CLIMATE SCIENCE FORUM

Autumn 2010 #12

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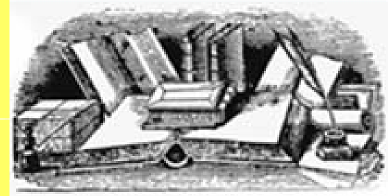

Increasing Drought now Limits Global Water Cycle

Lands in warm climates and wet climates experience high evaporation rates, but scant evaporation in cool and dry climates. Scientists had expected the rate of evaporation to accelerate as the world warms, and indeed the global rate of evaporation from land did rise from 1982 to 1997, but since 1998 the rate has fallen. This is the surprising finding of a study by Martin Jung and 33 co-authors[1] in a recent issue of *Nature.*

The evaporation rate from wet land and ocean surfaces sets the pace of the hydrological cycle on Earth. If liquid water is available, evaporation will speed up very quickly as temperature rises, and the change is nonlinear. In air at room temperature (20°C) the evaporation rate almost doubles as the air warms up by 10 degrees.

Living plants also put water vapor into the air in a process known as *transpiration*. We include transpiration when we discuss global evaporation. The water cycle is completed when water precipitates as rain or snow, and returns to lakes, rivers and the sea.

Climatologists anticipated that the pace of the

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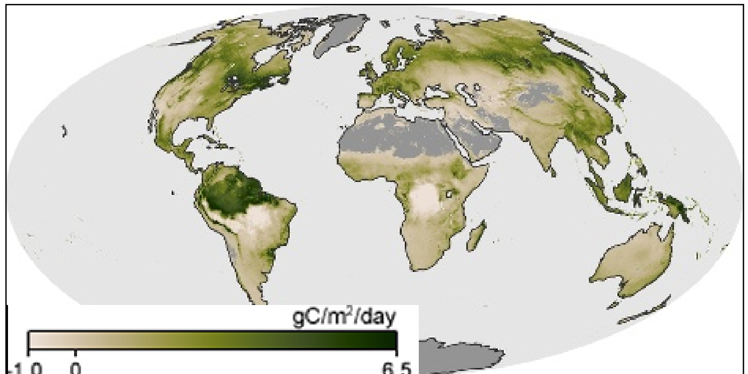

Map of net primary production (NPP) of vegetated ecosystems on land in Sep. 2010, from satellite observations. Green scale measures net production of carbon by plants, per area of land, each day. No data available in grey areas. CREDIT: NASA

global water cycle would pick up as the Earth, on average, warms up. Jung's team attributes the remarkable turnaround of the water cycle since 1998 to drought in Australia and parts of Africa. Satellite observations show that soil moisture has declined in these regions and in Argentina since 1998.

If the evaporation rate (from land) continues to decline, for lack of available water, it may mean that the speedup of the global hydrological cycle is limited, and the limit may have been reached. If so, the productivity of vegetation on land (including agriculture) may also be limited, as well as the ability of forests to sequester carbon. There are more unpleasant effects. When moisture is limited, less solar energy is absorbed in the evaporation of water, and more energy is available to warm the lower atmosphere. That ramps up the rate of warming at the surface – which is why Arizona heats up so much more than Florida on a summer day.

In another study[2] this year, University of Montana scientists Maosheng Zao and Steven Running looked at the global trend of *"net primary production"* (NPP), which measures the productivity of all vegetation on land (see map above). NPP is a measure of the amount of organic carbon that land plants have produced, mainly through photosynthesis; it excludes the carbon that

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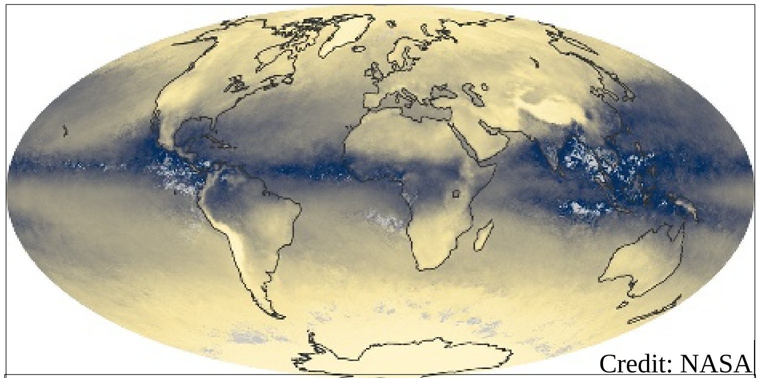
News in this Issue

Why Carbon Dioxide, not Water Vapor, Controls Temperature on Earth



Water vapor content of the atmosphere in one month (Sep 2010) observed by satellite. Darker blue indicates a moister column of air. Dry areas (Tibet, south Africa, the western US) appear white.

