

# Estimating surface water availability in high mountain rock slopes using numerical energy balance model

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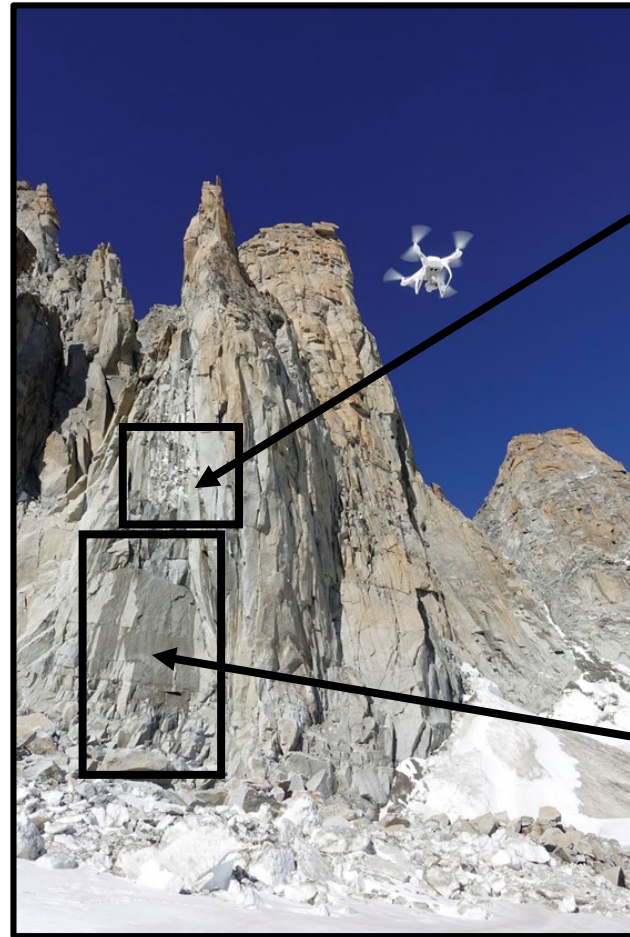
<sup>3</sup>Styx 4D, Le Bourget du Lac, France.



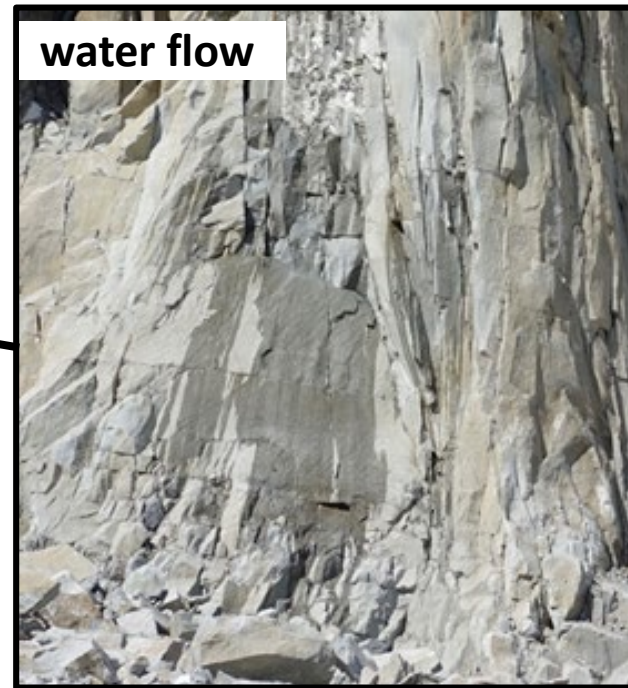




# Water in steep high mountains



Rockfall car on the Trident du Tacul rock fall (Mont Blanc), 26<sup>th</sup> September 2018.



