



Supplement of

Contrasting patterns of change in snowline altitude across five Himalayan catchments

Orie Sasaki et al.

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Supplementary information

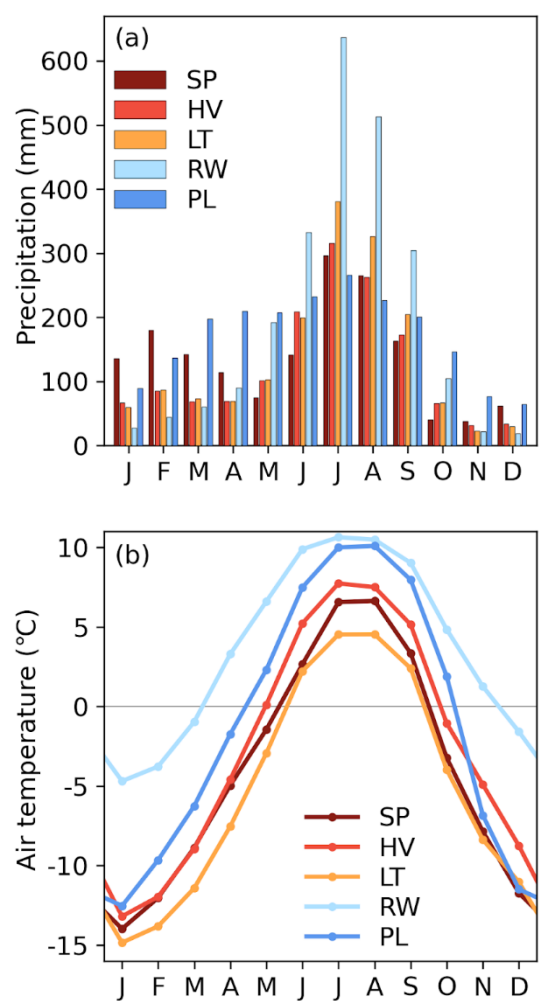


Figure S1: (a) Monthly total precipitation and (b) mean air temperature obtained from the ERA5 reanalysis climate data (Hersbach et al., 2020). The data were averaged for the period from 1999 to 2019 at the grid that includes most of the target catchment without any corrections. Catchment abbreviations denote SP: Satopanth, HV: Hidden Valley, LT: Langtang Valley, RW: Rolwaling Valley, and PL: Parlung, respectively.

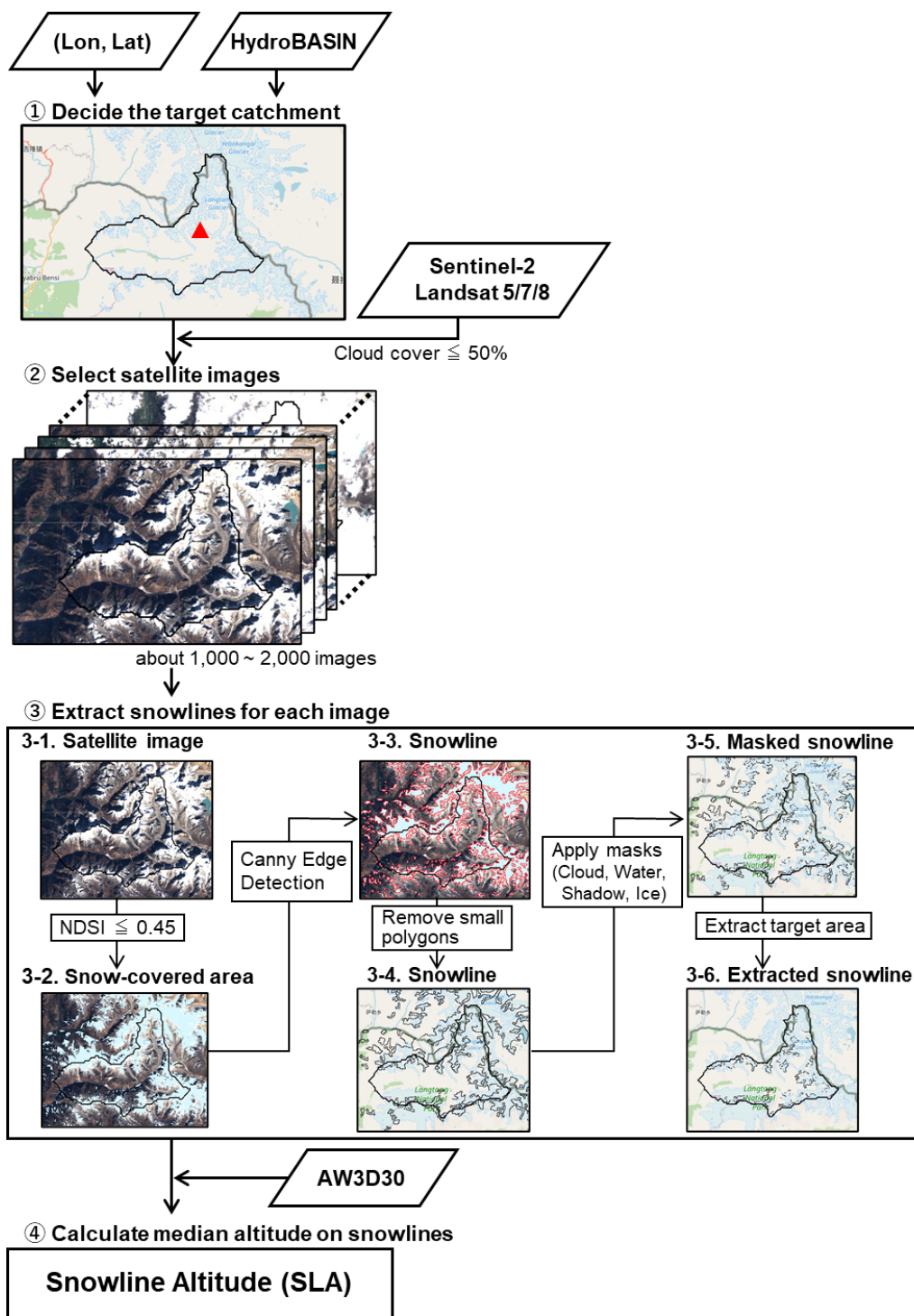


Figure S2: Schematic diagram of the snowline detection algorithm with a sample image obtained from Landsat 8

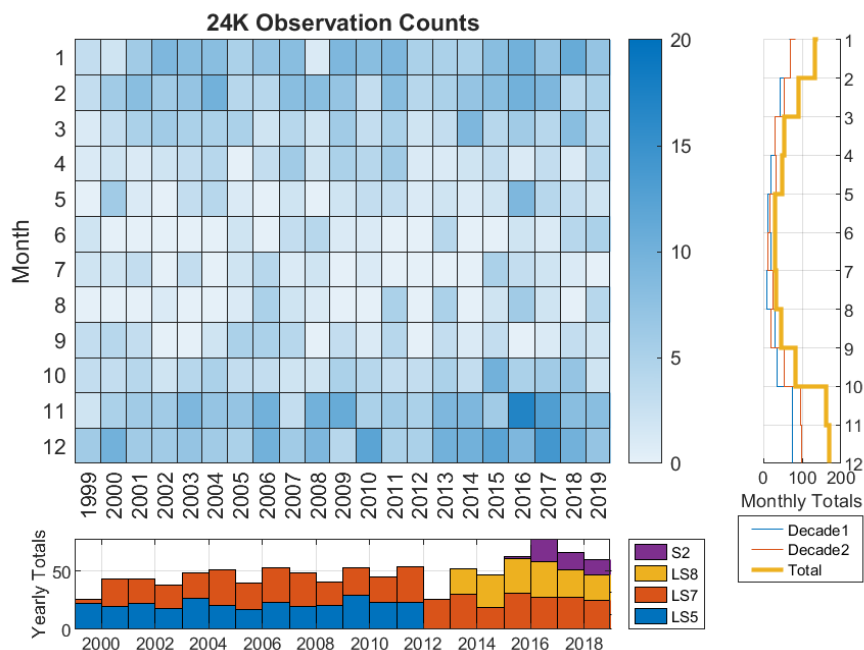


Figure S3. Depiction of monthly and annual snowline retrievals at 24K (Parlung), including interannual breakdown for different sensors and seasonal breakdown between decades.

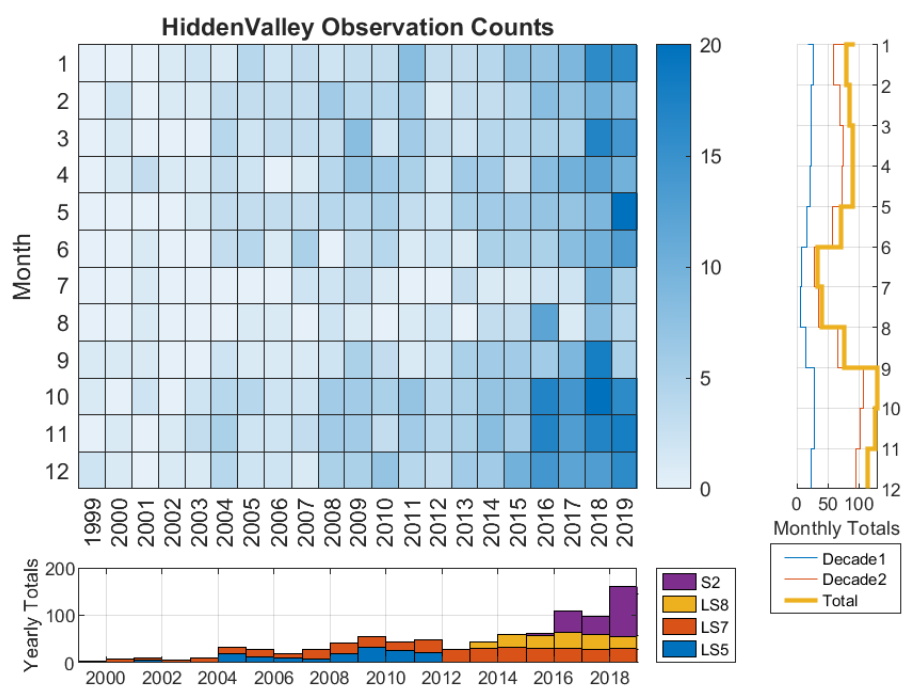


Figure S4. Depiction of monthly and annual snowline retrievals at Hidden Valley, including interannual breakdown for different sensors and seasonal breakdown between decades.

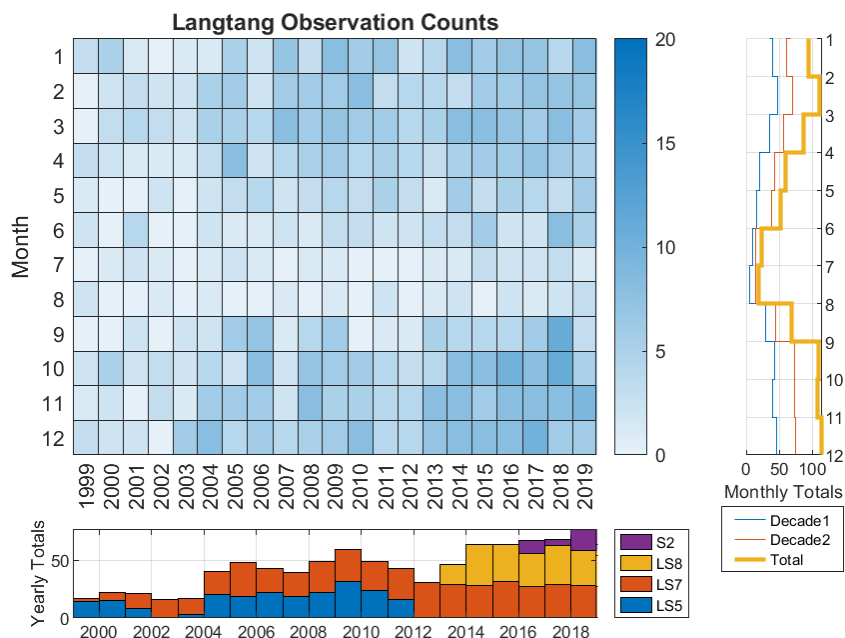


Figure S5. Depiction of monthly and annual snowline retrievals at Langtang, including interannual breakdown for different sensors and seasonal breakdown between decades.

