Where is This Chunk of Earth Moving? Using the Positional Technologies of Geodesy to Explore Science

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Abstract

Most students are leveraging geodesy every day through GPS technology embedded in commonly used devices: smartphones, cars, cameras, health trackers, computers, and many others. High-precision GPS used by researchers can measure rates of motion of tectonic plates and volcanoes at millimeter precision providing timely updates for ongoing assessment of natural hazards. GPS is one of many geodetic techniques utilized in the field of geodesy - the study of the size, shape, and mass of the Earth and changes with time (SERC, 2017). Geodesy is the science of how Earth is changing now, providing measurements on human relatable temporal and spatial scales.

This article provides an overview of geodesy and briefly describes the current applications of geodesy to Earth sciences. It describes online tools to find, download, and analyze data for the classroom, identifies freely-available data-rich educational resources aligned to Next Generation Science Standards that leverage modern geodetic data for secondary to introductory college students, and provides examples of selected lessons for the classroom.

Refer to the "What is Geodesy?" infographic for a brief introduction useful for students: (unavco.org/education/outreach/infographics/infographics.html).

Introduction

Most students have smart phones that use the Global Positioning System (GPS) to determine location. Students have come to rely on this "location" feature and often don't realize that they are leveraging geodesy. GPS[1] technology is also used to conduct scientific investigations. High-precision GPS used by researchers can measure rates of motion of tectonic plates and volcanoes at millimeter precision providing timely updates for ongoing assessment of natural hazards. GPS is one of many geodetic techniques utilized in the field of geodesy – the study of the size, shape, and mass of the Earth and changes with time (SERC, 2017).

1 Throughout we use GPS for simplification. GPS is the United States satellite navigation system. Global coverage is referred to as Global Navigation Satellite System (GNSS) of which the U.S. GPS network is a part.

Geodesy is the science of how Earth is changing now, providing measurements on human, relatable, temporal and spatial scales. Rather than students trying to imagine how much the Atlantic Ocean has opened over the past 100 million years, students can look at the data and determine that the Atlantic Ocean is an inch wider than it was about this time last year. Geodesy and GPS are inherently data rich, are applied in multiple disciplines (earth sciences, atmospheric sciences, environmental sciences, hydrology, cryosphere, and engineering), and encourage system-thinking. These aspects of geodesy provide strong linkages to the Next Generation Science Standards (NGSS) Science and Engineering Best Practices and Cross-cutting Concepts, are relevant to many Disciplinary Core Ideas and Performance Expectations, and support foundational concepts taught in introductory-level college science courses (NRC, 2013) (See Tables 1 & 2).

This article provides an overview of geodesy, briefly describes the current applications of geodesy to Earth sciences, geodetic data and tools available for educators, and describes freely-available data-rich lessons and materials for the classroom aligned to the NGSS that leverage modern geodetic data for secondary to introductory college students.

Applications of Geodesy Across Earth System Science

Surveying has been the primary application of geodesy throughout history. Advances in GPS and other geodetic instruments, as well as rapid improvements in communication and networking technologies over the past two decades, have transformed our ability to measure and track the changing shape of our Earth to millimeter precision. Geodesy is more than just GPS. The geodetic toolbox of techniques also includes borehole geophysics tools such as strainmeters, tiltmeters and geodetic imaging (radar, LiDAR and gravity). Geodetic techniques and instruments are now used in scientific research beyond plate motion.

