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Potential of the use of high-resolution meteorological forecasts for snowpack modelling in the Pyrenees

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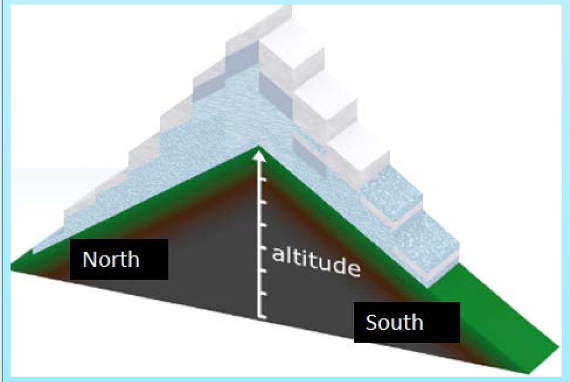
1. Context

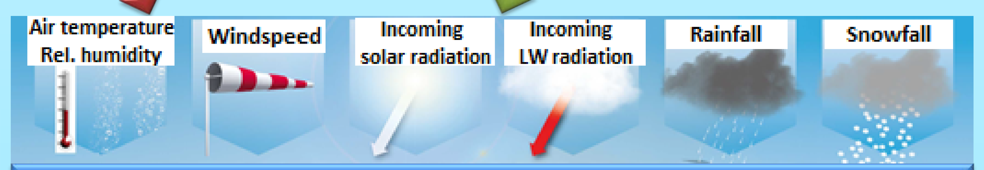
A major challenge of avalanche hazard forecasting and mountain hydrology is to take into account the **high spatial variability of the snow cover in mountains**. This variability depends on the regional climatology, geographical location within the mountain range, orography (altitude, slope, aspect) and microscale processes. **High-resolution meteorological forecasts** at kilometre scale over mountainous terrain offer new potential for the atmospheric forcing of snowpack models in order to represent the regional snowpack variability.

Current and new atmospheric forcing for snowpack modelling

Current forcing:
SAFRAN [Durand et al., 1993]
• Analysis/forecasts by « massif » by altitude step (300 m)
→ conceptual relief
• Massif considered homogeneous

This study:
NWP **AROME** [Seity et al., 2011]
• High-resolution topography (2.5 km)
→ Finer meteorological forcing (rain/snow limit, precipitations localisation, wind…)
→ Intra-massif variability





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

2. Snowpack simulations and evaluation methods

Snowpack modelling

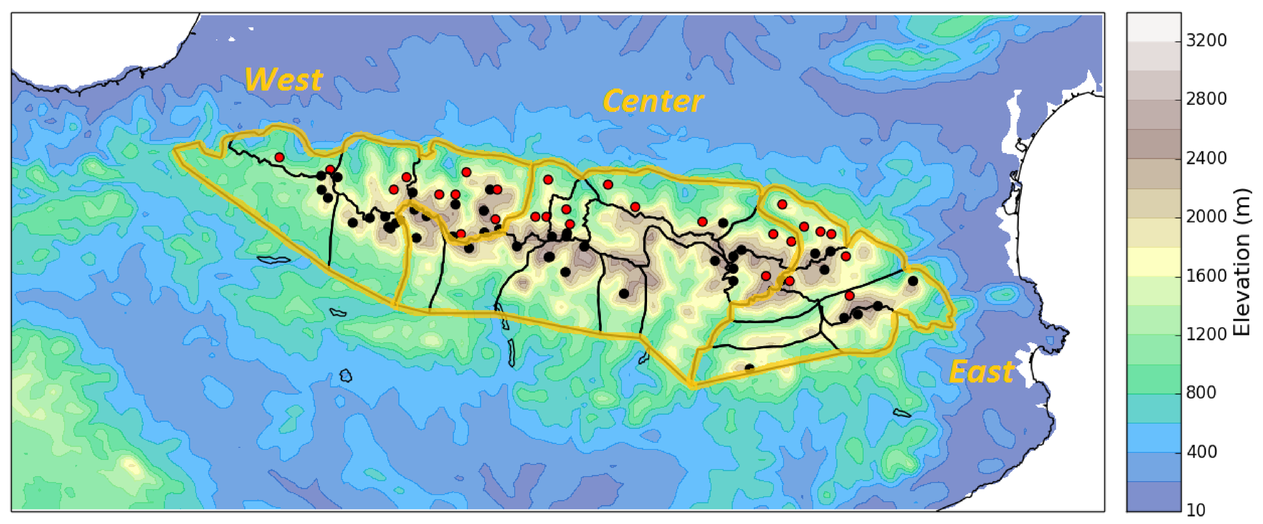
- **Crocus** standard version (50 layers), 15 min time step
- Domain: **Pyrenees** (France and Spain), 500 km x 220 km, 2.5 km resolution
- Period: 08/2010 to 07/2014 (four **contrasted winters**)

