Coastal Sand Transport and Morphodynamics:

A Review of Field Data

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Summary

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This report contains a review of field data collected in the coastal zone, including measurements of sediment transport and sea bed evolution. Purely hydrodynamic experiments are omitted, as are those involving mud or gravel.

The report was commissioned by the UK Ministry of Agriculture, Fisheries and Food (MAFF) as part of the Flood Defence Research Programme. The aim of the review is to assess whether new data is needed for validation of medium scale coastal numerical models, or whether existing data is sufficient.

The author concludes that a new coastal field exercise specifically directed towards validation of coastal profile and area models would indeed prove valuable. Much of the data already collected has not been specifically directed towards this aim, and often lacks vital measurements for validation of a full morphodynamic model.

This unrestricted subject area review is intended to be of use to any engineer or scientist interested in coastal sand transport. For further information please contact Dr H M Wallace or Dr H N Southgate at HR Wallingford.

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1 *Introduction*

As part of the Flood Defence Research Programme of the UK Ministry of Agriculture, Fisheries and Food, HR Wallingford was asked in January 1993 to assess whether a new coastal field exercise in the macro-tidal regions of NW Europe is necessary and feasible. The aim of such an exercise would be the validation of numerical models of the coastal zone, including hydrodynamics (waves and currents), sediment transport and seabed evolution on a medium scale, ie a timescale of the order of several weeks and a length scale of the order of a few kilometres.

To help answer the question of whether such a field measurement programme is necessary, this report contains a review of field data already collected in the coastal zone. Chapter 2 contains a brief description of the data required for model validation, Chapter 3 a summary of available data, and Chapter 4 reviews of those experiments which appear most useful for the purpose of medium scale coastal model validation. The findings are summarised and conclusions drawn in Chapter 5. Only sandy coasts are considered, since models of mud transport are not so well advanced, and in any case are generally more applicable to estuaries than to the coastal zone.

2 *Coastal model validation requirements*

2.1 Minimum requirements

For proper validation of any numerical model of the coastal zone the first requirement must be that the boundary conditions (required as model inputs) are known. This leads to the following minimum set of measurements.

1. The wave height, period and direction offshore (beyond the breaker point) for the full duration of the experiment.

2. Tidal elevations and velocities at the model boundaries.

3. Sediment grain size and bed state (for friction).

4. Initial bed levels and mean water level.

Data which omit some of these measurements can often be utilized by estimating the missing information (eg by predicting wave heights from meteorological records) but this can never be fully satisfactory.

For validation of the models, some measurements are obviously required of the effect of the applied (measured) boundary conditions on the area under investigation. As a minimum, this would consist of the final bed levels after the duration of the experiment (the final model output). However, this information alone is insufficient to identify the areas where models need improvement.

2.2 Full validation

The applied wind and tidal driving forces in the coastal zone generate a complex pattern of flows which in turn transport sediment and can result in changes to the shape of the beach, including erosion or accretion of the shoreline. Proper validation of a coastal model requires measurements of each aspect of this complex process, in order to validate each module of the models. Ideally the following measurements should be made, in addition to the boundary conditions given in Section 2.1.

Waves	-	Wave height, period and direction (*) Bottom orbital velocities and moments Setup Runup Breaking point (*) Energy dissipation Turbulence Type of breaker (surging, plunging or spilling)
Currents		Depth averaged currents (*) Surface currents Velocity profiles through vertical Locations of rip currents
Water levels		Tidal elevations Storm surge levels
Water properties		Temperature and salinity
Sediment properties	-	Grain size (*), density, porosity
Sediment transport	-	Bottom shear stresses Concentration and velocity profiles through vertical Bed load transport rates and directions (*) Suspended load transport rates and directions (*)
Morphology	-	New bed levels (*) Ripple height and length.

Knowledge of the above parameters at every model grid point would enable a detailed validation of the models, but would be unfeasibly expensive to obtain from field experiments. Different experiments therefore tend to concentrate on different aspects of the physical processes involved. For validation of a medium-scale morphodynamic model, the most important parameters are marked (*). Measurement of at least these parameters at several points in the cross-shore direction would be required, extending out beyond the breaker point. Some indication of longshore variation is also required, the detail necessary being determined by the degree to which the coast displays longshore uniformity. Since the hydrodynamic part of the models is the best understood it is the sediment transport and morphological modules which require most validation.

Measurements of wind speed and direction and sand transport by wind on the upper beach might also prove informative, along with studies of the vegetation on dunes and in the water. (Suspended organic matter can distort the picture of sand transport).

2.3 Suitable sites

The various types of coastal model can only be applied to certain types of site. In particular, for this exercise we require a sandy bed. Many models can also deal with mud in some form, but since the processes of mud transport are less well understood we do not propose to consider them in this study. Likewise, gravel beaches are omitted from this review. The site requirements for validation of coastal profile models (which assume local alongshore uniformity) and area models (which do not) are listed in Table 1, along with some indication of the spatial resolution required. Profile models tend to have a more detailed description of physical processes in the surf zone, whereas a state-of-the-art area model is likely to use a coarser grid and extend further offshore. The temporal resolution needed depends to a certain extent on how active the beach is. The bed must have evolved measurably over the duration of the experiment to validate the morphodynamic module. A beach may be made more active artificially eg by adding a mound of dredged sand or digging a trench.

Both types of model require a variety of hydrodynamic conditions for proper validation, including both large and small waves and tides. Periods of both erosion and accretion should ideally be measured.

3 *Summary of available data*

Table 2 contains a summary of field measurements of sediment transport, seabed morphology and associated hydrodynamics, in the nearshore coastal zone. Purely hydrodynamical investigations are omitted, as are those involving gravel or mud. The field investigations are grouped according to the country in which the measurements were taken. A broad indication of the measurements made is given according to the following key:

W - waves
C - currents
T - tides
S - sediment properties
ST - sediment transport
B - bed levels
M - meteorology

The area, duration, date and principal reference for each experiment is also tabulated, where this information is available.

Many of the experiments do not satisfy the requirements for model validation given in Chapter 2. However, the data may prove useful in validating a particular aspect of a model (eg vertical concentration and velocity profiles at a point, for formulation of the suspended transport law), giving measurement techniques for a particular parameter (eg description of new instrument) or giving background knowledge on the morphological development of a coast. No attempt is made to comment on the usefulness, extensiveness or reliability of the measurements listed. However, the most promising experiments from the point of view of coastal model validation are reviewed in Chapter 4.

The following reviews provided useful information for completion of the table: Bodge (1989), Brampton (1993), DeGraauw and Hamm (1988), Holmes et al (1988), Greer and Madsen (1978), Basinksi (1989) and Schoonees and Theron (1993). Basinski (1989) also provides detailed information on the planning and instrumentation needed for any coastal measurement programme. Schoonees and Theron (1993) give an assessment of the quality of longshore sediment transport data.

4 Reviews of selected experiments

4.1 Introduction

In this chapter, a selection of the experiments listed in Table 3.1 are reviewed in more detail. The reviews include a description of the site, the measurements made and the instrumentation used. An attempt is made to assess the usefulness of each experiment for coastal model validation, given the information available in the literature. Only those experiments which may be potentially useful for validation of a full morphodynamic model (rather than only one aspect of it) are reviewed.

4.2 Reviews

4.2.1 Pointe Sapin, Canada

Experiment No.	C3
Title/Organisation	Canadian Coastal Sediment Study, National Research Council, Canada
Duration	16 October - 7 November 1983

Environment

Sand veneer over a sandstone ledge, with bedrock at a water depth of only 2m, although some sand extends to 7m water depth, 1km offshore. Gravel further offshore. Study centred on the beach immediately northeast of an artificial harbour and sandtrap (detached breakwater).

Coast is storm-wave dominated with strong seasonal variability (changes in wind regime and 3-4 months of winter ice cover). 10% exceedance characteristic wave height is 1.5m, modal wave period 3-4s. Storm surges up to 1.3m, tidal range 1.4m, rising relative sea level. Net southerly longshore drift. Estimates of annual longshore sediment transport vary from $10^4 m^3$ to $2x10^5 m^3$.

Measurements

Waves and currents - WHOI offshore wave data, 550m north of beach. 6 electromagnetic current meters (2-axis) and 4 pressure transducers (cross-shore and long-shore lines of approx 300m). Two offshore current meters. 'Ralph' tripod-mounted instrument package (2 electromagnetic current meters (0.3 and 0.1m above bed), 1 pressure sensor (1.3m), 1 transmissometer (0.5m), camera (also measured tides). Various bottom drifters and drogues for Lagrangian current measurements.

Sediment properties - cores and grab samples (200 samples), out to 22m depth.

Sediment transport - 2 transmissometers, 2 optical backscatter sensors. Surveys of sand trap, every 2-4 days. Nephelometer and suspended sediment pump sampler. Radioactive sand tracing.

Bed levels - shore surveys using staff and level out to wading depth. 9 cross-shore lines at 50m intervals, surveyed at 2-3 day intervals. Boat surveys of shoreface and inner shelf at one week intervals, using echo sounder and electronic distance measurement. Design and testing of High Resolution Remote Tracking Sonar (HRRTS).

Applications

Possible area model validation, provided the model can incorporate hard bed areas. The spatial scale of the measurements is rather small for this type of model, however.

