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*Short paper*

**Transit boosting of trans-Channel katabatic winds by depressions associated with west European storms tracks: impact on Pleistocene loess deposits.**

Running header: Katabatic wind and storms

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**Abstract:** Onshore and offshore sedimentological, geochemical, geomorphological, paleontological and geochronological studies of loess deposits located under and around the English Channel revealed that they were transported by katabatic winds generated by the British-Irish Ice Sheet. Katabatic winds, which are low-altitude wind flows, were able to jump over the low southern British hills but were stopped by the higher Brittany and Normandy hills. This regional topography is interrupted by a north-south corridor linking the northern and southern shores of Brittany where loess propagated down to the mouth of Loire River. This long transit shows that the total distance travelled by the katabatic wind was around 750 kilometres, which represents an unusual distance for the propagation of this wind under continental conditions. Strong

similarities with Antarctica and Greenland, where well documented cases of katabatic winds are known, show that the transit of the trans-Channel katabatic winds were strongly enhanced by the seasonal drift of storms propagating in an eastward direction along the axis of the English Channel. This increasing strength of the North-South katabatic flux was probably at the origin of the transport of loess particles down to the mouth of Loire River.

Keywords: Westernmost Europe, British-Irish Ice Sheet, katabatic wind, Channel storms track, loess transfer.

## **Introduction**

There are currently three major solutions to explain the collection, transfer and deposit of the loess particles during the Upper Pleistocene around the English Channel. All three models involve different modes of transport by the wind.

- The first one, based on the “General circulation Model” involves the long-standing eastward atmospheric circulation above Western Europe (Rousseau et al. 2007; Sima et al., 2009; Rousseau et al. 2011) and use numerical modelling to investigate the relationship between the North-Atlantic abrupt climate changes and the environmental variations revealed by loess profiles. Unfortunately, this model does not incorporate the most recent onshore or offshore data from Brittany.

- The second one or “Storm Model” suggests that the transport of loess particles was associated with an eastward drift of periodic storms passing above the Western English Channel (Antoine et al., 2009). It partly used some onshore data (Lautridou, 1970; 1985; Antoine et al., 2003) but does not explain why the transfer of the particles transported by the anticlockwise vortex generated by the

low-pressure centre was effective in the north-south direction but not in the south-north direction.

Neither of these two models takes into account of the close proximity of the British-Irish Ice Sheet.

- Differing from these two models, the “katabatic Model” (Lefort et al., 2011; 2019) is based on field evidences alone and considers, for the first time, the past wind field not just in two dimensions (2D) but also in three (3D). This model incorporates different onshore and offshore studies such as: 1/the contribution of topography, 2/the rare earth elements, 3/ the loess fauna, 4/ the orientation of loess cliffs, 5/ the contribution of Icelandic basalts, 6/ the orientation of Neanderthals dwelling, 7/ the granulometry of loess, 8/ the distribution of heavy and flaky minerals and 9/ the thickness of the initial wind field; it is probably very close to the past reality.

However, the problem of the distance of propagation of the katabatic winds remains to be discussed to firmly establish this model; this is the main purpose of this paper.

Before discussing the problems of interference between the katabatic winds and the depression centres, it is necessary to summarize a certain number of results obtained at a regional scale for clarity.

### **Palaeometeorological backgrounds**

#### *The katabatic winds in the peri-Channel context*

Katabatic winds, which are also known as “gravity” or “down slope” winds, originate over a glacier or an ice sheet. In Antarctica (Parish and Cassano, 2003), wind speeds above 10 m/s are commonly recorded; they result from the drainage of the chilled air seaward from the interior ice cap (Rubin and Weyant, 1965). Two parameters are of particular interest and need to be commented in greater detail.

- All the available data collected in Brittany and Normandy indicate a British or Channel origin for the winds blowing from the North and Northwest (Lautridou, 1970; 1985; Antoine et al., 2003; Lefort et al. 2019; Lefort et al., 2021) (Figure 1). It is certain that the wind directions based on the heavy minerals are not very accurate since the sources of these particles are often spread over a large longitudinal distance. By contrast, the orientation of the cliffs which collected the aeolian dust provides (Lefort et al., 2019) more accurate wind directions since the south, west and east facing cliffs are generally free of important loess thicknesses (Lefort et al. 2021). The more useful criterion for the determination of the wind direction is certainly that of granulometric study (Bigot, 1986). The general direction given by the drift of the Icelandic ice-rafts is also useful but a little bit more speculative (Lefort, 2016).

