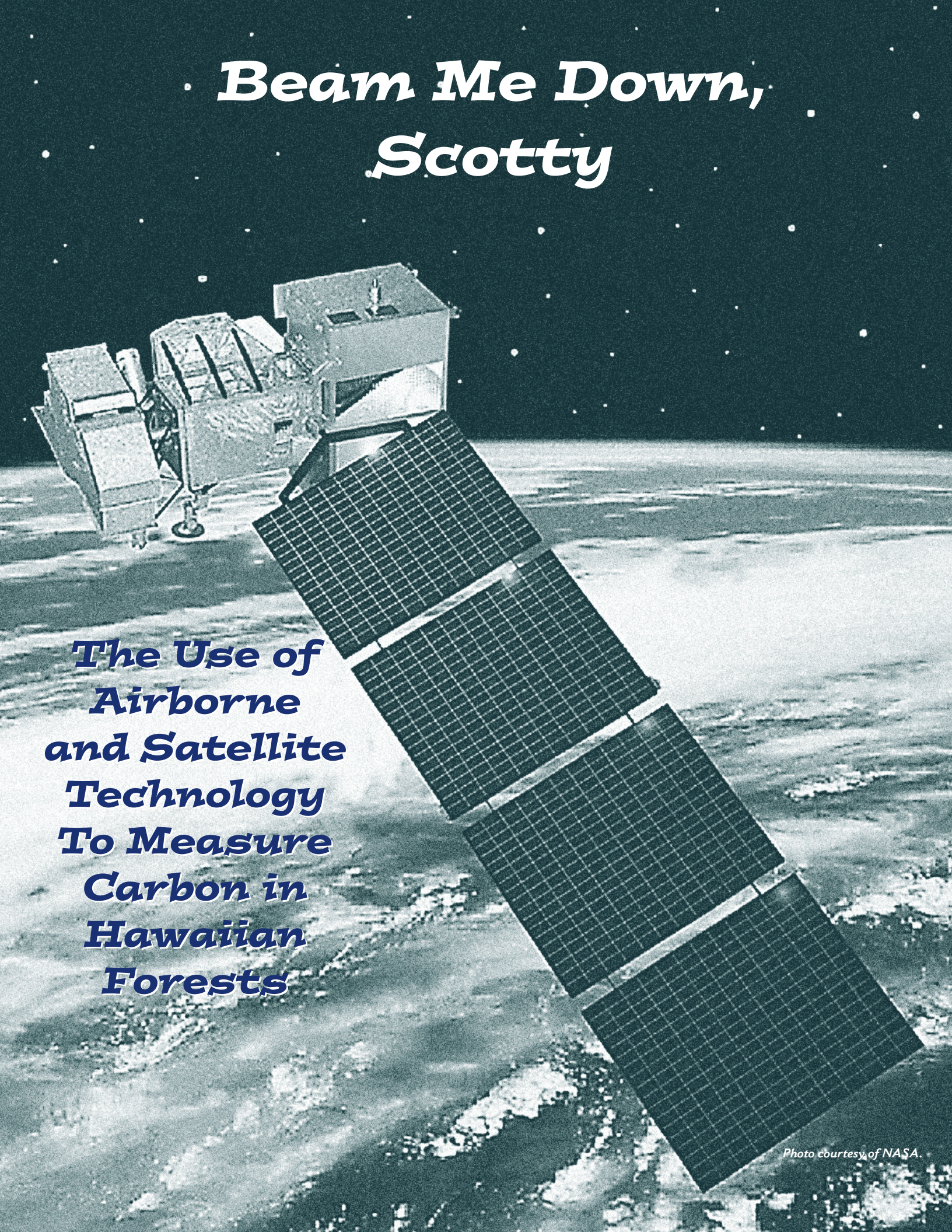
Beam Me Down, Scotty



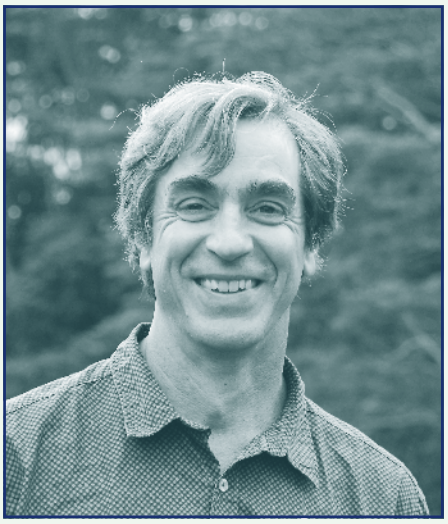
The Use of Airborne and Satellite Technology To Measure Carbon in Hawaiian Forests

Photo courtesy of NASA.

Meet the Scientists

▶ **Dr. Greg Asner,** Tropical Ecologist: My favorite science experience occurred in 2009 when my team and I climbed upward from the Amazon forests into the Andes mountains in Peru. After we made it to the mountain **summit**, we could look back, eastward, and see thousands of lightning strikes in the storms that normally occur over the Amazon forest. It made me think of standing on the summit of *Mauna Loa* in Hawai'i, looking down on the incredible Hawaiian rainforests that still exist high above where people live along the coast. Photo courtesy of Greg Asner, Carnegie Institution for Science.

