Meteorological Processes Relevant to Forest Fire Dynamics on the Spanish Mediterranean Coast

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ABSTRACT

The Valencian region on the Spanish east coast has experienced a significant increase in wildfires in the last 20 years, as have other areas in the Mediterranean basin. Experimental data and modeling results, obtained within several European Commission (EC) projects in southern Europe, indicate that specific mesometeorological circulations develop in these regions during the summer. Analysis of the available evidence further indicates that the resulting flows could be instrumental in the evolution of wildfires in this area. Three situations have been identified that cover the most likely interactions between the synoptic conditions and the regional winds, and their implications for the dynamics of fires in this region. These situations are 1) diurnal cycles of sea and land breezes with a thermal low developing over the Iberian Peninsula; 2) ''ponientes,'' that is, a Föhn effect producing westerly winds when a traveling low-pressure system crosses the Iberian Peninsula; and 3) combined cycles, when the diurnal cycle of sea breezes is followed by coupling of the land breeze and drainage flows with upper westerlies at night. In the Valencian region, the highest frequency of fires and the largest burnt areas appear to occur under the latter conditions.

For the Spanish Mediterranean coast, the meteorological situations described can be identified easily, and their most probable evolution scenarios forecasted 12–24 h before their occurrence. Equivalent situations may be expected in other parts of the Mediterranean basin and, to this effect, this work is also intended to serve as a stimulus to study the relations between synoptic meteorological conditions and the orography, the resulting local winds, and the fire dynamics in other southern European regions.

1. Introduction

The occurrence of wildfires in the Mediterranean basin appears to have been a fact of life for most of its recorded history and may now be aggravated by recent changes in human activities. Both marginal farming in the mountains and gathering of firewood in the forests have been, essentially, abandoned over the last 30 years or so, leading to the wide spread of fire-prone vegetation and the accumulation of fuel. On the Spanish east coast, the Valencian community (Fig. 1) is one of the regions that has experienced a significant increase in wildfires in the last 20 years (Fig. 2).

Another problem related to wildfires has been the elevated number of accidents, some of them fatal, involving firefighters working to extinguish the fire. Available evidence indicates that these are related to ''unexpected and sudden shifts'' in the dynamics of the fire, which can leave whole groups trapped in ravines and other hard-to-get-out-of places. It is also a confirmed fact that most of these shifts tend to occur toward the end of the afternoon and early evening.

A review of the scientific literature on forest fires indicates that most studies deal with their effects on ecosystems, the changes in soil properties, and the regeneration of the forest ecosystems (Trabaud 1982; Moreno and Oechel 1994). There are far fewer studies concerned with the influence of meteorology on the behavior of the fire (Brotak and Reifsnyder 1976; Rothermel 1983), and the available ones tend to be very generic (Chandler et al. 1991; Johnson 1992). They are also mainly based on North American experiences, where the science of applied meteorology has permeated other fields, is well developed, and the products are readily available.

This does not appear to be the situation in Europe where the ''meteorological input'' is confined mainly to the elaboration of ''indexes'' that relate ''fire hazard potential'' to other variables such as ground moisture, relative humidity, temperature, maximum wind speed, etc. (ICONA 1988; Carrega 1991; Alcover et al. 1994). This situation may arise from considering fires as unavoidable events that will occur with the highest probability under certain conditions and thus require a matching degree of readiness. This approach is widespread and represents a static conception of the atmospheric processes.

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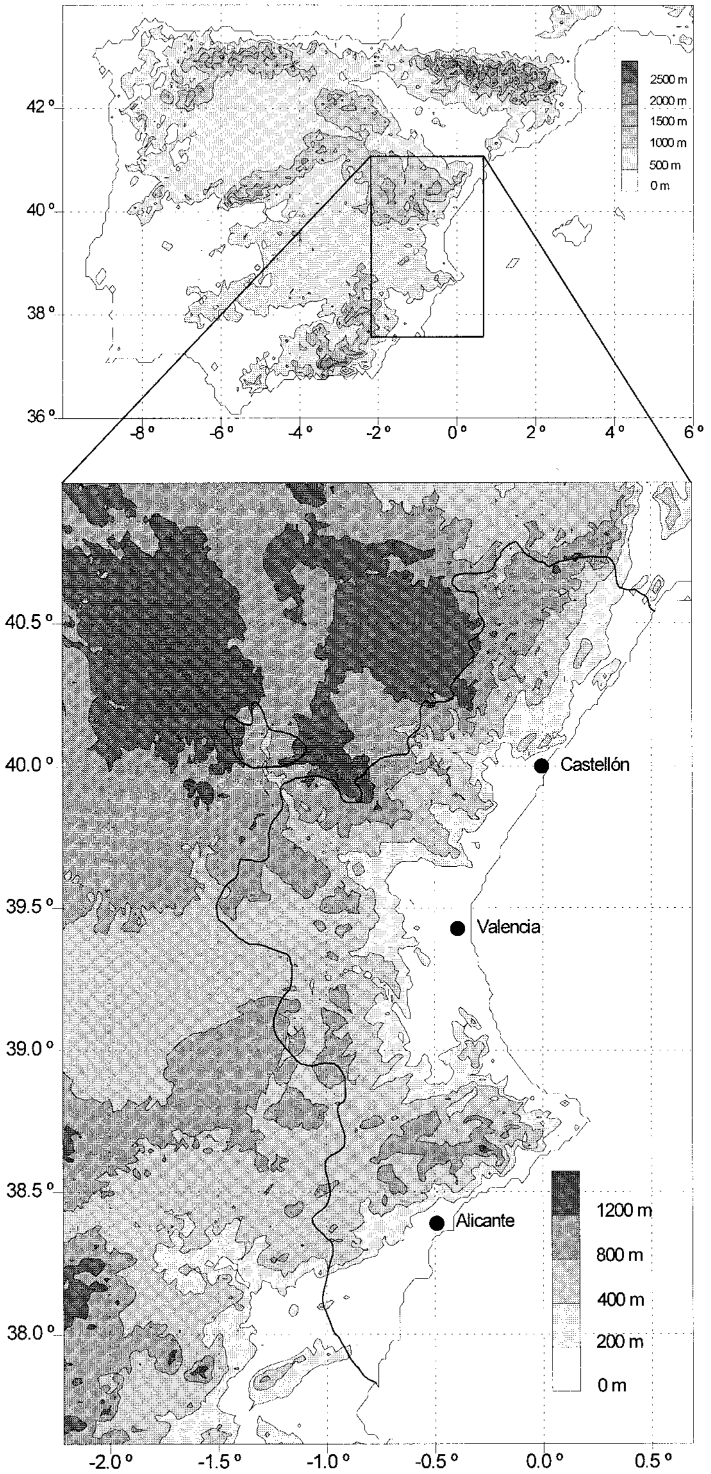

FIG. 1. Map of the Iberian Peninsula showing the major orographic features and Valencian region. It also shows some of the points refered to in the text.

Results from projects supported by the European Commission (EC) over the Iberian Peninsula and the western Mediterranean basin have shown that most atmospheric processes in this region in summer are dominated by mesometeorological circulations with marked diurnal cycles (Millán et al. 1991, 1992, 1996, 1997). Some of these can reach depths of 2–3 km over the coastal areas and up to 5 km or more over the main

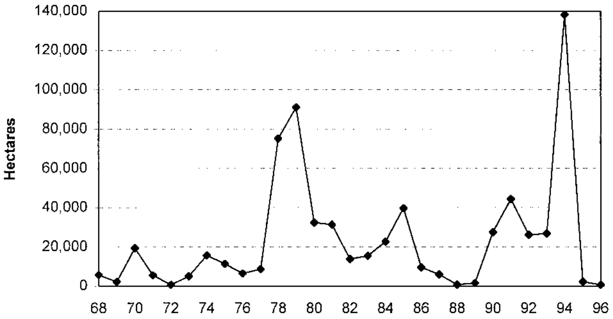

FIG. 2. Number of fires per year in the Valencian region for the period 1968–96 (ICONA 1996).

land areas. During the evening and night, these circulations relax or collapse, often involving coupling and/or decoupling cycles with the upper winds and rapid reversals of the surface wind direction. Thus, their diurnal evolution and interactions with the upper flows, at any given time, can prove fundamental in understanding the dynamics of wild fires in this region.

The present work is based on the available experimental evidence and modeling results from the EC projects, backed by field reports from the fire brigades and direct observations by Centre for Environmental Studies of the Mediterranean (CEAM) personnel. Its area of application is shown in Fig. 1, and the period considered will be centered on summer conditions.

2. Background: The geographical and meteorological settings

The Mediterranean basin is located in the subtropical latitudes, where good weather prevails most of the year and the ground properties undergo very marked seasonal changes. The orography is complex and includes extensive coastal areas, most of which are backed by high mountain ranges that surround a sea that is both deep and warm, that is, abyssal temperatures of 13° versus 4°C for the oceans. The weather and climate in this region have been described by the British Air Ministry, U.K. Meteorological Office (1962), and Barry and Chorley (1987).

The meteorological processes across the entire Mediterranean in summer are dominated by two large, semipermanent weather systems located at each end of the basin. At the western edge is the Azores anticyclone, and over the eastern borders is the low pressure monsoon system that extends from the Middle East to the whole of southwestern Asia. Important effects on the atmospheric flows are caused by the major mountain ranges surrounding the western basin. These can act as constraining barriers to the north–south and east–west movement of air masses and can generate either mountain-induced aerodynamical vortices or large-scale blocking. The development of ''mountain gap winds'' as a result of large-scale channeling (Scorer 1952) is also a fact in the entire region.