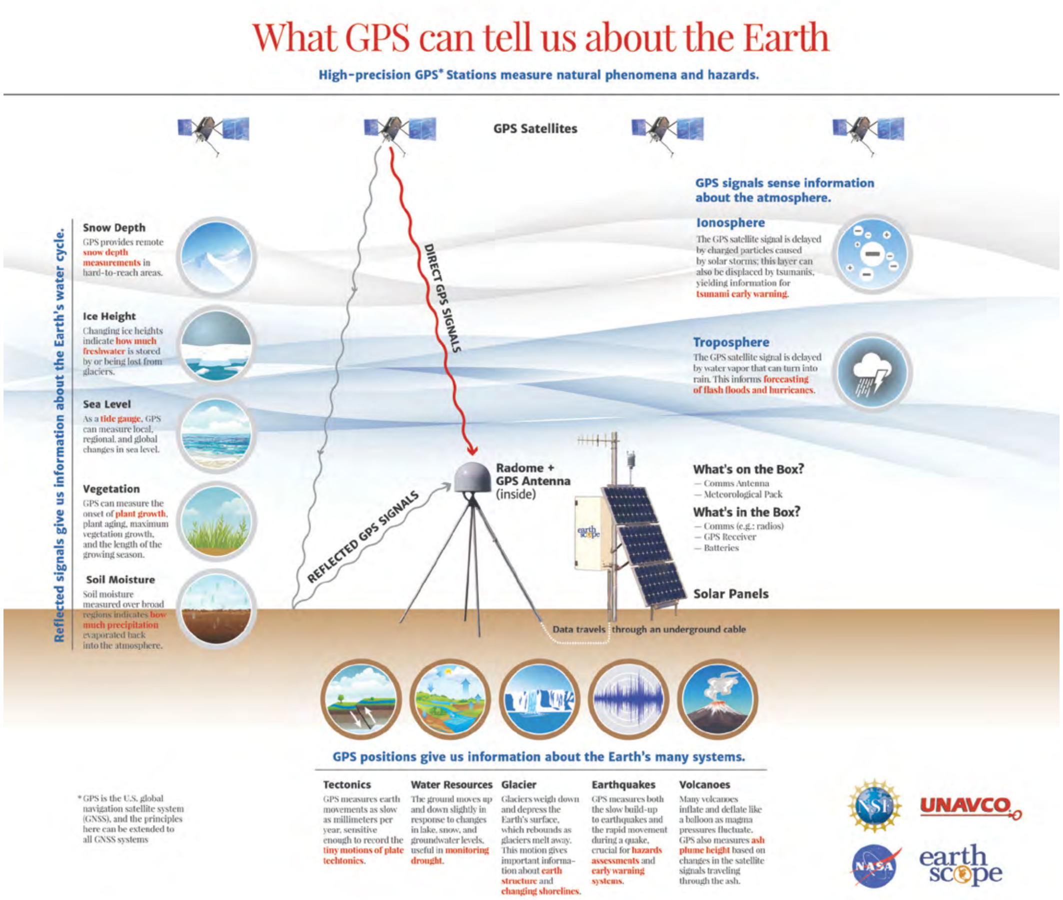

Figure 1. What GPS can tell us about Earth. GPS is helpful for more than just navigation. Explore how scientists can use GPS to measure snow depth, sea level, and more with this infographic available for educational use. Created by Beth Bartel and Daniel Zietlow with assistance from Gene Malowany.

Currently, the GPS constellation has more than 30 satellites allowing continuous monitoring by GPS instruments permanently deployed around the globe. These permanent stations continuously collect data, which is made available to researchers, educators, and the public (See Figure 1). In past decades before the full constellation of satellites was deployed and permanent GPS stations installed, researchers had to go out to a field site each year to deploy temporary instruments to collect data.

Some recent socially relevant discoveries and applications include:

- Improving the development of risk models of earthquakes at and within plate boundaries, through new models of global plate motions and strain
- Contributing to earthquake early warning systems through the collection of real-time GPS data to more rapidly estimate earthquake magnitude and tsunami heights
- Identifying and tracking Episodic Tremor and Slip (ETS) near subduction zones. ETS is more common than earthquakes in some areas of the world, accounting for frequent changes in direction of Earth motions between punctuated large earthquakes in those regions.
- Detecting and better understanding subsurface activity within volcanoes
- Measuring mass changes of Earth's ice sheets in Greenland and Antarctica resulting in changes in Earth's local gravity
- Detecting land surface changes in landslide zones, stream-bed changes, wildfire-denuded slope changes, fault scarps, geomorphic change, and vegetation characteristics through the use of 3-dimensional imaging with laser and radar technologies
- Gathering data about soil moisture, atmospheric water vapor content, snow depth, and vegetation cover
- Monitoring drought and other groundwater changes
- Measuring sea level rise through tide gauge systems

This list of science applications is not comprehensive and continues to grow as new science and novel approaches to analyzing geodetic data are developed. To learn about more scientific discoveries using geodetic technologies, short articles are available as supplementary reading for students:

- Science Snapshots (unavco.org/science/science.html)
- Highlights (unavco.org/highlights/highlights.html)
- As the Earth Turns newsfeed (unavco.org/science/news/news.html)

