

Salt marsh resilience to sea-level rise and increased storm intensity

N. Panno^{a*}, Nicoletta Leonardi^a, Iacopo Carnacina^b, Rachel Smedley^a

^aDepartment of Geography and Planning, School of Environmental Sciences, University of Liverpool, Chatham Street, Liverpool, L69 7ZT, UK

^bDepartment of Civil Engineering, School of Civil Engineering and Built Environment, Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK

[*sgnpanno@liverpool.ac.uk](mailto:sgnpanno@liverpool.ac.uk) (corresponding author)

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1) Context

- Salt marshes are ecosystems of high economic and environmental value (Townend et al., 2011).
- There are many uncertainties about their resilience to sea-level rise and possible increase in storm activity.
- Sediment budget - quantity of sediment entering and exiting the system during each tidal cycle :

positive -> accretion vs negative -> degradation
(Ganju et al., 2015).



2) Aim and objectives

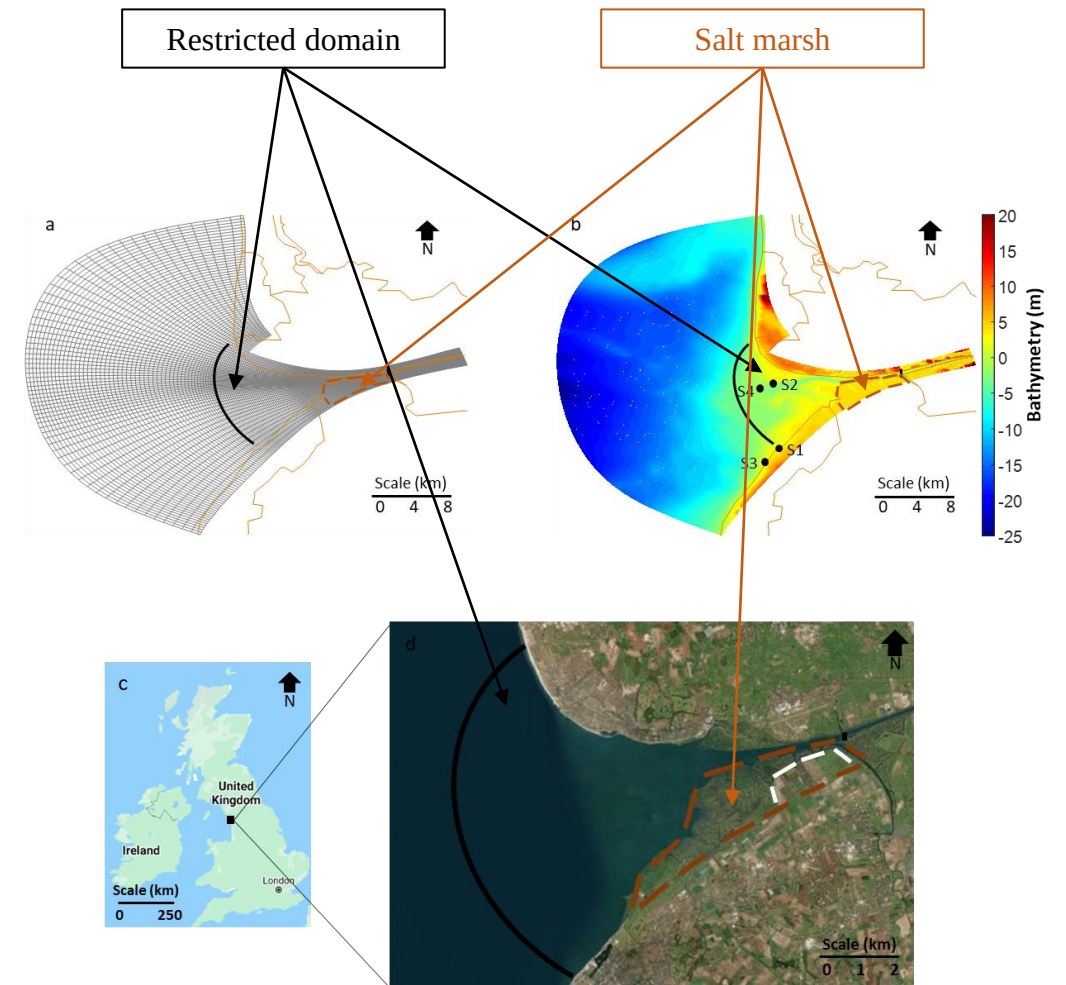
Investigate marsh resilience under various storm surge and sea-level scenarios by using a sediment budget approach and the hydrodynamic model Delft3D:

- Change in sea-level only;
- Change in surge intensity only
 - +
 - timing of the storm surge relative to high or low tide,
 - duration of the surge,
 - change in tidal range;
- Combination of storm surge and sea-level scenarios.

