Flood-regulation promotes salt-marsh drowning and enhances loss of geomorphic diversity in shallow tidal embayments

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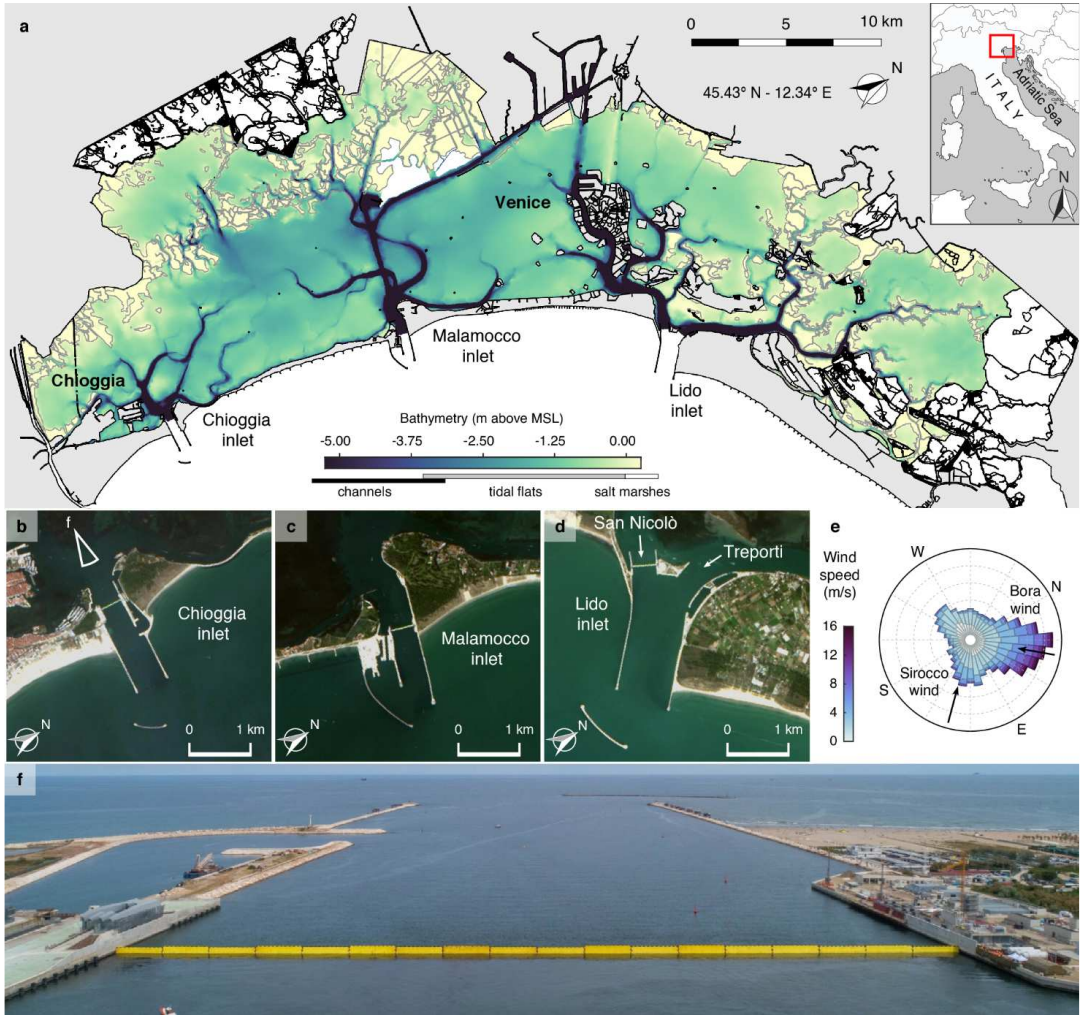
The lagoon of Venice and the Mo.S.E. floodgates