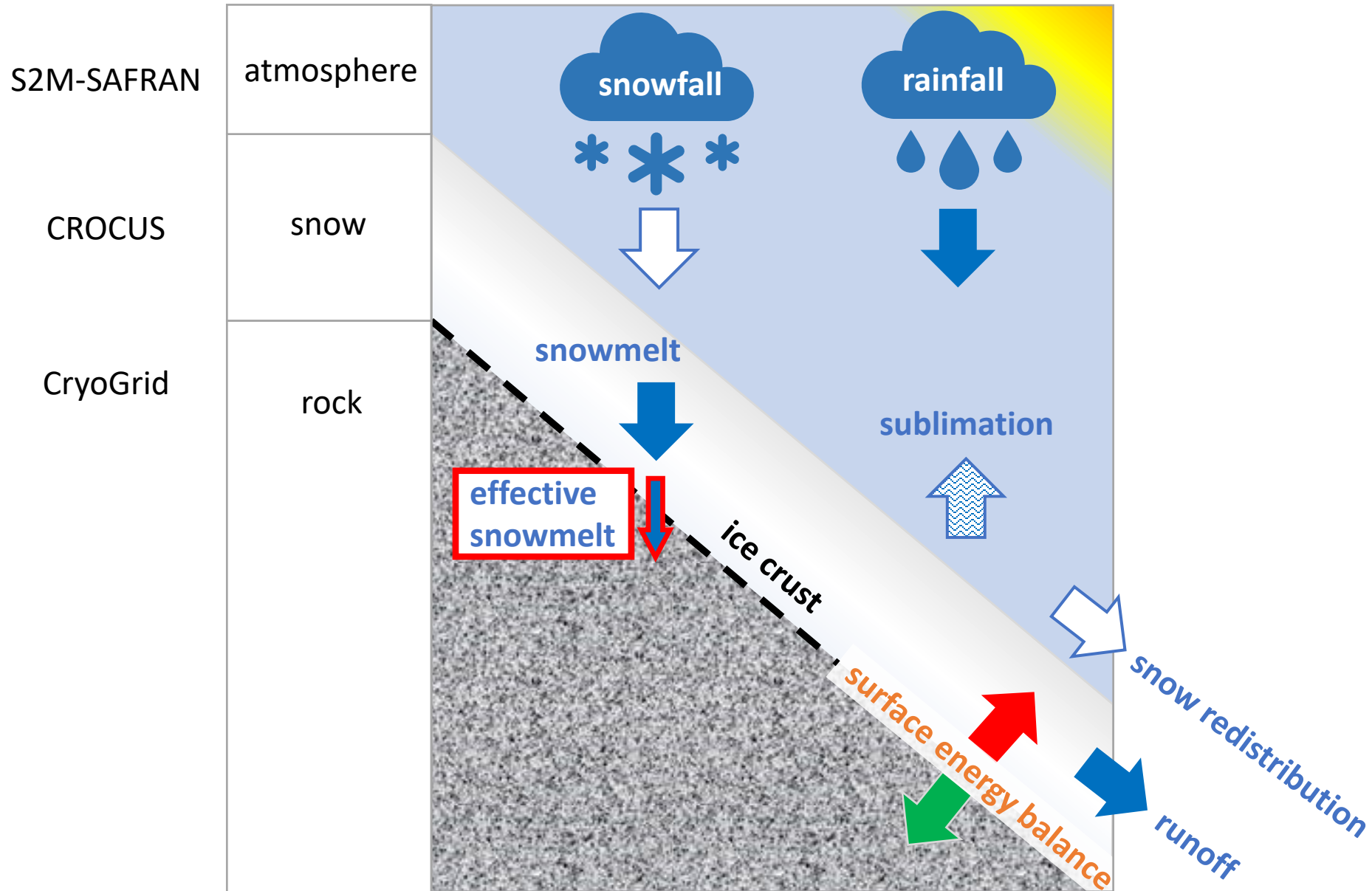
*L. Ravanel*



# Study site – Aiguille du Midi 3842 m



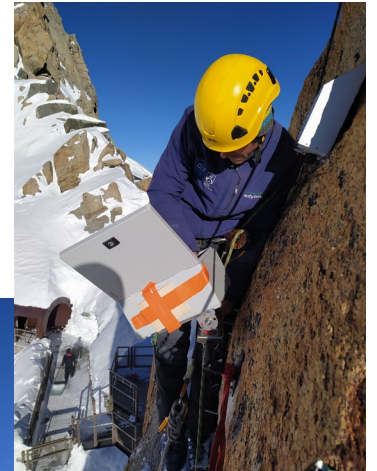
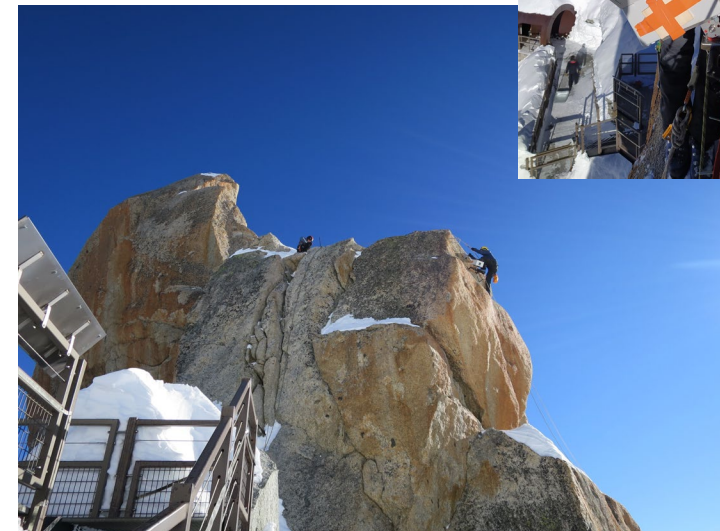
# Numerical model setup





# Field measurements

4 × 10 m deep boreholes installed in 2009  
Time lapse camera  
Snow accumulation measurements poles  
Surface temperature: i-buttons  
3D high resolution surveys using a drone

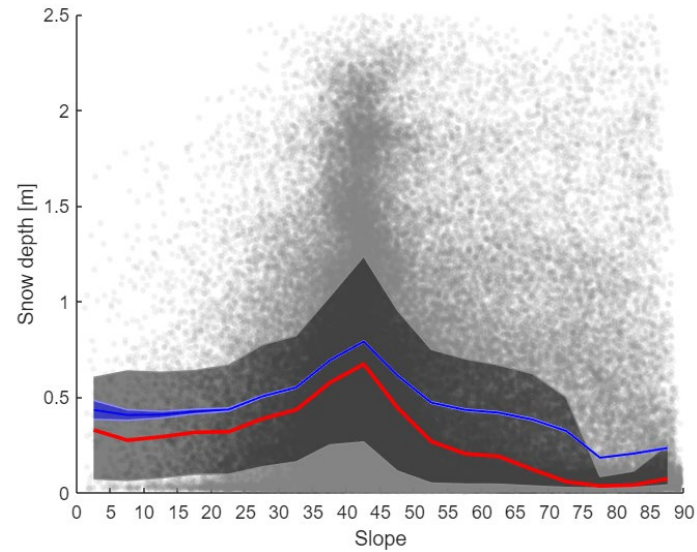




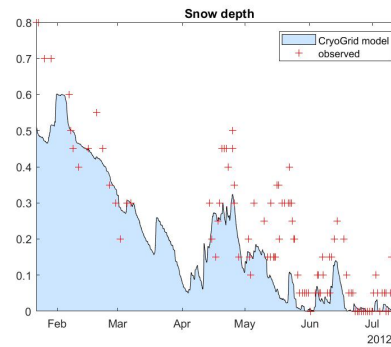


# Results – snow accumulation

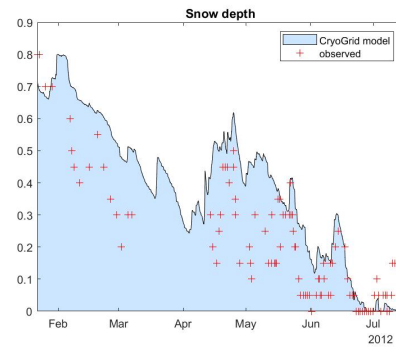
Snow accumulation decreases from 80 cm to 0 cm between slope angles 40°-70°



