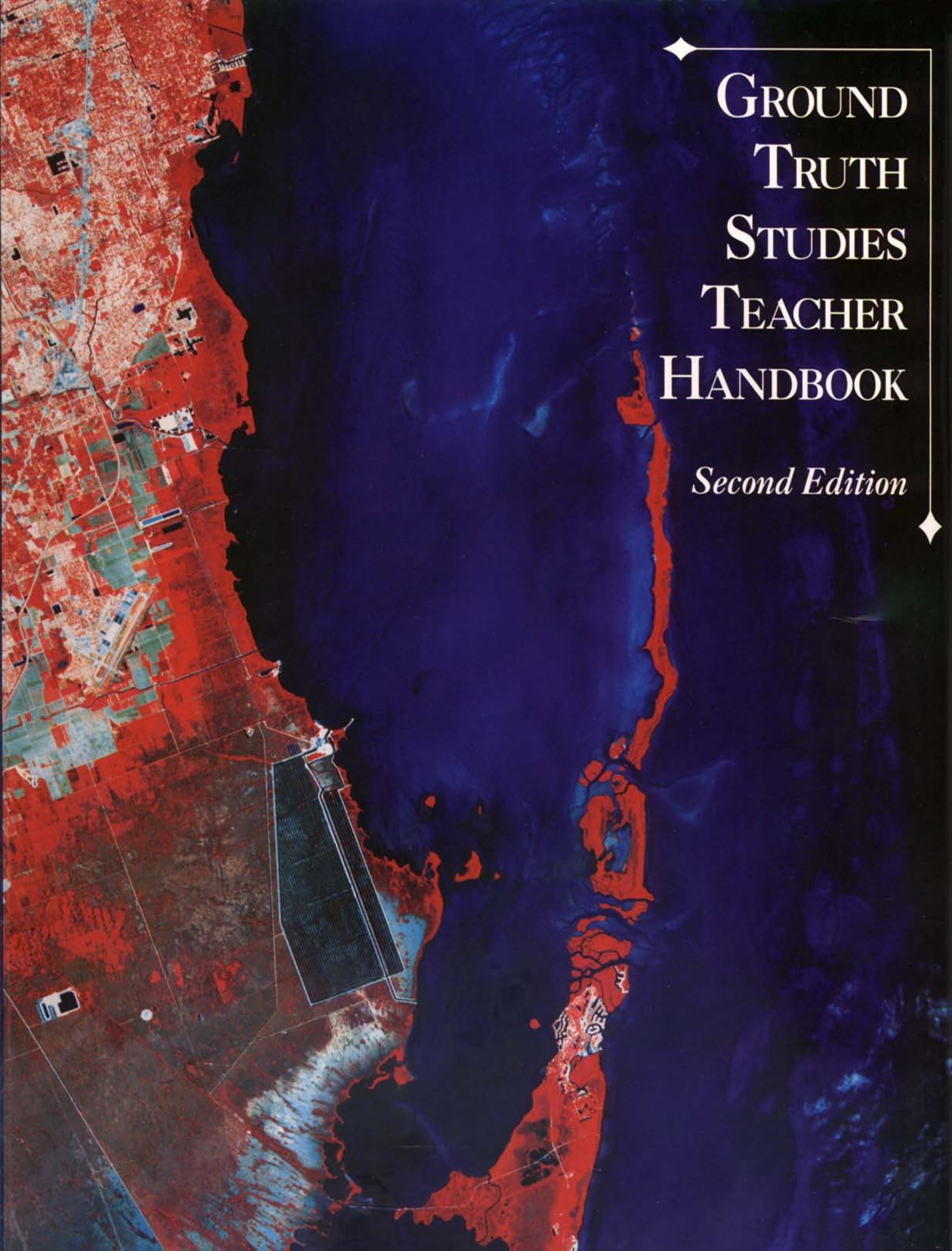
Ground Truth Studies Teacher Handbook

Second Edition



ASPEN GLOBAL CHANGE INSTITUTE

Ground Truth Studies

Teacher Handbook

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✦ Comments Welcome

Ground Truth Studies is an ongoing curriculum development project. The GTS Teacher Handbook *is revised periodically to incorporate teacher evaluations and new approaches. We welcome your comments, criticisms, and suggestions about your experience using GTS activities. Your evaluations will be reviewed each time the Teacher Handbook is revised. Please send your comments to the Aspen Global Change Institute.*

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Preface

Ground Truth Studies is an interdisciplinary activity-based program that draws on the broad range of sciences that make up the study of global change and the complementary technology of remote sensing. Satellite and aerial imagery open a unique window onto the face of the Earth. These images are inviting and, once they become familiar, offer the learner — of any age — a new visual language with direct relevance to local as well as global environmental change. A key element of remote sensing is to go out into the area covered by an image and make observations and measurements. This direct observation or "ground truthing" complements and verifies the remotely-sensed data, hence the title of this book. The *Ground Truth Studies Teacher Handbook* provides supplementary program material for use by both primary and secondary teachers. The Handbook contains an introduction to global change and remote sensing, a generic set of images, a set of student activities, and reference materials.

Critical global change issues which are gaining recognition in this decade — unprecedented biodiversity loss, climate change, and stratospheric ozone depletion — will all remain center stage as we enter the 21st century. A clear and necessary educational challenge is to face these issues with the information to make wise decisions. These issues are rich in the fundamentals of science. Educational approaches which build on the strength of an individual discipline such as biology, while at the same time fostering the integration across disciplines, are required for gaining a grasp of the complex new field of study described as Earth system science. How people interact with the process of global change is not only fascinating, it is becoming central to how we chart our future as a species.

The aim of the *GTS Teacher Handbook* is to explore these global change issues with the aid of the powerful tool of remote sensing. The National Aeronautics and Space Administration describes the role remote sensing will play in gaining new knowledge of how Earth systems work as "Mission to Planet Earth." The range, quantity, and complexity of satellite data require a new commitment to its interpretation and use. The knowledge gained is a critical piece of the puzzle of our dynamic planet and lays the foundation for the development of global environmental policy, such as the international accord for CFC regulation. It can also serve as a guide for making personal decisions that impact one's local environment and, ultimately, the global environment.

The 20th century is perhaps the last century humanity will view the Earth as an *infinite* expanse from which to appropriate the necessary resources for supporting human activity. What we do, from clearing forest cover to growing rice to burning fossil fuels to manufacturing and transporting goods, transforms essential elements of the biosphere. Where are the models to guide us toward a sustainable use of resources in the 21st century? What tools do we have to mitigate our global impacts or to approach whole ecosystems wisely? What is required to approach these questions with even tentative confidence? The challenge of this decade is to assemble the data, the ideas, and the models that transcend the limits of single-disciplinary research and forge new modes of cross-disciplinary research. The educational challenge is to provide approaches that embrace the natural *and* social sciences, and provide the basis for policy and practice that is sensitive to the immediate and long-term needs of our complex, miraculous home planet.

The study of global change is as close as your backyard or school grounds. This Handbook is an invitation to link local environmental conditions to the broader topics of global change.

John Katzenberger
Aspen, Colorado

Introduction

- ***GTS Overview***
- ***How to Use This Book***

Ground Truth Studies

Overview

Ground Truth Studies (GTS) is a K-12, activity based, science education program that integrates local environmental issues with global change topics, such as the greenhouse effect, loss of biological diversity, and ozone depletion. GTS activities use aerial and satellite imagery of the Earth as a powerful tool for learning about local, regional and global environmental topics.

Ground Truth refers to the use of field measurements to validate remotely sensed data. Field trips and classroom activities demonstrate the need for ground truthing when using remotely sensed images for environmental studies. Student activities illustrate the use of the synoptic, or "bird's eye" view for recognizing patterns in Earth systems and changes in patterns over time, such as urban growth or deforestation. The activities are interdisciplinary and integrate basic science and math skills with other disciplines such as geography, social studies, art and writing to address critical issues in local and global environmental change.

Ground Truth Studies Key Concepts

- Change is the norm for the Earth's natural systems
- Recently, humans have become a key agent of change
- Earth systems are linked through interactive processes
- Global change impacts all life
- Local changes have global consequences

Ground Truth Studies and Mission to Planet Earth

Mission to Planet Earth is an initiative to understand our home planet, how forces shape and affect its environment, how that environment is changing, and how those changes will affect us.
—Dr. Sally K. Ride

Over the next 20 years, the dominant source of data about the global environment will come from space observations in which the Earth's land, oceans, and atmosphere will be measured by remote sensing from a network of satellites. Mission to Planet Earth is the central NASA contribution to the US Global Change Research Program. Mission to Planet Earth involves government agencies and the research community in an exciting and challenging task with enormous social consequences.

Each satellite image requires interpretation to be of value to researchers, educators, students, policy makers — anyone interested in the state of the planet. Learning how to interpret remotely sensed images is like learning a new language — a visual language vital for understanding Earth Systems

Ground Truth Studies is designed to introduce remote sensing as an exciting tool at the elementary and secondary levels. By utilizing remotely sensed images of their own region, students gain new skills and insights into local environmental issues and global change topics.

Ties to Basic Science

Global change is rich in its range of topics from both the natural and social sciences. Since all Earth systems are interrelated, global change science requires perhaps the greatest integration of disciplines ever undertaken. Chemistry, physics, ecology, geology, sociology, economics and ethics are just a few of the disciplines involved. Students experience this interplay of subjects and learn essential skills, such as collecting, graphing and interpreting data, which are vital to the process of exploring their own environment. Student observations and measurements are linked to global change topics.

GTS Activities are interdisciplinary and help to reinforce core curricular objectives and complement the aim of the science content standards developed in the draft *National Science Education Standards.*

The Ground Truth Studies Teacher Handbook

This handbook is designed to supplement existing curricula and has been used successfully at all age levels. It is available to elementary and secondary teachers either directly or through AGCI workshops. Teacher support materials such as remotely sensed images, educational videos, or related information on teaching about global change are available from the Aspen Global Change Institute.

About the Aspen Global Change Institute

AGCI was founded in 1989. Its mission is to further global change science and to develop educational materials about global change. Since 1990 AGCI has convened international groups of scientists from both the natural and social sciences for in-depth two-week sessions on current topics in global change research. The *GTS Teacher Handbook* is the first project of AGCI's educational program and was part of the educational activities of the International Space Year.

How to Use This Book

There are many approaches to learning about global change and any attempt to categorize global change is difficult because Earth systems are so interrelated. The air we breathe is intricately affected by processes occurring simultaneously in the atmosphere, water, land and life on Earth. This handbook is the first in a series that will examine the issue of global change from the perspective of four familiar, important and interrelated Earth systems: air, water, land and living things.

It is important to develop the flexibility to step back and view complex Earth systems as one immense whole, as well as to delve into its parts. This notion of viewpoint, or perspective, is essential to the study of global change. For example, Earth, observed from the surface of the moon, provides a global perspective while the Earth observed from the edge of a pond, provides a local view which is equally necessary to our understanding of Earth systems. The activities in this handbook address both of these perspectives through the use of remotely sensed images that give a synoptic, or bird's eye view, and through ground truthing field trips and activities to obtain a detailed view of our planet.

Many issues, such as global warming, the ozone hole and the loss of biological diversity, will be familiar to you and your students, but the details of the role of humans in causing global scale change will not be so clear. As educators, we need to engage students in an exploration of changing Earth systems and the role humans play in some of those changes. Your students will be keenly interested because it is their future which is at stake. Global Change Studies are exciting because of the linkages they forge between a multitude of disciplines, and this Handbook is designed to provide you with relevant activities to supplement your courses.

Background Information — The Primers

To aid you in teaching about global change, we have provided a **Global Change Primer** which answers many frequently asked questions about a number of major global change topics. This will give you a head start on many global change issues, enable you to interpret the discussions and events covered by the media, and provide you with answers for many of the questions of your students.

This handbook uses remotely sensed images and ground truthing activities to provide both large scale perspectives and tools for the study of global change in the area where you and your students live. The **Remote Sensing Primer** provides an overview of the theory and application of remote sensing technology. The bibliography lists a number of excellent references on remote sensing that also include striking images and case studies in the application of remote sensing.

Remote sensing and ground truthing make use of the knowledge and skills students acquire from many traditional school subjects. These activities also remove the physical walls between students and their environment. Their improved ability to "see" and experience their world can bring them closer to understanding the interdependence of all life and the fragile systems of this complex planet, Earth.

Instructional Framework

The instructional framework of this handbook is constructed using three levels of activities:

Tool box — activities designed to explore and develop essential skills and concepts for field observation, measurement, etc. These activities also provide an orientation to important components of the local environment.

Local and regional issues — activities designed to develop the student's understanding of what we know about Earth Systems, and how we know. These activities develop and apply the basic "toolbox" skills by combining the interpretation of remotely sensed images of the Earth with ground truth activities for studying the local environment. Field observation complemented with remotely sensed image interpretation leads to a better understanding of local and regional environmental issues.

Global Change: The big picture — activities that are aimed at integrating the skills, concepts and observations developed in the preceding activities in ways that increase the student's understanding of how local scale environment relates to regional and global scale Earth systems. Students will learn how the actions of individuals and communities add up to regional and global effects and how an individual's vision can help shape the Earth of the future.

As the first handbook in this series, there is an emphasis on the toolbox activities, but there are also extensions to lead you and your students far beyond the limits of the local school yard. The satellite images contained within this handbook, and others available through your library or other local sources, provide an excellent resource for stepping back from our usual up-close view and adopting a global perspective. To fully utilize the activities in this handbook, we highly recommend that each school develop a set of local images. For assistance, please contact AGCI, or consult the Sources for Remote Sensing Imagery located in the appendices.

Suggestions for K through 6 Grade Teachers

Many of the activities in this handbook are well suited for students as young as Kindergarten. The younger children (grades K—3) will gain the most from the hands-on and visually and sensory oriented activities, such as "Learning to Look, Looking to See", "Goldilocks Effect", "Birds Eye View" and "Sandboxes and Satellites". You should feel free, however, to adapt any of the activities to fit topics you are covering in your classes. The remotely sensed images fascinate young and old alike, and the opportunity to trace the route home or around school, using an aerial image, provides a powerful learning experience.

Ground Truth Studies is designed as a hands-on, interdisciplinary program. The activities are equally applicable to art, science, math and writing classes, and your students will learn most effectively from hands-on involvement in these activities. Building models, tracing features on acetate over the aerial images, and taking field trips to "ground truth" the images are essential elements of Ground Truth Studies. Look over all of the activities offered in this handbook for only you can judge the level of your students and determine how these activities can be used to supplement your class work.

To build a foundation for their future classes, encourage your students from the beginning to record their observations and thoughts in writing or pictures, to count the numbers of objects rather than classify them as a few, many or a lot and to verbalize what they have learned by writing stories, poems or songs. Students too young to write can report orally, or they can build models, draw or paint pictures to express what they have learned. Give your students the opportunity to complete their learning experience by letting them teach their classmates what they have learned.

Suggestions for 7 through 12 Grade Teachers

The suggestions for primary teachers certainly hold true at the secondary level. All of the activities in this handbook should also be considered for use with secondary level students. Experience has shown that older students have much to gain by carrying out the activities suggested for younger class levels.

At the secondary level specialization intensifies and math, science, geography, language and art classes are usually taught as distinct disciplines. Ground Truth Studies strives to bridge the divisions between subjects while respecting the needs of teachers to cover their assigned material. The GTS activities provide compelling and relevant materials to engage students and to carry their lessons beyond any given discipline.

