Habitable Environments of Early Earth: Assessing the Effects of Rotation Rate and Land Area/Distribution

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Introduction

Understanding the climate of early Earth is essential for understanding the conditions that supported the emergence of life here, and may support the emergence of life on other Earth-like worlds. However, the early Earth is poorly known, because very little evidence remains for this time in the geologic record. The ocean temperatures may have been higher - studies suggesting temperatures ranged from 20° to 80° [11][12][13] - and the sea water itself may have been less viscous, which could have had an impact on how life originated.

In this study, we examine two key characteristics of the Earth that we expect had an importance influence on early Earth climate: the amount of land area and how it was distributed (continental configuration), and the rate of Earth's rotation [9]. It is thought that early Earth had significantly less land [8]. Early climate model simulations [5] that focused on analyzing the effects of a water-covered Earth on climate and clouds found that polar temperatures would be warmer that expected, and that cloud cover would be reduced [5][10]. The rotation rate of the Earth was faster 4 billion years ago, and the length of day was 12 hours or less, compared to our modern 24-hour day [15][16]. This faster rotation rate has been shown in theoretical experiments [17][18] to alter how the atmosphere circulates and transports heat and energy from the tropics to the polar regions, which in turn influences the climate.

The climate model simulations we explore here use a state-of-the-art model to determine whether we would be able to detect these and other changes for early Earth's climate compared to modern Earth, and to evaluate whether a particular combination of faster rotation rate and land area would produce a world that could support a sizeable habitat space suitable for life as we know it.

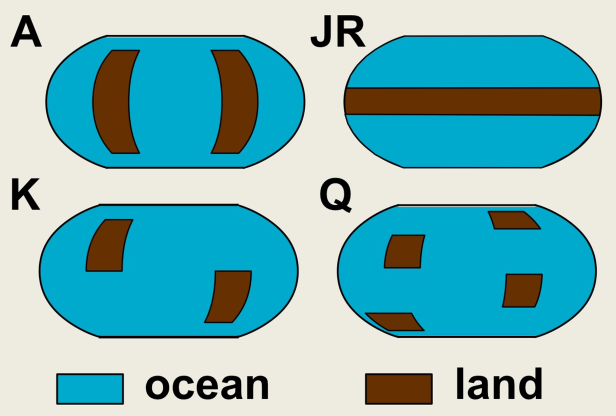
Simulation and Analytical Methods

We used ROCKE-3D, a general circulation model (climate model) used to simulate climate conditions of non-modern Earth and other planets [14]:

- Four idealized continent configurations
  - Scenarios A and JR have 25% land area
    Scenarios K and Q have 12.5% land area
- Both 12-and 24-hour rotation rates

We used Panoply, software designed for visualizing climate data in map form, for our analyses:

