Using kilometric-resolution meteorological forecasts and satellite-derived incoming radiations for snowpack modelling in complex terrain

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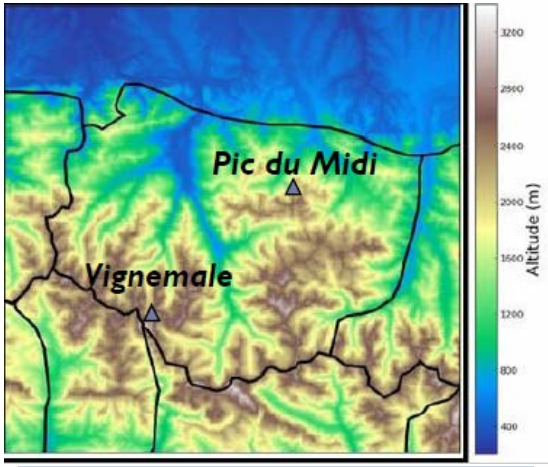
Introduction

High spatial snowpack variability in mountains

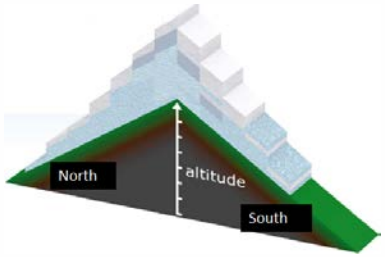
- Meteo variability inter and intra massif
- Orographic variability (altitude, aspect, slope)
- Small scale processes (preferential deposition, wind-blown snow…)



Massif of Haute-Bigorre (2000 km²)

Analysis system **SAFRAN**
- Analysis/forecast by massif
- By altitude step (300m)

Meteo fields from high resolution NWP **AROME**
- 2,5 km grid spacing (1,3 km since 2015)
- Domain: Pyrenees (and Alps)
- Period: 2010-2014
- Intra-massif variability
- Finer meteorological forcing (rain/snow, precipitations…)



Snowpack model : **SURFEX-Crocus** (Crocus)
[Vionnet et al., 2012]

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Plan

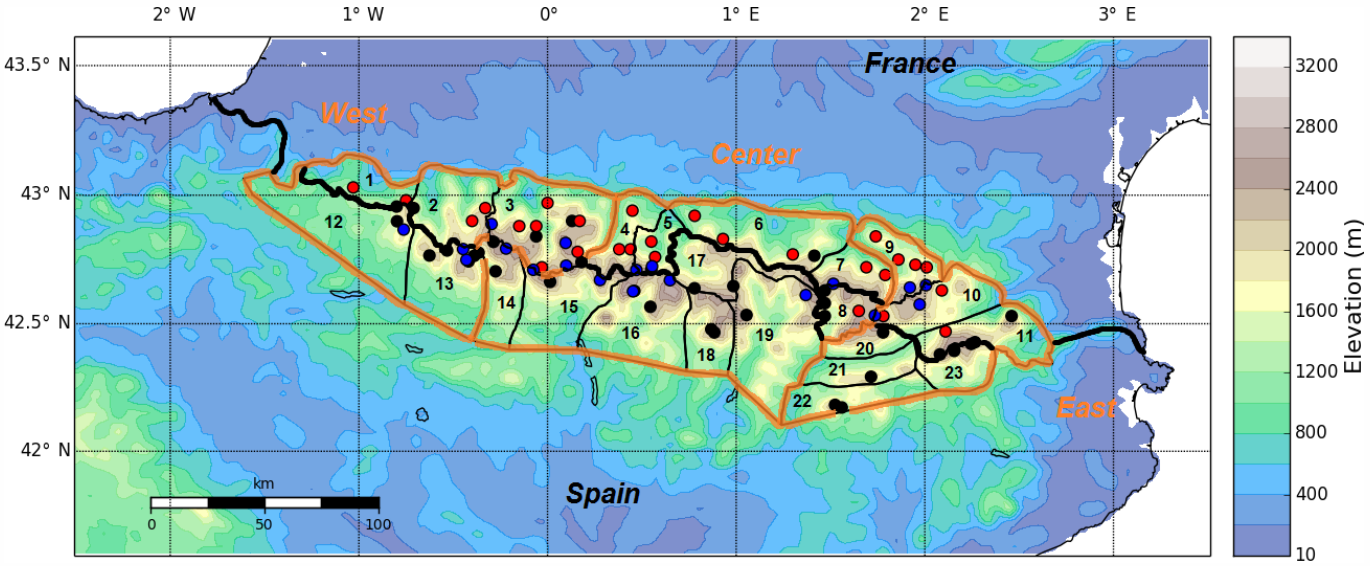
1. Evaluation of AROME-Crocus in the Pyrenees

2. LANDSAF satellite products for incoming radiations

3. Conclusion and outlooks

1. Evaluation of AROME-Crocus in the Pyrenees

Data and methods



Distributed snowpack simulations

- Crocus snowpack simulations
- Atmospheric forcing from AROME
- Domain: Pyrenees
- Period: 2010-2014

