QUANTIFYING NEARSHORE MORPHOLOGICAL RECOVERY TIME SCALES USING ARGUS VIDEO IMAGING: PALM BEACH, SYDNEY AND DUCK, NORTH CAROLINA

Roshanka Ranasinghe[1,2,3], Rob Holman[4], Matthieu de Schipper[2], Tom Lippmann[5], Jennifer Wehof[6], Trang Minh Duong[1,3], Dano Roelvink[1], and Marcel Stive[2]

Time scales of post-storm nearshore morphological recovery and physical processes governing these time scales are poorly understood at present. The ability to predict nearshore morphological recovery time scales based on pre-, during- or post-resetting storm conditions is an essential requirement for building and validating scale aggregated models that operate at macro- and higher spatio-temporal scales. In this study, quality controlled ARGUS video derived beach states at Palm Beach, Sydney (4 years) and Duck, NC (2 years) and concurrent wave data are analysed to quantify the nearshore morphological recovery time scales (T_{mr}) and to determine the physical processes that may govern T_{mr}. The results show that T_{mr} is of the order of 5-10 days at these two beaches. T_{mr} is moderately positively correlated with the averaged longshore current over the 3 days immediately after the resetting storm, indicating that it might be possible to develop a predictor for T_{mr} based on wave conditions immediately after the resetting storm. Weak correlations are present between T_{mr} and several pre-storm, during-storm and post-storm parameters at the two sites. However, these correlations are inconsistent between the two sites. A thorough analysis employing long-term beach state and wave data at several different study sites is required to fully understand this phenomenon.

Keywords: Morphological resets, Storm impact, recovery time scales, ARGUS

INTRODUCTION

How long does it take for nearshore morphology to recover after a storm induced morphological reset event? Is the morphological recovery time scale (T_{mr}) more or less the same at beaches with similar characteristics, or is it completely random? Are there any physical processes that govern T_{mr}, or is it governed by scale-aggregated self-organising behavioural characteristics? These are important questions that need to be answered to further our understanding of macro-scale coastal behaviour, which is a pre-requisite to build and validate predictive models at macro- and higher spatio-temporal scales. From an applied point of view, even a qualitative knowledge of T_{mr} will aid amphibious operations. Furthermore, coastal management/planning decision support tools that account for long term (decadal to centennial) coastline behaviour (e.g. Callaghan et al., 2008; Ranasinghe et al., 2012) will greatly benefit from a knowledge of T_{mr} because it is unlikely that dune recovery will occur before the nearshore morphology recovers after storm induced resets (i.e. initiation of dune recovery will almost always occur after T_{mr} has been reached).

Over the last three decades, a considerable amount of research effort has gone into understanding the morphodynamic processes governing the upstate/downstate transitions between beach states (as defined by Wright and Short, 1984), using field observations (Wright et al., 1985; Brander 1999), ARGUS video imaging (Lippmann and Holman, 1990; Ranasinghe et al., 2004, Turner et al 2007; Ojeda et al., 2011; Price and Ruessink, 2011), and numerical modelling (Damgaard et al., 2002; Reniers et al., 2004; Drønen and Deigaard, 2007; Calvete et al., 2007; Smit et al., 2008; Castelle et al., 2012). However, to date, there has been no concerted research effort focussing specifically on the important issue of nearshore morphological recovery time scales. The present study takes an initial step towards addressing this knowledge gap.

[1] UNESCO-IHE Institute for Water Education, Delft, The Netherlands.
[2] Coastal Engineering, Section of Hydraulic engineering, Delft University of Technology, Delft, The Netherlands.
[3] Harbour, Coastal and Offshore Engineering, Deltares, PO Box 177, 2600 MH Delft, The Netherlands
[4] Oceanography Department. Oregon State University, Corvallis, Oregon, USA.
[5] Center for Coastal & Ocean Mapping, University of New Hampshire, Durham, New Hampshire, USA.
[6] Environmental Engineering, Stevens Institute of Technology, Hoboken, New Jersey, USA.

METHODS

Here we define T_{mr} as the time (days) it takes for the nearshore morphology to evolve from a post-storm Dissipative or Longshore Bar Trough state (D/LBT) to its modal state (i.e. the most frequently occurring beach state), be it Rhythmic Bar Beach (RBB), Transverse Bar Rip (TBR), Low Tide Terrace (LTT), or Reflective (R). The critical requirement for the quantification of T_{mr} is the availability of a beach state and wave characteristics data set that is of high quality, sufficient length (multi-year) and sufficient temporal resolution (daily). The ARGUS video data presented by Lippmann and Holman (1990) (2 Years of daily data at Duck, NC- Oct 1986 to Oct 1988) and Ranasinghe et al. (2004) (4 years of daily data at Palm Beach, Sydney - Jan 1996 to Dec 1999) satisfy these requirements (Figures 1 and 2). These two data sets are the only ARGUS beach state data sets that have been rigorously quality controlled. Random samples from both data sets were subjected to independent visual beach state classifications by a panel of coastal experts/non-experts and the levels of consensus were quantified. In both cases, the overall agreement between the classification panels and the authors exceeded 75% (i.e. over 75% of the states classified by the authors were classified as the same state by the panel members). Therefore, a high level of confidence can be placed on these two data sets.

