Indirect Evidence for Substantial Damping of Low-Mode Internal Tides in the Open Ocean

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OUTLINE

- Background...
- PhD Research
- Climate Process Team (CPT) projects
  - Parametric Subharmonic Instability (PSI) in a global ocean model
  - Global ocean model versus Observational data comparison
  - Indirect evidence for substantial damping of low-mode internal tides in the open ocean

Damongo Secondary School with Brian

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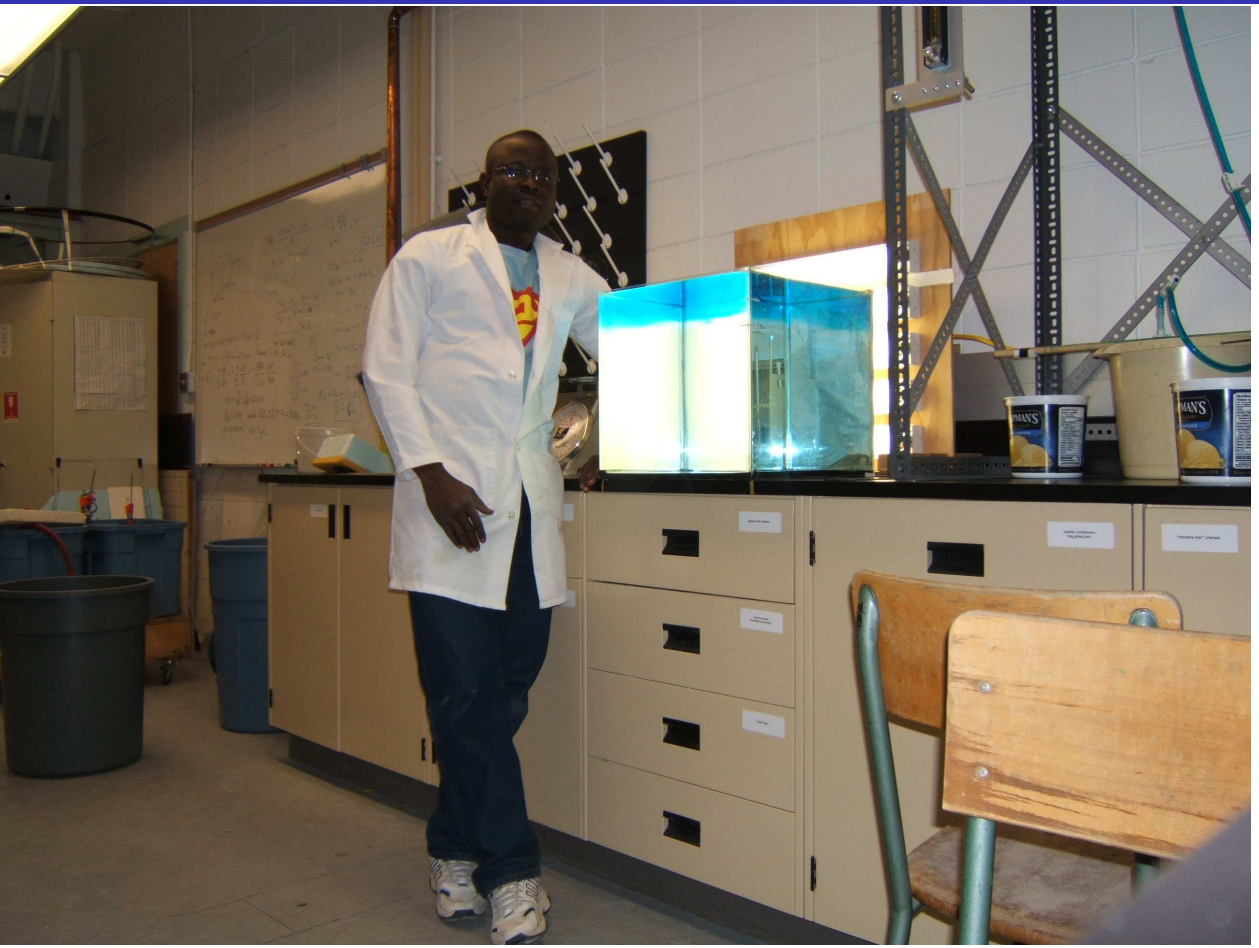
PhD RESEARCH...

University of Alberta (Canada): 2004-2009



Sutherland et al. (2012), Physics of Fluids, vol. 24

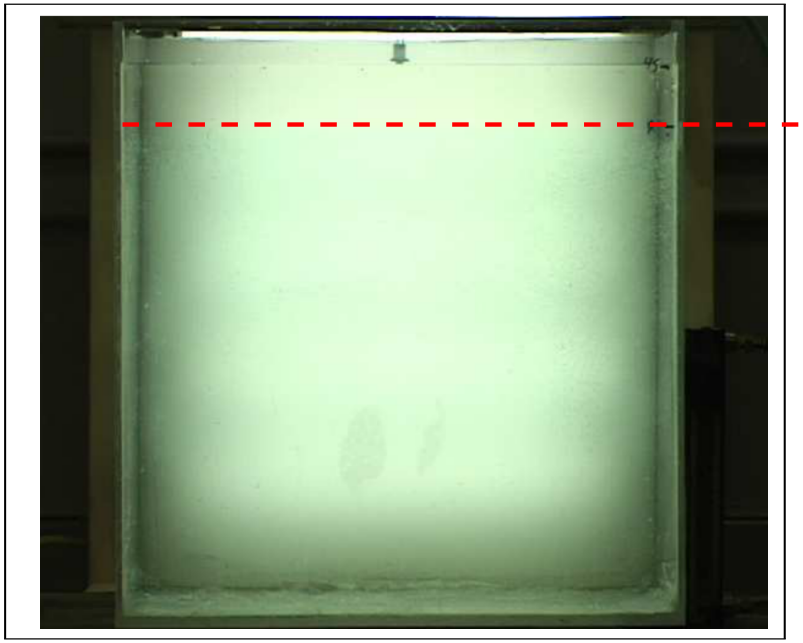
- Ansong et al. (2008), JFM, vol. 595
- Ansong & Sutherland (2010), JFM, vol. 648
- Ansong et al. (2011), JFM, vol. 689

Motivation 1: Dispersion of pollutants

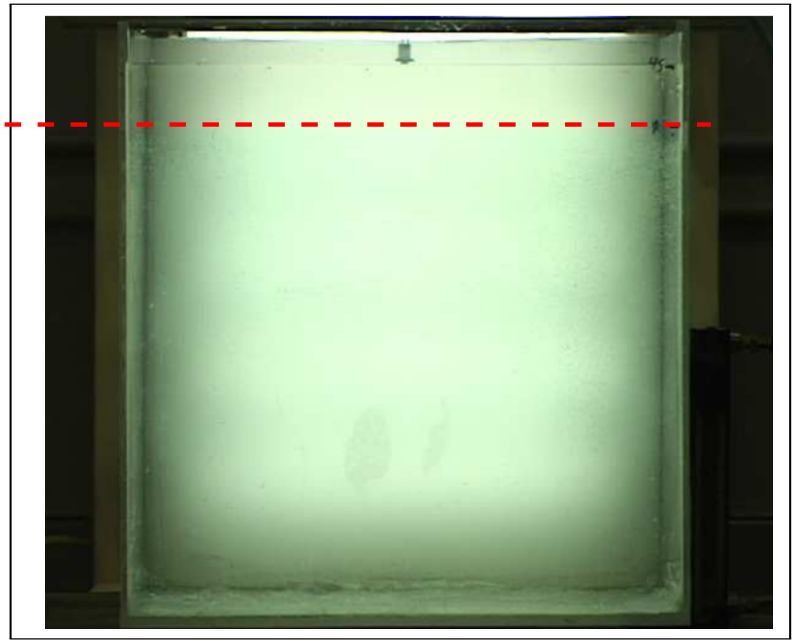
- How does ash from volcanic eruptions spread in the stratosphere?
- How does smoke from stacks spread at an atmospheric inversion?

