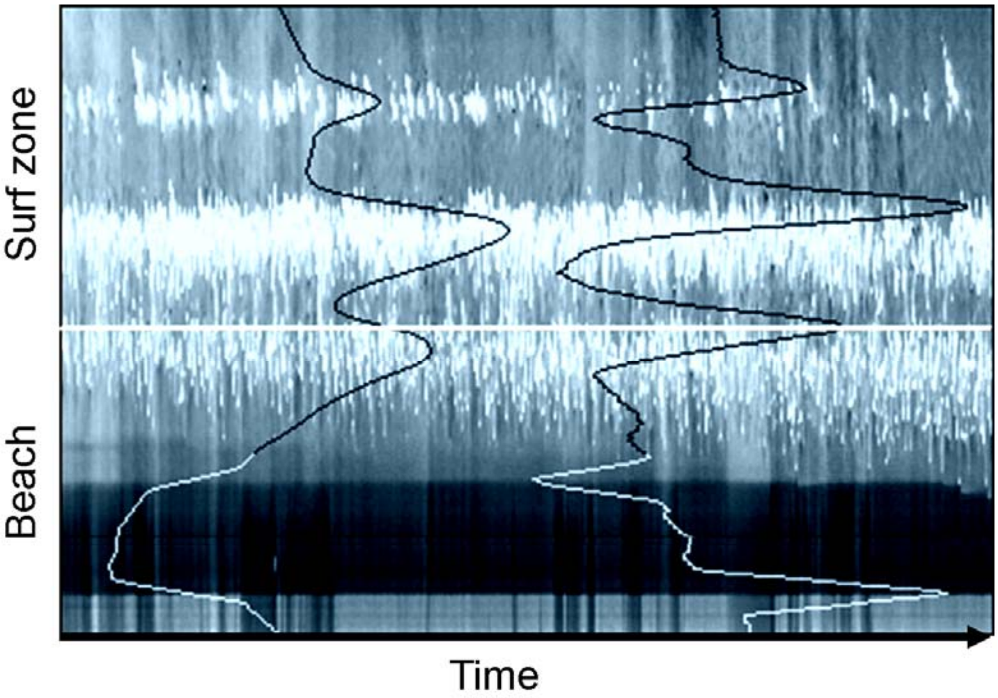
Videographic acquisition of surf zone data:

a summary of present techniques and future possibilities

R. D. Shand and D. G. Bailey



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Cover image

Fifty two minute long video time-stack image covering beach (lower-mid) and surf zone (mid-upper) and sampled across a single shore-normal transect with the camera located ~44 m above MSL and facing seaward. This image appears in the paper as Figure 4B and its construction and characteristics are discussed in Sections 4 and 6.

ABSTRACT

There is an increasing demand for quantitative information about the dynamic coastal zone at 'intermediate' temporal and spatial scales. Methods of morphological and hydrodynamic sampling are described and subjected to a comparative analysis with the most generally acceptable method being elevated terrestrial electronic sensing using video cameras coupled with subsequent digital image processing (i.e. videography). ‘Time-stacking’, an image processing procedure common to many of the data abstraction algorithms is described with reference to existing and potential uses of videography for acquiring and interpreting geo/hydro-physical data. Additional advantages of the image-based approach, including retrodictive data acquisition and flow visualization, are also documented.

1.0 INTRODUCTION

With increasing pressure being placed on the world's oceanic coastal resources, together with emphasis on 'sustainability' (Carter, 1987; de Viend, 1993; Ward, 1993), and the threat of greenhouse induced sea-level rise (Viles, 1989), the acquisition of both shorter and longer-term quantitative geophysical data is becoming increasingly important to coastal planners, engineers and scientists.

The coastal environment, however, presents logistical difficulties which make it one of the potentially most difficult, dangerous, and expensive locations to collect data. There are many morphological and process variables which can be measured, so the question of which parameters or indicators to monitor becomes significant. Resource-management researchers stress the necessity to clearly define monitoring objectives, as the purpose of the monitoring will influence both the parameters measured and the nature of the sampling programme, and these in turn, govern the effectiveness and cost of the monitoring (Ward 1993). Objectives, however, change with time, so there is a need to develop monitoring systems that are capable of detecting the widest range of data types.

The active coastal zone can be divided into a number of subzones (Figure 1) each characterised by distinctive morphological and hydrodynamic characteristics (e.g. see Wright and Short, 1984). While energy levels and associated sediment transport are greatest within the surf zone, the hostility of this environment has tended to impede data collection and this has resulted in the inshore region, probably the most significant to human activity, being relatively poorly understood. This paper addresses data acquisition across the surf zone.

There exists a hierarchy of process-response scales operating within the surf zone. At the micro-scale (minutes-hours), bed dynamics are influenced by the passage of a single wave (e.g. Marra, 1992). At the meso-scale (days to weeks), individual meteorologically driven events (storms-fairweather episodes) alter beach and bar form (e.g. Goldsmith et al., 1982;

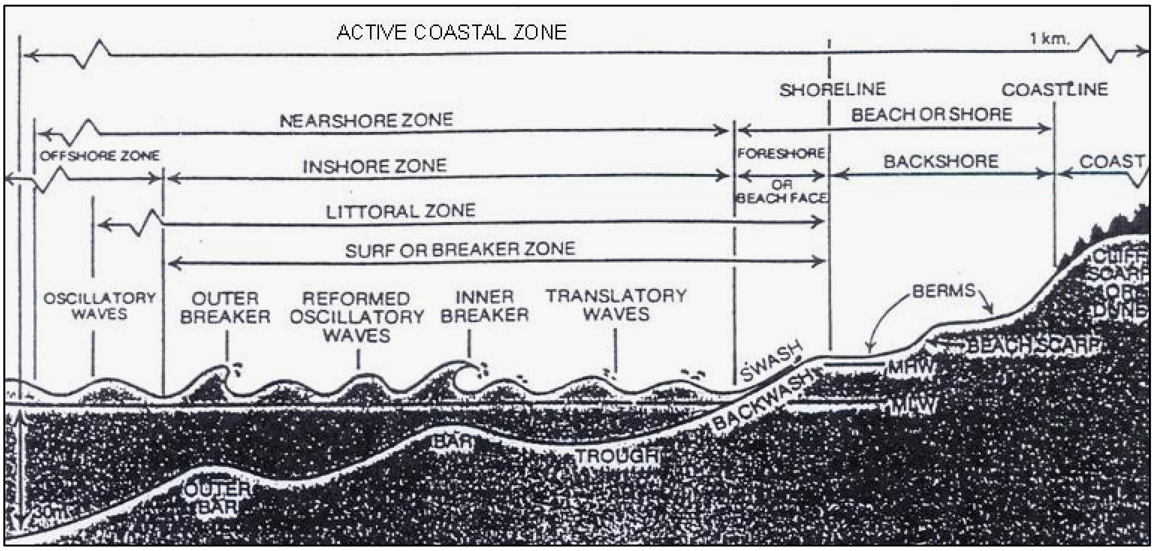

Figure 1
A typical coastal profile depicting the various zones of active sediment transport and common terminology.

Sallenger et al., 1985; and Aagaard, 1991). At the macro-scale (months to yrs), larger-scale atmospheric/oceanic processes influencing coastal morphology (e.g. McLean and Thom, 1975; Aubrey, 1979). At even larger (mega) time scales (10^2 to 10^7 years) process-response interactions associated with secular climatic change can dramatically change coastal environments at regional and global scales (e.g. Gibb, 1979; Roy and Thom, 1981; Sallenger, 1988; Peltier, 1987). Factors other that climatic forcing also influence coastal change, for example natural and man induced variation in sediment supply (e.g. Komar, 1983; McFagen, 1985; Shepherd, 1987; Carter, 1988; Eliot and Clarke, 1989).

Morphological data at the meso-scale has important application for scientific, engineering, planning, and recreational interests, so it is the scale that this study focuses on. The spatial dimension of interest is 10^1 to 10^4 m, and temporal resolution at c. 5 to 30 days. The associated process (hydrodynamic) data, however, must be sampled at much shorter temporal scales (10^0 to 10^1 sec) over intervals up to 10^2 sec and then synthesized (Balsillie and Carter, 1984; De Viend, 1993; Goda, 1983). Spatial variability occurs vertically, cross-shore, and often also alongshore.

In the past, field methods for morphological sampling have required instruments to physically traverse the surf zone. For short-term morphodynamic studies, instruments are fixed within the surf zone itself; however, for longer-term data they may be located in the less energetic region further offshore with wave theory being used to equate deepwater and breakpoint parameters (see CERC, 1984). Water contact, and spatially discrete sampling of these approaches have precluded comprehensive monitoring, especially on moderate to higher energy coasts. These methods are generally time-consuming, expensive, and reliant on specialist technical staff both for data collection and for the subsequent processing-reduction phase (Hemsley et al., 1991).

A need therefore exists for surf zone data acquisition systems that meet the following criteria:

- wide-ranging in terms of type of acquired data;
- flexible in terms of operating environment and in particular can operate in moderate to high energy conditions;
- able to meet meso-scale spatially continuous sampling requirements;
- able to meet the corresponding temporal scale sampling requirements;
- capable of achieving meso-scale accuracy in terms of morphological and hydrodynamic elevation plus the other hydrodynamic 'core' parameters;
- user-friendly in terms of operator skill level with respect to establishment, operation, and information abstraction, and
- relatively low cost for establishment, operating, data reduction and capital depreciation.

The present study will not consider the various manual-visual observation methods which have often been used to collect surf zone morphological and hydrological data. While such approaches have definite logistical and cost advantages they contain varying degrees of subjectivity and are limited in terms of spatial and temporal scales, and accuracy. Given such limitations, together with the general requirement of surfzone-nearshore process-response studies for continuous data, the visually based methods find greatest use in providing long-term data where cost or accessibility constraints apply. A description of these techniques, their characteristics, and major monitoring programmes using them can be found in: Chappell and Eliot, 1979; Short, 1979; Patterson, 1985; Smith and Wagner, 1991; Hamsley et. al,. 1991; Schneider and Weggel, 1980; Patterson and Blair, 1983; Balsillie and Carter, 1984; Plant and Griggs, 1992; and Smith and Wagner, 1991.

Data acquisition typically occurs in two stages: data (field) collection, and data abstraction which may include visual interpretation or manual/automated digitization methods. However, when collection involves remotely sensed images the abstraction phase can be subdivided into a capture stage a subsequent processing stage where specific data sets are obtained and analysis may be included (Austin et al 1994).

