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EUCLEIA

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EUropean CLimate and weather Events: Interpretation and Attribution

Deliverable D5.*2*

Analysis of "never observed before" events

Deliverable Title	*Analysis of "never observed before" events*	
Brief Description	*The deliverable synthesizes statistical analyses leading to rare or extreme events that have unusual characteristics. It is based on the analysis carried out in Task 5.3. The aim of this task was to provide a basis for the evaluation of attribution models used in WP7 and WP8.* *In this report, we focus on the atmospheric circulation, and patterns leading to extreme climate events. Blocking conditions have been responsible for most cases of summer heatwaves. The case study of the summer 2015 (the second hottest summer in France since 1900, after 2003) shows that the atmospheric circulation had a southerly flow with no analogues in the past. We argue that the persisting lack of good circulation analogues is a proxy for rare climate events. This can be quantified in continuous time and we can determine return times for weather patterns (or their probability of occurrence).*	
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Lead Beneficiary	*Pascal Yiou, Robert Vautard, CNRS*	
Contributors		
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		P - Prototype
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		PP - Restricted to other programme participants, including the Commission services
		RE - Restricted to a group specified by the consortium, including the Commission services
		CO - Confidential, only for members of the consortium, including the Commission services

Contents

1. Executive Summary

Atmospheric patterns

- We have developed a methodology to identify unusual weather patterns. This methodology is based on observations/reanalyses only and relies on the “flow analog” methodology.
- We have assess seasons characterized by unusual weather patterns.
- We have calculated trends in unusual weather patterns.

Warm anomalies

- An analysis of the summer of 2015 in France without blocking pattern was developed.

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOW, Section B1.1):

No.	Objective	Yes	No
1	Derive the requirements that targeted user groups (including regional stakeholders, re-insurance Companies, general public/media) have from attribution products and demonstrate the value to these users of the attribution products developed under EUCLEIA.		x
2	Develop experimental designs and clear ways of framing attribution studies in such a way that attribution products provide a fair reflection of current evidence on attributable risk.	x	
3	Develop the methodology for representing the level of confidence in attribution results so that attribution products can be trusted to inform decision making.	x	
4	Demonstrate the utility of the attribution system on a set of test cases of European weather extremes.	x	
5	Produce traceable and consistent attribution assessments on European climate and weather extremes on a range of timescales; on a fast-track basis in the immediate aftermath of extreme events, on a seasonal basis to our stakeholder groups, and annually to the BAMS attribution supplement.	x	

3. Detailed report

Motivation

Events that “never occurred before” are not necessarily extreme in terms of consequences, but they often require a revisit of the process understanding that is used to describe the dynamics of climate. Such events have been called « black swans » in the economics literature [*Taleb*, 2007]. More generally, rare or unusual events play a special role in climate dynamics, although they are not necessarily extreme in any of the individual climate variables that generated it (e.g. pressure, temperature or precipitation). This can be illustrated by the centre of the « wings » of the *Lorenz* [1963] attractor, which are not extreme in any of the variables, but very seldom visited because they are unstable fixed points.

Here, we report on a methodology to make an assessment of unusual events in the atmospheric circulation, by detecting patterns that have very few or no “analogues”. We use the method of flow analogues to analyse trends in the rarity of weather patterns. An application to summer heatwaves, with an emphasis on the Summer 2015 is developed.

Methods

We compute analogues of circulation from sea-level pressure (SLP) data computed by the NCEP reanalysis [*Kistler et al.*, 2001], with a weekly update [*P Yiou et al.*, 2012]. For each day, we determine the 20 best analogues (within 30 calendar days, but in a different year to ensure independence) of circulation by minimizing a Euclidean distance. The spatial rank correlation is then computed between each daily SLP and its 20 best analogues. This computation is performed automatically in continuous time. So far, most studies have focused on “good” analogues, for climate reconstructions [*Schenk and Zorita*, 2012; *P. Yiou et al.*, 2014] or predictions [*Lorenz*, 1969]. Although there is no universal definition a good analogue for SLP, we heuristically use two criteria to sort analogues: the Euclidean distance (which is used for their computation) and the spatial correlation. Both criteria optimize different features of resemblance between multivariate patterns. Hence an analogue is defined to be “good” when the Euclidean distance is smaller than the 25th quantile of all distances among the 20 best, and when the spatial correlation exceeds the 75th quantile of all correlations (among the 20 best analogues). The number of “good” analogues for each day provides a proxy for the probability to observe an SLP pattern given a long enough climate database. The time distance between a given SLP observation and its “good” analogues is a proxy for the waiting time of this given SLP pattern. On average, the waiting time of SLP patterns in the NCEP reanalysis (1948-2015) is 30 years, with a large variability. An example for December 2015 is given in Figure 1 below. It shows the number of good analogues since December 1st 2015, and the average waiting time between analogue dates and December 2015. In this case, we observe for instance a sequence of rare events in the middle of the month.

