A Review of the Physical Oceanography of Torres Strait

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Introduction

The Torres Strait is a topographically very complex, shallow, body of water, heavily studded with reefs and islands. The water circulation is influenced by runoff from Papua New Guinea, Australia, and Irian Jaya, the local winds, and tidal and other oceanographic events in the Arafura and Coral seas. There has been an increasing interest in the physical oceanography of the Torres Strait for the last 10 years. This is reflected in a rapidly growing scientific literature. This literature is reviewed below.

Figure 1 shows a chart of the northern Great Barrier Reef, the Torres Strait, the Fly River estuary and the Gulf of Papua. The Fly River estuary has four major channels forming a delta. These are the far northern, northern, southern and far southern channels. The northwestern region of Torres Strait (stipled in Figure 1) is uncharted but reported to be very shallow (depth <10 m) with numerous shoals and reefs.

Review

Gulf of Papua and the Northwest Coral Sea

Wyrtki (1960) showed the monthly surface salinity distribution by one degree in the northwest Coral Sea. The data suggested southeastward flow of brackish water at the surface. Scully-Power (1973) conducted more detailed field studies that implied, from geostrophic calculations, the existence of an eastward flow in the northern Coral Sea. Pickard *et al.*, (1977) further reviewed the very sketchy knowledge of the circulation in the northwestern Coral Sea.

