# The sensitivity of the modelled Beaufort Gyre to different vertical mixing prescriptions

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## 1. Background and Motivation

- ❑ Climate models exhibit biases and inter-model spreads when representing the structure and features of the Arctic Ocean [1].
- ❑ One of these features which experiences large amounts of bias in its representation is the Beaufort Gyre (BG) [1] which is the largest reservoir of freshwater in the region [2].
- ❑ The stratification structure of the Arctic Ocean including the structure of the halocline, an important feature of the region, has been shown to be highly sensitive to changes in vertical mixing strength in models [3].
- ❑ The total vertical mixing strength in models is set by multiple parameterizations to represent different processes including mixing due to eddies, mixing in the surface layer, mixing due to background turbulence, and convection.

## 2. Study Goals

Overall:

- ❑ to examine the sensitivity of the modelled Beaufort Gyre to different variations and inclusions of vertical mixing parameterizations in an intermediate complexity Arctic Ocean regional model; and further,
- ❑ to gain insight into these sensitivity study results by comparing the relative contributions of the different vertical mixing parameterizations to the modelled vertical mixing fluxes of heat and salt

Here:

- ❑ to explore the sensitivity of modelled Beaufort Gyre structure to:
  1. variations in the strength of the background vertical diffusivity (Experiment 1)
  2. the inclusion of a salt plume parameterization to avoid excessive convective mixing associated with the rejection of salt during sea ice formation (Experiment 2)

## 2. Methodology

### Model

- ❑ intermediate complexity regional model of the Arctic Ocean based on MITgcm [4]
- ❑ 210x192 horizontal grid cells (~36-km horizontal resolution)
- ❑ 50 vertical levels (10-m to 450-m vertical resolution).
- ❑ initial conditions from WOCE Global Hydrographic Climatology [5]
- ❑ boundary conditions from ECCO climatology (see [6])
- ❑ integrated from January 1979 – January 2013
- ❑ mixing parameterized using the KPP scheme [7], GM-Redi [8,9] and a spatially uniform background diffusivity

### Experiments

#### Experiment 1: Varying background vertical diffusivity

- ❑ mixing due to background turbulence is parameterized by via a background vertical diffusivity set to be a constant value in time and space
- ❑ In this experiment, the magnitude of the background vertical diffusivity, $\kappa_{BG}$, is varied over three orders of magnitude:

| Run | $\kappa_{BG}$ |
|---|---|
| LO | $1.7 * 10^{-7}\ m^2s^{-1}$ |
| MED | $6.6 * 10^{-6}\ m^2s^{-1}$ |
| HI | $3.5 * 10^{-5}\ m^2s^{-1}$ |

#### Experiment 2: Turning on and off a salt plume parameterization

- ❑ the salt-plume parameterization adds rejected salt during sea-ice formation to a depth of neutral density with minimal mixing as opposed to adding the rejected salt to the uppermost grid cell [10]
- ❑ in this experiment, the salt-plume parametrization is turned on and off in two runs: SP ON and SP OFF respectively

## 3.a Results: Experiment 1 Varying background vertical diffusivity

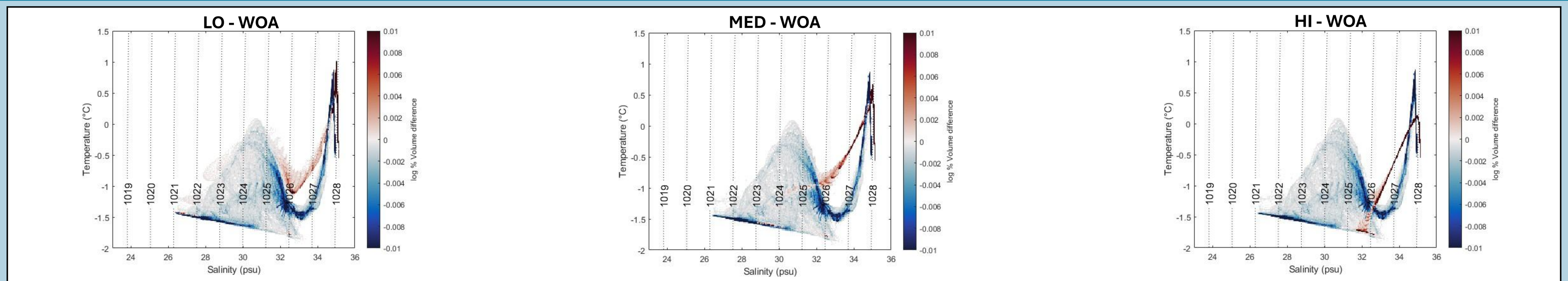


Figure 1: Volumetric temperature-salinity (T-S) diagrams illustrating the representation of water mass properties in the Beaufort Gyre region for each of the model runs. The volumes are displayed as the anomaly relative to the World Ocean Atlas 2005-2014 climatology. Two distinct water masses of specific interest are present in the BG region; Pacific Summer Water (PSW) and the Pacific Winter Water (PWW). Both can be defined based on salinity with PSW having a salinity range of 29-33 PSU and PWW having a salinity of 33.1 PSU [2].

