Exercise 5 - Radar and satellite analysis of an intense precipitation event

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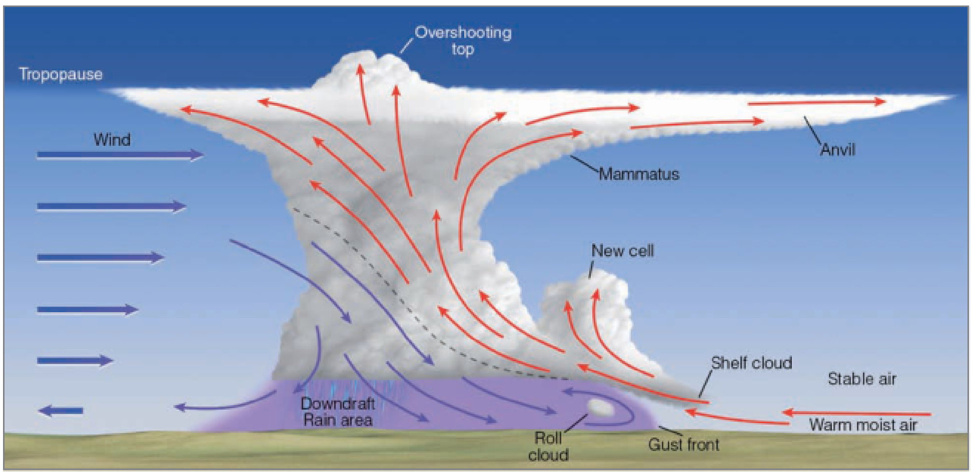
LTE, EPFL, Switzerland

On June 15th, 2019, a low-pressure system associated with deep convection hit Switzerland, with violent thunderstorms causing heavy damage in the western part of the country. Abundant precipitation was recorded, as well as strong wind gusts and hail in some locations (see some information on this event in the Swiss or French media, as well as a video of the squall line passing over Geneva).

The purpose of this exercise is to analyze this event from a remote sensing perspective, using passive and active sensors from satellite and ground instruments. For reference, a simplified description of a mature multicell thunderstorm is shown in Figure 1.



ACTIVE FIGURE 14.5 A simplified model describing air motions and other features associated with an intense multicell thunderstorm that has a tilted updraft. The severity depends on the intensity of the storm's circulation pattern. Visit the Meteorology Resource Center to view this and other active figures at academic.cengage.com/login

Figure 1: Description of a multicell storm. Source: C.D. Ahrens and R. Henson, *Meteorology Today*, 2015 [1]

1 SEVIRI: Satellite Imagery in the Visible and Infrared

First, data from one of Meteosat's second generation satellite sensors will be used. The Spinning Enhanced Visible and Infrared Imager measures radiation from the Earth in several spectral channels, from visible to infrared frequencies, at a high temporal resolution. More information can be found here (in French).

1. Explain how the different channels of the SEVIRI telescope can be used for the detection and analysis of cloud layers.

Start a new QGIS project, and **set the CRS to CH1903/LV03 (EPSG:21781)**. Then, load the Swiss DEM that is provided: this will be useful to keep in mind the geographical setting. You can re-use the same colorbar that you implemented in the first exercise of the semester.

Through your file explorer, look at the SEVIRI data that is provided, in the visible and infrared channels (don't load it to QGIS at this stage). The time spans 13:30 to 16:30 UTC, which covers the arrival of the storm over western Switzerland. Qualitatively, identify terrain and meteorological features in the SEVIRI images (Hint: since the spatial resolution is low, it can be useful to scroll through the sequence of images to understand what the different signatures correspond to).

NOTE: In infrared imagery, the color bar is usually reversed in comparison with the one used here, which is the standard grayscale (0 = black, 255 = white). If you prefer, you can invert the color bar of the IR images in QGIS to visualize the infrared images in a more classic way. In the following, "dark" and "bright" denote respectively pixel values close to 0 and 255.

In your QGIS project, load the images of the VIS006, IR039, IR087 and IR134 channels, for **one timestep of your choice between 13:45 and at 14:30 UTC**. The projection should be converted to your project's CRS using the transformation indicated in Figure 2.

