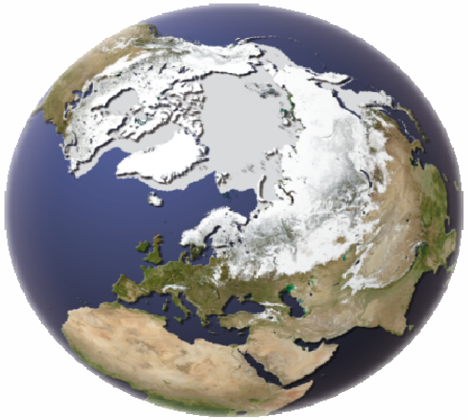
On the benefit of using spectral albedo and light penetration depth in detailed snowpack simulations

M. Dumont[1], M. Lafaysse[1], G. Picard[2], L. Arnaud[2], Q. Libois[2,3] and S. Morin[1]

1: Météo-France – CNRS, CNRM UMR 3589, Centre d'Études de la Neige, Grenoble, France
2: UGA / CNRS, Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE) UMR 5183, Grenoble, 38041, France
3: now at: ESCER Centre, Department of Earth and Atmospheric Sciences, Université du Québec à Montréal, 201 Av. du Président-Kennedy, Montréal, H3C3P8, Canada

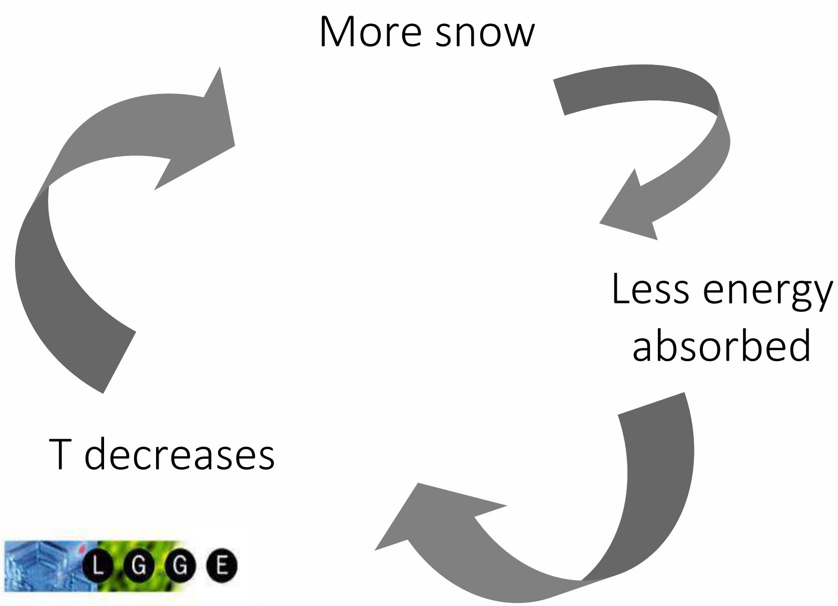
4th Workshop on Remote Sensing and Modelling of Surface Properties, Grenoble, 14-16 March 2016

White snow



Snow is white which implies that it reflects much more solar light than other earth surfaces.

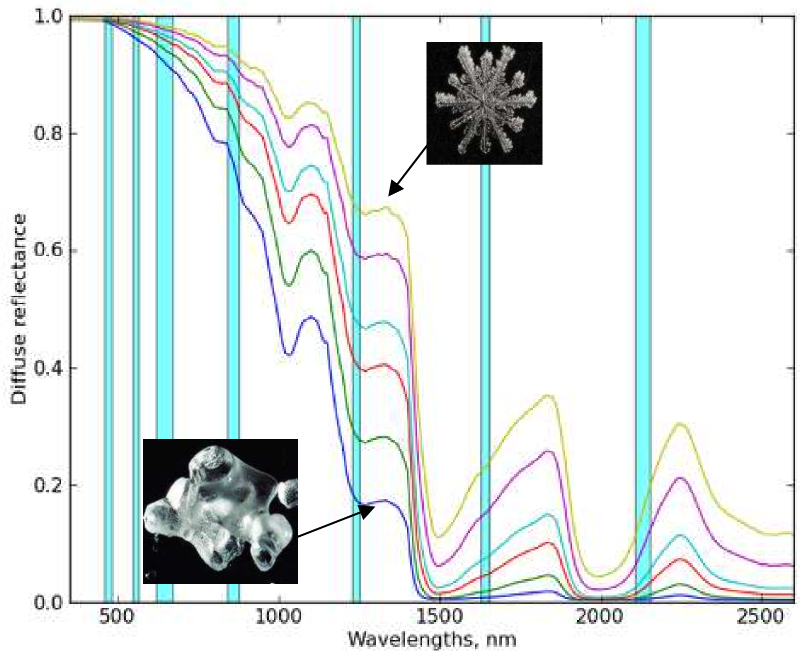
Impact on the Earth energy budget and on the global climate



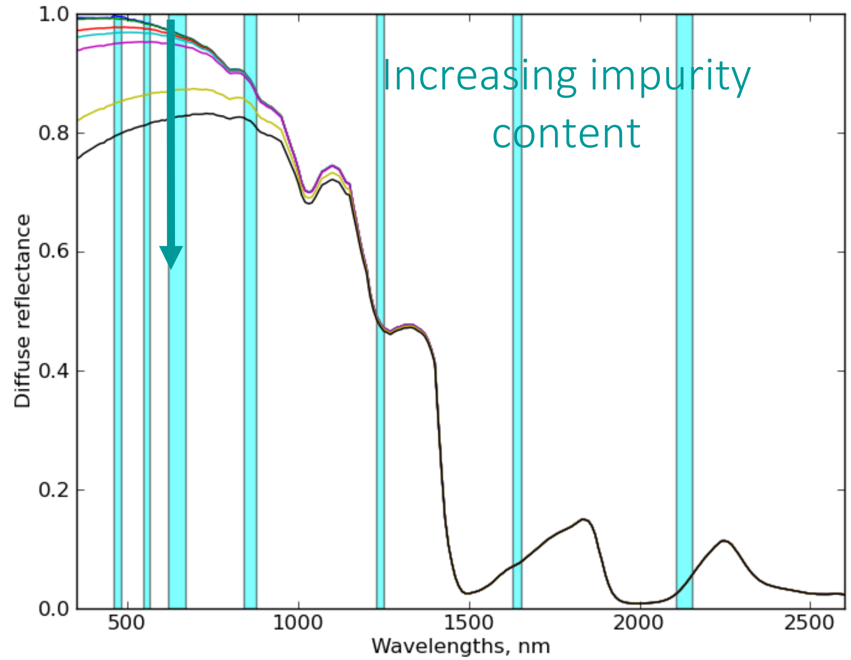
[Imbrie & Imbrie, 1980]

