Section 3: Science

Section 3: Science

This Country Coordinator Implementation Guide has been developed as a resource guide to assist GLOBE Country Coordinators in the operations and implementation of The GLOBE Program in their countries. Section 3: Science contains:

1. Summary of GLOBE Science Spheres and Protocols
2. Protocol Deactivation and New Protocol Processes
3. Science Objectives and Use of GLOBE Data
4. GLOBE's Approach to Ensuring Data Quality
5. Measurements and Instruments
6. Instrument Specifications and Suppliers
7. GLOBE International Science Network (GISN)
8. Science Opportunities

1. Summary of GLOBE Science Spheres and Protocols

The GLOBE Program provides protocols developed by the scientific community and specifications for the instruments required to take environmental measurements in the following scientific discipline areas: Atmosphere (Atmosphere Investigation Area), Biosphere (Land Cover/Biology Investigation Area), Hydrosphere (Hydrology Investigation Area), Pedosphere (Soil Investigation Area). To gain a better understanding of how the Earth works as a unified system, groups of protocols, called bundles, have been assembled by the Science Working Group to promote understanding of how the Atmosphere, Biosphere, Hydrosphere, and Pedosphere together form an interconnected system with many interactions.

The GLOBE Program supports students, teachers and scientists to collaborate on inquiry-based investigations of the environment and the Earth system, working in close partnership with two U.S. agencies: the National Aeronautic and Space Administration (NASA) and their Earth science missions and the National Science Foundation (NSF). This gives the entire GLOBE community access to professional scientists around the world and exposes students to programs that are on the cutting edge of Earth system science research. GLOBE promotes focused activities and campaigns around the NASA Earth science missions and has established the GLOBE International STEM Network (GISN), an international network of scientists and other STEM professionals that work with GLOBE students around the world conducting science.

Globe Science Protocols

Earth is a complex, dynamic system we do not yet fully understand. Our planet is changing on all time and space scales, and GLOBE hopes to engage students in exploring Earth systems locally, regionally, and globally to contribute to understanding Earth system interactions. We

need to understand the Earth's spheres as a single connected system. GLOBE protocols fall within four spheres, and GLOBE Protocol Bundles have been assembled to understand how they together form an interconnected system (Earth as a System).

1. **Atmosphere:** Explore different aspects of our planet's weather and climate
   - Students monitor atmospheric conditions every day. All measurements may be taken at an appropriate study site adjacent to the school. Many measurements are taken within one hour of local solar noon, although some measurements may be taken at other times throughout the day. Instruments that measure daily high, low, and current temperatures and amounts of precipitation can be installed at the study site. Other instruments may be brought to the study site as needed, and other instruments are used in the classroom.
2. **Biosphere:** Explore cycles of plant life
   - Students assess the land cover of a 15 km by 15 km area (their GLOBE Study Site) centered at or near their school. Ultimately, they track changes to land cover over time by comparing ground-based measurements to satellite imagery data acquired in different years.
3. **Hydrosphere:** Explore water properties including impacts on animal life (mosquitos and macroinvertebrates)
   - For all protocols except freshwater macroinvertebrates, students take weekly measurements of surface water properties at a near-by water body (river, stream, bay, ocean, lake, pond, etc.) that serves as their hydrology study site. Students may also collect data about the types and abundances of freshwater Macroinvertebrates, marine invertebrates and mosquitoes.
4. **Pedosphere (Soil):** Explore soil physical and chemical properties
   - Students measure soil moisture and temperature at a study site near their school. Students characterize the top meter of soil at this and other sample sites, use an infiltrometer to measure the rate at which water soaks into the soil and a frost tube that provides climate information about frozen soils.
5. **Earth as a System:** Understanding how the Atmosphere, Biosphere, Hydrosphere, and Pedosphere together form an interconnected system with many interactions. Figuring how each sphere interacts with one another allows us to make more accurate predictions within each individual sphere.
   - To study Earth as a System, GLOBE Protocol Bundles have been assembled to investigate system interactions more holistically by measuring various interactions in the local community. Students explore bundles like the Agriculture Bundle, Air Quality Bundle, ENSO Protocol Bundle, Mosquito Protocol Bundle, Ocean Bundle, Rivers and Lakes Protocol Bundle, Soil Bundle, Urban Protocol Bundle, Water Cycle Bundle, Water Quality Bundle, and Weather Bundle.

