Differential SAR interferometry for estimating snow water equivalent in central Apennines complex orography from Sentinel-1 satellite within SMIVIA project

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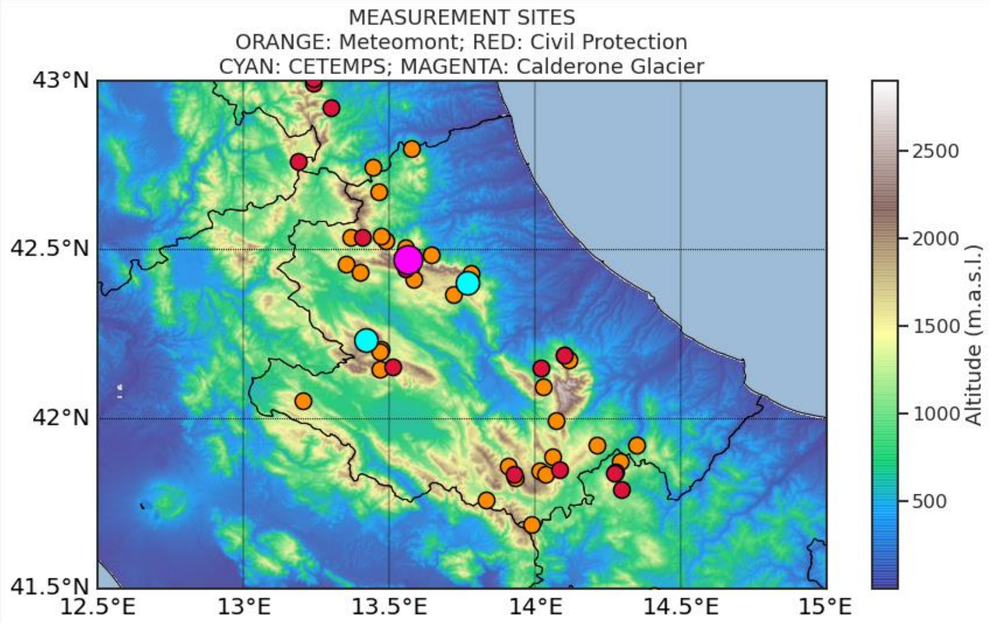
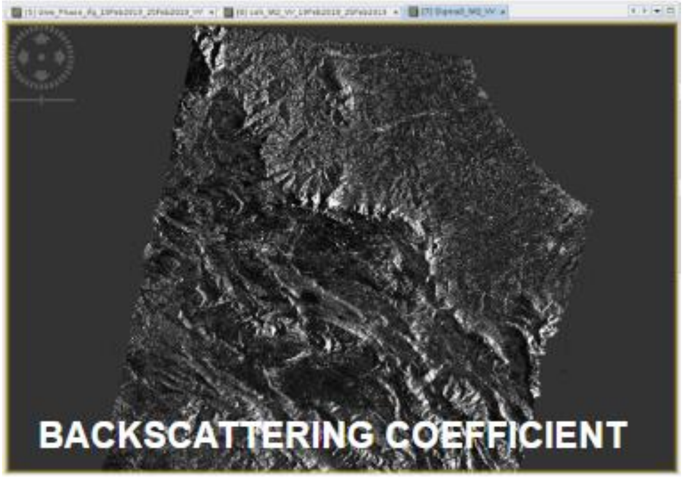
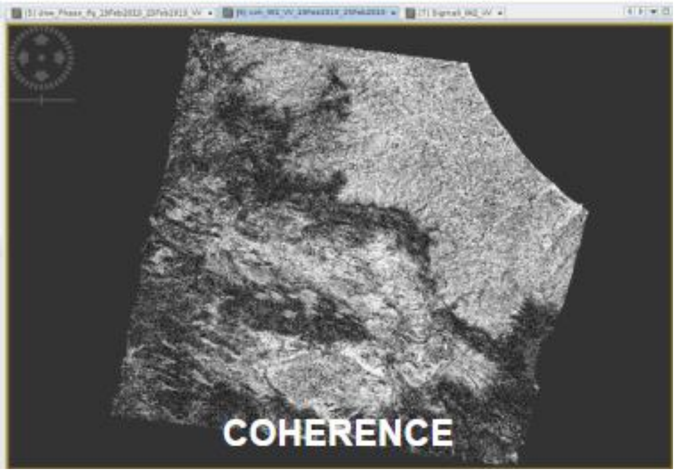
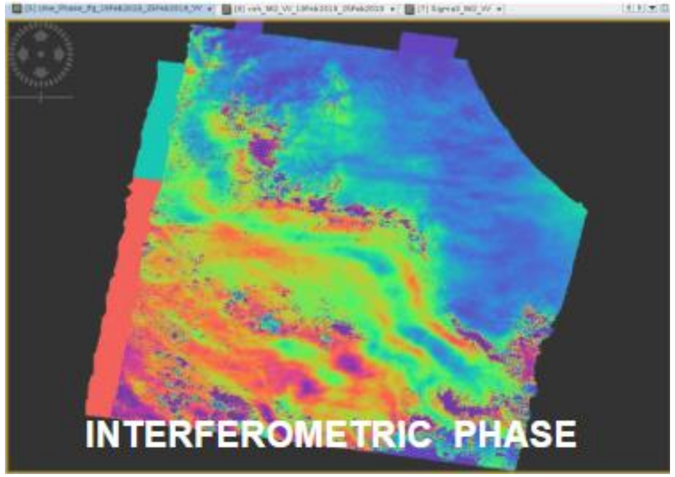
Objectives of the study:

- Retrieve snow properties in the Italian Central Apennine with Differential Interferometric spaceborn SAR data, using some auxiliary data.
- Estimate snow cover extension and classify snow (dry snow, wet snow).
- Estimate snow depth.
- Validate estimates with in-situ data obtained with measurement campaigns.
- Provide useful information in terms of avalanche warning, monitoring of climate change evolution, flood forecasting and water volumes expected for the hydric supply.









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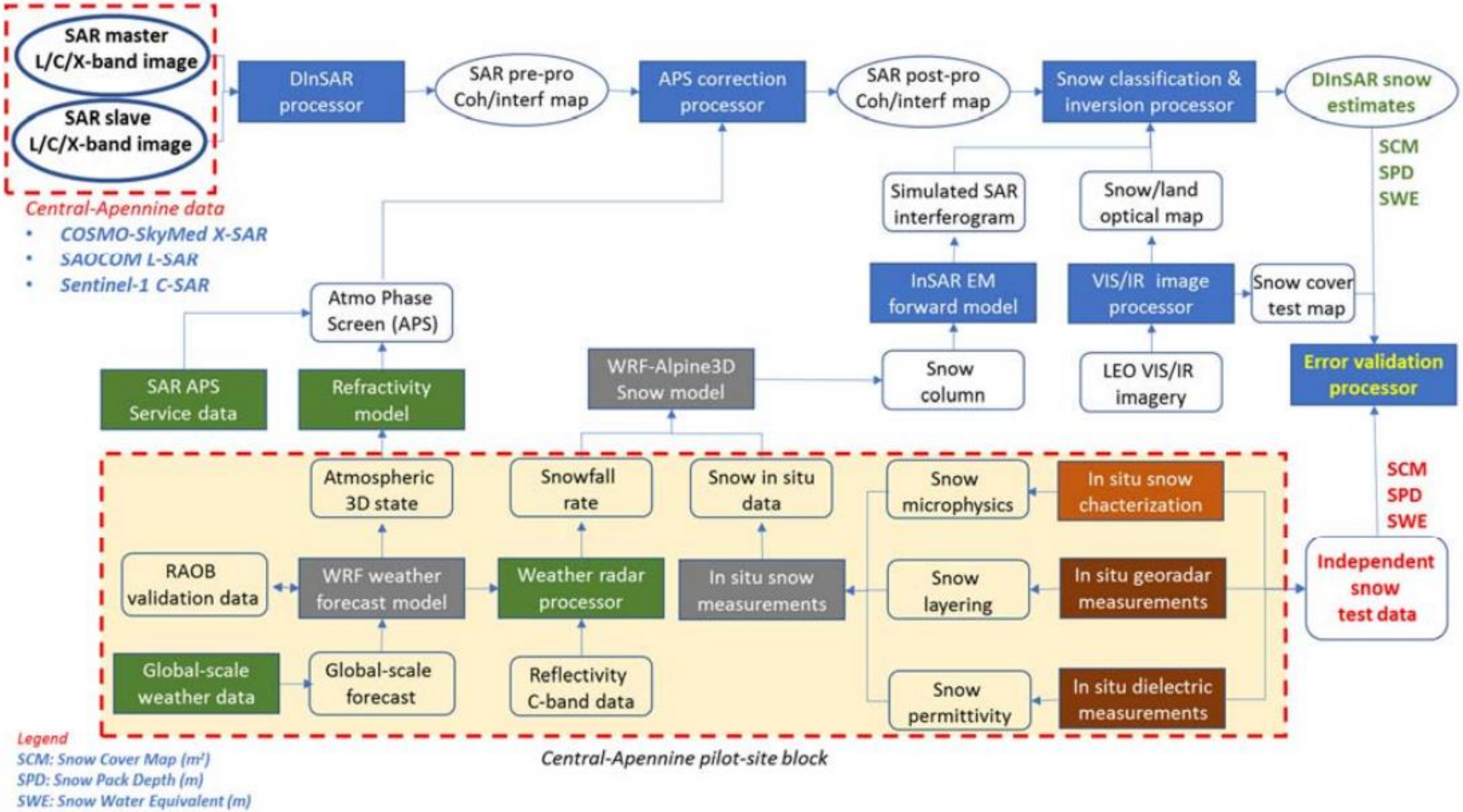
THE SMIVIA INTEGRATED APPROACH