Snow optical properties : fifty shades of white

Snow microstructure



Snow impurity content



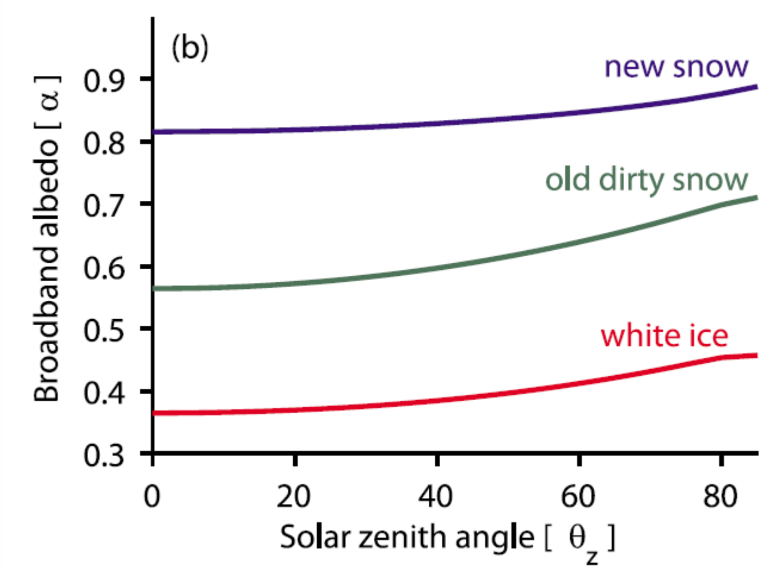
Snow optical properties are mainly determined by its microstructure and the light absorbing impurity content

This leads to several positive snow albedo feedbacks.

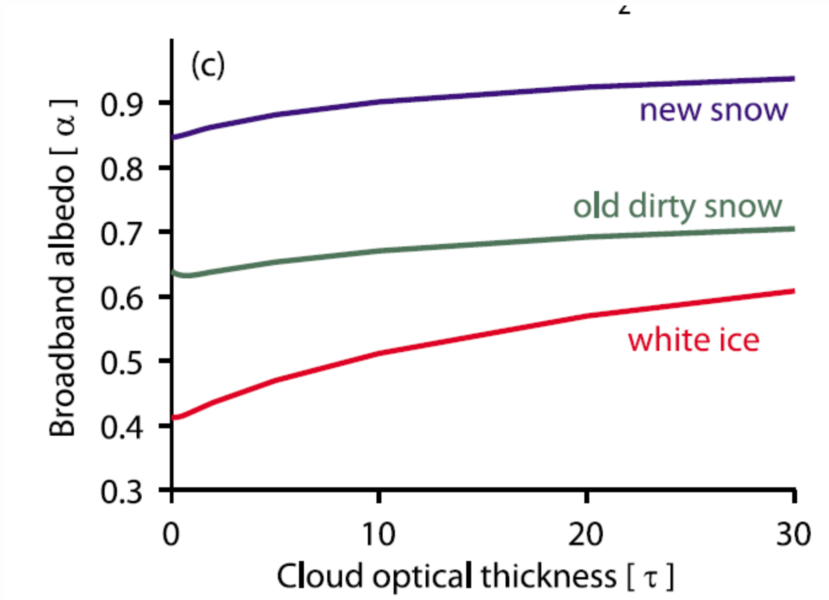
OSUG TERRE UNIVERS ENVIRONNEMENT
CNRS
LGGE
Université Joseph Fourier GRENOBLE
CNRS
METEO FRANCE

Snow optical properties and solar irradiance

Solar zenith angle



Cloud optical thickness

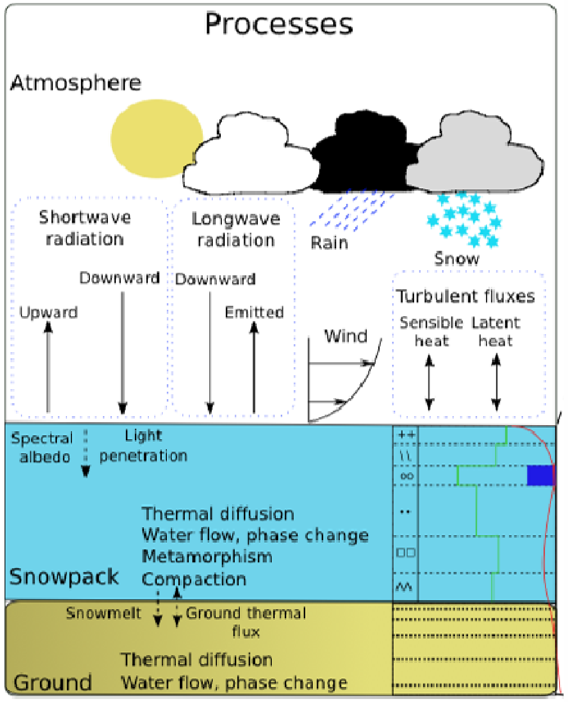


[Gardner and Sharp, 2010]

Snow albedo is also influenced by the angular and spectral characteristics of the solar incoming irradiance.

OSUG TERRE UNIVERS ENVIRONNEMENT · CNRS · LGGE · Université Joseph Fourier Grenoble · CNRS · METEO FRANCE

Detailed snowpack modelling



Detailed snowpack model Crocus *[Brun et al., 1992 ; Vionnet et al., 2012]* :

