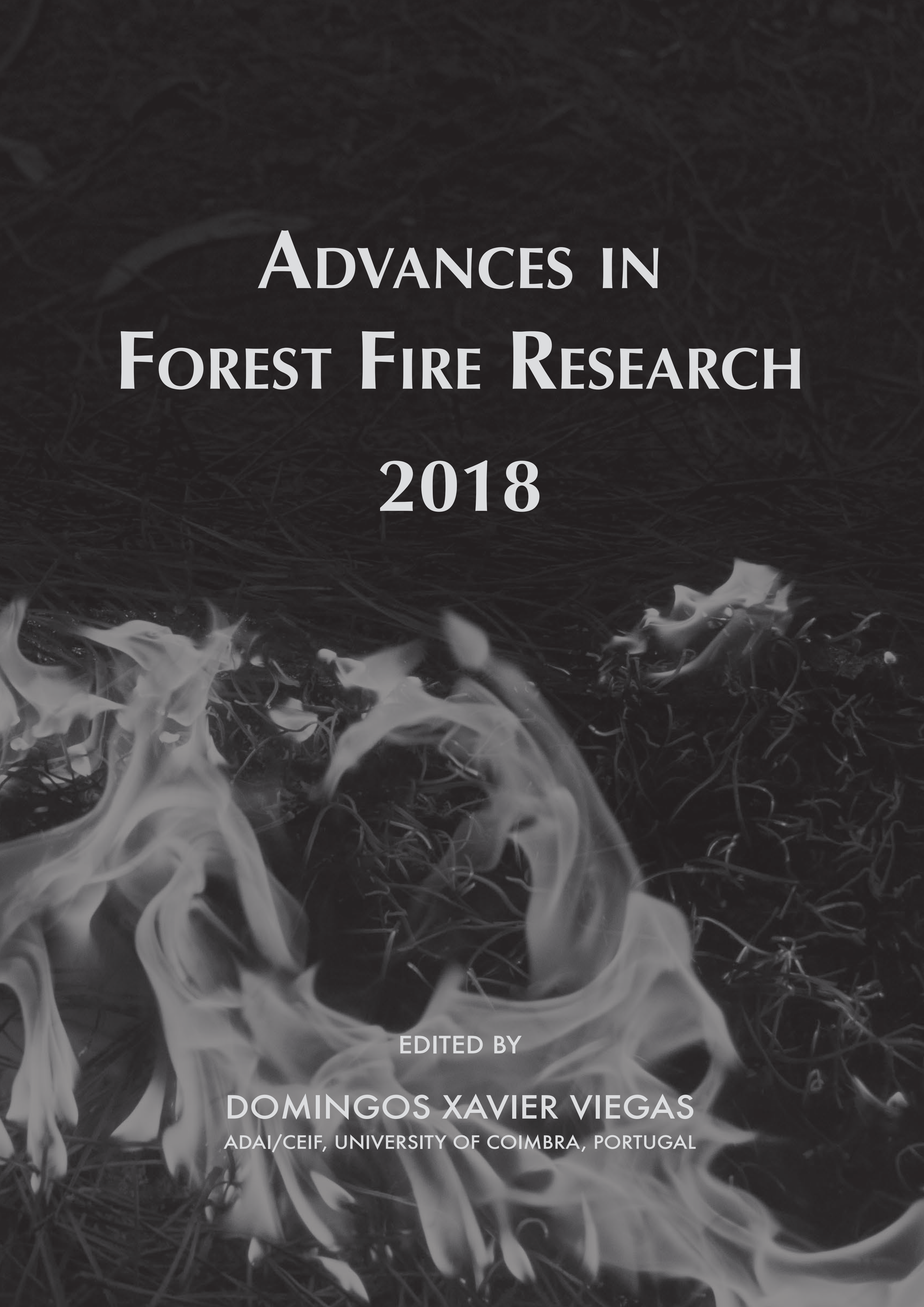

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Fires in Portugal on 15th October 2017: a Catastrophic Evolution

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Abstract

In 2017 Portugal mainland was affected by two events with major forest fires, that caused a large number of casualties and extensive property loss. Both events happened outside the typical forest fire season, which goes between July 1st to September 30th. Severe drought since the early spring 2017 and extreme heat in the summer are factors that may lead enhance the size, severity and spread rate of forest fires (Pereira et al, 2015). On October 15th, a number of factors joined together simultaneously: very low humidity in both the boundary layer and cumulated biomass (Gouveia et al., 2012), unseasonably high temperatures and a tropical cyclone (Ophelia) located to the west of Iberia, enhancing a south-easterly flow over mainland Portugal. The combination of these factors leads to a record number of forest fires in a single day with serious consequences, including the loss of lives and property.

Keywords: Weather Pattern, Anomaly, Hurricane, Forest Fire Risk, Pyroconvective Plume

1. Introduction

On 15th October 2017 mainland Portugal was affected by a major forest fire event that occurred outside the typical forest fire season (1s^{t} July and 30th September). Severe drought in spring and hot, long lasting summer conditions, are among those factors that may enhance the size, intensity and rate of spread of forest fires (Pereira et al, 2005) and cumulated biomass (Gouveia et al., 2012). Besides these long term factors, a combination of weather conditions and orography lead to a record number of forest fires on a single day, in Portugal. The goals of this study are to find out which weather factors did play an important role in the event and which was the relevancy of a particular flow-orography driven interaction, to the onset of hazardous conditions, in the scope of forest fire propagation and intensity. This event has caused a large number of casualties and an extensive property loss, having been one of the worse ever recorded over territory.

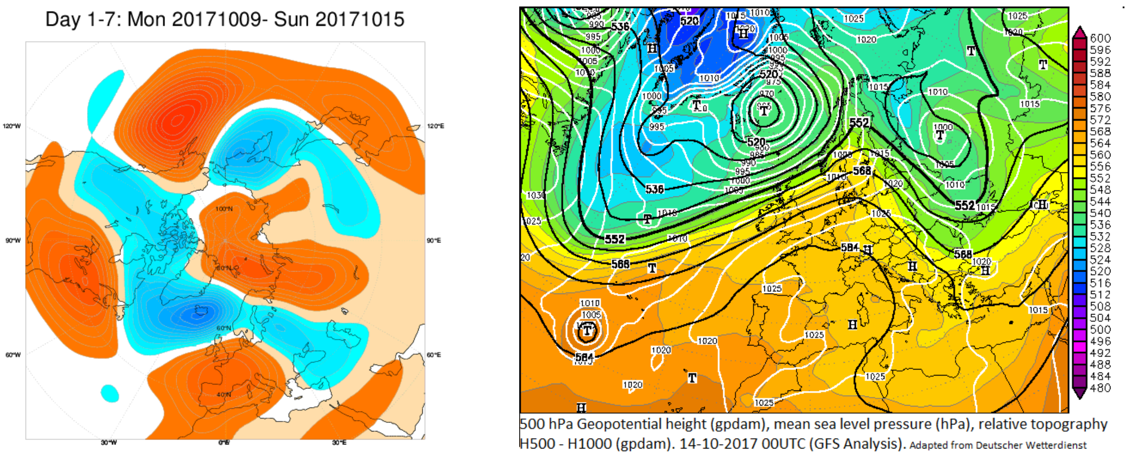
2. Data

For the study of the weather pattern, ECMWF (European Centre for Medium-Range Weather Forecasts) model analysis and forecasts were used, as well as other numerical products, DWD (Deutscher Wetterdienst) 500 hPa chart, HYSDPLITT Trajectory Model, information about Hurricane Ophelia from NOAA (National Ocean Atmospheric Administration, USA) and satellite images from EUMETSAT (European Organization for the Exploitation of Meteorological Satellites). To analyze the meteorological conditions on a mesoscale, it was used information from two IPMA radars systems, one located in northern Portugal, Porto radar (A/ PG), and another one located near Lisbon (C/CL). Upper air sounding at Lisbon weather station (Lx/GC), ground observations from IPMA weather network and indexes of risk and fire danger, computed at IPMA on a daily basis, were used.