References

Aubrey and Spencer (1983), Baird et al (1986), Bowen et al (1986), Daniel (1985), Daniel (1986), Doering and Bowen (1987), Drapeau and Pade (1984), Fleming et al (1984), Fleming et al (1986), Forbes et al (1986), Forbes (1987), Gillie (1984a), Gillie (1984b), Gillie (1986), Greenwood and Dingler (1984), Hay and Heffler (1983), Huntley (1982), Huntley and Hanes (1987), Kooistra and Kamphuis (1984), Long (1986), Marine Environmental Data Service (1984), Morse (1984), Nova Scotia Research Foundation (1983), Readshaw et al (1987), Rochon et al (1984), Skafel (1985), Willis (1987).

4.2.2 Bluewater Beach, Queensland Beach and Stanhope Lane, Canada

Experiment No.	C6, C7 and C8
Title/Organisation	C-COAST
Duration	1987-1989. Measurement programmes lasted approximately one month at each site (two experiments took place at Bluewater beach).

Environment

Bluewater Beach -	Barred shoreface of Great Lake, alongshore uniformity. Slope of 0.014. Medium to fine sand. Normally incident waves, no tide.
Queensland Beach -	Non-barred shoreface, 3-D topography. Slope of 0.03-0.10. Medium sand. Spring tide range of 2m.
Stanhope Lane Beach -	Triple barred shoreface. Medium to fine sand. Normal or obliquely incident waves. Micro-tidal.

Measurements

Each site had several sediment transport stations measuring vertical velocity and concentration profiles, placed along a cross-shore line, out to a depth of 5-7m.
Waves and currents - 1 pressure gauge and up to 3 2-component flowmeters (electromagnetic or electroacoustic) at each station on profile.
Sediment properties - bed and suspended samples.
Sediment transport - Optical Backscatterance Suspended Solids sensors (OBSS), one at each station on profile. Remote Acoustic Sediment Transport System (RASTRAN) Video.
Bed levels - High Resolution Remote Tracking Sonar (HRRTS) for bedforms and local bed elevation changes.
Depth-of-Activity rods and standard survey.
Meteorology - wind speed and direction.

Applications

It is not clear from the references whether the bed level measurements are extensive enough for morphodynamic model validation, nor whether continuous directional wave data exists outside the breaking point. Sediment transport measurements are quite detailed and may prove useful in validating this aspect of profile models.

References

Greenwood et al (1990a), Greenwood et al (1990b), Greenwood et al (1991), Hazen et al (1990), Van Hardenberg et al (1991).

4.2.3 *Kaergaard plantation, Denmark*

Experiment No.	D1
Title/Organisation	Danish Hydraulics Institute (DHI)
Duration	February 1982-July 1983

Environment

150m wide, straight, sand beach. 1200m wide breaker zone with 3 bars. Monitoring of infilling of 5m deep x 40m wide x 1500m long trench dredged through nearshore zone, at an angle of 65° to coast. Alternating layers of fine and medium to coarse sand covering sandy gravel. The bottom of the trench was muddy. Mean tidal range 0.95m. Mean annual gross longshore transport rate $1.5x10^6 m^3$.

Measurements

Waves and currents - waverider buoy at 12m water depth. 2-component electromagnetic current meter to measure current and wave-induced orbital velocities, 1.5m above sea bed (at 12m water depth). Directional information often missing and refraction calculations had to be used instead. Water level recorder.
Sediment Properties - 4 surveys by grab sampler (before and after dredging).
Bed levels - 3 longitudinal profiles spaced 200-300m (one along central line of trench) and over 30 cross-sections (25 to 50m apart, 600-800m long), surveyed by echosounder and electronic positioning systems, for one year (7 surveys).
Meteorology - wind speed and direction.

Applications

Verification of area models. However, there are gaps in the wave data and no sediment transport measurements.

References

Danish Hydraulics Institute (1984), Mangor et al (1984).

4.2.4 *Dunkirk, France*

Experiment No.	F1
Title/Organisation	Laboratoire National d'Hydraulique EDF Chatou France
Duration	Various periods from 1960-1977
Environment	Site of a new outer-harbour for large oil tankers, field measurements took place before and after its building. The site is bounded offshore by numerous narrow, high banks. Strong tidal currents and severe wave climate. Sandy bed.

Measurements

Currents - 17 self-recording current meters, 3m above bed, covering an area of 30km (longshore) by 10km during about 2 weeks. Also at 3 points close to proposed harbour in shallow water, 1.5m below surface.

Waves - 7 self-recording pressure gauges on bed covering an area of 15km (longshore) by 5km. 20 min sequence at each high water for several years. Also visual observations.

Sediment - Bed samples at 55 points using a Mecabolier bucket.

Suspended concentrations - 1 sample/month for 10 months in 1975, for about 15 stations

Sediment transport - Tracking of luminescent tracers on 23 April 1967 for 32 days (5 points)

Tracking of radioactive tracers in 1965 for 1 week and in 1967 for 6 months (5 points).

Morphology - Experimental trench dug in spring 1973 and surveyed from 20 June 1973, regularly for 11 months. Hydrographic surveys in 1879, 1894, 1910, 1932 and 1962 (4km x 12km).

Applications

Potentially useful for verification of area models. However, the various measurements were taken at different times, thus limiting their usefulness. It is not clear whether directional wave data is available during the trench experiment.

References

Allen (1982), Bonnefille et al (1971), Centre National pour l'Exploration des Océans (1977), Institut de Biologie Marine et Regional de Wimereux (1976), Latteux (1988), Lepetit and Levoy (1977).

4.2.5 Channel Islands Bay, France

Experiment No. F6
Title/Organisation ROMIS, University of Caen
Duration 1991-1993

Environment
Complex bathymetry. The Channel Islands are surrounded by numerous shoals. Low-height beaches bordered by rocky platforms. Shoreline retreat is 5m/year at some places. Sandy bed. Long waves from the North Atlantic sometimes propagate up to shoreline. Prevailing swell is from the West. Very strong tides (up to 15m tidal range and 3m/s velocities).

Measurements

Regional scale studies:

Waves - on 4 sites over 3 years. 3 directional wave sensors at -5m below MLWS, together with a high resolution pressure sensor and a bicomponent electromagnetic current meter. Directional wave buoy offshore.
Tides - 3 tide gauges, one in subtidal zone.
Bed levels - Topographic surveys 3 times a year of intertidal areas at low tide, using triangulation and electronic distance measuring (with vehicle). Shoreline mobility at 100 points along 80km, by measuring distances from landmarks to shoreline after every spring tide.
Meteorology - Wind data from 2 locations.

Local studies:

Field observations in 10 coastal cells, 4-5 days observation each month in a different cell each time.
Waves and Tides - 4 electromagnetic current meters, one assigned to determine wave height, period and direction.
Sediment Properties - samples from sand traps sometimes sieved for grain-size analysis.
Sediment Transport - Fluorescent and radioactive tracers (4 to 8 injections at low tide during each survey). Galvanized sediment traps on rocky platforms to measure multidirectional bedload transport and vertical suspended transport. Streamered traps in the breaker zone to measure longshore transport (bed and suspended load) at several different stages of one tide. Also measurement of wind-blown sand with 2 types of trap.
Bed levels - Aerial views and videos by plane at low tide, correlated with regional scale topographic surveys to produce morphodynamic maps.
Meteorology - Anemometer and wind-direction sensor used with wind-blown sand traps.

Applications
Potentially a very useful data set for area model validation, although a major drawback is that topographic surveys extend only to low tide level. The reference was written before detailed data analysis, so the success and reliability of the measurements is not known.

References
Levoy and Avoine (1991).

4.2.6 *Sylt Island, Germany*

Experiment No.	G2
Title/Organisation	Untersuchungen zur Optimierung des Küstenschutzes auf Sylt
Duration	1987-1991

Environment

West coast of Sylt Island. Straight, sandy beach with longshore bars (ridge and runnel system). High energy coast (exposed to North Sea). Tidal range of nearly 2m. Maximum storm surge, 3m. Longterm eastward recession of the island (approx. 1m/yr). Mean slope of dry beach is 1:17, of wet beach 1:15.

Measurements

Waves and currents - 4 stations, 10km apart with measurements on a cross-shore line. Each have 4 pressure gauges, 2 PUV stations (with a pressure gauge and 2-component current meter) and an offshore directional wave buoy (in 13-15m water depth).
Tides - 11 pressure sensors at 5 positions along the West coast. 2 tide gauges in harbours at the north and south ends of the East coast.
Sediment properties - sediment samples along 2 profile lines (over about 600m cross-shore distance).
Sediment transport - luminous tracer experiments.
Bed levels - Surveys of dunes, beach and nearshore (echosounder).
Meteorology - Wind speed and direction at 2 sites.

Applications

Validation of profile models, particularly for long-term use. It is not clear whether the frequency of surveys is sufficient to observe changes over a single storm. No suspended sand measurements.

References

Dette (1985), Dette and Oelerich (1992), Oelerich (1990).

4.2.7 *Kokkino Limanaki, Linoperamata and Rio Beaches, Greece*

<u>Experiment No.</u> Gr1
<u>Title/Organisation</u> Technical University of Athens
<u>Duration</u> 1986-1987

<u>Environment</u>
Kokkino Limanaki Beach -
Pocket beach with bounding headlands to north and south. Medium to coarse sand and pebble. Medium energy, microtidal. Weak longshore sediment transport.
Linoperamata Beach -
Linear beach on north coast of Crete. Medium sand. Mild slopes and unobstructed longshore transport. High energy, microtidal.
Rio Beach -
Recurved spit on south shore of Rio-Autimo Straits. Steep slopes. Coarse sediment. Low energy, microtidal.