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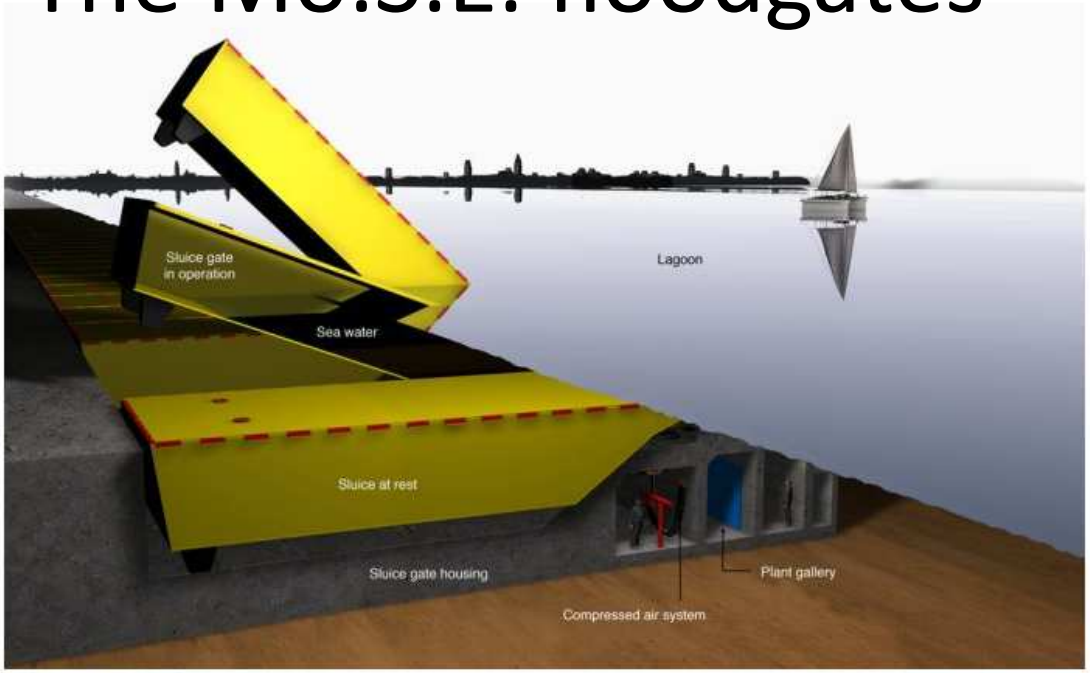
- Total area: 550 km^2
- 3 inlets
- Spring tidal range 1 m
- Max. tidal oscillation 1.5 m
- Average water depth 1.5 m
- Prevailing winds:
  Sirocco (SE) -> storm-surges
  Bora (NE) -> large waves
- Mo.S.E. floodgates system designed to protect Venice city and other settlements from flooding

