Change Detection of Shallow Water Estuarine Inlet Morphology Using Remote Sensing Technologies

Author

Broadfoot, MSS, Burke, AC, Hemer, MA, McInnes, KL, Murray, TP, Power, HE

Published

2023

Conference Title

The Proceedings of the Coastal Sediments 2023

Version

Accepted Manuscript (AM)

DOI

10.1142/9789811275135_0141

CHANGE DETECTION OF SHALLOW WATER ESTUARINE INLET MORPHOLOGY USING REMOTE SENSING TECHNOLOGIES

M.S.S. BROADFOOT[1], A.C. BURKE[2], M.A. HEMER[3], K.L. MCINNES [4], T.P. MURRAY[5], and H.E. POWER[6]

1. *School of Environmental and Life Sciences, University of Newcastle, Box 118, S-221 00, Newcastle, NSW, Australia. madelaine.broadfoot@uon.edu.au.*
2. *School of Environmental and Life Sciences, University of Newcastle, Box 118, S-221 00, Newcastle, NSW, Australia. annette.burke@newcastle.edu.au.*
3. *CSIRO Oceans and Atmosphere, Climate Science Centre, GPO BOX 1538, Hobart, TAS, Australia. Mark.Hemer@csiro.au.*
4. *CSIRO Oceans and Atmosphere, Climate Science Centre, Aspendale, 3195 VIC, Australia. Kathleen.Mcinnes@csiro.au.*
5. *Coastal and Marine Research Centre, Griffith University, Queensland, Australia. t.murray@griffith.edu.au.*
6. *School of Environmental and Life Sciences, University of Newcastle, Box 118, S-22100, Newcastle, NSW, Australia. hannah.power@newcastle.edu.au.*

Abstract: The amount of wave and tidal energy entering an estuary from the ocean is highly influenced by the entrance morphology, therefore, the ability to accurately detect and measure bathymetric changes in morphology is highly desirable for coastal managers. As in-situ bathymetric data collection is often costly and/or logistically challenging, bathymetry derived from multispectral and hyperspectral imagery has become widely used. This paper details an ongoing investigation into the suitability of using UAV captured multispectral imagery to develop a repeatable methodology to detect and measure inlet morphological variability. Specifically, this study utilises multispectral imagery to derive bathymetric models using the empirical algorithm first proposed by Stumpf et al (2003) to determine inlet variability through time. This paper and presentation documents an ongoing field campaign of UAV multispectral imagery capture, the development of bathymetric models from this imagery and the validation of these bathymetric models using contemporaneous single beam sonar surveys. The study inlet, Moonee Creek, is on the south-east Australian coast and is a small, microtidal, wave dominated inlet.

Introduction

An estuary represents the transition zone from an inland river to the ocean, creating a unique environment where waves and tides extend landwards of the coast (Leuven et al., 2019). Around the world an estimated 680 million people live within low lying coastal areas (IPCC, 2019) and 21 of the 30 largest cities surround an estuary (Oppenheimer et al., 2019). Estuaries are surrounded by low elevation terrain which is increasingly impacted by inundation, which in turn affects any infrastructure or sensitive habitat found in this domain (Hanslow et al., 2018). As entrance morphology is highly influential on the shoaling or amplification of the tidal wave understanding and detecting changes to entrance morphology is key to understanding tidal movement in and out of an estuary (Masselink et al., 2011).

Satellite, aerial and unmanned aerial vehicle (UAV) mounted optical sensors have become key tools for coastal researchers and managers to monitor changes in the environment. Multispectral and hyperspectral remote sensing can be used to estimate bathymetry in optically shallow water coastal environments, using empirical models based on the wavelength dependent attenuation of light transmission in water (Zhang et al., 2020). Documenting changes in bathymetry can be an effective method to identify morphologic variability in shallow water environments such as at estuarine inlets. As estuarine inlet morphology is an intrinsic boundary condition controlling the movement of wave and tidal energy into, and freshwater flow out of, an estuarine system (Hinwood & McLean, 2018) any change in entrance configuration will affect inundation regimes further into the estuary. Changes to entrance morphology occur when the hydrodynamics induce sediment transport resulting in a new morphology (Wright & Thom, 1977). Documenting these morphological shifts is fundamental to investigating how tidal progression, extreme water levels and inundation regimes may be influenced.

