Tethys
Journal of Mediterranean Meteorology & Climatology

Tethys 2011, **8**, 21–30
www.tethys.cat
ISSN-1697-1523
eISSN-1139-3394
DOI:10.3369/tethys.2011.8.03
Journal edited by **ACAM**

Thermodynamic characteristics of air masses along the Guadalquivir valley determined through the calculation of trajectories

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Received: 1-VI-2010 – Accepted: 2-II-2011 – **Translated version**

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Abstract

The Guadalquivir valley favors the channeling of air masses from coastal areas to inland Andalusia. This paper presents a first approximation of the spatial variation along the Guadalquivir valley in some of the representative thermodynamic properties of air masses. We have selected three representative sites of its lower, middle and high course, analyzing all of them on their daily trajectories and hourly records of potential temperature, specific humidity and wind speed during the period 2000-2007. The set of trajectories has been calculated using the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory), establishing 12 UTC as the arrival time, a duration of 120 hours and a final height of incidence of 500 m. The cluster analysis has allowed the selection of ten different types of air masses, and those with a clear origin from the west were selected from this group. Analysis in the three sites of the daily cycles of potential temperature show a gradual cooling (3-4 K) during the cold period (November-February) of the year and warming during the warm period (June-September) in the range of 5-6 K between the ends of the valley. The specific humidity experiences a drop, regardless of the period and type of air mass, as the air mass travels through the valley, being more intense during the warm period with up to 8 g kg^{-1} instead of the 1-2 g kg^{-1} in the cold period. The wind speed cycles show a progressive drop of intensity along the valley, more marked in the final section with a reduction of up to 3 m s^{-1} per 100 km, the more intense values being recorded during the warm period of the year with average values of up to 4 m s^{-1}.

Key words: Guadalquivir valley, air masses, HYSPLIT, daily cycles

1 Introduction

The thermodynamic properties of air masses are not constant in their movement but they can be modified depending on the characteristics of the zones where they pass through, whether these are inland or maritime zones. This temporal and spatial variation of their thermodynamic properties affects the substance found inside them, either gases or particles (Millán et al., 1997; Evtyugina et al., 2006).

Several studies, such as Hernández-Ceballos et al. (2010a) and Toledano et al. (2009), have allowed identifying and characterizing the arrival of air masses over western Andalusia, in the southwest of the Iberian Peninsula. This area is characterized by the presence of the Guadalquivir valley, which acts as a natural channel for the transport of air masses from the Atlantic coast to inland. In addition, the presence of atmospheric emission sources, both natural (Doñana National Park, Seville north range, Pedroches valley) and anthropogenic (industrial area of Huelva, the cities of Seville and Cordoba), must be highlighted, which together with the channeling effect of the valley make it possible for these substances to be transported from their emission sources to inland areas.

In recent years several studies have been performed in order to establish the characteristics of the air pollution processes, both by surface ozone (Adame et al., 2008; 2010) and particle material (Rodríguez et al., 2001; Querol et al., 2002), that occur in the area.

Given the importance that meteorological conditions have on the processes of formation, transport, transformation and disposal of gases or particle material, the objective of this work has been focused on identifying synoptic scenarios that show meteorological situations favorable to the occurrence of channeling and movement of air masses along the Guadalquivir valley. The selected cases have allowed to study the daily cicles of wind speed, potential temperature and specific humidity at three representative sites, in order to get an approximation of the spatial variation of these variables along the valley.

2 Study area, measurement sites and methodology used

The Guadalquivir valley, the main topographical feature of western Andalusia (Figure 1), has a triangular shape oriented SW-NE, limited by Sierra Morena to the north and by the south Baetic system to the south, which acts as the transverse axis of the region.

Three sites along the Guadalquivir valley have been selected in order to have i) a good spatial coverage of the valley, ii) a representation of the three areas in which it is divided (low, middle and high) and iii) surface meteorological information available. The Atmospheric Sounding Station "El Arenosillo" (37.1°N -6.7°W, 40 meters above sea level (masl) has been selected as coastal point. The city of Cordoba (37.84°N -4.85°W, 91 masl), located 200 km from the coast, has been selected as representative of its middle area, and as representative of the high area, the town of Santa Elena (Jaén) (38.37°N -3.51°W, 750 masl), at about 330 km from the coastline. In each of them, meteorological information is provided every 10 minutes by automated stations belonging to the Spanish Meteorological Agency (AEMET).

Each of the sites has a wind rose along the axis west/southwest-northeast (Figure 1), which is representative of the flow dynamics of the valley (southwest-northeast axis), thus ensuring its location in it. During the cold period (November-February), the northeast flows with moderate intensity of less than 5 m s^{-1} predominate. In the months considered warm (June-September), the predominant flows are those from the southwest with an intensity that do not exceed 7 m s^{-1}.

The data of wind speed, humidity, temperature and pressure during the period 2000-2007 have been used for each of the sites. This period has been selected because there is a high availability of hourly data simultaneously in the three selected sites. The comparison of annual values of temperature in this period with the annual climate records provided by the AEMET for the period 1971-2000 at the stations of Huelva (18.1°C) and Cordoba (17.6°C) makes it possible to classify the study period as warm regarding that climatic period.

The choice of wind speed is justified as it is a parameter that helps to estimate the dispersive and ventilation capacity of the atmosphere, while the potential temperature is a conservative magnitude for ascents and descents. Finally specific humidity is also a conservative magnitude that represents the absolute amount of humidity in the atmosphere.

