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Automatic detection of snowline altitude at five glacierized catchments over the high-mountain Asia

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Background

Snow cover is decreasing (e.g., IPCC SROCC, 2019)

- ✓ Decrease in water resources
- ✓ Affects on crop production
- ✓ Natural hazards (e.g. Floods)

It is important to understand the past and current changes in snow cover and driving factors.

Snow cover in High Mountain Asia (HMA) is still largely unknown

- ✓ Few in-situ observations
- ✓ Difficulties of remote sensing due to heavy clouds
- ✓ Most satellite observations are conducted with MODIS; The resolution (250/500 m) is a bit coarse considering the complex topography of the Himalayas
- ✓ Poor reproducibility of climate models due to complex terrain and lack of observations

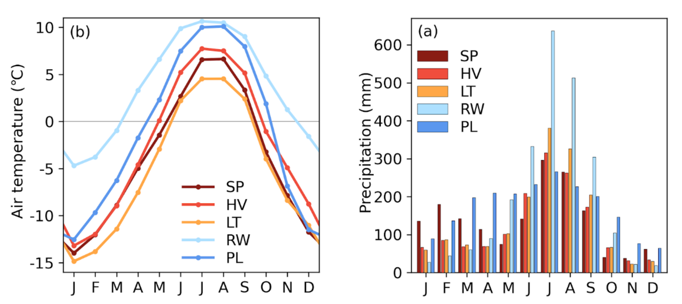
"Snowline altitude (SLA)"

- ✓ Good indicator of snow covered area (Girona-Mata et al., 2019, Tang et al., 2021)
- ✓ Less biased by cloud cover than snow cover products
  → Suitable for **Monsoon Asia**

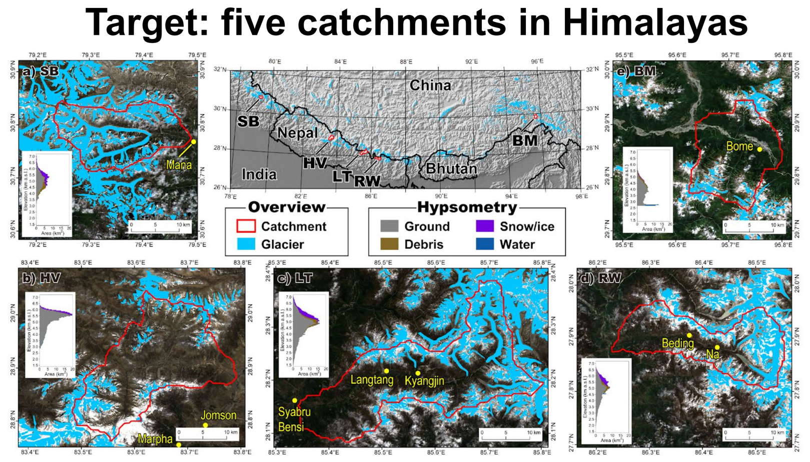
Objective

- Develop an automatic SLA detection algorithm using Google Earth Engine to enable detailed SLA analysis on large-scales and long period by using high-resolution satellite images
- Investigate the changes in snow cover and primary controls at five glacierized catchments in Himalayas

Climatic factors in target catchments



Target: five catchments in Himalayas



Data

[1] Satellite data

	Period	Time	Bands for NDSI	Res.	Others
Landsat 5	1999/1～2013/1	10:00	Band2, Band5	30m	
Landsat 7	1999/4～2019/12	10:00-10:15	Band2, Band5		
Landsat 8	2013/2～2019/12	10:00	Band3, Band6		
Sentinel-2	2015/6～2019/12	10:30	Band3, Band11	20m	(Band3: 10m, Band11: 20m)

