Comparisons of global and regional internal wave simulations with observations and theory

USING: Realistic Global Simulations of HYCOM, MITgcm, and Mercator/NEMO and Regional MITgcm simulations

SWOT Science Team Meeting, 2018

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Florent Lyard, LEGOS
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Dedication
Joel Bernard Arbic
April 11, 1969-December 2, 2017

Brian and Joel
Dec 1969

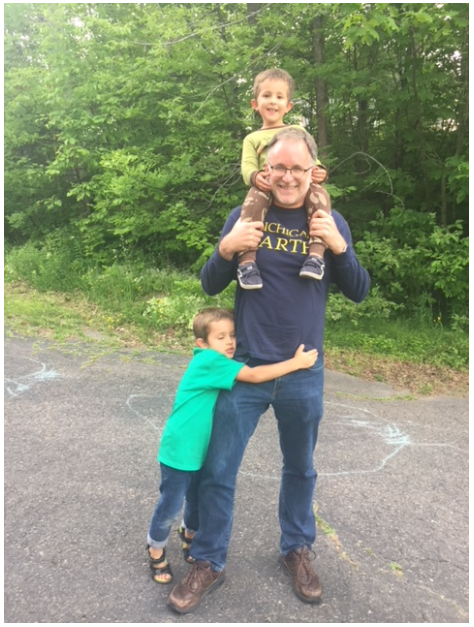
Dan, Brian, Joel
Mom, Dad
Late 1980s

Machapuchare Base Camp, Himalayas
2008

Joel, Shantala, Rowan, Remy
2017

April 2018 Phoenix trip

June 2018 Northern Michigan trip



The Coastal Ocean Environment Summer School in Ghana (coessing.org)

Second summer school

--August 2016

--University of Ghana

The Coastal Ocean Environment Summer School in Ghana (coessing.org)

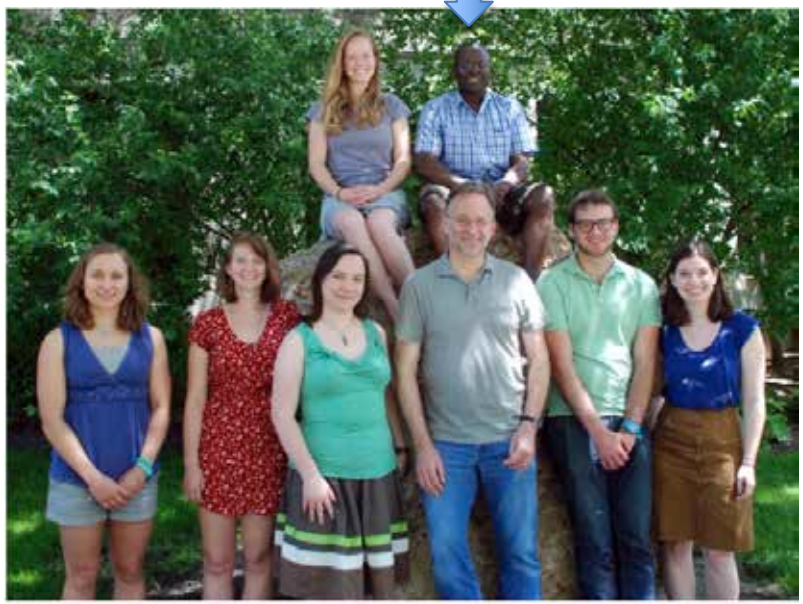
- Has been running for one week per year since 2015
- Will return in 2018
- Dimitris Menemenlis is one of the instructors
- Joseph Ansong, who helped me start it, is now a lecturer (equivalent of assistant professor) at University of Ghana

My history with Joseph Ansong

With my Form 5 science class, Damongo Secondary School, Ghana, 1992

Peace Corps service

Joseph Ansong



Group photo, June 2, 2016
Top, left to right: Paige Martin, Joseph Ansong
Bottom, left to right: Eliana Crawford, Anna Savage, Amanda O'Rourke, Brian Arbic, Conrad Luecke, Molly Range

