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Brief communication "An extreme meteorological event at the ISMAR oceanographic tower"

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Abstract. We report the evidence of a remarkable meteorological event in the Northern Adriatic Sea. Following the irruption of cold northerly air into the previously hot and humid eastern part of the Po valley, a strong instability developed with violent thunderstorms. At the ISMAR oceanographic tower, 15 km off the coast of the Venice lagoon, although no one was on board, the records of 6 July 2008 from the various instruments coherently show the presence of an extreme and short-lived event that we associate either to a water spout or, more likely, to the strong downdraft of a mesoscale convective system

1 The meteorological situation and the area of interest

During Summer the flat part of Northern Italy, the Po valley, enclosed between the Alps to the North and the Apennines to the South, is often characterised by a hot and humid climate. On 6 July 2008, following the irruption of cold northerly air along the Garda lake valley in the Alps, the strong ensuing instability led to the formation of violent thunderstorms. Beginning on the Alps (Fig. 1a), these thunderstorms moved eastwards with increasing intensity (Fig. 1b), reaching their maximum on the coast of the Adriatic Sea (Fig. 1c), before moving with a progressive attenuation toward Slovenia (Fig. 1d).

We focus our attention on the most northerly part of the Adriatic Sea (Fig. 2), enclosed between the Italian peninsula and the Balkan countries. Located 15 km off the coast of the Venice lagoon (Fig. 1b), the Institute of Marine Sciences (henceforth ISMAR) of the Italian National Research Council manages an oceanographic tower, fully equipped with meteorological and oceanographic instruments. The local depth is 16 m, the flat bottom sloping gradually (1/1000) towards the coast. Cavaleri (2000) provides an extensive review and description of the tower and related activities. Although frequently visited for maintenance and special measurement campaigns lasting up to several days, most of the local instruments are fully automatic (data is transmitted to land in real time) and no one was on board on 6 July 2008.

2 The making of a tornado and a downdraft

Figure 3 shows a strong rotating convective system similar to the one just described in Fig. 1. Among other things, a strong indication of the violence of the system is given by the overshooting of the tropopause and, at its edge, by the waving of the anvil due to possible gravity waves associated to a strong rotation of the system. Most of rain and hail are concentrated in the area below the overshooting. The front of the wind gusts generated by the downdraft is made evident by the wall cloud, whose area is often characterised by tornados (see Fig. 3). The strong overshooting is even more evident in the visible image of Fig. 4 (Meteosat 9 HRV 0.7 micron) focused on the most northerly part of the Adriatic Sea. More details are provided by other satellite images taken on different colour bands and showing the intense electrical discharge concentrated in the area around the Venice lagoon, and the NEFODNE visualisation of the temperature at the top of the overshooting (−65 °C) and of the strong gravity waves.

From the collective information we conclude that (a) the mesoscale convective system that affected the coast of the Northern Adriatic Sea in the afternoon of 6 July 2008 could be assimilated to a mesocyclone, (b) the associated phenomena can be classified as extreme.

A full description of the characteristics and dynamics of a mesoscale convective system is found in the book by Cotton and Anthes (1989).

