

## Chapter 2: The Working Planetologist

### Speculative Worlds and the Practice of Climate Science

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In a 2010 editorial in the journal *Nature*, the climate scientist and Executive Director of the International Geosphere–Biosphere Programme, Sybil Seitzinger, argues that scientists ought to be more centrally involved in international policy discussions about sustainable development. “In Frank Herbert’s 1965 science-fiction classic *Dune*,” she writes, “the number-one position on the planet is held not by a politician, but by a planetary ecologist” (Seitzinger 2010: 601). Seitzinger invokes Herbert’s novel here to make a pointed comparison. In *Dune*, the inhabitants of the planet Arrakis are engaging in a long-term terraforming project that necessitates the oversight of a planetary ecologist. But here on Earth, we too have been making such changes, “altering, in profound and uncontrolled ways, key biological, physical and chemical processes of ecosystems.” For Seitzinger, grappling responsibly with these processes requires a global, far-sighted perspective that she finds lacking in most Earth politicians. She advises that, while the governments of Earth have not yet considered appointing a planetary ecologist, “perhaps it is time to take the idea seriously.”

And she is dead serious, both as a worried scientist and policy analyst, and also as a reader of *Dune*. Although she discusses the novel explicitly only in the first and last sentences of her editorial, Seitzinger does not invoke *Dune* merely to provide a bit of ‘science communication’ flavor to entertain *Nature*’s interdisciplinary readership. After all, the perspective she takes in the editorial is profoundly similar to Frank Herbert’s vision in *Dune*: both pragmatic and theoretical, it subsumes socio-political concerns as components of a *planetary* ecological model.

What is striking about Seitzinger’s claim about the “planetary ecologist” in *Dune* is not that she wants to see political systems that take a more ecological, more global, or longer-term view of the planet. Rather, it is that she believes that it is her own discipline that provides the best model for this political work. Seitzinger calls for a kind of leadership that “builds up a picture of Earth” as a complex system, to make sense of its points of resilience and vulnerability. To provide evidence for the special ability that scientists might have to keep track of a whole planet, Seitzinger refers to climate science. Beginning in the 1980s, climate modelers increasing-

ly sought to couple standard atmospheric climate models with other ecological, geological and even social models. The complexity of such models dramatically increased in the early 2000s: Seitzinger highlights that, in addition to “the basics of the nitrogen cycle,” climate models now included “elementary descriptions of social and economic systems.” She uses this “explosion in our knowledge of Earth as a complex system” to demonstrate what she sees as shortcomings in the contemporary political landscape: the United Nations, in spite of “these advances,” has failed to acknowledge that “Earth’s restless and powerful social system operates within a complex and intricately linked ecological system.” Noting that the UN has missed out on the insights provided from “advances” in Earth system modeling, Seitzinger implies that climate modeling may be necessary training for adequate world governance.

This editorial suggests that, because Earth system science is a capacious discipline that studies the entire planetary ecology, Earth system models afford a synthetic perspective that can encompass all scientific work about any Earth phenomenon.<sup>1</sup> Seitzinger calls for the inclusion of scientists “with a long view and an understanding of how Earth operates as a complex social–ecological system,” and she later refers to scientists’ grasp of the Earth system’s “economic, political and social sub-systems.” The editorial thus implies that scientists can model how Earth operates both socially *and* ecologically by embedding models of society into Earth system models, using the same methods that they have used to add complexity to climate models in the past. We live in an Earth system, Seitzinger suggests, and if scientists don’t yet know how to couple full-blown economic models or models of political choice to an atmospheric general circulation model (GCM), they will achieve this unification soon enough.

This approach to a planetary system is strongly reminiscent of *Dune*. To Pardot Kynes, first planetary ecologist of Arrakis, “the planet was merely an expression of energy, a machine being driven by its sun” (Herbert [1965] 2010: 797). Kynes, whom Frank Herbert has claimed was the original intended protagonist of *Dune*, is also represented in the novel as the first off-worlder to truly see the potential of the planet. His perspective is rigidly top-down, subsuming social and political concerns to ecological ones. For example, he tells his son and successor as Imperial Planetologist that, “to the working planetologist, his most important tool is human beings” (440). But while it is important for the Fremen, the native inhabitants of Arrakis, to know they are working towards increasing the available water on the

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<sup>1</sup> Although this is the rhetorical implication of Seitzinger’s argument, it is to be taken metaphorically rather than literally: Earth system modeling has its own limitations, many of which stem from the difficulty of coupling different scales of data and simulation. For more about the rise of Earth system models and the challenges thereof, see Edwards (2010: 418–21). On the difficulties of multi-scale modeling, see Winsberg (2010).

planet, it is unimportant that they understand it in a way that goes beyond “semi-mystical” (444). Instead, “an act of disobedience [to their ecological aims] must be a sin and require religious penalties,” as this is what will give the population the “bravery” to follow through on their multi-generational mission, even when none alive will witness the results (444). For Kynes, the entire political, social and ecological transformation he orchestrates on the planet is unified under a fundamental conception of the planet as an energy system.

However, as I will argue, it is not just Kynes (or even just Frank Herbert) who manifests this perspective on the relationship between a whole planet and what is found within that world. The world-building for which *Dune* is famous is characteristic of a wide swathe of planetary science fiction, all relying on the same basic operation. The operation relies on a sense of causal closure with the planetary scale as its object, looping questions about individual aspects of life or nature on that world back into the equation of the planet as a whole. In other words, the basic perspective that makes *Dune* iconic is that of a climate modeler. As in a climate model, the thing being explained is always the planet itself. Combined with her reference to *Dune*, Seitzinger’s suggestion that a computational model of Earth’s climate and biosphere might serve as a model for how to approach politics invokes this practice of world-building, which I call *speculative planetology*. This practice is common in speculative fiction and is emblematised by the Imperial Planetologists in *Dune*. But it is also, as Seitzinger reveals, a speculative practice for climate modelers, an important method for thinking holistically about worlds and what makes them work.

As we have just seen, this speculative practice is sometimes explicitly linked by planetary scientists to science fiction. In this chapter, I will trace the feedback relationship between the speculative world-building done by science fiction authors and the speculative world-building done by climate scientists. The practices of science fiction authors and of planetary scientists differ: one group is engaged in narration, while the other is engaged in simulation. However, it is also possible to observe narration and simulation acting upon one another, speculatively coevolving as part of an ongoing discourse about planets and their workings. For this reason, I am arguing for the existence of a shared practice of speculation that links these two activities: not two separate lines of development, but one speculative planetology that is negotiated across multiple domains.

