As land absorbs water, sea level rise slows

Melting glaciers and ice sheets continue to push up global sea levels, but a new paper published in Science has found a recent abatement of rising waters due to changes in the global water cycle that are causing soils, lakes, and underwater aquifers across the world to absorb more water. The study, which found that these features are storing more than 3 trillion extra tons of water, could significantly influence how scientists measure and predict global sea level changes in the future.

The research benefitted from the Gravity Recovery and Climate Experiment (GRACE) satellites, which were launched in 2002. Through the precise measurement of the distance between the two GRACE satellites—a calculation the researchers say was made with near certainty—they were able to discern changes in Earth’s gravitational pull caused by variations in the amount of water at Earth’s surface.

“An important piece of this work was making sure that we could reduce the uncertainty in the measurement enough to be able to draw these conclusions,” explains the study’s lead author, John Reager of the Jet Propulsion Laboratory. “This is the first paper to really reduce the uncertainty enough that we could make a statement about what’s happening with glaciers and hydrology together…”

With the satellite data, the scientists calculated how much the liquid water storage on Earth’s continents had changed, while also determining variations in ice sheets and glaciers. They found that over the past decade, Earth’s soils, lakes, and underground aquifers have taken in and stored approximately 3.2 trillion tons of additional water, which has temporarily curbed the rise of global sea levels by 20%—or about 0.7 millimeters per year—even as glaciers and ice sheets have continued to melt.

According to Reager, scientists have generally believed that “the largest contribution from hydrology to sea level rise was through groundwater depletion: people use groundwater for agriculture and it ends up in the ocean.” But over the past decade, he explains, “changes in the global water cycle more than offset the losses that occurred from groundwater pumping, causing the land to act like a sponge—at least temporarily.”

Reager said that the researchers are not certain what is causing the increase in stored water on land, but speculate that natural effects such as El Niño and La Niña along with anthropogenic climate change could be significant influences. [Sources: NASA, environmentalresearchweb.org]

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**ECHOES**

“It is like comparing an old standard-definition television screen to today’s ultra high-definition screens.”

—NOAA fisheries scientist Vincent Saba, on the difference in resolution between the Geophysical Fluid Dynamics Laboratory (GFDL)’s CM2.6 global climate model and the models utilized by the IPCC in its climate change projections. Saba is the lead author of a recent study published in the Journal of Geophysical Research-Oceans that suggests ocean waters off the coast of the northeast United States may warm twice as fast as predicted by the IPCC, and almost three times faster than the global average. The study looked at four GFDL models, and the CM2.6 “matched the Northwest Atlantic circulation and water mass distribution most accurately,” Saba says, adding that “prior climate change projections for the region may be far too conservative.” This acceleration has been especially pronounced in the Gulf of Maine, which is warming faster than 99% of the world’s oceans. With an ocean grid of about 10 kilometers, the CM2.6 model has 10 times more resolution than those assessed by the IPCC, which is important because, as Saba states, “when you are studying a unique location like the Gulf of Maine, with its complex bathymetry of deep basins, channels, and shallow banks combined with its location near the intersection of two major ocean current systems, the output from the coarser models can be misleading.” [Source: NOAA Northeast Fisheries Science Center]
Study Connects Electron Energy to Van Allen Belt Shapes, Sizes

Located in Earth’s magnetosphere, the Van Allen belts are layers of charged particles that are fixed in place by Earth’s magnetic field. The high levels of radiation in the belts can cause significant damage to satellites, so understanding why and how the two belts change their shape and size is important. A new study in the *Journal of Geophysical Research* has found that those properties of the belts fluctuate much more than scientists had thought, with most of the variability dependent upon the observed energy levels of the electrons in the belts.

“It’s like listening to different parts of a song,” explains the study’s lead author, Geoff Reeves of Los Alamos National Laboratory. “The bass line sounds different from the vocals, and the vocals are different from the drums, and so on.”

The researchers discovered that different energy levels of electrons in the Van Allen belts can lead to vastly different shapes and sizes of the belts themselves. It has commonly been believed that the Van Allen belts comprised a small inner belt, a predominantly empty middle space (known as the “slot region”), and a larger, more active outer belt. But the new study found a number of configurations that changed depending on the electron energies observed; viewing lower energies made the inner belt much larger than the outer belt, while the opposite was the case with higher-energy electrons. When the energy level was extremely high, the inner belt was completely absent.