The list is extensive and rich in materials from which to weave basic natural and social science themes:

- Science and math classes may monitor the local environment by identifying, classifying and measuring different variables such as temperature, dust, plant cover, and urbanization. Students will then tabulate, map, graph and report their results with explanations of their findings.
- Geology classes can trace watersheds, map rock outcrops and features of the area on the remotely sensed images, and take field trips to ground truth their interpretation of the image.
- Geography classes can use the aerial images to make their own map and compare it with other maps of the same area.
- Social studies, history and language classes can research and report on the history of their watershed, look at the past and speculate about the future of their community, and look at the role of regulatory agencies in the community.
- Theater classes can research and enact an activity such as "Your Watershed's Story".
- Debate teams can use the materials "Regulatory Agencies on the River" or "Dead Right, Dead Wrong" for relevant, topical debates.

Appendices

The appendices include a temperature data set, glossary, two sections on remote sensing, and a bibliography.

The **Global Temperature Data Set** is for use with the "How When Affects What" set of activities and provides one set of data used by scientists when conducting research on global climate change.

The **Glossary** supplies standard definitions of terminology found in the primers or activities. Scanning through it beforehand may help you avoid problems with some of the inevitable jargon and specialized terminology.

The next two appendices supply additional information on remote sensing applications. The **Image Application Chart** is inevitably incomplete as remote sensing is constantly being applied to new applications across the entire range of disciplines from archaeology to zoology. The appendix, **Sources of Remote Sensing Imagery**, provides a list of sources for remotely sensed images.

Finally, a short **Bibliography** contains both background information and further reading on remote sensing and global change. Some useful webpages including AGCI are listed. If your favorite book or article on the topic is missing, please let us know!

Primers

- ***Global Change Primer***
- ***Remote Sensing Primer***

Global Change Primer

These are unique times. Our use of energy and other resources has increased to the point where we are having a measurable effect of a global scale on Earth systems such as the atmosphere. Humans have moved from mere spectators of Earth processes to center stage in the twentieth century, where we have become major players. It is no accident that we are hearing about many different global change issues all at once: climate change, the ozone hole and worldwide loss of biodiversity, just to name a few. It is, in fact, because we humans have become so numerous and consumptive, that our combined individual effects are precipitating changes on a global scale. A number of key concepts are central to the scientific study of global change and help put the issue of natural and human induced global change into perspective.

Change is the norm for Earth's natural systems

The Earth is constantly changing. Some of this change occurs slowly over many millennia, and some occurs relatively rapidly over decades. Major natural forces cause such changes as volcanoes, continental shifts, building and erosion of mountains, reorganization of oceans, appearance and disappearance of deserts and marshlands, advances and retreats of great ice sheets, rise and fall of sea and lake levels, and the evolution and extinction of vast numbers of species.

Recently, human beings have become a key agent of change

In addition to the changes brought about by natural forces, it has recently become apparent that a relative newcomer to planet Earth — the human being — has become a powerful agent of environmental change. The chemistry of the atmosphere has been significantly altered by the agricultural and industrial revolutions. The erosion of continents and the sedimentation of rivers and shorelines has been accelerated by construction, agriculture, and other human activities. The production and release of toxic chemicals has affected the health and distribution of plant and animal populations. The development of water resources for human use has affected patterns of natural water exchange in the hydrologic cycle (e.g., enhanced evaporation from reservoirs and irrigation as compared to that from unregulated rivers). As human population grows and technology develops, the role of human beings as agents of global change will undoubtedly expand.

Earth's systems are linked through interactive processes

Evidence accumulated in the last two decades indicates that environmental changes are the result of complex interactions between natural and human-related systems. For example, the Earth's climate changes are due not only to wind and clouds in the atmosphere, but also the effects of ocean currents, human influences on atmospheric chemistry, the Earth's orbit and albedo, the Sun's energy output, and the distribution of water between the atmosphere, hydrosphere (oceans, lakes, rivers), and cryosphere (icecaps, glaciers, sea ice). The aggregate of these interactive linkages among the major systems that affect the environment is known as Global Change.

Global Change impacts all life

Many environmental changes have substantial impacts on the welfare of humans and all other life on the planet—such as changing growing seasons, extreme climatic events like protracted droughts, and increased exposure to damaging ultraviolet radiation. During most of human existence, the only response to such changes was to learn to cope by building better shelters, altering agricultural practices, or migrating. Advances in Earth sciences over the last several decades, however, have revealed: 1) the causes of some changes, 2) the processes whereby they occur, and 3) their local environmental consequences (although it remains difficult to prove precise cause and effect relationships between global activity and local consequences). As a result of what we learn from Earth sciences, people can now anticipate some of these changes and make proactive rather than reactive decisions and responses which can reduce the severity of Global Change impacts and mitigate their effect.

Local changes have global consequences

It is increasingly clear that the cumulative effect of individual human activities is precipitating profound change on a global scale. As a corollary, it also follows that individual actions can have an equally profound effect on the reduction of detrimental human impacts on the Earth. Through awareness, education and informed action, the human race has the opportunity to seize the initiative and avert, rather than adapt to or endure, an environmental crisis.

Thus, scientists are seeking to develop an integrated systems understanding of changes that relate to the welfare of the entire planet. Such an understanding could greatly assist policy makers as they grapple with how to mitigate the impacts of the key global change phenomena of our time: global climate change, stratospheric ozone depletion, acid deposition, loss of biological diversity and changes in human population.

What are the key elements of Global Change research?

Shortly after the U. S. Global Change Research Program became organized it defined the large issue of Global Change research into seven interdisciplinary science elements (in priority order) for the purpose of allocating the funding of global change research:

1 **Climate and Hydrologic Systems**
This incorporates the atmospheric, oceanic, and land surface processes that govern atmospheric and oceanic circulations and the associated distributions of temperature, moisture, clouds and precipitation over the surface of the Earth. Key sub-elements include: the role of clouds in the Earth's heat budget, greenhouse warming, sea level rise, water supplies and stratospheric ozone depletion.

2 Biogeochemical Dynamics

An essential part of reliably predicting change on a global scale is an adequate understanding of the cycling of the key nutrient elements — carbon, nitrogen, oxygen, sulfur, and phosphorous — through their major reservoirs: the oceanic and freshwater aquatic systems, the solid Earth component, the biosphere, and the atmosphere. Sub-elements include: greenhouse warming, acid deposition, deforestation, coastal pollution, and ozone depletion.

3 Ecological Systems and Dynamics

These are important to global change as both cause and effect. Ecosystems provide food and fiber for humans and wildlife. They also influence air and water quality, the amount and distribution of surface and ground water, and the habitats of both human and wildlife. Therefore, ecosystem destruction has direct effects on our economic and social well-being. Variables such as temperature, precipitation, and biotic interactions ultimately control the distribution of species. Species, in turn, influence the characteristics of ecosystems, and ecosystems influence the physical environment through such phenomena as reflectance, evapotranspiration, and the emissions of important greenhouse gases, such as carbon dioxide and methane. Therefore, ecosystems with altered structural and functional properties can have feedback effects on the physical and chemical environment. Sub-elements include: biodiversity, coastal pollution, sea level rise, erosion, ozone depletion, greenhouse warming, and acid deposition.

4 Earth System History

The Earth's geologic record provides a valuable source of information about past changes in climate, ecosystems, hydrologic conditions, and landscapes. Evidence of major variations in sea level, lake and ground water levels, extent of glacier ice and sea ice, changes in atmospheric composition, and dramatic changes in ecosystems in the past provide us with important insights into what the future may hold. We learn about natural climate variability by indicators such as tree rings, ice cores, fossils, and sediment. Information about the causes, rates, and consequences of climate change can also be extracted from the geologic record. Such information can improve our ability to make predictions about future climate change.

5 Human Interactions

Human activity is a critical element in global change, both in terms of initiating processes of change, as well as altering ongoing processes. Research into the human dimensions of global change will help us to understand the patterns of direct human action or impact, as well as the indirect structural and institutional causes of change in Earth systems, including such factors as economic markets, national legal and regulatory systems, and social and economic aspirations of various nations. Such research will provide the scientific background for public policy studies, which should address the response of human institutions to global change in terms of both mitigation strategies and processes of adaptation.

6 Solid Earth Processes

Surface and sub-surface processes which produce changes on land, in the oceans, and in the atmosphere, are processes studied under this research heading. Understanding solid earth processes is key in long-term planning in coastal regions most at risk from rising sea levels or volcanic eruptions. Examples of solid earth processes are; melting of glaciers and the effect on sea-level; volcanic eruptions (such as Mt. Pinatubo in 1991) and their effect on climate; and rate of methane release from permafrost and gas hydrates as a potential positive feedback to the climate system.

7 Solar Influences

The most well-known, explainable climatic variations, the Ice Ages, were caused by small variations in the solar forcing of the terrestrial atmosphere due to small changes in the Earth's orbit about the sun. A significant issue in global change is in solar output variability and activity, and the understanding of the effect these have on the chemistry and energy dynamics of the terrestrial atmosphere. Such understanding will help in modeling the type of climate anomalies we can expect and the role of the Sun in these anomalies.

There are many ways to divide or categorize global change. While the above seven categories are useful for the purpose of investigating what is not known or well understood about global change, less technical categories are useful for primary and secondary education. We have approached the issue of global change from the perspective of four familiar, important and interrelated Earth systems: air, water, land, and living things. Any attempt to categorize global change themes is limited, because global change topics are so interrelated: The air we breathe is intricately related to processes occurring in the atmosphere, water, land, and, of course, in the ecology of Earth, of which we are an essential part. It is also important to step back and view complex Earth systems as one immense whole, as well as to explore the parts. This notion of viewpoint, viewing the Earth from the surface of the moon, for example, provides only one data set. The view of the Earth from a point on the edge of a pond provides an equally essential view. This Handbook explores....

The changing atmosphere

Along with widespread popular concern over such global change issues as global warming and ozone depletion, there are equally widespread misconceptions. While these issues are only part of the global change arena, the attention given them in the popular media and in political and environmental discussions warrants that they be specifically dealt with. This section will attempt to offer a simple but accurate understanding of these phenomena, and clear up some of the confusion. The concern about these issues centers around human induced, or anthropogenic change to the atmosphere. Thus, it is important to review the basics of the Earth's atmosphere in order to place human influences in their proper context.

The atmosphere is the gaseous envelope that supports life on Earth by providing chemicals necessary for life, protecting the Earth's inhabitants from harmful solar radiation, and acting as a transport mechanism for heat, moisture and essential chemicals throughout the climate system. Through many complex processes, the atmosphere provides us with a comfortable environment for life.

The structure of the Earth's atmosphere

Atmospheric scientists commonly divide the atmosphere into four layers, or regions, on the basis of the vertical distribution of temperature (figure 1). Conditions vary greatly over this large altitude range in which the pressure and density decrease by 7 orders of magnitude (from about 1,000 millibars (mb) of pressure at the Earth's surface to 0.0001 mb at the top of the thermosphere). The layers of the atmosphere which concern us here are the two layers closest to the Earth's surface, the troposphere and the stratosphere, which extend from the Earth's surface to an altitude of about 50 km (30 miles).

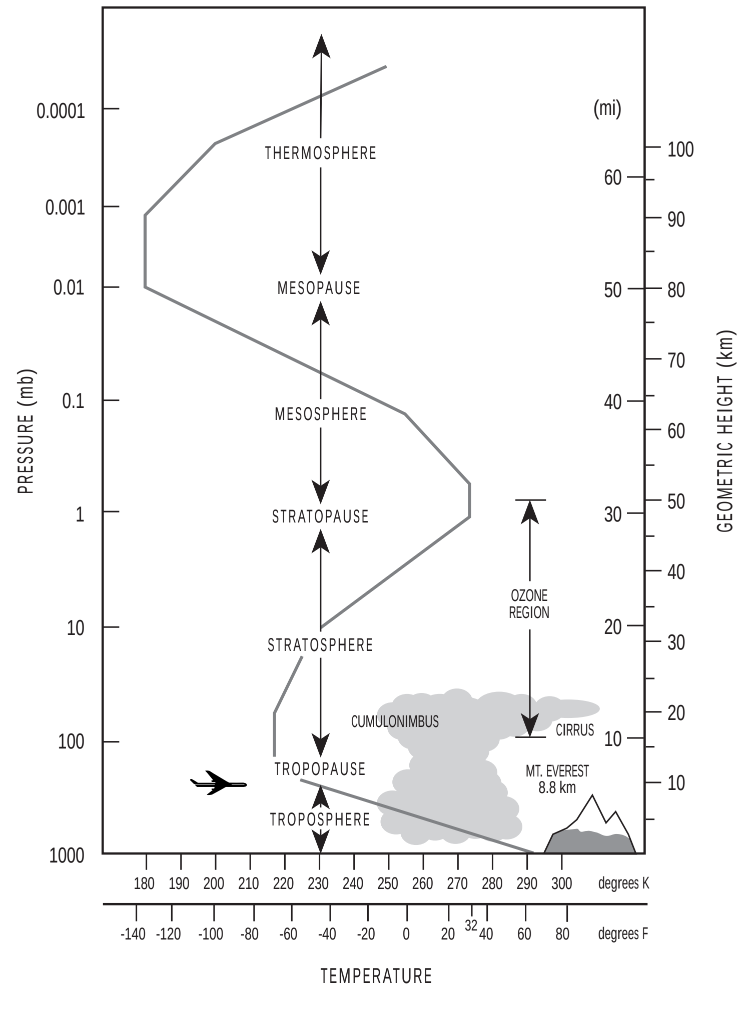


Figure 1

Plot of vertical temperature distribution in the Earth's atmosphere from the surface to 100 km in altitude, giving the names of the atmospheric regions. For comparison, the heights of high clouds and Mt. Everest are also shown. (Adapted from: From Pattern to Process: The Strategy of the Earth Observing System, vol. II, NASA)

The troposphere

The region nearest the Earth's surface, the troposphere, is the region in contact with the biosphere. It is the region in which we live and into which the gaseous by-products of our activities are released. It is characterized by a decrease of temperature with increasing altitude. The major heat source for the lower atmosphere is the absorption of solar energy by the surface of the Earth. This heat is then transferred to the atmosphere by a variety of processes and contained there by the "greenhouse effect". This is the region where almost all weather and clouds occur, although vigorous convective systems, like thunderstorms, can push through the upper boundary and reach the lower stratosphere. The troposphere extends upward to approximately 6 to 8 km (4 to 5 miles) at the poles and about 17 km (11 miles) at the Equator. Air thins quickly as one goes up in altitude and breathing

becomes difficult for humans above about 5 km (3 miles). Mount Everest reaches an altitude of just over 8.8 km (5.5 miles). The boundary zone between the upper troposphere and the lower stratosphere is the tropopause.

The stratosphere

The stratosphere is distinguished from the troposphere by the fact that its temperature remains nearly constant or increases with increasing altitude to its upper boundary (the stratopause) at about 50 km (30 miles). After entering the mesosphere, temperatures again begin to decrease with height. In the stratosphere, solar ultraviolet radiation causes some molecular oxygen (O_2) to dissociate, and the resulting atomic oxygen (O) then combines with the remaining O_2 to form ozone (O_3). The relatively higher concentration of stratospheric ozone is of critical importance because it absorbs much, though not all, of the ultraviolet radiation at shorter wavelengths (80 to 90% of UV-B is absorbed by the atmosphere under clear conditions, with almost no UV-B reaching the ground under heavily clouded skies) preventing it from reaching the Earth's surface, where excessive amounts are harmful to plant and animal life.

