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Author(s): Chuang Jin, Zheng Gong, Liang Geng, Kun Zhao, Beibei Xu and Giovanni Coco
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Observations of Surface and Subsurface Processes on a Saltmarsh in the Central Jiangsu Coast (China)

Chuang Jin§†, Zheng Gong§*, Liang Geng§, Kun Zhao§, Beibei Xu§, and Giovanni Coco†

†School of Environment, Faculty of
Science
University of Auckland
Auckland, New Zealand

§State Key Laboratory of
Hydrology-Water Resources and
Hydraulic Engineering
Hohai University
Nanjing, China

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ABSTRACT

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Studies of tidal flats morphodynamics tend to ignore subsurface processes like bioturbation or underground water dynamics so that changes in the surface elevation are always considered to be the result of sedimentation/erosion on the soil surface. However, at times, subsurface variations can be as large as elevation changes driven by sedimentation and so control the evolution trend of surface elevation. In this study, four observation sites were set up on the salt marsh in the central Jiangsu coast (China). A three-year field observation campaign has been carried out studying seabed elevation changes. The Surface Elevation Table-Marker Horizon (SET-MH) technique was applied to measure surface elevation and net sedimentation. The subsurface variation was derived from the difference between the surface elevation and the sedimentation. Results show that the changes in surface elevation are not equal to the sedimentation and that subsurface process, responsible for such deviation, are strongly affected by storm surge. Storm surges increase the underground water content leading to the observed expansion of the subsurface soil. The expansion results in the rapid increase of surface elevation and it takes almost one year to recover to the surface elevation before the storm season.

ADDITIONAL INDEX WORDS: *Subsurface processes, Saltmarsh, Rod SET, Jiangsu coast*.

INTRODUCTION

Coastal wetlands are important ecosystems providing habitat for aquatic biota and salt marshes. They maintain carbon cycling and "defend" the coastline from storm damage. At the same time, tidal flats can be vulnerable (Lovelock *et al*., 2011; Webb *et al*., 2013) and in fact are likely to be negatively impacted by processes associated to sea level rise and extreme weather condition. If the development of tidal flats is slower than the increase of sea level rise, tidal flats will be in a vulnerable situation. The dynamics of the upper-intertidal flats, which are covered by the salt marshes, is more complicated. The combination of surface processes (*e.g.* soil surface erosion and deposition) and subsurface processes (decomposition and growth of the plant roots, underground water discharge and recharge, bioturbation and natural consolidation and expansion) affect the overall development of upper-intertidal flats. In previous research, the elevation of soil surface was considered to be equivalent to the balance between surface deposition and eorsion. However, in salt marsh systems, the shrink and swell of shallow soils affect the surface elevation (Cahoon *et al*., 1995; Krauss *et al*., 2003; Lovelock *et al*., 2011). Cahoon *et al*. (2011) carried out long-term measurements on the deposition and elevation change at different locations using the Rod-Surface Elevation Table (Rod SET for short hereafter). Results indicated it was misleading to use the surface accretion as a proxy for surface elevation variation since subsurface processes can play a first-order role in the evolution of surface elevation.

The Rod SET is the most precise and portable instrument for the salt marshes monitoring (Cahoon *et al*. 2002). This measuring system is widely spread all over the world. For example, there are over 350 SET monitoring sites around the Mexico Bay, which consists the Coastwide Reference Monitoring System (CRSM). Similarly, over 100 Rod SET observation sites were arranged along the Australia coast (Rogers *et al*. 2014). The Rod SET is also a key instrument in the study of other research topics such as carbon sequestration, the growth of salt marshes, and the influence on sea level rise (Lovelock *et al*. 2011; 2015; Swales *et al*., 2016). 100 years ago, coloured sand was used as marker horizon (MH) for the measurement of surface soil deposition. This method remains widely used in field observations. With the development of SET and MH, surface accretion and elevation variation were separated and high-resolution technology RSET-MH could be used to study the role of subsurface processes. The results of RSET-MH have confirmed the hypothesis of Kaye (1964) indicating that subsurface processes like consolidation and expansion could be the dominant factors in tidal flat morphodynamics. According to concurrent observations of underground water, surface soil elevation and surface deposition, Cahoon *et al*. (2011) suggested the possibility of hysteresis between underground water and the variation of subsurface soil. However, most of the study concentrated on a micro tidal estuary, characterized by the presence of mangroves and with limited