Remote sensing is used here to imply a separation between observer or recorder and the object of measurement. Remote sensing field techniques from elevated terrestrial sites is a relatively new and promising option. In this situation ‘elevated’ refers to the instrument platforms being well above the sea surface. The evolution of such an approach has an interesting history. Briefly, remote sensing using aerial photography and image rectification by analogue or perspective grid processing has been successfully used to collect moderate to long term coastal morphological data since the 1930's (e.g. Eardley, 1941; Slama, 1980). While remotely sensed surf zone process data has been satisfactorily acquired from elevated platforms, it has mainly been limited to scientific experiments where photographic and radar sensing have been used (e.g. Crowson et al., 1988; Bailey and Shand, 1994; Goda, 1983). More recently, technological developments have enabled the use of video sensing and digital image processing to acquire both morphological and hydrodynamic surf zone data. This approach is referred to as **videography** (Placio-Prieto and Lopez-Blanco, J., 1994).

The present paper begins (Section 2) by describing and evaluating existing methods of morpho/hydro geophysical data collection and reduction for the purpose of assessing the relative significance of the videographic approach. As videographic methodology is relatively unknown, a general description of image sensing and processing characteristics is given in Section 3. Section 4 describes ‘time-stacking’, a newly developed and significant image processing technique being incorporated in many videographic data abstraction algorithms. The visualization permitted by time-stack imagery suggests a variety of potential methods for deriving surf zone data and these are described in Sections 5 and Section 6 for morphological and hydrodynamic videographic data acquisition respectively. Finally, the discussion section (7) focuses on relative and additional advantages of the video/image processing approach for surf zone data acquisition and research in general.

2. DATA ACQUISITION TECHNIQUES

Instrument-based morphological data acquisition methods and their salient features are listed in Table 1 and hydrodynamic methods are summarised in Table 2. The listed methods are not exhaustive, but they do cover the main alternatives. The field-techniques appear in the left-hand column where they have been classified with respect to instrument location, the nature of the platform, and the sensor type. Across the top of the tables are listed the characteristics associated with the study criteria identified in Section 1. Due to the diverse nature of the methods only a categorical assessment using 'first order' grouping has been attempted. At the meso-scale, a wide range of data types are required and this further complicates assessment and inter-method comparison, and necessitates the assignment of some conditions, particularly regarding costs. These assumptions are detailed in the extensive notes accompanying the tables.

Evaluation has simply been based on three classes: high, moderate and low. As an approximation "high" (or in some cases "low") grading relate to short-term or micro-scale investigations, and "moderate" grades relate to meso-scale work. If a method has a particular characteristic evaluation satisfying the micro-scale criterion, it will, therefore, probably also meet meso-scale requirements. A description of the groupings associated with each characteristic together with the acceptance grade are provided in the table notes. In cases where the criteria are satisfied, the ratings given in the tables have been underlined.

Morphological techniques

The five foreshore techniques considered in Table 1 (coded $) are generally more successful than the inshore methods as is evidenced by the greater numbers of acceptance criteria satisfied. No particular characteristic was consistently weak and, in contrast with most inshore methods, skill and cost levels were acceptable. These results reflect the relative ease of access to and within the survey environment and the ability of sensors to have direct contact with the measurement surface.

The other 16 techniques in Table 1 relate to the hostile and logistically more difficult inshore zone. While in general they met less acceptance criteria than the foreshore methods, there are distinct patterns both within and between the methods. The underlined evaluation ratings tend to group with respect to "Instrument Location", indicating that particular types of instrument measure (successfully) similar things. There is a strong division between the water/ground-contact and the aerial/space-based methods in terms of depth delineation (elevation resolution) versus data output, sampling environment, and spatial coverage. However, all require high skill level and have greater cost. By contrast, the elevated terrestrial methods also have the positive evaluation characteristics while avoiding the high skill/cost requirements. The ease of 'access' of the sensor platform to the survey area, together with the need for less sophisticated and expensive equipment accounts for this situation.

There are some problems with the elevated terrestrial techniques. The results in Table 1 show that both the photographic and videographic approaches struggle with elevation. These techniques, together with certain aerial and space-based methods, use wave breaking patterns to infer depth variation, thereby providing a measure of relative elevation. Variation in the location of wave breakpoints characterize natural wave-fields and these modulations reduce the accuracy of the foam-intensity/morphology relationship. The terrestrial methods, however, enable the use of time-averaging which result in a statistically stable sample with detailed depth graduation based upon intensity change (Lippmann and Holman, 1989). The information loss is thus minimised and there is a future possibility of metrication being achieved. This approach is considered further in Sections 3 and 4.

A further limitation of the elevated terrestrial methods is the requirement of a raised platform. While there is a tendency for moderate to higher energy coasts to be associated with regions of greater relief (Davies, 1980), in many instances it will be necessary to use an artificial means of elevation. If existing buildings are not available, then a tower 20 to 40 meters high (depending on site and the nature of the investigation) would need to be erected such as has occurred at the CERC Field Research Station in North Carolina (see Holman and Lippmann, 1987). The expense of providing such a platform was not taken into account when calculating the costs in Table 1.

Table 1

Surf zone morphological data acquisition: instrument-based methods and characteristics

FIELD METHOD (location of platform & sensor @1)	Output Data @2	Sampling Environment @3	Spatial Scale @4	Temp Scale @5	Elevation Resolution @6	Skill Level @7	Total Cost @8	References @9
Acceptance Criteria #1	3D or Plan	mod/high	mod/high	mod/high	mod/high	low/mod	low/mod	
Ground Contact								
Level: Eye $	Profile	low/mod	low	mod/high	high	mod	low	24
Theodolite: Laser $	3D	low/mod	low/high	mod/high	vhigh	mod/high	mod	
Photo$	3D	low	low/high	mod	high	mod/high	mod	25
Skids: Laser	Profile	low/high	low	high	mod/high	mod/high	high @8*	18
Pressure	Profile	low	low	mod	mod	high	high	22
Tracked Gyroscope	Profile	low/mod	low	mod	high	mod/high	high	11, 30
Wheeled Laser	Profile	mod	low	mod	high	mod/high	high	14
Sea Surface								
Vessel: Depth Sonar	Profile	low	low	low	mod	high	high	26, 28
Vessel: Sidescan Sonar#	Profile#	low	low	low	mod	high	high	33, 28, 29
Terrestrial (elevated)								
Elevated: Photo $	Profile	mod	low	high	high	mod	low	21
Elevated: Photo	Plan	mod/high##	mod/high	mod/high	low	mod	low	3, 10
Elevated: Electr:video$	Profile	low/mod	low/mod	high	high/mod	mod	low	20
Elevated: Electr:video	Plan	mod/high##	mod/high	mod/high	low	mod	low	4, 19
Aerial								
Balloon: Photo$	Plan	low##	mod	low	low	mod/high	mod	27
Aircraft: Photo (vertical)	3D	low/mod*#	high	low	mod	vhigh	high	5,9,31
Aircraft: Photo (vertical)	Plan	mod/high*##	high	low/mod	low	vhigh	high	1,6,7,8
Aircraft: Photo (oblique)	Plan	mod/high##	high	mod	low	mod/high	high	8
Aircraft: Electr:radar	Plan	low*	high	low	low	vhigh	high	2
Aircraft: Electr:lazer	3D	low/mod	high	mod	mod/high	vhigh	high	2,32
Space								
Satellite: Electr: MSS	Plan	mod/high*##	vhigh	low/mod	low	vhigh	vhigh	2
Satellite: Electr:radar	Plan	low	vhigh	low	low	vhigh	vhigh	2, 33

Notes for Table 1

Assessment Grading: Low, Mod(erate), High. Where greater detail is required: a slash (/) e.g. mod/high is used to Indicate that value could lie in either group. V(ery) is used to indicate value at extreme end of overall range. Details of the grades are given in the the following notes.

1# Acceptance Criteria: These evaluation grades meet the study (acceptance) criteria.
As a first order approximation "high" (or in some cases "low") gradings relate to short-term or micro-scale investigations, and "moderate" grades relate to meso-scale work. If a method has a characteristic evaluation satisfying the micro-scale criterion, it will, therefore, probably also meet lower scale requirements.
In the Table the underlined grades meet the acceptance criteria for this study.
Note that for Data Output entries the actual measurement has been recorded in the table to assist cognition. Assessment and study criterion acceptance (underlining), however, have still been based on the low/medium/high System detailed below.

@1 Platform: For sensor or target; documented if notable
Side-scan sonar#: Option using the submerged 'fish' to house the sensors is impractical for the surf zone so only surface traveling sensors are considered here.
Sensor: For elevation detection, position fixing is by predetermined transits, GPS, or photogrammetry.
Photo = chemically sensitive emulsion (visible spectrum)
Electr. = electronic detection (type described)
$ = Subaerial/foreshore features are detected. All the other methods survey the inshore region.

@2 Acquired data: Primary nature of data collection: profile (shore-normal distance and elevation measured. No data on longshore dimension), plan (location data with relative elevation data), 3D (position and elevation measurements are recorded).
* side-scan or multi-beam sonar is effected by depth limitations in the inner nearshore/surf zone which results in the typical 60 degree scan covering only approximately 2 metres of sea-bed! and this makes continuous spatial coverage infeasible as traverse lines are usually spaced, for practical reasons, at least 20 metres apart.
High = 3D, Medium = Plan, Low = Profile.
Study criterion: Moderate/High but for clarrity the actual data types are listed in the table under Data Output.

@3 Sampling Enviromnent: Relates to instrument design atmospheric and oceanographic energy levels
* Requires no cloud cover if platform at high altitude.
\# Requires high water clarity (visible sea-bed)
\## Requires wave breaking (inferred depth) and lower tidal stage.
High: Hb > 2m, Wind speed >45Kh^-1. Moderate: Hb = 1 to 2m, wind = 25 to 45Kh^-1, Low: Hb < 1m, wind <25Kh^-1.
Study Criterion: Moderate/High

@4 Spatial scale: longshore swath only as all methods satisfy sampling criteria in the cross-shore direction.