3. Weather Patterns

3.1. Anomaly and Extremes

The upper-level (500hPa) circulation geopotencial anomaly over Northern Hemisphere on October (first half of the month), shows west-east trough/ridge pairs with a highly meridional state, being positive anomalies associated with upper-level ridges at mid latitudes and negative anomalies associated with upper-level troughs (Figure1a). Over North America and Western Europe there was a strong positive anomaly related with a strong ridge over mid Atlantic there was a strong negative anomaly related with a deep trough (Figure 1b).



(a) (b)

Figure 1- (a) ECMWF weekly-mean 500hPa geopotential anomaly for the ensemble mean (contours of 2 gpdam), orange positive anomaly, blue negative anomaly, (b) 500hPa geopotencial analysis 20171014 00UTC, adapted from DWD.

Over Iberian Peninsula (IP), particularly in Portugal, this meridional weather pattern brought a very dry and hot October, reaching the peak by 15th October. The geopotential height anomalies clearly show a positive value over PI and the advection of very warm, +10ºC anomaly at the 850 hPa level, and dry air, below 30% anomaly of relative humidity (Figure 2).

At surface level, extremely high temperatures were recorded over mainland Portugal with 2 m air temperatures above 35ºC in coastal areas. The exceptionality was such that the maximum absolute high records for October were, during this day, exceeded in the vast majority of coastal weather stations. On the other hand, the low temperature value records for October 15th were extremely high, exceeded in some inland weather stations the climatological value.

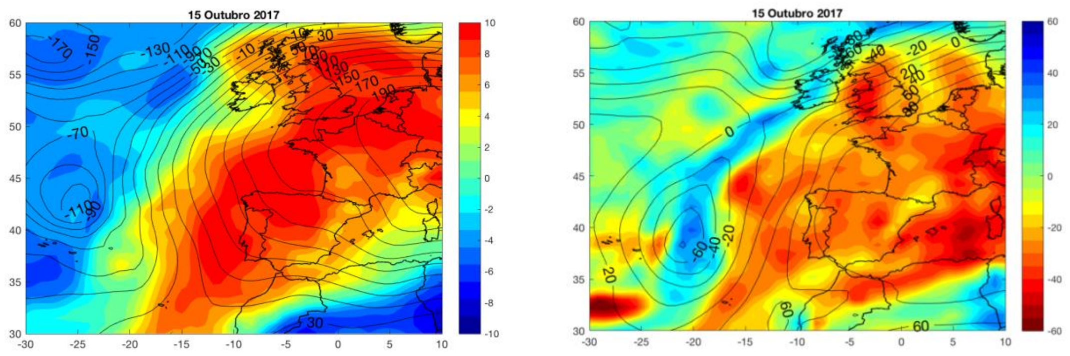


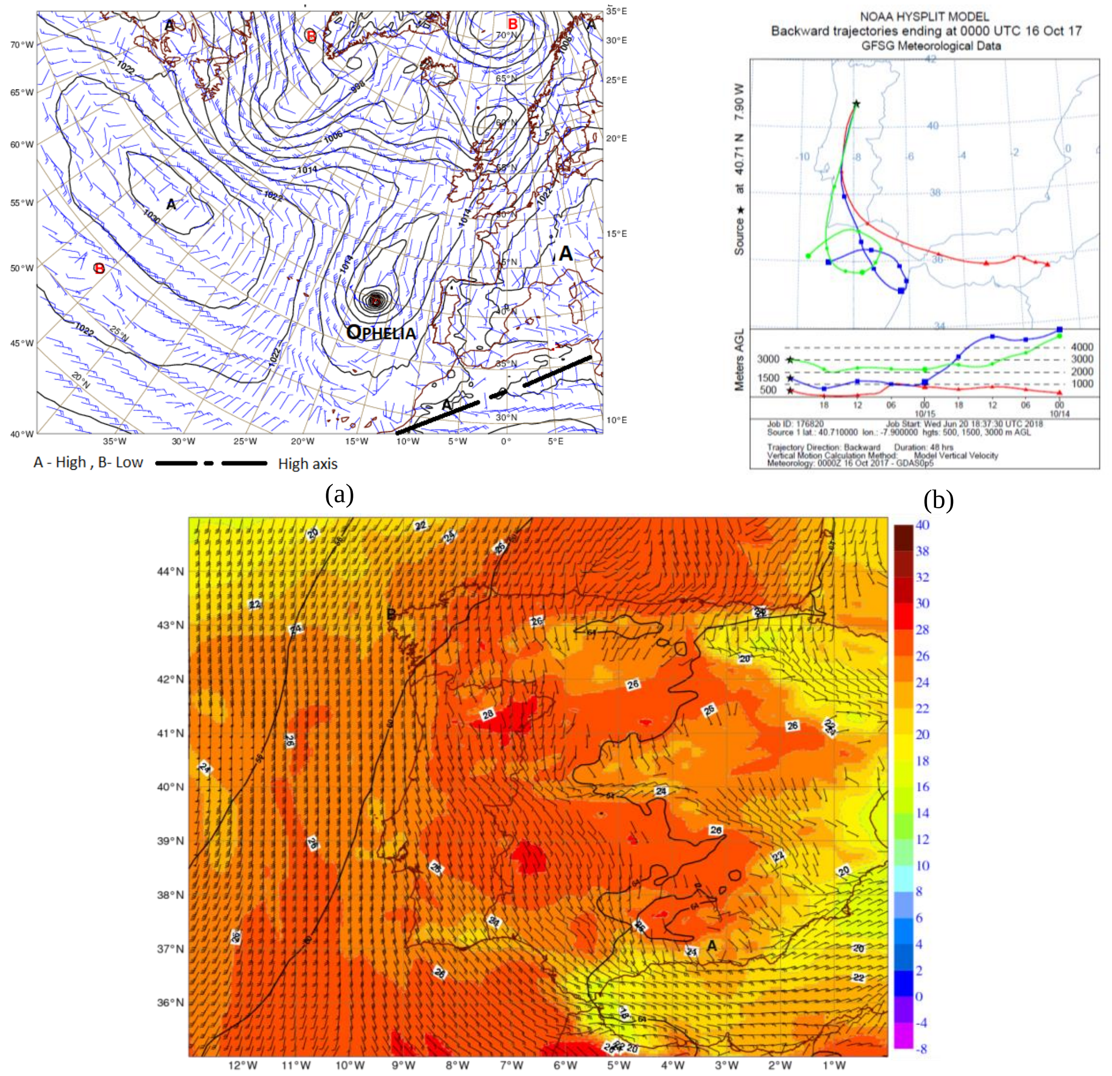
Figure 2 - Left panel: geopotential height anomaly (lines, in m) at the 500 hPa level and temperature at the 850 level (shaded, ºC). Right panel: geopotential height anomaly (lines, in m) and relative humidity at the 850 hPa (shaded, %).

On the 15th October, it was also reached the highest level of meteorological drought in the territory for the entire year of 2017, as estimated by the Palmer Drought Severity Index (PDSI): 100% of the territory was in severe or extreme drought conditions.

3.2. Synoptic Analysis

Since early October a block ridge with a large and intense high settled over Iberia and the Atlantic adjacent area was settled in. By 15th October, (Figure 3b), the high was located over the Alpine region, extending to North Africa (Morocco, Algeria), thus promoting a more intense flow from south/southeast over IP, as well as an increase in the transport of warmer and drier air (Figure 3b, c). Figure 3d reveals the trajectory of air parcels at levels of 500m, 1500m and 3000m, crossing North Africa and southern Spain before being transported over Portuguese territory. For levels above 4000m the trajectories the air particles were across Atlantic (not shown).

In this synoptic configuration the usual Iberian thermal low does not establish, neither any sea breeze circulation over the west coast. This weather pattern is, in fact, a non-characteristic summer pattern over Iberia.