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*Corresponding author: gongzheng@hhu.edu.cn

sediment supply. The effect of subsurface processes in estuaries characterized by rich sediment supply and large tidal range is rarely studied.

This paper aims at comparing surface elevation changes using three years of observations across the central Jiangsu coast (China). The controlling factors determining salt marsh evolution (*e.g.* surface accretion and subsurface processes) are analyzed at distinct sites and the observed changes are related to storm surge dynamics.

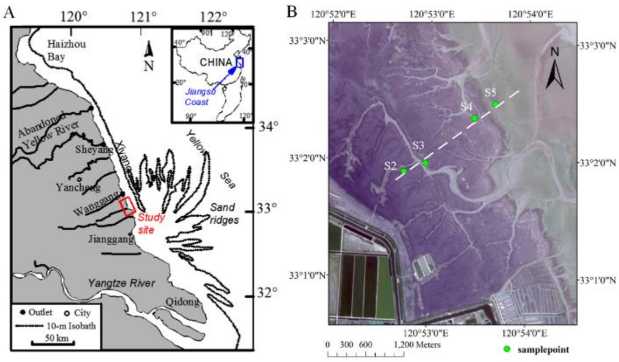

Figure 1. Study site. A. The location of study site in the central Jiangsu coast (China). B. Location of the four observation sites across the South Chuandong tidal flat.

STUDY SITE AND METHODOLOGY

Study Site

Over 90% of the 964 km coastline of the Jiangsu region is mudflat. Currents are the dominant forcing. The wave climate is milder during the summer and stronger in winter. Tidal flats south of the Chuandong Estuary are a natural reserve area and there has been no large-scale reclamation in this area over the last few decades. The central part of the coast presents a double convex profile as result of the large sediment supply (Gong *et al.* 2017). Tides are dominated by an irregular semidiurnal cycle. The tidal regime is flood dominated and the duration of the flood tide is shorter than the ebb tide. Tidal range is about 2.5-5 m. The bed is composed of silt and mud with medium grain size of about 0.06-0.07 mm (Gong *et al.* 2017). Saltmarshes are widely spread and grow vigorously over the upper tide flats. The average width of the saltmarsh area is about 3-4 km although, according to our measurements, this area keeps expanding seawards at a speed of 50-100 m/y.

Methodology

Surface accretion and elevation in the tidal flat were measured during flood tide each month at the four observation sites, named S2 to S5. Sites (herein also defined as "stations") were set up with an interval of 500 m (Figure 1). Stainless steel piles and nylon rod were chosen as benchmarks. Three ceramic tiles were buried 5 cm under the surface soil as MH at each site (see Gong *et al.*, 2017). S2 and S3 sites were set up in Aug. 2012. At sites S4 and S5, the Rod SET was installed in Aug. 2012 and MHs were set up the following month. The S5 site was located at the frontier of the salt marsh at the beginning of the measurements and was gradually surrounded by the propagating salt marshes. Details of the Rod SET set up and the measuring method have already been presented in Gong *et al.* (2017). The initial elevation of each of the four sites are listed in Table 1.

