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A FIVE-YEAR CLIMATOLOGY OF BACK-TRAJECTORIES FROM THE IZAÑA BASELINE STATION, TENERIFE, CANARY ISLANDS

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Abstract—As a contribution to the climatological characterization of the Izaña baseline observatory (Tenerife, Canary Islands, Spain), back-trajectories were calculated and an air mass climatology was developed for a 5-year period. On a daily basis, 5-day back-trajectories were computed for the 850- and 700-HPa levels from January 1983 to December 1987. Trajectories were separated into long- and short-range flows and classified into categories depending on the path followed by the air masses. Flows from the North Atlantic Ocean were much more frequent than flows from continental sectors. In addition, seasonal variations of the sector frequencies were studied and synoptic meteorological patterns were associated with each trajectory category.

Key word index: Izaña baseline observatory, trajectories, flow climatology, synoptic patterns.

1. INTRODUCTION

The characterization of different air masses arriving at a baseline station is a great aid in determining atmospheric background conditions. The features of the air masses depend on their source areas as well as their trajectories. When the air masses move over the ocean, their physical and chemical properties are different from those of air masses that pass over land. For example, air masses passing over western Europe on the way to Izaña observatory often show evidence of anthropogenic pollution, whereas maritime air masses are usually very clean.

A climatology of back-trajectories is useful in analysing the changes of daily mean concentrations of trace compounds and aerosol particles sampled at baseline stations. In this study, we establish a climatology of back-trajectories from Izaña observatory (Tenerife, Canary Islands, Spain). An antecedent of this study for the Canary Islands is that of Coude-Gaussen *et al.* (1987), who computed several trajectories to Fuerteventura, Canary Islands, using wind analyses at 925 HPa produced by the European Center for Medium Range Weather Forecast. Bergametti *et al.* (1989) have computed back-trajectories from Fuerteventura in order to study the transport of Saharan dust; Haagenson and Sperry (1989) studied trajectories in the North Atlantic Ocean, using the National Center for Atmospheric Research isentropic model. In addition, they investigated the relationship of back-trajectories with wind direction and synoptic patterns.

2. GEOGRAPHICAL AND METEOROLOGICAL FEATURES

Izaña baseline observatory belongs to the World Meteorological Organization's worldwide Background Air Pollution Monitoring Network (BAPMoN), which measures background levels of various atmospheric constituents. It is the only baseline station in the North Atlantic region and has been operational since 1984. The Izaña baseline station (28° 18′ N, 16° 29′ W) is on a mountain platform at 2367 m above sea level on Tenerife Island, 400 km west of Africa (Fig. 1). The observatory is on a natural volcanic platform (Montaña de Izaña) in the middle of the mountainous ridge that runs from the Caldera de las Cañadas, on the base of the volcanic cone of Pico del Teide (3717 m), toward the northeast side of Tenerife island (Fig. 1). Sparse vegetation grows at this altitude. However, a lush pine-tree forest exists between 1200 and 2000 m altitude, and laurel forest (laurisilva) continues downward. The most important

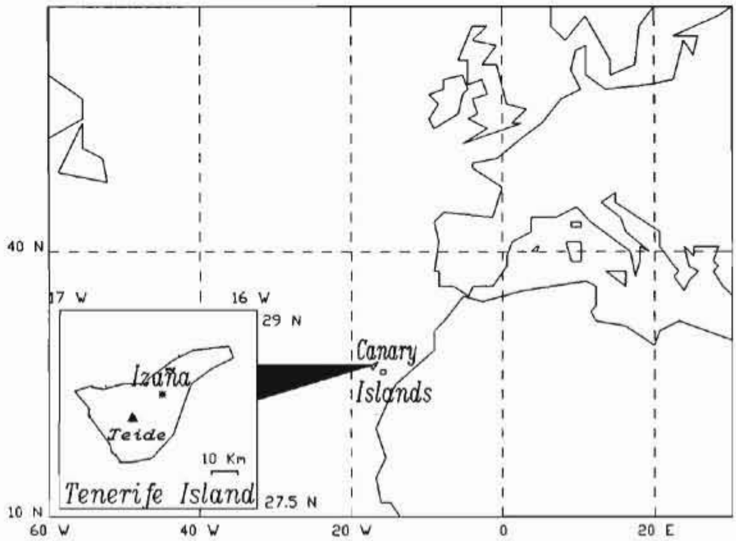


Fig. 1. Location of Canary Islands, and of Izãna Baseline Station on the Tenerife Island.

"green" area close to the observatory is in a valley northwest of Izaña (Valle de la Orotava).

The meteorological features of the Canary Islands are dominated by the strength and position of the subtropical anticyclone, which is normally situated over the Azores Islands to the northwest of the station. A subsidence inversion layer is usually present below 2000 m above sea level, resulting in two distinct air masses. The lower air mass is cooler and more moist, while the upper one is warmer and drier. This occurs about 90% of the time in summer and 70% of the time in winter. The inversion layer prevents the arrival at the observatory of polluted air masses from the lower layer because the height of the inversion top is normally below the station altitude (Hernández et al., 1988).

The northeastward movement of the anticyclone, sometimes as far as western Europe, gives rise to the arrival of polar air masses to the Canary Islands. These air masses pass over the European continent and/or northwestern Africa en route to Izaña. When this situation occurs in winter, the weather at Izaña station is dry, sunny and chilly. During summer, some short-duration thermal low-pressure systems appear over the Sahara Desert. This circumstance added to the movement of the so-called Intertropical Convergence Zone northwards, causes the arrival of hot and dry ariflows, loaded with dust, at Izaña (Dubief, 1979). Sometimes, the influence of a low-pressure system produces airflows of maritime polar or subtropical origin, depending on the strength and relative position of the cyclone. Heavy rain and decreased atmospheric stability usually result.

The climate statistics of Izaña can be summarized as follows.

(a) *Temperature.* The annual mean temperature is 9.4°C (about 4° in winter and 16° in summer). The daily mean variations range from 6° in winter to 8° in summer.
(b) *Precipitation.* The mean precipitation is 481 mm per year, and there are about 40 precipitation days per year. During winter, snow is the dominant form of precipitation, but it occurs only 10 days per year on average.
(c) *Moisture.* The inversion layer, which is usually below the altitude of the station, keeps the relative humidity low. The average relative humidity for the year is 43%.
(d) *Pressure.* In stationary conditions, the daily atmospheric pressure fluctuation is about 2 HPa. On average, the frequency of cyclones passing Izaña is about one per week, varying with the seasons of the year. The station average pressure is 770 HPa.
(e) *Wind.* At the Izaña baseline observatory, the most frequent wind direction is northwest. In the daytime the air above the observatory is generally heated more than the air above the inversion layer which more frequently is below the station level over the forest. It gives rise to a weak upslope wind. The mean wind speed is 8 m s^{-1}. The maximum recorded gust exceeded 50 m s^{-1}. The wind is rarely calm.

3. CLASSIFICATION OF IZAÑA BACK-TRAJECTORIES

The computer model that produced the atmospheric trajectories for this study was developed by Harris (1982). The primary input for the trajectory program consists of gridded wind components at mandatory pressure levels, produced at the National Meteorological Center (NMC), Suitland, MD, U.S.A., by a global atmospheric circulation model. The resolution of the NMC data grids used in this study is

2.5° of latitude and longitude. Meteorological observations from around the globe constrain the atmospheric model that produced the gridded data for 0000 Z and 1200 Z each day. Coverage of meteorological observations is naturally sparse over the poles and oceans compared with well-populated land areas, but aircraft reports and satellite data supplement for areas where the regular rawinsonde observations are not possible.

