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1 Analysis of the exceptionally warm December 2015 in France using flow analogues

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4 and U Paris Saclay, Gif-sur-Yvette, France.

5
6 Capsule December 2015 in France was an extreme of circulation and temperature. Both circulation
7 and climate change partly explain the 4°C anomaly. We found no link between climate change and
8 circulation.

9

10 The event

11 The December 2015 average temperature broke a record in France, with an anomaly of
12 +4.1°C (Fig. 1a) with respect to the 1949-2015 climatology. The linear trend of average December
13 temperature (in red in Fig. 1a) is not significant (p-value > 0.05), as regional temperature variability
14 is high in winter. Such a positive temperature anomaly has impacts on the vegetation cycle (the
15 French press covered this topic in the daily newspaper Le Monde¹). It also affects local economies,
16 e.g. tourism in ski resorts. The temperature anomaly was concomitant with a zonal atmospheric
17 circulation over Western Europe (Fig. 1b), directing mild subtropical air masses towards France. We
18 found that the mean monthly SLP (sea level pressure) anomaly over the black box of Fig.1b is also
19 a record high for the NCEP reanalysis. Such a circulation type generally leads to warm temperatures
20 over France (Yiou and Nogaj, 2004).

21 In this paper we seek to address three questions: How much does the circulation anomaly
22 explain the temperature anomaly during December 2015 in France? What is the influence of climate
23 change on the occurrence of the circulation anomaly? How does the distribution of temperature
24 conditional to the atmospheric circulation evolve with climate change? We hence perform a
25 *conditional attribution* exercise (NAS, 2016, p. 30), with a circulation that is fixed to the

1 [1http://abonnes.lemonde.fr/biodiversite/article/2015/12/30/la-nature-deboussolee-par-un-hiver-tres-](http://abonnes.lemonde.fr/biodiversite/article/2015/12/30/la-nature-deboussolee-par-un-hiver-tres-doux_4839801_1652692.html?xtmc=temperature&xtcr=1)
2 [doux_4839801_1652692.html?xtmc=temperature&xtcr=1](http://abonnes.lemonde.fr/biodiversite/article/2015/12/30/la-nature-deboussolee-par-un-hiver-tres-doux_4839801_1652692.html?xtmc=temperature&xtcr=1)

26 observation of December 2015. This estimates the thermodynamic contribution of climate change
27 on the increase of temperature (Vautard et al., 2016; Yiou et al., 2017).

28

29 Flow analogues and the role of circulation

30 We evaluated the link between the SLP anomalies over the black box in Fig. 1b and temperature in
31 France using the method of flow analogues (e.g. Yiou et al. 2017). We considered the French
32 national temperature index supplied by Météo France (Soubeyroux et al. 2016). This daily index is
33 computed as the average of 30 stations distributed over France and starts in 1949. We use
34 temperature anomalies with respect to a daily seasonal cycle obtained by spline smoothing (cf. Yiou
35 et al., 2008). The circulation proxy is the SLP from the National Centers for Environmental
36 Predictions (NCEP) reanalysis, between 1949 and 2015. For each day of December 2015 we
37 identified the 30 best analogues of SLP (with a Euclidean distance) from 1949 to 2015 on the
38 domain delimited by the black rectangle in Fig. 1b. Jézéquel et al. (2017) showed that the results on
39 analogues are qualitatively insensitive to the number of analogues (between 5 and 30 analogues).
40 We simulate daily sequences of SLP by randomly picking one of the 30 best analogues within the
41 NCEP dataset for each day. The repetition of this random selection (with replacements) builds an
42 ensemble of *uchronic* months. Those *uchronic* months reproduce the SLP anomaly of December
43 2015 (see Fig. S1a-d in Supplementary Material). We then compute monthly averages for December
44 of the national temperature index. We hence obtain *uchronic* French seasonal anomalies of
45 temperature for December. We iterated this process 10^4 times in order to produce *uchronic*
46 probability distributions of monthly mean temperatures (see Jézéquel et al. 2017 for more details).
47 This *uchronic* distribution of temperatures represents the ensemble of temperatures that could have
48 been expected for the circulation observed in December 2015. We compared the *uchronic*
49 distribution of temperature anomalies to a distribution built from randomly picked December days.
50 In Fig. 1c, the *Control* experiment corresponds to a monthly average of the daily temperature
51 anomalies from the 10^4 random samples without conditioning on the atmospheric circulation. In

52 order to take into account the dependence between consecutive days in the *Control* distribution, we
53 calculated the monthly means using only every third day (Jézéquel et al. 2017).

