Last scientific evolutions in the Crocus snowpack model

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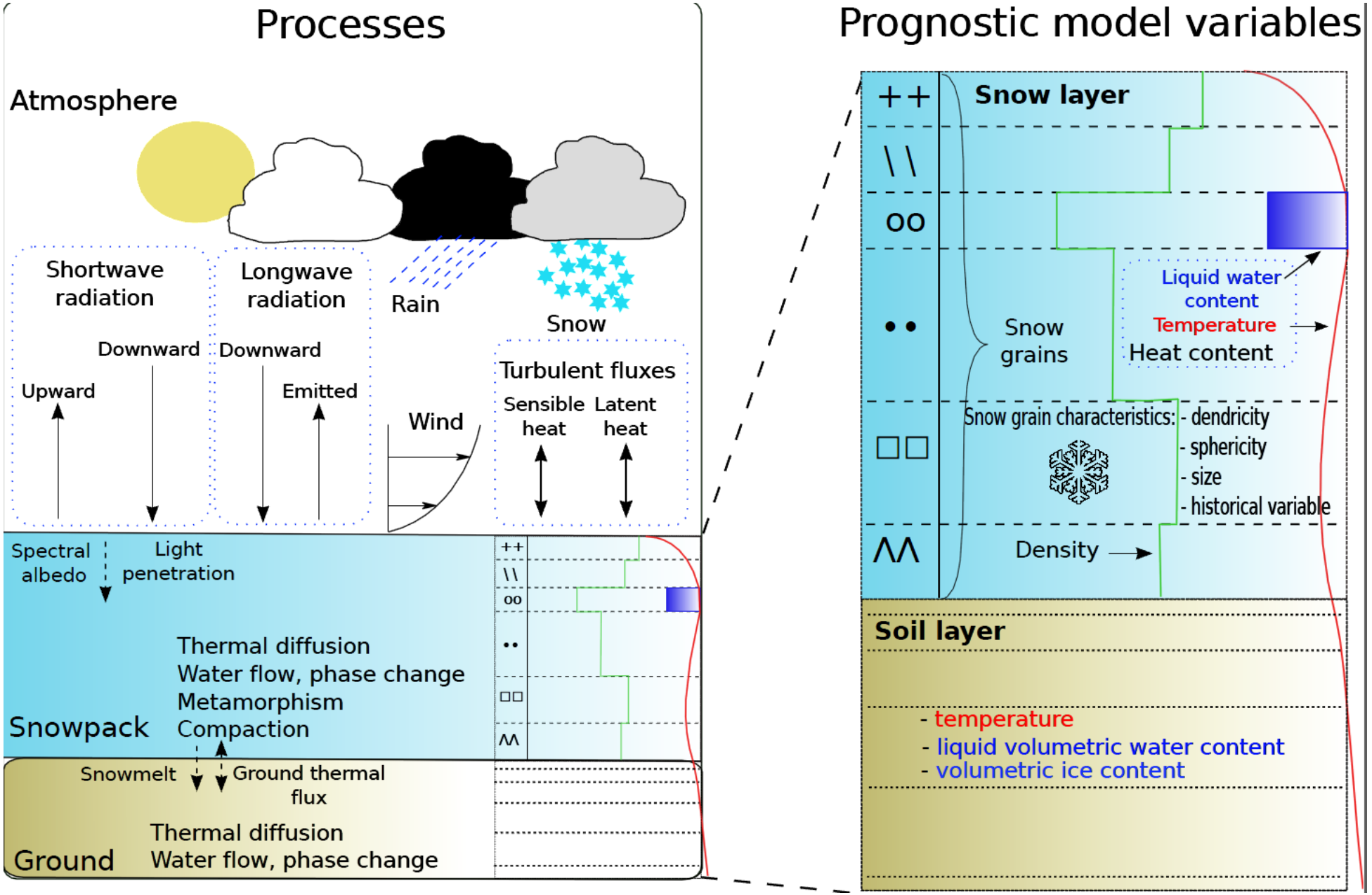
Outlook

- Basics principles of Crocus

- New implementations available in SURFEX V9
  - Light Absorbing Impuritites
  - Multiphysics
  - SYTRON (Blowing snow)
  - MEPRA (Mechanical stability)
  - Coupling with MEB (snow under forest)
  - Crocus-RESORT

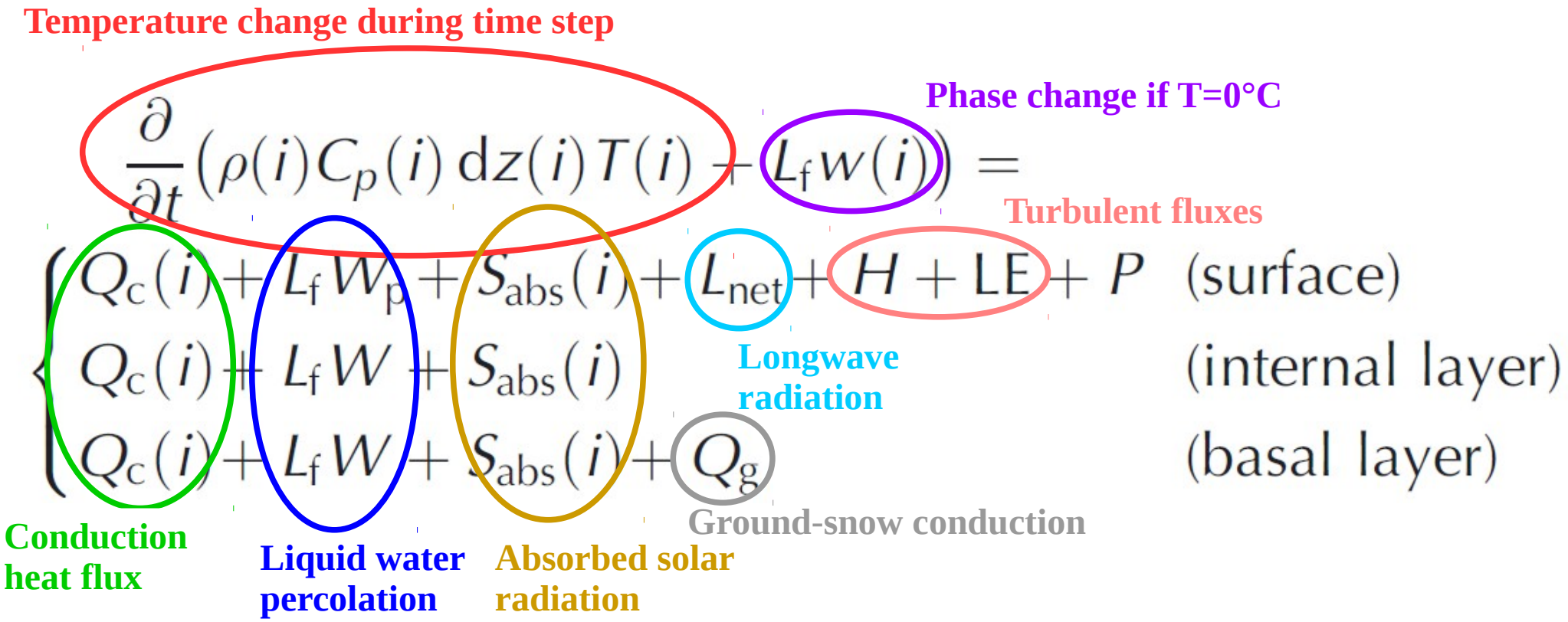
- Works in progress

Basics


Processes
Atmosphere
Shortwave radiation
Downward
Upward
Longwave radiation
Downward
Emitted
Rain
Snow
Wind
Turbulent fluxes
Sensible heat
Latent heat
Spectral albedo
Light penetration
Thermal diffusion
Water flow, phase change
Metamorphism
Compaction
Snowpack
Snowmelt
Ground thermal flux
Thermal diffusion
Water flow, phase change
Ground
Prognostic model variables
Snow layer
Snow grains
Liquid water content
Temperature
Heat content
Snow grain characteristics:
- dendricity
- sphericity
- size
- historical variable
Density
Soil layer
- temperature
- liquid volumetric water content
- volumetric ice content

