VENICE: The exceptional high sea level event of 12/11/2019. Preliminary analysis of the data and description of the phenomenon

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Introduction

On the 12th November 2019, an exceptionally high sea level event occurred in Venice, second only to the event that occurred on November 4th, 1966. Although an exceptional high tide (>140 cm) was predicted by the numerical models in use, during the evening, sudden gusts of wind at more than 100 km per hour generated a further local intensification of this phenomenon.

The Institute of Marine Sciences (ISMAR) of the Italian National Research Council (CNR), which was opened in Venice in 1969 as the CNR's response to the 1966 high water event, collaborates with the Tide Forecasting and Reporting Center of the Municipality of Venice (Centro Previsioni e Segnalazioni Maree del Comune di Venezia) and the institutes ISPRA and ARPA of Emilia Romagna for developing sea level and wave forecasting models. This applied research provides an important contribution to the preservation of the coastal areas and to safeguard the population and the artistic and architectural heritage of the city of Venice and the islands of its lagoon.

The event that struck Venice on November 12th, although having certain conditions seemingly typical of the events that cause exceptional high waters, it had some peculiar characteristics not observed before, that require an in-depth analysis in order to draw conclusions to improve future forecasting and alert systems. However, it is possible to provide a preliminary interpretation, based on the data available from the observational networks of the institutions in charge of monitoring the weather-marine system.

Meteorological framework

On November 12th, 2019, a deep low pressure system was present over the central-southern Tyrrhenian Sea ("**L1**" in Figure 1), which generated strong Scirocco (south-easterly) winds along the main axis of the Adriatic Sea, while, at the same time, Bora (north-easterly) winds (Figure 2) blew over the Northern Adriatic. This synoptic configuration is normally the cause of high sea level events in the Venice Lagoon, with the Scirocco wind pushing the Adriatic waters to the north and the Bora wind, which locally deflects the accumulation towards the western coasts. In addition to this "large scale" configuration, the northern Adriatic was affected by the passage of a secondary cyclonic vortex rotating and moving rapidly ("**L2**" in Figure 1), which quickly deepened (i.e. intensified) causing very strong winds (**70 km/h on average and 110 km/h gusts**). This second very low-pressure system induced a further increase in the water level due to the so-called inverse barometric effect (sea level tends to rise when the atmospheric pressure at sea level is lowered, and vice versa). The passage of this cyclonic vortex (Figure 3) is clearly evident from the data measured at the CNR platform "Acqua Alta", located in the Gulf of Venice, 8 nautical miles from the coast. As can be seen in the data shown in Table 1, after 8 pm the wind began to rotate from Bora (blue in Table 1) to Scirocco (pink in Table 1): the arrival of the warm front, with the consequent increase in the air temperature (by 5-6 ° C) and the rapid descent of the minimum barometric pressure (3 mb in half an hour) are clearly displayed by the data in the table, until the minimum transit time (986.6 mb) at 9.30 pm. Subsequently, the rotation of the winds to south westerlies (green in Table 1) was accompanied by a severe intensification of wind speed (**100 km/h on average and 110 km/h gusts**, red in the columns "Wind Speed" and "Gusts", in Table 1). After the passage of the barometric pressure minimum and the rotation to south-west, the sea level in the Northern Adriatic began to descend rapidly, while the delay of the propagation of the tide in the lagoon made the presence of the most intense south-western gusts coincide with an already critical value of sea level. These phenomena led to a rapid rise in water levels and to greater damage to the city, especially in the areas of the historic center which were more exposed to the south-west wind, causing increased stresses on the structures due to wind and waves.

