ECSS 2009 Abstracts by session

ECSS 2009 - 5th European Conference on Severe Storms 12-16 October 2009 - Landshut – GERMANY
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METHODS FOR REANALYSIS OF HISTORIC TORNADOES

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(Dated: 15 September 2009)

I. INTRODUCTION

Many important tornado events around the world have happened but, because they occurred many years ago, these events are poorly documented. The so-called "Tri-State" tornado of 18 March 1925 is an example. Its place in history is dominated by the fact that it produced the most fatalities (695) of any single tornado in United States (US) history, and its recorded path length of 219 miles (352 km) is also at the top of recorded US tornadoes. However, some questions linger about the nature of the event (e.g., Doswell and Burgess 1988), as well as the about the meteorological setting that produced this record-breaking tornado.

In order to try to answer some of these lingering questions, a team of researchers was formed to reassess the facts regarding this case, including the continuity of the damage along the path and the environment associated with the storm. Methods for conducting this research have been developed and are presented herein, with the hope that sharing them might prove useful for researchers around the world seeking to reinvestigate historical events. The ultimate goal of such work is to have as much information about past events as possible in order to anticipate the future.

II. ABOUT THE TRI-STATE TORNADO

It is somewhat surprising that this event has never before been the subject of a detailed meteorological analysis in a refereed publication. A brief account to the storm was published in 1925 and an article appeared in the unrefereed publication *Weatherwise* (Changnon and Semonin 1966 – hereafter, CS66). In CS66, the track was shown (Fig. 1) and various meteorological aspects of the event were described.

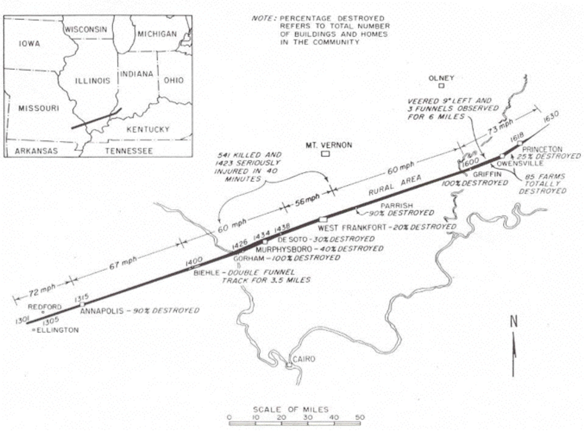

FIG. 1: The tornado track, showing significant damage locattions.

In this short summary, space doesn't permit much of a discussion about prior or revised understanding of this event. However, it is of interest to illustrate the current level of detail our team has been able to reconstruct along the path (Fig. 2) by using the methods summarized herein. We have been able to locate and verify more than 1500 damage points along the track, although there are still some data gaps along the track. New interpretations of this event are likely.

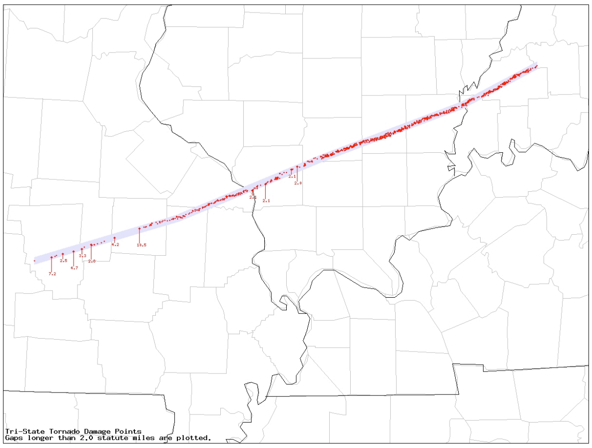

FIG. 2: Preliminary map of verified tornado damage points along the track resulting from the reanalysis research. Data gaps of more than 2.0 miles (5 km) are indicated. State boundaries are in heavy gray; light gray depicts county boundaries

III. REANALYSIS RESEARCH METHODS

There are two primary reanalysis research topics within the Tri-State Reanalysis Project: (1) the meteorological setting within which the event took place, and (2) verification of the continuity of damage along the track. For brevity's sake, only the damage path reanalysis methods will be summarized herein; the conference presentation will include both, however.

Counties along the track were assigned to the team members. Contacts with individuals in each county were developed at first via Internet searches and phone calls to local libraries, county officials, and local historical societies. Team members then travelled to each county to interact with their initial contacts. New contacts would be found during research visits; sometimes those contacts could be developed during that visit or might need to be scheduled for a subsequent visit. In general, investigations into multiple counties would take place during each data-gathering trip.

A high priority was associated with obtaining interviews with eyewitnesses. After letting them first describe the event in their own way, specific questions about important elements of the event were asked. On many occasions, these eyewitnesses were able to take researchers on a driving tour of the area, pointing out locations where significant things happened, even if there currently is no visible evidence remaining. During the course of this investigation, many of those interviewed have since died, which underscores the high priority we assigned to obtaining such interviews. Their information has been invaluable.

Contemporary accounts of the event, often in local newspapers that could be reviewed in libraries, usually would list damage locations by the name of the residents (e.g., the Smith farm, a home belonging to Mr. Johnson). This necessitated obtaining information about the approximate location of these locations in geospatial terms. In many US counties, information about property owners is documented on a "plat map" that is revised at intervals, showing the locations of tracts of land and designating the name of the owners. For many documented damage locations, it was not possible to locate them and so they couldn't be included. School and church locations in rural areas also provided information about the track if they were hit by the tornado. In many cases, if these buildings are still standing, their exact location could be determined (often with the help of a GPS device). In locating the track, non-damage points also proved to be helpful, when the point was close to the track. These have been recorded, but aren't shown in Fig. 2.

Collection of field data in this fashion requires multiple visits to each county, to follow up on new information sources and occasionally to re-interview eyewitnesses. Creative ways to locate and document damage have been found, although some leads that promised to be helpful proved to be unfruitful. The field data collector must be willing to pursue unexpected leads, but have a consistent set of goals for the process. Gaps in our data were understood to be inevitable at the outset. Nevertheless, a considerable mass of information has been collected and is currently being archived so that future researchers can conduct their own investigations of this event without having to re-locate all of the data.

IV. RECOMMENDATIONS

Space does not permit a comprehensive set of recommendations but the following represent some of the lessons we have learned during the course of this project:

•*Living eyewitnesses* are critically important information sources and should be the highest priority

–Record the interviews for reviewing later, if possible. Ask for their permission to do so. Keep detailed notes, if it is not possible to record the interview. Photograph your interviewees, if they're willing (ask for their permission).

–Let the interviewee describe the event in their own way at first and only ask questions after that first description is complete

–Interviews can corroborate or refute newspaper accounts, so be prepared to ask questions about issues obtained from your prior research

–80 years is about the farthest back this method can be used because eyewitnesses die or become unable to recall important details

–Second-hand histories from eyewitnesses (i.e., from surviving friends, family) can be nearly as useful as first-hand accounts

–Physical visits are preferred, but phone interviews with eyewitnesses can be a useful alternative

–Driving tours should be suggested, if the eyewitness is willing and able physically to do so

–Try to obtain copies of any documentation (photographs, newspaper clippings, etc.) in their personal possession

–Seek independent corroboration for eyewitness accounts wherever possible

–Assess the credibility of the information obtained

•*Physical evidence*, if available, can be located precisely

–Damage remnants (rebuilt structures, foundations, debris, gaps in vegetation, etc.)

•For *field research trips*:

–Keep up with a *daily diary!* - record as much detail about what you did and what you heard as possible, including items that are interesting but may not seem to be directly relevant to your goals

–GPS for site location is a powerful tool

–Use Internet and phone calls to develop contacts

–Be prepared to follow up on new contacts and investigate new leads for filling data gaps and corroborating the information you've already obtained

–Genealogical research sources are useful for clarifying information about individual names in the documentation

–Newspaper accounts often include errors or conflicting reports - have multiple sources wherever possible

–Take numerous photographs, with documentation of what the photograph represents, as well as where and when the photograph was made. Even if no physical evidence at a damage location remains, it can helpful to have an image of what that location looks like currently.

•*Potentially useful sources*: city, county, state, and national government archives, newspapers, libraries, churches, historical societies, local schools (including universities), weather service records, weather data archives, records of local businesses, real estate and census records (if available) are all useful sources.

•*Aerial photographs* may be available and strong tornadoes can leave physical damage that might remain visible for decades

•*Don't be afraid to knock on doors or ask people* in the area to develop new contacts – explain what you're doing and request information or contact information for people that could help fill in data gaps

•*Develop a permanent archive* and retain therein as much of your data as possible. This greatly simplifies and enhances the potential value of any future investigations and confirmation of your work.

•*Share your results* with those who helped you during your research, as well as the scientific community

V. AKNOWLEDGMENTS

The author acknowledges that this project has been a *team effort* – it has been a privilege to work with and learn from all the members of this team: R. A. Maddox, C. Crisp, D. W. Burgess, J. Hart, R. H. Johns, S. Piltz, and M. S. Gilmore. We greatly appreciate the time and effort given freely by our field contacts, without whom this project would not have been possible.

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YEARLY FLUCTUATION OF HAIL PRECIPITATION IN FRANCE

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I. INTRODUCTION

Former studies on long-term fluctuations of hail in different countries in the world are based on subjective observations of hailfalls and on crop damage insurance data (Genève, 1961; Changnon, 1977; Xie et al., 2008). It is only a few decades ago that physical data became available, with the development of hailpads and other measuring systems. Unfortunately, most of the field projects involving hailpads have not lasted long enough to constitute consequent data series. In order to control its hail prevention project with silver iodide ground generators, the Association Nationale d'Etude et de Lutte contre les Fléaux Atmosphériques (ANELFA) has installed hailpad networks in four of the most hailed regions of France. This paper presents a first survey of the data collected during 21 years of continuous measurements.

II. HAILPAD DATA

At each hailpad station, during a hailfall, the hailstones impact a polystyrene plate which is processed semi-automatically (Dessens et al., 2001). The networks are displayed in 4 main areas: Atlantic (31,000 km²), Pyrenean (20,000 km²), Central (7,000 km²) and Mediterranean (8,500 km²). These networks have been in operation since 1988, 1988, 1990 and 1994 respectively (Dessens et al., 2007). The first two networks are much more developed than the other two, so that their data allow the examination of the yearly fluctuations, while in the Central and Mediterranean areas, only the mean values of the hailfall characteristics can be considered for now. During the 21 years of the 1988-2008 measurement period, the total point hailfall number in the four networks is 4,975 for a yearly mean value of 915 hailpad stations.

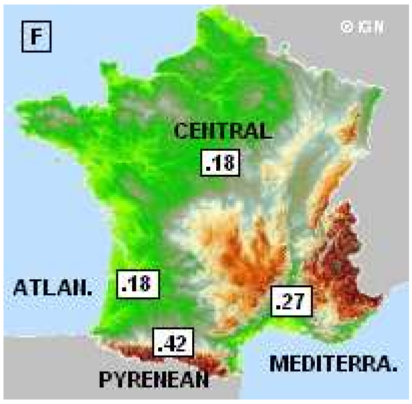
In this paper, the total kinetic energy of the hailstones larger than 0.5 cm of a point hailfall will be the parameter under study, but the results do not change significantly when the mass is considered instead of the kinetic energy.

III. REGIONAL VARIATIONS

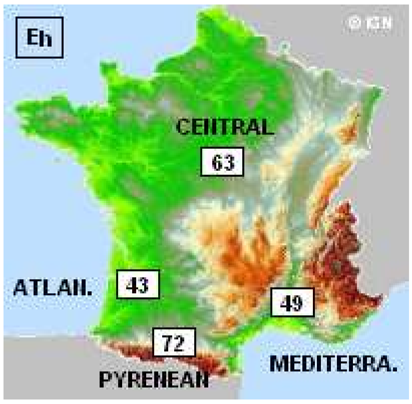
In order to examine the spatial variations of hail, the following parameters are examined for each hail season:

- frequency, F
  F = number of impacted pads / number of stations,
- energy per hailfall, Eh
  Eh = total energy of the year / number of impacted pads,
- energy per station, Es
  Es = total energy of the year / number of stations

The mean values of the yearly parameters are given on FIG.1 for the various regions.



F→ Frequency per station, per year.



Eh (J.m^{-2}) → Energy per hailfall.

Es (J.m^{-2}) → Energy per station, per year.

FIG.1: Mean regional values of F, Eh and Es in France.

The frequency has its highest values near the Pyrenees (mountain range effect and proximity of the summer Iberian low). The energy per hailfall is maximum in the same region, but it is also high in the central area. The spatial variations of Eh confirm that continental storms are more intense than maritime ones, probably due to differences in convection intensity and in atmospheric nuclei content. The variations of the third parameter, Es = F x Eh, is evidently also maximum in the Pyrenean region.

IV. YEARLY FLUCTUATIONS

Yearly values of F and Eh for the whole of France can be estimated by combining the four areas together (FIG.2). F and Eh have a very poor year-to-year correlation (coefficient r = 0.14), which means that, when there are more storms, they are not necessary more severe.

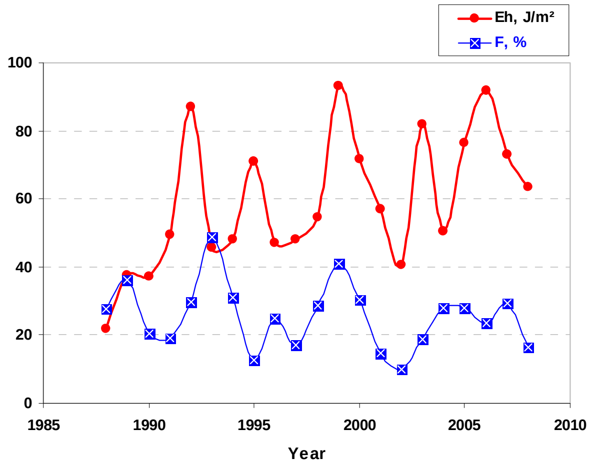


FIG.2: Yearly variations of hail frequency, F, and hailfall energy, Eh, in France

The yearly variations of F shown on FIG.2 suggest that, for the frequency, hail years are more or less organized in a succession of three years with high values followed by three years of low values. With this series of 21 years, it is only possible to have a first look at the autocorrelations between successive years. For the two parameters, the correlations are negative (significant at the 0.5 level) for the pairs (year, year + 3), and negative (significant at the 0.1 level) for the pairs (year, year + 6). One can then suggest that there may be a 6 year periodicity in the frequency of hailfalls in France. Many more years and physical support are necessary to confirm this observation already suggested by insurance data.

Moreover, it is of interest to notice that the yearly values of F are well correlated with the loss-to-risk ratio, R, of the insurance data published by the "Association Internationale des Assureurs Grêle" (AIAG, Zurich). For the 19 years of the 1988-2006 period, the correlation coefficient is r = 0.74, corresponding to a 0.01 significance level. The correlation of R with F is lower, which means that for the insurance companies the number of hailfalls is more important then their intensity.

V. CONCLUSION

With this first 21-year series of continuous measurements in several hailed regions, a physical climatology of hail is developing in France. Some interesting preliminary results are already suggested, like the effect of the air mass origin on the hail intensity or the hail frequency oscillations. A good knowledge of hail climatology would be of interest for the severe storm scientific community, for the insurance industry, and for the general public. Our first results, and the hypothesis that severe convective phenomena may increase in the future, should initiate the organization of a European hailpad network under the ESSL coordination.

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ASSESSMENT OF THE HAIL HAZARD IN SOUTHWEST GERMANY

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I. INTRODUCTION

Severe hailstorms pose a significant and increasing threat to modern societies and their assets. In the federal state of Baden-Württemberg in Southwest Germany, nearly 40% of the total damage to buildings (1986-2008) are related to large hail, with a mean annual loss amounting to almost EUR 50 million. For loss prevention and risk management purposes, comprehensive information about the local probability and intensity of severe hail storms is required. This is a difficult task because hail is not captured accurately and uniquely by a single observation system. By combining 3D reflectivity data from a C-band radar with insurance loss data, the constraints inherent in both data sets are assumed to be compensated, enabling high-resolution detection of hail streaks and assessment of the hail hazard (Kunz and Puskeiler, 2009).

II. DATA SETS AND METHODS

Data from the IMK radar located 10 km north of Karlsruhe were used to identify hailstorm tracks and intensities between 1997 and 2007. To consider severe hailstorms only, a lower threshold of 55 dBZ was defined for the maximum radar reflectivity in a vertical column (Hohl et al., 2002). Frequency and intensity of convective cells are determined by applying the tracking algorithm TRACE3D (Handwerker, 2002) to the 3D reflectivity data. The algorithm identifies convective cells by specific radar signatures and follows them in space and time.

To close the gap between radar reflectivity measured at a certain level in the atmosphere and hail occurrence on the ground, insurance loss data (hereinafter: SV data) were additionally used. A building insurance against natural hazards was mandatory in Baden-Württemberg until 1994 and offered exclusively by a monopolist. Hence, the data are characterized by a high areal coverage and consistency. Hailstorm tracks as determined by TRACE3D are merged with SV loss data using a geographical information system (GIS). A total of 65 days with damage-causing hailstorms were considered in the study.

III. RESULTS

A. Hailstorm Tracks

Significant spatial differences in hail climatology can be derived from the track density displayed in Figure 1. Highest density is found over the agglomeration of Stuttgart, whereas the activity is lowest over the two mountain chains of Black Forest and Swabian Jura as well as over the northern parts of the study area. A striking feature is the sharp gradient in track density at the northwestern edge of the Swabian Jura, where most of the cells proceed approximately parallel to the mountain ridge. It is obvious that orography play a decisive role for the spatial distribution of hail occurrence.

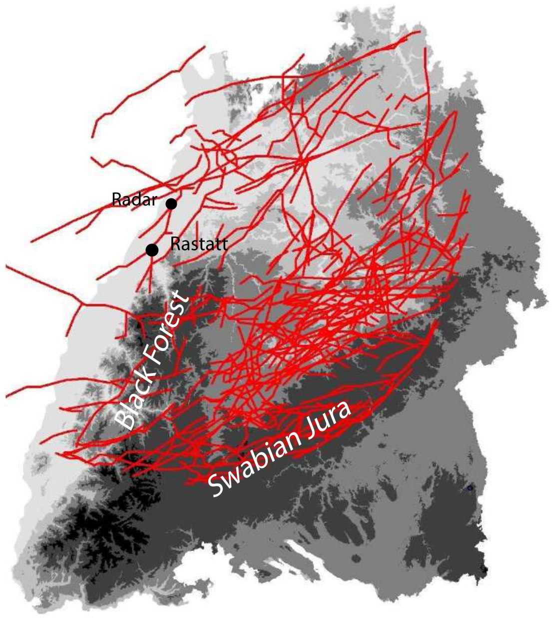

FIG. 1: Tracks of hailstorms ($Z > 55$ dBZ) according to radar data between 1997 and 2007. Only tracks that were related to damage to buildings according to SV data are displayed.

The majority of hailstorms proceeds from southwest to northeast, which corresponds more or less to the mean wind direction in the middle troposphere according to sounding data at the station of Stuttgart. In most cases, the tracks have a length of more than 70 km. Given a mean wind speed of 15.1 ± 6.5 m s^{-1} between 700 and 500 hPa for the days considered, this yields a persistence in excess of 1 or 2.5 hours, respectively. Note that during this time span, the convective cells exhibit a radar reflectivity above 55 dBZ. Assuming additional time scales for development and dissipation in the order of 30 min each, it may be inferred that damage-related hail usually is associated with organized convection like multicells, supercells, or mesoscale convective systems. This finding is supported by the fact that substantial vertical wind shear, a prerequisite for organized convective systems, was present on most of the hail days.

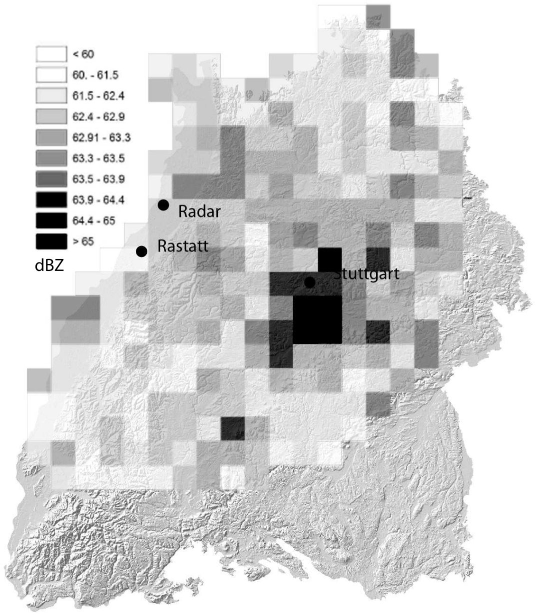

FIG. 2: Radar reflectivity in dBZ for a 1-year statistical return period projected on a 10×10 km^2 grid.

B. Hail Hazard Assessment

In order to consider not only the number of hailstorms, but also the intensity related to probability, extreme value statistics was applied to the radar data. To ensure a sufficient number of events for the samples, the analyses were performed on a 10×10 km^2 grid. For each grid cell, maximum radar reflectivity was determined on each of the selected 65 hail days. If a grid cell was hit more than once by hail on the same day, the highest radar reflectivity only was selected for the sample to ensure statistical independence of the events. The samples in the different grid cells comprise between 10 and 50 events.

As shown in Figure 2, the radar reflectivity for a one-year return period varies between approximately 60 and 65 dBZ within the study area. For the interpretation of the results, it should be borne in mind that radar reflectivity in dB is a logarithmic unit. The results closely resembles the density of hail tracks. This applies to the spatial variability of hail activity as well as to the location of the minima and maxima. Accordingly, in regions, where hailstorms are rare events, like the Rhine valley of Black Forest and Swabian Jura, storm intensity is also low on average. Conversely, over regions, where hailstorms occur frequently like the region south of Stuttgart, they are also more intense.

From various studies it is well-known that the orographic structures of the Black Forest favor the development of deep convection. After triggering, convective cells are advected approximately with the mean wind, while they are intensified further. This advection hypothesis may partly explain the high density of thunderstorms downstream of the mountains of the Black Forest, i.e. the region around Stuttgart, but not their high intensity.

Analyses of radiosounding data on the selected hail days revealed a low Froude number, which is defined as $Fr = U/(NH)$, where U is the wind speed perpendicular to the mountains, N is the static stability, and H is the characteristic mountain height (approx. 1.000 m). It is assumed that in the low Froude number flow ($\bar{Fr} = 0.32 \pm 0.15$ in the mean), the air from southwesterly directions tends to go around the southern Black Forest mountains, causing a convergence zone south of Stuttgart that favors the onset or further intensification of deep convection.