Atmospheric forcing

- AROME at 2.5 km grid spacing: succession of operational **daily forecasts** at 00UTC: +06Z to +29Z
- Reference forcing: **SAFRAN reanalyses** (including precipitation analysis) distributed on the same grid

Evaluation of simulated snow depth (SD) and precipitations

- 74 SD stations, 28 precip. gauges (between 1000 m and 2600 m)
- Stations selection: $|z_{station} - z_{model}| < 150\ m$
- Scores: bias and Standard Deviation Error (STDE)



SAFRAN massifs (black lines), regions (yellow lines), SD only stations (black points), SD and precip. stations (red points)

3. Evaluation of AROME-Crocus (2.5 km) in the Pyrenees

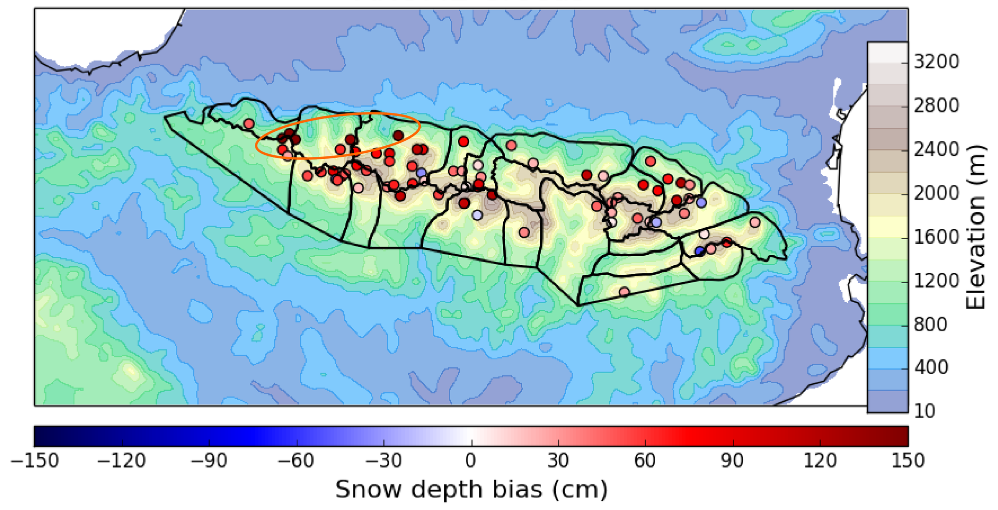
- **Global overestimation of snow depth**, particularly on the Atlantic foothills

