Barotropic and Baroclinic Tide Models For and From SWOT

Richard D. Ray, NASA/Goddard Space Flight Center
Edward D. Zaron, Gary D. Egbert, Oregon State University
Sam M. Kelly, University of Minnesota

Overview

The main goal of our work has been to construct models of both barotropic and baroclinic tides which the SWOT project can use to remove tidal variability from the sea-surface height (SSH) measurements. The problem of baroclinic tides is an exceedingly difficult one. We have concentrated on (1) constructing models of a few primary tidal constituents that remain phase-locked with the tidal potential, and (2) assessing the non-phase-locked components, mapping how these vary geographically, and identifying what (alias) frequencies are most affected.

Our models have been independently tested, and they can be employed by the project as anticipated. The models will remove from SWOT most of the variance associated with phase-locked internal tide signals.

Accomplishments:

1. Refined the SWOT tidal models, both barotropic and baroclinic.
2. Investigated the predictability of deep-ocean internal tides and their expression in sea surface topography.
3. Collaborated with SWOT Science Team groups to analyze tidal signals and supplemented those studies with investigations of historical surface drifter, bottom pressure, and other measurements.
4. Prepared for handling future SWOT measurements to allow successful estimation and prediction of phase-locked and non-phase-locked tides.

Barotropic and Baroclinic Tide Models

Barotropic "Ground Truth" Comparisons (RMS cm)

Publicly-available tide models routinely achieve centimeter-level accuracy in the deep ocean, but larger errors occur on the continental shelves and at coastal stations.

We are developing new tide models, GOT5 and TPXO10, which continue to improve in accuracy.

With the continuation of the reference missions, improvements in hydrodynamic models, and refinement of altimeter processing methods, we are resolving increasingly smaller lines in the tidal spectrum.

Deep (BPR) stations (151)

	Q1	O1	P1	S1	K1	J1	2N2	μ2	N2	M2	S2	K2	M4	MS4
FES14	0.136	0.181	0.138	0.296	0.227	0.450	0.095	0.096	0.192	0.300	0.266	0.148	0.120	0.128
EOT20	0.297	0.252	0.280	0.498	0.386	0.276	0.190		0.346	0.482	0.439	0.328	0.176	
GOT4.8	0.165	0.296	0.234	0.331	0.423				0.252	0.510	0.369	0.209	0.089	
GOT5.1	0.131	0.172	0.132	0.277	0.239	0.116	0.092	0.068	0.191	0.305	0.261	0.138	0.054	0.060

Shelf stations (195)

	Q1	O1	P1	S1	K1	J1	2N2	μ2	N2	M2	S2	K2	M4	MS4
FES14	0.79	0.92	0.66	0.88	1.29	0.97	0.54	1.53	1.48	3.47	2.18	0.91	0.65	1.71
EOT20	0.80	0.90	0.71	0.87	1.39	0.80	0.51		1.43	3.18	2.11	0.84	0.70	
GOT4.8	0.82	1.00	0.84	0.90	1.54				1.98	4.88	2.78	1.48	2.23	
GOT5.1	0.80	0.92	0.70	0.76	1.37	0.80	0.56	1.46	1.45	3.28	2.12	0.86	0.63	1.23

Coastal (no estuarine) stations (262)

	Q1	O1	P1	S1	K1	J1	2N2	μ2	N2	M2	S2	K2	M4	MS4
FES14	0.26	0.96	0.50	0.55	1.37	0.63	0.32	1.11	1.71	7.63	3.26	1.06	1.35	1.93
EOT20	0.35	0.94	0.54	0.80	1.29	0.34	0.36		1.57	7.03	3.10	0.92	1.26	
GOT4.8	0.58	1.80	0.92	0.82	2.52				3.61	16.25	9.50	2.47	2.63	
GOT5.1	0.34	0.94	0.54	0.43	1.37	0.30	0.38	1.10	1.68	7.26	3.17	1.01	1.30	1.57

HRET14 baroclinic tide model:

Implements a new estimator using mixed L1/L2 optimization.

Constrained by 30-years of altimetry and 20 years of surface drifter data.

Noticeably reduced noise level, slightly improved SSH predictions, and greatly improved tidal current predictions.

Provides predictions for M_2, S_2, N_2, K_1, and O_1 tides.