Past to present atmosphere

The gases of Earth's atmosphere have changed dramatically since the formation of the Earth 4.6 billion years ago. The early atmosphere consisted primarily of hydrogen which was poorly held by Earth's gravity and escaped to space. Heavier gases were released from the crust and an atmosphere consisting of nitrogen, ammonia, carbon monoxide, hydrogen sulfide, and methane formed. Water vapor escaping from the crust condensed and formed the oceans. Energy sources such as ultraviolet light, lightning, radioactive decay, and geothermal energy contributed to the formation of the first organic molecules, eventually leading to early forms of life. After about 2 billion years, the presence of oxygen in the atmosphere emerged as a byproduct of photosynthesis. Between two and three billion years after the Earth's formation, the buildup of oxygen from photosynthesis led to the development of ozone in the upper atmosphere, protecting life from ultraviolet radiation. The presence of a strong component of oxygen in the atmosphere sets the Earth apart from all the other planets in the solar system and is vital to life as it has evolved.

The primary dry air gases of the present atmosphere are nitrogen (N_2) making up 78.1%, oxygen (O_2) contributing 20.9%, and Argon (A) at 0.9%. The remaining gases are present in trace amounts totaling about 0.1%.

Trace gases

Not all trace gases are greenhouse gases, some trace gases have both natural and anthropogenic sources like carbon dioxide (CO_2) and methane (CH_4), and some trace gases are only anthropogenic like the chlorofluorocarbons (CFCs). Some trace gases are fairly stable and well mixed in the atmosphere such as the remaining "noble" gases like neon, while others, such as water vapor (H_2O), varies in concentration between 0 and 4%, and in distribution. Another gas that is poorly mixed in the atmosphere is sulfur dioxide (SO_2) which varies between 0.3 and 50ppbv (parts per billion by volume). Sources of sulfur emissions into the atmosphere are a combination of natural processes such as volcanic and biological activity (ocean organisms giving off dimethyl sulfide — DMS), and anthropogenic processes such as the combustion of fossil fuels with sulfur content.

A striking example of a natural change in SO_2 was the eruption on June 15, 1991 of Mt. Pinatubo in the Philippines which injected an estimated 20 Tg of SO_2 (a teragram is a trillion grams) into the stratosphere which was then converted into sulfuric acid/water aerosols (sulfate aerosols). A satellite sensor tracked the distribution of the sulfate aerosol from the point source at Mt. Pinatubo to a haze that circled the globe in 22 days and is thought to have lowered global average temperatures by approximately 0.5 degrees C . Fortunately sulfur dioxide is not long-lived in the atmosphere. Two and one-half years after the eruption, the amount of sulfur dioxide in the stratosphere from Mt. Pinatubo was estimated to have decreased to 5 Tg. The estimate for emissions of SO_2 from all natural sources is 147 Tg per year however, emissions from humans burning fossil fuels is estimated at 80 Tg per year, 4 times the amount from Mt. Pinatubo!

As the Mt. Pinatubo example illustrates, sulfur dioxide is a radiatively important trace gas, but not a greenhouse gas because it has a cooling effect by reflecting incoming solar radiation back to space. The example of sulfur dioxide from Mt. Pinatubo is one of rapid change with temporary effects from a natural source. The human caused release of sulfur dioxide is one of a gradually increasing and continuous effect with a magnitude on a par with the natural system — a definite example of global change. Since SO_2 has a short lifetime in the atmosphere the effects of decreasing emission rates from anthropogenic sources are realized soon after the rates are changed.

Greenhouse gases

Another set of trace gases, that like sulfur dioxide are radiatively important, are the greenhouse gases. Unlike sulfur dioxide however, the greenhouse gases are important in that they are mostly transparent to incoming solar radiation and opaque to outgoing longwave radiation (figure 2). This trapping of energy is commonly called the “greenhouse effect,” the basic physics of which has been understood since the last century as described in a paper by the Nobel Prize winning chemist, Svante Arrhenius in 1896. This small group of gases has the remarkable effect of keeping the Earth about 33 degrees Celsius warmer than the moon, our cold and lifeless neighbor that receives the same amount of energy from the sun. Concern is not with the greenhouse effect or the naturally occurring greenhouse gases. The concern is with the additional greenhouse gases that have been added in increasing amounts this century creating an enhanced greenhouse effect with as yet unknown consequences.

The greenhouse gases include water vapor, carbon dioxide (CO_2), tropospheric ozone (O_3), nitrous oxide (N_2O), chloroflurocarbons (CFCs), and methane (CH_4). Anthropogenically important greenhouse gases are depicted in Figure 3. Greenhouse gases trap incoming solar radiation and contribute to the warming of the Earth’s average temperature. In addition to changes in temperature, there are other important aspects of the climate system that may respond to increased concentration of greenhouse gases and the cooling effect of gases like sulfur dioxide. Examples of other potential changes in climate are altered precipitation patterns, wind intensity and direction, frequency and severity of droughts, and tropical storm formation and intensity.

	Carbon Dioxide	Methane	CFC-11	CFC-12	Nitrous Oxide
Atmospheric concentration	ppmv	ppmv	pptv	pptv	ppbv
Pre-industrial (1750-1800)	280	0.8	0	0	288
Present day	355	1.72	254	453	310
Current rate of change per year	1.8	0.015	9-10	17-18	0.8
	(0.5%)	(0.9%)	(4%)	(4%)	(0.25%)
Atmospheric lifetime (years)	(50-200)	10	65	130	150

ppmv = parts per million by volume; **ppbv** = parts per billion (thousand million) by volume; **pptv** = parts per trillion (million million) by volume (Adapted from IPCC Scientific Assessment, 1990, and the 1992 IPCC Supplement)

Carbon dioxide

In relation to climate change, the most significant of the greenhouse gases is carbon dioxide, which has increased from about 280 ppmv (parts per million by volume) during the pre-industrial period of 1750 to 1800 to the present day value of 356 ppmv (1993) primarily due to human combustion of fossil fuels and deforestation. This represents an increase of about 25% in the past 100 years. Since 1958, measurements made at Mauna Loa, Hawaii by Charles David Keeling

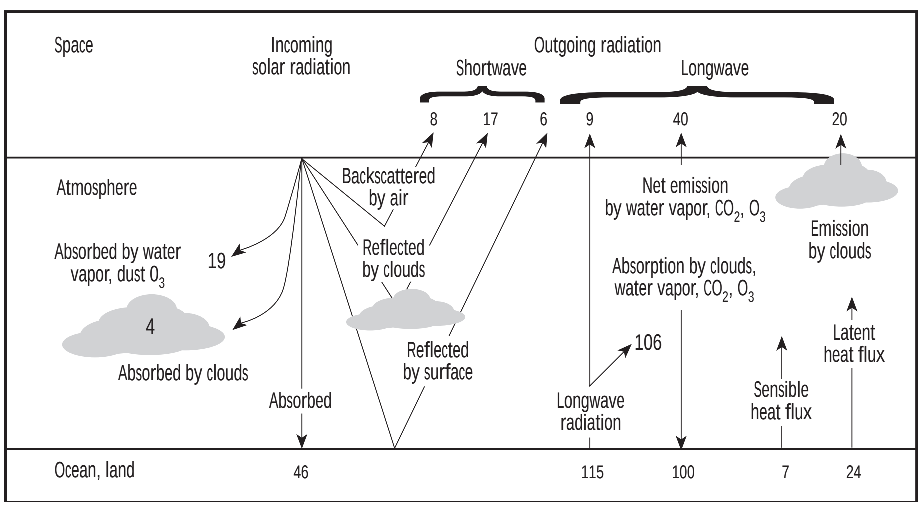


Figure 2

Schematic diagram of the global average energy balance. The units are percent of incoming solar radiation. The solar energy absorbed at the Earth's surface directly heats the atmosphere and evaporates moisture. Atmospheric emission of infrared radiation back towards the Earth is more than twice as large as the amount of solar radiation absorbed at the surface. This greenhouse energy permits the surface to warm significantly more than would be possible by the solar radiation alone. (Adapted from MacCracken , M. C. and F. M. Luther (Eds.) Projecting the Climatic Effects of Increasing Carbon Dioxide (1985), DOE/ER-0237, US Department of Energy, Washington, D.C.)

provided for the first time accurate data on the increasing concentration of carbon dioxide, a sign of measurable human impact on the Earth's system (figure 4) at a global scale.

What about carbon dioxide concentration in the past? Did it go up and down with the changes in global temperature coincident with the on-and-off cycles of the ice ages? Analysis of air bubbles trapped in ice cores at the Vostok research station in Antarctica shows the fluctuation of carbon dioxide back in time 160,000 years (figure 5). The concentration of CO_2 closely correlates with estimates of the Antarctic temperatures during the same time. As the temperature went down, so did the concentration of CO_2, and as it went up, so did CO_2. This does not provide a cause and effect relationship; however it provides critical data relevant to understanding changes in climate with levels of CO_2 higher than at any time in the last 160 thousand years.

Just how much CO_2 will there be in the atmosphere in the next century? The Intergovernmental Panel on Climate Change (IPCC) future carbon emissions scenarios range from emissions lower than today's, to emissions that are as much as 6 times greater than today's. These scenarios are based on estimates of change in human population, economic growth, and the relationship between economic growth and energy obtained from different sources. Today, emissions are about 6.2 GtC (gigatons or billion metric tons) of carbon per year.

Concentration of a gas in the atmosphere is only part of the story. The rate of change is of equal importance. CO_2 has been increasing at a rate of approximately 0.5% per year which has lead the nations of the world to focus attention on carbon emissions. While there is little dispute about the amount or sources of carbon emissions, there is uncertainty about the rate of carbon uptake in carbon "sinks" — the places carbon is stored after it leaves the atmosphere (biomass, soils, oceans). This is a good reminder that science deals as much with what isn't known as with what is known.

The increase of carbon dioxide in the atmosphere and its potential effects on the Earth system led to the signing of the Climate Change Convention in 1992 at the UN Conference on the Environment and Development (UNCED) in Rio de Janeiro, where 178 governments were assembled for the first time to address topics such as climate change, biodiversity loss and economic development concerns. Work has continued on the climate portion of the UNCED agenda through a series of UN sponsored meetings to work toward a carbon emission plan that developing and developed countries can utilize to reduce carbon emissions.

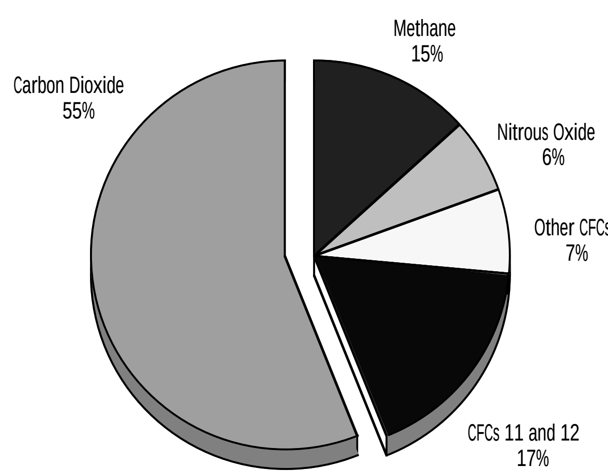


Figure 3
The direct contributions of greenhouse gases to global warming.

Methane

Methane, the second most significant greenhouse gas has as primary natural sources wetlands and termite metabolism. Anthropogenic sources are coal mining, leaks in natural gas systems, rice paddies, enteric fermentation from the digestion of grazing animals like cows, from animal wastes, landfills and biomass burning. Methane concentration in the atmosphere has more than doubled from its pre-industrial levels and until recently was increasing at about 1% per year. Over the last decade this rate has slowed and is now at about 0.6%. This is still a significant rate, especially when one considers that each molecule of methane has many times the warming potential as a molecule of carbon dioxide (see Global Warming Potential (GWP) below).

CFCs

Not all greenhouse gases are naturally occurring like carbon dioxide or methane. Some of the trace gases are artificially manufactured and are new to this century. They include the chloroflurocarbons (CFCs), invented in the 1930s, and the recently developed CFC-replacement family of hydrogenated chloroflurocarbons (HCFCs), hydrogenated fluorocarbons (HFCs), and various compounds with bromine (halons). These trace gases often have long lifetimes in the atmosphere, and on a per molecule basis, some are equivalent to thousands of CO_2 molecules in their greenhouse heat-rapping effect. Coincidentally, CFCs and related chemicals are also responsible for the loss of ozone in the stratosphere due to the release of chlorine and bromine when the compounds are transported by convection to the stratosphere and are exposed to more intense ultraviolet light. Chlorine and bromine catalyze the destruction of ozone above natural rates. More about CFCs and ozone later. Recent research has indicated that ozone depleting chemicals such as the CFCs, that have a direct warming effect as greenhouse gases, also have an indirect cooling effect by removing ozone, which itself is a greenhouse gas from the lower stratosphere. Because of this development, the net effect of some of the halocarbons as greenhouse gases is unclear.

Tropospheric ozone

Tropospheric Ozone is a greenhouse gas of increasing significance. This lower atmosphere ozone is photochemically (chemical reaction driven by sunlight) produced when nitrogen oxides (NO_x) react with carbon monoxide (CO), CH_4, non-methane hydrocarbons (NMHCs), and sunlight. Most of the pollutants which lead to the formation of tropospheric ozone in cities come from automobiles, power plants and other human activities. In addition to its long-term effects as a greenhouse gas, ozone is a major component of "smog," which causes significant health problems for people in many cities, notably acute respiratory disorders. Ozone at

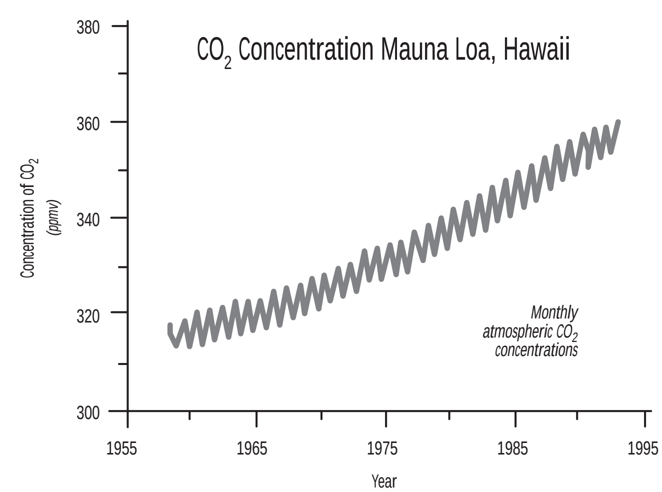


Figure 4 Annual average carbon dioxide at Mauna Loa Hawaii, 1958 – 1993.

ground level also has adverse affects on trees, and is thus implicated in the degradation and decline of forests. Tropospheric ozone is thus the "bad ozone," not to be confused with the "good ozone" in the stratosphere, which protects life from excess ultraviolet radiation.