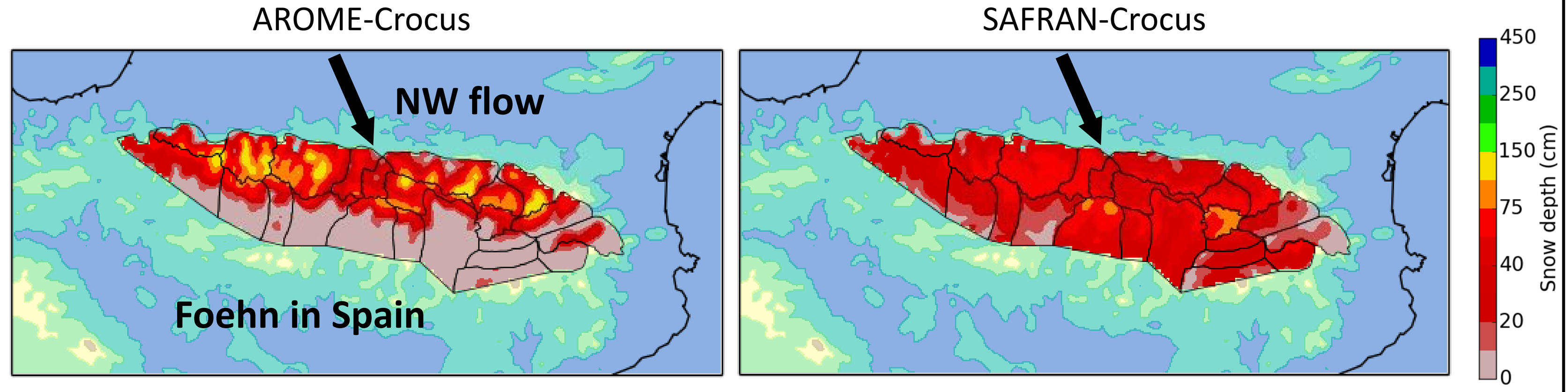
region	stations	bias (cm)		STDE (cm)	
		AROME	SAFRAN	AROME	SAFRAN
West	27	65.3	17.5	84.5	54.2
Center	31	58.1	32.3	63.3	50.0
East	16	34.9	0.1	62.9	60.6
Overall	**74**	**56.7**	**21.5**	**72.4**	**54.8**

Scores for simulated ← snow depth, 2010/2014

Snow depth bias, by station, for AROME-Crocus, 2010/2014 ↓

- Results sorted by weather patterns (9 types):
  - AROME: better representation of **orographic blocking**
  - Excessive orographic blocking very locally (Atlantic foothills)





Cumulated winter snowfalls (cm) for days of NW disturbed flow with foehn in Spain, 2011/2012

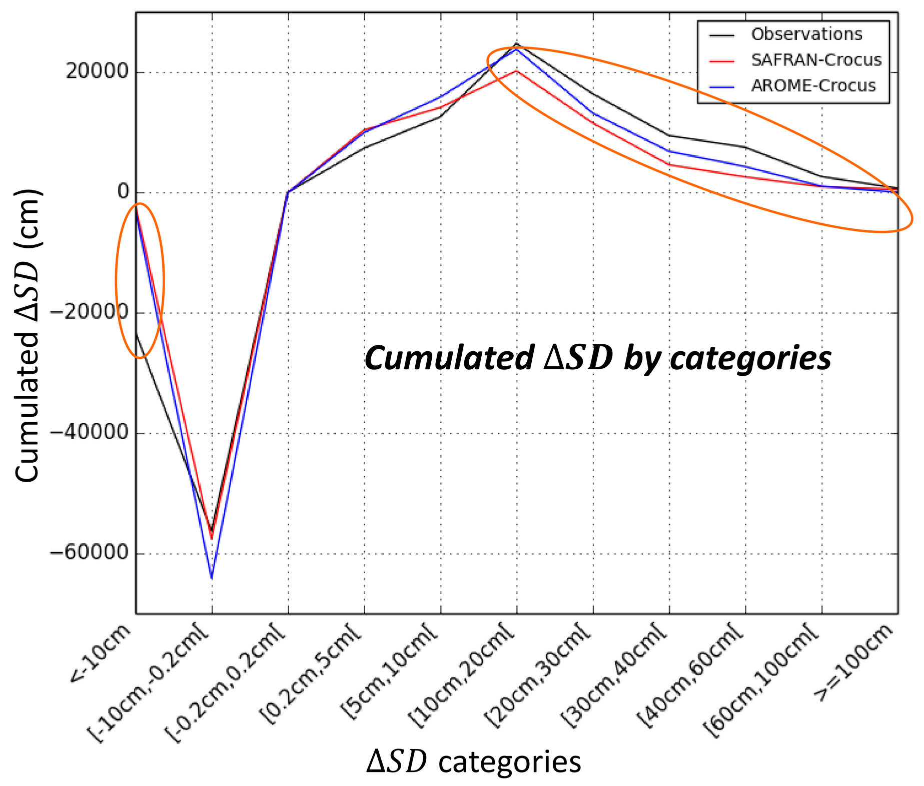
4. Daily snow depth variations : accumulation and ablation processes

