Sediment dynamics and wave attenuation at the marsh edge

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State of the Estuary 2019

Background

Marshes and other shallow water habitats are particularly threatened by sea-level rise.

Accretion: Deposition of sediment from adjacent waters can counter drowning and help marshes maintain elevation as sea level rises.

Elevation-based models of marsh evolution show that many SF Bay marshes may be drowned by sea-level rise

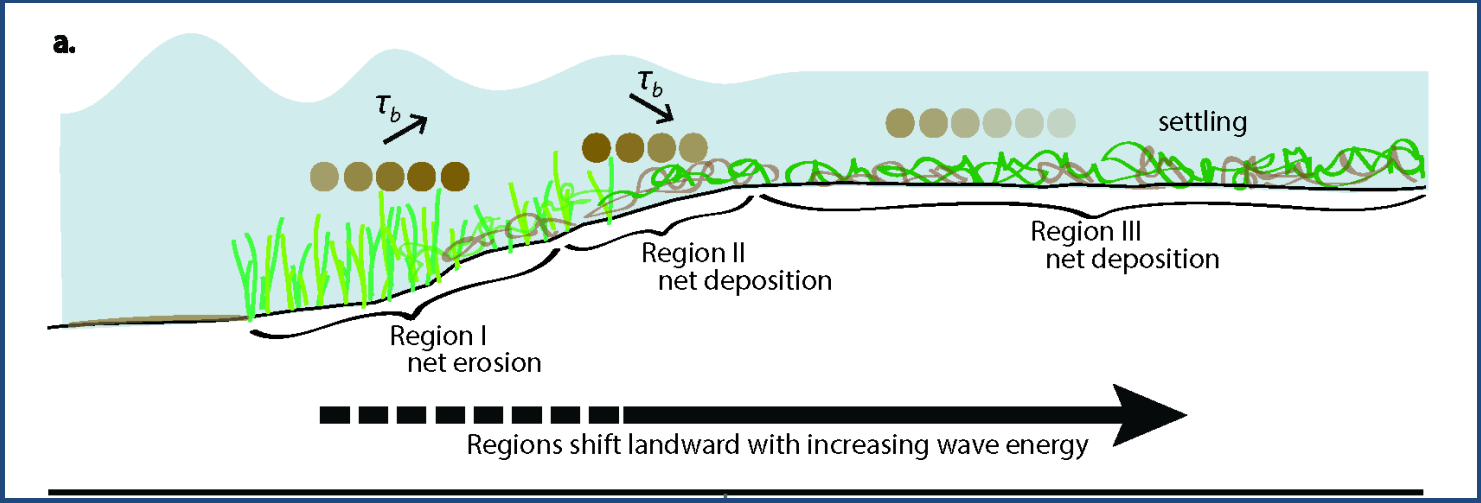
Questions:

How does sediment supply to the marsh vary with wave conditions, seasons?

How much are waves attenuated at the marsh edge?

Focus on wave-exposed marsh edge

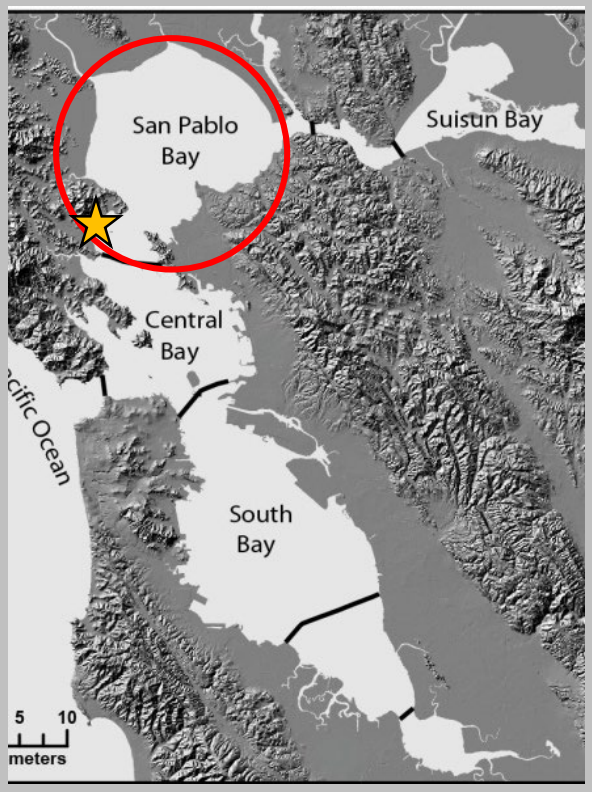
- threatened by both lateral erosion and drowning
- provides coastal protection by attenuating waves
- strong potential for sediment delivery and erosion
- less studied than tidal creeks as a pathway for sediment delivery
- Strong connection to conditions in adjacent shallows



Conceptual model of sediment processes at the marsh edge

Why?

- Large-scale models of marsh resilience have a very simplistic treatment of sediment supply, and do not account for erosion
- Data are needed to validate models of marsh-edge regions which include complex biogeomorphic processes
- Results can support prioritization of sites for conservation or restoration and selection or timing of restoration actions



Study site: China Camp marsh in San Pablo Bay (northern San Francisco Bay)

Collaboration with Callaway (USF) and Ferner (SF Bay NERR)

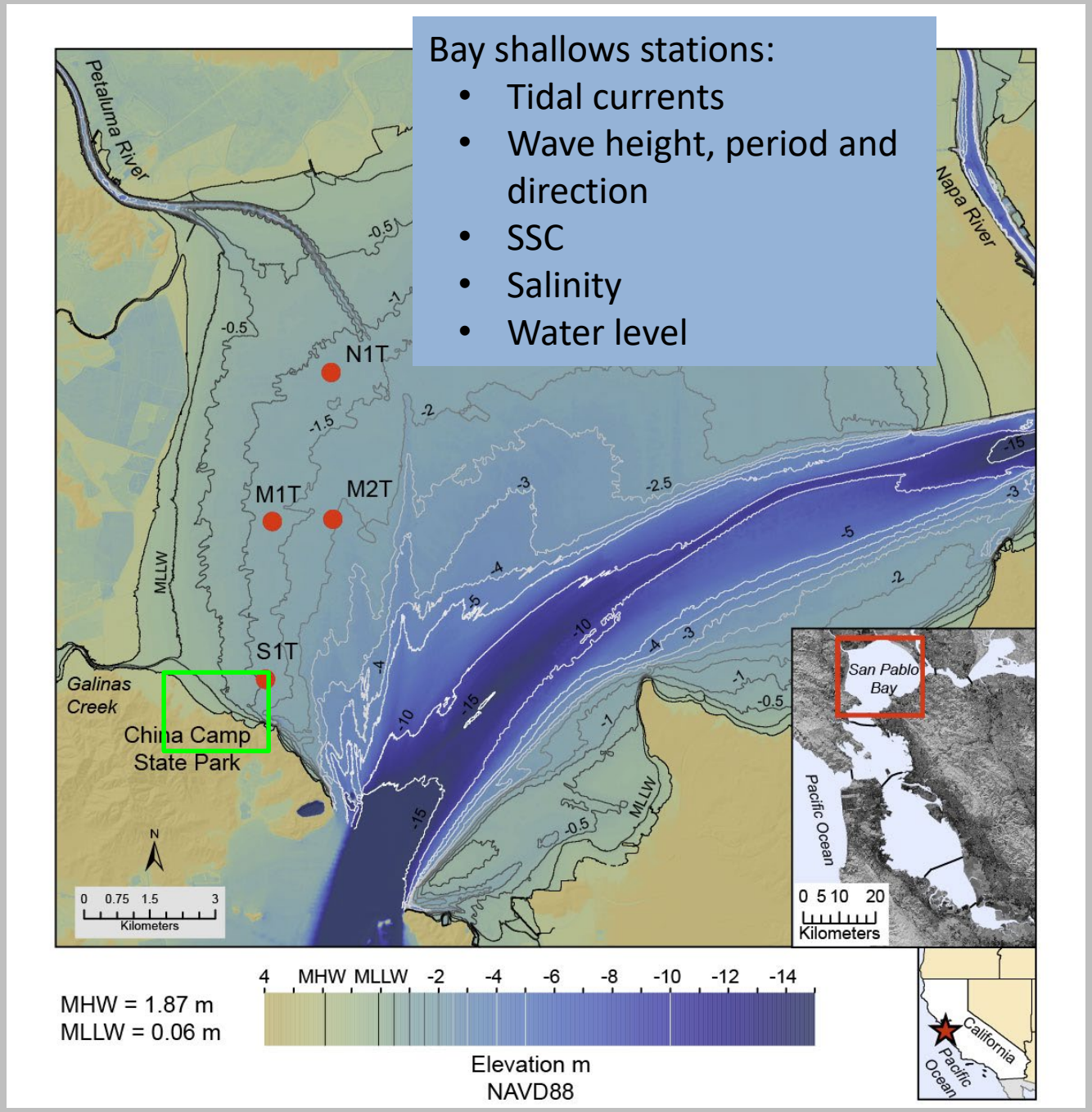
One of the few marshes in SF Bay that was not diked or drained. It accreted following the Gold Rush.

