Can mesoscale eddy kinetic energy sources and sinks be inferred from sea surface height in the Agulhas Current ?

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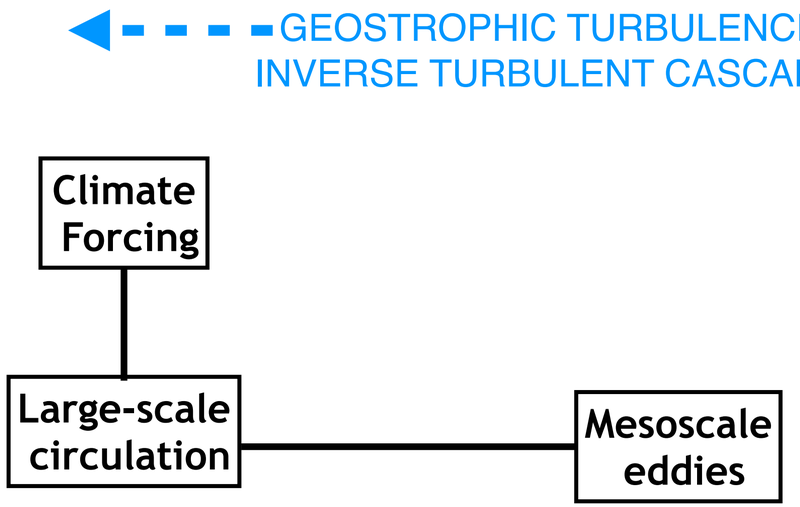
Context - How do mesoscale eddies dissipate their energy ?

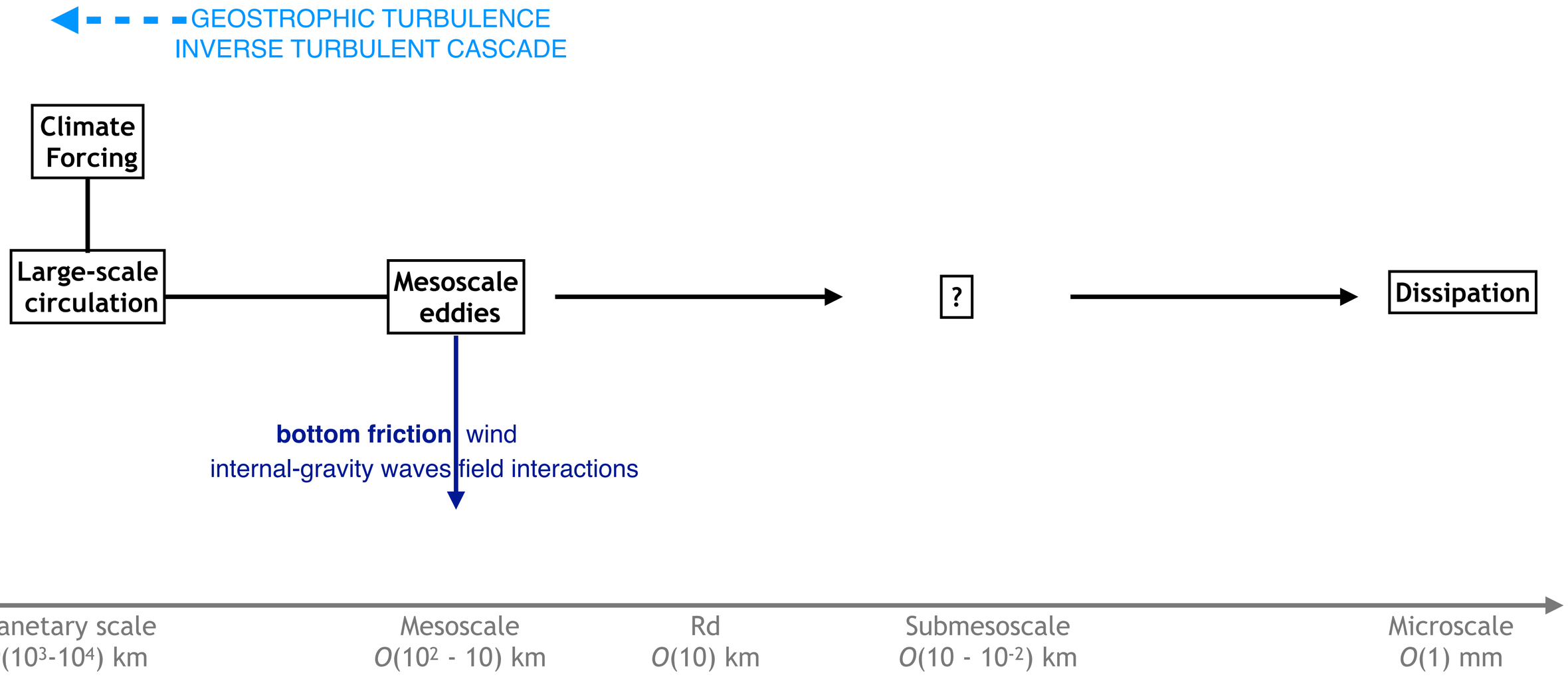
Mesoscale eddies represent a key reservoir for the global ocean energy budget
(90 % of the surface Kinetic Energy) (Wunsch et al. 2007, Ferrari and Wunsch, 2009)



Scheme inspired from McWilliams et al. (2016)

Context - How do mesoscale eddies dissipate their energy ?