You can find the GLOBE Science Protocols and Bundles on the GLOBE Website.

Location

Summary: At all sites where GLOBE measurements are taken, the latitude, longitude, and elevation are determined to within 30 meters.

Description: Students determine latitude, longitude, and elevation using hand-held Global Positioning System (GPS) receivers.

Instrument: GPS receiver

2. Protocol Deactivation and New Protocol Process

The objective of deactivating protocols is to conserve financial resources and help focus community efforts on a slightly narrower set of protocols that best meet the community's needs. The Science Working Group (SWG) evaluated existing protocols to determine if any should be deactivated. SWG developed criteria based on science, education, implementation, and society (environmental awareness) criterion. They then assessed each protocol against these criteria, presented initial results at the 2020 GLOBE Annual Meeting, gathered perspectives during a community comment period, revised their findings, and documented their recommendations.

The process for deactivation includes 1) clear community notification, 2) removal of data entry options for deactivated protocols (and associated maintenance in DIS and for data retrieval options), and 3) a way to keep the deactivated protocols and datasets on the GLOBE Website so that they are available to the community. Deactivation does not need to be permanent—GLOBE can update and reactivate them if it is in the community's best interest.

The following protocols are planned to be deactivated and are marked by asterisks in this document: Surface ozone, lilac phenology, ruby throated hummingbird, mosquito larvae (in Teacher's Guide), soil moisture sensor, and optional salinity titration.

The SWG currently is reviewing and updating the "Guidelines for Proposing New GLOBE Measurement Protocols."

3. Science Objectives and Use of GLOBE Data

The table below was generated earlier in the program to list some of the ways in which GLOBE student data have been used by previous Principal Investigators (PIs) or could be used by future PIs as well as scientists external to GLOBE. Additionally, environmental data almost always have additional uses beyond those originally planned. Some of these uses arise long after the data are collected. Therefore, taking Earth science data has both current and future value.

GIO plans to update this table to reflect the current sphere groups and include all current protocols.

INVESTIGATION	PURPOSES OF DATA
Atmosphere	Help scientists improve weather forecasting, predictions of climate change, and interpretation of satellite observations.
Aerosol	• Provide calibrated ground-based observations to help assess the performance of space-based instruments and to fill in the global views of aerosol distributions provided by satellite remote sensing; • Detect the presence of dust, smoke, soil particles, and other aerosols and help scientists track their movement around the world.
Air Temperature, Liquid and Solid Precipitation, and Relative Humidity	• Provide a denser network of observations than is available using only official weather stations; • Provide finer resolution data crucial for investigating localized variations (e.g., urban heat islands, microclimates); • Augment data needed for regional forecasts and climate records in areas of the world where there are few official weather stations.
Clouds and Contrails	• Help tie new measurements of clouds by automated sensors to long-term historical data records of ground-based observations; • Help to identify cloud type more accurately than is possible by remote sensing; • Contribute to determination of how cloud climatology may be changing (a major issue in assessing climate change); • Contribute to improved interpretation of satellite observations of Earth's radiative balance; • Provide one of the only sources of ground-based observations of contrails, which are challenging to detect by remote sensing due to their small width.
Combined Atmosphere, Surface, & Soil Temperature	• Help scientists calculate the rate of heat exchange between the atmosphere and the soil, and the potential for decomposition and soil weathering (see also entries for Atmosphere Temperature & Soil Temperature).
****Ozone**	• Identify areas of high and low ozone concentrations and the times of year and weather conditions when they occur; • Help scientists interpret satellite observations of tropospheric ozone; • Provide quantitative measurements of ozone to help local agencies determine the extent of widespread pollution episodes.
UV-A	• Provide calibrated ground-based observations to help assess the performance of space-based instruments and to fill in the global views of UV distributions provided by satellite remote sensing; • Provide time series and high spatial density views of the effects of clouds on the distribution of UV-A radiation on the ground.
Water Vapor	• Provide calibrated ground-based observations to help assess the performance of space-based instruments and to fill in the global views of water vapor distributions provided by satellite remote sensing; • Provide time series of water vapor to supplement non- geosynchronous space-based observations, especially in places where other ground-based instrumentation does not exist.