The Mo.S.E. floodgates



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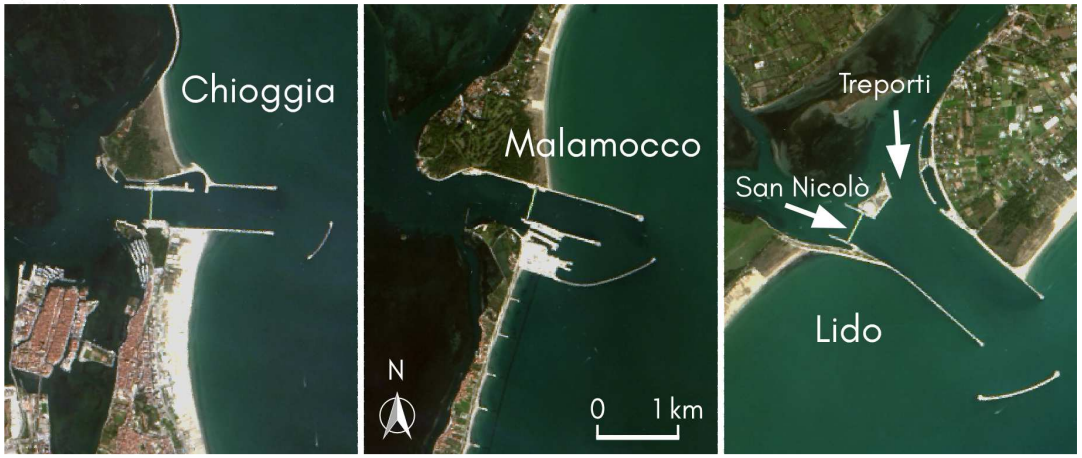
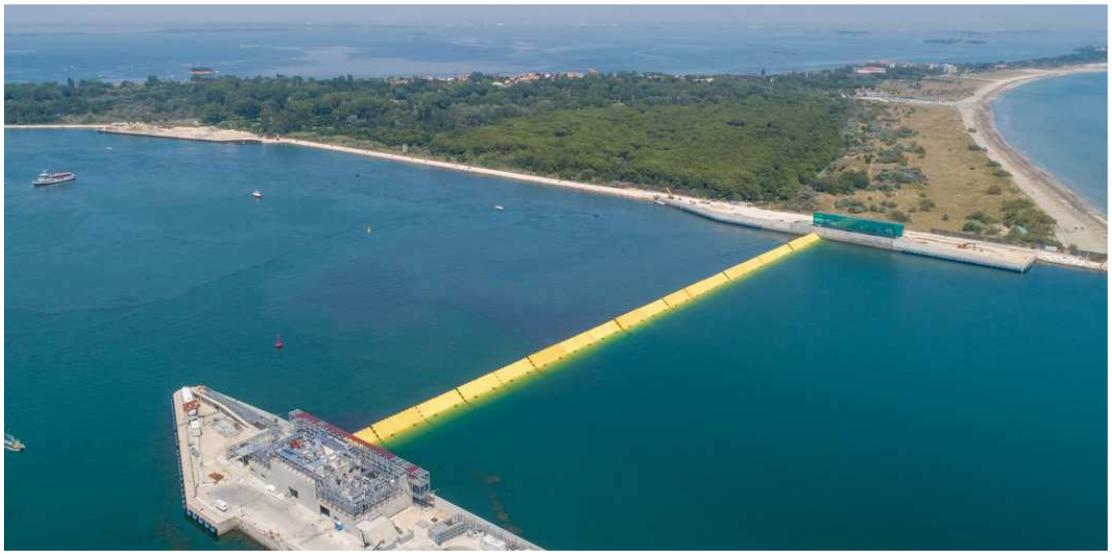
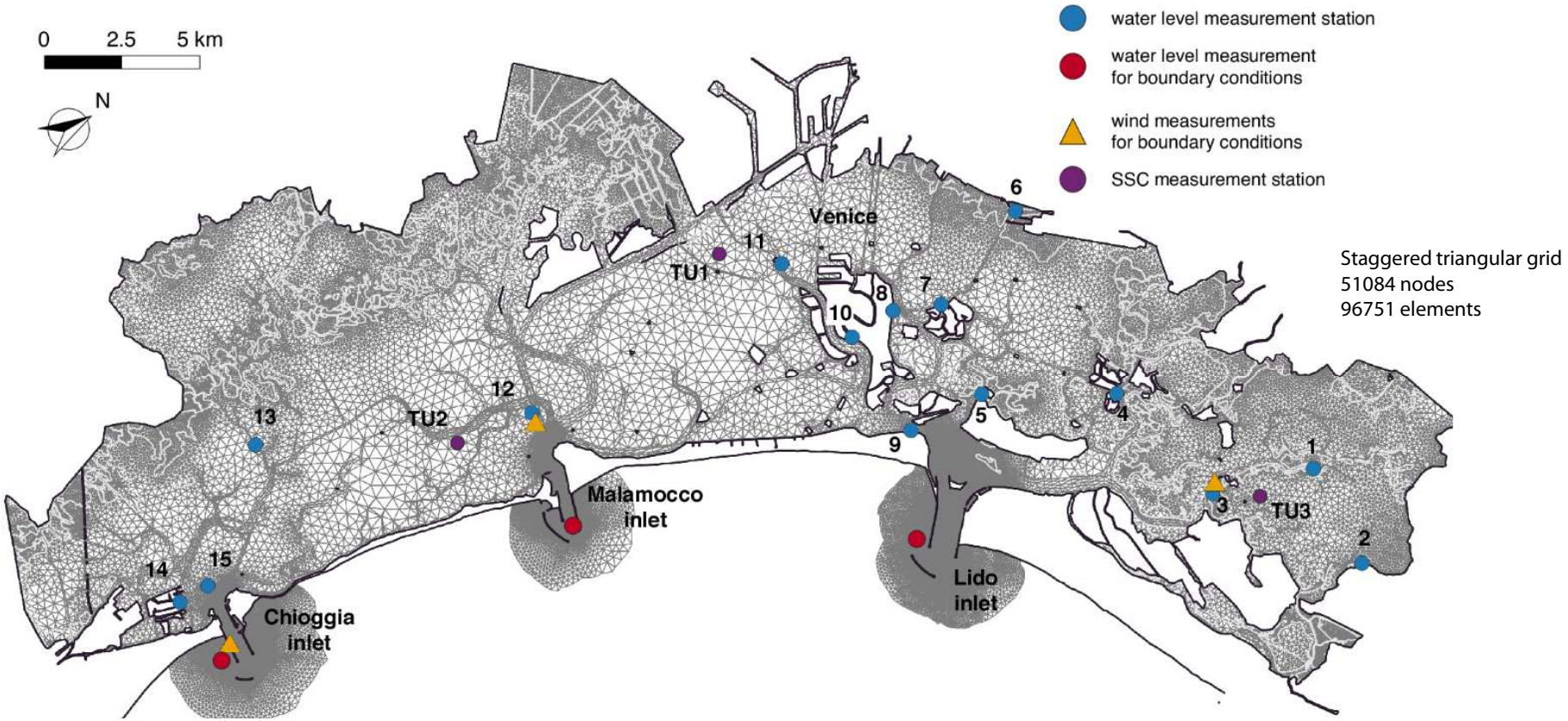




- 4 floodgates (1560 m in total)
- 78 sluice gates in total
- First operations: October 2020
- Effects on lagoon morphodynamics remain largely unexplored

