Accuracy assessment of recent empirical and assimilated tidal models for the Great Barrier Reef region

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1. OUTLINE

In this study the performance of recently regional and global tidal models in tidal constituent estimation and tidal height prediction over the Great Barrier Reef, Australia is assessed. Nine models, including TPX08, EOT11a, HAMTIDE, FES2012, FES2014, OSUNA, OSU12, GOT 4.10 and DTU10, were considered.

To evaluate the accuracy of the models in tidal constant estimation, eight major constituents (i.e. K_1, O_1, P_1, Q_1, M_2, S_2, N_2 and K_2) were extracted based on analyzing sea level observations in 926 altimetry along track locations and tide gauge stations using the response method and harmonic analysis, respectively. The outcomes were compared to those of the model estimations in corresponding points at spatial scales of coastline, coastal, shelf and deep ocean zones. These zones are defined according to depth. Also, to assess the tidal prediction ability, the sea level anomaly (SLA) from the recent Sentinel-3A mission was detided using the tidal height predicted by each model and the RMS of the SLA residuals (SLAR) was computed.

2. GREAT BARRIER REEF

- the largest reef system in the world with more than 2500 coral reefs [1].
- The strip of coral reefs is ~2600 km long and ~200 km wide with an average depth ~35 m in its inshore waters
- Reefs exert a considerable effect on tides, causing complicated tidal behaviors in the region.. This area is featured with [2]:
  - Highly variations of drag coefficients over reefs
  - Fluctuations in bathymetry and sea-floor topography

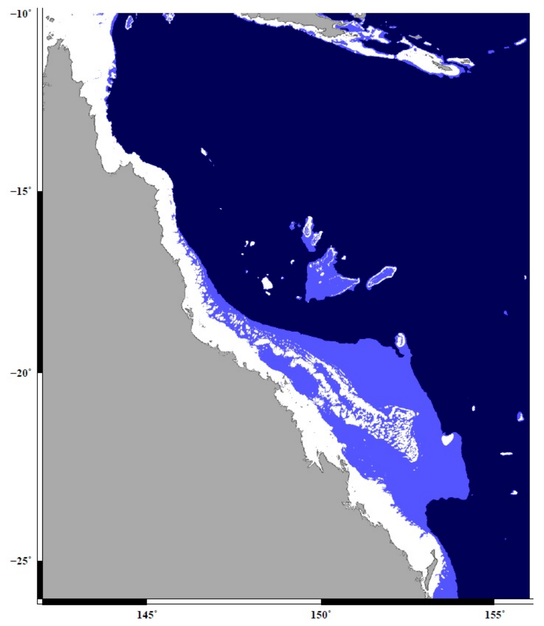
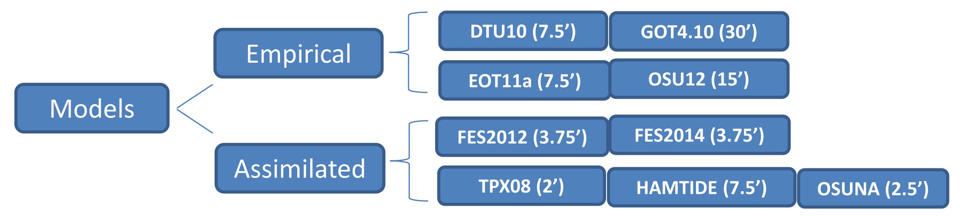


Fig. 1 Different zones defined by depth

- Coastline
- Coastal Zone, 0 m < Depth < 40 m
- Shelf Zone, 40 m < Depth < 400 m
- Ocean Zone, 400 m < Depth

3. MODELS AND DATA

- Nine tidal models are considered:



- Performance of the models in estimation of both tidal constants and the tidal height prediction is assessed.

Tidal Constant Estimation Assessment

Time series of sea level observations made by T/P, J1 and J2 and coastal tide gauges are analyzed to extract tidal constants and are compared to those of the models.

Tidal Height Prediction Assessment

Sentinel-3A Sea Level observations are detided using the tidal height predicted by each model and the residuals are assessed.