To obtain the elevation at each site, 20 groups of elevations are measured using the RTK-GPS along four orthogonal directions. The average value is then translated into an absolute elevation. The elevation measured in the first month is regarded as an initial value and is set to zero. The surface elevation measured subsequently is relative to the initial elevation and hereafter is referred to as the relative elevation. Similarly, the accumulated surface accretion obtained in the first month is also set to zero and regarded as the reference value for the following observations. According to the absolute elevation and accumulated surface accretion, the relative location of the soil surface and MH were derived (Figure 3). The variation of subsurface soil is calculated using the following equation,

$$E_{sub,i} = E_{tot,i} - E_{sur,i} \tag{1}$$

where $E_{tot,i}$ represents the total change of the elevation at each site, $E_{sur,i}$ is the variation of the surface soil (the amount of erosion or deposition each month), and $E_{sub,i}$ is the monthly variation of subsurface soil. In contrast, if the value of $E_{sub,i}$ is negative, it means the subsurface soil compacted during the past month. Then contribution factor is defined as following:

$$f = \frac{E_{sub,i}}{E_{tot,i}} \tag{2}$$

where f represents the contribution of subsurface variations. If f is positive, it means the contribution of subsurface variation is positive. The subsurface variation has a positive influence on surface elevation. In contrast, if f is negative, the contribution of subsurface has negative effect on surface elevation. If f is equal to 0.5, the surface and subsurface equally contribute to the elevation change. If f is larger than 1, the elevation is dominated by the subsurface variation. With this simple parameter, the main factors that influence the surface elevation can be analyzed.

RESULTS

Evolution of Surface Elevation

The S2 observation site is located at the highest elevations of the salt marsh. This site is hardly submerged except for the highest water level. The sediment transported from seaward has mostly settled before reaching this site. Therefore, the elevation changed slightly and was between 2.72-2.75 m (Figure 2A). The S3 and S4 stations are located at the upper convex point of the profile. From Apr. to Nov., with the increase of the highest tidal level, surface elevation increased gradually, but the increasing rate reduced over time. In 2013, the increase rate was about 17 mm/month from Apr. to Nov. and it reduced to 10 mm/month during the same period in the year of 2014 and 2015 (Figure 2B). Due to the increase in elevation, the submergence frequency reduced accordingly (refer to Figure 4 in Gong *et al.*, 2017). We notice that the submergence frequency can be considered as representative of the tidal forcing (Voulgaris et al., 1998). Therefore, the increasing rate of elevation reduced from 19mm/month during Mar. to Nov. in 2013 to only 8 mm/month in 2015 (Figure 2C). The S5 observation site was at the edge of the salt marsh when the field campaign started. However, together with the elevation increase of S3 and S4, salt marsh propagated seawards. As a result, S5 was gradually surrounded by salt marshes and experienced a more rapid increase in surface elevation (Figure 2D).

Table 1. *Inundation frequency at the four observation sites in 2013. The initial elevation at each site is also provided.*

	Sites	S2	S3	S4	S5
	Elevation (m)	2.694	2.300	2.046	1.449
Inundation frequency (year 2013)	Jan.	0	0	0.033	0.235
	Feb.	0	0	0.008	0.199
	Mar.	0	0.010	0.061	0.272
	Apr.	0	0	0.048	0.263
	May	0	0.010	0.0461	0.259
	Jun.	0.004	0.034	0.084	0.320
	Jul.	0.011	0.056	0.128	0.343
	Aug.	0.020	0.068	0.134	0.321
	Sep.	0.002	0.062	0.136	0.312
	Oct.	0.012	0.088	0.176	0.367
	Nov.	0.018	0.073	0.133	0.319
	Dec.	0.004	0.016	0.064	0.291