Methods: field data and numerical model

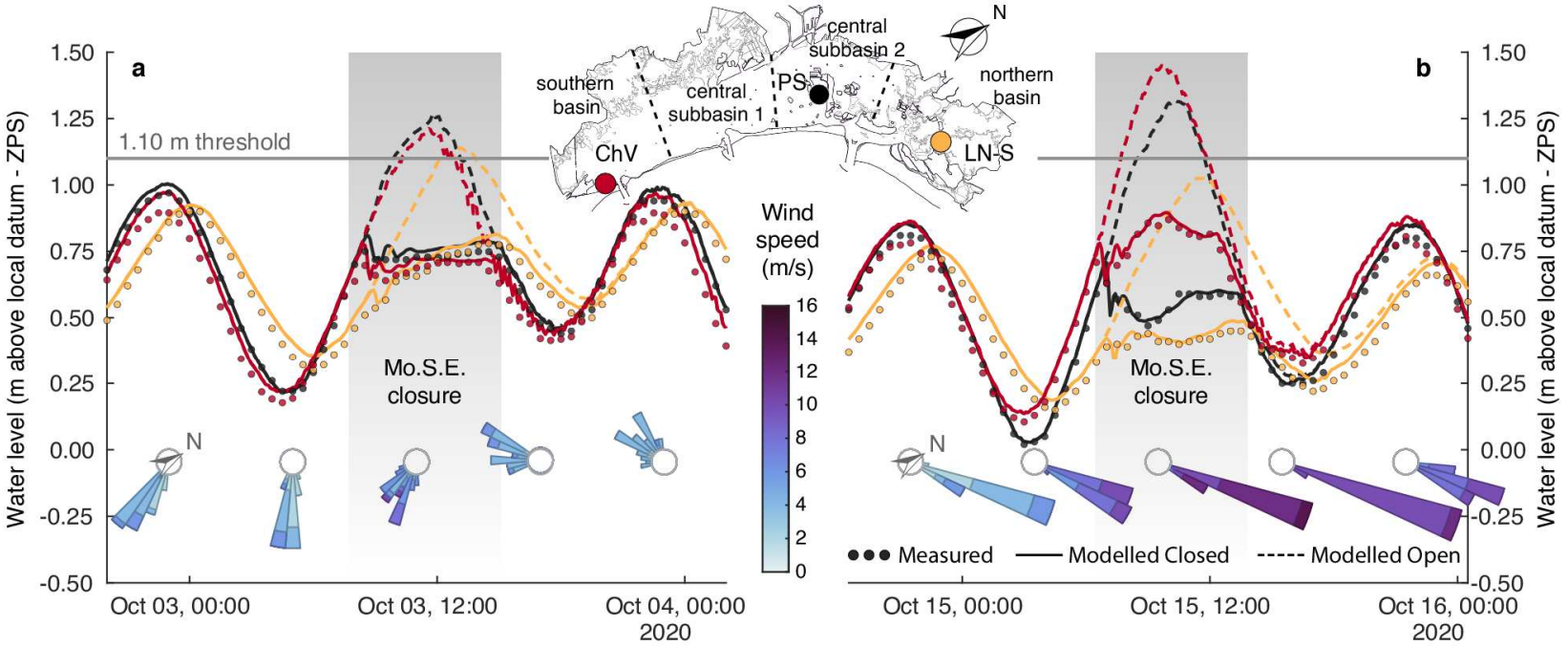


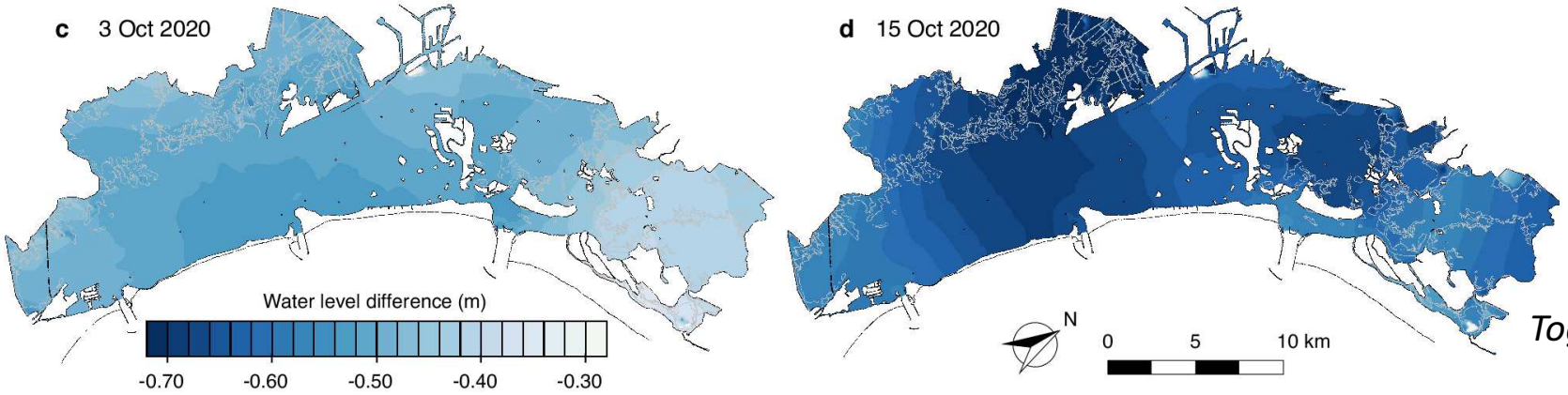
WWTM (Wind Wave Tidal Model) + STABEM (Sediment Transport And Bed Evolution Model) numerical models:

- *Carniello et al., Modeling wind waves and tidal flows in shallow micro-tidal basins. Estuar. Coast. Shelf Sci. 92, 263–276 (2011).*
- *Carniello et al., Modeling sand-mud transport induced by tidal currents and wind waves in shallow microtidal basins: Application to the Venice Lagoon (Italy). Estuar. Coast. Shelf Sci. 102–103, 105–115 (2012).*

Mo.S.E. floodgate operations: *Mel et al., The first operations of Mo.S.E. system to prevent the flooding of Venice: Insights on the hydrodynamics of a regulated lagoon. Estuar. Coast. Shelf Sci. 261 (2021)*

