3D ASPECTS OF SHALLOW WATER ISLAND WAKES

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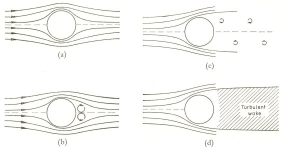
Abstract

Field observations and satellite imagery have previously shown that island wakes have important implications for mixing, sediment transport and the distribution of biological species. While laboratory experiments and numerical modeling of the flow around hills and structures such as buildings and piers have shown that the wakes produced are complex and strongly three-dimensional, there has been more limited investigation of the 3D structure of island wakes. This poster presents some preliminary results of 3D numerical simulations of the flow around real and idealised shallow water islands.

Background

In the classical laboratory experiments of the wake behind a circular cylinder, the form of the wake is dependent on the Reynolds Number, R_e=UL/ν, where U = incident flow velocity, L = horizontal length scale and ν = molecular viscosity.



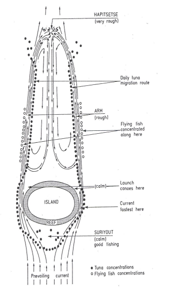
Flow past a circular cylinder

(a) $R_e < 4$, symmetric flow
(b) $4 < R_e < 80$, trapped eddy pair
(c) $80 < R_e < 4000$, von Karman vortex street
(d) $R_e > 4000$, turbulent wake

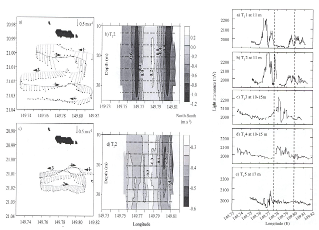
In shallow water island wakes, the influence of bottom friction dominates and the flow is no longer two-dimensional. An island wake parameter, $P = UD^2/\nu_z L$ has been used to characterise the form of the wake, where D = water depth and ν_z = vertical eddy viscosity coefficient.

For P << 1, there is no flow separation, for P ~ 1 there is a stable eddy pair and for P >> 1 eddy shedding is observed. A number of other parameters have also been found to influence the form of shallow water island wakes.

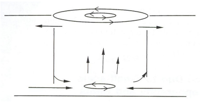
There have been numerous observations of the effects of island wakes on the distribution of biological species and sediments, examples of which are shown below.



Idealised current patterns around the island of Tobi (Johannes, 1981) showing the distribution of fish species.

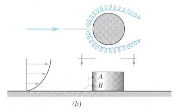


Observations of current and light attenuance from a tidally generated wake at Derwent Island, Great Barrier Reef (Suthers et al., 2004). The peaks are indicative of higher levels of particles such as suspended sediment and plankton.



Topographic eddy

Upwelling occurs at the centre of the eddies with downwelling and surface flow convergence at the edges. Upwelling and downwelling also occurs at the sides of the island due to flow curvature and Coriolis force (Alaee et al., 2004).



Horseshoe Vortex

Horseshoe vortices are generated in the bottom boundary layer. These flow structures have been well studied in the literature relating to flows around buildings and other structures. It is hypothesised that these vortices may also be generated in the flow around islands and headlands.

Aim

The aim of the study is to understand and quantify the three-dimensional aspects of island wakes for different island shapes and incident flow characteristics, including their biological and sediment transport implications.

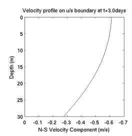
Method

The numerical simulations presented here were carried out using ROMS (Regional Ocean Modeling System) with 50m grid spacing and 20 vertical levels. 3D velocities were specified at the northern (upstream) boundary, free slip boundaries were applied at the side boundaries and a radiation boundary condition at the southern (downstream) boundary. A no slip boundary condition was applied at land boundaries.

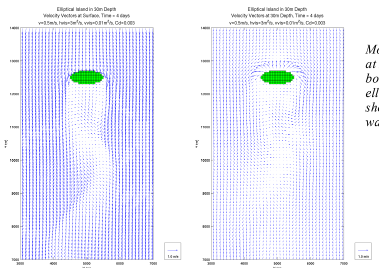
The simulations were carried out with a quadratic bottom friction of 0.003, horizontal viscosity 3m^2/s and vertical viscosity of 0.01m^2/s.

