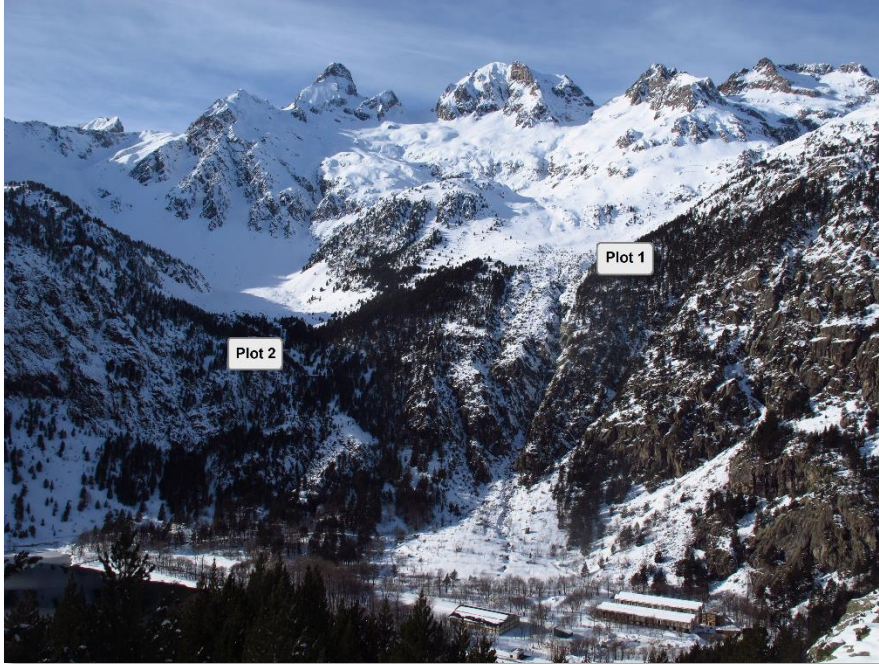




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Balneario de Panticosa Valley, Central Spanish Pyrenees.



Factors Impacting Performance of the NDSI-Based Operational Snow Cover Monitoring Algorithm in Forested Landscapes

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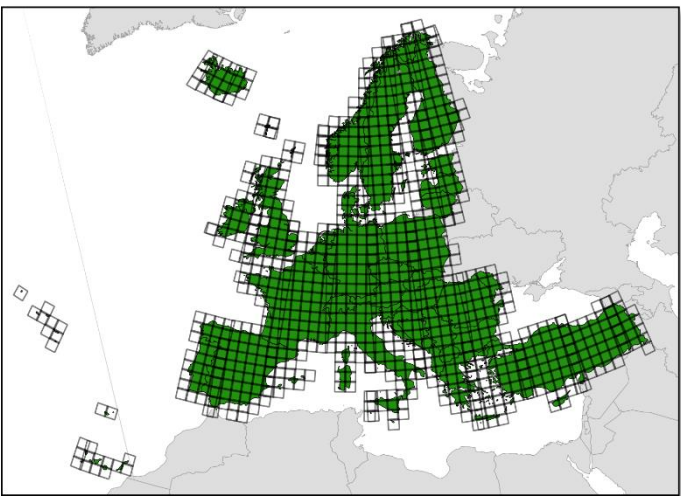
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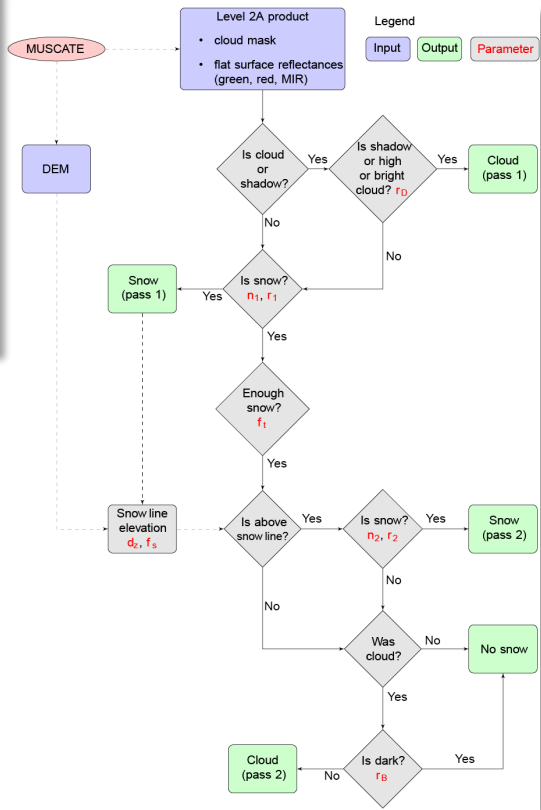
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Operational Snow Cover Monitoring Algorithm: Theia Snow Collection