Basics

- Heat diffusion in a stratified snowpack



Basics

- Heat diffusion in a stratified snowpack

$$\frac{\partial}{\partial t}\left(\rho(i)C_p(i)\,\mathrm{d}z(i)T(i) + L_f w(i)\right) =$$

$$\begin{cases} Q_c(i) + L_f W_p + S_{abs}(i) + L_{net} + H + \mathrm{LE} + P & \text{(surface)} \\ Q_c(i) + L_f W + S_{abs}(i) & \text{(internal layer)} \\ Q_c(i) + L_f W + S_{abs}(i) + Q_g & \text{(basal layer)} \end{cases}$$

- Many compent involves empirical parameterizations

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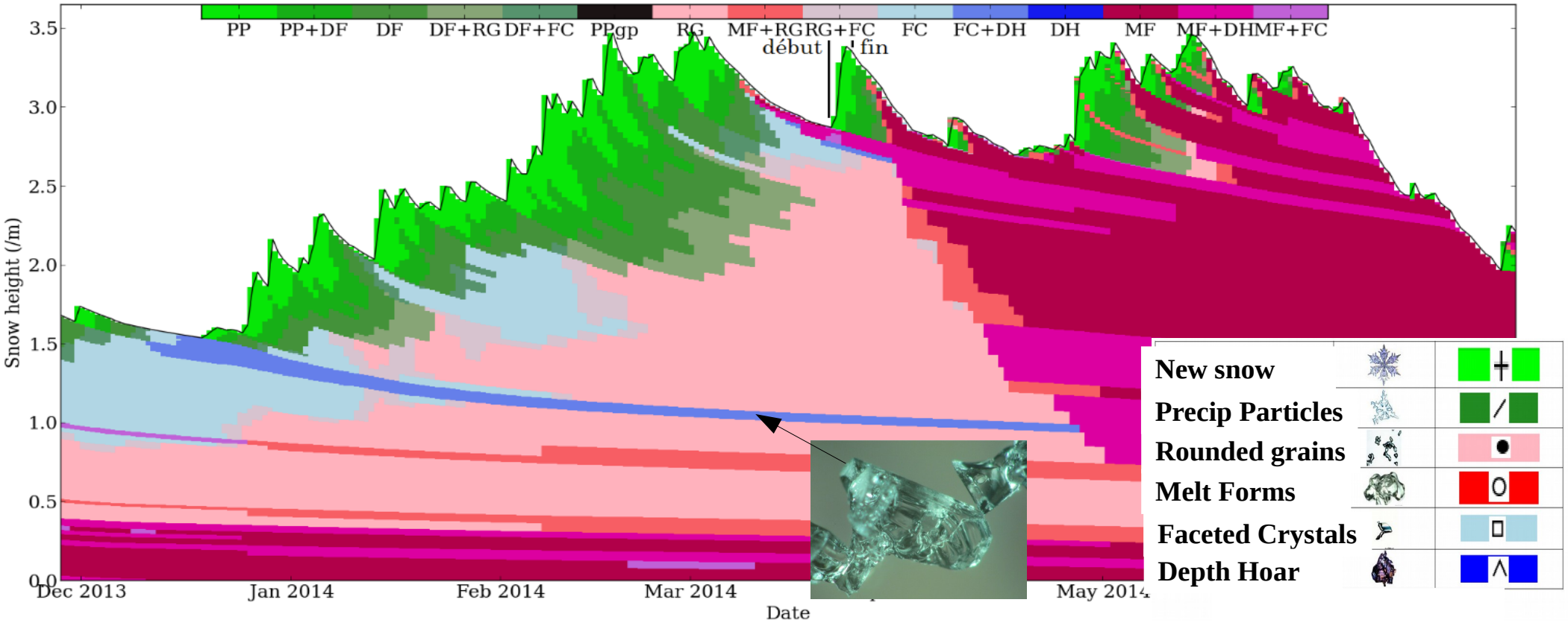
Basics

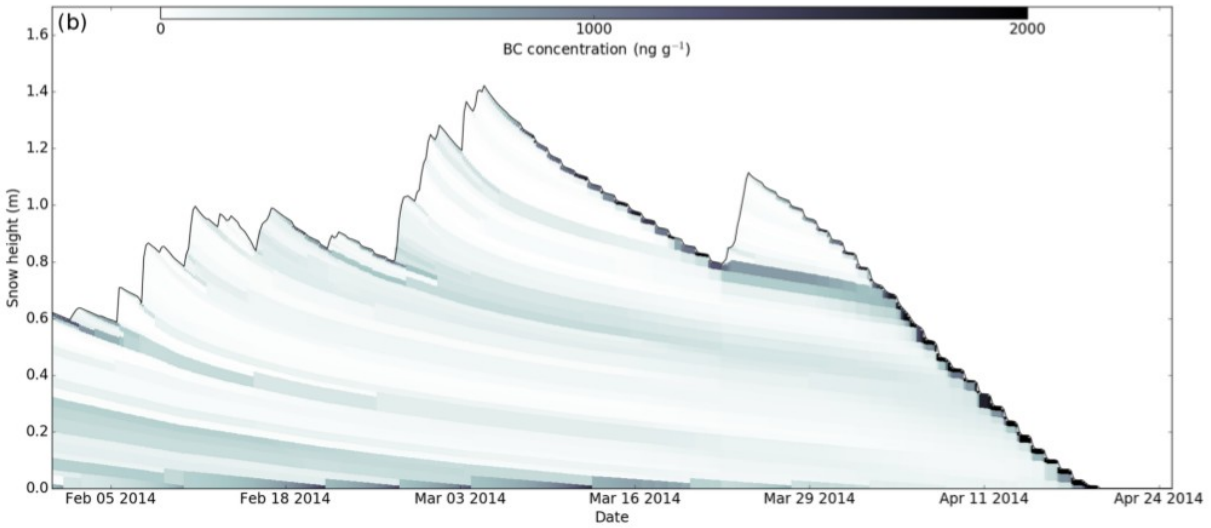
- Main specificities of Crocus (compared to ES):
  - **Lagrangian discretization**, maximum of **50 snow layers**
  - Explicit representation of **snow microstructure**
    Prognostic variables : Specific Surface Area and grain sphericity
    with empirical evolution laws