Note: At this point, it is possible that you get an error message "No transform available between EPSG:2056 and EPSG:21781". Go to the "Details", and use the provided link to download the required Grid Shift File; then hit "Install CHENyx06a.gsb from Folder...", select the path that you have just downloaded and follow the installation instructions. At the end of the procedure, you will need to restart QGIS.

2. Clouds appear brighter in the visible range, but darker in the IR : why is that?

3. In the IR134 image, where is (are) the brightest area(s) in Western Switzerland, and what do they correspond to?
You can use the Swiss political canton boundaries to identify the locations (*cantons.dxf*).

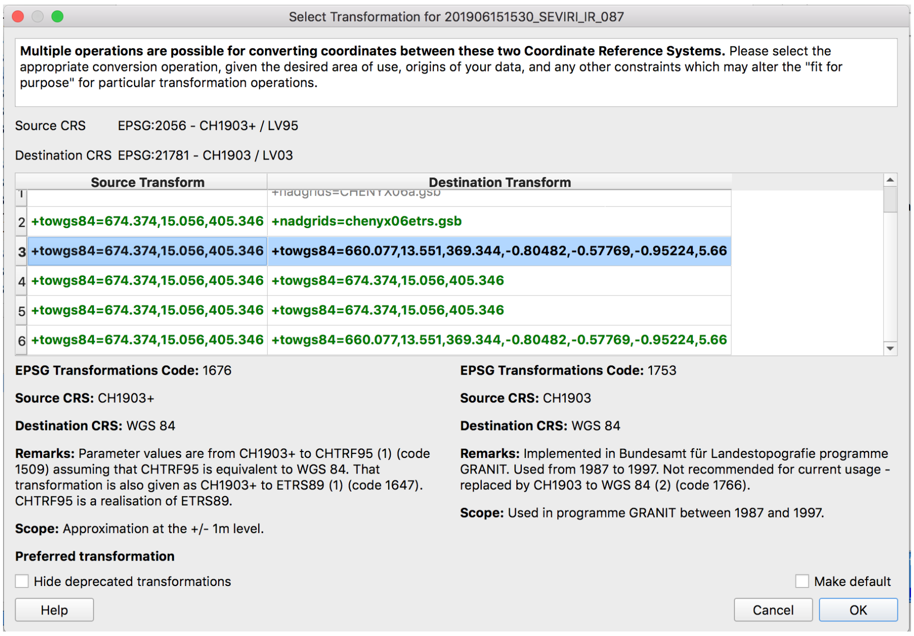


Figure 2: Choice of CRS transformation

Next, we will make a cloud mask to highlight the clouds over Switzerland. First, use the transparency of the visibility and infrared channels to choose suitable thresholds to identify clouds. In the Raster Calculator, combine these thresholds into one mask using the boolean operators. Multiply your cloud mask by the IR087 image, in order to show the IR texture where the mask is 1 and a clear background where the mask is 0. To make the 0 values of the resulting image transparent, click on the layer's *Properties - Transparency* tab and specify the interval value 0 in the *From* and *To* fields. The pixel values to be set transparent can also be queried by clicking on the left side button portraying a mouse arrow and a question mark.

The purpose is not to define a perfect and completely robust indicator, but to construct a reasonable mask for the time step you are looking at.

4. From your cloud mask image, what do you infer about the cloud top heights of the three cloud groups visible between 13:45 and at 14:30?

Let us now move on to a later time step, where the thunderstorm is intense over western Switzerland. Load the SEVIRI images at 16:00 UTC. Choose the channel which you think is the most appropriate for the study of this part of the event. *Hint: Think about how different channels may "see" clouds at different altitudes*

5. Looking at the main storm cloud, where do you expect the most intense precipitation? You can narrow down the colorbar to make this more visible.

2 MeteoSwiss radar network

2.1 Precipitation

The weather radar network of MeteoSwiss comprises 5 operational C-band radars (blue triangles in Figure 3). They are an essential tool for short-term weather forecasting (nowcasting), and allow for a high spatial and temporal resolution in quantitative precipitation estimation (QPE). In this section, two radar-based MeteoSwiss products will be examined.