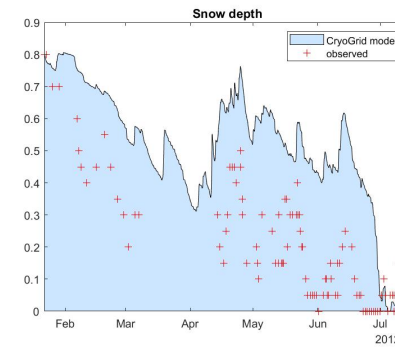
snow accumulation factor  
20%



25%



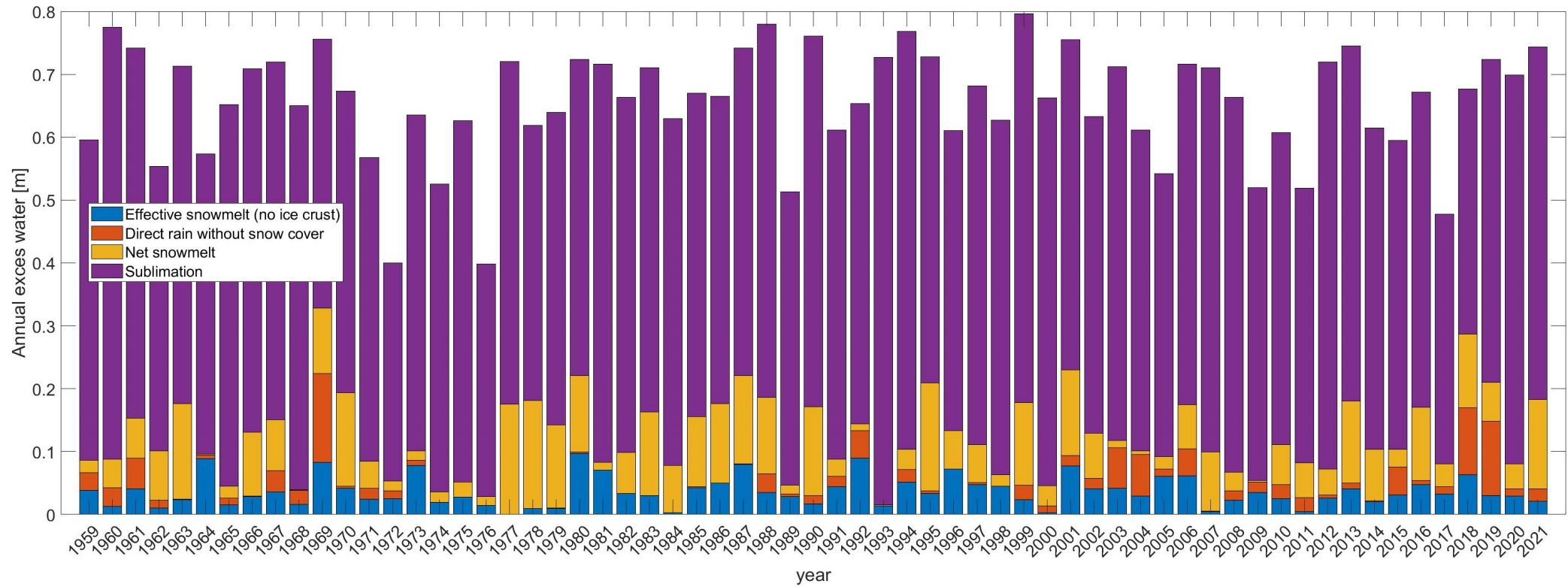
30%



~75% of the snowfall does not accumulate in our study site (slope angle 45° -55°)

