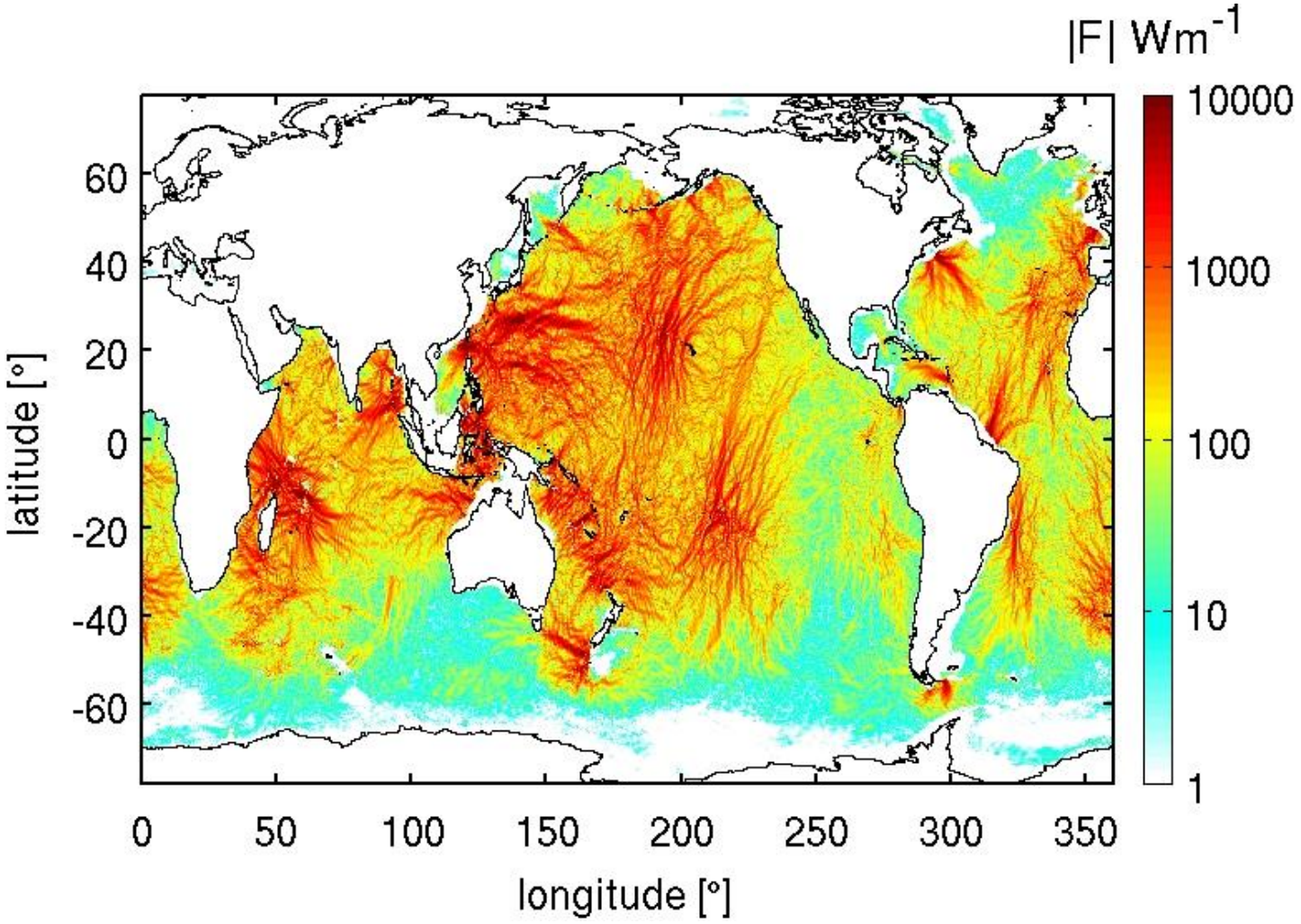
Impact of Internal Wave Drag on the Semidiurnal Energy Balance



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Questions

1. How does wave drag affect the semidiurnal
    a. surface tides?
    b. internal tides?
2. What is the fate of the internal tides?

Contents

1. 3D HYCOM set up
2. Linear wave drag
3. Energetics
4. Fate of the internal tides

3D HYCOM

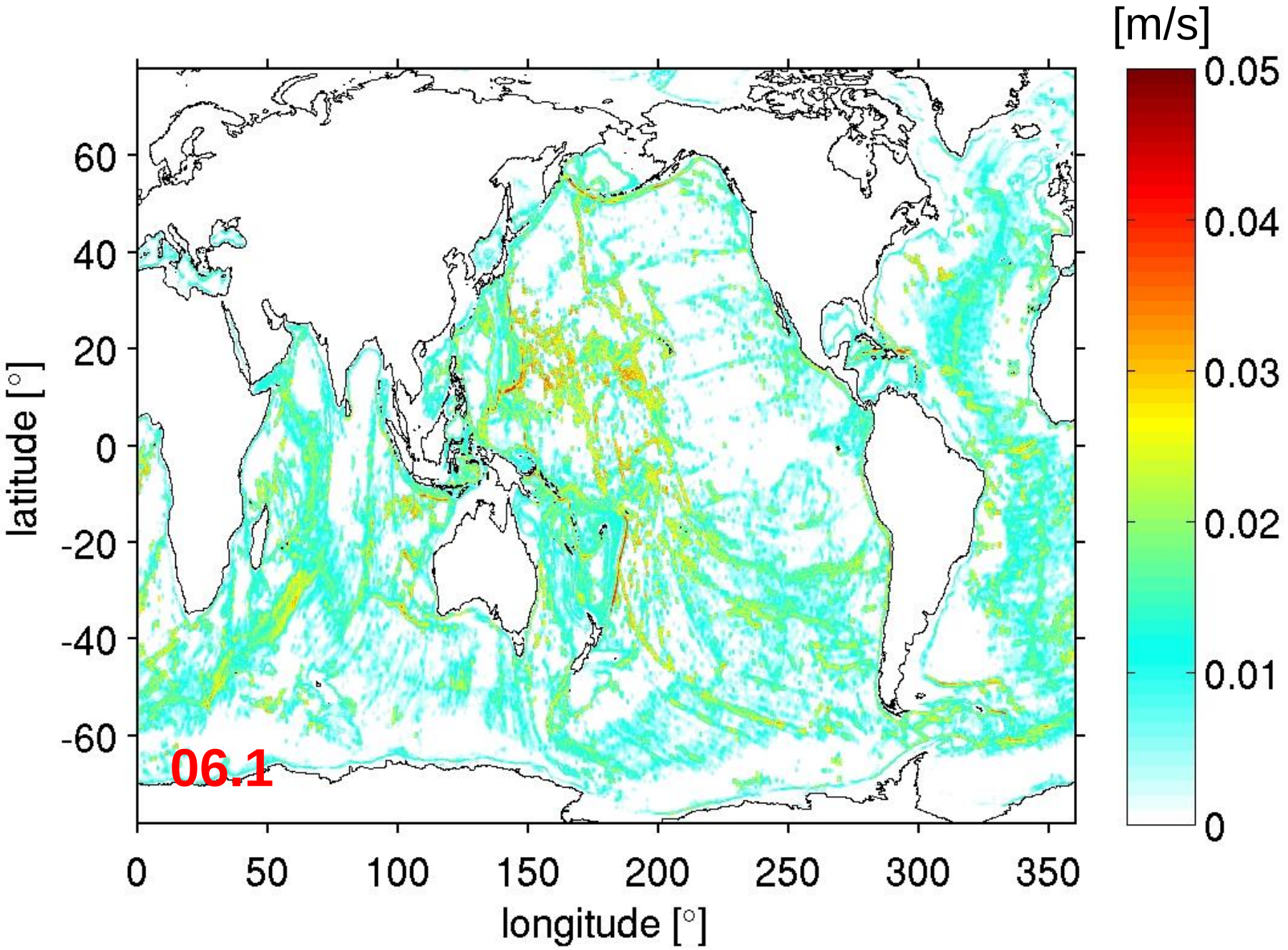
- Analyze one month of HYCOM experiments Expt18.5 and ***NEW*** **Expt06.1**
- 2/25 degree horizontal resolution and 32 **(41)** layers
- Forcing in forward model: surface fluxes and 8 **(5)** tidal constituents, **(spatially varying scalar)** SAL
- Internal wave drag scheme applied to the barotropic *and baroclinic* tidal flow in the bottom 500 m: $\frac{\partial \mathbf{u}}{\partial t} = \cdots - \chi \frac{\mathbb{C}\mathbf{u}}{H}$,

  wave drag $\mathbb{C}$ $[\mathrm{m/s}]$, χ = tuning parameter (Buijsman et al, 2015)
  - Expt18.5: drag by Garner (2005); $\chi = \mathbf{1}$
  - **Expt06.1: drag by Jayne and St Laurent (2001); $\chi = \mathbf{0.5}$**

Internal Wave Drag

- Only interfacial ("**low-mode**") waves are generated in 3D HYCOM
- Internal wave beams due to "**high-mode**" waves are not generated or resolved
- **Hypothesis**: 3D models need internal wave drag to account for energy conversion from surface tide to unresolved high-mode internal tide