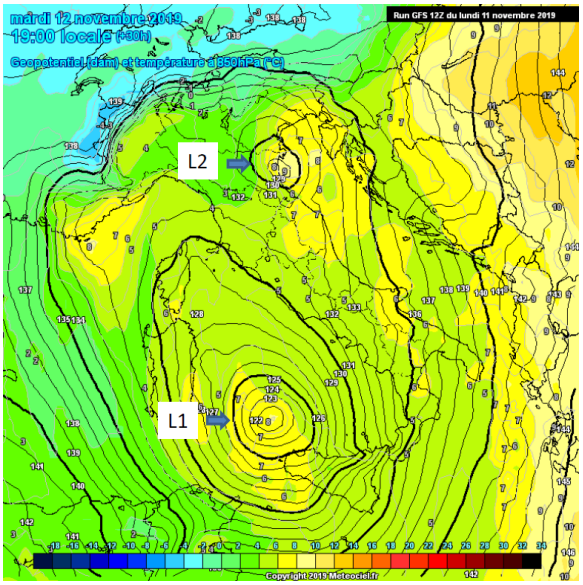

Figure 1: Height of the geopotential (dam) and temperature (°C) at 850 mb provided by the GFS model (issued on 11th November 12:00 UTC) relating to 12th November 2019 at 19:00 local time (graphic rendering: METEOCIEL).

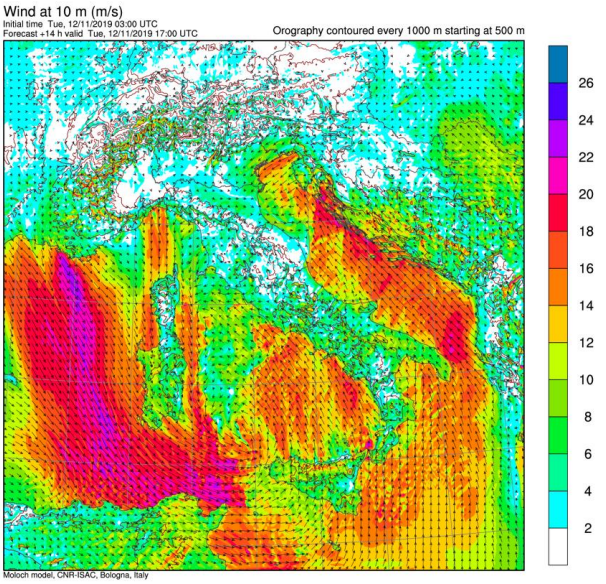

Figure 2: Wind at 10m provided by the MOLOCH model, of the CNR Institute of Atmospheric Sciences and Climate (CNR-ISAC) at 17:00 UTC (18:00 local time) on 12th November 2019. Note how the Adriatic is subject to intense Scirocco and the Northern Adriatic to Bora winds.

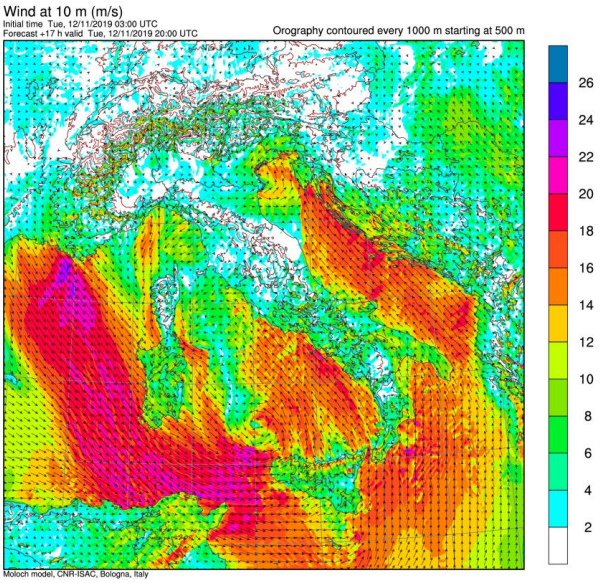

Figure 3: Wind at 10m provided by the MOLOCH model, of the CNR Institute of Atmospheric Sciences and Climate (CNR-ISAC) at 20:00 UTC (21:00 local time) of 12 November 2019. Note the cyclonic vortex in the northern Adriatic (L2 in Figure 1).