One outcome of this analysis is that it forces a recontextualization of the oft-repeated idea that climate change is a kind of invisible monster only revealed by science, that it occurs at scales of space and time that dwarf human perception, forcing us to rely on models created by experts.<sup>2</sup> The idea that we depend on

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<sup>2</sup> For a scattering of examples, see Beck ([1986] 1992: 27); Heise (2008: 150–51, 206); Chakrabarty (2009: 221); and Clark (2015: 8, 140). For more critical discussions of scale and the Anthropocene, see Woods (2015) and Horton (2019).

scientific mediation to ‘see’ climate change (at least in a global sense) may be true, but this notion is often used to imply that climate modeling was developed apart from other ways of knowing—that it is an inhuman, computationally-sublime perspective, with little relationship to other domains of culture. To the contrary, I claim that the labor of Earthly self-understanding that revealed the climate crisis, and which continues to make sense of it, has been the collective work of scientists, artists, and members of the public. I call this “collective work” to draw attention to the fact that science is always bound up with other parts of culture, despite the efforts of science communicators to make the natural and the cultural seem easily separable.<sup>3</sup> I demonstrate this by drawing attention the active cultural participation of scientists themselves: their performance of, and participation in, science fiction fandom, and their efforts to engage the public by invoking science fiction tropes. However, as I will claim, the relationship goes much deeper than scientists’ enjoyment of science fiction. After all, the central premise of climate modeling, that *things could be otherwise*, is also the central premise of science fiction.<sup>4</sup> This relationship is deepened by the role of science fiction in reworking, consolidating, speculating upon, and mutating existing science fact.

Among references to science fiction by climate scientists, Frank Herbert’s *Dune* is a touchstone. I treat the novel as an ideal place to discuss the feedback relationship between science fiction and science: not only did *Dune* become an important cultural resource for climate modeling, but the novel itself draws from scientific sources in mid-twentieth century working ecology. In *Dune*, Frank Herbert repurposed many quotations from a short, popular science book, *Where There Is Life* (1962), by the ecologist Paul Sears. I show that when Herbert directly copied these passages from 1960s ecological science, he often simply altered the context from a regional to a planetary scale. And yet, by extrapolatively limning an entire planet out of these smaller-scale borrowings, Herbert is able to build the kind

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3 Bruno Latour refers to this process as “purification” (Latour 1993: 10). Climate science—a discipline that has experienced an unusually high degree of political and ideological intervention—has every reason to participate in the work of purification, as attacks on the authority of climate scientists are very often attacks on their objectivity or on the clarity of the signals that they interpret from the natural world. The presumed capacity of natural things to ‘speak for themselves,’ and the presumed identity of the scientist as someone who straightforwardly communicates these matters of fact to the public, have become part of a battleground which climate scientists are often called upon to defend.

4 Fredric Jameson: “Its multiple mock futures serve the [...] function of transforming our own present into the determinate past of something yet to come” (Jameson 1982: 153). Darko Suvin: “At all events, the *possibility* of other strange, covariant coordinate systems and semantic fields is assumed” (Suvin 1979: 5). Or, more simply and echoing many others, James Gunn: “Science fiction, then, is the literature of change” (Gunn 2005: 10).

of simulated world that characterizes both planetary science fiction and climate models.

Indeed, the historical ties between climate modeling and science fiction go as far back as the very first implementation of the so-called standard model of planetary climate.<sup>5</sup> The ability to calculate a planet's surface temperature involves a few key insights. First, the atmosphere needs to be imagined as having layers. A climate model balances energy inputs and outputs—solar radiation on its way in and mainly infrared radiation on its way out—and this balance must be calculated from the top of the atmosphere, not from the Earth's crust. Second, equations for atmospheric convection must be used to describe how heat is transported around inside that envelope between the crust and the top of the atmosphere. When climate science was in its infancy, scientists regularly failed to incorporate each of these elements into a single model. The first person to manage this wasn't a meteorologist, and it wasn't done with respect to Earth. It was a 27-year-old Carl Sagan who, in 1962, applied a radiative-convective model to Venus in order to determine the structure and temperature of its lower atmosphere (Sagan 1962).

A year earlier, in 1961, Sagan had written an article on "The Planet Venus" in the journal *Science* that indicated the science-fictional thought processes behind his modeling of planetary temperature. Theorizing about Venus's greenhouse effect, he argued that the planet's carbon dioxide levels would explain recent temperature readings of 600 degrees Kelvin. Sagan opened the article with a quip about various speculative and fanciful scenarios that had previously been imagined for Venus's climate:

The state of our knowledge of Venus is amply illustrated by the fact that the Carboniferous swamp, the wind-swept desert, the planetary oil field, and the global Seltzer ocean each have their serious proponents, and those planning eventual manned expeditions to Venus must be exceedingly perplexed over whether to send along a paleobotanist, a mineralogist, a petroleum geologist, or a deep-sea diver. (Sagan 1961: 849)

The article also included an imaginative illustration of Venus by the well-known science fiction magazine artist Chesley Bonestell (851). For Sagan, this image of Venus as a windswept "dust bowl" represented the only science-fictional scenario that still remained plausible: "temperatures are too high for the Carboniferous swamp, the planetary oil field, or the global Seltzer ocean, but, the desert [...] is

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<sup>5</sup> R.T. Pierrehumbert uses the term "standard model," adapted from physics, in his Tyndall lecture to the AGU (Pierrehumbert 2012: 11:30). It was this lecture that called my attention to Carl Sagan as the first to apply the standard model to a planet (23:50).

still roughly consistent with the data,” he wrote in conclusion, adding that readers should “See Fig 1” [Bonestell’s illustration] for reference (857).

Drawing attention to the history of wild theories about Venus, Sagan suggested the alignment of planetary science with the imaginative practices of science fiction. His own scientific work relied extensively on such practices: he was committed to thinking of distant planets as places, and to imagining what it would be like to inhabit them (Messeri 2016: 6). Furthermore, as complex as climate models have become over time, they remain bare-bones pictures of worlds. Sagan had no knowledge of Venus’s actual surface temperature to trip himself up, and this situation necessitated using the standard model. Because the surface could not be seen through Venus’s impenetrable shroud of clouds, Sagan was forced by circumstance to speculate upon it, and thus to recognize that the surface temperature depends on a balance between incoming and outgoing energy at the top of the atmosphere—that is, from outside the planet.<sup>6</sup> This emphasizes that the basic viewpoint of a climate modeler is a deeply estranged one, not the intuitive perspective of a citizen of Earth at all. An understanding of planetary climate—that is, the idea of climate as a planetary phenomenon—begins with looking at that planet from the outside, from space.<sup>7</sup>

Sagan was, of course, not alone. The planetary sciences, emerging around the same time as Frank Herbert’s *Dune*, were already thinking in science-fictional terms about the other planets in our solar system, such as Mars and Venus. What has perhaps gone unrecognized are the ways that this mode of thinking about planets from a distance, as well as thinking of planets as energy systems, has become the backbone of a certain kind of speculative thinking about planetary climate and climate change in general, even on Earth and amongst scientists who are not compelled to it by distance from their planet of study. As evidence of the role of this speculative climate imaginary, I turn to examples of climate scientists who have written publicly about their interest in science fiction.