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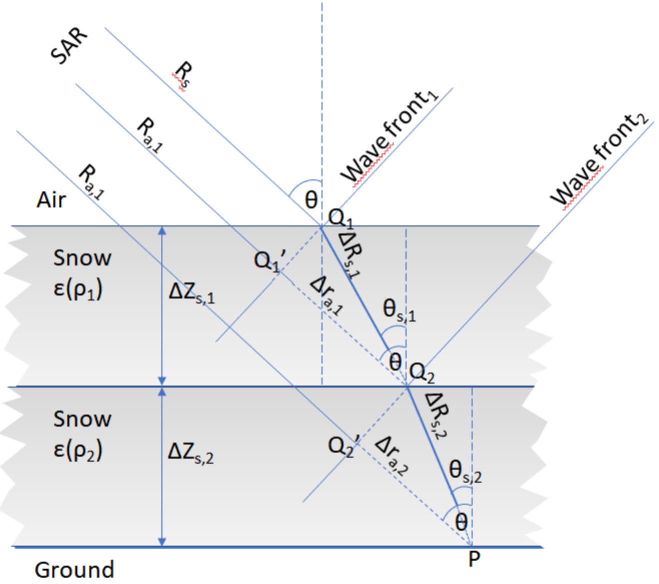
DInSAR snow retrieval method

The signal delay caused by snow refraction can be measured **<u>if snow permittivity is known</u>**.
Therefore snow depth variation between two dates can be estimated by calculating the SAR signal phase difference between two satellite passes.



Snow Permittivity

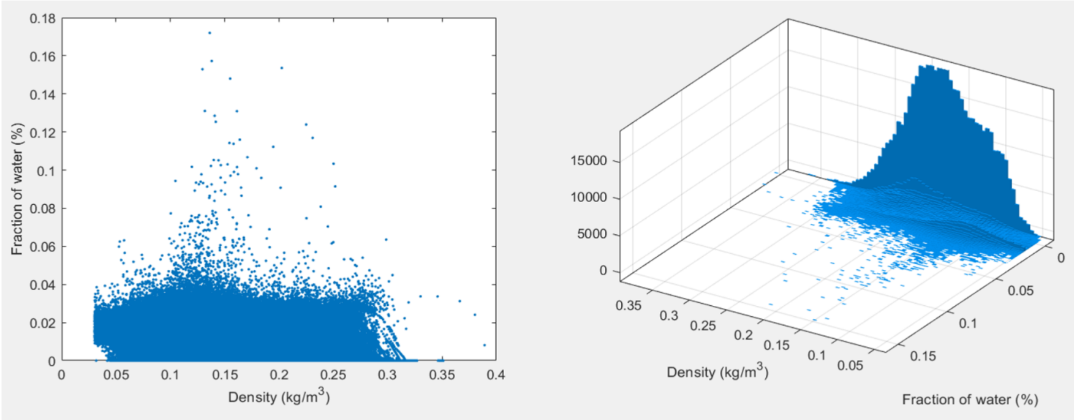
- Snow permittivity depends on snow water fraction and snow density values.
- Different models are available to estimate snow permittivity.