Movies: Regimes of flow

Surface Flow



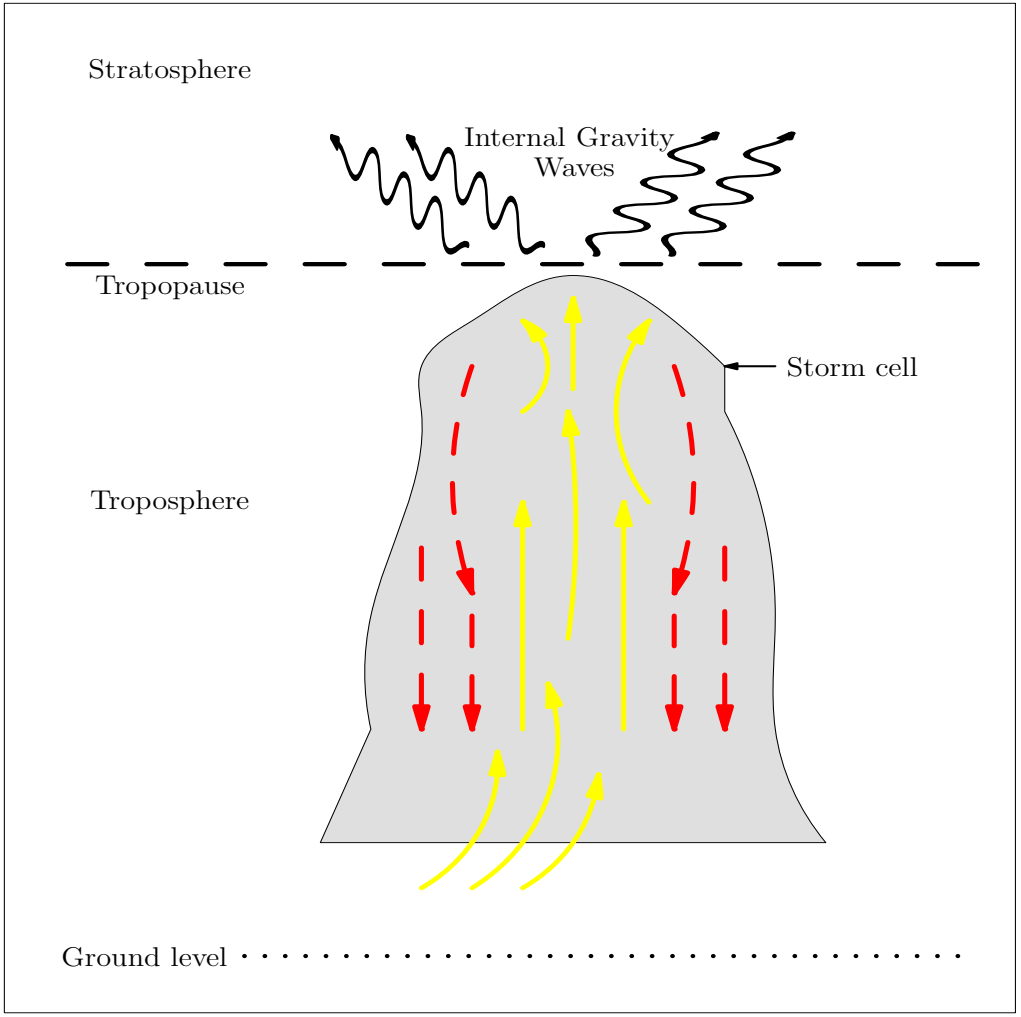
Interface Flow



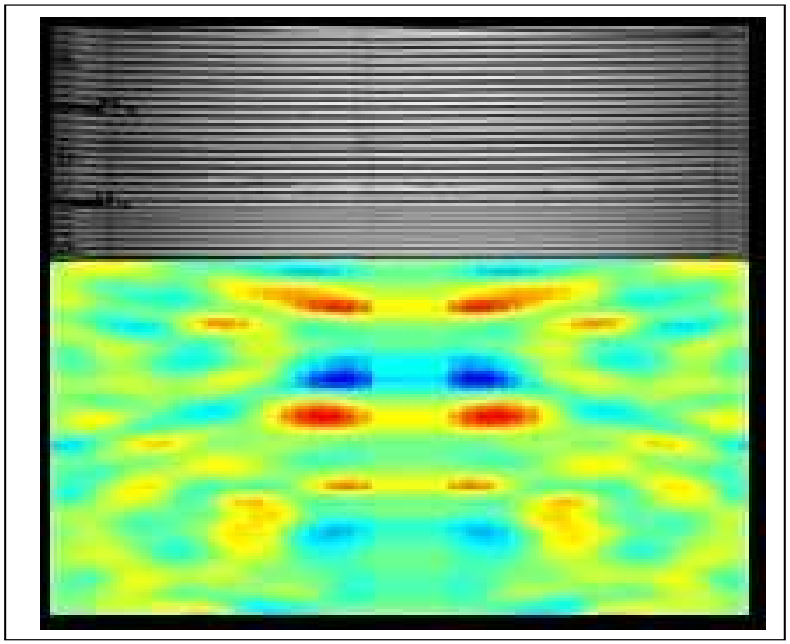
Play/Pause

Motivation 2: Generation of IGW by storms

- Generation by convective forcing:
- mechanical oscillator effect
- Vertical oscillations of updrafts about neutral buoyancy level generate waves



Internal Gravity Waves



- Axisymmetric waves...
- Waves propagate down as conical beams
- The upshot:
  - amplitude of waves linearly related to penetration depth
  - about 4% of energy of plume (at interface) goes into waves

Play/Pause

CURRENT RESEARCH...

Climate Process Team:

improving representations of internal-wave driven mixing in global ocean models

http://www-pord.ucsd.edu/∼jen/cpt/

"...created to develop, test, and implement dynamically appropriate parameterizations for diapycnal mixing due to internal-wave breaking for use in global climate models."

- Dr. Jennifer MacKinnon

The CPT Team

Official CPT Post-docs

Joseph Ansong (U Michigan)
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William Large (NCAR)
Sonya Legg (GFDL/Princeton)
Jennifer MacKinnon (SIO) **
Jonathan Nash (OSU)
Rob Pinkel (SIO)
Kurt Polzin (WHOI)
Harper Simmons (UAF)
Lou St. Laurent (WHOI)

The BIG picture

- Vertical mixing by breaking internal waves has a strong influence on the stratification and general circulation in the ocean.
- The general circulation in turn determines the distribution of heat and vital nutrients and gases around the globe.
- General circulation models (GCMs) used for climate research often use over-simplified parameterizations to capture the impact of small scale processes like breaking internal waves because of limited resolution.
- GCMs do not generally include most of the spatial variability of mixing patterns.

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- GCMs do not generally include most of the spatial variability of mixing patterns.
- The goal of the CPT is to develop parameterizations of internal wave driven mixing for global circulation ocean models. The parameterizations are meant to capture the spatial and temporal variability in ocean mixing patterns using appropriate physics. The parameterizations will also allow the mixing rates and patterns to evolve with a changing climate.

The BIG questions

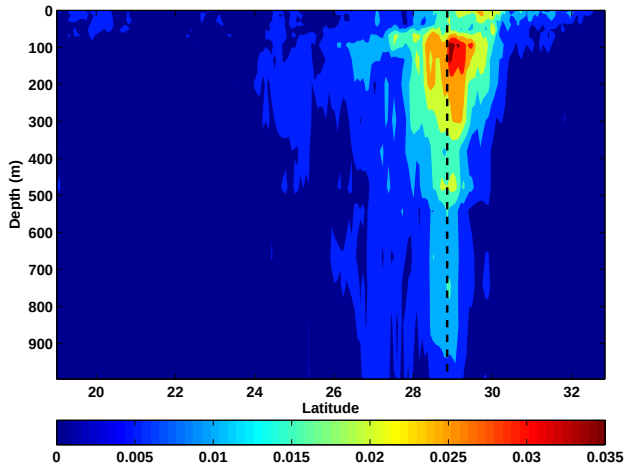
Some important questions for the CPT:

- Where do the low-mode internal waves seen crossing ocean basins dissipate?
- What are the dominant processes?
  - Upper ocean wave-wave interactions (including PSI)?
    (PSI = Parametric Subharmonic Instability)
  - Dissipation over topographic features?
  - Dissipation over continental slopes?
- Is the dissipation primarily in the deep or upper ocean?
  - The geography of dissipation is very important for the large scale circulation in the ocean

Contributions to CPT Projects at Michigan: Summary

Use a high resolution global ocean model, HYCOM, to study/find...

- A wave-wave interaction mechanism (PSI)
  - Find PSI mostly along critical latitudes
  - Paper under revision...



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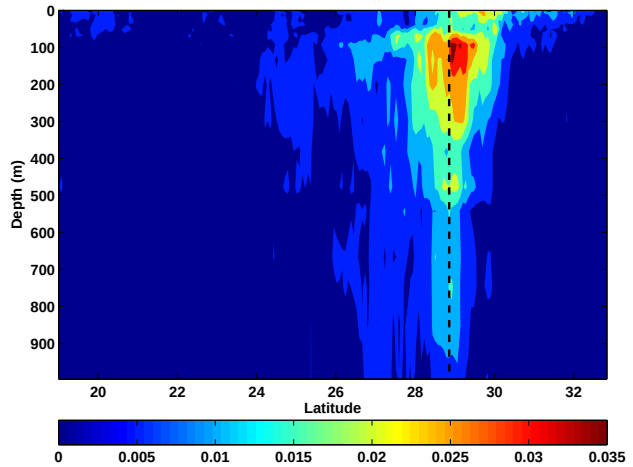
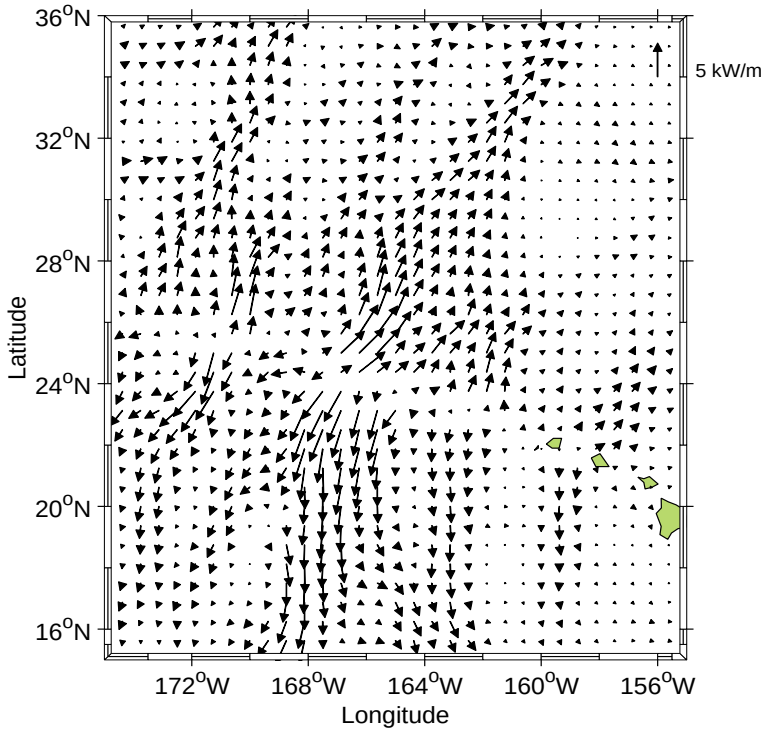
  - Compare to observed energy fluxes
  - Paper in preparation





