Ice Sheet Models for Exoplanets

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In brief

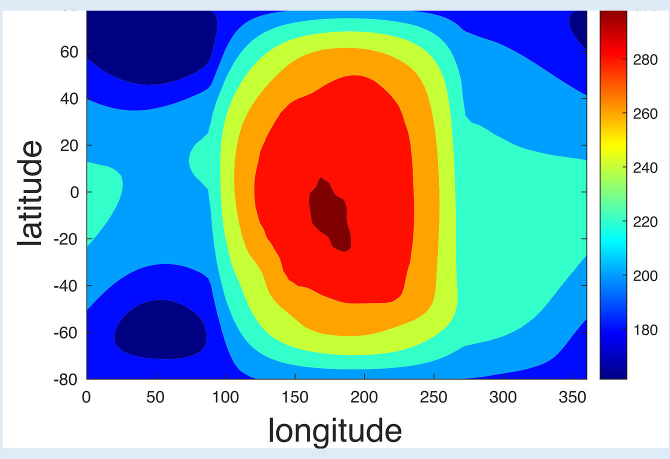
It is expected that most exoplanets will have a climate very different to the Earth's because one side of the planet's surface receives constant light from the star and the other side is permanently kept in the dark . We set out to study the ice sheets of ocean-covered planets to determine if they could be a habitable environment. In this climate, we want to know if liquid water is available on the warm dayside and how much ice will accumulate on the nightside. We adapted a global ice flow model study the evolution of the ice sheet. We now have a tool to test out potential scenarios to constraint the water budget on various exoplanets given surface temperature and initial ice coverage.

Tidal locking

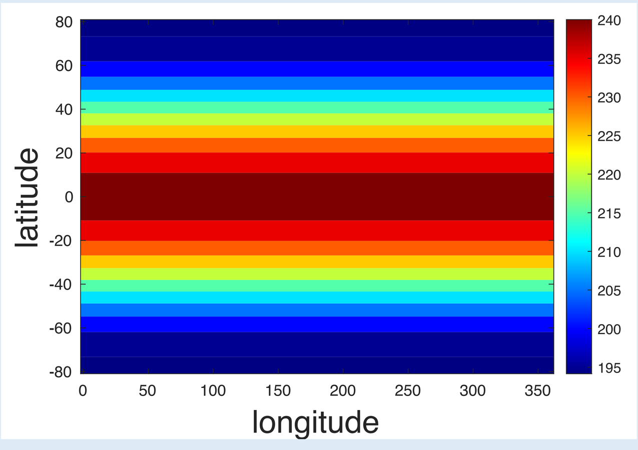
To study potentially habitable worlds, we look for exoplanets in the habitable zone of their star. This is the distance from the host star at which the planet is warm enough to have liquid water at its surface [1]. The most common stars in the galaxy are low mass stars, for which the habitable zone is very close to the star [2]. Due to the gravitational attraction from orbiting so close, the planets are likely tidally locked [2]. This results in a permanent dayside and a permanent nightside, like the moon.

Tidal locking causes a difference in the surface temperature profile of the planet. In the model, this is the difference between the two:

Tidally Locked
- Coldest zone at the pole
- Hottest zone at substellar point
- Eyeball feature



Fully rotating (like the Earth)
- Coldest zone at the pole
- Hottest zone at equator
- Longitudinal average



Color bar: temperature (K)

Motivation

We are interested in studying the climates of potentially habitable exoplanets to learn about the availability of liquid water at their surface. This has been done before with climate models, but never using a global ice flow model.

What is an exoplanet?

It's any planet outside of our solar system. We have found over 5000 exoplanets since discovering the first one in 1996 [1]. By measuring a planet's mass and radius, we can infer its density and learn about its composition [1]. In this study, we focus on exoplanets with surface oceans.

The Model

We want to study the evolution of ice sheets for tidally locked water worlds. Global Climate Models (GCM) can inform us on the atmospheric properties, but the flow of ice is an important factor in the stability of the climate state [3]. The goal is to couple these two types of models to study the availability of liquid water. To do this, we adapted a two-dimensional ice flow numerical model of Snowball Earth (630 Ma) to tidally-locked exoplanets [3].

