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Relationship of runoff, erosion and sediment yield to weather types in the Iberian Peninsula

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A B S T R A C T

Precipitation has been recognized as one of the main factors driving soil erosion and sediment yield (SY), and its spatial and temporal variability is recognized as one of the main reasons for spatial and temporal analyses of soil erosion variability. The weather types (WTs) approach classifies the continuum of atmospheric circulation into a small number of categories or types and has been proven a good indicator of the spatial and temporal variability of precipitation. Thus, the main objective of this study is to analyze the relationship between WTs, runoff, soil erosion (measured in plots), and sediment yield (measured in catchments) in different areas of the Iberian Peninsula (IP) with the aim of detecting spatial variations in these relationships. To this end, hydrological and sediment information covering the IP from several Spanish research teams has been combined, and related with daily WTs estimated by using the NMC/NCAR 40-Year Reanalysis Project. The results show that, in general, a few WTs (particularly westerly, southwesterly and cyclonic) provide the largest amounts of precipitation; and southwesterly, northwesterly and westerly WTs play an important role in runoff generation, erosion and sediment yield as they coincide with the wettest WTs. However, this study highlights the spatial variability of erosion and sediment yield in the IP according to WT, differentiating (1) areas under the influence of north and/or north-westerly flows (the north coast of Cantabria and inland central areas), (2) areas under the influence of westerly, southwesterly and cyclonic WTs (western and southwestern IP), (3) areas in which erosion and sediment yield are controlled by easterly flows (Mediterranean coastland), and (4) lastly, a transitional zone in the inland northeast Ebro catchment, where we detected a high variability in the effects of WTs on erosion. Overall results suggest that the use of WTs derived from observed atmospheric pressure patterns could be a useful tool for inclusion in future projections of the spatial variability of erosion and sediment yield, as models capture pressure fields reliably.

1. Introduction

Precipitation has been recognized as one of the main factors driving soil erosion for a long time (Wischmeier and Smith, 1958; Fournier, 1960), and soil erosion and sediment yield are the most important environmental problems worldwide (Bakker et al., 2007). The spatial and temporal distributions of soil erosion and sediment yield are difficult to assess because of high variability in precipitation on temporal and spatial scales, and this is particularly true in areas with a strongly

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contrasting seasonal rainfall regime and long history of human intervention, such as exists in the Mediterranean basin (Grove and Rackham, 2001).

Climate research has tried to analyze the variability of precipitation from several points of view, and among others, the weather types (WTs) seem to be one of the most promising. Basically, the WTs approach tries to categorize the continuum of atmospheric circulation into a small number of classes or types (Trigo and DaCamara, 2000), and it has been used extensively in different research areas: e.g., climatology, including droughts and precipitation patterns (Vicente-Serrano and López-Moreno, 2006; Fleig et al., 2011; Rust et al., 2013), temperature (Piotrowicz and Szlagor, 2013) and snow dynamics (López-Moreno and Vicente-Serrano, 2007; Biggs and Atkinson, 2011), air quality (Fraile et al., 2013; Vanos et al., 2014), hydrology and floods (Andrade et al., 2011; Pattison and Lane, 2012; Wilby and Quinn, 2013; Foulds et al., 2014), agriculture (Lorenzo et al., 2013; Sturman and Quenol, 2013), and wildfire occurrence (Rivas-Soriano et al., 2013; Trigo et al., 2013). To our knowledge, little research has been conducted into the relationships between WTs and soil degradation by rainfall (e.g., Wilby et al., 1997; Fernández-Raga et al., 2010; Nadal-Romero et al., 2014), with promising results from these authors, who have identified different atmospheric patterns (i.e., WTs) relating to geomorphological processes.

Precipitation in the IP exhibits high variability on spatial and temporal scales (de Castro et al., 2005; González-Hidalgo et al., 2011), and previous research has demonstrated the usefulness of the WT approach in determining its spatial and temporal distribution (Trigo and DaCamara, 2000; Cortesi et al., 2013, 2014). These studies have shown that high amounts of monthly, seasonal, and annual precipitation are caused by a few WTs; that precipitation depends on more WTs to the west than to the east of the IP; and lastly, they found that the most prominent WTs for generating rainfall vary from region to region and particularly along the Mediterranean coastland, the precipitation depends on only a few WTs that usually affect small areas.

Soil degradation in the IP has been the subject of a great deal of research over the last 30 years (see review in García-Ruiz and López-Bermúdez, 2009), and the results show a high spatial and temporal variability of soil erosion processes (at plot level) and sediment yield (at catchment level), but the global view of this variability is not clear. Thus, this paper sets out to analyze the spatial variability of soil degradation in the IP from soil erosion and sediment yield through their relationships with the WTs. This was done by collecting data from various study areas and identifying the role played by different WTs in soil degradation.