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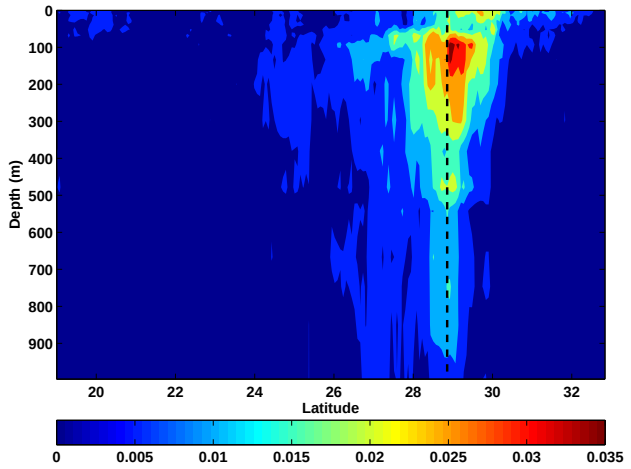
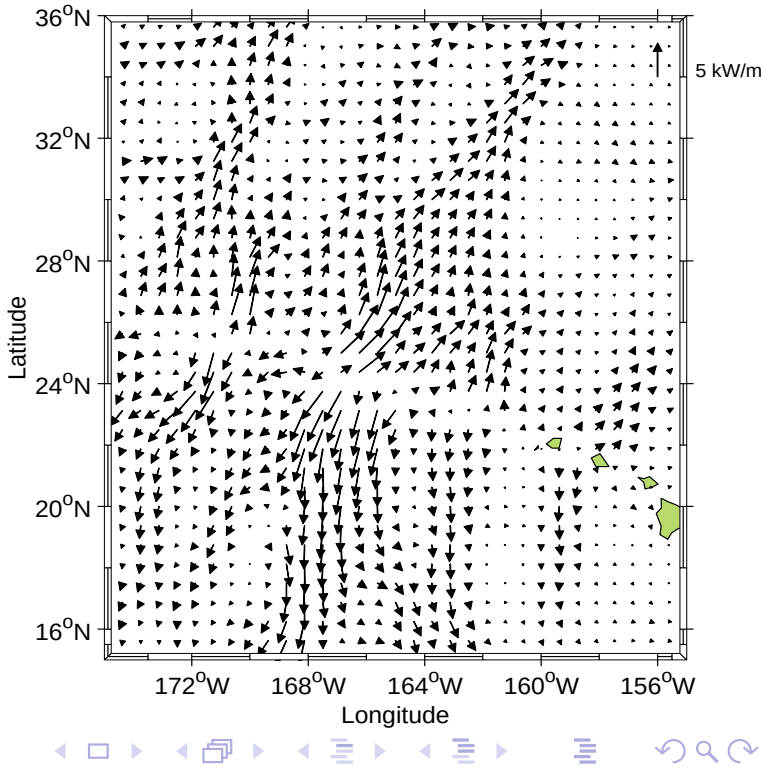
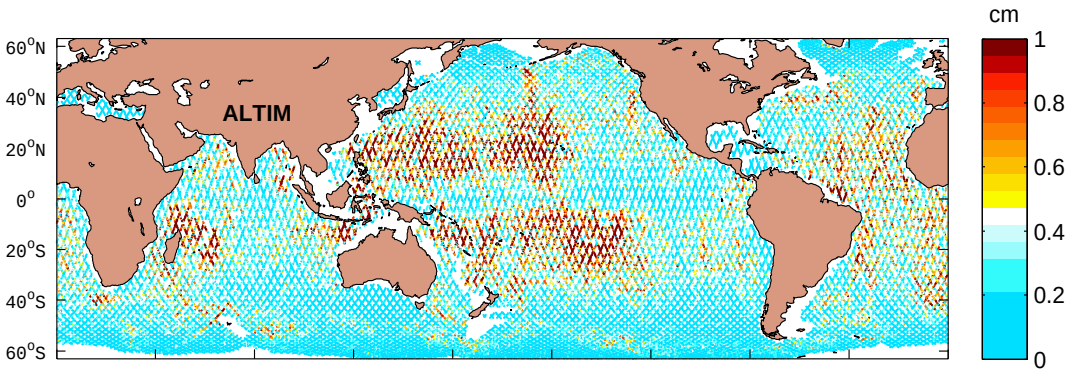
- Where are the internal tides dissipating?
  - Ansong et. al. 2015 (*in-press*)

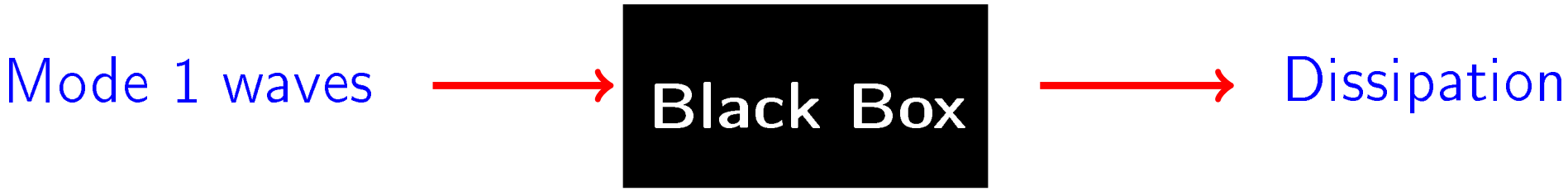






PROJECT 1: Parametric Subharmonic Instability (PSI) in HYCOM

What's the fate of mode 1 (large scale) internal waves that radiate away?



- break on topographic features, break on continental shelves, wave-wave interactions, ...
  [Johnston et al (2003), Legg (2013), Kelly et al (2013), ...]
- PSI (Parametric Subharmonic Instability) is a culprit

$$\omega_0 = \omega_1 + \omega_2, \quad \omega_1, \omega_2 \approx \omega_0/2$$

$$(\omega_1, \omega_2) \rightarrow \text{small vertical scales} \Longrightarrow \text{Mixing}$$

McComas & Bretherton (1977), Hibiya et al.(1998, 2002), MacKinnon & Winters (2005), MacKinnon et al. (2011, 2012), Furuichi et al.(2005), Alford(2008), Hazewinkel & Winters (2011), Simmons(2008), Sun (2010), Sun & Pinkel (2013), ...

Motivation

e.g. $M_2/2 = f = 2\Omega \sin\phi, \quad \phi = \sin^{-1}(M_2/4\Omega) \Longrightarrow \phi \approx 28.8^\circ$

