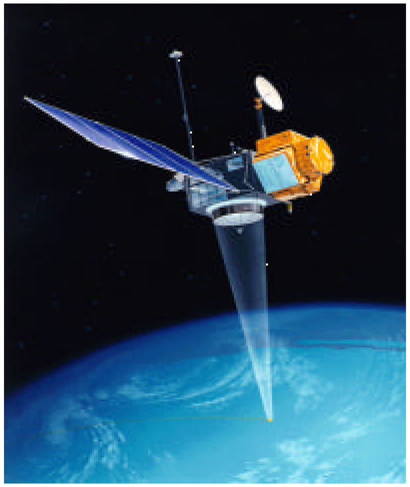
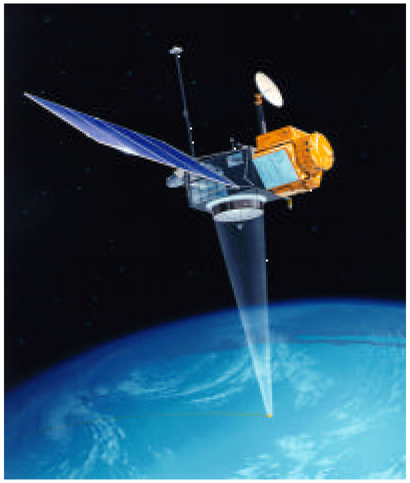


Geostrophic Currents in the Western Coral Sea from TOPEX and JASON altimetry



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ABSTRACT

The growing emphasis on observing and understanding coastal circulation provides the motivation to refine tidal corrections for altimetry in coastal seas. We have compared TOPEX-derived Sea Surface Height (SSH) data with observations from long-term moorings of tide gauges and current meters deployed on the NE Australian continental shelf and slope adjoining the Western Coral Sea. Using a limited area regional tidal model, we corrected TOPEX SSH data collected within a macro-tidal region located in the wide SE Queensland shelf and inside the Great Barrier Reef (GBR) Lagoon. Corrections within the Coral Sea were made using the CSR 3.0 global tidal model. We found moderately high correlation between SSH and coastal sea level stations within both the larger Coral Sea and regional tidal model domains. SSH-derived geostrophic current anomalies (GCA) were also correlated with data from a long-term shelf and slope mooring array.

A newly developed regional tidal model now spans the entire NE Australian continental margin and GBR. Model boundary conditions are set by combining data from global tidal model results and in situ moorings. We will use this model in combination with recent global tidal models to correct SSH data from the TOPEX/Jason tandem mission. The resulting GCAs will be compared with data from the long-term mooring array.

A barotropic model of the Coral Sea circulation has also been developed to provide boundary conditions for high resolution models of mesoscale and wind-driven circulation on the upper slope and continental shelf, for the purposes of decadal scale larvae dispersal studies. This model, together with a nested high resolution counterpart which resolves the reef scale variability, will be used to study the circulation on the NE Australian continental shelf and slope, and for comparison with SSH and GCA fields derived from the TOPEX/Jason tandem mission.

INTRODUCTION

We report a continuing study of circulation of the Coral Sea and the adjoining NE Australian continental margin using TOPEX (and now JASON) altimetry combined with data from *in situ* tide gauges and current meters. The in situ data will be derived from long-term moorings deployed as part of the Transports of the East Australian Current System (TEACS) program, which was initiated by the Australian Institute of Marine Science in 1988 (Burrage and Steinberg, 2002).

Our study region includes the topographically-complex Coral Sea and adjoining NE Australian continental slope, and the Great Barrier Reef (GBR) lagoon, in the southern part of which tides are significantly amplified as they propagate around the reef matrix and over the expansive continental shelf.

The poster summarises early results obtained using TOPEX (see Burrage et al, 2002 for details), and introduces plans to take advantage of the higher resolution and near-simultaneity of altimetric Sea Surface Height (SSH) and Geostrophic Current Anomaly (GCA) data obtainable from the TOPEX/JASON tandem mission.

MAJOR GOALS

To combine the available TOPEX/JASON-1 altimetry records over a decadal time span with *in situ* data from the TEACS array, and with simulations using numerical hydrodynamic models, in order to study mesoscale, seasonal and inter-annual, regional SSH variability in the Coral Sea and Great Barrier Reef Lagoon.

To improve the spatial resolution of tidal and low frequency mesoscale processes in the Western Coral Sea by merging altimetry data obtained from TOPEX and JASON-1.

To develop methods for computing geostrophic current anomalies from the TOPEX/JASON tandem mission and to compare the results with data obtained from in situ current meter moorings.

To study the influence of wind-driven currents and coastal trapped waves on sea level and current variability on the continental shelf and slope, and to develop methods for correcting TOPEX and JASON altimetry for their effects.

