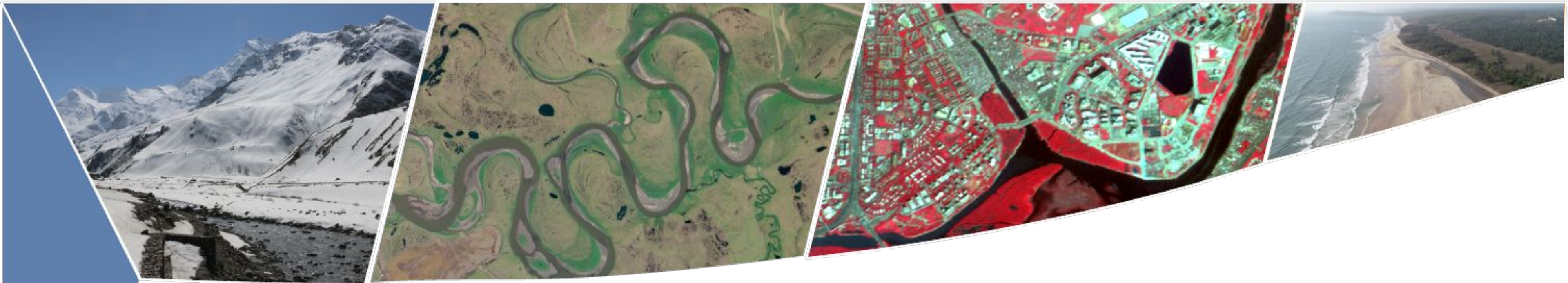

Aga Khan Agency for Habitat
(AKAH)

International Conference on

Cryosphere and related hazards in High Mountain Asia in a changing climate

(01.11.2022 – 04.11.2022)

High resolution snow depth estimation in Hindu Kush Himalayan regions -Challenges and Way Forward

By

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IIT Bombay

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H-RSA

Hydro – Remote Sensing Application Group

Department of Civil Engineering

Indian Institute of Technology Bombay

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Govt of India

Contents

Hindu Kush Himalayan Region

- Extends over 8 countries between 61° to 105° East and 16° to 40° North
- Area = ~4.2 x 10^6 km^2
- Water tower of Asia, Third pole
- Affects lives of 2 billion population
- Major river head waters – Indus, Ganges, Amudarya etc.
- Cryosphere – important part of ecosystem
- Snow in this region linked with – water security, local hazards etc.

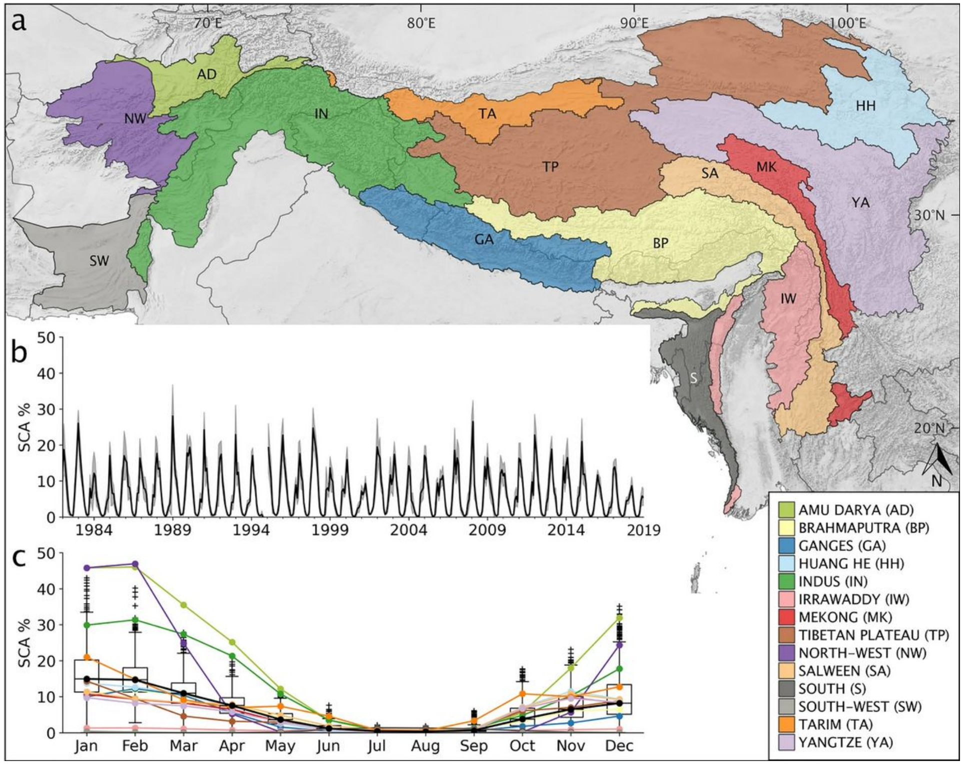
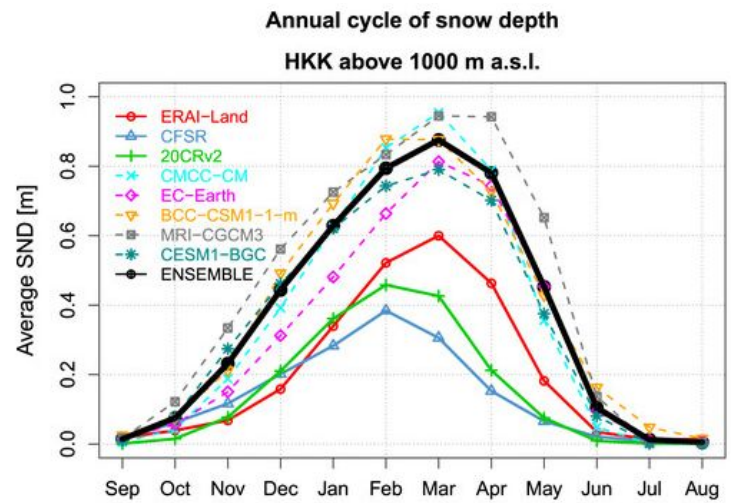