Scientists and climate skeptics have often said that water vapor is a stronger greenhouse gas than carbon dioxide (CO_2) or any other gas that influences climate on Earth. Water vapor contributes to at least 49% of the warming associated with the greenhouse effect, while carbon dioxide contributes 20%. Why, then, do climate scientists pay so much attention to carbon dioxide? What would happen to the atmosphere if all of its CO_2 were removed? What would happen if all of its water vapor were removed?

According to Andrew Lacis and 3 co-workers, CO_2 is truly important for maintaining life-supporting temperatures on Earth. Without CO_2, the temperature of the planet would drop well below freezing (0°C) and most of the planet's surface would be covered in ice or snow. They performed this thought experiment with a simple model, and present their findings in an article in *Science*[1].

These authors did not speculate about a world without water vapor, but we can. Without water in the atmosphere, the Earth would remain frozen, as water vapor is responsible for half of the greenhouse warming. However, as long as water covers 71% of the surface of the Earth, the air above will have water vapor in it.

The key difference between the gases is that water vapor can and does condense into rain drops and ice crystals, which fall out. As temperatures drop, more water vapor is removed this way, and the greenhouse effect of the remaining vapor greatly diminishes. As the role of water vapor becomes minor, that of CO_2 remains major. CO_2 remains a gas at all temperatures encountered on Earth.

Water vapor itself cannot keep the planet above freezing without CO_2.

The greenhouse effect warms the Earth by 33 degrees K (59 Fahrenheit degrees) above the temperature the Earth would have otherwise (a frigid −18.5°C or 0°F.)

In the thought experiment, after all greenhouse gases (except water vapor) and all aerosol particles were removed, Earth cooled by 20°C after 5 years, and 30°C after ten years. As the planet cooled, the amount of water vapor in the air dropped substantially: by 70% after five years, 85% after ten years. The authors add that water acts as a climate feedback, not as a climate forcing agent like CO_2.

Major global cooling causes other widespread changes. The area covered by clouds expands, and the fraction of the oceans covered by ice goes from 5% to 47% after fifty years. Because clouds and ice are white and reflect sunlight, they both prevent the surface from absorbing sunlight, therefore the planet cools further. After 30 to 50 years the planet stabilizes at −21°C: a good temperature for a deep freeze.

In those frigid conditions the atmosphere holds ten times less water vapor than it does today. Given such large changes, water vapor cannot regulate global temperature, but carbon dioxide can. Water vapor does magnify the small changes that other greenhouse gases cause.

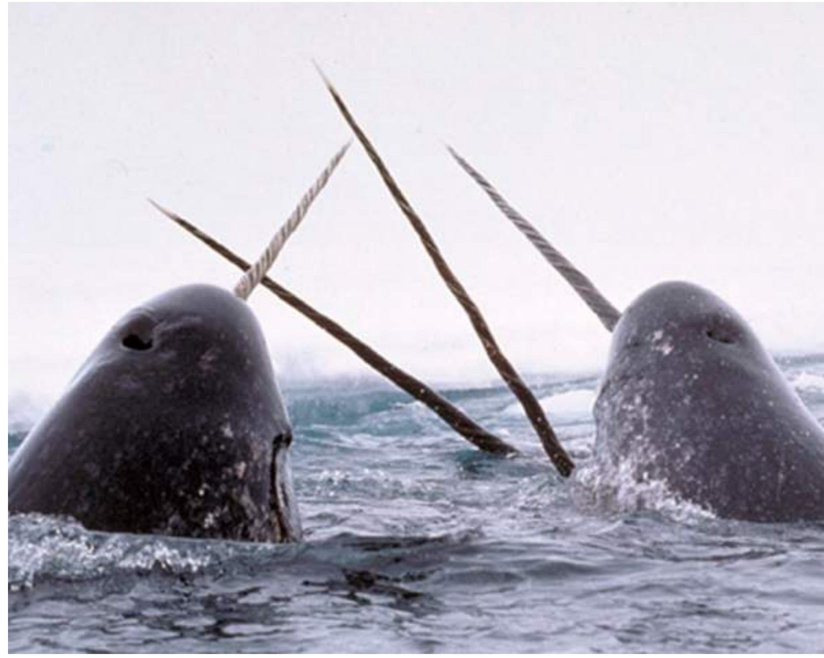
There is some evidence that the Earth fell into an icebound state some 700 million years ago, long before familiar multicellular forms of life evolved and before life emerged on land. It is good to know that the planet did emerge from its icebound state.