Geodetic Data and Tools Available for Educators

Geodetic data is collected and archived by multiple organizations. UNAVCO, one of the providers of geodetic data and support, is a non-profit organization funded by the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) to support scientists in their collection and use of geodetic data for research and education. These networks consist of instrumentation located around the world (Figure 2). The Plate Boundary Observatory (PBO) is a network of geodetic instrumentation, including GPS, designed to monitor surface motions in Alaska and western United States. PBO is operated by UNAVCO as part of the NSF-funded EarthScope Project, which explores the North American continent to better understand the materials it is made of, how it was assembled, and how it works, and offers GPS data covering the past decade or longer. Data from two additional GPS/GNSS networks, the Continuously Operating Caribbean GPS Network (COCONet) and Trans-boundary, Land and Atmosphere Long-term Observational and

Collaborative Network (TLALOCNet), are also available through UNAVCO. Data collected through these geodetic networks are transferred via telecommunications to centrally located servers. The data are processed, archived, and made available for use. Users, including educators, can download the data or products created from the data. The geodetic data, resources, and tools are available for educators.

GPS data that is ready to use in educational settings are available from thousands of permanent GPS stations from multiple data providers, such as UNAVCO, the United States Geological Survey, Nevada Geodetic Laboratory, and Pacific Northwest Geodetic Array. UNAVCO manages three networks across western North American, Alaska, and the Caribbean (PBO, COCONet, and TLALOCNet). Data from individual GPS stations are offered as spreadsheet-friendly files, as images of time-series graphs, and through online interfaces that display velocity vectors.

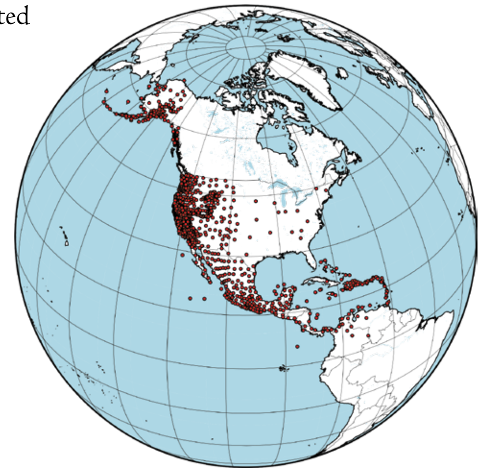

Figure 2. The UNAVCO PBO, COCONet and TLALOCNet GPS networks.
Credit: UNAVCO.

Spreadsheet-friendly GPS data. Time-series data provide the daily average change of the GPS station's position in three directions: north-south, east-west, and vertical up-down. This data can be downloaded into a spreadsheet program, graphed as a time series plot, and studied for more than 2000 GPS stations available through the UNAVCO GPS networks. Long-term average GPS velocities are also available as a single file and can be plotted onto maps.
Map-based, graphical interfaces of GPS data. Vectors showing the velocity of individual GPS stations are viewable on interactive web-based maps, UNAVCO Velocity Viewer (unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html) and GeoMapApp (geomapapp.org/). The GPS Velocity Viewer allows exploration of geodetic velocities determined by GPS data. By displaying the station labels, students can find details about individual GPS stations including downloadable GPS data and the station's pre-plotted time series graph. Additional geophysics layers of plate boundaries, earthquakes, volcanoes, and faults can be added to the map. GeoMapApp is a data exploration and visualization computer-based application developed by the Lamont-Doherty Earth Observatory of Columbia University, is free to the public, and offers geodetic velocity data from UNAVCO and other data providers.

Geodetic imaging uses radar and laser data for tracking centimeter-scale motions at Earth's surface over several square meters to hundreds of square kilometers. These remote sensing data include 3-dimensional imagery that are also available and relatively easy for students to use.

Geodetic Imaging data. OpenTopography provides classroom-usable high-resolution (meter to sub-meter scale) topography of 3-dimensional imaging of Earth's surface, collected through airborne and land-based LiDAR. These images can be imported into Google Earth as kmz shaded relief images or downloaded as point cloud data (which can be used for 3-D printing). UNAVCO has developed instructional tutorials for GPS and LiDAR data, including YouTube step-by-step walkthroughs for accessing, downloading, and importing the imagery.

