Assessing Climate impacts on the Quantity and quality of WAter

Deliverable D.S.2.4 : Development of new methods to assess heavy precipitation events in the Alps - month 47

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Introduction

The cut-off low systems appear in the upper and middle troposphere as closed cyclonically circulating eddies. They are stationary or quasi-stationary systems with a typical life span of few hours to a few days. They are more frequent in summer and Europe is the most favoured region (33% of total no of CoLs occurring in Northern Hemisphere). It is also worth mentioning that they are smaller than extra tropical cyclones (spatial scale of CoL is 5-10 degrees) and more often the region affected by heavy precipitation ranges from a few hundred to several thousand square kilometres. In general, the life cycle of a CoL can be divided into four stages.

1. Upper level trough: theoretically, a CoL manifests from an unstable geopotential wave in the upper troposphere which extends southward (in Northern hemisphere) in the form of a deep trough in the westerlies. The temperature wave is often behind the geopotential wave therefore, the air inside the trough is colder than its surrounding.
2. Tear-off: the cold air is advected into the trough and this trough deepens eventually forming an inverse omega shape of the isolines,
3. Cut-off, this deepening continues and finally this trough cuts off from the main westerly flow.
4. Final stage: the air below the CoL is unstable and prone to convection. The warm air that is brought in by convection slowly weakens the CoL. Often CoLs which are weakened by convection dissolve and merge with the main meridional flow.

In addition to this baroclinic mechanism of precipitation generation, the quasi stationary behavior of CoLs is also very important. This can enhance the condensation process by up-gliding moist air on mountain ridges and hence increase the intensity of precipitation. Especially, CoLs with centers southwest and northeast of the main Alpine ridge lead to a perpendicular flux of moist Mediterranean air to the Alps which increases the precipitation amount due to the aforementioned up-gliding mechanism.

In weather charts, one can recognize a CoL from its distinguished closed isolines with cold air at the core at 200 hPa and sometimes even extending to the surface. As mentioned earlier, the air below the COLs is unstable and prone to convection. Hence, depending upon the surface conditions (e.g. surface temperature, moisture availability) CoLs can initiate and sustain heavy precipitation events. A typical CoL prevailing during May 20 – 22, 1999 is depicted in Figure. 1.

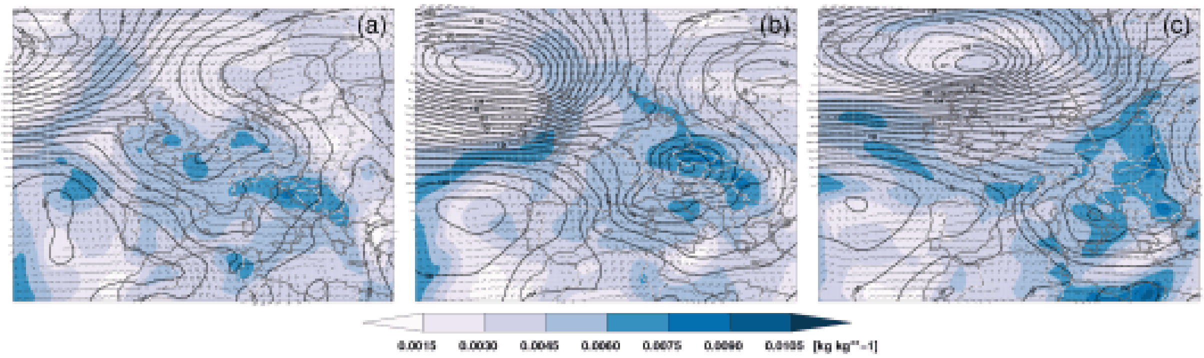

Figure 1. The study domain along with depiction of manifestation and life span of a typical CoL situation that prevailed during 20th - 22nd of May, 1999. a) 20th of May 1999, 06 UTC, b) 21st of May 1999, 06 UTC, c) 22nd of May 1999, 06 UTC

Data and Methods

The method developed for this study is based on the physical characteristics of CoLs. In this method three main physical characteristics of CoLs have been used to identify a CoL, that is;

1. A minima in the geopotential height (GH) at 200 hPa, which has also been cut-off from the main circulation.
2. The Equivalent thickness field calculated from GH at 200 hPa and 300 hPa.
3. The frontal thermal parameter which is the measure of baroclinity. Therefore, GH at 200hPa and 300 hPa, horizontal wind component and temperature at 200 hPa are used.