From: Dr. Jennifer MacKinnon

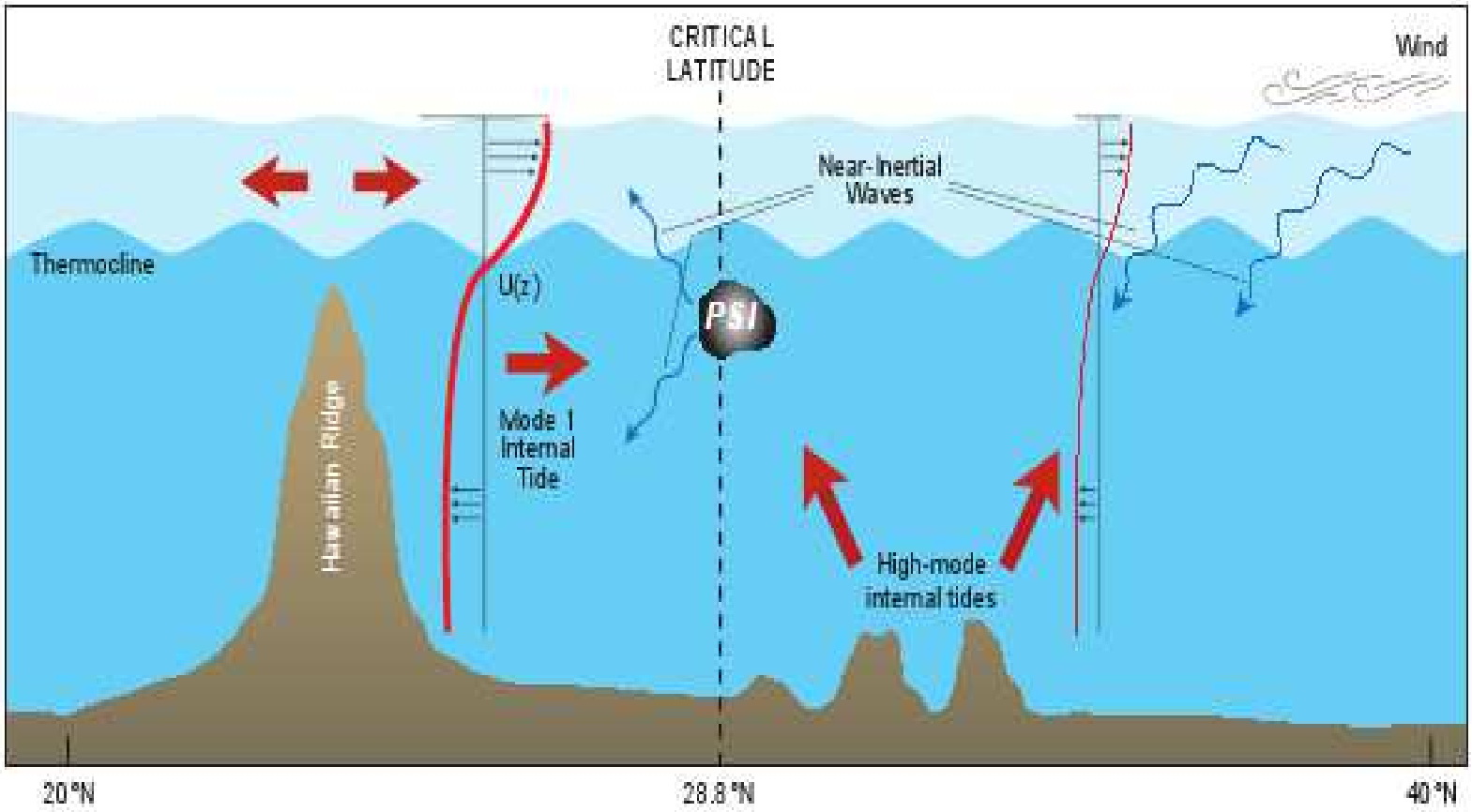
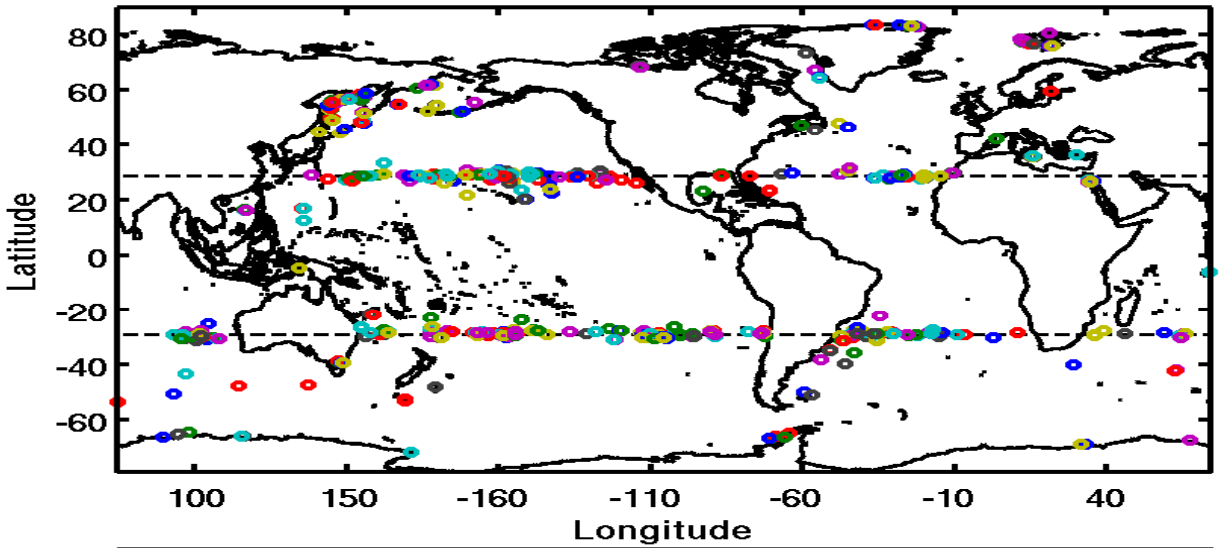


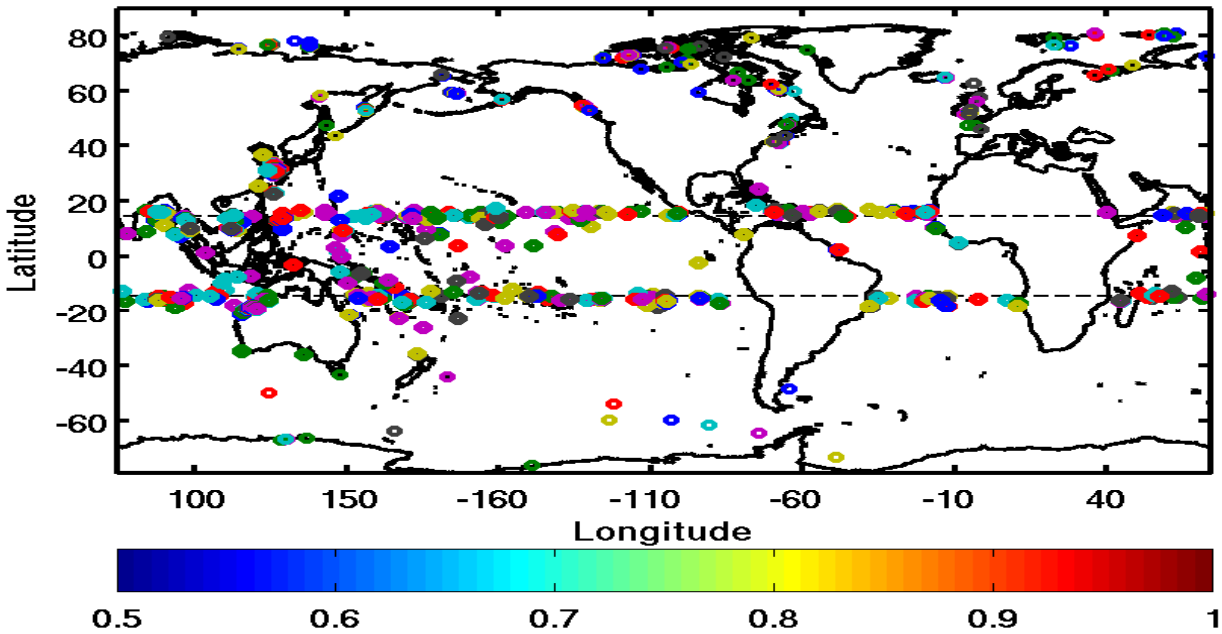
FIG. 10. Cartoon of PSI in the North Pacific. A combination of internal tides from remote (mode 1) and local (higher mode) generation leads to generation of near-inertial waves through PSI near a critical latitude of 28.8N. These waves propagate both upwards and downwards as they travel equatorwards. At other latitudes, high-mode near-inertial internal waves are generally wind-generated and are constrained to propagate downwards from the ocean surface.