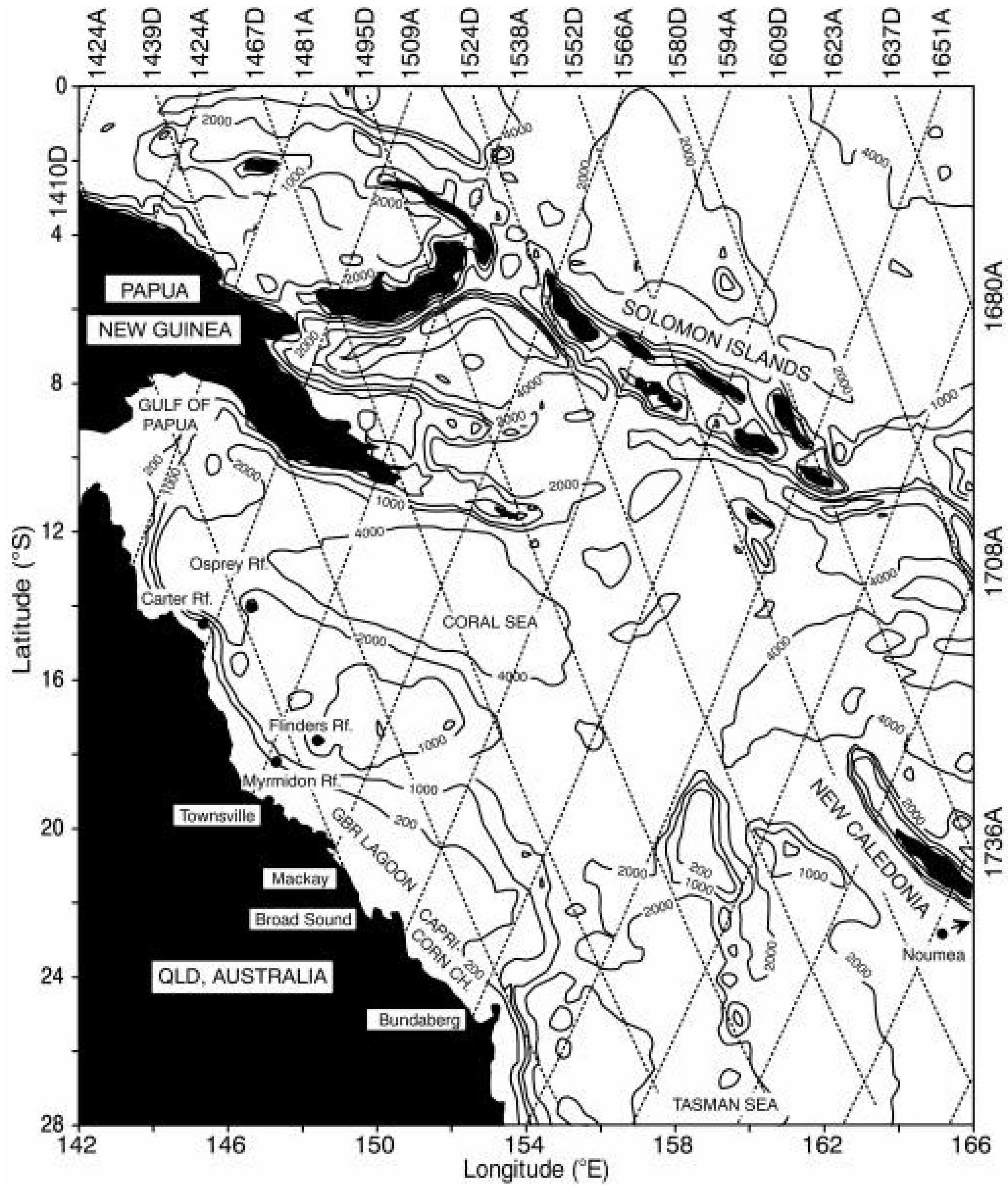


Figure 1. Coral Sea bathymetry (with isobaths in meters) with locations of TOPEX (now JASON) ground-tracks overlaid. Track labels indicate equatorial crossing longitude x 10, and distinguish Ascending (A) and Descending (D) passes.

The Coral Sea contains a deep basin (exceeding 4000m in the center) bounded by continental masses and island arcs, and is penetrated by a series of major coral reef platforms and the Great Barrier Reef.

The Great Barrier Reef lies off the Qld coast, inside the 200 m isobath. Selected locations of long-term tide gauges from the TEACS mooring array are also shown. The new inter-leaved TOPEX ground-tracks fall between the tracks shown here.

Fig. 1

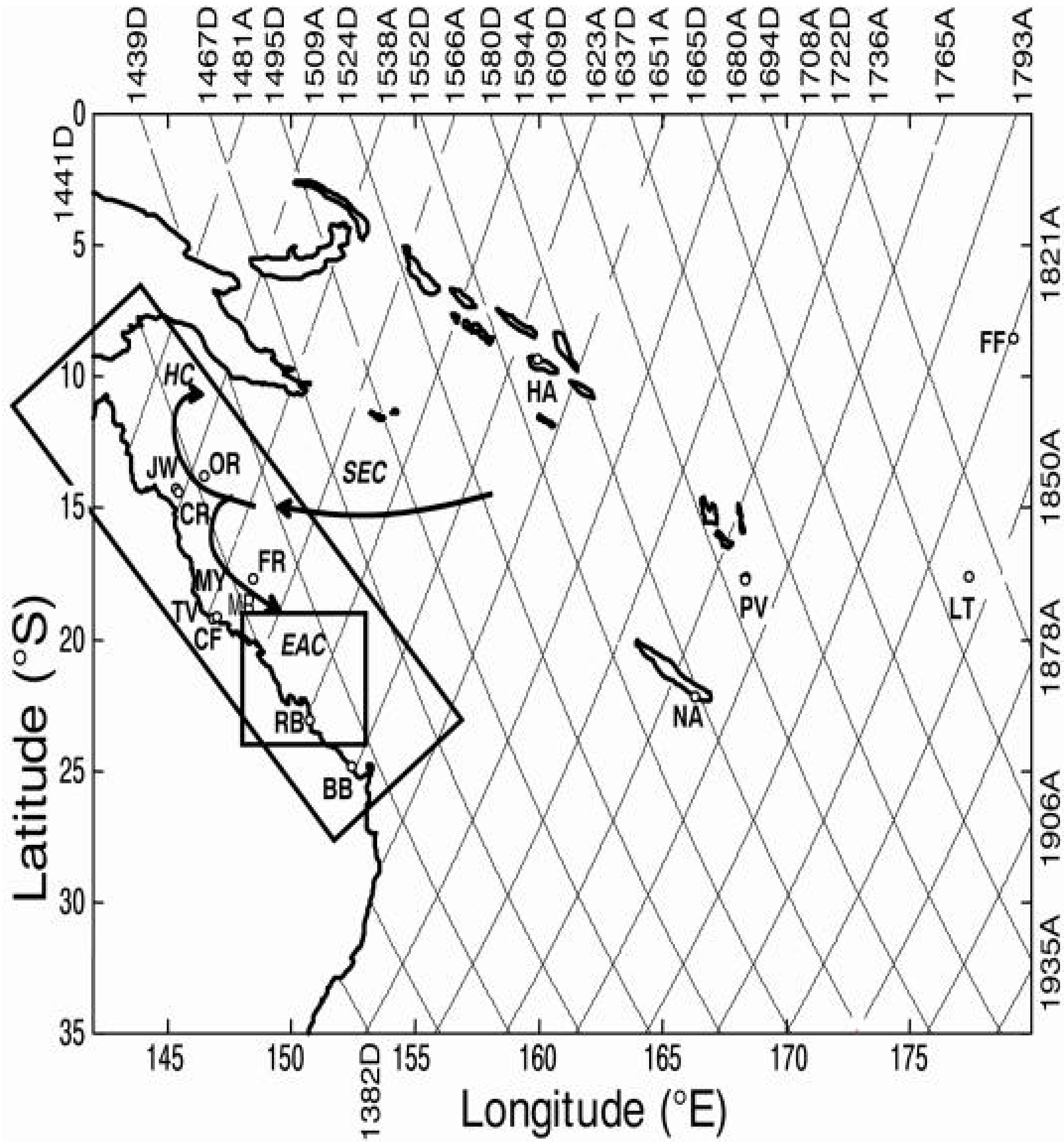


Figure 2. Map showing Coral Sea and western South Pacific to the dateline with major Coral Sea currents including the South Equatorial Current (SEC), East Australian Current (EAC) and Hiri Current (HC). Original TOPEX ground-tracks are overlaid.

In situ tide gauges and current meter mooring stations shown include: Pressure gauges on offshore reefs at Carter Reef (CR), Osprey Reef (OR), Myrmidon Reef (MR), Flinders Reef (FR), Coastal sea level stations at Townsville (TV), Cape Ferguson (CF), Rosslyn Bay (RB) and Bundaberg (BB), Pacific island stations at Honiara (HA), Port Vila (PV), Funafuti (FF), Lautoka (LT) and Noumea (NA) and Current meter moorings in slope water near Jewell Reef (JW) and Myrmidon Reef (MY).

