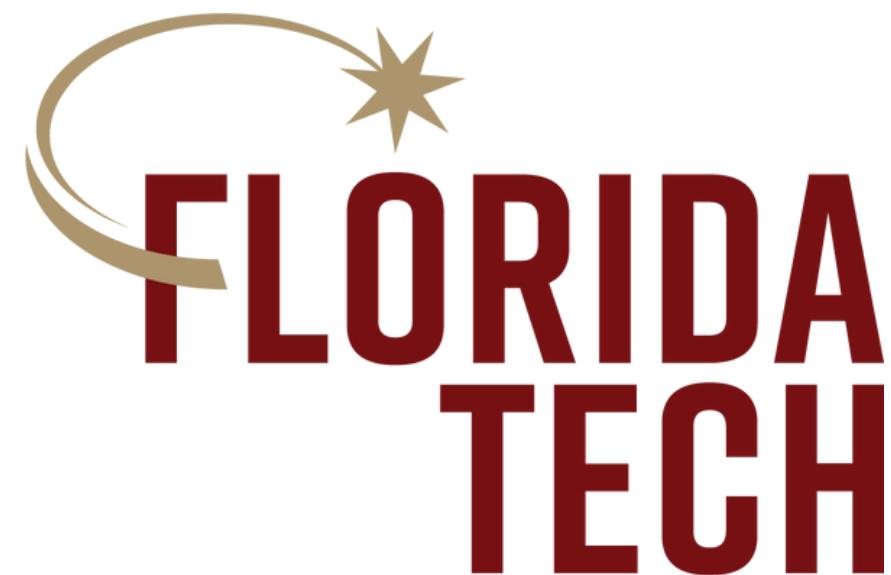


Modelling temperature over varied metrics to determine habitability on exoplanets

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Contents

02

01

Background and Problem
Description

02

Methods

03

Results

04

Discussion and Future work

Habitability

Importance:

Are we alone?

Challenges:

- Finding the exoplanets
- Testing habitability

Conditions of exoplanets

Temperature



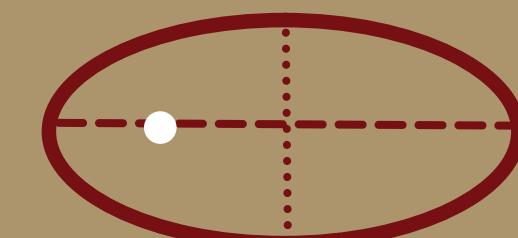
273K - 373K

Obliquity



axial tilt

Eccentricity



0 - 1

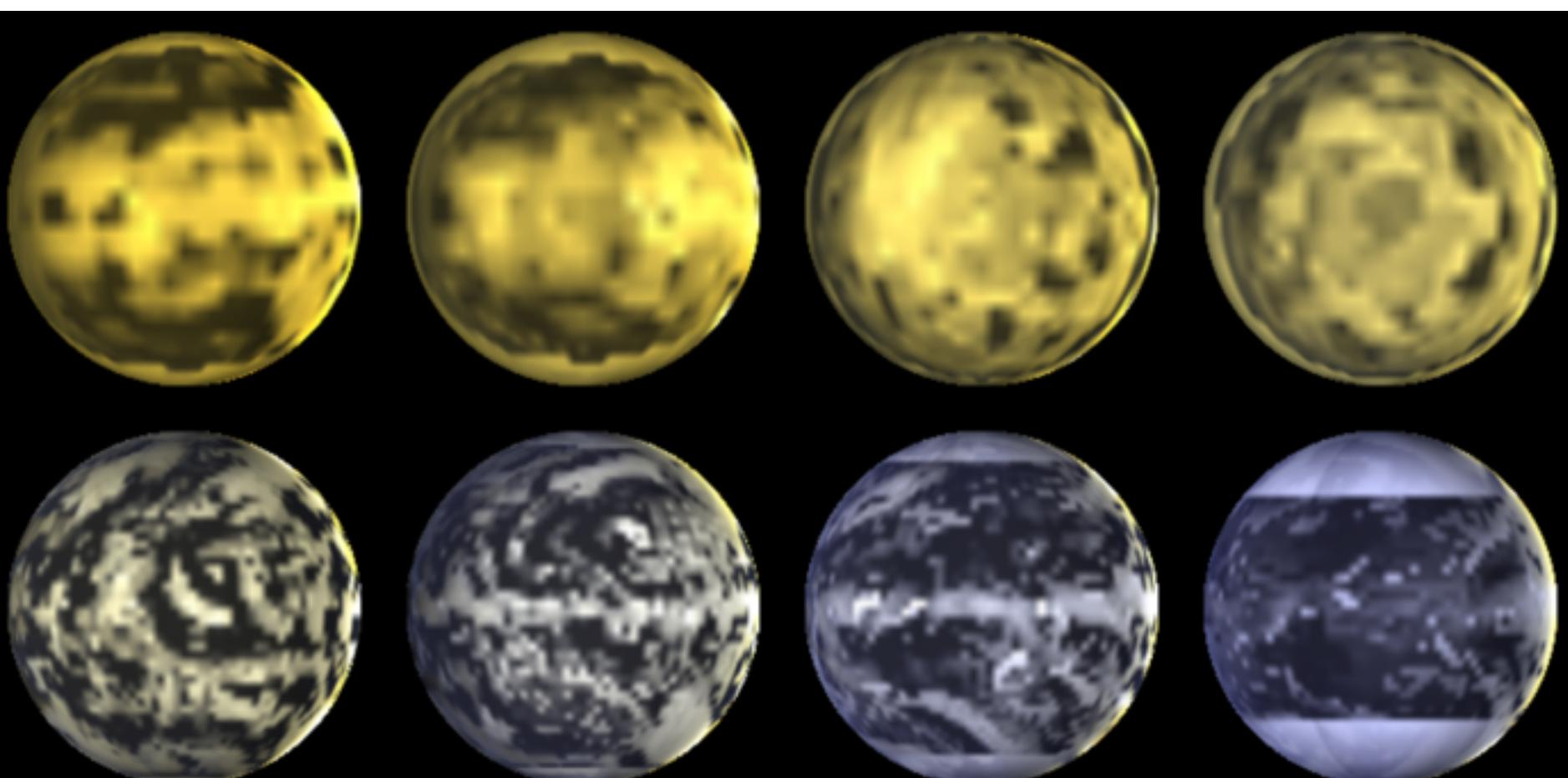
ExoPlaSim

Adiv Paradise

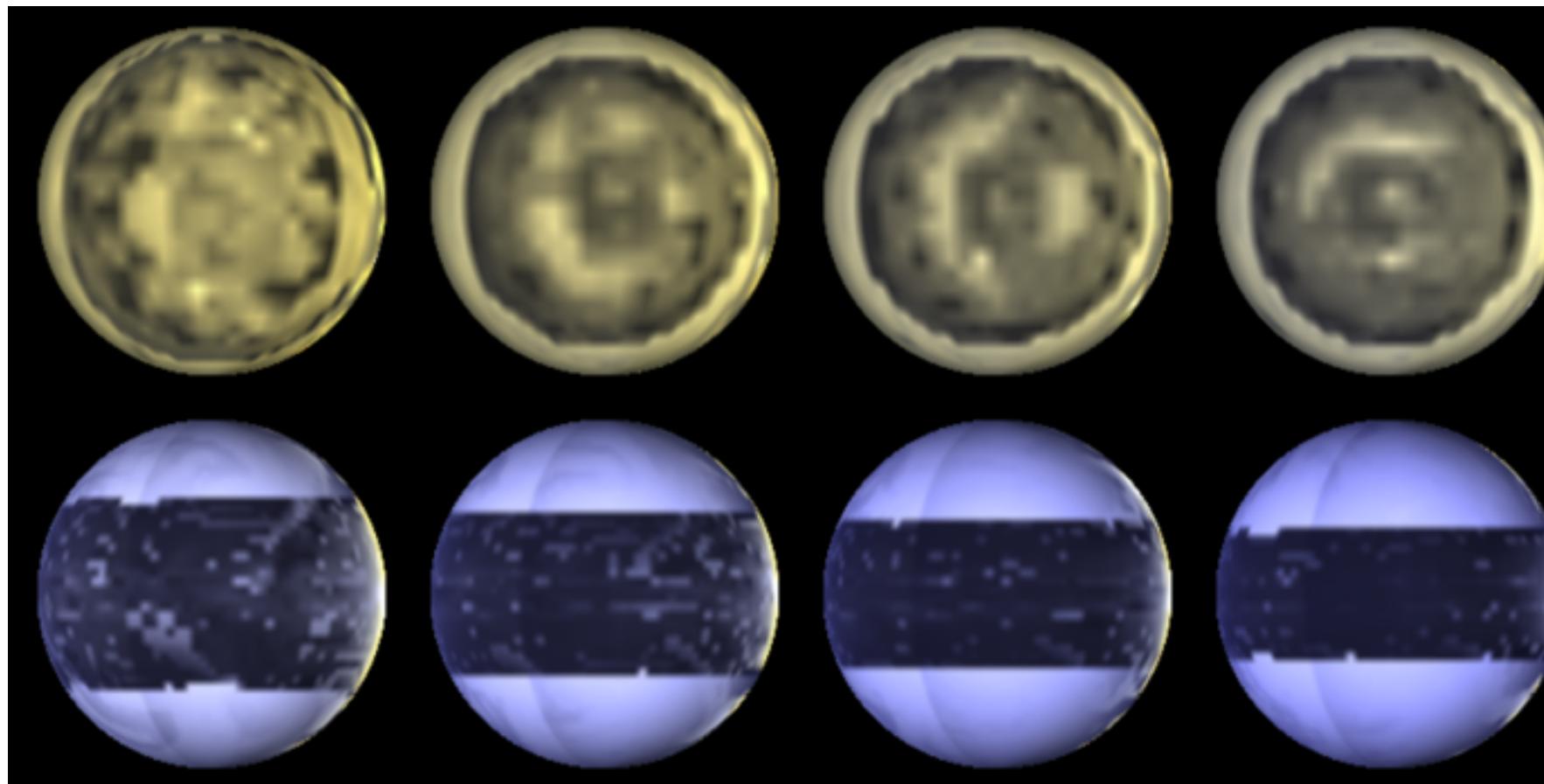
$$\frac{\partial \mathbf{u}}{\partial t} = -(\mathbf{u} \cdot \nabla) \mathbf{u} + v \nabla^2 \mathbf{u} - \frac{1}{\rho} \nabla p + \mathbf{f}$$

change
in
velocity = advection + diffusion + pressure + body
force
with time

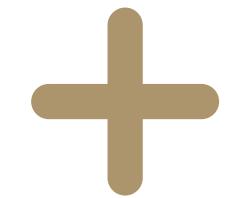
ExoPlaSim, a modified version of the Planet Simulator (PlaSim) that is designed to be applicable to synchronously rotating terrestrial planets, planets orbiting stars with non-solar spectra, and **planets with non-Earth-like surface pressures**. ExoPlaSim is a **General Circulation Model (GCM)** commonly used by meteorologists to model atmospheres using mathematical models and the **Navier-Stokes equations**