Bicoherence Results



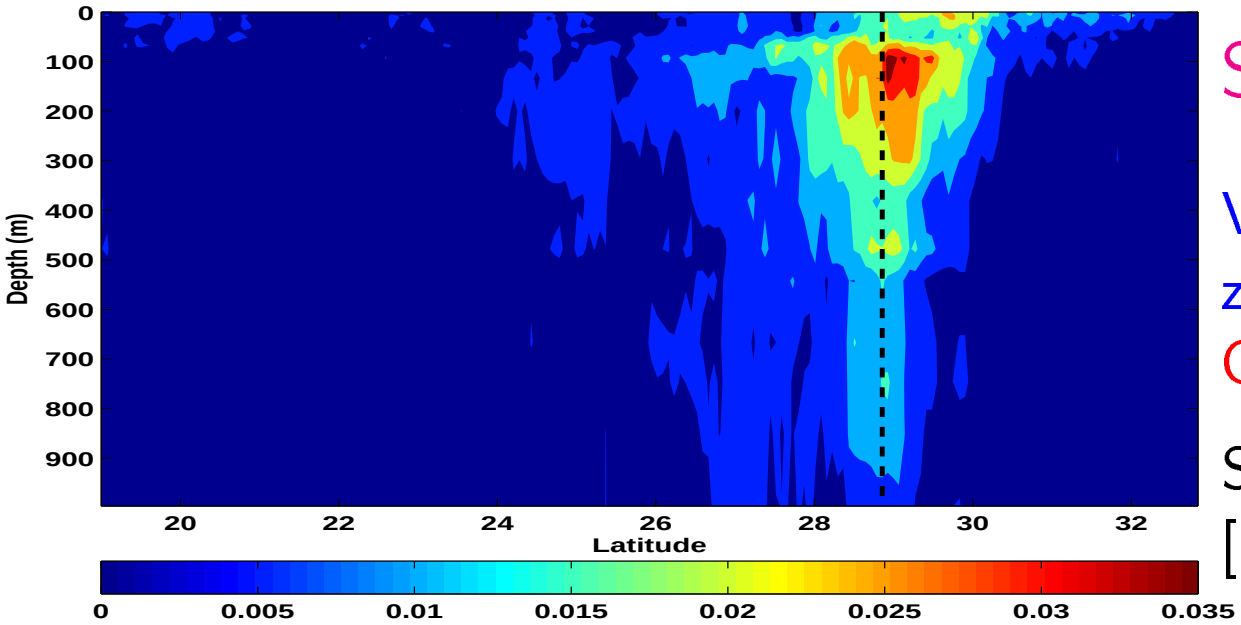
Semidiurnals

Significant values localized around critical latitudes



Diurnals

Depth vs Zonally-averaged bicoherence

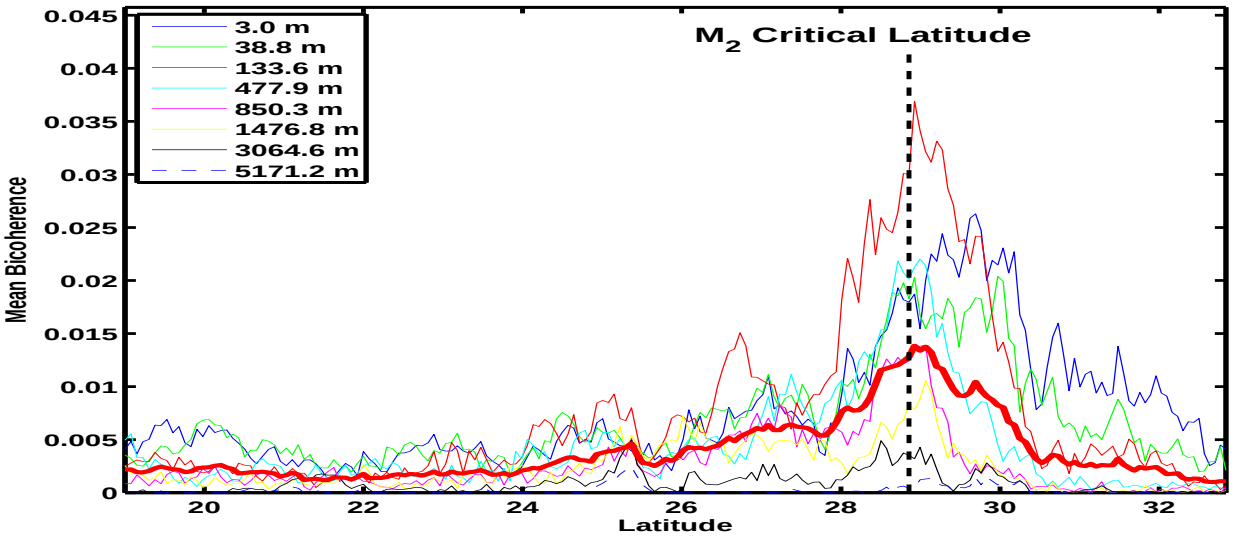


Semidiurnals

Variation in depth of zonally-averaged bicoherence

Only showing $0 - 1000m$

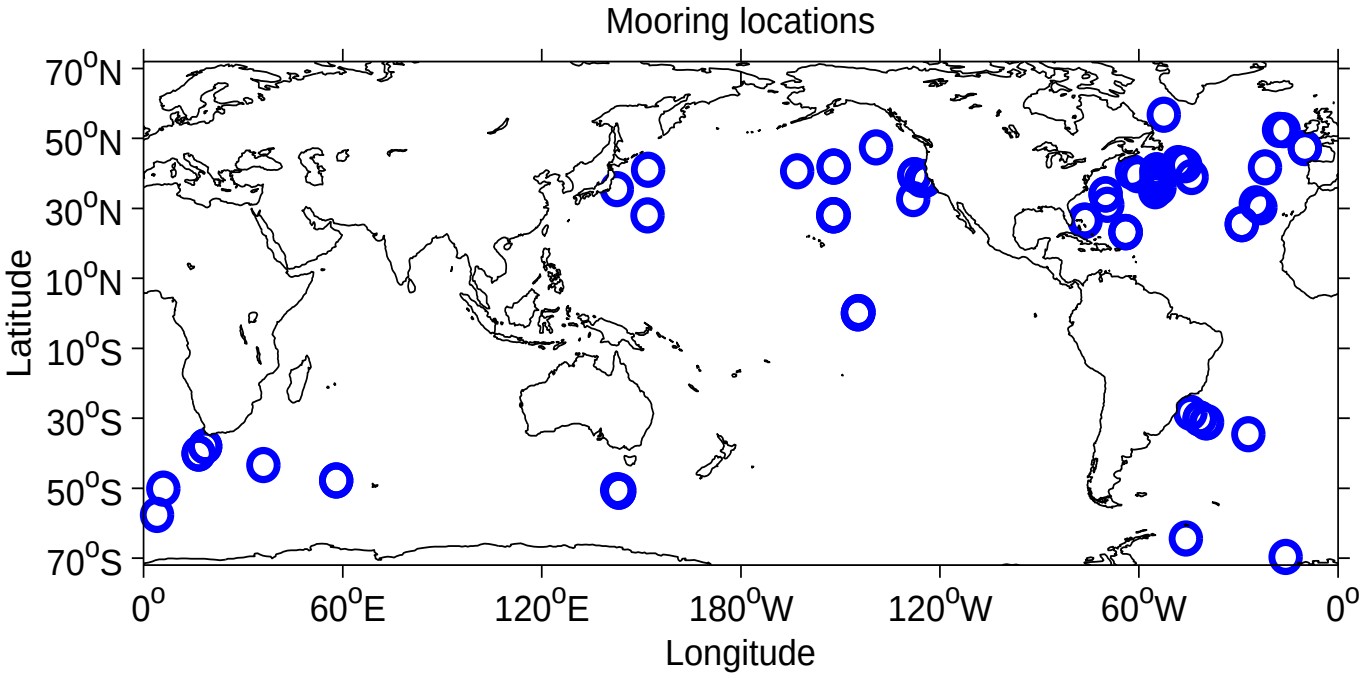
Surface intensified [Hazewinkel & Winters, 2011]



Highest bicoherences centered on M_2 Critical Latitude

Intensity falls around $\sim 3°$ [Furuichi et al. 2005]

PROJECT 2: Comparing tidal energy fluxes to observations



Mooring data

From 78 locations...

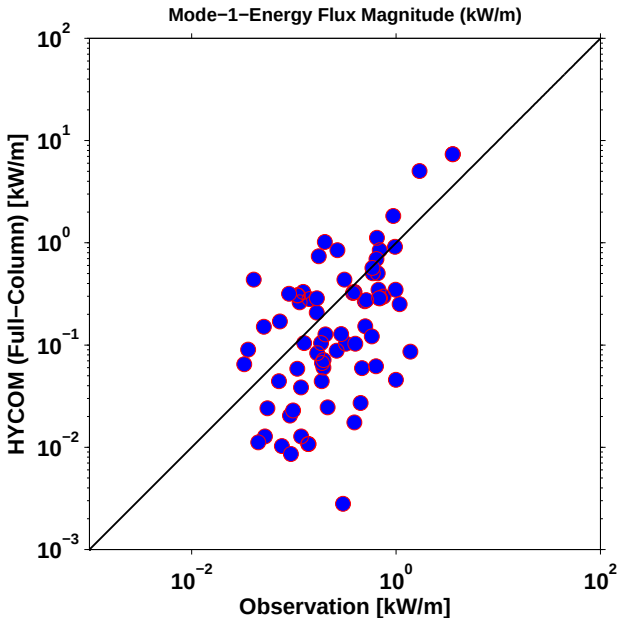
(Moored instruments sampled at few vertical locations)

Alford & Zhao (2007)

Will only show semidiurnal, mode 1 results

- Full-column HYCOM vs observed magnitude of fluxes
- Subsampled HYCOM vs observed magnitude of fluxes
- Global map of fluxes

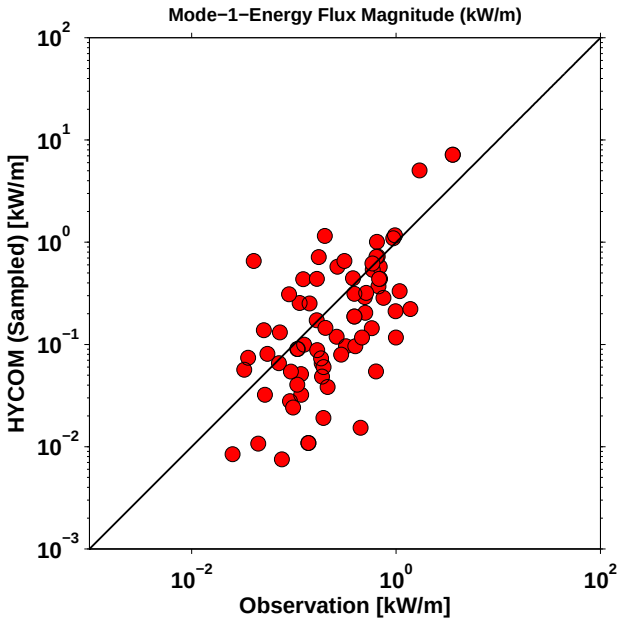
HYCOM vs Observations: Mode 1



Full-column fluxes

Correlation is good ~ 0.88, but...