Subsurface variation

Based on the absolute value of surface elevation and the amount of surface erosion and deposition, the relative elevation of the soil surface and the marker horizon are calculated with respect to the first measurement (Figure 3). The accumulated surface deposition and erosion are equal to the thickness of soil above the MH. The variation of the marker horizon shows the changes of subsurface soil. The increase of the relative location of MH indicates the expansion of the subsurface soil. On the other hand, the subsurface soil is consolidating (or similar compaction process) if the location of MH decreases. Because of the high location of S2 (Table 1), the relative elevation almost keeps pace with the change of MH (Figure 3A). The main reason might be related to the high location and low inundation frequency (Table 1). The wide salt marshes dissipate the tide energy and lead to settling of sediments as the tide progresses across the flat so that overall it is hard for sediment to be transported and deposited at this site. As a result, the elevation is almost entirely controlled by subsurface processes. In particular, the influence of subsurface was evident in Jun. 2014 when the variations of the soil surface and marker horizon were highly consistent. During Jan. to Apr. 2013, the surface soil was eroded but the expansion of subsurface soil was large enough to compensate and result in an overall increase of the surface elevation. The evident increase of soil surface as well as the relative location of MH during Sep. to Nov. 2015 were affected by a storm event. The underground water increased causing the large expansion of subsurface soil (Figure 3A). According to the calculation of the contribution factor (Esub/Etot) for each month (Figure 5A), the subsurface contributed positively for most of the time and, especially, during Feb. to May, the contribution of subsurface processes was extremely large. A negative contribution of subsurface processes was only observed for a number of months and most of them were in 2015. But the reason is still unclear for the occurance in 2015. Overall, the variation in the S2 site was less influenced by sediment deposition and erosion. Even during storm conditions, sediment deposition is almost the same as during calm conditions. The subsurface expansion dominated the evolution of surface elevation.

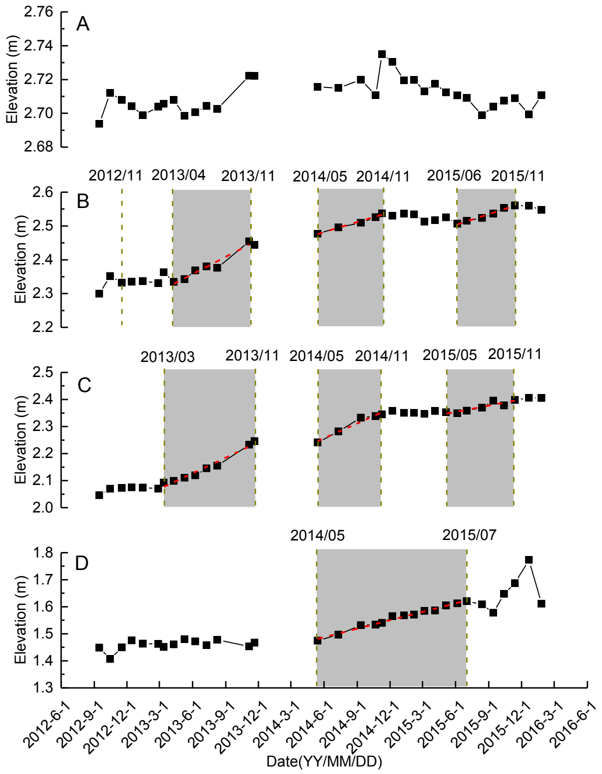

Figure 2. Variation of surface elevation at S2 (A), S3 (B), S4 (C) S5 (D). The shading area shows the continuous increasing of elevation.

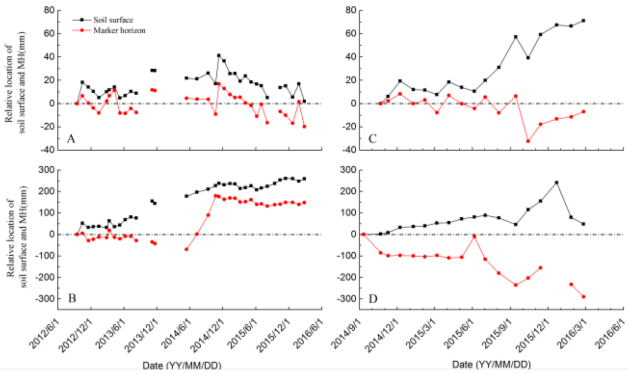

Figure 3. Relative location of soil surface and marker horizon at S2 (A), S3 (B), S4 (C) and S5 (D).

