# The Spatial Coherence of European Droughts - Summaries of Major Historical Droughts

Science Report – SC070079/SR4

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Steve Killeen

**Head of Science**

# 1 Background

This report presents information on the spatial coherence and temporal evolution of five major European droughts in the period 1961 – 2005. This work was carried out for the 'Spatial Coherence of UK and European Droughts' project, which aimed to investigate large-scale spatial coherence, with a view to developing improved mechanisms for drought monitoring and forecasting in Europe and, in particular, in the UK. This report complements the final project report (Hannaford *et al.* 2009) and a Catalogue of drought characteristics for the UK and Europe (Lloyd-Hughes *et al.* 2009).

The rationale behind the major drought summaries featured on the following pages was to present data and associated narratives illustrating the spatial coherence of droughts on an event-by-event basis, to accompany the quantitative analyses presented in Hannaford *et al.* (2009). A consideration of this information is potentially useful in highlighting common patterns in the spatio-temporal evolution of droughts on a pan-European scale, particularly where such relationships have not proven to be statistically significant in quantitative analyses. The statistical analyses were carried out on long time-series of drought indicators, which may mask a great deal of complexity found in individual events. The event-based analyses were therefore conducted in order to investigate the following questions:

- How did the major droughts develop in space and time?
- Are there common patterns in drought onset and evolution, which occur between drought events?
- Is there any systematic time-lag between drought development in Europe and the UK, which could be used to inform the development of forecasting methods?

Although drought behaviour and evolution has been characterised previously through analysis of major historical episodes, such attempts have only considered a limited sample of events and are constrained by the timescale over which data are available. For example, Zaidman *et al.* (2002) investigate the 1975-76 and 1989-90 periods, but a consideration of 1960-1995 omits the more recent significant drought phases. This project benefits from an extra decade of data (1996-2005), allowing the analysis of two additional episodes. The five major droughts summarised over the following pages illustrate the wide variety of spatial and temporal behaviour and complexity that such events often exhibit.

The principal aim of these summaries is therefore to characterise the spatio-temporal development of a number of large-scale European droughts, using a consistent dataset and using drought indicators which enable comparisons to be made between disparate areas of Europe, and between seasons. Section 2 briefly discusses the drought indicators and the European regions used in the analysis. Each drought is characterised in a 3-page summary, which uses a consistent format to present key aspects of the spatio-temporal evolution of the event, along with a text commentary. Section 3 discusses the format of each of these pages.

# 2 Drought Regions and Indicators

As with the accompanying drought catalogue (Lloyd-Hughes *et al.* 2009), the Regional Deficiency Index (RDI) and the Regional Standardised Precipitation Index (RSPI) underpin the analyses of the major droughts that are summarised over the following pages. These indicators were derived for a series of 24 regions which were delineated as being relatively homogeneous in terms of their drought characteristics. The regions are shown in Figure 1. A full description of the regions and the drought indicators is given in Hannaford *et al.* 2009; a brief synopsis of the indicators is given in the following paragraphs.