Validation data

- 83 stations measuring snow depth + SWE (20) or precipitations (28)
- Reference simulations driven by SAFRAN reanalyses
- MODIS fractional snow cover images

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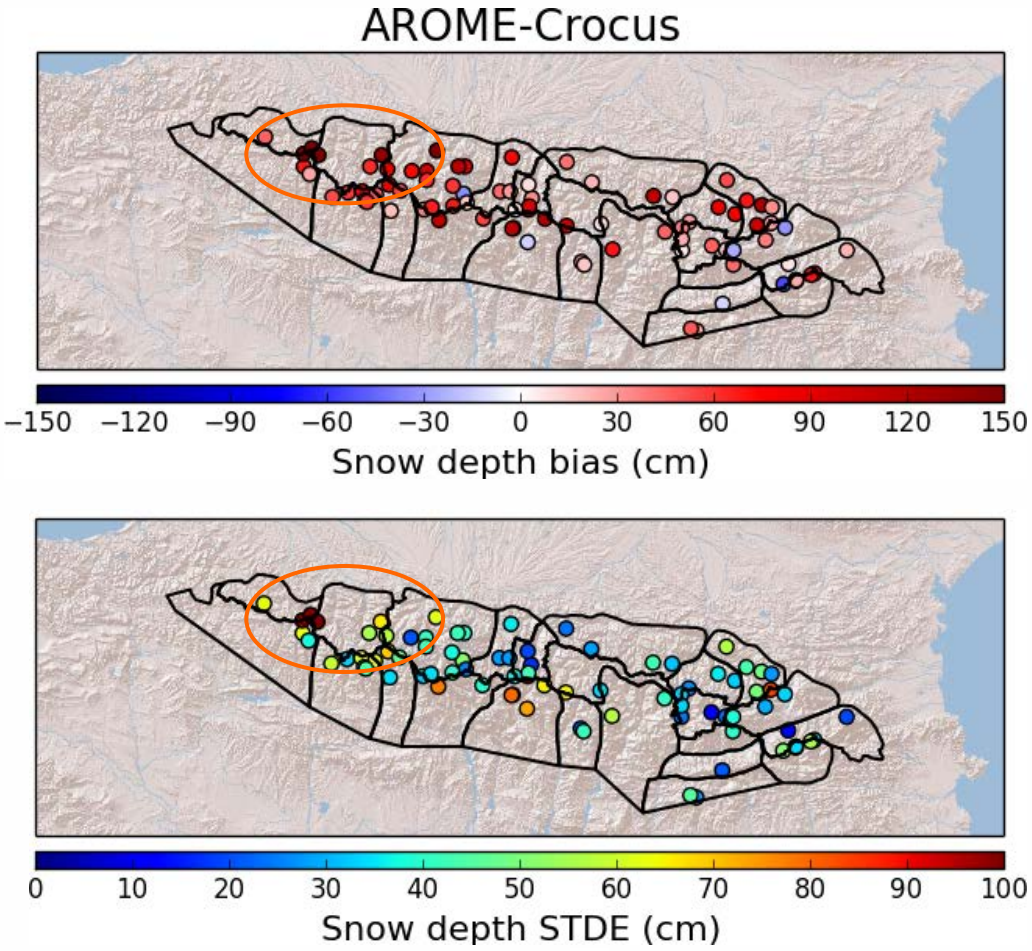
1. Evaluation of AROME-Crocus in the Pyrenees

Scores

First results

- Strong overestimation of snow depth (bias: +55 cm)
- Particularly in the Atlantic foothills
- Better scores for SAFRAN-Crocus (bias: +22cm)