High > 100m, Moderate = 10 to 100m, Low <10m.
Study Criterion: Moderate/High

@5 Temporal scale refers to the sampling rate (in days) likely for required monitoring environment, i.e. mod/high energy.
High < 5 days, Moderate 5 to 20 days, Low > 20 days.
Study Criterion: Moderate/Hig

@6 Elevation resolution refers to vertical measurement accuracy. Different grading is used for the foreshore and the inshore zones reflecting different processes, measurement methods and data usage.
Foreshore: High < .05m, Moderate = .05m to .15m, Low > .15m
Inshore: High < .1m, Moderate = .1 to .5m, Low > .5m
Study Criterion for both the Foreshore and Inshore: Moderate/High

@7 Skill: refers to the overall level of user training and experience required for equipment establishment, operation/maintanenence, data reduction etc.
High = extensive professional training/experiemce, Moderate = technical training/experience required,
Low = little training/experience required.
Study Criterion: Low/Moderate

@8 Total Cost: refers to cost per survey of equipment and labour for establishment, operating, maintenance, reduction, capital cost depreciation etc.
Assumptions: Number of surveys; 50 to 100 over 2 to 5 years at 14 to 30 day intervals.
For non-imaging (profiling) methods minimum of 10 profile to be measured.
Profile lengths: foreshore 200m, nearshore 1000m
@8* Only two fixed shore-normal transits possible for this technique.
Low < $500, Moderate = $500 to $1000, High = > $1000.
Study Criterion: Low/Moderate.

@9 References: literature cited is either technique-focused, or for a major project utilising the technique.
1: Horikawa (1978), 2: Lillesand and Kiefer (1987), 3: Bailey and Shand (1993), 4: Lippmann and Holman (1989), 5: Okamoto (1982), 6: Chandler et al (1989), 7: Wolf (1974), 8: Salma (1980), 9: Karara (1980), 10: Holman and Lippmann (1987), 11: Seymour et al (1978), 12: Fox and Davis (1978), 13: Emery (1961), 14: Birkemeier (1984), 18: Sallenger et al (1983), 19 Lippmann and Holman (1993), 20: Holman et al., (1991), 21: Hoad (1991), 22: Seymour and Bothman (1984), 24: Wilson (1977), 25: Collins and Madge (1981), 26: Admiralty (1938), 27: Preu et al (1989), 28: Ingham (1975), 29: Black and Healy (1983), 30: Aubrey and Seymour (1989), 31: Colwell (1960), 32: Penny et al (1986), 33: Lewis (1994).

Hydrodynamic techniques

The hydrodynamic techniques in Table 2 also exhibit, albeit to a lesser extent, the underlined evaluation ratings' tendency to group with respect to "Instrument Location". There is a division between the water-contact and the aerial/space-based methods, in this case in terms of the temporal sampling/accuracy versus sampling environment/spatial coverage. However, once again the division is less well defined than with the morphological techniques. High skill/cost levels again dominate these extreme groups. As with the morphological methods, the centrally located terrestrial options tend to incorporate the advantages of the other groups while avoiding the skill/cost disadvantage.

The water-contact options appear to be more successful in achieving the necessary range of data output. However, closer inspection shows that this is the result of instrument combination. The only individual methods presently capable of satisfying acceptance criteria were the dual balloon or dual helicopter techniques. The elevated terrestrial video option fails to meet acceptance criteria only with respect to short wave elevation (wave height) and this limitation is potentially solvable (addressed later in Section 6). We therefore think that this approach has potential to be a successful stand-alone technique for some applications. However, its inability to sense the water column itself, in particular subsurface currents, i.e. orbital velocities and mean flows, which are a fundamental requirement for scientific applications such as micro-scale process-response studies. It should be noted that some researchers argue that to numerically model meso-scale morphodynamics it it necessary to integrate micro-scale behaviour (Sherman and Bauer, 1993) hence making it mandatory to be able to acquire data at this level. But others question this approach, due to the inherent nonlinearities within natural systems (de Vriend, 1991; Terwindt et al., 1991).

Table 2

Surf zone hydrodynamic data acquisition: instrument-based methods and characteristics

FIELD METHOD (location platform & sensor @1)	Measured Output(s) Data @2	Sampling Environment @3	Spatial Scale @4	Temp Scale @5	Accuracy @6	Skill Level @7	Total Cost @8	References @9
Acceptance Criteria #1	mod/high	mod/high	mod/high	mod/high	mod/high	mod/low	mod/low	
Sea-Bed/Water Column								
Beach-face:Restistance	L(RF)	low/high	low/high#	low/high	high	high	low/mod	18,19
Bed: Pressure (PS)	S(EPF),L(EF)	Low/mod	low	low/high	high	high	high	1,3
Bed: Cluster PS array	S(EDPF),L(EF)	low/mod	low	low/high	high	high	high	1
Bed: Acoustic #	S(EPF),L(EF)	Low	low	low/high	high	high	high	1
Coln: Ducted Impellor	CC	Low	low	low/high	high	high	high	1
Coln: Electromagnetic(EM)	CC	low/mod	low	low/high	high	high	high	1,21
Coln: Doppler Accoustic	CC	low/mod	low	low/high	high	high	high	1
Coln: Puv meter; PS plus EM	S(EPF),L(EF),CC	low	low	low/high	high	high	high	1
Bed/coln: Mobile sled mast PS and EM	S(EDPF)L(EF),CC	low/mod	low/high#	low/high	high	high	high	20
Surface								
Buoy Accelerometer#	S(EDPF)	low	low	low/high	high	high	high	1,3
Bed fixed & Surface piercing:								
Staff: Stepped electrodes	S(EPF),L(EF)	low	low	low/high	mod/high	high	high	1,3
Staff: resistance wires	S(EPF),L(EF)	low	low	low/high	high	high	high	1,3
Cluster: staff array	S(EDPF),L(EF)	low	low	low/high	mod/high	high	high	1
Spatial arrays: staff and/or PS, EM	S(EDPF),L(EF),CC	low/mod	low/high	low/high	mod/high	high	high	19
Terrestrial								
Surface: Microsiesmograph.	S(ET)	Low/high	low??	low/mod	mod	mod	low/mod	7 *
Surface: Electr: radar	S(DP)	Low/high	low/high	low/mod	high	mod	low/mod	4,8,9
Elevated: Photo Emulsion	L(RF) CS	low/high	low/high	low/mod	mod	mod	low/mod	13,14,22
Elevated: Electr: video	S(DPF)L(RF)CS	low/high	low/high	low/high	mod/high	mod	low/mod	6,15,16,17
Aerial								
Balloon:(2) Photo Emulsion	S(EDT)L(RF)CS	low	low/high	low/mod	mod	mod/high	mod/high	10,12
Helecop:(2) Photo Emulsion	S(EDT)L(RF)CS	low/mod	low/high	low/mod	mod	high	high	11
Aircraft: Photo Emulsion	S(ED)	low/high*	low/high	low/mod	mod	high	high	3
Aircraft: Electr: radar#	S(EDL)	low/high	high	low	mod/high	high	high	9,5
Space								
Satellite: Electr: radar#	S(EDL)	low/high	high	low	mod/high	high	high	2,5,9
Satellite: Electr. MSS	CS	low/high*	high	low	low	high	high	23

Notes for Table 2

Assessment Grading:
Low, Mod(erate), High. Where greater detail is required: a slash (/) eg mod/high, is used to indicate value could lie in either group. V(ery) is used to indicate value at extreme end of overall range.
Details of the grades are given in the the following notes.

1# Acceptance Criteria: These evaluation grades meet the study (acceptance) criteria.
As a first order approximation "high" (or in some cases "low") gradings relate to short-term or micro-scale investigations, and "moderate" grades relate to meso-scale work. If a method has a characteristic evaluation satisfying the micro-scale criterion, it will, therefore, probably also meet lower scale requirements.
In the Table the underlined grades meet the acceptance criteria for this study.
Note that for Data Output entries the actual measurement has been recorded in the table to assist cognition.
Assessment and study criterion acceptance (underlining), however, have still been based on the low/medium/high system detailed below.

@1 Sensor detail: Electr: = electronic detection of electromagnetic radiation followed by spectral range of sensor e.g.
radar = microwave.
Radar#: land contamination is likely to influence nearshore hydradynamic data collected by space-based radar sensing.
Accoustic#: Foam from breaking waves contaminates signal therefore not suited to surfzone unless very low energy
Buoy#: Direction can only be derrived if fitted with pitch, roll and heave detectors.

@2 Output Data
Short Wave (S): Elevation (SE), Direction (SD), Phase Speed (SP), Frequency if continuous record (SF), Period if discrete record (ST), Lengths (if determined independent of period and phase speed) (SL).
Long Wave (L): Elevation for inshore zone (LE), Frequency for inshore zone (LF), Runnup (horizontal) using swash(LR), Runup Frequency (LRF).
Current Velocity (C): Surface (CS), Water Column (CC).

Grading catagories: the medium catagory (meso-scale) has been set so as to enable the application of general sediment transport formulae.
High = S(*), C(*), and either LE and LF or else LR and LRF. Medium = SE, SF, either SD or CS or CC, and either LF or LRF. Low = any other combination.
Study Criterion: moderate/high but for clarity the actual parameters are listed in the Table under Data Output.

