Seasonal variations in SPM and floc characteristics in a hypertidal estuary

David Todd [a, b, c], Alex Souza [a] and Colin Jago [b]

[a] NOC Liverpool, [b] Bangor, [c] now at HR Wallingford

Introduction

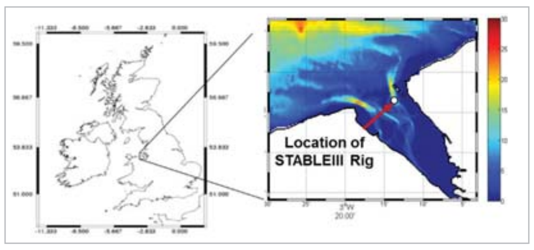
The Dee Estuary is a hypertidal coastal plain estuary, formed by the flooding of the river valley cut by the River Dee during the last major glaciation. One of three major estuaries emptying into Liverpool Bay along with the Ribble and Mersey it is located at the junction of north-east Wales and north-west England, on the eastern side of the Irish Sea.

The estuary section of the Dee is 20 km long, and 8.5 km wide at the mouth. The sea bed is covered by a thick (up to 18 m) sediment layer, deposited after the last Ice Age, consisting of fine-grained sands, silt muds, and some gravel beds. Infilling has led to the gradual accretion of the sand and mudbanks, and an increase in saltmarsh area.

The estuary has a maximum spring tidal range in excess of 10 m, with an increase in tidal prism in excess of 80 % occurring between mean low and mean high water during spring tides, causing tidal currents in excess of 1.2 ms^{-1}. The 110 km (68 mi) length of the River Dee drains from a catchment area of ~1816 km^2 (701 sq mi). Average discharge during the year is 37 m^3s^{-1}. This roughly equates to 0.4 % of the tidal prism over an entire tidal cycle.

The main discharge channel bifurcates approximately 12 km after the canalised section into two main channels - the Welsh channel to the western side, and the Hilbre channel to the east - both of which extend into Liverpool Bay, and are approximately 1 km wide, 4 km long and 20 m deep.

The physical characteristics of the Dee make it an ideal location for studying turbulence-sediment interactions and flocculation: It has a large tidal prism, high tidal range, and abundant cohesive sediment. In addition, even with the small freshwater to tidal prism ratio, the freshwater input creates a horizontal density gradient that, through interaction with tidal forcing, creates both periodic stratification and a residual, gravity-driven circulation as it has a horizontal Richardson number of ~0.5.



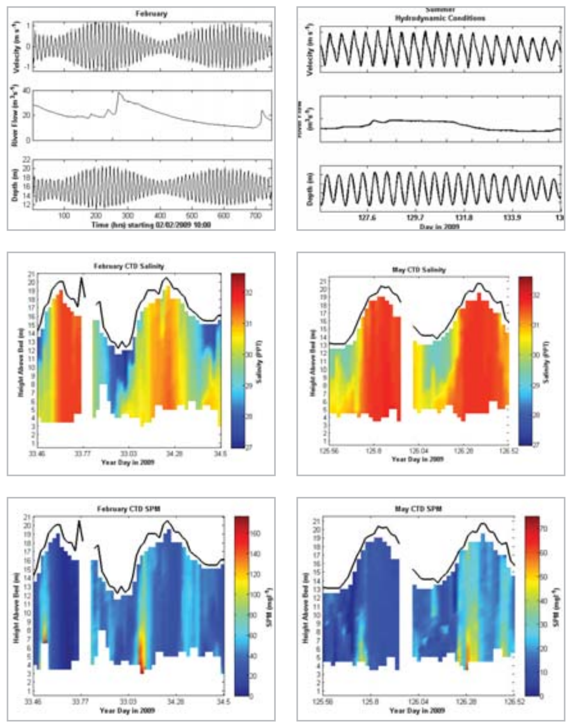
Data collection

Data was collected over 2 month-long deployments of a benthic tripod (STABLEIII) in the Hilbre Channel during February-March and May-June. CTD profiles were taken at half-hourly intervals at the beginning and end of each deployment. The CTD included a transmissometer, while mass concentrations were obtained through the gravimetric filtering of water samples. Only the first 2 weeks of the May-June data were available due to biofouling.

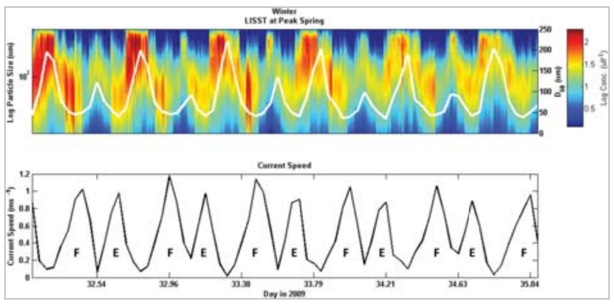
The salinity profiles show stratification at low water during both periods as higher river flow during February resulted in stronger stratification.

Calibrated SPM concentrations from the CTD transmissometer show resuspension of material from the bed on each tide.

SPM concentrations were higher during February-March.



Seasonal variations



February-March

> Particle size is large at both low and (less) high slack water.