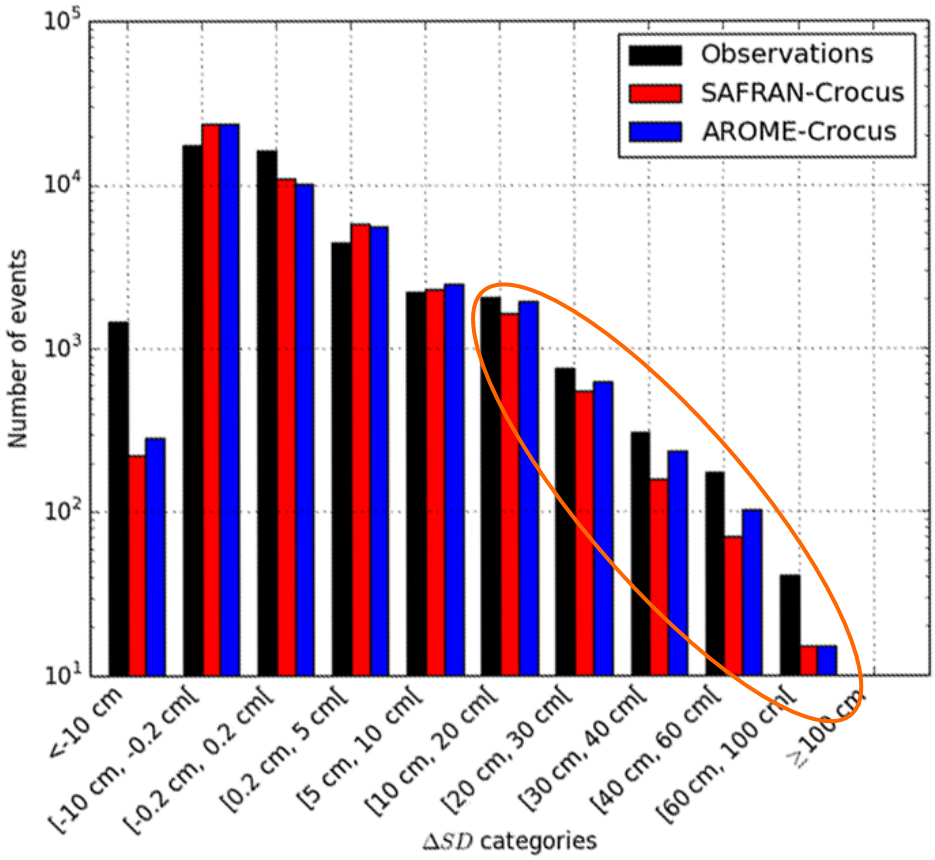


1. Evaluation of AROME-Crocus in the Pyrenees

Study of daily snow depth variations

Accumulation

- Underestimation of strong accumulations (>20cm/day)
- But AROME overestimates precipitations when compared to precipitation gauges !
- Undercatch of gauges, assimilated in SAFRAN reanalysis



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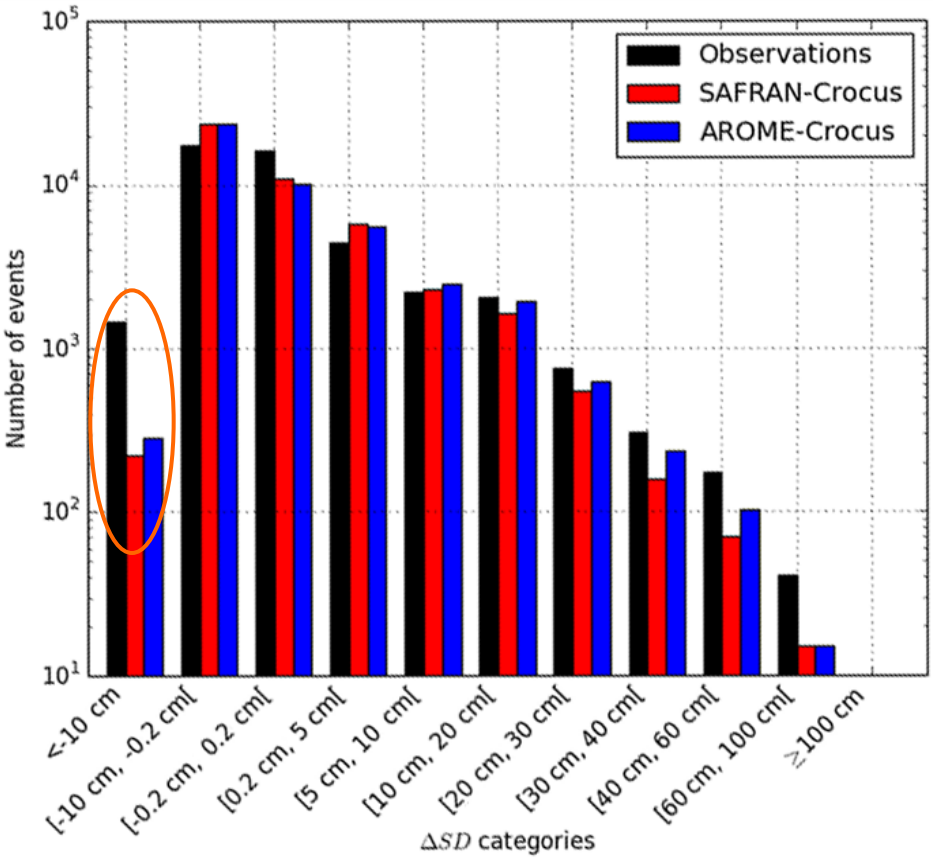
Ablation processes

- Days with wind-induced erosion: 71% of high decreasing rates of SD (>20 cm/day) not simulated (7 high altitude stations)
- Melting days: 42% of high decreasing rates of SD not simulated (all stations)



