FINAL REPORT PROGRAM LEFE

Program LEFE IMAGO et MANU	ASSURANCE : Satellite data assimilation for snow cover simulation in the Alps	Years 2016 – 2019

PI : M. Dumont, marie.dumont@meteo.fr, CNRM
Participating Laboratories : IGE

Other funding sources : CNES Kalideos-Alpes, ANR JCJC EBONI, AXA post-doctoral grant, ESA S3-SEOM snow and 3 PhD grants, CNES APR MIOSOTIS

Context and objectives: Snow on the ground is a crucial component of the Earth system. However, our current knowledge on the state of the snow cover in mountain areas is currently limited by the poor spatial representativity of in-situ observations and uncertainties affecting snow cover simulations. Recently, we investigate the possibility of improving the accuracy of snow cover simulations by assimilating surface reflectance using a particle filter (PF). ASSURANCE project aims at (i) demonstrating the ability of the PF to improve the accuracy of snow cover simulations using real observation data at one point (Action 1) and (ii) extent the capability of the PF to a spatialized context (Action 2).

Main results: Regarding action 1, an extensive field-measurement campaign was conducted during two winter seasons at Col du Lautaret (French Alps) (Tuzet et al., 2019 ; Tuzet et al., in review). The field campaign included automatic measurements of spectral surface reflectance every 12 min (Dumont et al., 2017), detailed chemical measurements of light absorbing particles (LAPs) in snow and evaluation of surface reflectance derived from optical satellite (Cluzet et al., 2019). Several assimilation experiment at one point were conducted using observed surface reflectance. The results were very satisfying for in situ measured reflectance (see Figure 1, Charrois, 2017). However, when it comes to satellite data, we tested both Sentinel-2 and MODIS surface reflectance. Both data exhibit strong bias probably due to unadequate topographic corrections (Cluzet et al., 2019 ; Lamare et al., in prep.).

Regarding action 2, we first implement and evaluated a version of the detailed snowpack model Crocus that includes an explicit representation of LAP in snow since they strongly impact surface reflectance (Tuzet et al., 2017 ; Tuzet et al., in review). Snow cover simulations were established in a spatialized context with several geometry (Revuelto et al., 2017), later in an ensemble configuration (Lafaysse et al., 2017 ; Cluzet et al., 2019). Methodoligical developpement were also performed to develop localization methods for the PF in order to spread the benefit of the assimilation to non-observed pixels (Cluzet et al., in prep ; see Figure 2). This method was first tested with synthetic observation and then with real observation of snow depth. Finally, since action 1 revealed that satellite surface reflectance were not correctly retrieved due to the topography, we also implemented a new model to accuratly account for topography (Lamare et al., in prep).

In the future, the assimilation system will be implemented operationally to improve snow avalanche hazard forecasting in mountain areas in Météo-France forecasting system. The code for satellite surface reflectance retrieval in mountainous terrain will also be distributed.