The surface and subsurface processes alternatively dominate the changes in elevation at the S3 site. In fact, the location of MH changes simultaneously with the relative surface elevation from Oct. 2012 to May of the following year. During Mar. to May. 2013, a sharp increase and the subsequent decrease of elevation occurred. This phenomenon can be explained by the variation of the submergence frequency (see Gong *et al*. 2017) which could be considered as representative of the tidal forcing (Table 1). The variation over this period was affected by sediment deposition and erosion. From the existing data over the period May. 2013 to the following year, the surface deposition was larger than the subsurface variation (indicated from the variation of MH) and the contribution of subsurface processes was low (Figure 5B, May, Jun. and Jul. in 2013). During the first year of observations, the soil surface accreted of about 200 mm, while the subsurface soil compaction accounted for 56 mm. From May to Oct. 2014, the surface elevation increased more than 500 mm, but the surface soil was largely eroded. The increase in elevation was caused by the subsurface expansion which in turn might be driven by the influence of storm events during those months (Figure 4). Underground water was largely recharged and increased following the storms and the expansion of subsurface soil led to the increase of surface elevation. At the same time, the soil surface was largely eroded by the stronger hydrodynamic forcing. The observations in the following years showed a similar trend of dominant processes (Figure 5B)

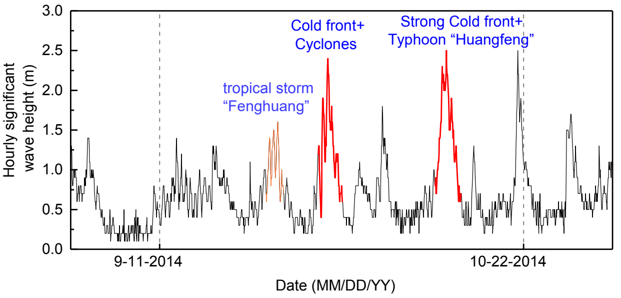

Figure 4. Hourly wave height on the central Jiangsu coast from Sep. 2014 to Nov. 2014

The S4 station appears to be alternatively controlled by surface and subsurface processes although the duration of the observations was limited. The simultaneous observation of surface accretion and elevation started in Sep. 2014. Soil surface elevation changed only slightly as a result of subsurface processes during Oct. to Jul (Figure 3C). Figure 5C shows that the contribution of subsurface soil processes exceeded sedimentation during Mar. to Jun., indicating that the subsurface variation controlled the changes of surface elevation. From July to Oct. due to the increasing of inundation frequency (Table 1), a large amount of surface deposition occurred at this station (Figure 3C, Figure 5C).

Spartina alterniflora expanded and reached S5 station after Sep. 2014, which is also the beginning time of the simultaneous observation of surface elevation and sedimentation (Figure 3D). During the six months after the *Spartina alterniflora* reached this station, the relative location of the marker horizon was extremely stable and the elevation changes were small. In Jun. 2015, there was sharp erosion of soil surface with less change in elevation. In the following year, the marker horizon returned to the same level as it was before Jun. This was supposed to be influenced by some extreme weather conditions. Since the *Spartina alterniflora* reached this site, the elevation kept growing because of surface deposition until Jul. 2015. The subsurface contribution factor was below 0, which means that consolidation is likely to have occurred in the subsurface soil while the elevation increased (Figure 5D). At this stage, the influence of subsurface processes was small and overall it could be neglected. The advance of *Spartina alterniflora* resulted in more sediment settling so that a large amount of sedimentation occurred at this station. However, after Oct. 2015, subsurface processes contribution was larger than surface variation as the *Spartina alterniflora* advanced and by this point this site was totally covered by *Spartina alterniflora*. A large amount of sediment deposited near the frontier of the salt marsh and subsurface processes dominated the changes in elevation at this site (Figure 5D).

