Copernicus Climate Change Service

FLAUDE PROJECT

Analyses and projections of flood events in Occitanie, tools for potential replicability

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1. Introduction

The Flaude project aims to contribute to the understanding of extreme hydro-meteo phenomena in The department of Aude and the elaboration of methods for prevention and risk reduction, adapted to the use by local decision makers. The possibility of using climate data for the preparation of territorial adaptation measures to floods requires highlighting the link with climate change.
On a global scale, numerous scientific papers have identified the observed or expected increase in the frequency and intensity of extreme rainfall events with climate change (IPCC 2013). At the scale of Mediterranean regions, several recent papers (Vautard et al, 2014, Ribes et al, 2018) have highlighted the observed worsening of intense rainfall events in series starting in the 1960s.
Within the framework of the FlAude project, different datasets and indicators have been mobilised to characterise the extreme rainfall events that cause flooding and an inventory of extreme events has been drawn up with their characteristics: maximum cumulative rainfall, surface and volume of the event.
In the first section, this deliverable aims to analyse the climatic trends of the characteristics of the identified events by considering different spatial scales.
Then, the evolution of extreme rainfall on the territory of the Aude and the Occitanie region is approached in the context of future climate by identifying the climate signal and its uncertainties

2. Past Evolution

2.1. Context

In this section we analyze the past evolution of extreme precipitation events. Several aspects are covered : maximum intensity, frequency, spatial extent and total precipitation on the area affected.

In Ribes et al. 2018, those changes are analyzed over the period 1961-2015, using a reference datasets of observations and an original method to get information aggregated over the Mediterranean region. An estimation of the expected change of precipitation intensity is obtained by combining the Clausius–Clapeyron rate of +6.8%/K with the observed annual mean warming in the region of about +1.7 K (± 0.5 K) over the period 1961-2015, this leads to an expected increase of annual maximum rainfall intensity (RX1d) by +11.8 % over the period. Conclusions point toward an intensification of the most extreme events over the last decades, coherent with the Clausius-Clapeyron relationship.

2.2. Data and indicators

2.2.1. Data, interest and limitations

PRESCILIA data are used to characterize the evolution of the same indicators as Ribes et al 2018. PRESCILIA data consist in fields of daily precipitation available on a 1km*1km grid over France, currently until 2018. They have been described in DCOP_063_CNES.D3.1-2.Recommendations on C3S data report.
As a product on a 1km grid, PRESCILIA data enable easy aggregation of information on the desired domain. But there is no guarantee of temporal homogeneity of PRESCILA data. As all the available

observed data for one day are used, the stations are not the same all over the time as some may have opened or closed.

2.2.2. Indicators

The different aspects used to define a multi-dimensional climate indicator of rainfall and flooding event in the first part of the project are considered separately as different indicators :
- the intensity (maximum 2-day precipitations in mm), annual maximum 1-day precipitation (RX1D)
- estimation of the spatial extension (km²), and
- the total precipitated volume in the area (m^3 or meter).

These indicators are analyzed over three nested domains presented on Figure 1.

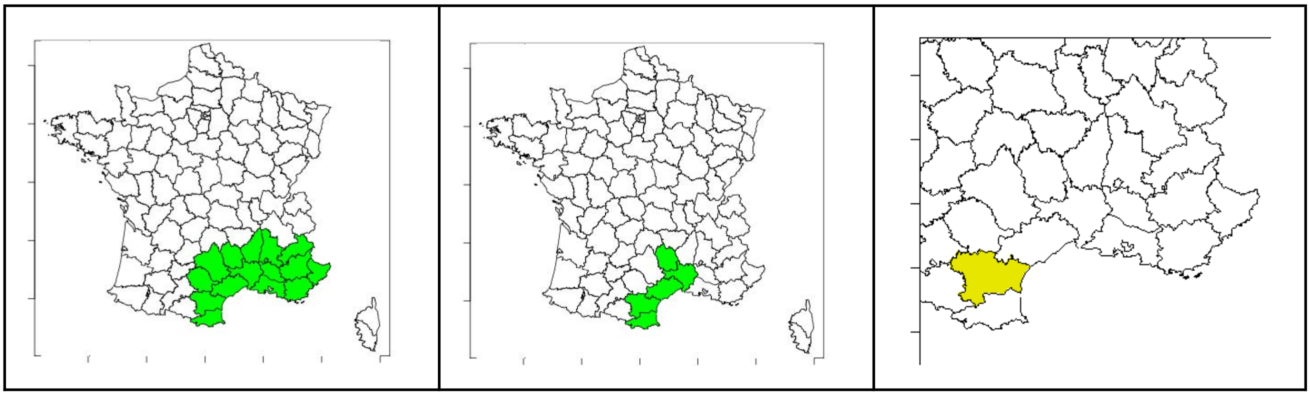


Figure 1 – Three nested geographical domains where indicators are aggregated and analyzed: Mediterranean region (left), Languedoc-Roussillon region (middle) and Aude (right).

2.3. Evolution of intensity

As in Ribes et al 2018, the evolution of extreme rainfall is characterized by the annual maximum 1-day rainfall (RX1d).
Prescilia Rx1d data are aggregated over the domain of interest. We focus here on the regions affected by heavy daily precipitation, defined by a mean climatological value of Rx1d higher than 60 mm (estimated over the 1961-2018 period). The temporal series of Rx1d in each grid-point is divided by its mean value over the 1961-2018. Then the data are averaged over the grid-points in the domain. Aggregated series for intensity are computed over the Mediterranean region, Languedoc-Roussillon and Aude.
This enables a quantitative estimation of recent changes, and a direct comparison to the expected change according to the Clausius–Clapeyron relationship.

The evolution of aggregated intensity series over the Mediterranean is presented in Figure 2.
The **mean intensity increase** is significant and **estimated over the period 1961-2018 at +15%, [+2 ; +30%]** at the 90% confidence level. This result is coherent with the expected change according to the Clausius-Clapeyron relationship. Note that the change of intensity over the period 1961-2015 is estimated at +17% [+3 ; +33%], that is similar to the evolution coming from Ribes et al : +22% [+7; +39%].

The intensity is aggregated over Languedoc-Roussillon and Aude, and results presented on Figure 3.
The evolution of intensity over the period 1961-2018 is estimated at :

- + 6% [-10 ; +24%] over Languedoc-Roussillon
- + 8% [-18 ; +43%] over Aude

The mean intensity of heavy precipitation aggregated over the 3 domains is increasing. This increase is significant at a 90% confidence level over the Mediterranean area, but not significant on the smaller domains, where the uncertainty becomes higher as the area becomes smaller.

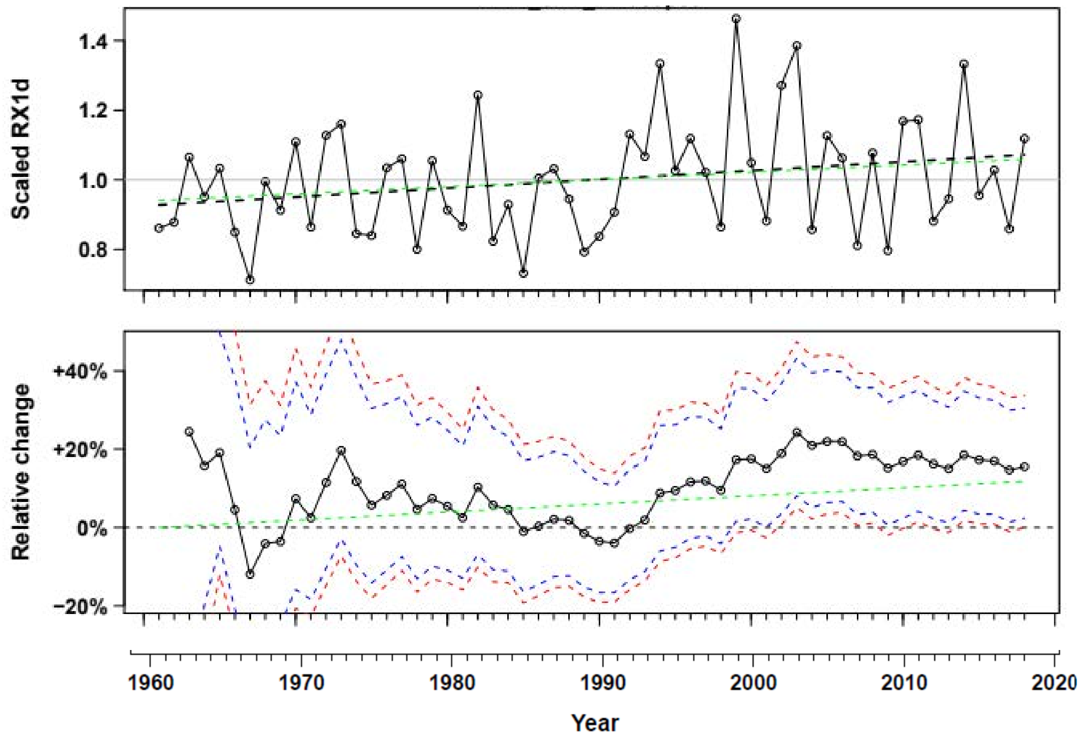


Figure 2 – Top : The regionally aggregated time-series of scaled RX1d over the Mediterranean region (solid black). The best linear fit over the entire period is shown in dashed black, and the change expected from the observed warming assuming a simple Clausius–Clapeyron rate is shown in green. Bottom : The change in scaled RX1d as estimated by a linear trend over the period 1961– yyyy, where the ending year yyyy is that shown in the x-axis. The associated 90% (95%) confidence intervals are shown in dashed blue (dashed red). The expected Clausius–Clapeyron response is also shown in green.

