Impact of Internal Tides on Regional Ocean Model Boundary Conditions

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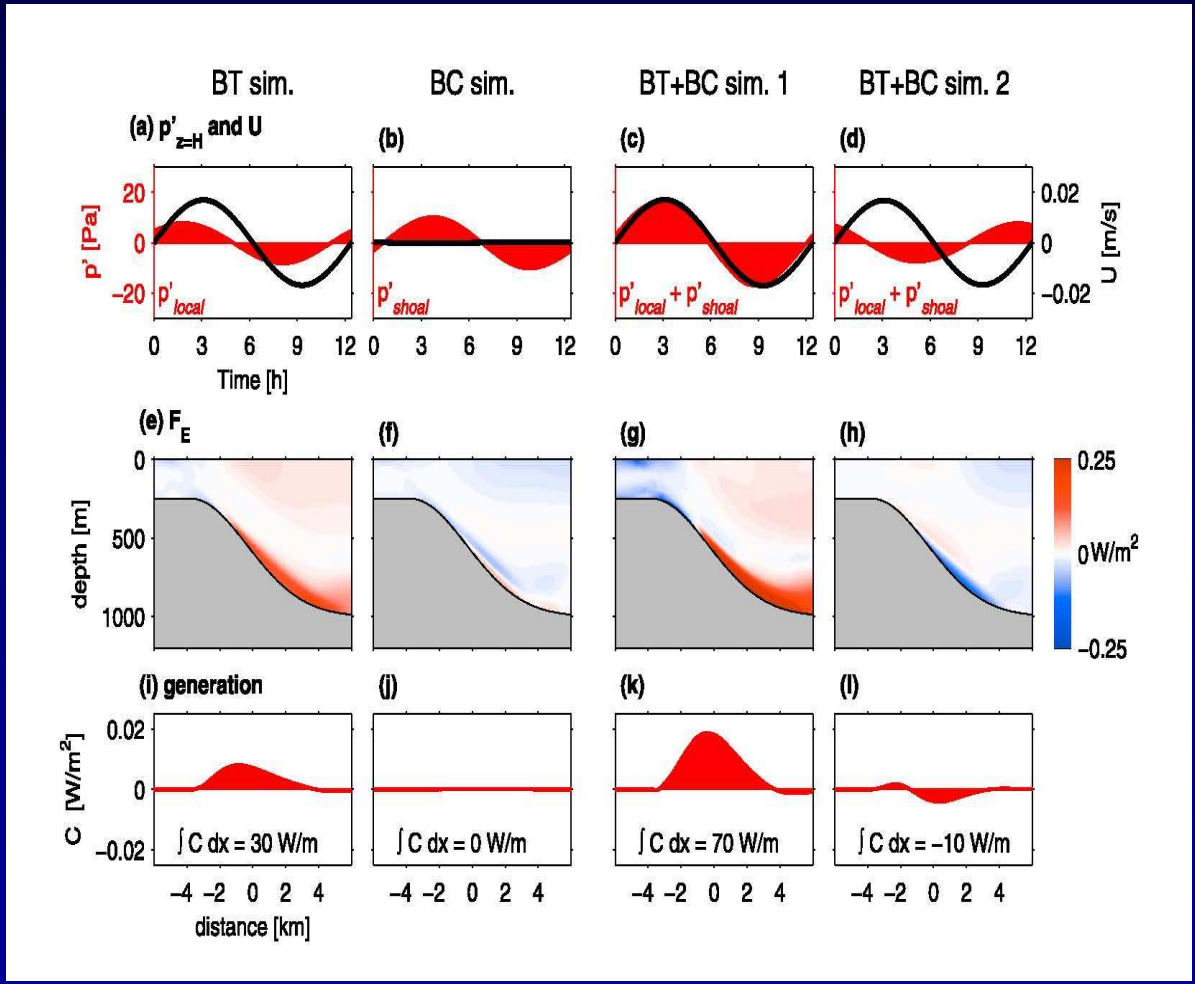
Miami, FL

Nesting Regional Models in the Global Model

- Global Models reproduce the large and meso-scale circulations
- Regional Models obtain low frequency BCs from the global model
- Tides are added from an independent source as elevation and transport BC
- However, the barotropic tide is not the only wave propagating in from the boundary
- Global model resolutions are approaching nested regional model resolution

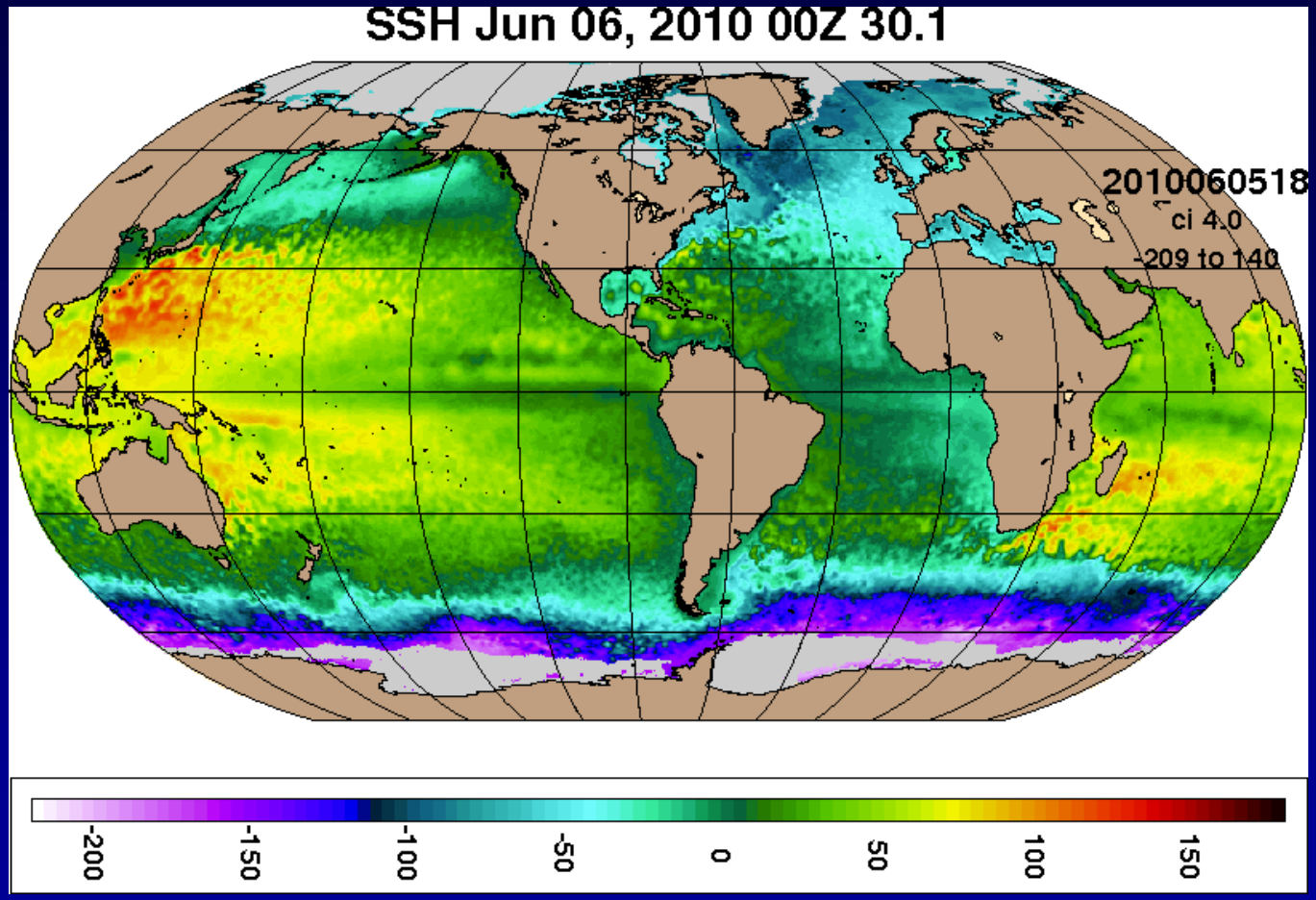
Impact of Remotely generated internal tides with locally generated internal tides (Kelly & Nash GRL 2010)

Four simulations of internal tide generation. Columns from left to right: BT sim. is forced by a surface tide. BC sim. is forced by a shoaling mode 1 internal tide. BT+BC sim. 1 is forced by surface and shoaling internal tides that are phased to maximize internal tide generation. BT+BC sim. 2 is identical to BT+BC sim. 1, except the shoaling internal tide is phase shifted by 180° to minimize internal tide generation. (a–d) Timeseries of internal tide bottom pressure and surface tide velocity at x = 0 km. The amplitudes and phasing of U and p′ determines internal tide generation. (e–h) Internal tide energy flux. (i–l) Internal tide generation and its horizontal integral.



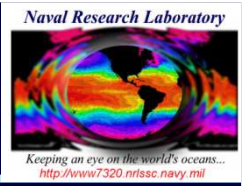
GOFS 3.5: 1/25º Global HYCOM with NCODA assimilation

Started 01 May, 2010 from free-running 1/25° model



9000 x 9595 x 32 dimensions; FNMOC/NOGAPS surface forcing;
Realistic coastline (5 m minimum depth); monthly river runoff

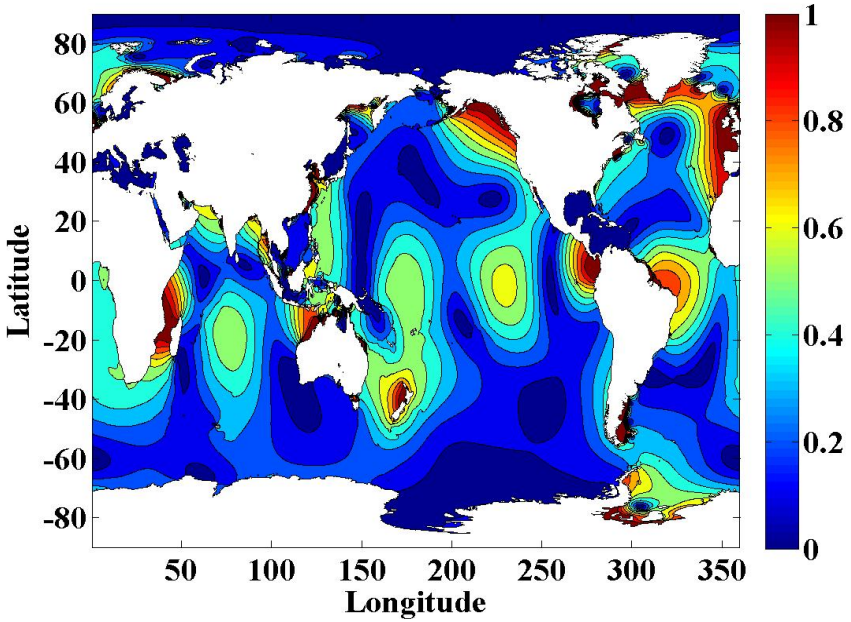
Modeling tides in the 1/12°global HYCOM System



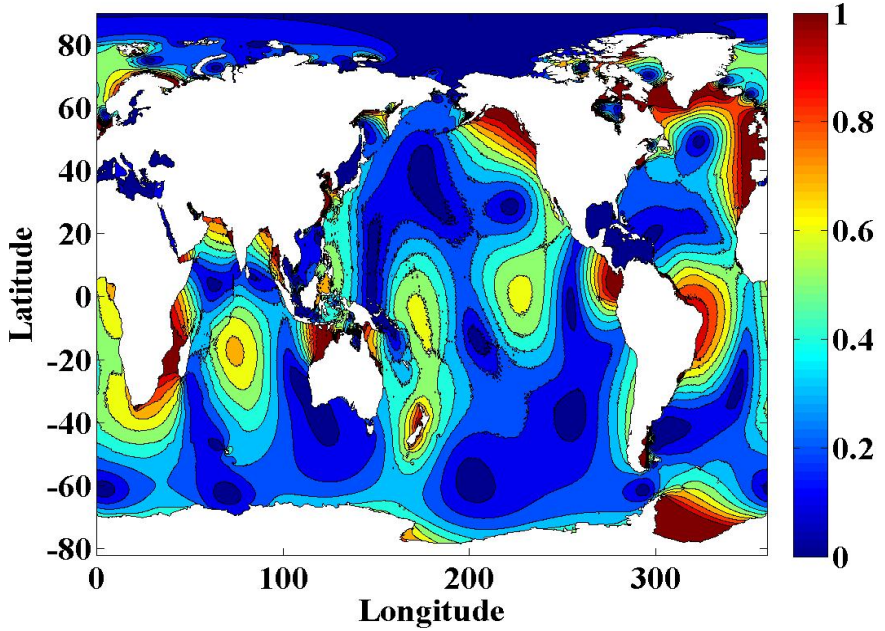
- The global model provides low frequency boundary conditions to regional models
- Tides are added as a barotropic transport and elevation boundary conditions for the regional models
- In the global model, the body forces due to the tidal potential, self attraction and loading have been added
- Astronomical Tidal Forcing with 8 constituents:
  - Semidiurnal M_2, S_2, N_2 and K_2
  - Diurnal O_1, P_1, Q_1 and K_1
- Topographic wave drag is applied to the tidal motions
  - Jayne & St Laurent (2001) form drag
    - $\mathbf{D} \sim 0.5\rho_0 \kappa h^2 N \mathbf{U}$ where κ is an averaging wavenumber, h^2 is the rms roughness over the averaging wavenumber, N is the stratification and **U** is the bottom velocity
  - Following Bell (1975), the topographic form drag is reduced for the diurnal tides

