Assimilation of snowpack-related variables in SURFEX: context and prospects

Samuel Morin, Marie Dumont, Fatima Karbou, Eric Brun etc.

CNRM-GAME (CEN, GMGEC, GMME …)

SURFEX assimilation workshop, 5 March 2012

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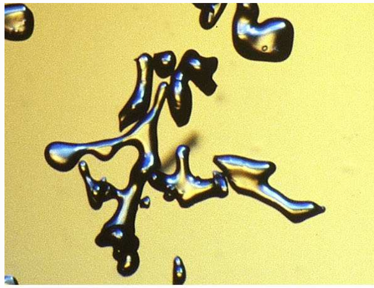
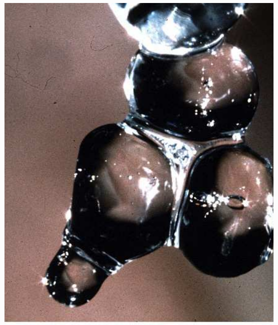
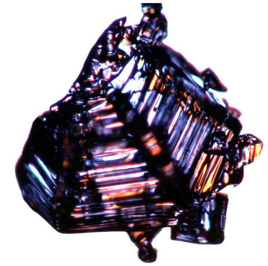
Snow on the ground

- Constantly **evolving** layered medium

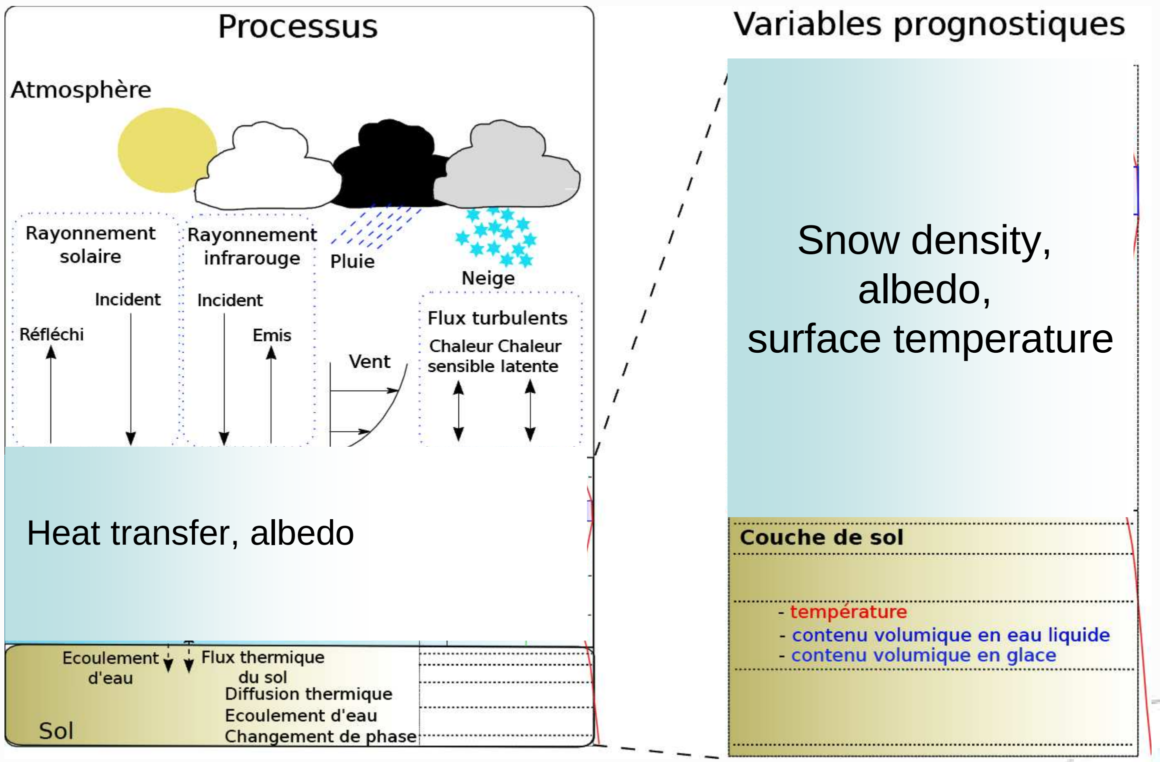





- Significant impact on **surface** properties (albedo, thermal properties …)
- Induces **feedback** at meteorological and climate timescales
- Natural and accidental **snow avalanches** hazard
- Connections to high altitudes/latitudes **hydrology**

Snowpack modeling in SURFEX

- All the snowpack modeling at CNRM-GAME now takes place within SURFEX
- Snow energy and mass balance schemes coupled to ISBA
- Same driving data as ISBA
- Variable levels of complexity:

(***single layer,*** ***Explicit Snow (ES), Crocus***)



Douville et al., 1995

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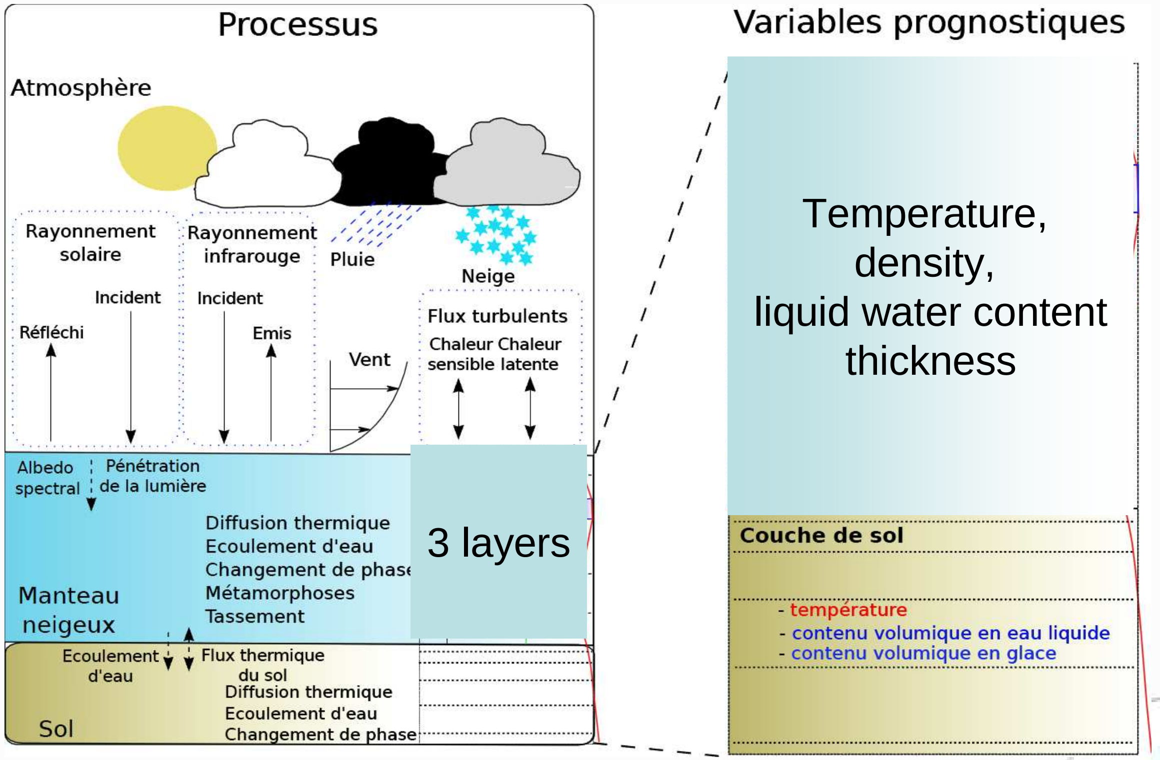