My research group in 2016

University of Michigan

Back to internal tides and internal gravity waves (IGWs)…

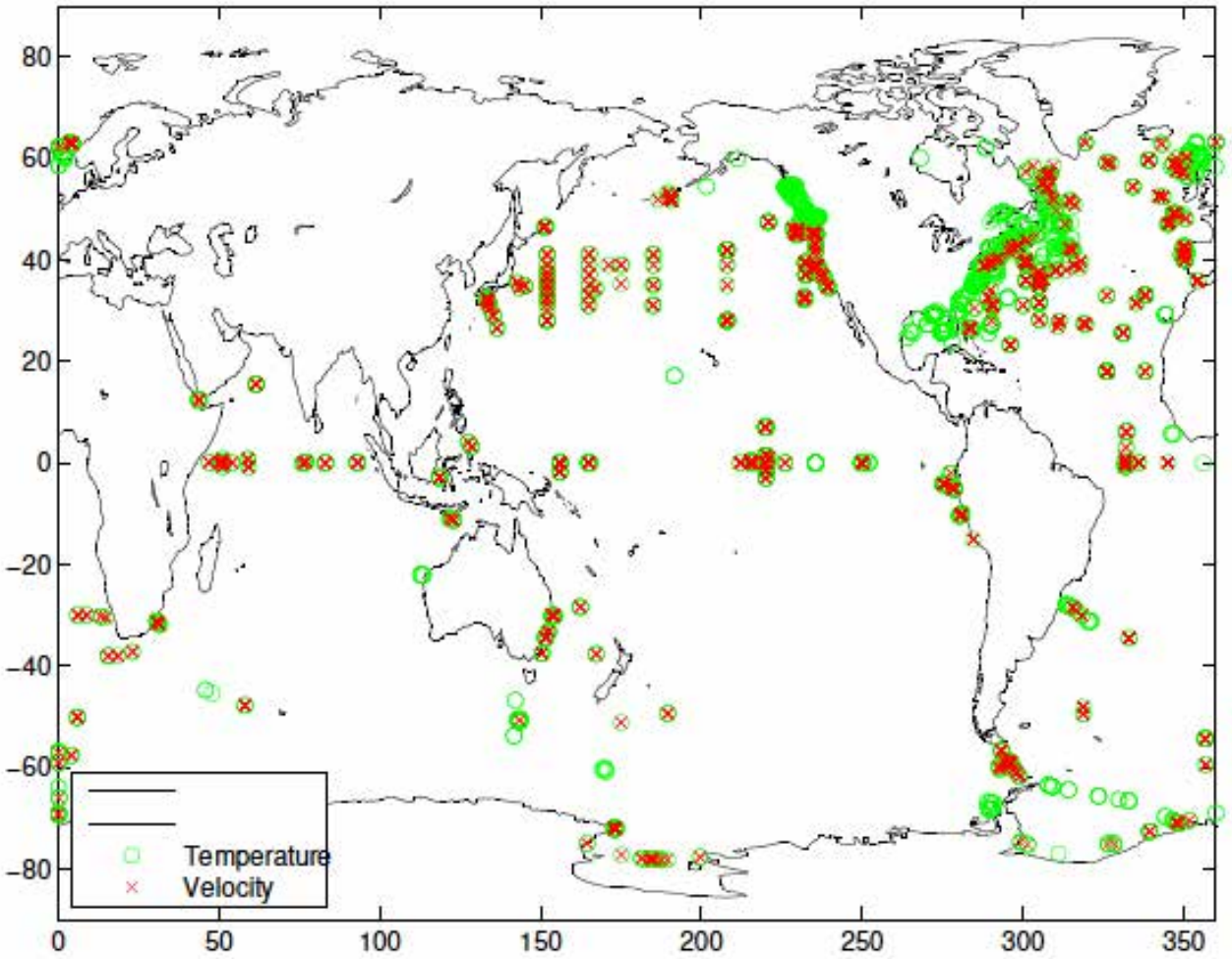
Relevance: Global IGW models can…

- Map the geography of high-frequency SSH signals seen in altimetry:
  - Stationary internal tides. SEE ALSO JAY SHRIVER TALK IN TIDES SESSION.
  - Non-stationary internal tides. SEE ARIN NELSON TALK IN TIDES SESSION.
  - The supertidal IGW continuum.
- Quantify partition of high- vs. low-frequency motions in high-wavenumber SSH spectrum measured by SWOT
  - Richman et al. 2012 (HYCOM) ←OUR WORK SHOWN IN RED
  - Rocha et al. 2016a,b (MITgcm)
  - Savage et al. 2017 (HYCOM and MITgcm)
  - Qiu et al. 2018 (MITgcm)
  - Ongoing work by Torres et al. (MITgcm)
  - Ongoing work by Ansong et al. (HYCOM and MITgcm)

Global/basin-scale models with high-resolution + atmospheric forcing + tidal forcing →ingredients needed for IGW continuum spectrum

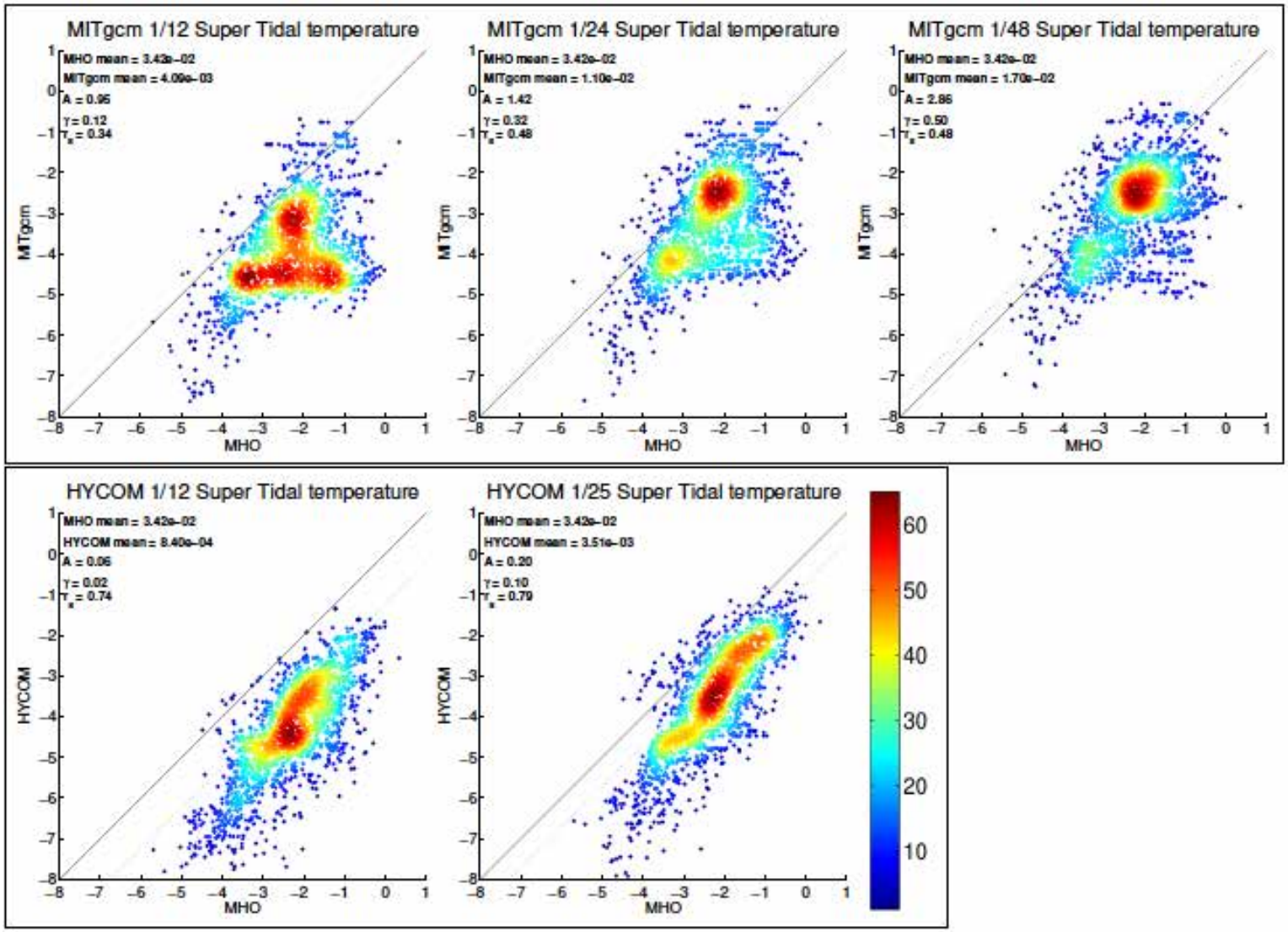
- HYbrid Coordinate Ocean Model (HYCOM) simulations (Arbic et al. 2010, 2012, many other papers)
  - Began with 1/12.5° resolution
  - Now up to 1/25° resolution
  - First demonstration of IGW continuum spectrum in models (Müller et al. 2015)
- 1/48° global MITgcm simulations
  - Also contains an IGW continuum spectrum (Rocha et al. 2016a,b, others)
- New French NEMO efforts
  - 1/60° North Atlantic model in Grenoble
  - 1/12° global Mercator model in Toulouse → heading to 1/36° operational simulations
- Upcoming Los Alamos effort
  - DOE has largest supercomputers in US
- Other efforts
  - Simmons et al. GOLD simulations
  - Müller et al. STORMTIDE simulations