Local Time (UTC+1)	Sea Level PTF (m)	Wind Direction	Wind Speed (m/s)	Gust (m/s)	Atm Pressure (hPa)	Air Temp (°C)	Sea Level (m) PS
19.00	1.16	31	15.4	18.4	992.7	11.6	0.86
19.10	1.21	27	15.3	17	992.5	11.4	0.9
19.20	1.24	24	15.5	18.3	992.3	11.6	0.92
19.30	1.27	21	16.3	19.4	991.6	11.2	0.95
19.40	1.33	25	16.9	19.4	991.5	11.3	0.98
19.50	1.39	24	16.7	20.5	991	11.9	1.02
20.00	1.44	23	18	21.5	990.4	12.3	1.05
20.10	1.54	22	18.7	21.8	990.2	12.5	1.08
20.20	1.6	29	18.5	22	990	13.2	1.12
20.30	1.63	43	17.4	21.8	990.6	15.8	1.17
20.40	1.61	109	15.1	17	989.5	17.7	1.22
20.50	1.64	107	14.6	19.5	989.2	16.8	1.25
21.00	1.72	97	15.8	20.5	987.9	16.4	1.28
21.10	1.74	94	17.6	21.3	987	16.8	1.33
21.20	1.75	104	17.4	18.9	986.8	16.7	1.38
21.30	1.81	131	14.1	17.1	986.6	17.2	1.43
21.40	1.82	157	14.4	17.6	987.2	16.7	1.47
21.50	1.77	168	14.4	16.3	987.7	16.7	1.52
22.00	1.75	180	18.2	23.5	988.4	14	1.56
22.10	1.72	192	22.1	29.8	989.2	12.8	1.64
22.20	1.57	214	28.1	31.5	991.1	12.4	1.7
22.30	1.39	216	26.8	30.3	991.1	12.4	1.74
22.40	1.3	218	24.2	28.3	992	12.3	1.83
22.50	1.22	222	21.5	24.6	992.7	12.3	1.87
23.00	1.14	222	18.3	20	993	12.6	1.81
23.10	1.08	221	15.5	19.7	993.2	12.8	1.69
23.20	1.09	228	14.7	18.7	993.6	12.6	1.6
23.30	1.11	222	13.1	14.5	994	12.3	1.54
23.40	1.1	228	11.8	12.9	993.9	12.3	1.48
23.50	1.09	229	10.6	11.3	994.3	12.2	1.43
00.00	1.05	226	9.2	10.2	994.8	11.8	1.36

Table 1: Meteomarine data measured in the CNR Platform "Acqua Alta" (PTF) and sea-level peak data measured at "Punta della Salute" (PS). The blue in the "wind direction" column shows the Bora period, then its rotation to Scirocco (pink) and finally south-west (green), after the passage of the barometric pressure minimum (yellow values in the "Atmospheric Pressure" column). The maximum wind intensity (red) occurs partly after the maximum level values in the Platform "Acqua Alta"but in correspondence with the maximum levels at "Punta della Salute". Data from the telemareographic network of the municipality of Venice (not yet validated).

Sea level evolution

The sea level is given by the sum of the astronomical component (tide), the meteorological contribution (storm surge, determined by wind and pressure) and the mean sea level (MSL). The maximum sea level value of **187 cm** was recorded in Venice at "Punta della Salute"and occurred at 22:50 with a delay of about an hour compared to the peak of **182 cm**, recorded offshore by the Platform "Acqua Alta". The exceptional high water of November 12th was determined by the coincidence of the maximum meteorological contribution (127 cm) with the maximum tide (26 cm) (Figure 4). The mean sea level in the last 2 years in the Northern Adriatic is 34 cm (referred the datum of Punta della Salute).

It is also important to specify that the wind and pressure-induced meteorological contribution of the event on November 12th was lower than the maximum meteorological contributions recorded during the events of 1966 and 2018.

