Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2020-774-RC2, 2020

Atmospheric Chemistry and Physics Discussions

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Interactive comment

Interactive comment on "Influence of low-level blocking and turbulence on the microphysics of a mixed-phase cloud in an inner-Alpine valley" *by* Fabiola Ramelli et al.

Anonymous Referee #2

Received and published: 16 November 2020

Review for ACP-2020-774

Influence of low-level blocking and turbulence on the microphysics of a mixed-phase cloud in an inner-Alpine valley

by

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General comments

This manuscript uses a wide variety of ground-based observations to investigate the

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impact that orography can have on cloud microphysics in an Alpine environment. Understanding this impact is obviously important for increasing the accuracy of weather and climate forecasts in orographic regions, and the applications that depend on these forecasts.

According to the title, the major objective is to examine the effect of low-level blocking and turbulence on mixed-phase cloud microphysics, and a conceptual figure is given and discussed. The scope of the manuscript is rather broad, and tries to cover too many aspects without enough attention to detail. Many possible processes are described but, often, not enough evidence is presented in interpreting the observations. To be published, this manuscript reqires major revisions. In my opinion, the manuscript would benefit from a much tighter focus, and a discussion reduced to the relevant processes backed by evidence. A major issue is that low-level blocking and wind shear are not likely to be having an impact on the formation of the mixed-phase cloud (the supercooled liquid layer at cloud top) but possibly modifying the precipitation as it falls, i.e. through seeder-feeder processes.

Specific comment and questions

This case study observes the passage of a synoptic-scale frontal system, and some of the features described in the manuscript can be directly attributed to the large scale motion rather than the orography. The sloping shear feature above 2.5 km in Figure 5 is common to many synoptic scale frontal systems (e.g. Keyser and Shapiro, 1986), and similar wind and shear patterns are often seen in weather radar, radar windprofiler or scanning cloud radars in fronts passing over much flatter, homogeneous terrain. The vertical wind shear values are also similar to those observed in fronts over more homogeneous terrain (Chapman and Browning, 2001).

As shown in Figure 8, the highest radar reflectivity values are expected at the upper boundary of the sublimation zone, before the falling ice particles start to sublimate and reduce in size. Figure 8 and 9 show that the sloping shear feature appears to coincide with this sublimation zone, with the location of the maximum radar reflectivity values lowering in altitude over time just above the 0.01 s-1 wind shear contour also lowering in time. This is what would be expected if the sloping shear feature indicates the frontal boundary between two air masses, one saturated, and one subsaturated. This correlation between the upper edge of the sloping shear zone and the maximum radar reflectivity values therefore suggests that the large scale forcing could be responsible in this case.

Hence, without additional observations, or using output from a high resolution numerical weather prediction model, it is difficult to determine whether the changes at low-level (blocked/unblocked flow) are responsible for any changes at upper levels.

Keyser, D., and M. A. Shapiro (1986), A review of the structure and dynamics of upper-level frontal zones. Mon. Wea. Rev., 114, 452–499, https://doi.org/10.1175/1520-0493(1986)114<0452:AROTSA>2.0.CO;2

Chapman, D. and Browning, K.A. (2001), Measurements of dissipation rate in frontal zones. Q.J.R. Meteorol. Soc., 127: 1939-1959. https://doi.org/10.1002/qj.49712757605

The wind shear values derived from the two instruments are not always consistent with each other. Is this due to the differences in spatial and temporal resolution, scan pattern or integration time? Please include the elevation angle that the wind profiler operates at and the scan pattern used by the Doppler lidar for deriving winds. The wind calculations assume a homogeneous wind field and it is known some scanning patterns are more susceptible to turbulence, which can mean that this assumption is no longer valid (Päschke et al., 2015). How much of an impact could the turbulent zones have on the horizontal wind and shear calculations? How about variations in the particle fall velocity?

Päschke, E., R. Leinweber, and V. Lehmann (2015), An assessment of the performance of a 1.5 μm Doppler lidar for operational vertical wind profiling based on a

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1-year trial, Atmos. Meas. Tech., 8, 2251–2266, doi:10.5194/amt-8-2251-2015.

Section 4.2 attempts to describe the influence of shear on the particle microphysics, but insufficient evidence is given to support this. It is obviously difficult to use the Doppler velocity values directly, as these are compromised by the unknown vertical air motion, but the Doppler spectra do show important information. Figure 10 shows one example of the the Doppler spectra following one fall streak, and the broadening is consistent with changes in the particle microphysics; the broadening occurs in a temperature range that coincides with the temperature range for the Hallet-Mossop process for secondary ice production (-8 to -3 C). This increase in Doppler spectral width is clearly seen in Figure 3c between 3000 and 2500 m. However, this increase in Doppler spectral width is more or less constant in altitude throughout the entire time period, and not correlated with the wind shear, suggesting that temperature (possibly the Hallet-Mossop process) is responsible for this microphysical process, not shear.