The model "Hybrid Single Particle Lagrangian Integrated Trajectory" (HYSPLIT) (Draxler and Hess, 1998; Draxler et al., 2009), developed by NOAA's Air Resources Laboratory (ARL), is widely used for the calculation of trajectories (Jorba et al., 2004; Shan et al., 2009; Hondura et al., 2010; Davis et al., 2010; Hernández-Ceballos et al., 2010b). The meteorological files FNL (Final Analysis) and GDAS (Global Data Analysis System), which have precise information on the evolution of the vertical wind component, have been used as input information. For this reason, kinematic trajectories (3D) have been calculated, as they show higher precision than the other calculation options allowed by the model (isobaric, isentropic ...) when this information is available for their calculation (Stohl, 1998).

The calculation of a daily trajectory at 12 UTC was considered appropriate because the study of the daily variability of air masses along the valley is not the aim of this work. The final height of 500 m has been selected so that the height of incidence is within the atmospheric boundary layer (ABL) (Warneke, 1997), and it was also used as a reference in Toledano et al. (2009) for the analysis of aerosols over El Arenosillo. Finally, the previous 120-hour course was selected because it will reveal the movement of air masses with a synoptic origin.

In order to extract information from a wide range of individual trajectories, it is common to apply statistical techniques that allow the grouping of these similar trajectories in different groups, called clusters. Thus, each cluster is formed by trajectories that have a similar course, with the centroid or cluster center representing the average of all trajectories included in that cluster.

The HYSPLIT model has a clustering tool based on the variations of both the total variance among the cluster (TSV, Total Spatial Variance) and the variance among each of the elements that compose them (SPVAR, Spatial Variance) (Draxler et al., 2009). The first index provides information on the degree of similarity (dissimilarity) among the different groups or clusters that are formed, while the second indicates the internal level of resemblance (difference) among the elements that make up each of the groups formed.

The clustering process starts with an initial number of individual trajectories and ends with the creation of a single cluster that groups all of them, joining in each stage those two elements that cause the minimum increase in the TSV and SPVAR indexes. This percentage variation will be increased as the number of clusters is reduced, since the groups have to be increasingly less similar among them.

The HYSPLIT model provides information on the percentage change experienced by the TSV index at each stage of the process compared with the previous one; this variation is used in the definition of the optimal cluster number (Stunder, 1996), which is one that represents the number of circulation patterns that best summarize the existing variabil-