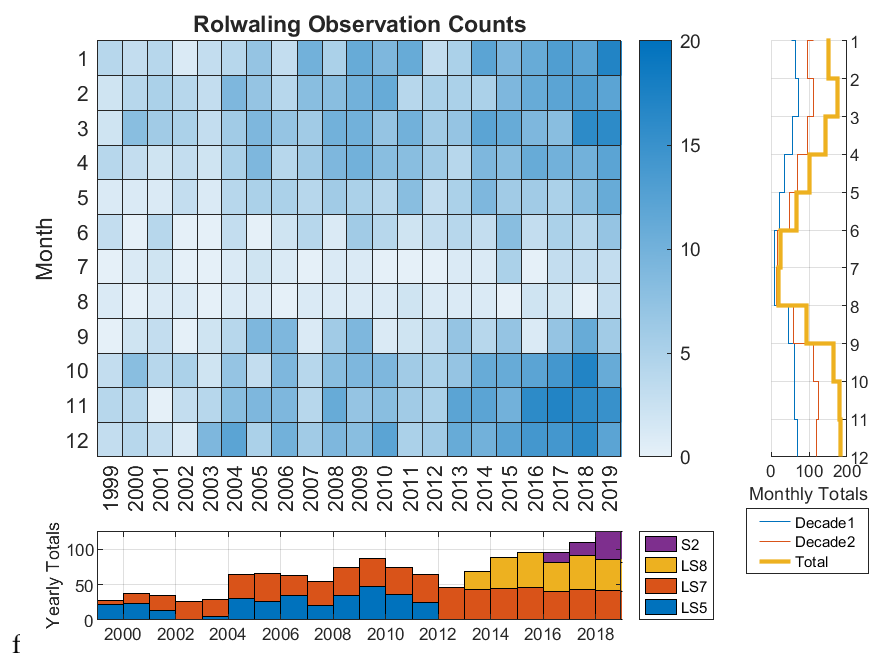


Figure S6. Depiction of monthly and annual snowline retrievals at Rolwaling, including interannual breakdown for different sensors and seasonal breakdown between decades.

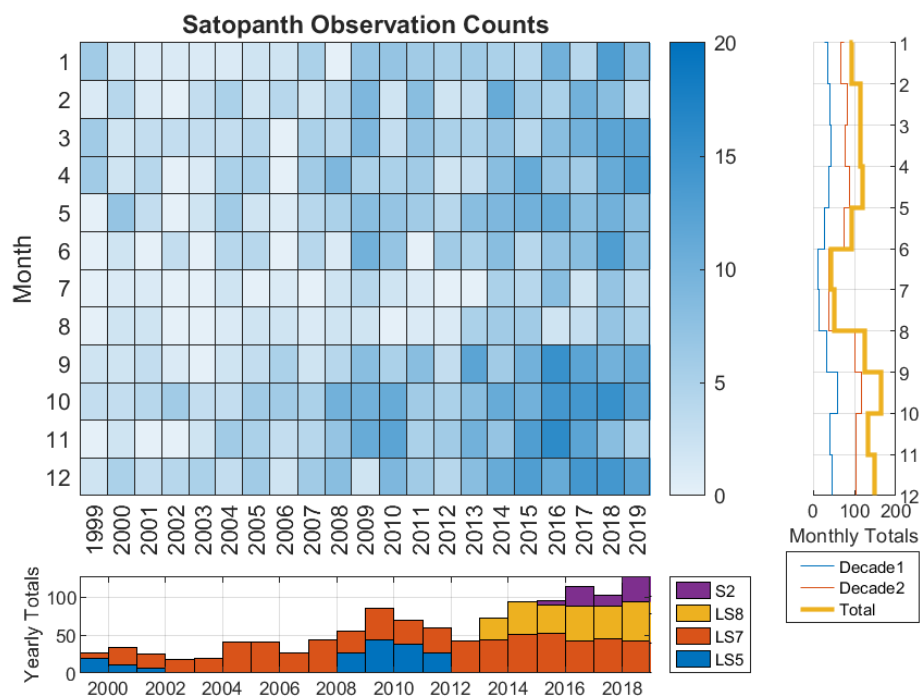


Figure S7. Depiction of monthly and annual snowline retrievals at Satopanth, including interannual breakdown for different sensors and seasonal breakdown between decades.

HV_20201012_S2

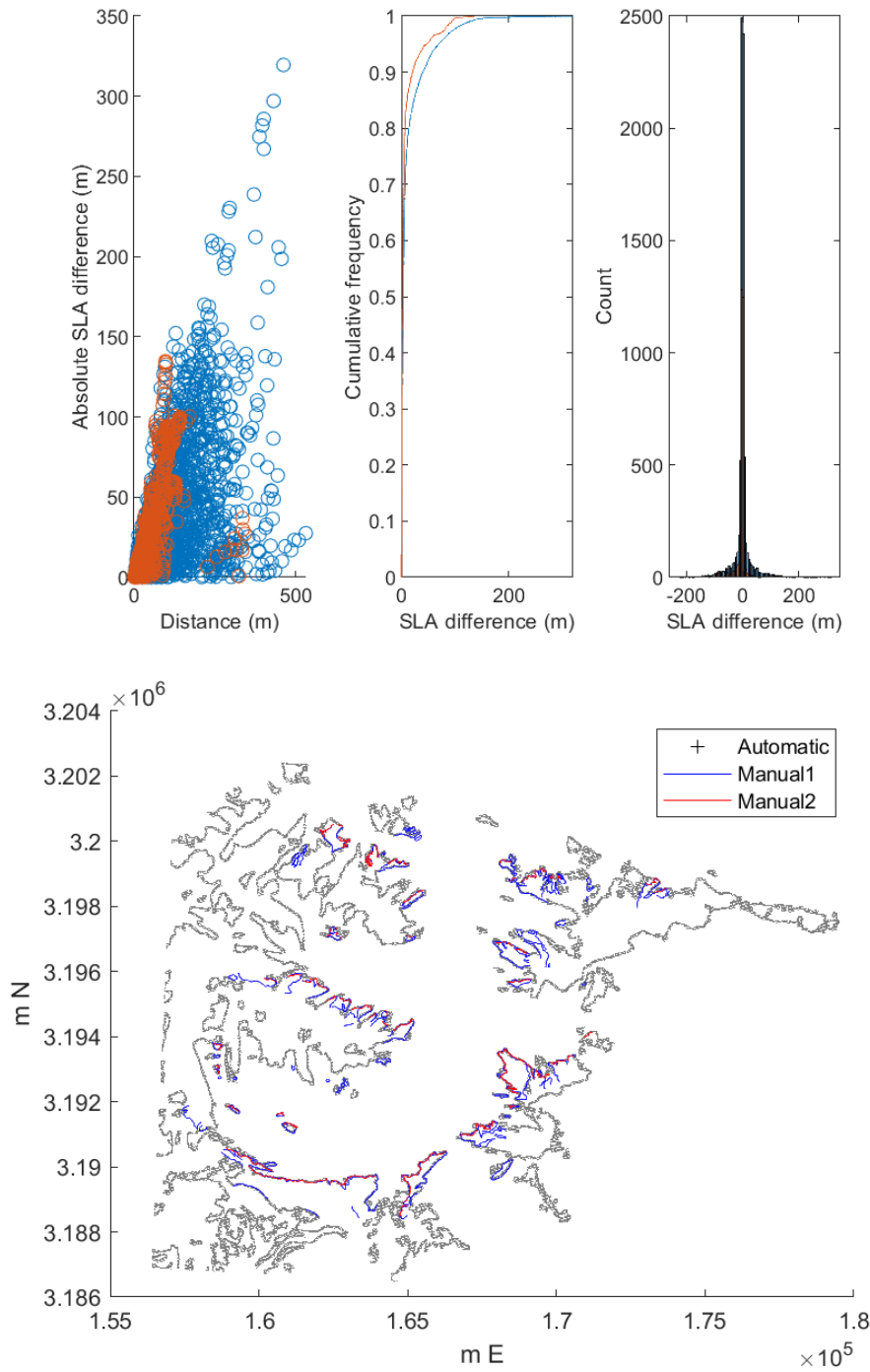


Figure S8. Correspondence of manual and automatic snowlines at the Hidden Valley site in October 2020. The manual snowlines were delimited from a cloud-free PlanetScope image, the automatic snowlines from Sentinel-2. Comparing corresponding nearest snowline points, the automatic snowline had a median absolute deviation of 3m (3 m) elevation and 10 m (9 m) horizontal distance relative to the Manual1 (Manual2) snowline.

HV_20190615_L8

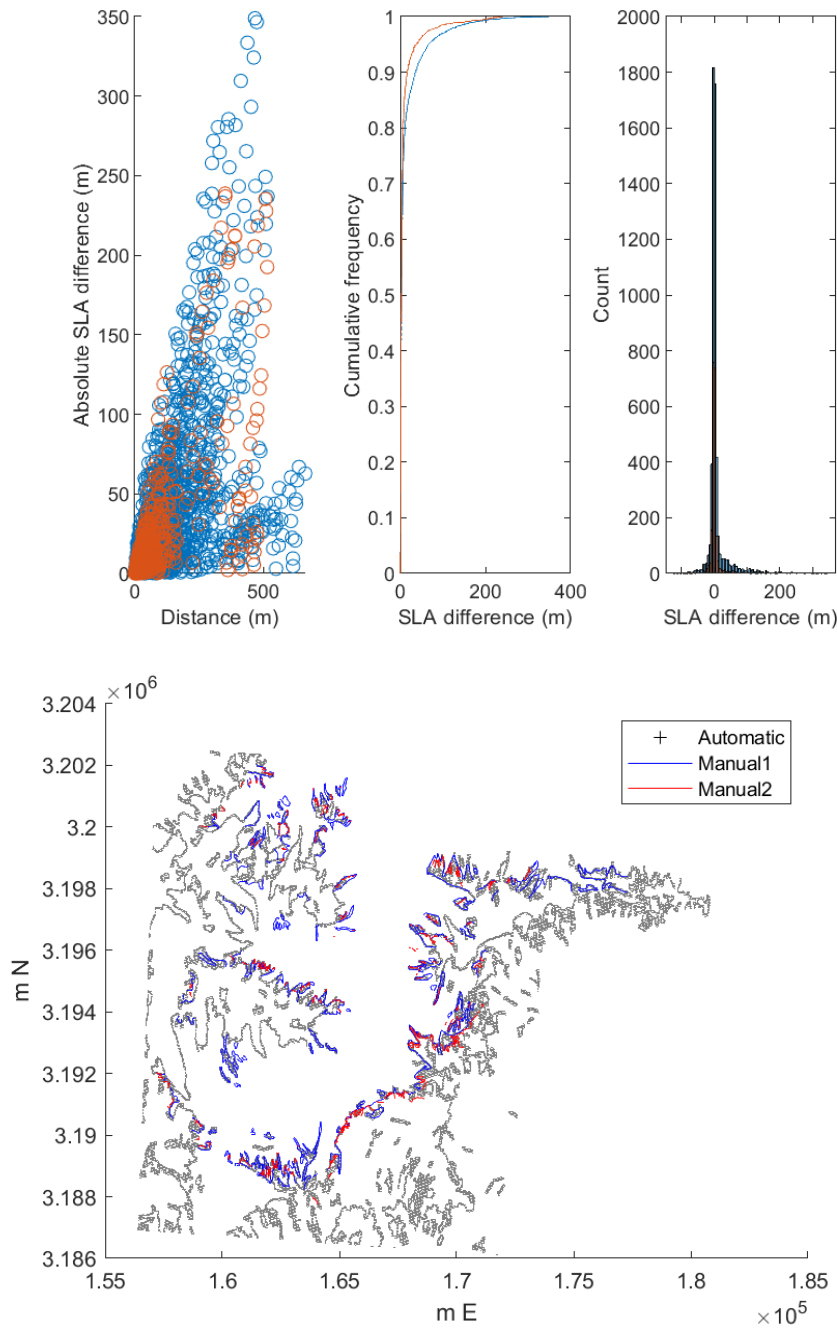


Figure S9. Correspondence of manual and automatic snowlines at the Hidden Valley site in June 2019. The manual snowlines were delimited from a cloud-free PlanetScope image, the automatic snowlines from Landsat 8. Comparing corresponding nearest snowline points, the automatic snowline had a median absolute deviation of 3 m (3 m) elevation and 10 m (9 m) horizontal distance relative to the Manual1 (Manual2) snowline.

