EARTH'S BIG HEAT BUCKET

story and design by Michon Scott · April 24, 2006

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Coral reefs, octopi, eels, offshore oil rigs, El Niño, La Niña, the birthplace of life, tasty seafood, even assorted bottom feeders. All these things come to mind when we think of the world's ocean. Researchers at NASA's Jet Propulsion Laboratory and Goddard Institute for Space Studies have learned to think of the ocean as something else, something that might not occur to the rest of us. The ocean, they say, is Earth's "biggest heat bucket." And like a bucket placed under an overflowing sink, the ocean is filling up with the heat that increasing levels of greenhouse gases are preventing from escaping to space.

Recent studies have shown that the world's ocean holds more than colorful coral reefs. It also acts as a reservoir for excess energy. (Photo courtesy Photos.com.)

By comparing computer simulations of Earth's climate with millions of measurements of ocean heat content collected by satellites and in-the-water sensors, a team of climatologists and oceanographers has provided what leading NASA climate scientist James Hansen calls the "smoking gun" of human-caused global climate change: a prediction of Earth's energy imbalance that closely matches real-world observations.

Where Greenhouse Heat Hides

Like any planet, the Earth absorbs some radiation and emits some radiation back into space. If the amount of energy Earth emits matches the amount it absorbs, the planet's energy budget is in balance, and its temperature remains steady. If the incoming and outgoing energy don't match, the planet is either warming or cooling over time, even if the change isn't immediately obvious. If greenhouse gases are forcing Earth to absorb more energy than it emits, why wouldn't global surface temperatures increase right away?

It sounds reasonable that if excess greenhouse gases in the atmosphere are causing Earth to absorb more energy than it reflects back into space, that excess energy should heat up the atmosphere first. Something that many people find odd—but climate scientists have long known—is that most excess energy would really hide elsewhere.


In his study of ocean heat storage, Josh Willis conducted experiments between New Zealand and Hawaii. (Photo courtesy NASA Jet Propulsion Laboratory.)

"It turns out that the atmosphere, the air, really can't hold that much heat," explains Josh Willis, an oceanographer with the California Institute of Technology working at NASA's Jet Propulsion Laboratory. Heat capacity is the amount of energy that must be put into something to change its temperature, and air has a very low heat capacity. "If you put energy into the ocean, on the other hand, its temperature changes only very slightly."

One reason the ocean heats more slowly than the atmosphere is the difference in their total mass. "The atmosphere only weighs a tiny fraction of what the ocean weighs," Willis explains. "But there's also a sort of intrinsic property of the air that makes it not quite as good at holding heat as the ocean. That property is called the specific heat. You probably have a feel for this if you've ever tried to boil a pot of water. You have to burn a lot of gas or wood to heat up the water. But if you had a similar quantity of air, it would take a lot less energy to heat it up to the same temperature. The water's heavier, and it has a higher specific heat, and both of those things give it a much bigger heat capacity."

What this means for planet Earth is that excess energy might not make itself immediately obvious by strongly warming the atmosphere. Instead, that energy might hide in the ocean, in the form of warmer ocean temperatures.

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"The ocean's a big place, and it's not doing the same thing everywhere," says Willis. "In some places, it's warming. In some places, it's cooling, and the quantity we need is the average over the whole thing." Getting that average has entailed overcoming several challenges, the biggest of which is probably learning how to take the ocean's temperature everywhere.

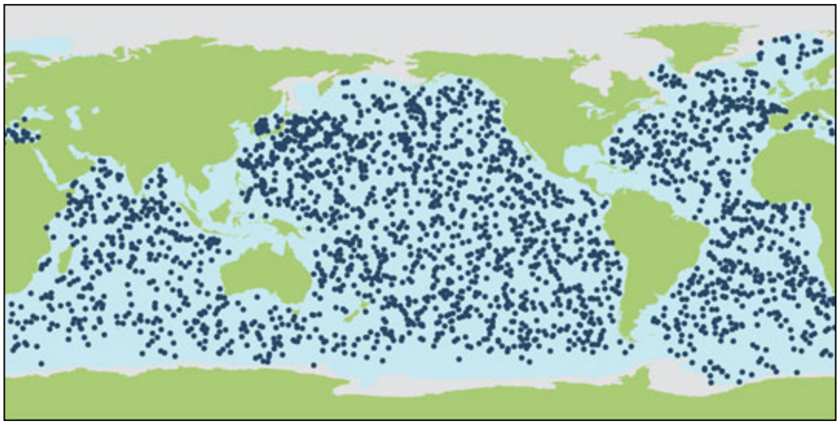
"There's a long history of shipping back and forth between the U.S. and Europe," Willis explains. As a result, temperatures in the North Atlantic have been studied carefully over the last century. Ships often dropped thermistors—devices that exhibit rapid changes in electrical resistance based on small temperature changes—along their routes. Although this approach yielded excellent temperature records for some areas, it offered far from universal coverage. "The Pacific is a huge ocean, and even if you count all the shipping lanes—the places where people go all the time—there are still big gaps." Sparsely sampled as it historically has been, however, the Pacific ranks above what Willis calls the "worst place for sampling": the Southern Ocean.