Internal Wave Drag



3D Semidiurnal Energetics

- Barotropic balance (time-mean and depth and globally-integrated)

$$P = C + D_{w0} + D_{b0} + \mathcal{R}_0$$

input | con-version | wave drag | bottom drag | residual

- Baroclinic balance (time-mean and depth-integrated)

$$C = \nabla \cdot \mathbf{F} + D_l$$

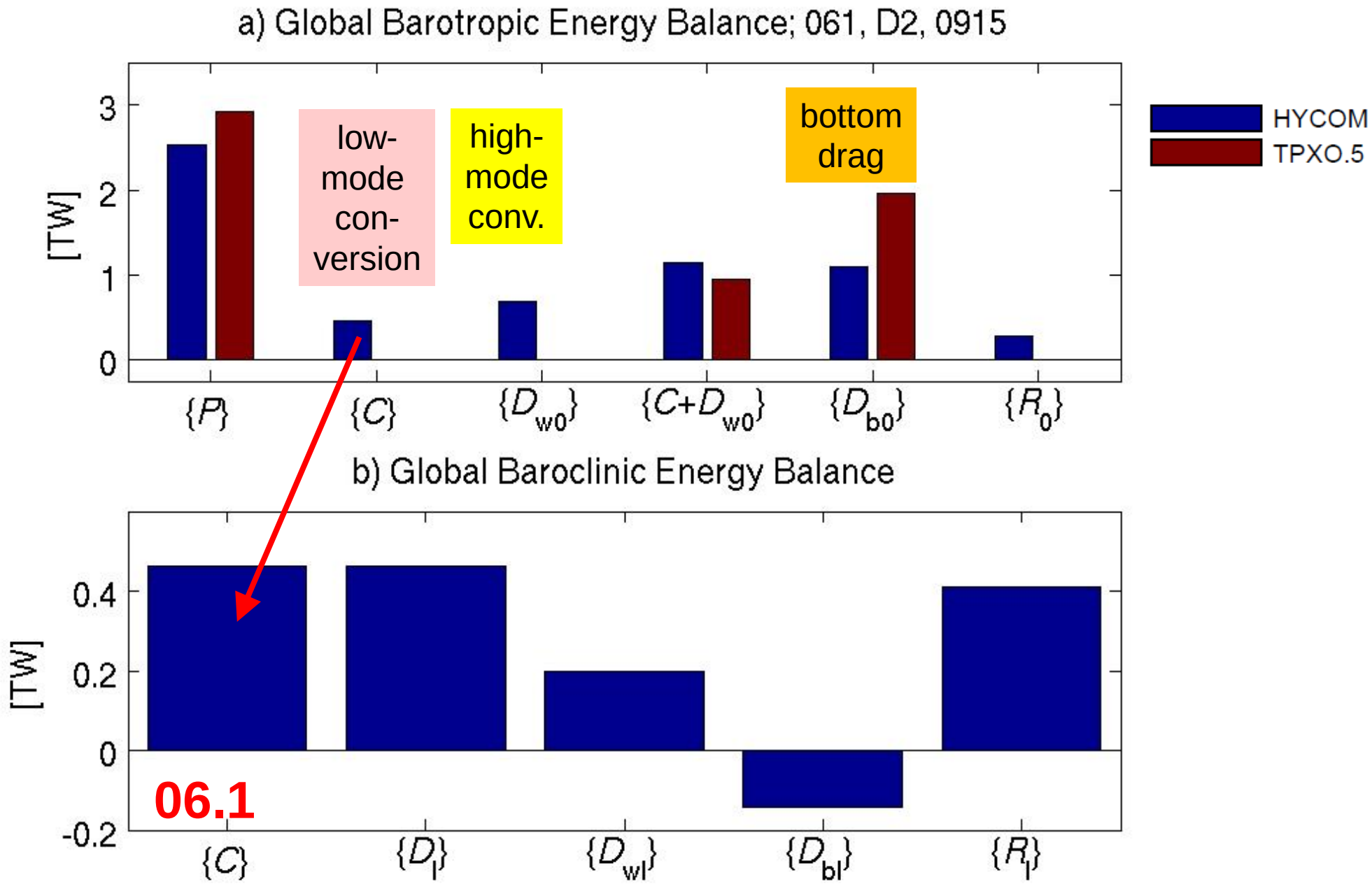
flux div. | low-mode dissipation

$$D_l = D_{wl} + D_{wb} + \mathcal{R}_l$$

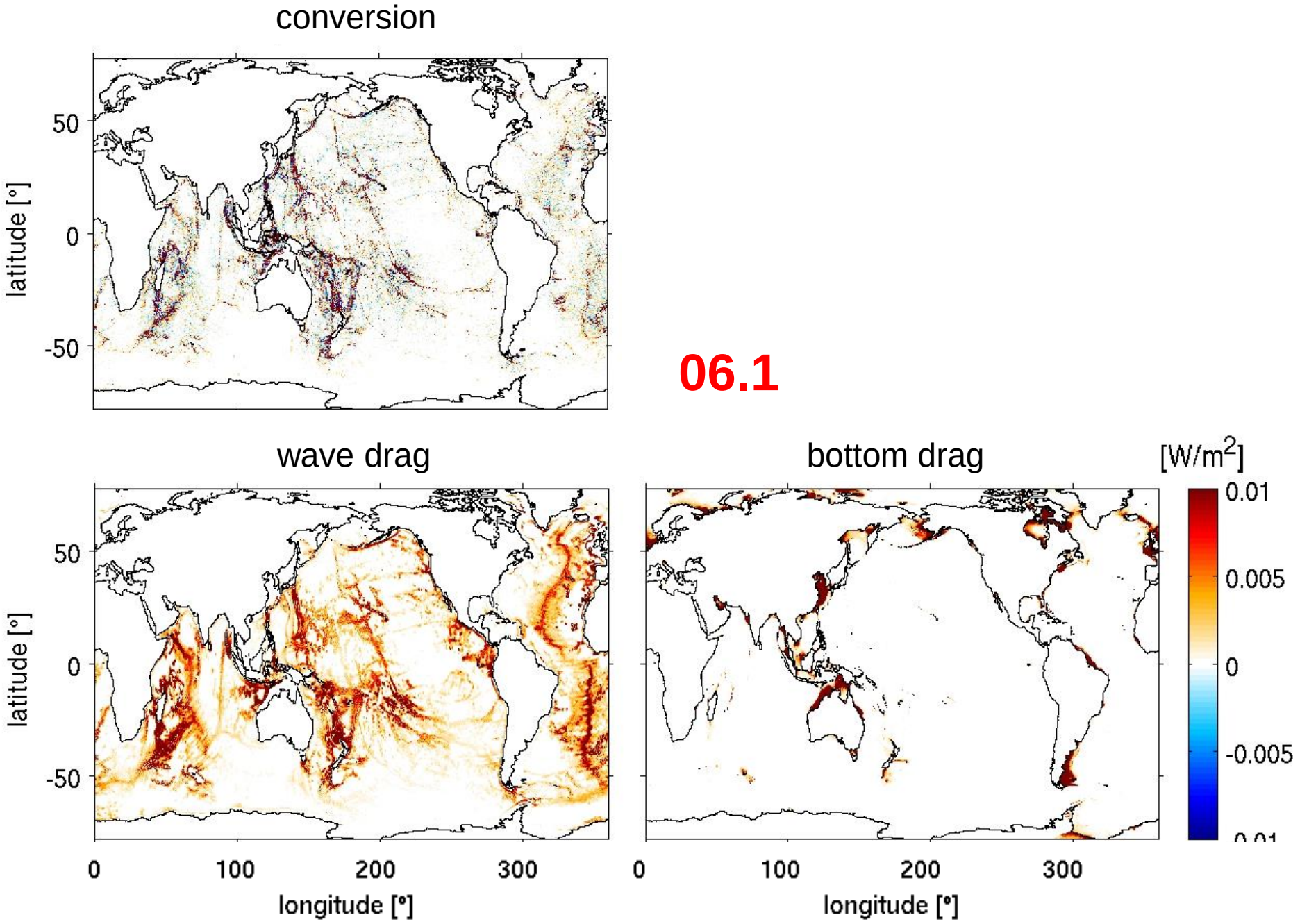
wave drag | bottom drag | residual = viscous dissipation

- 30-day long, 1-hourly time series of 3D fields are bandpassed to extract the semidiurnal tides

Global Energy Balance



Barotropic Energy Terms



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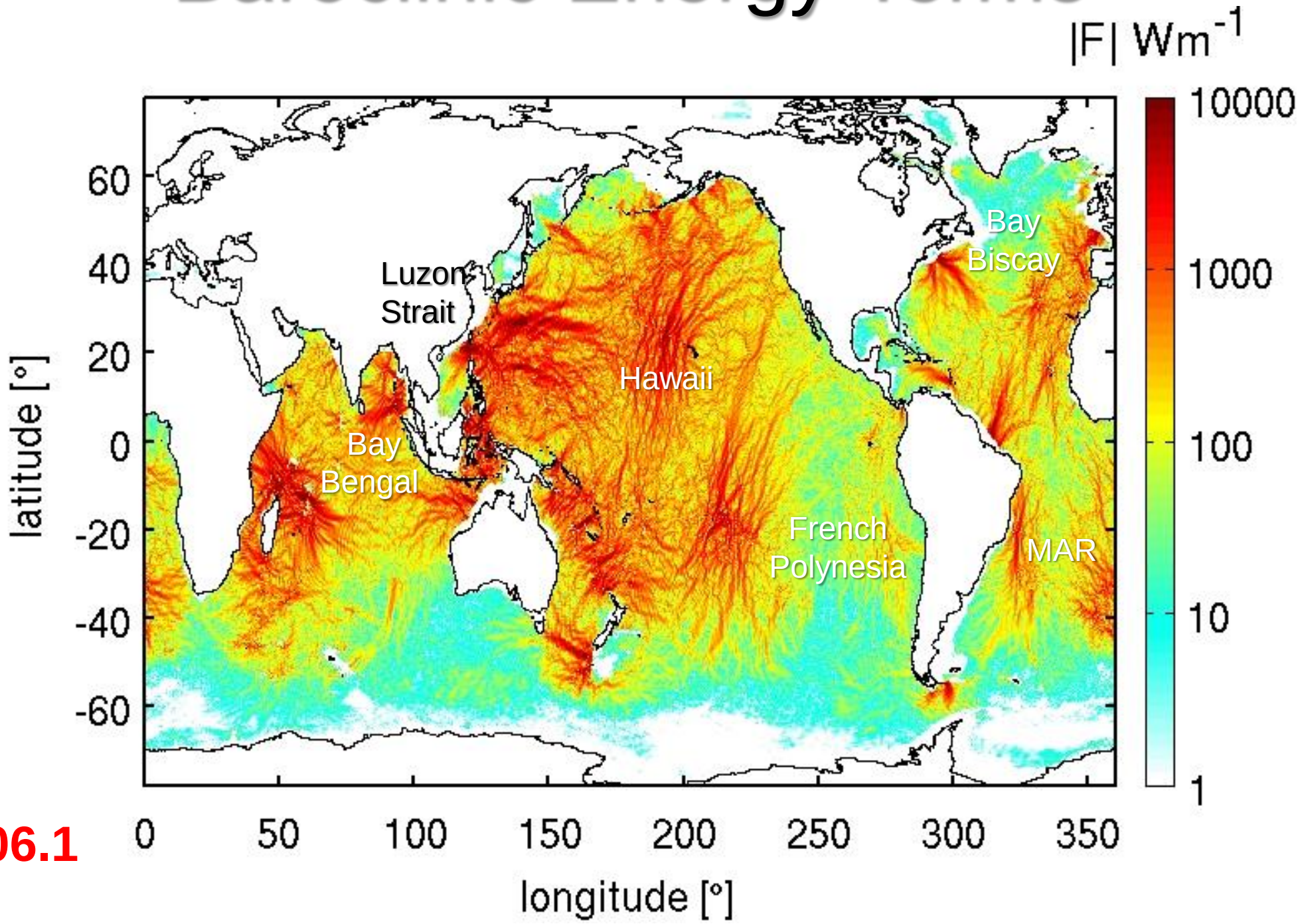
Baroclinic Energy Terms