Lacis concludes that CO_2 acts as the primary "control knob" of Earth's temperature. As its concentration in the atmosphere has increased by 38% in the modern era, the control knob is being turned up ever faster, the authors assert. Even more troubling is the long residence time (over 100 years) of CO_2 molecules in the atmosphere, which makes it difficult to quickly bring down the level of CO_2 after a period of emission of this gas.

CITATION:

1. "Atmospheric CO2: Principal Control Knob Governing Earth's Temperature" by Andrew A. Lacis, Gavin A. Schmidt, David Rind, Reto A. Ruedy, *Science*, Vol. 330, pp. 356–359, October 15, 2010. **RETURN**

Narwhals recruited as climate monitors in deep Arctic waters



Scientists seek to monitor climate trends everywhere on Earth, but hostile environments and inaccessible locations challenge them. In the Arctic, they enlisted mammals that thrive in conditions that would kill a human. In the winter, the deep waters of Baffin Bay, between Greenland and Canada, are cold, dark, and practically impossible to monitor under the extensive polar ice pack. For some 70,000 marine mammals collectively known as narwhals (scientific name *Monodon monoceros* – "one-toothed unicorn"), these waters are the perfect hunting ground. Related to porpoises but larger, narwhals repeatedly dive to the bottom of Baffin Bay to feed on halibut, a bottom-dwelling fish, and return to the surface to breathe. When pack ice covers the sea in the six months of winter, narwhals dive from 10 to 25 times per day, as deep as 1800 meters below the ice. Narwhals are best known for their single long, straight tusk, which is actually a tooth that grows through the lip.

Why do scientists care what goes on deep down? Water from Baffin Bay flows south into the Labrador Sea, one of only three regions in the Northern Hemisphere where cold ocean water sinks from the surface more than halfway to the bottom – stirring the ocean like boiling water in a tea pot does – except that in Arctic seas, cold water drives the circulation downward, unlike hot water that rises up in a tea pot. These three regions play a key role in forcing the circulation of the entire global Ocean, a circulation sometimes described as an ocean "conveyor belt," and formally known as the *meridional overturning circulation*. Oceanographers use the term "ventilation" to describe the sinking cold water. The process is key to understanding the ocean's overall circulation and its "climate."

Although Baffin Bay and the Davis Strait are critically important to the circulation of the Atlantic Ocean, oceanographers have collected most of their data in summer and fall when the region is free of ice. To get data in the winter, K. Laidre and colleagues at the Polar Science Center of the University of Washington, and M. Heide-Jorgensen of the Greenland Institute of Natural Resources, recruited 14 narwhals to take the observations for them. *"Recruit"* may not be the best word to use here, as the narwhals were given no choice in their assignment. The mammals were caught and held in large nets between two boats while sensors were clipped to their dorsal fins.

The whales brought back the first wintertime observations of the temperature of Baffin Bay water, not only at the surface but all the way to the bottom. Temperatures ranged from 0.4°C to 1.5°C higher than the climatological values estimated more than a decade earlier, so Baffin Bay has warmed at all depths in those years. This is significant for three reasons. If the water flowing from Baffin Bay to the Labrador Sea is warmer than it has been, it may make the "ventilation" of the ocean more difficult in the all-important sinking zone. Secondly, warmer surface water favors further melting of the Arctic ice pack, already in decline over the past decade; and finally, warmer water may change the marine ecosystem at all depths, including the cold-loving, bottom-feeding halibut, the main prey of narwhals.

