WATERSPOUT OUTBREAKS OVER EUROPE AND NORTH AMERICA: ENVIRONMENT AND PREDICTABILITY

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I. INTRODUCTION

Waterspouts are defined as tornadoes over a water surface of a sea or lake. One of the most impressive waterspout occurrences are the so called "waterspout outbreaks", that are referred to as multiple simultaneously or successively waterspout forming. As Galway (1977) stated for tornado outbreaks, "a waterspout outbreak can mean many things to many people". In *Glossary of Meteorology* (Glickman, 2000) a tornado outbreak is defined as a ''multiple tornado occurrences within a single synoptic-scale system''. Within the context of this study a waterspout outbreak is considered as multiple waterspout events over a region and for given period of time, generally produced by the same synoptic system.

Meteorological aspects in terms of synoptic, mesoscale and thermodynamic environments are examined in order to identify weather patterns most conducive to waterspout outbreaks. This examination also included the use of the Szilagyi Waterspout Index (SWI) (Szilagyi, 2009), which is used for predicting waterspout events. Inter-comparisons between waterspout outbreak characteristics for the different geographical areas are also examined.

II. PRESENTATION OF RESEARCH

The areas of research are those of the Aegean and Ionian Sea and the Baltic Sea of Europe and the Great Lakes of North America. On September 5, 2002, Keul documented a series of 13 waterspouts in the Eastern Mediterranean off the Cretan north coast (Keul, 2003). ESWD documented two outbreak days (August 11 & 13, 2006) over the Baltic Sea in which 10 waterspouts occurred on each day. During the fall of 2003, Szilagyi documented a record breaking outbreak of 66 waterspouts over a seven day period over the Great Lakes of North America (Szilagyi, 2004). Waterspout outbreaks for the purposes of this study are classified as either small SO (2-9 waterspouts), moderate-MO (10-19), or large-LO (20 or more) occurring on a single calendar day (12:00 through 11:59 UTC).

During the period 2000-2011, 165 individual waterspouts were reported in 47 outbreak days over the Aegean and Ionian Sea, and were classified as SO (45 days), MO (1 day) and LO (1 day). For the same period, 176 waterspouts were reported in 27 outbreak days over the Baltic Sea, and were classified as SO (25 days), MO (2 days) and no LO days. During the period 1994-2010, 731 waterspouts were reported in 158 outbreak days over the Great Lakes, and were classified as SO (149 days), MO (7 days) and LO (2 days). The waterspout outbreak approximate locations for the three areas of research are shown in Fig 1a,b,c.

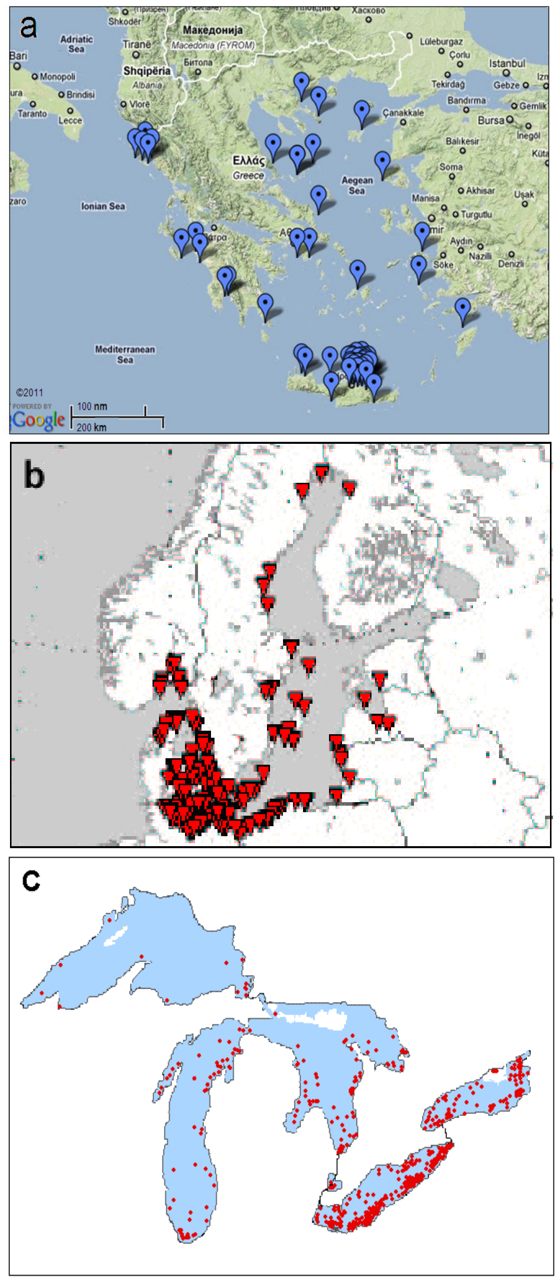

FIG. 1: Waterspout outbreak locations for a) The Aegean and Ionian Sea (2000-2011) b) The Baltic Sea (2000-2010, ESWD) and c) the Great Lakes, North America (1994-2010).

