Cut-off lows: Their characteristics and their effects

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What is a "closed upper-level low", or cut-off low, and why do we term it thus?

The reader who has begun their perusal of this article is already likely to have some notion of the subject to be discussed — the cut-off low and its potential effects. The trouble is that defining a cut-off low is no straightforward matter. Firstly, because we have to refer to other facts about how the atmosphere behaves. Secondly, because many of them (as we shall see presently) morph over their lives into other structures or modes which have their own nomenclature, which gives rise to occasional misunderstandings and controversy. It is for this reason that this article starts off with an explanation of what a cut-off low is without attempting to provide an unequivocal definition.

As is described in the *MeteoGlosario Visual* (visual weather glossary) that is posted on the AEMET website, the term "DANA" (the Spanish acronym for a cut-off low) is currently used instead of the phrase "cold drop", which has thus far been the term generally applied, sometimes erroneously. The term "cold drop" was coined by the German meteorological school, which named this phenomenon *Kaltlufttropfen*, meaning "cold air drops". In Spanish, the equivalent expression of gota fría became distorted and associated with any situation involving heavy downpours, for which reason AEMET has preferred to avoid using it and instead to speak of a *Depresión Aislada en Niveles Altos* or "Cut-off Low" (literally a "Closed Upper-Level Low" in Spanish), which was lexicalised as the acronym "DANA" and also represents a tribute to the meteorologist Francisco García Dana, who passed away in 1984. It is not just us meteorologists who employ acronyms in this way, as there are other very well-known examples, such as DNA or NATO. The Foundation of Emerging Spanish recommends that, in general, when acronyms are no more than four letters long, they should be written in capital letters, except when they have become so commonplace in everyday parlance that they are used as ordinary words (such as ufo, aids etc.) and so lower-case lettering is used for them.

The parts of the acronym help define it. “Low” refers to a spatial or positional property where the atmospheric pressure in an area diminishes as we move towards its centre. “Upper-Level” is also a simple reference: within the vertical structure of the atmosphere and keeping to its nether region, the troposphere, and the middle latitudes where a cut-off low forms, it applies to levels above five kilometres high. Nonetheless, the term “Closed” or “Cut-off” entails greater difficulty as a defining feature, since we first have to determine what this is relative to. This calls for more care to be exercised, because a whole series of references have to be embraced here. What is being cut-off from is what is known as the circulation of westerlies in mid-latitudes and the polar jet stream.

Formation of a cut-off low

At this point it seems appropriate to move from the general to the specific and scale steadily down in a geographic sense until we arrive at the cut-off low. As it orbits the sun, the earth receives the energy which the star gives off. The amount of energy any given area of surface receives depends on its orientation with respect to sunrays. When this is perpendicular, the amount of energy captured is at its greatest and this is reduced to zero when the area of surface shares the same orientation as the rays. An initial consequence of this is the fact that there are seasons. The particular phenomenon whereby the earth’s axis of rotation is tilted with respect to the plane of its orbit around the sun, known as the plane of the ecliptic, means that for a point or place on the earth’s surface, sun-rays are closer to the perpendicular of the surface in summer, for which reason we say that the “sun is plummeting (i.e. beating) down”, while they hit the earth at a greater angle to absolute vertical (“more obliquely”) in winter, with the resulting annual temperature cycle. If we now examine what occurs as regards the variation in latitude for any specific day of the year, the sun-rays reach earth more vertically in zones close to the equator than at latitudes nearer the poles, meaning that the latter receive less energy, hence the temperature difference between the equator and the poles. The atmosphere takes care of keeping a balance in the temperature difference between both zones by carrying energy from the equator towards the poles. Initially, being lighter, the over-heated air in the equatorial zone rises towards the tropopause and descends on both sides of the equator several thousand kilometres away, warming up due to compression and giving rise to the belt of subtropical anticyclones. A boundary forms between this warm air which is dry over the continents, or very humid over the oceans, and the cold polar air, from the ground to the tropopause. Here the westerly winds predominate (the pressure difference between both sides and the fact that the earth is rotating about its axis brings about this wind belt). The strength of these winds generally increases with height. This is at its greatest near the tropopause and is concentrated in what is known as the polar jet stream, which is dozens of kilometres wide, going around the poles and leaving the region warm to its right, towards the south in the northern hemisphere.

The polar jet stream does not follow the parallels consistently, but instead undulates successively northwards and southwards, giving rise to troughs and ridges in latitude. A trough is a breaking southward of air which is colder than that around it. Within it, low-pressure areas or depressions form with fronts that separate the cold from the warm air. The succession of troughs and

CUT-OFF LOW FORMATION PROCESS

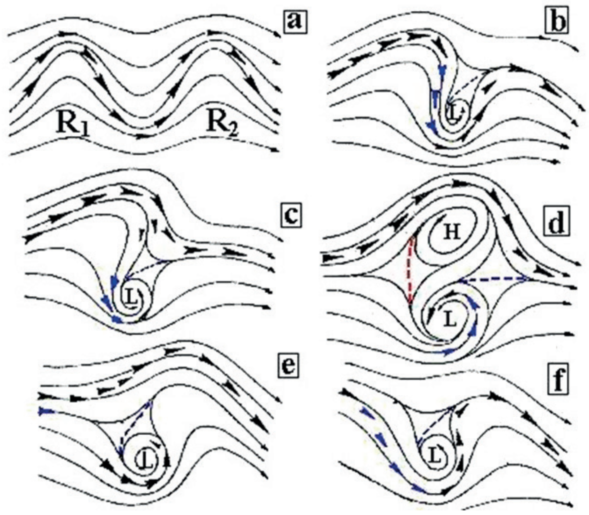

Figure 1. Shows two processes where a cut-off low (indicated as L) detaches itself from the circulation of westerlies. The letter H shows a high-pressure centre, while the R represents a ridge.

