COMPOSITE MEAN AND ANOMALY OF SYNOPTIC CONDITIONS FOR WATERSPOUT DAYS OVER SOUTH AEGEAN SEA (S. GREECE)

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I. INTRODUCTION

Waterspouts (WS), funnel clouds (FC) and tornadoes could be characterized as the most spectacular and violent of all small-scale natural phenomena. Such extreme weather events always fascinate the mankind, motivate studies and attempts to understand the mechanisms that produced them.

Fundamental processes of waterspout formation and detailed structural analyses have been examined by Golden (1973, 1974a, 1974b, 1977) describing the five stages of waterspout: a) the dark spot, b) the spiral pattern, c) the spray ring, d) the mature waterspout and e) the decay stage. Golden (1974 b) introduced waterspouts association with energy and angular momentum fluxes among five scales of circulation: a) the funnel scale (3-150m), b) the spiral scale (150-1000m), c) the individual cumulus-cloud scale (from less than 2 to 10 km), d) the cumulus cloud-line scale (10 – 200 km) and e) the synoptic scale.

The complex inland terrain of Greece along with the Ionian Sea at the west and the Aegean Sea at the east, appears to be a vulnerable area for violent phenomena such as tornadoes, waterspouts and funnel clouds. However, tornadic literature for Greece was very limited up to 2000. Significant research has been carried out during the last decade, including tornado and waterspout overviews and the first climatology for Greece (Sioutas 2003; Matsangouras 2011b), waterspout occurrences and forecasting (Sioutas and Keul, 2007; Keul *et al*., 2009) and a 20th century climatology (Nastos and Matsangouras 2010). In addition to these publications, reports and analyses of some important tornado and waterspout case studies have been carried out (Sioutas *et al*. 2006; Matsangouras and Nastos 2010; Matsangouras *et al.* 2010; Matsangouras *et al*. 2011a; Matsangouras *et al*.2012; Nastos and Matsangouras 2012).

Apart from the aforementioned studies, several reports submitted to the European Severe Weather Database (ESWD) and the Greek tornadic-report-database at University of Athens, have given evidence that south Aegean Sea (and especially the water body located northly from the coasts of Crete island) is a vulnerable area for waterspouts and funnel clouds to occur. Occasionally waterspouts have been appeared on shore over the north coasts of Crete island, causing significant impacts to the local society. In this study, daily composites (averages) of the mean and anomalies (with respect to 30 years climatology 1981-2010) of synoptic conditions for waterspout days over the south Aegean Sea were quantified, based on National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis datasets. Additionally, an updated climatology of the phenomena is presented and analyzed.

II. DATA AND METHODS

Our area of inetrest is located over the south Aegean Sea and especially the north coasts of Crete island. As south Aegean Sea is defined the water body oriented by the Cyclades complex island and the north coasts of Crete island.

The Laboratory of Climatology and Atmospheric Environment (LACAE, http://lacae.geol.uoa.gr) of the University of Athens has undertaken a systematic effort in recording tornadoes, waterspouts, and funnel clouds in Greece since 2007. LACAE developed in 2009 an open-ended online tornadic report database web system (http://tornado.geol.uoa.gr), contributing to the compilation of a climatology of these extreme weather events. We used datasets containing 139 waterspouts and 16 funnel clouds in 54 and 12 days respectively over south Aegean Sea of Greece (1957-2012). From the total of 139 recorded waterspouts 8 of them came onshore and caused significant damage to the local society.

In this study, the daily composite mean and anomaly of synoptic days for waterspouts over south Aegean Sea (south Greece) were analyzed and discussed based on the aforementioned climatology. Funnel clouds that were spotted over the water body of Aegean Sea were characterized as waterspouts at composite stage. The environment of each waterspout day was interpreted by NCEP–NCAR reanalyses datasets (Kalnay et al. 1996) for the period February 2, 1954 to October 23, 2012. The daily composite anomalies were calculated with respect to 30 years climatology (1981-2010) of the synoptic conditions.

The analysis of composite mean and anomaly of synoptic conditions is carried out in terms of seasonal variability for specific barometric pressure level of 500 hPa, and the Mean Sea Level Pressure (MSLP), along with the dynamic Lifted Index (LI) from NCEP/NCAR Reanalysis datasets. .

III. SOUTH AEGEAN SEA WATERSPOUTS' SPATIO-TEMPORAL ANALYSIS

Our analysis concerns the period 1954-2012, as the first event was recorded on February 2, 1954 at Rethymno prefecture coasts and the latest event on October 23, 2012 at Heraklion prefecture coasts of Crete island (Fig. 1). A total of 155 events have been recorded and catalogued on 59 days, as there were several days with multiplied events. It is worthy to mention that 8 more historical events of waterspouts were recorded before 1954, 5 of them came onshore with significant damage.