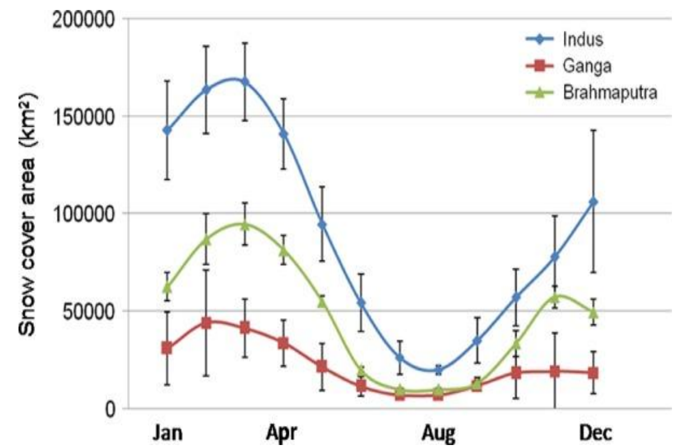
Fig. Snow cover seasonal variability1

1. Naegeli et al. (2022), Scientific Reports;

Snow Depth & Importance



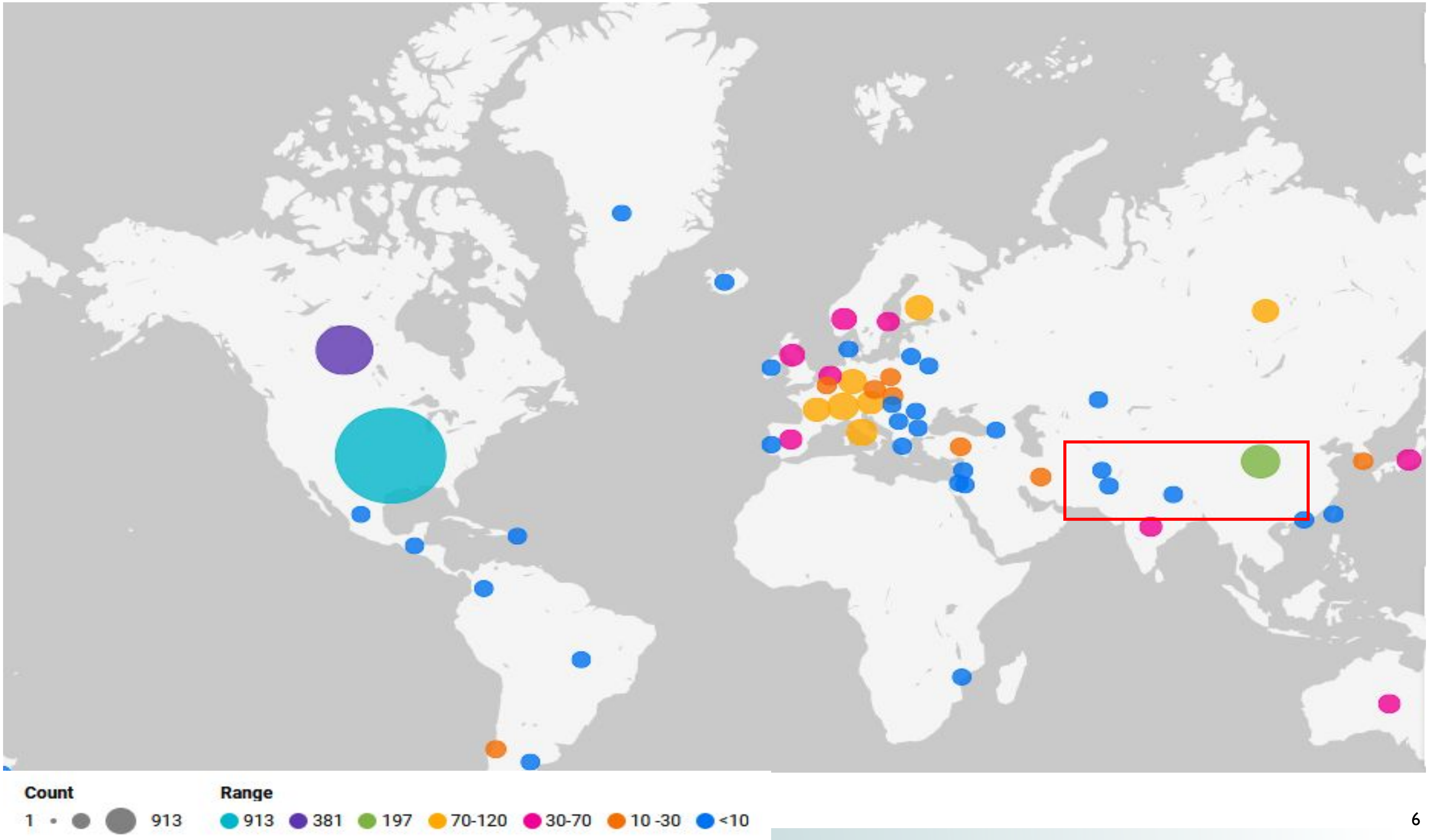
Average snow depth variation over HKK region as given by different GCMs (1980-2005)[2]



Average MODIS Snow Cover over Indian Himalayan basins (2000-2011) [3]

2. Terzago et al,. (2014), J. Hydrometeorol; 3. Singh et al. (2013), Int. J. Climatol;

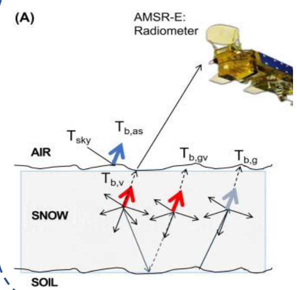
Global trend of Snow depth and SWE studies as per keyword search in SCOPUS database (2000-2020)



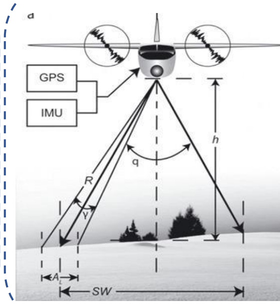
Need for snow depth monitoring in Himalayan

Snow Depth Retrieval Methods:

- Extremely challenging and expensive task.
- Limited number of stations.



- Good spatial, temporal coverage.
- Cannot resolve the high spatial variability - Saturate at ~0.8 m snow depth.



- Airborne lidars are limited to targeted areas and favorable weather conditions.
- Space borne lidars have less temporal resolution.

1. Ground stations, and Field surveys

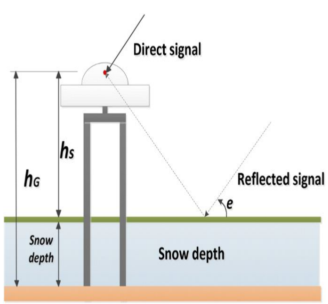
3. Passive Microwave System

5. Airborne and Space borne Lidar Systems

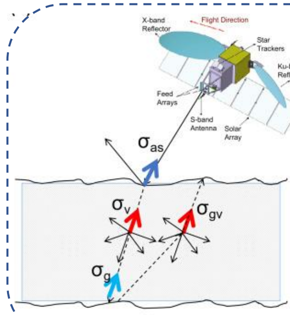
Snow Depth

2. GNSS*

4. Active Microwave System



- Provides small footprint of data with high temporal frequency.
- Low cost data acquisition



- Presence of geometric distortions and speckles.
- Good spatial resolution, high Penetration.

Insitu methods

Remote sensing

*Note: *requires satellite signal as*

Snow Depth Approaches – Merits Comparison (for different platforms)

Merits	Ground	Ground + Space	Air	Space	
	In-situ	GNSS	UAV (Lidar & Optical sensors)	PM W	AM W
Snow depth accuracy					
Simple (direct measurement of snow depth)					
Daily temporal resolution					
Good spatial resolution					
Good spatial coverage					
Deep snow pack monitoring					

Capabilities: Excellent; Moderate; Poor; Not applicable;

Snow Depth Approaches – Limitations Comparison (for different platforms)

Limitations	Ground	Ground+ space	Air	Space	
	In-situ	GNSS	UAV (Lidar & Optical sensors)	PMW	AMW
Sparsely distributed discrete measurements					
Limitations in spatial coverage					
Inaccessible terrain					
Requires work in severe weather conditions					
Maintenance and measurement issues					
Coarse resolution					
Wet snow problems					

