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Hailpad-based research: A bibliometric review

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ABSTRACT

This paper is an overview of hailpad research from its origin until today using as a search criterion the bibliographic references on the subject in the Web of Science database (ISI). The search was carried out on 1st September 2008. Among the more than $3 \cdot 10^7$ scientific documents included in the Science Citation Index Expanded (SCI-EXPANDED) from 1945 to the present, the search engine identified 41 containing the word "hailpad*" (the asterisk is a wildcard for any letter or group of letters).

The results have been analyzed according to various criteria: countries with hailpad networks or studies on hailpads; date of the first article; evolution of the number of articles per decade; concepts studied and research lines followed in each article; and finally, a bibliometric analysis of the journals where these articles have been published. It was found that 70% of the articles on hailpads were published in 2 journals: *Journal of Applied Meteorology* and *Atmospheric Research*. These two journals also concentrate most of the citations. The number of articles on hailpads and the documents that cite them have grown steadily, and it is expected to grow still further in the present decade if we take into account the trends found.

1. Introduction

The interest of human beings in atmospheric phenomena is as old as mankind itself. This interest grows when the phenomenon affects people's everyday life, and this has been proved in the recent past by the effects of relatively unexpected extreme weather events that have become more and more frequent.

Hail in particular has always raised interest due to the important damages it may cause to crops, other goods, and even to human beings. From the seventh plague described in the *Book of Genesis* until the most recent hailfalls affecting, for example, the cyclists taking part in an international race (Tour de Suisse, 21 June 2007), hail has affected many human activities, and usually with a negative effect on human interests.

These destructive consequences have lead humans to develop weather modification methods and procedures in an attempt to reduce the damages caused by hail. From the end of the 19th century numerous hail suppression projects produced research in the formation and growth of hailstones. However, it is not until well into the 20th century that the evolution of hailstones inside clouds began to be studied using radar technology. It was also in the 20th century that new observation methods were developed to characterize the hailstones that reach the ground, a type of investigation which for many scholars is more interesting than any remote observation inside clouds.

In the second half of the 20th century the need for more objective data than those provided by networks of voluntary observers leads the scientific community to design and use hailpads (Schleusener and Jennings, 1960), an extremely simple instrument which is very useful in describing the physical parameters of hailstones. From the invention of the hailpad in the mid-20th century, scientists have used it more and more to

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obtain a lot of information from hailstones that hit it and very few innovations have been added to its original design.

This paper investigates the bibliographic resources available on hailpads to assess the interest of scholars in this particularly simple measurement instrument. The most interesting scientific results are usually published in articles in peer-reviewed journals. One of the most prestigious databases for scientists worldwide is the one compiled by the Institute for Scientific Information (ISI), by Thomson, with several thousand indexed journals. This database was used to investigate among the scientific publications on hail and identify those based on the use of hailpads. This is a task that has not been carried out before, and the scientific community demands it.

2. Hailpads

In the 1960s Schleusener and Jennings (1960) developed the hailpad as a cheap and efficient system for measuring hailstones. A hailpad is a flat plate made of some type of material sensitive to the impact of hailstones. This plate may or may not be covered by an aluminum sheet and is slightly deformed when it is hit by a solid object. In addition, the hailpad retains that deformation for some time. The study of the dent left by any object on the material enables scientists to determine several features of the object that hit the plate, in particular its size (Long et al., 1980).

From the invention of the hailpad other instruments were developed based on the same principles, but they were all rather unsuccessful. For example, Towery and Changnon (1974) described different types of hail sensors according to whether they were passive or capable of registering data. In their study these authors list the *hailpad* (horizontal plate), the *hailstool* (a cylindrical sensor), the *hailcube* (formed by the five sides of a cube), the *hail-wind detector* (to detect wind direction), the *Illinois recording hailgage* (to determine the moment and duration of a hailfall), the *NOAA momentum sensor* (to determine the momentum, but too sensitive to wind), the *NHRE non-recording rain-hail separator* (separates rain and hail in two different containers), the *recording hail-rain separator* (similar to the previous one, but registering volume too) and the *geophone gage of South Dakota* (a plate that transfers the impact and the momentum, and transmits an electric pulse as a function of the linear momentum of the hailfall).

Of all the different types of hailpads initially developed the one that is still in use today, with very few variations, is the simple horizontal plate made of some type of sensitive material (Styrofoam or other similar materials). In some cases the plate is covered with a thin sheet of aluminum (Colorado) and in other cases it is protected from the effect of solar radiation by white paint, for example in France and Spain (Palencia et al., 2007).