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6 As Pierrehumbert (2012: 21:09) points out, even the equations that make up the convection part of the standard model were formulated several centuries earlier by astronomers seeking to measure the temperature of stars.

7 There are scientific theories of planetary climate that seem to approach climate from within the planet rather than outside of it, such as the Gaia hypothesis with its focus on the planet’s biota. But even the Gaia hypothesis was originally formulated as an interplanetary thought experiment: James Lovelock (serving as a NASA astrobiologist at the time) claims to have first had the idea for Gaia when he considered how one might be able to tell from afar if a planet was inhabited by life (cf. Hitchcock/Lovelock 1967). For more about Lovelock’s interactions with the space sciences, see Conway (2008).

## “SFnal”

Notably, the *Bulletin of the American Meteorological Society*, the top-ranked journal in atmospheric science, has featured increasingly deep engagements with science fiction since the 1980s, from including science fiction texts in its book review section to publishing articles and even special issues discussing the utility of science fiction as a tool for climate science. In one such instance, climate physicist and Royal Society fellow Tim Palmer wrote an article titled, “Is Science Fiction a Genre for Communicating Scientific Research? A Case Study in Climate Prediction” (Palmer 2010a). His case study was a science fiction short story, “Sunrise,” which he wrote and published as an online supplement in the same issue of *Bulletin of the American Meteorological Society* (Palmer 2010b). Palmer treats “Sunrise” as a kind of doubled thought experiment. Within the story, he speculates on the implications of climate models’ low resolution with regard to regional change patterns. He allegorizes the problem on a recently climate-changed fantasy planet, Migosh, where scientists predict favorable new average values for weather but fail to anticipate extreme weather events, leaving the populace unprepared for a natural disaster (Palmer 2010b). In the essay accompanying the story, Palmer claims that the story tests a hypothesis: that when communicating scientific findings to decision makers, science fiction might “sometimes be a more effective genre for communication than conventional means” (Palmer 2010a: 1413).

In the essay, Palmer writes of his childhood experiences reading science fiction:

I can still vividly recall Isaac Asimov’s *Nightfall*, [which] describes a civilization’s first encounter with darkness for thousands of years. [...] I started to wonder whether such an overwhelming existential crisis, in experiencing for the first time some dramatic and totally unforeseen natural phenomena, could be brought to bear in communicating my concerns about current uncertainties in the science of climate prediction? (Palmer 2010a: 1413)

For Palmer, and specifically in cases where what is at stake is helping policymakers understand the uncertainty behind predictions and the value of continued scientific research, science fiction can communicate about what one might call the “unknown unknowns” of climate prediction. In other words, what Palmer recognizes and values in science fiction is an aspect of his own work on chaos and predictability: the capacity of the nonhuman world to throw up the truly unan-

ticipated, and the importance of maintaining a speculative attitude in order to appreciate what cannot be anticipated.<sup>8</sup>

Also in the *Bulletin of the American Meteorological Society*, Raymond T. Pierrehumbert, a lead author of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published a short article called “Science Fiction Atmospheres” (Stocker et al. 2001; Pierrehumbert 2005). In this piece, he considers various science fiction texts and wonders about the atmospheric physics of their worlds. Regarding *Dune*, he frets, “But how is the aquifer recharged if it never rains?” He then offers a speculative answer:

My best guess is that *Dune* is a dying world, with slow leakage of water into an atmosphere that is becoming gradually warmer on account of the water vapor greenhouse effect. A word of warning to those *Dune* scientists to wish to re-engineer the climate to bring on rain and surface water: if they succeed, they will almost certainly precipitate a runaway greenhouse. If *Dune* is already in a habitable temperature range without much water vapor greenhouse effect, introducing an ocean is likely to be fatal. (Pierrehumbert 2005: 696)

In “Science Fiction Atmospheres,” Pierrehumbert uses science fiction worlds as the occasion for showing off a climate modeler’s mentality, which involves flexible inference about how atmospheric and terrestrial systems interact to produce the conditions on the planet. Does Arrakis have plate tectonics? If so, the lack of surface water will prevent weathering of rocks and lead to a build-up of carbon dioxide in the atmosphere. Is it possible to have an aquifer without also having a water-saturated atmosphere? No—although precipitation could evaporate before it reaches the ground. He playfully evaluates several science-fictional climates (as seen in *Dune*, Kim Stanley Robinson’s Mars trilogy, and a few others) in this manner, adding, “Graduate students take note: This is good fodder for general exam questions!” (Pierrehumbert 2005: 696).

This last suggestion appears to be something Pierrehumbert has truly taken to heart, for he builds science fiction directly into his pedagogy. In several of the problems from his textbook *Principles of Planetary Climate* (2010), students are asked to read science fiction stories, such as Geoffrey Landis’s “Ecopoiesis” or Fritz Leiber’s “A Bucket of Air,” before attempting a solution. Other problems casual-

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<sup>8</sup> Palmer is not the only climate scientist to write a short story exploring a climate-related hypothesis and paired to a scholarly publication. NASA climatologist and Director of the Goddard Institute for Space Studies, Gavin A. Schmidt, coauthored the article “The Silurian Hypothesis: Would It Be Possible to Detect an Industrial Civilization in the Geological Record?” (Schmidt/ Frank 2018). To accompany this piece, he published a science fiction story entitled “Under the Sun” (Schmidt 2018) about a scientist discovering that there had been an ancient industrial civilization in Earth’s deep past.

ly describe science-fictional entities, as we see in the following exercise entitled “Springtime for Europa”:

Something is about to happen. Something wonderful. To promote life on Jupiter’s moon Europa, which currently is composed of a liquid water ocean covered by a very thick water ice crust, the alien race which built Tycho Magnetic Anomaly 1 ignites thermonuclear fusion on Jupiter, heating Europa to the point that its icy crust melts, leaving it with a globally ocean covered surface having a temperature of 280K. Water vapor is the only source of atmosphere for this planet. Describe what the atmosphere would be like, and calculate  $T(p)$  for this atmosphere. Give a rough estimate of the depth (in km) of the layer containing most of the mass of the atmosphere. (Pierrehumbert 2010: 128)

The aliens referenced here are the same aliens who placed the obelisk in *2001: A Space Odyssey*, though the suggestion that “something wonderful” is about to happen on Europa is an allusion to the film’s 1984 sequel, *2010: The Year We Made Contact*. Why does Pierrehumbert use this story as a way into the problem? In the first place, it is clear that he is a fan of science fiction and that he enjoys exhibiting his knowledge of the genre. This in itself is significant: in some disciplinary cultures, it is common for scientists to conceal their fandom, or to dismiss science fiction as something they used to read in their childhoods. The idea of science fiction somehow “infecting” or “planting a seed” in a scientist’s mind might seem to threaten certain notions of scientific authority and rationality (Milburn 2010: 563). Considered in this light, the wide range of climate scientists who are willing to go ‘on record’ as science fiction enthusiasts of one kind or another speaks to a more pervasive disciplinary openness to the genre, even amongst those who are not actively blogging or giving talks about science fiction.