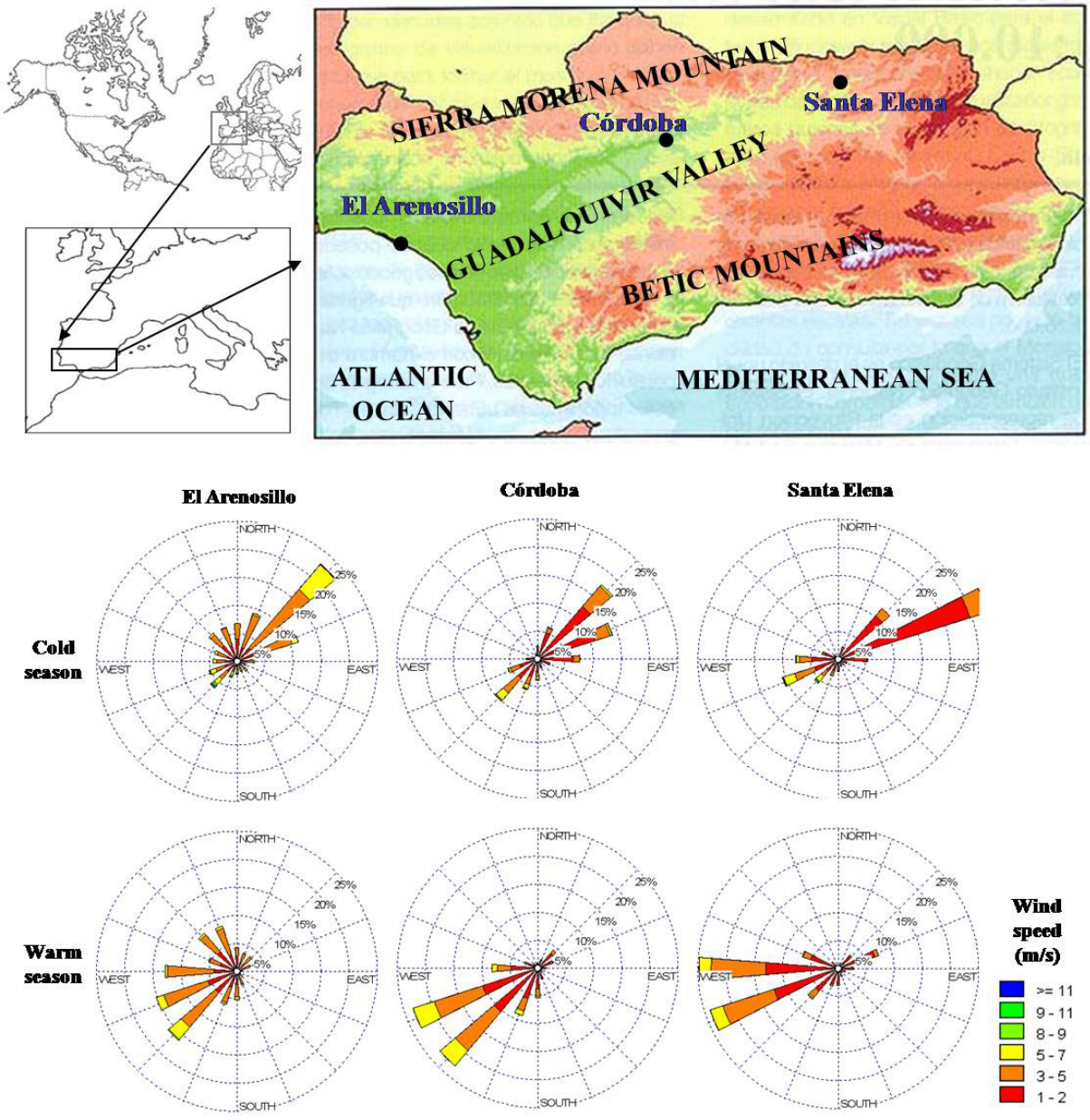

Figure 1. Main topographic elements of the study area and location of the selected meteorological stations. Wind roses in each of the selected sites corresponding to the cold period (November-February) and warm period (June-September) calculated during the period 2000-2007.

ity within an initial set of trajectories. A way to select this optimum number of clusters is to set a percentage variation of the limit TSV index, so that the optimal number corresponds to the stage where this threshold is first exceeded. In this work, considering the overall results obtained in Stunder (1996) as well as the studies carried out in the area (Toledano et al., 2009; Hernández-Ceballos et al., 2010a), a limit value of the TSV index of 40% has been imposed in order to prevent that the union of two very different clusters causes a considerable loss of information in the development of the work.

3 Results

3.1 Gulf of Cadiz characteristic air masses

During the study period, 2000-2007, a total of 2912 daily trajectories with endpoint at El Arenosillo (coastal zone) have been calculated. On the other hand, it is well known that in this coastal area, mainly during the spring and summer months, the atmospheric dynamic of the lower atmosphere is governed by mesoscale circulations. In previous studies (Adame et al., 2010), the periods in which coastal

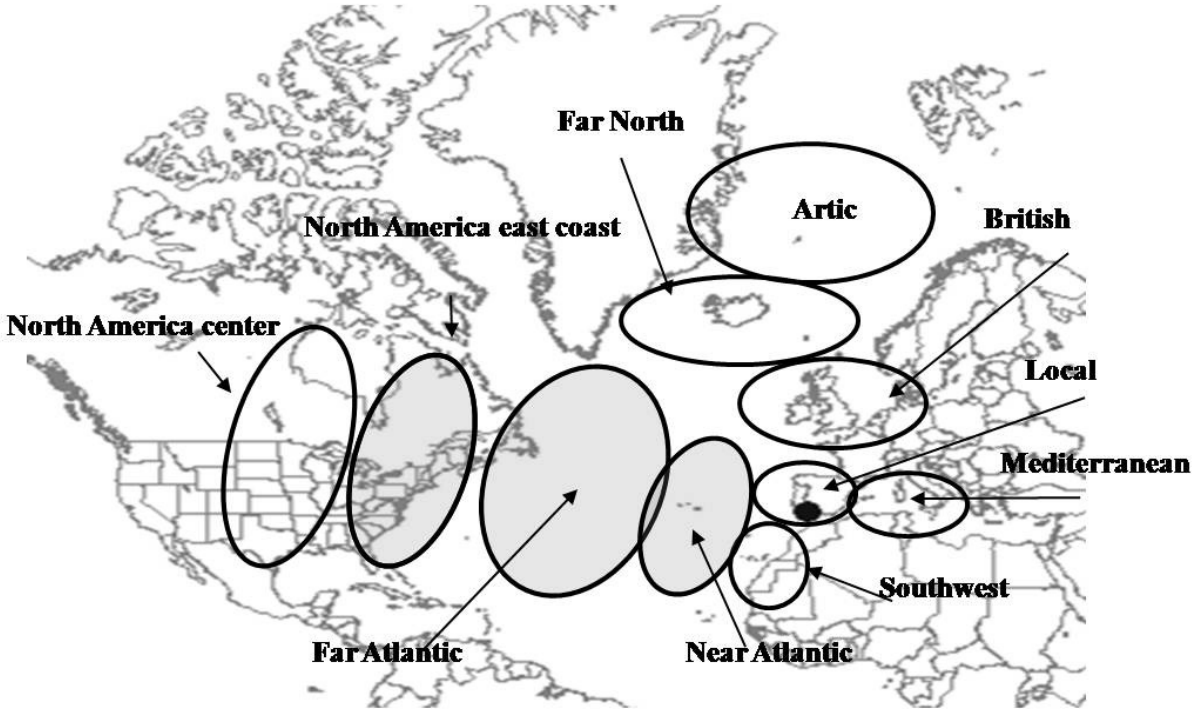

Figure 2. Location of the provenance areas of air masses at 120 hours of their arrival to the Gulf of Cadiz, at 500 masl during the period 2000-2007.

breezes are developed over the Andalusian Atlantic coast have been identified and counted from the hourly records of wind speed and direction recorded at the coastal station of El Arenosillo. Because of the spatial resolution of the meteorological input files used (190 km and 111 km), the HYSPLIT model cannot reproduce these mesoscale situations. For this reason and in order to avoid a distortion of the results obtained, we proceeded to eliminate those trajectories belonging to periods in which the establishment and development of breeze circulations in the study area were detected. Applying the same approach followed in Adame et al. (2010), there is a reduction in the number of trajectories above 20% for each of the years. Finally, a total number of 2119 trajectories was used.