Severity/Susceptibility: High; Moderate; Less/Not present; Not applicable

Review of PMW SD Techniques Over Indian Himalaya

Authors	Study Area	Data / Method/ Resolution	Maximum Validation Depth	Error	Limitation	Operational Algorithms (Y/N)
Singh et al., (2007)	Greater Himalayan	SSM/I/ Regression / 25 km	210	50 cm	Limited validation point , coarse resolution	N
Das and Sarwade (2008)	Greater Himalayan	AMSR-E/ Regression/	70 cm	20.34	Limited validation point , coarse resolution	N
Gusain et al., (2016)	Lower and middle Himalaya	MODIS, DEM & in-situ data/ Spatial interpolation/ 500 m	300 cm	42 cm	Large number of in-situ data required every time and algorithm is elevation dependent	Yes
Singh et al., (2020)	Middle Himalaya	AMSR-2/Regression /10 km	140 cm	16 cm	coarse resolution, simple regression model, applicable for middle Himalaya	Yes, for middle Himalaya

Our ongoing works (related to snow depth) at H-RSA Laboratory – IIT Bombay

Passive microwave
- Use of machine learning for improving SD
- Use of snow pack emission models for improving estimates
- Downscaling of existing coarse products using statistical and machine learning models

Active microwave
- Use of sentinel data for high resolution SD
- Use of machine learning models
- Use of assimilation for improving snow depth estimates

UAV
- Use of low-cost UAV's for SD estimation

GNSS
- Low cost GNSS for continuous SD estimation

Ongoing, and manuscript works | Early stage works | Planned works

In this presentation

Two passive microwave approaches for snow depth estimation

1. Multifactor model	2. Machine learning model

1. Multifactor model

Considers AMSR-2 PMW observations, auxiliary parameters as input	Spatial variability of brightness temperature, climatic conditions are considered to develop model	Linear, and non-linear empirical relations are developed specific to Himalayan region

2. Machine learning model

Considers AMSR-2 PMW observations, auxiliary parameters as input	Used for building more dynamic non-linear models for SD	ERT model is used

DGRE-DRDO snow-meteorological observatories

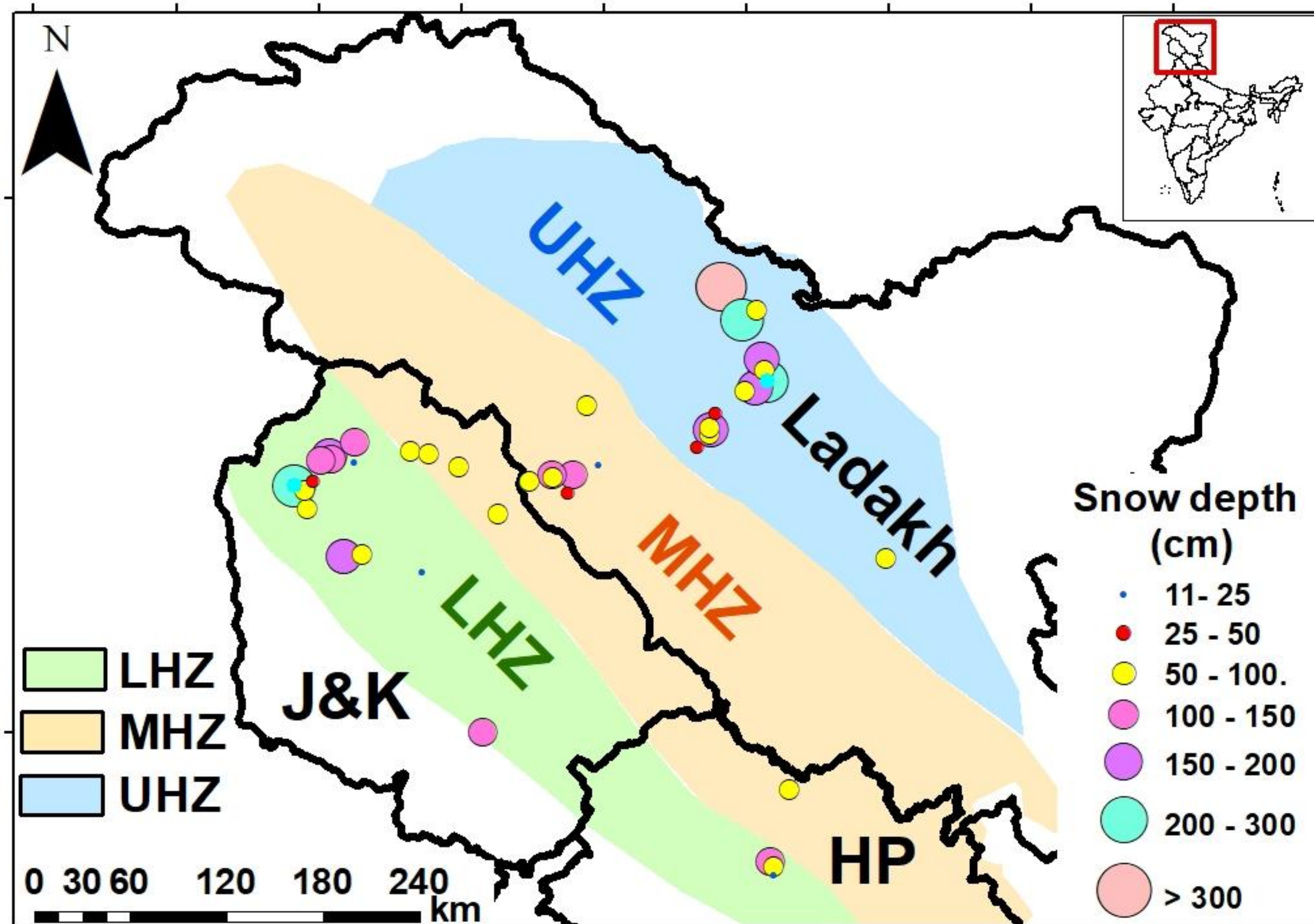


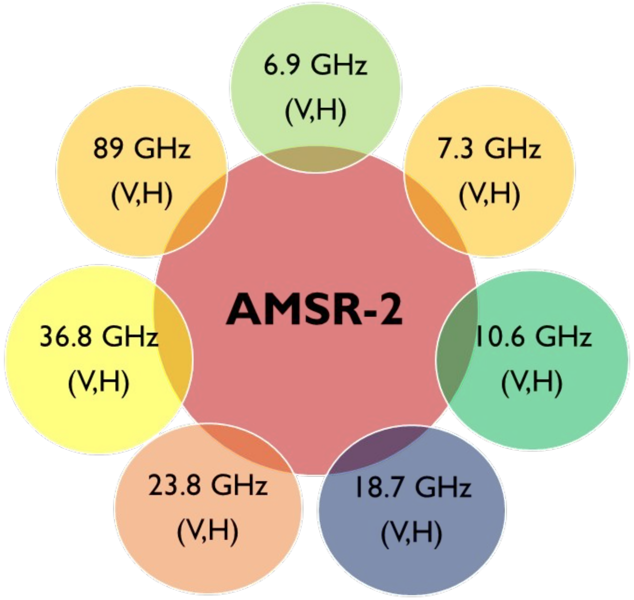
Fig. Mean SD from Oct to Mar. during 2012-19 from observatories

- **Total Manual Observatories: 42**
- **Lower Himalaya (LH) Total Area : 41,075 km^2 Observatories: 16**
- **Middle Himalaya (MH): Total Area : 84,718 km^2 Observatories: 12**
- **Upper Himalaya (UH): Total Area : 49,923 km^2 Observatories: 14**