The orography, the soil properties, and their annual variation also favor the formation of extensive and deep convective cells and/or thermal lows over the major peninsulas and other landmasses. Thus, subordinate to the larger weather structures, other thermally driven, mesoscale systems develop during the day with important compensatory subsidences, for example, the Iberian and Anatolian thermal low pressure systems, the convergence along the Apennines in Italy, etc., which can strongly modify the regional flows during the day.

Evidence accumulated to 1986 indicated that the diffusion and transport of air pollutants over Spain could be dominated by mesometeorological processes of diurnal cycle acting at the peninsular scale, that is, the Iberian thermal low (ITL) (Millán et al. 1991). As a result, a project was launched to document the relationship between the observed pollutant behavior and the mesometeorological processes over Spain. Other projects followed[1] to document the same processes over the western Mediterranean basin and over the whole Mediterranean basin (Millán et al. 1992, 1996, 1997).

In these projects, air pollutants have been considered as tracers of opportunity of the atmospheric circulations, and the study of concentration cycles at the surface and aloft has been used to provide evidence for the meteorological processes involved. Most of the experimental results have been obtained from spring to late summer. As a result of these projects, much more knowledge has now become available about specific meteorological processes prevailing in the Mediterranean area, as well as their continuity from the local to the subcontinental scales. The available information includes the structure of the circulations, their diurnal evolution and, to a lesser extent, their annual variation.

3. Available evidence and experimental data

a. *Climatological records*

The frequency and size of wildfires in the Valencian community for the period 1968–96, and their main causes are shown in Fig. 3. The major fires have occurred in summer, essentially in July and August. At this time of year, several factors combine to foster the right conditions for the onset and propagation of wildfires. It is the driest time of year as well as the season for tourism, which includes camping and picnicking, and it is also the time when agricultural refuse and slash have been traditionally cleaned and burned after harvesting any crop.

In this region, the available meteorological data comes from two airports and four other primary stations

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[1] These projects were MECAPIP (Mesometeorological Cycles of Air Pollution in the Iberian Peninsula, 1988–91), RECAPMA (Regional Cycles of Air Pollution in the West-Central Mediterranean Area, 1990–92), and SECAP (South European Cycles of Air Pollutants, 1992–95).

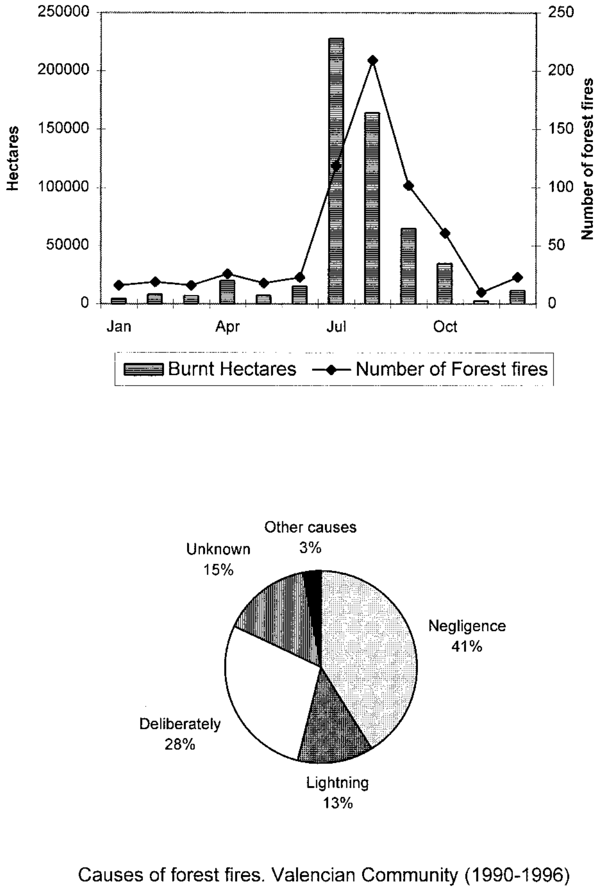

FIG. 3. Frequency and size distribution of fires as a function of time of year for the period 1968–96 (ICONA 1996) and the main causes of forest fires in the Valencian region according to the Consellería de Agricultura (1996).

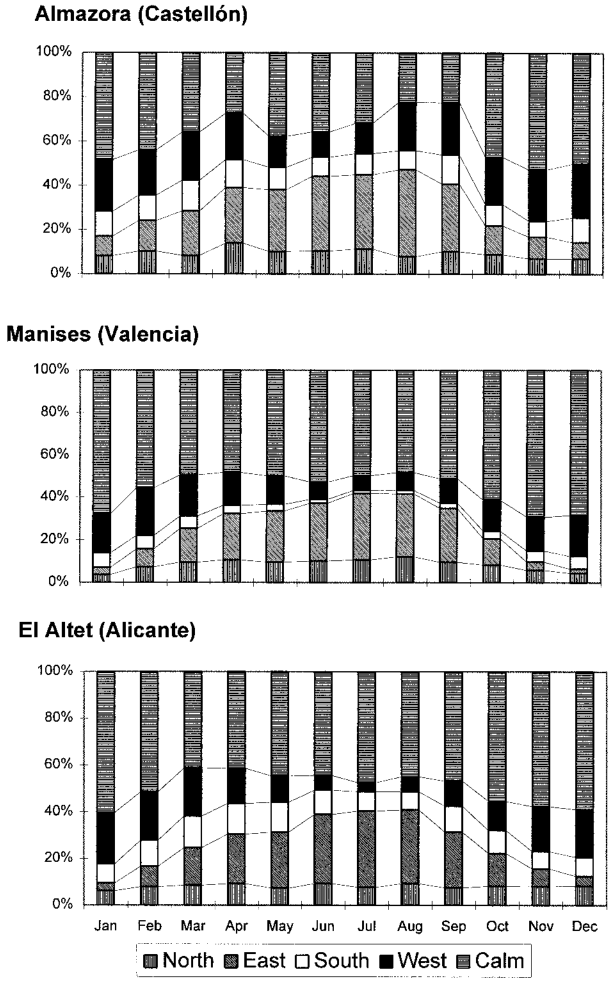

FIG. 4. Frequency of winds in three sites within the Valencian region based on the statistical analysis of climatic records for the period 1960–90.

located in the coastal plains, and thus none of these can be considered as truly representative of the processes farther inland. Data from three[2] of these were used to prepare Fig. 4, which shows the frequencies of wind directions in the airports of Alicante (El Altet), Valencia (Manises), and the meteorological center in Almazora near Castellón for the period 1961–86.

The most obvious sequences are those for the east winds, which reach a marked frequency maximum in midsummer, and the west winds, which reach a much broader maximum during the winter. The sea breezes are included under the heading of east winds, and the land breezes and drainage winds are incorporated in the westerly winds; thus, the observed evolution of east and west winds in Fig. 4 reflects, to a great extent, the seasonal evolution of the local winds. The Almazora site, located near the Mijares River in Castellón, is affected by the east–west orientation of the river course and is also where the strongest sea breezes and most persistent drainage winds are observed. Finally, the Manises site, at the Valencia International Airport, shows the greatest percentage of calms.

The highest frequency of fires appears to occur with easterly winds, that is, when the sea-breeze regime dominates. This is apparently in conflict with the widespread assumption that most fires occur with westerly poniente winds, and this incongruence will be reexamined after evaluating all the available evidence at the end of this work.

b. Results from European projects in southern Europe/Mediterranean basin

The conditions that favor the development of the Iberian thermal low in summer, and its diurnal evolution in the surface pressure maps, are illustrated in Fig. 5. Its effects on the development of the combined sea-breeze and upslope winds can be visualized via the O_3

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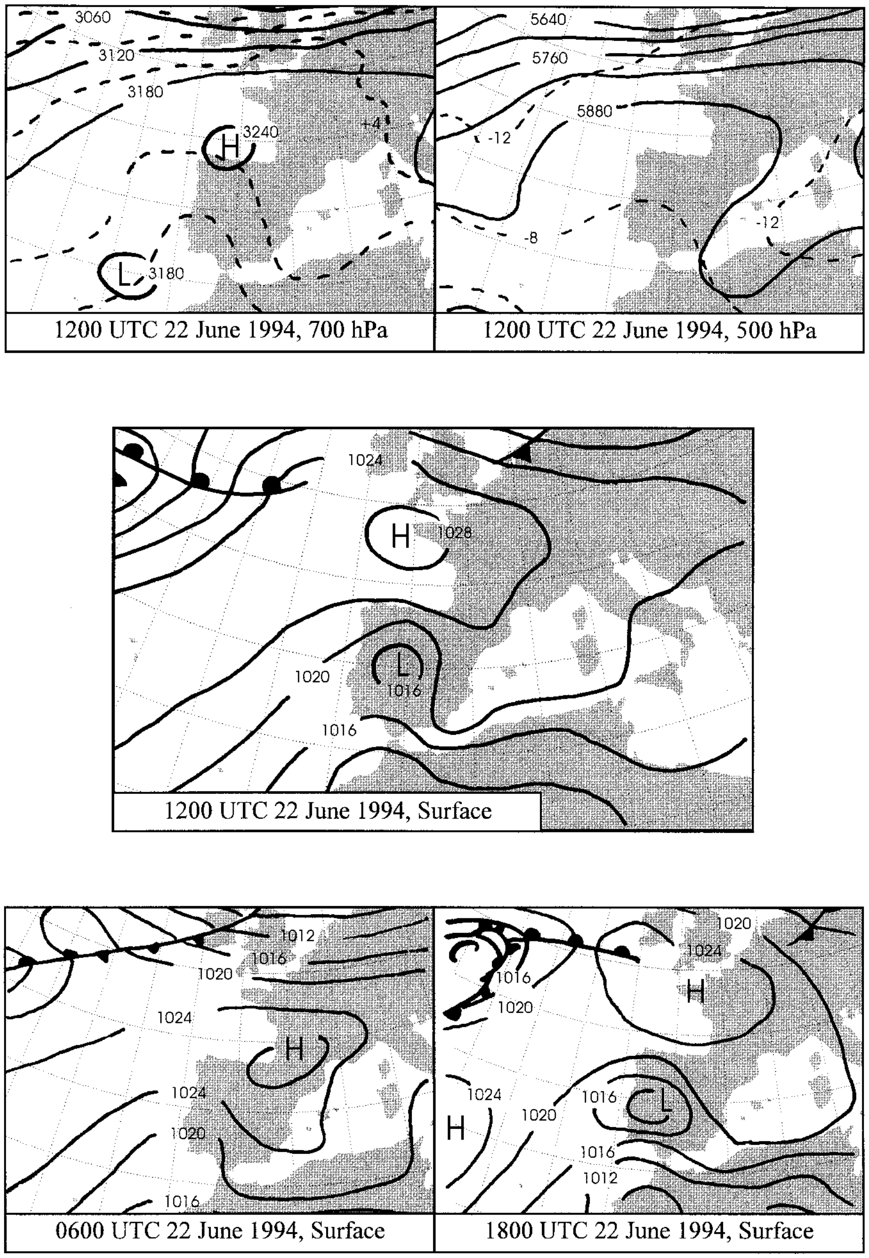
[2] The other three have fallen to urban sprawl and are now surrounded by buildings much higher than the stations.