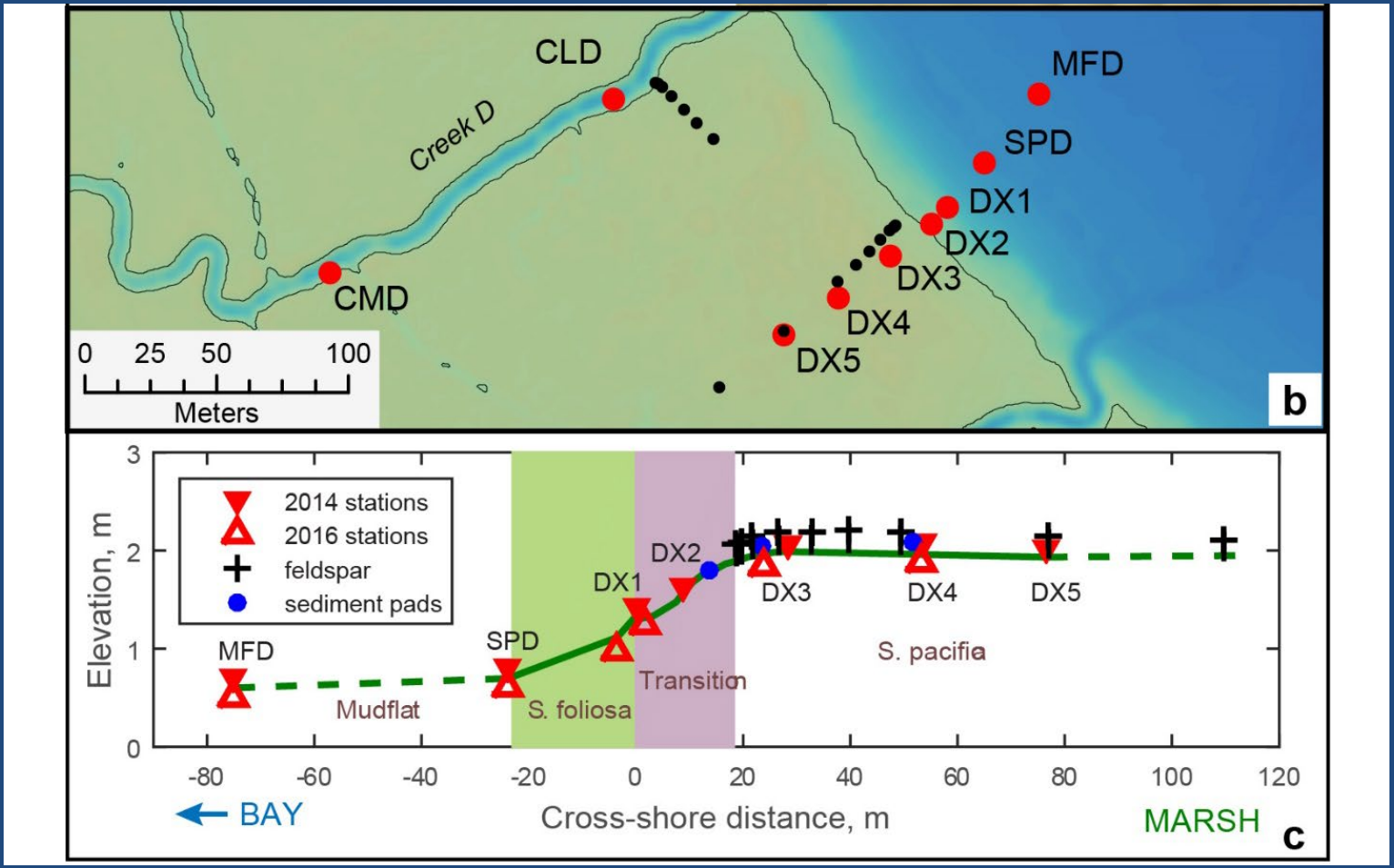
Long-term accretion rates show that the China Camp marsh arise keeping up with recent rate of sea-level rise:
> 3 mm/yr accretion, based on Pb and Cs dating of cores.
(*Callaway et al., 2012*)

Sediments on tidal flats and marsh are mud: D_{50} ~ 10 microns

Marsh elevation mostly close to MHHW, significant inundation only during spring tides

2 study periods: Winter 2014/15, Summer 2016, spanning biggest tides of the year

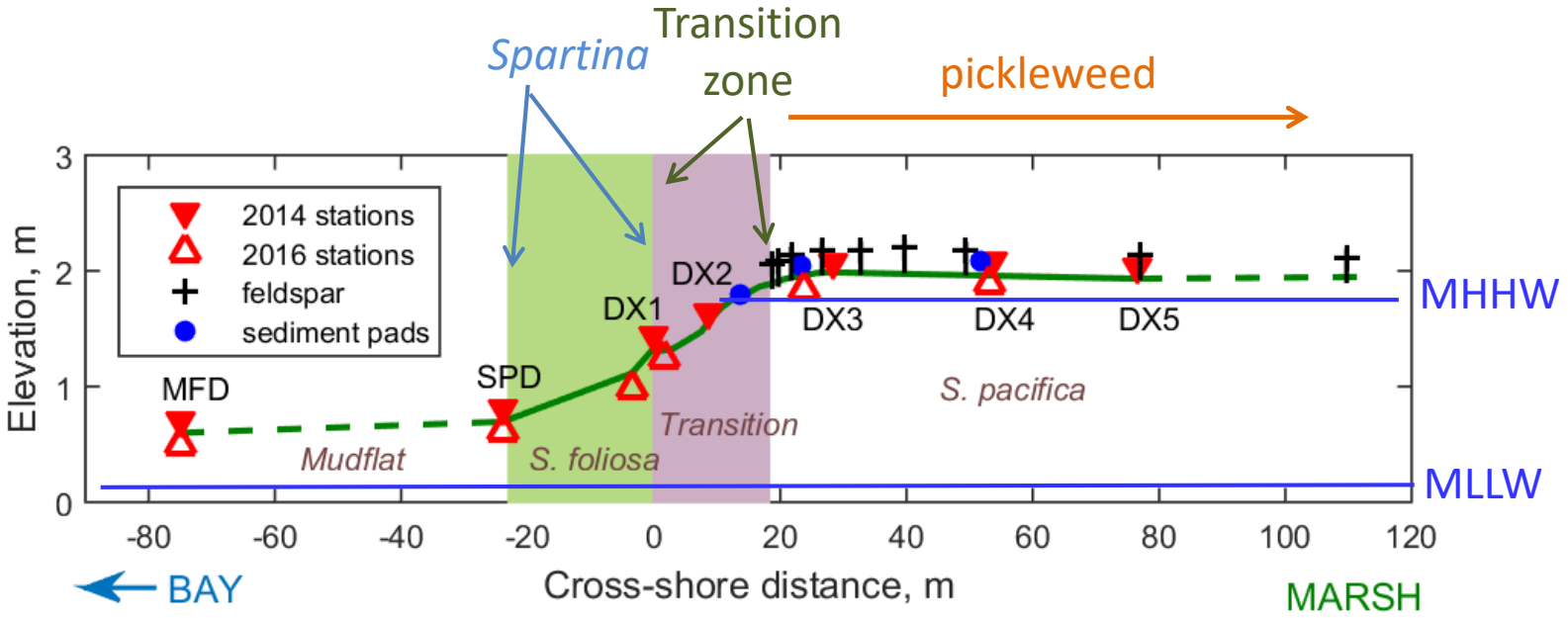




Measured SSC and wave energy adjacent to marsh and at 5 locations within the marsh, in winter (W14) and summer (S16).

Measured accretion within the marsh over 4 years at 8 locations.

Marsh edge at China Camp is gently sloped, not scarped.



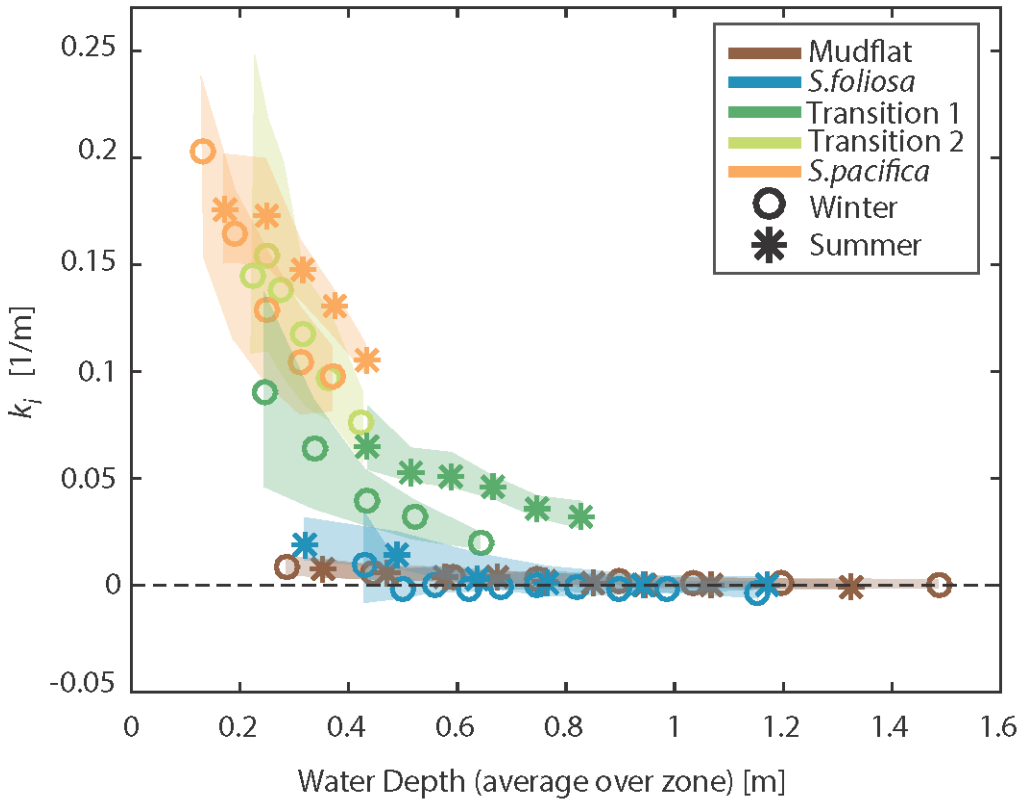
Wave attenuation results

Assume exponential decay:

$$H = H_0 e^{-kx}$$

- Attenuation varied between vegetation types
- Attenuation was less in winter, when vegetation was less dense and shorter
- Incudes shoaling effects

Wave height exponential decay constant (*k*) binned by water depth



Foster-Martinez, M.R., J.R. Lacy, M.C. Ferner, and E.A. Variano, 2018. Wave attenuation across a tidal marsh in San Francisco Bay. *Coastal Engineering* **136**, 26-40.

