

The Dynamics of the Biosphere

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Abstract: The biosphere is the thin, interconnected system of all living things and three environmental matrices of atmosphere, ocean, and soil. Organisms are coupled to each other in the traditional ecological interactions, such as the food webs. But organisms are also coupled by nutrient intakes from the matrices and waste inputs to the matrices. All together, these intakes and inputs create a global metabolism. The result is a biosphere system in which wastes from certain biochemical guilds of organisms are nutrients for other guilds, and in which free by-products from different guilds have affected the large-scale chemistry and thus habitability of the biosphere's environmental matrices. Today, humans, through the combustion of fossil fuels and the waste emissions of the greenhouse gas carbon dioxide, are altering the chemistry of the atmosphere and the other environmental matrices, faster than the global carbon cycle can adjust. We are responsible for these changes, which will cause ever more global warming and other effects, and therefore we must look for ways to create a more sustainable future.

Key words: Sustainable, carbon emissions, biosphere, global warming.

Resumen

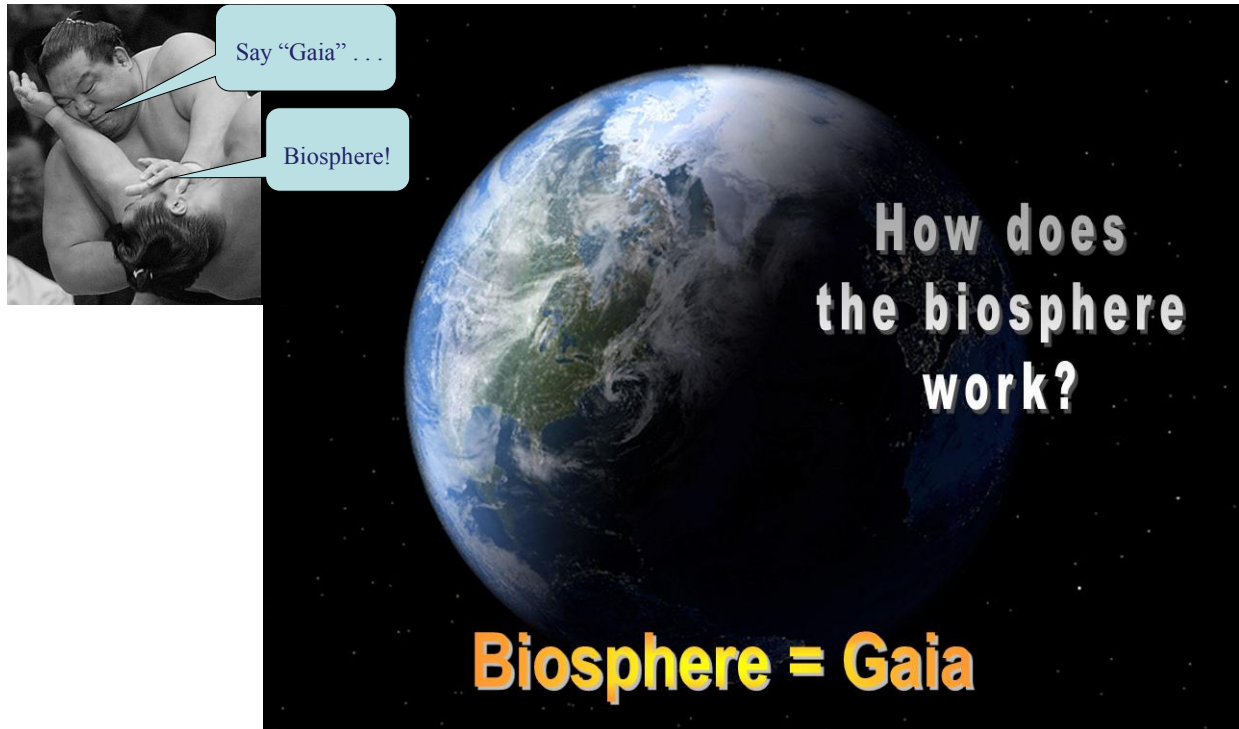
La biosfera es el fino e interconectado sistema de todos los seres vivos y las tres matrices ambientales; la atmósfera, el océano y la tierra. Los organismos están en par entre ellos mismos en interacciones ecológicas, como la cadena alimenticia. Pero también están a la par con nutrientes que reciben de las matrices y de la desecha de esas matrices. Todo unido, estos consumos y aportaciones crean un metabolismo global. El resultado es un sistema de biosfera en el cual los desechos de algunos gremios de organismos son nutrientes de otros. Estos subproductos gratuitos de diferentes especies han afectado la química en gran-escala y la habitabilidad del medioambiente y sus matrices de las biosferas. Hoy nosotros humanos, por la combustión de los combustibles de los fósiles y las emisiones de rechazo del dióxido de carbono, que causan el efecto invernadero, estamos causando un cambio en la química de la atmósfera y las otras matrices del medioambiente, más rápido que lo que el ciclo de carbón del planeta se puede ajustar. Somos responsables por estos cambios, los cuales causaran más calentamiento global y otros efectos y por ende debemos buscar maneras de crear un futuro más sustentable.