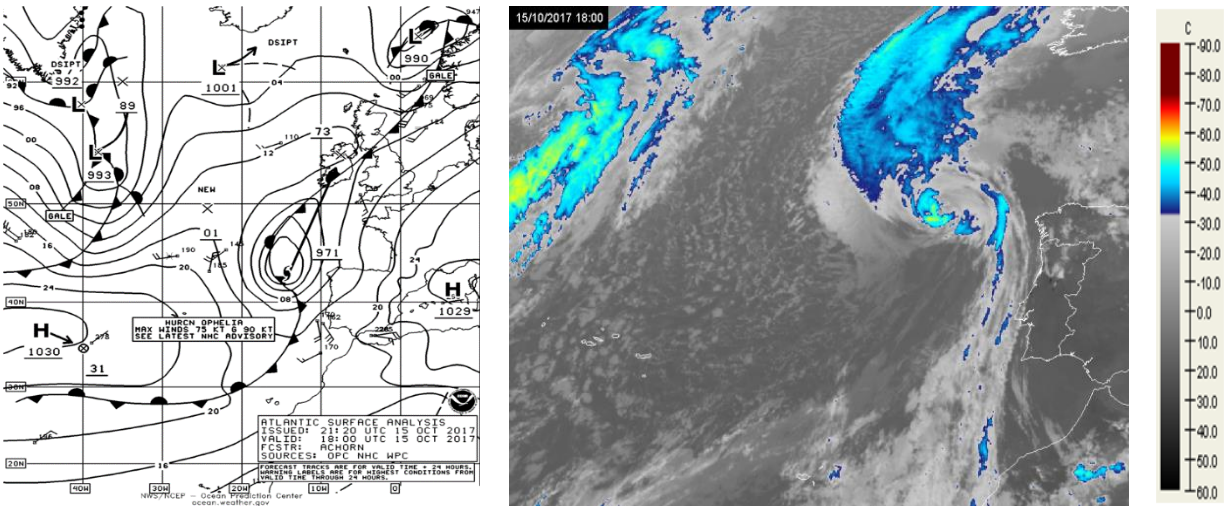
(a) (b) (c)

Figure 3 - ECMWF Analysis valid at 12UTC, 20171015 (a) pressure at mean sea level (pnmm, lines, hPa), wind barbs at 10m (kt), (b) HYSPLITT Trajectory Model, NOAA, backward trajectory from 2017/10/14 at 00 UTC to 2017/10/16 at 00 UTC, level: 500m, 1500m 3000m, (c) ECMWF H+12 forecast valid at 12 UTC, 20171015, geopotential height at the 950hPa (lines, gpdam) at the 950hPa, temperature at 950hPa (shadow, °C), wind barbs at 950hPa (kt).

3.2.1. The role of hurricane Ophelia

Hurricane Ophelia was born as an extratropical low in the mid Atlantic, west-southwest of Azores, during the first week of October. A sea surface temperature (SST) near 27°C and a weak wind shear across the troposphere, held the system to become a tropical storm, on the 9th October, and a hurricane, by 18UTC of the 11th October, when it was located about 1200 km southwest of the Azores (National Hurricane Centre, NHC). On 14th October, a broad mid-latitude trough over North Atlantic moved east-southeastwards. The southwesterly flow ahead of the trough and associated cold front, turned Ophelia's track to the northeast, followed by its forward speed increase and intensification. It became a Hurricane 3 category during the afternoon of the 14t^{h} October, when was located 900 km southwest of the Azores.

As Ophelia continued its track to the northeast, embedded in the stated trough, decreased its strength, being located about 460 km west-northwest of the northern coast of Portugal by 15th October, 18UTC (Figure 4). At this time, maximum wind speed was about 80 kt and minimum pressure 959 hPa. By 00UTC of 16th October, over Ireland, Ophelia turned into an extratropical low, as it merged with the cold front.



(a) (b)

Figure 4 - (a) Surface Analysis to 2017/10/15 valid 1800 UTC (NOAA), (b) MSG IR_10.8µm 201710151800 UTC.

On satellite imagery (Figure 4b) the cold tops (light blue and green) mark the centre of Ophelia and a stratiform cloudiness band, associated to the cold front (lower tops, grey shades), is organized close to the west coast of IP. In Figure 4a, the mean sea level pressure field, 18UTC of 15th October, shows the high pressure system over the western Mediterranean. Hurricane Ophelia and this high pressure system generated a strong pressure gradient over IP, forcing an increase in flow intensity, as shown in Figure 5. During the morning there was an intensification of the south-southeast flow (Figure 5a) while during the afternoon the flow turned south, and intensified slightly (Figure 5b, c), as the hurricane was crossing the Atlantic near Iberia west coast. Afterwards it gradually turned to the southwest, slightly decreasing (Figure 5d).

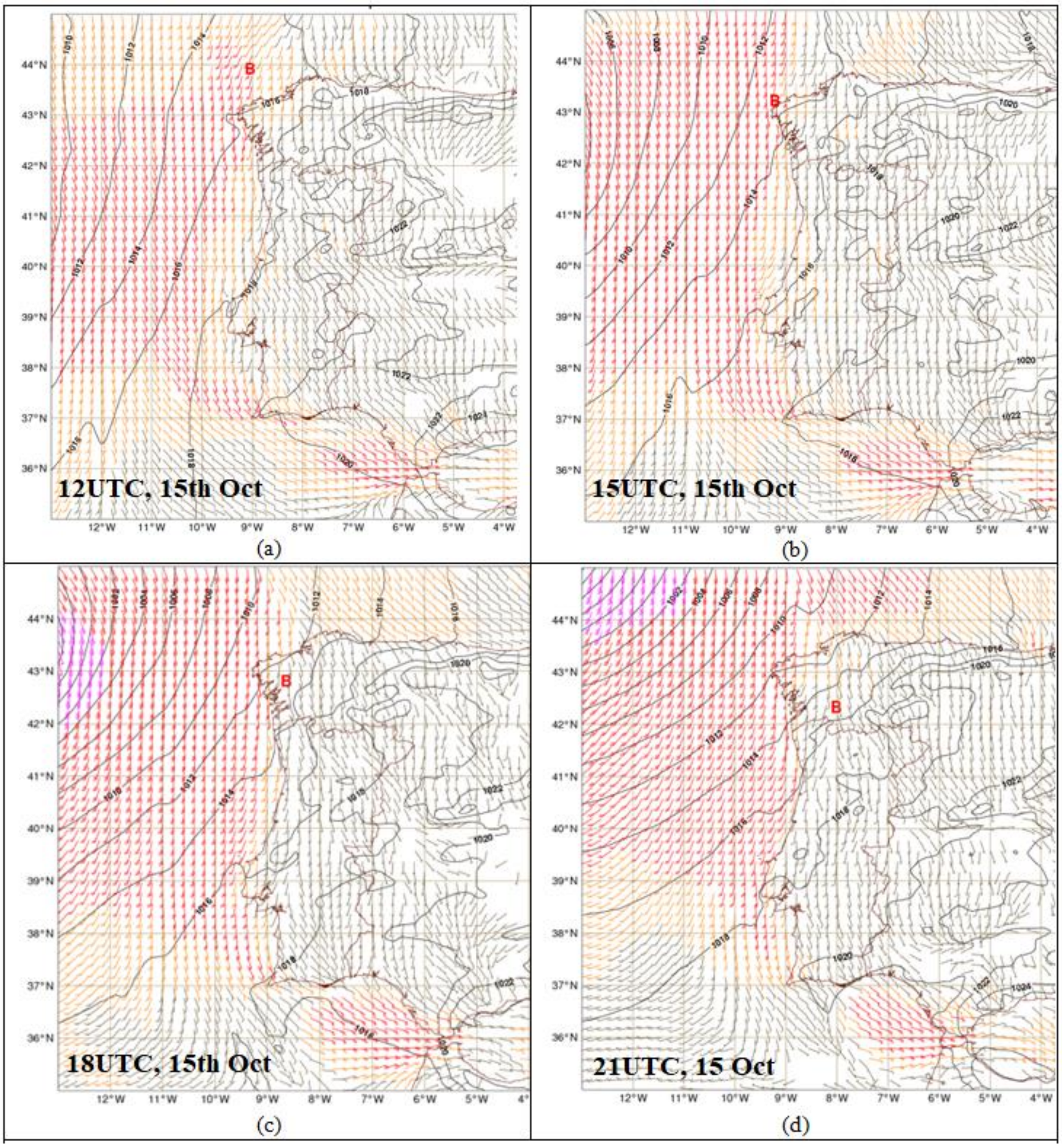


Figure 5- ECMWF forecasts pressure at medium sea level (pnmm, lines, hPa), barbs wind (kt): equal 5 kt and less than 15 kt, grey, equal 15 kt and less than 20 kt, yellow, equal 20 kt and less than 30 kt, red, equal or greater 30 kt, pink. (a) H+12 valid 12UTC 2017/10/15, (b) H+15 valid 12UTC 2017/10/15, (c) H+18 valid 18 UTC 2017/10/15, (d) H+24 valid 00 UTC 2017/10/16.