Germany conducted a major oceanographic research project between 1925 and 1927. On the research vessel *Meteor,* the German Atlantic Expedition measured the temperature, salinity, and density of the surface waters of the Atlantic. The expedition included a trip through the Straits of Magellan. (Photo courtesy NOAA Photo Library.)

Global measurements of changes in ocean temperature could only come from satellite. In 1992, NASA and the French Centre National d'Etudes Spatiales launched the TOPEX/Poseidon oceanography satellite; in 2001, they launched the successor, Jason 1. These satellites have provided researchers with global records of sea surface height. "As the water column warms up, the water expands, and that causes a change in the height of the sea surface. A satellite can measure sea-surface height very accurately, and it can cover the globe," Willis says.

The Jason-1 satellite doesn't work alone. In the ancient Greek myth, the explorer Jason was accompanied by his trusty shipmates, the Argonauts. Reminiscent of that legend, the international Argo float program complements the satellite's observations. By the end of 2006, the Argo program is expected to operate 3,000 floats, mechanical devices that measure temperature and salinity, drifting at specified depths and spaced roughly every 3 degrees (at the Equator, this equals 360 kilometers). "We haven't sampled the ocean with direct temperature measurements nearly as much as we probably should, but the Argo floats are starting to provide really good coverage," Willis remarks.

A growing collection of satellite observations and direct temperature measurements of the ocean enabled Willis to try to assess the ocean's average temperature. "Many, many researchers worked over many, many years" to collect all the data, says Willis. In 2004, he and two colleagues assembled the pieces for a paper published in the *Journal of Geophysical Research*. Along with satellite data, he incorporated roughly 1 million temperature profiles. "Each profile really includes measurements of temperature with depth between the sea surface and several hundred meters, so there are actually lots of measurements within each of those million profiles," he explains.



The goal of the Argo float program is to operate 3,000 floats in the world's ocean. This map shows the distribution of active Argo floats as of March 2006. (Map courtesy The Argo Information Centre.)

After combining all the data, Willis found that between mid-1993 and mid-2003, the heat content of the upper 750 meters of Earth's global ocean increased at an average rate of 0.86 watts (plus or minus 0.12 watts) per square meter. Just 0.86 watts per square meter may not sound like much until you consider that we are talking about an area of about 337 trillion square meters (the 93 percent of the world ocean that Willis studied).

He also points out that ocean temperatures actually fall into two categories. "It's important to make a distinction between warming at different depths. People are most familiar with sea surface temperature because it's where we live. We live on the Earth's surface. But a lot of this action and this heat-content signal are really beneath the surface of the ocean, and you have to go to hundreds of meters in depth to measure it. And what's going on right at the surface and what's going on at depth can sometimes be different."

Sea-surface temperature is a bigger driver of weather, but ocean temperature at depth tells researchers more about the planet's energy imbalance. To a climate modeler, a real-world estimate of the ocean's energy imbalance provides a rare opportunity to test model predictions of how increasing amounts of greenhouse gases are affecting Earth's climate. Soon after he published his paper, Willis learned he had caught someone's attention.