Snow Cover Detection: SCA Algorithm



Coverage of the Theia snow collection tiles.

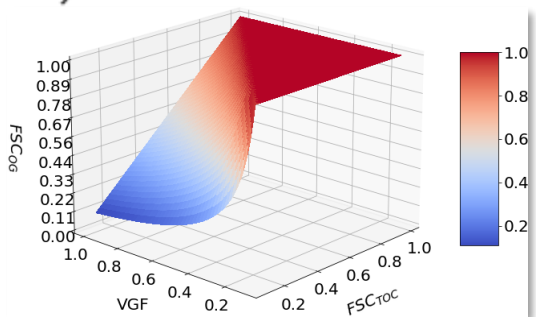


Flowchart of the snow detection algorithm.

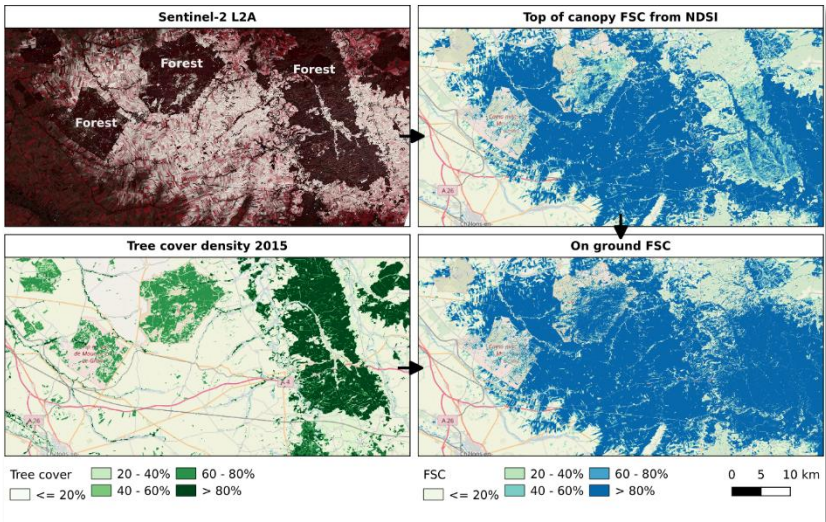
Fractional Snow Cover Estimation: FSC Algorithm

$$FSC_{TOC} = \frac{1}{2}(\tanh(2.65 \times NDSI - 1.42) + 1)$$

$$FSC_{OG} = \min(FSC_{TOC}/VGF, 1)$$
$$VGF = 1 - TCD$$



On-ground FSC as a function of top-of-the-canopy FSC and viewable gap fraction (VGF).



Effect of tree cover density adjustment of top-of-the-canopy FSC over the on-ground FSC. Sentinel-2 scene acquired near Reims, France on 21st of January 2019.

