Razor-thin Films: Earth's Atmosphere and Seas

Is our planet fragile or robust? If the functioning of natural systems is robust, and if the earth's water, seas, and atmospheric resources are immense, then pollution and other human abuses might be viewed as relatively minor insults to an otherwise robust and pristine system. Thus, if our worldview envisions the immensity of the earth and the vastness of its seas as beyond harm from human activities, then our economic and societal behavior will reflect that perception. But is such a worldview justified?

Or is it an artifact of the fact that we ourselves are such tiny beings and that our planet simply seems large and immense as a result of our own diminutive size? In this PDF, we will see that earth's atmosphere and seas are actually *thin and fragile films* vulnerable to damage and destruction.

As a planet, earth has several characteristics that allow life as we know it to exist. First, it has immense quantities of water, so that we could call ourselves the "Water Planet." Secondly, it orbits the sun at a distance that allows most of this water to exist in its liquid state. If we were a little further from the sun, our water would freeze and exist as ice. If we were a little closer to the sun, our water would exist primarily in its gaseous state. In these respects, then, we can think of the earth as an "Unlikely Planet" (IOF, 1977). In this chapter, we examine earth's atmosphere and seas through two vastly different lenses – and we will better appreciate these thin and fragile films when we have finished.

Immense Quantities of Water?

Compared to other known planets, earth has immense quantities of water. Approximately 77% of its surface is covered with some form of water (for example, as oceans, lakes, glaciers, and snow). The Pacific Ocean alone covers more of the earth's surface than all of our land masses combined. In addition, water covers 60% of the northern hemisphere and approximately 80% of the southern hemisphere. Furthermore, if we were to use all earth's mountains and land masses to fill in the deepest parts of the sea, we would end up with no land at all. Instead, earth would be covered with a layer of water 2.5 kilometers deep (after IOF, 1977; Anson, 1996; 1991).

In addition to these immense reservoirs of water, earth also has hidden reservoirs of water. Its atmosphere is filled with clouds, rain, water vapor, fog, and humidity. Our farms and cities rely on vast underground aquifers containing fossil water that fell as rain thousands of years ago. And even the cells, tissues, and bodies of living things constitute rich reservoirs of water. Living cells, for example, are up to 98% salt water. Lettuce and celery are good diet foods because they are composed mostly of water. When jellyfish wash onto a beach, they soon disappear through evaporation – as one writer has put it, they literally “disappear into thin air.” In Arizona, each seven metric ton *Saguaro* cactus contains nearly six metric tons of water. Finally, not only does water make up 60-70% of our body weight, but even our blood, sweat, and tears (and amniotic fluid) are composed of salt water (ibid).

Or a Thin and Fragile Film?

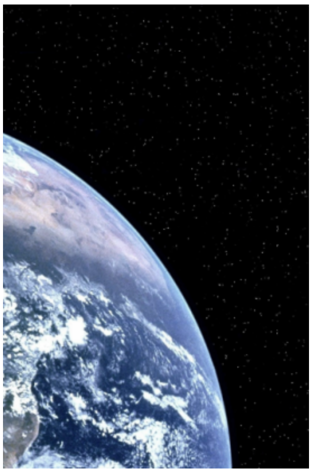
All of these numbers seemingly suggest that our planet has an abundance of water. If we accept this impression as true and our seas are as immense as they seem, then it seems nearly impossible that we could damage them with our pollutants, or overfish them, or drive vast deep-sea regions to anoxia. In reality, however, this apparent immensity is simply an illusion. As living organisms, each of us is so tiny compared to the size of our planet, that earth's oceans, which can drown us a few dozen yards offshore, only *seem* large in comparison to our own diminutive body size.

If we consider earth's oceans as simply a surface feature of our planet, an entirely different perspective emerges. Mathematically speaking, 99.94% of our planet consists of its crust, mantle, and its molten interior. The thin layer of water that we refer to as an ocean exists only as a thin and precarious surface film that is only six one-hundredths of 1% as thick as the earth itself.

To illustrate this depth to scale on a classroom globe, we would need a layer of water twelve one-thousandths of an inch deep to proportionately depict the depth of earth's oceans (ibid). If we were to wipe a wet paper towel across a twenty-inch globe, the film it leaves behind would be too deep to properly represent the depths of earth's oceans. Thus, the apparent immensity of earth's ocean is actually an illusion. When appraised mathematically, our oceans constitute a precariously thin and fragile film with far greater vulnerabilities to damage than we initially suppose.