Once the initial number of trajectories was defined, the previously mentioned cluster technique were applied on each annual set. The analysis and comparison among the annual clusters results made it possible to identify ten different types of air masses over the Gulf of Cadiz at 500 m during the period 2000-2007 (Figure 2). Each of the zones do not correspond to source regions of air masses, but are representative areas of the air mass location 120 hours before impacting on the Gulf of Cadiz at 500 m asl, and can be referred to as source areas. Of these, the local air masses represent circulations characterized by a path shorter than 1200 km. This set of areas is consistent with those obtained in Hernández-Ceballos et al. (2010a) during the period 1997-2007.

In this work, from this set of air masses, we have selected those that verify the following conditions: i) circulations with synoptic origin that show a uniformity in the type of area covered, ie, marine or continental, ii) origin in the southwest-northwest sector and iii) a percentage of occurrence during the period 2000-2007 of over 10%. This guarantees the use of those that did not undergo major changes in thermodynamic properties, and that its incidence was high during the study period.

Applying the above criteria to the ten types of air masses, only three verify them (Figure 2, gray area): circulation from the east of North America (264 days), far Atlantic (501 days) and near Atlantic (446 days). Figure 3 shows the average horizontal and vertical (centroid) movement of each of them.

In general, the arrival of air masses originating from North America happens under a low pressure system centered in the North Atlantic, in latitudes similar to the British Isles and relatively close to them. This isobaric configuration favors the path of air masses from North America to Europe across the North Atlantic. As an example, it can be seen in Figure 4a the trajectory of the air mass on February 17, 2006 together with the surface pressure map.

Far and near Atlantic air masses have very similar synoptic settings, and different to those found for the first case above, the North American. Associated synoptic meteorology is characterized by the combination of centers of high and low pressures in the Atlantic, with the path of air masses

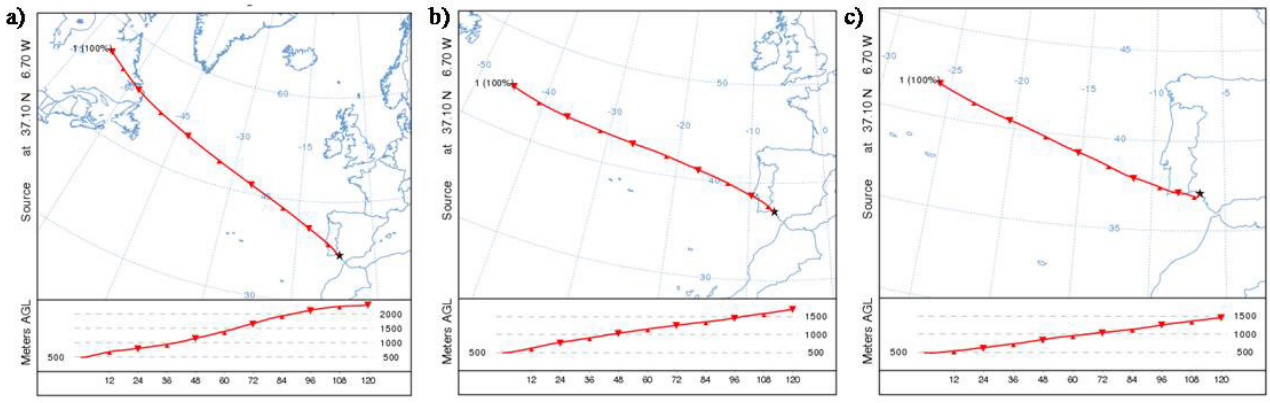

Figure 3. Average circulation (centroid) of the three types of air masses selected a) East coast of North America, b) far Atlantic and c) near Atlantic.

conditioned, and therefore, the incidence of one or another over the southwestern Iberian Peninsula, to the position that these centers take in the Atlantic. This way it is possible to discriminate between far and near Atlantic. As an example of near Atlantic circulation, Figure 4b shows the situation which occurred on August 10, 2005.

From the set of trajectories obtained for the three types of air masses selected, we applied a selection procedure in order to extract those days when the same type of air mass is detected simultaneously along the valley. The far Atlantic typology is taken as reference with the goal of exposing the procedure used. From the days in which this type of circulation is identified at El Arenosillo, the trajectories for the same days in Cordoba are calculated. Cluster technique is applied to Cordoba trajectories. From the clusters obtained, only the one or ones defined by far Atlantic circulations are selected. This way we obtain a new set of days with the same type of air masses in El Arenosillo and Cordoba. In the next phase the trajectories in Santa Elena are calculated for the last set of days referred to and the cluster technique is re-applied to the trajectories of Santa Elena. Of the centers of the clusters obtained, only the one that meets the criteria of being far Atlantic is selected.

The application of this criteria ensures the consideration of the same type of air mass simultaneously along the valley; however it should not be the same air mass for all cases. Thus, the air mass reaching Santa Elena traveled throughout the valley but it does not have to be the same as in El Arenosillo in that moment, although this criteria forced the existence of an air mass of the same type in all locations.