A 5-day trajectory consists of 40 individually computed 3-h trajectory segments placed end to end. To compute each segment, the trajectory program interpolates in time between two NMC grids (0000 Z and 1200 Z) to the midpoint of the 3-h period in question. The winds at the previous trajectory segment endpoint are calculated from the winds at the four grid points surrounding the endpoint. A first-guess trajectory segment is computed, assuming that this wind is constant for the 3-h duration. At the midpoint of the first-guess segment the winds are again calculated by bilinear interpolation. These latter winds are then used to compute the final trajectory segment because they are assumed to be more representative of winds for the 3-h segment. This iterative approximation technique is called the modified Euler method (Stark, 1970).

The trajectories produced by this model are best used as an indication of the general airflow pattern. Errors that may be introduced by interpolation, poor data coverage or the model's approximation of the real atmosphere could be compounded as trajectory segments are added further back from the destination. Thus, the apparent origin of a 5-day back-trajectory should be considered an approximation, and, as indicator of source regions, should be supported by other atmospheric data or, as is done here, used in a climatological sense.

Despite their limitations, atmospheric trajectories have been frequently employed in studies of long-range transport of gases and aerosols. Using back-trajectories, Herbert *et al.* (1982) found evidence that Asian deserts are the source of crustal material arriving at Mauna Loa Observatory, Hawaii. Halter and Harris (1983) investigated causes for CO_2 variability at Barrow, Alaska, using trajectories and other analysis methods. A study in Harris and Bodhaine (1983) found that pollution episodes at Whiteface Mountain Observatory, NY, were often associated with trajectories arriving from the west after passing over the Great Lakes industrial region, and clean air conditions at the observatory were associated with trajectories over the Atlantic. A 7-year back-trajectory climatology by Miller and Harris (1985) characterized airflow to the island of Bermuda and found a strong positive correlation between highly acidic rainfall and the trajectories from the North American continent.

Five-day back trajectories were computed for Izaña on the 850- and 700-HPa pressure surfaces. They were displayed on a map with symbols along each track to identify the level and the number of days back (Fig. 2). We used these mandatory pressure levels because the altitude of the Izaña station (2367 m) falls between them. The period of study was from January 1983 to December 1987. Over 7000 individual backward trajectories were computed.

To establish a climatology of trajectories, the directions of the trajectories were classified according to the meteorological features of the Canary Island region and to the geographic locations of pollutant source areas. A 2000-km radius circle was drawn with its center at Izaña observatory in order to distinguish between long- and short-range transports. Trajectories coming from beyond 2000 km represent the

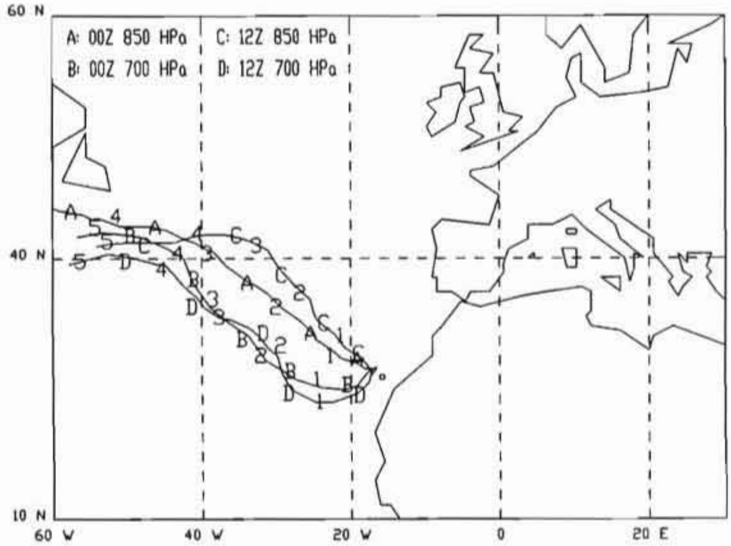


Fig. 2. An example of back-trajectories from the Izaña station. The numbers on the tracks indicate the number of back day.

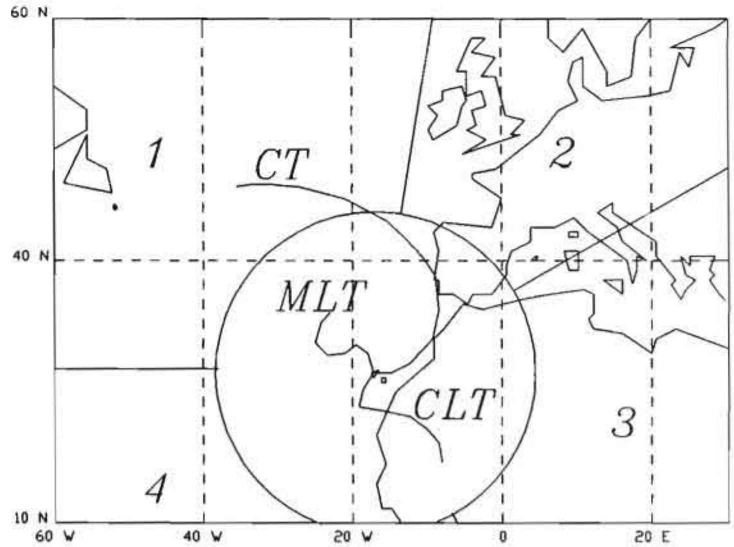


Fig. 3. The classification system used for the period of study and some examples of curved, marine local and continental local trajectories. The circle has a radius of 2000 km.

strongest flow and have a minimum average wind speed of $5\ m\,s^{-1}$ along the 5-day trajectory. The classification criterion is shown in Fig. 3 and is described as follows:

- Sector one (27°–10°) Air masses from North Atlantic excluding Europe.
- Sector two (10°–60°) Air masses (potentially polluted) arriving from Europe.
- Sector three (60°–150°) Saharan air masses sometimes carrying high dust concentrations (Carlsson and Prospero, 1972; Prospero *et al.*, 1979; Schutz, 1979).
- Sector four (150°–270°) Air masses arriving from the equatorial Atlantic Ocean. These air masses, as well as those in sector 1, usually reflect background measurements at the Izaña observatory. Nevertheless, the equatorial oceanic air masses have very different background levels of greenhouse gases due to the latitudinal gradients of these species.
- Curved trajectories (CT, hereafter). Air masses beginning in sectors 1 and 2, but then describing a curve and arriving Izaña via other different sectors. They are influenced first by the westerlies and then by the easterlies.
- Marine local trajectories (MLT, hereafter). Trajectories being within a 2000-km radius circle and air masses flowing mainly over the ocean.
- Continental local trajectories (CLT, hereafter). Trajectories being within a 2000-km radius circle and being located mainly over the African continent. Air masses with these trajectories can transport airborne crystal particles from the coastal region of the Sahara Desert.

However, the emphasis in this paper is on the categories of trajectories reflecting long-range transport. This classification scheme avoids a source of error that would result if the wind speed were not taken into account and trajectories were categorized merely by direction.

- No reported (NR, hereafter). Trajectories that were not calculated because of missing data.