A study by Broadfoot (2020), investigated the interaction between morphology and tidal dynamics within a shallow water estuary on the east coast of Australia: Boambee Creek. The study identified a 17% increase in estuarine tidal range in 2009 (Figure 1A), which was not observed in the ocean water levels, suggesting a localised influence on the estuary tidal dynamics (Figure 1A). Using aerial imagery, the study identified that the entrance channel migrated northward between September 2009 and January 2010. The observed morphological shift coincides with a high intensity coastal storm that impacted the region and likely altered the entrance dynamics (Figure 1B & C). Based on the timeline of the observed changes at Boambee Creek it is suggested that the increase in tidal range is linked to the observed changes in inlet morphology. However, this study relied upon aerial imagery to detect changes in the inlet morphology, and to confirm this link, site specific bathymetric data would have been required.

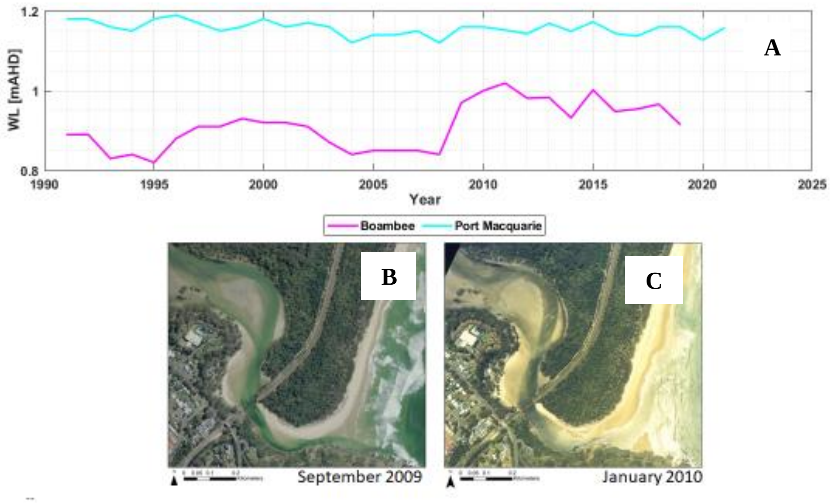

Fig. 1. A: Tidal range, as defined by the difference between the 95% and 5% exceedance water levels, at Boambee Creek and Port Macquarie Ocean gauge NSW, Australia, B & C. The ocean gauge is approx. 120 km south of the estuary. Aerial imagery collected by DPE. While tidal heights are different between the imagery the variance in inlet channel morphology is evident.

While obtaining in-situ bathymetric measurements has historically been logistically and financially challenging within shallow water environments, the advancements in remote sensing technology to derive bathymetry from satellites has proven to be a useful tool in overcoming these challenges (Ierodiaconou et al., 2022; Traganos et al., 2018; Turner et al., 2021). Additionally, with the rapid advancements in UAV technologies there is a growing interest in using such technologies as platforms to detect changes in coastal environments (Long et al., 2016; Rossi et al., 2020). Of particular interest to this study is the ability to employ such technologies at regular time intervals to reliably measure and detect changes to inlet morphology to understand the effects on tidal propagation upstream.

Aims

Field observations of morphological variability are an important element in resolving the extent to which morphological variability influences water levels upstream of the inlet and assessing potential impacts of morphological changes on inundation regimes. This paper documents an ongoing campaign of repeat multispectral imagery capture using UAV mounted sensors at an estuarine inlet on the Australian east coast. Bathymetric models are derived using the algorithm documented in Stumpf et al. (2003) and are validated via contemporaneous single beam bathymetric sonar and topographic surveys. UAV derived models will be compared to bathymetric models derived from publicly available satellite datasets of varying temporal and spatial resolution, including Sentinel, Landsat, and Planet imagery. This project aims to develop a reliable and repeatable methodology for using a UAV mounted with multispectral sensors to derive bathymetric models of shallow water estuaries, suitable for coastal researchers and managers.

