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An assessment of waterspout occurrence in the Eastern Adriatic basin in 2010: Synoptic and mesoscale environment and forecasting method

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ABSTRACT

In this paper we performed a comprehensive analysis of 19 waterspout events that occurred in the Eastern Adriatic basin in 2010. Data were collected from the synoptic and climatological weather stations and from eyewitness reports from newspapers and the internet. The geographical and temporal distributions of the waterspouts, as well as the absolute frequencies of four synoptic types relevant to waterspout development (south-west flow (SW), long-wave trough (LW), closed low (CLOSED) and short-wave trough (SWT)), are presented. The synoptic and mesoscale weather conditions were analyzed using the ERA-Interim reanalysis data, satellite images, data from synoptic and automatic weather stations and atmospheric soundings. To test waterspouts for thunderstorm relations the LINET network sensor data were used to infer lightning activity. Because thermodynamic instability indices are usually insufficient for forecasting waterspout activity, the performance of the Szilagyi Waterspout Nomogram (SWN) and the Szilagyi Waterspout Index (SWI) were tested using the ALADIN model. The results of the analyses of the 2010 cases show that the SWN successfully forecasted 15 out of 19 events (hit rate of 78.9%). This is a significant hit rate but is not as high as in the work of Keul et al. (2009), in which 96% of the Adriatic cases satisfied the nomogram. In addition, four selected waterspout cases, which represent the four basic synoptic types, were analyzed in detail to provide an overview of favorable atmospheric environments for waterspouts throughout the year.

1. Introduction

Tornadoes, dust devils and waterspouts are impressive meteorological phenomena not only to scientists but also to the general public. This work focuses on waterspouts that occur frequently in the Mediterranean basin and the Adriatic Sea region.

A waterspout is an intense columnar vortex (usually appearing as a funnel-shaped cloud) that occurs over a body of water and is connected to a cumuliform cloud (Glossary of Meteorology, AMS, 2000). Another descriptive explanation was given by Dotzek (2003): “Tornadoes are vortices which form from convective clouds and extend to the ground. Waterspouts are tornadoes over extended water surfaces.”

Although some waterspouts are strong and tornadic in nature, they are usually much weaker than tornadoes and are caused by atmospheric dynamics similar to the thermodynamic theory of dust devils proposed by Renno et al. (1998) and further developed by Renno and Bluestein (2001). Golden (1974) and Simpson et al. (1986) demonstrated that waterspouts are often initiated by fair-weather cumuli or cumulus congestus and not necessarily by thunderstorms (Dotzek et al., 2010).

Ruđer Bošković (1749) performed the earliest pioneering work on waterspouts in this region. His meteorological discussion *Sopra il turbine che la notte tra gli XI, e XII Giugno del MDCCXLIX danneggiò una gran parte di Roma dissertazione* (Dissertation about the storm of the night between 11 and 12 June of 1749 that damaged a large part of Rome) was the first written document on several waterspout events, some of which were waterspout outbreaks. Recently, comprehensive studies on this topic were undertaken by Poje (2004) and

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Ivančan Picek and Jurčec (2005). They showed that waterspouts are more frequent in late summer and in autumn than in other seasons. Moreover, they estimated that 40% of waterspouts last between 11 and 20 min (Poje, 2004).

Several studies on Adriatic Sea waterspouts were performed by Sioutas and Keul (2007) and Keul et al. (2009). Waterspouts typically form from spring to autumn, when colder air masses meet warm and moist air and/or move over the warmer sea surface (Sioutas and Keul, 2007). Giaiotti et al. (2007), in their preliminary survey of tornado and waterspout climatology in Italy, reached a similar conclusion that waterspouts are more frequent in late summer and in autumn than in other seasons. They interpreted this behavior as an interplay between perturbations (essentially cold air advections) and the occurrence of Mediterranean lows on the Tyrrhenian and Ionian coasts.

Keul et al. (2009) studied the typical synoptic circulation types associated with waterspout formation. For the Adriatic region, they assigned the following frequency rankings: SW, CLOSED, SWT and LW. This ranking differs from the findings of Sioutas and Keul (2007), in which the LW and CLOSED types were most frequent. Sioutas (2011) showed that SWT is the dominant synoptic type in the Ionian and Aegean Seas; SWT occurs in 33.4% of the days and is responsible for 47.1% of waterspout events. The CLOSED, SW and LW types follow with decreasing frequencies.

After analyzing the thermodynamic environment, Keul et al. (2009) also concluded that the K-Index and Total Totals Index produced relative frequencies that indicated the prognostic validity of the two markers. Because waterspouts can develop not only in the thunderstorm-related environment but also in fair weather, the thermodynamic instability indices are usually insufficient for forecasting. However, providing this information to specific communities, especially to sailors and marine facilities, is of great importance. Most of the previous work has focused on explaining physical processes and collecting data in an attempt to quantitatively assess the meteorological conditions that are favorable for the development of waterspouts. However, no forecasting method was available until 2005, when Szilagyi (2005, 2009) proposed an empirically developed method, known today as the Szilagyi Waterspout Nomogram (SWN). This method was developed as a result of continuous investigations of waterspout activity over the Great Lakes of North America and is based on a large sample of observed waterspouts. The nomogram is still being updated with new data. Two instability parameters, the water − 850 hPa temperature difference (ΔT) and convective cloud depth (ΔZ), and one wind constraint, the 850 hPa wind speed (W_{850}), were judged to be most strongly correlated with waterspout occurrence (Szilagyi, 2009). Keul et al. (2009) showed that the SWN could be used as a valid waterspout prognostic instrument for the Aegean, Ionian and Adriatic Seas.

Encouraged by the results described above and motivated by the large number of waterspouts observed during 2010, we conducted the research described in this report. Specifically, we examined the synoptic and mesoscale conditions that favor waterspout development and tested Szilagyi's forecasting index on the cases of waterspouts that occurred over the Adriatic Sea during 2010.