Palabras claves: Sustentable, emisiones de carbón, biosfera, calentamiento global.

Introduction: In this manuscript, I will outline the five major topics of my conference:

1. The biosphere is a true system with spatial integrity.
2. The various chemical transformations within the biosphere create what might be thought of as a "global metabolism."
3. The main way in which the biochemical guilds of the biota are linked to each other and to the environmental matrices is related to the fact that wastes from one guild are nutrients for a different guild.
4. What is happening today to the cycle of carbon? Carbon dioxide is rising, with implications for global warming.
5. Conclusion: We have responsibility for the future.

1. The biosphere is a true system with spatial integrity: I will use the term “biosphere” to refer to the interconnected system of atmosphere, ocean, soil, and all of life (collectively known as the “biota.”). Some might prefer to call this system the “Earth’s surface system.” Others might prefer more poetic language, such as “Gaia.”

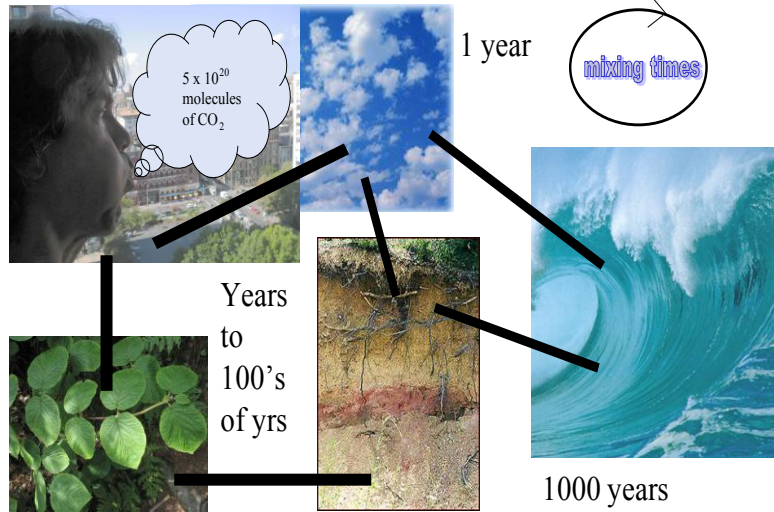


But whatever the name, the following numbers show us that there really is system to talk about:

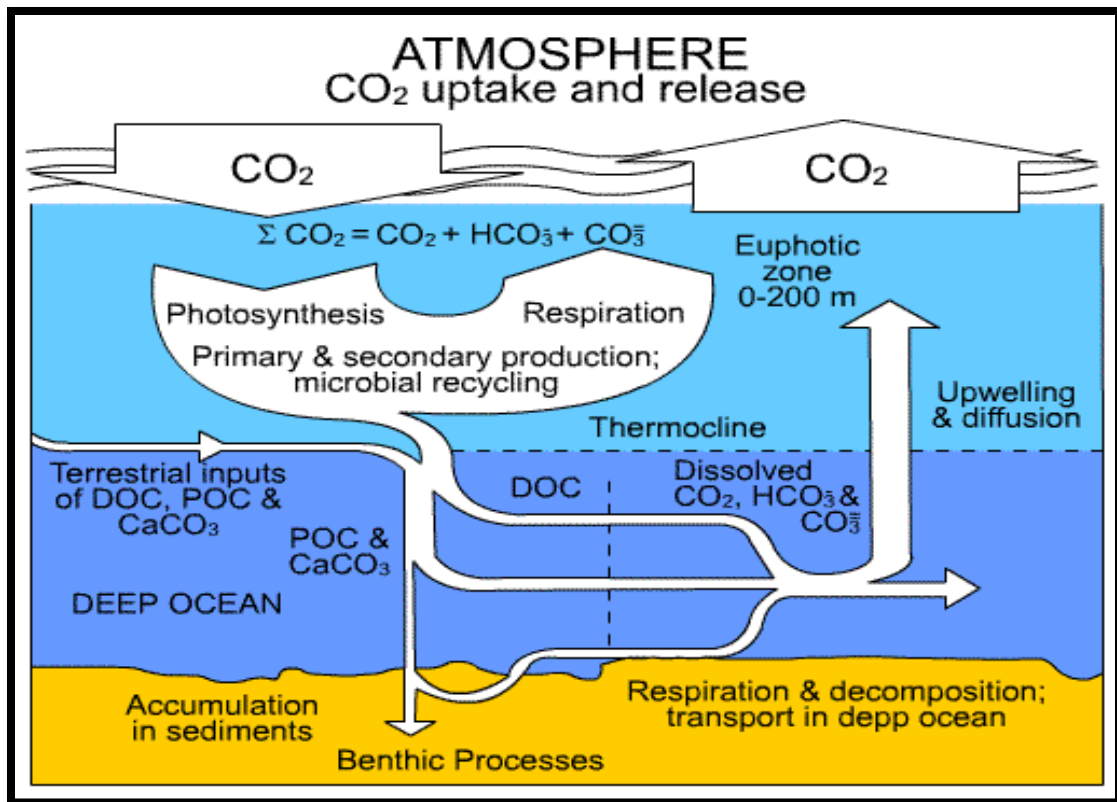
- The atmosphere mixes in about one year.
- The ocean mixes in about a thousand years.
- The soil mixes mostly on the scale of decades to hundreds of years.
- Organisms are mixed continuously, on time scales that range from minutes in the case of bacteria to tens or hundreds of years, in the case of most trees.