#### Figure 1

- The vertical thickness of a katabatic flow over a moderate slope is usually limited between 200 to 220 metres and the maximum velocity concentrates at about 25 m above the ice sheet (Renfrew, 2004). In Brittany, the difference in altitude between the upper and lower limits of the initial loess deposits recorded offshore and onshore is always slightly lower or close to these thicknesses (Lefort et al., 2019) (see the discussion showing that loess erosion was very limited in this paper) and demonstrates that loess of northern Brittany was transported by low and not by high altitude winds. Another consequence of the limited thickness of the “heavy” katabatic flow is that such winds were not able to override high grounds higher than 220 metres. This is in accordance with the observation that there is no loess south of the two hilly areas of

Brittany (mean altitude 240 m) and Normandy hills (mean altitude 254 m). Furthermore, between these two hilly areas an onshore corridor oriented in a North-South direction (Figure 2) is linking the English Channel to the Bay of Biscay. Because the altitudes within this corridor are always less than 150 m, katabatic winds were able to propagate southwards down to the mouth of the Loire River. In the south of England (except in the SW Peninsula), katabatic winds were able to override the southern English Hills characterized by an approximate difference of less than hundred metres respect with the outwash plain. Because the strength of the katabatic winds was decreasing in a southward direction, loess was deposited on the lee side of the hills in southern England and on the windward side in northern Brittany (Lefort et al., 2021).

#### *Previous discussions on the distances reached by katabatic winds*

- Onshore, it is often considered that the propagation of katabatic winds is very limited. Long distance transport of dust particles by katabatic winds was first proposed for the Ukraine (Tutkovsky, 1910) in an area located at 400 kilometres from the Fennoscandian Ice sheet, but this assumption has been challenged. In Alaska, located close to an ice sheet but in a mountainous area, loess has been transported over a distance of 80 kilometres (Thorson and Bender, 1985). The assumption that katabatic winds may not travel over long distances and are limited to a displacement of 20 to 100 kilometers (Adolph and Wendler, 1995) is often accepted but is contradicted by satellite observations (Bromwich et al., 1992) since NASA infrared satellite photos demonstrate that katabatic winds may propagate over distances of more than 1000 km above the sea, during 14% of the time.

- If we incorporate the results of the different studies dedicated to the heavy and flaky minerals in England and Brittany (Lefort et al., 2019) we can estimate that the maximum distance reached by the katabatic winds is close to 750 km, which is in the range of the distances observed by Bromwich et al., (1992). However, the distance reached by the katabatic winds above the sea cannot be fully compared with the distance of propagation measured between the top of the English-Irish ice sheet (Boulton and Hagdorn, 2006) and the mouth of the Loire river where a very limited migration of augite (the southernmost heavy mineral marker) can be still observed (Lefort et al., 2019; 2021), since the north-south corridor funnelling the katabatic winds is not completely flat like the sea but affected by small topographic rugosities (Figure 2).

## Figure 2

### *Effects of low pressure centres on katabatic winds.*

- The classical descriptions of the genesis of katabatic winds always insist on the opposition between two different meteorological environments. On top of the ice sheet, the air is cold, dense and dry; by contrast above the sea (where all the katabatic winds finish in the Antarctic) the air is warmer, less dense and more humid. These differences are at the origin of two different air pressures. This pressure gradient shows that the difference in altitude between the top of the ice sheet and the sea level is not the only parameter responsible for the down-slope katabatic flow.

- Thorson and Bender (1985) also noted that the approach of a low-pressure centre towards a glacial plateau accelerates the velocity of the katabatic winds and generates particularly strong and gusty



winds. The relationships between these two types of meteorological phenomena have been recently studied in greater detail in Greenland and Antarctica. In Southeast Greenland, the results of a three-dimensional model associated with a realistic case depict the basic mechanisms for the interaction between katabatic winds and an offshore cyclone. This study also suggests a close relationship between the occurrence of katabatic winds and the generation of mesoscale vortices (Klein and Heinemann, 2002). In Antarctica, the strong winds are a feature of the extended winter season and involve a complex interaction between the downslope buoyancy forcing and the pressure gradient force of cyclones. Around the coast of East Antarctica a significant majority of strong winds are associated with the enhancement of the downslope katabatic flow by the broad-scale circulation, involving a deepening of pressure off the coast and an increase of pressure inland. Comparison with high-resolution numerical simulations shows that the wind field analysis is able to capture the large-scale meteorological features and the associated enhancement of the katabatic flow but also underestimates the observed wind speed if it is strongly influenced by local topographical conditions (Turner et al. 2009). This study is in agreement with observations made by Parish and Cassano (2003) and was confirmed by Wenta and Cassano, (2020).