Fig. 1 is the type of hailpad used in León (Spain), with a vertical metal base supporting a horizontal plate. The sensitive material is attached to this metallic plate by means of a number of buckles. The metallic plate protects part of the sensitive plate from the impact of hailstones. This area is used to calibrate the hailpad by throwing on it a number of steel balls from a height such that they reach the plate with the same kinetic energy as hailstones of a similar size. A dented hailpad is calibrated and then inked black using a press roll. The result can be seen in Fig. 2, with the dents left by hailstones and by the calibration balls in the central band marked in white. Other procedures expose a larger surface to the impact of hailstones and do not preserve any area for calibration. In these cases, the calibration is carried out using other plates from the same batch (Palencia et al., 2007).

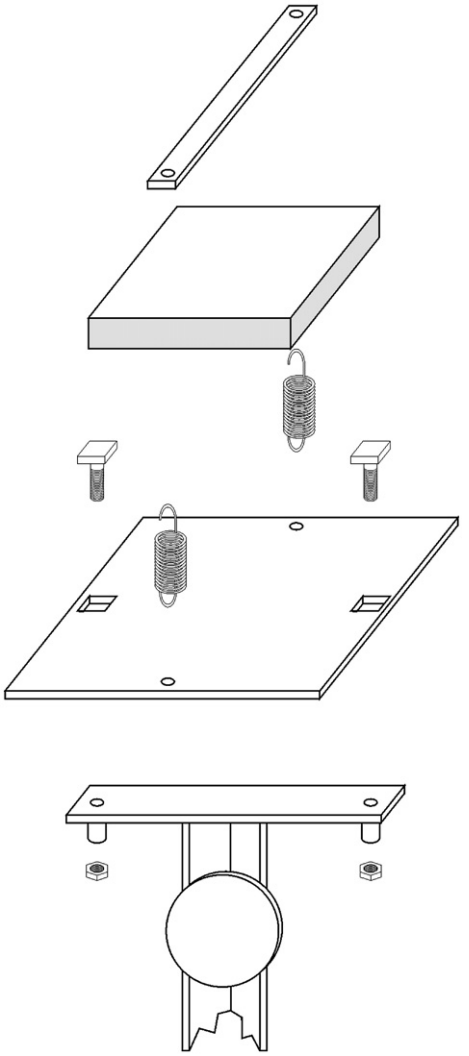

Fig. 1. Hailpad used in León (Spain) (Fraile et al., 1992).

The size of each hailstone that hit the plate is estimated by measuring its dent, as shown in Fig. 2. When the relationship between the size of the calibration balls and the dents they leave on the hailpad is known, the size of each hailstone can be inferred assuming a number of preliminary hypotheses on hailstone shape and terminal velocity.

The dent-measurement process has evolved through time from the initial method where a technician measured every single dent manually with a ruler or a caliper and wrote down the sizes in a notebook, to the current methods based on shape-recognition software applied to the digitalized images of the hailpads, by extracting and storing in a file the size of the hailstone that left each particular dent.

The final output of a hailpad is a number of very interesting parameters, such as hailstone sizes, the number of hailstones

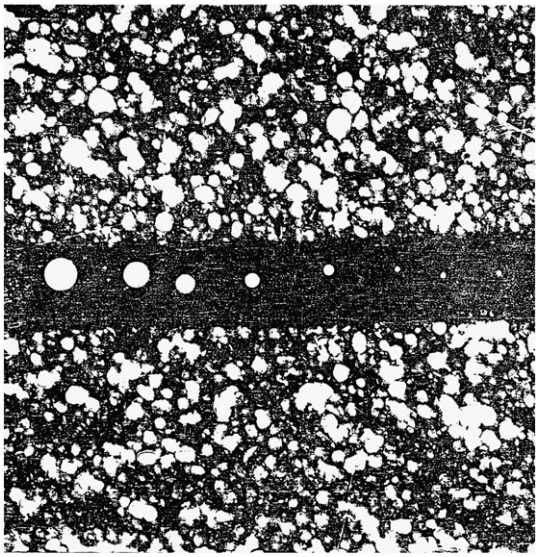

Fig. 2. Hailpad of 30*30 cm^2 after a hailfall, calibrated and inked in black.

registered per square meter, the ice mass, and the kinetic energy per unit area (Fraile et al., 1999). The most important among these parameters are the number of hailstones and the energy, as they are indicators of the intensity of the hailfall.