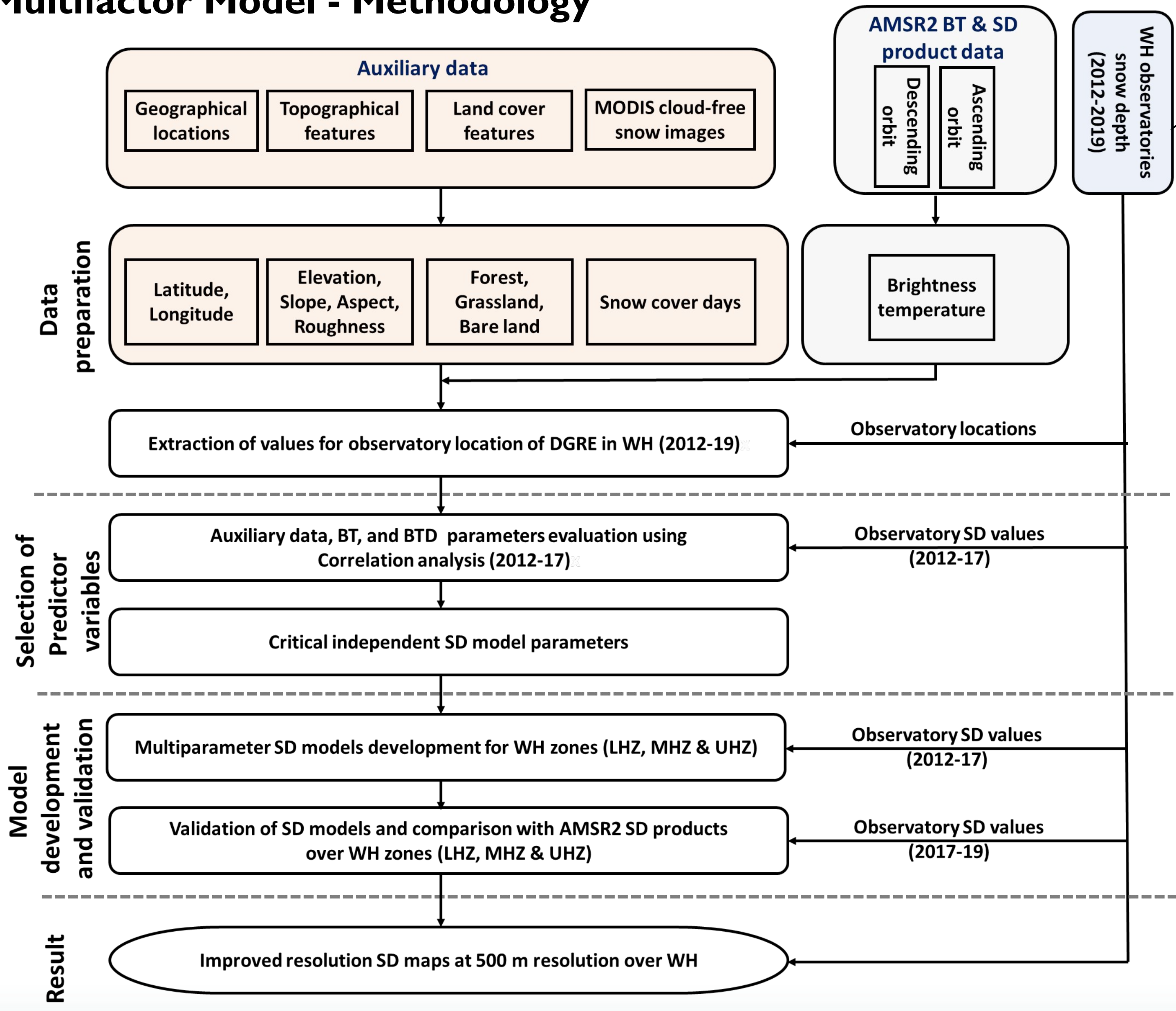
LH Observatories	MH Observatories	UH Observatories
HP:3; J&K:13	HP:1; J&K:4; Ladakh:7	Ladakh:14

AMSR-2 PMW data

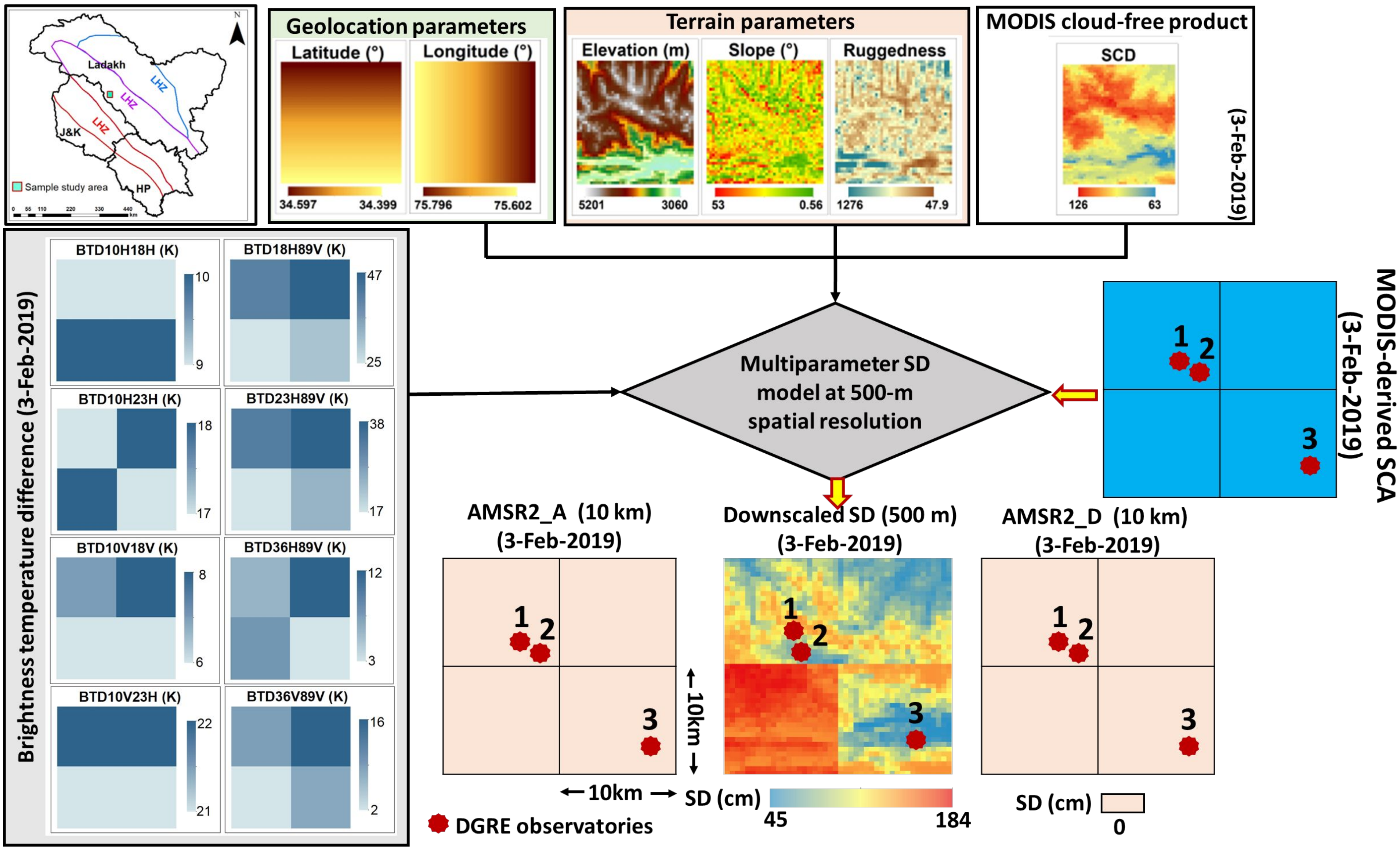
- Onboard GCOM-W1 satellite (2012-23)
- Orbital height: ~700km
- 14 channels in 7 frequencies
- Ascending pass: 1:30 PM
- Descending pass: 1:30 AM
- Swath: 1450 km
- Global coverage: once a day
- Spatial resolution: varies with frequency
- Predecessor: AMSR-E over Aqua (2002-16)
- Successor: AMSR-3 over GOSAT-GW (2023-30)