▼ **Dr. R. Flint Hughes,** Ecologist: My favorite science experience was working with local villagers in the rain forests of southern Mexico. I was working to understand how **deforestation** and **land use** were changing those forests and all the incredible insects, birds, and other animals living within them. During this time, I had the opportunity to see and learn about the beautiful, large trees and associated plants of those forests. I saw and heard howler monkeys, toucans, and multicolored snakes that made those forests their home. I also saw first-hand how the people living in and around such ecosystems–the people who became my friends–profoundly affect the ecosystems in order to exist themselves.

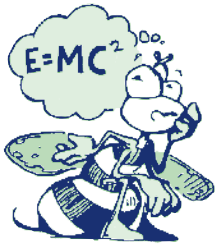


Working with the villagers affected me deeply. It was a real-world example of the common conflict between the livelihoods of people and the preservation of valuable tropical forests that are in danger of being lost forever. That experience fueled my motivation and desire to understand and protect native forests in Hawai'i and elsewhere in the world.

▼ **Ms. Amanda Uowolo,** Forest Ecologist: My favorite science experience occurred while collecting data on **species diversity, density**, and size in a forest in the Republic of Palau. We had our noses to the ground looking at tree seedlings. We came across a newborn fruit bat that had fallen from his mother's wing in the tree canopy. We rescued the baby bat and named him Henry. These types of surprises are what make my job exciting. This is often how scientific research works: You go into a situation expecting to find something specific, but end up finding the unexpected.

Glossary words are in **bold** and are defined on page 65. Hawaiian words are in *italics* and their pronunciation is given on page 106.

Thinking About Science



You know that scientists do research to learn new things. They also do research to test what they believe to be true. Scientists may also do research to improve scientific methods. New types of technology are available all of the time. You can see changes in technology in the way that cell phones continue to be improved. Research that explores the use of new technologies helps all scientists to use the new technologies. Scientists use these technologies to tackle important questions in new ways that help us better understand our planet.

In this research, the scientists combined three different ways of gathering information: an older, traditional method along with two new technologies. The older method involved going out into the forest to collect information by hand. The two new technologies involved airplanes, satellites, and computers. By combining these three methods of collecting information, the scientists were able to produce new information. This new information increases our understanding about 1 million hectares of land–an area about the size of Connecticut. This research enabled the scientists to test a new scientific method that will help other scientists do research about large, **diverse** areas of forest.

Be sure to read "Mālama ʻāina" on page 68.

Thinking About the Environment

Every tree contains carbon. If you remove the liquids from a tree, about one-half its weight is carbon. When trees are growing, they help to combat climate change by absorbing carbon from the atmosphere. Trees store carbon in their wood. When trees are cut and burned, the carbon in them is released back into the atmosphere in the form of carbon dioxide (CO_2). There, it contributes to climate change by heating our planet. It is, therefore, important to protect our forests worldwide. When forests are left standing and protected, their carbon is kept out of the atmosphere and the forests are able to collect and store even more carbon.

Scientists want to know how much carbon our forests contain. Knowing the amount of carbon is the only way to keep track of any change over time. In a way, tracking the amount of carbon is like keeping track of your own weight. If you never weighed yourself, it would be hard to say for sure whether or how much weight you were gaining or losing. When you think about the amount of carbon in forests, you can see what a big job this tracking is. Forests cover a lot of land and are different in terms of their structure and types of species that live there. Scientists need to use new tools and technologies, therefore, to help them estimate how much carbon large areas of forests contain.

Carbon dioxide in the atmosphere

Without a certain level of carbon dioxide in the atmosphere, Earth would be too cold, and life as we know it could not exist. Within the past 100 years, however, more and more carbon dioxide has been **emitted** into the atmosphere. Too much carbon dioxide causes the planet to warm beyond its normal range. This increase in carbon dioxide emissions comes from human activities, such as burning fossil fuels. Although too much carbon dioxide in the atmosphere is contributing to global climate change, it is important to remember that a certain level of carbon dioxide in the atmosphere is necessary for life on Earth.

Introduction

You may have heard about carbon trading and carbon credits. These phrases refer to programs aimed at reducing carbon dioxide emissions to the atmosphere. These programs involve balancing an amount of carbon emissions with activities that reduce an equal amount of emissions. If someone were driving across the United States, for example, his or her car would **emit** a certain amount of carbon dioxide during the trip. To make up for these emissions, the driver might voluntarily contribute money to an organization that protects forests. To balance the car's emissions, the driver would have to know three things: (1) how much carbon dioxide the car would emit during the trip, (2) how much forest land would contain that same amount of carbon, and (3) how much money it would take to help protect that much forest land.