Lessons and Materials for the Classroom

Most students are leveraging geodesy every day through GPS technology embedded in commonly used devices: smartphones, cars, cameras, health trackers, computers, and many other devices. This familiarity with the technology provides an opportunity to segue from a familiar navigational experience of a GPS-enhanced mapping application to the scientific applications recorded by permanently installed high-precision GPS and other geodetic techniques. In collaboration with master teachers and college faculty, UNAVCO has developed learning materials and has led teacher professional development workshops for over ten years, focusing on providing examples of geodetic applications. This broad suite of contextualized educational resources is available on UNAVCO's

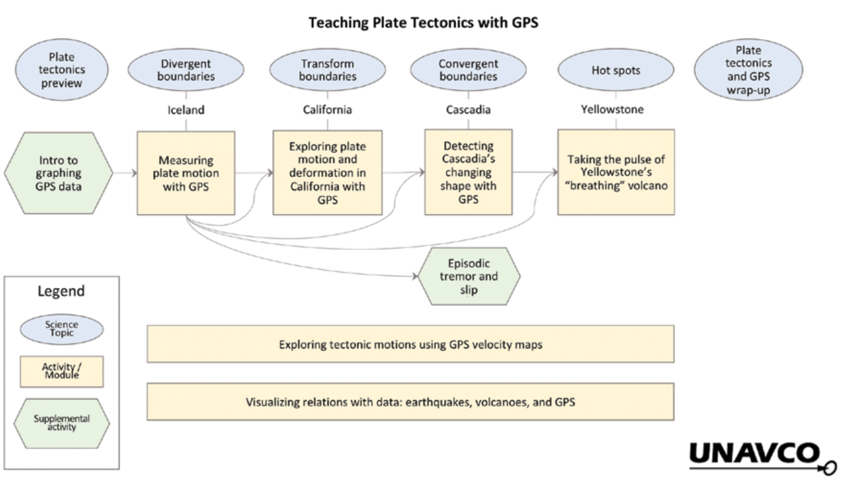

Figure 3. A learning sequence of classroom activities from UNAVCO that allows students to discover plate tectonic motions within the context of GPS data collected from worldwide networks. Combined with earthquake, volcanic, and other Earth science data, jigsaw-strategy and problem-based-learning, modules explore multiple lines of scientific evidence leading to a connection between the theory of plate tectonics to current motion of the tectonic plates.

website: lesson modules and activities, hands-on demonstrations, animations, teacher guides, tutorials, web-based data exploration tools, and online interactives. Module and activity lessons feature best-practice approaches that use student-centered inquiry-based teaching methods, data-rich explorations of an Earth science topic, and math and computational skills, (Figure 3) (NRC, 2012). As shown in Tables 1 and 2, the UNAVCO geodesy learning sequence falls within the fundamental concepts students should know on Earth-related topics from the Earth Science Literacy Principles (Earth Science Literacy Initiative, 2009). The learning resources are three-dimensionally aligned to NGSS and support many NGSS performance expectations.

Turning plate tectonics into a theme of discovery rather than a historical, fait accompli, the UNAVCO geodesy learning sequence guides learners through data-rich activities to discover the types of plate boundaries and motions. One suggested sequence of activities begins with "Measuring plate motion with GPS: Iceland" (unavco.org/education/resources/modules-and-activities/gps-measuring-plate-motion/gps-measuring-plate-motion.html). This activity begins with a demonstration on how GPS works as a satellite and ground system. The lesson guides students to learn how to interpret GPS time series graphs, applying math skills to calculate the horizontal components of velocity, then draw the components as velocity vectors on a map and add the vectors to create a total horizontal velocity vector. They apply their observational skills to discover that the Mid-Atlantic Ridge is rifting Iceland, extend their understanding by exploring motion vectors in the context of global plate tectonics, and complete their activity through an assessment.

In the activity, "Exploring plate motion in California with GPS" (unavco.org/education/resources/modules-and-activities/gps-california-plate-motion/gps-california-plate-motion.html), students learn how to find GPS time series plots on the UNAVCO website, then follow, analyze, and interpret data from multiple GPS stations in California. Students develop explanations of the relative transform motion between the plates in the San Andreas fault zone then expand their interpretation skills by detecting and measuring the magnitude of a recent earthquake in GPS time series plots. The modules, "Detecting Cascadia's Changing Shape with GPS" (unavco.org/education/resources/modules-and-activities/cascadia-changing-shape/cascadia-changing-shape.html) and "Taking the pulse of Yellowstone's "breathing" volcano: Problem-based learning in America's first national park" (unavco.org/education/resources/modules-and-activities/gps-yellowstone/gps-yellowstone.html) present multiple lines of evidence to explore subduction and hotspots, respectively. Instructors can choose components or the complete suite of visual, animations, hands-on, and data-investigations.