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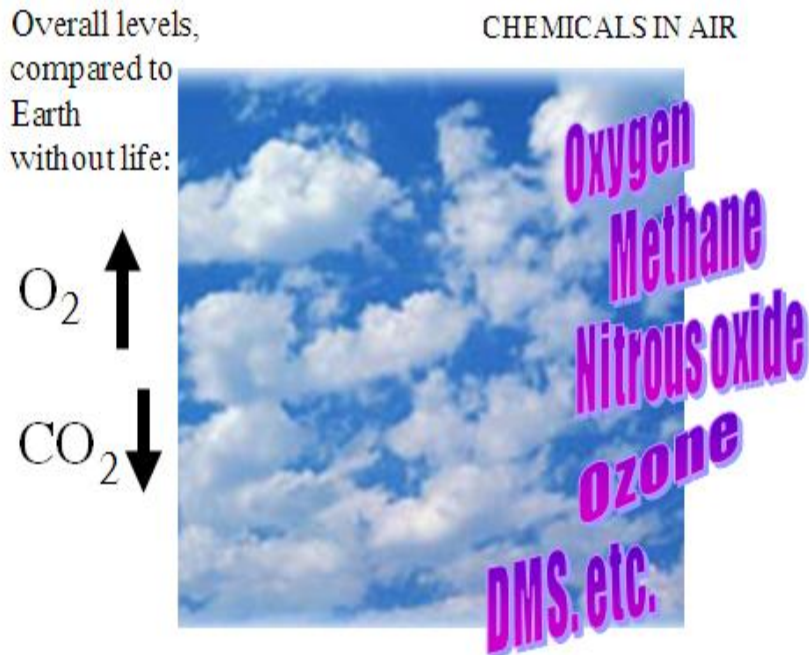
By the mixing of air, water, and soils, I mean physical stirring, so that the chemistry of one place affects the chemistry of other places. For the mixing of organisms, we can speak of the throughput of matter, because organisms take in nutrients and eject wastes. Or we can talk of residence times of, say, carbon, in the trunks of trees. Either way, it is obvious that the components of the



biosphere are linked to each other. A lichen on a rock is more chemically connected to deep waters around Antarctica than to the minerals in the rock just a centimeter beneath the rock's surface, because the elements in those minerals might have been removed from active circulation within the biosphere for tens of millions of years.



There are other ways of conceiving the parts of the biosphere. But a reasonable one for education, and the way many biosphere scientists would divide up the planet is into the four main components outlined above: atmosphere, ocean, soil, and life. Taken as a whole, the biosphere system is a thin, well-mixed film of Earth's surface, only about 1/400 of Earth's radius.



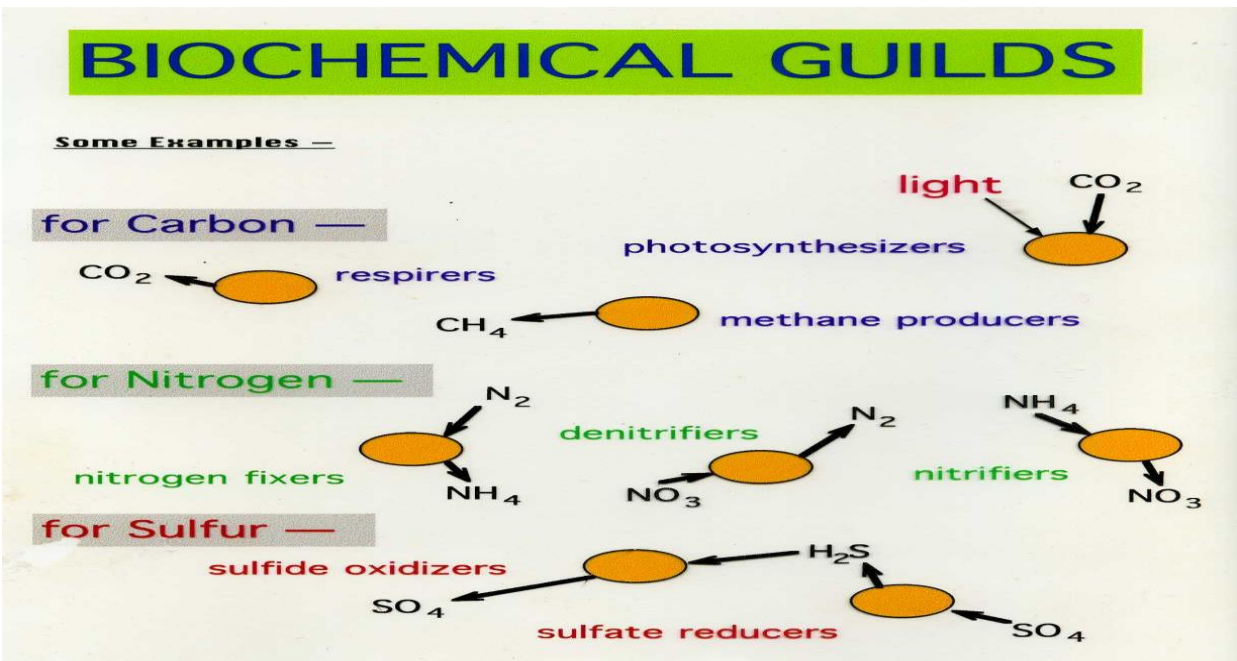
(Note: I have neglected to mention but did not intend to ignore snow, and ice, and fresh water. We could include them as part of “ocean” (meaning water), or as part of the soil system, taken broadly. This is a technicality that does not affect the main point of the integrated nature of the parts of the biosphere.)