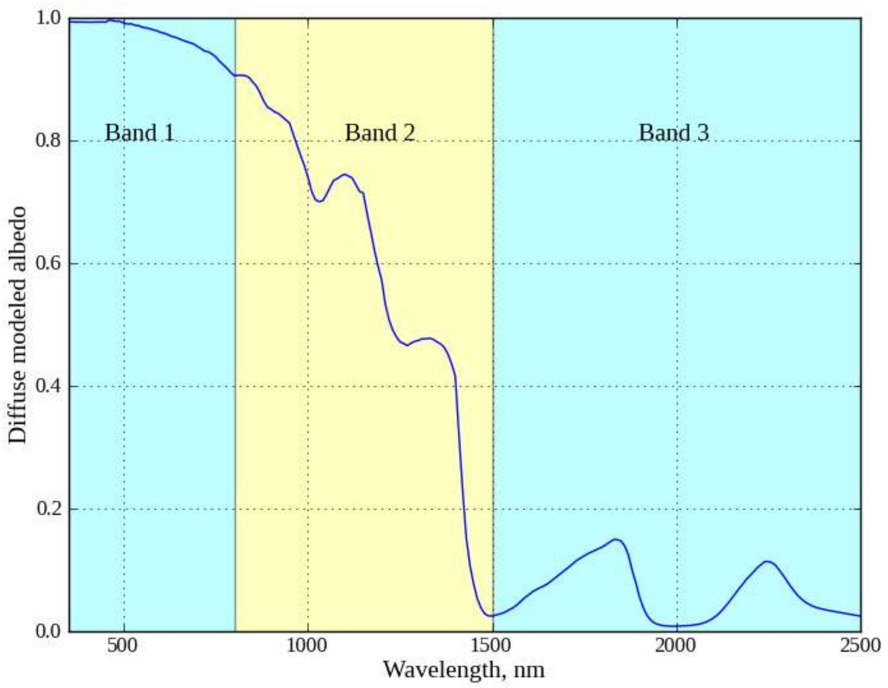
•Lagragian representation of the snowpack

•Handles the major physical processes leading to snowpack evolution

Crocus is used for operational avalanches forecasting in Météo-France but also for a wide range of applications including hydrological and climatic studies.

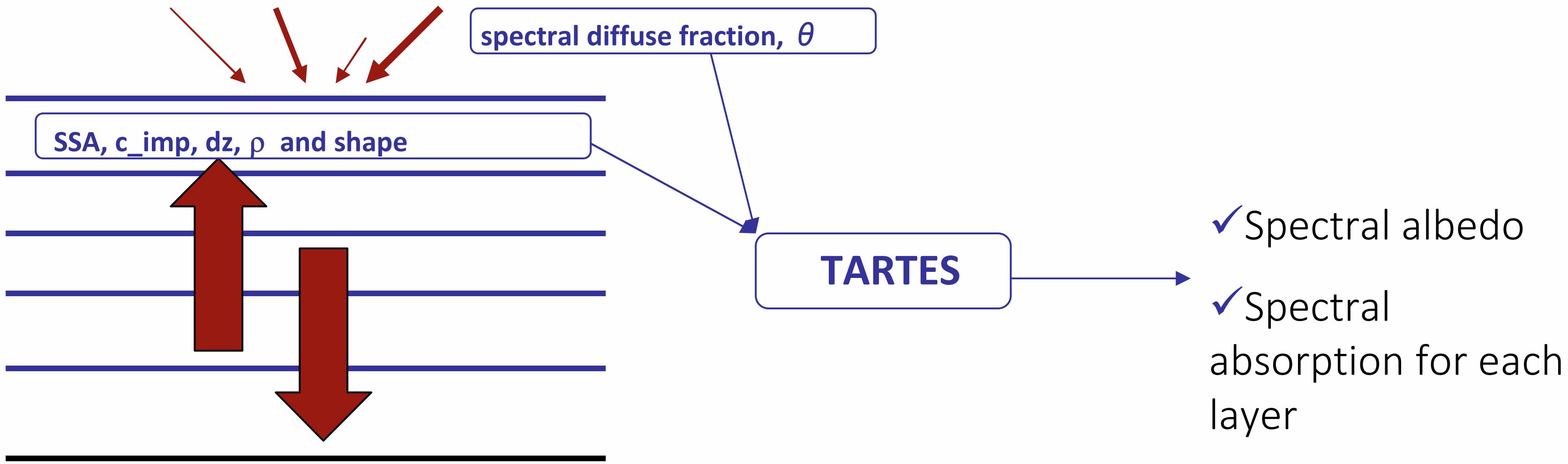
Crocus original radiative scheme

- 3 large spectral bands
- No dependance on solar zenith angle
- Account for the broadband diffuse to direct irradiance ratio only
- Parametrisations derived from *Wiscombe and Warren, 1980*
- Implicitely account for the impurity effect via an ageing coefficient
- Only one or two snow layers accounted for in the albedo calculation



Two-streAm Radiative TransfEr in Snow, TARTES

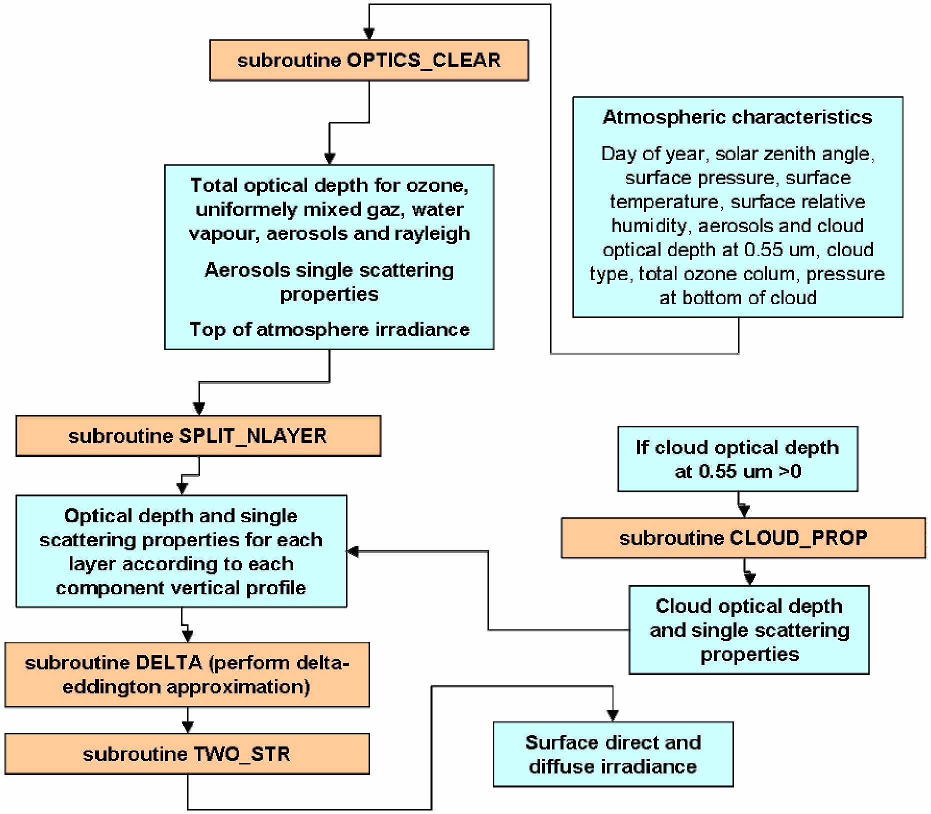
- ✓ Two stream radiative transfer model based on *Kokhanovsky et Zege 2004* -> account for all the snow layers
- ✓ Explicit impurity content
- ✓ 10 nm spectral resolution
- ✓ Account for shape factor (snow grains differ from spheres)
- ✓ Account for spectral and angular characteristics of the incoming radiation