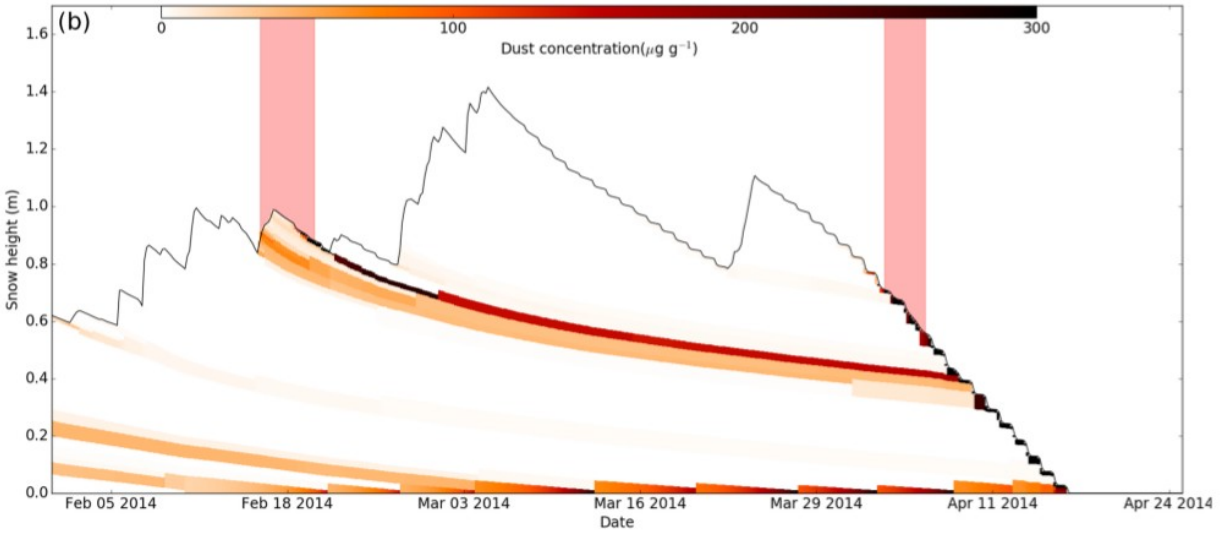
New implementations available in SURFEX V9

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

Black carbon



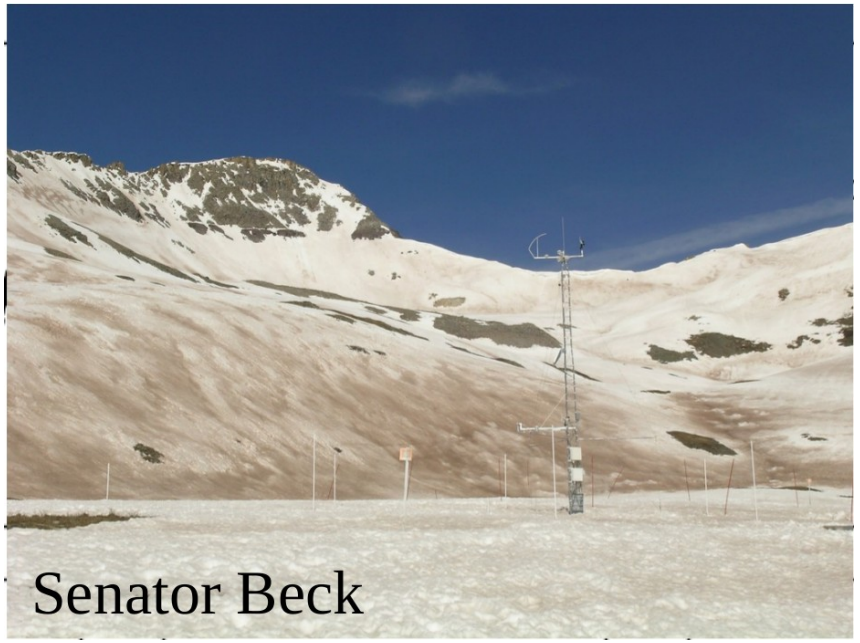
Dust

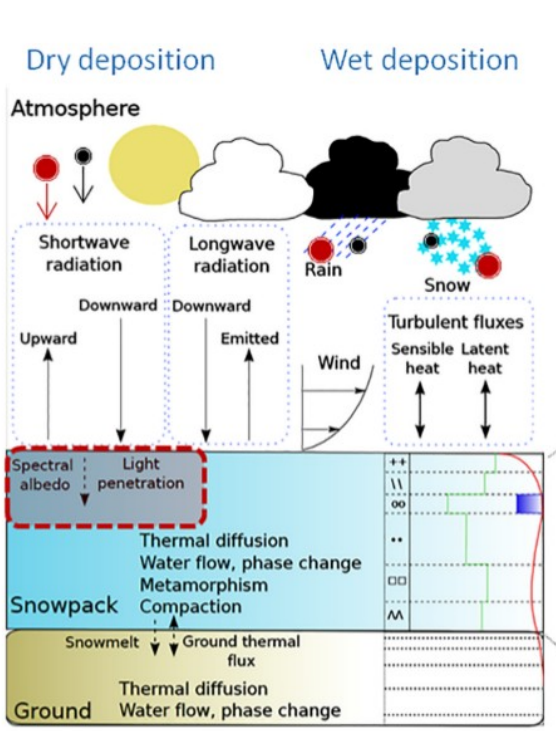


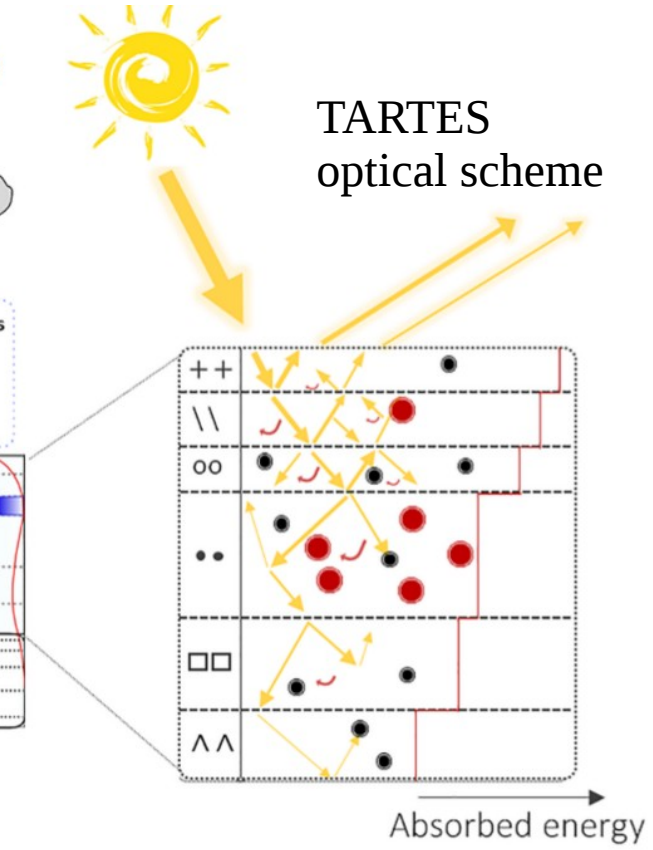
New implementations available in SURFEX V9

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

  → Impact on **absorption of solar radiation**



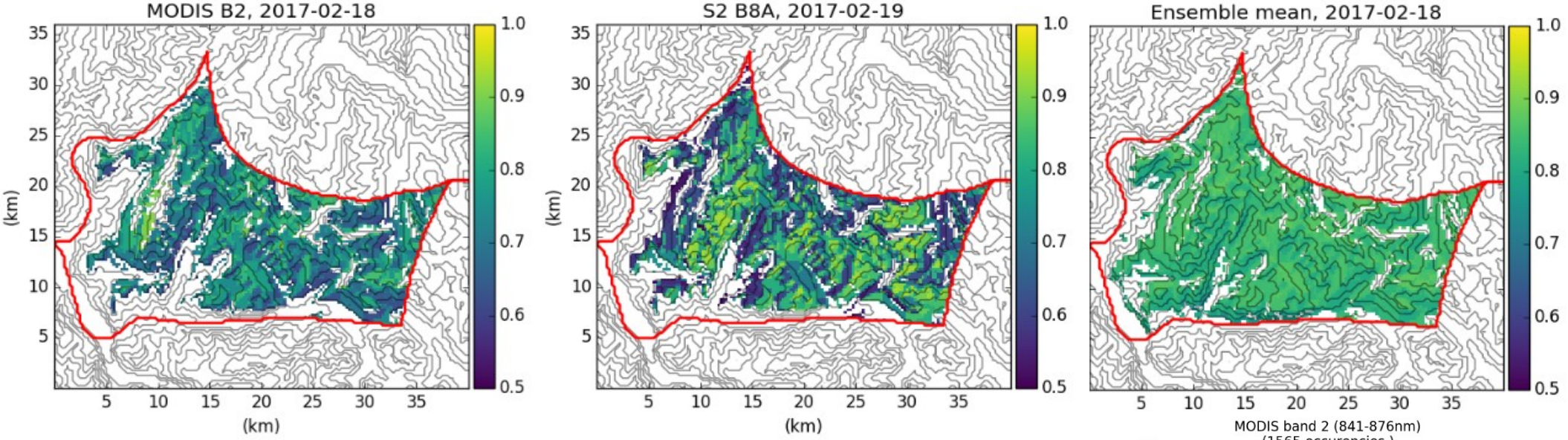




→ Necessary to apply the same snowpack models in contrasted areas (mid-latitude vs polar areas)