References:
Gascoin et al., Theia Snow collection: High-resolution operational snow cover maps from Sentinel-2 and Landsat-8 data, Earth System Science Data, Vol. 11, No. 2, Pg. 493-514, 2019.
Gascoin et al., Estimating Fractional Snow Cover in Open Terrain from Sentinel-2 Using the Normalized Difference Snow Index, Remote Sensing, Vol. 12, No. 18, Pgs. 2904 (1-19), 2020.
Copernicus, EC, and European Environmental Agency, Pan-European High-Resolution Snow & Ice Monitoring of the Copernicus Land Monitoring service: Production of Basic Products, ATBD for Snow Products, 2020.

Confusion Matrix Parameters

Observed Accuracy

$$Ac_{obs} = \frac{TP + TN}{TP + TN + FP + FN}$$

Random Accuracy

$$Ac_{rand} = \frac{(\sum R_1)(\sum C_1) + (\sum R_2)(\sum C_2)}{N^2}$$

$$\sum R_1 = (TP + FN)$$

$$\sum C_1 = (TP + FP)$$

$$\sum R_2 = (TN + FP)$$

$$\sum C_2 = (TN + FN)$$

Kappa Coefficient

$$\kappa = 1 - \frac{1 - Ac_{obs}}{1 - Ac_{rand}}$$

Satellite Data Derived SCA/FSC

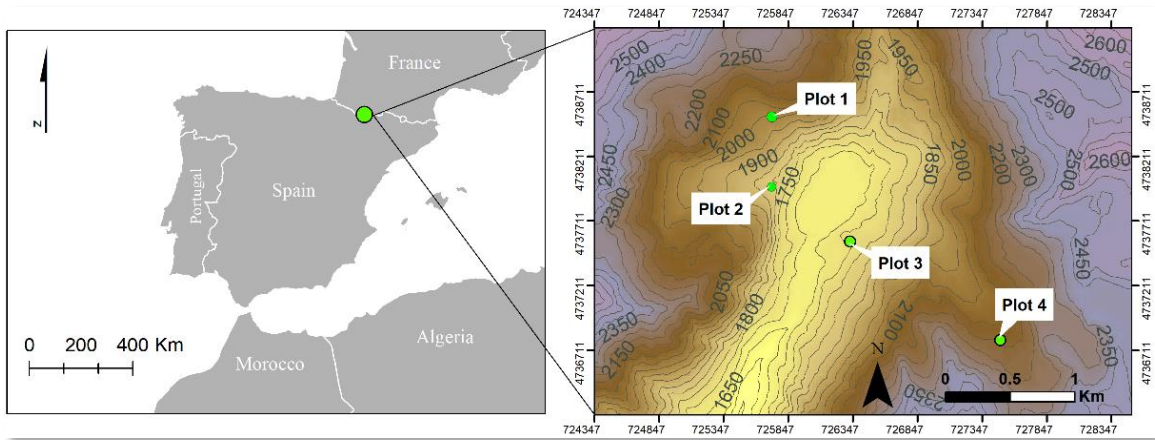
		S		
		Snow	Snow-Free	Total
G	Snow	TP	FN	TP + FN
	Snow-Free	FP	TN	TN + FP
Total		TP + FP	TN + FN	N

TP: True Positive, TN: True Negative,
FP: False Positive, and FN: False Negative.
N = TP + TN + FP + FN.

Note: The TP/FN/FP/TN are normalized by dividing each one of them with the sum of the elements in the corresponding row of the confusion matrix. These elements are then termed as the normalized confusion matrix elements and the variation of the normalized elements is constrained between 0 and 1. Therefore, for example, the normalized TP is obtained by dividing TP by (TP+FN) and similarly the normalized FP is obtained by dividing FP by (TN+FP). Hence, the denominators for normalizing each one of the elements of the confusion matrix are their corresponding row sums.

SCA Algorithm

Test Site: Balneario de Panticosa, Central Spanish Pyrenees



Location of the Balneario de Panticosa valley.
Test plots at varying elevation, canopy cover, solar irradiance, and slope aspect. UTM Zone: 30N, Datum: WGS84.



