

## Towards an understanding of the flushing of Bass Strait

Paul A. Sandery<sup>1</sup>

<sup>1</sup>*School of Chemistry, Physics and Earth Sciences Flinders University Adelaide-Australia*

*e-mail of corresponding author: paul.sandery@flinders.edu.au*

### Introduction

Bass Strait is an area of shallow continental shelf located between Victoria and Tasmania connecting the south-east Indian Ocean with the Tasman Sea (Figure 1). The region supports a diverse marine ecosystem with a wide range of habitats. The submerged temperate rocky reefs and canyons contain high species biodiversity with a large proportion being endemic to the area [3]. Marine activities of environmental significance include fisheries, shipping, oil drilling/processing and coastal riverine discharges. All are potential sources of pollutants and contaminants. In winter and to a large degree in spring, strait waters are well mixed with little or no apparent stratification [1], [6] [14]. In the passages strong vertical and horizontal

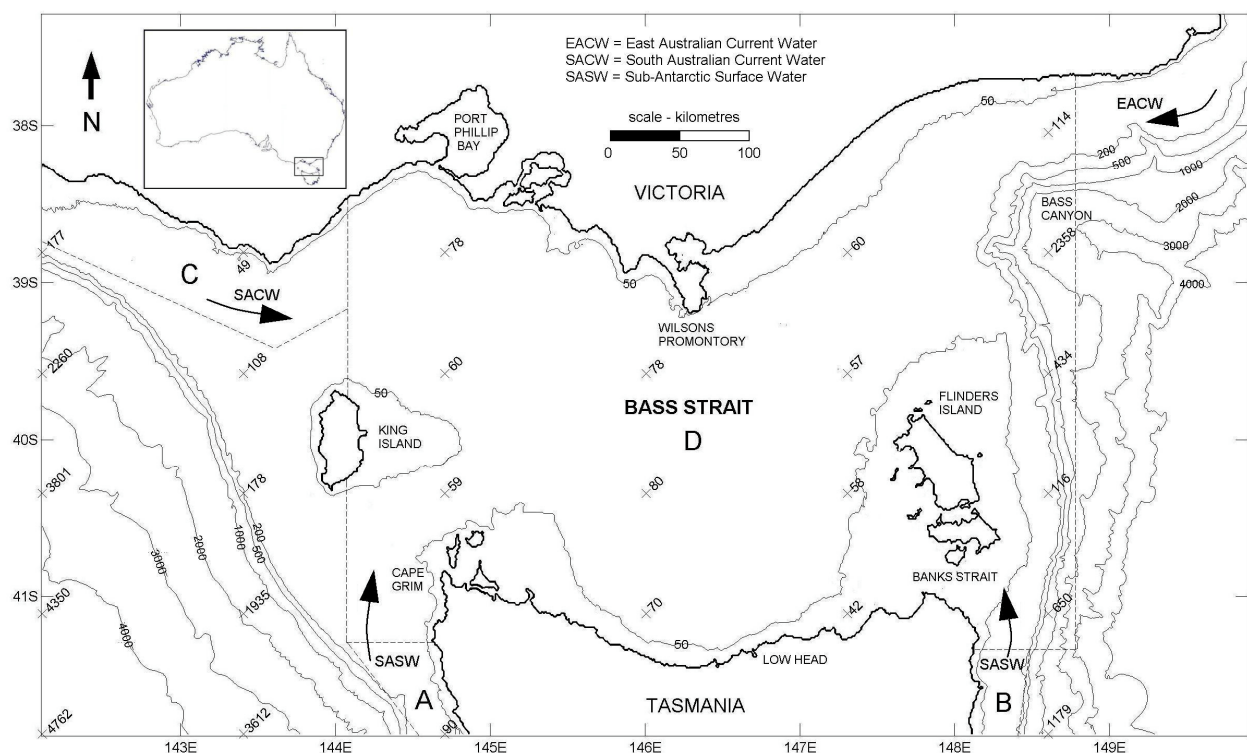


Figure 1. Diagram showing bathymetry of Bass Strait and surrounding region. The initial locations of tracers A, B, C and D representing different water masses are delimited by dashed lines. Depth contours and spot levels are in metres.

tidal mixing occurs. These areas are always well mixed. The central region becomes stratified in summer. The approach of the next winter sees the entire strait becoming well mixed again. Lateral flushing results from inflows of three primary water masses (Figure 1). These are South Australian Current Water (SACW), East Australia Current Water (EACW) and sub-Antarctic Surface Water (SASW) [7]. Primary water mass relative contributions have an influence on local