Comparison of M_2 tide from Data-Assimlative Shallow Water Model (TPXO7.2) and HYCOM Simulation

TPXO7.2 M_2 Tidal Model



HYCOM M_2 Tide



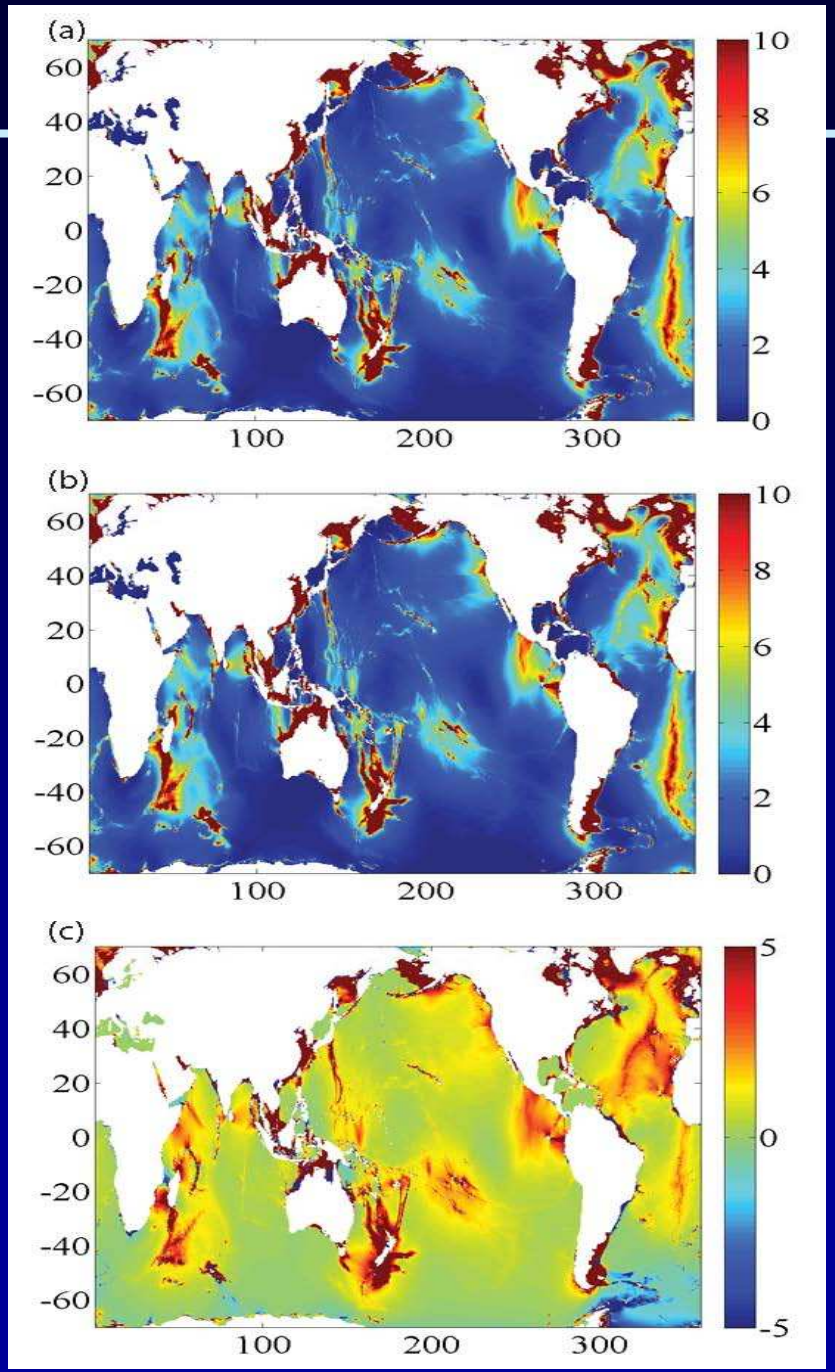
Difference with 102 pelagic tide gauges 7.8 cm rms

Difference with TPXO7.2 model 5.4 cm rms

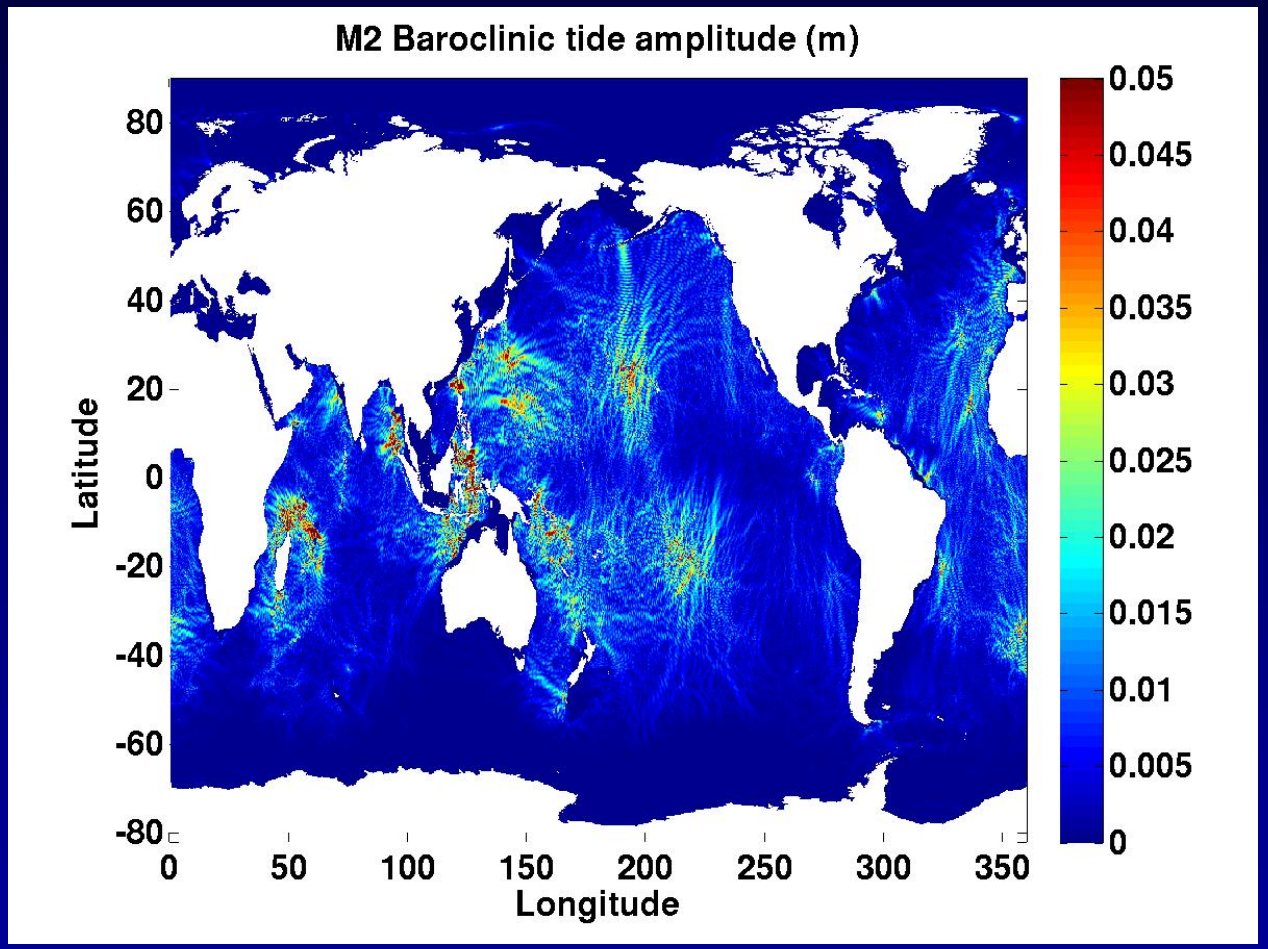
M_2 Tidal Kinetic Energy Maps

- The spatial maps of the observed (TPXO) and modeled M_2 tidal kinetic energy are very similar

- The difference between the observed and modeled KE shows that HYCOM tends to underestimate the KE over most of the globe with the exception of the Southern Ocean, particularly the Atlantic and Weddell Sea portions