Locations of (thousands of) historical moored temperature and velocity time series observations



Luecke et al.,
in preparation

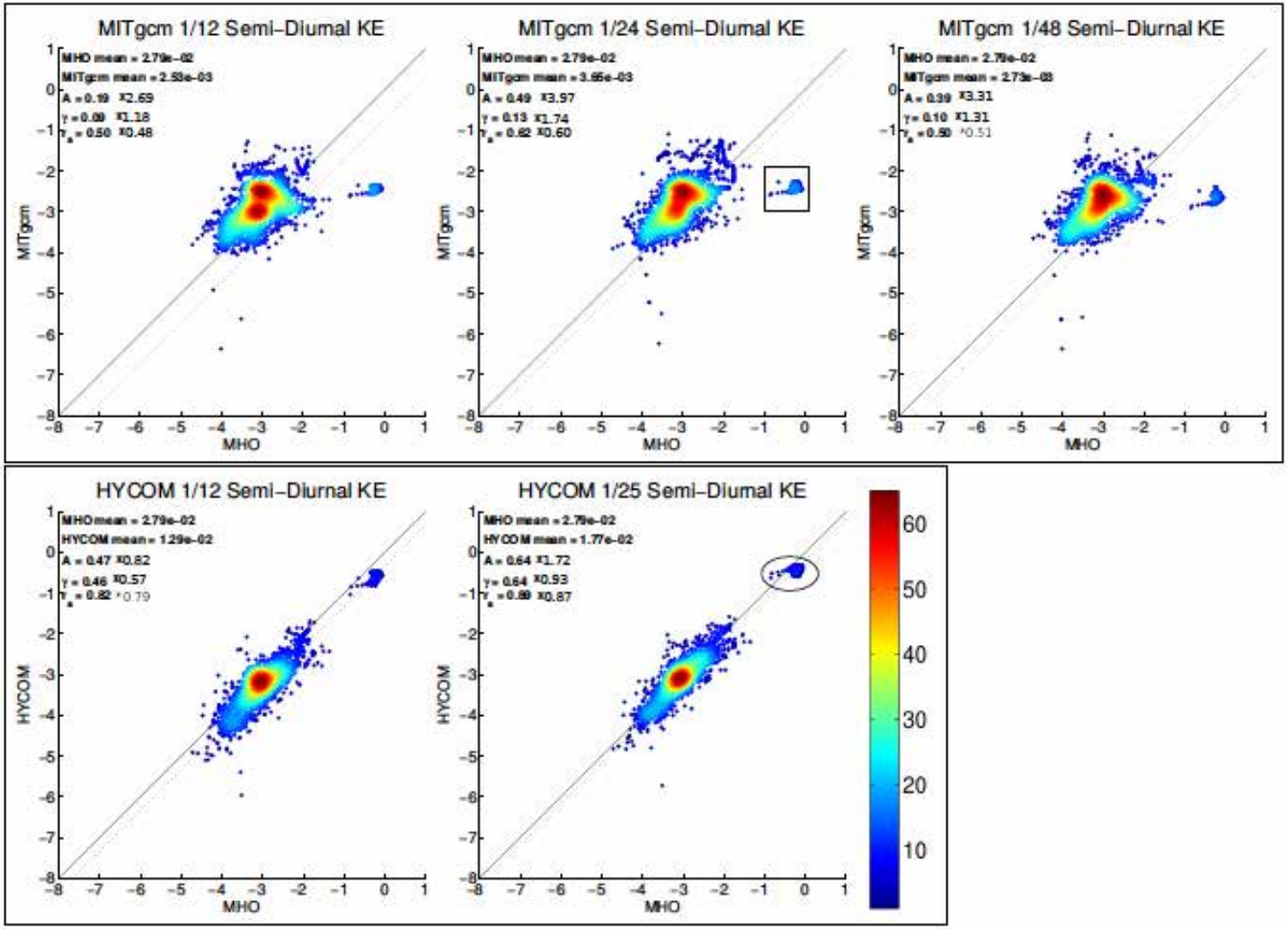
Band-integrated supertidal temperature variance in MITgcm and HYCOM vs. MHO (moored historical observations). Luecke et al., in preparation.



Units are $\log_{10}[(°C)^2]$

HYCOM levels are too low but show higher spatial correlations in this and most other frequency bands

Band-integrated semidiurnal kinetic energy in MITgcm and HYCOM vs. MHO (moored historical observations). Luecke et al., in preparation.



Units are $\log_{10}[(m/s)^2]$

Again HYCOM shows higher spatial correlations.

Very strong velocities some near-land regions such as Strait of Gibraltar (shown here) not handled well in MITgcm.