Idealised Island Wakes

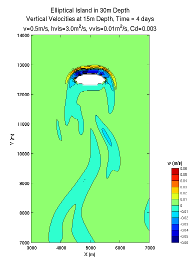
Examples of the modelled current velocities and Lagrangian particle tracks for circular and elliptical shaped cylindrical islands are shown below. Both island shapes have been modeled with a 0.5m/s (depth averaged) incident current in 30m water depth with the vertical profile shown.

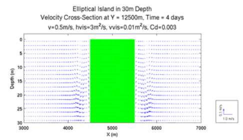


Incident Velocity Profile



Modelled velocities at surface (left) and bottom (right) for elliptical island shows a vortex street wake

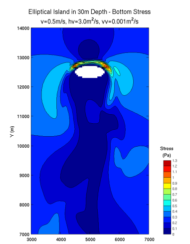




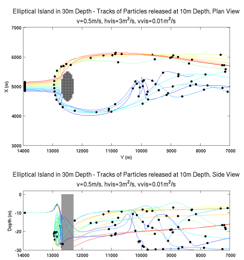
The modelled velocities show reversal of the bottom flow direction and strong downwelling and upwelling immediately upstream of the island.

Upwelling within the horizontally circulating eddies downstream of the island is comparatively weak.

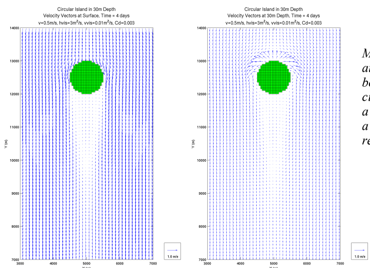
The vortices generated upstream of the island can also be seen in the vertical cross-section above.



Bottom stresses and sediment transport potential are also maximum on the upstream side of the island.



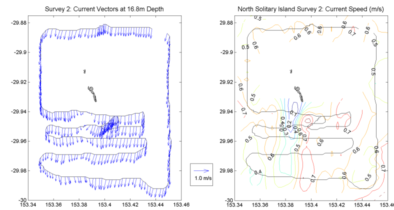
Tracks of particles released at 10m depth show vertical recirculation cells upstream of the island. These are consistent with the generation of horseshoe vortices and result in a high degree of vertical mixing in the shear layer at the edge of the wake.



Modelled velocities at surface (left) and bottom (right) for circular island shows a wake consisting of a pair of recirculating eddies

North Solitary Island Wake

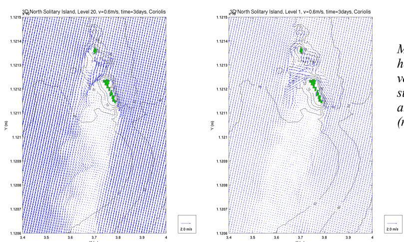
Field data was collected around North Solitary Island in September 2004. The island is located on the continental shelf off the East coast of Australia in water of 20-50m depth, and the prevailing current is the East Australian Current which flows from north to south.



ADCP current measurements from North Solitary Island show a reduction in current speeds extending at least 6km downstream of the island. The horizontal velocity gradient is particularly strong on the eastern edge of the wake.

The area was modelled using ROMS with the available bathymetry data over a model domain of 10km x 20km with an upstream current of 0.6 m/s (depth averaged).

The modelled velocities show considerable 3D structure, some of which is generated by the smaller island to the north and the associated reefs.

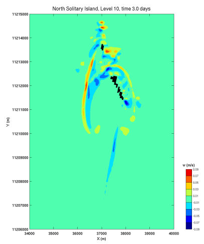


Modelled horizontal velocities at surface (left) and bottom (right).

The eastern edge of the wake is much more distinct than the western edge, as was observed in the field data.

There is a reversal in the direction of the bottom currents to the north of the island which is similar to that in the idealised islands.

The vertical velocities also show evidence of vortical structures extending south of the island – these appear stronger on the western side of the wake.



Modelled vertical velocities

Additional field work is planned to better characterise the flow patterns close to the island.