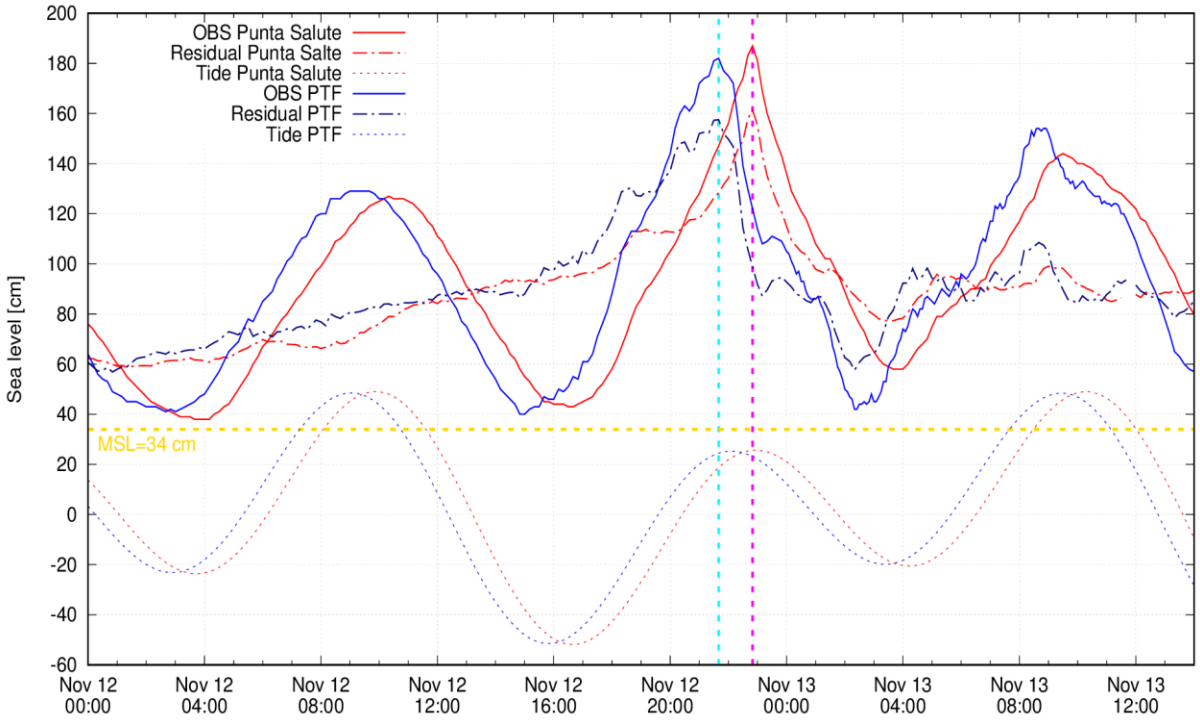

Figure 4: Sea level evolution in Venice ("Punta della Salute") and at the "Acqua Alta" platform. The residual level corresponds to the sum of the storm surge and the MSL.

The maximum water levels in the Lagoon

The peculiar local meteorological situation associated with the local minimum that occurred on November 12th resulted in a high variability of the maximum water levels in the lagoon. The recordings acquired from the tidal stations of the Municipality of Venice (shown in Fig. 5) show maximum levels above 170 cm only in the open sea and in the historic center of Venice. Note the strong difference between the levels measured south of the city of Venice (**187 cm at Punta Salute**) and north (**173 cm at the Misericordia station**) in conjunction with the maximum wind from the south-west. In the northern part of the Lagoon, maximum values of less than 160 cm have been recorded, while in Chioggia the level has stopped at a height of 170 cm.

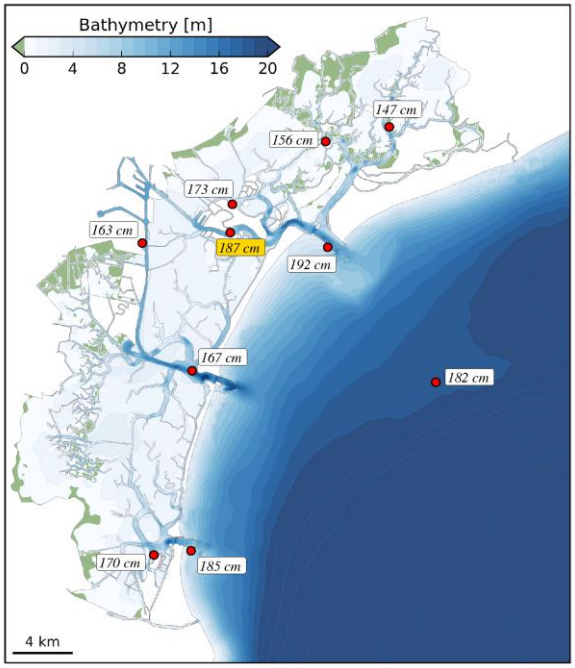

Figure 5: Maximum sea-level values recorded in the Venice Lagoon (non-validated data from the Municipality of Venice).