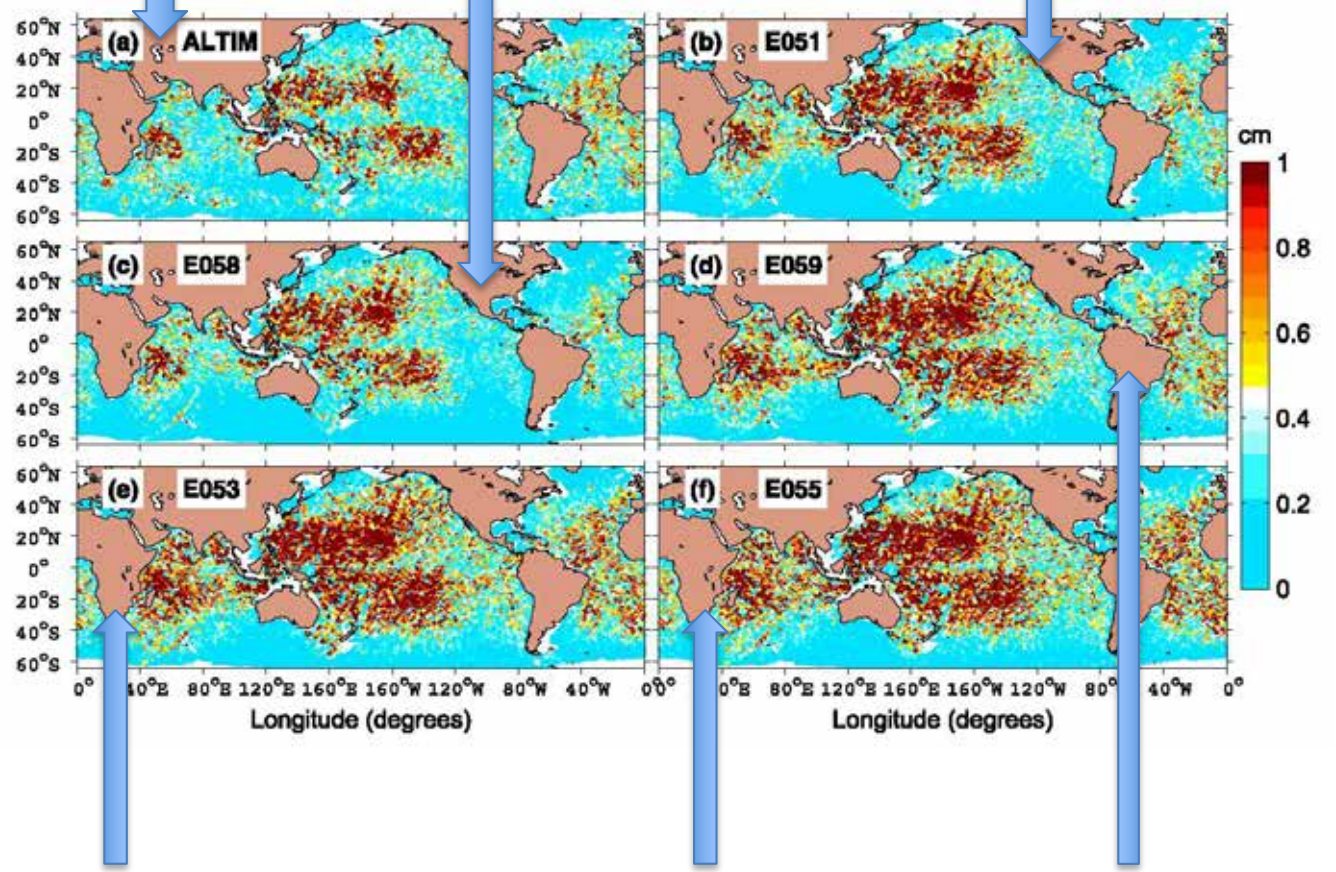
Comparison of hydrodynamical internal tide models with altimetry

- Analysis conducted by Joseph Ansong
- Stationary M_2 internal tides in models vs. altimetry
- Results shown for:
  - 1/12° HYCOM with different wave drag strengths (Ansong et al. 2015)
  - 1/12° Mercator/NEMO (no wave drag)
  - 1/48° MITgcm (no wave drag)
    - Preliminary analysis only done for 2 months of output
- Coming:
  - 6 months of 1/48° MITgcm
  - 1/12° MITgcm
  - Hopefully: 1/12° MOM6