HYCOM fluxes are generally weaker.

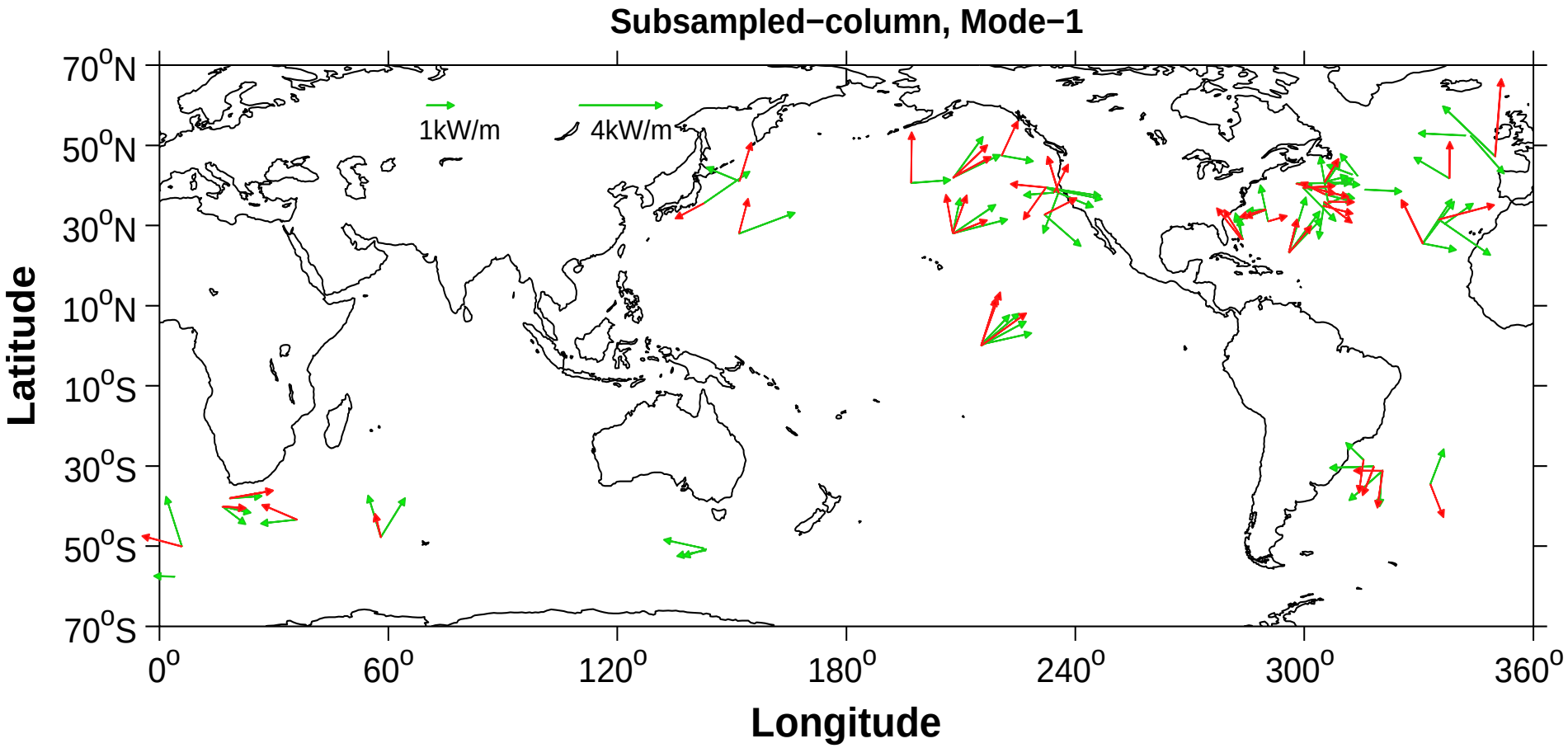


Subsampled fluxes

Correlation is good ~ 0.89, but...

HYCOM fluxes are generally weaker.

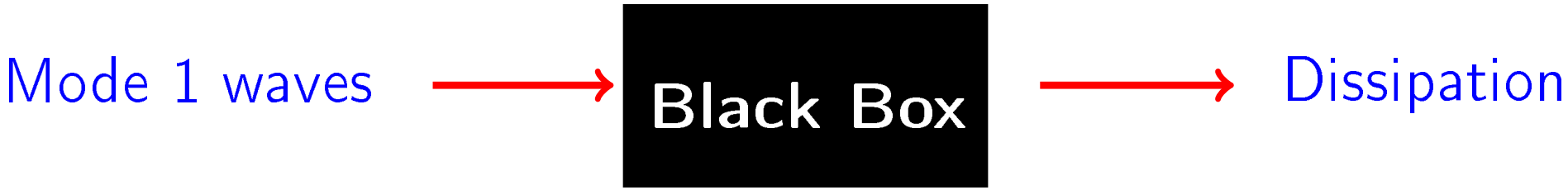
HYCOM vs Observations: Mode 1



- Averaged over all locations, HYCOM agrees to within a factor of about two with observed fluxes.
- New simulations with longer time series records,...Draft paper ready

PROJECT 3: Where are the tides dissipating?

What's the fate of mode 1 (large scale) waves that radiate away?



Hypothesis:

- cascade to turbulence at source
  (Legg & Klymak 2008; Buijsman et al. 2012)
- scatter off bottom topography (Dunphy & Lamb 2014; Kerry et al. 2014)
- wave-wave interactions (Muller et al. 1986; Eden & Olbers 2012)
- break on remote continental shelves (Nash et al. 2004; Kelly et al. 2013)

NOTE: These scenarios manifest as a drag on internal tides

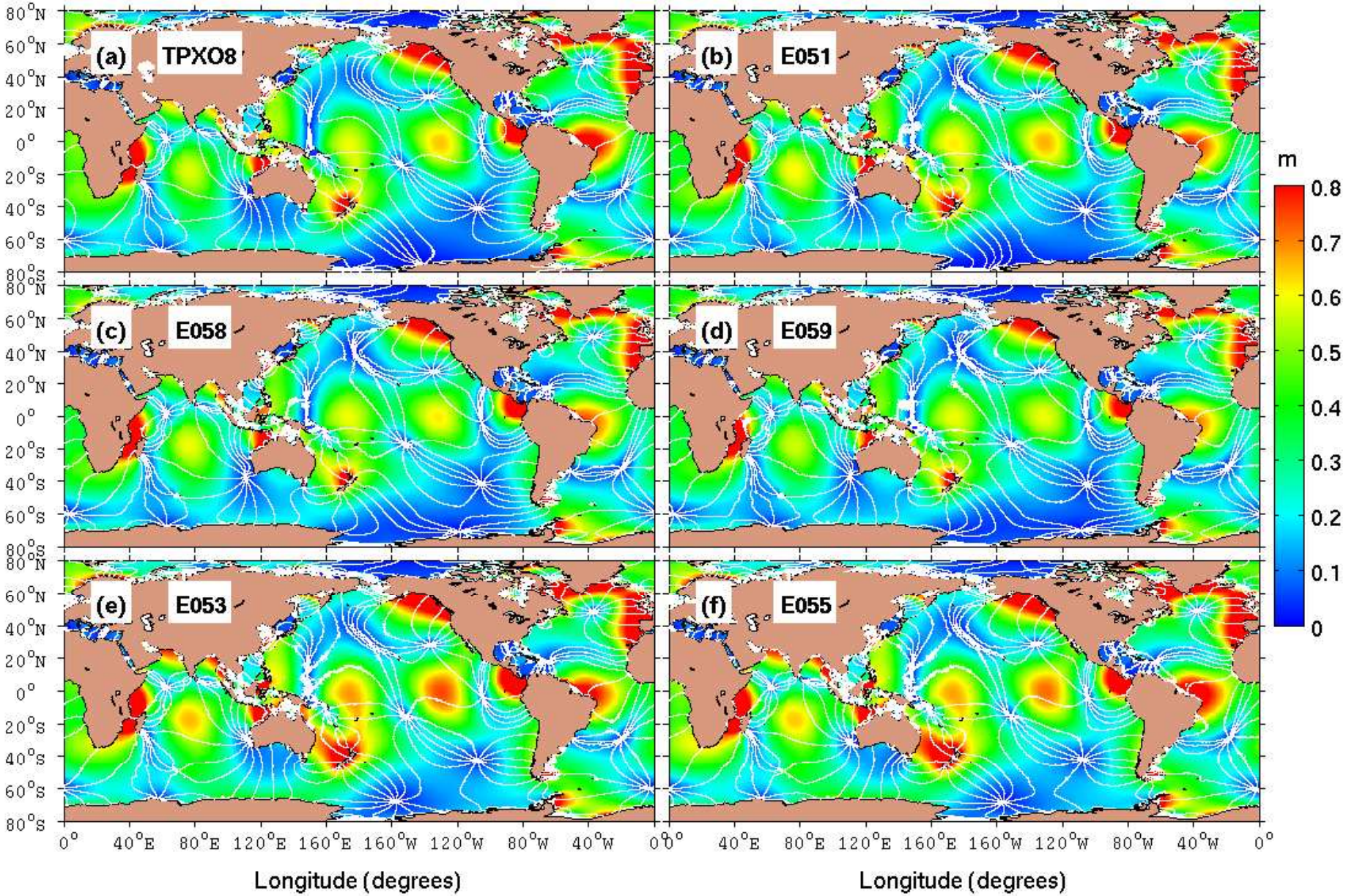
Test a couple scenarios...

