Development of a habitable early-Earth atmosphere: sensitivity to atmospheric dynamics and composition

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Project background

The Earth is on at least its third distinctive atmosphere. The development of our current atmosphere occurred rapidly over a geological timescale of 600 million years or so, and was characterized by discrete jumps in atmospheric oxygen (oxygenation events) associated with a planetary environment that could support widespread emergence of microbial life. The atmosphere, its evolving composition, and its response to changes in solar radiation played a key role in enabling the Earth to become habitable. Here, we explore how sensitive the development of Earth's atmosphere is to modest changes in solar radiation (e.g., different solar activity or distance away from the Sun), planetary rotation, and atmospheric composition. Just how lucky is our planet?

Primarily, the project will improve our fundamental understanding of the evolution of Earth's atmosphere, and provides new tests for established Earth system models. Diverse counter-factual Earths with different stars, for example, are now being observed outside our solar system (exoplanets). Some of these planets may be habitable at their surfaces, in the sense that they are warm enough to sustain liquid water, a necessary ingredient for life as we know it. Ground-based telescopes provide small amounts of basic information about atmospheric composition, and it is anticipated that the upcoming James Webb Telescope will improve this situation. Because of the vast distances associated with exoplanets it will be decades before we can comprehensively characterize their atmospheres. Earth system models, which embody known physics, chemistry, and biology, offer indirect methods of testing whether individual exoplanets meet the criteria to support biological life as we known it on Earth.

The project aims to better understand coupled dynamical and physical processes that control the planetary climate. Changes in stellar and thermal radiation, moderated by clouds, gases and aerosols, will affect the general circulation of the atmosphere, which affects vertical mixing and atmospheric transport and in turn the emission of material from the surface to the atmosphere. Figure 1 shows an example how changes in the molecular weight of the atmosphere can impact fundamental features of the atmosphere, namely the day-night temperature difference and the maximum speed of the lower-tropospheric jet.

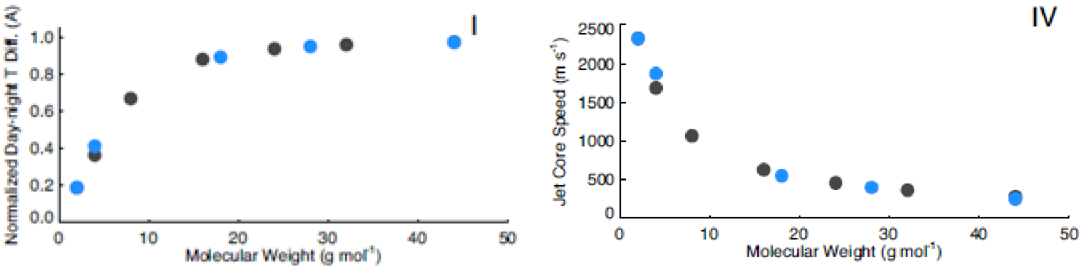

Figure 1 Changes in (left) day-night temperature difference (K) and (right) speed of the core of the 700-hPa jet (m s^{-1}) as a function of the molecular weight of the atmosphere. From Zhang and Showman (2016).

Key research questions

- How sensitive is the development of Earth's atmosphere to modest changes in solar radiation and planetary rotation?
- How do inter-related changes in atmospheric composition and dynamics determine the habitability of early Earth?
- How robust is the development of early Earth's habitability?

Methodology

The project will use the established NCAR CESM climate model to perform simplified and idealized numerical experiments. CESM has been used previously to address various questions related to the climate of early Earth (e.g., Wolf and Toon 2015). We will run sensitivity experiments by varying planetary and atmospheric properties.

Training

A comprehensive training programme will be provided, comprising both specialist scientific training and generic transferable and professional skills. The student will attend relevant atmospheric science and programming courses in GeoSciences, and will gain experience in using state-of-the-art observational datasets, models, and analysis tools through research. More generally, the student will develop critical thinking and communication skills. The student will be encouraged to attend relevant NERC summer schools (e.g., NCAS climate modelling) and to present results at international scientific meetings. The student will also become part of the new University Centre for Exoplanet Science.

Requirements

The project would suit a student with a strong physics background, some familiarity with programming, and interest in atmospheric and climate science.

References

Kaspi, Y., and A. P. Showman, 2015: Atmospheric dynamics of terrestrial exoplanets over a wide range of orbital and atmospheric parameters. Astrophysical J., 840-860.

Wolf, E. T., and O.B. Toon, 2015: The evolution of habitable climates under the brightening Sun. JGR-Atmospheres, 120, 5775-5794.

Zhang, X., and A. P. Showman, 2016: Effects of bulk composition on the atmospheric dynamics on close-in exoplanets. Submitted.

Project Summary

This project will explore the conditions that allow the existence of the Earth's present-day atmosphere by investigating its sensitivity to atmospheric dynamics and composition using (simplified) global climate model simulations.