Boone, 2000

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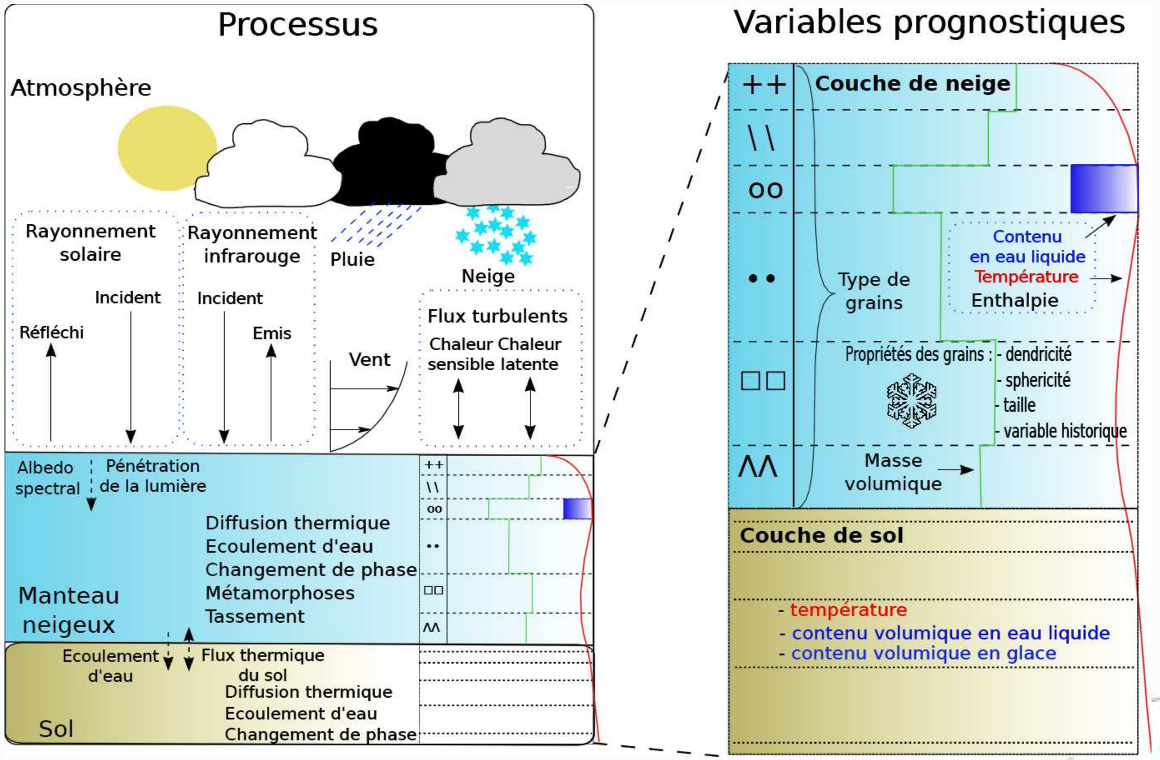


Brun et al., 1992
Vionnet et al., 2011

Levels of complexity linked to model use

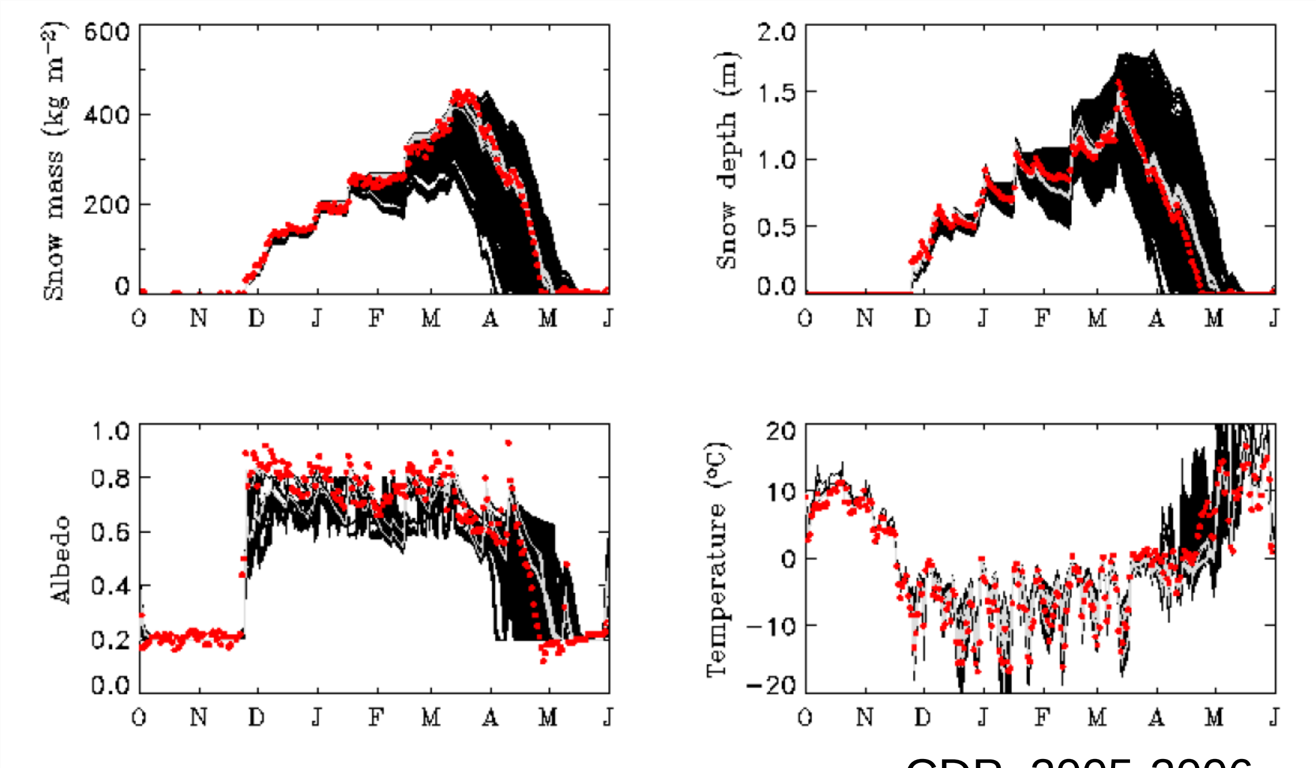
- Numerical weather forecast, climate, hydrology :
  - focus on snow mass (SWE), snow height, surface temperature, albedo, runoff
  - intermediate complexity models (ISBA-ES) often sufficient
  - limited numerical costs ; less trouble with model initialization

- Detailed snowpack models needed for issues where snow stratigraphy matters:
  - focus on stratification (density, snow type, optical radius …)
  - needed for avalanche warning systems,
  - combinations to grain-sensitive remote sensing applications (near-IR, active/passive microwave)

- Somewhat limited needs for improvement in snow model physics:
  - meteorological input is the main source of uncertainty
  - issues with snow/vegetation interactions
  - wind redistribution

« there is no perfect snow model » (Essery et al., 2012)

- Simulation of an ensemble of 5000+ snowpack models of varying complexity at an alpine site.
- Multi-year performance assessment (4 winters) : there isn't any combination of model parameterization and levels of complexity providing best results for all years (« best » models vary from year to year)