Note that Doppler spectra wouldn't necessarily show discrete multiple peaks with secondary ice production in turbulent regions, or if sublimation is occuring (evaporation broadens the size distributions).

The conceptual picture shows ice above a supercooled liquid layer, which, although possible, is not that typical for mixed-phase clouds with relatively warm (above -27 C) cloud tops (e.g. Westbrook and Illingworth, 2011; Battaglia and Delanoë, 2013), and is not supported by the remote-sensing observations shown here. The one occasion during P2_unblocked where the base of the supercooled liquid layer is not at the top of the cloud layer seen by the cloud radar is when there is appreciable LWP. LWP of 100 gm-2 implies a liquid layer that is likely to be at least 400 m thick from theoretical adiabatic considerations (e.g. Merk et al., 2016, https://doi.org/10.5194/acp-16-933-2016), which would place the top of the liquid layer at the top of the cloud layer seen by the cloud radar. This means that the observed case study agrees with previous studies.

Battaglia, A., and J. Delanoë (2013): Synergies and complementarities of CloudSat-CALIPSO snow observations, J. Geophys. Res. Atmos., 118, 721–731, doi:10.1029/2012JD018092.

Westbrook, C. D., and A. J. Illingworth, (2011): Evidence that ice forms primarily in supercooled liquid clouds at temperatures > -27C, Geophys. Res. Lett., 38 (L14808), doi:10.1029/2011GL048021.

The data presented does indicate that low-level blocking influenced the presence of low-level cloud in the valley. The three periods selected showed clearly that low-level cloud was present during blocked low-level flow, but not once this blocking weakened.

One option would be to investigate the reasons for this further. The radar Doppler velocity plot suggests that the low-level liquid layer is being formed in updrafts, as almost all Doppler velocities appear to be slightly positive (i.e upwards) for this layer. Is this the case? Or is this due to the difficulty in reading the color scale? The typical vertical air velocity in this layer could be determined from either the Doppler spectra (similar to Fig. 10) or from CFADs of Doppler velocity (similar to Fig. 8). If the air motion is upwards, it would still be weak (< 1 m s-1), so would not necessarily counter the blocked flow argument but be a result of in-valley circulation. Does the LWP correspond to the updraft speed? How about the cloud droplet number or size (Figure 12)?

The wind direction changes and speed slows (in general) at Wolfgang during P2, which coincides with precipitation and no low-level liquid water (Figure 7). Is this just because there is enough time for the precipitation to fall before evaporating (shallower sub-saturated layer)? Is this precipitation solid or liquid? What is the size distribution?

Also of interest is why the seeder-feeder mechanism did not appear to operate in this particular case study, presumably due to the fact that the upper level precipitation rarely fell far enough to benefit. E.g Fig. 12 shows precipitation not quite reaching to 1800 m.

Figure 9. Is it likely that the TKE measured close to the surface at Gotschnagrat is

representative of the turbulence in the atmosphere? Isn't it more likely to be due to local shear close to surface? What are the wind speeds at this location? The direction is the same as at the surface, but Fig. 5a suggests high wind speeds at this height, is the increase in TKE just due to an increase in wind speed close to the surface? Why would this then correlate with the precipitation rate elsewhere in the valley? How does this relate to the conceptual figure?

I'm not convinced of the usefulness of any the correlation coefficients described here. How do they relate to any expected dynamical or microphysical processes? The shear layer appears to coincide with the sublimation zone. For this case study, any attempt to link the surface precipitation to the maximum reflectivity in the profile should at least take the varying sublimation depth into account.

Technical comments

Line 52: Is this wind shear value for wind shear in the horizontal or in the vertical?

Lines 91-92: Do you mean 'the mean ridge height'?

Line 116,118: Isn't Vaisala a Finnish company?

Figure 2 caption: This should state 'taken by the Meteosat 2nd Generation (MSG) satellite'.

Line 228: Cloud base? The ice cloud continues to the surface during P1 and P2. Since all ice is falling (precipitating), the ice cloud base is defined in terms of visibility, not in terms of relative humidity (changes in growth or evaporation rate). Hence it is only during P3 that there is an ice cloud base.

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