INT. J. REMOTE SENSING, 1998, VOL. 19, NO. 8, 1455–1460

Cover

A digital elevation model of the inter-tidal areas of the Wash, England, produced by the waterline method

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Figure 1 (cover) shows a digital elevation model (DEM) of the inter-tidal areas within the Wash, England, produced by the waterline method using ERS-1 SAR images and hydrodynamic modelling.

The waterline method (Cracknell *et al*. 1987, Koopmans and Wang 1995, Mason *et al*. 1995, Ramsey 1995) involves finding the georegistered positions of the shoreline (the land–sea boundary) from a remotely sensed image using image processing techniques, then superimposing the heights of the shoreline relative to mean sea level on the corresponding positions. These heights are predicted using a hydrodynamic tide-surge model run for this area with the atmospheric conditions pertaining at the time of image acquisition. From multiple images obtained over a range of tide and surge elevations, it is possible to build up a set of heighted shorelines within the inter-tidal zone, and from this a gridded DEM may be interpolated. Such a DEM is useful for developing improved tide-surge models, and changes in the DEM over time allow measurement of sediment mass transfers in the inter-tidal zone due to storm or seasonal changes.

Figure 2 shows the shorelines used to produce the DEM. These were extracted from thirteen ERS-1 SAR images obtained mainly during the winter months of 1992–1994, using the semi-automatic shoreline delineator described in Mason and Davenport (1996). They were heighted using shoreline elevations generated by a hydrodynamic tide-surge model of the English east coast similar to that of Flather (1994). Model heights were corrected using local tide gauge information as described in Davenport *et al*. (1996). The lowest shoreline present had a mean elevation of $-2{\cdot}8$ m ODN, whilst the highest shoreline had a mean elevation of $2{\cdot}9$ m ODN.