In the next section, we present data collected along the Croatian Adriatic coast in 2010. The geographical distribution and frequency of the phenomenon are illustrated. One of the four synoptic patterns most relevant to waterspout formation [south-west flow (SW), long-wave trough (LW), closed low (CLOSED) and short-wave trough (SWT)] was assigned to each case. Finally, the results of a forecasting method based on the ALADIN model are discussed.

2. Data and method

2.1. Waterspout cases in 2010

Nineteen waterspout events were recorded along the Croatian coast of the Adriatic Sea in 2010. Information and data were collected from the synoptic and climatological weather stations and from eyewitness reports available from newspapers and the internet. The approximate locations of the waterspouts are shown in Fig. 1 and have a regular distribution along the entire Eastern Adriatic coast.

The time, location, presence of lightning activity, weather type and SWN quality for the 19 events are listed in Table 1. In the majority of cases, the exact time of the event is known but the duration is uncertain. The number of individual waterspouts in each case is also unknown. Among the 19 cases, seven occurred before noon, three occurred around noon, and eight occurred in the afternoon. One occurred at night and may be questionable. Because of the small sample size, an hourly event distribution is unreasonable; therefore, Fig. 2 shows the distribution according to the time of the day and not the exact hour of occurrence.

Approximately 50% of the events were thunderstorm-related and were identified by the presence of lightning activity using the lightning data available from the LINET network (Betz et al., 2009), whereas the other events occurred in fair weather conditions. The synoptic and mesoscale weather conditions were analyzed using the ERA-Interim (Simmons et al., 2007; Dee et al., 2011; Berrisford et al., 2011) reanalysis fields as provided by ECMWF (European Centre for Medium-range Weather Forecast), satellite images, data from synoptic and automatic weather stations and atmospheric soundings. The synoptic weather types were distributed into four groups: south-west flow (SW), long-wave trough (LW), closed low (CLOSED) and short-wave trough (SWT). The corresponding synoptic types were obtained based on the circulation patterns at the 500 hPa level and the position and orientation of the trough and ridge axes in conjunction with surface features (Sioutas and Keul, 2007). The frequencies of the four synoptic types in the 19 analyzed cases are given in Fig. 3. Waterspouts occurred most frequently when the closed low is present.

2.2. Szilagyi Waterspout Nomogram and calculation methods

For the SWN (Szilagyi, 2005; Keul et al., 2009), the combination of three parameters correlates strongly with waterspout events:

- Water − 850 hPa temperature difference (ΔT − instability parameter below 1500 m)
- Convective cloud depth, EL−LCL (ΔZ)
- 850 hPa wind speed (W_{850})

ΔT is an instability parameter of the atmosphere below 1500 m. ΔZ is both an instability parameter and a moisture

Fig. 1. Map of the Adriatic Sea region with approximate locations of waterspout events recorded along the Croatian coast in 2010.

parameter; it is the difference between the equilibrium level (EL) and the lifted condensation level (LCL) of a packet of air lifted over a body of water. W_{850} is a wind speed constraint that can also be thought of as a proxy for shear below 1500 m (Keul et al., 2009). If the values for the associated case lie within the "waterspout threshold lines", conditions are favorable for the development of waterspouts. Otherwise, waterspouts are not likely to occur.

In our study, ΔT, ΔZ and W_{850} were calculated using the ALADIN model. ALADIN (Air Limitee Adaptation Dynamique development InterNational) is a limited-area model (LAM) built on the basis of the global IFS/ARPEGE model. ALADIN is

Table 1
Waterspout occurrences along the Croatian coast of the Adriatic Sea in 2010: day, time, duration, location, lightning in the area, synoptic type and SWN ("Yes" if the conditions were favorable or "No" if otherwise).

No.	Date	Time (UTC)	Duration	Location	Long	Lat	Lightning	Weather type	SWN
1	1.1.2010.	12:40	Unknown	Makarska	17.02	43.28	Yes	SW	Yes
2	2.1.2010.	16:25	Unknown	Vela Luka	16.72	42.97	Yes	SWT	Yes
3	9.2.2010.	15:07	3 min	Šibenik	15.92	43.73	No	SW	Yes
4	5.4.2010.	9:53	5 min	Makarska	17.02	43.28	Yes	LW	Yes
5	6.5.2010.	22:15	Unknown	Primošten	19.92	43.59	Yes	LW	Yes
6	15.5.2010.	10:30	Unknown	Funtana	13.60	45.15	No	CLOSED	No
7	30.5.2010.	9:00	2 h 20 min	Poreč	13.60	45.22	Yes	SWT	Yes
8	21.6.2010.	11:55	17 min	Dubrovnik airport	18.08	42.65	Yes	CLOSED	Yes
9	26.7.2010.	12:30	Unknown	Zadar	15.22	44.13	No	LW	No
10	6.8.2010.	5:25	5 min	Dubrovnik airport	18.08	42.65	Yes	CLOSED	Yes
11	7.8.2010.	Before noon	Unknown	Šibenik	15.92	43.73	No	CLOSED	Yes
12	8.9.2010.	11:30	Unknown	Poreč	13.60	45.22	Yes	SW	Yes
13	26.9.2010.	8:40	Unknown	Pula	13.85	44.87	No	CLOSED	Yes
14	27.9.2010.	8:45	Unknown	Rovinj	13.65	45.10	No	CLOSED	Yes
15	17.10.2010.	8:40	1 min	Makarska	17.02	43.28	Yes	SW	Yes
16	11.11.2010.	Sunset	Unknown	Dubrovnik	18.08	42.65	No	LW	Yes
17	18.11.2010.	12:15	Unknown	Makarska	17.02	43.28	No	SW	No
18	23.11.2010.	Before noon	Unknown	Krk	14.60	45.03	No	LW	Yes
19	12.12.2010.	Before noon	Unknown	Dubrovnik	18.08	42.65	No	SWT	No

