

Mapping Wet Snow in Karakoram By Incorporating SAR and Topographic Data

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Introduction: Wet Snow Mapping using SAR Imagery



Sentinel-2, RGB



Sentinel-1, R_c

Challenges in Karakoram

- Rugged terrain significantly distorts the backscatter ratios.

Solution:

- SAR + Topographic Data

- Wet snow appears much darker in radar images than dry snow or no snow.

$$\sigma^0_{ws} < \sigma^0_{free}\ OR\ \sigma^0_{dry}$$

- We can map wet snow using the change of backscatter between seasons.

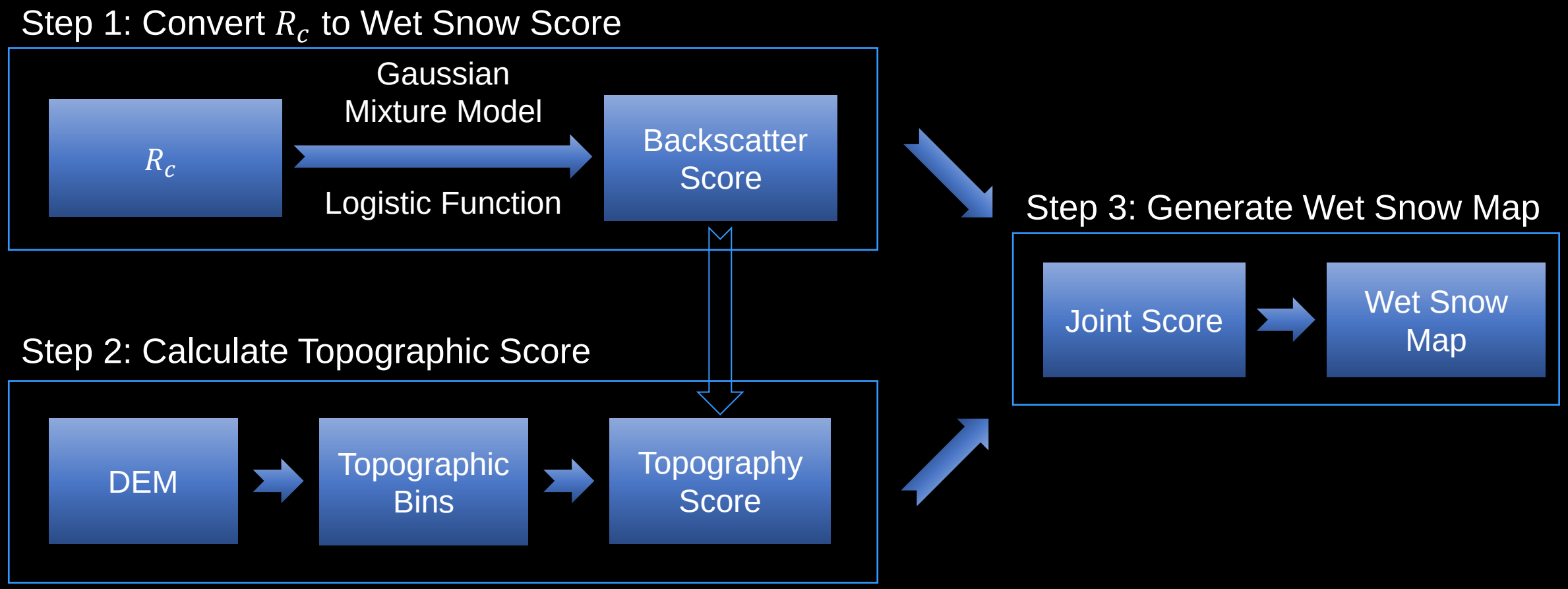
$$R_{vv} = \frac{\sigma^0_{vv}}{\sigma^0_{vv,ref}}, \qquad R_{vh} = \frac{\sigma^0_{vh}}{\sigma^0_{vh,ref}}$$

$$R_c = WR_{vh} + (1 - W)R_{vv}$$

$$R_c \leq -2\ dB$$

T. Nagler, H. Rott,.et al, 2016

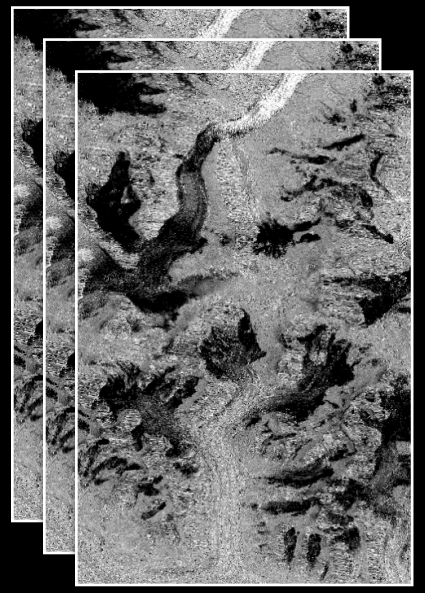
Method


Step 1: Convert R_c to Wet Snow Score
R_c
Gaussian Mixture Model
Logistic Function
Backscatter Score
Step 2: Calculate Topographic Score
DEM
Topographic Bins
Topography Score
Step 3: Generate Wet Snow Map
Joint Score
Wet Snow Map

Step 1: Convert R_c to Wet Snow Score $p(R_c)$

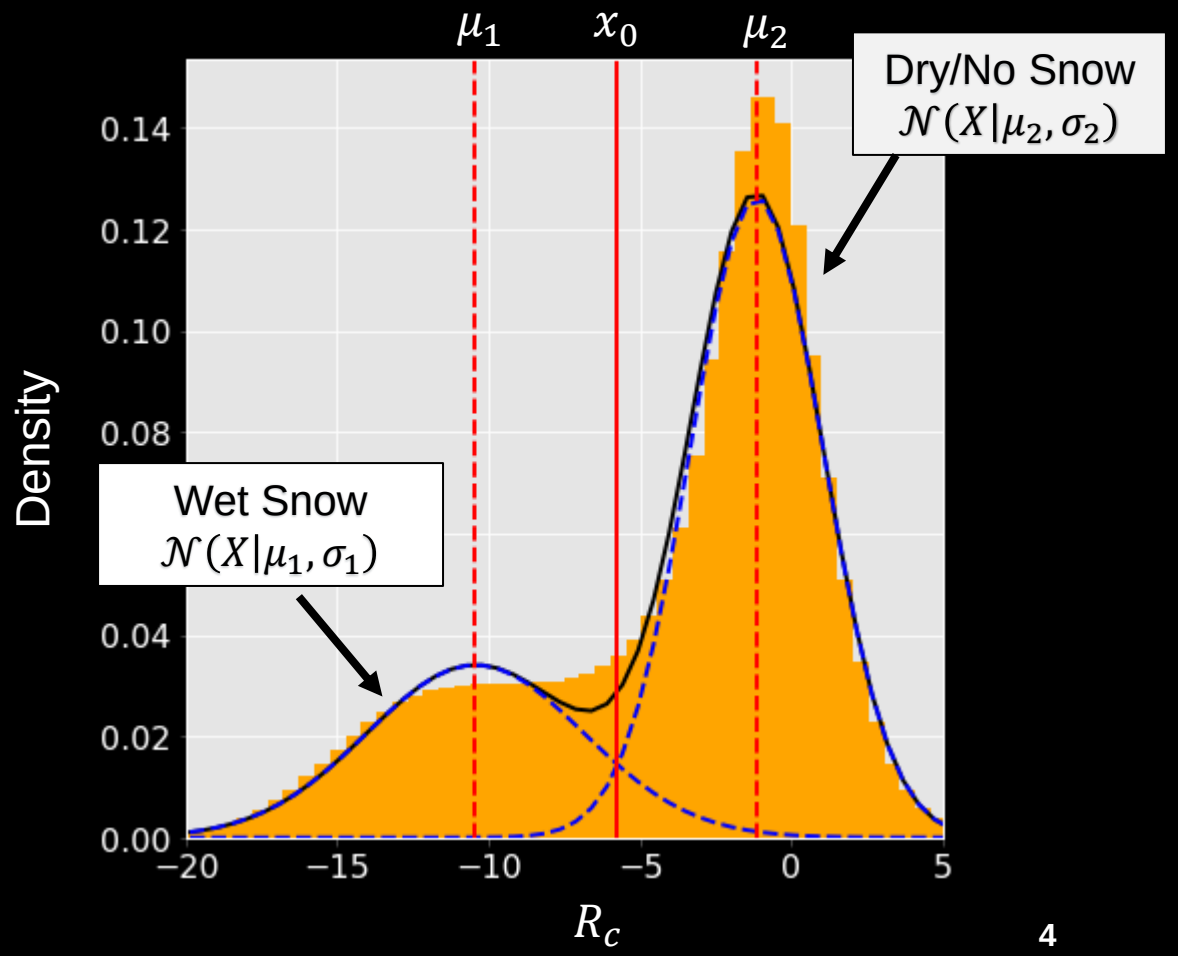
Gaussian Mixture Model (GMM)

