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Are meteorological conditions favoring hail precipitation change in Southern Europe? Analysis of the period 1948–2015

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ABSTRACT

In the context of a warming climate, one of the variables currently under investigation is related to the detection of possible changes in hail precipitation. In this work, we analyze hail frequencies in one of the most affected areas by this phenomenon in Europe, southern France. Here, an extensive hail detection network has been in operation since 1988.

In general, the detection of hailfall is very uncertain. To overcome the constraints of scarcity and poor standardization of hail detection and monitoring systems, some relationships between hailstorm occurrence and synoptic, mesoscale or thermodynamic atmospheric characteristics have been proposed in different areas. Therefore, we analyzed meteorological fields at synoptic scale that are related to the formation of hailstorms in the study area, i.e., geopotential height at 500 hPa, sea level pressure, and lapse-rate between 850 and 500 hPa. These fields describe the state of the atmosphere at low and mid levels, and facilitate the evaluation of thermal and dynamic instability.

Using the Mann–Kendall test and Sen estimator, we examined trends in the three fields during the period 1948–2015 and their spatial patterns, revealing an evolution toward synoptic environments that favor hail precipitation in the Mediterranean region.

1. Introduction

According to projected climate change scenarios, global temperatures may increase as much as 2 °C by 2050 (IPCC, 2012), which could dramatically increase damage from convective episodes at midlatitudes during coming decades (Botzen et al., 2010). An increase of mean surface temperature should invigorate updrafts and thereby increase hail intensity (Dessens, 1995), and some microphysical processes may increase in importance (Wang et al., 2010). An increase in altitude of the 0 °C isotherm can change the melting level (Xie et al., 2008) and could augment the importance of collision-coalescence, which is responsible for rain formation in warm clouds (Lin et al., 2005).

Currently, one of the greatest uncertainties lies in evaluation of changes in the frequency of hailfalls. The development of storms is usually at small spatial and temporal scales (Kunz, 2007). Hermida et al. (2013) studied spatial, altitudinal and temporal hail trends by means of a dense hailpad network, finding very high variability, with opposing results even between very close network stations because of the small scale of the phenomenon. The scarcity and poor standardization of hail detection and monitoring systems is a critical issue in determining trends in hail events.

Hail is monitored using different tools, with information not always comparable: damage data in Australia (Schuster et al., 2005) and Italy Eccel et al. (2012); insured building damage data in Germany (Kunz et al., 2009); synoptic stations in Serbia (Ćurić and Janc, 2016); radar detection in Spain (Sánchez et al., 2013), Austria (Kaltenboeck and Steinheimer, 2014), the Czech Republic (Skripniková and Řezáčová, 2014) and Germany (Kunz and Kugel, 2015); hailpad networks in Spain, France and Argentina (Sánchez et al., 2009), France (Dessens et al., 2015; Hermida et al., 2013, 2015; Melcón et al., 2017), Spain (Gascón et al., 2015), Italy (Manzato, 2012) and Croatia (Počakal et al., 2009).

Despite the above disadvantages, several studies have analyzed the hail evolution in several regions of Europe with high risk of hail toward understanding the influence of climate change and finding changes in its frequency or intensity. For the period 1974–2003 in Germany, Kunz

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et al. (2009) observed an increase in the number of hail days and its intensity. In northern Italy, hail losses of crops have shown a positive trend since 1974 (Eccel et al., 2012). However, there are no significant trends in the frequency of hailstorms, although several thermodynamic indices do show an evolution toward more unstable environments. In Serbia, Ćurić and Janc (2016) observed mostly decreases in hail frequency, especially in the warm season. In contrast, Burcea et al. (2016) found for contiguous Romania that a majority of stations with hail records during 1961–2014 had positive trends.

Hermida et al. (2015) analyzed the evolution of the number of hail days, frequency and intensity by region for the Atlantic and Pyrenean portions of a network. The three variables showed a negative trend in the first zone, and positive in the second zone.

Similar studies have been carried out in other regions of the world where hail poses a major risk. In Argentina, trends in the frequency of hail events are positive in northern and southern Patagonia, whereas central and southern regions show negative trends (Mezher et al., 2012). In China, Li et al. (2016) found negative trends in the frequency of hail days since the 1980s, most notably in the north of the country.

To overcome a lack of observations, relationships between hailstorm occurrence and synoptic or/and mesoscale atmospheric patterns have been proposed (García-Ortega et al., 2012; Merino et al., 2013). Authors have studied anomalies, trends and variability in certain atmospheric patterns related to hailstorm occurrence (García-Ortega et al., 2014; Sioutas and Flocas, 2003; Suwała and Bednorz, 2013; Berthet et al., 2013; Merino et al., 2014).

Sioutas and Flocas (2003) determined various types of atmospheric circulation at synoptic scale related to hailstorm formation in northern Greece between April and September. Those authors also studied the distribution of thermodynamic instabilities linked to each synoptic type. Kapsch et al. (2012) reported a relationship between four large-scale meteorological configurations and damaging hailstorms (with hailstones > 2 cm) in Germany. García-Ortega et al. (2011) classified five synoptic patterns related to hailstorms in the Middle Ebro Valley (MEV) of Spain, and Berthet et al. (2013) identified synoptic patterns related to extreme hail events in southwestern France. Wang et al. (2015) analyzed synoptic environments associated with convective episodes during the summer monsoon in southeastern China.