The spatial distribution depicts that waterspouts are favored over specific sub-regions: a) north coasts of Chania Prefecture, b) north coasts of Rethymno Prefecture and c) north coasts of Heraklion Prefecture of Crete island (Fig.1). Almost 2/3 (73%) of total waterspouts occurrence over south Aegean Sea concern the north coasts of Heraklion perfecture, while the rest of waterspouts are equally distributed over the two aforementioned sub-regions.

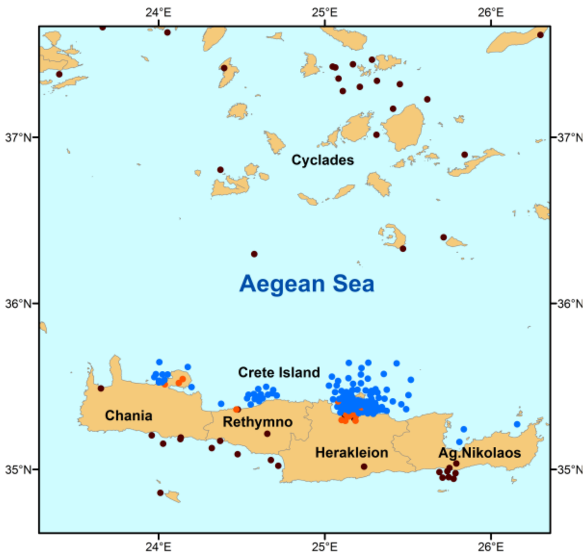

FIG. 1: Spatial distribution of tornadic events (brown dots) over south Aegean Sea. Blue dots and red dots represent the waterspout and funnel clouds activity north of Crete island, respectively.

Based on number of waterspout events, autumn is characterized as the dominant season for waterspout development over south Aegean Sea, followed by winter, summer and spring (Fig.2). Regarding the waterspout days the dominant season is autumn, followed by winter, spring and summer (Fig.2).

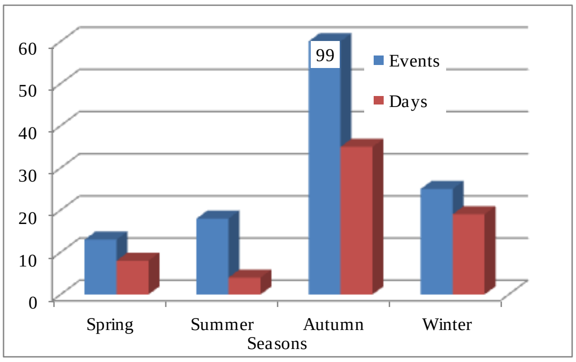

FIG. 2: Seasonal distribution of waterspout events (blue bars) and waterspouts days (red bars) from 1957-2012, over south Aegean Sea.

The monthly distribution depicts that September is the primary month based on the number of waterspout events followed by October and July (Fig.3). Taking into account the waterspout days , it is revealed that October is the dominant month for waterspout development followed by November and September. Waterspouts diurnal distribution (not shown) presents two diurnal peaks (not shown): the first happens early in the morning (07:00-09:00 UTC) and the second one after noon time (14:00-15:00 UTC). These two maxima of diurnal distribution reveal a diurnal pattern of activity, broadly similar to the behavior in Key West Florida vicinity (Golden, 1973), in Nassau Bahamas (Petersen, 1978) and around Catalonia during 1950-2009 (Gaya *et al*. 2011).

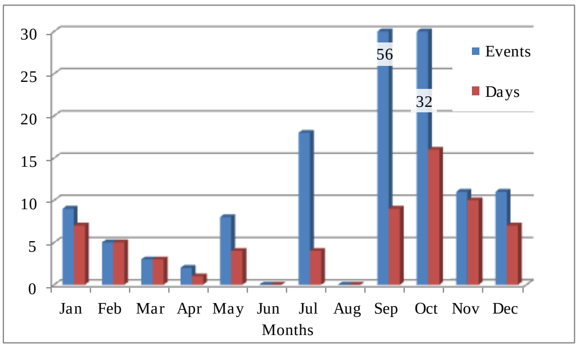

FIG. 3: Monthly distribution of waterspout events (blue bars) and waterspouts days (red bars) from 1957-2012, over south Aegean Sea.

IV. SYNOPTIC-SCALE METEOROLOGICAL CONDITIONS

The synoptic-scale conditions associated with the development of waterspout events, based on seasonal and geographical composite analyses, are discussed in this section.

During autumn season, a very broad trough at 500 hPa is located along Aegean Sea, suggestive of W-NW upper-air flow over Crete (Fig. 4). As far as the composite mean of MSLP is concerned, the combination of high pressure over central Europe and low pressure over the eastern Mediterranean Sea, establishes N-NW air flow at the surface over the area of interest.