Table 1 shows the results obtained after applying this procedure to each of the three types of air masses. It is observed that the total reduction in percentage is lower in air masses coming from the Atlantic, with 75% and 85% respectively for near and far Atlantic, while it is 91% for those from North America. Thus, the reduction in the detection of similar air masses in the Guadalquivir valley would be related to their previous displacement, and therefore with the synoptic settings that their arrival cause on the Gulf of Cadiz. Those with a larger path, linked to large west flows, have greater difficulty in channeling along the valley than those originating from closer areas.

Also, we have observed that the three types of air masses studied do not have the same occurrence throughout the year (Table 1) over the Guadalquivir valley. In general the path of the air masses along the valley is longer during the cold period than in the warm period. In addition, it is necessary to indicate the lack of days from the east coast of North America particularly during the warm period. These results could be attributed to a greater homogenization of the thermal conditions of the valley during the cold period of the year. By contrast, during the warmer months there could be a larger decoupling in the surface dynamics between the different sections of the valley.

3.2 Daily evolution of wind speed, temperature and specific humidity in the Guadalquivir valley under synoptic scenarios with west/southwest flows

After selecting the days when the same type of air mass was observed in the three sections of the valley, the daily fluctuations experienced by the potential temperature, specific humidity and wind speed in each of the three representative sites and in both seasons (Figure 5) were calculated and analyzed, in order to establish a first approximation to the spatial variation presented by each of the types of air masses in the Guadalquivir valley. In order to know with greater accuracy the characteristics that these variations show it would be necessary to extend the set of representative stations.

When interpreting the results shown in Figure 5, we must bear in mind that these have been obtained from the set of days shown in Table 1, which are mostly isolated days and therefore not consecutive. For this reason, and despite the fact that the results are representative of days with southwest flows advection during the period 2000-2007, the daily cycles have a minimum gap between the ends,

Table 1. Results obtained from the reduction process of the initial number of days when each type of air mass is detected in the Gulf of Cadiz and the total number of days for the warm period (June-September) and cold period (November-February) used in the three selected sites for the calculation of daily variations.

	North American	Far Atlantic	Near Atlantic
Initial number of days	264	501	446
Final number of days	25	124	66
Reduction (%)	91%	75%	85%
Number of days for	- (warm)	23 days (warm)	17 days (warm)
defined period	20 days (cold)	53 days (cold)	27 days (cold)

also recording different hourly peaks in the case of wind speed.

3.3 Potential temperature

Daily cycles of potential temperature show the existence of a well-defined daily cycle throughout the year in each of the three sections. Based on these results, during the warm period, a warming of the air mass from the coast to the interior is observed. However, this spatial variation is not continuous since the peak values recorded in Cordoba are higher than in Santa Elena. These results may be related to the topographic configuration of the Cordoba area, which is characterized by a narrowing of the valley that favors a greater probability of atmospheric stagnation and consequently more warming in the warm months.

By contrast, during the cold period, cooling increases with the distance to the coast, with the lowest values of potential temperature recorded at the station of Santa Elena. Within this period the high similarity between the daily cycles of El Arenosillo and Cordoba must be noted, with differences not exceeding a degree, which can be explained by the greater thermal homogeneity registered between these two sections of the valley during this period.

The Atlantic influence is reflected in the sections of the valley through the differences between the maximum and minimum daily temperature. These differences are smaller in the coastal zone, settling among 5-10 K, while reaching its maximum value at the middle area, with a range of 5-15 K, associated to its topographic conditions. In the upper part these differences are slightly lower than in the middle, ranging from 5-13 K. Therefore, the existence of a progressive loss of the Atlantic influence as we enter the valley may be indicated and therefore an increase in continentality, which is more marked in the middle area.

Regarding the spatial variation experienced by the minimum values of potential temperature along the valley, they do not exceed a difference of 2 K in any of the three types of air masses, while the differences in maximum values can reach values up to 5 K in American air masses and 5-7 K for near and far Atlantic circulations respectively.

On the other hand, the daily cycles of potential temperature are very similar in the three types of masses considered, finding no significant differences between them. The thermal differences along the valley, therefore, are defined by the time of the year and the section of the valley considered but not by the type of air mass.

3.4 Specific Humidity

The daily evolution of specific humidity shows different daily variations depending on the period considered. This variation is likely due to the evaporation/condensation phenomena that occur along the valley, conditioned by the thermal, topographic, vegetation cover or land use characteristics presented by the different sections, as well as air entrainment processes from higher levels to the ABL.

During the cold period a greater homogeneity in the daily cycles is observed in all stations, in contrast with a greater hourly change in the warm period. The range in the cold period is set between 5-8 g kg^{-1}, while in the warmer months it reaches 5-13 g kg^{-1}. This difference between periods of the year may be associated with the greater homogenization of meteorological conditions along the valley that occurs in the colder months, versus the greater variation that is recorded during the warm period.

Despite this large difference between periods, there are no great differences observed among the three types of air masses, with their respective specific humidity daily cycles being similar to each other. Only during the cold period of the year in El Arenosillo station a constant difference of 1 g kg^{-1} between the North American and Atlantic types is observed, while during the warm period the greater differences are recorded in the station in Cordoba, where the near Atlantic air mass shows a higher content of water vapor: about 1 g kg^{-1}, regarding the far Atlantic types.