In this study, the scientists were interested in the second item. They wanted to test a method of calculating the amount of carbon stored by plants across a large area of land. They chose the island of Hawai'i to test their method. Hawai'i is the largest island in the Hawaiian Islands (**figure 1**). It contains 1,000,000 hectares. Hawai'i has volcanoes, forests, pastures, grasslands, developed areas, and many types of **ecosystems** and land cover (**figure 2**). Hawai'i is one of the most **ecologically** diverse places on Earth. It has areas with high rainfall and also deserts with low rainfall. It has areas at sea level and at very high **elevations**. Each of these areas contain a different amount of carbon. Forests, for example, hold more carbon than grasslands.

Figure 1. Hawai'i is the largest of the Hawaiian Islands.

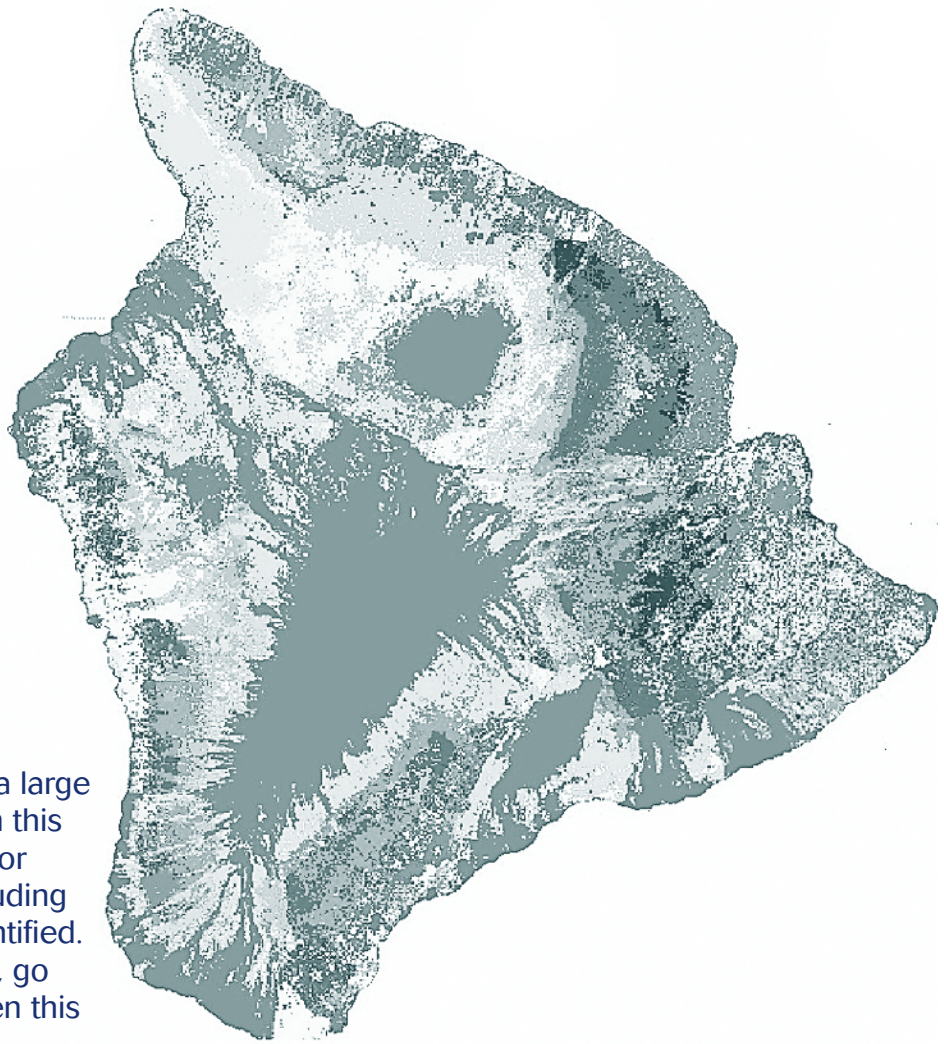


Figure 2 (at right). Hawai'i contains a large variety of ecosystems. Each shade on this map represents a unique ecosystem or **land cover**. Forty types of areas, including ecosystems and land covers, are identified. To see or download this map in color, go to http://www.naturalinquirer.org, open this journal and click on this article.

Number Crunches

- How many acres is 1,000,000 hectares? Multiply the number of hectares by 2.47 to find out.
- How many square kilometers is 1,000,000 hectares? Divide by 100 to find out.

In the past, people working directly on the land estimated the amount of carbon stored in plants. This method, although fairly accurate for the actual trees being measured, was expensive and took a long time to get enough **samples**. In addition, this method could estimate only the amount of carbon in small areas of land. This information was not enough to understand forests across large areas. Remember that there is now a need to understand how much carbon large areas of forest and other types of land cover store. To meet this need, the scientists decided to combine the old method with new technologies.

The scientists used new laser technology called Light Detection and Ranging (LiDAR). The scientists also used satellite technology that estimates how much land has certain types of vegetation. Combining old and new methods enabled the scientists to estimate the amount of carbon stored in different types of forests. They could then create a carbon map of the whole island of Hawai'i.

Reflection Section

- Why did the scientists study Hawai'i?
- What was the problem the scientists were trying to solve?

What is LiDAR?