<u>Measurements</u>
Waves - Data-well wave-riders.
Currents - Electromagnetic current meters for longshore currents.
Sediment properties - detailed analyses of grab samples obtained on a grid of transect lines.
Bed levels - Beach profile surveys and bathymetric surveys with echosounder, monthly and after selected storms.

<u>Applications</u>
References give little detail on hydrodynamic measurements and surveys, concentrating on grain-size distribution. However, verification of profile and/or area models may be possible. The need to incorporate different grain sizes is emphasised. Negligible tides.

<u>References</u>
Moutzouoris and Kypraios (1987), Moutzouris (1988a), Moutzouris (1988b), Moutzouris (1991).

4.2.8 *Ajugura and Oarai Beaches, Japan*

Experiment No.	J7
Title/Organisation	Japanese Nearshore Environment Research Centre (NERC)
Duration	1978-1984 (6 series of measurements, 2 to 4 weeks each)

Environment

Two east coast beaches, facing Pacific.
Ajugura beach - straight, sandy, 9km long, 1:40 slope. 200m long pier, extending to 5m depth.
Oarai beach - sandy beach beside a harbour, affected by breakwaters and groynes. 1:60 slope.

Measurements

Waves and currents - Ultrasonic wave gauges (typically 5, covering 100m longshore line in 6m water depth), pressure type wave gauges (typically 4, covering 400m longshore distance, in 3m water depth), capacity type wave gauges (typically 15, covering 400m longshore, 150m cross-shore distance, in surf zone) and electromagnetic current meters (typically 12, one in 3m water depth, the others in surf zone, associated with the wave gauges). Currents by colour pictures of floats and dye tracers, from helicopter, balloon or platform. Wave transformation across surf zone by camera system, photographing water surface elevations at a line of poles at fixed time intervals.
Sediment properties - Grab and core samples.
Sediment transport - Longshore transport using multi-colour fluorescent sand tracer.
Sand traps (box, cylinder and streamer types) for both cross-shore and longshore transport in surf and swash zones. Ultrasonic sediment flux meter, optical concentration meters and mechanical samples.
Bed levels - Topographic surveys at least twice during each observation period out to about 6m water depth (transits on land, fathometer on boat and radio-controlled amphibious vehicle). Some additional longer term profile surveys at Oarai.
Meteorology - Wind speed and direction.

Applications

Possible verification of profile (Ajugura) and area (Oarai) models. It is not clear from the references whether there are any significant tides. It is also unclear whether significant morphological changes occurred during any of the series of measurements. Measurements may not be on a large enough scale for area model validation.

References

Horikawa and Hattori (1987), Kraus and Harikai (1983), Kraus et al (1981), Sasaki and Horikawa (1978), Uda and Hashimoto (1983).

4.2.9 *Iioka Coast, Japan*

Experiment No. J11
Title/Organisation
Duration May-December 1987

Environment
Sandy beach with seawalls and detached breakwaters (150m to 160m in length, 250m offshore, openings mostly 80-100m). Beach erosion accelerated by construction of breakwaters at fishery harbour (updrift from beach). Maximum significant wave height during experiment was 4.78m (period 11.3s) during a typhoon. Monitoring of sand dumping (70m x 70m area, 500m offshore at furthest updrift point, 8 times over 27 day period). Dumped sand grains had median diameter of 0.21mm. Approximately 500m^3 dumped on each of 6 occasions, then 1000m^3 on each of 2 occasions.

Measurements
Waves and currents - Wave data from 3 measurement stations off fishery harbours nearby (6km offshore). Electromagnetic current meters installed at the same location to measure currents and wave directions. Data is missing from nearest station during sand dumping.
Sediment transport - Fluorescent sand tracer experiment, 2 weeks after sand dumping.
Bed levels - Area 300m x 300m surveyed 3 times. First 2 surveys were 1 month apart. Third survey showed only small changes.

Applications
Validation of area models from 2 surveys, with some sediment transport information. Unfortunately, wave data is limited to distant sites and no tidal information is given. Area covered is also rather small.

References
Uda et al (1991).

4.2.10 Ogata Coast, Japan

Experiment No.	J15
Title/Organisation	TOP (T-shaped Observation Pier) Kyoto University
Duration	3 winter seasons (1988, 1989, 1990)

Environment

Straight, sandy beach, 20km long, facing the Japan Sea. Depth contours are parallel in shallow water (less than 4m) but 3-D features (shoals and dips) exist in deeper water. Crescentic bar system. T-shaped observation pier, extends to about 6m water depth (250m long and 100m wide at offshore end). Waves are predominantly directed around the perpendicular to the beach and are high only in winter. Microtidal (range less than 40cm).

Measurements

Waves and currents - Usual instruments are 7 ultrasonic wave gauges, one 2D and the two 3D ultrasonic current meters on pier. Intensive observation (28 November-7 December, 1987) also used two 3D ultrasonic current meters, 1m apart vertically, and 10 capacitance wave gauges. A wave-rider buoy is anchored 3km offshore, in line with pier.
Sediment properties - Mean diameter of bed sediment measured (0.25mm), and also of trapped sediment (0.3mm).
Sediment transport - Cross-shore sediment transport rate (bed load only) by trap. Video recorder and a 2-component electromagnetic current meter on trap.
Bed levels - Bed state (rippled or plane) measured using a comb 1.8m long, with 61 strings. Depth sounding with lead along pier. Surf sled with semiconductor pressure transducer to measure profiles at longshore intervals of 5m.

Applications

Potentially useful for area model validation. It is not entirely clear from the reference whether continuous, directional wave data exists or whether topography has been measured far enough offshore. The frequency of the surveys is also not obvious. The flow will be complicated by the pier and crescentic bar system.

References

Kawata et al (1990).

4.2.11 *Kashima, Japan*

Experiment No.	J16
Title/Organisation	Hazaki Oceanographical Research Facility (HORF) Port and Harbour Research Institute
Duration	12-26 September, 1988 (Measurement A) 13-21 July, 1989 (Measurement B) 9-28 February, 1990 (Measurement C) 25 June-10 July, 1990 (Measurement D)

Environment

Contour lines fairly parallel to shore, although sometimes small undulations.
Average beach slope 1/60, with bar and trough.
427m long research pier.
Sand, with median diameter 0.18mm.
Maximum significant wave height was 5.4m (during a typhoon in Measurement A).
Microtidal (< 2m range).

Measurements

Offshore ultrasonic wave gauge 7km north of HORF in 23m water depth.
Waves and currents - Electromagnetic current meters and ultrasonic wave gauges (usually one of each).
Measurements A and B near wave breaking positions in different wave conditions. Measurement C in the middle of the surf zone in a storm. Measurement D both at breaking point and in middle of surf zone.
Water surface elevations and horizontal velocities measured for 20 minutes at a sampling frequency of 2Hz.
Visual observations of the fraction of breaking waves, ratio of plunging breakers to all breakers, wave breaking positions, locations of shoreline and presence of rip currents.
Bed levels - Beach profiles (11, 40m apart) on foreshore surveyed with level and staff before and after each series of measurements (every 5m for 200m length).
Beach profile along south side of platform surveyed daily, every 5m for 500m length (exposed beach with level and staff, the rest with a lead weight).

Applications

Possible verification of profile models. Note that only a median grain size is given and there are no sediment transport measurements. Offshore wave data does not include direction so is of no use for model boundary conditions. However, measurements on the pier are outside the surf zone in most cases, so this information could be used as the model boundary condition. Longshore uniformity assumption may not always be valid (eg due to rip currents).

References

Kuriyama (1991).

4.2.12 Egmond, The Netherlands

Experiment No.	N6 and N7
Title/Organisation	TOW Study Programmes for Coastal Sediment Transport (Field Experiments Task Group) Rijkswaterstaat, Delft University of Technology and Delft Hydraulics Laboratory.
Duration	May-June 1981 (calm weather) September 1982-January 1983 (rough weather).

Environment

Straight, sandy beach. Longshore bars (double bar system). Mean tidal range of 1.5m, storm surges can be 1m or more. Offshore significant wave height varied from 0.2-2.5m in 1981 programme, and up to 4.6m in 1982/83 programme.

Measurements

Waves and currents - One cross-shore survey line with 3 surf zone stations and 2 offshore stations for 1981 programme. 2 cross-shore profiles (main one with 4 surf zone stations and 5 offshore), 100m apart for 1982/83 programme. Surface elevations with wave riders (1 in 1981, 3 in 1982/83) and wave staffs (3 in 1981, 6 in 1982/83). Mean water level with 1 pressure sensor and 2 meters (1982/83 only) plus a float. Instantaneous water velocities with electromagnetic current meters (3 in 1981, 7 in 1982/83) and 4 acoustic current meters. Mean current velocities with underwater current meters (1 in 1981, 5 in 1982/83). Wave direction in surf zone with video. Water temperature.

Sediment properties - Bottom samples.

Sediment transport - Acoustic backscatter probes (1 in 1981, 2 in 1982/83), suction samples.

Bed levels - Rod and level surveys of beach. Echosounding from boat.