[Libois et al., 2013 ; 2014]

Spectral solar irradiance : ATMOTARTES

Two-stream model derived from SBDART [*Richiazzi et al., 1998*]



- Account for ozone, aerosols, mixed gaz, water vapour and clouds
- Evaluated vs SDBART (r^2 >0.988)
- Used to compute the spectral diffuse to total ratio of the solar irradiance from either diffuse and direct or total broaband irradiance

[Dumont et al., 2015 ; AGU]

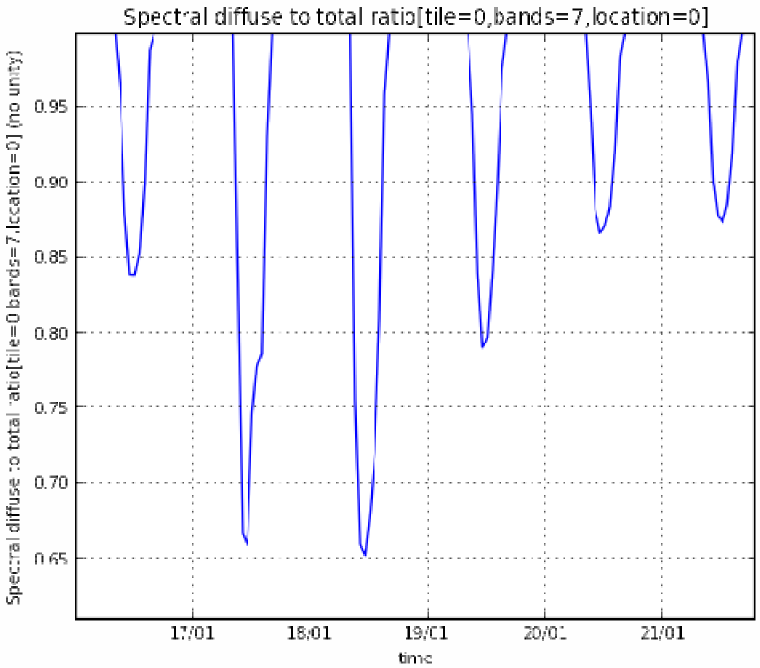
OSUG TERRE UNIVERS ENVIRONNEMENT

LGGE

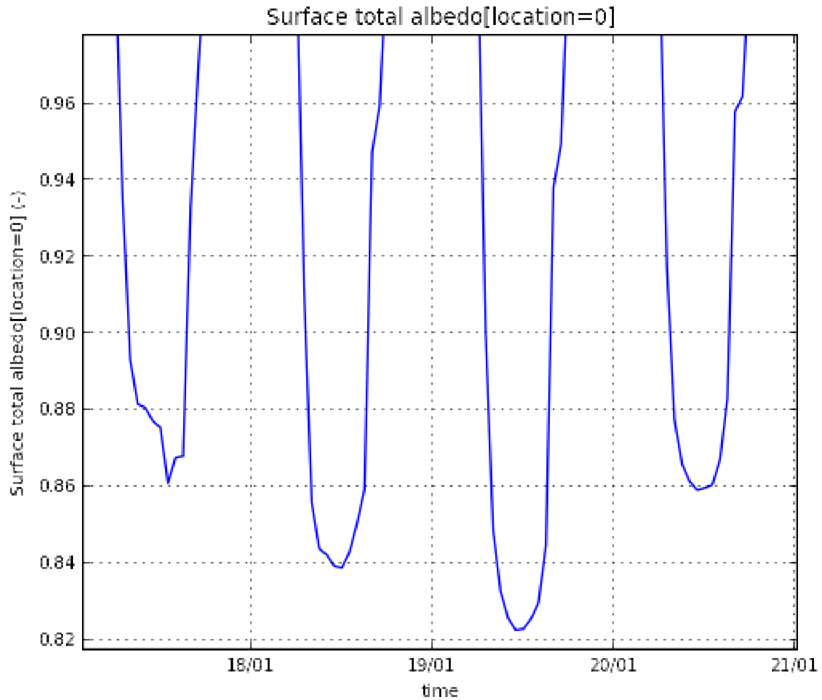
Université Joseph Fourier GRENOBLE

METEO FRANCE

Crocus with the full radiative transfer schemes



At 420 nm



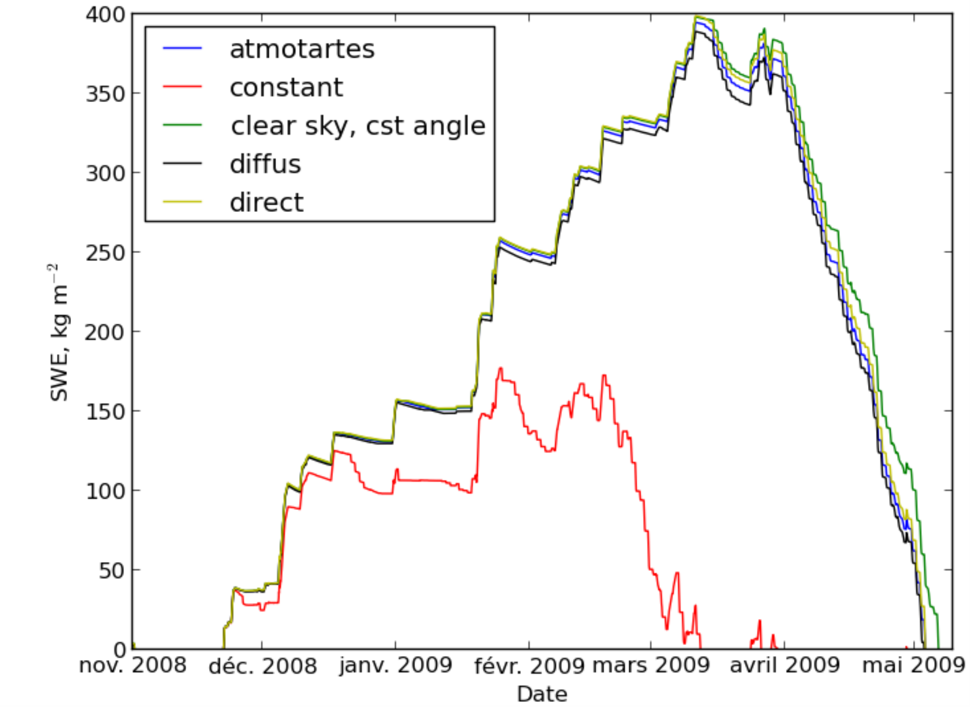
Diurnal cycle of broadband albedo

OSUG TERRE UNIVERS ENVIRONNEMENT

Pôle Grenoblois d'étude et de recherche pour la prévention des Risques Naturels