## **Discussion**

- There are so many similarities with the series of data collected in and around the English Channel that an application of this mechanism to Westernmost Europe during the Upper Pleistocene is more than likely. As shown for the Upper Saalian glacial episode, some of the loess particles were transported by north–south

katabatic flows coming from the British- Irish ice sheet at a time where there was still a remnant left of the English Channel Sea (Lefort et al, 2019). Furthermore, as in Antarctica, low-pressure centres sometimes approached and even crosscut the katabatic flow. In Western Europe the migration of low-pressure centres is well documented and described in marine forecast studies (Mayençon, 1989; Bernot, 2020). Now and probably also during the Upper Pleistocene the low pressure centres followed more or less (Figure 3) the axis of the Western English Channel. In terms of meteorology this axis is called « the West European Storms track » (Antoine et al., 2009).

### Figure 3

- Katabatic winds only developed during the different glacial episodes but the Upper Saalian and Weichselian are the best-documented episodes. Their duration is very variable since they may not blow just for a few hours but can also last a few months (a duration of 203 days has been recorded in Antarctica) with a maximum velocity of 327 km/h. Outside the occurrence of the katabatic winds, regular storms occur about 8 times a year at our latitude and can statistically last during one week but these values can change a lot from one area to another. Under these conditions it is very difficult to know when these two meteorological phenomena were interfering with each other. It is only clear that they were both more active during the winter, even if it is impossible to detect any regular cycle.

- The excellent correspondence between the variations of the aeolian deposits observed in the site of Nussloch (Rhine Valley, Germany) (Antoine et al., 2009) and the atmospheric circulation over

the North Atlantic (Rousseau et al., 2007) suggests a possible link between the sedimentation rate and the change in strength of the wind. This correlation is difficult to observe in Southern England (Catt, 1978; Barrie, 1980; Catt and Staines, 1982; Parks and Rendell, 1992) Brittany (Lefort et al. 2019) and Normandy (Lautridou, 1985), first because this kind of detail cannot be deciphered in the much thinner westernmost European stratigraphic sections but also because many of these sections are relatively close to the limits of the British-Irish Ice Sheet. Because of this proximity an increasing strength of the wind flow was more likely responsible for a stratigraphic gap than for a change in granulometry as in Germany.

- Epidotes, amphiboles, tourmalines and andalusites which are ubiquitous minerals do not allow to comment on the amount of their transit. On the contrary, augites, olivines, anatases and garnets that are unusual or very rare in the study area can be used as mineralogical markers when it is possible to locate their source. Study of these heavy minerals and of the flaky particles show a clear distinction between their transit distances: it is of 150 km for the silt minerals, 110 km for anatases, 90 km for garnets and 6 km for augites between the southern limit of the British-Irish Ice Sheet and the Mouth of the Loire River (Lefort et al. 2019). This result has been interpreted as a decreasing competency of the katabatic winds toward the south (Lefort et al. 2019). However, when looking at the details of these transfers it is possible to show that there was no mixing of the mineral markers during the katabatic transfer. Taken as a whole, it seems that there existed a succession of deflation zones (such as the British glacial outwash plain (1 figure 1), the Western English Channel (2 Figure 1) or Central Brittany (3 figure 1) alternating with areas of small uplands (such as the British hills (4 figure 1), the Armorican and Normandy hills (5 Figure 1) or the

“Sillon de Bretagne” (6 Figure 1). These behaved like loess collectors or slowed down the wind flow. This process is very similar in its principle to the gold prospectors sluice boxes that were used during the gold rush times.

- During the southward transfer of the loess particles in the north-south corridor cutting across Brittany, the Vilaine gorges (G Figure 2) located south of the Rennes Basin (R Figure 2), acted like a venturi structure. This impressive narrowing of the Vilaine river, bounded on both sides by steep to vertical cliffs reaching 50 to 60 meters (and even 80 to 100 metres with respect to the local plateau) reinforced the velocity of the katabatic winds. The result of this local acceleration is that no loess was deposited in Central Brittany (C Figure 2). Loess was only able to be deposited (D Figure 2) south of a little morphological step called the “Sillon de Bretagne” (S, Figure 2).