Two streamlined activities "Exploring tectonic motions using GPS velocity maps" (unavco.org/education/resources/modules-and-activities/exploring-tectonic-motions/exploring-tectonic-motions.html), "Visualizing relationships with data: Exploring plate boundaries with earthquakes, volcanoes, and GPS data" (unavco.org/education/resources/modules-and-activities/visualizing-relationships-with-data/visualizing-relationships-with-data.html), provide students with opportunities to apply cross-cutting concepts of patterns, scale, and stability & change to analyze and interpret multiple types of Earth science data displayed on maps in the UNAVCO Velocity Viewer or printed posters. To view examples of curricular sequences that integrate GPS-focused data activities with other geophysical data sources, such as earthquake and volcano data, two units from the Diversity & Innovations in Geoscience (DIG) Texas Blueprints in their Dynamic Earth, Plate Tectonic Processes (serc.carleton.edu/dig_blueprints/units/tectonics.html) and "Plate Tectonics: Earth in Motion" (serc.carleton.edu/dig_blueprints/units/earth_beneath.html) combine many of the UNAVCO activities with lessons available from other projects to create complete curricular units. Additional teaching materials from the GEodesy Tools for Societal Issues (GETSI) project (serc.carleton.edu/getsi/index.html), led by UNAVCO, feature geodetic data and quantitative skills applied to societally important issues (climate change, natural hazards, water resources, environmental management). While the learning activities are geared toward college-level instruction, many ancillary materials provide supplements to secondary-level instruction.

Videos, animations, and hands-on demonstrations available from UNAVCO and others provide engaging resources to enhance classroom activities. For example, the NASA YouTube, Looking Down a Well: A Brief History of Geodesy (youtube.com/watch?v=_Cj1vgmXr5M), provides a basic understanding of geodesy. Hands-on demonstrations, such as Science with Flubber: Glacial Isostasy (unavco.org/education/outreach/demonstrations/science-with-flubber-glaciers/science-with-flubber-glaciers.html), are an effective way for learners to experience geoscience processes and the geodetic techniques used to measure these processes.

Table 1. Geodesy connections to Earth Science Big Ideas and Literacy Principles

Theme	Earth Science Big Idea & Literacy Principle
A. Scientific inquiry / active research	E-1. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.
B. Complex systems	E-3. Earth is a complex system of interacting rock, water, air, and life.
C. Continuous change	E-4. Earth is continuously changing.
D. Human interactions	E-8. Natural hazards pose risks to humans.

Table 2. Geodesy Connections to the Next Generation Science Standards / UNAVCO Secondary Education Resource alignment to NGSS

Performance Expectations

MS-ESS2-2: Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.

MS-ESS2-3: Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.

HS-ESS1-5: Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

Science and Engineering Practices

- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)

Disciplinary Core Idea

- ESS2.B: Plate Tectonics and Large-Scale System Interactions: Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart. [Grade 8]
- ESS3.B: Natural Hazards: Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. [Grade 8]
- ESS3.B: Natural Hazards: Natural hazards and other geological events have shaped the course of human history by destroying buildings and cities, eroding land, changing the course of rivers, and reducing the amount of arable land. [Grade 12]

Cross-Cutting Concepts

- Patterns: Graphs, charts, and images can be used to identify patterns in data. (MS-ESS3-2)
- Scale, proportion, and quantity: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. (MS-ESS2-2)
- Stability and change: Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible

Summary

GPS as a commonly used technology provides a connection to the broader application of geodesy to the Earth sciences. Advances in geodetic, networking, and communication technologies have led to societally relevant Earth science discoveries. The long-term installation of GPS sites throughout the Americas as part of the PBO, COCONet, and TLALOCNet observatory networks provide students unprecedented access to ready to use GPS data. Data available through Open Topography provide students with three-dimensional imaging of Earth's surface. A broad suite of educational resources support NGSS goals by providing GPS datasets in an Earth Science context which students can use to analyze and interpret data. The variety of resources available online for free provide educators and their students a range of learning experiences from in-depth investigations to brief highlights of geodesy and geodetic applications to explore our changing planet.

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References

Earth Science Literacy Initiative. 2009. "Earth Science Literacy Principles." Earth Science Literacy Initiative. Retrieved from earthscienceliteracy.org

NASA. 2017. NASA | Looking Down a Well: A Brief History of Geodesy. Retrieved from youtube.com/watch?v=_Cj1vgmXr5M

National Research Council (NRC). 2012. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press. doi.org/10.17226/13165

National Research Council. 2013. Next generation science standards: For States by States. Volume 1: The standards. Washington, DC: The National Academies Press. doi.org/10.17226/18290

Science Education Resource Center (SERC). 2017. Teach the Earth, the portal for Earth Education: Teaching Geodesy. Retrieved from serc.carleton.edu/NAGTWorkshops/geodesy/index.html

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