How much does the seasonal variation in attenuation affect waves in the marsh?

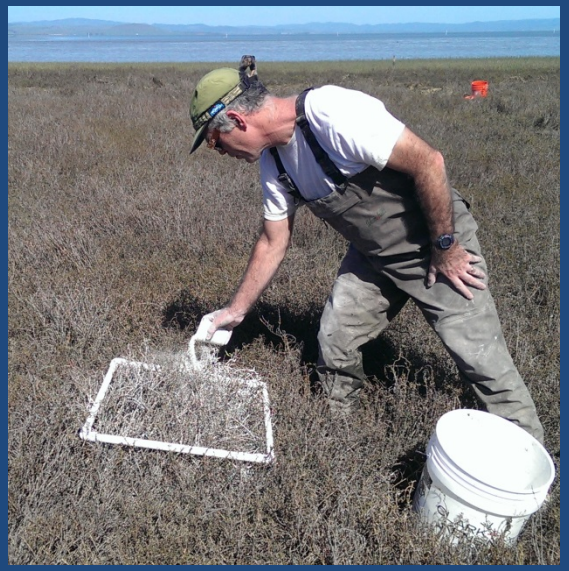
- In both seasons, waves are attenuated by more than 90% within 50 m of the bayward edge of the *Spartina* (~10 m into pickleweed)
- Wave exposure in the transition zone is greater in winter than summer

Effect of sea-level rise?

- Currently, wave height is significantly reduced (~50%) as waves cross the mudflats adjacent to marshes, due to bottom friction. This effect will be reduced with SLR, so that larger waves reach the marsh.
- Wave attenuation in the marsh decreased with increasing water depth. Marshes will be less effective in attenuating waves as sea level rises.

Accretion measurements: methods

Feldspar plots
Established March 2014



Sediment pads
Deployed for 5 tidal cycles during spring tides in June 2016

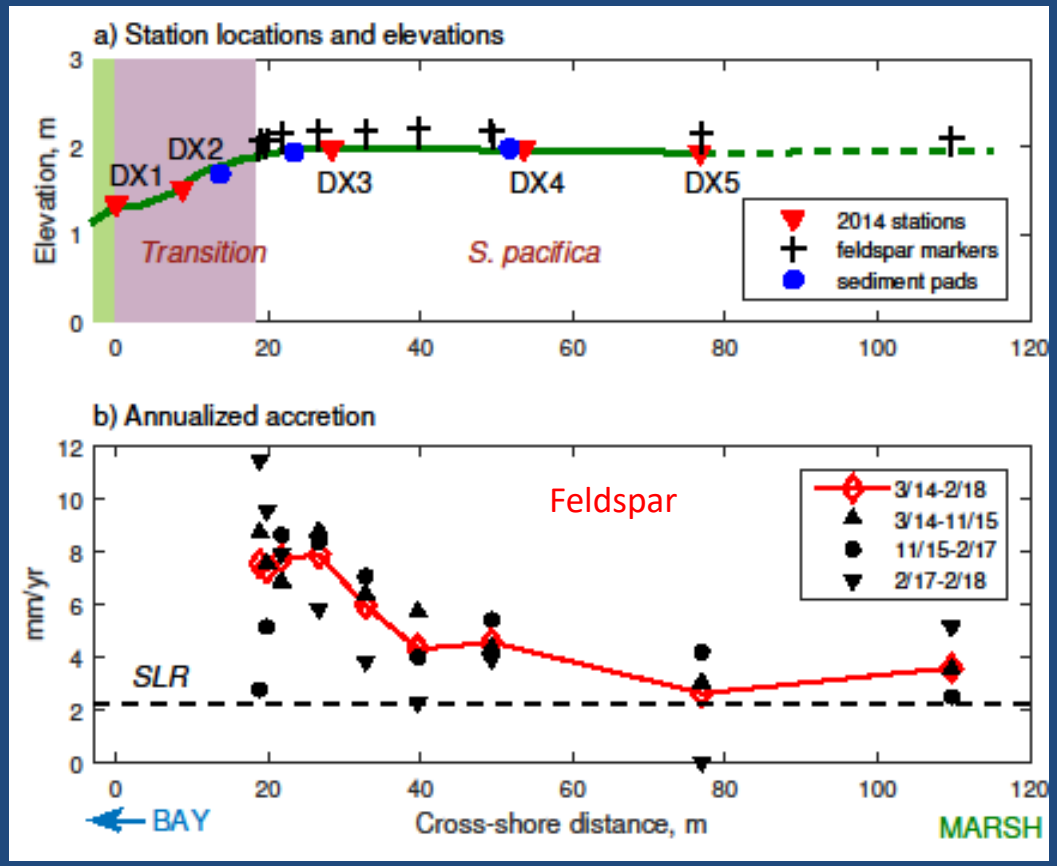
Accretion measured
Nov 2015
Feb 2017
Feb 2018

Accretion results

Accretion up to 9 mm/yr in the upper transition zone!

Highly variable between years in the transition zone and the bayward edge of the *Salicornia*.

Accretion rates are greater adjacent to the Bay margin than adjacent to tidal creeks.



SSC in bay shallows

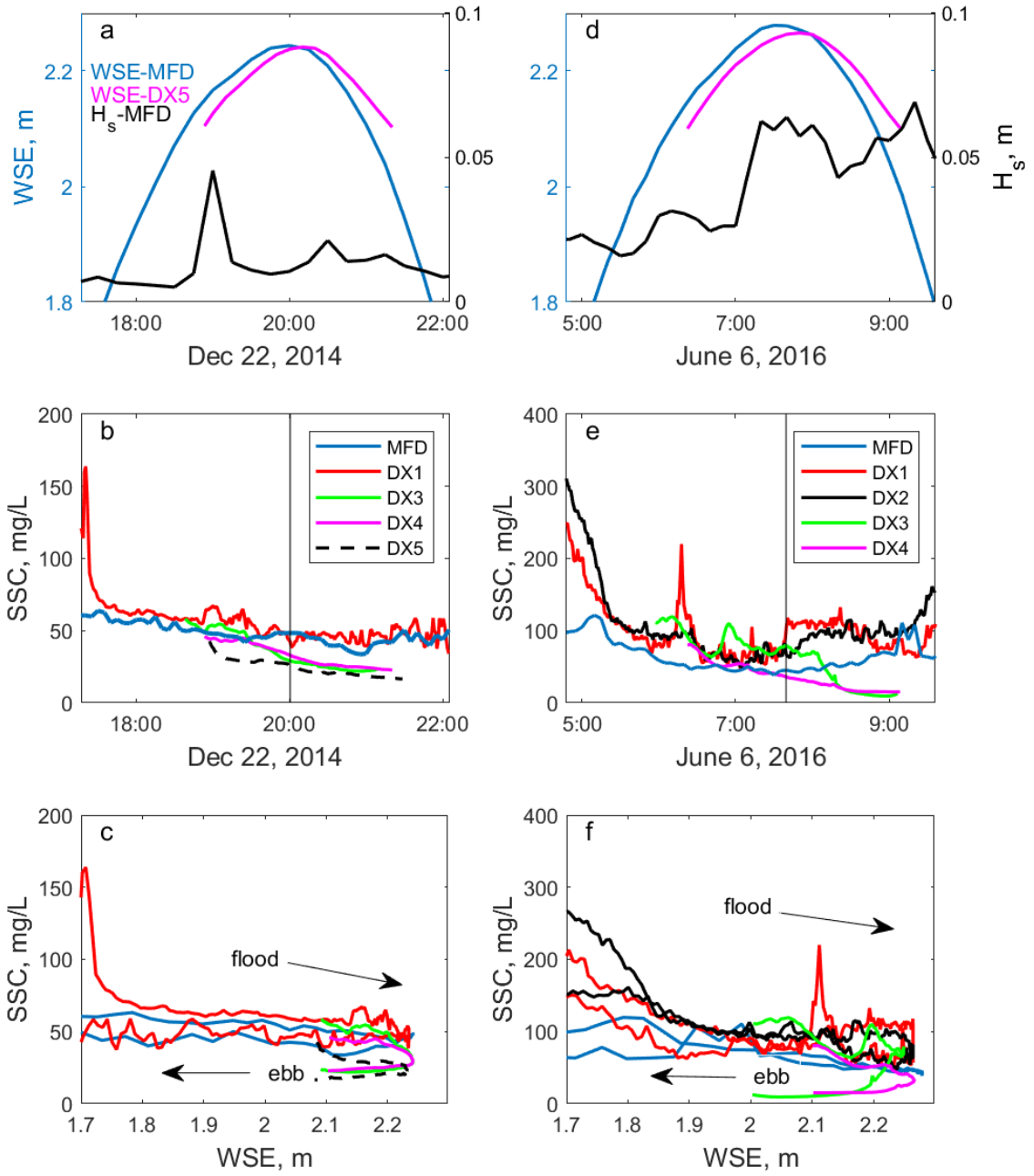
- SSC lower at high than low tide
- SSC greatest at marsh edge
- SSC increases with wave energy
- Waves are attenuated over mudflats
- Waves account for greater percentage of bed shear stress in shallower water

In characterizing SSC as an input parameter to marsh models, this temporal and spatial variability needs to be taken into account.