Applications

Topography was discovered to be less uniform than expected alongshore (particularly the first bar) so use in validating profile models may be limited. Morphological measurements probably do not give sufficiently detailed information about topographic changes. Sediment transport measurements were not very successful.

References

Battjes and Stive (1984), Boer et al (1984), De Vriend et al (1988), Derks (1982-1984), Derks and Stive (1984), Gerritsen and Van Heteren (1984), Graaff et al (1985), Van Heteren and Stive (1984).

4.2.13 Lubiatowo, Poland

Experiment No. P2
Title/Organisation LUBIATOWO '76
CMEA

Environment
Sandy beach with isobaths parallel to shoreline. Three longitudinal underwater bars. Microtidal.

Measurements
Instruments were:

- Conventional anemometers.
- Conventional apparatus for measurements for air temperature and pressure, humidity, precipitation, evaporation, solar radiation and soil temperature.
- Sand traps for wind-driven suspended sediment.
- Conventional thermographs for measurement of water temperature.
- Conventional tide gauges.
- Radar for measurement of wave incidence.
- Wire-type wave staffs, with analogue recording (IBW PAN design).
- Contact-type wave staffs, with digital recording (IBW PAN design).
- Pressure-type wave probes (Chatou design).
- Glukhovsky's wave probe.
- Contact-type device for measurement of wave run-up.
- BVP propeller current meter.
- VDK orbital velocity meter.
- Fluorimeter for measurement of fluorescent dye concentrations.
- Drogues for tracking surface currents.
- Thermistor probes for measurement of water velocity in soil.
- Luminophore for sediment transport studies.
- Sand traps (IOAN SSSR design).
- Conventional equipment for soil analysis.
- Radioisotopic probe for measurement of suspended sediment concentration.
- Echosounder with radio range finder.
- Bed samplers (for surface and subsurface layers).
- Device for measurement of sand ripple parameters.
- Geodetic equipment (for bearing of measuring stations etc).

Applications
Possible profile model validation, but morphodynamic measurements are probably insufficient.

References
Antsyferov (1977), Basinski (1976), Basinski (1980), Mielczarski (1977), Roniwicz and Rudowski (1977).

4.2.14 *Sondags River, South Africa*

Experiment No.	SA2
Title/Organisation	CAESAR Port Elizabeth 1 (PE1) Council for Scientific and Industrial Research (CSIR)
Duration	25-30 April 1983

Environment

Sandy beach near Sondags (Sunday's) River mouth on east coast of South Africa. South facing, crenulate-shaped bay, with rapidly changing bars and channels. Breaker zone slope is 1:60, but the seaward slope of the bars is often as steep as 1:10. Dominant wave direction is the sector 225° to 255° with median incident deep sea wave height about 3m (high-energy). Strong rip currents.

Measurements

Waves - Offshore by wave rider (10m water depth, opposite measuring site) and clinometer (graded telescope on observation tower in dunes). Surf zone waves continuously for 4 days with wave gauges at up to 7 locations. Visual observations hourly.
Currents - Drogues and dye plus aerial photographs.
Sediment properties - Over 3000 bottom samples taken on a regular grid.
Sediment transport - Over 100 sets of suspended sediment data collected with bamboo poles, deployed for an hour at a time. A further 20 sets of data from sampling bottles.
Bed levels - Surveyed for about 1km along beach, out to 1m below low tide level.

Applications

Area model validation. The topographic surveys are probably not sufficient for validation of morphodynamics, however the sediment transport information may be useful. It is unclear what tidal information is available.

References

Swart (1984), Swart (1986), Swart (1988).

4.2.15 *Walker Bay, South Africa (1987)*

Experiment No. SA6

Title/Organisation CAESAR 3

Council for Scientific and Industrial Research (CSIR)

Duration 5-11 November 1987

Environment

Large, sandy bay, with beach face slope 1/20, nearshore slope 1/55. Unrippled sea bed. Median grain size 0.3mm. Completely exposed to southerly (dominant) waves (1 in 1 year H_s=7.6m). Surf zone widths of up to 500m. Mean tidal range 1.44m. Strong longshore currents (0.5m/s).

Measurements

Instruments deployed in a line perpendicular to shore and a line alongshore. Electronic equipment recorded in 3hr bursts from 1.5hr before turn of tide, every 0.5s.

Waves and tides - Wave rider, wave resistance staffs, pressure sensors to record water level fluctuations, electromagnetic current meters. Wave staffs were attached to poles jetted into bed with compressed air. Triangular frames for current meters. Aerial photographs.

Sediment properties - Sand sampled for grain size analysis.

Sediment transport - Suspended sediment concentrations by pump sampling, and bamboo tube sediment traps. Transmissometer with 7 sensors (25cm apart) for instantaneous recording of sediment concentrations. Trapped sand also analysed for grain size.

Bed levels - Beach and hydrographic surveys. 4 beach surveys (to about 1m water depth) and one hydrographic (to about 6m water depth).

Meteorology - Wind data recorded, and temperature (air and water).

Applications

Insufficient bed level data for verification of morphodynamic models, and in any case beach profiles changed little. However, sediment transport rates combined with hydrodynamic data could prove very useful in validating sediment transport module of either area or profile models.

References

Schoonees (1991), Swart (1988).

4.2.16 Walker Bay, South Africa (1990)

Experiment No.	SA7
Title/Organisation	CAESAR 4 Council for Scientific and Industrial Research (CSIR)
Duration	February 1990

Environment

See Section 4.2 (CAESAR 3).
During CAESAR 4, significant wave height was between 1.5m and 2.5m.

Measurements

Pressure transducer and electromagnetic current meter in shallow water (< 1.5m).
Pressure transducers and arrays of current meters at 5m and 10m depths.
Endeco directional wave buoy at 20m depth.
Two 2mx5m frames placed by helicopter, one with a suction sediment sampler, an optical transmissometer and a water-level recorder, the other with an electromagnetic current meter and a pressure transducer.
Electronic measurements were made over 3h period at the turn of each tide.
Frame deployments for 25 minutes each, usually inside surf zone (56 successful deployments).
Regular beach and bathymetric surveys, several techniques using helicopter.

Applications

It is not clear from the reference (the extended abstract only was available) whether there is sufficient bed level data for validation of morphodynamic models. The data looks potentially useful for validating sediment transport rates.

References

Coppoolse et al (1992).

4.2.17 Torrey Pines, USA

Experiment No. US20

Title/Organisation: US Nearshore Sediment Transport Study (1st NSTS)
National Oceanic and Atmospheric Administration

Duration: 27 October-6 December 1978

Environment

Straight, sandy beach, with nearshore slope of 1:43. Reasonably parallel depth contours. Bar within surf zone. Exposed to waves from north and south Pacific, but partially sheltered by islands 100km offshore. Complicated structure to directional wave spectra. Typical significant wave heights are less than 1m but may vary up to about 1.5m, with big seasonal variations. Maximum tidal range 2.2m. Estimated net littoral transport is $2x10^5 m^3/yr$.

Measurements

Waves and currents - 10 pressure sensors, 7 wavestaffs, 22 current meters, 1 runup meter, time lapse photography (poor quality). Offshore directional wave spectra limited to waves of periods greater than 9s.

Tripod-mounted current meter and pressure sensor plus photography, dye measurements and visual observations for rip currents.

Still water level gauge.

Sediment properties - grab samples collected on grid and analysed. Core samples.

Sediment transport - fluorescent sand tracer measurements of total longshore transport, sand concentration measurements in surf zone using a suspended sediment cover, bed load transport measurements with an acoustic bed load meter (poor data). Swash sampler bag. Optical suspended sediment meter did not function properly.

Applications

Bed level data probably not sufficient for morphodynamic model validation. Limited tidal information and directional wave data.

References

Aubrey et al (1976), Bailard (1982), Gable (1979), Guza and Thornton (1985), Huntley et al (1981), Nordstrom and Inman (1975), Pawka et al (1976) Seymour (1983), Seymour (1986), Seymour (1987a), Seymour (1987b), Seymour and Aubrey (1987), Seymour and Duane (1978), Seymour and Gable (1980).

4.2.18 *Leadbetter Beach, USA*

Experiment No.	US23
Title/Organisation	US Nearshore Sediment Transport Study (2nd NSTS) National Oceanic and Atmospheric Administration.
Duration	October 1979-December 1980: Sediment Trap Study 27 January-25 February 1980: Intensive experiment.

Environment

Fairly straight, unobstructed beach with a steep slope and narrow surf zone. Some longshore variation in bottom topography. Harbour sand trap. Well sorted, medium to fine sand. Fairly constant wave direction (high angle of incidence) due to sheltering by offshore islands. Maximum significant wave height during experiment was 1.9m. Average wave period, 12s. Mean tidal range is 1m. Strong, nearly unidirectional, longshore current.

Measurements

Waves and currents - 24 electromagnetic current meters, 18 pressure sensors, 2 still water level reference gauges, 5 resistance type wave height probes.
Instruments arranged in 170m cross-shore line and 200m longshore line.
Tide data from station in Santa Barbara Harbour and from offshore pressure sensor. Water temperature measurements.
Wave staffs deployed in swash zone. Run-up meter. Current meters failed during high wave activity. Tripods for rip current measurement were also overturned in high waves.
Sediment properties - Grab samples collected on a grid. Core samples.
Sediment transport - Fluorescent sand tracers. Suspended sediment samples with water core devices. Swash sampler bag. Acoustic bed load sensor. Optical backscatter sensor for suspended sediment concentration (5 logarithmically spaced sensors across surf zone). Surveys of sand trap at harbour.
Bed levels - 5 cross-shore lines, covering 200m alongshore, surveyed daily by rod and level to wading depth (at low tide). 9 longshore lines also surveyed to determine longshore variability of beach cusps. 2 boat-fathometer surveys, one before and one after intensive experiment. Tractor profiles to a depth of 4m for first 2 weeks of experiment.