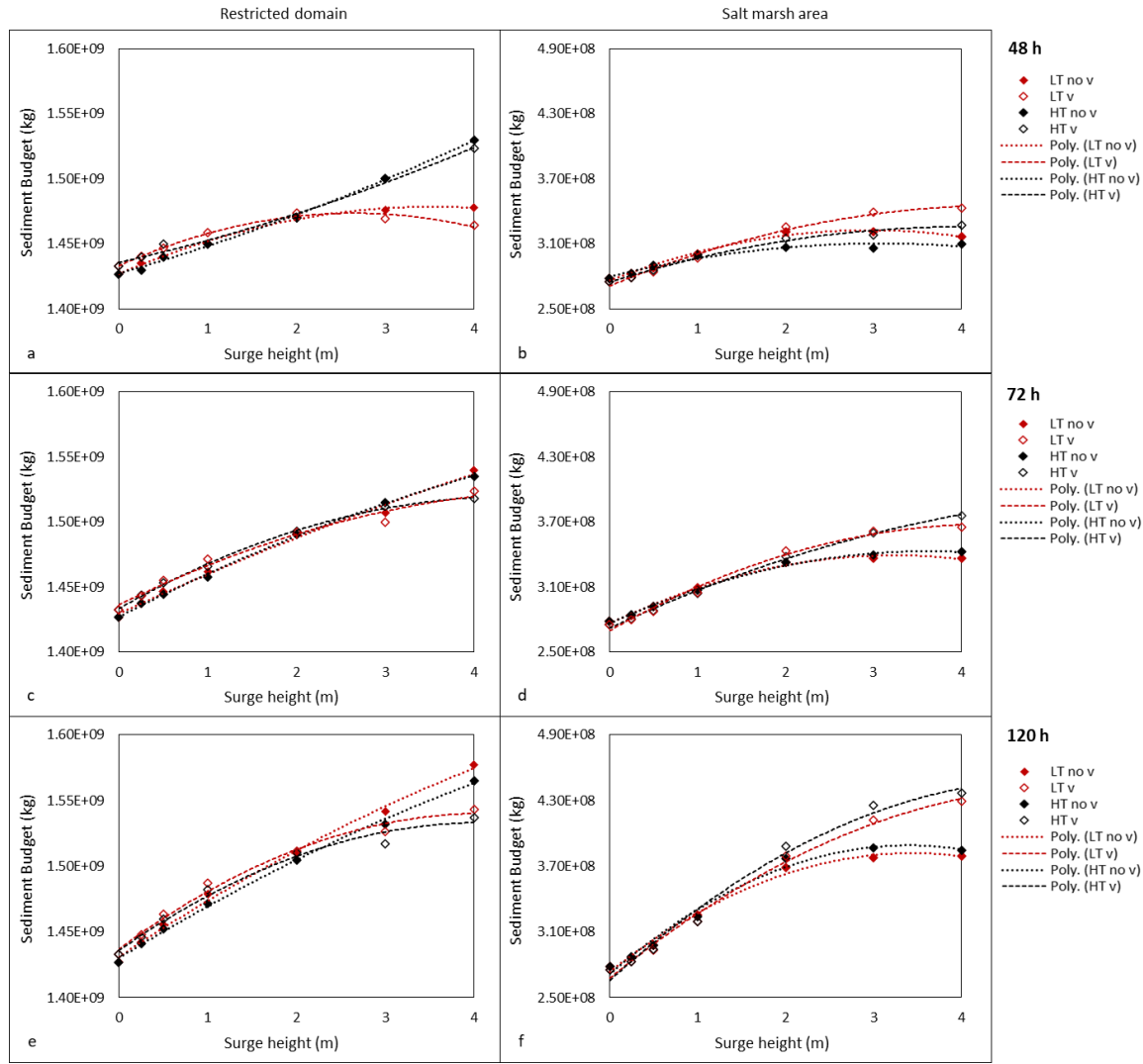
3) Case study

Ribble estuary, North West England (Van der Wal et al., 2002):

- Funnel shaped, hypertidal.
- Marsh recently restored.
- Restricted domain and salt marsh area.