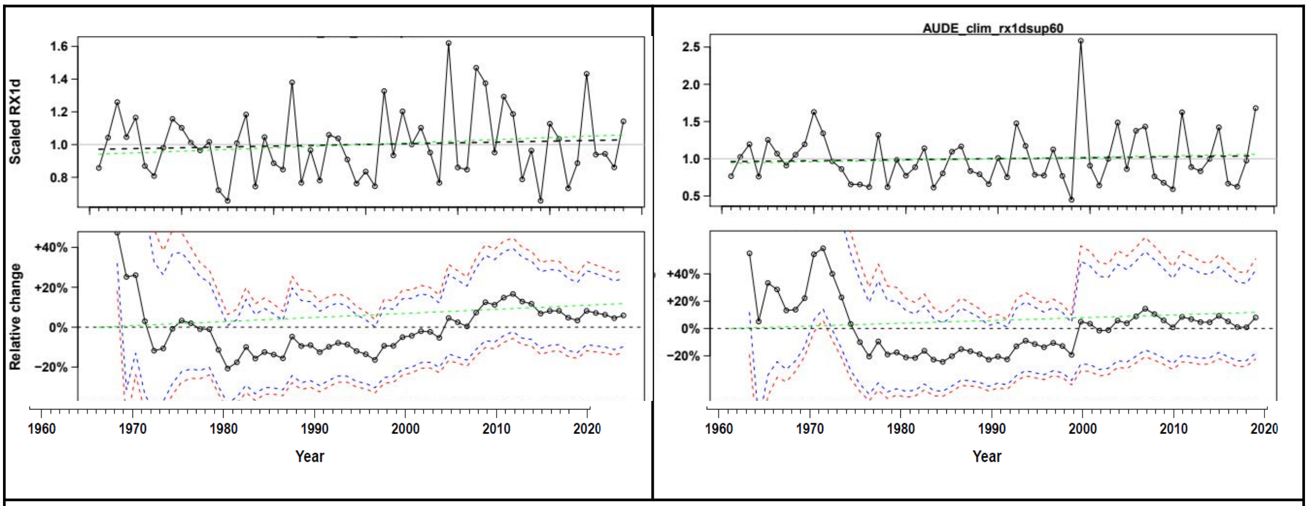


Figure 3 – same as Figure 2, for Languedoc-Roussillon (left) and Aude (right)

2.4. Evolution of frequency

In the first deliverable DCOP_063_CNES.D3.1-2.Recommendations on C3S data, 17 extreme rainfall events have been identified over Aude department during the 1970-2020 period, using *Extreme rainfall Meteo France database (http://pluiesextremes.meteo.fr/)*, and 47 independent events with 2-day cumulative precipitation exceeding the threshold of 200 mm on at least one point of the domain have been selected from PRESCILIA data over the 1961-2018 period.

To describe past evolution of the frequency of extreme rainfall events, we count the annual number of days when a given threshold (eg 200 mm) is reached or exceeded on at least one grid-point of the studied domain, Then possible changes in the time-series are analyzed with a Generalized Linear Model (GLM) with a Poisson distribution.

200 mm

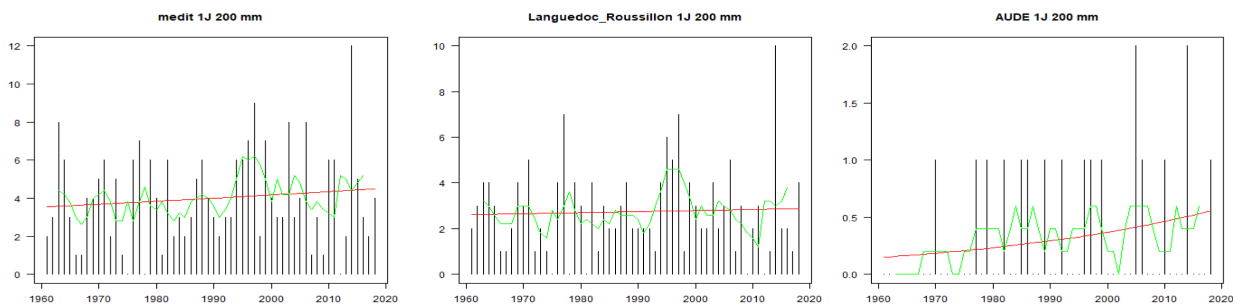


Figure 4 – Evolution of the number of 200 mm exceedances over the 3 domains (columns): left Mediterranean domain, middle: Languedoc-Roussillon, and right Aude department. A five years moving average of the frequency is plotted in green. In red, the fitted non linear trend.

The estimated trend over the Mediterranean region, Languedoc-Roussillon and Aude is positive for 200 mm. The estimated change of frequency is

- +0.9 day [-0.5 ; +2.4] between 1961 and 2018, not significant at 90% confidence level over the Mediterranean region,

- +0.3 day [-1 ; +1.5] not significant at 90% confidence level over Languedoc-Roussillon,
- +0.4 day [-0. ; +1.8], not significant at 90%, but at the limit of significance over Aude.

As in Ribes et al, the statistical significance is computed for a range of thresholds using the p-value for all the periods 1961-yyyy. The same results with PRESCILIA gridded data are shown in figure 5. **Over the Mediterranean region, there is a clear significant increase over the whole period 1961-2018 of the frequency of events higher than 150 mm.** This result is similar to Ribes et al who describes “a significant positive trend for thresholds above 180-200 mm”. As observed in the temporal series figure 4, the increase is not significant regarding the Languedoc-Roussillon region. Over Aude, the increase is strong as an increase of +0.4 day per year between 1961 and 2018 corresponds to +272% of relative change compared to 1961, but the estimation comes with a large uncertainty.

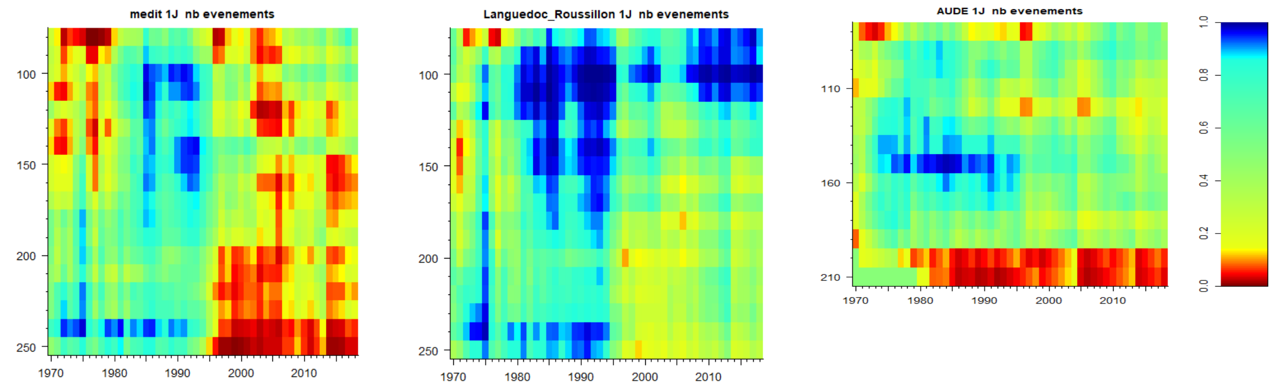
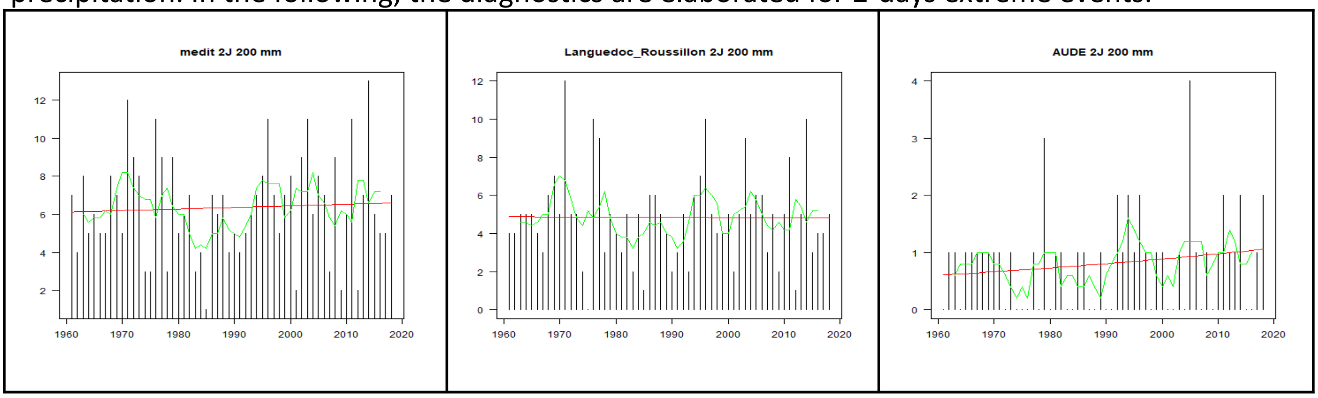


Figure 5 – Estimated change in thresholds exceedance frequency. Statistical tests are applied for thresholds and for different time periods 1961-yyyy, yyyy corresponding to the xaxis. Blue and red colors highlight significant decreasing and increasing trends.