Data from the marsh transect

Collected data for 10 tidal cycles in winter, 6 in summer

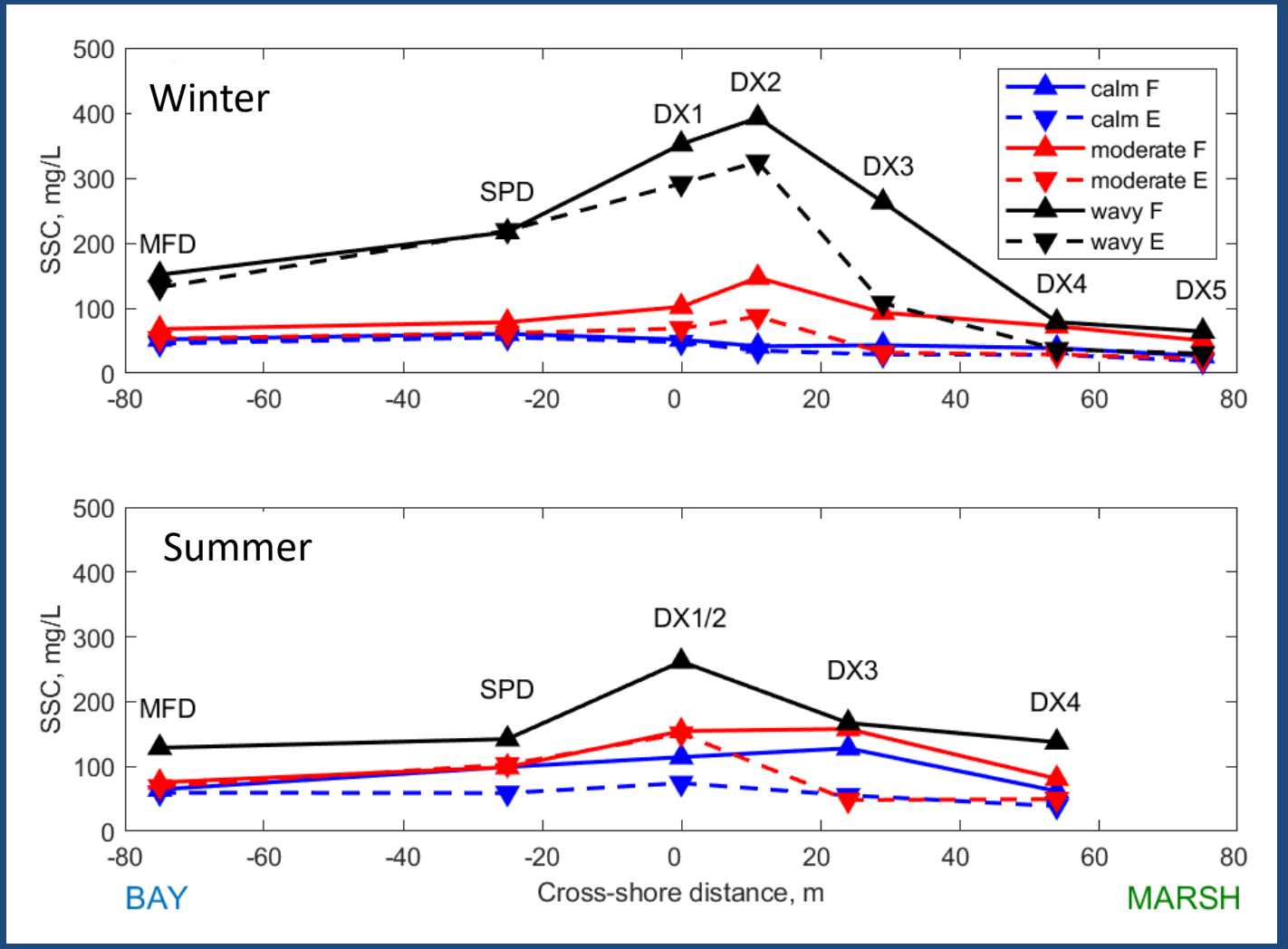
Waves affect SSC at DX1 and DX2, not at stations further from marsh edge



Data classified by wave height and water level

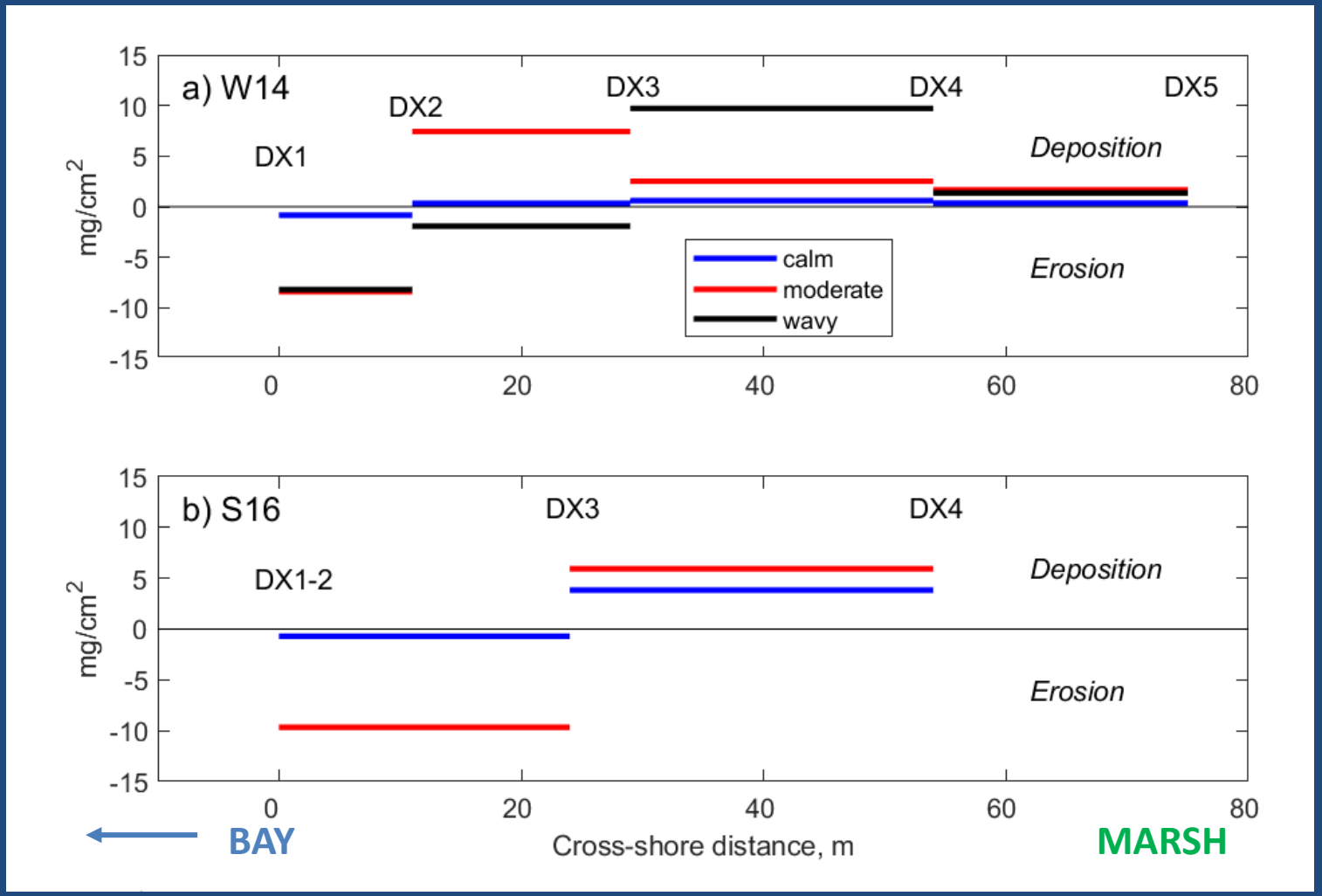
Data for WSE> 2m

Average SSC for flood and ebb.



- SSC increases with wave energy
- SSC less dependent on wave energy during ebb than flood.
- Less dependence on wave energy in pickleweed.
- Flood-ebb differential in pickleweed greater in summer than winter.