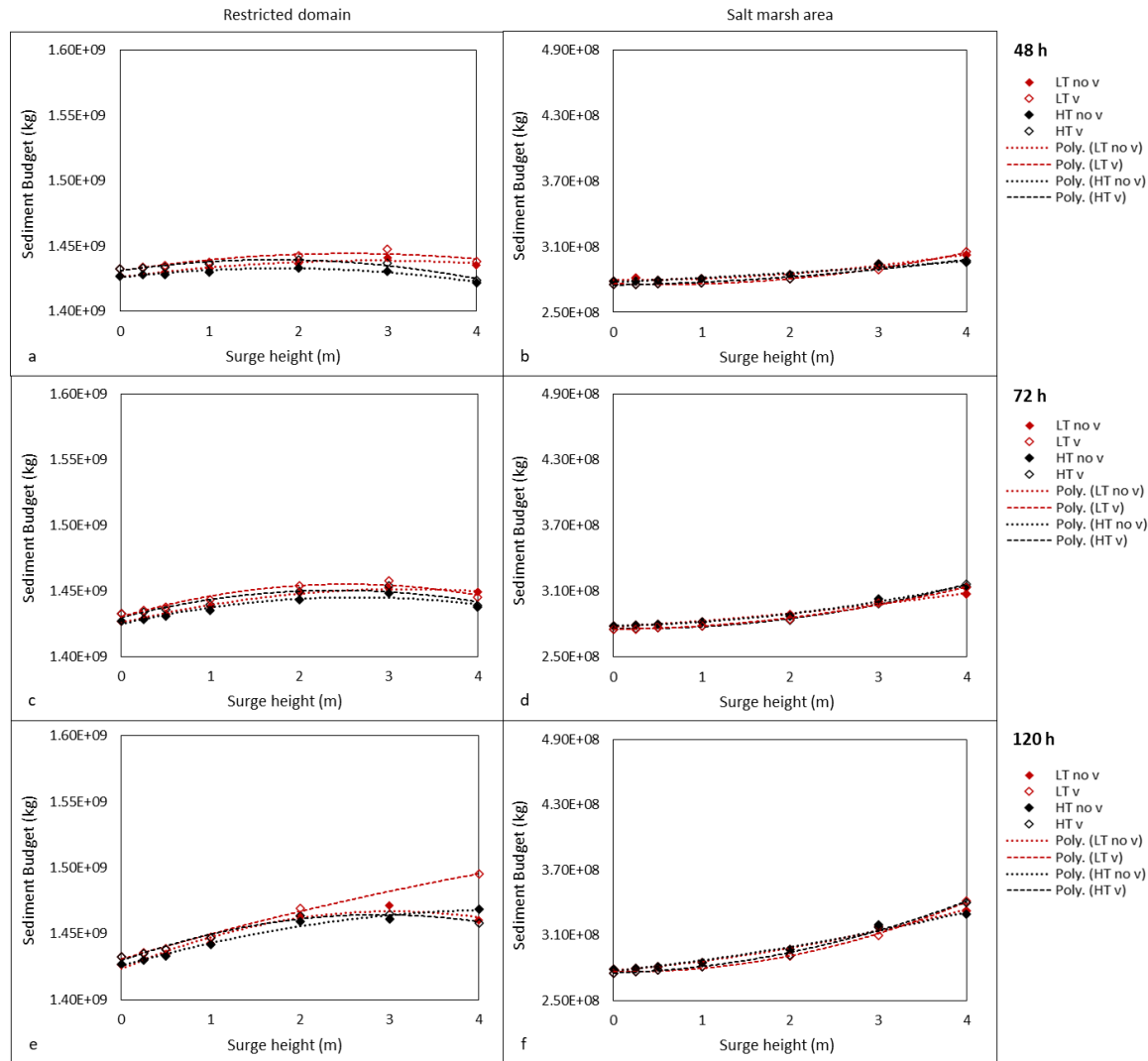
4) Results: deposit



Surges occurring at spring tide

- Deposit increases overall in both the restricted domain and on the marsh platform when the surge height increases.
- 48 hours scenarios:
 - in the restricted domain, for higher surges, deposition is more substantial when the peak of the surge coincides with the high tide peak;
 - on the marsh platform, the rise is more pronounced when the peak of the surge coincides with the low tide peak.
- Longer durations (72 hours and 120 hours scenarios):
 - this difference decreases visibly and becomes negligible.
- When vegetation is added:
 - in the restricted domain, the deposition in the vegetated scenario is greater than the non-vegetated scenario for surges up to 2 m and lesser for surges >2 m;
 - on the saltmarsh, the deposition in the vegetated scenario is lesser for surges up to 1 m and greater for surges >1 m compared to the non-vegetated scenario.