A moving nine pt search is carried out throughout the domain to locate the grid points that satisfy the following criterion. The grid point under consideration should have:

a) a lower value (minima) than a certain threshold in the 200 hPa GH as compared to seven out of eight neighboring grid points,

b) u-wind component should have opposite direction to any of the two adjacent grid points present in the north,

c) lower value of Equivalent thickness as compared to adjacent grid point on the east,

d) lower value of Thermal frontal parameter (TFP) than that of its neighboring eastern grid point.

When all these criteria are met the grid point is marked as a CoL. The process is repeated for the whole domain and for all the time steps and locations of all the CoL centers are saved. Moreover, if two or more CoLs are detected than it is also checked if they are part of the same system or different systems. If the CoLs are less than five degrees apart than they are considered as unique systems otherwise the grid point with minimum GH is taken as the center of the CoL and other are disregarded. This ensures that one CoL center is considered and fake centers are eliminated.

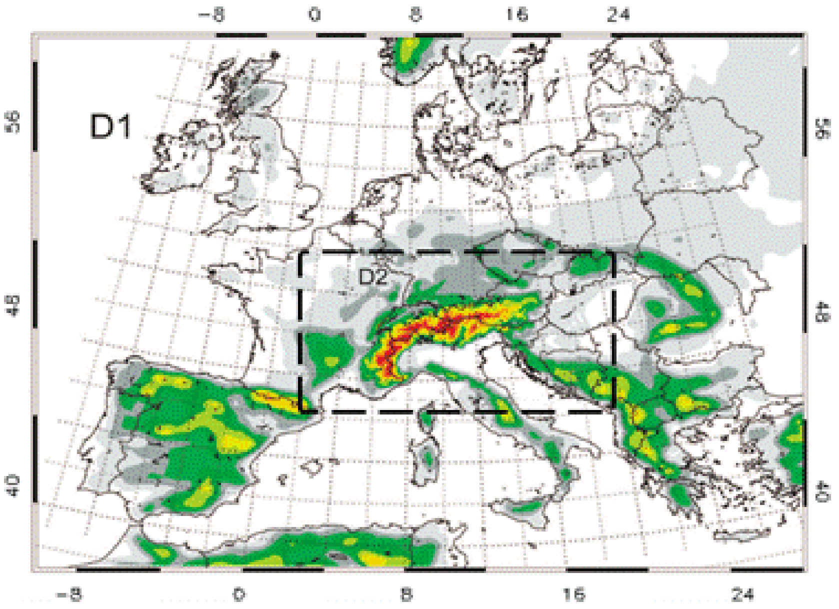

Figure 2. The geographical extent of the study region D1 is used for detection of CoLs while D2 is used for detection of large scale heavy precipitation events.

The region of interest is shown in Figure. 2. For detection of CoLs the large domain one (D1) is considered while for large scale heavy precipitation events the domain two (D2) is used. The aforementioned method is applied to European Center for Medium range Weather Forecasting (ECMWF) re-analysis ERA-40 dataset [Uppala et. al. 2005] to obtain a new dataset containing the latitudes and longitudes (locations) of center of CoLs. That is, GH at 200 hPa and 300 hPa, Temperature and Horizontal wind component at 200 hPa from ERA-40 re-analysis are given as input to the algorithm which returns the location of the center of CoLs.

In order to show the relevance of these processes to manifestation of large scale heavy precipitation events we have used the Swiss Federal Institute of Technology Zurich dataset [Frei and Schar 1998, Frei et. al. 2006] (referred to as ETH dataset) dataset which has a grid spacing of approximately 20 km. As mentioned earlier our foci was heavy precipitation events in which large areas were effected, i.e., approximately 3100 sq. km. (in case of ETH dataset it is a least nine grid-points) from here onward referred to as large scale heavy precipitation.