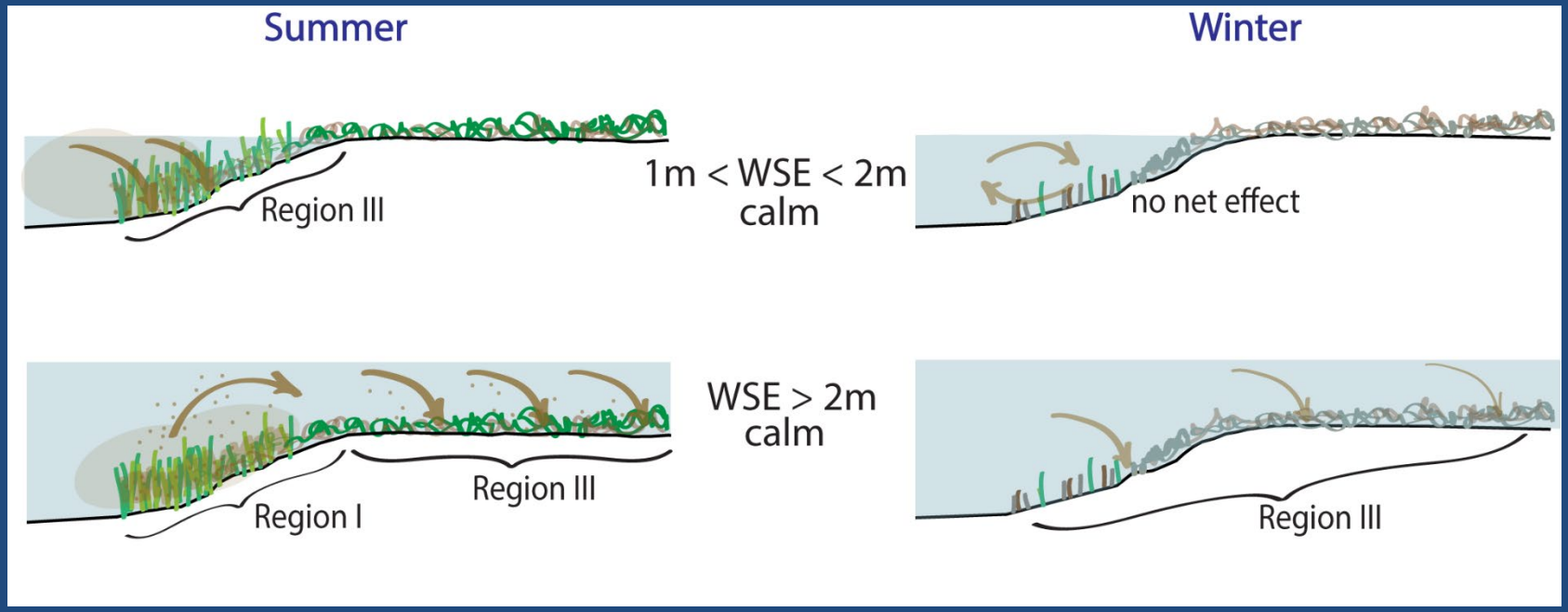
Deposition per tidal inundation: divergence of sediment flux



- Erosion in transition zone, deposition in pickleweed zone
- Both increase with wave energy
- More deposition in pickleweed in summer than winter, for a given wave class

Why is there more deposition in summer? Hypothesis:

- Fringing *Spartina* is taller and denser in summer.
- At lower high tides, that do not inundate the marsh, the denser *Spartina* traps more sediment
- That sediment is carried on to the marsh during the next high tide.



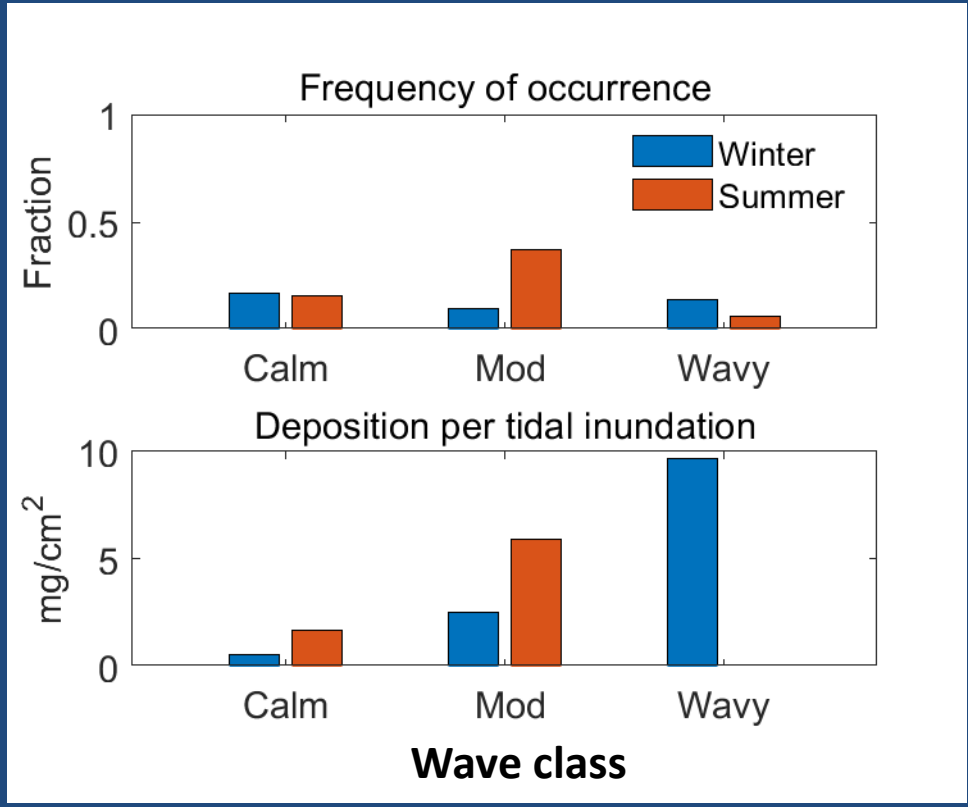
How important are the wave classes to deposition over the course of the year?

- Depends on frequency of occurrence as well as deposition for each wave class

- results for the pickleweed segment

On an annual basis, moderate waves of summer contribute more to annual deposition than winter storms

Total annual estimate for this region is 7 mm/yr: compare to 7.8 mm/yr measured at DX3 and 4.7 mm/yr at DX4



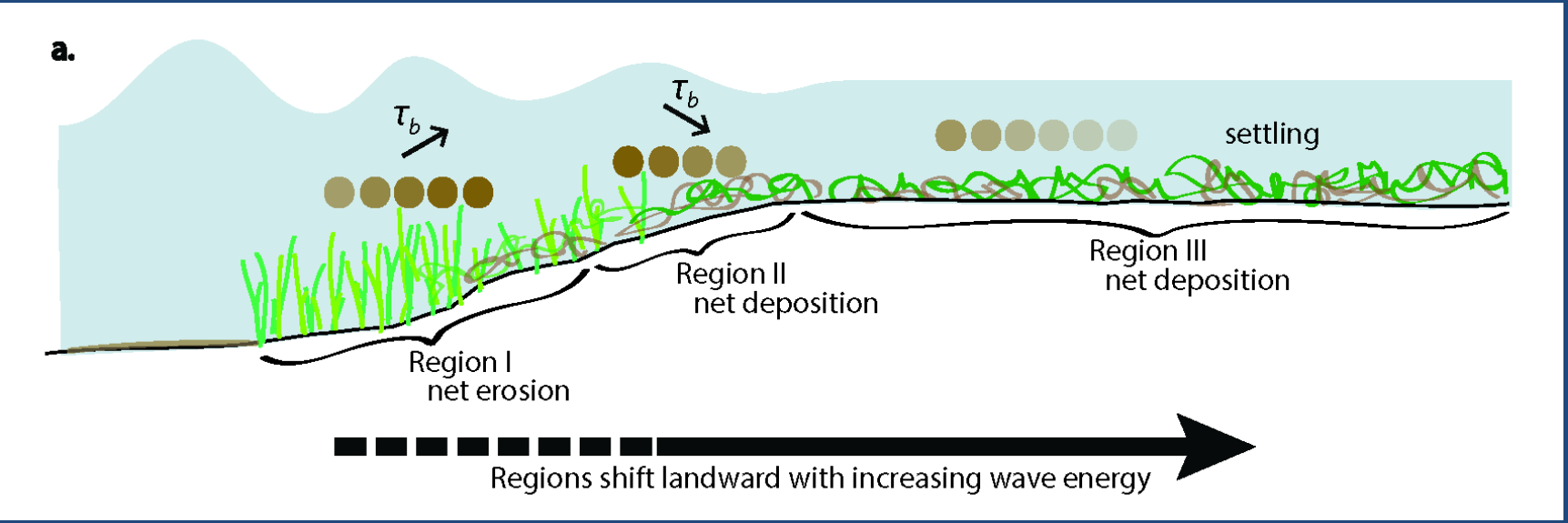
How important is supply across the marsh edge to the marsh sediment budget?

The marker-horizon results indicate that approximately 24 tons/yr of sediment were delivered across 200 m of shoreline (distance between tidal creeks), to the region within 60 m of the marsh edge.

For comparison, data collected in the tidal creek showed 10 tons/month of import during moderate tides and 30 to 40 tons of export during the largest spring tides of the year.

Tidal creek instrumentation

- Waves resuspend sediment that is carried into the marsh
- Waves can erode sediment at the marsh edge
- Wave attenuation at the marsh edge allows the sediment to deposit landward.



Conceptual model of sediment transport regions at the marsh edge

Conclusions

- SSC in the shallows increases towards the marsh edge, and is largely a function of depth: can influence design of monitoring programs.
- Marsh vegetation attenuates waves reaching the marsh within 50 m in both winter and summer, but attenuation is more rapid in summer.
- Twice as much vertical accretion adjacent to bay-marsh interface as adjacent to tidal creeks. On an annual basis, supply across marsh edge is similar to that though tidal creeks.
- Delivery of sediment to the marsh increases with wave energy
- For a given wave class, SSC over the marsh and sediment deposition are greater during summer than winter:

  Can influence timing of sediment placement in shallows
- The margin of the marsh plays an important role in attenuating waves and trapping sediment.

