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Seasonality of floods and their hydrometeorologic characteristics in the island of Crete

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SUMMARY

The seasonality of the hydrometeorologic characteristics of floods that occurred in Crete during the period 1990–2007 is presented. Hydrological characteristics were analyzed using seasonality indices based on a dataset of 53 daily precipitation stations as well as 15 daily and 7 monthly recording flow stations. The atmospheric circulation conditions during the flood events were examined based on a joint subjective classification and meteorological analysis. The flood event-based seasonality was found to coincide with the seasonality of the daily precipitation maxima of November and December. The seasonality of the three largest long term daily precipitation maxima indicates that 50% of the maximum precipitation events occur from November to January (NDJ period). Analysis showed that the maximum annual stream flows in Crete are lagging by approximately 1 month from annual maximum daily precipitation in the region. The circulation type classification of the flood events showed that most of the weather systems occurring in the Mediterranean and passing over Crete have SW, NW and W direction. For the majority of the events, a common mean sea level pressure gradient field was observed over Europe. This comparison of the seasonality of selected hydrometeorologic characteristics reveals valuable information within the context of flood occurrence.

1. Introduction

Flood timing and magnitude data are used in local, seasonal and regional flood frequency analyses for estimating design flood values required in engineering design and planning (Cunderlik et al., 2004a; Ouarda et al., 2006). On a larger spatial scale, the hydrological characteristics such as precipitation and stream flow depict the regional climate mechanisms and therefore the seasonality of flood occurrence is strongly connected to the climate forcing mechanisms of each region. The knowledge of weather patterns associated with extreme rainfall and runoff events can serve as a reliable early flood warning system and a non-structural approach for flood mitigation. Especially for the case of events such as flash floods, that are seldom predictable and have severe consequences, understanding the "*how*" and the "*when*" can be indispensible for civil protection.

Storm events are often associated with the development of low-pressure systems. Over the Mediterranean these systems are approaching from three main directions which can be roughly distinguished as West (W), Southwest (SW) and Northwest (NW). According to Barry and Chorley (2003), depressions that enter the Mediterranean from the Atlantic Ocean (W source) and baroclinic waves from the Atlas mountain range (SW source) account for 9% and 17% of the low-pressure systems respectively. The remaining 74% form at the lee of the Alps and Pyrenees (NW source). This is a weather classification mentioned in literature (e.g. Barry and Chorley, 2003) with the effects of each class being well documented. In general, a weather classification method can be an algorithm or concept used for type definition and assignment of objects to those type. Any method (algorithm) may be applied in different variations, e.g. using different distance metrics, numbers of types, spatial domains, temporal configurations or input parameters. Weather types may be regarded as the driving forces of the hydrologic subsystems which together form the complex hydrologic system of a catchment (Van de Griend and Seyhan, 1984), and thus the identification of dominant types can be used in a hydrologic context.

Flood seasonality can be effectively described in terms of directional or otherwise orientation statistics (Mardia, 1972 and Fisher, 1993). Bayliss and Jones (1993) also described previous flood seasonality in Great Britain by means of seasonality indices derived from directional statistics. Castellarin et al. (2001) combined flood and rainfall seasonality descriptors and basin relative permeability in a regional model for ungauged basins in Northern Italy. Cunderlik and Ouarda (2009) studied the trends in the timing and magnitude of seasonal maximum flood events across Canada taking into account the directional character and multi-modality of flood occurrences. Magilligan and Graner (1996) used directional

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statistics to express some of the hydroclimatological and geomorphic controls on flooding in New England and to reveal the regional groupings of similarly responding basins. The authors conclude that directional statistics are an appropriate method for depicting regional hydrologic regimes and in describing some of the hydroclimatological controls on flood occurrence.

The objective of this paper is to narrow down specific seasonal and climatic characteristics that can be associated with extreme rainfall and runoff in the island of Crete. For this reason, large and smaller scale meteorological characteristics that precede extreme events in the area have been identified and analyzed. The direct relation of large and small scale weather structures with regards to flash flood generation is not clear (e.g. even though a significant number of flash flood generating storms have occurred under the presence of a given large scale structure, the presence of this structure is not alone indicative of a flash flood occurrence). Possible correlations between extreme daily and monthly rainfall and runoff with larger scale phenomena will allow for a better understanding of the flood occurrence process. Determining flood occurrence seasonality, and spatial extent and therefore flood risk periods and areas for the island of Crete, can be used as basic but effective flood hazard mitigation and risk management planning. At the same time, this kind of information may be used to support a simplified flash flood alert system, based on the computation of critical rainfall threshold values, as shown by Martina et al. (2006) and Norbiato et al. (2008).