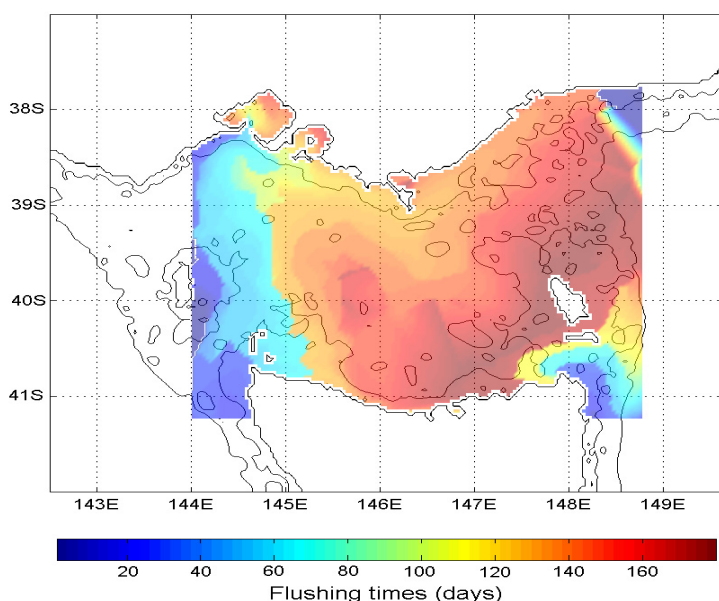
marine ecosystems owing to their different nutrient contents. During the southern winter SASW is found widely present in the strait [7]. SASW contains higher nutrient levels [2]. It is therefore important to know how much SASW spreads through strait waters. The flushing times of Bass Strait water are unknown. A zone of long flushing times is a zone where seasonal scale air-sea fluxes influence water mass properties. Such a zone therefore promotes dense water formation and export which is characteristic of the region [8], [9]. The aim of this study is to estimate the flushing times of Bass Strait waters and investigate the mixing of different water masses within the strait.

## **Experimental Methods**

The study proceeds by establishing time dependent tidal and atmospherically forced circulation patterns. In the period of winter to spring, this can be achieved with a numerical model using the non-linear depth-averaged shallow-water equations. The depth-averaged shallow-water equations are suitable for modelling particular dynamical processes. They describe barotropic motion in a single layer un-stratified ocean. An explicit Eulerian forward finite-difference numerical scheme is used on an Arakawa C type grid [5]. Turbulent horizontal diffusion of momentum is parameterized with a constant diffusion coefficient of  $1 \text{ m}^2 \cdot \text{s}^{-1}$ . Bathymetric data from ETOPO2 (c/- National Geophysical Data Centre), is used on a Cartesian grid with a horizontal resolution of 2 nautical miles ( $\sim 3.71 \text{ km}$ ) (Figure 1). The model grid spans  $215 \times 150$  grid cells. The domain is the extent of the area represented in Figure 1. The model is forced with tides and an observed 180 day hourly-averaged (derived from minutely data) wind time-series. This data is obtained from the National Tidal Facility of Australia and Cape Grim Baseline Air-Pollution Station respectively. The wind time-series used to force the model corresponds to the winter-spring period of 1988. Climatologically averaged winds vary by about 5-10% in strength and direction between Cape Grim, Wilsons Promontory and Low Head during this period. Although the wind field used does not exactly represent the spatial distribution of winds over the region it still provides a first approximation of currents and flushing during a winter-spring period. It is noted that using climatologically averaged winds produces a similar flushing response at the time scale focused on in this study. Tracer concentrations represent the volume fraction of particular tracer in the total volume of the water column. Predefined source regions are initialized with tracers A, B & C at unit concentration. An area in the domain is delimited to represent the strait interior and initialized with tracer D at unit concentration. Boundaries representing these regions are shown in Figure 1. Zero gradient open-sea boundary conditions for tracers are adopted. Tracers A, B & C are placed in locations where primary source water masses occur. After an elapsed time, tracer concentrations represent the fraction of source water mass in the water column combined with a boundary source. Far field forcing modulates the intensity and flow directions of SACW and SASW. This has not been accounted for in the present study which only attempts to investigate influences of these water masses assuming constant source at the boundaries. EACW is disregarded because flushing mainly occurs with water mass from the west in the winter-spring period. Flushing times are calculated using tracer D (Figure 1). An arbitrary minimum tracer concentration is required to define the flushing time. [10] uses the time it would take for tracer to reach  $1/e$  or  $\sim 37\%$  of its initial concentration for estimating flushing times of Port Phillip Bay with respect to Bass Strait. For comparison this is adopted. The flushing time is recorded when local concentrations of tracer D have decreased to  $\sim 0.37$  of their initial value. When tracer D concentration reaches this minimum the remaining volume fraction is  $\sim 0.63$  water mass originating outside the predefined boundaries. At this minimum the local water column flushing time is recorded.