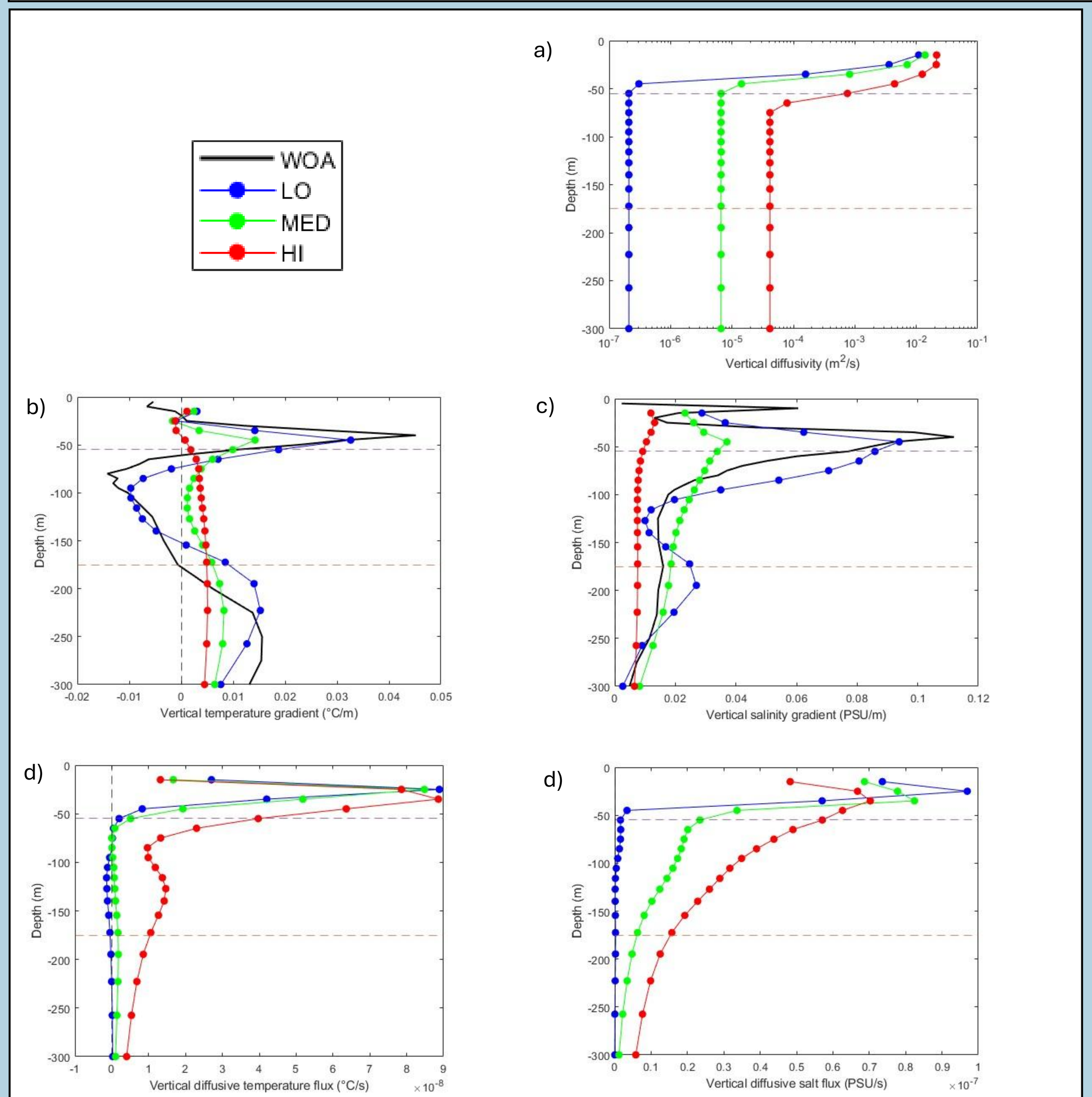


Figure 2: Average vertical profiles of (a) total vertical diffusivity; model vertical gradients of (b) temperature and (c) salt; and total vertical diffusive fluxes of (d) temperature and (e) salt for each of the model runs. Average profiles represent the average in space over the BG region (defined as 70.5–80.5°N, 190–230°E where seafloor depth is greater than 3000m) and an average in time over the period 2008-2013 (the last 5 years of the model integration). Also shown is the average vertical profiles of the vertical gradients of (b) temperature and (c) salt from the WOA climatology (black lines). Dashed purple line represents the depth of the PSW temperature maximum and dashed orange line represents the depth of the temperature minimum of PWW in the WOA climatology.

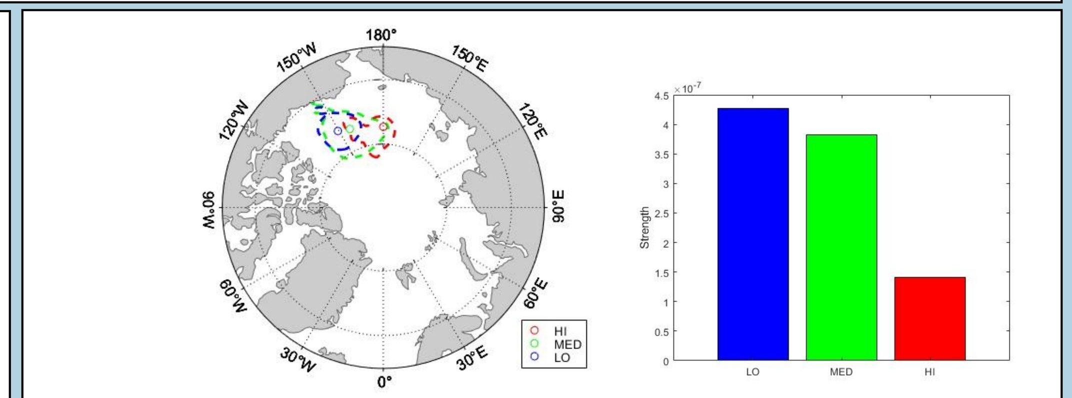


Figure 3: (Left) BG extent for LO, MED, HI defined as the lowest closed contour of sea surface height withing the BG region. BG centres for these runs, defined as the location of maximum sea surface height in the region (circles). (Right) BG strengths for the LO, MED, HI runs, defined as the maximum difference in sea surface height across the gyre divided by the mean gyre radius

- Increasing the background vertical diffusivity:
  - Erodes the distinction between warm and fresher Pacific Summer Water (PSW) and the cold and salty Pacific Winter Water (PWW)
  - makes the Beaufort Gyre larger and weaker as implied from sea surface height
  - decreases the magnitude and deepens the extent of key features in the vertical structure of the temperature and salt gradients
- total diffusivities vary by a factor of 2-5 in the upper ~25m and by a factor of 6-200 below this
- vertical diffusive fluxes also vary:
  - to a lesser degree in the near-surface (a factor of 1.1-1.3 at their peak at ~25 m depth) but more significantly at the depths of the PWW (a factor of 2-10 at ~175 metres depth) for temperature
  - significantly at all depths (a factor of 9-18 at ~50 m depth) for salt