INVESTIGATION	PURPOSES OF DATA
Biosphere	Help scientists study the terrestrial components of the energy, water, carbon, nitrogen, and other cycles of the Earth system. Help in the understanding of local climate and watersheds.
Biometry	• Help scientists determine the amount of biomass present; • Help validate land cover classifications of sample sites.
Change	Determine land cover change in support of the study of changes in local climate, watersheds, and the cycles of the Earth system.
Fire Fuel: Fuel loadings	• Determine the spread rate and intensity of wildland fires; Calculate the amount of smoke emissions from the fire; • Compute the amount of carbon added to the atmosphere due to a fire; • Calculate the carbon reserves in the dead biomass.
Fire Fuel: Fuel characteristics	• Calculate fuel consumption and soil heating; • Estimate habitat for organisms depended on coarse woody debris; • Compute tree mortality from fire.
Mapping	Guide systematic observation of land cover classification.
Sample Site	Classify land cover for comparison with maps derived from satellite remote sensing.

INVESTIGATION	PURPOSES OF DATA
Hydrosphere	Improve the monitoring of surface waters both inland and along the coasts of oceans and seas.
Transparency	Determine how far light can penetrate the water and support the growth of algae and submerged aquatic vegetation.
Alkalinity	Help determine the vulnerability of fresh waters to changes in pH from inputs of acidity.
Conductivity	• Determine the overall loading of salts and other compounds dissolved in freshwater; • Help determine the usability of fresh water for different purposes.
Dissolved Oxygen	• Determine what animals can live in the water; • Help scientists determine the mixing of air and water at the water's surface.
Freshwater Macroinvertebrates	• Help determine the biodiversity of a freshwater ecosystem; • Help scientists determine the overall state of a water body.
Marine Invertebrates	• Help determine the biodiversity of coastal beach ecosystems; • Help determine the overall state of coastal beach ecosystems; • Test the hypothesis that the distributions of marine animals will change with climate change.
Nitrates	• Help scientists determine the potential uses of water; • Help determine the effects of inputs of nutrients from surrounding areas on a water body.

INVESTIGATION	PURPOSES OF DATA
pH	• Help scientists determine what can live in the water, both animals and plants; • Track the mixing of waters in estuaries and along coasts; • Help scientists relate water quality to surrounding soil and geology and to the pH of rain and snow melt.
Salinity	• Track the mixing and source of waters in estuaries and along coasts; • Help track the state of saline inland waters.
Temperature	• Determine the overturning of lakes; • Track the mixing of waters in estuaries and along coasts; • Help determine evaporation rates; • Help scientists determine what can live in the water.

INVESTIGATION	PURPOSES OF DATA
Phenology	Help scientists detect the nature and extent of climate change and its effects on plants and animals.
Arctic Bird Migration	Determine changes in Arctic bird migration as both an indicator and response to global and regional climate changes.
Green-up, Green-down Budburst, **Lilacs, Phenological Gardens	• Delineate the length, start and end of the growing season; • Help scientists interpret satellite observations of greenness.
**Hummingbirds	Determine changes in hummingbird migration as both an indicator and response to climate changes and land cover.
Seaweed Reproduction Phenology	Determine changes in seaweed reproduction as both an indicatorand response to climate changes.

INVESTIGATION	PURPOSES OF DATA
Pedosphere (Soil)	Help scientists understand soils and how they function, change, and affect other parts of the ecosystem, such as climate, vegetation and hydrology.
Bulk Density	• Help in the interpretation of soil temperature and moisture measurements; • Help determine soil porosity (volume of empty space for air and water) in combination with Particle Density; • Provide some indication of mineral versus organic content of soils; • Help understand the ability of roots or organisms to penetrate the soil horizon.
Field Characterization (structure, color, consistence, texture, and the presence of rocks, roots, & carbonates)	• Help scientists create soil maps; • Help track the global carbon cycle; • Provide information for interpretation of soil temperature and moisture measurements; • Help to interpret the history of the soil; • Provide information to determine the appropriate uses of a soil.