Altimeter

Stronger wave drag

Weaker wave drag

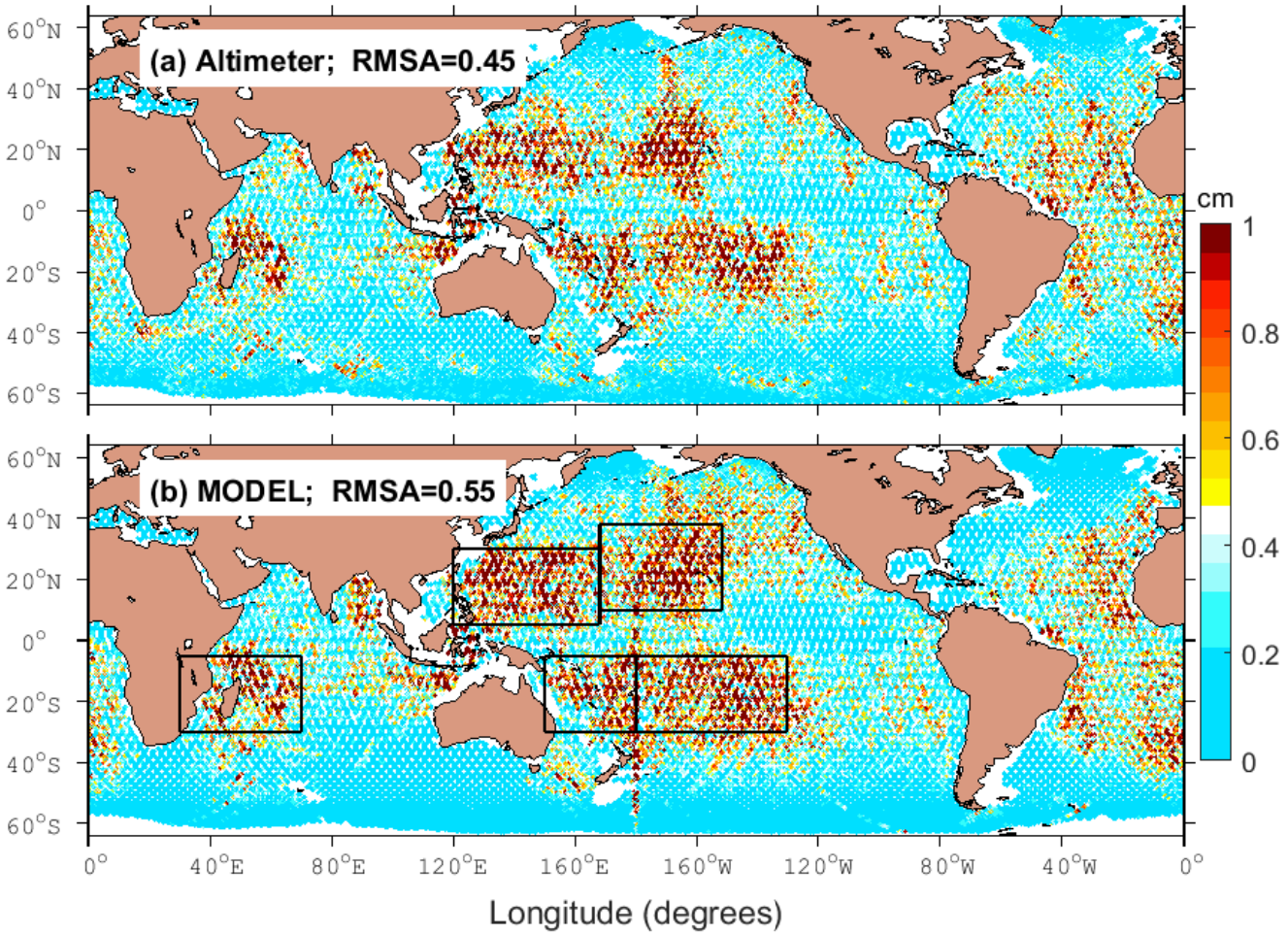


1/12° HYCOM results, from Ansong et al. (2015)

Some damping of low mode internal tides is needed for agreement with altimetry.

No wave drag acting on internal tides

Preliminary Mercator 1/12° NEMO results



Run by Romain Bourdalle-Badie of Mercator.

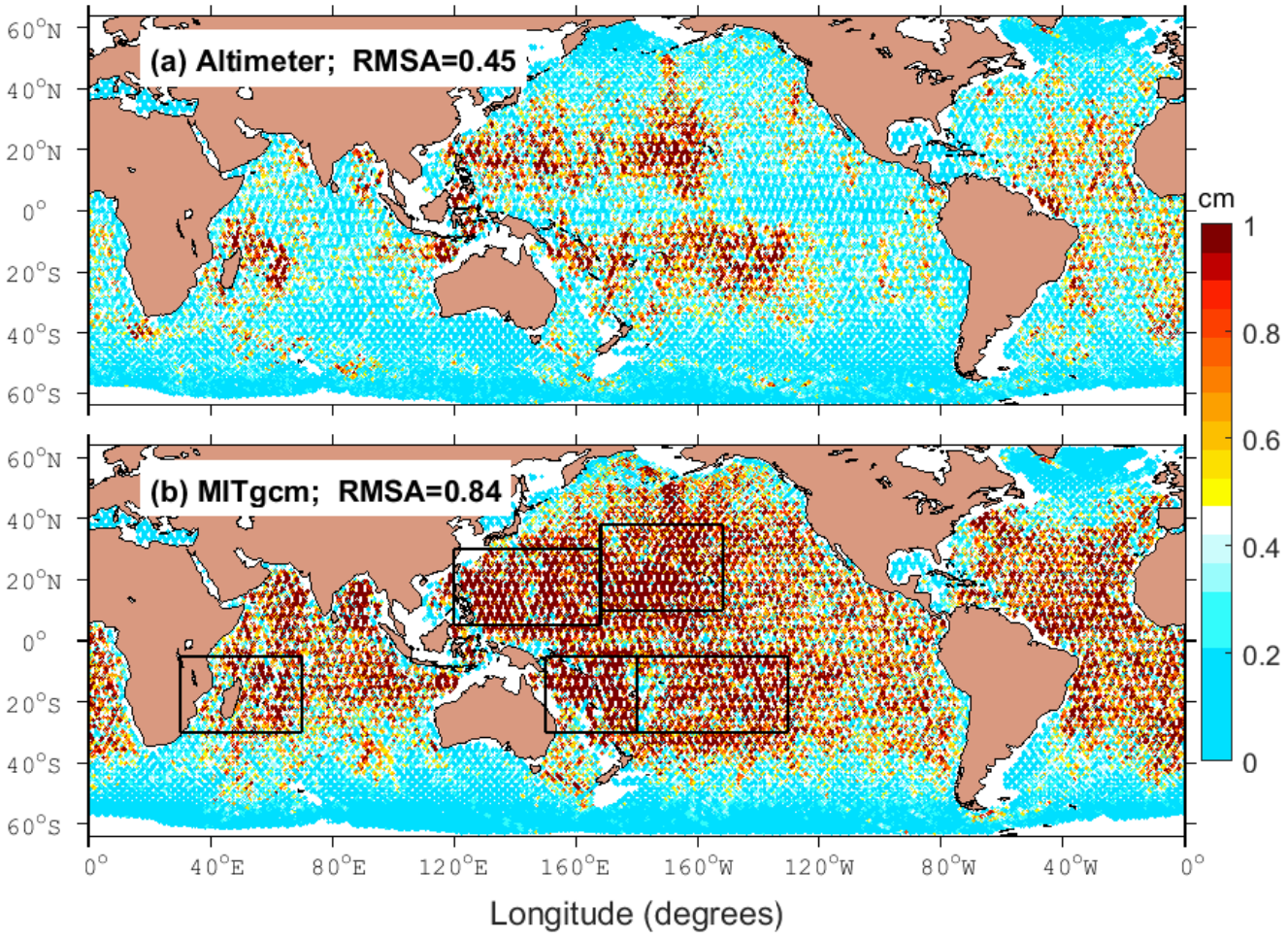
No wave drag.

NEMO internal tides slightly too large.

Romain and Jérôme Chanut are testing vertical coordinates and numerical schemes.

Hypothesis: less "viscous/diffuse" model → larger internal tides → must insert physical damping to obtain better agreement with altimetry.

Preliminary analysis of 1/48° MITgcm



No wave drag.

MITgcm internal tides much too large.