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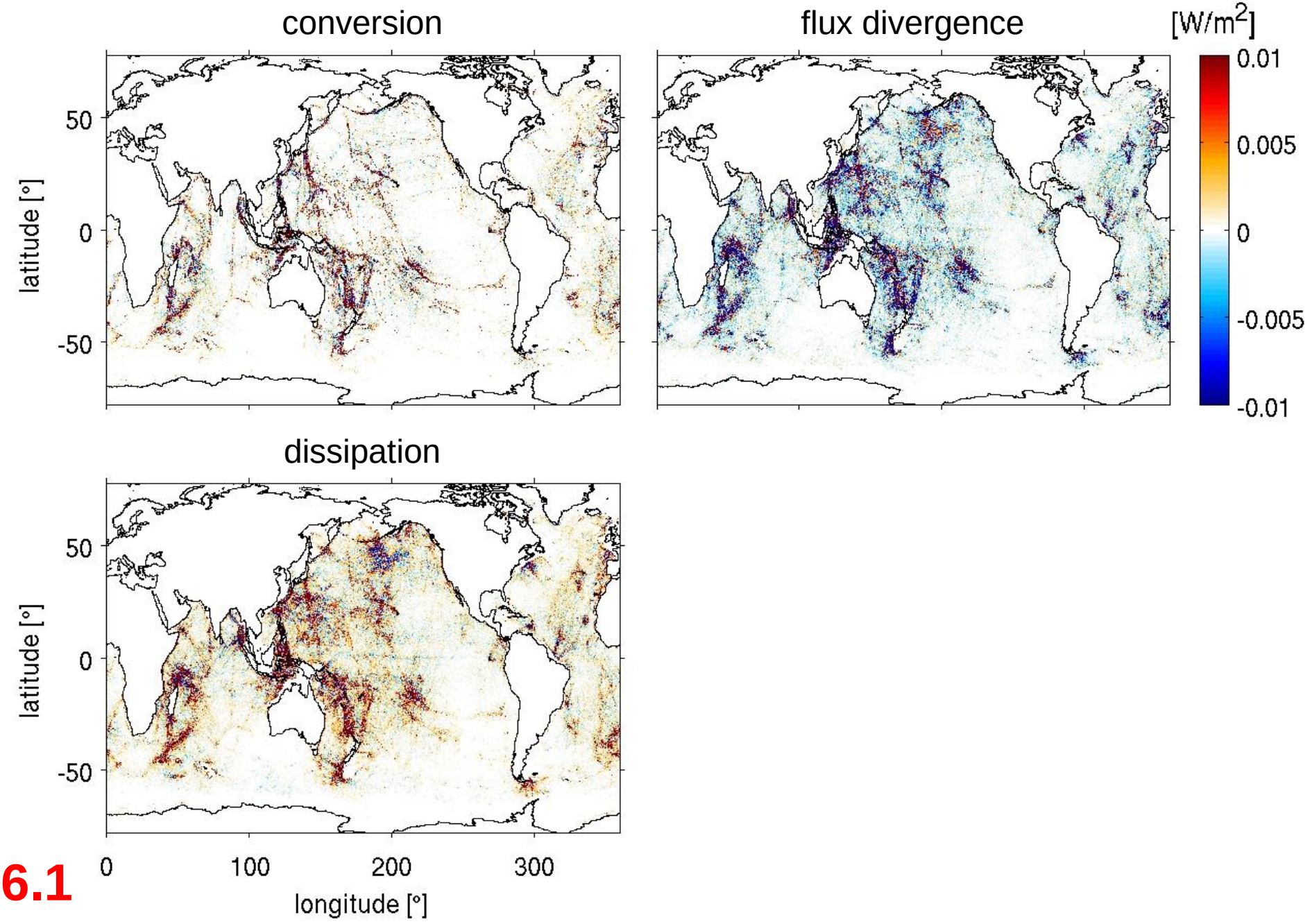
Baroclinic Energy Terms



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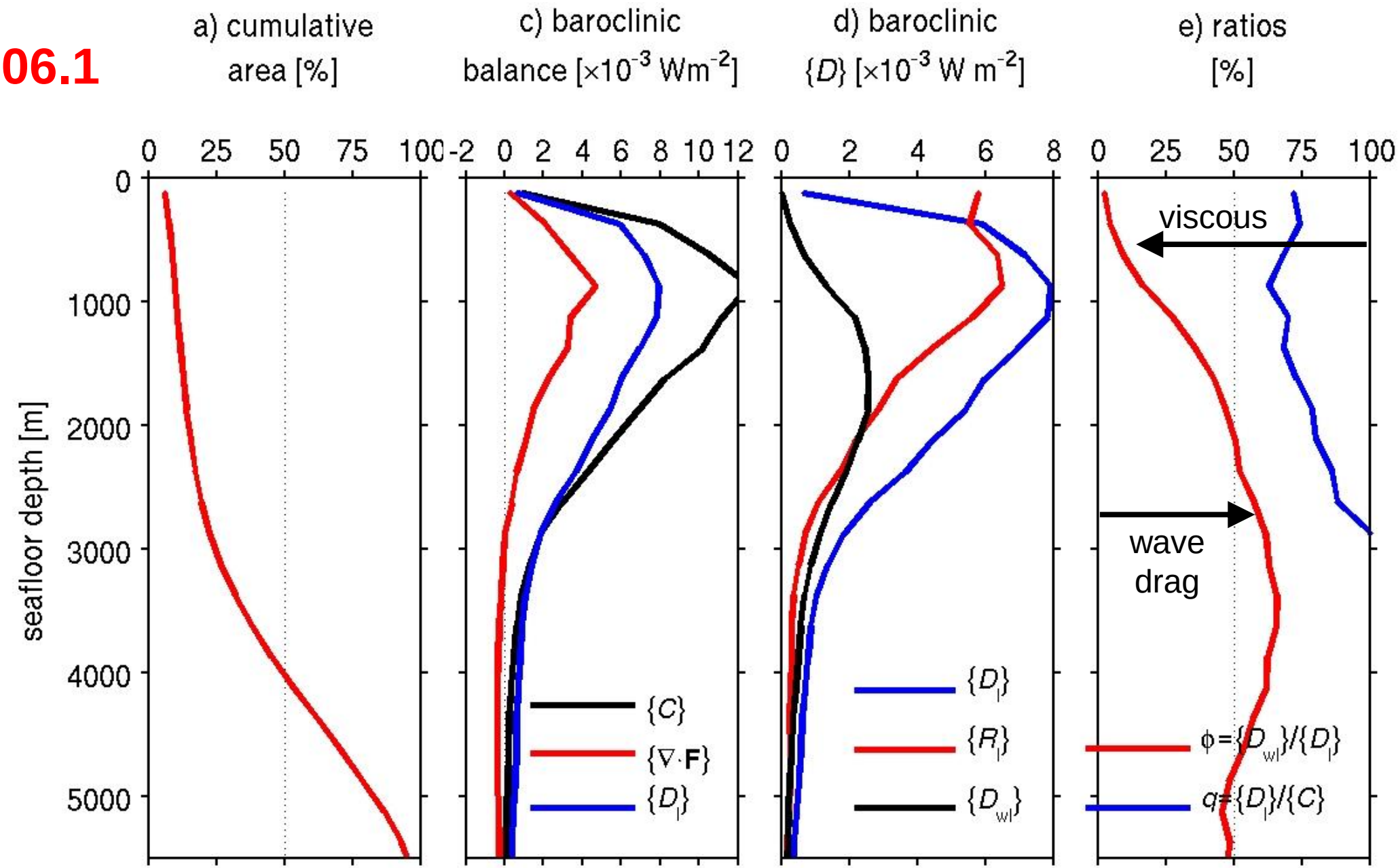
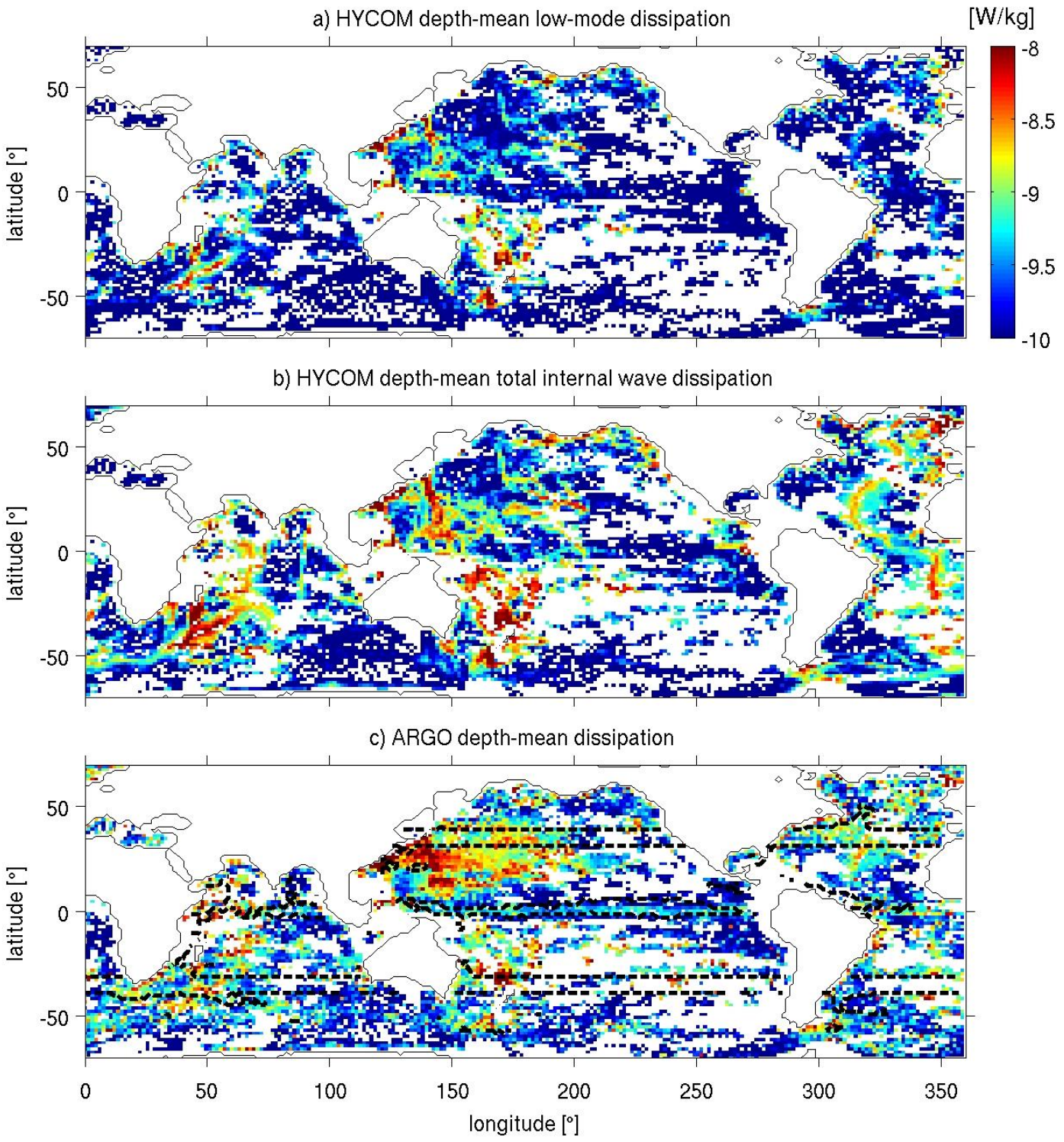
Baroclinic Energy Terms