Exact Repeat Mission SSH explained variance [rms cm]:

	O_1	K_1	N_2	M_2	S_2
HRET8.1	0.17	0.23	0.06	0.40	0.15
HRET14	0.18	0.24	-	0.41	0.16

Geodetic Mission SSH explained variance [rms cm]:

	O_1	K_1	N_2	M_2	S_2
HRET8.1	0.18	0.24	0.05	0.48	0.15
HRET14	0.18	0.26	-	0.51	0.14

GDP Surface Currents explained variance [rms cm/s]:

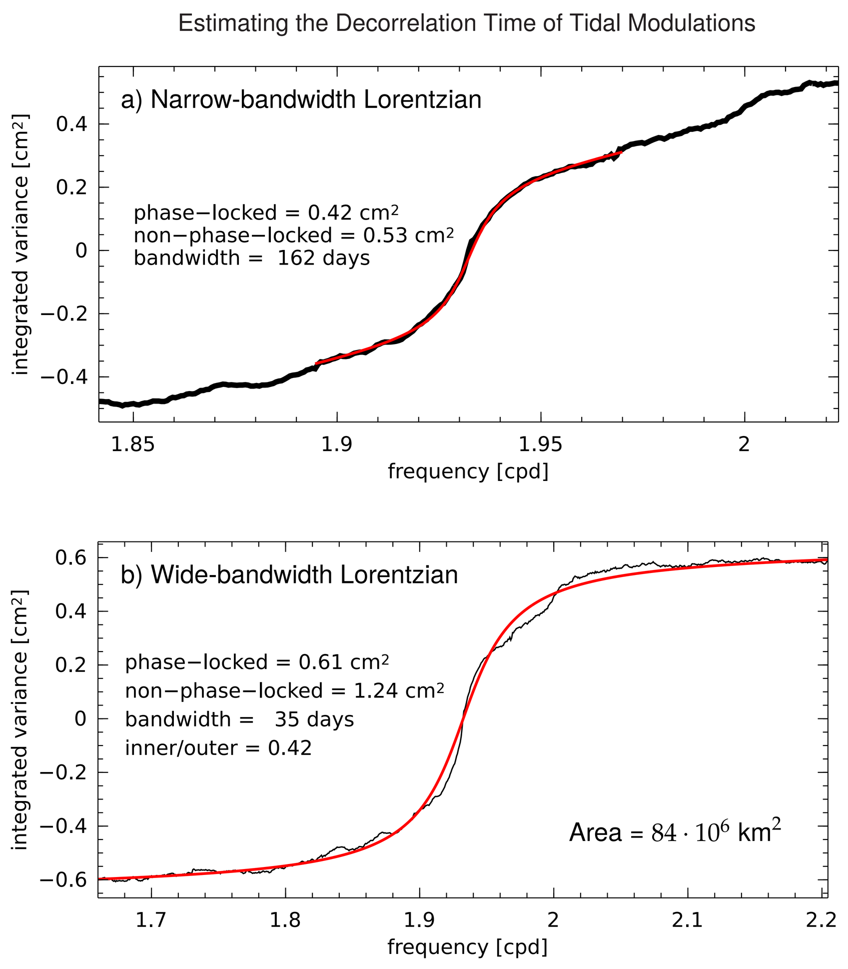
	O_1	K_1	N_2	M_2	S_2
HRET8.1	0.36	0.45	0.37	0.52	0.13
HRET14	0.67	0.72	-	1.13	0.62

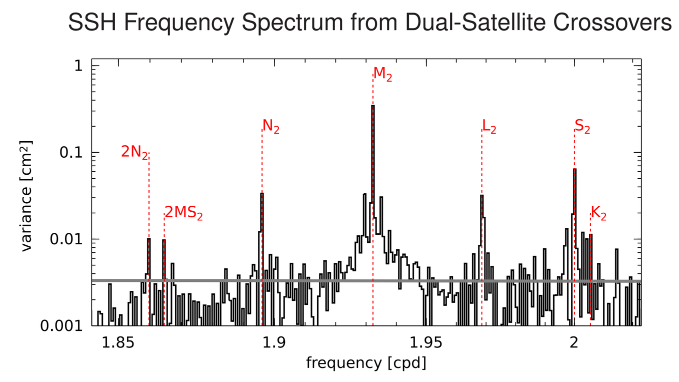
- E. D. Zaron and S. Elipot. New Estimates of Baroclinic Tidal Sea Level from Lagrangian Drifters and Satellite Altimetry, *J. Atmos. Oceanic Technol.*, in review, 2023.
- L. Carrere, B. K. Arbic, B. Dushaw, G. D. Egbert, S. Y. Erofeeva, F. Lyard, R. D. Ray, C. Ubelmann, E. Zaron, Z. Zhao, J. F. Shriver, M. C. Buijsman, and N. Picot. Accuracy assessment of global internal tide models using satellite altimetry. *Ocean Sci.*, **17**:147–180, 2021.
- E. D. Zaron and S. Elipot. An assessment of global ocean barotropic tide models using geodetic mission altimetry and surface drifters. *J. Phys. Oceanogr.*, **51**(1):63–82, 2021.