Furthermore, the threshold for daily precipitation was set such as, one grid point must receive 80 mm/d and the mean of nine grid-points (the grid cell plus the neighboring eight grid points) have to be greater than 50 mm/d (so only those events where mean daily precipitation is equal or above 50 mm/d and affected consecutive area is equal or above 3100 sq. km are considered). This analysis helped to identify the past events in which we were interested. In the next phase we compared the dates of these heavy precipitation events with the CoL dataset to check if there was a CoL present on that day or not. The location of these CoLs were plotted to check if the location of the center of CoLs has some relationship with manifestation of heavy precipitation events. It was found that heavy precipitation events in the Alps showed significant correlation (several regions show 60 % – 80 % correlation) in several regions in the European domain.

Moreover, Alpine regions which are more vulnerable to large scale heavy precipitation events stemming from CoLs were also identified.

This was done by comparing the days with large scale heavy precipitation and a CoL with all days with large scale heavy precipitation. The threshold set was 50 mm/d; this means that grid pts exceeding 50 mm/d were considered only. In other words grid pts exceeding 50 mm/d from the ETH dataset when there was a large scale heavy precipitation event and a CoL was also present was compared to grid pts exceeding 50 mm/d from ETH dataset when large scale heavy precipitation events took place. Please consider, that 1 grid pt of the ETH dataset represents an area mean precipitation of ~ 400 square kilometers. This fraction for each grid pt provides the percentage of large scale heavy precipitation events stemming from CoLs. For example, higher percentage means stronger influence of CoLs and vice versa.

Results

Figure. 3 presents the annual climatology (1971-1999) of CoLs derived from the ERA-40 re-analysis dataset for Europe. From this figure one can also infer the location of center of CoLs, frequency of their recurrence during the above mentioned period. One can infer from this figure that CoLs occur in most part of Europe (domain D1) with an exception of north western region where their number is very low. In general, frequency of CoLs occurrence on the Southern side of D1 is much higher than on the northern side. One can also notice that in some regions their recurrence is more often. For example, over the Atlantic, near the Iberian Peninsula, and over the Alps their recurrence is very prominent. In the Alpine region their recurrence is most often (there are 17 – 19 events located over the Alps, approximately a similar no of CoLs were also centered on the southern side of the Alps).

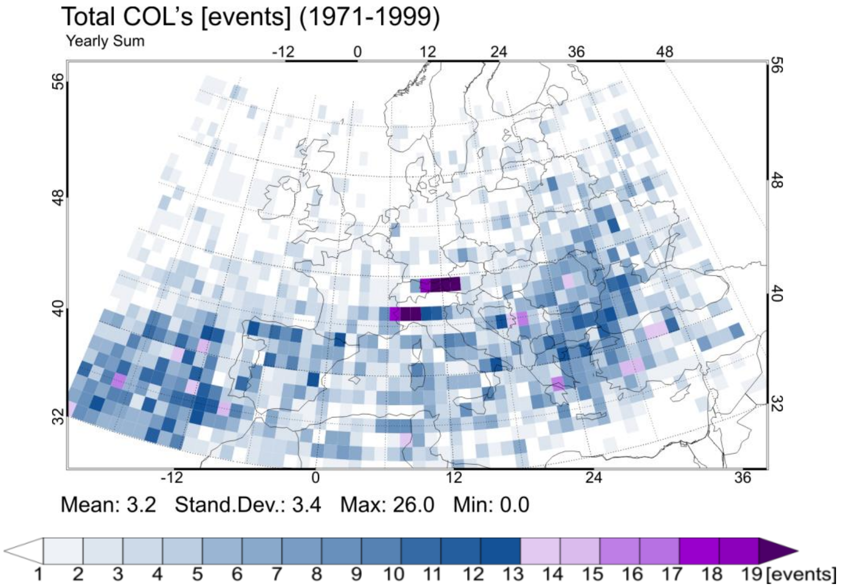

Figure. 3. Total no of CoLs (1971 - 1999) derived from ERA-40 re-analysis dataset