ridges at high levels usually moves eastwards. Sometimes this movement is hindered by the well-established presence of potent masses of warmer air that occupy the entire troposphere and a cut-off low breaks away southwards from a trough in a vortex shape as it tries to pass round the block. Once it is away from the conveyor belt, the cut-off low moves more haphazardly and unpredictably, being subjected to the conditions in the zone which it is passing through: mountain systems, warm seas, etc. Let us imagine a river current, stronger in the middle and slow next to its banks. At times whirlpools become detached, which swirl at speed to start with and move towards the bank. Could we compare this to how a cut-off low is created and progresses? We might, but with several qualifications and only by way of a visual metaphor. The eddies in the river are characterised by mere movement about their central axis. In the case of a cut-off low, there are also thermodynamic processes on account of water vapour condensing, which releases energy in the form of heat. These processes moreover take place in an environment where density, temperature and wind vary according to height. In fact these characteristics mean that the structure of cold air surrounded by warmer air can also gradually spread down to lower levels until it reaches the surface in a final state known as a "cold cut-off low pressure area", occupying the whole troposphere and appearing on surface maps as a low pressure centre, normally accompanied by fronts.

Having contextualised how cut-off lows are formed and progress, what can we say about them as an individual entity? Do they represent a disruption? Although a natural and normal phenomenon should not be viewed as a disruption, just as low-pressure areas are defined as an atmospheric disturbance, we can treat cut-off lows in the same way. It does not seem appropriate to include them among atmospheric phenomena. We usually reserve the term "atmospheric phenomenon" for meteorological phenomena in their own right, and we ought to speak of atmospheric phenomena that originate from a meteorological disruption. In short, if we wish to apply nomenclature for the whole category, this ought to be "elements in global circulation", which is apt for more technical studies but not particularly suited for use in a normal conversation.

How do cut-off lows progress?

Normally when associating the appearance of a cut-off low over our latitudes with very heavy rainfalls, this gives the idea that they are not very frequent. Yet this is not so. Studies made to count the number of cut-off lows (database made by Rico, 2005) within a window that covers Western Europe and the eastern Atlantic talk in terms of some 15 a year on average, these being more prevalent in spring and summer. Two zones can be marked out as those more commonly beset by cut-off lows: the south-east of the Iberian Peninsula and the Mediterranean zone to the south-east of the Iberian Peninsula. Here we should point out that frequency refers to where the centre of the cut-off low lies, which does not always overlap with the zone where the effects are at their most devastating. One detail to mention about the studies discussed is that there is a great degree of year-on-year variation, with years when 20 or even more are recorded, while there are others where they barely amount to 10. Another notable fact is that there is a falling trend in the number of cut-off lows that form in spring and a rise in those that occur in summer and autumn. This is highly significant, given that it squares with the warm sea and on-shore conditions in the Mediterranean zone, which probably work in favour of instability and are likely to increase the heaviness of downpours.

Cut-off lows do not originate all around the world; in the northern hemisphere there are three zones that are sources of these phenomena: the eastern Atlantic, the eastern Pacific and the zone that encompasses China and the ocean that borders on it. The life cycle of a cut-off low usually lasts for about two days and only one third of them reaches, or goes on for more than, three. In their final phase, cut-off lows are equally divided between those that abate and fade away, and those that are subsumed into a more potent system.

What are the reasons for masses of cold air breaking away at higher levels of the westerly belt? Everything appears to suggest that they are linked to patterns of large-scale atmospheric circulation, specifically to the blockage situations that impede the eastward spreading of the waves absorbed in the circulation of westerlies and to certain states of what are called teleconnections, such as, for example, in the cases of the "El Niño" weather phenomenon or the El Niño Southern Oscillation (ENSO) and to the North Atlantic Oscillation (NAO), which can be gauged by comparing pressures in the Azores zone with that in Iceland. To summarise, it can be said that the trend towards more cut-off lows originating relates very directly to a weakening of the polar jet stream due to a diminishing of the thermal contrast between the polar mass and the subtropical mass of air. As an initial result of this fact, the polar jet stream starts to meander or fork apart, which makes the breaking away of cut-off lows more likely.

What are the effects of this?

A cut-off low can bring about several different adverse phenomena: strong winds, heavy downfalls of rain or snow and storms. Starting with heavy downfalls, these are usually linked to convection within unstable air. Strong convection, accompanied by severe storms arranged in structures that can act for several hours, occurs when there is a notable difference between the temperature near the surface and that at higher levels. We have already seen that a cut-off low has colder air at its centre, which is why it is predictable that, when it passes over zones with hot air, convection is unleashed as soon as a trigger mechanism comes into play, such as, for example, rising up the sides of coastal mountain systems. If, besides being warm, the air that sustains the storm is humid, we find that, on the one hand, it supplies more water that can precipitate and in addition to this, where there is enhancement or intensification of the convection due to the effect of the warmth given off into the atmosphere because of the water vapour condensing as it rises, this adds more energy to the storm. We can therefore conclude the following noteworthy fact: the adversity of a cut-off low depends on both its own structure and conditions external to it. When it travels through cold zones the phenomena will not be so violent, since the temperature contrast between low and high levels is not as great and the convection is not so intense. With respect to Spain, the most dangerous situations arise when the cold air at high levels draws closer to the Mediterranean Sea at the end of summer, when the temperature is higher.

Broadly speaking, two zones of downfall that are associated with each cut-off low can be discerned: those that originate in its centre due to instability deriving from the core of cold air at upper levels and those that occur in what is known as the “baroclinic leaf shield” in the eastern zone of advance of the structure and which, normally, is shown on surface charts as a front. The strongest levels are usually associated with the baroclinic leaf shield. The high degree of instability and the presence of input at lower levels lead to convection becoming organised and gives rise to storm structures that last for several hours and can persist over a single point, causing flooding. This contrasts with the less organised, shorter-lived convection that forms below the core.

As has already been described, precipitation strengths rely heavily on both humidity input conditions at low levels on account of a large amount of water vapour resulting from the continuous evaporation from a warm sea at the end of summer and the presence of wind maximums in conjunction that drive this highly unstable air towards the orographic barriers in coastal systems that force it to rise and act as a trigger for powerful convection. This combination of elements characteristic of a cut-off low and the environment within which it moves, together with the differentiating fact that the paths of a cut-off low lack any powerful steering element and are more erratic, make forecasts during these episodes particularly difficult. Furthermore, it should be remembered that at times, owing to the position of the cut-off low, there is powerful westerly circulation over the Bay of Biscay, which causes heavy and persistent downpours.

