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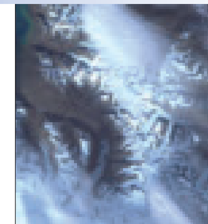


ICESat 2: Laser eyes on Earth's changing ice

When climate scientists began using the laser-equipped ICESat spacecraft to measure the thickness of the Earth's ice sheets in 2003, they encountered a series of technical and scientific problems. Engineers hope to overcome these by shifting to a completely new design for ICESat 2.

That mission is now in its definition phase for a January 2016 launch and is one of NASA's top Earth science priorities.

ICESat was equipped with three lasers that were turned on in succession as each wore out. Forty times a second, ICESat bounced lasers off the ice, received the reflections through its telescope, and used the transit time to calculate the height of ice sheets in Greenland, the Arctic, and Antarctica. Formally known as the Ice, Cloud, and Land Elevation Satellite, it took atmospheric readings and studied forests. But its primary mission was to help determine whether the planet is in fact losing ice due to global warming, information that could improve predictions of sea level rise.

With ICESat, scientists knew that they would need about 12 passes over a location to assure themselves they were measuring actual changes caused by melting or accumulating ice. Ice sheets are often sloped, and when the lasers landed a few meters uphill or downhill on subsequent passes—as is inevitable when a laser is pointed earthward from 600 km in orbit—readings could look like changes in thickness. The only way to subtract the changes would be to determine the slope first by making multiple passes.

Accomplishing the required passes turned out to be harder than expected. The first ICESat laser fizzled in just 37 days because of what engineers suspect was electronic erosion caused by solder. Because ICESat's goal was to look for changes over time, NASA was forced to conserve ICESat's laser power by turning the instrument on just three times a year—typically February, June, and October. The device was operated on 33-day collection campaigns and at lower temperatures to slow the erosion.

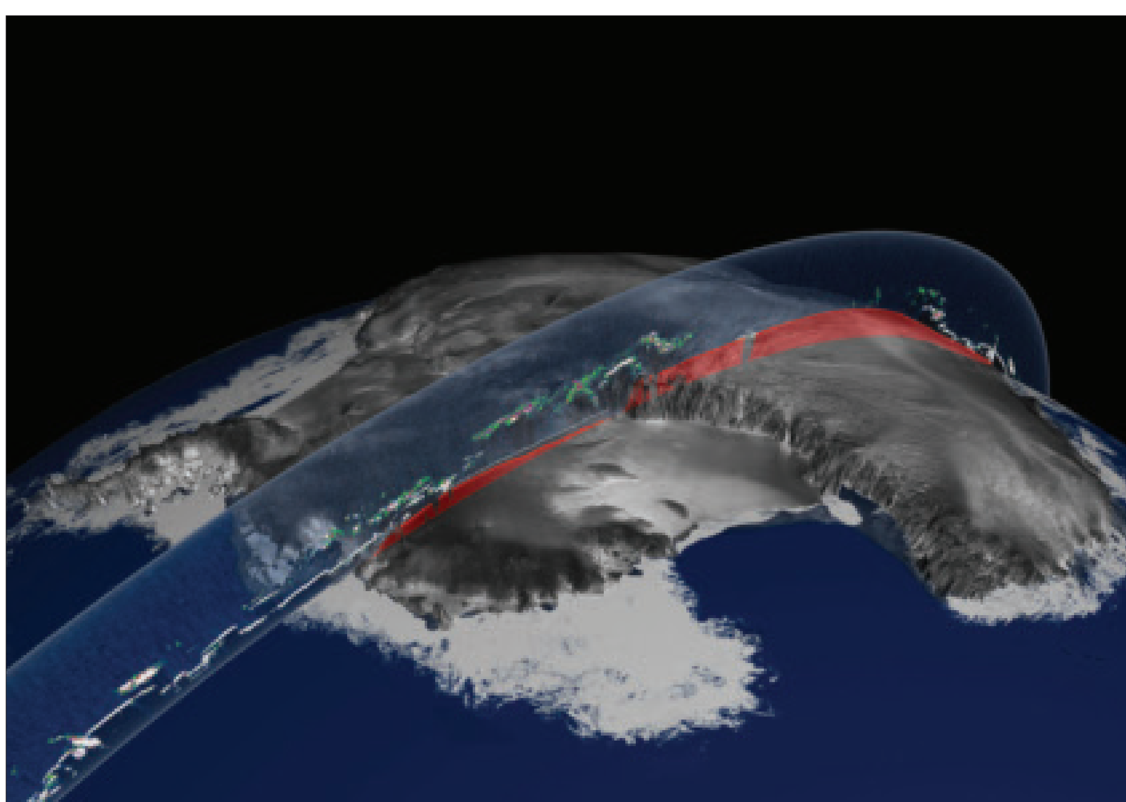
"We had to collect five years of data to get good solutions," laments NASA glaciologist Jay Zwally, who came up with the basic concept behind ICESat in the 1980s. Even with its shortcomings, ICESat delivered valuable data before losing laser power in 2009 and reentering the atmosphere in August 2010. ICESat depicted the subsidence and uplift that occurs when water flows beneath glaciers, and it measured sea ice freeboard, the distance between the surface of the ice and the water.