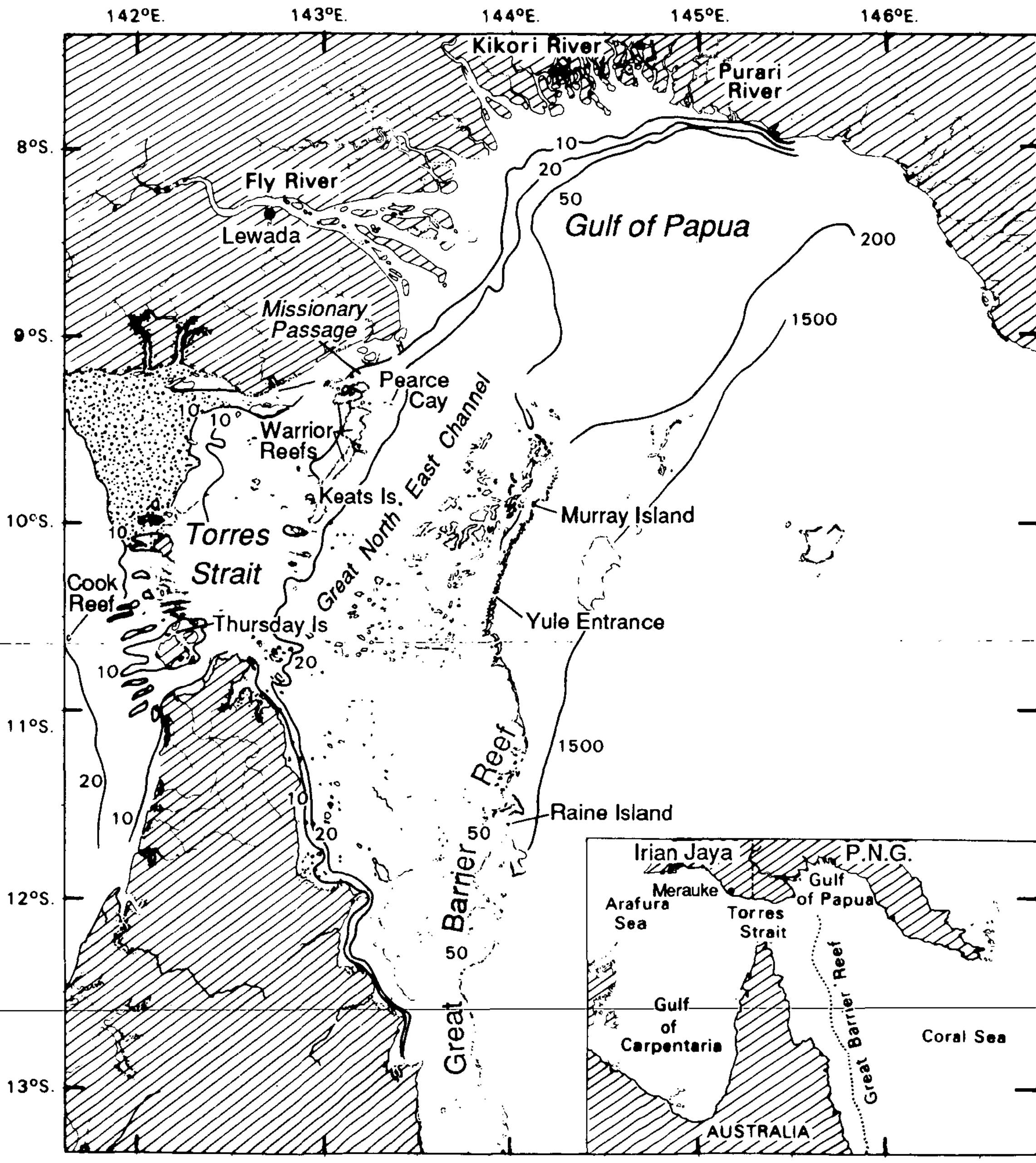

Figure 1. Map of the Torres Strait and surrounding waters. The insert is a general location map. The stipled area represents an uncharted area believed to be between 5 and 10 metres deep with numerous reefs and shoals.

Andrews and Clegg (1989) demonstrated the existence of the Coral Sea coastal current, flowing north along and offshore from the Queensland shelf break and turning eastward in deep water offshore from the Gulf of Papua. More recently CSIRO and AIMS scientists (Burrage, pers. com.) have carried out oceanographic cruises in the north-western Coral Sea confirming this surface circulation. These data also suggest the existence of a westward current in shallow coastal waters off Port Moresby during strong southeasterly tradewinds.

Rochford's (pers. com.) surface salinity data also suggest a clockwise circulation at the surface in the northwest Coral Sea.

MacFarlane (1980) studied the circulation in the Gulf of Papua using bottom and surface drifters. The drogues were left to drift with the currents in the Gulf of Papua and the experiment depended on people finding and returning the drogues from along the coast of the Gulf of Papua. This coast is sparsely populated and the return rate of the drifters was very small. But, for those drogues that were returned, there was evidence for a (wind-driven?) westward flow along the coast of the Gulf of Papua during southeasterly trade winds. The surface currents were eastward the rest of the year. Because so few drogues were returned, it is not possible to say if this pattern is typical of the bulk of the flow.

Wolanski and Ruddick (1981) mapped the salinity distribution in the Gulf of Papua and the northern Great Barrier Reef and showed that Torres Strait waters were vertically well-mixed. Brackish waters from the Gulf of Papua were found to intrude in the Great North East Channel as a tongue of water 70 kilometres long squeezed between the Warrior Reefs to the west side, and the matrix of reefs to the east of the Great North East Channel. In the Gulf of Papua, the river plumes extended up to 100 kilometres offshore. The surface waters were highly stratified in salinity, the plume being confined to the top 20 metres or so of the water column.

Wolanski *et al.*, (1984) estimated the mean freshwater runoff in the Gulf of Papua to be about 13,000 $m^3 s^{-1}$. The residence time of this water in the Gulf of Papua was estimated to be about one to two months, with the bulk of the water flowing eastward.

Torres Strait

Easton (1970) showed some tidal data in the southern region of the Torres Strait implying that the tides do not appear to propagate much across the Torres Strait but the data was inconclusive for a quantitative analysis.

Amin (1978) showed that storm surges (meteorological tides) do not propagate across the southern region of the Torres Strait.

The Australian Department of Transport in the late 1970s is known to have undertaken a study of tidal currents in the southern Torres Strait using Decca current metres, but no data or report seem to have been published.

Wolanski and Ruddick (1981) deployed current meters and tide gauges in the northern and far northern Great Barrier Reef, including a meter in the shipping channel off Thursday Island and another meter near Yorke Island in the Great North East Channel.

Long waves (waves of low-frequency, with period of one to several weeks) were found and these raised and lowered the low-frequency sea level by up to 0.5 metre peak to trough. Low-frequency currents were also associated with such waves. Evidence was presented indicating that the matrix of reefs east of the Great North East Channel largely blocks the longshore currents on the continental shelf of the Great Barrier Reef.

Wolanski (1982) showed that the trade winds over the western Coral Sea, including Torres Strait, are coherent over long distances of the order of 1000 kilometres.