Problem description



**Linux OS &
Python 3**



**Specifications
of the planet**



**Temperature
map of
exoplanet**

Methodology

```

toi700d = exo.Model(workdir="toi700d_run",modelname="TOI-700d",
                     ncpus=1,resolution="T21",outputtype=".npz")

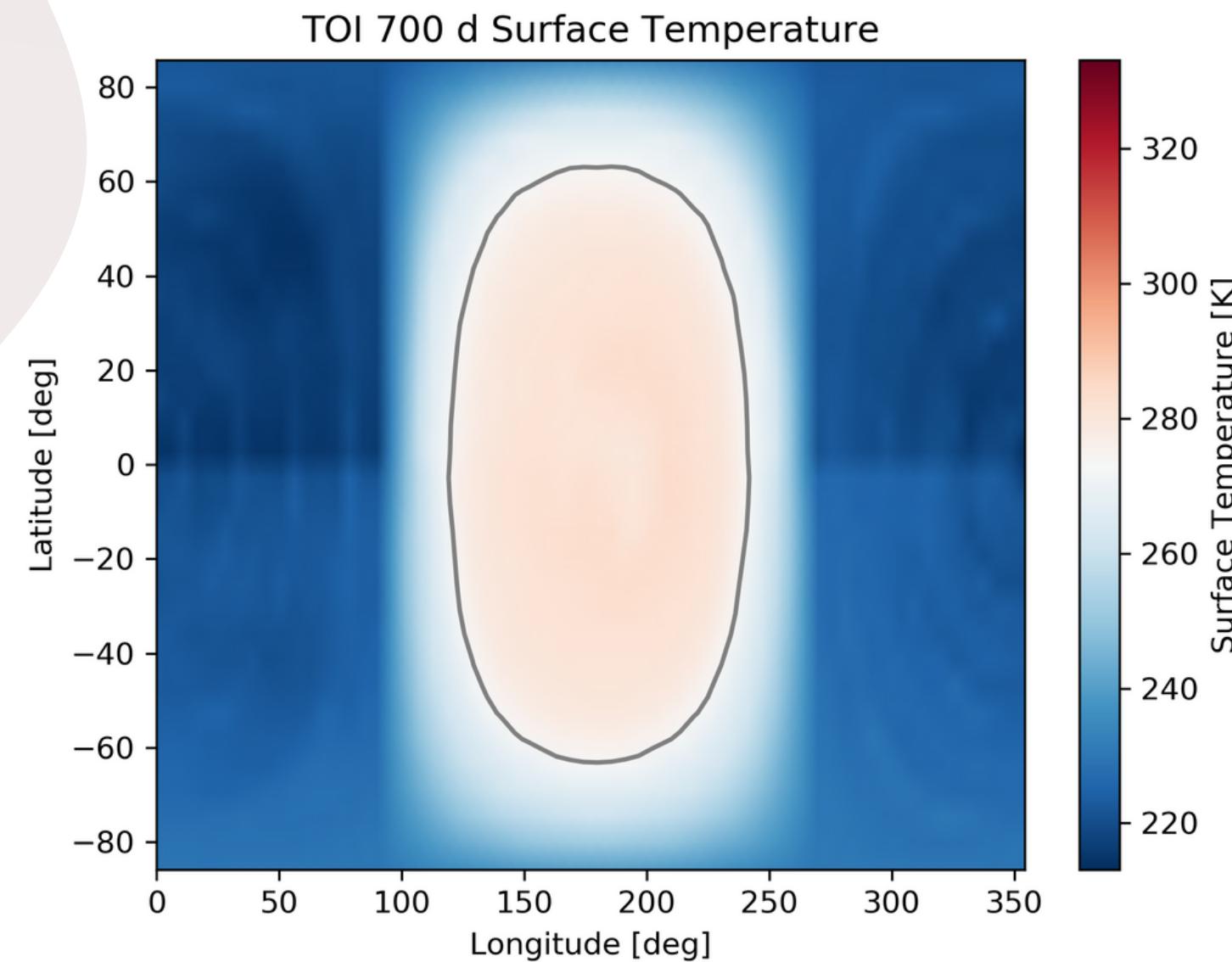
toi700d.configure(starttemp=3480.0, flux=1167.0,
                  eccentricity=0.,obliquity=0.,fixedorbit=True,
                  synchronous=True,rotationperiod=37.426,
                  radius=1.19,gravity=11.9,aquaplanet=True,
                  pN2=1.47*(1-360e-6),pCO2=1.47*360e-6,ozone=False,
                  timestep=30.0,snapshots=720,physicsfilter="gp/exp/sp")* # Model dynamics
toi700d.exportcfg()

toi700d.run(years=1,crashifbroken=True)

```

* We can mitigate the lack of sharp features with the use of physics filters. These are mathematical filters included in the dynamical core at the spectral transform stage. Here we have told ExoPlaSim to use an exponential filter, and to apply it both at the transform from gridpoint space to spectral space, and at the transform from spectral space back to gridpoint space.