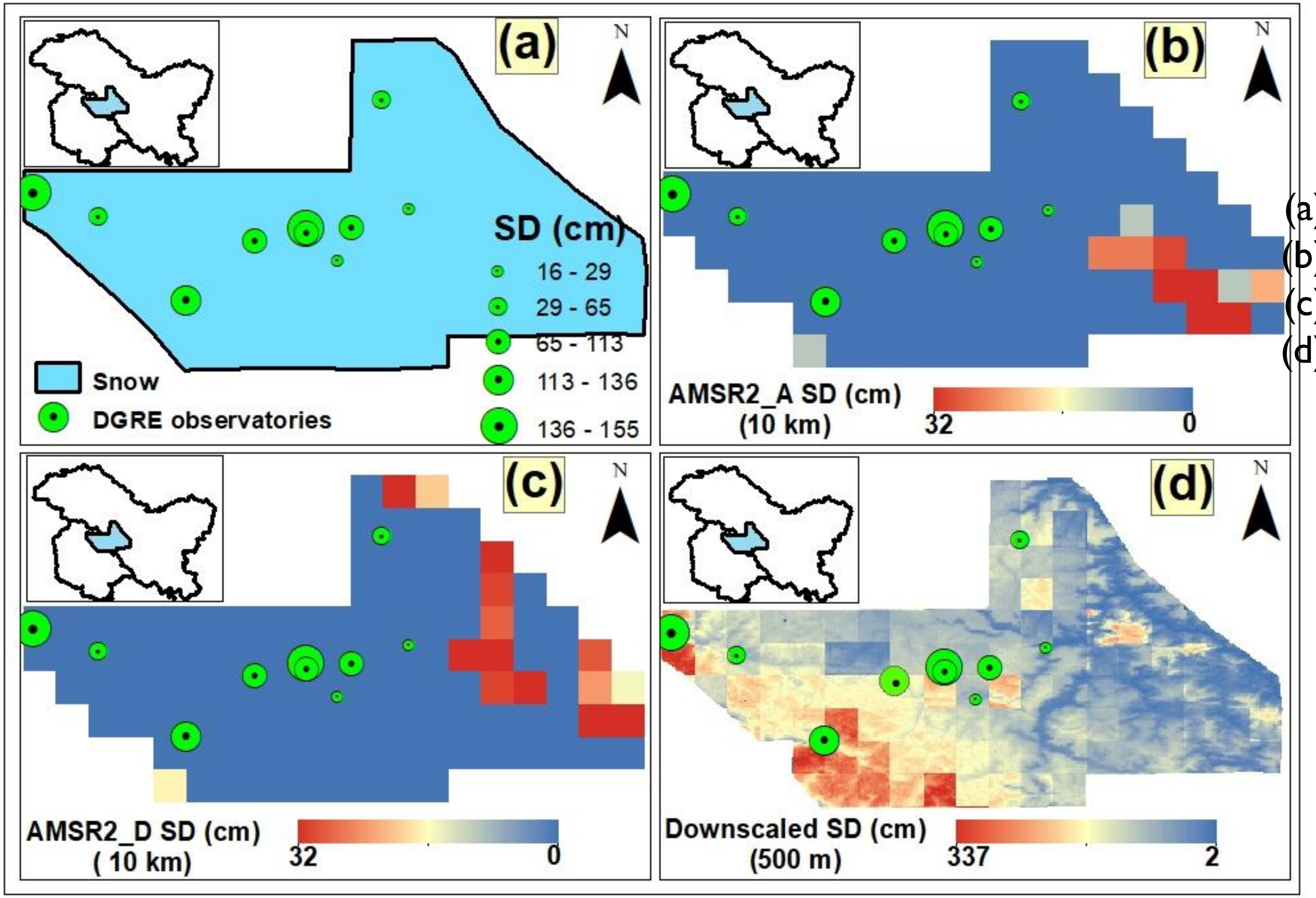
1. Multifactor Model - Methodology



DGRE Network From DRDO

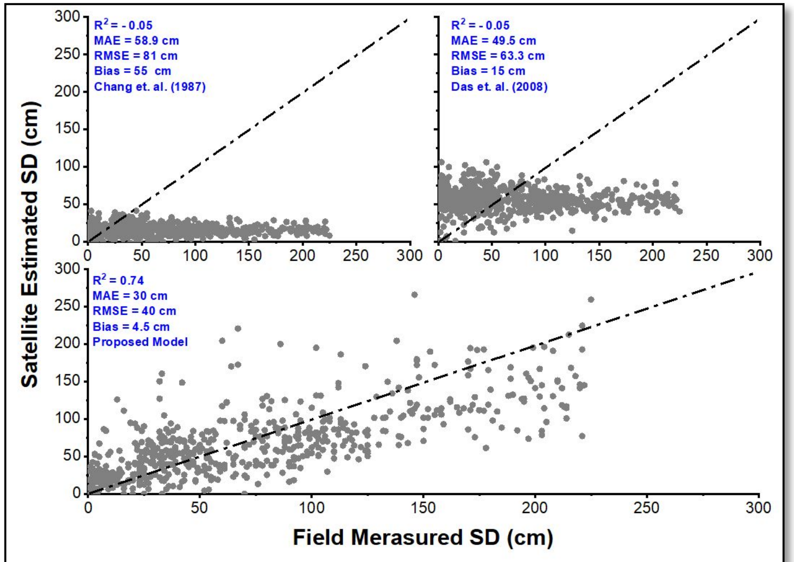

Ladakh
J&K
HP
LHZ
Sample study area
Geolocation parameters
Latitude (°)
Longitude (°)
34.597
34.399
75.796
75.602
Terrain parameters
Elevation (m)
Slope (°)
Ruggedness
5201
3060
53
0.56
1276
47.9
MODIS cloud-free product
SCD
126
63
(3-Feb-2019)
Brightness temperature difference (3-Feb-2019)
BTD10H18H (K)
BTD18H89V (K)
BTD10H23H (K)
BTD23H89V (K)
BTD10V18V (K)
BTD36H89V (K)
BTD10V23H (K)
BTD36V89V (K)
Multiparameter SD model at 500-m spatial resolution
MODIS-derived SCA (3-Feb-2019)
AMSR2_A (10 km) (3-Feb-2019)
Downscaled SD (500 m) (3-Feb-2019)
AMSR2_D (10 km) (3-Feb-2019)
10km
SD (cm)
45
184
0
DGRE observatories