New implementations available in SURFEX V9

- 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, CRST, submitted

New implementations available in SURFEX V9

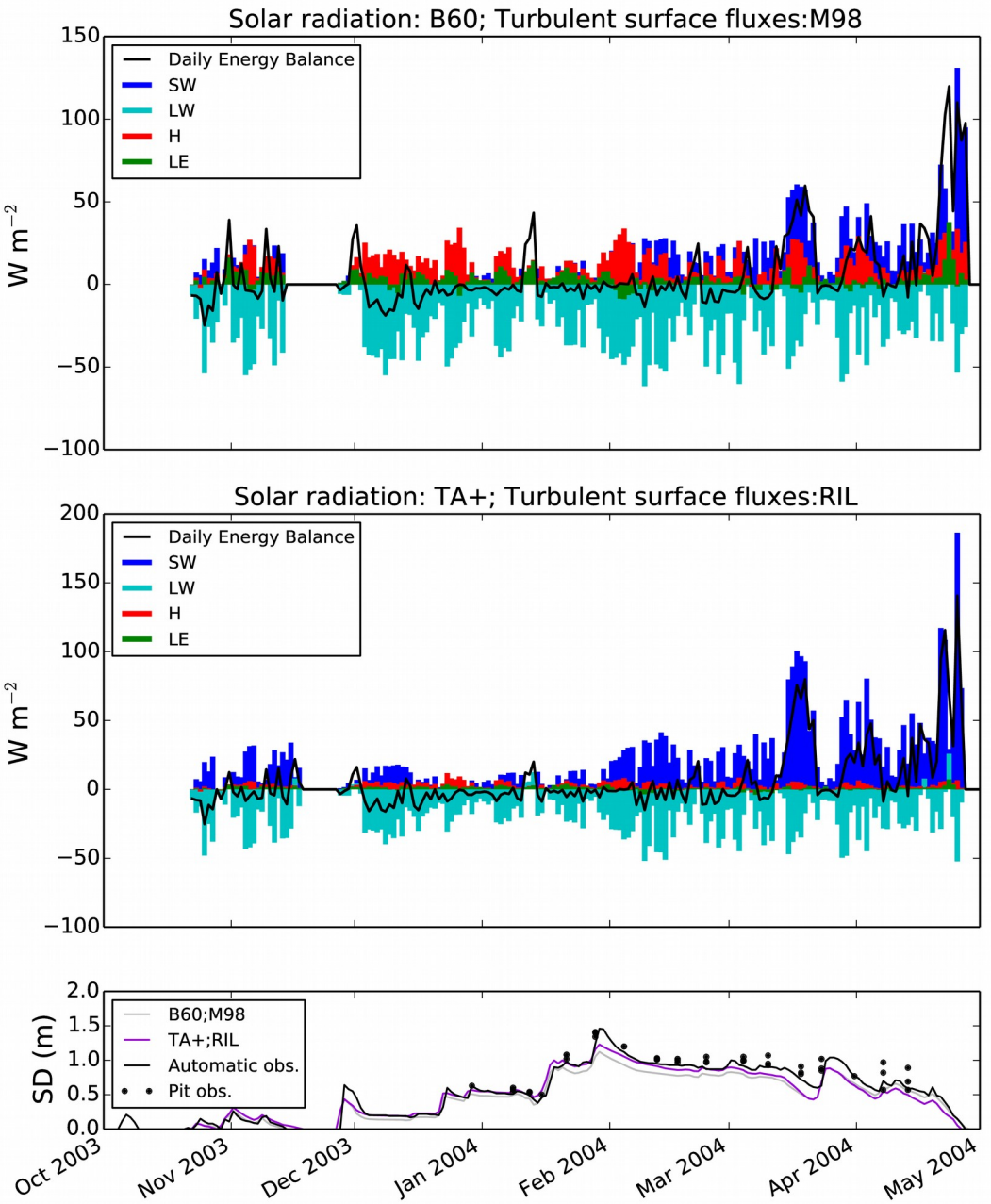
- **Equifinality** between parameterizations :

- 2 different model settings

  — Very different contributions to the energy balance

  — Very close simulated snow depths

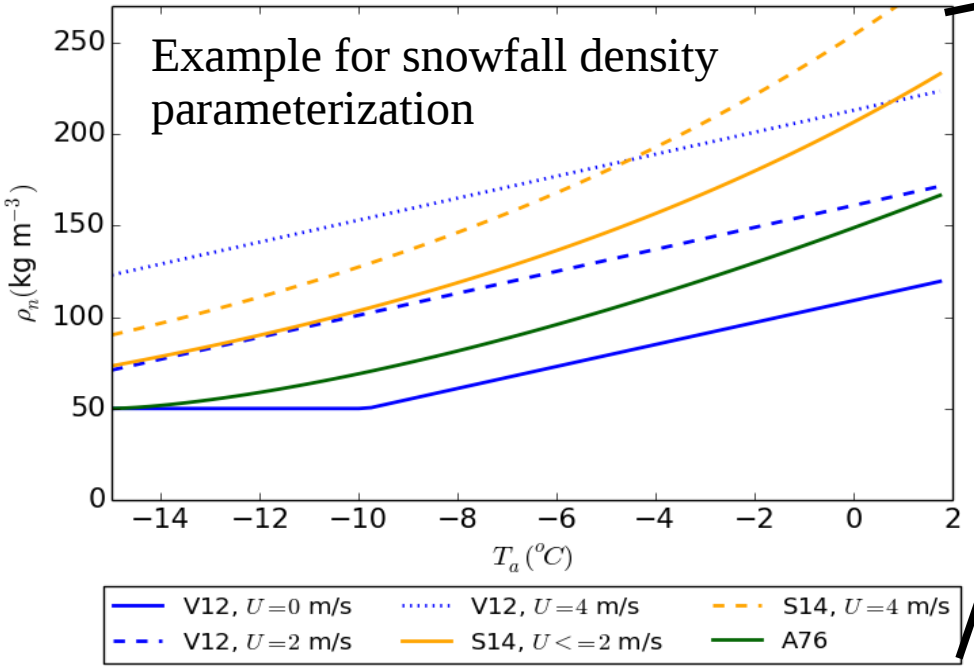
  — Same statistical skill on various evaluation variables, long periods and various sites