GWPs

In attempting to compare the effect of different greenhouse gases (there are dozens), the Intergovernmental Panel on Climate Change developed the Global Warming Potential (GWP) for different gases. The GWP assigned to a gas is basically a tool for policy discussions on the relative importance of different gases to the greenhouse effect.
By setting the greenhouse warming potential of CO_2 equal to 1, the effect of all other greenhouse gases can be calculated.

Gas	GWP†
CO_2	1
CH_4	11
N_2O	270
CFC-11	3,400
CFC-12	7,100
HCFC-22	1,600

† time horizon of 100 years. From IPCC 1992.

Since different gases have different resident times in the atmosphere, the GWP index is a time-integrated measure of warming potential.

Modeling climate

It is important to know how the climate will change globally, such as altered global average temperature and precipitation, but for most of us we want to also know how climate will change regionally, and even locally. Modeling future climate at any scale is one of the challenges of global change science. Information on radiatively important gases, the role of clouds in warming or cooling the Earth, and other variables are used to build supercomputer models of the atmosphere. These models, known as General Circulation Models (GCMs), are now being developed to couple with models of the biosphere and hydrosphere to gain insight into how Earth systems as a whole interact.

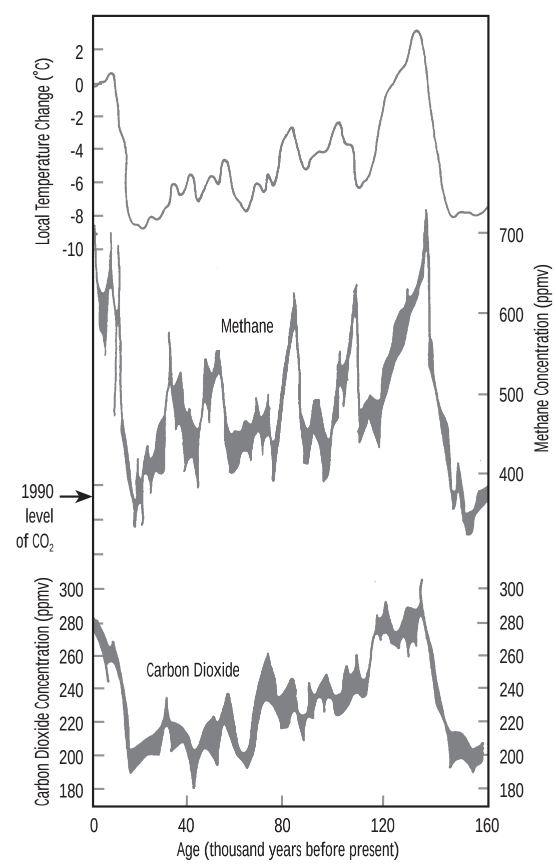


Figure 5
Entrapped methane, carbon dioxide, and derived temperatures, Antarctic ice cores. Adapted from IPCC 1990 Scientific Assessment.

A doubled CO_2 scenario

One experiment that is run on the GCMs is the climate response to a doubling of the CO_2 from pre-industrial levels. The model experiment introduces a doubled CO_2 concentration into the model atmosphere and then the model is run until it reaches equilibrium. Currently GCM's give a range of global average temperature increase of between 1.5 and 4.5 degrees C for a doubled CO_2 scenario. Since the atmosphere is expected to have increased concentrations of greenhouse gases in the next century equivalent to a doubling of CO_2, the reliability of the GCMs is of critical importance in determining a wise policy toward greenhouse gases, particularly carbon dioxide.

Is it getting hot or not?

Scientists agree about the physics of the greenhouse effect and they agree that since the industrial revolution, the greenhouse gases have been increased by anthropogenic emissions. Now, has there been an observed rise in global temperature? Yes. Over the past hundred years, a rise in global average temperature of about half a degree Celsius, or close to one degree Fahrenheit has been recorded (fig. 6). Though it may not sound like much, one degree of temperature is significant in global terms and might take nature thousands of years to bring about on its own (fig. 12)

The problem becomes even more serious when one considers that trends of greenhouse gas emissions are strongly upward, due to population growth and increasing development around the world. Currently, the U.S. is the largest

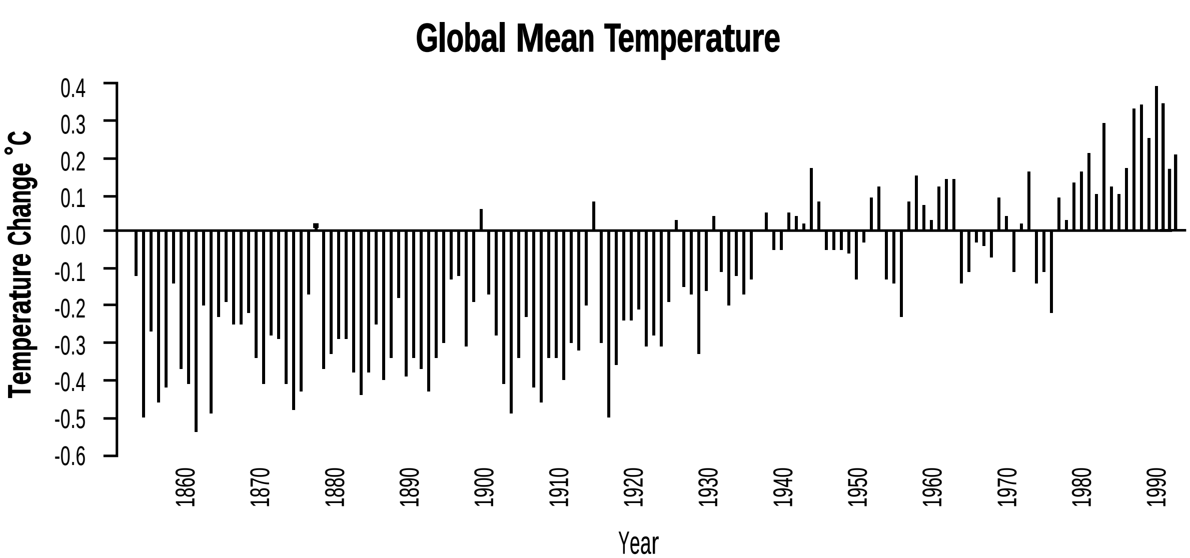


Figure 6

Deviations from a global temperature of 15°C for the period from 1854 to 1992. The average temperature of 15°C was calculated from a reference period of 1950 to 1979. Data from P. D. Jones and T. M. L. Wigley, CDIAC 1991, 1993. See page 119-120 for data set and full reference.

contributor to global greenhouse gas emissions, but as China, India, and other developing countries grow and industrialize, their emissions are expected to surpass those of the U.S.

The phrase "global warming" refers to the predicted warming expected to result from the build-up of the above-mentioned greenhouse gases. Scientists agree about the physics of how greenhouse gases respond to incoming solar radiation and outgoing longwave radiation. What is difficult to know is whether the observed changes in global temperature are caused by the increased concentration in greenhouse gases. Global average temperatures have been rising since the late 1970s, but could this be due to natural variability in the Earth's system? It is hard to tell.

One place to look is temperature records of the past. By knowing the difference between the temperature at the peak of an ice-age and in the middle of an interglacial period a sense of natural variability can be established on time scales of tens of thousands of years. Its also important to know the rate of change for temperatures in the past. For example, is a half a degree C change per thousand years, slow, fast or typical of past rates of change in the temperature record of past climates (figurs 6 and 12)? As figure 6 reveals, the global average temperature has increased about 0.5 degrees C in about the last 100 to 150 years. Is it now poised to go back down from the hot decade of the 1980's or is it about to exceed the natural variability and continue to increase?

So what's a few degrees

In as little as a few decades, Earth's climate could be as different from today's climate as it was at the height of the Great Ice Age, only warmer instead of colder. What would such a change mean for human life on Earth? One important consequence of global warming is that sea levels will rise because water expands as it warms and due to increased melting of mountain glaciers and polar ice. In fact, new satellite data confirms that sea level is rising consistent with model predictions. The IPCC estimates that by the year 2030, sea level will likely have risen by 15 cm (about 6 inches), and that by 2100 the rise will be 50 cm (about 20 inches). These estimates are based on a "business-as-usual" scenario, i.e., on the assumption that humankind will continue to burn fossil fuels as its primary energy source, thus increasing the atmospheric concentrations of greenhouse gases in the future much as it has done in the past. Low-lying parts of Bangladesh, Florida and several Pacific islands would be significantly affected. About half the world's people live in coastal regions and this number is growing. Furthermore, some of the most fertile and densely populated regions are found at the very lowest altitudes above present-day sea level.

Another ramification is likely to be widespread change in both natural and managed ecosystems. Change in physical factors such as the maximum, minimum and average temperatures, the amount and seasonal timing of precipitation, soil moisture, humidity, and wind have dramatic effects on living systems. Given enough time to respond to change, living systems adapt as the fossil record reveals, but rapid change makes it far more difficult for successful adaptive strategies to emerge.

Uncertainties

There is considerable uncertainty about how various elements of the climate system will respond to an enhanced greenhouse effect. This uncertainty exists largely because as the climate warms, a lot of things begin to happen which we cannot accurately predict; and these may lead to "feedback" effects which in turn influence the climate. As the climate system changes, it generates processes that affect the original change. If one of these processes amplifies the change (such as increasing warming) we call it a positive feedback. If it dampens the change, we call it a negative feedback. The role of clouds is one these major uncertainties. We don't know if cloudiness will increase or decrease as a result of global warming, or how much the altered clouds will reflect sunlight away or retain heat in the atmosphere. We don't know if clouds will act as a stabilizer or amplifier of climate change. There is also uncertainty about how ocean circulation may change in response to warming and if ocean circulation changed, how it would affect climate.

Given that there is uncertainty about the Earth system response to global change factors like an enhanced greenhouse effect, when is action merited? If we wait for greater certainty, it may well be too late to act effectively to slow the process and adapt to it. On the other hand, if we act with poor information, our actions could be damaging or wasteful. One approach is to take action that makes sense for other reasons. Examples include increasing energy efficiency and accelerating the transition from fossil fuels like coal to renewable or more benign sources. Making changes such as these will also help with other problems such as acid rain, and urban smog.

The protective ozone

The ozone layer is a blanket of ozone (O_3) molecules in the stratosphere that protects Earth's inhabitants from excess ultraviolet radiation from the sun. Ozone is continually being created, destroyed and transported around the globe by winds. The amounts vary both by latitude and season, with the lowest concentrations occurring near the equator and highest amounts near the poles. This means that living things in the tropics are least protected from solar ultraviolet radiation and therefore must have developed the strongest defense mechanisms against it.

The depletion of the ozone layer by human-made chemicals is a global change issue of enormous importance, and unlike climate change, there is a high degree of certainty about cause and effect, and what we can do about it. Measurements reveal losses of up to about three quarters of the ozone over the South Pole in Spring time (the ozone hole) as well as significantly reduced levels of ozone globally. There is nothing hypothetical about this problem - it has been happening for decades and human activity is the cause. Moreover, ozone depletion raises serious health concerns for humans and other species.

The Culprits - CFCs and Halons

The major culprit is a family of gases called halocarbons, most notably CFCs and halons. Entirely artificial, chlorofluorocarbons (CFCs) were invented about 60 years ago as coolants for air conditioning and refrigeration. They have also been used as propellants for aerosols, blowing agents for plastic foams, and solvents for electronics. Halons are used primarily in fire extinguishers. In the 1970s, scientists began to discover a very serious down side to these two groups of

wonder chemicals. The chlorine from CFCs, and the bromine from halons, destroy stratospheric ozone molecules, and each atom of these elements can destroy thousands of ozone molecules.

The Ozone Hole

In the 1970s, two scientists predicted that CFCs would cause a global decline in stratospheric ozone. Years later satellite sensors recorded a drop in ozone over Antarctica, and even flagged the lowest values, but the ozone levels were so low, they were outside the range the computers had been programmed to accept as valid data and so the early warning was missed. Looking back at the data revealed that in 1984, the unsuspected ozone hole was already larger than the continental U.S. By 1987, the average ozone concentration over the South Pole was down 50%; during springtime it was down 70%, and in some spots, had essentially disappeared altogether. By 1992, the ozone hole had grown in area to nearly three times the size of the continental U.S. Though scientists had predicted the global decline in stratospheric ozone, no one had anticipated that ozone loss would appear so dramatically and suddenly in the form of a "hole" in the ozone layer over Antarctica.

If chlorine and bromine from CFCs and halons released from populated areas cause ozone destruction, then why is the ozone hole at the South Pole? The CFCs and halon sources are primarily from the mid-latitudes and after their release are transported by convection to the upper atmosphere and eventually the stratosphere. There are a couple of unique features that make the stratosphere over the poles particularly the South Pole more susceptible: First, Antarctica and the air above it is extremely cold and this leads to the formation of Polar Stratospheric Clouds (PSCs). Tiny ice crystals in PSCs provide chemically-active sites where the chlorine and bromine can catalyze the breakup of the ozone. The other feature is the polar vortex, a spiral of winds that swirls around the South Pole, isolating the Antarctic stratosphere during the winter and early Spring so the ozone destruction process goes on without Antarctic ozone being replenished by ozone rich air from lower latitudes.

Global Ozone Depletion

But ozone losses are not confined to the South Pole. In 1988, over 100 international experts reported that the ozone layer around the entire globe was eroding much faster than anticipated. Between 1969 and 1986, the average global concentration of ozone in the stratosphere had fallen by approximately 2%. By 1991, losses of 6 to 8% per decade had been measured at high latitudes (nearer to the poles) and

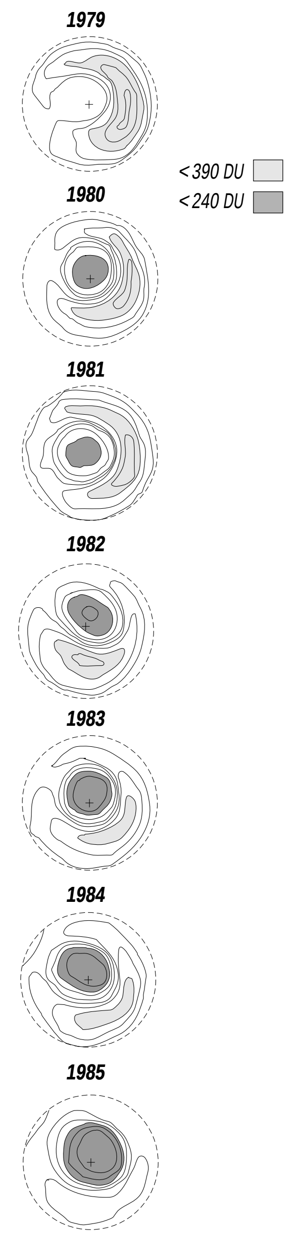


Figure 7
These pictures show the increase in size of the Antarctic ozone hole during successive winters. October monthly average TOMS total O_3. The crosses indicate South Pole.

losses of 3 to 5% per decade appeared at mid-latitudes (closer to the equator). Global average ozone in 1992 was 2 to 3% lower than the lowest level previously observed, and 1993 measurements broke even those records.