Methodology



TOI-700d

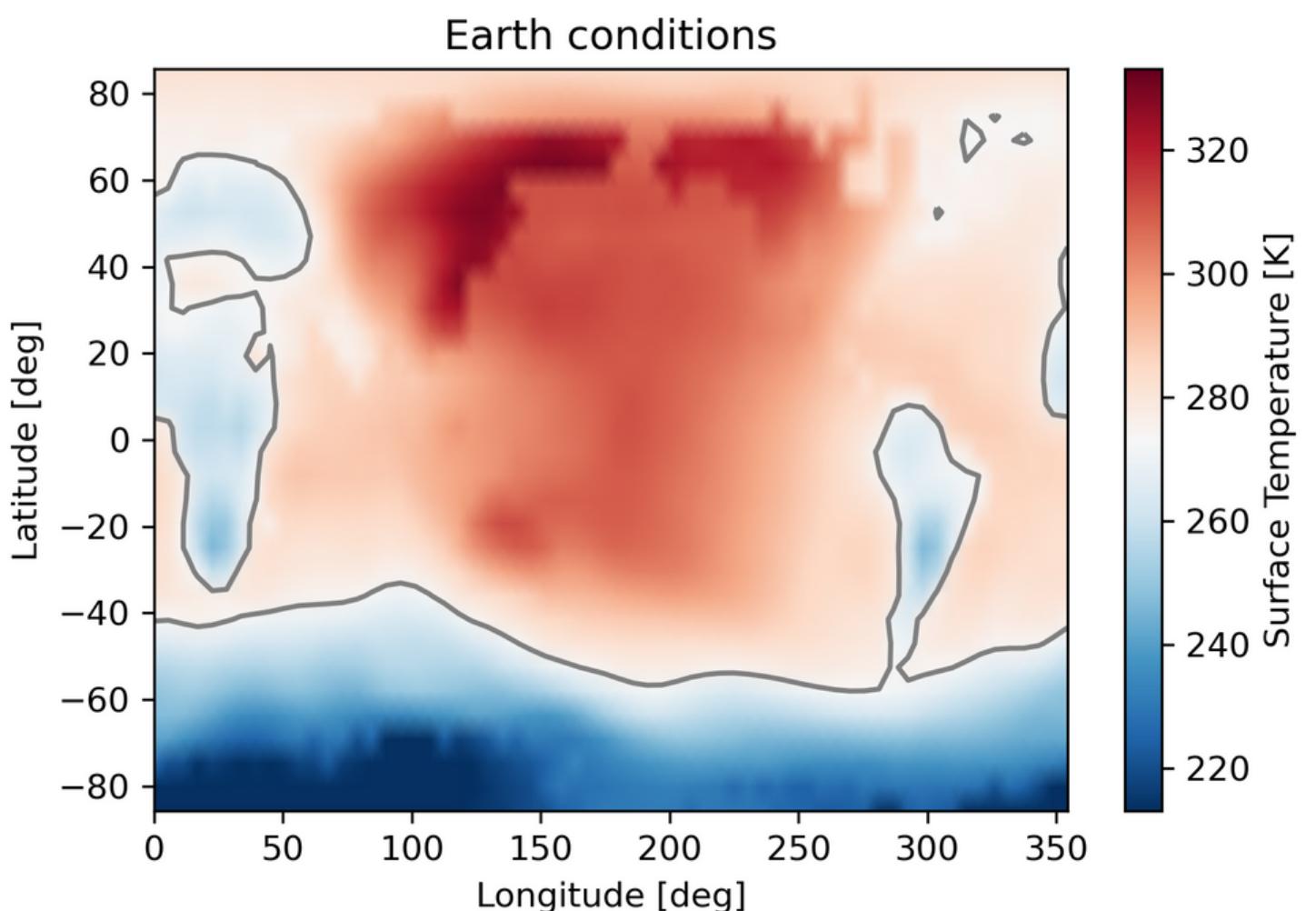
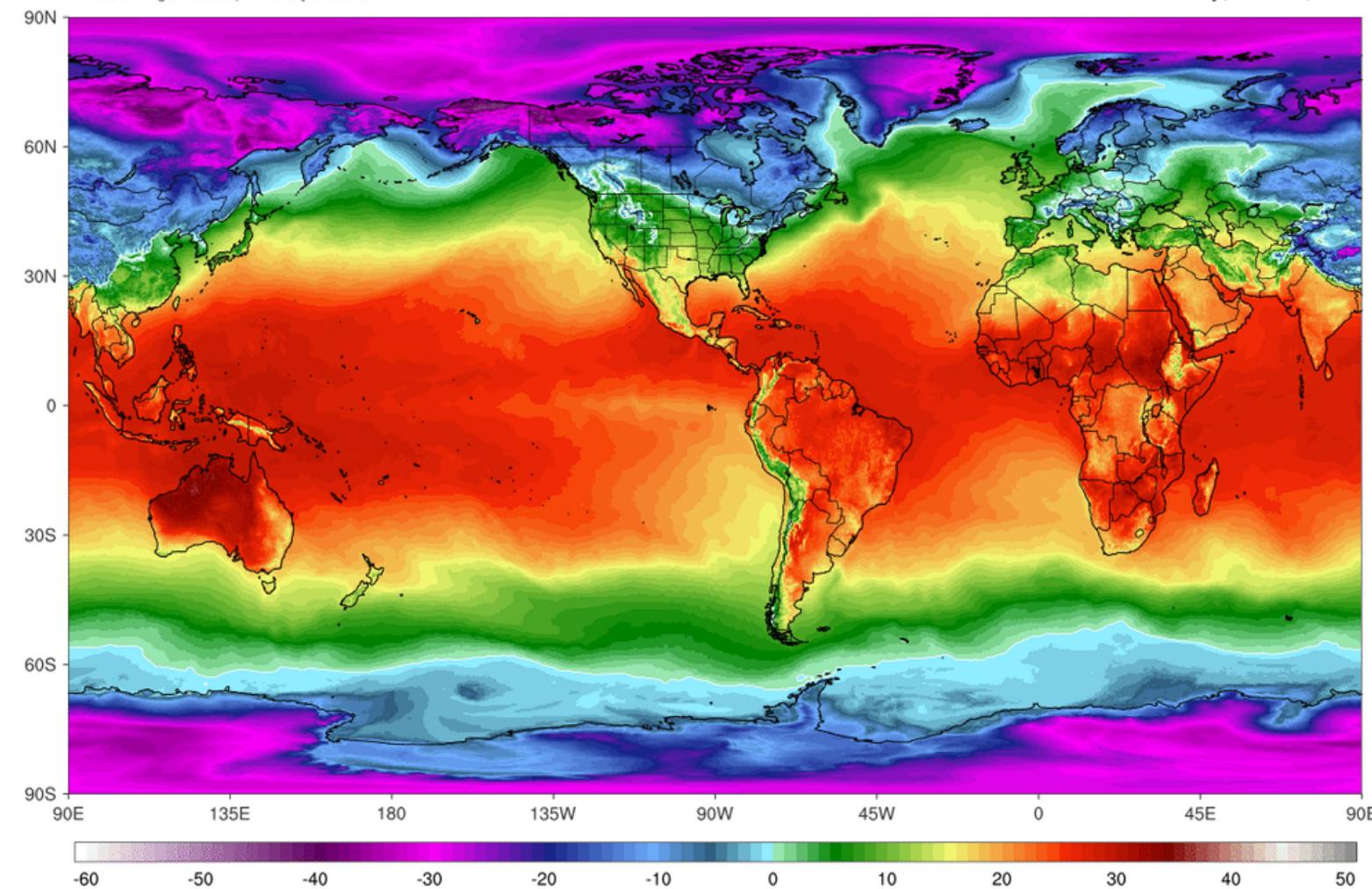
TOI-700 d is a super Earth exoplanet that orbits an M-type star. It is in the Habitable zone of a system with 3 planets. TOI-700 is 102 light years away.