“The shape of the belts is actually quite different depending on what type of electron you’re looking at,” Reeves says. “Electrons at different energy levels are distributed differently in these regions.”

The study also looked at how geomagnetic storms affect the belts, and when the researchers examined a broad range of energies, they found “consistencies in storm dynamics,” says Reeves, who noted some common behavior in the electron response at different energy levels, even as the details varied. For example, according to Reeves, the researchers discovered “that electrons fade from the slot regions quickly after a geomagnetic storm, but the location of the slot region depends on the energy of the electrons.”

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Specifically, the study showed that when the electrons were at lower energy levels, the slot forms farther from Earth, causing the inner belt to grow as large as the outer belt. When the electron energies are greater, the slot is closer to Earth and the comparative belt sizes are reversed with the inner belt all but disappearing.

The researchers utilized data taken from the Van Allen Probes satellites and focused on events of 2013. The probes provide data on a much greater range of electrons than has previously been possible, measuring hundreds of electron energy levels compared to the handful that prior instruments assessed. Scientists can use the bevy of electron energy level observations to hypothesize and subsequently model in rigorous detail what is happening inside the Van Allen belts, both during and in between geomagnetic storms.

“’You can always tweak a few parameters of your theory to get it to match observations at two or three energy levels,” Reeves says. “But having observations at hundreds of energies constrain[s] the theories you can match to observations.”

[Source: Los Alamos National Laboratory]

**Scientists Develop Warning System for Rogue Waves**

When ships encounter the massive walls of ocean water known as rogue waves, there is practically no time to react and take protective action. Even though they are twice as large as surrounding waves, due to their unpredictability there has never been a way for sailors to know when a rogue wave is approaching, other than for a few terrifying seconds when they can actually see the wave before it strikes their ship. But two researchers at the Massachusetts Institute of Technology have created a warning system that will at least give sailors a couple of minutes of warning to prepare, shut down vital operations, and possibly even change the direction of their ship to lessen the impact.

The scientists, Themis Sapsis and Will Cousins, expanded on their prior research in which they found that rogue waves sometimes emerge from collections of waves that join together as groups and concentrate their energy.

“These waves really talk to each other,” Sapsis says. “They interact and exchange energy.”

In their new research, which was published recently in the *Journal of Fluid Mechanics*, Sapsis and Cousins set out to look for patterns that characterize these rogue-forming wave groups. They combined ocean wave data collected by buoys with nonlinear analysis of the underlying water wave equations and created a range of wave possibilities for a given body of water. From this they were able to determine that the length and height of a wave group could predict the groups that created rogue waves. This knowledge of critical wave length and height allows them to determine “for any given sea state the wave groups that can evolve into rogue waves,” Sapsis explains. “Of those, we only observe the ones with the highest probability of turning into a rare event. That’s extremely efficient to do.”

According to Sapsis and Cousins, their new algorithm can accurately forecast rogue waves 2–3 minutes before they fully develop, provided ships are utilizing high-resolution radar or LIDAR to measure surrounding waves.

“It’s precise in the sense that it’s telling us very accurately the location and the time that this rare event will happen,” Sapsis explains. “We have a range of possibilities, and we can say that this will be a dangerous wave, and you’d better do something. That’s really all you need.” [Source: Massachusetts Institute of Technology]

**Seafloor Turbulence Helps to Drive Major Ocean Circulation**

The global ocean circulation system known as the meridional overturning circulation (MOC) plays a critical role in transporting heat, salt, and carbon across the Earth, while also impacting the rate of deep-water carbon exchange with the atmosphere. High-latitude surface waters of the MOC are cooled and flow in deep currents toward the equator. There they mix with warmer water and rise to the surface, eventually finding their way back to higher latitudes, where

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**ECHOES**

“I have no words to tell you how powerful it was.”