$$p(X) = \sum_{k}^{K} \pi_k \mathcal{N}(X|\mu_k, \sigma_k), \qquad (K = 2)$$

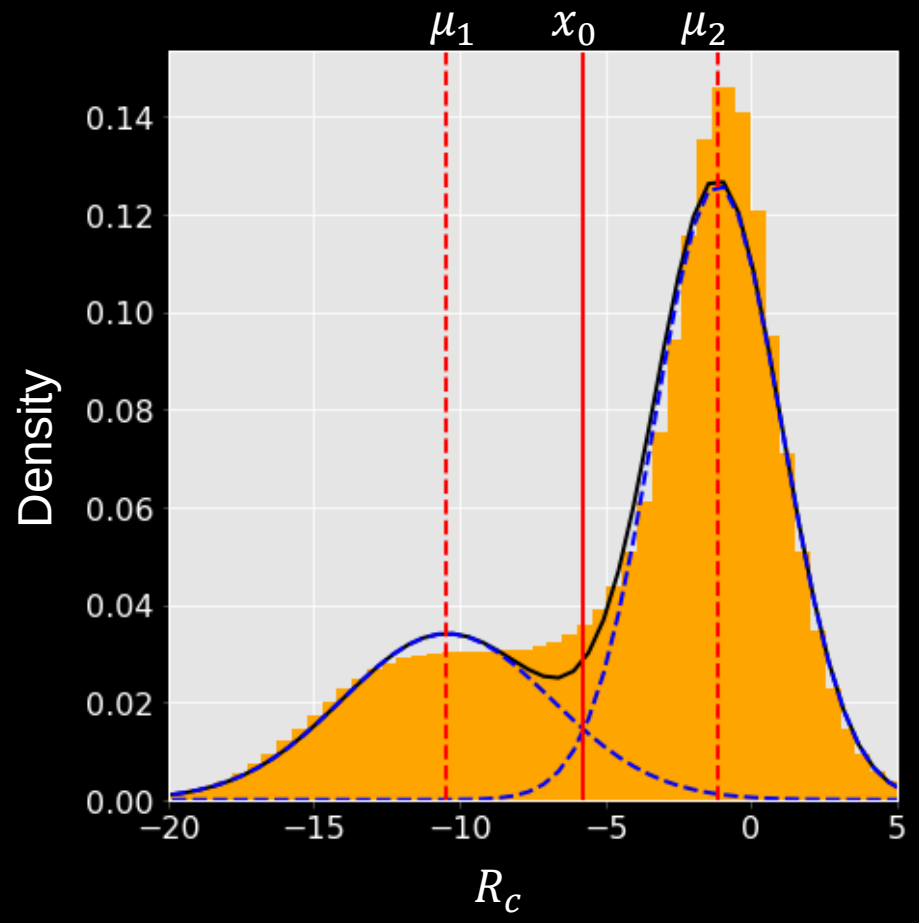


R_c of summer acquisitions

Randomly Sample Pixels



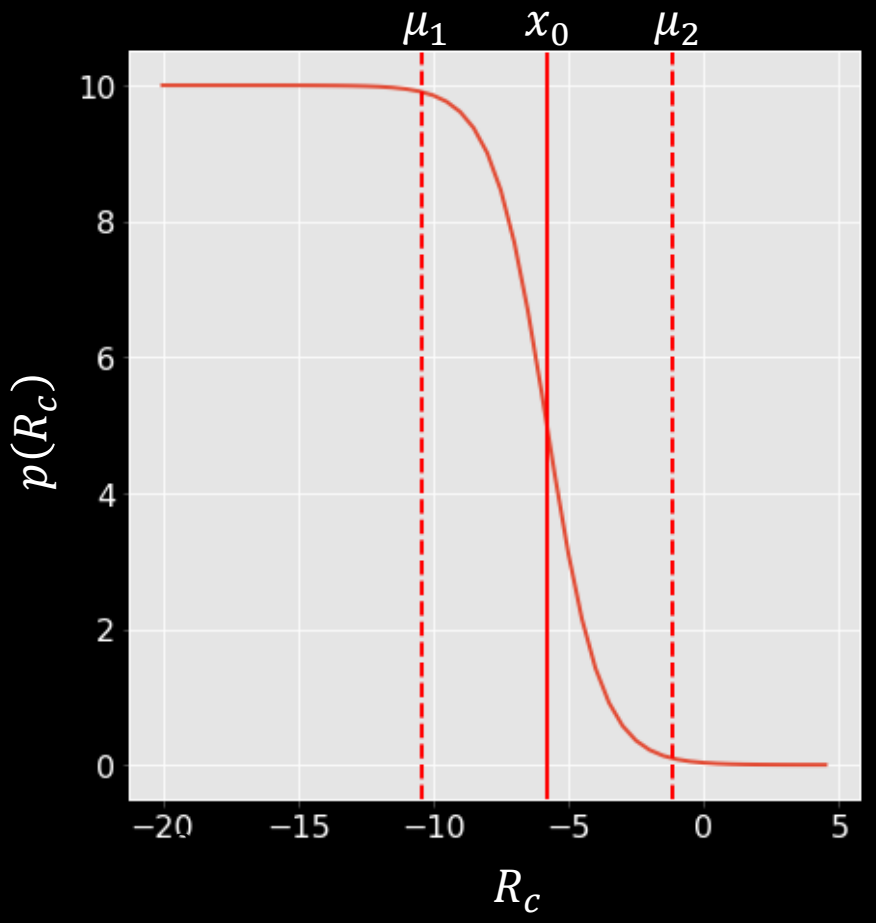
Step 1: Convert R_c to Wet Snow Score $p(R_c)$



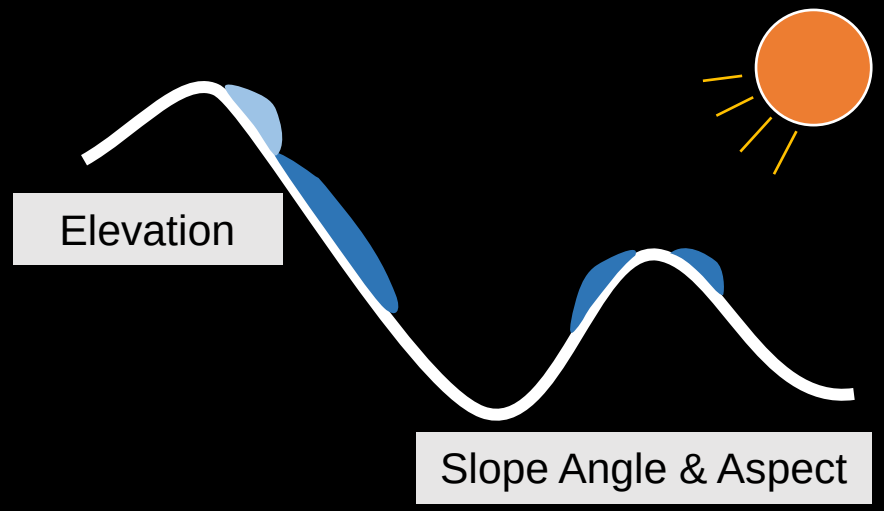
Logistic Function

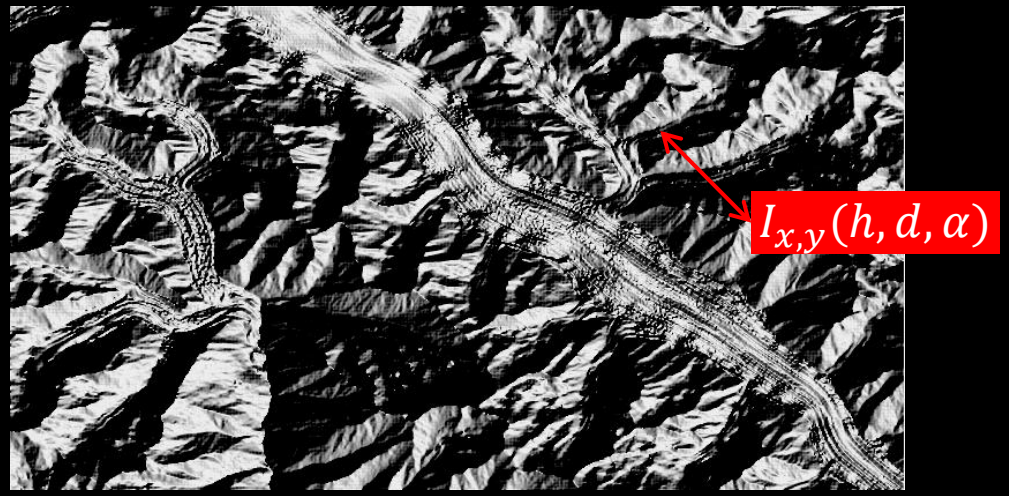
$$p(R_c) = \frac{10}{1 + e^{k(R_c - x_0)}}$$

$$\begin{cases} x_0 = \frac{1}{2}(\mu_1 + \mu_2) \\ k = \frac{|\mu_1 - \mu_2|}{\sigma_1 + \sigma_2} \end{cases}$$