The flow intensification was mainly felt on the west coast and over central and southern mainland Portugal. In the northern region, however, a weaker flow persisted during almost the entire period, as Figure 5 illustrates, as well as ground station observations (not shown). The cause for this behaviour is not clear. There is some radar observational evidence suggesting that a certain obstacle effect (Austin, 1969) may have been produced by the presence of extensive pyroconvective plumes located in the atmospheric volumes, upwind of the northern region. This effect may have joined other undetermined causes.

3.2.2. The Ophelia Cold Front

Over IP, the airmass exhibited very low values of dew point (below 6°C), associated to a very dry airmass (Figure 6a). On the other hand, over the Atlantic area adjacent to western Iberia, dew point values of 18-20°C (Figure 6a) and total precipitable water of 30-35mm (even about 50mm close to the centre of Ophelia, Figure 6b) were typical of a Tropical Maritime airmass. So, an extremely warm and moist airmass was available close to the coast, in the circulation of Ophelia and associated cold frontal system. This cold front moved slowly to the east-northeast, approaching the west coast of IP in the evening of 15th and the early morning of 16th October. At the same time, the pressure field over eastern Iberia intensified and blocked the westerly transport of the moist and unstable (Jefferson stability index > 30°C, Figure 6d) air band associated with the cold front, making it stationary (Figure 6c). Thus, the cold frontal system barely affected the coastal area and slowly propagated inland during the beginning of day 16th, while dissipating, also due to some pressure build up in the post-frontal sector (Figure 6c). This situation did not allow expressive convective developments and only the formation of low and stratified cloudiness was observed during the morning of 16th October.

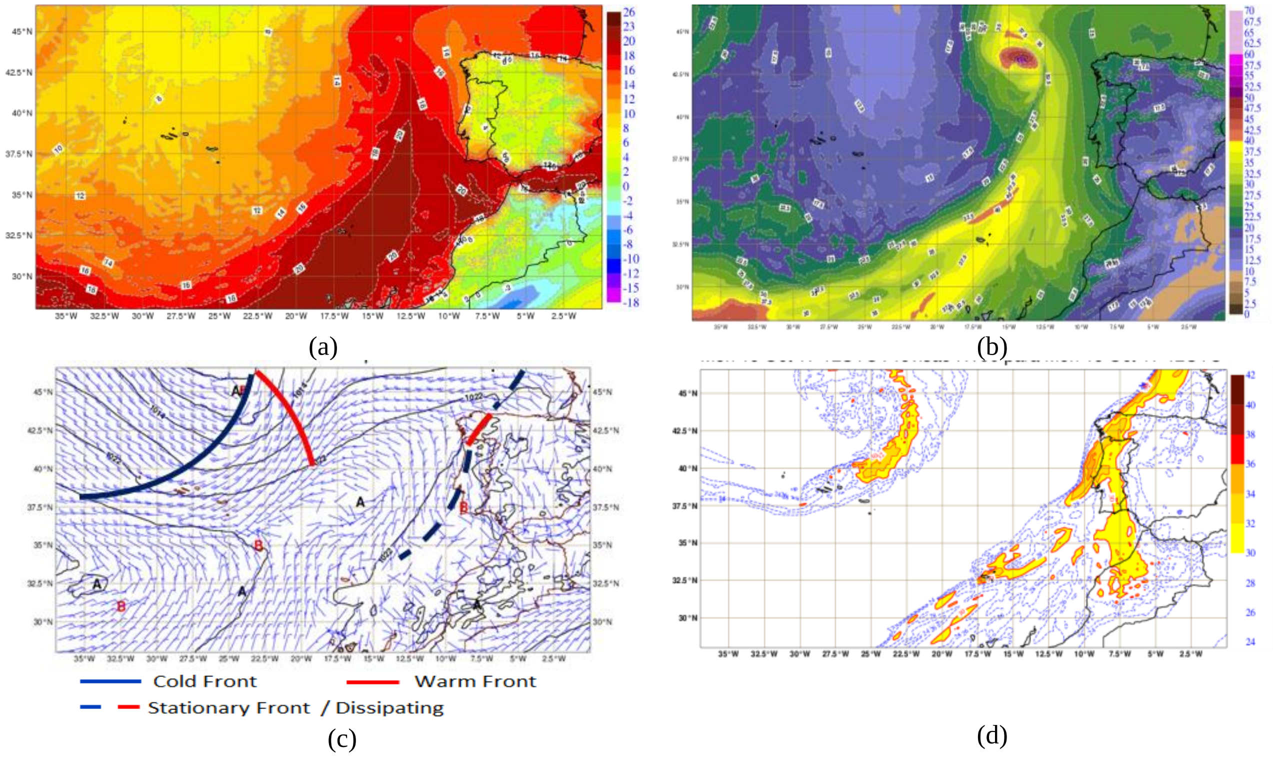


Figure 6 - , ***(a) ECMWF forecast H+18 valid 18 UTC 20171015 2m dew point temperature (shadow, in ºC), (b) ECMWF forecast H+6 valid 12 UTC 20171015 Total Water Precipitation (shadow, in mm).*** **(c) ECMWF analysis valid 12 UTC 2017/10/15** ***mean sea level pressure (pnmm, lines, hPa), wind barbs at 10m (kt), fronts are marked, (d) ECMWF analysis valid 12 UTC 20171016 Jefferson stability index (shadow, °C). (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).***

So, in spite of this warm and moist airmass near the coast, the referred factors have prevented a significant change of the existing environment. A sharp change in weather conditions did, in fact, occur just by the end of 16th, beginning of 17th October, when another frontal system propagated from the west (frontal system west of IP, Figure 6c), causing widespread precipitation from early morning onwards (Figure 7).