4. 5-YEAR CLIMATOLOGY OF BACK-TRAJECTORIES

In Figs 4a and 4b, histograms of all 850- and 700-HPa 0000 Z trajectories to Izaña are represented for the period of study (1983–1987). For the 850-HPa level, sector 1 has the highest frequency of occurrence (36.6%), more than twice the frequency of the next sector (18.2% in sector 2). Likewise for 700-HPa trajectories, sector 1 dominates. Air masses arriving from sector 1 (North Atlantic) are generally clean and moist. The frequency of occurrence of trajectories from Europe (sector 2) drops from 18.2% at 850 HPa. Trajectories arrive from Africa (sector 3) with roughly the same frequency of occurrence (12%) for both levels. Thus, for the 850-HPa level, the European trajectories are more frequent than the African ones, whereas for the 700-HPa level, the opposite occurs. A higher percentage of trajectories in sector 4 at the 700-HPa level than at the 850-HPa level is observed. A significant number of local trajectories (CLT and MLT) were noted for both levels (about 18%). Marine local trajectories are clearly more frequent than continental local trajectories. Finally the number of curved trajectories represents percentages of about 11% at the 850-HPa level and 8% at the 700-HPa level. In general, curved trajectories are associated with non-polluted air coming from the North Atlantic Ocean. However, in rare cases, these air masses could travel

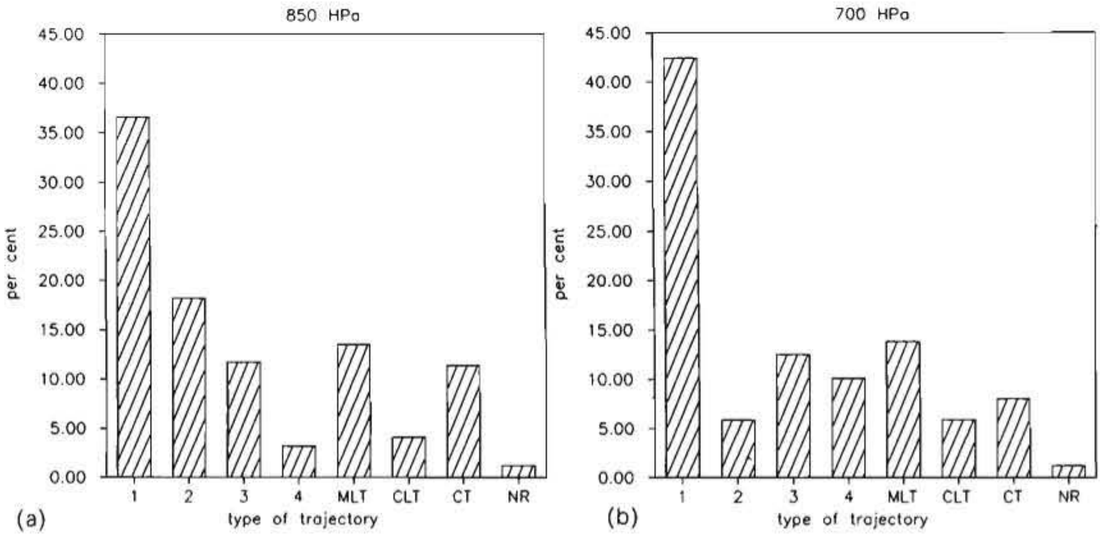


Fig. 4. Percentage of all (a) 850-HPa and (b) 700-HPa back-trajectories of each category.

over some continental areas like the southwestern Iberian Peninsula or western Africa over 1 or 2 days. Percentages of curved trajectories travelling over some continental areas were lower even than those of the CLT category. The distribution of percentages of all 850-HPa trajectories differs from that of the 700-HPa level mainly because of the altitude of trade-wind inversion over the Canary Islands area. This altitude oscillates around the 850-HPa surface (Huetz de Lemps, 1969; Neiburger *et al.*, 1961). It means that in some cases the inversion is sited between the 700 and 850 HPa surface.

The major features observed in the total 5-year study for each individual year are shown by analysing the percentages of a given category plotted for each individual year in Figs 5 and 6. Despite the relatively low year-to-year variability, the differences between 1983 and 1986 must be pointed out. During 1983, trajectories from sector 1 predominated clearly at the 850- and 700-HPa levels, whereas the percentages were less than that for all 5 years. Alternatively, for 1986, the number of cases of trajectories at the 850-HPa level coming from sector 1 is the minimum. However, the percentage of the CT category is maximum as a result of a higher intensity Azores anticyclone. These features are similar, but not so much as at the 700-HPa level for 1986. As during 1986, percentages of sector 1 were low in 1985 but high percentages of curved trajectories were observed. However, percentages of local trajectories (especially CLT trajectories at 700-HPa level) and trajectories from sector 3 increased significantly from the mean values. Air masses coming from the North Atlantic area, i.e. air masses following trajectories sorted as sector 1 or CT, predominated during 1987 at the 850-HPa level. Trajectories of sector 4 at both levels also scored the highest percentages during 1987 for the whole 1983–1987 period. Percentages of each category during 1984 are closest to the mean values for both levels.

Percentages of trajectories of a given type are plotted for each month over the 5-year period in Figs 7 and 8. For sector 1, a maximum in May and a minimum in September appear at both levels, being more pronounced at the 700-HPa level. For sector 2, the maximum occurs in June for both levels, whereas the minimum is in April at the 850-HPa level and in July at the upper level. Percentages of sector 3 peak at 700 HPa in July, but the percentages are low in summer at the 850-HPa level. Furthermore, percentages of sector 3 on a monthly basis at the 850-HPa level show a gradual decreasing from a weak maximum in January to a weak minimum in May. These results for sectors 2 and 3 agree with the observations of Saharan air flowing over the Canary Islands. The Saharan air is more frequent in summer, and its effects are noted primarily at the 700-HPa level and less at lower levels. This is because the lower air is cool and moist, as a result of the trade winds (Neiburger *et al.*, 1961; Pierotti *et al.*, 1978), and the hot continental airflows above the trade-wind air. Moreover, the temperature of the neighbouring sea is relatively low because of the cold Canary Islands Stream, which does not allow warming of the air lying on the ocean (Schutz *et al.*, 1970; Schutz, 1979). This phenomenon also explains the observed veering of wind direction with elevation as a result of thermal wind action. This occurs mainly in summer because a very strong eastward temperature gradient exists between the ocean and the African air masses during this season. Therefore thermal wind would be northward. So, trajectories belonging to sector 2 could appear in sector 3 at the 700-HPa level. The 700-HPa secondary maximum observed in sector 3 in winter agrees with the 850-HPa pattern and may be partly a result of the observed cool