Figure. 4 (a - d) show the seasonal variation in no of CoLs. These results indicate a high seasonality in the occurrence of CoLs. Most of the CoLs occur in summer while the second favorite season is autumn. The number of CoLs in winter and spring is relatively low. The days with CoLs per year also exhibits some variation as seen in Figure. 5 (a). In this figure the total no

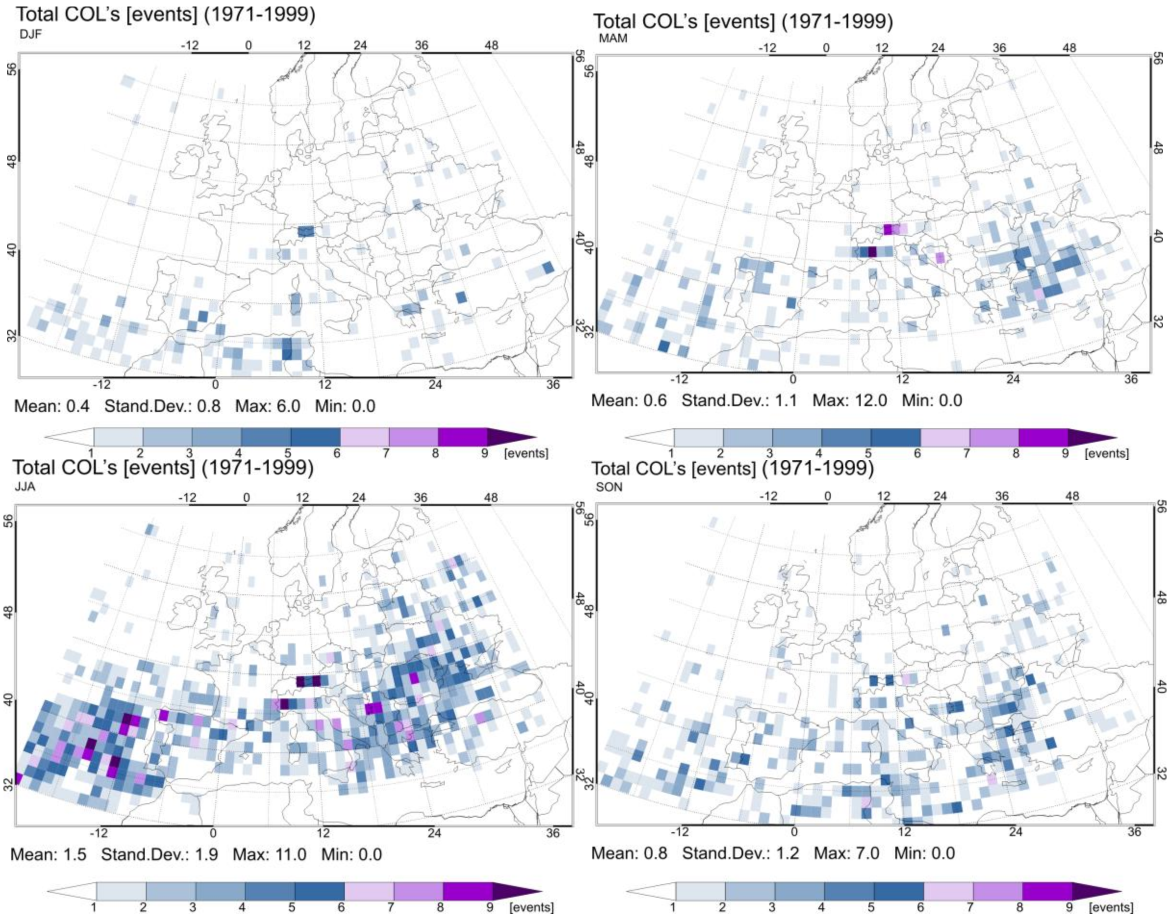

Figure. 4. (a - d) Seasonal variation of no of CoLs from DJF - SON

of days with a CoL present per year are for the whole period (1971 - 1999) are shown. From this figure it can also be seen that CoLs occurrence presents some inter-annual variability however, the period under consideration is not sufficient for trend analysis. On monthly scale the no of CoLs also show a large variation.