1200 UTC 22 June 1994, 700 hPa

1200 UTC 22 June 1994, 500 hPa

1200 UTC 22 June 1994, Surface

0600 UTC 22 June 1994, Surface

1800 UTC 22 June 1994, Surface

FIG. 5. Conditions at 700 and 500 hPa, which favor the formation of the Iberian thermal low. Its diurnal cycle for 22 June 1994 is illustrated by the surface maps at 0600, 1200, and 1800 UTC.

mixing ratios measured with an instrumented aircraft, as shown in Fig. 6. On the first flight (1303–1348 UTC) they reach approximately 60 km inland, and on the return flight (1449–1535 UTC) they reach more than 80 km inland. The existence of a column of clean(er) air located between the coast and the central plateau suggests that the flight cuts through two circulatory cells within the thermal low system and that the clean(er) air column corresponds to subsiding air separating those cells.

The wind field and the relative humidity obtained during the return flight are shown in Fig. 7. The first documents a region of wind convergence near the top of the coastal mountains ahead of the leading edge of the sea-breeze front. In this process, several return layers develop above the coastal area, which can also be observed in Fig. 6. It shows that the column of cleaner air in Fig. 6 is also very dry and supports the notion that the air is sinking to complete the circulatory cells. As discussed in section 4a, this mass of dry air can have major implications for the behavior of forest fires on the inland side of the coastal mountain ranges.

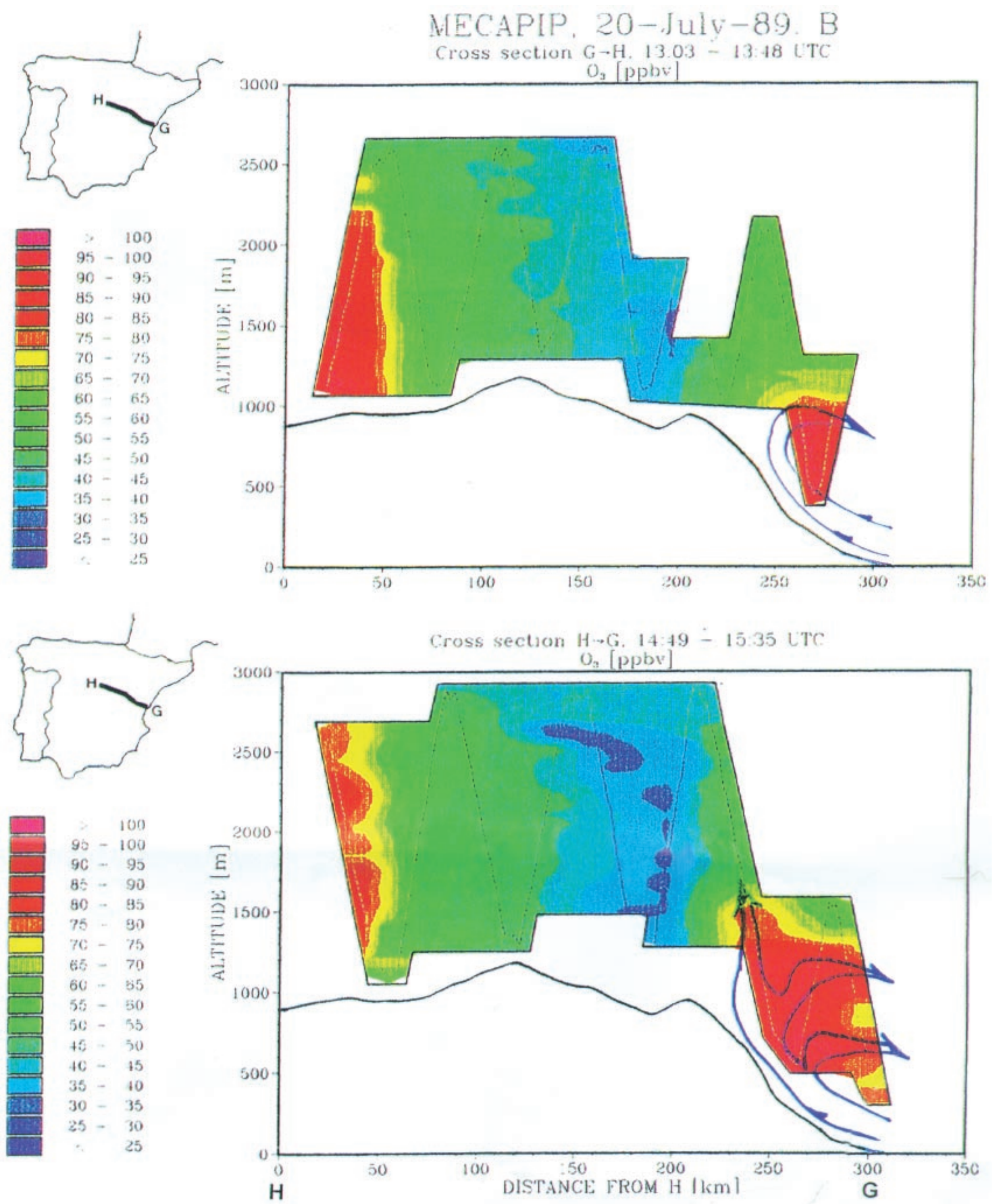


FIG. 6. Two stages in the entrance of the sea-breeze front from the east coast and the development of deep convective activity over the central plateau as documented with an instrumented aircraft on 20 July 1989. The aircraft trajectories are shown by dotted lines.

Figure 8 shows the wind field measured by the aircraft while maintaining a (nearly) constant surface altitude of approximately 500 m over an area of approximately 105 km × 100 km west of Castellón, which is near point G (Fig. 6). It also shows winds converging along the top of the coastal mountains that separate the central plateau from the Mediterranean coast. The diagonal line shown in Fig. 8 follows the footpath of the flight track of Figs. 6 and 7 and is intended to emphasize how the convergences observed in the vertical and horizontal cross sections in Figs. 6–8 are complementary.

Figures 9 and 10 show schematics of the thermal low circulations over the Iberian peninsula. After the thermal low relaxes during the night, subsidence predominates over the whole region while the upper winds (≈2500–3000 m) have been observed to range from southwest