@3 Environment: Relates to instrument design atmospheric and oceanographic energy levels.
A low grading can imply instrument can cope with high energy if sited seaward of the surf zone.
* Requires no cloud cover if platform at high altitude.
High: Hb > 2m, Wind speed >45Kh^-1. Moderate: Hb = 1 to 2m, wind = 25 to 45Kh^-1, Low: Hb < 1m, wind <25Kh^-1.
Study criterion: moderate/high

@4 Spatial scale: refers to a longshore swath only as all methods (except those tagged #) satisfy sampling criteria in the cross-shore direction.
refers to cross-shore spatial scale as this differs from longshore sample spacing.
High > 100m, Moderate = 10 to 100m, Low < 10m.
Study criterion: moderate/high

@5 Temporal Scale: refers to the nature (discrete/continuous) and rate of sampling.
High = continuous sampling @ < 10^5 seconds, ie approximatey 24 hours (spectral components obtainable).
Medium = discrete sampling @ < 10^5 seconds (parameters obtained).
Low = discrete sampling @ > 10^5 seconds (parameters obtained)
Study criterion: moderate/high

@6 Accuracy; includes measurement limitations plus system errors

	SE(m)	SD(degr)	SP(ms-1)	SF(Hz)	ST(sec)	SL(m)	LE(m)	LF(Hz)	LR(m)	LRF(Hz)	CS(ms-1)	CC(ms-1)
High	.1	10	.1	.001	.1	1	.1	.001	.1	.001	.1	.05
Medium	.25	20	1	.015	1	5	.1	.001	1	.001	.25	.1
Low	>	>	>	>	>	>	>	>	>	>	>	>

If not all data output parameters for a particular method fit a single grade (high/med/low) then the group tendency, which was always evident, was assigned.
Study criterion; moderate/high

@7 Skill Level; refers to the overall level of user training and experience required for equipment establishment, operation/maintanence, data reduction etc.
High = extensive professional training/experiemce, Moderate = technical training/experience required, Low = little training/experience required.
Study Criterion: low/moderate

@8 Total Cost; refers to cost per month for equipment and labour to cover establishment/recovery, operating, maintenance, downloading and reduction, depreciation etc.
Assumptions: Data collection period of 2 to 5 years,
Minimum of one set of readings per day,
For instruments capable of measuing at a single site 3 units are required to achieve spatial coverage.
Low < $1000, Medium = $1000 to $2000, High > $2000.
Study Criterion: low/moderate

@9 Reference literature is either specifically techique focused or is a major project utilising the technique.
1: Hemsley et al (1991), 2: Shum et al (1993), 3: Goda (1983), 4: Stewart and Teague (1980), 5: Lillesand and Kiefer (1987), 6: Lippman and Holman (1991), 7: Fox and Davis (1978), 8:Mattie and Harris (1978), 9:Shemer (1993), 10: Sasaki et al. (1976), 11: Horikawa and Sasaki(1972), 12: Katoh (1981), 13: Holman and Bowen (1984), 14: Carlson (1984), 15: Holland and Holman (1993), 16: Bailey and Shand (1994), 17: Holland et al (1991), 18 Thornton and Guza 1982 19: Guza and Thornton 1989 NSTS, 20: Sallenger et al 1983, 21: Aubrey 1989 NSTS, 22: Tang and Dalrymple 1989 NSTS, 23; Nayak and Sahai 1985.

The acceptance criteria achievement results for the different morphological and hydrodynamic measurement techniques are summarized in Table 3. These results demonstrate better all around performance by the elevated terrestrial-based methods.

Table 3

Relative performance of measurement methods.

METHOD		MORPHOLOGICAL			HYDRODYNAMIC	
(location based)	n	Mean	Range	n	Mean	Range
Ground Contact	6	2.2	2 to 3	2	2.0	2 to 2
Water column	1	1.0	1 to 1	3	2.0	2 to 2
Sea surface	1	1.0	1 to 1	3	2.0	2 to 2
Terrestrial	4	4.5	4 to 5	4	4.25	3 to 7
Aerial	5	1.9	1 to 3	4	2.25	1 to 5
Outer Space	2	2.0	2 to 2	1	4.0	4 to 4

3. IMAGE SENSING and PROCESSING

Remotely Sensed Images

Remote sensing implies the observation and measurement of an object without contacting that object, thereby including force fields, acoustic wave distributions, or electromagnetic radiation. The previous section identified methods using sensors elevated above the sea surface as being most likely to meet the study objectives for both morphological and hydrodynamic data acquisition. Such sensors usually detect electromagnetic radiation. This energy has interacted with the atmosphere and earth surface features thereby containing signals from which information can be extracted (Curran 190). The energy source may be externally generated by for example the sun (passive systems), or self generated such as with radar (active systems) (Wolf, 1974).

With remote sensing, the term 'image' is used generically for any pictorial representation of data (Lillisand and Kiefer, 1987). In the case of elevated sensing, the image data has usually been detected either electronically or photographically using solid state or chemical emulsion to 'sense' electromagnetic radiation (Lillisand and Kiefer, 1987). Whereas photographic sensors detect both the signal and its record (by the emulsion), detected video signal (like that of other electronic sensors), is recorded separately, either onto a magnetic tape as occurs with a video, or to computer disc (Lillisand and Kiefer, 1987). These recorded signals are the image data, hence produce images upon display, either a photograph or on a VDU.

Video and photographic comparison

Elevated terrestrial data collection equipment includes both video and photographic cameras. This was to be expected as their sensors sample a similar portion of the electromagnetic spectrum and produce similar images both of which may be subjected to digital image processing. However, there are several important differences between photographic and videographic methods which should be recognised.

Video sensors have a broader spectral range, narrower spectral band imaging ability, improved calibration, can electronically transmit data, the system is interactive, cheaper to operate, can have audio input and provides a moving record of an event (Everitt, 1988; Lillisand and Kiefer, 1987; Meisner and Lindstrom, 1985). By cantrast, the photographic image, however, has greater spatial resolution and is more suited to hard copy end use (Lillisand and Kiefer, 1987).

Image information abstraction

Obtaining information from images was initially limited to visual image interpretation methods which utilized the ability of the human mind to qualitatively evaluate spatial pattern within a scene (Lillisand and Kiefer, 1987). However, in addition to the high labour/skill requirement, limitations in detecting tonal differences, or simultaneously analysing multiple spectral images, encouraged the development of quantitative methods (Lillisand and Kiefer, 1987).

Optical filtering techniques to enhance first photographic and later radar images began in the 1950's (Marion, 1991). Later, with the advent of third generation digital computers, image digitisation (based on intensity variation) and subsequent processing became possible (Marion, 1991). With developments in (remotely sensed) object capture and digital image processing hardware and software these methods have now found application in most disciplines (Marion, 1991).

With image processing, the image data may represent an object which is itself an image such as a map, or alternatively has only an immaterial existence such as a mathematical concept, (Marion, 1991). Image processing consists of procedures involving: object illumination; image capture, i.e. sensor imaging and digitisation; and algorithm development and implementation, i.e. the actual image processing (Bailey, 1985). Image processing is often defined or described by the types of applications it is used for (Gonalez and Wintz, 1977, Marion, 1991) and the main applications are:

1) “Image coding” where image processing is used to reduce the volume of data in an image for storage or transmission by coding, compression, and image approximation techniques.

2) “Computer assisted vision” where pictorial information is improved in preparation for human interpretation. These techniques include:

- mathematical transformations for image rectification associated with lens distortion, perspective distortion, or to achieve a particular map projection,
- image enhancement which involves processes such as noise reduction, nonlinearity compensation, contrast adjustment, and edge sharpening,
- image restoration recovers information from a degraded image such as a blurred photograph, and
- Image reconstruction which restructures information into a more convenient form for display or further processing, and

3) “Image (or scene) analysis” to extract information contained in the various objects of an image for uses such as automated machine control of an activity (machine vision), or pattern recognition using mathematical morphology. The basic techniques are attribute or invariant property extraction, and segmentation. However, such algorithms may incorporate techniques already described for computer assisted vision as preprocessing steps.

Image processing enables the potentially huge amounts of spatial and temporal data contained in surf zone image sets to be rapidly utilised. Recent coastal studies incorporating such techniques include: dune morphology (Jungerius and Schoonderbeek, 1992); step/bar crest detection (Lippmann and Holman, 1990; Lippmann et al., 1993); beach-face effluent zone detection (Shoshany and Degani, 1992); and swash-front detection (Holman et al., 1990, Holland and Holman, 1993; Bailey and Shand, 1994).

4. TIME-STACK IMAGERY

An image processing technique recently used in several surf zone data abstraction algorithms, is 'time-stacking'. The resulting image provides an alternative way of viewing time-dependent data for interpretation and analysis purposes. It appears Aagaard and Holm (1989) were the first to use time-stack images in coastal investigations and their application is described later in Section 6.

The time-stack process is based on the construction of a new image comprising a particular section of image (intensity data) from an overlaid sequence of images (photos, video frames) being stacked along another (time) axis. If the entire (registered) photo, video or map series is utilized, the then the resulting image may be described as a **three-dimensional (3D) time-stack.** However, image-based 3D site-stacks are not at present used due to computing/memory limitations. Alternatively, if a slice of each input image is used for the input image set, (say sampled along a transect on each photo), then the result may be described as a **2D time-stack**. Finally, if a single point (or group of adjacent points) are sampled from each image and stacked, then the result may be referred to as a 1D time-stack.

The nature of the time-stack is also a function of the type of input image. For our purposes the following types are used:

- ‘instantaneous images’ where the exposure time is < ~1 sec such as individual video frames, cine film or photographs.

- ‘time-averaged images’ where numerous instantaneous images have their corresponding intensity values averaged. Such images are referred to as ‘time-exposure’ images where a number of video or cine frames are used, or ‘time-lapse or long exposure’ images in the case of still photography where averaging is achieved by the use of extended shutter times and compensating neutral density filters,

With respect to surf zone data, time-stacks created using instantaneous images depict the sea surface as influenced by the passage of individual incident waves, so the output image essentially contains hydrodynamic information and may thus also be referred to as a **hydrodynamic time-stack**.

In practice, a hydrodynamic time-stack is formed by playing the video record of interest through a VCR connected to a PC fitted with a frame grabber card. This captures the assigned intensity values from a point, line, or plane (the entire image), into the frame buffer memory and this digital output image is then transferred to computer storage. By repeating the process on each sequential video frame at a predetermined sampling rate, the time-stack is constructed.

To demonstrate this, along with a variety of other videographic techniques considered in this document, a surf zone video record from a site on the moderate to high energy, sand dominated New Zealand west coast will be used. Figure 2 shows a sample video frame from the seaward orientated camera located on cliff top 44 m above MSL. The image processing system we use consists of a 66MHz DX2, 16MB ram, frame grabber card, 14" SVGA monitor, 17" image display consol, and operates VIPS6 (vision image processing system) originally developed by Bailey and Hodgson (1988).

An example of a 1D instantaneous or hydrodynamic time-stack, for the location marked A in Figure 2, is shown in Figure 3. This image represents the sea-surface change as it is affected by gravity waves in the region of the inner bar break point over a 60 second interval.

Examples of 2D-hydrodynamic time-stacks from the central shore-normal transect in Figure 2 are shown in Figure 4A and Figure 4B. These two images illustrate individual wave histories using different record lengths and sampling rates. The higher time resolution in Figure 4A enables visualisation of wave transformation from shoaling to runup to bachrush. In Figure 4B, longer-term breakpoint and run-up variations are demonstrated. Further interpretation of these hydrodynamic time-stacks is included within Section 6.