Effects of closures on tidal water levels





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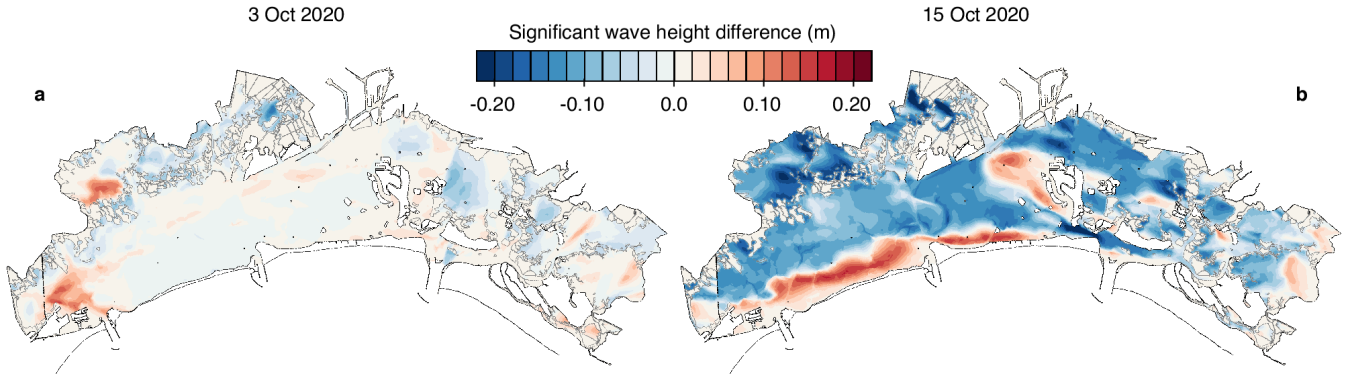
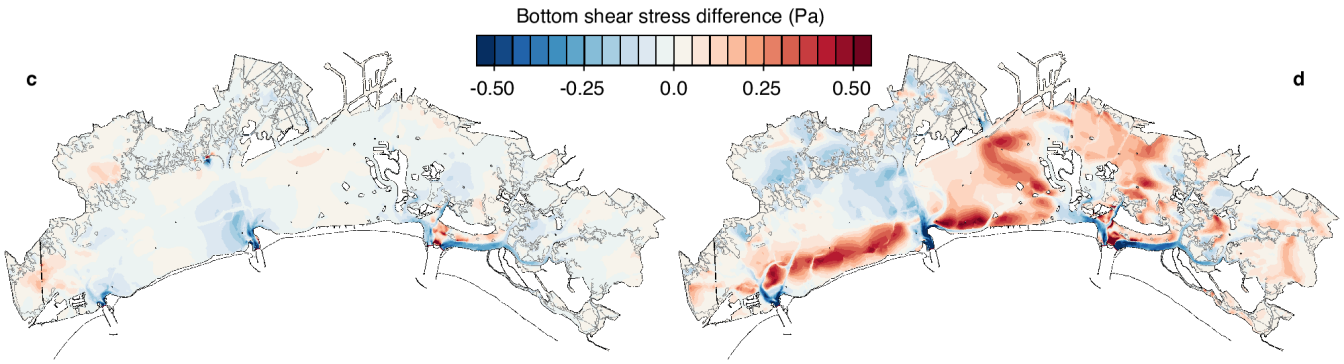
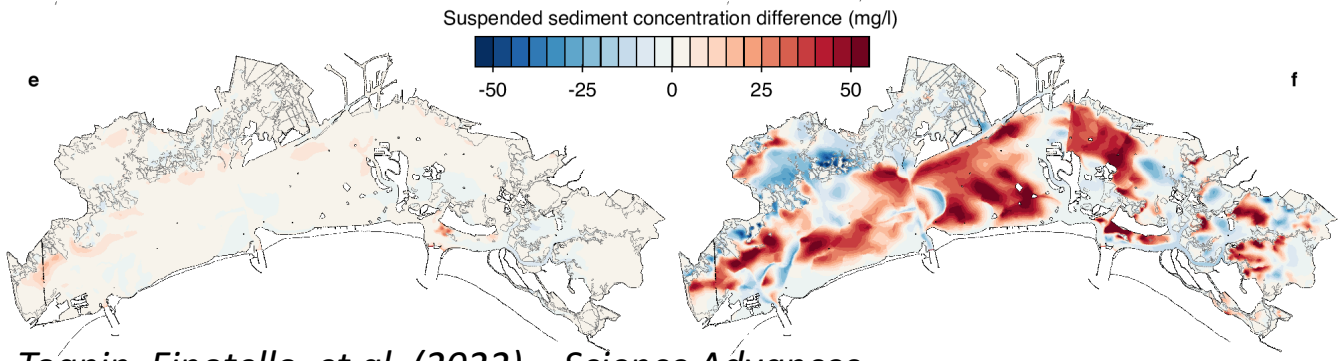
Effects of closures on sediment entrainment



Reduced significant wave height due to enhanced bottom friction:
-8% on October 3
-20% on October 15

Enhanced bottom shear stress due to shallower water depths:
+5% on October 3
+20% on October 15





Net increase of suspended sediment concentration due to enhanced resuspension from tidal flats:
+4.5% on October 3
+21% on October 15