Regardless of the type and time of year considered, a progressive loss of water vapor content was observed in the air masses in the valley. However, due to the thermal conditions of the valley, this decrease is much higher during the warm period, with differences of up to 8 g kg^{-1}, than during the cold period, in which no changes above 2 g kg^{-1} between the ends of the valley are registered. Breaking down these differences by area, we can see that the loss of water vapor is intensified in the middle area (Cordoba) and head of the valley (Santa Elena). Thus, during the warm period this loss is intensified, settling differences of 5-7 g kg^{-1} between these stations, while between the coastal area (El Arenosillo)

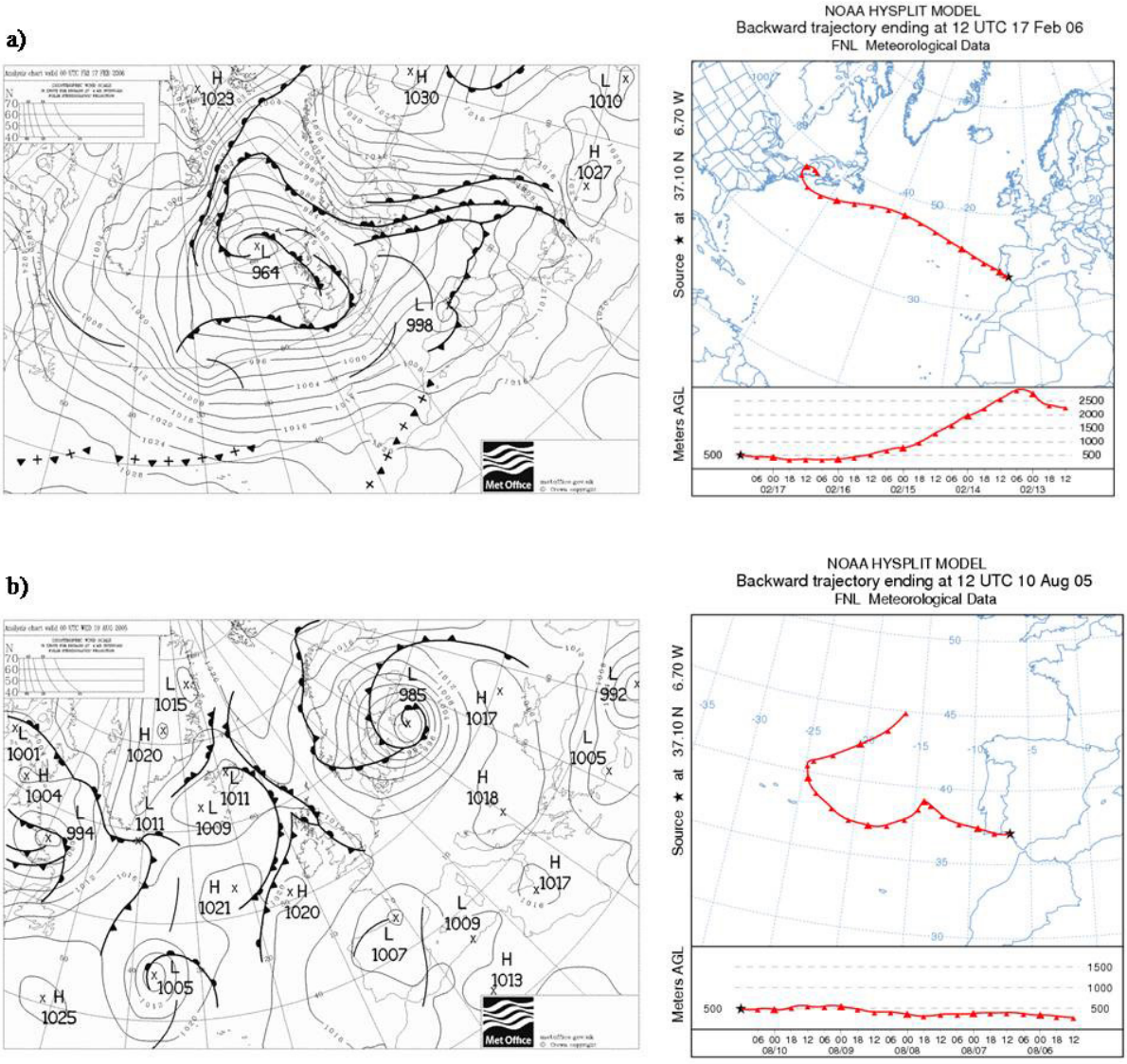

Figure 4. Synoptic configurations (00 UTC) favorable to the incidence over the Gulf of Cadiz of a) North American air masses (17/02/2006) and b) Atlantic air masses (10/08/2005).

and Cordoba this difference fluctuates between 0-3 g kg^{-1}. This large decrease recorded in the final section of the valley could be explained by the development of processes of air flows entering from high levels over the diurnal variation of the boundary layer.

In the warm period an inverse daily cycle is observed, as well as a greater hourly variation between the ending stations of the valley, El Arenosillo and Santa Elena, compared to the lesser variability showed by the station located in the middle area, Cordoba. In the latter, the values obtained show a lower hourly fluctuation of 1 g kg^{-1}, while in the station of El Arenosillo and Santa Elena the differences between their maximum and minimum daily values reach 2-3 g kg^{-1}.

3.5 Wind speed

The daily cycle of wind speed shows, both in the cold and warm months and regardless of the type of air mass, a decrease in wind speed as it moves into the valley. Thus, while in the coastal area, El Arenosillo station, wind intensities over 4 m s^{-1} are reached; in the section that is farthest from the coast, Santa Elena station, these speeds are kept below 3 m s^{-1}, with prevailing hourly values below 2 m s^{-1}.