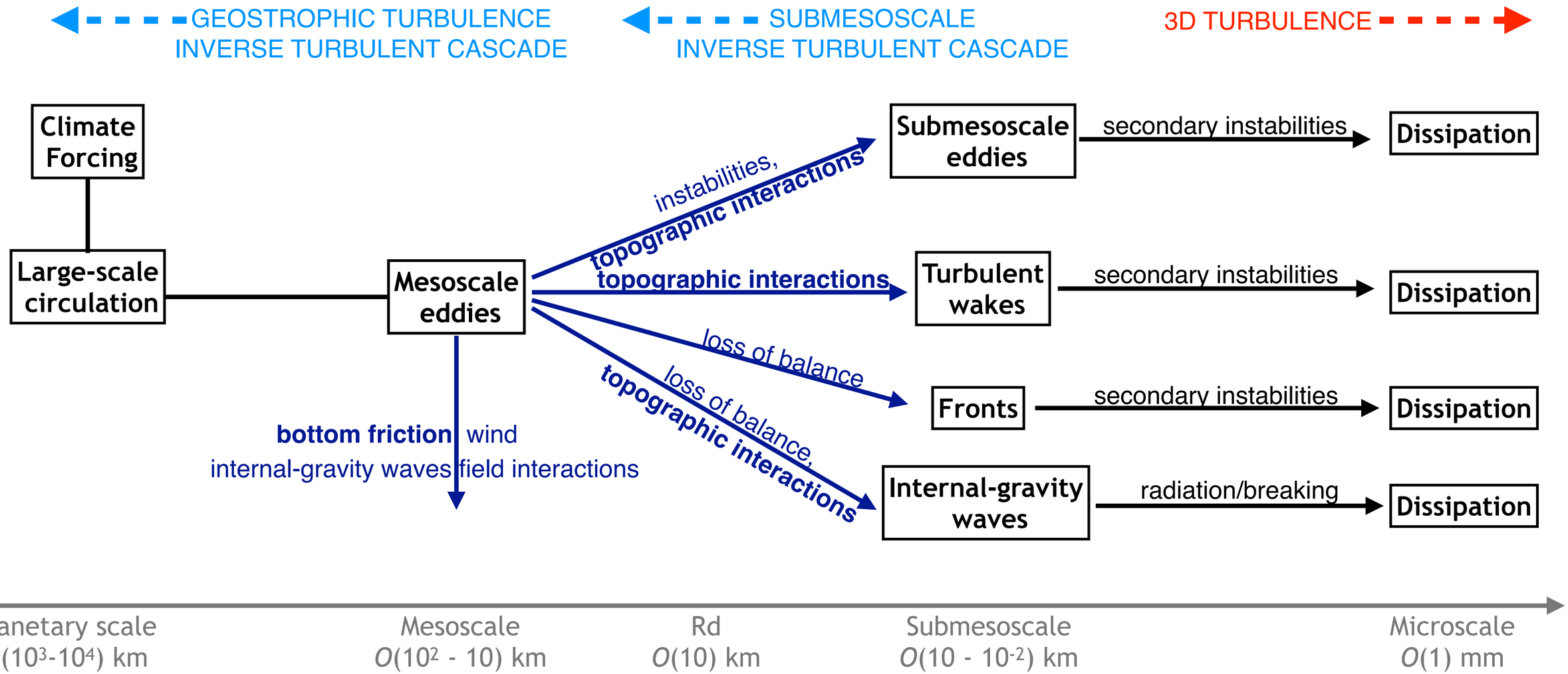
Mesoscale eddies generation is well documented, but how they dissipate their energy remains uncertain



Scheme inspired from McWilliams et al. (2016)

Context - How do mesoscale eddies dissipate their energy ?

Topographic interactions play a significant role at channeling direct EKE routes, down to dissipation
(Wunsch et al. 2007, Ferrari and Wunsch, 2009)



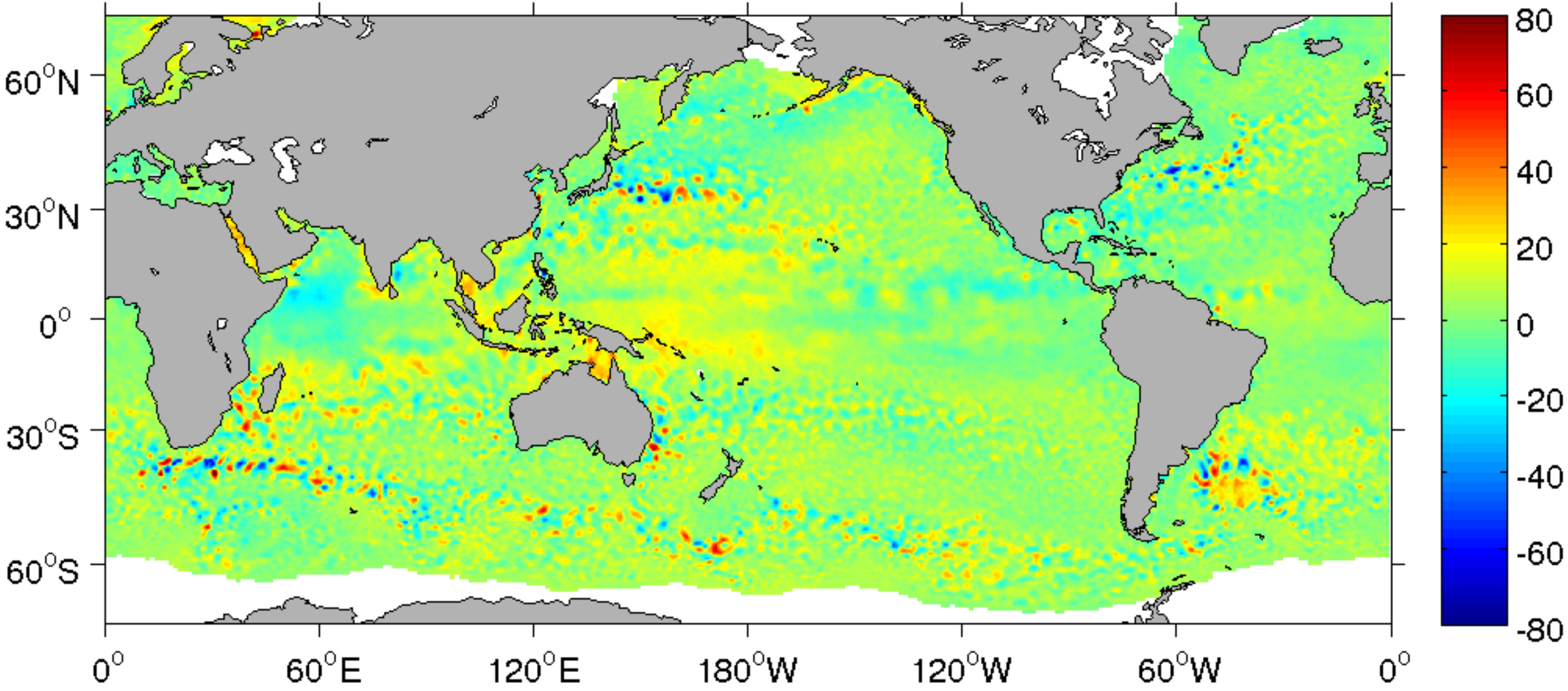
Scheme inspired from McWilliams et al. (2016)