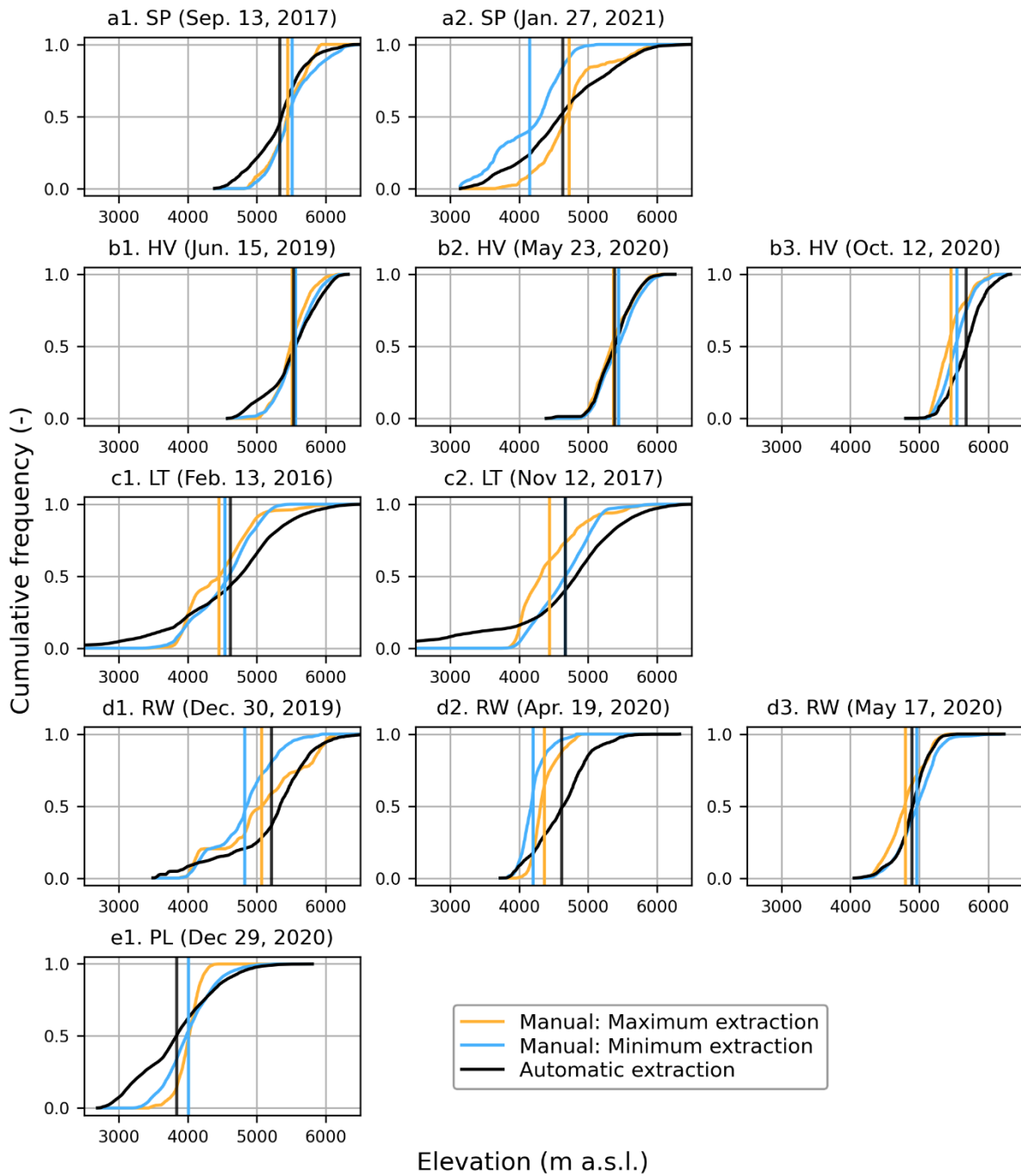


Figure S10: Comparison of cumulative frequency of SLA between the automatically detected snowlines and the manually delineated ones. The vertical lines for each dataset indicate the median values of the snowline dataset. Note that not all datasets have the full catchment coverage. a1-2, b1-3, c1-2, d1-4, and e1 show the comparison in Satopanth (SP), Hidden Valley (HV), Langtang (LT), Rolwaling (RW), and Parlung (PL), respectively.

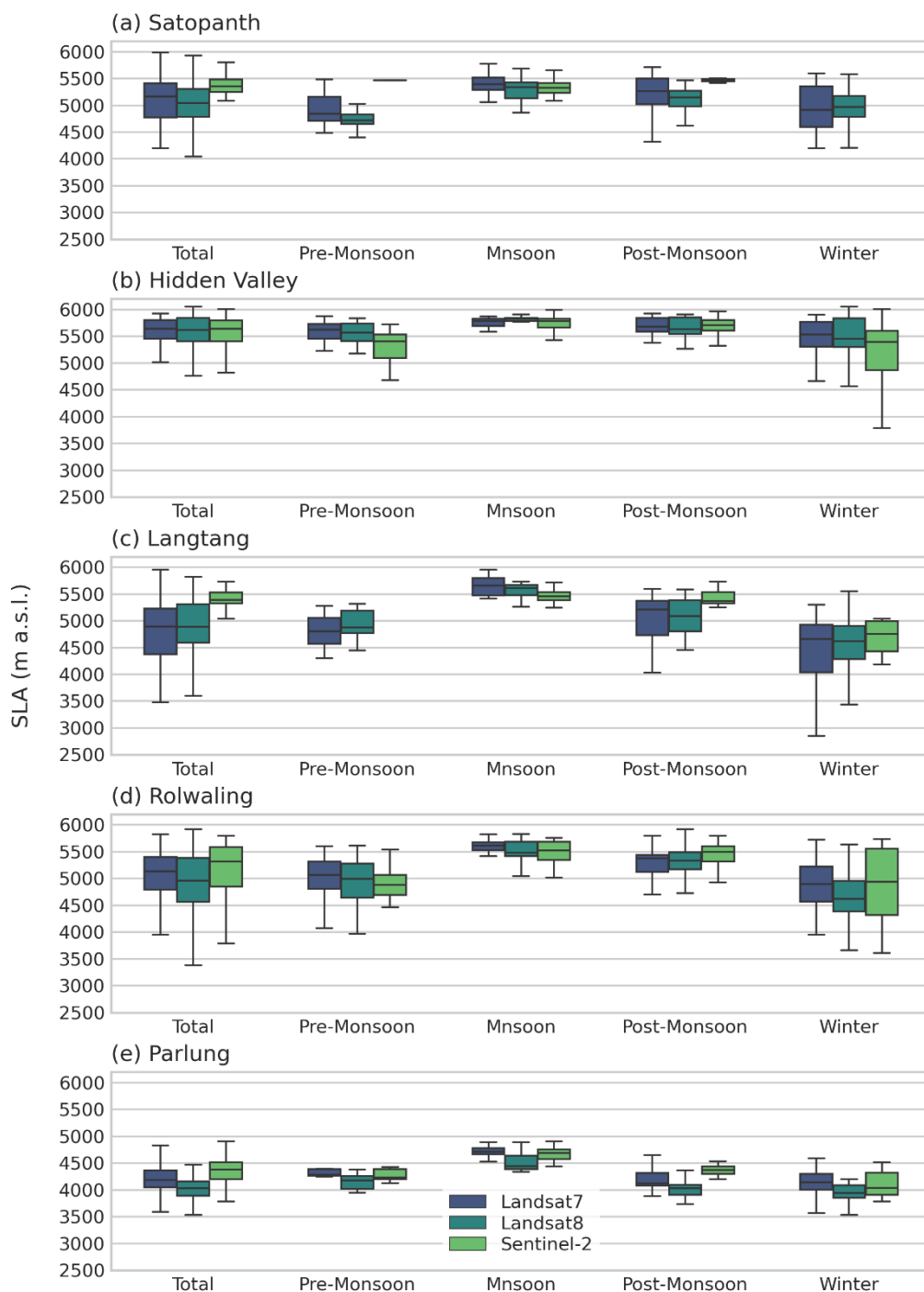
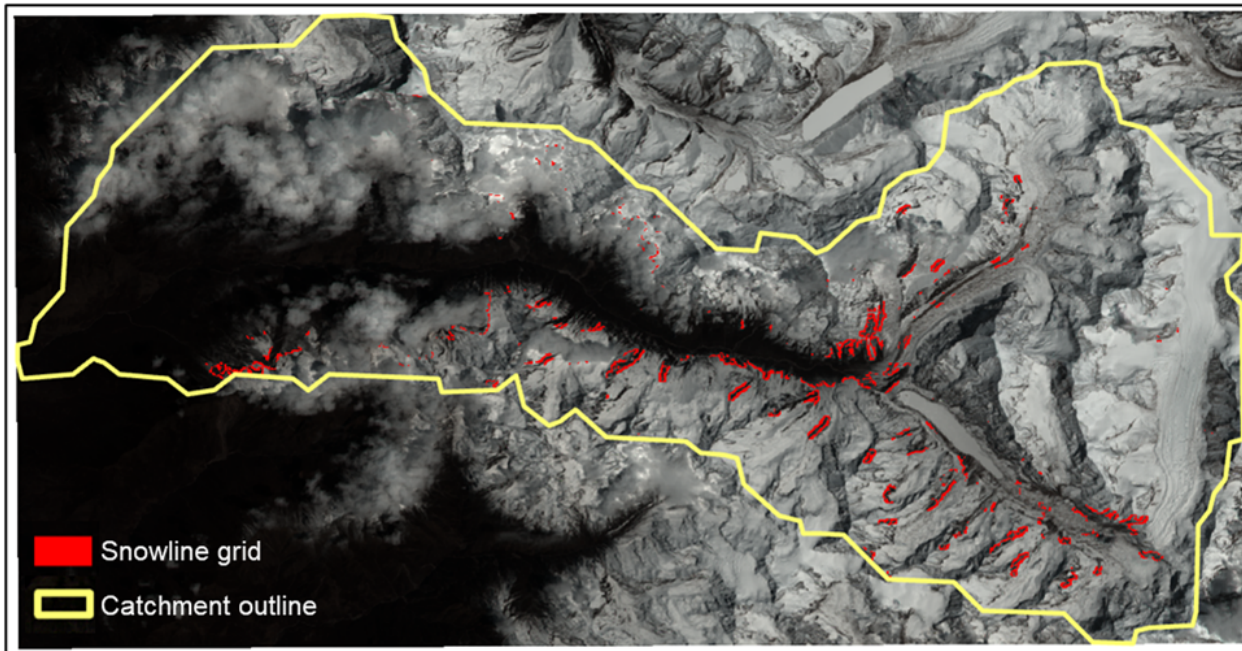


Figure S11: Comparison of seasonal SLA distributions from different sensors.

(a) Automatic detection



(b) Manual detection

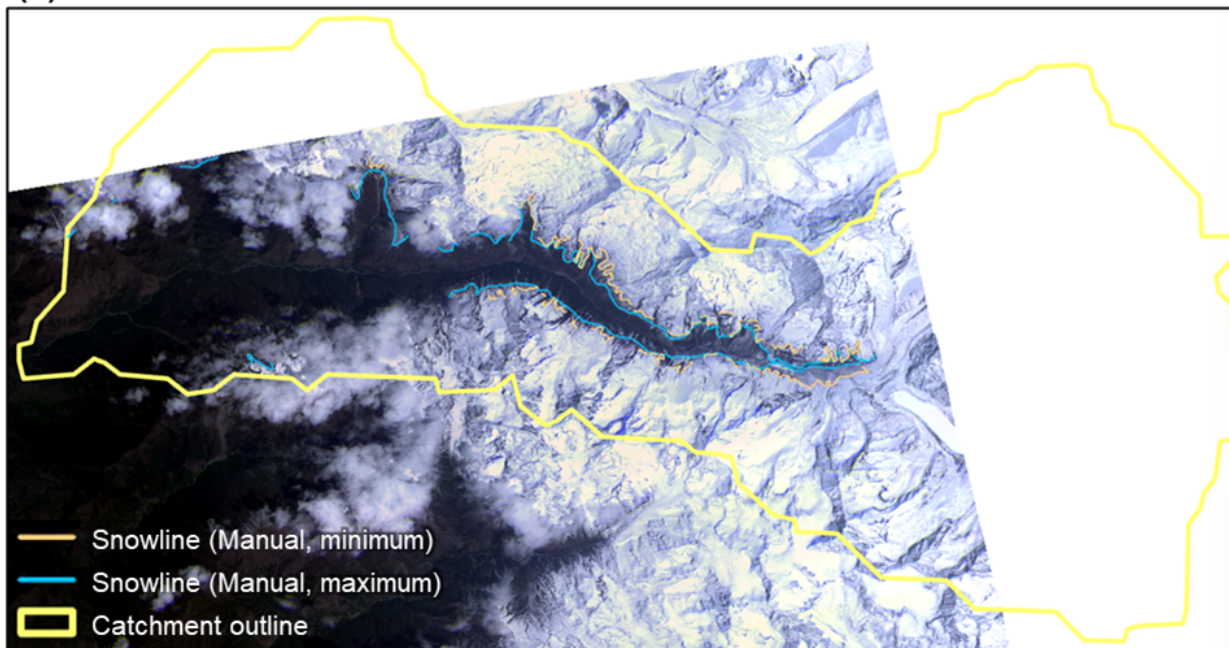


Figure S12: Snowlines derived from (a) automatic detection and (b) manual detection. The background images are the satellite images used for snowline detection: (a) Landsat 8 on April 20, 2020, and (b) PlanetScope on April 19, 2019.