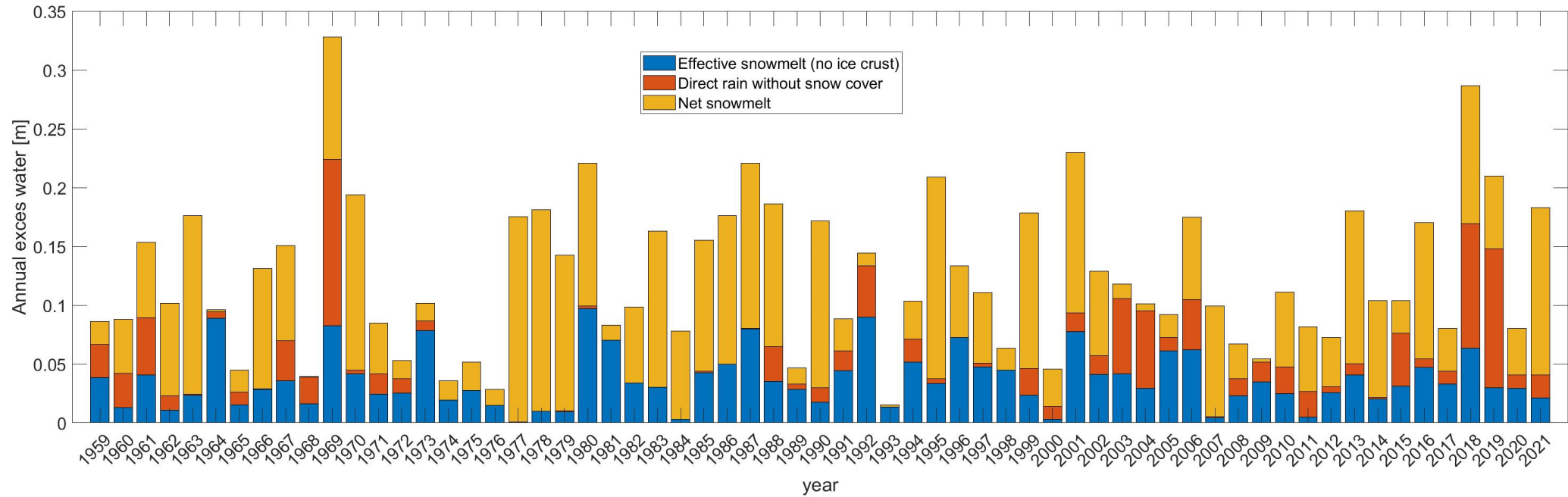


# Model results – Annual water balance

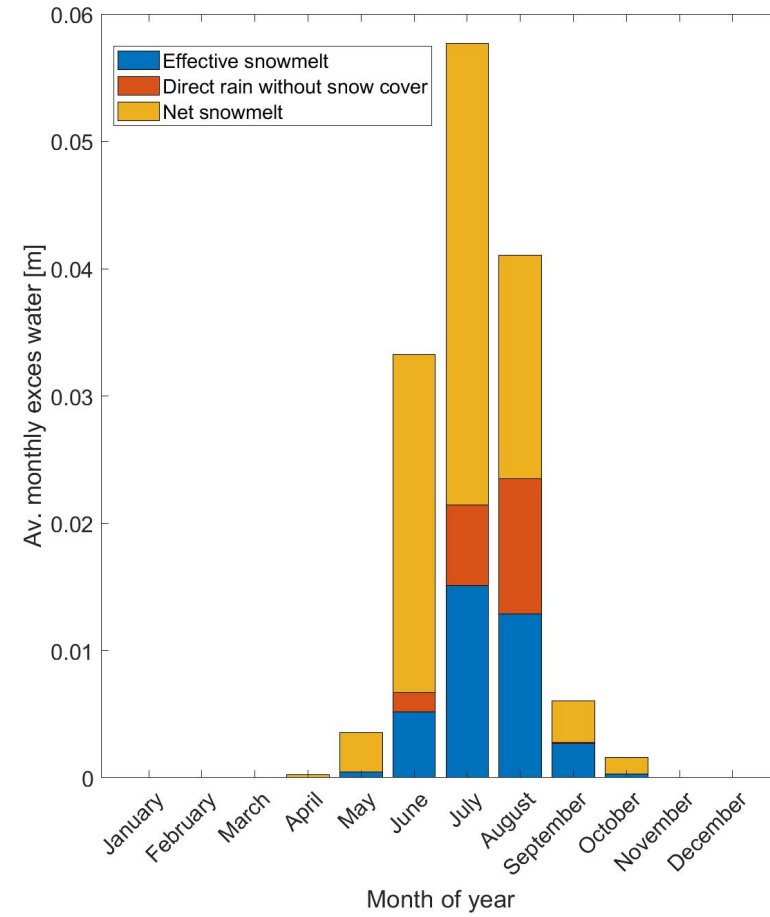




# Model results – Annual water balance

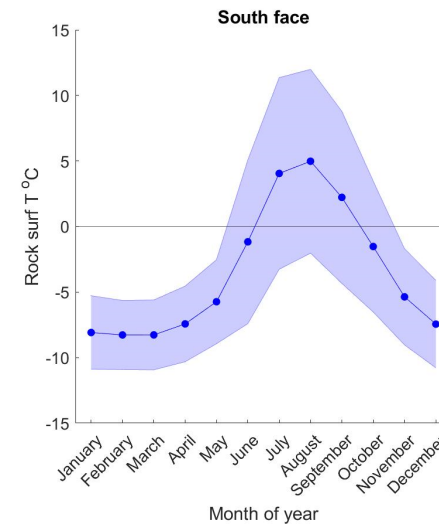
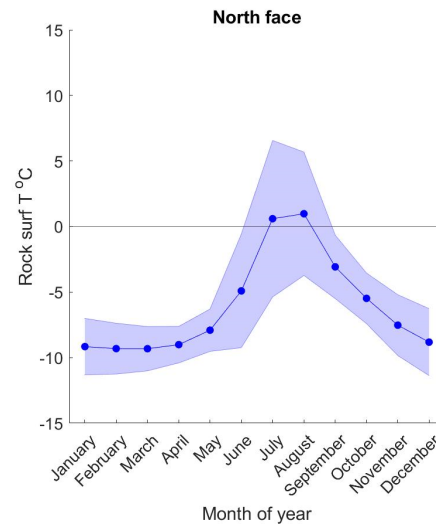
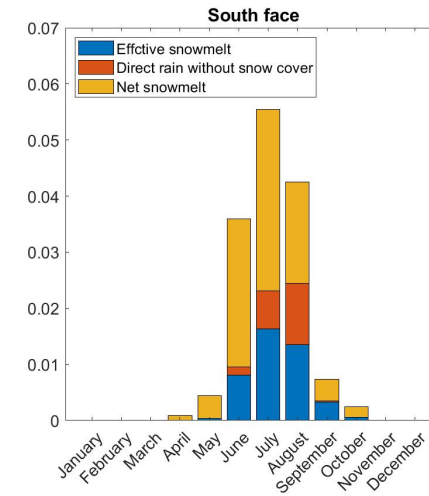
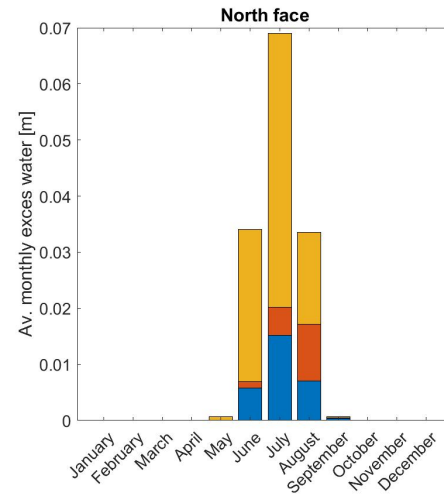


