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The missing link between Alpine potential-vorticity banners and banded convection: A case study of a severe Alpine snow storm

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Motivation

On 01 February 2014, the southern side of the Alps was affected by a heavy snow storm with widespread orographic precipitation causing authorities to issue the highest level of avalanche risk in parts of Austria. The northern side of the Alps was mostly dry. Nevertheless, quasi-steady convective cloud bands developed over the northern Alpine foreland with a remarkable length of several hundreds of kilometers (band 1, band 2 and minor bands in Fig. 1). This study tries to illuminate the mechanisms of these cloud bands based on high-resolution numerical simulations with the Weather and Research and Forecasting (WRF-ARW) model.

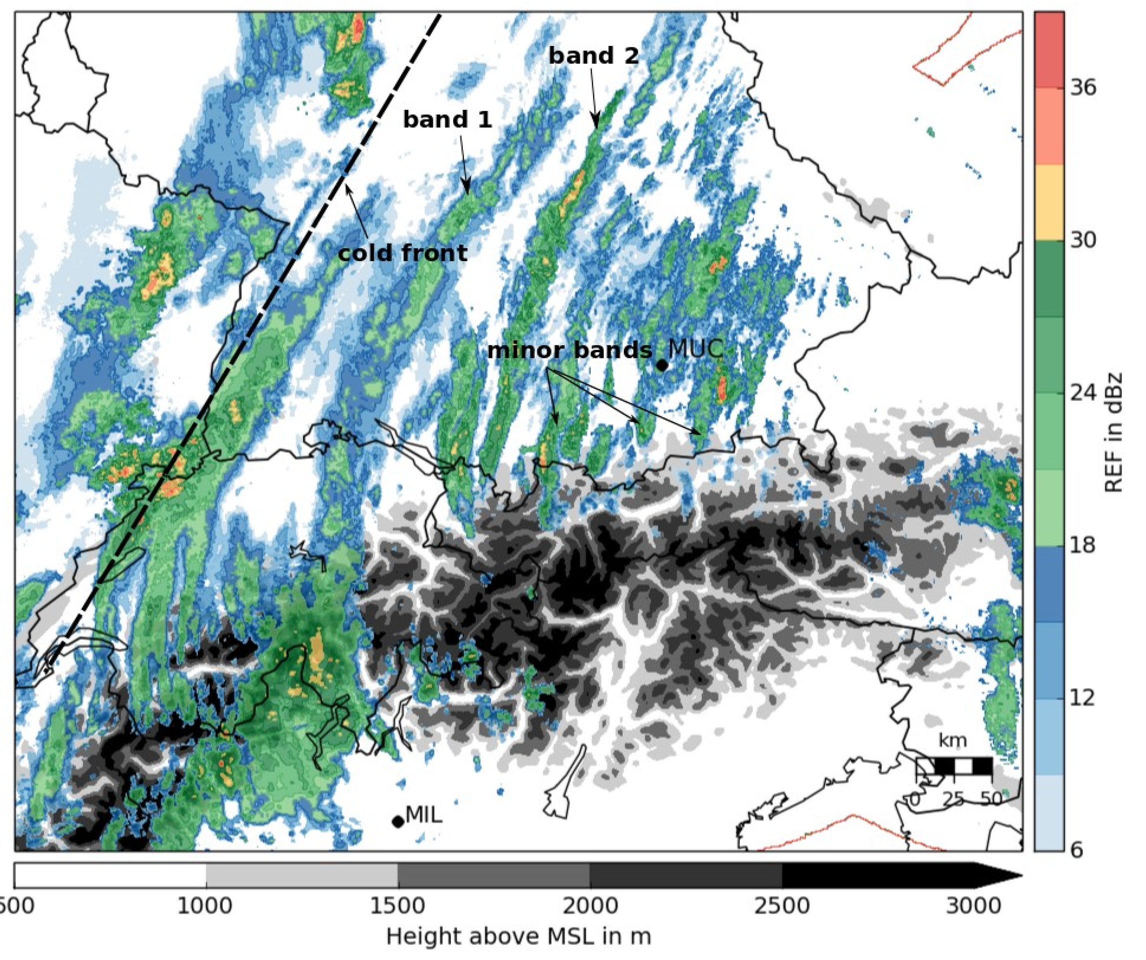

Figure 1: Observed radar reflectivity in dBz at 16 UTC 01 Feb 2014, with model topography shaded in gray, sounding stations Munich (MUC) and Milano (MIL).