## 3.b Results: Experiment 2 Turning on and off salt plume parametrization

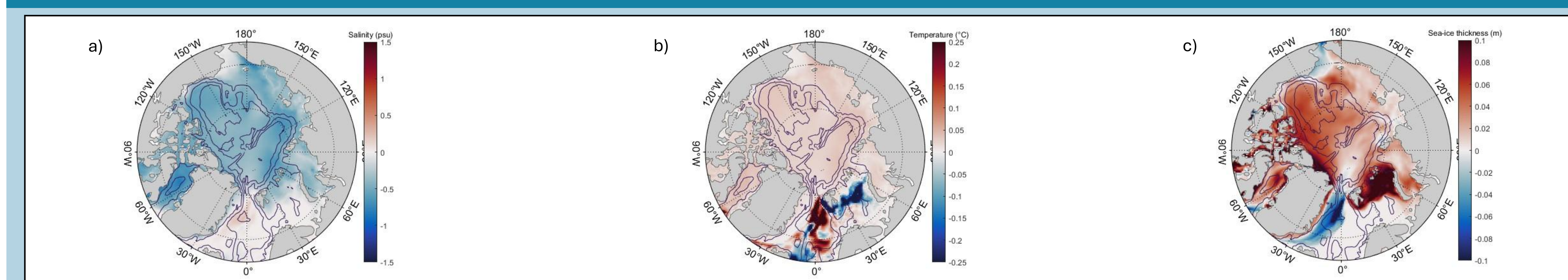


Figure 5: Anomaly plots (SP ON – SP OFF) showing the difference between mean wintertime (a) surface salinity; (b) surface temperature; and (c) sea ice thickness in the model run with the salt plume parameterization turned on vs. the run with the salt plume parameterization turned off. The mean is the average of the months of January – April over the 5-year period 2009-2013.

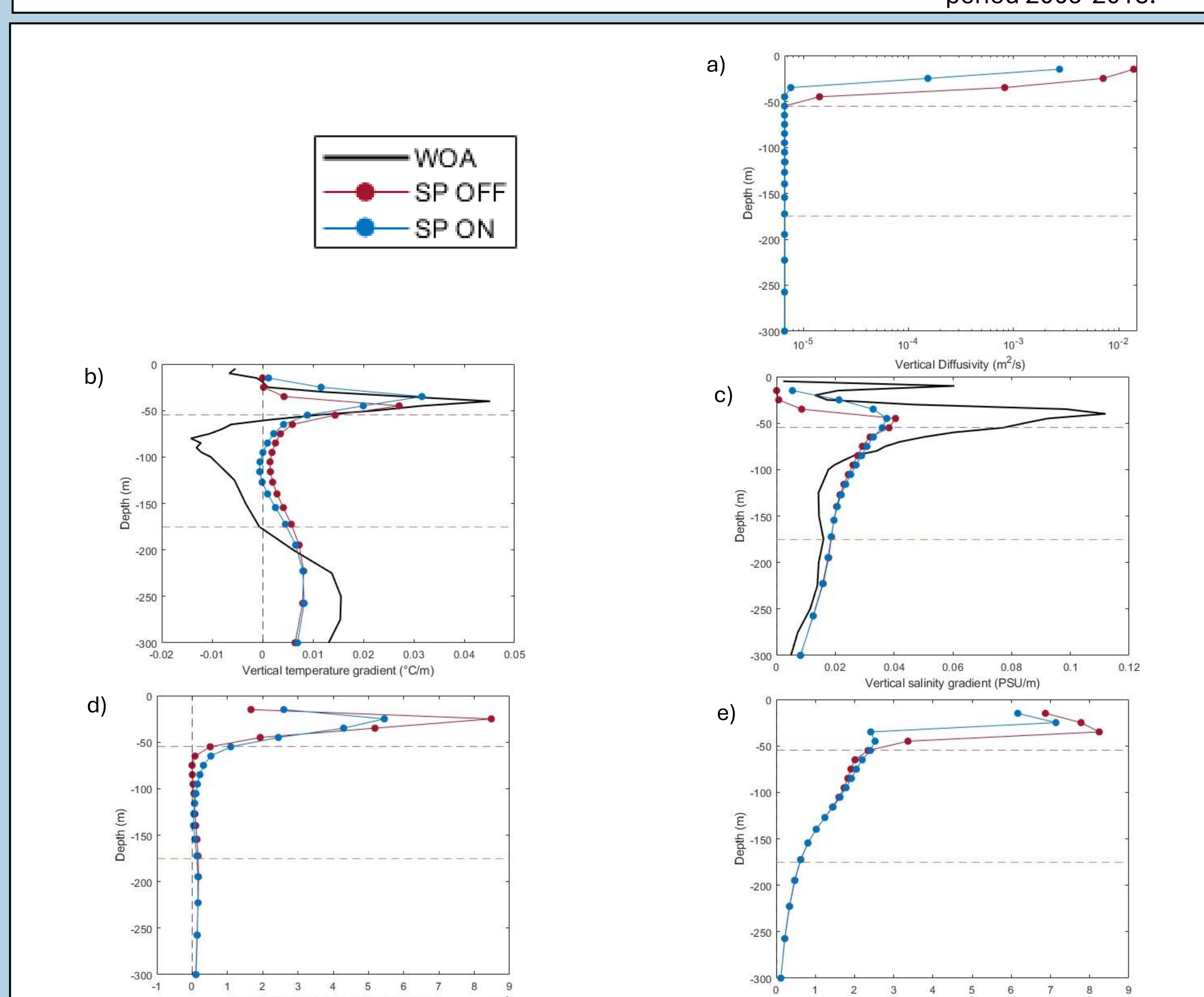


Figure 6: As in Figure 2 for average vertical profiles of (a) total vertical diffusivity; model vertical gradients of (b) temperature and (c) salt; and total vertical diffusive fluxes of (d) temperature and (e) salt for each of the model runs.