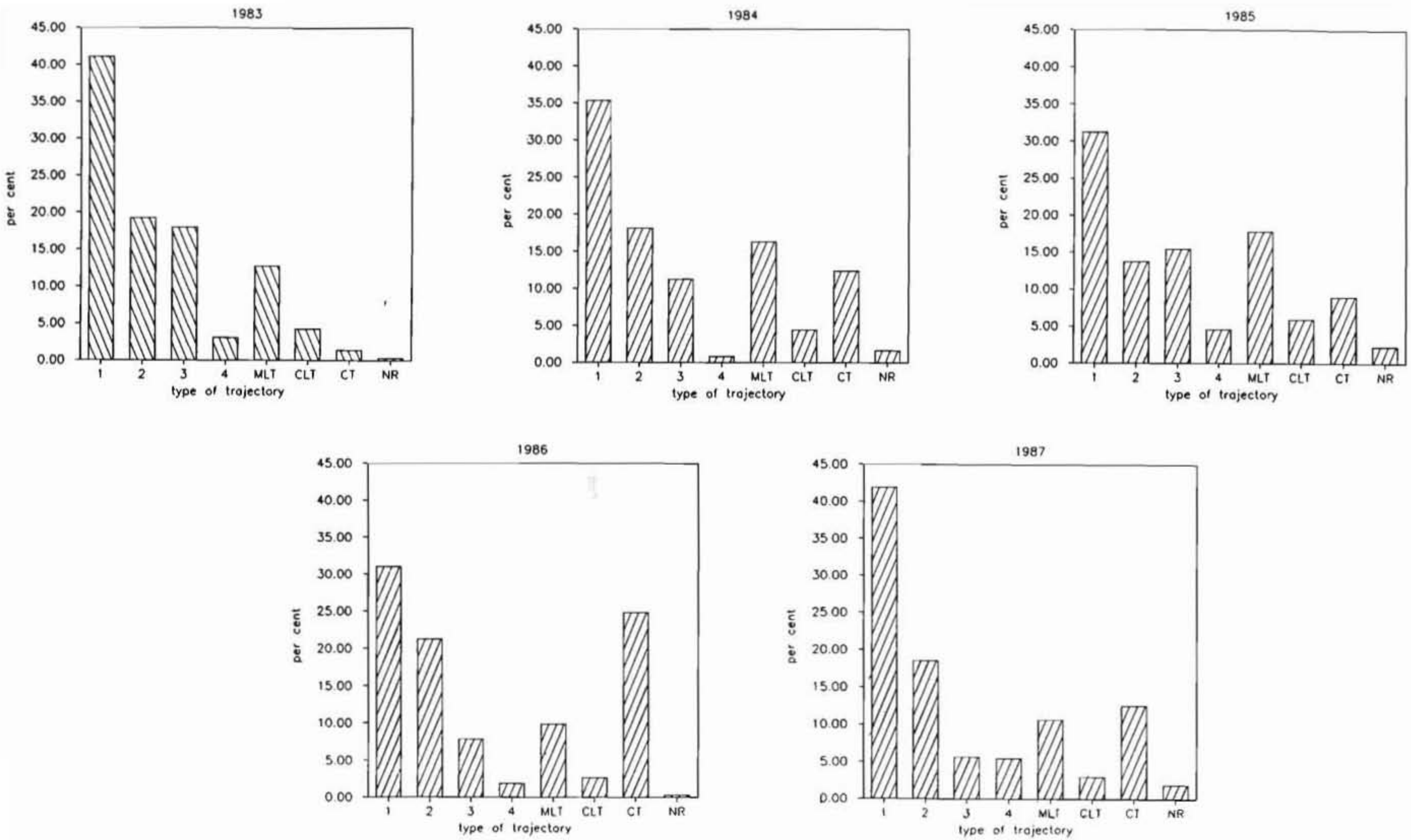


Fig. 5. Percentage of 850-HPa back-trajectories of each category and for each year.

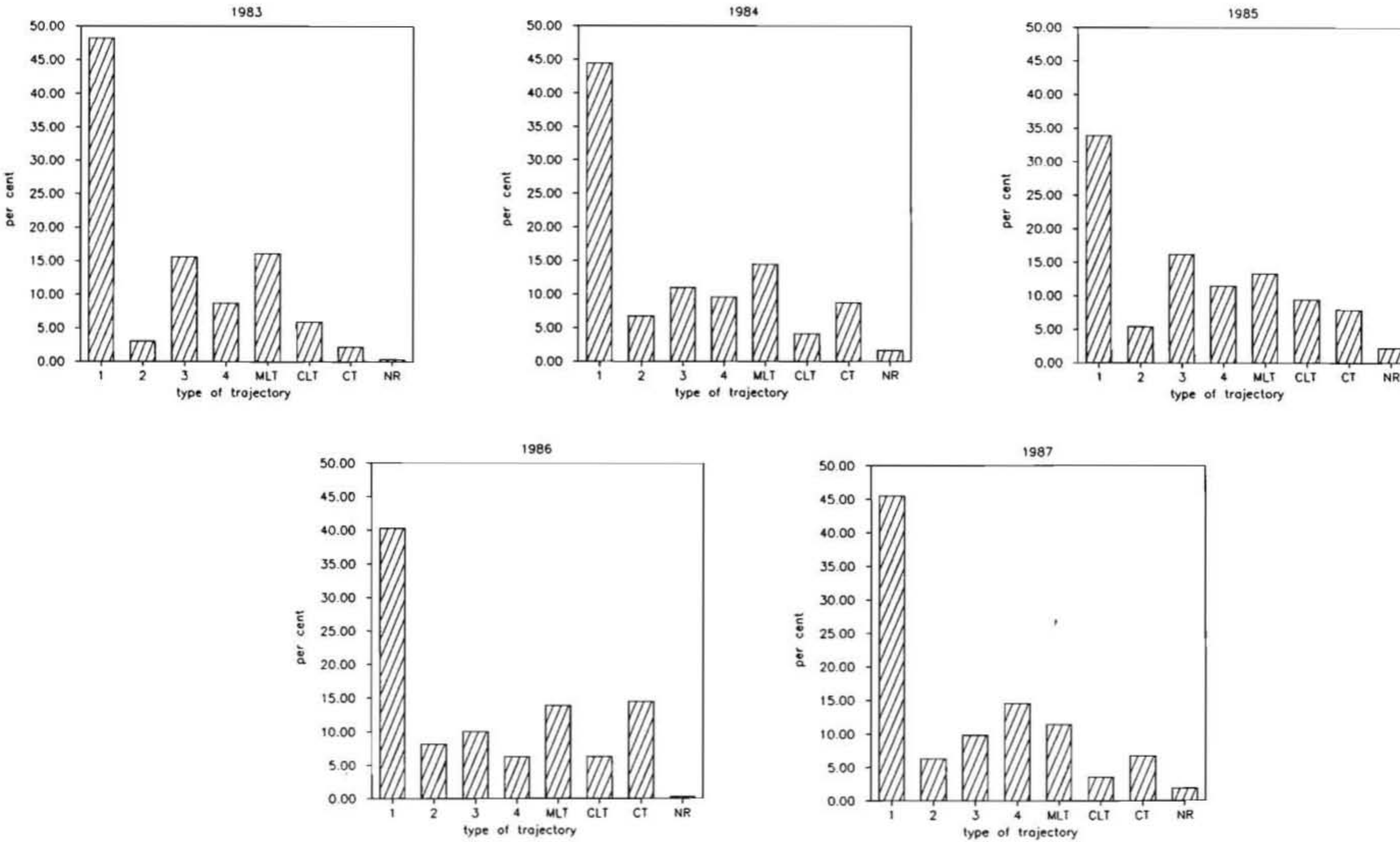
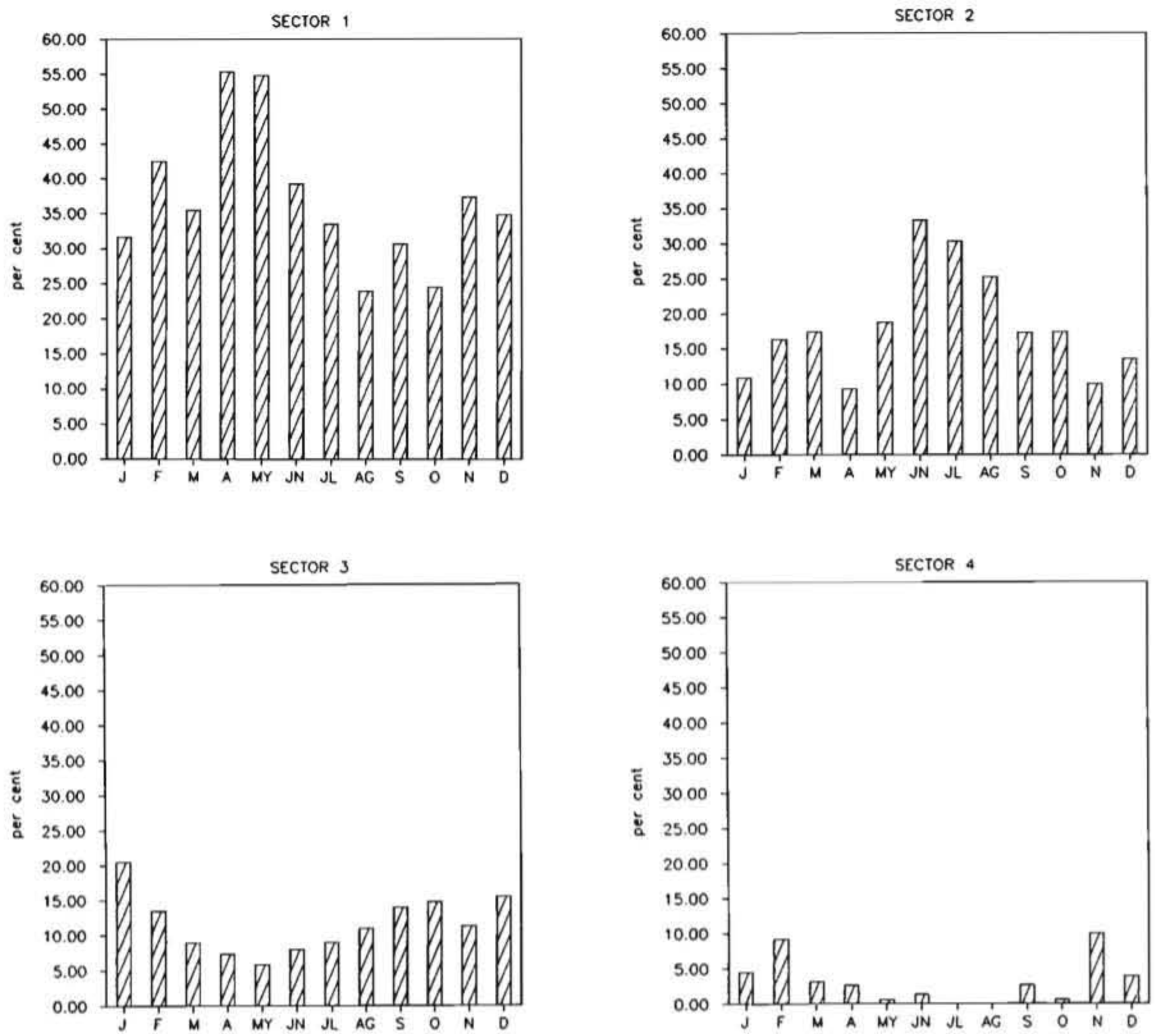