06.1



Comparison With Argo Rates

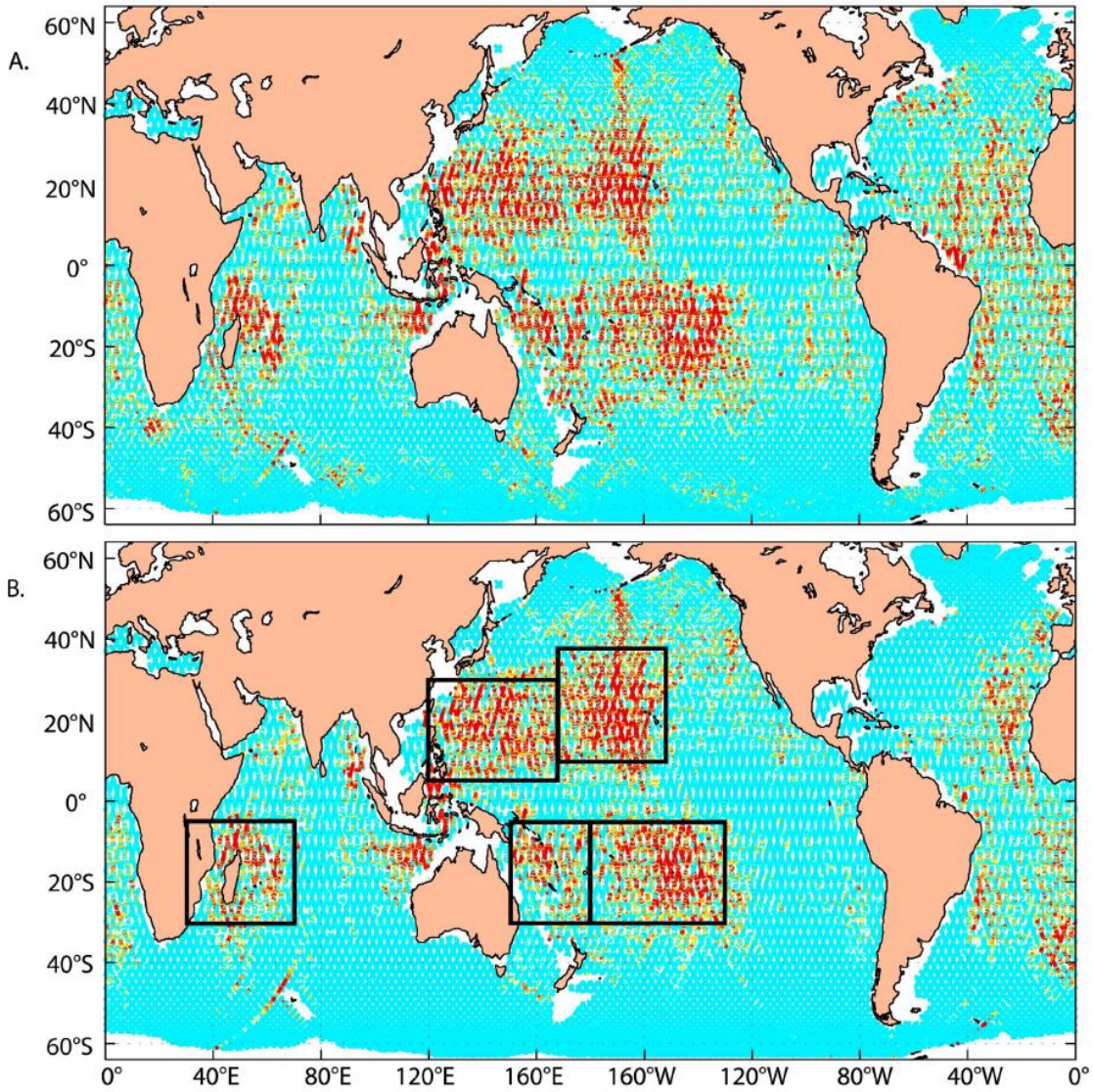


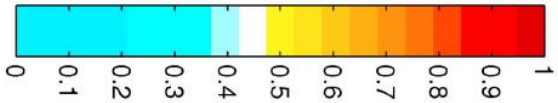
06.1

Comparison with Altimetry

altimetry-derived
internal M2 tide
sea surface heights

HYCOM
Expt18.5

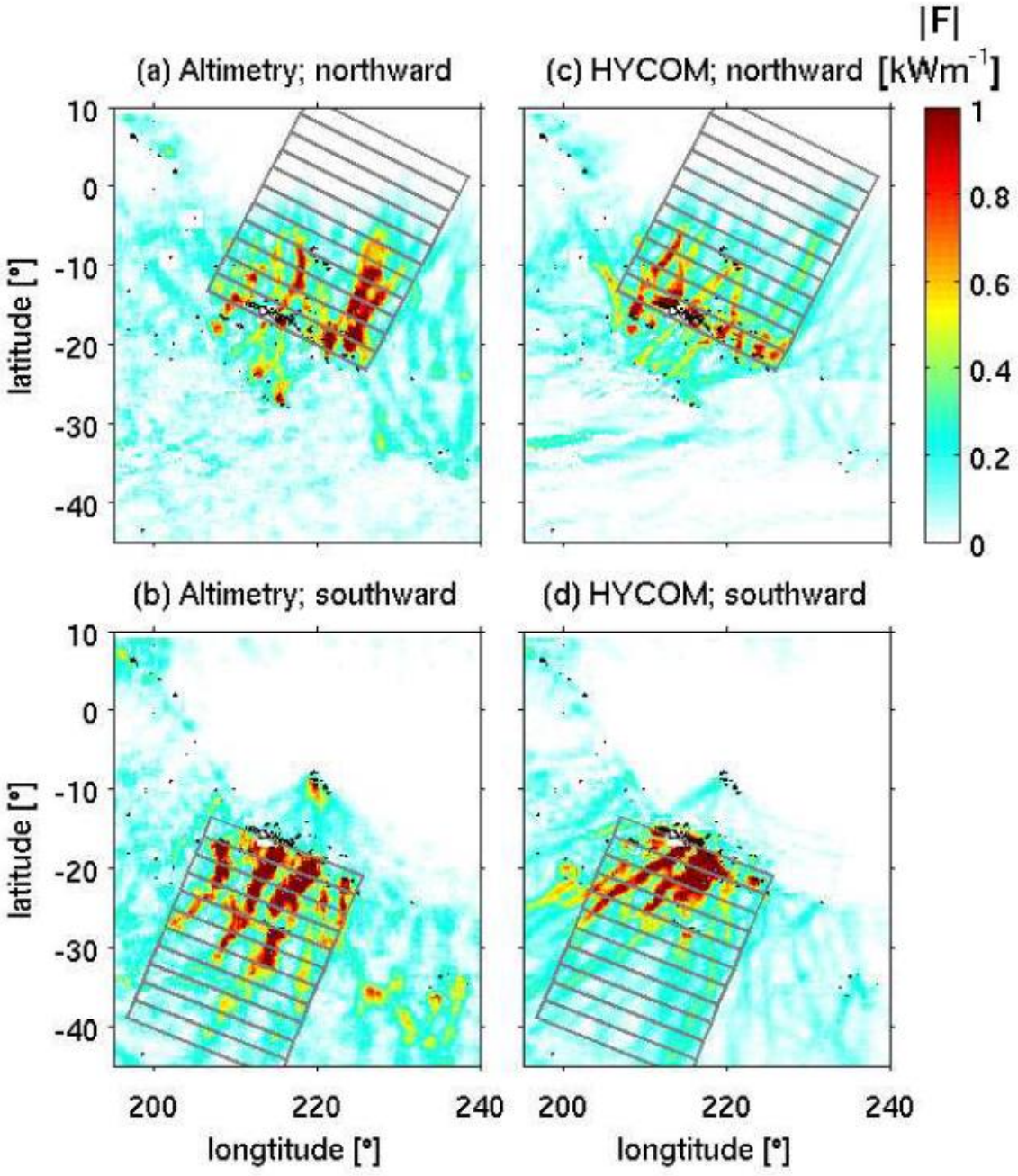




Surface amplitude [cm]

