The exceptional rainfall event in Lisbon on 18 February 2008

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Introduction

On 18 February 2008, the Lisbon city district, in the capital of Portugal, suffered the rainiest day on record since the continuous daily precipitation data at the D. Luís Observatory was first published in 1864 in the Observatory's log books (Annales). On this day, 118.4 millimetres was recorded at the Observatory, exceeding the previous highest daily total recorded as long ago as 1876 (Figure 1).

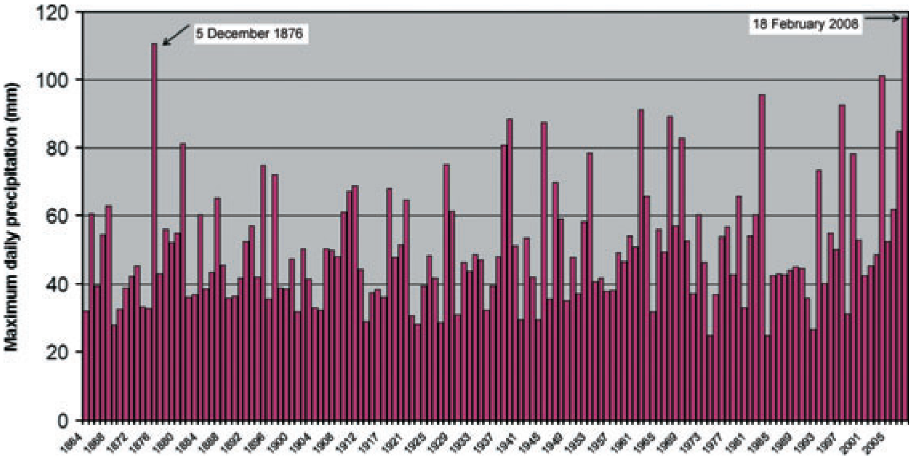

Figure 1. Interannual variation of maximum daily precipitation in Lisbon/D. Luís Observatory (1864–2008).

This extreme event was responsible for a wide variety of negative impacts, namely urban inundations (motivating hundreds of calls to the fire-fighters and civil protection brigades), flash flooding (occurring mostly in small drainage basins with short concentration times, such as the one shown in Figure 2), and landslides (a total of 64 occurrences related to slope instability were reported). The National Authority of Civil Protection reported four deaths, 65 people dislodged and 121 evacuated in safety and rescue operations. No official information is available concerning the estimate of total financial costs associated with this extreme event, considering that other direct and indirect impacts of the storm should be taken into consideration: namely those associated with disruption of train services, blocked roads and electric power breakdowns.

Figure 2. (a) Inundations in the quarter of Sacavém, located in the north of Lisbon city district; (b) the vehicle shown was captured by the torrential flow of a stream (Ribeira do Jamor) that was suddenly raised, surprising the two occupants who died as a consequence of the flash-flooding.

In this paper, we study the spatial distribution and temporal evolution of this extreme rainfall event. Then we fit an appropriate extreme values distribution and compute the return period associated with this event for several stations available in the Lisbon area. Finally, we provide a short description of the evolution of the synoptic situation leading to this extreme rainstorm.

Spatial distribution

The spatial distribution of daily precipitation amounts for 18 February 2008 is represented in Figure 3(a). Two radar images obtained during the most intense hourly precipitation periods are also shown in Figures 3(b) and 3(c), corresponding to the observations recorded at 0300 UTC and 0500 UTC. The defining characteristic of the rainstorm was its spatial confinement, with a strong concentration over the Lisbon region. This is suggested by the pattern of isohyets, with the highest values being centred just north of the city district limits (Figure 3(a)). The cloud systems associated with this intense rainstorm were formed over the Atlantic Ocean, but relatively close to the Portuguese western shore. Their precipitation activity increased considerably when reaching land, during their northeastwards movement crossing the Lisbon area (Figures 3(b) and 3(c)). For the sake of simplicity, the complete sequence of radar images is not shown here, but the intense showers depicted by the higher reflectivity areas were observed for roughly six hours (between 0100 UTC and 0700 UTC). The precipitation intensity during this critical period was responsible for the large number of urban inundations and floods occurring in minor streams, especially in the areas within the 100 mm/24 hours isohyet (Figure 3(a)).

