MULTI-FREQUENCY SAR IMAGES FOR INVESTIGATIONS OF THE CRYOSPHERE: PRELIMINARY RESULTS OF CRIOSAR PROJECT

S. Pettinato[1], E. Santi[1], S. Paloscia[1], F. Baroni[1], S. Pilia[1], L. Santurri[1], E. Palchetti[1], F. Bovenga[2], A. Belmonte[2], A. Refice[2], I. Argentiero[2], R. Colombo[3], G. Bramati[3], B. Di Mauro[4], C. Marin[5], G. Cuozzo[5], L. De Gregorio[5], M. Callegari[5], M. S. Heredia[5], V. Premier[5], C. Notarnicola[5], M. Pasian[6], M. Lodigiani[6], L. Silvestri[6], E. Cremonese[7], A. Montuori[8]

[1]IFAC - CNR, [2]IREA - CNR, [3]Univ. Milano Bicocca, [4]ISP – CNR, [5]EURAC Research, [6]Univ. Pavia, [7]ARPA AOSTA, Italian Space Agency - ASI

CRIOSAR
ASI
(Contract n. 2021-12-U.0)

SUMMARY

- Aim of the project
- Test Sites
- Retrieval of SD by SAR
- Retrival of SD by integration of SAR and microwave radiometer
- Retrieval of LWC «model driven» by SAR
- Retrieval of SWE by DinSAR technique
- Comparison of Backscattering and Thermal Inertia
- DInSAR for assessing rock glacier activity
- Displacement maps of rock glacier by Intensity Tracking
- Snowave radar technology
- Conclusions

AIM OF CRIOSAR PROJECT

«Applicazioni SAR multifrequenza alla criosfera», Jul. 2021- Jul. 2023 FUNDED BY ASI

Assess the potential of L-, C- and X-band SAR sensors (SAOCOM, Sentinel-1 and COSMO-SkyMed-1/2, to obtain information on snow parameters, the prevention and assessment of risks and the estimation of water resources

The project objective was achieved by investigating the following issues:

- Deformation of permafrost areas
- Water equivalent of snow (SWE) – Snow Depth (SD)
- Estimation of wet snow and liquid water content (LWC)
- State of frozen / thawed soil

Using:

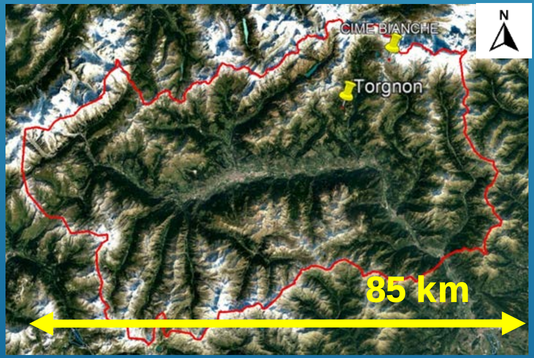
- Magnitude and phase of SAR data at different frequencies
- Interferometric techniques
- Experimental measurements of the extinction coefficient of the SAR signal
- Data from optical sensors

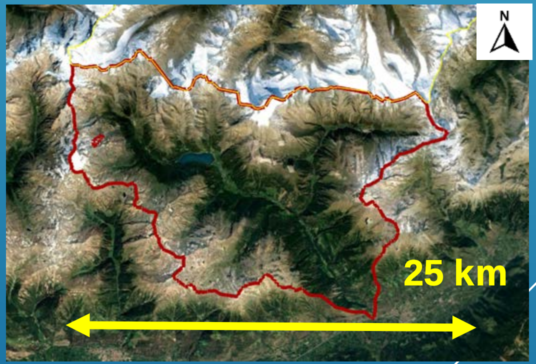
TEST SITES

Valle D'Aosta – Alto Adige

Measured surface parameters:

- Soil moisture
- Snow Depth
- Snow Water Equivalent
- Snow wetness
- Etc…



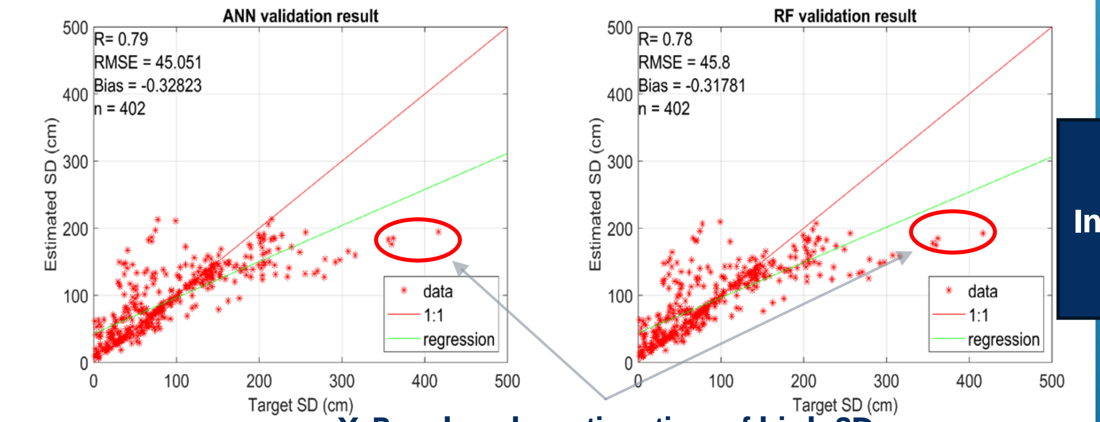


IGARSS
Pasadena, California 2023

SNOW DEPTH RETRIEVAL

- Val D'Aosta test area
- Central part of the winter seasons 2018 - 2022
- CSK + Sentinel-1 – validation over weather station data (36 stations)
- Training/testing strategy (10% training/90% test)
- CSK + Sentinel-1
- ANN – RF comparable accuracy and computational cost
- Multifrequency approach tested over a couple of CSK+S-1 in 2018 (largest SD)

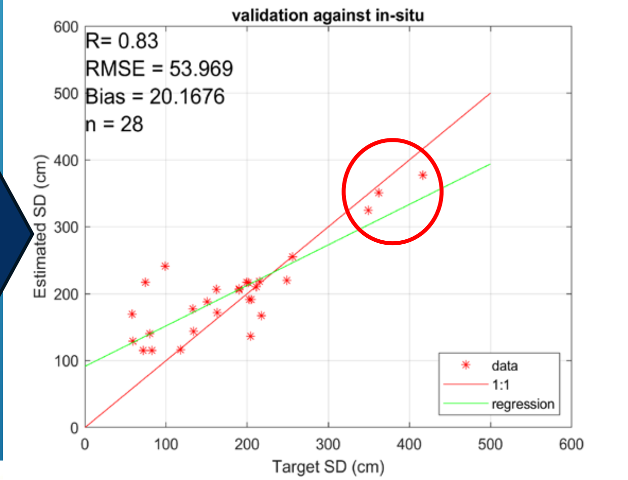
CSK



X-Band underestimation of high SD

Integration (X + C)