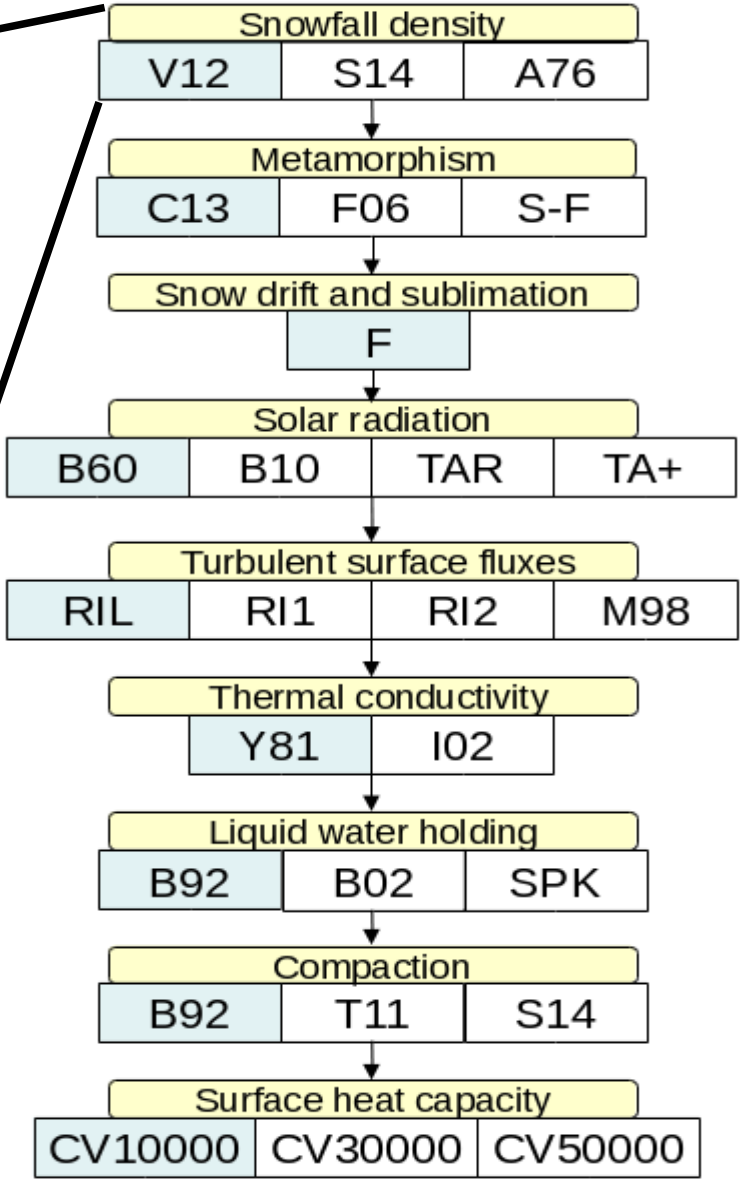


Lafaysse et al 2017

New implementations available in SURFEX V9

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



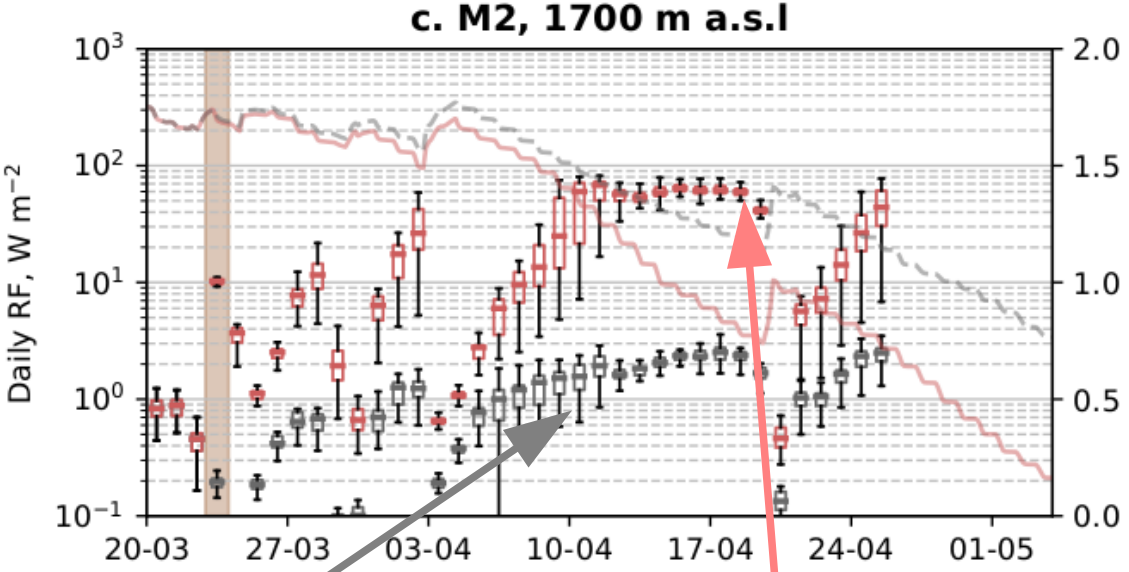


- 2 to 4 physical options for 8 key processes
  → **7776 possible members**
  → **35 members selections**
- Various applications :
  - **Climate projections** (Verfaillie et al 2018)
  - **Data assimilation** (Cluzet et al 2018)
  - **Process studies** (Dumont et al, in prep)

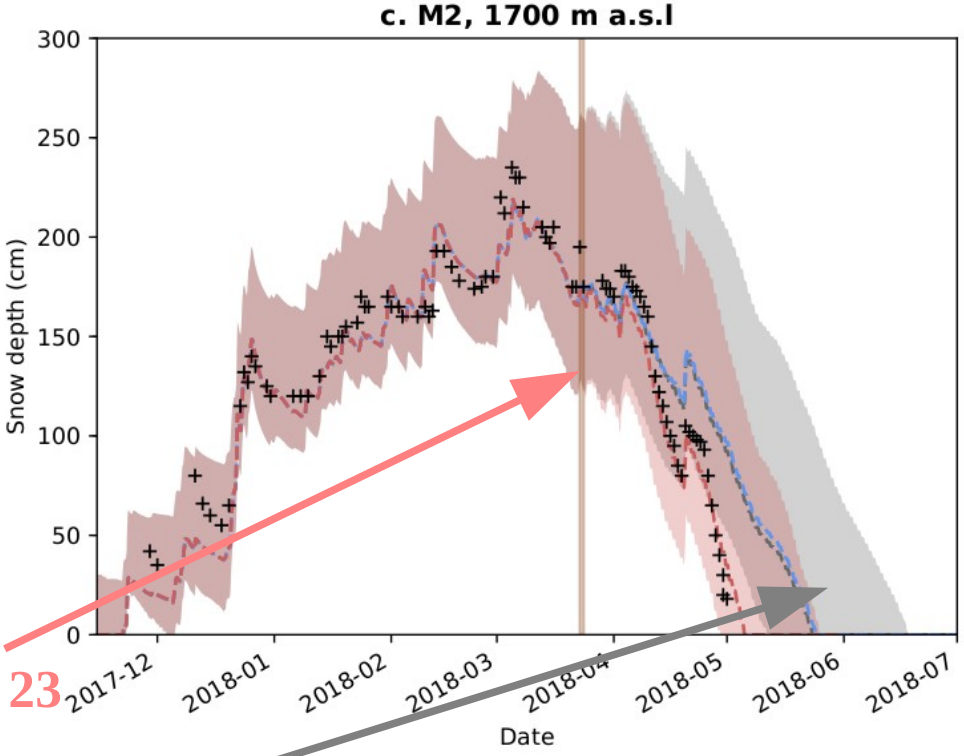
New implementations available in SURFEX V9