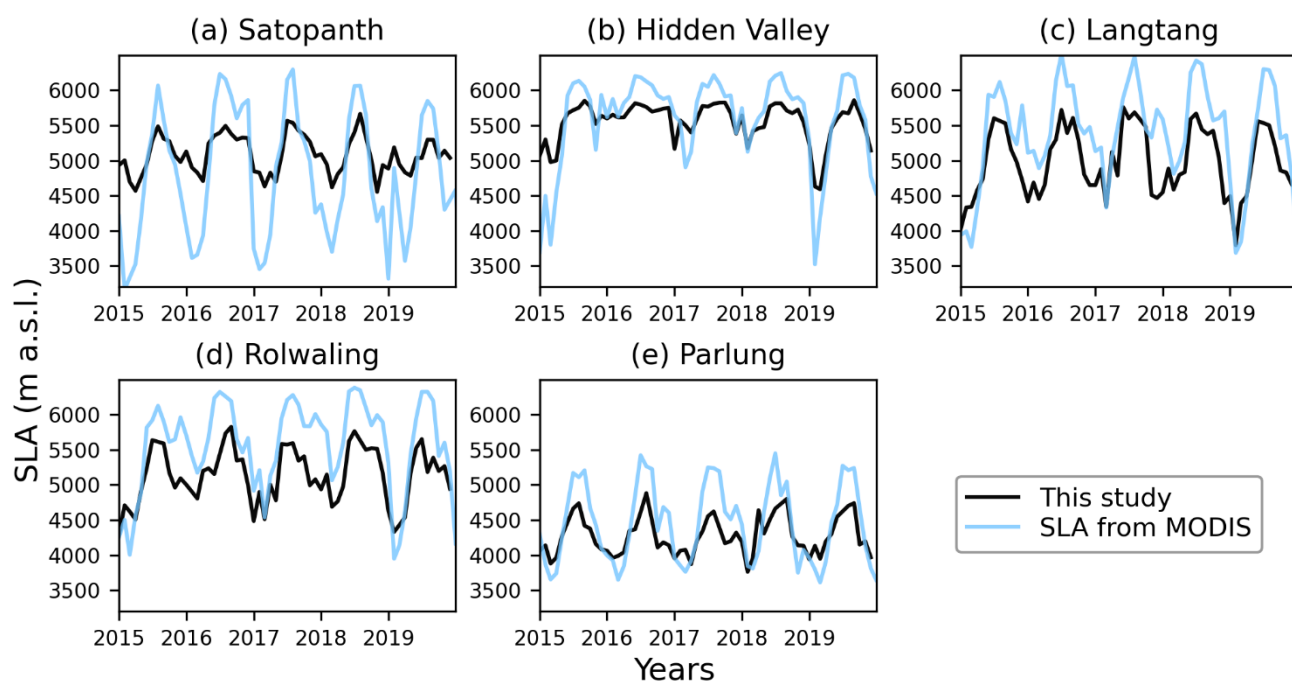


Figure S13: Comparison of detected SLAs from this study and standard detection method using MODIS.

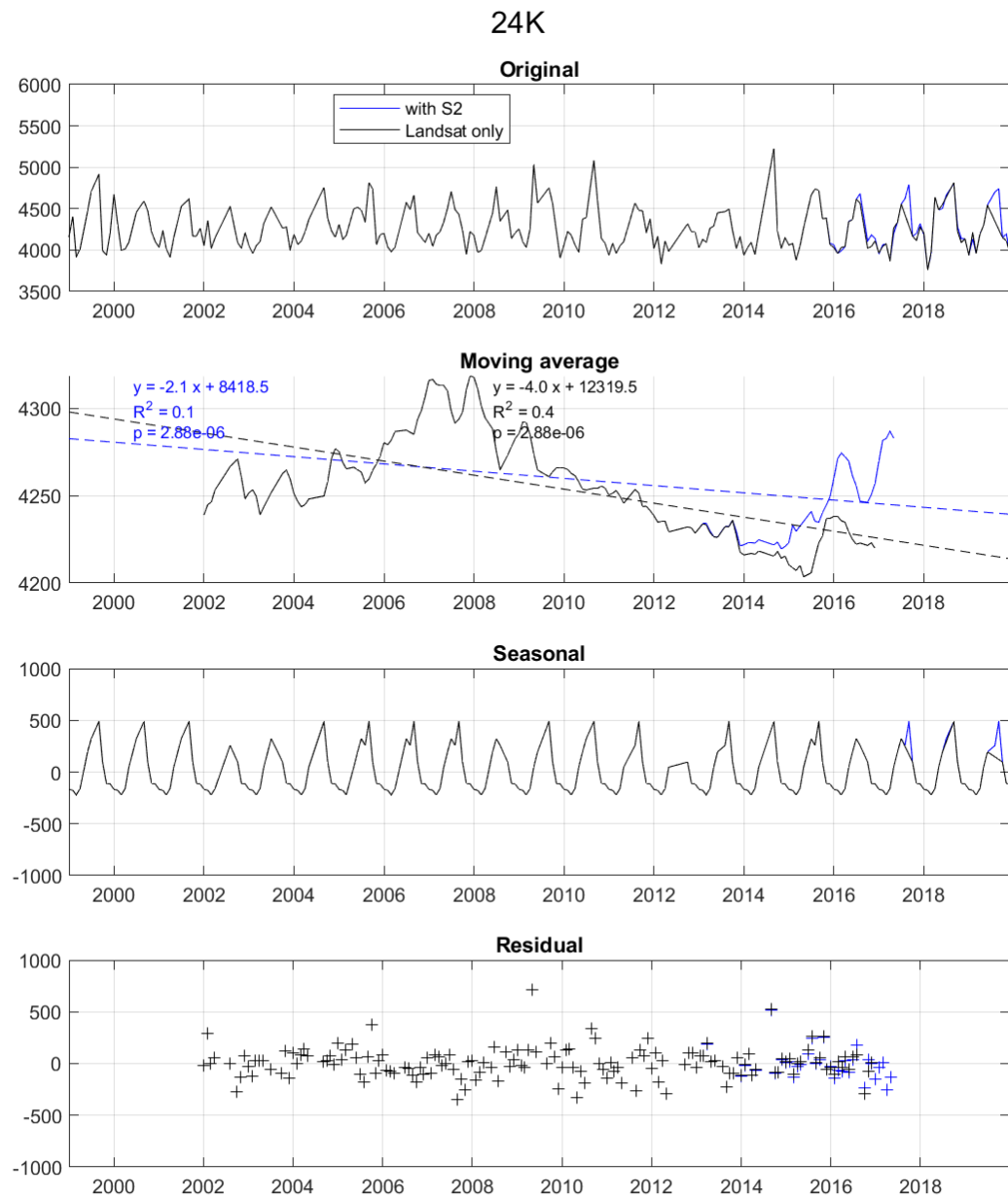


Figure S14: Decomposition of seasonal snowline and trends for the 24K (Parlung) site, with and without inclusion of Sentinel-2 data.

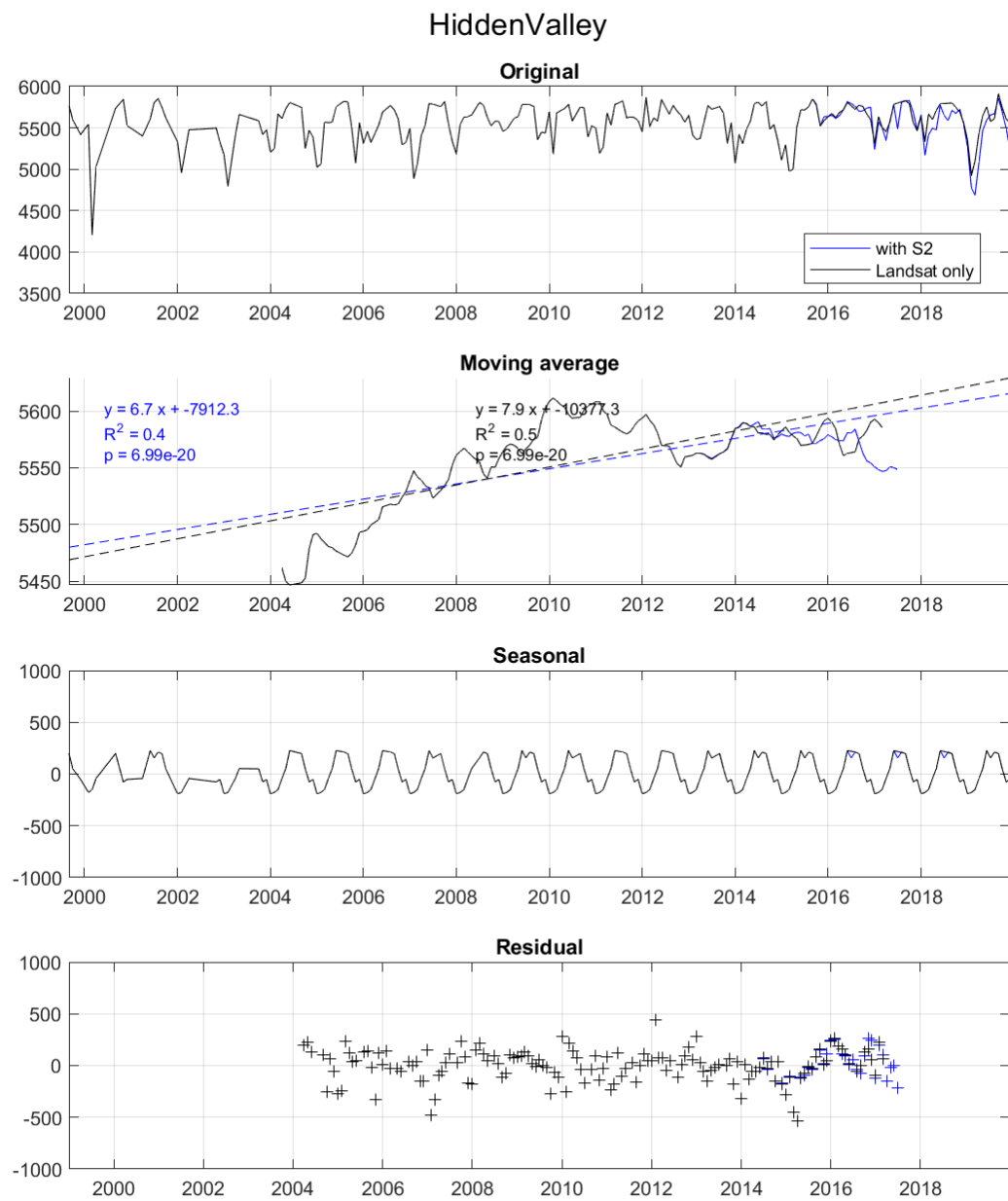


Figure S15: Decomposition of seasonal snowline and trends for the Hidden Valley site, with and without inclusion of Sentinel-2 data.