Wolanski and Thomson (1984) reported data from a five month deployment of a weather station, several tide gauges and current meters in the far northern Great Barrier Reef continental shelf. Additional current meter data were obtained for five months at two sites in the Great North East Channel (near Pearce Cay and Keats Island). Low-frequency currents were found and could be attributed to wind-driven arrested topographic shelf waves. These authors modeled the circulation in the Great North East Channel and were able to reproduce with some success the time-series of low-frequency currents near Pearce Cay. The net currents were always small (<0.1 m s^{-1}), reversing direction at periods of days to weeks. Over 140 days of observations, the net currents were too small to be measured reliably. They also showed that the low-frequency currents were small because of the non-linear interaction due to bottom friction between tides and low-frequency currents in these shallow waters.

Wolanski *et al.*, (1984) confirmed the finding of Wolanski and Ruddick (1981) of the intrusion of brackish Gulf of Papua waters in the Great North East Channel and found this intrusion even in May 1982 during the southeast tradewind season. This finding suggests that this intrusion is a permanent feature. Some brackish water from the Gulf of Papua also intruded into the Torres Strait through Missionary Passage (the smaller passage between the mainland of Papua New Guinea and the Warrior Reefs, see Figure 1). Tidal mixing, enhanced by the trapping effect from island wakes, appears to be the dominant process responsible for the intruding tongue of brackish water in the Torres Strait.

Wolanski (1983) argued that the tides in the northern Great Barrier Reef continental shelf, including the Great North East Channel, are controlled by the Coral Sea, not the Gulf of Carpentaria and the Arafura Sea located west of the Torres Strait. Wolanski (1986) reviewed the physical oceanography literature for this area up to 1983.

Wolanski *et al.*, (1988a) undertook a detailed field and numerical study of the flow through the central and southern region of Torres Strait, with five months of field data on sea levels and currents at several locations. They showed that tides and low-frequency sea levels fluctuations were incoherent on either side of the Strait; that the low-frequency currents through the Strait were very small and reversed direction at periods of days to weeks; that these currents were dependent on both the sea level slope across the Strait and the local wind stress. Their analysis also showed that these low-frequency currents were very small because of the non-linear interaction due to bottom friction between weak low-frequency currents and very strong tidal currents in the shallow waters of the Strait. High-frequency sea level fluctuations were also observed and were attributed to waves moving northward or southward, with the reefs and islands of Torres Strait acting as a weakly porous solid boundary.

Clarke (1990) showed that the tidal currents in the Prince of Wales Channel, in the southern region of Torres Strait, are controlled primarily by the acceleration, the bottom friction and the sea level slope.

Upwelling at the Shelf Break

Thomson and Wolanski (1984) showed that tidal period upwelling, a phenomenon first proposed by Thompson and Golding (1981) for the Ribbon Reefs further south on the Great Barrier Reef, is an important mechanism for effectively upgrading nominally low nutrient levels on the continental shelf near Raine Island (11°38'S latitude). Temperature data from a current meter deployed one kilometre inshore from Yule Entrance (9°40'S latitude) along the axis of the channel, also suggest tidal period upwelling (Wolanski and Ruddick, 1981). Presumably tidal period upwelling occurs all along the outer reef of the far northern Great Barrier Reef from Murray Island to Raine Island. It is believed that reef growth should be more prolific near the shelf break where the time-integrated contribution of the upwelling is greatest. However, in a study of tidal period upwelling further south at the Ribbon Reefs offshore Cooktown, Wolanski *et al.*, (1988b) showed that the bulk of the upwelled nutrients may not be available for corals on the shelf break but is instead advected shoreward by a tidal jet - vortex pair system. This mechanism explains the presence of extensive *Halimeda* meadows near the shelf break in the far northern Great Barrier Reef, such as near Raine Island Entrance. Wolanski (1987) suggested, from an examination of Landsat images, that some of the upwelled material and detritus from the reefs at the shelf edge around Raine Island Entrance may then drift back offshore and enrich the reefs of Raine Island, an important rookery for sea turtles.

Gulf of Carpentaria and Irian Jaya

While CSIRO undertook oceanographic studies in the Gulf of Carpentaria in the 1970s, these studies were concentrated in the southern region of the Gulf of Carpentaria.

Mulhearn (1989) found in February and March 1988, that a brackish water tongue west of the Warrior Reefs did not seem to originate from the brackish waters in the Gulf of Papua. He attributed this finding to an intrusion of brackish water from the Irian Jaya coast, in the northern region of the Torres Strait.