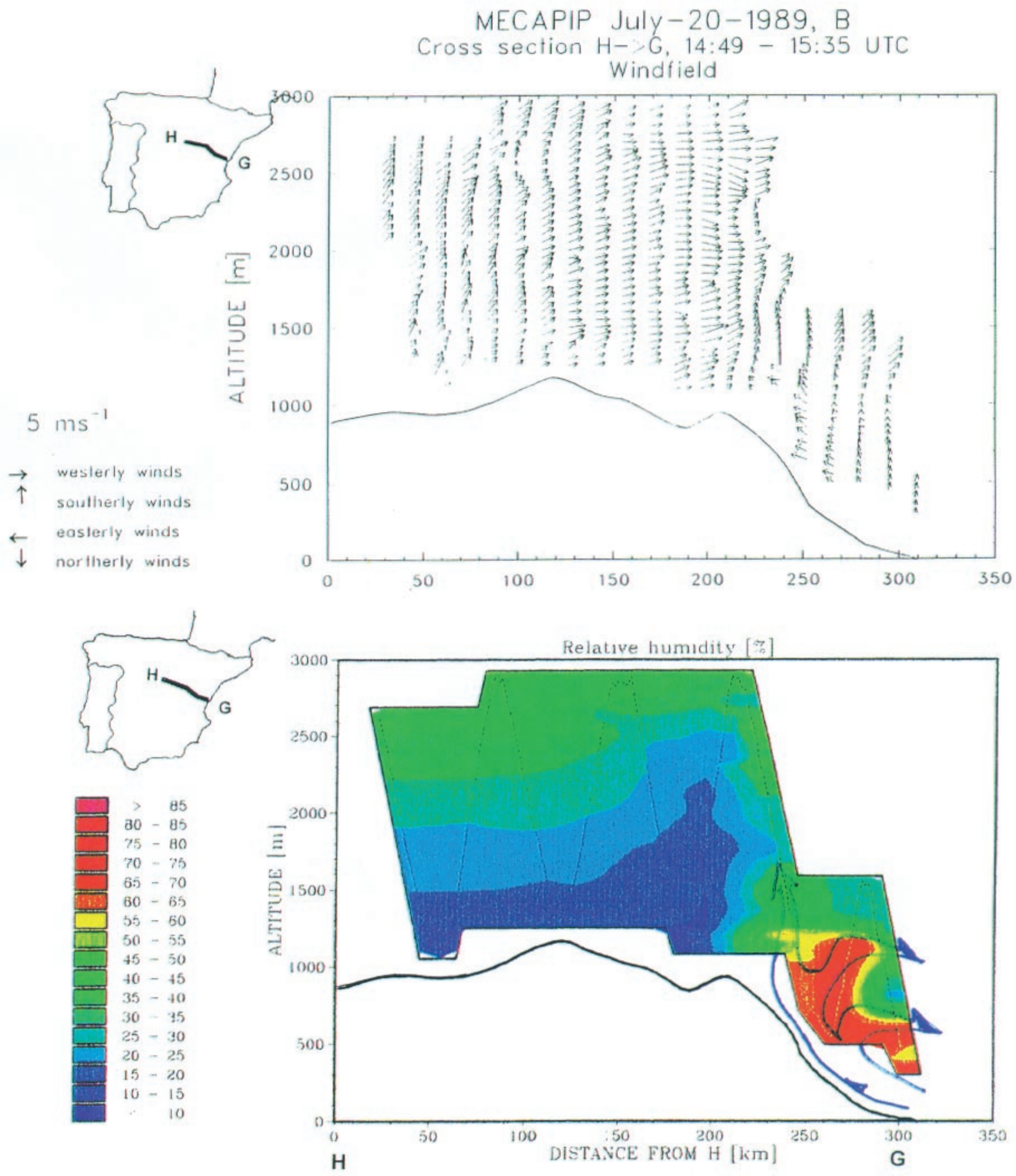


FIG. 7. Wind field and relative humidity obtained on the return flight of 20 July 1989. The relative humidity distribution shows the lowest values in the areas with subsiding air.

through west to northwest and north. The onset of solar heating initiates the formation of sea breezes that progress radially inland, while their return flows move toward the sea under a general level of subsidence aloft. The compensatory subsidence for the circulation in the central cell and for the converging flows in the coastal cells, shown with cleaner air in Figs. 6 and 7, appears to take place over land at distances varying from 100 to 200 km from the coast. The development of the thermal low system and the resulting convergence at ground level along all the coastal areas are also compensated by an increased amount of subsidence over the Mediterranean Sea and the Atlantic (Millán et al. 1992, 1997).

During the evening and night, ground cooling sets in. In this terrain, stabilization is associated with the accumulation of cold air in the shallows followed by drain-

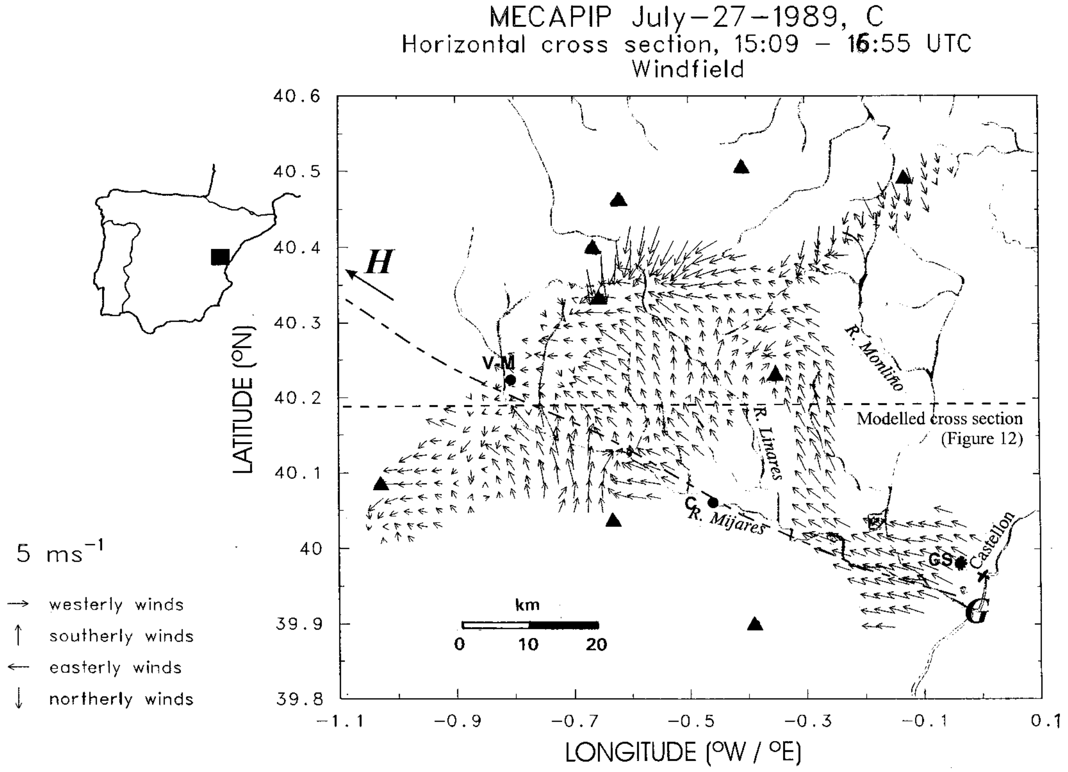


FIG. 8. Wind field at aircraft height (≈500 m above ground) in the mid-to-far field of the Castellón industrial complex obtained on 27 July 1989. The main area covers approximately 105 km × 100 km, and the wind field indicates strong convergence approximately 80 km inland, along a line following the mountain ridges; it represents the leading edge of the combined upslope and breeze front. The footpath of the 20 July flight (Figs. 6 and 7) and the cross section for the modeling in Fig. 12 are also shown.

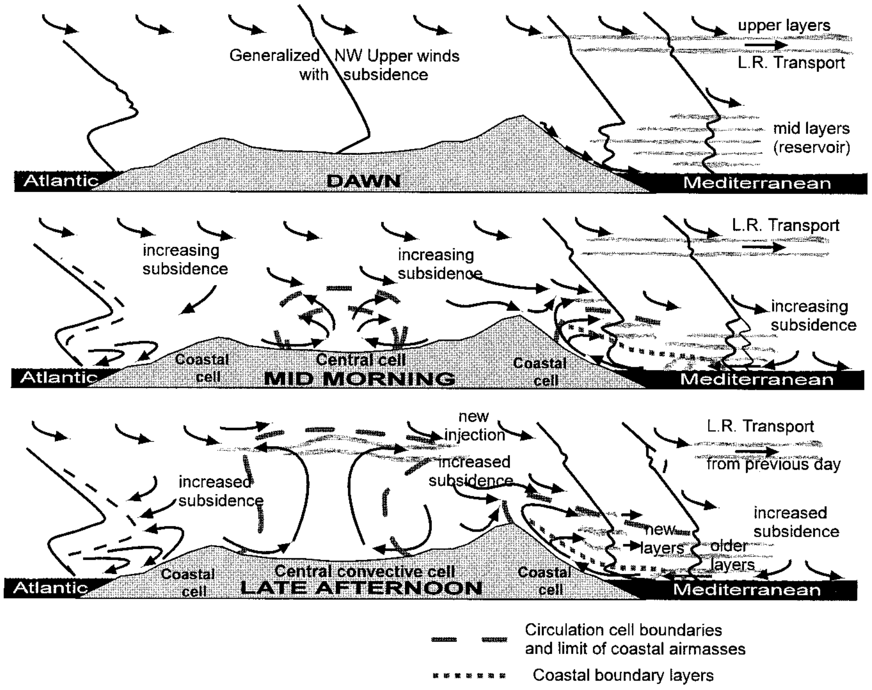


FIG. 9. Schematic cross section of the Iberian thermal low circulation as deduced from the meteorological and air quality observations.