Context - Western boundaries as hotspots for mesoscale EKE decay ?

Based on satellite altimetry data (SSH), a closure to mesoscale eddies lifecycle has been suggested
(Zhai et al. 2010)

- Mesoscale eddies are generated almost everywhere, propagate westward and decay at western boundaries due to topographic interactions

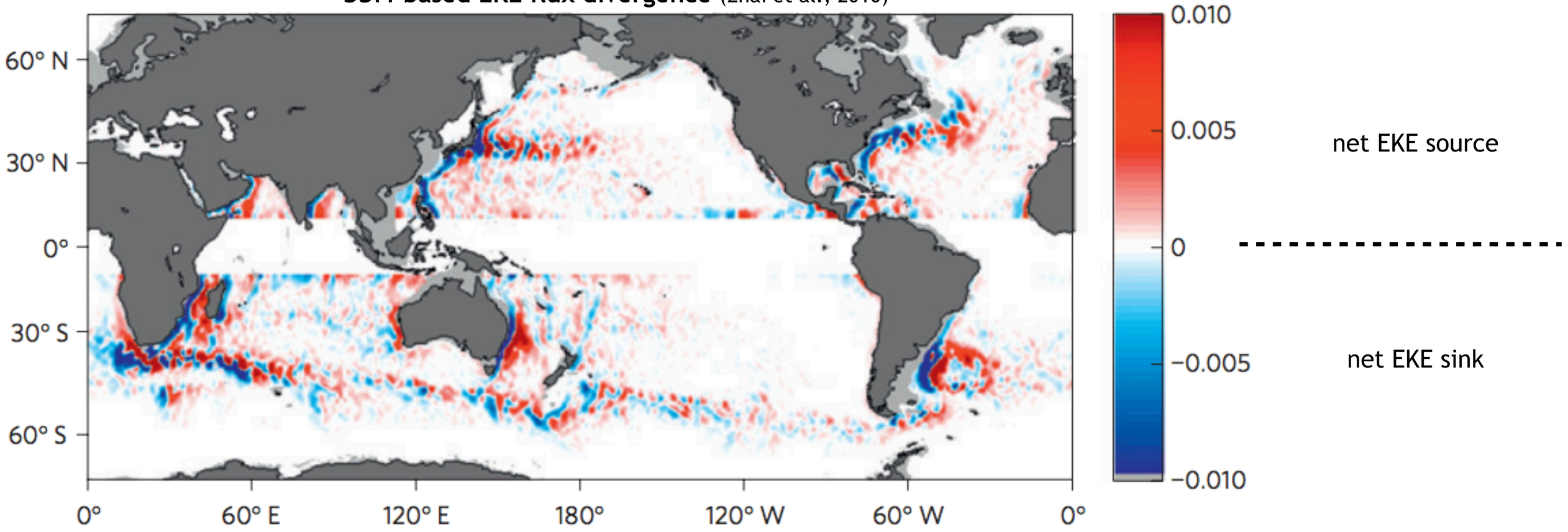
Animation of SSH anomaly from altimetry (Zhai et al., 2010)



Context - How do mesoscale eddies dissipate their energy ?

An SSH-based eddy kinetic energy (EKE) flux divergence highlights net EKE sinks (< 0) at western boundaries

