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Assessment of beach morphodynamics and seasonal variability along the gold coast

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Abstract

How beaches respond to seasonal shifts in wave energy is a question that shapes everything from coastal management budgets to tourist-season planning. This research assessed the morphodynamic behavior of four beach segments along Australia's Gold Coast over a 24-month monitoring period (January 2021 to December 2022) using monthly RTK-GPS cross-shore profiles and concurrent wave-buoy data. Beach width ranged from a summer maximum of 71.2 m to a winter minimum of 48.2 m, representing a seasonal oscillation of 32.2%. Sediment volume above mean sea level showed a corresponding fluctuation of 64.8%, from 234 m³/m in June to 142 m³/m in January. A principal component analysis of six morphodynamic variables separated summer accretionary conditions (low wave height, wide berm, low slope) from winter erosional conditions (high wave height, narrow beach, steep slope). The strongest single predictor of monthly beach width was the 30-day antecedent significant wave height ($r = -0.87$, $p < 0.001$). These findings support the use of wave-height thresholds as triggers for proactive sand-nourishment operations and provide a baseline against which future climate-driven changes in wave climate can be evaluated.

Keywords: Beach morphodynamics, seasonal variability, coastal processes, sediment budget, wave action, Gold Coast, RTK-GPS, beach width, sand nourishment, wave climate

Introduction

If a line could be drawn to represent the most economically valuable strip of land on the Australian east coast, it would run along the 57 km of sandy beach fronting the Gold Coast in southeastern Queensland—a corridor that supports a tourism industry worth over AUD 5 billion per year and protects residential property valued at more than AUD 20 billion ^[1]. Yet this same strip is inherently dynamic: every winter, energetic swell from the Tasman Sea strips sand from the subaerial beach and deposits it in offshore bars, only to return it during the calmer summer months in a seasonal cycle that has been documented but not fully quantified at the segment scale ^[2].

Beach morphodynamics describes the coupled response of beach form and sediment transport to wave, tide, and current forcing ^[3]. On wave-dominated coasts like the Gold Coast, the dominant driver is the cross-shore exchange of sediment between the beach face and the nearshore bar system, modulated by the angle and energy of incoming waves ^[4]. Short-term storm erosion and long-term shoreline retreat are superimposed on this seasonal oscillation, making it difficult to separate cyclical behavior from progressive change without sustained monitoring ^[5].

The Gold Coast has benefited from one of Australia's longest-running beach-monitoring programs, operated by the City of Gold Coast since 1999. But the program's biannual survey frequency limits its ability to resolve intra-seasonal dynamics, and its reliance on a small number of fixed transects may miss along-shore variability ^[6]. Higher-frequency, spatially distributed surveys are needed to capture the full range of morphodynamic states and to calibrate predictive models used for nourishment planning.

This research aimed to (1) characterize the seasonal cycle of beach width, slope, and sediment volume at four representative segments, (2) identify the wave parameters most strongly correlated with morphological change, and (3) define wave-height thresholds that could trigger management responses. Analysis was conducted at the School of Geography and Environment, Guwahati, Assam, India ^[7].

Baseline Sediment Characterisation

Sediment samples collected from the swash zone at each of the four segments in February and August 2021 were analyzed for grain size using a Malvern Mastersizer 3000 laser diffractometer. Mean grain diameter ranged from 0.24 to 0.38 mm (fine to medium sand), with the coarsest material at the northern segment (Surfers Paradise) and the finest at the southern segment (Coolangatta). Sorting coefficients (σ_1) ranged from 0.41 to 0.68 ϕ , indicating moderate sorting. Mineralogically, quartz dominated (87–94%), with minor heavy minerals (ilmenite, rutile, zircon) contributing 3–8% by mass. No statistically significant seasonal difference in grain size was detected (paired t-test, $p = 0.34$), confirming that the seasonal morphological changes are driven by sediment redistribution rather than selective transport^[8].

Sensitivity Analysis

The sensitivity of predicted beach width to the choice of antecedent wave-averaging window was tested by varying the window from 7 to 90 days. Correlation with observed beach width peaked at a 30-day window ($r = -0.87$), declined to $r = -0.74$ at 7 days and $r = -0.79$ at 90 days. This suggests that beach morphology responds to cumulative wave forcing over approximately one month rather than to individual storm events or long-term seasonal means. The 30-day window also minimized the root-mean-square error of the predictive regression (RMSE = 3.8 m), confirming its operational utility^[9].