Caveats:
--results very preliminary
--amplitude will reduce as model record length increases
--astronomical forcing **may** have been too large by factor of 1.12.
--Rough corrections based on latter two effects still yield internal tides too large by factor of about 1.4.
--need to analyze 1/12° MITgcm

Boundary forcing very-high resolution regional simulations

- Collaboration between
  - Dimitris Mememenlis
  - Arin Nelson
  - Brian Arbic
  - Dick Peltier
  - Nicolas Grisouard
  - Jody Klymak
- Regional run, on ~40,000 cores, over 6 by 8 degree box
  - Horizontal grid spacing decreased to 250 meters
  - Tripled the number of vertical levels
- Preliminary vertical wavenumber spectrum lies closer to theoretical predictions than spectra from global MITgcm and HYCOM
- Analysis will be stepped up later this summer.

Summary

- High-resolution simulations of models with simultaneous atmospheric and tidal forcing, carry
  - stationary internal tides
  - non-stationary internal tides
  - partial IGW continuum
- Comparison of simulations to observations and to theoretical predictions is ongoing.
  - HYCOM has been compared to in-situ and altimetric observations most frequently.
- The 1/48° MITgcm simulation is being used to boundary force very-high-resolution regional patches.
- The number of groups running, or planning to run, global high-resolution "wind plus tides" simulations is relatively small, but growing:
  - HYCOM
  - MITgcm
  - NEMO
  - Los Alamos DOE modeling group

  - GOLD
  - STORMTIDE

New slides

Does the lack of African oceanographers matter for our field?

UNIVERSITY OF HAWAII
SEA LEVEL CENTER

Data Network Research Products GLOSS About

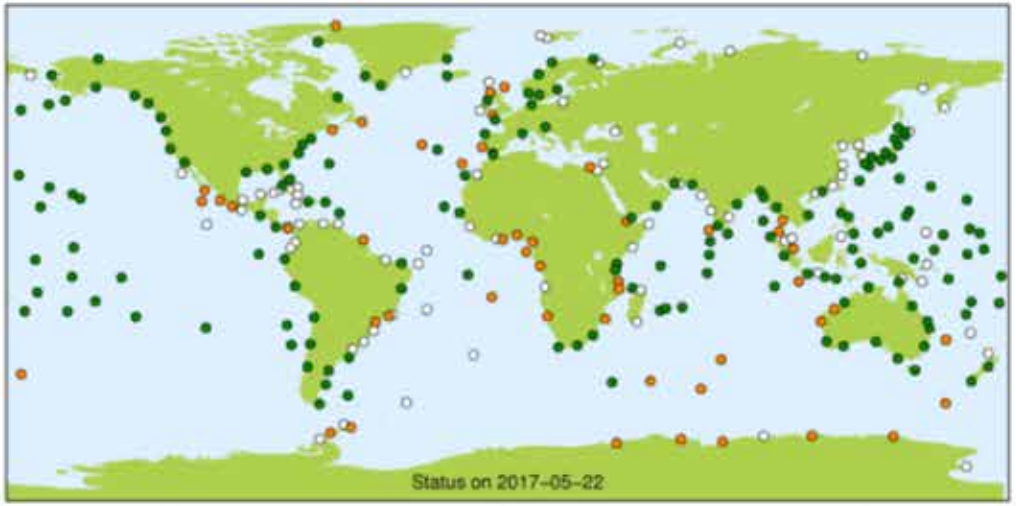
Network Status

The UHSLC datasets are GLOSS data streams (read more here). There are many tide gauge records in the UHSLC database, but the backbone is the GLOSS Core Network (GCN) – a global set of ~300 tide gauge stations that serve as the foundation of the global in situ sea level network. The network is designed to provide evenly distributed sampling of global coastal sea level variation at a variety of time-scales. For more information on the selection and standards required of GCN stations, please see the GLOSS Implementation Plan 2012.

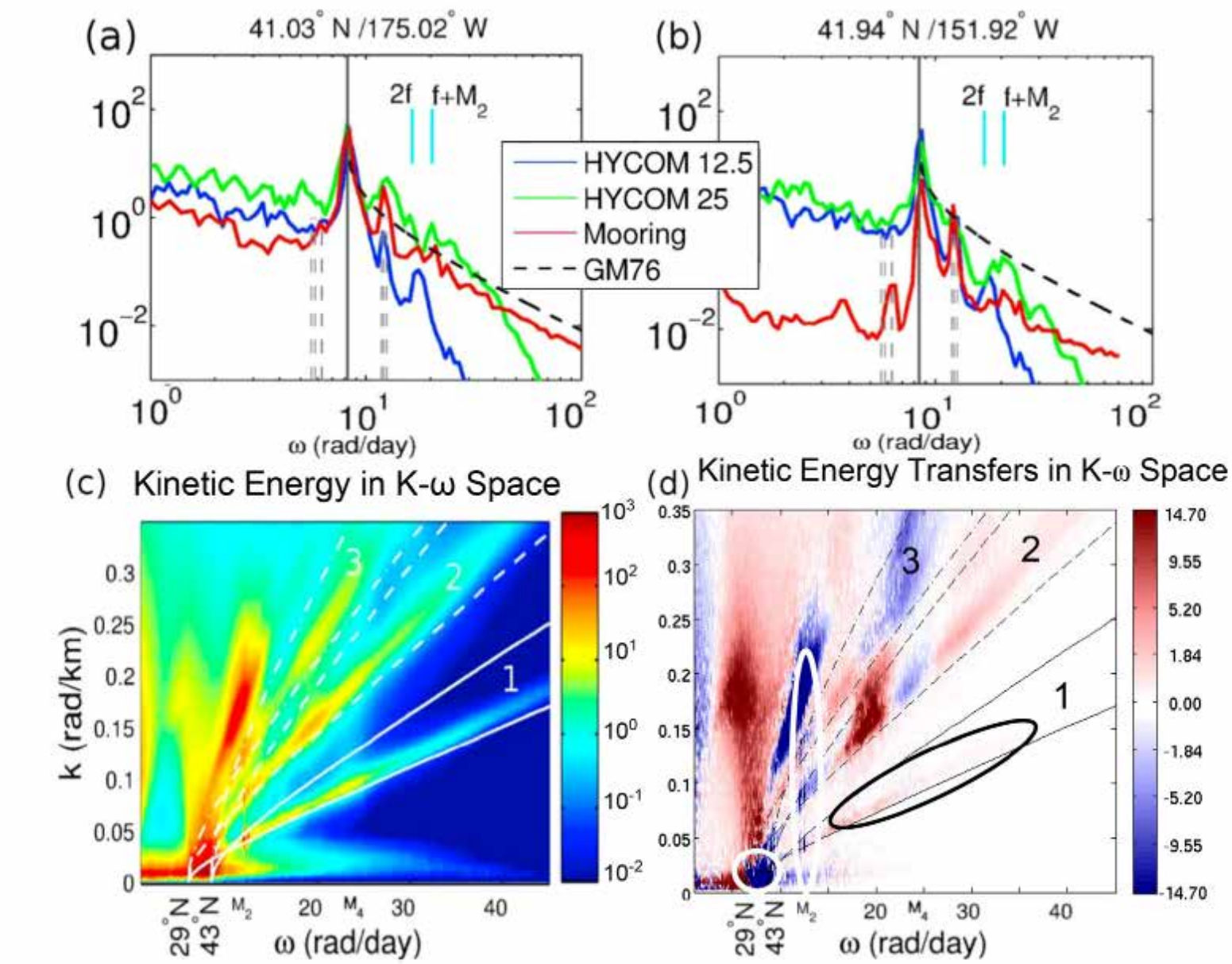
The maps to the right show the status of GCN stations in the UHSLC data streams (graphics courtesy of PSMSL). For each stream, the colored circles indicate whether a site is operational (green marker), has been operational in the past (orange marker), or never operated successfully for that particular stream (white marker).