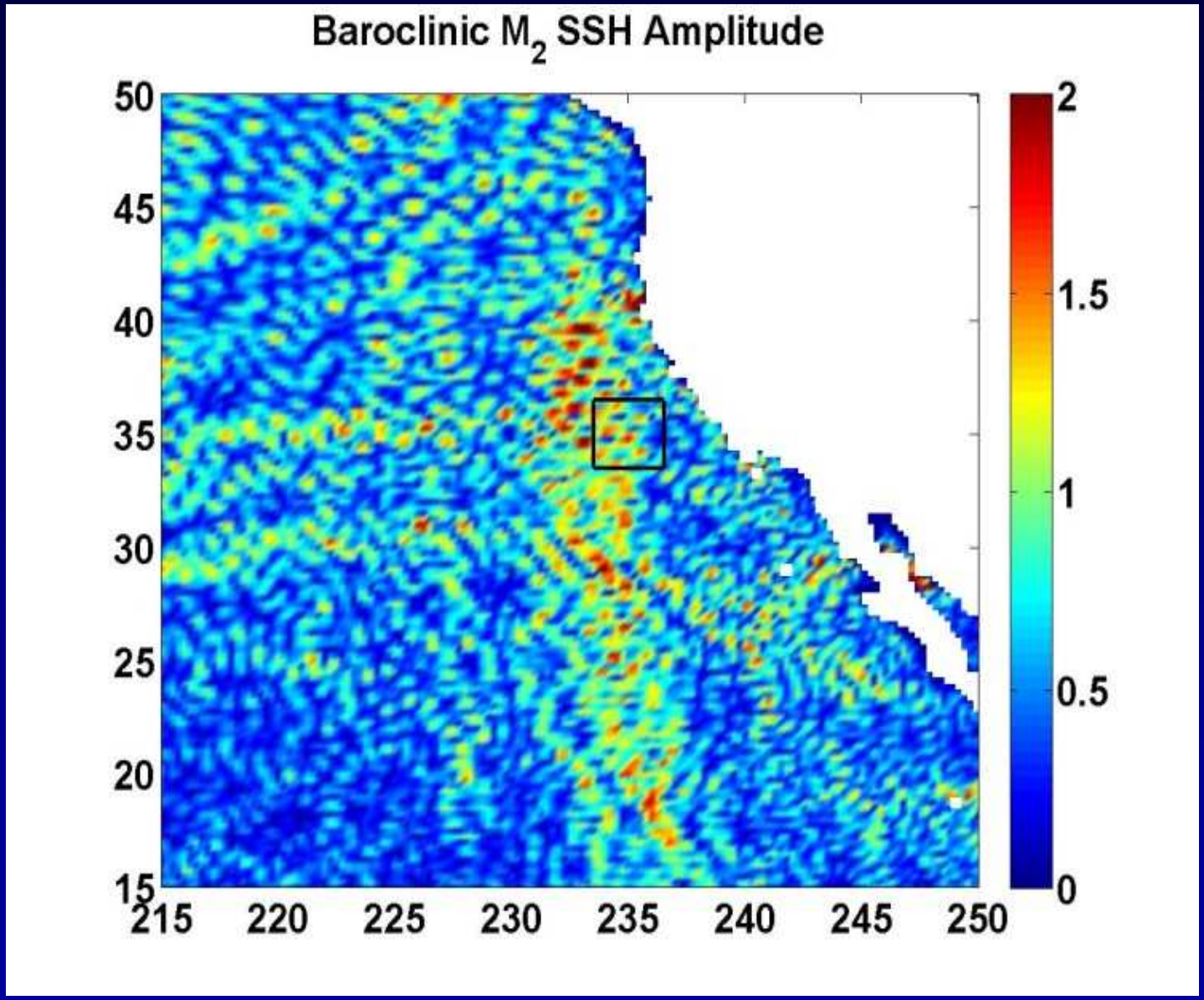


Internal Tide in the 1/12°HYCOM Model



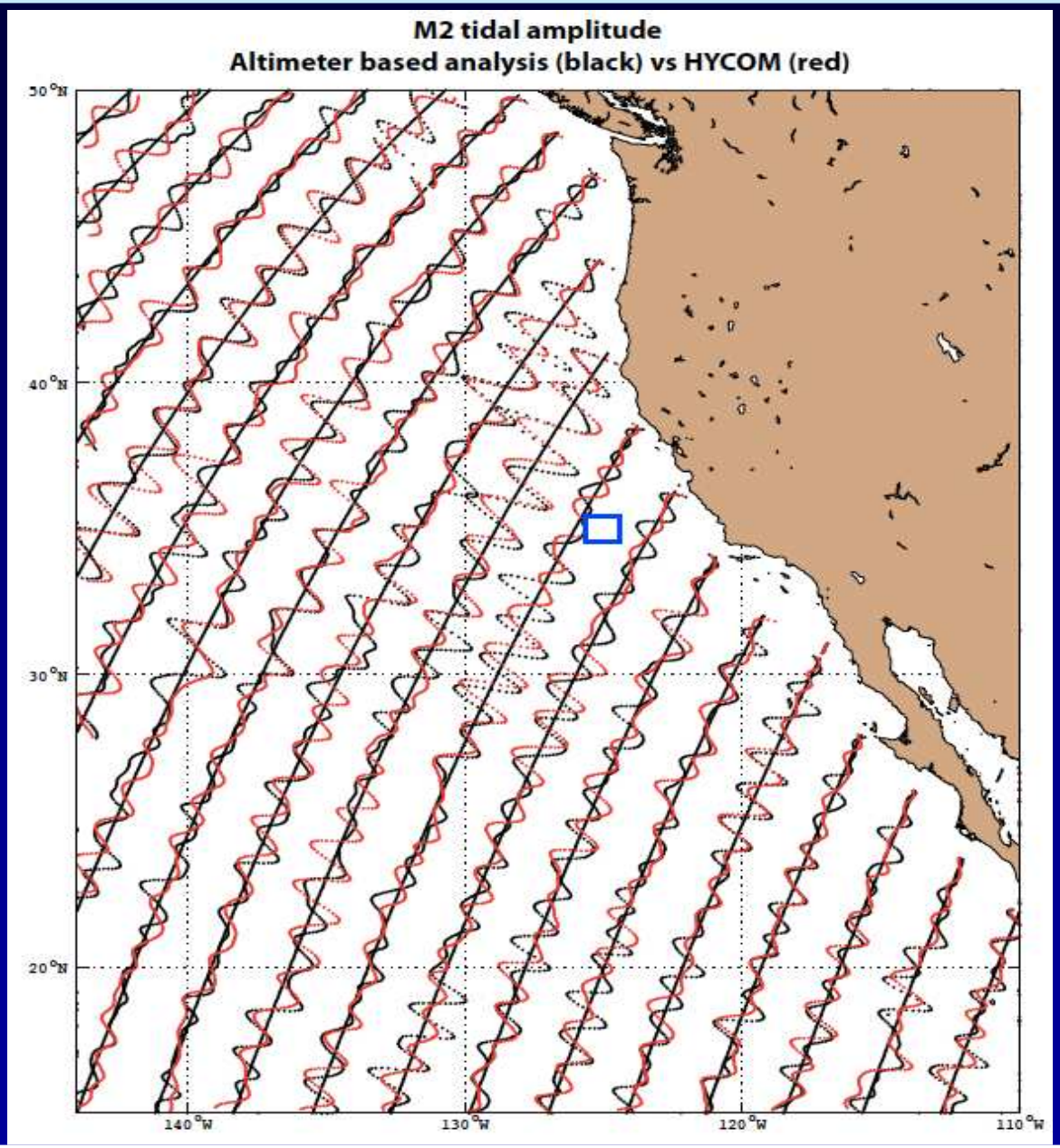
Internal tides have generated a few “hot spots” with beams of energy propagating away from the hot spots for 1000’s of kms

California Zoom from the Global 1/12^{o} HYCOM



Comparison of HYCOM and Jason M2 short wavelength tides

Peak-to-peak range is about 2 cm

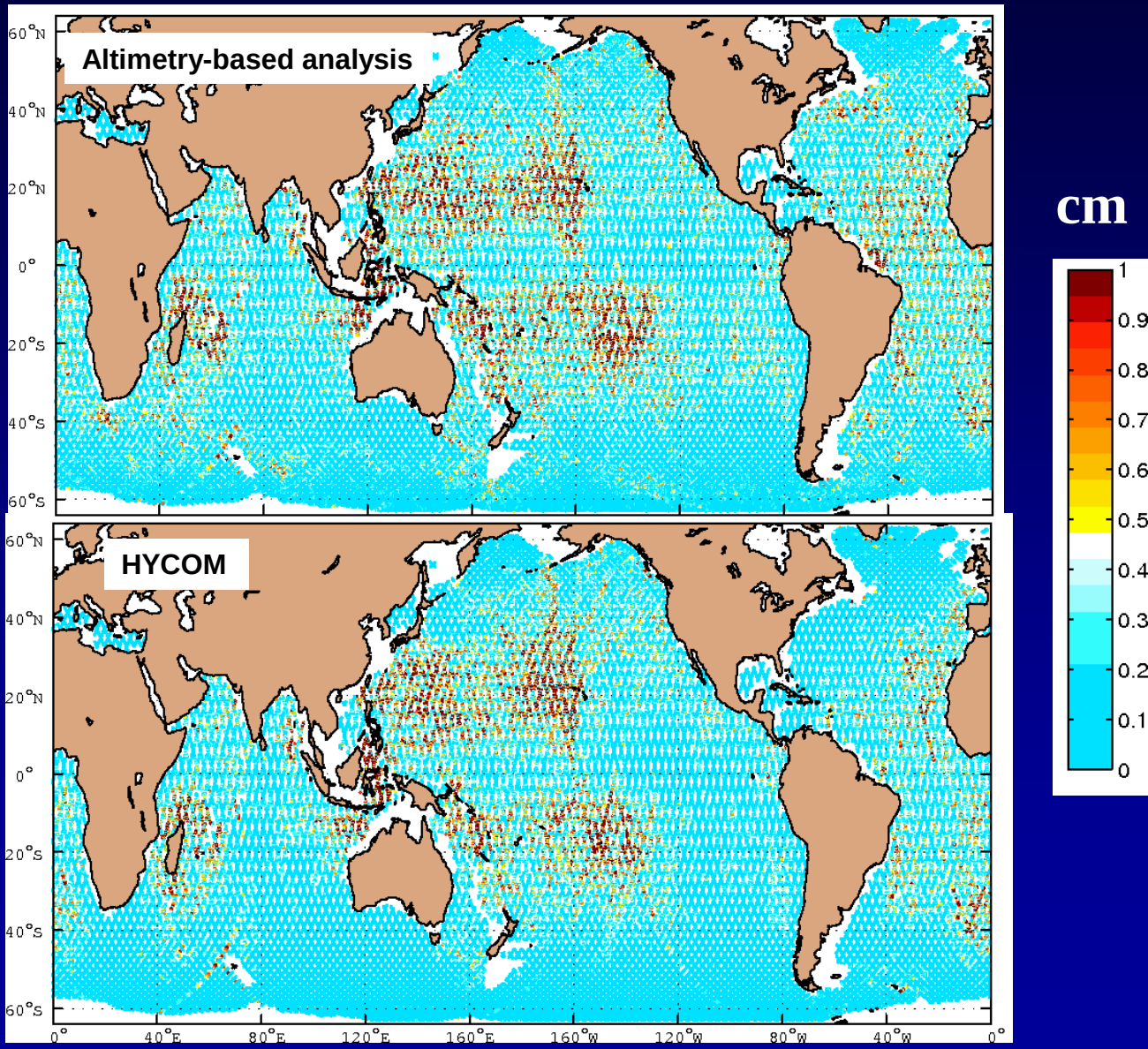


M_2 internal tide amplitude: along-track altimetry data vs 1/12° Global HYCOM

Analysis of along-track altimetry data based upon extracting the aliased tidal signal from the repeat-cycle data as described by Ray and Mitchum (1996, 1997)

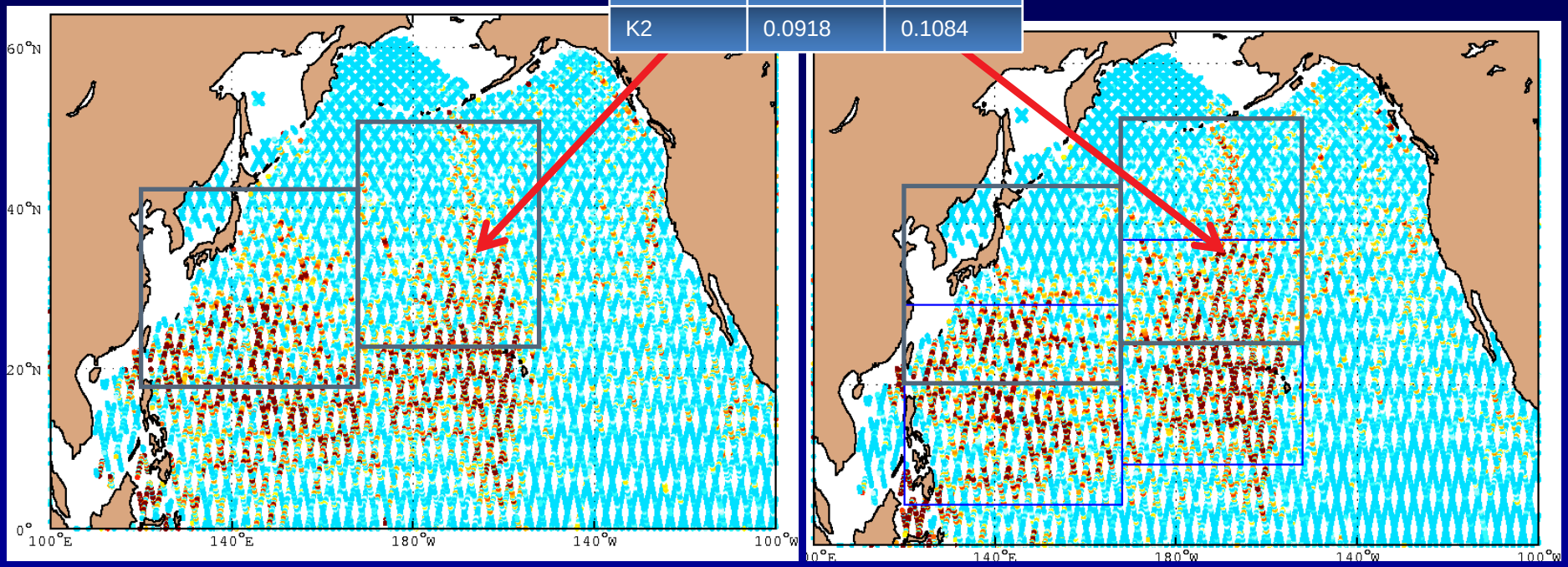
The internal tide is recovered by a spatial filter to separate the barotropic and baroclinic tides

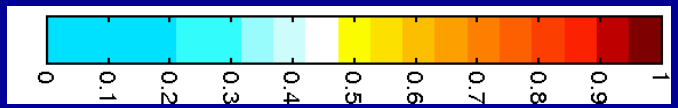
HYCOM SSH analyzed for tides, sampled along track and filtered similar to altimeter



M_2 internal tide amplitude: along-track altimetry data vs 1/12° Global HYCOM

	Altimeter data	HYCOM model
M2	0.5649	0.6512
S2	0.2997	0.3897
N2	0.1497	0.1197
K2	0.0918	0.1084

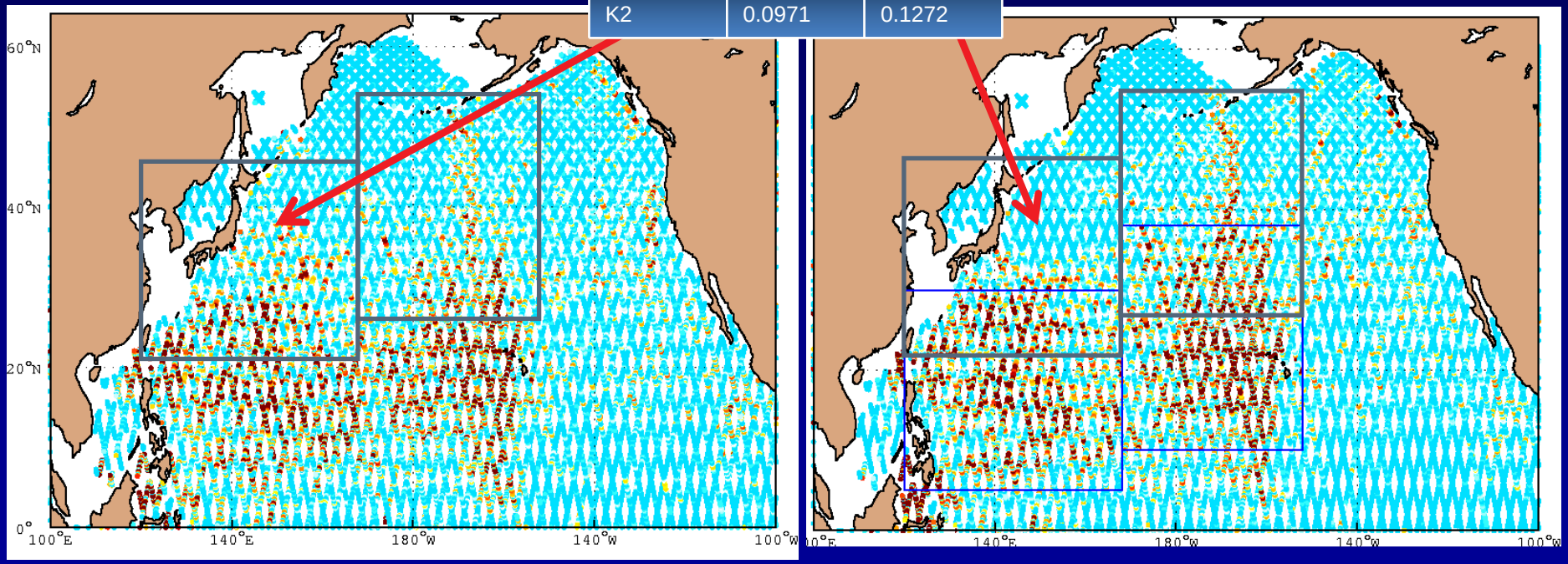


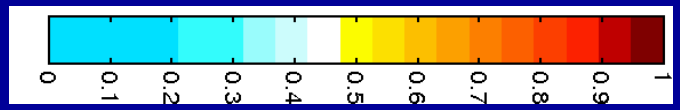


cm

M_2 internal tide amplitude: along-track altimetry data vs 1/12° Global HYCOM

	Altimeter data	HYCOM model
M2	0.6377	0.6430
S2	0.3187	0.3504
N2	0.1781	0.1367
K2	0.0971	0.1272