# Results – Water availability during the year

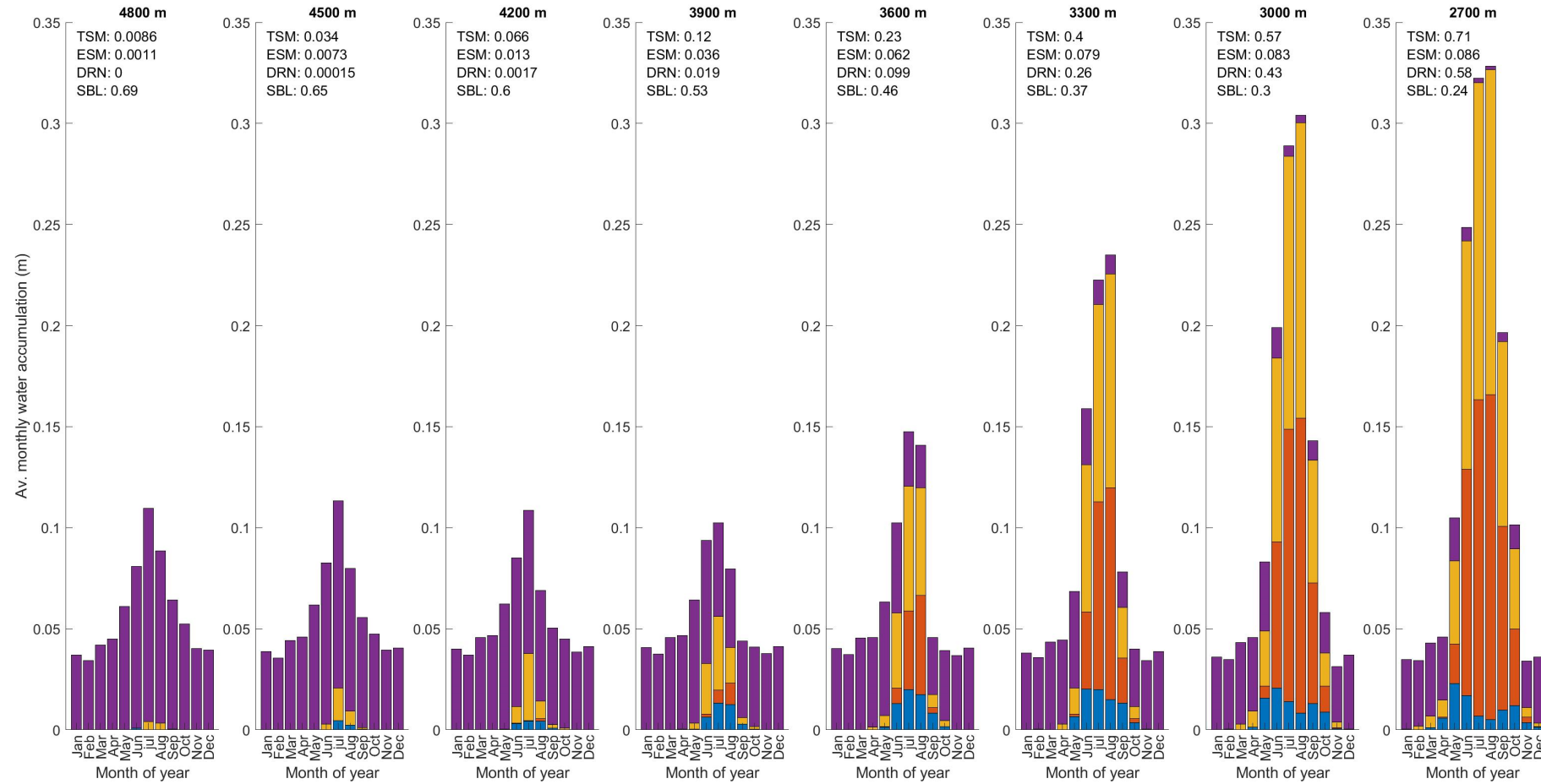




# Model results – North vs. south

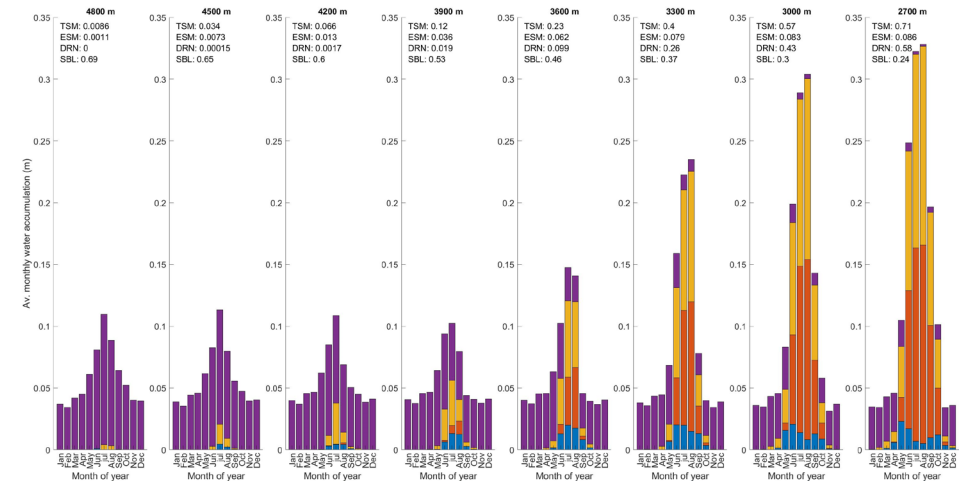
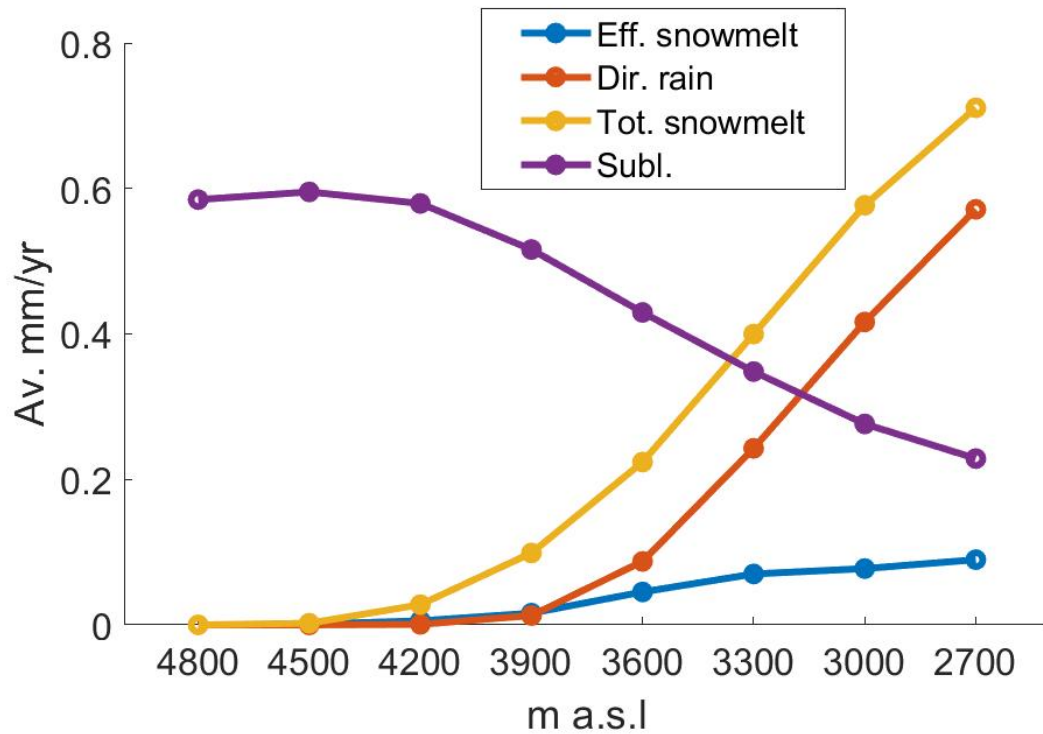


# Model results – Changing elevation

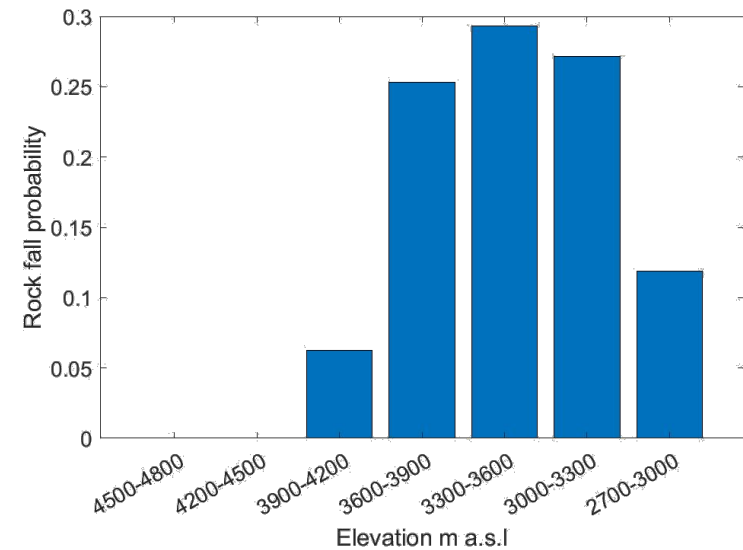




# Results – Changing elevation



Rockfalls in the Mont Blanc massif 2007 – 2015 (Legay et al., 2021)



