The modern predictability of the 1966 big Venice flood

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1. The fact and the idea

In early November 1966 the northern part of Italy was hit by a very severe south-easterly storm. More than 130 persons lost their lives and, although for different reasons, the two top art treasured cities, Florence and Venice, suffered tremendous damage. In the former one this was caused by an unprecedented overflow of the Arno river. In Venice the problems were associated with the high level the sea reached in the lagoon, flooding more than 90% of the town at a level exceeding any previous record by more than 40 cm. The peak level was 1.94 metre above the nominal sea level. In a town whose pavement is on average one metre above it, this meant that large part of the town was under one metre of water (1.20 m in S.Mark square, see Figure 1).

Figure 1 – S.Mark square flooded on November 4, 1966 (after Obici, 1996)

At the time, and one of us is old enough to remember everything in vivid details, there was practically no warning of the severity of the storm, which of course added to the consequences. Four years ago we had the lucky chance, while at the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, U.K.) to listen to the 50 years anniversary talk of the 1953 dramatic flood of Netherlands. Inspired by this talk, the question naturally arose if the lack of forecast of the 1966 storm had to be associated to the lack of data as compared to the ones present today, or to the lack of computer power and the related highly sophisticated meteorological models we enjoy today. Of course both the reasons could stand, but we formulated the question in a slightly different way: should we have had at disposal in 1966 the present hardware and software, but still only the data of the time, how good would our forecast have been? Implicit in this question is the argument that, if the reply will be positive, i.e. our forecasts would have been good, a fortiori one could expect today in simlar conditions a good forecast.

This is the problem we tackle in this paper. At this aim in Section 2 we describe the meteorological event. In 3 we describe our approach to the hindcast, actually done as forecasts a posteriori. The results are reported in Section 4, followed in 5 by a brief discussion.

2. The storm

In this paper we focus on the marine aspect of the storm, i.e. on the wind and wave conditions (see Figure 2) present in the Adriatic Sea from November 2 till the 4th. This sea is located to the East of Italy, with an elongated shape enclosed between the Italian peninsula and the Balkan countries. Mountain ranges border the sea on both the sides for most of its length, a characteristic that helps to force the southerly wind along the axis of the basin, leading to the frequent storm surges in its northern part, where Venice is located. Very shallow waters within a few tens of kilometres from the Venetian coast add to the local enhancement of the surge.