Fig. 6. Percentage of 700-HPa back-trajectories of each category and for each year.


SECTOR 1
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J F M A MY JN JL AG S O N D

Fig. 7. (contd)

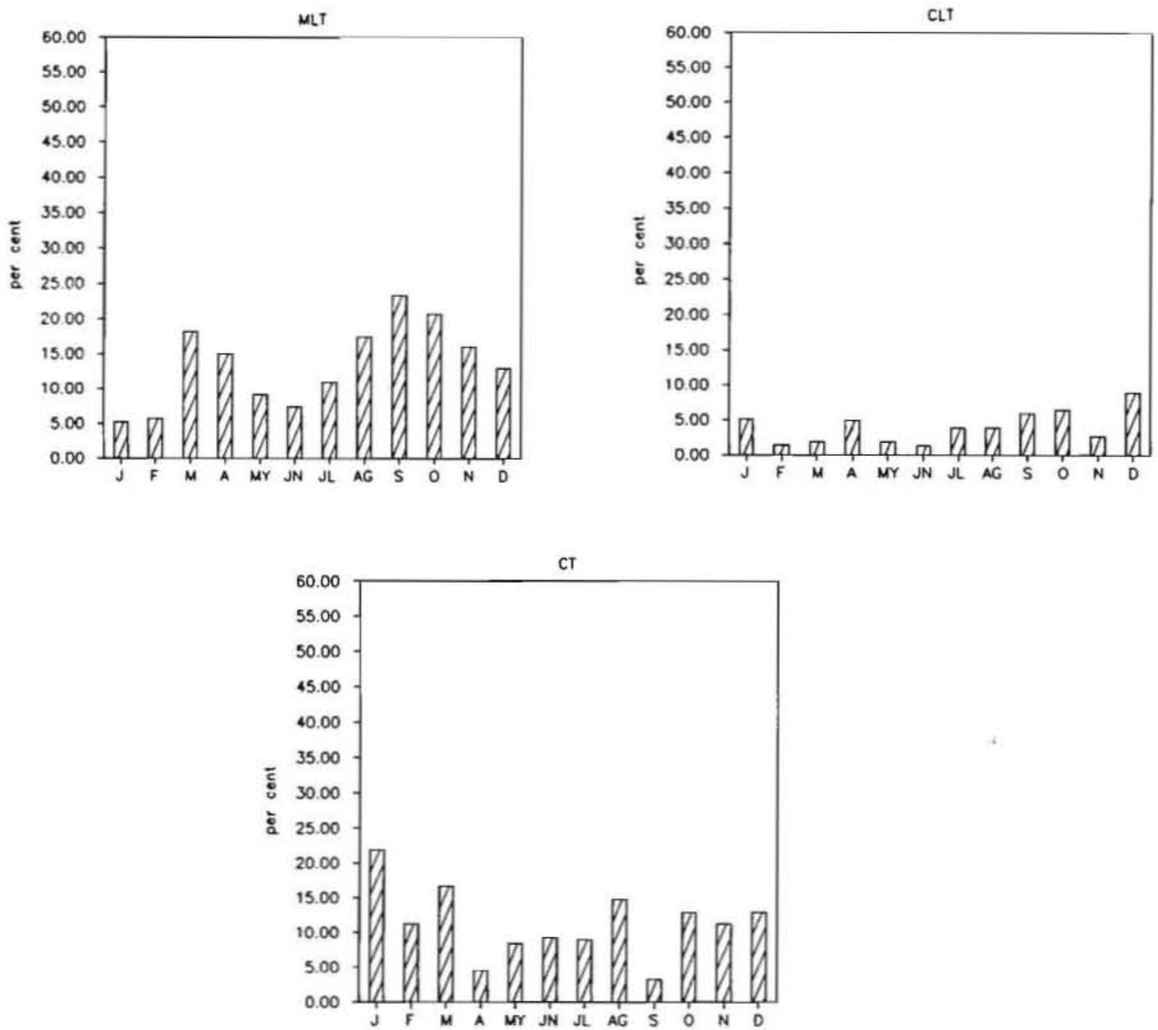
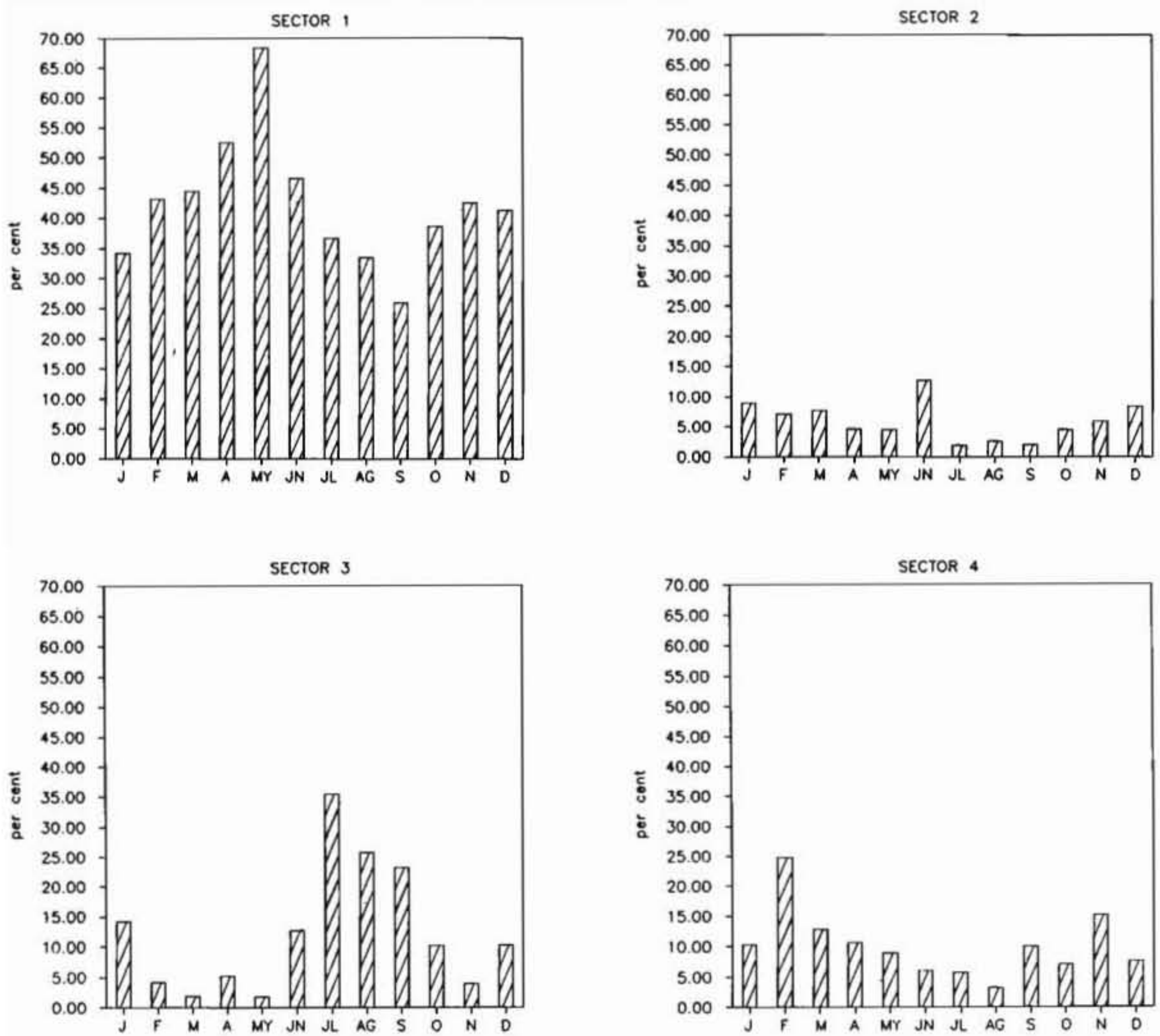