The events studied in the first deliverable were defined using a threshold on the 2-day cumulative precipitation. In the following, the diagnostics are elaborated for 2-days extreme events.



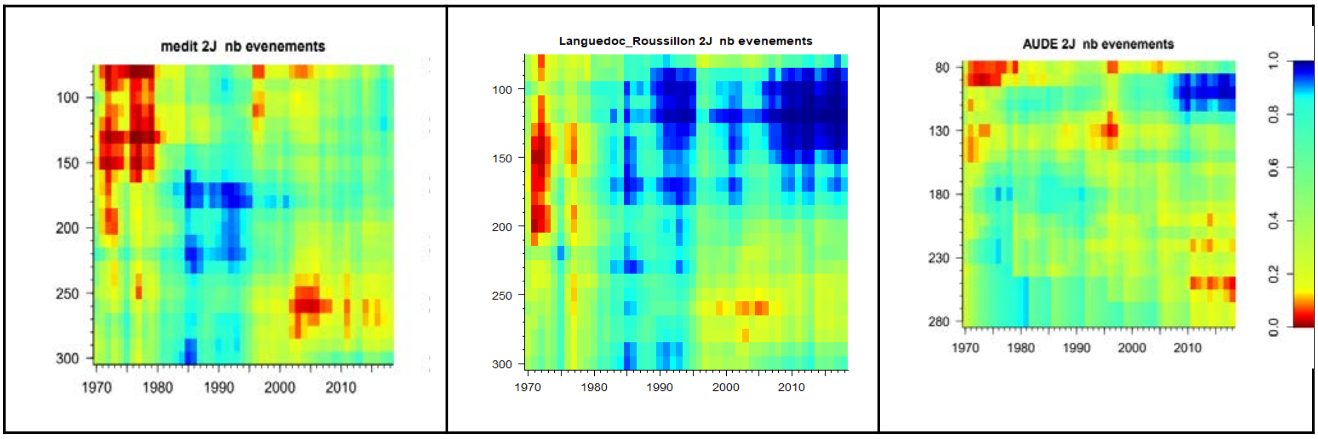


Figure 6 - Top : Evolution of the annual number of 200 mm threshold exceedances over the 3 domains (columns): left Mediterranean domain, middle: Languedoc-Roussillon, and right Aude department. A five years moving average of the frequency is plotted in green. In red, the fitted non linear trend. Bottom : same as Figure 5 for the frequency of 2-day cumulative events

Figure 6 indicates an increase of the frequency of 2-day cumulative precipitation higher than high thresholds (200mm and more), but this increase is generally not significant at the 90% confidence level. As the thresholds become higher, the events become rarer and the trend uncertainty is larger.

	Mediterranean region	Languedoc-Roussillon	Aude
200 mm	+0.5 [-1.4 ; +2.3]	-0.1 [-1.7 ; +1.5]	+0.4 [-0.2 ; +1.1]

Table 1 - Estimated change in the annual number of 2-day events higher than 200 mm between 1961 and 2018, and its 90 % confidence interval.

2.5. Evolution of surface areas and volumes

The surface area affected by events is computed for different thresholds, it is defined as the sum of all the grid points with daily (respectively 2-day cumulative) precipitation higher than a defined value. The selection of events, and computation of areas higher than a threshold is done for the 3 domains. For each aggregated series, the temporal evolution is performed using a Generalized Linear Model (GLM) with a quasi-Poisson distribution.
Results are analyzed as previously for different thresholds in the following figure :

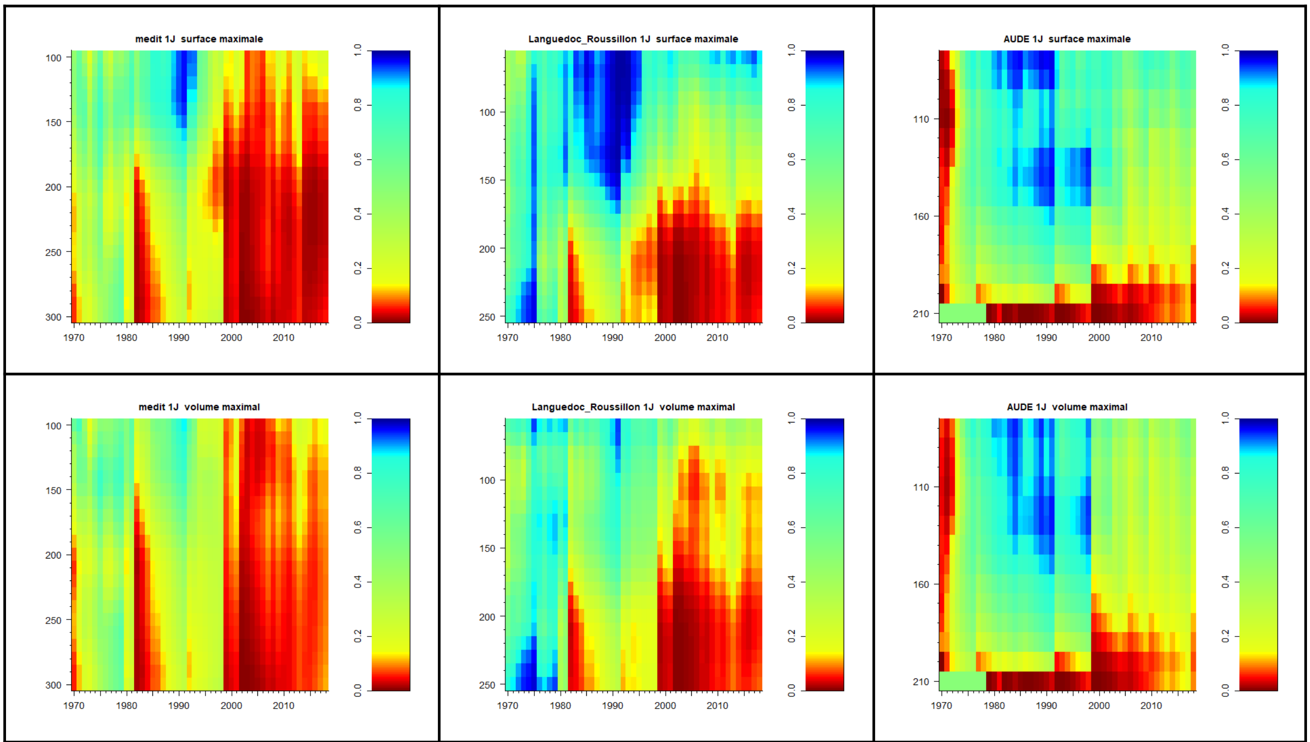


Figure 7 - Estimated change (top) : the annual maximum extent of events above the thresholds, and (bottom) the maximum volume of water computing on the corresponding pixels. Statistical tests are applied for thresholds and for different time periods 1961-yyyy, yyyy corresponding to the xaxis. Blue and red colors highlight significant decreasing and increasing trends.

There is a clear significant increase of both the area impacted and the precipitated volume for events above thresholds 100-300 mm over the mediterranean region. The significance of the increase comes for higher thresholds in Languedoc -Roussillon and for 190 mm and more on Aude. Regarding 2-day cumulated events, the significance is not so clear.

2.6. Conclusion

The past evolution of extreme precipitation events has been analyzed through several characteristics using PRESCILIA gridded data. The evolution over 1961-2018 shows:

- an increase of annual maximum intensity using aggregated RX1d index: +15%, [+2 ; +30%] over the Mediterranean region, + 6% [-10 ; +24%] over Languedoc-Roussillon and 8% [-18 ; +43%] over Aude, coherent with the expected change coming from the Clausius-Clapeyron relationship,
- an increase, not significant of the frequency of 1-day and 2-day events higher than 200 mm
- a clear significant increase in the area affected by 1-day severe events and the water volume precipitated during those events. The evolution is not so clear for spatial extent and water volume for 2-day extreme events.

As indicated in the context section, there is no guarantee that PRESCILIA data are homogeneous over time, this has to be kept in mind, when looking at the results. When possible, the results are compared to the expected change coming from the Clausius-Clapeyron relationship.

