BUOY DATA WORKSHEET

Use data from buoy web site @ www.pmel.noaa.gov/co2/coastal

Research into the ocean's carbon storage capability is important and has become a controversial issue as entrepreneurs promote carbon sequestration schemes as a way to reduce the impacts of climate change. Carbon cycling is poorly understood and it is uncertain whether marine and coastal regions can continue to serve as a limitless sink for CO_2 from the atmosphere without significant consequences.

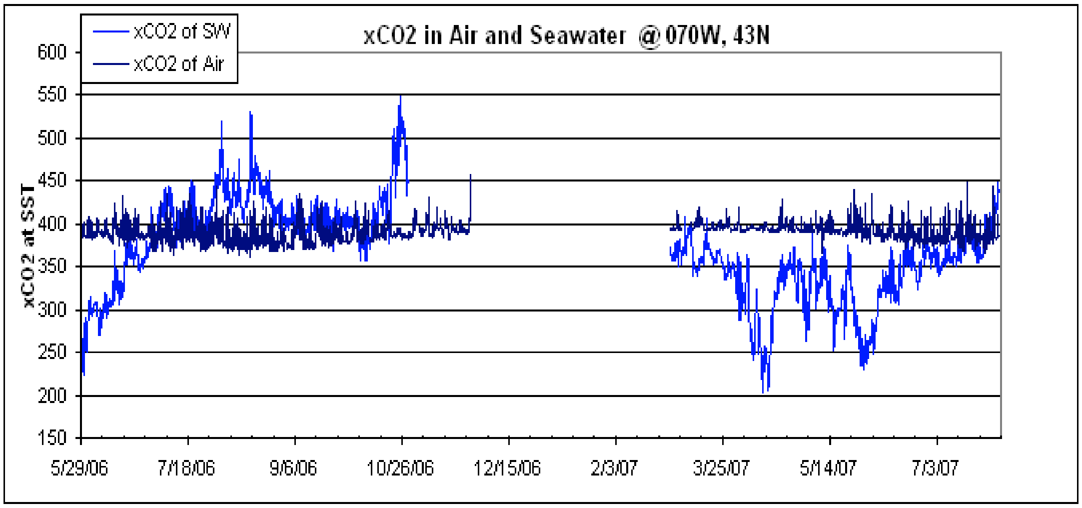
Due to the continual balancing (partial pressure) of carbon dioxide between air and seawater, there is a temporal variability in CO_2 concentrations referred to as "fluxes". Seawater CO_2 concentrations seem to be ever increasing as carbon dioxide keeps increasing in our atmosphere. Researchers hypothesize that as CO_2 increases in our atmosphere - it will continue to increase in seawater until it reaches a saturation point. They are now collecting data to measure the ocean's capacity for this gaseous exchange at buoy monitoring sites around the world.

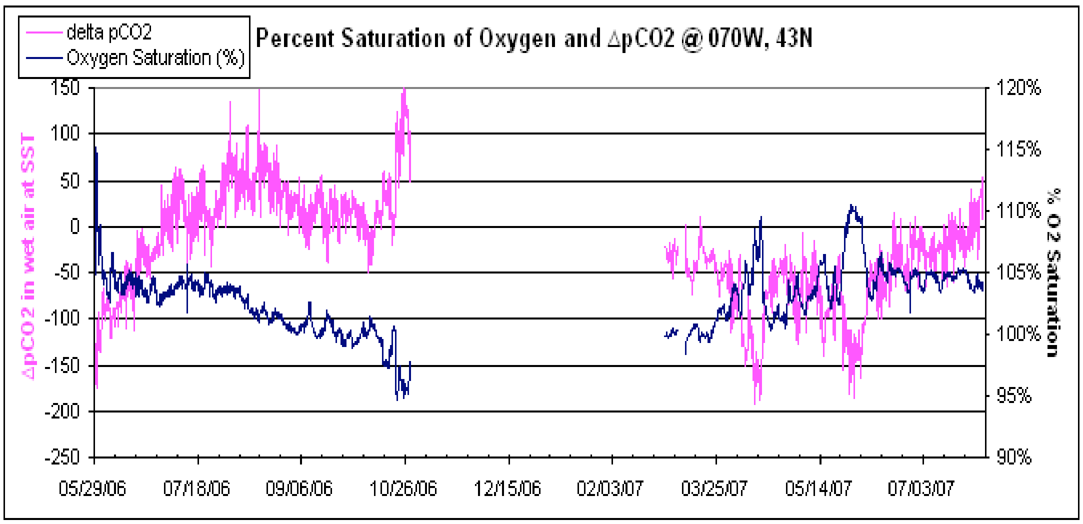
Location of Buoy (state, latitude and Longitude)	**Sea Surface Temp. Range**	**CO_2 in water Concentration Range**	**CO_2 in air Concentration Range**	**Wind Speed Range**

