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To the Editor
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Dear Editor,

We are submitting a *Technical Note* entitled "*Addressing tidal flooding induced uncertainties in satellite derived global salt marsh change studies: Impact on Blue Carbon Monitoring*". This paper is a non-peer reviewed preprint submitted to EarthArXiv. It has not been submitted to any journal for peer review.

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Sincerely,

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Addressing Tidal Flooding Induced uncertainties in Satellite Derived Global Salt Marsh Change Studies: Impact on Blue Carbon Monitoring

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Abstract:

In the past few years, it has been established that remote sensing of wetlands change analysis studies would require careful examination of tidal flooding produced uncertainties in satellite datasets. Tide flagging and filtering mechanisms are required to reduce per-pixel variabilities and errors in change detection. We present a technical note summarizing the potential impact of a lack of tide flagging mechanism in a recent study by Campbell et al. entitled "Global hotspots of salt marsh change and carbon emissions". Through this note, we highlight the presence of potentially large uncertainties and spatio-temporal variabilities in their wetland change analysis map products propagating to their final carbon emission estimations.

Technical Note:

In a recent study, Campbell et al.[1] conducted a large-scale change analysis using Landsat satellite data from 2000 to 2019 to estimate global changes in the salt marsh ecosystem coverage and their impact on blue carbon stock. Based on 20-yr satellite change detection, they reported that more than 1400 km^2 of marshes had been lost, with the USA and Russia contributing 64% of the total loss. Their findings highlight salt marsh vulnerability to rapid environmental change and its resulting impact on blue carbon stocks. This comprehensive salt marsh change study comes at an important juncture when climate change induced sea level rise (SLR) has been accelerating in the past few decades. In 2021, the global mean sea level experienced the highest annual average increase (3.8 inches above 1993 levels) in the entire satellite record[2]. Such increases in global mean sea level, accompanied by increasingly unpredictable regional weather patterns (extreme precipitation and storm events), are changing the flooding dynamics (frequency, magnitude, duration) in salt marshes[3–5]. However, research suggests these changes in flooding dynamics in salt marshes are spatially complex and dependent on nonlinear feedback between local and regional geomorphology and ecosystem production. In essence, the flooding pattern is highly variable spatio-temporally and may introduce large uncertainties in wetland loss/gain analysis[3].

Uncertainties in wetland change analyses are compounded when using moderate to coarse resolution satellite data (Landsat-MODIS) due to complications, including (a) variability in tidal flooding status during satellite overpass[6], (b) the resulting interaction between vegetation and water reflectances introducing increased variabilities in per-pixel satellite reflectance[7], (c) site-specific spatial patterns due to local geomorphology resulting in uneven tidal flooding[8], and (d) scale mismatch between high fragmentation level in wetlands and spatial granularity of the input satellite data (30-m Landsat pixels)[9]. Previous work has shown that in salt marshes, tidal flooding can impact a significant proportion of satellite images (Landsat: 13%[5]; MODIS: 30%[4]). The result of which is a reduction in near-infrared reflectance that is dependent on inundation depth and species and can range from 7-90% compared to non-flooded conditions[7]. Spatial inundation patterns also vary across the marsh surface[5], leading to higher uncertainty in marsh extent analysis. Areas experiencing more frequent flooding are at risk of being labeled as a loss when, in fact, they are low marsh areas experiencing more frequent and higher tidal flooding levels[8].

To demonstrate these uncertainties, we conducted a test comparing the impact of tidal signal on loss and gain of salt marsh area estimations in Landsat pixels following the same temporal intervals presented in Campbell et al.[1] (Figure 1). We measured per-pixel differences in epoch averaged normalized vegetation index (NDVI) for data with no tide filtering as used in Campbell et al.[1] and with tidal filtering[5]. The data were reduced by an average of 38% per pixel for each epoch after tide filtering. We found that not filtering tidally inundated pixels increased estimated marsh loss by up to 150% (110 km^2), while gains were overestimated by 170% (30 km^2) (Figure 1). These differences observed between filtering techniques can be attributed to the dampening of surface reflectance from tidal waters on the marsh surface[7], resulting in reduced variance in pixel values within an averaging period. Further, flooding frequency on a per-pixel basis is spatially dependent, increasing the probability that certain pixels may be flooded more often during Landsat overpasses. In Campbell et al.[1], the authors restricted their analysis to peak biomass months (August-September). However, some regions experience high seasonal variability in flooding frequency and magnitude, and depending on the location, these months may experience different flooding patterns and intensities[5]. Because tidal flooding magnitude and duration are highly variable across space at local[8] and regional to global scales[10], uncertainties resulting from tide contaminated pixels will vary in global studies. Further, long-term change analyses such as Campbell et al.[1] are more likely to be affected by temporal and sampling bias caused by decadal tidal cycles and sun-synchronous satellite overpasses, as discussed by Bishop-Taylor et al.[6]. As an example, Bishop-Taylor et al.[6] highlighted in their Figure 3 that the sun-synchronous overpass of Landsat can be spatially biased in capturing tidal cycles across the Australia coastline. This could affect Campbell et al.'s[1] estimations of loss and gain in regions such as the northern and southern Australian coasts (Campbell et al.[1]: Figure 1b). For example, along the northern coast of Australia, Landsat overpass timing coincided either with the full range of tidal cycle instances (Bishop-Taylor et al.[6]: Figure 3a) or excluded lower tide periods (Bishop-Taylor et al.[6]: Figure 3b). This increases the probability of capturing tidal flooding in Landsat pixels and could alter the reflectance values leading to larger estimated salt marsh change as seen in Campbell et al.'s[1] Figure 1b and our test in a Georgia salt marsh site (Figure 1).