Step 2: Calculate Topographic Score





Steps:

Given an image of $p(R_c)$ of a specific day:

(1) Classify pixels into topographic bins:

$$I_{x,y}(h,d,\alpha) \in T_i(h_i,d_i,\alpha_i)$$

(2) Calculate the ***median*** of $p(R_c)$ for each topographic bin:

$$p(T_i) = Med(p_{x,y}(R_c))$$

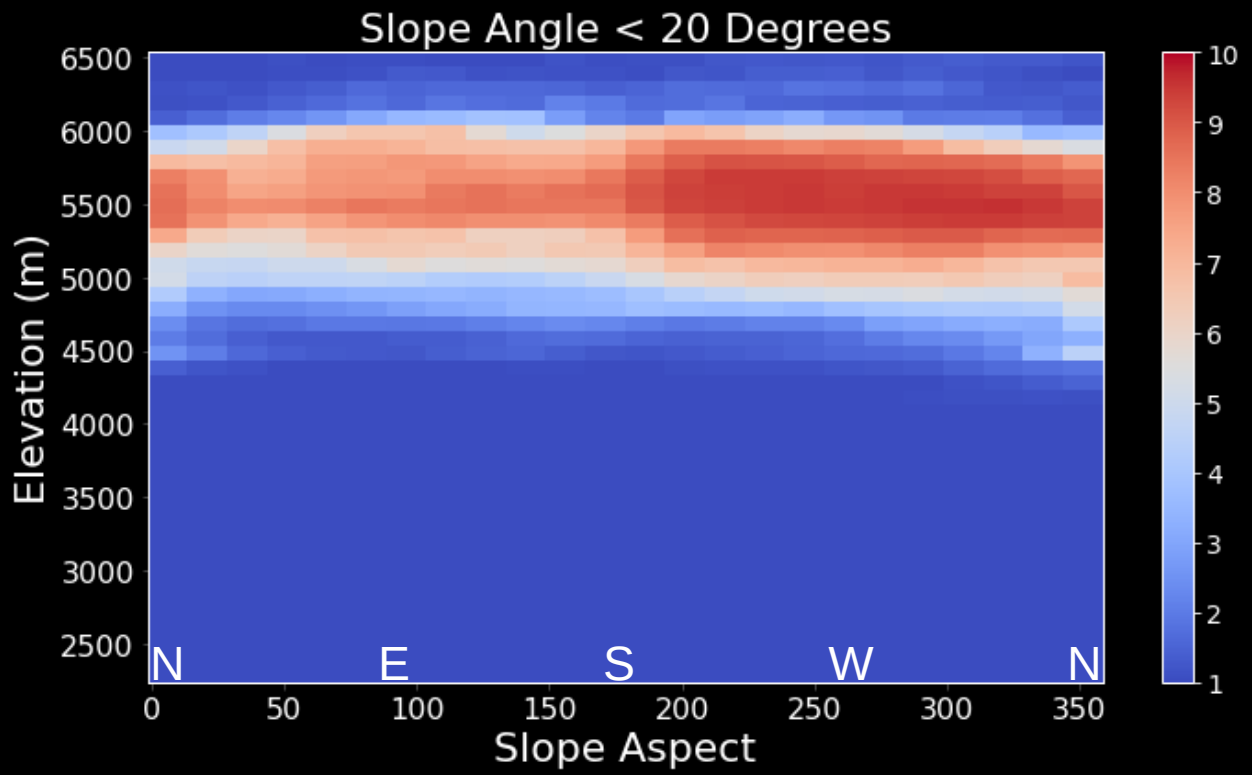
(3) Generate topographic score map:

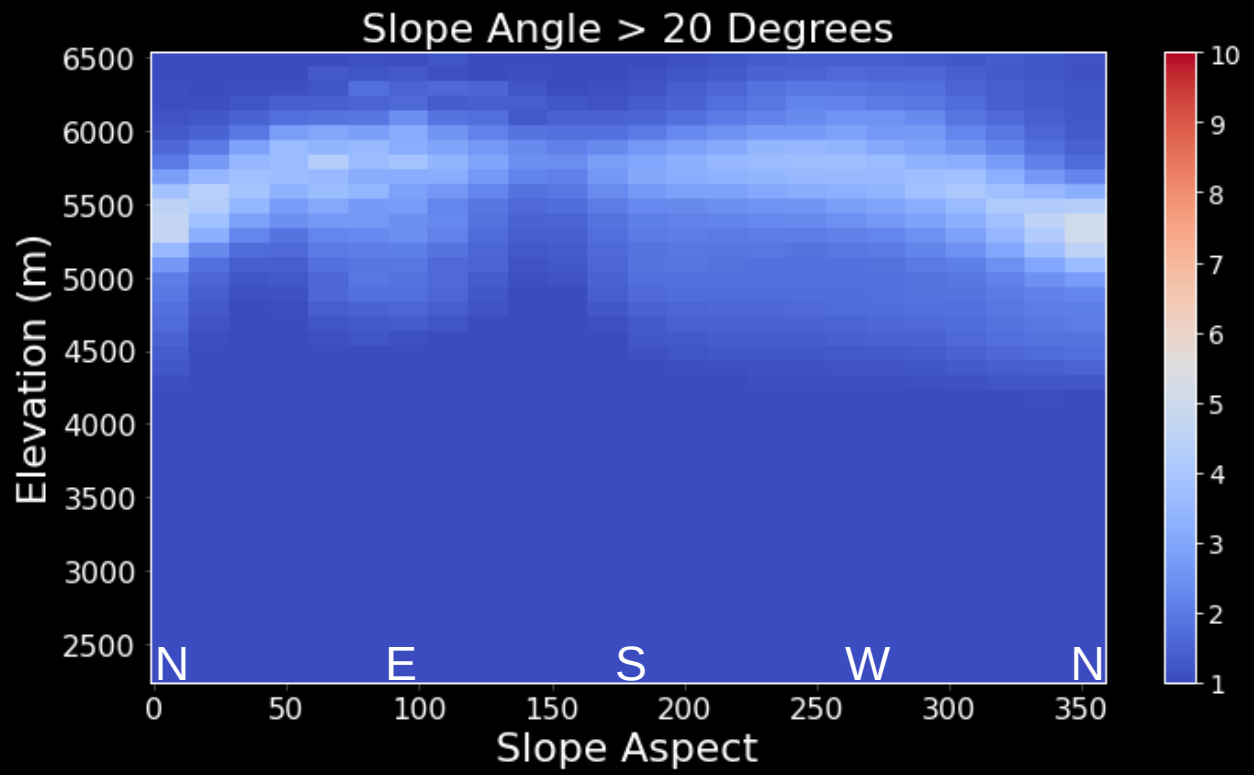
$$I_{x,y}(h,d,\alpha) \Rightarrow p_{x,y}(h,d,\alpha)$$

Step 2: Calculate Topographic Score

Flat Terrain: Slope aspect ratio has little influence on the vertical distribution of snow

