# Latest scientific evolutions in the Crocus snowpack model

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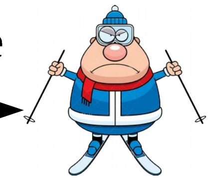
# Outlook

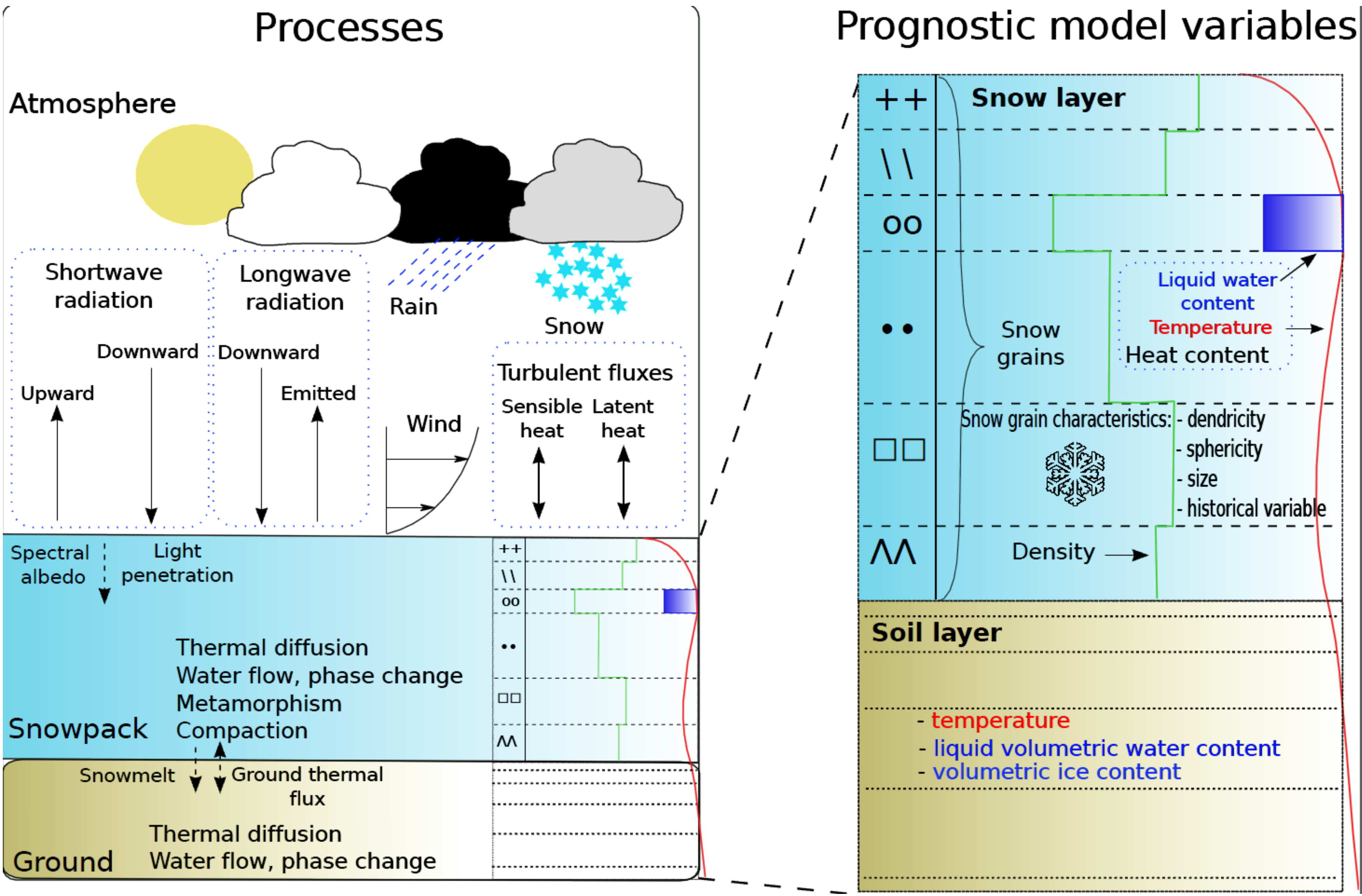
- Basics principles of Crocus snowpack model
- New implementations available in last stable release:
  - Light Absorbing Impuritites
  - Multiphysics
  - SYTRON (Blowing snow)
  - MEPRA (Mechanical stability)
  - Coupling with MEB (snow under forest)
  - Crocus-RESORT
- Works in progress
- Code access and conclusion