Fig. 7. The seasonal variation of trajectory categories over the period 1983–1987 for 850-HPa trajectories.


SECTOR 1
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60.00
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Fig. 8. (contd)

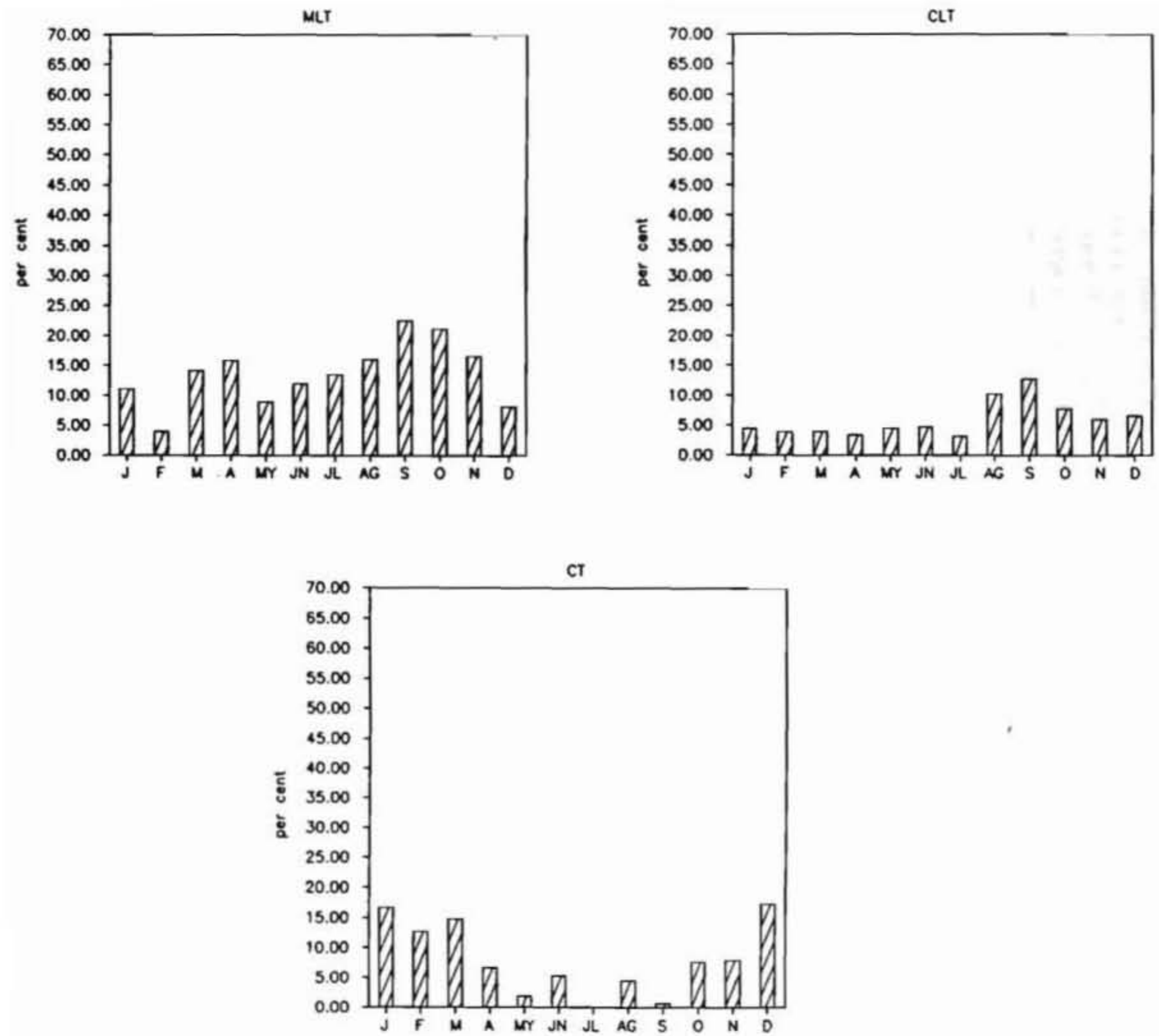


Fig. 8. The seasonal variation of trajectory categories over the period 1983–1987 for 700-HPa trajectories.

airflows off the Algerian plateau and the Atlas Mountains, which occur more frequently at this time of year. The maximum frequencies for sector 4 are in February and November, dropping to almost zero in summer.

Marine local trajectories are more frequent in the beginning of the spring (16%) and in the autumn (24%). Continental local trajectories are negligible except in August and September at the 700-HPa level. Curved trajectories have the highest frequency in winter for both levels because of the persistence of the Azores anticyclone at this time of the year.