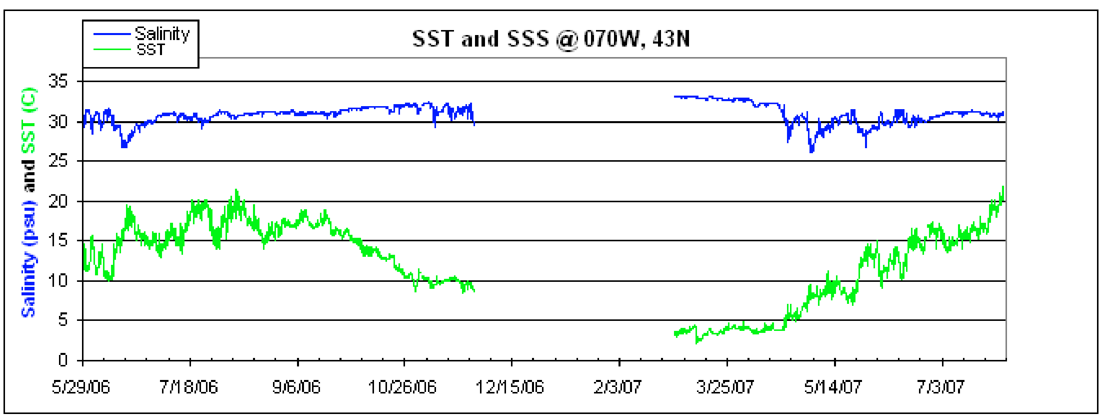
After recording the buoy data in to the table above, ***write a few paragraphs*** (on back of this sheet) ***that compare and contrast CO_2 fluxes between data results among 4 U.S. coastal observation buoys***. e.g. What are these buoys measuring? Are there CO_2 concentration differences between buoy locations? How does weather and wave height or mixing of the water column affect CO_2 concentrations? What is happening over time? Hypothesize what other variables you think might affect the exchange of CO_2 in air and seawater?

FURTHER RESEARCH: Read Blue Planet's (Aug 2006) *"**Pumping Iron**"* magazine article, < http://www.oceanconservancy.org/site/News2?abbr=bpm_&page=NewsArticle&id=8929 > then **summarize in writing** (on back of this paper) ***scientists concerns about the potential effects rising CO_2 levels in seawater*** could have on marine ecosystems?