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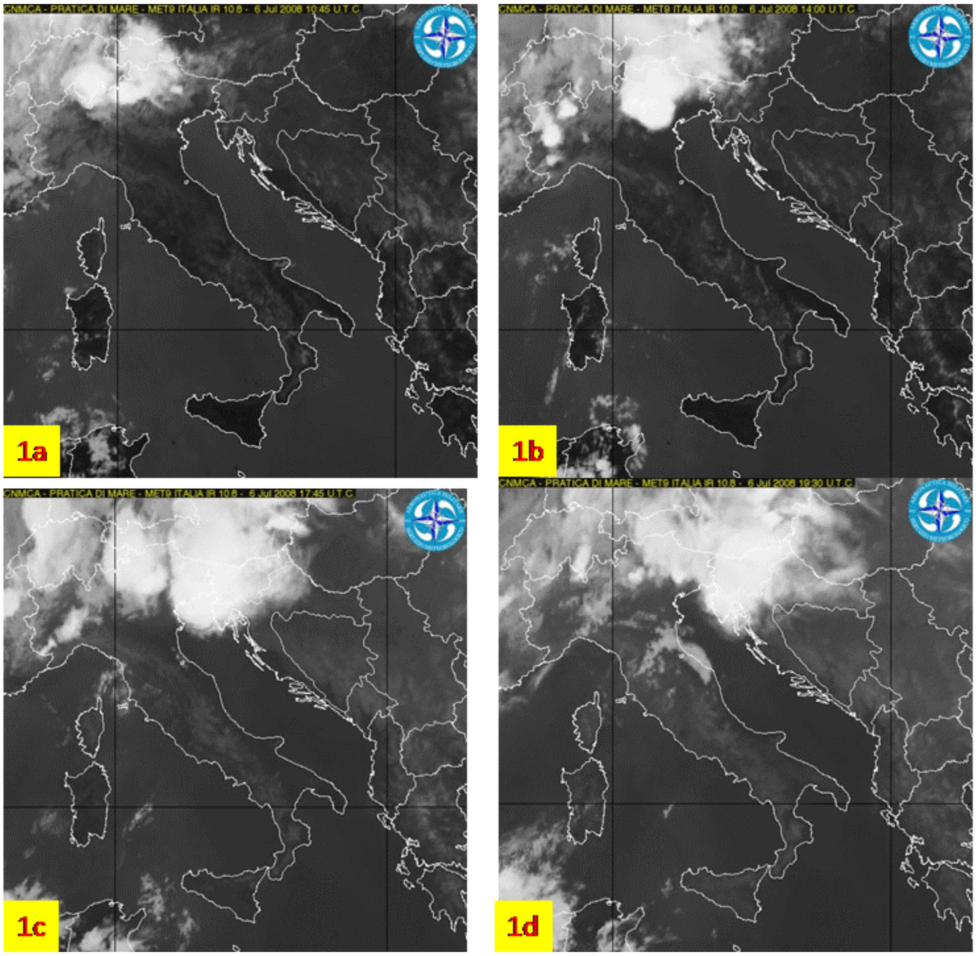

Fig. 1. Evolution of the mesoscale convective system in the afternoon of 6 July 2008. Infrared images. **(a)** spread thunderstorms begin on the Alps, **(b)** propagation and intensification of the phenomena on the North-East part of Italy, **(c)** the convective system has moved also on the Northern Adriatic Sea. Observe the "arc cloud", a typical cloud band indicating the downdraft outgoing the thunderstorm, **(d)** with progressive attenuation the system moves towards Slovenia. The four images were taken at 10:45, 14:00, 17:45, 18:30 UTC.

3 The local evidence

The oceanographic tower is seen in Fig. 5. Its position is shown in Fig. 2b. The various floors of the tower are at 4, 6.5, 9 (living and working quarters) and 12.5 m above the mean sea level. Among the various instruments present on board, we focus here on wind, sea level, wave data (Fig. 6) and on atmospheric pressure, air and water temperature and humidity (Fig. 7). All the meteorological instruments are located on various masts on the top floor.

Figure 6a shows the time history of the wind speed (five minute mean and max values) and direction from 16:15 to 18:15 (we use UTC throughout the paper). We show two hours of data to highlight the characteristics of the transient event.

The background meteorological situation was characterised by a light, distributed 10 m s^{-1} wind from ESE with significant wave height around 0.7 m (Fig. 6c). Air-sea conditions were stable, as shown by the air and water temperature (Fig. 7b, both equal to 20.3 ± 0.1 °C), and by the limited differences between maximum and mean wind speeds (Fig. 6a) during each five minute record. A general view of the situation in the area is available from the local wave forecast system (Bertotti et al., 2011) based on the analysis and forecast surface wind fields from the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, UK). While the possibility of thunderstorms was clearly present in the forecast, the 2008 resolution of the ECMWF meteorological model (T799, corresponding to about 25 km) did not allow for the identification of a small scale wind event as the one under discussion.