The authors conclude that whales present a unique opportunity to sample regions at low cost in locations where traditional measurements are otherwise impossible.

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CITATION:

"Narwhals document continued warming of southern Baffin Bay" by K. L. Laidre, M. P. Heide-Jørgensen, W. Ermold, and M. Steele. *Journal Of Geophysical Research*, Vol. 115, C10049, doi:10.1029/2009JC005820, 23 Oct. 2010.

Greener Oceans may Allow More Hurricanes to Form

A recent modeling study found that the amount of single-celled plant-like plankton, known as *phytoplankton*, can favor the formation of hurricanes. Like all plants on land, phytoplankton contains chlorophyll, a green pigment that enables the plankton to convert the energy of sunlight into stored food energy (calories). More chlorophyll makes water more green, which means that surface waters absorb more sunlight that heats the water. Warmer water is known to favor the formation and growth of tropical storms and hurricanes in the subtropical oceans.

Blooms of phytoplankton in the Barents Sea, north of Russia, color the water various shades of green. The colors are due to different species and concentrations of plankton. CREDIT: NASA Earth Observatory

The analysis by Dr. A. Gnanadesikan[1] and colleagues at NOAA's Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey demonstrated that ocean color can influence the winds and atmospheric circulation above the ocean. By removing all chlorophyll from the water in the North Pacific Subtropical zone (in his modeling experiment) and comparing the results to the case in which he used the observed concentrations of chlorophyll to model the real world, Gnanadesikan obtained as much as a *70% decrease* in the rate of formation of tropical storms over water containing no chlorophyll. Removing chlorophyll allows light to penetrate deeper into the water – to a depth of about 40 meters rather than the typical 23 meters, for the same per cent reduction in light intensity. In water that is more transparent, sunlight is absorbed by a deeper layer of water; so surface water warms up less as deeper waters warm up more. Since water in the North Pacific Subtropical gyre is already quite clear and transparent (some call this region a "biological desert"), it surprised the author that removing chlorophyll from already-clear water would cause noticeable cooling near the surface.

In the no-chlorophyll experiment, widespread changes in the tropical atmosphere were seen. Equatorial waters warmed up as subtropical waters (where the chlorophyll had been removed) cooled down, so that the entire circulation of the tropical atmosphere strengthened in a way that did not favor the formation of tropical cyclones. The average wind speed was boosted which did not help the formation of storms. Conversely, greener ocean water with more chlorophyll present would foster growth of more tropical storms and hurricanes, and more of them would become intense.

The team found that tropical cyclones would move farther from the equator when chlorophyll was present in the water, and that storms that became hurricanes would be more intense. The team cited evidence that chlorophyll levels dropped to 50% of normal in the decade of the 1960's, so large natural variations in water transparency may occur again. Apparently the biological productivity of ocean waters has an impact on tropical storms and hurricanes.

Citation

1. "How ocean color can steer Pacific tropical cyclones" by A. Gnanadesikan, K. Emanuel, G. A. Vecchi, W. G. Anderson, and R. Hallberg, in *Geophysical Research Letters*, vol. 37, L18802, doi:10.1029/2010GL044514, year 2010.

CLIMATE SCIENCE FORUM

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Controlling soot and polluting gases can quickly reduce climate warming trend

The burning of fuels releases many noxious byproducts in addition to the two primary products of combustion, carbon dioxide (CO_2) and water vapor. Particles of soot and organic carbon, both present in smoke, are top culprits, but gases like carbon monoxide and methane are also released. Carbon dioxide is usually fingered as the main cause of global climate warming due to humans, yet reducing CO_2 emissions will not reverse the warming trend quickly, because the long lifetime of CO_2 in the atmosphere introduces a tremendous lag before there is a response. In a recent paper[1] in the *Journal of Geophysical Research*, Mark Jacobson of Stanford University maintains that control of other byproducts of combustion will yield earlier results in slowing global warming, slowing Arctic warming, improving human health and clearing the air.

Three types of airborne particles (or *aerosols*) affect climate in different ways. Sea salt, at left, aids condensation of water vapor into liquid drops in clouds. Mineral dust, middle, scatters visible light back to space, which tends to cool the surface below. Black carbon, or soot, at right, absorbs sunlight, and heats the air containing the particles. PHOTO CREDIT: Katherine Mann.