Relative location of the test plots in the valley with semi-automatic snow depth (SD) measurement: Time-lapse camera and snow-poles.

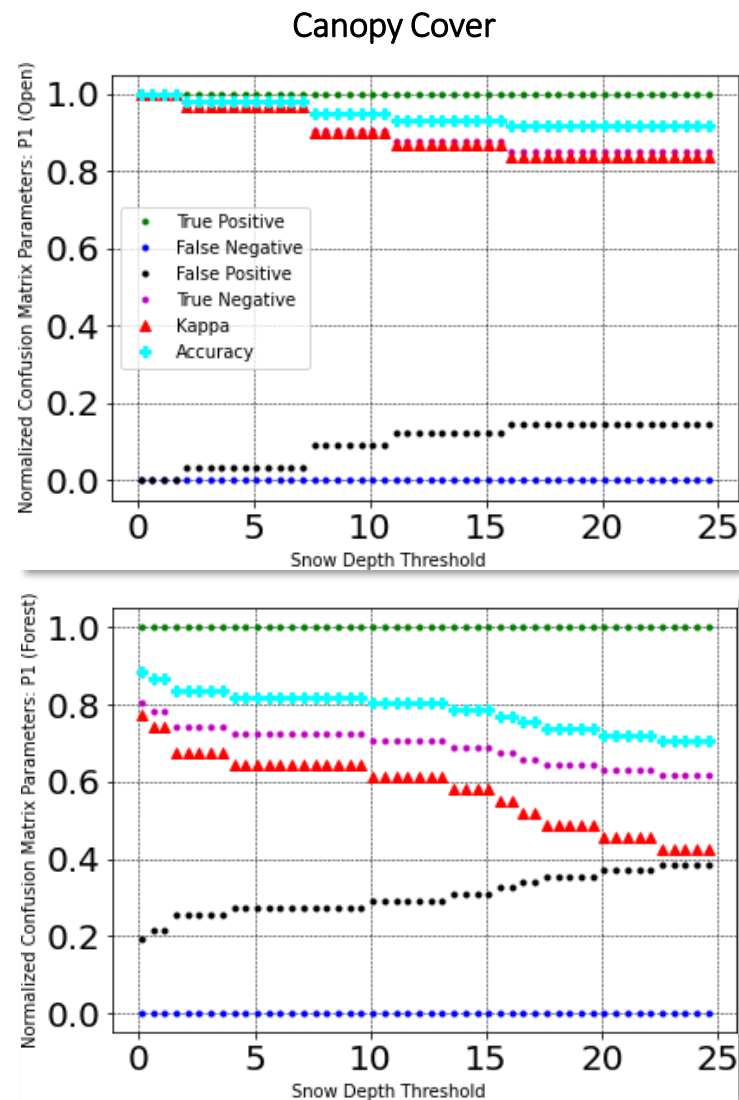
Plots	Elevation (m a.s.l.)	Aspect (degrees)	Canopy Cover (%)	Potential Solar Irradiance	Observed Solar Irradiance
P1 (Upper)	2008	S (193.66)	156	165.3	154.4
P2 (Lower)	1814	E (79.92)	85	129.6	167.6
P3 (Lower)	1674	W (261.7)	119	140.2	192.7
P4 (Upper)	2104	NE (48.3)	29	122.6	195.1

The Potential and Observed Solar Irradiance are expressed as 1000*Wh per sq. m and W per sq. m.