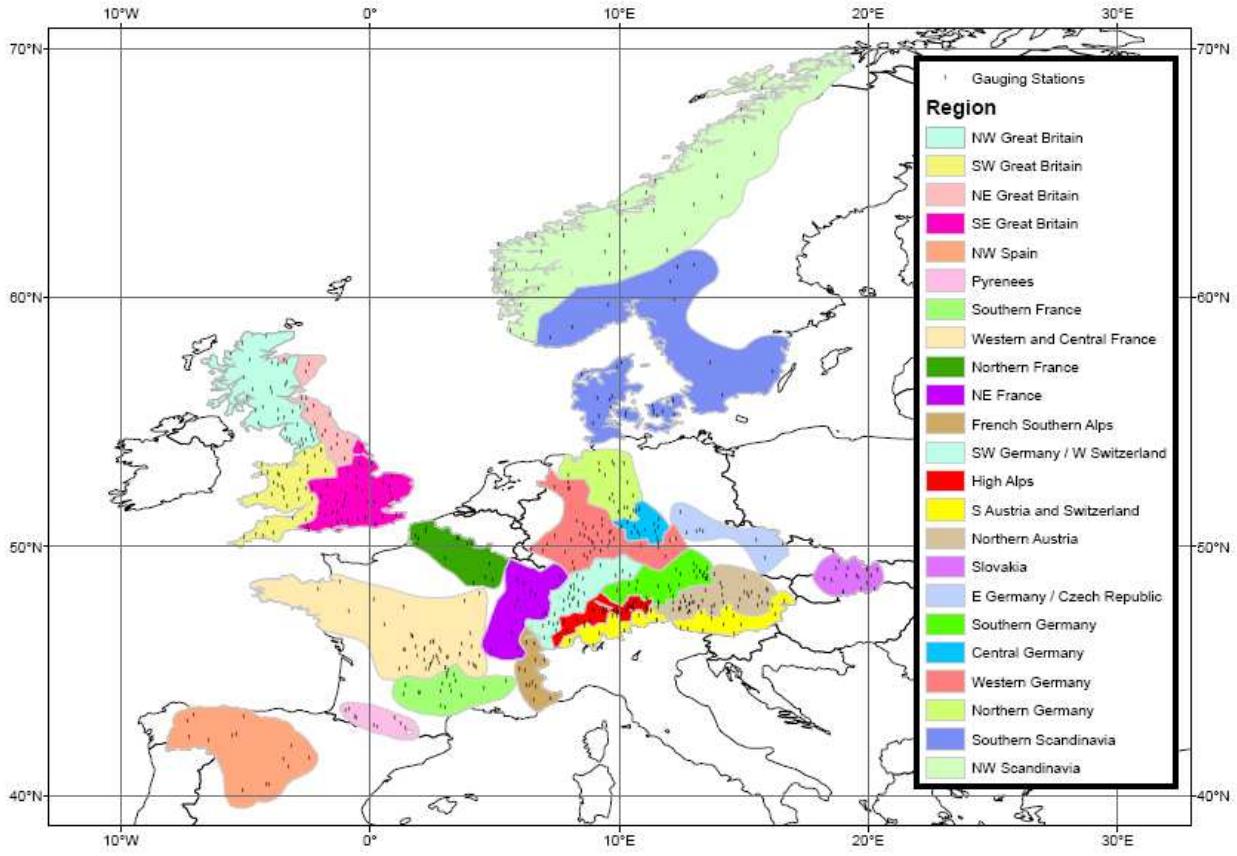


**Figure 1: Map of Regions**

## 2.1 Regional Deficiency Index (RDI)

For each region, a binary deficit index (DI) is produced for each of the stations by evaluating whether the flow on any given day falls below a daily-varying threshold. The RDI of a region is the arithmetic mean of the DI time series of each of the stations that fall within the region's boundaries, thus always lying between 0 and 1. A value of 0 represents a day on which no daily flows of any of the stations within a region are below their corresponding thresholds. Similarly, a value of 1 signifies an entirely

spatially coherent drought day in which the flow at all stations was in deficit (i.e. below the threshold). This is illustrated in Figure 2.

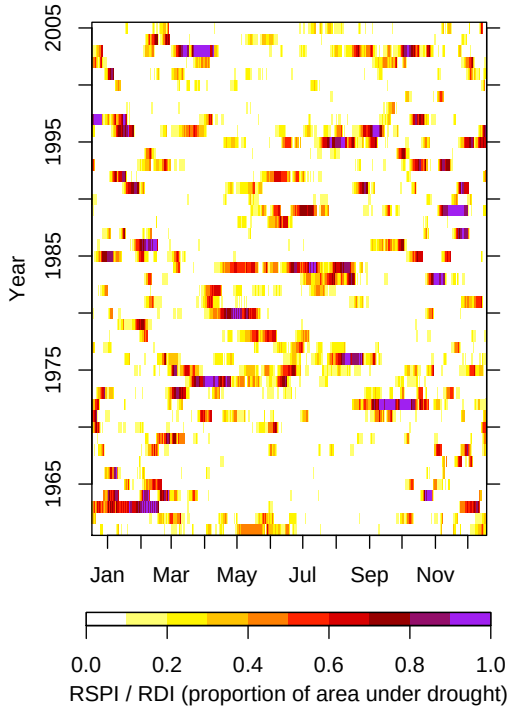


**Figure 2: Example RDI plot from final report**

Such an approach considers drought in relation to average flow for the time of the year and the station in question, allowing rivers with different catchment characteristics and flow regimes to be objectively classified as 'in drought', or otherwise.

In the major drought summaries that follow, the daily index is aggregated to a monthly time step to facilitate inter-comparisons with the RSPI (see 2.2).

## 2.2 Regional Standardised Precipitation Index (RSPI)

Just as the RDI methodology is universal in its application through its use of an objective definition, the RSPI is similarly applicable to a range of rainfall regimes. As with the RDI, the RSPI must be preceded by a derivation of the Standardised Precipitation Index (SPI) before regional averaging can occur. The SPI is the unit normal transformation of the time-averaged precipitation timeseries climatologically appropriate to the particular location and time of year. This standardisation procedure is akin to assigning return periods to monthly rainfall, relative to the average. The RSPI is an expression of the proportion of cells within the homogeneous reporting units that are experiencing 'moderate' drought.

## 2.3 Selection of drought events

The development of a drought catalogue has allowed the identification of ‘drought rich’ and ‘drought poor’ periods on a pan-European scale in the second half of the 20th century (see Figure 3).