LiDAR stands for Light Detection and Ranging. Light beams, or laser pulses, are sent from an airplane towards Earth. When the light beams reach something on Earth, they are reflected back to the airplane. A computer onboard calculates how long it takes the light beam to return. Because we know the speed of light and the technology can measure time accurately, the computer can calculate the distance between the airplane and the object on Earth that was hit by the light beam. Using LiDAR, scientists can calculate the height of many trees across large areas. When LiDAR is used in forests, some of the light beams travel through the leaves before being reflected back. This characteristic of LiDAR enables scientists to estimate the amount of vegetation between the ground and the treetops **(figure 3).**

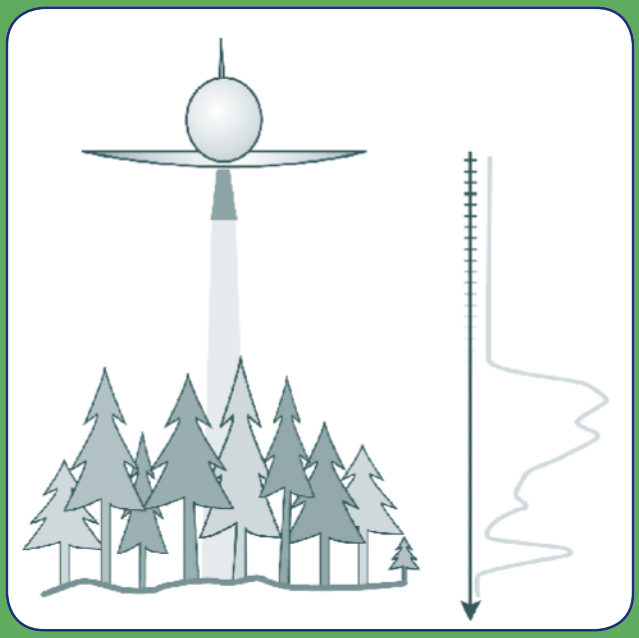


Figure 3. LiDAR enables scientists to measure vegetation over large areas of land.

Methods

The scientists used four steps to test their method for carbon mapping. First, they used existing maps of the land cover of Hawai'i. People working on the land created some of these existing maps, and satellites and computers created others (**figures 4 and 5**). Using these maps, the scientists identified the land cover of different areas. Using information from the satellite and a computer program, they identified areas that had forests and areas with no forests or those that might have been **deforested** (**figure 6**). Have you used Google Earth to see objects on Earth close up? If you have, you can see how the scientists identified conditions of forests and other areas on Hawai'i using satellite photos. Google Earth uses Landsat photos, just like the scientists did.

The scientists then used LiDAR to better understand the **vertical** structure of the plants and trees (**figure 7**). About 25 percent of the island was sampled. The areas sampled included a wide variety of land cover and ecosystems.

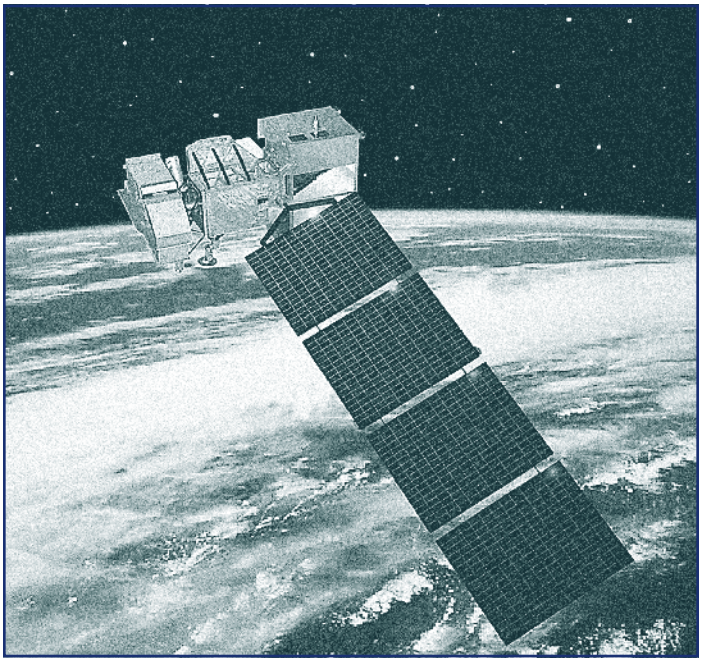


Figure 4. The National Aeronautics and Space Administration, or NASA, uses satellites to take photographs of Earth from space. This satellite is called Landsat. Scientists use Landsat to study Earth's land cover. Image courtesy of NASA.