With respect to the distribution of precipitation in the different areas over Spain that are caused by cut-off lows, studies (Nieto, 2005) show that, as regards the north-western quadrant of the Peninsula, the contribution of downpours prompted by cut-off lows only accounts for one fifth of the annual total, whereas the share of these in the north-eastern quadrant is 60% of annual precipitation.

To sum up, we can state that not all cut-off lows produce strong downfalls over the Iberian Peninsula and that the fact that they happen depends on other conditions to which the position of the centre of the cut-off low is very sensitive, which in turn determines the position of the baroclinic leaf shield and the intensive transportation of very humid air groundwards.

The effects of any natural disaster are related to the power of the phenomenon that provokes them, though also to the vulnerability and exposure of the affected zone. For our purposes, the strength of the phenomena that are triggered by a cut-off low will depend on two factors, as has been discussed:

- The structure of the cut-off low with respect to how deep it is. In other words, with respect to how much the pressure at its centre diminishes and how unstable it is, which is in turn conditional upon the decrease in temperature at height.
- External conditions. Essentially on the supply of energy at lower levels associated with the temperature of the air, its water vapour content and the strength of the winds that carry it along, as well as the presence of agents that trigger convection, such as the convergence of winds or orographic rises.

We have already made mention of the role of wind, its course over the sea and surface temperature. A characteristic feature that is common to many situations involving torrential rain is the formation of a corridor of wind from the east travelling a long distance over the sea due to the combined action of anti-clockwise circulation around a low-pressure centre in the south and clockwise circulation around a high-pressure centre to the north. The stronger the winds will be, the greater the difference in pressure between the two centres and the narrower the boundary between both of them.

How are cut-off lows forecasted and monitored at AEMET?

Although we have said that forecasting these episodes is difficult, global weather forecasting models such as the one at the European Centre for Medium-Range Weather Forecasts (ECMWF) manage to capture the formation of cut-off lows with increasing accuracy and sufficiently in advance both to track the successive forecasts available every day (every twelve hours for the ECMWF model) and to depict the degree of uncertainty regarding their course and characteristics using probabilistic forecasting systems. Probabilistic forecasting is based on the information provided by a set of models (50 for the ECMWF system) that have lower spatial resolution but which simulate uncertainty with respect to precise knowledge of the initial state and mathematical approximations used in calculation. This allows the State Meteorological Agency to issue briefing notes and special warnings days in advance. These bulletins cannot pinpoint the location of rainfall highs that will occur or quantify them, but they are useful for initiating protocols for tracking and readying emergency services so as to be able to respond quickly if necessary, as well as for conveying recommendations to members of the public that might be affected. When the event begins and forecasts from the Harmonie model have also become available every six hours with resolutions of 2.5 kilometres and 48 hour time-spans, greater detail can be specified about the strength of downpours as well as their location, which in any event will never extend to the spatial boundary for a place. These forecasts are expected to be supplemented with a probabilistic forecasting system developed by AEMET that uses very high-resolution sets from 2020, once sufficient calculating power becomes available with the new super-computer.

The time has therefore come for weather monitoring, a concept which involves continuous tracking of how the situation is unfolding by forecasters thanks to data observed from satellites. Every 15 minutes pictures become available that have resolutions of even one kilometre in several channels, as well as products that are obtained on the basis of this information, such as estimated downfall strength, instability indices, estimates of water prone to precipitation, etc. Work is also carried out using the information that is provided by AEMET's radar network, which offers data on the location of precipitation and an estimate of its strength, and using the lightning

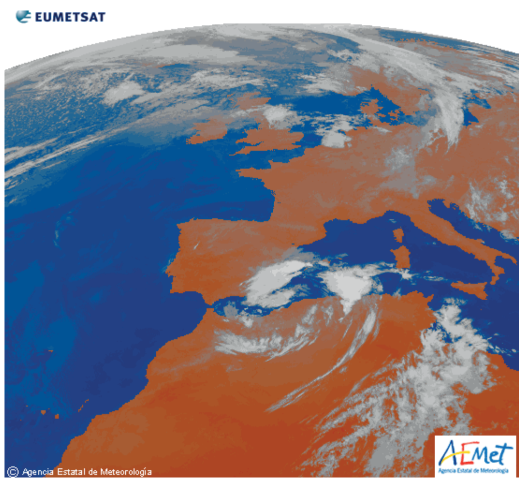

Figure 2. Meteosat picture via an infra-red channel (12/09/2019 00UTC).

detection network, which locates storms to one kilometre of accuracy, as well as readings from the network of conventional surface stations, which provide 10-minute information from a network of over two hundred specially-purposed stations. The aim of monitoring efforts is to use the know-how and experience of forecasters to detect potential deviations relative to current warnings so as to update them appropriately and so that they can be automatically circulated to the emergency services and published to inform the public. This is the critical moment when the entire chain of information on the weather, communication with emergency services and notification to the public must function for the response to be effective and risks mitigated.

To illustrate the observation and remote sensing tools that AEMET's forecasters use we go on to show various different satellite pictures (infra-red, visible and water vapour channels) from AEMET's remote sensing networks (radar and lightning) and the surface observation network, all of which relate to the cut-off low which hit Spain in September 2019.

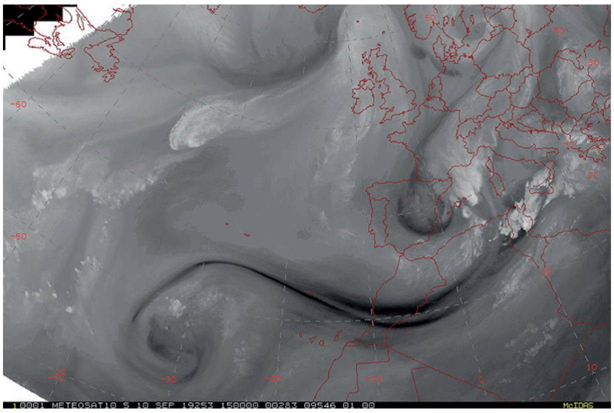

Figure 3. Picture from the water vapour channel that shows the cut-off low crossing the Peninsula on its course to the south-east (10/09/2019).

