Apport de la télédétection satellite pour la modélisation du manteau neigeux en montagne / Satellite observations in support to mountain snow modelling

PhD project ; October 2024 - September 2027

Supervisors :

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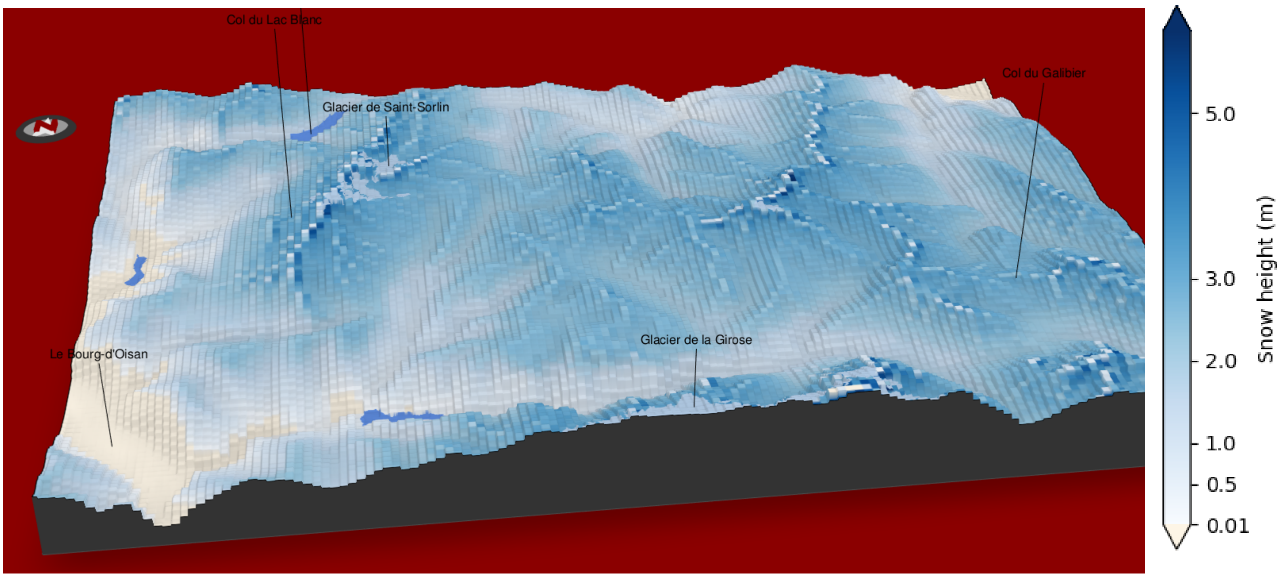
The PhD student will mainly work in Grenoble, with visit periods in Toulouse.

Application opened **between 1st Februray 2024 and 15 March 2024** through the CNES platform: https://recrutement.cnes.fr/fr/annonces

Context

In mountains, an accurate knowledge of snow physical properties is critical to anticipate snow-related hazards (avalanches, floods) and optimize water resources management and hydropower production. Various research groups are developing spatialized snow modelling systems (Marsch et al., 2020; Mott et al., 2023) but their accuracy is limited by uncertain meteorological inputs (Raleigh et al., 2015) and snow model errors (Lafaysse et al., 2017). Meteo-France is developing an ambitious snow modelling system expected to cover all French mountains at 250 m horizontal resolution, dedicated to all snow-sensitive applications (Lafaysse, 2023). This resolution is a compromise between the spatial scales of snow variability, the affordable numerical cost and the contrasted resolutions of available meteorological data and satellite observations. Recent works now allow us to improve the spatial scale of the simulated processes (Haddjeri et al., 2023) but the simulations still need to be constrained by the assimilation of remotely sensed observations.