Like the Skin of an Onion

It turns out that our ocean of air, earth's atmosphere, can be viewed in a similar way. If we analyze the proportional depth of earth's atmosphere, we find that what appears to be a seemingly endless atmosphere is also little more than another thin and fragile film. Astronauts and cosmonauts, while taking photographs from space, have likened earth's atmosphere to a single layer of skin on an onion.



If we examine the earth as photographed from space, it is easier to notice how thin, comparatively speaking, is its atmosphere. And as mountain climbers, pilots, and skiers know, most of the high-altitude regions of earth's atmosphere are also so thin in the gaseous sense as to be uninhabitable for most terrestrial organisms. Seen from this perspective, our collective individual impacts may constitute an unfolding disaster as the onion-skin-thin film of air that comprises earth's atmosphere may be in far greater danger than we dare to imagine.

No Other Animals Do This

As a test of this last observation, envision an individual animal of any species other than our own. In virtually all of these cases, the organism's daily pollution of its environment is limited to its daily production of its bodily wastes. Next, however, envision an ordinary human being living in an industrialized country. One's daily body wastes are again a factor, of course, but humanity's collective biological wastes are natural productions that have, in a planetary sense, little impact on global systems.

Continuing, however, envision this same human being in an automobile, backed up in crowded traffic on a busy eight-lane highway. All around in every direction are hundreds of other cars and trucks and buses, each spewing exhaust from an internal combustion engine. This indicates that each of us as individuals are contributing much more than our body wastes to our surroundings. Notice also that these additional wastes do not constitute a once-in-a-lifetime contribution by each of us.

Instead we repeat these assaults again and again and again, day after day after day, throughout our lives. Every day, from all of those tailpipes on each and every bumper-to-bumper interstate, boulevard, and highway, we spew molecules of carbon dioxide and carbon monoxide and other noxious fumes. We are the only animals on earth that do this, and we do so during each and every rush hour, on every grocery run, on every holiday trip to visit family, and during every postal delivery.

And we repeat this behavior *every day* - again and again and again – in Beijing, Los Angeles, Mumbai, Tokyo, Cairo, Karachi, Jakarta, Paris, Moscow, Rio de Janeiro, and New York City - releasing more multiple billions of tons of waste, without fail, relentlessly into the onion-skin-thin layer of air that makes up earth's atmosphere.

We are the only animals on earth that do this - *and we are not even at home or at work yet*. Now we switch on our heating or air-conditioning units, run a dishwasher and clothes drier, run our lawnmowers and weed-trimmers, our refrigerators and freezers, our street lights, fluorescent lights, toaster-ovens, microwaves, hair-dryers, steel mills, shopping malls, motor-boats, televisions, computers, and hot-water heaters.

And then we repeat these same activities every day, again and again and again, so that our power plants, on our behalf, release still more tons of wastes and fumes, without fail, relentlessly and endlessly, into the onion-skin-thin layer of air that constitutes earth's atmosphere. We are the only animals that do this, and we still have not yet added the wastes generated by unwanted catalogue mailings, tons of throw-away containers, and all the items that we ship halfway around the world.

No other animals on earth do this –

how can we imagine that endless billions of us can
endlessly behave in this way with-out calamitous repercussions?

If we intend to enjoy such extravagance,
our populations must be smaller.

In his book HOT, FLAT, AND CROWDED (2008) Pulitzer prize winner Thomas Friedman quotes California Institute of Technology chemist Nate Lewis: "Imagine you are driving your car and every mile you drive you throw a pound of trash out your window. And everyone else on the freeway in their cars and trucks are doing the exact same thing, and people driving Hummers are throwing two bags out at a time – one out the driver-side window and one out the passenger-side window. How would you feel? Not so good. Well, that is exactly what we are doing; you just can't see it. Only what we are throwing out is a pound of CO_2 – that's what goes into the atmosphere, on average, every mile we drive" (Fried-man, 2008).

If world population did not grow at all, all of these impacts would likely double as the world's poorest nations industrialize and seek to emulate our own standard of living. Knowing that earth's atmosphere is not responding to our assaults very well right now, we are nevertheless on-track to add at least a 7^{th}, 8^{th}, and 9^{th} billion to our numbers by mid-century.