This idea - that society "gains more bang for the buck" by first controlling the air pollution released by burning of fuels, rather than the associated CO_2 – has been debated in the science press for years (see Jacobson's article[2] from 2002 and *Climate Science Forum*, summer and autumn 2002). In his 2010 paper, Jacobson looked at gases and soot particles released by burning biofuels in addition to soot particles from burning fossil fuels, as he did earlier. Biofuels include wood, agricultural waste and animal dung which people use to cook food and heat homes. People also burn such material to clear land.

He used newer models to simulate the behavior of soot and smoke, and considered their impacts on Arctic climate, on air pollution and on human health.

Jacobson notes that global warming is caused primarily by fossil fuel greenhouse gases. Yet the removal of soot particles pays off quickly. Removal of all soot emissions from both fossil fuel and biomass combustion cuts the rate of warming by 20%. When polluting gases from biomass burning are also stopped, the three actions together lower the trend of global temperature by 0.4° to 0.7°C over the next 15 years. Society gets a temperature reduction one-third greater when the byproducts of biomass burning (not just fossil fuel soot) are also controlled.

In almost any scenario of the future, getting a one-half degree reduction in global temperature trend is possible much more quickly when soot rather than carbon dioxide is controlled, Jacobson says. Benefits are even greater in the Arctic: over the same 15-year planning horizon, the Arctic would warm 1.7°C less than it would warm without any controls in place.

Jacobson states once again that the release of soot and combustion byproducts is the second leading cause of global warming, after CO_2 which is in first place. This means it causes more warming than methane does, although methane has received more attention. Eliminating soot particles from the exhaust of combustion is relatively easy: it can be trapped by filters, and since carbon particles often result from incomplete combustion, making combustion more efficient also reduces particle emissions.

CITATIONS:

1. "Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health" by Mark Z. Jacobson. *J. of Geophysical Research*, vol. 115, D14209, 29 Jul. 2010.

2. "Control of fossil fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming", by M. Jacobson. *Journal of Geophysical Research*, vol. 107 (D19), 4410, 15 Oct. 2002.

(**Drought Limits Water Cycle,** *Continued from page 1)*

plants respire to maintain their own life.

As the growing season became longer in a warming world, and as carbon dioxide levels rose (CO_2 stimulates plants to grow more biomass), many expected that the NPP index would increase. Indeed it has increased in the Northern Hemisphere. With Alaska, Canada and Russia comprising a large area of land, the Northern Hemisphere continents experience an average of 125 days of snow cover per year. Climate warming in these northern regions has led to longer growing seasons. Productivity as measured by NPP thus has increased in the Northern Hemisphere. Yet the high-latitude and high-elevation lands where NPP did increase still account for only 24% of the globe's vegetated land area, much of it in the tropics.

In the Southern Hemisphere, by contrast, warmer climates led to much greater evaporation and much less water available to plants. There is not much land with snow cover south of the equator, in proportion to the extensive forested acreage in tropical South America and Africa. Thus warmer temperatures had little effect on the length of the already-long growing season. Zhao and Running used the *Palmer Drought Severity Index* as an indirect measure of water available to plants; a low value generally indicates drought. South of the equator, the Palmer Index was well correlated with net primary productivity: low (dry) values of the Index were associated with low vegetative productivity. But north of the equator, the correlation was weak.

The drying trend in the Southern Hemisphere overwhelmed the positive influence of the longer growing season in the Northern Hemisphere; so that over the whole Earth, *net primary productivity has decreased since 2000*. Severe regional droughts have been more frequent. If the drying trend continues, the consequences include less capacity to sequester carbon on land, less ability to produce biofuels, and a less secure food supply.

CITATIONS

1. "Recent decline in the global land evapotranspiration trend due to limited moisture supply" by Martin Jung and 32 co-authors, *Nature,* vol. 467, pg. 951–954, 21 October 2010. doi: 10.1038/nature09396.

2. "Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 through 2009" by Maosheng Zhao and Steven W. Running, *Science*, vol. 329, pg. 940-943, 20 Aug. 2010.

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