As wave breaking is a function of water depth, the foam pattern shown on an instantaneous image is indicative of the underlying morphology. In any sample involving gravity waves, however, a height distribution occurs resulting in some cross-shore variation in the breakpoint location. The foam pattern will also vary intensity-wise from instant to instant depending on the location of shoreward propagating broken waves. If the instant images are intensity averaged over say 5 to 10 minutes, then all information concerning individual waves is lost; but by filtering out the intensity variations associated with individual waves, the resulting intensity pattern provides a stable signal of seabed (relative) topography, thus defining surf zone morphology with higher intensity areas inferring wave breaking and thus shallower than areas without wave breaking (deeper). Figure 5A depicts a time-averaged image, referred to as a time lapse or **time-exposure image**, derived from 5 minutes of record of the scene in Figure 2. Note that two adjacent time-lapse photos, taken with a Kodak Wratten 4.60 Neutral Density filter, have been joined to create the Figure 5A raw image. Also note that the intensity profile for the central transect in 5A is identical to that shown by the curve on the left side of Figure 4B

To be more useful for data abstraction these time-averaged images are next ‘rectified’ to remove perspective distortion (thereby creating a ‘birds eye’ view), and then ‘georeferenced’ to ground co-ordinates allow direct comparison with other media. This is described in Bailey and Shand (1993). The transformation of Figure 5A is depicted in Figure 5B. The three white lines shown in Figures 5 illustrate the level of perspective correction carried out the rectification algorithm. To further facilitate subsequent analysis, a 'coastline straightening' transformation (Bailey and Shand, 1993) was written to providing a rectilinear planimetric view.

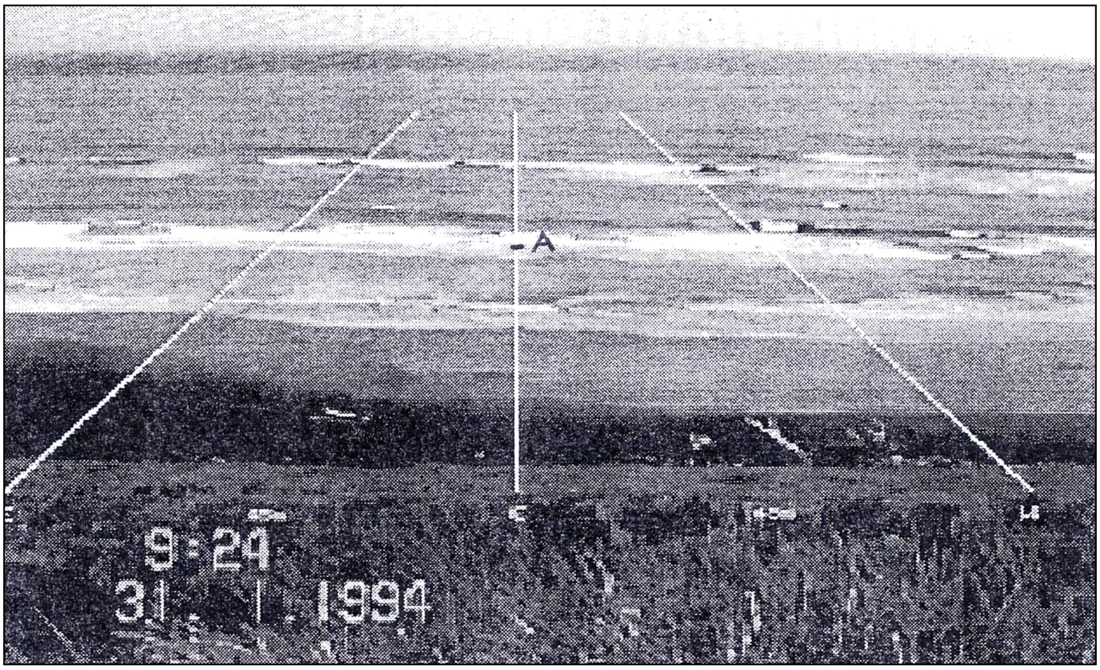

Figure 2
A video frame image of a surf zone from the moderate to high energy sand dominated New Zealand west coast. The camera has been orientated seaward and three shore-normal transects marked.

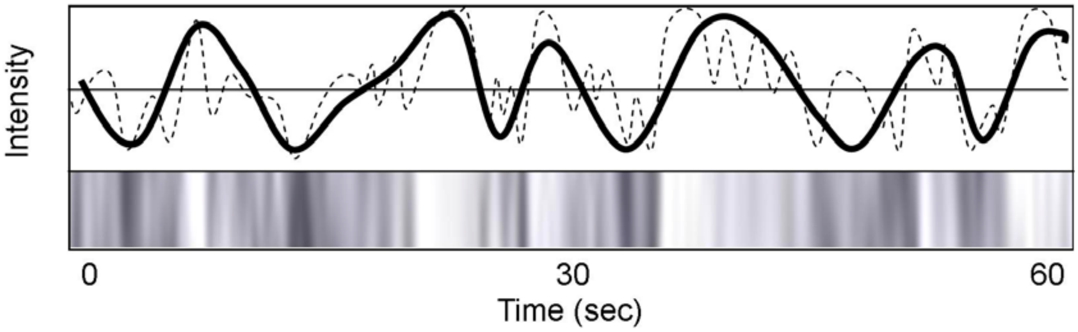

Figure 3
A 1D hydrodynamic time-stack image depicting the sea surface at point A in Figure 2, i.e. this time-stack comprises sequential intensity values from a single point. Note that along the base of the image the intensity values have been expanded in width for illustrative clarity. Depicted above this time-stack is a graph of the intensity values with the thick line having been smoothed to define six wave motions.

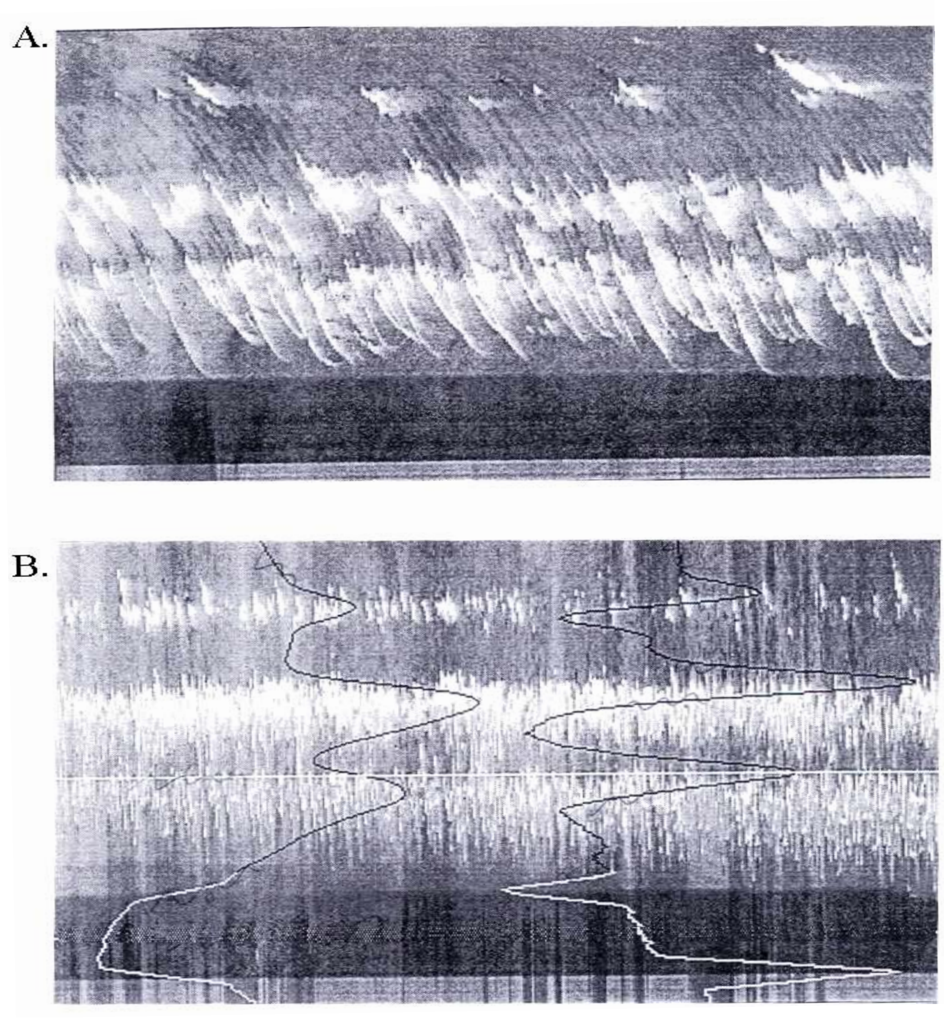

Figure 4
Both figures depict 2D-hydrodynamic time-stacks images from the central transect of Figure 2. Figure 4A was sampled every 0.25 seconds over 6 minutes while Figure 4B was sampled every 2 seconds over 52 minutes. Note that the vertical curve on left of B denotes time-averaged intensity which in fact infers the underlying morphology (see text). The curve on right depicts the derivatives used to help locate change in intensity.

The time-stack image constructed using time-averaged input images is referred to as a **morphological time-stack**. . Figures 6A and B show examples of such time-stacks using time averaged, rectified input images. In these cases the slicing has been carried out shore-normally so the vertical axis represents offshore distance. Interpretation and data obtainable from time-averaged images and morphological time-stacks will be considered further in Section 5.