# Basics

Vionnet et al., 2012

Click on the skier to navigate from the outlook





# Basics

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

Temperature change during time step

Phase change if T=0°C

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

Turbulent fluxes

Longwave radiation

Ground-snow conduction

Conduction heat flux

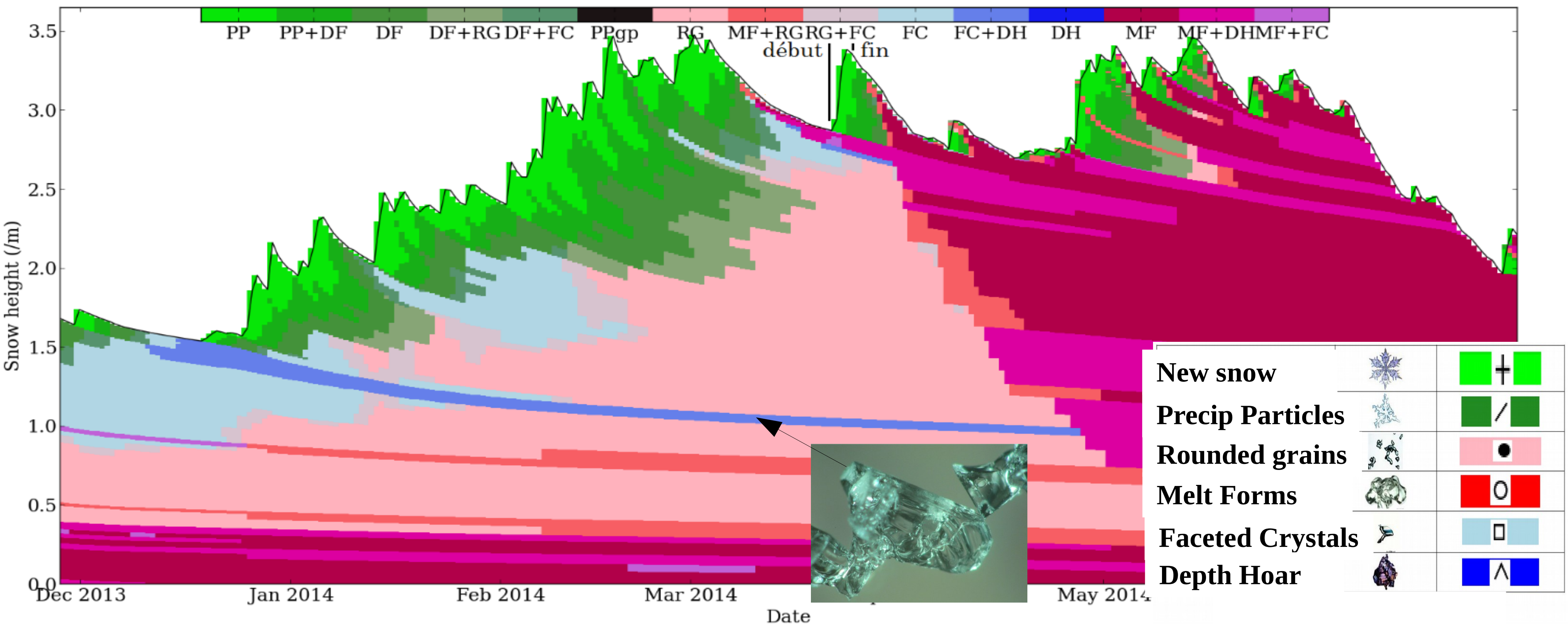
Liquid water percolation

Absorbed solar radiation

But many processes rely on **empirical parameterizations**

# Basics

- 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

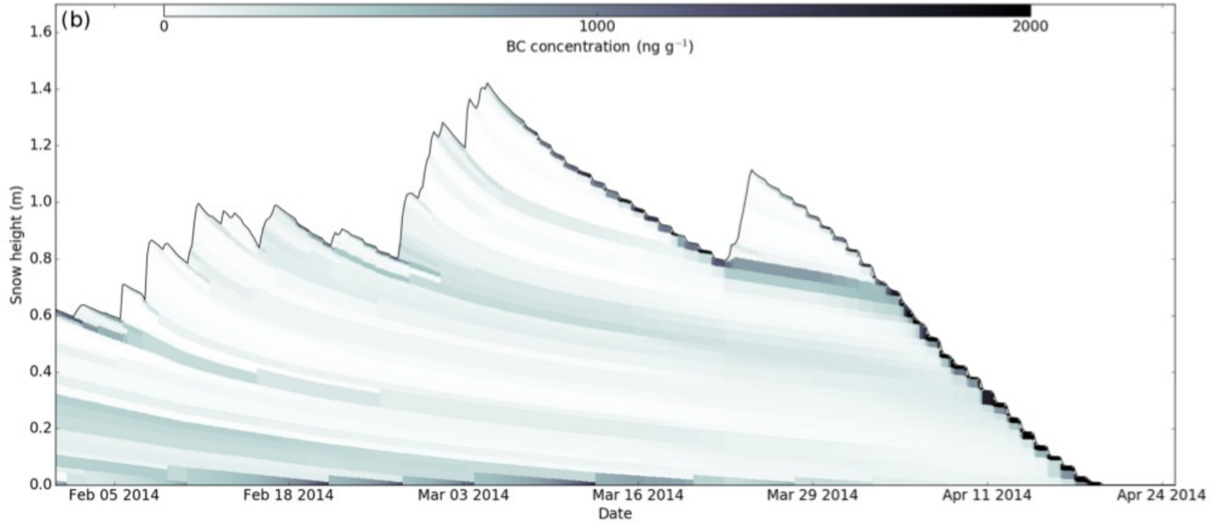


![CC BY]

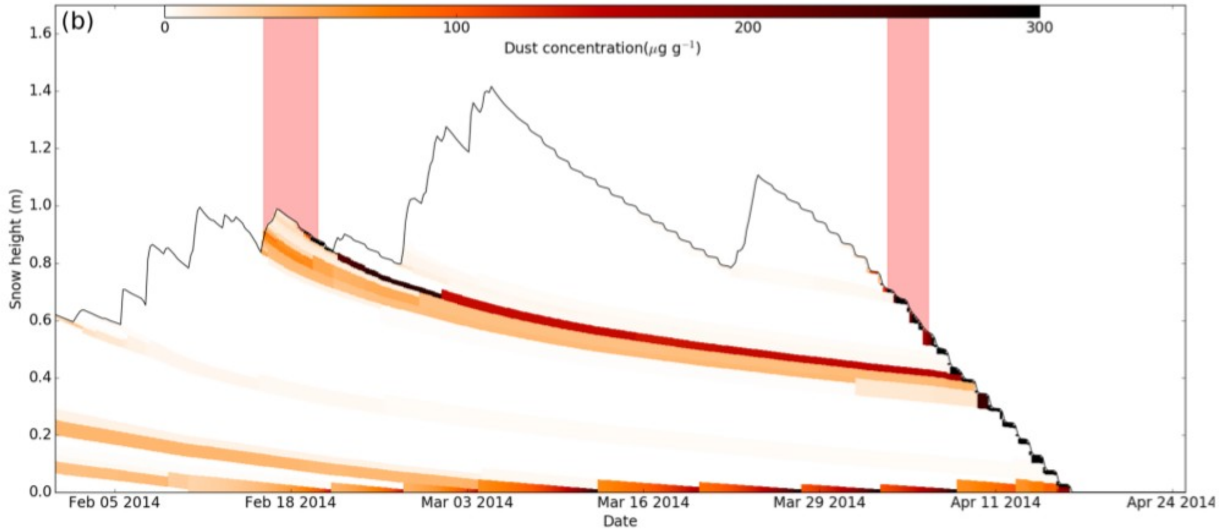
# New implementations available in last stable release

