

Solutions to the exercise 2 on radar

Question 1:

Recall the physical meaning of radar reflectivity (Z_e) and mean Doppler velocity (MDV).

What are the radar targets here? What information do Z_e and MDV respectively convey?

- Z_e gives us information on the size of the targets (strong relationship, 6th order moment $\rightarrow D^6$) and their concentration (weaker relationship, linear dependence). It is also affected by the phase of targets: ice particles will have a weaker backscattering cross section than liquid water ones.
- MDV gives us information on the fall speed of the targets (because the radar is vertically pointing), which in turn is affected by their terminal velocity and any vertical air motion in the volume.

Question 2

What value did you choose for the threshold in SNR? Explain your choice.

Any value between -16 dB and -10 dB is technically fine. We have chosen -16 dB, since this threshold allows us to detect faint signal (especially at the edge of the precipitation system) while filtering most of the background noise.

Question 3

When is precipitation observed at the ground, and what type(s) of precipitation is (are) observed? Explain.

Precipitation is observed at the ground level in discontinuous intervals between 05:00 of the 27/01 and the end of the time series. These intervals are determined by a valid signal (i.e. a pixel in the plot with non-null Z_e and MDV values once the previously defined SNR threshold has been implemented) reaching the lowest range gate in the time series.

Rain can be seen between 23:00 of the 27/01 and 12:00 of the 28/01 (faster vertical velocity and higher reflectivity), while all precipitation outside of this interval is likely snow.

Question 4

Identify at least 3 different types of clouds in these timeseries. Specify at what time steps and in which altitude range you identify them, and how.

- cirrus clouds above 6 km, after 18:00 of the 28/01;
- nimbostratus around 06:00 on the 27/01, above the snowfall that reaches the ground;
- stratus before 12:00 on the 26/01 close to ground level.

Question 5

What microphysical process do you think is taking place below 1 km between 03UTC and 04:15UTC approximately? What might cause it? (e.g. in terms of atmospheric state variables)

It is the sublimation (solid to gas phase) of the precipitating particles, likely caused by the existence of a sub-saturated layer in the lowest part of the atmosphere.

Question 6

Identify fall streaks of precipitation. Explain why we observe such structures. What do you think influences their shape (in terms of microphysical and/or atmospheric descriptors)?

They appear as “banana-shaped” filaments of higher reflectivity, starting slightly above the 4 km height line and extending down below the 1 km height.

They are likely caused by regions of enhanced formation and growth of ice particles, which fall and encounter a wind shear. The change of horizontal wind speed (speed shear), combined with the fallspeed of the particles, produces the bend in the fall streak.

Question 7

7.a) Looking at these profiles, what is the main change between 03 and 06UTC, and how does this relate to the radar reflectivity timeseries you observed before (03:00 – 06:30UTC)?

The main difference is in the relative humidity (with respect to liquid water, we will omit this clarification from now onward). The region of low humidity coexists with the lack of precipitation at the ground at 03:00, while the higher value of humidity at 06:00 is associated with a period of snowfall at the ground in the radar measurements.

7.b) Do these profiles help confirm/revisit your answers to question 5, and how?

About 03UTC, the precipitating particles encounter a region of low humidity, which is the sub-saturated environment we mentioned before.

The falling snowflakes encounter this relatively dry region, and start sublimating, until they eventually disappear. This causes the lack of precipitation at the ground level in this period of the time series.

As snowflakes sublimate, the environment receives water vapour, becoming more and more saturated, until the higher relative humidity values seen in the profile at 06:00 are finally reached. In this environment, snowflakes do not sublimate anymore (or sublimate less, if saturation with respect to ice is not yet reached), and they can reach the ground.

7.c) How about question 6?

The streaks are likely related to the sudden change in wind speed that can be seen in the 06:00 profile between 1000 and 1500 m of altitude. This is the shear we mentioned in the answer to question 6.

Question 8

Identify signatures of clouds, precipitation, and virgae in these timeseries (define their temporal and altitude range).

- Clouds: close to zero MDV, very low Ze. Example: above 6 km, between 08:00 and 09:00.
- Precipitation: high MDV (very high for rain, smaller for snowfall), medium-high Ze (depending on the particle type). In this case we only have snowfall. Example: below 1 km and after 10:15.
- Virgae: can have high MDV, but particles get smaller as they sublimate and the velocity decreases. Ze starts high and decreases as the particles sublimate. Example: below 1 km, between 8:30 and 9:00.

Question 9

Describe the structures that can be observed in radar reflectivity and mean Doppler velocity around 3-3.5km range, e.g. betw. 08:30 and 09:30 UTC? What do you think they can be due to?