> Particle size decreases during flood & ebb

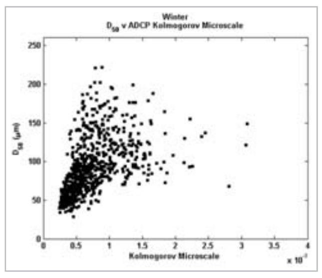
> Good relationship between size & Kolmogorov microscale

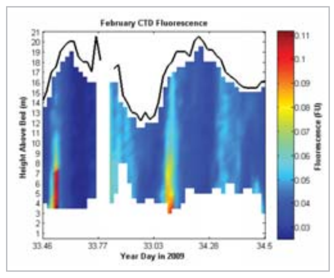
This indicates a flocculating environment as a resuspension signal would be expected to show particle sizes increasing with increasing turbulence

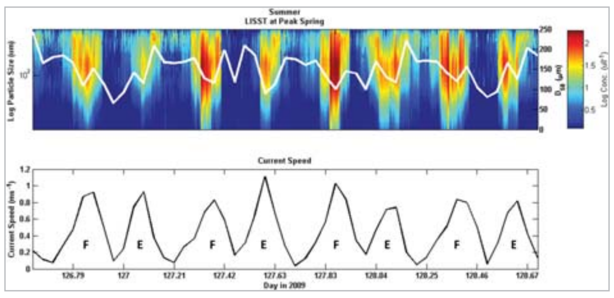
> Fluorescence values are low (different scales on figures) with fluorescing material mainly resuspended from the bed

> Indicates that biological activity is low

> Fluorescing material mainly resuspended from the bed







May-June

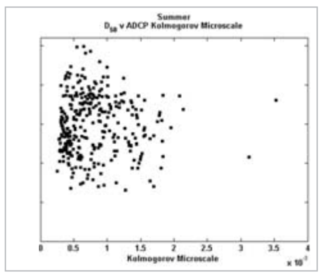
> Particles of all sizes occur during peak current speeds

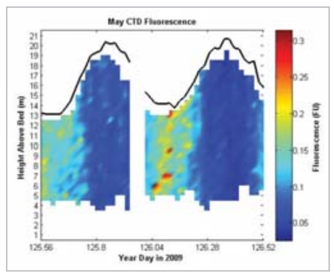
> Small decrease in particle size at peak flood & ebb

> No relationship between size & Kolmogorov microscale

> Fluorescing material arrives late on ebb & over low water

This is similar to a resuspension signal, indicating that flocs are not breaking down during periods of high turbulence. This may be related to the presence of organic material that is washed off the salt marshes high up the estuary and therefore passes the frame during the late ebb and over low water.



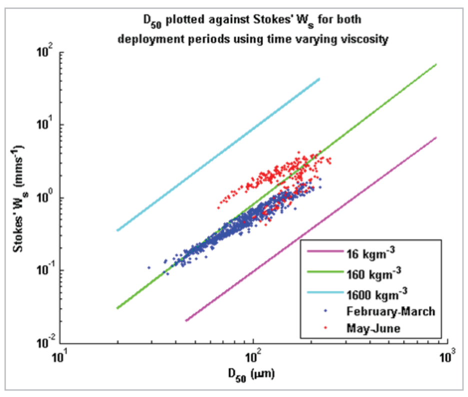


Settling velocities

The LISST is a laser transmissometer, providing a measure of particle size and volume concentration, while the central ring of the LISST can be calibrated using in-situ SPM samples to provide mass concentration.

The effective particle density (ρ_e = mass concentration (C_m) / volume concentration (C_v)) can then be derived. Using the D_{50} measure of particle size enables the bulk settling velocity of the suspension to be calculated using Stokes law:

$$w_s = \frac{g\rho_e D_{50}^2}{18\mu}$$



Settling velocities are higher during May-June than February-March for similarly sized particles, with some overlap.

Proposed mechanism

Biological substances (e.g. Polysaccharides) were washed off the salt marshes high up the estuary in May-June, increasing the collision efficiency of the flocculation process, enabling particl es to grow faster under low turbulence conditions.

The increased stickiness creates stronger bonds between particles, resulting in the larger, denser, faster settling, stronger, shear-resistant flocs observed during May-June.

Some flocculation & breakup still occurs over the tidal cycle, but the denser core of the floc is not broken up.

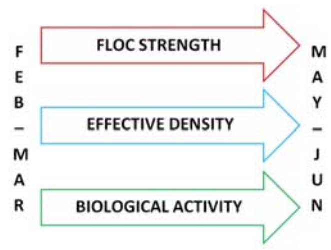
Three flocculation regions therefore exist:

> Low turbulence region of varying biological influence controlled by differential settling

> Turbulence controlled region in which Turbulence > Biological influence

> Biologically influenced region in which Biological influence > Turbulence

February-March is located in the Turbulent Shear Controlled region, while by May-June a transition into the Biologically Influenced region has occurred.



Summary	Peak flow	Slack water	Dominant process
February-March	Large, weak flocs ruptured by turbulence to generate small, dense, slow sinking particles. Small particles resuspended	Large, low density, weak flocs grow. Settling of larger flocs	Flocculation & breakup
May-June	Large, strong, denser flocs resuspended without rupture	Large, strong, denser flocs settle	Biological strengthening

Contact

d.todd@hrwallingford.com

info@hrwallingford.com www.hrwallingford.com