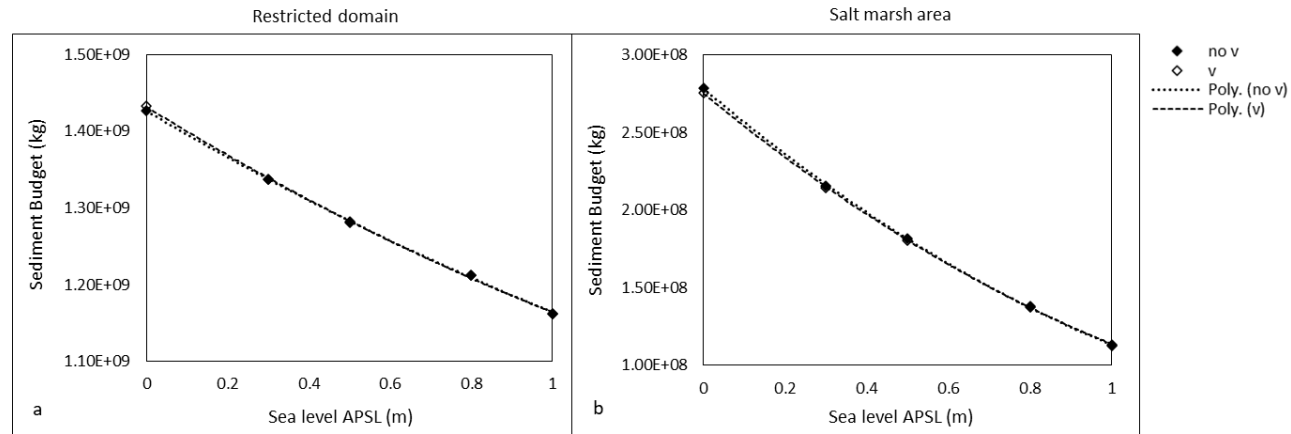
4) Results: deposit



Surges occurring at neap tide

- Trends remain comparable to spring tide scenarios, but the difference between deposition driven by surges peaking at high tide and surges peaking at low tide becomes less significant.
- When vegetation is added, the inversion in the trends does not occur or it only occurs for surges >3 m.

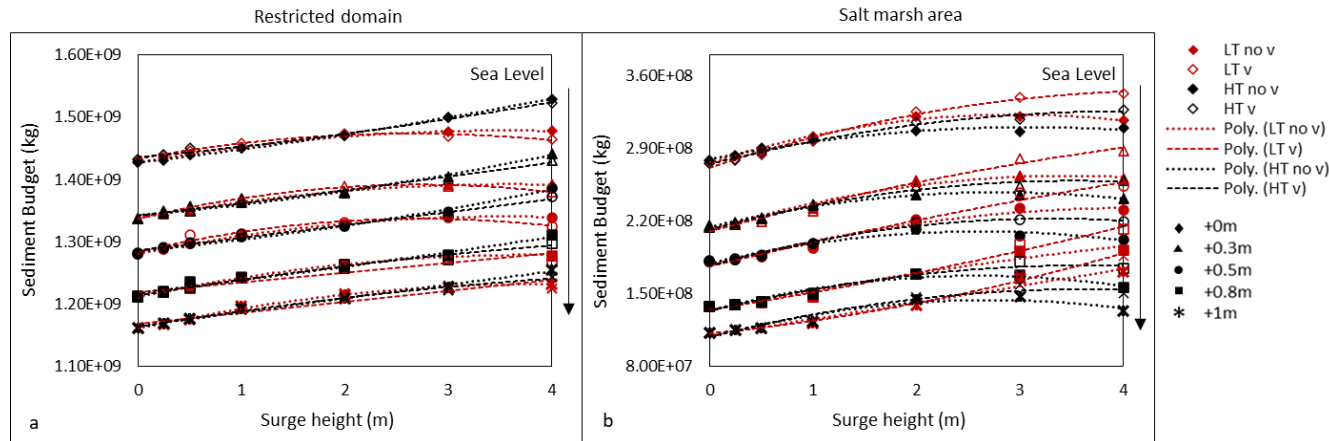
4) Results: deposit



Sea-level

- Deposition decreases both in the restricted domain and on the marsh.
- When vegetation is added, no significant difference is noticeable in the trend.

