ANALYSIS AND FORECASTING OF WATERSPOUTS ON LAKE CONSTANCE

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I. INTRODUCTION

Waterspouts have been described in many parts of the world in the literature (Simpson et al, 1986): Wegener (1917), in his early work on tornadoes in Europe, already mentioned the abundance of waterspouts over Lake Constance and Dotzek et al. (2010) confirmed this finding with a climatology of waterspouts in Germany, based on more recent data. Golden (1974) described the life cycle of Florida waterspouts, and Wakimoto and Wilson (1989) provided a conceptual model of how waterspouts form over open ocean waters. Markowski and Richardson (2010) described well the mesoscale formation mechanism of intense vortices due to shear instability. Recently, Szilagyi (2009, referred to as SZ09 hereafter) as well as Keul et al. (2009) have shown how these events can be forecast in various regions and with different forecast approaches.

Most of these studies focussed either on coastal waters or large inland lakes such as the Great Lakes of the US-Canadian border, but only little is known about waterspout formation over small inland lakes surrounded by significant orography. Here we focus on the Lake Constance, an inland lake situated at the northern rim of the Alps at the Swiss-German-Austrian border (Fig. 1).

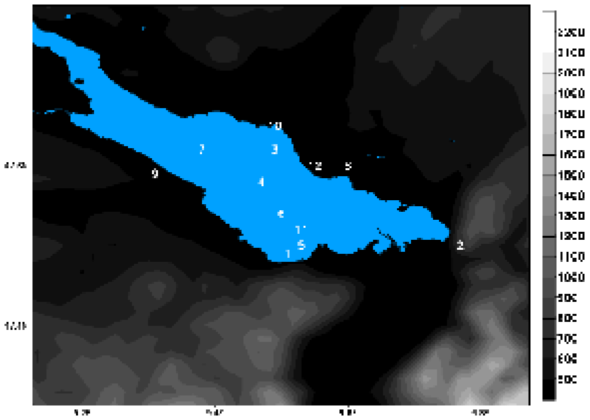

FIG. 1: Map of the study area (orography shaded in grey) with approximate location of events, numbers refer to Table 1.

The aim of this study is to identify the synoptic weather situations under which waterspouts occur and to test the Szilagyi Nomogram (Szilagyi 2009) as a possible forecast method for application in this area. The data set consists of a sample of 12 well documented events between 1999 to 2010 from the European Severe Weather data base ESWD (available online: www.essl.org/ESWD). Some events were characterized more precisely in regard to time of observation and geographical location based upon photographic material and eye-witness reports in various internet sources (weather fora, newspaper reports). Funnel clouds both over water and over land were excluded from the analysis, as well as tornadoes over land. Events over the western part of the lake were not taken into account either, because the orographical influence on the formation mechanism is much smaller in this area, if at all. Figure 1 shows the geographical locations of the 12 events. Note that some events are listed with the geographical coordinates of the reporting observers on the lake shore in the ESWD, although they probably occured on the open lake at some distance to the shoreline.

#	Date	Time	Location	Type
1	20100925	0815	Rorschach	cold air
2	20100805	1645	Bregenz	cold air
3	20080720	1600	Friedrichshafen	supercellular
4	20071021	1500	mid lake	cold air
5	20060804	0800	Rorschach	cold air
6	20041108	0900	mid lake	cold air
7	20030511	0900	mid lake	other
8	20030828	2230	Kressbronn	supercellular
9	20030831	1130	Kesswil	cold air
10	20010907	1445	Friedrichshafen	other
11	20000905	0730	Rorschach	cold air
12	19990707	1445	Langenargen	cold air

TABLE I: Waterspout events used in this study. Numbers in column one refer to map depiction in Fig. 1, date format is year-month-day, time in UTC. Location refers to closest city on lakeshore or to observer location. Subjective categories as explained in text.

II. SYNOPTIC WEATHER SITUATIONS

Standard meteorological fields were analysed for every single event within a 96-hour time window centred on observation time. The weather situations were then subjectively classified into three categories: the majority of events occurred after the passage of a high amplitude trough (sometimes cutting off over the central-eastern Alps) and accompanying surface cold front, followed by the buildup of an anticyclone over western Europe. These events were classified as "cold air events" since they usually occured in the cool westerly to northerly boundary layer flow over the warm lake waters. Composite maps of standard meteorological fields of all cold air events at observation time, based on ECMWF ERA-Interim reanalysis data (Dee et al., 2011) are shown in Figures. 2 and 3. Although the events occured at different seasons (May to November) the similarity of large scale meteorological conditions favouring waterspout formation on Lake Constance reveals the distinct synoptic structures that can be applied in an analog case-manner to forecast potential for occurence of waterspout.