5. SYNOPTIC METEOROLOGICAL PATTERNS

An analysis of both 850- and 700-HPa synoptic weather maps corresponding to the months with maximum frequencies for each trajectory classification has been carried out to ascertain the cause of these common pathways by determining the synoptic patterns responsible for them. The choice of these patterns was made by studying the frequency and persistence of the synoptic situation. So, two meteorological synoptic patterns were found as causes of trajectories from sector 1. One of them is characterized by a low pressure system situated over or west of Great Britain (Fig. 9a). The other pattern consists of a semi-stationary low-pressure system isolated from the westerly general circulation and situated west of the Iberian Peninsula (Fig. 9b). It was observed that similar meteorological patterns appear in both the 700- and 850-HPa levels for trajectories coming from sector 1. For sector 2, the most important feature of the synoptic pattern is a strong anticyclone spread from the

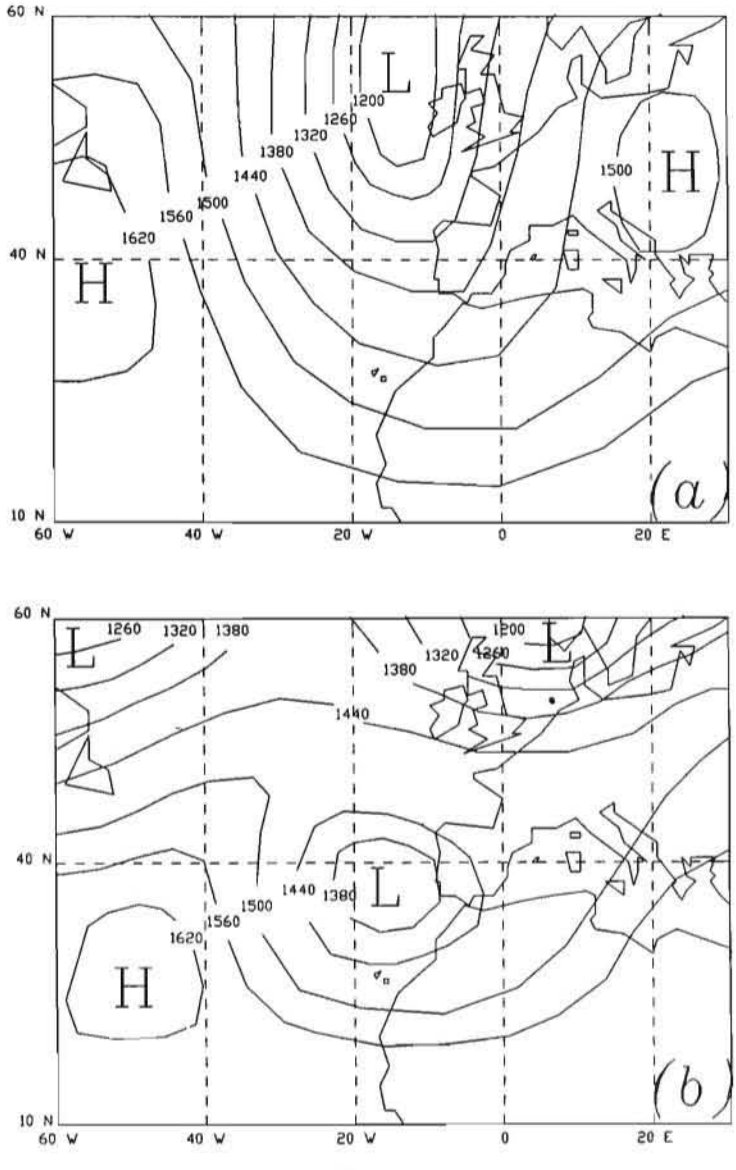
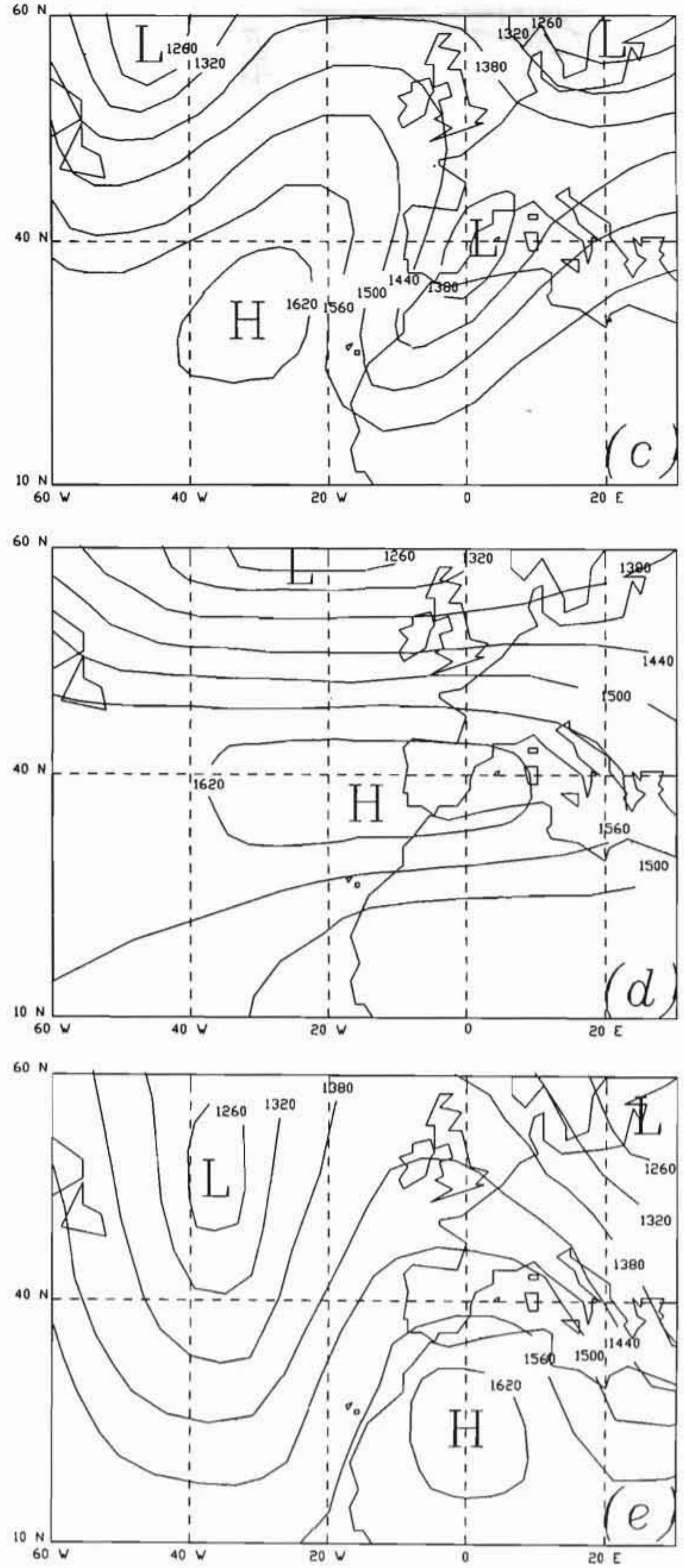


Fig. 9(a, b).


60 N
40 N
10 N
60 W
40 W
20 W
0
20 E
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H
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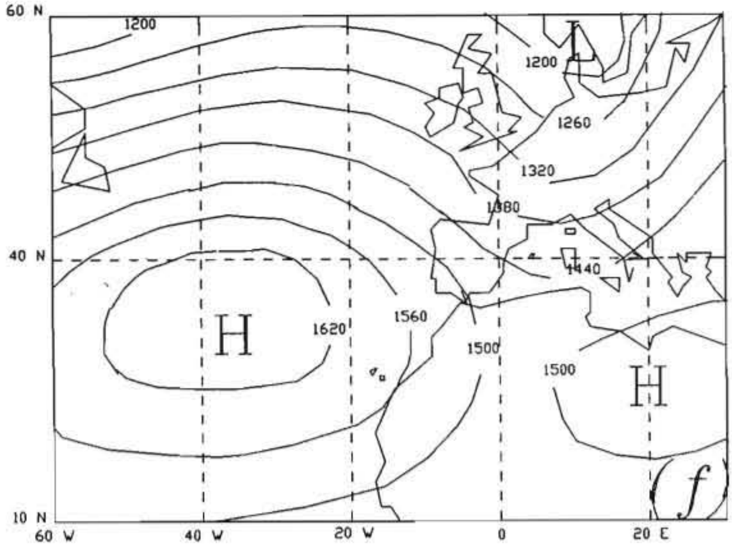
1320
1380
1440
1500
1560
1620
(c)
(d)
(e)

Fig. 9(c–e).