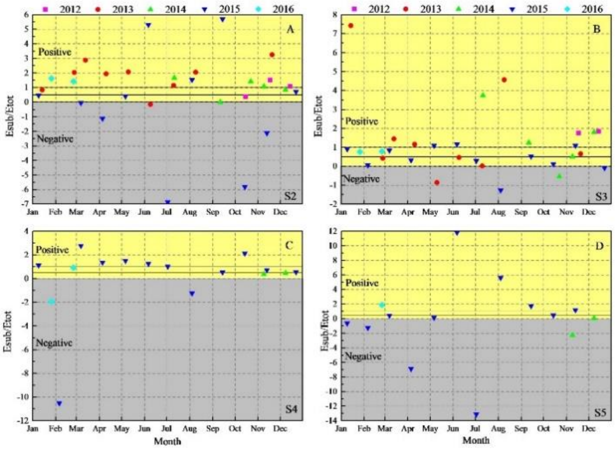

Figure 5. The contribution of subsurface processes to the surface elevation change (E_{sub}/E_{tot}) at S2, S3, S4 and S5 station. The symbols with different color represent the different year from 2012 to 2016. The yellow region highlights the positive contribution of the subsurface processes. The gray region highlights the negative contribution of the surface processes.

DISCUSSION

Influence of Underground Water

Previous research showed that underground water recharge and discharge, salt marsh root growth and decomposition caused the shrink and swell of subsurface soil, which largely influences the surface elevation (Cahoon *et al*. 2011). According to our previous study on the frequency of inundation, the frequency in Mar. and Apr. was almost the lowest and it reached the highest values in Nov (see Gong *et al*. 2017). Frequency of inundation can be regarded as representative of the strength of the tidal forcing and the amount of sediment transport. Between Apr. and Nov., with increasing tidal levels, stations S5 to S2 were gradually submerged and the underwater duration increased as well. During this period, the porosity of the subsurface soil was filled with underground water. The influence of the subsurface at this stage was low. The enhanced inundation frequency gradually increase the transport of suspended sediment to the upper intertidal flat while the high dense salt marsh enhanced settling of suspended sediment. Therefore, surface erosion and sedimentation dominate the evolution of surface elevation. Between Nov. and Apr. of the following year, because of the low inundation frequency, tidal forcing caused limited transport of sediment to the upper intertidal flat. However, variations of underground water affected the underground soil, which in turn resulted in the elevation increase of the soil surface.

Storm Surge Influence

During the months characterized by frequent occurrence of storm surge, wave forcing was enhanced and the tide level was increased. The soil surface was highly eroded and the elevation decreased. The largest erosion was about 60 cm/month. However, the elevation kept growing in the salt marshes despite the large erosion of soil surface. This was caused by the large expansion of subsurface soil. At station S2, a 20cm sharp increase of surface elevation was observed between Nov. and Dec. 2014 during the extreme weather conditions. We measured almost no soil change above the MH, which indicated that the subsurface variations controlled the evolution trend of the surface elevation. The subsurface expansion was even evident at the S3 station from May to Oct. Large expansion of subsurface soil contributed to the increase of surface elevation. Additionally, the underground water variation was also affected by the distance to the shoreline at low tide and by the permeability of the subsurface soil. For example, the subsurface soil at station S2 responded more slowly than station S3 and the influence was smaller than at S3. With respect to the recovery process, after the extreme weather conditions, all the elevations returned to their initial status. The recovering rate of S2 was much quicker than S3. After six months, the S2 station recovered to its initial condition, while the S3 station did not. This might depend on the soil characteristics and tidal levels. Although the elevation difference between S2 and S3 was just 25 cm, and the distance was 500m, the S3 station was more influenced by the tidal levels since the flood tide provided an additional source of underground water. Therefore, the seaward stations did not respond as fast after the storm surge and the elevation recovered slowly.