INVESTIGATION	PURPOSES OF DATA
Fertility	• Indicate the suitability of the soil for supporting growth of crops and other plant life; • Provide indication of nitrate and phosphate inputs to water bodies.
Moisture	• Help track the water cycle in the Earth system; • Help determine the times of plant sprouting and growth; • Help scientists improve weather and climate prediction; • Help understand the potential for decomposition and weathering of soil; • Compare with existing models and data sets for validation and for local detail.
Particle Density	• Help determine soil porosity (volume of empty space for air and water) in combination with Bulk Density; • Provide some indication of mineral versus organic content of soils; • Help in the interpretation of soil temperature and moisture measurements.
Particle Size Distribution	• Determine the mixture of sand, silt, and clay particles in soil; • Provide information to help determine the appropriate uses of a soil; • Provide information for interpretation of soil temperature and moisture measurements. • Provide critical information for mathematical modeling of water, energy, and carbon dynamics in soils.
pH	• Help determine what can grow in the soil; • Help determine the effect on the pH of water flowing through soil; • Give insight into other chemical properties in the soil.
Temperature	• Provide new data for tracking climate and annual cycles; • Help scientists determine times of insect emergence and plant sprouting; • Help determine heat transport in near-surface soil; • Help understand the potential for decomposition and weathering of soil; • Help scientists monitor the energy balance of the Earth system.

4. GLOBE's Approach to Ensuring Data Quality

Training

GLOBE requires training to ensure quality and consistency in data collection.

Teacher training

GLOBE teachers are trained to understand and implement the protocols through workshops or other training forums. The training is held in a person-to-person format and involves hands-on conduct of the protocol by the trainee. Training is delivered by GLOBE Trainers. Teachers can also complete required online protocol eTraining modules and assessment tests on the GLOBE Website as approved by their Country Coordinators (CCs). CCs increasingly have been employing a hybrid approach to teacher training, with teachers completing some eTraining modules prior to a training workshop and then completing additional eTraining modules after the completion of the workshop.

Trainer training

It is important to have GLOBE Trainers leading GLOBE workshops who are knowledgeable in The GLOBE Program with a firm understanding of protocols, procedures, quality of data being collected and recorded, and who can guide teachers in how to implement GLOBE in their educational setting. These GLOBE Trainers must be able to educate as well as support teachers to ensure GLOBE protocols are conducted properly. Currently there are two certified types: GLOBE Trainers and GLOBE Mentor Trainers. The GLOBE Program has developed a GLOBE Trainer Process that provides opportunities for individuals worldwide to become GLOBE Trainers.

Best Practices Guides

In addition to training, written step-by-step instructions are given in the Teacher's Guide for each science protocol, providing rigorous guidance on best practices for making observations. The science protocols are intended to be implemented as instructed, using instruments that meet certain specifications in order to ensure data accuracy worldwide. A list of instruments as well as instrument suppliers are available below in number 5 and 6.

Completeness

A measurement must contain all required elements before it can be submitted and stored in the GLOBE database.

Range and Logic Checks

Observations submitted to GLOBE must pass range and logic checks before the data are allowed in the database. Future time cannot be entered and minimum values cannot be greater than maximum values. Instant feedback is provided at the time of data entry to indicate if the value(s) pass checks and likewise will be stored in the GLOBE database. For example, the enforced maximum value for dark voltage in the aerosol protocol is 0.02. If a GLOBE participant tries to enter a value of 0.03, which exceeds the maximum allowed value, they will get an error message and not be allowed to submit the data. The data entry form does not default to a value (e.g., 0.02) when an error message is triggered; a valid data value must be entered by the participant in order to submit correctly to the database.

Location Data

Location data has become more accurate over time. From 1995-2014, GLOBE members had two options to enter the latitude and longitude coordinates associated with their measurement site: (1) GPS or (2) other. The "other" category includes techniques such as estimating latitude and longitude coordinates from a map. Not all techniques categorized as "other" are known. GLOBE requested five decimal places for all reported latitude and longitude coordinates to achieve high and consistent spatial accuracy. Four significant digits after the decimal place implies 100-meter accuracy; five digits implies 5-meter accuracy.

After 2014, GPS is the standard for obtaining latitude and longitude coordinates. When the GLOBE data entry app was used, the measurement is associated with the user's GLOBE site's latitude and longitude.