The smaller and larger rectangles, respectively, show the SGBR and GBR tidal model domains.

Fig. 2

OBSERVING CORAL SEA CIRCULATION WITH ALTIMETRY

In a topographically complex setting, such as the Coral Sea and adjoining Great Barrier Reef region (**Fig. 1**), it is virtually impossible to obtain sufficient data from conventional moorings to adequately characterize the regional circulation. Previous studies combining in situ and remote sensing data for specific purposes (eg., Burrage et al, 1995, 1996) have demonstrated a complex mean circulation and moderately energetic mesoscale variability in the Coral Sea and on the adjoining continental shelf.

The TEACS mooring program (**Fig. 2**) was designed to determine the direction and strength of the EAC transport and to infer the location of the bifurcation of the SEC to form the poleward EAC and equatorward HC (Burrage and Steinberg, 2002). To effectively expand the observational domain to the greater Coral Sea we have taken advantage of the geostrophic relationship between surface currents and orthogonal sea surface slope which is demonstrated by TEACS (**Fig. 3**), and by results of linear systems modeling studies (Burrage et al., 1994, 1995). We plan to exploit this relationship by using SSH determined from TOPEX and JASON altimetry to map sea level variability and surface geostrophic currents over the entire Coral Sea domain (Burrage et al 2002).

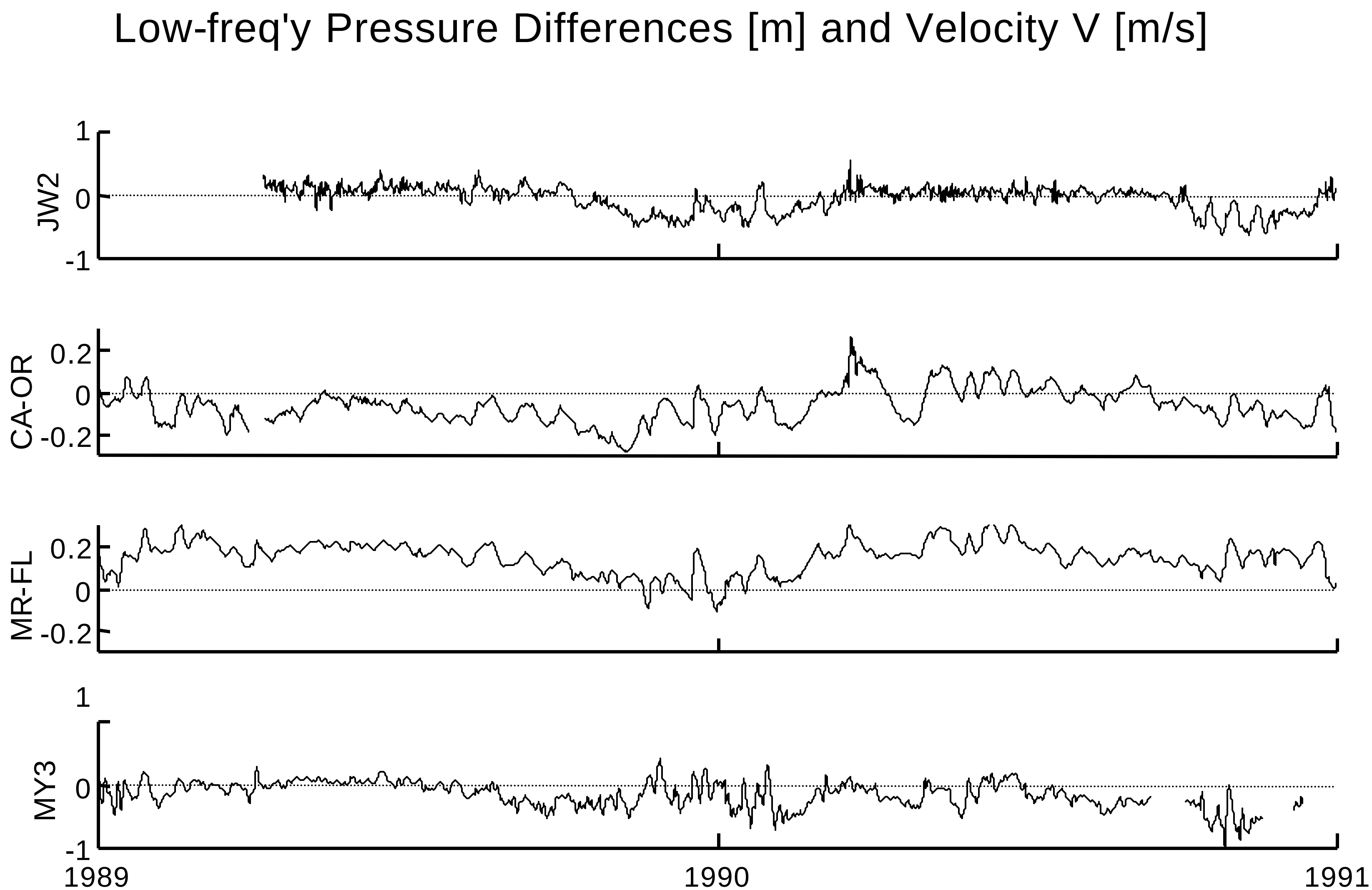


Figure 3. Time series of along-shelf current on the continental shelf at Jewell Reef (JW2) and Myrmidon Reef (MY3) and across-slope subsurface pressure (sea level) differences for corresponding station pairs (Carter Reef –Osprey Reef and Myrmidon Reef – Flinders Reef, respectively).

Fig. 3

CORRELATING ALTIMETRIC SSH AND SITU DATA

SSH time series extracted at selected intervals along passes close to each *in situ* station were lag-correlated with sea level time series from the station (**Fig. 4** upper panel) and the location yielding the highest (optimal) correlation was selected for regression analysis (**Fig. 4** lower panel).

At the Port Vila station (**Fig. 4 a**), which is typical of the Coral Sea stations analyzed, the optimal lag correlation was 0.74 (R^2=0.55). The altimetry data from the Coral Sea were corrected using the CSR3.0 global tidal model. Similar correlation results for all the stations analyzed are summarized in **Fig. 7** which shows circles with radii proportional to the correlation and lines indicating the direction and magnitude of the corresponding lags.

The corresponding optimal lagged correlation for Rosslyn Bay (RB, Fig. 4b), located in the Southern GBR Lagoon, had a correlation of 0.80 (R^2=0.64). The altimetry data in this area was corrected using the SGBR regional tidal model. The results for the other stations in this region are summarized in **Fig. 8**. The correlations are surprisingly high, considering the complexity of the mesoscale circulation in this region (**Fig. 6**).