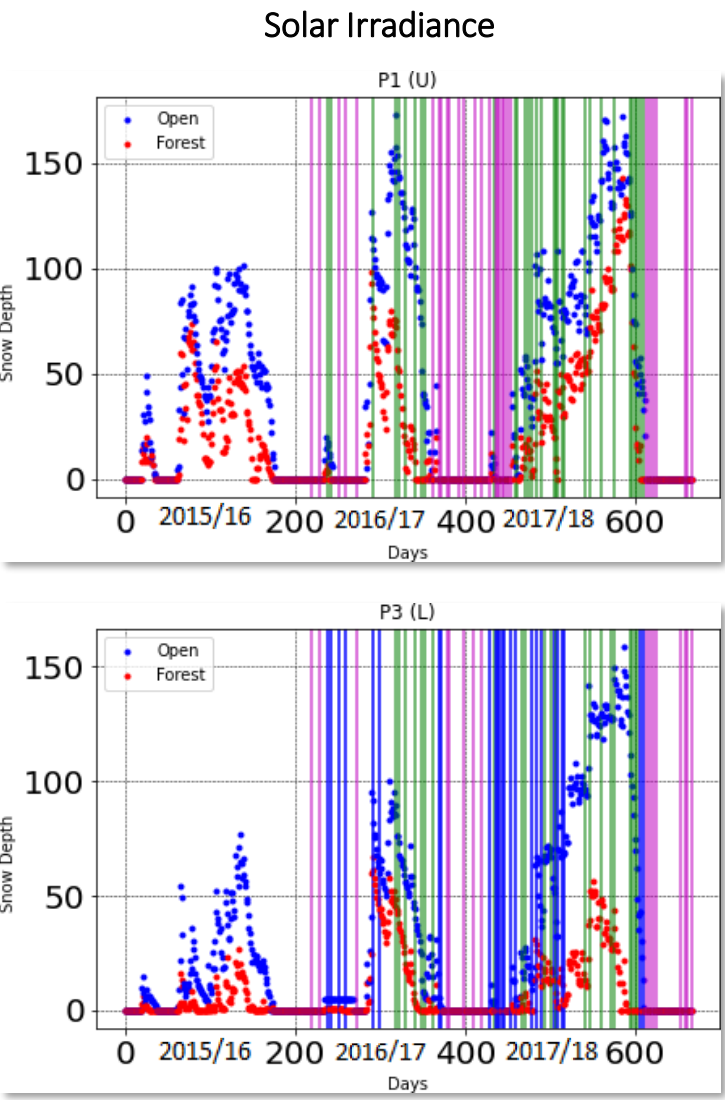


References:
Sanmiguel-Valladolid et al., Variable effects of forest canopies on snow processes in a valley of the central spanish pyrenees, Hydrological Processes, Vol. 34, No. 10, Pg. 2247-2262, 2020.

Factors Impacting SCA Algorithm



The snow depth threshold indicates the satellite requirement on the snow depth for its remote detection. In this graph we observe that as this requirement increases the snow detection algorithm's performance decreases.



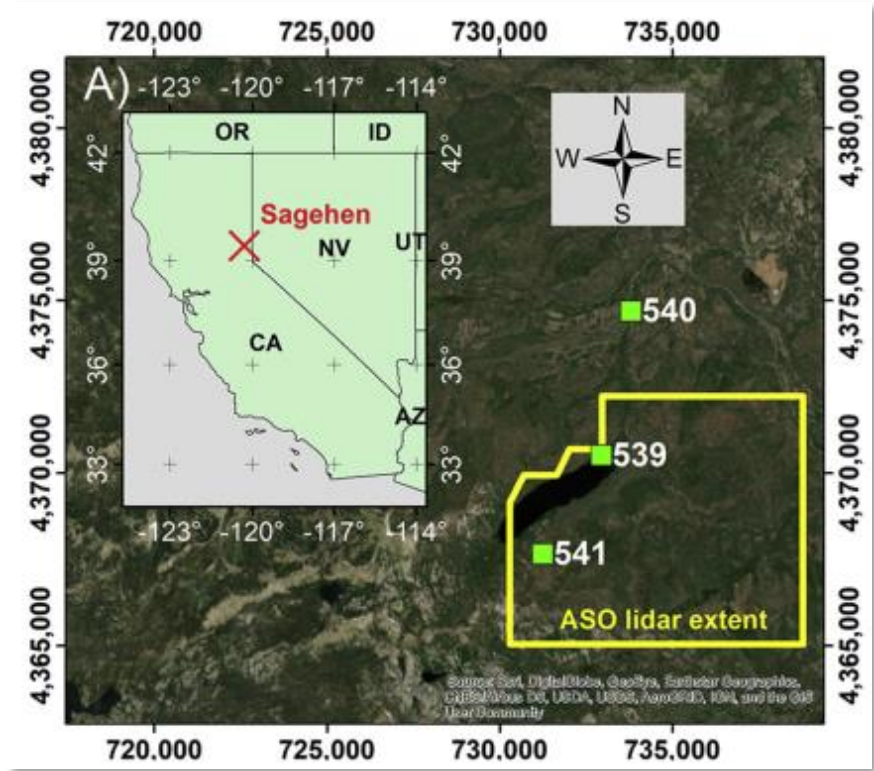
Note: Even though P1 has the highest percentage of canopy cover, the upper location of P1 along with its south-facing aspect renders it a suitable location for satellite observation of snow cover.