Other variables may also be obtained directly or indirectly from a hailpad. The most immediate example is the maximum hailstone size, which provides information about the intensity of the updrafts that have sustained these hailstones and about the time the hailstone remained inside the convective cell. Other parameters that may be obtained are the ones that characterize size spectra: assuming that hailstone size distribution follows an exponential form (Marshall and Palmer, 1948), the parameter is λ, and if it follows a gamma distribution (Smith, 2003), there is a shape parameter and a scale parameter (without considering the number of hailstones or the concentration parameter). More precisely, the probability density functions are: $f_e(x) = \lambda \exp(-\lambda x)$, the exponential, and $f_g(x) = \beta^{\alpha} x^{\alpha-1} \exp(-\beta x) / \Gamma(\alpha)$ the gamma (Fraile et al., 1999).

Calculating these parameters is not an easy task (Fraile and García-Ortega, 2005); the results must be properly fitted because on some occasions their value is decisive in determining whether two samples are considered to come from the same population or not (Dessens et al., 2001).

From the point of view of climatic studies, it is advisable to analyze all of these parameters described above and observe their temporal variation. Then, a hail climatology may be set up including the frequency of a particular event or its return period (Fraile et al., 2003).

3. Bibliometric study of publications on hailpads

Hailpad-based research can be found in many studies published in international journals. The contents of these studies are spread because the journals are indexed in various databases available to the scientific community.

The most prestigious international bibliographic database has been used for this study: the Web of Science® (henceforth WOS). The bibliographic search was carried out previously, but by the date when this paper was finished, September 1st 2008, the results had not changed.

Among the more than $3 \cdot 10^7$ scientific documents included in the Science Citation Index Expanded (SCI-EXPANDED), from 1945 to the present, the search engine found 41 documents on this topic containing the word "hailpad*", where the asterisk is a wildcard for any letter or group of letters (this was done mainly to include the plural). The database searches the topic in title, abstract and keywords. Out of the 41documents, 30 items were articles, 5 meeting abstracts, 4 notes and 2 letters. These documents have been published in 10 different journals, but two of them stand out for the volume of publications: *Journal of Applied Meteorology*, published by the American Meteorological Society, with 15 documents, and *Atmospheric Research*, published by Elsevier, with 13 articles.

3.1. Geographic study

A geographic analysis of these articles was undertaken in an attempt to identify the places of the world where hailpad-based research has been carried out. The results are summarized in Fig. 3, which includes the countries with any type of research articles on hail using hailpad networks. European countries are predominant, in particular Mediterranean countries. Outside Europe the only other countries with published results on hailpad networks are USA, Canada, Argentina and New Zealand.

A chronological study was also carried out. Table 1 lists the countries ordered by the year of the first article and the number of items found. It can be seen that the first results were published in the second half of the 1970s. The first hailpad networks are found in central Europe (France, Italy and Switzerland), Canada and USA. Later, this type of study spread to the rest of Europe (Spain, Hungary, Greece, Bulgaria and Croatia) and to other continents (New Zealand, Argentina).

The countries with more results published in indexed journals are France and Spain, both with important agricultural productions that are greatly affected by damages on crops caused by hail. Next in Europe come Italy, Switzerland and Hungary.

3.2. Evolution

It is interesting to analyze the evolution of hailpad-based research. This has been done using the number of documents published in each decade from the 1970s (Fig. 4).

The following aspects need to be pointed out:

- The first decade considered, the 1970s, represents a boom in hailpad publications: 10 articles are found in the database. This is a high number taking into account that all the articles were published in the second half of the decade only. However, it must be noted that in the case of one article, comments to that article were published and later its corresponding reply, thus increasing the number of documents. Considering this decade as exceptional (only the current decade contains more articles), a rising trend is observed in hailpad-based publications.