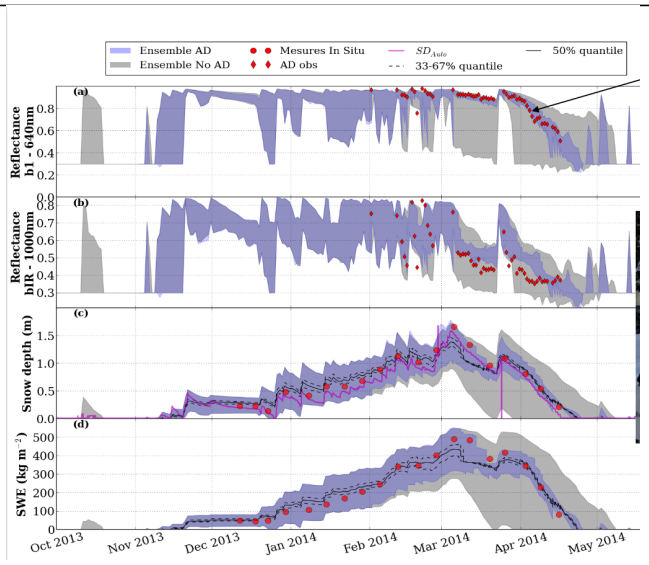

Figure 1

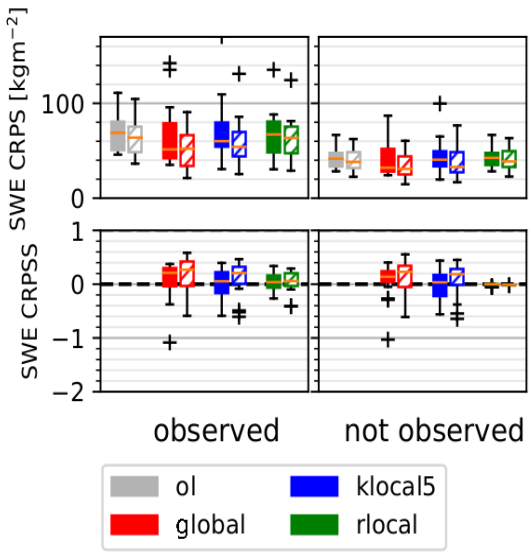

Figure 1 – Assimilation of in situ surface reflectance (red diamonds) in ensemble snowpack simulations. Gray envelop correspond to the ensemble without assimilation and the blue envelop with assimilation. Red dots and purple line are measured snow depth and red square are measured snow water equivalent. This figure shows that the PF with real data works extremely well for one point. Figure from Charrois, 2017 (PhD manuscript).

Figure 2 - Assimilation performance (measured with the Continuous Rank Probability Score, CRPS and skill score, CRPSS) on the snow water equivalent, for areas where surface reflectance observation are available (observed) or non available (not observed). In grey , the results of the simulation with no assimilation of reflectance, in red with the PF applied globally over the whole area, in green the PF is applied only at the observation point and in blue, the PF is applied with a localization method (Cluzet et al., in prep). This shows that the new methodology is able to spread the benefit of the assimilation to non observed areas. In this case, the observation are synthetic.

Number of PhD grants : 3 (2013-2017 : L. Charrois, Assimilation of optical reflectance to improve snowpack simulations, http://www.theses.fr/2017GREAU001; 2016-2019 : F. Tuzet, Impact of light absorbing impurities on the alpine snow cover ; B. Cluzet, Data assimilation to improve detailed snowpack simulations).

Number of communications : 39

Number of publications : 9 and 3 in review., and 5 in prep. → *5 more relevant publications :*

- *Charrois, L., Cosme, E., Dumont, M., Lafaysse, M., Morin, S., Libois, Q., and Picard, G.: On the assimilation of optical reflectances and snow depth observations into a detailed snowpack model, The Cryosphere, 10, 1021–1038, https://doi.org/10.5194/tc-10-1021-2016, 2016.*
- *Tuzet, F., Dumont, M., Lafaysse, M., Picard, G., Arnaud, L., Voisin, D., Lejeune, Y., Charrois, L., Nabat, P., and Samuel, M. : A multi-layer physically-based snowpack model simulating direct and indirect radiative impacts of light-absorbing impurities in snow, The Cryosphere, 11, 2633-2653, https://doi.org/10.5194/tc-11-2633-2017, 2017.*
- *Tuzet, F., Dumont, M., Arnaud, L., Voisin, D., Lamare, M., Larue, F., Revuelto, J., and Picard, G.: Influence of light-absorbing particles on snow spectral irradiance profiles, The Cryosphere, 13, 2169–2187, https://doi.org/10.5194/tc-13-2169-2019, 2019.*
- *Dumont, M., Arnaud, L., Picard, G., Libois, Q., Lejeune, Y., Nabat, P., Voisin, D., and Morin, S.: In situ continuous visible and near-infrared spectroscopy of an alpine snowpack, The Cryosphere, 11, 1091-1110, https://doi.org/10.5194/tc-11-1091-2017, 2017.*
- *Cluzet, B., Revuelto, J., Lafaysse, M., Tuzet, F., Cosme, E. , Picard, G., Arnaud, L. & Dumont, M. Towards the assimilation of satellite reflectance into semi-distributed ensemble snowpack simulations, Cold Regions Science and Technology, 2019.*