Note: P3 is located at the bottommost portion of the valley away from sufficient solar irradiance.

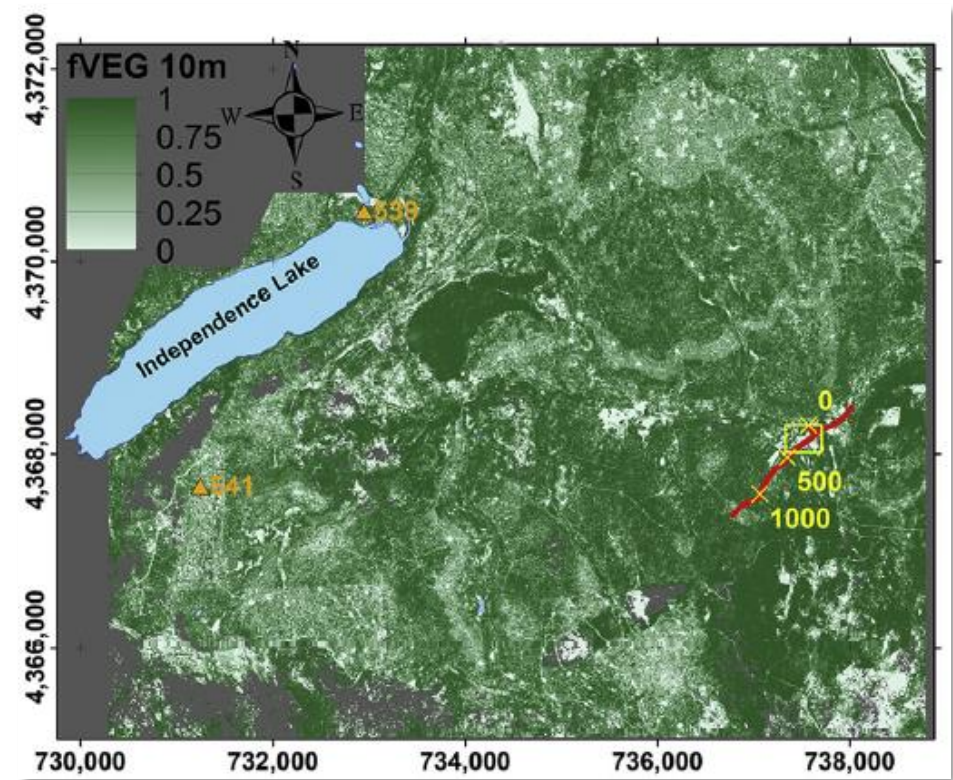
Legend: TP: |||, TN: |||, FP: |||, FN: |||, and No-Line: Either cloud-covered or absence of Sentinel-2 data acquisition in 2015/16.