A raster DEM was interpolated from the heighted shorelines using universal

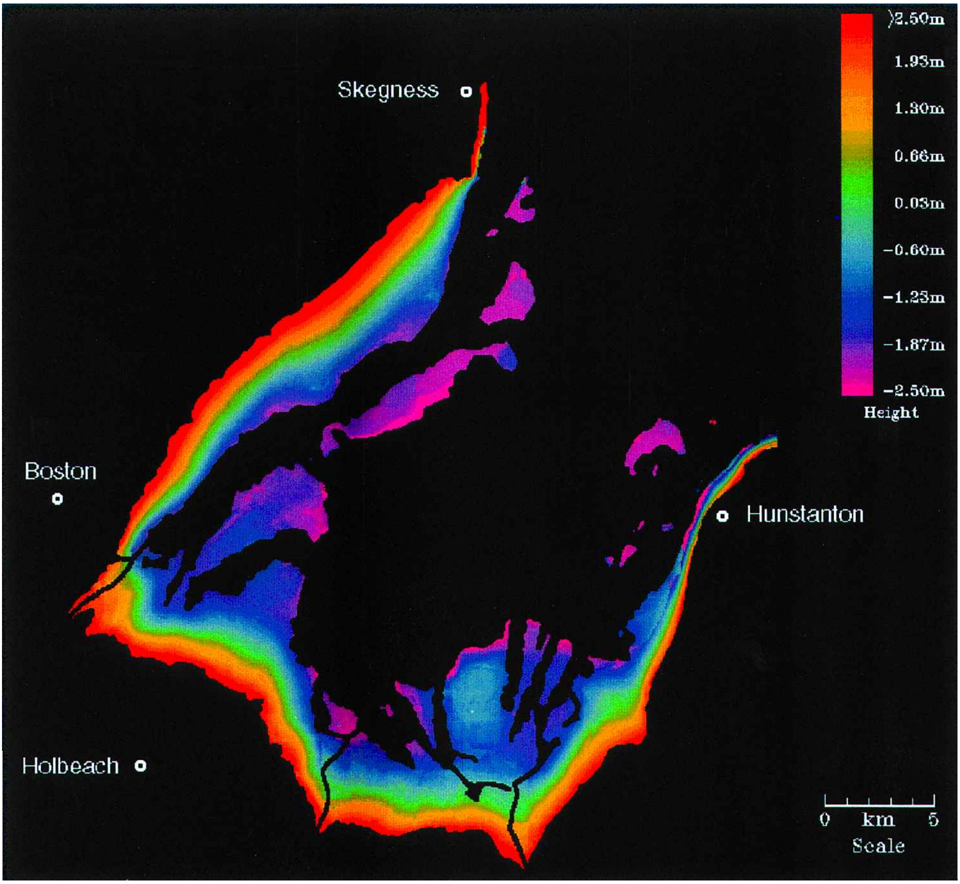

Figure 1. A digital elevation model (DEM) of the inter-tidal areas of the Wash, England.

block kriging (Mason *et al*. 1996). This involved kriging in the two horizontal spatial dimensions and also in time, allowing a linear drift in the direction perpendicular to the local shoreline to account for the slope of the beach. The experimental variograms were similar to those found for the western Wash (Mason *et al*. 1996). The cover figure was produced using a block size of 60 m × 60 m × 1100 days.

Figure 3 shows the map of estimation standard deviations generated in kriging. The average standard deviation of the interpolated heights is 22 cm. Confidence in these estimation errors was provided by a jackknife analysis comparing beach profile heights measured in summer 1993 with heights estimated at the profile sample points using nearby shoreline data. The UK Environment Agency (Anglian Region) measures beach heights along transects up to 2.5 km long from the sea wall perpendicular to the sea edge over most of this coastline. Transects are generally spaced at 1 km intervals and are sampled at 20 m intervals, using conventional geodetic levelling in the inter-tidal zone. The difference between the observed and the estimated heights, after normalization by the estimation standard deviation, was found to have a mean close to 0 and a standard deviation close to 1.

The waterline method gives the advantage of being able to construct an inter-

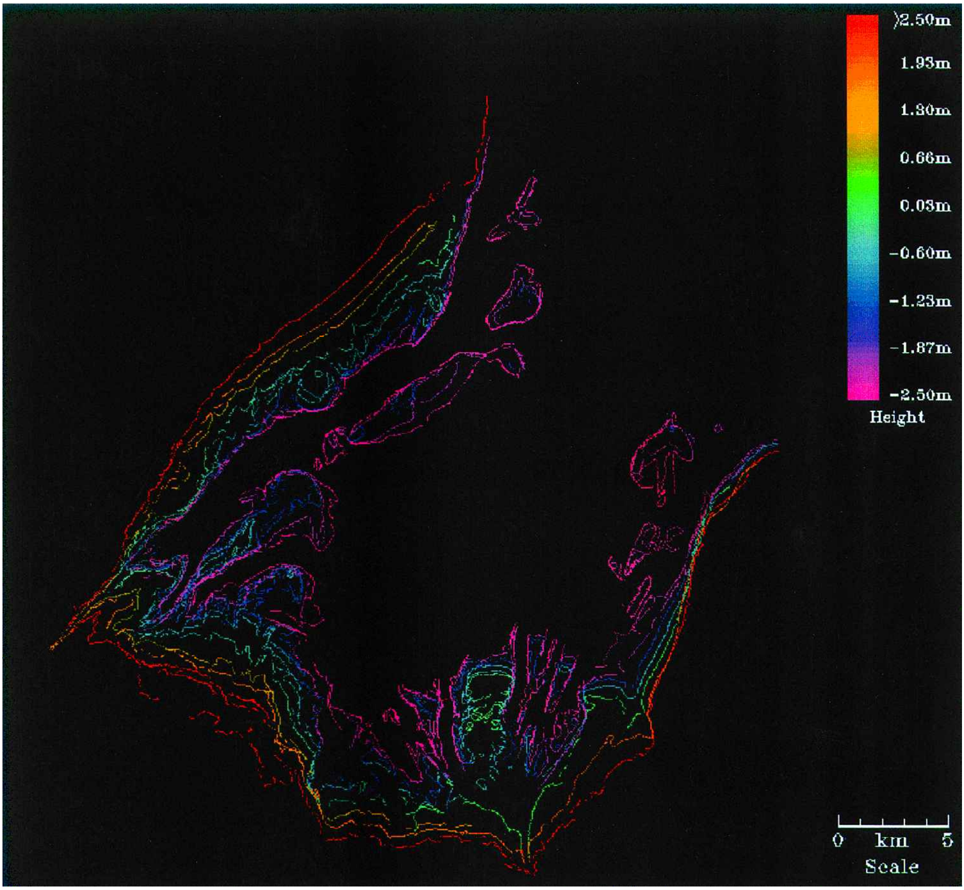

Figure 2. Shorelines used to construct the DEM.