CSK+S1



«CONVENTIONAL» RETRIEVAL USING CSK

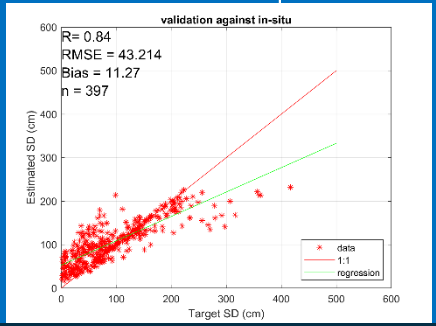
- SD retrieved directly from CSK and auxiliary data
- ANN and RF algorithms

CSK + Auxiliary (LIA, LCC)

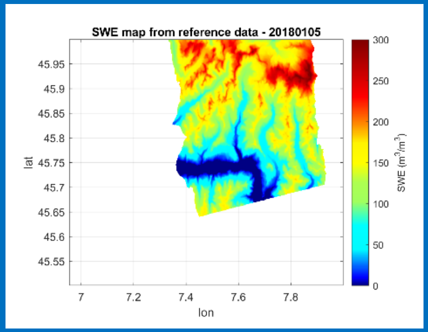
ANN and RF Training/Test

Reference SD

Validation report



SNOW MAPS

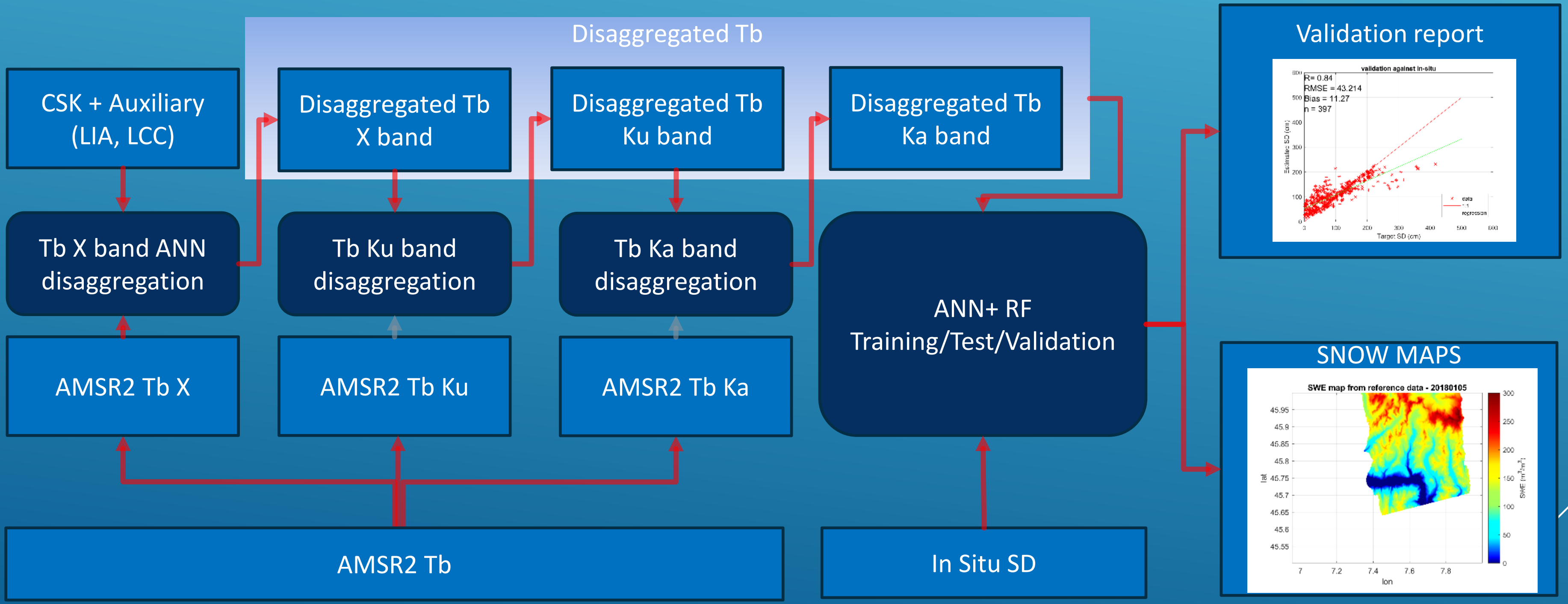


IGARSS Pasadena, California 2023

SD RETRIEVAL BY ACTIVE/PASSIVE MICROWAVE

AMSR2 disaggregation + training/test/validation:

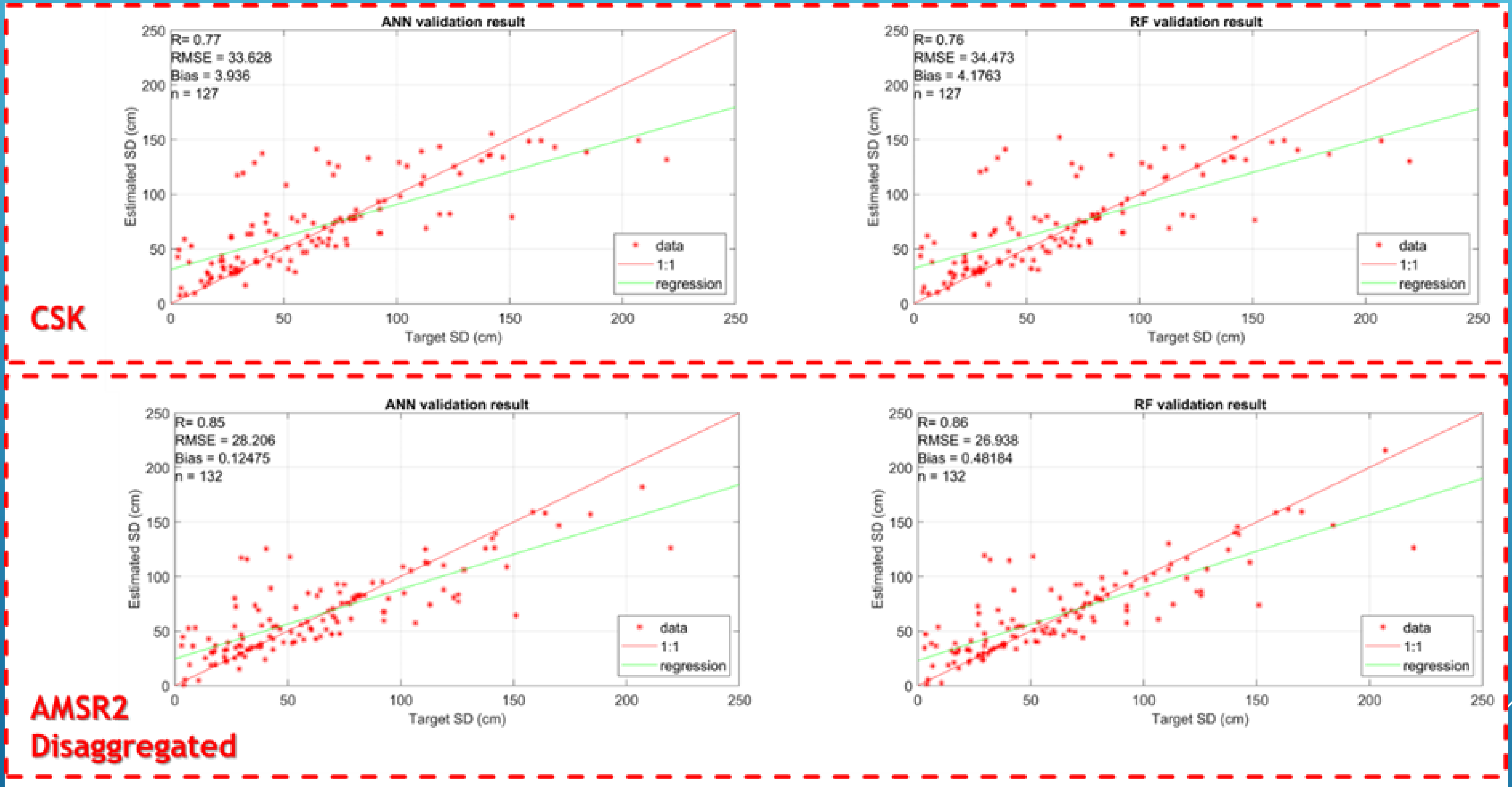
- Co-registering CSK and AMSR-2
- Disaggregating Tb X using CSK and ANN
- Disaggregating Tb Ku using disaggregated TbX and ANN
- Disaggregating Tb Ka using disaggregated TbKu and ANN
- ANN + RF training/test/validation using disaggregated Tb