METEO FRANCE

Impact on snow simulations



Limited impact of the direct/diffuse repartition as long as the spectral repartition in known, but depends on SZA.

OSUG TERRE UNIVERS ENVIRONNEMENT

CNRS

LGGE

Université Joseph Fourier GRENOBLE

CNRS

METEO FRANCE

Impurity content as a prognostic variable

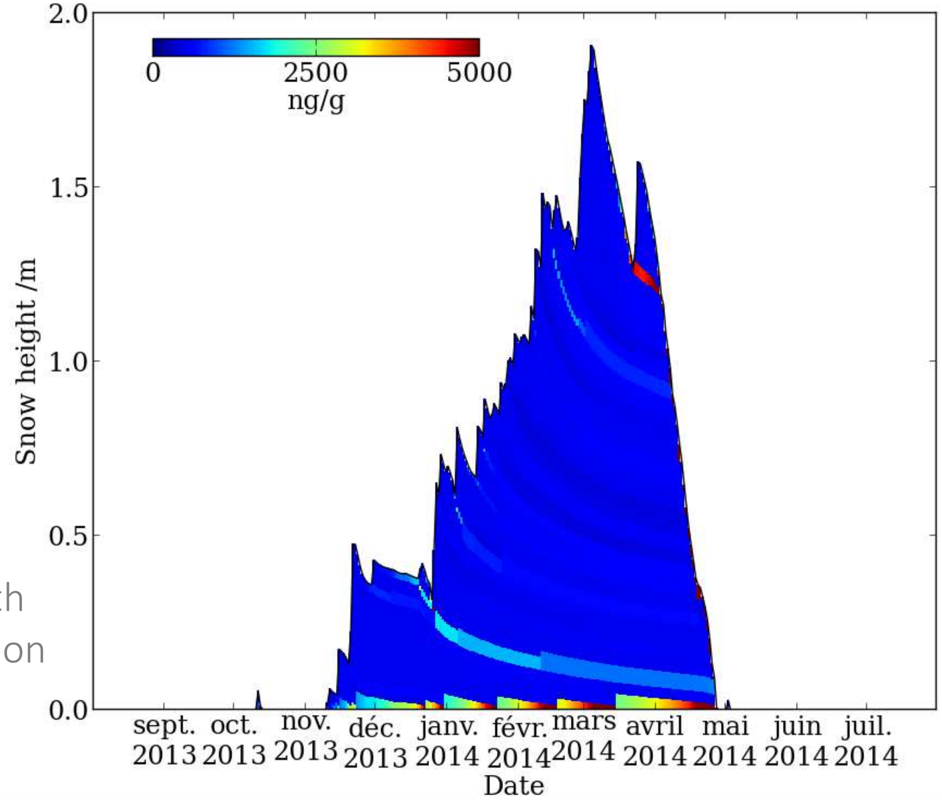
- As for now, only one type « BC equivalent», dry and wet deposition fluxes are set to constant values
- Total conservation of the impurity mass

$$c(t+\Delta t) = c(t) + \Delta t \tau_{\mathrm{dry}} e^{-D/h_{\mathrm{ref}}}$$

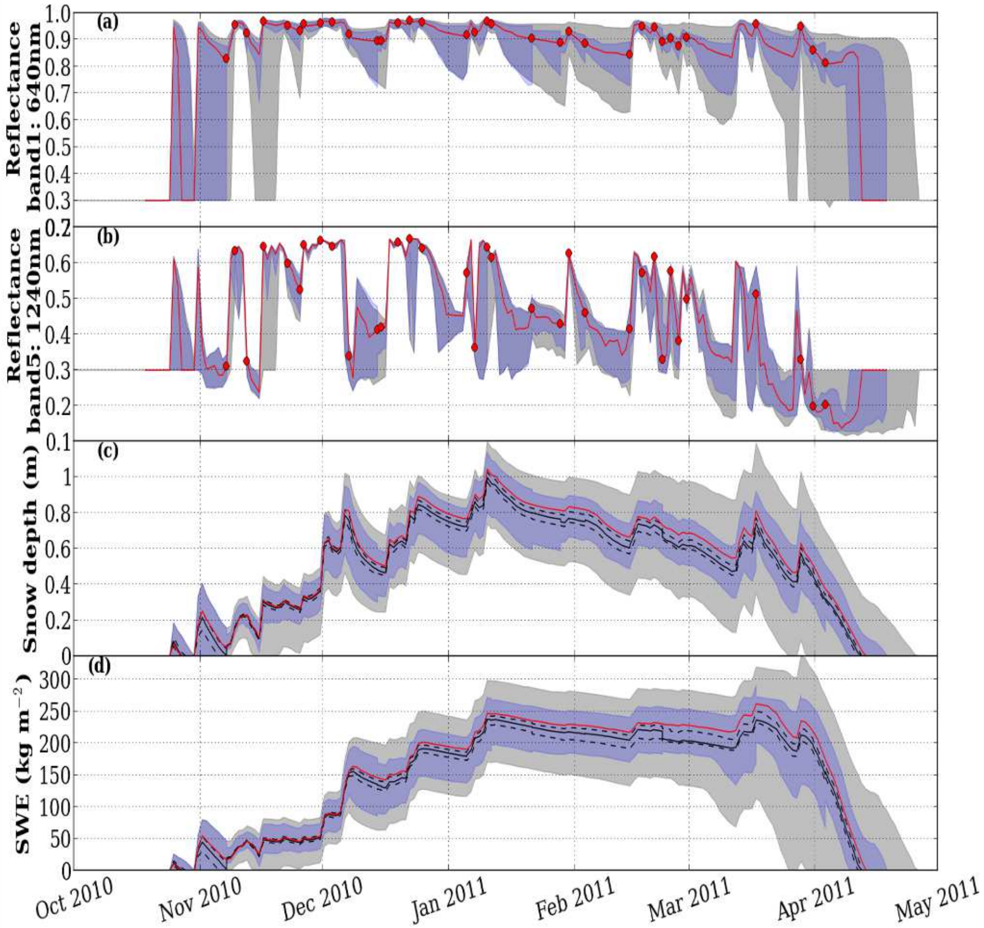
Depth

Dry deposition flux

e-folding depth for dry deposition



Application 1 : Assimilation



This new scheme allows the direct assimilation of satellite surface reflectance in the snow model.