Methane Hydrates and Warming

What other impacts do we exert today? Rising levels of the greenhouse gas CO_2 have been repeatedly implicated in studies of global warming (For example see IPCC, 2007; Schellnhuber, 2006; Kluger, 2006; Salleh, 2003; Houghton, 1987; Bacastow, et al., 1985, and Neftel, Moor, et al., 1985). But methane gas (CH_4) is also a greenhouse gas. And when compared to carbon dioxide, a single molecule of CH_4 has twenty times the warming effect of a molecule of CO_2 (Weiner, 1990). Among the broader public, it is less well known that "methane levels in the atmosphere have been increasing approximately 1% per year, from 0.7 to 1.6 to 1.7 ppm in the last 300 years" (Prescott, et al., 1999). Some of this methane is released from rice paddies, marshes, coal mines, and sewage plants. Even microbes inhabiting the intestines of termites release methane daily, along with the intestinal microbes of cattle and similar ruminants that release about 200 to 400 liters per animal per day (ibid).

A particularly immense storehouse of methane is also currently locked away in earth's permafrost, and in the form of "massive deposits of methane hydrate...in ocean sediments" (Prescott, et al., 1999). In these frozen muds of the deep sea, methane is trapped in tiny lattice-like cages of crystalline water, representing an estimated "10,000 billion metric tons of carbon...as methane hydrate worldwide" (ibid).

If present warming continues and both earth's permafrost and its deep-sea muds begin to warm, a self-fueling release of ever more gigatons of CH_4 could result (e.g., Revelle, 1983; Bell, 1982; IPCC, 2007). If rising levels of CO_2 induce enough warming, they could trigger the addition of billions of tons CH_4 gas by release from permafrost and deep sea muds - setting off a runaway and essentially unstoppable cascade of self-amplifying climate change.

Interactions and Impacts

As organisms carry out their life activities, there are three patterns that characterize their interactions with each other and with their environments. First, <u>the abiotic</u> (non-living) <u>environment can affect living things</u>. Here we might think of lightning striking a tree or a fire burning a forest. Alternatively, we can imagine late freezes, avalanches, extended droughts, tidal waves, tornados, and floods that dramatically affect living things.

Secondly, living things can affect each other. We might picture an Alaskan bear, for instance, capturing a salmon. Or we can imagine a pet that has a quieting effect on one's blood pressure. Or we can envision bryozoans, sea squirts, and encrusting sponges competing for attachment sites on a pier piling. Or we might observe a butterfly pollinating a species of flowering plant.

Less intuitively, however, but of special importance to our discussion, there is a third major pattern: Living things can affect the non-living environment. Thus, we can think of beavers building a dam across a mountain creek. Or we can think of marine dinoflagellates releasing brevetoxins during an outbreak of red-tide. Or we might think of corals building a reef that produces and then protects a shallow and placid lagoon.

It is important that all of us envision this latter principle at work on a planet-wide scale. We might contemplate, for instance, all of the plants and other photosynthetic organisms that generate the molecular O_2 that makes up 21% of earth's atmosphere – the very oxygen that we breathe.

Our Neighbor In Space - Venus

In the early decades of the U.S. space program, NASA began to investigate the possibility of manned research stations on other planets. Most intriguing of these, of course, is the possibility of a near-term manned research station on Mars. But Carl Sagan and other scientists also offered intriguing speculations about possible missions to earth's other near neighbor in space - Venus.

At the present time, any thought of manned missions to Venus is out of the question. At its surface, Venus has a temperature of about 900 ^{o}F, and above that surface lies a crushing atmosphere of carbon dioxide laced with enveloping clouds of sulfuric acid. Sagan and his colleagues suggested, however, that the currently harsh conditions on Venus might be made more moderate and earth-like by a process they called terraforming – a biologically-based method of planetary engineering.

Terraforming Venus

The innovative suggestion that the harsh conditions on Venus might be ameliorated and made more earth-like, though speculative, is nevertheless informative. Imagine sending a rocket to Venus containing a single, photosynthetic thermoacidophilic bacterium (an organism that thrives in hot, acidic conditions). Today, bacteria with these approximate characteristics exist in boiling pools in Yellowstone National Park, and genetic engineering would allow us to fine-tune a candidate organism as needed. Thus, Sagan and his colleagues envisioned the following scenario: Release such a bacterium at high altitude on Venus where temperatures are cooler.