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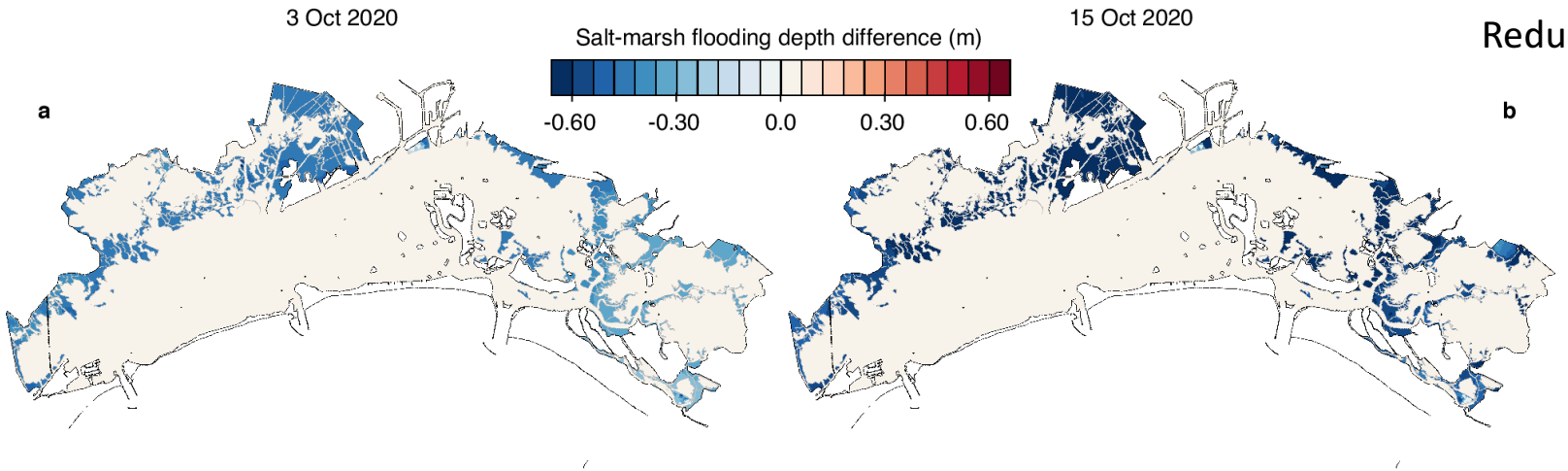
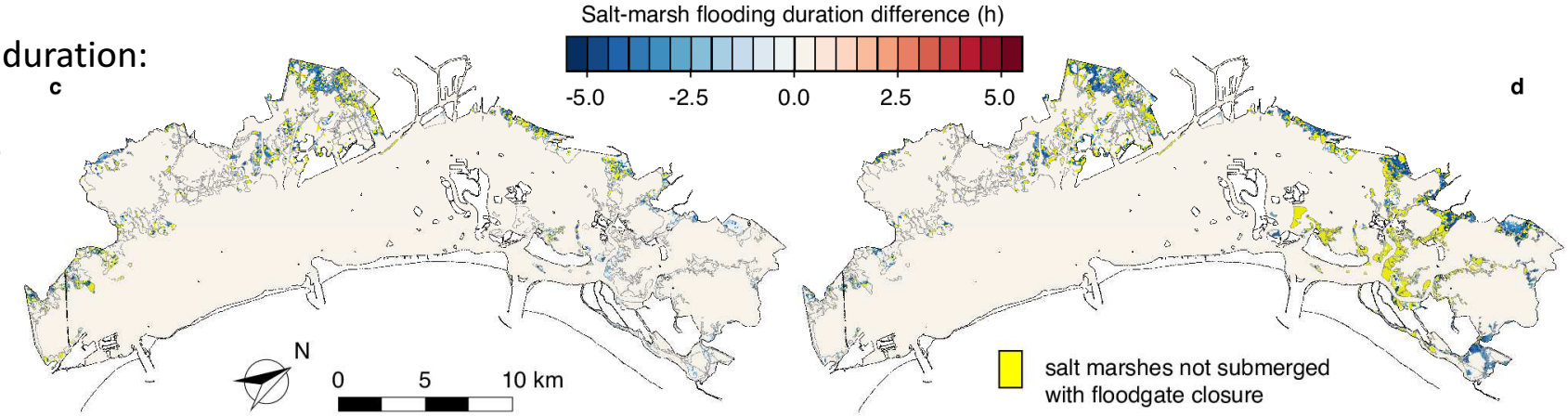
Effects of closures on salt-marsh hydroperiod



