Large-scale atmospheric dynamics and local intense precipitation episodes

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[1] Weather extreme events have important consequences in the environmental, social and economic sectors. Numerous efforts have been devoted to identify the large-scale (LSC) climate dynamics connected to them. In this paper we show that the LSC circulation patterns associated with intense precipitation episodes (IPE) over a specific domain can be identified from clustering algorithms. For an extended winter season (from 16th October to 15th April), using daily maps of geopotential height at 500 hPa selected on the basis of precipitation threshold exceedence, we found that over western France, the LSC pattern linked to IPE occurrence displays a strong negative anomaly over Great Britain. This pattern corresponds to the structure observed during the transition from Zonal to Greenland Anticyclone standard weather regimes. It is the least likely transition from the Zonal regime, suggesting potential links between atmospheric dynamics and the occurrence of IPE. **Citation:** SanchezGomez, E., and L. Terray (2005), Large-scale atmospheric dynamics and local intense precipitation episodes, *Geophys. Res. Lett.*, *32*, L24711, doi:10.1029/2005GL023990.

1. Introduction

[2] The challenge of understanding the large-scale (LSC) dynamics of the extreme events is crucial, since their socio-economic impacts on society have many important consequences. At present, General Circulations Models (GCMs) have not been successful in representing the occurrence of extremes, suggesting the need for alternative approaches [*Meehl et al.*, 2000]. If we are able to identify the LSC dynamics favoring the development of extreme events over a specific domain, then we could assess the risk of an extreme to occur by looking at the LSC circulation. In this work we present a variant of the standard weather regime approach to search the LSC patterns associated with the occurrence of extremes over a certain domain. Weather regimes can be defined as peaks in the probability density function of the atmosphere [*Kimoto and Ghil*, 1993]. In other words, they are the preferential states of the atmospheric circulation, characterized by various properties such as persistence, recurrence and stationarity. They are usually obtained from classification techniques or cluster analysis, in which a large number of geopotential daily maps are organized into a few groups or classes.

[3] Previous works [*Robertson and Ghil*, 1999; *Plaut and Simmonet*, 2001; *Yiou and Nogaj*, 2004] have established links between weather regimes and local extreme episodes over different regions of the Northern Hemisphere. They show that weather regimes are able to describe many features of some local extremes, such as persistent blocking episodes yielding high (low) temperatures in summer (winter) over Northern Europe. However, standard weather regimes do not provide an adequate description of the LSC dynamics associated with intense precipitation events (IPE), as shown in this paper for the western France region. The methodology consists of a classification of LSC daily geopotential maps corresponding only to days with an IPE recorded in the domain. The selection of the days is based on a threshold value exceedence.

[4] We also examine the possible linkage between weather regime transitions and precipitation extremes over the same domain. This was motivated by the high percentage of IPE (more than 40%) observed during the break and/or onset phases of some weather regimes.

[5] The paper is presented as follows: section 2 describes briefly the methodology and the results of the classification of LSC maps corresponding to IPE. Section 3 is devoted to the associated weather regime transitions, and the last section gives a summary and some perspectives.

2. Large-Scale Dynamics for Intense Precipitation Events: Data and Methodology

2.1. Standard Weather Regimes Approach

[6] Four weather regimes have been traditionally identified in both winter [*Vautard*, 1990], and summer seasons [*Cassou et al.*, 2005] for the North Atlantic sector (Figure 1). The Zonal (ZO) regime is characterized by an intense zonal flux towards Northern Europe; Greenland Anticyclone (GA) shows an anticyclonic cell over Greenland; Atlantic Ridge (AR) displays an anomalous anticyclonic core in the center of the North Atlantic basin; Blocking (BL) is represented by an intense anticyclonic cell centered over the Scandinavian Peninsula. Here, we have obtained the four standard weather regimes using the 500 hPa geopotential height (Z500) from ERA40 data set [*Uppala et al.*, 2004] over 1958–2001. The decomposition of the LSC flow into four regimes have been achieved using the $k - means$ algorithm [*Michelangeli et al.*, 1995]. Before the classification, we performed an empirical orthogonal function (EOF) analysis of the daily anomalies of Z500 maps for an extended winter season (from 16th October to 15th April). The Z500 anomalies are filtered to remove periods shorter than 10 days. The first 10 EOFs have been retained, capturing about 90% of the total variance and $k - means$ is applied in the space spanned by the leading PCs.