## Results

Flushing times after 180 days simulation time are illustrated in Figure 2. A stagnation-area of long flushing times ( $>160$  days) is evident in southern-central Bass Strait. A zone of long flushing times also extends from the stagnation-area to Bass Canyon. This zone appears to be where the oldest water is in Bass Strait. Water in this zone is most affected by local air-sea buoyancy fluxes and this zone is likely to be where dense water formation occurs. Water from this zone may trigger or be a source of the Bass Strait Cascade. Concentrations of water masses A and D are shown in Figure 3 at the end of each month in the 180 day simulation. The importance of water mass A in this period is evident. The movement of the tracers reveals that a proportion of shelf-water (C) entering the strait from outside the north-western corner is advected eastwards, mostly adhering to the Victorian coastline (not shown). A small portion of this water branches off just south of Wilson's Promontory and flows south-eastwards towards Flinders Island.



Shelf-water (B) moves into Banks Strait and northwards past Flinders Island but does not enter Bass Strait in any significant proportion (not shown). Shelf-water (A) is mostly transported into Bass Strait through the passage between King Island and Cape Grim. Some is rapidly advected eastwards along the northern Tasmanian Coastline, whereas a large proportion is entrained in the residual circulation in the strait. Of the three source water masses, shelf-water (A) is most widely dispersed in Bass Strait.

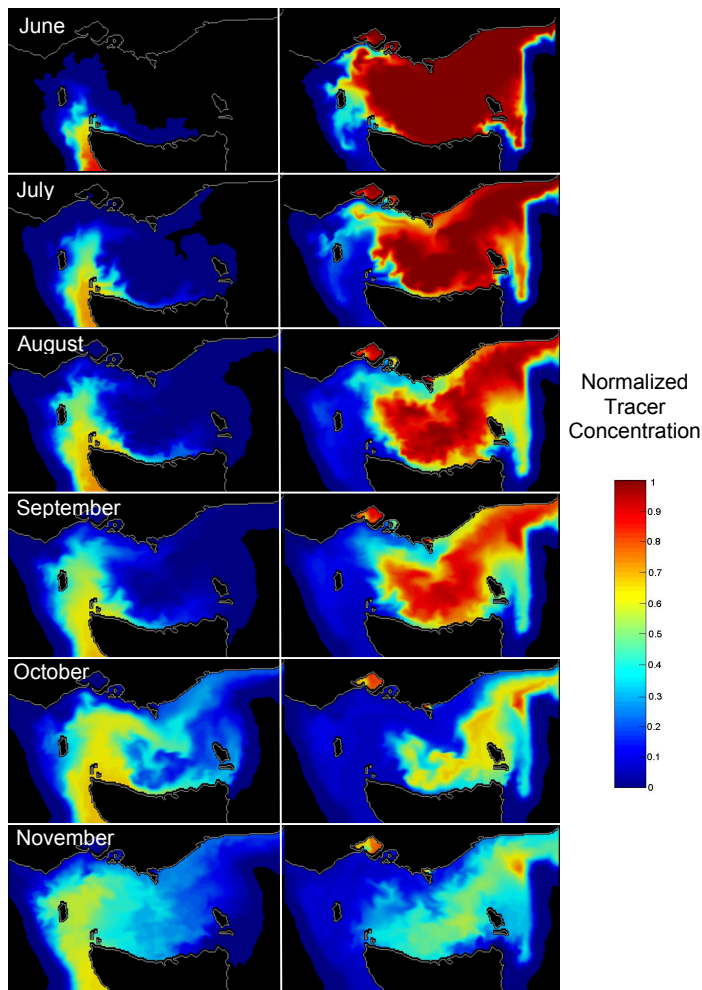
Figure 2. Flushing times (days) of Bass Strait waters.

Analysis of the fraction of each water mass A, B, and C in the total local mass of water after 180 days yields insight into their respective relative contributions. The most significant water mass involved in the flushing of strait waters in winter-spring is water mass A. Water mass C is present in the lowest concentrations presumably resulting from advection out of the north-western boundary. Results also show that the stagnation-area contains  $\sim 40\%$  water mass D with the remaining fraction comprising of water masses A and C. Water mass A is  $> 90\%$  of the mixture of A and C. Water mass B has a less significant influence on flushing in the strait, however it is significant in flushing part of north-eastern Tasmanian coastal waters and waters along the inner side of the eastern shelf-break.