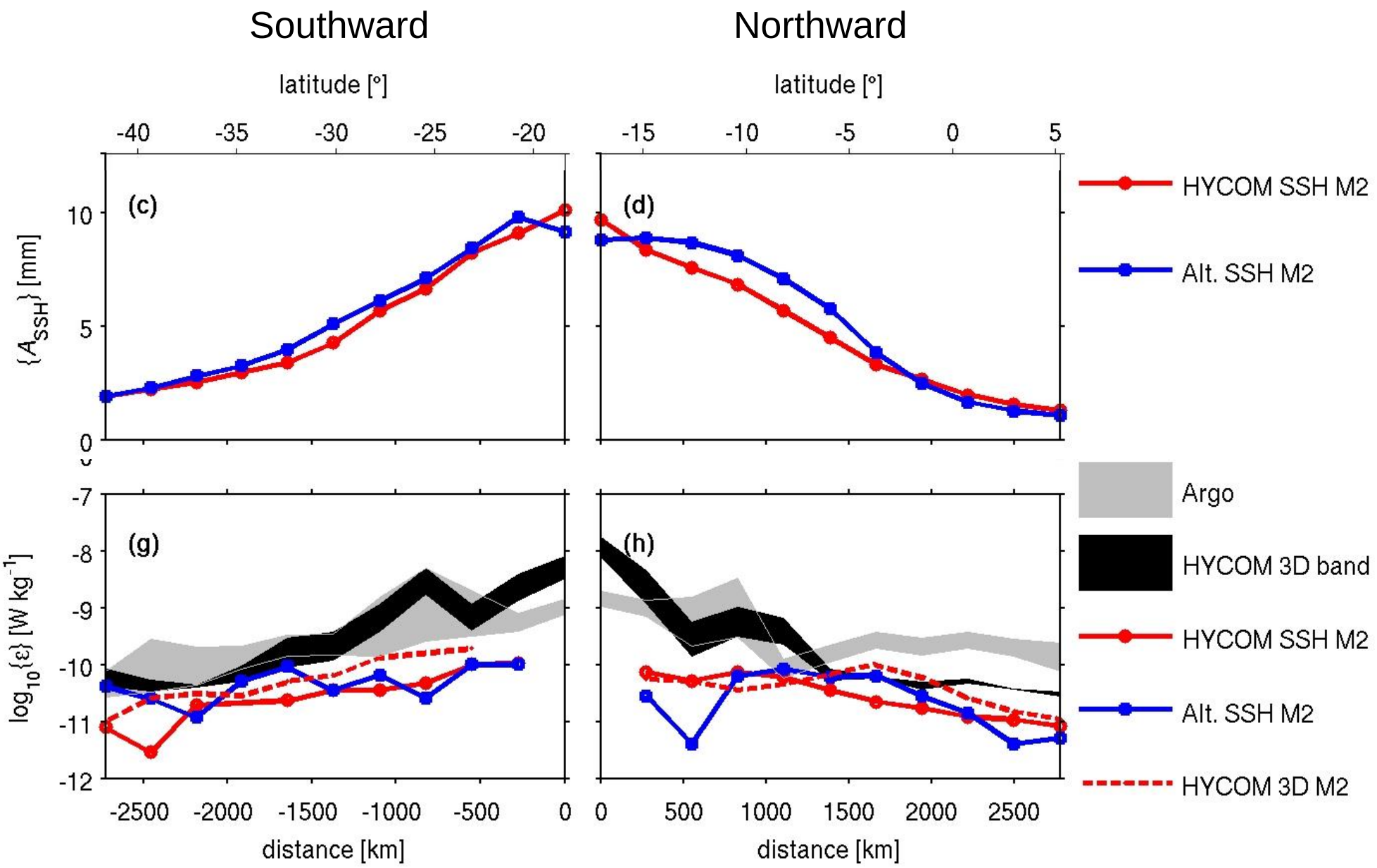
Shriver et al. (2012)

Comparison with Altimetry

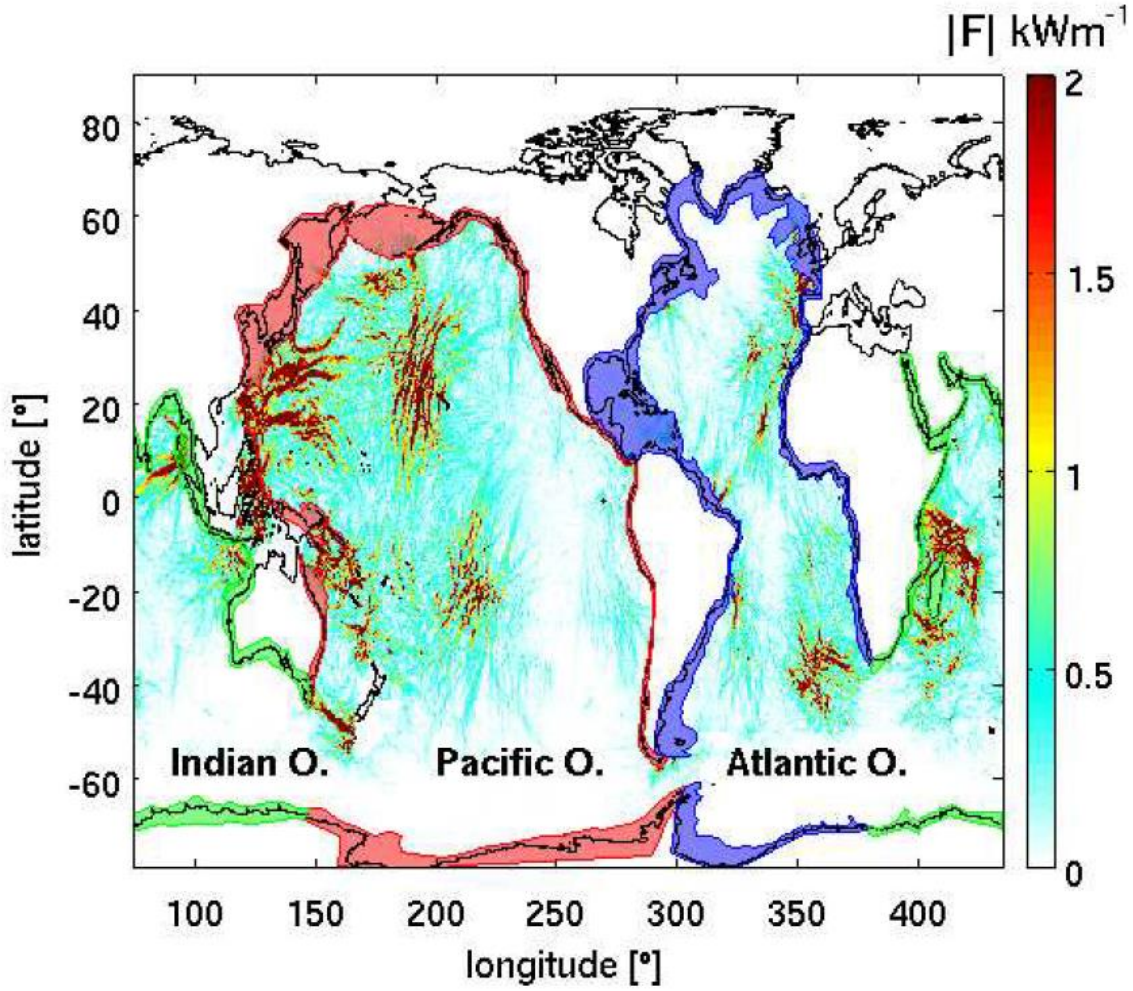


- Extract internal tide SSH amplitudes with plane wave fitting technique (Zhao et al., 2010)
- Compare decay along a ray at French Polynesian Islands

Comparison with Altimetry



Are the Shelves Energy Sinks?



Ocean	$\{F_{\text{plane}}\}/\{C\}$ [%]
Pacific	8.8
Atlantic	19.2
Indian	15.3
total	12.4

- Waterhouse et al (2014) estimates *F*/*C*=31%

Conclusions

- Expt06.1 is better than Expt18.5
- In 06.1 wave drag strength is halved, but deep water drag is increased relative to 18.5
- Barotropic deep/*shallow* water dissipation is larger/*smaller* than in TPXO5
- In 06.1 wave drag near steep topography is smaller and flux divergence larger than in 18.5
- Wave drag causes >50% of the deep water IT decay
- Decay agrees with Argo rates and altimetry => need drag!
- ~12% of the low-mode internal waves generated in deep water propagate onto the continental shelves in Expt18.5

The Future ….

