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Insights from extremum principles:\\The effects of diffusivity parameters on entropy budgets within an ocean-atmosphere-ice model

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Entropy budgets can potentially offer new and valuable insights into the dissipation of energy in the climate system. Previous studies that assumed entropy produced via the latitudinal flux of heat in the Earth's atmosphere was at a maximum have given good agreement with empirical data. Here, we extend such approaches to a four box ocean-atmosphere-ice model. We test the hypothesis that the Earth system is in a state of maximum entropy production with respect to the flux of heat within, and from low to high latitudes via the oceans and atmosphere. Extending a model developed by Jochem Marotzke, we calculate the total *internal* entropy production (the sum of entropy production associated with the four ocean and atmosphere boxes), and go on to decompose this into the low/high latitude oceanic and low/high latitude atmospheric boxes (*latitudinal*), as well as ocean/atmosphere boxes (*vertical*). By adjusting rates of diffusivity between low and high latitude ocean (k_O) and atmosphere (k_A) boxes we construct an entropy landscape.

When adjusting k_O and k_A to maximize total system entropy production ($k_O = 3.3 \times 10^{14}\mathrm{WK}^{-1}$ and $k_A = 3.2 \times 10^{14}\mathrm{WK}^{-1}$) the model produces low latitude ocean temperatures within 3°C and high latitude ocean temperature within 1°C of observed values. This compares favourably to empirically determined values for k_O and k_A which produce ocean temperatures within 5°C for low latitudes and 3°C for high latitudes, and both models are within standard deviation for observational data.

The landscape of *internal* entropy production created by the oceanic and atmospheric diffusivity was found to be fairly smooth, with non-linearities primarily due to ice albedo. We note that the total *internal* entropy production in the modelled climate system is maximised by a lower *internal* ocean entropy production than that produced using empirically determined parameters. *Vertical* entropy production over the entire parameter space is dominated by lower latitude interactions. However, total system entropy production is maximized with values of k_O approximately 50% higher than empirically derived values. These are within a regime where higher latitude *vertical* interactions can have a significant impact on total *vertical* entropy production, due to a discontinuity arising from ice extent and thus albedo changes. Atmospheric *internal* entropy production (significantly larger than oceanic *internal* entropy production) is strongly determined by k_O. We interpret this as a result of the ocean's role as a heat reservoir, and the atmosphere as the main transport mechanism.