On the other hand, Pierrehumbert is also performing his interest in science fiction for heuristic purposes. He wants his students to think creatively about planetary atmospheres. He could have simply posed a series of equations about an atmosphere composed of water vapor, but by presenting a narrative context, he can instead ask students to “describe what the atmosphere would be like”: a qualitative question. This recalls Lisa Messeri’s point that for planetary scientists, thinking of planets as places that one “can imagine being on” is a crucial method that “potentially opens up new questions that can be asked about the planet” (Messeri 2016: 12). Asking what the atmosphere *would be like* invites the students to consider questions that are more experiential: not just what temperature and what depth, but also what weather, what kinds of clouds, what color the sky? Such

open-ended speculations are part of the practice of world-building that science fiction authors have honed over more than a century of planetary science fiction.<sup>9</sup>

Pierrehumbert clearly aims to produce a kind of “cognitive estrangement” (Suvin 1979) for readers of his textbook. This aim is made evident in the workbook questions, but also in his concerns about generalizing climate knowledge. He remarks somewhat regretfully that “it is inevitable that any discussion of planetary climate will draw heavily” on our observations of Earth, which remains “our best-observed example of a planetary climate” (Pierrehumbert 2010: xi). Yet climate science’s inheritance of Earthly terminology seems to be a source of consternation for Pierrehumbert:

For example, if I sometimes refer to “the sun” or “solar radiation,” it is to be thought of as referring to whatever star the planet under discussion is orbiting, and not necessarily Earth’s Sun or even a star like it. In the same spirit, the term solar constant will be used to refer to the rate at which a planet receives energy from its star [...] regardless of what that star may be and where the planet may be located. (Pierrehumbert 2010: xii)

Noting that the standard vocabulary of climate science too often presumes our own solar system as a frame of reference, Pierrehumbert instead proposes more estranging terms, such as *stellar radiation* and *stellar constant*, to “help the reader get used to the idea that there are a lot of stars out there, with a lot of planets with a lot of climates” (xiii). The same work must be done in relation to other aspects of planetary climate, adapting terms from climate science but emphasizing their generality, their ability to detach themselves from the parochial Earthbound context in which they were developed:

In a similar vein, “air” will mean whatever gas the atmosphere is composed of on the planet in question—after all, if you grew up there, you’d just call it “air.” When I need to refer to the specific substances that make up our own atmosphere, it will be called “Earth air.” (Pierrehumbert 2010: xiv)

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<sup>9</sup> World-building has for the most part been a science fiction practitioner’s term of art, rather than a scholarly one, because the term is so difficult to delimit. However, many genre definitions of science fiction imply some degree of comparison between our own world and the world of the narrative. Delany ([1978] 2009) is of particular note for approaching the topic through language. On world-building as a collective transmedia practice, see Wolf (2012). On the practice of planetary world-building for science fiction authors, see Gillett (1996).

Earth air: just one flavor among many.<sup>10</sup> Pierrehumbert's comment that "[I]f you grew up there, you'd just call it 'air'" helps to get at one of the most significant moves that climate science shares with—or, as I am arguing, often explicitly borrows from—speculative fiction. In *Principles of Planetary Climate*, the science fictionality serves a purpose beyond that of enlivening an otherwise technical subject. It is a literal invitation to extrapolation, a mode that can be invoked in order to bridge between the known and the unknown. In a set of exercises about the boiling point of liquids, Pierrehumbert transitions from discussing water to the following: "Now, think of Glurg the Titanian, who would like to boil up liquid methane to make his tea. The surface pressure of Titan is about 2 bars (mostly nitrogen). How hot does his stove have to get?" (Pierrehumbert 2010: 124). Part of this pedagogy is not merely to teach the basics of thermodynamics, but to open up spaces for speculative thought about climatological concepts. Both the idea that "if you grew up there, you'd call it air" and the silly notion of "Glurg the Titanian" with his implausible thirst for methane tea invoke a science-fictional methodology that is part and parcel with what the textbook means to convey to the budding climate scientist.

Robert Grumbine, a climate modeler and oceanographer who works for the United States National Oceanic and Atmospheric Administration (NOAA), has written about this relationship between climate science and science fiction in a blog post entitled "Science Fiction and Science." After declaring himself a lifelong science fiction fan, he launches into an extended reflection on the relationship between the two fields. While he acknowledges that "Bad SF [...] can fuel some bad ideas about science," he suggests that, more importantly, science fiction shares with science a set of common assumptions about how "interesting" a place the universe is, about how "problems are (generally) solvable," how "the universe is (often) understandable," and how "science translated to technology can affect how you live (so think about the social effects sooner rather than later)" (Grumbine 2008). These are somewhat standard tropes of the "why science fiction?" discourse in popular culture—which makes sense, as Grumbine is clearly invested in science fiction as a genre. He consistently comments on blog and forum posts in which other scientists mention science fiction, often verifying or registering appreciation for a mention of a science fiction story or novel. For several years circa 2007, he also participated in the Usenet listserv *rec.arts.sf.science*, a discussion forum in which science-fictional scenarios—often world-building questions, resolving issues of scientific plausibility about a particular fictional world—are worked out

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<sup>10</sup> One might note, as Pierrehumbert does elsewhere, that Earth air itself has not been uniform across geological history: some of the most important questions in climate science are about past changes in Earth's atmospheric composition. For example, see Pierrehumbert (2010: 11–14).

by a community of lay fans, scientist-fans, and authors. For instance, Grumbine weighed in on a conversation about how long it would take for fast-growing Venusian sky-cities to exhaust the planet's sulphuric acid clouds by hydrogen mining—not long—and whether the climatic effect would be warming or cooling—definitely warming (Grumbine 2007).

However, Grumbine's reflections on why science fiction is important to him as a climate scientist, rather than as a scientist in general, are more specific, and could easily be taken to describe the same dynamics visible in Pierrehumbert's textbook:

I do take advantage of a somewhat SFnal view of the universe in doing my research. That is, I'm trying to understand, say, the earth's climate. That's only one place with one particular set of conditions. What (the SF-fan in me asks) would it be like if the earth rotated much faster, more slowly, if the sun produced less UV (hence less ozone on earth, hence less greenhouse effect in the stratosphere, hence ...?), if the earth were farther away/closer in, and so on. I can't say that it's resulted in any journal articles that I wouldn't have written anyhow, but it does make it easier for me to, say, read paleoclimate papers (the earth did rotate faster in the past, sea level has been much higher and lower than present, ...). (Grumbine 2008)

“What (the SF-fan in me asks) would it be like?” This series of questions and concerns directly echo the sorts of questions performed by Pierrehumbert as a way of initiating students into the basics of planetary climate. Grumbine, like Pierrehumbert, refers to the idea that Earth is “only one place with one particular set of conditions,” suggesting that there could be—and, as he notes, *has been*—any number of different Earths (or other planets) with different conditions.