tidal DEM over large areas relatively rapidly and cheaply. As the height errors it produces reduce with beach slope, the method is particularly useful in tidal flat regions such as the Wash, with its vast inter-tidal area of 29 770 ha. The Wash shoreline length is about 100 km (Pye 1995), still only approximately half the total shoreline length in the ERS-1 SAR scene containing it.

Figure 4 (*a*) is an extract from 1 : 25 000 Ordnance Survey (OS) maps of the area (last revised 1977) including the mean high and low water marks. Figure 4 (*b*) shows the shoreline DEM flooded to mean low water level to match the low water mark on the map (the shoreline DEM extends below mean low water). Comparison of these shows evidence of some changes in the intervening period, for example in the area of the Skegness Banks off Gibraltar Point, south of Skegness. These are borne out by surveys carried out as part of the Mablethorpe to Skegness beach nourishment programme (Swiers *et al*. 1996).

Figure 1 must be regarded as a first approximation to an inter-tidal DEM of the Wash, as the hydrodynamic model itself uses estimates of the inter-tidal bathymetry obtained from hydrographic charts in order to produce its shoreline heights. The next step will be to feed the preliminary DEM back into the model to achieve an improved set of shoreline heights from which a more accurate DEM could be

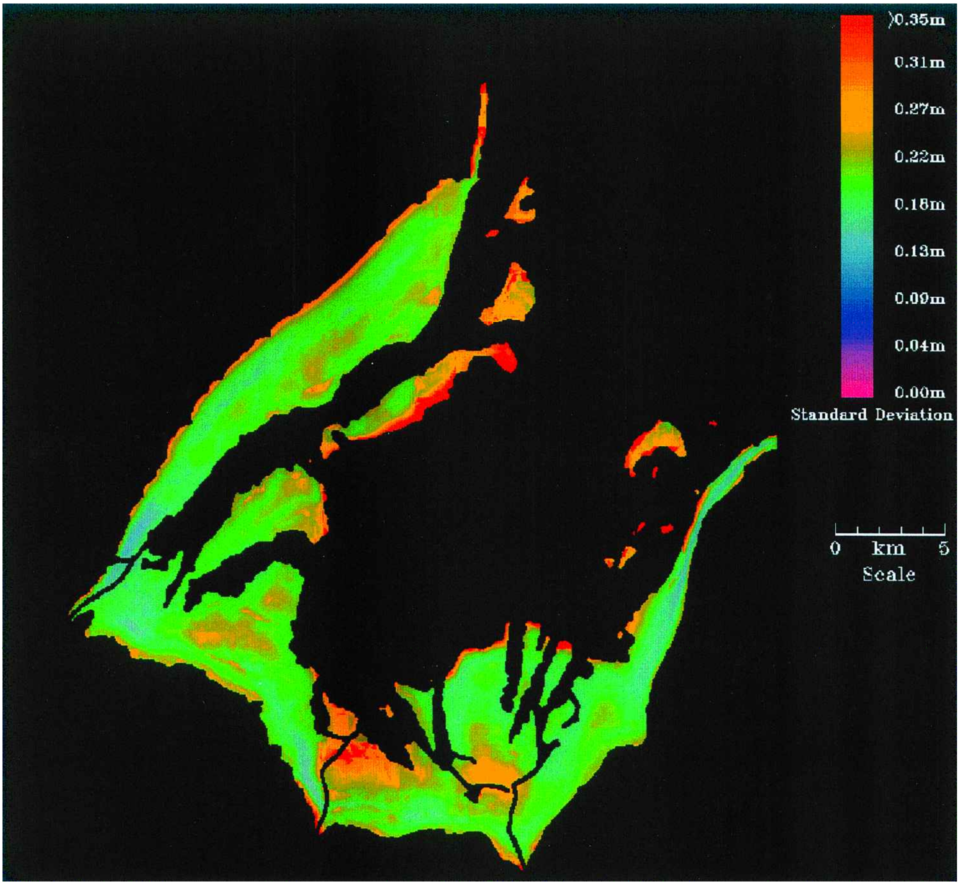

Figure 3. Estimation standard deviations.