2. The various chemical transformations within the biosphere create what might be thought of as a “global metabolism”: First, it is important to note, that although at first examination the biosphere’s metabolism might seem to be somewhat like that of an organism, the biosphere is very different from any organism in a fundamental way.

The biosphere is a singular unit. It is a population of one and did not evolve by selection from a population of similar entities with inheritance and variation. The parts of the biosphere cannot be said to have functions in support of the whole in the way that we can speak of functions of parts of organisms that support their life cycles and life styles.

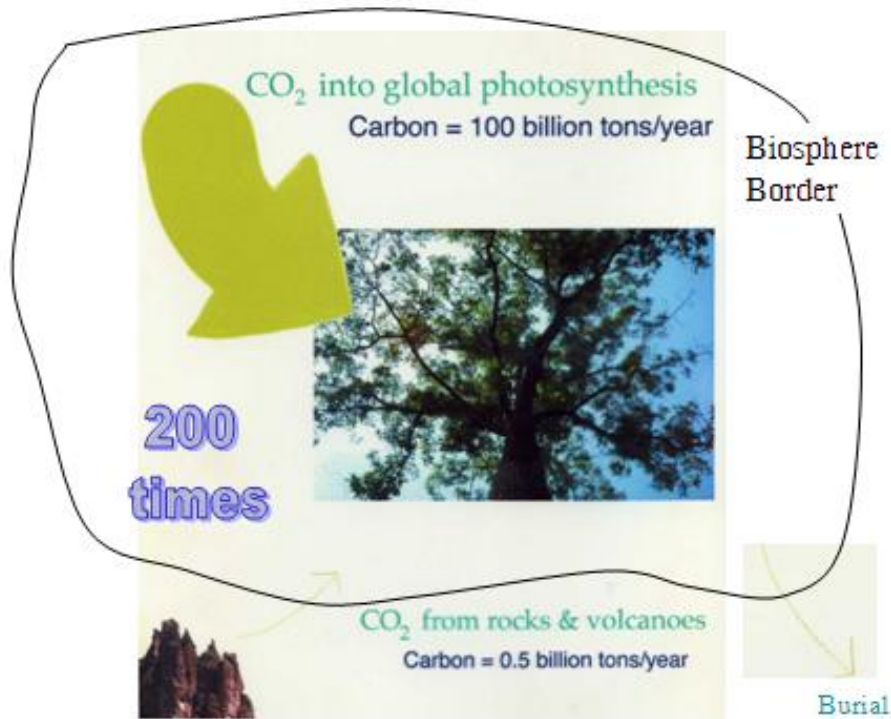
But yet the biosphere seems so tightly connected, with chemical cycles in which elements pass in and out of different states, both within the environmental matrices and within organisms. How should we then understand the global metabolism of the biosphere?

The key, I propose, is what could be called the “biochemical guilds.” Life, collectively known as the biota, has traditionally been divided into species as the main units, which live in populations in communities, which form ecosystems, and then biomes. But for life’s influence on the chemistry of the biosphere, it is useful to designate a subdivision of the biota that might be called the biochemical guild. The biochemical guilds are groups of organisms that perform the same chemical transformations, with respect to a particular element.



For example, the biochemical guilds of carbon include the photosynthesizers, the respirers, the methane emitters (methanogens), and those who use methane as a resource (methanotrophs).

There are also biochemical guilds within the nitrogen cycle, such as nitrogen fixers, denitrifiers, nitrifiers, ammonium assimilators, and nitrate reducers. For sulfur, there is the guild whose members oxidize sulfide and the guild whose members reduce sulfate.



Furthermore, these biochemical guilds hugely affect the three environmental matrices of atmosphere, ocean, and soil. James Lovelock, early on in formulating the Gaia Hypothesis, noted that the dynamics of the biota put the chemistry of air, soil, and water into states of non-equilibrium.

Without life, the oxygen of the atmosphere would be much less than one-millionth of what it is. Without life, the air would not contain much (if any) methane, nitrous oxide, ozone, dimethyl sulfide, and many more. Without life, there would be no rich soil.