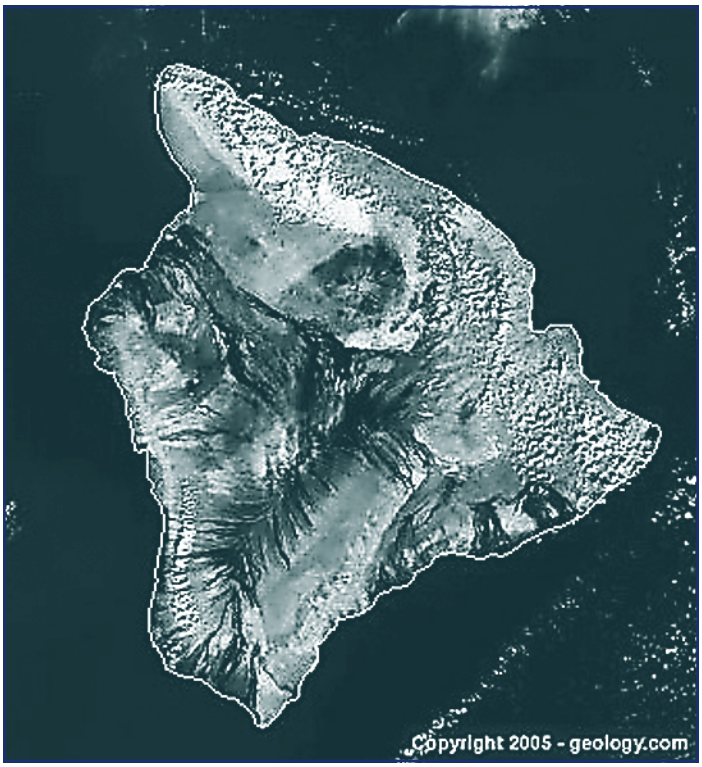


Figure 5. A Landsat photograph of Hawai'i. Image courtesy of http://geology.com.

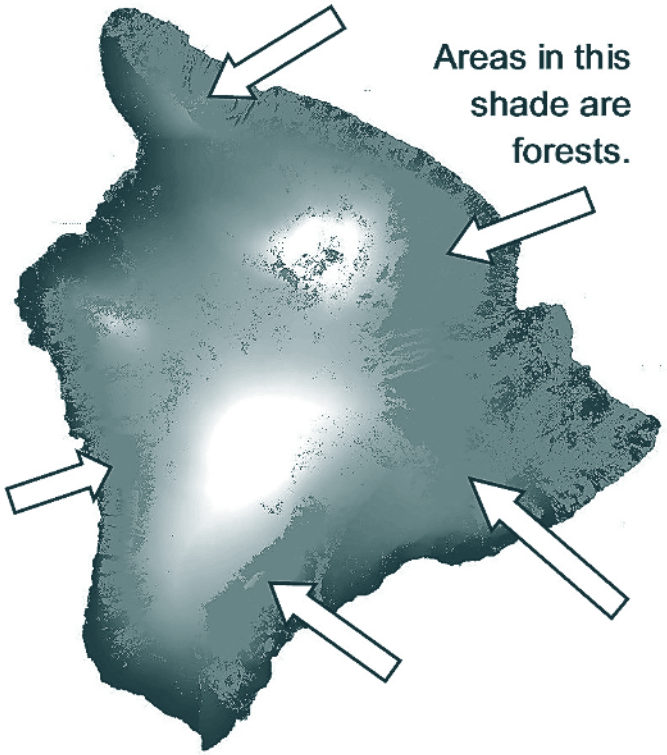


Figure 6. This map shows forests and other areas on Hawai'i. A computer program called CLASlite, which stands for Carnegie Landsat Analysis System-Lite, created this map.

Figure 7. The vertical structure of a forest is the way the vegetation looks from the ground up to the treetops. Compare the vertical structure of these four different forests. What is similar and what is different about the vertical structure of these forests?

The third step was to identify areas on land to study in person. The scientists identified 126 areas for sampling where they established plots. Each plot was an imaginary circle with a radius of 30 meters. Each of these 126 plots had also been sampled using LiDAR. In each plot, the scientists identified and measured all trees that were 5 centimeters or larger diameter at breast height (DBH) (see sidebar). The scientists then used existing equations that related DBH to the amount of carbon in the tree. For example, trees with a DBH of 5 to7 centimeters were already known to contain a certain amount of carbon. In this way, the scientists were able to estimate the amount of carbon contained in each of the 126 plots.

Number Crunches

- What was the diameter of each of the 126 plots?
- What was the area of each plot? Area is calculated using this formula: $A=\pi*(r*r)$, where A=area, $\pi=3.14$, and r=radius. This formula is also written $A= \pi r^2$.

What is DBH?

DBH stands for diameter at breast height. In the United States, this distance is 1.4 meters (about 4.6 feet) from the ground. This method is a standard way to measure the size of trees (**figure 8**). When the tree is growing on a hill, DBH is measured on the uphill side of the tree.

Figure 8. One way to measure the size of a tree is to measure its diameter at breast height. Photo by Paul Scowcroft.

In Step 4, the scientists looked at the LiDAR information on vertical structure in each of the 126 plots. They compared this information with their direct measurements of the plants' carbon content. The scientists discovered that the amount of carbon in each plot was related to the center of the vertical height of the trees. If the scientists could calculate the center of the vertical height of any forested area in Hawai'i, they could estimate the amount of carbon being held in that area. Plots with taller trees, for example, held more carbon. In other words, the scientists found that by using LiDAR to identify the average height of the trees in an area, they could accurately estimate the amount of carbon stored by plants in that area.