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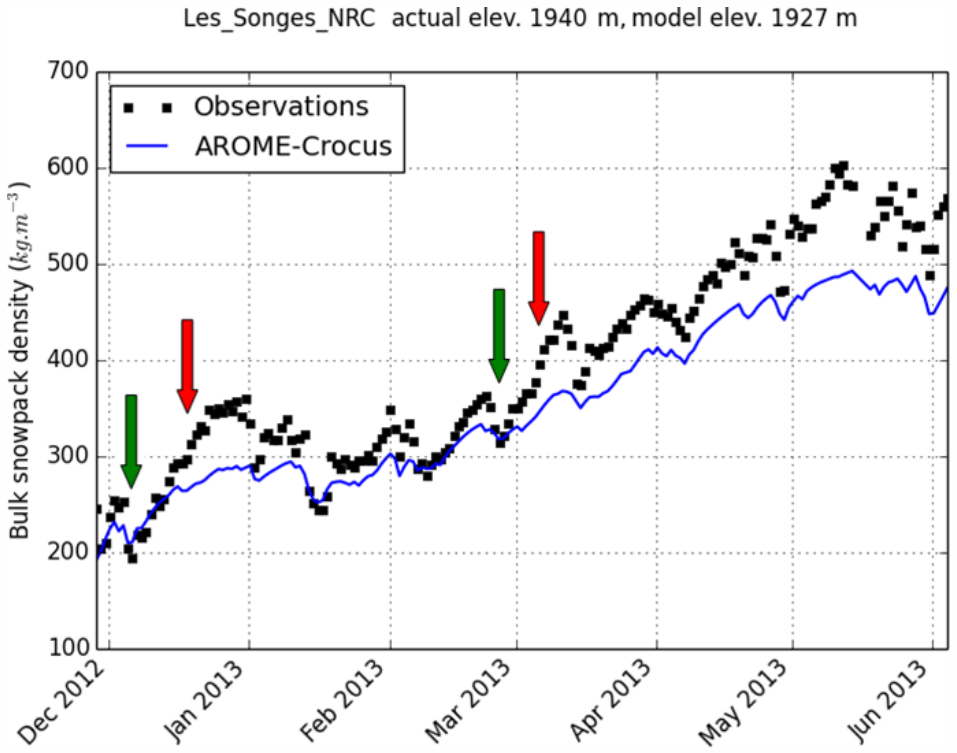
Settling

- Bulk snowpack density derived from stations measuring SWE and SD.
- The densification following a snowfall is too low.



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- Bulk snowpack density derived from stations measuring SWE and SD.
- The densification following a snowfall is too low.

- The high overall positive bias of SD is NOT the consequence of overestimated snowfalls (except on the Atlantic foothills).
- Wind-induced erosion is not simulated.
- Strong melting and settling are underestimated.