When using The GLOBE Program's app, GLOBE Observer (described in Section 5: Technology), a person's location is automatically located on a map. The Land Cover and Trees tools in the app have a button users can press to refresh their automatic GPS location (via their cellular device) to potentially improve the location accuracy. If users judge that their device places their location incorrectly as indicated by a red pin on the map, users have the option to manually adjust their location on the map.

Photograph Approval

Photographs submitted through The GLOBE Program's app, GLOBE Observer are screened automatically before being added to the public GLOBE database. Photographs containing inappropriate content, faces, or personally identifiable information (e.g., automobile license plate numbers) are removed or blurred.

5. Measurements and Instruments

GLOBE environmental measurements are categorized into four study areas: Atmosphere, Biosphere, Hydrosphere and Pedosphere (Soil).

The following pages summarize the current specifications for the required instruments for the protocols listed. The GLOBE measurements and instruments are differentiated by skill level. The Instrument Landing page, www.globe.gov/en/do-globe/research-resources/globe-equipment, allows the user to explore all the instruments associated with each sphere.

This information can also be found on the GLOBE Website at www.globe.gov/sda/tg/toolkit.pdf. The Science Working Group is currently updating the instrumentation information in this document.

MEASUREMENT	INSTRUMENT	SKILL LEVEL
ATMOSPHERE		
Aerosols	Sun photometer, digital voltmeter	Middle, Secondary
Air Temperature Maximum/ Minimum & Current	Maximum/Minimum thermometer, Calibration thermometer, Instrument shelter	All
Automated Weather Station Protocols	Weather station with a data logger attached to a suitable computer, calibration thermometer, rain gauge	Middle, Secondary
Digital Multi-day Maximum/ Minimum Air & Soil Temperatures Protocol	Digital multi-day maximum/minimum thermometer, calibration thermometer, soil thermometer, instrument shelter	All

MEASUREMENT	INSTRUMENT	SKILL LEVEL
Barometric Pressure	Aneroid barometer or altimeter or digital barometer	All
Cloud Cover and Contrails/Type	Cloud chart	All
Precipitation, Liquid	Rain gauge	All
Precipitation, Solid	Snow board, Rain gauge, Snow depth pole	All
Precipitation pH	pH indicator paper	Primary
	pH meter, three pH buffers (7, 4, and 10)	Secondary
Relative Humidity	Digital hygrometer, Thermometer (calibration or maximum/minimum)	All
	Sling psychrometer, instrument shelter, calibration thermometer	All
Surface Temperature	Infrared thermometer (IRT)	Middle,
****Surface Ozone**	Ozone test strip scanner, ozone chemical test strips, ozone measurement station, sealable bags, wind direction device	All
Water Vapor	GLOBE/GIFTS Water Vapor Instrument	Middle, Secondary

MEASUREMENT	INSTRUMENT	SKILL LEVEL
BIOSPHERE		
Biometry Canopy Cover Ground Cover Tree Circumference Tree Height	Clinometer and densiometer (both may be student- made), 50m tape measure	All
Biometry Grass Biomass	Drying oven (plants)	All
Land Cover Mapping	Remote sensing image, MultiSpec software	All
Species Identification	Dichotomous keys	All
Budburst	Local plant identification guide	All
Green-Up	Local plant identification guide, compass, camera, mm ruler	All
Green-Down	Local plant identification guide, compass, camera, GLOBE Plant Color Guide	All
Latitude and Longitude of study sites	Smartphone	All

MEASUREMENT	INSTRUMENT	SKILL LEVEL
HYDROSPHERE		
Alkalinity	Water Alkalinity kit	Middle, Secondary
Dissolved Oxygen	Dissolved oxygen kit	Middle, Secondary
Electrical Conductivity—Fresh Water Sites Only	Total dissolved solids (conductivity) tester, calibration solution	All
Freshwater Macroinvertebrates	Latex gloves, clear plastic jars, small plastic vials, plastic squirt or spray bottles, 20 mL bulb, basting syringes, eyedroppers, plastic or metal forceps, magnifying glasses or loupes, 5 L white buckets, white trays, sub-sampling tray, 0.5 mm sieve (or smaller), sieve between 2-5 mm, locally applicable macroinvertebrate identification keys, specimen bottles with preservation solution (70% ethanol) and tight lids (optional), 1 x 1 m quadrat (optional)	Middle, Secondary
Nitrate	Water Nitrate kit	Middle, Secondary
Salinity—Brackish and Salt Water Sites	Hydrometer, 500 mL clear plastic graduated cylinder, organic liquid-filled thermometer	All
Salinity Titration Method—Brackish and Saltwater Sites	Salinity kit	Middle, Secondary
Transparency—Deep Water Sites Only	Secchi Disk, 5 m rope	All
Transparency—Surface Water	Turbidity tube	All
Water pH	pH indicator paper	Primary
	pH meter, three pH buffers (7, 4, and 10)	Middle, Secondary
Water Temperature	Organic liquid-filled thermometer	All