Thanks to many collaborators

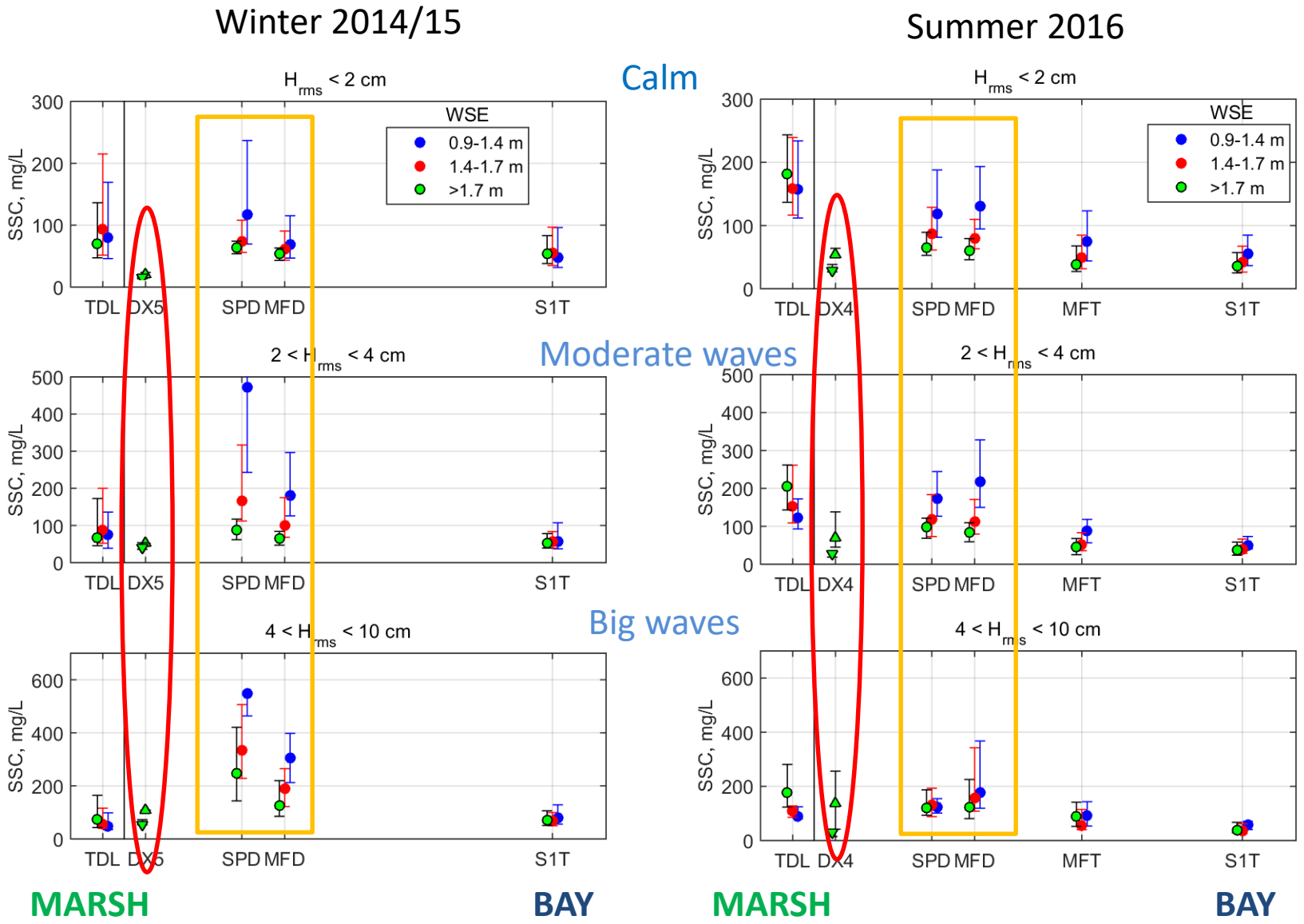
Matt Ferner and John Callaway

Maddie Foster-Martinez and Rachel Allen

Tim Elfers, Joanne Ferreira, Cordell Johnson, Pete Dal Ferro, Jenny White, Rob Wyland, Peter Harkins, Anna Deck, Josh Logan, Emily Carlson, Christie Hegermiller

SF Bay NERR and China Camp State Park

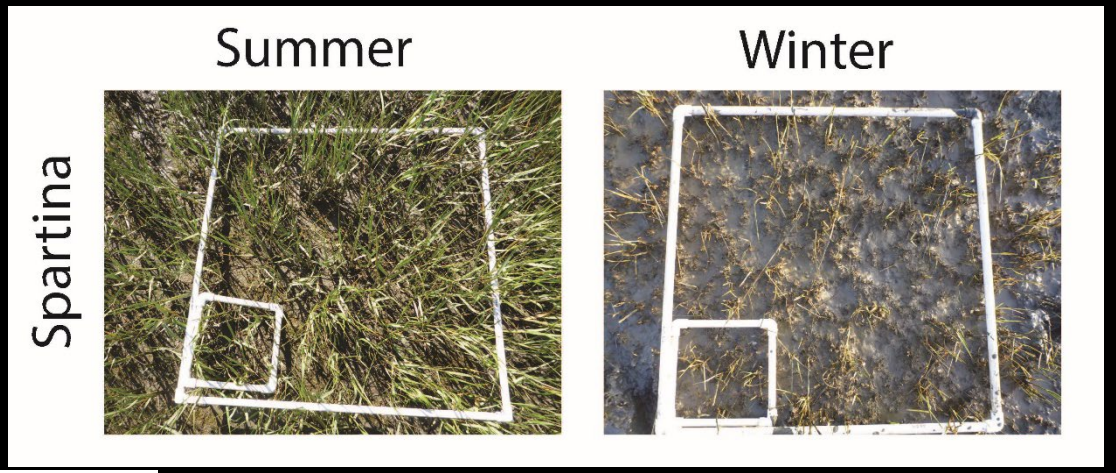
Questions?

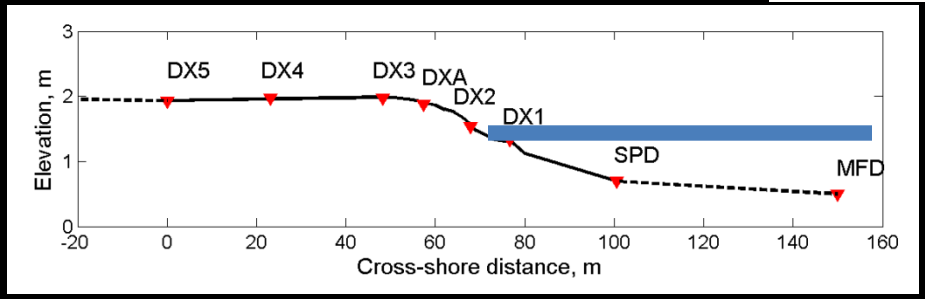


- SSC lower at high than low tide
- SSC greatest at marsh edge
- SSC within marsh greater in summer than in winter data set.

Also, maximum SSC within the *Spartina* and transition zone is much more pronounced in summer than winter.

- *Spartina* is taller and more dense in summer than winter.





- The *Spartina* zone is inundated during lower high tides, which do not reach the marsh plain.

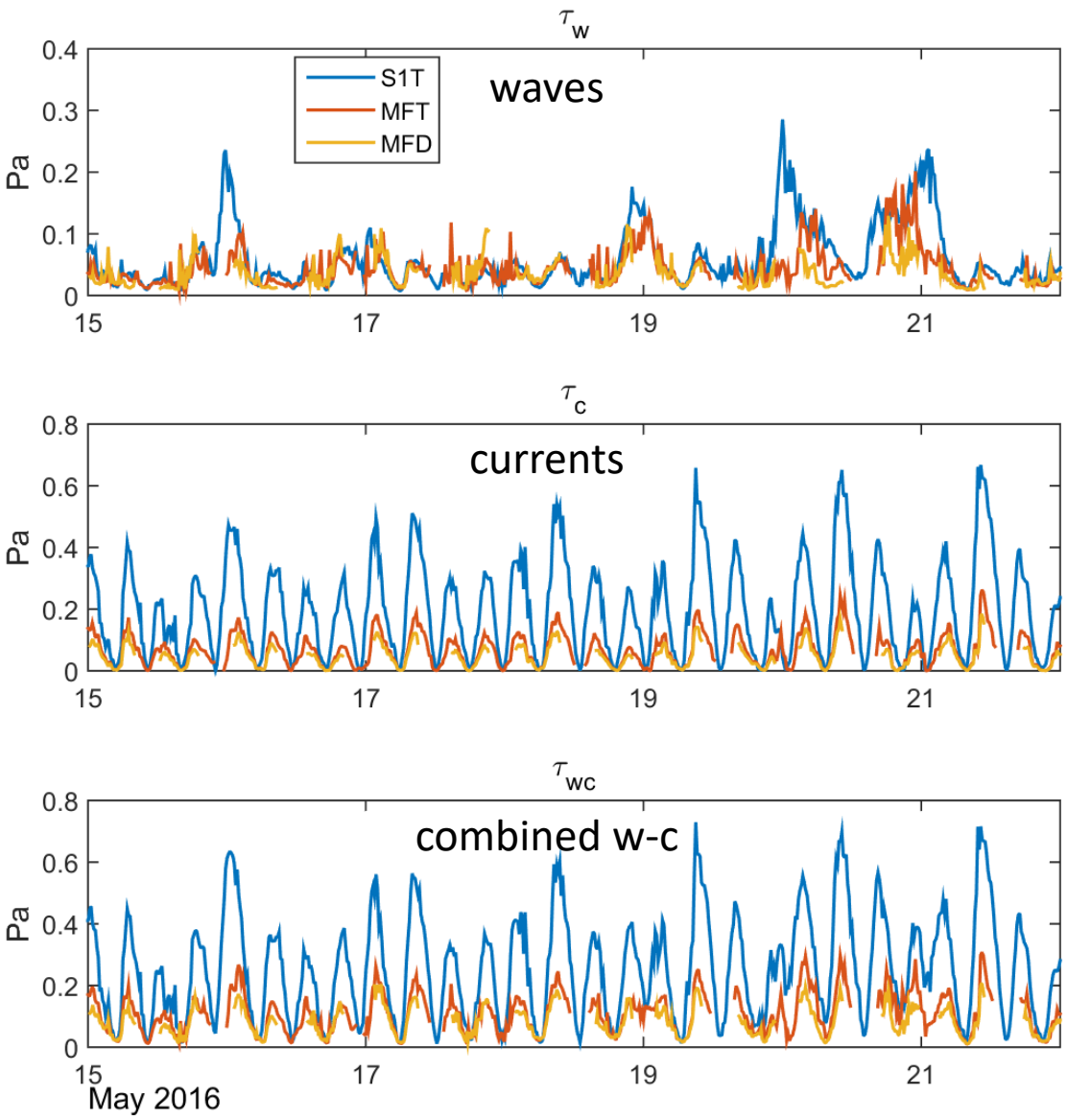
Hypothesis: during lower high tides, the dense summer *Spartina* traps sediment, which is easily resuspended and carried onto the marsh during the following flood tide.