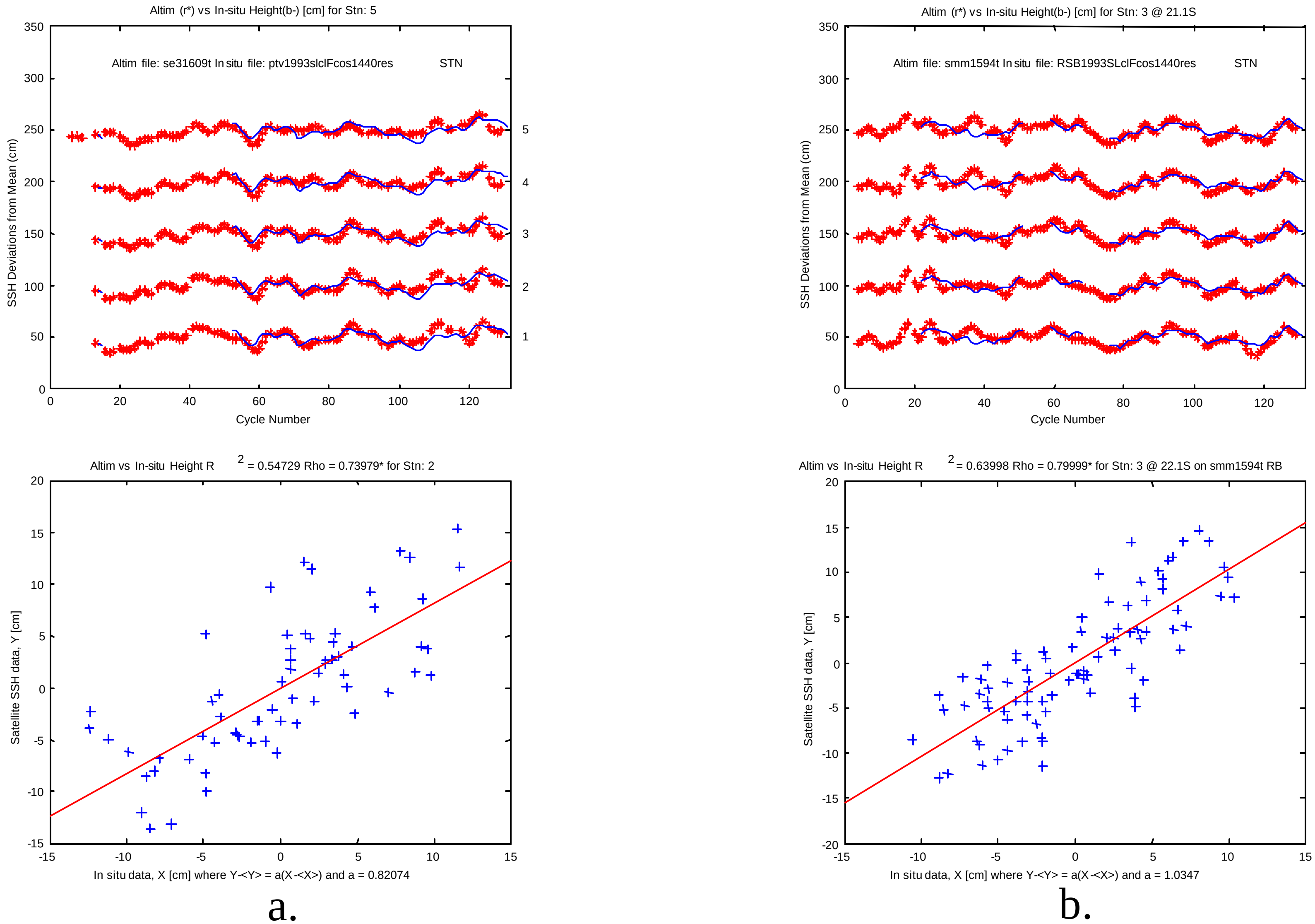


Figure 4. Optimal lag correlations for monthly smoothed sea level data for (a) Port Vila and (b) Rosslyn Bay. Time series of demeaned in situ (solid) and altimetric (asterisks) sea levels at adjoining Stn intervals along track after lag adjustment (upper panels). The series from each along track position are offset vertically. Corresponding lagged regression plot for station showing optimal correlation (lower panels).

Fig. 4

CORRELATING ALTIMETRIC GCA’S AND SITU DATA

Across-track Geostrophic Current Anomalies were computed from the along-track gradients of tidally-corrected and monthly-smoothed SSH data. They were then compared with low-pass filtered (sub-tidal frequency) currents obtained from the current meter moorings.

Lag correlation was performed on GCA’s extracted from TOPEX passes near the slope water current meter moorings near Myrmidon Reef (MY) and Jewell Reef (JW). Correlation for data obtained at MY2 from a depth of 50 m in water 240 m deep (**Fig. 5**) was high, 0.92 (R^2=0.85). However, the correlation results for Jewell Reef were less impressive(~0.6), due perhaps to its proximity to the SEC bifurcation (**Fig. 2**), where flows might be significantly ageostrophic. The results for both moorings and all available depth levels are summarized in **Fig. 9**.