—Hurricane chaser Shazeel Moho, on witnessing Severe Tropical Cyclone Winston tear through Fiji in February. Winston was the most powerful storm to ever hit the South Pacific island nation, and the strongest tropical cyclone ever recorded in the Southern Hemisphere, with maximum sustained winds estimated at 185 mph and a pressure reaching 915 hPa. The Category 5 storm killed 44 people in Fiji and damaged or destroyed more than 50,000 homes, and in some villages every home was destroyed. The storm was powered by unusually warm waters in the Pacific, with ocean temperatures as high as 2°F above normal in the area covered by Winston. [Sources: The Washington Post, Weather Underground]
the process starts over. Scientists have struggled to identify where exactly in tropical oceans the upwelling occurs, but a new study published online in *Geophysical Research Letters* has found that extremely intense turbulence near the ocean floor is driving the process.

Researchers on an expedition in the equatorial Pacific utilized a new sensor called a χ-pod (pronounced “kai-pod”) to measure turbulence all the way to the seafloor.

“Upwelling requires mixing of waters with different temperatures and therefore different densities. What we measured using the χ-pod is the turbulence that generates this mixing,” explains Stanford University graduate student Ryan Holmes, a coauthor of the study. “This marked the first time that anyone had ever measured mixing to these depths on the equator.”

The χ-pod detected an area of strong vertical turbulence near a relatively flat area of the seafloor, which was unexpected, as scientists have generally believed that intense deep-ocean mixing was driven by water flowing over more jagged terrain. In fact, according to Holmes, it was “the first time that anyone had observed turbulence over smooth topography that was as strong as that found over rough topography.”

Holmes and coauthor Leif Thomas of Stanford utilized computer models to simulate winds blowing over the ocean surface, which can provoke internal waves that move vertically through the ocean and transfer energy to the seafloor. The models didn’t show the deep-water mixing, however; instead, they showed the internal waves “trapped to the equator between two vertical bands [of water] that act like fun house mirrors bouncing light rays back and forth,” Thomas explains. The waves also bounced off the flat seafloor, but didn’t reproduce the observed turbulence.

Thomas then added the horizontal component of Earth’s spin into the models, as he theorized “that internal waves at the equator, where the effects of the horizontal component of Earth’s spin are most pronounced, could experience an analogous behavior when the waves reflect off the seafloor.” With this adjustment, the model showed that in the equatorial waters, the rotation of the Earth slightly pushes moving objects in a vertical motion, which upsets the reflection of the internal waves and traps them near the ocean floor. There, they focus their energy and create turbulence that helps drive the MOC.

“We included this horizontal component and found that it changed the physics of waves in the deep equatorial oceans, potentially causing them to break and drive turbulence and mixing,” Holmes explains.
Because one cycle of the MOC can take thousands of years to complete, the new research sheds light on how deep equatorial waters influence Earth’s climate system, which could aid climate forecasting. [SOURCE: Stanford University]

**Defining a Heat Wave**

Surprisingly, there is no universal definition of a heat wave. The National Weather Service institutes heat alert measures when the heat index is expected to exceed 105°F–110°F for two or more consecutive days, depending on the region. The Intergovernmental Panel on Climate Change has defined a heat wave as at least five consecutive days when maximum temperatures are approximately 9°F above normal. Not only are these definitions different, but they also may not be applicable to all areas, as some places are warm almost year-round and lack true seasons. The lack of consensus can make it difficult for health agencies to determine when to take action during hot weather. In response to this problem, a group of researchers has designed a heat wave formula using Florida as a model.

The researchers utilized historical weather records and also accounted for missing weather data to create the new definition, which considers relative and absolute heat index thresholds for a given area and period of time. The study took great care to fill in missing data, using averaging and multiple spatial and temporal regression modeling as well as standard interpolation methods. Under the new formula, a heat wave is defined as when the temperature exceeds the 80% relative heat index threshold (i.e., the heat index must be higher than 80% of the area’s temperatures for a given period). Additionally, the area must have at least three days, which don’t need to be consecutive, when the heat index rises above an absolute regional heat index threshold, which is a pre-determined temperature dependent on regional climate.

“This formula better explains when a heat wave is occurring because it accounts for missing weather data and better captures what extreme heat means for a region,” explains the University of Missouri’s Emily Leary, lead author of the study, which was recently published in *PLOS ONE*. “Because this formula uses National Weather Service regions, there also is an existing infrastructure to communicate alerts.”