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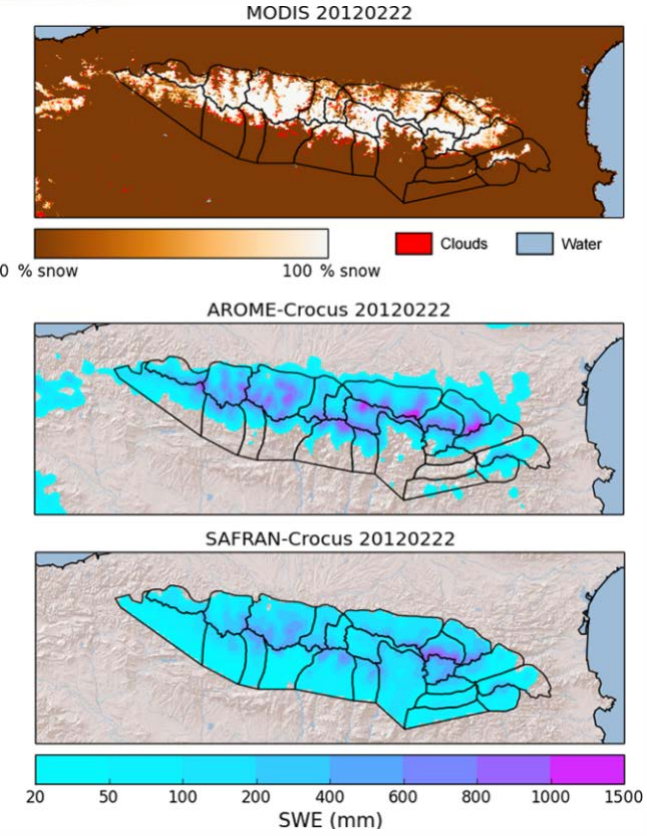
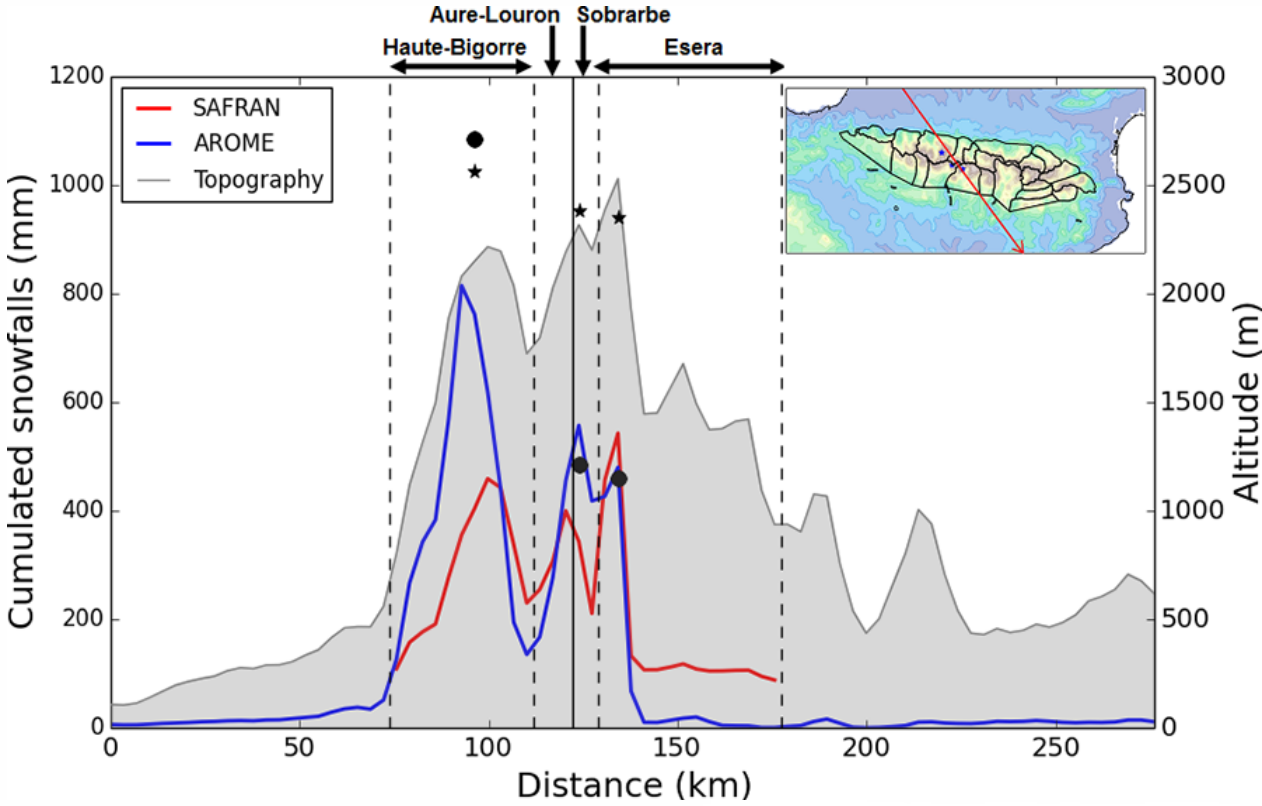
1. Evaluation of AROME-Crocus in the Pyrenees

Snow cover spatial distribution



Assessment of the spatial similarity with MODIS snow cover images

- Better representation of the spatial snow cover distribution than SAFRAN-Crocus
- Realistic intra-massif snowfall variability (dynamical behaviour in mountains)



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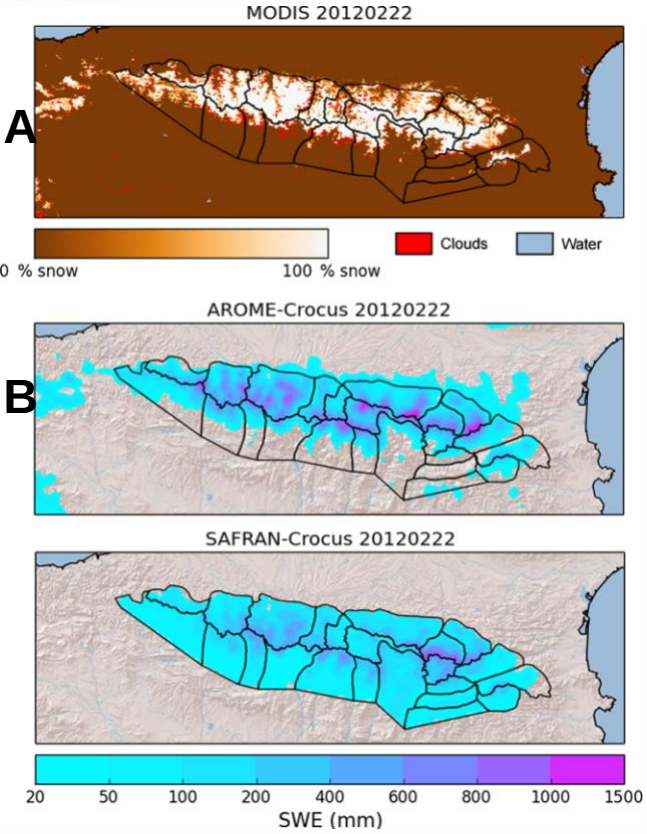