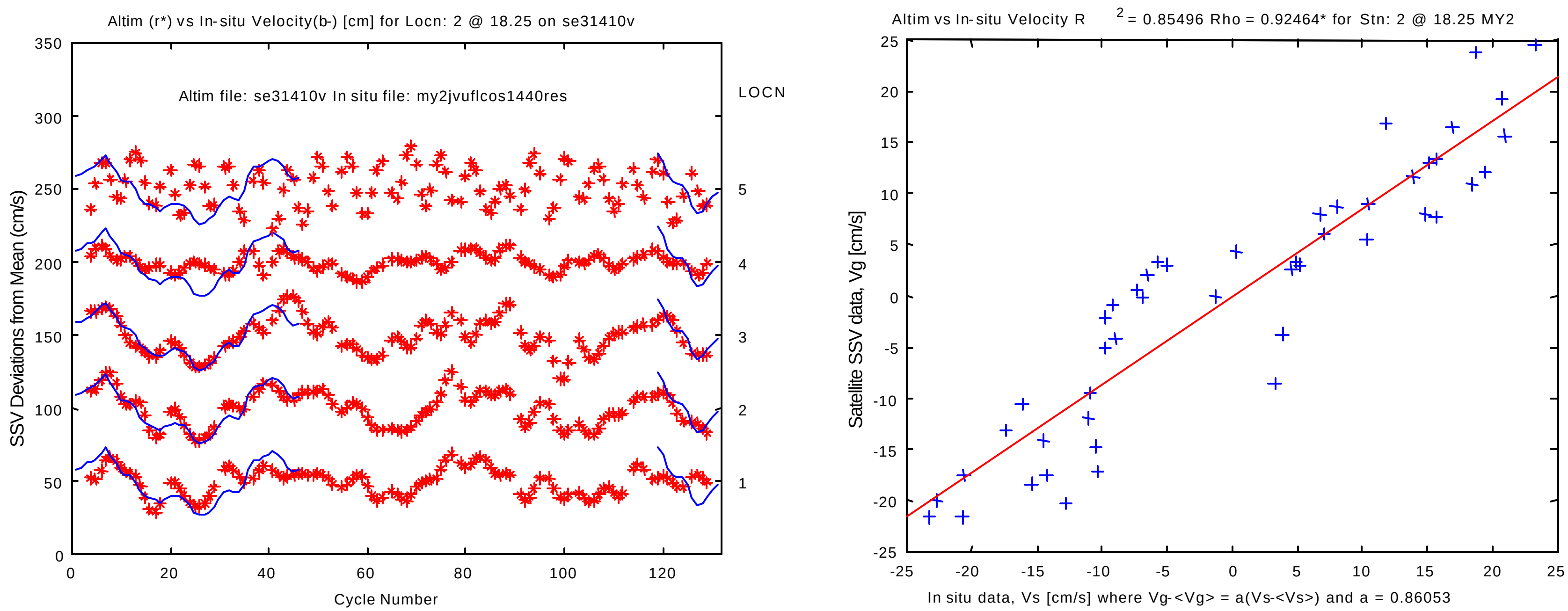


Figure 5. Optimal lag correlations of monthly smoothed geostrophic current anomalies with observed Myrmidon Reef currents. Time series of demeaned along-slope in situ currents (solid) and altimetric GCAs (asterisks) at adjoining Stn intervals along track (left panel). Corresponding lagged regression plot (right panel). Increased noise levels at Stn 5 are due to tidal errors and dropouts over the Reef.

Fig. 5

CIRCULATION IN THE SOUTHERN GBR

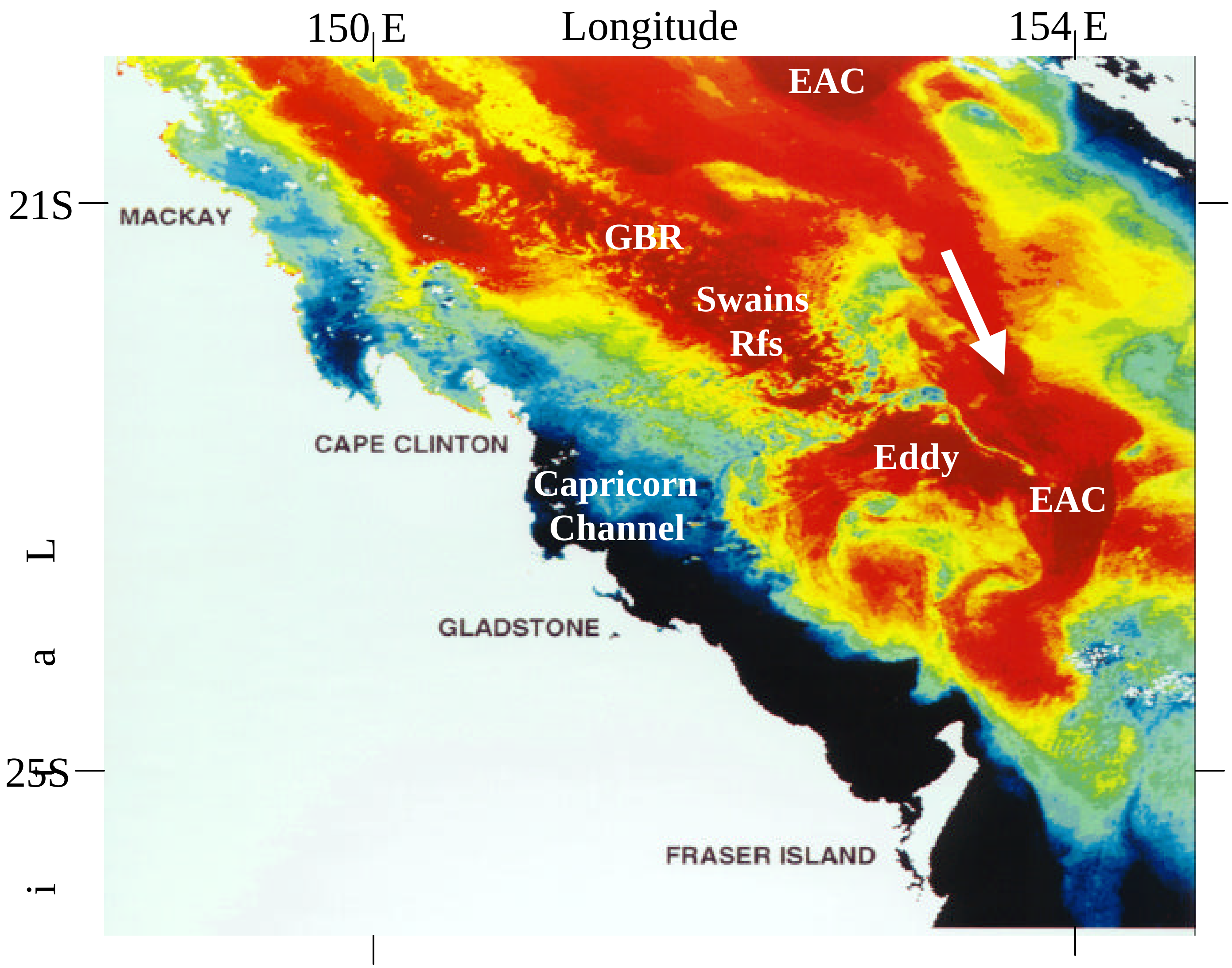


Figure 6. NOAA9 SST Map of SGBR for 19th. Sept., 1988 showing the EAC flowing southward off the GBR, crossing the Capricorn channel and reattaching to the shelf at Fraser Island. A clockwise circulating 'lee eddy' lies north of the Island. Pairs of TOPEX (now JASON) ground-tracks intersect near Mackay, in the Swains Reefs and just north of Fraser Island. The Tandem Mission will improve resolution of such mesoscale circulation features.