Reduced salt-marsh flooding depth:
-64% on October 3
-73% on October 15

Reduced salt-marsh flooding duration:
-64% on October 3
-73% on October 15



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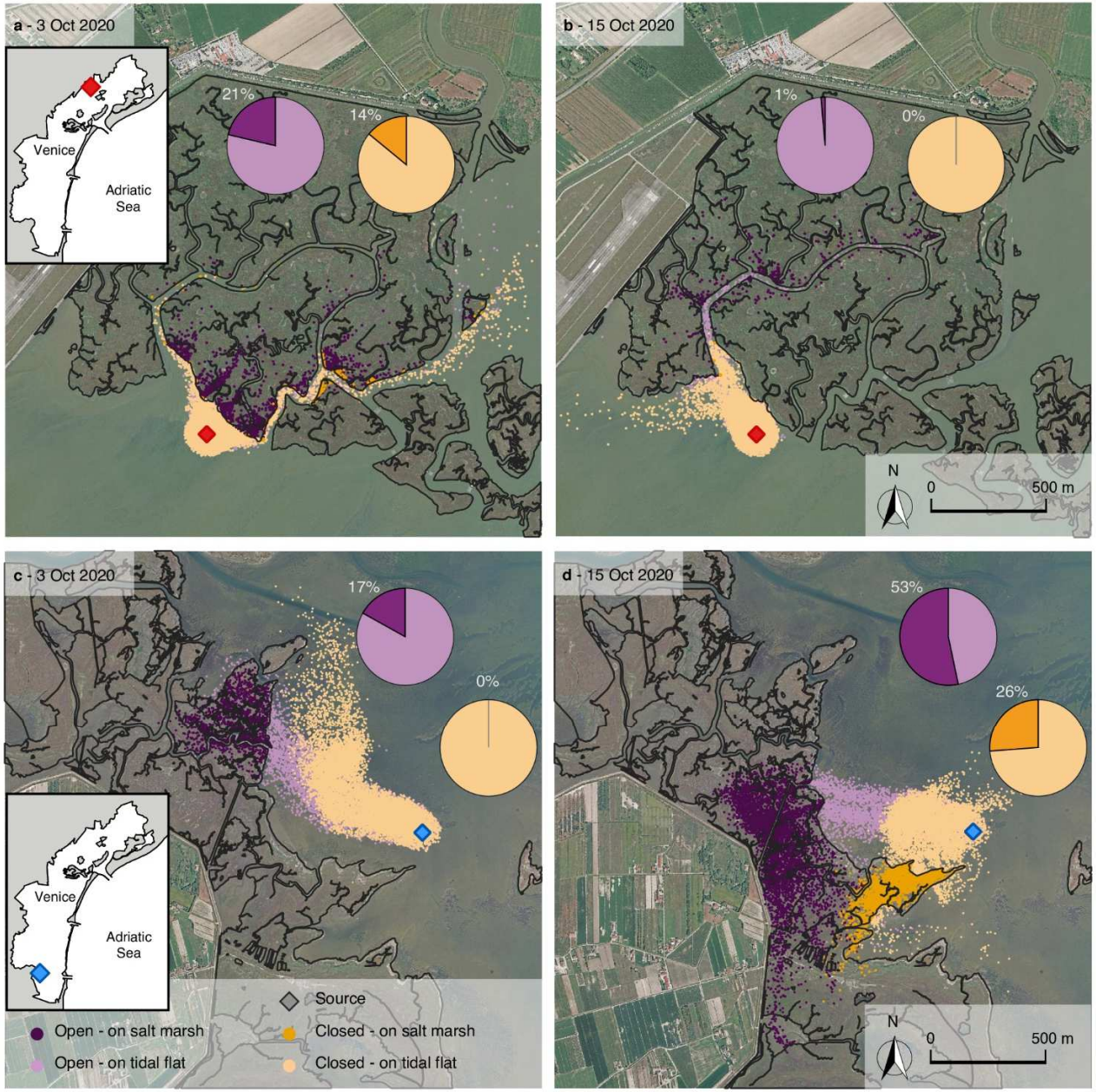

Even though floodgate closures enhanced SSC, reduced marsh hydroperiod limits the overall amount of sediment delivered to the marsh platform

Floodgates can potentially
inhibit sedimentation
and compromise
marsh resilience to sea-level rise.