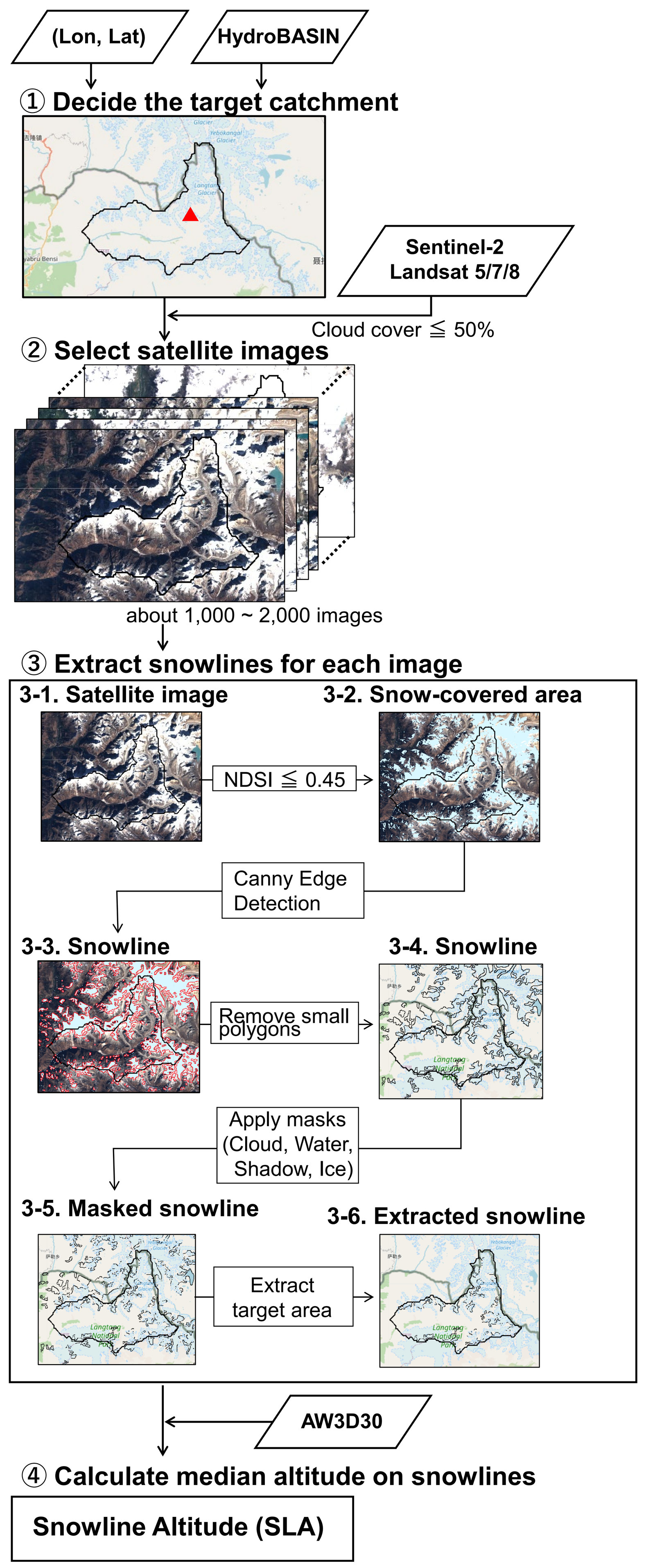
[2] Elevation data: AW3D30 (DEM from the ALOS PRISM, 30m res)

[3] Outline of target watersheds: Hydro BASIN, Region 9

[4] Surface classification data:
- Glacier outlines: GAMDAM Inventory (Sasaki et al., 2019)
- Outlines of debris on glaciers: Product of Scherler et al., 2018
- Water body map: Global Surface Water (Pekel et al., 2016)

Method

[Flow of SLA detection]