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

**Black carbon**




**Dust**



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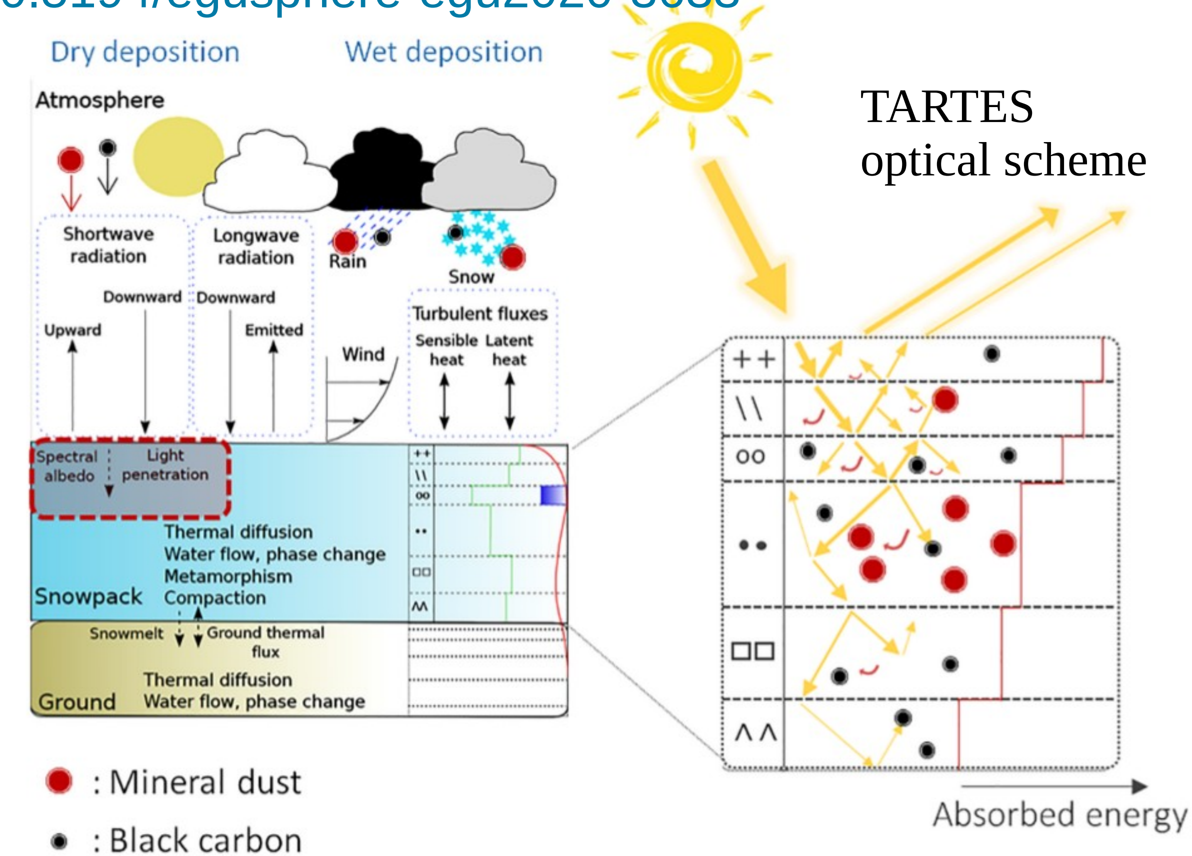
# New implementations available in last stable release

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

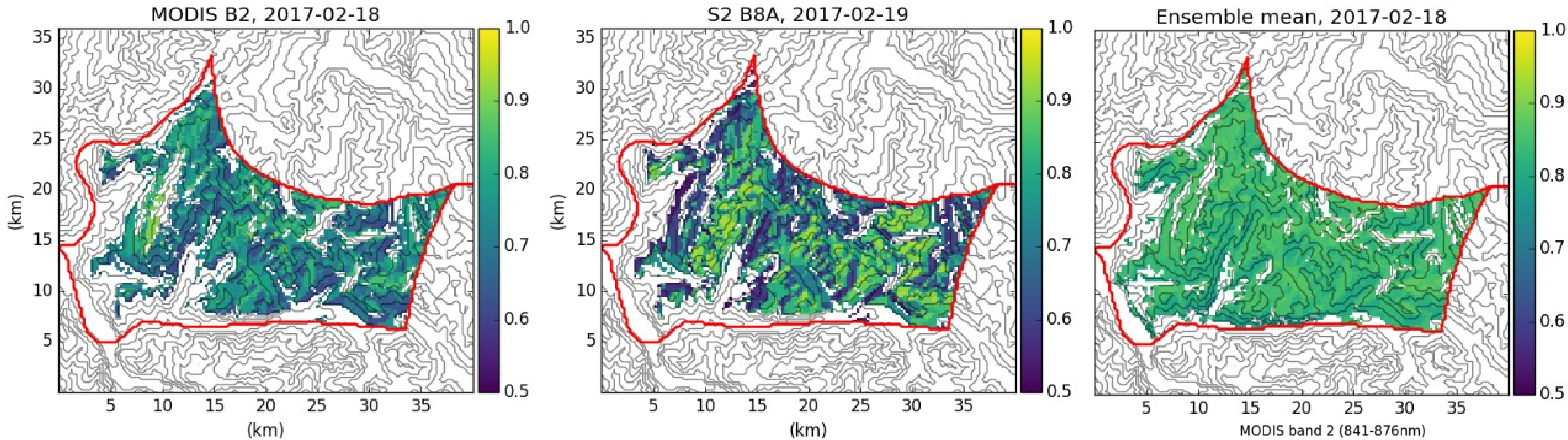
  → Impact on **absorption of solar radiation:** more details in EGU2020-3633 in session AS2.10 https://doi.org/10.5194/egusphere-egu2020-3633

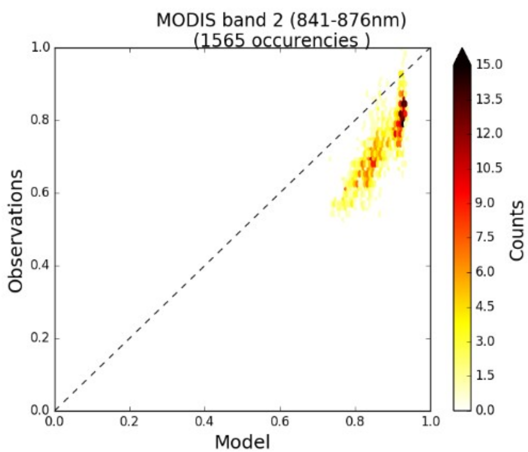




→ Highly variable process responsible for
**large albedo differences between mid-latitude and polar areas,**
not explained by the simple albedo parameterizations currently implemented in most Land Surface Models