One interesting "signature" of the power of life is the way that the concentrations of the two key ocean nutrients, nitrate and phosphate, are both low at the surface and high at depth. As they increase, they do so together in about a seven-to-one mass ratio of nitrogen-to-phosphorus. Both the biological pump and also the dynamics of nitrogen's biochemical guilds acting across biosphere-scales cause this correlation.

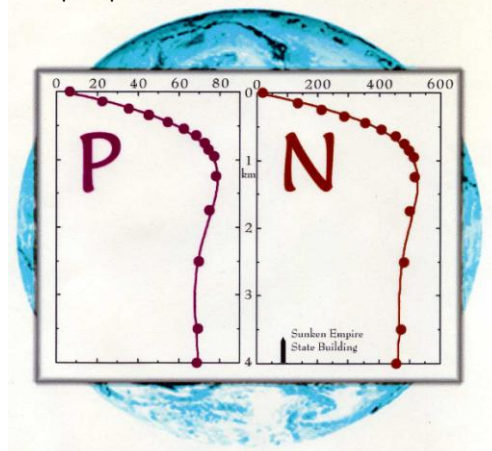
3. The main way in which the biochemical guilds of the biota are linked to each other and to the environmental matrices is related to the fact that wastes from one guild are nutrients for a different guild: Wastes are free. These free-byproducts from the metabolisms of the organisms in one guild are often useful as nutrients to the organisms in a different guild.

The nitrogen gas (N_2) that is produced during denitrification is the form of nitrogen that is used by nitrogen fixers. The carbon dioxide that is produced as a waste during the metabolism of respirers (clams, humans, coqui frogs, and many bacteria) is the form of carbon that is needed by green plants for photosynthesis. There are many other examples.

The linking of the guilds creates the global biogeochemical cycles, which are biological, geological, and chemical. Furthermore, we can calculate how efficient these cycles are for various scales of systems within the biosphere and for the biosphere itself. This is the “cycling ratio.” The cycling ratio for any system is the ratio of the input of an element into the photosynthesizers to the entry flux of that element into the system itself.

For example, the total carbon that annually goes into photosynthesizers (both terrestrial and marine) is about 100 billion tons of carbon. But the supply of “fresh” carbon to the biosphere, from volcanoes and the chemical dissolution of rocks is only about half a billion tons per year. Thus the cycling ratio is about 200 ($100/0.5=200$). This number means that each atom of carbon that enters the circulation of the biosphere from volcanoes or rocks goes around about 200 times before it leaves in the form of material that is buried in sediments out of circulation within the biosphere.

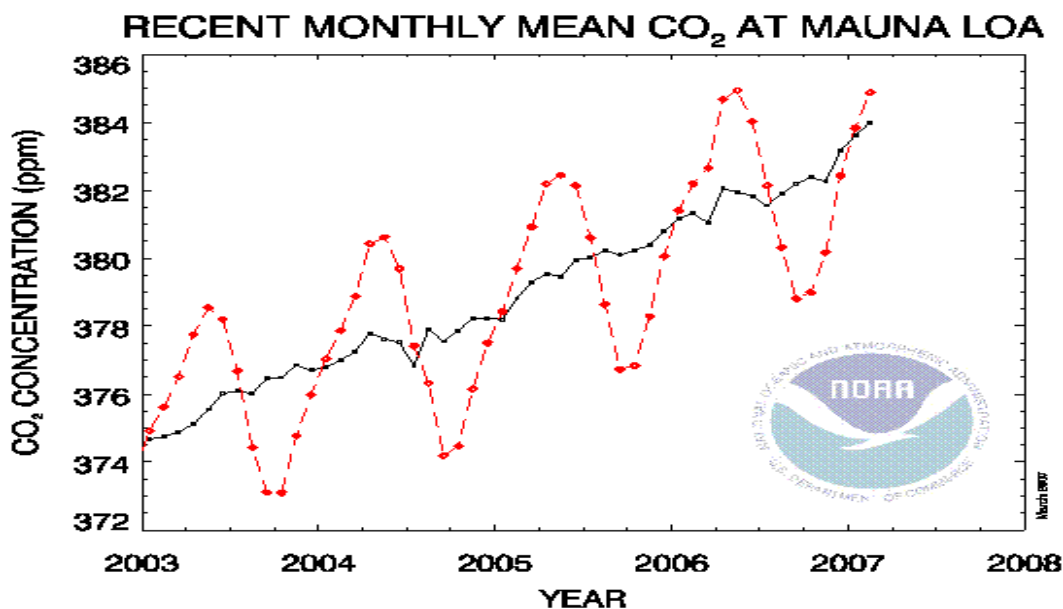
Global phosphate and nitrate in ocean, as function of depth in