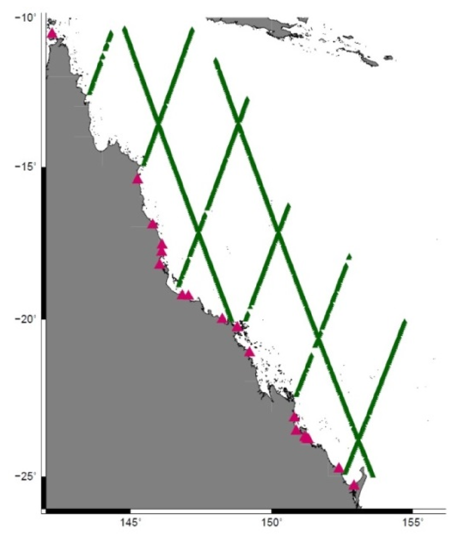


Fig. 2 Along track locations of T/P and coastal tide gauges used to extract tidal constants

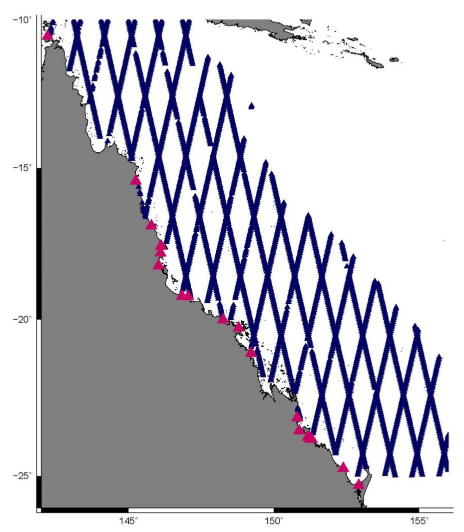


Fig. 3 Along track locations of Sentinel 3A used to assess tidal height prediction ability of the models

4. METHOD

For a given constituent of t, the RMS of misfits, between , model and observed tidal constants, is calculated as [3]

$$rms_t = \left(\frac{1}{2L}\sum_{i=1}^{L}(H_i^m - H_i^o)^2\right)^{1/2} \qquad (1)$$

where L is the number of positions in a zone, superscripts m and o stand for the model output and observed tidal constants, respectively, and H is the complex expression of tide amplitude and phase at position which is computed as:

$$H = A(cos(G) + isin(G)) \qquad (2)$$

where A is the tidal amplitude and G the Greenwich phase of the constituent for the i-th position. Considering the real part of Eq. (2) gives:

$$rms_t = \left(\frac{1}{2L}\sum_{i=1}^{L}\left[\left(A_i^m\cos(G_i^m) - A_i^o\cos(G_i^o)\right)^2 + \left(A_i^m\sin(G_i^m) - A_i^o\sin(G_i^o)\right)^2\right]\right)^{1/2} \qquad (3)$$

In addition, to assess the performance of each model, the root sum square (RSS) is calculated using the RMS misfit of the selected tidal constituents as [4]

$$RSS = \left(\sum_{i=1}^{T} RMS_i 2\right)^{1/2} \qquad (4)$$

where T is the number of constituents.

5. ABILITY TO ESTIMATE TIDAL CONSTANTS

- The two main semi diurnal constituents, M_2 and S_2, are the more inaccurate components for all the models over different zones of the study area. This is compatible with all previous studies that have shown tidal regime of this region to be of mainly semi diurnal pattern.
- Of all, OSUNA and TPX08 stand for the best estimators of M_2 on the coastline with mean RMS of ~13.5 cm and 13.6 cm. HAMTIDE and EOT11a however, are the most inaccurate with mean RMSs of 40 cm and 42.4 cm respectively.