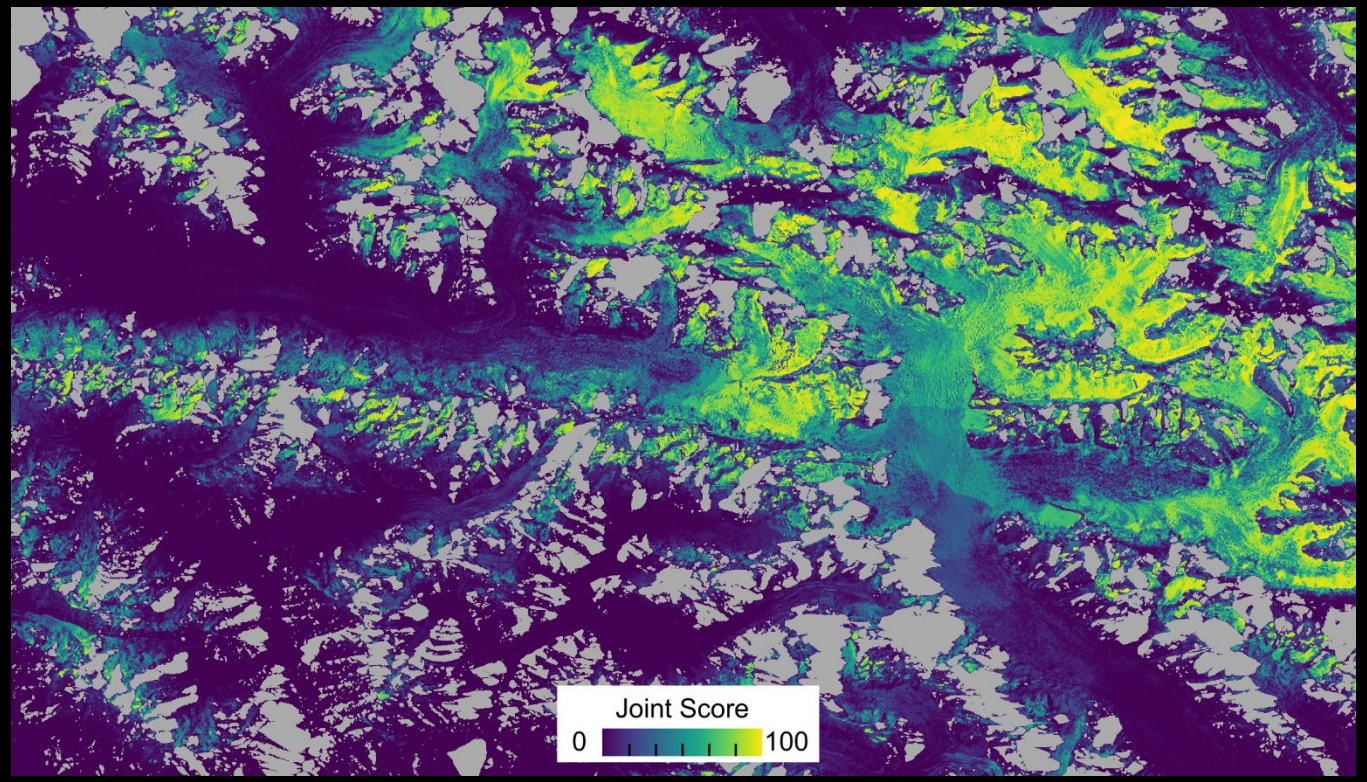
Steep Terrain: South facing slopes have relatively higher snowline than north facing slopes.