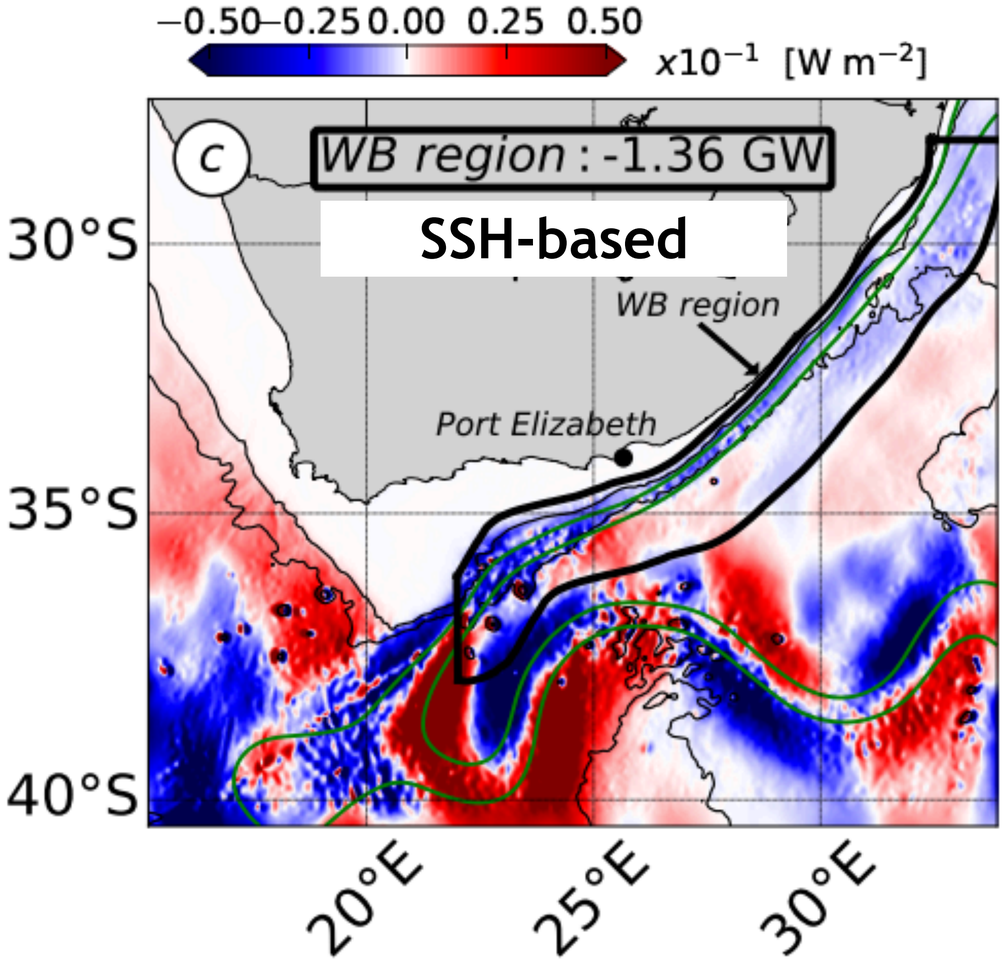
SSH-based EKE flux divergence (Zhai et al., 2010)



Motivation - Contrasted altimetry- and model-based paradigms

In the Agulhas Current, SSH- and model-based EKE flux divergence support different paradigms

Net EKE sink (< 0) :
Local EKE decay dominates



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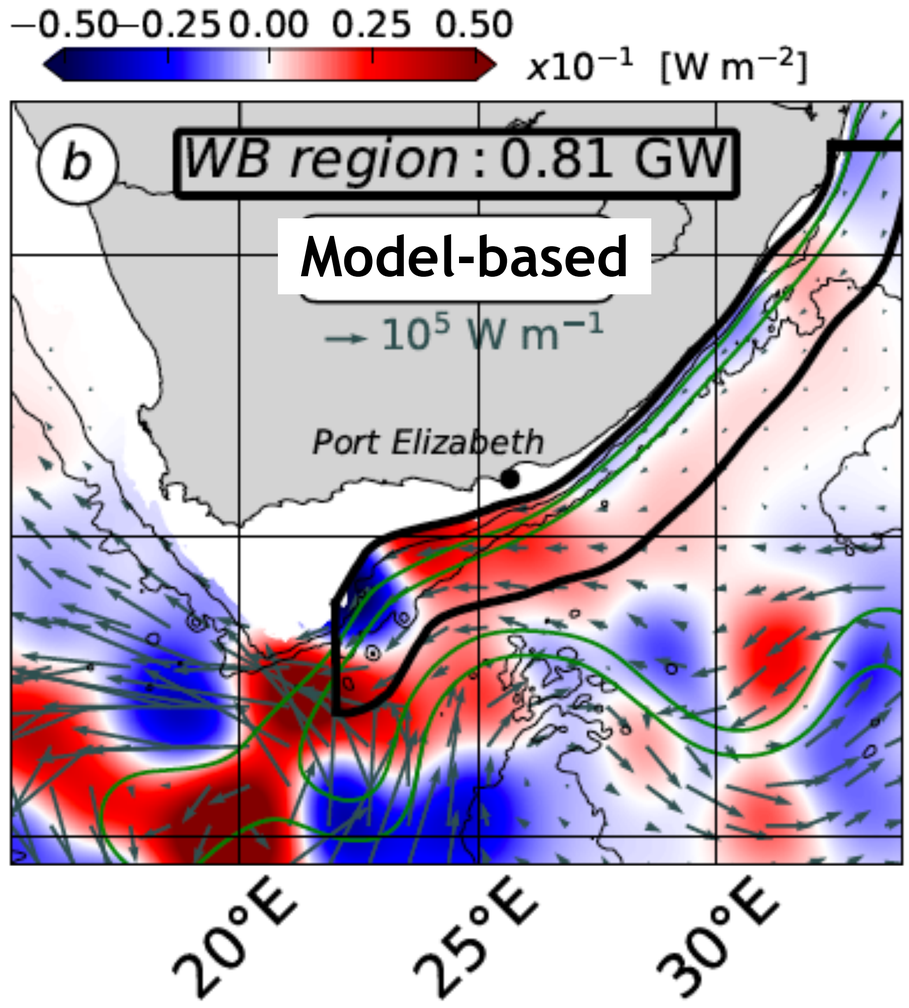
Net EKE source (> 0) :
Local EKE generation dominates



Motivation - Contrasted altimetry- and model-based paradigms

The use of SSH to infer the EKE flux divergence requires approximations

$$EKE\ flux\ divergence = \underbrace{\boxed{\nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}'_n p'_n \phi_n^2\, dz}}_{Eddy-pressure\ work} + \underbrace{\frac{\rho_0}{2} \nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}_n \phi_n \,||\, \mathbf{u}'_n \phi_n \,||^2\, dz}_{Advection\ of\ EKE\ (AEKE)}$$

true EPW

$$\boxed{\nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}'_n p'_n \phi_n^2\, dz}$$