Ozone and life

What does declining ozone mean for human beings or other forms of life? Less stratospheric ozone means more ultraviolet-B (UV-B) radiation and that means more sunburns, skin cancer, cataracts, and immune system deficiencies, other factors being equal. It is estimated that each 1% decline in ozone allows about 2% more UV radiation to reach Earth, and is thus projected to result in 4-6% more cases of the most common types of skin cancer. In 1991, the US Environmental Protection Agency estimated that over the next 50 years, about 12 million Americans (equal to the entire population of Florida) will develop skin cancer, and more than 200,000 of them will die from the disease (a 50% increase over the current death rate from skin cancer). Also, ozone depletion has continued to worsen, so if the EPA estimate is valid, the numbers would now be even higher. Having light skin coloring, living near the equator, and living at high altitude increases the risk of exposure to UV-B.

New research strengthens the link between ozone depletion and increased ultraviolet-B (UV-B) radiation at Earth's surface. UV-B is radiation from a portion of the ultraviolet spectrum (from 290 to 320 nanometers; a nanometer is a billionth of a meter) to which many living organisms appear to be especially sensitive. Researchers in Toronto, Canada measured UV-B levels at various wavelengths and found that at 300 nanometers (a wavelength at which ozone absorbs UV-B), the intensity of the radiation reaching Earth's surface at the test site shot up, with summertime levels increasing by 7% per year and wintertime intensities increasing by 35% per year from 1989 to 1993. The summertime increases, though smaller in percentage, may prove even more damaging to humans and other living things as they are occurring at a time of year when UV-B is already at its highest levels in Canada and people are outdoors for longer periods of time.

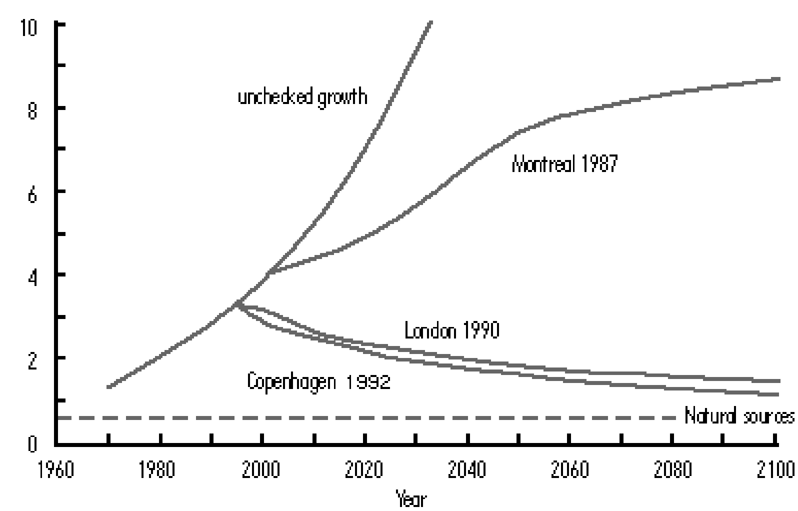


Figure 8

Chlorine loading of the stratosphere as modified by international agreements. Adapted from NASA Goddard Space Flight Center, WAL-144, January 1994.

The Montreal Protocol

Beginning in the 1980's representatives from industry, the science community, governments got together under the auspices of the United Nations to address the

ozone issue. This dialogue led to the Montreal Protocol which set limits on some of the ozone damaging chemicals. Subsequent international meetings in this process prescribed more stringent restrictions and phaseouts of damaging chemicals (figure 8).

Addressing the Problem The Montreal Protocol

Since the 1985 revelation of the ozone hole, global stratospheric ozone levels have continued to decline, and the Antarctic ozone hole has grown considerably larger. The magnitude of the problem is so large that even if we stop producing the offending compounds immediately, scientists estimate it will take several generations for concentrations of chlorine monoxide (the key molecule in ozone destruction) in the stratosphere to return to pre-ozone-hole levels. In spite of such distressing news, there is cause for guarded optimism. An international effort is underway which intends to help slow and eventually stop further ozone depletion and it appears to be having some effect. How did this unprecedented effort begin?

By the mid-1970s, many experts had grown convinced that chlorofluorocarbons (CFCs) and other similar compounds posed a serious threat to the ozone layer. In the U.S. - the world's largest producer and user of CFCs - the public called for the government to place limitations on these chemicals. Boycotts against items that used CFCs were launched, and some companies eliminated the compounds from their products. The U.S. government responded in 1979 by banning the sale of aerosol cans containing CFCs. Because spray cans represented the largest use of these chemicals, the ban led to an abrupt leveling off of CFC production.

But the U.S. ban on CFC propellants in spray cans caused only a temporary pause in the growing demand for the compounds. Worldwide use continued and by 1985, the production rate was growing by 3% a year. (A 3% growth rate means that production would double in about 23 years.) This increase brought the world's attention back to the threat of ozone depletion, prompting the 1985 signing of the Vienna Convention, an agreement to draw up a plan for worldwide action on this issue. Then, in May of 1985, British researchers reported the discovery of the ozone hole over Antarctica. This news spurred the nations of the world to action.

In 1987, diplomats from 24 nations, representing most of the industrialized world, forged a remarkable treaty, agreeing to set sharp limits on the use of CFCs and halons. In addition to such unprecedented international cooperation, the treaty marked a unique example of scientists and industry working with governments to seek a global solution to an environmental challenge. The Montreal Protocol on Substances that Deplete the Ozone Layer declared that by 1989, production of halocarbons (CFCs and halons) would be frozen at 1986 levels and then cut in half over the next decade. The framers of the Protocol also realized that their agreement might not suffice if future research revealed an even greater threat. So they included a provision calling for negotiators to reconvene periodically to examine new evidence that might necessitate deeper cuts.

Such evidence did indeed come to light, and several revisions have since been made. The 1990 London amendments and the 1992 Copenhagen amendments sped up the halocarbon phase out and controlled several other chemicals that were not

in the original agreement: methyl chloroform, carbon tetrachloride, methyl bromide, and HCFCs (hydrochlorofluorocarbons, replacements for CFCs which are less ozone-depleting than CFCs but not totally ozone-safe; HCFCs are also “greenhouse gases,” contributing to global warming). The revised agreement now calls for the phase-out of CFCs to be complete by 1996. The treaty also attempts to make the phase-outs fair to developing countries, which cannot easily afford to make the transition to higher-priced substitutes that will replace the banned compounds. The revised agreement sets up a fund - paid for by developed nations - to assist developing countries in making the switch.

Good News and Bad News About the Treaty

The good news is that the treaty is already beginning to have an effect. Significant decreases in the growth rates of CFC-11 and CFC-12, which together account for half the total chlorine monoxide in the stratosphere, were reported in August 1993. If the growth rates of these two CFCs continue to slow in line with predicted changes in industrial emissions, emissions should peak before the turn of the century and then begin to decline - sooner than predicted.

The bad news is that even if the treaty process continues to work, there will be elevated levels of chlorine and bromine compounds in the stratosphere able to continue catalyzing the destruction of ozone for generations to come, perhaps well into the 22nd century. So even though the response to the ozone problem is on track toward a solution, the effects of this human caused change to an important part of the Earth system will linger with unclear consequences to life on Earth.

Biodiversity loss

Of all the human-caused global change challenges we face, one of the most dramatic and irreversible is the increasing extinction of the world’s species. As with other issues in global change, extinction is a natural part of a changing Earth. However, the rate at which species are now facing extinction is cause for concern. Due to human activity, the current rate of extinction is far greater than the estimated natural rate of species extinction that has prevailed for millions of years. And unlike air or water pollution, or even deterioration of the ozone layer, loss of biodiversity is irreversible. Once a species is gone, you can’t get it back, because it took millions of years to become what it was. It is currently believed that we are losing perhaps as many as 10 to 20 species per day, up to 7,000 each year.

Biodiversity has to do with the variety of living things in an ecosystem. No one knows how many species exist on Earth, though current estimates range from 5 to 100 million. Only about one and a half million species have been catalogued to date. The large numbers of species now being forced to extinction by human activity has been likened to burning down the world’s greatest library before anyone had even catalogued, let alone read the books.

Habitat destruction

What do humans do to cause this great loss? People have cleared forests and other critical habitat to expand farming, ranching, mining, fishing, and other activities. When humans cut down forests to create grazing land for cattle, for example, species that depended on those sections of forests are eliminated or forced into smaller and smaller areas and may finally succumb to extinction. Take for example Western Ecuador, which once contained an estimated 8,000 to

10,000 plant species, about half of them endemic to the region. Each plant species supports between 10 and 30 animal species. Since 1960, nearly all the western Ecuadorian forests have been cleared for banana plantations, oil wells, and human settlements. The number of species lost in this area in just 25 years is estimated at 50,000.

Introduced Species

After habitat loss, the next most important factor in loss of biodiversity is biological invasion by non-indigenous organisms. Biological invasion occurs by accident and by design. The intentional introduction of a species for a particular purpose, such as a new agricultural crop, weed control, pest control, or erosion stabilization are invasions of the first type. Invasion by accident occurs where plants and animals are introduced without human design, such as the introduction of the Zebra mussel into the Great Lakes from the ballast water of ships from foreign ports. The mussels attach to and clog freshwater intake pipes that supply cities along the lakes. Billions of dollars are spent each year in attempting to deal with the unwanted effects of biological invasion, but how is it a threat to biodiversity and how is it a global change?

Much of the new disturbance of species by invaders is the byproduct of ever-increasing numbers and movement of human beings around the globe. Unique flora and fauna of islands and island continents like Australia is due to the long term biological isolation created by the physical separation of the continents beginning hundreds of millions of years ago. As continents drifted apart, the physical separation enabled separated species to evolve on different continents for millions of years in isolation. Once physically and biologically separated, the process of evolution began to fill similar habitats in unique ways. The marsupials are an example of this process, very different from mammals in form, less so in their ecosystem function.

Human activity has created artificial "bridges" between the continents and geographically isolated regions of the world through trade, tourism, and agricultural development. Human activity is blurring or homogenizing the flora and fauna of distinct geographic areas, but wouldn't new species in an area increase biodiversity?

Some invaders become dominant in their new environment and crowd out native species. In some unique situations, they are so successful at displacing the natives become extinct. As more of the land surface becomes altered by human activity, the displaced species has no other place to go with suitable conditions for survival.

The appreciation that global changes such as climate change, stratospheric ozone loss, tropospheric pollution, and land use change, affect biodiversity has increased over the last decade. The recognition of the value of biodiversity has led to a UN process similar to the Climate Convention, but with the issues of biodiversity as its focus.

The change in human population

Human activity on the planet drives global change. It took perhaps two million years to get from the beginning of the human era on Earth to a population of two billion. And then, in only 30 years, another billion people were added. Human population doubled, from 2.5 to 5 billion, in just 37 years, and it is now increasing by about 90 million people a year. Each month, the world adds the equivalent of the population of Switzerland. About 94% of this growth is occur-

ring in the developing countries, home to 78% of the world's population, where local life-support systems are often deteriorating as human demands exceed the capacity of available resources.

Earth's human population is expected to double again, topping ten billion in the next 50 years or so. Each human has energy and resource requirements that affect the Earth system. When these effects are taken in total the result is global change. Finding a sustainable path is a challenge today and a necessity in the coming century. Better understanding of population-environment dynamics is a critical area of global change research and one that unites the social and natural sciences.

Non-Human Influences

Were it not enough that human beings are causing significant change in Earth's systems, consider the fact that there are a multitude of non-human disturbances occurring as well. Variations in solar radiation, volcanic eruptions, earthquakes, meteor impacts, and other such planetary traumas can certainly throw a wrench into our "planetary management" efforts. As discussed, Mt. Pinatubo is a recent example that reminds us of the importance of change to the Earth system from natural causes. Though such events are completely out of our control, we must respond to their impacts nonetheless. The better we understand these phenomena, the better equipped we will be to prepare for and manage their effects.

The Challenge Ahead

As evidenced by major extinction events and the fossil record, extinction and the evolution of species is a process that marches forward with or without our influence. Fortunately many of the global changes discussed here are becoming better understood. With this knowledge comes the ability to make wiser choices and a better view of where we are heading. It seems especially important at this juncture for young people to learn about Earth systems and global change as a necessary step in building the capacity to care for generations to come.

Remote Sensing & Ground Truth Primer

An Introduction to Remote Sensing and Ground Truth

It is said that the human eye provides us with about 90% of the information we receive about our environment. As well as giving the most varied information, visual appearance is the only source of information at great distance, without the aid of complex instruments. Since we are so visually oriented, people have long been striving to develop technological means of continually expanding our ability to see.

Remote sensing is the process of obtaining information from a distance, especially from aircraft and satellites. Modern remote sensing technology has greatly expanded our ability to see and understand the Earth and its systems and to observe spatial patterns and change over time. Remote sensing has become a critical tool in activities ranging from the verification of arms control treaties to the provision of emergency aid to disaster-stricken regions. Through remote sensing we learn about problems such as droughts, famines, and floods; we obtain information about agricultural practices, weather conditions, transportation systems, river flows, and terrain changes. We use remote sensing to locate Earth's natural resources and can then use that information in their management.

Light and the Electromagnetic Spectrum

Because most of the data we receive from remote sensing comes to us in image form, the light which produces images is central to the process. Light gives us two different kinds of information about objects. Size, shape and texture are revealed by the way the object is illuminated and shadowed in relationship to the light source. The second kind of information comes mainly from the way light is absorbed and reflected by the object; this information shows up as the object's brightness and color.

Light is a form of electromagnetic radiation (figure 9). Only a small part of the electromagnetic spectrum is visible light. Wavelengths just shorter than visible are ultraviolet (UV) and wavelengths just longer than visible are infrared.

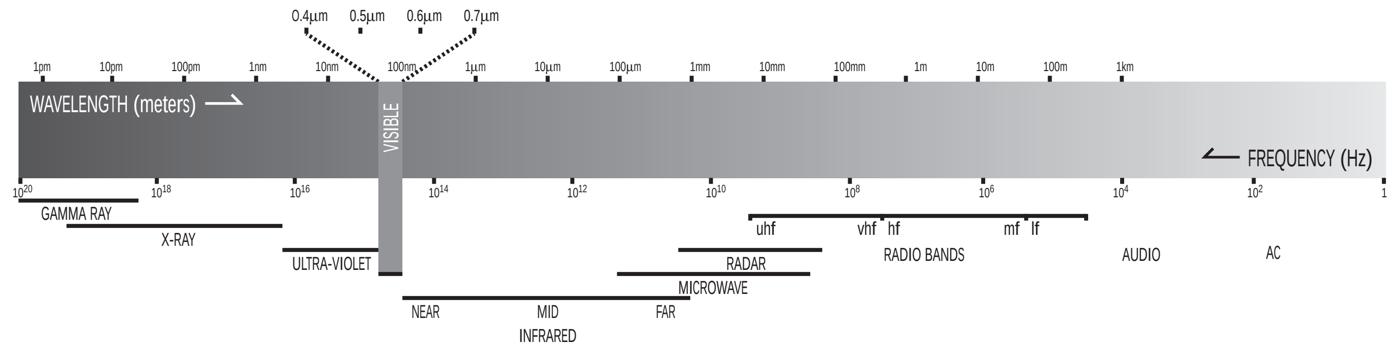


Figure 9
A diagram of the electromagnetic spectrum. It is important to note the location of visible light and that it occupies only a small portion of the electromagnetic spectrum.