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

Radiative forcing due to impurities



Snow depth



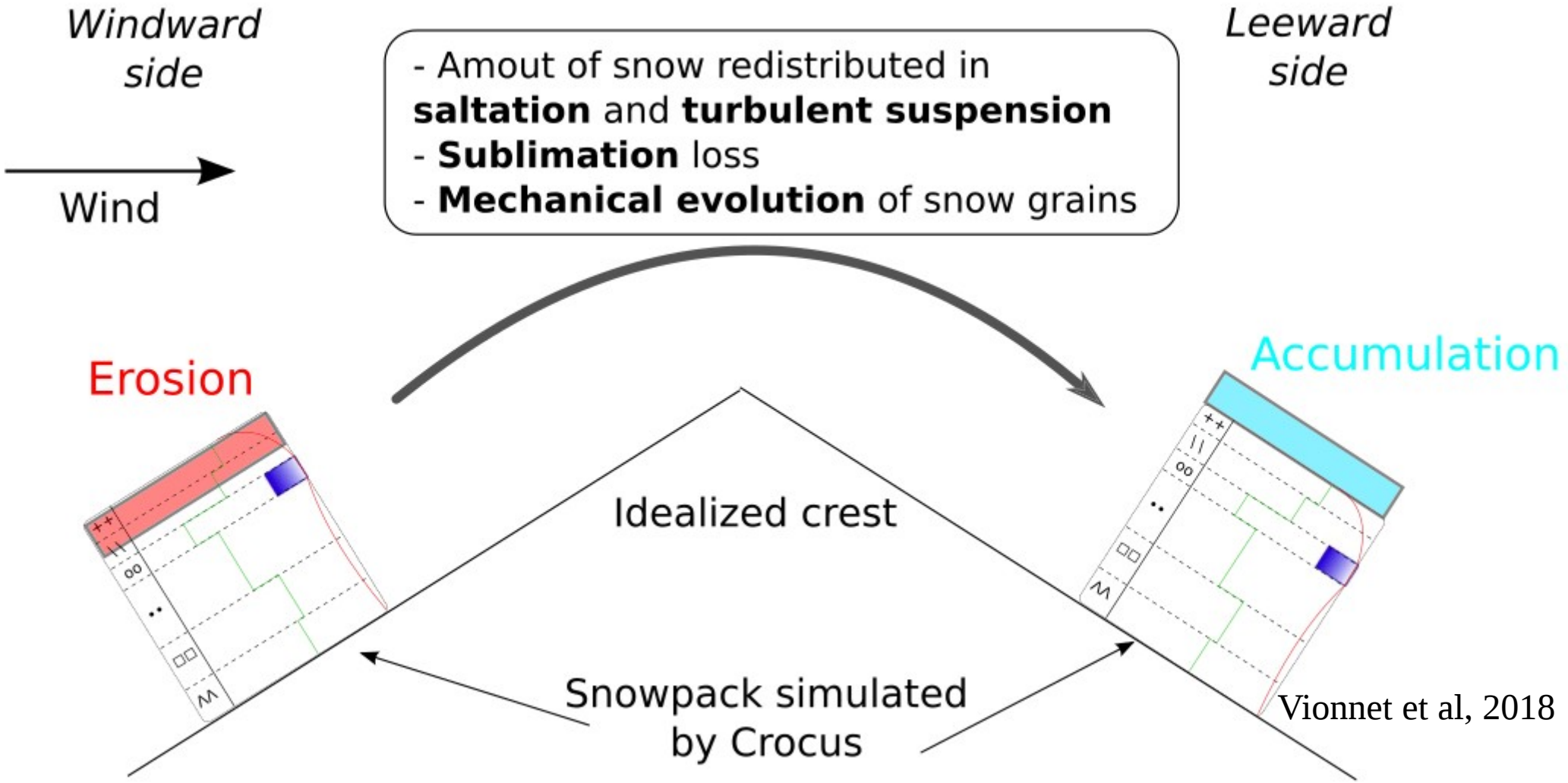
Forced by additional observed dust deposition of 7 g/m² on March 23

Constant dust deposition close to climatology

Dumont et al, in prep

New implementations available in SURFEX V9

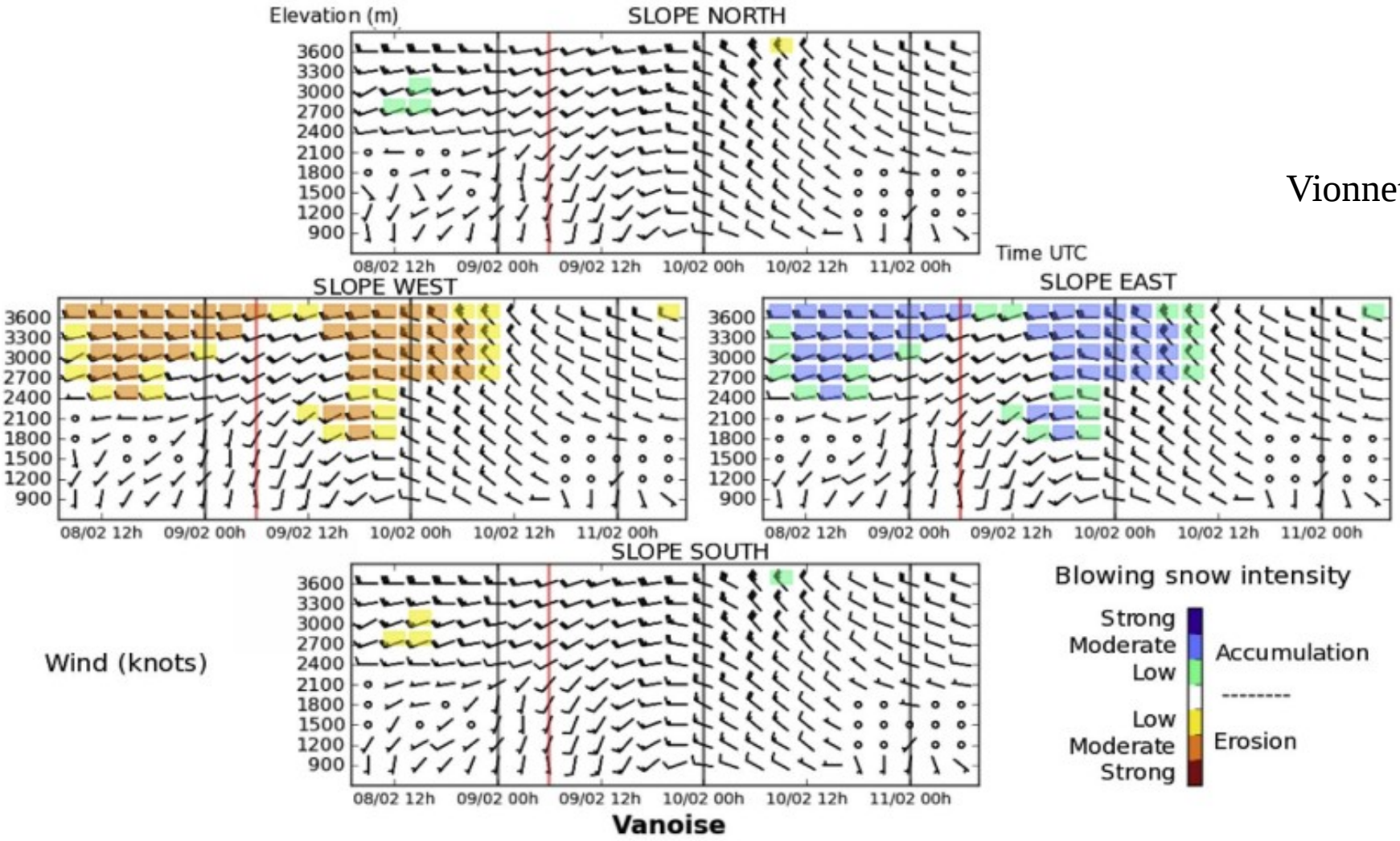
- SYTRON module for blowing snow
  - Only suitable for a specific geometry with topographic classes