ATMOTARTES + TARTES being the observation operator.

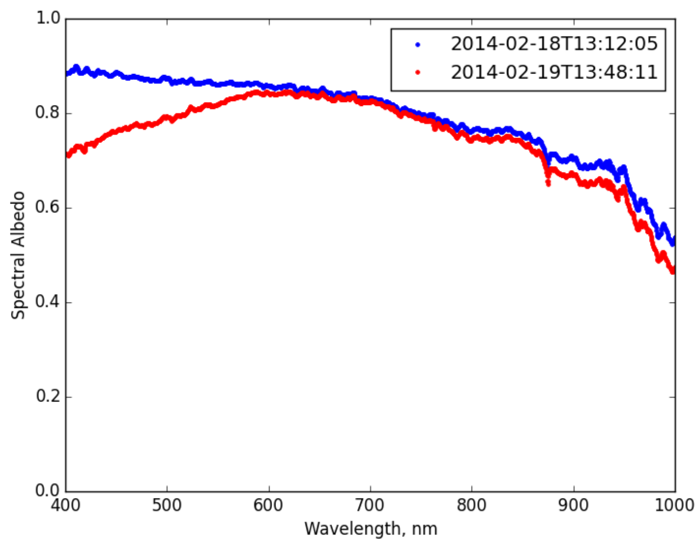
This is detailed in L. Charrois talk on Wednesday morning.

[Charrois et al. ,2015]

OSUG
TERRE UNIVERS ENVIRONNEMENT
CNRS
LGGE
Université Joseph Fourier GRENOBLE
METEO FRANCE

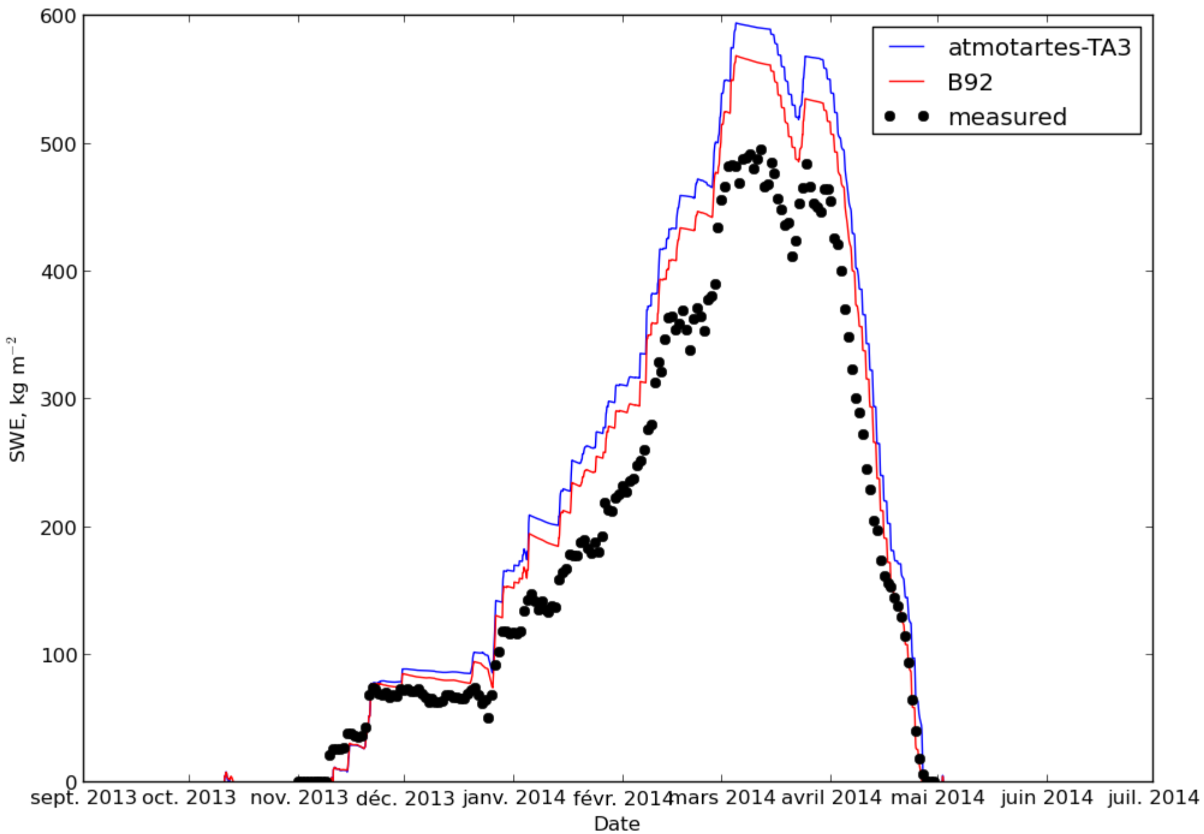
Application 2 : Spectral albedo measurements at Col de Porte, 1325 m a.s.l

- Operations : December 2013-May 2014
- Spectra collected every 12 min, spectral resolution >1 nm, spectral range 300-1100 nm
- Raw spectra are corrected for : (i) dark current, (ii) calibration and (iii) angular response of the light collector using modelled diffuse to total irradiance ratio *[Picard et al, 2015]*