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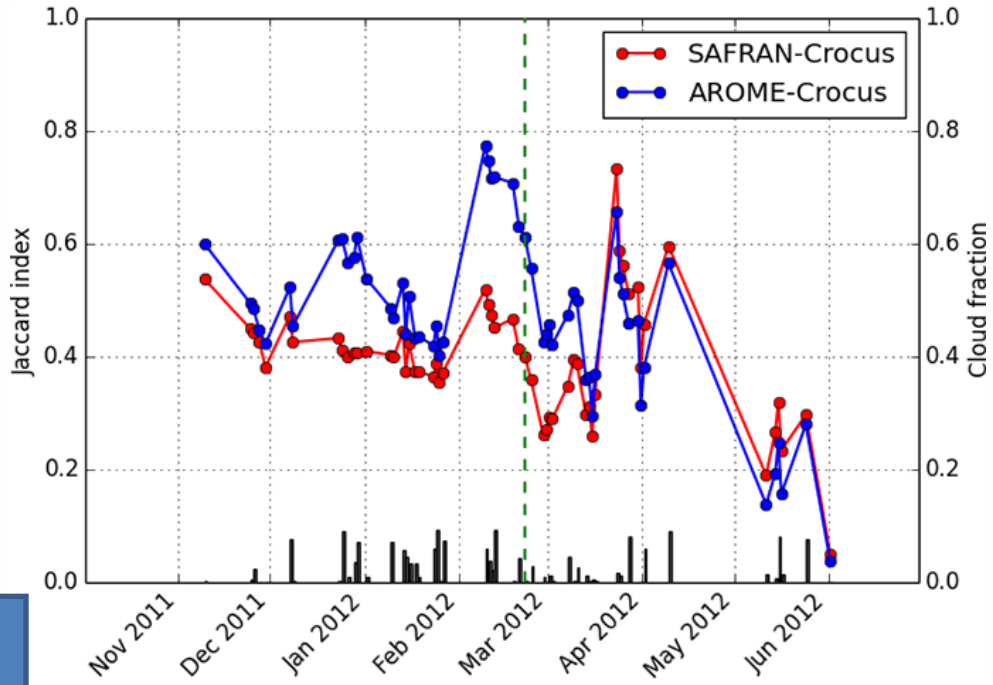
$$J = \frac{|A \cap B|}{|A \cup B|}$$



Similarity metrics for an objective validation

- Jaccard index and modified Hausdorff distance
- Higher scores for AROME-Crocus than SAFRAN-Crocus

Quéno, L., Vionnet, V., Dombrowski-Etchevers, I., Lafaysse, M., Dumont, M., and Karbou, F.: Snowpack modelling in the Pyrenees driven by kilometric-resolution meteorological forecasts, The Cryosphere, 10, 1571-1589, doi:10.5194/tc-10-1571-2016, 2016.

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2. LANDSAF satellite products for incoming radiations

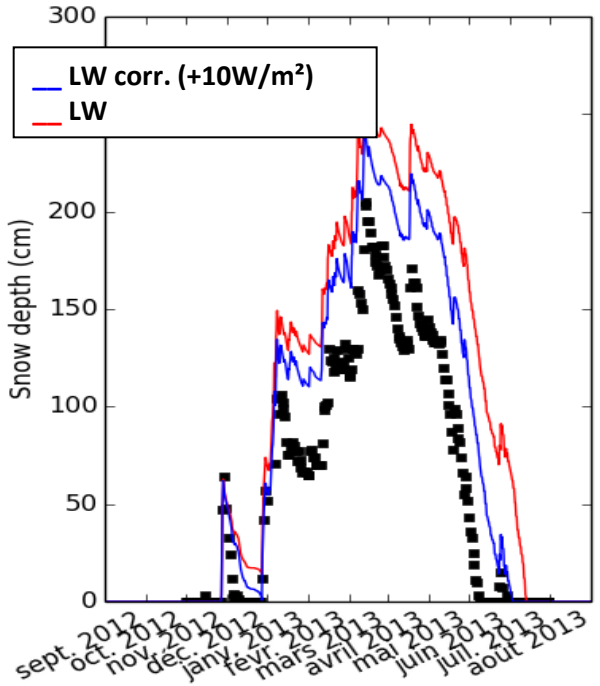
Aims and context

Aims of the study

- How to use **new observations in complex terrain** to complement these benefits ?
- Significant impact of the incoming radiations (particularly LW) on the snowpack **surface energy budget**
- Evaluation of AROME and SAFRAN incoming radiations over the Pyrenees and the Alps
- Comparison to LandSAF satellite products and in-situ observations

State of the art

- Vionnet et al., 2016 : assessing SW/LW incoming radiations from AROME at 3 alpine stations
  - ➢ Over-estimation of SW, under-estimation of LW
  - ➢ Under-estimation of the cloud cover
- Carrer et al., 2011 : assessing SAFRAN-France and LandSAF radiations over France
  - ➢ Better quality of LandSAF products (in plains)



(Figure by M. Lafaysse)