IV. CONCLUSIONS

The estimation of hail occurrence and hail hazard at high spatial resolution is a new and innovative task and can be applied for several purposes. The information can be used to identify regions, where prevention and mitigation measures are most effective. Considering the increasing damage by hail due to both, a higher number of intense hailstorms and the increasing vulnerability of buildings and assets, mitigation of damage will become more and more important. As regards to operational weather forecasting, the warnings can be adapted to the present hail hazard. Regions can be identified, where issuing of early warnings is of paramount importance.

The work presented is a first step in assessing the hail hazard at a high spatial resolution. Within the project HARIS-CC (Hail Risk in a Changing Climate) we intend to expand the investigations to a wider area by using radar composites and highly resolved reanalysis data and to analyze trends in hail climatology (see Kunz and Mohr in this abstract band).

V. ACKNOWLEDGMENTS

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The moisture variability during pre-monsoon over Bangladesh

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I. INTRODUCTION

In the northeastern region of the Indian subcontinent, the severe local storms, sometimes associated with tornadoes, damaging hail and strong wind, frequency occur during the pre-monsoon season from March to May (e.g., Peterson and Mehta, 1981, 1995; Goldar et al., 2001). Such kind of the disturbances during the pre-monsoon season cause severe damage almost each year. In climatology, the high density of occurrence of tornadoes is located around Bangladesh and the West Bengal, India. The most high season of tornadoes is in April (Peterson and Mehta, 1995). Recently, high thermal instability and vertical wind shear occur in Bangladesh and the northeastern part of India during the pre-monsoon season (Yamane and Hayashi, 2006). There is great potential for severe local storms during the pre-monsoon season in Bangladesh and northeastern part of India. Meanwhile, such kind of favorable environment for the severe local storms during pre-monsoon is not explained yet.

The region of this study has restrictive observation; especially the upper air observation is limited for analysis of vertical condition. To obtain higher time-resolution of the upper air data, we had carried out the intensive observation period (IOP) of the upper air observation during the period from 20th April to 15th May in 2007. During this IOP, we could have two active phases and one inactive phase. From this upper balloon observation, the passage of upper trough was detected around 4,000-5,000m during the active phase (Kiguchi et al., 2008). The southwesterly in lower troposphere was dominant during active phase. This dominance of southwesterly might produced the increase of moisture during the active phase over Bangladesh.

In this study, the pre-monsoon rainfall phenomena over Bangladesh and the northeastern part of India are investigated using wind and moisture fields by the reanalysis and OLR (Outgoing Longwave Radiation; that indicates the convective activity) data during the period from 1984 to 2007. Also, the moisture field during the pre-monsoon period over Bangladesh in 2007 is investigated using OLR and the reanalysis data during the period from March to May in 2007.

We used the reanalysis dataset to investigate the atmospheric condition widely. Wind and specific humidity data are obtained by the daily mean values of the reanalysis of the National Centers for Environmental Prediction / National

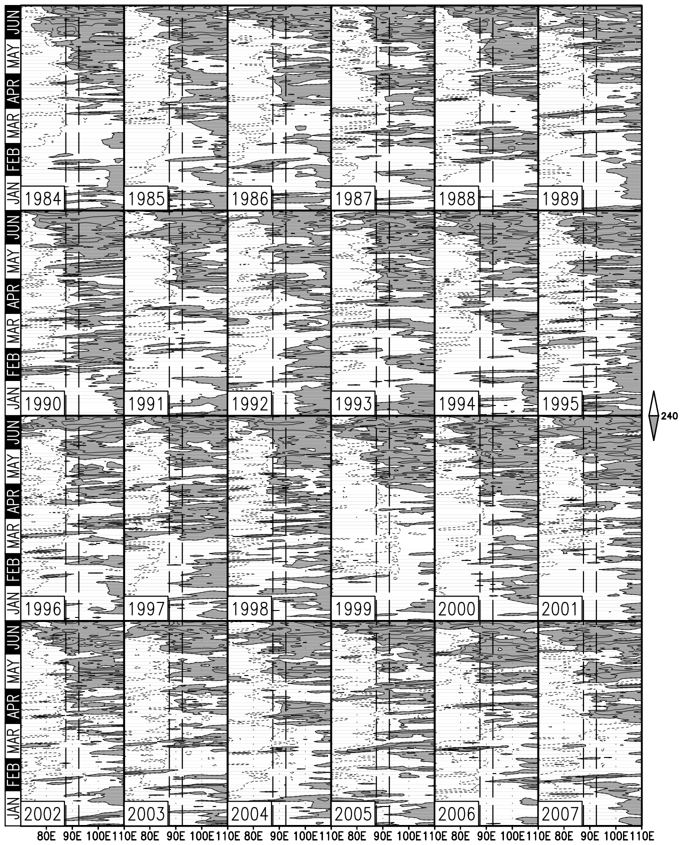

FIG. 1: The time-longitude cross section of area-averaged (22.5°N - 27.5°N) OLR from January to June during the period 1984 to 2007. Shading is less than 240 W/m^2. Dashed line indicates the location of Bangladesh.

Center for Atmospheric Research (NCEP/NCAR) (Kalnay et al., 1996). As an indicator of the convective activity, the daily mean interpolated OLR data provided by the National Oceanic and Atmospheric Administration (NOAA) are utilized (Liebmann and Smith, 1996).

II. RESULTS

According to the time-longitude cross section of OLR over Bangladesh (22.5-27.5°N), the active rainfall activity is seen

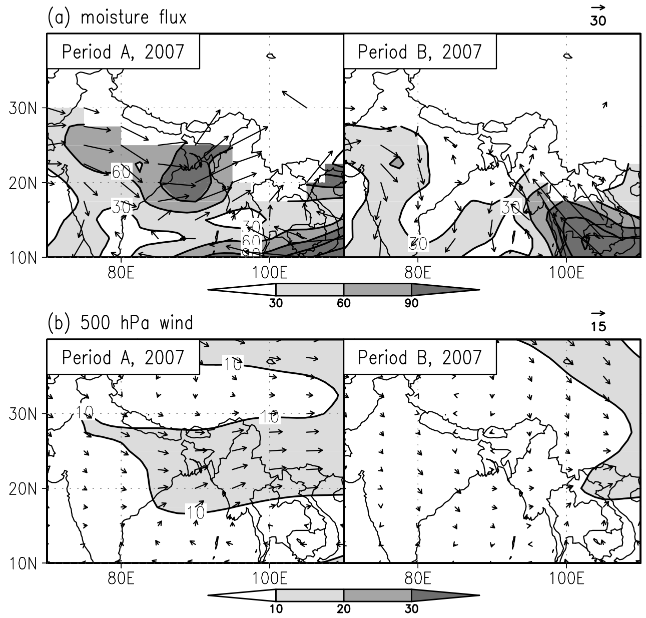

FIG. 2: (a) The composite map of the integrated moisture flux between 925 hPa and 700 hPa during the Period A (left panel) and Period B (right panel) in 2007. (b) The composite map of the wind direction and speed on 500 hPa during the Period A (left panel) and Period B (right panel) in 2007. Shadings of (a) and (b) are more than 30 kg m^{-1} s^{-1} and more than 10 m/s, respectively.

approximately every year before the beginning of June when the averaged monsoon onset occurs (Fig. 1). In addition, it is not seen in the Indian northern part equal to the Bangladesh west in the same latitude zone, however, in the northern part of Myanmar and the southern part of China equal to the Bangladesh east, it is seen the active rainfall activity. It is connected with a rainfall phenomenon of the pre-monsoon period in Bangladesh from the southern part in China, and it is suggested that this pre-monsoon rainfall is a synoptic phenomena. During the rainy season in Okinawa Island and the southern part of China where is located in same latitude of east of Bangladesh, there are the rainfall variability which has active/break phase. The rainfall variability in Bangladesh might affect to that in the southern part of China and Okinawa island.

Concentration of moisture might provide the rainfall activity during the pre-monsoon season in Bangladesh. The horizontal distribution of southwesterly already suggested as considerably brought the increase of a potential temperature and the relative humidity in the lower troposphere from upper air observation in 2007 (Kiguchi et al., 2008). A large lower troposphere integrated moisture flux flows into Bangladesh area from the Indian northern part in period A in contrast with period B when a integrated moisture flux is weak (Fig. 2). The large integrated moisture flux in the northern part of India has already exists, and it is suggested that only the southwesterly from Bay of Bengal is not enough.

III. SUMMARY

In early June, the heavy convective activity appears from Bangladesh to eastward area in almost each year. That means this pre-monsoon rainfall events are synoptic phenomena. The increase of lower tropospheric moisture associated with southwesterly is contributed by the lower tropospheric moisture inflow not only from the Bay of Bengal but also from the northern part of India. The composite analysis in wind system shows the presence of trough located over Bangladesh in upper/middle troposphere. These aspects of phenomena are similar to the case in the inland region of the Indochina Peninsula (Kiguchi and Matsumoto, 2005). In future, we focus to that the rainfall variability in the southern part of China and Okinawa Island be affected by the periodical rainfall activity during pre-monsoon in Bangladesh, or not.

IV. ACKNOWLEDGMENTS

Part of this work is financially supported by the Global Environment Research Fund (GERF) of the Ministry of the Environment of Japan.

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HIGH-LATITUDE MESOSCALE CONVECTIVE SYSTEMS: AN 8-YR CLIMATOLOGY OF SUMMERTIME MCSS IN FINLAND

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(Dated: 15 September 2009)

I. INTRODUCTION

We do not know much about the occurrence of mesoscale convective systems (MCSs) and their synoptic and mesoscale environments in high-latitude areas. This lack of knowledge and understanding becomes concrete as convective weather forecasts fail and the extent and longevity of episodes of deep moist convection surprise forecasters. Although most results from MCS studies in the United States are undoubtedly valid in high-latitude areas, knowing the special characteristics of local MCSs is priceless when forecasting organized deep moist convection. As this study shows, summertime MCSs, which are sometimes even intense, are a frequent occurrence in Finland and nearby regions.

II. DATA AND METHODS

Eight warm seasons (Apr–Sep 2000–2007) of CAPPI composite radar images were manually browsed to find mesoscale areas of convective precipitation. Areas with the maximum dimension of at least 100 km, duration of at least 4 hours, and maximum radar reflectivity exceeding 40 dB*Z* lasting over two hours were classified as MCSs. If maximum reflectivity exceeded 50 dBZ during at least two hours, the MCS was classified as intense. Similar or nearly similar definitions were also used by Punkka and Bister (2005), who studied two warm seasons of CAPPI data in Finland, and by Geerts (1998), who surveyed the occurrence of MCSs in the southeastern United States.

In this study, duration is not the same as lifetime because of the limited size of the study area. Thus, an MCS can form and/or decay beyond the range of the Finnish radar network.

This MCS definition allows fairly weak mesoscale precipitation areas to be classified as MCSs, which partly explains their frequent occurrence. Most non-intense MCSs do not cause damage, and many of them do not even produce lightning. However, the definition is consistent with earlier radar studies on MCSs (e.g. Geerts 1998; Parker and Johnson 2000) and with the general MCS definition by Houze (1993). To demonstrate the variety of MCSs included in this study, Fig. 1 shows an example of a typical non-intense MCS, an intense well-organized MCS, and an intense but poorly organized MCS.

III. RESULTS AND CONCLUSIONS

Over 200 MCSs were found on average each year out of which one third were intense (Fig. 2). Only 10–20% of the MCSs were intense in spring, but 53% were intense in July (Fig. 2).

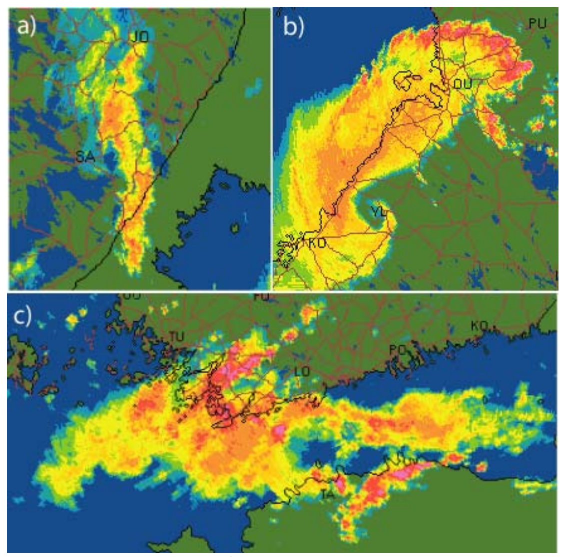

FIG. 1: Radar imagery of a) a typical non-intense MCS, b) an intense and well-organized MCS, c) an intense but poorly organized MCS. (Red 40–50 dBZ, violet > 50 dBZ)

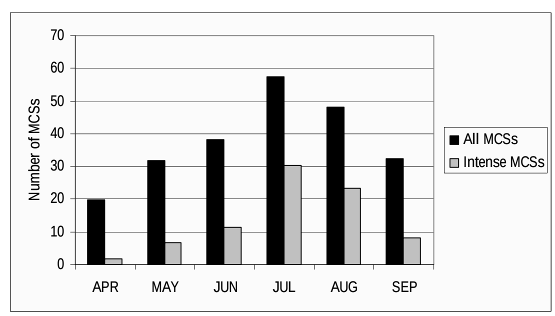

FIG. 2: Average number of all MCSs and intense MCSs in Finland 2000–2007.

The average duration of all MCSs was 10.7 hours, with durations of 4–5 hours being most common. The mid-summer (Fig. 3) and afternoon MCSs were shortest-lived (9–10 h), whereas spring and nocturnal systems lasted a couple of hours longer (12–13 h).

Most MCSs reach their maximum intensity during afternoon, early evening, or morning. The afternoon peak mainly consists of intense MCSs and the morning peak of non-intense MCSs (Fig. 4). Although the afternoon peak coincides with the time of maximum heating, why the morning peak occurs is less certain, but this agrees with results from the United States (e.g. Geerts 1998) and results from studies on mesoscale convective complexes, MCCs

(Laing and Fritsch 2000). However, a one-to-one comparison of non-intense MCSs and MCCs is not possible.

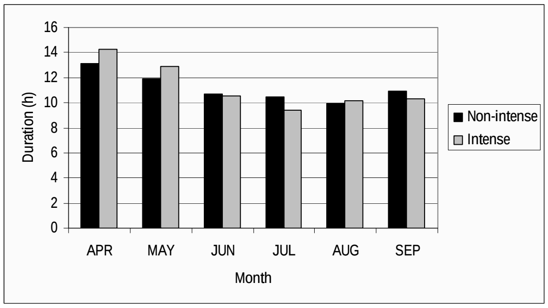

FIG. 3: Average duration of non-intense and intense MCSs in Finland 2000–2007.

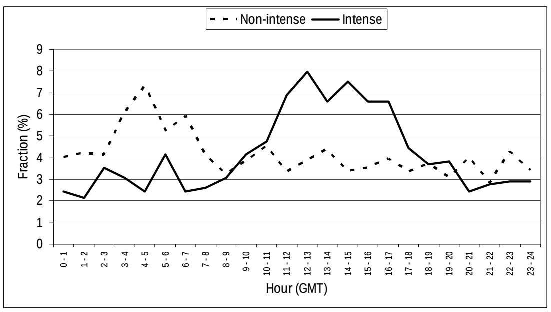

FIG. 4: Distribution of time of maximum intensity for non-intense and intense MCSs in Finland 2000–2007. Local time is GMT + 3 h.

Although half of the MCSs that developed during afternoon became intense, only a quarter of those that developed during the night became intense (Fig. 5). The gap between the time of initiation and maximum intensity was 3 h for intense afternoon systems and 6 h for intense nocturnal systems.

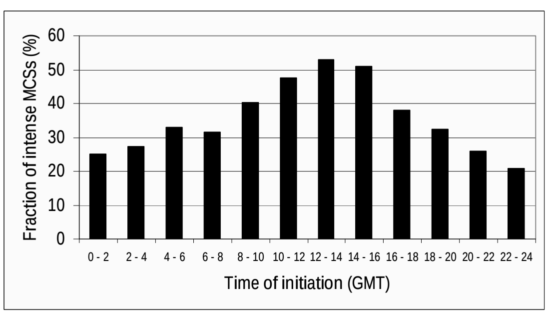

FIG. 5: Fraction of intense MCSs as a function of time of initiation.

A notable fraction of the intense MCSs developed south of Finland or entered the study area from the south (not shown). Moreover, the most common direction of system movement was northeast. For linear systems, southwest–northeast, south–north and southeast–northwest line orientations were most common (Fig 6).

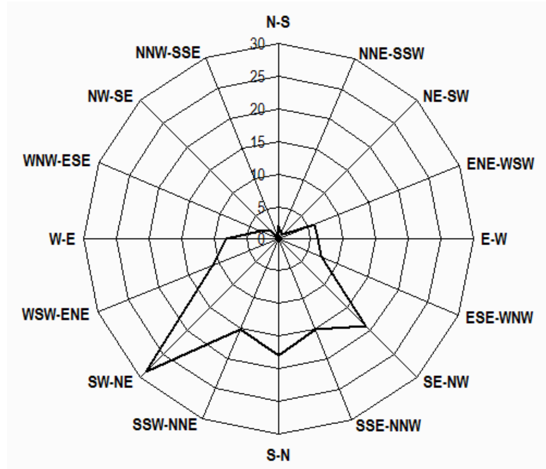

FIG. 6: Distribution of the line orientation for linear MCSs in Finland in 2002–2007. A S–N-oriented line moves toward the east and a N–S-oriented line moves toward the west.

MCSs in Finland can produce wind damage, large hail, tornadoes, or flash floods. Knowing the statistical behaviour of convective systems over a certain area may help in MCS forecasting in general. However, issuing forecasts or warnings in an occasional weather situation will still rely on an understanding of the synoptic, mesoscale and storm-scale environments. Therefore, studying the synoptic and mesoscale environment favourable for MCS development is the next inevitable step to take on the way toward improved MCS forecasts in high-latitude regions.

IV. ACKNOWLEDGMENTS

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SYNOPTIC CLIMATOLOGY OF TORNADO ENVIRONMENTS IN FINLAND

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I. INTRODUCTION

Setting up an effective tornado warning process, requires, among other aspects (e.g., Rauhala and Schultz 2009), knowledge of the environments favourable for tornadic storms. Recognizing such a weather pattern may help to forecast the potential for severe weather days in advance. If storms develop in an environment favourable for tornadoes, tornado warnings may be issued significantly in advance, compared to if only radar detectable severe storm signatures or spotter reports are used.

Although severe-storm forecasting parameters have been widely used in forecasting, they have many weaknesses (Doswell and Schultz 2006). A better approach to forecasting deep moist convection and its associated severe weather is through the ingredients-based approach. To best prepare forecasters for 1–3-day forecasts of severe-weather potential, forecasters will want to know the most common ways that these ingredients are brought together for a given region. The purpose of this paper is to determine what weather patterns bring together the ingredients for convective storms that produce tornadoes in Finland.

II. DATA AND METHODS

We used a climatology containing 253 tornadoes and 184 tornado days in Finland (1948–2007). The environment of each tornado day was characterized by data from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalyses (Kalnay et al. 1996) plotted from the Web page at the Physical Sciences Division (PSD) of the NOAA/Earth System Research Laboratory. For each tornado day, the reanalysis data at the time (0000, 0600, 1200 or 1800 UTC) preceding the first tornado observation was used. For each tornado day, 300-hPa, 500-hPa, 850-hPa and surface maps were produced, and they were clustered manually into four distinct tornado environments, plus an unclassified category (Doswell 1991).

To produce composite synoptic maps, the PSD Web page was used to create composites from the NCEP–NCAR reanalyses. For the synoptic composite figures presented in this paper, we used only the significant (F2+) tornadoes of each class. Observed tornado locations of significant tornado days are plotted on the figures.

III. SYNOPTIC PATTERN COMPOSITES

a. Class A synoptic pattern

The most common tornado environment is Class A with 27% (50) of the 184 all-tornado days in Finland. This pattern included 33% (10) of the 30 significant-tornado days. The pattern is characterized by a westerly or southwesterly 300-hPa jet southwest of Finland (Fig. 1). The tornadoes form in the jet-exit region. An 850-hPa low-level jet stream is parallel to the upper-level jet. A 500-hPa large-scale trough is situated over Scandinavia or the Norwegian Sea. An area of low surface pressure is west of Finland resulting in strong west to south surface winds.

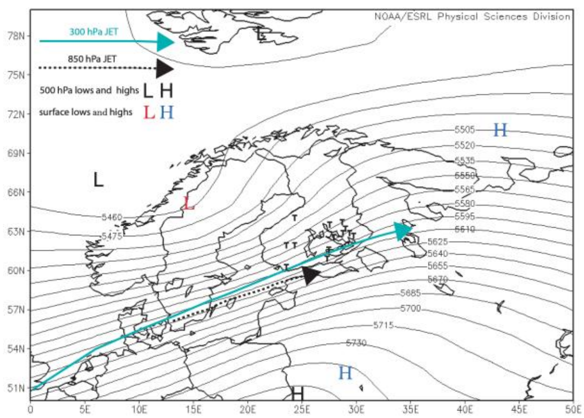

FIG. 1: Class A synoptic composite chart. Solid lines are the composite mean of 500-hPa height. Tornado locations during significant-tornado days in this class are denoted by T.

b. Class B synoptic pattern

The second pattern includes 13% (24) of all-tornado days and 20% (6) of the significant-tornado days. It is characterized by a strong low both at surface and at 500 hPa, south or southwest of Finland, resulting in easterly or southeasterly flow at both heights (Fig. 2). The primary feature of this pattern is a southeast–northwest-oriented 300-hPa jet axis slightly south of the tornado area. At 850 hPa, a southeasterly low-level jet stream advects warm air from Russia to the tornado area.

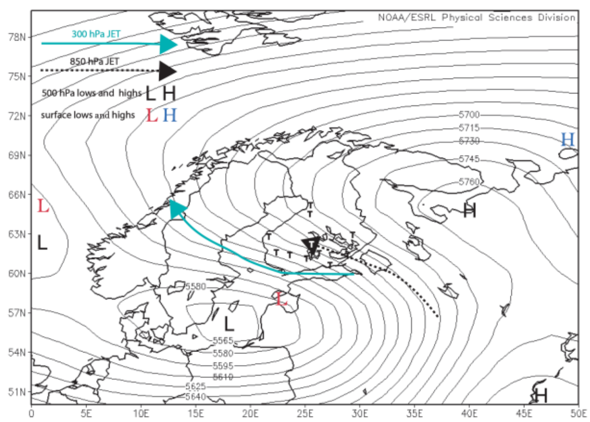

FIG. 2: As in Fig. 1, except for Class B synoptic composite chart.

c. Class C synoptic pattern

The Class C pattern includes 11% (21) of all-tornado days and 10% (3) of significant-tornado days. The tornadoes form in the 300-hPa jet right entrance region, west of the southerly or southeasterly low level jet (Fig. 3). A 500-hPa large-scale trough is situated west of Finland at the Norwegian Sea or Scandinavia, and the surface low center is west of Finland often with a secondary low just southwest of the tornado area. Also, a tongue of warm 850-hPa air travels from the south and southeast to southeastern Finland.