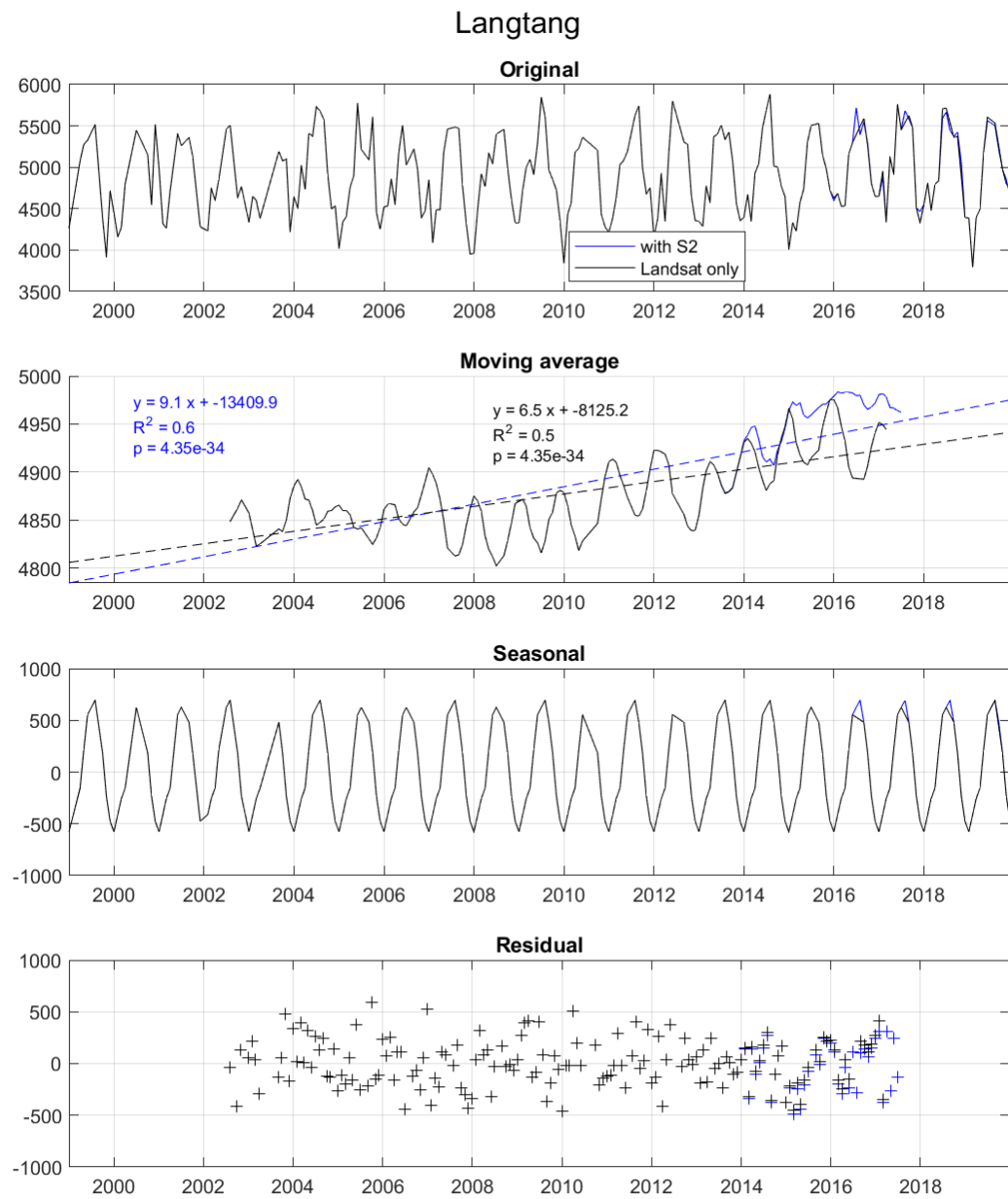


Figure S16: Decomposition of seasonal snowline and trends for the Langtang site, with and without inclusion of Sentinel-2 data.

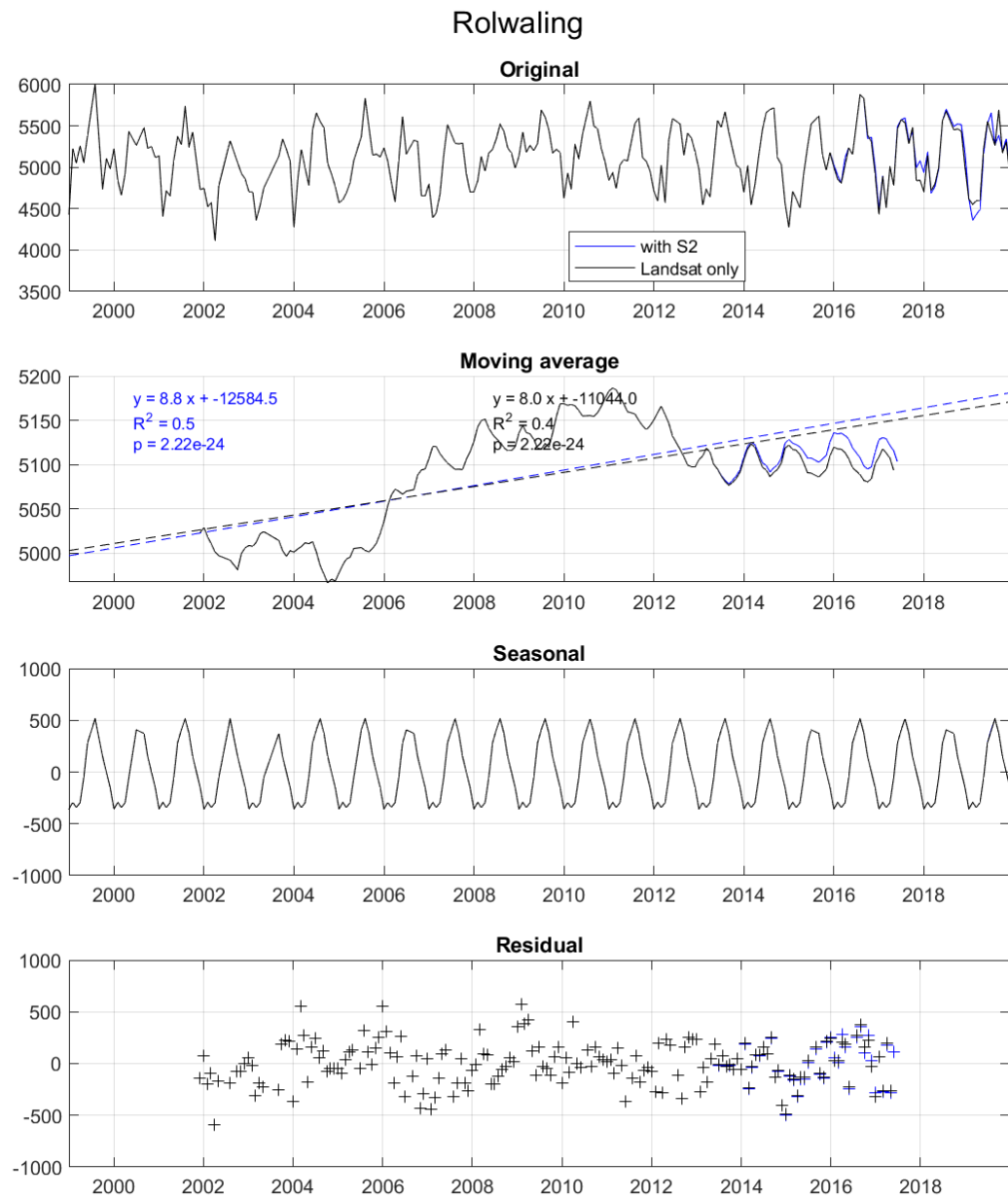


Figure S17: Decomposition of seasonal snowline and trends for the Rolwaling site, with and without inclusion of Sentinel-2 data.

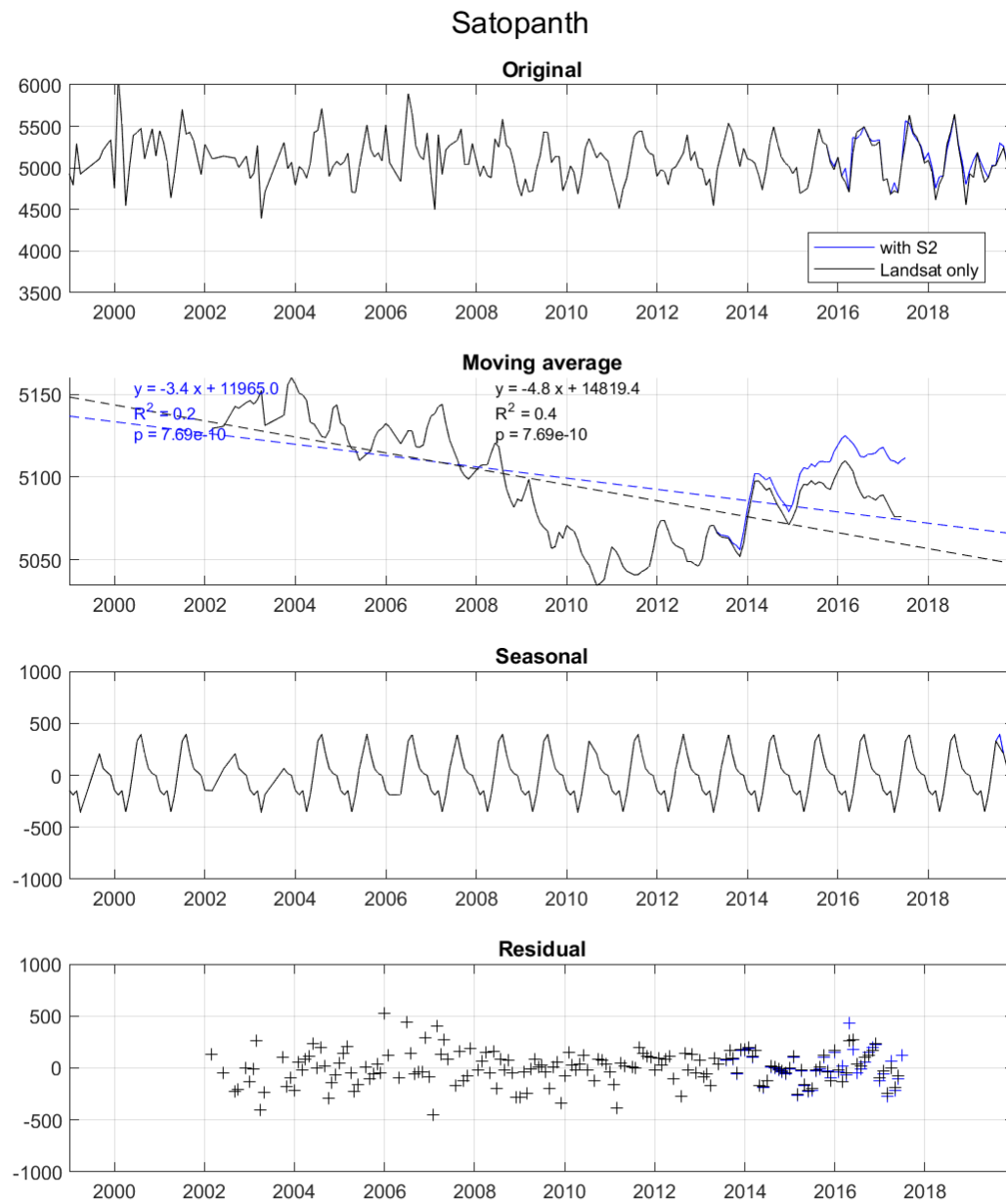


Figure S18: Decomposition of seasonal snowline and trends for the Satopanth site, with and without inclusion of Sentinel-2 data.

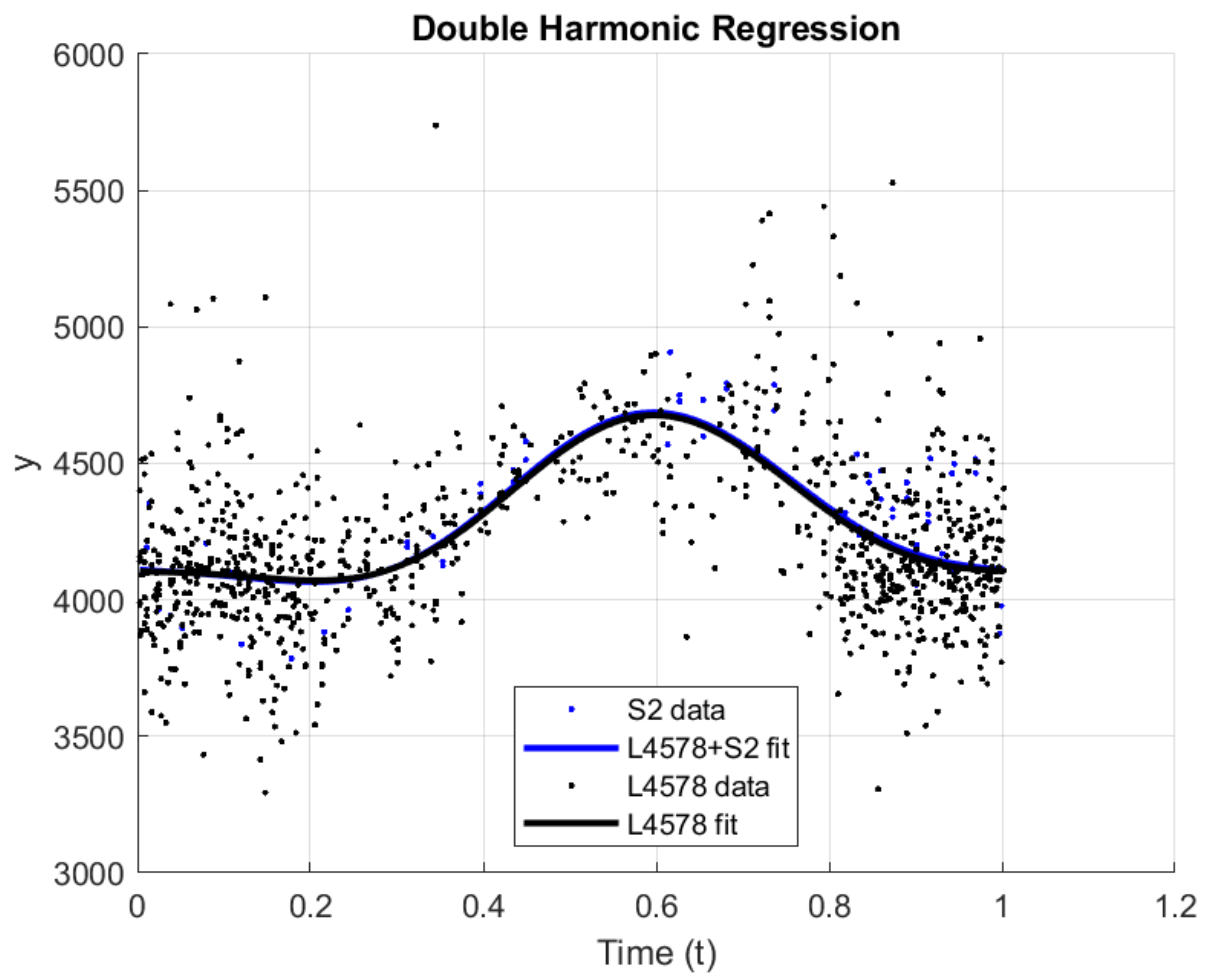


Figure S19: Harmonic regression of observed snowlines at 24K (Parlung) site including and excluding Sentinel-2 data.