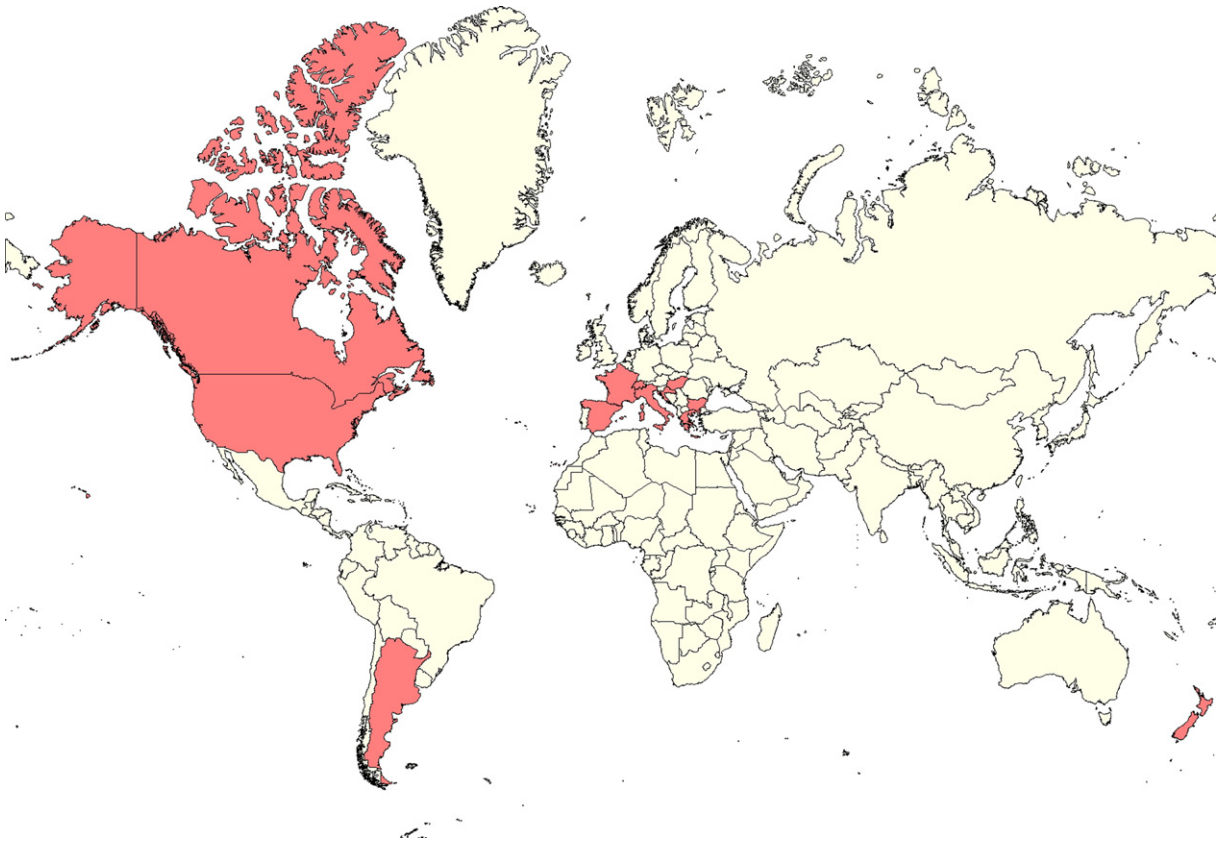

Fig. 3. Countries with hailpad networks or hailpad studies cited in the bibliometric sources used.

- The line in Fig. 4 represents an increase in the number of publications: on average, in every decade two more documents are published than in the previous decade, as illustrated by the slope of the line.
- The last decade represented in Fig. 4 also requires special attention because there have been 15 publications (the maximum in one single decade until now) and the decade has not finished yet. This fact makes us think of a significant rise in future research on this topic.
- It would be interesting to know whether the increase in the number of articles on hailpads runs parallel to the increase in the number of meteorological papers (articles published in journals included in the subject category *Meteorology and Atmospheric Sciences*). A similar relative increase has been observed in both, articles on hailpads and meteorological papers. In the 1990s the number of meteorological papers was twice the number published in the previous decade, the 1980s. A similar increase is observed in the case of hailpad papers, but in the following decade, from 2000 on. In any case,

Table 1
Countries with hailpad networks or hailpad studies cited in the Web of Science database (by ISI).