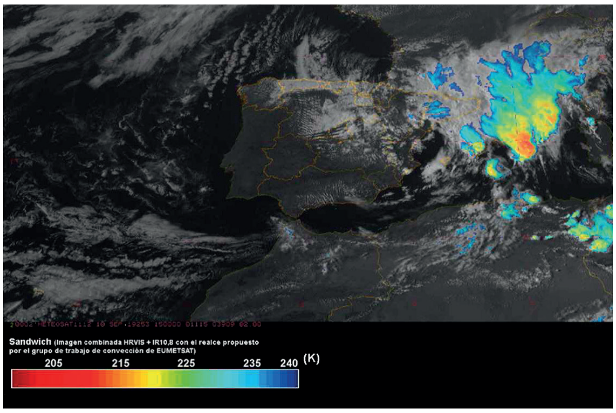

Figure 4. Picture which several different channels process and combine to highlight deep convection (10/09/19).

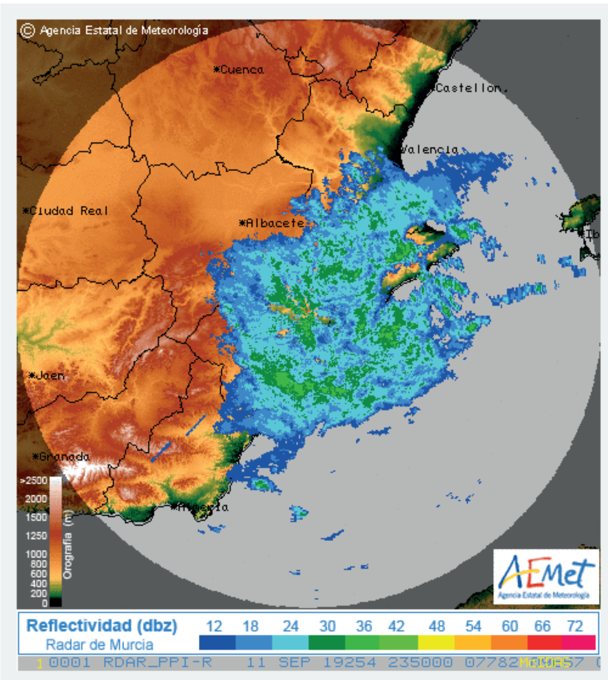

Figure 5. Image captured by the Murcia radar on 11 September.

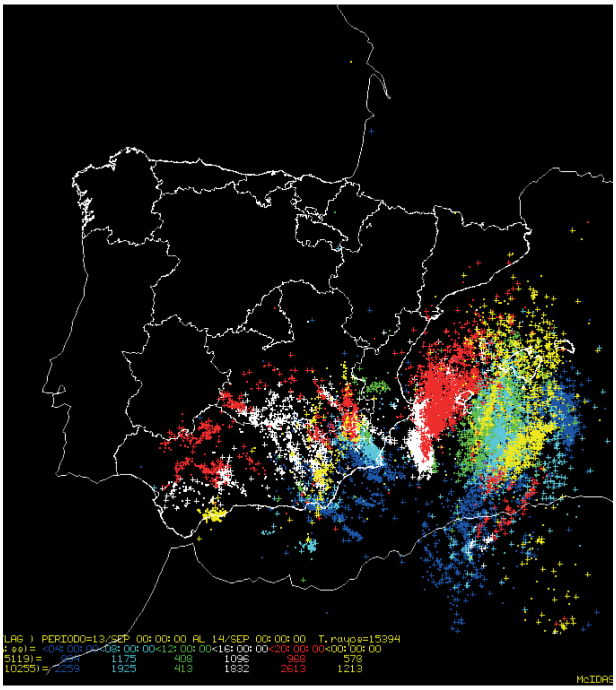

Figure 6. Lightning bolts detected on 13 September 2019.

Is the number of cut-off lows growing? Are their effects intensifying as part of a trend in climate change?

These questions emerge against a backdrop of widespread interest in attributing adverse weather events to climate change, specifically to global warming, more precisely of the anthropogenic kind. Here we should distinguish two aspects to take into account. One, which is more immediate, refers to the increase in the intensity of precipitation from the interaction of cut-off lows with the Mediterranean environment. In this case, there is no room for doubt: the rising temperatures and water evaporation, according to the laws of physics that apply to meteorology, tend towards ensuring that rainfalls should be more intense or, what amounts to the same thing, an increase in the torrential nature of downpours. Given the intrinsic spatial and temporal variability of torrential rain events originating from convection (it can happen that only 10 kilometres away from a weather station that reads 200 litres per square metre another one barely shows 10), it is not easy to detect and show trends of this impact in a quantified way. It can be identified indirectly by analysing the contribution to total annual rainfall at a station of the five percent of the days with the heaviest downpours, where this percentage is understood to represent the rate of torrential falls. The other aspect that is even more difficult to assess is identifying trends in the formation of cut-off lows which can subsequently shift towards Spanish regions and come across an environment that is suited to heavy raining. We have seen that the number of cut-off lows or the formation of them correlates with larger-scale patterns such as the NAO or the ENSO index. Specifically, the North Atlantic Oscillation, and this is borne about by numerous studies, is the factor that relates more closely to Spain's rainfall systems. One should act prudently here, since the correlation with the index that measures this pattern has a varying influence depending on the season of the year. The most significant positive correlation in Spain occurs in relation to rainfalls in autumn (Nieto, 2006). If we bear in mind that the NAO index has a rising trend, this would also justify the increase in the number of cut-off lows in autumn. On the other hand, there does not appear to be a significant positive correlation with the number of cut-off lows that occur in spring or winter, even though in those seasons the appearance of cut-off lows correlates well with the presence of blocking situations, which in turn have an origin that is fraught by complex factors that are still being studied. The formation of cut-off lows in summer correlates closely with the QBO (quasi-biennial oscillation) index, which describes wind systems in the stratosphere over the equator.