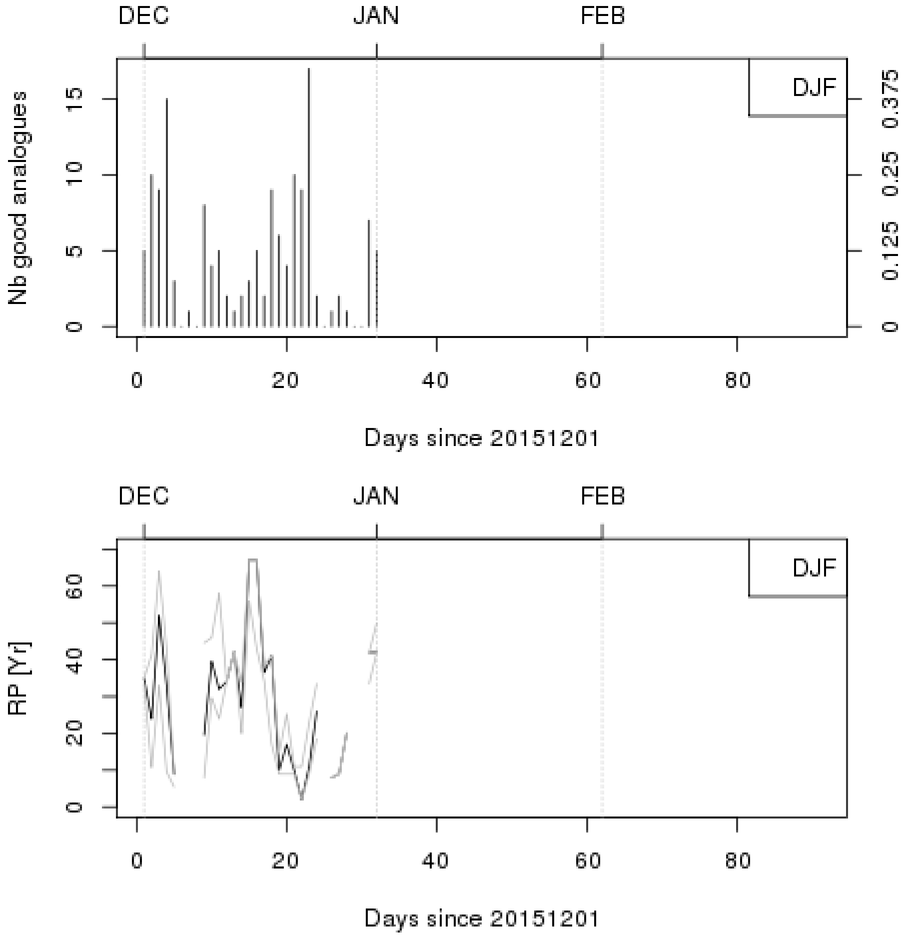

Figure 1: Upper panel : number of good analogues for December 2015. Lower panel: waiting times (or Return Periods, in Years) for the SLP patterns of December 2015. The grey lines are the confidence intervals obtained from the good analogues. When there is no line, the number of good analogues is zero, and the waiting time is infinite (given the NCEP reanalysis).

For a given season, the average number of daily “good” analogues is a proxy for the rarity of the SLP patterns during that season. This diagnostic is used to detect sequences of exceptional SLP patterns, for all summers since 1948.

We also compute weather regimes of the atmospheric circulation with a k-means algorithm [*Michelangeli et al.*, 1995; *P Yiou et al.*, 2008]. The weather regimes are computed for each season (JJA, SON, DJF and MAM) on daily SLP anomalies over the North Atlantic region, for a climatological period (1970-2010). Here, we impose four weather regimes. Then all daily SLP data are classified onto those four weather regimes. This allows qualifying the circulation patterns in terms of known flows (for instance the phases of the North Atlantic circulation, or Scandinavian Blocking).

Climate events

The summer of 2015 was unusually warm, being the second warmest in France and southern Europe (after 2003) since 1900. The atmospheric circulation during this summer was very different from 2003, with very few blocking episodes, and rather zonal and southerly circulation patterns. Therefore, an analysis of this event within the framework of EUCLEIA is relevant.

