Comparing water, energy and entropy budgets of aquaplanet climate attractors

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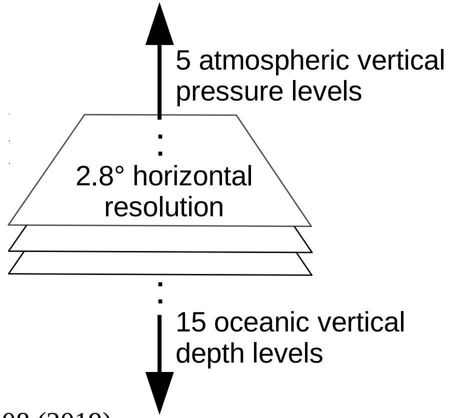
Brunetti et al. (2019) obtained alternative climate attractors using the MIT general circulation model (MITgcm) in coupled aquaplanets under the same forcing (*i.e.* same solar energy input and CO_2 content in the atmosphere) [1].

To evaluate the impact of model configuration on energy, water mass and entropy budgets and associated transports, we apply the Thermodynamic Diagnostic Tool (TheDiaTo) [2] to these climate attractors and different model configurations.

Goal: identify which configuration is the best from the point of view of global conservation and efficiency of the thermal engine

Consider a hot state attractor (*i.e.* without ice) in two configurations, where heating caused by friction and momentum dissipation is:

- re-injected to the system
- lost



[1] Brunetti M., Kasparian J., Vérard C., Co-existing climate attractors in a coupled aquaplanet, Climate Dynamics 53, 6293-6308 (2019)
[2] Lembo V., Lunkeit F., Lucarini V., TheDiaTo (v1.0) – a new diagnostic tool for water, energy and entropy budgets in climate models, Geosci. Model Dev. 12, 3805-3834 (2019)

Energy and water mass budgets

- 20-year average of hot-state simulations:

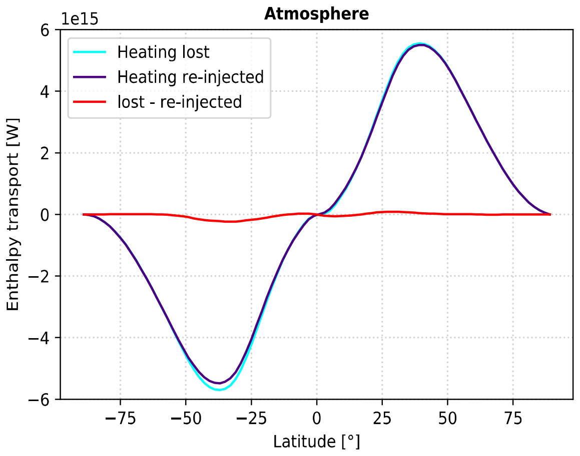
	Heating lost	*Heating re-injected*
Energy budget at top of the atmosphere [W/m²]	2.49	-0.05
Energy budget at the ocean surface [W/m²]	0.21	0.16
Evaporation – Precipitation [kg/(m²·s) x 10⁻⁸]	0.39	0.49

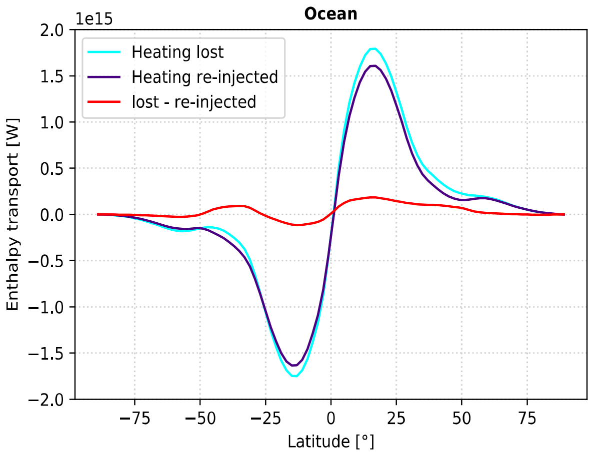
→ energy imbalance is significantly reduced

→ close to zero in the two cases since both simulations reach a steady-state

→ well closed in both configurations

- Meridional enthalpy transport:

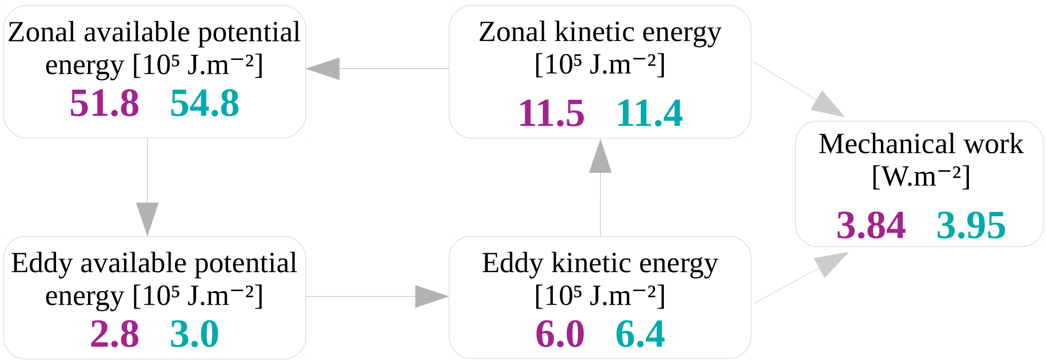




→ Atmospheric heat transport pretty similar in the two cases

→ More intense oceanic heat transport when friction heating is lost: peaks about 6.9% (resp. 11.2%) more in southern (resp. northern) hemisphere

Lorenz Energy Cycle



Friction heating is re-injected
Friction heating is lost

→ Storage terms of energy and dissipation are of the same order of magnitude for the two configurations

→ Storage of zonal available potential energy is slightly smaller when friction heat is re-injected in agreement with what is found in warmer climates [2]

Material entropy production (MEP)

MEP [mW/(m².K)] associated to…	Evaporation	Rainfall (including both water and snow)	Potential energy of droplets	Hydrological cycle	Sensible heat fluxes	Kinetic energy	$\mathbf{MEP}_{total}$
Heating re-injected	-376.9	419.0	6.5	48.6	0.9	13.0	**62.6**
Heating lost	-370.8	412.1	6.3	47.6	1.1	13.5	**62.1**

→ Indirect method cannot be used because the number of pressure levels is too low (N=5) and it does not permit a sufficiently good representation of vertical processes
→ Friction heating has little impact on the total entropy production

Summary and future work

The main signature of re-injecting friction heating into the system is a more balanced energy budget at the top of the atmosphere, associated to a less intense meridional heat transport in the ocean and to a smaller storage of zonal available potential energy.
Outlook: extend the analysis to other MITgcm configurations (e.g. different cloud parameterizations, CO_2 exchange between atmosphere and ocean) and to different climate steady-states.