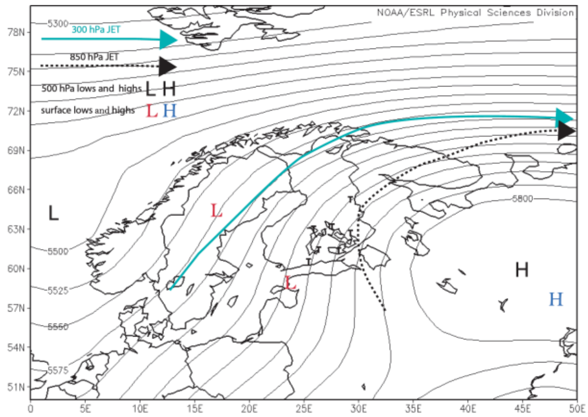

FIG. 3: As in Fig. 1, except for Class C synoptic composite chart.

d. Class D synoptic pattern

This pattern includes 7% (13) of all-tornado days and 10% (3) of significant-tornado days. This pattern is similar to Class A as the tornadoes form in the left-exit region of the westerly 300-hPa jet (cf. Figs. 1 and 4). The major difference is in the 500-hPa flow, which features a large-scale trough west of Finland in Class A and zonal flow in Class D (Fig. 4). Also, the 850-hPa wind maximum is located further south of the tornado area in Class D compared to Class A. The tornadoes form close to the rapidly eastward-moving surface low.

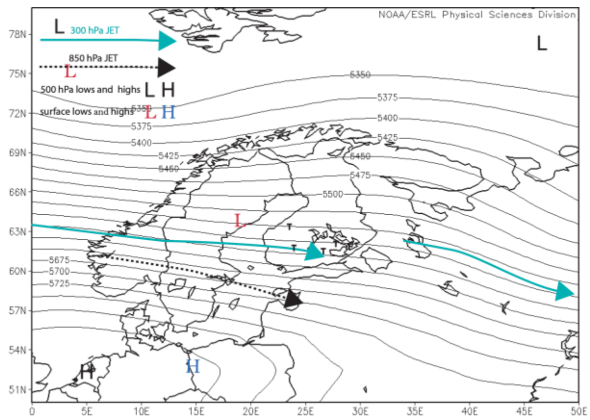

FIG. 4: As in Fig. 1, except for Class D synoptic composite chart.

IV. CONCLUSIONS AND RELATIONSHIP TO OTHER CLASSIFICATION SCHEMES

These four patterns classify 73% (22) of the 30 significant-tornado days in Finland since 1948, leaving 27% (8) cases unclassified. When all-tornado days are included, the number of unclassified cases increases to 41% (76) of all 184 cases. One explanation is that many of the weak tornadoes in this study have likely formed within non-supercell storms, which can form in a large variety of weather situations.

If we compare these four patterns to those observed in the United States (Miller 1972), most U.S. patterns show a much clearer wind veering with height than our patterns. Only in the Class C (Fig. 3) composite does the wind veer with height in the tornado formation area. The Class C pattern has similarities with Miller's Type B tornado-producing pattern as both have a low-pressure centre, a major upper-level trough and a frontal boundary west of the tornado area. The Class C tornadoes occurred in the right-entrance region of a jet streak, which supports both a low-level jet and synoptic-scale ascent.

The Class B pattern has similarities with Miller's Type D pattern with warm low-level air underneath a cold 500-hPa low, although our Class B pattern is rotated 45˚ counterclockwise relative to Miller's Type D pattern.

Both our Class A and Class D patterns are similar to Miller's Type E tornado-producing pattern with westerly 500-hPa flow and a surface low centre northwest of the tornado area. The Class A and Class D tornado cases occurred in the exit region of a 300-hPa jet streak, where the jet-streak circulation is associated with a low-level jet (Uccellini and Johnson 1979). According to Rose et al. (2004), based on their 10-yr climatology in U.S., tornadoes occur primarily in the jet-exit region, more commonly in the left-exit region than right-exit region.

The cases in Class A and Class C occurred in an upper-level southwesterly flow in front of an approaching 500-hPa trough. Similar results have been found by Rogash and Racy (2002) in significant tornadoes occurring in proximity to flash flooding.

V. ACKNOWLEDGMENTS

The composites were provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their Web site http://www.esrl.noaa.gov/psd. David Schultz is partially funded by Vaisala Oyj.

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A Tornado And Waterspout Climatology For Greece

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I. INTRODUCTION

Tornadoes were generally neglected in the climatological records of Greece, considered as very rare events or of an anecdotal character. Except some academic references and very few articles including reports of a waterspout case and a remarkable fish rain event, there was not any essential tornado research and literature (Livadas, 1954; Kanellopoulos, 1977; Flocas, 1992). A systematic recording of tornado and waterspout occurrence has been started in Greece from the year 2000, in an attempt to develop a reliable and possibly comprehensive database (Sioutas, 2002 and 2003; Sioutas and Keul, 2007). Data originate from various sources, including eyewitness, site investigations, mass media, administrations and damage reports to crop and infrastructure. This database has already completed 10 years of data, that are used to define a preliminary climatology of tornado and waterspouts for Greece.

II. PRESENTATION OF RESEARCH

A number of about 250 tornado and waterspout events were catalogued during the 10-year period 2000-09, in a total of 145 days, in Greece. These data result to a yearly average of 14.5 days of tornado and waterspout activity or a yearly number of about 1.1 day per 10,000 km^2, suggesting a rather high frequency of tornado events between European countries (Dotzek, 2001; Paul, 2001; Tyrell, 2003; Giaiotti et al., 2007).

As it can be seen in Figure 1, the number of tornado and waterspout days fluctuates largely from year to year of the examined data sample. An upward trend line is evident, primarily attributed to an increasing tornado reporting coupled with enhancing public awareness and systematic recording, rather than representing an actual increase in the annual frequency of tornadoes and waterspouts.

FIG. 1: Yearly distribution of tornado and waterspout days in Greece, upon 10-year data (2000-2009).

The geographical distribution of tornado and waterspout day number is plotted in Figure 2, where the total day number is indicated (circles) for greater than 3 days. Although tornadoes can occur everywhere, however the 10-year database reveals that they are more frequent over the western Greece and the Ionian coasts with a maximum located over northwest Peloponnese. Over this area, namely the Elias prefecture, a total of 13 tornado and waterspout days was recorded in the 10-year period. Considering waterspout activity, although it seems also high for the Ionian Sea, however, a significant local maximum is located in the southern Aegean Sea, over north off coast of Iraklion, Crete Isl., with a total of 23 waterspout days and about 70 waterspouts recorded during the 10-year period. Considerable outbreaks with a total of 13 waterspouts on 5 September 2002 and more than 20 waterspouts on 21 September 2006 were also observed in this area (Keul, 2003; Keul et al., 2009).

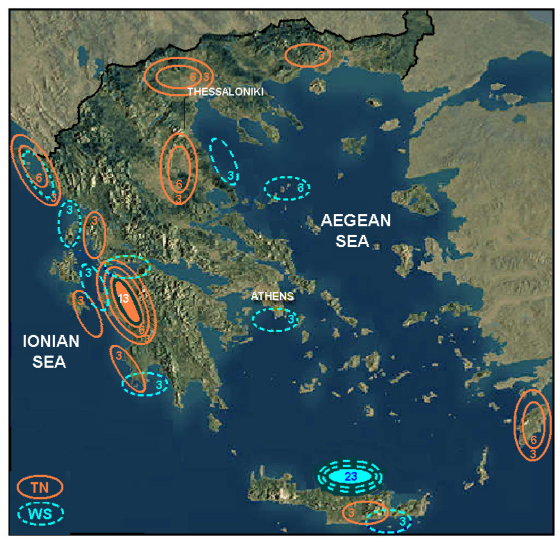

FIG. 2: Tornado and waterspout day distribution in Greece for total number of occurrences above 3, upon 10-year data (2000-2009).

Geographical effect in tornado formation and intensification is expected, considering the complexity of Greek territory. Spatial analysis showed that tornadoes are more frequent in coastal and flat areas than over rough areas. Waterspouts are mainly recorded near or in small distances from the coasts that is primarily related to the ability to observe and record it, than in the open sea.

The monthly totals of tornado and waterspout days along with the tornado and waterspout numbers are graphed in Figures 3a,b. July is the highest frequency month in both tornado days and tornado number (Fig. 3a). Tornado days are similarly distributed from November to March, however, July, January and November is the monthly ranking for tornado number. July is a month characterized by atmospheric instability for northern Greece, while November and January are related with instability for western and southern Greece. Considering waterspout days (Fig. 3b), their majority is appearing in the fall months, with September dominating in both waterspout days and number, a feature primarily related to the warmer sea surface temperatures of this period.

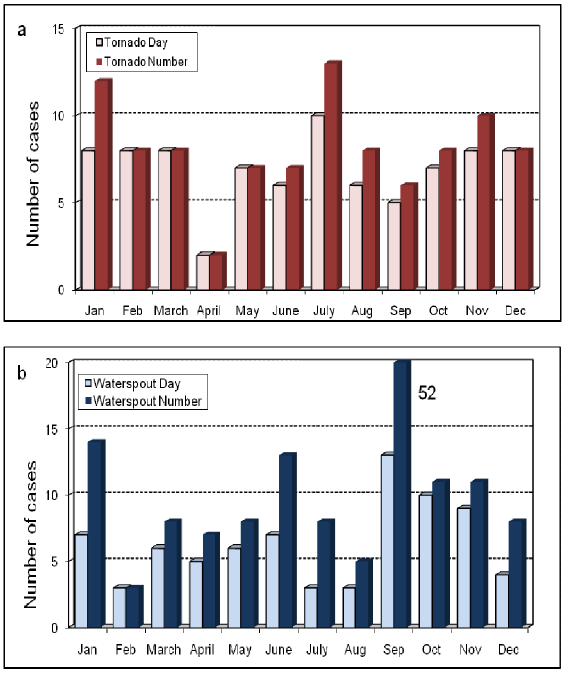

FIG. 3: Monthly tornado and waterspout activity distributions upon 10-year data (2000-2009) for Greece: a) tornado days and tornado number, and b) waterspout days and waterspout number.

Considering seasonal distributions as they displayed in Figure 4, tornadoes and waterspouts are recorded in all seasons of the year in Greece. A clear tendency is evident, for waterspout days to be maximized in fall, while tornado days appear their maximum activity in winter and summertime.

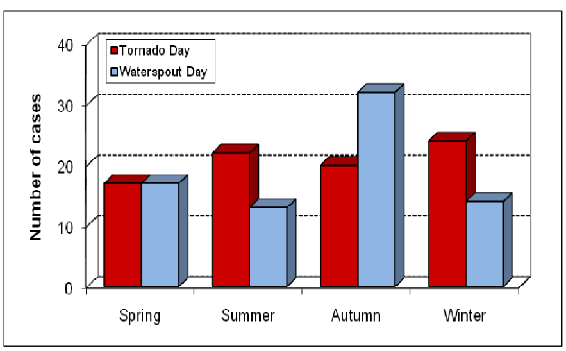

FIG. 4: Seasonal distribution of tornado and waterspout days for Greece, upon 10-year data (2000-2009).

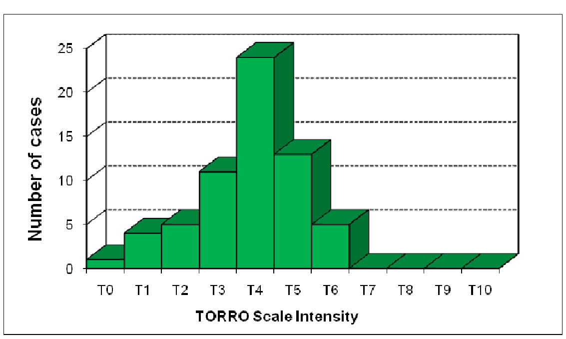

FIG. 5: Intensity distribution for Greek tornadoes by using of the T-scale, upon 10-year data (2000-2009).

Intensity analysis based on a data subset for which tornado intensities could be assessed (Fig. 5), indicated that, the majority of about 39% of the cases, reached at T4 of the TORRO scale or F2 of the F-scale.

III. RESULTS AND CONCLUSIONS

A preliminary climatology of tornadoes and waterspouts for Greece is defined in this work, based on a 10-year database (2000-2009). These data suggest to a yearly average of 1.1 tornado/waterspout days per 10.000 km^2. Spatial distribution showed that tornadoes are more frequent over the western Greece and the Ionian coasts with a local maximum of tornado days located over northwest Peloponnese. Waterspout maximum activity is located over north off shore of Iraklion, Crete. Monthly and seasonal distributions showed some differences for various parts of Greece, with winter as the most active tornado season for western Greece and summer for northern Greece. July is the highest tornado frequency month, in both tornado days and tornado number observed. Waterspouts occur in the Aegean and the Ionian Sea mostly in late summer and autumn, with a peak in September.

Analysis based on intensities as assessed by damage data, indicated that the majority of tornadoes reached at T4 of the TORRO scale or F2 of the F-scale. Further climatological research is necessary, with the effort for quantitative and qualitative improvement of Greek tornado database remaining as a challenge and priority.

IV. AKNOWLEDGMENTS

The author would like to thank anonymous people, weather amateurs, mass media and authorities for providing tornado and waterspout information.

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TRENDS IN HAILSTORM FREQUENCY AND ATMOSPHERIC CHARACTERISTICS IN SOUTHWEST GERMANY

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(Dated: September 18, 2009)

I. INTRODUCTION

In light of global warming (IPCC, 2007), the question arises whether any evidence suggests an increase in severe thunderstorms either in number or intensity. This question is difficult to answer, because current surface observation systems are too coarse to capture all convective events. A way to overcome the problem of insufficient observations is an approach that links thunderstorm occurrence to large-scale atmospheric conditions. Changes in both the synoptic-scale circulation patterns and atmospheric stability are assumed to have a direct influence on the intensity or the number of thunderstorms. The purpose of the study is to examine whether there are any trends in the atmospheric conditions detectable suggesting alterations in the frequency of hailstorm occurrence in the last decades. The study area is Baden-Württemberg in Southwest Germany, where hail is responsible for nearly 40% of the total damage to buildings.

II. DATA SETS AND METHODS

To obtain complementary information about days with severe thunderstorms and a high convective potential of the atmosphere, data sets from different observation systems were combined. Synoptic station data (1949-2003) were used to quantify the number of thunderstorm days according to visible lightning or audible thunder as registered in the past and present weather code. Data relating to losses from a building insurance company between 1986 and 2008 were taken in order to estimate the annual variability of loss and hail days. The data were inflation-adjusted and corrected for the annual variability of the portfolio. Large-scale weather patterns based on the objective weather type classification from German Weather Service (DWD) are related to hail days as detected by the insurance loss data (not discussed here). Finally, several convective indices derived from radio-sounding data at the station of Stuttgart are used to investigate possible long-term trends in atmospheric static stability from 1974 to 2003.

In all examinations the summer-half year (April-Sept) is considered only, where hail occurs almost exclusively.

III. RESULTS

To investigate the annual variability of hail events, all days with hail occurrence in the whole observation period irrespective of the location and the amount of loss was determined

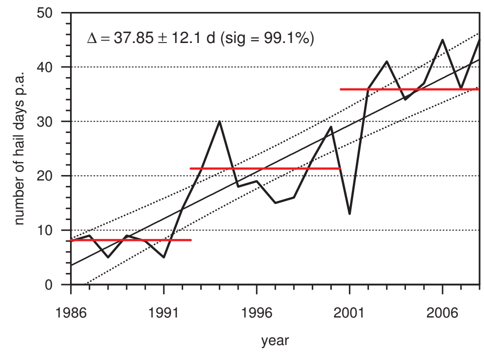

FIG. 1: Number of hail days per year according to damage reports of the SV building insurance company. If on a day a threshold of 10 claims is exceeded, it is defined as a hail day; indicated is the linear trend with 95% confidence intervals and 8-year averages as horizontal bars.

from the insurance data. A day was classified as a hail day when a lower threshold of 10 claims was reached on a day, yielding 23 hail days on average. As can be seen in Figure 1, there is a strong increase in the number of hail days per year over the last decades. According to the trend-to-noise ratio and t-statistics, the linear trend indicated is significant on the 99% level. In contrast, the number of thunderstorm days detected at the synoptic stations confirm the high annual variability in the occurrence frequency, but not a trend.

Hence, the rising number of hail days and claims may be attributed to two different scenarios concerning atmospheric stability: the number of days with a potential for deep convection could have increased and/or atmospheric instability on thunderstorm days could have increased. To examine the two possible scenarios separately, the analyses of the convective indices is based on the number of days per year above a certain threshold according to the study of Kunz (2007) and different percentiles of the respective convective index. An example is shown in Figure 2 for the convective available potential energy (CAPE). Both the number of days above certain thresholds and the different percentile values show a significant increase in the past decades (sign. level of 95%).

Considering the large variety of convective indices, it is found that all indices determined from temperature and moisture of the lowest layers show an increase in both extreme values and the number of days above/below certain thresholds (Fig. 3). In contrast, indices based on levels above the surface exhibit either a negative or no significant trend. A relationship can be established between the number of hail days according to insurance data (Fig. 1) and all indices with a positive

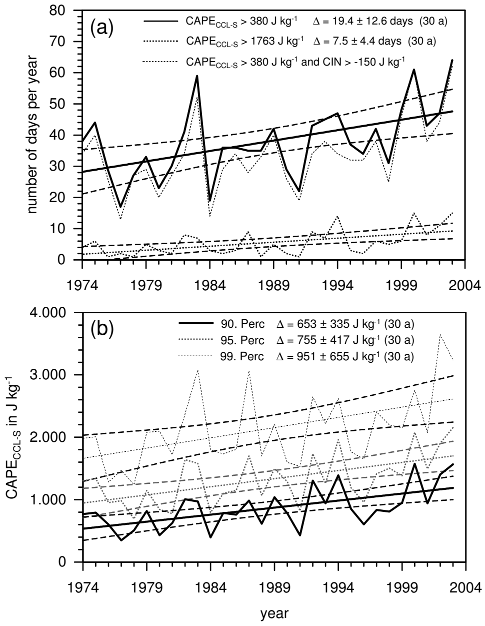

FIG. 2: Time series of different percentiles of the CAPE (a) and number of days per year above two specific thresholds (b) with 95% confidence intervals.

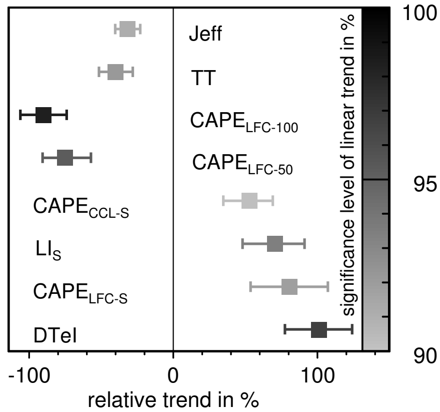

FIG. 3: Relative linear trends of the number of days per year above / below a thresholds of the convective indices where thunderstorms are expected (1974-2003) with 95% confidence intervals.

trend, yielding correlation coefficients between 0.74 and 0.8. This means that more than 55% of the annual variance of the damage-related hail days can be explained by the convective indices and, hence, by an increase of days with an unstable atmosphere.

The different trend directions of the convective indices is due to a strong increase of temperature and moisture in the lowest layers, and only marginal or even reverse trends aloft. The increase in wet-bulb potential temperature indicates the presence of warmer parcels throughout the whole troposphere during convection.

IV. CONCLUSIONS

The examinations provide some evidence suggesting an increase in hailstorm intensity and probability. Whereas thunderstorm occurrence remained constant in the last decades, severe thunderstorms associated with hail show a significant increase, in particular due to an increase in temperature and water vapor at near-surface levels.

However, the reasons for the opposing trends observed on lowest and higher levels in the atmosphere, in particular that of moisture, are not yet fully understood. One plausible physical argument is that air masses of the free atmosphere likely have their source over the Atlantic, where global warming exhibits a certain time delay due to the damping effect of the ocean. On the other hand, air parcels within the planetary boundary layer are altered by exchange processes between the land surface, which is strongly modified by global warming, and the atmosphere. This hypothesis is supported by the fact that the surface-based relative humidity shows no trend at all as also suggested by global or regional climate models.

Even if our analysis provides an indication for an increase of severe thunderstorms in the past decades, these trends cannot be extrapolated into the future. Within the scope of the project HARIS-CC (Hail Risk and Climate Change), the investigations will be extended to Central Europe by examining in detail the prevailing atmospheric conditions from highly resolved re-analysis data and from an ensemble of regional climate models.

V. ACKNOWLEDGMENTS

The authors thank the SV Sparkassenversicherung for providing detailed insurance data and the DWD for providing station and radiosounding data. The work is partly funded by the Center for Disaster Management and Risk Reduktion Technology (CEDIM).

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Thunderstorm-related extreme weather in Armenia

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I. INTRODUCTION

The monitoring of severe convective weather from severe thunderstorms with hail, straight-line winds, tornadoes, flash floods, and lightning is very difficult due to its local character. Armenia is a climatically diverse region. About 90% of all territory has height more than 1000m above sea level and 40% of the territory has more than 2000m above sea level. The average level of territory is 1830m, the maximum height is about 4090m, the minimum is about 373m.

The climate varies both vertically and horizontally. Various climate zones, everlasting snow caps and glaciers, warm humid subtropical forests and humid semi-desert steppes.

The average annual temperature for the territory of the republic is 5.5 0C, the absolute maximum temperature +43 0C, and minimum -42 0C..

Eighty meteorological stations worked in the territory of the RA in different periods of time, dynamics of their quantity adjustment are set forward. Now the meteorological network of Armstatehydromet consists of 45 meteorological and 3 specialized stations, 5 of which have a series of data for hundred and more years.

Hydrometeorological Dangerous Phenomena (HDP) typical to the territory of Armenia have been studying in this work: flood, hail, abundant precipitation, strong winds. It come obvious the tendencies of their change have been evaluated.

II. PRESENTATION OF RESEARCH

The broken relief, and different climate zone existance on small territory is reason for development of strong convection.

By another hand Armenia is influenced by the western air waves, which are typical of subtropical zone:In summer the territory of Armenia is all influenced by the Middle East heat cyclone, which is more obviously observed in July. With the low pressure of that period the circulation of the atmosphere is weakened. And local processes are produced like convection. The mountenious relief forms active atmosphere circulation, the cold air waves which enter the Southern Caucasia, cross the Caucasian chain of mountains from West or East. Crossing over the Black Sea and Caspian Sae the waves are partly transformed and the amount of humidity was increased.