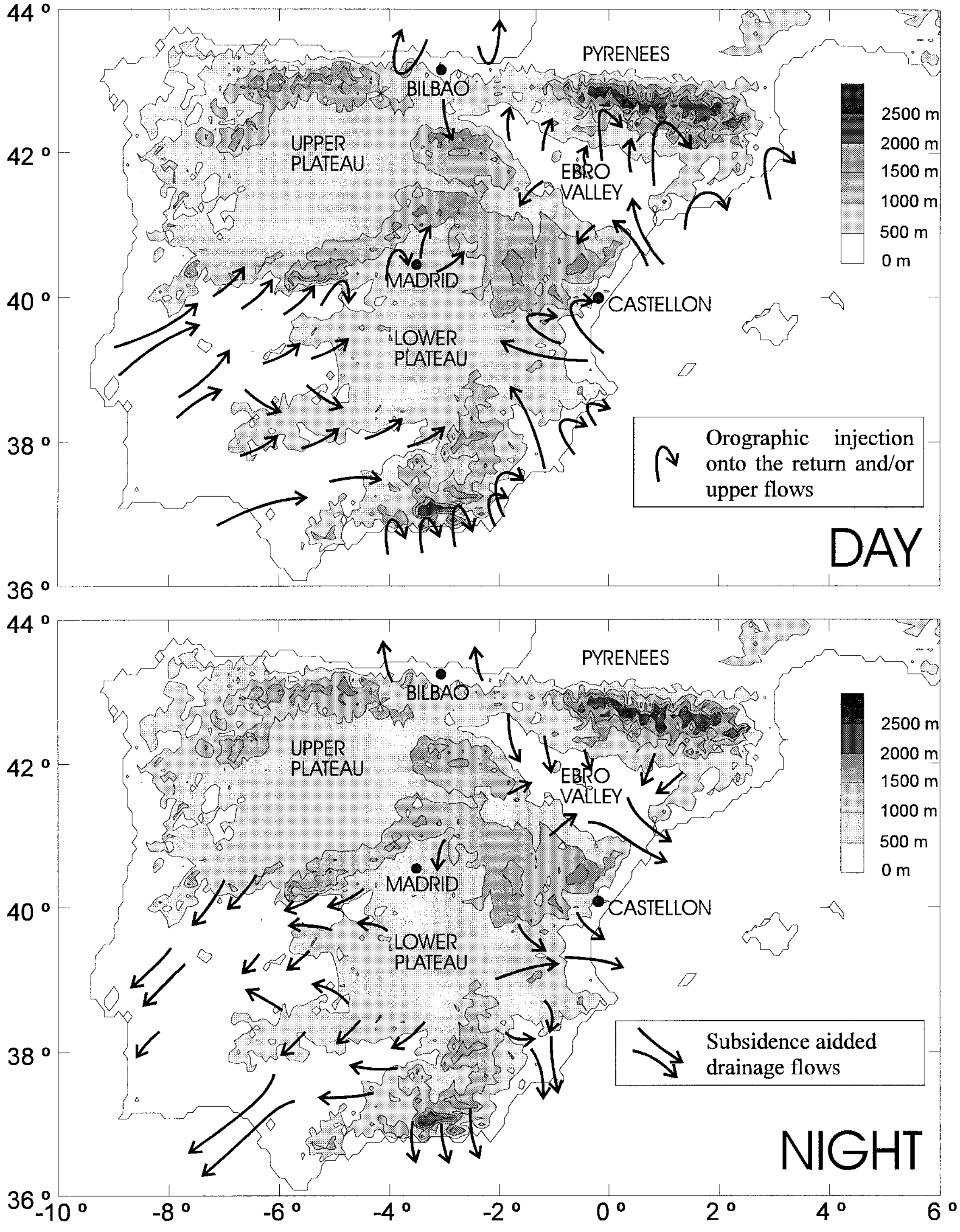


FIG. 10. Proposed structure for circulations within the Iberian thermal low system: horizontal view. This figure complements Fig. 9 and relates the characteristics of the observed and expected circulations to the prevailing orography.

age into the valleys. As Fig. 5 shows, the solar-driven circulations develop during the day under anticyclonic conditions and sinking air aloft, and their development holds and/or lifts the main level of subsidence during the same period. As soon as the solar heating ceases, however, stabilization and sinking motions are reestablished, and the onset of drainage winds in the main valleys during the night may thus become ''aided'' by the subsidence aloft.

This type of flow has also been documented in the

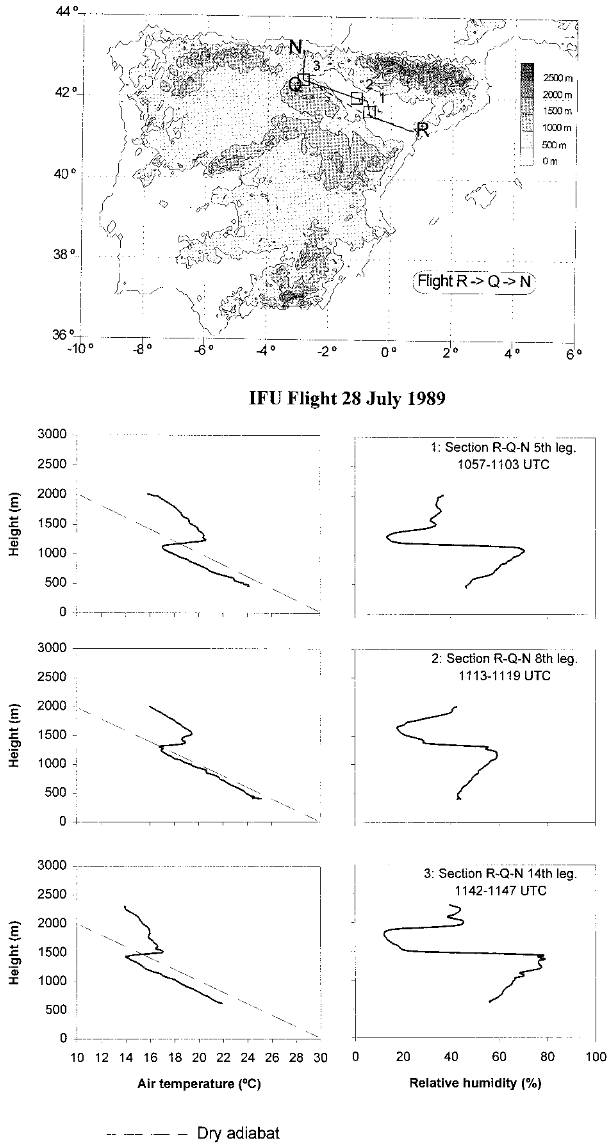


FIG. 11. Composition of temperature and relative humidity soundings along the Ebro valley obtained on 28 July 1989. These parameters were measured along three legs of the RQN flight over the points shown by squares. In the sounding closer to the mouth of the valley, the height of the subsidence inversion base at approximately 1100 m is already lower than the heights of the mountains that conform the valley and will leave them out of the surface flow.

Ebro valley during the Mesometeorological Cycles of Air Pollution in the Iberian Peninsula (MECAPIP) project (Millán et al. 1992). As shown in Fig. 11, the drainage flows were separated from the upper air mass by a subsidence inversion that had formed during the night. In the sounding closer to the mouth of the valley, the base of the subsidence inversion, at approximately 1100 m, is lower than the mountain ridges conforming the valley, which could be left immersed in the upper (synoptic) flows during the night. Similar effects could occur in other valleys draining onto the Mediterranean Sea. Thus, the key questions are as follows: How important are the synoptic conditions? How do they affect the nocturnal wind regime in this region? And how do they affect the transitions from day to night and night to day regimes? The cases that follow will attempt to answer these questions.

4. Meteorological situations: Type and interactions with the upper flows

a. Diurnal cycles of sea and land breezes with a thermal low

For this case, as Fig. 5 shows, the development of solar-driven mesoscale circulations during the day are favored by weak pressure gradients from the surface to 500 hPa.

1) MECHANISMS AND CHARACTERISTICS

On the Spanish east coast, sea breezes occur most of the year. However, it is only during the summer that they reach their maximum penetration inland when they become part of the Iberian thermal low system. In very dry years, these processes can start as early as March, and the maximum wind speeds are reached toward the end of May or early June, when the temperature contrast between the land and the sea reaches a maximum. However, their maximum frequency (almost daily), duration (up to 12 h a day), and penetration inland (up to ≈80–100 km) occur in midsummer due, in part, to favorable synoptic conditions, longer daylight hours, and much drier ground. Some of these facts are reflected in Fig. 4.

2) EVOLUTION

A more detailed view of the resulting flows has been obtained with the RAMS model (Pielke et al. 1992). Figure 12 shows the development of the sea breeze and upslope flows on the Mediterranean coast in a day with thermal low. The sea-breeze front penetrates inland in a steplike manner as it grows in reach by incorporating, successively, weaker upslope circulatory cells. At 0600 UTC a convective cell can be observed near the shore as the colder drainage air (≈22°C) encounters the warmer sea (≈26°C). By 1200 UTC several convective cells can be observed with the leading edge of the breeze front at approximately 40 km inland. By 1600 UTC the breeze has incorporated all other upslope cells and reaches the top of the mountain ranges at approximately 80 km inland, as documented experimentally in Figs. 6, 7, and 8. By 2200 UTC drainage is setting in all along the mountain slopes toward the sea.

In Fig. 13, the modeling results at the peninsular scale show that, by late afternoon, the leading edges of the sea breezes around the peninsula merge into a series of convergence lines that become organized (or locked) roughly along the top of the main mountain ranges, and