Certain catastrophic flooding events and how they relate to cut-off lows

To conclude, we will review certain historical catastrophic flood events to identify what features in common they exhibit and which of them show variations. For each situation we will see whether the occurrence is linked to the presence of a cut-off low. We will use this review as an opportunity to provide some significant rainfall data that has been logged, some of which represents genuine weather records.

So as to be able to take ourselves back to events in the 19th or early 20th century we have to count on the assistance of a tool that was widely used among meteorologists and climatologists. This concerns numerical reanalysis. Numerical atmospheric models enable simulation of how the atmosphere behaves and use certain observed data to reconstruct the state of the atmosphere going forward, although calculations can also be directed at the past using historical data. This allows us to obtain the "weather maps" from decades ago, provided that we have enough observations of those years available. These kinds of studies are feasible given that, ever since meteorological services were established, or even before that, records have existed of atmospheric parameters such as pressure, temperature, humidity, etc. from many cities and specialist scientific observatories.

Firstly, we shall go back to the first significant date of 14 October 1879, on which day the river Segura burst its banks and caused over a thousand deaths. Reconstruction using reanalysis places a cut-off low opposite Morocco's Atlantic coast which provoked a marked moisture flow towards the south-east of the Iberian Peninsula at surface level.

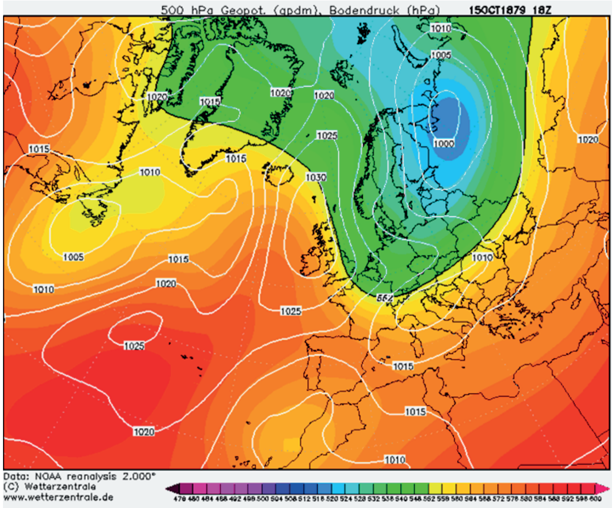

Figure 7. Reanalysis of 15 October 1879. Numerical model from America's National Oceanic and Atmospheric Administration (NOAA). Source: Wetterzentrale.

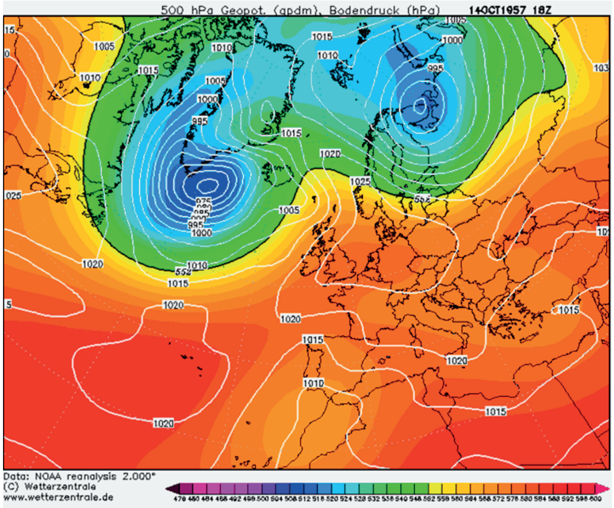

Figure 8. Reanalysis of 14 October 1957. Numerical model from America's National Oceanic and Atmospheric Administration (NOAA). Source: Wetterzentrale.

The unbroken white lines in the figure above represent the surface pressure field which makes it possible to estimate the direction and strength of the wind. The coloured bands indicate the mean state of the troposphere. The colour gives an idea of the temperature (the warmer the colour, the hotter it is, while the colder the colour, the lower the temperature) and marks out the high or low-pressure systems.

Another historic flood is the one which took place in Valencia on 15 October 1957. During this event an upper-level low slowly drifting over the south-west of the Peninsula was reflected on the surface by a low-pressure centre focussing on the gulf of Cádiz, which, as in the previous example, generated a flow from the south-east on the Mediterranean coast.

The most significant rainfalls included in this event are given in the table below:

Figures from 15/10/1957		
CODE No.	**NAME**	**QPF (mm)**
8050	JÁVEA-POU DEL MORO	300.0
8056	EL VERGER RACONS	298.0

If we move forward in time, we come to the flooding from overflowing of the rivers Llobregat and Besós in Barcelona, of the Rambla de la Viuda in Castellón and the torrential rainfalls in Palma de Mallorca, which occurred on 25 September 1962. Although the effects are similar to other events occurring, it should be pointed out that in this case they were not caused by a cut off low, but instead by the passing of a trough (an upper-level low immersed in the zonal circulation of westerlies that is associated with undulations in the polar jet stream). The unbroken lines join up points at the same height, in tens of metres, of the surface with a pressure of 500 hPa. The temperature data at these levels is given in colour.

The situation for the surface atmosphere is shown in the figure 10.

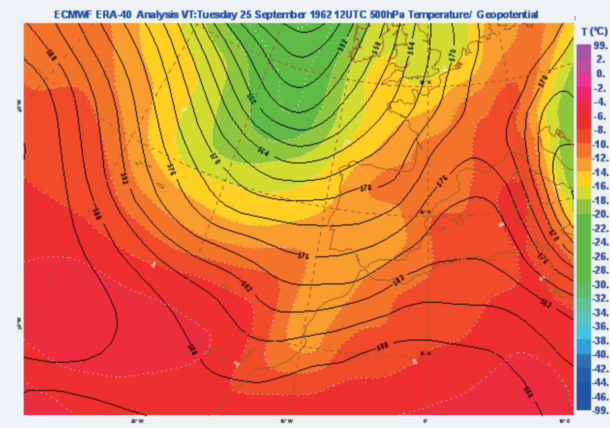

Figure 9. Reanalysis of the 500 mb field of the ECMWF model for 26 September 1962.
Source: ECMWF.