IGARSS
Pasadena, California 2023

SD RETRIEVAL BY ACTIVE AND PASSIVE MICROWAVE DATA INTEGRATION

1) Use of CSK data to disaggregate the AMSR-2 Tb up the SAR resolution
2) Estimate SD by using the disaggregated Tb



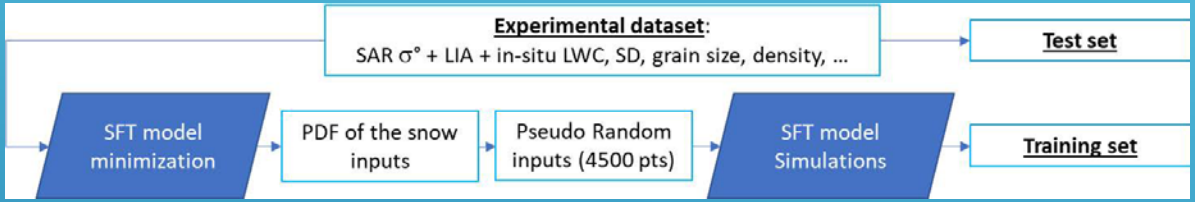
IGARSS
Pasadena, California 2023

LWC – «MODEL DRIVEN»

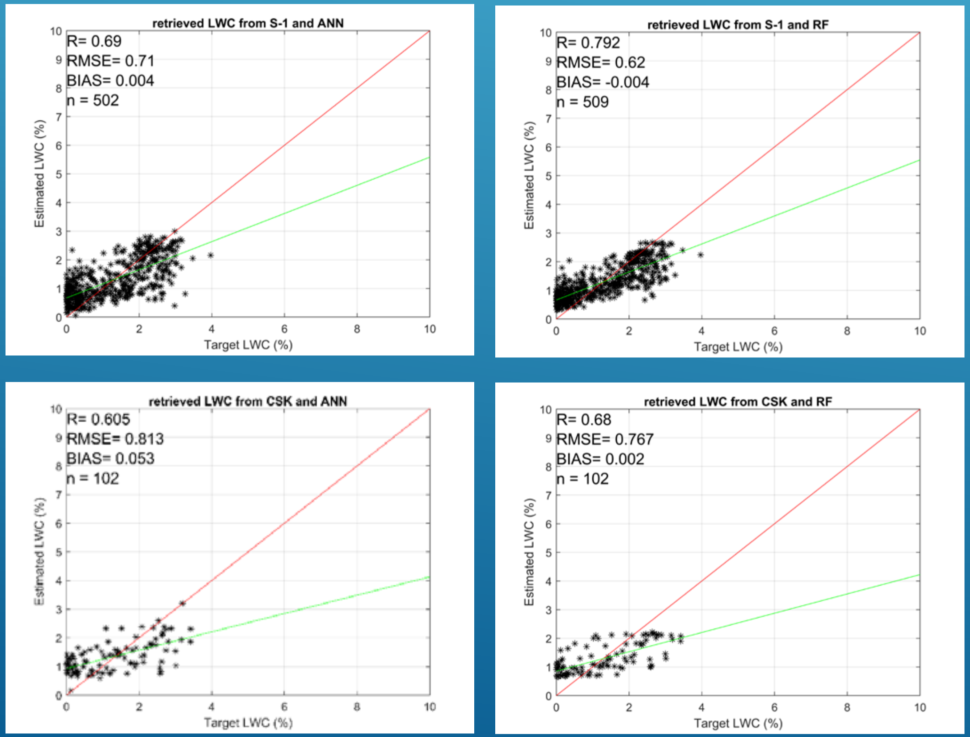
Inputs: S1 and CSK (2017 to 2023)
Training: ANN + **RF** on SFT
Test: Torgnon and Cime Bianche

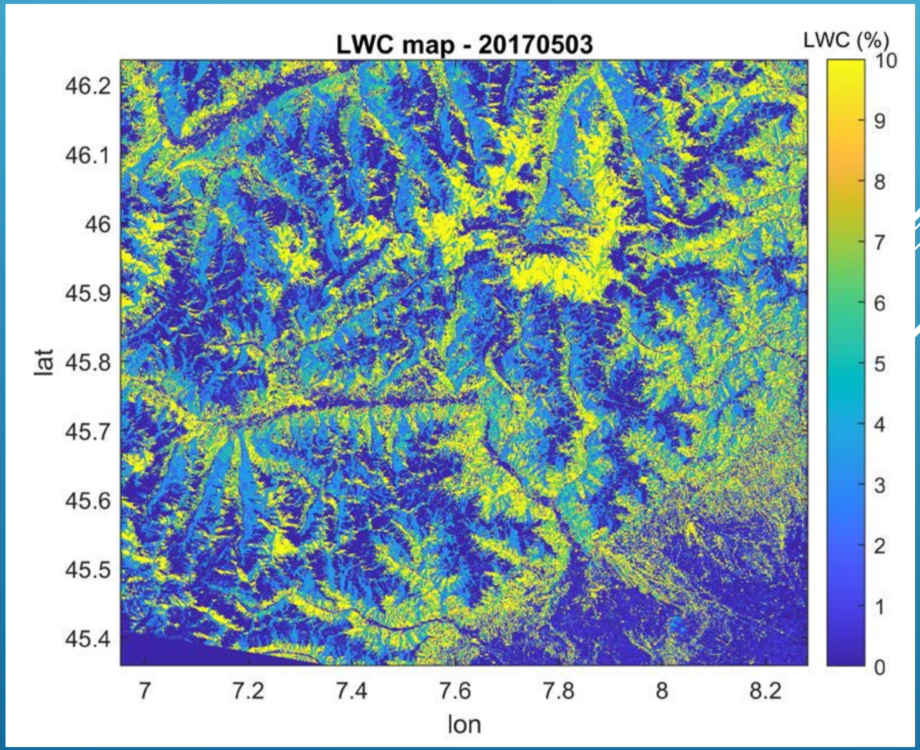
Results:

- S1 better than CSK (but dataset is different)
- RF better than ANN

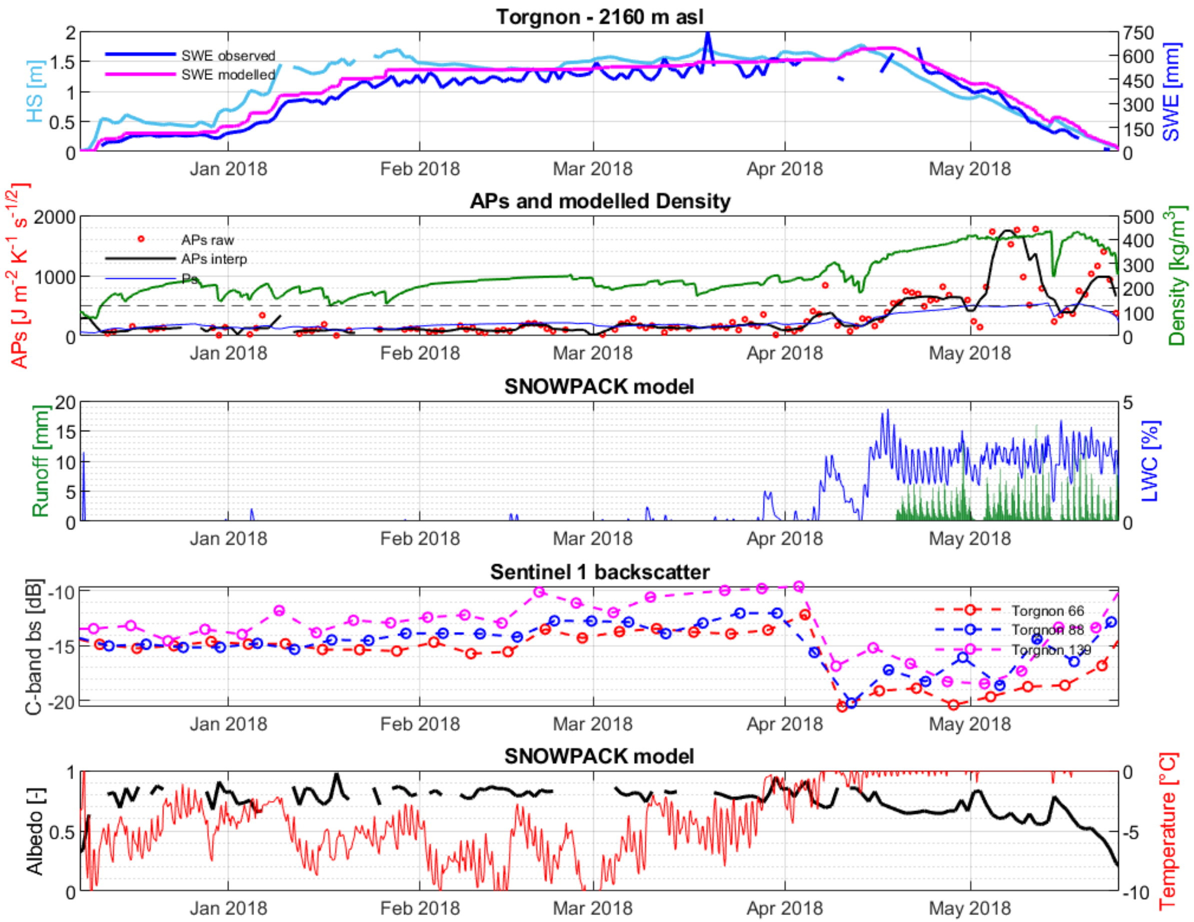


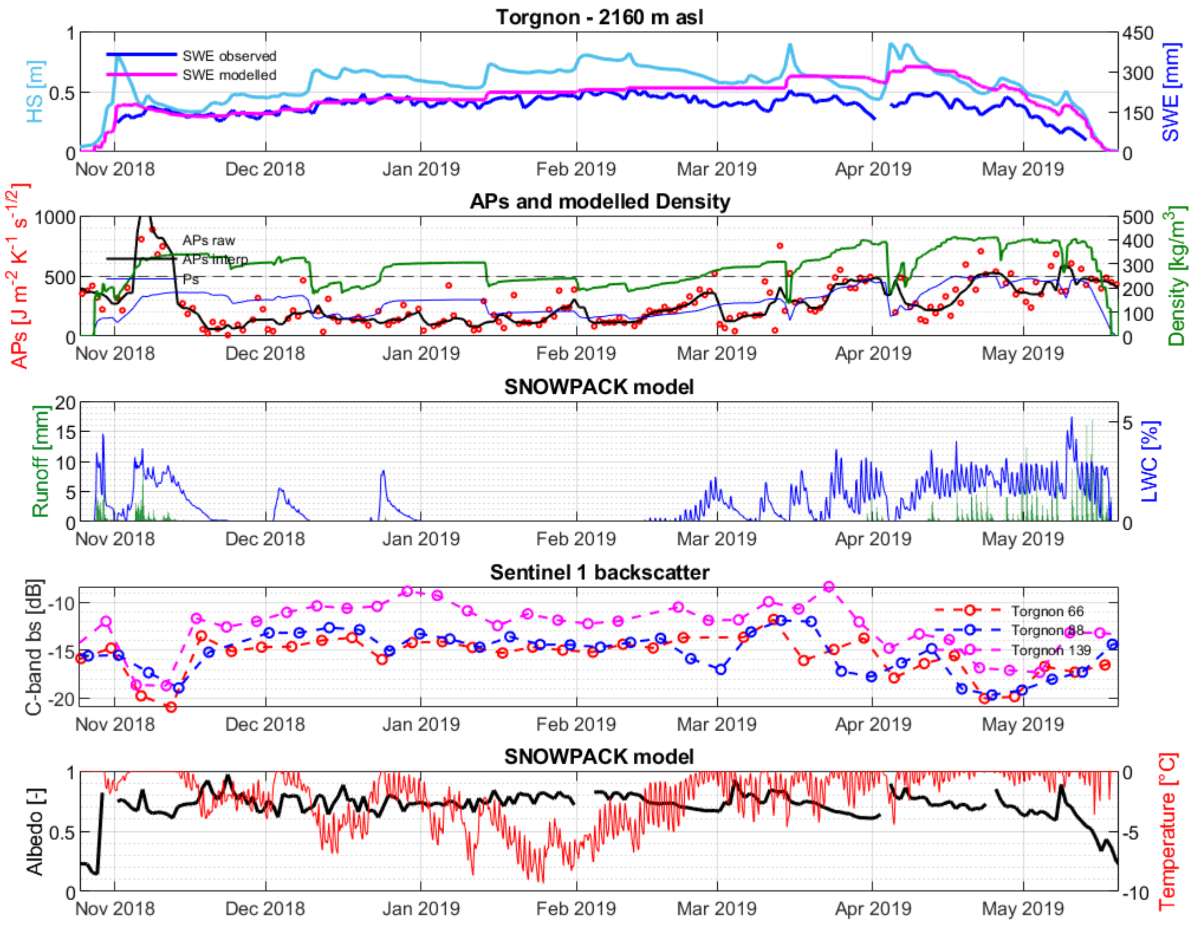
R	ANN	RF
S1	0.71	0.79
CSK	0.80	0.88





Time series of thermal inertia and backscatter at the Torgnon experimental site





Seasonal time series of variables computed at the AWS, simulated with SnowPack model and from satellite for two hydrologic years in the Torgnon site