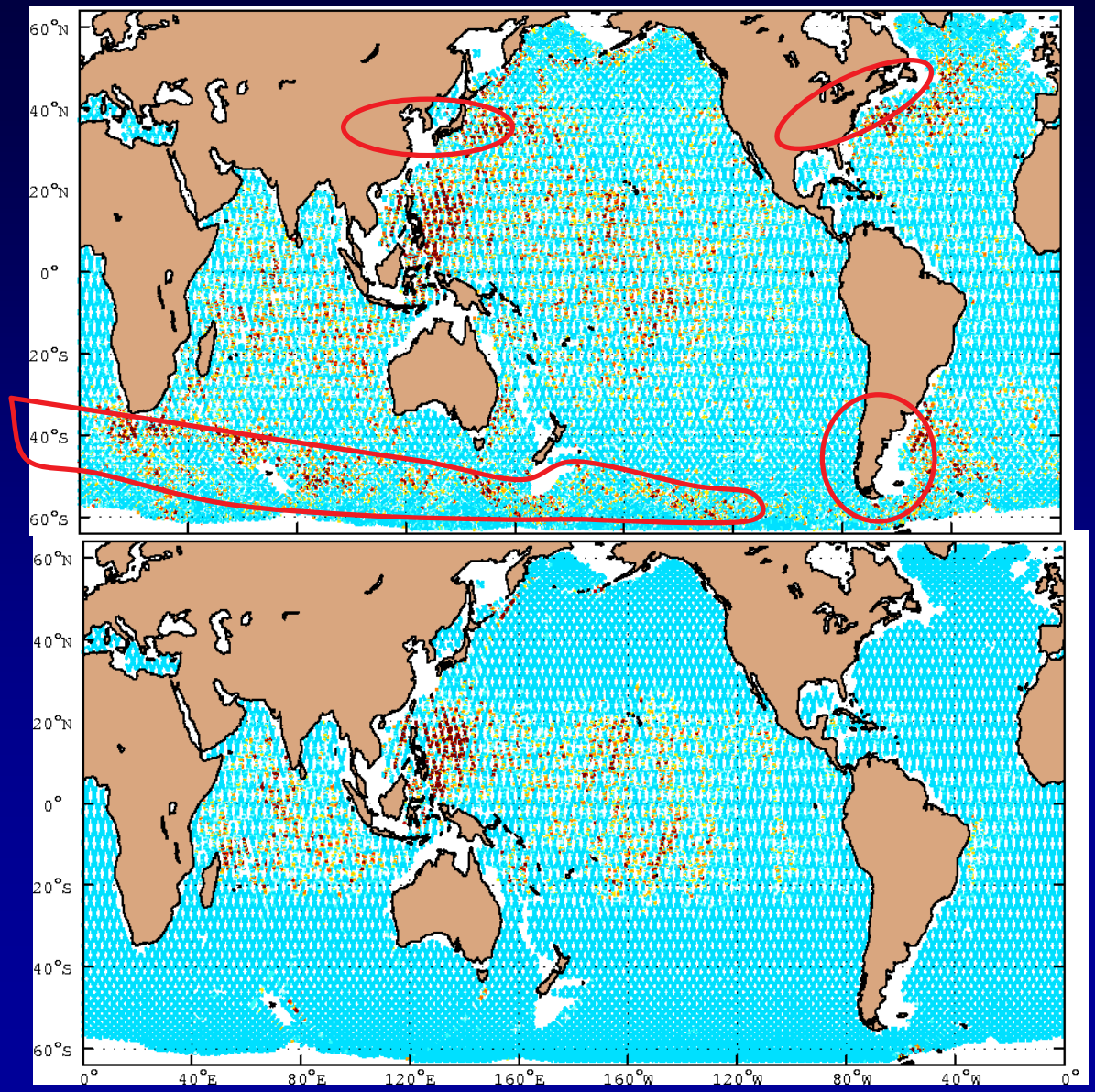




cm

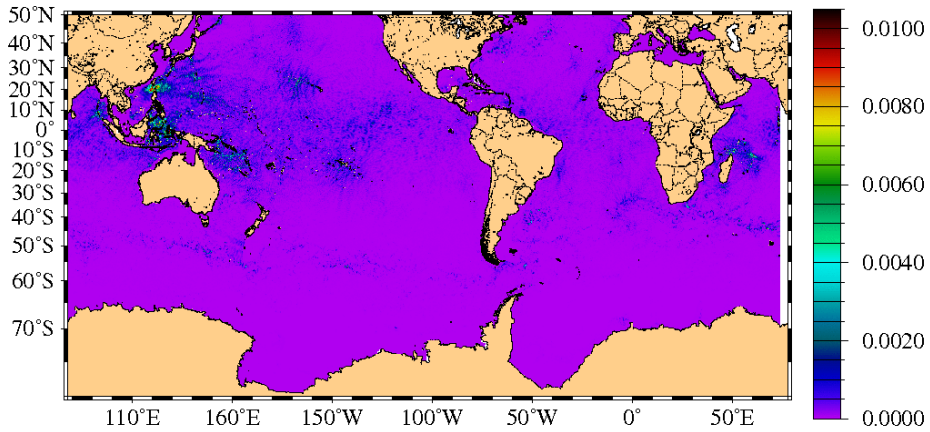
K_1 internal tide amplitude: areas of mesoscale leakage in along-track altimetry data

Diurnal internal waves are bound between +/- 30 by the dispersion relation (Gill, 1982)

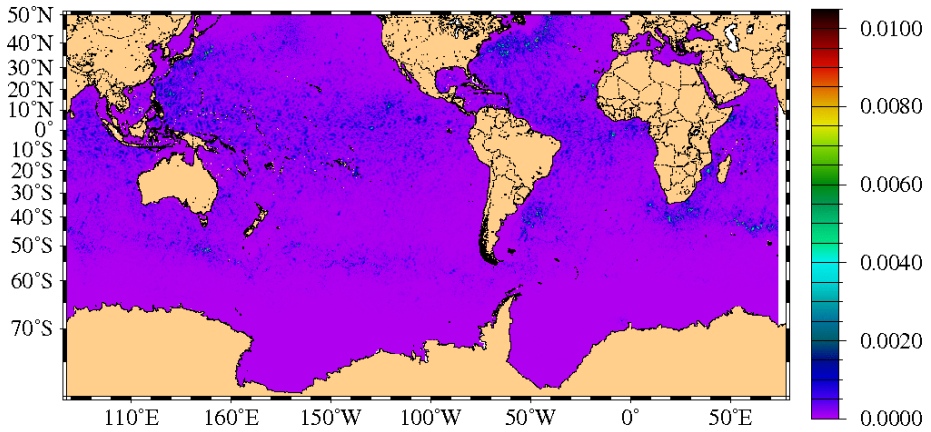


1/12° Global HYCOM / Tides only / Assimilation only / Both tides and assimilation

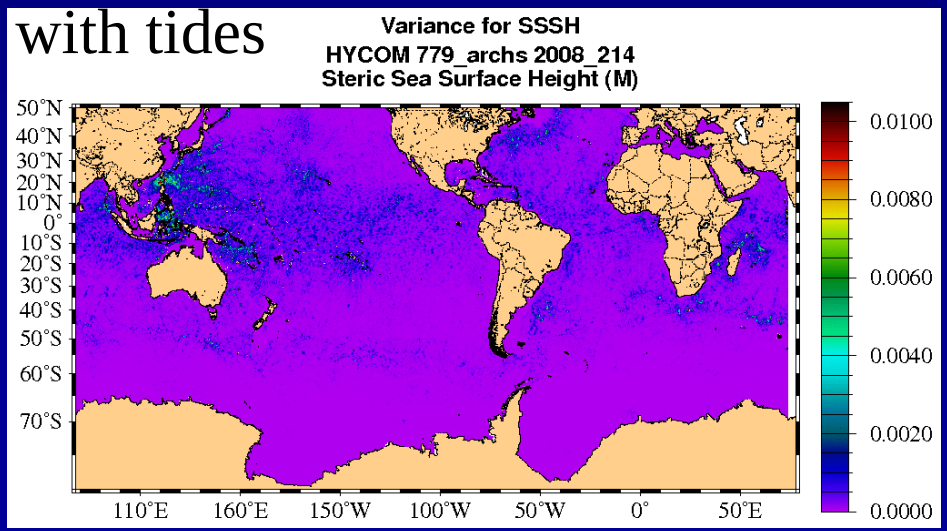
Tides only



DA no tides

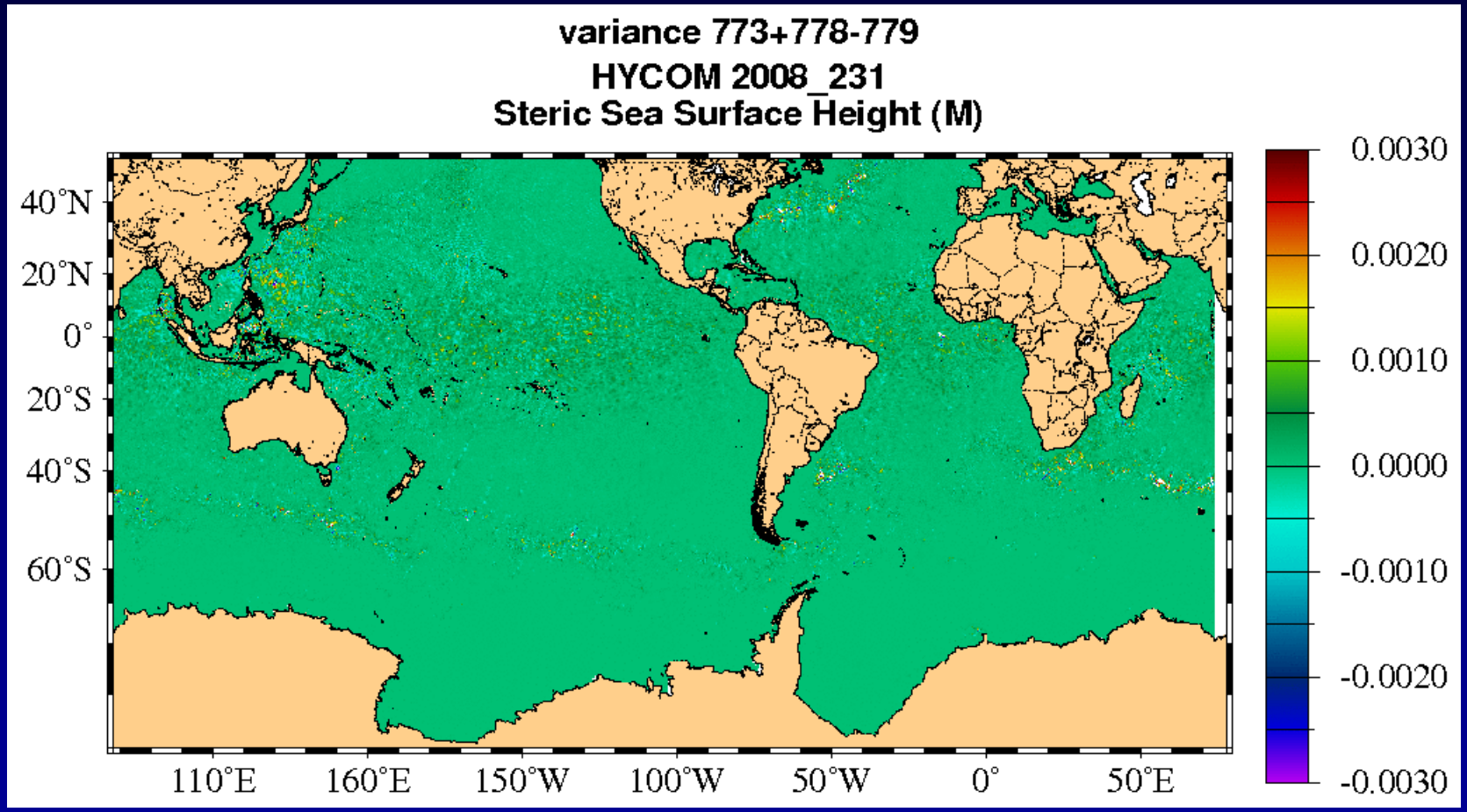


DA with tides



Shows strong generation of Internal tides at hot spots and the transient waves from the insertion of analysis increments