Vionnet et al, 2018

New implementations available in SURFEX V9

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



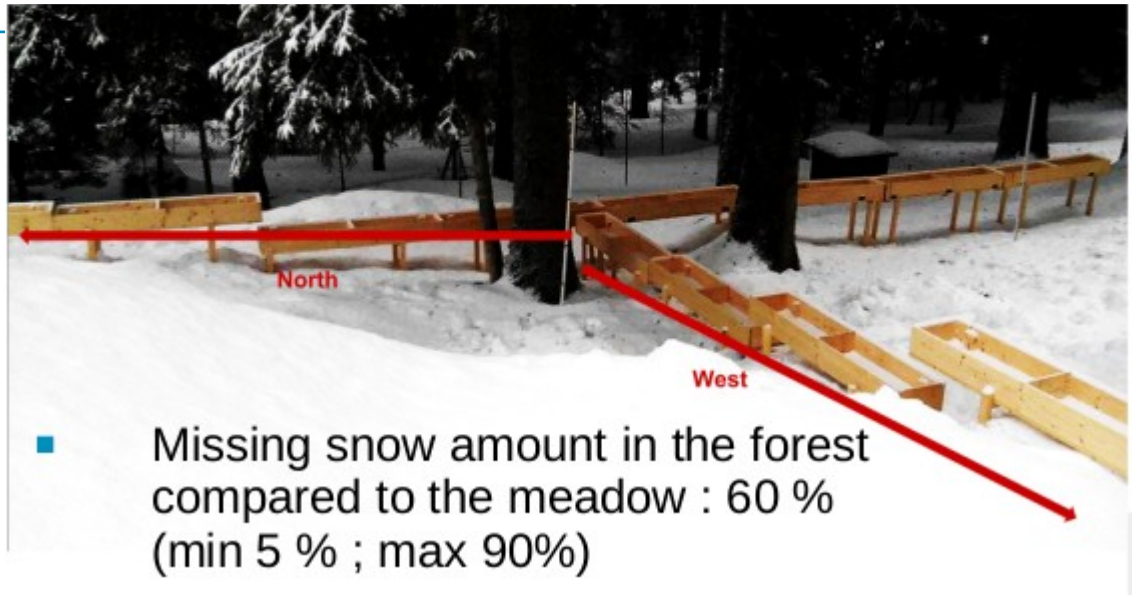
Vionnet et al, 2018

New implementations available in SURFEX V9

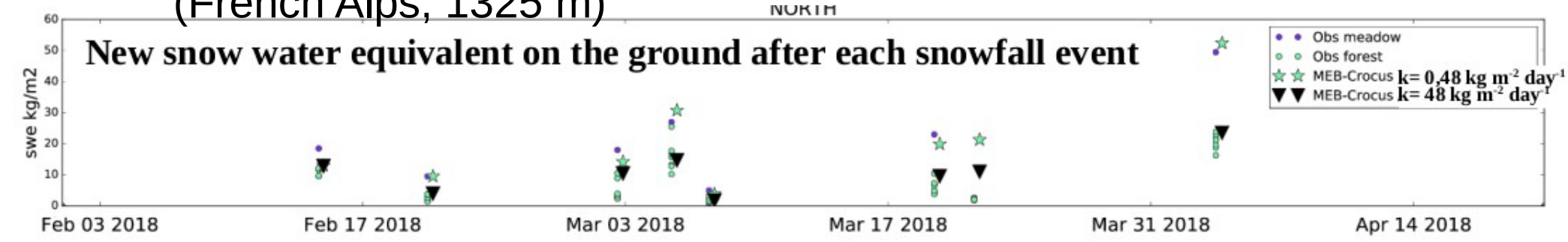
- MEPRA module (Giraud et al, 1992) : mechanical stability of the snowpack
  - Empirical computation of shear-constraint ratio from Crocus density and microstructure
  - Relevant for steep slopes (40°)
  - Transfer in SURFEX for optimization

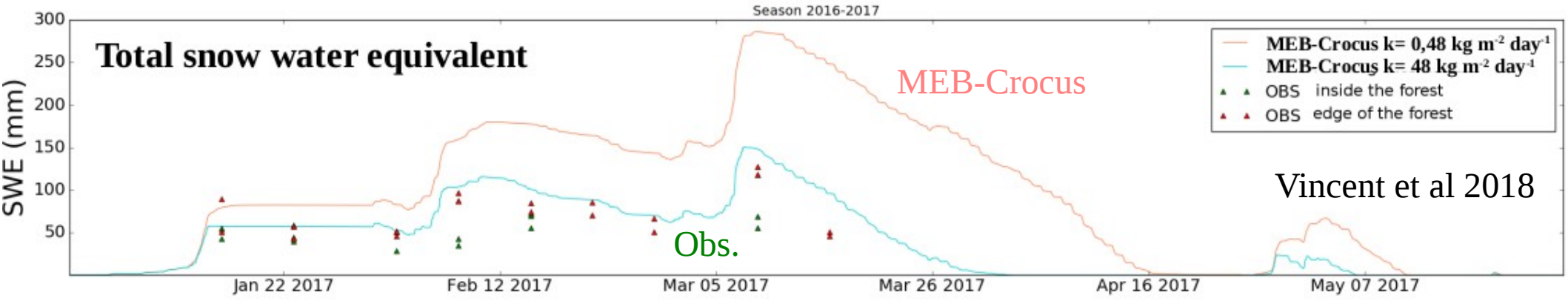
New implementations available in SURFEX V9

- Coupling with MEB (Boone et al 2017) for snow-vegetation interactions
  - Satisfactory results in Saskatchewan, Canada (ESM-SnowMIP sites)
  - Poor results at Col de Porte (French Alps, 1325 m)



- Missing snow amount in the forest compared to the meadow : 60 % (min 5 % ; max 90%)