Research Questions

- Under which conditions did the observed cloud bands develop?
- Are the observed bands linked to orographic produced PV banners and if not, what other processes organized the clouds into bands?
- What scales of topography were dominant in organizing those banded cloud structures?

Observations

- A trough was located over Great Britain causing southwesterly winds in the Alps with wind speeds up to 38 m s^{-1} (Fig. 2a)
- The upstream flow was nearly saturated up to a height of 600 hPa (see sounding Milano Fig. 2c) and caused heavy precipitation on the windward side of the Alps
- The downstream flow at Munich was dry and relatively warm due to foehn-like subsidence (Fig. 2d), however the foehn did not penetrate to the surface
- Band 1 was stationary from 14 UTC to 18 UTC and formed at the border of dry and moist air masses east of the cold front (Fig. 2b)
- Band 2 and the minor bands were stationary from from 15 UTC to 18 UTC and formed in a rather dry environment compared to band 1 (Fig. 2b).

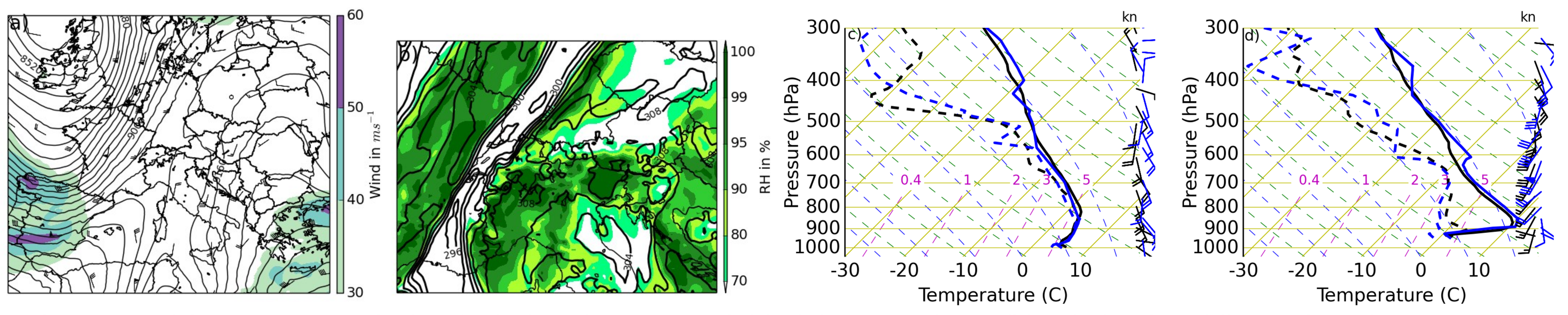

Figure 2: (a) ECMWF analysis of wind and geopotential height at 300hPa, (b) relative humidity and equiv. pot. Temp. at 700hPa, (c) sounding of Milano, observed sounding blue, model sounding black, (d) same as in (c) but for Munich.

Model Setup

- WRF model, Version 3.6.0, advanced research core
- The model was initialized at 12 UTC 31 Jan 2014 and integrated over 36 hours until 00 UTC 02 Feb 2014
- Three two-way nested domains with 90 levels (see Fig. 3)
- Horizontal resolution of **15.0, 5.0 and 1.6 km**
- **Control run and numerical sensitivity studies (SM16, SM40, SM80, SM160)**
- **Numerical sensitivity studies:**
  The topography was smoothed by deleting all wavelengths of the topography shorter than a certain threshold. This was done by a Fourier Analysis of the topography (Schumacher, 2015). In this poster only two runs with smoothed terrain are shown:
  i. All wavelengths shorter than 16 km were removed (this is 10 times the model resolution (DX) of the innermost domain) → **SM16**
  ii. All wavelengths shorter than 160 km were removed (this equal to 100 times DX) → **SM160**