54 We find that the SLP partly explains the monthly temperature anomaly in France during
55 December 2015 (Fig. 1c). The median of the *uchronic* temperature anomaly distribution is 1.3°C,
56 i.e. ~30% of the anomaly. The other ~70% of the anomaly could be explained by other factors (e.g.
57 snow cover feedback). This positive anomaly demonstrates the link between the synoptic situation
58 and the anomaly of temperature in France, and justifies the choice of a conditional attribution
59 approach.

60

61 Role of climate change

62 In order to estimate the role of climate change we rely on the CESM1 model large ensemble,
63 CESM-LENS (Kay et al., 2015). We use 30 members for both surface temperature and SLP using
64 historical runs between 1951 and 2005 and RCP8.5 between 2006 and 2100. We reconstitute the
65 French national temperature index from the surface temperature using the coordinates of the 30
66 stations used to calculate the index. Kay et al. (2015) showed that CESM-LENS reproduces
67 reasonably well features of the Northern Hemisphere atmospheric circulation. An analysis of the
68 SLP distances between those observed during December 2015 and CESM simulations indicates that
69 they are not statistically different from the NCEP reanalysis (Fig.S1e in the Supplementary
70 material). We hence consider that this model does not yield biases that prevent its use for the
71 purpose of this study.

72 We estimate the influence of climate change on the circulation pattern leading to December
73 2015 by computing the probability distributions of distances between SLP anomalies among all the
74 December days in both NCEP and CESM and the closest day of December 2015 (Fig. 2a). We keep
75 only the distances below the 5th percentile of the distribution, in order to focus on the days with SLP
76 anomalies closest to those observed in December 2015. For each December, we count the number
77 of days below this threshold for each ensemble member (NCEP and CESM). If the circulation that

78 prevailed in December 2015 became more frequent with time, then a trend should be detected in
79 this number of days. We detect no such trend. Therefore it is not possible to conclude there is an
80 impact of climate change on the atmospheric circulation itself.

81 We then estimate the temperature anomaly for a similar event in terms of synoptic
82 circulation without climate change, and in future climate change scenarios by computing analogues
83 of circulation from different periods of observations and CESM simulations. We analyzed the
84 *uchronic* temperature anomalies constructed with analogues of the December 2015 flows from two
85 time periods of the NCEP dataset. We compared an early subset of 33 years (1949-1981) to a more
86 recent one (1982-2014). The two gold boxplots in Fig. 2b represent those two experiments. We
87 detected a difference of 0.4°C between the two distributions, in contrast with the monthly
88 temperature trend for 1949-2015 displayed in Fig. 1c, which is not significant. However, it is not
89 possible to attribute this difference of temperature to climate change, as it could also relate to
90 interdecadal variability, especially for very small subsets of 33 years, whose length was imposed by
91 the NCEP reanalysis length.

92 In order to study the relative influences of climate change and variability, we rely on CESM-
93 LENS. We study three periods of 50 years: 1951-2000, 2001-2050, and 2051-2100. Using 30
94 members, we have 1500 years of data for each sub-period from which we can calculate the
95 analogues (which correctly represent the observed SLP anomaly as displayed in the supplementary
96 material Fig. S1a-d). This reduces the uncertainty related to the quality of the analogues we picked.
97 The three pink boxplots in Fig. 2b represent the *uchronic* distributions for SLP analogues picked
98 from CESM-LENS. The three red boxplots represent the *control* distributions for the same sub-
99 periods. We observe that the December 2015 anomaly of temperature was never reached before
100 2000. It is still not reached for 2001-2050 under the RCP8.5 scenario. For the second half of the
101 21st century the temperature anomaly is expected to exceed 4°C for the same synoptic situation.
102 The observed anomaly is still warmer than the median of the *control* distribution. A caveat of this
103 study is that we only used one model, which could have biases especially in the future.

104 Conclusion

105 The month of December 2015 set a record temperature in France. The zonal circulation that
106 prevailed over Western Europe during the whole month accounts for ~30% or 1.3°C of the
107 temperature anomaly. No trend was found in the atmospheric circulation patterns themselves (Fig.
108 2a). For this given circulation, our analysis shows that the observed temperature is never reached in
109 the second half of the 20th century (Fig. 2b), and the model is unable to reach it even during the
110 first half of the 21st century. However, the December temperature observed in 2015 is projected to
111 be exceeded in the second half of the 21st century under the same synoptic situation. Cattiaux et al.
112 (2010) found with a similar analysis that the cold winter of 2009/2010 would have been colder if
113 not for climate change. Our analysis of December 2015 is a warm counterpart to that study. We find
114 a 1.4°C difference between the median of the uchronic temperatures of the second half of the 20th
115 century and the first half of the 21st century and an additional 1.9°C for the second half of the 21st
116 century. We find approximately the same differences between *Control* distribution medians, which
117 means that the trend conditional to the circulation equals the unconditional trend.