In other words, the basic premise of science fiction—that things could be different—is also a basic premise of climate modeling. Is a set of observations about the likely climatic conditions on Gliese-581D science fiction or science? What about extrapolations regarding the atmosphere of Earth if its axial tilt were much greater? Much as they are perfectly reasonable topics for a climate science textbook, these questions are inevitably under the gravitational influence of a long history of speculative fiction, not only in terms of their content but in terms of method. This—Grumbine's “SFnal view of the universe”—is a method for thinking about planets that has been developed as a shared practice, a product of feedback between science and culture.

## Dune Worlds

To provide more direct evidence of this feedback loop, I look to Frank Herbert's *Dune*, which is something of a touchstone for scientists interested in planetary climates. Both Pierrehumbert and Grumbine, for example, have written about it (Pierrehumbert 2005: 697; Grumbine 2008). But *Dune* also enjoys a more specific role as part of the field of planetary science—not just one imaginary planet among many, but a term of art that describes a *kind* of planet. As I will explore in the remainder of this chapter, *Dune*'s iconic status has to do with the way that it works as an imaginary system.

William Michael Connolley was a climate modeler at the British Antarctic Survey until 2007.<sup>11</sup> His climate science outreach blog, *Stoat*, was hosted for a time at the science communication hub *RealClimate*. Both *Stoat* and Connolley's personal blog are full of evidence of his status as a science fiction and fantasy reader. His posts abound with references, both oblique and explicit, to the work of Jack Vance, Samuel Delany, Ursula K. Le Guin, John Crowley and others. In a post entitled "Whats Wrong with the World" [sic], Connolley tasks himself with describing why he thinks future generations will resent the present generation. He lists several reasons, including the following:

Waste and general "fatness." Not fat as in your body being overweight, though that is a small part of it. Water-fat, as in Dune. Fat as in all the rest: the fools who drive SUV's, who need ridiculous numbers of toys (who, after all, could possibly need a GPS watch? This one folds into "environment," too. (Connolley 2010)

Connolley's use of the phrase "Water-fat, as in Dune" indicates the extent to which fictional climates can come to be part of shared worlds and ways of knowing worlds. The idea of "water-fatness" in the novel evokes an understanding that off-worlders' bodies automatically carry a surplus of water that the native Arrakeen population and long-term immigrants do not. But it also indicates a sense that those off-worlders are soft, undisciplined, and ill-prepared for life on Arrakis. Using this phrase carries with it a whole world adapted to a shocking level of scarcity, indicating that Connolley imagines some future generation sneering at his own generation for their ignorance of what survival really means. Connolley's use of this term demonstrates how a fictional climate can become emblematic of a set of meanings, and that he may expect his own readership to recognize this set

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<sup>11</sup> After a series of controversies related to his role as a *Wikipedia* editor and as a *RealClimate* blogger, Connolley quit climate science and switched to electrical engineering, saying that he felt that science was no longer what would advance the climate conversation: political change was needed.

of meanings, signifying not only a dry climate but the ecological and social resonances of that climate.

It is not for nothing that the fictional climate of Arrakis can do this kind of cultural work. *Dune* has been hailed as “the first planetary ecology novel on a grand scale,” and it certainly aims to convey a sense of system (Slonczewski/Levy 2003: 183). Each organism, each technology, each language, and each landscape in the text seems to have its own intricate and often diasporic natural history, evoking a planetary past that has been endlessly interlayered, obscured by cycles of mutation, adoption, or occlusion by other histories. These entangled elements are depicted not only in the novel’s narration, but also in an extensive collection of appendices: a fictional scholarly apparatus including ecological histories, biographies of the central characters, a glossary, a map, and sociological tracts relating to the deep history of the planet and its inhabitants.<sup>12</sup>

Until this point, I have restricted my overview of planetary scientists and their interactions with science fiction to those who can be best described as climate modelers. And indeed, Pierrehumbert, Connolley and Grumbine have each posted online about their experiences reading *Dune*. But by comparison, *Dune*’s reach is even more unmistakable in the fields of astrobiology and planetary science focused outside of Earth.<sup>13</sup> As Stephen Dick and James Strick write in *The Living Universe*, their history of NASA astrobiology,

American culture was influenced strongly in [the] direction [of believing life on Mars not to be impossible] by Frank Herbert’s science fiction novel *Dune*, [which was] released in mass paperback just at the time of the Mariner 4 results from Mars and posit[ed] an entire complex culture exquisitely adapted to the conditions of a desert planet. (Dick/Strick 2004: 87)

Dick and Strick do not quite say this, but it seems clear that Norman Horowitz, head of the Biology Division at NASA’s Jet Propulsion Laboratory at the time, was particularly influenced by *Dune*. Writing in *Science* about the worrisomely dry surface of Mars just one year after *Dune*’s publication, he offered hope for the possibility of life on the red planet by noting that “one of the most interesting drought-loving forms is the kangaroo rat” which can produce “all its water

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12 Some aspects of Arrakis’s ecosystems and their history are addressed only elliptically. For example, in a single sentence, the novel hints that the giant sandworms—huge beasts that swim in the desert sand like sea serpents—are not, in fact, indigenous to Arrakis. Instead, they are an invasive species, brought by some other people to Arrakis. This is never mentioned again in the novel and is only resolved two sequels later in *Children of Dune*.

13 For more about the relationship between climate modeling and planets other than Earth, see Weart (2019).

[...] metabolically" when fed on certain foods. "I am not suggesting that Mars is inhabited by kangaroo rats and that the first life-detection device on Mars should be a mousetrap," he quipped, but he nonetheless felt the kangaroo rat could serve as an example of "what evolution can accomplish" (Horowitz 1966: 790). And yet there appears to be more to this choice of example than he lets on: as every *Dune* fan reading Horowitz's piece no doubt noticed, the "kangaroo mouse," close relative to the kangaroo rat, is the specific animal after whom the protagonist, Paul "Muad'Dib," is supposed to be named. In the novel, when Paul asks to be named after a mouse he had seen, the Fremen receive it as a hopeful omen. Their leader says that "Muad'Dib," their word for the kangaroo mouse, "is wise in the ways of the desert. Muad'Dib creates his own water. Muad'Dib hides from the sun and travels in the cool night. [...] Muad'Dib we call 'instructor-of-boys.' That is a powerful base on which to build your life, Paul-Muad'Dib" (Herbert [1965] 2010: 497). Apart from the kangaroo mouse, Horowitz could hardly have chosen a creature more evocative of *Dune*'s hopeful message about the possibilities of life on a desert world than the kangaroo rat.