Results

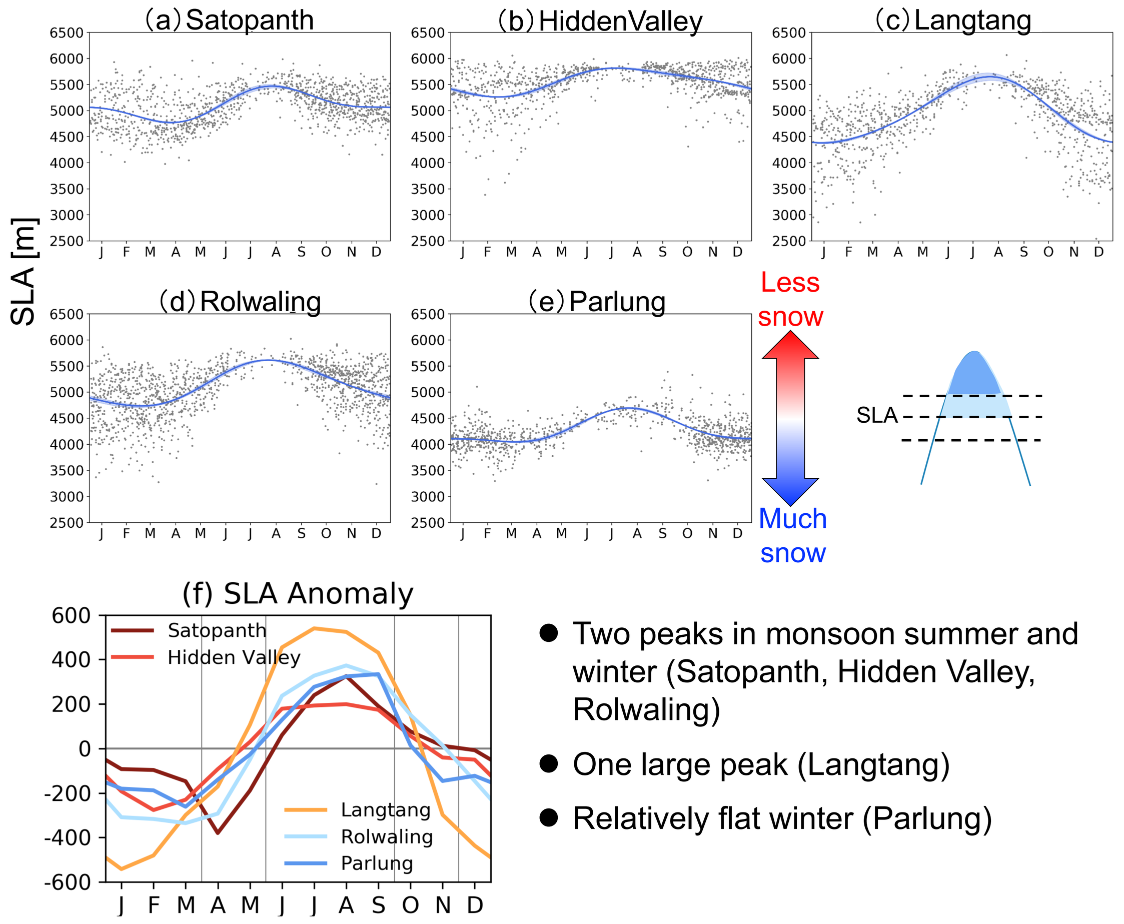
[1] Obtained available images

Target period: 21 years (Jan 1999～Dec 2019)

	Lon. & Lat.	Altitude [m] (Max, Min)	Area [km2]	Monthly precip. [mm]	Daily temp. [℃]	Total number of images
Satopanth (ST)	79.36, 30.78	5031.38 (7080, 3154)	243.0	127.8	−3.7	1,387
Hidden Valley (HV)	83.63, 28.91	5383.52 (6492, 2876)	445.0	123.8	−2.3	1,173
Langtang (LT)	85.58, 28.21	4879.37 (7156, 1461)	587.7	135.2	−5.0	967
Rolwaling (RW)	86.41, 27.89	5007.55 (6897, 1621)	309.5	195.6	3.8	1,520
Parlung (PL)	95.71, 29.84	3863.58 (6052, 2678)	253.2	171.3	−0.7	1,084