MEASUREMENT	INSTRUMENT	SKILL LEVEL
PEDOSPHERE (SOIL)		
Automated Soil Moisture and Temperature Station Protocols	Soil Moisture/ Temperature Station attached to a weather station with a data logger attached to a computer, Calibration thermometer	Middle, Secondary
Automated Soil and Air Monitoring Protocol	4-Channel data logger and software, 1 Air temperature sensor, 3 soil temperature sensors, data logger-to-computer interface cable, watertight box, Desiccant, Instrument shelter	Middle, Secondary

MEASUREMENT	INSTRUMENT	SKILL LEVEL
Bulk Density	Metal sampling cans or other containers, drying oven, graduated cylinder, sieve	All
Digital Multi-Day Soil Temperatures Protocol	Digital Multi-day Maximum/Minimum thermometer, Calibration thermometer, Soil thermometer	All
Infiltration	Dual ring infiltrometer	All
Particle Size Distribution	500 mL graduated cylinders, soil dispersing reagent (Sodium Hexametaphosphate), 250 mL or larger containers, thermometer, 100 mL graduated cylinder, meter stick	
pH	pH paper or meter and pH buffers, 100 mL beaker, balance	
Soil Characterization—Field Slope, Horizon Depth, Structure, Color, Consistence, Texture, Carbonates	Clinometer, camera, meter stick, color chart, sample cans, other containers, shovel or auger	All
Soil Fertility	Soil NPK kit	
Soil Moisture	Balance, Meter stick, Drying oven (soils), Sample Cans Other soil containers, Auger (depth sampling), 50 m tape measure (transect)	All
Soil Moisture Meter	Soil moisture meter, soil moisture sensors, Gypsum block, PVC piping	Secondary
Soil Particle Density	100 mL volumetric or Erlenmeyer flask with stoppers, heat source, thermometer, balance	All
Soil Temperature	Soil thermometer	All

6. Instrument Specifications and Suppliers

Specifications

All GLOBE instrument specifications represent the minimum specifications necessary to collect scientifically valid data. GLOBE schools may use instruments that meet or exceed these specifications. For example, the GLOBE specifications for pH paper call for a range of 2 to 9 pH units. A pH paper with a range of 1 to 14 exceeds specifications and may be used by GLOBE schools. GLOBE instrument specifications can also be found in the GLOBE Teacher's Guide (Pages 12 through 24) at: www.globe.gov/sda/tg/toolkit.pdf.

CCs are responsible for finding instruments that meet the minimum specifications necessary for data collection.

The GLOBE Implementation Office (GIO) has sent the GLOBE Instrument Specifications to potential instrument suppliers. A number of suppliers have provided information sheets

with catalog/ordering numbers and prices of items which they offer, and which the suppliers state meet GLOBE specifications. This information is available on the GLOBE Website in the "Resource Room" under the "Scientific Instrument and Equipment Suppliers" link or at: www.globe.gov/fsl/html/templ.cgi?inst_suppliers&lang=en&nav=1

The GLOBE Program does not endorse any of these suppliers but hopes that this information will assist GLOBE schools in the purchase of instruments needed to participate in the program. Prices and other information from the suppliers may change, so it is important to contact any supplier for the latest information prior to ordering instruments.

Regional Equipment Suppliers links are also available.

- Africa
- Asia and Pacific
- Europe and Eurasia
- Latin America and Caribbean
- Near East and North Africa
- North America

CCs should notify GIO of any local or regional equipment suppliers that they or their teachers have used or recommend in the purchasing of GLOBE equipment. It is assumed that the equipment offered by these regional equipment suppliers meets GLOBE instrument specifications.

