STATISTICAL DOWNSCALING OF NEAR-SURFACE WIND FIELD OVER COMPLEX TERRAIN IN SOUTHERN FRANCE

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Abstract: Our study aims at inferring the small-scale near-surface wind in southern France from the synoptic atmospheric circulation over northern Atlantic and Europe.

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1. INTRODUCTION

The Mediterranean region features a near closed sea surrounded by very urbanized littorals and mountains from which numerous rivers originate. This results in a lot of interactions and feedbacks between oceanic-atmospheric-hydrological processes which frequently cause extreme events (heavy precipitation and flash-flooding, strong winds and large swell, droughts) that produce heavy damages and human losses. The ability to predict such dramatic events remains weak because of the contribution of very fine-scale processes and their non-linear interactions with the larger scale processes.

In this context, trends in near-surface wind speeds are acknowledged as having particular importance for climate change impacts on society (e.g., the insurance industry, coastal erosion, forest and infrastructure damage, storm surges, and air-sea exchange). They also have relevance for applications such as pollutant diffusion evaluation, wind energy resource estimation and construction issues. Surface wind speeds however exhibit variability at much smaller spatial scales than that resolved by general circulation models (GCM) and hence there is a need to develop tools for downscaling GCM projections to generate finer scale projections of near-surface wind climatologies.

In the present study, the region of interest focuses on the northwestern Mediterranean basin in southern France which is a region with complex coast shapes and high orography (the Alps, the Massif Central and the Pyrénées culminating at 4807 m, 1885 m and 3298 m, respectively; see Fig. 1). The major fine-scale

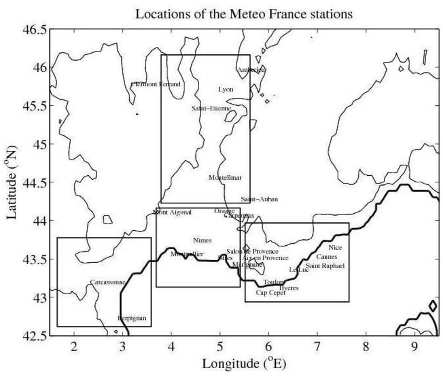

Figure 1: Map of southern France with the locations of the operational meteorological surface stations of Météo-France used in this study. The rectangles delimit 4 regions in southern France (southwest region or region 1, Rhône valley delta region or region 3, Rhône valley region or region 2 and southeast region or region 4).

wind regimes are thus largely due to this complex coastal environment and are dominated by: (1) the Mistral and its companion wind, the Tramontane which are frequent (5 to 15 days per month all year long) severe northerly/northwesterly winds that develop along the Rhône and Aude valleys (Fig. 1) and are preconditioned by cyclogenesis over the Gulf of Genoa and the passage of a trough through France (these wind storms can cause severe damage to farm plantations, hazardous conditions for aeronautics and ship, increase forest fire risks in the region and are one of the primary causes of storms over the Mediterranean; e.g. Drobinski et al., 2005); (2) the breezes during summer (the sea/land-breeze impacts on air quality in the region; see Drobinski et al., 2007 for a review); and (3) the onshore winds during fall season (causing frequent intense precipitations and flash-flooding in the Cévenes region; e.g. Ducrocq et al., 2002).

If during summer, the Mediterranean climate system is relatively isolated, during other periods teleconnections are more important (e.g. Dünkeloh and Jacobeit, 2003). The aim of the present study is thus to identify during winter, the possible relation between the dominant fine-scale patterns of near-surface winds with large-scale weather regimes characterizing the typical large-scale atmospheric circulation in the northern and meridional European area.

2. WEATHER REGIMES TO LOCAL CIRCULATIONS

Large-scale atmospheric circulations during winter (from November to March) are classified into four weather regimes following commonly used techniques consisting in clustering the 500-hPa geopotential heights from the ERA-40 reanalyses (horizontal resolution 1°) (e.g. Cheng and Wallace, 1991; Plaut and Simonnet, 2001). The choice of 500 hPa is to be far enough from the surface influence, since our domain contains heights culminating until 4000 m. The weather regimes are: Blocking (BL) with a north flux over central and southern France and a depression on the west of Groenland (regime 1); Atlantic Ridge (AR) with a north-west flux over France and the depression over Groenland is more to the north (regime 2); Greenland Anticyclone (GA) with a west flux over France (regime 3); Zonal (ZO) with a west to north-west flux and the Groenland depression is more to the south-est (regime 4).