Two events were classified as "supercell type" since they occured under typical summertime thunderstorm-prone gross weather types, characterised by (potentially) unstable, strongly sheared cyclonic southwesterly flow.

The two remaining events did not fit in the cold air or supercellular type patterns and were classified as "other".

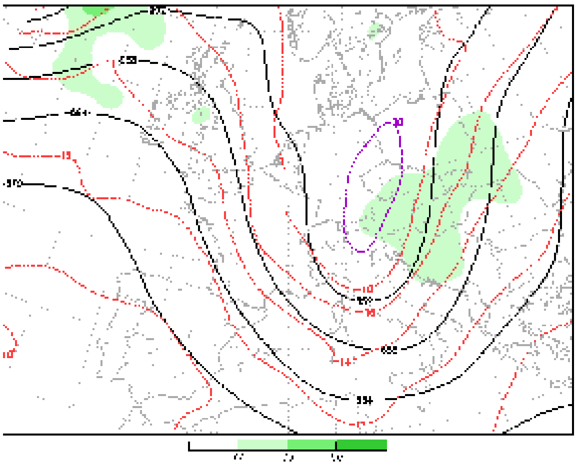

FIG. 2: Composite map of geopotential height (black contours), temperature (in degrees Celsius, colour contours) and relative humidity (shaded, according to colour scale) on 500hPa at observation time of all cold air events (see Table 1), based on ERA-Interim reanalysis data.

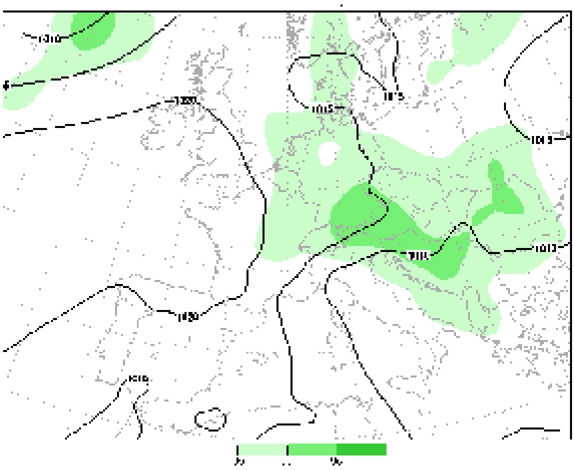

FIG. 3: Composite map of all cold air events, as in Fig. 2, showing mean sea level pressure (black contours) and relative humidity at 700 hPa (shaded, according to colour scale).

III. THE SZILAGYI NOMOGRAM

Three different sources of lake surface temperature point measurements were used that altoghether covered the whole period 1999 to 2009. Since the lake level is situated 400 Meters above mean sea level (amsl) the lake temperature was artificially reduced to 100 Meters amsl in order to make the results comparable with the data set used in SZ09. Assuming the missing column of air between 400 and 100 Meters amsl being stratified either isothermal, moist or dry adiabatic we added zero to three degrees Celsius to the original lake surface temperature readings to place the events in the Nomogram. Given the rather moist nature of waterspout-prone boundary layers a vertical lapse rate close to moist adiabatic is most probable. Convective Cloud Depth (equilibrium level - lifting condensation level) is diagnosed in a postprocessing manner in the three-hourly analysis fields from the MeteoSwiss' mesoscale COSMO model with seven kilometers horizontal resolution and up to 70 vertical levels (note that the model configuration changed several times during the period under consideration). For the four events from 1999 to 2003 model analysis are not available and the cloud depth was subjectively diagnosed from the three closest radiosoundings at Payerne (Switzerland), Stuttgart and Munich (Germany). The variability of the convective cloud depth even at those few model grid points over the lake is very high both in time as well as in space. To apply the method we have taken the average cloud depth over all lake-grid points at analysis time closest to the observation time. In the Nomogram (not shown) the events cluster in an area close to the one depicted by SZ09 as "Great Lakes Land Breeze-" and "Upper Low-waterspouts", but the majority of the events falls slightly outside the area where waterspouts are expected to form.

IV. CONCLUSIONS

A sample of Lake Constance waterspout events has been analysed. Subjective classification of the synoptic weather types indicated that the majority of the events occured during a distinct pattern of weather development that reflected well in a composite map of standard meteorological fields. Testing the SZ09 Nomogram method we found that most events fall slightly outside the region in the Nomogram that identifies waterspout-prone environments. At this stage we hypothesize that this lack of favourable environmental factors might be compensated for by additional low level convergence due to orographical effects, but more work is needed to corroborate this hypothesis. Since neither the composite map nor the Nomogram can discriminate weather situations that do or do not lead to waterspout formation with sufficient accuracy we advocate the use of a combination of these two methods together with climatological factors when trying to forecast probabilities of occurrence of waterspouts on Lake Constance.

V. REFERENCES

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