# 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



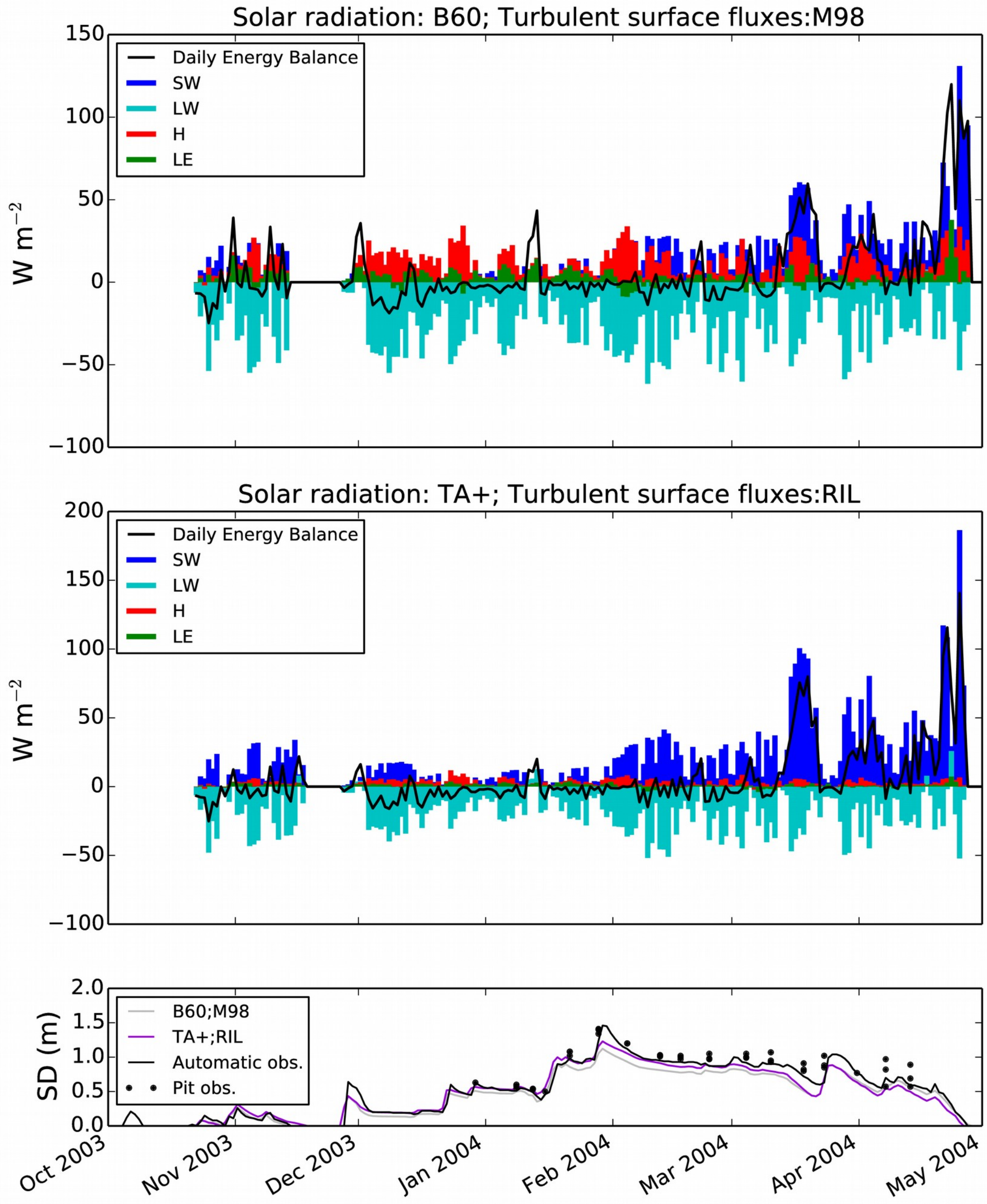

Example : Near Infra Red reflectances (~ 860 nm) for MODIS, SENTINEL2 and SURFEX-Crocus ensemble simulations on topographic classes, Grandes Rousses area

Cluzet et al., 2020

# New implementations available in last stable release

- **Equifinality** between parameterizations :

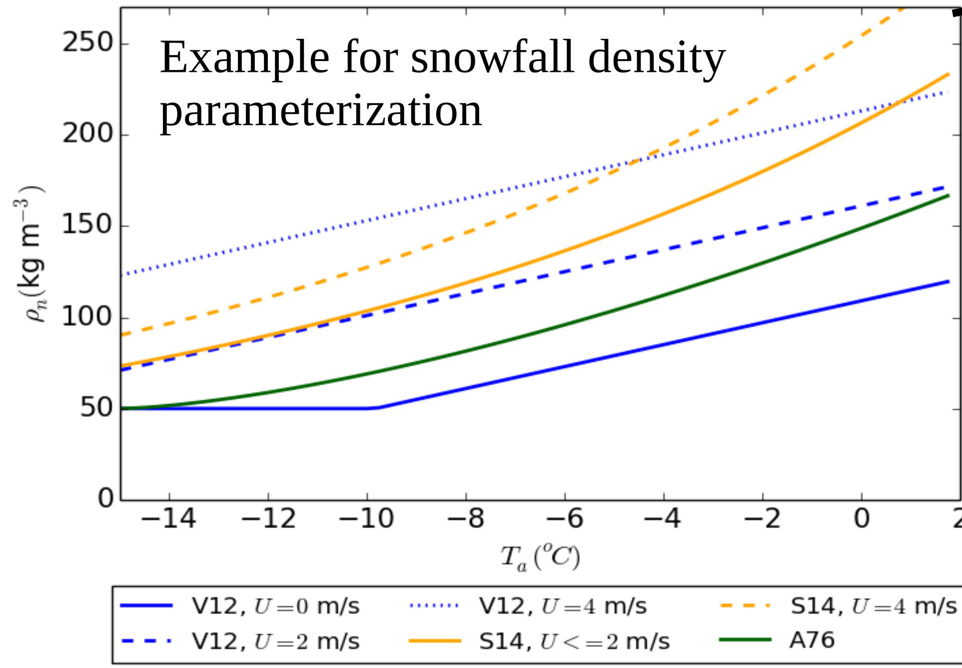
- 2 different model settings
  - Very different contributions to the energy balance
  - Very close simulated snow depths
  - Same statistical skill on various evaluation variables, long periods and various sites