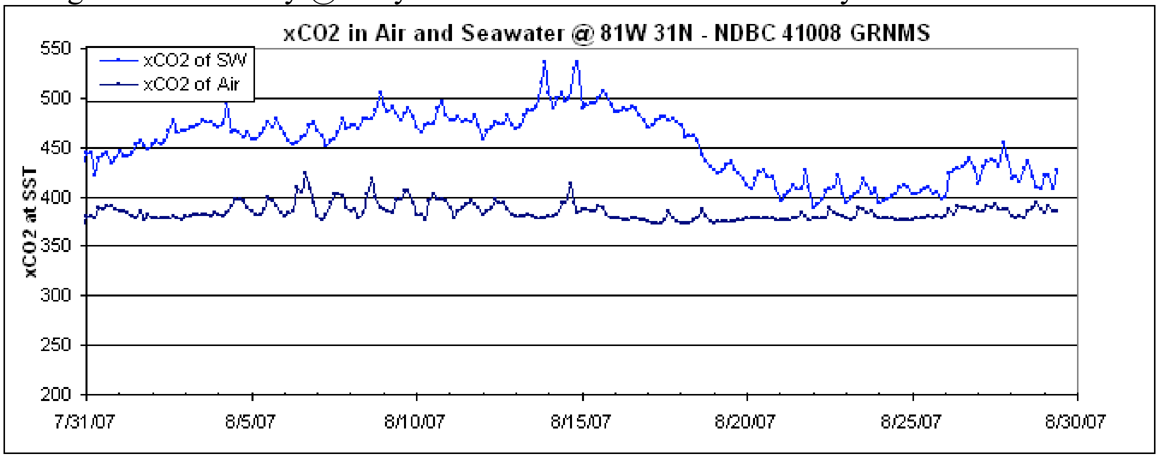
Gulf of Maine’s Buoy

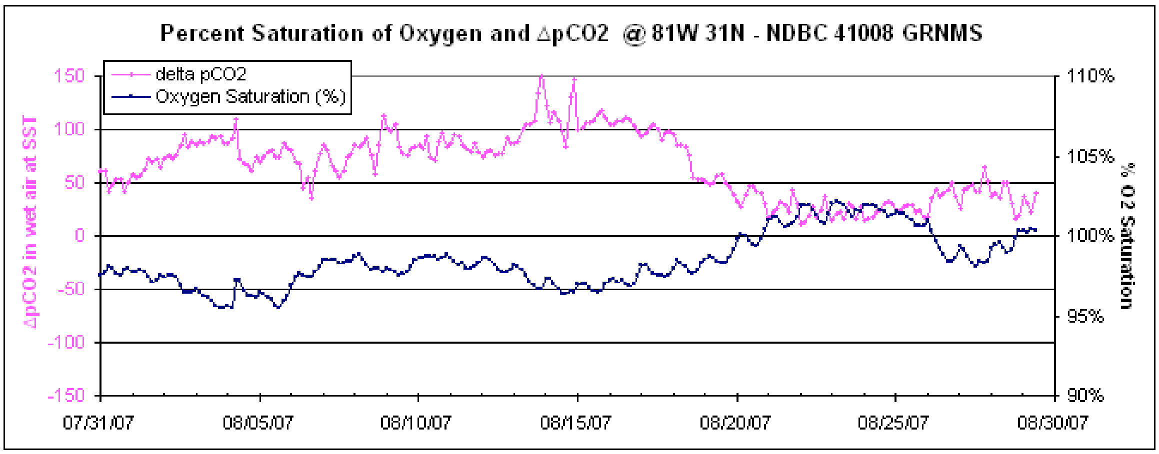


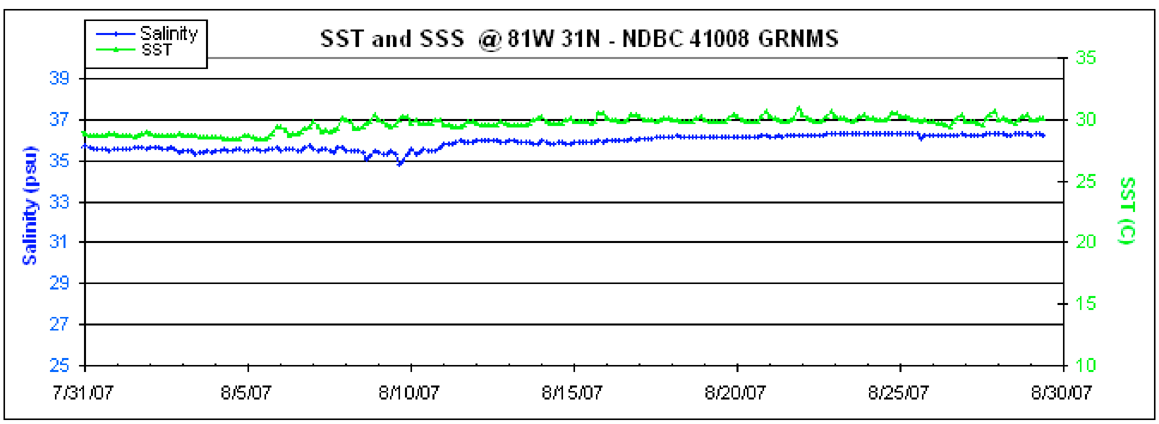




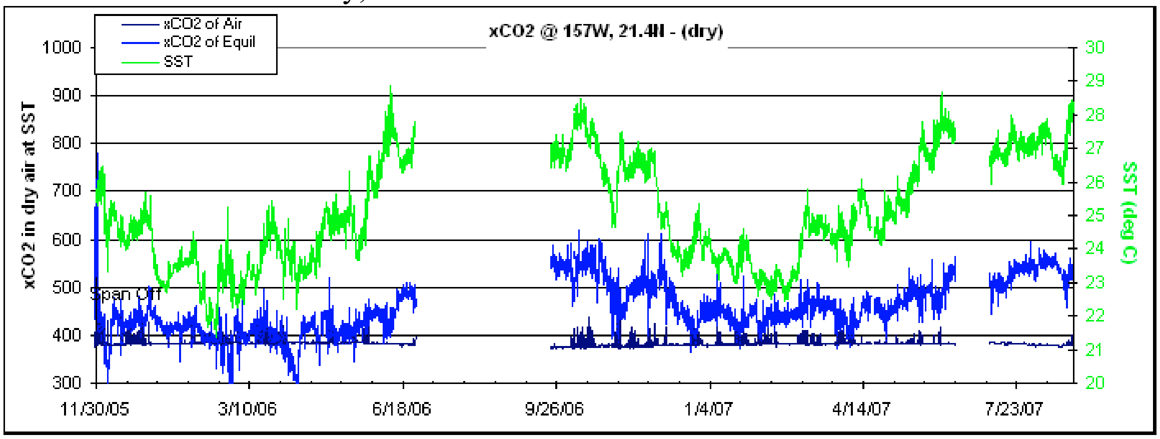
Georgia's PEML Buoy @ Gray's Reef National Marine Sanctuary