The uncertainty on past evolution becomes higher when the evolution is computed on a smaller area. Thus it is recommended to analyze the large climatically coherent domain.

This methodology to characterize extreme event evolution can be extended to C3S gridded precipitation products, such as UERRA or ERA5-Land reanalysis.
The methodology is also relevant for other climatically homogene areas, thresholds needed to be adapted to the local climatology for extreme precipitation.

3. Future evolution

3.1 DRIAS-2020 ensemble

A set of 42 climate simulations (12 models for historical experiment, 12 for RCP8.5 projection, 10 for RCP4.5 et 8 for RCP2.6), which constitutes DRIAS-2020 ensemble model, derived from CORDEX ensemble is analysed. For more details about CORDEX data, model selection processing and bias correction method, see DCOP_063_CNES.D3.1-2.Recommendations on C3S data report.
Analysis of precipitation indices and projected change in future is carried out across Languedoc-Roussillon region, consisting of 5 administrative departments : Aude, Eastern Pyrenees, Herault, Gard and Lozere departments.

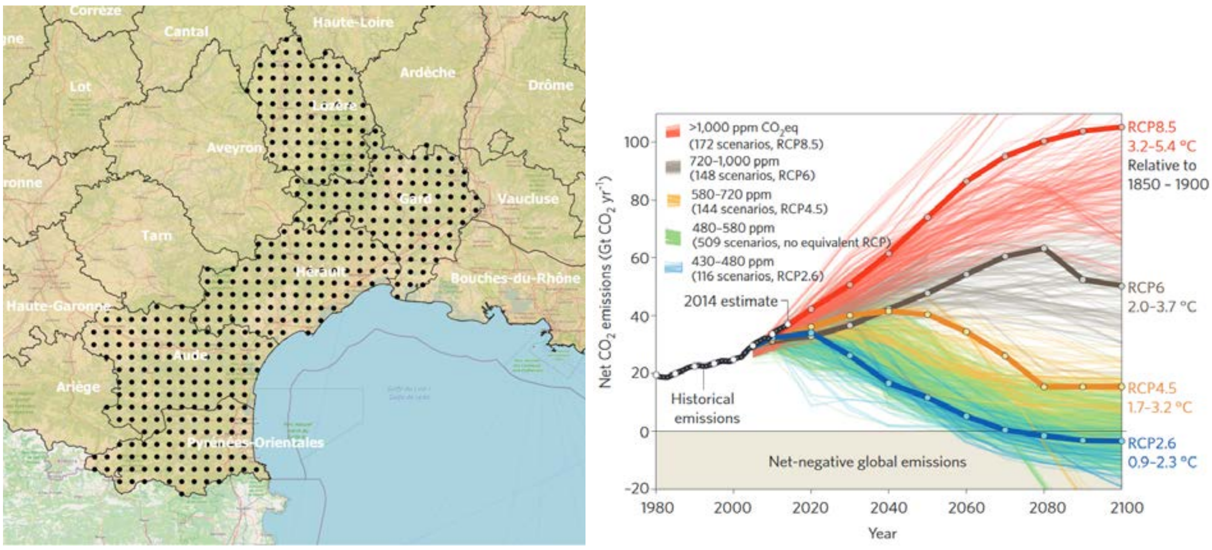


Figure 8 - Languedoc -Roussillon DRIAS-2020 grid points (left) - Carbon dioxide emission pathways between 1980 and 2100 Source : Global Carbon Project (right)

3.2 Extreme precipitation indices

The present analysis focused on 3 indices related to climate change and allowing to evaluate the evolution of extreme rainfall.

Three of these indicators (prcptot, rx1day and r99p) are developed within the framework of the ETCCDI (Expert Team on Climate Change Detection and Indices) program, defining standard indicators widely used by the climate science community. They are robust and allow the detection of extreme changes in climate, while remaining valid and applicable over a large number of climate regions. Moreover, Rx1day indice was previously used to characterize extreme rainfall in the past period with Meteo-France and C3S products (see DCOP_063_CNES.D3.1-2.Recommendations on C3S data report).

- prcptot is the total wet-day rainfall,
- rx1day is the annual maximum of daily precipitation,
- p99 is the 99th percentile of daily precipitation (all days percentile)
- r99p is the amount of precipitation from extremely wet days : a reference threshold, a 99th percentile, is computed from daily precipitation (wet days only) over the historical period 1976-2005. In the future part, r99p is the annual amount of daily precipitation above this reference threshold.

Name	Description	Note	Time scale	Unit
rx1day	Maximum amount of rain that falls in 1 day	-	Annual Monthly	mm
p99	99th percentile of daily precipitation	all days percentile	Annual Monthly	mm
r99p	Amount of rainfall from extremely wet days	Annual sum of daily precipitation > P99 – (wet-days percentile)	Annual	mm
prcptot	Total wet-day rainfall	Sum of daily precipitation >= 1.0 mm	Annual Monthly	mm

Table 2 - Description of indices used on this analysis

These indices are performed from the daily DRIAS-2020 dataset, directly derived from the CORDEX project and available on the Copernicus climate data store.

Historical reference conditions are defined as the period 1976-2005. For future conditions, three periods are considered : the near horizon 2021-2050, the mid-term horizon 2041-2070 and the long-term horizon 2071-2100. Rx1day, p99.5 and prcptot indices are performed at annual and seasonal time scale (SON=September-October-November, DJF=December-January-February, MAM=March-April-May, JJA=June-July-August).

3.3 Spread of DRIAS-2020 ensemble model

In order to analyze the behavior of extreme rainfall over the study area using DRIAS-2020 climate models, a scatter diagram (McSweeney and al., 2015) is plotted using 2 parameters:

- ΔTemperature-mean : relative change of temperature (30-year average) over 2041-2070 time horizon compared to 1976-2005 historical reference period – x-axis

- ΔPrecipitation-P995 : relative change of extreme precipitation (30-year average of 99.5th all-days percentile) over 2041-2070 time horizon compared to a 1976-2005 reference period – y-axis

These scatter plots provide a synthetic view of climatic variations, calculated over the fall season.

Almost all models (11 out of 12 models) of the RCP8.5 scenario show an increase of 99.5 daily precipitation percentile compared to the reference period. The relative change ranges from +4.4% (IPSL-WRF381P/IPSL-IPSL-CM5A-MR) to +21.5% (KNMI-RACMO22E/CNRM-CERFACS-CNRM-CM5). 10 models show an evolution between +10% and +20%.
Regarding RCP2.6 and RCP4.5 radiative scenarios, KNMI-RACMO22E/CNRM-CERFACS-CNRM-CM5 model shows the highest positive variation of P99.5 indicator, compared to the baseline period, with +25.1% for RCP4.5 and +15.0% for RCP2.6 and 2041-2070 mid term horizon.

RCP26 radiative scenario also shows the same dispersion trend for the 8 selected climate models. 7 out of 8 models show a positive evolution, between +6.5 % and +15 %.

NCC-NorESM1-M/GERICS-REMO2015 is the sole model showing a slightly negative change in extreme precipitation for 2 radiative forcing scenarios RCP2.6 (-3.4 %) and RCP8.5 (-3.7 %).

GCM	RCM	RCP85	RCP45	RCP26
CNRM-CERFACS-CNRM-CM5	KNMI-RACMO22E	21,5	25,1	15,0
MOHC-HadGEM2-ES	ICTP-RegCM4-6	19,1	-	12,2
ICHEC-EC-EARTH	SMHI-RCA4	18,1	5,0	13,5
ICHEC-EC-EARTH	KNMI-RACMO22E	17,6	-0,4	12,8
IPSL-IPSL-CM5A-MR	SMHI-RCA4	14,7	-1,0	-
CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN63	14,2	8,7	12,2
MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17	13,4	13,0	-
NCC-NorESM1-M	DMI-HIRHAM5	12,1	4,1	-
MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	11,4	8,1	9,8
MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	11,2	18,3	6,5
IPSL-IPSL-CM5A-MR	IPSL-WRF381P	4,4	6,0	-
NCC-NorESM1-M	GERICS-REMO2015	-3,4	-	-3,7
Mean temperature change period 2041-2070		+2.7°C	+1.8°C	+1.4°C

Table 3 - 99.5th percentile of daily precipitation change (%) of DRIAS-2020 ensemble - Languedoc- Roussillon domain - 2041-2070 time horizon