DInSAR-based SWE estimation

- **SWE estimation**: C and L bands are the more promising to overcome some of the factors limiting the SWE estimation, especially in mountainous areas, (such phase decorrelation, phase aliasing, and the presence of artifacts coming from orbital and topographic errors, unreliable phase unwrapping, and residual atmospheric signals.
- **Processing strategy** for deriving differential SWE (ΔSWE): **generation of interferometric** pairs with the smallest temporal baselines to minimize temporal decorrelation effects. Each pair is processed to remove atmospheric phase by leveraging GACOS products, and to generate reliability masks ($Mask$) and expected error ($\epsilon_{\Delta \mathrm{SWE}}$).
- Figure 2 shows both differential SWE and coherence maps from Sentinel-1

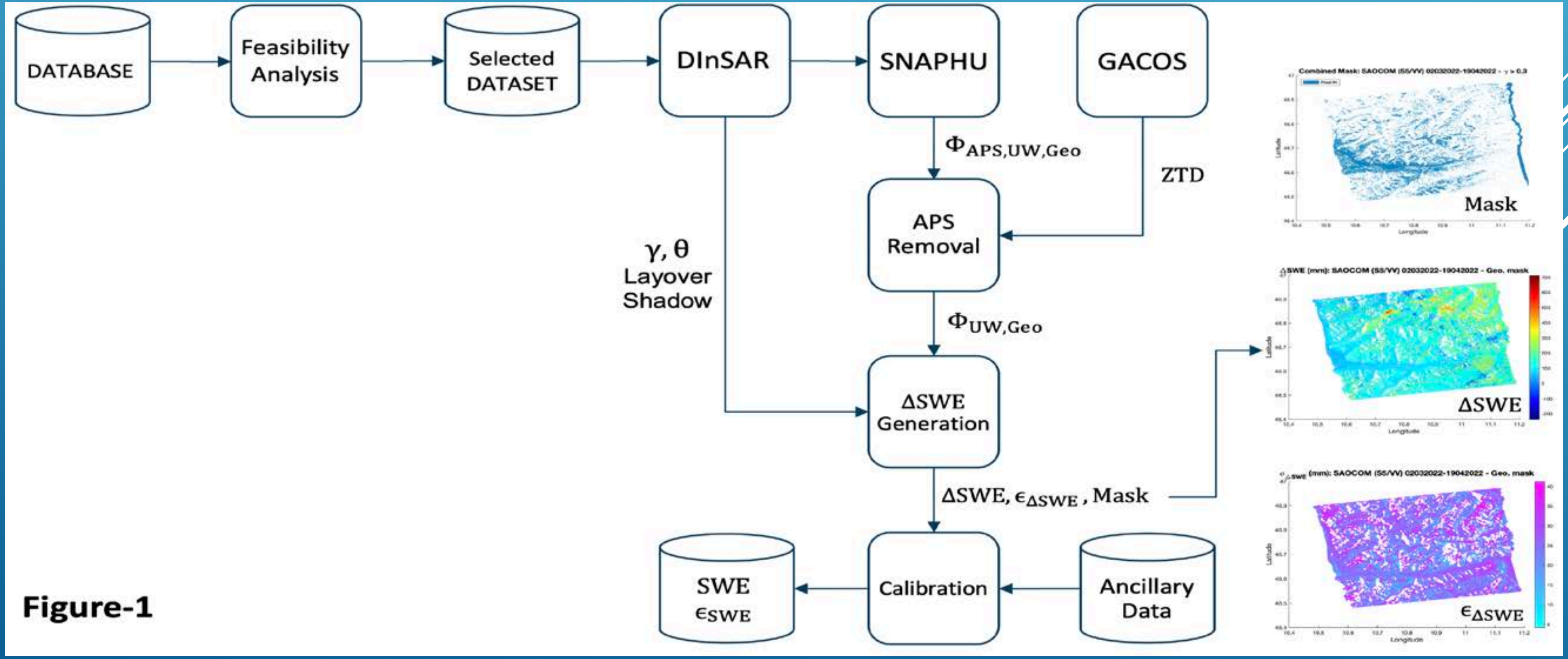


Figure-1

Val senales Test Site

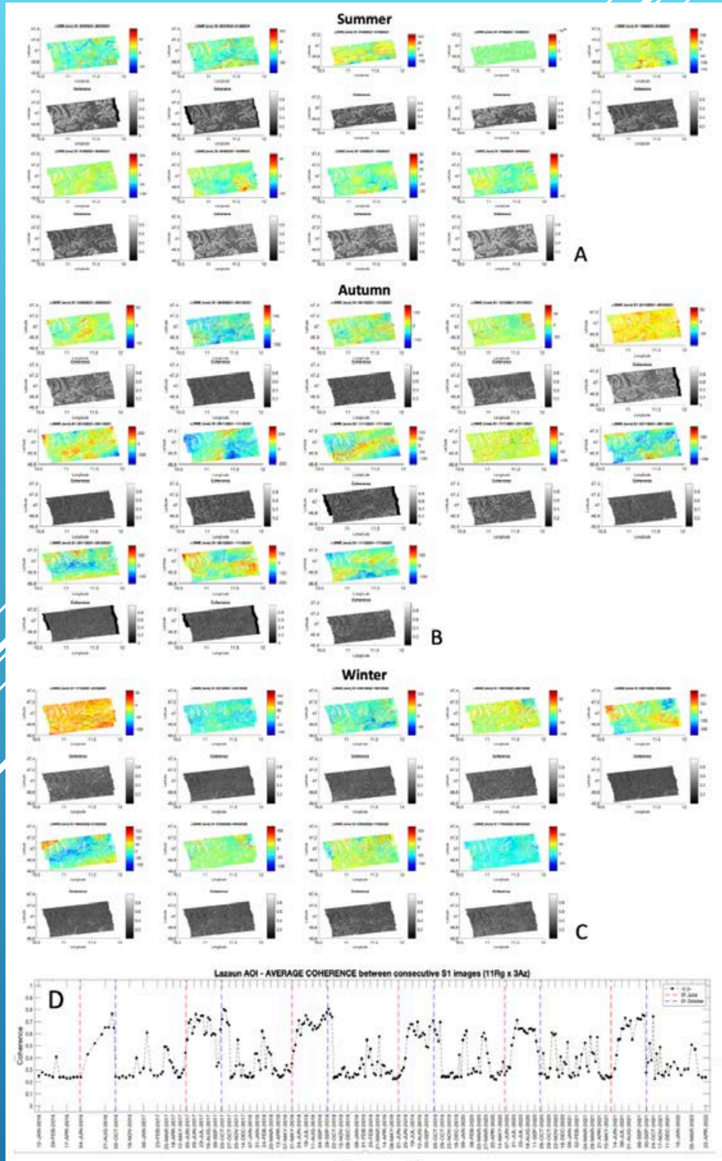


Figure-2

Average coherence time series are higher in summer and autumn

DInSAR for assessing rock glacier activity in Val Senales

- MTInSAR processing has been refined in order to overcome both **signal decorrelation** due to changeable snow cover conditions, and **aliasing due to very high displacement rates**. The resulting mean LOS displacement rate from Sentinel-1 data (Figure-1 B) has a **spatial density of coherent targets** much higher than that of the map from standard processing (Figure-1 A), showing large number of targets basically stable and several areas affected by ground displacements. Moreover, the spatial distribution of the displacement rates shows several areas affected by ground displacements, which lay on exactly within the borders of rock glaciers derived from an independent inventory map.
- By leveraging this interesting MTInSAR result, a classification of rock glacier activity has been developed (Figure 2) and validated. The proposed procedure combines **MTInSAR products with DInSAR phase and coherence from consecutive pairs**, mean SAR amplitude, deformation features derived from historical optical orthoimages, probability of the presence of permafrost, and presence of vegetation from NDVI.
- The new rock glacier classification (Figure-3 B) has been compared to that derived according to (Bollmann et al. 2012) (Figure-3 A) showing several differences. For instance, 3 out of the 6 rock glaciers classified as undefined were reclassified as relict or translational, 6 out of the 11 rock glaciers classified as relict were reclassified as transitional, and conversely, one rock glacier classified as active was reclassified as relict.