Check out the Exoplanet-catalog – Exoplanet Exploration: Planets Beyond our Solar System TOI-700 d (nasa.gov)
exoplanets.nasa.gov/exoplanet-catalog/7658/toi-700-d/

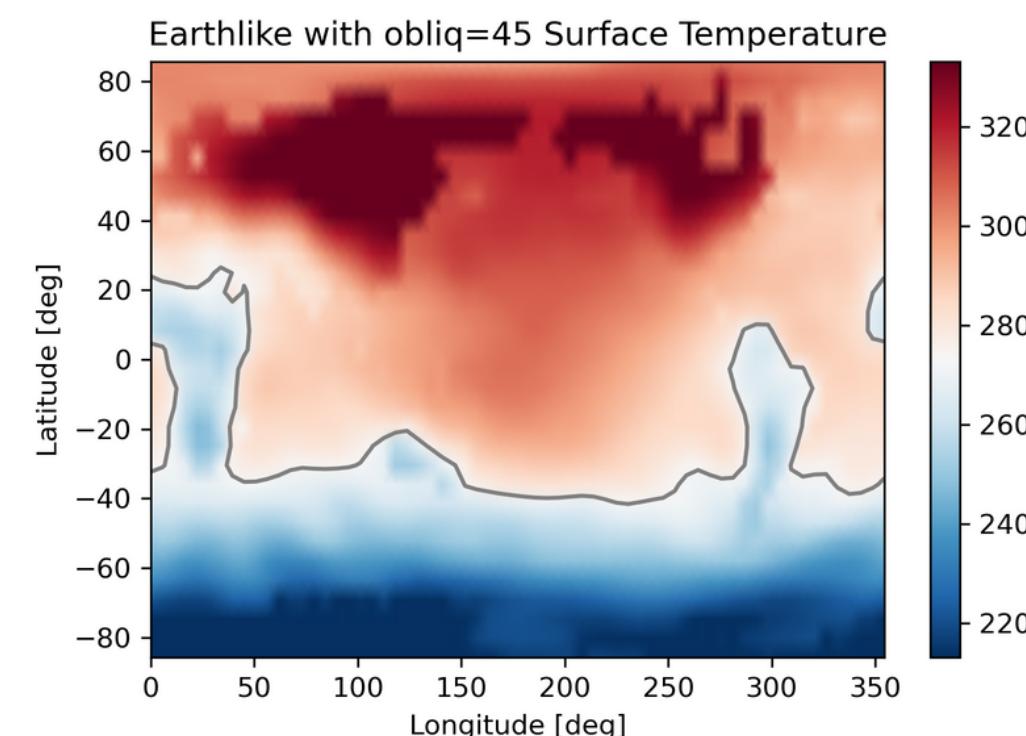