The average number of good daily analogues in the summer (June to August), between 1948 and 2015 is shown in Figure 2. We checked that the dates of the analogues are uniformly chosen along the whole period, indicating no clear bias due to a change of the assimilated data in the reanalysis procedure. Overall, we find a significant decreasing trend of the average number of good analogues in summer, between 1948 and 2015. The summer of 2015 yields a record of low number of days with good analogues. Most of the days in the summer of 2015 have no good analogues and hence exhibit unusual patterns of the atmospheric circulation.

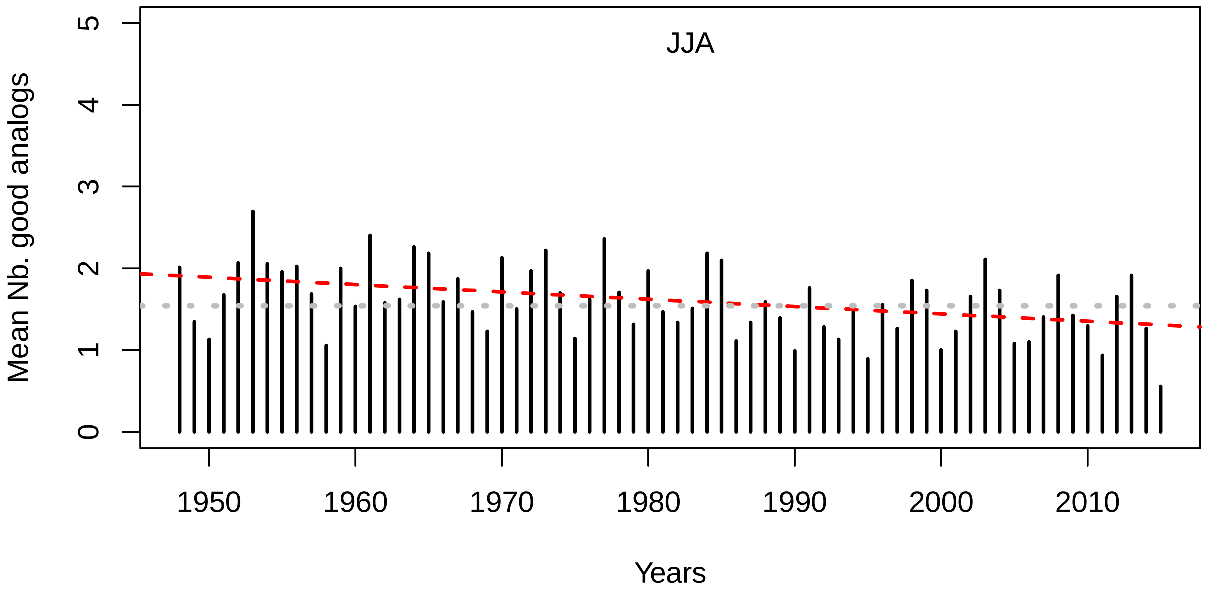

Figure 2 : Average number of good analogues for each day in the Summer (June-July-August), between 1948 and 2015 (vertical bars). The dotted grey line shows the average number of good daily analogues. The dashed red line shows the linear trend.

An analysis of the atmospheric circulation during major summer heatwaves in France and the Iberian Peninsula can also be performed by projecting the SLP onto summer weather regimes [*Cassou et al.*, 2005]. This analysis is shown in Figure 3 for the summer of 2015.