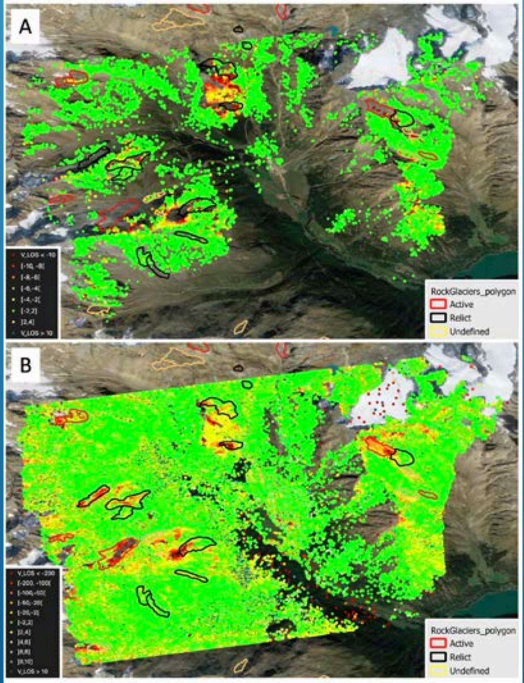


Figure-1

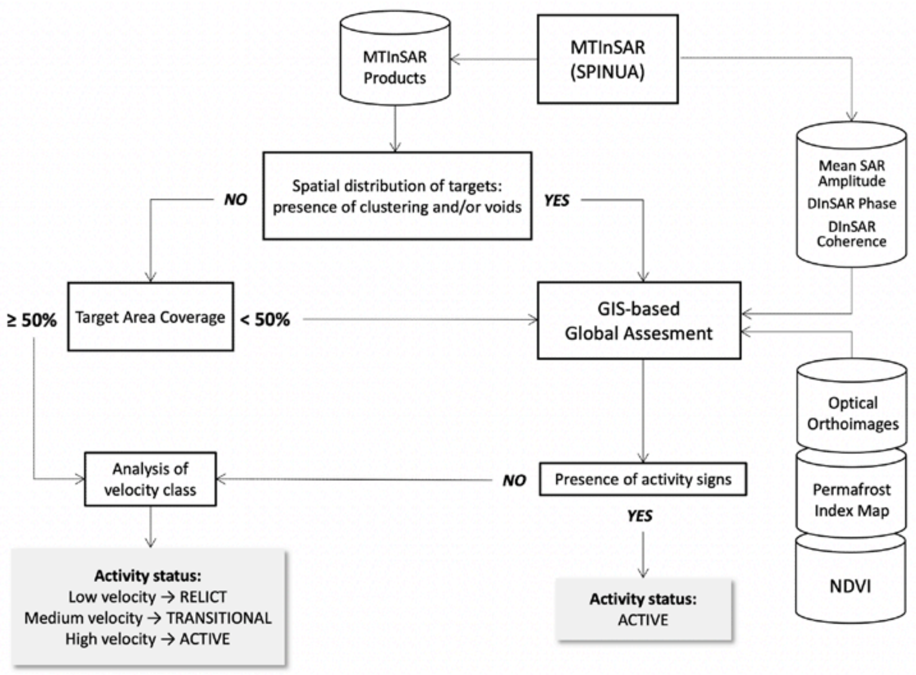


Figure-2

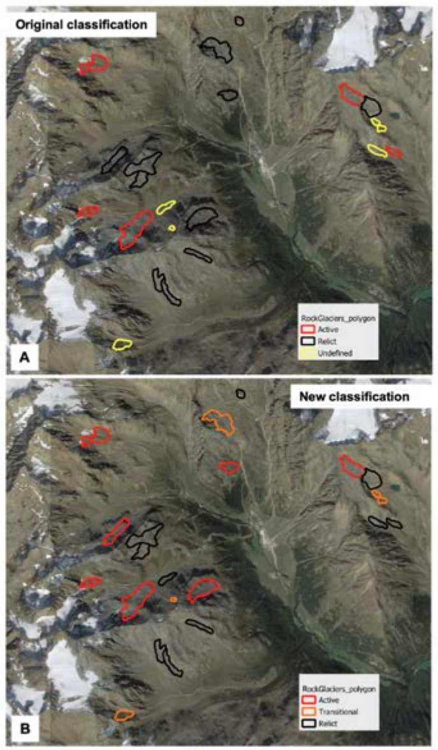
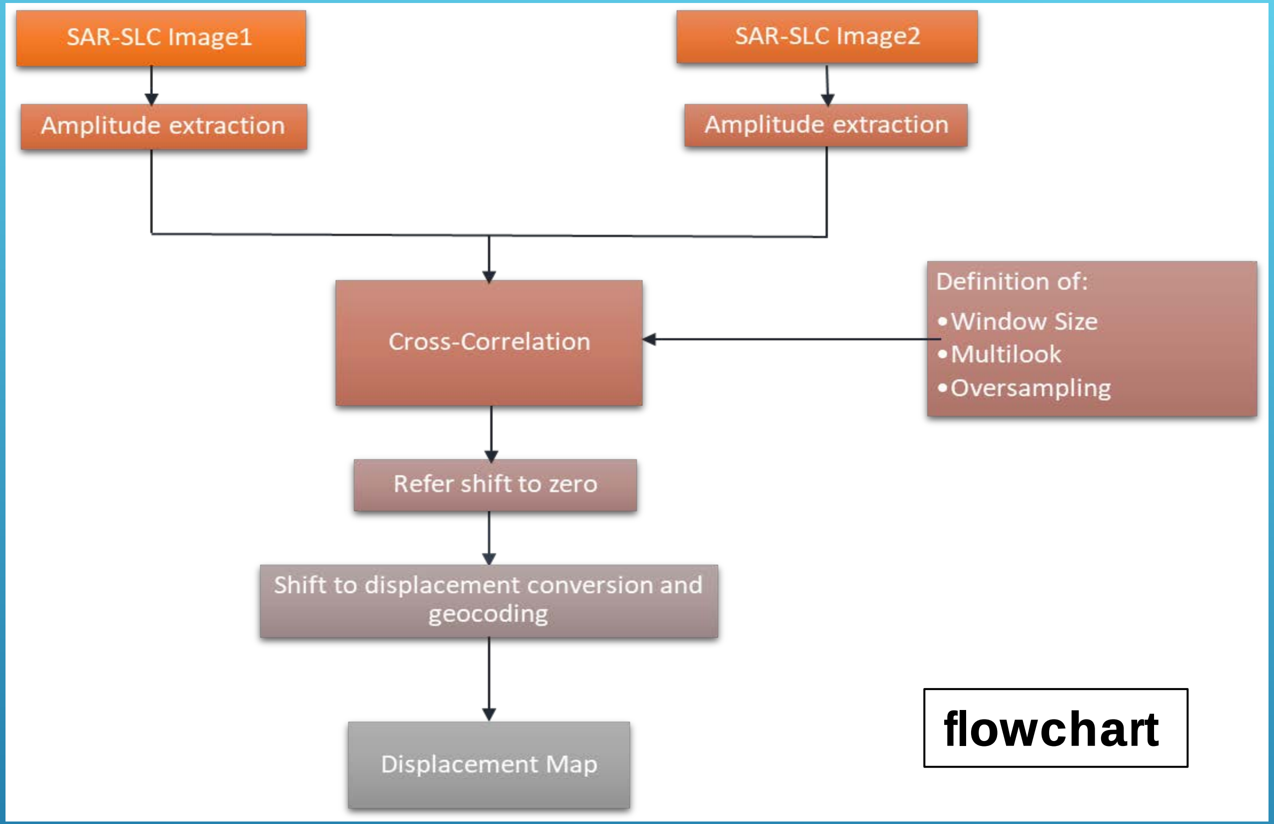


Figure-3