7. GLOBE International STEM Network (GISN)

The GLOBE International STEM Network (GISN) is the bridge connecting the researchers of today with those of tomorrow. An international coalition of science, technology, engineering, and mathematics (STEM) professionals, members of the GISN work to promote Earth science and education in schools and classrooms. These professionals can act as student mentors for research projects, volunteer as judges for school and virtual science fairs, or serve in other educational relationships with students, teachers, and STEM professionals.

Scientists in the GISN mentor students and teachers, present scientific ideas, and/or collaborate on scientific research. Each relationship between a scientist and a GLOBE school is unique and is determined by the scientist and the school. This relationship can be established in different ways. Here are a few reasons why scientists participate in GLOBE:

Mentor and Inspire: Scientists working with GLOBE have a strong desire to mentor and inspire young minds by interacting with the next generation.

Education and Community Outreach: The GLOBE Program offers an ideal means to partner science and education. The hands-on nature of GLOBE allows students to become involved in authentic scientific research. Since GLOBE relies on a network of partners to implement the program, it is possible to find partners eager to work with scientists' projects or to become partner themselves. These partnerships involve a variety of groups such as satellite missions, university departments, zoos, science centers and museums.

Research Quality Data: All data are collected following scientifically valid protocols, and research scientists work to ensure the accuracy of all measurements. All data reporters have undergone first-hand training.

Spatial and Temporal Coverage: GLOBE has a scientific database extending over 25 years with data in most Earth system science research areas that can be used to supplement standard research data. As of 2022, over 220 million environmental measurements have been collected by students around the world.

Field Campaigns: GLOBE students can collect data related to scientists' research expanding their observation network. For example, GLOBE students have partnered with several NASA Earth science satellite missions to provide measurement data to the missions.

Contribute to Science Education: GLOBE students want to be a part of real world, cutting edge science that matters to them, their community and scientists. GLOBE scientists contribute to science education in a unique way that can have a lasting impression on student interest in science as well as scientific literacy.

International Reach: The international nature of GLOBE provides a unique opportunity for scientists to add an international, or even global, component to their research.

Name Recognition: Established in 1994, GLOBE is an internationally recognized and respected program in the realm of science education.

Ways Scientists Can Participate in GISN

Each relationship with a GLOBE student is unique and is set by the scientist and school. GISN members are mentors and role models for students**,** and scientists participate at a level that is appropriate to their skills, resources, availability, and interest.

Inspire:

This "Inspire" level of involvement in GLOBE is typically incidental to a scientist's regular work and may fulfill outreach requirements of the scientist's employment. Options under this level include:

- Visit a GLOBE school to do an activity
- Write blogs about science topics and experience related to GLOBE and their field of expertise on the GLOBE Blog
- Judge GLOBE International Virtual Science Symposium projects
- Judge local, in-person GLOBE science fairs

Engage:

The "Engage" level of involvement in GLOBE involves a sustained effort in the network. The scientist is expected to secure institutional support for this level of involvement or to be self-supported. Options under this level include:

- Partner with a GLOBE teacher or school
- Use GLOBE data in their research

Educate:

The "Educate" level of involvement in GLOBE involves the scientist taking an initiative toward a dedicated effort that will promote learning among the GLOBE community. Support for this level of involvement is expected from an institution or organization that is sponsoring a student science fair or from a GLOBE Partner. Options under this level include:

- Sponsor a GLOBE student science fair
- Affiliate with a GLOBE Partner
- Become a GLOBE Trainer

Lead:

The "Lead" level of involvement in GLOBE will require significant interactions with GLOBE management at the country and international levels consistent with sponsorship arrangements. Support for this level is expected to come through grants made in response to proposals; the sponsors of GLOBE may occasionally or periodically solicit such proposals. Support for this level also may be a significant component of the engagement and public outreach activity of a science mission or institution and supported as part of a partnership agreement with GLOBE. This will include reporting requirements. Options under this level include:

- Assume responsibility for a GLOBE protocol (Guidelines for Proposing New Protocols)
- Involve GLOBE teachers and students in scientific research
- Assume responsibilities for GLOBE student research campaigns or Intensive Observation Periods (Guidelines for Proposing a New Campaign or IOP)
- Become a GLOBE Partner

8. Science Opportunities

Research Process

GLOBE provides students the opportunity to participate in the scientific research process and provides details on the nine steps in the scientific process and the GLOBE Science Process.