The Predictability of Internal Tides

Timescales of variability:

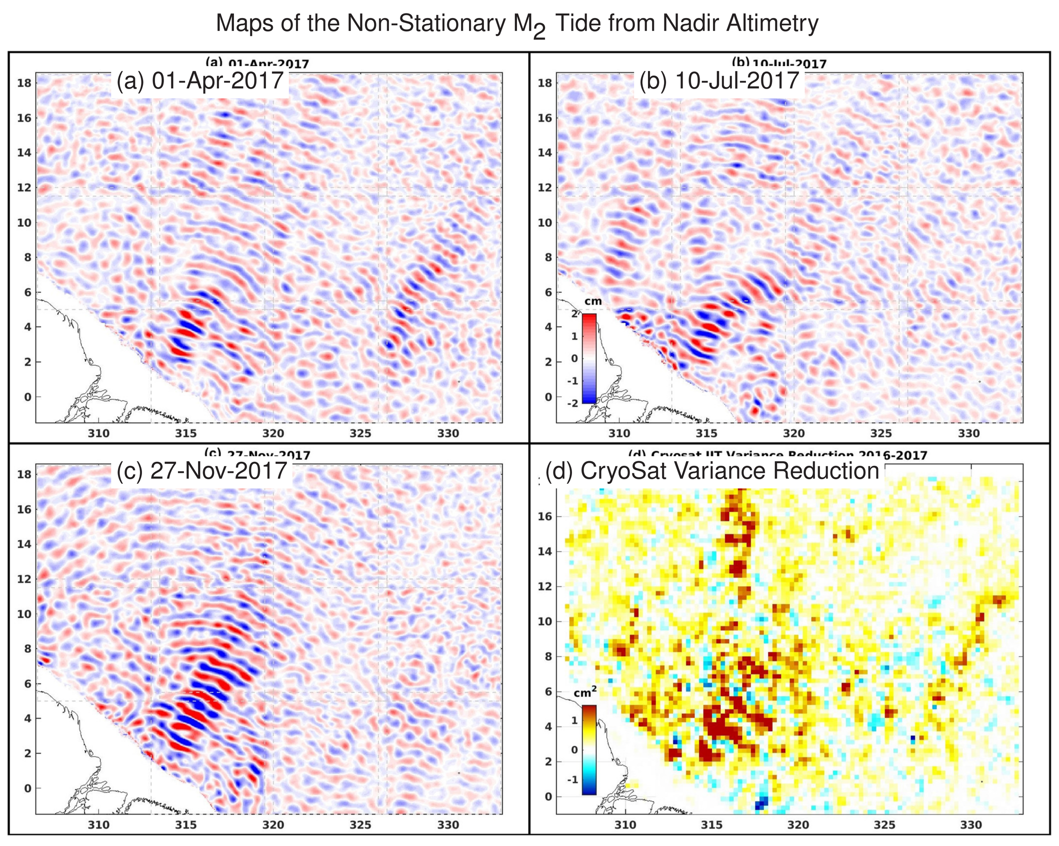
Zaron (2022) estimated the time-lagged autocovariance function of SSH at hourly resolution using dual-satellite (CryoSat-Jason) altimetry. The SSH power spectrum shows clear evidence of a continuum associated with variability of the M_2 tide (figure below). The tidal variability was found to be associated with two timescales (figures at right).