Researches concerning heavy rain, strong wind, hail and flood for the period 1975-2007 years were made. 46 hydrometerological station's data for 1975-2007 were analysed as well as synoptical and baric maps of surface, satellite images.

The study has shown that the the amount of hailing days during 1990-2009 increased for 2-3 days in compered with 1975-1990. Especially the growth is obvious in north-east region (Lori-Tavush). Along with altitude rising the hail days average quantity also increasing by gradient 1day/200m. The hail, thunder and heavy rain frequency is higher in May-June but most hazardous from July to August, The most hailing time is 13:00-20:00 max at17:00, but in Ararat valey at 19:00-21:00.

Days of heavy precipitations (20mm and more) are increasing all over the Armenia. In 1990-2005 the amount of precipitations increased for 1-3 days in compared with 1975-1990.

In Lori-Tavush, Ararat Valley and Syuniq the growth of precipitations is more obvious 2-4 days. Data analysis on dengerous phenomena make it clear that during the recent years the size of the hail has enlarged.

According to survey results in Ararat region (main agriculture area of Armenia) in the considered period the most frequent disasters wear: heavy rain, hail, landslides and floods.

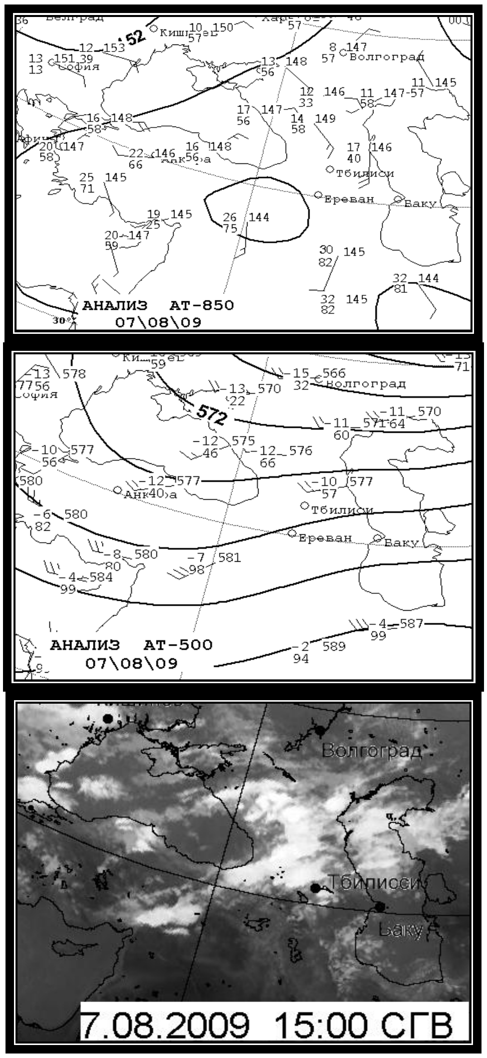
Case study: This year unusually intense hails were recorded in Shirak, Ararat, Lori, Tavush and Sevan areas and caused significant economic losses. August 7th , in Artik in afternoon hail of 5-6 cm was observed, in Tsakhadzor 2,5 cm, in Vanadzor 2,8 cm, in Dilidjan 2,3 cm and in Tashir heavy rain of 30mm/12h.

The synoptic condition was the following.

On see level Armenia was located in the northern part of tropical termal cyclone, from which frontal cyclone is parted towards the Northern parts of Iraq.

In the centre of the cyclone the atmosphere pressure was about 997-998mb. The frontal wave is spread from west to east.It observed the pressure fall by 4.8-5mb/3h.

On 850mb surface the centre of the cyclone is in Diarbeqir region. The territory Armenia located in the frontal part of the cyclone in the southern streams. The difference of the temperature between west of the Armenia and the Eastern parts of Black Sea was 8-100C.On 500mb surface map the difference of temperature was about 5-6.The analises shown that cold and humid air advection from Asia Minor to the Republic was observed. On satellite images at 20:00 cumulo-nimbus clowds were formed. In all cases of synoptic situation, when Armenia located in the southern streams and cold air there is on east of Black sea, severe convection is developed on second part of day.



The weather condition under influence cold from west

III. RESULTS AND CONCLUSIONS

In this work it is shown that the average amount of hail, straight-line winds, flash floods, and heavy rainfalls was risen. Along with altitude rising the hail days average quantity also increasing by gradient 1day/200m. The most observed hail affected area are Shirak, Lori, Tavush. The severe convective weather frequency is higher in May-June but most hazardous from July to August, The most observed time is 13:00-20:00,max at17:00, but Ararat region at 19:00-21:00. In last years the diameter of hails The observed heavy rain and hail were caused by the appearance of the frontal wave, a difference of temperature on the territory of Armenia and the Black Sea regions on 850mb surface, on 500mb surface high labina, on HT500/1000mb surface with properly expressed frontal zone. Besides all these phenomena, convective activity at noon times was also an important matter for heavy rains and hail. tones has risen, the diameter of hailstones sometimes reaches 6 cm.

IV. ACKNOWLEDGMENTS

I would like to thank all persons who have been involved in this work from observers as well as the scientists. Armstatehydromet's weather forecasting and climatological departments. Without their effort, this work couldn't be completed.

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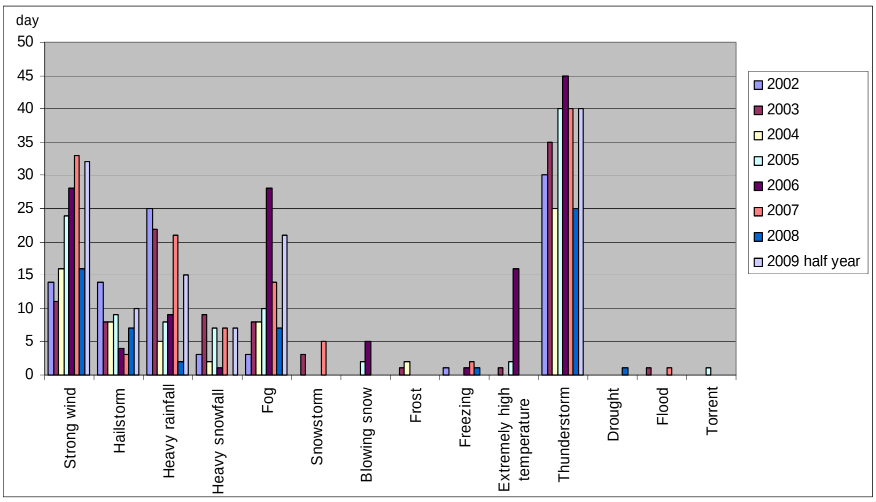

Fig. 1 Main disasters in Armenia during 2002-2009

RELATIONSHIP BETWEEN PRECIPITATION AND WEATHER TYPES IN LEÓN, SPAIN (1948-2008)

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I. INTRODUCTION

Atmospheric pressure is a fundamental variable when carrying out meteorological and climatological forecasts. Since the early twentieth century, when Walker observed the oscillations of the pressure centres of the two hemispheres of the earth, studies have intensified on the North Atlantic Oscillation (NAO).

In recent decades (especially since 1989), a strong increase in the NAO index has been observed on a yearly basis, especially in the months between December and March. The main consequences of this increase in the NAO index are regional changes in the rainfall models (Hurrell and van Loon, 1997).

The rainfall regime in the Iberian Peninsula is highly irregular, on both a spatial and temporal scale (Esteban Parra et al., 1998). In the Iberian Peninsula, a significant decrease has been observed in winter rainfall in the central and western regions (López-Bustins et al., 2007).

The study carried out is focused on finding a relationship between the rainfall registered in León (a city in north-western Spain) and the type of weather in the zone during this period.

II. PRESENTATION OF RESEARCH

In order to reach our objective, we have calculated the type of weather in the study zone between January 1948 and March 2009, using an objective classification method developed by Trigo and DaCamara (2000), which, by using pressure at sea level from 16 points on a grid (Fig. 1), classifies the synoptic situation for each day in one of the 26 possible types of weather (Table I).

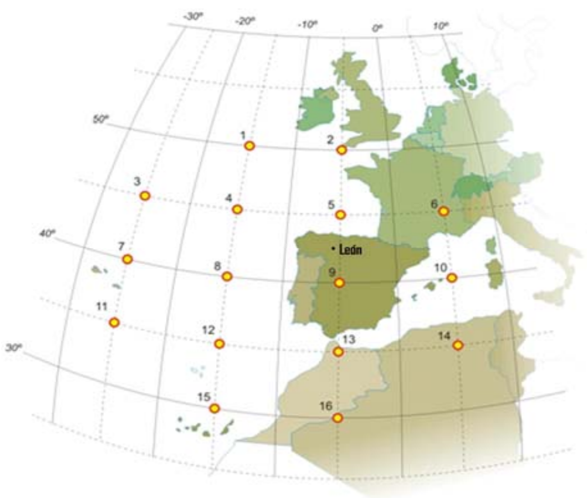

FIG. 1: Location of León. Grid formed by 16 points used to obtain pressure values at sea level.

TABLE I: Classification of the 26 existing weather types.

WEATHER TYPES (26)			
Pure directional	**Non-directional**	**Hybrids**	
North (N)	Anticyclone (A)	AN	CN
South (S)	Cyclone (C)	ANW	CNW
East (E)		AW	CW
West (W)		ASW	CSW
North-west (NW)		AS	CS
South-west(SW)		ASE	CSE
South-east (SE)		AE	CE
North-east(NE)		ANE	CNE

This method is based on the direction and vorticity of geostrophic wind. Based on the pressure values at sea level and at 500 hPa from the 16 points mentioned above, 7 parameters are obtained, from which the weather types shown in Table I are defined.

The study was carried out using daily pressure data at sea level from between January 1948 and March 2009 from the National Centre for Atmospheric Research (NCAR). The rainfall data was provided by the Spanish National Meteorology Agency (AEMET). These are from the weather station located at the aerodrome of La Virgen del Camino, 6 km from the city of León. We have monthly rainfall data from 1948 until 1993, and daily data from January 1994 until March 2009.

III. RESULTS AND CONCLUSIONS

One of the most important results obtained was the fact that the closest relationship between the NAO index and rainfall in León occurs during the winter months (December-March), and so this study focuses on this period.

Firstly, we verified that only 3 weather types ("pure cyclone", "western flow" and "south-west flow") provided 64% of the winter rainfall (from December to March) between 1994 and 2008 (Fig. 2). These results coincide with those obtained by Trigo and DaCamara (2000), in their study of the rainfall regime in Portugal.

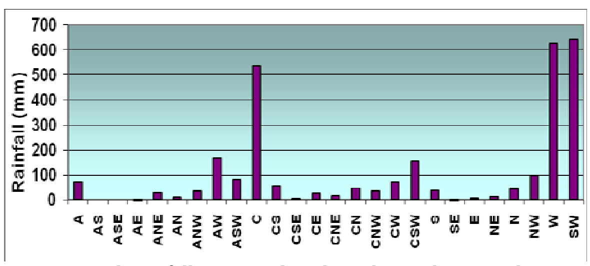

FIG. 2: Total rainfall measured with each weather type between December and March of 1994 and 2008.

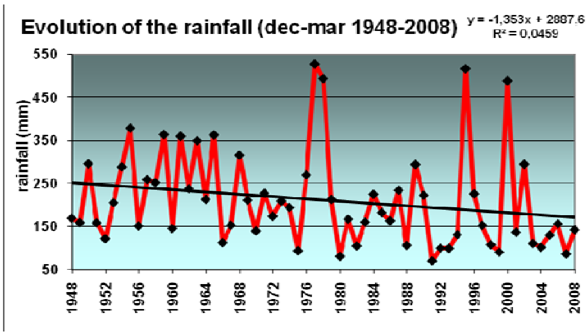

FIG. 3: Descent in rainfall between December and March in León. (1948-2008).

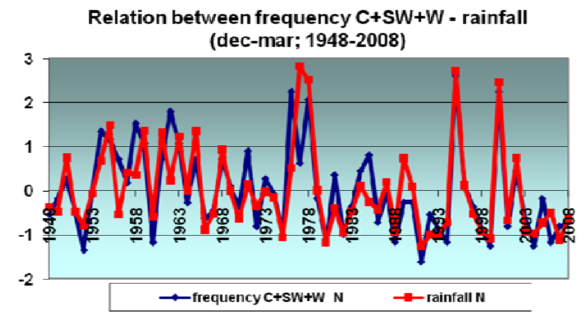

FIG. 5: Relation between the frequency of the 3 rainiest weather types and rainfall between December and March (1948-2008).

The decrease observed in recent years of the frequency of these 3 weather types as a result of the NAO index has led to a decrease in the rainfall in these 4 months (Fig. 3). This descent in rainfall is reflected by a correlation coefficient of -0.21, or more conclusively, that rainfall decreases each winter by 1.4 mm with respect to the previous winter. These results concur with those obtained by Río et al. (2005), for Castile-León.

On comparing the monthly rainfall between the periods 1948-1989 and 1990-2008, we observe major decreases in the rainfall in the months of January, February, March, April, June, July, November and December, while considerable increases are only seen in May, August and October (Fig. 4). We have chosen these 2 periods as from 1989 onwards a clearer increase of the NAO index is seen.

The descent in rainfall between December and March has a strong correlation with respect to the equally strong decrease of the winter frequency of the rainiest types of weather ("pure cyclone", "western flow" and south-west flow) (FIG.5). This correlation is statistically significant (correlation coefficient=0.82).

In turn, the winter frequency of the 3 rainiest weather types is correlated with the winter NAO index, meaning that if we had long-term forecasts of the NAO index expected for the following winter, we could estimate with a relatively low error rate the rainfall that would be collected in León in the following winter.

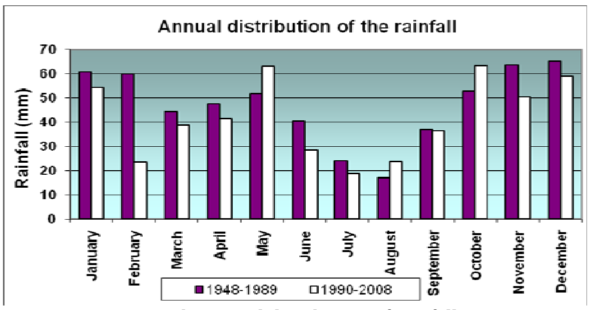

FIG. 4: Variation in the annual distribution of rainfall.

As a result, it is demonstrated that the North Atlantic Oscillation (NAO) is the phenomenon that controls to a large extent the winter rainfall in the west of the Iberian Peninsula.

The strong increase seen in recent decades of the NAO index, higher between the months of December to March, leads to a decrease in the frequency of the 3 types of weather responsible for the majority of rainfall, and as a result a statistically significant decrease in winter rainfall has been observed.

IV. ACKNOWLEDGMENTS

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HAILSTONE-TO-HAILSTORM RELATION IN NORTHERN GREECE

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I. INTRODUCTION

Hailpads constitute the commonest method of hailfall studies on a global scale, both in research and operational programs (Changnon and Towery, 1972; Strong and Lozowski, 1977; Dessens, 1986). Hailfalls in the region of Central Macedonia show a space-time variability, as well as a limited availability of actual observations. A hailpad network, consisting of about 140 hailpads, installed in this area, is used to better display the intensity and areal coverage of hail activity. Objective operational parameters can result from a hailpads examination, like days with hail on ground (hail days) and the number of hailpads hit for each hail day.

II. PRESENTATION OF RESEARCH

Collected pads are checked the day following a storm day to confirm a supposed hailfall. The limits of storms' track are easily extracted with the aid of the radar recording system (TITAN). Hailpad data cover the period 1984-2008, from April to September, with the exception of years 1991, 1994-95 and 2003, that is a total of 21 years. Since the exposure period of the network varied between 126 and 183 days, normalized monthly averages were taken into account for the months of April and May.

Since the limits of the area of study varied from time to time, with a subsequent addition of new hailpads, normalized averages were taken also into account, so that the mean frequency of hail occurrence at the site of each pad represent correctly the years of each pad's exposure. A percentage of 80% of hailpads were exposed for the entire period.

The data used in this study are: the hailfall date, the location of hailpads hit, the number of hailstones on each hailpad hit and the diameter of the biggest hailstone on each pad hit. The storm that produced a certain hailfall was identified with the aid of the digital radar recording system. Physical characteristics of hailstorms were also used, like its maximum reflectivity and maximum top height, as well as the time of storm onset. Seeding data were finally used, namely whether a certain hailstorm had previously been seeded or not. A total of 198 hail days, 369 hailstorms and 1081 hailpads hit was recorded.

The spatial distribution of hail occurrence, normalized according to the years of exposure of each hailpad appears in Figure 1. Five frequency classes are distinguished, and neighbouring sites belonging to the same class are enclosed within the same isopleth. The maximum frequency of hail occurrence is found in the north part of the area, with the absolute maximum to the northwest. The effect of topography is obvious: hail maxima occur in high terrain locations, while minima in plain and coastal areas. Similar results were obtained by Sioutas et al., 2009 in an independent study.

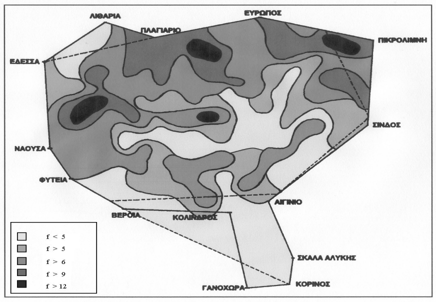

FIG. 1: Spatial distribution of hail occurrence in Central Macedonia, Greece.

Figure 2 shows the time series of the number of hail days for the period of study, in which the dashed line represents the mean value and the continuous line the trend, which is increasing, implying a tendency towards extreme phenomena. A similar distribution and trend was found for the number of hailstorms and of hailpads hit.

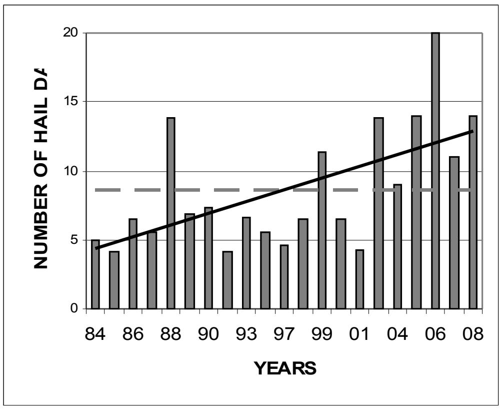

FIG. 2: Yearly distribution and trend of the number of hail days.

The yearly distribution of mean maximum daily diameter of the hailstones shows a decreasing trend. The decreasing trend of the absolute maximum yearly diameter, combined with the slightly increasing trend of the yearly number of hailstones, might imply the effect of seeding. The absolute maximum diameter ever recorded was 34.7 mm. Mean, maximum values and trends are presented in Table 1.

Parameter	Mean	Max	Trend
Number of storms	18	48	Increase
Number of haildays	9	20	Increase
Number of pads hit	51	124	Increase
Number of stones	3440	9525	Slight increase
Maximum hailstone diameter (mm)	23.3	34,7	decrease
Mean maximum daily diameter (mm)	13.9	20,8	decrease

TABLE I. Mean values, maxima and trends of several hail and hailpad parameters.

From the examination of the monthly distribution of the number of hailstorms and of hailpads hit per day, it is concluded that the maximum convective activity occurs in June. From the distribution of the number of stones per pad, per storm and per day, one can state that weaker storms (with a great number of stones, however of small size) occur in April, while the maximum number of hailpads hit per storm occurs in September, when storms are more extended and faster moving (Foris et al., 2006). By examining the monthly distributions of the relative frequency of occurrence of hail days (Figure 3), of hailstorms, of hailpads hit and of the total number of hailstones (all of them having similar distributions), it is concluded that the most frequent and most intense convective activity occurs in June and May, when the atmospheric instability is maximized.

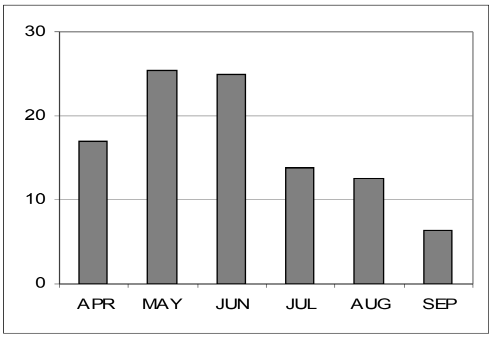

FIG. 3: Relative monthly frequency of hail days.

Since hailpads do not record the time of hailfall, it was decided to record the time of initiation of the hailstorm that produced a certain hailfall. It is reasonable to assume that the time of hailfall occurs 30 to 60 minutes after the time of onset, depending on storm structure and evolution. Its distribution is nearly normal, centred around 15 UTC, which for the warm season coincides with maximum heating, implying that convection plays a key role in storm development, especially for air-mass thunderstorms. Furthermore, it is observed that storms develop also during the early evening hours, in accordance with other findings (Karacostas, 1991). This is partly due to the orientation of certain mountain slopes relative to solar radiation and the duration of this exposure, and partly to cloud destabilization occurring in evening hours owing to radiation emission from cloud tops.

By examining the maximum diameter of hailstones produced by a hailstorm in relation to the storm's maximum reflectivity it is concluded that seeding reduces the maximum diameter of hailstones. This result holds also true for the number of hailstones per storm, and is still verified when the data are stratified in three reflectivity classes, namely Z≤45 dBZ, 45<Z≤55 dBZ and Z>55 dBZ. The effect of seeding is most pronounced in the first two classes, while for the highest reflectivities it is reduced.

In Table 2 the minimum values of radar characteristics producing hailfalls are given in relation to hail size classes. Both maximum reflectivity and maximum top height values are higher in cases of seeding, implying that a certain maximum hailstone diameter can be reached with weaker storms if seeding does not take place.

Hail size	Minimum reflectivity (dBZ)		Minimum top height (km)	
	Seed	No seed	Seed	No seed
Pea	37	35	6	5.5
Grape	43	33	8	7
Walnut	55	50	10.5	7

TABLE II. Minimum radar characteristics for hail size occurrence in cases of seeding and non-seeding.

III. RESULTS AND CONCLUSION

The study of hailpads hit in a 21-year period in the area of Central Macedonia leads to the following results: 1. Hailfalls are more frequent in the north part of the project area, in a close relation to terrain features. 2. Hail activity shows an increasing trend, while the maximum diameter of hailstones a decreasing trend. 3. The most intense convective activity occurs in June and May, in accordance to the existence of increased atmospheric instability. 4. The timing of storms' onset coincides in general with the maximum heating hours of the day. 5. The seeding of storms reduces the maximum diameter and the number of hailstones.