This result can be understood as consistent, since due to the effects of friction with the surface a loss of energy can occur and thus air masses reduce their speed. In addition, we must also consider factors such as the momentum exchange with upper layers and the influence of the prevailing pressure gradient in each of the zones when justifying this difference

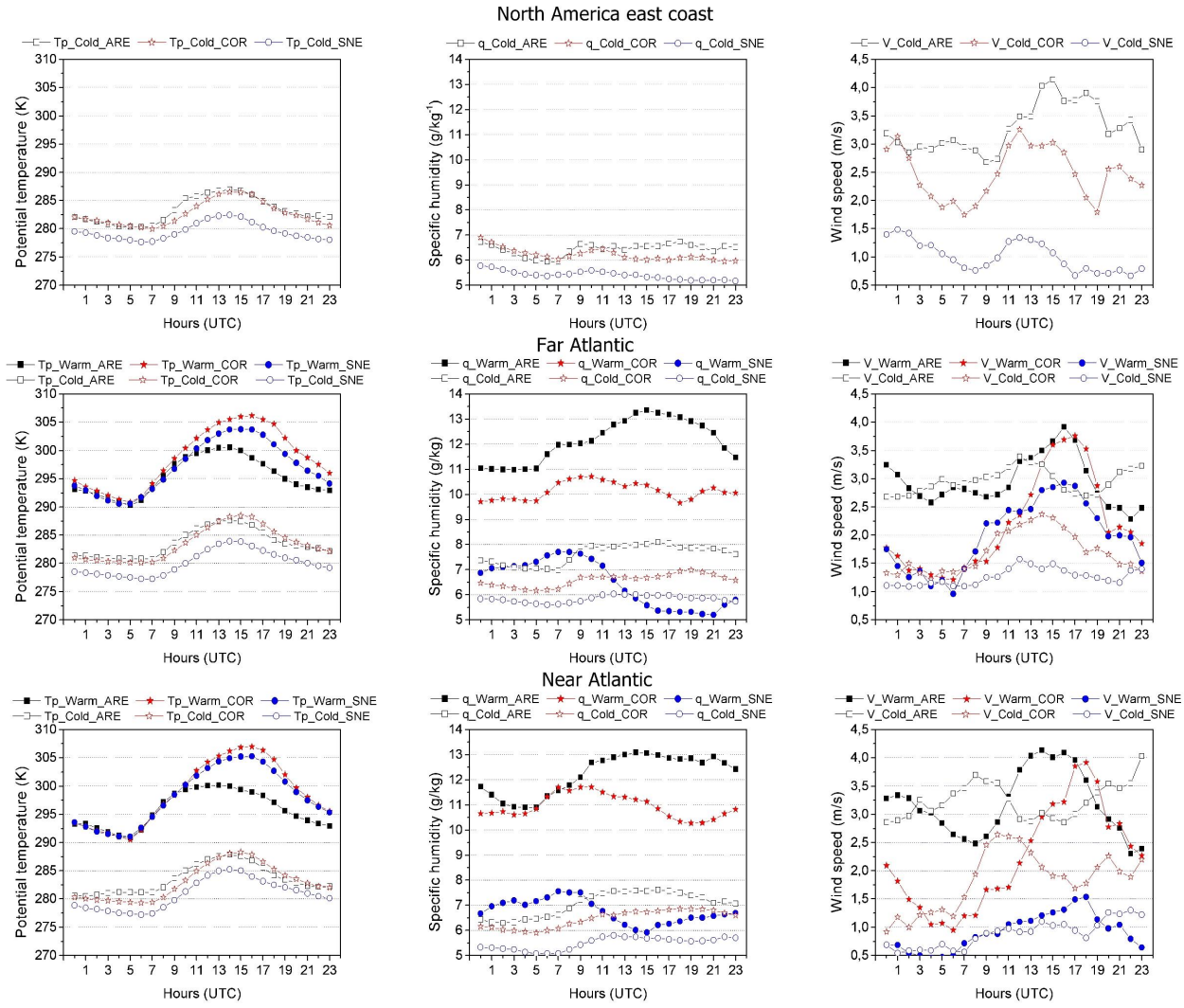

Figure 5. Daily cycles of potential temperature (Tp), specific humidity (q) and wind speed (V) obtained for the cold period (*Cold*) (November-February) and warm period (*Warm*) (June-September) in each of the three sites, El Arenosillo (*ARE*), Cordoba (*COR*) and Santa Elena (*SNE*) for each of the types of air masses studied: North American east coast, far Atlantic and near Atlantic.

in speed. This lower wind speed in the station of Santa Elena, in addition is also observed in the wind roses representing the entire period 2000-2007 (Figure 1).

However, this reduction is not constant throughout the year, being more intense during the cold period, nor between sections of the valley, being most pronounced between the middle and final sections than between the coastal and middle sections. Taking as reference the maximum speed values, the differences during the warm period between the stations of El Arenosillo and Cordoba are less than 0.5 m s^{-1} while between Cordoba and Santa Elena they range from 1-2.5 m s^{-1}; whereas during the cold period, the differences increase to 1-1.5 m s^{-1} between the first and second sections, and to 1.5-2.5 m s^{-1} between the second and third sections.

