Copernicus Sentinel-2 satellite captures the flood barriers at work in Venice amid stormy weather

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"Then Moses stretched out his hand over the sea, and the Lord drove the sea back by a strong east wind all night and made the sea dry land, and the waters were divided." (Exodus 14:21)

Last week, on November 4th 2021, while the 78 mobile gates of the MoSE, the system for the defence of Venice and the lagoon islands from storm surges, were about to retract in their housing on the bottom of the inlets, the Copernicus Sentinel-2 satellite captured an outstanding image of the upper Adriatic Sea during one of the first events of the season (Figure 1).

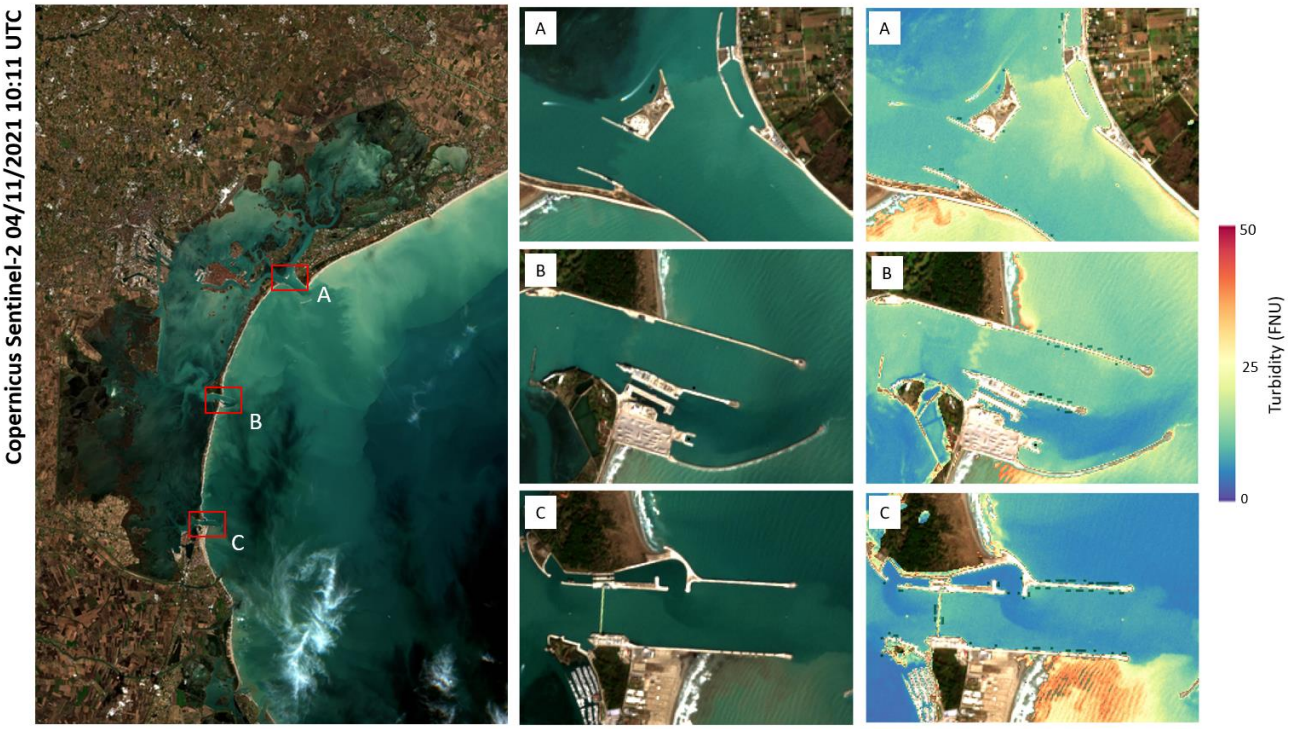

Figure 1. Copernicus Sentinel-2 true colour composite of the Lagoon of Venice (left panel) and details of the three inlets (middle panel) acquired on November 4th 2021; corresponding satellite-derived turbidity maps (right panel). Lido (A), Malamocco (B) and Chioggia (C) inlets. The Lido inlet is split in two channels by an artificial island: Treporti Channel to the North and S. Nicolò Channel to the South.

The flood barriers were activated on Wednesday 3rd afternoon, based on a forecast that the tide would reach up to 140 cm during the night, when a south-southeasterly wind of more than 15 m s^{-1} (about 30 knt) battered the Venetian coast (Figure 2). Without them, a tide at that level would have flooded 60% of the city with the ritual major consequences for the iconic tourist attraction of St. Mark's Square.