## Discussion

Additional experiments were carried out with the model using transient synoptic scale winds and with tidal forcing alone. These confirm that flushing is controlled by the mean climatologically averaged winds. The main findings of the 180 day simulation suggest winter-spring flushing of

Bass Strait waters results from eastward advection of SACW and SASW. Flushing in the central area depends on longer term mean winds (weeks to months) rather than shorter term winds (tens of hours). Time scales for flushing vary according to mean wind strength. Results also suggest strait waters can be replenished to some degree in most places with SASW (excepting minute concentrations in the stagnation-area) in a period of approximately 30 days in conditions of strong mean westerly winds. Sources of error in the model come from dynamical approximations, topographic errors, finite difference approximation truncation errors, interpolation errors in the representation of coastlines and islands on the grid [4].



Despite the importance of tidal currents which cause strong vertical mixing at the edges of the strait, wind-driven currents determine the overall seasonal-scale circulation and flushing. The scale of residual tidal currents is relatively small compared to the scale of wind-driven currents. The symmetric nature of tidal currents means that residual flow is dominated by wind-driven processes. Issues of uncertainty in the bathymetric data and in the spatial distribution of winds in the region are the most important sources of uncertainty in determining the winter-spring flushing of strait waters.

Figure 3. Tracer transport in Bass Strait in the 1988 winter-spring period. Tracer A (left) represents shelf water originating from north-western Tasmania and Tracer D (right) represents Bass Strait Water.

## Conclusions

The study provides a first approximation of the winter-spring flushing of Bass Strait in unstratified conditions. It also highlights the dominance of mean wind driven flow over tidal flow at the seasonal scale. Wind-driven depth-averaged currents are largely topographically controlled and geostrophic in nature. These currents determine meso-scale residual flow in Bass Strait in the winter-spring period and the presence of the stagnation-area depends on this. Advection of tracer from the three different locations suggests SASW from the south-western corner of the region is the most widely dispersed and rapidly transported water mass in the strait in the winter-spring period. Winter-Spring flushing with SASW is a significant inter-annual process replenishing nutrients and supporting ecosystems. Water in the stagnation-area takes the longest time to be replenished by external water mass and occurs at timescales of the order of  $> 6$  months. A significant volume of water remains in the strait for periods of the order of months to seasons. The 'stagnation-area' is a dynamical aspect of the dense water formation process.

## References

- [1] Baines, P. G. & Fandry, C. B., Annual Cycle of the Density Field in Bass Strait. *Australian Journal of Marine and Freshwater Research* **34**, 143-153 (1983)
- [2] Gibbs, C. F., Tomczak, M. Jr. & Longmore, A. R., The Nutrient Regime of Bass Strait, *Australian Journal of Marine and Freshwater Research* **37**, 451-466 (1985)
- [3] Neil, A. (Ed), *Under Southern Seas: The Ecology of Australia's Rocky Reefs*, Malabar FLa, Kreiger, UNSW press, Sydney. 238 pp. (2000)
- [4] McIntosh, P. C. & Bennett, A. F., Open ocean modelling as an inverse problem: M2 tides in Bass Strait. *Journal of Physical Oceanography* **14**, 601-614 (1984)
- [5] Mesinger F., & Arakawa, A., *Numerical Methods Used in Atmospheric Models. Vol. 1*, GARP Publications Series No. 17, World Meteorological Organization, 64 pp. (1976)
- [6] Middleton, J. F. & Black, K. P., The low frequency circulation in and around Bass Strait: a numerical study. *Continental Shelf Research* **14**, 1495-1521 (1994)
- [7] Newell, B. S., Hydrology of south-eastern Australian waters: Bass Strait and New South Wales tuna fishing area. *CSIRO Australian Division of Fisheries and Oceanography*, Technical Paper No. **10** (1961)
- [8] Tomczak, M. Jr., The Bass Strait water cascade during winter 1981. *Continental Shelf Research* **4**, 255-278 (1985)
- [9] Tomczak, M. Jr., The Bass Strait water cascade during summer 1981-1982. *Continental Shelf Research* **7**, 561-572 (1987)
- [10] Walker, S. J., Coupled hydrodynamic and transport models of Port Phillip Bay, a semi-enclosed bay in south-eastern Australia. *Australian Journal of Marine and Freshwater Research* **50**, 469-481 (1999)