The historical daily precipitation maxima obtained for stations with the longest continuous records available in the Lisbon region are shown in Table 1. This table reveals that both stations (D. Luís

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Observatory, hereafter LDLO, and Gago Coutinho, hereafter LGC) located inside the Lisbon city district (Figure 3(a)), registered their highest amount of precipitation on 18 February 2008. However, in the rural and suburban areas of Lisbon the existing maximum daily totals, recorded on 26 November 1967 and/or 19 November 1983, were not surpassed. In fact, the occurrence of heavy rainfall events in southern Portugal (including Lisbon) is more frequent during the autumn season than during winter or spring (Fragoso and Tildes Gomes, 2008).

In order to put this extreme precipitation event into a wider context, we have estimated the return periods for the daily precipitation amounts recorded on 18 February 2008 for the four available longest-running stations located in the Lisbon area (Table 2). The estimation of the 24-hour precipitation return periods was obtained after the verification of the closeness of fit to the Gumbel distribution (Gumbel, 1958). The extreme nature of the event is reflected in the return periods estimated for the LDLO (220 years) and São Julião do Tojal station (160 years). In contrast, at Sobral de Monte Agraço, located just 25 kilometres north of Lisbon, the magnitude of the 18 February rainfall event can be expected almost once every year. In any case, we must acknowledge that this analysis can be slightly misleading if we take into account the length of the time series available, particularly when evaluating return periods that are longer than the original time series.

Temporal evolution

It must be mentioned that LDLO belongs to the subset of long-term Portuguese classical stations, i.e. those with manual readings that allow comparisons with previous events (unlike many automated stations). Daily precipitation records obtained at classical stations for any given day *n* correspond to the precipitation registered between 0900 UTC of day *n-1* and 0900 UTC of day *n*[1]. Therefore, the maximum at LDLO on 18 February 2008 reflects the 24-hour rainfall that fell between 0900 UTC 17 February and 0900 UTC 18 February. Nevertheless, the intense precipitation continued through the morning of 18 February, although precipitation registered after 0900 UTC was reported on the following day (19 February). In practical terms, this outstanding rainfall episode over the Lisbon region began on the afternoon of 17 February, but the most critical period was between 0200 UTC and 1000 UTC of 18 February. The hyetograph represented in Figure 4 shows the precipitation for the two Lisbon city district stations between 2200 UTC 17

[1] Editor's footnote: NB, this is at variance with UK practice where rainfall read at 0900 UTC on day *n* is attributed to day *n*–1.