- Higher resolution: 41 layers and 4 km
- Use a drag scheme that accounts for the high-mode dissipation only (Falahat and Nycander, 2014)

Linear vs Nonlinear Split

$$(u, v) = (u_{\mathrm{l}} + u_0, v_{\mathrm{l}} + v_0)$$

$$D_{\mathrm{b}} = \langle \rho_0 C_{\mathrm{D}} |u_{\mathrm{a}}| (u_{\mathrm{a}} u_{\mathrm{a}} + v_{\mathrm{a}} v_{\mathrm{a}}) \rangle \qquad D_{\mathrm{w}} = \langle \rho_0 \mathbb{C} (u_{\mathrm{a}} u_{\mathrm{a}} + v_{\mathrm{a}} v_{\mathrm{a}}) \rangle$$

Linear Split

$$D_{\mathrm{b0}} = \langle \rho_0 C_{\mathrm{D}} |u_{\mathrm{a}}| (u_{\mathrm{a}} u_0 + v_{\mathrm{a}} v_0) \rangle \qquad D_{\mathrm{w0}} = \langle \rho_0 \mathbb{C} (u_{\mathrm{a}} u_0 + v_{\mathrm{a}} v_0) \rangle$$

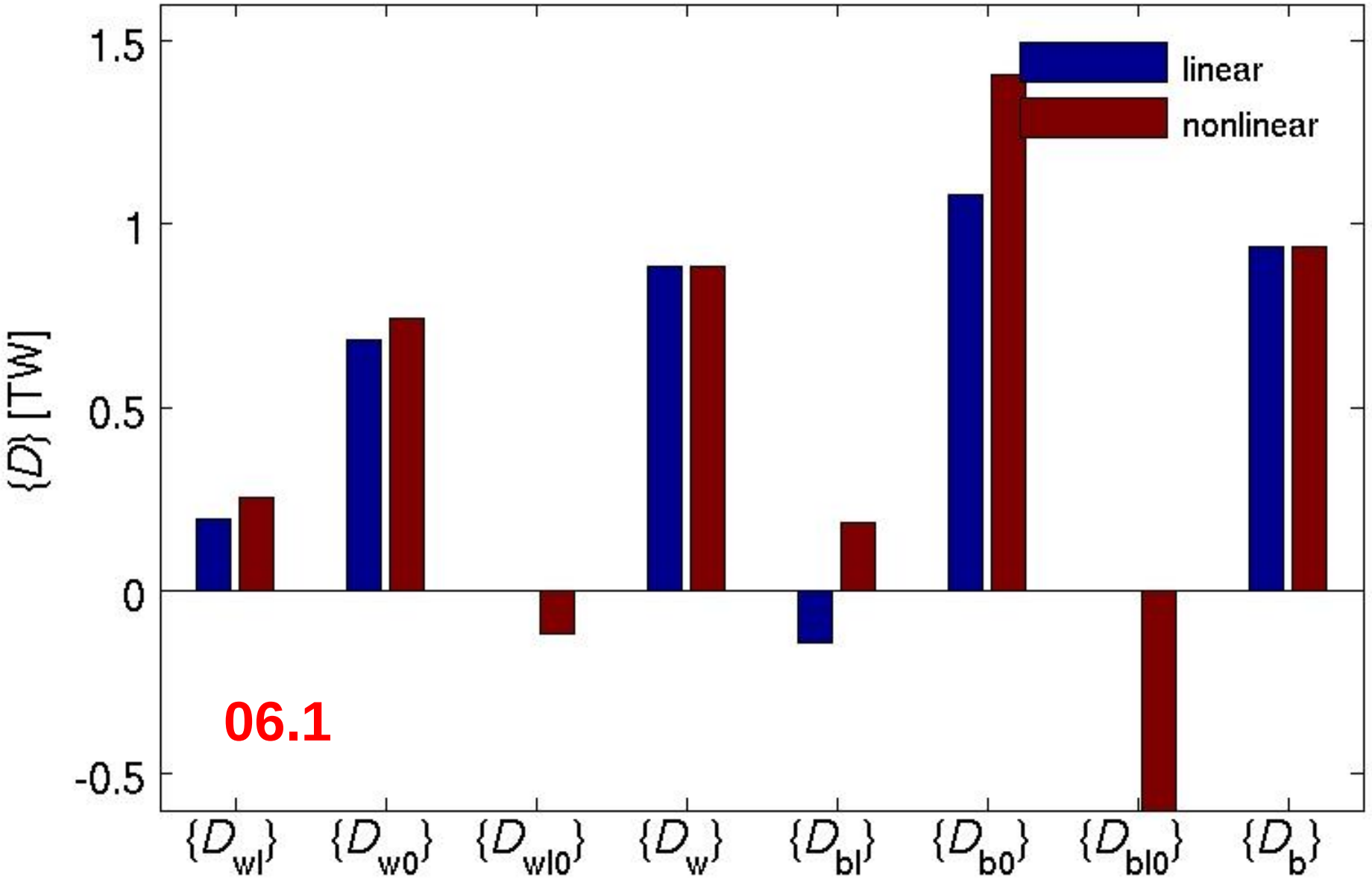
$$D_{\mathrm{bl}} = \langle \rho_0 C_{\mathrm{D}} |u_{\mathrm{a}}| (u_{\mathrm{a}} u_{\mathrm{la}} + v_{\mathrm{a}} v_{\mathrm{la}}) \rangle \qquad D_{\mathrm{wl}} = \langle \rho_0 \mathbb{C} (u_{\mathrm{a}} u_{\mathrm{la}} + v_{\mathrm{a}} v_{\mathrm{la}}) \rangle$$

Non-linear Split

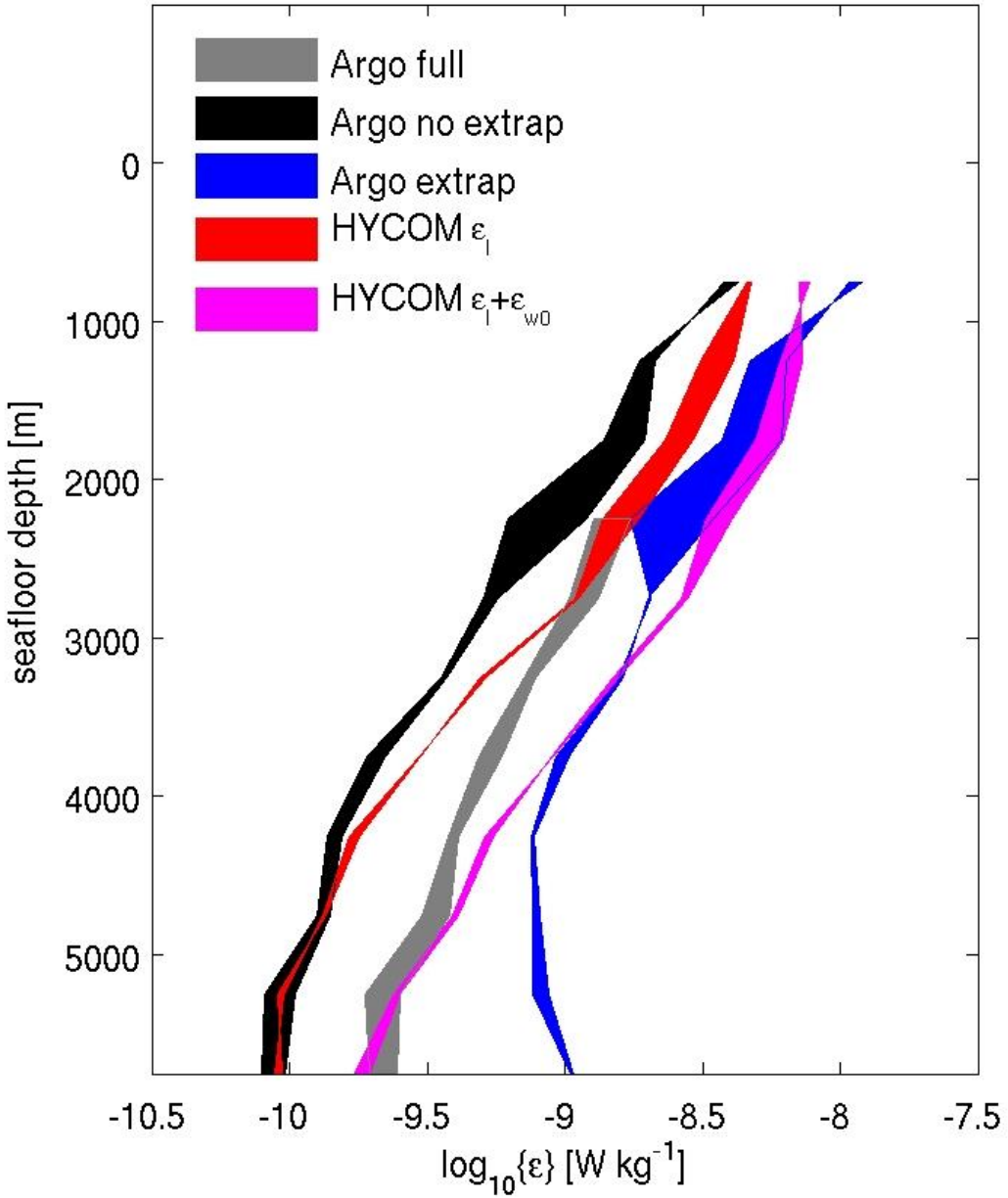
$$D_{\mathrm{b}} = \langle \rho_0 C_{\mathrm{D}} |u_{\mathrm{a}}| (u_{\mathrm{la}} u_{\mathrm{la}} + v_{\mathrm{la}} v_{\mathrm{la}} + u_0 u_0 + v_0 v_0 + 2 u_0 u_{\mathrm{la}} + 2 v_0 v_{\mathrm{la}}) \rangle$$

$$D_{\mathrm{w}} = \langle \rho_0 \mathbb{C} (u_{\mathrm{la}} u_{\mathrm{la}} + v_{\mathrm{la}} v_{\mathrm{la}} + u_0 u_0 + v_0 v_0 + 2 u_0 u_{\mathrm{la}} + 2 v_0 v_{\mathrm{la}}) \rangle .$$