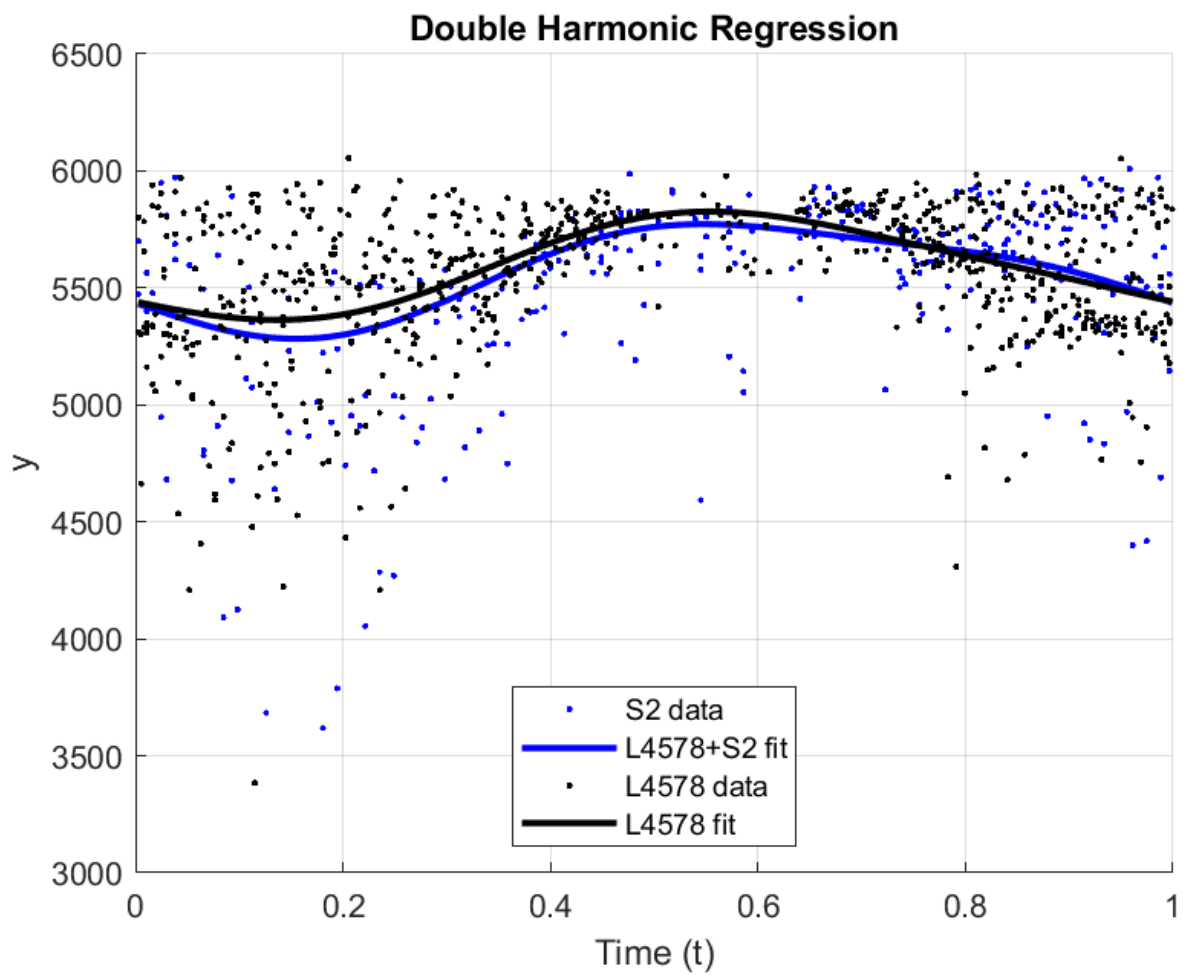


Figure S20: Harmonic regression of observed snowlines at Hidden Valley site including and excluding Sentinel-2 data.

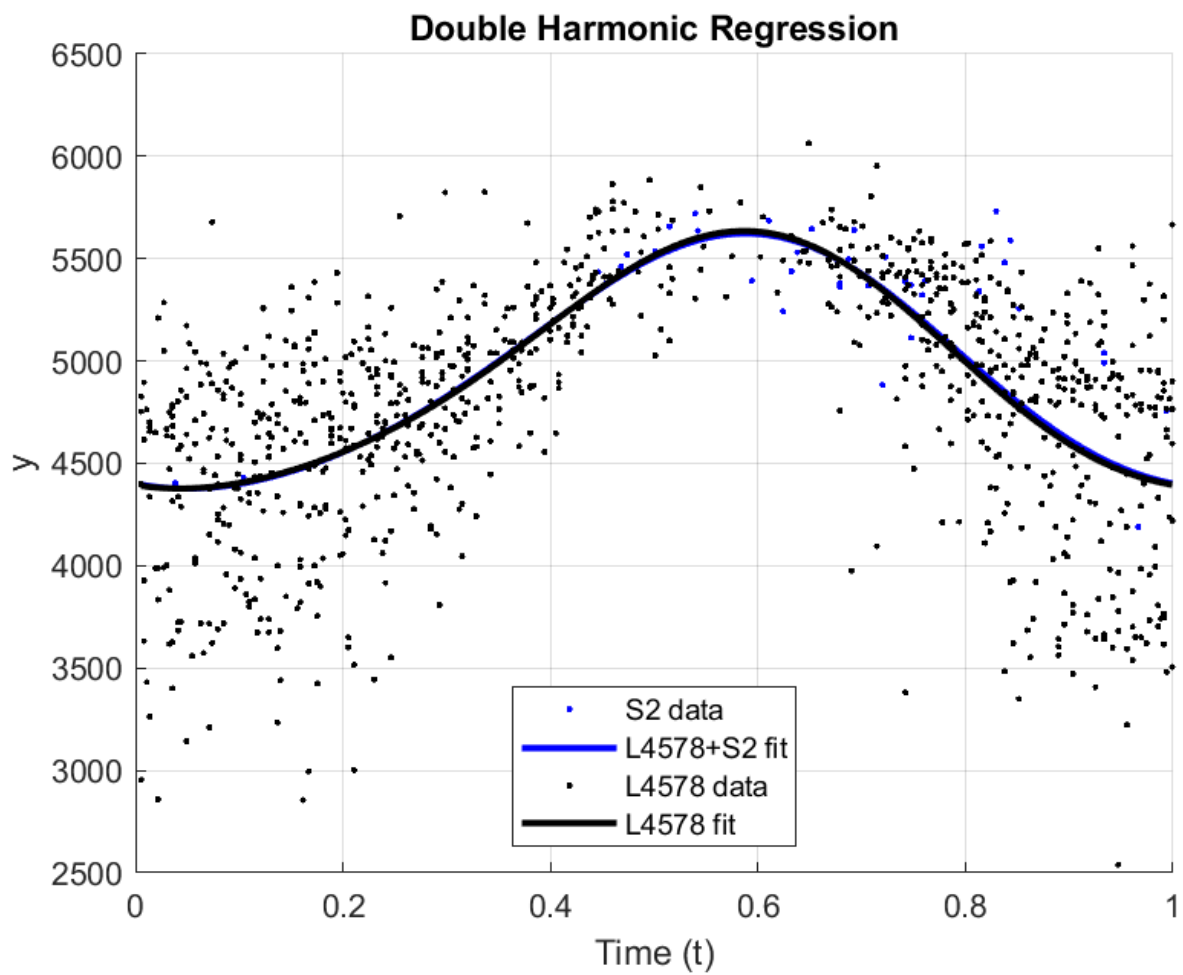


Figure S21: Harmonic regression of observed snowlines at Langtang site including and excluding Sentinel-2 data.

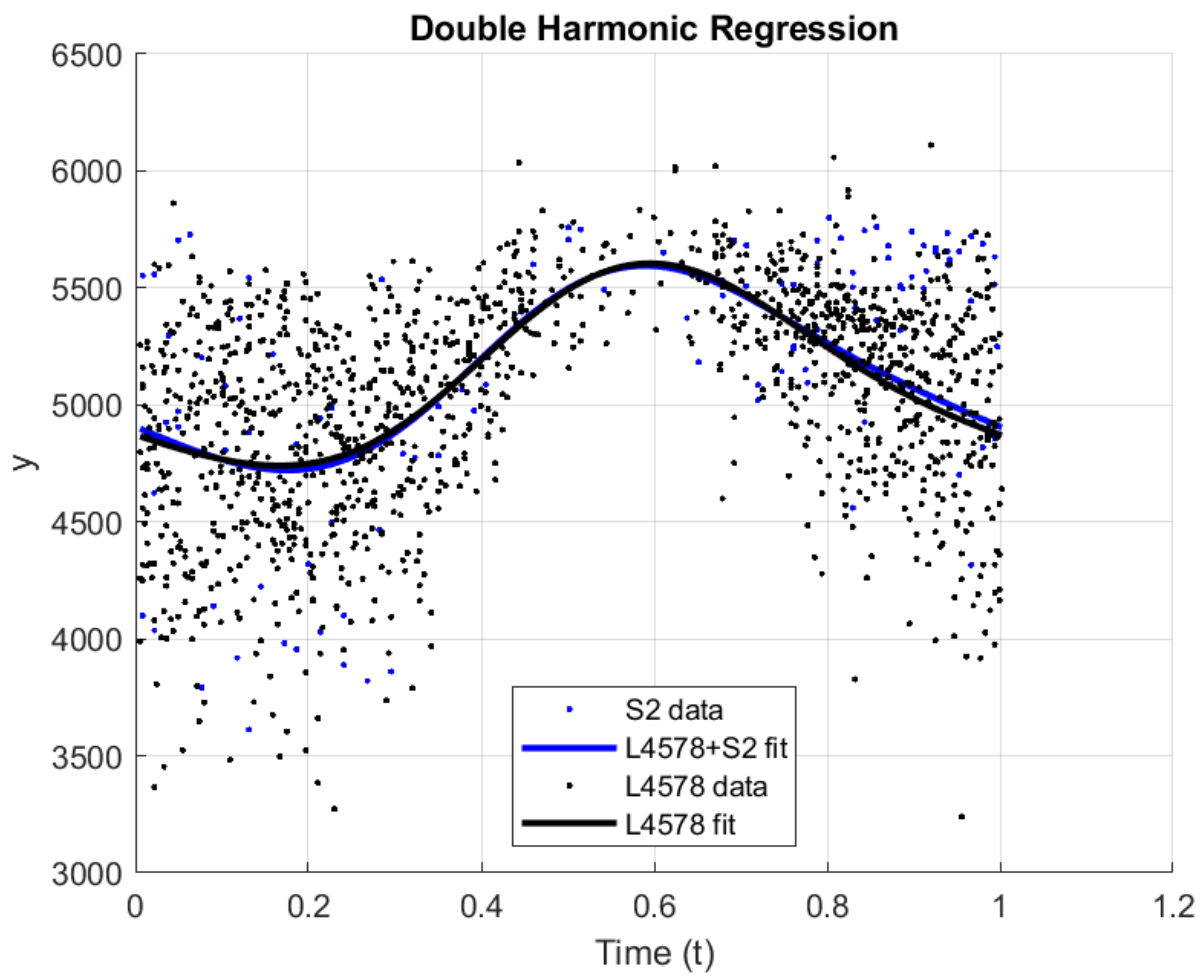


Figure S22: Harmonic regression of observed snowlines at Rolwaling site including and excluding Sentinel-2 data.