Case study: 23 Feb 2019

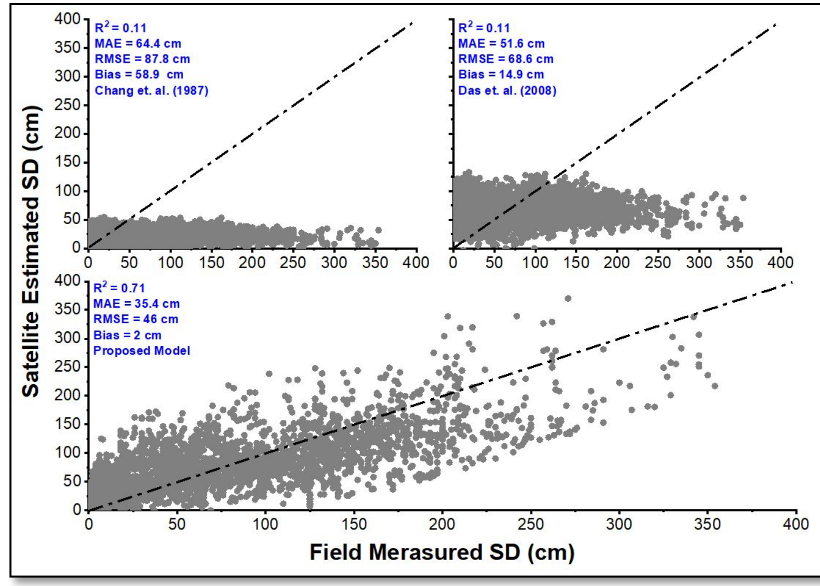


(a) MODIS SCA
(b) AMSR2_A
(c) AMSR_D
(d) Proposed

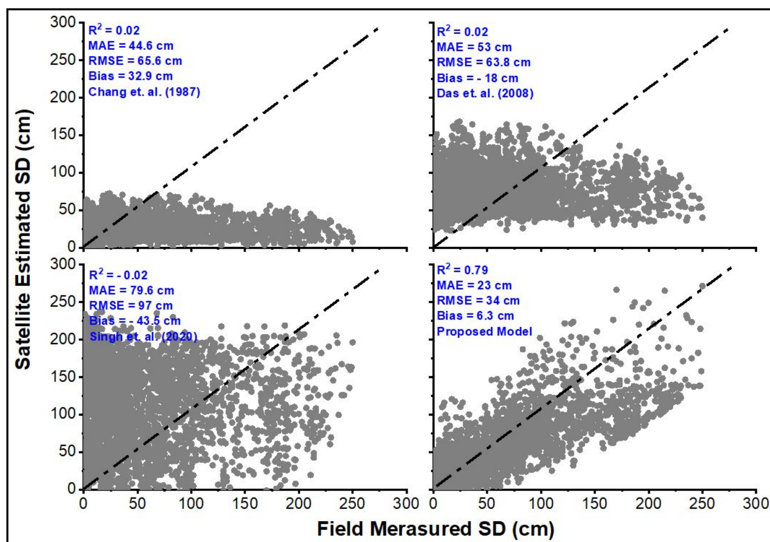
Comparison of PMW SD model with global and regional models over WH