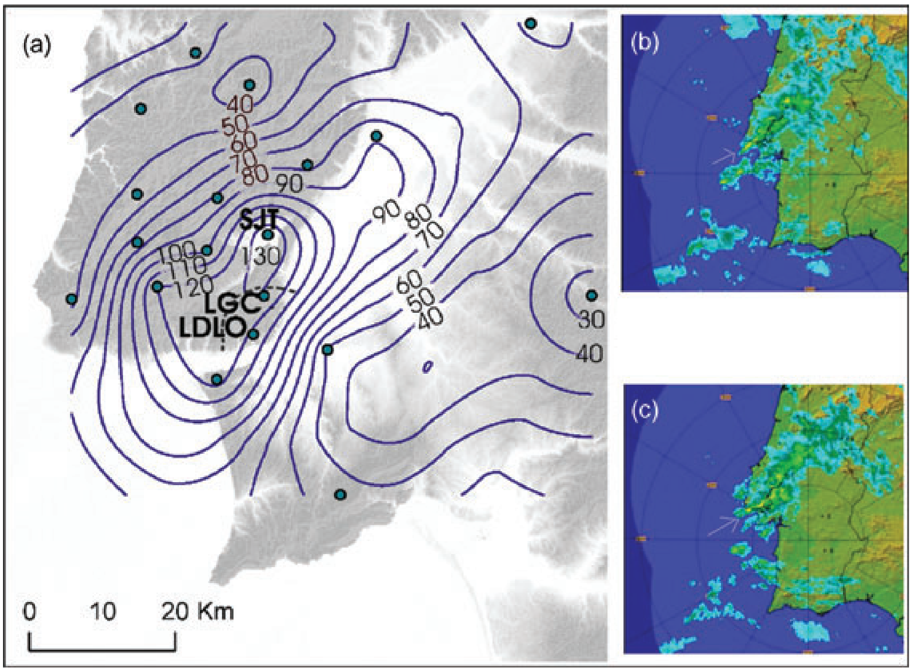

Figure 3. Spatial distribution of rainfall on 18 February 2008 over the Lisbon region. (a) 24 hours rainfall (mm). The Lisbon city district limit is represented by the hatched line and the circles are the rain stations used in this study; (b) and (c) Radar images obtained at 0300 UTC (b) and 0500 UTC (c) on 18 February 2008. The arrows indicate the direction of the main rainfall system´s movement. (Source: INAG and IM.)

Table 1

Historical daily maxima precipitation in the Lisbon region. The stations in bold are located within the Lisbon city district.

Meteorological stations	Highest daily precipitation (mm) and date		Earliest year of record
Cacém	173.8	19 November 1983	1979
São Julião do Tojal (SJT)	163.7	19 November 1983	1938
Vila Franca de Xira	145.0	19 November 1983	1957
Sobral de Monte Agraço	137.5	26 November 1967	1915
Cheleiros	134.0	19 November 1983	1979
Sobral da Abelheira	129.5	19 November 1983	1979
Lisboa/Gago Coutinho (LGC)	129.0	18 February 2008	1982
Calhandriz	120.0	19 November 1983	1980
Lisboa/D.Luís (LDLO)	118.4	18 February 2008	1864

Sources of data: Instituto de Meteorologia (IM) and Instituto da Agua (INAG)

Table 2

Estimated return periods of the daily precipitation registered in four meteorological/rain gauge stations located in the Lisbon region.[a]

Meteorological stations with longest-running daily precipitation series	18 February 2008 daily precipitation (mm)	Return period (years)	Start of data period for the estimation
Sobral de Monte Agraço	32.3	1-2	1915
Vila Franca de Xira	88.7	20	1957
São Julião do Tojal (SJT)	140.9	160	1938
Lisboa/Geofísico (LDLO)	118.4	220	1864

[a] Return periods obtained after fitting appropriate Gumbel distributions to each individual station.

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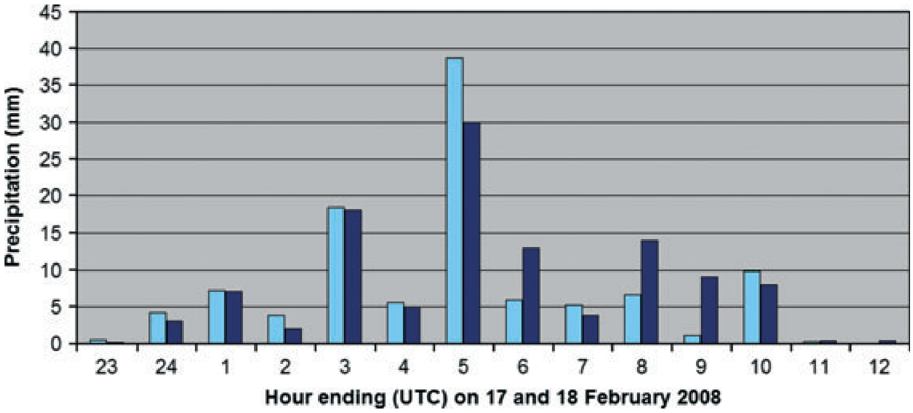

Figure 4. Hourly precipitation in two Lisbon meteorological stations, from 2200 UTC 17 February until 1200 UTC 18 February 2008: D. Luís Observatory/LDLO (light-blue columns) and Gago Coutinho/LGC (dark-blue columns). (Source: IM and University of Lisbon.)