Both sites are located in microtidal environments. The annual average significant wave periods are similar at the two sites, while annual average wave height is about 50% higher at Palm beach (i.e. 1.6m vs 1.0m). The average storm wave heights and periods for Palm Beach and Duck are 2.9m, 9s and 1.6m, 8s. The foreshore grain size (D_{50}) is 0.3mm at Palm Beach while it is about 1mm at Duck. Palm beach is single barred, while Duck fluctuates between a single (25% of the time) and double barred beach. For consistency, Lippmann and Holman's (1990) beach state classifications of the inner bar at Duck which followed their 8 state scheme, were re-classified into Wright and Short's (1984) 6-state model.
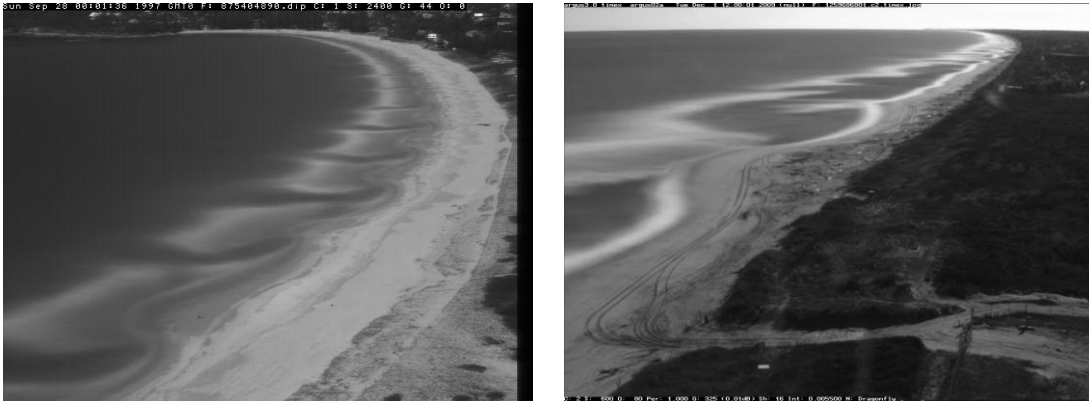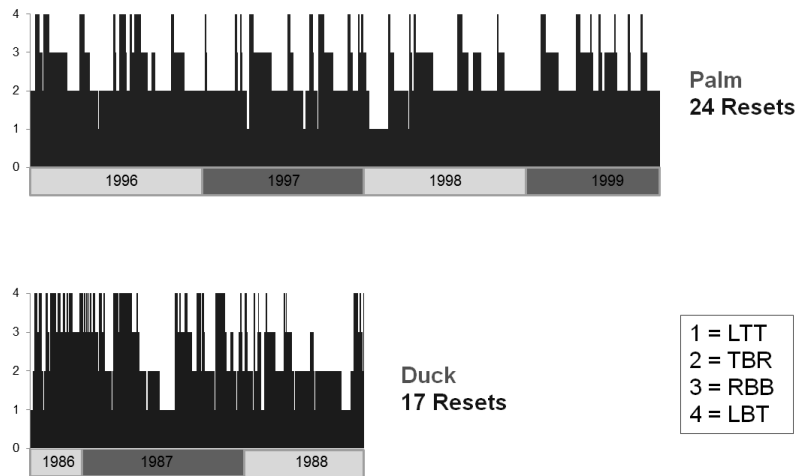

Figure 1. Time averaged Argus video images of Palm Beach, Sydney (left) and Duck, North Carolina (right).

RESULTS

Beach state time series for both beaches are shown in Fig. 2. A reset event is indicated by a beach state transition to D/LBT (or State 4) from any other state. The modal beach state at both sites is the TBR state (55% and 36% at Palm beach and Duck respectively).

Figure 2. Beach state time series for Palm Beach, AUS (top) and Duck, NC (bottom).

Summary statistics of the morphological recovery durations determined at the two sites, using the definition for T_{mr} given above, are shown in Table 1. The high standard deviations and the low count numbers associated with the mean and modal values indicate that these statistics may not be of any significance in these two data sets. Therefore, the median value appears to be the best statistical indicator of T_{mr}. Interestingly, T_{mr} at Palm Beach is about double that of Duck. It is also noteworthy that previous numerical modelling efforts which mimicked Palm beach conditions predicted recovery durations that are 50% lower (Reniers et al., 2004) or 50% higher (Damgaard et al., 2002) than the observed T_{mr} of 11 days at Palm beach.