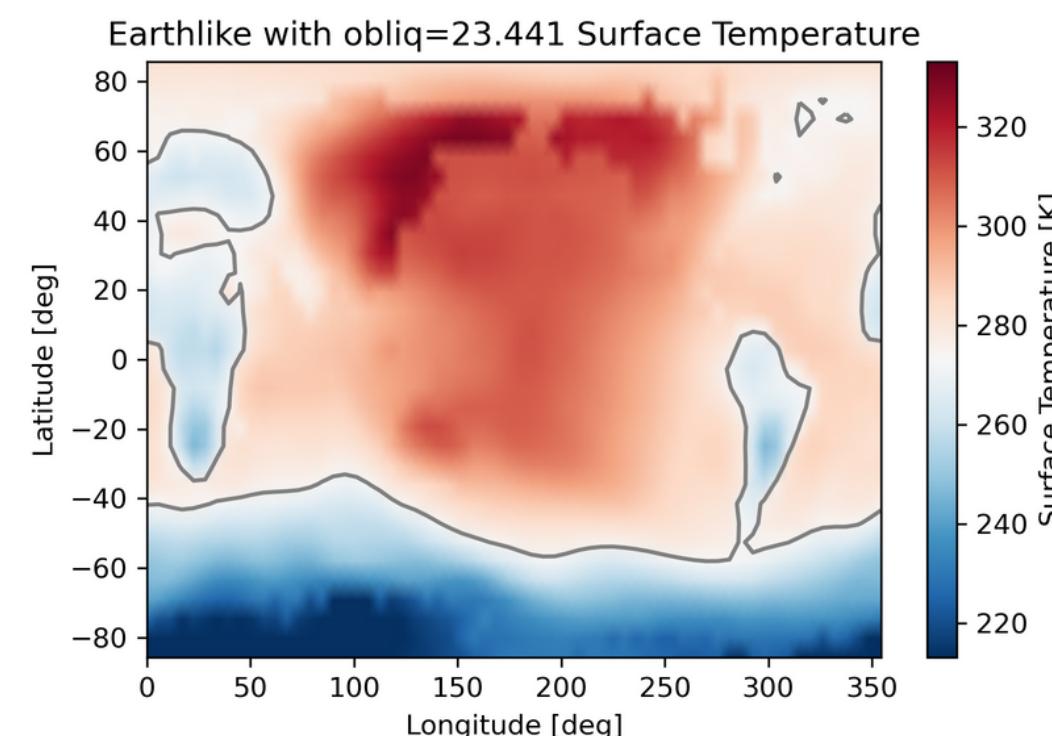
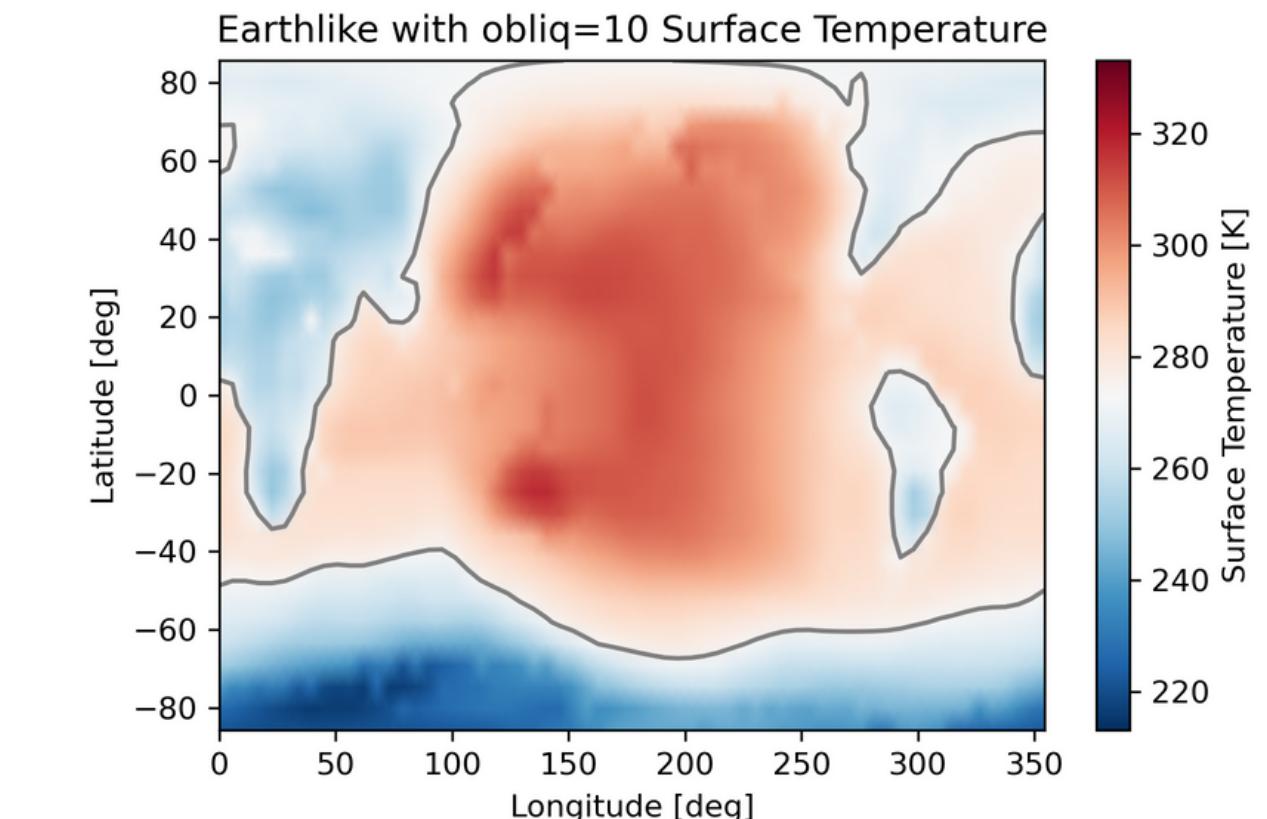
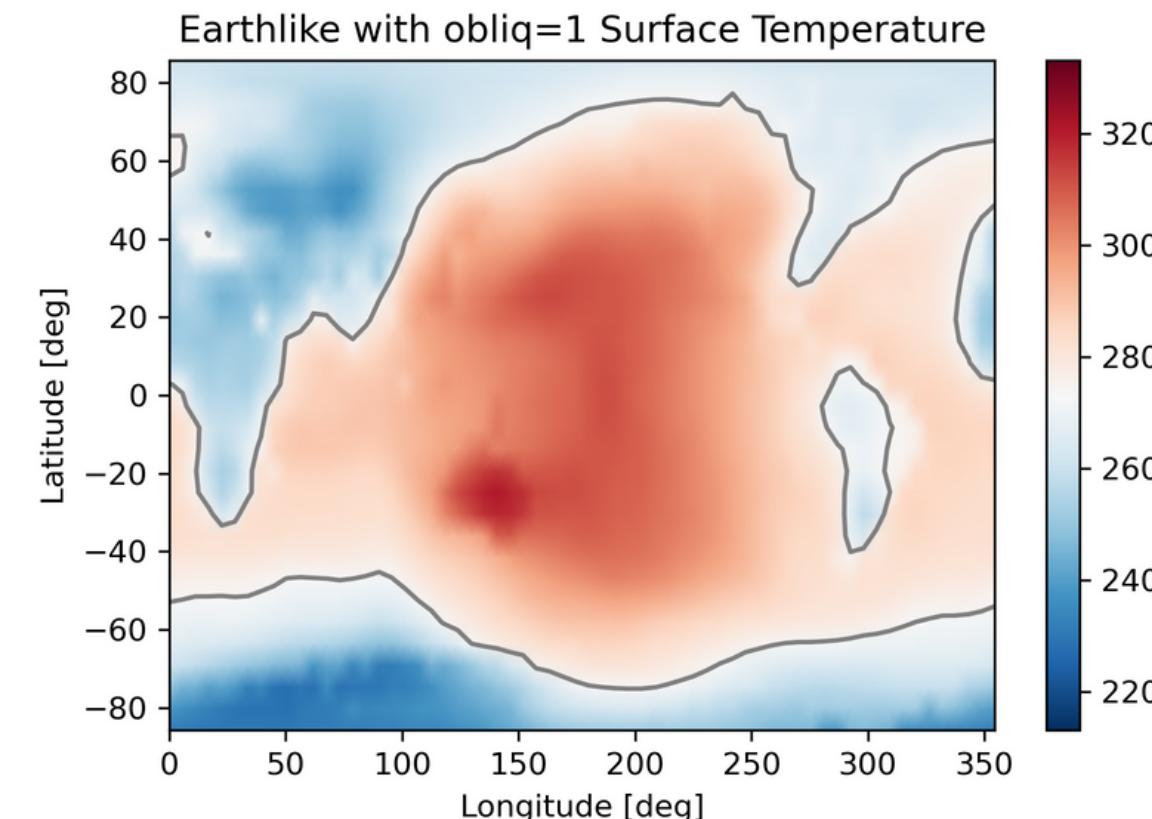
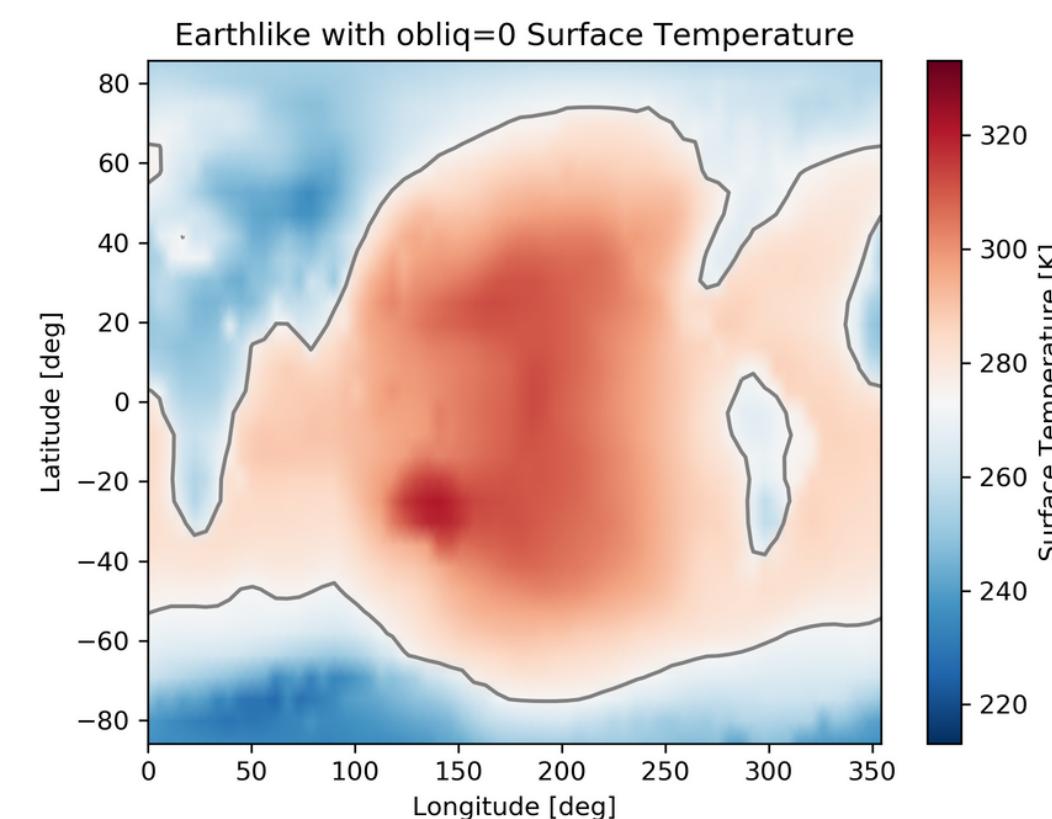
09