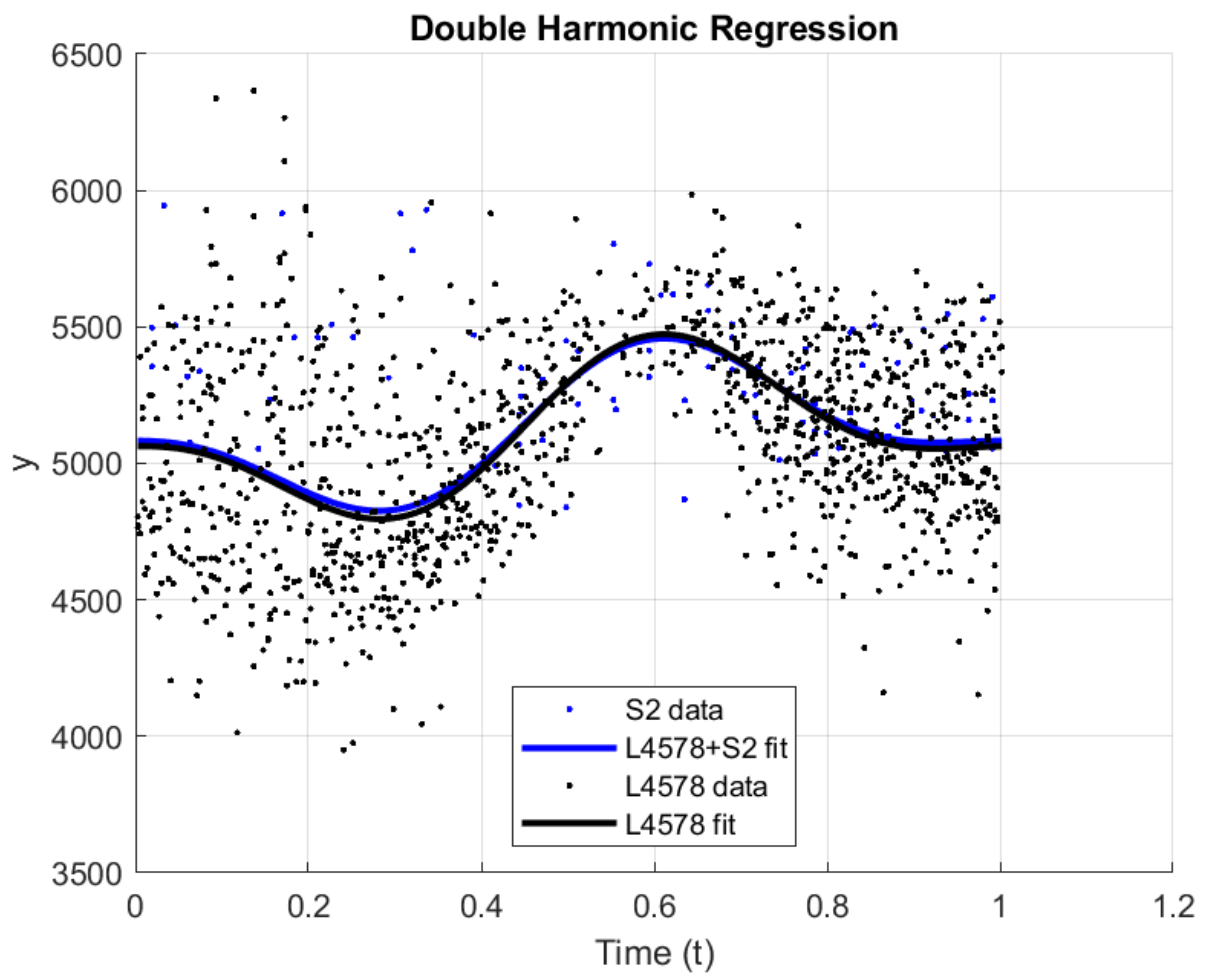


Figure S23: Harmonic regression of observed snowlines at Satopanth site including and excluding Sentinel-2 data.

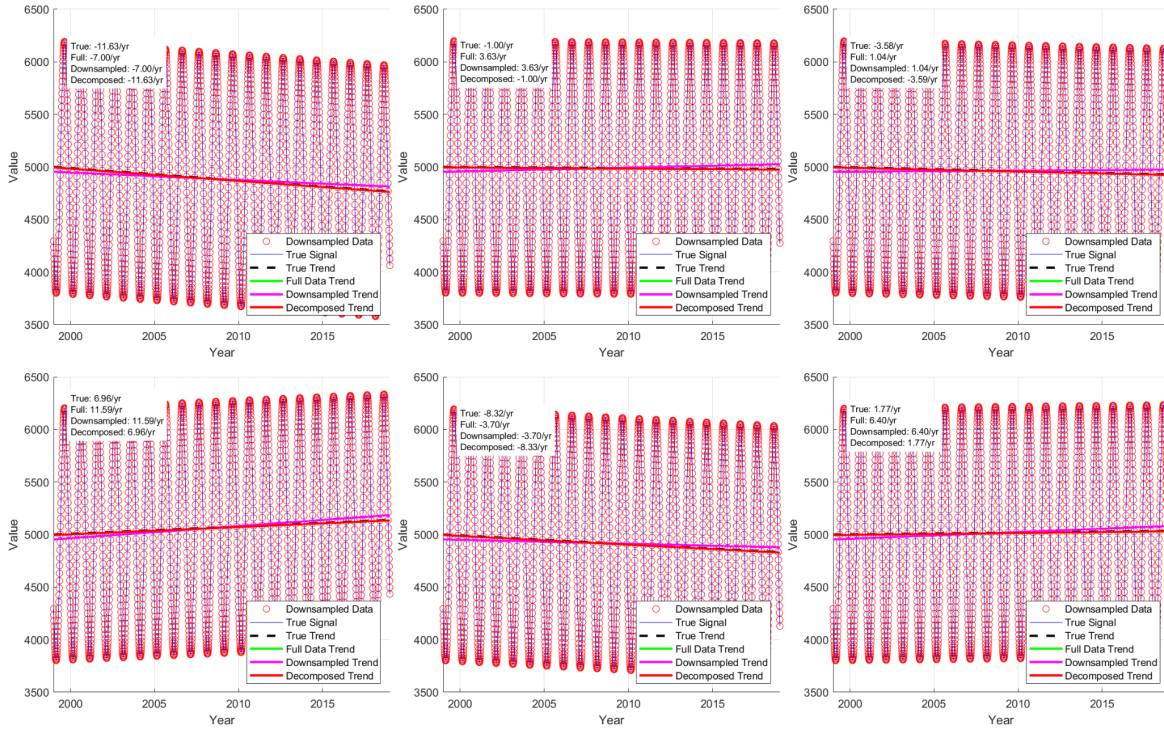


Fig S24: Trend retrieval experiment for 6 synthetic datasets. 'True Trend' is the trend built into the timeseries, 'Full Data Trend' is the regression of the full timeseries, 'Downsampled' is just a regression of the downsampled data, and 'Decomposed' is based on our approach.

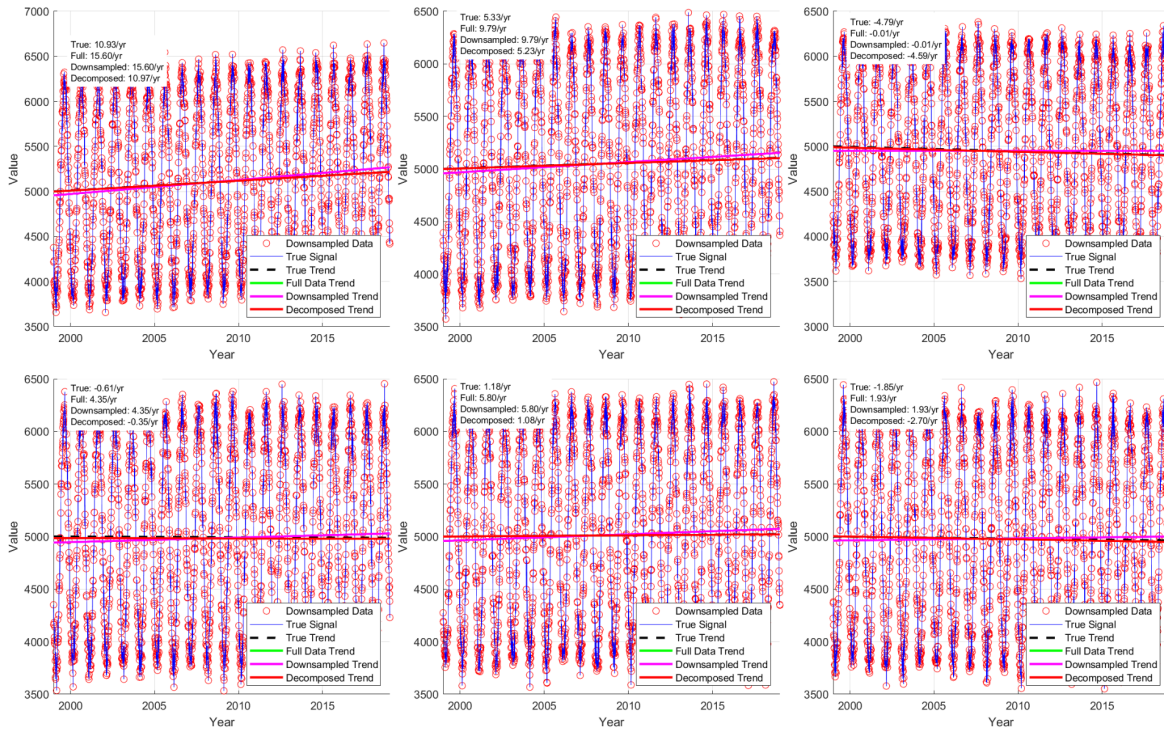


Fig S25: Trend retrieval experiment for 6 synthetic datasets including a 100m random variation. 'True Trend' is the trend built into the timeseries, 'Full Data Trend' is the regression of the full timeseries, 'Downsampled' is just a regression of the downsampled data, and 'Decomposed' is based on our approach.

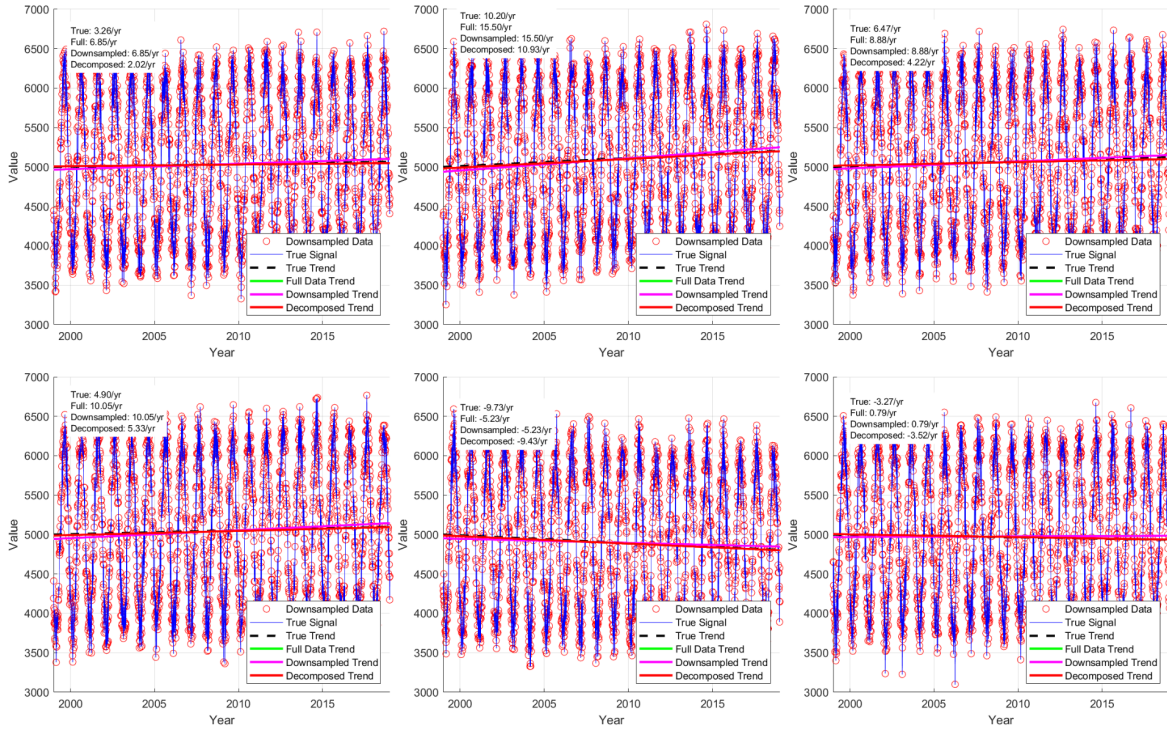


Fig S26: Trend retrieval experiment for 6 synthetic datasets including a 200m random variation. 'True Trend' is the trend built into the timeseries, 'Full Data Trend' is the regression of the full timeseries, 'Downsampled' is just a regression of the downsampled data, and 'Decomposed' is based on our approach.