FSC Algorithm

Test Site: Sagehen Creek, Sierra Nevada, USA



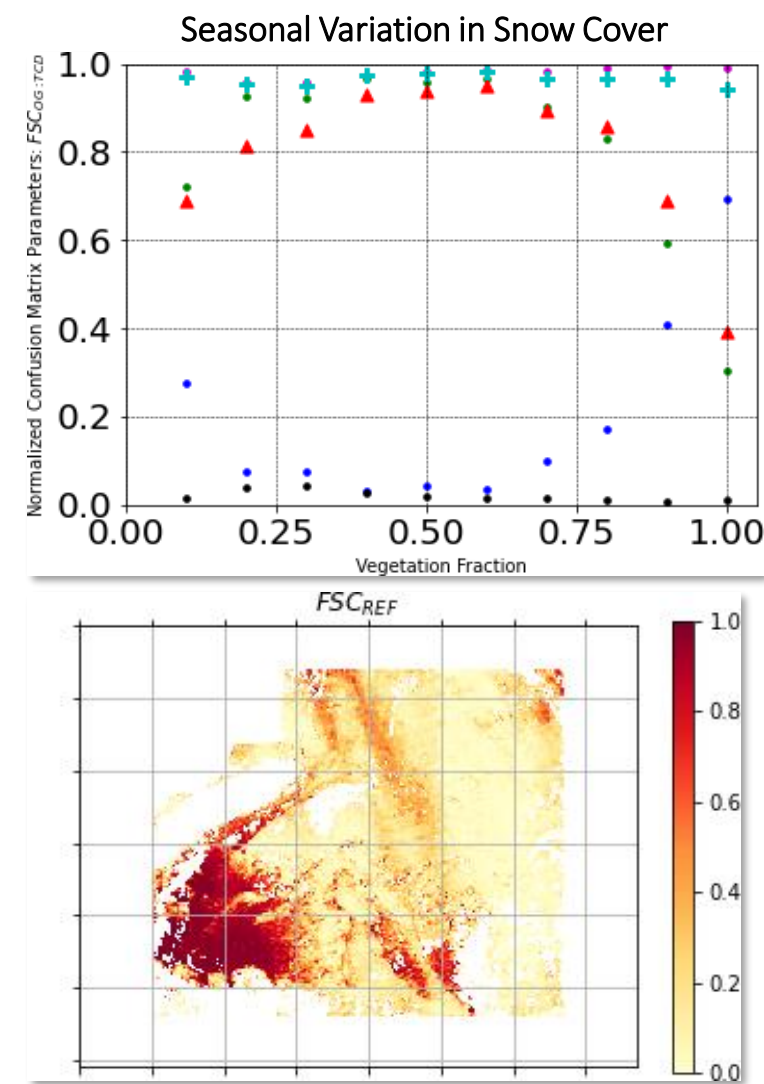
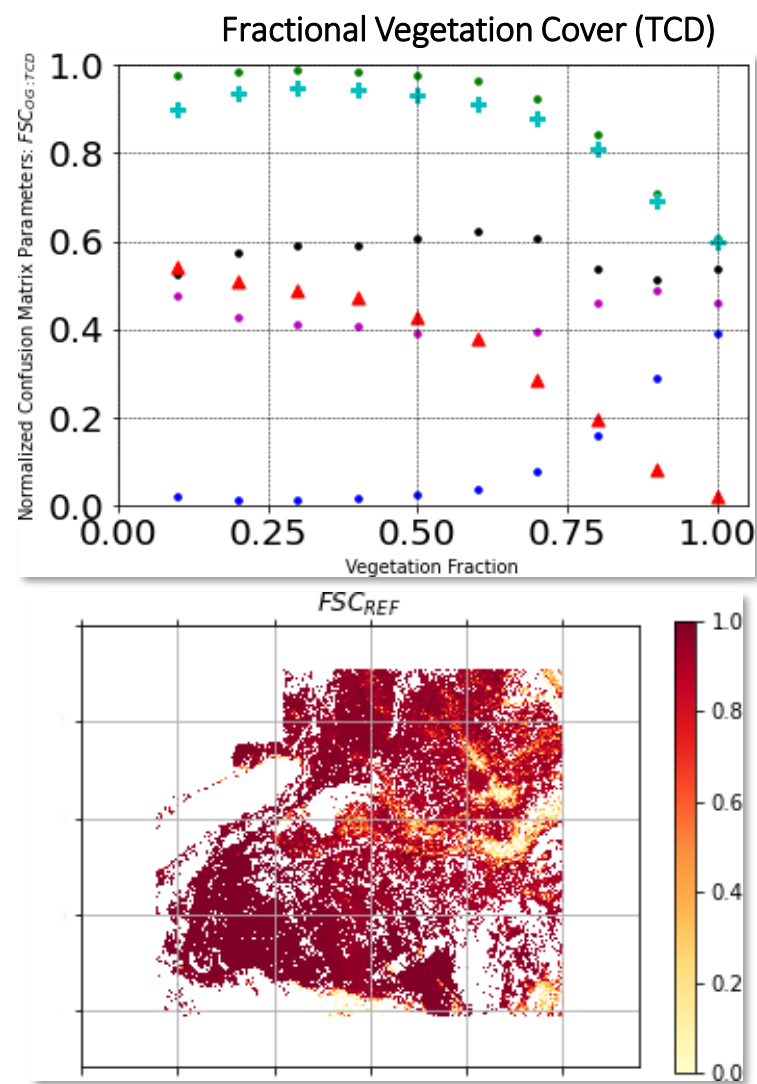
Location of the Sagehen Creek watershed.
NASA's Airborne Snow Observatory (ASO) footprint (in yellow).