Linear vs Nonlinear Split



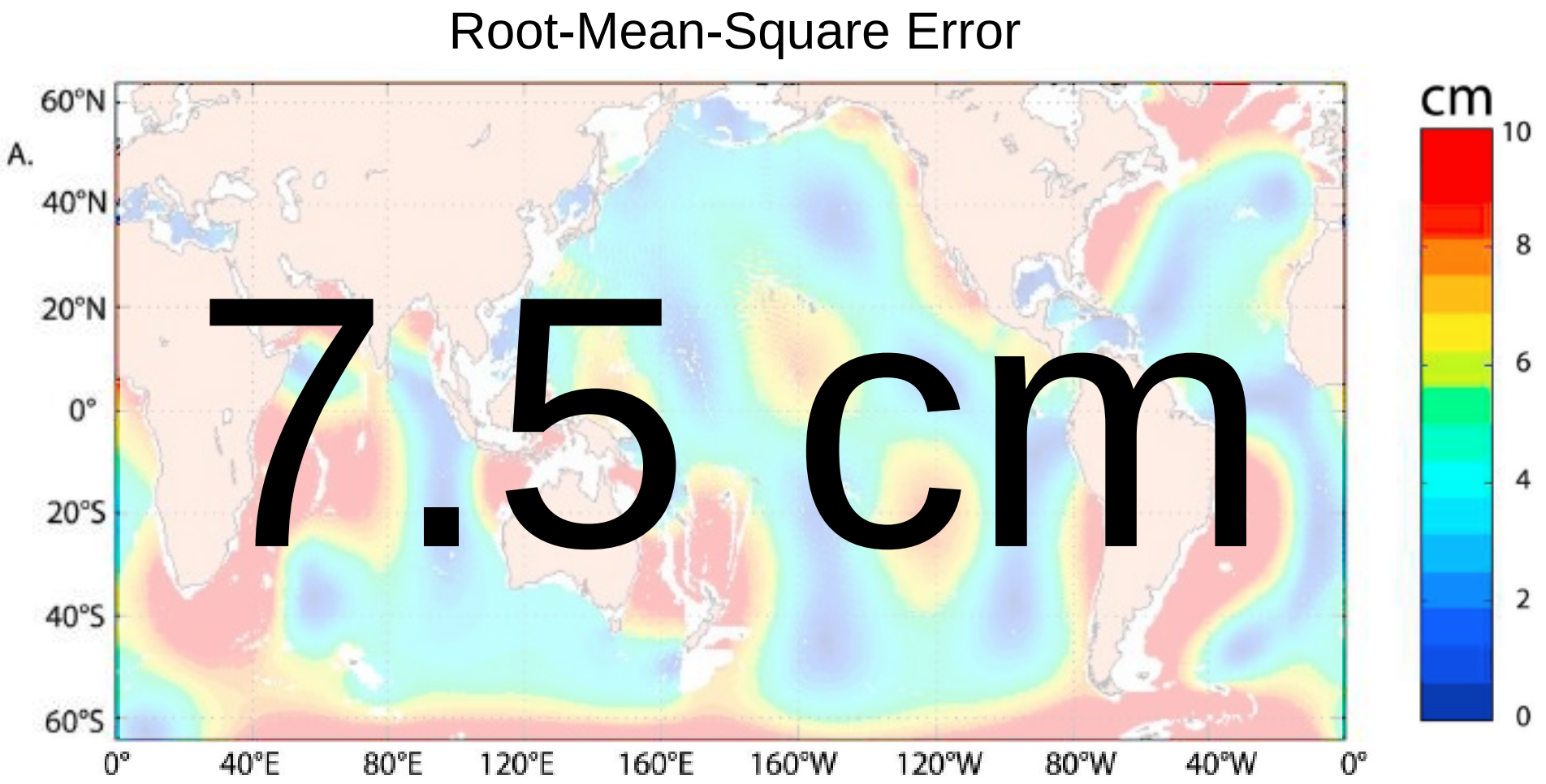
Comparison With Argo Rates



06.1

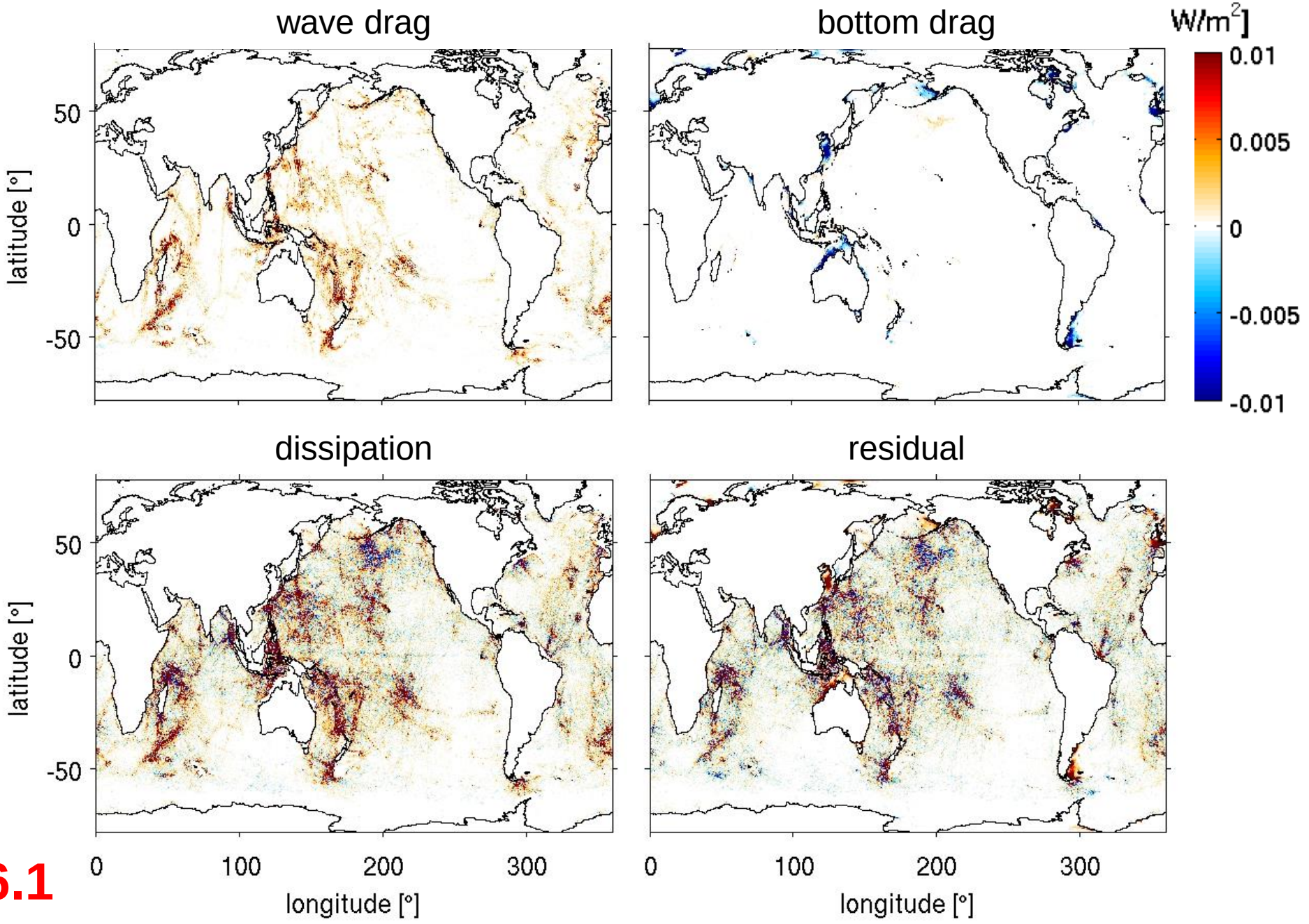
Whalen et al (2015)

Surface M_2 Tide Predictions



Shriver et al. (2012)

