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Modeling Planetary Climates with Python

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Preface

Although this is a book on the climate of all kinds of planets, it is most definitely Earth-centric. My hope is that by helping to train the mathematically literate, it can do its little part to steer humanity away from our tendency to view our world through lenses of hubris and anthropocentrism.

That said, a bit of anthropocentrism can make us grateful. We may not actually live on the best of all possible worlds, but present-day Earth comes pretty close. Any time spent thinking about what things are like on most (if not all) other planets can make a person just plain thankful for how nice it is on Earth. We've got water in all three phases, beautiful forests, plains, beaches, mountains, and deserts, oxygen to breathe, and enough other life to feed us and replenish the oxygen we happen to consume. In the end, human beings evolved on Earth. Compared to other planets, it's not too hot, not too cold, not too stormy, and a few minutes in the sunshine won't destroy all of our DNA. It's certainly worth our time to quantitatively understand why Earth's climate is the way it is, and what changes its conditions.

While our scientific understanding of Earth's climate system is based on fundamental physics and chemistry, it is powerfully augmented by data from 1) other planets and 2) the geologic past. I like to think that we can attain greater clarity of thought when we consider our own planet as just one manifestation of the realm of possibility.

Importantly, the same physics that set conditions on other planets or that operated in Earth's past also apply to the modern Earth. Therefore paleoenvironmental records as well as observations from planet-like bodies both serve as base cases for refining conceptual and numerical models of Earths climate physics.

One important message that planetary and exoplanet research brings us is that planets can take a wide variety of forms depending on their elemental abundances, size, and relationship to their host star. Meanwhile paleoclimate and paleoceanographic research shows us that life has been a geologic force on planet Earth for the majority of its history, modifying climate parameters through biogeochemical processes. In fact, it is only through the geochemical effects of ancient simple life that Earth's physical environment ever became habitable for humans.

With this book, I hope to increase the reader's understanding of the physical and biogeochemical processes that determine planetary conditions through hands-on modeling and comparison of models with observations.

From the airless bodies in our solar system such as the Moon and Mercury, to the runaway greenhouse of Venus, and distant possible magma ocean worlds like 55 Cnc e, there is a rich set of important test cases for framing our understanding of the Earth environment. Likewise, certain episodes from Earths environmental history also serve as good test cases, from the proto-Earth, the Boring Billion years, and the Snowball Earth periods to the much more recent Mystery Period of the last deglaciation, as well as the Anthropocene in which we now live.

Python is a powerful tool in this context, because for most of us non-computer scientists it is easier to use than the alternatives out there, especially its predecessors. Earth and planetary science is a data-driven endeavor, and many useful libraries have been developed to help work with and present data. I have included modeling with Python in this book because I believe that numerical modeling forces a researcher to think deeply about a specific case, developing intuition that is hard to gain in any other way.

I am in effect scratching my own itch with this extended tutorial. I have found that most existing resources on programming, numerical methods, modeling, and even quantitative Earth science in general are either too esoteric or too qualitative and general to be useful. I hope I strike a balance between scientific detail, accessibility, and practical explanations.

While this book is intended to apply to the modeling of planets of all kinds, it is decidedly Earth-centric, and is an unapologetic effort to help the scientifically minded better understand our own world through observation and modeling.

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