CDP, 2005-2006

Data assimilation needed to improve the representation of snowpack properties

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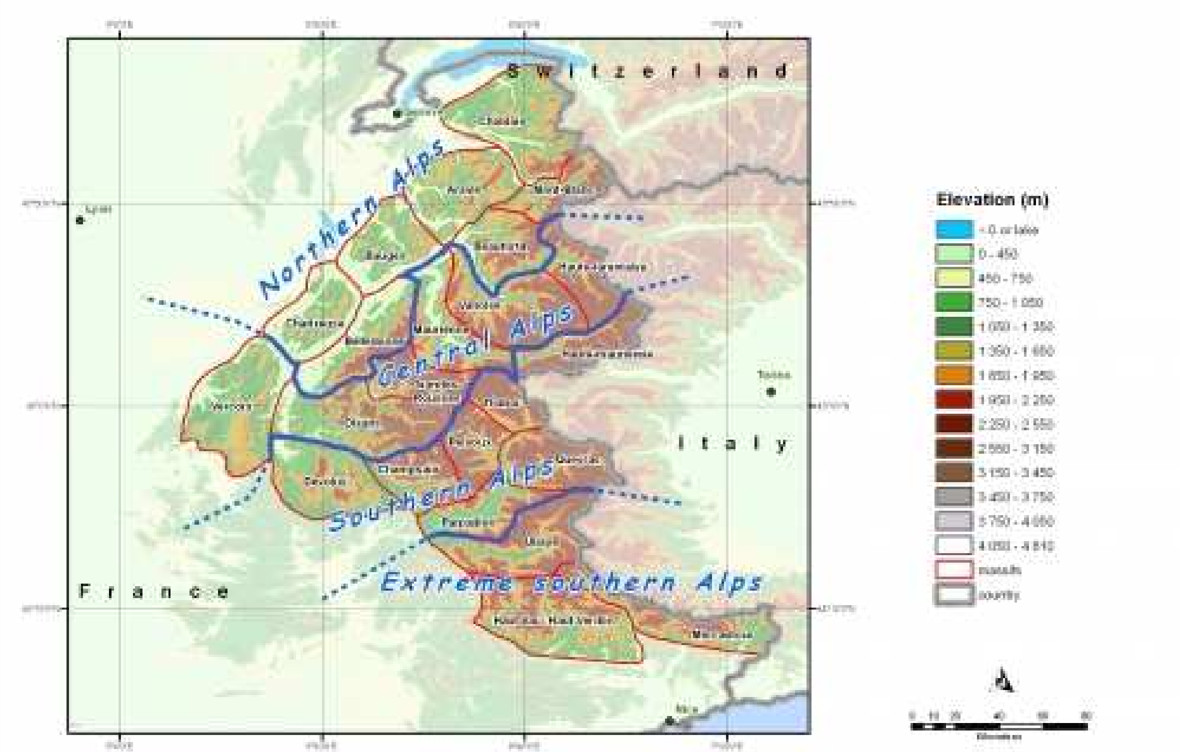
What observations to assimilate ?

- On the ground:
  - Automatic and manual point measurements of snow depth (hourly/weekly)
  - Manual point measurements of snow stratigraphy (weekly ; 150 obs./week)
  - SWE on the ground (automatic / manual)

- From space:
  - Snowcover area (visible/NIR ; MODIS – 250m resolution)
  - Surface snow properties (albedo, impurities optical radius) using visible/NIR data (MODIS – 250m resolution)
  - Surface/skin temperature (thermal IR) (MODIS ~ 1km resolution)
  - Depth integrated properties in the active (~30m)/passive(~25 km) microwave
    - L and C band: dry snow is « transparent »
    - X and Ku band : backscatter/emissivity depend on internal stratification
    - wet snow fully absorbs microwaves (detection means in C band SAR)
    - Microwave-based algorithm for SWE (GlobSNOW) estimation (requires a guess in snow properties (grain size and SWE))

Current operational snowpack simulations

- For avalanche forecasting applications:
  - SAFRAN meteorological forcing: guess from ARPEGE synoptic fields ; analysis using ground and RS observations (including precipitation) ; analysis/forecast mode. Key concept : idealized mountain ranges.

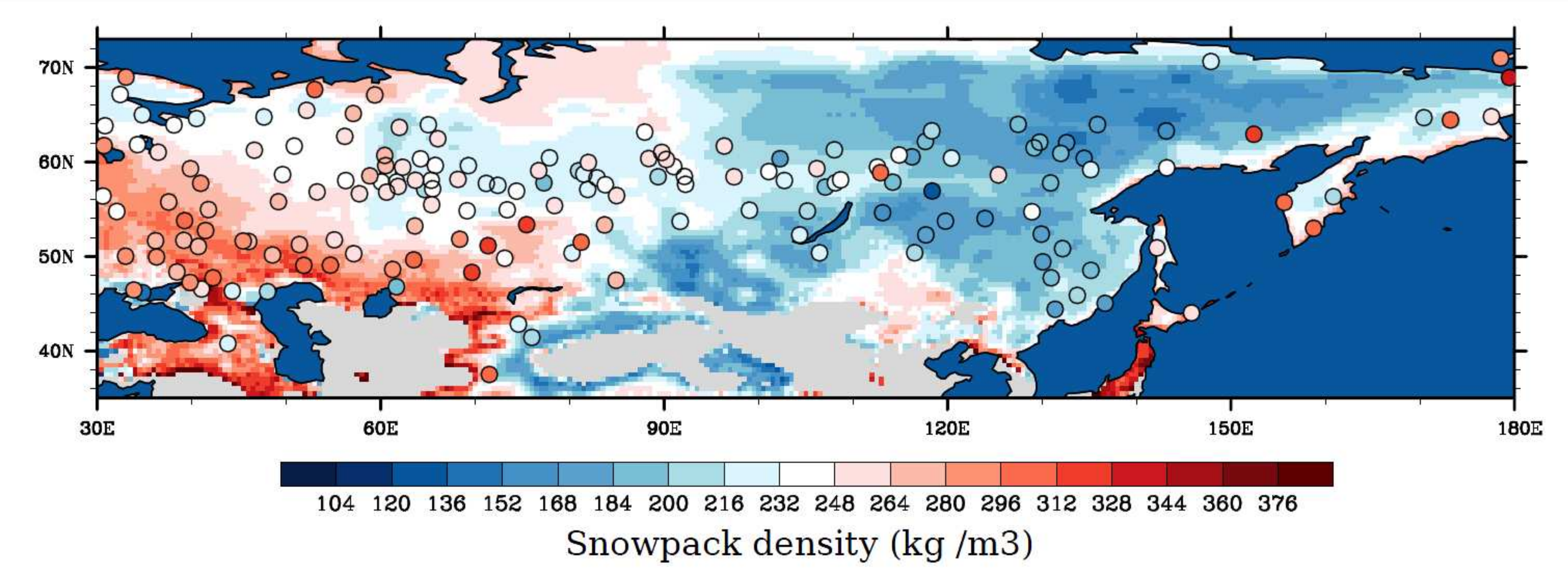


- assumption of homogeneous conditions on a mountain range
- meteorological conditions for 300m altitude ranges + 8 aspects ; computations using Crocus for 3 slopes (0, 20° and 40°)
- NOT a gridded product

- For hydrological applications; SAFRAN/ISBA/MODCOU : extension of the SAFRAN framework to the whole country

Snowpack simulations / links to remote sensing

- Large domains (Eurasia):
  - Simulations using ERA-i forcing : good results over Eurasia in terms of snow depth/SWE using SURFEX/ISBA/Crocus