[7] For the identification of weather regimes all the days are classified in a first stage. Then, in order to obtain a more accurate representation of the weather regimes, we have

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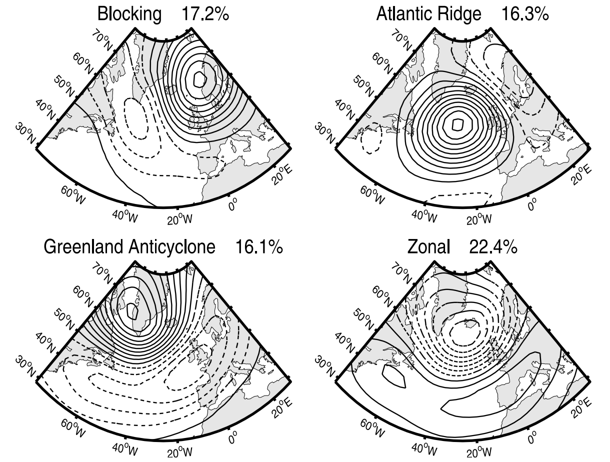

Figure 1. Four standard weather regimes obtained from the winter Z500 field by using the $k - means$ clustering algorithm. The isolines are the Z500 composite (solid lines are positives values and dot dashed are negative values). Contour interval is 20 gpm. The relative frequency of occurrence for each weather regime is also indicated.

introduced the concept of transition days. First, we remove the first two and last two days of each season, to avoid possible weather regimes episodes concatenated between two consecutive seasons. Second, we consider as weather regime the episodes lasting at least 4 days. For ranges of more or equal than 4 days we also remove the onset (break) day, which is the first (last) day of each weather regime episode. At the end, we have eliminated about 23% of days in the whole data set, which can be considered as transition days. For four weather regimes, there are twelve possible kind of transitions (we do not consider the transitions between the same weather regime).

[8] The region of study goes from the Normandy coast to the Atlantic Pyrenees. An IPE is simply defined as any day when at least one station in the domain exceeds its 99th quantile. To construct the distribution of precipitation for the determination of the quantiles, we only keep the days with values of precipitation different from zero. The reason why we have chosen the western of France is twofold. First, a number of extended and dense daily precipitation records at different meteorological stations over the selected region allows for a complete study of the local variability. These observations come from the Météo-France SQR data set [*Moisselin et al.*, 2002]. A total of 82 stations for the period 1950–2003 are available in the domain. Second, in western France, topography influence on weather disturbances is almost negligible, and we can assume that most synoptic phenomena are strongly linked to the LSC atmospheric circulation.

2.2. Intense Precipitation Events and Discriminating Power

[9] At this point, it is essential to introduce the concept of Discriminating Power (DP) [*Plaut et al.*, 2000] to assess whether a LSC pattern is clearly associated with an IPE. Given a weather regime, the DP measures the percentage of probability of finding IPE days close to its centroid. Here, DP is determined by the distance d_c between all daily Z500 maps in the data set and the center of a given regime. The distance d_c is defined as the correlation between the cluster center C_r and any day J, both preferably represented as vectors in the PC space:

$$d_c(r) = 1 - corr(C_r, J)$$

[10] Note that d_c ranks from 0 (perfect correlation) to 2 (completely uncorrelated) and $d_c > 1$ implies a negative correlation. The values of d_c can be organized into different categories and an histogram for the distance is created. For each of the categories in the histogram, we determine the probability of finding an IPE (that is, the ratio between the number of IPE and the total number of days belonging to the category). In the case that a cluster presents a high DP, the shape of the histogram would correspond to a decreasing function, indicating that the closest we are to the cluster center (lowest distance), the strongest is the probability of IPE occurrence.

[11] Figure 2 illustrates the concept of DP for the four standard weather regimes. The four regimes, except for Greenland Anticyclone, have a very low DP. In other words, IPE in western France are not associated with the preferred states of the atmosphere circulation. Thus the identification of LSC dynamics yielding IPE in western France must proceed differently.

2.3. Classification of Large-Scale Circulation Maps

[12] The methodology proposed here was previously introduced by *Plaut et al.* [2000]. It consists of a classification of only the LSC maps of Z500 corresponding to the IPE defined above. A total of 978 daily maps are selected and they are represented as vectors in the PCs space. The classification is then carried out, as for the standard weather regimes, by $k - means$. When classifying only the LCS maps corresponding to an IPE, to determine the optimal k, a new significance test slightly different to the $k - means$ red noise test is used. The value of the classifiability index is compared with the one calculated from a number of classifications of a set of maps selected randomly from the whole data set. Results show that only a repartition in one cluster exists, leading to one IPE cluster (IPEC hereafter) for the western France. The IPEC (Figure 3a) is characterized by a strong negative anomaly centered over the Great Britain and weak positive anomalies over Green-

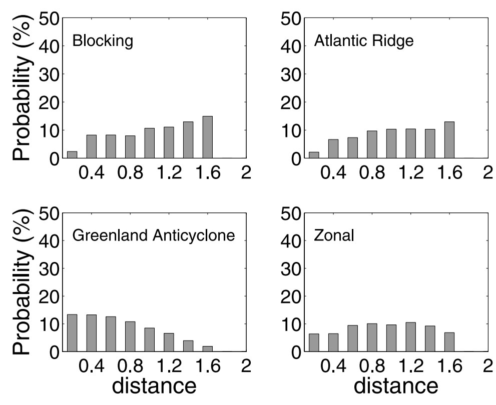

Figure 2. DP for the four standard weather regimes, indicating the percentage of probability of finding an IPE for each category of values of distance to the centroid.