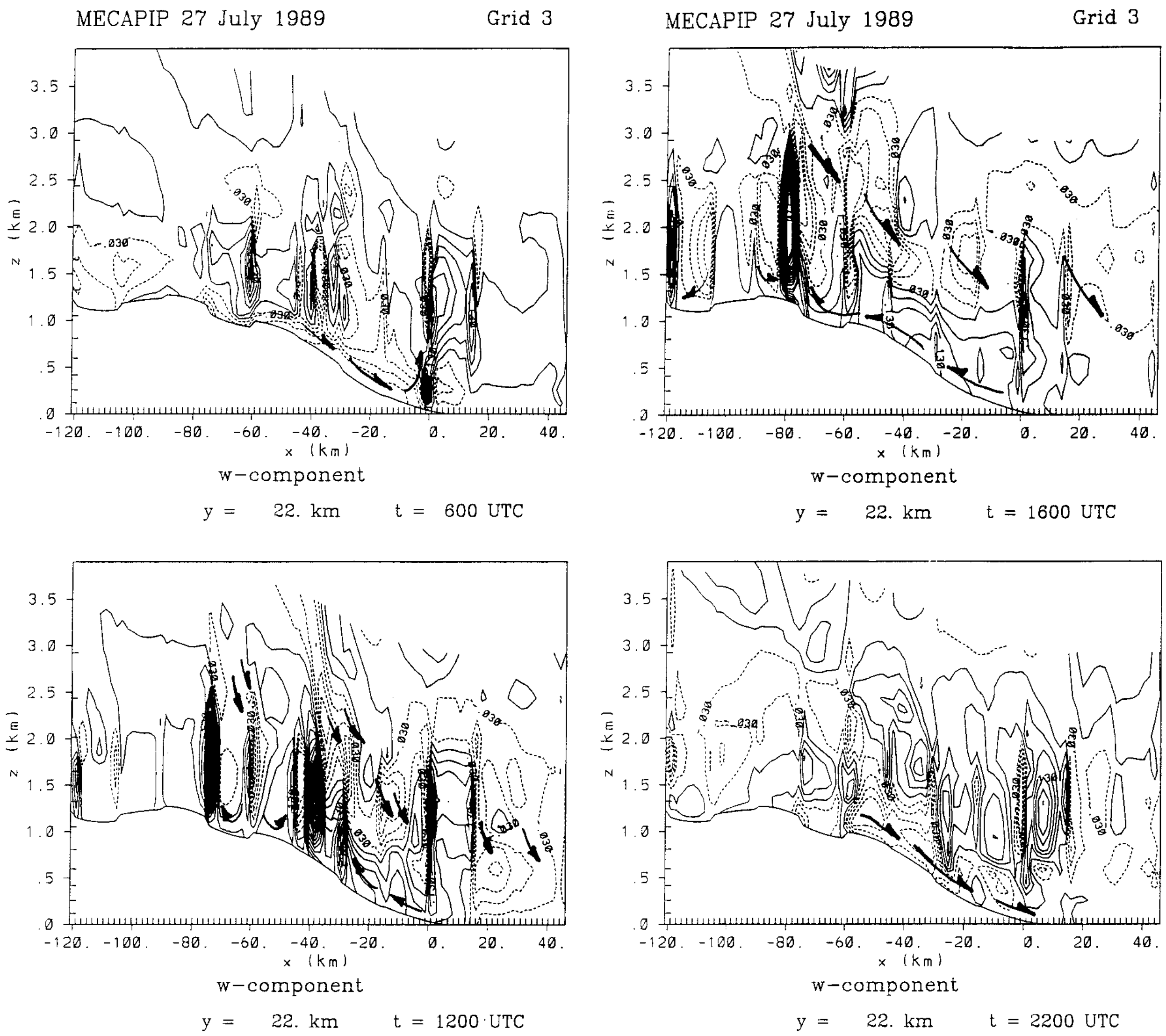


FIG. 12. Modeled vertical wind component (m s^{-1}) along an east–west transect cutting through point G (Figs. 6 and 8) at 0600, 1200, 1600, and 2200 UTC 27 July 1989, illustrating the steplike penetration of the breeze as it incorporates various upslope wind cells during the day.

that there is a great variability in this structure from day to day.

The diurnal evolution of these flows has the following characteristics.

- During the day they become strongly channeled along the valleys connecting the coast with the central plateau. Wind speeds of 8–10 m s^{-1}, lasting for several hours, have been recorded.
- In the valleys, the most intense winds are confined to a core, located roughly along the center of the valley axis with the maximum winds at approximately 100–200 m above the ground.
- Upslope winds with east-southeast to southeasterly components also develop along most of the slopes oriented to the south. Thus, a spiral-like flow could be expected along the valleys oriented east–west with compensatory (weak?) subsidence down the north-facing slopes.
- As a result of the previous characteristics, some of the mountain ridges conforming the valley may be located in the return flows of the combined sea-breeze and upslope winds during the whole or part of the day. This situation can vary from valley to valley on account of differences in aspect, height of the ridges, orientation of the slopes, and time of day.
- In the evening, there is an extended period of calm (up to a few hours) before the land breeze and drainage winds become well established during the night.
- These are mostly confined to the valleys and attain their maximum intensity before sunrise, although rare-

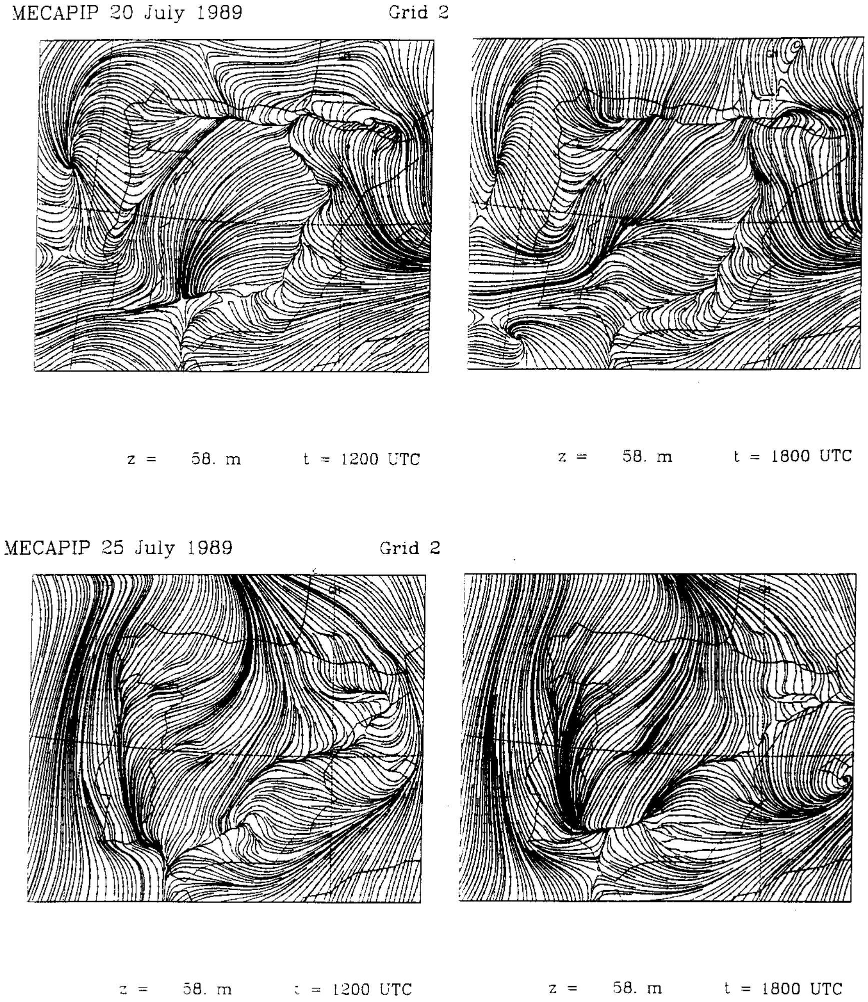


FIG. 13. Modeled surface flow streamlines at 1200 and 1800 UTC 20 and 25 July 1989. In both cases, a thermal low developed. In the first case, it was well centered over the peninsula and the resulting flow is dominated by a series of convergence lines with an almost closed structure following the major mountain ranges. In the second case, the thermal low formed over the southern half of the peninsula and the resulting flow becomes dominated by a line of intense convergence in the shape of a U.

ly reaching depths of more than 150 to 200 m. During this period, therefore, the mountain ridges may remain immersed in a weak synoptic flow if any develops during the night.

- Additionally, because the Mediterranean Sea can be very warm (25°–27°C) at this time of year, the drainage winds can become blocked upon reaching the sea, as illustrated in the modeling results in Fig. 12 at 0600.

With respect to interactions with wildfires, the most dangerous period in this cycle appears to occur during daylight hours as the sea breezes tend to become strongly channeled inland along the natural passes (valleys), which connect the coast to the central plateau. In these valleys, the cores of strong easterly winds are reinforced by (or reinforce) upslope winds along most of the south-facing slopes, which experience easterly to southeasterly winds as one progresses up the valley wall. The possibility of runaway fires started by careless outdoor cooking becomes important. The areas with the highest risk would be associated with picnicking sites by the rivers and, once started, a fire could propagate upslope very rapidly in a chimneylike flow.

Inland of the coastal mountain ranges and of the main convergence lines, another situation can be important. As Figs. 6, 7, 9, and 12 show, the compensatory flows between the coastal circulatory cell(s) and the deep convection inland involves the *slow subsidence of upper air*. This, in turn, results in heating and drying of the sinking air mass, which can yield values of relative humidity near 10% or less (Fig. 7). Fires starting in these regions could be extremely hot. After the Maestrazgo fires of 1994, which essentially occurred under the main subsidence area in Figs. 6 and 7, glass bottles were found showing the results of partial or total melting.

During the night, the intensity of the drainage winds is weak near the valley ridges and increases downslope toward the bottom of the valley. Near the top of the slopes, they could be too weak to override the thermal circulation of a strong fire, and the dynamics of the flame front could become dominated by its own thermal properties and may tend to keep propagating upslope at a slower speed than during the day. This, in turn, may result in a more intense and thorough combustion of the vegetation during the night. Farther down the slope, however, the drainage winds may be strong enough to reverse the direction of the flame front and drive it into an area already burned during the day.

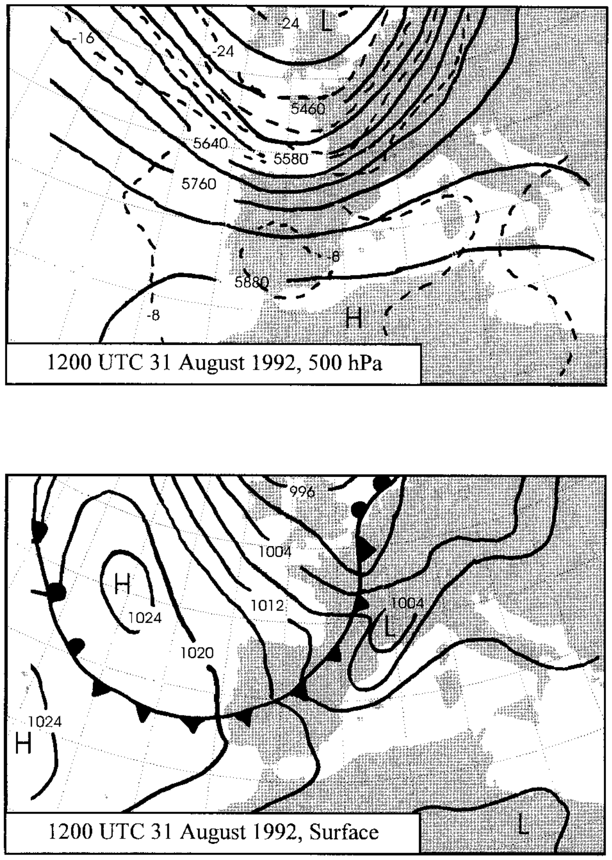
b. *Ponientes: Westerly winds with traveling low pressure systems*

These represent the opposite case to the thermal low. Here, the macrometeorological (synoptic) conditions override the formation of regional circulations and represent the strongest case of coupling of the synoptic flow with the surface.