Brun et al., submitted

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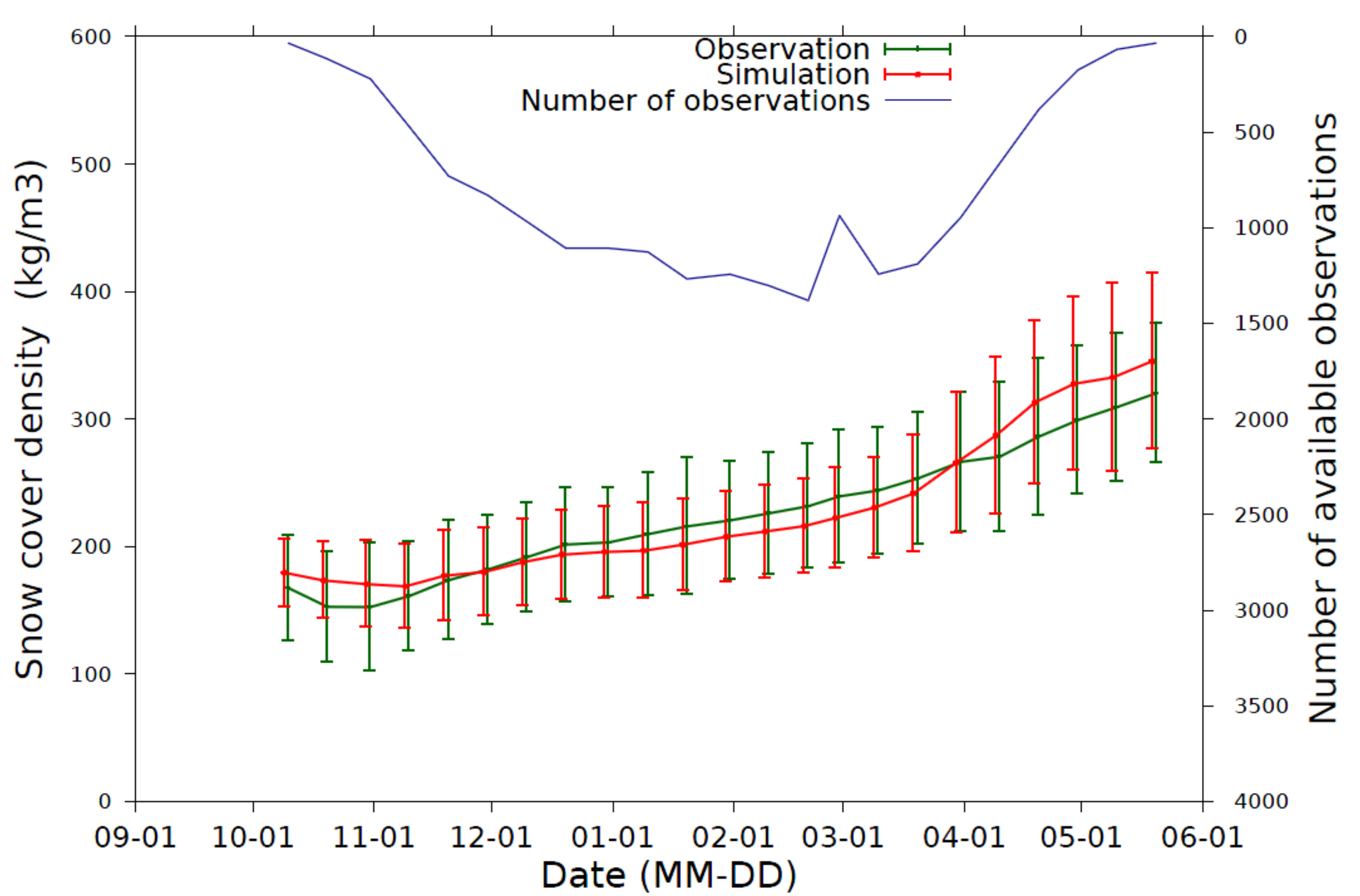

Brun et al., submitted

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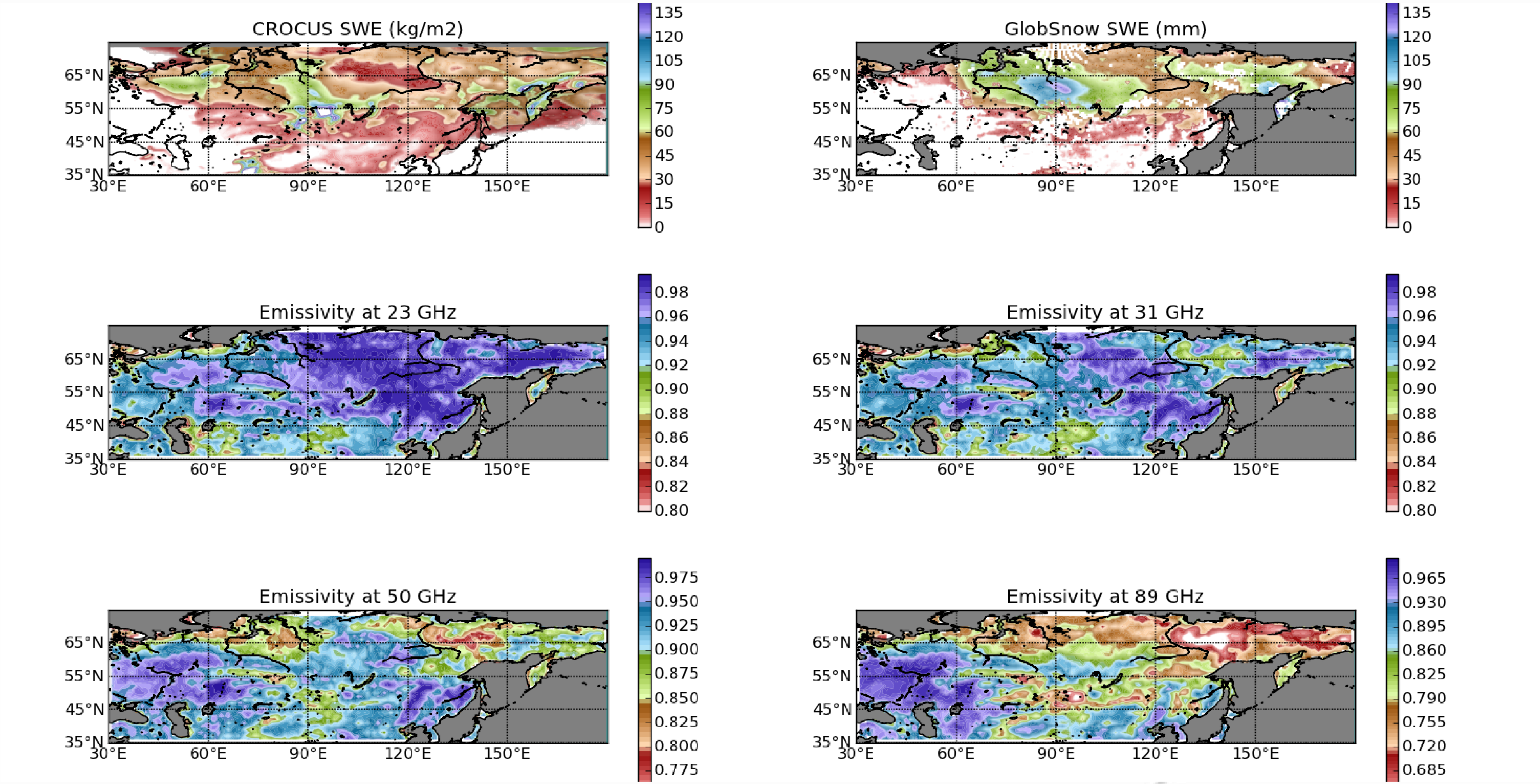
Snowpack simulations / links to remote sensing

- Large domains (Eurasia):
  - Comparison to MW emissivities using AMSU-A (F. Karbou) ; 3 December 2009