Figure. 5 (b) depicts the monthly variation in no of CoLs per month with the aid of a box and whisker plot. The mean, median, and 25th and 75th percentiles are shown. One can see that CoLs present an annual cycle and large variation for each month during this period. In DJF the mean no of CoLs stays between 5 and 7 while for JJA it is increased to 25 to 30.

The presented analysis includes all the CoLs. As mentioned earlier, one of the main objectives was to differentiate between CoLs that produce heavy precipitation from those which do not. Theoretically it is known that air under the CoLs is potentially unstable and is prone to convection. Therefore, depending upon the local conditions CoLs can initiate and sustain convection which can lead to severe precipitation. In Figure. 6 we compared the center of CoLs to

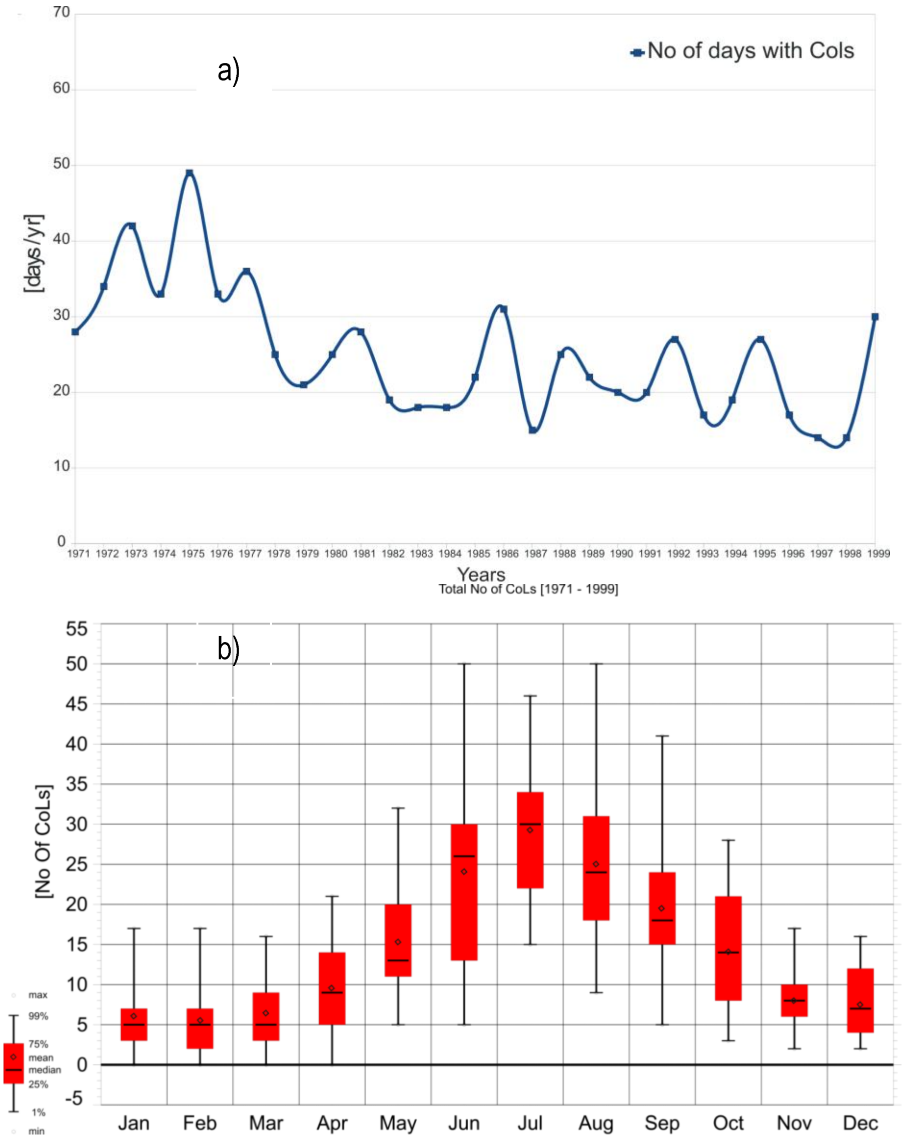

Figure 5. a) The total no days per year when a CoL was present, b) the total no of CoLs per year during (1971 - 1999)

the ETH dataset and highlighted the centers of CoLs which have prevailed during a large scale heavy precipitation event. As one can see that a large majority of CoLs are excluded with the help of this analysis. A few regions where the presence of CoLs has a strong influence on heavy precipitation events in the Alps are visible in this figure. For example, CoLs that were centered over the mid and eastern side of the Alps have caused more than six large scale heavy precipitation events in the Alps.