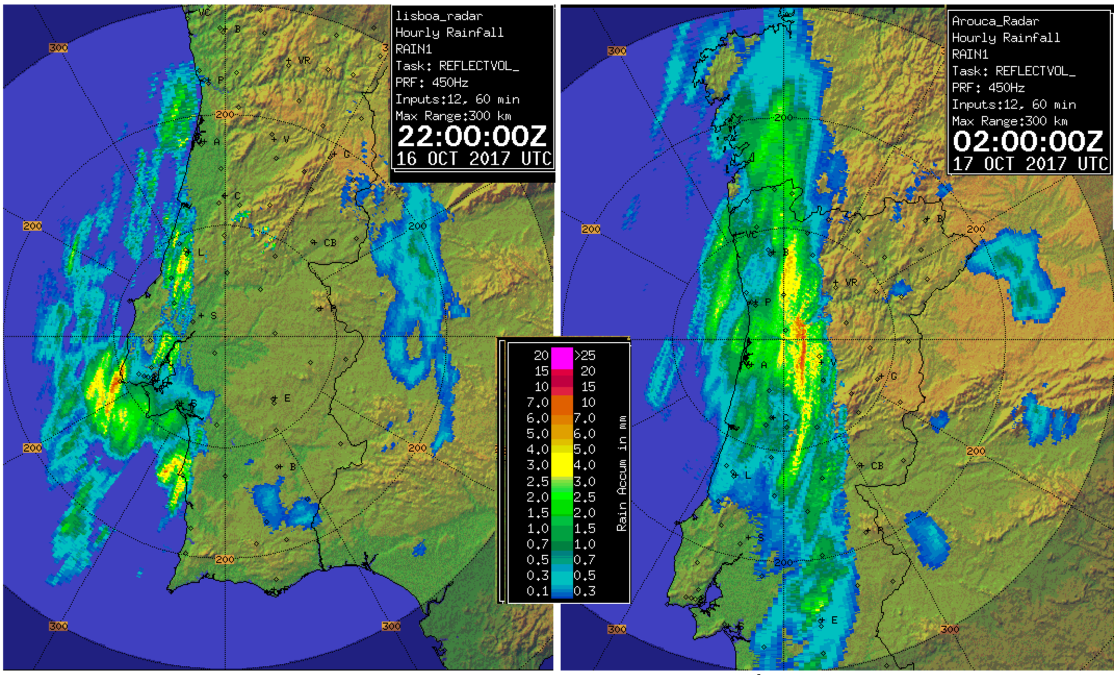
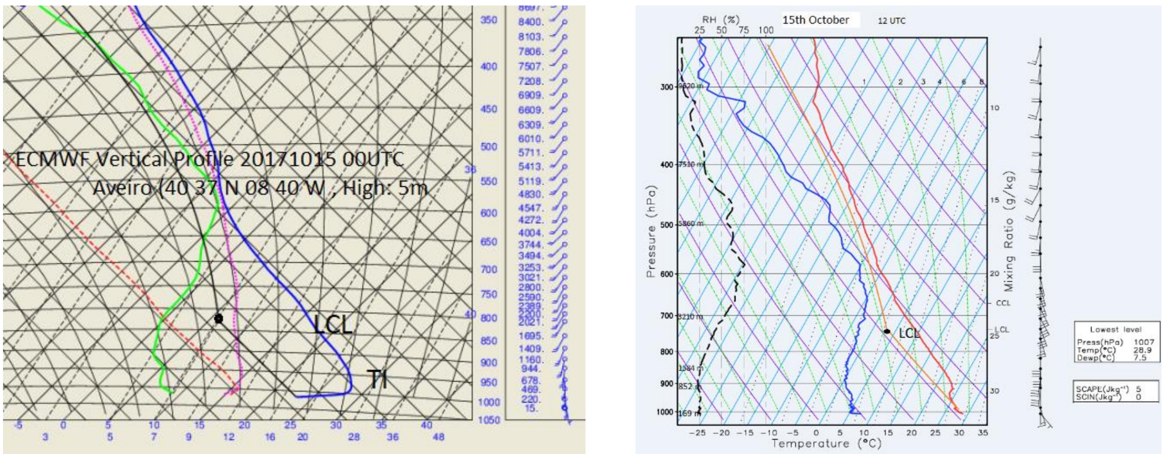


Figure 7- Hourly rainfall, RAIN1 (mm), (a) C/CL radar, 22UTC 16th October 2017, (b) A/PG radar, 02UTC 17thOctober 2017 (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).

3.3. Low level weather conditions on 15th October

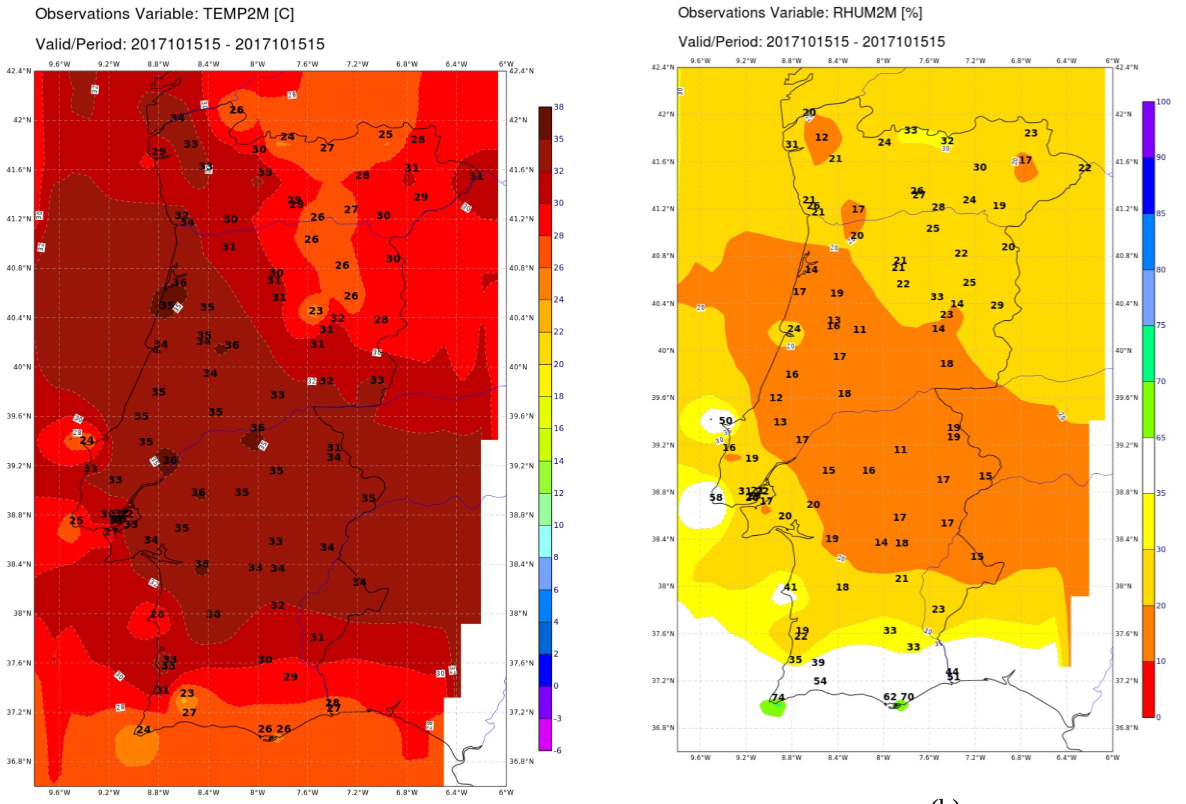
On 15th October, as previously discussed, it was in place a widespread transport of hot and dry air, caused by an intense advection from North Africa. The involved anticyclonic circulation has contributed to extensive air subsidence and, thus, further dryness and heating of the air at the lower levels, with the onset of temperature inversion layers that were specially noted by the surface, at the sea level (Figure 8). A temperature inversion for Aveiro (ECMWF profile, at 00UTC) and a very dry atmosphere up to mid levels is shown in Figures 8 a, b. As an example, the lifting condensation level (LCL) is about 3000m high in the Lisbon sounding (Lx/GC, at 12 UTC). These profiles also show an increasing in moisture by mid-upper troposphere, but the value of the lift index (LI), at 00UTC, in Aveiro, was about 5°C and showing no CAPE (Convective Available Potential Energy). These values are indicative of a stable atmosphere. On both profiles the flow was from the southern quadrants at middle levels, being stronger by 12 UTC (up to 20 to 40 kt). This was confirmed by radar (not shown).



(a) (b)

Figure 8 - ECMWF Vertical profile 20171015 00UTC (Extract) in Aveiro, (b) Lisbon air sounding 20171510 12UTC. (adapted from Novo, I. and Pinto, P. 2017, in portuguese).

During this day, high values of maximum temperature and very low values of relative humidity were recorded over almost the entire territory (Figure 9). By the coast, in the central part of mainland Portugal, air temperatures exceeding 35°C coexisted with very low (10-20%) relative humidity records by 15 UTC (Figure 9).



(a) (b)

***Figure 9** - (a) 2m temperature, (b) and relativity humidity at 15UTC, 15thOctober 2017. (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).*

The largest mean wind and gust values were recorded near the coast and high elevations, from the early afternoon of the 15th October until the evening of the same day.

Alcobaça and Viseu AWS were chosen as representative of air temperature, relative humidity, average wind and gust observations, for each corresponding area: Alcobaça for west coastal areas and Viseu for inland areas. Figure 10 illustrates a relevant wind behaviour directly related with the wind regime.