In addition to the factors discussed above, one of the possible causes for the great decrease in the intensity of the wind between the middle and final sections, could be explained with the blocking caused by the cooling of the flows that occur in the upper valley, which would indicate that the air mass flowing up the valley from the middle area, would ascend over the cooler stagnant air, which would act as a wedge. This possible explanation, however, would mean that the air mass was not the same, and therefore there is no movement up the valley reaching to this station, thus producing a blocking in the upper valley.

Furthermore, and motivated by the location of the maximum values during the warm period of the year, it stands out that in each of the sections of the valley the speed range during the warm period of the year is higher than that recorded during the cold period, with the greatest differences between minimum and maximum daily values registered at the station of Cordoba, reaching 3 m s^{-1} during the warm period compared to 1.5-2 m s^{-1} in the cold period. By contrast, in the stations of El Arenosillo and Santa Elena these

Table 2. Variation ranges of the gradients of potential temperature ($\nabla\theta$), specific humidity (∇q) and wind speed (∇v) each 100 km in the Guadalquivir valley sections. Abbreviations: El Arenosillo (*ARE*), Cordoba (*COR*), Santa Elena (*SNE*).

		Section ARE $\longrightarrow$ COR	Section COR $\longrightarrow$ SNE
Warm period	$\nabla\theta$	+(2,5-3 K)	-(1-2 K)
	∇q	-(1,5-2 g kg^{-1})	-(5 g kg^{-1})
	∇v	-(0,5 m s^{-1})	-(3,5 m s^{-1})
Cold period	$\nabla\theta$	-(0,5 K)	-(2-3 K)
	∇q	-(0,5 g kg^{-1})	-(0,5-1 g kg^{-1})
	∇v	-(0,5-1 m s^{-1})	-(1-1,5 m s^{-1})

differences are not higher than 2 m s^{-1} during any of the periods.

Regarding the differences that are seen between the types of air masses, it is notable that during the warm and cold periods, in Santa Elena, the far Atlantic air mass recorded higher speeds, with maximum differences of up to 2 m s^{-1}, in comparison with the near Atlantic type, which shows minimum intensities in the first half of the day. Also, during the cold period, Atlantic air masses show lower peak intensities than the circulations from North America in both the first section of the valley, as in the second.

3.6 Horizontal gradients

In order to determine the spatial variation experienced by the potential temperature, specific humidity and wind speed between the different sections of the valley, the variation range experienced every 100 km was calculated considering the three types of air masses together (Table 2). This union of results is due to the slight difference between the results obtained for each type of air mass. These gradients have been calculated from the differences between the daily maximum values recorded between each of the sites for the warm and cold period of the year.

It can be concluded from these results that the progressive loss of the thermodynamic properties of air masses as they move inside the valley (negative gradient) is practically generalized; those that are higher in the second sections are possibly associated with the greatest difference between their topographic, land use or vegetal cover characteristics. This generality is not observed only in the spatial variation of potential temperature on the first section + (2.5-3 K), which may be associated with the topographic features already discussed in the area where Cordoba is located. In the specific case of potential temperature, the differences between two stations at different heights can only be associated with horizontal gradients if the air is very mixed and this should only happen during the warm period in the central hours of the day. If not, it is likely that much is due to vertical gradients, which can be very important in cases of thermal inversion.

A greater variation of thermodynamic properties during the warm period than during the cold period is also observed, which is possibly associated with the greater thermal uniformity that governs the valley during that time of year. Thus, as an example, in the second section there is a reduction of specific humidity of 5 g kg^{-1} in the warm period while in the cold period this drop ranged between 0.5 and 1 g kg^{-1}.

4 Conclusions

In this paper we studied the changes experienced in the thermodynamic properties of air masses from the west along the Guadalquivir valley. From a set of trajectories calculated by the HYSPLIT model, those circulations with a clear origin from the west were extracted, such as the east type from North America, that of the most westerly Atlantic area and an area closer to the Iberian Peninsula. Among them, the far Atlantic (25%) trajectories are the ones that show a greater frequency of being detected equally in the different sections of the valley, followed by the near Atlantic (15%) and North American (9%).

When there are meteorological scenarios that favor the arrival of the three considered mass types over the valley, during the winter months there is a drop of its potential temperature (3-4 K), specific humidity (1 g kg^{-1}) and speed along the valley. That is, they are cooler, less wet and dispersive. By contrast, during summer months, the potential temperature of air masses increases (5-6 K), but their humidity (8 g kg^{-1}) and speed decrease.

Both in summer and winter, when these types of air masses are detected in the Guadalquivir valley, the primary chemical species that are embedded in them will have a lower tendency to disperse as they move into the valley. However, in the summer months and mostly in the case of secondary substances, they could show higher concentrations when they move inland, as the increase of the temperature and decrease of both specific humidity and velocity of the air masses that carry them will favor photochemical reactions and their accumulation in the lower layers of the atmosphere.

Therefore, the results obtained in this work intend to be a source of useful information to support in the interpretation of air quality problems in this region. In addition, the methodology applied can be used in other areas of similar topographic features.

Acknowledgements. The authors of this work would like to acknowledge the help and cooperation provided by the NOAA, Air Resources Laboratory (ARL), and especially to Dr. Ariel Stein. Likewise, we would like to acknowledge the Environmental Council of the *Junta de Andalucía* for their support and interest in the work of this group and the Spanish Meteorological Agency (AEMET) for the use of their databases.

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