(i) geostrophic velocities

EPW$_{(i)}$

(ii) 1st baroclinic mode

EPW$_{(i,ii)}$

(iii) weak EKE flux-topographic interactions

EPW$_{(i,ii,iii)}$ in Zhai et al. (2010)

$$\boxed{-\frac{\beta \rho_0 g^2}{2f^2} \frac{\partial}{\partial x} \left(\frac{\int_{-H}^{\eta} \phi_1^2\, dz}{|\phi_1^2|_{z=0}} \eta'^2 \right)}$$

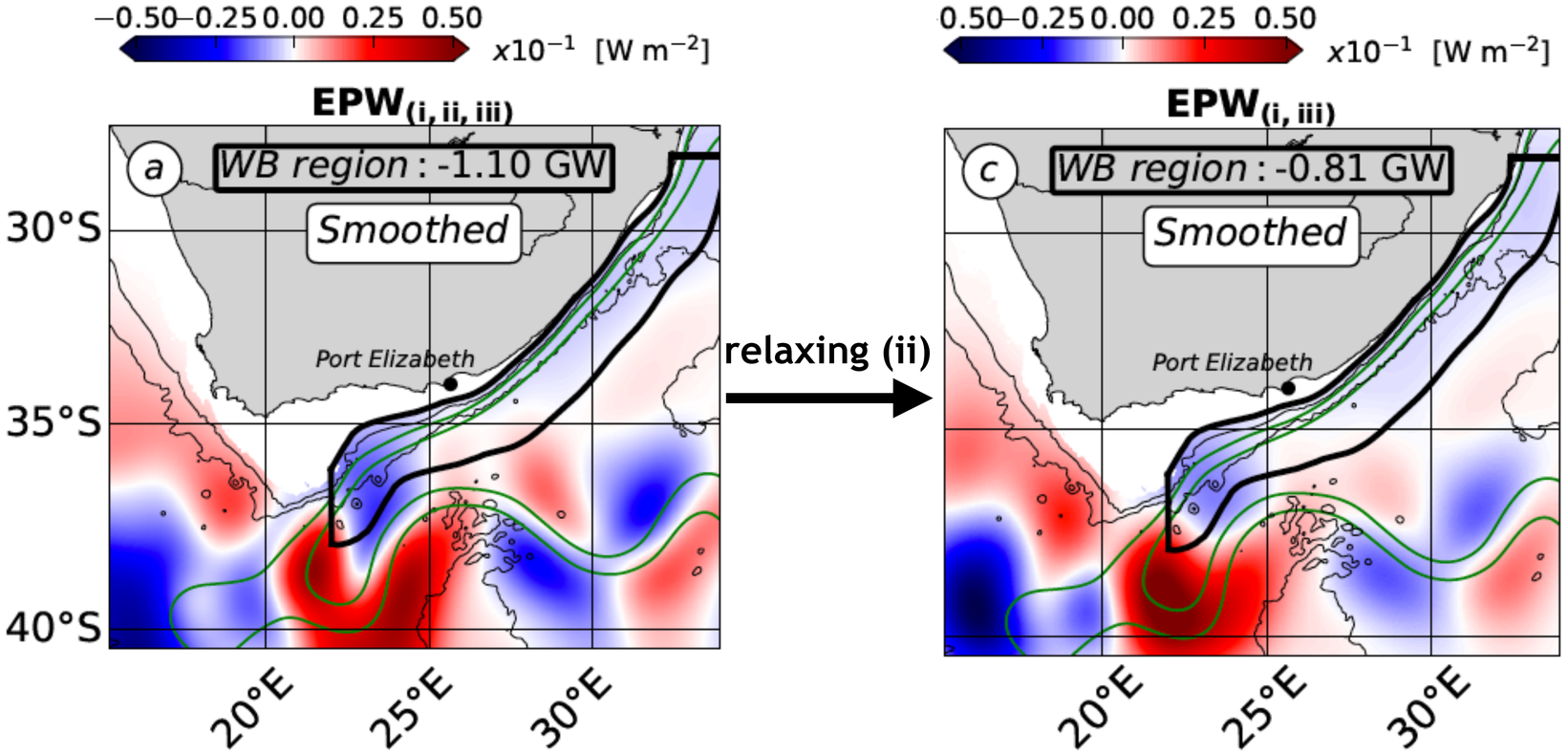
- EPW$_{(i,ii,iii)}$ corresponds to linear EKE flux driven by the β-effect acting on the 1st baroclinic mode
- Is EPW$_{(i,ii,iii)}$ a reliable approximation of the true EPW ?

Results - Impacts of approximations on the eddy-pressure work (EPW)

Is $EPW_{(i,ii,iii)}$ a reliable approximation of the true EPW ?

- mesoscale EPW using 1st baroclinic mode
- no EKE flux-topographic interactions

- **mesoscale EPW using barotropic + 1st baroclinic modes**
- no EKE flux-topographic interactions



- **$EPW_{(i,iii)}$** : Barotropic (-0.51 GW) and 1st baroclinic mode (-0.30 GW) have significant contributions to the SSH-based EPW

Results - Impacts of approximations on the eddy-pressure work (EPW)

Is $EPW_{(i,ii,iii)}$ a reliable approximation of the true EPW ?