# Summary

- ❖ Our results provide new information about water balance at the surface of steep alpine rock slopes.
- ❖ The combined application of the S2M-SAFRAN dataset with the CryoGrid model is a powerful tool to study cryogenic and hydrologic processes in high alpine landscapes.
- ❖ Sublimation is systematically the main process of snow mass loss in our study site.
- ❖ Snowmelt occurs between late spring and late summer, and most of it does not reach the rock surface due to a formation of an impermeable ice layer at the base of the snowpack.
- ❖ The annual effective snowmelt that is available for infiltration is highly variable and ranges between 0.05 and 0.28 m in our study site.
- ❖ Effective snowmelt is the main source of water for infiltration at elevation >3600 m a.s.l.
- ❖ Below 3600 m, direct rainfall is becoming more dominant and water availability increases rapidly – making this transition elevation highly sensitive to climate change, as snowmelt-dominated permafrost-affected slopes experience an abrupt increase in water input

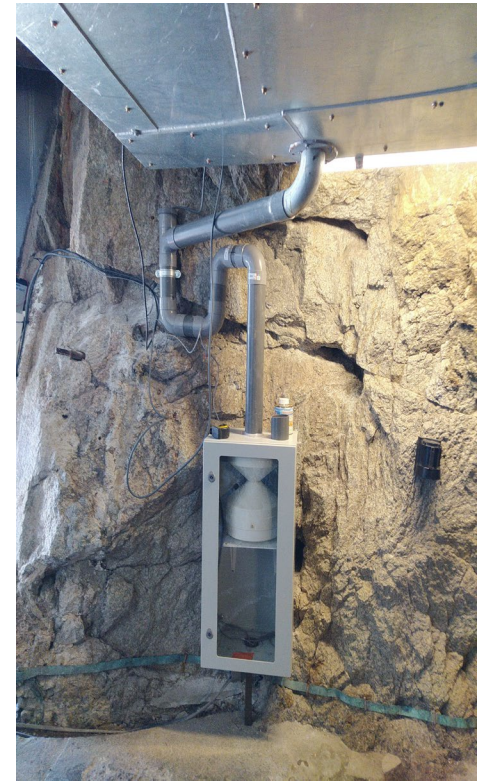


# Field experiment – real-time monitoring of snowmelt using fluorescent dyes



Dye #1

Dye #2

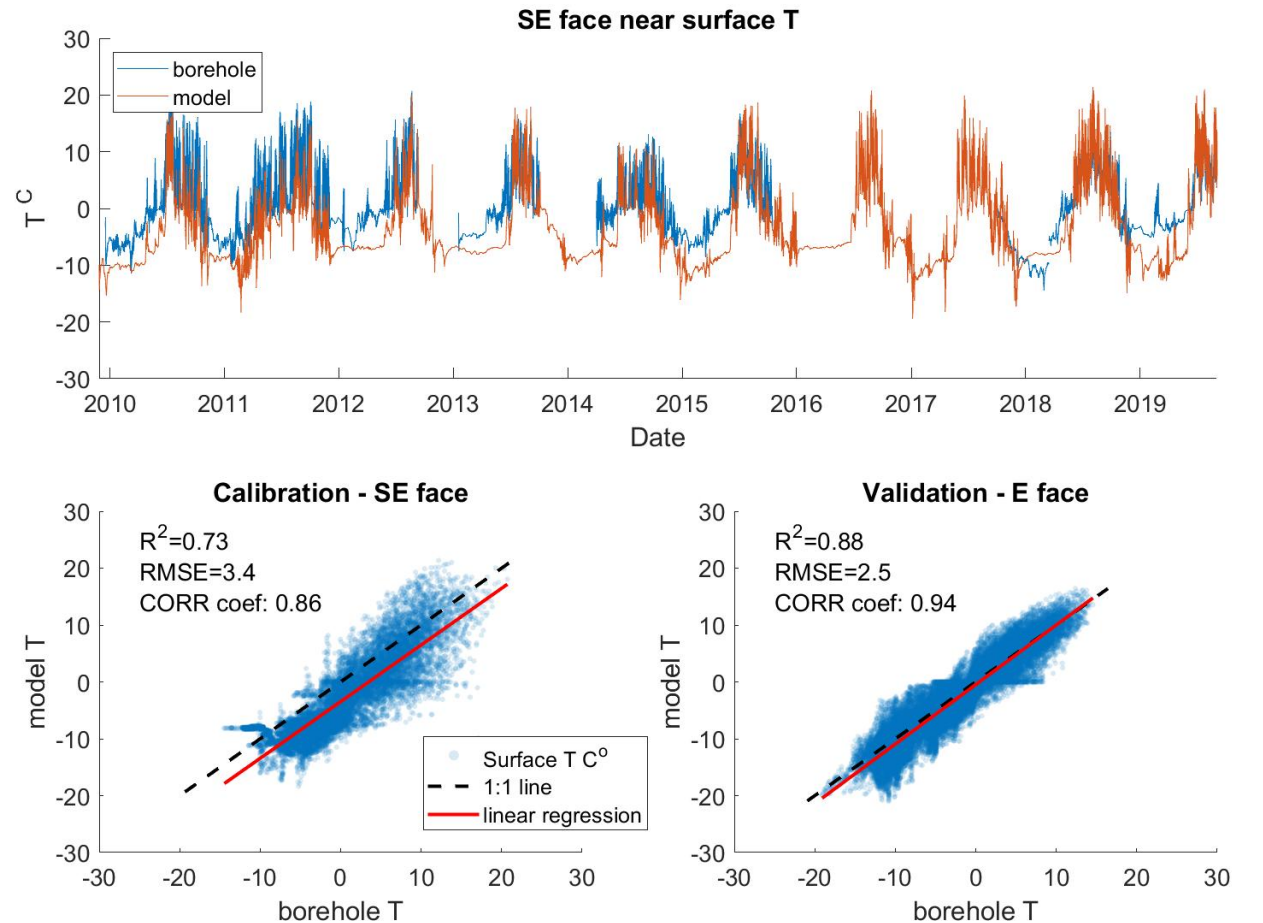


**Figure 3 – Comparison of near surface T data from model and borehole measurements**

A) Comparison of modelled near-surface T (orange) at depth 0.3 m, with borehole measurement from the SE face study site (blue).