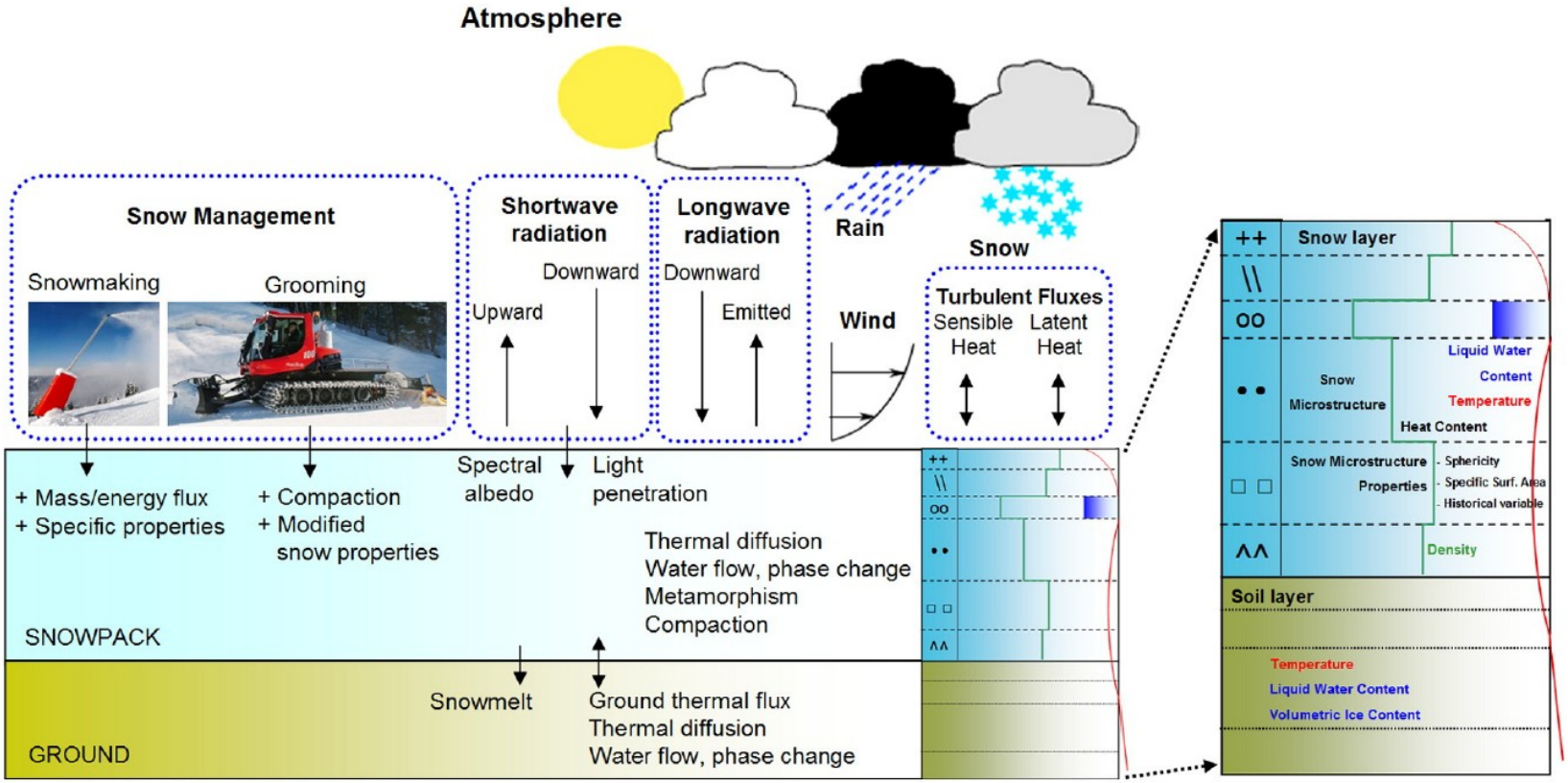




Vincent et al 2018

New implementations available in SURFEX V9

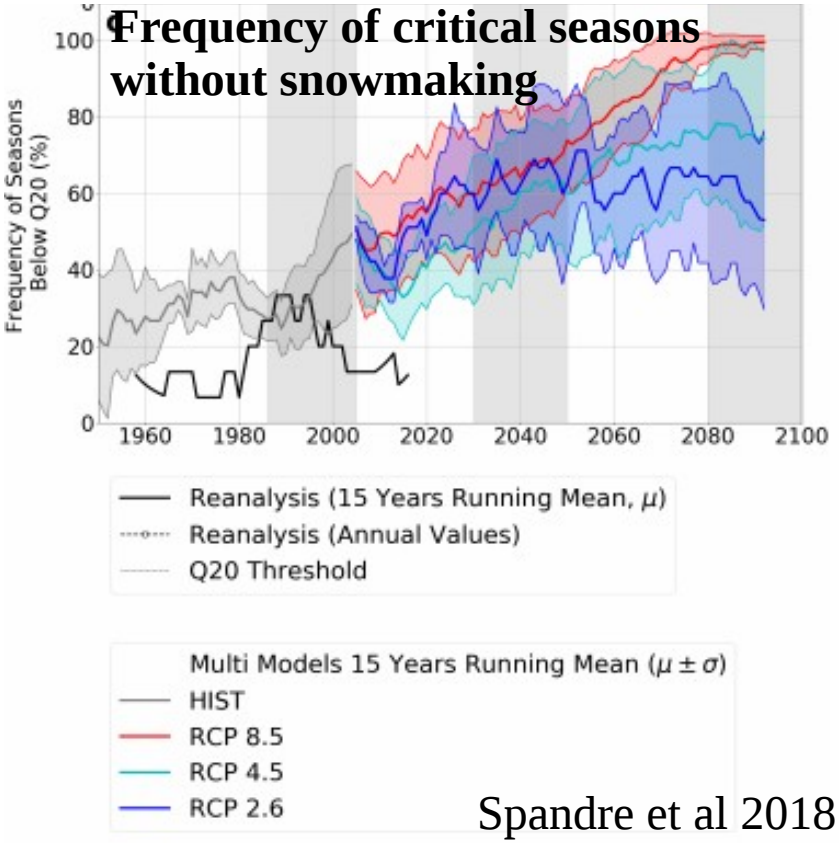
- Crocus-RESORT : optional module for grooming and snowmaking
  - Impact of **grooming** on density and microstructure
  - **Snowmaking** dependent on meteorological conditions and snow production strategy



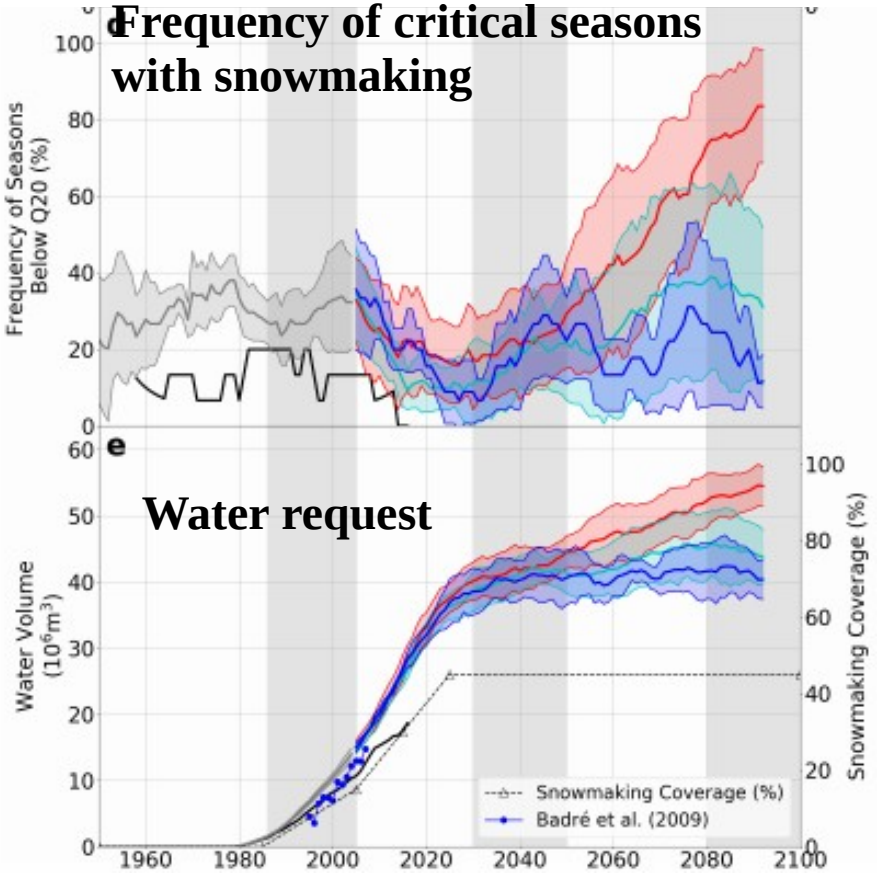
Spandre et al., 2016 : Crocus-RESORT

New implementations available in SURFEX V9

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



Spandre et al 2018



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

Works in progress (for after V9)

- **Data assimilation** for Crocus in **SODA** (PhD B. Cluzet 2017-2020)
  - Algorithm : particle filter (local or with localization)
  - Variables : visible and NIR reflectances, snow depths, ...

- Consolidation of MEB-Crocus coupling (PhD project 2019-2022)
  - Parameterizations of **intercepted snow**

- Numerical **optimizations** in Crocus : (R. Nheili 2019)
  - Improvement of vectorization (less « IF » when possible)
  - Analysis of optimal solution for loops layers/points, not obvious !
  - Spectral resolution of TARTES optical scheme
    - Required for **future operational system** for avalanche hazard forecasting (ensembles, high resolution, reflectances DA)
    - Required for an increasing use in **coupled mode**

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