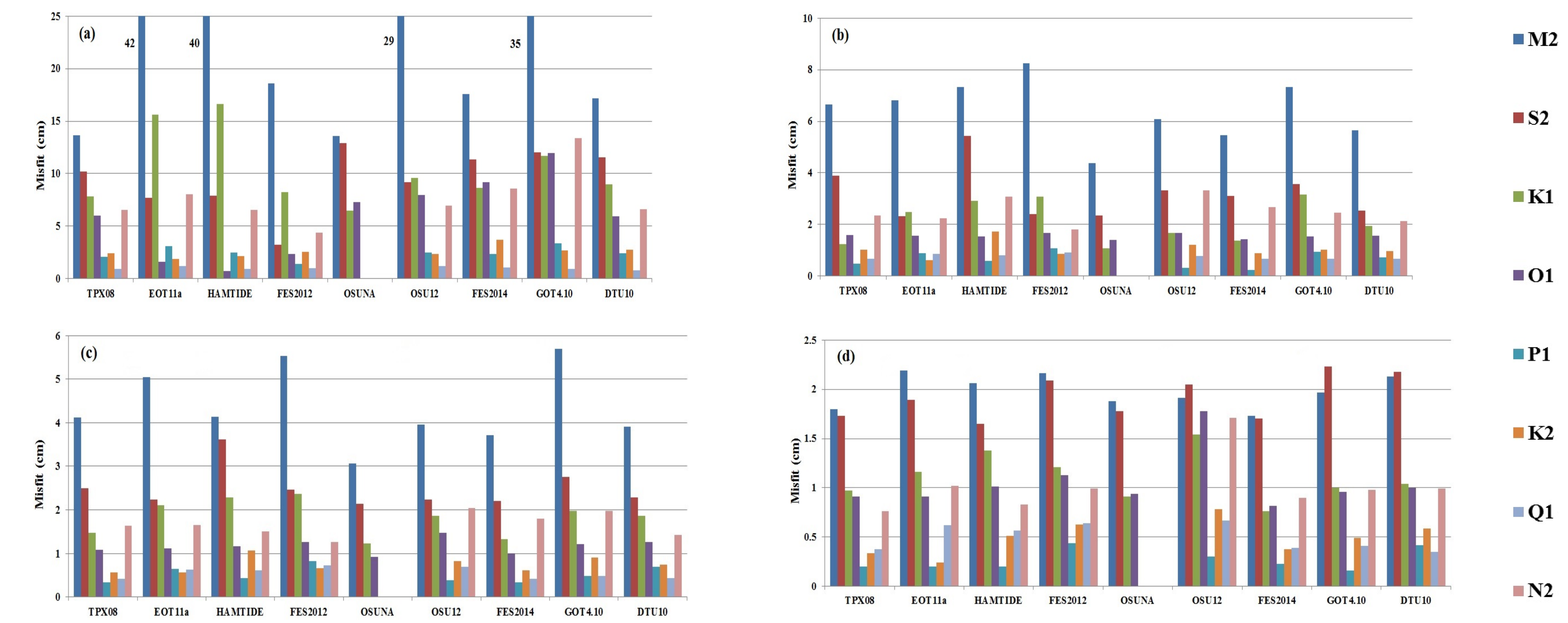


Fig. 4. The mean RMS of differences between tidal major constants calculated for coastline (a), coastal (b), shelf (c) and deep ocean (d) zone and tidal models (cm). The numbers in (a) show the misfit values more than 25 cm.

- Over coastal zone all the models show a fairly similar accuracy ranging from ~7 to ~10 cm of RSS with DTU10 ranking as the better one at ~ 7.1 cm.

Table 1
The mean RSS (in cm) of all 8 major tidal constants for the tidal models over coastline (CL), coastal zone (CZ), shelf zone (SZ) and deep ocean zone (OZ).

Zone	TPX08	EOT11a	HAMTIDE	FES2012	OSUNA*	OSU12	FES2014	GOT4.10	DTU10
CL	21.04	46.32	45.38	21.39	21.13	34.28	23.28	43.14	24.52
CZ	8.40	8.21	10.36	9.60	5.28	8.17	7.21	9.34	7.13
SZ	5.46	6.33	6.37	6.86	4.05	5.64	5.03	7.12	5.37
SZ	5.46	6.33	6.37	6.86	4.05	5.64	5.03	7.12	5.37

***OSUNA contains only four major constituents.**

- On the shelf zone, while all the models estimate the major constituents at a similar accuracy of ~5 to ~7 cm, FES2014 (~5 cm) and GOT 4.10 (~7 cm) mark the slightly more and less accurate models respectively.
- It should be noted that the OSUNA's smaller RSSs in Table 3 can be due to fewer number of constituents involved in this model's RSS calculation.

6. ABILITY TO PREDICT TIDAL HEIGHT

- The SLAs of the tide gauges and Sentinel-3A along-track positions are detided using tidal heights (TH) that are estimated by different models and consequently SLA residuals (SLAR) are calculated based on Eq. (5).

$$SLAR = SLA \quad - TH \qquad (5)$$

- Since Sentinel-3A data have not been used in tidal modelling, they can be used as independent datasets in comparison.

Table 2
Mean RMS (in cm) of the SLARs, calculated by detiding SLA using different ocean tidal models, based on one year of hourly tidegauge observations in the coastal zone and one year of Sentinel-3A data (10 cycles) over other zones, in the GBR. The smallest RMS is indicated by bold number.

Zone	TPX08	OSUNA	EOT11a	EOT11ag	DTU10	GOT4.10	FES2012	FES2014	HAMTIDE	OSU12
Coastline	30.16	27.81	41.93	41.88	24.10	36.31	24.36	24.39	41.88	37.3
Coastal	12.07	20.52	21.44	21.65	11.91	11.82	9.82	14.91	17.19	25.47
Shelf	8.01	18.25	15.42	15.56	8.48	8.30	6.63	11.81	13.13	17.95
Deep	7.18	15.49	10.03	10.13	7.25	7.22	6.99	6.95	8.88	12.64

- Overall, except for the twin model EOT11a and EOT11ag,HAMTIDE, OSU12 and GOT4.10other models show a similar accuracy ranging from ~24 to ~30 cm of RMS over coastline.
- At the coastal, shelf and deep ocean zone FES models, DTU10, TPX08 and GOT 4.10 feature the more efficient models in terms of prediction ability with the mean RMSs of ~9 to ~14 cm (coastal zone), ~7 to ~11 cm (shelf zone) and ~7 cm (deep ocean zone). Models EOT11a, EOT11ag and OSUNA form the second group in terms of accuracy with mean RMSs up to ~21 cm (coastal zone), ~18 cm (shelf zone) and ~15 cm (deep ocean zone).