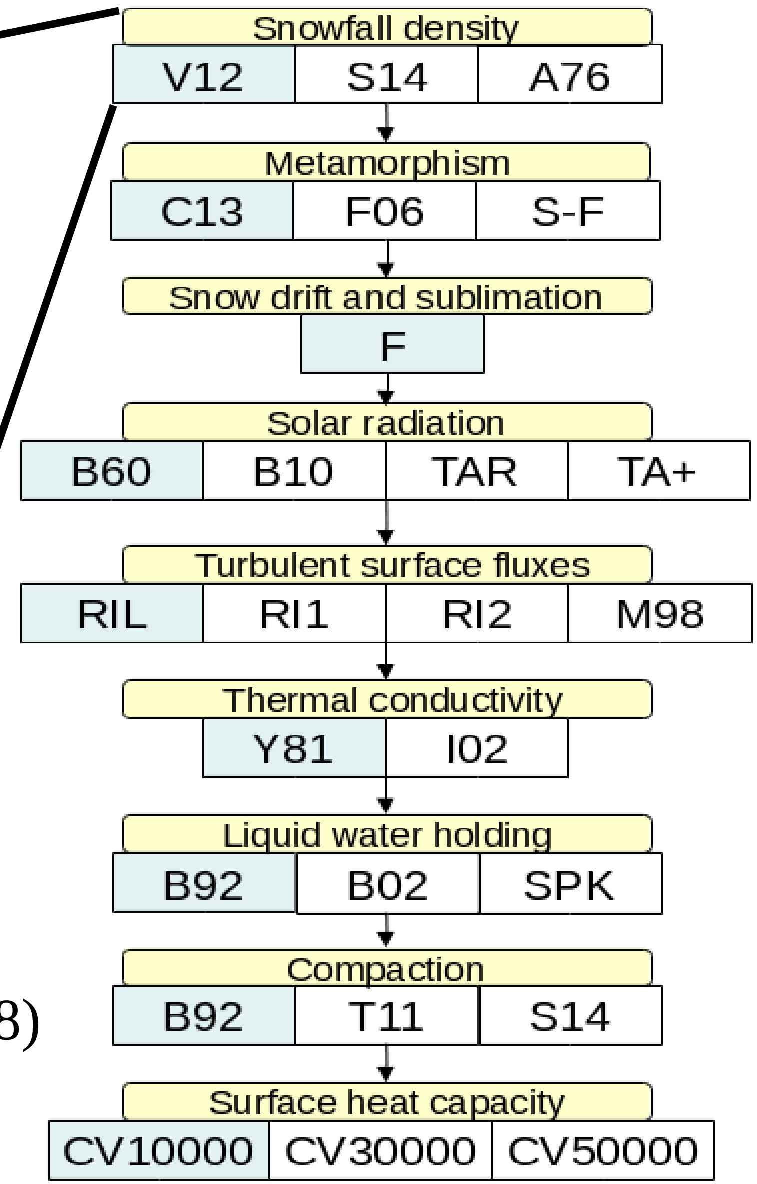



Lafaysse et al., 2017

# New implementations available in last stable release

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



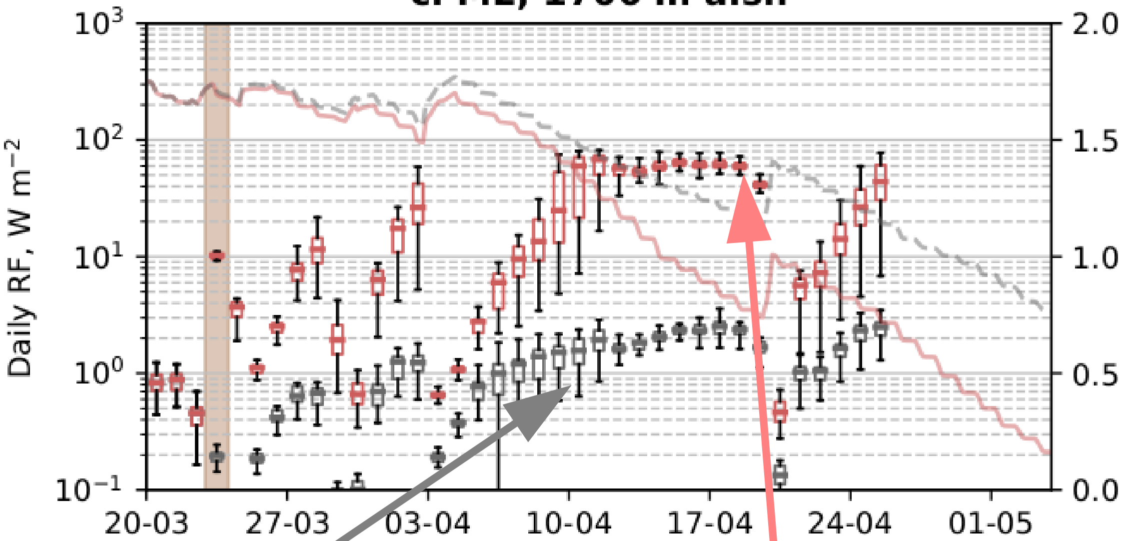




- 2 to 4 physical options for 8 key processes
  → **7776 possible members**
  → **35 members selections**
- Various applications :
  — **Climate projections** (Verfaillie et al., 2018)
  — **Data assimilation** (Cluzet et al., 2020)
  — **Process studies** (Dumont et al, submitted)

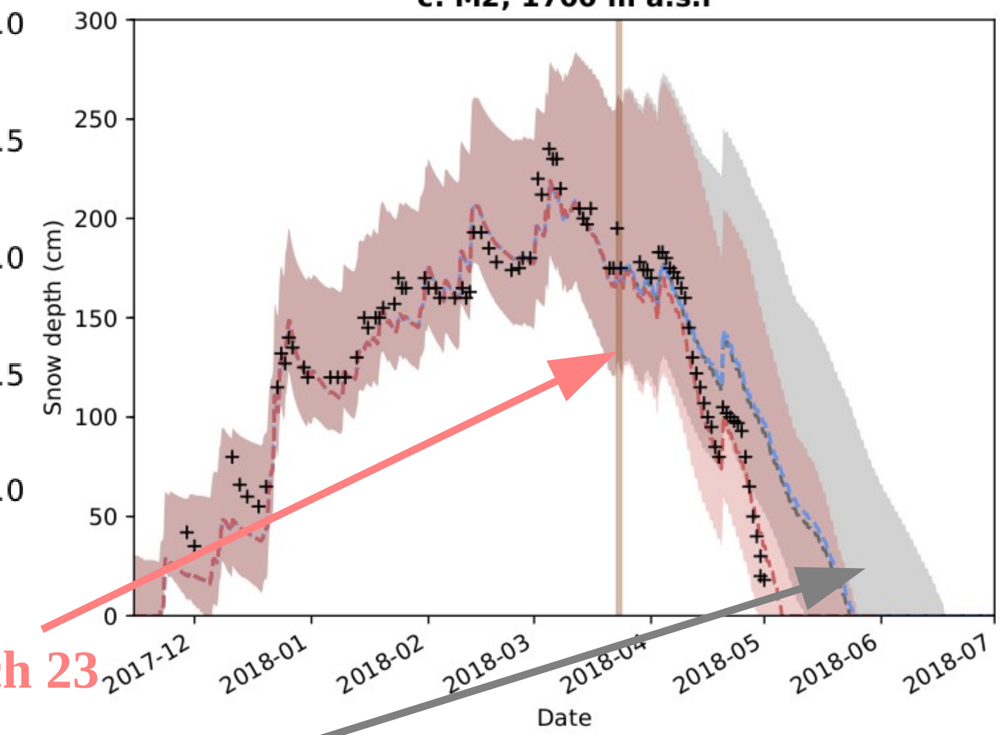
# New implementations available in last stable release