Sensors

In the process of remote sensing, information about our environment is conveyed by electromagnetic energy and received and recorded by sensors. Most modern technological sensors have counterparts that occur in nature. For example, the photographic camera and the human eye both sense visible light; the microphone and the ear pick up sound waves; smoke alarms and noses both sense molecular dispersions we call odors. The sensors used in remote sensing are primarily sensitive to UV, visible, infrared, and microwave wavelengths; they sense and record data in these spectral bands. These data are then generally converted to image form for print or computer viewing and enhancement. Radar senses in the microwave region of the spectrum; the Landsat thematic mapper sensor senses in the visible and near to mid infrared.

Platforms

The physical platforms that carry sensors affect their capabilities and provide their perspectives. Platforms for remote sensing can be on land or in water, air or space. Aircraft platforms are typically flown at altitudes between 3,000 and 21,000 meters (figure 10). The data they deliver are either digital or photographic. The information we receive from space is generally digital and comes from NOAA weather satellites like GOES, earth resources satellites like Landsat and SPOT, and from manned missions such as the Space Shuttle. In the near future, information will also come from the SeaStar ocean color satellite, as well as the Earth Observing System (EOS) satellites, which will make a wide range of environmental measurements.

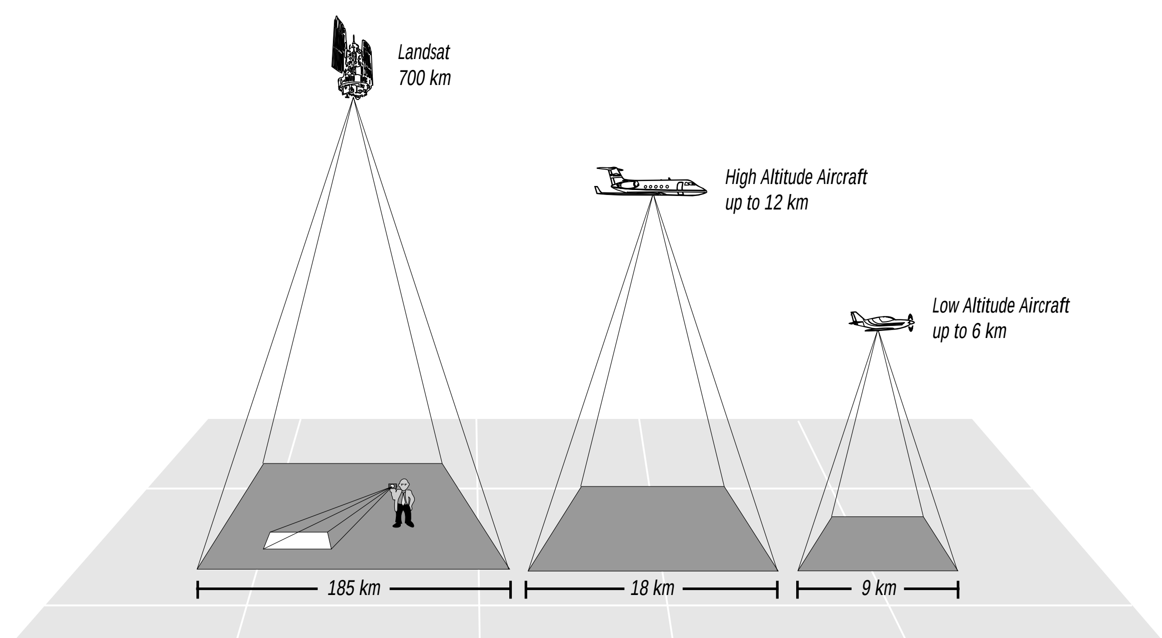


***Figure 10**:* Altitudes of three commonly used remote sensing platforms and the approximate width of their images.

Altitude, Scale, and Resolution

Several common characteristics of all images, regardless of the sensor from which they come, help us in understanding the information they can provide about land cover. Scale, the ratio between the size of the image of an object and the size of the actual object, is a primary concern. Spatial resolution of an image is closely related to scale. Spatial resolution refers to the smallest object that can be detected in an image, and is stated as a linear dimension (e.g., the AVHRR sensor has 1 kilometer resolution, whereas the SPOT panchromatic sensor has 10 meter resolution). Spectral resolution indicates the portion or band of the electromagnetic spectrum recorded by a sensor. Temporal resolution is the time interval between measurements of the same location on Earth. For example, Landsat views the same location every 16 days, whereas NOAA satellites view the same location every day, or even twice a day.

The spatial resolution of satellite images is determined by the size of the picture elements or pixels (figure 12, page 52). Pixels are like mosaic tiles or square puzzle pieces that are arranged in rows and columns to make up the whole image. All the information within each pixel is averaged together into a single value so that objects or features smaller than the size of the pixel are not distinguishable.

Processing Data

Data processing is the intermediate step between collecting remotely sensed data and using the information derived from it. Most data processing involves image enhancement and analysis. Images can be analog (photographic) or digital (electronic) - that is, continuous tone on photographic film, or digitized pixels of information stored on electronic media such as magnetic tape.

Analog and Digital

An analog image refers to an image in which variation in the object being sensed is represented by a continuous variation in image tone, such as in a photograph. Photographs capture large amounts of data all at once; however, they cannot be directly manipulated by a computer unless they are first converted to a digital format.

A digital image refers to an image made up of pixels where the average brightness or tone within each pixel is represented by a single number. The numbers are often simple counts in which the count indicates the brightness level of the pixel. When data are captured in discrete wavelength bands, each spectral band is a separate digital image (this kind of data is called multispectral). Electronic digital computer processing is generally more flexible and more quantitative than photographic processing.

Displaying the Information

Remotely sensed images are usually displayed as color prints or on computer screens. Three different spectral bands can be displayed simultaneously using three colors: red, green, and blue. When red, green and blue spectral bands are displayed using the same three colors, the result is a ‘true color’ image. However, when these three colors are used to

display different spectral bands, the image is called a 'false color' image. In color infrared photography, the color red is traditionally assigned to the near infrared band, which results in healthy vegetation showing up as vibrant red, because it radiates strongly in the infrared region of the spectrum. At first, one may be disoriented by the "false color" of color infrared images. There is a "standard" color key used in color infrared imagery, but a scientist studying a specific feature with a particular reflectance or emittance characteristic might choose to highlight these features by assigning different color codes.

Geographic Information Systems

Geographic Information Systems (GIS) use computers to combine remote sensing data with other information (e.g., topographic, political, cultural, economic, ground truth). In essence, a GIS is a way of managing Earth science data to bring out geographical interrelationships. Such systems provide powerful ways to use and compare remote sensing data. A satellite image of a country's vegetation can receive overlays of roads, district or county boundaries, population statistics, etc. In essence, a GIS is a database management system specifically designed for simultaneous processing of spatial data with many capabilities similar to automated map making.

Ground Truth

Ground truth refers to field observations and measurements which provide the link between remotely sensed data and the environmental information that is desired. Satellite data can often be ambiguous, since the information is based on radiation measurements with limited spatial and spectral resolution. For example, forests can usually be distinguished from fields, and sometimes the type of trees present (deciduous vs. conifers) can be inferred. Scientists may then visit a forest to verify that it is composed of pine trees. The field data gathered is called "ground truth." Such "ground truth" information may be used calibrate the remote sensing data for local conditions, and to interpret and analyze the data. It may also be used to validate the results of the interpretation and analysis process. Ground truth observations by students can be used to analyze aerial photographs and satellite images of their own location.

Teaching Remote Sensing and Ground Truth

Remotely sensed images may be used very successfully as educational tools with students of all ages. It is sometimes useful to begin with images closest to your neighborhood and progress to images obtained from greater distances. For example, start with hand-held photos and then move to low-altitude aerial photos, to high-altitude aerial photos, and then to satellite images. The false color may initially be confusing, but this can be quickly remedied by explaining that it is similar to assigning a color code to a map. When remotely sensed images are compared to maps, the effects of scale should be considered to avoid confusion about an object appearing larger on one than the other.

Remote sensing and ground truthing are activities that make use of knowledge and skills which students acquire from many traditional school subjects. Their improved ability to "see" and understand their world can bring them closer to experiencing the interdependence of all life and the complex systems of planet Earth.

Activities

Activities by Grade Level

Kindergarten through grade 3

Grade 4 through grade 6

Grade 7 through grade 12

** From Project WILD, adapted with permission*

Learning to Look, Looking to See —
Silent Walk

From Project WILD: adapted with permission. © 1983, 1985 Western Regional Environmental Education Council.

Age
Grades K-12

Subjects
Language Arts, Science, Social Studies, Art

Duration
45+ minutes

Skills
comparing, classifying, describing, discussion, inferring, listing, observation, predicting

Key Vocabulary
appreciate, see, sense, observe

Objectives
Students will be able to: 1) describe differences seen in an environment as the result of casual and detailed observations; and 2) give reasons for the importance of looking closely at any environment.

Method
Students list what they remember seeing in a familiar environment, check their accuracy, and discuss the results. Then they apply their experiences and new skills to an unfamiliar outdoor setting. It is very useful to repeat this activity several times, because students like to try to "get better" at it. Repeating it at different seasons produces interesting results which can be related to the seasonal differences detected by satellites.

Background
Looking and seeing are two entirely different processes depending on who we are, what we are concerned about, where we are located, and why we are looking. We look at our classrooms every school day, but if questioned about simple details, we often discover that we are totally unaware of certain objects, colors, sounds, and textures. As we walk through our neighborhoods, we probably notice only those things which are necessary to aid us in getting to our destination. We may not see a soaring bird even though we may be looking at the sky. We may not notice a community of ants, even though we are looking at the sidewalk. During a walk in the woods, we may leave the trail to see a tree better — and then not see the wildflower we trample, even though we are looking at the forest floor as we walk to the tree.

Each of us, however, can train ourselves to see or sense more. This takes at least three elements: 1) to learn to be a careful observer, **even if we do not have sight through our eyes**; 2) to be aware of our surroundings; and 3) to recognize any part of our environment as being part of a larger whole. As we enter a forest community, for example, we become part of that community in much the same way as we are part of our school or neighborhood communities. Thus, we are members of every community we enter. As a result, we have an opportunity and an obligation to see our neighbors and to be responsible members of each of these communities.

The major purpose of this activity is for students to be given an opportunity to enhance their powers of "seeing."

Materials
note pads, lapboards/clipboards

Procedure

1. Have your students pair off and sit back to back with their partners. Without looking, each student lists the color of their partner's eyes, hair color, etc., and a description of what they are wearing. After a few minutes, have them turn around and check to see if they were right.

2. Now practice seeing things. Cover a desk, bulletin board, or table with a large sheet before students come to class. Ask your students to list all the things they thought they saw there before the area was covered. When their lists are completed, ask them to turn over their papers. Remove the sheet. On the backside of their first lists, have your students make a new list of what they see. What kinds of things did they remember? What kinds of things were most often missed? Let them come up with reasons why they think this happened.

3. Take your students outdoors and have each pick a spot near a tree, fence, brook, field, etc. Each student should find a spot alone, at least 50 feet from the closest human neighbor. Allow 15 minutes for this solo, or approximately five minutes for younger students. **Your students should sense or "look" in the broad sense of the word — seeing, touching, listening, and smelling.**
They should record everything they "see." Fifteen minutes will provide time for an initial spurt of observations, a plateau, and then another spurt as they begin to realize how much they missed the first time around. (Younger children need only record in their minds; no need to write.)

Note: Our role as teachers is a difficult one in that we are most effective when we teach our students **how** to look and see, without telling them **what** to see.

4. Bring your students together for a discussion of the process they went through, as well as their list of sightings. Did they focus on any one area for a long time? Did they continue to shift their gaze? How did they focus their hearing and smelling? Cupping hands around their ears to simulate animal hearing has a dramatic effect on the ability to hear. Blindfolding seems to cause a compensation toward better hearing as well. Moistening the undersurface of the nose and the entire upper lip area increases smelling ability. Repeat the exercise using these suggestions. How are the results different?

5. Discuss the two statements: "Can't see the forest for the trees" and "Can't see the trees for the forest."

6. Talk with your students about the joy and importance of seeing as fully as we can — as a way of appreciating, respecting, and learning more about the world in which we live. Older students: Discuss the importance of careful observation of our environments beginning with the basis for our fundamental life support systems — air, water, land, plants, and animals.

7. Optional, with older students: Talk about the process of sensory attenuation as being a life-long process for each of us. We are always learning, and can learn even more. Sensing more in our surroundings can help us detect changes in our environment, cause us to become curious and ask questions, and help us to become better, more aware and informed decision-makers.

Extensions

1. Blur your eyes. What patterns and shapes do you see?
2. What else did you see? Any living things? What were they? Were they plant or animal?
3. Categorize what was observed as living/non-living — and/or as animal, plant, mineral.
4. Play the game "Animal, Vegetable, Mineral" or "What Am I?"
5. Repeat with different groups focusing on the different senses (sight, sound, smell, touch, etc.)

Discussion

Relating this activity to Remote Sensing and Ground Truthing.
It is difficult, often impossible, to see everything at once: to watch for birds in the sky while paying attention to ants, trees and wildflowers on the ground. We must often decide what we want to see before we can look for and find it. **Thus, the question we ask determines what we will find.**

Before scientists can "sense" the Earth, they must decide what it is they want to "see". The proper instruments and sensors must be developed and sent into space or put on an aircraft and flown over the area of interest. By carefully selecting the best instruments for recording the most relevant data, scientists can acquire the exact information they need.

Just as scientists develop better sensors to put on a satellite, we can train ourselves to become better observers, by paying better attention to our senses. We can become aware of a bird hidden by the leaves of a tree just by opening our ears to listen for its call. We can "see" not just the bird, but the species of tree it is in. We may notice a wildflower first by its perfume, or a change in the weather by a cool breeze or the sudden warmth of the Sun.

When we "ground truth" an area, we are able to "see" much of what may be missing in a remotely sensed image:

- An aerial image may indicate the presence of a forest; on the ground, we can determine the species of trees.
- A satellite may detect water; on the ground, we can determine whether it is a breeding site for disease-carrying mosquitoes.
- An infrared image may indicate uneven coloration of a crop, such as corn; on the ground, we can determine whether the crop is diseased or unevenly watered.

Armed with this information, we can make hypotheses about other, similar areas on the same or other images. For example:

- We can estimate the extent of oak forests.
- We can predict breeding sites of malaria mosquitoes.
- We can warn farmers of a regional outbreak of a corn pest.

Learning to Look, and Looking to See are essential elements of ground truthing.

Just Right: The Goldilocks Effect

Objectives

Students will be able to: 1) explain perspective, range and resolution; 2) explain how the optimal viewing zone varies with what it is they want to know—how the "Goldilocks Principle" applies: they can be too hot (too close), too cold (too far), or just right for any given investigation.

Method

Students view a large object such as a poster, store front, or even a brick wall from various distances and observe the difference in the information they can get from each perspective. The experiment can be repeated with arrangements of other common objects.

Background

The Goldilocks Effect is a term used by astronomers when comparing the distances from the Sun and the climates of Venus (too hot), Mars (too cold) and Earth (just right). Similarly, when aerial and satellite photographs are used to gather information about the Earth, the distance, range, and resolution of the pictures to be taken are determined by considering what data is required for the given investigation. For example, if you want to map forest cover, you do not need nor want to see each tree, and vice versa. In the activity, **Learning to Look, Looking to See**, students learned to turn on their sensors. In the "Goldilocks" experiment, students will grasp the concept that being closer is not necessarily better or more informative — the optimal point of observation, or perspective, depends upon what it is that you want to find out.