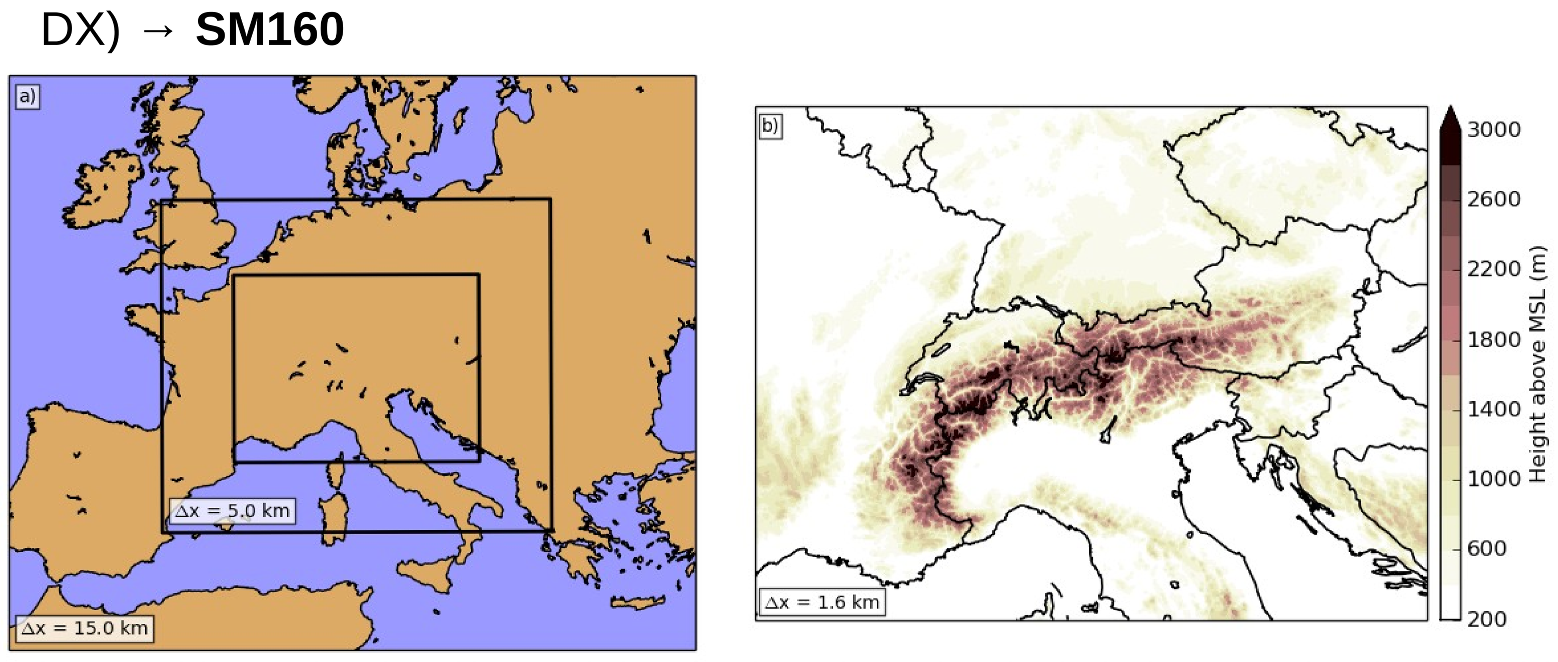

Figure 3: (a) WRF domains with a resolution of 15 km, 5 km and 1.6 km in the innermost domain. (b) Model topography of the innermost domain.