- A very simple model can be used as a rough approximation:

$$\in_{snow} = \in_{dry\text{-}snow} (1-f_w) + \in_{water} f_w$$

- More complex models are available in the literature

For water fraction and snow density values two options have been explored:
- a synthetic scenario with uniform distributions of values;
- a realistic scenario (shown below) made of estimates calculated by a dynamic snow-mantle evolution model (Alpine3D).



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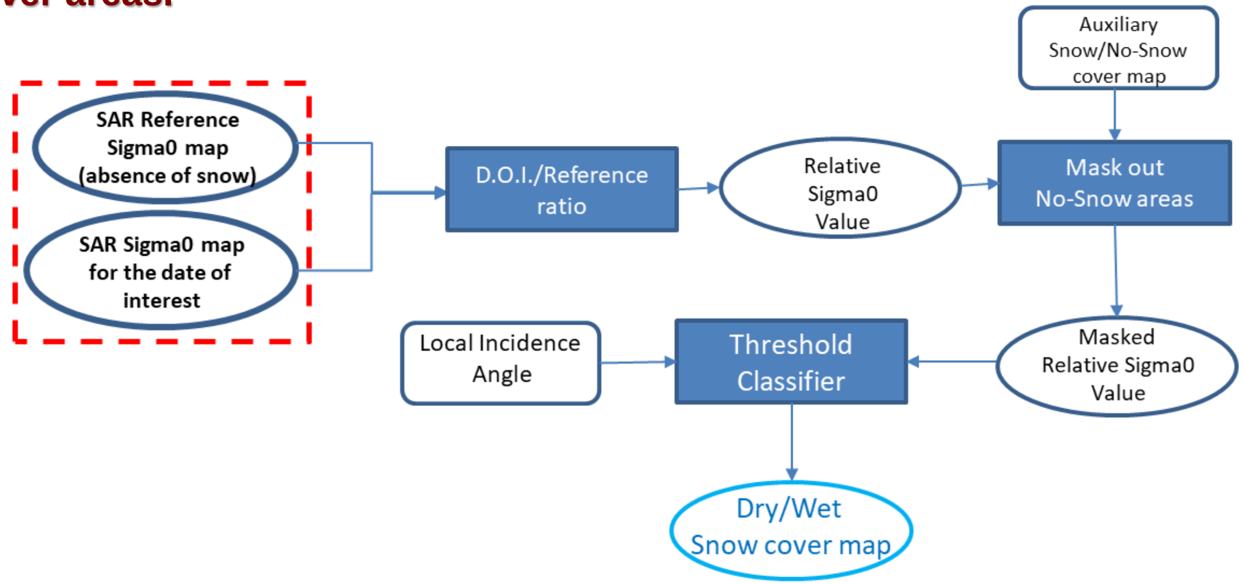
SNOW CLASSIFICATION: identification of dry snow and wet snow cover areas.