B) Correlating modelled near-surface T with borehole measurements on the SE face after calibration of snow fraction factor (0.25) and maximum snow depth (0.8 m).

C) Validating the modelled near surface T at depth 0.14 m, with near-surface T data from a second borehole on the E face of AdM.



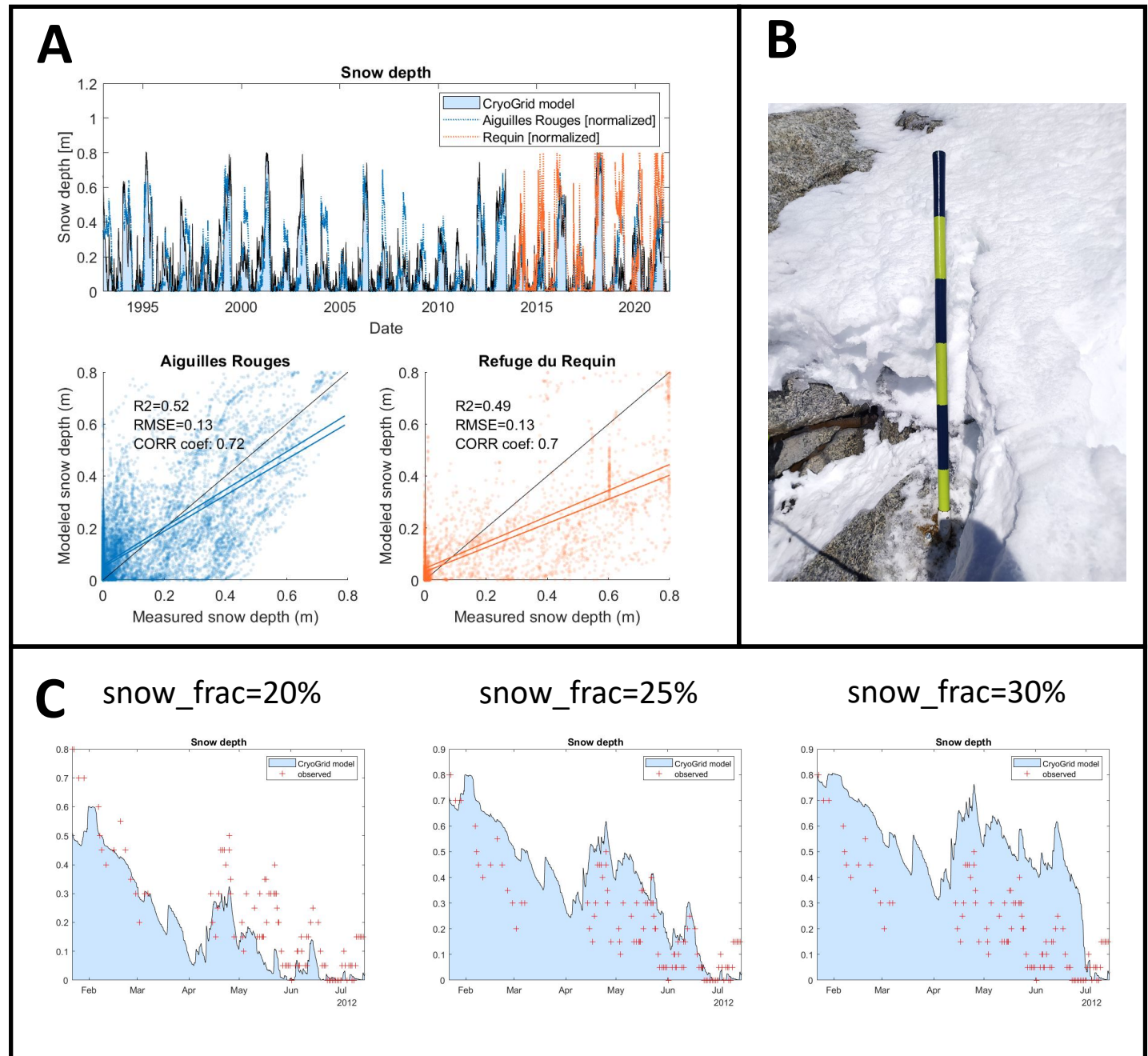


**Figure 4 –Comparison of modelled snow accumulation with field measurements**

A) Comparison of modeled snow depth (black line + light blue area) with snow depth measurement in proximal stations (See Fig. 1 for locations) in the Mont Blanc massif and its area: Aiguilles Rouges (blue) and Refuge du Requin (orange). Measurements were normalized to 0-0.8 m depth range for comparison.

B) Snow depth pole installed on the SE facing rock slope to monitor snow depth time series with a time lapse camera.

