The Application of High-resolution PlanetScope Dove Satellite Imagery for Near-daily Shoreline Monitoring

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Abstract
Strong, evidence-based coastal management and planning relies on routine monitoring to quantify and understand shoreline position over a variety of timescales. The recent advances and availability of satellite-derived products provides new and exciting data streams for coastal monitoring around the world. This study evaluates the capacity of the high-resolution PlanetScope Dove satellite constellation to capture near-daily shoreline change along sandy coastlines. Shoreline position from four years of PlanetScope imagery is compared against in-situ RTK-GPS survey data (n=385) from Narrabeen-Collaroy beach in the Northern Beaches of Sydney, Australia. Through the implementation of a robust shoreline extraction algorithm, the accuracy of PlanetScope derived shorelines was determined with a mean observed horizontal root mean square error (RMSE) of 4.13m. These results present a twofold increase in shoreline accuracy relative to previous satellite remote sensing studies, such as CoastSat, employing publicly available lower resolution Landsat satellite data. An example application for the July 2020 storm that impacted Wamberal, NSW is also presented to highlight the capability of this emerging data stream for routine and targeted coastal monitoring of storm events.

Keywords: remote sensing, beach monitoring, coastal storms, CoastSat.

1. Introduction
The dynamic nature of sandy coastlines around the world poses a major threat to local communities who live within the active coastal zone. With major hazards including (but not limited to) widespread erosion, storm damage, flooding and inundation of low-lying areas, the risks associated with coastal living are set to increase into the future with a changing climate and rising sea levels [7]. Central to mitigating the risk to human life and infrastructure is a clear understanding of both short- and long-term shoreline behaviour and of the underlying sediment transport processes and system response to change [e.g., 6,11]. In formulating such estimates, routine, long-term monitoring and data collection are essential to help understand and predict the complex behaviour of shorelines. Historically, however, this has been a significant challenge, with only a limited number of long-term, routine monitoring sites around the world [9,13]. More recently, satellite technologies have been used to map shorelines using the Google Earth Engine platform (e.g. *CoastSat*, [15]). These new platforms are providing unprecedented data and insight into our coastlines, with satellite-derived shoreline RMSE on the order of 10m. This level of accuracy allows for shoreline variability on the order of 6 months or greater to be captured at most sites worldwide [14].

One emerging field is that of satellite constellations comprised of hundreds of small (10x10x30cm) CubeSat micro-satellites equipped with RGB and infrared sensors [10]. Compared to the more traditional Landsat and Sentinel-2 satellites that provide images with resolutions between 10-30m and a revisit time every 2-4 weeks, the PlanetScope Dove constellation is capable of imaging the entire globe near daily at a spatial resolution of 3m [10]. First launched in March 2016, the PlanetScope constellation is comprised of 130+ satellites arranged in a sun-synchronous orbit around the earth [10]. Due to their small size, CubeSat satellites are cheap to manufacture and launch relative to traditional custom-built satellites. As such, the PlanetScope fleet is regularly updated via opportunistic third-party rocket launches. At present however, PlanetScope Dove images lack the panchromatic and short-wave infrared bands commonly employed in satellite derived shoreline studies that use the coarser resolution Landsat and Sentinel-2 platforms [5,8,14].

This paper presents a summary of the assessment of the positional accuracy of PlanetScope derived shorelines against high resolution in-situ measurements from the long-term survey program conducted at Collaroy-Narrabeen beach (hereafter referred to as Narrabeen). As an additional example for its applicability in targeted coastal monitoring, PlanetScope derived shorelines from the June 2020 storms that impacted Wamberal, NSW are also presented.

2. Methods
2.1 Study site and In-situ data
Located in the Northern Beaches of Sydney along the south-eastern coast of Australia, Narrabeen

beach is one of the longest continually monitored beaches in the world [12]. With surveys commencing in 1976, the modern RTK-GPS survey program is coordinated by the UNSW Water Research Laboratory (WRL) and records monthly cross-shore beach profiles along five transects to an approximate vertical accuracy of ± 3cm [4]. For the purpose of this validation study, WRL survey data was utilised for the study period from July 2016 - May 2020 encompassing 77 individual survey dates. For comparison with PlanetScope (PS) derived shoreline data, in-situ shoreline position was defined as the 0.7m AHD elevation contour (approximating local Mean High Water Springs). For a full description of the Narrabeen study site the reader is referred to Turner et al. [13].