- **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




Snow depth



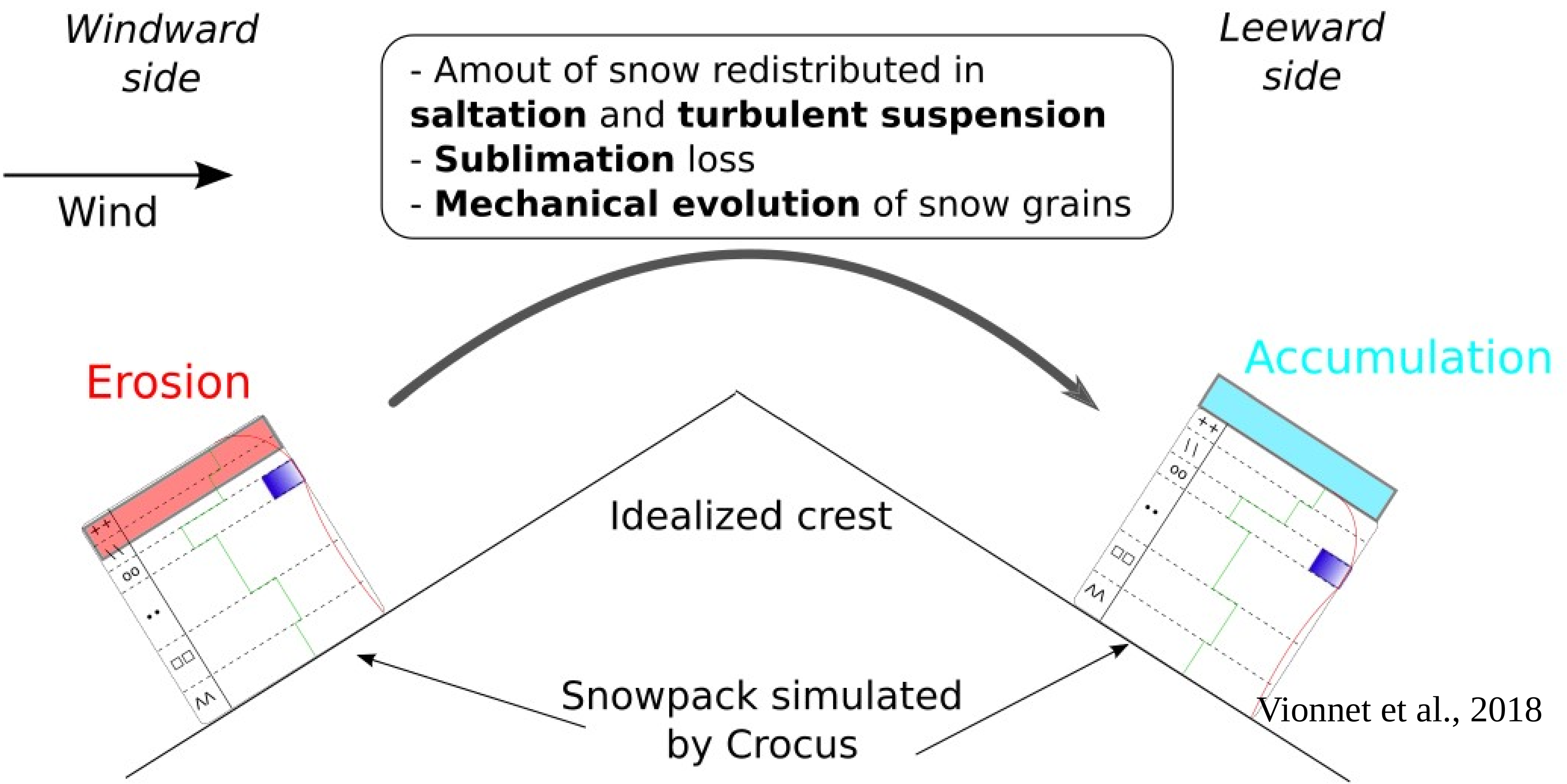

**Forced by additional observed dust deposition of 7 g/m² on March 23**

**Constant dust deposition close to climatology**

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

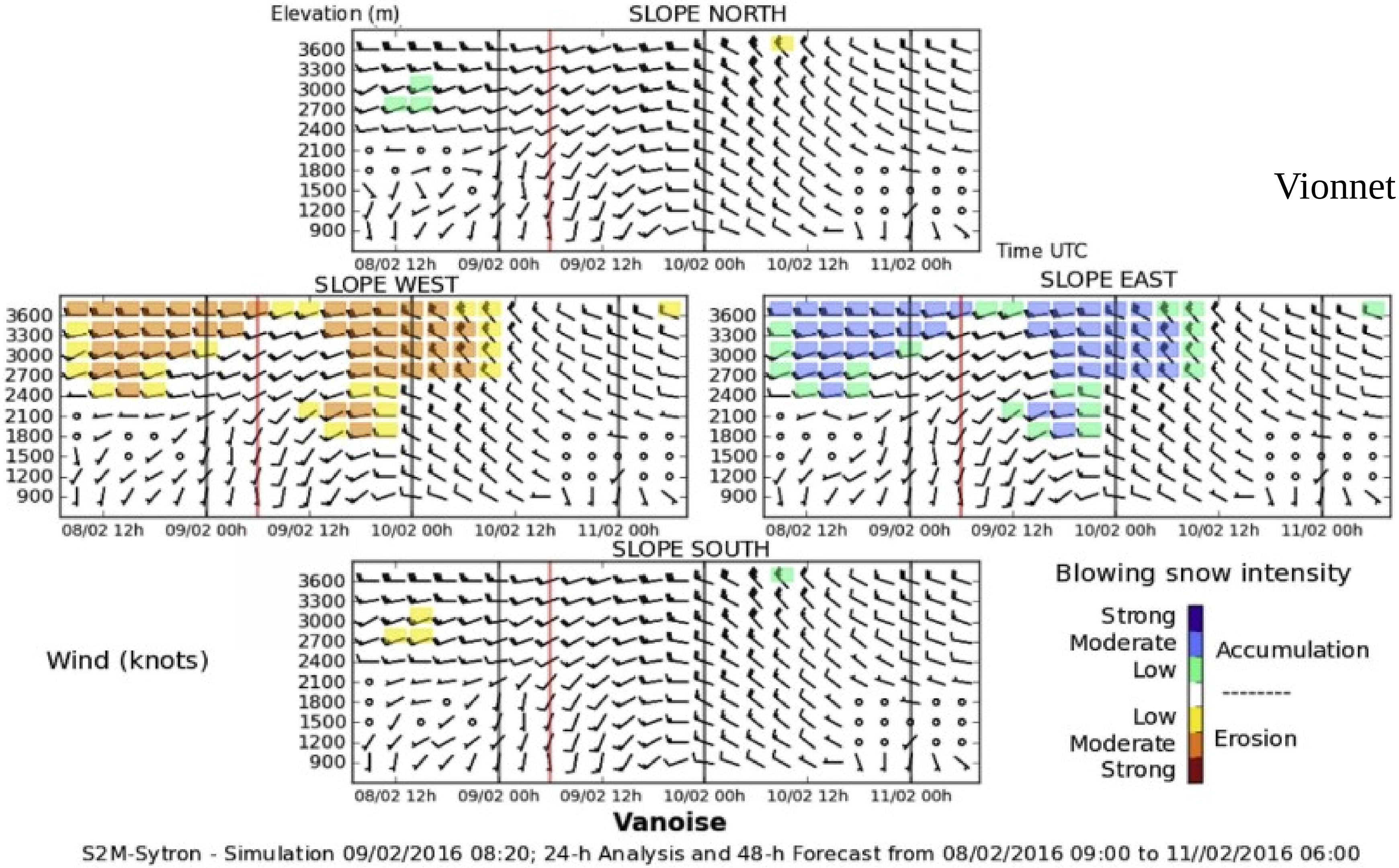



Vionnet et al., 2018

# New implementations available in last stable release

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

Vionnet et al., 2018

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# 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