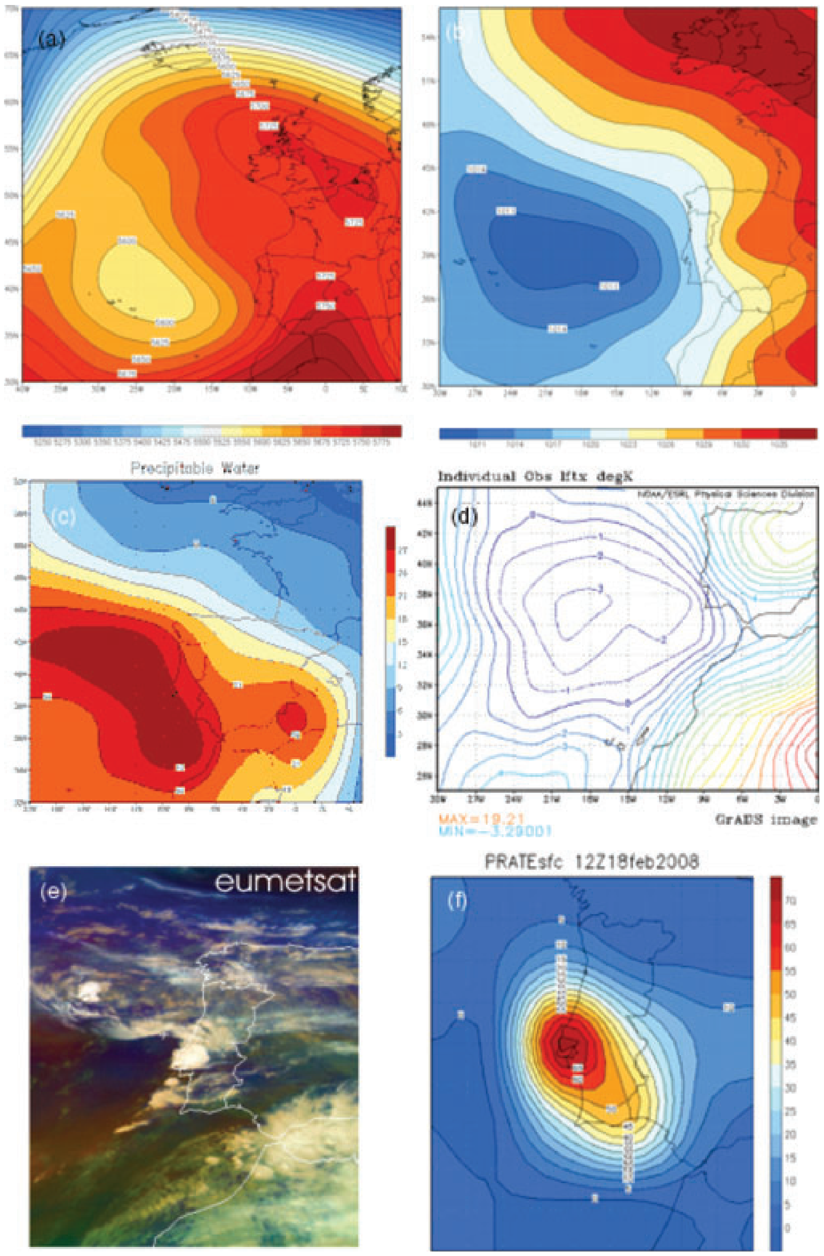

Figure 5. The cut-off low system affecting the Portuguese area, 18 February 2008. (a) 500 mbar geopotential height (metres, colours), 0000 UTC; (b) sea-level pressure (mbar, colours), 0000 UTC; (c) precipitable water (millimetres, colours), 1800 UTC 17 February; (d) lifted index (°C, 0600 UTC); (e) Meteosat image, 0500 UTC 18 February; (f) precipitation rate (millimetres/day, 0000 UTC). (Source: NCEP Reanalysis-2 and EUMETSAT.)