1. The first one, **RZC**, is the rain rate estimate derived from **radar measurements only**, according to Germann et al. 2006 [2] and Gabella et al. 2017 [3]. It relies on measurements of radar equivalent reflectivity.

2. The second one, referred to as **CombiPrecip**, is a rain-rate estimate obtained by **combining radar and rain gauges measurements**. It builds on RZC and incorporates pluviometric data through geostatistical methods. It was developed by Sideris et al. 2014 [4] and refined by Barton et al. 2020 [5] to increase the temporal resolution. The Swiss network of rain gauges (whose measurements are used in CombiPrecip) is shown in Figure 3. More detailed maps are available here.

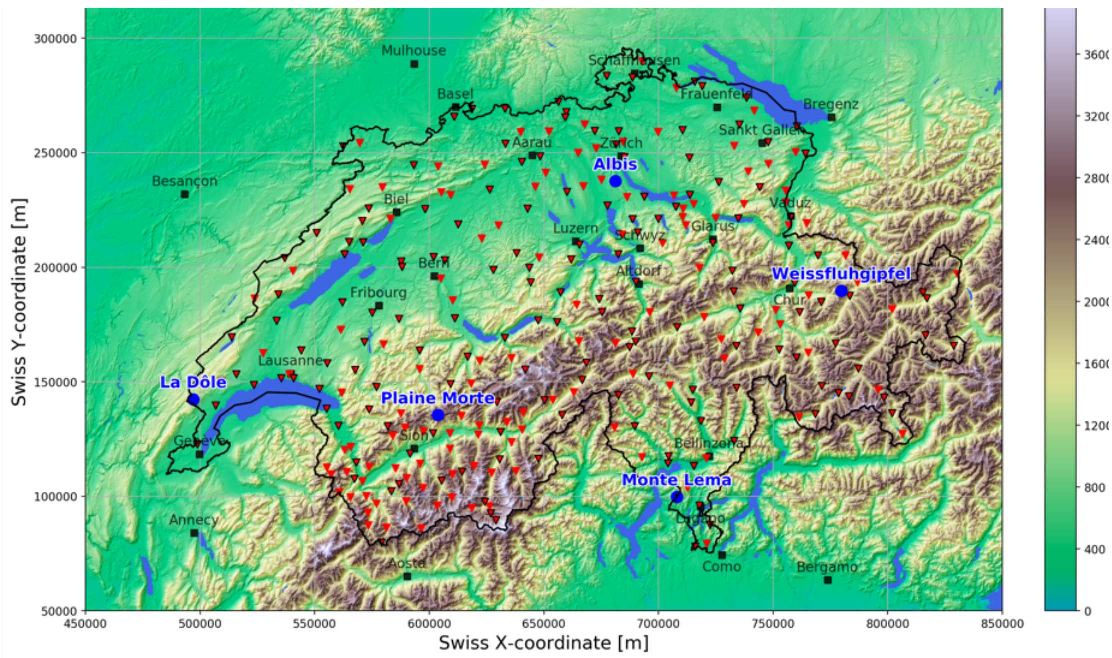


Figure 3: Topography of Switzerland with the five Swiss operational radars (blue circles), the 160 synoptic weather stations (red triangles with black border) and the 128 rain gauges (red triangles without borders). Major cities are indicated with black squares. Source: Wolfensberger et al. 2020 [6]

In your QGIS project, load the RZC rain rates for 16:00 and 16:02 UTC (*RZC191661600VL.tif* and *RZC191661605VL.tif*) as well as the CombiPrecip product for the same time frame (*CPC1916616009_00005.801.tif*). CombiPrecip rain rates are provided with a 5-minute resolution. Both RZC and CombiPrecip files contain rain rate values in mm/h. Compute the average RZC between the two timesteps, which will allow for a more robust comparison with CombiPrecip. For this, you can either use the *Raster calculator* or the *r.series* function in the GRASS field of your *Processing Toolbox*.

In order to better visualize precipitation fields, it is common to use a logarithmic scale, since rain rates typically span a large range of values. Using the raster calculator and the transparency tab in the layers' properties, display the area with precipitation, for CombiPrecip and RZC. Feel free to adjust the color scale as you wish.

