When oceans drop

“GRACE is our latest favorite toy. This idea that you can weigh a continent or weigh the ocean from outer space is kind of cool.”

Josh Willis
NASA Jet Propulsion Laboratory

by Laura Naranjo

“Sea level is one of the most important yardsticks for measuring how humans are changing the climate,” said Josh Willis, an oceanographer at the NASA Jet Propulsion Laboratory. He and colleague Carmen Boening have watched sea level creep upward at a slow but steady three millimeters per year. “We pay a lot of attention to this number,” Willis said, “so it was kind of surprising in 2010 and 2011 when we saw a dip, a reversal.” Sea level had suddenly dropped a half centimeter. What caused the drop? And did it mean sea level was no longer rising?

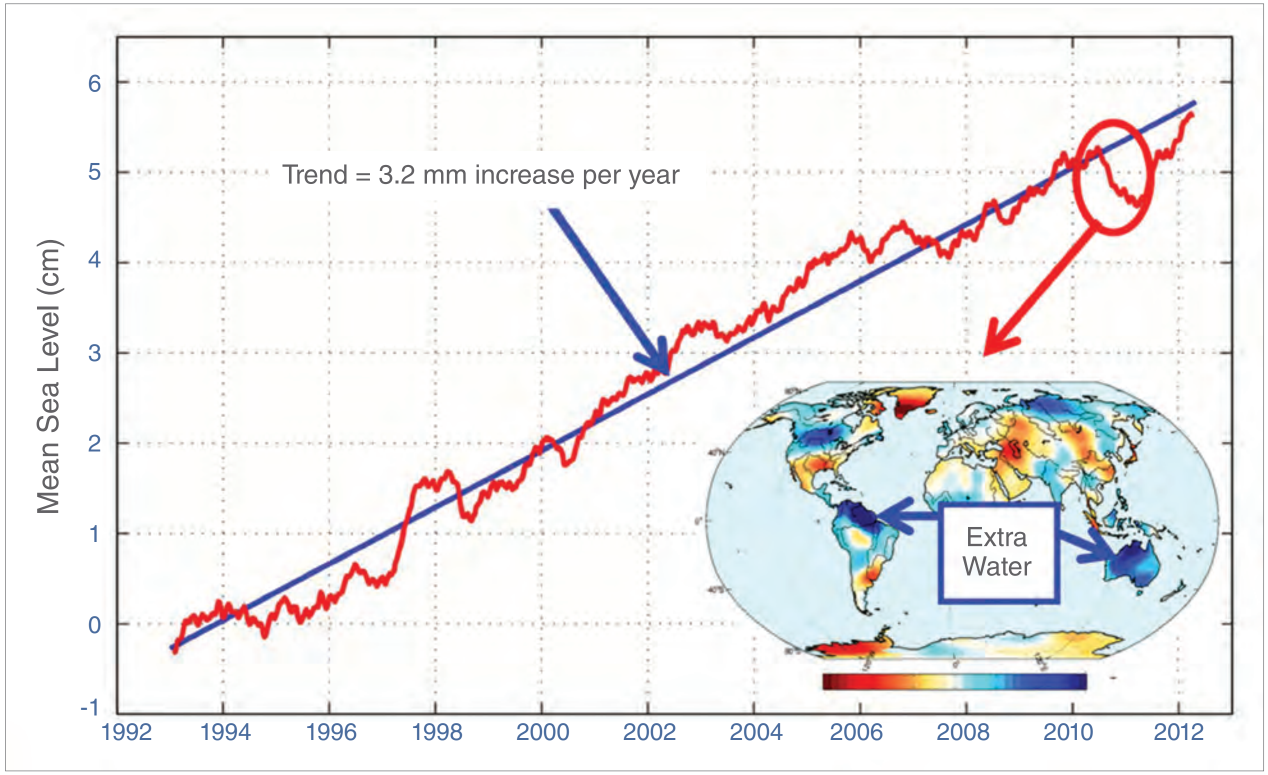
Heat versus movement

Scientists long thought that global ocean levels changed primarily in response to temperature. Willis said, “We thought that sea level changes were simply the ocean heating up and expanding or cooling and shrinking.” As global temperatures have increased, the oceans have expanded,

The strong La Niña in 2010 and 2011 produced torrential rain that inundated many low-lying areas around the globe. Floodwaters completely engulfed this house in Bangkok, Thailand. (Courtesy R. J. Maurer, U.S. Marine Corps) ice has melted, and sea levels have crept upward. Low-lying island nations like Tuvalu in the South Pacific are already losing ground as rising seawater erodes coastlines and contaminates fresh inland water supplies.