The study of trends in atmospheric environments associated with hail can be used to infer changes in the frequency and intensity of this phenomenon. In that sense, Eccel et al. (2012) identified a notable (albeit irregular) increase in general instability over northern Italy during 1975–2009, especially when analyzing indexes related to the hailstorm intensity. Kunz et al. (2009) studied the evolution of convective indexes and synoptic circulation patterns during 1974–2003 in southwestern Germany. They observed an increase in the frequency of synoptic situations related to hailfalls and a positive trend in thermodynamic instability based on indexes calculated at the surface, but negative or non-significant trends based on indexes at mid and upper levels. Mohr and Kunz (2013) extended the study area and found a positive trend in instability over central Europe beginning in 1978. These results were supplemented by those of Mohr et al. (2015) using a logistic model of hail-related meteorological indexes and parameters, calculated by regional climate models between 1951 and 2010 for most of Europe. Those authors observed that hail potential had positive trends in western and central Europe, whereas these decreased in Eastern Europe. However, for the most part, these trends were not significant, because of strong interannual variability. García-Ortega et al. (2014) observed significant trends beginning in 1950 in temperature and geopotential height fields at 850 hPa, which over time reinforces synoptic situations previously identified as most favorable for the development of convection in the MEV. In China, Li et al. (2016) analyzed various indexes of instability and synoptic patterns for the period 1960–2012, observing progressive weakening of atmospheric conditions and patterns linked with hail, especially over the Tibetan Plateau where hailstorms have traditionally been more frequent (Zhang et al., 2008). Thus, not all mid-latitude regions show a positive trend in environments favorable for the development of severe convection and hail. This illustrates that it is impossible to generalize the effect that climate change has had on such phenomena, and underscores the need for exhaustive regional studies on this issue.

The main objective of the present study was to evaluate trends of hailfalls in France. To that end, we first compiled hailpad databases from 1989 onward and determined trends in observed frequencies. However, given the strong variability and limitations of direct observations, we subsequently evaluated various synoptic fields to determine whether atmospheric environments are more or less favorable for the development of severe convection, thereby inferring with respect to synoptic environment the past, present and future evolution of hail potential in the study region.

2. Study area and databases

Inland regions of the western Mediterranean have the greatest frequency of hail in Europe (Punge and Kunz, 2016). A great variety of methods to measure the frequency and intensity of hail in these areas has been used, including hailpad networks (Berthet et al., 2011), damage claims from insurance companies, and remote sensing instruments (Melcón et al., 2016; Kunz and Puskeiler, 2010).

However, sufficient monitoring of hail events over long periods is necessary to determine changes of hailfall patterns in robust fashion. The south of France has one of the best hail databases in Europe. The Association Nationale d'Etude et de Lutte contre les Fleáux Atmosphériques (ANELFA) maintains an extensive hailpad network that has been in operation since 1988. This has enabled the creation of one of the largest databases of direct hail measurements in the world in terms of its large spatial coverage and number of stations as well as its long temporal continuity. These characteristics have resulted in the database being used as “ground truth” in many hail studies (e.g., Berthet et al., 2011, 2013; Dessens et al., 2015; Hermida et al., 2013, 2015; Merino et al., 2014; Sánchez et al., 2009).

Given the above, we used ANELFA hailpad network datasets in the present study, with the aim of extracting long-term hailfall datasets. Owing to climatic differences across the area covered by the hailpad network, a classification has been established according to the proposal of Hermida et al. (2015), which includes a new region in the eastern part of southern France. The location and extent of the three areas selected for our study are shown in Fig. 1. The Atlantic region embraces hailpads in the departments of Charente, Dordogne, and a large part of Charente-Maritime and Gironde. The Pyrenees region includes most of the hailpads in the departments of Pyrenees-Atlantiques, Hautes-Pyrenees, Ariège, and southern parts of Haute-Garonne and Gers. The Mediterranean region is the same as that defined by ANELFA (Merino et al., 2014).

For this study, only hailpads stations with continuous data records over the period analyzed were used (Hermida et al., 2013). The calibration, analysis, and data extraction of the hailpads have been extensively described (e.g., Dessens et al., 2001; Sánchez et al., 2009). The database contains detailed information of hail days (HD hereafter), impacted hailpads, spatial and temporal distributions of hailfalls, number of hailstones per square meter, and various physical characteristics of hail such as maximum diameter and total kinetic energy. The method used to obtain the hail spectra of impacted hailpads did not change over the period analyzed.

After exhaustive filtering of the cases, we selected HD recorded in the database for hail seasons (the period of most hail events, from May through September in the Northern Hemisphere) between 1989 and 2014 in the Atlantic and Pyrenees regions, and between 1994 and 2014 in the Mediterranean region. We considered HDs to be days on which at least one hailpad was impacted in one of the three study areas.

Once the HD databases for each region were extracted, atmospheric conditions in the study area were characterized by daily 1948–2015