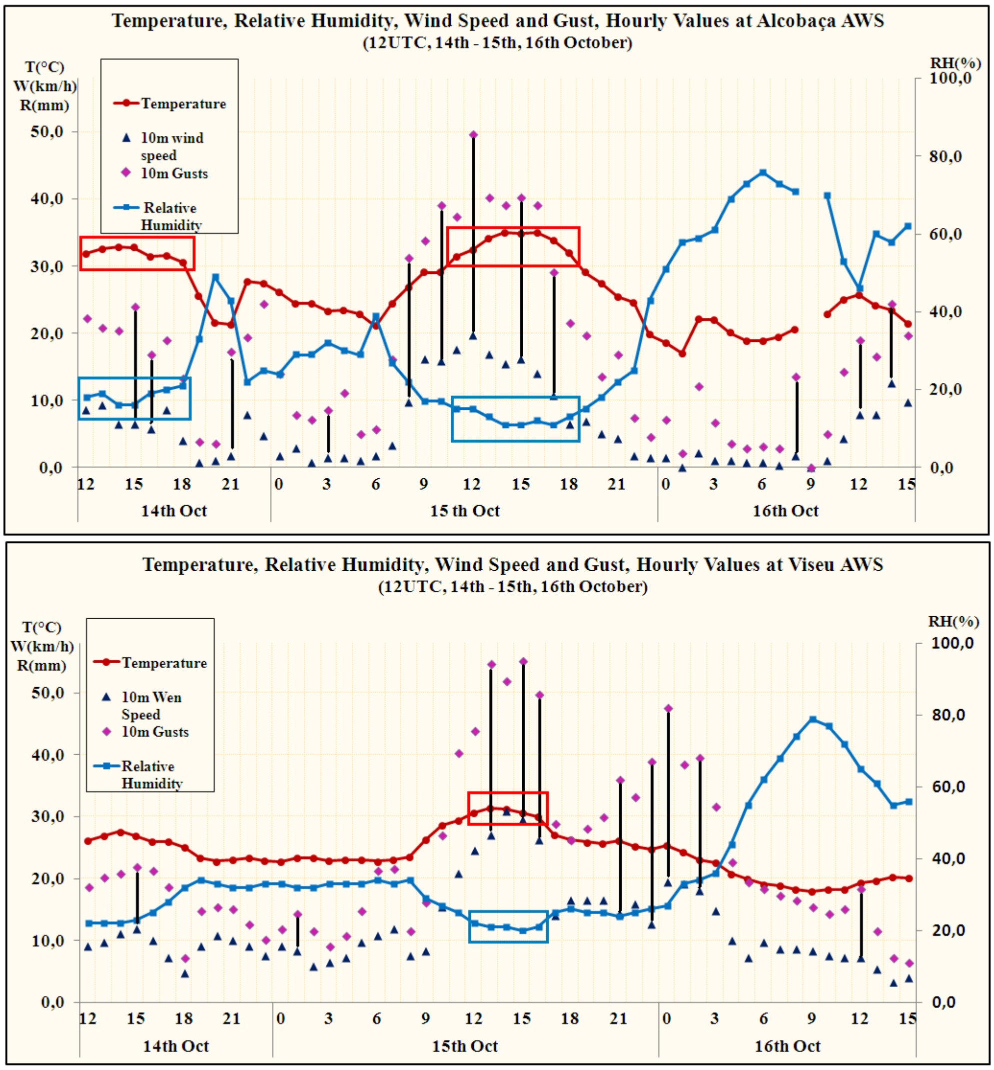


***Figure 10** - Hourly values recorded of 2m temperature (T, °C), 2m relativity humidity RH(%), 10 m wind speed (V, km/h), 10 m wind speed (V, km/h), 12UTC 14^{st}-15UTC, 16th October 2017. Upper panel: Viseu AWS, Lower panel: Alcobaça AWS (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).*

In fact, the gustiness (relationship between mean wind and gust for a 10 min average period) at each station, clearly increased from the 14^{th} October until the central hours of the 15^{th}, decreasing thereafter. The vertical black segments marked in Figure 10 materialize the gustiness, being evident that this was at a maximum during the early afternoon of the 15th October. So, it was during this period that the turbulence of the regime was at a maximum level and, simultaneously, minimum relative humidity and maximum temperature values were being recorded. Similar behaviour was observed on other locations (not shown).

Mesoscale phenomena (spatial scale in the range 200-2000 km, alpha scale), such as sea breeze fronts or other low level convergence fronts, may have strong influence on fire propagation intensity. Weather radars did not show any sea breeze fronts, on these days. Nevertheless, the C/CL radar enabled the identification of thin reflectivity lines usually corresponding to wind surface discontinuities. During the early afternoon several of these lines, exhibiting spectral width patterns suggestive of large horizontal wind shear values (not shown), were captured, being consistent with the turbulent nature of the flow, already detected on AWS. The turbulence nature of the regime was a supplementary adverse factor regarding fires propagation.

As already mentioned, the anticyclonic circulation has caused air subsidence in the large scale, thus enhancing further dryness and heating of the air towards low levels. On the other hand, the Montejunto-Estrela mountainous system, predominantly southwest-northeast oriented, may also have played a role in interacting with a predominant southeasterly flow. The classical Foehn effect, described in literature, involves condensation in upwind slopes. However, there are cases involving dry airmasses without condensation, which was the current situation, in which the air, while plunging from higher levels, dries and warms due to adiabatic compression, as it descends the downwind slope. This effect is called "dry Foehn" (Sharples et al, 2010) and was suggested by comparing dewpoint depression and wind gust records at two AWS (Figure 11). One of them, located upwind (Tomar AWS) and the other one, downwind (Lousã AWS) of the referred mountainous system. At Lousã AWS, the air was drier than at Tomar, for nearly 30 successive hours (Figure 11, dew point reached about -1°C at Lousã whereas Tomar reached +7°C) and the southerly wind was stronger (wind gust about 60 km/h at Lousã whereas it reached 45 km/h at Tomar). This long lasting behaviour was also observed on another AWS.