Note: you can zoom into the timeseries by changing the bounds in the line:

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ax.set_xlim(datetime.datetime(2021, 1, 27, 6, 30), datetime.datetime(2021, 1, 27, 12, 20))
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We see alternating updrafts and downdrafts over short periods of time, that are likely generated by turbulence. It is probably due to the cooling at the top of the cloud by thermal emission or by sublimation, which cools down the air and the particles in the top layer, increasing the density. Negative buoyancy triggers downdraft and local circulation.

Question 10

10.a) Look at the shallow layer around 1 km range, which persists from ~07:00UTC to ~11:00UTC. What do you think it corresponds to in terms of hydrometeors? To answer this question, take into account the signatures in Ze and Doppler velocity, as well as the spatio-temporal structure of the layer.

It is probably a cloud, since it has low Ze and the fall speed is positive (upward motion) or close to zero (stationary), which means it is not precipitating.

10.b) What do you observe in this layer around 1 km range between ~06:50UTC and ~07:30UTC, in MDV?

It is a region of positive MDV, indicating an upward air motion at this location and time.

10.c) Identify time steps and height ranges when various cloud structures "merge" in the radar signal: what is happening here? From your knowledge of usual microphysical processes, what process(es) do you think may take place in these conditions?

We can see cloud structures merging around 1 km above the radar and between 07:30 and 08:30, as well as between 10:30 and 11:00. This is likely the seeder-feeder process taking place, as we see enhanced "streaks" of cloud and precipitation particles below this merging (seeded particles feed on the feeder cloud particles, via aggregation or riming).

Question 11

11.a) Are these profiles compatible with / do they confirm your answer to question 10a?

They confirm the hypothesis, since we have a region in which the relative humidity profiles are saturated in both radisoundings that coincide with the height of the cloud.

11.b) Looking at the wind information, can you get an intuition of how this layer (i.e. around 1 km range) could be formed?

We have a strong shear in wind direction. This shear can cause turbulence at this height, which in turn causes small-scale upward motions, which may lead to the formation and growth of cloud particles.

Question 12

What is happening around and below the 1000m level in these timeseries?

It is raining, since we see high Ze (liquid phase + relatively large targets) and very high MDV (raindrops fall faster than snowflakes or ice particles in the cloud).

Question 13

13.a) What do those features (i.e. the ones you identified in the previous question) correspond to in the RHIs of MXPOL? Look at the different variables and the hydrometeor classification.

We see higher values of Z_H in the lowest part of the RHI, below the 1 km height.

This region is delineated by a region of enhanced Z_H, called the bright band. This band is also characterized by relatively high Z_DR and low rho_hv.

13.b) What do the high and low Z_{DR} features in the top left of the RHI (between 3 and 5 km of altitude and within 6-10 km of horizontal distance) correspond to in the hydrometeor classification? Why?

The high Z_{DR} region are likely crystals that are growing along a particular axis more than the others, resulting in very asymmetrical shapes. The reflectivity of these particles will be much higher along the polarization axis that is more aligned along their growth axis, resulting in high Z_{DR}. The low Z_{DR} region are probably aggregates, that are much rounder and “fuller”, resulting in values along the horizontal and vertical polarization more similar to each other.

Question 14

Are the COSMO profiles consistent with your interpretation of the radar measurements (questions 12 and 13.a)?

Yes, since we see high relative humidity in the lowest part of the profile, indicating a saturated environment that we would expect to have during rainfall.

Temperature is also close to the value of 0°C, which is consistent with the presence of liquid precipitation.

Question 15

Explain how Doppler spectra can help get insight into the microphysical properties of clouds or precipitation.

Spectra give us the distribution of the measured radial velocities within a radar sampling volume, weighted by the reflectivity.

The location and strength of the main peak in the distribution can help us understand which types of particles dominates the return from the volume (big particles falling faster, smaller one falling slower).

Multiple peaks indicate the presence of multiple populations of particles within the sampling volume, with the location and strength of the peak that may denote the type of hydrometeors that could be causing the peak.

Finally, broadening of the peak may indicate the presence of turbulence.