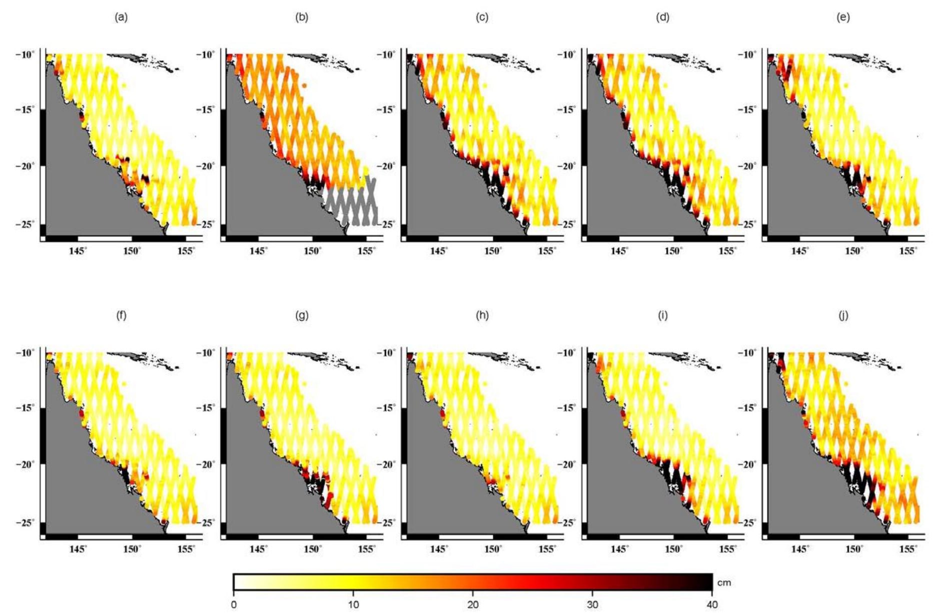


Fig. 5. The RMS of the SLA residuals over Sentinel-3A along-track locations, detided by (a) TPX08, (b) OSUNA, (c) EOT11a, (d) EOT11ag, (e) HAMTIDE, (f) DTU10, (g) GOT 4.10 ,(h) FES2012, (i) FES2014 and (j) OSU12 over the GBR region. Gray value in (b) is for locations beyond the geographic coverage of OSUNA.

7. DISCUSSION

- As expected, regional model OSUNA, which was efficient in estimation of the four major tidal constants in the coastal and shelf zones (Figs. 5b, c), is marked as the most inaccurate model in terms of tidal height prediction ability over shelf and deep ocean zones. The less available tidal components in this regional model can be the reason that affects its tidal prediction performance.
- The geographic range, between latitudes from -19° to -23° and longitudes from 148° to 153°, due to highly variant bathymetry and existence of the coral reefs features the area where the constituents show intense variation in comparison to other zones of the GBR.
- Models TPX08, FES2012, FES2014, GOT 4.10 and DTU10 have RMS of ~9 – 15 cm, ~6 – 12 cm and ~7 cm showing better performance over coastal, shelf and deep ocean zone respectively.
- A combination of intense variations of bottom topography in the challenging zone and existence of coral reefs and small islands contribute to the model's accuracy and performance.
- The influence of GRACE data in tidal analysis over this region was revealed to be insignificant showed by the comparison between prediction ability of EOT11a and EOT11ag.
- Prediction performance of FES2012 is 55% better than it's successor over the challenging zone.

8. REFERENCES

[1] Great Barrier Reef Marine Park Authority, Australian Government, 2016. Facts about the Great Barrier Reef, Retrieved from: http://www.gbrmpa.gov.au/about-the-reef/facts-about-the-great-barrier-reef

[2] Bode L., Mason L.B, Middleton J.H. (1997). Reef parameterisation schemes with applications to tidal modelling. *Pro Oceanography*, 40, 285-324.

[3] King A. M., Padman L. (1995). Accuracy assessment of ocean tide models around Antarctica. *Geophysical Research Letters*, 32.

[4] Oreiro F. A., D'onofrio E.,Grismeyer W., Fiore M.,Saraceno M. (2014). Comparison of tide model outputs for the northern region of Antarctic peninsula using satellite altimeters and tide gauge data. *Journal of Polar Sciences*, 10-23.