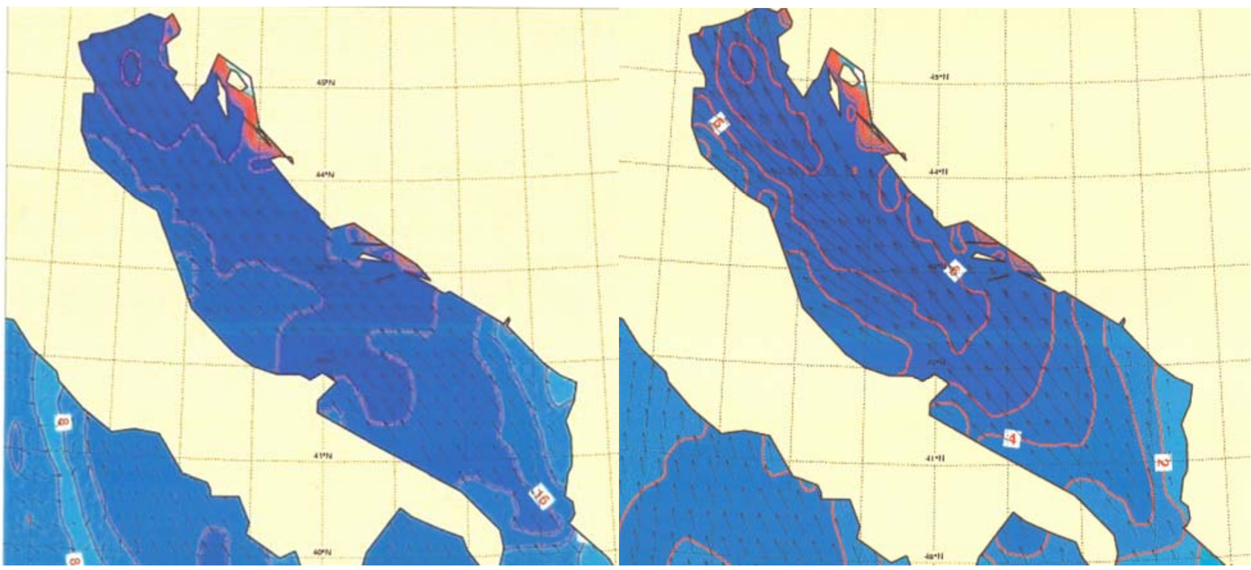

Figure 2 – Wind (left) and wave (right) conditions in the Adriatic Sea, East of Italy, at the peak of the storm of November 4, 1966. Isotachs at 4 m/sec intervals. Isolines of wave heights at 1 metre intervals. Peak conditions in front of Venice (upper-left part of the sea) were 28 m/sec and 8 metres respectively.

In early November 1966 a depression located west of Italy was counteracted by a high pressure on the Balkan countries. This led to a very strong pressure gradient, hence to a strong south-easterly wind, all along the basin that peaked at 12 UTC of November 4 with an estimated wind speed in front of Venice of more than 28 m/sec. Wind speed, wave height and the surge, all peaked at about this time. There were extensive damages all along the coastal defences on the islands separating the Venice lagoon from the sea (one of them had to be hastily evacuated). In the lagoon, due to the limited water depths and fetches, the wave heights were limited, which somehow limited the damage of the storm. Here the flood was somehow static, but high enough to lead to economical and technical damages beyond any previous imagination. Compared to Florence, because of the different mechanics of the storms and structure of the towns, the artistic damage was relatively limited.

3. The analysis

The reanalysis by ECMWF of the 1957-2002 period provides a good starting point for a keen analysis of the storm. The T159 spectral resolution used for the reanalysis, corresponding to about 125 km spatial resolution, is by far too coarse to analyse the wind fields in a 750 x 200 km basin. Therefore we have analysed (hindcast) the storm, starting from 20 days before the event, with T511 spectral resolution (~40 km spatial one), i.e. the resolution of the operational ECMWF meteorological model at the time we did our experiments (Simmons and Hollingsworth, 2002). However, we were mainly interested in the forecast, and, emulating the forecasters of the time, but with the modern software and hardware, starting from October 29 we issued a forecast every 12 hours, i.e. at 12 (UTC) of Oct 29, 00 Oct 30, 12 Oct 30, 00 Nov 01, and so on till Nov 04. From each forecast we extracted the sequence of wind fields to drive the marine side of our experiments.

We have used two marine models, respectively for waves and for circulation (that includes surge). For waves we used WAM (Komen et al., 1994) with 1/12 degree resolution. The narrow opening at the southern end, Otranto, of the Adriatic Sea and the focus of interest on its northern section allowed us to consider for waves only this sea. On the contrary for circulation we were forced to consider the whole Mediterranean Sea as the tidal conditions at Otranto are an important boundary condition. For this we have used SHYFEM (Umgiesser et al., 2004), a finite element model that allows a denser mesh in the northern part of the basin (and in the Venice lagoon), where we expect the higher surface gradients.

Clearly in our marine model runs there is no feed back on the atmosphere (the wave conditions change indeed the roughness of the surface, hence the profile of the marine boundary layer). However, all our meteorological experiments were done in coupled mode, i.e. running in parallel and with cross-talking with the wave model. While the resolution was too coarse for any practical consideration, the wave-effect on the atmosphere was taken into account, implicitly affecting in the correct way our following marine runs.