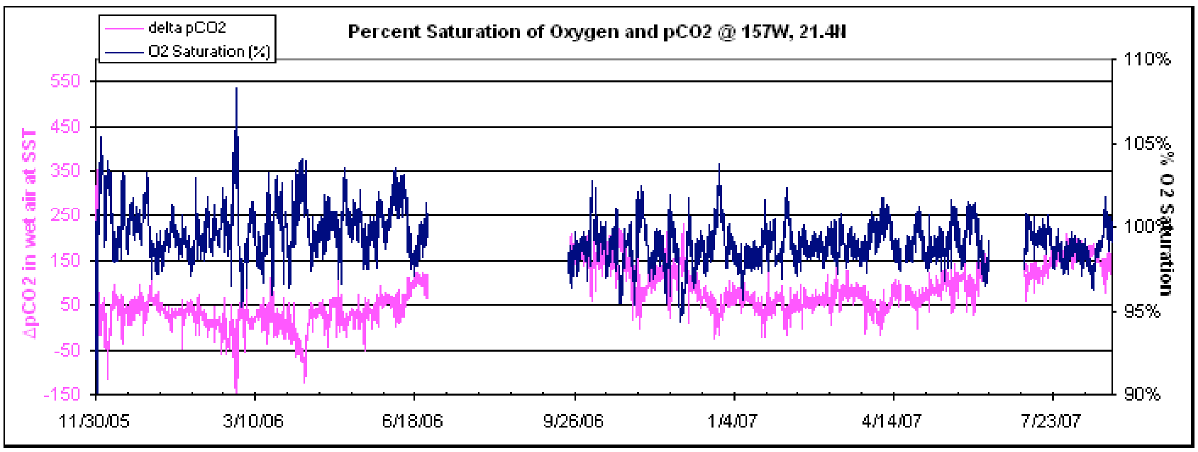


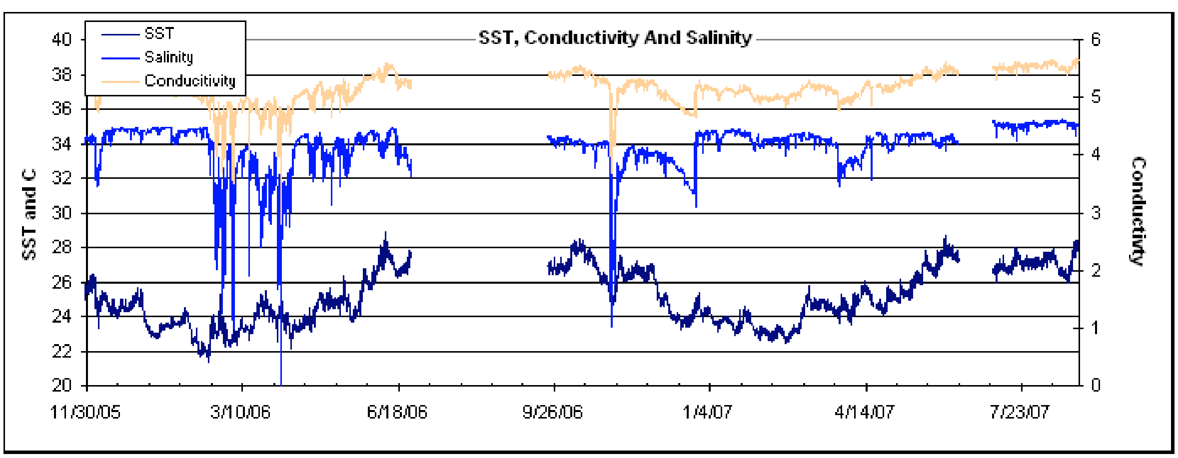




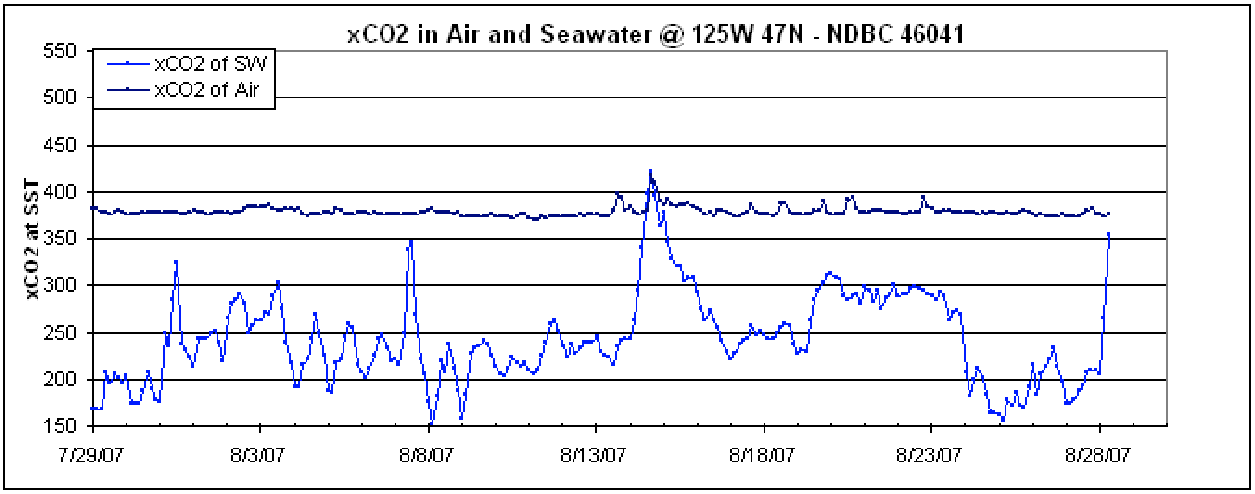
Hawaii's Kanoehe Bay, Oahu

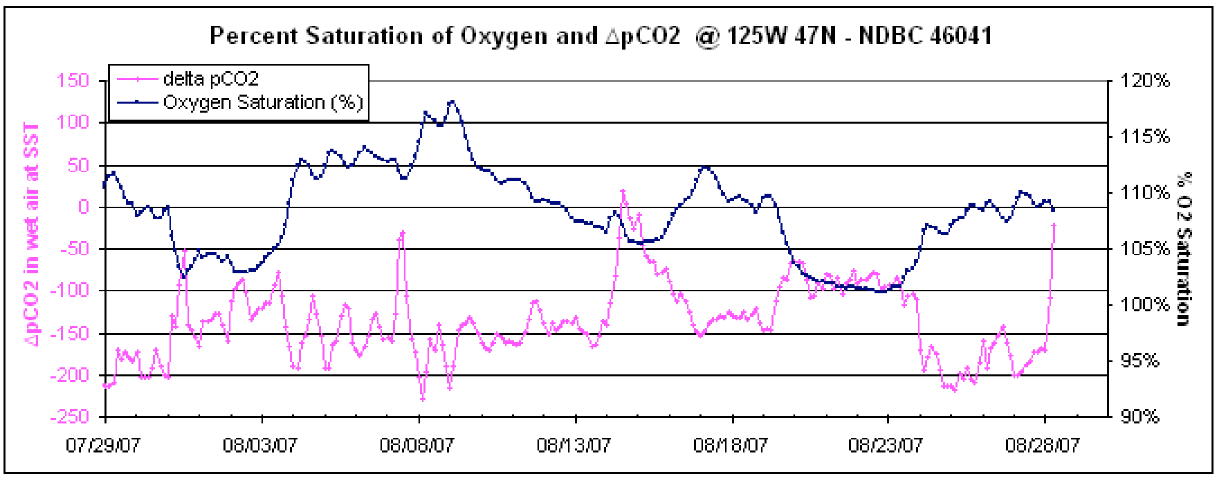






Aberdeen, Washington


xCO2 in Air and Seawater @ 125W 47N - NDBC 46041
xCO2 of SW
xCO2 of Air
xCO2 at SST
550
500
450
400
350
300
250
200
150
7/29/07
8/3/07
8/8/07
8/13/07
8/18/07
8/23/07
8/28/07


