Investigating the Dynamics of Hothouse Earth Climates with a Simplified GCM

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November 28, 2022

Abstract

There are records of past Earth climates that were ice-free all the way to the poles (Barron 1983), which can be described as "hothouse" climates. These hothouse climates can be contrasted with an "all-tropics" planet, where the tropics are defined by the atmospheric dynamics, i.e. the Hadley Cell extent (Faulk et al. 2017). This classification is thus primarily dependent on a planet's rotation, rather than its ice-free extent or surface temperatures. We investigate the parameter space between Earth and an all-tropics world using the open-source GCM Isca, developed by Vallis et al (2018). We take an Earth analog and perform a parameter sweep in two dimensions: global reservoir depth (10m, 1m, 1cm) and rotation period (8 days, 4 days, 1 day). The sweep will allow us to explore the effects of surface liquid coverage and large-scale atmospheric circulation on an Earth-like climate. To better represent the distribution of surface water, we utilize the surface hydrology scheme developed by Faulk et al. (2020) for the Titan Atmosphere Model. In this presentation we provide a status report and analysis of initial findings.

Investigating the Dynamics of Hothouse Earth Climates with a Simplified GCM

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PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

INTRODUCTION

What is a Hothouse Earth?

- An Earth-like planet with no permanent ice, even at the poles.
- Limited inventory of surface liquids, such that most of the condensable is in the atmosphere as vapor.

Real-World Comparison

- The Saturnian moon Titan is a close analog to a hothouse Earth.
- It has an abundant condensable, methane, but most of it is in the atmosphere as vapor (Lorenz et al. 2008; Penteado & Griffith 2010).
- The surface has no permanent methane ice, with the poles instead dominated by methane lakes (Stofan et al. 2007).
- Titan has weak rotation, allowing its tropics to extend from pole to pole, effectively an all-tropics world (Faulk et al. 2017).

METHODS

Research Hypothesis

- Our hypothesis is that an Earth-like planet with similar parameters to Titan will have similar dynamics and climatology.

Experimental Approach

- We use the open-source Global Climate Model (GCM) Isca, developed by Vallis et al. (2018), and add the surface hydrology scheme from the Titan Atmosphere Model (TAM), developed by Faulk et al. (2020).
- Each experiment varies two parameters in three values, for 9 individual experiments:

1. Initial surface water depth in each grid cell, with the possible values: 10m, 1m, 10cm.
2. Rotation period, with the possible values: 1 Earth-day, 4 days, 8 days.

Universal Settings

- All experiments use Isca's built-in Full Betts-Miller convection scheme;
- Large-scale condensation with reevaporation;
- Constant planetary albedo of 0.3;
- Flat global topography with runoff.

RESULTS 1: SURFACE WATER & HUMIDITY

- For low-level humidity on Earth, we expect to see higher specific humidity in the tropics where temperatures are highest.
- In a Titan-like state, this is reversed, with the highest specific humidities at the poles where temperatures are coolest.

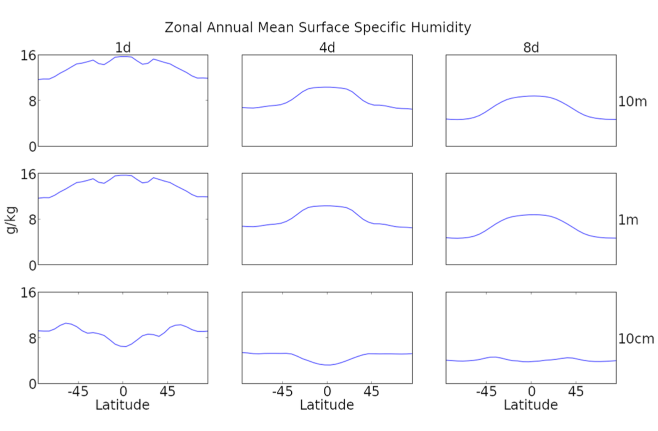

Figure 1: Zonal annual mean surface specific humidity for final 2 years of experiments. A regime change between Earth-like and Titan-like conditions occurs for all rotation periods in the 10cm cases.