4. Results

Figure 3 shows the time series of the sea level (surge only) in Venice during the flood. Note that for our present aim of analysing the predictability of the storm, it would have been natural to focus on the sea side of the problem, neglecting the subsequent dynamics of the Venice lagoon. While its complicated geometry (very shallow waters, with a network of narrow canals a few metres deep) makes it interesting from the hydraulic point of view, this is clearly not relevant for our present purposes. We refer the interested reader to the many examples and extensive discussion offered by

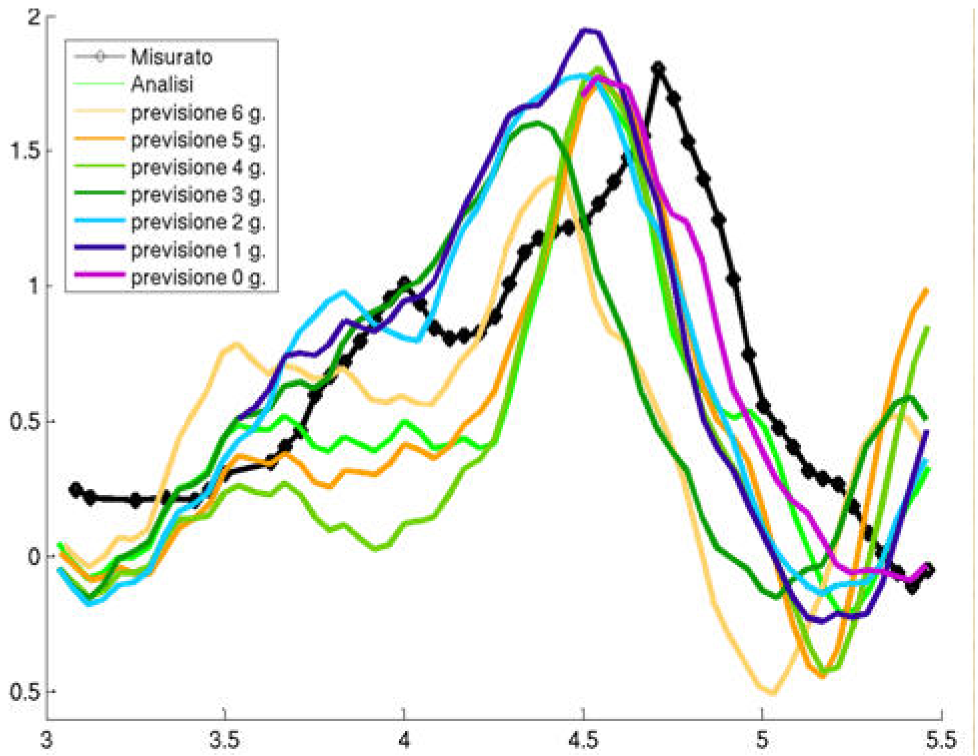

Figure 3 – Time series of the meteorological surge (metres) along the November 1966 days. The curves show respectively measured data, the analysis (hindcast) and the forecasts issued, a posteriori, at different days before the storm.

Umgiesser et al (2004). However, all the outer parts of the six jetties bordering the three inlets to the lagoon were completely destroyed during the storm. With them went also the open sea tide gauges there located. So we resorted to use the Venice tide gauge, located close to the Salute church at the entrance of the Gran Canal. Compared to the coastal waters, this tide gauge displays practically the same excursion, with only a minimal attenuation and a delay of about 35 minutes.

The time history of the surface level at one location represents the sum of the perfectly predictable astronomical tide (the spring tide excursion is about one metre in the Northern Adriatic) and of the meteorological component, i.e. the oscillations of the basin surface related to the wind and atmospheric pressure distributions. Note that in the case of November 4, 1966 event the resulting sea level, maximum at 1.94 metre above the nominal sea level, was in practice due only to the surge, the astronomical tide at the nominal time of the peak being only +0.12 metre.

In Figure 3 we compare the record with the result of our analysis. Focusing for the time being only on the hindcast ("analisi" in the figure) we see that the peak value is rather well represented (simulated surge at +1.80 metre instead of the official 1.82). There is an apparent time shift of 3-4 hours. However, it is worthwhile to point out that there is no official record of the highest peak of the tide. The reason is that no one expected such a strong flood and all the tide gauges had been designed with 1.80 metre maximum. So in practice the instrumental record is a growing line till 1.80 metre, followed for a few hours by a horizontal line (during the time the sea level was higher) and then by the final decreasing line. As a matter of fact the 1.94 figure was derived from the mark left on the house walls by the combustion oil floating on the water. The relevant point for what Figure 3 is concerned is that the upper part of the record line was completed by hand, and there is much uncertainty (a few hours) on the actual time of the peak. For this reason we focus our attention on the value of the peak.