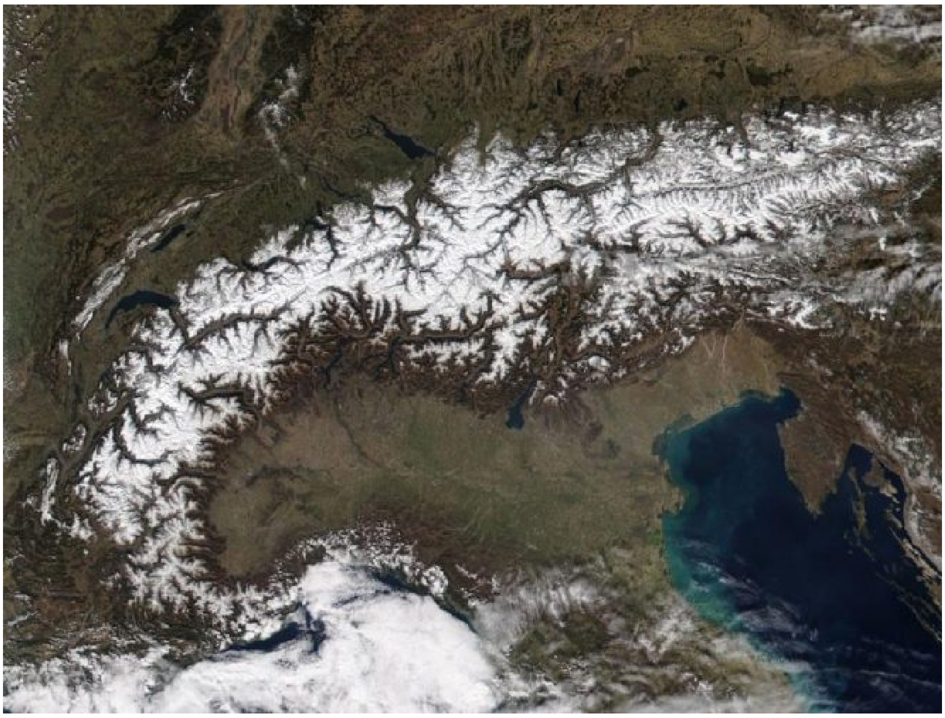


Snow depth simulated by the EDELWEISS numerical system at 250 m horizontal resolution (Grandes Rousses, 15 April 2018)

Recent algorithmic developments in data assimilation have proved their ability to improve snow simulations even if the availability of observations varies in space and time (Cluzet et al., 2021). However, the convergence of these works in an operational system depends on the availability of operational processing of satellite observations and on their accuracy over complex topographies. Although theoretical experiments have shown the potential of highly informative observations (optical reflectance, Cluzet et al., 2021; surface temperature, Alonso-Gonzalez et al., 2023), their accuracy in mountains postpone the feasibility of their assimilation (Cluzet et al., 2020; Revuelto et al., 2021).

Goals
In this context, the goal of the PhD is to identify the satellite observations both realistic and useful to improve operational snow simulations at short lead time (4-5 years), investigate their complementarity, and prepare the use of such simulations in real-time applications. The strategy consists in giving a higher priority to well mature and operational products and progressively extending the assimilation framework to more challenging observations.

Methods
The first part of the PhD consists in the assimilation of Snow Cover Fractions derived from optical imagery. To take benefit from operational processing chains already operated by CESBIO, CNES, and Meteo-France, the complementarity between the high resolution of Copernicus/Sentinel-2 (Gascoin et al., 2019) and the high temporal repetitivity of NASA/VIIRS will be investigated. This step requires (1) an accurate quantification of observation error that will be achieved by the comparison between both products on a long archive, (2) the implementation of state-of-the-art parameterizations of Snow Cover Fraction as observation operators (Helbig et al., 2021), (3) a calibration of the spatial propagation allowed by the k-local particle filter assimilation algorithm, as snow coverage information on certain pixels can inform on the realism of the snowpack state on other pixels. Evaluations will be done by cross-validation among available observations and with independant data such as snow heights from Pléiades stereo-imagery (Deschamps-Berger et al., 2020).



Snow cover map obtained from MODIS optical imagery

As Snow Cover Fractions are mainly informative at the very beginning and at the end of the snow season, in a second time, the complementary assimilation of snow height products will be considered. The C-Snow product (Lievens et al., 2022) derived from Sentinel-1 will be assimilated after a detailed quantification of observation error.

Finally, the third part of the PhD will consist in applying the previous assimilation frameworks in a known future for reanalysis purpose. This requires to replace the assimilation algorithm dedicated to real-time applications (sequential particle filter) by an algorithm allowing a better temporal propagation of information (batch smoother, Alonso-Gonzalez et al., 2023). A 8-year long high resolution snow reanalysis will allow the climatological characterization of real time simulations in the same geometry. This is a critical requirement identified by the skateholders for the usability of snow simulations in operational applications.

Outlook

This project will provide an assimilation framework that can realistically run operationnally at the end of the PhD and open the door to the assimilation of more challenging observations in the future : snow heights from ICESat-2 (Deschamps-Berger et al., 2023), wet snow fraction from Sentinel-1 (Karbou et al., 2021), broadband albedo from Sentinel-3 (Sanchez-Zapero et al., 2023), optical reflectances with enhanced topographic corrections (Lamare et al., 2020), surface temperatures from TRISHNA. It combines an innovative scientific approach with fast operational prospects and will answer to the increasing needs of winter mountain skateholders in the context of climate change and challenging energy supply.

Expected skills

The candidate has to be interested in snow science and exhibit scientific curiosity. He/she must me able to develop Python codes and manage big volumes of data. He/she must be able to write scientific documents in English. The PhD will allow to expand or acquire skills in numerical modelling, remote sensing, snow science, geostatistics, data assimilation, and HPC computing.

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