118

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122

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157 Figure caption list

158 Figure 1:

159 (a) Evolution of the French national temperature index for the month of December between 1949
160 and 2015. The red line is the (non significant) linear trend. (b) SLP anomalies for December 2015
161 relative to the 1949-2015 average of the NCEP Reanalysis I dataset (Kalnay et al. 1996). (c)
162 Comparison of uchronic monthly seasonal anomalies of the national index distribution for randomly
163 picked days (Control) and randomly picked analogues. The red line is the observed temperature
164 anomaly (+4°C). The three lines composing the boxplots are respectively from bottom to top, the
165 25th (p25), median (p50) and 75th percentile (p75) of the uchronic temperature anomaly
166 distribution. The value of the upper whiskers is $\min(1.5 \times (p75 - p25) + p50, \max(\text{temperature}$
167 $\text{anomaly}))$. The value of the lower whiskers is its conjugate. The circles represent the values that are
168 outside of the whiskers.

169 Figure 2:

170 (a) Number of days per year with SLP distances below the 5th percentile of the distribution of daily
171 distances to the closest December 2015 day. The boxplots show the dispersion of CESM ensemble
172 members. The blue lines-dots are the values for the NCEP reanalysis. The red line is the (non
173 significant) linear trend of the median of the CESM ensemble members. (b) Boxplots of the
174 distributions (respectively uchronic distributions) of anomalies of the national temperature index
175 relative to the observed climatology of this index between 1948 and 2015, in yellow (orange) using
176 NCEP and in red (pink) using CESM-LENS subsets.

177

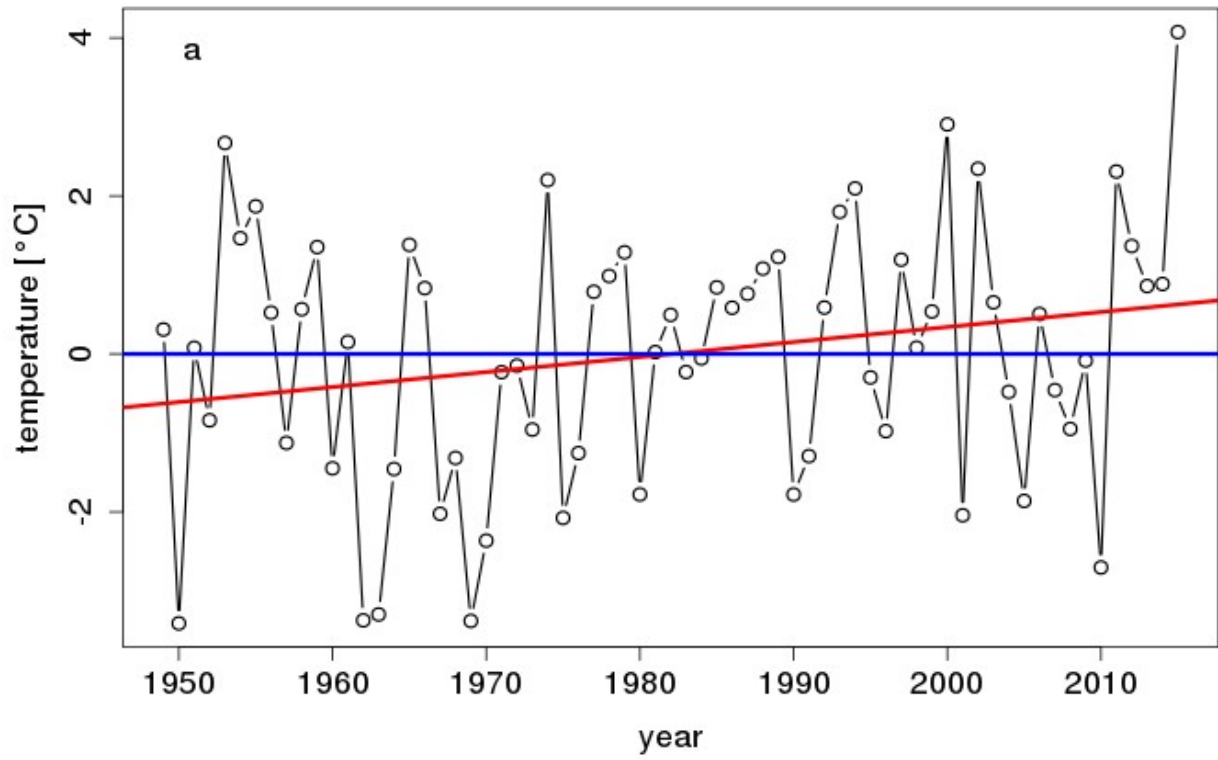
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180 Figures