At fine scale, the 10 m wind data available from the Météo-France surface stations for the last three decades are used to derive the fine-scale patterns of the near-surface winds. Figure 1 displays the locations of the meteorological surface stations in southern France. Figure 2 shows the probability of occurrence as a function of the weather regime of wind speed versus wind direction at the station of Lyon, located at the Rhône valley entrance. It shows a large occurrence of strong northwesterly winds for regimes 1 and 2 (maximum around

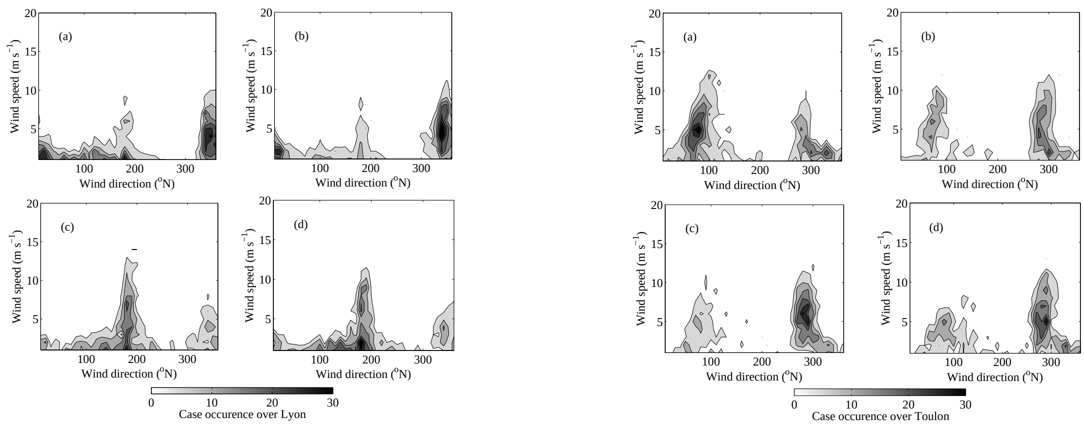

Figure 2: Lyon Toulon
Probability of occurrence as a function of the weather regime of wind speed versus wind direction at the station of Lyon (left figure) and Toulon (right figure). Panels a, b, c and d correspond to regimes 1, 2, 3 and 4, respectively.

10 m s^{-1} and a mean around 4.4 m s^{-1}), and strong southwesterly winds for regimes 3 and 4 (maximum around 12 m s^{-1} and a mean around 5.5 m s^{-1}). For all regimes we however have bimodal distributions for the strong winds peaking around the south (between 160° and 230°) and north (between 310° and 40°) directions. This allows to conclude that there is no bi-univocal relationship between the large-scale weather regimes and the local circulations. Local circulations are mainly controlled by the orography since the main wind directions are north and south which corresponds to the valley axis direction in the area of Lyon (see Drobinski et al., 2003 in the Rhine valley). These occurrence of northerly and southerly winds represents 87 % of the total wind

observations at Lyon. Similar bimodal distributions are found at all the meteorological surface stations (see wind data at Toulon in Fig. 2).

3. CLUSTERING OF NEAR SURFACE WINDS

To derive near-surface wind clusters, the probability of occurrence of wind speed versus wind direction at all stations, conditioned to the wind direction at Lyon (northerly or southerly wind) are computed (not shown). It is found that most stations in the Rhône valley (regions 1, 2 and 3) are correlated with each other so the near-surface wind at Lyon can be related to the near-surface wind at the other stations (in other words, the wind statistics become unimodal when the southerly or northerly wind sector is chosen at the station of Lyon). Conversely, the wind statistics derived at the stations located to the east of Marseille (from Toulon to Nice in region 4) remain bimodal. At Toulon, the bimodal distributions for the strong winds peak around the east (between 40° and 180°) and west (between 250° and 340°) directions. Finally, it is found that the near-surface wind pattern in southern France can be predicted in about 80 % of the cases by the surface wind measurements at Lyon and Toulon (or stations in the vicinity of Toulon). So four clusters representing about 80 % of all wintertime situations can be derived and are displayed in Fig. 3 which shows the fine-scale pattern of the mean wind for the following four clusters: northerly wind and easterly wind at Lyon and Toulon, respectively (cluster 1); northerly wind and westerly wind at Lyon and Toulon, respectively (cluster 2); southerly wind and easterly wind at Lyon and Toulon, respectively (cluster 3); and southerly wind and westerly wind at Lyon and Toulon, respectively (cluster 4).

