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
- Conceptual relief
- Masif considered homogeneous

This study:
- NWP AROME (Beji et al., 2011)
- High-resolution topography (2.5 km)
- Finer meteorological forcing (rain/snow limit, precipitation localisation, wind...)
- Intra-massif variability

Snowpack model: SURFEX/SBA-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 precipitation
- 74 SD stations, 28 precip. gauges (between 1000 m and 2600 m)
- Stations selection: \( |Z_{\text{station}} - Z_{\text{model}}| < 150 \) m
- Scores: bias and Standard Deviation Error (STDE)

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

- Global overestimation of snow depth, particularly on the Atlantic foothills
- Results sorted by weather patterns (9 types):
  - AROME: better representation of orographic blocking
  - Excessive orographic blocking very locally (Atlantic foothills)

Scores for simulated snow depth, 2010/2014

<table>
<thead>
<tr>
<th>Region</th>
<th>Stations</th>
<th>AROME</th>
<th>SAFRAN</th>
<th>AROME</th>
<th>SAFRAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>27</td>
<td>65.3</td>
<td>17.5</td>
<td>84.5</td>
<td>56.2</td>
</tr>
<tr>
<td>Center</td>
<td>31</td>
<td>58.1</td>
<td>32.3</td>
<td>63.3</td>
<td>50.0</td>
</tr>
<tr>
<td>East</td>
<td>16</td>
<td>34.9</td>
<td>0.1</td>
<td>62.9</td>
<td>60.6</td>
</tr>
<tr>
<td>Overall</td>
<td>74</td>
<td>56.7</td>
<td>21.3</td>
<td>72.4</td>
<td>54.8</td>
</tr>
</tbody>
</table>

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

4. Daily snow depth variations: accumulation and ablation processes

\( \Delta SD = SD_t - SD_{t-1} \) [Schirmer and Jamieson, 2015]
- Enables to prescind from the cumulative errors during one season

Categorical study
- Overall understimation 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

\( \Delta SD \) at Maupas station, obs. vs AROME

5. Comparison to precipitation measurements

- 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.

6. Conclusion and outlooks

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