- If we take account of the approximate position of the low pressure centres when they were drifting along the storms track of the Channel (Figure 3) we can speculate that loess sediments deposited between the southern rim of the British-Irish Ice Sheet and Northern Brittany were ruled by the activity of the katabatic winds alone and that the extension of the sedimentation between the Rennes Basin and southern Brittany resulted from the deepening of the low pressure centre when the eastward drifting storms were crossing the katabatic flow.

- Even if these data are not directly connected to Quaternary geology, it is intriguing to learn that at present birds migrating between Northern and Southern Europe are using exactly the same route as the Upper Pleistocene katabatic flow recognized between England and the mouth of Loire River; this may be an atavism that has lasted since the Pleistocene.

## Conclusions

- The easy transit of the katabatic flow recognized between the top of the British-Irish ice sheet and the mouth of Loire River (Figure 1) is well explained by the orientation of the corridor linking the northern and southern shores of Brittany (Figure 2) since it shows an almost perfect continuity with the katabatic winds blowing from England.
- Because the polar front was moving toward during the glacial episodes, the location of the storms track shown on figure 3 was not always exactly located at the same place, but the principle of a deepening of the katabatic low-pressure centre by the depression associated with the east drifting storms stays the same.
- Many authors working in Greenland and in Antarctic have insisted on the importance of topography to understand the different mechanisms associated with katabatic winds and, significantly, the presence of valleys. The onshore topography of Brittany illustrates this conclusion.
- Comparison between the limited transit of the different heavy minerals transported with loess and the long distance of propagation of the katabatic winds between England and southern Brittany shows that loess sediment was not transported as an undifferentiated sedimentary mass showing everywhere the same mineral composition but rather like the concatenation of a series of successive deflation-accumulation ensembles since the heavy minerals taken as markers are never mixed...

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## Captions

Figure 1. Contours of the British Ice sheet and simplified distribution of loess deposits recognized in England, Brittany, and Normandy and under the English Channel during the Late Pleistocene (around MIS 6). The directions of katabatic winds are shown. Onshore loess deposits and offshore conglomerates (which correspond to remnants of the offshore loess deposits) are shown with the same pattern. B: Brittany; CO: Cotentin; CS: Celtic Sea; EA: East Anglia; EC: English Channel; G: Guernsey; IS: Irish Sea; J: Jersey; LR: Loire River; N: Normandy; NS: North Sea; P: Picardie; SR: Seine River; V: Vendée; Red numbers 1 to 3 correspond with deflation zones and 4 to 6 to

loess deposits. The British-Irish outwash plain corresponded to the deflation zone number 1. The contours of the LGM British-Irish Ice sheet are taken from Emery (2020), slightly modified.

Figure 2. Distribution of the loess outcrops in Brittany and Normandy. Dash lines: Limits of the corridor funnelling the loess particles down to the mouth of Loire River. Black: loess deposits; Grey: Brittany, Vendée and Normandy hills. C: no loess deposits; D: mouth of Loire River loess deposits; G: Vilaine Gorges; R: Rennes Basin; S: Sillon de Bretagne. Arrows are katabatic wind. Note the absence of loess south of the Brittany and Normandy hills.

Figure 3. Interference between the katabatic wind coming from the British-Irish Ice Sheet (yellow arrows) and a storm drifting along the West European storms track. L: Low-pressure centre associated with a storm; H: high-pressure centre associated with the British-Irish Ice Sheet.