Methods

To develop a reliable and repeatable methodology to detect morphological variability in shallow water environments this study examines a wave-dominated, shallow water barrier estuary on the south-east coast of Australia: Moonee Creek. The entrance morphology of Moonee Creek is highly dynamic making it an ideal case study to track morphological variability using remote sensing (Figure 2). Additionally, Moonee Creek has an average depth <1.5 m and low turbidity (DPE, 2021), which makes it ideal for deriving bathymetric models from multispectral imagery as the adopted algorithm has been shown to have optimal results in clear shallow water environments (Caballero & Stumpf, 2020; Turner et al., 2021).

Fig. 2. Aerial imagery of Moonee Creek demonstrating the monthly variation in morphology. Imagery was taken a month apart and obtained from Nearmaps.

Bathymetric models of the Moonee Creek inlet are derived from the multispectral imagery via the algorithm first proposed by Stumpf et al. (2003) where relative depth is a function of the log ratio between reflectance values of two bands, typically 'blue' and 'green' wavelengths in coastal waters, ($nRw(\lambda i)$, $nRw(\lambda j)$) (Eq1). Absolute depth (z) is obtained through scaling factors (m0 and m1) which are derived through tuning the log ratio to measured depths:

$$z = m_1 (ln\ (nR_w\ (\lambda_i)))\ /(ln\ (nR_w(\lambda_j))) - m_0 \qquad (1)$$

Measured depths contemporaneous to the UAV imagery capture, are obtained using a CEE ECHO single beam echosounder. This sensor is vessel mounted and operates with a 20 Hz ping rate and resolution of 1 cm in the vertical.

To determine the repeatability of the method and measure short term changes to inlet morphology a monthly data collection campaign is being undertaken with multispectral imagery captured using the Phantom 4 real-time kinematic (RTK) UAV. The Phantom 4 RTK is equipped with a 1-inch CMOS sensor which includes an RGB sensor for imaging the visible light and five monochrome sensors for multispectral imaging. The monochrome sensors capture the following spectral wavelengths: 450 nm ± 16 nm (Blue), 560 nm ± 16 nm (Green), 650 nm ± 16 nm (Red), 730 nm ± 16 nm (Red edge), and 840 nm ± 26 nm (Near-infrared)

In addition to monitoring bathymetric variability at the study sites, subaerial topographic changes in the estuary entrances are being monitored using a RTK GPS. The combination of topographic and bathymetric data is being used to create a continuous elevation surface which will enable change detection and exploration of the dynamic linkages between subaerial and subaqueous zones. This will be particularly useful for identifying changes in the intertidal zone. The topographic-bathymetric models derived in this study are an important element in resolving the extent to which morphological variability of the inlet influences water levels upstream and will assist in assessing potential impacts of morphological changes on inundation regimes.

Outcomes

Bathymetric models are an important element in resolving the extent to which morphological variability influences water levels upstream of the inlet and assessing potential impacts of changes to inundation regimes. To help future management and research in understanding inlet dynamics this study will develop a robust method that can be utilised in detecting inlet dynamics of shallow water estuaries. Specifically, the study will investigate the reliability of using UAV multispectral imagery to derive bathymetry and its suitability to repeatedly detect morphological changes within shallow water estuaries. As well, the study will document key challenges of validating the derived bathymetry with measured topographic and bathymetric data.

Conclusion

The ability to document inlet variability in a rapid and resource-effective way will help manage current and future challenges within estuarine systems and will help create more resilient communities. This study hopes to provide a methodology that will help understand the variability of coastal inundation under varying morphological entrance scenarios, which will support current and future coastal management decision making and planning. The methodology to detect inlet variability of shallow water estuary inlets outlined in this paper is currently under development, the findings of this research will be presented at the 2023 Coastal Sediments Conference in New Orleans, Louisiana, USA.