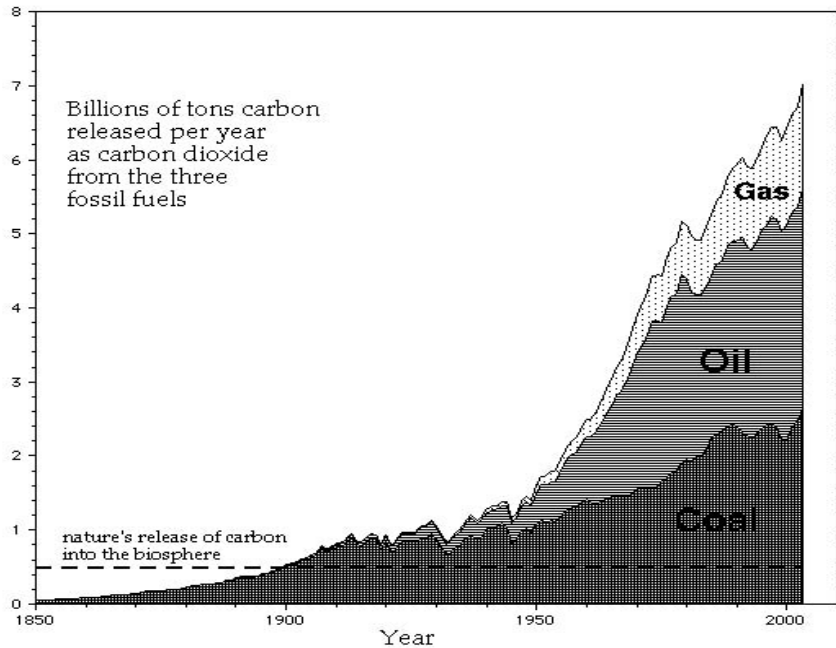


Nitrogen also has a very high global cycling ratio. For phosphorus, the cycling ratio taken over all the continents is between 40 and 50. So we can use the concept for subsystems of the biosphere as well. And not all elements have such high cycling ratios. The cycling ratio for calcium, taken over the continents is only about 1. This is because calcium is highly available from the dissolution of rocks each year, and also because calcium is not needed by organisms in such large quantities as those required for fluxes of carbon or nitrogen.

It is interesting that the elements with some of the largest cycling ratios (nitrogen, phosphorus, and potassium) are the elements most often required for agricultural fertilizers. Thus the elements with the largest cycling ratios seem to be most crucial for the ongoing cycles of the biosphere.

4. What is happening today to the cycle of carbon? Carbon dioxide is rising, with implications for global warming: The carbon cycle illustrates the complexity of the cycles of the biosphere and how they can be influenced by human activities. Data from Mauna Loa, Hawaii, and everywhere else around the world show a yearly rise in the amount of carbon dioxide in the atmosphere. We know this is due to human releases of carbon dioxide from fossil fuel combustion.