Fig. 6

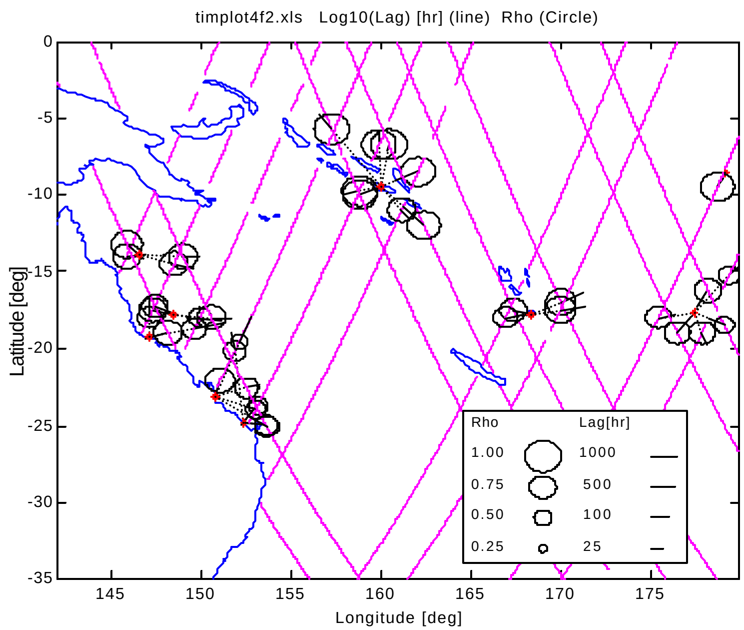


Fig. 7

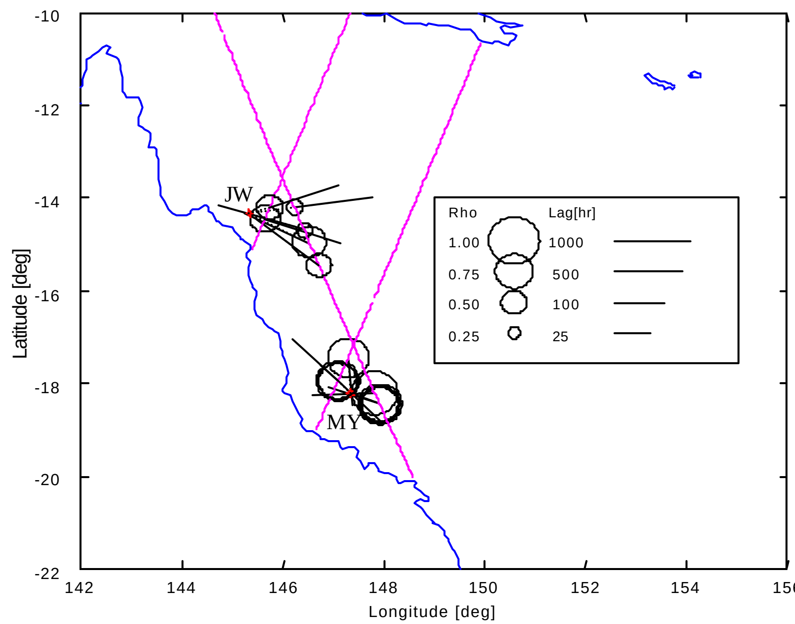


Fig. 9

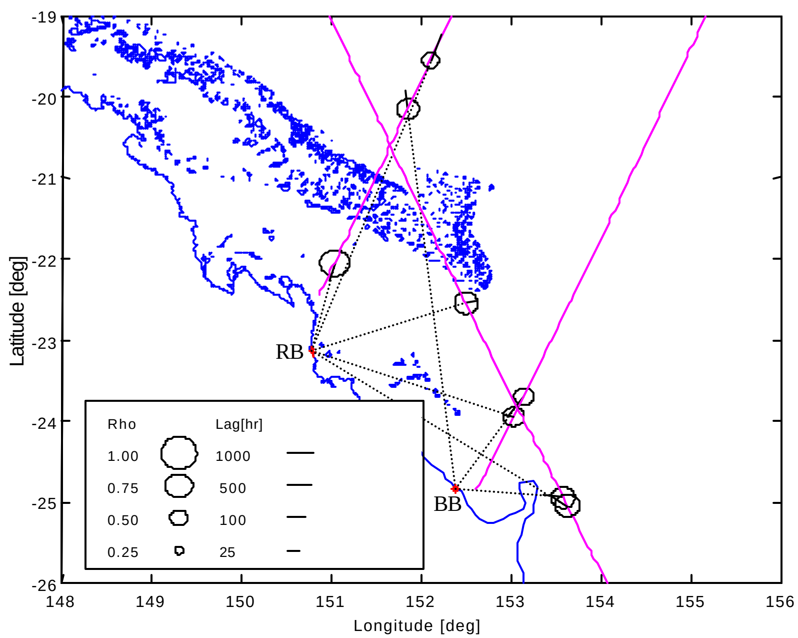


Fig. 8

Figure 9. Optimal lag correlations of monthly smoothed geostrophic current anomalies with observed Myrmidon Reef currents.

Figures 7-8. Optimal lag correlations of monthly smoothed altimetric sea surface height with sea levels observed in the Coral Sea and GBR Lagoon.

TEACS-2

The original TEACS(-1, **Fig. 1**) mooring array was reconfigured by AIMS in 2001 (TEACS-2, **Fig. 10**). This was done partly to reduce maintenance costs, but also to optimize station locations with respect to the JASON and TOPEX ground-tracks (**Fig. 10**). The deployment details for the revised mooring array are shown in **Table 1**.

The current meter mooring locations (CH and PR) are close to JASON (formerly TOPEX) ground-tracks, while the tide gauges will provide measures of both along-slope and across-slope sea surface pressure gradients. The tide gauge pair FR-MR, which spans the EAC where it flows along the Queensland Trough (**Fig. 1**), will indicate EAC geostrophic transport and currents observed at the slope water mooring and CH currents should correlate with this.

Both the MR and OP tide gauges are close to JASON ground tracks. When paired with coastal sea level station CF (**Fig. 1**), MR will give an estimate of geostrophic current on the shelf for comparison with current meter mooring PR and with altimetric GCA's computed in the GBR Lagoon, after correction using the GBR tidal model.