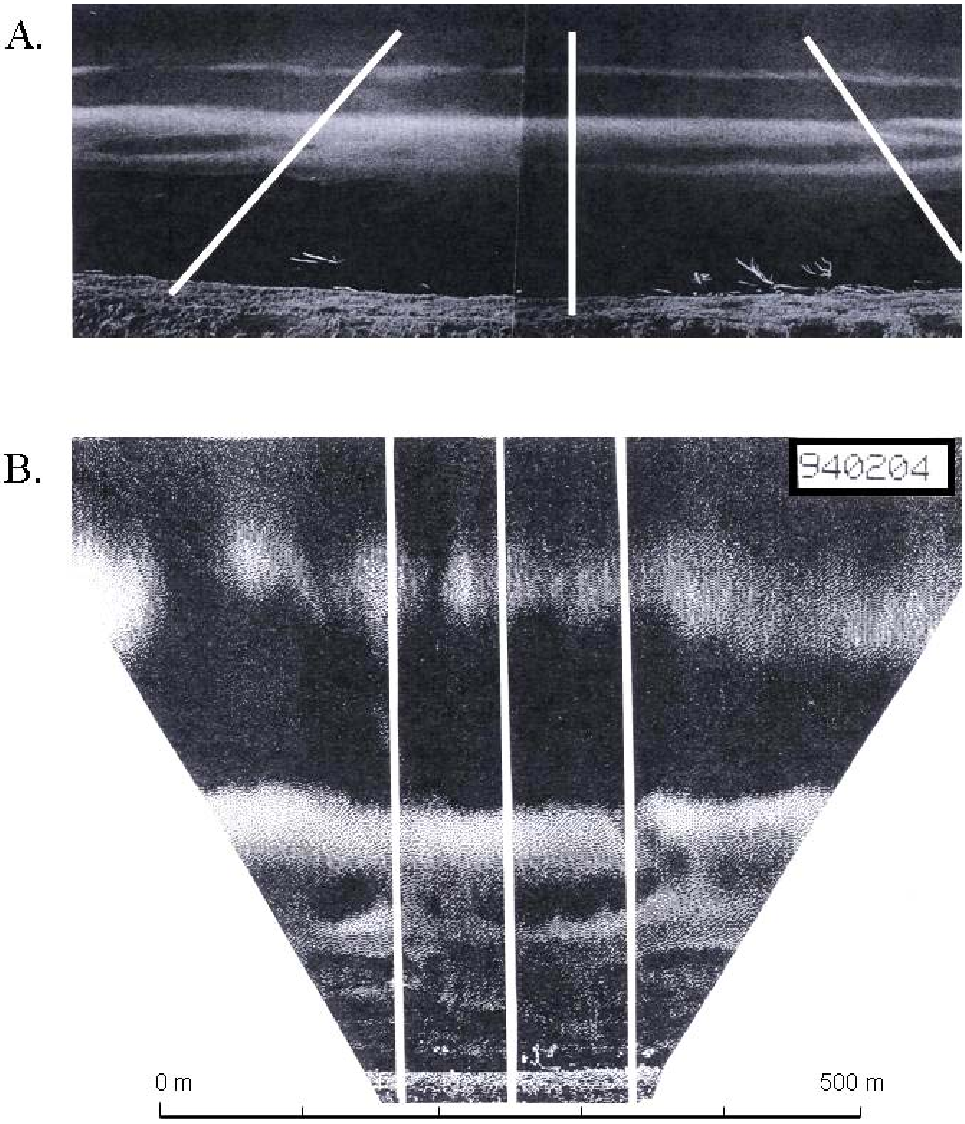

Figure 5
The upper figure (A) depicts a time-exposure image created by time-averaging intensity values from a set of video frames (or by taking a filtered time-lapse photograph). The resulting image infers the underlying morphology across the area of interest. Figure B displays the corresponding perspective-corrected or ‘rectified’ image from which spatial measurements can be made directly. The white 3 lines illustrate the extent parallel lines (Fig B) are perspective distorted in an oblique image (Fig A). Also note that the intensity variation along the central transect in Fig A, is identical to that shown by the time-averaged curve in the hydrodynamic time-stack in Figure 4B.

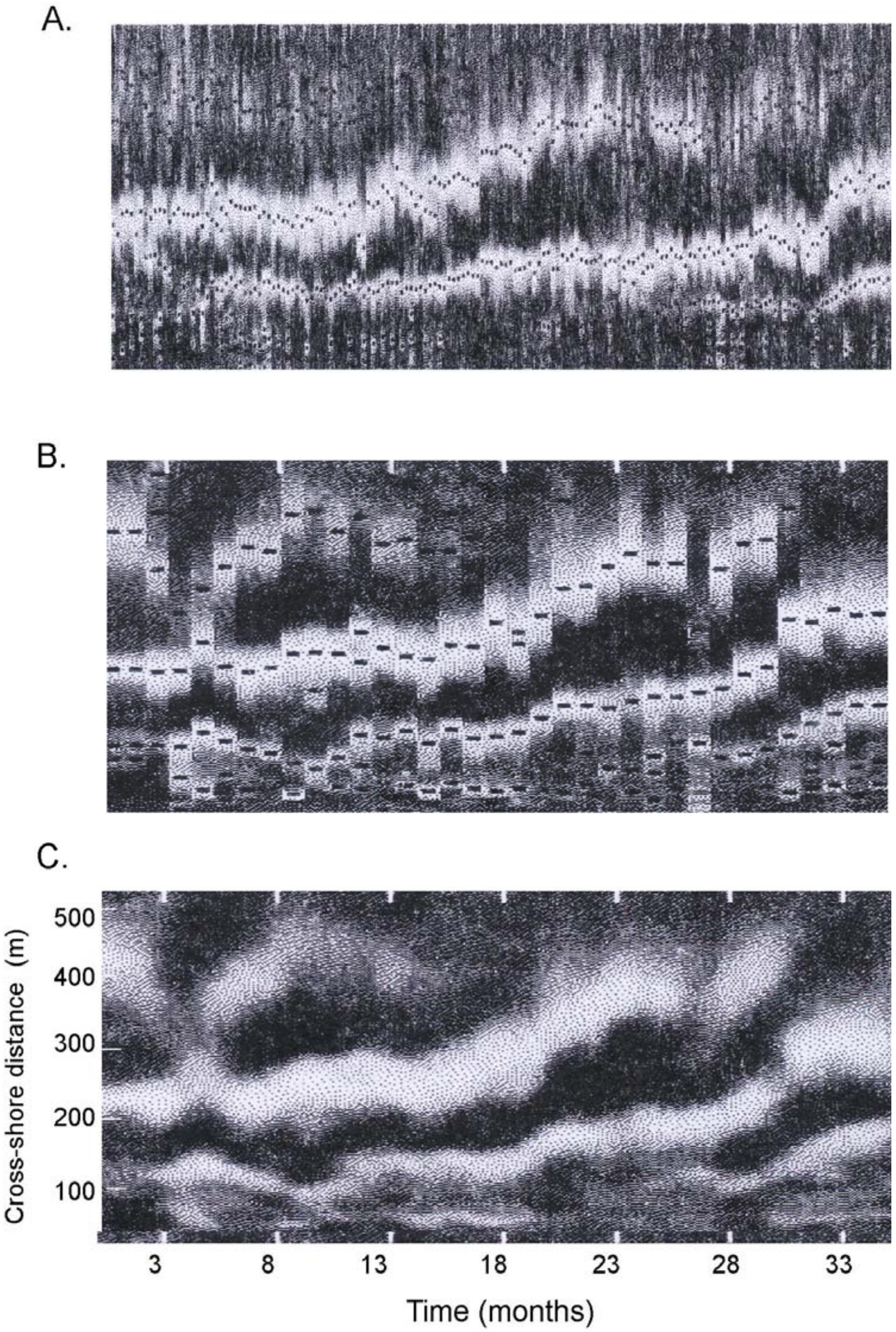

Figure 6
These examples of 2D-morphological time-stacks show beach and bar change through time along transect C in Figures 2. The input sequence for Figure 6A is sampled at 3 to 5 days over a 36 month period. The black rectangles define bar crests based on the location of intensity maxima determined by fitting a parabola to each intensity profile. Figure 6B used the same record but sampled at monthly intervals. In Figure C, the data for B has been interpolated and intensity-normalized.

5 MORPHOLOGICAL DATA FROM VIDEO RECORDS

Beach morphology

Beach (foreshore) profile data have recently been obtained by Holman et al. (1991) using terrestrial video records from a single camera site and subsequent image processing. While their field images were captured at low tide from an elevated location, some form of physically marking the transect surface was required prior to recording. Vertical resolution was controlled by pixel size to 0.1 m. More labour-intensive methods have been used such as recording a set of permanent calibrated poles and manually reducing the beach surface intersection (Hoad, 1991) using photographic images; the technique applies equally well to video frame images.

As described in Section 4, planimetric (2D) data of foreshore morphology can be derived from a single elevated video frame or photographic image taken at low tide and subjected to filtering and oblique photogrammetric rectification. To incorporate elevation to derive 3D data, photogrammetric analysis of a stereo pair is required (Slama, 1980). Although variations are possible such as the single image system developed by Collins and Madge (1981) for obtaining discrete 3D coordinates for a set of vertically graduated targets using manual photogrammetry.

Inshore Morphology

The main morphological use of video records has been to provide information seaward of the low-tide step (Lippmann and Holman, 1989; Lippmann and Holman, 1990; Lippmann, et al., 1993). As with aerial photographic images, determining surf zone morphology has been based on the preferential breaking of incident waves in shallower water and as described in Section 4 with the intensity profile mimicking bar - trough bathymmetry (N.B the average intensity curve in Figure 4B which is equivalent to the intensity variation along the central transect on Figure 5A.

Ground truthing at the CERC Field Research Centre at Duck, North Carolina by Lippmann and Holman (1989) verified that such digitised intensity curves were similar in form to their associated surveyed morphological profiles. We may thus refer to these analogues, i.e. the intensity image and associated digitised curve as **morphological intensity images**. While geometric transformation to a horizontal plane was described earlier, the intensity profile cannot be directly calibrated with elevation or position as the intensity at each point (or pixel co-ordinates) on the transect is influenced by, i.e. is a function of, several variables. These variables will either horizontally translate the intensity values, which in this case alter cross-shore distance, i.e. the length scale or location (L) of features such as bar crests or troughs, and/or alter the intensity contrast which changes the profile amplitude scale or relief (R). These problematic variables can be grouped as equipment limitations, photogrammetric parameters, environmental controls, and sampling variations. Of particular significance are breaking wave height, and sea level, in particular tidal change.

While some of the limiting factors can be minimized by, for example, successive samplings at the same sea-level and similar wave height, it is important to understand the nature and magnitude of these intensity controls as they determine the final image resolution. With these constraints in mind, the image-based technique can successfully detect morphological features at various spatial and temporal scales unobtainable using conventional methods in moderate to high energy environments. The data abstracted from ‘morphological intensity images’ is usually limited to bar crest and trough location because of the relative nature of the elevation dimension. As noted in Section 4, feature-detection algorithms have been written by the authors to automatically detect these locations (e.g. bar crests) on the intensity profiles and these are depicted by the black rectangles in Figure 5A and B.

Further detail on morphological intensity image techniques including photographic and video recording, error analysis, image rectification, and image analysis, can be found in Lippmann and Holman (1989), Lippmann and Holman (1993), Bailey and Shand (1993) and Bailey and Shand (1994).