Age

Grades K-12

Subjects

Science, Math, Language Arts,

Duration

30-60 minutes

Skills

analysis, observation, prediction

Key Vocabulary

data, distance, perception, perspective, range, remote sensing, resolution

Materials

A large sign or poster, metric ruler or measuring tape, chalk, magnifying glass, note pads to record discoveries. For younger students, cookies or their names on tags as mentioned under procedure is a good variation.

Procedure

1. Set up a large poster, photograph or sign on an outside wall of the school at eye level, in a location that allows you to view the poster from far away (a gymnasium or a long hallway are a good indoor alternatives). Bring the class into view of the poster from so far away that they cannot tell what it is.
2. Have your students slowly approach the poster in small groups or one at a time. Have them approach in stages of an appropriate distance (maybe 10 meters or paces each time) and at each stage have them write

down what they see and what they think is on the poster. Have them continue until they can identify it. At that point, they should stop and mark the ground with chalk. They should then continue approaching the poster until they are so close they can no longer tell what it is. At this point, they mark the floor again. Finally, have them move right up to the poster and examine some detail of it with the magnifying glass and record what they see.

3. Students then measure the two distances from the poster. These distances define the range or "window" within which their "remote sensors" (eyes) are capable of gathering the most useful information. That window might be called the "Goldilocks Window" — not too hot, not too cold, but just right — for gathering information about the poster.

Discussion

1. Your students should discuss what kinds of information they observed from each of the various distances. They should try to frame questions that can be answered only from close up, but not from far away, vice-versa, and some questions that can be answered only from a medium distance.

2. You can then explain that when people want to know something about the Earth, they sometimes take pictures of it from airplanes and spaceships so they can get a perspective which is different from the one they have when looking at it from the ground. This is just like how your students got different perspectives on the poster from varying distances. Scientists gathering data by remote sensing do the same kind of exercise that your students just did. They figure out just how close or far away the camera needs to be to give them the information they want. Using analogies such as this, young students can begin to understand the concept of remote sensing and how it is used.

Extension

1. Give a slide show or show a video on the possibilities and limitations of remote sensing and the different "windows". A slide set and a video on remote sensing are available through the Aspen Global Change Institute.

2. Watch the video "Powers of Ten" and discuss the differences in perspective each power of ten reveals. (Available through most libraries, or order the VHS cassette "The Films of Charles & Roy Eames, Volume One, Powers of Ten" from Pyramid Film and Video, Box 1048, Santa Monica, CA 90406 / 800-421-2304)

Where Are You From A Bird's Eye View?

Age

Grades K-12

Subjects

Art, Geography, Science, Social Studies

Duration

One hour or longer depending on the number of images available

Skills

analysis, deciphering images, identifying similarities and differences, interpretation, making comparisons, map reading, observation, predicting land use trends, spatial relationships

Key Vocabulary

aerial photo, compare, ground truth, map, observe, remote sensing, representation, scale

Objectives

Students will be able to: 1) interpret an aerial photograph of their town and locate their school, neighborhood, and travel routes; 2) discuss and explain what kinds of information they can obtain from aerial photos.

Method

Students will first try to imagine what their school and neighborhood look like from "A Bird's Eye View" and draw a detailed picture. They will follow this with a study of an aerial photo of their town. They will compare their pictures with the aerial image and answer questions based on the information it supplies.

Background

We often have an idea of the area in which we live, but we rarely have the opportunity to test our "minds eye view" against accurate information. Even good maps are at best a stylized representation of our neighborhoods. Large scale aerial photographs of familiar surroundings help young students understand the concept of remote sensing. This kind of photography is remote, but not too remote, and being able to find places they see everyday makes the activity relevant and exciting for your students. This exercise should also help develop your students' geographical literacy.

It may be helpful to refer back to the **Primer on Remote Sensing,** at the front of this book, before beginning this activity. At first, the color infrared images may confuse your students, but with a small amount of coaching, and pointing out some familiar areas of vegetation, your students will quickly learn that red actually represents healthy vegetation.

Materials

Drawing materials; remotely sensed images of your area, including a large scale aerial photo of your town (one inch to 200 feet, or up to one inch to 10,000 feet would work—usually available from local or city planning office, the Soil Conservation Service, your County Extension Office, or the U. S. Geological Survey); any other maps or representations of your area and neighboring/connecting areas. For younger students, an acetate overlay of the aerial image, with important landmarks drawn on it. (See appendices for more information on how to obtain satellite and aerial images.)

Procedure

1. Mind's Eye View: Have students work in groups to draw a picture of the school and its surroundings as they imagine it would look from a "bird's eye view". The idea is to have your students imagine the site from a point directly above them, but some students may choose different perspectives. These differences in perspective should be encouraged and should be a point of discussion when the pictures are finished. Have your students pay attention to detail and scale.
2. After they have drawn and labeled reasonably detailed images, give them the aerial photos of their town. They should identify the orientation, find their neighborhoods, their school, parks, and other areas and buildings of relevance to them and compare it with their "mind's eye view" pictures. **Note -** for younger students, an acetate overlay of the aerial image, with important landmarks drawn on it, is often a good aid for recognizing the perspective.
3. Students should then answer the following questions from their observation of the photo: What season was it when the photo was taken? What time of day? What day of the week? Does it look the same as it does now?
4. Have your students show how they travel from home to school, from school to a friend's house and then home, to the store, etc. Have your students formulate other questions relevant to your area.

Discussion

Close this part of the activity by returning to the students' drawings and have them compare between groups and with the actual aerial photos. Your students should explain their purpose in the perspectives they chose and look at the differences in information available. Discuss how each perspective has its own value, and thus, the greater the number of perspectives, the more information is available.

Extensions

1. **Follow this up with the activity "Back to the Future".** Obtain two aerial photos of your town which show the same area — one taken about ten years ago and the other taken this year. Students should compare the two photos and identify any changes that have occurred, 10 items which are still the same and 10 items which have changed between the dates the two photos were taken. Follow this with a "ground truth investigation" — visiting some of the places that appear different in the two photos.
2. Compare the image with other representations of the same area, such as a topographic map, city street map, others.
3. Compare images in color infrared with black and white photos, true color photos, X-ray images, etc. and discuss the different kinds of information available in these different images.

Sandboxes & Satellites

Age
Grades K-12

Subjects
Geography, Social Studies, Science

Duration
Several hours or class periods.

Skills
group planning, mapping, modeling, observation, spatial relationships

Key Vocabulary
dimension, map, model, perspective, scale, spatial relationships, surface, terrain, topography, 3-D representation

Objectives
Students will be able to: 1) discuss how reality is represented by maps and models; 2) recognize and determine spatial and size relationships between objects; 3) design and create their own maps and models.

Method
Students will recreate their school grounds in a sandbox, with clay inside a large shallow box, or with a cardboard model. They will then photograph or video tape their model from above and from the sides. They can also observe the school grounds from a window on an upper floor to gain different perspectives of the topography.

Background
It is evident that many people in our society lack basic geographical skills. This activity will help your students gain an understanding of topography, spatial relationships, mapping, and modeling, helping them attain a measure of geographical literacy. Recognizing relationships between objects and seeing how they can be represented in maps and models is also a first step toward understanding how scientists use various means of sensing our environment in order to learn more about it.

Materials
Sandbox or clay, Polaroid camera with color and black and white film or a video camera and TV for playback, paper, crayons, markers, pencils, a ladder, an aerial photo of your area including the school.

Procedure
1. Explain to your students that they will be making a three dimensional model of their school and its surroundings. Team your students in small groups and have them walk around school grounds, carefully observing and noting the terrain, objects, and their spatial relationships. Ask them to recreate the school grounds in a sandbox or with clay. They should take turns building representations of different objects within the complete model, with the other students in the group acting as a reality check on the builder by asking questions such as: Is that the right scale (the right size in relation to the other objects)? Is that in correct spatial relationship to the other objects (in the right place)?

2. When the models are finished, your students should use remote sensing (video tape or photograph) to capture images of their model. Images should be made from above and from the sides, changing the 3-dimensional representation into 2 dimensions and obtaining various perspectives. Students can also draw pictures that represent the grounds. Use ladders and balconies to observe, draw, and photograph the grounds to get additional perspectives.

3. Look at an aerial photo of the area, including the school and its grounds and compare it with the students' remotely sensed images. Your students should pay attention to how their photos and maps fit into this larger one, and gain a broader, more regional perspective.

Extension

1. This activity can be followed with an introduction into surveying techniques:

Students (7-12 grades) can use "plane table mapping" to make a highly accurate 2-dimensional representation of the school grounds. This technique was used by the British to map the entire Indian sub-continent.

Students can also use the "T-stick method" of adding topographic relief to their maps. This technique was developed by the Egyptians for mapping their fields following the annual Nile floods.

Books on these techniques may be found under **surveying** in the library.

Evaluation

1. The groups of students should share their models and maps, comparing and discussing them with the larger group. Some possible questions to consider: Why does one model look different from another if they are based on the same reality? Why would someone represent a particular object as bigger or smaller than someone else? Do the photographs vary from group to group? Why or why not? What uses might the models and maps serve? What kinds of questions can be answered by each of the different kinds of representations: maps, models, and photographs?

Digital Faces

How Satellites See

Objectives

Students will be able to: 1) digitize and interpret photos; 2) recognize and begin to interpret remotely sensed images, such as aerial photos and satellite images; 3) understand the significance of computers in satellite imaging; 4) determine the range and resolution necessary for given investigations.

Method

Students will bring in a photo of themselves or some other person. Use simple, high contrast photos. Students will "digitize" the photos using various grid sizes and shades of gray to gain an understanding of image resolution and how much information is needed to answer various questions. In part two, students will observe satellite and aerial images and extend the understanding they have gained to interpreting these images. It is important to follow this activity with **Zooming In** and **Ground Truthing Your Image.**

Age

Grades 4-12

Subjects

Science, Math, Art, Language Art

Duration

At least two one-hour class periods, part may be assigned as homework

Skills

analysis, drawing, graphing, interpretation, observation

Key Vocabulary

analog, digital, digitize, grid, pixel, range, remote sensing, resolution, scale

Background

Remote sensing, for the purposes of this activity, means obtaining information about the Earth's surface and atmosphere from airborne or space-borne sensing instruments. Remotely sensed images are produced at various resolutions, depending on their intended use. The proper range and resolution are critical if the images are to be useful. Limited data will not answer the questions posed, while too much data can be confusing and wastes valuable computer time and storage space. Simply put, enough is enough. If one wants to view a forest, for example, one does not need, nor want, to see each tree.

There are many examples of this is daily life. When viewing a billboard on the highway, there are various levels of information we can gather from the sign, depending upon our position. When far away, we can see that it is a billboard, but we can't tell what it says — so there is a level of recognition, but it is not complete. At the optimal distance, we can tell it is a sign and can read what it says. When we are very close to it, we can again see that it is a sign, but we cannot read it. So, we need to be neither too close nor too far away to see the entire message. When too close or too far away from something, we cannot get a perspective on the whole thing (see **Goldilocks Effect** activity). There is more to interpreting images, however, than resolution. There are also visual cues that aid our understanding. Students will discover what some of these cues are, both in the faces they draw and in the aerial and satellite images they observe.

Materials

For Part I: Large (8"x10") black and white head shots of students (pictures of themselves as younger children are often a good subject), or full-page black and white magazine photos of famous faces. A copying machine that can reduce and enlarge, transparencies to make various size grids on transparencies, graph paper, pencils.

Procedure

1. Each student selects a photo and lays a 1/8 inch or 1/4 inch grid over it. They set this image next to a piece of 1/4 inch graph paper and set up an identical system of coordinates on the x and y axes, one on the photo and one on the blank graph paper.

2. The students then transfer the image onto graph paper, simplifying the image into boxes and all of its shades into three tones: the lightest colors become white (leave paper blank), the middle tones become gray (color lightly with pencil or a light color), and the darkest third of the shades become black (color heavily with pencil or a dark color). If a particular pixel (box) is approximately half white and half black, it should be averaged to become gray. If a pixel is more black than white it becomes black. And likewise, if a pixel is more white than black, it becomes white. This represents a digitizing process in three shades of gray. **Note:** Students should avoid the temptation to "make it look right" by, for example, making the eyes stand out; they should pretend to be digitizing robots, simply averaging each pixel, selecting the proper shade and filling it in. **Variation:** Instead of using just white, gray and black, students could use three different colors. It is best to use colors which contrast strongly with each other, like red, blue and green. This can be likened to "false color" photography.

Students may find it easier to go down one row at a time, from left to right, using a ruler, scanning and filling in each subsequent box in the row, just like a computer. It is also possible to let students work in teams, one as scanner, one as digitizer. The scanner will call out the x-y coordinates and the shade value (white, gray, black), and the digitizer will fill in the pixels on a separate grid.

For younger students, a numbered grid can be prepared beforehand, with the individual grid squares coded with different numbers which correspond to different colors to form an image of some well know image, such as Waldo or Mickey Mouse. Assign colored squares to the children and have them match them to grid locations called out by the teacher or have them match them to coded numbers on the grid. Then see who can first recognize the image.

3. Allow students about 30 minutes to get the hang of it and to see how far they get. The rest may be assigned as homework to save classroom time.

4. When they are finished, your students should observe the image they have created and analyze it. At this resolution, does the image offer enough information? That depends on the questions you want to answer!

Have your students pose different questions and consider whether their image answers each question. For example: Is the image recognizable? Can you tell it is a face? Can you tell who it is? Can you tell what or who it is by viewing it from across the classroom?

5. For the second class period, the students lay a finer - 1/8 inch - grid (more pixels) over the photo and perform the experiment again. (If this is too difficult for some of the younger students, say grades 4-6, you could do this part of the activity on a board or overhead projector with your students gathered around to help and observe.) Another way your students can add more information to their images, besides changing grid size, is to add more tonal values by making several shades of gray. The students continue adding information by increasing the number of tones and number of pixels until they can tell who the person in the photo is. The students can then analyze what questions could be answered by the images they create at each level of detail.

Extension

Use your students' digitized images to make a poster to display in the school, explaining the steps and showing the final products.

Figure 11 and 12 show the effect of digitization and how the information content of an image changes at lower resolution.

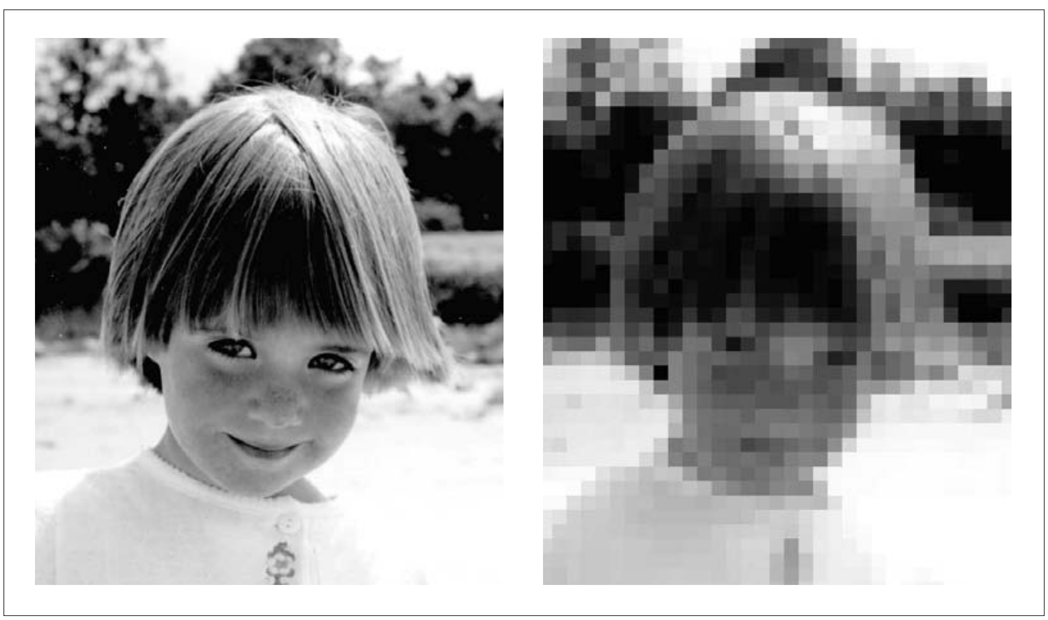


Figure 11*:* An example of a digitized photograph.