181 Figure 1:

182 (a)

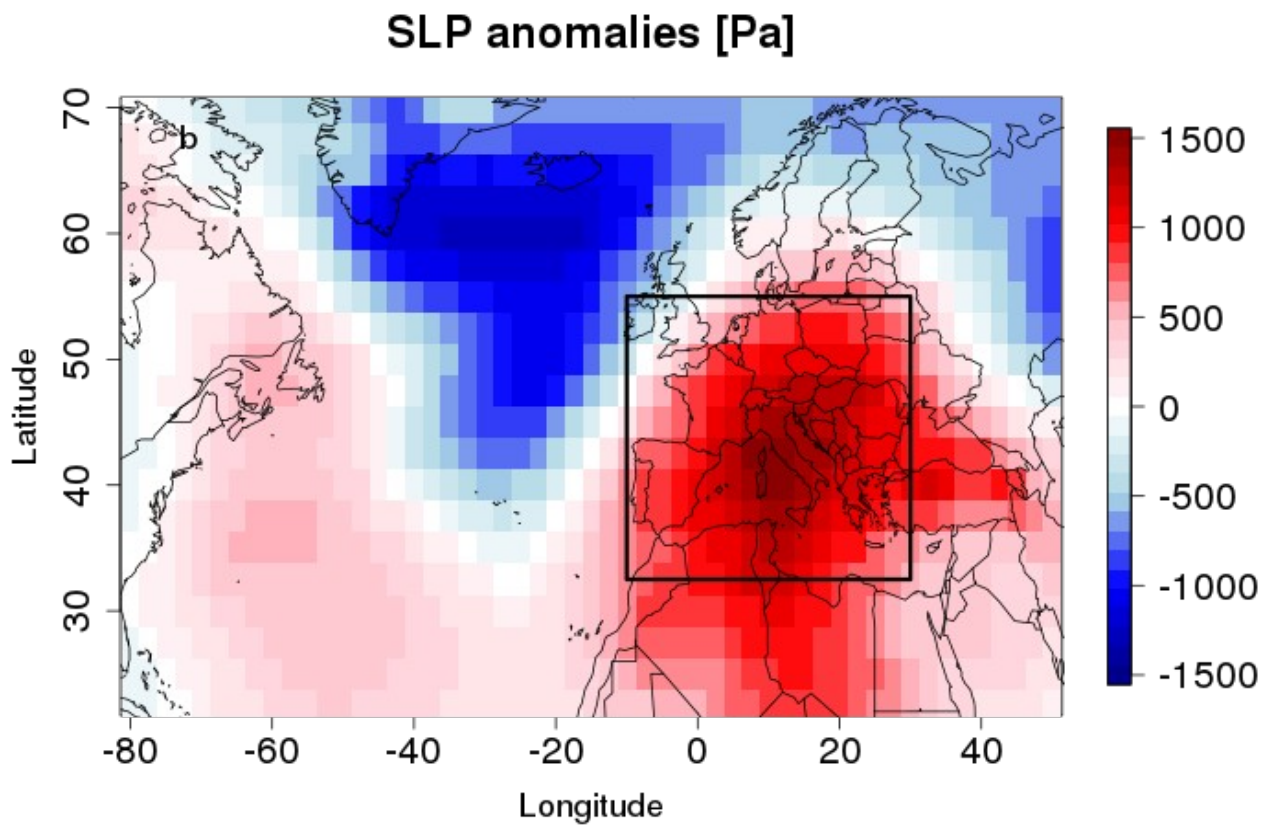


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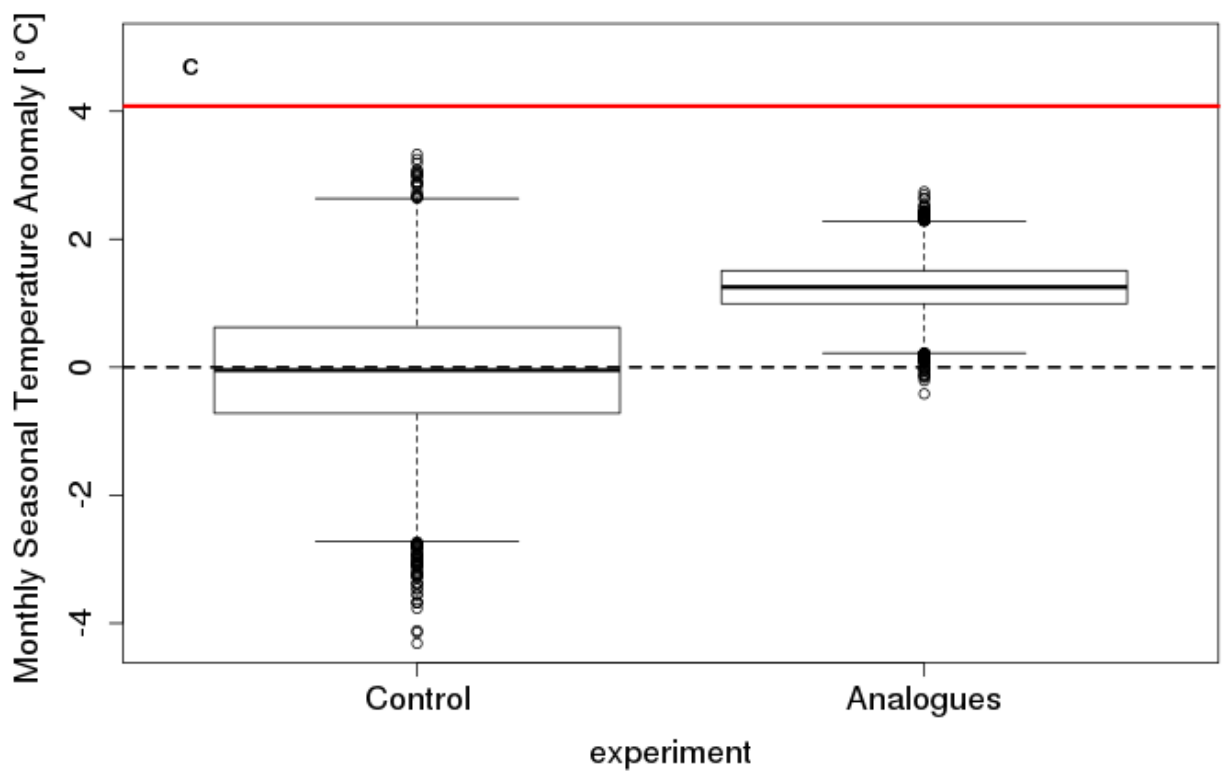