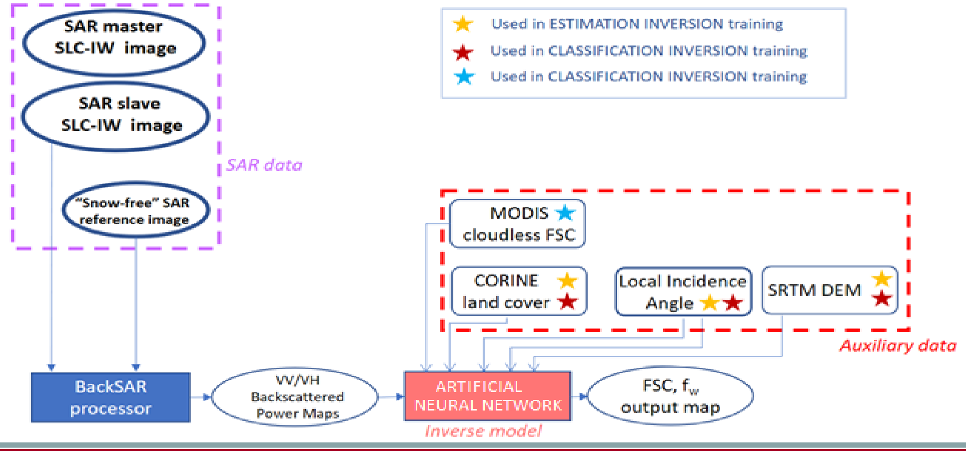
- A first approach has been adopted for the snow classification problem which employed the backscattering-coefficient threshold-based algorithm proposed by Nagler-Rott for the dry-wet snow classification task.

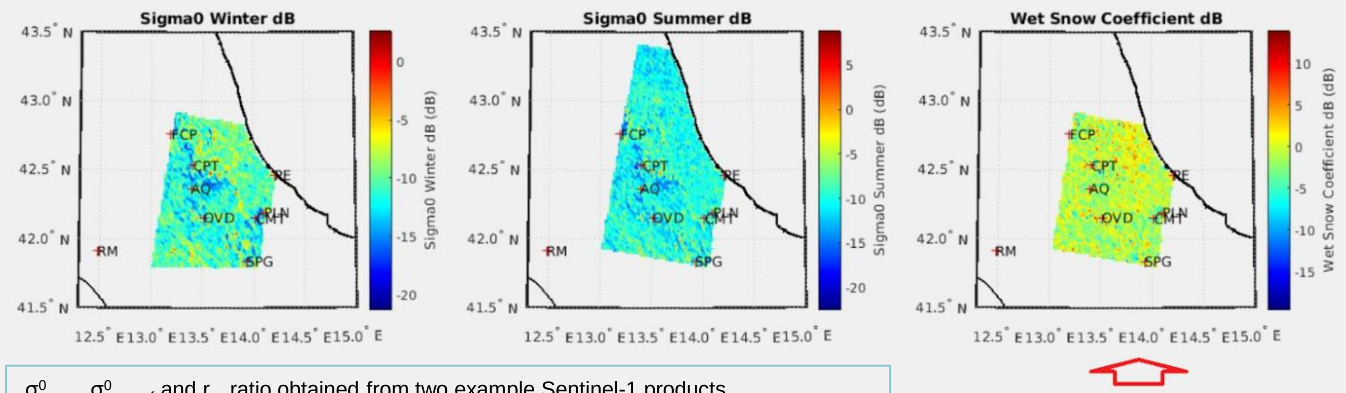
$$r_{vv}(x,y) = \frac{\sigma^0_{vvm}(x,y)}{\sigma^0_{vvmref}(x,y)} = \begin{cases} \leq r_{0wet} & \textit{Wet snow} \\ > r_{0wet} & \textit{Dry snow} \end{cases}$$



- This approach showed poor results on the considered AOI (Italian Central Apennines)

- Another approach based on an Artificial Neural Network (ANN) is currently being experimented.





σ^0_{vvm} , σ^0_{vvmref} and r_{vv} ratio obtained from two example Sentinel-1 products (27 Dec. 2018 - left panel, 26 Aug. 2018 - center panel) on the Central Apennines AOI.

Sigma0 Winter - Sigma0 Summer

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SNOW ESTIMATION: retrieval of snow depth and snow density.

• The **PAI algorithm,** which is obtained by inverting the DInSAR equation with $\Delta h_s=\Delta Z_s$:

$$\Delta\hat{h}_s(x,y) = \frac{\Delta\Phi_{ppsm}(x,y)}{2\,k_i\left(\sqrt{\varepsilon_{Rrs}-\sin^2\theta_l}-\cos\theta_l\right)}$$

The main limitation of the PAI inversion algorithm is that it requires ρ and f_w values to be known in order to perform the inversion; since ρ and f_w are, in general, not known, they need to be assigned estimated values, potentially resulting in a poor accuracy of the model.