The scientists then combined the vegetation maps that they used in Step 1 with the carbon estimates made using LiDAR in Step 4. If they identified an area as being deforested or **degraded** (Step 1), they reduced their estimate of the amount of carbon in that area. This method enabled them to apply the carbon estimates to each of the land cover areas in the existing maps. By applying carbon estimates to each area of land, they were able to create a carbon map of Hawai'i.

Reflection Section

- How was the old method of estimating carbon in person combined with new technologies?
- What if the scientists wanted to map the carbon contained in the State of West Virginia? Should they use the same estimate of carbon related to the vertical center as they did in Hawai'i? Why or why not?

Findings

The scientists discovered that the amount of carbon in an area was related to the type of soil and climate conditions in the area. Areas with older Hawaiian soils contained more carbon than areas with young soils. Areas of Hawai'i with high rainfall contained more carbon than areas with lower rainfall. The scientists also found dry areas, whether they were warm or cool, contained smaller amounts of carbon (**figure 9**).

The scientists discovered that areas with little or no forest land contained less carbon than forested areas. Forests that had been planted in the 1930s in areas where rainfall was plentiful contained the highest amount of carbon.

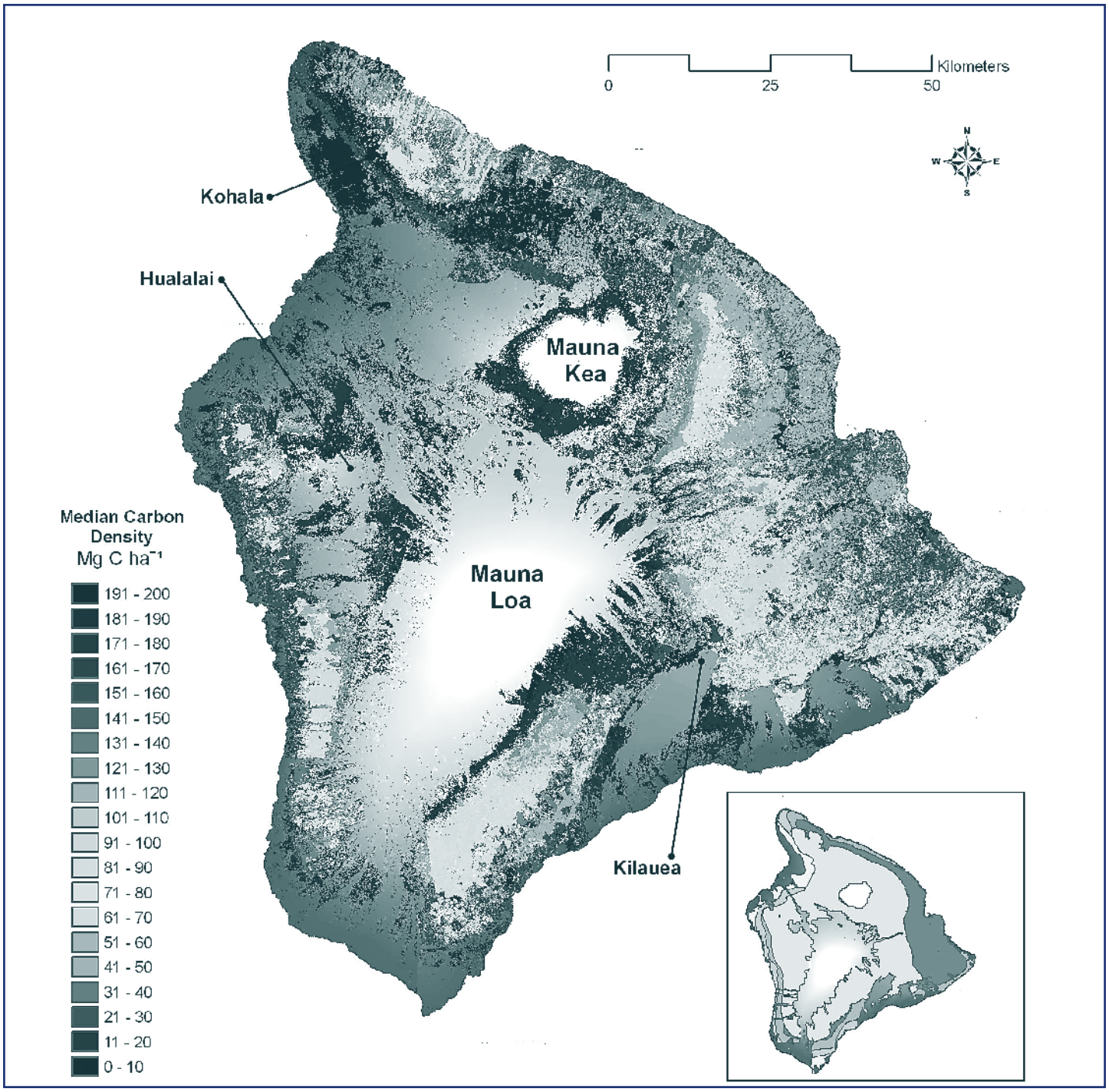


Figure 9. Carbon map of Hawai'i. In these two colors, the areas with the highest and lowest levels of carbon appear the same. In full color, however, these differences would be visible. To see the map in color, look at the cover of this journal. You may also visit http://www.naturalinquirer.org and click on this journal and this article to view the map in color. The inset shows the level of detail in carbon mapping available prior to this method being tested. What differences do you see? Compare this map with the Landsat image in figure 5.