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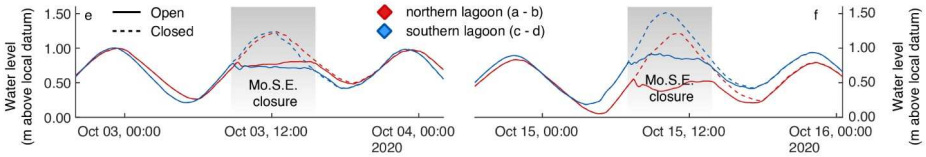
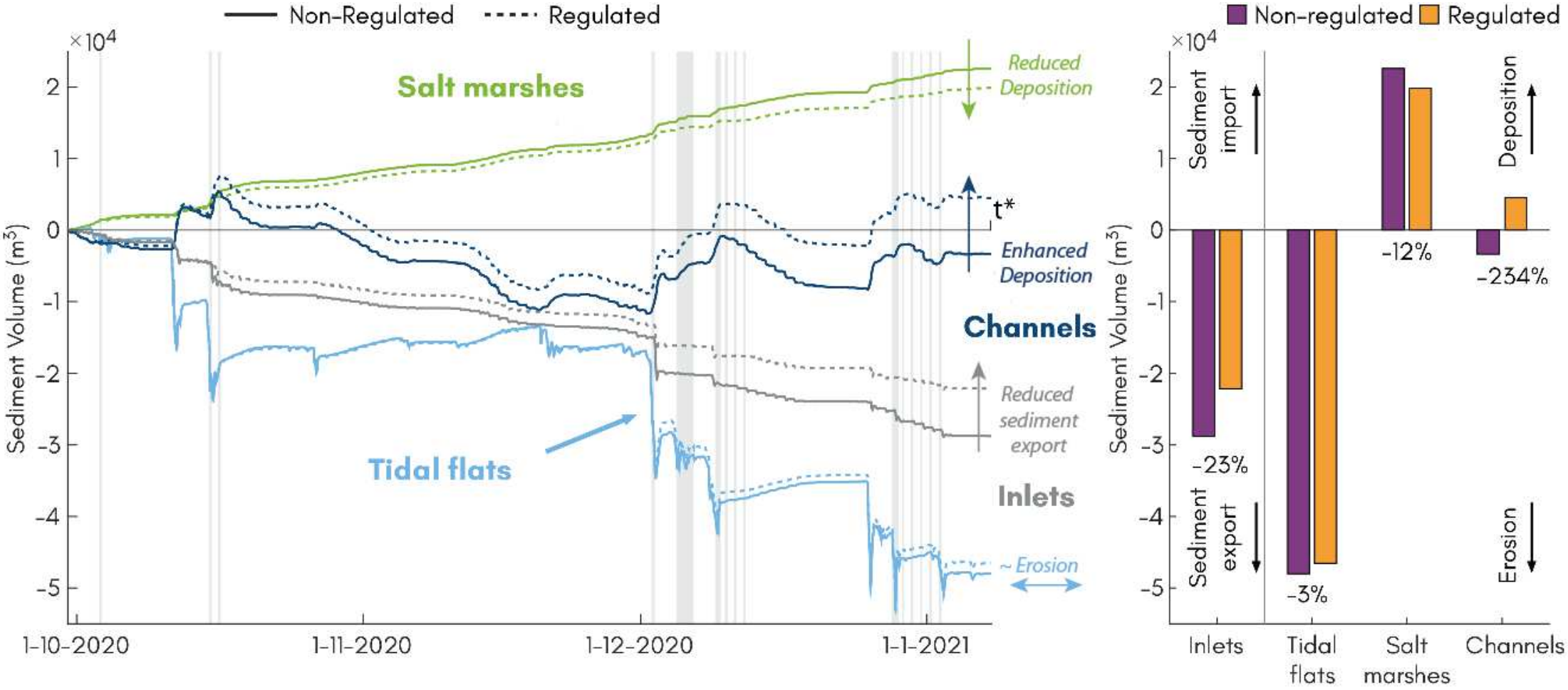
Marsh resilience to sea-level rise reduced by storm-surge barriers in the Venice Lagoon

Davide Tognin[1,2], Andrea D'Alpaos[2,3], Marco Marani[1,2] and Luca Carniello[1,2]



Sediment budget at the basin scale



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SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

Loss of geomorphic diversity in shallow tidal embayments promoted by storm-surge barriers

Davide Tognin[1,2]*†, Alvise Finotello[2,3]*†, Andrea D'Alpaos[2,4], Daniele P. Viero[1], Mattia Pivato[2], Riccardo A. Mel[5], Andrea Defina[1,2], Enrico Bertuzzo[3], Marco Marani[1,2], Luca Carniello[1,2]

Coastal flooding prevention measures, such as storm-surge barriers, are being widely adopted globally because of the accelerating rise in sea levels. However, their impacts on the morphodynamics of shallow tidal embayments remain poorly understood. Here, we combine field data and modeling results from the microtidal Venice Lagoon (Italy) to identify short- and long-term consequences of flood regulation on lagoonal landforms. Artificial reduction of water levels enhances wave-induced sediment resuspension from tidal flats, promoting in-channel deposition, at the expense of salt marsh vertical accretion. In Venice, we estimate that the first 15 closures of the recently installed mobile floodgates operated between October 2020 and January 2021 contributed to a 12% reduction in marsh deposition, simultaneously promoting a generalized channel infilling. Therefore, suitable countermeasures need to be taken to offset these processes and prevent significant losses of geomorphic diversity due to repeated floodgate closures, whose frequency will increase as sea levels rise further.

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Marsh resilience to sea-level rise reduced by storm-surge barriers in the Venice Lagoon

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Salt marshes are important coastal habitats and provide ecosystem services to surrounding communities. They are, however, threatened by accelerating sea-level rise and sediment deprivation due to human activity within upstream catchments, which result in their drowning and a reduction in their extent. Rising seas are also leading to an expansion of coastal flooding protection infrastructures, which might also represent another serious if poorly understood threat to salt marshes due to effects on the resuspension and accumulation of sediment during storms. Here, we use observations from the Venice Lagoon (Italy), a back-barrier system with no fluvial sediment input recently protected by storm-surge barriers, to show that most of the salt-marsh sedimentation (more than 70% in this case) occurs due to sediment reworking during storm surges. We also prove that the large, yet episodic storm-driven sediment supply is seriously reduced by operations of storm-surge barriers, revealing a critical competition between the objectives of protection against coastal flooding and preservation of natural ecosystems. Without complementary interventions and management policies that reduce barrier activations, the survival of coastal wetlands is even more uncertain.