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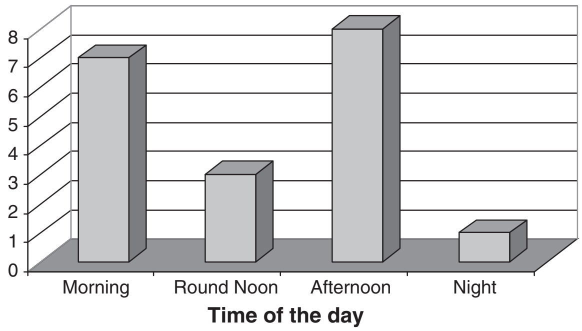

Fig. 2. Day and night time distribution of waterspouts recorded along the Croatian coast of the Adriatic Sea in 2010.

an operational model in the National Meteorological and Hydrological Service of Croatia (Ivatek-Šahdan and Tudor, 2004). The ALADIN model was initialized using the digital filter initialization (DFI) procedure described in Lynch et al. (1997) using a simple optimal filter with a Dolph–Chebyshev window (Lynch, 1997) and backward and forward integration of 24 time steps of 327.273 s, which corresponds to a time span of 2.182 h; this is greater than the required minimum time span of 2.05 h. The initialization times were 00 UTC for all cases.

Values were calculated for all grid points and plotted in a nomogram. To better illustrate the results, the Adriatic Sea region was divided into five regions (see Fig. 4 and Table 2), which represent geographical sub-areas of the eastern part of the Adriatic Sea. It should be noted that the regions are not equal in size, and some of them overlap to a minor extent. The values for all the grid points were plotted in colors associated with the defined regions (blue for Istria, yellow for Kvarner, gray for Zadar–Šibenik, purple for Split and red for the Dubrovnik region).

In this way, general overviews of all the regions were obtained that distinguish whether the conditions in a particular region were favorable for waterspout formation. The results of the analysis of all 2010 cases show that SWN successfully forecasted 15 out of 19 events (78.9%). This is a significant hit rate but is not as high as in the work of Keul et al. (2009), in which 96% of the Adriatic cases satisfied the nomogram.

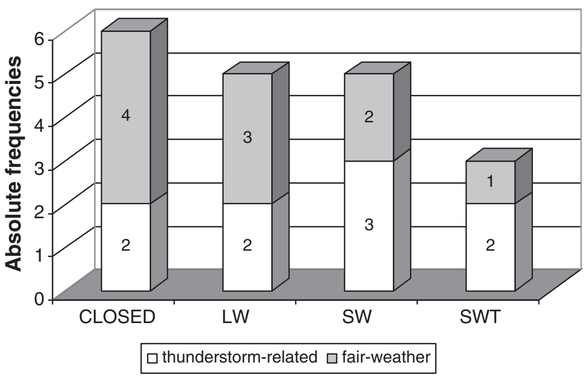

Fig. 3. Absolute frequencies of four basic synoptic types and lightning activity of waterspout cases recorded along the Croatian coast of the Adriatic Sea in 2010.

3. Case studies

In this chapter, four cases of waterspout occurrence will be analyzed in detail. The cases were selected to represent all four basic synoptic types and to provide an overview of atmospheric conditions favorable for waterspouts throughout the year.

3.1. 01 January 2010, South Adriatic, Makarska

On January 1, 2010, a waterspout was observed at 12:40 UTC over the sea between Makarska and the island of Hvar. According to meteorological observations from nearby weather stations, conditions were cloudy with rain and thundershowers. The 2 m temperature was between 13 and 15 °C, and the dew point was between 10 and 12 °C, which are similar to the sea surface temperature (SST) of 11 °C. A significant south-west wind was measured south of the waterspout location. A single well-developed vortex that was connected to the base of a large convective cloud that can be seen in Fig. 5a. The convection was clearly indicated by lightning strikes (Fig. 6a) that were recorded by LINET network sensors (Betz et al., 2009). The associated synoptic environment (Fig. 7) was characterized by strong south-west flow in the middle troposphere on the leading side of a trough extending from North Africa to the Alpine region that affected most of the Balkans. The surface analysis showed a low pressure system centered on the Gulf of Genova. In this case, cold advection was present in the Adriatic area in the form of a cold front passing from the south-west, which is also seen in the satellite image.

The nearest sounding from Brindisi, located on the western Adriatic coast in south-eastern Italy, recorded a significant vertical wind shear connected to the upper-level jet with a maximum wind speed between 30 and 35 m/s at 300 hPa (Fig. 8). The thermodynamic environment was favorable for waterspout development and was reflected in the instability indices of KI (26) and TT (51), which were found to be most representative (Sioutas and Keul, 2007). Atmospheric instability, the presence of a jet streak in the upper levels and cold advection were sufficient for waterspout development, but local convergence caused by the coastal topography also likely affected the development.

The SWI values for the area of interest (the Split region) are between 5 and 6 (Fig. 9a), indicating favorable conditions for waterspouts, even thunderstorm-related waterspouts. Conditions were similar in other regions except some minor parts of the Istria region.

3.2. 30 May 2010, Istria, Poreč

On May 30 at approximately 09:00 UTC, waterspout activity was observed in the vicinity of the town of Poreč on the west coast of the Istrian peninsula in the northern Adriatic. The number of vortices is unknown, but based on the duration of the activity it is assumed that a multi-vortex event took place. As in the previous case, this waterspout event was connected to well-developed convection, as can be deduced from the satellite image (Fig. 5b) and the lightning strikes (Fig. 6b). The relative humidity was high with a 2 m temperature of 19 °C and a dew point temperature of 17 °C. The sea surface temperature was