Reflection Section

- Why would areas with old soils contain more carbon than areas with young soils?
- Why do you think the amount of carbon was related to the amount of rainfall in different areas of Hawai'i?

Discussion

The scientists concluded that the use of LiDAR to estimate carbon is as accurate as making the estimates in person. Because LiDAR can be used over a large area, the cost of using LiDAR is much less than trying to make in-person estimates over the same large area. Using LiDAR, moreover, enables scientists to make carbon estimates in remote areas people would have a hard time visiting.

The scientists also concluded that after they made an initial carbon map, they can easily update it using Landsat photographs that show changes in land cover over time. In particular, Landsat photographs will show the locations of new deforestation and degradation as well as new forest growth. Existing carbon maps can be updated to show the decrease or increase in carbon storage due to these conditions.

Reflection Section

- Would you say that the scientists' test of their new method to estimate the amount of carbon in Hawai'i was successful? Why or why not?
- Do you think that this method could be used for other large areas of forest and other land cover? Why?

Adapted from: Asner, G.P.; Hughes, R.F.; Mascaro, J.; Uowolo, A.; Knapp, D.E.; Jacobson, J.; Kennedy-Bowdoin, T.; Lark, J.K. 2011. High-resolution carbon mapping on the million-hectare Island of Hawai'i. *Frontiers in Ecology and the Environment:* 110301094720075 DOI: 10. 1890/100179. http://www.fs.fed.us/psw/publications/hughes/psw_2011_hughes(asner)001.pdf.

Glossary

Deforest (dē **for** əst): The act or process of clearing forests.

Degrade (di **grād**): To lower the character of.

Density (**den(t)** sə tē): The quantity of something per a particular space, length, or volume. A measure of how close things are to one another.

Diverse (di **vərs**): Differing from one another.

Diversity (də **vər** sə tē): The condition of having or being composed of differing elements; variety.

Ecological (ē kə **läj** i kəl): Having to do with ecology. Ecology is the study of the relationship of living things with each other and their environment.

Ecosystem (ē kō **sis** təm): A system made up of an ecological community of living things interacting with their environment especially under natural conditions.

Elevation (**el** ə **vā** shən): The height above the level of the sea.

Emit (ē **mit**): To throw or give off or out.

Land cover (**land kəv** ər): The observed cover of Earth's surface, such as vegetation and manmade features.

Land use (**land** ūs): The way the land is being used, such as for homes, agriculture, roads, or forests.

Sample (**sam** pəl): A part (as a set of individuals chosen from a whole population) used for investigating the whole.

Species (**spē** sēs): A class of individuals having common characteristics and designated by a common name.

Transpiration (**tran(t)s** pə **rā** shən): The process by which plants give off water vapor through the stomata in their leaves.

Vertical (**vərt** i kəl): Going straight up or down from a level surface.

Accented syllables are in **bold.** Definitions and marks are from http://www.merriam-webster.com.

FACTivity

Time Needed

1 class period

Materials

- This article.
- The article, "The GLAS Is Half Full," from the Climate Change edition of the *Natural Inquirer*. You may download this article at http://www.naturalinquirer.org/satellites-and-changing-tropical-forests-a-109.html or order the Climate Change edition from http://www.naturalinquirer.org.
- Graphic organizers on pages 66-67.

In this FACTivity, you will answer the question, "What are the similarities and differences of two recent studies of carbon storage in tropical forests?" It is your job to identify how these studies are alike and how they are different.

The method you will use to answer this question is: Read "Beam Me Down, Scotty." Then read "The GLAS Is Half Full" from "Thinking About the Environment" through the "Discussion" section. You do not need to do the Reflection Sections.

Now, compare and contrast "Beam Me Down, Scotty" with "The GLAS Is Half Full" by completing the first graphic organizer on page 67. After you have completed the graphic organizer, hold a class discussion about your findings. Then, summarize your findings by completing the second graphic organizer below.

Graphic Organizer: Summarize

What are three differences between these two studies?	
What are three similarities between these two studies?	
Write a research question that all of the scientists in these two studies could answer together.	

Graphic organizer: Compare and contrast the two studies.

	Beam Me Down, Scotty	The GLAS Is Half Full
What question did the scientists want to answer?		
How was carbon involved in the research?		
Name four characteristics of the land being studied.		
What was the role of in-person information collection?		
How were Landsat photographs used?		
How was LiDAR used? (GLAS is a type of LiDAR)		
What did the scientists conclude about the use of technology to collect information?		

Mālama ʻĀina (Care for the Land)

This research highlights the importance of Hawaiian forests as places where carbon is stored on Earth. When forests are healthy, more carbon is stored on Earth. This can prevent more carbon dioxide, or CO_2, from entering the atmosphere. Most CO_2 enters the atmosphere from burning fossil fuels. Too much of this gas contributes to the planet's warming. Reducing CO_2 in the atmosphere, therefore, will slow climate change.