Data Assimilation in the global ocean circulation model with tides



The difference between the variance of the tidal model without DA plus the DA model without tides minus the DA model with tides. The difference is much smaller than the individual

Status of Global HYCOM with Tides

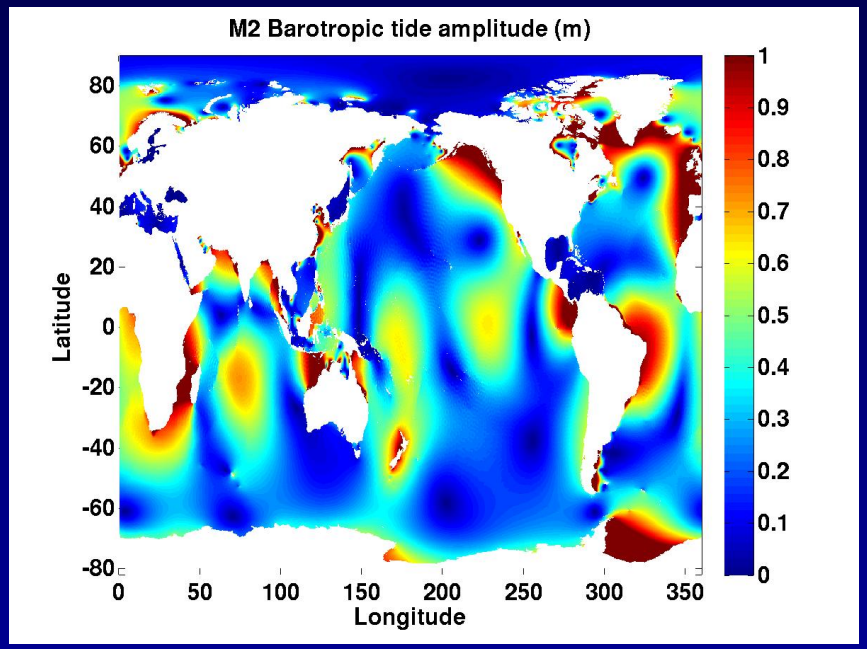
- The tides in the global model compare well with the altimetric barotropic and baroclinic tides
  - Velocity comparison is not as good
  - Phase errors in barotropic tide affect the details of the baroclinic tide generation
- 3DVar data assimilation maintains the tides while adjusting the mesoscale circulation
- Can the 1/25° Global Model replace the existing 3 km Regional Models?

Comparison of 1/25° HYCOM with tides to Regional Model

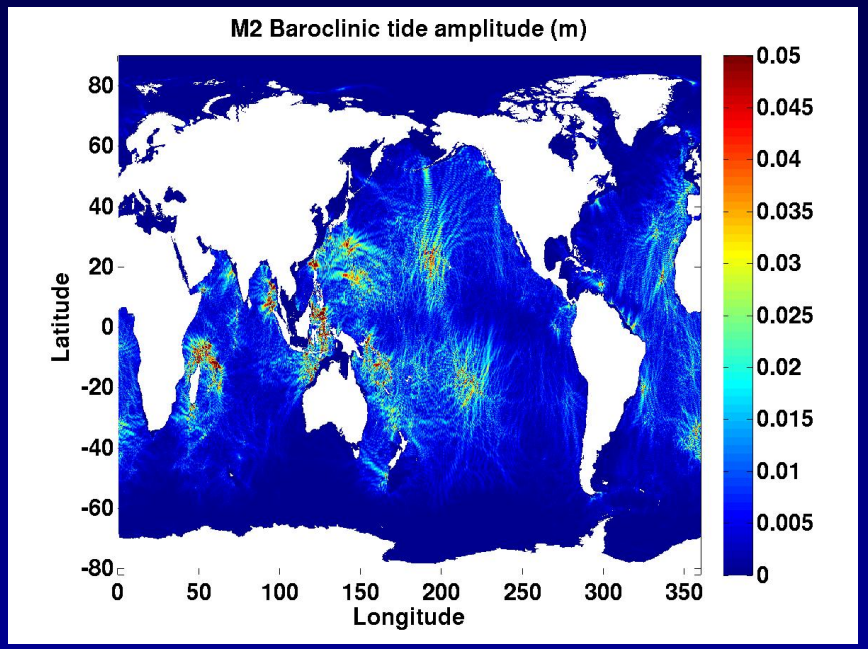
- Study the internal tides in Australian North West Shelf (NWS) an area with complex bathymetry and strong tides
- Evaluate Internal Tide generation and energetics
- Configure and develop high resolution numerical models
- Provide numerical modeling support for upcoming field measurements