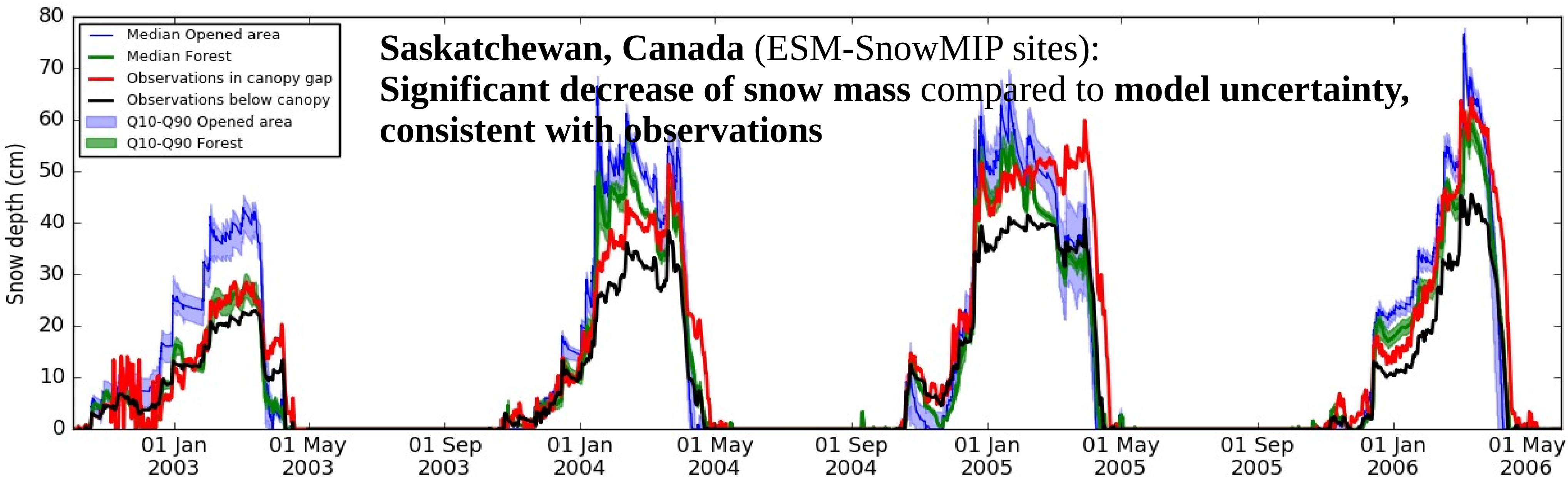
  — Expert rules to estimate **hazard indexes** of **natural** and **accidental** avalanche triggering based on the **stress-strength ratio**

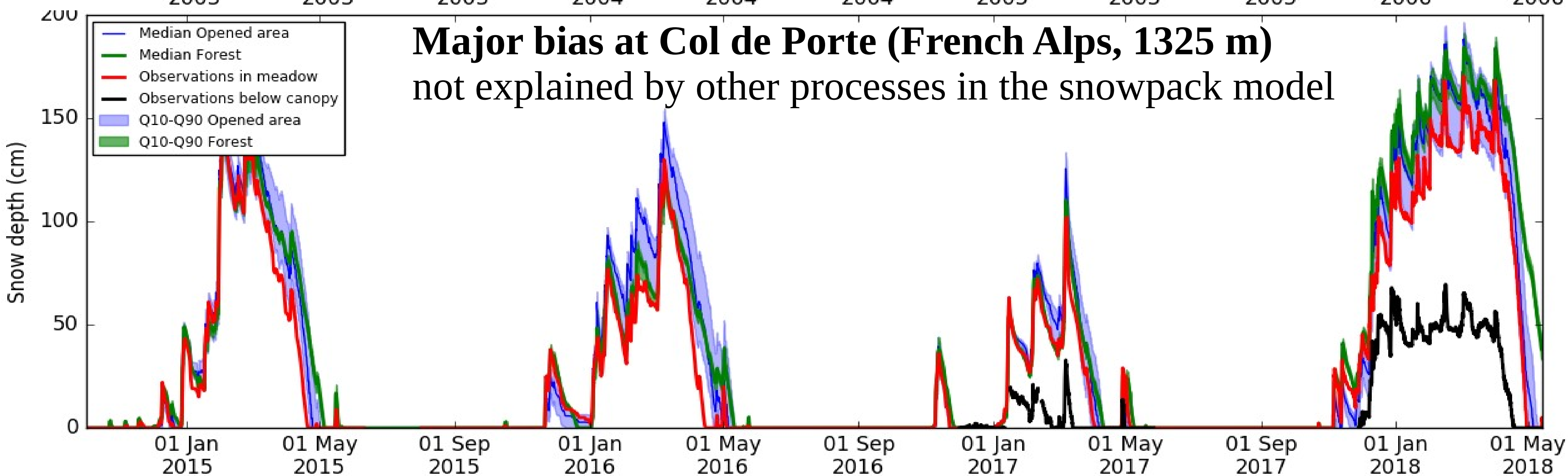
  — Relevant for **steep slopes** (40°)