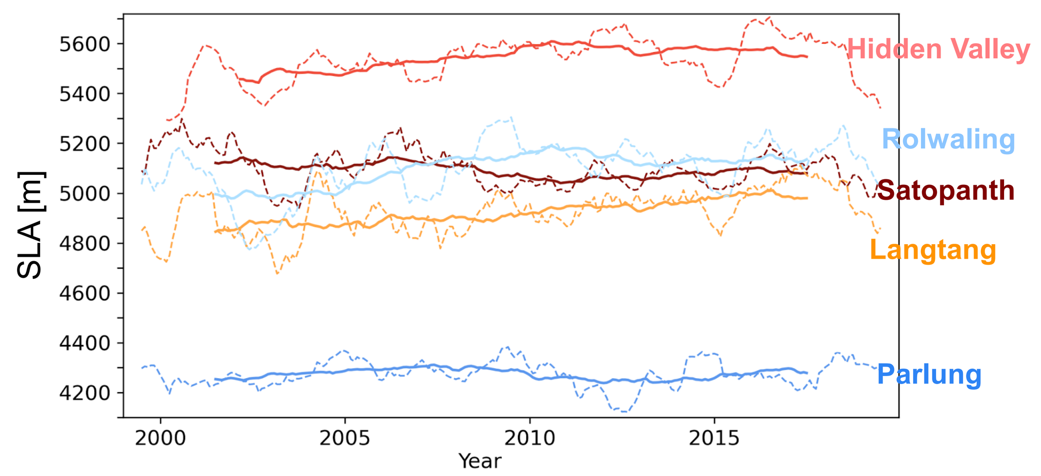
Total: 6,131 images

[2] Detected SLAs



- Two peaks in monsoon summer and winter (Satopanth, Hidden Valley, Rolwaling)
- One large peak (Langtang)
- Relatively flat winter (Parlung)

[3] Time-series of SLA

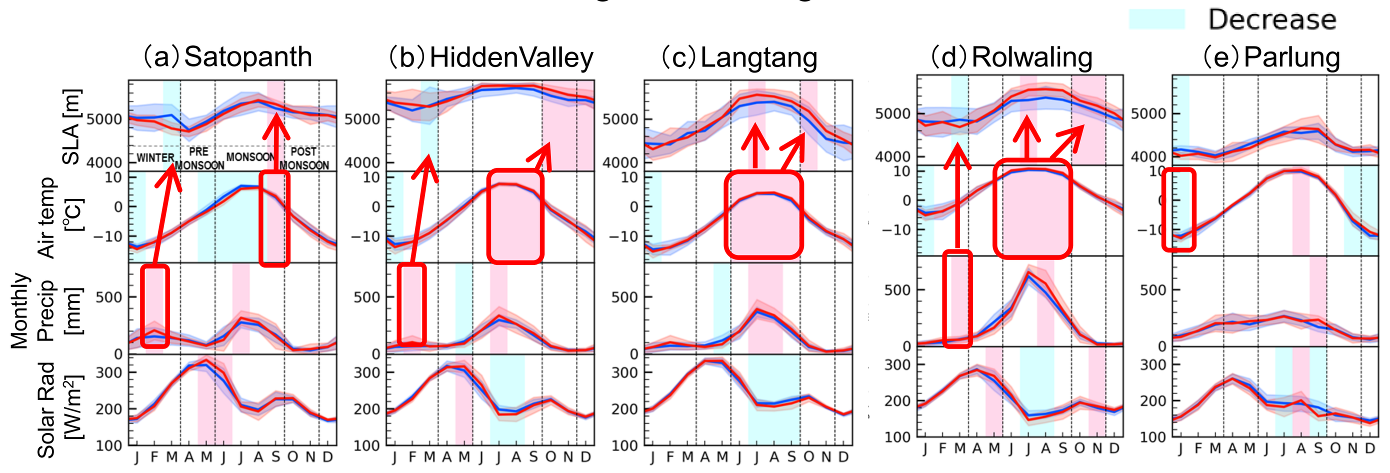


Trend-detection was done by Mann-Kendall test (significant level = 0.01).