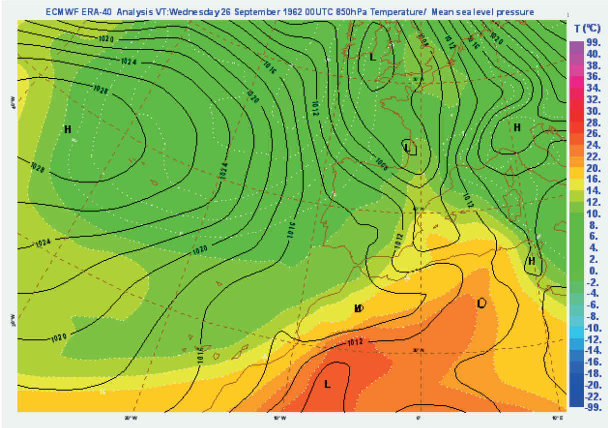

Figure 10. Reanalysis of the surface pressure field of the ECMWF model for 26 September 1962, together with the temperature picture at a level of 850 hPa (at an altitude of roughly 1.5 km).
Source: ECMWF.

Figures from 25/09/1962

CODE No.	NAME	QPF (mm)
220	MARTORELLES	250.0
188	CORBERA DE LLOBREGAT	240.0
163	ESPARREGUERA	212.5
185	GELIDA	212.0
160	OLESA DE MONTSERRAT	210.6

The floods in Alicante and Valencia of 19 and 20 October 1982, known as the "*pantanada de Tous*" (Tous reservoir event) when the dam gave way due to the strong downpours, waterlogging several population centres and leading to the deaths of dozens of people, were caused by a cut-off low. In this case the cut-off low was over North Africa, close to the strait of Gibraltar. A band of wind from the east was channelled towards the ground, being guided by the combined action of a low pressure centre south of the Atlas and an anti-cyclone over France.

The charts below show the state of the troposphere at upper levels, at an altitude of some nine kilometres, and the surface pressure field, as reconstructed by the ECMWF model.

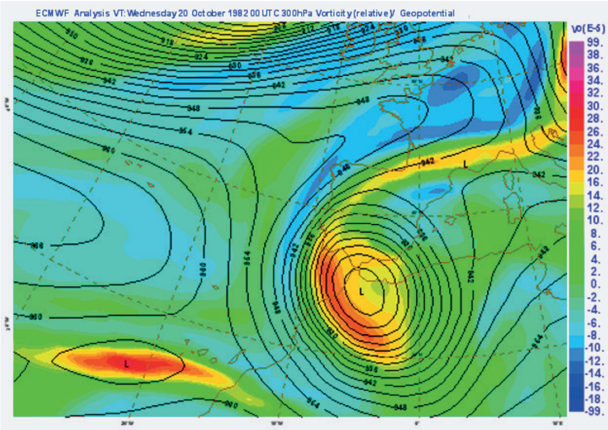

Figure 11. Reanalysis of the 300 hPa field of the ECMWF model for 20 October 1982.
Source: ECMWF.

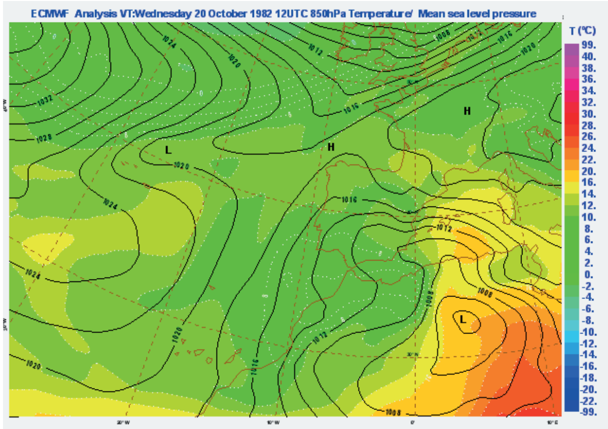

Figure 12. Reanalysis of the surface pressure field of the ECMWF model for 20 October 1982.
Source: ECMWF.

The table below shows some of the cumulative levels logged in the space of 24 hours.

Figures from 20/10/1982		
CODE No.	**NAME**	**QPF (mm)**
82700	BICORP (BARRANCO SALADO)	632.0
8204A	JALANCE AGROMET	425.5
8269	SALTO DE MILLARES (CENTRAL JUAN URRUTIA)	280.0
8276	ENGUERA C H JUCAR	278.4

The record rainfall recorded by a weather station in 24 hours was attained in Oliva (817 mm) on 3 November 1987. This event was in fact not triggered by a cut-off low but by the interaction of a cut-off low-pressure area that occupied the entire troposphere on the vertical plane over the gulf of Cádiz. The following pictures illustrate the structure of atmospheric circulation at middle levels of the troposphere and at surface level for this event.

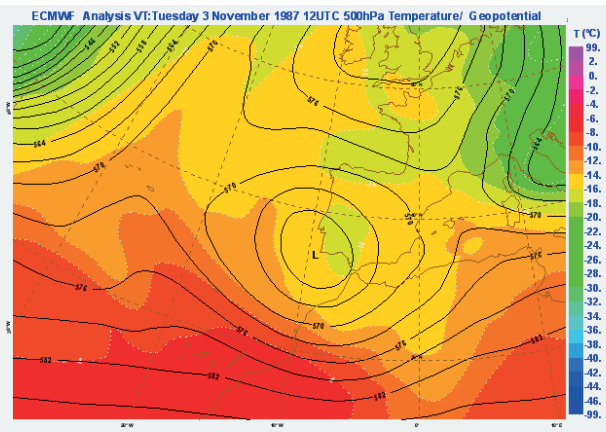

Figure 13. Reanalysis of the 500 hPa level (some five kilometres high) of the ECMWF model of 3 November 1987.
Source: ECMWF.