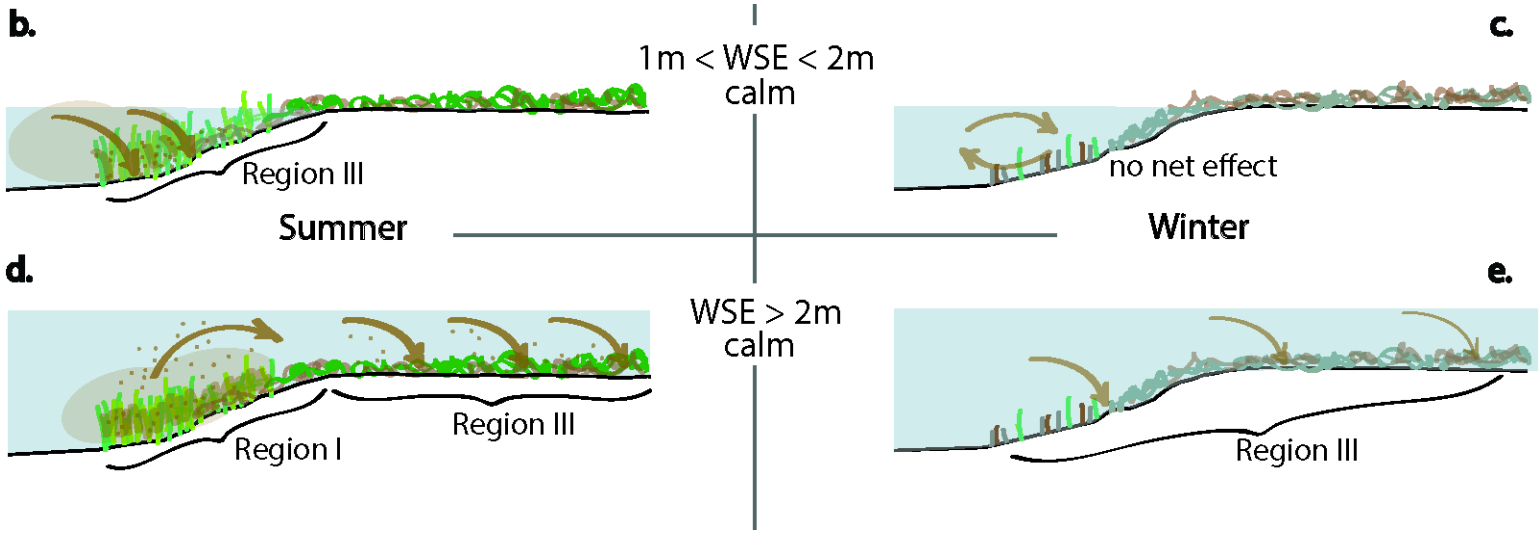
Why is SSC greatest at the marsh edge?

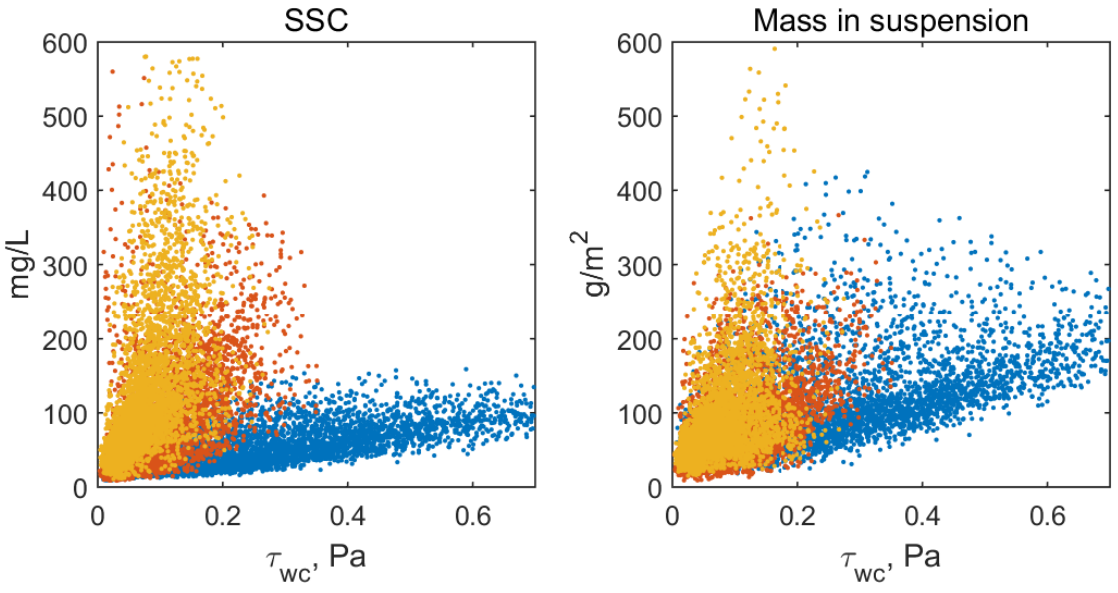
Because waves impact the bed more in shallower water?

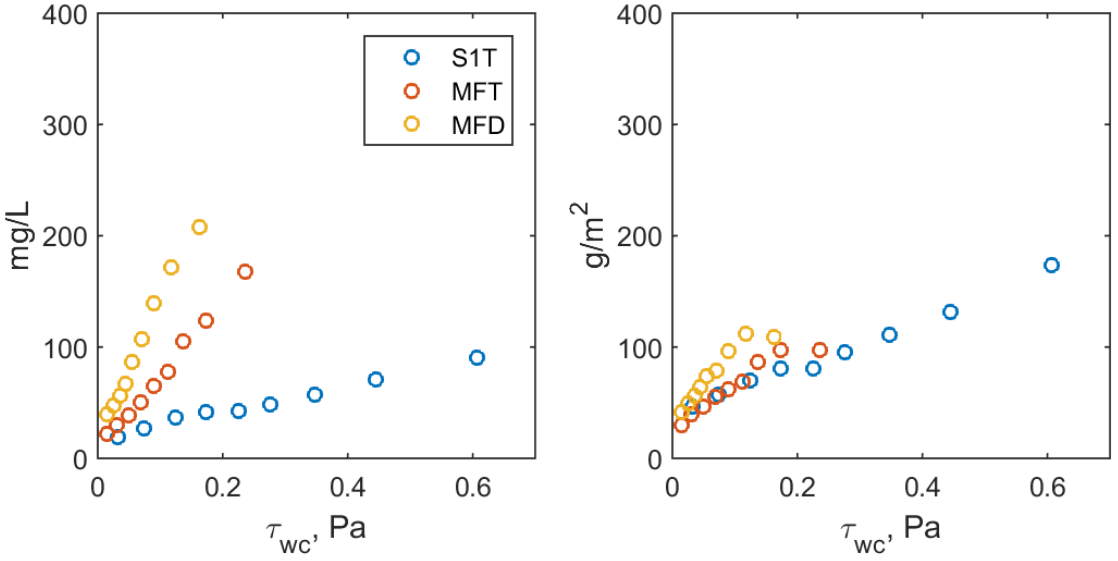
No. While relative importance of waves increases towards shore, total bed shear stress decreases.

Bed shear stress: summer 2016




b.
1m < WSE < 2m
calm
c.
Region III
no net effect
Summer
Winter
d.
e.
WSE > 2m
calm
Region I
Region III
Region III





Why is SSC greatest at the marsh edge?

In lower water depth, thickness of boundary layer decreases.