Table 1. Summary statistics of morphological recovery duration (T_{mr}) at Palm beach, and Duck.					
	Total recovery events	Mean T_{mr} (days)	Std. deviation (days)	Modal T_{mr} (days)	Median T_{mr} (days)
Palm beach	24	17	14	6 [7 occurrences]	11
Duck	17	7	5	5 [6 occurrences]	5

The significant differences between the T_{mr} values observed at the two sites raises the 'why' question. To seek answers, a series of cross-correlations between T_{mr} and wave/morphological characteristics were undertaken. Cross correlations performed included those between T_{mr} and maximum wave height and wave power during the storm, between T_{mr} and averaged wave height, period, direction, wave steepness, wave breaking intensity and longshore current 3-7 days immediately after the storm, 3-7 days immediately prior to recovering to the modal state, and during the entire recovery duration. Wave breaking intensity was estimated by the Iribarren number (Battjes, 1974) and longshore current was approximated by $H^2 cos\theta$. Correlations were also performed between T_{mr} and the antecedent (to the reset event) beach state. The results are given below in Tables 2-9. Correlations that are statistically significant at 95% are shown in bold font in all tables, and are the only correlations that are discussed below. All wave heights are significant wave heights, periods are peak periods, and directions are relative to the shore normal.

Conditions just before and during resetting storm

Table 2 indicates that there is a weak positive correlation (bold) between antecedent beach state and T_{mr} at Duck such that T_{mr} increases when antecedent beach state is in a higher state. Correlations between T_{mr} and resetting storm conditions are given in Table 3 and indicate weak positive correlations

between storm power and T_{mr} at Palm beach and between maximum offshore storm wave height and T_{mr} at Duck.

Table 2. Correlation coefficients T_{mr} and antecedent morphology. Bold values indicate 95% significance.		
	Beach State	Bar position
Palm beach	-0.11	0.1
Duck	**0.43**	-0.25

Table 3. Correlation coefficients T_{mr} and storm characteristics. Bold values indicate 95% significance.		
	Max wave height H_s offshore	Storm Power
Palm beach	0.07	**0.47**
Duck	**0.43**	0.38

Conditions immediately after the resetting storm

Tables 4 and 5 show correlations between various wave parameters immediately after the storm (averaged over 3, 5 and 7 days after the resetting storm subsided) and T_{mr} at Palm beach and Duck, respectively. Wave height observations offshore overestimate the inshore waveheights for highly oblique waves due to refraction. Therefore waveheights are also translated to an estimated waveheight H_b at the surfzone egde. The inshore waveheight estimation was calculated by using the linear dispersion relation and including refraction and shoaling effects on the wave height. Note that wave direction was not available at Duck for this analysis and hence parameters that require wave angle to obtain an inshore wave height estimate (i.e. H_b, H_b/L, Iribarren$_b$) and longshore current could not be estimated for Duck. Table 4 indicates a moderate (italic bold) positive correlation between T_{mr} and the 3-day averaged longshore current. Weak positive correlations are indicated between the 5-day averaged longshore current, and the 3, 5 and 7-day averaged offshore wave heights (H_o) and T_{mr} and a weak negative correlation is indicated between T_{mr} and the 3-day averaged offshore Iribarren number. At Duck, the only statistically significant (at 95%) correlation that can be seen is the weak positive correlation between T_{mr} and the 3-day averaged offshore Iribarren number (Table 5).

Table 4. Correlation coefficients T_{mr} and wave conditions immediately after the storm for Palm Beach, Aus. Bold values indicate 95% significance.									
Average over	H_o	T_p	θ	H_b	H_o/L	H_b/L	Iribarren w. wave height H_0	Iribarren w. wave height H_b	Longshore current magnitude ($H^2\cos(\theta)$)
3 days	**0.55**	0.12	0.36	0.23	0.38	0.13	**-0.41**	-0.18	**0.60**
5 days	**0.46**	0.32	0.27	0.37	0.13	0.05	-0.07	-0.10	**0.54**
7 days	**0.42**	0.31	0.01	0.46	0.10	0.17	-0.06	-0.14	0.50

Table 5. Correlation coefficients T_{mr} and wave conditions immediately after the storm for Duck, NC. Bold values indicate 95% significance.				
Average over	H_o	T_p	H_o/L	Iribarren w. wave height H_0
3 days	-0.20	0.38	-0.37	**0.42**
5 days	-0.20	0.02	0.09	0.15
7 days	-0.23	0.01	0.04	0.06

Conditions during the entire recovery duration

Tables 6 and 7 show correlations between various wave parameters during the entire recovery duration and T_{mr} at Palm beach and Duck, respectively. Table 6 indicates weak positive correlations

between T_{mr} and averaged H_o, H_o/L, H_b/L, and longshore current and a weak negative correlation with averaged Iribarren$_b$ at Palm beach. Table 7 indicates a weak negative correlation between T_{mr} and averaged H_o at Duck.