Applications

Potentially useful for area model validation although profiles are possibly too short and boat data may be inaccurate. Large erosion (2.5m downcutting) observed during second half of experiment.

References

Dean et al (1982), Dean et al (1987), Gable (1981), Guza et al (1986), Thornton and Guza (1986).
See also Section 4.2.17 (1st NSTS).

4.2.19 Duck, USA (1982)

Experiment No.	US32
Title/Organisation	DUCK82 Coastal Engineering Research Center (CERC) Field Research Facility (FRF)
Duration	October 1982

Environment

Sand beach with generally straight and shore-parallel depth contours, but with a deep trough in the vicinity of the research pier. Sediments vary greatly in size (0.1mm-1mm). Nearshore bar. Exposed to Atlantic Ocean storms.

Measurements

Waves and currents - 1 waverider buoy 3km offshore (in 20m of water).
4 electromagnetic current meters and 7 staff wave gauges on pier.
Movie cameras at shore end of pier for wave runup.
Vertical array of 6 electromagnetic current meters, a pressure wave gauge and an optical suspended sediment meter, all mounted on a sea sled. Sled was towed along a shore normal transect about 457m north of pier.
Bed levels - Fifteen profiles, 300m long and 23m apart were surveyed, using infrared beam and optical prisms from an amphibious buggy (the CRAB). Profiles were north of pier, outside its influence.
One profile surveyed with a sled system (this could operate in all wave conditions). Frequent surveys.
A grid of steel pins covered a small area, for measurement of microscale erosion and deposition on the foreshore.
Meteorology - Wind speed and direction (anemometer).

Applications

Potentially useful for profile model validation (including checks on assumption of longshore uniformity). No tidal information is given in references, but presumably this is available. No sediment transport measurements.

References

Birkemeier et al (1981), Birkemeier and Mason (1984), Birkemeier (1984), Holman and Sallenger (1984), Howd and Holman (1984), Jaffe et al (1984), Mason et al (1984), Miller (1980), Richmond and Sallenger (1984), Sallenger et al (1983), Sallenger and Holman (1984), Sallenger et al (1985).

4.2.20 Duck, USA (1984-1985)

Experiment No.	US34
Title/Organisation	Coastal Engineering Research Center (CERC) Field Research Facility (FRF)
Duration	March 1984-September 1985

Environment

See Section 4.2.19 (DUCK82).
Measured profile is 490m north of FRF pier and outside its influence.

Measurements

Wave and tide gauges on FRF pier (approx. 7m water depth).
Sediment properties - surface grab samples on 21 occasions, simultaneous with depth surveys, at 17 points along profile line. Subaqueous samples collected using a Ponar Grab Sampler from the FRF Coastal Research Amphibious Buggy (CRAB).
Bed levels - Single profile surveyed with FRF CRAB and Zeiss Elta-2 electronic surveying instrument. Dry beach and dune surveyed by standard rod method. Surveys roughly bi-weekly.

Applications

Very useful for profile model validation, although profile showed some overall accretion due to alongshore variability. Hydrodynamic information is sufficient to drive a model but there are no process measurements for validation of velocities or sediment transport.

References

Stauble (1992).

4.2.21 *Duck, USA (1985)*

Experiment No.	US36
Title/Organisation	DUCK85 Coastal Engineering Research Center (CERC) Field Research Facility (FRF)
Duration	3-21 September 1985 (low wave conditions) 15-25 October 1985 (storm conditions)

Environment

See Section 4.2.19 (DUCK82).
Hurricane Gloria passed over the site on 26/27 September.
Most studies conducted 500m north of pier to avoid its influence.

Measurements

Waves - waverider buoy 6km from shore (20m water depth), another in 10m of water.
Photopoles to record surf zone breaker heights.
5 electromagnetic current meters and 5 pressure wave gauges along a cross-shore profile (innermost always in surf zone).
4 tripod-mounted pressure gauge/current meter instruments for longshore variations in offshore velocity field.
Vertical array of current meters on sled.
Radar system for field surface currents.
Sediment properties - Remotely operated coring system. Grain size analysis of sand in sediment traps.
Sediment transport - Streamer sediment traps for longshore transport rate.
Cross-shore array of 5 sets of electromagnetic current meters, pressure sensors and optical backscatter suspended sediment sensors (OBSS).
2 tripods containing electromagnetic current meters, pressure wave gauges and OBSS sensors. Dyed sand near the tripods monitored by divers.
Bed levels - Zeiss total survey instrument from amphibious buggy (the CRAB), surveying about 500m longshore distance, to 1km offshore, with profiles 25m apart. 10 surveys between 3 and 20 September, and frequently during October phase (up to 6 times daily on some profiles). Another survey area of 25 profiles from dune to 9m water depth, 580m either side of pier.
Pre- and post-storm surveys covering Hurricane Gloria.
Meteorology - Wind speed and direction.

Applications

Useful data set on bar evolution through a storm. 3-D topography developed (crescentic bar) so data is probably not useful for profile model validation. It is not clear what tidal information is available.

References

See also Section 4.2.19 (DUCK82).
Beach and Sternberg (1987), Bodge and Kraus (1991), Ebersole and Hughes (1987), Fields and Weishar (1987), Hands (1987), Holman and Lippman (1987), Holman and Sallenger (1986), Howd and Birkemeier (1987b), Hubertz et al (1986), Hubertz et al (1987), Kraus and Dean (1987), Kraus et al (1989), Long and Hubertz (1986), Mason et al (1987), Miller et al (1983), Sallenger et al (1986), Weisher and Meadows (1987), Wright, Boon et al (1986).

4.2.22 *Duck, USA (1986)*

Experiment No.	US37
Title/Organisation	SUPERDUCK Coastal Engineering Research Center (CERC) Field Research Facility (FRF)
Duration	September 1986 (low wave conditions) October 1986 (storm conditions)

Environment

See Section 4.2.19 (DUCK82).
600m long region, centred 500m north of pier, used for most experiments.
September phase wave heights always below 1.5m. Two large northeasters occurred during the October phase.

Measurements

Continuous FRF measurements of hydrodynamics.
Linear wave array - 10 pressure gauges (9 in longshore line) all in about 8m of water (0.5m above bed).
Longshore current array - 10 2-component electromagnetic current meters in a longshore line.
Cross-shore pressure wave array - 7 pressure gauges in cross-shore line (from 1.3 to 3.25m water depth).
South tripod - 1 pressure gauge, 1 2-component current meter.
FRF pier - 1 combination PUV gauge for directional wave spectra, 5 wave gauges. Also atmospheric pressure and air temperature measurements, plus anemometer for wind speed and direction.
Bed levels - 600m x 600m region, centred on primary instrument hire, surveyed with FRF Coastal Research Amphibious Buggy (CRAB) Zeiss surveying system.
20 profile lines up to 600m long surveyed 23 times (roughly weekly in September, daily in October).
Wave angle, width of surf zone, water temperature and density also monitored.
An additional 30 experiments by various institutions.

Non-storm wave studies:

Surf Zone Sediment Trap - portable traps together with 1 or 2 electromagnetic current meters. Temporal sampling. Longshore sampling, consistency checks. Additional profile surveys. Analysis of trapped sand samples.
Photopole - cross-shore line of 22 photopoles jetted into bed in surf zone and just outside. Water surface fluctuations filmed.
Surf Zone Rip Currents - portable array of 2 electromagnetic current meters and pressure wave gauges.
Surf Zone Waves - 2 resistance wave staff gauges and 2 pressure sensors attached to photopoles for comparison.
Littoral Environmental Observation (LEO).

Storm wave studies:

Infragravity Wave Climatology - Longshore array of 10 electromagnetic current meters in surf zone, to measure longshore wavenumber spectrum of infragravity wave energy.
Nearshore Profile Response - 7 pressure and 7 sonar gauges in cross-shore array, to relate profile changes to hydrodynamics.

Infragravity Wave Dynamics - Remote sensing. Video.
Wind and Wave Forcing of Mean Nearshore Currents - Sled, orientated normal to local bathymetric contours. 2 differential pressure slope arrays and an absolute pressure reference gauge used to measure radiation stress gradient. Mast-mounted anemometer. 3 current meters for vertical structure.
Momentum Balance and Surface Slope - Longshore pressure gradient with 7 gauges, covering 27km. 2 tripods each with electromagnetic current meter and pressure sensor (PUV) in 7 and 12m of water.
Inner-Shelf Dynamics (Process Measurements) - 2 bottom-mounted tripods with PUV wave and current meter and vertical array of 5 Optical Backscatter Sensors, deployed outside surf zone.
Inner-Shelf Dynamics (DARTSII) - Digital Automated Radar Tracking System for directional wavenumber spectra measurements, from breaker zone to 4km offshore.
Foreshore Sedimentation Processes - 3 or 4 short cores collected along 10 profile lines at high and low tides during and after one storm, otherwise just at low tide. Upper swash limit mapped.
Sedimentary Micro Structures - Cores across surf zone analysed by x-ray and microscope.
Effects of Coastal Processes on Sand-Dwelling Organisms - Surface sediment cores from morning low tide analysed for interstitial organisms.
Application of a Photographic System for Evaluation of Sediment Transport using Fluorescent Tracers - Fluorescent tracer sands monitored with a benthic sediment profiling camera which makes vertical slice to image sediment-water interface. 16 sample stations on 61m x 61m grid, monitored on 2 days, 1.3-1.5km offshore. 3 sizes of tracer (0.44, 0.34, 0.12mm) of different colours injected and monitored after 22-28h.
Short-Term Disturbance Effects of Storms on the Subtidal Benthic Communities of Duck, NC - Grab sampler and benthic profiling camera along a cross-shore line from 4m to 14m depth, after storm.
Dune Erosion - 2 days of dune construction and erosion experiments.