- Increasing trend: Hidden Valley, Langtang, Rolwaling
  + 11.9 m yr-1 at Hidden Valley
  + 14.4 m yr-1 at Langtang Valley
  + 8.2 m yr-1 at Rolwaling Valley
- Decreasing trend: Satopanth
  −15.6 m yr-1 at Satopanth
- No significant trend: Parlung

[4] Decadal changes in seasonal SLA

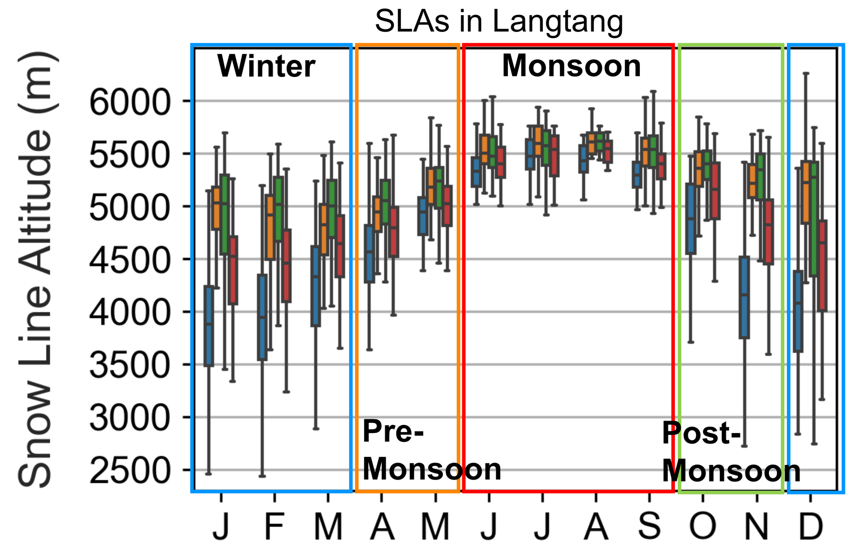
What climate factors cause the long-term changes in SLA?



	Trend	Driving factors
Satopanth	− 15.6 m yr^{-1}	Increased winter snowfall => Much accumulation
Hidden Valley	+ 11.9 m yr^{-1}	Temperature increase during the monsoon and post-monsoon => Much snowmelt
Langtang	+ 14.4 m yr^{-1}	
Rolwaling	+ 8.2 m yr^{-1}	
Parlung	No trend	SLA decreases in January due to lower temperature, but not causing long-term changes.

[5] SLAs among different aspects

Aspect dependency provides information about climatic factors driving seasonal variation (Today's example: Langtang region)



[Monsoon]
Few differences between aspects
- ✓ Snowmelt controls SLA
- ✓ Precipitation maintains SLA
- ✓ Less impact of solar radiation
  High zenith angle
  High diffuse radiation due to heavy clouds

[Winter]
Clear SLA difference between aspects
- ✓ Large SLA ranges due to winter storm (heavy but occasional snowfall)
- ✓ Winter storm originated from west (westerly) leads SLA differences between west and east
- ✓ Large impact of Solar radiation
  Low angle of solar zenith
  Few clouds

[Post-monsoon]
Increasing SLA differences
- ✓ Effects of solar radiation gradually increases
- ✓ Occasional but heavy snowfall increases the uncertainty range of SLA

[Pre-monsoon]
Decreasing SLA differences
- ✓ Decreasing effects of solar radiation
- ✓ Increasing effects of snowmelt due to rising temperature

Summary

- We develop an automatic detecting system of snowline altitude (SLA) using Google Earth Engine
- SLAs are detected and analyzed at five catchments in HMA
  - Long-term trend of SLA varies from −15.6 m/yr to 14.4m/yr for the period from 1999-2019.
  - The increasing SLA trends are mainly caused by increased snow melting during the monsoon, whereas the decreasing trend are caused by increased winter snowfall and reduced monsoon snowmelt.
  - Aspect dependency provides information about climatic factors driving seasonal snow cover changes in each catchment.

Further works: Larger scale analysis (whole HMA or global?) to clarify the spatial and temporal distribution of snow cover and its driving factors.