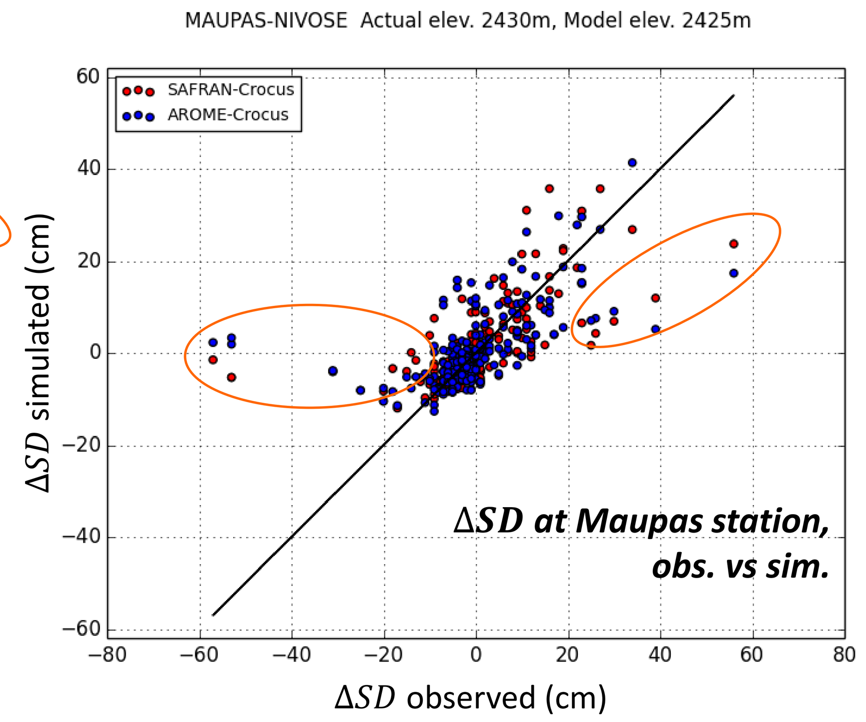
$\Delta SD_J = SD_J - SD_{J-1}$ [Schirmer and Jamieson, 2015]

- Enables to prescind from the **cumulative errors** during one season

Categorical study

- Overall underestimation of accumulations, less marked for AROME-Crocus
- Strong ablations (< -10 cm/day) almost not represented by both forcings