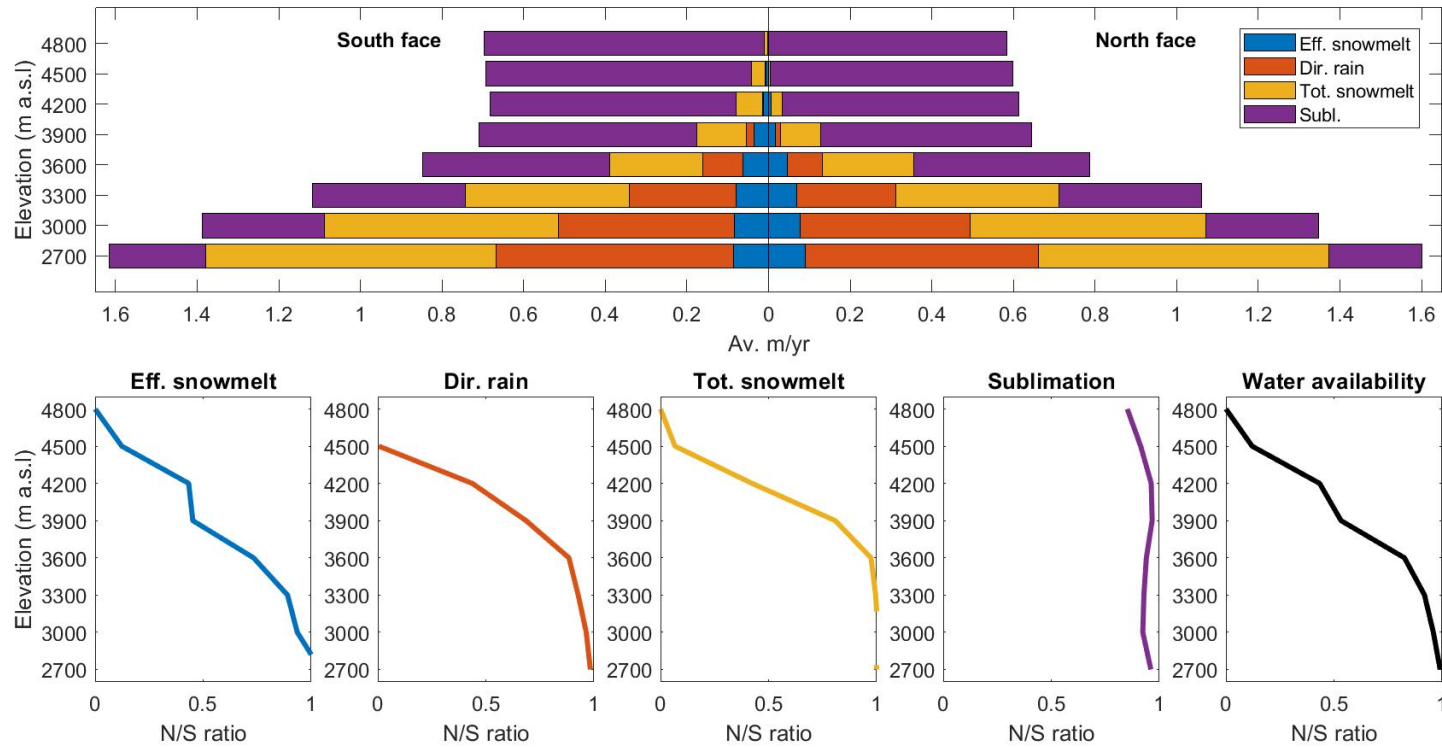
C) Comparing modeled snow depth, under different snow fraction values used in calibration, with measurements made in-situ using snow poles and time lapse camera. Note the optimum results with snow fraction value of 0.25 (25% accumulation).

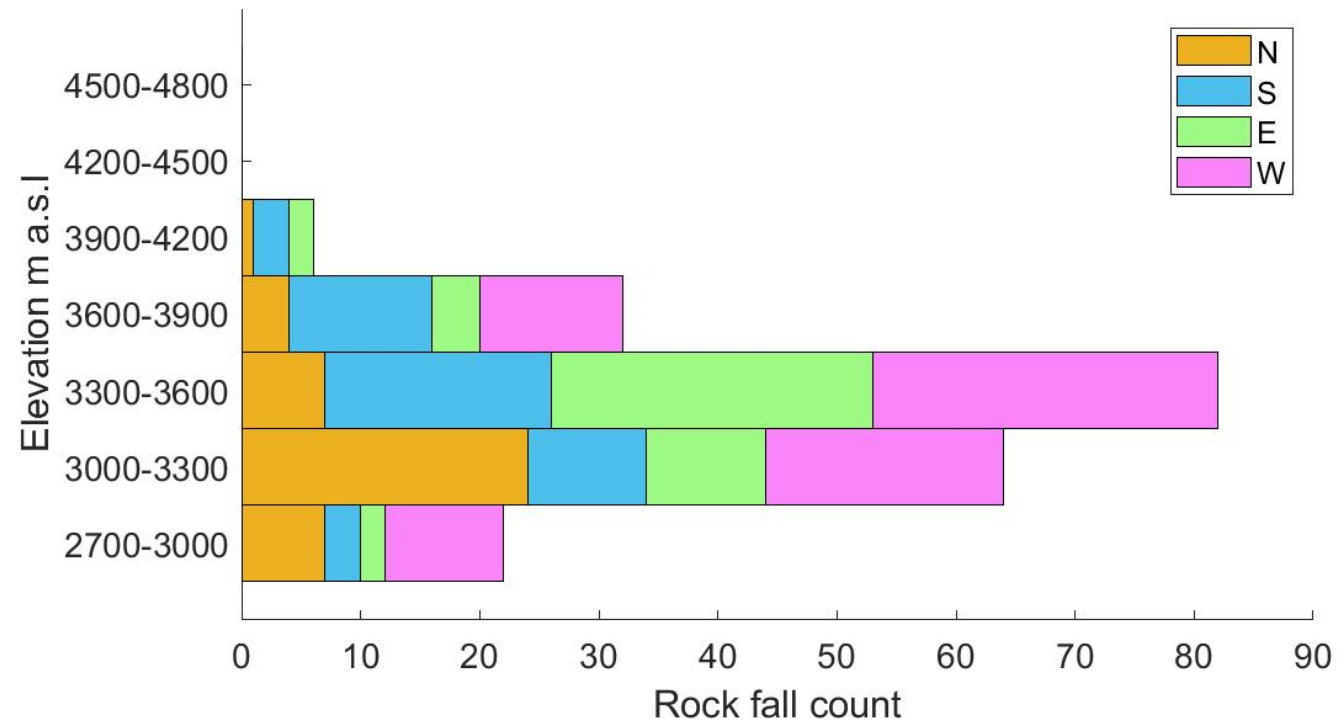


**Figure 9 – North vs. south comparison of average monthly distribution of water fluxes at elevations of 2700 – 4800 m a.s.l.**

Top - Comparison of average annual water fluxes, at elevations of 2700, 3000, 3300, 3600, 3900, 4200, 4500, 4800 m a.s.l. on north (left) and south (right) facing rock slopes.

Bottom – The ratio between north to south of each water of the water fluxes described above, in each of the modelled elevations. A value of 1 represents equal flux on both aspects and values decreasing toward 0 represent larger ratio between S to N face (for example, a value of 0.5 corresponds to  $\times 2$  higher flux on the S face). The bottom right image shows the flux of net water availability at the rock surface, that is available for infiltration (effective snowmelt + direct rain). Note that at elevations  $< 3000$  m a.s.l. fluxes are similar on both aspects and the ratio decreases at higher elevations but the water fluxes magnitudes decrease.







**Figure 11 – Slope distribution and hypsometric curve**

Spatial analysis of a digital elevation model with a resolution 0.2 m cell size and an area of 100 km<sup>2</sup> around the AdM. A) Average slope at elevation bins on 300 m between 1200-4800 m a.s.l. Analysis was made on pixel with slope angle >40° which was shown to be the threshold value for the slope influence on snow accumulation. B) Elevation distribution in the Mont Blanc massif.