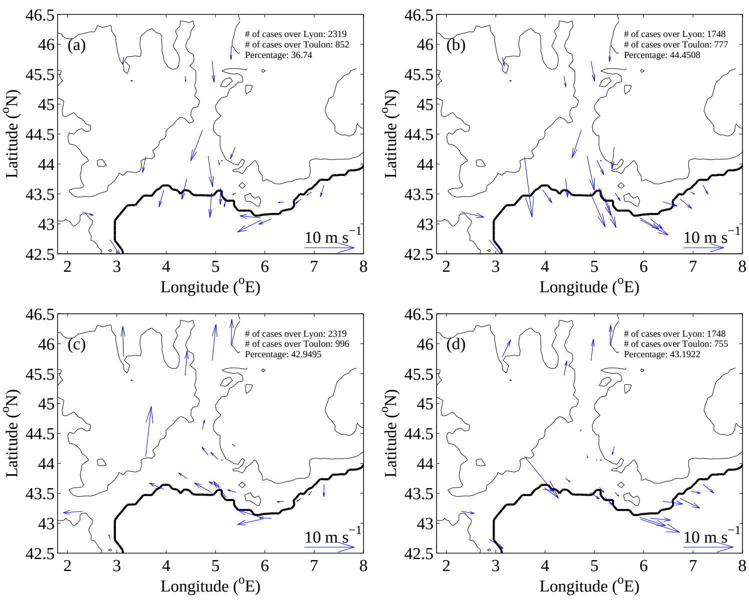

Figure 3: Mean winds for northerly wind and easterly wind at Lyon and Toulon, respectively (cluster 1) (a); northerly wind and westerly wind at Lyon and Toulon, respectively (cluster 2) (b); southerly wind and easterly wind at Lyon and Toulon, respectively (cluster 3) (c); and southerly wind and westerly wind at Lyon and Toulon, respectively (cluster 4) (d).

For each of the near-surface wind clusters, the average 500-hPa geopotential height and mean sea level pressure are displayed in Fig. 4. It shows that clusters 1 and 2 are linked to large-scale circulations very similar to the BL and AR weather regimes, respectively. This is not very surprising since Fig. 2 shows that the occurrence of southerly wind in Lyon for these two weather regimes is very low compared to the occurrence of northerly wind. The relation between clusters 3 and 4 (i.e. southerly winds blowing at Lyon) with GA and ZO weather regimes is less neat and in agreement with the fact that the occurrence of northerly winds at Lyon for the GA and ZO weather regimes is not negligible.

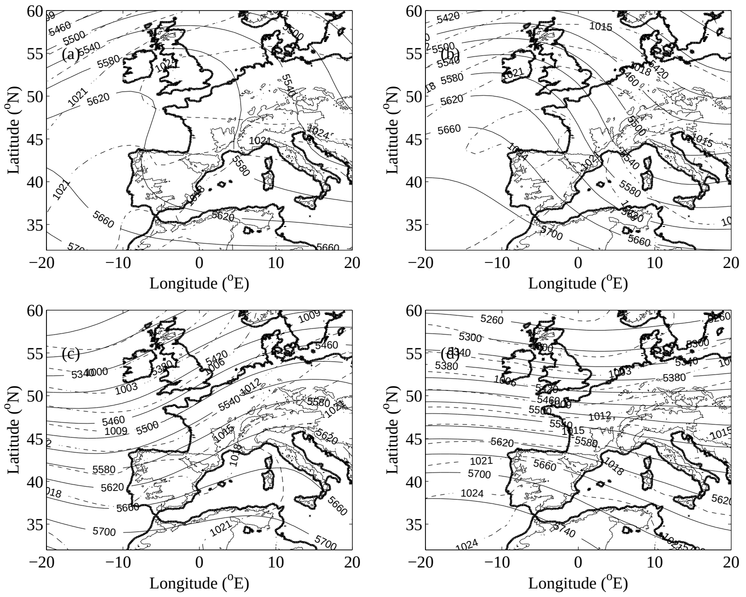

Figure 4: Mean geopotential height at 500 hPa and mean sea level pressure corresponding to cluster 1 (a), 2 (b), 3 (c) and 4 (d).

4. RELEVANT LARGE SCALE PREDICTOR OF NEAR SURFACE WINDS

The near-surface wind pattern can thus be predicted from the wind observations at Lyon and Toulon. There is thus a need to have more relevant predictors than the weather regimes only. The near-surface wind field in regions 1, 2 and 3 in the Rhône is predominantly govern by the presence of the Rhône valley. Overland (1984) shows that the along-valley wind can be predicted by the along-valley pressure gradient (in steady conditions and for sufficiently strong winds). In the present case, the mean-sea level pressure difference between the entrance and exit of the Rhône valley proved to be an excellent predictor for both the wind speed (magnitude of the pressure difference) and direction (sign of the pressure difference) at Lyon regions 1, 2 and 3 (not shown). Another relevant predictor must be found for the wind blowing in region 4 (the pressure difference along upstream and downstream of the Rhône valley does not apply).

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