Science Fiction Atmospheres

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One of the first science fiction books I can remember, apart from early encounters with Mr. Bass and his mushroom planet, is J.G. Ballard's apocalyptic duo, "The Drowned World" and "The Wind from Nowhere." It arrived one mild summer day in the form of an inexpensive but sturdy Doubleday hardcover edition – the obligatory part of the monthly shipment from a science fiction book club – and swiftly made its way up into the tree where I'd hide out with such booty. The titles alone were evocative, in the way Ballard has, and I still cannot call to mind the cover art without a certain feeling of *tristesse*. I would like to say that these stories were the start of a long fascination with climate dynamics, but the fact is that, at age 11, I found them bewildering. They talked a lot about, well, *people*, baffling at the best of times. Almost as baffling was the scientific framework of wind and temperature – something that seemed rather more difficult to grasp than things like positronic brains and faster-than-light drives. In retrospect, I can see that Ballard actually had a quite reasonable premise in *The Drowned World*. A long-lived solar storm increases luminosity to the point that the equatorial regions become uninhabitable and the ice caps melt, drowning the continents. Civilization clings desperately to life in scattered outposts in Greenland and Antarctica. More precisely, Ballard supposes that the solar wind destroys the "ionospheric shielding" of insolation, leading to increased solar heating of the Earth. Probably, it was UV shielding by the stratospheric ozone layer that he had in mind. Letting through more UV wouldn't increase the surface insolation by enough to serve Ballard's plot line, but let's give him the benefit of the doubt and assume he had in mind that the Solar luminosity increased in step with the general instability of the Sun. The fact that Ballard went the solar route rather than invoking elevated CO_2 is an interesting testament to how little the importance of greenhouse gases had seeped into the public consciousness. At the time Ballard was writing, Revelle and Suess had already revived interest in Arrhenius' quaint idea, Keeling was several years into his historic CO_2 measurements, and Manabe had just made the first proper calculations of the effect with modern radiative-convective physics. It was to be nearly two more decades before the public awakened to the importance of this work. Be that as it may, the Sun can do the job Ballard needs it to do. In fact, the main problem is that Ballard may get more bang from his solar storm than he bargained for: Any increase in solar luminosity sufficient to increase the tropical temperatures to 70C, as Ballard supposes, is almost certainly enough to put the Earth over the limit for initiating a runaway water vapor greenhouse. To be fair, the question of the rate of warming in a runaway greenhouse scenario has never been studied; Ballard says it took 50 years from the initiation of the storm for tropical temperatures to reach 70C. Could the thermal inertia of melting ice sheets cause a delay of this magnitude? The time required for evaporating water into the atmosphere? The thermal inertia of the deep oceans? Can this planet live? The treatment of these questions is left as an exercise for the reader (Graduate students take note: This is good fodder for general exam questions!)

The climate dynamics in *The Wind from Nowhere* is rather more obscure. The midlatitude jets begin accelerating at a rate of 5mph per day, eventually becoming so strong that they scour the Earth's surface, rendering it uninhabitable. Civilization clings desperately to life in a few scattered underground outposts. Ballard never gets around to telling us why the winds might suddenly do this, but we are all meteorologists here, so we are equipped to engage in a little speculation. One is tempted to think in terms of some mechanism that would push the boundary of the Hadley cell deep into midlatitudes, causing a strong jet by angular momentum conservation. Closely allied with this is the notion of flipping over into a super-rotating state like the atmosphere of Venus or Titan. The problem is that Ballard's global windstorm has bottom-trapped surface westerlies everwhere, which are strongest at the Equator. That's hard to reconcile with any notion of angular momentum balance. On the subject of Hadley cells let's not forget the crucial role played by this circulation in Neville Shute's *On the Beach*, surely the grimmest novel of nuclear apocalypse ever written. It's a hard novel to read even now, but in the 60's when such things seemed terrifyingly possible, it was not for the faint of heart. As one of Shute's characters explains, it is the seasonal reversal of the Hadley circulation, and the associated migration of the ITCZ, which allows the deadly radioactive dust to mix into the Southern hemisphere.

The planetary settings of many other science fiction stories pose interesting questions from the point of view of physics of climate. On Frank Herbert's *Dune*, it never rains, and there is no surface water; all water needed to sustain life must be pumped up from deep wells. A completely dry planet with a habitable temperature range is no problem, at least if one only needs it to remain habitable for a few hundred million years. For example, Venus with a pure Nitrogen-Oxygen atmosphere would have a mean surface temperature of around 300K. One needs to allow for a bit of CO_2, so that photosynthesis has something to work with to create the free O_2 in the atmosphere – though maybe sandworms eat SiO_2 and exhale O_2? In any event, a little CO_2 wouldn't hurt, in view of the high albedo of the sand which covers the planet. However, unless the planet is tectonically dead, outgassed CO_2 would build up in the absence of silicate weathering (which requires surface water), eventually rendering the planet uninhabitable. Note, though that without water vapor feedback, the hazard of high CO_2 is not nearly so extreme as it would be on Earth. However, if there's water in an aquifer, is it reasonable to suppose that the atmosphere is unsaturated? It only takes a few cm of precipitable water to saturate a column of air at Earthlike temperatures, and far less to saturate air aloft. There would almost certainly be some clouds and precipitation, though the precipitation could well evaporate before it reaches the ground. But how is the aquifer recharged if it never rains? 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.