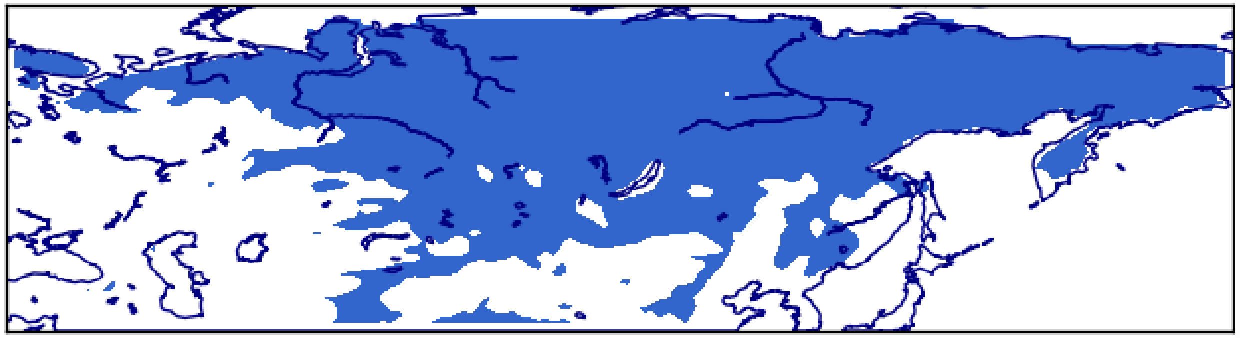


Snowpack simulations / links to remote sensing

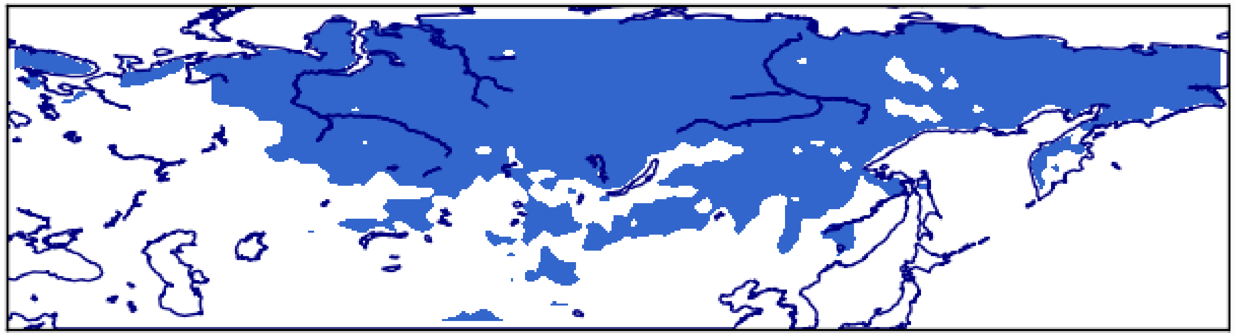
3 december 2009 ;
preliminary results F. Karbou ; M. Dumont ; E. Brun

CROCUS
(threshold
SWE > 5 kg m^{-2})

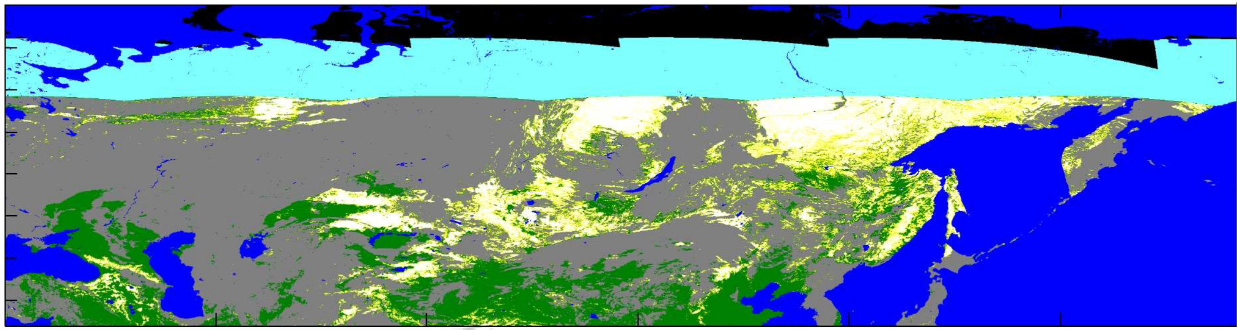
Passive MW
(combination of
emissivities at 31 and
50 GHz)

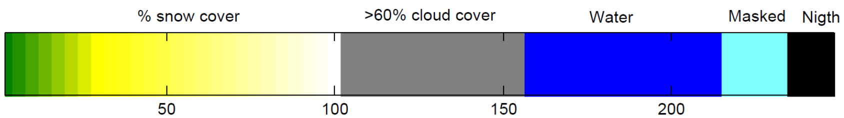


GlobSNOW



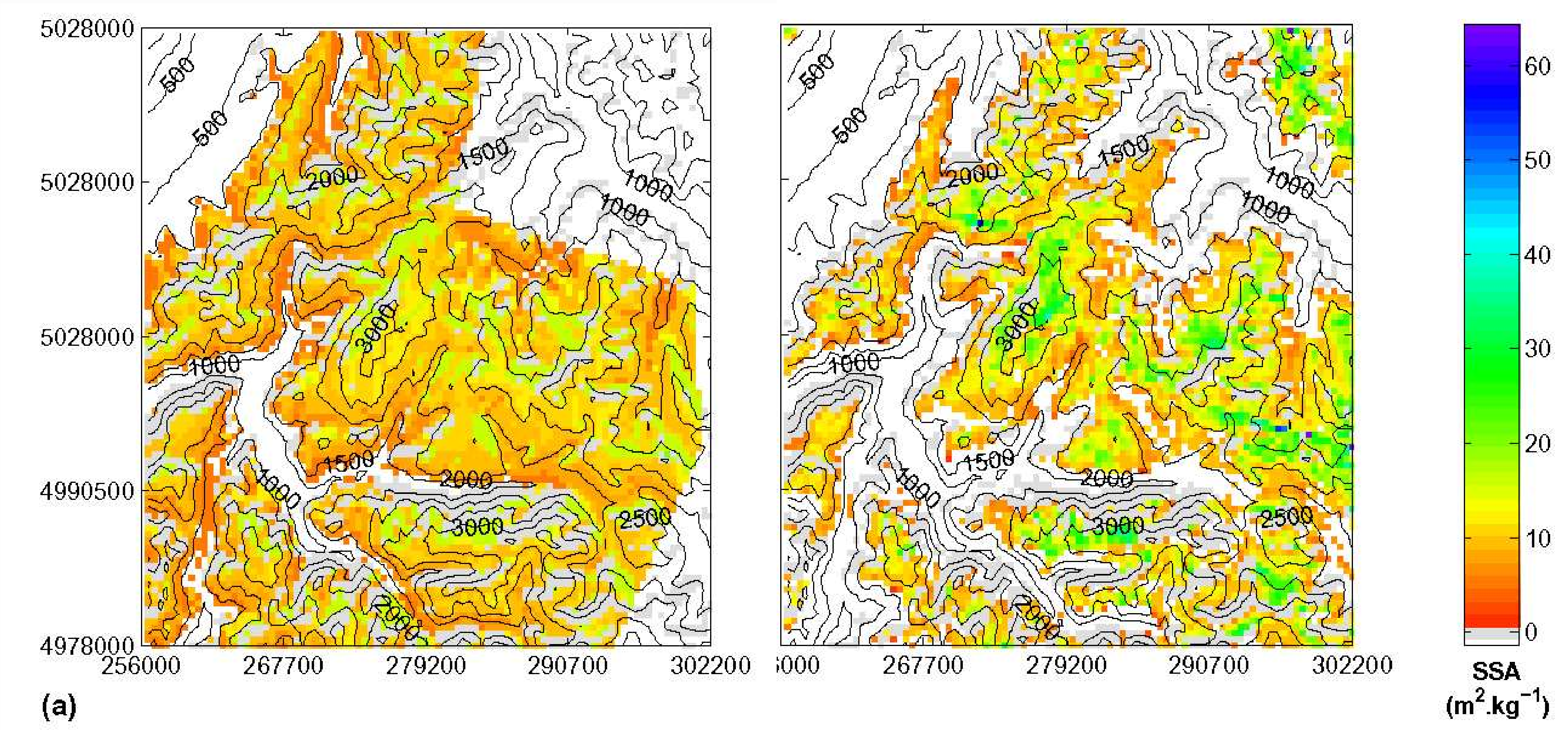
MODIS SCA 5km





Snowpack simulations / links to remote sensing

- Massif-scale (Grandes Rousses Range) ; 21 March 2009:



Distributed rendering of SAFRAN/Crocus simulation

SSA/optical radius maps (derived from MODIS ; master A. Mary ; collab. LTHE)

Mary, Dumont et al., in prep

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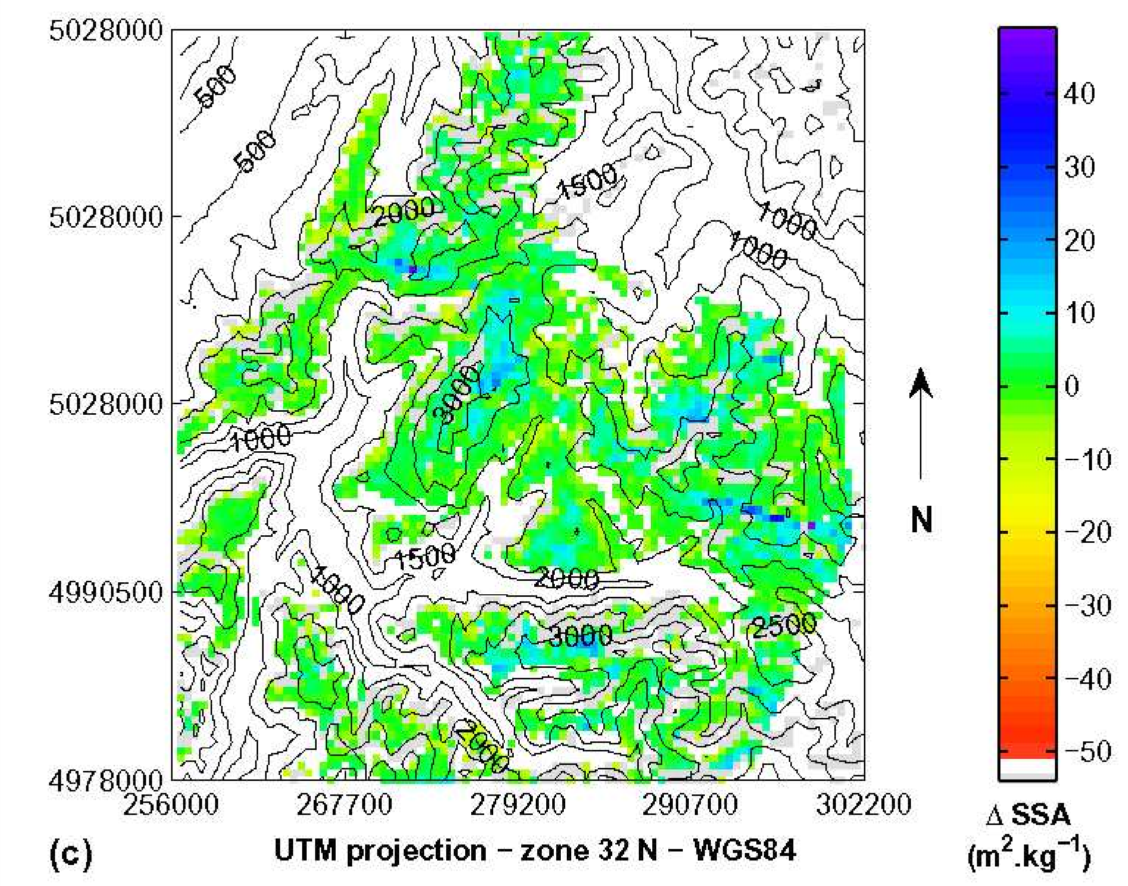
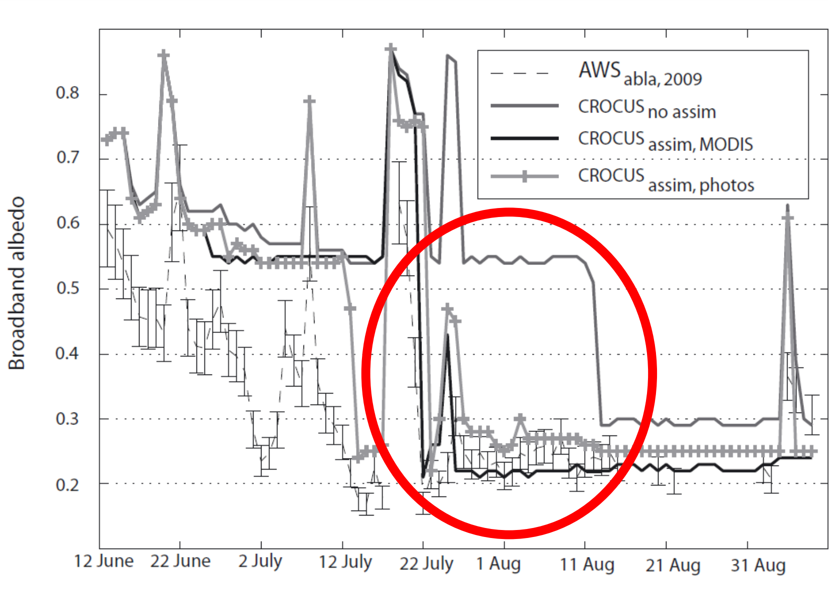


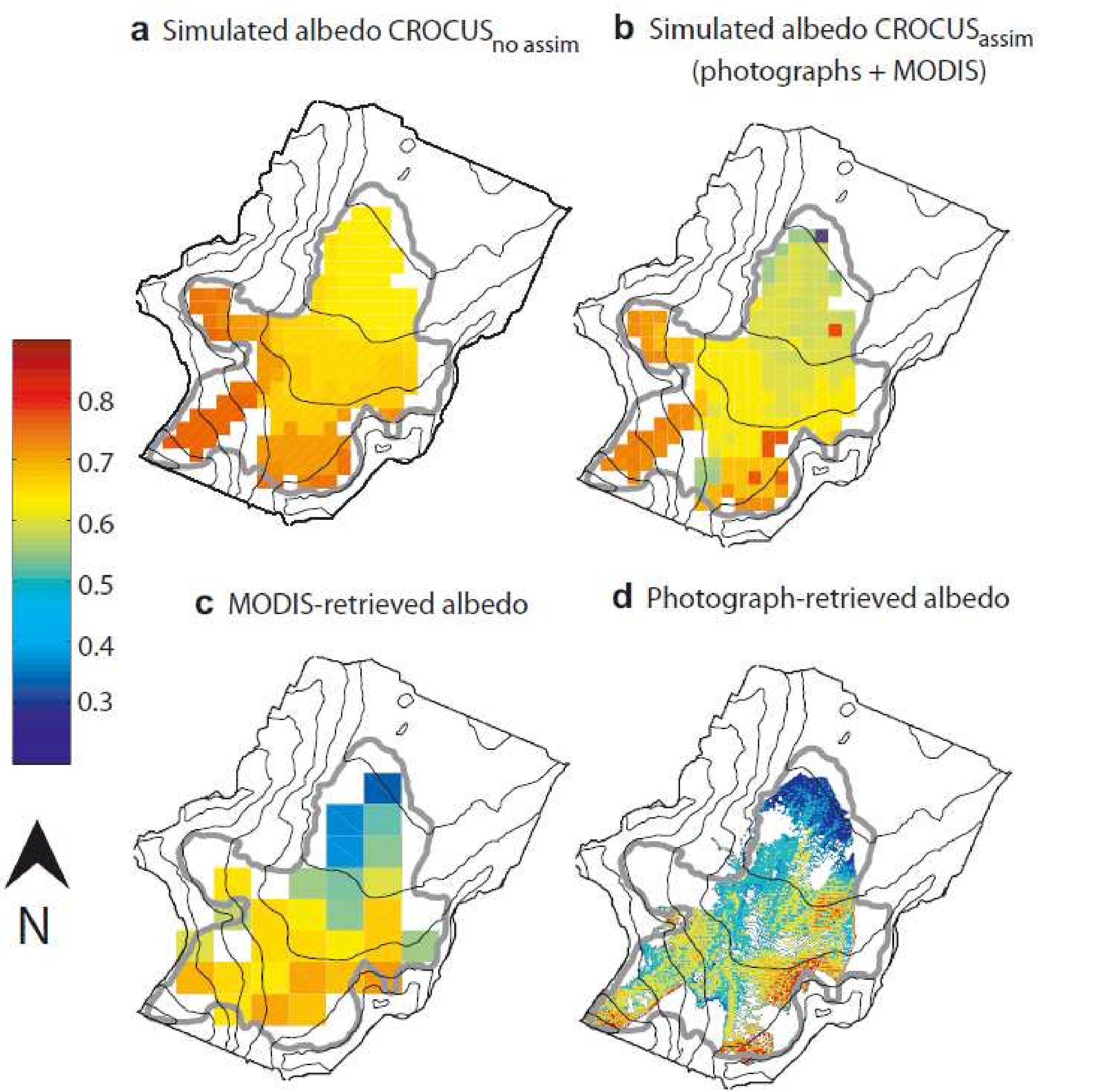
Difference (MODIS – Crocus SSA)