a) LHZ

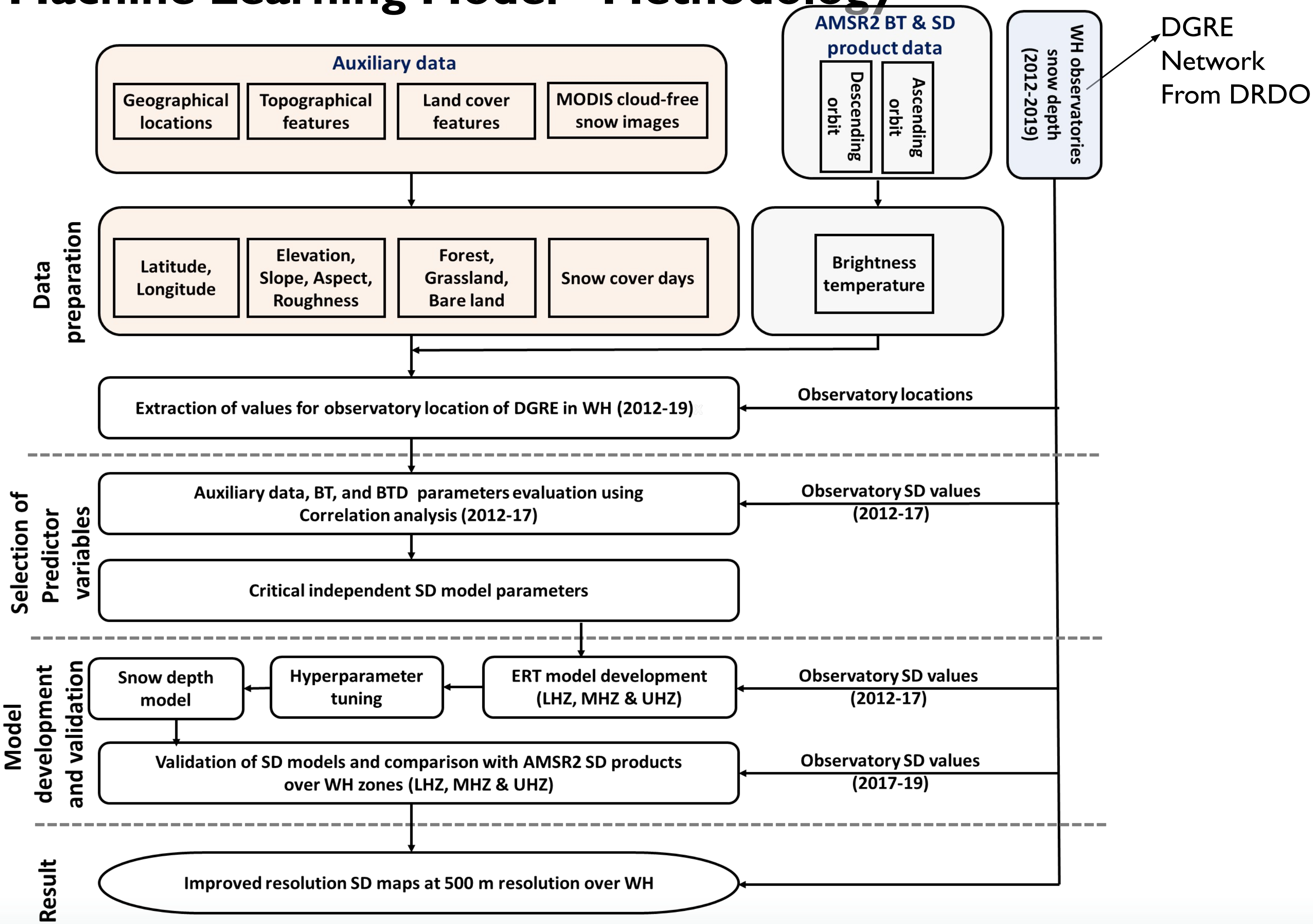


c) UHZ

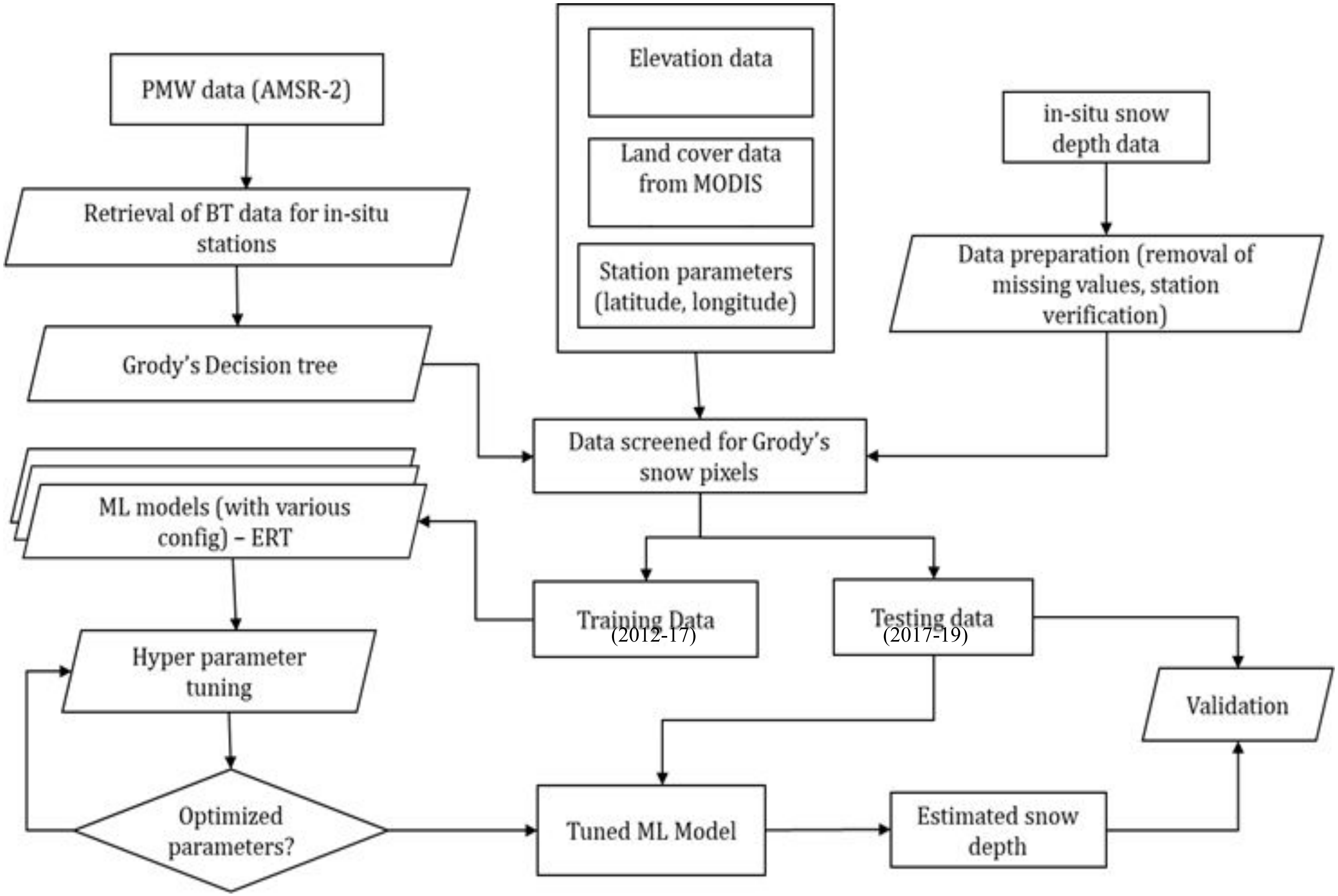


b) MHZ

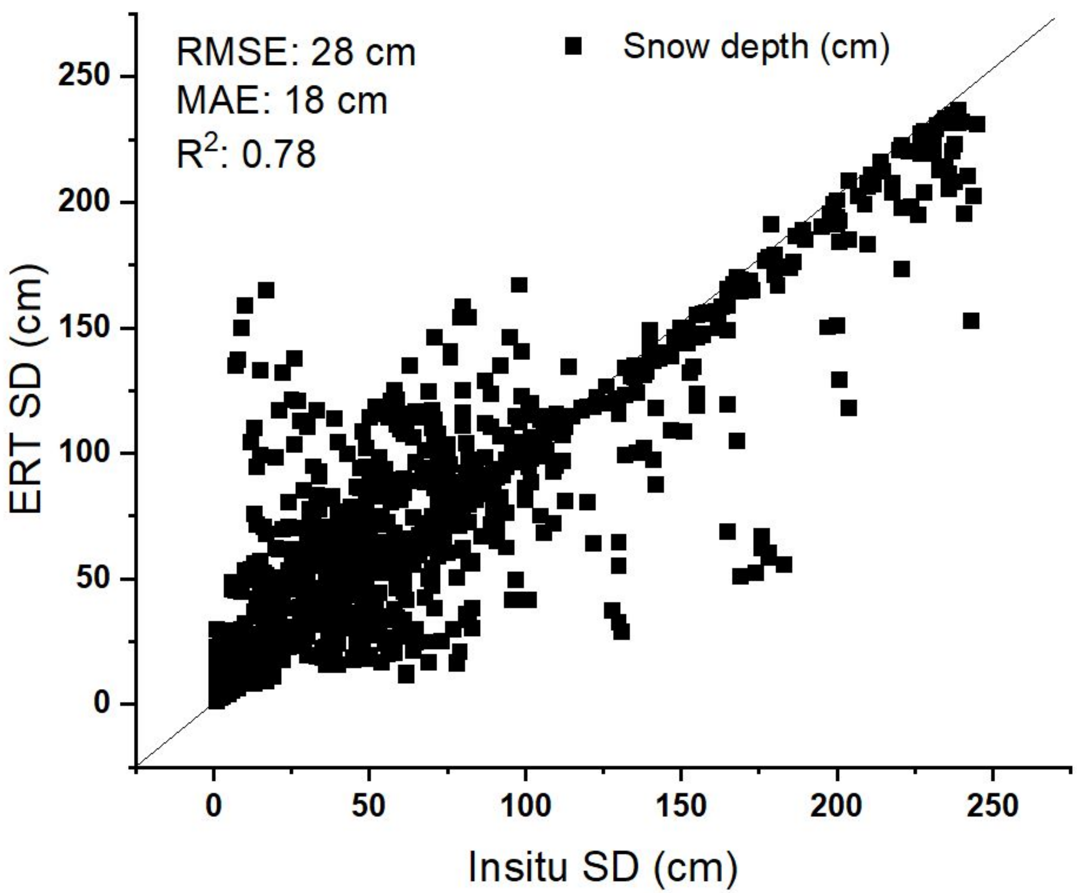
2. Machine Learning Model - Methodology



2. Machine Learning Model - Methodology

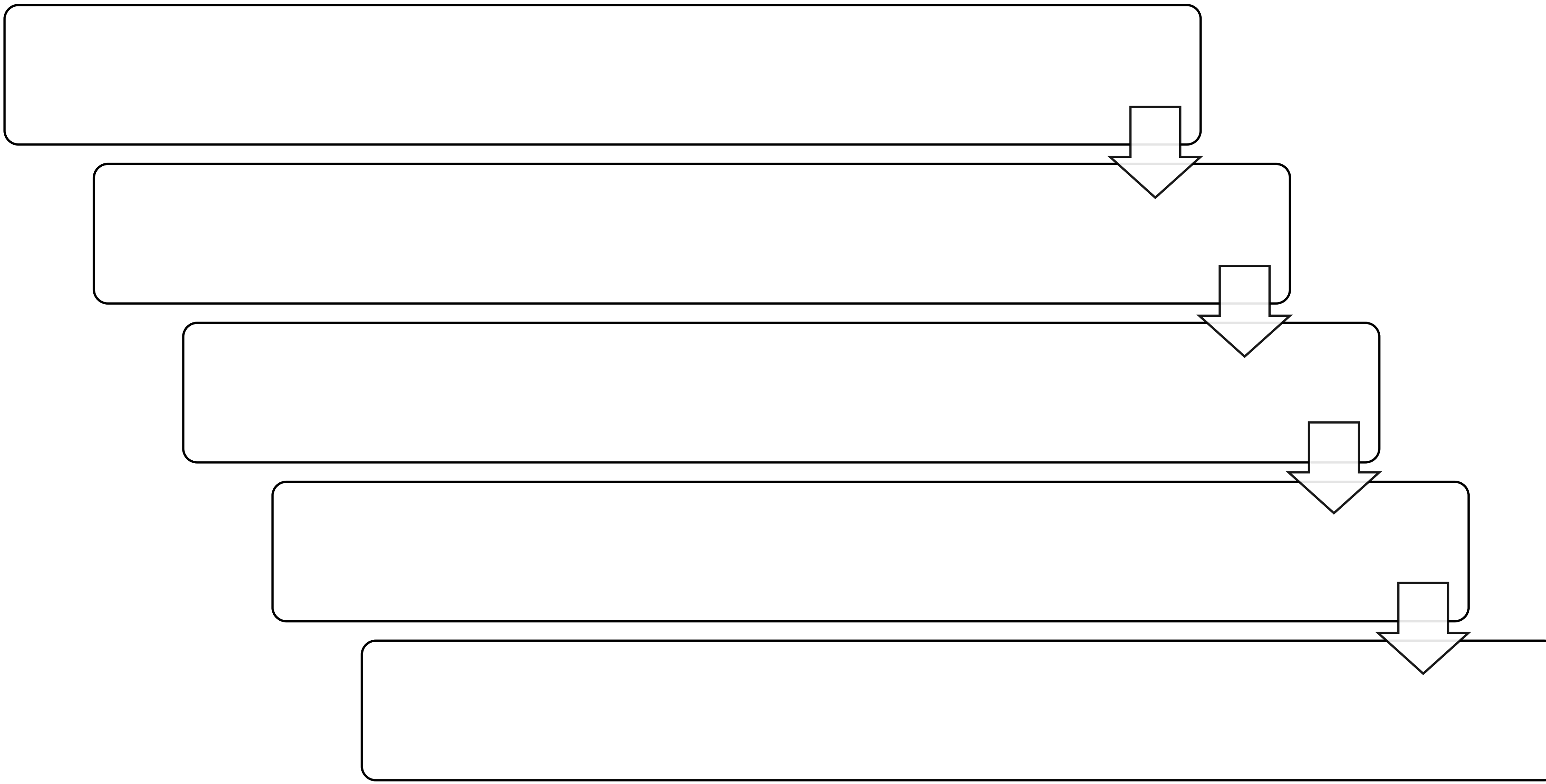