Mapping Non-Stationary Internal Tides:

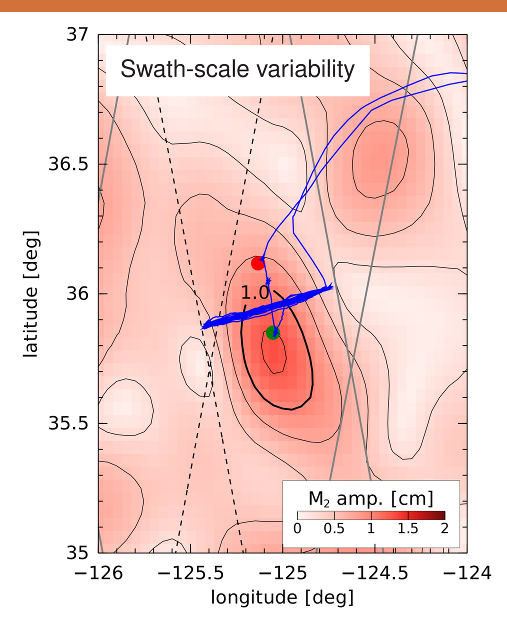
Egbert & Erofeeva (2022) demonstrated that a significant fraction of the non-stationary tide could be mapped by interpolating sparse nadir and simulated SWOT data using spatial basis functions derived from a (1/25)° global tides-resolving HYCOM model.

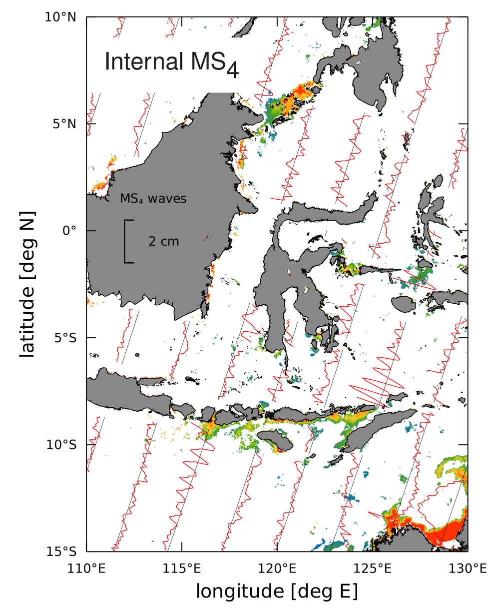


- E. D. Zaron. Baroclinic tidal cusps from satellite altimetry. *J. Phys. Oceanogr.*, **52**(12):3123–3137, 2022.
- G. D. Egbert and S. Y. Erofeeva. An approach to empirical mapping of incoherent internal tides with altimetry data. *Geophys. Res. Lett.*, **48**, e2021GL095863, 2021.

Collaborations with the Science Team

1. Working with Arbic et al on analysis of HYCOM model outputs. One outcome of this effort is Zaron and Ray (2023), which clarifies the distinction between steric height and baroclinic sea surface height.
2. Working with Wang et al to characterize small-scale internal tide variability around the California Current SWOT Ocean Cal/Val site (figure at right, upper).
3. Used ROMS and MITgcm model outputs to test the Egbert & Erofeeva approach (text box above), and found that results depend strongly on model details. Arbic's post-doc, R. Thakur, is now working on a comprehensive global assessment.
4. Assessing HYCOM and MITgcm surface currents with tide-resolving observations (Arbic et al, 2022).
5. Working with Koch-Larrouy et al to investigate the Indonesian Seas, including fornightly variability of surface chlorophyll and MS_4 nonlinear overtides (figure at right, lower).





- E. D. Zaron and R. D. Ray. Clarifying the distinction between steric and baroclinic sea surface height. *J. Phys. Oceanogr.*, at press, 2023.
- E. D. Zaron, T. A. Capuano, and A. Koch-Larrouy. Fortnightly tidal variability of Chl-a in the Indonesian Seas. *Ocean Sci.*, **19**:43–55, 2023.
- B. K. Arbic, S. Elipot, J. M. Brasch, D. Menemenlis, A. L. Ponte, J. F. Shriver, X. Yu, E. D. Zaron, M. A. Alford, M. C. Buijsman, R. Abernathey D. Garcia, L. Guan, P. E. Martin, and A. D. Nelson. Near-surface ocean kinetic energy distributions from drifter observations and numerical models. *J. Geophys. Res.*, **127**(10):e2022JC018551, 2022.