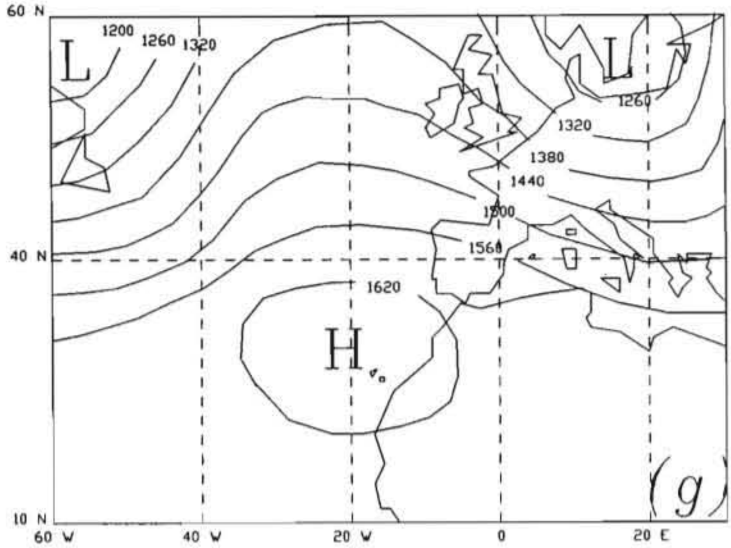


Fig. 9. Typical synoptic patterns for trajectories surface from (a) sector 1, pattern 1; (b) sector 1, pattern 2; (c) sector 2; (d) sector 3; (e) sector 4; (f) curved trajectories; (g) local trajectories.

Azores Islands to Great Britain and a low pressure system over the western Mediterranean Sea. A northeasterly flow between both pressure systems is established, bringing air masses from Europe to the Canary Islands (Fig. 9c). During the summer season, this situation is enhanced by a thermal low pressure system over the Sahara Desert and Iberian Peninsula. The most frequent synoptic pattern of sector 3 is a persistent high pressure system over Spain giving rise to easterly flows over the region (Fig. 9d). In summer, this meteorological pattern at 700 HPa is generally associated with a thermal low pressure system over the Iberian Peninsula and Sahara Desert at and below the 850-HPa level causing trajectories from sector 2 at the latter level (Figs 10a and 10b). It agrees with the percentages of sector 2 and 3 at both levels during summer (see Figs 7 and 8). A high-pressure system over the Sahara Desert can explain most of the trajectories coming from sector 4 (Fig. 9e). Curved trajectories are associated with a strong subtropical anticyclone sited over the Azores Islands (Fig. 9f). Non-significant differences have been found between synoptic patterns for MLT and CLT categories. Local trajectories are produced primarily when the Azores

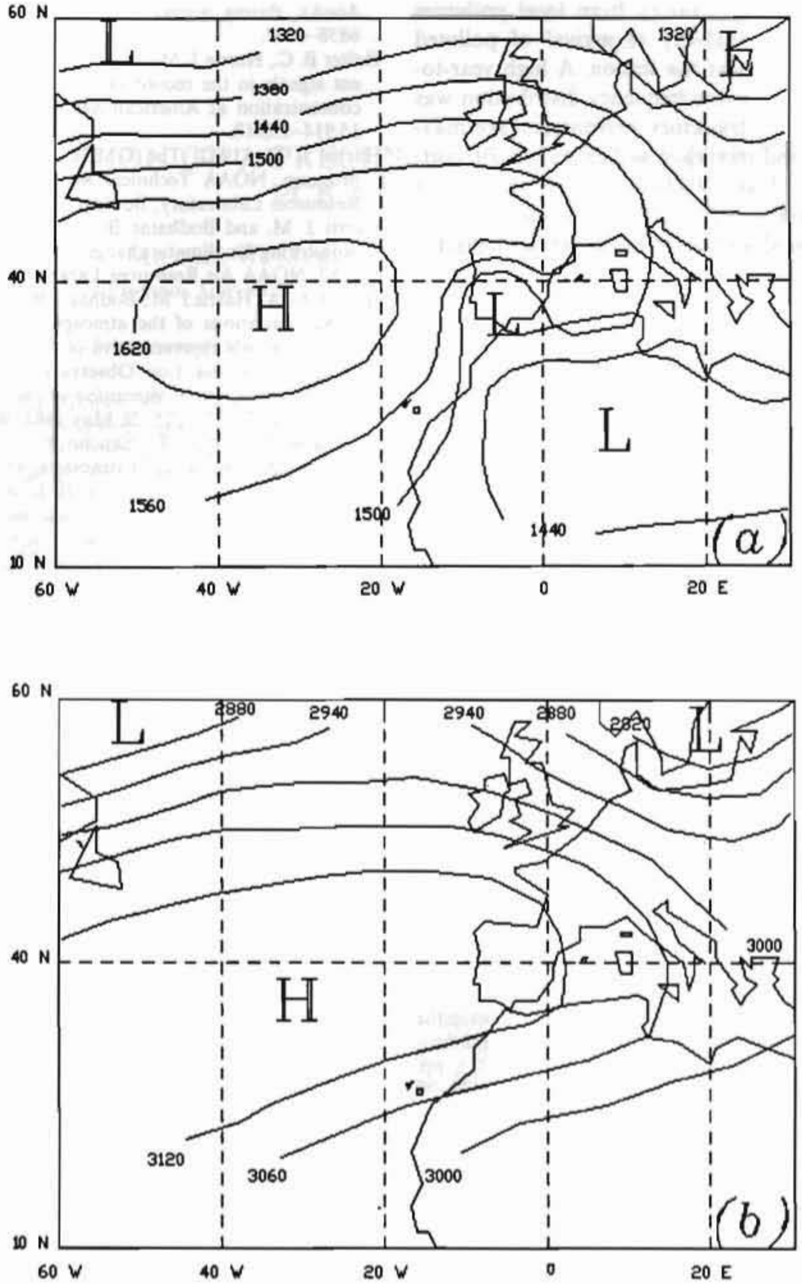


Fig. 10. Typical synoptic patterns for trajectories in summer (a) at 850 HPa and (b) at 700 HPa.

anticyclone is sited over the Canary Islands (Fig. 9g). It causes low pressure gradients and hence, weak flows.

Since the relative position of pressure systems must be the same at 850 and 700 HPa to cause the same category of back-trajectories, only 850-HPa charts have been drawn.

6. SUMMARY AND CONCLUSIONS

For the first time a comprehensive study of synoptic conditions affecting the Izaña baseline station has been performed using back-trajectories to characterize the air masses arriving at the observatory. The trajectory model has been shown to be very suitable in describing the flow climatology of Izaña.

Seven categories were established to classify the trajectories. Five-day trajectory starting outside a 2000-km radius circle defined long-range transport. The North Atlantic Ocean sector was the most frequent origin of air masses, confirming the suitability of the observatory to measure clean background conditions and to represent the North Atlantic area in the BAPMoN network. The trade-wind inversion further isolates the Izaña observatory from local pollution and lowers the probability of arrival of polluted European air masses at the station. A high year-to-year persistence of sector frequency distribution was observed. Sector 1 trajectory percentages are maximum in May and minimum in September. Percentages for sector 3 at 700 HPa and for sector 2 at 850 HPa peak in summer. This can be explained by both thermal-wind and trade-wind inversion effects.

The synoptic meteorological patterns that explain the observed trajectories were determined. These patterns confirm the very important influence of the strength and position of the subtropoical high pressure system normally situated over the Azores Islands.

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