Table 6. Correlation coefficients T_{mr} and wave conditions averaged over the entire recovery duration for Palm Beach, Aus. Bold values indicate 95% significance.								
H_o	T_p	θ	H_b	H_o/L	H_b/L	Iribarren w. wave height H_0	Iribarren w. wave height H_b	Longshore current magnitude ($H^2\cos(\theta)$)
0.46	0.11	0.03	0.35	**0.57**	**0.56**	-0.39	**-0.42**	**0.41**

Table 7. Correlation coefficients T_{mr} and wave conditions averaged over the entire recovery duration for Duck, NC. Bold values indicate 95% significance.			
H_o	T_p	H_o/L	Iribarren w. wave height H_0
-0.48	0.13	-0.13	0.27

Conditions immediately prior to recovery

Tables 8 and 9 show correlations between various wave parameters immediately prior to recovery (3, 5 and 7 days prior to reaching modal beach state) and T_{mr} at Palm beach and Duck, respectively. At Palm beach (Table 8), moderate positive correlations are indicated between T_{mr} and 7-day averaged H_o, H_b and longshore current. Weak positive correlations are indicated between T_{mr} and 7-day averaged H_o/L and H_b/L and a weak negative correlation is indicated with 7-day averaged Iribarren$_b$. At Duck (Table 9), a moderate negative correlation between T_{mr} and the 7-day averaged H_o is indicated. T_{mr} is also weakly positively correlated with the 3-day averaged Iribarren and weakly negatively correlated with the 5 day averaged H_o and the 7 day averaged T_p.

Table 8. Correlation coefficients T_{mr} and wave conditions averaged over the period immediately before full recovery for Palm Beach, Aus. Bold values indicate 95% significance.									
Average before reaching modal state over	H_o	T_p	θ	H_b	H_o/L	H_b/L	Iribarren w. wave height H_0	Iribarren w. wave height H_b	Longshore current magnitude ($H^2\cos(\theta)$)
3 days	-0.29	-0.14	-0.16	-0.15	-0.23	-0.01	0.27	0.06	-0.37
5 days	-0.30	-0.15	-0.11	-0.09	-0.04	-0.09	0.11	0.17	-0.25
7 days	**0.61**	0.27	-0.19	**0.75**	**0.48**	**0.44**	-0.08	**-0.50**	**0.61**

Table 9. Correlation coefficients T_{mr} and wave conditions averaged over the period immediately before full recovery for Duck, NC. Bold values indicate 95% significance.				
Average before reaching modal state over	H_o	T_p	H_o/L	Iribarren w. wave height H_0
3 days	-0.30	0.24	-0.39	**0.42**
5 days	**-0.44**	0.14	-0.20	0.29
7 days	**-0.66**	**-0.47**	0.25	0.04

CONCLUDING REMARKS

Multi-year time series of ARGUS derived beach states at Palm Beach, Sydney and Duck, NC and concurrent wave data were analysed to quantify the nearshore morphological recovery time scales (T_{mr})

and determine the physical processes that may govern T_{mr} . The analysis shows that T_{mr} is of the order of 5-10 days at these two beaches. While T_{mr} at the single barred Palm beach (11 days) is double that of the double barred Duck beach (5 days), whether morphological recovery is indeed generally slower at single barred beaches relative to double barred beaches is a question that cannot be conclusively answered without investigating this phenomenon at several other sites.

T_{mr} is moderately positively correlated with the averaged longshore current over the 3 days immediately after the resetting storm at Palm beach (longshore currents at Duck could not be estimated as wave direction information was not available). While this indicates that it might be possible to develop a predictor for T_{mr} based on wave conditions immediately after the resetting storm, the general applicability of this correlation needs to be rigorously investigated at other sites.

The only other moderate correlations are seen between T_{mr} and the wave heights during the latter part of the recovery process (last 7 days of the recovery duration). However, the positive and negative correlations between T_{mr} and wave height at Palm beach and Duck (respectively) are confounding. As these correlations are with a property at the end of the recovery period, it is not possible to develop a useful predictor of T_{mr} based on this observation.

Weak correlations are present between T_{mr} and several pre-storm, during-storm and post-storm parameters at the two sites (e.g. antecedent beach state, maximum wave height during storm, storm power, Iribarren (3 day post storm average), longshore current (5 day post storm average at Palm). However, these correlations are intriguingly inconsistent between the two sites.

While this study has resulted in some first insights into nearshore morphological recovery time scales, it highlights the need for a thorough analysis employing long-term beach state and wave data at several different study sites to fully understand this phenomenon.

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