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THE ROLE OF THE LOW LEVEL JET IN A FLASH FLOOD EVENT OVER CENTRAL ARGENTINA

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I. INTRODUCTION

Flash flood events occur within minutes or hours of excessive rainfall, this kind of events can destroy buildings and triggers catastrophic situations due to sudden water stream. The central region of Argentina presents a flat terrain with a weak slope to the Atlantic Ocean. March 26 to April 1, 2007 was a week characterized by the presence of successive convective systems over central Argentina that generate strong rain rates, flooding large areas and producing important damages and lost of lives.

A primary goal of the present work is to describe the synoptic and mesoscale characteristics of the environment associated to a flash flood case over the central region of Argentina, with a special emphasis in the relationship between the behaviour of convective precipitation and the evolution of the low level jet. In order to achieve this objective a numerical simulation is performed considering a version of the Brazilian Regional Atmospheric Modeling System (BRAMS), that include a microphysics scheme and explicit convection in the finest resolution grid and estimations of precipitation.

II.DATA

The evolution of the successive mesoscale convective systems (MCSs) that affect the area of interest and their impact on precipitation rain rates have been studied considering satellite images every half hour and 4km-resolution and satellite estimation every one hour and 8km-resolution.

In order to evaluate the evolution and life cycle of different convective systems that impact over central Argentina, a clusterization and tracking technique called ForTraCC (Vila et al 2008) are employed to determine the life-cycle of each system considering two temperature thresholds 235 and 218 K. 235 K was considered to determine the contour of the rain area and 218 K was considered in order to follow areas associated with deep convection.

CMORPH information is considered in order to determine stratiform and convective precipitation regions, this estimation is considered due to the lack of radar observations and hourly precipitation information over the area. 235 K contour in IR images is used as a threshold to identify the precipitation areas associated with each system. Then stratiform and convective areas are differentiated considering the threshold of 7.5 mm hour-1 suggested by Mc Annelly and Cotton (1989) using CMORPH. Areas with values higher than 7.5 mm hour-1 are considered as convective and areas with values lower than this threshold are denoted as stratiform, all precipitation regions must be contained by a 235 K contour.

This case study was simulated with BRAMS. It is a regional non-hydrostatic, primitive equation model, formulated with an interactive multi-scale grids nesting capability. A complete and general description of the model can be found at Cotton et al (2003). Version used in this experiment includes several improvements from the original one. It includes a shaved ETA vertical coordinate, making it suitable to use in steep topographies as the Andes Mountains (Tremback and Walko, 2004). It also includes a shallow cumulus parameterization (Souza and Silva 2002) that complements the Grell cumulus scheme for deep convection (Grell and Devenyi, 2002). BRAMS model was applied in the region to simulated different mesoscale phenomena and results shows that it satisfactorily represents the observed conditions (Salio et al, 2006; Saulo et al, 2007; Nicolini et al, 2005a and Nicolini et al, 2005b).

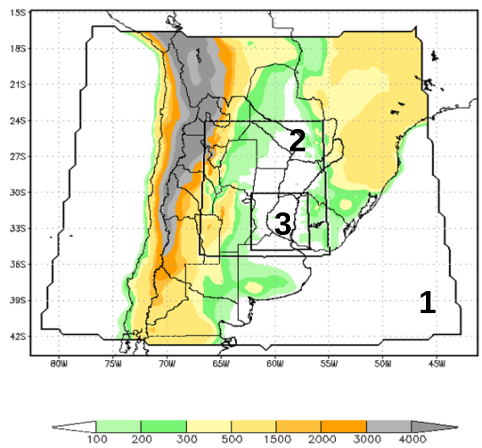

Figure 1: BRAMS nested domains considered in the simulation.

To simulate this case study a 156 hours simulation was performed starting at 12 UTC March 25, 2007. Outputs were extracted every 3 hours. Global Data Assimilation System (GDAS) analyses from National Oceanic and Atmospheric Administration/ National Center of Enviromental Prediction (NOAA/NCEP) were used as initial and boundary conditions. Numerical experiment was configured with three nested domains, with an increasing horizontal resolution of 50, 12.5 and 3.125 km. Geographical location of nested domains is shown in figure 1. Grell cumulus parameterization and shallow convection scheme were only activated in the lower resolution grid. It was used the “bulk water” scheme for the microphysical representation in all grids. Shaved eta vertical coordinate was applied and the model was configured with 30 atmospheric and 9 soil vertical levels, including topography data (1km resolution), terrain land use (1km resolution), soil types (50km resolution) and weekly sea surface temperatures.

III. RESULTS AND CONCLUSIONS

Mesoscale convective activity from March 26 shows that all systems tend to generate during the beginning of the night and decay during the day (Figure 2). The maximum extension of the systems varies from small systems to the bigger one on March 29 at 8Z that cover all area, and shows also developments over northwestern Argentina. Most extreme rainfall producer systems area detected on March 26 and 31 with maximum rates close to 12 UTC. Strong convective rates are detected at these times, these rates overpass by three times the total stratiform precipitation generated by the systems. Systems during the rest of the period present an equivalent total stratiform and convective precipitation but, in general, convective maximum precipitation occurs before the stratiform precipitation.

Convection generated before March 26 are principally associated with stratiform precipitation over the whole area, but this situation evidences potential conditions of soil saturation over the flat terrain of central Argentina.

The thermodynamic environment is characterized by strong CAPE, low CINE and the presence of a deep flow from the north that shows a low level jet (LLJ) profile. These environmental features present the ideal conditions to the formation of convection, because they establish a favorable situation associated with large-scale vertical ascent and potential instability over the area.

Preceding the clear development of convective precipitation rates the northerly ageostrophic wind tends to increase denoting an interaction between the incipient development of convection and the intensification of the circulation directed toward the storm.

IV. AKNOWLEDGMENTS

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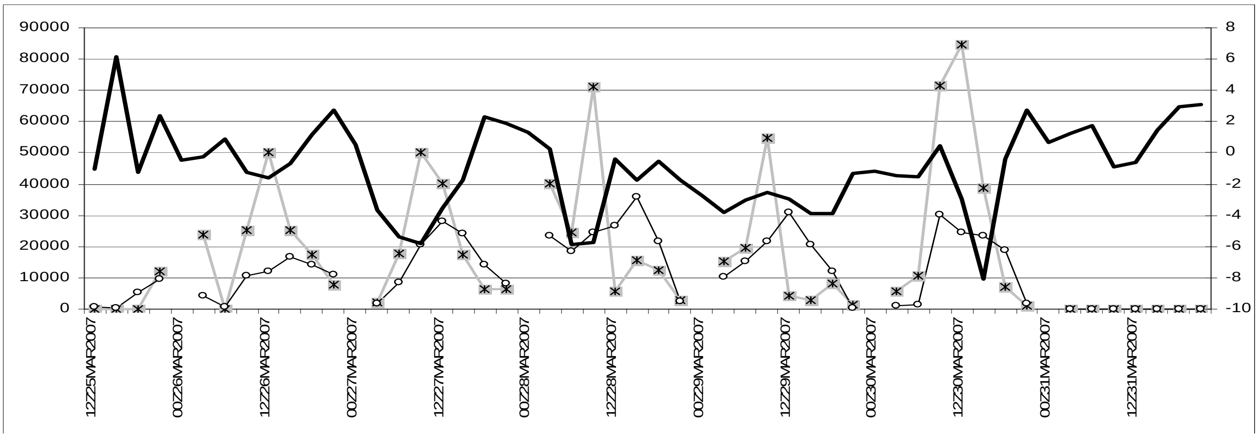

Figure 2: Evolution of ageostrophic wind at 32 ºS averaged between 58 and 62ºW (solid black line), convective precipitation (grey with black asterix) and stratiform precipitation (thin black line with open circle).

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RECENT SEVERE RAIN/HAIL STORMS AND SEVERAL TORNADO EVENTS IN BULGARIA (2001-2008)

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1. INTRODUCTION

This research contains two parts. The first one is an extended study of rain/hail/wind –severe convective storms (SCS) classified as Small-Scale Weather Phenomena (SSWP) that normally occur in the warm half of the year (April-September). The study covers the period 2001-2008. The second part consists of analysis and classification of five tornado events that occurred between 2006 and 2009. The research approach for the analysis of the tornado cases is similar to that used in Simeonov and Georgiev, 2003. The aim is to contribute to the country's long-term set of tornado events like in Dessens, 1989; Dotzek, 2001; Sioutas, 2003, and to enrich the European tornado data base (Dotzek, 2003).

II. RESEARCH APPROACH

In this work the analyzed SCS are selected on the basis of criteria defined and used in Simeonov et al., 2009. They are applied for the identification of extreme values and space-dissemination of database of the NIMH and are as follows:

- total precipitation amount $Q \geq 30$ and $Q \geq 60$ mm/24 h;
- thunderstorm/hailfall events, registered at least in 4 or more provinces;
- wind speed ≥ 20 m/s.

Meteorological data from for 131 meteorological and 244 precipitation stations were processed by program procedures. They are from the warm half of the year for the period 2001-2008.

The selected convective storm days are separated into five classes:

A - days with Q≥ 30 mm and thunders (Ts), with or without hailstorm (Hs);

B - days with Q≥ 30 mm and thunders (Ts), with hailstorm (Hs);

C - days with Q≥ 30 mm and thunders (Ts), with or without hailstorm (Hs), and wind (w≥20 ms^{-1});

C2 - days with Q≥ 30 mm in ≥ 8 stations, Ts in all stations, hail in more than 4 station, w≥20 ms^{-1} (with or without tornado), sup severe events.

D – as C2 but days with Q≥ 60 mm.

The frequency of the days with torrential rainfall (Q≥ 60 mm/24h), extended Ts and hailfall, and w≥20 ms^{-1} have been analyzed separately.

Case-study analyses on five stormy days with six tornado events were carried out. The work required the use of meteorological, synoptic and aerological data, radar records, expert inquiry, and media information. The set of environmental parameters describing the state of the troposphere is calculated using the same method as in Simeonov and Georgiev, 2003. The sounding data most representative for the storm location have been used. The radar records from suitable position (Gelemenovo, airports-Sofia and Varna) are used for the analysis of the storm characteristics and structure.

An attempt for tornado classification according to Fudjita scale is made. The tornado's environment characteristics have been used. The synoptic analysis suggests there is one typical structure that favors the development of tornados. It is a deep trough or a detached cyclone system to the west of the Balkans so that the frontal jet goes through Bulgaria from southwest to northeast. Thus the generated convective systems are forced to migrate rapidly northeastward and this provides the Coriolis effect to take place and strengthen the tornados below the convective clouds. This is the type of events 1, 3, 5, and 6 from TABLE 1 and to some extend event 4. Event 2 develops in the context of a detached cyclone centered to the south of Bulgaria. The dominant flow over the country therefore is from the northeast.

III. RESULTS AND CONCLUSIONS

The statistics of the thunder/rain/hail/wind storms divided into 5 classes is presented on Figure 1. The maximum occurrence among all 473 stormy days was in 2005 (81 days). The number of severe storm days (class C2) is 15 and heavy rain days (class D) is 7. In the summer of that year there were floods which caused damages and victims. One can notice some increase of the days in categories C2 and D in the recent 4 years compared to the previous 4 years.

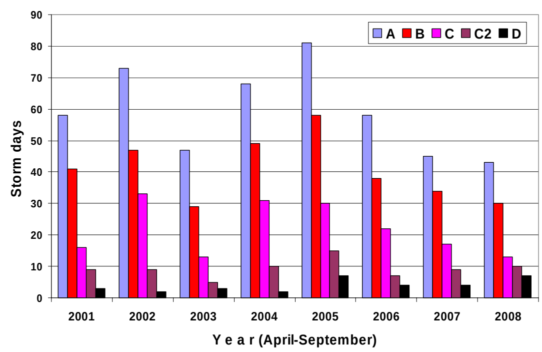

FIG. 1: Statistics of the clasified stormy days from 2001 to 2008.

The five analized damaging tornadoes developed in 2006-2009 period. FIG. 2, 3, and 4 illustrate them. TABLE I and II give their characteristics and clasification. The radar image presented on Fig. 2 shows bow echo (Oprea and Bell, 2009) in the maximum stage of storm development. The maximum sizes of observed hailstones for the tornado cases were from 1.5 cm for case No.1 to 8 cm for case No.5A.

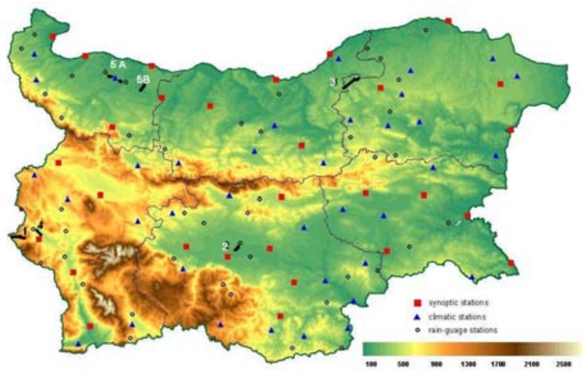

FIG.2. Locations of six tornadoes: 2006 Bobeshino (1); 2007 Kalekovetz (2); April 2008 Kostandenets (3) and July 2008 Kjustendil; 2009 Hayredin (5A) and Tarnava (5B).

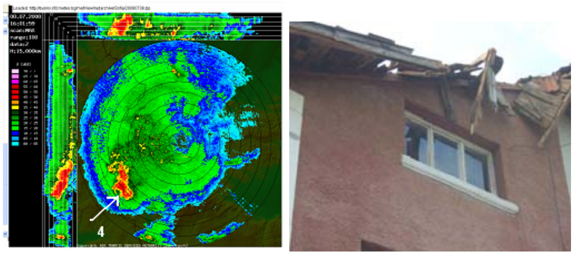

FIG.3. 08 July 2008 1602 UTC CAPI image of Kjustendil tornado (4) produced by Gematronik C-band radar in airport Sofia and the broken roof of NIMH Building.

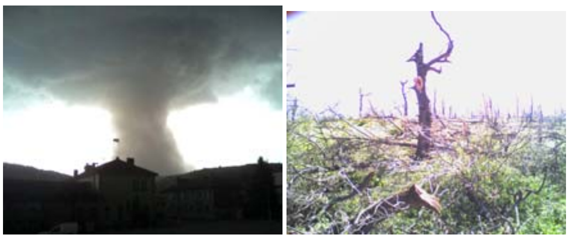

FIG.4. 22 April 2008 1300 UTC: The funnel of tornado (3) near to Konstandenets village and uprooted trees.

TABLE 1: Main tornado characteristics obtained by visual and radar observations in Bulgaria

No	Date	Time UTC	Max radar echo dBZ	Cloud top km	Max. wind speed ms^{-1}	Path L km	Path W m	F-scale
1	2 June 2006	0520	52	12.7	25	6	60	F1
2	21 May 2007	1320	50	11.5	>20	3	450	F1
3	22 April 2008	1355	63	13.1	29	15	30	F2
4	8 July 2008	1602	55	12.8	27	2	40	F0
5	2 June A 2009	1558	62	15.0	>35	14	100	F2
6	2 June B 2009	1335	62	15.1	35	3	80	F2

TABLE 2. Instability charcteristics of the throposhere, obtained by the Sofia sounding which is closest to the 5 tornadic storms location.

Index	Unit	2006 06.02 0000 UTC Belgrad	2007 05.21 1200 UTC Sofia	2008 04.22 1200 UTC Bucha-rest	2008 07.08 1200 UTC Sofia	2009 06.02 1200 UTC Sofia
DTm	°C	7.3	11.1	17.7	19.7	12.6
S_{DT75}	°C	8.4	15.8	19.9	19.8	16.4
S_{DT754}	°C	10.6	26.0	36.1	36.0	28.4
w_{max}	m/s	13.7	19.6	26.0	26.8	19.8
Z_{wmax}	km	4.2	10.0	10.3	10.5	8.4
Z_{EL}	km	9.2	12.0	12.8	13.5	12.6
E_i	J/kg K	1597	3421	5387	5518	3712
R_E	ratio	0.38	0.68	0.77	0.78	0.72
Δv	m/s	25	0	29	15	20
TT	°C	42.5	71.8	54.4	75.4	75.3
K	°C	25.3	48.5	19.5	61.3	54.2

The analyzed cases will enrich the database of severe storm events and can be used for further improvement of techniques and practices for severe weather warning forecasting.

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ATMOSPHERIC CIRCULATION PATTERNS ASSOCIATED WITH HAIL EVENTS IN LLEIDA (CATALONIA)

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(Dated: 15 September 2009)

I. INTRODUCTION

Although the advance of powerful computers has improved the outputs of meteorological models, a good synoptic classification (SC) can be very useful for long-range forecasting. In this way, the Meteorological Service of Catalonia is working on elaborating an accurate SC for extreme events. In this study it will be presented the atmospheric circulation patterns associated with hail events in an agricultural area of Catalonia.

One of the biggest arable lands in Catalonia (northeast of Spain) is the plain of Lleida (fig. 1) with about 200.000 hectares of crops. From 1990 the Associació de Defensa Vegetal - Terres de Ponent (ADV-TP), a local organisation for crop protection, is working to collect information of hail events and damages. In 2001 they built a hailpad network in this arable land with 170 hailpads distributed every each 16 square kilometres (Fraile et al. 1992).

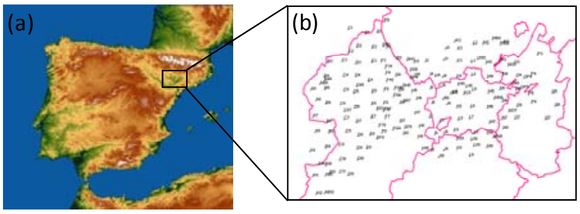

FIG. 1: (a) Iberian Peninsula (b) Hailpad network in the plain of Lleida.

In the second section it is presented the methodology used. The hail event database is detailed in section three. In the fourth section it is presented the results obtained with this methodology. Also it will be included a comparative study with a subjective synoptic classification (Pascual, 2002). Finally, in the fifth section some discussions are presented.

II. METHODOLOGY

In this section it is presented the different objective methodologies tested. As a first approach, the principal component (PCA) analysis is used as a classification technique. The data matrix is in T-mode (Huth 1996, 2000), where the date is the variable and the grid points are the cases. This semi-objective classification was applied to the sea level pressure (SLP) of the NCEP-NCAR reanalysis (2,5º resolution). However, a disadvantage of this method is that can only be used at one atmospheric level. For this reason, it was designed a methodology where the classification was structured using at the same time PCA in S-mode and cluster analysis (CA) (Yarnal, 1993; Esteban et al., 2006). This method allows working with different levels (Houssos et al. 2008): SLP, temperature at 850 hPa and geopotential height at 500 hPa. Furthermore, it was used a precipitation matrix (data from automatic weather stations of the National Service of Catalonia) to take into account mesoscale aspects. Figure 2 shows the scheme of the methodology that is based on three steps: PCA to reduce the dimension of the variables, CA to classify and, finally, discriminant analysis to verify and reclassify the classification obtained by means of CA.

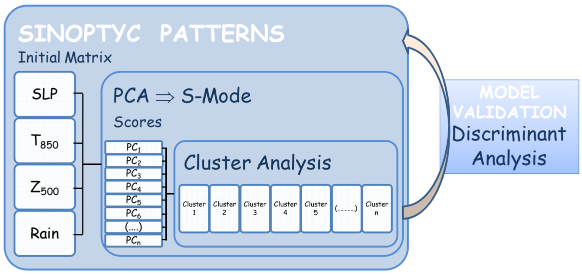

FIG. 2: Scheme of the methodology used.

III. DATABASE

From 2001 to 2007, 83 hail events were detected in the area covered by the hailpad network. These events were used to test different techniques. However, the definitive methodology was only applied to the events with more impact. So, a new database was built using a risk index estimated with the total number of dents and the maximum diameter recorded for each day. A threshold for this index to discriminate a high-moderate event was defined according to the description of each event done by the local association for crop protection in the plain of Lleida (ADV-TP). As a result, only 42 hail events were defined as a moderate to high risk events.

IV. RESULTS

The methodology shown in figure 2 was applied to the 42 hail events. At first, ten groups were obtained after CA analysis. But, verifying this first classification with the discriminant analysis only seven groups were significant.

Figure 3 shows that the clusters 2, 3 and 4 explain the 70% of all the hail events.

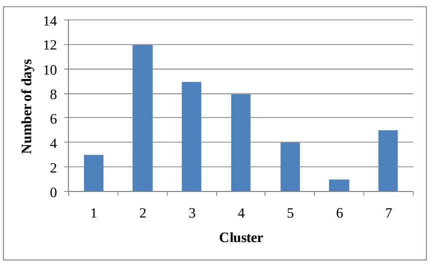

FIG. 3: Number of hail events for each cluster.

These three clusters are characterized by the presence of a trough at medium atmospheric levels, but in cluster 3 and 4 the trough is deeper and over west of Iberian Peninsula (fig.4). This result is in concordance with previous subjective classification done by Pascual (2002). In both studies this synoptic configuration accounts for nearly 40% of the events.

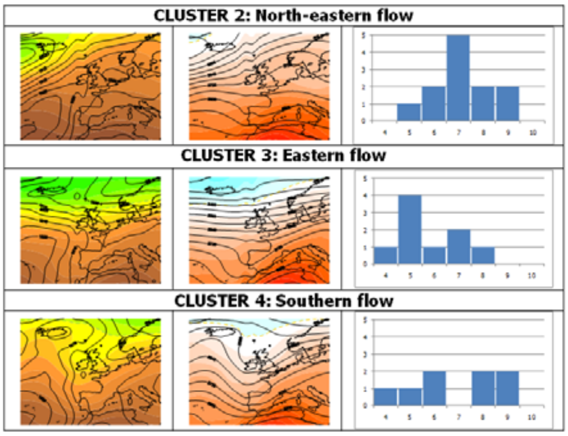

FIG. 4: Clusters accounting for 70 % of the hail events. In column 1 surface level pressure (hPa); column 2 geopotential height (mgp) at 500 hPa and in colour temperature (ºC) at 850 hPa; column 3 monthly distribution of the hail events.

V. DISCUSSION

Although the results have been suitable for our aim, we intend to go on with different trials. A first attempt has been done applying this methodology with ECMWF Interim re-analysis at a 1.5º resolution. The first result doesn't show a significant improvement.

We are carrying out a feasibility study to decide if this methodology can be applied to obtain an analogous method. It would be necessary to use the component matrix obtained by PCA of each variable and the classification function coefficients obtained by cluster analysis.