Morphological behaviour

Morphological change can be visualised using morphological time-stacks. As noted Section 4, the 1D time-stack displays relative bed elevation change at a point within the scene view. The 2D stack displays the relative elevation over time along a line (usually a shore-normal transect for surf zone studies), and the 3D stack (future display option)) depicting plan-view relative elevation. The latter case is equivalent to the area-time prism developed by Davis and Fox (1972) for visualisiing erosion and deposition change in the surf zone.

The following points of geomorphological interest are evident in the time-stacks displayed in Figure 6:

- Primary sand bars **form** on the lower beach (base of image);
- The bars **systematically migrate** seaward (toward the top);
- The bars appear to **dissipate** in the outer surf zone a couple of years later, and
- The bars may **bifurcate** during their offshore migration with the inner segment migrating landward and either dissipating within the trough, or else welding onto the adjacent bar or beach-face, a process taking up to 3 months.

These different features are significant in terms of assessing and developing morphodynamic models for the littoral environment. For example, these data challenge the generally accepted behaviour of inshore sand-bars as being features in dynamic equilibrium (O'Hare and Huntley, 1994). While experimental work (e.g. Bowen and Inman, 1971) and numerical modeling (e.g. Davidson-Arnott, 1981; Dally and Dean, 1984) have demonstrated such stability can occur under certain conditions, field verification has been generally lacking, possibly due to the difficulty in acquiring comprehensive data. The extensive CERC foreshore/nearshore profile archive collected by the CERC Field Research Facility at Duck North Carolina provides the exception. Three net offshore bar migrations can be identified in 11 years (1981 to 1992) of fortnightly profile data (Birkemeier, 1984; Lee and Birkemeier, 1993; Lippmann et al., 1993). Some of these authors speculated this behaviour may have been associated with migrating oblique bars such as noted by Short (1975), Verhagen (1989) and Kroon (1991); however, such bars have been attributed to high tidal currents (Van de Meene and Van Rijn, 1994) which neither either on the Duck coast nor at the New Zealand study site. Terrestrial-based videographic data may now help resolve the matter of how widespread systematic seaward migration is on the worlds open coasts.

Data in the nearshore literature provides evidence for a number of apparent bifurcations of inshore sand bars, although this behaviour was not recognised by any of the authors (e.g. Greenwood and Davidson-Arnott, 1975; Owens, 1977; Holman and Sallenger, 1986; Holman and Lippmann, 1987; Bauer and Greenwood, 1991; Kroon, 1991; Van de Meene and Van Rijn, 1994). To explain such phenomena it is necessary define the process and closely sampled time-exposure images offer a feasible way of achieving this. Animating the rectified images and producing/analysing morphological time-stacks are also promising.

Shorelines

Video imagery and its analysis can clearly show the location and behaviour of the boundary between the dry upper beach face and the saturated lower beach. In the 6 min time-stack (Figure 7A) the boundary is controlled by wave runup, while in the 6 hr time-stack (Figure 7B) the influence of the high tide is evident. The wet/dry boundary on historical aerial photographs has been used as a shoreline proxy in coastal change studies (Morton, 1991; Thieler and Danforth, 1994). However, even the simple video imagery presented here show such an approach must be used with caution. Nonetheless, such imagery offers future potential for defining more stable shoreline indicators.

6. HYDRODYNAMIC DATA FROM VIDEO RECORDS

Foreshore techniques

Video records have recently been used to obtain overwash velocities by Holland et al. (1991) using methodology similar to that described below for deriving wave phase speed. Others such as Marra (1992) have obtained swash/backwash velocities and depths via manual frame by frame digitization procedures.

Photographic of cine movie film, and more recently video records, have been used in a number of studies investigating wave run-up by collecting slope excursion data (Wright,

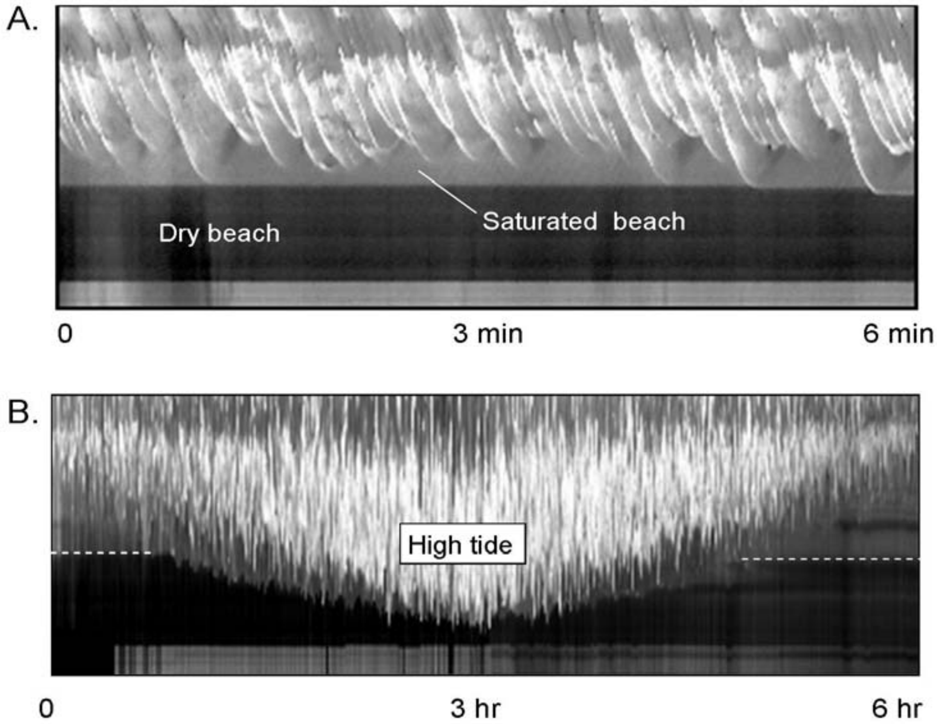

Figure 7
Two-dimensional hydrodynamic time-stacks from the field site illustrating wet and dry beach-face partition sometimes used in shore-line change studies. In Figure A the boundary is controlled by wave run-up. By contrast, the longer sampling period in B (6 hours c.f. 6 minutes) illustrates the tidal influence.

1976; Carlson, 1984; Holman and Bowen, 1984; Holman and Sallenger, 1984; Holman and Sallenger, 1985; Holman and Sallenger 1987; Aagaard, 1990; Holman et al., 1990; Holland and Holman, 1993). The history of the development of such techniques can be found in Bailey and Shand (1994) by way of introducing an automated swash-front detection algorithm which uses an instantaneous video sequence of images to make a 2D-hydrological time-stack covering the swash zone. Their programme detects and tracks the swash-front under all but the lowest light and contrast conditions and a manual override is available is these situations. Applying this algorithm to the time-stack in Figure 4A yields the track shown in Figure 8.

Inshore Methods

Video (or photographic) records have been used to a lesser extent in the acquisition of surf zone hydrodynamic data. Huntley and Bowen, 1975; Hotta and Mizuguchi, 1980; Carlson, 1984; Crowson et al., 1988, obtained water level and breaking wave data at discrete locations across the surf zone using cine film and graduated pole arrays Lippmann and Holman (1991) have measured wave phase speed and direction using video records and 1D-hydrodynamic time-stacks, such as shown in Figure 3. In this case, input image sequences from video tape

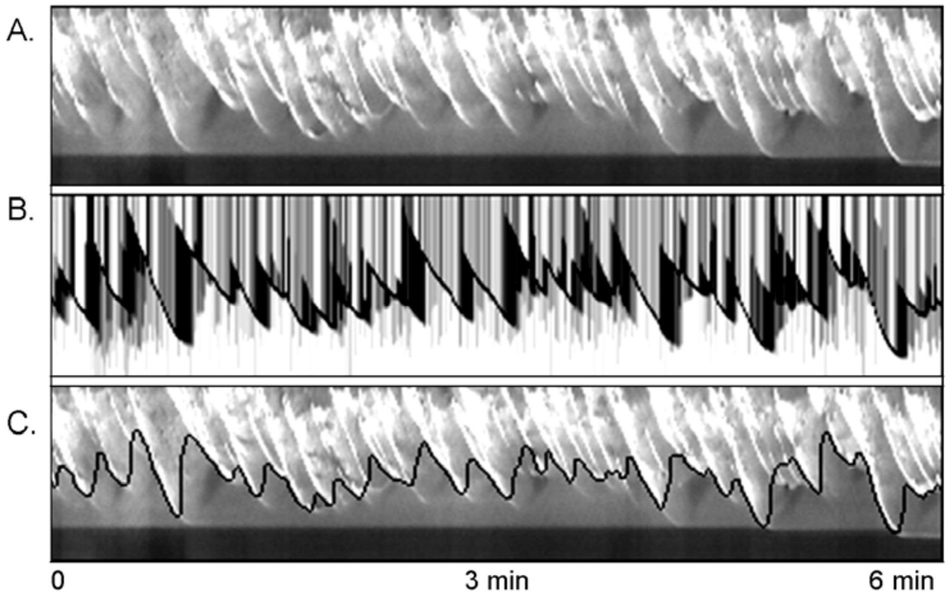

Figure 8
A raw 2D-hydrodynamic time-stack (A) depicting waves running up and down beach face. Swash-front detection using the automated tracking algorithm (Bailey and Shand, 2004) is, in part, (graphically) illustrated in B, with final result overlaid in C.

are obtained for known locations within the surf zone. By comparing the time- stack images with corresponding pressure transducer records they demonstrated that the images were analogous to surface elevation changes corresponding to broken gravity waves. Velocity components of the primary wave train were then determined by two methods: firstly using celerity and peak wave number spectra, and secondly using sensor separation and time lag between individual breakers using both the cross- covariance function and phase spectrum. Results showed "close agreement" between different methods and also with wave theory.

It should be possible to derive other standard wave properties including wave height at the break-point(s), wave period(s), wave length, and wave speed by utilizing 2D-hydrodynamic time-stack. These parameter signatures are illustrated in Figure 9 which depicts a series of incident waves being transformed as they cross the surf zone. Such features can be metricated for individual waves using image geometry, and image processing can also define breakpoint modulation. Determining wave parameters by repeating the process to gain a statistically representative sample, however, would be time consuming and impractical on anything other than an experimental basis**.** At present the authors are developing algorithms which will automate the extraction procedure thereby providing a viable means of collecting such hydrodynamic data. In addition, we anticipate the isolation of a continuous water level records for sites across the surf zone suitable for Fourier Analysis.

