3-D CLIMATE MODELING OF THE CRETACEOUS: CAPACITY AND CONUNDRUMS THAT REFLECT ON THE PROMISE OF SIMULATING HABITABLE EXOPLANETS. M. A. Chandler[1,2], L. E. Sohl[1,2], J. A. Jonas[1,2], and D. O. Carter[3], [1]Center for Climate Systems Research, Columbia University, 2880 Broadway, New York, NY 10025, mark.chandler@columbia.edu, [2]NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, [3]The Bronx High School of Science, 75 West 205th Street, Bronx, NY 10468.

Introduction: 3-D global climate model (GCM) simulations of potentially habitable worlds have shown that the definition of the habitable zone inner edge can be dramatically impacted by features such as stabilizing cloud feedbacks [1] and dynamic responses to changes in land/ocean distribution [2]. Coupled atmosphere-ocean GCMs also provide the capability to explore the climate dynamics that can lead to either enhanced global habitability or limited regional habitability. Paleo-Earth simulations for time slices within the last 1 Gyr of Earth history offer a means to evaluating GCM performance against proxy data, and suggest both lines of inquiry and benchmarks for improving model performance.

Approach: The Mid-Cretaceous Period (ca 100 Mya) is the archetypal warm, equable planetary greenhouse environment and was likely the warmest, most extensively inhabited time on Earth since continents became emergent. The oceans teamed with life, continental floral and faunal coverage was maximal, and both ocean ice and land ice coverage was minimal. Proxy evidence indicates that the warm temperatures were a result of higher atmospheric carbon dioxide levels, with from 4X to 20X preindustrial atmospheric levels [3]. Carbon dioxide was elevated in part due to increased volcanic activity and higher spreading rates at the Earth's mid-ocean ridge plate boundaries [4]. The higher geothermal heat flow expanded the ocean floor, displacing water onto continents and, combined with the lack of ice sheets on land, caused Cretaceous sea level to reach the maximum height for any time period since terrestrial life evolved. Abundant proxy data reveals that tropical to temperate climates extended to the poles, with evidence showing angiosperms (flowering plants), having originated in the Early Cretaceous, dominated by the Mid-Cretaceous [5]. These included tall broadleaf tree canopies with a strong leaf red edge combined with a high area of foliage per ground area, which would provide the most demonstrable red edge signal, presenting a clear contrast with other Phanerozoic and Proterozoic time periods being simulated.

Since the earliest days of 3-D global climate modeling many GCM development programs have tested their models by attempting to simulate the Cretaceous climate [6, 7]. Cretaceous simulations represent some of the first efforts to simulate, using complex 3-D computer models, planets with non-modern geographies and atmospheres that at the time would have seemed extreme compared to that used in modern Earth GCMs. Once the challenge (and it is a difficult challenge) of successfully creating realistic boundary conditons for the paleoEarth is met, the elevated CO_2 levels and lower continental albedos make it rather simple for GCMs to simulate a Cretaceous climate having global surface air temperatures that are much warmer than the present, with a severely reduced cryosphere, and a strongly enhanced hydrologic cycle. However, throughout nearly four decades of model development, a persistent problem in simulating the Cretaceous climate has been a limited ability to simulate the meridional temperature gradients that most paleoclimatologists believe existed based on fossil and sedimentological proxy evidence. Attempts to simulate polar temperatures that match proxy data always require greenhouse gas forcings that then yield tropical temperatures which exceed the levels consistent with Cretaceous tropical life.

A search for ways to alleviate the meridional temperature gradient model/data disconnect has borne some results through the generations of model improvements and re-evaluations of Cretaceous paleoclimate data. However, we know that the polar amplification problem remains a conundrum for simulating an array of warm paleoclimates in Earth's past. Using the latest versions of NASA's coupled ocean atmosphere Earth System Model [8] and NASA's newest planetary GCM [9], we explore the problem in more depth with an eye to understanding how warm, equable and super-habitable exoplanets would be simulated using GCMs, and how their dynamic atmospheres, oceans and land surfaces operate.

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