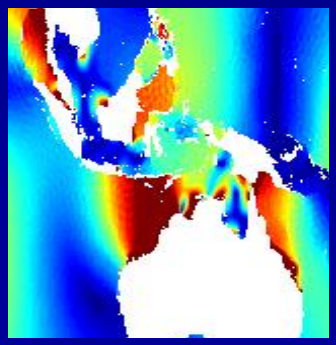
Global Tidal Model

Barotropic Tidal SSH

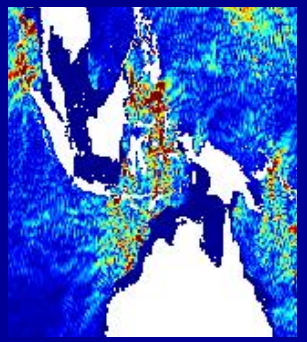


Baroclinic Tidal SSH

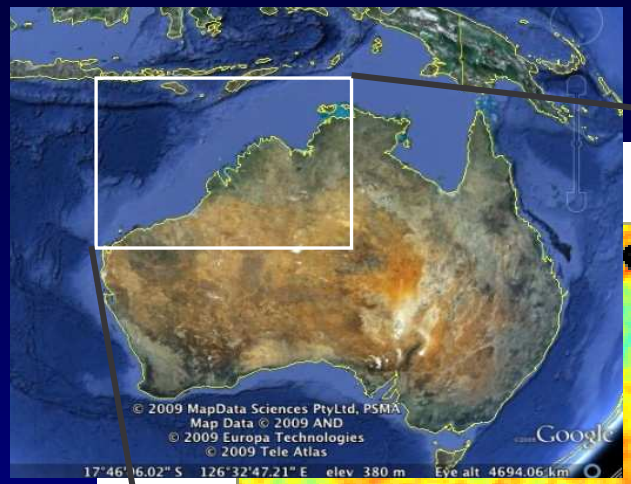


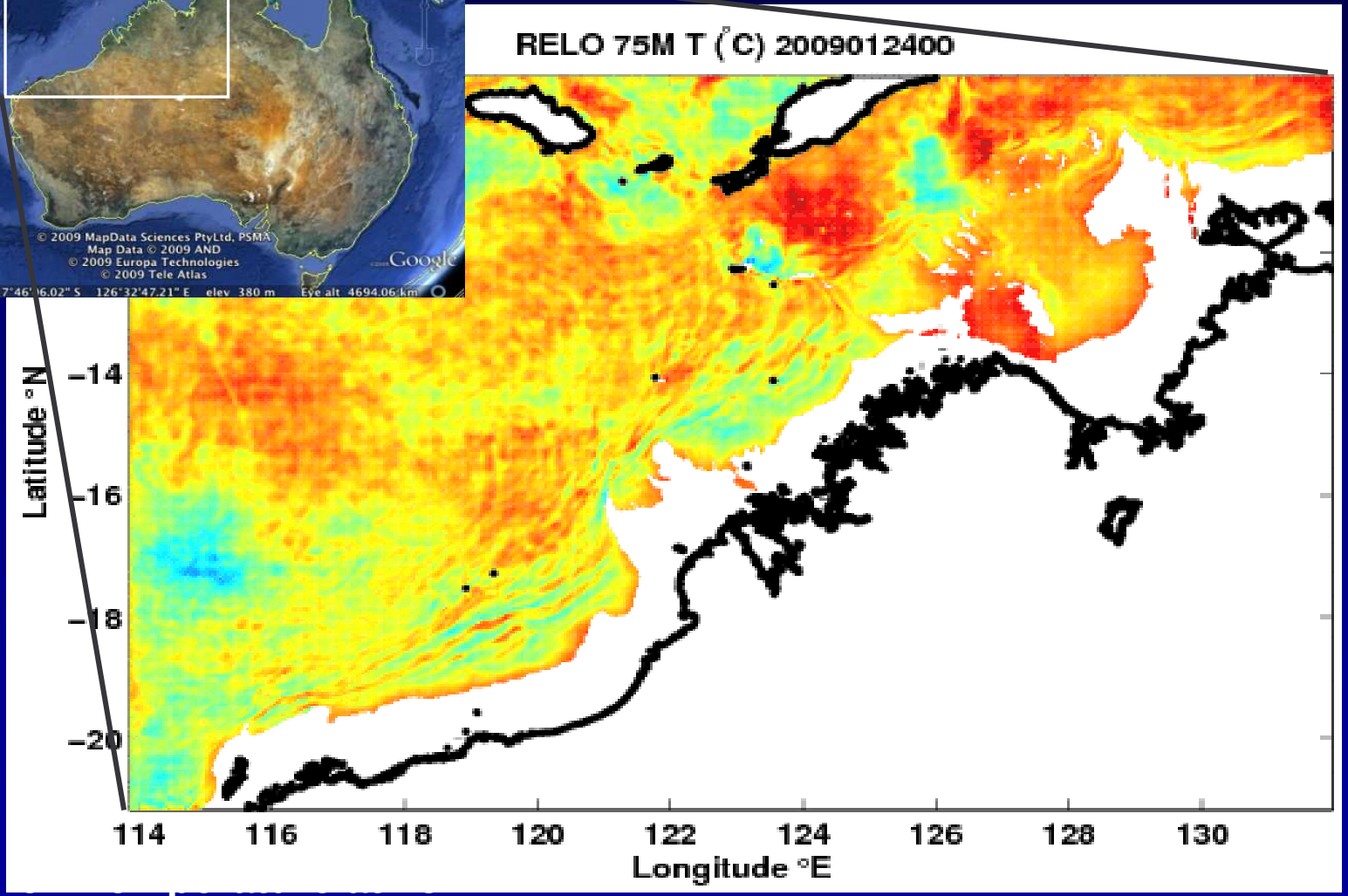


The Australian NW Shelf has strong barotropic and baroclinic tides



Numerical Experiments





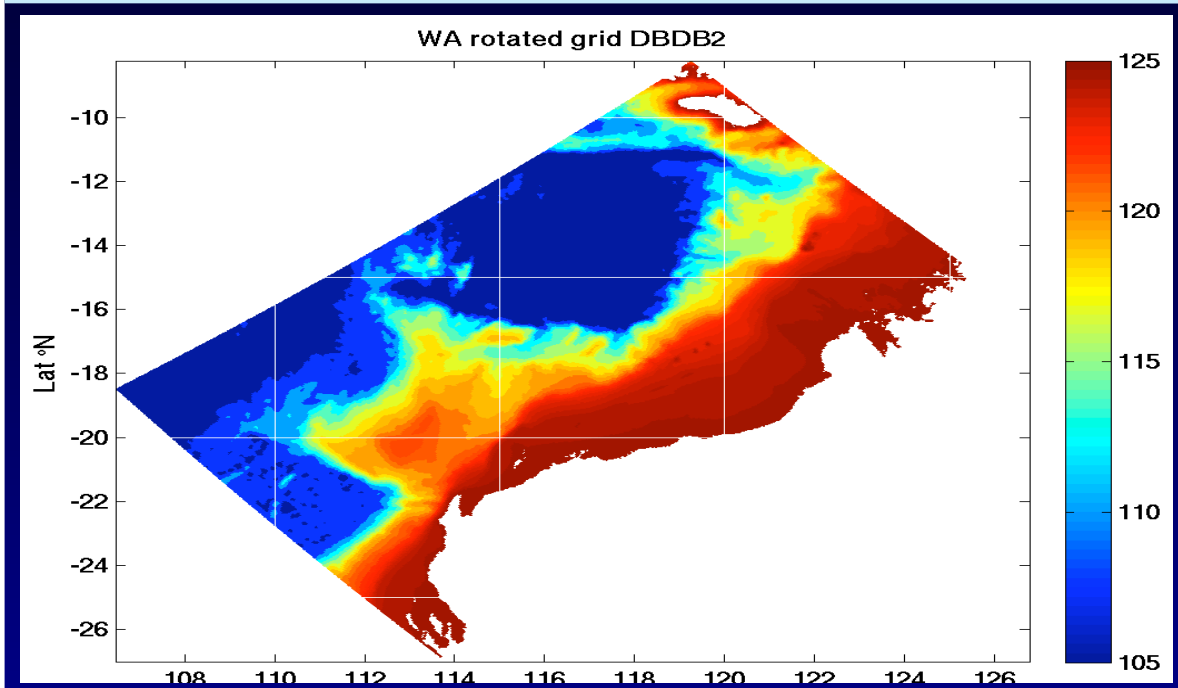
Numerical Modeling and Experiments

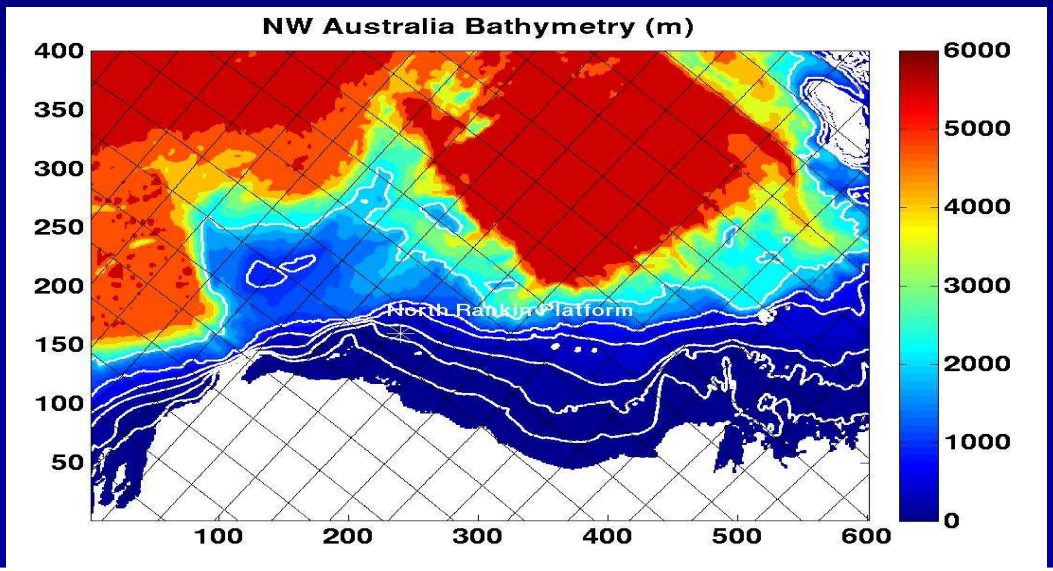
- Relocatable Navy Coastal Ocean Model
- (Relo-NCOM)
- 1800x1200km domain at 3 km resolution
- 49 vertical layers
- DBDB2 Global Bathymetry Database
- Boundary condition from 1/8°global NCOM
- NOGAPS wind and flux
- OTIS tidal solution at domain boundary
- Simulation w/Tide and without Tide every 3-hour el, T, S and u for Feb, March 2011

Numerical Modeling and Experiments

- Boundary Condition Experiments
  - Replace OTIS Barotropic tide with HYCOM
  - Replace Global NCOM with low frequency HYCOM
  - Replace low frequency HYCOM and Barotropic Tidal BC with hourly HYCOM with tides
- Compare Regional Models with 1/25 Global HYCOM with tides
- Compare models with field trial on NW Australia Shelf – April 2012

Relo-NCOM Australia NWS domain

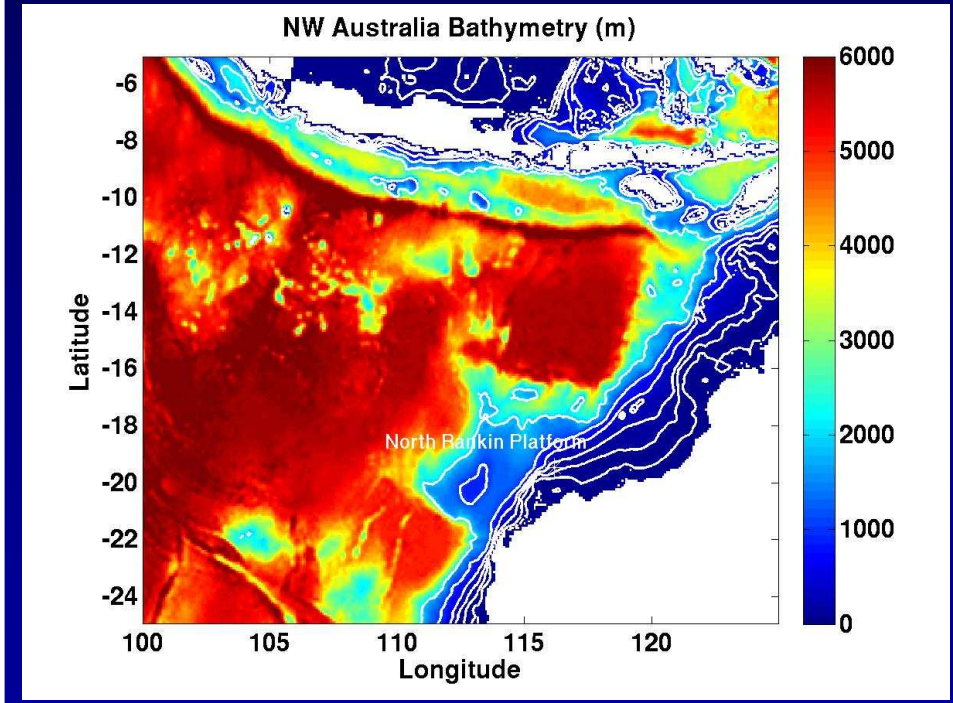




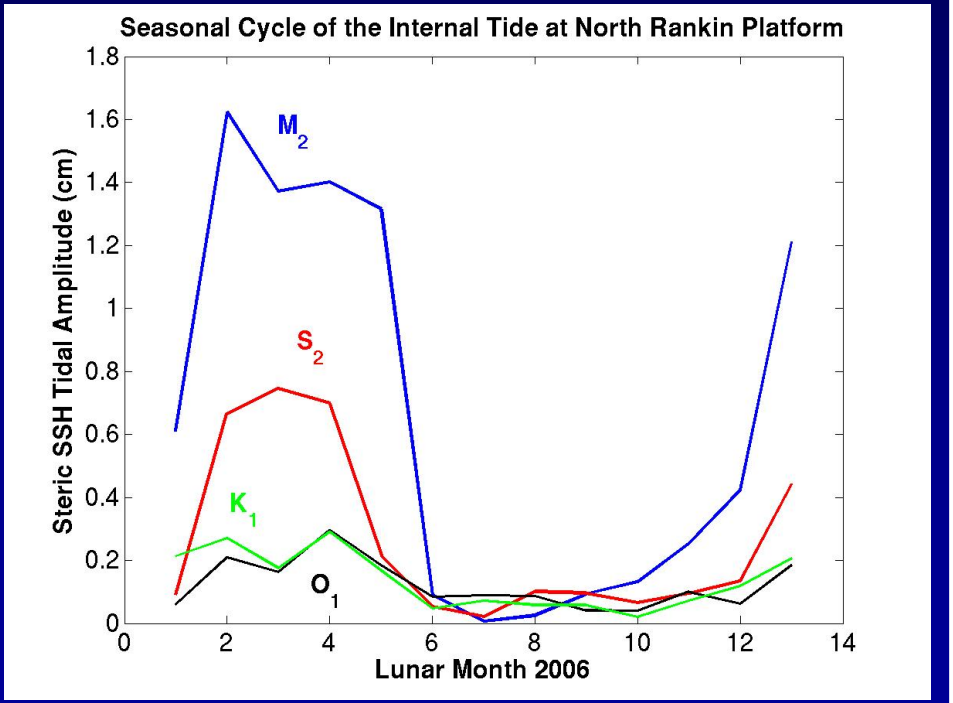
- 1800x1200km domain
- 3km resolution
- 49 vertical layers
- OTIS Tidal Database Open BC
- NOGAPS wind forcing
- 2011/02/01-03/31
- Dampier and NRA 2x2 subset

Seasonality in 1/12.5° Global HYCOM Tidal Model

Bathymetry from global Model

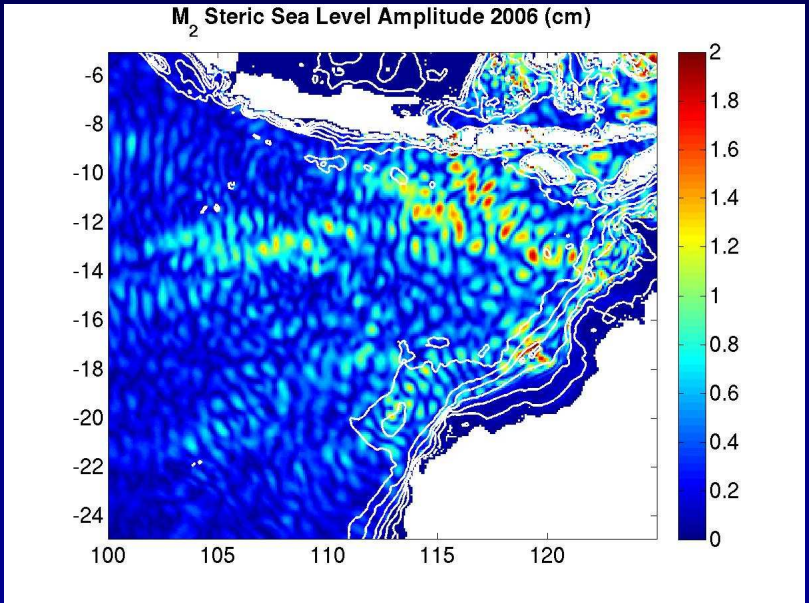


Seasonality of the steric sea surface height by lunar month

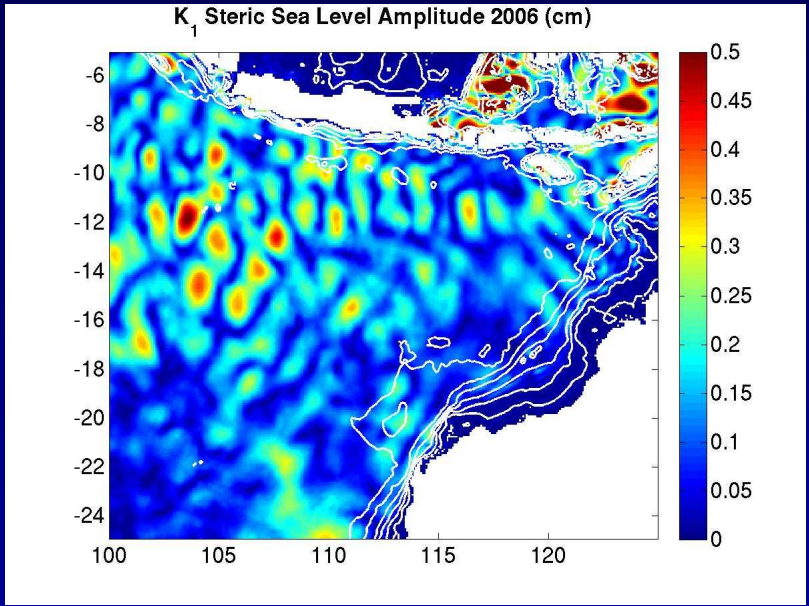


1/12.5°Global HYCOM Tidal Model

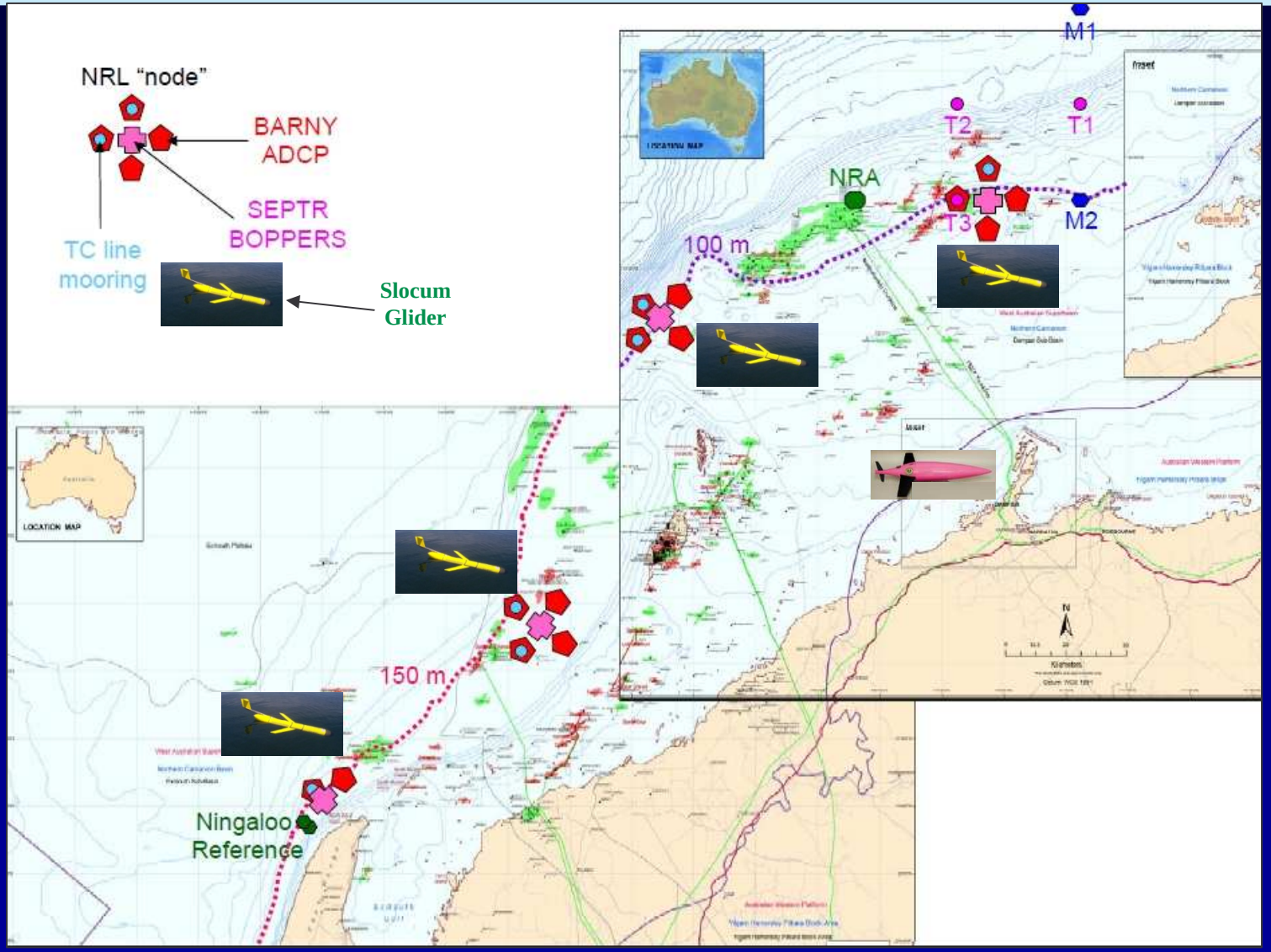
M_2 Internal Tide from steric sea surface height