2. LANDSAF satellite products for incoming radiations

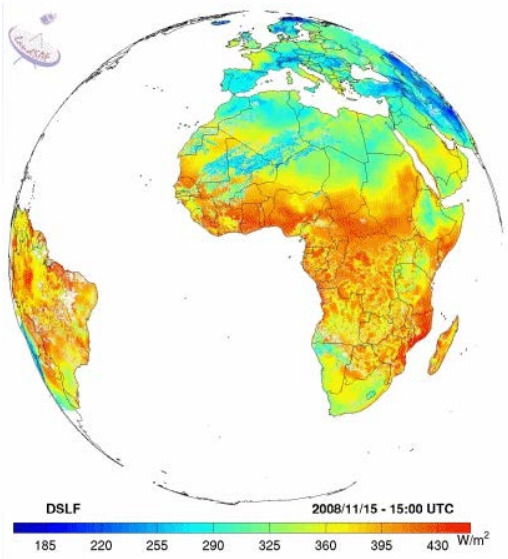
Data and models

AROME

- Radiative transfer schemes from ECMWF
- 2,5 km resolution

SAFRAN

- Analysis of vertical profile of humidity and temperature
- Cloudiness (satellite)
- Radiative transfer schemes



LSA SAF

- Satellite products using MSG/SEVIRI
- Time frequency : 30 min
- Spatial resolution : 3 km
- DSLF (LW) and DSSF (SW)

- Cloud mask: clear sky or cloudy sky method
- Algorithms combining ECMWF forecasts, climatological data, satellite observations (cloud mask, cloud type)

- Accuracy 10% or 20W/m²

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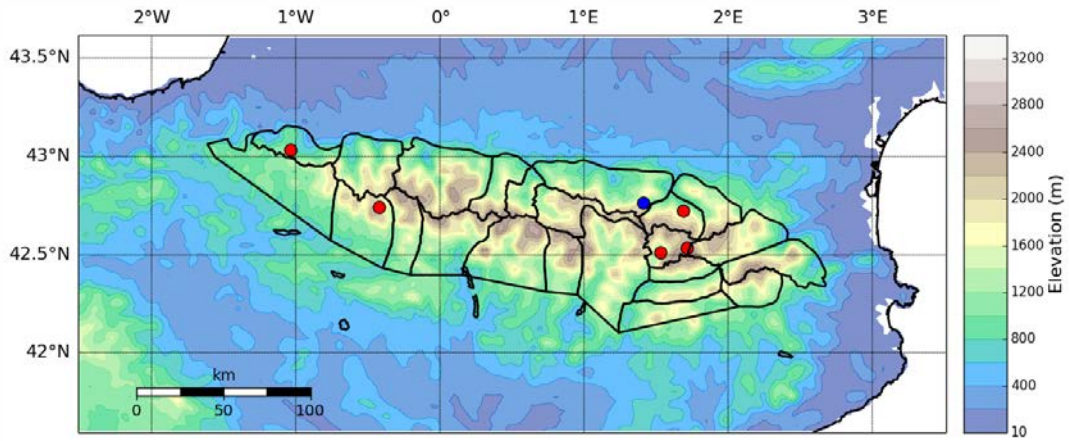
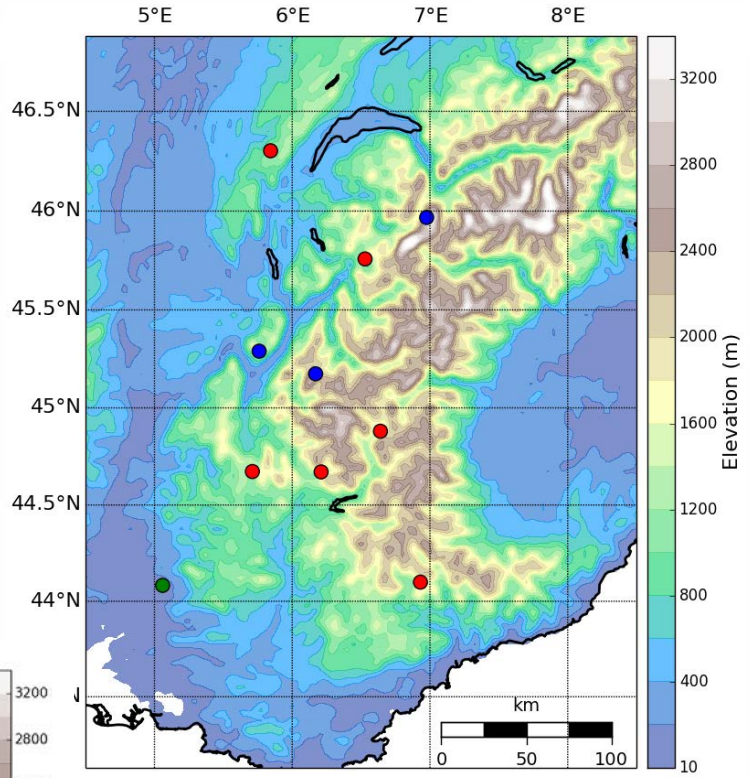
2. LANDSAF satellite products for incoming radiations