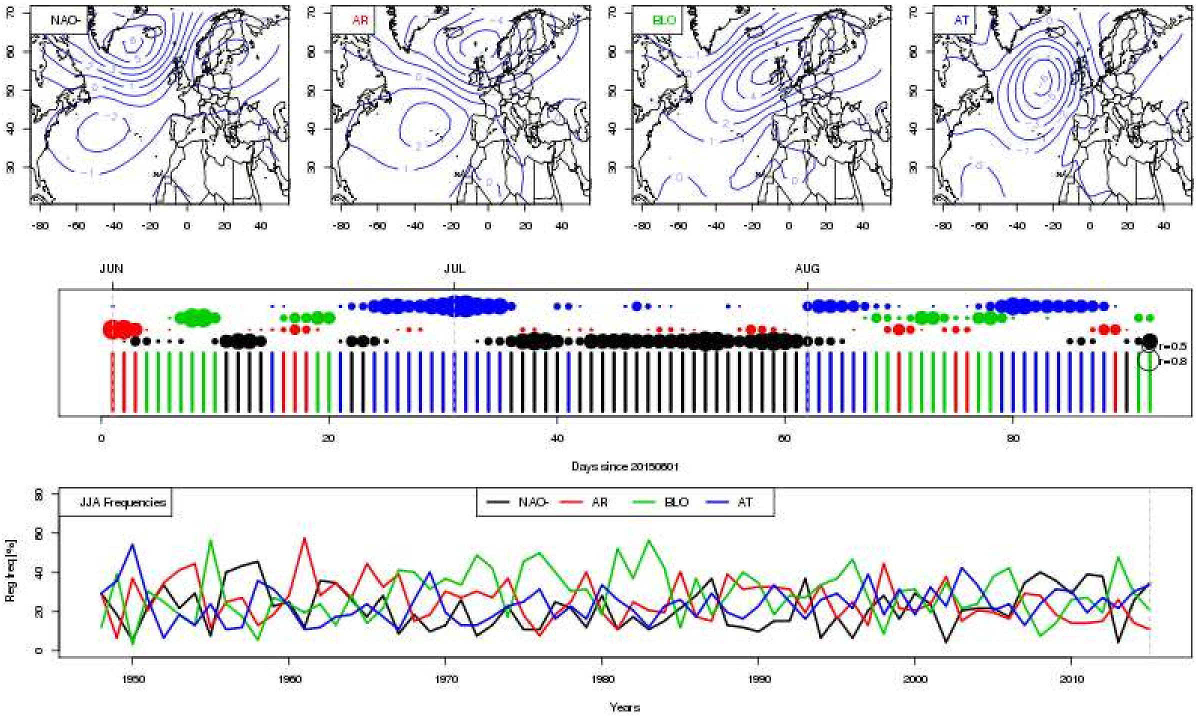

Figure 3: Summer weather regimes. Upper panels: four summer weather regimes from NCEP SLP (NAO-, Atlantic Ridge, Scandinavian Blocking and Atlantic Low). Middle panel: Classification of summer days (starting on June 1st 2015) to the summer weather regimes, identified by colours. The upper circles give the positive and significant spatial correlation to the weather regimes. Lower panel: weather regime frequencies in JJA between 1948 and 2015.

To synthesise the dynamical information from the major heatwaves in Europe, we project the daily summer SLP anomalies onto NAO- and Atlantic Ridge (AR) weather regimes, determined on the NCEP reanalysis (1970-2010). All the summer heatwaves before 2015 have trajectories evolving on the left side of Figure 4 (the barycentre of the NAO- marginal is shown with a black dot). We show that the summer of 2015 stays on the right side of the projection, unlike all the other warm summers, which also supports the result of unprecedented circulation patterns, leading to that heatwave [*Alvarez-Castro et al.*, 2016]. Hence we can argue that the hot summer of 2015 is an “outlier” (i.e. an event that was never observed before) in terms of atmospheric circulation. It was not characterized by a surface anticyclone and fell into rather cyclonic weather regimes, possibly because of cancellation of surface anticyclone by the strong heat. In particular, it plays against the general intuition that heatwaves occur during anticyclonic conditions [*Quesada et al.*, 2012]. An analysis will be carried out with upper-air geopotential height in order to investigate this issue.

Those analyses depend on the dataset that was used (here NCEP reanalysis). We have performed tests with the 20CR reanalysis [*Compo et al.*, 2011], with similar results, although this reanalysis does not extend beyond 2011 and its resolution is finer that for NCEP.

In this deliverable, we only make a detection assessment of the atmospheric circulation patterns during heatwaves. We do not try to explain the mechanism of heatwave generation, which is part of D6.2.