But global oceans are also governed by shifts between El Niño and La Niña, a large-scale climate pattern in the Pacific Ocean. Called the El Niño Southern Oscillation (ENSO), this cycle has far-reaching impacts. A strong El Niño phase can cause drought as far away as Canada and Europe, and La Niña can send torrents of rain halfway around the world to Bangladesh. During the warmer El Niño phase, warm water pools in the eastern Pacific. The resulting impact on the jet stream fosters warm, dry weather around much of the globe. During the cooler La Niña phase, the eastern Pacific cools, changing the jet stream so that it carries wet and cool weather to many regions.

South American sailors documented this pattern more than one hundred years ago, noticing changes in water temperature along the coast of Ecuador and Peru. The oceans swing between the two phases about every three to five years. Such a pulse of heat and movement in the oceans is nothing out of the ordinary. However, the 2010 La Niña was the strongest in eighty years, devastating parts of Colombia, South Africa, Southeast Asia, and Australia with heavy rain and flooding. So scientists wondered if La Niña was behind the sea level drop. Boening said, "This drop could have two reasons. Either the ocean was cooling a lot, or there was less water in the ocean." Could ENSO cool and shrink oceans enough to create a half-centimeter drop? If not, did the shift between El Niño and La Niña somehow move that much water out of the ocean?



This plot shows ocean levels since 1993. The red line shows sea level rise and the blue line indicates the trend. The red circle shows the sudden dip in 2010 and 2011, and the arrow points to a map of where that missing water went: primarily to Australia and northern South America (indicated by blue arrows on the inset map). While the ocean lost water, the continents experienced a gain because of increased rainfall brought on by the 2010/2011 La Niña. By mid 2012, global mean sea level had recovered by more than the five millimeters it dropped. (Courtesy NASA JPL)

Jason and the Argonauts

Boening and Willis had eighteen years of sea level data from a series of remote-sensing missions: TOPEX/Poseidon and its follow-on missions, Jason-1 and Jason-2. "Satellite altimetry measures the total sea surface height," Boening said, "and so it measures the changes in sea level." Those records indicated that sea level steadily rose an average of three millimeters per year. The dramatic drop during 2010 had not only negated the average annual 3.2 millimeter rise, but dropped sea level an additional two millimeters.

To see if sudden cooling was to blame, the researchers turned to temperature data, which proved trickier to obtain. Willis said, "With satellites we can only see the temperature of the ocean surface. But sea level rise really comes from warming through the whole depth of the water." So to complement the data from the mythically named satellites, the researchers turned to a global network of ocean floats, deployed by the Argo program. "Argo floats drift around at about 1,000 meters, and then dive down to about 2,000 meters, which is about the top half of the ocean," Willis said. "As they come back up, they

This comparison photograph of the Gurra floodplain in Australia, northeast of Adelaide, was taken in February 2012. The inset photograph was taken in February 2011, when rains inundated the plain. (Courtesy C. Nickolai)

measure temperature and salinity." More than 3,000 floats had been deployed by 2007, providing the deeper temperatures researchers needed to see if oceans had cooled and contracted.

Between Jason-1, Jason-2, and the floating Argonauts, Boening and Willis found that while this La Niña was extraordinarily strong, temperature data ruled out ocean cooling as the culprit behind the drop in sea level. This meant that water had disappeared from the ocean, and the researchers needed to find out where it went.

The weight of water

If the water was no longer in the ocean, then it must have ended up somewhere on land. It was not feasible for researchers to inspect every drainage basin, or examine water volume for every river across the globe. But they could try to find changes in weight around Earth. Five millimeters of global ocean water weighs about 1.5 trillion tons, and that much water cannot just disappear. A set of twin satellites, called the Gravity Recovery and Climate Experiment (GRACE), provided researchers with a fresh measurement of Earth's surface: gravity. Gravity exerts more pull on things that weigh more, so the scientists thought they could use the gravity measurements to locate the weight missing from the oceans. Willis said, "GRACE is our latest favorite toy. This idea that you can weigh a continent or weigh the ocean from outer space is kind of cool."