The last aim of our study was to identify the regions which are more vulnerable to CoLs or in other words we wanted to investigate in which regions the CoL process has the most influence. As mentioned in the data and methods section for this purpose we used the ETH dataset and compared the days with a CoL and a large scale heavy precipitation episode with all those days where there was a large scale heavy precipitation event. Than we only compared the grid points that received more than 50 mm/d. The fraction gave us in percentage the contribution of CoLs to total large scale heavy precipitation event for each grid point.

Figures 7. shows the total contribution of CoLs during the period 1971 – 1999. As one can notice CoLs have a significant contribution to large scale heavy precipitation events in the Alps. Especially the eastern Alps and here also the north eastern side are highly affected by CoLs, with contributions to large scale precipitation of approximately 95 % or more. They also contribute significantly in the Lago Maggiore region. In general, for most of the Alpine region their

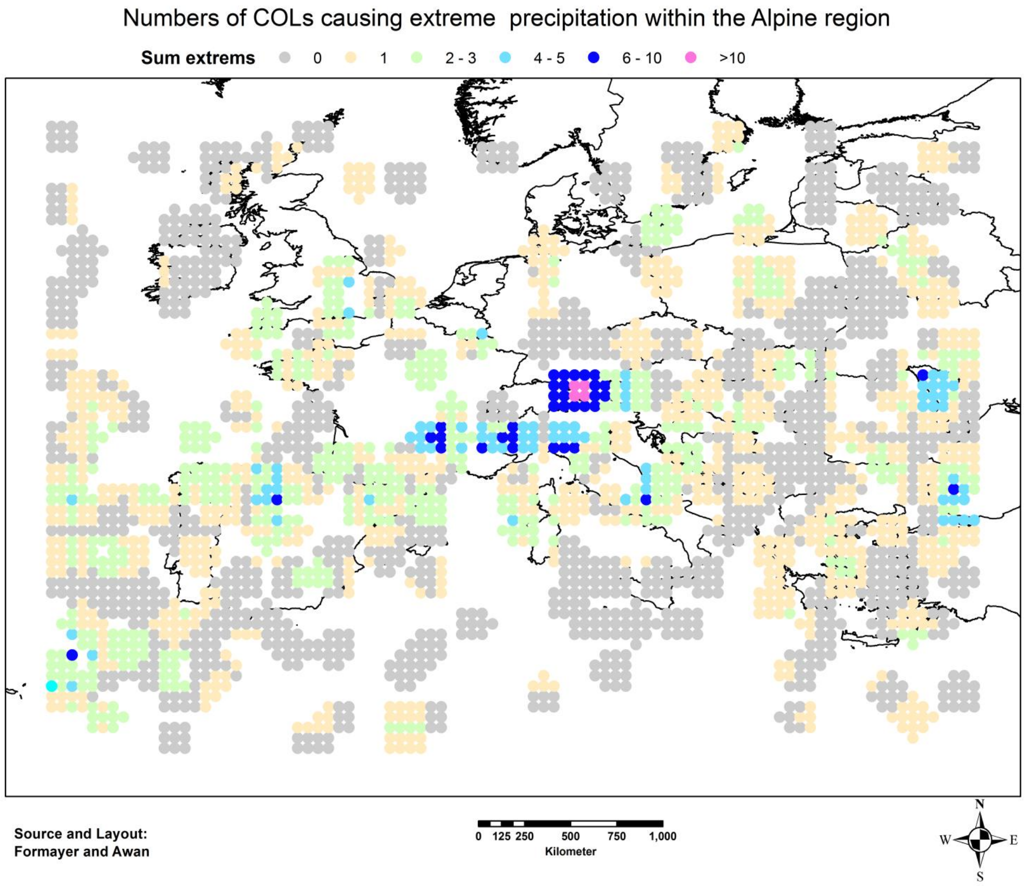

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Figure 6. Location of center of CoLs causing extreme precipitation in the Alpine region, the number represents the no of extreme events that happened when the center of CoL was located at the said position.