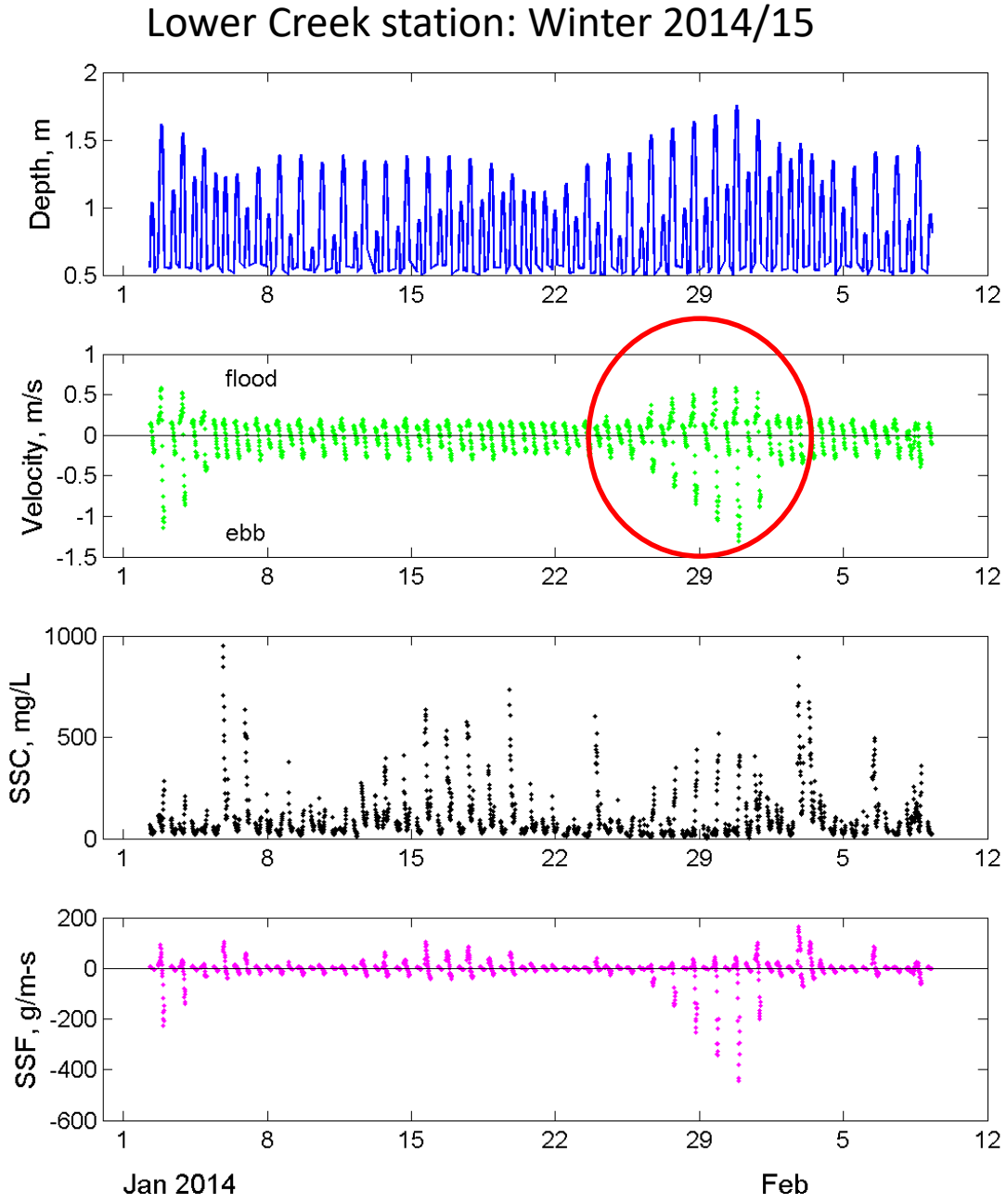
Equivalent erosion of sediment in lower water depth results in greater SSC adjacent to marsh.

1. Sediment flux

Very high velocities on ebb King tides.

SSF = *uhc*

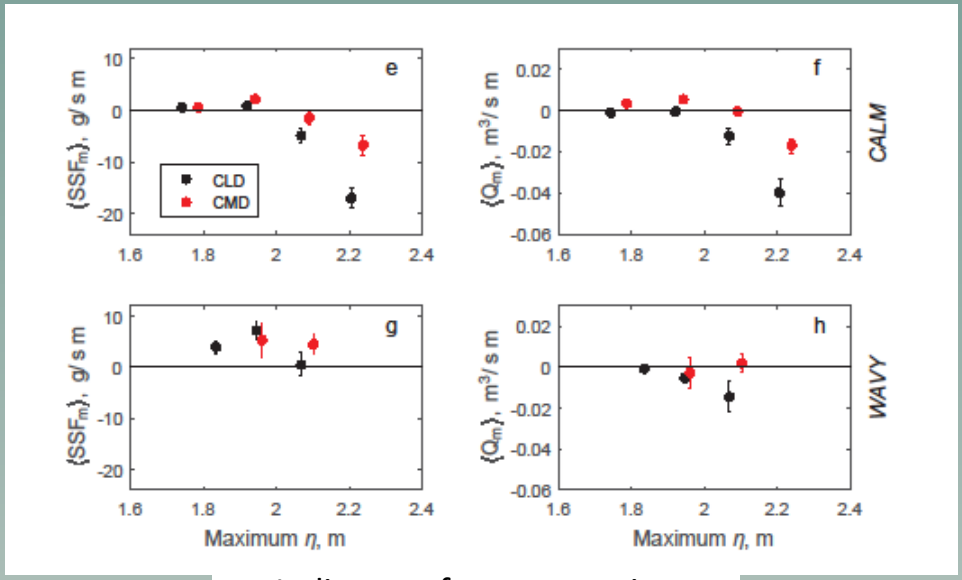
u: velocity
h: depth
c: SSC



Why is SSC greater over the marsh during summer than winter?

Important because spring tides are considered important for sediment delivery to marshes (because of extended inundation), and flux in tidal creeks is often assumed to represent delivery to marsh.

- Sediment (and water) is exported from marsh tidal creeks during spring tides.
- Export is greatest close to creek mouth.
- Import when conditions are wavy in adjacent shallows (i.e. SSC in shallows is greater).



Indicator of neap to spring

Lacy, Ferner, and Callaway 2018. Earth Surface Processes and Landforms **43**, 2384-2396, doi: 10.1002/esp.4401

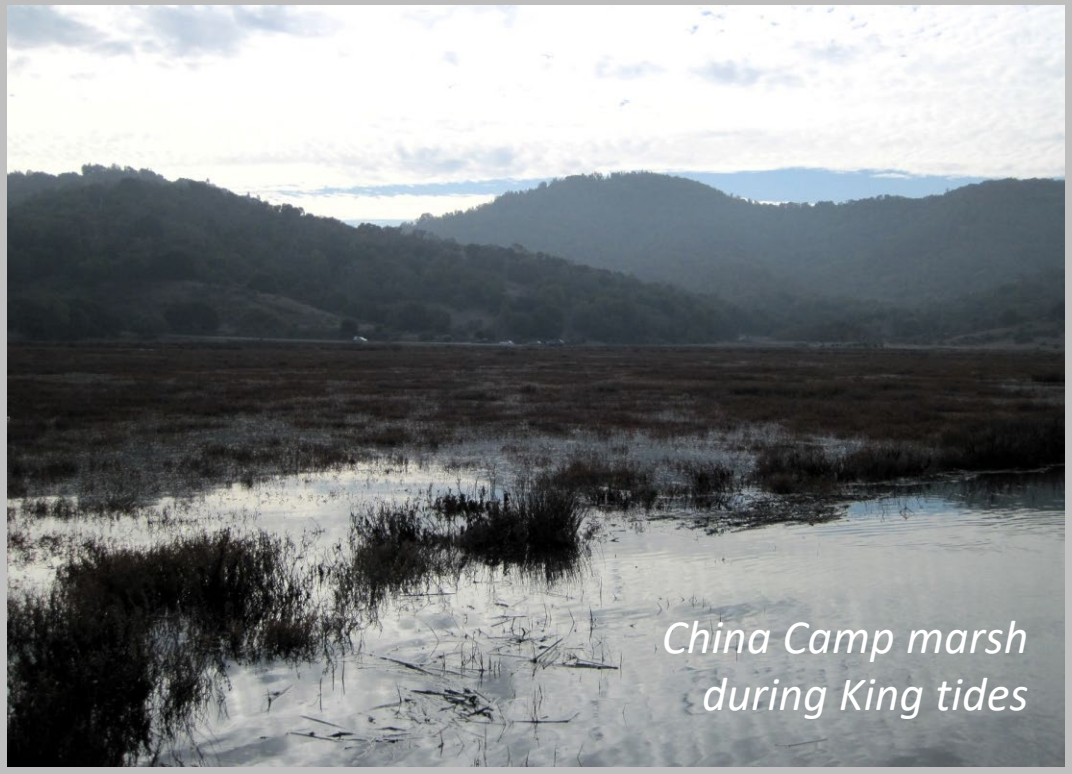
Sediment export of very similar magnitude was measured during large spring tides in winter 2013/14 and summer 2016.

In summer, export during ebbs was comparable to winter, but import on floods was slightly greater, due to regular afternoon wind waves.

Results suggest that sediment supply across the marsh edge may be important.

Tidal creek instrumentation

- San Francisco Bay tide range is about 2 m.
- Salt marsh is relatively high in the tidal frame.
- The highest (`King') tides of the year provide the longest inundation periods.



China Camp marsh during King tides

SSC at the marsh edge

- In subtidal shallows, both tidal currents and wind waves mobilize sediment.
- Adjacent to the marsh edge, waves are much more important.
- SSC in subtidal shallows not necessarily representative of marsh edge.