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187 (b)

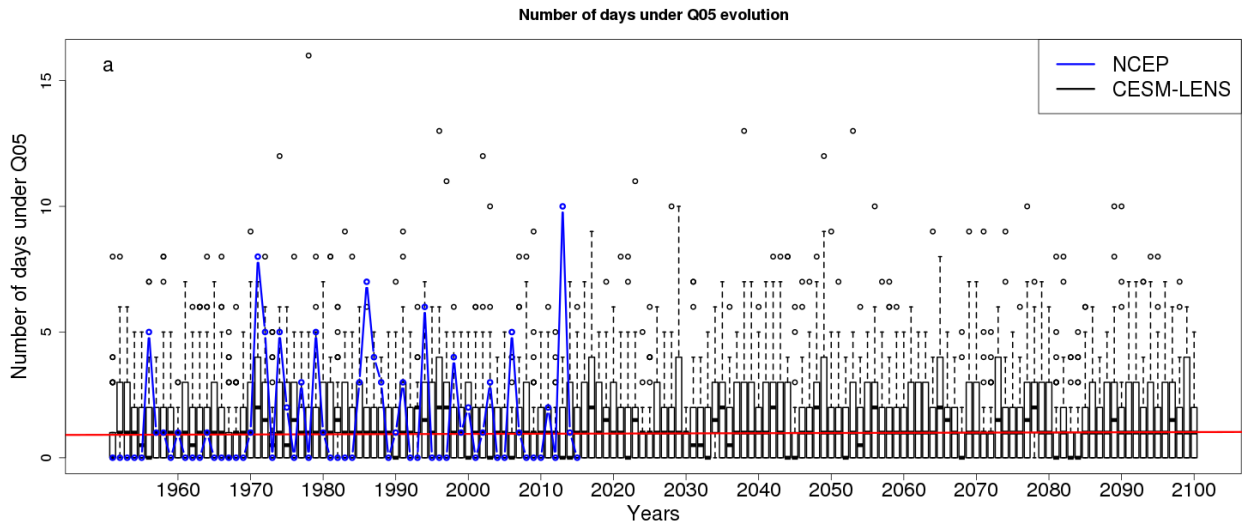


189 (c)



192 Figure 2:

193 (a)



195 (b)