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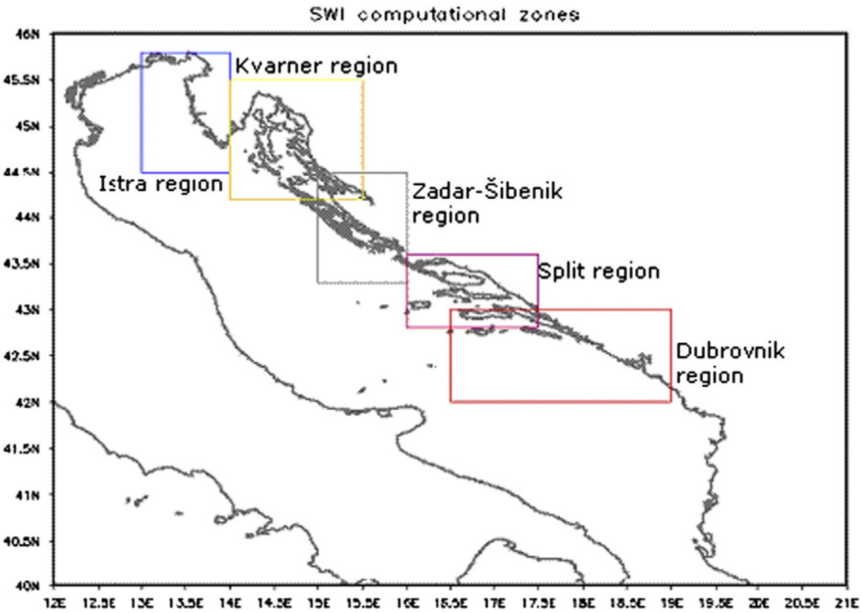

Fig. 4. ALADIN SWN computational zones: Istra region in blue, Kvarner region in yellow, Zadar–Šibenik region in gray, Split region in pink and Dubrovnik region in red.

19 °C, which is similar to the average value for the time of year. The wind was weak to moderate from the south and south-east.

Convective clouds were associated with the frontal cloud band. The dominant flow was south-west and was caused by a short wave trough in the upper levels of the atmosphere (Fig. 10). Vorticity advection maxima were present in the North Adriatic and were connected to the left exit region of a jet streak with wind speeds between 20 and 25 m/s at the 250 hPa level, which enhanced the convection.

The 00 UTC sounding at Zadar on the Croatian Adriatic coast (not shown) indicates that the atmosphere was quite unstable; most of the instability indices (KI of 23, TT of 46) indicate possible thunderstorm development.

Upward motion was favored because of the presence of upper level vorticity advection maxima, the passage of a convergence line and preexisting instability. Together with local wind shear due to coastal effects, the conditions contributed to waterspout formation.

The SWN and the corresponding SWI indicate favorable conditions for thunderstorm related waterspouts over the entire Adriatic and especially in the Istria region (values between 7 and 10, Fig. 9b).

Table 2
Area and corresponding number of grid-points — NGP (in the model) above the sea and above land surface.

Area	NGP-sea	NGP-land
Dubrovnik region	386	133
Split region	289	179
Zadar–Šibenik region	182	84
Kvarner region	208	66
Istra region	192	90

3.3. 21 June 2010, South Adriatic, Dubrovnik

Waterspout activity in the Adriatic was also recorded on the first day of summer 2010. A waterspout was observed in the early afternoon hours near the Dubrovnik airport in the southern Adriatic and lasted for 17 min. The satellite image shows a small line of convective clouds above the sea surface (Fig. 5c) that was accompanied by lightning (detected by LINET sensors). One to 21 mm of rain were recorded at nearby meteorological stations between 06 and 18 UTC, which indicates that rainfall was convective and related to the pronounced atmospheric instability. The surface wind was weak to moderate from the south and south-east near the coast but was south-west in the open sea. Because it was the beginning of summer, it was quite cold; temperature at Dubrovnik airport was 20 °C and the dew point was 13 at 12 UTC. The sea surface temperature was 24 °C.

A synoptic circulation pattern can be recognized as a closed low over the Adriatic (Fig. 11). There was a shallow low pressure system at the surface over the Apennine and Balkan Peninsulas. In the middle troposphere, cold advection connected with a cold core, together with positive vorticity advection into the region, produced favorable conditions for instabilities. The left exit area of the a upper level jet streak with a maximum wind speed in the range of 30 and 35 m/s at the 250 hPa level was also present over the southern Adriatic.

The vertical structure of the atmosphere at the time of the event can be observed from the upstream sounding at Brindisi at 12 UTC (Fig. 12), where instability is evident. In particular, instability indices KI (27) and TT (53) values are common in waterspout cases in the Adriatic. The analysis also shows some vertical wind shear in the area.

The SWI values between 6 and 10 (Fig. 9c) indicate positive waterspout potential in the Dubrovnik area and in

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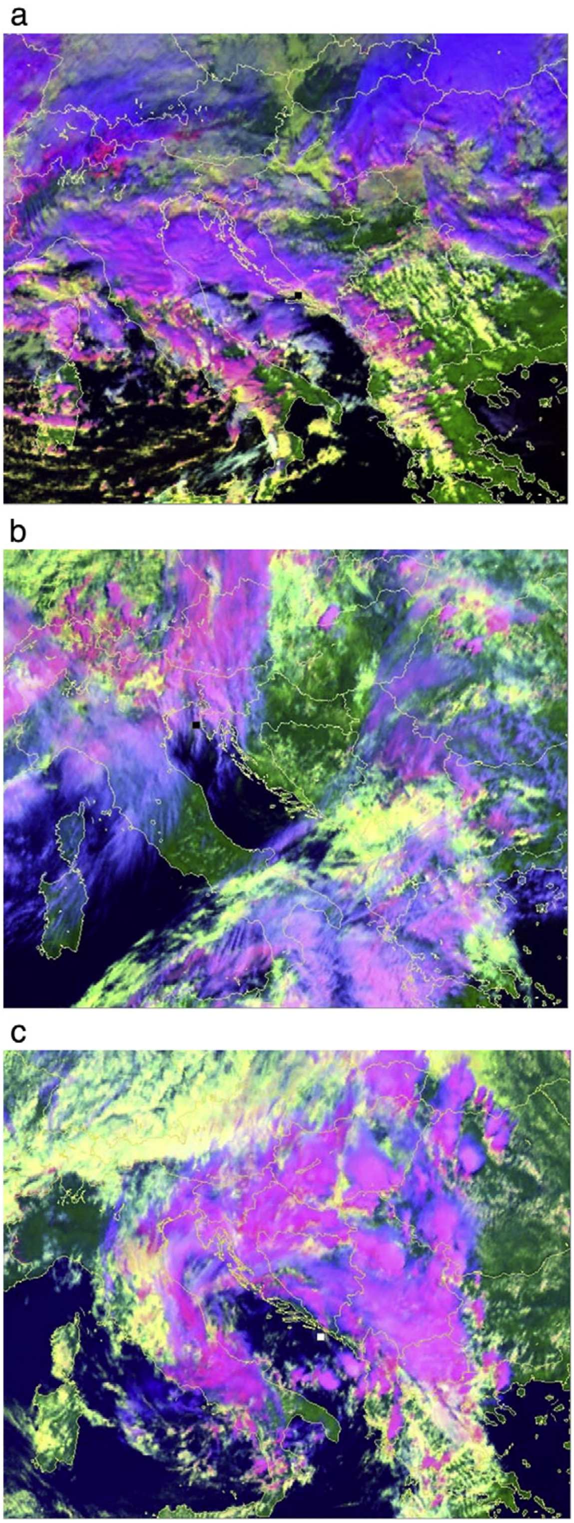