The flood barriers were closed during the main peaks of the tide and were partially opened, with only S. Nicolò Channel closed permanently, in the intermediate interval (Figure 3). As shown by the image (Figure

1), at the time of the satellite overpass (10:11 UTC) the flood barriers were still closed at Chioggia and apparent in the imagery as a yellow solid sea-wall, while in Malamocco they were already underwater retracting into their housing on the seafloor. At the inlet of Lido the barriers were instead in the early phases of movement: some barriers were still partly visible under the surface at Treporti Channel, while most barriers were just under the water surface at S. Nicolò Channel.

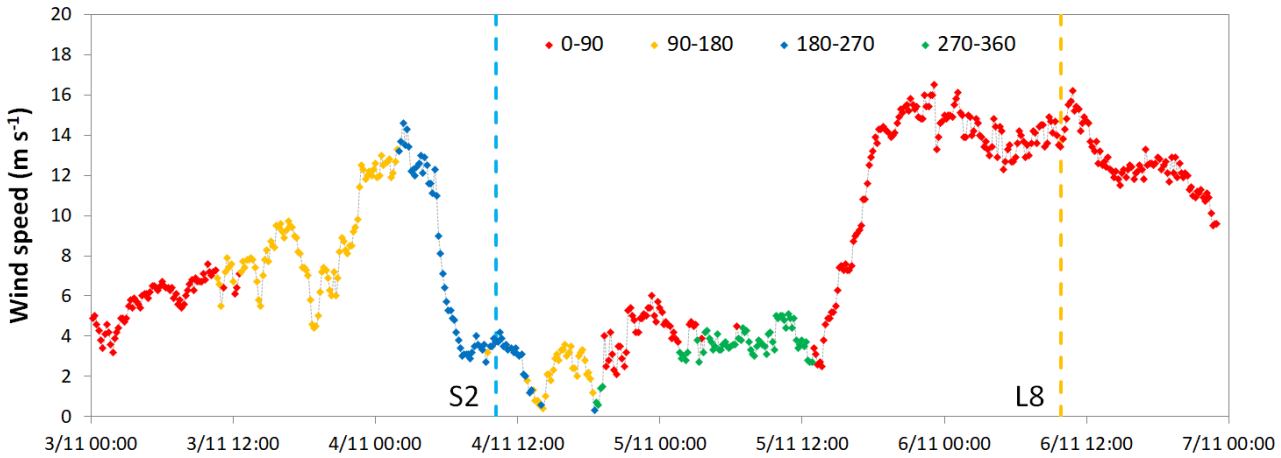

Figure 2. Wind speed and direction recorded from Acqua Alta Oceanographic Tower, located at 8 nm off the Venice lagoon in the northern Adriatic Sea (12.51° E, 45.31° N).

The different timing of the operations in the inlets clearly affects the patterns of water turbidity, as apparent in the 10 m spatial resolution Sentinel-2 image and turbidity maps of Figure 1. For instance, in the inlet of Chioggia the turbidity is slightly higher on the sea side of the gates. In the inlet of Malamocco a zig-zag pattern is visible at the centre of the channel, where the accumulated sediments are likely mobilized by the turbulence associated with the retreat of the gates. In the Lido inlet, it is noteworthy the peculiar behaviour of the S. Nicolò Channel where the different relative position reached at the time of acquisition by the 20 mobile gates force the flow to move through openings of variable depth, creating a sawtooth-like pattern in the turbidity front. Another outstanding feature of the image is the low turbidity of the seawater trapped into the refuge harbours of the navigation locks in Malamocco and Chioggia inlets, that are hydraulically isolated from the circulation in the nearby channels.