4) Results: deposit

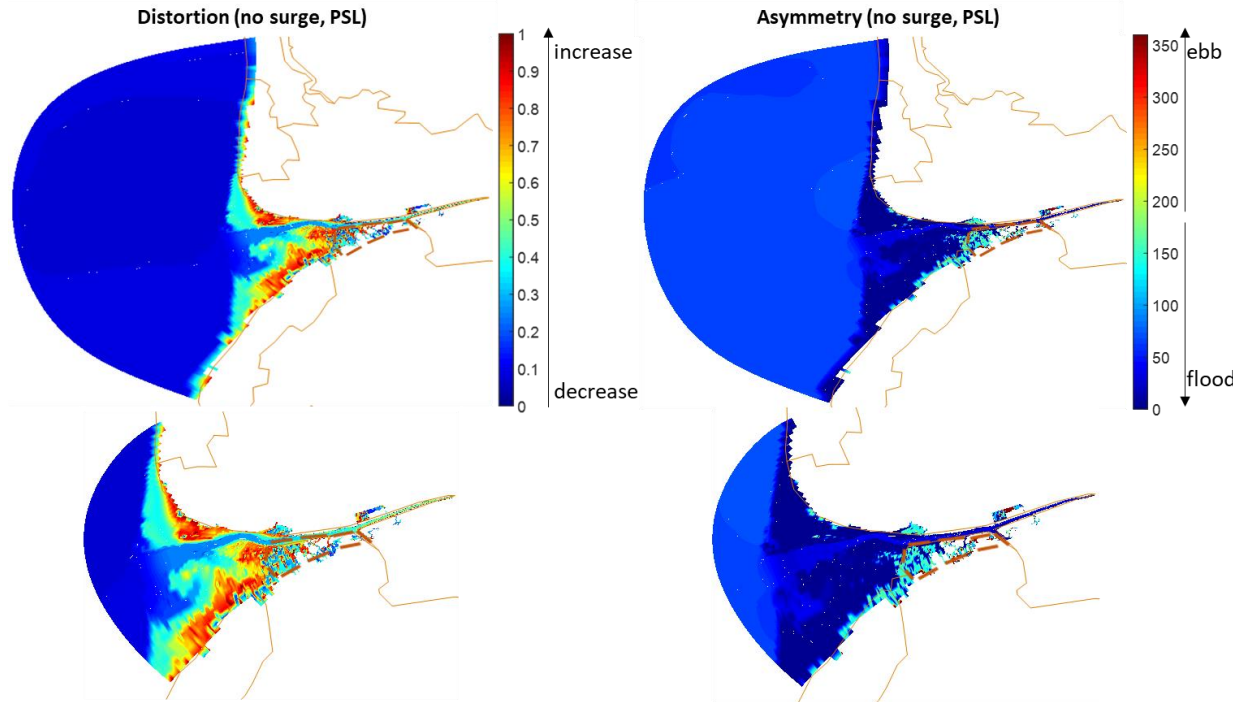


Sea-level + storm surges (48h spring)

- The trends in deposition caused by the increase in surge height remain similar in all sea-level scenarios.
- The main visible difference is:
 - in the restricted domain, decrease in the difference between deposition during surges occurring at low tide and high tide;
 - on the marsh, this difference increases.
- There is an overall decrease in the magnitude of deposition with the increase in sea-level.
- The effects of storm surges mask the effects of sea-level rise on the sediment budget; this is especially true for surges with the highest intensities (>3 m).

