

Project Assignment

Florian Sévellec

These instructions, the code, and the needed restart file are accessible at:

http://people.umr-lops.fr/~fsevelle/Teaching/advanced_methods_2026.html

For this Assignment, you will use an idealized model of the heat content and stratification of the ocean (mainly relevant for the Atlantic). This model is based on Marshall and Zanna (2014), it is an adapted version not the exact same model. In the first part you will assess in this model how the circulation, heat content, and stratification are modified when we change the two main parameters (vertical diffusivity and wind stress over the Southern Ocean) controlling the AMOC “regime” (*i.e.* the two paradigms of the AMOC). In the second part you will assess how the heat content and stratification are modified under transient scenarios (AMOC reduction and global warming scenarios). For both part relating your results to the state-of-the-art knowledge of the real ocean circulation is crucial (*i.e.* keeping in mind the limits of the idealized model).

The numerical model is a layer model. This means that the temperature is not modified but the thickness of the layer representative of this temperature. In this model the vertical thermal structure is constrained by 4 fluxes (or water mass transformation rates):

- a) Southern Ocean wind-induced transport,
- b) Southern Ocean eddy-flux,
- c) Interior upwelling by diapycnal mixing, and
- d) North Atlantic deep water formation.

In this model the vertical temperature solution is given by a single value at each levels (or more accurately a single value of layer thickness is given for each temperature values). We could interpret this value as a horizontal average for the Atlantic between 35°S and 35°N (*i.e.* north of the Southern Ocean and south of the deep water formation).

Part A [50%]: The two paradigms of the AMOC and its associate heat content

Using `heat_structure.py` (or `heat_structure.m`), answer the following questions, with the aid of tables or figures where appropriate:

In this first part you will be a “user” of the `heat_structure.py` routine (or `heat_structure.m`). You will only have to change parameters, ensure that the code have run correctly and make figures of diagnostics you want. This is for you to decide which diagnostic seems relevant to answer the questions below. Note that unlike the next part this part mainly deals with equilibrate/asymptotic results (long time integration).

(1) [15/50] How does the vertical diffusivity qualitatively modify the heat content, thermal vertical stratification, and mass transport in the North Atlantic? Quantitatively estimate the sensitivity of the heat content vs vertical diffusivity. Do the same quantitative estimate for the AMOC, *i.e.* North Atlantic deep water formation, evaluated at 500 m.

(2) [15/50] How does the wind stress over the Southern Ocean qualitatively modify the heat content, thermal vertical stratification, and mass transport in the North Atlantic? Quantitatively estimate the sensitivity of the heat content vs Southern Ocean wind stress. Do the same quantitative estimate for the AMOC, *i.e.* North Atlantic deep water formation, evaluated at 500 m.

(3) [20/50] Quantitatively estimate the cross-sensitivity of the vertical diffusivity and the wind stress to heat content and mass transport in the North Atlantic.

Part B [50%]: Transient scenarios

Starting from `heat_structure.py` (or `heat_structure.m`) and `heat_exp0.mat`, answer the following questions, with the aid of tables or figures where appropriate:

In this second part you will be a “developer” of a new routine based on `heat_structure.py` routine (or `heat_structure.m`). You will need to change the code to build your experiments. This is still for you to decide which diagnostics seem relevant to answer the questions below.

You will start from the equilibrate results with the default parameters (`heat_exp0.mat`), that will be considered as the current state of the ocean, *i.e.* the initial state before which the transient scenarios are applied.

(1) [20/50] Test the AMOC (North Atlantic deep water formation) reduction trend (-0.25 , -0.5 , and -1 Sv yr^{-1}) and event (and 50% reduction for 2 years) for heat content and vertical heat structure, in a decadal simulation (*i.e.* 10 years). Such trends were detected by Smeed et al (2014, lecture 3), whereas the event corresponds roughly to the 2009/2010 events (lecture 3). Compare the relative impact of event and trend.

(2) [20/50] Test the impact of Global Warming following three typical scenarios of surface warming for the next century (1, 2, and 4 K per century) on heat content and vertical heat structure.

(3) [10/50] In the context of the global warming scenario (question – B2), future changes in wind, and thus Southern Ocean wind stress, are relatively unknown. Build a set of experiments to test the impact of this uncertainty on previous results (B2).

Marking criteria:

For each part

Aim/Context. Have you **briefly** described the question and put it in the wider scientific context?

Results. Have you concisely presented the key results? Have you made appropriate use of tables and/or figures? Is your work well presented?

Discussion. Have you correctly interpreted the results of your experiments? Have you assessed how limitations in the model (compared to state-of-the-art knowledge) may specifically affect your conclusions? Are your conclusions clear and consistent with the evidence?

References:

- Marshall, D. P. and L. Zanna, 2014: A Conceptual Model of Ocean Heat Uptake under Climate Change. *J. Climate*, 27, 8444-8465. doi: <http://dx.doi.org/10.1175/JCLI-D-13-00344.1>
- Gnanadesikan, A., 1999: A simple predictive model of the structure of the oceanic pycnocline. *Science*, 283, 2077-2081. doi:10.1126/science.283.5410.2077
- Nikurashin, M., and G. Vallis, 2011: A theory of deep stratification and overturning circulation in the ocean. *J. Phys. Oceanogr.*, 41, 485-502. doi:10.1175/2010JPO4529.1.
- Nikurashin, M., and G. Vallis, 2012: A theory of the interhemispheric meridional overturning circulation and associated stratification. *J. Phys. Oceanogr.*, 42, 1652-1667. doi:10.1175/JPO-D-11-0189.1.

FURTHER REQUIREMENTS AND GUIDANCE

- 1) The formal length limit for this work is **7 A4 pages** including all submitted material.
- 2) Submit your final assignment as a single PDF file by email to Florian Sévellec (florian.sevellec@univ-brest.fr).
- 3) Ensure that Parts A and B are clearly separated, and that each of the individual questions are clearly identified.
- 4) Use figures and time-series to support your conclusions.

DEADLINE

Submit on **27 March 2026, 11:59 pm**, by email to Florian Sévellec (florian.sevellec@univ-brest.fr). This assignment counts for 50% of the total for the module.

Florian Sévellec; Revised version February 2026