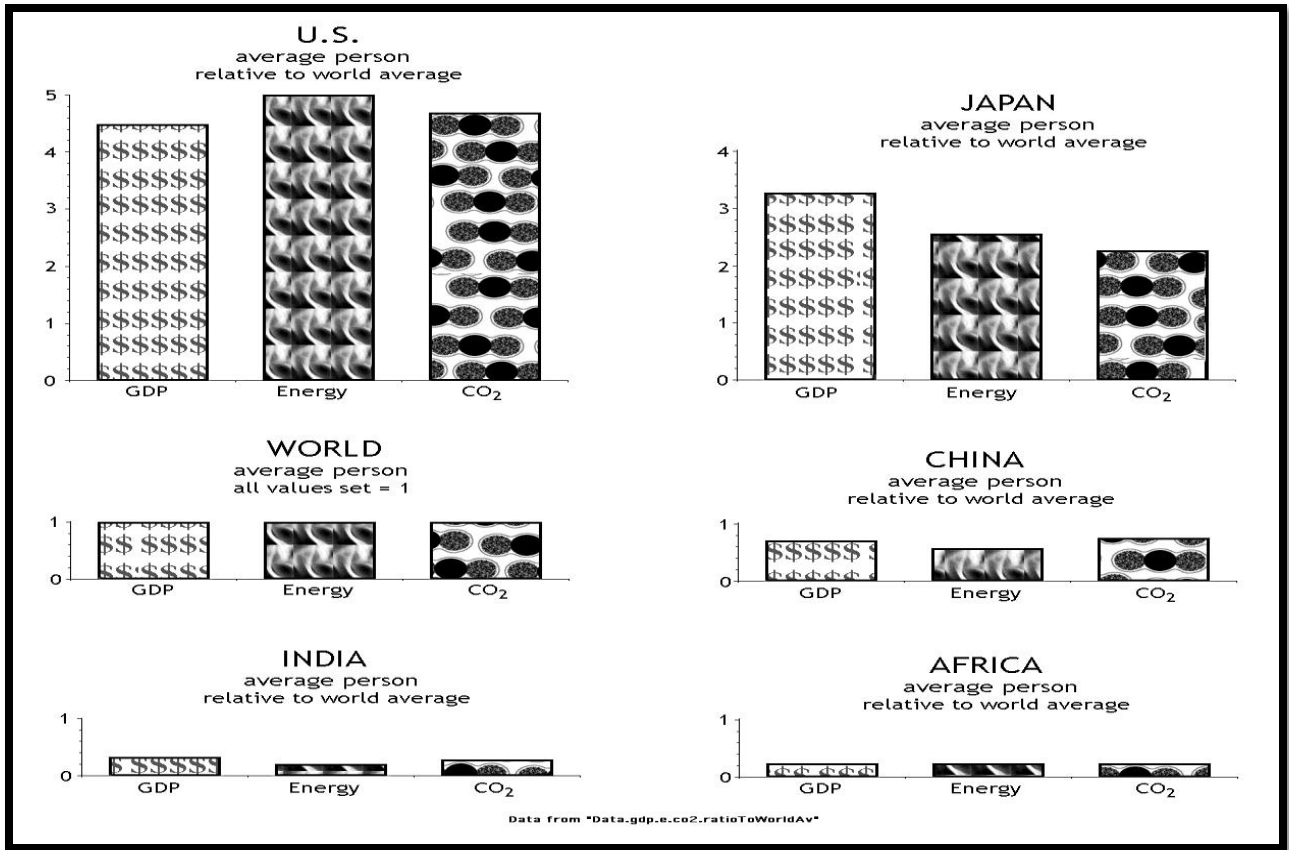
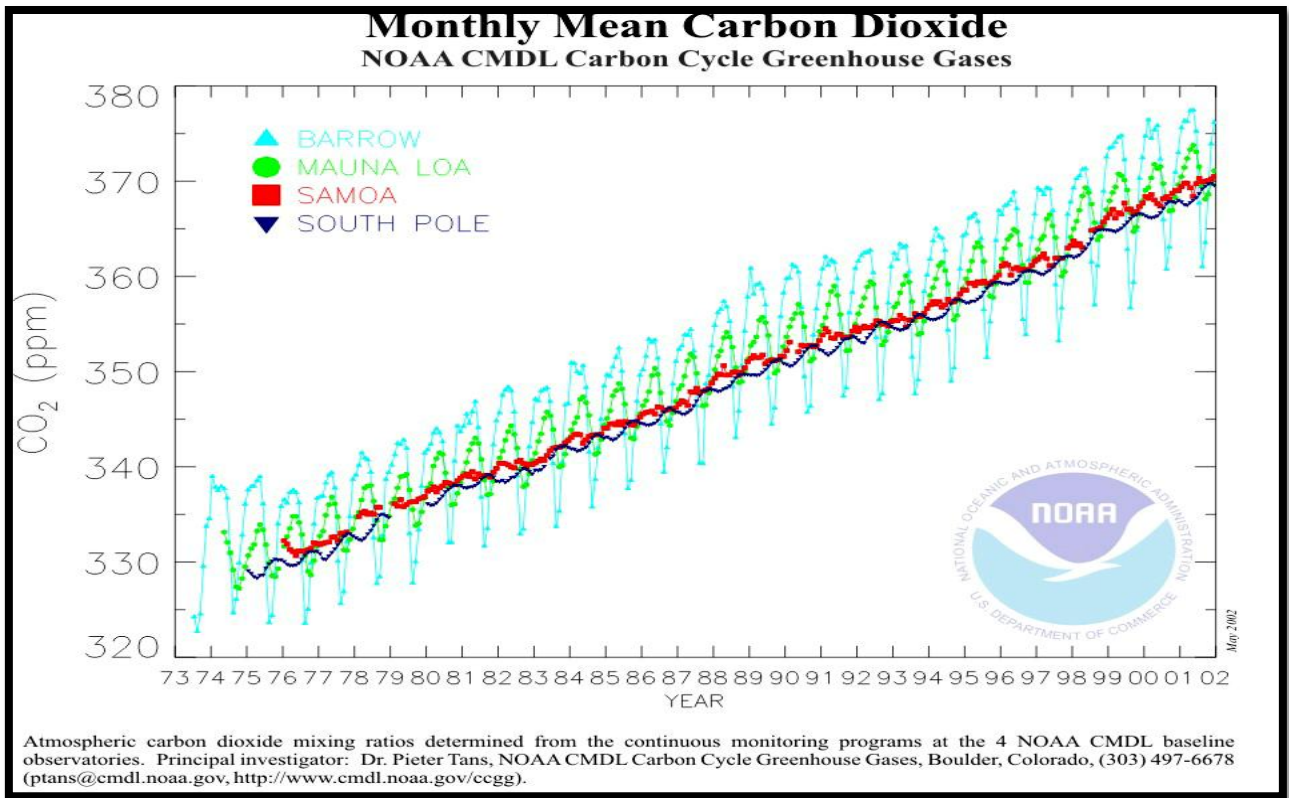


The magnitudes are correct: there is more than enough carbon dioxide released each year in the combustion of fossil fuels to explain the rise in the atmosphere, and the cause can be confirmed by analyzing the isotopes of carbon (carbon-13 and carbon-14). But why doesn't all

the carbon dioxide from fossil fuel combustion remain in the atmosphere? In fact, consistently for the last nearly fifty years of monitoring, about half remains. Interestingly, the fraction that remains each year can vary quite a bit, but averages out over decades to be close to half.

We see in this data the operation of the global carbon cycle, which shunts carbon back and forth, from air to ocean and back again, from air into the photosynthesizers and back to the air again from the respirers. The carbon cycle is complex, with many pools, or places that the carbon can go. But one thing is clear: we are putting carbon dioxide into the atmosphere at a rate faster than the carbon dioxide can be dispersed into the other environmental matrices of the biosphere.