OSUG
TERRE UNIVERS ENVIRONNEMENT
cnrs
LGGE
Université Joseph Fourier GRENOBLE

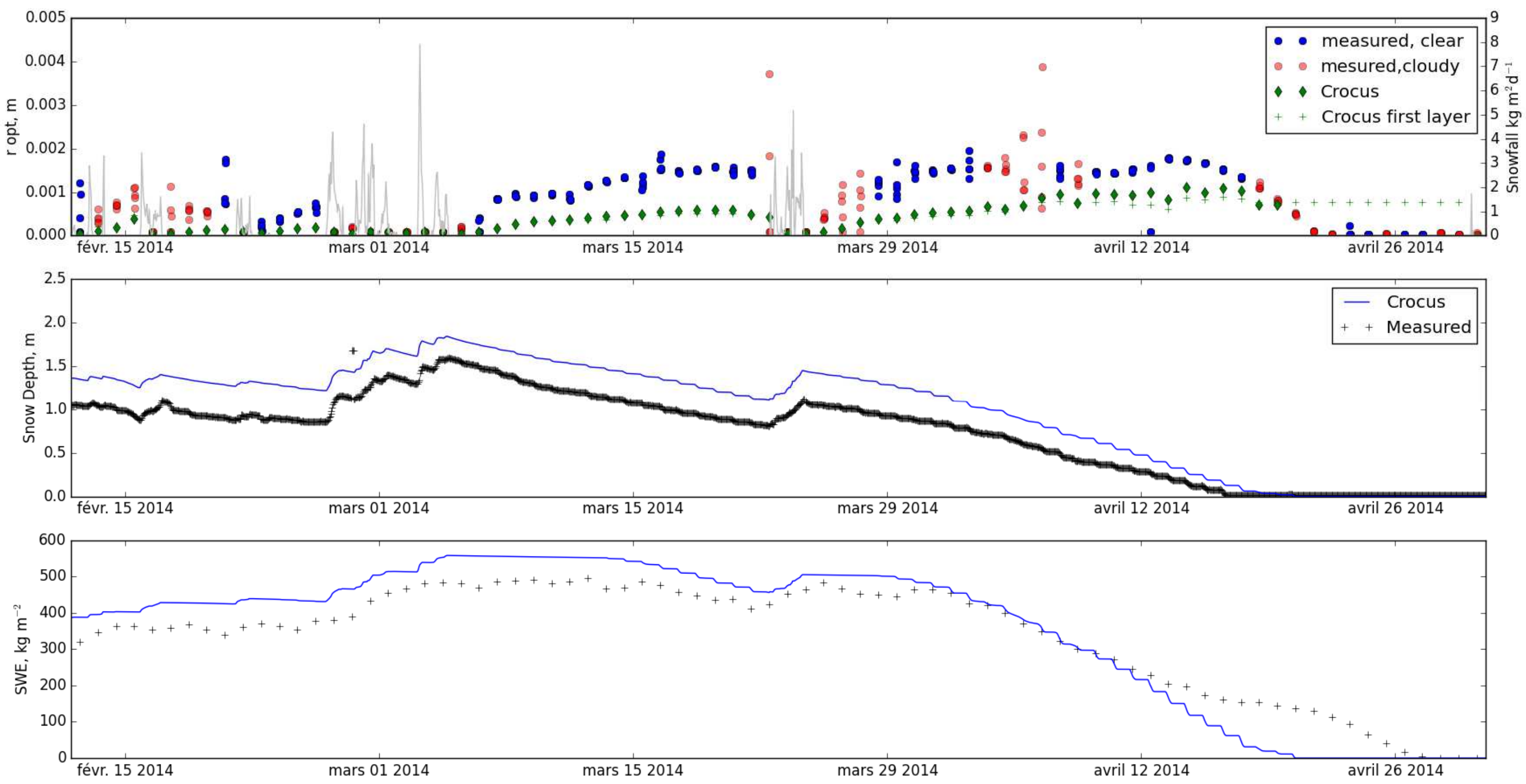
Crocus simulations



New doesn't necessarily mean better …. Probably less error compensation. Need to optimize wet and dry deposition fluxes of impurity and scavenging rates with melt water

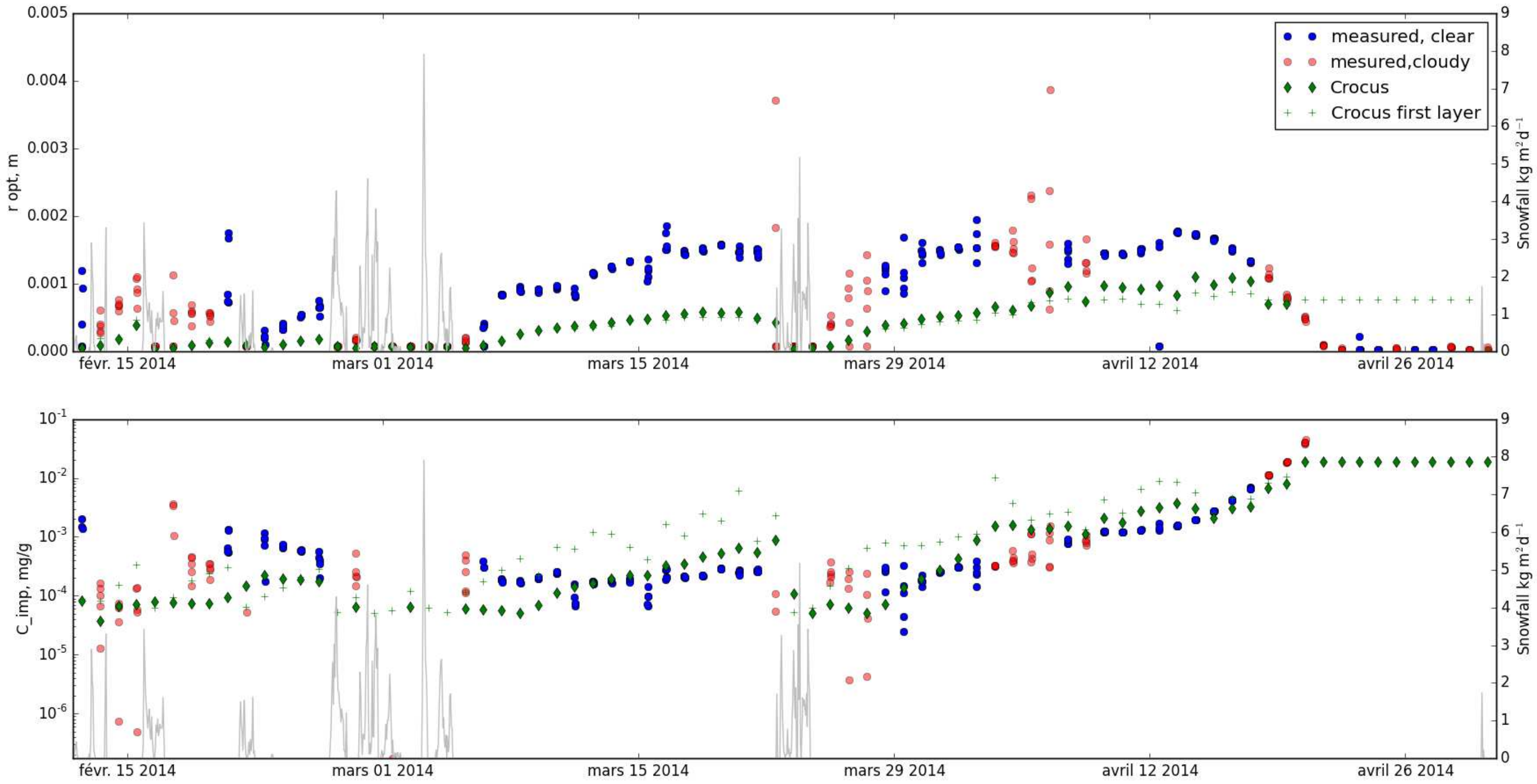
OSUG TERRE UNIVERS ENVIRONNEMENT
CNRS
LGGE
Université Joseph Fourier GRENOBLE
CNRS
METEO FRANCE