2.2 PlanetScope Data

2.2.1 PlanetScope images

To investigate the suitability of PS imagery for routine shoreline monitoring, all available Analytic Ortho Scenes up to May 2020 with a cloud cover <10% were downloaded for Narrabeen beach. This cloud cover percentage was found to remove most of the un-useable cloud impacted scenes while allowing for manual filtering to determine the suitability of partially cloud impacted scenes. To minimise the impact of shading from buildings and trees on shoreline detection on the east facing study site, images with a timestamp later than noon local time were discarded. As such, 479 image scenes satisfying the cloud cover and timestamp criteria were downloaded spanning 364 unique dates. Manual checking of the images resulted in the removal of 20 additional images due to clear visual errors. Of these errors, 8 were associated with cloud shadows, 12 with partial cloud cover and 7 with PS data issues. Most of these errors were not detected in the PS provided Unusable Data Mask (UDM). As a sun-synchronous constellation orbit, many images occurred within an hour of the median Narrabeen local solar image timestamp of ~9:30am. With a near-daily image recurrence, it was found that the filtered subset of available images with <10% cloud cover had a median image return period of 2 days.

2.2.2 Image pre-processing

Derived from raw sensor data captured at an average ground sample resolution of 3.7m, the 4-band multispectral Analytic Ortho Scene product was deemed most suitable for shoreline mapping. During the orthorectification process, pixel size is resampled down to 3m. Composed of Red, Green, Blue and Near Infra-Red (NiR) bands, image pixel data is provided as Digital Number (DN) values which correspond to at-sensor detected radiance. To reduce scene-to-scene variability and enable direct comparison between images [1], DN values were converted to Top of Atmosphere (TOA) reflectance via PS provided conversion factors.

2.2.3 Shoreline extraction

This paper will present one set of methods tested for shoreline extraction using the PlanetScope data. Additional methods are discussed in [2]. With each image composed of a Red, Green, Blue and NiR colour band, individual bands may be extracted and manipulated to contrast the sand/water interface. As each pixel in each colour band is comprised of a numeric TOA reflectance, simple arithmetic may be performed between bands for each pixel resulting in a single band greyscale image. For the purpose of water delineation this resultant image is referred to as a water index (Figure 1).

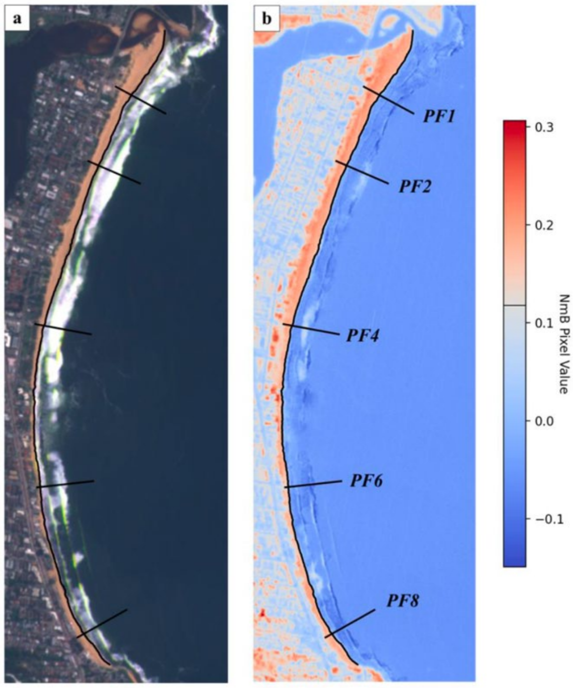


Figure 1. Shoreline sand/water contouring based on optimal threshold value (a) PlanetScope satellite image with superimposed derived shoreline (b) Colourised greyscale (single band) water index image highlighting pixel value variation and optimal threshold shoreline value.

Specifically utilising the high absorption of red and NIR wavelengths by water and the high reflectance of blue wavelengths by sand, this paper uses a NIR-Blue index to determine a suitable sand/water interface:

$$\mathrm{NmB} = \mathrm{NIR} - \mathrm{Blue} \tag{1}$$

From the resultant greyscale water index image, a weighted peak (WP) pixel value thresholding algorithm is utilised to determine a suitable boundary between sand and water:

$$\mathrm{NIndex}_{\mathrm{Opt}} = \hat{x}_{\mathrm{water}} + 0.7(\hat{x}_{\mathrm{sand}} - \hat{x}_{\mathrm{water}}) \tag{2}$$

where $\hat{x}_{water}$ and $\hat{x}_{sand}$ correspond to peak (mode) water and sand class PDF histogram values, respectively.

A contouring algorithm is then employed to extract the shoreline for each scene (Figure 1) before corrections are made for water level variations based on a generic intertidal beach slope.