All weather studies:

Offshore Material Placement - Sediment traps connected in a diamond pattern, installed by divers to monitor dredged material seaward of surf zone (11m water depth). Vertical logarithmic spacing of traps. 3 deployments, one with PUV wave and current gauge.
Sea scour - coloured sand pipes installed at various depths and locations on profile normal to beach.
Seabed Drifters - Two types of weighted drifters deployed for nearshore current patterns. Hydrophone from pier and a trawler used to track path.
Nearshore Wind Stress - 2 sets of meteorological sensors for mean air temperature, humidity, sea surface temperature, wind speed, wind direction, and high frequency response devices for air velocity, temperature and humidity.
Marine Radar - Study to assess capability of radar for determining wave field.
Coastal Ocean Dynamics Application Radar (CODAR) - 8 days of continuous wave and current data, up to 40km from shoreline.
Linear Array Wave Gauge High-Resolution Directional Wave Array - Long-term offshore linear array of 10 pressure sensors, for directional wave information, installed in 8m water depth parallel to survey baseline.
Remote Acoustic Doppler Sensing System - Doppler current profiler for near surface measurements.

Short Baseline Slope - A 3.7m right triangle slope array, with nested 2.4m and 1.8m slope arrays of high resolution pressure sensors, to verify whether these could provide accurate estimates of mean wave direction.
Measurement of Long-Period Microseisms - Long-period vertical seismometer data analysed for correlations with ocean wave energy.
Improvement of Operational Surf Forecasts - tests of real-time operation of a surf forecasting model.

References
Birkemeier et al (1989), Byrnes (1989), Crowson et al (1988), Ebersole and Hughes (in press), Hughes et al (1987), Katori (1982), Katori (1983), Kraus (1987), Kraus et al (1988), Kraus and Nakashima (1986), Rosati and Kraus (1988), Rosati and Kraus (1989), Rosati et al (1990), Stauble et al (in press).

4.2.23 *Silver Strand Beach, USA*

Experiment No.	US41
Title/Organisation	USA (Los Angeles District) Corps of Engineers (LADCOE)
Duration	December 1988-November 1990

Environment

Underwater disposal mound constructed off Silver Strand State Park, using material dredged from San Diego harbour. Berm was approximately 400m (longshore length) by 200m (cross-shore length), with an average relief of 1.5m. The berm crest was about 3m below the low water line. Berm was constructed from approximately 150,000m^3 of medium sized sand.
Some waves are blocked by islands. Waves approach site from the north west to the south. Significant wave heights were < 1m 93% of the time during the experiment. Average period was 8s. No tidal information is given in the references. Annual longshore sediment transport about 180,000m^3/yr.

Measurements

Waves - Bottom-mounted pressure and velocity gauge in 10m of water, 500m NNE of disposal area. 114 days of measurement giving directional wave spectra. Also data available from wave buoys and arrays 5km south of study site in 10m of water.
Bed levels - 7 profile lines, from beach berm to 10m water depth, surveyed every few months.

Applications

Potentially useful for profile and area model validation, however there is no water level information. There were also no control surveys away from the berm and no supporting hydrodynamic or sediment transport data.

References

Andrassy (1991), Juhnke et al (1989), Larson and Kraus (1992).

4.2.24 Duck, USA (1990)

<u>Experiment No.</u> US47

<u>Title/Organisation</u> DELILAH (Duck Experiment on Low-frequency and Incident-band Longshore and Across-shore Hydrodynamics)
Coastal Engineering Research Center (CERC)
Field Research Facility (FRF)

<u>Duration</u> 1-21 October 1990

<u>Environment</u>
See Section 4.2.19 (DUCK82).

<u>Measurements</u>
Waves - 2 wave gauges on sled.
15 element crossed array of pressure sensors in 8m water depth to measure directional wave spectrum. Cross-shore array of pressure sensors for waves and setup. Video for setup at shoreline and infragravity waves.
Currents - 9 electromagnetic current meters in a cross-shore array, plus two long-shore arrays of 10 electromagnetic current meters. Instrumented, mobile sled with current meters for vertical structure.
Bathymetry - Measured daily (except during largest waves) using Coastal Research Amphibious Buggy (CRAB) - Zeiss surveying system. 20 profile lines to 4m depth. Video.
Meteorology - 2 anemometers (one on sled) for wind speed and direction.

<u>Applications</u>
Erosive and accretive events observed, including formation and migration of a bar system. Likely to be useful data for profile model validation.

<u>References</u>
Birkemeier (1991), Howd et al (1991), Scott et al (1991).

5 Conclusions

1. A need exists for more extensive validation of coastal numerical models against field data, so that they can be applied with more confidence to practical engineering problems.

2. Numerous field measurements of coastal processes have been made but few are ideal as test cases for the kinds of numerical models currently in use or under development. Many are nevertheless invaluable in other ways (eg improving crucial elements of the models such as sediment transport formulae).

3. Most measurements are directed towards solving a site-specific engineering problem, or investigating (often poorly understood) physical processes.

4. There is a clear lack of data to check predictions of morphodynamic changes in response to measured hydrodynamic boundary conditions. In particular, continuous, directional wave data and accurate, frequent bathymetric surveys are required.

5. The most useful sets of measurements for profile model validation are those undertaken at Duck, North Carolina, USA. Many lessons can be learnt from these large data collection programmes and applied to other sites, for example in macrotidal regions in NW Europe, where there is a shortage of data.

6. None of the experiments reviewed appear ideal for area model validation, although some data sets deserve further investigation, and an experiment in Spain is planned specifically with this aim, as part of the EC MAST-G8M programme (Experiment No. S1). The larger scale of area models presents problems that have not been addressed in measurement programmes designed with profile models in mind.

7. The aims and objectives of any data collection project must be decided in advance. Model validation is unlikely to be achieved using data that has been collected with some other purpose in mind, although other experiments may be run concurrently with obvious benefits. The use of modelling in planning and modifying a field programme is invaluable.

8. Whilst application of the models to practical engineering problems must be the ultimate aim, validation on relatively simple, easy-to-model sites is an essential stage in model development.

9. Sediment transport and morphological changes in coastal regions are the results of complex interactions between waves, currents, sediments and bottom topography. Existing experiments have demonstrated some of the shortcomings of the models currently in use (which are often depth- and wave-period-averaged, for example). However, little effort has been directed towards assessing how good or bad the final model results are when applied to real-life situations. This requires larger-scale measurements but not necessarily detailed small-scale measurements of physical processes. After this kind of validation, more detailed

measurements of a particular process can be used to improve the model, before comparing again with the test case.

10. A wealth of experience has been built up on both the organisation and instrumentation required to undertake a coastal measurement programme, in a variety of countries and including severe surf-zone conditions. Many lessons have been learnt and problems overcome. This experience should prove invaluable in planning any future measurement programme.

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Tables

Table 1 Site requirements for validation of coastal models

Profile Model	Area Model
Parallel depth contours (long, straight beach)	General depth contours
Sandy bed only	Sandy bed only
Large cross-shore transport rates and changes	Dominated by longshore transport (preferably)
No structures that destroy longshore uniformity (eg groynes, breakwaters or offshore bars)	Structures possible
Measurements on 1 or 2 cross-shore profiles (several hundred metres in length)	Measurements on grid (a few square kilometres)
Fine grid to resolve longshore bars (a few metres spacing)	Medium grid
Measurable bed evolution over timescale of experiment	Measurable bed evolution over timescale of experiment

Table 2 Summary of available field data

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
A1	1971-1977	Moruya, Broulee and Bracken Beaches, Australia	University of Sydney	1 or 2 days & long term morphology		W,C,S,B	Wright et al (1979)
A2	1976-	Goolwa, Seven, Narabeen, Collaroy & Fishermens Beaches, Australia	University of Sydney	1-6 years		S,B	Short & Hesp (1982)
A3	1977-1984	Narrabeen Beach, Australia	University of Sydney	6½ years		W,S,B	Wright et al (1985), (1987)
A4	1979-1982	26 beaches, Australia	University of Sydney	Various		B	Wright & Short (1984)
A5	1980-	Seven Mile Beach, Australia	University of Sydney			B	
A6	1980	Cable Beach, Broome, Western Australia	University of Sydney	20 days	600m x 1.5km	W,C,T,S,ST,B	Wright et al (1982)
A7	1980-1982	Various sites, Australia	NIELSEN		Vertical lines	W,C,S,ST	Nielsen (1984)
A8	1981	Eastern beach, Victoria, Australia	University of Sydney		250m x 150m	W,C,ST,B	Wright, Nielsen et al (1986)
A9	1982-	Bracken Beach, Australia	University of Sydney			B	
A10	1986	Port Phillips Bay, Australia	University of Sydney				
A11	1987	Queensland Coast, Australia	University of Sydney				
A12	1989	Apollo Bay, Australia	Victorian Institute of Marine Studies		Vertical line	W,C,T,S,ST	Black and Rosenberg (1991)
An1		Lobito, Angola				ST	Castanho (1966)