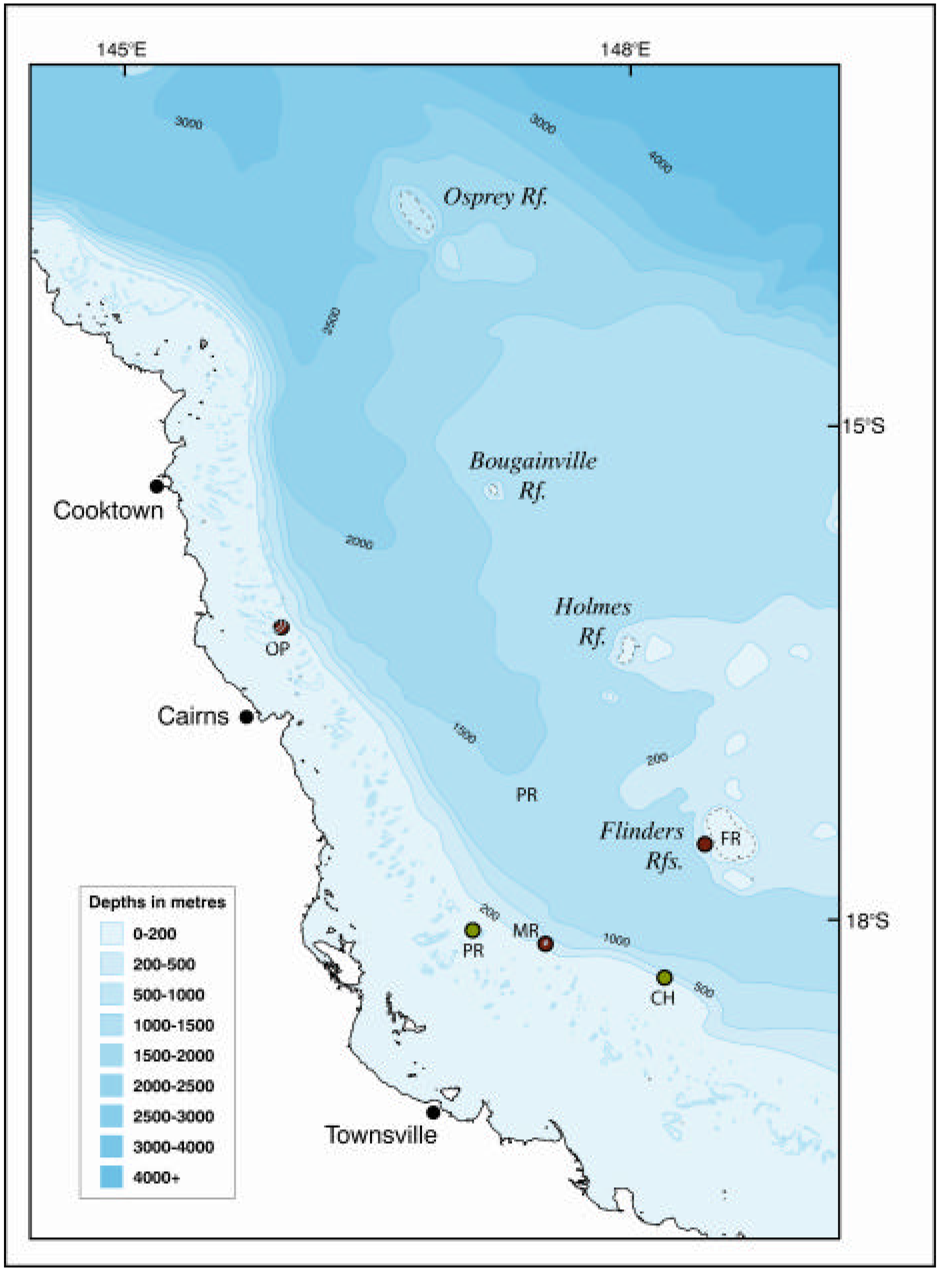


Fig. 10

Figure 10. Locations of TEACS-2 long-term tide gauge stations (Red dots) and current meter moorings (Green) deployed to coincide with the TOPEX/JASON tandem mission for comparisons with altimeter-derived SSH and GCA's.

Table 1.

TEACS-2 Mooring Array

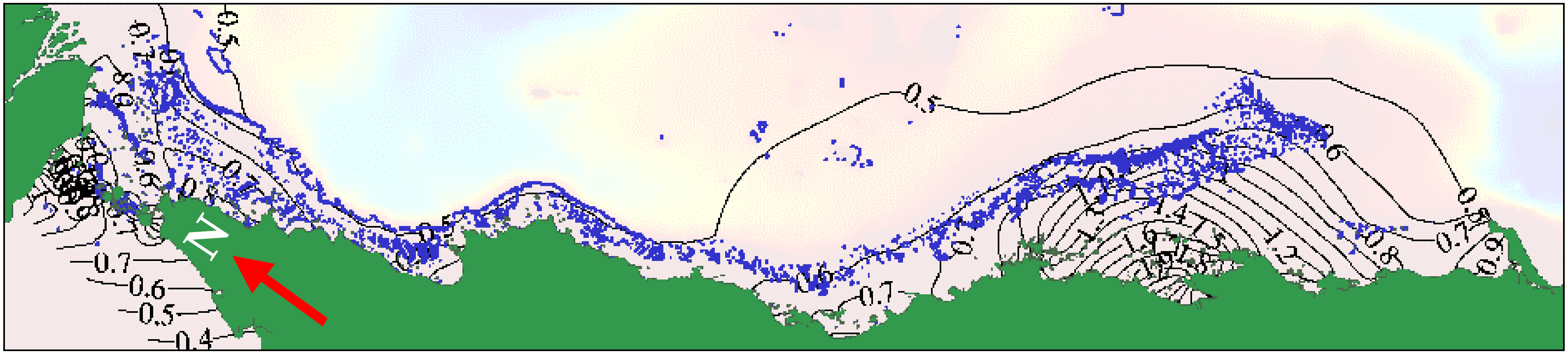
Stn	Lat(S) (dd mm.m)	Lon(E)	Water Depth(m)	Date Deployed
		Current Meters		
PR	18 11.5'	146 57.9'	50	Apr. 2001
CH	18 33.6'	147 57.1'	258	Apr. 2001
		Pressure Gauges		
FL	17 42.9'	148 26.8'	9	Oct. 1988
MR	18 16.3'	147 22.7'	12	Oct. 1988
OP	16 11.2'	145 53.4'	8	Oct. 1990

GBR TIDAL MODEL

A depth-varying barotropic numeric hydrodynamic model (**Fig. 11**) was specifically designed to simulate tides throughout the entire GBR and NE Australian continental shelf and slope. This model, whose domain includes that of the original SGBR model (**Fig. 2**), will be used to correct TOPEX and JASON altimetry along the continental slope and in the GBR Lagoon.

The original SGBR tidal model exhibited typical M2 amplitude errors of 2-4 cm and M2 phase errors of 2-3 degrees. The new tidal model is expected to have comparable or better performance, but over a much larger domain.

M2 Tidal Amplitude



GBR TIDAL MODEL - M2 TIDAL CONSTITUENT

Barotropic 2D, depth-integrated hydrodynamic model with implicit time-stepping. Domain includes entire Great Barrier Reef and Torres Strait.
Spherical Grid of size 1221 x 271 grid points.
Resolution is 1 minute of arc (approx. 1 Nautical mile) .
Transformation places "equator" just south (to lower right) of the grid.
Tides modelled: 22 primary tidal constituents.
Boundary conditions employ Eane’s CSR3.0 tidal model with careful manual adjustment and calibration using in situ data.
An embedded Reef Scale Parameterization scheme (Bode et al., 1997) accounts for frictional effects of sub-grid scale reefs (blue). The model is run for 6 months of simulated time, at which point model data are analyzed harmonically to extract all tidal constituents. **Fig. 11**

EAC/CORAL SEA MODEL

A depth-limited barotropic numeric hydrodynamic model (**Fig. 12**) was specifically designed to simulate the influence of the South Equatorial Current (SEC)/East Australian Current (EAC) system on continental shelf currents for the purposes of multi-decadal larval transport studies.
The model domain covers the western Coral Sea at a resolution of 5 minutes of arc (approx. 5 Nautical miles). The model simulation combines both tidal and sub-tidal circulation processes. Friction is intentionally reduced to very small values in the deep ocean to simulate the effects of stratification, which tends to isolate the surface circulation from deeper topographically-steered geostrophic currents. Boundary forcing employs a mean sea level signal along with seasonal sea level variations (repeated annually) derived in part from linear systems model results and tides.
Model calibration seeks to match on-shelf currents to in situ measurements acquired at various current meter mooring stations in the central GBR. The depth-limited 1-layer approach is economical, but makes calibration of tidal circulation difficult, so development of a multi-layer model is planned to improve accuracy in setting boundary conditions for modeling continental shelf currents.