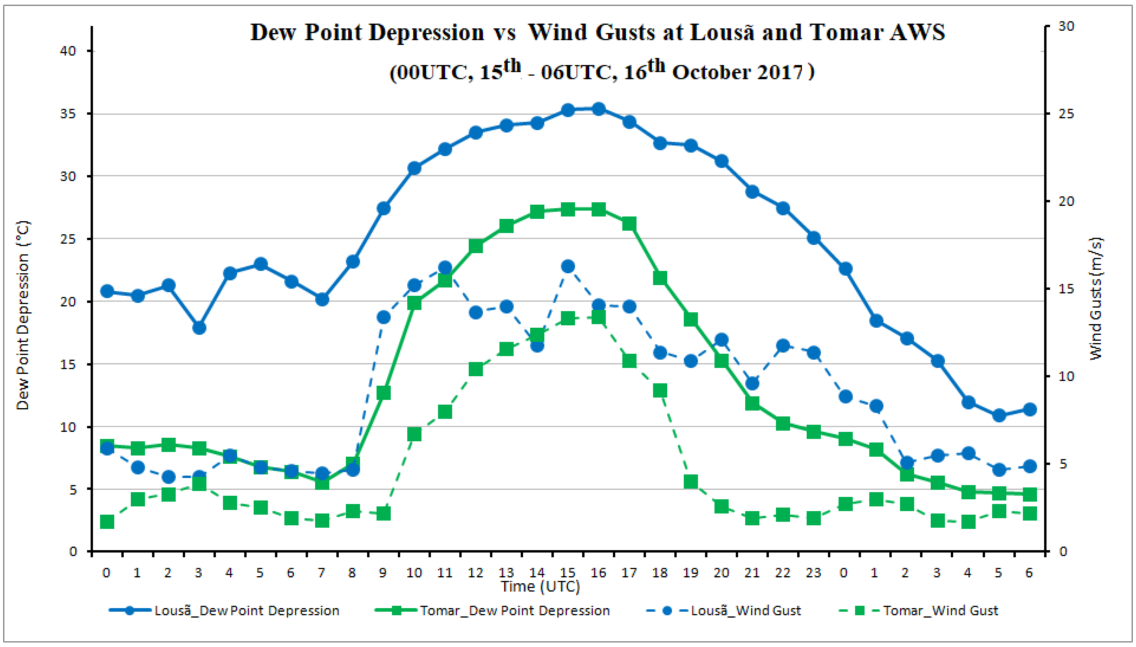
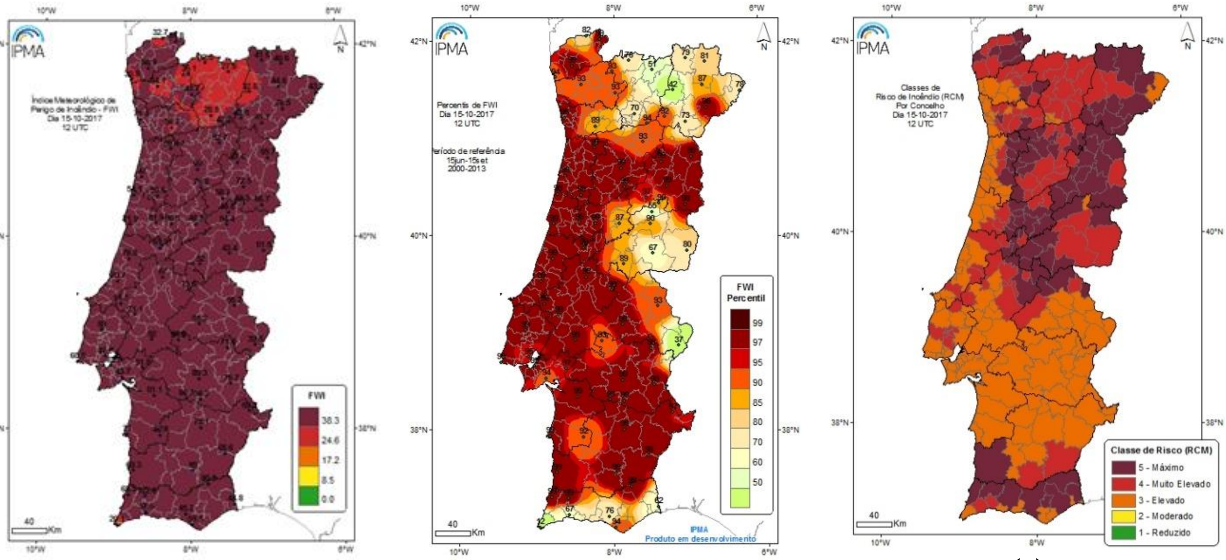


Figure 11 - Hourly Dew point depression(°C) and Wind gust (m/s) records in Lousã (blue colour) and Tomar (green colour), 00UTC, 15th October – 06UTC, 16th October 2017).

4. Forest Fire Risk

The meteorological conditions on 15th October, bringing great adversity in the fight against forest fires, were reflected in danger and fire risk index values, operationally computed on a daily basis at IPMA, namely the six components of the Canadian Forest Fire Weather Index (FWI) System. The FWI values were extremely high over the majority of the country (98th percentile), breaking a record in the historical period since 1999 (Figure 12a, b).



(a) (b) (c)

Figure 12 - Forest fire risk on 15th October 2017, (a) FWI, (b) FWI percentile, (c) RCM. Risk classes: Low ("1- Reduzido"), Moderate ("2-Moderado"), High ("3-Elevado"), Very High ("4-Muito Elevado") and Maximum ("5-Máximo"). *(adapted from Novo, I. and Pinto, P. 2017, in Portuguese).*

The fire risk index disseminated daily by IPMA, RCM ("Risco Conjuntural e Meteorológico") is a combination of FWI index with a structural risk. This structural risk includes burnt areas, fire climatology, land cover and land use. This structural risk is annually updated by the National Forests Service, ICNF. Risk index values are divided into five risk classes: Low, Moderate, High, Very High and Maximum, computed for a county area. On 15th October this risk index was the highest since 2006 (Figure 12c), with all the administrative areas in mainland Portugal at their maximum class of risk.

5. Pyroconvective plumes identified on radar

In the scope of weather radar observation, the term pyroconvective plume refers to a radar reflectivity pattern associated to a certain location (approximate fire area), corresponding to a relative maximum of radar reflectivity, revealing a divergent structure downwind of the fire area spot. Gravity tends to sort out smoke particles in a way such that a greater concentration of larger particles tends to be located closer to the fire spot. Thus, it is admissible that a relative maximum of reflectivity tends to be observed closer to the fire spot. Nevertheless, it is to be noted that this procedure was just intended to follow up the general evolution of the fire plumes, both in space and time. It was not meant to identify the approximate number of fires. Since 1) several plumes may be below the minimum radar observation height during their entire life cycle (beam overshooting) and 2) radar beam resolution issues and the coexistence of smoke scatterers and spurious echoes, it is possible that the number of fires may have exceeded the number of detected independent plumes.
In the following discussion, the time each plume was detected refers to its first detection. As an example, by 16:10 UTC of 15th October, several plumes were being identified (Figure 13). Using both mentioned radars, it was possible to identify a large number of plumes. Plumes were identified between 5 UTC, 15th October, and 00UTC, 16th October.

Using the subjective technique, thirty one (31) plumes were identified. The graphic (Figure 14) shows, on an hourly basis, the number of plumes detected (first detection) during that specific hour.

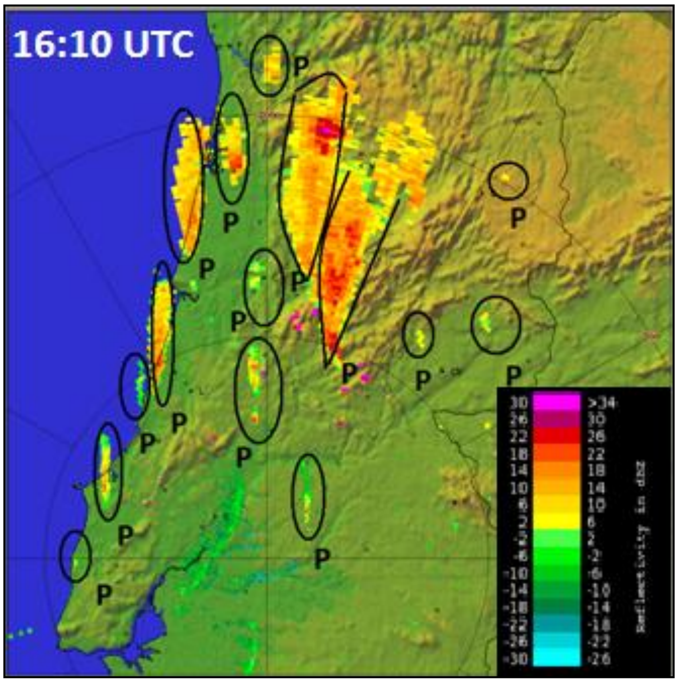


***Figure 13** - Plane Position Indicator of Z (dBZ), 0.1° elevation, 16:10UTC, 15th October 2017, radar. Black segments mark 15 plumes that were identified on radar (C/CL), by this time (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).*