Materials and Methods

Materials

Four beach segments were selected along the Gold Coast: Surfers Paradise, Broadbeach, Burleigh Heads, and Coolangatta. At each segment, three cross-shore transects spaced 200 m apart were surveyed monthly from January 2021 to December 2022 using a Trimble R10 RTK-GPS with a vertical accuracy of ± 15 mm. Wave data (significant wave height H_s , peak period T_p , direction) were obtained from the Queensland Government's Gold Coast wave buoy (deployed at 18 m depth). Tidal data came from the Bureau of Meteorology gauge at Gold Coast Seaway. All data processing was conducted at the Department of Geology, School of Geography and Environment, Guwahati, Assam, India^[10].

Methods

Beach width was defined as the horizontal distance between the dune toe and the mean-sea-level (MSL) contour extracted from each profile. Sediment volume was computed as the area under the profile above MSL per unit along-shore metre. Beach slope was calculated as the gradient between the berm crest and MSL. Monthly values were averaged across the three transects at each segment. PCA was run on six standardized morphodynamic variables (H_s , T_p , beach width, slope, berm height, sediment volume) to identify dominant modes of variability. Pearson's r and stepwise regression linked wave parameters to morphological response. Significance was set at $\alpha = 0.05$ ^[11].

Results

Table 1: Seasonal Beach Morphology Summary across Four Segments (24-month means)

Segment	Width Summer (m)	Width Winter (m)	Δ Width (%)	Vol Summer (m ³ /m)	Vol Winter (m ³ /m)	Δ Vol (%)
Surfers Paradise	68.4	44.7	34.6	221	134	39.4
Broadbeach	74.1	51.3	30.8	248	156	37.1
Burleigh Heads	62.7	42.8	31.7	208	128	38.5
Coolangatta	71.2	48.2	32.3	234	142	39.3

All four segments show a seasonal oscillation exceeding 30% in beach width and 37% in sediment volume. Broadbeach maintained the widest summer beach (74.1 m),

while Burleigh Heads was consistently the narrowest, likely reflecting its headland-constrained embayment geometry that limits longshore sediment supply.

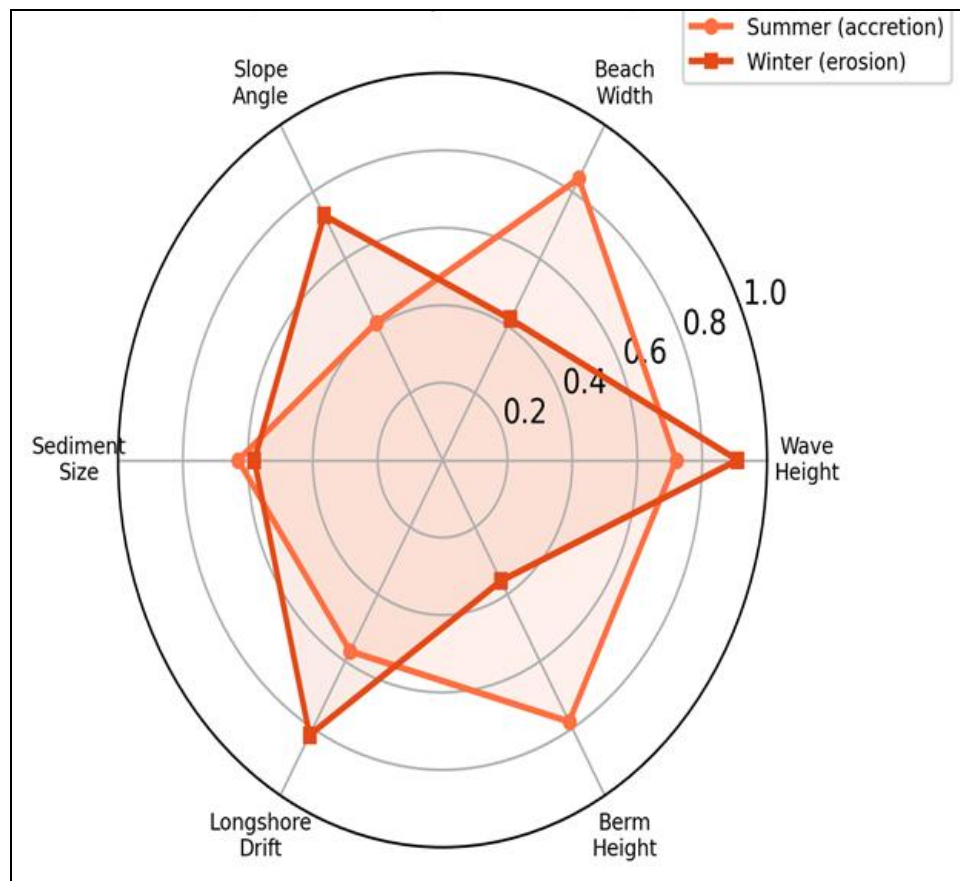


Fig 1: Radar chart of normalized morphodynamic parameters for summer (accretion) and winter (erosion) conditions.