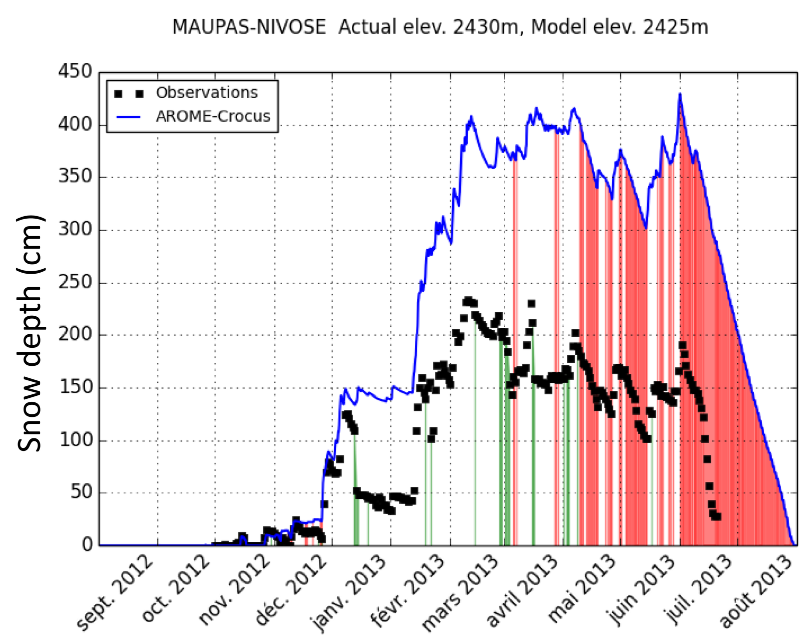


Accumulation processes

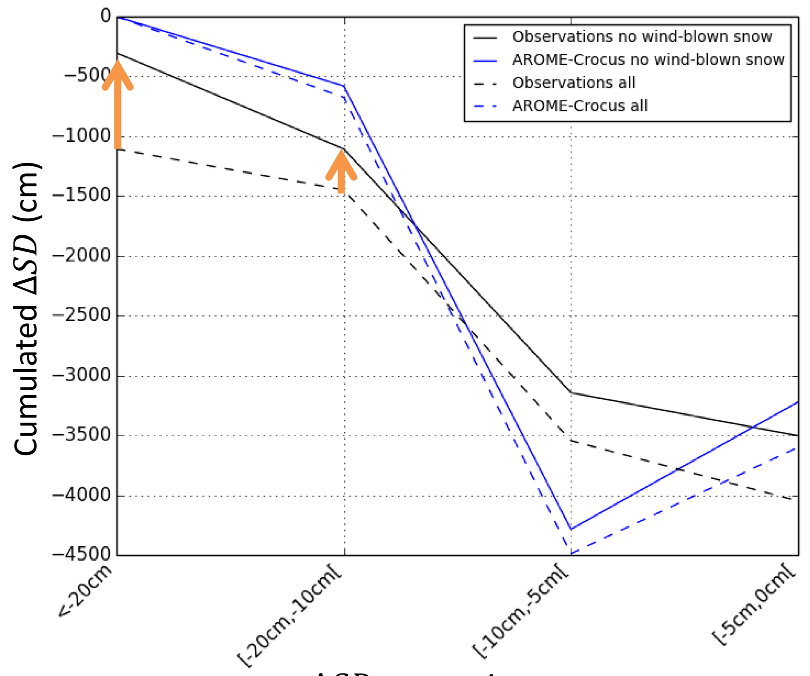
- Strong accumulations (> 10 cm/day) underestimated, but closer to observations for AROME-Crocus than SAFRAN-Crocus
- Small accumulations (< 10 cm/day) overestimated

Ablation processes

- **Melting days** diagnostic: upper snow layer at 0°C at 12Z
- **Wind-blown snow** diagnostic: no melting and measured wind speed > 8 m/s in the day
- « Strong ablations gap » largely reduced when wind-blown snow days excluded
- Strong melting (< -10 cm/day) highly underestimated

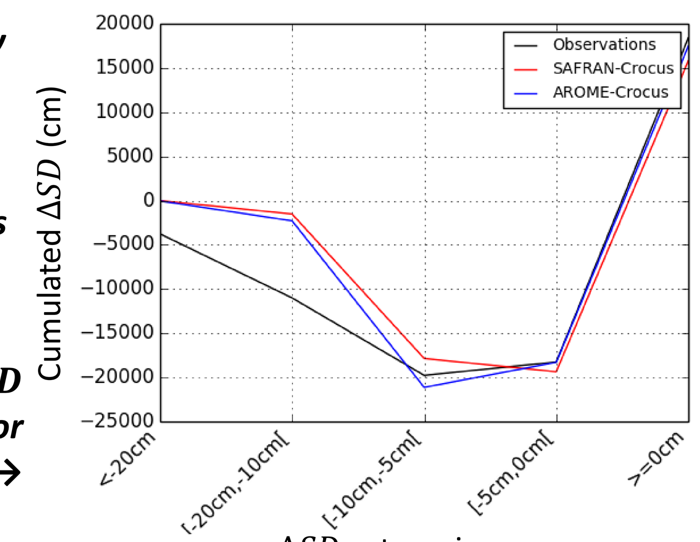


Snow depth at Maupas station, with blowing snow (green) and melting snow (red), 2012/2013