Numerical Simulations

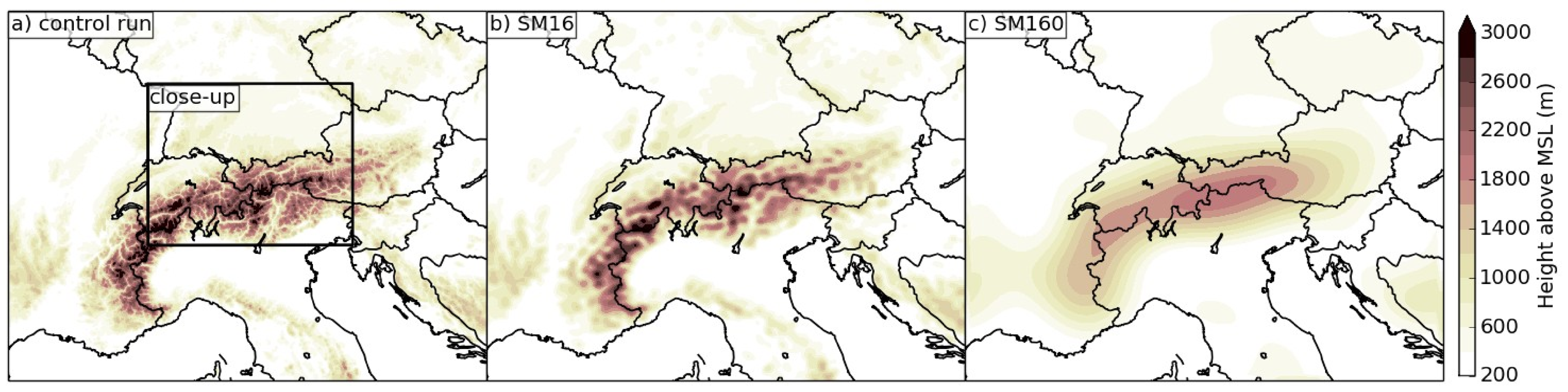

Figure 4: WRF topography of innermost domain with horizontal grid spacing of 1.6 km for (a) control run, (b) smoothed topography with no wavelengths shorter than 16 km and (c) 160 km, respectively .

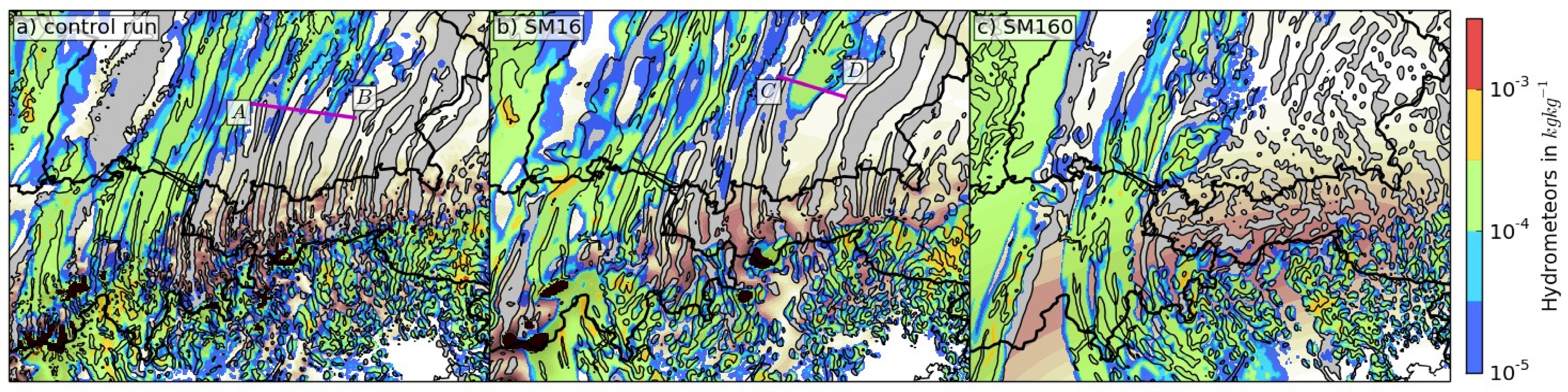

Figure 5: (a) Close-up of Alpine foreland at 15 UTC 01 Feb 2014 (marked in Fig. 4a) with negative PV shaded in gray, hydrometeors in colored contours. (b) and (c) same as in (a) but for the smoothed runs SM16 and SM160.