To nourish itself, the organism would require the usual raw materials for photosynthesis, namely, carbon dioxide, sunlight, and (as condensed high altitude droplets) water. Since Venus has all these, the bacterium ought to be able to accomplish photosynthesis as summarized by this equation:

$$\boxed{6\,CO_2} + 6\,H_2O + \text{light} \rightarrow C_6H_{12}O_6 + \boxed{6\,O_2}$$

Notice that photosynthesis causes carbon dioxide (on the left-hand side of the equation) to be systematically *removed* from the atmosphere. Since CO_2 acts as a greenhouse gas that traps heat, this ongoing removal would have the effect, over time, of cooling the planet. Secondly, notice the right-hand side of the equation where one of the two products of photosynthesis is molecular oxygen that would be released into the Venusian atmosphere. Thus, by employing biology alone, we see both a reduction in CO_2 (producing a gradual cooling), along with a gradual increase in atmospheric O_2.

Under these conditions, the bacterial population would grow (by dividing repeatedly) and set off a cascade of subsequent events. With no competitors, predators, or diseases present to hold their numbers in check, the bacterial population would increase exponentially. And as their numbers increase, the bacteria would remove more and more CO_2, systematically reducing greenhouse conditions and allowing planetary temperatures to cool more and more. Eventually, as a result of falling temperatures, some of Venus's water vapor would begin to condense and fall as rain, thereby producing a startling new set of conditions - including puddles, lakes, and streams - on the Venusian surface.

Living Things Can Change Entire Planets

The events we have just envisioned illustrate two key biological principles: First, living things have the capacity to change entire planets. Even a single cell, so small that it can only be seen using 400x magnification under a microscope, and so fragile that it can be killed by osmotic imbalance, an antiseptic rinse, or warm salt water, has the potential to change an entire planet. Secondly, in an ironic and paradoxical way, living things can be, simultaneously, both fragile and extraordinarily powerful.

Unfortunately, the capacity to change entire planets can be a double-edged sword. Sometimes, for instance, the activities of living things can be beneficial, as illustrated by NASA's scenario for terraforming Venus. But population explosions of living things can also be harmful to their environments.

We are reminded of this by such phenomena as algal blooms (population explosions of algae) and dinoflagellate red-tides that produce toxins or deplete oxygen supplies that often induce mass mortality in marine and aquatic systems.

Finally, while red-tides and algal blooms are localized phenomena, our own impacts are a **planet-wide** phenomenon, so that our own activities today already appear to be having global effects… right now. Despite this and our current impacts, we seem mindlessly intent upon adding still additional billions of extra persons to our population by mid-century. In other PDFs comprising this collection, we assess the implications of complacency compounded by unwarranted assumptions.

Mathematical footnote

Some readers may be interested in the mathematics behind this discussion of earth's thin films. Here in outline form is that mathematics. (i) Earth's oceans are, on average, approximately 3.6 kilometers deep. If we have 3.6 kilometers of water on one side of our planet and another 3.6 kilometers on the opposite side, this serves an addition of 7.2 kilometers added to earth's overall diameter. (ii) Earth's overall diameter (including its molten interior, rocky mantle, crustal plates, and covering of oceans) is approximately

12,740 kilometers. (iii) Thus, without the 7.2 kilometers of ocean, the earth's diameter would only be 12,732.8 km. (iv) This means that 12,732.8 km out of 12,740 km (or 99.94%) of earth's diameter consists of its molten interior, rocky mantle, and crustal plates. (v) Notice that the average depth of the oceans accounts for only six one-hundredths of one percent of earth's diameter – an inexpressibly thin film indeed. (For a twenty-inch classroom globe, .0006 times 20 inches would equal oceans, so that the classroom scale model would need a layer of water that is 12/1000ths of an inch deep to represent the ocean's depth in proportionally correct terms.)

A continuation of today's demographic tidal wave *may constitute the greatest single risk that our species has ever undertaken.*

Excerpted from
What Every Citizen Should Know About Our Planet
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Critique of Beyond Six Billion

Delayed feedbacks, limits, and overshoot

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