VI. ACKNOWLEGMENTS

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ATMOSPHERIC CONDITION AND SEVERE STORMS OCCURRENCE IN POLAND

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I. INTRODUCTION

In Poland severe storms, especially those accompanied by intense precipitation, are counted amongst the most extreme events causing damage to environment and strongly influencing human well-being. In Poland yearly number of storm days varies from 15 days in north-west to 33 days in south-east. Most of such days (85%) are accompanied by precipitation of which 7-8% is higher than 20 mm and 3% exceeds 30 mm. The long-term course of the number of storm days with precipitation is spatially incoherent and even differentiated from station to station. On the other hand storms are recorded on nearly 50% of days with more than 20 mm of precipitation (Bielec-Bakowska, Lupikasza 2009). Moreover, it was proved that the frequency of the storm days with precipitation in cyclonic synoptic types almost equals to their frequency in anticyclonic types (Bielec, 1997). However, the most severe storms (with the highest precipitation) are recorded in anticyclonic situations.

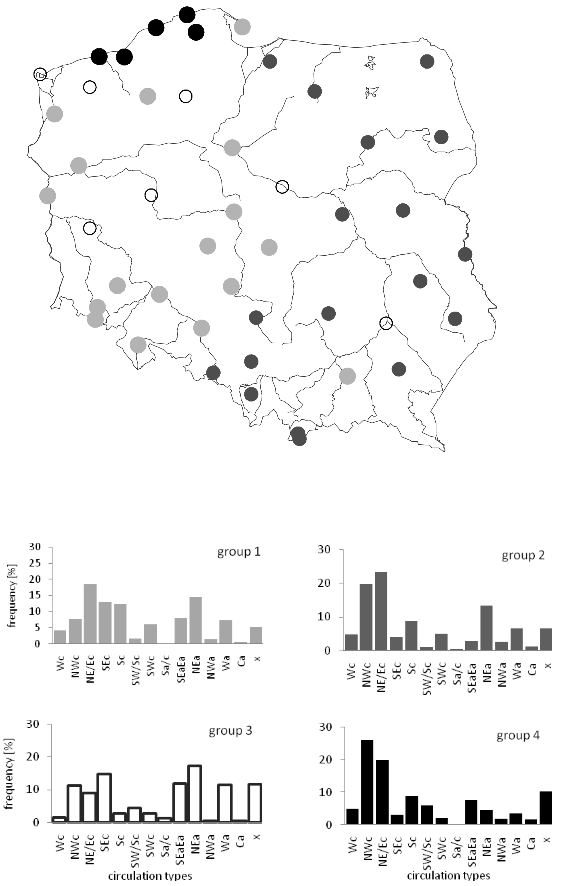
II. GOALS AND METHODS

The results described above encourage us to research the relationships between severe storms (with precipitation higher than 30 mm) occurrence and synoptic conditions. Series of meteorological observations from 47 synoptic stations and circulation types by B. Osuchowska-Klein (1978, 1991, 2001) and synoptic charts for the 1951-2000 period were used.

All the severe storms selected from the database were focused upon based on the precipitation criterion. A storm was recognized as severe when it was accompanied by precipitation higher than 30 mm. In the next step, using synoptic charts, each of the severe storms selected was classified as frontal or inter-air mass one. Further research aimed to determine synoptic situations the most favourable to the severe storms occurrence. It was also checked if there is seasonal and long-term variability in the relations between severe storm occurrence and atmospheric circulation. The researches were completed by detailed analysis of synoptic conditions at days with the most severe storms, i.e., the highest precipitation.

III. RESULTS

In Poland days with storm and very strong precipitation are recorded relatively rarely. More often than once a year they occur in the mountains in the south of Poland with maximum at Mt. Kasprowy Wierch (2.1 days/year on average).



W, NW, ... – directions of air mass advection
c / a – cyclonic / anticyclonic situation

FIG. 1: Frequency [%] of the occurrence of days with storm and precipitation higher than 30 mm during particular circulation types in Poland in the period 1951-2000

Depending on the region the storms in question accompany particular types of circulation with different frequency. On this basis 4 groups of stations were distinguished where days with storm and very strong precipitation occurred during specific circulation types. Storms with precipitation higher than 30 mm occur the most often during air mass advection from east and north-east (NE/Ec i NEa) at the majority of stations in Poland. It applies both with anticyclonic and cyclonic situations (Fig. 1). Severe storms occurring during north-west cyclonic situations (NWc) are also significant at stations located at the seaside and those situated in the east area of Poland. The storms in questions occur the least frequently during the south air mass advection at the meeting of cyclonic and antyciclonic situations as well as central anticyclonic situation (Ca) (Fig. 1).

The most severe storms are connected with atmospheric fronts passing over Poland. Intermass storms were extremely rare and they occurred the most often in south-east Poland.

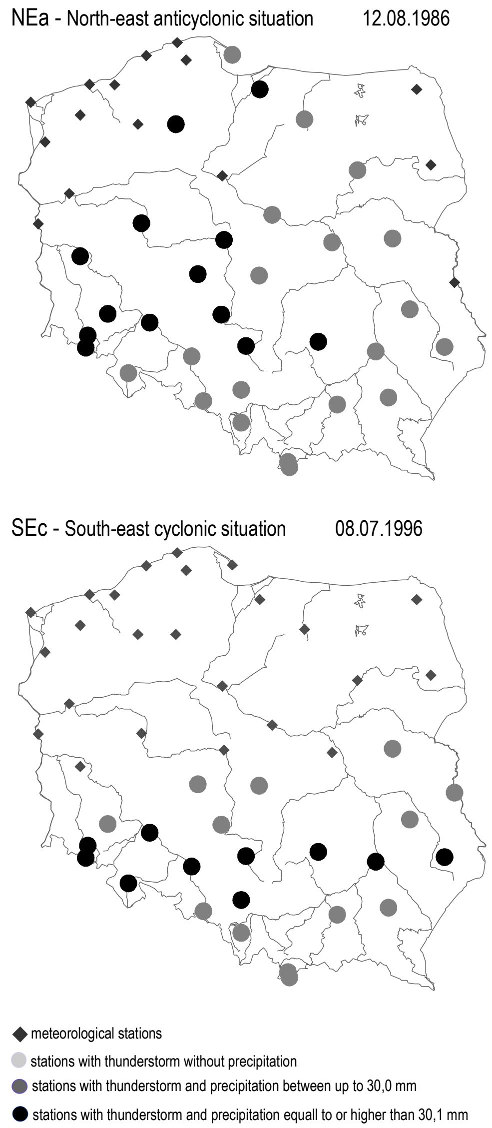


FIG. 2: Days with storms and precipitation higher than 30 mm in Poland in the period 1951-2000 - selected cases

The most interesting cases of storm with very strong precipitation are those that occurred in the coldest months (Nov-Mar). In this period the storms analysed were recorded in Poland only at 6 stations: at the Baltic seaside (Koszalin, Ustka, Łeba) and in the highest Polish mountains – Tatras (Zakopane and Kasprowy Wierch). At the Mt. Kasprowy Wierch a storms with precipitation higher than 30 mm occurred two times. The storms usually accompanied the air mass advection from west sector (Wc, NWc, SWc), as well as from east and north-east (NE/Ec) and also atmospheric fronts.

The research conducted shows also that days when storms with precipitation higher than 30 mm occurred at 1 or 2 station (ca. 96%) were the majority of cases. Only in 2% of the days analysed (17 days) they occurred at 6 or more stations (13 station maximum). In most of the cases storms with precipitation between up 30 mm or without precipitation were recorded also at other stations in Poland (Fig. 2). During the days in question air mass advection from north-east and east (NEa, NE/Ec) and from south sector (SW/Sc, SEc, SEaEa, Sc) dominated.

IV. AKNOWLEDGMENTS

This study was supported by a grant from the Ministry of Science and Higher Education (PBZ-KBN-086/P04/2003).

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On Change in Extreme Daily Precipitation Characteristics in Bulgaria (1961 – 2007)

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I. INTRODUCTION

The upward tendency of damages caused by natural disasters supports the idea that extreme events, such as torrential precipitations, associated with the effects of climate change, occur with greater frequency (Easterling et al., 2000). The same tendency is observed in Bulgaria during the last decade of the 20th century (Bocheva et al., 2006). Many studies aimed at analyzing the variations of heavy and extreme precipitation are interesting as these events cause considerable damage and loss of life worldwide each year. Negative trend in annual and seasonal precipitation totals, associated with an increase in the contribution of heavy rainfall events to total precipitation, is observed in some countries from South Europe especially in Southeastern part of the continent (Alpert et al., 2000; Brunetti et al., 2001; Bocheva et al., 2009; Nastos and Zerefos, 2008).

The main objectives of this study are climatic variations in heavy (30-59.9 mm/24h) and torrential (totals ≥ 60 mm/24 h in one station are considered) precipitation amounts in different parts of Bulgaria. We focused our attention in this group of torrential precipitation, because daily amount ≥ 60 mm/24 h often caused significant damage and loss of life. During the last 10-15 years this events caused floods and economic losses more often in northeastern Bulgaria and in eastern and central parts of South Bulgaria. They are usually connected with severe convective storms.

A classification of synoptic situations for each part of Bulgaria is carried out and some of the most typical ones are presented. The NCEP/NCAR Reanalysis data and the fields of air pressure and wind velocity are considered.

II. METHOD OF INVESTIGATION

Precipitation data from Meteorological database of the National Institute of Meteorology and Hydrology (NIMH) for 112 meteorological stations (29 synoptic, 46 climatological and 37 rain-guage) with altitude below 1000 m (Fig.1), were processed by program procedures for the period 1961-2007. In all station daily precipitation total is measured in 7.30 a.m. (local time) with classic ground-level precipitation gauges. The automatic stations data is not included in this study.

The territory of Bulgaria is small, but it is characterised with very diverse relief. Also our country is located on the transition between two climatic zones – moderate continental and Mediterranean. So by the orographic and climatic features we can divide Bulgaria on 6 parts: North-West (NW), North-Central (NC), North-East (NE), South-East (SE), South-Central (SC) and South-West (SW) Bulgaria (see Fig.1).

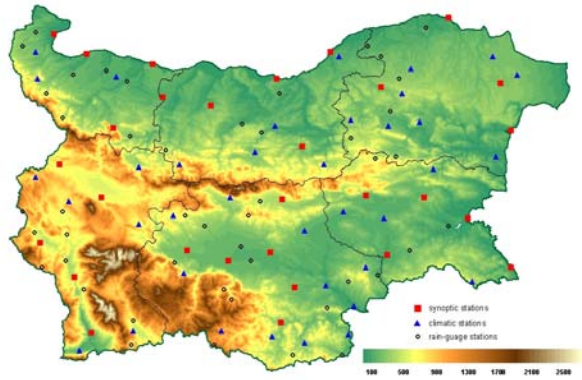


FIG 1: Meteorological stations used in the study.

The results for the periods 1961-1990 (accepted as a basic period) and 1991-2007 were compared. In order to show the contribution to observe annual totals of heavy/torrential rain, five daily rainfall categories were suggested (as percentage from the total annual amounts) as follows: Light (A) 0.0-4.9 mm; Light-Moderate (B) 5.0-14.9 mm; Moderate-Heavy (C1) 15.0-29.9 mm; Heavy (C2) 30.0-59.9 mm and Torrential (D) ≥ 60.0 mm. The mean annual and mean monthly number of wet days as well as days with extreme precipitation is summarized for each of the six parts of the country for two periods 1961-1990 and 1991-2007. Brief statistical analysis is applied for the assessment of variability and possible differences in the torrential precipitation from long-term data series. The Poisson distribution and corresponding nonparametric tests are applicable to such discrete samples of large-scale heavy rain days.

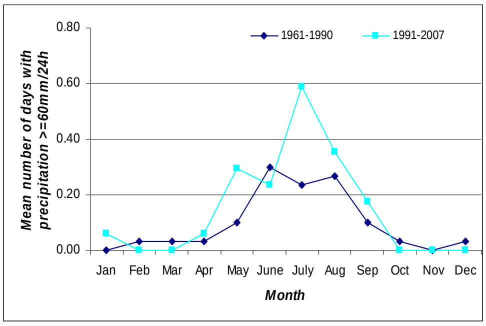
The NIMH historical archive of synoptic maps and NCEP/NCAR Reanalysis data files were used for analysis and classification of synoptic situations causing torrential precipitation (group D) for each part of the country.

III. RESULTS AND CONCLUSIONS

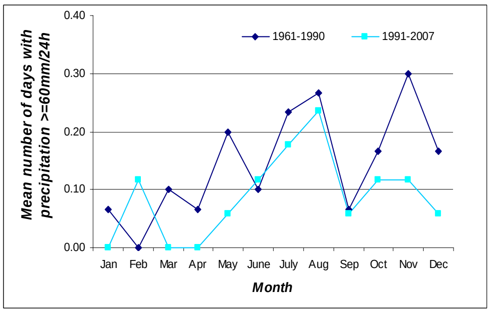
Climatic study

The absence of significant trend in annual precipitation for all country is observed. In the same time the negative trend in wet days (not statistically significant) for almost all examined parts of the country, with exception of NE Bulgaria, is determined. All this indicate an increase in extreme daily precipitation.

The regime of such extreme precipitation events is compared to those of total rain/snow amounts for two periods: 1961 – 1990 and 1991 – 2007. Significant increase of days with torrential 24-hours precipitation is revealed during the second period in NC Bulgaria (about 50%) and NE parts of the country (about 27%), while in West Bulgaria (especially in SW Bulgaria) these dangerous events decrease with about 20-35%.(Fig. 2a,b).



a) NC Bulgaria



b) SW Bulgaria

FIG. 2: Mean monthly number of days with precipitation ≥60 mm/24 h.

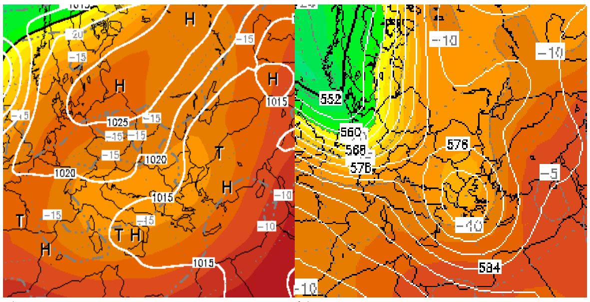
Monthly distribution of wet days as well as the two groups of precipitation C2 and D show a statistically significant increase in all events in September recently. In the same time mean monthly number of wet days decrease during the period 1991-2007 not only in winter (especially in February), but also in June all over the country.

Synoptic classifications

The synoptic situations, connected with 682 days with torrential rain events (≥ 60 mm/24 h) during the period 1961-2007, were examined and classified for each of the 6 parts of the country.

For example, Northeast Bulgaria is endangered by extreme precipitation mostly in late summer and early autumn when cyclonic systems with Mediterranean origin block over the Balkan peninsula suppressed by a well developed anticyclone over Eastern Europe. The combination of warm and humid air from the Black Sea coming inland and the cold air influx from the northeast produce a continuous in time and stationary in space convective systems that generate strong precipitation at one and the same place for as long as 12 to 48 hours. This is illustrated in Fig. 3a with the case of 21-22 September 2005 when the town of Shabla at the north coast of Black Sea is hit by a flood. The reported cumulative amount of precipitation in Shabla for that process is 900% of the monthly normal.

Southwest Bulgaria, as another example, is particularly endangered in late spring and early to mid-summer season when relatively small cyclonic systems, born in the Mediterranean to the south of the Alps, move into the West Balkans and become stationary. They produce powerful mesoscale convective systems particularly over the mountainous central Balkans including Southwest Bulgaria. The convection feeds back the cyclonic circulation with fresh energy and thus sustains the strong precipitation for a couple of days. This is illustrated in Fig.3b with the case of 4-6 August 2005 when the town of Ihtiman in Southwest Bulgaria is flooded. The reported cumulative amount of precipitation in Ihtiman for that process is 356 mm for less than 48 hours.



a) b)

FIG. 3: a) Height (dm) of geopotential surface 500 hPa in color and surface pressure (hPa, white contour), 22.09.2005; b) Height (dm) of geopotential surface 850 hPa (white contour) and temperature (ºC) in color, 06.08.2005.

Conclusions

The observed increase of torrential precipitation events during the last 10-15 years is statistically significant in NC, NE and SE Bulgaria. In the contrary in SW Bulgaria, where precipitation regime is mainly caused by Mediterranean cyclones circulation, the significant decrease of such type of precipitation is established.

The increase in frequency of heavy precipitation days in the autumn months September and October is observed in all parts of the country during the second period (1991-2007).

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HYDROLOGICAL RAINFALL ANALYSIS COUPLED WITH METEOROLOGICAL INFORMATION

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I. Introduction

Rainfalls represent the final step of a complex process of atmospheric moisture transport and interactions with land and sea. Extreme precipitation events, although localized, especially in case of intense convective rainfalls which can produce flash-floods in small catchments, are clearly included in a broader meteorological context which feeds them in energy and moisture. Presence of orography greatly influences rainfall intensity at both local and regional scale and, for an exhaustive analysis of extreme events, coupling of meteorological and hydrological data is desirable.

Regional analysis of rainfall characteristics is widely used in hydrology to reduce uncertainty in estimation of maximum rainfall of assigned return period. Identification of "homogeneous" region, wherein statistical index like skewness or coefficient of variation (Matalas et al., 1975) may be considered constant, allows to estimate the parameters of the rainfall frequency distribution using a great amount of data. Normally, the investigation of homogeneity in the area of interest is pursued using rain gauges data and numerical modelling like cluster analysis, but at-site data are not always able to identify comprehensive spatial trend. Moreover, in areas affected by frequent convective storms, with high rainfall variability in space and time, also dense rain gauge networks may fail to identify homogeneity.

This study analyzes meteorological characteristics, in terms of distribution of CAPE (Convective Available Potential Energy) values during events that represent the annual maxima of daily rainfall, to verify the possibility of identify meteorological homogeneity which can be assimilated with hydrological homogeneous areas.

II. PRESENTATION OF RESEARCH

For this study, rainfall data are retrieved from SIVAPI (informative system for Italian flood evaluation) archive, containing daily rainfall for the whole Italian territory from the 1921 till today.

Meteorological analysis was carried out using the re-analysis GRIB files of the ECMWF (European Centre for Medium-Range Weather Forecasts) data archive ERA-40 (ECMWF 40 Year Re-analysis). The horizontal resolution of the GRIB files is 0.5°x0.5° and the level type are 23 pressure levels; data are available at main hours 00:00, 06:00, 12:00 and 18:00 TU. While ERA-40 archive starts from 1958, the analysis based on both meteorological and hydrological data has been realized in the interval 1958-1988.

For each rain gauge station the CAPE was computed for the days corresponding to annual maxima of daily rainfall, considering the maximum value in the four available GRIB intervals. The atmospheric data contained at different pressure levels of the GRIB file, at the coordinates corresponding to the position of the rain gauge station, were considered as result of a radiosounding and a synthetic CAPE index was then calculated using the Lifted Parcel Theory (Manzato and Morgan, 2003):

$$CAPE = g \int_{LFC}^{EL} \frac{T_p - T_e}{T_e} dz \cong g \sum_{LFC}^{EL} \frac{T_p - T_e}{T_e} ,$$

where T_p and T_v are the virtual temperatures of parcel and environment respectively (Doswell and Rasmussen, 1994). Values of the CAPE, for about 2500 stations, are then obtained for events corresponding to maximum annual rainfall from 1958 to 1988. Finally, a frequency analysis of CAPE values is carried out calculating, for each rain gauge station, the percentage of cases with CAPE > 500 J.

III. RESULTS AND CONCLUSIONS

Figure 1 shows, black lines, the actual 12 homogeneous regions defined in Italy with VAPI (Italian Flood Evaluation) project where homogeneity has been verified independently for each region of the "hydrologic compartment" of the Italian Hydrological Service (Fiorentino et al., 1987). Symbols over regions represent the frequency of CAPE > 500 J. The frequency is evaluated using all the available events at each station. High values mean that the events causing annual maxima for that station are probably due to convective events.

According to the Two Components Extreme Value (TCEV) distribution, which hypothesizes that hydrological events are a mixture of "normal" and "extraordinary" population (Rossi et al., 1984; Gabriele and Arnell 1988), regions in Figure 1 with high value of skew indicate a presence of a significant percentage of extraordinary events. Normally, extraordinary events in Italian peninsula are associated with convective storms while normal events happen during stratiform rainfall. Looking the map, the occidental and south side of the peninsula shows high percentage of convective events that decrease in the north-east side.

Except in border lines, the map shows a good agreement with homogeneity valuated with rainfall data. Figure 1 suggests also that Italy can be split in three regions alone instead of the 12 considered in VAPI: west-south (red circles prevalent), centre (green triangles prevalent), north-east (dark circles prevalent).

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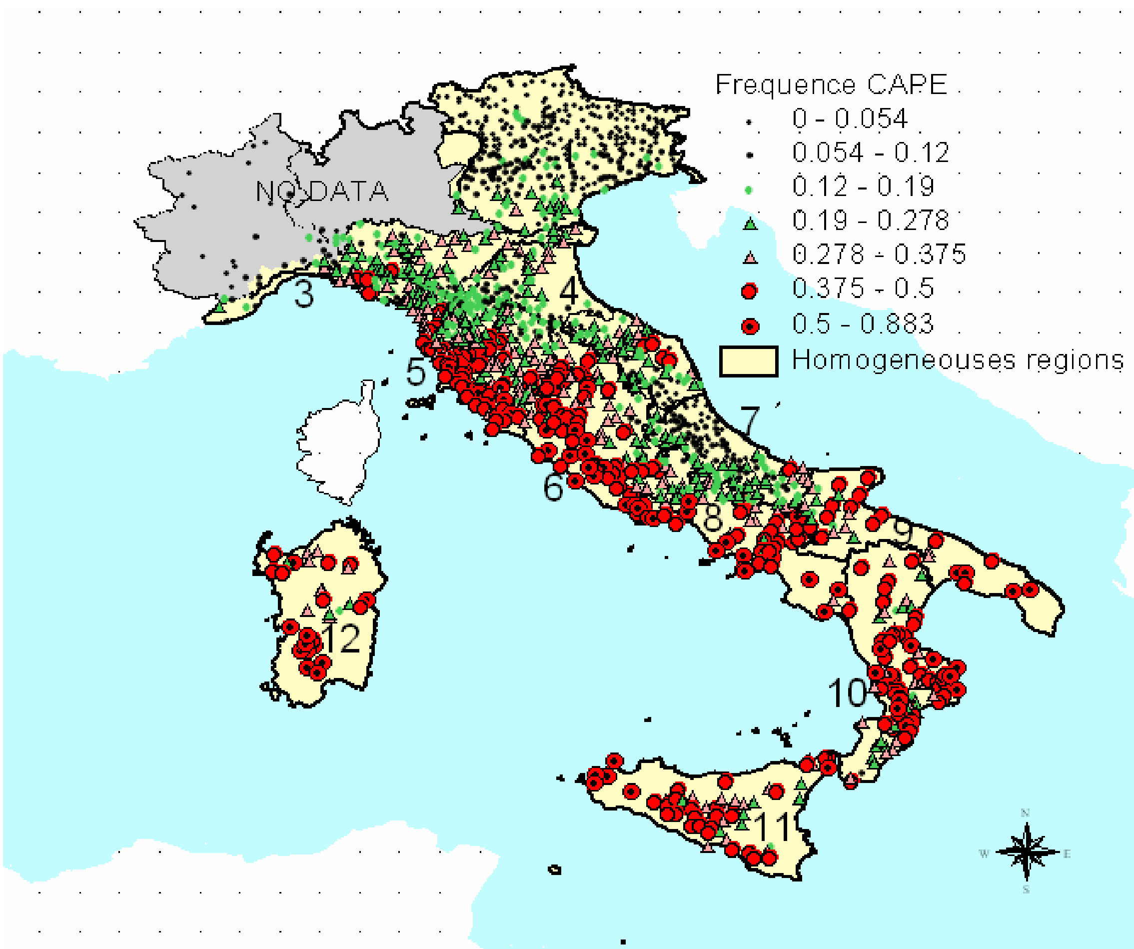

FIG. 1: Frequency of CAPE > 500 J for about 2500 rain gauges for events corresponding to maximum annual rainfall from 1958 to 1988; the 12 homogeneous regions (black lines) defined in the VAPI (Italian Flood Evaluation) project also are shown.