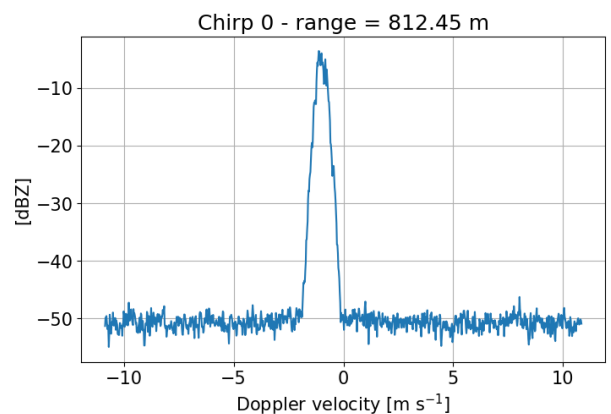
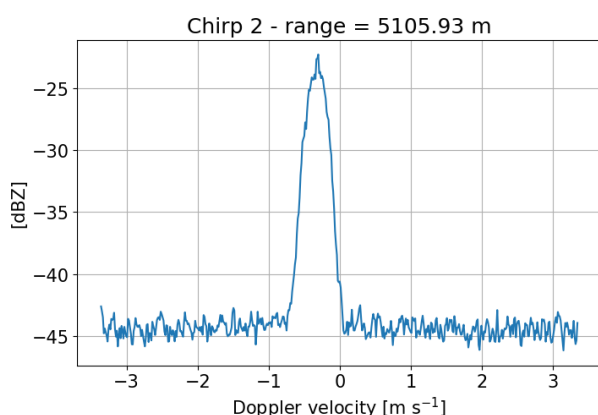
Question 16

Look at the full spectrogram plotted above (27/01, 05:09 UTC). What do you observe at ~2000m and ~3000m above ground, and what do you think it reveals?

It is likely turbulence, since the spectrum becomes suddenly much wider.

Question 17

17.a) In the cell above, change the chirp and nrg parameters to display one example of spectrum at low altitude (below 1000 m) and one at high altitude (above 5000 m). Describe the differences, e.g., in terms of amplitude, width, velocity range. What does this reveal about cloud / precipitation microphysical properties in these two regions? Is this expected and why ?



Chrip = 2, nrg = 49: we see a narrow symmetrical spectrum, with a mode around -0.5 m/s and about -22 dBZ for the spectrak Z.

Chrip = 0, nrg = 95: we see a broader spectrum ($-2 < < 0$ m/s), a higher mode (1 m/s) and a much higher spectral reflectivity peak (~ -5 dBZ).

17.b) Starting from the top of the spectrogram, indicate what are in your view the microphysical processes (e.g. growth/ decay mechanisms) that are taking place?

At the top of the spectrogram (~ 6000 m) the first ice particles are formed (nucleation + vapor deposition).

At lower levels, we see larger and larger particles (stronger return, more negative velocities), which indicates growth.

Particles in the lowest part (< 2000 m) are particularly large and fall to the ground at increasingly larger fall velocities, potentially corresponding to aggregation. Riming is less likely as there is no clear acceleration.

The sharp broadening of the spectra around 3100 and 2000m are likely due to turbulent layers at those altitudes.

Question 18

In this new example (28/01, 05:04 UTC), make the link between what you observe in the spectrogram and your answers to question 12: where do you see the signatures that were visible in Ze and MDV? What additional information do you get from the spectrogram (compared to the timeseries), focusing on altitudes below 1000 m?

We see that the average radial velocities are more negative (higher absolute values) in the region that we identified as rain below 1000 m. This is a behaviour that we expect in rain.

The additional information that we obtain from the spectrum is the large spread in the speed of particle: the spectrum is much wider than in the region above, indicating that there is a large diversity in the fallspeed of the raindrops.

Question 19

19.a) In this last example (27/01, 15:39 UTC), the spectrogram looks very different. Explain what this multimodal signature reveals

The presence of 2 modes indicates that there are two distinct populations of particles in the sampling volume.

19.b) What microphysical processes can be happening here? Try to address in particular the following points: what does the Doppler velocity of the leftmost mode suggest? What could cause the occurrence of the second mode below ~ 3000 m?

The second mode could be caused by two phenomena:

- the presence of supercooled liquid water droplets;
- the splintering of ice particles, creating secondary ice particles.

In this case maybe some supercooled liquid water exists in the region just below 3000 m (velocity close to 0m/s), but most of the mode at lower velocity in the region below is probably secondary ice, since we have a relatively large spread in the distribution and fallspeeds are farther from the 0 m/s. The third mode visible at about 600-800 m is caused by a population of supercooled droplets, since it is very narrow and close to 0 m/s.

Question 20

Comment the images and put it in perspective with your answers to questions 15 a) and b). What would each mode correspond to? Explain the signatures in terms of both velocity and reflectivity.

We see the elongated (columnar) crystals, which are the ones causing the increase in Z_{DR} . They are small, which results in a low fallspeed and consequently low MDV. Their Z_e is low (ice and small), but the differences along the vertical and horizontal polarization planes causes a high Z_{DR} . We also see big particles in the image. They are aggregates: they appear rounder (low Z_{DR}) and larger (which results in higher Z_e and fallspeed, so high MDV).