As from the records, the wind speed begins to increase after 16:30. The abrupt change steps in slightly before 17:00. The wind speed rapidly climbs to 26 m s^{-1} (Fig. 6a), but the most evident feature is the increase of the atmospheric instability, with U_{max} climbing to 40.7 m s^{-1}. The relatively

a) b)

Fig. 2. **(a)** The Italian peninsula and the Adriatic Sea to its right. The enclosed area is enlarged in **(b)**, where the dots show the position of the ISMAR oceanographic tower and of the tide gauge at the Lido exit of the Venice lagoon.

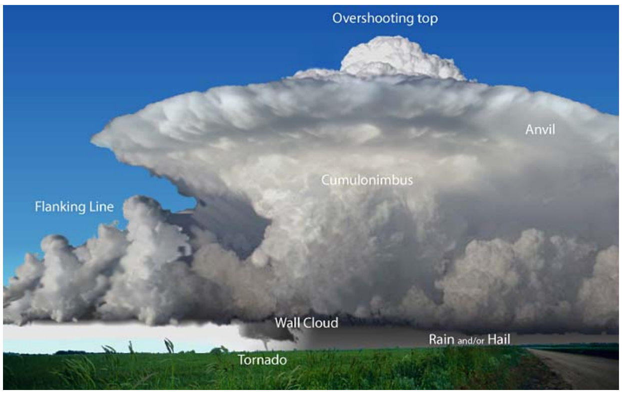

Fig. 3. Typical structure and main characteristics of a mesoscale rotating convective system.

Fig. 4. Image (visible band, Meteosat 9 HRV 0.7 micron) of the situation in Fig. 1c, focused on the most northerly part of the Adriatic Sea. Note the strong complex overshooting and the surrounding gravity waves approaching the coast from inland.

low contemporary U_{mean} value (15.7 m s^{-1}) suggests that the change took place sometime along the record. Note that the three consecutive data at the same maximum speed suggest this was the maximum speed achievable by the instrument (nominal maximum slightly higher). At the same time the direction keeps changing shifting from ESE to South, West, North, to end up again, after a full turn, at the original direction. The wind speed, both mean and max ones, progressively decreases after 17:10, with only a small rebound just after 17:30, when also the direction shows a small step back (350 deg, 10, 20, 20, 350, 340, 20, 80, ...). Across the event there is only a temporary limited decrease of the atmospheric pressure (Fig. 7a, −2.8 hPa) followed by a slight rebound (+2 hPa). Contemporarily to the maximum gust, the humidity (Fig. 7c) increases from 75 to 98 %.

The related tide-gauge time series is given in Fig. 6b, showing the difference between the onboard instrument and the one located at the end of the jetty of the Lido exit of the lagoon, 13 km away (see Fig. 2b). Note that the maximum variations correspond in time to the maximum wind speeds in Fig. 6a. For the values of the atmospheric pressure and the sea level difference please note that, because of the need to filter out, respectively, sudden pressure variations and wind waves, both these instruments has a time constant of several minutes. This implies that the actual pressure and local sea level variations were larger than seen in the records.

Finally, we consider the recorded wave heights (at 15 min interval). The original high frequency (1 Hz) time series are not available. However, the time history (Fig. 6c) of the significant wave height H_{s} and the associated single maximum

Fig. 5. The ISMAR oceanographic tower. See Fig. 2 for its position. The upper terrace is 12.5 m off the mean sea level.

value H_{max} during each record (lasting for the first 3 of each 15 min period) provides enough evidence of the abnormal situation during the hour centred around 17:05. Starting from a 0.7 m background, as soon as the wind increases (Fig. 6a) the wave heights increase as well, reaching 3.5 m H_s and 5.8 m H_{max}. These figures show by themselves the violence of the situation, the ratio H_{max}/H_s, given the length of the record (three minutes), being more typical of a hurricane rather than regular storm conditions (see for this Holthuijsen, 2007, p. 71, Fig. 4.10). Also, that this is not due to an incoming sea storm is proven by the soon following similarly rapid decrease of both H_s and H_{max} and by the corresponding analysis ($H_s = 0.70$ m) of the local operational wave forecast system (Bertotti et al., 2011).