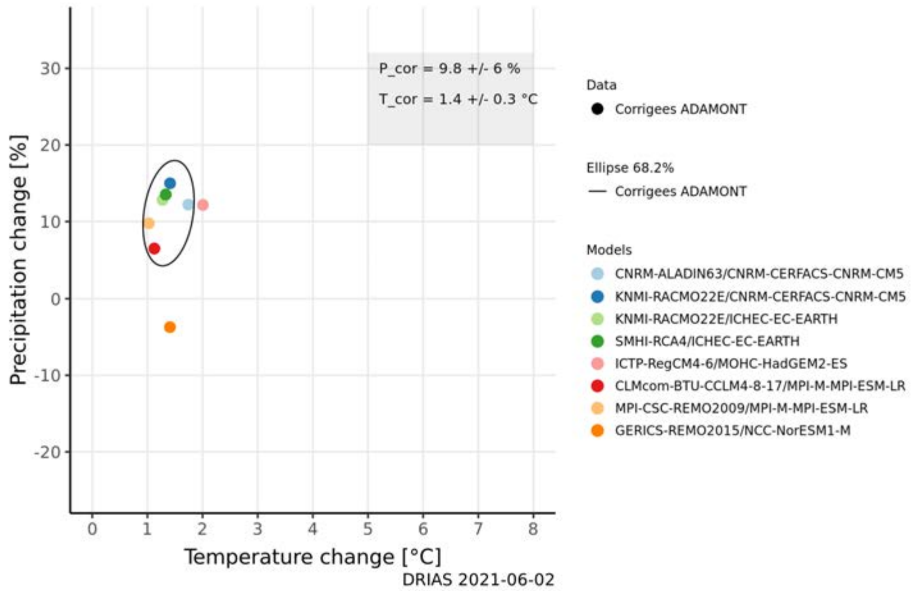


Figure 9 - Spread (ΔTmean)/ΔPp99.5) of DRIAS-2020 ensemble projections - time horizon : 2041-2070 – RCP2.6 gas emission scenario – Languedoc Roussillon departments - ΔT(mean)=+1.4°C – ΔP(p99.5)=+9.8 %

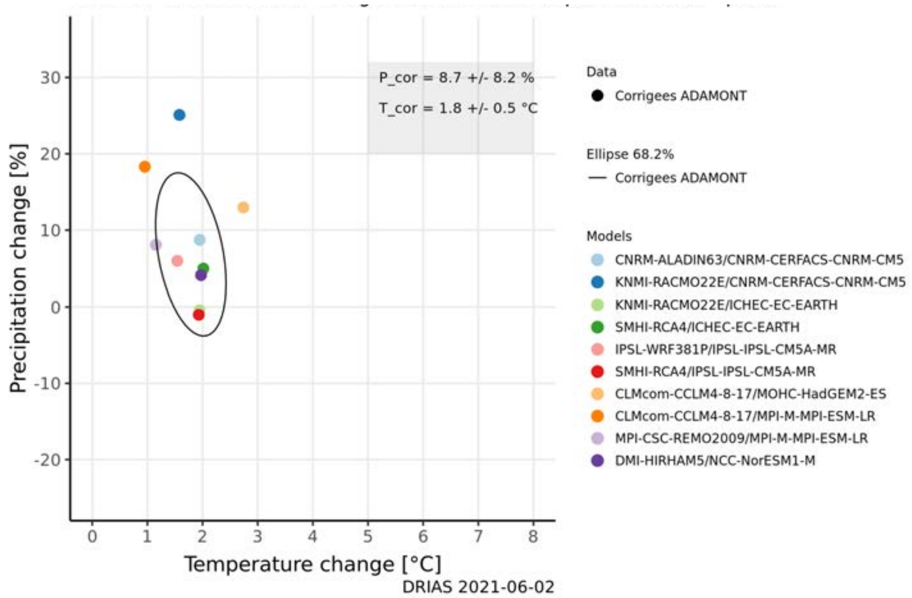


Figure 10 - Spread (ΔTmean)/ΔPp99.5) of DRIAS-2020 ensemble projections - time horizon : 2041-2070 – RCP4.5 gas emission scenario – Languedoc Roussillon departments - ΔT(mean)=+1.8°C – ΔP(p99.5)=+8.7 %

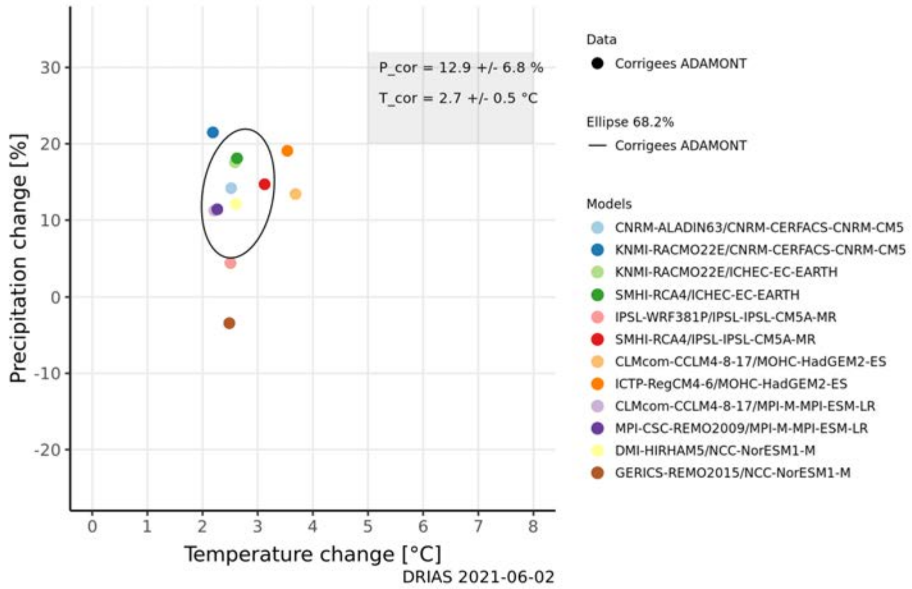


Figure 11 - Spread (ΔTmean)/ΔPp99.5) of DRIAS-2020 ensemble projections - time horizon : 2041-2070 – RCP8.5 gas emission scenario – Languedoc Roussillon departments - ΔT(mean)=+2.7°C – ΔP(p99.5)=+12.9 %

3.4 Seasonal precipitation

Mean projected changes of seasonal precipitation over Languedoc-Roussillon departments, for each climate model of DRIAS dataset are summarized in the figure below.

Regarding the SON fall season and RCP4.5 and RCP8.5 emission scenarios, DRIAS-2020 ensemble models show a poor agreement, signals are uncertain, independent of time horizon. RCP2.6 scenario shows on average a relatively moderate increase (5 out of 8 models) in autumn precipitation. For the mid-term horizon, projected change in fall precipitation ranges between +6.1% (CLMcom-CCLM4-8-17/MPI-M-MPI-ESM-LR) and 13.6% (MPI-CSC-REMO2009/MPI-M-MPI-ESM-LR).

Significant increase and coherent models signal are projected for winter precipitation. For mid-term horizon 2021-2050 and RCP2.6 scenario, relative evolution vary from +0.7 % (GERICS-REMO2015/NCC-NorESM1-M) to +19.4 % (KNMI-RACMO22E/ICHEC-EC-EARTH). RCP8.5 from -0.9% (GERICS-REMO2015/NCC-NorESM1-M) to 16.7% (CNRM-ALADIN63/CNRM-CERFACS-CNRM-CM5). Projected changes are larger for RCP4.5 scenario and mid-term horizon, and range between +1. 7% (CNRM-ALADIN63/CNRM-CERFACS-CNRM-CM5) to +29.3% (MPI-CSC-REMO2009/MPI-M-MPI-ESM-LR).

At long-term horizon 2071-2100, 4 out of 12 models show a strengthening of winter precipitation : SMHI-RCA4/IPSL-IPSL-CM5A-MR, KNMI-RACMO22E/ICHEC-EC-EARTH, MPI-CSC-REMO2009/MPI-M-MPI-ESM-LR and ICTP-RegCM4-6/MOHC-HadGEM2-ES.

Regarding the summer season, which is little or not affected by extreme Mediterranean rainfall, projected change is characterized by a significant drying up for the RCP4.5 scenario and worsening with the RCP8.5 emission scenario. The relative decrease of total precipitation amount is up to 50%

for the SMHI-RCA4/IPSL-IPSL-CM5A-MR and CLMcom-CCLM4-8-17/MOHC-HadGEM2-ES climate models at the end of the century.

Ensemble signals for the spring season are not clear, drying out on average for the RCP4.5 and RCP8.5 emission scenarios. RCP2.6 emission scenario shows a slight positive or non-significant signal in projected change.

