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What can land-free Earth teach us about climate evolution?

by **Ariadna Fossas Tenas**[1] | PhD Student

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[1]: Environmental Sciences Institute, University of Geneva, Geneva, Switzerland

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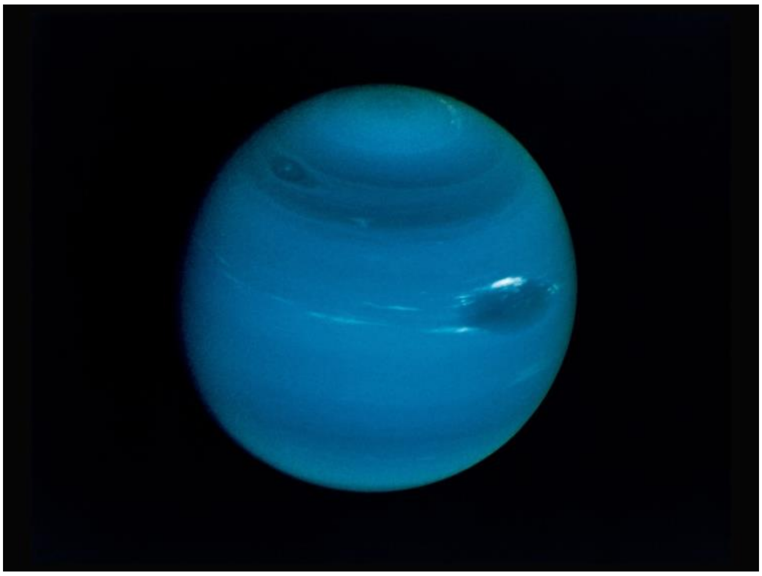
The Earth's climate is a complex, dynamic system and understanding of how it evolves still poses challenges. In a new study, researchers simplified Earth to a model Aquaplanet – a land-free version of our planet – and discovered five climate scenarios.



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Predicting how the climate on our planet is evolving is crucial, especially under the ongoing climate change. But it is a challenging task, because the Earth climate is a complex, ever-changing system, involving many different factors influencing each other: sunlight, atmospheric carbon dioxide, polar ice cover, ocean circulation to name a few. In a new study, the researchers simulated an imaginary, land-free Earth to model the climate and its changes over time.

It has been increasingly challenging to understand the evolution of the climate system, especially considering human influence. However, the changes are not random and follow certain 'rules' – the climate tends to evolve into a stable state that is called an 'attractor' of the dynamic system. An attractor is a stable point towards which variables of a dynamic system tend to evolve over time (visit this link that visually represents the concept). Importantly, this 'goal' – which attracts all the variables – is the same for a wide range of starting conditions. Imagine you throw a cherry into an empty breakfast bowl. It will randomly move around until it stabilizes on the bottom. This flat bottom is the attractor of the bowl system – no matter how you throw the cherry into the bowl, it will always stop moving there.

Back to the Earth's climate system, which is much more complex than the simplest breakfast bowl system, it is not even clear if it has single or multiple attractors. If the dynamic climate system includes multiple attractors, its evolution could take different possible scenarios. Knowing how many climate attractors are present is crucial because when multiple attractors coexist, minor changes could irreversibly decide the fate of the climate evolution. Imagine two breakfast bowls (two different attractors) placed on the table next to each other, and you hold a cherry on the boundary between them. When you gently release the cherry, it falls into either bowl. Following this gentle action, once the cherry begins to fall into a bowl, it is nearly impossible to move into another bowl.

To identify the attractors, scientists carry out computational simulations to model the evolution of the dynamic system in many different initial settings. However, the modeling of the highly complex climate system is too time-consuming even using a supercomputer. To solve this problem and identify climate attractors, the researchers simulated an imaginary Earth called Aquaplanet – excluding all the land (continents and islands), which simplifies the computations enough to identify climate attractors.

The researchers applied a numerical climate model called MITgcm for the Aquaplanet. This model allowed them to predict atmospheric temperatures on the imaginary Earth in various settings considering clouds, ocean circulation and temperature, polar sea ice cover, etc. To simplify computer simulations, they supposed that sunlight intensity and carbon dioxide levels in the atmosphere don't change over time. They also took into account the interactions between these climate factors. For example, polar sea ice cover is highly interactive because when ocean temperatures rise, the ice melts more, which, in turn, causes even more warming as water traps more heat than ice does. Indeed, climate scientists increasingly raise a concern about this negative climate feedback – warning that today's global warming may eventually lead to ice-free poles.

This climate modeling enabled the researchers to find five different climate attractors that the Aquaplanet could reach under the same solar irradiation and atmospheric carbon dioxide levels, depending on initial conditions. The five different climate attractors broadly range from a cold Aquaplanet fully covered by ice to a hot Aquaplanet where atmospheric temperatures are higher than today's Earth and the polar ice is completely melted. Once climate reaches one of these attractors, it becomes stable and won't change unless considerable changes in sunlight intensity or atmospheric carbon dioxide amount happen.

Even though the climate system of the Aquaplanet does not simply reflect that of our planet, this study suggests that the Earth has multiple climate attractors. Other studies support this multiple attractor hypothesis. For example, scientists recently proposed that glacial and interglacial cycles are driven by two different climate attractors. These are similar to two of the five attractors on the Aquaplanet the researchers found in this study. Further extending our understanding of Earth's climate attractors will help us to sort out towards which goal the climate is heading and to put forward mitigation and adaptation strategies.