Similar information is provided by the mean and maximum periods, respectively T_m and T_{max}, the latter again derived with wave by wave analysis. Starting from a background value of about 3 s, T_m jumps suddenly to 5.45, to drop again soon after. The overall abnormal sea conditions are confirmed by the corresponding single value of T_{max}, 15.5 s, out of a 5 s background.

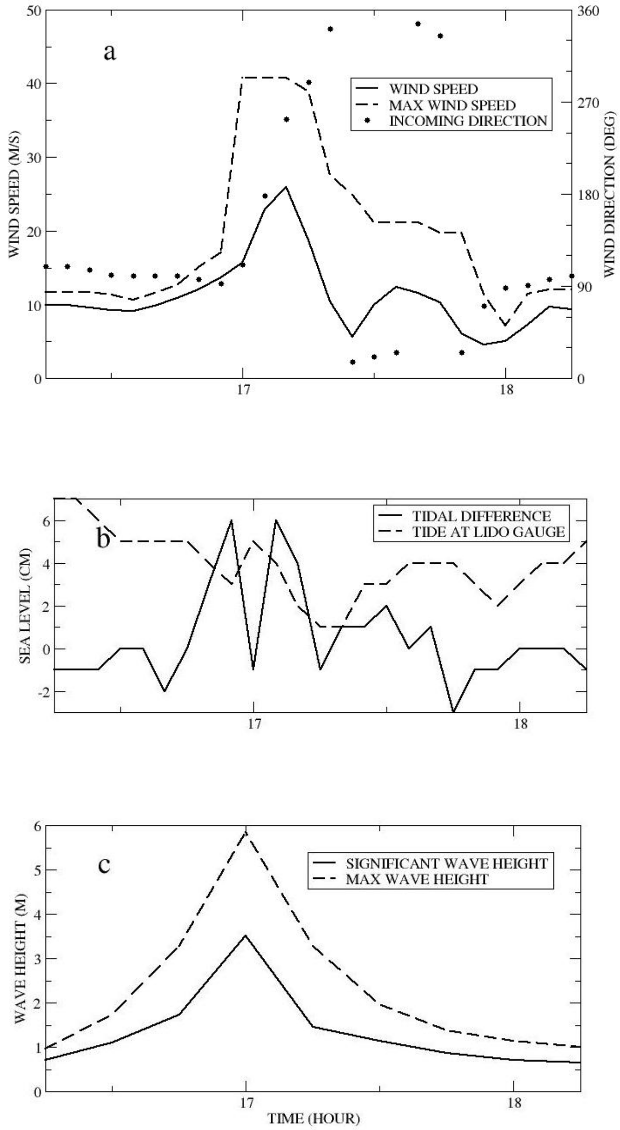

Fig. 6. Time history of **(a)** the mean and maximum wind speeds and related directions during consecutive five minute records at the ISMAR oceanographic tower (see Fig. 2 for its position). **(b)** Sea level difference between the ISMAR oceanographic tower and the tide gauge at the Lido exit of the Venice lagoon (see Fig. 2 for their position). The second line shows the tide history at Lido (an arbitrary zero has been used). **(c)** Significant and maximum wave heights during consecutive 3 min records at 15 min intervals Time UTC.