The spatial maximum of waterspout outbreak days for the Aegean and Ionian Sea, is located in the area north off shore of Crete Isl. (Fig. a). This area north of Iraklion, Crete Isl., exhibits the majority of outbreaks recorded, 21 out of 47 WSO days, concentrating also the great majority of waterspout activity of the Aegean Sea (Sioutas, 2003 and 2011). Primary role for waterspout favour conditions seems the dominant northern flow in the southern Aegean Sea, interacted with local conditions such as land breeze and low level enhanced instability.

The Baltic Sea map depicts all ESWD-reported tornado events over water. As can be seen in Figure 1b, the Baltic Sea has both most waterspout events and most events associated with outbreaks in the southwestern area between Germany, Denmark and Sweden.

For the Great Lakes, Lake Erie exhibits the highest frequency of outbreaks. Lake Erie is the shallowest and warmest of the Great Lakes, resulting in the greatest instability and, hence, largest waterspout activity (Fig. 1c).

Considering yearly distribution of the examined 11-year data sample for the Aegean and Ionian seas, 2010 was the dominant year with 11 waterspout outbreak days followed by the 2006 with 8 days and 2008 with 6 days. 2006 was a singular year for the Baltic Sea with 11 outbreak days and 2010 had eight outbreak days. In the Great Lakes, 1999 was the dominant year with 16 waterspout outbreak days followed by 2006 with 15 and then 1996 with 14 waterspout outbreak days.

The monthly distribution, of waterspout outbreak days is displayed in Figure 2 for the three areas of the research. Most outbreaks occur in September, normally a month with warmest sea waters. October is followed and then in the summer months June and July. Similar to the Great Lakes of America, most Baltic outbreaks occur in August. For the Great Lakes, August exhibits the highest frequency of outbreak. This is the time of year when convergent line land breezes reach at their maximum. Land breezes are highly conducive to waterspout outbreaks.

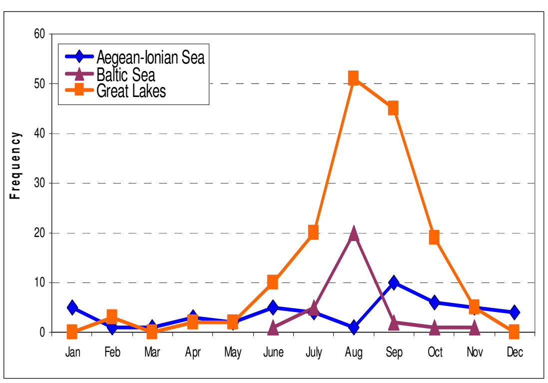

FIG. 2: Monthly distribution of waterspout outbreak days for the Aegean and Ionian Sea, Mediterranean the Baltic Sea and the Great Lakes, North America.

Synoptic conditions during waterspout outbreaks were examined by using of a synoptic scheme based on the circulation type of the 500 hPa level and the position and orientation of trough and ridge axes in conjunction with surface features (Sioutas and Keul, 2007). Four basic synoptic types were identified as most related to waterspout outbreaks, namely: south-west flow (SW), long-wave trough (LW), short-wave trough (SWT) and closed low (CLOSED). As illustrated in Figure 3, CLOSED type prevailed for the Aegean and Ionian Sea waterspout outbreaks, followed by SWT type. Baltic cases show the highest relative frequency of the CLOSED type, followed by SWT and then LW type, with no SW type. For the Great Lakes, the LW type pattern was most related to waterspout outbreaks. LW form quite frequently over North America to the lee of the Rocky Mountains.

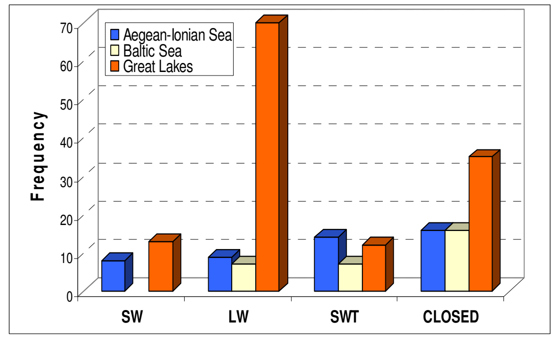

FIG. 3: Synoptic types on waterspout outbreak days, for the Aegean and Ionian Sea, Mediterranean, the Baltic Sea and the Great Lakes, North America.

The mesoscale conditions on WSO days was investigated by using of closed in space and time sounding data. Preferably upwind upper air stations data were chosen as most representative according to the prevailing synoptic flow. Mean values and standard deviations of thermodynamic parameters, conventional instability indices, wind and moist parameters, are illustrated in Table 1 for the Aegean, Ionian and Baltic Seas (no data for Great Lakes).