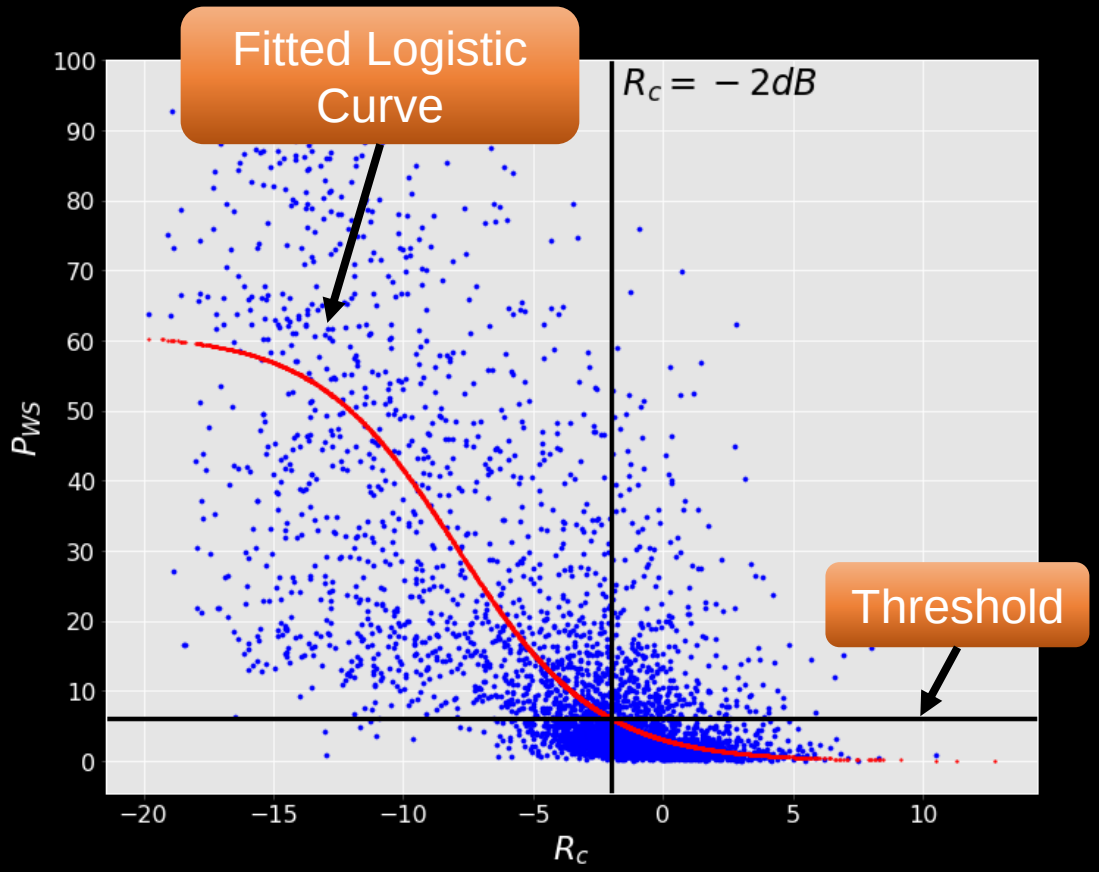




Step 3: Generate Wet Snow Map

Joint Wet Snow Score: $P_{ws} = p(R_c) * p(h, d, \alpha)$

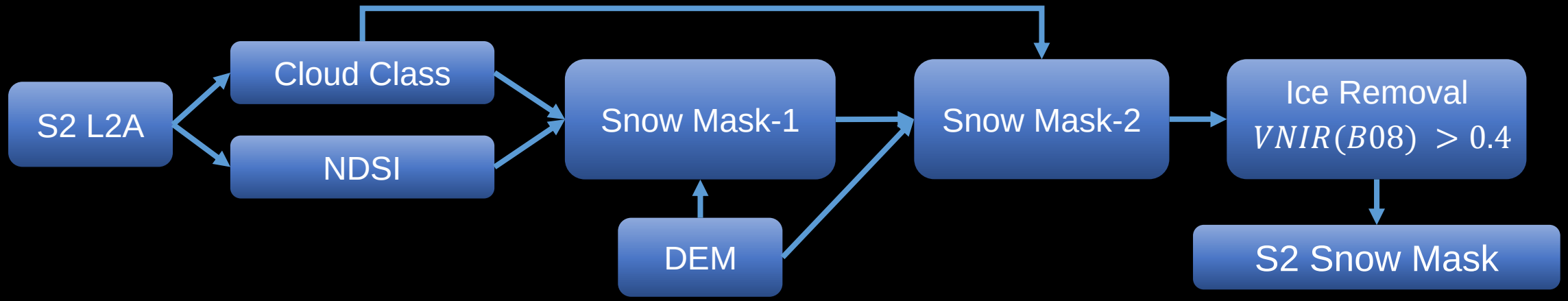




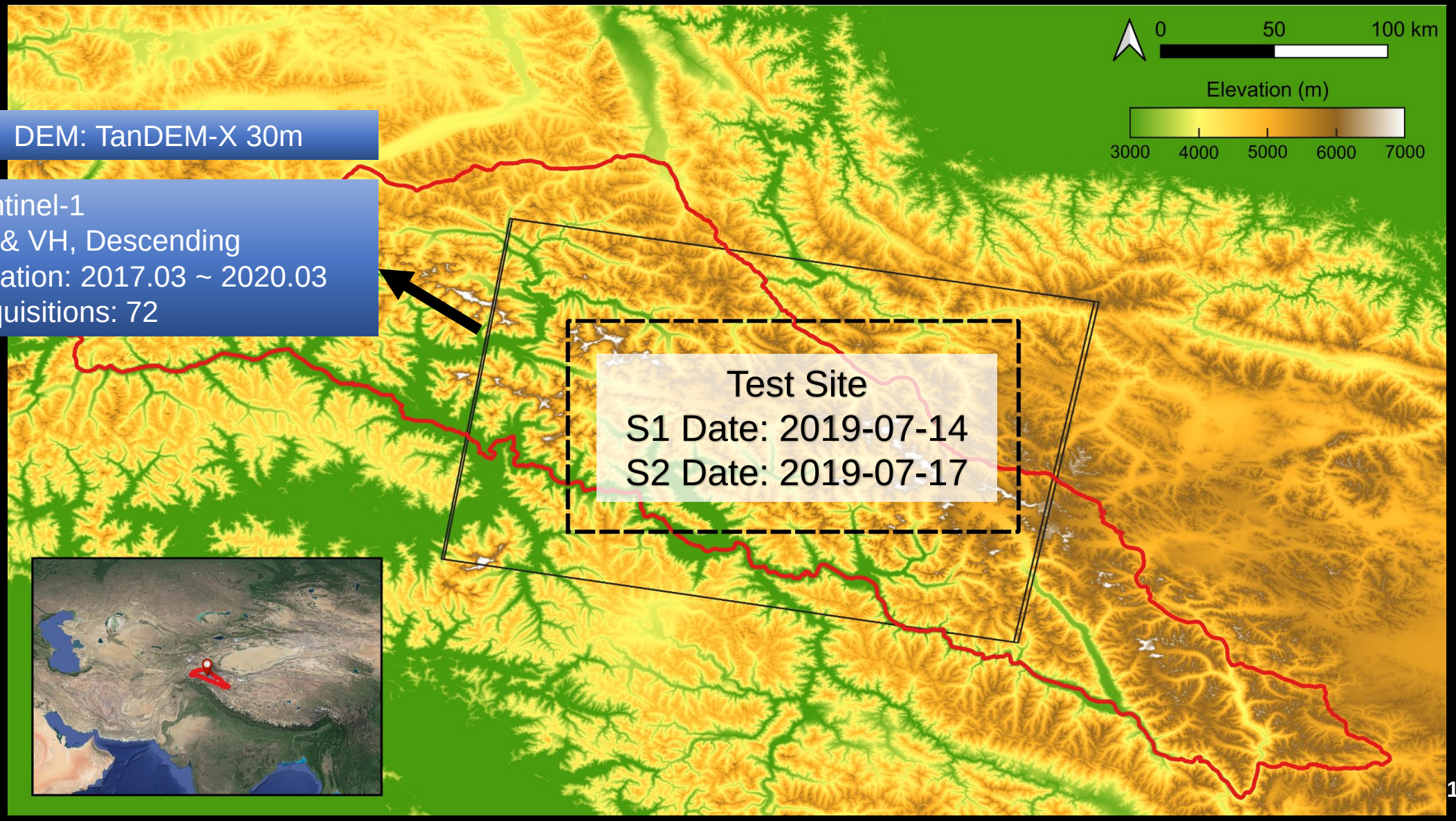
Validation

1. Backscatter Ratio Thresholding Method
   - Filter pixels using $\mathrm{R}_c < -2\ dB$

2. Sentinel-2 Snow Map (including dry snow)



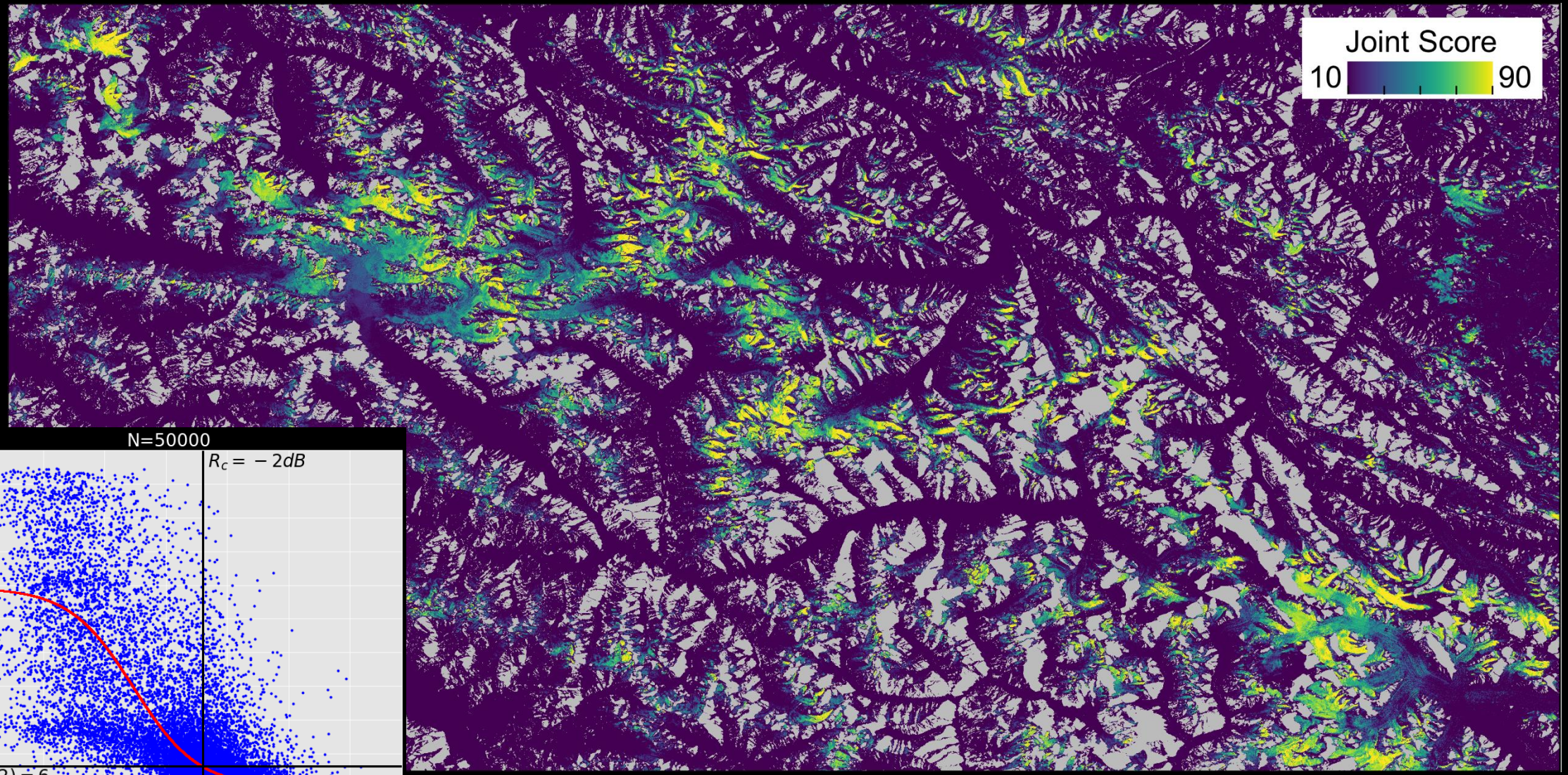