K_1 Internal Tide from steric sea surface height



Experiment Plan for Northwest Australian Shelf with NRL and Australian National Projects



NRL nodes dispersed among AIMS moorings (Ningaloo Reference), UWA tropical cyclone moorings (T1, T2, T3), & Woodside Petroleum moorings (NRA, M1, M2)

Tidal Elevation at North Rankin Platform

	Obs Amp	Obs Phase	Model Amp	Model Phase
M2	**73.3**	293	72.8	289
S2	41.3	359	50.5	357
O1	13.7	270	13.9	282
K1	21.1	290	15.4	21
M4			0.4	14

Comparison to Internal Tide Observations of Holloway, et al. (1995)

North Rankin Line

Moorings at C2, C6, C10, C12

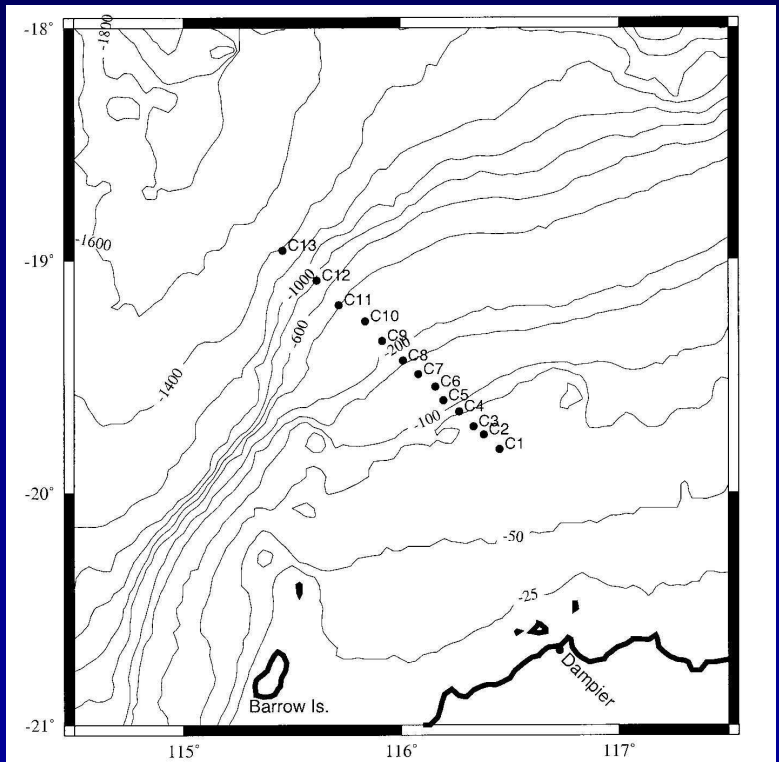
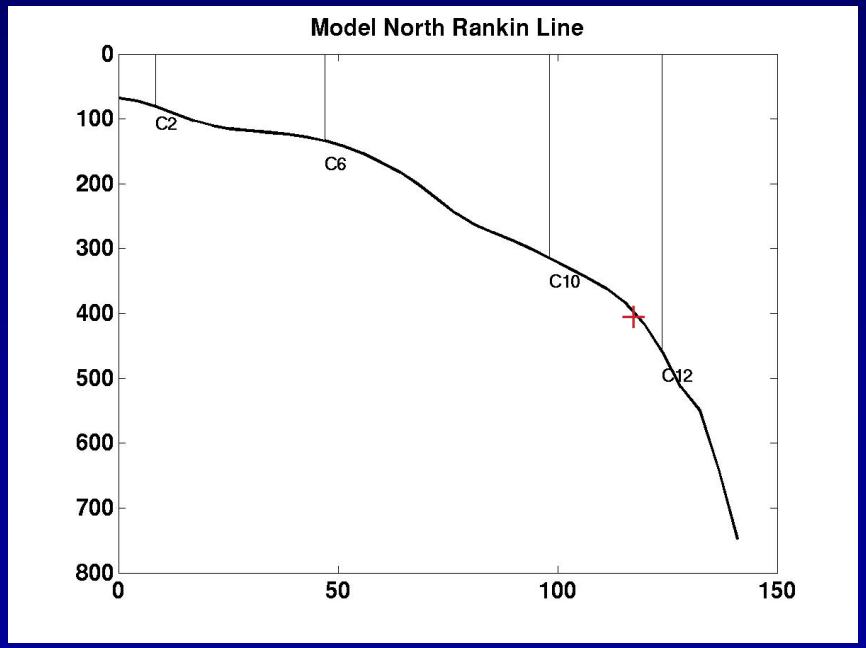


FIG. 1. Map showing bathymetry, mooring, and CTD/ADCP stations on the Australian North West Shelf.

Bathymetry along Model North Rankin Line



Critical Slope for M2 Internal Tide occurs at 118 km along the line marked by red +

Comparison to Internal Tide Observations of Holloway, et al. (1995)

North Rankin Line

Moorings at C2, C6, C10, C12

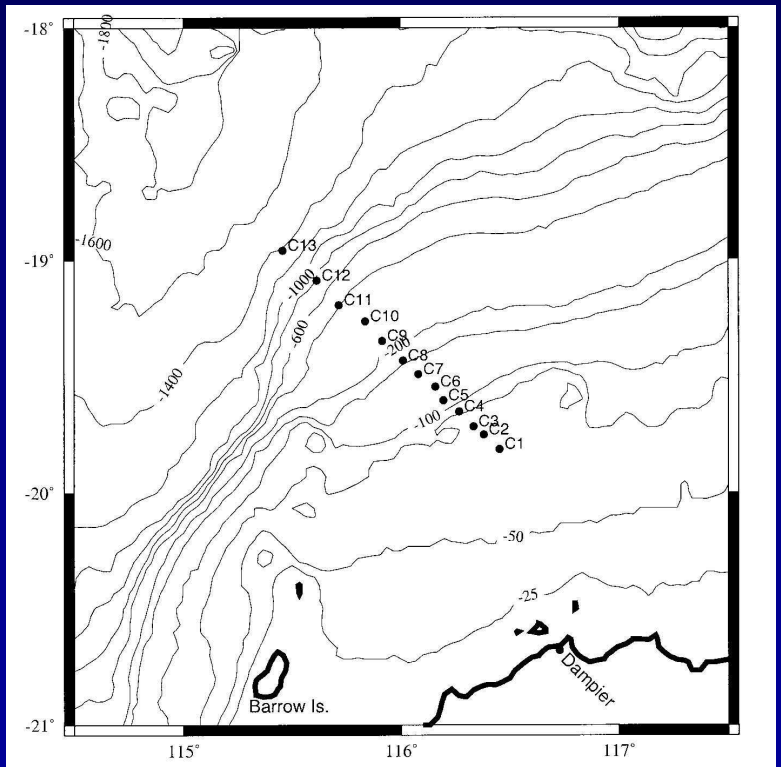
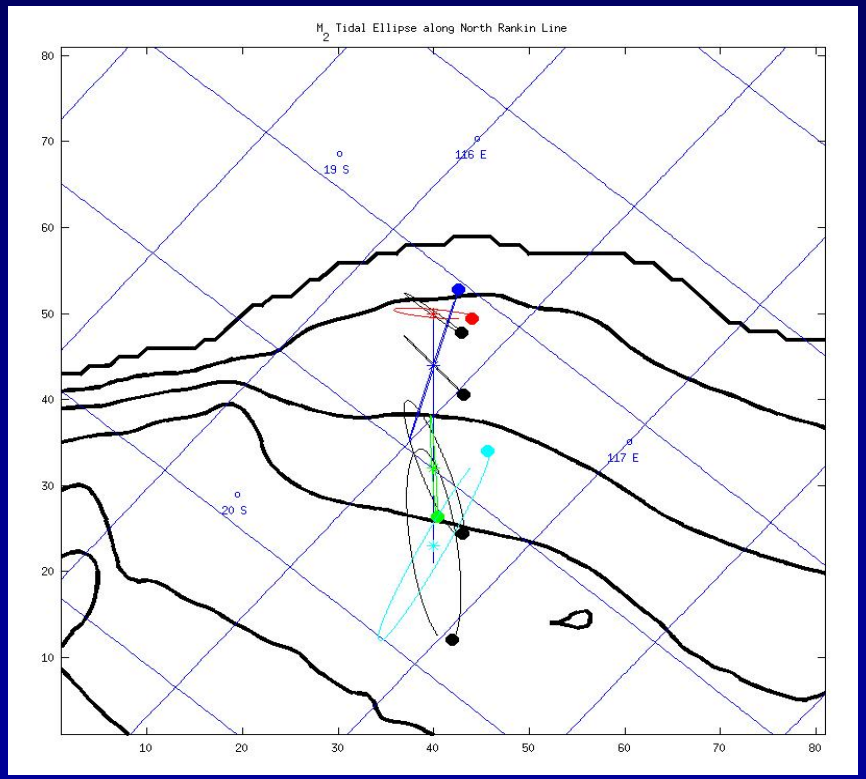


FIG. 1. Map showing bathymetry, mooring, and CTD/ADCP stations on the Australian North West Shelf.

Modeled Barotropic and Baroclinic Tidal Ellipses along North Rankin Line



Comparison to Internal Tide Observations of Holloway, et al. (1995)