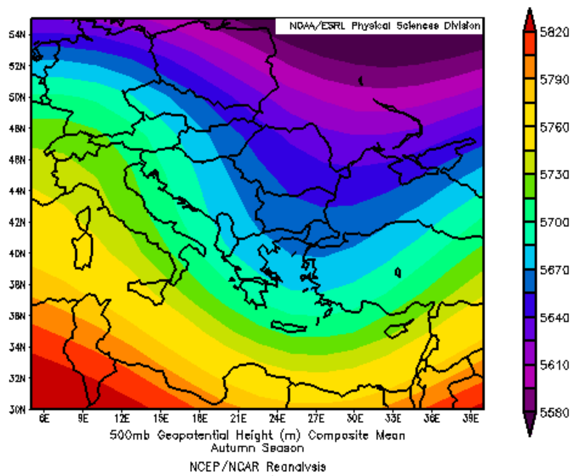

FIG. 4: Daily composite mean of waterspout days during autumn at 500 hPa pressure level for the period 1954 to 2012.

Finally, the composite daily anomaly at 500 hPa barometric pressure level during autumn, presents a deepening of geopotential height at least equal to 60 m over south Aegean Sea (Fig.5). The daily composite anomaly of MSLP during this season reveals a pressure decrease more than 8 hPa (not shown) over an extensive region at south Turkey.

Long term means (clino) during autumn season (not shown); based on NCEP-NCAR Reanalysis 1981-2010 period, at 500 hPa reveals a zonal flow over south Europe. Based on this long term climatology of MSLP, the combination of high pressure over Balkans and low pressure over east Mediterranean Sea establishes a NE and N-NW air flow over north and south Aegean Sea respectively.

During winter period (not shown) the composite mean at 500 hPa reveals a deep through (which is evidence also in lower levels) along the south Ionian Sea causing a W-SW air flow over south Aegean Sea. Looking at surface, a shallow cyclonic circulation is depicted over the south Aegean Sea, while the composite anomaly of MSLP is equal to -8 hPa over Crete island. The composite anomaly at 500 hPa (not shown) is equal to -80 m over the south Ionian Sea (SW Greece).

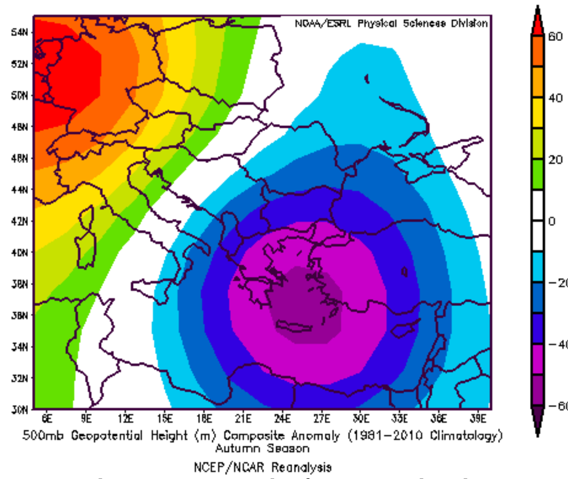

FIG. 5: Daily composite anomaly of waterspout days during autumn for 500 hPa pressure level for the period 1954 to 2012.

The daily composite mean synoptic conditions at 500hPa for waterspout days during spring season is characterized by a broad trough along eastern Aegean Sea, and is associated with a NW-W upper-air stream over the area of interest (not shown). The composite daily anomaly at 500 hPa during this season appears to be more than -100 m centered over the south Aegean Sea. Over the same vicinity the MSLP daily mean anomaly for waterspout days is calculated to -3 hPa and the maximum deepening is located over Turkey mainland (not shown).

A long trough located along SE Balkans and central Greek mainland is the main characteristic at 500 hPa during summer waterspout days. At the surface, a shallow cyclonic circulation is located over eastern Mediterranean Sea causing N-NW surface winds over the area of interest (not shown). Concerning the daily composite anomaly at surface, it is equal to -2 hPa over the south Aegean Sea while a deepening of -50gpm over SE Balkans and NE Greece (not shown) is obvious at 500 hPa pressure level

The Lifted Inded (LI) daily composite mean seasonal variability over south Aegean Sea reveals low values of -1 to 0 during autumn season, followed by spring and summer. During waterspout days the daily composite anomaly was maximum (-1.5 to -2°C) during autumn and winter season.

Our daily composite mean synoptic results within 1954-2012 are in agreement with the favor synoptic types for tornadoes and waterspouts development in Greece within 2000-2009, presented and discussed by Sioutas (2011), Nastos and Matsangouras (2012) and Matsangouras *et al.* (2011b)

V. ACKNOWLEDGMENTS

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