Method

By comparing HYCOM tides to altimeter observations, we can determine which drag scenarios are plausible and which are not.
We will:

- apply it on the total bottom flow ("Bottom wave drag")
- apply it on only the barotropic (depth-averaged) component ("Barotropic wave drag")
- remove the wave drag
- increase the bottom drag along the continental shelves
- apply it in the upper ocean to mimic wave-wave interactions (to be done with a simpler model from GFDL-Princeton)

HYCOM barotropic tides vs TPXO8



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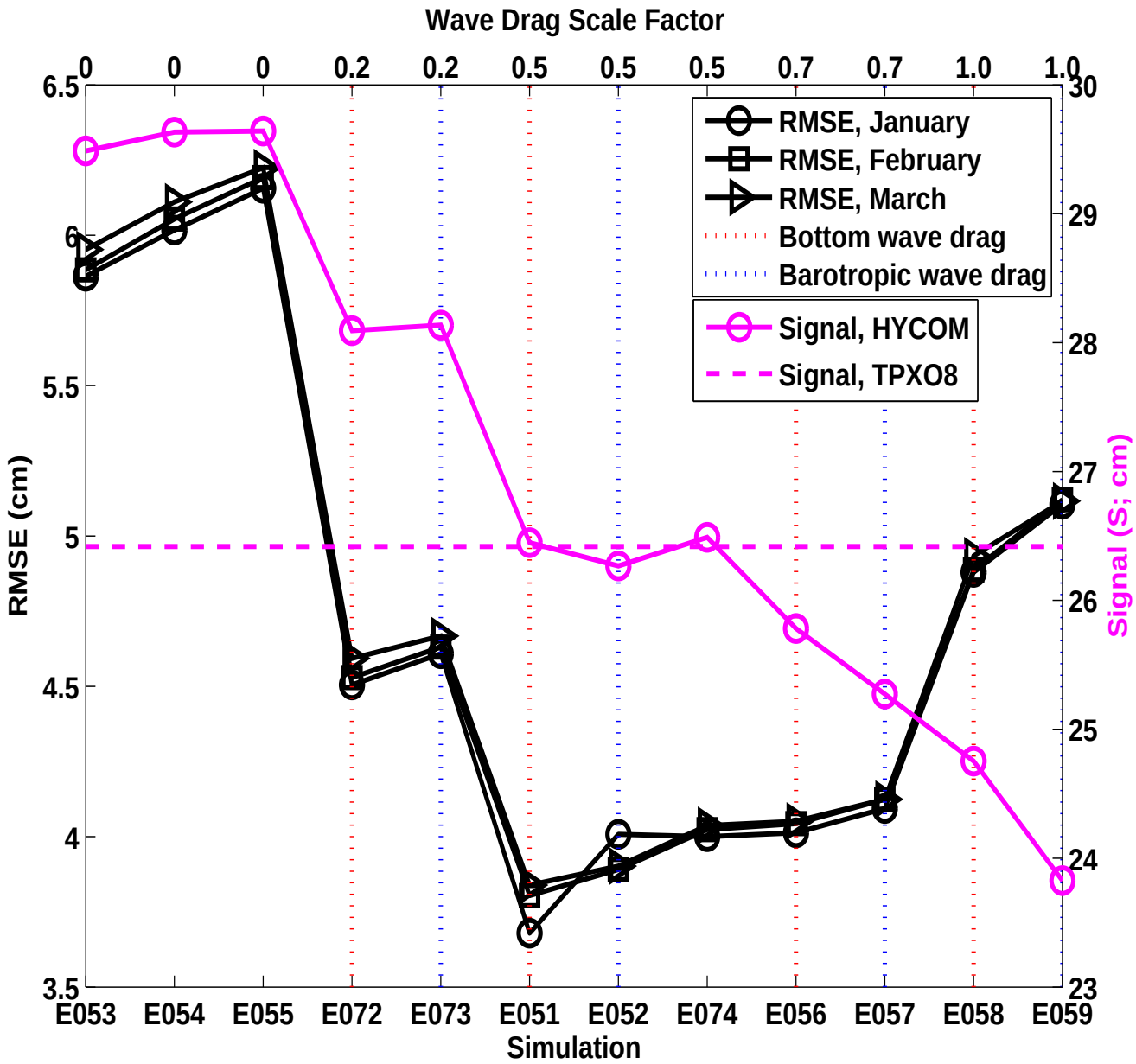
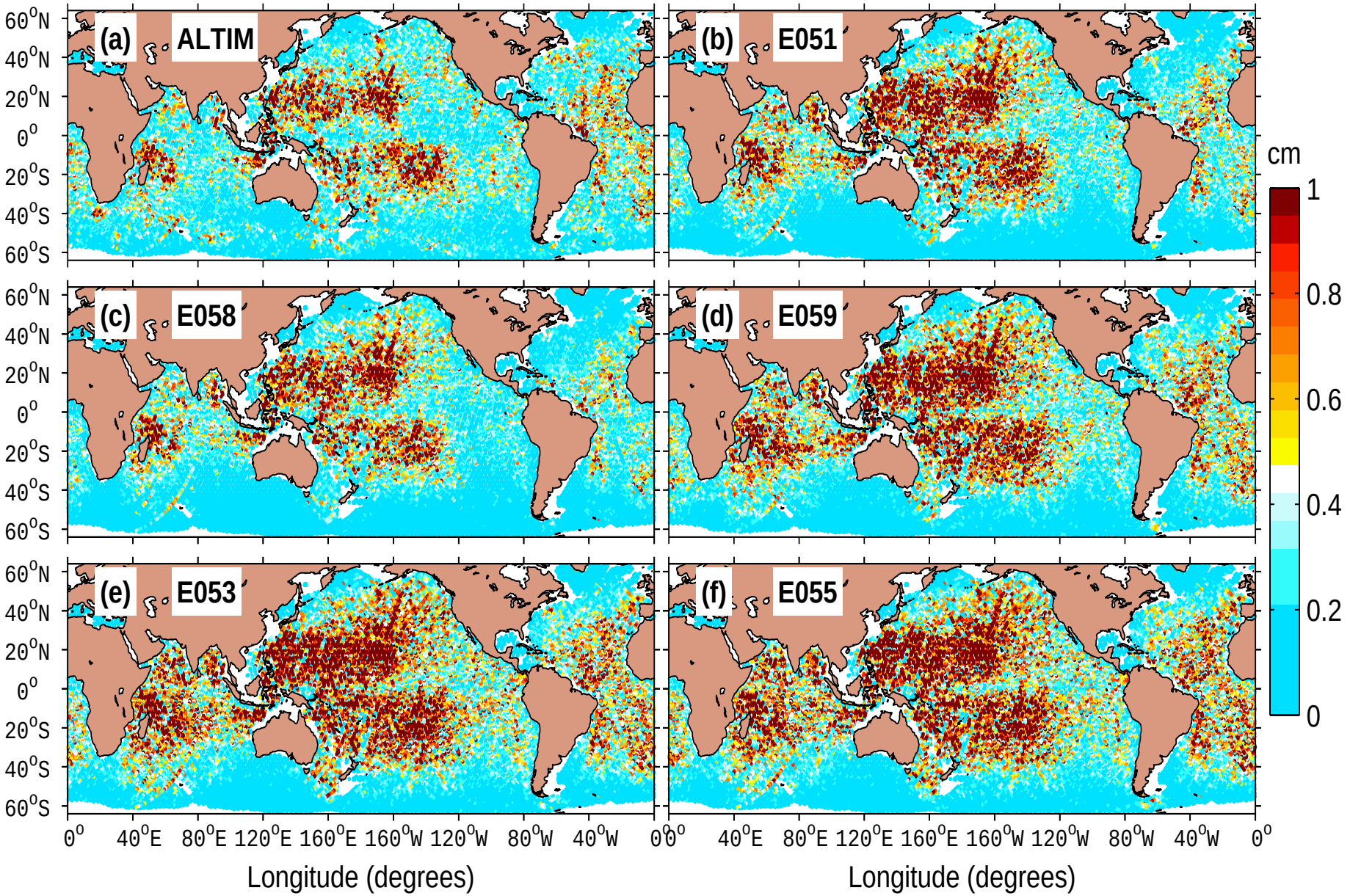


$$\text{RMSE}=\sqrt{\frac{\int\int<[\eta_m(t)-\eta_0(t)]>\mathrm{d}A}{\int\int \mathrm{d}A}}$$

$$\text{Signal}=\sqrt{\frac{\int\int A_m^2\,\mathrm{d}A}{\int\int \mathrm{d}A}}$$