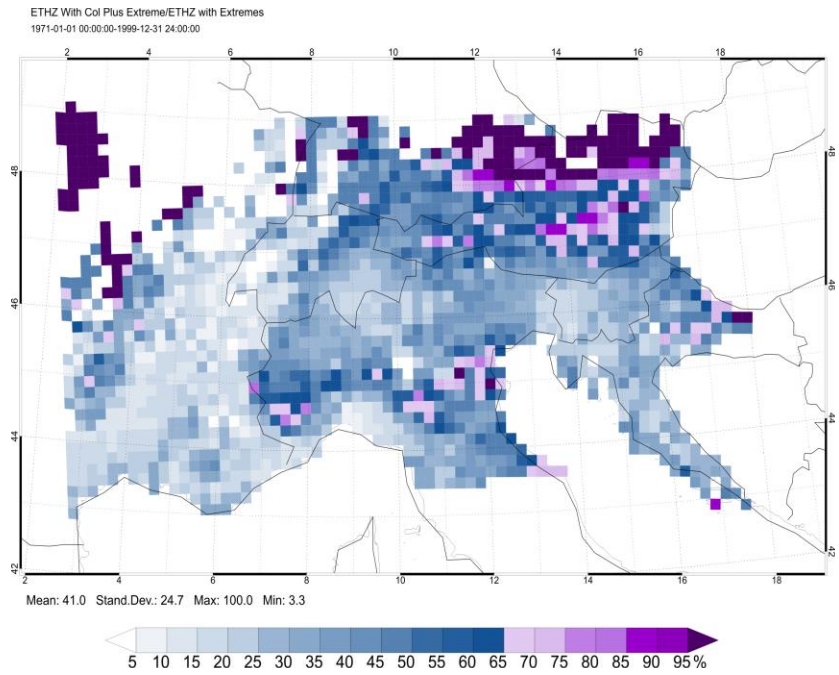

Figure 7. Percentage of heavy precipitation stemming from CoLs

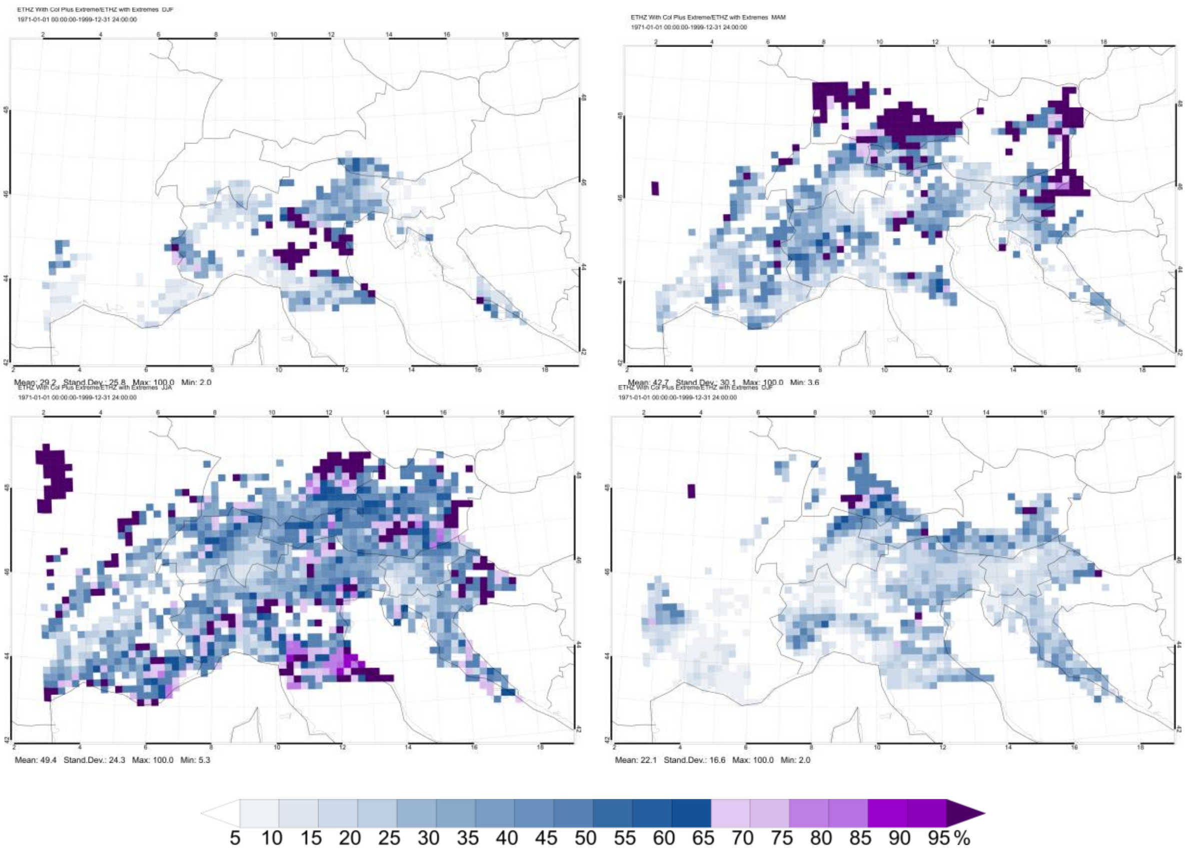

Figure 8 (a - d). Seasonal contribution of CoLs to large scale heavy precipitation events contribution is more than 50 % of the total large scale heavy precipitation. Figure 8 (a - d) represent the same percentage as shown in Figure 7. for seasonal scale. From this figure one can notice that regions most influenced by CoL also vary with seasons. It is also noticeable that contribution of CoLs also differs for each season. For example, for regions around east of Austrian Alps, southern parts of Germany and Switzerland, MAM is mainly under the influence of the CoLs.

While in SON major contribution of CoLs is in the southern side of Austrian Alps, Lago Maggiore and Southern parts of Germany. In JJA most parts of the Alps are vulnerable to large scale heavy precipitation events stemming from CoLs. In DJF their contribution is also on the southern side of the Alps with Lago Maggiore region being most affected by them. These results highlight the not only the contribution of CoLs to heavy precipitation events in the Alps, they also provide basis for identification of most vulnerable regions.

Summary and Conclusions

In this study we have shown that CoLs are significant contributors to large scale heavy precipitation events in the Alps. With the aid of a numerical method we have pointed out hot spots for center of CoLs where their presence can be used as an indicator of heavy precipitation event in the Alps. Moreover, we have also identified the regions which are more vulnerable to large scale heavy precipitation events originating from CoLs.