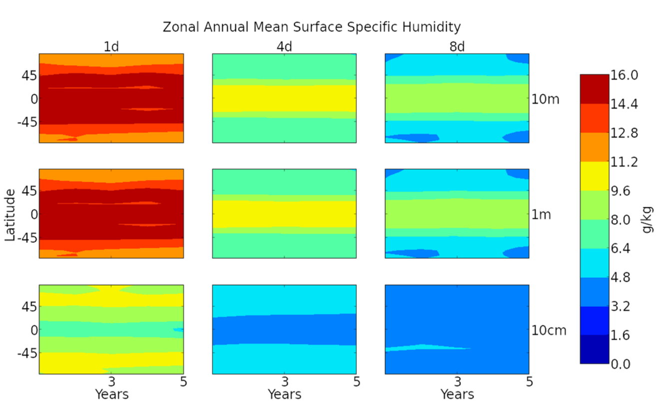

Figure 2: Zonal annual means of surface specific humidity for each of last 5 years of experiments.

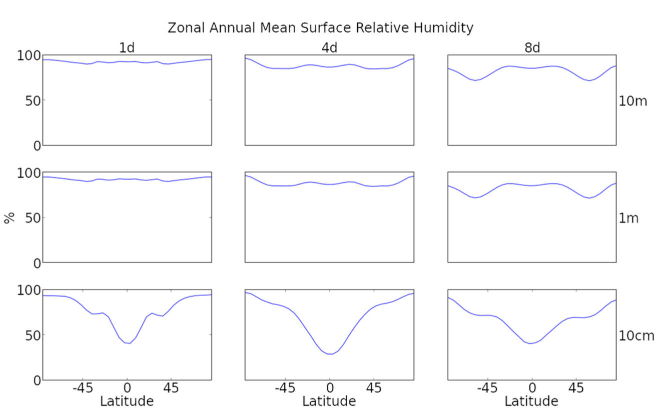

Figure 3: Same as Figure 1, but for relative humidity.

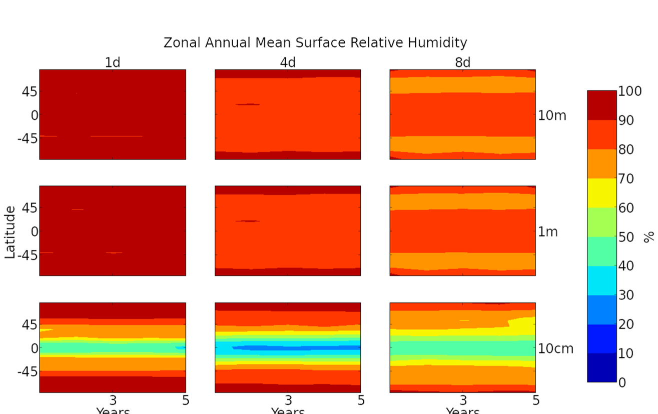

Figure 4: Same as Figure 2, but for relative humidity.

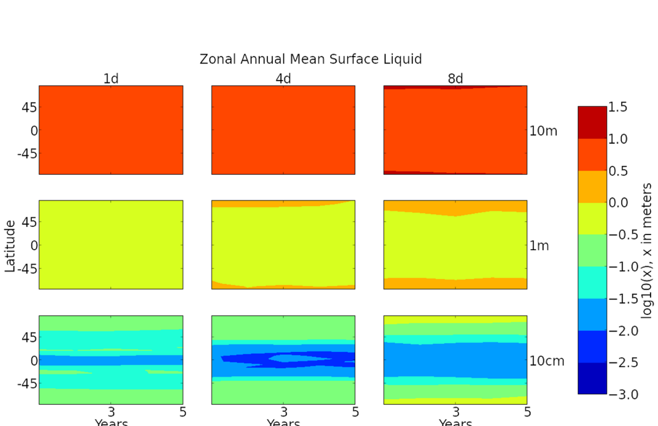

Figure 5: Same as Figure 2, but for the surface water depth. Contour axis is in log10 scale. Significant drying occurs in the tropics of the 10cm cases.