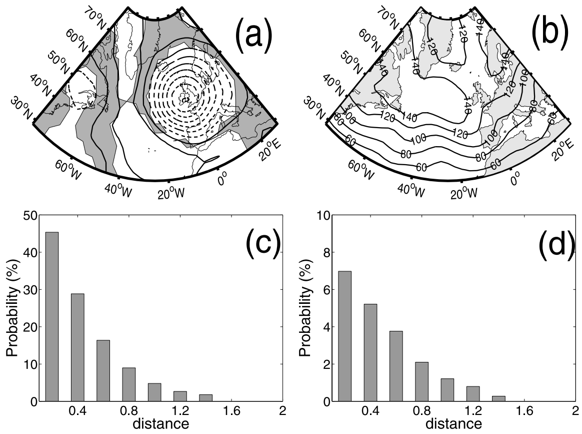

Figure 3. (a) IPEC obtained by the classification of daily maps corresponding to the IPE over western France. The isolines are the Z500 composite (solid lines are positives values and dot dashed are negative values). Contour interval is 20 gpm. Nonsignificant areas at 95% level are indicated by the shading. Statistical tests have been carried out following *Terray et al.* [2003] not for determining the optimal number of clusters but for testing the robustness of the composites. (b) Standard deviation of the Z500 composite. Units are in gpm. (c) DP of the IPEC. (d) Same as Figure 3c but for IPE defined with the 99.9% quantile.

land and in the center of the North Atlantic ocean. The strong negative anomaly brings maritime air masses directly into the French coast, favoring the risk of heavy rainfall. Low-frequency variability (Figure 3b) presents maxima over the Labrador Sea and south of Greenland. But, more importantly, the IPEC presents a high DP (Figure 3c). More than 45% of days with $d_c < 0.2$ turns out to be IPE. Moreover, the DP of IPE defined by increasing the threshold value to 99.9% quantile (Figure 3d) confirms this relationship.

[13] We conclude that if we are preferably interested in rare events, this method of classification of LSC maps provides an efficient and attractive approach (similar to a downscaling scheme) to determine the LSC structures related to climate extreme occurrence over a selected domain.

3. Weather Regimes Transitions

[14] It has been suggested that weather regimes are generated by the interaction between planetary-scale waves forced by topography and the day-to-day weather disturbances [*Reinhold*, 1987]. It is well known that these quasi-stable flow configurations may be responsible for climate extremes as droughts, heat waves, deep freezes and even excessive precipitation if they are sufficiently persistent. The quasi-equilibrium can be broken up by an atmospheric disturbance, inducing the onset and break of weather regimes. One may wonder what happens during the development or disappearance of a weather regime. We have observed that a nonnegligible percentage of IPE in western France (40%) can occur during a weather regime transition.

[15] Table 1 summarizes some properties of the 12 weather regimes transitions, as defined in the previous section. The frequency of transition is computed for each of the regimes, as the ratio between the number of cases observed for one transition and the total number of transitions found for this regime. We also find that, although the probability changes for each transition, the mean duration of the transition phase remains almost constant, between 2 and 3 days. Statistical significance of transitions are addressed by a Monte Carlo test consisting of randomly reordering the sequence of weather regimes episodes lasting at least 4 days [*Kondrashov et al.*, 2004].

Table 1. Relative Frequency of Occurrence (%) and Number of Days of a Weather Regime Transition[a]

	Probability %				Number of Days			
	BL	AR	GA	ZO	BL	AR	GA	ZO
BL	– –	26.2[b]	36.1[b]	37.7	– –	117	164	193
AR	21.5	– –	28.2	50.3[b]	98	– –	116	191
GA	32.7[b]	26.7[b]	– –	40.6[b]	131	102	– –	165
ZO	42.6[b]	37.8[b]	19.6[c]	– –	200	206	114	– –

[a]The sense of the transition goes from the left to the right.
[b]Significant probabilities at the upper 95% significance level.
[c]Significant probabilities at the lower 95% significance level.