Here are some of the implementations we made:

- ✓ Constrained initial parameters with GCM input
- ✓ Changed to a 2D surface temperature profile
- ✓ Exported outputs as netCDF to couple with GCM
- ✓ Create an ice-free evolving open ocean mask
- ✓ Adapt the continental mask to work with the ocean mask

We now have a fully functional floating ice sheet model adapted for exoplanets we can use to run simulations.

Next steps

We continue to improve the model and are still perfecting the feature to account for exoplanets with continents as well as oceans. In the future, we will run scenarios until the model reaches a steady state to study various different exoplanets and constraint the availability of liquid water given the surface temperature. We also hope to couple the model with a global climate model, to inform the parameters used by the ice flow model and get to a steady state that accounts for atmospheric climate.

Acknowledgements and References

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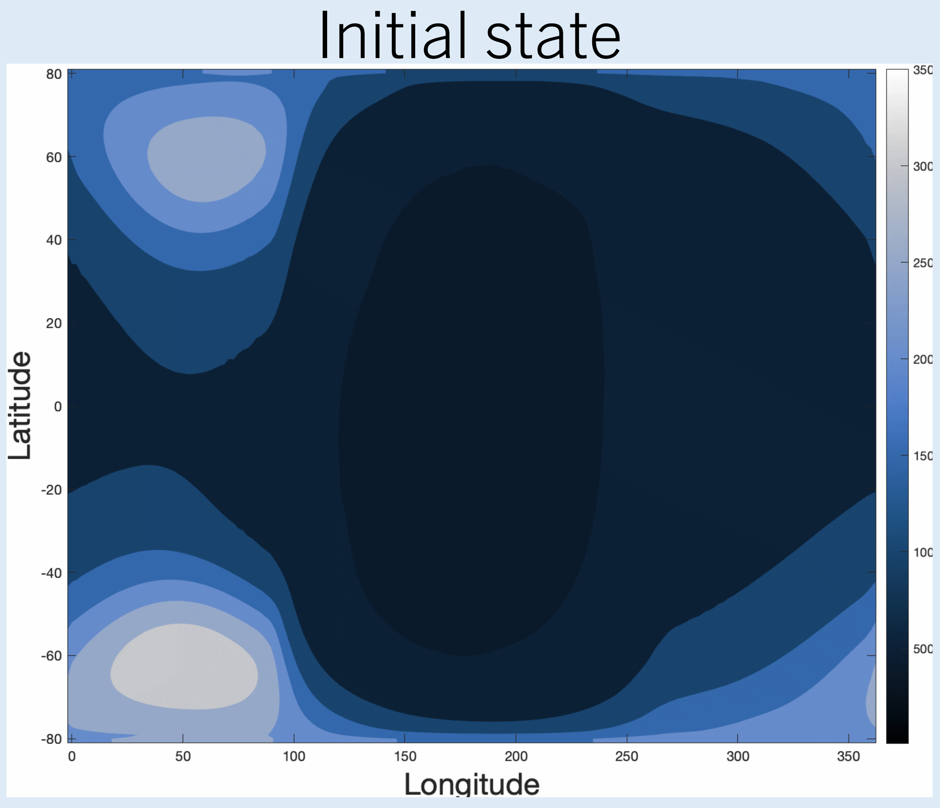
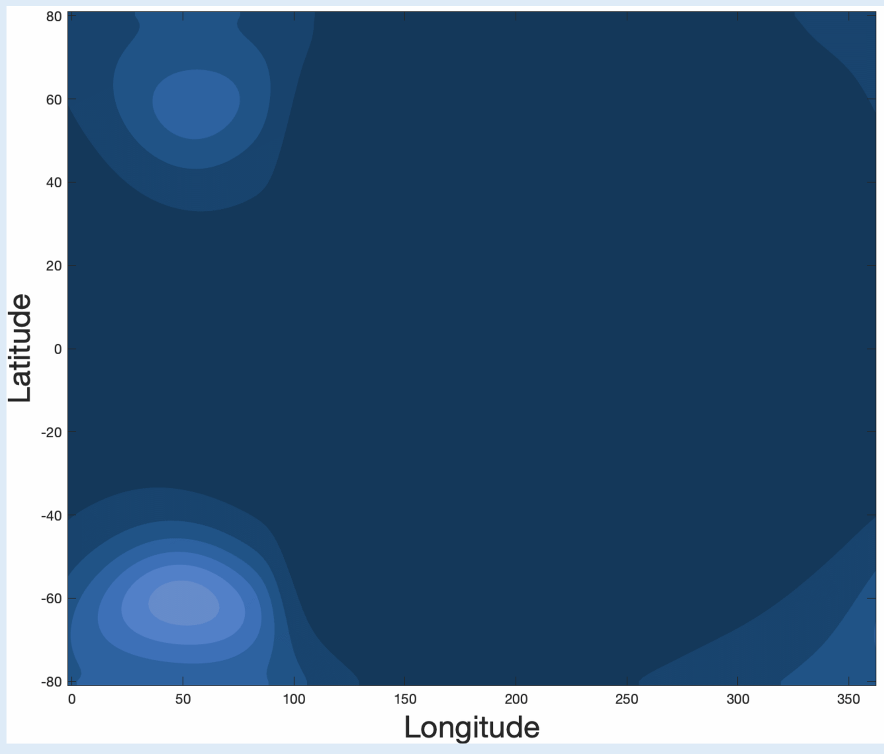
[1] Nasa. https://exoplanets.nasa.gov
[2] Menou. 2013. Astrophys. J. 10.1088/0004-637X/774/1/51
[3] Tziperman et al. 2012. J. Geophys. Res. 10.1029/2011JC007730