'able 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
Ar1		Mar del Plata, Argentina		13 months		W,ST,B	Caviglia et al (1991)
B1	1979	Black Sea, Bulgaria	KAMCHIYA '74				Belberov (1983)
Be1		Cotonou, Benin				W,ST,B	Sireyjol (1964)
C1	1978	Kouchibouguac Bay, New Brunswick, Canada	University of Toronto			W,C,ST,B,M	Greenwood & Mittler (1984)
C2	1980	Wendake Beach, Georgian Bay, Canada	University of Toronto		150m x 60m	W,C,B	Greenwood & Sherman (1984)
C3	1983	Pointe Sapin, New Brunswick, Canada	C^2S^2 (NERC)	23 days	500 x 300m	W,C,T,S,ST,B	Bowen et al (1986)
C4	1984	Stanhope Lane, Price Edward Island, Canada	C^2S^2 (NERC)	36 days	Vertical line	W,C,S,ST	Bowen et al (1986)
C5	1985	Wymbolwood Beach, Georgian Bay, Canada		2 months	150m x 150m	W,C,S,B	Bauer & Greenwood (1990)
C6	1987& 1988	Bluewater Beach, Nottawasaga Bay Southern Georgian Bay, Ontario, Canada	C-COAST		220m cross-shore line	W,C,T,ST	Greenwood et al (1990)
C7		Queensland Beach, St Margarets Bay, Nova Scotia, Canada	C-COAST		220m cross-shore line	W,C,T,ST	Greenwood et al (1990)
C8	1989	Stanhope Lane, Prince Edward Island, Canada	C-COAST		Vertical line	W,C,T,ST	Van Hardenberg et al (1991)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
C9		Queensland Beach, Nova Scotia, Canada			100m cross-shore line	W,C,ST	Vincent et al (1991)
D1	1982-1983	Kaergaad Plantation, Denmark	DHI	6 months	1500m x 40m trench	W,C,T,S,B,M	Danish Hydraulics Institute (1984)
D2	1987-1988	Trybleskoven & Staenghus, Zealand, Denmark	University of Copenhagen			W,B	Aagaard (1990)
D3	1993-	Denmark	NOURTEC	one year, possibly longer	7km x 1.5km	W,C,T,S,B,M	
F1	1960-1977	Dunkirk, North Sea Coast, France	LNH	Various periods	20km x 8km	W,C,S,ST,B,M	Latteux (1988)
F2	1965-1966	Bas-Champs, France	SOGREAH	6 months	40m x 2km	W,C,T,S,ST,M	Bellesort (1988)
F3		Arachon, Aquitaine Coast, France	SOGREAH	1 day	800m cross-shore line	W,T,S,ST	Bellesort (1988)
F4		Loire Estuary, France	SOGREAH		100km x 3.5km	C,T,S,ST	Bellesort (1988)
F5	1988	Bay of Seine, France	SAM		Vertical line	C,ST	Levoy & Avoine (1991)
F6	1991	Cotentin Peninsula, Channel Islands Bay, France	ROMIS	4 days/ month	80km x 50km	W,C,T,S,ST,B, M	Levoy & Avoine (1991)

'able 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
G1		Germany	Sandbewegi ng in Küstenraum				Führböter (1979)
G2	1987-1991	Sylt Island, North Sea, Germany	Leichtweiβ Institute			W,C,B,M	Dette & Oelerich (1992)
G3	1993-	Germany	NOURTEC	one year detailed then ongoing	2km x 500m	W,C,T,S,B,M	
Gr1	1986-1987	Kokkino Limanaki Linoperamata and Rio Beaches, Greece	LHW	Various periods	300m x 15m	W,C,S,B	Moutzouris (1988a)
I2		Montalto di Castro, Grosseto, Italy	Tecnomare	Every 3 months for 1½yrs		W,S,B	
I3		Paola - S Lucido, Cosenza, Italy	Tecnomare			W,S,B	
I4		Gaeta & Formina Coast, Latina, Italy	Tecnomare			W,S,B	
I5		Tiber river mouth, Roma, Italy	Tecnomare			W,S,B	
IC1		Ivory Coast				ST	Bijker (1968)
J1		North Akashi, Miyazu, Japan				ST,B,M	Ishihara et al (1958)
J2		Miyazu, Japan				ST, M	Adachi et al (1959)
J3		Fukue, Atsumi, Japan				W,ST,M	Sato (1962)
J4	1962-1966	Port Kashima, Japan				W,C,S,ST,B	Sato & Tanaka (1966)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
J5		Isonura & Matsuko Beaches, Japan	Osaka University			W,S,T	Sawaragi & Deguchi (1978)
J6	1978-1982	4 beaches in Japan	AJIGAURA 78 & 79 SHIMOKITA HIRONO -1, -2 OARAI 80, 81, 82		100m x 5km	W,C,S,ST	Kraus et al (1982)
J7	1978-1982	Oarai Beach & Ajugura Beach, Ibaraki Coast, Japan	Japanese NERC	7 series		W,C,S,ST,B,M	Horikawa & Hattori (1987)
J8	1978-1986	5 beaches in Japan				W,T,B	Kuriyama et al (1988)
J9	1980-1981	Naka Beach, Ibaraki Prefecture, Japan	University of Toronto		100m x 150m	W,C,ST,B,M	Greenwood & Mittler (1984)
J10	1982-1984	Bashinji Coast, Ehime Prefecture, Japan	Ehime University	3 months (twice)	2 vertical lines	W,C,T,S,ST	Ifuku & Kakinuma (1988) Ifuku (1988)
J11	1987	Iioka Coast, Japan		7 months	300m x 300m	W,C,ST,B	Uda et al (1991)
J12	1987	Kashima, Japan	HORF	4 days	430m pier	W,C,T,ST	Nadaoka et al (1988)
J13	1988-1989	Akashi Strait & Osaka Bay, Seto Inland Sea, Japan			30km x 40km	C,T,ST	Fujiwara et al (1991)
J14	1987-1990	Kashima, Pacific Coast, Japan	HORF	Daily for 3½ years	430m pier	W,B	Katoh & Yanagishima (1992)
J15	1988-1990	Ogata Coast, Japan	TOP		250m x 100m	W,C,T,ST,B	Kawata et al (1990)
J16	1988	Kashima, Japan	HORF	4 periods of 9 to 20 days	430m pier	W,C,T,B	Kuriyama (1991)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
N1		Whole Dutch Coast, Netherlands		Yearly for 30 years	3 points every 1km	B	
N2		Wadden Sea basins, Netherlands		Every 5 years for 60 years	250m x 250m grid	B	
N3		Whole Dutch Coast, Netherlands		Yearly for 30 years	800m cross-shore line, every 250m	B	
N4		Western Sheldt Estuary, Netherlands		Every 2-5 years for 20 years	50m x 50m grid	B	
N5		Friese Zeegat, Netherlands		Every 5 years for 20 years	50m x 50m grid	B	
N6	1981	Egmond, Netherlands	TOW	2 months	250m cross-shore line	W,C,T,S,ST, B,M	Derks & Stive (1984)
N7	1982-1983	Egmond, Netherlands	TOW	5 months	100m x 2.5km	W,C,T,S,ST, B,M	Derks & Stive (1984)
N8	1983	Eastern Scheldt Estuary, Netherlands	VESSEM		Vertical line	W,C,S,ST	Van Rijn (1991)
N9	1987	Eastern Scheldt Estuary, Netherlands	VOOGT		Vertical line	C,S,ST	Voogt et al (1991)
N10	1989-1991	Egmond, Netherlands	DH		Vertical line	W,C,T,ST,B	Van Rijn & Kroon (1992) Kroon (1991)
N11	1993-	Netherlands	NOURTEC	one year detailed then ongoing	15km x 2km	W,C,T,S,ST, B,M	

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
P1	1974	Lubiatowo, Baltic Coast, Poland	LUBIATOWO -74 (CMEA)	36 days	6km cross-shore line	W,C,S,ST,M	Druet et al (1976)
P2	1976	Lubiatowo, Baltic Coast, Poland	LUBIATOWO '76 (CMEA)	53 days	3.5km cross-shore line and 1km^2 area	W,C,S,ST,B,M	Basinski (1980)
P3	1983	Lubiatowo, Baltic Coast, Poland		5 days		W,C,ST	Owczarczyk et al (1989)
S1	1993	El-Saler Beach, Valencia, Spain	CEPY-CEDEX/ MAST-G8M		21 profiles 2km long	W,C,S,B	
SA1	1979-1985	Port of Richards Bay, South Africa	CSIR	6 years		W,T,S,B	Laubscher et al (1991)
SA2	1983	Sondags River, Port Elizabeth, Algoa Bay, South Africa	CAESAR PE1	5 days	200m x 100m	W,C,S,ST,B	Swart (1984)
SA3	1984	Sondags River, Port Elizabeth, Algoa Bay, South Africa	CAESAR PE2	10 days		C,B	Swart (1984)
SA4	1986	Walker Bay, South Africa	CAESAR WB1	4 days	700m long-shore line	W,C,T	Swart (1988)
SA5	1986	Walker Bay, South Africa	CAESAR WB2	9 days	700m x 75m	W,C,T	Swart (1988)
SA6	1987	Walker Bay, South Africa	CAESAR 3	7 days	150m x 100m	W,C,T,S,ST,B, M	Schoonees (1991)
SA7	1990	Walker Bay, South Africa	CAESAR 4		Cross-shore line	W,C,T,ST,B	Coppoolse et al (1992)
SA8		Walker Bay, South Africa	CSIR			W,ST	Mocke & Smith (1992)