Horowitz wrote his piece referencing the kangaroo rat a year after *Dune* was published, and his reference to the novel is clear but not overt. By contrast, more recent astrobiological work has cited *Dune* explicitly. In one article, entitled "Habitable Zone Limits for Dry Planets," the authors praise *Dune* for what they call "an exceptionally well-developed example of a habitable land planet" (Abe et al. 2011: 443). They delve somewhat deeply into the details about Arrakis, noting for example that there is evidence of liquid water in the planet's past, as well as the presence of polar ice caps and aquifers. "The tropics are exceedingly dry, but the polar regions are cool enough and moist enough to have morning dew," they write, recalling the brief scene in *Dune* where Duke Leto watches the morning dew collectors. Using a 3D model, they conclude that dry planets like Arrakis may be more likely to exist as habitable worlds than water worlds like our own, because water creates feedbacks that narrow the habitability range.<sup>14</sup> Abe et al. also show that it is possible for a planet, including perhaps the future Earth, to lose most of its water without experiencing a Venus-like runaway greenhouse effect that would sterilize life on its surface.

Following the Abe et al. article but performing his own reading of *Dune* (and several of its sequels) on his blog, *PlanetPlanet*, astrophysicist Sean Raymond wrote a post adding to the knowledge of Arrakis by working out the particulars of Arrakis's orbit and proximity to its star, Canopus, as well as describing what would happen to the planet's climate when Canopus goes supernova. Raymond seems to have engaged deeply with the *Dune* novels, as he notes that "the source of oxygen

<sup>14</sup> As a vapor,  $H_2O$  contributes to the greenhouse effect, encouraging more evaporation, whereas when frozen it increases planetary albedo and cools the planet more quickly.

is sandworm metabolism instead of oxygenic photosynthesis,” a detail from the novel that Pierrehumbert and others seem to have missed (Raymond 2014).

In fact, since the paper by Abe and colleagues, a discourse within astrobiology seems to have converged on the terms “Dune planet,” “Dune-like planet,” or sometimes “Planet Dune” to describe what another paper calls “hot, rocky planets with small water endowments and low obliquities [that] could conceivably remain habitable in their polar regions. Such planets would resemble the planet Dune in Frank Herbert’s famous science fiction novel by that title; hence, the name ‘Dune-like’ planet has stuck” (Kasting et al. 2014: 12643).<sup>15</sup> This adaptation of the name of Herbert’s desert world speaks to its iconic status, as well as to the speculative orientation of planetary science, especially in the world of astrobiology.<sup>16</sup>

In 2014, NASA scientists Ralph Lorenz and James Zimbleman published the geophysical science book, *Dune Worlds: How Windblown Sand Shapes Planetary Landscapes*. These planetary scientists, though highly gratified that Herbert dedicated his novel “to the dry-land ecologists, wherever they may be, in whatever time they work” (Herbert [1965] 2010: vii; Lorenz/Zimbleman 2014: 283), seem unsurprised that Herbert was so excited by sand dunes. They return the favor by citing Herbert, both in genuine attempts to extrapolate the plausibility of the novel’s setting and in moments of lighthearted celebration of discoveries, as when the recent identification of Titan as the “most dune-covered world we know of” lead to a region of the moon being named “Arrakis Planitia” (Lorenz/Zimbleman 2014: 284). Not least of this homage to Herbert is the fact that they seem to have named the entire volume *Dune Worlds* after the 1963 serialization of *Dune* in *Analog: Science Fact and Science Fiction*, when it was titled *Dune World* (Herbert 1963).

To begin to explain the exemplary status that *Dune* seems to hold for planetary scientists, it is helpful to understand that the novel was itself already the result of feedback between science and science fiction. Frank Herbert’s formula was simple but transformative. He took inspiration from mid-century ecology but reworked the pragmatic, local ideas he encountered there as globe-spanning patterns, extending them to cover a whole world. The remainder of this chapter will track this formula in Herbert’s work, showing its kinship with climate modeling practices.

15 Cf. Cresto Aleina et al. (2013); Kalidindi et al. (2018); Catling/Kasting (2017: 426).

16 It’s worth noting that these astrobiologists citing *Dune* are also using models of planetary climate as evidence of their claims.

## Science Fiction's Sources

In 1957, Frank Herbert, then a journalist and modestly successful science fiction author, traveled to Florence, Oregon to report on a United States Department of Agriculture project to stabilize sand dunes that were migrating across a highway. According to literary biographer Timothy O'Reilly, Herbert "became fascinated by sand dunes—the irresistible way they move, swallowing roads, houses, and on occasion entire towns." He "imagined an entire planet that had been taken over by sand dunes, and an ecologist faced with the task of reclaiming it" (O'Reilly 1981: 39). Set 200 centuries in our future, *Dune* extends the Oregon dune project that Herbert visited in 1957, envisioning the dunes creeping inexorably across an entire planet over the course of deep time. The terraforming process that the ecologist Kynes is implementing on the desert planet Arrakis mirrors the Oregon dune stabilization project and the theory of ecological succession that was cutting edge in the middle of the twentieth century:

Our first goal on Arrakis [...] is grassland provinces. We will start with these mutated poverty grasses. When we have moisture locked in grasslands, we'll move on to start upland forests, then a few open bodies of water. (Herbert [1965] 2010: 440)

The specific terraforming process enacted in the novel (and on the Oregon dunes) demonstrates an effort on Herbert's part to scale local working ecology up to a planetary size. This is made even more explicit if we consider Herbert's sources. In Herbert's initial imagining of the novel, the ecologist Liet Kynes was to be the main character. Kynes was partly styled on the ecologist Paul Sears, a mid-century scientist most famous as the author of *Deserts on the March*, a timely 1935 account of the Dust Bowl and the problem of soil erosion from the perspective of succession ecology. In his essay collection, *The Maker of Dune* (1987), Herbert says that he put the following quotation from Sears directly in the mouth of his character Kynes: "The highest function of ecology is the understanding of consequences" (104).<sup>17</sup> Actually, this is not the only thing that Herbert copied from Sears's work. Though Herbert claimed to have read "over two hundred books as background for this novel" (104), many of them about ecology, it is nonetheless possible to identify nearly every ecologically oriented statement in *Dune* as originating in one slim 1962 volume by Sears called *Where There Is Life*.

I have found more than twenty examples of Herbert lifting elements directly from *Where There Is Life* and duplicating them in *Dune*. A few are mere references.

<sup>17</sup> Despite Herbert's claim, this is not a verbatim quotation of Sears. The precise wording in Sears's *Where There Is Life* is as follows: "For the highest function of science is to give us an understanding of consequences" (Sears 1962: 128).