We commend the authors for making the first attempt to derive the global distribution of wetland carbon storage using long-term satellite data and change analysis products. Spatially explicit mapping framework involving blue carbon storage will play an important role in the near future for making critical decisions on nature-based voluntary carbon offset benchmarks as proposed in 26th UN Climate Change Conference of the Parties (COP26). Therefore, it is of utmost importance that such studies focus significantly on uncertainties associated with satellite based estimates of wetland biophysical parameters. The authors have acknowledged the uncertainties associated with exclusively using remote sensing techniques for blue carbon monitoring in their previous studies[11]. In a 2020 study[12] similar to the current analysis, they specifically acknowledged the importance of tide filtering techniques such as Tidal Marsh Inundation Index (TMII)[4] in the accurate historical assessment of salt marshes.

Conclusion

We recognize the need for further discussions and additional experiments to properly evaluate the performance of the tide filtering algorithms at a global scale. We are not advocating the superiority of a specific tide flagging algorithm over others. We are arguing that a potentially significant source of uncertainty in satellite images of tidal wetlands has not been acknowledged or addressed by Campbell et al[1] despite their prior study[12], at a regional scale, concluding that tide filtering should be a necessary preprocessing step. Since this is the first spatially-explicit open-source global blue carbon mapping study, we anticipate there will be a great deal of interest amongst end-users (public and private) to use the map products in decision-making without realizing that there may be large site-specific uncertainties associated with this product. Through this response document, using our preliminary analysis and literature review, we highlight these potential uncertainties to raise awareness for the end-users. We conclude that some form of Landsat pixel-specific tide filtering mechanisms should be implemented as a necessary pre-processing method to reduce uncertainties in future salt marsh change detection studies.

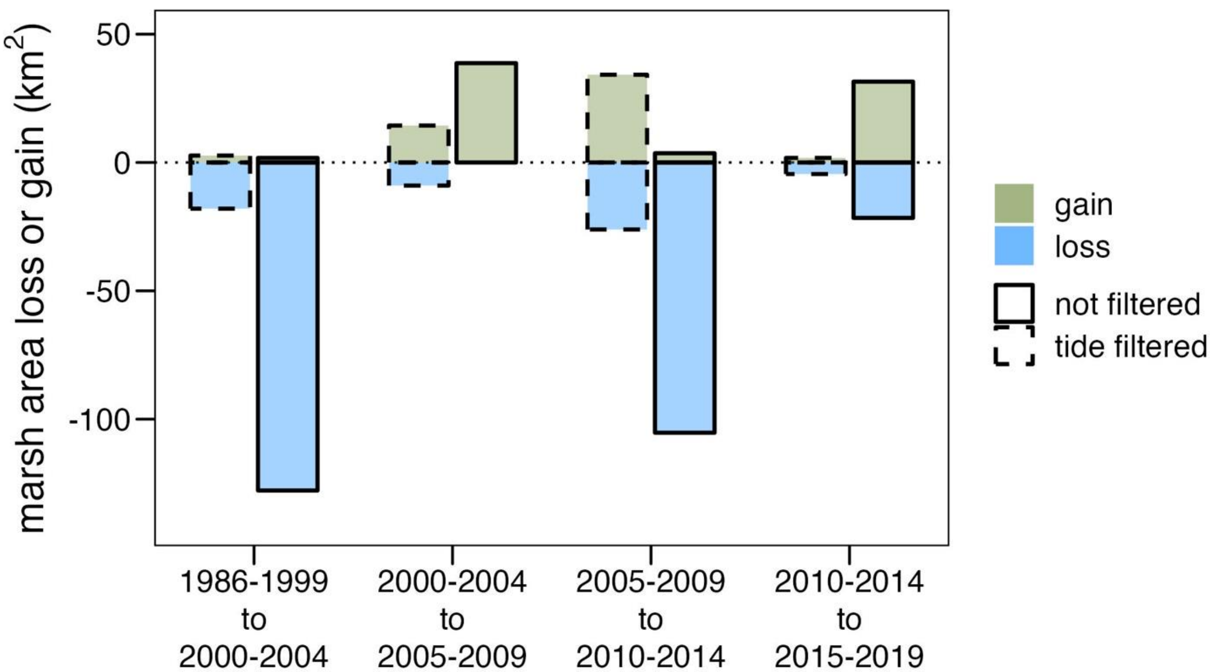

Figure 1: Comparison of salt marsh loss and gain estimations between epochs using no tide filtering as in Campbell et al.[1] and tide filtering following Narron et al.[5] in a Georgia, USA tidal salt marsh (30.83°N, -81.61°W). Landsat 5, 7, and 8 data for the months of August and September from 1986 to 2019 were retrieved from Google Earth Engine[13] and filtered using the quality control band for clouds and cloud shadows and radiometric saturation. Change in normalized vegetation index (NDVI) was measured between epoch averages of NDVI per pixel. Pixels were only considered gain or loss if the change in NDVI was >0.2.

Author Contributions:

Both authors contributed equally to developing the ideas presented in this study and writing this comment. Both authors approved the final submitted version.

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