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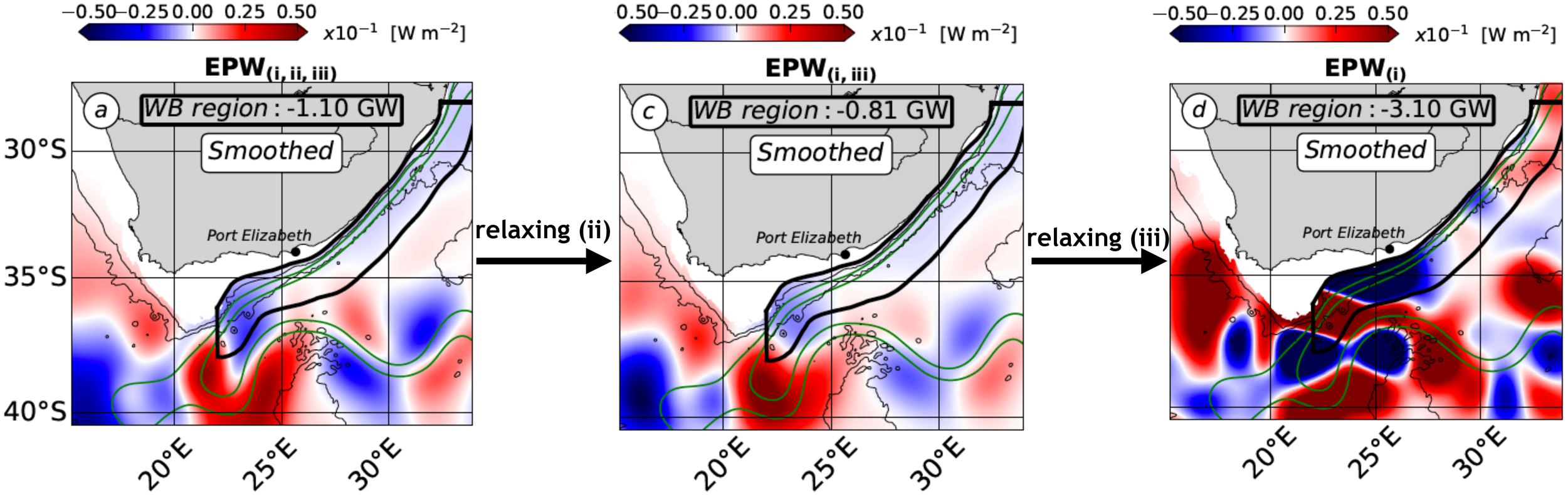
- mesoscale EPW using barotropic + 1st baroclinic modes
- **EKE flux-topographic interactions**

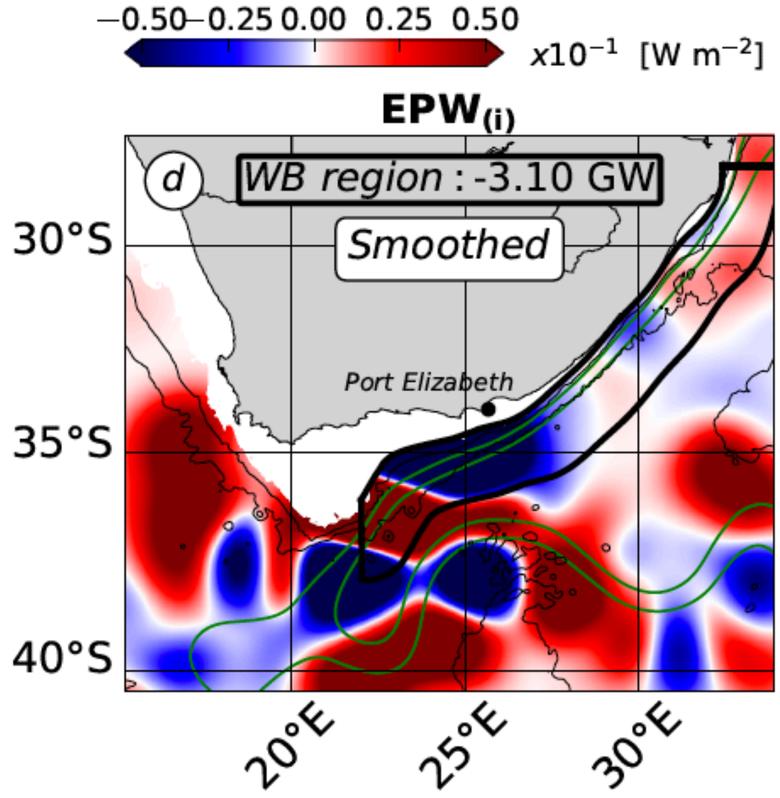


- **$EPW_{(i,iii)}$** : Barotropic (-0.51 GW) and 1st baroclinic mode (-0.30 GW) have significant contributions to the SSH-based EPW
- **$EPW_{(i)}$** : EKE flux-topographic interactions are not weak

Results - Impacts of approximations on the eddy-pressure work (EPW)

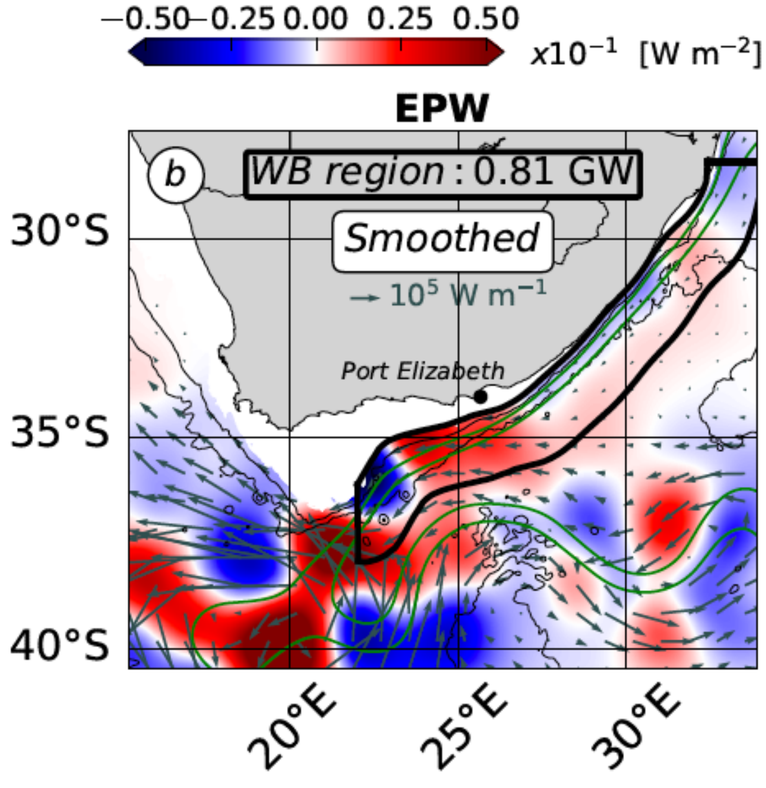
Approximations (ii) and (iii) impact SSH-based EPW, but support WB as a net EKE sink