Wolanski and Ridd (1990) undertook a detailed field and numerical study of the barotropic circulation, driven by tides and wind, in the Gulf of Carpentaria. The study was based on five months of current meter data at seven sites, sea level data at three sites, and weather data. These data, together with tidal data from Cook Reef and several locations in the Torres Strait, were used to calibrate and verify a numerical model of the water circulation in the Gulf of Carpentaria including the coastal waters of Irian Jaya. They showed that a coastal boundary layer forms, trapping water in shallow water (depth <15 m) for a long period (months). This water flows along the western side of Torres Strait and would be coastal water from the Gulf of Carpentaria in the tradewind season and coastal water from Irian Jaya in the monsoon season. This finding may explain the observations of Mulhearn (1989) who found Irian Jaya coastal waters in Torres Strait west of the Warrior Reefs in the monsoon season.

Wolanski (unpubl. data) found that the waters in the northern region of the Gulf of Carpentaria near Cook Reef are vertically stratified in temperature with a sharp

thermocline at typically 15 metres depth, in the monsoon season, unless a tropical cyclone has passed over the area, and that the thermocline oscillates both at tidal and low frequencies. The bottom waters do not appear to be entrained eastward in the Torres Strait.

Little oceanographic data appears to have been collected in the northern region of the Gulf of Carpentaria, north of Cook Reef, including the coastal waters of Papua New Guinea and Irian Jaya west of the Torres Strait. Zijlstra *et al.*, (1990) and Ilahude *et al.*, (1990) reported oceanographic observations in coastal waters of the northwest Arafura Sea, west of 138RE (ie. over 500 kilometres west of Torres Strait), where they found that river plumes from Irian Jaya extended over 100 kilommetres offshore. They suggested that the coastal currents were eastward on the monsoon season and westward in the southeasterly tradewind season, a finding that is reproduced by the numerical model of the water circulation by Wolanski and Ridd (1990).

Fly River

SMEC (1978) used a rainfall-runoff model, calibrated using five years of data, to estimate the monthly runoffs of the Fly River from 1928 to 1977, using the available rainfall data at Merauke in Irian Jaya.

Taylor (1978) conducted an exploratory oceanographic cruise in the far southern and far northern channels of the Fly River estuary. Because the water was fresher in the far southern channel than in the far northern channel, he suggested that the bulk of the freshwater flows through the far southern channel. He attributed that to Coriolis effects, but this interpretation is incorrect since the Coriolis force alone would deflect the Fly River plume to the east in order for the plume to travel with the coast on its left hand side.

Harris *et al.*, (1988) discussed observations of sand waves in the shipping channel near Cape York, as well as sediment sorting in a north-east direction in the Great North East Channel. Harris and Baker (1988) described the different mineralogy prevailing respectively east and west of the Warrior Reefs and the sediment sorting in coastal waters in the Gulf of Papua and in the Torres Strait as affected by the Fly River. The Warrior Reefs appeared to be a significant barrier to sediment transport.

SMEC (1982) undertook detailed bathymetric surveys in the freshwater region of the Fly River and in the far northern channel of the estuary. SMEC also collected some tidal information along the far northern channel for one month. The data showed the dominance of semi-diurnal tides, up to five metre peak to trough, with a strong diurnal inequality. SMEC showed that the flood tidal wave progressively steepens as it propagates up-river. Upstream of Lewada (the junction between the channels of the estuary), a tidal bore has been observed at spring tides.

OTML (1988) summarised their data on freshwater discharges and suspended sediment concentration entering the estuary. OTML also reported occasional data on suspended sediment concentration in the far northern channel. A field and modelling study is underway since February 1990, sponsored by OTML and carried out by AIMS, of the water circulation and the transport of fine sediment in the Fly River estuary, the western region of the Gulf of Papua, and the far northern Torres Strait.

Discussion

The last ten years has seen a rapid increase in the understanding of the water circulation in the Torres Strait. The area is topographically extremely complex and forced nearly independently by the Arafura Sea and the Coral Sea through the continental shelf of the Great Barrier Reef. Additional local forcings are river runoff and the local wind effects. A clear picture is rapidly emerging and some confidence can now be given to modelling the water circulation in Torres Strait as the open boundary forcings are better understood.

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