If you want to access the pixel values of different layers at one location, use the *Identify feature* button, then the *Identify all* option when you right-click on a pixel.

6. Where is the strongest precipitation taking place in Switzerland (focusing on the main storm cloud)? Compare this with your answer from question 5.

Now, compute the difference between CPC and the averaged RZC for this time period, in the logarithmic variables, and display it. Adjust the color scale to visualize the relevant differences in the two estimates. Do the same with the original variables (non-logarithmic). For the logarithmic scale, make sure that the color scale is centered on zero.

7. Identify the locations with significant differences in CombiPrecip and RZC estimates. What does the comparison in the logarithmic difference highlight? In the linear difference? Keeping in mind how the two products are computed, propose an explanation for what you observe.

2.2 Wind

The thunderstorms of June 15th, 2019, featured not only strong precipitation, but also strong winds, as experienced by sailers of the Bol d'Or race that took place on the Geneva lake on that day.

The Doppler velocity measured by the La Dôle radar (coordinates: X496041 / Y141800 in CH1903/LV03) at 16:00 UTC is provided in *DVD1916616007L.803.tif*: this is a PPI scan at 0.92 degrees of elevation. Here, by convention, Doppler velocity (in m/s) is negative when the motion of the targets is toward the radar, and positive when the targets are moving away from the radar. Load the file in your QGIS project on top of your previous layers. Define an appropriate colormap: Doppler velocities are typically represented with a blue-red colormap, centered at 0 m/s (i.e. zero velocity is white; refer to the course slides for examples). Set the layer to transparent where there is no data.

8. What is the main wind direction close to the radar? Estimate the wind speed in the vicinity of the radar (for example at 10 km)
You can use the *Measure line* and *Identify feature* tools in the toolbar)

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9. One major artifact is visible in this radar data. It can also be seen, to a lesser extent, in the RZC and CombiPrecip data. Can you identify it, and explain its cause?

Hint: you can look at an aerial view of the la Dôle radar to identify the cause.

Look at the Doppler velocity field close to the maximum of precipitation, which you identified in question 6: some physical signatures are visible.

10. Propose an explanation for the different signatures around the maximum of precipitation intensity: infrared (cf. question 5), RZC/CombiPrecip (cf. question 6) and Doppler velocity.

Hint: in addition to Figure 1, you can find some helpful explanations on thunderstorm structures here

References

[1] C. Donald Ahrens and Robert Henson. *Meteorology today: an introduction to weather, climate, and the environment.* Boston, Mass: CengageLearning, 2016.

[2] Urs Germann et al. "Radar precipitation measurement in a mountainous region". In: *Quarterly Journal of the Royal Meteorological Society* 132.618 (2006), pp. 1669–1692. DOI: https://doi.org/10.1256/qj.05.190. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1256/qj.05.190.

[3] Marco Gabella et al. "Measurement of Precipitation in the Alps Using Dual-Polarization C-Band Ground-Based Radars, the GPM Spaceborne Ku-Band Radar, and Rain Gauges". In: *Remote Sensing* 9.11 (2017). ISSN: 2072-4292. DOI: 10.3390/rs9111147. URL: https://www.mdpi.com/2072-4292/9/11/1147.

[4] I. V. Sideris et al. "Real-time radar–rain-gauge merging using spatio-temporal co-kriging with external drift in the alpine terrain of Switzerland". In: *Quarterly Journal of the Royal Meteorological Society* 140.680 (2014), pp. 1097–1111. DOI: https://doi.org/10.1002/qj.2188. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.2188.

[5] Yannick Barton et al. "A method for real-time temporal disaggregation of blended radar–rain gauge precipitation fields". In: *Meteorological Applications* 27.1 (2020), e1843. DOI: https://doi.org/10.1002/met.1843. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/met.1843.

[6] D. Wolfensberger et al. "RainForest: A random forest algorithm for quantitative precipitation estimation over Swizerland". In: *Atmospheric Measurement Techniques Discussions* 2020 (2020), pp. 1–35. DOI: 10.5194/amt-2020-284. URL: https://amt.copernicus.org/preprints/amt-2020-284/.