Fresh start

At an instrument science requirements review in December 2010, NASA engineers finalized the basic outline of their plan to avoid the pitfalls encountered during the first ICESat effort. Just about everything will be different on the follow-on mission, from the frequency of the laser signals to the number of beams.

"We're using a completely different kind of laser," says NASA Goddard systems engineer Tony Martino, the

ICESat data swath over Antarctica shows ice sheet elevation and clouds.



architect for ICESat 2's advanced topographic laser altimeter system, or ATLAS. "The big challenge is, we've never flown an instrument like this in space before," he says.

The original ICESat made altimetry measurements by transmitting pulses of laser energy 40 times a second in a single beam, with a power of 75 mJ for each pulse. For ICESat 2, engineers plan to transmit not one but six beams. The pulses will be rapid-fire, bouncing off Earth at a rate of 10,000/sec, which is what makes the effort unique for a space mission, Martino says. To make the overall power demands achievable, the pulses will be 1,000 times weaker than ICESat's altimetry pulses, creating a need for highly sensitive detectors in the craft's telescope. Three of the six beams will have an energy of 150 µJ per pulse, and the others about a quarter of that energy, "with the exact value to be determined," he says .

Engineers are banking that sending thousands of lower energy pulses every second will be less taxing on the laser system than sending dozens of more powerful ones.

"Since there's less stress on the components, these lasers should last longer," explains Tom Neumann, the ICESat 2 deputy project scientist.

Although the measurement approach is new for a space instrument, the technologies behind it are not considered to be particularly risky. "There is very little that is incredibly new," says Matthew McGill, the principal investigator for the ICESat 2's ATLAS instrument. Using all the components together may be new (or not)," he adds by e-mail. He says the Dept. of Defense has used the approach.

Multiple beams

Primarily, the switch to six beams is meant to improve the science readings. When a new measurement lands from a single beam, "you don't know whether it's because you hit a different place, or whether the ice has grown or shrunk," Martino says.

In the new approach, six beams will land perpendicular to the orbital path and track along the surface like a push broom. Originally, the scientists wanted 16 beams, but in 2009 they reduced the number to nine, then to six last year. "In order to get cost down, we had to do a number of descopes, and that was one of them—reducing the number of beams," Neumann says.

The mission's $650-million target cost includes three years of operation. It far exceeds the $300-million "rough cost estimate" envisioned for ICESat 2 in 2007 by NASA's first decadal survey of Earth science priorities. "The decadal survey numbers were a challenge to a lot of folks because they didn't include things like launch vehicle costs, which are large and growing," he adds.

Even with the six-beam compromise, scientists expect ICESat 2 to deliver more and better readings. With the original satellite, measuring the slope of an area took years, but "with ICESat 2, we'll be able to measure the slope on each pass," says Neumann. Scientists would be able to devote more time to looking for changes in ice cover.

"We are hoping from this approach we can take care of the problems on ICESat," adds laser physicist Anthony Yu, a member of the laser team at Goddard.

Technical solutions

As for workmanship issues, NASA engineers plan to build the instrument themselves with lasers procured commercially. In the case of ICESat, investigators concluded that excessive indium solder was used to attach the laser's heat sink, the device that was supposed to protect the laser electronics by absorbing excess heat. The indium caused a metallurgic reaction that eroded the gold wires that fed current to the laser diodes. Those diodes were critical, because they pumped energy to the laser source known as yttrium aluminum garnet, or YAG. After the first laser failed, engineers theorized that the gold would erode faster at higher temperatures, so ICESat managers lowered the operating temperature.

To avoid something like that on ICESat 2, engineers plan to capitalize on improvements made in the telecommunications industry, which uses diodes to help transmit data through fiber optic cables. "The telecommunications industry is helping out here because they have developed highly reliable pump modules that have essentially zero failure rate in the field," Yu says. "The workmanship and quality are much better."