[16] Considering IPE in western France, we have plotted the 12 composites of Z500 for each of the weather regime transitions and we have find that there is a striking resemblance between the IPEC and the Zonal-to-Greenland Anticyclone (ZOtoGA) composite and associated variability (Figure 4). Furthermore, the DP of this composite shows that almost 40% of days with $d_c < 0.2$ are IPE. During this transition, there is northwestward shift of the Azores High characteristic of the Zonal regime, together with an eastward displacement of the Icelandic Low. This spatial atmospheric configuration yields a zonal maritime flow into France. Table 1 shows that the ZO to GA transition is the least probable.

4. Conclusion and Discussion

[17] The objective of this work is to determine the LSC circulation patterns related to intense precipitation episodes

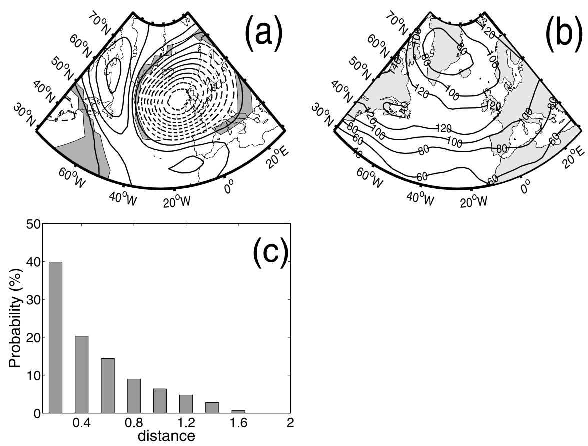

Figure 4. (a) Zonal to Greenland Anticyclone transition pattern. The isolines are the Z500 composite (solid lines are positives values and dot dashed are negative values). Contour interval is 20 gpm. Nonsignificant areas at 95% level are indicated by the shading. Statistical tests for the robustness of the composite have been carried out following *Terray et al.* [2003]. (b) Standard deviation of the Z500 composite. Units are in gpm. (c) DP of the ZotoGA transition pattern.

within a specific domain. We know that weather fluctuations over western France are mostly influenced by LSC atmospheric circulation rather than by topography or local atmospheric phenomena. This fact greatly simplifies the task of connecting the local precipitation to LSC dynamics. IPE are identified as any day when the 99% quantile exceedence is observed at least in one station in the domain. Daily precipitation measures are available from 1950 to 2003 at 82 meteorological stations from the SQR data set. In our study we have removed the warm season months, when the atmospheric circulation variance decreases. We argue that the standard weather regimes is not always the optimal approach to describe the LSC dynamics associated with local climate extreme events, as it has been shown in this case study applied to IPE in western France. An examination of the DP indicates that IPE situations are not particularly close to the centroids of the four weather regimes. When we apply the same clustering technique to the subset of Z500 daily maps corresponding to IPE, we obtain a LSC structure, which differs from the four standard weather regimes. This pattern shows a strong negative anomaly over the Great Britain and a weak positive anomaly over west of Greenland. Its DP indicates that more than 40% of the days which are the closest to the cluster center are IPE. Although the procedure used here can lead to several patterns [*Plaut et al.*, 2000], only one IPE cluster has been obtained, and the approach is then equivalent to composite analysis in our case.

[18] We have investigated the possible association between the weather regime transitions with IPE in western France. The links between weather regime transitions and climate extremes had not been documented previously. Results indicate that the IPEC strongly projects on atmospheric circulation corresponding to the break of the Zonal regime and the onset of the Greenland Anticyclone. This is an unlikely transition but it is not a rapid one as was argued in *Vautard* [1990]. One may question the robustness of results, since the identification of a transition is indeed subjective: in the sequence of days, a weather regime must have a duration of at least 4 days. To avoid the possible difficulties arising from this choice, we have repeated the same procedure by varying the size of the segment from 2 to 5 days, and computed the composites together with the DP for each experiment. For the composites, similar spatial structure is observed, only variations in the amplitude of anomalies have been detected. Concerning the DP, small and not significant changes are obtained.

[19] This study suggests that it may be worth looking at what happens during the onset and break of the weather regimes to describe the local extremes. This work enables to establish a starting point for a more complete and careful study on the role of the transitions between weather regimes. The development of a transition may be a process purely internal to the atmospheric dynamics and it has been suggested that they can also be connected to phase changes of intraseasonal atmospheric waves. The ZOtoGA transition can be interpreted as the shift of the North Atlantic Oscillation (NAO) phase [*Hurrell*, 1995], since the zonal regime corresponds to the positive phase of NAO and Greenland Anticyclone to the negative one. During this process the Icelandic Low moves southeastward and the Azores High migrates northwestward near west of Greenland.

[20] The identification of LSC patterns associated with climate extreme events can be applied to study the possible changes in the frequency and intensity of climate extremes induced by the anthropogenic radiative forcing. In the research of climate change scenarios built by the GCMs, it would seem more appropriate to study the evolution of the LSC and low frequency component of the atmosphere which can be viewed as precursors of climate events.

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