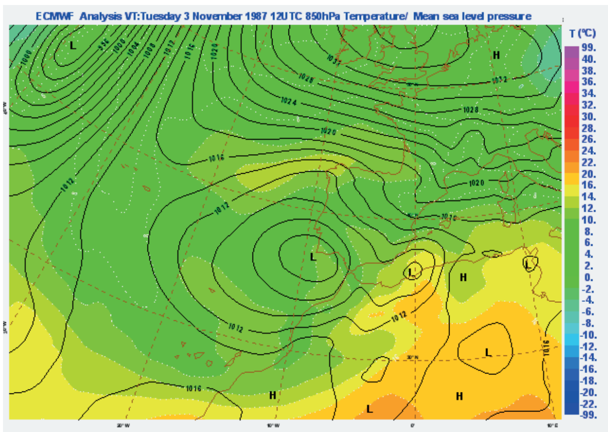

Figure 14. Reanalysis of the surface pressure field of the ECMWF model for 3 November 1987.
Source: ECMWF.

As with previous examples, we show tables of the most substantial daily cumulative figures.

Figures from 03/11/1987		
CODE No.	**NAME**	**QPF (mm)**
8058A	OLIVA S E AGRARIA	817.0
8071C	GANDIA (C. ROIG DE CORELLA)	720.0
8052B	DENIA LAS ROTAS	425.0
8051U	DENIA-CENTRO CIUDAD	377.0
8052C	DENIA (P.BOMBEROS)	374.2
8057A	PEGO CONVENTO	371.5
8286	BENIATJAR LES PLANISES	360.5
8058I	RAFELCOFER	350.0

Approaching the end of the 20th century, on 30 September 1997, Alicante and the south of Valencia province were struck by torrential rains that led to the overflowing of several tributaries of the Júcar. In Alicante 270 litres per square metre accumulated in under six hours. The heavy rainfalls over the city prompted four deaths. Again, this was a cut-off low focussing on the Atlantic coast of Morocco which sparked the event. The low pressures in northern Africa and the anti-cyclone centring on the north of France combined to produce a corridor of wind that moved across the western Mediterranean, becoming laden with moisture and feeding the rainfalls on the coastal strip with water and energy.

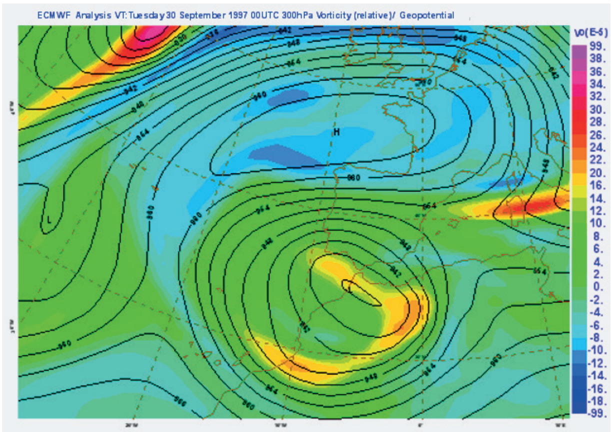

Figure 15. Reanalysis of the 300 hPa field of the ECMWF model for 30 September 1997.
Source: ECMWF.

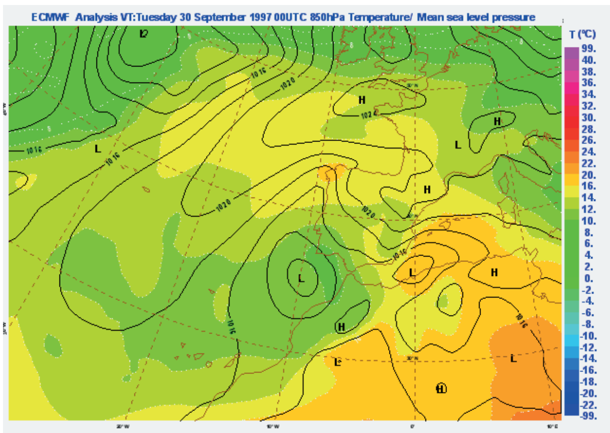

Figure 16. Reanalysis of the surface pressure field of the ECMWF model for 30 September 1997.
Source: ECMWF.

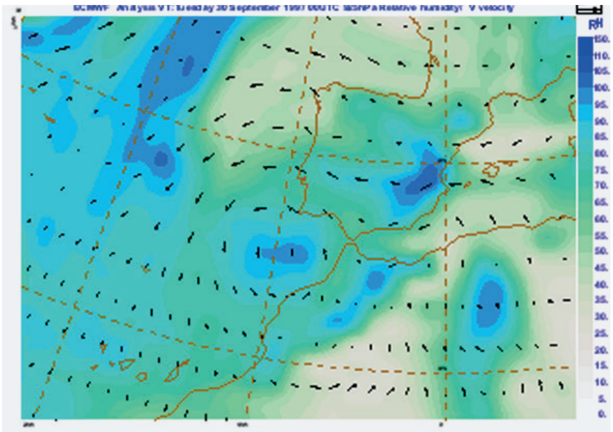

Figure 17. Reanalysis of the field of relative humidity and wind at levels close to the surface from the ECMWF model for 30 September 1997.
Source: ECMWF.

As in previous events, on separate charts we show the configuration of circulation at upper and surface levels. A third map illustrates how the wind channelled and carried very humid and warm air from the western Mediterranean towards the coast.

Moving on to the 21st century, the district of Marina Alta (Alicante) suffered a bout of torrential rains on 12 and 13 October 2007. At several points in excess of 450 litres per square metre fell under 24 hours. The rise in the level of the river Girona caused multiple cases of damage. This time there were two cut-off lows: one over the Iberian Peninsula and another in the central Mediterranean.