Results for Machine Learning Model – Middle Himalayan Zone

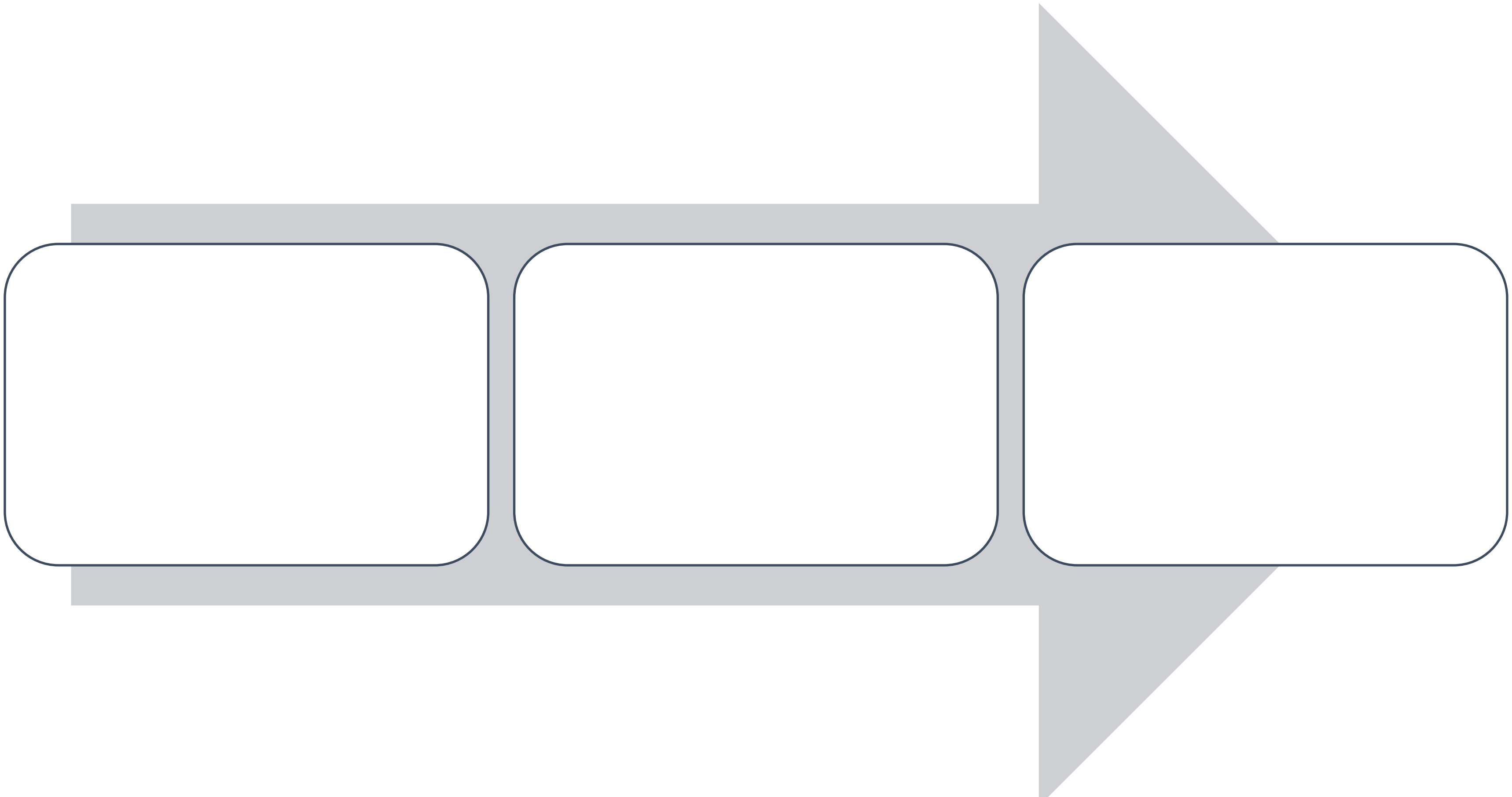


- Improved correlation in deep snow estimates
- Reduced RMSE, MAE error compared to Multifactor, and other models

Challenges for Model Development



Way forward



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