Surface snow optical radius



R_opt is retrieved from measured and modelled spectral albedo using *Kokhanovsky and Zege, 2004.*

Surface snow impurity content



Constant wet and dry deposition fluxes allows a first reasonable representation of the impurity content.

Remarkable r_opt decrease under large impurity loads … A negative feedback ? Still to be investigated

OSUG TERRE UNIVERS ENVIRONNEMENT

cnrs

LGGE

Université Joseph Fourier GRENOBLE

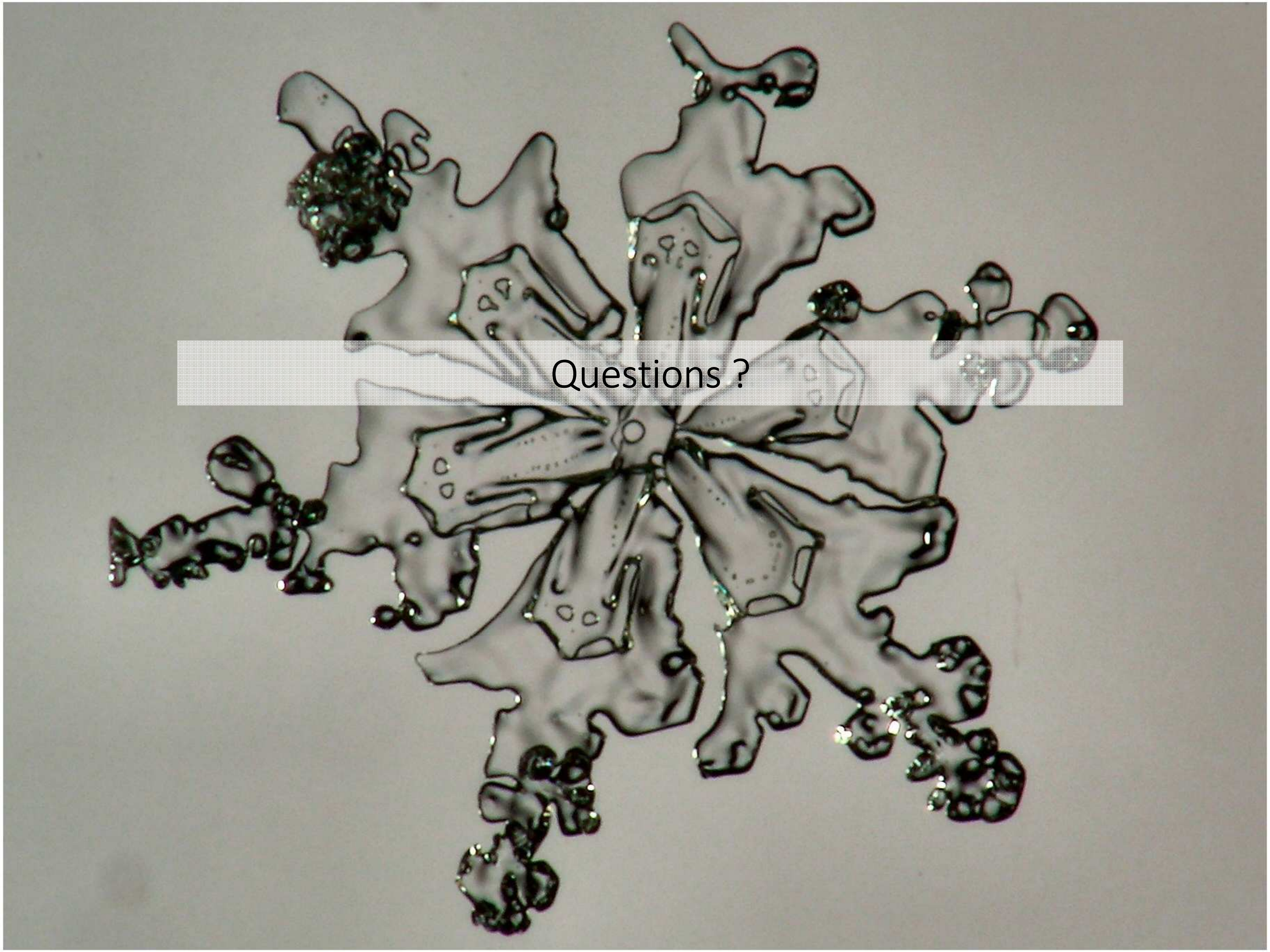
cnrs

METEO FRANCE

Conclusion and future works

- Crocus is now the only detailed snow model handling a spectral scheme for radiative transfer in the snow and in the atmosphere together with a prognostic impurity content
- It offers unique capability for optical data assimilation and to account for all the major snow albedo feedbacks in snowpack simulations e.g. needed for accurate climate projections of the Greenland ice sheet (*Tedesco et al., 2016*)

- We still need :
  - force the wet/dry deposition fluxes with an atmospheric chemistry-transport model (e.g. ALADIN-Climat)
  - implement different types of impurity (dust, bc, algae …)
  - investigate and adjust the evolution laws for impurity (scavenging rates …)


Questions ?