For instance, Herbert transforms Sears's claim that only three per cent of the sun's light is captured by photosynthesis on Earth into the notion that, in order to create a self-sustaining ecological system on Arrakis, the Fremen need only control three per cent of the land's surface. But the majority of examples—at least fifteen—are direct reproductions of specific phrases and sentences from *Where There Is Life*. Many of them are uttered by the two planetary ecologists (Liet Kynes and his father Pardot Kynes), while others are in the voice of Paul or Duke Leto.

*Table 2.1: Comparison of Sears's Where There Is Life (left column) and Herbert's Dune (right column). Colored text indicates replicated language; underlined text indicates a shift of scales.*

From <i>Where There Is Life</i> (Sears 1962)	From <i>Dune</i> (Herbert [1965] 2010)
<p>One cannot draw neat lines around such problems as these as he can in mathematical and experimental problems. [The] ecologist [...] is like the general practitioner in medicine, obliged at all times to consult specialists in various fields (41).</p>	<p>"We are generalists," his father said. "You can't draw neat lines around <u>planet-wide problems</u>. <u>Planetology</u> is a cut-and-fit science" (439).</p>
<p><u>Nature</u>, whether we relish the fact or not, is a vast, tightly interwoven fabric of activity (20).</p>	<p>A <u>planet's</u> life is a vast, tightly interwoven fabric (445).</p>
<p>This assurance seems to satisfy many [Americans] who forget that, beyond a certain critical point, freedom diminishes as numbers increase within a finite space. This is as true of humans <u>on a continent</u> as of gas molecules in a sealed flask. [The] real issue is not how many people can possibly survive, but what kind of existence will be possible if they do (23).</p>	<p>Beyond a critical point within a finite space, freedom diminishes as numbers increase. This is as true of humans in the finite space of a <u>planetary ecosystem</u> as it is of gas molecules in a sealed flask. The human question is not how many can possibly survive <u>within the system</u>, but what kind of existence is possible for those who do survive (797).</p>
<p><u>The Crusades</u>, which had become a system of mutual pillage and extortion, also helped create great mercantile and shipping cities <u>in the north of Italy</u> (194).</p>	<p>"The historical <u>system of mutual pillage and extortion</u> stops <u>here on Arrakis</u>," his father said. "You cannot go on forever stealing what you need without regard to those who come after. The physical qualities of <u>a planet</u> are written into <u>its economic and political record</u>" (443).</p>

As a creative method, Herbert seems to have repeatedly taken a localized, regional phenomenon—such as the Oregon dunes or a biographical sketch about a Chicago-based naturalist—and extrapolated that same phenomenon at a planetary scale. The following table provides a few examples. In it, I have used colored fonts to indicate words and phrases that Herbert copied exactly from *Where There Is Life* into *Dune*, while I have underlined the shifting scales of particular objects. In the case of Sears's *Where There Is Life*, the object is usually a specific ecosystem, while for Herbert it is the entire planet of Arrakis.

I have focused on these specific 'borrowings' on Herbert's part because they speak to the means by which *Dune* has become a touchstone amongst imaginary worlds. Imaginatively shifting local phenomena up to a planetary scale is what allowed a simple kind of mid-century working ecology to take on the proportions of planetary world-building that made *Dune* iconic. Even the concept of a 'climate' as applied to a whole planet results from this operation. The mid-century ecologist Sears never describes a planetary climate: even when he is talking about the history of geological epochs (i.e. climate *change*), he hedges about climate as a global phenomenon. Rather than describing an ice age as a single, unitary change, he writes that it is "reasonably certain the climatic changes responsible for [glaciers advancing and retreating] were general and fairly simultaneous in the Old and New Worlds and probably on northern and southern hemispheres" (Sears 1962: 152). He is aware that changes occurred globally, but he still differentiates climatic *changes* spatially. And why wouldn't he? From an Earthbound perspective, it is more interesting to think about the *various* climates of the planet, as proxies for describing the various kinds of ecosystems found on Earth. For Sears, the term "climates" is plural—a local or bioregional category, but not one that could characterize the atmosphere of the whole world. For example, he writes, "It is difficult to establish anything like precise boundaries between climactic provinces [...] In the transition belt between desert and oak woodland, one finds desert on the southwestern slopes and oak on the northeastern [...] The climates on two sides of a house differ" (Sears 1962: 150–151). In *Dune*, Frank Herbert posits a planetary climate—the singular term applied to the whole of Arrakis—but this is something that emerges from scaling a bioregional climate up to fill a whole planet.

A climate model, too, takes physics about specific phenomena and systems and extrapolates those connections to a planetary scale. In a general circulation model, the grid size is hundreds of miles. Climate models depict how clouds move across a square that is the size of a small state at each time step. This is the correct methodology with which to study a planet, at least until computing power allows finer-resolution models. Nonetheless, a climate model cannot help but have some of the same cartoonish enlargement of dynamics that we see in Herbert's exact duplication of passages from *Where There Is Life*. Speculative world-building in all of its forms requires generalizing phenomena and enforcing a kind of connect-

edness that speaks to the system as a whole. For example, a general circulation model ensures that local parameterizations communicate with one another in rule-bound ways: the conservation of mass and energy is adhered to at every time step, which prevents local errors from being amplified. Even though the specific modeled dynamics cannot represent the complexity of a real world, the causal connections between elements are enforced so that the ‘world-ness’ of the model is not at stake—circulations will still circulate, and no element will be magically conjured or disappeared between grid squares.<sup>18</sup>

I am not alone in identifying *Dune*’s world-building with climate modeling. In a discussion of terraforming narratives in science fiction, Chris Pak connects *Dune* with mid-century cybernetic theories. He writes, “Ecological principles fundamental to climate modelling, such as sensitive dependence on initial conditions, feedback systems, and cascading effects, are omnipresent in *Dune*, while Paul’s prescience is described as being subject to the same limiting factors as climatological models” (Pak 2019: 204). Noting that Paul is the culmination of a Bene Gesserit project to create “a human computer,” Pak reads *Dune* as a performance of cybernetic modeling in service of a critique of geoengineering. This warning, that computational modeling can never enable control or mastery over the future of a planetary system, is borne out especially strongly in the novel’s sequel, *Dune Messiah*. But despite the critique, *Dune* displays a mode of explanation, common in planetary SF, that nonetheless seems to require a character or the narrator to try to envision (if not control) the planet. However much they may fail, such efforts are crucial to the planetary scale’s emergence in the text.