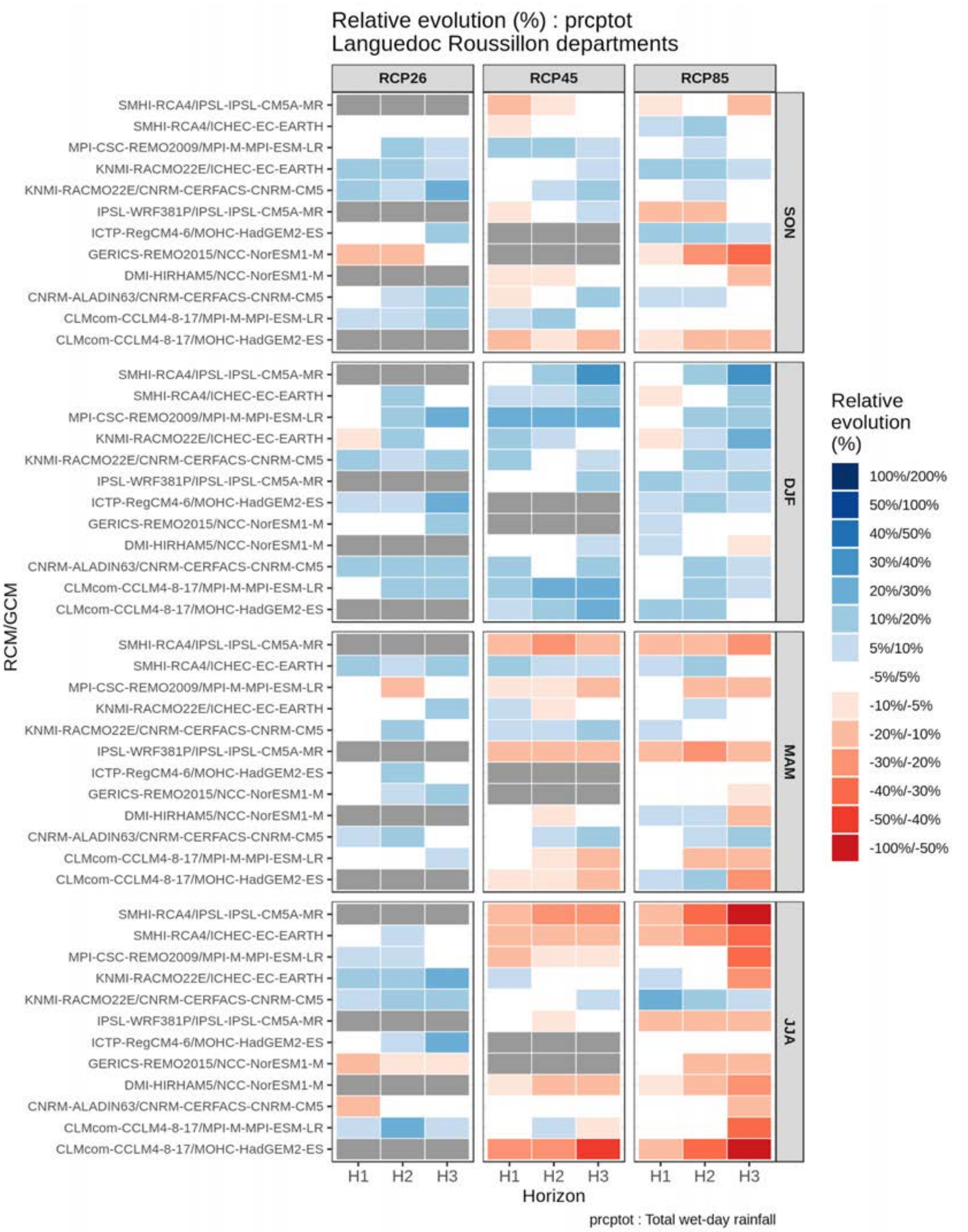


Figure 12 - Projected change (%) of total wet-day total precipitation (prcptot indicator) - x-axis : time horizons H1=2021-2050 H2=2041-2070 H3=2071-2100 ; – y-axis DRIAS-2020 : individual simulations – 4 seasons : SON (top panel)- DJF and MAM (middle panel) - JJA (bottom panel)

		2021-2050	2041-2070	2071-2100
Minimum	RCP2.6	-10,0	-11,1	-2,7
Median		4,5	6,5	11,2
Maximum		13,3	13,6	26,6
Minimum	RCP4.5	-12,7	-7,0	-19,3
Median		-6,5	-3,0	4,6
Maximum		13,3	15,2	19,4
Minimum	RCP8.5	-13,2	-21,0	-34,4
Median		-0,7	4,5	-3,1
Maximum		14,1	19,0	8,0

Table 4 - Minimum, median and maximum of seasonal precipitation relative change (%) - Autumn season

		2021-2050	2041-2070	2071-2100
Minimum	RCP2.6	-5,8	0,7	3,7
Median		0,6	11,2	13,2
Maximum		17,7	19,4	20,7
Minimum	RCP4.5	-1,0	1,7	3,9
Median		9,4	6,1	16,1
Maximum		23,6	29,3	38,5
Minimum	RCP8.5	-7,1	-0,9	-6,8
Median		3,7	11,9	9,0
Maximum		15,2	16,7	32,5

Table 5 - Minimum, median and maximum of seasonal precipitation relative change (%) - Winter season

3.5 Projected changes of extreme precipitation indices

2 indices of extreme precipitation are considered in this analysis : rx1day and r99p.

Maximum amount of rain that falls in 1 day (rx1day)

Overall, we note an increase in rx1day index for autumn season over Languedoc-Roussillon area, regardless of time horizon or radiative scenario chosen. For mid-term horizon, median values of the ensemble climate models are +7.6%, +11.4% and +12.1%, for RCP4.5, RCP8.5 and RCP2.6 emission scenarios respectively. Signals are relatively coherent. The extreme models show significant positive changes, ranging from +18% (RCP4.5 and KNMI-RACMO22E/CNRM-CERFACS-CNRM-CM5) to +27% (RCP8.5 and ICTP-RegCM4-6/MOHC-HadGEM2-ES). At the end of the century 2071-2100, these ranges of projected change are of the same magnitude as in mid-term horizon.

		2021-2050	2041-2070	2071-2100
Minimum	RCP2.6	-0,3	-8,3	-0,1
Median		6,8	12,1	8,9
Maximum		19,1	19,0	25,2
Minimum	RCP4.5	-8,5	-0,3	-2,0
Median		1,4	7,6	6,4
Maximum		14,3	17,8	24,7
Minimum	RCP8.5	-8,5	-6,4	-14,6
Median		6,2	11,4	11,6
Maximum		17,3	26,6	22,9

Table 6 - Minimum, median and maximum of rx1day relative change (%) - Autumn season

For the winter season, positive signals are clearly noted by the DRIAS-2020 dataset and trends are coherent and homogeneous among climate models. For the RCP2.6 and RCP4.5 scenarios, all selected models indicate an increase or a non-significant trend of rx1day indicator. At mid-term horizon, the median of relative change ranges from +3.7% (RCP2.6) to +8.8% (RCP8.5). Maximas of the ensemble model are significant and estimated between +22.2% to +28.8%. Regarding RCP8.5 emission scenario, only the model (DMI-HIRHAM5/NCC-NorESM1-M) indicates a decrease in rx1day indice over the century. Ensemble model provides a significant strengthening over the century, median and maximum values of relative change range from +7.2%/+19.5%, +8.8%/+23.4% and +13%/+30.7%, for H1 H2 H3 time horizons respectively.

		2021-2050	2041-2070	2071-2100
Minimum	RCP2.6	-3,0	-0,2	4,3
Median		1,5	3,7	10,5
Maximum		20,5	22,2	25,8
Minimum	RCP4.5	-0,7	-4,8	0,9
Median		9,3	5,6	14,4
Maximum		28,0	28,8	22,4
Minimum	RCP8.5	-4,0	-0,4	-7,1
Median		7,2	8,8	13,0
Maximum		19,5	23,4	30,7

Table 7 - Minimum, median and maximum of rx1day relative change (%) - Winter season

Evolution of rx1day indice in spring and summer seasons is variable, depending on the models considered and time horizon. For these 2 seasons, we note a greater uncertainty of projected change, related to climate models.