Countries	Number of documents	Year of first document
Italy	6	1976
Canada	3	1977
Switzerland	6	1978
France	10	1978
United States (Colorado and Nebraska)	5	1979
Hungary	6	1983
New Zealand	1	1990
Greece	2	1991
Spain	9	1996
Bulgaria	1	1996
Croatia	1	2003
Argentina	1	2007

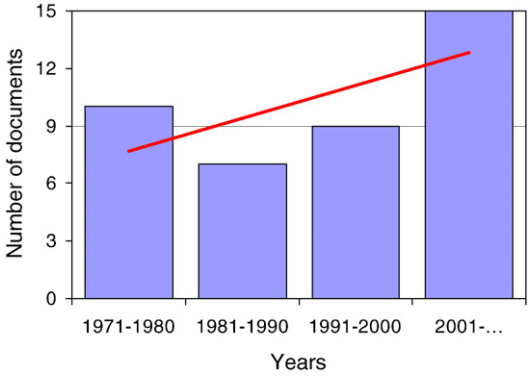

Fig. 4. Evolution of the documents published in each decade.

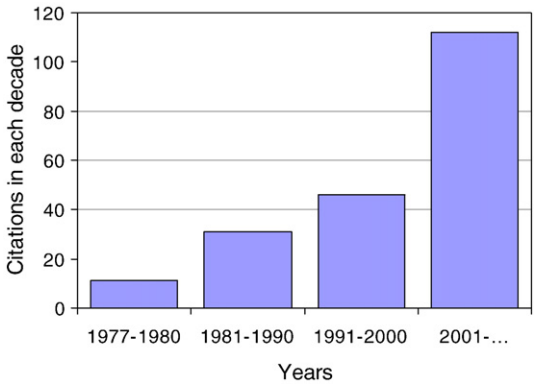

Fig. 5. Number of citations per decade.

the current decade has not finished yet and both papers may continue increasing in number, but their relative growth is not predictable.

The growing trend marked by publications on hailpads coincides with the rising trend in the number of citations of these documents (Fig. 5). This graph must be interpreted in the context of the importance of scientific research carried out by means of hailpad networks. If these documents are more and more cited (the rise is not linear, but much sharper), this means that the scientific community is more and more concerned in the results of hailpad-based research, and this is certainly promising.

This evolution is not surprising if we consider that the hailpad is to hail research what the rain gauge is to research on rain. Many studies focus on forecasting hail precipitation or on characterizing hydrometeors inside clouds, but it will always be necessary to know the main features of hailstones when they hit the ground in order to validate any theory. The rain gauge and the hailpad are the ultimate validation criteria for any hypothesis that may be established on precipitation, be it liquid or solid precipitation.

3.3. Research lines

The main topics found in the documents published are also of interest here:

- Authors initially tried to demonstrate the usefulness of hailpads when they were first introduced. The first stage (1971–80) concentrates above all on presenting hailpads and discussing their effectiveness (7 documents deal with calibration and measurement errors in hailpads).
- From 1981 to 1990 new research fields develop to analyze in more detail the influence of hailpad data in certain types of studies. For example, we find in this decade the first studies trying to establish relations between what is observed inside the cloud and what is registered on the ground. In this line, 3 studies are particularly interesting and deal with the correlation with radar data. Other articles deal with the application of hailpad data in hail suppression activities aimed at weather modification initiatives to reduce the damages caused by hail: when the data on the damages are not available or not reliable, a physical parameter of hail is shown to have been changed, and this can be measured by hailpad networks.
- Between 1991 and 2000 the three current research lines are defined: first, instrumental support of weather modification (hailpad networks are a must to carry out any hail suppression project); second, climatic studies (because in some areas the databases are large enough with respect to the size of the network and with respect to the length of the series); and third, purely meteorological-instrumental studies (relationships with atmospheric variables measured by radar systems and sounding balloons, and the discussion on the validity and accuracy of hailpad measurements).
- The current decade is characterized by an increase in hailpad research. Before, the average number of publications was of around 10 documents per decade; now, it is very likely that an average of two documents per year may be surpassed if the current trend continues. As for the main topics, most of the articles are devoted to one of the three areas outlined in the previous paragraph (justification of weather modification, source of data for climatic studies, and instrumental-meteorological studies), distributed in nearly equal parts.

Table 2
Journals with articles on hailpads.

Journals	N_1 (documents)	N_2 (citations)	N_2/N_1 (ratio)	N_3 (average cited)	N_4 (cited references)
Journal of Applied Meteorology	15	125	8.3	0.4	124
Atmospheric Research	13	35	2.7	0.5	46
Bulletin of the American Meteorological Society	5	0	0	0	20
Theoretical and Applied Climatology	2	4	2	0.2	5
Journal of Atmospheric and Oceanic Technology	1	4	4	0.8	10
Journal of Climate and Applied Meteorology	1	4	4	0.2	33
Meteorological Applications	1	3	3	0.4	0
Monthly Weather Review	1	24	24	1.6	6
Meteorology and Atmospheric Physics	1	1	1	0.1	4
Physics and Chemistry of the Earth	1	0	0	0	2
Journal of the Atmospheric Sciences	0	0	0	0	33

N_1: number of documents found.
N_2: number of citations of these articles.
N_2/N_1: ratio between the number of citations and the number of documents.
N_3: average number of documents cited per year (average n° citations/ n° years).
N_4: number of times each journal is cited in the references of the 41 documents found.