Fig. 5. Meteosat 9 RGB combination of channels 0.6, 1.6 and 10.8 μm for : (a) January 1, 2010 at 12 UTC, (b) May 30, 2010 at 12 UTC, (c) June 21, 2010 at 12 UTC, waterspout location (rectangular black or white dot).

the entire Adriatic region; this again shows that SWI is a good predictor of conditions favorable for waterspouts (and, in this case, even for the upper-low/thunderstorm related waterspouts). The dominant factors for waterspout formation were convergence connected to cold front displacement across the South Adriatic and upward motion, which was favored in the low pressure environment and the vicinity of the left exit region of a jet streak in the upper levels.

3.4. 11 November 2010, South Adriatic, Dubrovnik

According to an eyewitness, the first of two waterspout events in November took place near Dubrovnik around sunset on 11 November. Hence, we assume that the waterspout occurred between 16 and 18 UTC. According to the satellite image from 17 UTC (not shown), there was some cloudiness near Dubrovnik; however, the clouds were not related to deep convection because the LINET lightning data showed no activity.

The waterspout appears to have been connected to a line of cumulus congestus clouds; therefore, the weather can be considered to be fair. No rain was observed in the area. The temperature at 2 m was between 14 and 17 °C, the dew point was 11 to 13 and the SST was 19 °C. Weak to moderate south to south-west wind dominated at the time of interest.

This case was an example of a long wave waterspout in the Adriatic. The 500 hPa analysis (Fig. 13) shows a long wave trough oriented north to south with its axis crossing the central Adriatic. A thermal trough axis was located west of the pressure trough, indicating that cold advection was present at the mid-levels of the atmosphere. At the surface, a weak cold front was passing through the region and was connected to a shallow low pressure field with weak winds.

The sounding from the Brindisi station at 12 UTC (not shown) indicated no CAPE in the upwind direction, but the KI (26) and the TT (51) indices indicate some instability. The wind profile at 12 UTC shows the presence of wind shear, but 12 UTC may be too early in the day for it to be considered because the trough moved rapidly to the east.

As in the previous case, the sea surface temperature was much higher than the temperature in the lower parts of the atmosphere, suggesting pronounced low level instability. Together with the frontal convergence zone, this favored waterspout formation.

The SWN and associated SWI values for the Dubrovnik area, which range between 4 and 8 (Fig. 9d), again fulfill the conditions for waterspout development but are not necessarily thunderstorm related. According to the SWI values, the Dubrovnik area was also more prone to the waterspouts than the other parts of the Adriatic.

4. Summary and conclusions

Investigations of weather phenomena that may produce high risks to the community and significant property damage are motivated by marine traffic and rapidly growing tourism in the Adriatic region. Waterspouts are an example of this type of weather phenomenon.

Thanks to the internet, the number of reported waterspout events has increased over the past several years. Motivated by the previous success of the Szilagyi Waterspout Nomogram in predicting waterspouts, we began a detailed compilation of