This paper is original in that it combines different approaches of seasonality in order to identify flood occurrence characteristics for the island of Crete. For one of the approaches a small modification is proposed so that results have a better uniformity and are easier to evaluate. The advantages of a multi-scale approach are shown. The analysis presented in this paper is aimed towards a better understanding of extreme events over Crete.

2. Methodology

2.1. Circulation types

A widely used atmospheric circulation classification system for European conditions is that developed by Baur et al. (1944). The so called Grosswetterlagen and later HB-GWL classification (after Hess and Brezowscy) is based on large scale weather observations such as the location of semi-permanent pressure centers (e.g. the poles of the North Atlantic oscillation) the location and extension of frontal zones and the presence of cyclonic or anti-cyclonic conditions. Since its introduction, this classification method has been revised (Hess and Brezowsky, 1952; Hess and Brezowsky, 1969 and Hess and Brezowsky, 1977) and updated (Gerstengabe et al., 1999) and its variations are often used in literature (e.g. Caspary, 1995 and Caspary, 1996). Table 1 shows the current HB-GWL classification which reduces the initially 30 classes to 11, including a transitional class. Bearing in mind the inherent uncertainty of any classification approach of the complex and dynamic large scale meteorology (Yamal and White, 1987; Bardossy and Caspary, 1990; Yarnal, 1993), the HB-GWL is considered as the best available scheme (James, 2007) and is therefore used in this study.

2.2. Seasonality

Seasonality of hydrological time series can be effectively described in terms of directional statistics (Mardia, 1972; Fisher, 1993; Magilligan and Graner, 1996). Following Bayliss and Jones (1993), Burn (1997) and Cunderlik et al. (2004b) the *Julian date* of occurrence of an annual hydrologic event i can be transformed to a directional statistic:

$$\theta_i = (\textit{Julian date})_i \left(\frac{2\pi}{365}\right) \tag{1}$$

where θ_i is the angular value (in radians). The *Julian date* is Day 1 for January 1st and Day 365 for December 31st. The estimated vector has a magnitude $r_i = 1$ and a direction of θ_i radians. For a sample of n events, individual directional statistics components can be aggregated in order to estimate the x- and y-coordinates of the mean date of event occurrence (Burn, 1997):

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n}\cos(\theta_i) \tag{2}$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n}\sin(\theta_i) \tag{3}$$

The mean direction of the event dates is then obtained from (Burn, 1997):

$$\bar{\theta} = \tan^{-1}\left(\frac{\bar{y}}{\bar{x}}\right) \tag{4}$$

While the directional statistic of a single event has a unity magnitude, for the mean vector of n events, $\bar{r}$ can be defined as the measure of variability of the date of occurrence about the mean date (Burn, 1997).

$$\bar{r} = \sqrt{\bar{x}^2 + \bar{y}^2} \tag{5}$$

Table 1
Order of weather type classification according to the Hess and Brezowsky Grosswetterlagen (HB-GWL) Source: James, 2007.

HBGWT	GWL	Definition	HBGWT	GWL	Definition
01 West	Wa	Anti-cyclonic westerly	06 North	HB	High over the British Isles
	Wz	Cyclonic westerly		TrM	Trough over Central Europe
	WS	South-shifted westerly	07 NEast	NEa	Anti-cyclonic north-easterly
	WW	Maritime westerly (Block E.Europe)		NEz	Cyclonic north-easterly
02 SWest	SWa	Anti-cyclonic south-westerly		HFa	Scandinavian High, Ridge Central Europe
	SWz	Cyclonic south-westerly	08 East	HFz	Scandinavian High, trough Central Europe
03 NWest	NWa	Anti-cyclonic north-westerly		HNFa	High Scandinavia-Iceland, ridge Central Europe
	NWz	Cyclonic north-westerly		HNFz	High Scandinavia-Iceland, trough Central Europe
04 HighCE	HM	High over central europe	09 SEast	SEa	Anti-cyclonic south-easterly
	BM	Zonal ridge across Central Europe		SEz	Cyclonic south-easterly
05 LowCE	TM	Low over central europe	10 South	SA	Anti-cyclonic southerly
06 North	Na	Anti-cyclonic northerly		SZ	Cyclonic southerly
	Nz	Cyclonic northerly		TB	Low over the British Isles
	HNa	Icelandic High, ridge Central Europe		TrW	Trough over western Europe
	HNz	Icelandic High, trough Central Europe	11U	U	Transition (no distinct type)