Comparing water, energy and entropy budgets of aquaplanet climate attractors

Charline Ragon\textsuperscript{1,2}, Valerio Lembo\textsuperscript{3}, Valerio Lucarini\textsuperscript{3,4}, Jérôme Kasparian\textsuperscript{1,2}, and Maura Brunetti\textsuperscript{1,2}

\textsuperscript{1}Institute for environmental sciences, University of Geneva, Geneva, Switzerland (charline.ragon@unige.ch)
\textsuperscript{2}Group of applied physics, University of Geneva, Geneva, Switzerland
\textsuperscript{3}Meteorological Institute, University of Hamburg, Hamburg, Germany
\textsuperscript{4}Department of Mathematics and Statistics, University of Reading, Reading, UK

Brunetti et al. (2019) obtained alternative climate attractors using the MIT general circulation model (MITgcm) in coupled aquaplanets under the same forcing (\textit{i.e.} same solar energy input and CO\textsubscript{2} content in the atmosphere) \cite{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) \cite{2} to these climate attractors and different model configurations.

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

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

- re-injected to the system
- lost

\begin{enumerate}
\item Brunetti M., Kasparian J., Vérard C., Co-existing climate attractors in a coupled aquaplanet, Climate Dynamics 53, 6293-6308 (2019)
\item 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)
\end{enumerate}
Energy and water mass budgets

- 20-year average of hot-state simulations:

<table>
<thead>
<tr>
<th></th>
<th>Heating lost</th>
<th>Heating re-injected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy budget at top of the atmosphere [W/m²]</td>
<td>2.49</td>
<td>-0.05</td>
</tr>
<tr>
<td>Energy budget at the ocean surface [W/m²]</td>
<td>0.21</td>
<td>0.16</td>
</tr>
<tr>
<td>Evaporation – Precipitation [kg/(m².s) x 10⁻⁸]</td>
<td>0.39</td>
<td>0.49</td>
</tr>
</tbody>
</table>

→ 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
Material entropy production (MEP)

<table>
<thead>
<tr>
<th>MEP [mW/(m².K)] associated to...</th>
<th>Evaporation</th>
<th>Rainfall (including both water and snow)</th>
<th>Potential energy of droplets</th>
<th>Hydrological cycle</th>
<th>Sensible heat fluxes</th>
<th>Kinetic energy</th>
<th>MEP total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating re-injected</td>
<td>-376.9</td>
<td>419.0</td>
<td>6.5</td>
<td>48.6</td>
<td>0.9</td>
<td>13.0</td>
<td>62.6</td>
</tr>
<tr>
<td>Heating lost</td>
<td>-370.8</td>
<td>412.1</td>
<td>6.3</td>
<td>47.6</td>
<td>1.1</td>
<td>13.5</td>
<td>62.1</td>
</tr>
</tbody>
</table>

→ 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, CO₂ exchange between atmosphere and ocean) and to different climate steady-states.