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Watching a Changing Planet

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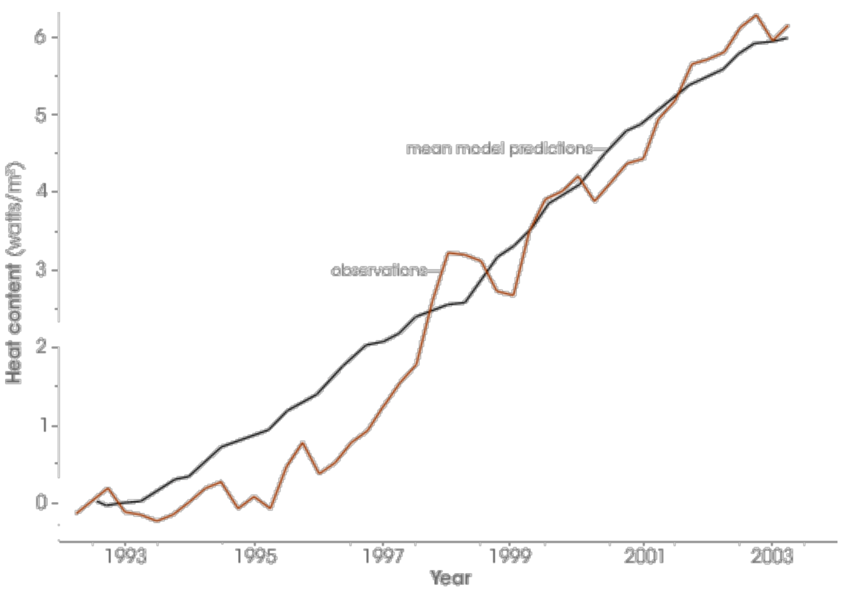
James Hansen heads NASA's Goddard Institute for Space Studies (GISS) at Columbia University in New York. In the mid-1970s, he was studying clouds on Venus when he fielded a request for help in studying the greenhouse effects of trace gases—gases that exist in miniscule amounts but that may still have significant climatic effects. About that time, Hansen's research interests shifted away from Venus and closer to home. "A planet that is changing on timescales that people are going to notice is a more interesting planet, and it obviously has more social relevance," he says.

After shifting his research focus in the mid-1970s, Hansen spent more than a decade studying the effects of greenhouse gases on Earth's climate. His research covered the effects of volcanic eruptions and aerosols (tiny liquid or solid particles suspended in the air), solar variability, increasing carbon dioxide, and increasing trace gases. He also studied atmospheric circulation, the sinking of surface water down into the deep ocean in the North Atlantic, and global trends in both sea level and surface air temperatures. He developed three-dimensional models of global climate. In 1988 Hansen testified before Congress, describing how different levels of greenhouse gases might affect future temperatures. Over the next 17 years, observed temperatures closely agreed with Hansen's 1988 predictions.

James Hansen has studied Earth's climate since 1976. (Photo courtesy Goddard Institute for Space Studies.)

But are recent temperature changes really from human-triggered global warming, or could they just be coincidence? The way to find out, Hansen explains, is to look at the planet's overall energy budget. If increasing greenhouse gases are exerting pressure on the planet's climate, the gases should create an energy imbalance in which the Earth absorbs more energy than it radiates back to space. Because most of the planet is ocean-covered and because those oceans have a high heat capacity, excess energy should show up in the ocean. So when Hansen saw Willis's paper on ocean warming, he sent an e-mail suggesting that they collaborate on a new study.

"Josh Willis' paper spurred my colleagues and me to compare our climate model results with observations," Hansen says. Hansen, Willis, and several colleagues used the global climate model of the NASA Goddard Institute for Space Studies (GISS), which predicts the evolution of climate based on various forcings—conditions or events that can cause climate change, such as water vapor and greenhouse gases, changes in solar radiation, or volcanic eruptions.



This graph compares observed (red) and modeled (black) heat content of the ocean between 1993 and 2003. The mean model predictions result from five runs of the NASA GISS ocean-atmosphere model. (Graph derived from Hansen et al. 2005.)

Hansen and his collaborators ran five climate simulations covering the years 1880 to 2003 to estimate change in Earth's energy budget. Taking the average of the five model runs, the team found that over the last decade, heat content in the top 750 meters of the ocean increased by 6.0 plus or minus 0.6 watt-years per square meter. (A watt year is the amount of energy delivered by one watt of power over one year.) What kind of energy imbalance would it take to generate that much heat? The models predicted that as of 2003, the Earth would have to be absorbing about 0.85 watts per square meter more energy than it was radiating back into space—an amount that closely matched the measurements of ocean warming that Willis had compiled in his previous work. The Earth, they conclude, has an energy imbalance.

"I describe this imbalance as the smoking gun or the innate greenhouse effect," Hansen says. "It's the most fundamental result that you expect from the added greenhouse gases. The [greenhouse] mechanism works by reducing heat radiation to space and causing this imbalance. So if we can quantify that imbalance [through our predictions], and verify that it not only is there, but it's of the magnitude that we expected, then that's a very big, fundamental confirmation of the whole global warming problem."

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◀ Taking the Ocean's Temperature