- turning on the salt-plume parameterization:
  - makes the surface fresher and warmer and increases the thickness of sea-ice
  - decreases the total diffusivity in the upper 50m by factors of 2-5
  - strengthens the upper PSW temperature gradient and shoals the PSW temperature maximum while starting to resolve the negative temperature gradient associated with the cold halocline
  - strengthens the salinity gradient in the upper PSW but decreases it below; further it strengthens the salinity stratification in the upper cold halocline
  - decreases the vertical diffusive salt flux in the upper 50m by factors of 1.1-1.4 and decreases the vertical diffusive temperature flux in the depth range 35m-45m by factors of 1.3-1.6
  - increases the vertical diffusivity of salt and temperature by factors of 1 and 7 respectively in the depth range of the upper cold halocline

## Conclusions

### Sensitivity of Beaufort Gyre structure and properties

Decreasing the background vertical diffusivity:

- ❑ better resolves the distinction in T-S properties between key water masses
- ❑ makes the Beaufort Gyre smaller and stronger
- ❑ increases the magnitude of vertical temperature and salt gradients and shoals key features in their vertical structure

Turning on the salt plume parameterization:

- ❑ makes the surface fresher and warmer and maintains thicker sea-ice pack
- ❑ strengthens the upper ocean temperature and salinity gradients but typically not deep enough to significantly impact cold halocline stratification
- ❑ starts to resolve the negative temperature gradient associated with the cold halocline

### Magnitude and structure of model diffusivity and fluxes

Decreasing the background vertical diffusivity:

- ❑ decreases the magnitude and vertical extent of enhanced total diffusivity in the upper 50m and changes the deeper total diffusivity by an order of magnitude or more
- ❑ decreases the magnitude and vertical scale of enhanced ocean diffusive fluxes of heat and salt, with effects especially pronounced in the depth range of the cold halocline

Turning on the salt plume parameterization:

- ❑ decreases diffusivity in the upper 50m
- ❑ decreases salt and temperature fluxes in the upper 50m but increases fluxes below thus compromising its promise in maintaining distinctive water properties of the cold halocline

## Next steps

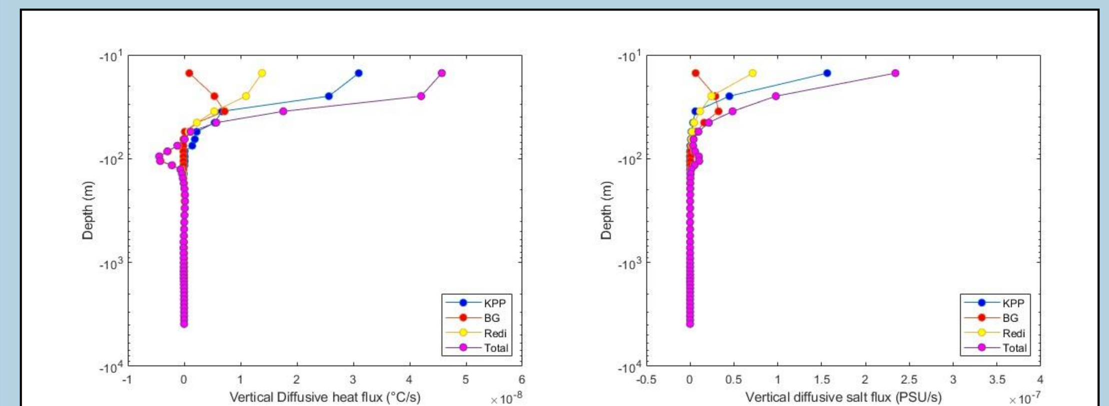


Figure 7: Flux breakdown of the contributions of different mixing processes in ASTE, a re-parameterization model.

- ❑ perform additional sensitivity experiments that vary the strength of the other vertical mixing parameterizations: KPP and GM-Redi
- ❑ diagnose the relative contributions of each of the different parameterizations to total diffusivity and total diffusive fluxes for all the different sensitivity experiments (for an example, see Figure 7).
- ❑ better understand the controls on BG horizontal structure including size, shape and strength in these model experiments
- ❑ consider the implications for BG heat and freshwater storage

## References

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