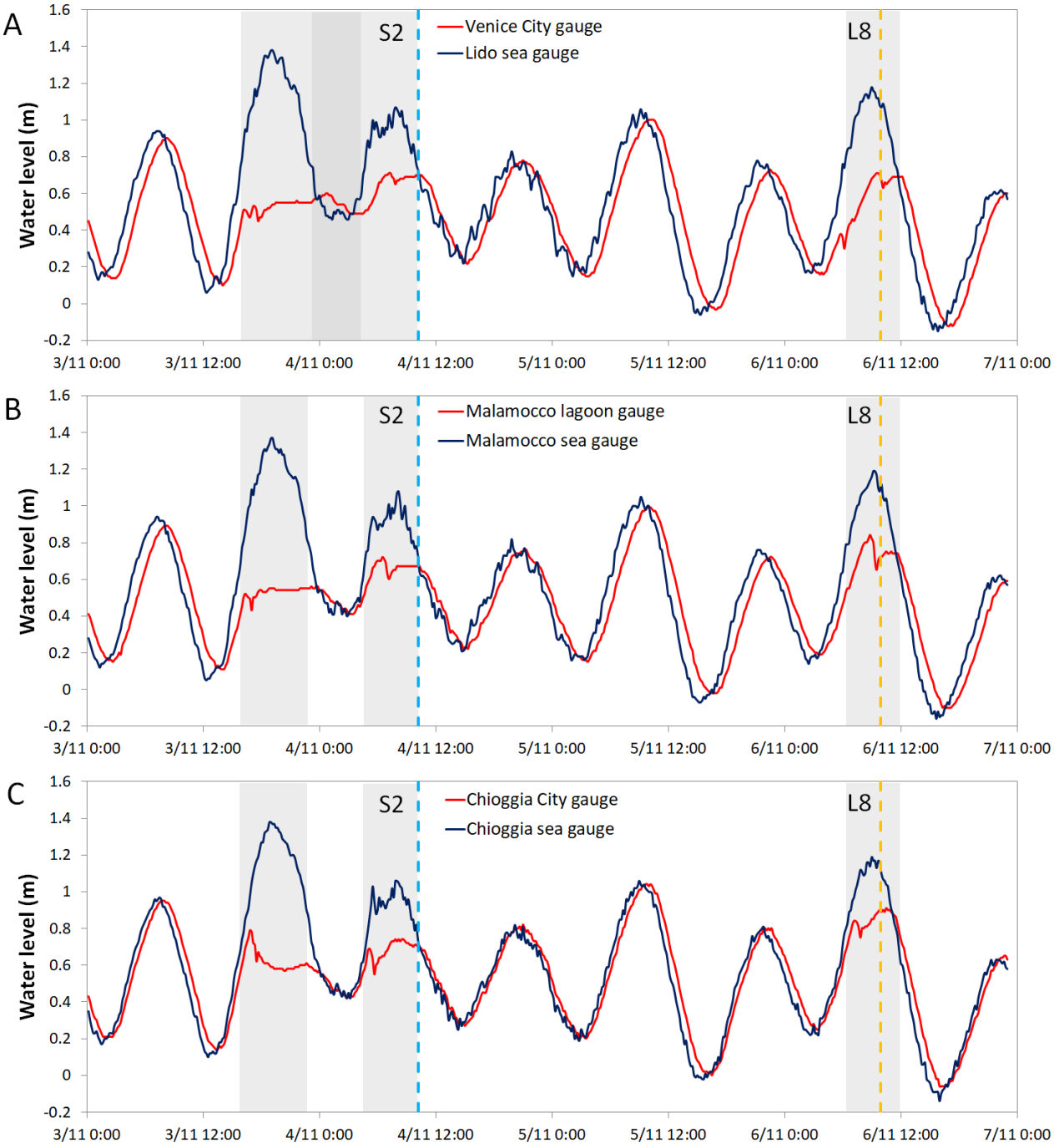

Figure 3. Tidal levels from gauge stations inside the lagoon (in red) and in the coastal area (in blue): A) Lido and Venice City; B) Malamocco; C) Chioggia. The areas shaded in light grey indicate the periods of closure of all barriers, while the darker grey indicates the period when only S. Nicolò barrier was closed at Lido. Tidal levels and wind data from the gauge stations were provided by the *Centro Previsione e Segnalazione Maree of the city of Venice*.

An example of the typical situation of a closed lagoon is captured by the NASA Landsat 8 image acquired on November 6th at 9.52 UTC (Figure 4), where all the barriers were in the working position in all the three inlets appearing in the imagery as yellow sea-walls. At the time of satellite overpass the wind (Figure 2) was from northeast with a speed of about 17 m s^{-1} determining high turbidity values along the coast as well as in the lagoon due to sediment resuspension over the tidal flats.

Figure 4. Pseudo-true-colour Landsat 8 imagery of the Lagoon of Venice (left panel) and details of the three inlets (right panel) acquired on November 6th 2021. Lido (A), Malamocco (B) and Chioggia (C) inlets.

The fine spatial resolution of these satellite imagery and of the derived products can be considered a key element for the effective management of coastal resources as communities worldwide are taking actions to protect from the effects of sea-level rise, as shown by this particular case-study.

Acknowledgements

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