Atmospheric patterns associated with hailstorm days in the Ebro Valley (Spain)

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(Dated: September 15, 2009)

I. INTRODUCTION

The Central Ebro Valley, in the Northeast of Spain (Fig. 1), is one of the regions in Europe with the highest number of summer convective storms that cause intense and heavy rain and hail precipitation (Font, 1983). The zone lies between parallels 39^o 51' and 42^o 55' of latitude north, and meridians 2^o 06' of longitude west and 0^o 44'of longitude east. The Group for Atmospheric Physics (GAP) at the University of León (ULE), Spain, has carried out a series of research projects in this area over the last ten years. The main aim of these projects is the study of severe convective events that affect the Central Ebro Valley, causing heavy rain and hail precipitation.

The GAP has investigated the nature of these convective events, in order to improve the forecasting and nowcasting of the hailstorms. García-Ortega et al. (2006) established the microphysical characteristics of a severe hailstorm in the study area. Different prediction techniques, using radiosonde data (López et al., 2007) and nowcasting, using meteorological radar (López et al., 2009) has been used. Numerical simulations via the Mesoscale Model MM5 have been carried out in order to analyse different study cases (Tudurí et al., 2003; García-Ortega et al., 2007).

The GAP is currently engaged in research work to develop a forecast model for hail precipitation risk, based on the identification of meteorological situations that may lead to convective events and cause hailstorms in the Ebro Valley. The main objective of the present study is to obtain an atmospheric pattern classification of a set of hailstorm days (hereafter, HD) that affected the Central Ebro Valley between 2001 and 2008.

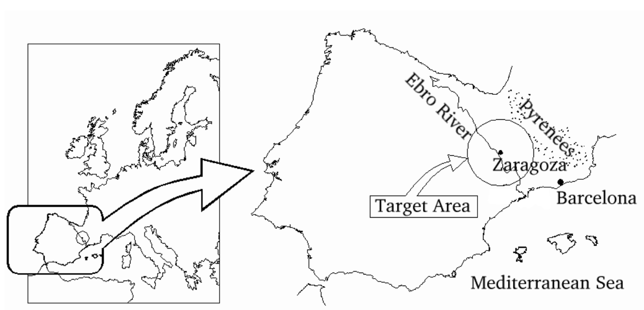

FIG. 1: Target area: the region of Aragón (Northeast of Spain). The circle comprises the area covered by the C-band radar (about 140 km of radius)

II. DATA AND METHODOLOGY

The database cointains 260 HD from 2001 to 2008. The HD data comes from the C-band radar database of GAP and a network of voluntary observers. The radar is deployed 10 km to the SW of the city of Zaragoza with a range of 140 km in radius (Fig. 1). The radar provides information on the horizontal and vertical structure of the storms with a spatial resolution of 1 km and a temporal resolution of 4 min.

Gridded reanalysis data from the National Centers for Environmental Prediction (NCEP) are used, with a $2.5^o \times 2.5^o$ latitude-longitude resolution. The area selected comprises the domain from 30^o N to 50^o N and from 40^o W to 10^o E. The selection of a group of independent variables representative of the state of the atmosphere will supply a synoptic meteorological categorization of the atmospheric characteristic of HD. The initial ensemble of atmospheric fields consists of the 850 and 500 hPa geopotential height and temperature (ϕ_{850}, ϕ_{500}, T_{850}, T_{500}) and the 850 hPa relative humidity (hr_{850}). In order to obtain the atmospheric pattern classification, a Principal Component Analysis (PCA) and a Cluster Analysis (CA) were carried out (Yarnal, 1993).

The PCA was applied to extract the most important components of the initial variables and to explore the joint space and time variations in the data set. The PCA in T-mode (day-by-day) has been used to isolate groups of time steps with similar patterns. Only the most important loadings -those that account for at least 90% of the total variance- were considered for each parameter. As a result, 6 components were stored for ϕ_{850}, 4 components for ϕ_{500}, 3 for T_{850}, 8 for T_{500} and 14 components for hr_{850} were selected. The CA was applied to the total matrix of 35 loadings of the 260 events.

The CA classifies events in groups whose loadings are similar. Therefore, events with similar extracted loadings will be clustered. The non-hierarchical k-means method (Andenberg, 1973) has been used. This algorithm minimizes the total within-cluster sum of squares. However, for this algorithm the number of groups (k) must be stated before the algorithm proceeds. In order to select the number k we have analysed the results obtained via PCA, other hierarchical methods such as Ward's method, and appliying the Elbow criterion to the results obtained with CA.

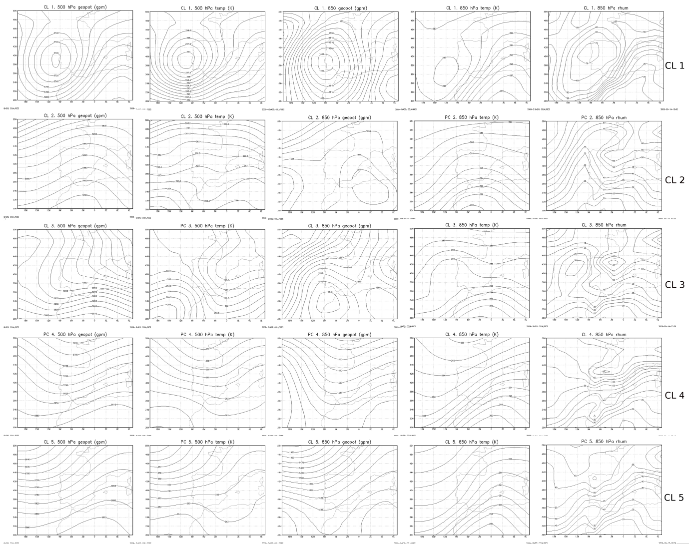

FIG. 2: Atmospheric patterns based on CA. Clusters 1 to 5 labeled as CL 1, CL 2, ..., CL 5 are in rows. The atmospheric fields are in columns: ϕ_{500} (gpm), T_{500} (K), ϕ_{850} (gpm), T_{850} (K), rh_{850} (%).

III. RESULTS AND CONCLUSIONS

Five atmospheric patterns were obtained (Fig. 2). The clusters are numbered following the order obtained on the k-mean output. In order to make the physical interpretation of the results, we have calculated the mean fields, for each cluster element (CL), averaging the atmospheric fields corresponding to the events grouped in each element. Obviously, each CL is not a real atmospheric pattern, but an average of real ones.

The CL 4 and CL 5 are the atmospheric patterns with the highest number of days (90 and 98 respectively). These two CL, together with CL 2 (39 days) configure a unique dynamic structure. CLs 2, 5 and 4 show a sequence corresponding to the arrival of a trough, ϕ_{500}, from the Atlantic Ocean with an associated cold advection (Fig. 2). From CL 2 to CL 4 the isotherm over the study area develops from 262.5 K to 259.5 K. At 850 hPa the entry of a trough is also noted, whose development is strongly influenced, particularly in CL 2, by a high-pressure center situated over Algeria. The hr_{850} reveals a center with maximum values in the NW and N of Spain.

CL 1 (17 days): At 500 hPa, the ϕ_{500} is characterized by a cut-off low centered over the west of Portugal and an associated low-temperature center (T_{500}). A similar structure can be observed at 850 hPa (ϕ_{850}). At low levels, the south-easterly flow over the northeast of Spain favours the entrance of warm and humid air over the study area. This is an important factor for the generation of heavy hailstorm events. The entrance of the cut-off low will favour the upward motion. The situations associated with this CL normally occur during the months of May and September, in which the formation of the low in the W of the Peninsula and the associated low temperatures are a characteristic event around this period.

CL 3 (16 days): At 500 hPa, the ϕ_{500} shows a through tilted to the southwest over the Iberian Peninsula generating a situation of instability. The cold air at 500 hPa comes from the interior of the European continent. At 850 hPa, there is a trough affected by a low-pressure center situated over the Gulf of Cádiz. The displacement of this low towards the NE favours the entrance of warm and humid air from the Mediterranean Sea. This structure is not too frequent but is related with strong rainfalls.

The results obtained reveal 5 clusters corresponding to three types of differentiated atmospheric patterns. CL 1 is characterized by the presence of a deep low-pressure center situated to the W of Portugal at both low and medium levels. CL 3 reveals a trough at 500 hPa tilted to the NW and a trough at 850 hPa influenced by a low-pressure area situated over Morocco. CL 2, 5 and 4 correspond to 72.3% of the cases studied. At 500 hPa the entrance of a trough is observed moving eastwards with a strong cold air advection.

IV. ACKNOWLEDGMENTS

The authors are grateful to Andrés Merino for their collaboration with the data bases. The study was supported by the Ministerio de Educación of Spain through the grants REN 2003-09617-C02-01 and CGL2006- 13372-C02-01. The authors are thankful also for the support of the Consejería de Agricultura del Gobierno de Aragón, Spain.

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SUMMER SHOWERS CHARACTERIZATION IN THE BASQUE COUNTRY.

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I. INTRODUCTION

In the Basque Country, severe storms take place usually from May to September. In this work, intense precipitation events related with convective summer storms in our territory are considered for a ten year period, focusing on severe convective cases.

In the Basque Country an Automatic Weather Stations (AWS) Network (BCAWSN) is present, in some sites there are some instruments called Datarains, connected to the rain gauges that record the instant (hour, minute, second) when a bucket of a rain gauge overturns. This parallel data measure system is useful to carry out a quality control of rain data as well as to perform high resolution precipitation intensity analysis.

As representative for summer showers cases, summertime events with precipitations that exceed ten millimetres in ten minutes in any rain gauge from the BCAWSN are studied based on Datarain instrumentation, using the particular features of the Datarain data to explore in detail the temporal structure and the intensity of selected events.

II. RAIN GAUGE NETWORK

Currently, the BCAWSN is a high density automatic measuring network for meteorology, hydrology, water quality and oceanography purposes. This network provides different meteorological measurements, every 10 minutes, in nearly 100 different sites all over the Basque Country area in a real time basis (see more details in Gaztelumendi et al 2003). More than 80 stations of the BCAWSN have tipping-bucket rain gauges. Since 1995, the number of AWS with rain gauges, which have incorporated Datarain instrumentation, has increased reaching practically all of them, nowadays (see FIG 1).

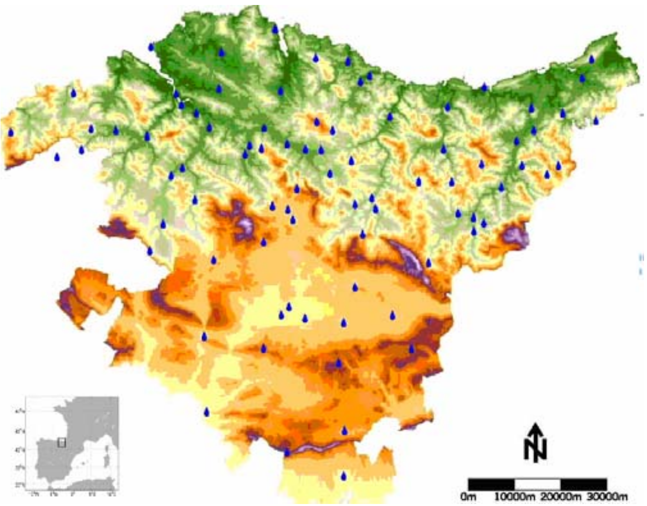

FIG. 1: Location of rain gauge with Datarains in Basque Country.

When a bucket of a tipping-bucket rain gauge overturns, it is automatically recorded by two different and independent systems: the AWSs Datalogger and the Datarains. Datarain recorded data allows to calculate the precipitation intensity with a resolution higher than 10 minutes. The Datarain register the instant in which has occurred every dump, generating a file in ascii format. In this file some relevant information is stored; the rain gauge code, the date and time of the dump, the ability of the bucket and an internal code (see more details in Otxoa de Alda K. et al 2003).

III. STUDY CASES

Intense precipitation events from 1999 to 2008 have been considered. Study cases are selected using precipitation rate threshold criteria If the threshold of ten millimetres in ten minutes is exceeded in any rain gauge of the BCAWSN, the day is selected in order to include intense precipitations events. To characterize these severe weather events and to improve its knowledge we include for each day its weather type (Egaña et al 2007). This classification of weather types is used in this work in order to find out some patterns.

For selected events, accumulated precipitation data every ten minutes, every minute and every 30 seconds are calculated. In the table 1 we present the study cases for each year detailing the number of AWS that have exceeded the record of ten litres in ten minutes. Number of events during this ten years period ranges from 6 to 13 cases, with an average value of 9.6. Respect to monthly distribution, most cases have occurred between May and September, as obvious consequence of summer convective activity (see FIG 2). Focusing on the spatial distribution, we can conclude that the majority of cases are concentrated in the east part of Basque Country and in mountainous areas (see FIG 3).

Number of AWS	1	2	3	4	5	6	7	9	13	tot
1999	5	3								8
2000	10			2						12
2001	3		2			1				6
2002	4	3	1							8
2003	1	1	1		2	1	1			7
2004	2	6						1	1	10
2005	5	1	2				1			9
2006	5	4	1	1	3					14
2007	5	1	2							8
2008	4	4		1	1					10

Table 1. Number of days where more than ten mm in ten minutes is registered and number of AWS where threshold is surpassed.

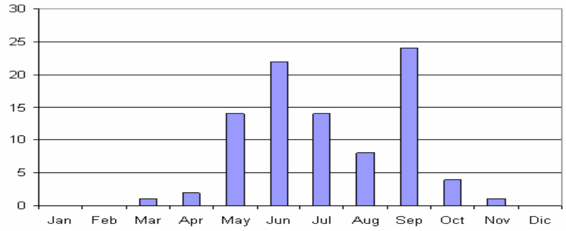

FIG.2: Number of cases by months.

FIG. 3: Spatial distribution of the study cases.

In summary, mean accumulated precipitations are 2.4, 4.5, 9.4 and 13.1 for 1-minute, 2-minute, 5–minute and 10-minute intervals respectively. For maximum accumulated precipitations, the values are 6.1, 10.2, 23.4 and 27.6 for 1-minute, 2-minute, 5–minute and 10-minute intervals respectively. On average, the data show that, the 73.1% of the precipitation registered in 10 minutes, is measured practically in 5 minutes.

The precipitations patterns have been analysed for 1 minute an 30 seconds intervals to characterize the precipitation distributions of a single shower. The mean summer shower duration is 25 minutes long.

When radar information is available, the convective systems responsible for the intense precipitations have been identified and studied. As a case study example, in FIG 4, radar images with 1-minute precipitation distributions for some stations affected by showers for the 2006 July 4th event are shown (see more details about this event in Gaztelumendi et al., 2008 and 2007). In this case, the 1-minute precipitation patterns are quite similar in the majority of the stations, since the storm crosses the studied area in 1-hour with nearly same structure.

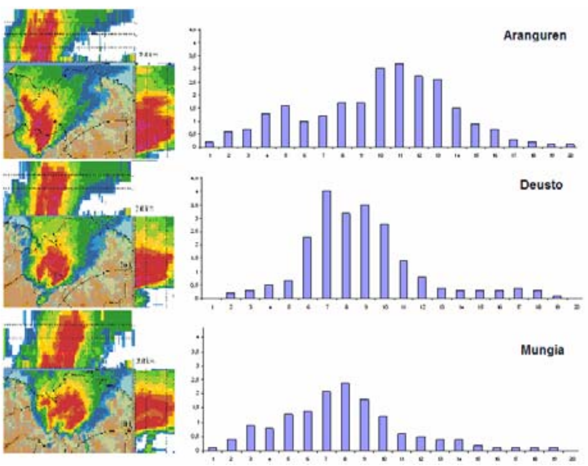

FIG.4: One-minute rain rate in Aranguren, Deusto and Mungia at showers from 4th july 2006 storm over Bilbao area.

In figure 5 a median time distribution derived from combining all the storms from the Basque Country network in the study period is shown. This curve shows that the rainfall in each quartile is 28%, 36%, 25% and 11% respectively.

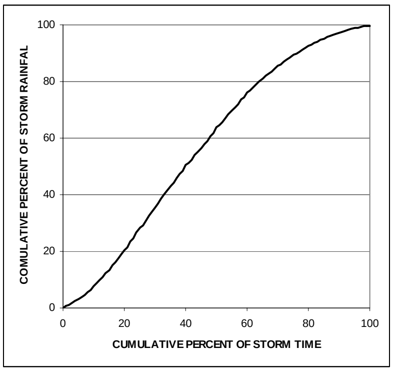

FIG 5. Median time distribution of the storms in the Basque Country (1999-2008)

IV. RESULTS AND CONCLUSIONS

In this work we have tried to characterize rain rates for intervals smaller than ten minutes in showers cases over the Basque country.

Significant rain events take place in the interval between May and September, when the troposphere is warmer and contain more water vapour.

Datarain instrumentation available in Basque Country mesonetwork seems to be useful as first attempt to characterize rain distribution smaller than 10 minutes interval, nevertheless the future incorporation of disdrometres in the network will improve this work.

V. AKNOWLEDGMENTS

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Circulation conditions of days with thunderstorm in Poland in the period 1971-2008

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ABSTRACT

The atmospheric circulation, observed on a synoptic scale, and atmospheric processes with a mezoscale coverage, are responsible for the occurrence of thunderstorm phenomena (Barnes and Newton 1986, Schaefer and all 1986). The said circulation processes, determining the transport of humidity and heat, also influence the intensity and duration of storm phenomena. Numerous authors occupied with thunderstorm activity have noted the strong connections of this activity with specific synoptic situations (Bielec-Bąkowska 2003, Brazdil 1998, Changnon 1998, Changnon and Changnon 2001, Kolendowicz 2006, Walker 1992). In the present study, we have performed an analysis of synoptic situations in the period 1971-2008 as a background of thunderstorm activity in Poland. The paper is based on the data pertaining to the occurrence of days with thunderstorm in 46 Polish synoptic stations within the IMGW (The Institute of Meteorology and Water Management) network in the years 1971-2008 (Fig.1). The analysis of lower synoptic maps for the researched period 1971-2008 made it possible to isolate seven types of synoptic situations characteristic of days with thunderstorms on the area of Poland. There were calculated in the study the probability of an occurrence of days with thunderstorms under the selected synoptic situations in each year of the period 1971-2008 in mean station fort the entire area of the country. The analyse of frequency of each synoptic situation and frequency of days with thunderstorm in distinguished situation during the period 1971-2008 were performed.

FIG. 1 Location of weather stations

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EFFECTS OF THE EL NIÑO – SOUTHERN OSCILLATION (ENSO) ON HEAVY PRECIPITATION AND ASSOCIATED LOSSES AT THE NORTH AMERICAN WEST COAST

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(Dated: 15 September 2009)

I. INTRODUCTION

According to NatCatSERVICE®-data on average 45 people per year died in the western parts of the USA and North Mexico between 1997 and 2007 due to catastrophes where heavy precipitation was involved. Estimated material losses summed up to about 800 Mio. US$ per year. Besides its devastating effect, heavy precipitation also contributes largely to annual rainfall (Gershunov und Barnett, 1998). At the same time the rainfall distribution and also the number of heavy precipitation events in America is biased by ENSO (e.g. Gershunov und Barnett, 1998; Cayan et al., 1999)). With growing knowledge this effect may be exploited to minimize losses due to severe precipitation events.

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II. PRESENTATION OF RESEARCH

In this work we analyse to what extend it is possible to infer seasonal estimates for extreme precipitation (EP) and associated losses exploiting SST-measurements with statistical means. The analysis is limited to extremes in the cold season, defined as the months Nov., Dec., Jan. and Feb., where the influence of ENSO is strongest.

The NCEP "US-MEX"-dataset which covers 1948-2005 is the basis of this study. It is a 1°x1°-gridded precipitation dataset derived from rain gauge measurements. Additionally excerpts of the NatCatSERVICE®-catastrophe-database are used. We analyse the connection between the frequency of EP-events and SST-anomalies of the previous months in three distinct regions of the Pacific. These anomalies are known as the Niño3-, the Niño3.4- and the Niño4-index.

As threshold for "extreme precipitation" we use the local 99.7th percentile of the daily precipitation amounts. This allows an assessment of the problem affecting different climatic regions. The choice of the 99.7th percentile is arbitrary, and is a result of balancing severity against number of detected events. It causes extreme events to be identified on long time average about once a year at every location. Evaluating climatological timescales of several decades in the period from 1950 to 2008, we find this to be a reasonable trade-off.

At first an ENSO-state was determined for every month out of each of the three Niño-indices. If the SST-anomaly of a month exceeded the 75th percentile of 1950-2008, this month was labelled El Niño (+), if the SST-anomaly lay below the 25th percentile, it was labelled La Niña (-). The remaining months were considered neutral (0). The results are three time-series of monthly ENSO-status, one for each Niño-index.

Calculating the frequency of EP for each grid point of the precipitation dataset, reveals an area covering South California, New Mexico, Arizona and northern parts of Mexico, which was more prone to EP in winter months that were labelled (+) according to the Niño3.4-index than in neutral ones. Less EP-events were registered in months labelled (-) than in neutral ones respectively. The study focuses on this geographic area (investigation area, IA) which is marked by the black rectangle in Fig. 1.