- Panoply maps were used to make comparisons and identify trends



Simulation Results

Fig. 1

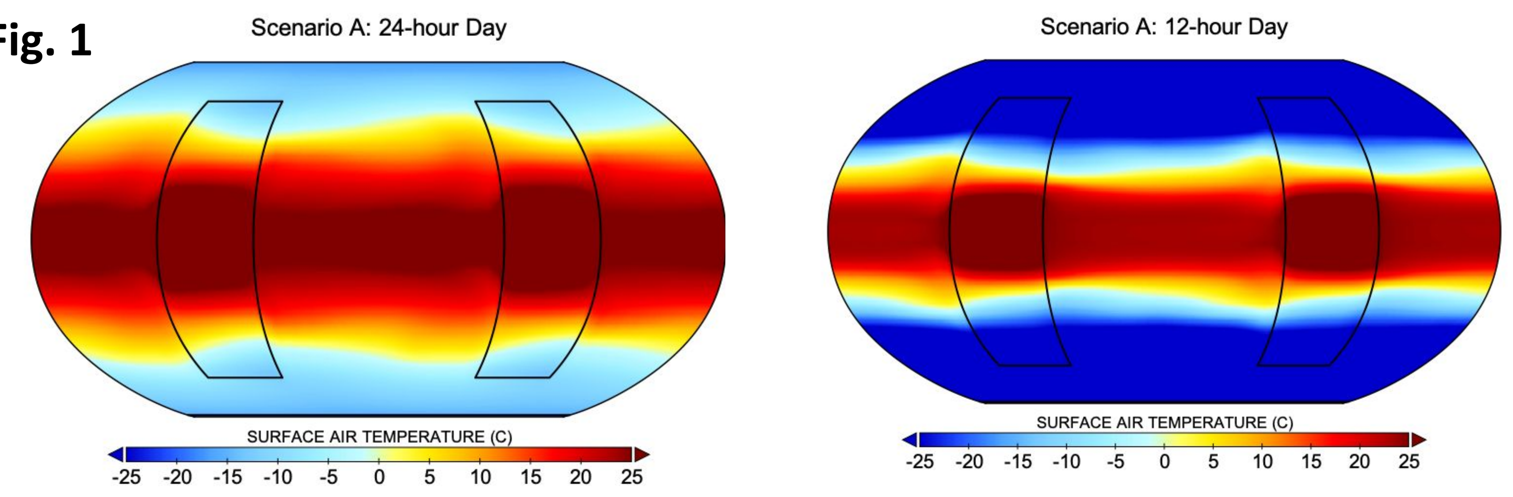


Fig. 2

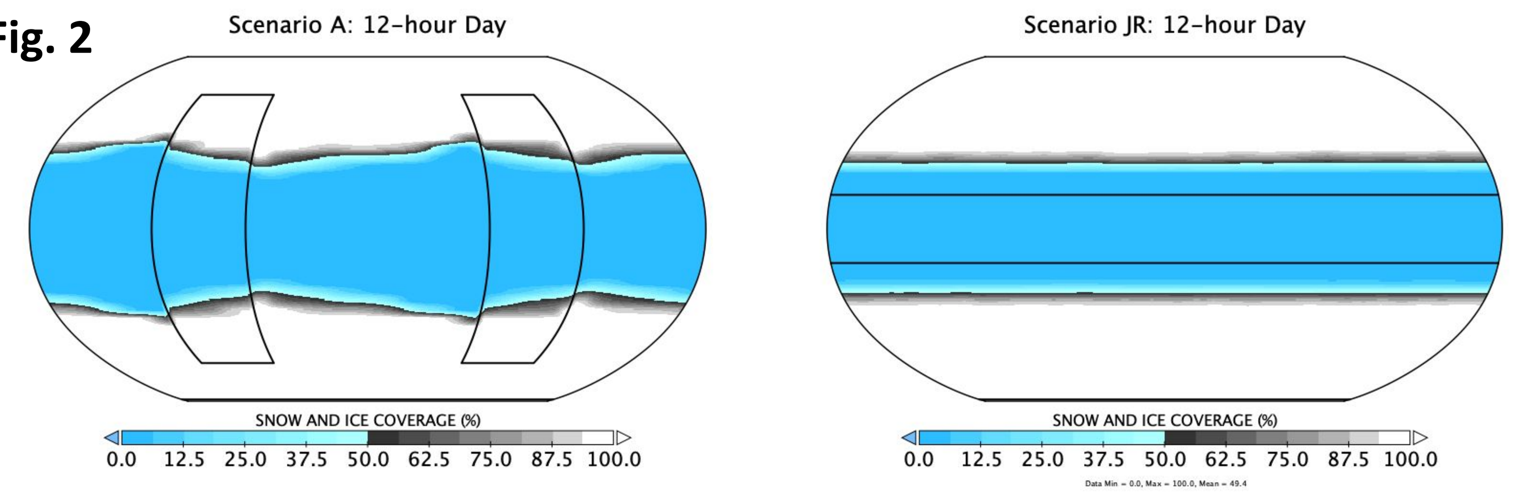


Fig. 3

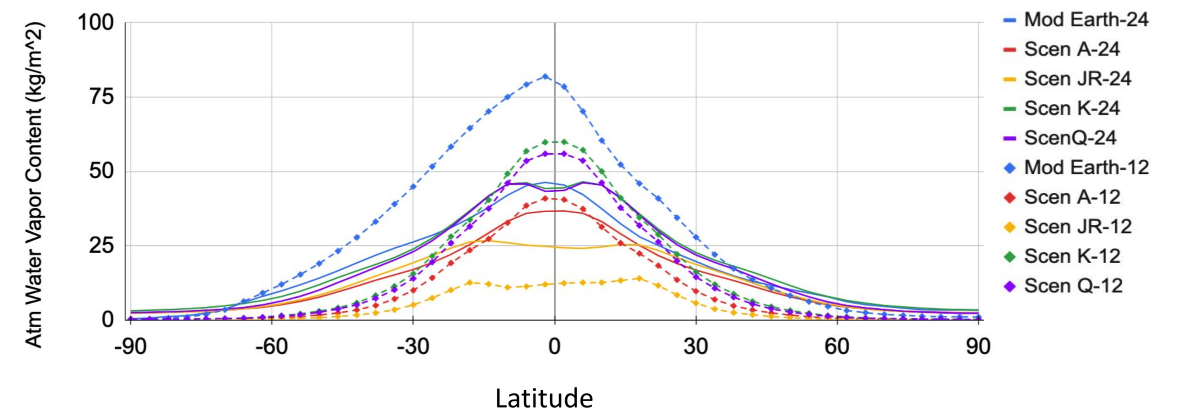


Fig. 4

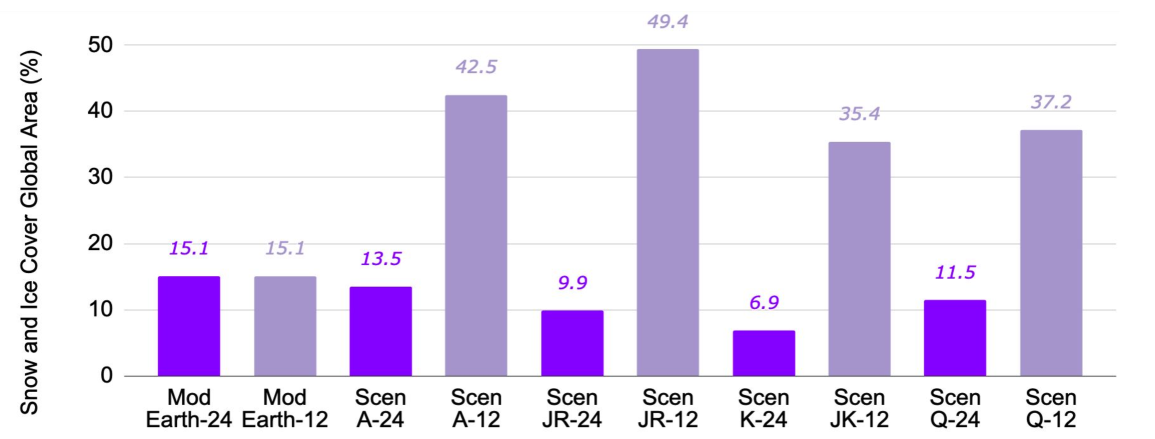


Fig. 1. Contrast between 24 (left) and 12 (right) hour day for Surface Air Temperature, showing the effects of rotation rate change.
Fig. 2. Contrast between continent configurations A (left) and JR (right) for Snow and Ice Cover showing the effects of different land mass contribution.
Fig. 3. Plot of Atmospheric Water Vapor for all scenarios, showing the change in atmospheric water vapor amount as it relates to surface air temperature caused by rotation rate increase.
Fig. 4. Snow and Ice Cover area for all continent configurations for 24 and 12 hour days, showing the difference which rotation rate changes have on snow and ice cover.

Table 1. Contrasts,12-hour days vs 24-hour days

Land Configuration	Surface Air Temperature (° C) Anomaly	Precipitation (mm/day) Anomaly	Snow and Ice Cover (%) Anomaly	Total Cloud Cover (%) Anomaly	Planetary Albedo (%) Anomaly
Modern Earth	-0.1	2.8	0	0	0
Scenario A	-19.2	-2.7	29	8.7	10.9
Scenario JR	-25.2	-19.6	39.5	6.3	12.7
Scenario K	-16.8	-1.1	28.5	10.5	10.7
Scenario Q	-16.4	0.4	25.7	10.5	10.3

Discussion & Future Work