CONCLUSIONS

Changes in tidal flat elevation do not reflect only surface sedimentation at the sites considered in this study. The observed variation of the elevation at the site closest to the sea dyke (S2), is mostly controlled by subsurface processes. Even under extreme weather conditions, the controlling factor is still the subsurface processes. The subsurface soil expanded during the extreme weather conditions resulting in a sharp increase of surface elevation. It took 1 year to return for this site to the same pre-storm elevation. At the seaward sites (S3 and S4), the surface elevation is controlled by both surface and subsurface processes. During the month with high inundation frequency, surface accretion dominated the evolution of surface elevation. During the months with low tidal forcing, elevation was controlled by subsurface processes. During the extreme weather conditions, the soil surface was largely eroded, but the expansion of subsurface soil was larger than the erosion, which eventually resulted in a increased elevation. In other words, the elevation was under the control of subsurface processes during storms. For the site which is located at the edge of the salt marsh, surface elevation is almost entirely controlled by surface deposition and erosion.

ACKNOWLEDGEMENT

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LITERATURE CITED

Cahoon, D.R. et al., 2002. High-Precision Measurements of Wetland Sediment Elevation: II. The Rod Surface Elevation Table. *Journal of Sedimentary Research*, 72, pp.734–739.

Cahoon, D.R., Reed, D.J. & Day, J.W., 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. *Marine Geology*, 128(1–2), pp.1–9.

Cahoon, D.R., White, D. a. & Lynch, J.C., 2011. Sediment infilling and wetland formation dynamics in an active crevasse splay of the Mississippi River delta. *Geomorphology*, 131(3–4), pp.57–68.

Gong, Z., Jin, C., Zhang, C.k., Zhou, Z., Li, H., 2017. Temporal and spatial morphological variations along a cross-shore intertidal profile, Jiangsu, China. *Continental Shelf Research*, 144.

Krauss, K.W., Allen, J. a. & Cahoon, D.R., 2003. Differential rates of vertical accretion and elevation change among aerial root types in Micronesian mangrove forests. *Estuarine, Coastal and Shelf Science*, 56(2), pp.251–259.

Lovelock, C.E., Cahoon, D.R., Friess, D.A., Guntenspergen, G.R., Krauss, K.W., Reef, R., Rogers, K., Saunders, M.L., Sidik, F., Swales, A., 2015.

Lovelock, C.E. et al., 2011. The Role of Surface and Subsurface Processes in Keeping Pace with Sea Level Rise in Intertidal Wetlands of Moreton Bay, Queensland, Australia. *Ecosystems*, 14(5), pp.745–757.

Rogers, K., Saintilan, N. & Woodroffe, C.D., 2014. Surface elevation change and vegetation distribution dynamics in a subtropical coastal wetland: Implications for coastal wetland response to climate change. *Estuarine, Coastal and Shelf Science*, 149(0), pp.46–56.

Swales, A., Denys, P., Pickett, V. I., Lovelock, C.E., 2016. Evaluating deep subsidence in a rapidly-accreting mangrove forest using GPS monitoring of surface-elevation benchmarks and sedimentary records. *Marine Geology*, 380, pp.205–218.

Voulgaris, G., Simmonds, D., Michel, D., Howa, H., Collins, M., Huntley, M., 1998. Measuring and modelling sediment transport on a macrotidal ridge and runnel beach: an intercomparison. J. Coast. Res. 14 (1), 315–330.

Webb, E.L., Friess, D.A., Krauss, K.W., Cahoon, D.R., Guntenspergen, G.R., Phelps, J., 2013. A global standard for monitoring coastal wetland vulnerability to accelerated sea-level rise. Nat. Clim. Change 3, 458e465.

Kaye, C.A., Barghoorn, E.S., 1964. Late quaternary sea-level change and crustal rise at Boston, Massachusetts, with notes on the autocompaction of peat. Geological Society of America Bulletin 75, 63–80.