The instantaneous boundary between sand and water pixels in the satellite-derived shoreline is highly dependent on local water level conditions. With each image nominally captured around 9:30am each day and therefore various stages of the tidal cycle, water level variability must be considered for comparison between image dates, and against alternate methods of shoreline monitoring. Following the method of tidal correction outlined by Vos et al. (2019a), shorelines were transposed to the 0.7m elevation contour to match the shoreline definition used in the WRL Narrabeen profile survey data. By matching each image timestamp with the corresponding local water level, shorelines are transposed horizontally by means of a generalised intertidal beach slope (m = 0.1 for Narrabeen):

$$\Delta x = \frac{z_{ref} - z_{wl}}{m} \qquad (3)$$

where z_{ref} is the desired elevation contour (0.7m for Narrabeen) and z_{wl} the instantaneous water level (assumed constant alongshore). For this study, water level is defined as the combination of astronomical tide and wave setup relative to mean sea level. No additional corrections for water levels and waves are included here but can be found in [2].

3. Results

The following section presents an analysis of the PS derived shorelines relative to in-situ data along Narrabeen transects PF1, PF2, PF4, PF6 and PF8. For validation purposes the closest PS shoreline within 5 days of a survey date was considered a match. Through this method, 385 shorelines were obtained with a mean absolute time difference between image collection and survey date of 30 hours with 90% of surveys lying within 76 hours.
Examining the timeseries for each of the five study transects (PF8 shown in Figure 3), a strong correlation (R^2 = 0.79 to 0.89) is observed between PS derived shorelines and in-situ data for all transects. PS shorelines were able to accurately detect annual cycles of erosion and accretion, sub-annual shoreline variability and episodic storm erosion. Additionally, the 2-day image recurrence of PS data delivers a higher level of temporal resolution than the in-situ data and provides information regarding shoreline behaviour between in-situ survey dates. Figure 2 provides a summary of error statistics for the Narrabeen data set comparison.

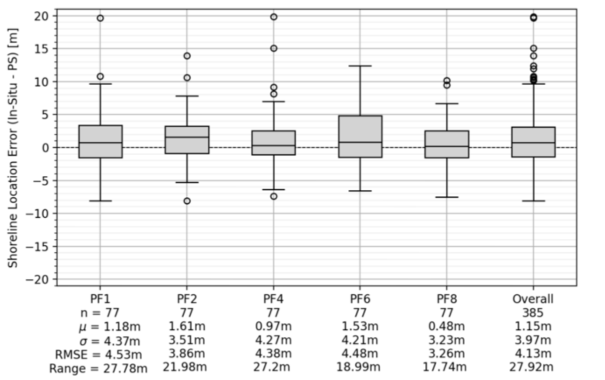
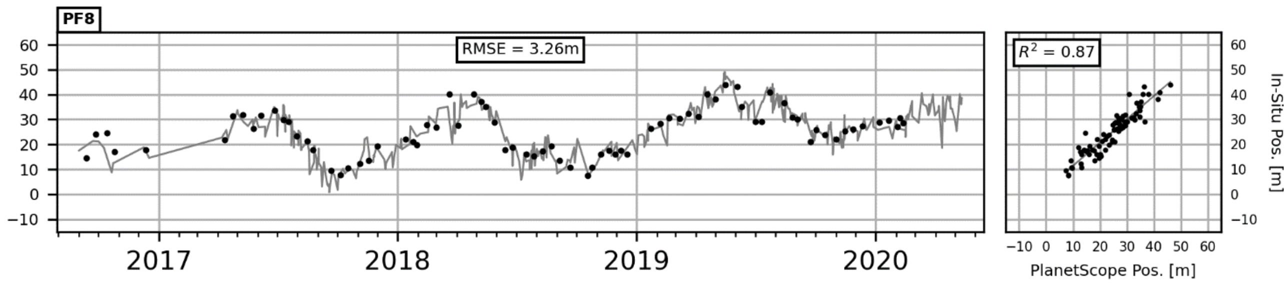


Figure 2. *PlanetScope Shoreline Accuracy Relative to In-Situ Transect Data*

With the five transect exhibiting distinct behaviours over the study period, no alongshore trends were noted regarding shoreline residual mean, standard deviation, RMSE or range. Overall, these results indicate the high degree of PS derived shoreline precision relative to in-situ survey data with an observed standard deviation of 3.97m and a range of SD values between transects of 1.14m. A mean landward offset of 1.15m was recorded with the range of offset values varying from 0.48m to 1.61m. With this offset increasing the observed RMSE value relative to the standard deviation, an overall RMSE of 4.13m was noted. This level of shoreline accuracy is comparable with far-field (~1000m) measurements from Narrabeen image based systems including Argus [4] and *CoastSnap* [3]. Relative to the *CoastSat* toolbox and previous satellite derived shoreline studies at Narrabeen [5,14], these results present an almost 50% decrease in observed RMSE values.