- mesoscale EPW using barotropic + 1st baroclinic modes
- EKE flux-topographic interactions
- **geostrophic velocities**



relaxing (i)

- mesoscale EPW using barotropic + 1st baroclinic modes
- EKE flux-topographic interactions
- **total velocities**



Approximations (i) of geostrophy is the last possible reason for the different paradigms

Results - Main contributions to the eddy-pressure work (EPW)

SSH-based paradigm relies on the β-effect being the main contribution to the mesoscale EPW

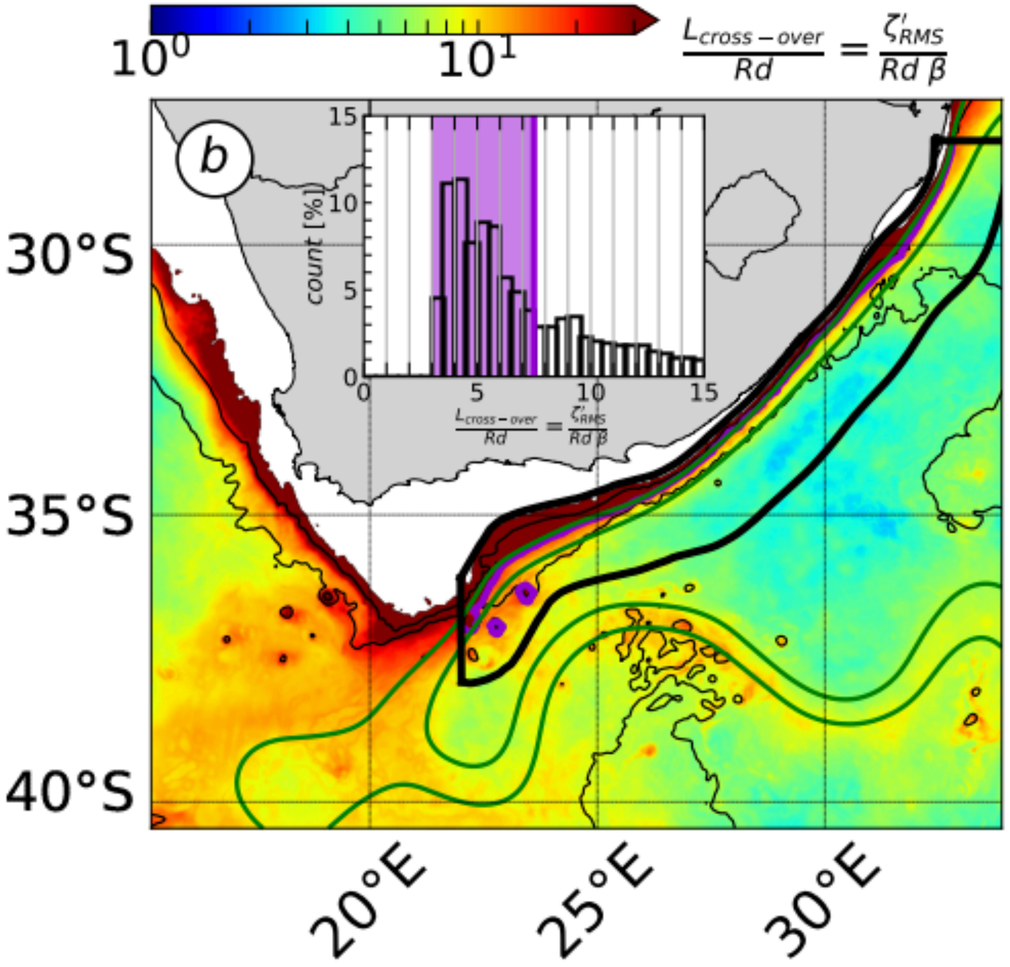
(Zhai et al. 2010)

- In the WB region, mesoscale eddies are mainly geostrophic (*Ro* = *O*(0.02-0.07))

- However, a scale analysis shows that the ageostrophic EPW dominates the β-contribution

$$\left| \frac{EPW_{ag}}{EPW_{(i,ii,iii)}} \right| \sim \frac{L_{cross-over}}{L}, \text{ with } L_{cross-over} = \frac{\zeta'_{RMS}}{\hat{\beta}}$$

In the WB region, $\frac{L_{cross-over}}{Rd} >> 1$



It questions the use of SSH to infer the true mesoscale EPW in the WB region

Results - Main contributions to the advection of EKE (AEKE)

The use of altimetry data (SSH) to infer the EKE flux divergence requires approximations

$$EKE\ flux\ divergence = \underbrace{\nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}'_n p'_n \phi_n^2\ dz}_{Eddy-pressure\ work} + \underbrace{\boxed{\frac{\rho_0}{2} \nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}_n \phi_n \,||\, \mathbf{u}'_n \phi_n \,||^2\ dz}}_{Advection\ of\ EKE\ (AEKE)}$$

true AEKE

$$\frac{\rho_0}{2} \nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}_n \phi_n \,||\, \mathbf{u}'_n \phi_n \,||^2\ dz$$