Mary, Dumont et al., in prep

Snowpack simulations / links to remote sensing

- Massif-scale:
  - Proof of concept ; MODIS vis/NIR albedo variational assimilation over a glacier (PhD M. Dumont)





Need to generalize to larger areas
(Crocus adaptations needed)

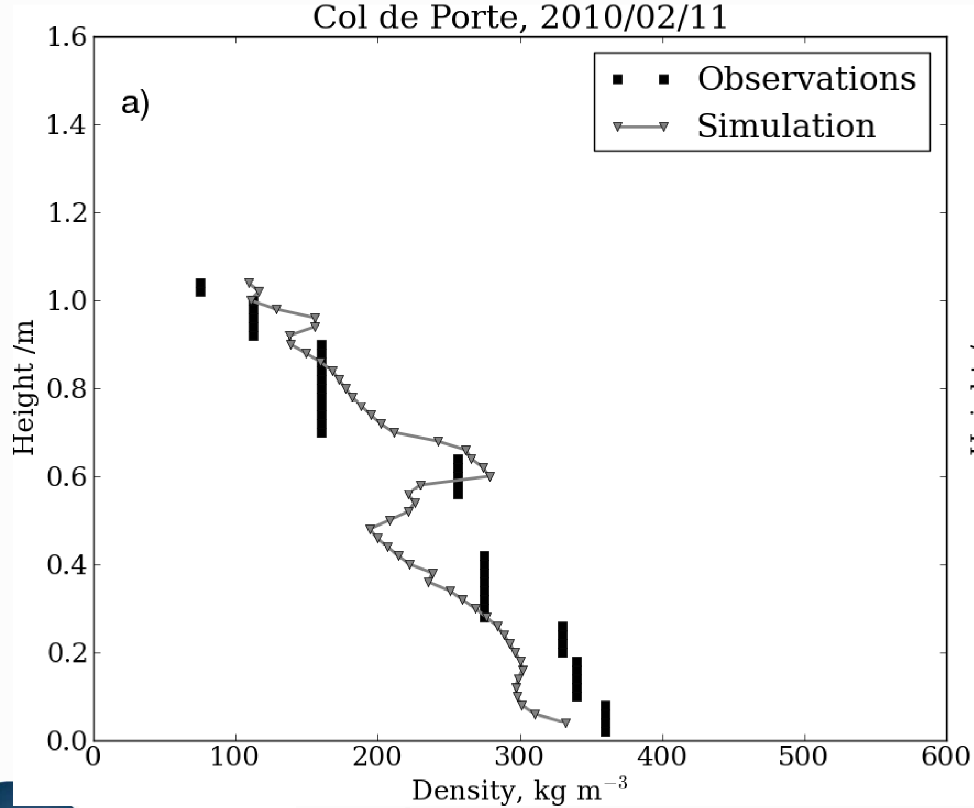
St Sorlin Glacier, Gdes Rousses massif

Intrinsic issues with snow assimilation:

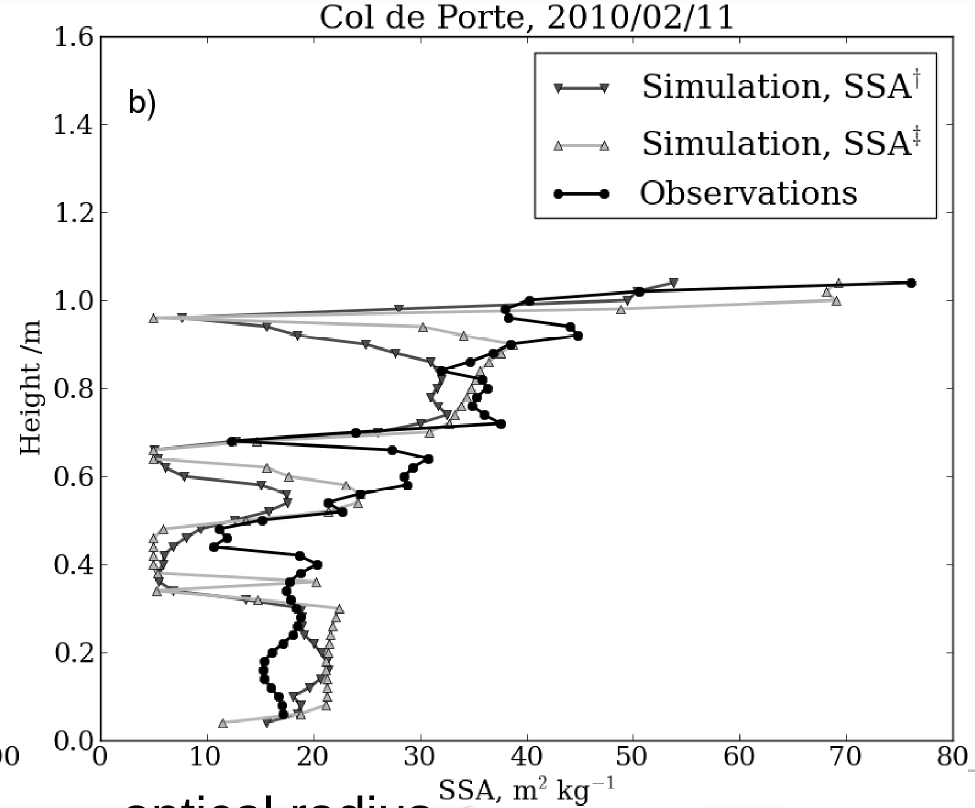
- Binary information snow/no-snow on the ground
  - How to consistently deal with obs/simulation mismatch in snow presence on the ground ?