'able 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
T1	1974-1976	Taichung Harbour, Taiwan	National College of Marine Science & Technology			W,ST,B,M	Hou et al (1980)
T2		Lin-Kou, Taiwan				W,S,B,M	Hou (1988)
U1		Black Sea, Ukraine				W,ST,B	Voitsek-hovich (1986)
UK1	1949-1950	Marsen Bay, County Durham, UK	University of Nottingham	Weekly for 2 years	1.2km x 100m	W,B,M	King (1953)
UK2	1960-1990	Lincolnshire coastline, UK		Monthly for 30 years	100m cross-shore x 20km (every 1km)	B	HR (1991)
UK3	1968-1970	Pendine Sands, Carmarthen Bay, Wales, UK		3 monthly surveys	8km x 1.5km	W,C,ST,B	Jago & Hardisty (1984)
UK4	1973-1975	Maplin Sands, Outer Thames Estuary, UK	HR		Vertical line	W,C,T,S,ST	Owen & Thorn (1978)
UK5	1976-1977	Margram Beach, Swansea Bay, Wales, UK	IOS			W,C,ST	Wilkinson (1980)
UK6	1977-1978	Boscombe Pier, Bournemouth, UK	HR		Vertical line	W,C,T,S,ST	Owen & Thorn (1978)
UK7	1977	Ynglas, Dyfed, Wales, UK	Polytechnic of Wales	1 month	1km x 250m	B	Williams et al (1978)
UK8	1979-1981	Hells Mouth Bay, Llyn Peninsula, Wales, UK	University of Wales	Fortnightly for 3 years	5km x 200m	B	Darbyshire (1993)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
UK9	1984	Sea Palling, Norfolk, UK	CIRIA	22 days	250m x 80m	W,C,B	CEEMAID (1984a)
UK10	1984	Anderby Creek & Sandilands, Lincolnshire, UK	CIRIA	22 days	3 points on groyne	W,C,B	CEEMAID (1984b)
UK11	1985-1988	Ballakinnag Cronk, Isle of Man, UK		3 days (+ 3 years beach surveys)	120m x 200m	W,C,B	Horn (1993)
UK12	1985	Ainsdale Sands, Merseyside, UK	University of Liverpool	11 days	600m cross-shore profile	W,C,B	CEEMAID (1985)
UK13	1988	Taw Estuary, England, UK	HR		50m cross-shore line	C,S,ST,B	Soulsby et al (1991)
UK14	1990	Llangennith Beach, Wales, UK	B-BAND	13 days	Vertical line	W,C,T,ST	Russell et al (1991)
UK15	1990	Slapton Sands, Start Bay, English Channel, UK	University of Hull	3 days	Point	ST	Hardisty (1991)
UK16	1990-1991	Spurn Point Field Station, Humberside, UK		9 months	120m cross-shore line	W,S,B	Hoad (1991)
UK17	1991	Spurn Head, UK	B-BAND		Vertical line		
UK18	1992	Seaton, Cornwall, UK	B-BAND		Vertical line		
US1	1937-1945	Scripps Pier, California, USA				B	Shepard (1950)
US2		Anaheim Bay, California, USA				W,B	Caldwell (1956)
US3		South Lake Worth, Florida, USA				ST,B,M	Watts (1953)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
US4	1953-1958	Cape Cod, Massachusetts, USA	WHOI	At least monthly for 5 years	10km of coastline	B	Ziegler et al (1959)
US5		Cape Thompson, Alaska, USA				W,ST,B	Moore & Cole (1960)
US6		Ventnor, New Jersey & Nags Head, North Carolina, USA				W,ST,B	Fairchild (1977)
US7		El Moreno & Silver Strand Beaches, USA				W,ST	Komar & Inman (1970)
US8	1970	Ludlam Island, New Jersey to Cape Cod, Massachusetts, USA	CERC	4 days		W,T,B	DeWall et al (1977)
US9		Delray Beach, USA	Every 2-5 years for 20 years	Active zone x 6km		B	
US10		Ocean City, USA				B	
US11		Point Megu, California, USA				W,ST	Duane & James (1980)
US12		Lake Michigan, USA				W,ST,B	Lee (1975)
US13	1974	Debidue Island, South Carolina, USA	University of South Carolina	14 days (quarterly)		W,C,T,B,M	Kana (1977)
US14		Channel Islands Harbour, California, USA				W,ST,B	Bruno et al (1981)
US15		Santa Rosa Island, USA				ST	Chang & Wang (1978)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
US16		North Bull Island, USA				ST	Knoth & Nummedal (1977)
US17		Torrey Pines Beach, California, USA				W,T,B	Aubrey et al (1976)
US18	1977	3 sites in North Carolina & New Jersey, USA	CERC	12 days	Total of 100km of coast	W,S,B,M	Birkemeier (1979)
US19	1977	Price Inlet, South Carolina, USA	University of South Carolina	22 days	3 vertical lines	W,C,ST,M	Kana (1978)
US20	1978	Torrey Pines Beach, California, USA	NSTS 1	20 days	500m x 500m	W,C,T,S,ST,B, M	Gable (1979)
US21	1978	Duck, North Carolina, USA	DUCK-X			W,S,ST,M	Kana & Ward (1980)
US22	1979	Twin Harbor Beach, Washington, USA	University of Washington	11 months	Vertical line	W,C,S,ST,B	Downing (1984)
US23	1979-1980	Leadbetter Beach, Santa Barbara, California, USA	NSTS 2	30 days (+ 14 month sediment trap study)	200m x 200m	W,C,T,S,ST,B, M	Gable (1981)
US24	1979	Folly Beach, South Carolina, USA		2 months	140m x 10km	W,T,B	Tye (1983)
US25		Duck, North Carolina, USA				W,ST,B	Bodge (1986)
US26		Torrey Pines & Scripps, California, USA				W,ST,B	White (1987)
US27	1979-1980	Russian River Mouth, Northern California, USA	GEOPROBE	11 months	Vertical lines	W,C,ST	Cacchione et al (1987)
US28	1981	Rudee Inlet, Virginia Beach, Virginia, USA	NSTS 3	5 months		W,ST,B	Seymour (1987a)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
US29	1981-1984	USA	CERC			B	Howd & Birkemeier (1987a)
US30	1981-1991	Duck, North Carolina, USA	CERC FRF	Every 2 weeks for 10 years	561m long pier	W,B	Larson & Kraus (1992)
US31		Duck, North Carolina, USA	CERC FRF		561m long pier	W,C,T,B,M	CERC monthly reports
US32	1982	Duck, North Carolina, USA	DUCK82			W,C,T,S,ST,B,M	Mason et al (1984)
US33		Myrtle Beach, South Carolina, USA				B	Kana & Svetlichny (1982)
US34	1984-1985	Duck, North Carolina, USA	CERC	14 months	1km cross-shore profile	W,C,T,B,M	Stauble (1992)
US35	1984	San Marine, Oregon, USA	Oregon State University	5 days	4m x 4m	W,C,T,ST	Beach & Sternberg (1988)
US36	1985	Duck, North Carolina, USA	DUCK85	19 days + 11 days	500m x 1km	W,C,T,S,ST,B,M	Mason et al (1987)
US37	1986	Duck, North Carolina, USA	SUPERDUCK	22 days + 22 days	150m x 1km	W,C,T,S,ST,B,M	Birkemeier et al (1989)
US38	1987-1988	El Segundo Beach, California, USA		200 days	300m x 4km	B	Anders & Egense (1989)
US39	1988	Ludington, Lake Michigan, USA	LUDINGTON	8 days	100m x 200m	W,C,S,ST,B	Rosati et al (1991)
US40	1988-1989	Canaveral National Seashore, Atlantic Coast, Florida, USA		Various days	100m cross-shore line	W,C,T,S,B	Allen et al (1991)

Table 2 Continued

No.	Year	Location	Title/ Organisation	Duration	Area	Measurements	Reference
US41	1988-1990	Silver Strand, California, USA		2 years (approx monthly)	600m x 600m	W,B	Andrassy (1991)
US42	1989	Twin Harbours, Washington, USA	State University	1 tide	Vertical line	C,S,T	Beach & Sternberg (1991)
US43	1989	Ocean City, Maryland, USA				W,B	Houston (1990)
US44	1989	USA				W,B	Eiser & Birkemeier (1991)
US45	1989	USA				W,B	Glover & Hales (1991)
US46	1989	South Carolina, USA			100km of coastline	B	Stauble et al (1990)
US47	1990	Duck, North Carolina, USA	DELILAH		400m x 200m	W,C,T,B	Birkemeier (1991)
US48		Topsail Beach, North Carolina, USA		1 year		B	McNinch & Wells (1992)