4) Results: fourier analysis

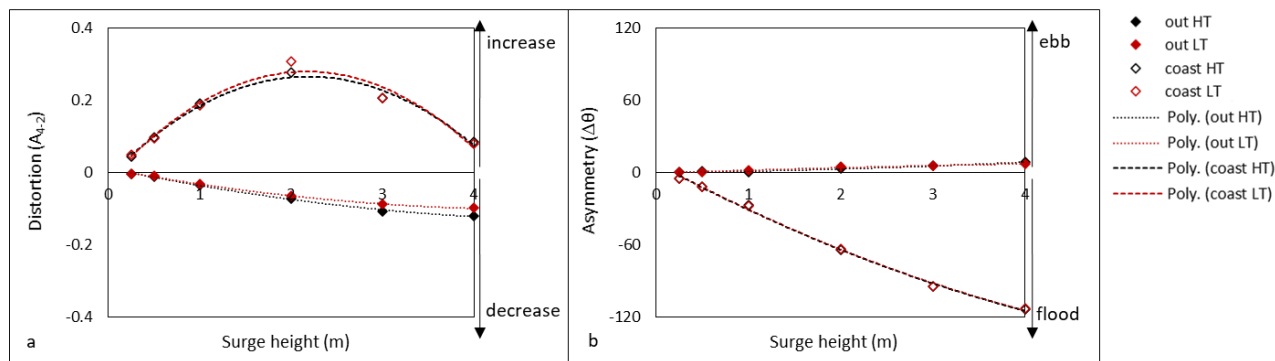
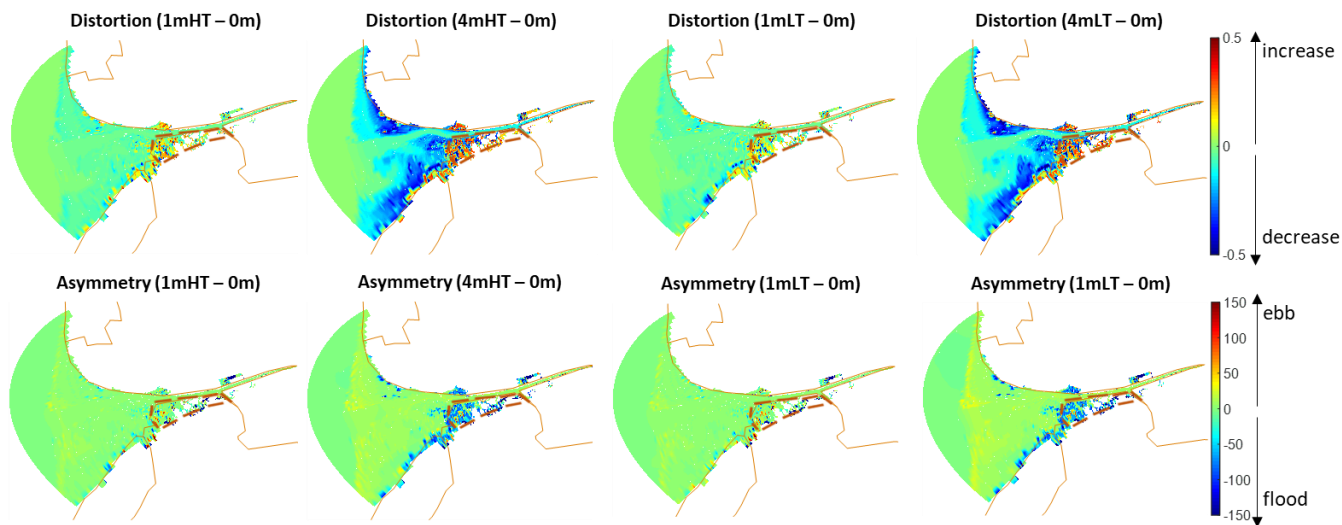
- The sediment budget depends on the quantity of sediment entering and exiting the system during each tidal cycle, and this is influenced by tidal asymmetry and distortion (Guo et al., 2016; Palazzoli et al., 2020).
- When there is a flood dominance (flood phase shorter and more intense than ebb phase), flood velocities can be sufficiently high to resuspend sediment and promote a net landward sediment import, and vice versa in the case of ebb dominance (Van Dongeren and de Vriend, 1994; Lanzoni and Seminara, 2002).



Present-day sea-level and no surges

- The estuary is characterised by a dominance of the flood phase.
- Flood dominance decreases landward due to a landward increase in friction, which reduces the velocity of the incoming tide (Friedrichs and Aubrey, 1988; Wang et al., 2002; Parker, 2007).
- Overall flood dominance explains the positive sediment budget.