GLOBE Student Research Campaigns and Intensive Observation Periods

GLOBE has active field measurement Student Research Campaigns and Intensive Observation Periods (IOPs) where students, teachers, and scientists around the world can collaborate. Available at country, regional and global scales, GLOBE hosts a variety of different initiatives to foster cooperation between the GLOBE community and professional scientists. All GLOBE Campaigns and IOPs take an inquiry-based approach to research that emphasizes hands-on learning and authentic science experiences.

Find more information about our current GLOBE Measurement Campaigns and IOPs Website.

Details on proposing a new Campaign or IOP are located here. GLOBE accommodates two to three Global Measurement Student Research Campaigns or IOPs per year, while it is

up to the country and/or region in accommodating Campaigns and IOPs on the country or regional level.

NASA Earth Science Satellite Mission Connections

GLOBE also provides opportunities for students to participate in GLOBE Campaigns and IOPs related to NASA Earth science satellite missions. Following are some examples of how GLOBE has collaborated with satellite missions. Please look here for current satellite mission collaborations.

Geostationary Operational Environmental Satellites—R Series (GOES-R)

The Geostationary Operational Environmental Satellites—R Series (GOES-R) is the next generation of geostationary Earth-observing systems. The advanced spacecraft and instrument technology employed by the GOES-R series provide significant improvements in the detection and observations of environmental phenomena that directly affect public safety and protection of property. The GOES-R program is a collaborative development and acquisition effort between the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA).

Soil Moisture Active Passive Mission (SMAP)

The NASA Soil Moisture Active Passive (SMAP) Mission provides measurements of soil moisture and freeze/thaw state. The SMAP Mission produces daily maps of soil moisture with global coverage every three days.

The SMAP team is looking for GLOBE Program students to take measurements at their schools. Students can compare remotely sensed SMAP data to the actual soil moisture data they collect at their school locations.

CloudSat

Clouds influence Earth's weather and climate. They bring water from the air to the ground and from one region of the globe to another. Clouds also have a large impact on Earth's radiation budget; even small changes in cloud abundance or distribution could affect climate.

GLOBE students and teachers can collect and enter data that will be compared to CloudSat measurements. CloudSat, in turn, contributes Earth science learning opportunities to lifelong learners and shares the results of CloudSats scientific research mission to improve our understanding of clouds and global climate change.

Global Precipitation Measurement (GPM)

Water participates in many important natural chemical reactions and is a good solvent. Changing any part of the Earth system, such as the amount or type of vegetation in a region or from natural land cover to an impervious one, can affect the rest of the system. Rain and snow capture aerosols from the air. Acidic water slowly dissolves rocks, placing dissolved solids in water. Dissolved or suspended impurities determine water's chemical

composition. Current measurement programs in many areas of the world cover only a few water bodies a few times during the year. GLOBE students provide valuable data to help fill these gaps and improve our understanding of Earth's natural waters.

CALIPSO

Aerosols, both natural and human-caused, can affect weather and climate. Launched on 28 April 2006 along with CloudSat, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite's mission is to study the role that clouds and aerosols play in regulating Earth's weather, climate and air quality. Both satellites fly in formation as a part of the international "A–Train" (Afternoon) constellation. CALIPSO is a collaborative NASA/CNES (Centre National D' Études Spatiales) satellite mission that uses lidar to profile the vertical distribution of clouds and aerosols to determine their role in the heating and/or cooling of Earth. CALIPSO and other A-Train satellites are substantially increasing our understanding of the climate system.

ICESat-2

The Ice, Cloud, and Land Elevation Satellite–2, or ICESat–2, will measure the height of a changing Earth, using technology that takes 10,000 laser pulse measurements per second. ICESat-2 will carry a photon-counting laser altimeter that will allow scientists to measure the elevation of trees, ice sheets, glaciers, and more.

The Trees Around the GLOBE campaign, launched in conjunction with ICESat-2, compares tree height data with ICESat-2 measurements. The tree height data can then be complemented with additional GLOBE protocol data for use in student research.