3.4. Research journals

To finish this bibliometric study, we will now turn to the journals most interested in publishing hailpad-based research articles. A few preliminary issues need to be clarified before presenting the results, as they affect the bibliographic analysis.

First, not all journals have been included in the Web of Science database (henceforth, WOS) at the same time. For example, *Atmospheric Research* was first indexed in 1994, and it had already published articles on hailpads before that. The studies published before that date are not included in the results presented here.

Second, the names of some journals have changed and the database considers each of them as a different journal. This is not relevant in the case of the *Journal de Recherches Atmosphériques*, which changed its name into *Atmospheric Research*, because it had not been indexed in WOS with the first name. However, this fact is important in the case of the *Journal of Climate and Applied Meteorology*, which was renamed in 1988 *Journal of Applied Meteorology* and again more recently, in 2006, *Journal of Applied Meteorology and Climatology*.

Table 2 lists the journals in which the 41 hailpad-based articles have been published. The following bibliometric parameters are included for each journal:

- the number of documents found in the journal (N_1);
- the number of times these articles have been cited (N_2);
- the ratio between the number of citations and the number of documents (N_2/N_1);
- the average number of documents cited per year (N_3 calculated from the ratio between the average number of citations and the number of years);
- the number of times (N_4) each journal is cited in the bibliography of the 41 documents found. For example, *Journal of Applied Meteorology* is cited 124 times in the references of the 41 articles, *Atmospheric Research* is cited 46 times, etc…

Table 2 shows that the journals that have published more articles on hailpads are *Journal of Applied Meteorology* and *Atmospheric Research*, comprising 70% of the total. The former journal had published articles on hailpads before (although they have not been included here) and the number of articles has decreased in recent times. In contrast, the latter journal seems to have taken over in the number of articles on hailpad-based research.

These two journals are also the ones that have published the most widely cited documents. Together with the *Monthly Weather Review*, these two journals contain 92% of the 200 citations of the articles. The most widely cited article is one (Houze et al., 1993) published in the *Monthly Weather Review*: this journal has published only one article in this field, but this one article has been cited 24 times, which amounts to 1.6 citations per year, the highest ratio of all documents.

One of the journals in Table 2 (*Journal of the Atmospheric Sciences*) has published no document on hailpads, but it has been included because it is one of the journals most widely cited in the 41 documents on hailpad research found in the database. A total of 33 articles are cited, as many as in the *Journal of Climate and Applied Meteorology*. Only *Journal of Applied Meteorology* and *Atmospheric Research* contain more citations and they may be considered the two journals that clearly lead in the publication of hailpad-based research. In fact, the last column in Table 2 gives us an idea of the sources of scientific research on hailpads.

Finally, it must be noted that even though the WOS database is a high-quality source and includes the most important journals in the field, there are many other publications not included in this database: theses, books, articles with a non-international character, non-periodical publications, etc. This paper does not analyze all existing articles on hailpads, but it does include a sufficiently representative sample of the articles with the highest quality standards enabling us to draw general conclusions on the trend in this particular field.

4. Conclusions

The following conclusions may be drawn from what has been said above:

- From its origin the hailpad has been used more and more often, as indicated by the growing number of research articles in the past few decades.
- Most of the publications on hailpads concentrate in 2 journals: *Journal of Applied Meteorology* and *Atmospheric Research*. These 2 journals also contain most of the citations. The articles proportionally most widely cited have been published in the *Monthly Weather Review* and in the *Journal of Applied Meteorology*.
- The references in the 41 articles on hailpads found in the WOS come mainly from *Journal of Applied Meteorology, Atmospheric Research, Journal of Climate and Applied Meteorology, and Journal of the Atmospheric Sciences*. In consequence, these journals are the main sources of information for researchers working with hailpads.
- The trends found anticipate an increasing relevance of hailpad-based research, as revealed not only by the increase in the number of articles on hailpads, but also by the considerable increase in the number of times the documents are cited.

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