The ability to determine H_b using the 2D-hydrodynamic time-stack would provide a means of testing various linear and nonlinear wave shoaling theories. Accurate calibration can also be carried out for wave height visual observations and instrument-assisted techniques such as the pole horizon method (Patterson, 1985; Patterson and Blair, 1983).

The surf zone video record would not directly enable the detection of sea-surface oscillations in the infragravity and far infragravity bands as they have no direct breakpoint intensity expression. However, such frequencies are discernable from either the run-up record as already described or, perhaps from the tide/gravity-wave height combination where preferential groups of incident waves break as illustrated by the sporadic wave breaking on the outer bar on the hydrodynamic time-stack in Figure 3. These breaking wind waves define infragravity motions as they lie in the depression between trapped, free, and interacting longwave peaks (Symonds et al., 1982; Huntley and Kim, 1984; Lippmann, 1993; List, 1992; O'Hare and Huntley, 1994).

The visual wave history presented in the 2D-hydrodynamic time-stack also provides a means to study other aspects of breaking wave dynamics including Galvanian (1968) wave types, nonlinear interactions associated with multi-wave trains, shoaling, and bar/beach-face breaking associations. For example, the formation and behaviour of secondary waves or solitons (Davidson-Arnott and Randall, 1984; Galvin, 1968; Huntley and Bowen, 1975), can be seen in Figure 4a and Figure 9.

Studying sea-surface dynamics associated with river inflow, rip-channel activity, or other surfzone/nearshore circulation, could also be facilitated by the use of elevated video records and image processing to track natural or artificially created (dye injection) colour boundaries. It is also possible that automated foam tracking algorithms could be written, thereby providing spatially extensive and temporally continuous surface current data.

Although not part of the present work, video images have recently been used in morpho-hydrodynamic wave flume experiments. In a comprehensive investigation of vortices associated with wave breaking Zhang (1994) was able to track their development and morphological impact using video records. Video cameras were also used to record a continuous image of surf zone wave transformation, swash, and run-up during the meticulously monitored SUPERTANK experiments at Oregon State University (Kraus et al., 1992). Time-stack techniques could be applied to such data. Wave-tank data may also be able to verify video-derived parameter values.

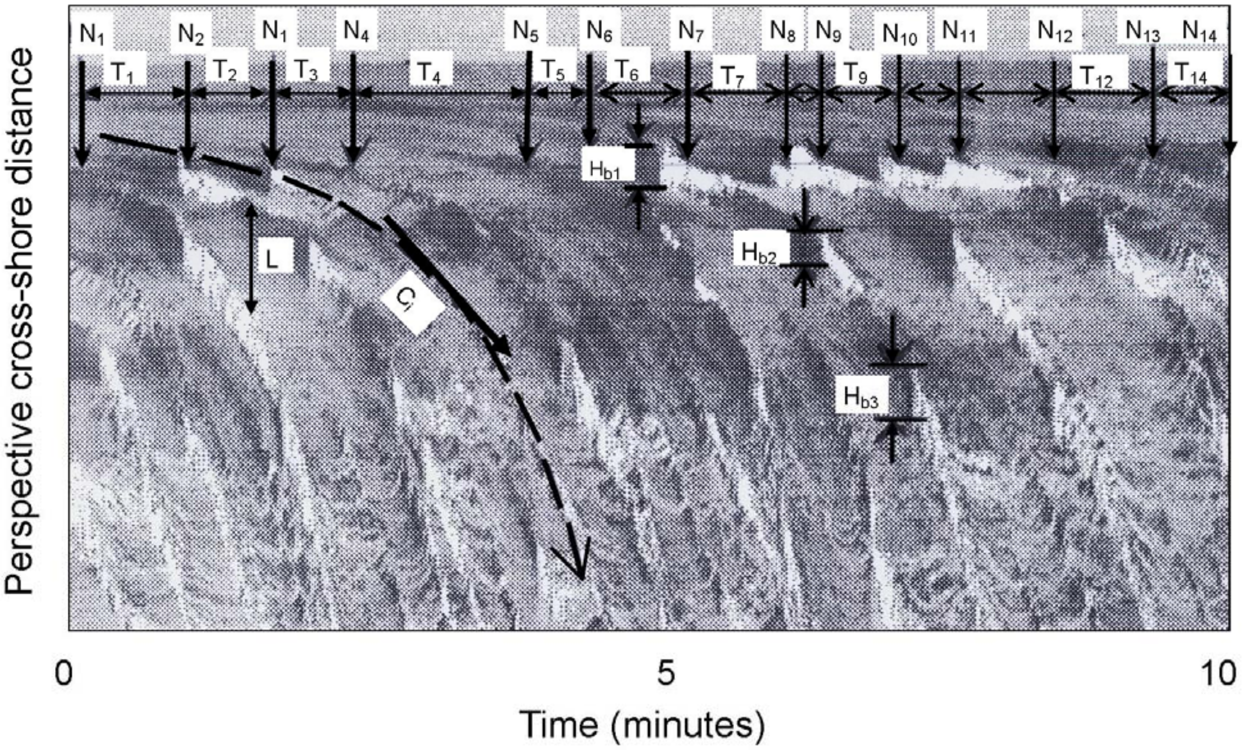

Figure 9
In this 10 min long 2D-hydrodynamic time-stack, a sequence of waves numbered ($_{\text{N1-14}}$) have been defined along an outer bar, plus two more further landward. Incident wave periods [T $_{1-14}$], are also marked along with examples of the breaking wave height signal at different cross-shore break-points (H_bn). Examples of instantaneous wave speed Ci at time t within the surf zone (where Ci = dDi/dt and Di is cross-shore distance to the wave at time t), and wave length (L) just landward of the outer ber are also marked.

7. DISCUSSION

The morphological and hydrodynamic data acquisition method comparisons (Tables 1 and 2) demonstrated the advantage of elevated terrestrial video sensing and image processing in meeting our monitoring criteria. The only significant morphological area of videographic limitation was an inability to deliver absolute bathymetric elevation data. The requirements for visible light and wave breaking during the data collection phase are not generally constraints at the sampling time-space scales under consideration. Other present hydrodynamic shortfalls such as automated acquisition of incident wave heights and current measurement, should be videographically derivable using the time-stack approach.

Sampling Advantages

Video sampling and other elevated image-based methods of field data collection, allow for a variety of sampling advantages which further increase its ability to meet our data acquisition objectives. The non-contact aspect of such data collection is particularly important for coastal monitoring where dangerous or difficult conditions, or access limitations hamper or prevent data collection at the required scales (Kidson and Manton, 1973; Lillisand and Kiefer, 1987). An image-based approach permits sampling at the required temporal scale rather that at a resolution constrained by the nature of the morphology under investigation (Lane et al 1993), and thus avoids the practical spatial/temporal scale mismatches which often occur with geomorphological field work.

As the image is an unbiased data source which records an infinite number of data points, potentially usable information is contained at each visible point (Chandler and Moore, 1989). This characteristic facilitates retrodictive data acquisition if alternative aspects, or even different phenomena, require investigation at a later date. For example, the identification of bar bifurcations during the net offshore bar migration process (Figure 6) was an unexpected result, and now the image data will enable subsequent in depth study of this phenomena.

Image Processing and Visualisation

We have shown how video records facilitate subsequent digital image processing and the construction of time-stack images. This hydro/morpho image, together with other artificial and raw images, offers a variety of computer-assisted vision opportunities both for data abstraction and system comprehension.

Computer-assisted vision is now a major user of image processing as the speed, memory and storage capacity of present generation of computers, together with the recent ability to collect comprehensive data, enable algorithms to now transform large data sets into the universal language of pictures (Kaufman, 1994). This is referred to as scientific visualisation which, often with the aid of interactive graphics, provides for provoking insights into the make up of the associated phenonemon (Kaufman, 1994).

The two primary subfields of scientific visualization are volume (static form), and flow (time varying) visualization (Kaufman, 1994). The latter, also referred to as dynamic scene or image sequence processing (Aggarwal, 1986), consists of visualizing features and tracking their evolution, thereby providing information on the nature, behaviour, and causal associations of areas of scientific interest (Samtaney et al., 1994). The application potential for coastal science is vast.

While flow visualization is ultimately concerned with 3D feature extraction, tracking, and modeling algorithms, i.e. quantitative analysis (Balder, 1983, Samtaney et al., 1994), as we have already demonstrated, visualising an object history with a time-stack can be of primary importance in identifying fundamental forms and processes. Simply viewing animated processed data using video technology, i.e. scientific video animation (Globus and Raible, 1994) is also a highly effective form of flow visualisation as is demonstrated by, for example, Cole and McGregor (1994) regarding sea surface temperature change, or phenomenon initialization with atmospheric circulation (Wood, 1992). Our initial video animation indicate such flow visualization will prove very useful for investigating the initial states, formative processes and evolutionary behaviour of surf zone features described earlier when considering morphogical time-stack examples.

Cognitive Psychology

To appreciate why we can gain information and insights when viewing images it is necessary to consider the work of cognitive psychologists. Gestalt psychologists have found that elements of an image look different when viewed in a wider context. Symmetry or continuity can be perceived when embedded in more general pattern (Haber and Henshenson, 1980). These psychologists have also found that we are able to detect unification when objects are placed near to each other (Haber and Henshenson, 1980). We would also expect this to occur temporally with animation.

Visualisation has been found to assist in the isolation of invariants and regions of interest and this enables the extensive data sets obtainable by remote sensing to be constrained thereby becoming more manageable for analysis and modeling (Samtaney, 1994). This is of particular relevance to surf zone scientists for whom the search for primary indices and associated data rendering has been fundamental in their attempts to model the multivariate, data rich coastal environment (de Vriend, 1993).

8. CONCLUSIONS

Videographic techniques have been shown to generally out perform other methods of surf zone geophysical data acquisition at medium spatial/temporal scales. Indeed, we consider this approach has the potential to almost be a successful stand-alone technique, i.e. is capable of providing all types of coastal data. This success is largely associated with the image-based nature of the system which facilitates sampling and post-processing including such as time-stack construction. More flexible sampling regimes can be achieved and visual inspection of both raw and processed images provide for new insights into the nature of the phenomenon under study. This can subsequently identify relevant data for rendering and analysis and also suggest the makeup of image processing algorithms to abstract these data.

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