4. Example Application: Wamberal, NSW

A severe weather event impacted the NSW coastline between the 14th and 19th July 2020. The event, termed an "East Coast Low", created large wave conditions that resulted in beach erosion at many NSW beaches, with particularly severe impacts experienced at Wamberal, on the NSW Central Coast. Beach erosion encroached on numerous private properties along the eastern side of Ocean View Drive and Pacific Street in Wamberal, resulting in structural damage to several dwellings and other built assets. Based on offshore met-ocean conditions, the storm was approximately a 10-year ARI level storm (H_s = 6.9m) and was ranked as the 6th most severe event recorded since 1958. The total volume of sand removed from the beach (above 0 m AHD level) was of the order of 65 m^3/m. Examining the pre- and post-storm shorelines captured from PlanetScope (Figure 4), shoreline erosion ranged from 0m at the southern end of the embayment (chainage ~ 2200m) up to 40m (chainage ~1100m) and was quite alongshore variable at alongshore scales of 200-500m. Examining the longer term shoreline position at chainage = 1300m between April-September 2020, it is also evident that the beach did not rapidly recover from the event, rather continued to slowly erode over the following months.

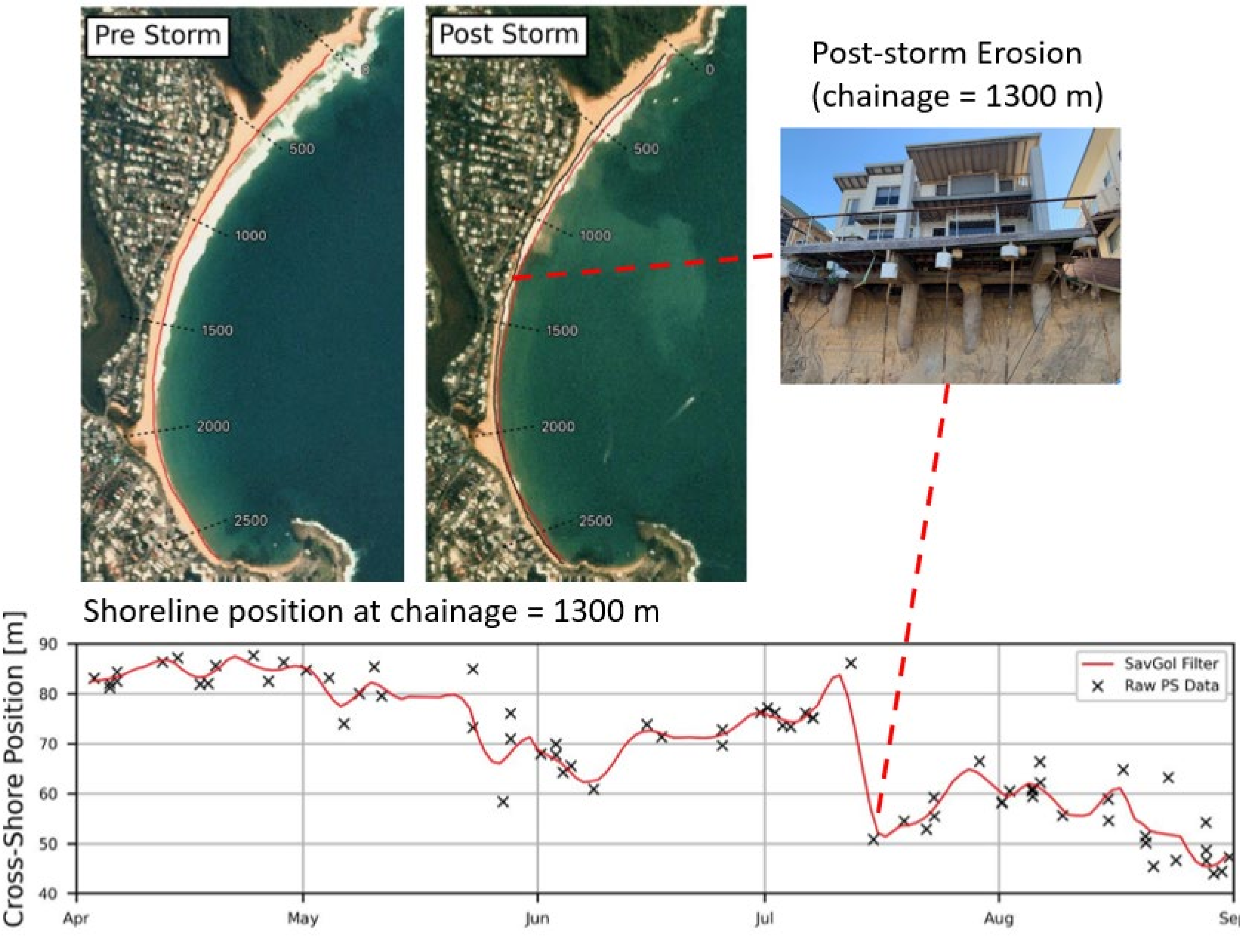


Figure 4. PlanetScope shoreline position at chainage = 1300m for the period April – September 2020, highlighting the large erosion event that occurred in July 2020 at Wamberal Beach, NSW. No in-situ data was available at the site for validation purposes.

5. Conclusions

Providing 4+ years of imagery with a median image recurrence of 2 days, PlanetScope data is well suited to capture annual, seasonal and short-term shoreline variability. As an expanding fleet of satellites with continual data collection, the value of

PlanetScope imagery as a source of long-term, high resolution shoreline data will only increase into the future as further data is collected.

6. Acknowledgements

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7. References

[1] Chander G, Markham BL, Helder DL. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors, Remote Sens. Environ. 113. 893–903.

[2] Doherty Y, Harley MD, Vos K, Splinter KDM. (n.d.). Evaluation of planetscope dove satellite imagery for high-resolution, near-daily shoreline monitoring, Prep Coast. Eng.

[3] Harley MD, Kinsela M, Sanchez-Garcia E, Vos K. (2018). Shoreline change mapping using crowd-sourced smartphone images, Coast. Eng. in review.