(i)
geostrophic velocities

AEKE$_{(i)}$

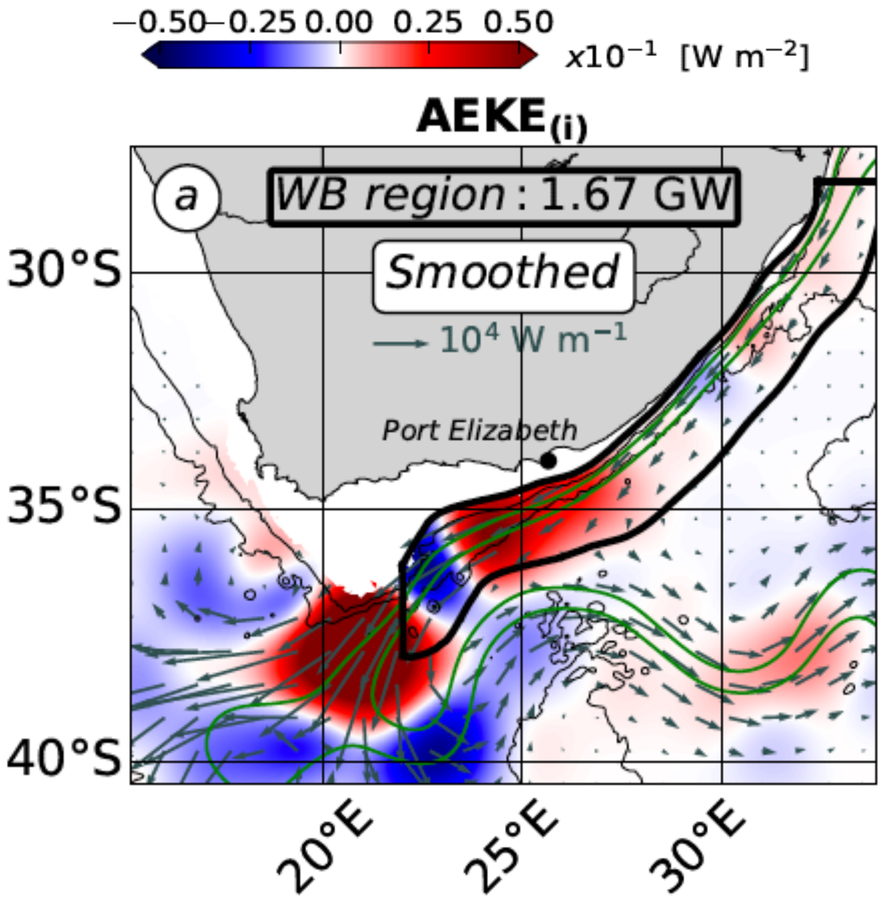
$$\frac{\rho_0}{2} \nabla_H \cdot \int_{-H}^{\eta} \mathbf{u}_{g,n} \phi_n \,||\, \mathbf{u}'_{g,n} \phi_n \,||^2\ dz$$

- AEKE$_{(i)}$ corresponds to advection done by geostrophic EKE flux of the barotropic and 1st baroclinic modes
- Is AEKE$_{(i)}$ a reliable approximation of the true AEKE ?

Results - Main contributions to the advection of EKE (AEKE)

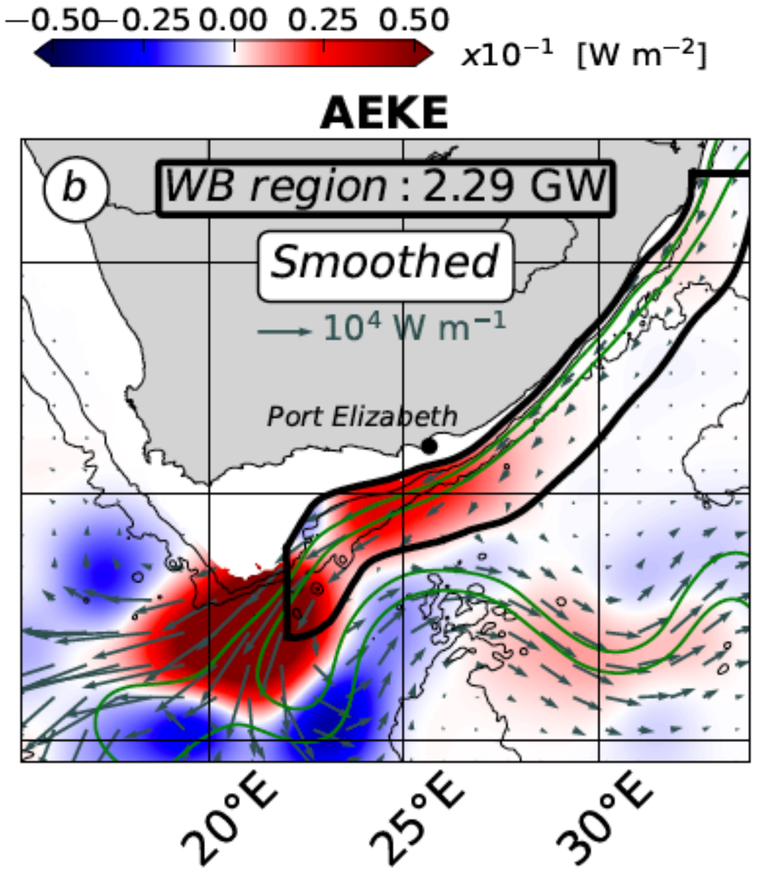
Is $AEKE_{(i)}$ a reliable approximation of the true AEKE ?

- **geostrophic velocities**



relaxing (i)

- **total velocities**



Approximations (i) of geostrophy is valid for AEKE (via the work of eddy-total flow interactions)

Conclusion

Our results are favorable to SSH-based diagnostics :

- EKE flux divergence is dominated by advection done by geostrophic EKE flux (AEKE)
- EKE flux divergence can be qualitatively inferred using SSH (up to 54 % in the WB region)

Our results support a dynamics in contrast with the decay's paradigm at western boundaries :

- Local generation of eddies, by instabilities of the Agulhas Current, overcomes the local decay due to topographic interactions
- EKE flux divergence is sensitive to regional dynamics