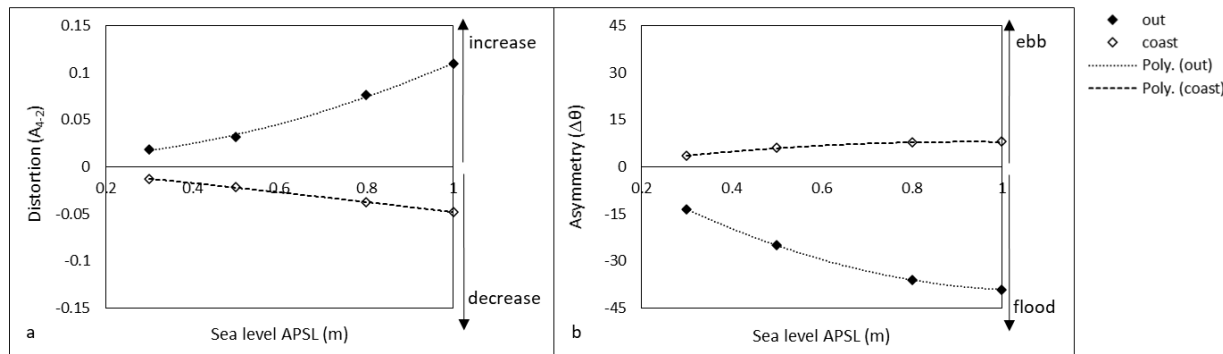
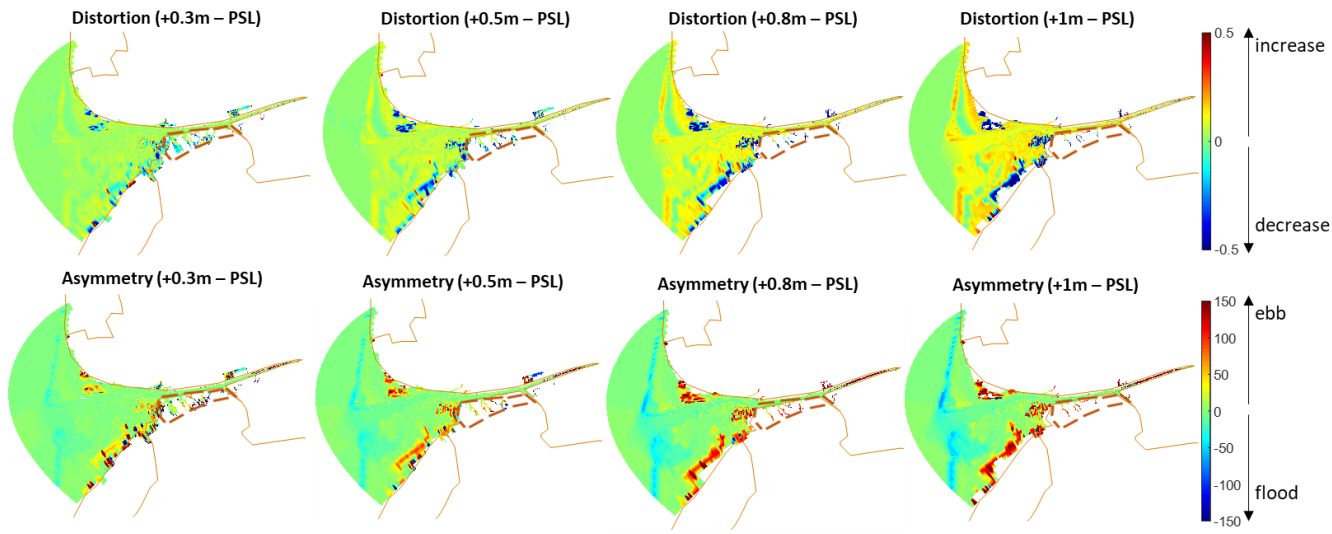
4) Results: fourier analysis



Storm surges (48h spring)

- Storm surge presence enhances the flood dominance near the coastline and causes a slight ebb dominance offshore.
- Flood dominance near the coastline caused by non-linear interaction between surge and tide (Zenghao and Yihong, 1996; Parker, 2007) responsible for increase in deposition.
- Ebb dominance offshore caused by the symmetric relationship of tide and velocity might be the dominant factor that controls the phase dominance (Savenije, 2012) responsible for differences between surges peaking at HT and LT - more pronounced when the surge peaks at LT compared to when it peaks at HT since in the first case the surge covers two high tide peaks and in the second case it covers only one high tide peak; the effect is negligible if tidal range decreases or storm duration increases because increase in number of tidal cycles affected or decrease in tidal amplitude reduce surge amplification.