February and 1200 UTC 18 February. Despite the differences in the accumulated rainfall (Figure 3(a)) both stations (LDLO and LGC) present a very similar temporal evolution at the subdaily scale. In particular, what is striking is the irregular nature of the hourly precipitation, with short periods of intense precipitation bursts, followed by less intense showers and subsequent heavy bursts of precipitation. These features are associated with the convective regime of the successive bands of intense rain depicted at different hours between 17 and 18 February (Figures 3(b) and 3(c)).

The maximum cumulative precipitation in just 12 hours was 101 millimetres at LDLO and 113 millimetres at LGC. For a six-hour period, the maximum cumulative precipitation registered was 67 millimetres at LDLO and 83 millimetres at LGC. Maximum hourly values recorded at LDLO and LGC were observed between 0400 UTC and 0500 UTC, with peaks above 30 millimetres in both cases. However, the highest rainfall registered in the area was observed in Monte da Caparica, a station located just southwest of Lisbon (on the left bank of the river Tagus), where 53 millimetres fell also between 0400 UTC and 0500 UTC.

The elements presented so far concern the temporal description of the precipitation event based on its incidence over the Lisbon region. However, the end of this event in Lisbon on the morning of 18 February (Figures 3 and 4) coincided with a displacement to the south and a subsequent reactivation of the same storm, so that it started to affect the region of Setúbal (40 kilometres south of Lisbon) by early afternoon, also causing numerous and severe inundations in this city.

Meteorological context

At the synoptic scale, the atmospheric circulation associated with this event was dominated by a blocked pattern, which had persisted for over a week, with high pressure over northern Europe and low pressure around the Azores. Settled weather over much of Europe and the western Mediterranean contrasted with the unsettled conditions that affected the Atlantic area between the Azores, Madeira and southwest Iberia from 11 to 19 February. Here we have made an effort to synthesize the most relevant features of the atmospheric circulation at the synoptic scale, using six-hourly NCEP reanalysis-2 data, and also illustrating the cyclonic activity with a Meteosat image (Figure 5).

The 500mbar geopotential height field shows the blocked circulation pattern over the British Isles and the associated cut-off low located between the Azores and western Iberia (Figure 5(a)). Cut-off upper lows are closed lows that form in the upper and middle troposphere and become detached (cut-off) from the mid-latitude Westerlies, often with little or no movement for several days (Gimeno *et al.*, 2007). In the present event, this blocked upper-level circulation over the eastern Atlantic was responsible for the quasi-stationary position of a weak low pressure centre just north of Madeira (Figure 5(b)), after 12 February. On 15 February, another weak surface low formed near the Azores connected with the previously mentioned low centre, inducing an increase of the cyclonic activity over the west of Portugal. It should be stressed that this configuration, i.e. a blocking anticyclone over the UK and a cut-off upper low system close to (or over) Iberia, is relatively common in winter and spring months, being responsible for a significant fraction of precipitation observed in southern Iberia (Trigo *et al*., 2004).