4 Discussion

An unusually strong mesoscale cyclone affected the North-East of Italy, then moving East, in so doing entering the Northern Adriatic Sea. The violence of the event is proven by the available large scale, in particular satellite, data. At the local scale the data recorded by the instruments (wind, atmospheric pressure, temperature, sea level, wave height,

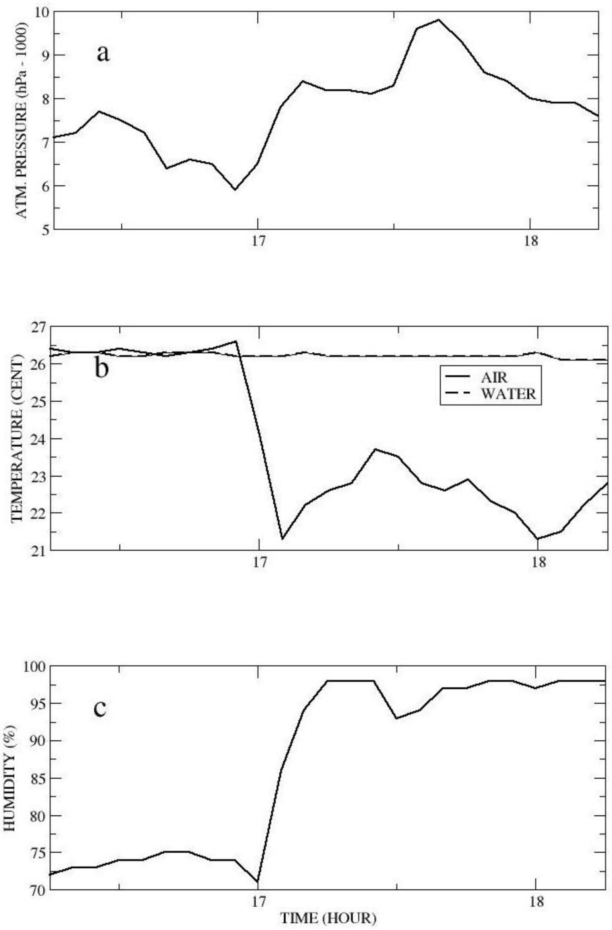

Fig. 7. Time history at the ISMAR oceanographic tower of **(a)** atmospheric pressure, **(b)** air and water temperature, **(c)** relative humidity. Time is UTC.

humidity) on board the tower provides enough evidence of an unusually strong, but short, event. In the almost forty years of wind data from the tower (Cavaleri, 2000) no similar episode has been previously recorded. While the passage of a katabatic bora front can sometime increase the local wind speed from 0 to 30 $m\,s^{-1}$ in a matter of minutes or less, the ensuing storm lasts typically one day or more. The present case was clearly different and we looked for a different explanation.

Our first thought was a tornado that, in our thinking, would have barely missed the tower following a path circling it. This hypothesis was mainly suggested by the very strong wind speeds (maximum values likely above the top value of the anemometer) and the rotation of the respective direction. The sudden large wave heights also indicate the local presence of an irregular (compared to the usual storms) and turbulent local wind field. However, the limited fall of atmospheric pressure seems to go against this hypothesis (but remember that the related instruments are equipped with low pass filters to avoid possible shock damages).

An alternative explanation, that on the whole we favour, is that of a downdraft associated to the incoming mesoscale convective system (see Fig. 3). This is supported by the strong, sudden intensification of the wind speed, by the rapid recovery of the atmospheric pressure, and by interpreting the wind rotation as the typical one from pre- to post-frontal conditions. There is also a substantial cold advection. Finally, the increase of relative humidity to almost the saturation value, but with lack of precipitation (only limited and scattered ones in the second half of the considered period) suggests that the storm centre left the tower in a peripheral position. We exclude the hypothesis of a cumulonimbus collapse because of the contemporary temperature drop.

No heavy damage was reported on board, but this has an easy explanation. Forty years of withstanding the violence of the open sea (see for a general review Cavaleri, 2000) has taught us to use only sturdy instruments and structures, and to tie everything down when no one is on board. As people fond of the sea and the natural phenomena, we can only regret not having been on board during this spectacular and hardly repeatable event.

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