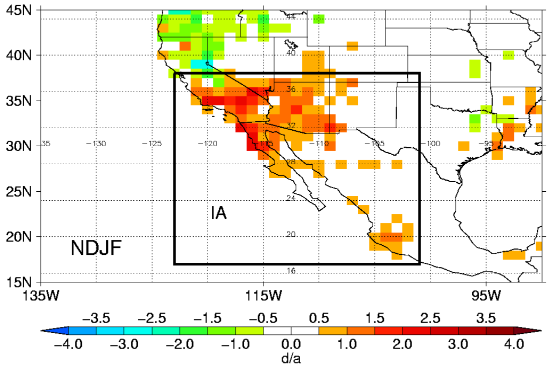

FIG. 1: Difference between El Niño- and La Niña-anomaly of EP-frequency in Nov., Dec., Jan. and Feb.. The investigation area (IA) is framed by a black rectangle.

We distinguish winter-seasons by the ENSO-status of one single month with a defined lead time. For example we compare all the cold-seasons where the ENSO-status with a lead time of five months (June) is positive (L5=+1) to all the cold-seasons where the ENSO-status with the same lead is negative (L5=-1). Another example would be comparing the winters where the month without any lead time (Nov.) is positive (L0=+1) to the (L0=0)-winters.

The labelling and therefore the comparison of the winters, is done separately for all of the three Niño-indices (Niño3, Niño3.4, Niño4). This allows assessment of which index is best suited to estimate the trend of an upcoming winter.

In general we found the count of EP-events to be higher in series of El Niño-labelled winters than the average count. To verify that this result is not by chance the Wilcoxon-Rank-Sum-Test on significance (e.g. Wilks, 2005) was used. It was performed for lead times ranging from zero to ten months and for all three Niño-indices. Also the EP-attenuating effects of La Niña were examined.

The differences in winterly EP-counts between positive labelled subsets and the whole series are quite remarkable in many cases. Thus we also computed the confidence levels of the El Niño average EP-count not just being higher than the overall average but also being higher than a defined threshold (115%, 130%, 145%, 160%). Fig. 2 shows the confidence-level for each threshold (different line-styles) for different lead times (x-axis).

Interpreting Fig. 2 in predictive sense one could say, if the July SST-anomaly in the Niño4-region is so warm that we can call July an El Niño-month, there is a chance of some 95% that in N, D, J, F the EP-count will exceed at least 145% of the average in the investigation area.

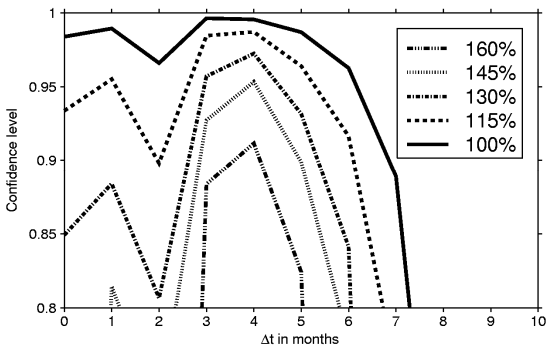

FIG. 2: Probability of EP-count in El Niño-winters being higher than the average multiplied by five different percentages when ENSO status is derived at lead time Δt.

Concerning the reinsurance loss data a similar scheme is applied. A series of an annual winter-damage-index is constructed. This index is based on the number of reported events with medium-severe to severe damage to infrastructure and/or death tolls ranging from 20 to 500 fatalities (NatCat-category three and four). In the aspect of reinsurance these are medium-severe events. The limitation to Cat3&4-events is a trade-off between a desired level of severity and a sufficient number of reports to make statistics. Comparing the El Niño-winters with the whole series yields similar results to that shown in Fig. 2. Only reports after 1975 are used, so the sample size is reduced to 32 years. This implies that for the same effect lower confidence-levels are to be expected. Nevertheless, we find that the damage-index is 15% higher than normal if El Niño conditions are met in the Niño4-region in July with a confidence of 95%.

One-point-correlation maps between monthly SST-anomalies out of a gridded dataset (EERSTv.3) and the winterly EP-frequency are calculated for different lead times for the period from 1951 to 2004. This suggests most preferable areas where SSTs should be monitored to gain the most value for estimating EP-frequency. Fig. 3 depicts the one-point-correlations between June-SST-anomalies and winterly EP-counts.

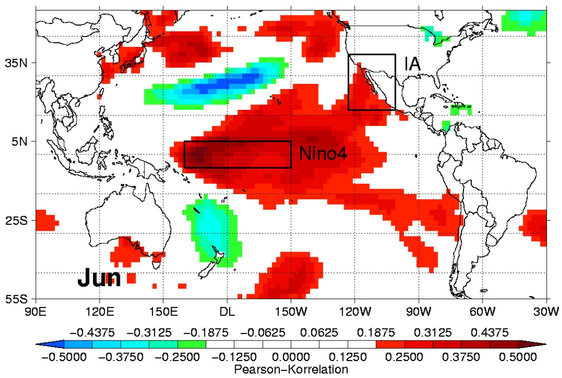

FIG. 3: Correlation-map of 1951-2004 June-SST-anomaly with winterly EP-frequency in the investigation area (IA). The Niño4-area is marked by the wide rectangle.

It reveals that the Niño4-region encloses a region of high correlation very well. The maps for increasing lead times show that the red area of high correlation is shrinking from east to west, so that the Niño4-area contains high correlation values longest compared to the other Niño-areas (Reinhardt, 2009).

Cox regression models are used for further analysis as suggested by Maia and Meinke (2008). The advantage over linear regression is that Cox models provide a) probabilistic results in terms of probabilities for the EP-frequency to exceed thresholds as well as related confidence intervals and b) a judgement if the used covariates (i.e. the different Niño-indices at different lead times) are appropriately chosen. Verification of the regression results identify the limitations of seasonal forecasts based on one single Niño-index value. For lead times between zero and five months one can expect 70%-75% correct forecasts in the sense of predicting winterly EP-activity above or below average. Computed probabilities of occurrence of very severe winters are connected with the highest uncertainty. This is also due to the low number of observations of such winters.

III. RESULTS AND CONCLUSIONS

In this work it is shown that exploiting the "July-or-later"-SST-anomalies in the Niño4-region yields a hint of above- or below-average precipitation in the winter-season. But it is also shown that Central-Pacific SSTs account merely for about a fifth of the variability of wintertime extreme precipitation.

A connection between the Central-Pacific SSTs and NatCat events exists but could only be detected at lower significance than for the extreme precipitation events.

Cox-type regression as suggested by Maia and Meinke (2008) can be applied quickly to detect weaknesses or limitations in the covariate selection. However, more research on the matter is needed if one wants to use this regression type operationally since the Cox-type approaches and associated methods are not as illustrative as plain tests on significance.

IV. AKNOWLEDGMENTS

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A CLIMATIC INVESTIGATION OF INTENSE PRECIPITATION ASSOCIATED WITH 500-HPA CYCLONES WHICH ARE AFFECTING GREEK TERRITORY DURING WARM PERIOD OF THE YEAR

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I. INTRODUCTION

Intense precipitation events are closely related to natural hazards such as flash flood and soil erosion. These natural hazards are usually producing severe damages in both natural and anthropogenic environment. They are also very destructive to plantations and agriculture in general, especially during the warm period of the year when plants are in active development stage. Precipitation occurrence in Greece under various synoptic conditions has been studied in the past (Laliotis, 1977) and several factors (surface depressions, fronts etc) were identified. However, during warm season of the year in this Mediterranean region these factors are lacking. Identifiable synoptic features are usually found only at the upper levels (i.e. 500 hPa). The most common features related to precipitation are closed lows which are also described as upper air cyclones. Cold air masses usually accompany such lows and extend to lower and higher levels. This is the reason for naming these synoptic features as "cold pools" (Papagiannakis, 1967) in the early stages of synoptic meteorology. Weather conditions have been studied only for certain places in Greece (Maheras, 1982) during the domination of such synoptic features. For example in Thessaloniki, Maheras notices the slow movement of cold pools toward the east and the production of a daily precipitation on the average 5.3 mm. The long lasting cloud cover, the high relative humidity (70% on the average) and the small daily variation of the temperature are also noticed.

II. METHODOLOGY AND DATA

The 40-year (1958-1997) NCEP/NCAR reanalysis gridded data of geopotential height with a 2.5ºx 2.5º spatial and 6-h temporal resolution (00, 06, 12, 18 UTC) are used in this study (Kalnay et al., 1996). The investigation covers the warm season of the year (15 April to 15 October). Lows or Cyclones were determined as local minima in each 3X3 matrix of geopotential height values in the area of investigation (Spanos et al., 2003). The investigated area covers parts of central and east Mediterranean region (30º north to 50º north latitude and 5º east to 35º east longitude). A variation of the "nearest neighbour" track algorithm (Trigo et al., 1999) is employed in the determination of tracks. A sub-area which consists of 36 grid points and includes Greek peninsula is selected for the investigation of the relationship between cyclone occurrence and intense precipitation events. When detected cyclones in the sub-area are parts of the same track, the occurrence with the lowest geopotential height is considered. Cyclone occurrence in the sub-area is divided in 9 groups. Each group consists of 4 grid points and is characterized by its orientation within the investigated area. The characterization involves two letters (i.e. SW represents the southwest group) and is presented in FIG. 1. The number below the name of the group indicates the number of cyclone occurrences. Intense precipitation episodes are examined only during these occurrences.

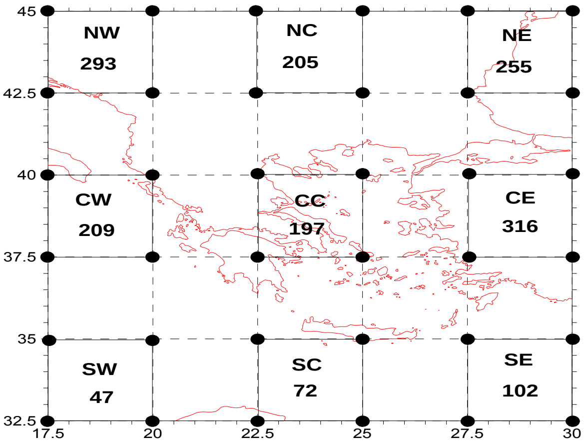

FIG. 1: Characterization of cyclone groups according to the relative orientation within the investigated area.

Intense precipitation events were determined from daily precipitation data collected at a 20-station network which was operational during the same time period. Intense precipitation days are defined those with a precipitation amount exceeding a threshold value. Intense precipitation is considered as rare event in each of the stations and a probability distribution is required to accurately determine the threshold. However, probability distributions are different in the 20 stations. In a similar study by Maheras et al., (1999) for Thessaloniki station (included in data base) a value of 30 mm/day is selected. The same value is maintained in this study also for comparison purposes.

III. SPATIAL DISTRIBUTION OF RELATIVE FREQUENCY OF OCCURRENCE

The spatial distributions of intense precipitation occurrence frequency for each of the nine cyclone groups are produced and examined. The distributions are presented in the form of relative frequency charts which are also used as a diagnostic tool for probability estimation. The examination of local maxima in these distributions, revealed two main patterns. The first is when local maxima or high frequency values coincide with cyclone centres and the second when spatial differences are observed. The coincidence indicates vertical instability as the primary factor for precipitation development.

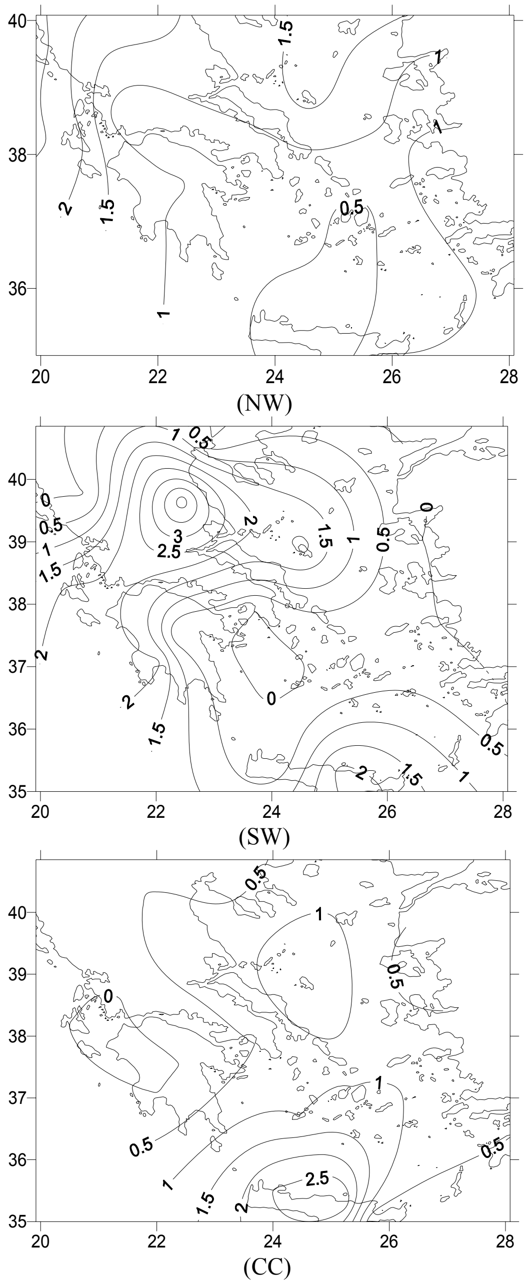

FIG. 2: Relative frequency (%) spatial distributions of intense precipitation for the cyclone groups NW, SW and CC.

In the second pattern the spatial differentiation can be attributed to two factors. The first factor is the mountain orientation relative to low level flow and the second is positive vorticity advection (PVA) related to major trough axis which accompanies the cyclone. FIG. 2 shows three representative distributions corresponding to the domination of the factors described above. Precipitation in the NW group of cyclones (FIG. 1) is related to vertical instability produced by the combination of upper cold air and low level heating over continental areas in the northwest of Balkans. Precipitation in the SW group (FIG. 1) is related to the orientation of Pindos mountain chain (at the centre of the Greek Peninsula) relative to low level flow. Cyclones of the SW group are usually accompanied by surface lows over Aegean Sea with an easterly flow toward the Pindos Mountains. The orographic effect enhances the precipitation over eastern slopes of the mountain chain (Prezerakos and Flocas, 1996). In the CC group (FIG. 1) precipitation is related to PVA centres which are usually located to the south or southeast of the cyclone centres (Spanos, 2004).

IV. CONCLUSIONS

Intense precipitation (more than 30 mm/day) during the warm season over Greek territory is a rare event with frequencies not exceeding 4% of the cases in which, a 500 hPa cyclone prevails in the synoptic situation. When a 500 hPa cyclone dominates in the vicinity of Greece three main factors contribute in the development of intense precipitation events. These factors act together but can be identified as primary factors for the various groups of cyclones. The first factor which is vertical instability is the dominant factor for the cyclones occupying the south and central parts (SC) or the northwest (NW) parts of the investigation area. The second factor is a combination of orography and the orientation of Pindos mountain chain relative to flow patterns. This factor plays an important role in the case of south west (SW) and central west (CW) cyclone groups. In all other cases the positive vorticity advection factor seems to be of primary importance for the intense precipitation events.

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SIMILARITIES BETWEEN SEVERE STORMS PRODUCED ALONG THE ROMANIAN BLACK SEA COAST

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I. INTRODUCTION

Previous studies on the genesis and evolution of storms produced along the Romanian shore showed that the most frequent and the most violent storms occurred during synoptic conditions described as the „couple anticyclone/ depression, with travelling disturbances from the Mediterranean sea to the Black sea". More than 50% from the 185 events identified in 20 years (1974 to 1993) are the consequence of this type of circulation (Chiotoroiu, 1999).

Violent storms are a major risk for human activities, for the infrastructure and the shoreline stability. Such events have already caused important damages along the Romanian Black sea coast: maritime accidents, shipwrecks, coastal erosion and coastline retreat etc.

In this study the most severe storms have been examined using the SLP, 500 hPa and 850 hPa maps, the meteorological parameters recorded by the coastal and offshore meteorological stations, as well as vertical soundings and different satellites images.

II. PRESENTATION OF RESEARCH

Storms in the western part of the Black Sea have been already defined using two hydro meteorological parameters: *wind speed >12 m/s* (force 6 Beaufort) for at least 12 consecutive hours and *sea state 4 near the coast* (wave height 1.25 m–2.50 m), in order to assess meteorological risks in navigation (Chiotoroiu, 1999). Based on these values, 316 storm situations were identified to have occurred over a period of 32 years (between 1974 – 2005) along the Romanian Black sea coast (Chiotoroiu, 2009). The distribution of the storm frequency over the 12 months of the year for the 1974-2005 period, clearly indicates the maximum frequency of the storms in the western part of the Black Sea in the cold season, between November and March, with a maximum in February, December and January (Chiotoroiu, 2009).

Storm situations studied in this paper have been considered when the above mentioned values were registered in at least one of the Romanian meteorological coastal stations, Sulina or Constanta. The following events have been selected, depending on the maximum wind speeds and waves heights and on their consequences (often catastrophic): 17-23 February 1979 (considered as the historic storm, because of its duration of 5-6 days and of the consequences on the shoreline retreat and on the Constanta port infrastructure); 6-12 December 1991, 3-5 January 1995 (when two ships sunk near the north breakwater), 17-20 November 2007 (the maritime disasters in the Kerci strait caused an ecological catastrophe), 1-5 January 2008 (a barge laden with grain sunk in the port of Constanta).

During these storms, there is a „couple" anticylone/ depression over the Romanian coast at sea level. The term is frequently used in the litterature, e.g. by Cordoneanu (2004) when describing the winter wind „Crivatz" large scale pattern. The cold anticyclone is situated in the northern or the north-eastern part of Europe and the Mediterranean depression extends over the Black sea. Strong winds are the consequence of a strong pressure gradient (figures 1 and 2).

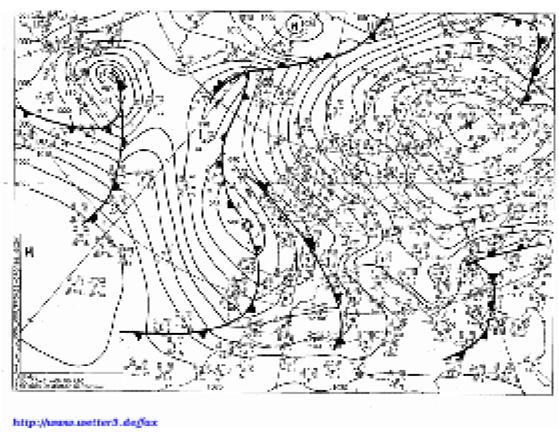

FIG. 1: SLP the 03.01.2008, 06UTC

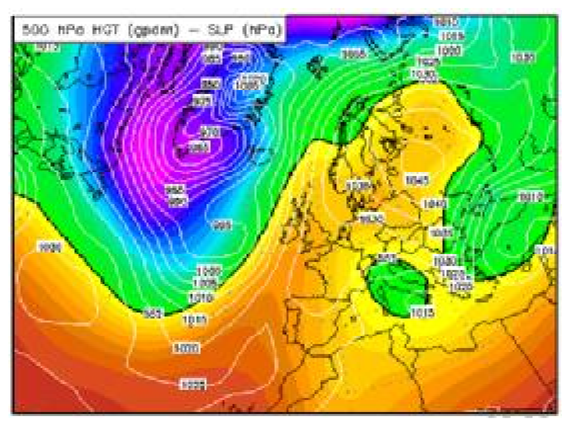

FIG.2 : SLP the 20.02.1979, 00UTC, www.wetterzentrale.de/topkarten/fsrea2eur.html

At 850 hPa and 500 hPa levels, a large trough can be observed, extended southerly over the Mediterranean sea. Its ascending part is situated over the Romanian Black sea coast. Cold air advections from the west or south-west can be observed, according to the position and movement of the cold air pools (figures 3 and 4). The upper trough position favours the further development of the surface low over the Black sea (Trigo et al., 2002).

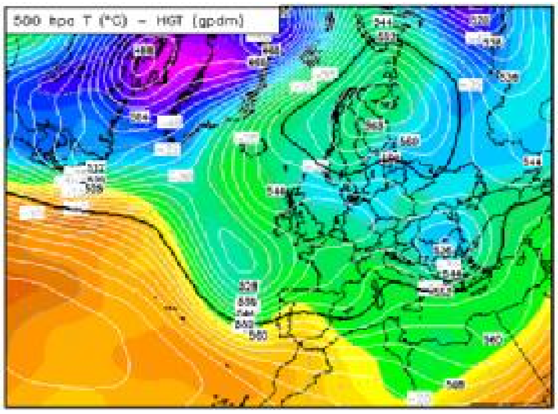

FIG. 3: 500 hPa temperature – gpdm the 03.01.2008, 00 UTC, www.wetterzentrale.de/topkarten/fsrea2eur.html

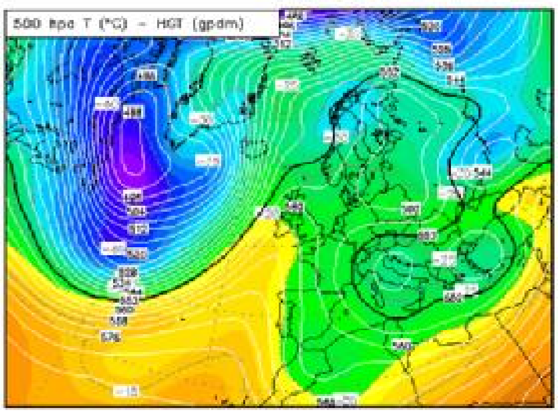

FIG. 4: 500 hPa temperature – gpdm, the 19.02.1979, 12 UTC, www.wetterzentrale.de/topkarten/fsrea2eur.html

Due to the location of the cyclone in the Black sea, winds blow constantly from north-east (4 cases) or north (December 1991). Maximum wind speeds exceeds 24 m/s in the open sea and waves height exceeds 8 m (figure 5). The vertical variation of wind speed and direction can be better examined on the vertical soundings.

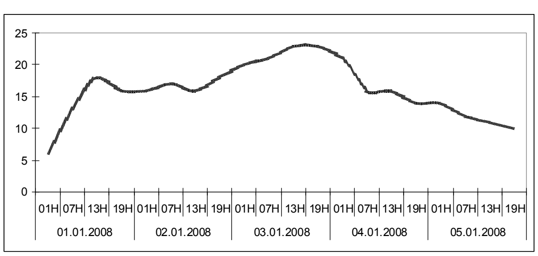

FIG. 5: Wind speed, m/s, Gloria offshore platform, 01.01-05.01.2008

The air temperature contrast between the cold and dry continental air and the warm and humid maritime air, which intensifies the wind, can attain 10°C (+5°C at Gloria due to the warm sea and –5°C at Constanta the 08.12.1991).

CONCLUSIONS

The most severe storms along the Romanian Black sea coast are the consequence of the decreasing geopotential associated with a mediterranean depression at sea level, with travelling disturbances from the Mediterranean sea to the Black sea. The dynamic of the two atmospheric centres at sea level - the continental anticyclone and the depression determines the wind force.

This study can contribute to a better recognition of similar synoptic situations with the main purpose to better evaluate severe storm risks.

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