Study Site and Data



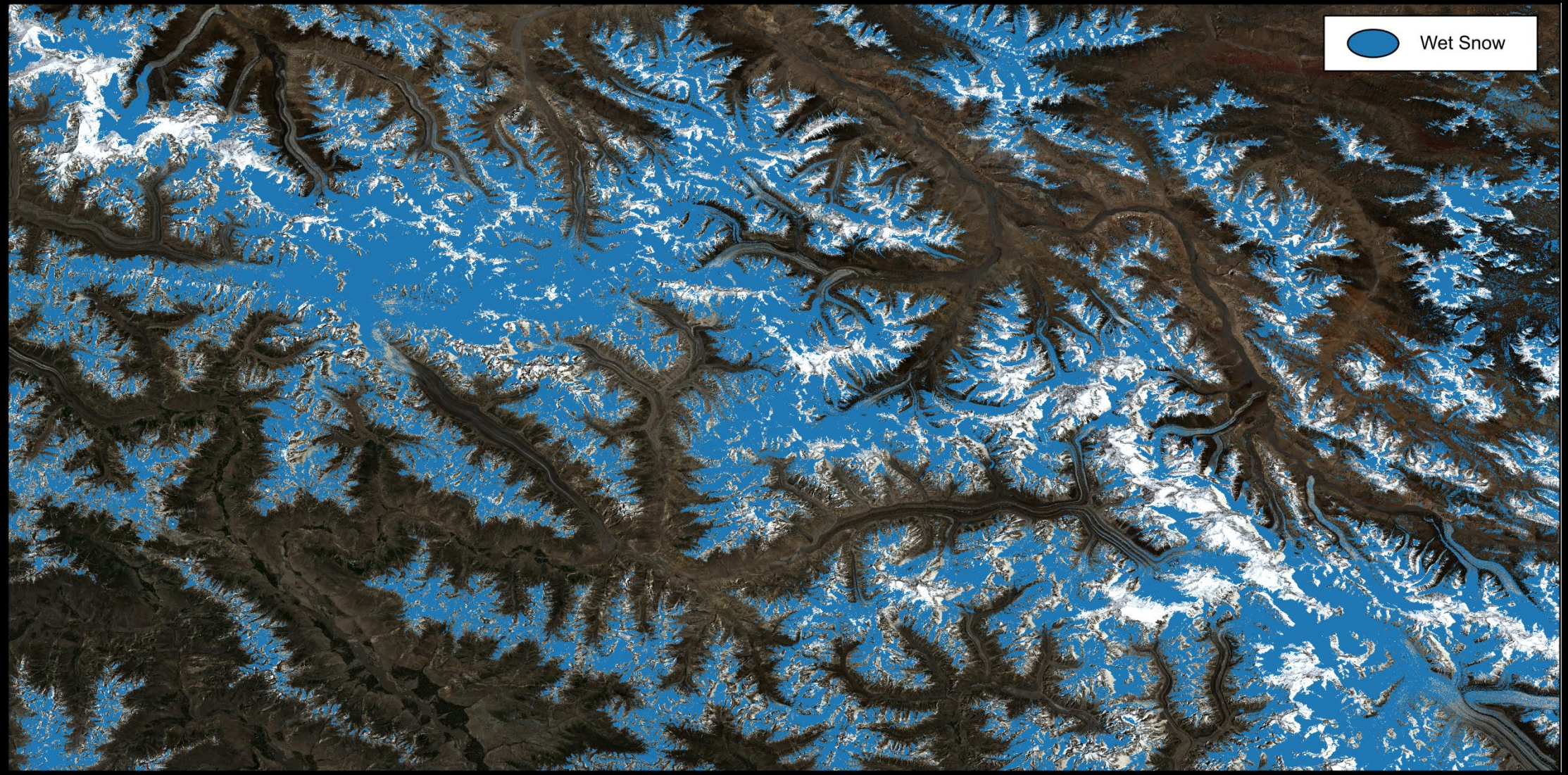
Test Site – Sentinel-2 RGB



Results – Joint Wet Snow Score

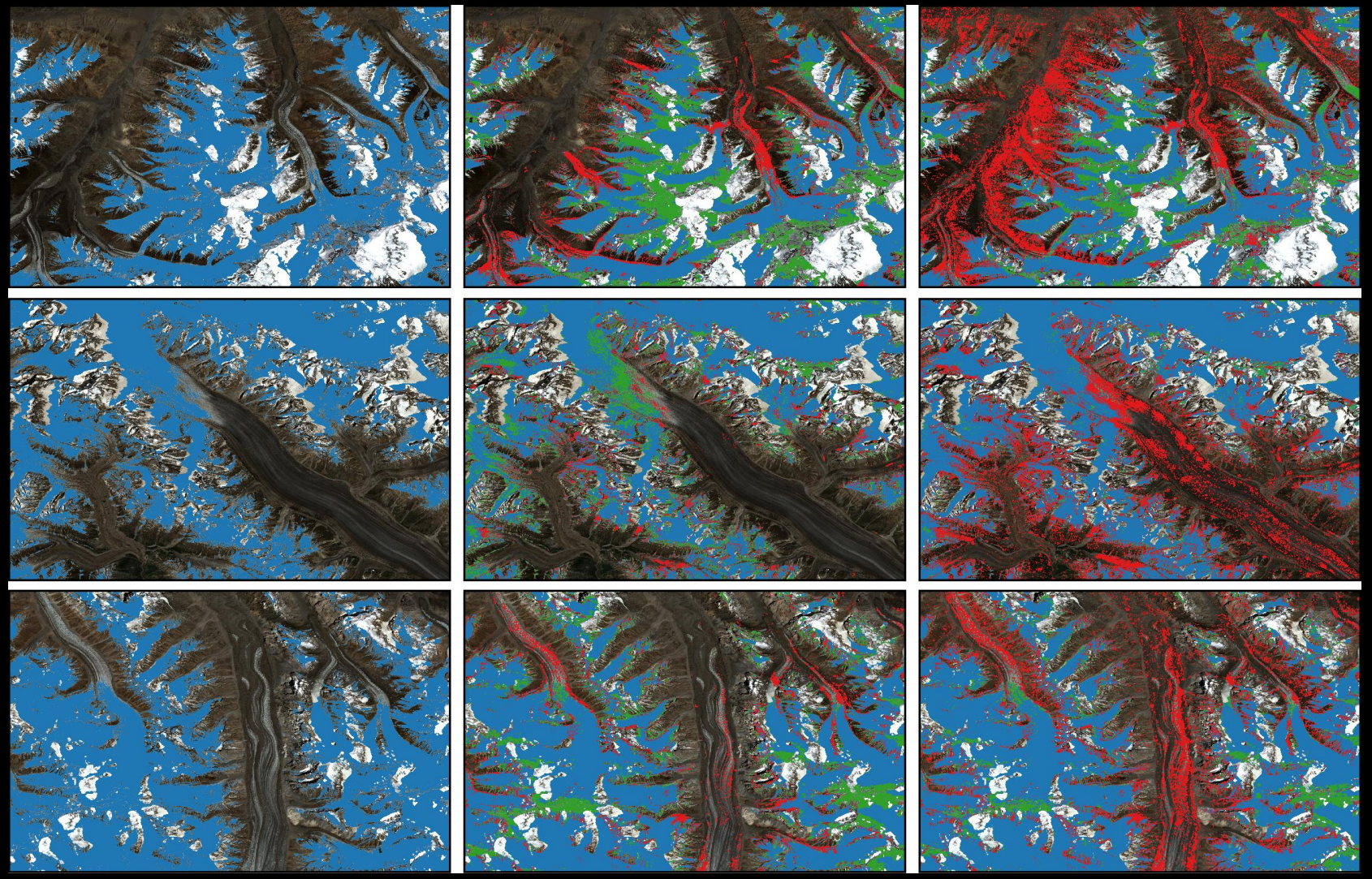


Results – Wet Snow Map [$p(WS) \geq 6$]



Comparison

S2 Snow Map | Joint Score | $R_c < -2\ dB$



True Positive

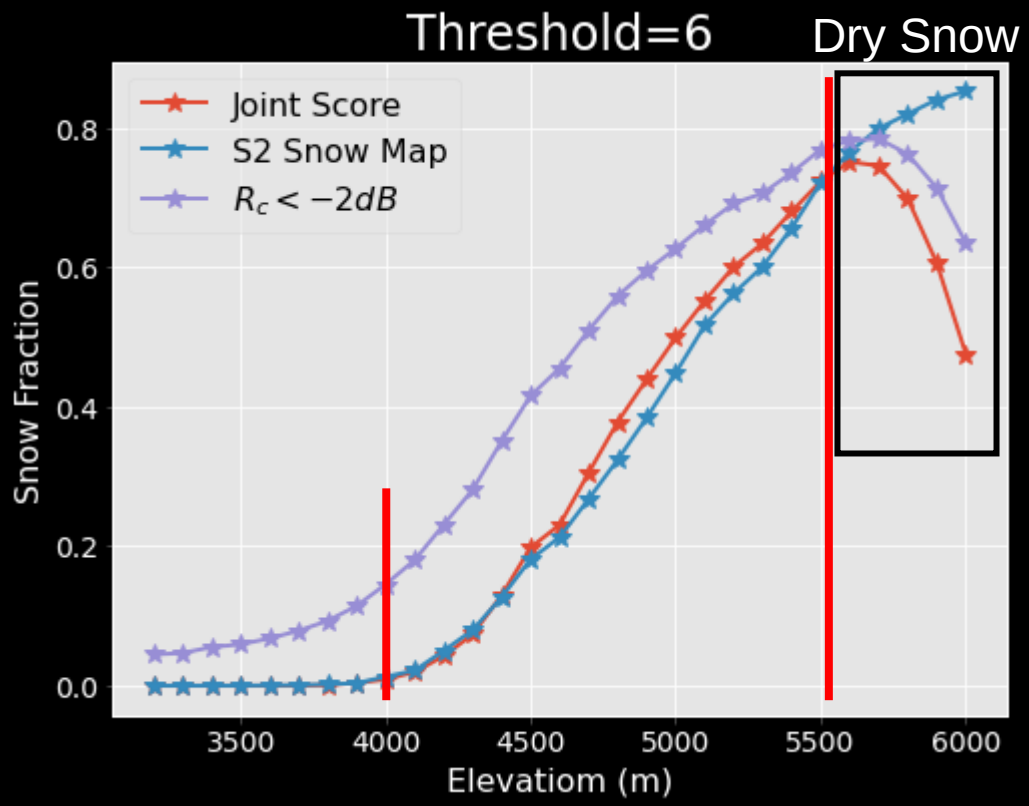
False Positive

False Negative
(Missed detection)