Forests also provide other benefits. They provide homes for animals, protect soil and water, and provide places for people to enjoy. Forests provide wood and nontimber products for buildings, furniture, musical instruments, medicine, food, and art. We recognize these benefits of forests today. Because we recognize these benefits, we take action to protect our forests. Did early Hawaiians understand the benefits they received from their forests? If so, did they take action to protect their forests? What did they do?

In 1987, Marion Kelley concluded that early Hawaiians had a strong tradition of caring *(mālama)* for the land *(ʻāina)*. They had an unwritten rule to take only what was needed from the island forests. This unwritten rule was explained by the following proverb: *"Hahai no ka ua i ka ululaʻau,"*–"The rains always follow the forests." Early Hawaiians observed that rains were associated with forests. We know now that tropical forests are dense and trees are tall where rain is plentiful. We also know that tree growth results in **transpiration** that can create mist and clouds that encourage rain. Because water is critical to life, the early Hawaiian observations about the relationship between rain and trees served them well. They cut down only the trees they needed. By cutting only what they needed, they made sure that rains would continue coming to their forests. Because they took only what they needed, the forests were available for generations of Hawaiians to use and enjoy.

The forests of Hawaiʻi are still loved and cared for today. In the Hawaiian Islands, the concept of *mālama ʻāina* is passed from parents to children. For example, Kamuela Meheula-Naihe of the First Nations' Futures Program, wrote "As a *keiki*, I spent most of my time outdoors. My parents taught me the concept of *mālama ʻāina* at a young age. I grew up always having a garden, spending a lot of time at the ocean and in the mountains. Because of these experiences...I am deeply connected to the environments around me." (From http://www.fnfp.org/.)

How do the people in your family and community feel about the land? How do you feel about using forests and protecting them? What can we learn from the concept of *mālama ʻāina*?

The title of this article is based on the TV show, Star Trek. "Beam me up, Scotty" is the command Captain Kirk reportedly gave to his chief engineer, Montgomery "Scotty" Scott, when he needed to be transported back to the Starship Enterprise. Although this phrase is close to what was said on the show, these actual words were never used on the show. In this research article, light beams were sent down to Earth from an airplane using LiDAR and reflected back to the airplane. In a way, these light beams were being beamed down from and back up to a "starship."

Additional Web Resources

NASA Landsat Resources for Educators:
http://landsat.gsfc.nasa.gov/education/resources.html

National Oceanic and Atmospheric Administration Carbon Cycle Education Resources:
http:// www.education.noaa.gov/climate/carbon_cycle.html

First Nations' Futures Program:
http://fnfp.org/

World's Forest edition of the ***Natural Inquirer***:
http://www.naturalinquirer.org/

National Education Standards

National Science Education Standard	Where and How the Standard Is Addressed
Abilities Necessary To Do Scientific Inquiry	Introduction: Use of math in science. Introduction Reflection Section: Communicate scientific procedures, identify questions. Method Number Crunches and What Is DBH?: Mathematics. Methods Reflection Section: Develop explanations, use appropriate tools and techniques. Findings Reflection Section and Discussion Reflection Section: Develop explanations. FACTivity: Identify questions, communicate procedures.
Understandings About Scientific Inquiry	Thinking About Science: Investigations generate new methods, use of technology. Thinking About the Environment: Technology improves data collection and analysis. Figures 3 and 4: Using technology in the investigation. Methods: Type of method used, method fits the problem, math is important, technology is used. Discussion: Conclusions about using technology. FACTivity: Analysis of methods used.
Structure and Function In Living Systems	Figure 6: The vertical structure of a forest.
Populations and Ecosystems	Introduction and figure 2: Diversity of ecosystems in Hawai'i.
Structure of Earth System	Thinking About the Environment: Carbon in trees. Carbon Dioxide in the Atmosphere: Function of carbon dioxide. Findings: Relation of carbon to soil. Findings Reflection Section: Soil structure and volcanic eruptions.
Understandings About Science and Technology	What is LiDAR?: Technology provides access to otherwise unobservable phenomena. Discussion: Technology has tradeoffs.
Natural Hazards	Thinking About the Environment and carbon dioxide in the atmosphere: Hazards of rising carbon dioxide.

Science and Technology in Society	Thinking About Science: Technology can cause change in society.
Science as a Human Endeavor	Meet the Scientists: Science requires different abilities.
Nature of Science	Methods: The use of existing information (land cover maps, DBH-carbon equations).

National Curriculum Standards for Social Studies	Where and How the Standard Is Addressed
Time, Continuity, and Change	*Malama ʻāina:* Comparison of historic attitudes towards forest use, comparison of forest values over time.
People, Places, and Environments	*Malama ʻāina:* Reasons for early Hawaiian views.
Individual Development and Identity	*Malama ʻāina:* Reflection on current values.
Production, Distribution, and Consumption	Introduction: Balancing carbon emissions (production, distribution, and consumption).
Science, Technology, and Society	Entire article: How might this technology affect society?
Global Connections	Entire article: Global climate change concerns.