Baroclinic Energy Terms

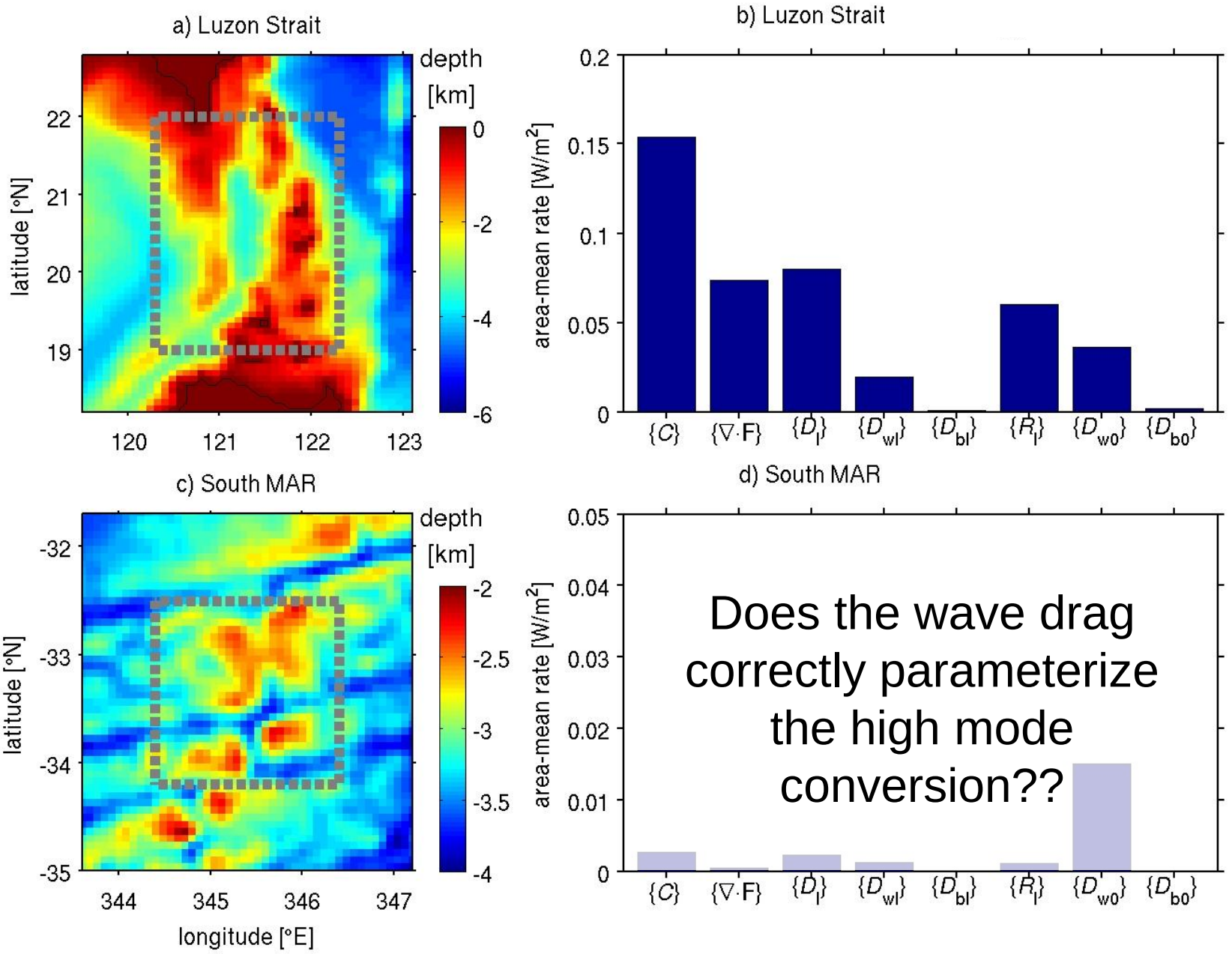


06.1

Deep and Tall Ridges

tall ridge

deep ridge

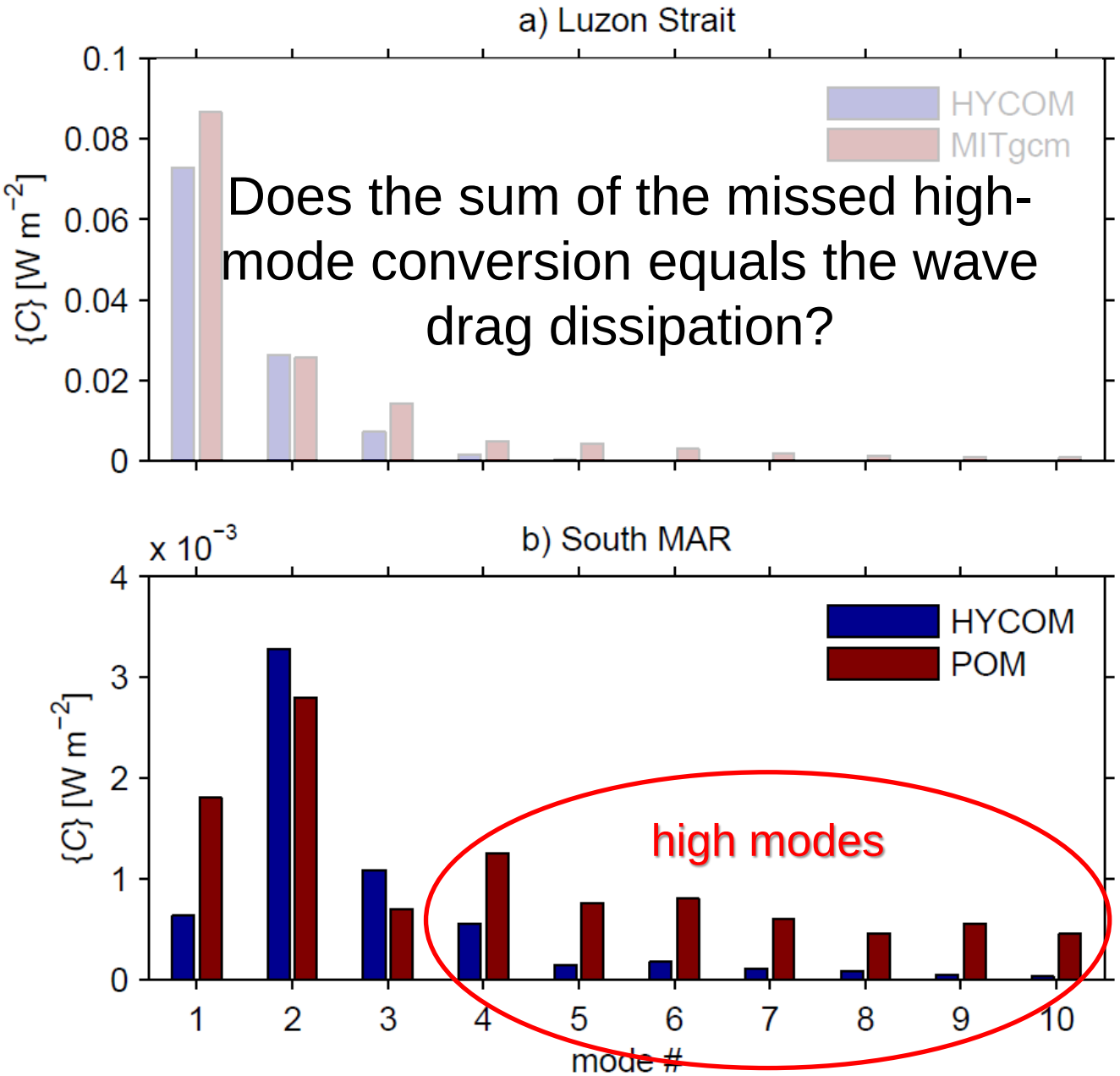


06.1

Conversion to Modes

tall ridge

deep ridge

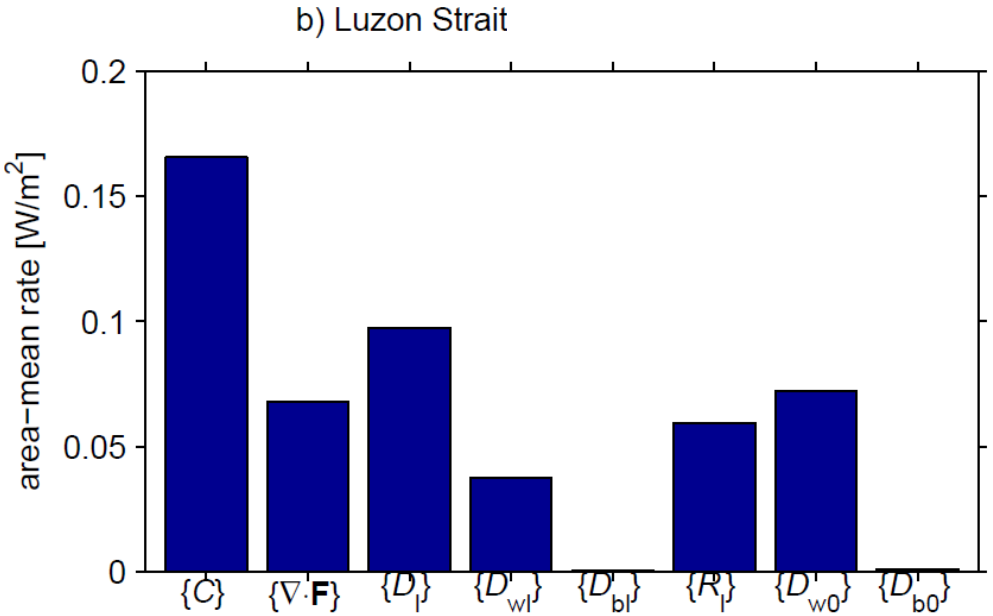


Buijsman et al (2014)

Zilberman et al (2009)

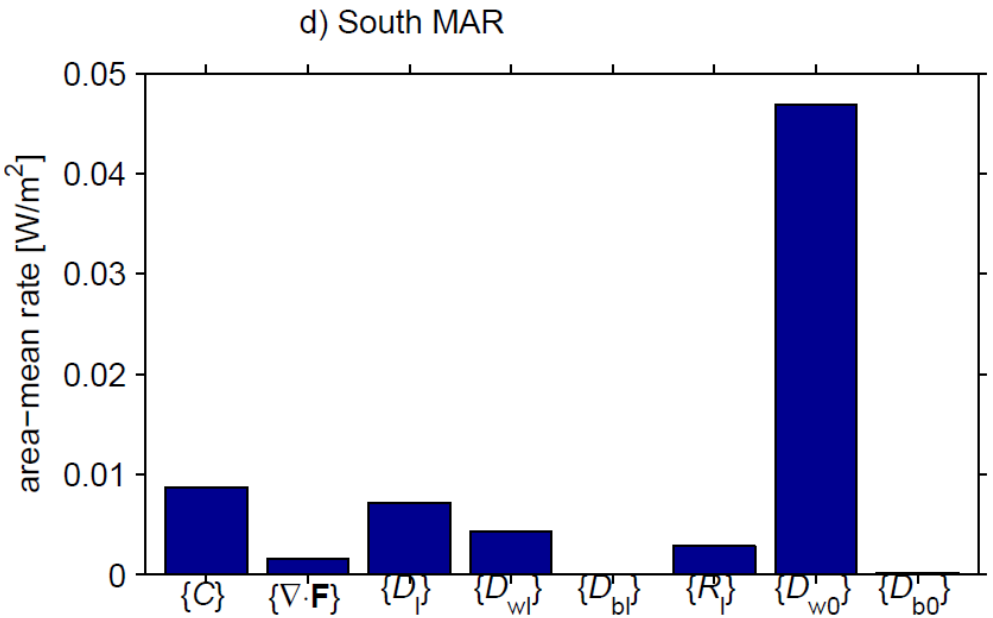
Deep and Tall Ridges

tall ridge



18.5 **(06.1)** overestimates
the energy input
in high modes (> x4) **(~x2)**

deep ridge



18.5 overestimates
the energy input
in high modes (> x4)