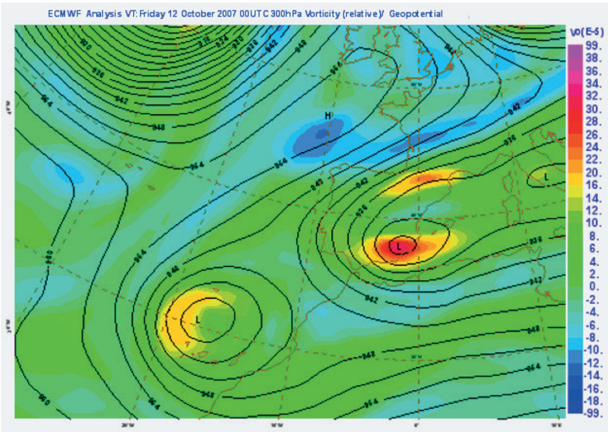

Figure 18. Reanalysis of the 300 hPa field of the ECMWF model for 12 October 2007.

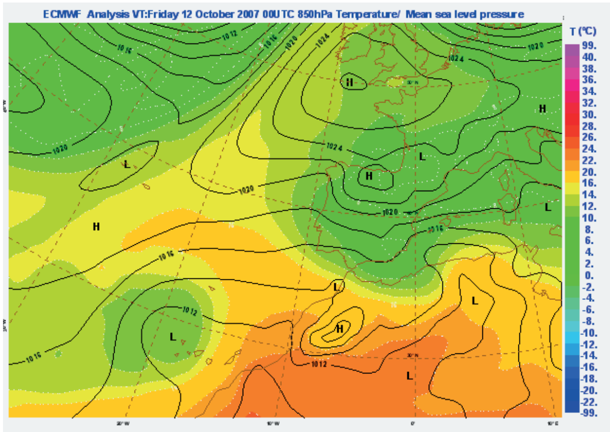

Figure 19. Reanalysis of the surface pressure field of the ECMWF model for 12 October 2007.
Source: ECMWF.

Figures from 12/10/2007		
CODE No.	**NAME**	**QPF (mm)**
8054O	TORMOS LES FONDOS	400.0(2)
8056C	VALL DE LA GALLINERA-PATRO	333.0
8051I	PEDREGUER	293.0
8048E	GATA DE GORGOS	258.9
8067	PANTANO DE BENIARRES	230.0

Climatic characterisation of the cut-off low in September 2019

The cut-off low which devastated a large part of the south-east of the Peninsula and triggered torrential rains in many regions of the Mediterranean area can be described as extraordinary, on account of both its life cycle (it went on for five days) and the path it took, since it took a course towards the south and subsequently returned northwards, which meant that in certain zones its impact was felt twice in only a brief time-span. In this case all the factors that make cut-off lows dangerous came together at once: an unusually warm Mediterranean Sea, the positioning of its centre, which directed the wind towards land after a long journey across the warm sea, and interaction with highly unstable subtropical air.

The anomaly of the depression, meaning the difference between the measured pressure and that which is the norm for a certain altitude within the troposphere, was in itself extraordinary, which is confirmed by the fact that it was the lowest recorded by the Murcia radiosonde since it was set up in 1984 (Núñez Mora, 2019). Secondly, the course of the cut-off low was somewhat strange, even given how erratic they tend to be, given that a movement southwards was followed up with another northwards.

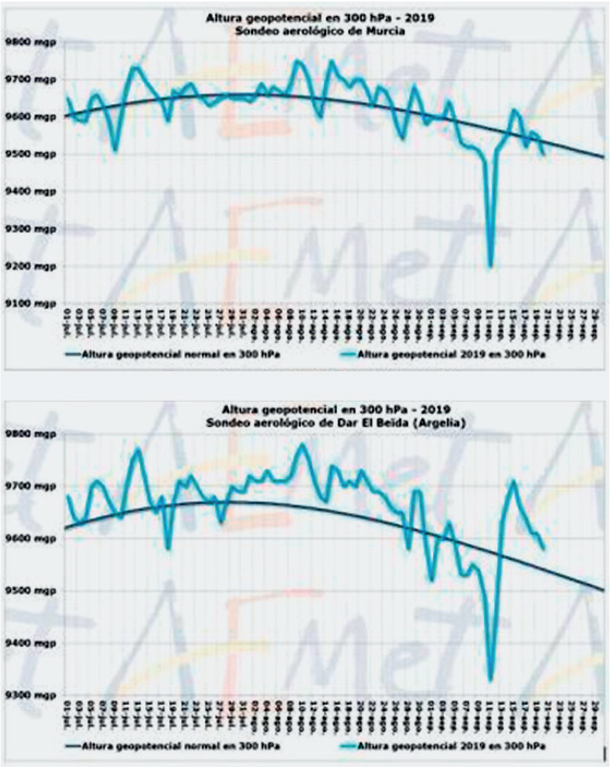

Figure 20. Trend in the geo-potential height at 300 hPa of the sounding in Murcia and Dar El Beida (Algeria) which show the strength of the depression in the cut-off low.
Source: AEMET.

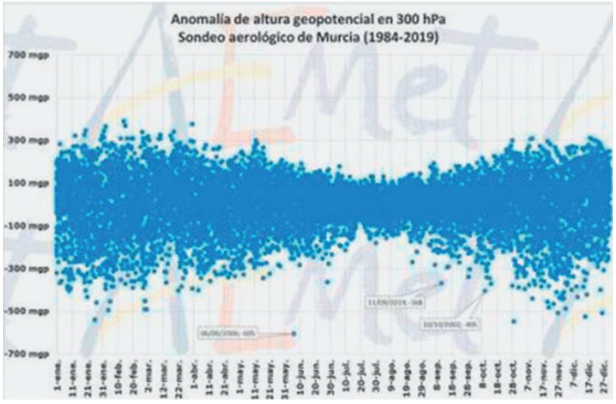

Figure 21. Distribution of the altitude anomaly (in metres) of the geopotential surface at 300 hPa relative to its mean value since 1984.
Source: AEMET.

According to the studies conducted at AEMET (Núñez Mora, 2017), *"we should conclude that the cut-off low that circulated in the south-east of the peninsula during the September storm is the deepest on record at the Murcia radiosonde weather station between 6 June and 10 October in the 1984-2019 period".*

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