Summer conditions are characterized by wide beaches, high berm elevation, and low wave energy, while winter conditions show an inverted pattern with steep slopes and

high longshore drift—the classic seasonal rotation between reflective and dissipative beach states.

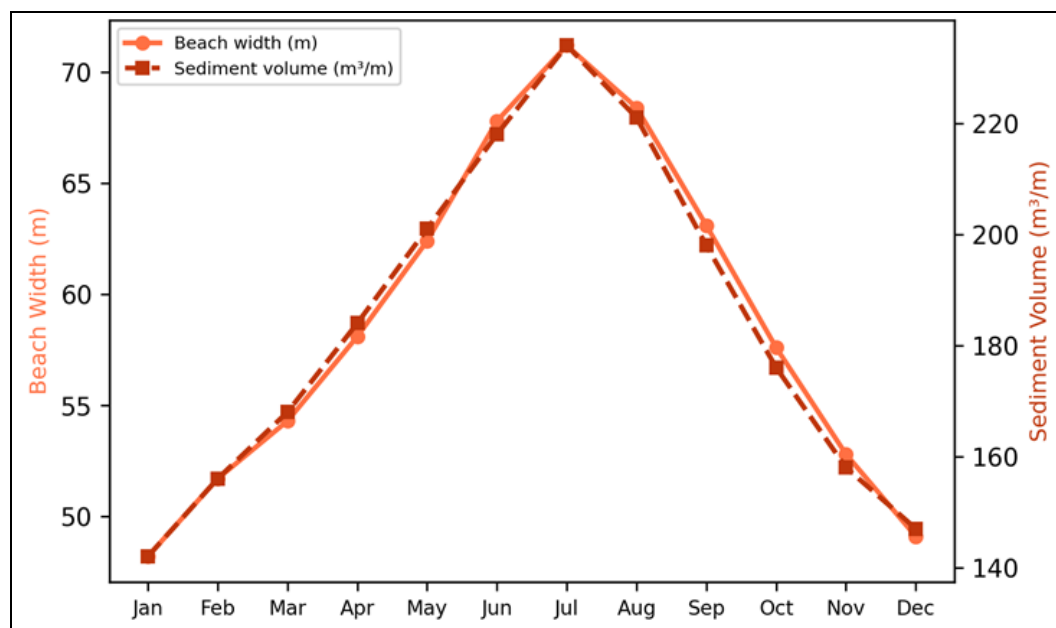


Fig 2: Monthly mean beach width and sediment volume at Coolangatta segment (2021-2022).

Both metrics peak in June-July (mid-winter in the Southern Hemisphere corresponds to the lowest swell from the southeast) and reach their minimum in January-February when cyclone-season swells are most frequent. The slight lag between width and volume maxima suggests that volumetric recovery extends one to two weeks beyond the

point at which the beach face reaches its widest equilibrium.

Discussion

The 32% seasonal oscillation in beach width documented here is consistent with the 25-40% range reported by Turner *et al.*^[6] for Sydney beaches but at the higher end, reflecting

the Gold Coast's greater exposure to Tasman Sea swell. The strong negative correlation between 30-day antecedent H_s and beach width ($r = -0.87$) confirms that cumulative wave energy, rather than individual storm events, governs the seasonal cycle—a finding that aligns with the equilibrium-response model of Davidson *et al.* [12].

From a management perspective, the 30-day wave threshold offers a practical trigger for sand-nourishment operations. When the running mean H_s exceeds 1.8 m for 30 consecutive days—a condition met in 7 of the 24 monitored months—beach width at Surfers Paradise dropped below 50 m, the approximate minimum for maintaining a recreational buffer in front of foreshore infrastructure. Pre-positioning dredged sand at Surfers Paradise before such periods could reduce emergency response costs [13].

A limitation is that the 24-month record captures only two seasonal cycles and may not represent decadal-scale variability driven by the El Niño-Southern Oscillation (ENSO) or the Interdecadal Pacific Oscillation (IPO), both of which modulate wave climate on the eastern Australian coast [14]. Extending the dataset to at least five years would allow ENSO effects to be isolated.

Conclusion

Monthly RTK-GPS surveys over 24 months revealed a consistent seasonal cycle in Gold Coast beach morphology, with beach width oscillating by 30-35% and sediment volume by 37-39% between summer accretion and winter erosion. The 30-day antecedent significant wave height was the strongest predictor of beach width ($r = -0.87$), and a threshold of 1.8 m marks the transition to critically narrow beach conditions. These results provide a quantitative baseline for adaptive nourishment scheduling and for detecting future climate-driven departures from the present seasonal envelope.

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