Observed Baroclinic M_2 Tidal Energy Flux

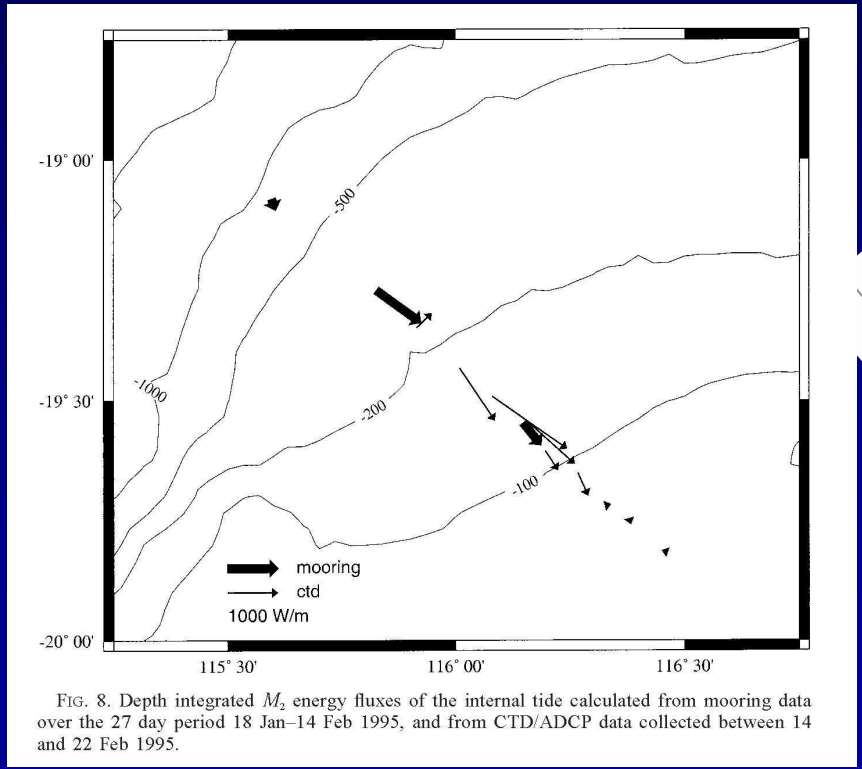
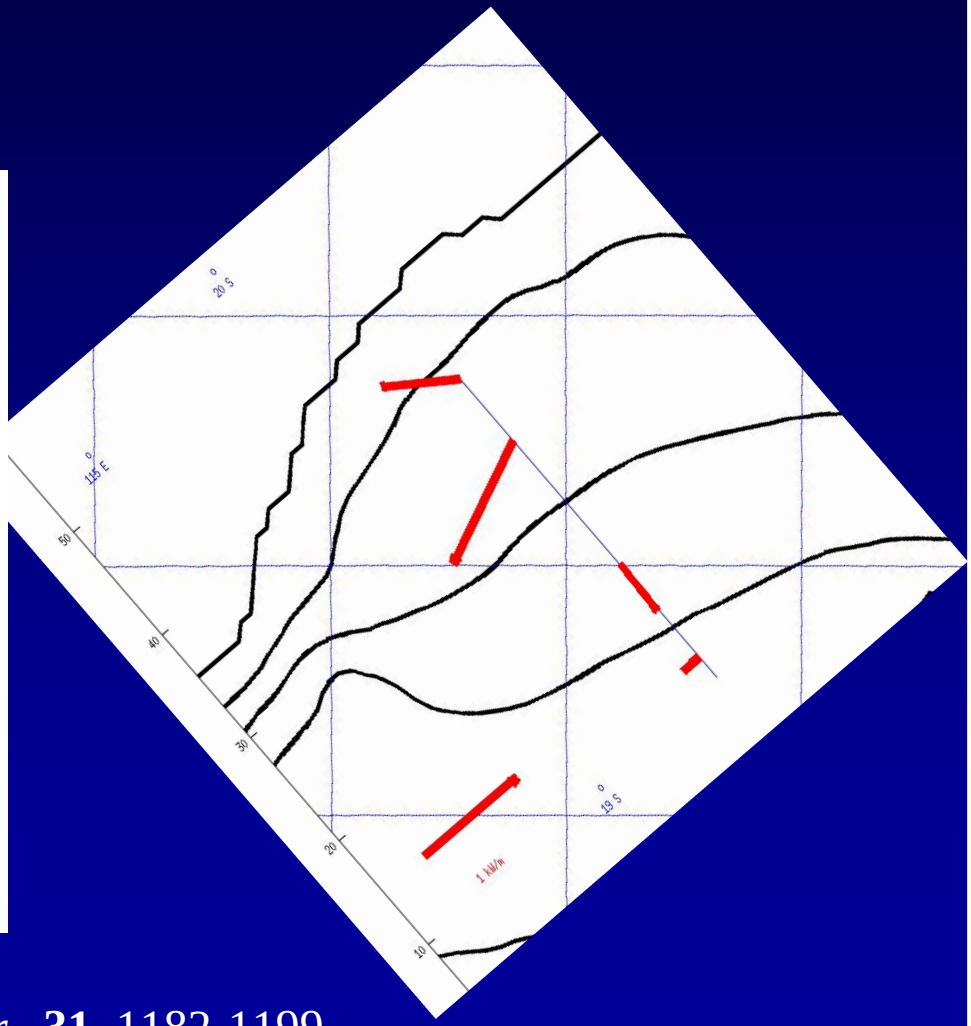


FIG. 8. Depth integrated M_2 energy fluxes of the internal tide calculated from mooring data over the 27 day period 18 Jan–14 Feb 1995, and from CTD/ADCP data collected between 14 and 22 Feb 1995.

Modeled Baroclinic M_2 Tidal Energy Flux



From Holloway et al., 2011, *J. Phys. Oceanogr.*, **31**, 1182-1199

Isopycnal Displacement Along North Rankin Line

Observed M2 Displacement

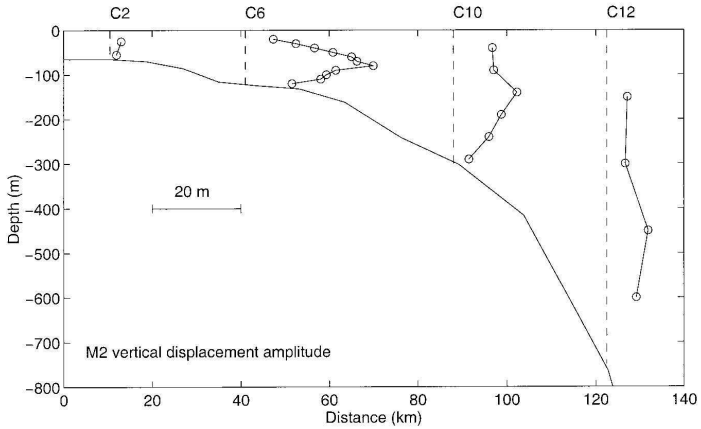
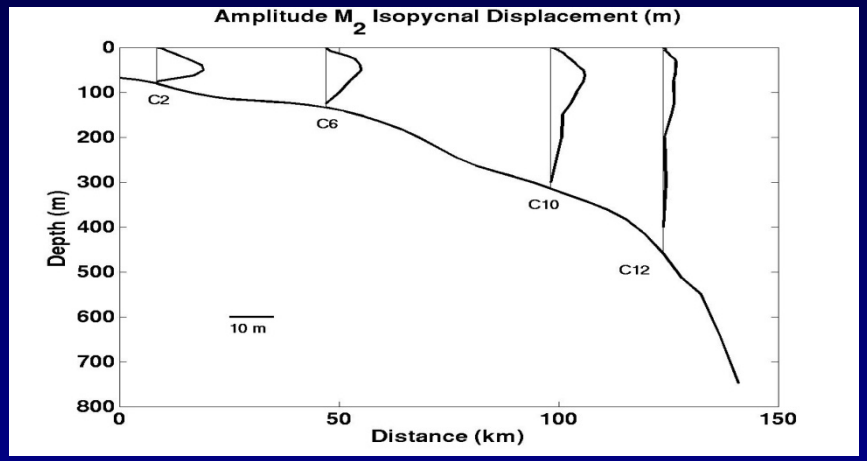
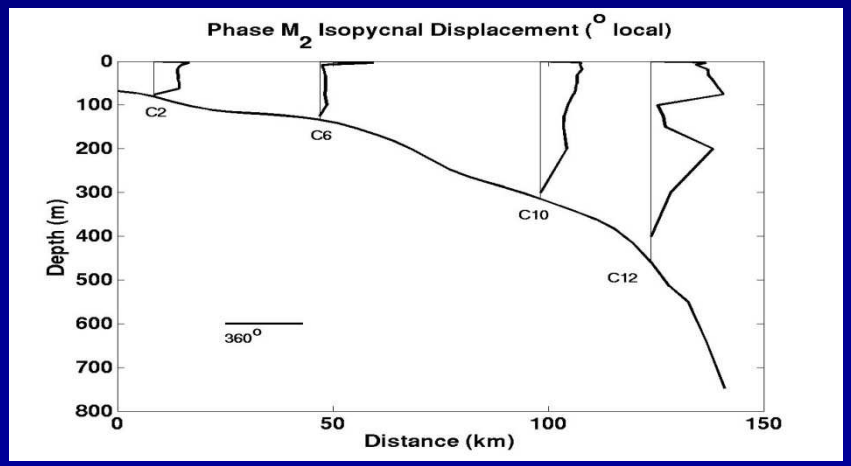


FIG. 7. Profiles of M_2 internal tide vertical displacement amplitude and phase from moored current meters from a 27-day data analysis over the period 18 Jan–14 Feb 1995.

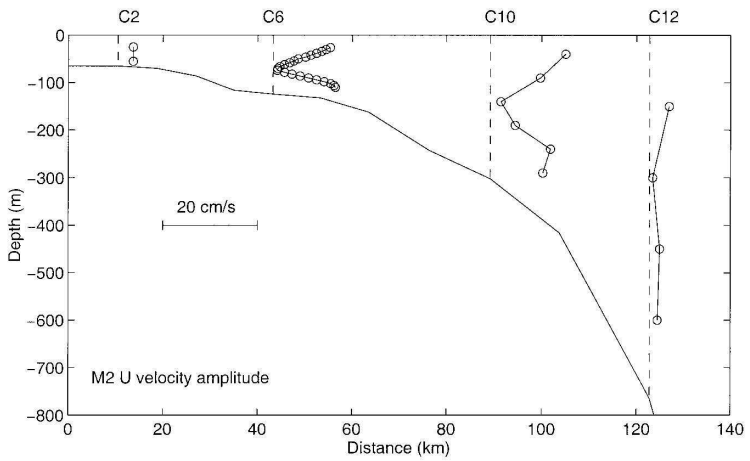
Modeled M2 Displacement





M_2 Cross-shelf Velocity along North Rankin Line

Observed M_2 Cross-shelf Velocity



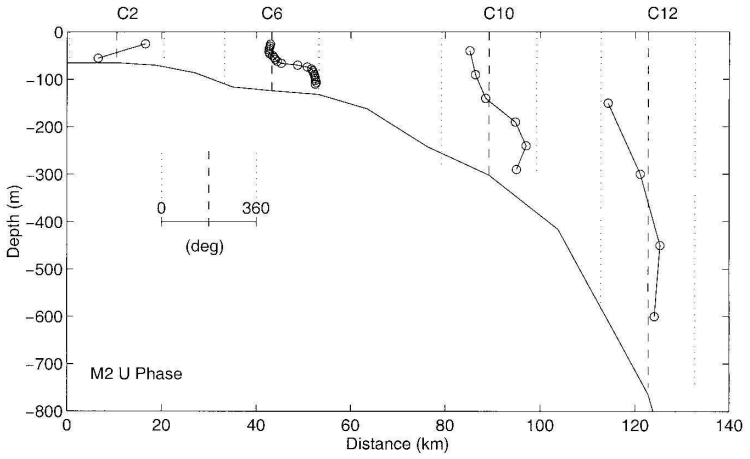
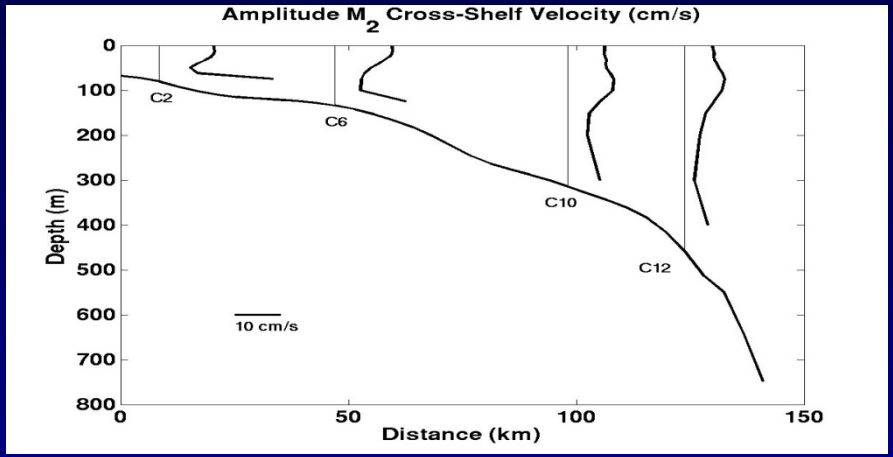
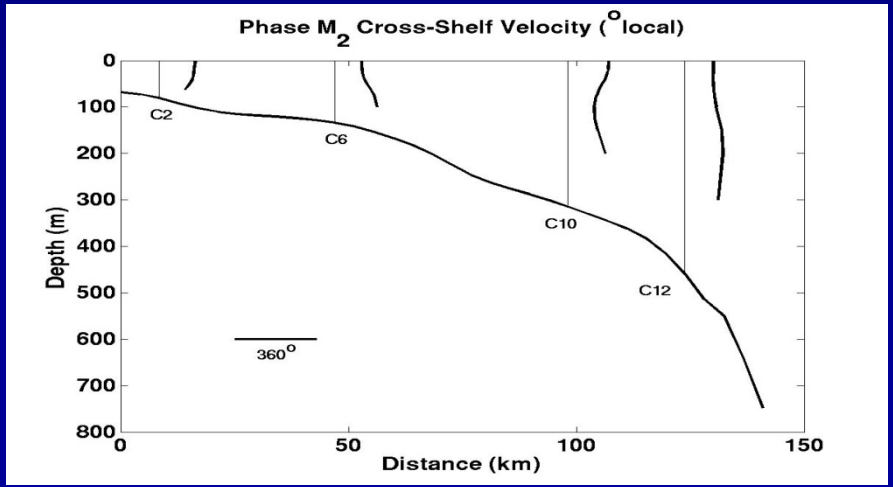


FIG. 6. Profiles of M_2 internal tide cross-shelf current amplitude and phase from moored current meters from a 27-day data analysis over the period 18 Jan–14 Feb 1995.

Modeled M_2 Cross-shelf Velocity





Comparison to Internal Tide Observations of Holloway, et al. (1995)

- The model underestimates the strength of the baroclinic tide
  - The energy flux is consistent with a critical topographic slope at 118 km along the North Rankin line with onshore flux inshore of the critical point and offshore flux farther offshore
  - The modeled baroclinic tide does not reproduce the nearly 1st baroclinic mode observed over the shelf
- The M_4 overtides are very strong in the model east of the North Rankin Line

Comparison to Internal Tide Observations of Holloway, et al. (1995)

- From a new global circulation model with tidal potential forcing
  - Strong sources of remotely generated internal tides occur in the region which can interact with the locally generated tides (Kelly & Nash GRL 2010)
  - The modeled baroclinic tide has strong seasonality with the internal tides much stronger at the North Rankin Line in summer than in winter