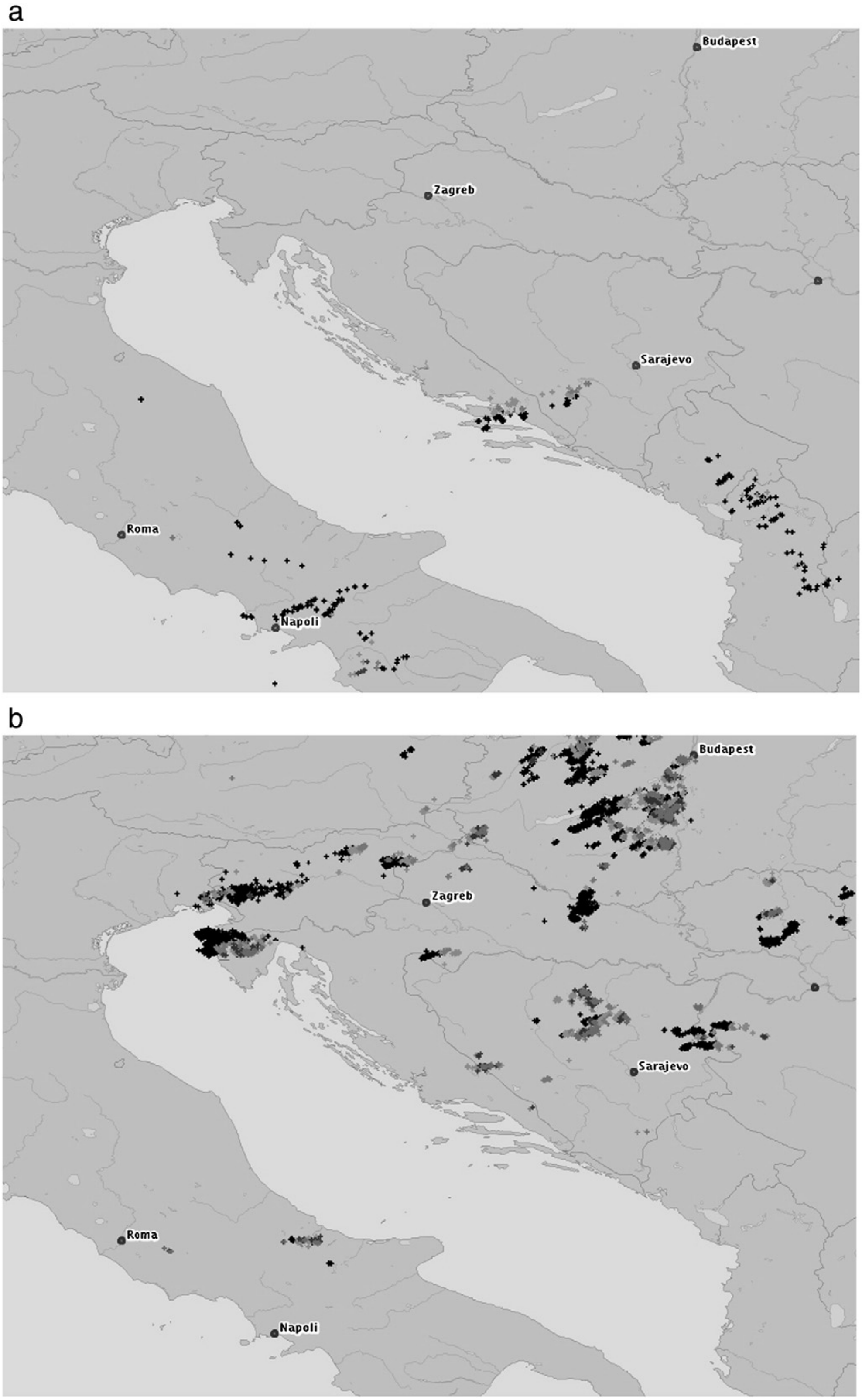

Fig. 6. Lightning strikes as detected by LINET network sensors: (a) between 10 and 13 UTC on January 1, 2010, (b) between 11 and 14 UTC on May 30, 2010.

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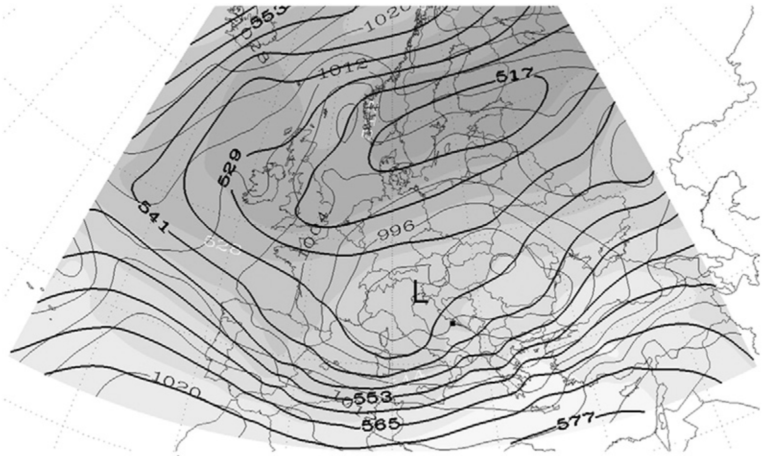

Fig. 7. ERA-Interim reanalysis for January 1, 2010, 12 UTC: MSLP (gray lines), 500 hPa geopotential height (black lines), RT 500/1000 (shaded), waterspout location (rectangular black dot).

waterspout data and tested the available forecasting methods. Because no radars are available on the Croatian Adriatic coast, the only forecasting methods other than the standard instability indices are the Szilagyi Waterspout Nomogram and the Szilagyi Waterspout Index. In this study, we analyzed 19 waterspout events from 2010. Four cases are presented in detail to show the characteristics of the four basic synoptic types relevant to waterspout development and to provide an overview of atmospheric conditions that are favorable for the development of waterspouts throughout the year.

The results of our research show the following:

- Approximately 50% of the analyzed waterspout events were thunderstorm related. Those that were not related to thunderstorms require analyses other than the common thermodynamic instability indices (Totals-Totals Index, KI Index, etc.).
- In 2010, the appearance of waterspouts was relatively evenly distributed along the coast, but they appeared to be more frequent in the morning and in the afternoon

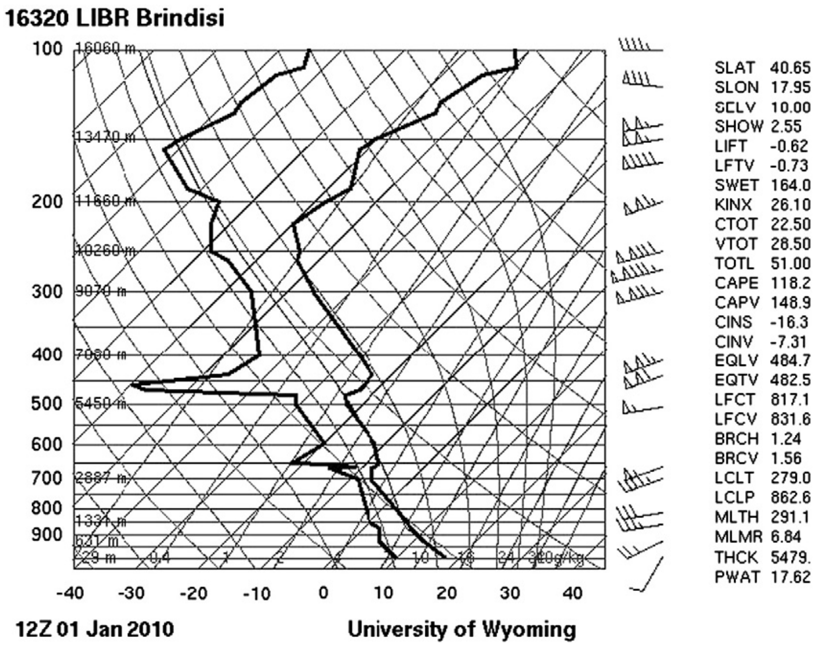

Fig. 8. Skew-T log-p diagram of the radiosounding at Brindisi, Italy on January 1, 2010 at 12 UTC.
Source: http://weather.uwyo.edu/upperair/sounding.html.