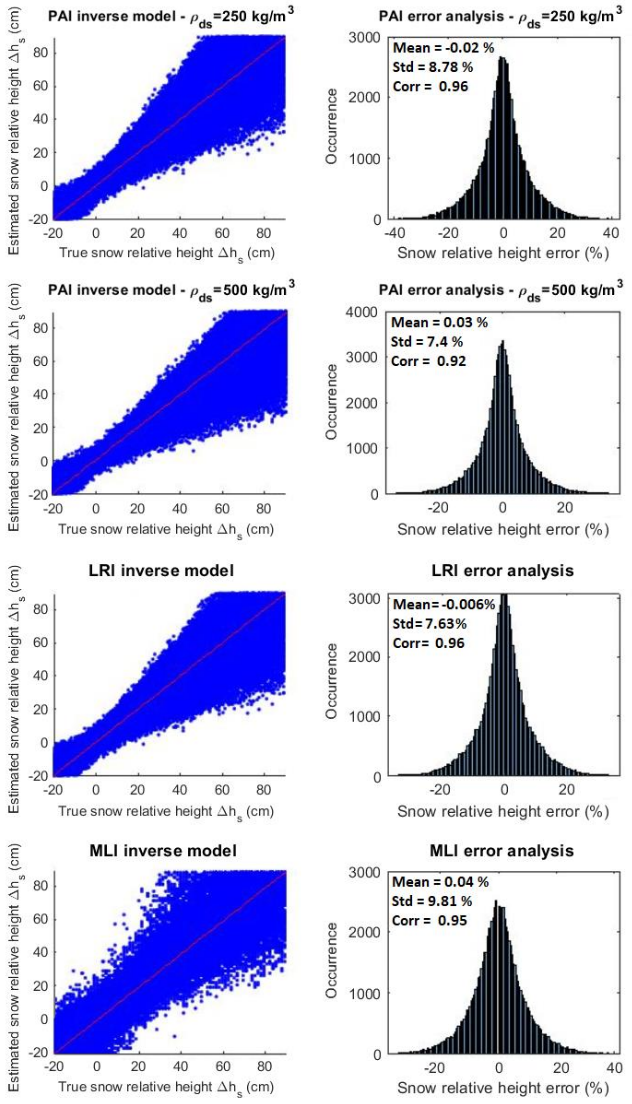
• The **LRI algorithm** which is based on the statistical linear-regression approach and is described by the following equation:

$$\Delta\hat{h}_s(x,y) = a_{h0} + a_{h1}\,\Delta\Phi_{ppsm}(x,y)$$

•

•The **MLI algorithm** which uses a statistical approach where the error probability density function is maximized, under a Gaussian hypothesis its negative argument is minimized.

$$\begin{bmatrix}\Delta\hat{h}_s(x,y)\\ \hat{\rho}_s(x,y)\end{bmatrix} = argmin\left\{\left[\Delta\Phi_{ppsm}(x,y)-\Delta\Phi_{pps}(x,y)\right]^2\right\}$$



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CONCLUSIONS

Current status of the study:

- We have implemented some dielectric models for snow permittivity estimation.
- We have used a realistic scenario based on a snow-mantle evolution model (Alpine-3D)
- We have implemented and tested a threshold-based algorithm which uses the backscattering-coefficient as input. This algorithm showed poor results on the Italian Central Apennine AOI.
- We have implemented and tested three different inverse models for snow depth estimation. They use differential SAR phase as input. MLI showed better performances.

Future developments:

- Multiband/multimission integrated analysis: combine C-Band (Sentinel-1), L-band (SAOCOM), and X-band (Cosmo SkyMed 1st and 2nd generation) data to take advantage of the different characteristics of each band.
- Implementing Artificial Neural Network based models to improve accuracy.
- Validation of the results with in-situ data.

Prof. Frank Silvio Marzano
1963 – 2022

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