1) Mechanisms and characteristics

They can occur as soon as the Atlantic depressions move toward the lower latitudes and start migrating through a corridor that extends roughly from the British Isles to the Gulf of Biscay and southern France. A typical situation is shown in Fig. 14. This period can start as early as the middle of August and last until late June. Under these conditions, the depressions and their fronts sweep across the Iberian Peninsula and rains occur over most of the territory with important orographic effects. In general, the westerly component of the winds extends from the surface to the upper levels, and the most intense events occur with cold lows.

In the Valencia region, the last mountain range encountered by the air masses before reaching the Mediterranean Sea is the Iberian system, which enhances the orographically induced precipitation on the windward side. On the lee side, however, a Föhn effect is produced, which results in strong westerly winds (ponientes) over most of the Mediterranean coast. The poniente winds can thus be considered as quasi-synoptic and, like all Föhn-type winds, are strong, gusty, warm, and very dry.


1200 UTC 31 August 1992, 500 hPa

1200 UTC 31 August 1992, Surface

FIG. 14. Meteorological maps corresponding to a typical situation of ponientes; a frontal system is crossing the peninsula with strong westerly flows aloft.

2) Evolution

The typical life cycle of poniente winds lasts for as long as it takes the frontal systems to cross the peninsula, that is, from one up to several days. During this period, the wind direction can change from south or southwest, at the beginning of the cycle, to west or west-northwest after the passage of the cold front. This last stage may also be accompanied by a significant increase in wind speed. These winds are accompanied by divergence at the lee of the mountains and strong subsidence over the coastal plains.

In the coastal strip, it has been noticed that the onset of poniente winds occurs mostly at night. This can be explained considering that the weather conditions leading to their development also produce sunny weather over the Mediterranean coast and that the east-facing slopes of these mountains encourage the early development of the sea breeze reinforced by upslope winds. Thus, the onshore easterly winds of a well-developed sea breeze tend to block, or deflect, the ponientes from reaching the surface, if their cycle starts during the day. Instead, a line of strong convergence develops at a certain distance inland. This situation has been documented in the Castellón and Valencia coastal plains during the EC projects mentioned.

During the ensuing evening, however, the sea-breeze circulation dies out and the surface winds change to westerly drainage flows. This process helps to couple the quasi-synoptic poniente (westerly) winds with the (also westerly) surface flow. Once coupled to the ground, the ponientes become well established through-

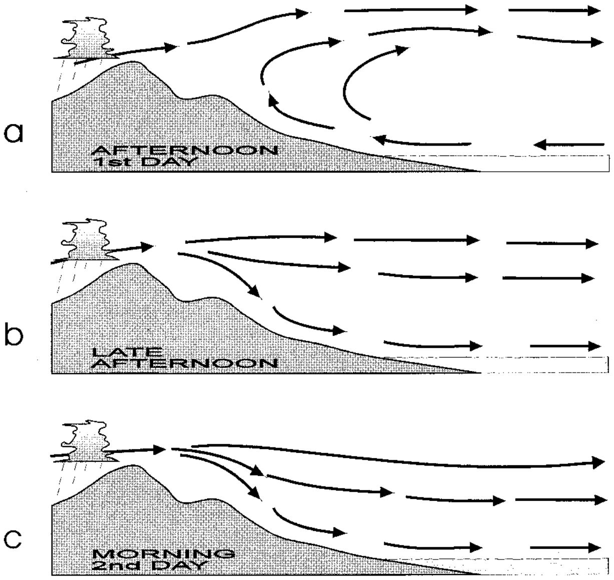


FIG. 15. Schematic of evolution and coupling when the prefrontal system (warm sector) reaches the coast and the sea-breeze cell is well developed. (a) Mountain wave clouds develop aloft while the breeze cell remains. (b) With the collapse of the sea-breeze cell in the evening, the upper winds drop to the surface and merge with the drainage flows. (c) The following morning the Föhn wind is fully coupled to the surface and may be strong enough to inhibit the development of the sea breeze.

out a deep layer and tend to block the formation of the sea breeze the next day(s). These processes are illustrated in Fig. 15.

3) EFFECTS

While they last, poniente winds usually override all mesoscale wind circulations, including sea breezes and upslope winds, and affect simultaneously high ground, that is, hill ridges and valleys oriented east–west, where they can be strongly channeled. With relation to wild fires, their main effects are related to

- their capacity to dry the surface and vegetation very quickly,
- their potential to activate smouldering fires, for example, in uncontrolled garbage dumps, and/or to propagate out of control fires used to burn agricultural refuse, and
- their capacity to propagate the fires through their persistence and intensity.

On the other hand, the persistence of the wind direction and thus the expected direction of propagation of the flame front, can be easily predicted and this information can be used to take remedial actions.

c. Combined cycles: Sea breeze followed by coupling of upper westerlies at night

Typical conditions for this situation to occur are shown in Fig. 16. The surface gradient favors the formation of the Iberian thermal low during the day. At 700 and 500 hPa, however, there is a weak westerly flow that tends to become coupled to the surface as soon as the surface drainage flows begin. This mechanism also favors the venting of cooler Atlantic air onto the western Mediterranean basin, the result of which can be observed as a ridge of high pressure associated with the colder air in the surface maps of 0600 UTC 12 August.

1) MECHANISMS AND CHARACTERISTICS

This type of situation is experienced during the transition from summer to fall. It begins to occur with increasing frequency toward the end of the summer, alternating with periods when the sea breezes and thermal low conditions develop fully, or with conditions leading to the formation of ponientes. These, however, are associated with widespread rains over the central plateau, and the increasingly moist ground begins to inhibit the development of the thermal low, which may stop occurring until the following spring. By the end of September, the frequency of occurrence and reach of the sea breezes drops significantly, as Fig. 4 shows with a marked decrease in easterly winds.

2) EVOLUTION

The initial development of ponientes is similar to that of the sea and land breezes with the thermal low. However, the end of the combined sea breeze and upslope winds and the transition to the drainage and land breeze becomes modified by the presence of westerly winds aloft. Coupling with the surface flows occurs on account of 1) both surface and upper winds have the same direction and 2) the onset of ''subsidence-aided'' drainage flows brings the upper winds down. The combination of these processes may actually inhibit or destroy the further development of the subsidence inversion during the night and produce a type of ''ponientes by subsidence-aided coupling'' during the night.

The following morning the sea breezes develop again on the east coast, as well as the thermal low over the central plateau, albeit at a later time, and the processes start anew. This cycle has been observed to last for one or several days after which it usually turns into a full cycle of thermal low. The main aspects of these winds are as follows.

- The Ponientes by subsidence-aided coupling develop in the late afternoon or early evening, just about sunset or as early as one or two hours before.
- They can be intense enough to dominate the fire dynamics and change the direction of the flame front.[3]

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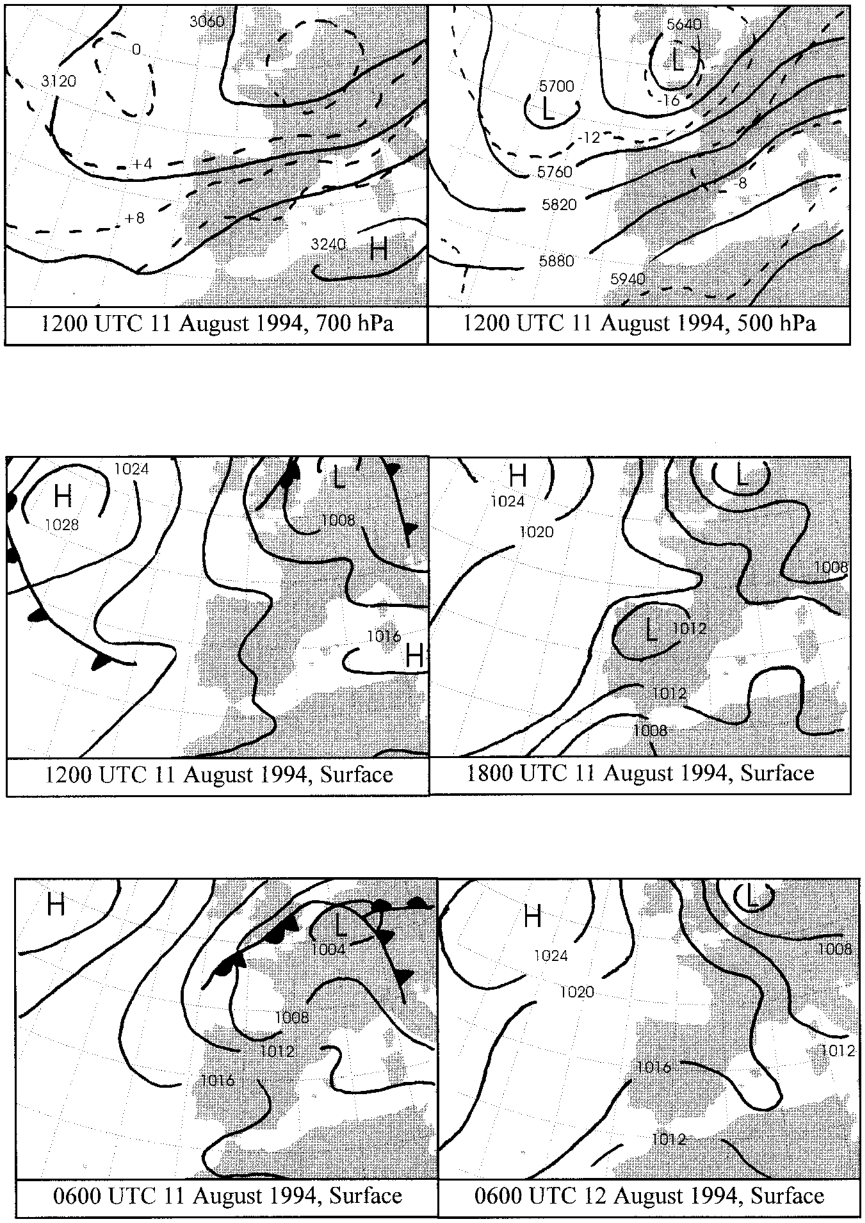
[3] Observed in two of the largest forest fires in this region: Buñol in July 1991 and Requena on 11–12 August 1994.