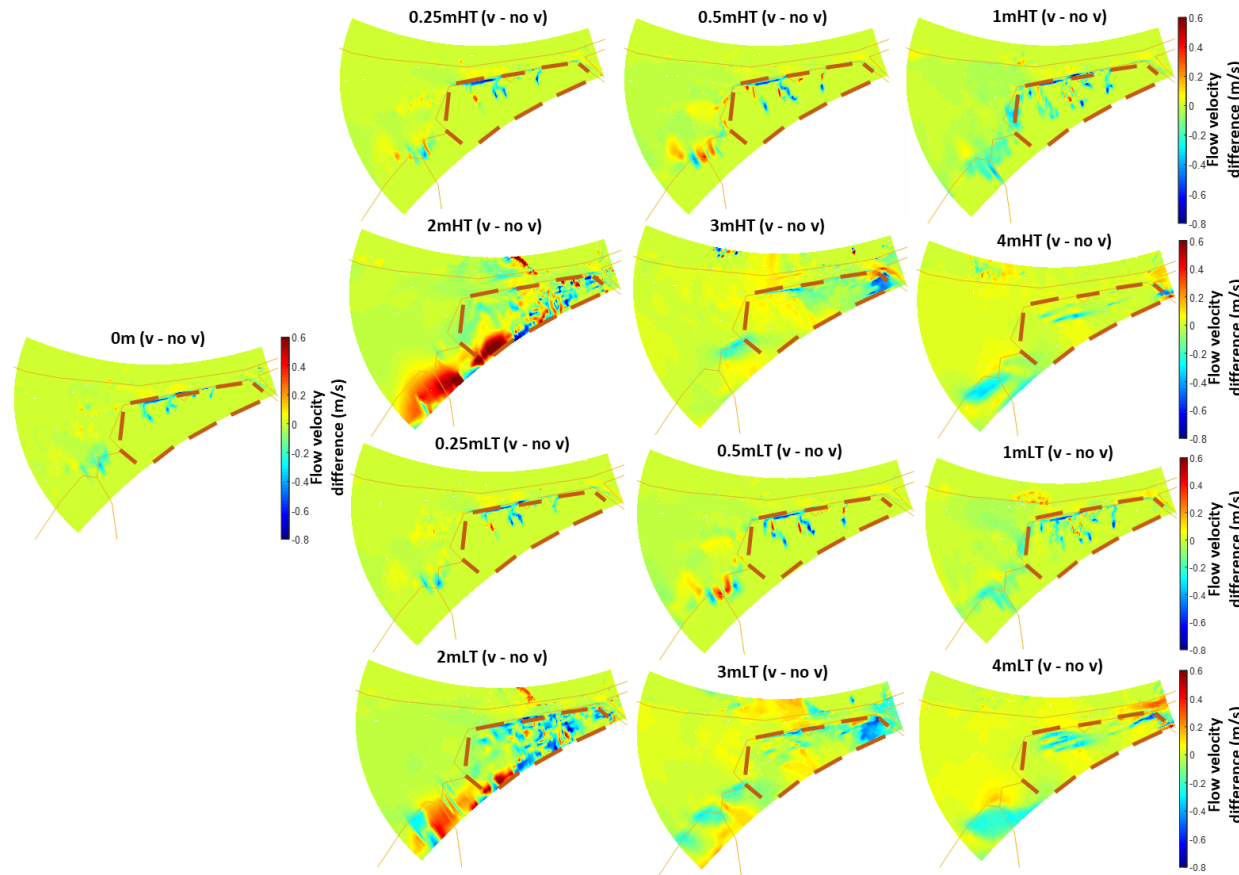
4) Results: fourier analysis



Sea-level

- An increase in sea-level causes ebb dominance near the coastline and enhanced flood dominance offshore.
- Ebb dominance nearshore caused by sea-level effects on the resonance of the basin causing an increase in the M2 component (Pickering et al., 2012; Idier et al., 2017), responsible for decrease in deposition.
- Flood dominance offshore caused by an increase in the tidal prism - increase in the velocity of the incoming tide across the mouth of the estuary (Sinha et al., 1997; Liu et al., 2020; Zhang et al., 2020) responsible for decrease in difference between surges occurring at HT and LT because of offsetting of surge effect; the increase on the marsh occurs because of the number of tidal cycles enhanced.

4) Results: vegetation effects



- Lower surges:
 - lower deposition on the marsh platform, water level is not high enough to overflow the tidal creeks and channel erosion prevails;
 - higher deposition in the restricted domain, water is not constrained and the frictional effect of the vegetation prevails.
- Higher surges:
 - higher deposition on the marsh platform, water level is high enough to overflow the tidal creeks and sediment trapping prevails;
 - lower deposition in the restricted domain, frictional effect effective on the high-water depths and off-site water channelization dominates.
- During neap tide, the water level is lower during flood phase, when the marsh is inundated, therefore the velocity profile typical of lower water depths persists for higher surges.
- With sea-level rise, effects similar to lower surges but is not visible because sediment export prevails.

5) Conclusions

- Investigate the resilience of salt marshes to the combined influence of sea-level rise and increasing storm surge intensity.
- Storm surges could contribute to salt marsh and estuarine resilience by causing a shift towards a more flood dominated system and by triggering a net import of sediment:
 - The degree of deposition can change slightly depending on the timing of the surge peak for short durations (48 hours) and high tidal range, while it is reduced if the duration increases (72 hours and 120 hours) or the tidal range decreases.
- Sea-level rise will threaten the stability of the marsh by causing a shift towards an ebb dominated system, triggering a higher export of sediment.
- Storm surges might contribute to increase salt marsh resilience to sea-level rise by masking the effects of sea-level rise on the sediment budget; this is particularly true for storms with highest intensities (>3 m surges).
- The addition of vegetation caused no variations to the trends produced by the sea-level analysis and only minimal variations to the trends produced by surge height analysis; the latter is due to the ability of vegetation canopy to modify flow velocity.

Questions?