Latest scientific evolutions in the Crocus snowpack model

Matthieu Lafaysse¹, Marie Dumont¹, Rafife Nheili¹, Léo Viallon-Galinier¹, Carlo Carmagnola¹, Bertrand Cluzet¹, Mathieu Fructus¹, Pascal Hagenmuller¹, Samuel Morin¹, Pierre Spandre¹, François Tuzet¹, Vincent Vionnet¹,²

¹ CNRM, Centre d’Etudes de la Neige, Grenoble, France
² Environmental Numerical Research Prediction, Environment and Climate Change Canada, Dorval, QC, Canada
Outlook

- Basics principles of Crocus snowpack model

- New implementations available in last stable release:
  - Light Absorbing Impurities
  - Multiphysics
  - SYTRON (Blowing snow)
  - MEPRA (Mechanical stability)
  - Coupling with MEB (snow under forest)
  - Crocus-RESORT

- Works in progress
- Code access and conclusion
Basics

- Physical basis: **Heat diffusion** in a stratified snowpack

\[
\frac{\partial}{\partial t} \left( \rho(i) C_p(i) dz(i) T(i) \right) + L_f W(i) = \begin{cases} 
Q_c(i) + L_f W_p + S_{abs}(i) + L_{net} + H + LE + P & \text{(surface)} \\
Q_c(i) + L_f W + S_{abs}(i) & \text{(internal layer)} \\
Q_c(i) + L_f W + S_{abs}(i) + Q_g & \text{(basal layer)} 
\end{cases}
\]

Temperature change during time step

Phase change if \( T=0°C \)

Turbulent fluxes

Conduction heat flux

Liquid water percolation

Absorbed solar radiation

Ground-snow conduction

But many processes rely on **empirical parameterizations**
Main specificities of Crocus (compared to more standard snow schemes):

- **Lagrangian discretization**, maximum of 50 snow layers
- Explicit representation of **snow microstructure**

Prognostic variables: **Specific Surface Area** and grain **sphericity** with empirical evolution laws
New implementations available in last stable release

- Explicit evolution of **Light Absorbing Impurities** (Tuzet et al., 2017)

**Black carbon**

**Dust**
New implementations available in last stable release

- Explicit evolution of **Light Absorbing Impurities** (Tuzet et al., 2017)
  - Impact on **absorption of solar radiation**: more details in EGU2020-3633 in session AS2.10 [https://doi.org/10.5194/egusphere-egu2020-3633](https://doi.org/10.5194/egusphere-egu2020-3633)

  → Highly variable process responsible for **large albedo differences between mid-latitude and polar areas**, not explained by the simple albedo parameterizations currently implemented in most Land Surface Models
New implementations available in last stable release

- Impurities scheme + TARTES optical scheme allow to compute **spectral visible and NIR reflectances**:
  - Comparisons with satellite reflectances
  - Perspective of data assimilation

Example: Near Infra Red reflectances (~ 860 nm) for MODIS, SENTINEL2 and SURFEX-Crocus ensemble simulations on topographic classes, Grandes Rousses area

Cluzet et al., 2020
Equifinality between parameterizations:

- 2 different model settings
  - Very different contributions to the energy balance
  - Very close simulated snow depths
  - Same statistical skill on various evaluation variables, long periods and various sites

Lafaysse et al., 2017
**ESCROC** (Ensemble System CROCus) **multiphysics** system
(Lafayse et al., 2017)

- Example for snowfall density parameterization

- 2 to 4 physical options for 8 key processes
  → **7776** possible members
  → 35 members selections

- Various applications:
  — **Climate projections** (Verfaillie et al., 2018)
  — **Data assimilation** (Cluzet et al., 2020)
  — **Process studies** (Dumont et al, submitted)

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- Impurities scheme + Multiphysics
  - Impact of a dust deposition event accounting for the uncertainties of the other processes (Russian Caucasus)

Surface radiative effect due to impurities

Forced by additional observed dust deposition of 7 g/m² on March 23

Constant dust deposition close to climatology

Page 11  Dumont et al., submitted
New implementations available in last stable release

- SYTRON module for blowing snow
  - Only suitable for a specific geometry with topographic classes

Windward side

- Amount of snow redistributed in saltation and turbulent suspension
- Sublimation loss
- Mechanical evolution of snow grains

Leeward side

Erosion

Idealized crest

Snowpack simulated by Crocus

Accumulation

Vionnet et al., 2018
New implementations available in last stable release

- SYTRON module for blowing snow
  - New operational product for avalanche hazard forecasters

Vionnet et al., 2018
New implementations available in last stable release

- MEPRA module (Giraud et al., 1992): mechanical stability of the snowpack
  - Shear strength and penetration resistance computed as functions of Crocus snow density and microstructure
  - Expert rules to estimate hazard indexes of natural and accidental avalanche triggering based on the stress-strength ratio
  - Relevant for steep slopes (40°)
  - Transfer in SURFEX for optimization
New implementations available in last stable release

- Coupling with MEB (Boone et al 2017) for **snow-vegetation interactions**

  **Saskatchewan, Canada** (ESM-SnowMIP sites):
  Significant decrease of snow mass compared to model uncertainty, consistent with observations

**Major bias at Col de Porte** (French Alps, 1325 m)
not explained by other processes in the snowpack model
- Crocus-RESORT: optional module for grooming and snowmaking
  - Impact of **grooming** on density and microstructure
  - **Snowmaking** dependent on meteorological conditions and snow production strategy

New implementations available in last stable release

Spandre et al., 2016: Crocus-RESORT
New implementations available in last stable release

- Crocus-RESORT: optional module for grooming and snowmaking
- Climate change impact studies for economic viability of ski resorts

Frequency of critical seasons

- Without snowmaking
- With snowmaking

Water request

Spandre et al 2019

- Development of forecasting tools to optimize snowmaking and slope management (PROSNOW project)
Works in progress (for incoming versions)

- **Data assimilation** for Crocus (PhD B. Cluzet 2017-2020)
  - Algorithm: particle filter with localization
  - Variables: visible and NIR reflectances, snow depths, …
    cf. EGU2020-9037 in Session HS2.1.2:
    https://doi.org/10.5194/egusphere-egu2020-9037

- Consolidation of MEB-Crocus coupling (PhD L. Vincent 2019-2022)
  - Parameterizations of **intercepted snow**

- Numerical **optimizations** in Crocus: (Rafife Nheili, 2019-2020)
  - Required for **future operational system** for avalanche hazard forecasting (ensembles, high resolution, reflectances DA)
  - Required for an increasing use in **coupled mode**
    - Improvement of vectorization (less « IF » when possible)
    - Optimal management of loops layers/points with incomplete arrays
  - Reducing the spectral resolution of TARTES optical scheme
Code access and conclusion

- Full documentation: https://opensource.umr-cnrm.fr/projects/snowtools_git/wiki

- All developments described in this contribution are gathered in a unique and stable code version. It opens numerous new research opportunities by combining all these possibilities and your dataset.

- A publication in GMD is expected to be submitted by a few weeks (including a zenodo archive) to update the current reference (Vionnet et al, 2012).
References