Lazaun rock glacier: offset tracking



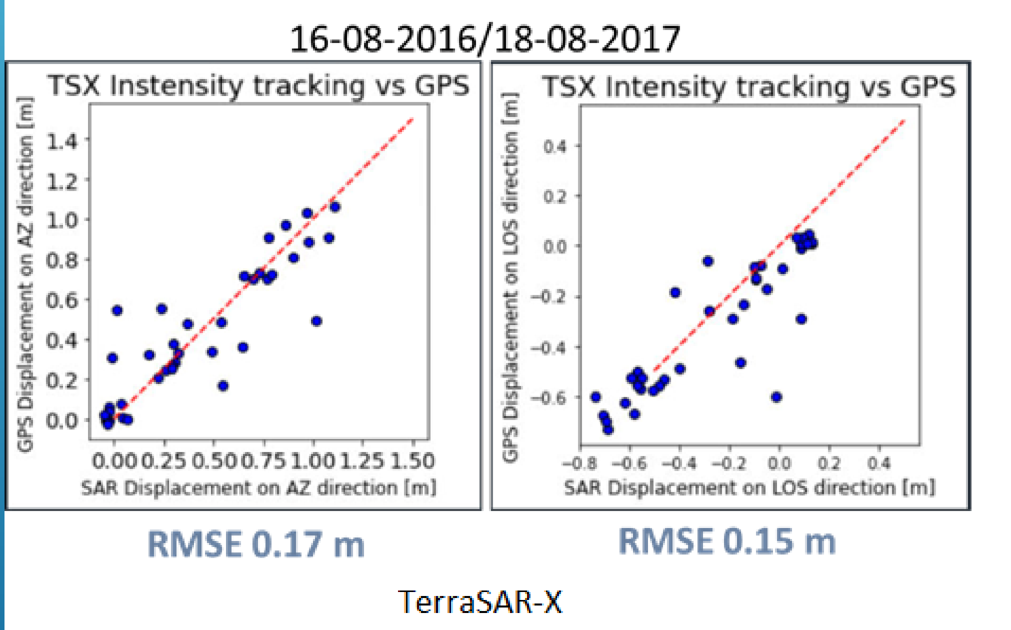
Active rock glacier:

Val Senales – South Tyrol - Italy

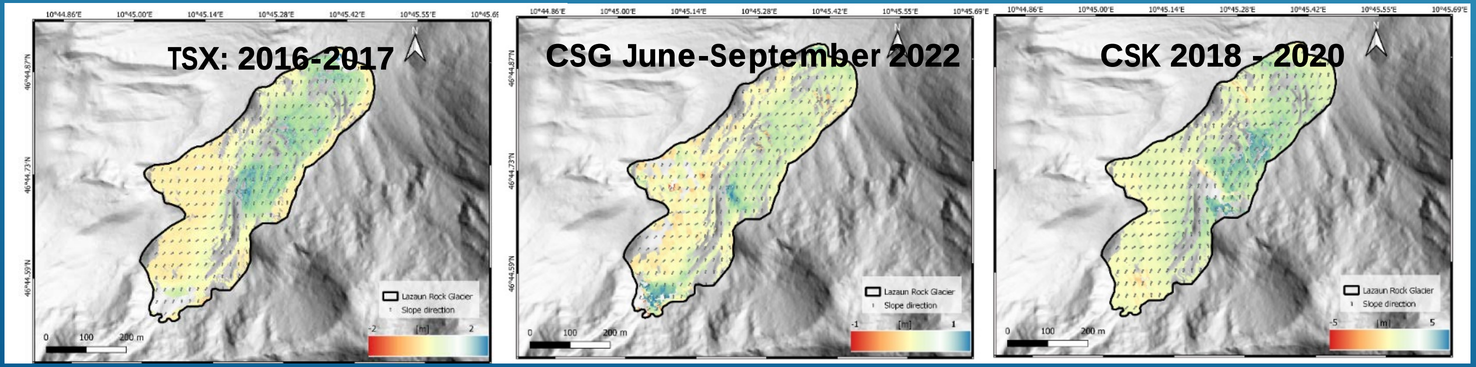
Area: 0.12 km²

Altitude: 2480 - 2700 m a.s.l.