In-situ observations

Domain: Pyrenees and Alps
Period: 2010-2014
15 SW stations
4 LW stations
1 SW and LW reference at low altitude





red: SW only
blue: SW and LW

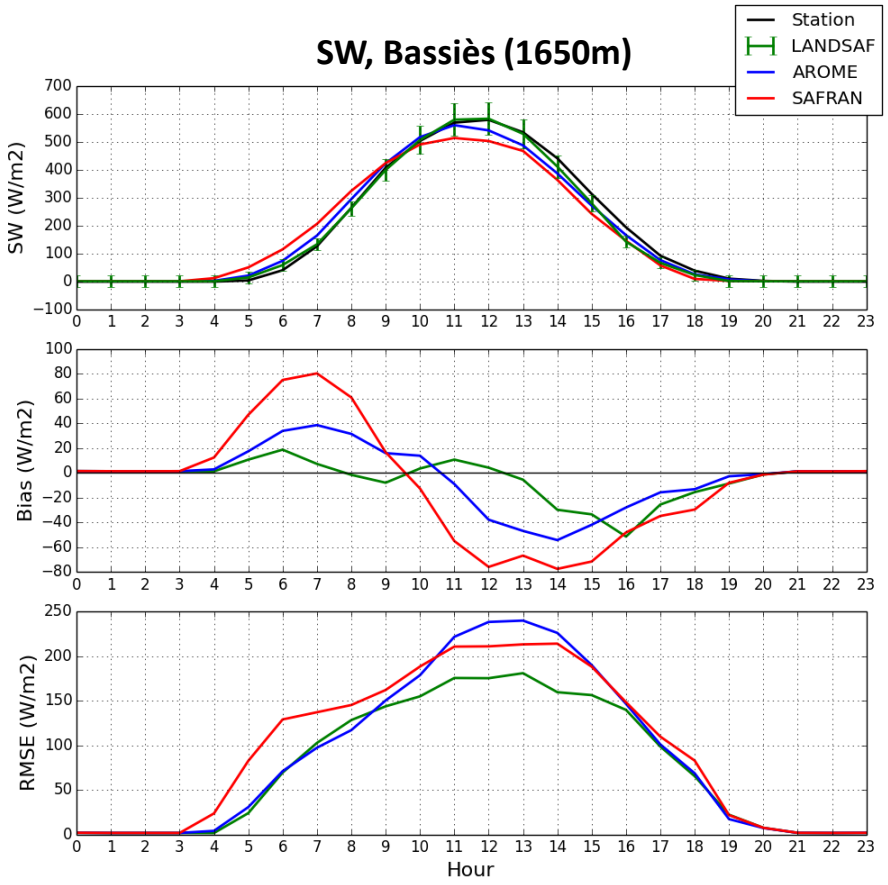
2. LANDSAF satellite products for incoming radiations

Evaluation

Global scores:

LW	Bias	RMSE
LANDSAF	-4%	13%
AROME	-7%	14%
SAFRAN	**+2%**	**11%**

SW	Bias	RMSE
LANDSAF	**-5%**	**34%**
AROME	+12%	44%
SAFRAN	-7%	41%



2. LANDSAF satellite products for incoming radiations
Evaluation

Key results of the evaluation

- Scores SW : high relative errors (AROME and SAFRAN)
- **Possible added value of DSSF LandSAF** for SW radiations
- LW: better scores for SAFRAN than LandSAF

- Added value of LandSAF products less obvious in mountainous terrain
- Hypothesis: worst scores caused by the low resolution of ECMWF forecasts
  - Solution: replace the ECMWF inputs by AROME forecasts (particularly for LW)
  - Better score in plains but equivalent in mountains
- Ongoing work to improve the LW product and assess the cloud mask in mountains

3. Conclusion and outlooks

Study of the potential of AROME forecasts for snowpack modelling

•Benefits of ***AROME forecasts for snowpack modelling*** at the scale of a mountain range (Quéno et al., The Cryosphere, 2016), (Vionnet et al., J. Hydromet., 2016)

- Overestimation of the snow depth by AROME-Crocus in the Pyrenees
- Smoothing of ***strong daily variations***
- Significant benefits in terms of ***spatial distribution of the snow cover*** (dynamical behaviour in mountains)

•Added value of AROME microphysics schemes associated with a new implementation in Crocus for events of ***freezing rain on the snowpack*** (Quéno et al., CRST, in prep.)

3. Conclusion and outlooks

Need to complement this potential in « forecasting mode » by a dedicated analysis in mountainous terrain

- ***Incoming radiations***
  - Promising potential of LandSAF satellite products
  - Impact on snowpack simulations? (work in progress)

- Outlook: ***precipitations***
  - Use of radar data
  - New precipitation analysis in mountains (from massif-scale to grid)
  - Combined with the satellite clouds informations used for incoming radiations ?

Thank you for your attention !