Thermo-dynamic parameters, indices, wind and moist parameters	**Aegean-Ionian Sea WSO days**		**Baltic Sea WSO days**	
	MEAN	**STDV**	**MEAN**	**STDV**
KI	27.8	3.9	18.0	12.8
TT	48.4	5.5	46.0	5.9
LI	0.3	2.3	2.5	3.2
SW	2.6	2.7	4.7	3.1
CAPE (J/kg)	264.2	329.9	154.3	109.6
BRN	31.2	65.4	27.7	26.1
SWEAT	136.2	55	103.7	42.2
MLMR aver. mix ratio low 500 m (g/kg)	9.4	2.2	7.5	1.9
THCK 1000-500 hPa (m)	5543.1	100.1	5360.0	83.4
PW (mm)	24.9	6.3	20.4	7.0

TABLE I: Thermodynamic parameters, indices, wind and moist parameters based on sounding data of WSO days in the Aegean, the Ionian and the Baltic Sea.

Generally higher values or clearly indicative of most unstable environment represent the Aegean and Ionian Sea data compared to the Baltic Sea. The mid and upper atmospheric role and contribution seems more significant in the Aegean and Ionian waterspout outbreaks than in the Baltic Sea outbreaks.

A correlation between outbreaks and the Szilagyi Waterspout Index (SWI) (Szilagyi, 2005, 2009) was investigated (Fig. 4).

The SWI is an index used to evaluate the potential for waterspout development. The development of the nomogram was initiated in 1994 with a large data set of 170 waterspout events that occurred over the Great Lake. This data set includes several meteorological parameters that were recorded at the time of each waterspout event.

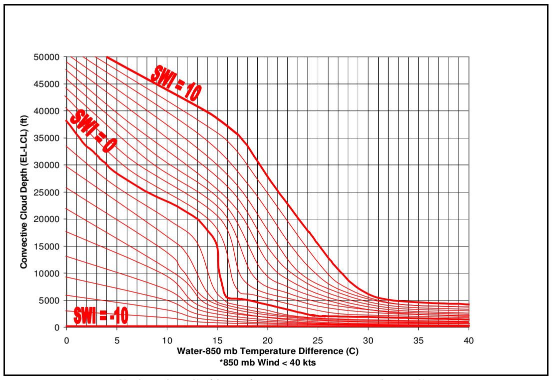

FIG 4. The Szilagyi Waterspout Index (SWI).

The SWI is based on 3 parameters that strongly correlate with waterspout events; Surface Water-850 hPa temperature difference, Convective cloud depth (EL-LCL) and 850 mb wind speed. The larger the value of SWI, the higher the potential for waterspout development.

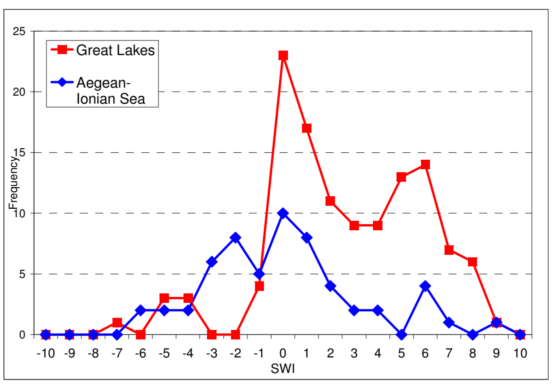

FIG. 5: SWI distribution for waterspout outbreak days, for the Aegean and Ionian Sea, Mediterranean and the Great Lakes, North America.

Outbreaks over both the Aegean and Ionian Sea, Mediterranean and Great Lakes of North America, are strongly correlated with SWI values of ≥ 0, and peaking at SWI = 0 as it is displayed in Figure 5. The Baltic Sea data, under further investigation have not included in this analysis.

III. RESULTS AND CONCLUSIONS

Meteorological aspects of waterspout outbreaks were studied in terms of synoptic, mesoscale and thermodynamic environments for three different areas over Europe and North America. Outbreaks showed strong correlation with certain environments and also showed some similarity between the different the areas of study.

For both Europe and North America, outbreaks peaked in the late summer months of August or September when water temperatures were at their highest and outbreaks of cooler air began.

Outbreaks were associated with all four synoptic types, however, favoured synoptic types differed between Europe (CLOSED) and North America (LW). These differences primary are attributed to the different geography and climatic backgrounds.

By using of the SWI nomogram, outbreaks were strongly correlated with the SWI for both the Mediterranean and North America. The great majority of waterspout outbreaks occurred with SWI values of ≥ 0, and peaking at SWI=0.

IV. ACKNOWLEDGMENTS

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