At the opposite extreme are waterworlds like the clone-masters' planet in the Star Wars *Attack of the Clones* episode. I'm quite sure the viewer is supposed to think that, on this planet, it rains everywhere all the time. Why else would the clone-masters choose to put their station in such a miserably rainy place? (Perhaps they came from Seattle, and were homesick.) Waterworlds have an even more limited time slice of habitability, because they are subject to a snowball catastrophe when the Sun is young and faint, and a runaway greenhouse catastrophe when the Sun is older and brighter;

without continents, there is no silicate weathering thermostat to keep these catastrophes at bay. As on Dune, this is not necessarily a problem, since the clone-masters are probably relatively recent arrivals, and may simply pull up stakes when the planet becomes uncomfortable. However, a planet with Earthlike temperatures can't have ubiquitous, perpetual torrential rains; at 300K, there is only enough rain in a column of air to yield 9cm of rainfall. Even at 320K, the water content only goes up to 40cm. Generally, water must be gathered in from a considerable area to sustain a torrential rain. An even bigger constraint comes from energetics: maintaining the evaporation to feed a sustained 10cm per hour rainfall requires $70,000 W/m^2$ of solar absorption, which would certainly trigger a runaway greenhouse, Apart from the energetic constraint, it's unlikely that evaporation could be sustained without a supply of dry air to the boundary layer from major subsiding regions. We can always expect rain to be a rather intermittent phenomenon. This conclusion applies as well to most other condensible substances, such as methane, though water is an extreme case because of its unusually large latent heat.

Then, there are the folks who just can't leave well enough alone, like the pro-terraforming faction in Kim Stanley Robinson's *Red Mars*. The quandary they are in is that they want to create a shirtsleeve environment on Mars – meaning high pressure, warmth, and oxygen – but they are precluded from using the most natural greenhouse gas (CO_2) because of its toxicity. Robinson didn't mix up CO_2 and CO: Good old CO_2 really is toxic, and immediately so at partial pressures of around 50mb. If you're far from home in a spacesuit with a broken CO_2 scrubber, then CO_2 build-up will get you long before you run out of oxygen. Though he doesn't make the point explicitly, one can get some additional warming by leaving around 10mb of CO_2 in the atmosphere, and boosting its greenhouse effect through the pressure broadening caused by adding N_2 and O_2 to the atmosphere. One doesn't get very far with this mechanism alone, but every little bit helps. Robinson has certainly set up the puzzle correctly, but the physics behind many of the solutions his characters propose is silly. Silliest of all are the windmills, which are supposed to heat the planet by using wind-generated electricity to drive heating coils. (I won't insult the reader's intelligence by spelling out why this wouldn't work.) One could argue that the windmills were really just a ruse for illegally dispersing Mars-adapted algae, but it's more than a little implausible that all the high-powered physicists among the Mars colonists would be taken in. There is other silliness. Polar caps are dissipated by albedo-reducing algae, and water vapor is added to the atmosphere by cometary impacts and "moholes" without regard to the constraints imposed by Clausius-Clapeyron. On the other hand, there are some interesting and workable ideas in Robinson's book. There is a space mirror to catch sunlight and turn Martian night into day, but to bring Martian insolation up to Earth levels would require a mirror with a cross sectional area equal to Mars itself; still, a more modest mirror with 10% of the Martian cross-section could make a useful contribution. The question of the microclimate of low-lying areas like the Hellas Basin, where surface pressure will be greatest, bears thinking about, as does the circulation one would get around the rim of the basin. It would be rather like Death Valley (how jolly!) or a drained Mediterranean, only more so. If it were up to me, I'd make some use of algae bio-engineered to release HFC's, and perhaps also synthetic cloud particles optimized to reflect infrared while letting through a lot of sunlight.

Despite these examples, and a few others, "Atmospheric Science Fiction" remains largely unexploited territory, at least in comparison to astrophysics, and (recently) nano- and bio- tech. One could think of interesting plot lines built around the methane hydrological cycle of Titan, the onset of a Snowball Earth episode, or an Earthlike planet which (lacking a large moon) undergoes extreme obliquity cycles. Or how about this one, verging on the world of fantasy: A cult of philosophers discovers a subtle knife which can open windows into the deep interior of the planet, bringing to the surface potent black fluids or solids whose energy transforms society and makes everybody more powerful than they could ever have dreamed of previously. But just when everybody is most hooked by the Dark Power, a lonely savant discovers that its use releases a substance that threatens to tear asunder the very fabric of the planet's habitable climate. At first, like Dr. Thomas Stockmann in Ibsen's *Enemy of the People* he is scorned and shunned, but eventually (unlike the case of poor Stockmann) the greatest savants and wizards of the world come to realize that he is right. Despite this, the faction favoring the Dark Power has the upper hand. The emperor of the most powerful kingdom on the planet dismisses the threat of Dark Power, and even wishes to use the subtle knife to expose more, in hitherto sacred areas of the Far North. In the innermost council chambers, the closest counselors to the emperor wave about propagandistic fictionalized accounts casting doubt on the threat of Dark Power, unable or unwilling to distinguish fabrication from reality. Meanwhile, inexorably, the world keeps getting warmer. No, that plot line is too improbable – and too scary. Better not go there. (But if you must, check out Kim Stanley Robinson's *Forty Signs of Rain*.)