The extremes in the climate models with 12 hour days could be explained by the Earth's atmospheric cells. A strengthened Coriolis Effect would cause reduction in size and strength of the atmospheric cells, and as such heat would not be transferred as easily from the equator. This can be seen from Figure 1. For the effects of the continent configurations, land in any Scenario but JR results in variability in climate patterns. This can be seen from Figure 2. For further research, we would like to focus on ocean circulation. We would also conduct new experiments using different atmospheric compositions since early Earth had a different atmosphere than modern Earth.

References Cited

[1] Hawkesworth C., Cawood P., Dhuime B., (2013) Tectonophys, 609: 651
[2] Charnay B., et al., (2017) EPSL, 474: 97
[3] Condie K. C., (1986) Precambrian Research, 32, I. 4: 261
[4] Hunt, B., (1979) Nature, 281: 188
[5] Jenkins G. S., et al., (1993) JGR: Atmospheres, 98, I. D5: 8785
[6] Kasting J. F., Tazewell H. M., (2006) Phil. Trans. R. Soc. B, 36: 1733
[7] Caldeira K., Kasting J., (1992) Nature, 359: 226
[8] Goodwin A. M., (1981) Science, 213 I. 4503: 55
[9] Ziegler, A. M., (1990) Geol. Soc. London, Memoirs, 12: 363
[10] NCAR, (2023) https://www2.acom.ucar.edu/gcm/waccm
[11] Knauth P. L., Lowe D. R., (2003) GSA Bulletin, 115 I. 5:566
[12] Robert, F., Chaussidon, M., (2006) Nature 443: 969
[13] de Wit M. J., Furnes H., (2016) Sci Advances, 2 I.2: e150036
[14] Way, M. J., et al., (2017) Astrophysical Journal, 213: 12
[15] Walker, J., Zahnle, K., (1986) Nature, 320: 600
[16] Zahnle K., Walker J. C., (1987) Precambrian Res, 37: 95
[17] Rhines P. B., (1979) Fluid Mechanics, 11: 401
[18] Kuo H., (1956) J. Atmospheric Sciences, 13: 561

Acknowledgements

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