The synoptic circulation pattern was bound to trigger atmospheric instability and to promote convective activity in the eastern part of the cut-off upper low, close to Portugal and in the vicinity of the Lisbon latitude. It must be emphasised that the southern flank of this cut-off upper low event reached subtropical latitudes, promoting the advection of relatively warm and very humid air masses at low and mid-levels. As underlined by Nieto *et al*. (2005), under such circulation conditions dominated by a cut-off upper low located southwest of Iberia, the air motion's vertical instability is enhanced, and convective – sometimes severe – events occur frequently. The moisture advection inside the southern and eastern flanks of the cut-off upper low can be confirmed through the analysis of the precipitable water (PW) field represented in Figure 5(c). From 17 February, values of PW above 27 millimetres were registered over this region, an amount consistent with the presence of a humid air mass, taking into account that the event occurred during the end of the cold season, therefore with lower sea-surface temperatures. Moreover, the atmosphere over the southwest of Iberia became potentially unstable, a condition that is confirmed by the extent of the area between the Azores and Portugal with the lifted index[2] exhibiting levels below −3°C (Figure 5(d)). Estimations of the convective available potential energy (CAPE) were performed based on values from the reanalysis grid point located inside this area (35°N and 15°W) for the preceding 12-hour period of the extreme rainfall event (from 1800 UTC 17 February to 0600 UTC 18 February). The pseudo soundings that allowed this computation (Figure 6) reveal a significant unstable layer at the lower troposphere,

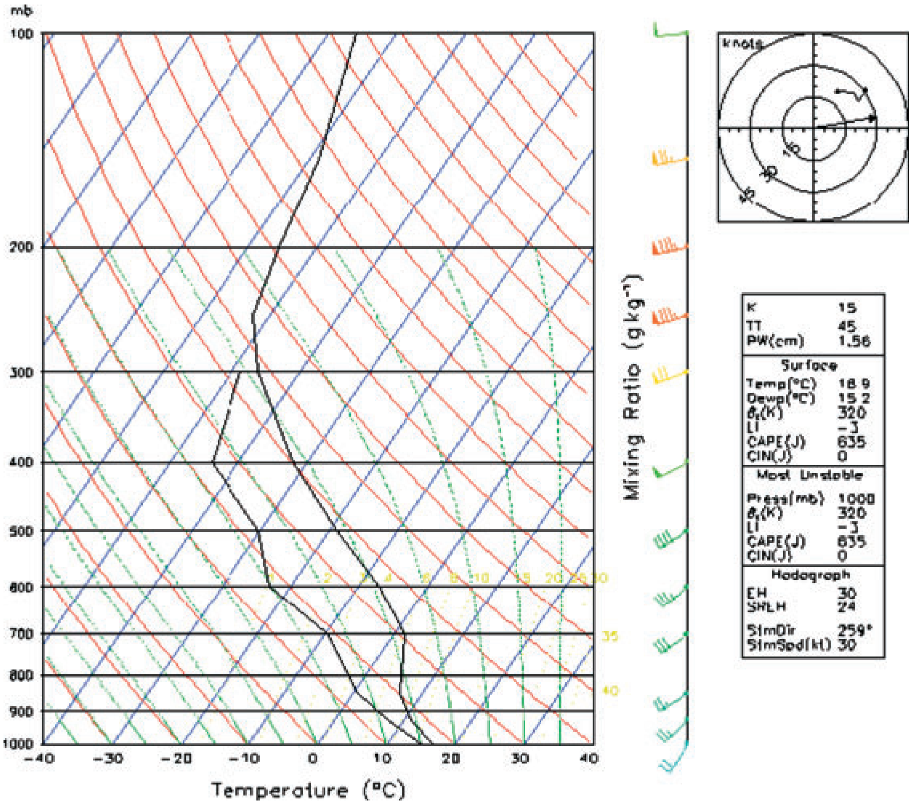

Figure 6. Sounding plot representing the tropospheric thermodynamic profile at 1800 UTC 17 February 2008 in the reanalysis grid point with 35°N and 15°W coordinates. The curves are drawn in a skew-T diagram, using GrADS software. (Source: NCEP reanalysis-2.)

resulting in positive CAPE values, varying between 493Jkg^{-1} (0600 UTC 18 February) and 635Jkg^{-1} (1800 UTC 17 February), thus corresponding to favourable conditions for convection, with probable development of severe thunderstorms.