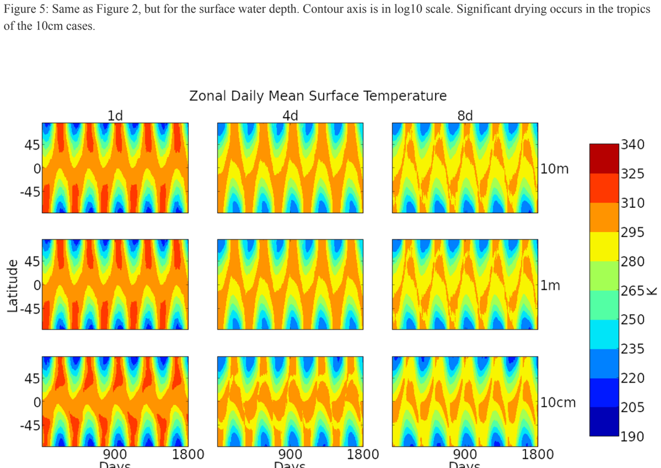

Figure 6: Zonal daily mean of surface temperature over last 5 years of experiments. Notably, the seasonal cycle is unaffected by the surface water depth as these experiments used constant surface heat capacities for any wet grid cell.

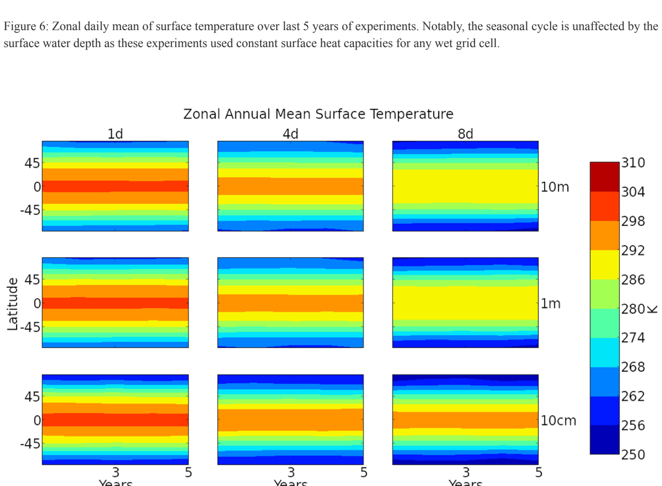

Figure 7: Same as Figure 2, but for surface temperature. The tropics are slightly warmer in the 10cm cases where the surface has dried out.

RESULTS 2: GENERAL CLIMATOLOGY

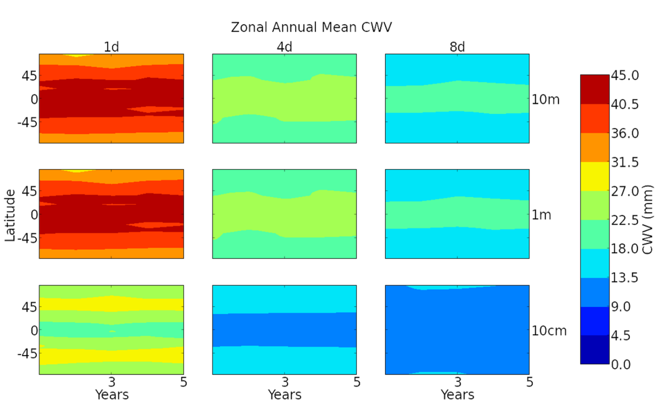

Figure 8: Same as Figure 2, but for column water vapor (CWV). The same regime change as in Figures 1-2 can be seen here in the 10cm cases.

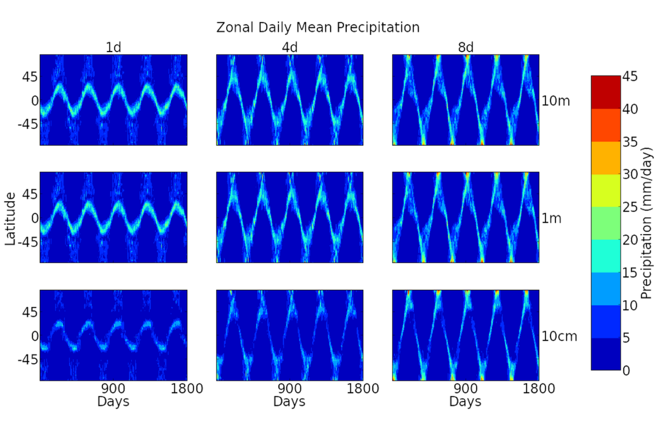

Figure 9: Same as Figure 6, but for precipitation. The ITCZ extent changes significantly as rotation is slowed, reaching the poles by the 8-day cases.