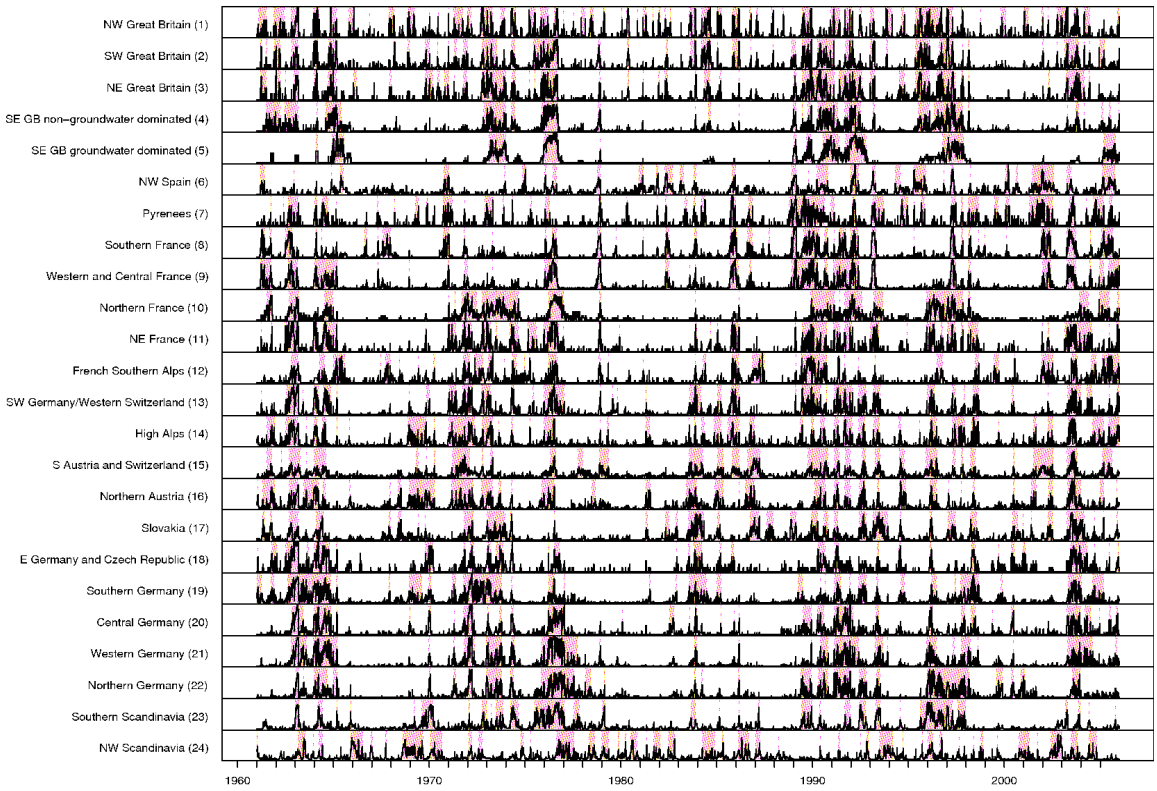


**Figure 3: droughts for all regions from final report**

The five major drought episodes summarised over the following pages have been widely accepted in the literature as being of significant magnitude on a continental scale and, more importantly, in the UK. Other authors identify important drought events which affected parts of Europe (e.g. Poland and Spain, amongst others, in 1971 (Bradford *et al.* 2000)) but did not manifest themselves in the UK; these were not considered due to the UK being the focus of the project. It should be noted that the most recent major drought event, 2004-06, could not be analysed in this project due to limitations in data availability.

The events selected exhibit conditions from across the spectrum of potential characteristics for major continental droughts, and each has had significant impact on society. The 1975-76 event marks the benchmark drought of the last half-century in many parts of northern Europe and, along with the 1962-64 episode, helped shape drought and water resource policy which remains in use today in the UK. Additionally, the highly contrasting behaviour and patterns of major droughts are aptly demonstrated through a comparison of the 1988-92 and the 2003 events. Whilst the former was a multi-year deficit period exhibiting a complex amalgam of spatially incoherent summer and winter deficiencies, the latter was a short, intense, single-season event which coincided with seasonal heatwave conditions.

# 3 Description of the Major Drought Summaries

Each of the five major droughts is summarised over three pages using a range of different information, outlined below. A more comprehensive description of the qualitative analyses that have been utilised in the production of these major drought summaries is given in Section 5 of the project Final Report (Hannaford *et al*. 2009).

## 3.1 Page 1: Drought Narratives

The initial text box contains a narrative of the spatial and temporal development of the event followed by a brief consideration of any notable impacts, in each case (and where applicable) from both a European and a UK perspective. The narratives are informed by the RDI and RSPI timeseries during the historical events, components of which are illustrated in the text box on page 1, and the selected maps shown on page 2.