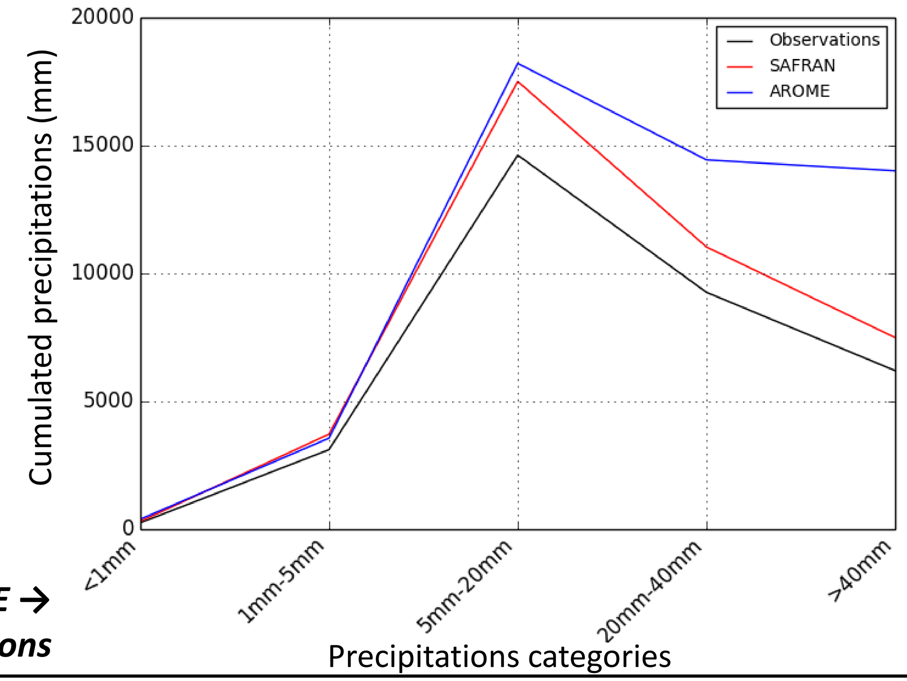
Cumulated ΔSD by categories for AROME-Crocus, including or not blowing snow days ←

Cumulated ΔSD by categories for melting days →



5. Comparison to precipitation measurements

- Comparison of daily precipitation forecasts to **precipitations gauges measurements**
  - Strong overestimation of precipitations by AROME (particularly > 20 mm)
  - Apparent inconsistency with ΔSD study: probably due to the **undercatch of winter precipitations**
- **ΔSD variable** offers a new point of view on snow accumulations, and questions precip. gauges data assimilation.



Cumulated precipitations by categories for AROME → and SAFRAN vs precip. gauges observations

6. Conclusion and outlooks

- Global overestimation of snow depth by AROME-Crocus
  - Despite an **underestimation of strong accumulations**
  - Mainly due to the **underestimation of strong ablations**, amongst which wind-blown snow events (small-scale process, not simulated) and strong melting.
- High-resolution meteorological forcing of snowpack models offers a better representation of **large-scale orographic effects** and **strong snow accumulations**.
- Potential of AROME for high-impact events : **freezing rain on snow** in the Pyrenees, which can create a dangerous thick ice layer. Possible diagnostic thanks to its **cloud microphysical** scheme.

References:
Durand et al. (1993), Ann. Glaciol., 18, 65-71
Schirmer and Jamieson (2015), The Cryos., 9, 587-601
Seity et al. (2011), Mon. Wea. Rev., 139, 976-991
Vionnet et al., (2012), Geosci. Model Dev., 5, 773-791

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