[4] Harley MD, Turner IL, Short AD, Ranasinghe R. (2011). Assessment and integration of conventional, RTK-GPS and image-derived beach survey methods for daily to decadal coastal monitoring, Coast. Eng. 58. 194–205.

[5] Liu Q, Trinder J, Turner IL. (2017). Automatic super-resolution shoreline change monitoring using Landsat archival data: a case study at Narrabeen–Collaroy Beach, Australia, J. Appl. Remote Sens. 11. 016036.

[6] Montaño J, Coco G, Antolínez JAA, Beuzen T, Bryan KR, Cagigal L, Castelle B, Davidson MA, Goldstein EB, Ibaceta R, Idier D, Ludka BC, Masoud-Ansari S, Méndez FJ, Murray AB, Plant NG, Ratliff KM, Robinet A, Rueda A, Sénéchal N, Simmons JA, Splinter KD, Stephens S, Townend I, Vitousek S, Vos K. (2020). Blind testing of shoreline evolution models, Sci. Rep. 10.

[7] Oppenheimer M, Glavovic B. (2019). Chapter 4: Sea Level Rise and Implications for Low Lying Islands, Coasts and Communities. IPCC SR Ocean and Cryosphere, IPCC Spec. Rep. Ocean Cryosph. a Chang. Clim. [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (Eds.)]. Press. Chapter 4. 1–14.

[8] Pardo-Pascual JE, Almonacid-Caballer J, Ruiz LA, Palomar-Vázquez J. (2012). Automatic extraction of shorelines from Landsat TM and ETM+ multi-temporal images with subpixel precision, Remote Sens. Environ. 123. 1–11.

[9] Pianca C, Holman R, Siegle E. (2015). Shoreline variability from days to decades: Results of long-term video imaging, J. Geophys. Res. C Ocean. 120. 2159–2178.

[10] Planet, Planet Imagery Product Specifications June 2020, (2020).

[11] Sanuy M, Jiménez JA. (2020). Probabilistic characterisation of coastal storm-induced risks using Bayesian Networks, Nat. Hazards Earth Syst. Sci. Discuss. preprint. 1–23.

[12] Splinter KD, Harley MD, Turner IL. (2018). Remote Sensing Is Changing Our View of the Coast : Insights from 40 Years of Monitoring at of, Remote Sens. 10. 1744.

[13] Turner IL, Harley MD, Short AD, Simmons JA, Bracs MA, Phillips MS, Splinter KD. (2016). A multi-decade dataset of monthly beach profile surveys and inshore wave forcing at Narrabeen, Australia., Sci. Data. 3. 160024.

[14] Vos K, Harley MD, Splinter KD, Simmons JA, Turner IL. (2019). Sub-annual to multi-decadal shoreline variability from publicly available satellite imagery, Coast. Eng. 150. 160–174.

[15] Vos K, Splinter KD, Harley MD, Simmons JA, Turner IL. (2019). CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery, Environ. Model. Softw. 122. 104528.