Following the text box is a matrix containing monthly mean RDI values for a select number of European regions. The rationale for featuring these regions is that they are close to the UK and were most closely correlated to UK regions in their drought characteristics (Hannaford *et al.* 2009). Monthly cells have been colour-coded based on the RDI within the region, with increasingly intense shades of orange indicating greater RDI. The thresholds for this colour-coding were pre-defined and applied consistently for each of the major droughts, to assist in inter-comparisons between episodes. It should also be noted that in the case of extended multi-year drought events, the specific months featured in the matrices necessarily reflect the most extensive or coherent phases. Where months are absent, it is generally fair to assume that they are largely unremarkable in terms of their deficits.

## 3.2 Page 2: Spatio-temporal evolution

The second page of each drought summary features a selection of maps of Europe that have been chosen to best reflect the spatio-temporal evolution of the event. Such maps are ‘screenshots’ taken from navigable monthly animations for both the RDI and the RSPI, from which the aforementioned narratives were derived. Whilst there is some overlap between the information provided by the matrices and these screenshots, each approach has its benefits and limitations, and taken together they provide the best summary. Unlike the matrices, these screenshots provide a wider spatial extent through the inclusion of all regions in Europe, and the parallel presentation of RDI and RSPI highlights any time lags between meteorological and hydrological drought onset and development. The animation screenshots also provide a better visualisation of the concepts outlined through the qualitative descriptions and matrices.

## 3.3 Page 3: synoptic background

The final page of each drought summary considers the synoptic climatic conditions over Europe during the periods of major drought across the continent. These indices were investigated in order to establish any possible drivers for pan-European drought, and for potential explanations for spatial coherence. Timeseries plots of the North Atlantic Oscillation and East Atlantic / West Russia Pattern are presented, as these teleconnections were found to be dominant drivers of drought on a European scale (Hannaford *et al.* 2009). Selected temperature and pressure anomaly plots, constructed from gridded NCEP/NCAR reanalysis data for Europe, are also provided. Together they highlight any links between temperature, pressure and drought. Finally, the text box summarises the index graphs and anomaly plots, and provides a more detailed analysis of any relationships between these indices and the RDI and RSPI. More information on the derivation and utility of the anomaly and index plots can be found in Sections 5.4 and 8, respectively, of the Final Report (Hannaford *et al.* 2009). Section 8 also gives a full account of the investigation into potential relationships between atmospheric circulation and the spatial coherence of droughts.

# 4 Principal Findings

Following these qualitative exploratory analyses, some remarks on the spatial coherence of major historical droughts can be made:

- Whilst there are some broad patterns between the major droughts, each tends to have a distinctive spatial signature; there are common elements associated with certain periods of each drought but, taken in entirety, there are few commonalities which recur in the major droughts.
- This feature of European droughts is likely to present challenges in identifying robust statistical relationships, particularly given the relatively short records involved (yielding a sample of only five major droughts).
- Often the UK is one of the first regions to experience drought, or experiences drought simultaneously with other parts of northwest Europe. This implies that there may be very little lead time between the onset of droughts in Europe and the UK, which may confound the development of forecasting tools based on drought development elsewhere.
- The west – east migration seen in some major events is potentially a useful phenomenon for assisting in the development of improved monitoring and forecasting on a European scale. Whilst this is a feature seen in some phases of the major droughts, it is certainly not universal – so caution should be exercised in assuming that a drought developing in western Europe will spread east (for example, 1984 was a severe summer streamflow drought in the UK, but did not express itself on the continent).
- Only the 1975/1976 drought is coherent on a pan-European scale for a persistent period. During other droughts, there are often short spatially coherent phases within droughts, the centres of action of which tend to shift in space.
- Some major UK droughts do not appear to have had any equivalent impact in Europe – for example, the summer droughts in 1984 and 1995. In contrast, there are some droughts which manifest themselves over a wide area in continental Europe, but are not expressed in the UK – for example in late 1971/1972, when a drought occurred across most of mainland Europe, but had very limited expression in the UK.
- During most long droughts there are distinct periods when the UK is in-phase and out-of-phase with Europe; even in intense summer droughts seen on a large scale over Europe, the UK is not necessarily in-phase with the continent.
- Some long droughts (1962 – 1964; 1995 – 1997; 1988 – 1992) result from a combination of both winter and summer deficiencies. The evolution of these events is very complex, in comparison with the major short-duration summer droughts, and is likely to escape classification by a simple index. Whilst there are often phases of intense summer drought, in these events the winter conditions are as important for dictating the overall deficiencies.
- Reviews of the synoptic situation associated with the drought reveal that they are all generally associated with major pressure anomalies, but that these differ substantially in terms of their intensity and location.

- All of the droughts (except 2003) were associated with anomalies in the large-scale atmospheric circulation but, again, the characteristics of these anomalies varied significantly from event to event.