Percent Saturation of Oxygen and ΔpCO2 @ 125W 47N - NDBC 46041
delta pCO2
Oxygen Saturation (%)
ΔpCO2 in wet air at SST
% O2 Saturation
150
100
50
0
-50
-100
-150
-200
-250
120%
115%
110%
105%
100%
95%
90%
07/29/07
08/03/07
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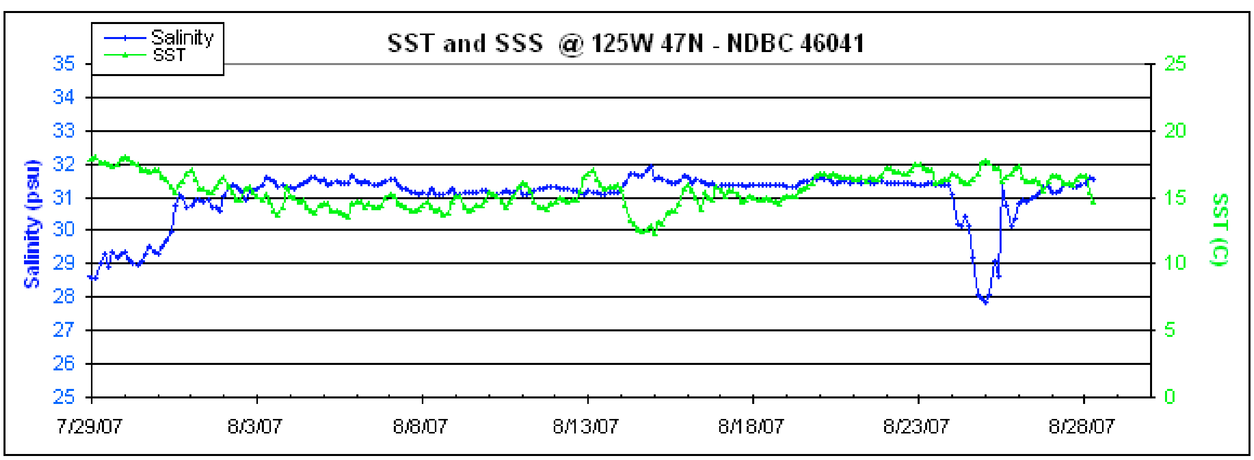
08/23/07
08/28/07


SST and SSS @ 125W 47N - NDBC 46041
Salinity
SST
Salinity (psu)
SST (C)
35
34
33
32
31
30
29
28
27
26
25
20
15
10
5
0
7/29/07
8/3/07
8/8/07
8/13/07
8/18/07
8/23/07
8/28/07

Pumping Iron (**Blue Planet,** Fall 2006)
Story by Andrew Meyers
http://www.oceanconservancy.org/site/News2?abbr=bpm_&page=NewsArticle&id=8929

Can raw iron, microscopic plants and a desolate stretch of ocean save us from global climate change?

Sometime in early April of 2001, a breeze swirled in the Gobi Desert. As it twisted and rolled over the ancient, desiccated land it swept up grains of soil and carried them aloft into the skies. The breeze then grew into a full-fledged dust storm large enough that NASA satellites began to take note. A day later, a khaki cloud moved over Japan and by April 12 ripples from the storm were first felt at Ocean Station PAPA at 50 degrees north latitude, 145 degrees west longitude in a swath of the north Pacific somewhere west of Alaska.

There, dust fell into the seas. A frisson of phytoplankton sprung to life. And, it grew. And, it grew some more. What happened at Ocean Station PAPA added an important piece to a theoretical puzzle scientists had been debating since at least 1989 when "Johnny Ironseed"—Dr. John Martin, director of the Moss Landing Marine Laboratory—first posited the "iron hypothesis" that terrestrial dust, borne by the winds, fertilizes aquatic plants that, in turn, check the level of carbon dioxide in the atmosphere.

The science behind this natural process operates on the tiniest scale. But, as some commercial interests quickly latched on to, the implication was potentially huge on another. Martin's iron hypothesis, they claimed, held nothing less than an answer to the problem of greenhouse gases filling the skies.

Life out of balance

Planet Earth and all that is hers—the land, the air and the water—acts as a single, integrated system of chemical checks and balances; a zero-sum game. You can't change one without affecting the others. Nonetheless, while most people think of global climate change as solely an atmospheric phenomenon, the oceans and the land are where the suffering is actually felt.

The debate about whether global climate change is occurring is no longer really a debate. Even the skeptics, what few of them there are, have conceded the point, although they look to the lower end of the accepted predictions and say the effects will be negligible. In the middle, there is plenty of wiggle room and the result is a political stalemate about what to do. The end-product, unfortunately, may be an inexorable march to catastrophe.