Leary noted that the new heat wave formula can be applied to all parts of the country. [SOURCE: University of Missouri, Columbia]

**Water Drained From Ancient Lake Influenced Ocean, Climate**

Between 13,000 and 8,000 years ago, a huge freshwater lake in South America about one-third the size of Wales drained swiftly in multiple stages into the Pacific Ocean when an ice sheet created dams that one after another melted away. In the first research of its kind about the Southern Hemisphere, a new *Scientific Reports* article reveals that the fresh water changed the Pacific’s circulation and significantly impacted regional climate. As noted by the study’s lead author, Neil Glasser from Aberystwyth University in Wales, the findings are relevant in today’s world “because we are currently concerned about the volumes of fresh water entering the oceans from the melting ice sheets in Greenland and Antarctica and this gives us an indication of the likely effects.”

According to Glasser, the “massive” lake released around 1,150 km³ of fresh water from the melting glaciers into the Atlantic and Pacific oceans—equivalent to around 600 million Olympic-sized swimming pools.”

In order to ascertain the timing of when it drained, Glasser and colleagues dated sediment samples left by the ancient lake, which was located in the Patagonian region on what is now the border of Argentina and Chile. They also modeled the altitudes of the lake’s shorelines, as well as the drainage routes and the amount of water that was released in several successive drainings, each one creating a new lake at a lower elevation as the ice sheet melted and the lake water repooled until it drained into the oceans. They then used an ocean–atmosphere climate model to analyze the effects of the fresh water on the Pacific.

The research revealed that after first flowing to the Atlantic, changes in drainage routes sent a majority of the fresh water flowing to the Pacific, where it created a salinity discrepancy around South America’s Cape Horn that significantly affected the structure of coastal ocean layers. This impacted regional ocean currents as well as climate, limiting rainfall in the winter while producing cooler ocean and air temperatures. Glasser noted that the freshwater effects were felt as far east as the Falkland Islands off the southern coast of Argentina.

The study could enhance research on the influence of glacial lakes on climate. [SOURCE: University of Bristol]
CLIMATE DRIVERS LINKED TO CHANGING ALASKA COASTAL TUNDRA VEGETATION PRODUCTIVITY

Alaska and Arctic coastal tundra vegetation has primarily greened over the satellite record. This greening is generally interpreted to be a product of increased vegetation productivity that has occurred simultaneously with reduced sea ice and a general terrestrial land surface warming over the same period. Alaska displays a unique gradient of vegetation trends within the Arctic, however, with substantial greening in northern Alaska and vegetation productivity declines or browning in southwest Alaska.

Our research analyzes the climate drivers of these contrasting tundra productivity trends in Alaska, and determines that there are large- and local-scale forces at work. Central to our analysis are climate-relevant remote sensing datasets for the period 1982–2013: Advanced Very High Resolution Radiometer (AVHRR)-derived Normalized Difference Vegetation Index (NDVI), sea ice concentration from passive microwave sensors, and AVHRR-derived land surface temperatures. These datasets allowed us to evaluate the mechanisms driving trends and variability of NDVI for tundra in Alaska along the Beaufort, east Chukchi, and east Bering Seas within the context of remote sensing, reanalysis, and meteorological station data as well as regional modeling.

In northern Alaska (i.e. along the Beaufort and east Chukchi Seas), declining sea ice has led to a longer open water period (i.e., reduced sea ice coverage) during summer, warmer adjacent land surfaces, and increased NDVI since tundra plants are temperature-limited. In southwest Alaska (east Bering Sea), greater open water is correlated with warmer land surface temperatures, however tundra vegetation (seasonal peak NDVI) has declined. This suggests that different processes are at play in these two regions.

Seasonality analysis of NDVI trends indicates that all regions display increases during the peak growing season but declines during spring—declines that have strengthened in the last decade.

Snow water equivalent (SWE) trends are positive during spring suggesting that increased snow cover is delaying vegetation productivity in spring. However, this snow mechanism is not conclusive because there is widespread concern about the reliability of long-term gridded snow data in the Arctic, something that needs to be addressed.