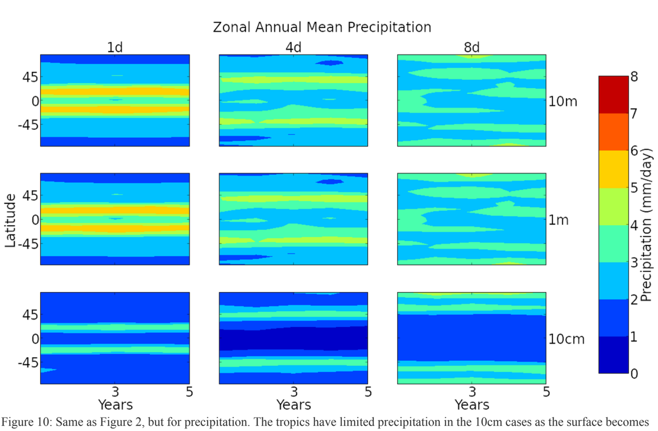

Figure 10: Same as Figure 2, but for precipitation. [illegible]

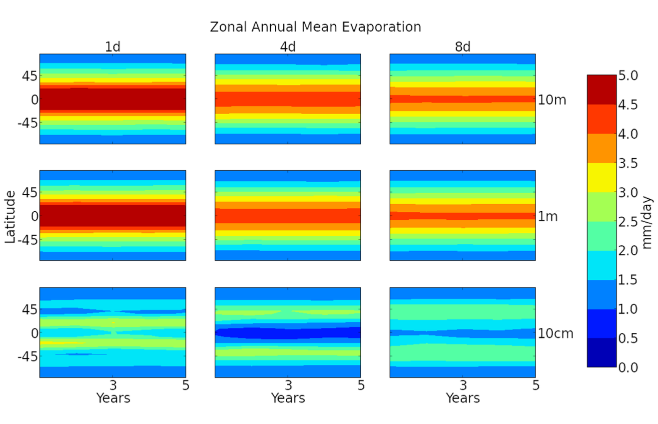

Figure 11: Same as Figure 2, but for evaporation.

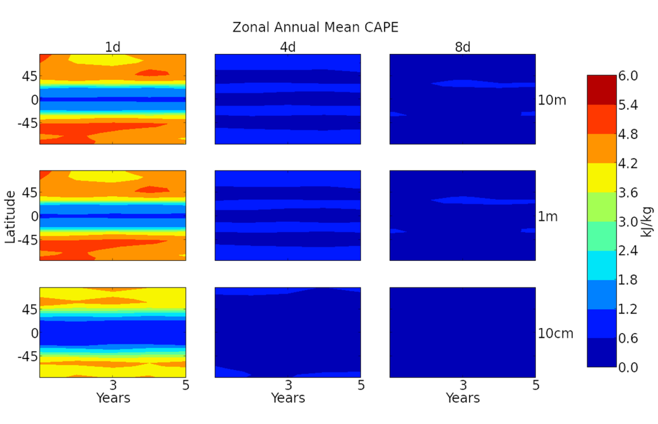

Figure 12: Same as Figure 2, but for [illegible]

DISCUSSION

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CONCLUSIONS AND FUTURE WORK

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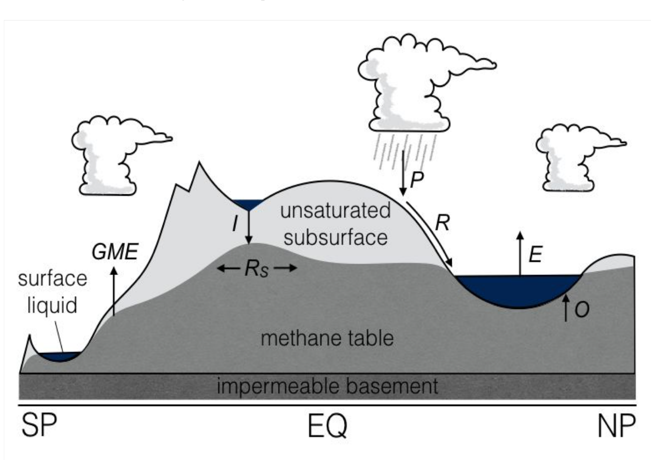

Figure 13: [illegible]

AUTHOR INFORMATION

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ABSTRACT

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REFERENCES

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