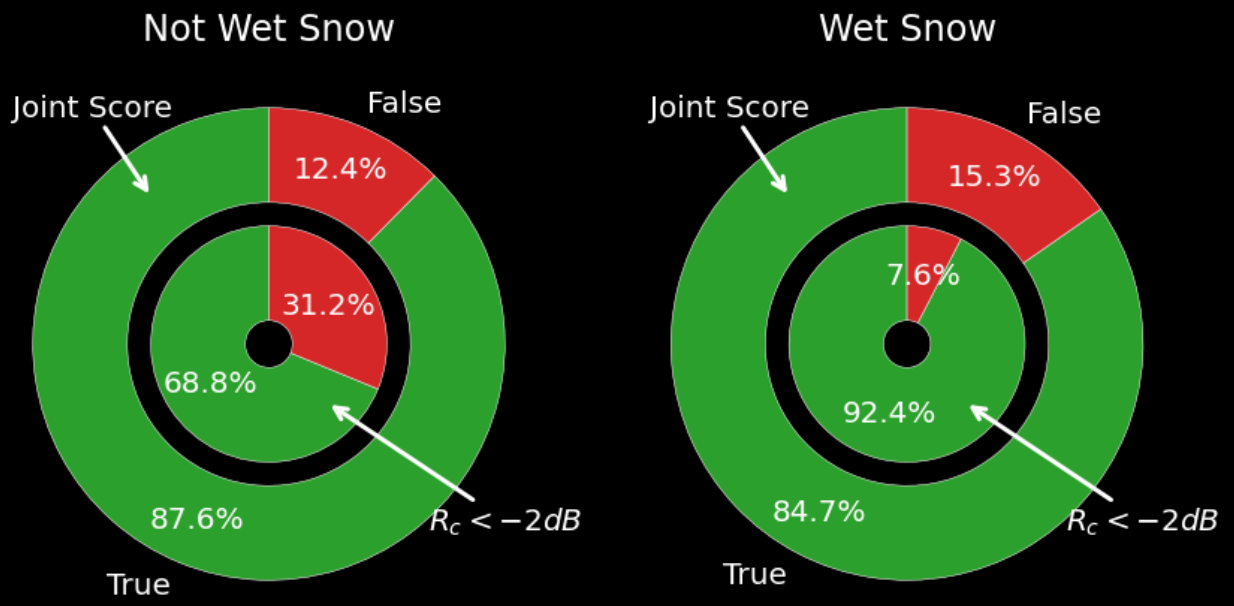
Note: Missing detection is also possibly caused by dry snow.

Validation

Snow Fraction along Elevation:



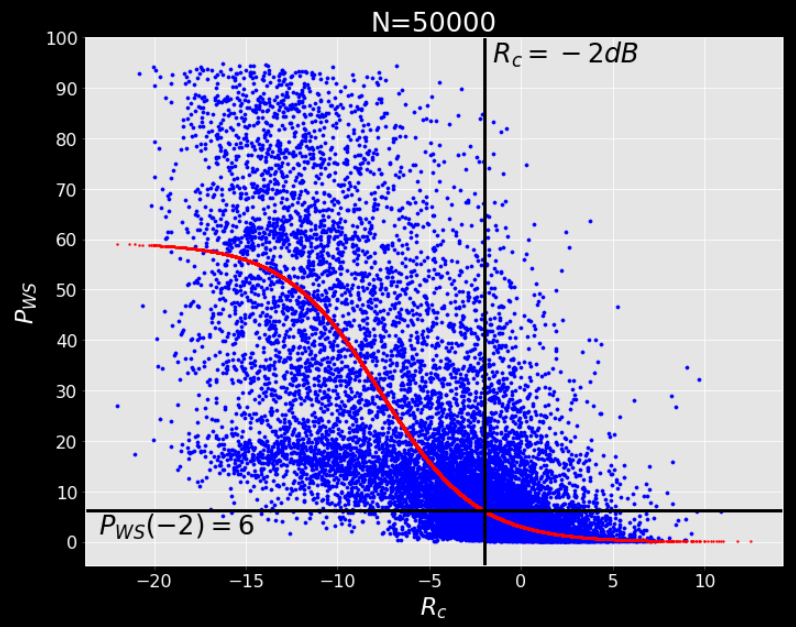
Confusion Matrix:



* Only regions with elevation between 4000m~5500m

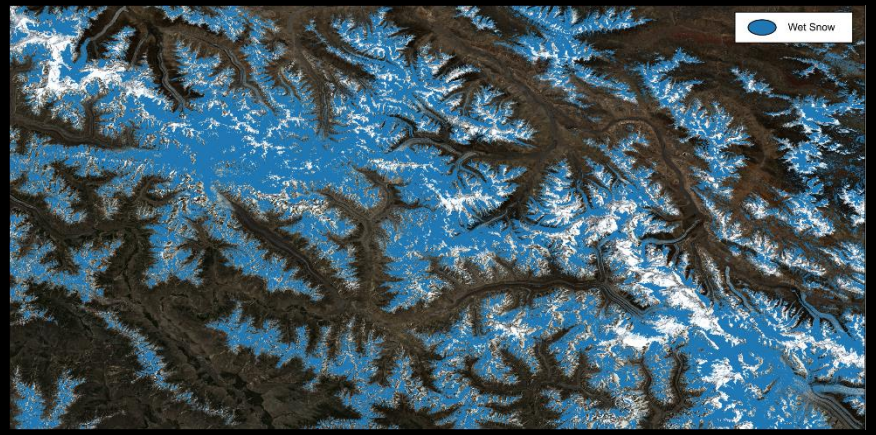
Conclusion & Outlook

- The proposed method can effectively incorporate SAR and topographic data to map the wet snow in Karakoram.
- The method is robust to complex terrain, and can be easily implemented for regional application.