Seasonality analysis of land surface temperatures displayed general cooling during the middle of the summer growing season,
which has strengthened over the past decade. Meteorological station data in Barrow display cooling and increased cloud cover, consistent with the idea that increased open water favors higher cloud amounts and the possibility of a change in the sea breeze circulation. Analysis of a highly idealized regional model sensitivity experiment over northern Alaska indicates that the atmosphere responds to a prescribed warmer land surface with an enhanced sea breeze circulation and increased inland convection. These idealized results are encouraging and motivate further investigation of the atmospheric response to tundra greening. Large-scale sea level pressure has decreased over Alaska during July coincident with the summer cooling trends and increased convection. Therefore, local climate feedback mechanisms combined with changes in the large-scale circulation patterns likely play roles in the observed midsummer cooling. The vegetation and terrestrial feedbacks in these changing climate patterns need closer examination. —Peter A. Bieniek (University of Alaska Fairbanks), U.S. Bhatt, D.A. Walker, M.K. Raynolds, J.C. Comiso, H.E. Epstein, J.E. Pinzon, C.J. Tucker, R.L. Thomas, H. Tran, N. Mölders, M. Steele, J. Zhang, and W. Ermold, “Climate Drivers Linked to Changing Seasonality of Alaska Coastal Tundra Vegetation Productivity,” in the December issue of Earth Interactions.

**THROUGH THE EXPERTS’ EYES: METEOROLOGISTS’ PERCEPTIONS OF THE PROBABILITY OF PRECIPITATION**

What does a 20% chance of rain mean, not to the public, but to the experts? Beyond the pioneering work of Allan Murphy and Robert Winkler in the early 1970s, relatively few studies have examined the definition, understanding, and uses of the probability of precipitation (PoP) among contemporary meteorologists. Therefore, we wanted to investigate how members of today’s professional atmospheric sciences community define PoP, ways to help the public understand PoP more fully, and possible alternatives to PoP for conveying the likelihood of precipitation. We examined these questions in an online survey of 188 public and private-sector meteorologists and broadcasters in the United States.

Approximately 76% of the participants produced definitions of PoP that fell into one of five categories (in decreasing frequency of endorsement): (1) the NWS-established definition of PoP (26%); (2) PoP over an area—essentially a scaling up of point PoP (26%); (3) a general spatial and temporal definition that involved PoP at a given point over a given period (24%); (4) the relative frequency of precipitation under forecast conditions (12%); and (5) confidence of precipitation occurrence multiplied by its expected areal coverage (C x A; 12%). The differences in the participants’ definitions stemmed from the way PoP was derived from model output statistics, the parsing of a 12-hour PoP over smaller time frames, and generalizing from a point PoP to a larger area. Interestingly, 43% of the respondents believed that there was no or very little consistency in the definition of PoP, however they were uniformly confident about the definitions that they supplied.

Those surveyed believed that only about 22% of the population had an accurate conception of PoP and thus felt that it was of limited benefit to the public. They made a number of suggestions for what the public needed to know to have a better understanding of PoP, the most common categories of which included (1) a common, clear, and consistent definition of PoP among the weather community (27%); (2) an understanding of what a particular PoP percentage means (11%); and (3) the role or contribution of the areal extent of the forecast (9%).

Additionally, the respondents generated a variety of possible alternatives to PoP or made suggestions for how to enhance the existing PoP product. The four most common categories of alternatives included (1) using more descriptive words or phrases about the precipitation event (48%); (2) providing additional information, explanation, and graphics (19%); (3) providing more information about the spatial distribution of precipitation (18%); and (4) the incorporation of quantitative precipitation forecast (QPF) information (9%). These results imply that the atmospheric science community should work to achieve a wider consensus about the meaning of PoP. Further, until meteorologists develop a consistent conception of PoP and disseminate it, the public’s understanding of PoP-based forecasts may remain fuzzy. —Alan E. Stewart (University of Georgia), C.A. Williams, M.D. Phan, A.L. Horst, E.D. Knox, and J.A. Knox, “Through the Eyes of the Experts: Meteorologists’ Perceptions of the Probability of Precipitation,” in the February issue of Weather & Forecasting.
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