Model results: Change in ice elevation in meters over time

Initial state





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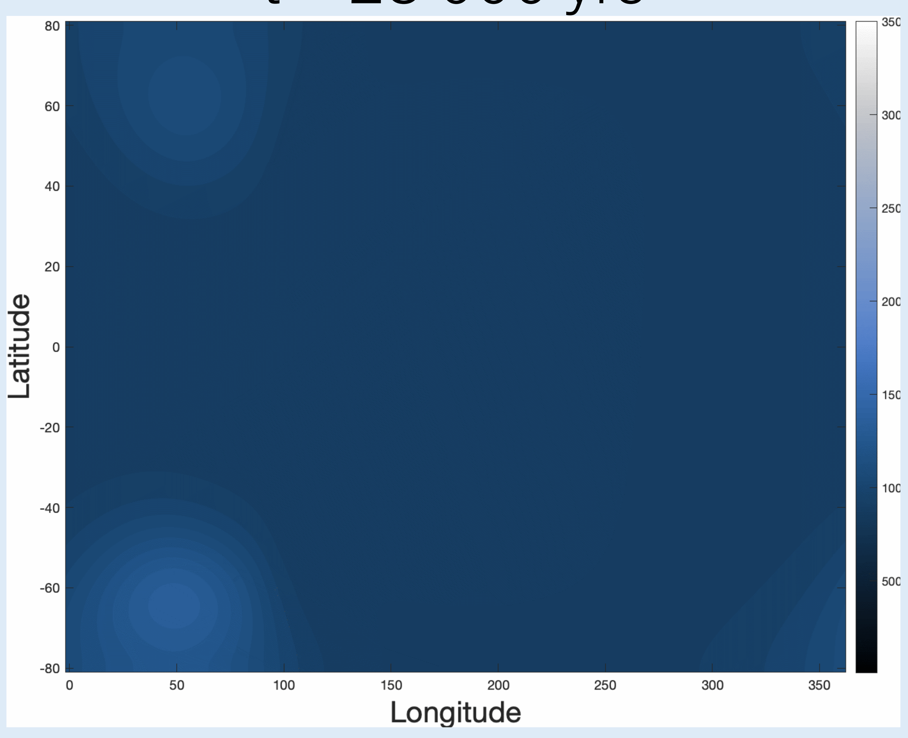

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