While there is debate over consequences and much that we don't know about global climate change, one thing we do know is that atmospheric carbon dioxide levels have risen sharply in the past 150 years, from 280 parts-per-million (ppm) to approximately 380 ppm today. To the total, we are adding another 1.5 ppm each year. That may not seem like much, but scenarios say we could see levels of 700 ppm or more in the not-too-distant future, almost triple the historical average. Carbon dioxide traps heat in the atmosphere. More CO2 means more heat, ergo global climate change.

The weight of the world

For the oceans, the potential consequences of global climate change are serious and many. Truth be told, the oceans are among the earth's systems most affected by global temperature fluctuation. Devastating coral bleaching episodes are now occurring due, at least in part, to warmer water temperatures. Species are shifting their ranges as tropical marine wildlife move to new areas that were once too cold for them. More severe, and perhaps more frequent, hurricanes are likely on the horizon, as well. And then there is the specter that melting glaciers may pour enough fresh water into the ocean to lower the salinity of seawater—slowing, if not stopping, the crucial ocean currents that regulate global temperatures and deliver much needed nutrients from the depths to the upper layers of the oceans.

One serious prediction that has become reality is ocean acidification, a result of carbon dioxide dissolving in the water. Since the start of the industrial age, seawater has grown slightly more acidic, a process that will continue for the foreseeable future. Adding 200 years of current emissions to the oceans would effectively double the acid in the water. Eventually, acidification will have a profound impact on all marine life that rely upon calcium carbonate to build shells and skeletons. Bedrock species of coral and plankton, species that anchor the ocean's food web, will literally dissolve in the waters that once sustained them.

Sea level rise is another serious threat. The increase in water levels, from both glacial melting and the physical expansion that occurs naturally as water warms, has been approximately a half-foot in the last century. Conservative estimates say a rise of another half-foot to a foot-and-a-half is likely—a troubling but manageable increase. More dire scenarios say the seas may rise three feet or more over the next century. The concomitant flooding could inundate important river deltas, wetlands, atolls and shorelines. The waters would threaten arable or inhabited land, including some major population centers and low-lying island nations. Tens- of-millions of people would be affected worldwide.

These are grim factors all, if they prove out.

Cause du jour

When scientists talk of controlling carbon dioxide they are trying to find ways to keep it out of the skies for a long time, eons preferably. Trees are a form of carbon storage, they take in CO2 and convert it to organic matter. The oceans, too, harbor carbon. In fact, next to limestone, the oceans are the biggest carbon repository on earth. It is estimated that the oceans already hold 39,000 billion tons of carbon. By comparison, the atmosphere now contains just 750 billion tons. So great is the ocean's capacity that if all the carbon dioxide in the atmosphere were dissolved in the oceans, the concentration would increase by less than two percent.

So it happened that John Martin's theory, the "Geritol solution," became the cause du jour in the clamor to mitigate the damage humans are causing through the burning of fossil fuels. What Martin realized was that phytoplankton—tiny floating marine plants after all—need basic nutrients for life, among them nitrogen, phosphorus, silicon, and iron. Certain areas of the oceans, while rich in most of those nutrients, lack the trace amounts of iron necessary to spark plant life. There are huge expanses of these high nutrient, low chlorophyll (HNLC) waters in the northern and equatorial Pacific and, especially, in the Southern Ocean surrounding Antarctica. And, while phytoplankton account for just one percent of the living matter on earth, they absorb almost the same amount of CO2 as all of the plants on land combined. What's more, ocean fertilization tests have shown blooms generated through ocean fertilization can produce 20- or even 30-fold increases in phytoplankton very quickly.

So, the theory goes, if we were to perpetually sprinkle iron over these ostensibly dead waters, phytoplankton would bloom. They, in turn, would absorb copious amounts of CO2 then die and sink to the deep ocean where they—and the carbon they contain—would remain for many decades, if not millennia as some have speculated. If Martin were right about phytoplankton and carbon fixation, something on the order of 100,000 atoms of carbon would be sequestered for every one atom of iron stirred into the ocean—an astounding uptake factor. So astounding, in fact, that Martin stated boldly, "Give me half a tanker of iron and I'll give you the next ice age."

It doesn't take a climatologist to fathom the potential: more phytoplankton mean less carbon dioxide. It wasn't long before the scientific community and the geoengineers were looking seriously to the oceans for an answer to global climate change. Then, in 1997, the Kyoto Protocols set out a worldwide agreement for the voluntary reduction of greenhouse gas emissions. Under Kyoto, CO_2 emissions are capped for each country through a yearly system of credits. Polluters who use all their credits can buy more from those who haven't. Suddenly, there was money to be made. The Department of Energy, even the behemoths of the energy industry, began to take note.