All full summary of the network status for all GLOSS data streams is available here: glossCoreNetwork.xml

Fast-Delivery | Research Quality (JASL)



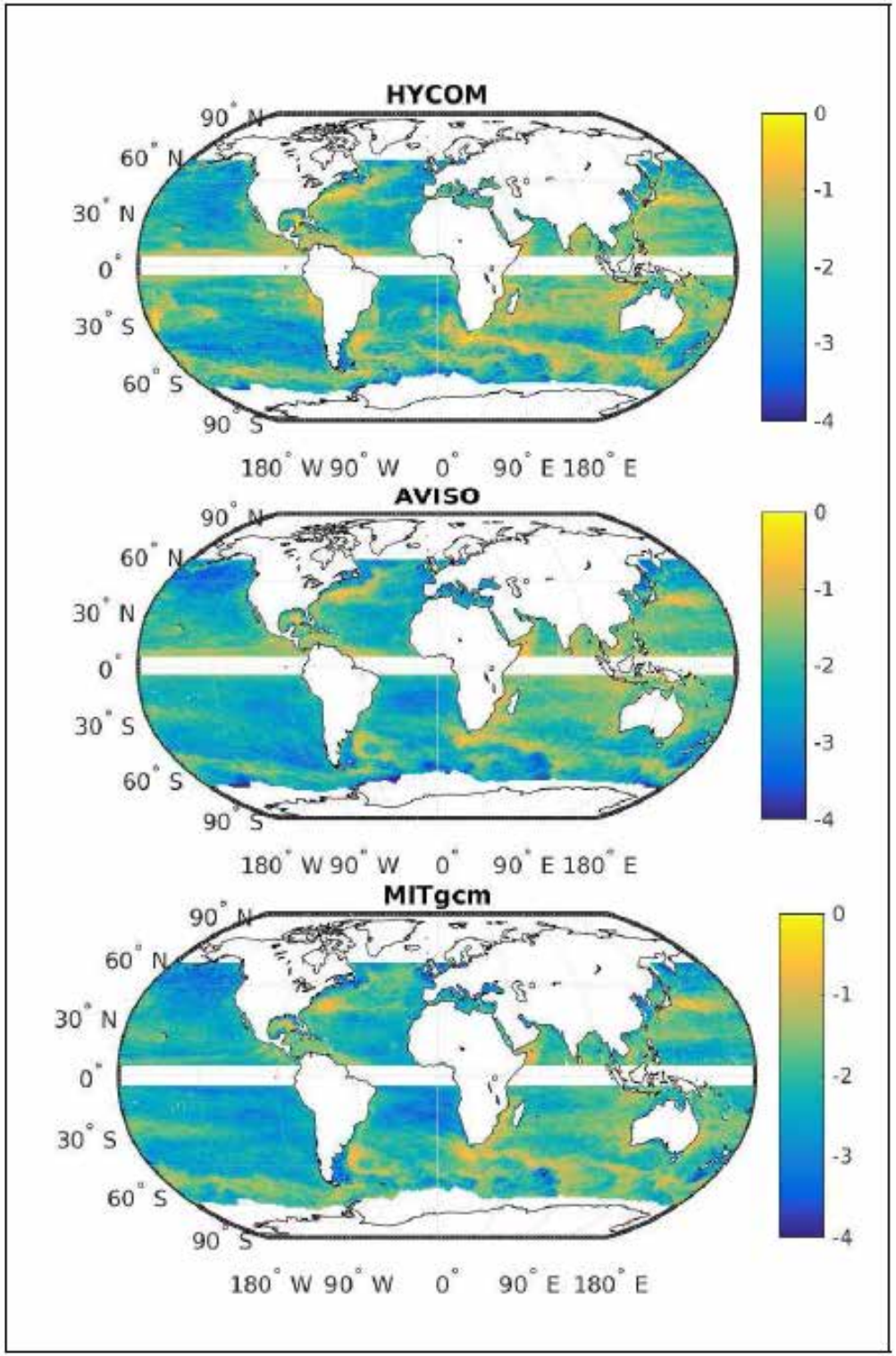
First evidence of IGW continuum in such models—analysis of suface kinetic energy in North Pacific region of global HYCOM (Müller et al. 2015; updated figure from Savage et al. 2017a)