Our analysis shows that CoLs occur in most parts of the Europe. However, the frequency of their occurrence on the southern part of Europe is much higher than on the northern side. CoLs exhibit a distinct annual cycle with summer being the season with most activity. Our analysis also highlights that location of center of CoLs is very important indicator for heavy precipitation events in the Alps. The recurrence of heavy precipitation events when the CoLs were centered in a specific location is proof of this hypothesis. For instance, each CoL that was centered over the mid and eastern side of the Alps has caused six or more large scale heavy precipitation events in the Alps. In this study we have also quantified the contribution of CoLs to large scale heavy precipitation events in the Alps. The results show that CoLs are significant contributors to large scale heavy precipitation events in the region. Their total contribution ranges between 20 % - 95 % or more. Furthermore, these results also highlight regions most vulnerable to heavy precipitation (the regions with highest contribution means that they are the most vulnerable regions prone to heavy precipitation events originating from CoLs).

Currently work is being carried out to evaluate the performance of global and regional climate models in simulating the frequency, intensity and location of CoLs. Moreover, the model biases originating from inadequate representation of CoLs are also being quantified. The method proposed in this study can be potentially used in weather forecast systems to improve forecast of heavy precipitation events in the Alps. However, any conclusion in this regard would be premature since further tests with forecast data are required for validation.

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