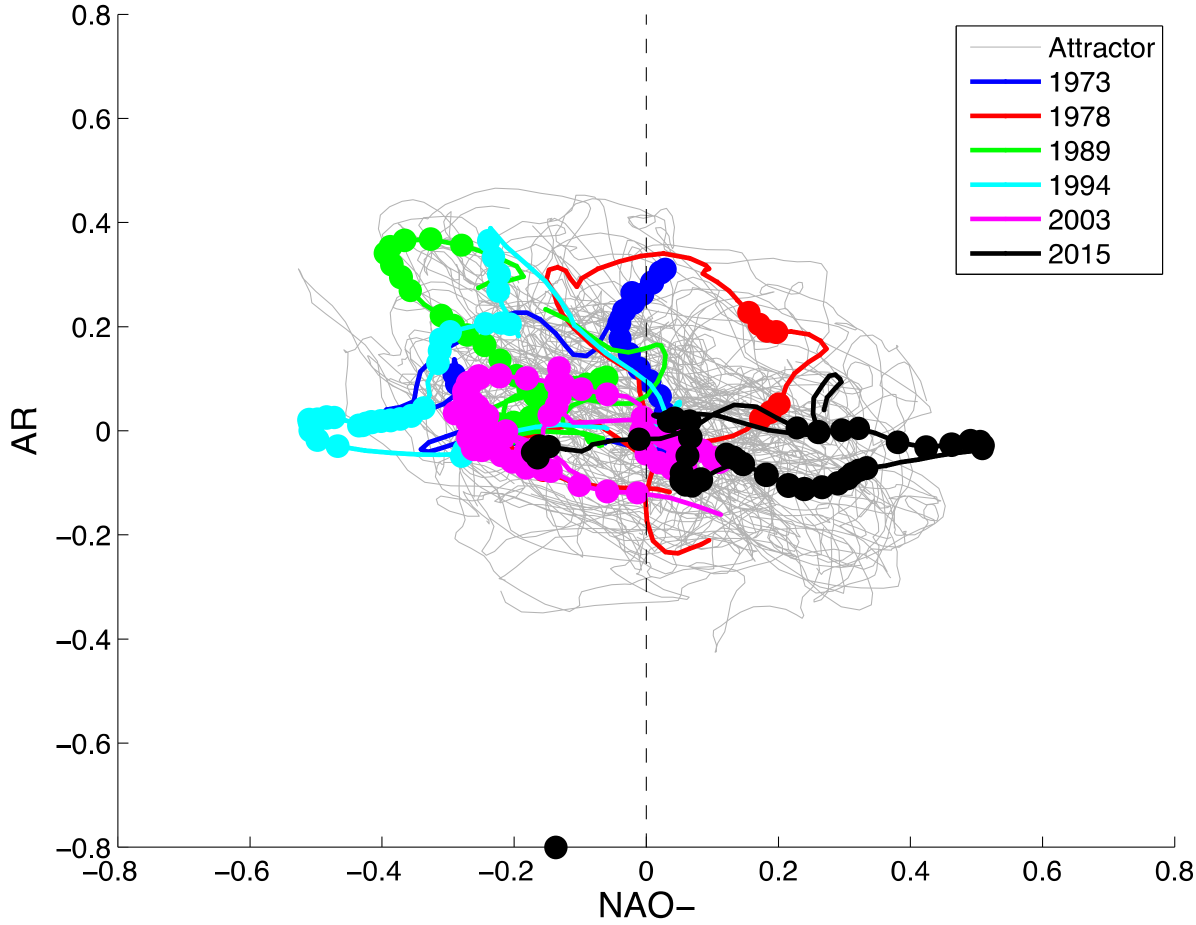

Figure 4: Projection of daily summer SLP onto two of the summer weather regimes (from *Alvarez-Castro et al.* [2016])

4. Lessons Learnt

The diagnostics that are proposed in this deliverable are computed automatically in continuous time (e.g. Figure 1 for the last week of December 2015). This computation is based on the SLP of NCEP reanalysis. A more robust version could add analyses of other types of reanalyses (20CR or ERA20C), which offer longer databases and a potential for better analogues. The computation of analogues on other pressure-related variables (e.g. geopotential height or wind speed) would complete such an analysis.

In this report, we have required an event time scale that is larger than one month in order to build a statistical confidence over the analogues. Our methodology cannot be applied to events that last for less than a week, let alone one day: many days have no “good” analogues, according to the definition we propose (~6%). The persistence of days without good analogues provides a more relevant definition of rare (or unprecedented) events.

From the analysis presented in this document, we can state that the summer 2015 event is exceptional (i.e. a detection statement) in terms of atmospheric circulation, but it is not possible from Figure 2 to make a direct attribution statement on the rarity of the weather patterns from an application of the method of analogues on reanalysis data. In order to do so, a computation of the analogues of 2015 from two distinct periods (e.g. recent and older periods from a long reanalysis, or from ensembles of Weather@Home simulations) would be necessary to estimate the change of probability of this rare event. From Figure 2 we would expect a lowering of the probability of observing a summer like 2015, but this remains to be verified.

As a consequence, a "fast track" discussion might not be very robust for such long events. A medium range (several weeks) delay is necessary to appreciate how rare a long lasting event has been. In addition, this type of diagnostic requires complementary analyses (such as in D5.1) for a thorough description of rare events.

5. Links Built

The work conducted within this deliverable contributes to deliverable D6.3 and also to WP7.

6. References

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