Intrinsic issues with snow assimilation:

- Vertical stratification of key properties (density, liquid water content, optical radius …)
  - Variations in time and space of the number and thickness of layers (in contrast to soil)
  - Vertical integration of properties ? (visible ; microwaves …)
  - Observed/simulated mismatch in layer height



density



optical radius (aka SSA)

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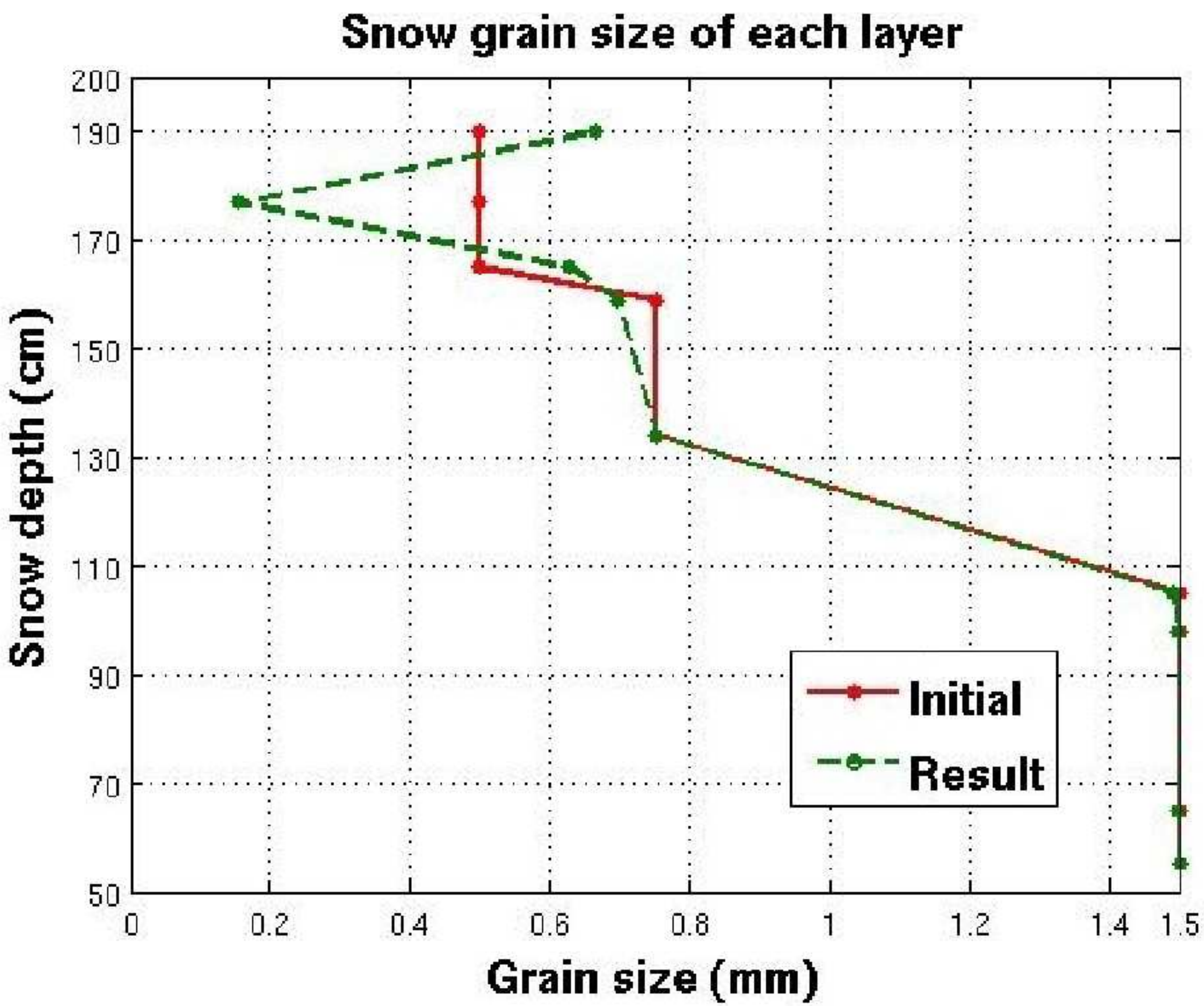
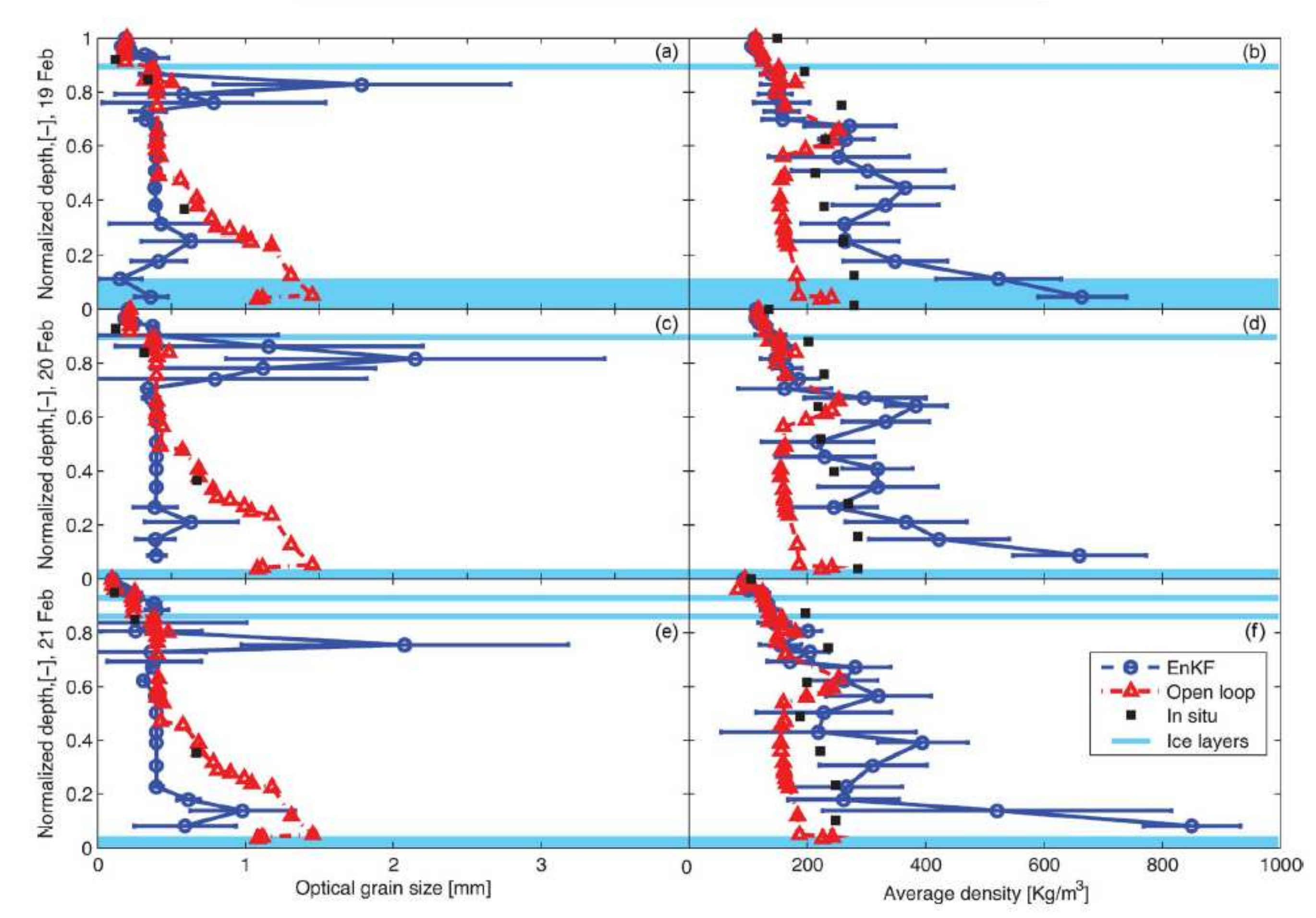
Other examples of snowpack assimilation:

- Radar backscatter (C and X band SAR) ; ongoing PhD (Xuan-Vu Phan)



Other examples of snowpack assimilation:

- Work carried out in Quebec (CARTEL) : microwave radiance assimilation using MEMLS (passive microwave forward model) + CROCUS



Toure, A.M., Goita, K., Royer, R., Kim, E.J., Durand, M., Margulis, S.A., Huizhong Lu, A case study of using a multilayered thermodynamical snow model for radiance assimilation, *IEEE Trans. Geosci. Remote Sens.*, 49(8), 2828 - 2837, doi :10.1109/TGRS.2011.2118761, 2011.

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Ideas ? Thoughts ?