Acknowledgements

We acknowledge the efforts and contributions of field assistances from the University of Newcastle and Griffith University. Additionally, the support from the NSW Department of Planning and Environment and Marine Parks NSW is recognized. Madelaine Broadfoot is supported by the University of Newcastle HDR scholarship and by the CSIRO through a top-up scholarship.

References

Broadfoot, M. (2020). Tidal Dynamics and Morphology of Riverine Estuaries in NSW Univeristy of Newcastle].

Caballero, I., & Stumpf, R. P. (2020). Towards Routine Mapping of Shallow Bathymetry in Environments with Variable Turbidity: Contribution of Sentinel-2A/B Satellites Mission. Remote Sensing, 12(3).

DPE. (2021). NSW Estuary Profiles. Retrieved 12/07/22 from https://www.environment.nsw.gov.au/topics/water/estuaries/estuaries-of-nsw/search-nsw-estuary-profiles

Hanslow, D. J., Morris, B. D., Foulsham, E., & Kinsela, M. A. (2018). A Regional Scale Approach to Assessing Current and Potential Future Exposure to Tidal Inundation in Different Types of Estuaries. Scientific Reports, 8(1), 7065. https://doi.org/10.1038/s41598-018-25410-y

Hinwood, J. B., & McLean, E. J. (2018). Tidal inlets and estuaries: Comparison of Bruun, Escoffier, O'Brien and attractors. Coastal Engineering, 133, 92-105. https://doi.org/https://doi.org/10.1016/j.coastaleng.2017.12.008

Ierodiaconou, D., Kennedy, D. M., Pucino, N., Allan, B. M., McCarroll, R. J., Ferns, L. W., Carvalho, R. C., Sorrell, K., Leach, C., & Young, M. (2022). Citizen science unoccupied aerial vehicles: A technique for advancing coastal data acquisition for management and research. Continental Shelf

Research. https://doi.org/https://doi.org/10.1016/j.csr.2022.104800

IPCC. (2019). Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Leuven, J. R. F. W., Pierik, H. J., Vegt, M. v. d., Bouma, T. J., & Kleinhans, M. G. (2019). Sea-level-rise-induced threats depend on the size of tide-influenced estuaries worldwide. Nature Climate Change, 9(12), 986-992. https://doi.org/10.1038/s41558-019-0608-4

Long, N., Millescamps, B., Guillot, B., Pouget, F., & Bertin, X. (2016). Monitoring the Topography of a Dynamic Tidal Inlet Using UAV Imagery. Remote Sensing, 8(5), 387.

Masselink, G., Hughes, M., & Knight, J. (2011). Introduction to Coastal Processes and Geomorphology https://doi.org/https://doi.org/10.4324/9780203785461

Oppenheimer, M., Glavovic, B., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., Deconto, R. M., & Ghosh, T. (2019). Sea level rise and implications for low lying islands, coasts and communities.

Rossi, L., Mammi, I., & Pelliccia, F. (2020). UAV-Derived Multispectral Bathymetry. Remote Sensing, 12(23).

Stumpf, R. P., Holderied, K., & Sinclair, M. (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnology and Oceanography, 48(1part2), 547-556. https://doi.org/https://doi.org/10.4319/lo.2003.48.1_part_2.0547

Traganos, D., Poursanidis, D., Aggarwal, B., Chrysoulakis, N., & Reinartz, P. (2018). Estimating Satellite-Derived Bathymetry (SDB) with the Google Earth Engine and Sentinel-2. Remote Sensing, 10(6), 859.

Turner, I. L., Harley, M. D., Almar, R., & Bergsma, E. W. J. (2021). Satellite optical imagery in Coastal Engineering. Coastal Engineering, 167, 103919. https://doi.org/https://doi.org/10.1016/j.coastaleng.2021.103919

Wright, L. D., & Thom, B. G. (1977). Coastal depositional landforms: a morphodynamic approach. Progress in Physical Geography: Earth and Environment, 1(3), 412-459. https://doi.org/10.1177/030913337700100302

Zhang, X., Ma, Y., & Zhang, J. (2020). Shallow Water Bathymetry Based on Inherent Optical Properties Using High Spatial Resolution Multispectral Imagery. Remote Sensing, 12(18).