By looking at gravity measurements of oceans and land around the globe, the researchers could spot areas that weighed more in 2011. Boening said, "GRACE allowed us to actually track down the water to see where it went. And it turned out it was in northern South America, Southeast Asia, and Australia." The strong La Niña had affected the oceans to an unusual extent, not by cooling the water so much as by moving the water on to land. Rainfall follows warm pools of water, and during El Niño, more rain tends to fall over the Pacific Ocean. But during La Niña, cooler oceans push that rainfall over continents. The researchers then compared their GRACE findings to data from the Tropical Rainfall Measuring Mission (TRMM). "TRMM measures precipitation, so we could make sure that the changes we were seeing with GRACE lined up with the precipitation that was measured in these areas during that time," she said. Indeed, torrential rains had fallen over Southeast Asia, parts of South America, and eastern Australia, which suffered its worst floods in more than one hundred years.

"So it turns out that the atmosphere is good at picking up this water, carrying it a little ways, and then dumping it back down," Willis said. "That's a big part of why sea level goes up and down every year."

The rise marches on

Scientists had suspected that the ENSO cycle was capable of such dramatic water transport, but previously did not have the direct proof GRACE provided. They now know that thermal expansion only accounts for 10 to 20 percent of these kinds of sea level changes. Willis said, "It wasn't until this last switch from El Niño to La Niña that we had good enough data: sea level from altimeters, temperature data in the ocean, and gravity data from GRACE. We really needed all three to be sure that this was caused by changes in mass and not by thermal expansion."

These more extensive observations have also proven that the sea level drop was only temporary. Even though La Niña-induced rainfall deposited massive amounts of water on land, it only takes six months to a year for that water to run back off into the ocean. "What we're seeing now, over the course of 2011 to 2012, is that sea level is going back up again," Boening said. Shifts in water storage caused by El Niño and La Niña are only short term against the ongoing backdrop of warming. "Even as sea level dropped a little bit, we had huge amounts of melting in Greenland and Antarctica. So the things that are causing long term sea level rise are still chugging right along," Willis said.

Still, knowing where Earth's water is, whether it is in the oceans, falling as rain, or frozen in ice sheets, is crucial for monitoring global ocean levels. Boening said, "As we gather more and more observations, we are able to understand these fluctuations better, and also make our predictions of sea level rise better."

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2013/when-oceans-drop

References

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NASA Goddard Earth Sciences Data and Information Services Center. Tropical Rainfall Measuring Mission Gridded Rainfall Data 3B42. Greenbelt, Maryland USA. http://disc.sci.gsfc.nasa.gov/services/opendap/TRMM.

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About the remote sensing data used

Satellites	Gravity Recovery and Climate Experiment (GRACE)	Tropical Rainfall Measuring Mission (TRMM)
Sensors	K-Band Ranging System	TRMM Microwave Imager
Data sets	JPL GSM RL05	3B42: 3-hour 0.25 x 0.25 degree merged TRMM and other satellite estimates
Resolution	300 kilometer by 300 kilometer	0.25 degree x 0.25 degree
Parameters	Gravity fields	Precipitation
Data centers	NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)	NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)

The researchers used sea surface height data processed by the CU Sea Level Research Group, based on TOPEX/Poseidon and Jason-1 and -2 data from PO.DAAC. Data from Argo floats were provided by the International Argo Project.

About the scientists

Carmen Boening is a climate researcher at the NASA Jet Propulsion Laboratory (JPL) and part of the Gravity Recovery and Climate Experiment (GRACE) team. She studies ocean-climate interactions and their role in sea level rise. NASA supported her research. Read more at http://science.jpl.nasa.gov/people/Boening. (Photograph courtesy NASA JPL)

Josh Willis is a project scientist for the Jason-3 mission at the NASA Jet Propulsion Laboratory (JPL). He studies global ocean warming, sea level rise, and large-scale changes in the ocean and its circulation on interannual to decadal time scales. NASA supported his research. Read more at http://science.jpl.nasa.gov/people/Willis. (Photograph courtesy NASA JPL)

For more information

NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)
http://daac.gsfc.nasa.gov

NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)
http://podaac.jpl.nasa.gov

Gravity Recovery and Climate Experiment (GRACE)
http://podaac.jpl.nasa.gov/GRACE

Jason-1 Mission
http://podaac.jpl.nasa.gov/Jason1

Jason-2 Mission
http://podaac.jpl.nasa.gov/OceanSurfaceTopography/OSTM-JASON2

TOPEX/Poseidon Mission
http://podaac.jpl.nasa.gov/TOPEX-POSEIDON

Tropical Rainfall Measuring Mission (TRMM)
http://trmm.gsfc.nasa.gov