Figure 1

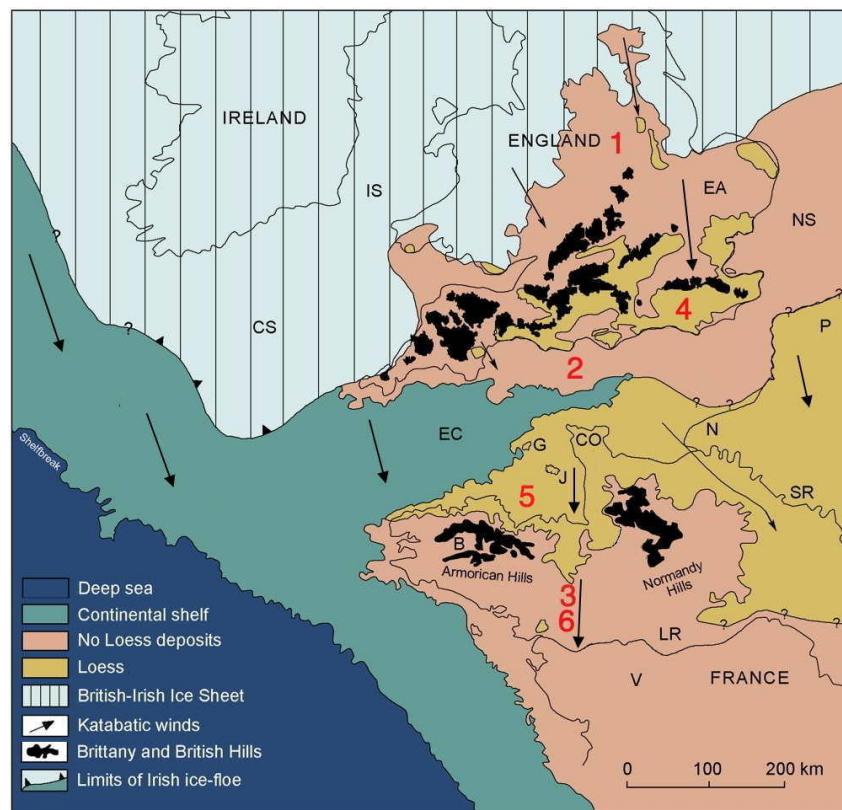


Figure 2

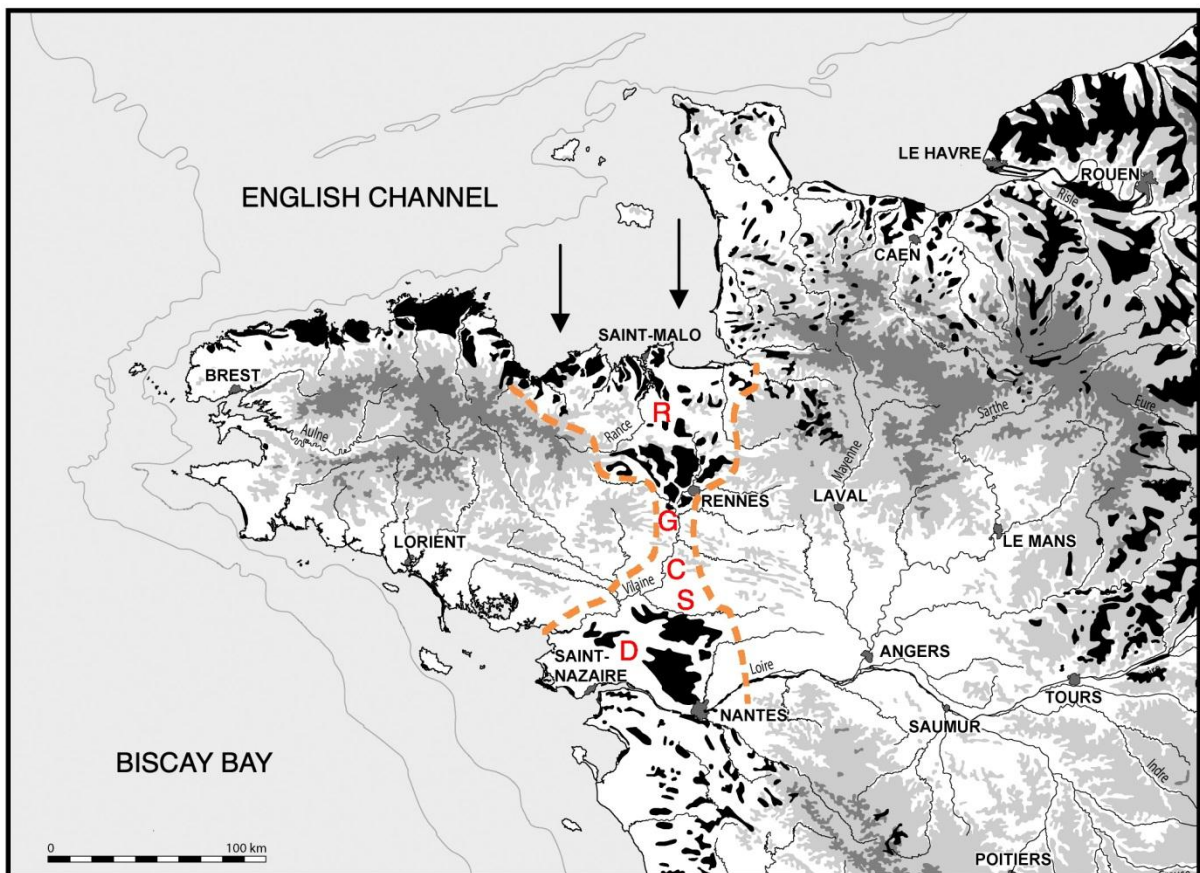


Figure 3