1200 UTC 11 August 1994, 700 hPa

1200 UTC 11 August 1994, 500 hPa

1200 UTC 11 August 1994, Surface

1800 UTC 11 August 1994, Surface

0600 UTC 11 August 1994, Surface

0600 UTC 12 August 1994, Surface

FIG. 16. Meteorological conditions that favor the development of a combined cycle on 12 August 1994.

In this region, and before sunset, this may involve a sudden and direct change in the wind from weak upslope, that is, with a southerly component, to becoming much stronger and westerly, that is, a 90° turn that redirects the *whole flame front* along the valley wall.

- The main difference between the "normal" cycles of sea breezes and thermal low is that the transition from east or southeasterly winds to westerly flow is very rapid, that is, on the order of half an hour or less. During the 1995 fire prevention campaign, full directional changes were observed in less than 15 min.
- Another important difference is that, along with the full collapse of the sea-breeze cell, the change in wind direction takes place almost at once over the whole of the coastal area, from the mountain ridges to the sea.
- Because they are the result of subsidence-aided coupling between the upper (weak) westerly winds and the land breeze drainage flows, the surface winds can become, as in the case of the ponientes, strongly channeled along valleys flowing to the sea, that is, aligned east–west in this region.
- On the other hand, valley ridges may not experience

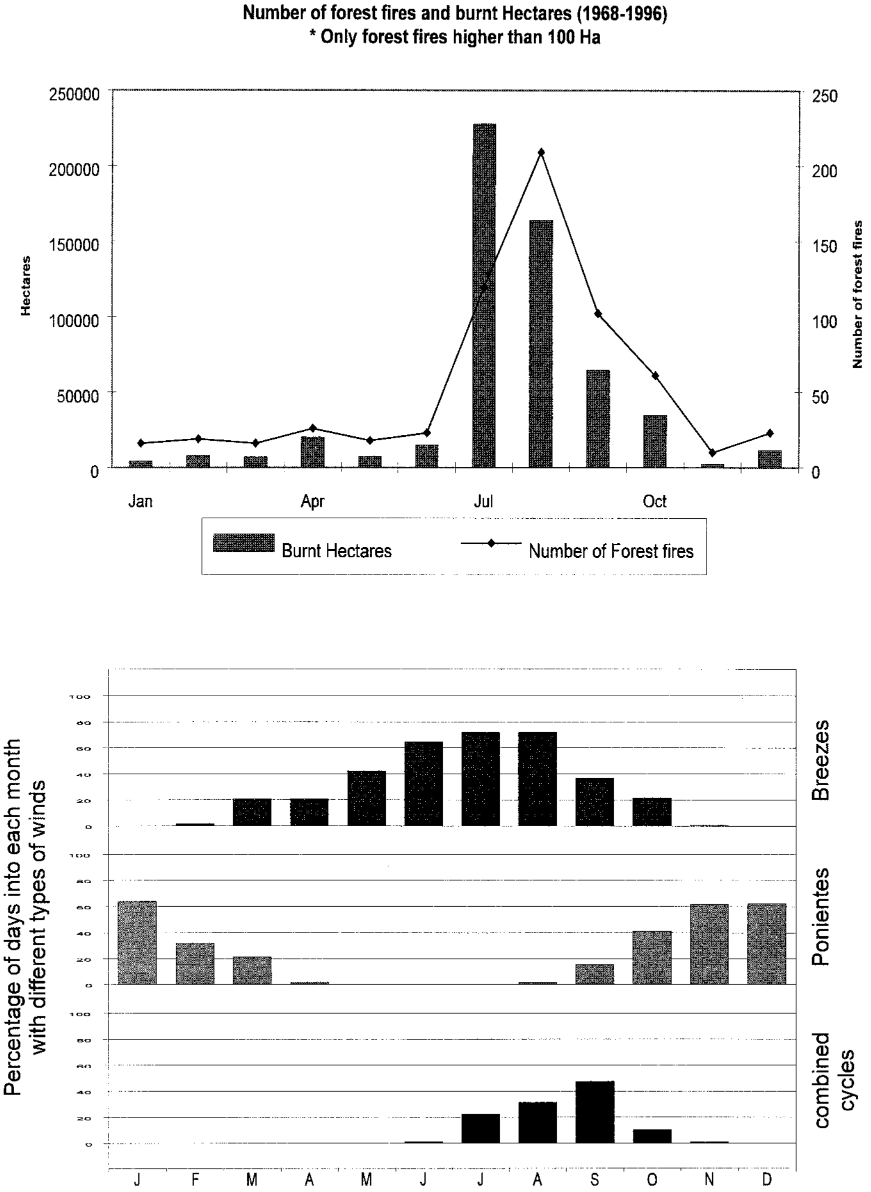


FIG. 17. Relationship between the fire statistics and the mesometeorological situations described in the Valencian community.

winds as strong as in the ''classic'' ponientes. Near the ridges, the wind could be weak enough for the dynamics of the flame front to be dominated by the fire itself, as in the case of the thermal low during the night.

- Their duration is limited to the night and early morning period. The next day, the flow reverts to sea breezes and upslope winds, as in the case of the thermal low.

The sudden shift in wind direction, which can take place along most of the valley wall in the late afternoon, can be extremely dangerous for firefighters working near the flame front up the slopes. The possibility also exists that the upper part of the fire may keep moving upslope, on account of weaker winds near the top, while the flame front initiates a new displacement along most of the valley wall with the new flow. This means that the onset of these winds may result in an important enlargement of the fire front during the night.

d. Some comments on the available statistics

Figure 17 combines Fig. 3 with the available data on the periods of occurrence and frequencies for the situations described. However, there are several points to mention regarding the data used to prepare this figure.

For example, the awareness of the processes described is very recent. The systematic gathering of experimental evidence began in 1988 within the EC projects mentioned, and most of the experimental data available, including atmospheric soundings and measurements with instrumented aircrafts, were obtained in intensive field campaigns lasting 2–3 weeks in the summer.

Increasing evidence about these processes came along with the interpretation of the incoming experimental data, and several extensive measurement campaigns (up to 3 months) were subsequently launched to expand the time coverage. Furthermore, a network of nine meteorological towers and five air quality stations with meteorological towers, all of them with continuous recording, have been installed in selected points of the region. These stations started operating in late December 1994, and the available data can now be used to relate surface winds to synoptic conditions.

The identification of the synoptic conditions, for which each process dominates, has been made directly by examining the available weather maps from 1983 to the present. However, a comprehensive validation of their effects in the surface wind field by using the data from the instrumented sites is still required. With this, we want to emphasize that we feel more confident about the periods when those processes dominate than about their relative frequencies.

Figure 17 also reinforces the point that the highest frequency of fires and the largest burnt areas appear to occur during the period where the easterly winds dominate. After analyzing the available information, it could be concluded that this period coincides with the cycles where the diurnal sea breezes and upslope winds change to westerly winds during the night. It further appears as if this combined cycle suffers from, and adds to, the worst features of the other two. According to our results, the direct effect of the ponientes appears to be mainly confined to the months of September and October.

5. Conclusions and recommendations

The most important conclusions of this work are 1) that the meteorological situations described here for the Spanish Mediterranean coast can be identified easily, and their most probable evolution scenarios are forecasted 12–24 h before their occurrence; and 2) that a characterization and foreknowledge of synoptic and regional meteorological conditions, and their potential influence on the onset and dynamics of fires, could be of great help not only in the preventive and early stages of the fire but also in its abatement and extinguishment.

The interactions between meteorology and orography vary from region to region, and this makes specific studies not only expensive but also of limited applicability to other places. Further, a judicious exploitation of the foreknowledge to optimize suppression procedures and minimize accidents needs, precisely, an expert operator with adequate training to help in making decisions before and during the event. It is fortunate, therefore, that as a result of the EC projects, this information now exists for the Spanish east coast and, because similar studies are now being carried out in other Mediterranean areas, the method could be conveniently extended to most of the Mediterranean basin.

The ‘‘fire hazard potential index’’ approach could thus be improved by indicating the situation type and the forecast of its most probable evolution. An advantage in this case is that in most of the Mediterranean basin, the weather types in summer are few and their interactions with the orography are very repetitive. Thus, whenever the meteorological information and the regional typology are available, or obtainable, this would imply no more than adding a list of do’s and don’ts to the index.

Finally, the knowledge about the mesoscale atmospheric processes, and the fact that these can be predicted on a regional scale, also has a strong potential for improving models of fire behavior and providing strategies for regional fire prevention and fighting plans.

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