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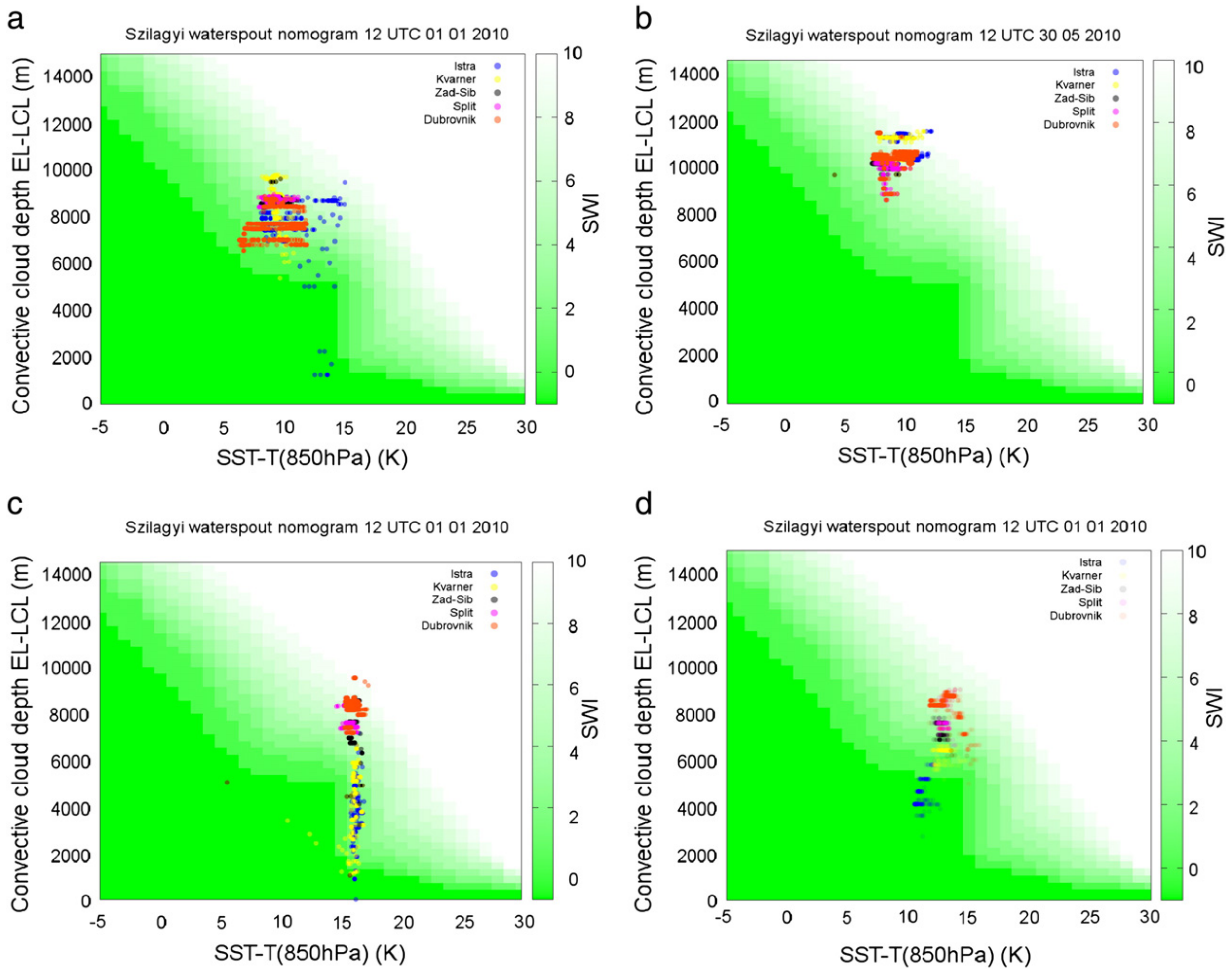

Fig. 9. Szilagyi Waterspout Nomogram for: (a) January 1, 2010, 12 UTC, Split region in pink dots, (b) May 30, 2010, 12 UTC, Istria region in blue dots, (c) June 21, 2010, 12 UTC, Dubrovnik region in red dots, (d) November 11, 2010, 17 UTC, Dubrovnik region in red dots.

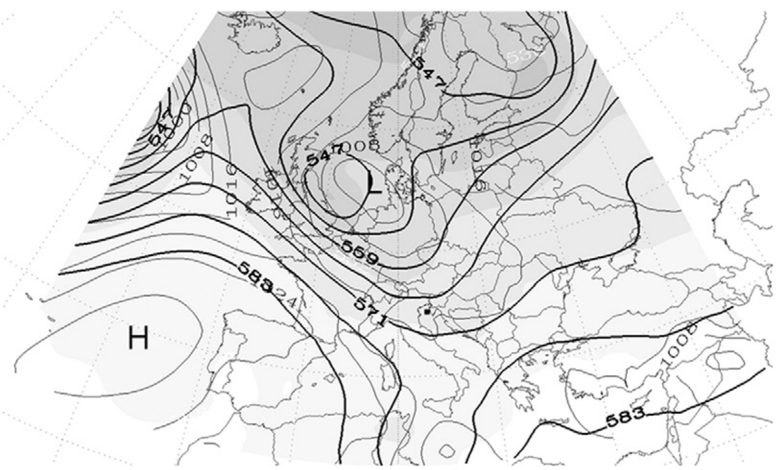

Fig. 10. ERA-Interim reanalysis for May 30, 2010, 12 UTC: MSLP (gray lines), 500 hPa geopotential height (black lines), RT 500/1000 (shaded), waterspout location (rectangular black dot).