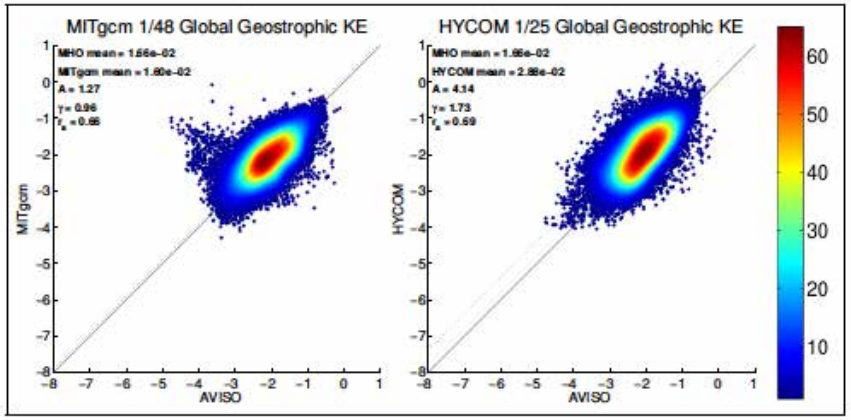
Summary of HYCOM/MITgcm/NEMO internal tide/IGW model comparisons to observations

- HYCOM
  - Altimetry
    - Barotropic and internal tides vs. altimetry: Arbic et al. 2010, 2012, Shriver et al. 2012, Stammer et al. 2014, Ansong et al. 2015, Buijsman et al. 2015, Ngodock et al. 2016
    - Barotropic tidal currents vs. altimeter-constrained models: Timko et al. 2012, 2013
    - Tidal dissipation vs. altimeter-constrained models and Argo: Buijsman et al. 2015,2016
    - Non-stationarity vs. altimetry: Nelson et al. 2018 in preparation
  - In-situ
    - Tidal currents and kinetic energy vs. current meters and acoustic tomography: Arbic et al. 2012, Timko et al. 2012, 2013, Stammer et al. 2014
    - Kinetic energy frequency spectra vs. current meters: Müller et al. 2015
    - Internal tide energy fluxes vs. current meters: Ansong et al. 2017
    - Barotropic tidal errors vs.tide gauges: Arbic et al. 2010, Stammer et al. 2014
    - SSH frequency spectra vs. tide gauges: Savage et al. 2017a
- MITgcm
  - In-situ
    - Along-track wavenumber spectra vs. ADCP data: Rocha et al. 2016a
- HYCOM and MITgcm
  - Altimetry
    - Barotropic and internal tides vs. altimetry: Ongoing work by Joseph Ansong
  - In-situ
    - Dynamic height frequency spectra vs. McLane profilers: Savage et al. 2017b
    - Vertical wavenumber-frequency spectra of kinetic energy vs. McLane profilers: Ansong et al. 2018b in preparation
    - Frequency-band integrated emperature variance and kinetic energy vs. historical observations: Luecke et al. 2018 in prep.
- NEMO
  - Altimetry
    - Barotropic and internal tides vs. altimetry: Ongoing work by Joseph Ansong

THIS SLIDE EMPHASIZES INTERNAL TIDE/IGW MODEL-DATA COMPARISONS. THERE ARE ALSO MANY NON-TIDAL COMPARISONS INVOLVING HIGH-RESOLUTION HYCOM AND NEMO.



Surface geostrophic kinetic energy in HYCOM and MITgcm vs. AVISO. Luecke et al., in preparation.



Units are $\log_{10}[(m/s)^2]$

Slightly higher correlation in HYCOM.

Thanks to Shuiming Chen and Bo Qiu for MITgcm nd AVISO results.

However…

- Correlation between models and AVISO at mooring locations is slightly higher in MITgcm.

However…

- Correlation between models and AVISO at mooring locations is slightly higher in MITgcm.

- “Model-data comparisons are harder than people think.”—Conrad Luecke, 2018

Last remarks on global models

- HYCOM and Mercator NEMO are operational models
  - →They will be continually improved.
  - →They will run in near-real-time.
  - →Both of these issues will be important for SWOT.
- Example problem, and potential solution, in HYCOM
  - – HYCOM has an instability in the North Pacific

HYCOM numerical instability in North Pacific

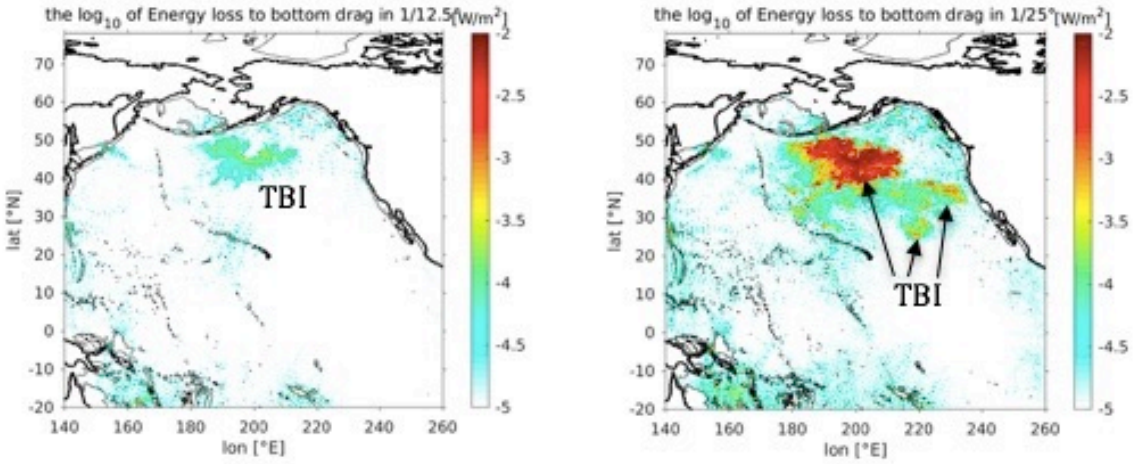


Figure 8. The thermobaric instability (TBI) occurs mostly in the North Pacific and manifests itself as high-mode waves that are partially dissipated by quadratic bottom drag. The TBI energy loss in the North Pacific is shown for the 1/12.5° (left) and 1/25° (right) HYCOM simulations. The TBI is worse in the higher resolution 1/25° simulation than in the 1/12.5° simulation. The energy loss in depths shallower than 2000 m are set to zero to emphasize the TBI losses in deep water. The 2000-m isobath and coastline are the thin and fat black curves.

How to fix? Instability apparently not present in MOM6, a model with a very similar structure to HYCOM→should work closely with NOAA MOM6 developers.