The formation of convective cells just southwest of the Lisbon region started on the afternoon of 17 February. The presence of the convective cloud system moving towards the Lisbon area from 0200 UTC to 0600 UTC 18 February produced irregular but often intense showers, resulting in a significant accumulation of precipitation. The Meteosat image illustrates the most intense rainfall period (from 0400 UTC to 0500 UTC) associated with the influence of this quasi-stationary convective system (Figure 5(e)). The precipitation rate field (Figure 5(f)) estimated from the NCEP reanalysis demonstrates, once again, the high intensity of the rainstorm and its peculiar confinement over the Lisbon region.

Conclusion

On 18 February 2008, the capital of Portugal was affected by an active low-pressure system that produced very intense precipitation (118.4 millimetres), surpassing the previous maximum of daily rainfall. This new record is particularly relevant considering that it corresponds to the highest daily precipitation amount registered in the oldest Portuguese meteorological station – LDLO – with continuous daily precipitation readings since 1864.

The exceptional nature of this precipitation event was evaluated through the computation of the long return period estimated for LDLO: 220 years. Long return periods were also estimated for other stations located in the vicinity of LDLO (e.g. 160 years in S. Julião do Tojal). The region most affected was restricted to the Lisbon metropolitan area, with maximum values distributed along a narrow, short band extending from southwest to northeast, crossing the Lisbon urban district.

Considering the corresponding synoptic weather circulation characteristics, the extreme event registered in Lisbon on 18 February 2008 was influenced by the occurrence of a blocked pattern at higher latitudes. This blocking pattern suppressed the natural progression of the Westerlies current, and was associated with the appearance of a cut-off upper low between the two archipelagos (Madeira and Azores) and mainland Portugal. Underneath the upper-level cyclone, the southerly advection of warm air and moisture provided energy to make the air masses involved highly unstable, triggering convective activity on the southern and eastern flanks of the cut-off upper low. With favourable thermodynamic conditions,

[2] The lifted index is the difference in temperature between a parcel of air lifted from the surface (using the sounding) to 500mbar and the actual temperature at that level, and so gives an indication of the instability of the air mass.

thunderstorm systems were formed over the ocean near to the western coast of Portugal and moved slowly towards the Lisbon region throughout the night, between the late hours of 17 February and the early hours of 18 February. By the time those convective cells reached the Lisbon area, deep cloud systems had moved and passed slowly over the study area for more than eight hours, being responsible for intense precipitation activity that resulted in accumulated values exceeding 100 millimetres.

The effects of the storm in the Lisbon metropolitan region were harmful and in some cases even ruinous. A large number of urban inundations and country flash-floods have caused loss of life and serious damage to property, demonstrating some lack of preparedness on the part of the city to respond suitably to these natural hazards and risks. These facts show the importance of studying with more detail the impacts and consequences of an extreme rainstorm in Lisbon, in order to prevent future disasters and to propose suitable mitigation measures.

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DOI: 10.1002/wea.513

Weather – February 2010, Vol. 65, No. 2

Transverse cirrus bands in weather systems: a grand tour of an enduring enigma

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Transverse cirrus banding (Figure 1) is defined by the American Meteorological Society *Glossary of Meteorology* (1999) as:

> *Irregularly spaced bandlike cirrus clouds that form nearly perpendicular to a jet stream axis. They are usually visible in the strongest portions of the subtropical jet and can also be seen in tropical cyclone outflow regions.*

However, this definition raises more questions than it answers. Why are transverse bands irregularly spaced? Why are they perpendicular to a jet stream axis? Do these traits differentiate the bands from other cloud

Figure 1. Transverse bands in cirrus clouds associated with the polar jet stream over Cape Breton Island in the Maritime Provinces of Canada, as viewed from the Space Shuttle looking east. From http://www.solarviews.com/huge/earth/jet.jpg, adapted from http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=STS039&roll=80&frame=60. (Image STS039–80–60 courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center.)