Results

- Good south pole approximation
- Missed the North pole
- Interesting artefacts
- Air pressure and water may be the reason



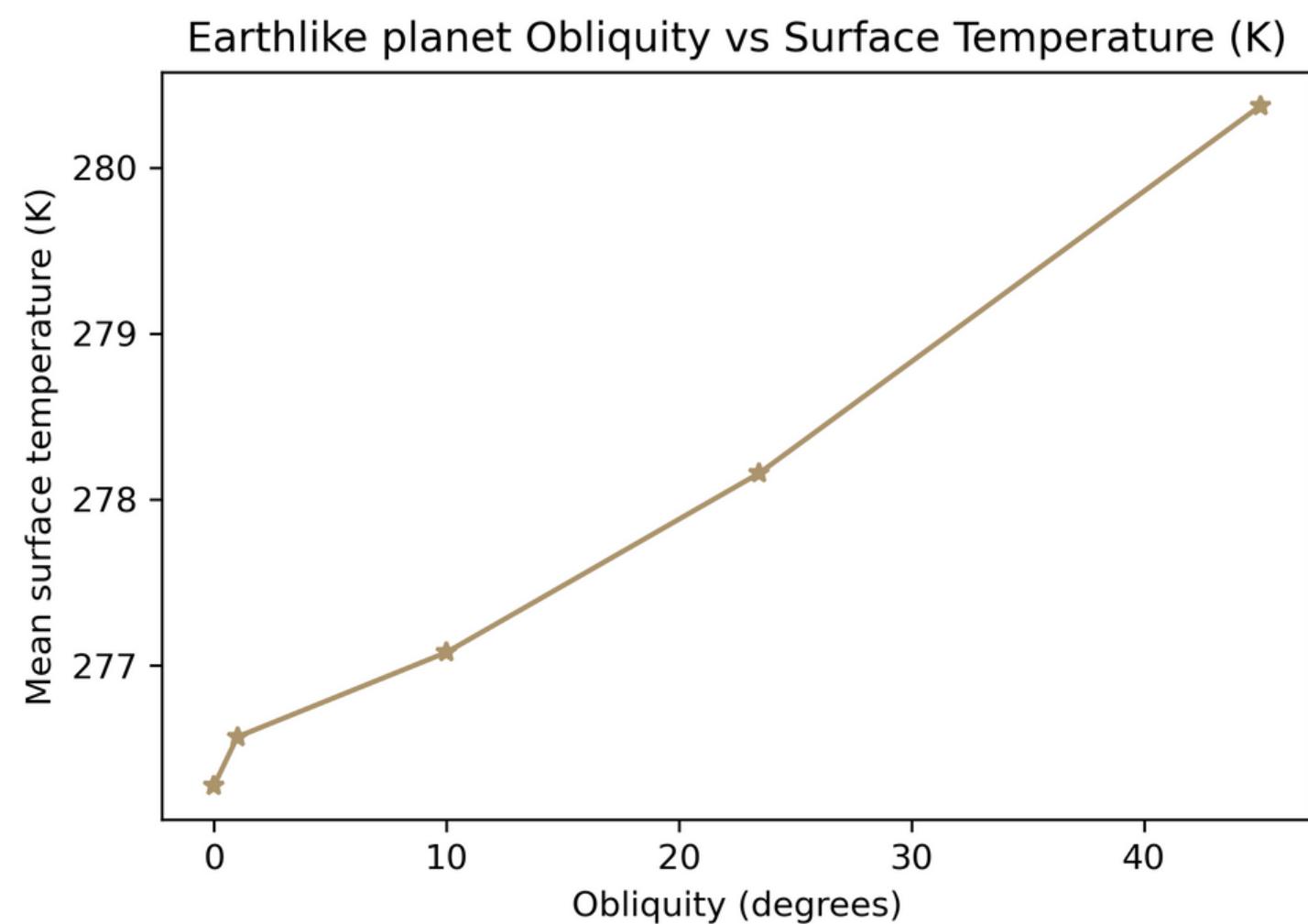
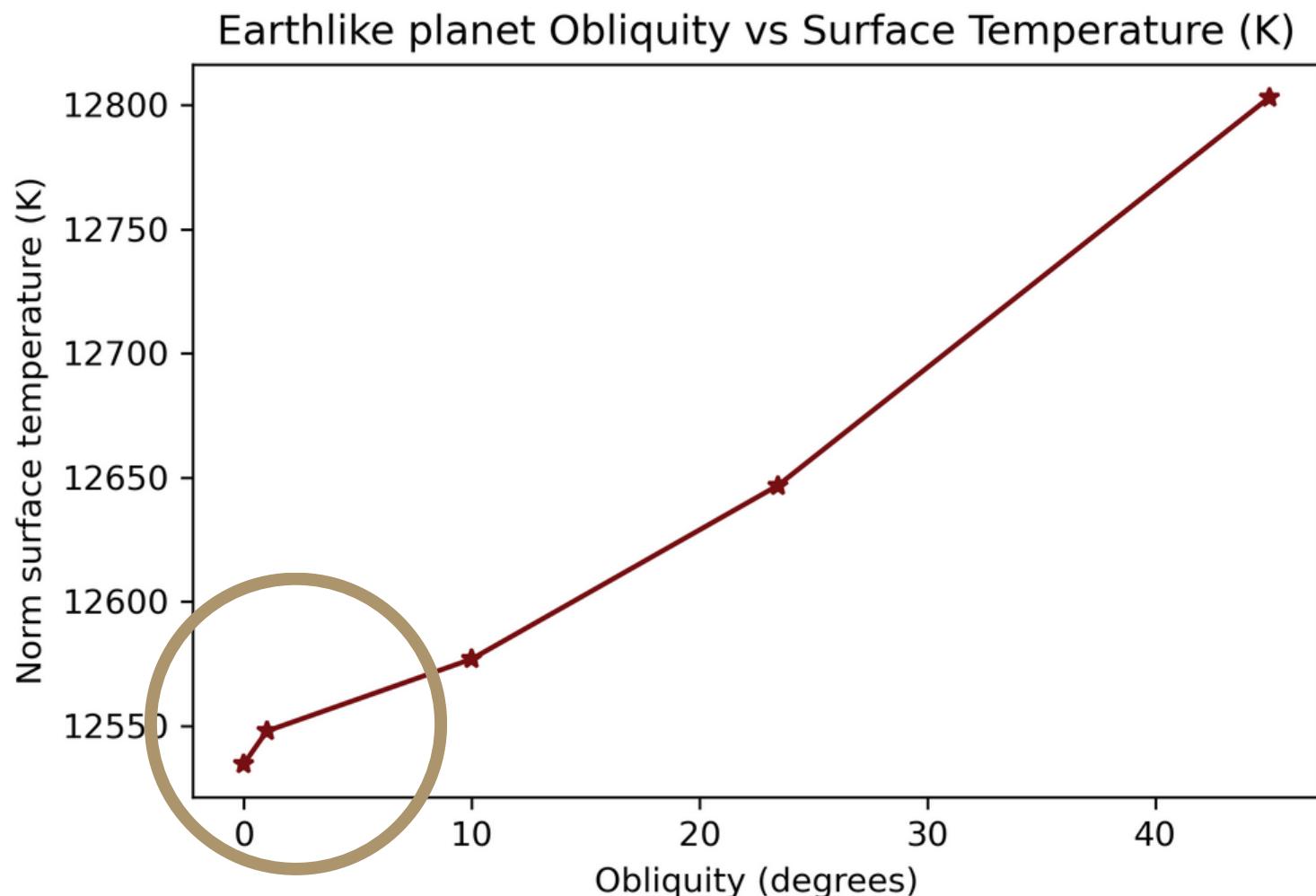
Results