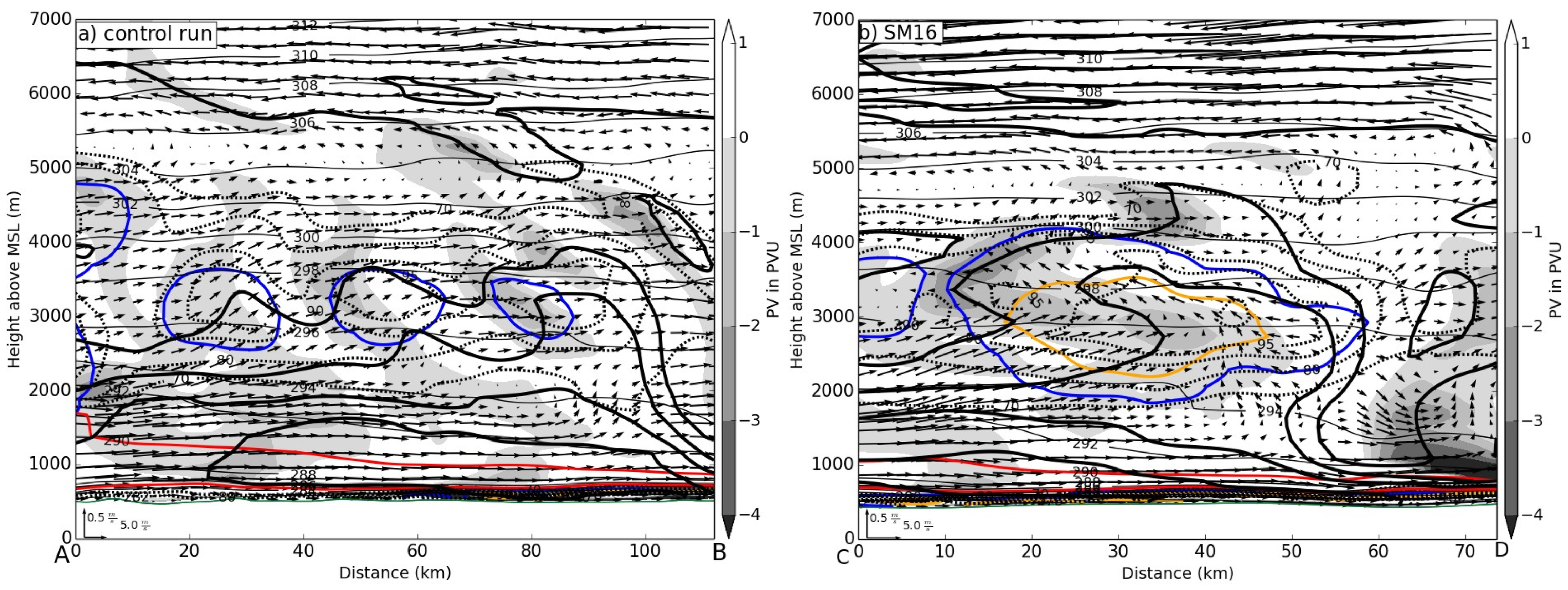

Figure 6: (a) Vertical cross section of control run along AB (Fig. 5a) and (b) SM16 along CD (Fig. 5b) at 15 UTC 01 Feb 2015. Fields contoured are mixing ratio of hydrometeors (10^{-3} g kg^{-1} blue and 0.1 g kg^{-1} orange), wind component perpendicular to transection contoured every 5 m s^{-1} (black thick contour lines) to emphasize the different jets caused by the Alps, potential temperature (thin black line every 2 K, 290 K and 286 K in red), relative humidity over water (dashed 70 %, 90 %, 95 %, 99 % and 100 %). Negative PV is shaded in gray. The cross sections are averaged over 8 km.

- Negative PV is an indicator for dry symmetric instability (DSI) (Hoskins, 1974)
- The PV banners resulted from flow-seperation and/or gravity-wave breaking at the Alpine divide (Schär, 2003)
- Potentially colder air was advected eastward at the surface (red potential temperature isolines in Fig. 6a and 6b)
- The minor bands developed in vicinity of negative PV (Fig. 5a-b, 6)
- Those minor bands developed in unsaturated air masses (Fig. 6)
- Negative PV banners and minor bands were sensitive to the topography:
  i. Along the cross section AB (Fig. 5a) three bands were seen, in the smoothed simulation SM16 only one band was observed along CD (Fig. 5b)
  ii. Further smoothing (SM160) (Fig. 5c) eliminated the PV banners, the minor bands and band 2, but a band in the west was still present, hence band 1 was unlikely caused by the release of DSI
  iii. The bands were more defined in the SM16 run compared to the control run

Conclusions

- During the whole simulation period Alpine PV banners were present (Fig. 5)
- The control simulation showed that the minor bands developed in areas with negative PV, therefore we propose that the minor bands developed due to the release of dry symmetric instability (DSI)
- Potentially colder air was advected at ground level in association with a cold front → this may have lifted the air and triggered the relase of DSI
- This hypothesis was tested by smoothing the topography (Fig. 4)
- A change in topography altered the structure of the Alpine PV banners and in the same way the structure of the cloud bands
- Band 1 was still present in SM160 simulation (Fig. 5)
- Therefore, it is unlikely that band 1 formed due to the release of DSI
- We propose that band 1 developed due to the lift of the moist air band prior the cold front (Fig. 2b)

References

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