Research Questions

UNIVERSITY OF GOTHENBURG

Using the depth of the centre of gravity as an indicator on the state of the general ocean circulation

by Benjamin Schmiedel and Fabien Roquet; University of Gothenburg

What are the processes that drive the overturning circulation and stratification?

Can the centre of gravity be used to describe their relative importance?

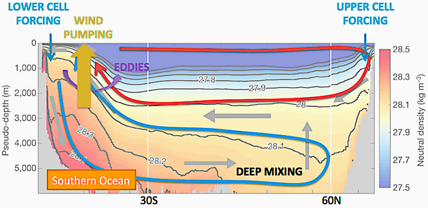


Fig.1: Meridional Structure of the global overturning circulation, adapted from de Lavergne (2017, Nature)

Contact: gusschmbe@student.gu.se

Theory and Explanation

This work proposes the use of the centre of gravity as a key variable to diagnose when interested in the energetic content of the stratification, and the processes that drive the general overturning circulation. It is **easy to diagnose** and can be **interpreted** in an intuitive way. Processes that provide energy to the system lower the centre of gravity, while others raise it.

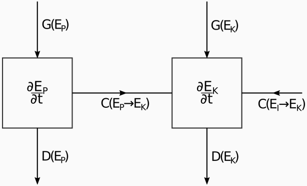


Fig. 2: Energy cycle scheme with generation G, dissipation D and conversion C, reworked from Oort, 1994.

The centre of gravity z_g is by definition equal to the potential energy E_P divided by mass M:

$$z_g = \frac{\iiint \rho z \, dV}{\iiint \rho dV} = \frac{E_p}{M} \quad \Longrightarrow$$

Making the replacement of potential energy with dynamic enthalpy h [Young, 2010] removes the inert contribution $\rho_0 gz$ and closes the energy cycle (Fig. 2) to just include h and E_K. In the boussinesq approximation we therefore introduce

$$z_g^b = \frac{\iiint h \, dV}{g \iiint dV}$$

$$\frac{Dz_g^b}{Dt} = \frac{1}{g}\left(< \frac{\partial h}{\partial \Theta}\mathring{\Theta} > + < \frac{\partial h}{\partial S}\mathring{S} > - < bw > \right)$$

The tendency terms correspond to the generation, dissipation and conversion terms of potential energy E_P (h) from Fig. 2, where bw provides the link to the kinetic energy E_K

The depth of z_g to reference

The comparison of z_g to $z_{g,0}$ (the centre of gravity for an ocean completely mixed), gives an estimate of the energy stored in the stratification. Applied for a simplified closed basin simulation generated with NEMO (Fig. 3), it results in values of around 35cm, which highlights how small the stratification energy is.

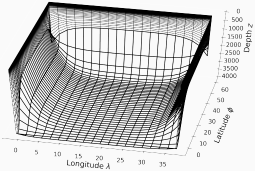


Fig. 3: Bathymetry of the ocean simulation performed with NEMO.

<u>Note on the reference state:</u>
The dynamic enthalpy h gives an energy relative to a state of reference z_r which resembles using available potential energy (APE). However, choosing $z_{g,0}$ is much easier to diagnose than the Lorenz state used for APE and gives an estimate of the total energy in the stratification.

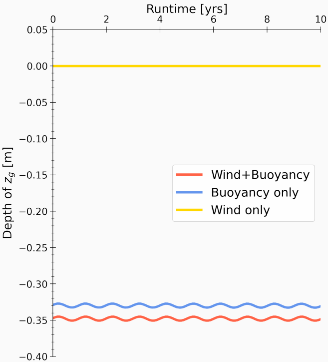
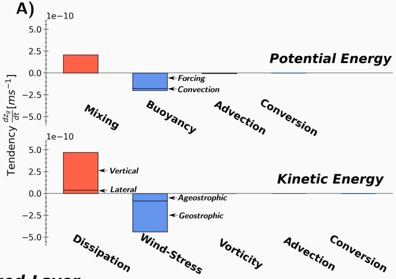


Fig. 4: z_g to reference, for three configurations different in their external forcing only. Note that with wind only no stratification is generated.

Process contributions to the z_g tendency

The processes that make up the tendency of z_g are separated by their nature and compared in their importance.
Positive sign: weakening stratification
Negative sign: enhancing stratification



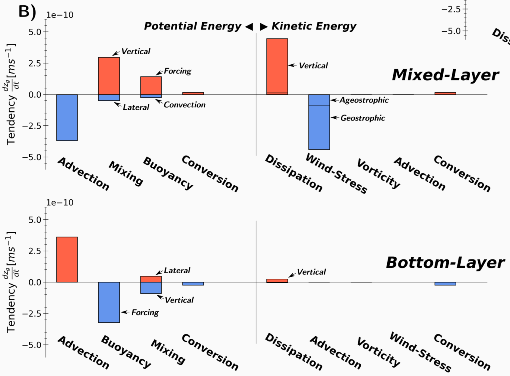


Fig. 5: Contribution to the z_g tendency, combined by process type and ranked by importance. Panel A shows the tendencies contributing to the globally integrated kinetic and potential energy, while in panel B it is distinguished by mixed (top) layer and bottom layer.

Conclusions and Improvements

UNIVERSITY OF GOTHENBURG

A method is proposed, putting the centre of gravity in the focus, to estimate the strength of the stratification and the state of the overturning circulation.

The method was successfully tested on simplified closed basin simulations generated with NEMO:

- ⇒ It highlights the smallness of the energy in the stratification/circulation
- ⇒ Processes could be ranked by their importance, with the surprising result of wind being rather unimportant to z_g
- ⇒ Top and bottom layers behave rather differently

Difficulties and future improvements:

- ⇒ Only a part of the ocean is represented with rather low resolution
- ⇒ Many processes are not included yet which may introduce substantial differences (Sea Ice, Eddies, ...)
- ⇒ Open a southern ocean channel to allow wind to act with the strong upwelling found in that region

---

Feel free to contact me for further discussions! gusschmbe@student.gu.se