  — Transfer in SURFEX for optimization

# New implementations available in last stable release

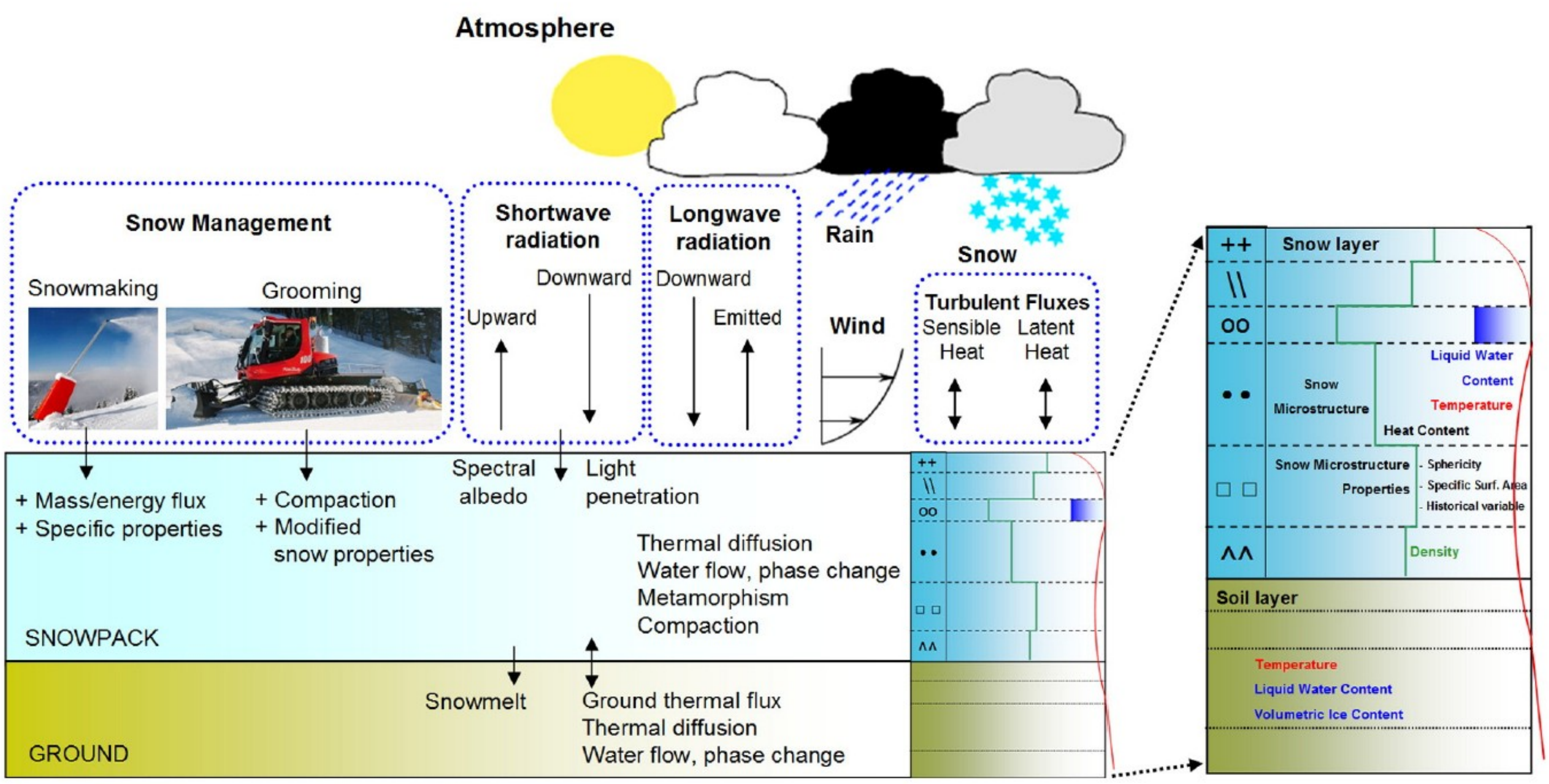
- Coupling with MEB (Boone et al 2017) for **snow-vegetation interactions**



# New implementations available in last stable release

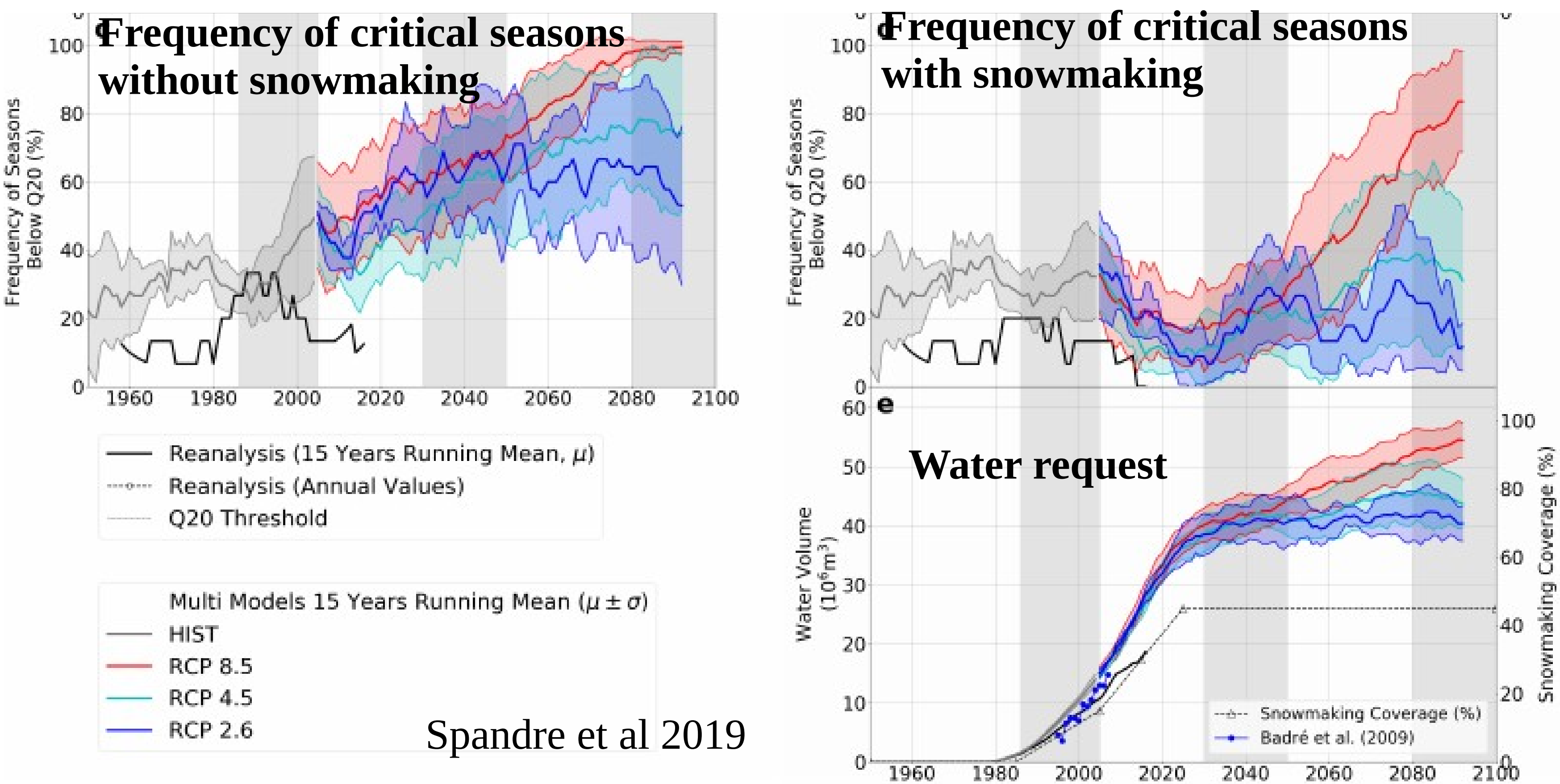
- Crocus-RESORT : optional module for grooming and snowmaking
  - Impact of **grooming** on density and microstructure
  - **Snowmaking** dependent on meteorological conditions and snow production strategy




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




- Development of forecasting tools to optimize snowmaking and slope management (PROSNOW project)



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# 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 managment of loops layers/points with incomplete arrays
  - Reducing the spectral resolution of TARTES optical scheme



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# 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).

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