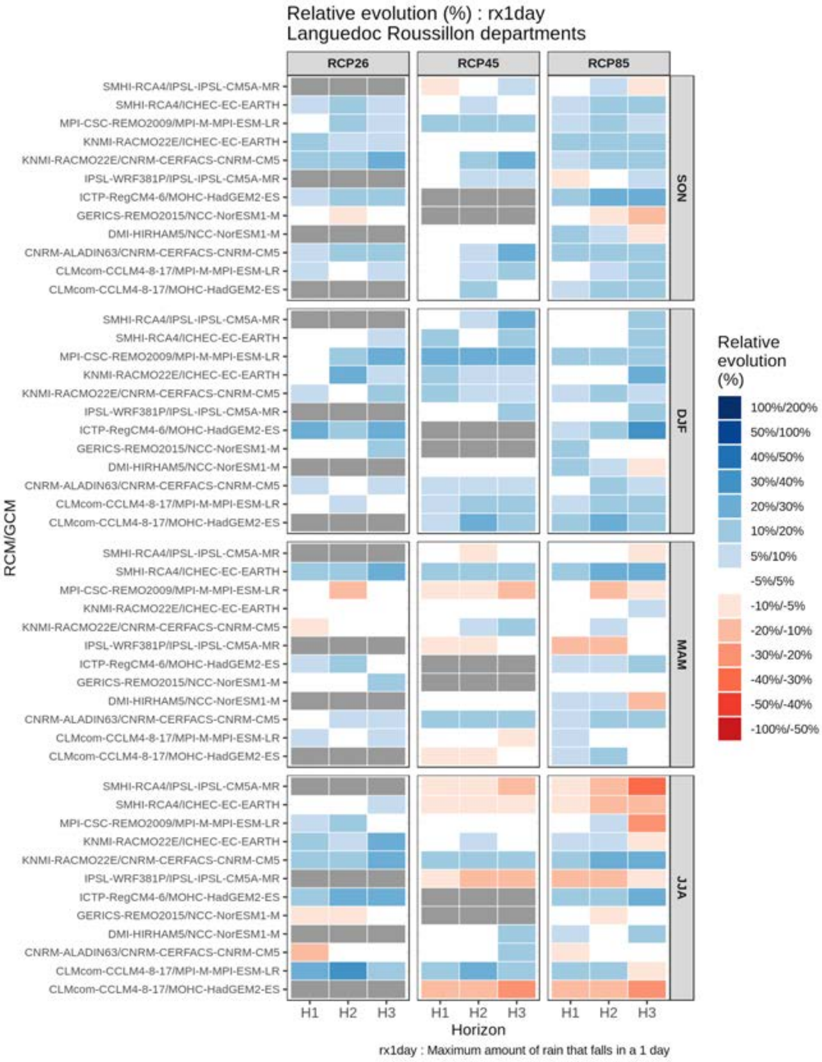


Figure 13 - Projected change (%) of maximum amount of 1-day total precipitation (rx1day indicator) - x-axis : time horizons H1=2021-2050 H2=2041-2070 H3=2071-2100 ; – y-axis DRIAS-2020 individual simulations – 4 seasons : SON (top panel)- DJF and MAM (middle panel) JJA (bottom panel)

Amount and frequency of precipitation from extremely wet days (r99p)

A very clear increase in total amount of extreme rainfall is established over the Languedoc-Roussillon region. 10 out of 12 climate models for the RCP4.5 scenario show an increase in r99p indice. For the mid-term horizon, the median/maximum changes are +27.9%/+65.3%. Ensemble signals are also clearly positive for RCP2.6 and RCP8.5 scenarios, median values range from +35.7% and +47,1% respectively. At long-term horizon, extremes of ensemble models show very significant changes : +71%, +86% and +88%, for RCP2.6, RCP4.5 and RCP8.5 emission scenarios respectively. Frequency of extreme precipitation event indice shows similar patterns : median of projected change is roughly up to +30% for RCP2.6 scenario, ranges from +22% to +36% for RCP4.5 and from +32% to 47% for RCP8.5 scenario.

As noted by Schär et al. (2016), these two indices are computed on wet-days daily percentile, and so based on a small sample over Mediterranean region. This could lead to an overestimation of projected change.

		2021-2050	2041-2070	2071-2100
Minimum	RCP26	1,2	-2,5	25,3
Median		32,9	35,7	38,4
Maximum		53,3	50,7	71,1
Minimum	RCP45	-9,5	0,0	8,9
Median		23,5	27,9	41,3
Maximum		42,4	65,3	86,2
Minimum	RCP85	-23,9	-4,0	-7,1
Median		31,8	47,1	43,6
Maximum		52,6	70,7	87,9

Table 8 - Minimum, median and maximum of r99p relative change (%) - Annual analysis

		2021-2050	2041-2070	2071-2100
Minimum	RCP26	2,3	-1,4	27,0
Median		33,4	34,5	38,8
Maximum		49,2	45,6	63,9
Minimum	RCP45	-8,9	0,8	10,8
Median		21,8	24,6	36,2
Maximum		39,9	56,8	75,6
Minimum	RCP85	-19,4	-6,0	-9,3
Median		31,4	47,4	37,3
Maximum		50,4	65,5	70,6

Table 9 - Minimum, median and maximum of freq-r99p relative change (%) - Annual analysis

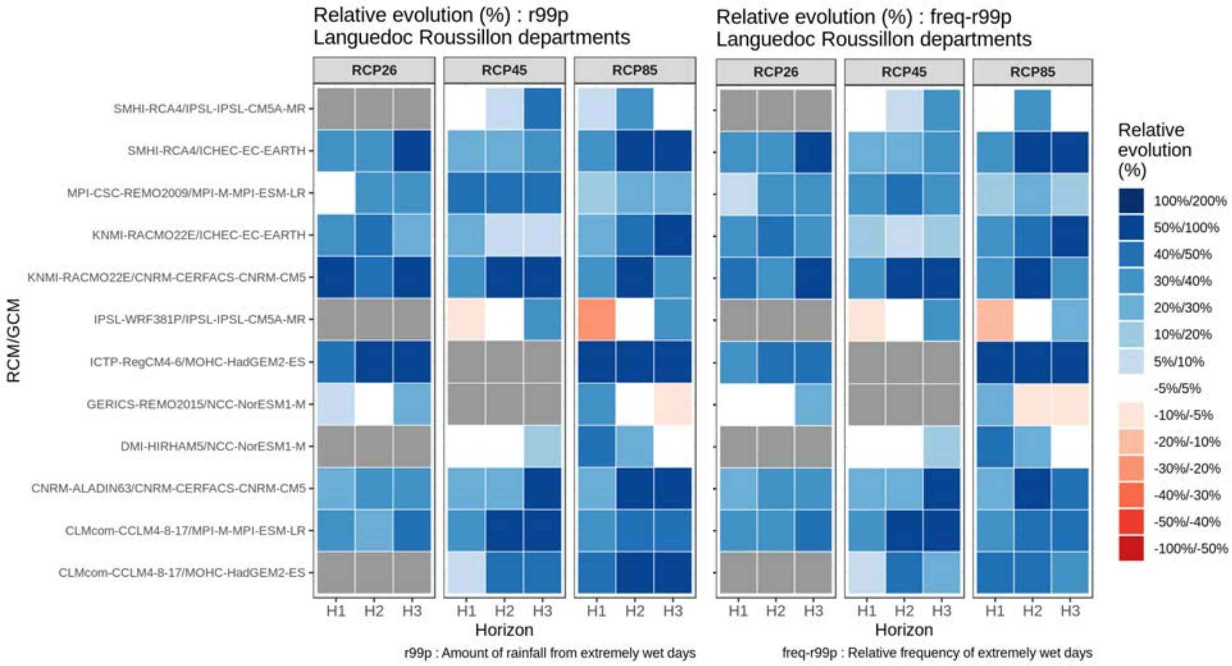


Figure 14 - Projected change (%) of amount of rainfall from extremely wet days (r99p indice, left) - Projected change (%) of extremely wet-days frequency (freq-r99p, right) - x-axis : time horizons H1=2021-2050 H2=2041-2070 H3=2071-2100 ; – y-axis DRIAS-2020 individual simulations

Multimodel map analysis

A spatial review over Languedoc-Roussillon region of rx1day relative change is carried out, using a multi-model analysis, which consists for a given greenhouse gas emission scenario and time horizon, to compare of several models and/or multi-model products derived from the DRIAS-2020 dataset. For this purpose, the 5th percentile, median and 95th percentile are computed, as well as the median of the distribution of all the models selected in DRIAS-2020.

The multi-model median of RCP4.5 scenario predicts a spatially homogeneous increase in rx1day, associated with a strengthening over the time horizons : the variations are thus +3.2% for 2021-2050, +6.6% for 2041-2070, +9.8% at the end of the century 2071-2100 on average over the Languedoc -Roussillon region. The 95th percentile of the distribution follows this trend : +21.9 % in 2021-2050, +26.5 % in 2041-2070, and +32.5 % in 2071-2100. RCP2.6 and RCP8.5 simulations provide similar spatial trends for these indices (see thumbnail maps) to the RCP4.5 scenario.

Note that some simulations (5th percentile thumbnail maps) predict a decrease in rx1day over the study area, with an average decrease between -12% and -9%. Thus, the distribution of values between 5th percentile and 95th percentile is large, reflecting an uncertainty in projected change, mainly related to the models, and not to the choice of the RCPs emission scenarios.