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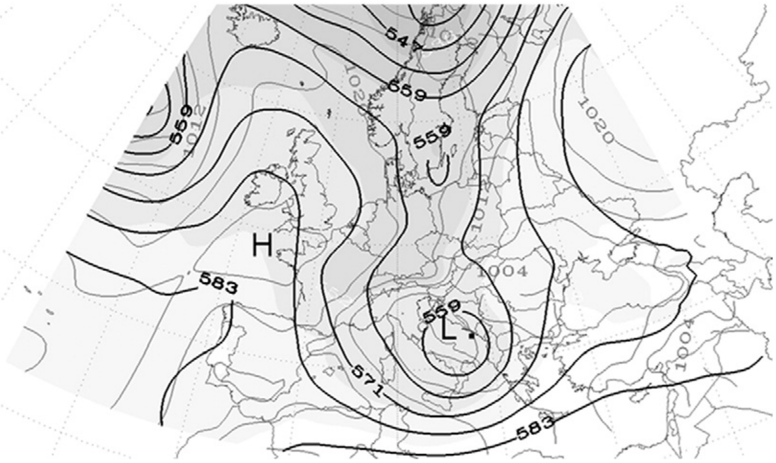

Fig. 11. ERA-Interim reanalysis for June 21, 2010, 12 UTC: MSLP (gray), 500 hPa geopotential height (black), RT 500/1000 (shaded), waterspout location (rectangular black dot).

than in the middle of the day and during the night. However, it should be noted that our statistics were based on a small sample and thus may suffer from statistical uncertainties.

- An analysis of the synoptic and mesoscale weather conditions indicates that waterspouts occur most frequently when a closed low is present.
- Our study shows that the SWN index improves the waterspout forecast. However, more data should be collected and additional waterspout occurrences should be analyzed.

In the 11 November case, which was characterized by fair weather, the main contributors to waterspout development were an unstable air mass on which cold air was advected and wind shear connected to a weak frontal zone. In the thunderstorm related cases that were examined in detail, the presence of a jet stream and positive vorticity advection, as well as the displacement of pronounced frontal zones or convergence lines, played important roles.

A collection of the waterspout events that occurred between 2001 and 2011 is in progress. When all the data become available, a more detailed statistical survey of waterspout occurrence will be undertaken; this will also improve the understanding of their spatial and temporal distribution. An important issue in this type of research is good communication between the professional meteorologists and scientists and the amateurs from whom the information on waterspout appearance has been obtained.

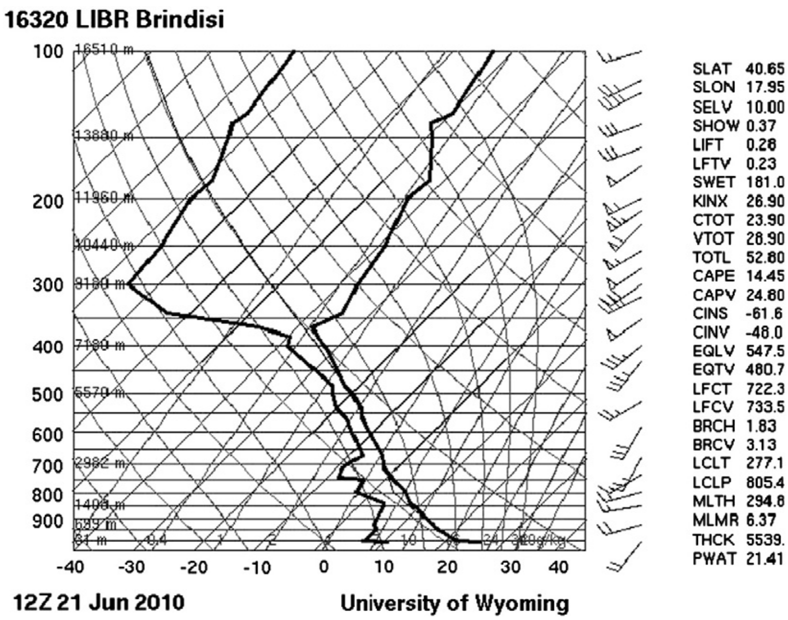

Fig. 12. Skew-T log-p diagram of the radiosounding at Brindisi, Italy on June 21, 2010 at 12 UTC. Source: http://weather.uwyo.edu/upperair/sounding.html.

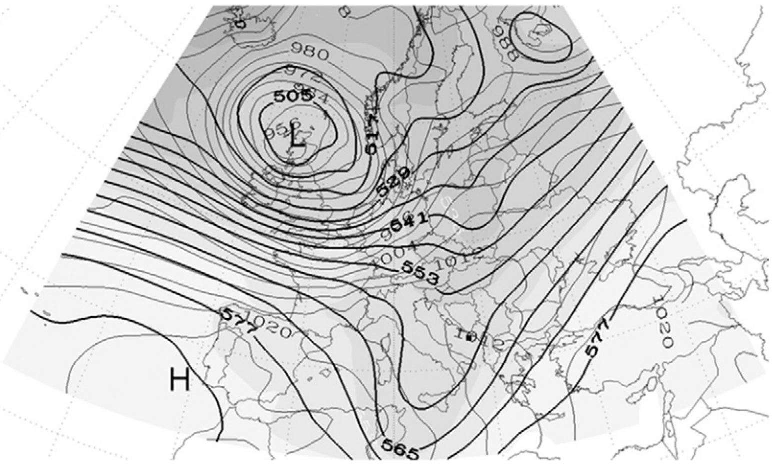

Fig. 13. ERA-Interim reanalysis for November 11, 2010, 18 UTC: MSLP (gray), 500 hPa geopotential height (black), RT 500/1000 (shaded), waterspout location (rectangular black dot).

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