Engineers also think they have a solution to a separate problem that cropped up when scientists began running ICESat's second laser. The engineers suspect this laser lost power rapidly, because hydrocarbons in adhesives vaporized in the vacuum of space and accumulated on the laser crystal, darkening it.

On ICESat 2, "that module is going to be pressurized with clean, dry air to mitigate that problem," Yu says.

New challenges

The decision to turn to a rapid-rate, low-energy approach solves some engineering issues but creates others. On ICESat 2, the detectors that receive the reflected energy via the spacecraft's telescope must be extremely sensitive because of the low energy.

The problem is, the most sensitive detector materials are designed for the green portion of the spectrum, but laser light is easiest to generate in the infrared. "You end up with this mismatch between what the lasers are good at and what the detectors are good at," Neumann explains.

The solution will be to generate infrared laser energy but use a set of optics called a frequency doubler that will shift the 1,064-nm IR wavelengths to higher frequency 532-nm green wavelengths. The first ICESat spacecraft's signals were strong enough that engineers had the luxury of making the altimetry readings in the infrared. The main purpose of that satellite's frequency doubler was to create green light for atmospheric measurements, Yu says.

With 10,000 pulses arriving at the detectors every second, the detector material will have little time for electromagnetic recovery between pulses. The light arrives so quickly that ICESat 2 must measure the transit time of individual photons. By contrast, the original ICESat received lots of photons measured as voltage.

"The detection system gets a little more complicated because we're responding to individual photons rather than the higher light levels," Martino says. The bottom line is that ICESat 2 will require detectors that are "sensitive, with a short dead time. That was most of the trade right there."

Mike Kapitzke, ER-2 lead engineer, inspects the MABEL installation in preparation for the initial flight.

The rapid-fire speed-of-light pulses also create a data-handling issue for the instrument's processor. "Because of the 4-msec transit time, you will have 40 pulses in flight at any given time. So you have to keep track of that many." This will be a major hardware and software challenge. "It's not like it's intrinsically hard, but it is new," Martino says.

As for the multiple beams, the basic approach is nothing new for a space instrument. The Lunar Reconnaissance Orbiter is equipped with a five-beam instrument called the lunar orbiter laser altimeter, or LOLA, whose data are turned into 3D maps of the Moon. A single beam is transmitted through a diffractive optical element consisting of a flat piece of glass with a hologram. The hologram divides the light into separate beams.

LOLA is far from a precursor to ICESat 2, however. It sends pulses 28 times a second, each with an energy of 3 mJ. Engineers also do not have to cope with atmospheric distortions.

A more accurate pointing mechanism for the laser was not considered a viable option. The original ICESat had a 30-m control accuracy, and so will ICESat 2. That is about the best that can be done for a reasonable cost, Yu says. Martino cautions that control accuracy is not the same as knowing where the laser landed. The knowledge accuracy will be about 6 m for ICESat 2, he says.

One planned improvement will be the ability to adjust the direction of the outgoing beam after launch to ensure the telescope catches the reflected light. ICESat did not have that capability. "We're looking at a smaller spot," a 10-m footprint compared to 70 m for the original ICESat, "so adjustment is more critical for us," Martino says.

Looking ahead

To test ICESat 2's multibeam concept, NASA has put together an airborne instrument called the multiple altimeter beam experimental lidar, or MABEL. It is not a prototype of ICESat 2, Martino cautions, but "it's going to be very useful for characterizing what the surface and atmosphere look like when we're using this technique."

In December, NASA installed the instrument in the nose of its high-flying ER-2 and flew it over five targets in the Southwest to collect elevation data similar to what they expect to receive from ICESat 2.

With the instrument science review behind them and the MABEL flights under way, ICESat 2 engineers have plenty of work ahead. Size, power, and mass are extremely important on any satellite, but at the moment, engineers do not know how big to make ICESat 2 because they do not yet know which rocket will launch the satellite. "We have made some allocations, but they're somewhat arbitrary because we don't have a launch vehicle," Martino says.

Few Delta 2 rockets are left in the inventory, and NASA's satellite builders do not yet have permission from the agency to consider a SpaceX Falcon 9 or an Orbital Sciences Taurus 2. Atlas-class rockets would be too large to launch ICESat 2 alone, so engineers are discussing the possibility of launching it into orbit in tandem with another satellite.

Scientists expect today's engineering work to pay off in the years after 2016. "With ICESat 2, knock on wood, all will go well, and we'll run it continuously. We won't turn it off for half the year," says Neumann.

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