As we mentioned in the previous section we have obtained time series of the forecast wind and pressure fields from different starting times distributed at 12 hour intervals. This is explained in Figure 4 where each horizontal line represents an experiment and the related time series of forecast fields at 6-hour intervals. For each experiment we ran the surge and the wave models, deriving the corresponding history of sea level in Venice.

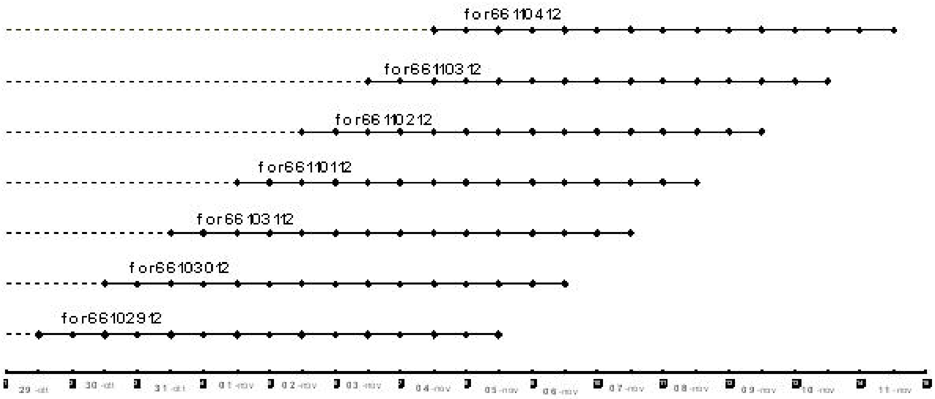

Figure 4 – Scheme of the forecasts issued, a posteriori, every 12 hours in the days before November 4, 1966. The dots, at 6-hour intervals, show the time of the output fields.

The key result is shown again in Figure 3. Here, besides the already discussed record and hindcast analysis, we provide also the surge forecasts issued on the base of the data available the day of the storm (Nov 4, 0 day), one day before (1 g), two days before (2 g), and so on till six days before the storm (6 g). It is evident that till five days before November 4 the forecast was very close to the final analysis. Even at -6 (forecast issued on October 29) there is a clear indication of an exceptional event.

The high value of the surge at the northern coast was caused by a wind field (see Figure 5) fully aligned along the axis of the Adriatic Sea. On top of this, according to our experiments, the highest wind speeds were reached just off the coast of Venice. Combined with the local shallow waters this caused the enhancement of the surge in the area.

Expectably such a long fetch and time extended conditions led to also exceptionally high waves in the Northern Adriatic Sea. Our estimates suggest more than 8 metre significant wave heights H_s before entering the shallow waters of the coast led to a substantial depth induced breaking.

The comparison of the H_s values in front of Venice derived from the different forecasts (not shown) confirm the predictability of the storm, with the waves happened on November 4 well forecast till six days in advance.

5. Discussion

In the case of the November 4, 1966 event our experiments have shown the predictability of the storm till six days in advance (we did not go further). This is not a unique result. Not shown in this paper, we have carried out the same sequence of experiments also for another strong storm, although certainly not as severe as the 1966 one. This storm peaked on December 22, 1979. Our results are very similar to the ones for the 1966 case, i.e. both the surge and the wave conditions were well predicted till six days in advance.

This strongly suggests that, should similar events happen today, we should be able of providing at least a forecast as good as the ones shown in the previous section. We purposely say “at least” because the enormous volume of information presently available is expected to lead to more accurate analysis and tendency, hence to better forecasts.

This result should not be generalised to all the storms. It is our opinion that such an extended (six days) predictability is related also to the intensity of the events, hence to the mark present in the atmosphere. Smaller storms, with a relatively diminished scale with respect to the 1966 event, are likely to have a more limited impact in the atmosphere, hence mark, hence predictability.

Acknowledgements

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