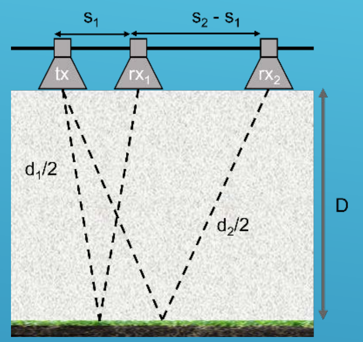
Steep, 35° - 45°



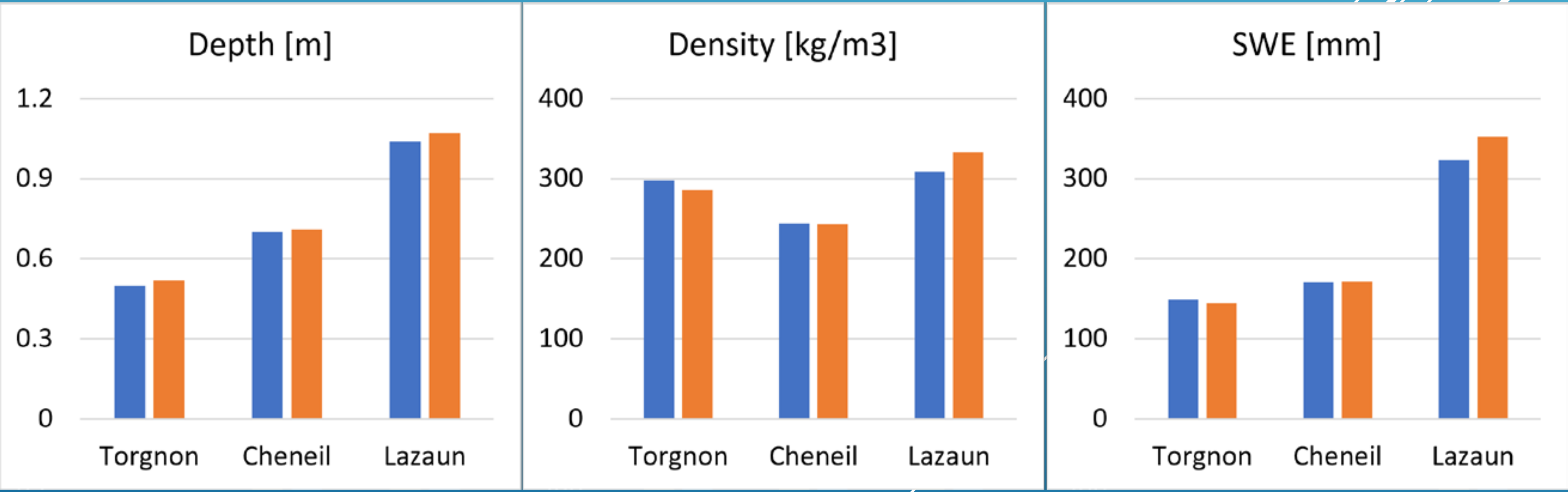
Displacement maps in the slope direction



SNOWAVE RADAR TECHNOLOGY



- S-band: 2 – 3 GHz
- C-band: 5.5 – 8 GHz
- X-band: 8 – 12 GHz



CONCLUSIONS

- All the implementations demonstrated that the retrieval of snow and soil parameters from EO data is feasible with encouraging results.
- Advanced techniques (e.g. ML) used to address the complex mechanisms that rule the physical behavior of snow and soil surface demonstrated to be able to retrieve surface parameters.
- Multi-frequency and multi-sensor integration is in general effective for improving the retrievals
- The availability of reference data to calibrate and validate the algorithms remains one of the main issues to deal with.
- the need of spatially and temporally co-located acquisitions is important for snow parameters that change during the day, so a novel SAR mission carrying onboard at least two frequencies (as in the CoreH2O and RISK mission concepts) could be really effective for snow applications.

THANK YOU FOR YOUR ATTENTION

This work is funded by Italian Space Agency (Contract n. 2021-12-U.0)

The Local Organizing Committee of the MicroRad 2024 Specialist Meeting enthusiastically invites you to the Washington, DC metropolitan area in Alexandria, Virginia! MicroRad provides a unique, intimate gathering of international scientists and engineers to share and highlight cutting-edge research and development in the field of microwave radiometry and applications.

SUGGESTED TOPICS - ABSTRACT SUBMISSION DEADLINE: OCTOBER 2, 2023

- Theory, physical principles, and electromagnetic models
- Soil moisture, soil state, and vegetation
- Snow, ice, and oceans
- Clouds and precipitation
- Temperature and humidity sounding
- Climate and global change
- Advanced radiometer techniques
- Sensor calibration
- Combined active/passive instruments
- Current and future satellite missions
- Small satellite instruments and missions
- Experimental campaigns
- RFI and spectrum management
- Submillimeter-wave technology
- Hyperspectral microwave systems
- Signals of opportunity (e.g. GNSS-R)

MicroRad 2024
April 8-11, 2024
in Alexandria (VA)

LOCAL ORGANIZING COMMITTEE:

- Ian Adams (General Chair), NASA Goddard Space Flight Center, USA
- Rachael Kroodsma (Technical Chair), University of Maryland-ESSIC/NASA GSFC, USA
- Mohamed Abdin, NASA Goddard Space Flight Center, USA
- Rajat Bindlish, NASA Goddard Space Flight Center, USA
- Justin Bobak, Naval Research Laboratory, USA
- Paolo de Matthaeis, NASA Goddard Space Flight Center, USA
- Christopher Grassotti, University of Maryland-ESSIC/NOAA, USA
- Benjamin Johnson, UCAR/JCSDA/NOAA, USA
- Roger H. Lang, George Washington University, USA
- David M. Le Vine, NASA Goddard Space Flight Center, USA
- Quanhua (Mark) Liu, NOAA, USA
- Lisa Milani, University of Maryland-ESSIC/NASA GSFC, USA
- S. Joseph Munchak, tomorrow.io, USA
- Sarah Ringerud, NASA Goddard Space Flight Center, USA
- Elizabeth Twarog, Naval Research Laboratory, USA

STEERING COMMITTEE:

- Marco Brogioni, CNR-IFAC, Florence, Italy
- Shannon Brown, Jet Propulsion Laboratory/CalTech, USA
- Dara Entekhabi, Massachusetts Institute of Technology, USA
- Paolo Ferrazzoli, Tor Vergata University of Rome, Italy
- Leila Guerriero, Tor Vergata University of Rome, Italy
- Martti Hallikainen, Aalto University, Finland
- David Kunkee, The Aerospace Corporation, USA
- Roger H. Lang, The George Washington University, USA
- David M. Le Vine, NASA Goddard Space Flight Center, USA
- Giovanni Macelloni, CNR-IFAC, Florence, Italy
- Simonetta Paloscia, CNR-IFAC, Florence, Italy
- Paolo Pampaloni, CNR-IFAC, Florence, Italy
- Nazzareno Pierdicca, University of Rome La Sapienza, Italy
- Jaan Praks, Aalto University, Finland
- Steven C. Reising, Colorado State University, USA
- Emanuele Santi, CNR-IFAC, Florence, Italy
- Domenico Solimini, Tor Vergata University of Rome, Italy
- Ed R. Westwater, University of Colorado, USA

2024.microrad.org