampler

ESA Harmony, ROSE-L

CRISTAL

(Copernicus Polar Ice and Snow Topography Altimeter)

1. To measure and monitor the variability of Arctic and Southern Ocean sea-ice thickness and its snow depth.

2. To measure and monitor the surface elevation and changes therein of glaciers, ice caps and the Antarctic and Greenland ice sheets.

Interferometric Radar altimeter for Ice and Snow (IRIS)