Predictability of the event

Nowadays the large-scale synoptic picture associated with important high sea level events is predictable several days in advance. However, the uncertainty associated with the exact intensity of a meteorological event is then reflected in the tide forecast. On this specific occasion, the rapid transit of a very local phenomenon, such as the cyclonic vortex **L2**, was difficult to predict. Atmospheric models are able to predict the development and evolution of these meteorological phenomena, however, small errors in the trajectory and/or intensification can lead to locally significant errors in wind intensity and direction. The underestimation of the wind speed has been reflected in an underestimation of the prediction of sea levels by the statistical and deterministic models.

Such intense atmospheric events are often underestimated by meteorological models on a global scale and, sometimes, even by local scale models. A future possible improvement in the forecast of such extreme events could come from the use of complex techniques for the assimilation of observed data, both atmospheric and marine.

A sequence of high sea level events

After the exceptional high water on November 12th, 3 successive events with tide level values higher than 140 cm occurred in just 5 days. The meteo-marine recordings show two overlapping dynamics:

- Scirocco events in succession in the Adriatic Sea on November 15th and 17th, with winds up to 15 m/s, i.e. significant but not exceptional;
- a persistent high level of the sea in the North Adriatic in November.

Figure 6 shows that the storm surge values prior to November 2nd remain around the value 0, while the period after November 4th is characterized by a series of events that oscillate around an average value of about 30 cm in the North Adriatic, induced by the meteorological situation in the Mediterranean Sea. This dynamic is also evident in the measurements of the Otranto station.

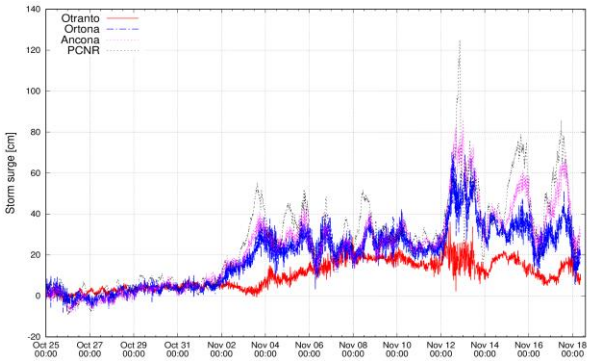

Figure 6: Time series of the meteorological contribution from 25th October to 18th November in the Adriatic registered at the ISPRA stations of Otranto, Ortona and Ancona, and in the CNR Acqua Alta platform.

Fortune in the misfortune

Since 1966 the scientific community has been repeating that in the **misfortune** of the catastrophic event, we have been **fortunate**. On **November 4th, 1966**, the maximum storm surge, and thus the maximum meteorological contribution, occurred during the minimum of the astronomical tide. On **October 29th, 2018** (the "Vaia" storm), the second strongest meteorological contribution event after the one of 1966, the same happened. What could have happened if the components were in phase, as happened on November 12th this year? A delay of a few hours in the peak of the storm would have led to sea levels in Venice of **230** and **215** cm, respectively in 1966 and 2018. If we project the 1966 event on to the present day, with the relative mean sea level having increased in the last 50 years by about 12 cm, we would get a maximum level of about **240** cm.

Contrary to what happened in the two extreme events described above, on **November 12th, 2019**, the peak of the storm was superimposed on the peak of the astronomical tidal and a high average sea level in the North Adriatic, thus bringing a less intense storm surge, compared to 1966 and 2018, to lead to exceptional level values in Venice. In this case, an advance or delay of **12 hours** of the peak of the event would have led to the overlapping of the meteorological contribution to the main tidal peak, with a resulting maximum sea level value of **210** cm in Venice.