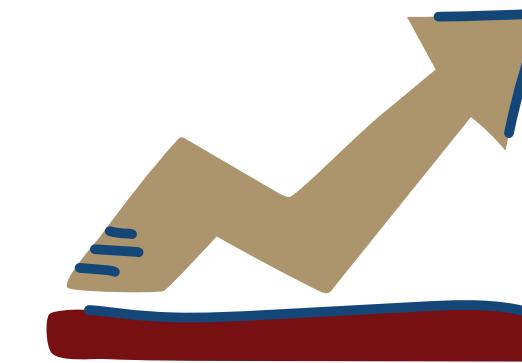
- colder south pole
- cold spot artifacts

Results

- Slightly linear relationship between obliquity and average temperature
- There is an interesting "knuckle" between 0 degrees and 1 degree

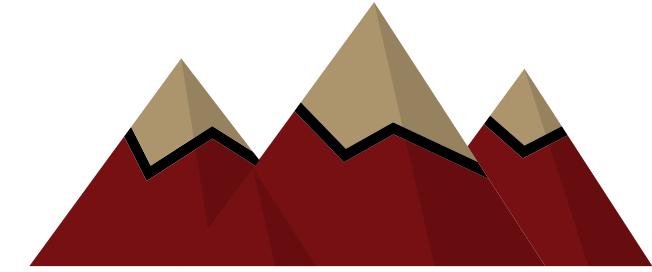


Discussion



Successes

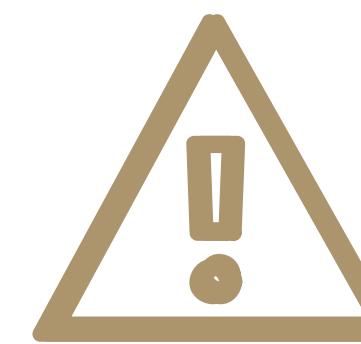
- Obliquity vs temperature has a linear positive relationship
- 0 obliquity shows a unique behaviour
- Fast execution - a couple hours



Limitations

- Crashes regularly
- Eccentricity and pressure can't be varied in earthlike planets
- Number of years and ncpus are limitations

Discussion



Error Mitigation

It's likely ExoPlaSim encountered a **numerical instability** of some kind. Some of these are physical (e.g. you ran a model at a thousand times Earth's insolation, and the oceans boiled, or the model was too cold and the **physics broke**), while some are not (something happened to violate the **CFL condition** for the given timestep, or an unphysical oscillation wasn't damped properly by the dynamical core and it grew exponentially). If this happens, either try a model configuration that is **more physically reasonable**, or if the problem appears not to have been physical, try reducing the timestep or increasing hyperdiffusion.

Future work

- Software and hardware limitation mitigations
- More metrics over more years
- Using other base cases other than Earth

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Thank you

Questions?