For instance, in one scene, Kynes describes his realization about the atmospheric composition of the planet:

So few people ever looked up from the spice long enough to wonder at the near-ideal nitrogen-oxygen-CO<sub>2</sub> balance being maintained here in the absence of large areas of plant cover. The energy sphere of the planet is there to see and understand—a relentless process, but a process nonetheless. There is a gap in it? Then something occupies that gap. [...] I knew the little maker was there, deep in the sand, long before I ever saw it. (Herbert [1965] 2010: 442)

In this passage, Kynes points to the nature of Arrakis as a chemical system and explains that a missing link in the cycling of nutrients around the planet was evident to him before he found the precise organism responsible for it. This moment exemplifies an epistemic habit of implicit causal completeness that is common in science fiction, but which *Dune* takes to an extreme. In the real world, there is

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<sup>18</sup> There are many overviews of climate modeling available. In writing this chapter, I consulted Edwards (2010), Neelin (2011), and Gettelman/Rood (2016), among others.

so much information that it would be impossible for a single person to infer the whole structure of a planet's energy sphere (this, in fact, is the whole project of climate modeling). It is only in a science fiction text like *Dune* that the reader is presented with a world that is absent of red herrings, causally complete, and simply waiting for its missing pieces to be slotted in by a science-minded observer.<sup>19</sup> As a performance of ecological knowledge, this scene makes sense: as we have seen in Sears's text, notions about ecology as made up of cycles and relationships were central to mid-century ecology.

But consider the following scene, in which the same kind of logic is performed but with a non-ecological (or only partially ecological) object. Here, Paul is just beginning to develop his prescient powers, while he and his mother are escaping from the Harkonnens by hiding in the desert. Paul begins to say that the Harkonnens have never truly ruled the planet, but Jessica doesn't understand:

“Paul, you can’t think that—”

“We’ve all the evidence in our hands,” he said. “Right here in this tent—the tent itself, this pack and its contents, these stillsuits. We know the Guild wants a prohibitive price for weather satellites. We know that—”

“What’ve weather satellites to do with it?” she asked.

Paul sensed the hyperalertness of his mind reading her reactions, computing on minutiae. “You see it now,” he said. “Satellites watch the terrain below. There are things in the deep desert that will not bear frequent inspection.”

“You’re suggesting the Guild itself controls this planet?”

She was so slow.

“No!” he said. “The Fremen! They’re paying the Guild for privacy, paying in a coin that’s freely available to anyone with desert power—spice. This is more than a second-approximation answer; it’s the straight-line computation. Depend on it.”  
(Herbert [1965] 2010: 311)

This passage is fascinating, as it attempts to mirror the same kind of logic that attended Pardot Kynes's claim, “There is a gap in [a process]? Then something occupies that gap” (Herbert [1965] 2010: 442). However, it also raises questions about

19 This feature of science fiction worlds is similar to what Fredric Jameson famously referred to as world-reduction, “a process of ontological attenuation in which the sheer teeming multiplicity of what exists, of what we call reality, is deliberately thinned and weeded out through an operation of radical abstraction and simplification” (Jameson 1975: 223). For Jameson, this enabled thought experiments with a kind of sociopolitical causal completeness that today looks oddly anti-ecological. In fact, he singles out *Dune* as inadequately ‘reduced,’ writing of *The Left Hand of Darkness* that its “peculiar ecology [...] along with the way of life it imposes, makes [it] something like an anti-*Dune*” (221). Nonetheless, the idea that SF represents simplified, implicitly causally-complete worlds is an analogy to modeling.

how a single process can be identified, and what constitutes a gap in the first place. Paul claims that “we’ve all the evidence” and begins to list the objects in the tent. Out of nowhere (or so Jessica thinks), he then adds the datum, “the Guild wants a prohibitive price for weather satellites.” But the gap between the Guild’s price for satellites and the desert survival technology in the tent is a bit more difficult to fill in than the gap in the cycling of atmospheric elements. This is why we are treated to a textual performance of causal closure as Paul’s “hyperalertness [...] computing on minutiae” swoops in to make the non-obvious seem obvious. We are left inhabiting the same position as Jessica while Paul thinks, “she was so slow.” In this case, just as in the case of the atmospheric cycle, the different elements of the process must be related to one another as part of some vast system of exchanges and relations. Here, the squares of the grid are so vast that only the fiction of Paul’s immense processing power makes the leaps of association seem reasonable.

Like the scene about the atmospheric chemistry of Arrakis, this scene has the purpose of establishing a planetary scope to the science fiction narrative—while the significance of desert power has already been described at great length by this point in the narrative, this scene serves as an introduction to Paul’s growing abilities. It communicates a way of thinking about how the different parts of the planet have to be connected in order to make it ‘planet-shaped.’ Paul’s deductions leap from facts about the tent he is in, to satellites that are not in orbit around the entire planet, to the relationship between the Fremen and the Guild, and to the resources under the sand. These leaps connect the different aspects of the world in a way that makes a planet emerge, and the reason it works is because the ultimate object of each of its loops is explaining the planet itself.

Bruce Clarke writes,

The planetary imaginary of any era is [...] an abiding creative resource that constitutes itself whenever an artist invents and communicates fictive images of living worlds—perhaps, also, of the cosmos that contains those imagined planets, or of the ecologies they sustain—and bodies these forth in some workable medium. (Clarke 2015: 152)

The reason *Dune* is such a touchstone for climate scientists isn’t only that it depicts a planet with a single unique climate. Rather, it has to do with the mode of inference—the planetary imaginary—that the novel performs. This mode of inference is, the dual action of bringing explanations up to a planetary scale (as when a comment about the crusades in *Where There Is Life* becomes a comment about a planet’s whole history) alongside the assumption of planetary closure. In Herbert’s words, a planet is “a system. A system! [...] A system has order, a flowing from point to point” (Herbert [1965] 2010: 806) in wide, repeating cycles. In other words, Arrakis’s construction is a form of speculative planetology: the closing of

causal loops is assumed to happen at the planetary scale, and this is what makes it 'work' like a climate model.

Reading *Dune* in light of climate modeling helps to explain how science fiction texts make objects that cohere at the planetary scale. Speculative planetology involves the same kind of inference about how worlds cohere across disciplines. In Lisa Messeri's terms, planetary scientists are "literally world-builders," in that they are "invested in questions of what it is like to be on other worlds" (Messeri 2016: 5). For scientists as well as for the public, science fiction texts have helped to provide the templates for how to think about worlds and world-making. The discursive and computational construction of worlds by planetary scientists draws on 'SFnal' thinking, and on the fundamental premise of science fiction, the idea that things could always be different than they are. In *Dune*, when Duke Leto is introduced to Liet Kynes, the Duke refers to him as an ecologist: "We prefer the old title here, my lord," Kynes said. 'Planetologist'" (Herbert [1965] 2010: 174).

With this term, Herbert anticipated a science that has only begun coming into its own in the last few decades, alongside advances in Earth system modeling and the increasingly vigorous field of astrobiology. The strategies *Dune* uses to create a world out of a desert ecosystem exhibit a kind of planetary consciousness that is shared between science fiction and the planetary sciences, including climate modeling. As this chapter has shown, planetary and climate scientists refer to science fiction pedagogically and methodologically to communicate this form of speculative planetology. In doing so, they teach us that the ability to comprehend our own planet requires embedding it in a multiverse of imagined otherworlds.

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