Science has its say

Could the answer to greenhouse gases really be as simple as fertilizing a desolate stretch of the Antarctic ocean with common, everyday iron? While most scientists agree that ocean fertilization could work to a degree, it will never be the cure the commercial enterprises have promised. One key question is just how much of the carbon would actually make it to the deep ocean, for only there does it remain long enough to be environmentally effective. As experiments have shown, most of the carbon trapped in the dead phytoplankton is converted back to CO_2 through decay in the water column—going right back where it came from very quickly; zero effect. Best estimates are that only perhaps one percent or less of all carbon taken up through photosynthesis in open-ocean surface waters makes it to the bottom.

In 2005, Richard E. Zeebe of the University of Hawaii, and David Archer of the University of Chicago, used various scientific computer models to show that even if 20 percent of the oceans were fertilized 15 times per year for 100 years, the expected reduction of CO_2 in the atmosphere would be approximately 15 ppm, and that from levels expected to reach 700 ppm or more by the year 2100. Recall that 70 percent of the earth's surface is ocean, so we are talking about fertilizing 14 percent of the surface of the entire planet, 15 times a year, for the next century to accomplish a reduction that would have very little impact on carbon dioxide levels.

So, though all the science indicates that ocean fertilization cannot reverse or even stanch the increase of atmospheric CO_2, some commercial entities, with much to gain, are intent on propagating the idea. To do so, they will, by the very definition of ocean fertilization, fundamentally alter our ocean ecosystems in order to do it. "The track record of humans in predicting the effect of large-scale ecological manipulations (including intentional introduction of species for biological control) is not at all good," says John Cullen, Killam Chair in Ocean Studies at Dalhousie University in Halifax, Nova Scotia. "It has been clearly shown that large scale ocean fertilization, operating at maximum efficiency—something that is unlikely to be possible—could not stop projected increases of atmospheric CO_2," he says. At best, he concedes, "ocean fertilization will merely delay the projected increases by several years."

<u>Truth and consequences</u>

And then, there are the side effects. Deep ocean hypoxia (low oxygen levels) or even anoxia (no oxygen) will likely occur, caused by decaying phytoplankton. Or, microbial communities at the bottom of the ocean, those which feed on the dead plankton, might emit other, more harmful gases like methane and nitrous oxide. Conversion of carbon to methane, with 21-times the heat trapping effect of CO_2, might actually make global climate change worse. Even the phytoplankton themselves have been shown to emit environmentally harmful gases like isoprene, dimethyl sulfide and others. Isoprene, an important precursor to ozone, increased four times in one experiment. Dimethyl sulfide might seed cloud formation, which would limit the amount of light reaching the water thus reducing the effectiveness of fertilization over time. And, of course, there's the lingering question of acidification, which will certainly grow worse with increases in dissolved CO_2 content of deep waters.

"We can predict deep ocean acidification and reduced oxygen, with numerous potential consequences that could offset the hypothetical benefits of fertilization," Cullen says flatly.

Mark Lawrence, an atmospheric scientist at the Max Planck Institute for Chemistry in Mainz, Germany, agrees and goes a step farther. "These are the consequences we currently know about, what about those we can't even predict yet? The potential for negative impacts, both known and unknown, appears to be particularly large for ocean iron fertilization, especially when compared to other geoengineering possibilities discussed thus far."

Back to the drawing board

Even those in the scientific community who support ocean fertilization sound a cautious note. Only as a last resort should ocean fertilization contribute and then as just one of a laundry list of other efforts to reign in greenhouse gases, a list topped by—you guessed it— reducing our reliance on fossil fuels. "In an imperfect world where we fail to stop using fossil fuels, ocean fertilization could help. But, it's not the whole solution. It's not a panacea," adds Dr. Kenneth Johnson, of the Monterey Bay Marine Research Institute, among those in favor of keeping ocean fertilization on the table. "The real answer is to ramp down carbon dioxide emissions to a sustainable level."

Others see it more simply. "The ocean has been proposed as a dumping ground of last resort for all sorts of human waste—everything from nuclear wastes to household trash—based on the idea that the ocean can absorb anything. Ocean fertilization is just another form of waste disposal," noted Mark Powell, an oceanographer and Director of Fish Conservation at The Ocean Conservancy. "Let's not trade the hell we know for the one we don't."