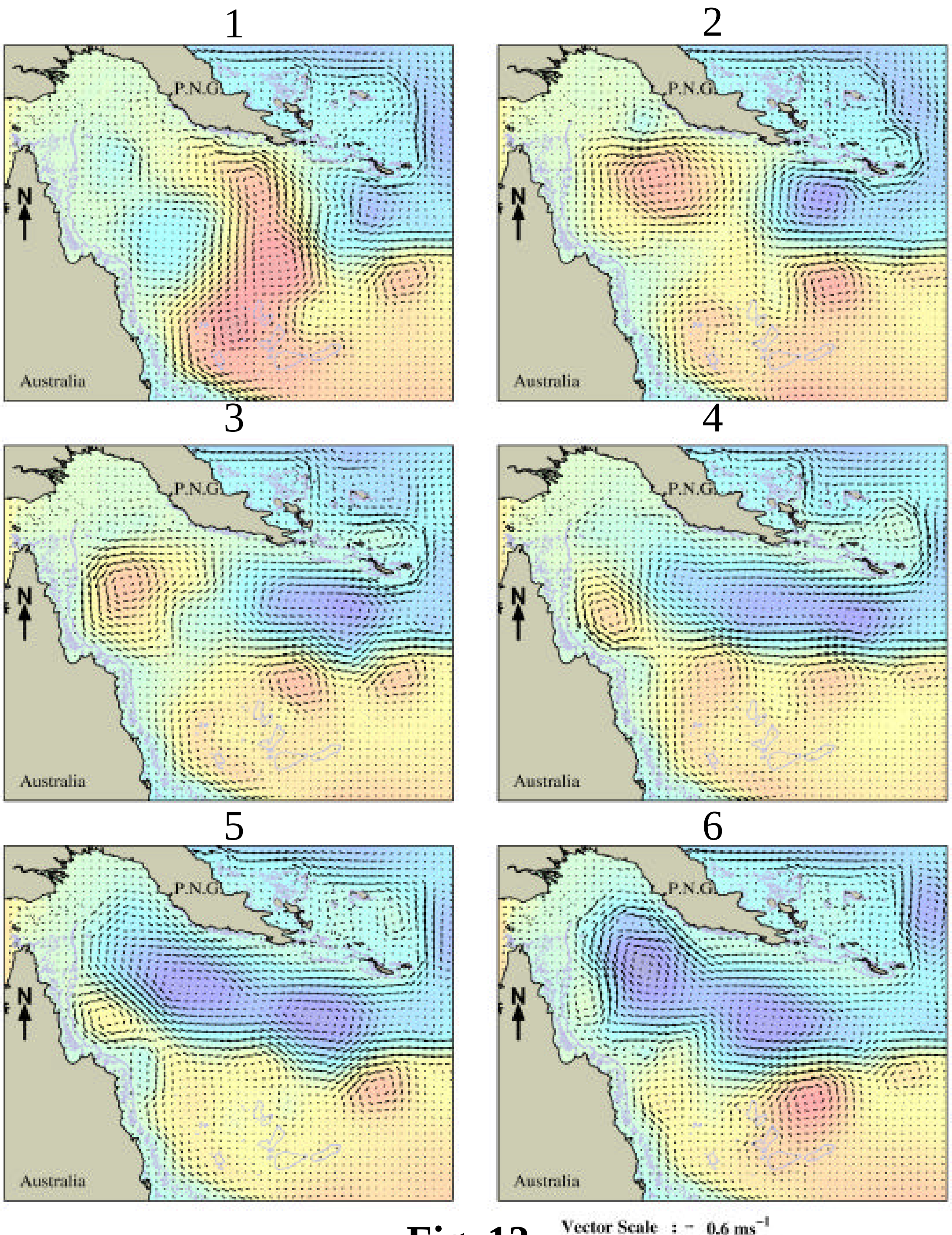


Fig. 12

Figure 12. Frame 1 shows a typical situation with cyclonic circulation dominating in the NW Coral Sea.

An anticyclonic eddy (orange) appears in this area in frames 2-3.

The eddy weakens in frames 4-5 then propagates equatorward in frame 6 as the cyclonic “Coral Sea Gyre” and equatorward Hiri Current become established.

Frames are separated by a time interval of one week.

SAMPLE RESULTS FROM EAC/CORAL SEA MODEL

Sample results from this limited-depth barotropic circulation model (**Fig. 12**) appear to the provide an explanation for strong poleward current pulses that have been observed at the Jewell Reef mooring (Burrage and Steinberg, 2002).

The model suggests that during the transition from strong to weak EAC that occurs at the end of the year, resulting adverse pressure gradients cause the HC to spin off anti-cyclonic eddies on the southern side of Papua New Guinea (PNG). These move across the entrance to the Gulf of Papua and impinge on the GBR shelf just north of Jewell Reef.

The eddies subsequently weaken and move equatorward along the shelf edge; the whole process taking 2 to 3 weeks. The model produces current anomalies near Jewell Reef that are of the same duration and intensity as similar episodes observed in the TEACS-1 current mooring data.

CONCLUSIONS

Our study region includes the topographically-complex Coral Sea, NE Australian continental slope, and GBR Lagoon, where tides are amplified as they propagate across the wide shelf and around the reef matrix.

1)Tidal model corrections made using the standard CSR3.0 global tidal model were found to be adequate in the Coral Sea, but deficient in the macro-tidal region off the NE Australian continental shelf/GBR, where a high resolution regional tidal model produced accurate tidal corrections.

2) Application of optimal lagged correlation techniques to the tidally corrected low frequency SSH showed high correlation (> 0.6) for locations throughout the Coral Sea, and in the Southern GBR within the regional tidal model domain.

3) Time series of Geostrophic Current Anomalies from slope water current meter moorings gave optimal lagged correlations of 0.6, and 0.8 near Jewell (14 S) and Myrmidon Reef (19 S), respectively.

FUTURE WORK

We have developed a high-resolution tidal model of the entire NE Australian continental shelf and slope and will use this model to generate tidal corrections in the Coral Sea for the TOPEX/JASON tandem mission.

The corrected SSH fields will be used to compute surface Geostrophic Current Anomalies for comparison with data from in situ current meter moorings located near TOPEX/JASON ground-tracks.

We have also developed a depth-limited barotropic numerical hydrodynamic model of the Coral Sea designed to provide nested boundary conditions for an existing high-resolution model of the tidal and sub-tidal circulation on the continental shelf and slope of the Great Barrier Reef.

We plan to upgrade this to a multi-level model and use it to investigate mesoscale variability in the Coral Sea and adjoining continental shelf for comparison with high resolution altimetric SSH and GCA fields derived from the TOPEX/JASON tandem mission.

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