NCALM 2014 snow-free lidar data derived fractional vegetation cover (fVEG).
UTM Zone: 10N, Datum: NAD83.

References:
Kostadinov et al., Watershed-scale mapping of fractional snow cover under conifer forest canopy using lidar, Remote Sensing of Environment, Vol. 222, Pg. 34-49, 2019.

Factors Impacting FSC Algorithm



Legend: κ : $\blacktriangle$, $A_{C_{obs}}$: $+$, TP: $\bullet$, TN: $\bullet$, FP: $\bullet$, and FN: $\bullet$

Note: NASA's Airborne Snow Observatory (ASO) was flown over the test site on 26th March, 17th April, and 18th May 2016, in order to acquire lidar measurements during the snow depletion phase of 2016. The estimation of the reference Fractional Snow Cover Area over the test site involved combination of the fVEG information, derived from the snow-free lidar point cloud NCALM data, and the snow presence/absence information, derived from the within-pixel mean lidar return elevation in the ASO data.

Conclusion

SCA Algorithm

The accuracy of snow detection is relatively higher in open vegetation-free areas as compared to the forested patches.

Snow detection is a challenging task for areas with aspects facing away from the direct solar irradiance, particularly if the location is also impacted by shadow and forest cover.

South-facing aspects with sufficient solar irradiance can have a compensating effect on the obscuring action of the overlying canopy cover and thus assist in the snow cover observation.

Snow depth or elevation does not indicate a direct influence on the performance of the snow detection. However, elevation can act as a factor for determining the location of the area whereas snow depth can control the level of reflectance emanating from that area.

FSC Algorithm

The accuracy of fractional snow cover estimation decreases with the increase in the fractional vegetation cover.

Since estimation of the on-ground FSC (FSC_{OG}) is dependent on the top-of-the-canopy FSC (FSC_{TOC}) and fractional vegetation cover, a certain combination of these factors may result in the overestimation of the FSC_{OG} .

Due to the occurrence of high FSC_{TOC} in the peak winters, the accuracy of the FSC algorithm is initially low. FSC_{OG} estimation gradually improves as the snow cover dissipates that causes a reduction in FSC_{TOC} below a critical value in relation to the fractional vegetation cover.