Right now, some of the fossil fuel carbon dioxide is going into the ocean (perhaps one-third), some is going into land plants and soil, and there is, in addition to the release of carbon dioxide from fossil fuels, an additional release from deforestation. All these processes must be accounted for in the budget of the global carbon cycle, to understand its past and to predict it into the future, as we continue to rely, speaking globally, primarily on the combustion of fossil fuels for our source of energy.



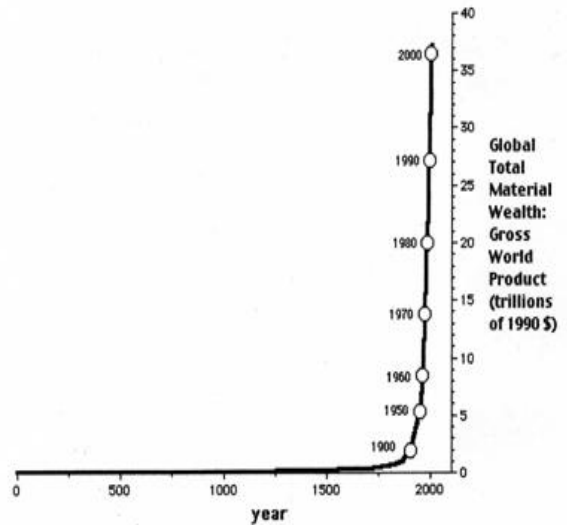
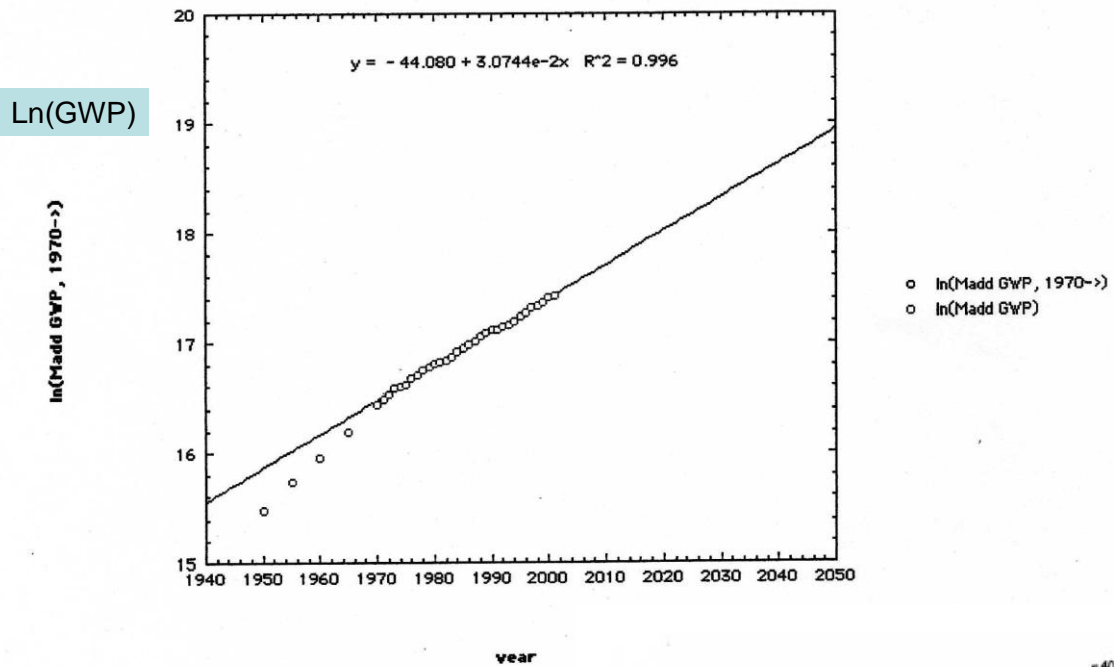
5. Conclusion - We have responsibility for the future: The biosphere is an intricate waste network of free, inadvertent by-products of organisms that have been selected on evolutionary timescales to thrive in particular environmental conditions. Thus, changes to the global systems of atmosphere, ocean, and soil impose changes in the next generations of organisms, as they adjust their populations through the dynamics of reproduction and death. These dynamics include the traditional food webs, as well as the chemical conditions of the environment. Thus we can predict changes to the distribution of organisms as the carbon dioxide levels rise and climate changes become more dramatic. We can see in the evidence of today's carbon cycle, that despite the interconnectedness of the parts of the biosphere, it is possible for the human species to significantly alter the chemical conditions of the atmosphere and the other matrices to which the atmosphere is connected. And we wonder what the future will bring, a future that we must take responsibility for.

What are the options?

[• Conservation/Efficiency]

- Nuclear fission • Nuclear fusion
- Hydroelectric
- Carbon sequestration
- Wind
- Solar
- Biomass
- Geothermal, and exotics
- [Geoengineering]

GIGA: The Global Industrial Growth Automaton



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