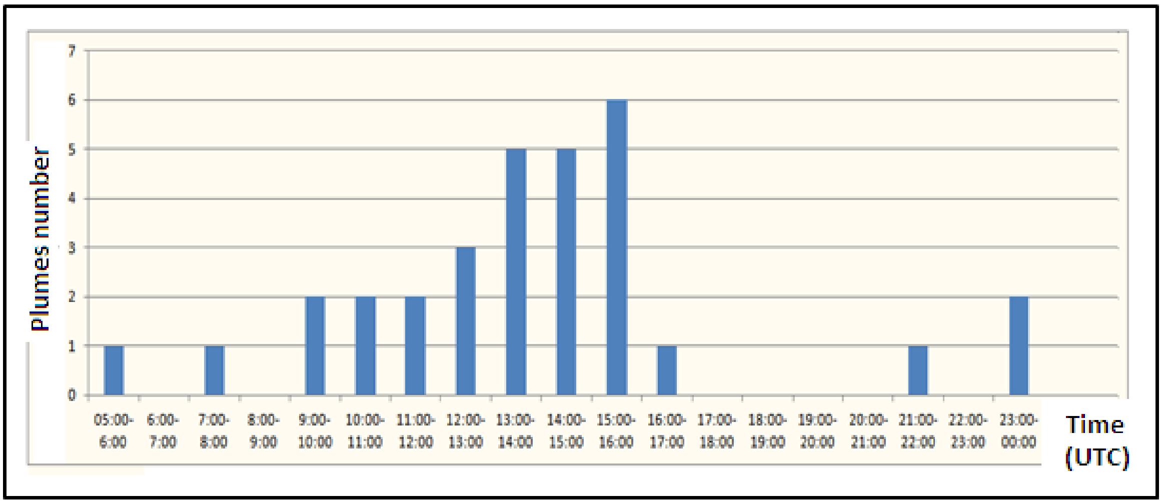


***Figure 14** - Number of plumes (first detection instant) between 5 UTC, 15th October and 00utc, 16th October, 2017. Diagnose based on A/PG and C/CL radars (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).*

It is impressive to see how the plumes detection rate, along the day, incremented substantially by early afternoon. It is noteworthy to realize that in a short period of just 4 hours (12-16 UTC), 19 plumes were detected, corresponding to more than 60% of the total amount that was detected during the entire 18 hours considered period. Thus, this short period has proven to be very favorable to fire development, and with no surprise. In fact, it was observed, then, that factors such as high air temperature, low relative humidity and a low level turbulent wind regime (see 3.3) have combined across a major part of north and centre mainland Portugal.

6. Pyroconvective plumes and glaciation

The dual polarization A/PG radar system processes an interesting parameter regarding the microphysical characterization of scatterers in the atmosphere. In fact, the correlation coefficient (ρ_{hv}) has been considered as a fine particle type discriminator. Lang *et a*l (2014) and LaRoche and Lang (2017) have found that a mixture of fire ash and rimed ice particles uses to have ρ_{hv} values larger than or equal to 0.8, whereas pure ash uses to have ρ_{hv} values lower than 0.8. Observational experience collected in Portugal, still to be published, sustains similar opinion. Thus, ρ_{hv} values less than 0.8 were considered as typical from dry pyroconvective plumes whereas larger than 0.8 were considered as characteristic of a mixture of ash and ice particles. On this concern, it is shown a pyroconvective formation example, as observed by 22:50 UTC of 15th October 2017. It was possible to detect a pattern of ρ_{hv} values larger than 0.8 (yellowish pixels, Figure 15), meaning that part of the top of this pyroconvective cloud had a glaciated (or partially glaciated) area.

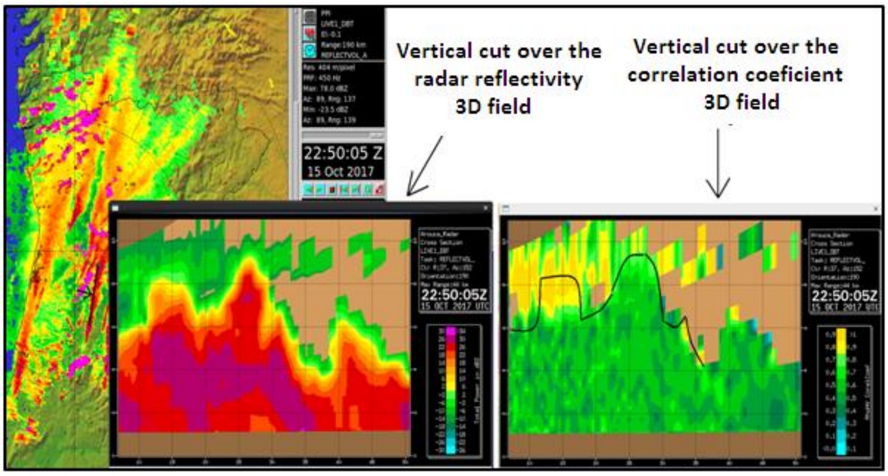


Figure 15 - Vertical cuts over 3D reflectivity field (Z, dBZ, left) and over 3D correlation coefficient field (no dimensions, right), 22:50UTC, 15th October 2017, A/PG radar. Transect cut and observer position marked with black line and arrow over PPI of reflectivity (left image in background). Cloud tops as detected by radar are marked with black contour lines in Vertical cut over correlation coefficient. Vertical scale discretization: 2 km. (adapted from Novo, I. and Pinto, P. 2017, in Portuguese).

This example shows that during the evening of 15th October 2017, there existed conditions that favoured the genesis of pryroconvective clouds. As stated in the specific literature, these developments are frequently seen as hazardous in respect to fire evolution in the short term.

7. Final Remarks

A catastrophic forest fire event occurred over mainland Portugal on the 15th October 2017, outside the typical forest fire season.

An accentuated meridional flow pattern over the Atlantic has caused a ridge settling over Iberia, promoting the extension of an already hot and dry summer throughout October. At the same time, the anomalous track of hurricane Ophelia, in the surroundings of western Iberia coast by the 15th October, has intensified the southerly flow and its turbulency. Furthermore, it has reinforced the advection of an unseasonal hot and dry airmass over mainland Portugal. Air turbulence, heat and extreme air dryness have combined with a 4th factor that, is suggested, has played a significant role in the hazardous environment. In fact, according to ground observations, a "dry Foehn" phenomenon has, likely, reinforced the large scale adiabatic compression effects. This was especially noted in the dryness of the air and flow intensity in downwind slope areas.

8. References and bibliography

Balakrishnan, N., and Zrnic, D., 1990: Use of Polarization to Characterize Precipitation and Discriminate Large Hail, Journal of the Atmospheric Sciences, Volume 47, No. 13, 1525-1540.

Gouveia C. M., Bastos A., Trigo R. M., DaCamara C.C. ,2012: Drought impacts on vegetation in the and post-fire events over Iberian Peninsula, Natural Hazards Earth System Sciences,12,3123-3137, 2012, doi:10.5194/nhess-12-3123-2012.

IPMA, 2017: Boletim Climatológico outubro 2017, Portugal Continental, ISSN 2183-1076 (in portuguese).

Novo, I., Pinto, P., 2018: Os Incêndios Florestais de 14 a 16 de Outubro de 2017 em Portugal Continental Caraterização Meteorológica. Relatório, DivMV, IPMA, 79pp. (in Portuguese)

Jason J. Sharples, Graham A. Mills, Richard H. D. McRAe, Rodney O. Weber, 2010: Foenh-Like Winds and Elevated Fire Danger Conditions in Southeastern Australia, Journal of Applied Meteorology and Climatology, volume 49, 1067- 1095.

Lang, T., B. Dolan, P. Krehbiel, W. Rison, and D. T. Lindsey, 2014: Lightning in wildfire smoke plumes observed in Colorado during summer 2012. Monthly Weather Review, 142, 489-507.

LaRoche, K., and Lang, T., 2017: Observations of Ash, Ice, and Lightning within Pyrocumulus Clouds Using Polarimetric NEXRAD Radars and the National Lightning Detection Network, Monthly Weather Review, Volume 145, 4899-4910.

Pereira, M.G., Trigo, R. M., DaCamara, C. C., Pereira, J.M.C., Leite, S. M., 2005: Synoptic patterns associated with large summer forest fires in Portugal, Agriculture and Forest Meteorology, 129, 11-25.

Stacy R. Stewart, 2017: Hurricane Ophelia, Tropical Cyclone Report, National Hurricane Center, 27 March 2018, NOAA.

Van Wagner, C. E., 1987: Development and Struture of the Canadian Forest Fire Weather Index System, Cabadian Forestry Service, and Forestry Technical Report 35 Ottawa 1987.