- Bottom wave drag better than Barotropic wave drag
- No wave drag is worst
- Minimal monthly variance

HYCOM Internal tides vs ALTIMETER



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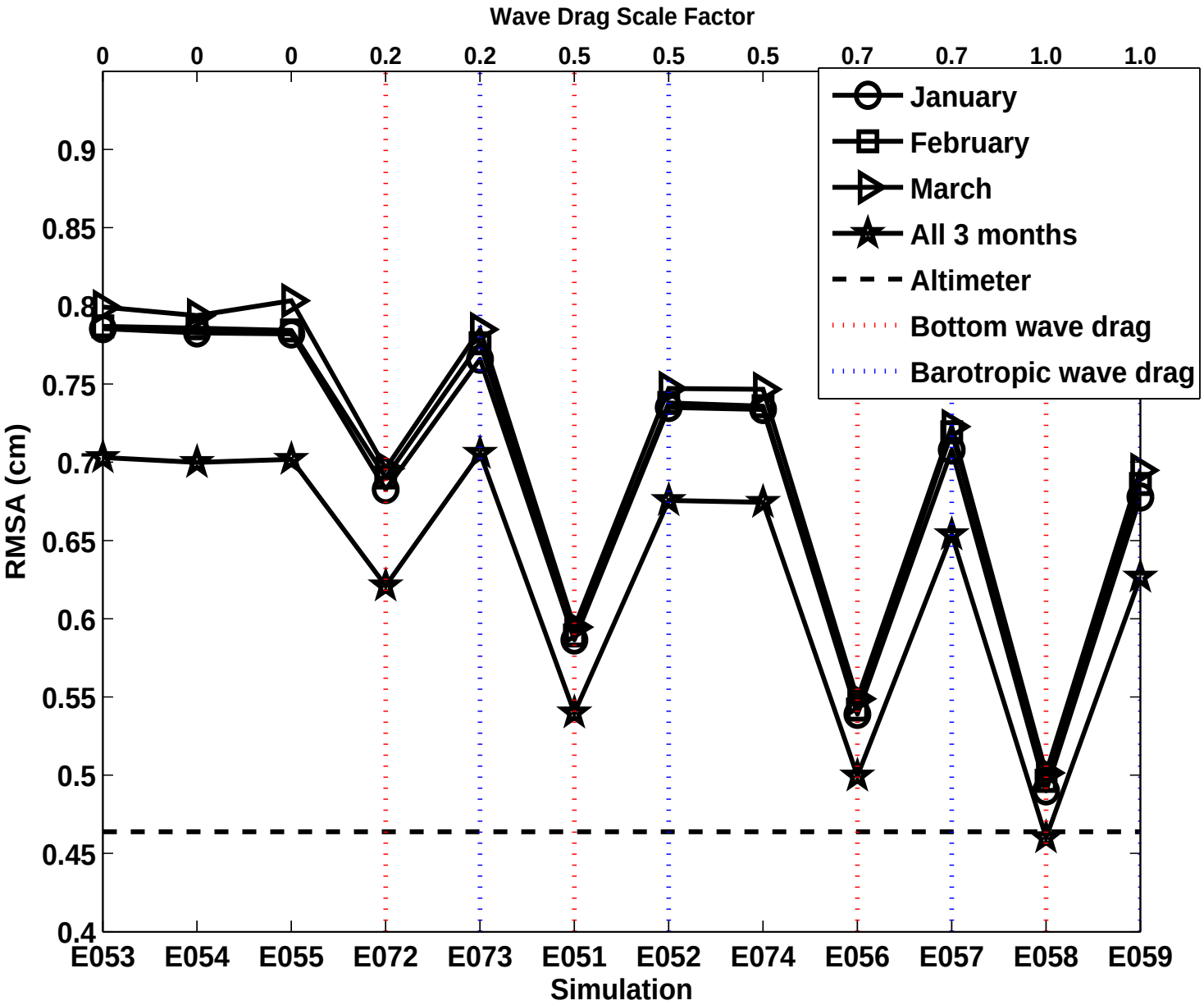
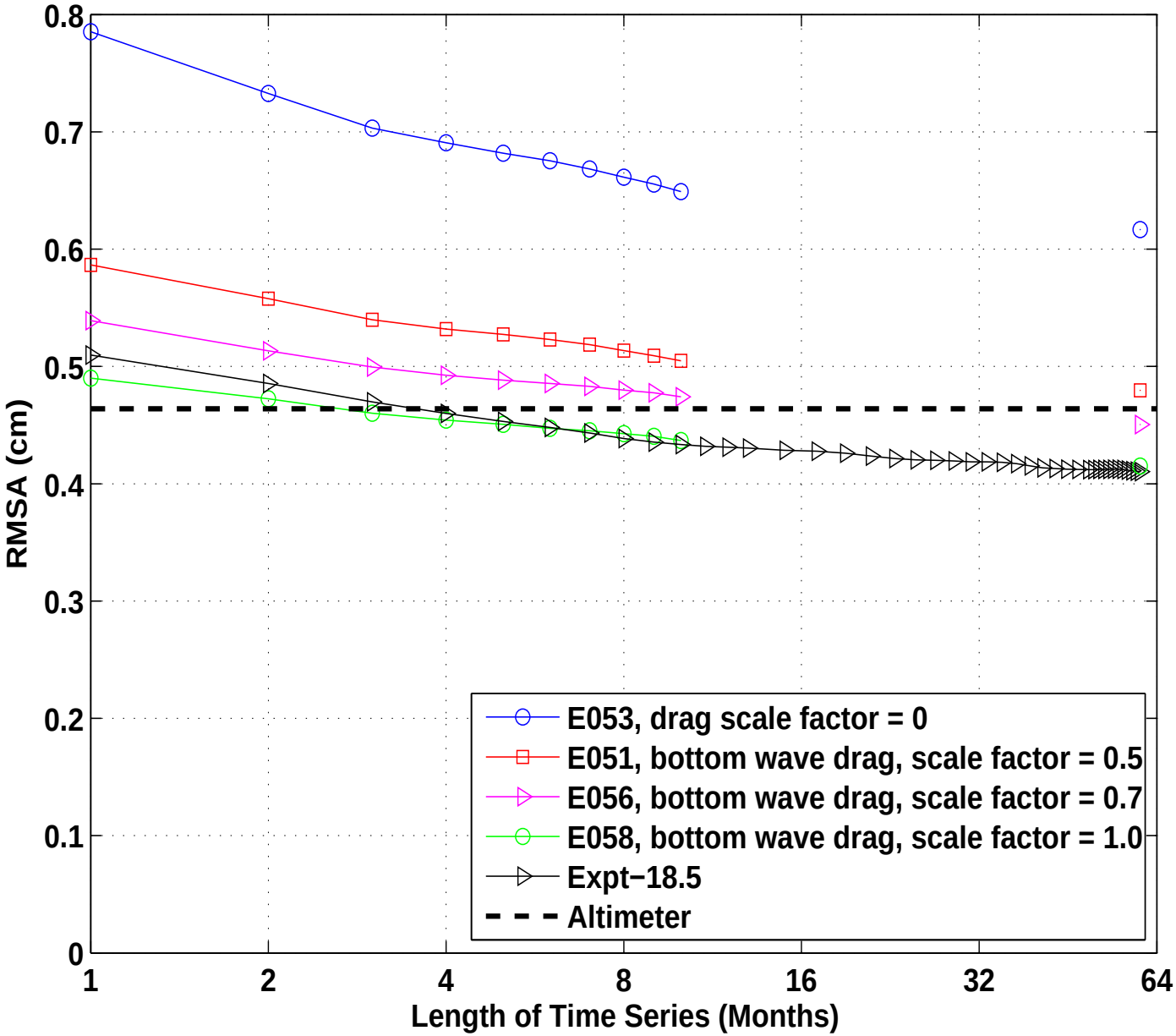


- Bottom wave drag better than Barotropic wave drag
- No wave drag is worst
- Minimal monthly variance
- 3-months analysis gives better results

HYCOM Internal tides vs ALTIMETER



Internal tide amplitudes require $\sim$ 4 years to converge!

Duration of model output plus damping strength affects comparison to altimetry.

Summary & Conclusions

Simulations were conducted in a high resolution global ocean circulation model (HYCOM) to examine the plausibility of various limiting cases of damping scenarios. We found that

- application of a damping scheme on the total bottom flow resulted in the most accurate barotropic and baroclinic tides.
- all other scenarios which do not utilize a bottom wave drag resulted in more energy barotropic and baroclinic tides that propagate too far from their generation sources.
- the duration of model output as well as the damping strength affects comparison to altimeter. – internal tides require about $3-4$ years to converge!

We plan to investigate other plausible scenarios in the future. Eg, upper ocean wave-wave interactions.

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