In the IP, the WTs and precipitation exhibit a clear spatial pattern (Cortesi et al., 2013); thus in this study we analyze two hypotheses: (i) the existence of links between WTs and runoff, soil erosion, and sediment yield in the IP, and (ii) the emergence of spatial patterns in WTs, erosion, and sediment yield in the IP according to the spatial distribution of the relationship between WTs and precipitation.

2. Materials and methods

2.1. Study area

The IP extends over 582,000 km^2 and is located in the extreme southwest of Europe. This location at the transition of the subtropical fringe makes it particularly interesting from a climatic point of view, not only because of its latitudinal position in the subtropical transition areas, but also because it is surrounded by two completely different water masses: the Atlantic Ocean in the north, west and southwest, and the Mediterranean Sea to the south and east. It is also interesting to note that, because of the west to east, and northwest to southwest distribution of the mountain ranges (Figs. 1 and 2), different rainfall areas can be distinguished in the IP for annual amounts and seasonal regimes: (i) in the north and northwestern areas, the typical mid-latitude oceanic rainfall regime occurs, with annual amounts of >800 mm, a winter maximum, and no summer drought (in these areas rainfall is heavily dependent on Atlantic storms from the northwest); (ii) on the eastern Mediterranean fringe of IP, the annual amounts vary greatly (between 250 and 700 mm), summer droughts and a bimodal rainfall regime with its maximum in autumn predominate (in these areas, precipitation depends to a large extent on eastern advections and local factors); (iii) and finally, in extended inland and southwestern areas of the IP, summer droughts occur; precipitation depends mostly on westerly and southwesterly advections from Atlantic Ocean that produce annual amounts decreasing gradually from west to east and changes in seasonal rainfall from the winter maximum on the Portuguese coastland and in southwestern areas of Spain, to a bimodal regime with a spring maximum in inland Spain (de Luis et al., 2010).

2.2. Database

The precipitation, runoff, erosion, and sediment yield database contains records of 11 small catchments and 26 experimental plots from 16 sites. Their locations are shown in Fig. 1, and Table 1 gives a brief description and an overview of their principal characteristics (see reference for details). Original data were collected using different instruments (i.e., erosion pins, Gerlach collectors, and gauging stations), from a variety of land uses and soil conditions, with different spatial and temporal scales. Measurement periods vary from 1 to 20 years. The database contains 5199 events with runoff and soil degradation. To avoid confusion, the text divides data on soil degradation into soil erosion (plot data from experimental sites) and sediment yield, SY (catchment data). We have homogenized the individual data set following the same criteria in all the cases and checking carefully for inconsistencies and odd data.

Some of the sites are located in temperate, humid, oceanic climate conditions to the north (Corbeira, Aixola, Añarbe, and Barrendiola catchments). Others are found in a variety of Mediterranean and subMediterranean climates in central, southern and eastern areas (Conchuela, Setenil, Puente Genil, Riera de Vernegà, and Barranca de los Pinos catchments; El Pinarillo and El Ardal experimental sites), including mountain areas in the Pyrenees (Aisa experimental site and Araguás catchment). Finally another group represents semiarid inland climate conditions to the northeast Ebro basin (Bardenas, Lanaja, Mediana, and La Puebla experimental sites). The spatial distribution of study sites covers all the spatial varieties of WTs and precipitation relationships presented by Cortesi et al. (2013); therefore, this data set is a promising sample of soil degradation research sites across the IP with which to verify the hypotheses previously indicated.

Finally, note that this database for soil degradation throughout Spain has been collected over long periods by different research groups belonging to the National Research Council (CSIC) and several universities, mostly with financial support from European, national, and regional governments.

2.3. Weather type database

The WT classification in this research relies on the daily pressure data from the NMC/NCAR 40-Year Reanalysis Project (Kalnay et al., 1996) and covers 1970–2012. Our approach to daily WT classification used the set of indices adopted by Trigo and DaCamara (2000), originally proposed by Lamb (1972), following the corresponding objective classification defined for the British Isles by Jenkinson and Collison (1977), which takes into account physical and geometric characteristics (see detailed formulation in Trigo and DaCamara, 2000; Cortesi et al., 2013).

The original classification defines 26 different WTs, with eight WTs being purely directional types (NE, E, SE, S, SW, W, NW, and N); two WTs dominated by the strength of vorticity (cyclonic C and anticyclonic A types); and the remaining 16 WTs are hybrid types (eight for each C or