constructed. Significant further improvements to the hydrodynamic modelling should also result from an on going study to develop methods of assimilating local tide gauge and other data collected near overpass time into the model run. The method will also be extended to other beach types in other areas.

A user requirements study has been conducted to survey potential users of inter-tidal DEMs and their requirements (Davenport *et al.* 1996). A set of basic requirements for any inter-tidal DEM construction technique was identified. In particular it was found that a large body of users require a vertical height accuracy of 10 cm. For the waterline technique, this should be possible on flatter beaches by improving the hydrodynamic model heighting accuracy as planned. The lower cost of the technique compared with the costs of other methods of generating inter-tidal DEMs should then make it an attractive survey option for such beaches (Davenport *et al.* 1996).

Acknowledgments

This work was funded under the NERC Land–Ocean Interaction Study (LOIS), the BNSC Earth Observation LINK Programme, ESA's ERS Pilot Project Programme, and NERC contract F60/G6/12. Thanks are due to the UK

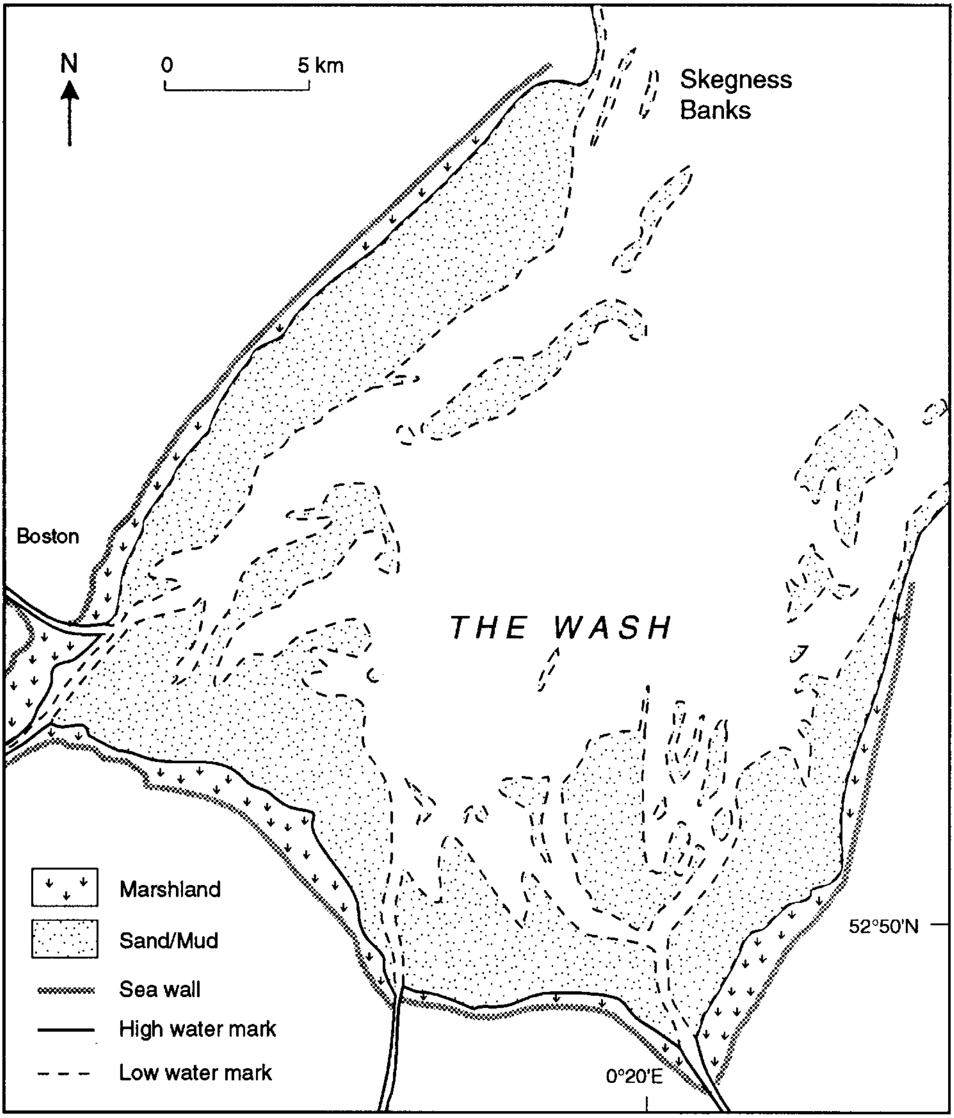

Figure 4. (*a*) Extract from 1:25 000 Ordnance Survey maps. (© Crown copyright C4/88-18).

Environment Agency for supplying beach transect and tide gauge data. This is LOIS publication number 303.

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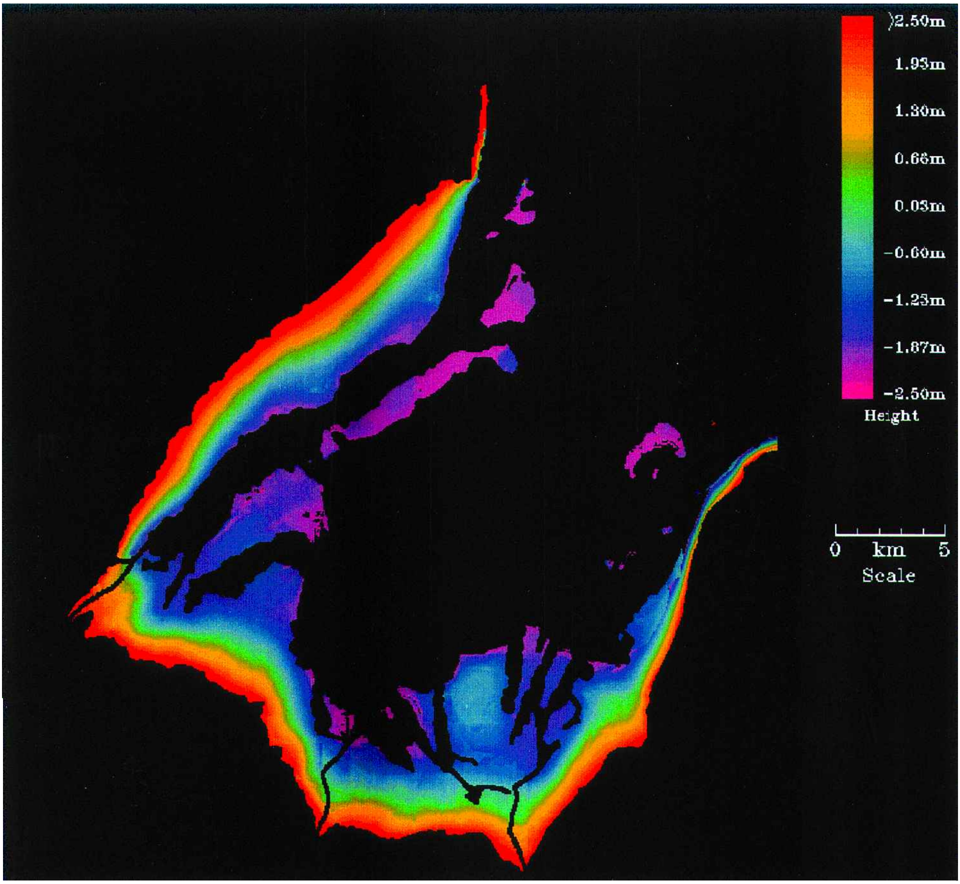

(*b*)

Figure 4. (*b*) Shoreline DEM flooded to mean low water level.

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