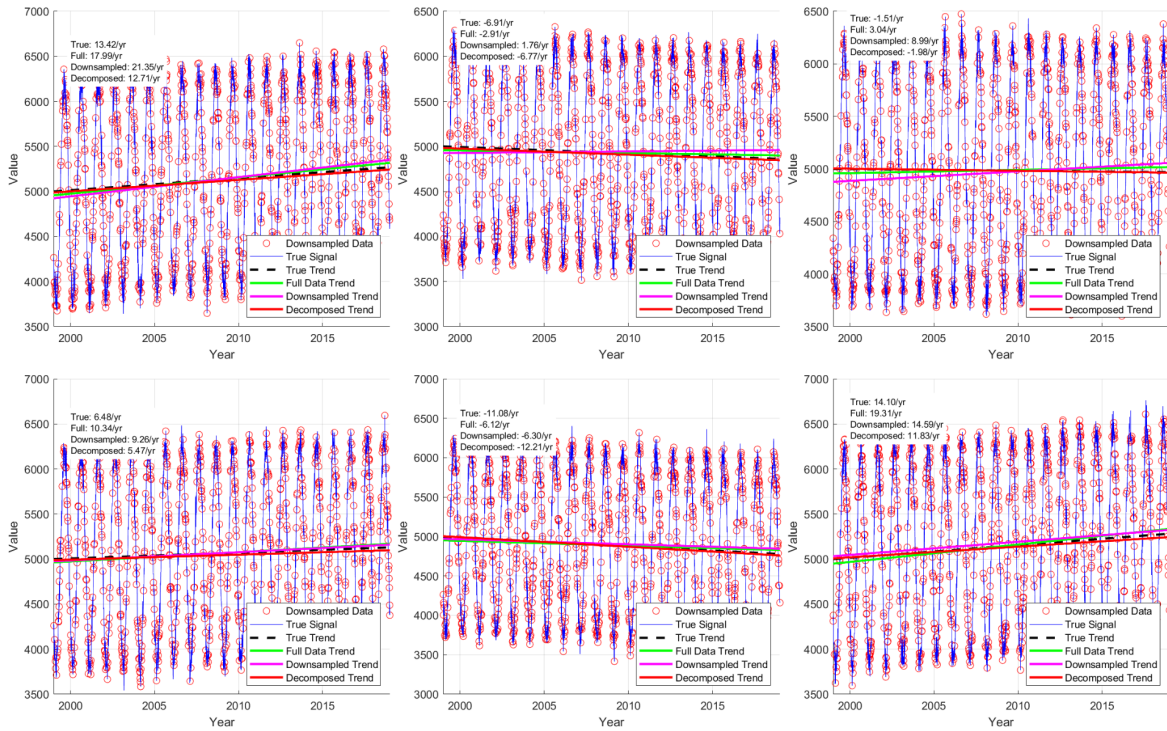


Fig S27: Trend retrieval experiment for 6 synthetic datasets including a 200m random variation and seasonal reductions in image availability (focused in the summer monsoon). 'True Trend' is the trend built into the timeseries, 'Full Data Trend' is the regression of the full timeseries, 'Downsampled' is just a regression of the downsampled data, and 'Decomposed' is based on our approach.

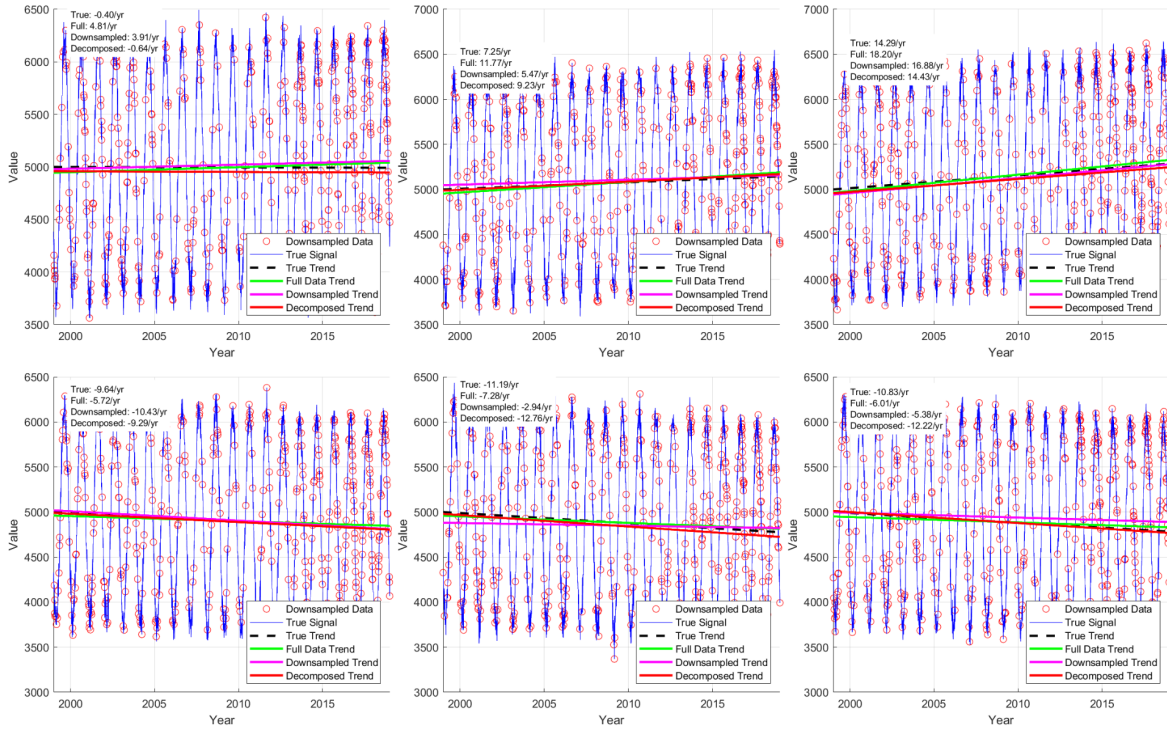


Fig S28: Trend retrieval experiment for 6 synthetic datasets including a 200m random variation, seasonal reductions in image availability (focused in the summer monsoon), and interannual variations in image availability (increased progressively at L8 and S2 launch years). 'True Trend' is the trend built into the timeseries, 'Full Data Trend' is the regression of the full timeseries, 'Downsampled' is just a regression of the downsampled data, and 'Decomposed' is based on our approach.

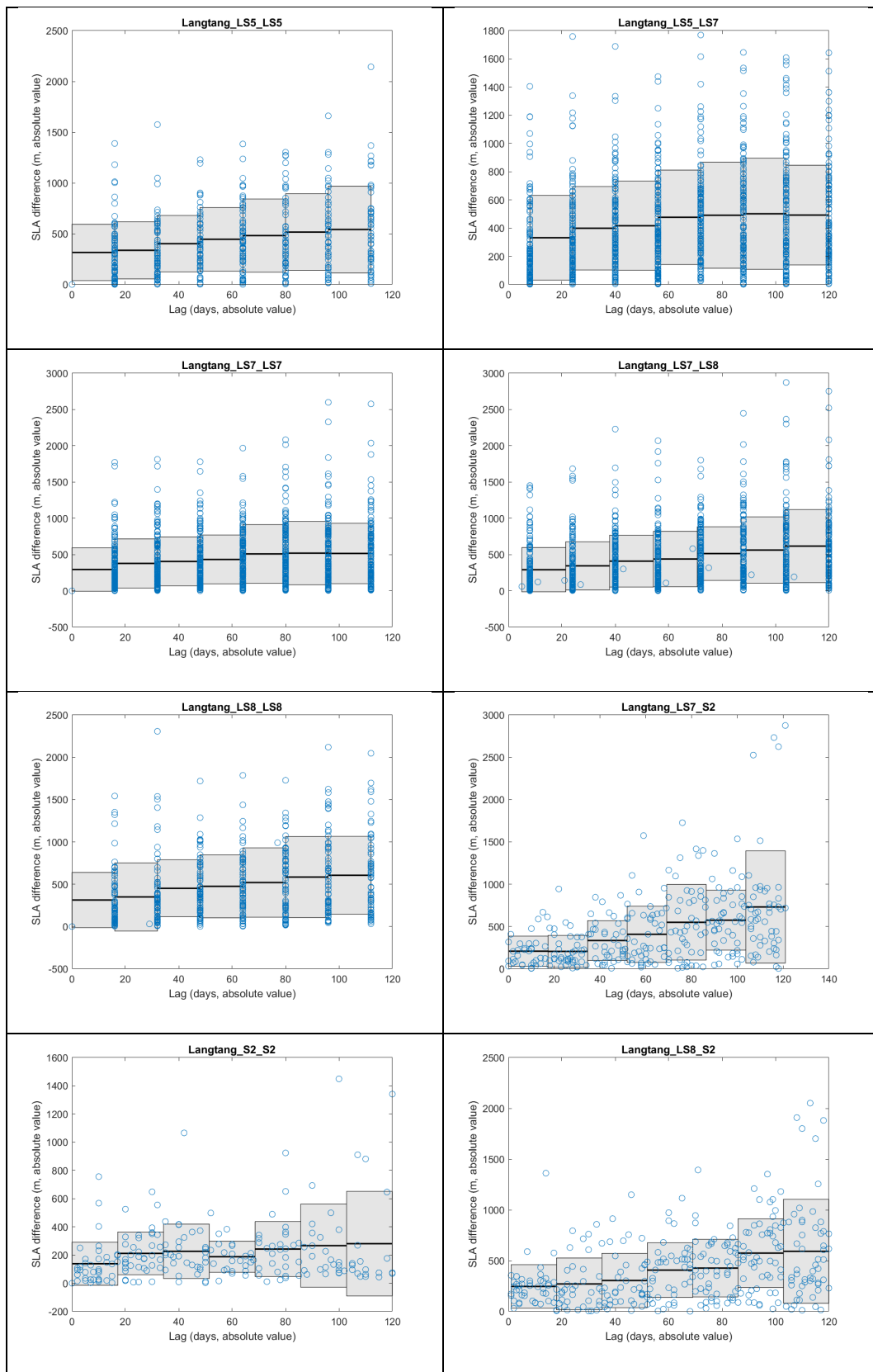


Figure S29: Boxplots of snow line altitude difference for scene-pairs with varying time lags, for different sensor combinations. For all sensors, snowlines typically vary by ~200m within 10-20 days. The variance increases, but not so dramatically, for longer lag times. Note that y-axis scales differ between panels.

Table S1: Results of the multiple regression analysis using 60-month moving averages of climate data and SLA. Influential factors (p-value < 0.05 and |t-value| > 2.0) are shown in bold. A positive or negative t-value indicates a contribution to the increase or decrease of SLA, respectively.

		Coefficient	Standard error	t-value	p-value
Satopanth	Air temperature	89.9	10.38	8.66	<0.001
	Precipitation	− 1.39	0.47	− 2.96	0.003
	Solar radiation	− 2.48	1.54	− 1.61	0.108
Hidden Valley	Air temperature	114.54	20.39	5.62	<0.001
	Precipitation	8.19	0.99	8.29	<0.001
	Solar radiation	24.83	5.42	4.58	<0.001
Langtang	Air temperature	123.29	16.59	7.43	<0.001
	Precipitation	7.94	0.85	9.37	<0.001
	Solar radiation	2.90	4.92	0.59	0.556
Rolwaling	Air temperature	224.13	6.34	35.35	<0.001
	Precipitation	7.72	0.36	21.59	<0.001
	Solar radiation	28.44	1.31	21.67	<0.001
Parlung	Air temperature	33.23	9.60	3.46	0.001
	Precipitation	− 0.03	0.27	− 0.12	0.905
	Solar radiation	1.34	0.84	1.29	0.114