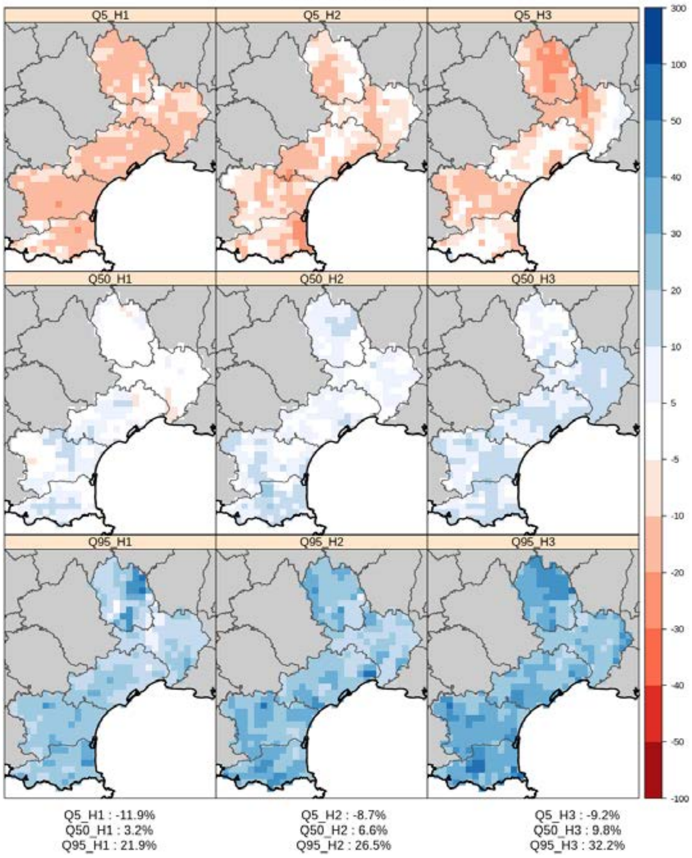


Figure 15 - Relative change of rx1day indice (%) Languedoc Roussillon region – RCP4.5 emission scenario - 5th percentile (top), median (middle) and 95th percentile (bottom) – H1-2021-2050 (left), H2 2041-2070 (middle), H3 2071-2100 (right) time horizons

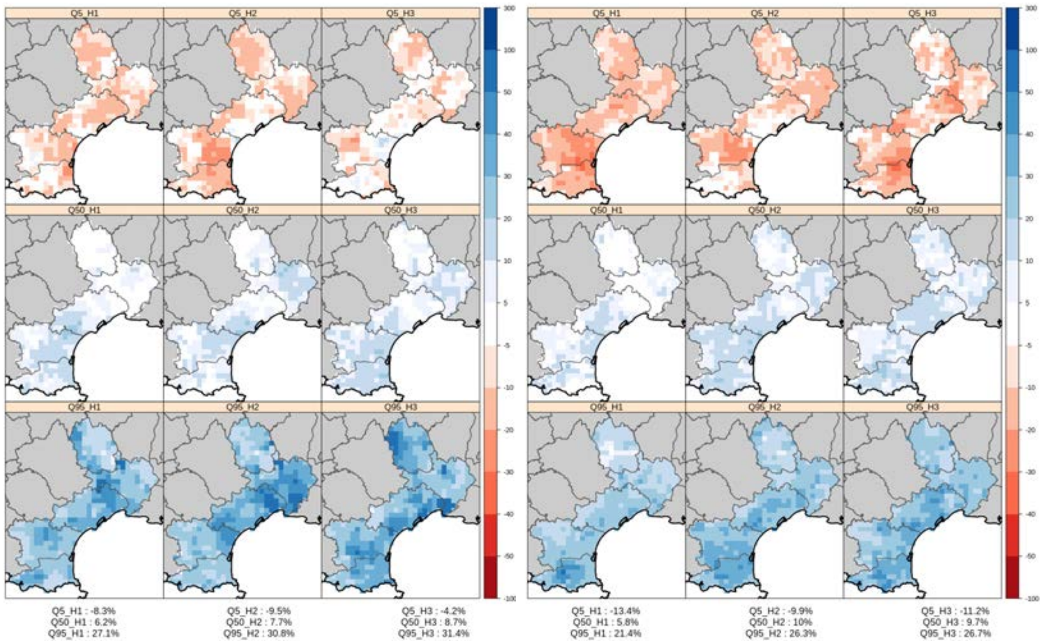


Figure 16 - Same as Figure 15 - RCP2.6 emission scenario (left) and RCP8.5 (right)

Worst case approach

In a worst-case approach, KNMI-RACMO22E Regional Climate Model (Royal Netherlands Meteorological Institute) driven by the CNRM-CERFACS-CNRM-CM5 Global Climate Model has been selected, this model increasing extreme rainfall indices (99th percentile, rx1day). The worst-case model shows a consistently positive median signal in extreme precipitation intensity, regardless of time horizons or emission scenarios. Maximum projected changes of rx1day over the study area are significant and can reach more than +50% compared to the historical period.

		2021-2050	2041-2070	2071-2100
Minimum	RCP2.6	-8,4	-8,2	-3
Mean		17	15,2	22,2
Maximum		49,4	40,6	56,6
Minimum	RCP4.5	-11,1	-0,3	-1,5
Mean		8,2	18,2	22,6
Maximum		33,1	51,4	53,5
Minimum	RCP8.5	-10,6	-1,3	-7,7
Mean		12,2	18,0	13,7
Maximum		34,7	42,3	44,9

Table 10 - Minimum, mean and maximum of rx1day relative change (%) - KNMI-RACMO22E/ CNRM-CERFACS-CNRM-CM5 climate model

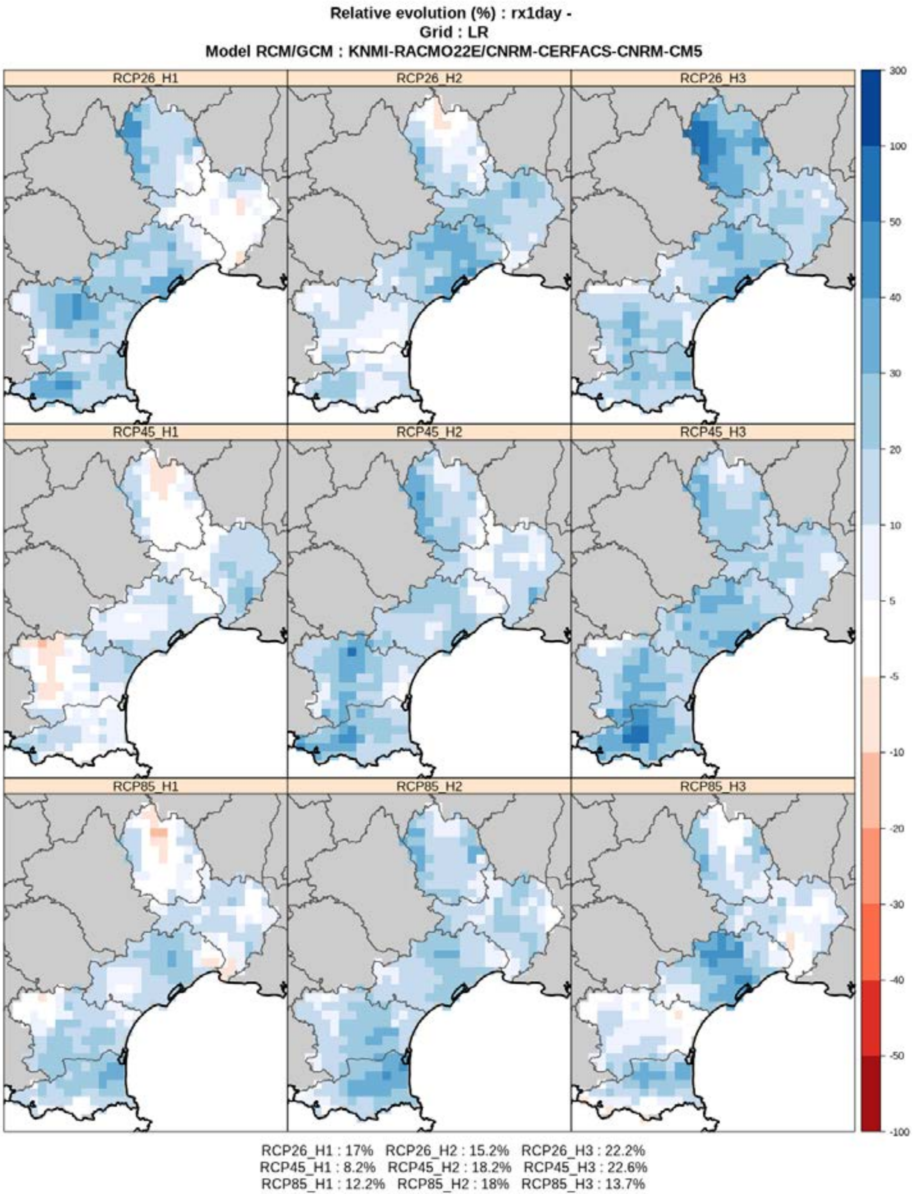


Figure 17 - Relative change of rx1day indice (%) Languedoc Roussillon region – RCP2.6 (top), RCP4.5 (middle), RCP8.5 (bottom) emission scenario – H1-2021-2050 (left), H2-2041-2070 (middle), H3-2071-2100 (right) time horizons - KNMI-RACMO22E/ CNRM-CERFACS-CNRM-CM5 model

Conclusion

Analysis of past extreme events using PRESCILIA gridded datasets over 1961-2018 shows increase of the intensity, the frequency, and a clear significant increase in the area affected by 1-day severe events and the water volume precipitated. These results are coherent with Ribes et al 2018 in the French Mediterranean. To be noted, the uncertainty associated with these evolutions becomes higher when the domain is smaller.

Analysis of future climate projections provided by CORDEX data in Languedoc-Roussillon region exhibits :

- a change in seasonal cycle of precipitation, with a significant increase in winter and drying in summer,
- an increase in extreme rainfall, in both intensity (projected change on average of 10%-20%) and frequency, in winter and autumn seasons,
- a large uncertainty, related to climate models, remains in projected change of extreme precipitation,
- considering the plausible worst case among all climate models can help to anticipate and to gauge the future risks of flooding in Mediterranean region, such as Aude department.

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