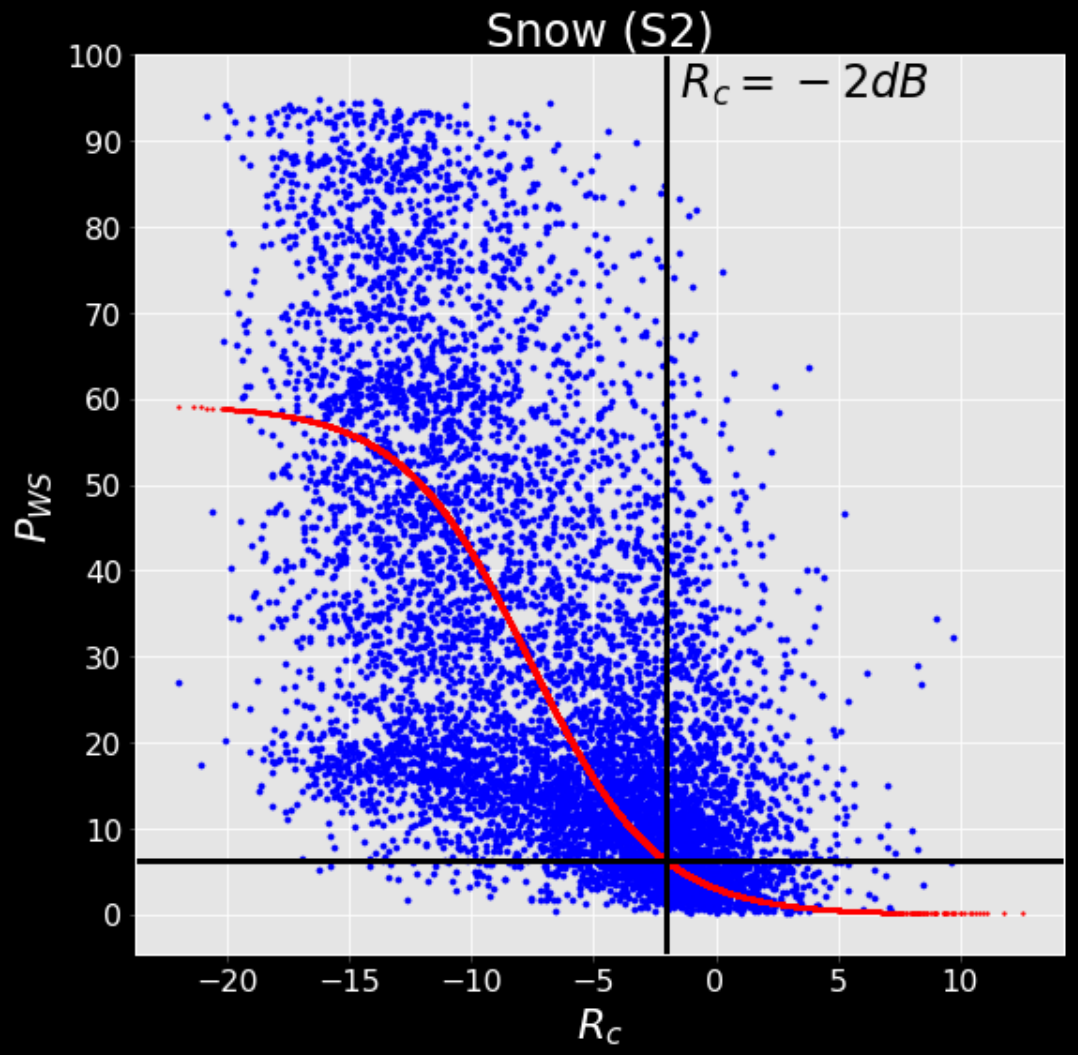


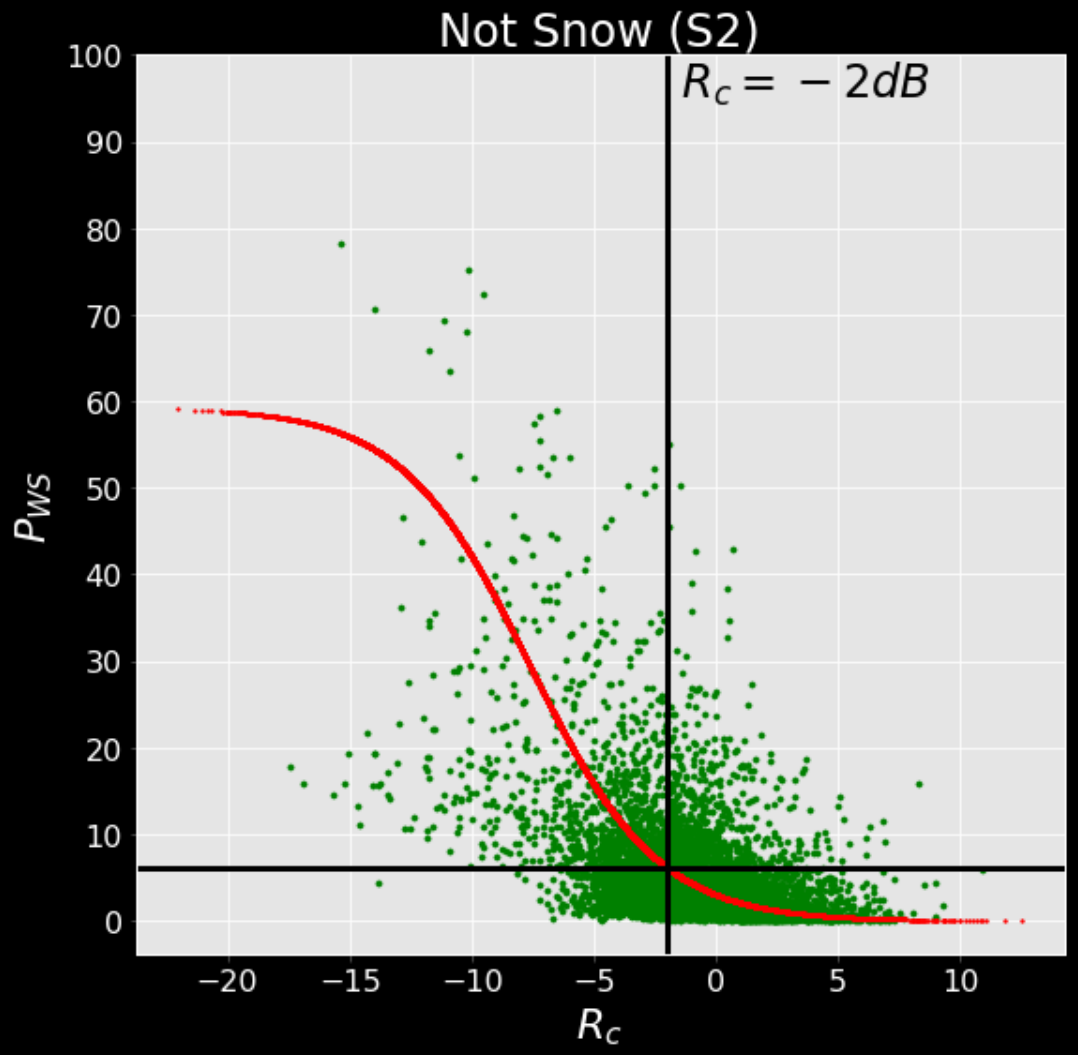
Further improvement:

- Incorporate more types of data
- Combine Ascending & Descending images
- Use advanced machine learning algorithm.
- Try more feature engineering technique.

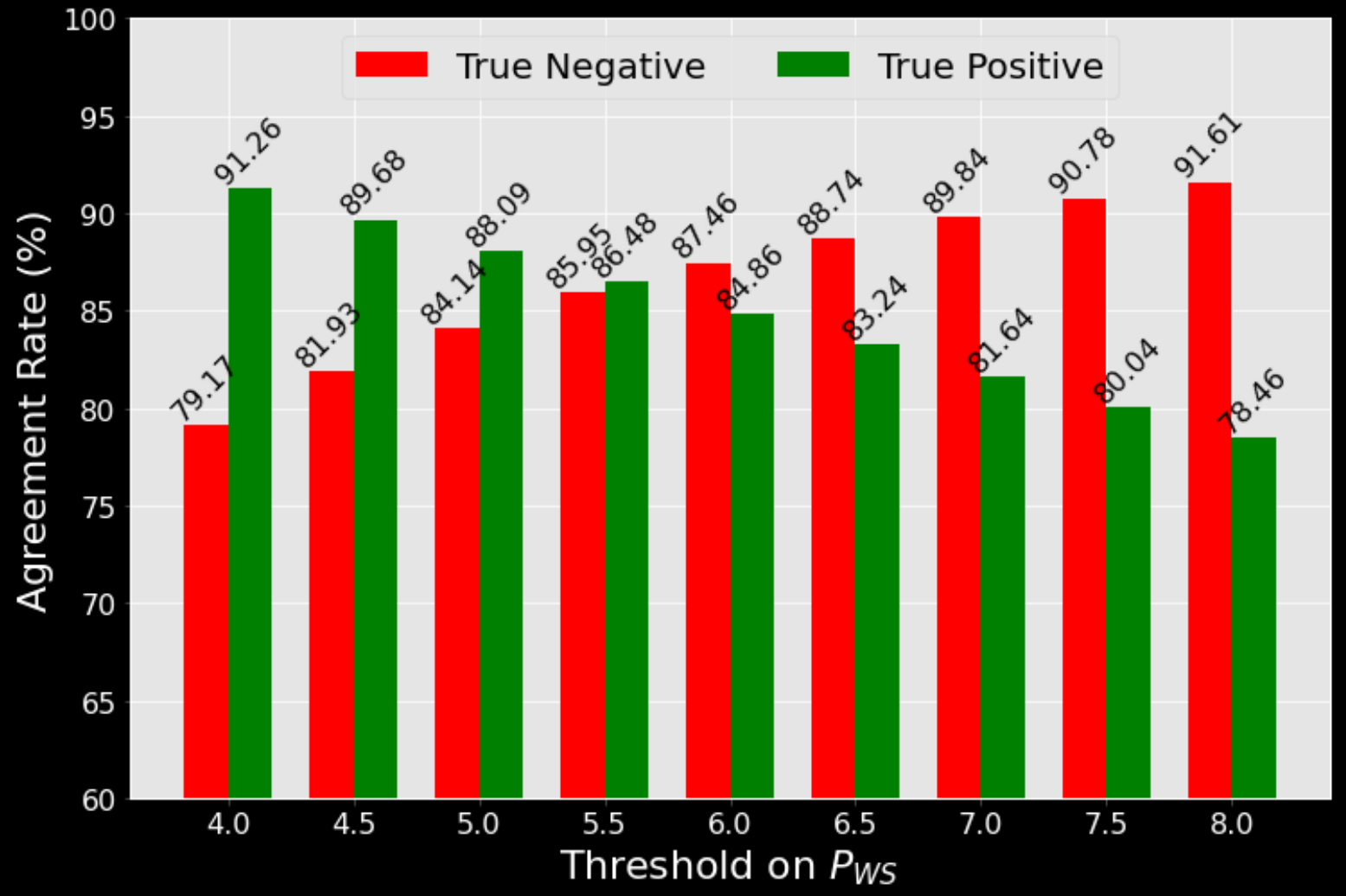


Backup


Snow (S2)
$R_c = -2dB$
P_{WS}
R_c
100
90
80
70
60
50
40
30
20
10
0
−20
−15
−10
−5
0
5
10


Not Snow (S2)
$R_c = -2dB$
P_{WS}
R_c
100
90
80
70
60
50
40
30
20
10
0
−20
−15
−10
−5
0
5
10

Backup


True Negative
True Positive
Agreement Rate (%)
100
95
90
85
80
75
70
65
60
91.26
89.68
88.09
86.48
87.46
84.86
88.74
83.24
89.84
81.64
90.78
80.04
91.61
78.46
79.17
81.93
84.14
85.95
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Threshold on P_{WS}