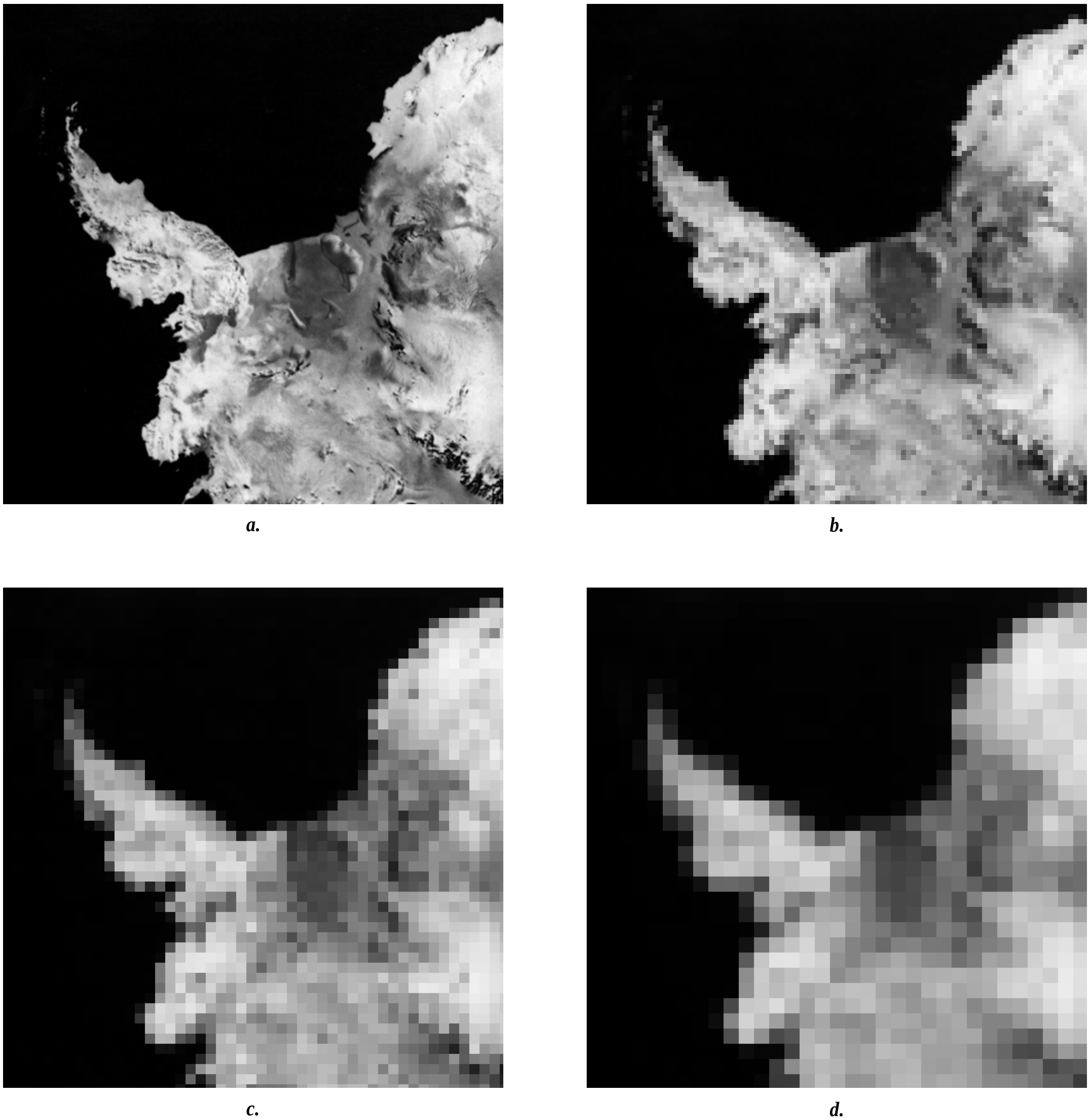


Figure 12
The image on the upper left is a satellite mosaic of the Antarctic Peninsula from NOAA/AVHRR data. Each subsequent image (b-d) shows the effect of decreasing resolution on the information content of the image.

Zooming In

Objectives
Students will be able to: 1) discuss how reality is represented by maps and models; 2) recognize and determine spatial and size relationships between Earth features and human objects, and; 3) design and create their own maps and models.

Method
Students explore the aerial and satellite images provided in the handbook. Using images of different resolution and scale, they are asked to identify specific features on each image, and compare and contrast the images.

Age
Grades K-12

Subjects
Geography, Science, Social Studies

Duration
One hour class period or longer

Skills
analysis, interpretation, spatial relationships

Key Vocabulary
human impacts, land use, scale, resolution, watershed

Background
The use of aerial photography and satellite imagery represents a major breakthrough in our ability to learn about and understand our global environment. For the first time in history, via imagery from space, humankind looks upon our planetary home as a whole, recognizing the fragility of the Earth amid the vastness of outer space. Conspicuously absent are the political boundary lines demarcating our self-imposed separations. This powerful technology gives us a unique perspective, enabling us to see the broad brush-strokes of the planet and our activities upon it.

An important concept of remote sensing is the understanding that different scales and resolutions provide different types of information. Looking at a tree while standing next to it provides an incredible amount of subtle information about it, but very little about its relation to the rest of the forest. An aerial photograph provides a much better view of the forest, yet relatively little about the single tree or the region the forest is located in. Likewise, a satellite image provides an incredible understanding about how the forest relates to its entire region, yet provides little detailed information about either the single forest or single tree. This concept of scale and resolution, of course, applies to all aspects of Earth; i.e. cities, farmland, oceans, etc. The scale and resolution of an image determines what can be learned from each perspective.

We recommend that you view the film or video "Powers of Ten" by Charles and Ray Eames. This is an adventure in magnitudes. Starting at a picnic by the lakeside in Chicago, this famous film transports you out to the edges of the universe and in to the micro-world of cells, molecules, and atoms. This video is available from Pyramid Film and Video (2801 Colorado Avenue, Santa Monica, CA 90404; 213-828-7577), and is highly recommended as a very easy and fun way to grasp the concept of scale.

The following images explain this concept in the same essential way, although not to such detail. Each of these four color images, plus the image on the cover of the Handbook, provides an incredible amount of information, but at different scales and resolutions. Therefore, each image offers a different type and quality of information. Students often find this exercise exciting, as they zoom in closer and closer to "home." These are a set of generic images, culminating in a very close look at San Francisco, California. This same exercise can, of course, be duplicated using local images directly relevant to your students. For assistance in obtaining such images for your class, please contact us directly, or consult the "Sources of Remote Sensing Imagery" appendix in the back of this handbook. It should be noted that these images are not true "Powers of Ten," but nevertheless do explain the same concept.

For the micro-scale view, it is only necessary to step outside and ground truth your images.

A Note About the Colors

With practice it is possible to distinguish between various land classes, such as undeveloped land, urban and agricultural areas and to make further inferences about remotely sensed images. The colors allow you to appreciate and interpret the imagery, and the following color definitions for a typical false color image will aid you and your students in this exciting exploration.
Note: these color definitions do not work for all false color images. (From: Educator's Guide for Mission to Planet Earth, by Margaret Tindal, NASA Goddard Space Flight Center, 1978).

Red to magenta - denotes vigorous vegetation, i.e. forests, farmlands (agriculture) near peak growth.

Pink - depicts less densely vegetated areas and/or vegetation in an early state of growth. Suburban areas around major cities with their green lawns and scattered trees normally show up pink.

White - areas of little or no vegetation but of maximum reflectance. White areas include: snow, clouds, deserts, salt flats, ground scarring, fallow fields, and sandy beaches.

Dark blue to black - normally identifies water, i.e. rivers, streams, lakes, the oceans. In the western U. S., however, particularly in Idaho and New Mexico, very dense black features are often ancient lava flows, rather than bodies of water.

Gray to steel blue-gray - indicates towns, cities, urban populated areas. These colors are produced by the reflectance from asphalt, concrete and other artificial features.

Light blue in water areas - denotes either very shallow water or heavily sedimented water.

Light blue in western areas - identifies desert scrubland capable of supporting limited vegetation.

Brown, tan and gold - indicates areas comprised primarily of open woodlands (piñon, juniper, aspen, chaparral).

Color Image Activities

North and Central America

(image source: TSW)

Description

This is a satellite image of North and Central America (with part of the Arctic) and covers an area of approximately 63,000,000 square miles. The scene was recorded by an electronic sensor known as the Advanced Very High Resolution Radiometer (AVHRR) onboard NOAA 9-11 weather satellites, from an altitude of approximately 840 km (520 miles), and a resolution of 1 kilometer by 1 kilometer. This entire image is a mosaic, or composite, of many AVHRR images recorded between December 1985 and July 1989.

Since the AVHRR sensor can detect wavelengths of light beyond the visible light spectrum, information about the Earth's surface that is normally invisible to the human eye can be displayed as false-color composites. Healthy, actively growing vegetation appears in vibrant reds. This is representative of the strong chlorophyll reflectance within the thermal infrared wavelengths. These wavelengths are longer than the band we experience as visible light. Water appears in black, while desert and snow appear white.

Procedure

Beginning without the aid of a map, ask your students to determine what features they can locate on this image. To begin with, try to find the location of your state and your city. How confidently can your students identify exactly where your city is located? Why? Can they actually see your city on the image? If an alien was looking at this image, would it be able to detect any human activity at this scale?

Some major geographic features can be identified without a map. Where are the Great Lakes? Can your students name them? Try to find the Great Salt Lake and Lake Okeechobee, or Great Slave Lake, Great Bear Lake and Lake Winnipeg in Canada. Can they pick out Lake Tahoe and Lake Powell in the West? What size are these lakes?

Locate the Rocky Mountains and the Appalachian Mountains. Can they distinguish the smaller mountain ranges within these two major ranges? Can they tell higher ground from lower areas?

Identify major rivers and trace the watersheds of the Mississippi and the St. Lawrence. Can your students find the drainage system of the Colorado River, the Columbia, the Rio Grande, or the Yukon? Locate the drainage system of your local river. Where does it flow from and where does it go?

Locate the following coastal features on the image: Hudson Bay and James Bay, Chesapeake Bay and Delaware Bay, San Francisco Bay and Monterey Bay. Can they locate Long Island, Cape Cod and Nantucket Island, or Vancouver Island?

Based on the information given in "A Note About the Colors," have your students explain the differences in color on the image. Outline areas of different terrain and vegetation. Separate densely vegetated areas (red) from the deserts and mountains (white and gray). Can they locate areas with permanent snow and ice? How can they tell these areas apart from the deserts?

National and state boundaries are not present on this image. Can the students identify the Canadian and Mexican borders? How sure are they? Can they locate the Central American countries: Guatemala, El Salvador, Nicaragua, Costa Rica, Panama? How about Cuba, Haiti and the Dominican Republic on Hispaniola Island, Jamaica, Puerto Rico or the Bahamas?

An excellent writing exercise is to ask the students to write a response to the question: "What was your first impression when looking at this image without national or state borders marked on it?"

Now let the students compare the satellite image with a map of North America in an Atlas. How similar or different are they? What differences are immediately obvious? Check the answers students gave before with the information on the map. At this scale they will find it difficult to locate smaller features precisely, especially specific cities, except by finding their geographic locations, such as San Francisco on San Francisco Bay, or New York City at Long Island, and Detroit by Lake Saint Clair.

Continental United States

(image source: EROS Data Center)

Description

This is a satellite image of the continental United States. Like the previous image, it is a false color composite mosaic of AVHRR images. The images were collected over a two year period from 24 May 1984 to 14 May 1986. The spectral bands displayed are the same, so healthy vegetation still appears in vibrant reds, but in this image, much, although not all, water has been specially coded to blue, making it easier to pick out lakes and waterways. The resolution in this image is the same as in the previous image (1 km by 1 km), because it was taken by the same sensors. Therefore, it also contains the same amount of information as the previous image, but it is much enlarged, so it is possible to make out more detail. This image has also been overlaid with the state boundaries and cropped at the Mexican and Canadian borders.

Procedure

First of all, if you are in an area covered by this image, locate the area in which your students live and go to school. If you aren't in the continental United States, have your students pick an area about which they know something, or would like to learn more. Can they actually pick out your city? Could our alien now detect any human activity in your area at this scale?

Indeed, it probably could. Very large cities, such as New York City, Chicago, Los Angeles, etc. show up as a light gray or blue-gray spot on the image. Small cities are unlikely to be visible, yet it is now possible to detect human influences on the landscape. As noted before, healthy vegetation shows up vibrant red. In this image, it is possible to detect human agricultural systems quite easily. At first, point out bright red areas along major river systems in the west, such as along the Arkansas River, running West to East in eastern Colorado, or the area just south of the Salton Sea, above the Mexican border with California. There they will see the bright red which indicates healthy vegetation in well irrigated agricultural fields. Using these areas as clues, can they find other areas which indicate agriculture?

What other features can your students identify at this scale? Watersheds and mountain ranges are more apparent, and state boundaries follow many watercourses. Several artificial water reservoirs are also conspicuous at this scale and resolution. For example, using a map and the image, ask your students to locate Lake Powell in Utah, Fort Peck Lake in Montana, or Lake Sakakawea in North Dakota. Can they locate natural and artificial features near your area on the image?

As a writing exercise or discussion, ask your students to respond to the question: "How do you think state boundaries were drawn? Do they correspond with natural features, or do they appear to have been made with other considerations in mind?" For example, ask them to compare the state boundaries of Virginia with those of Colorado.

The student should be able to outline major watersheds and differences in color and attempt to explain these differences. For example, why is the western region of the United States blotched with gray and white, while the eastern region is so red? What explains the bluish color of southern Florida, or the bright white patterns in Colorado, Wyoming, Idaho and other western states?

UNITED STATES AVHRR MOSAIC

U.S. GEOLOGICAL SURVEY

EROS DATA CENTER

San Francisco Bay Region

(image source: ERIM)

Description

This view of the Bay area around San Francisco, California is an enlargement of part of a Landsat multispectral scanner (MSS) image taken from an altitude of 700 km (438 miles), in the late 1970s. The MSS sensor records electromagnetic radiation in the green and red (visible light) and two infrared spectral regions and has a resolution of about 80 meters (250 feet). MSS images are more than 150 times sharper than those of the AVHRR and a wealth of detail is available. In fact, linear features as narrow as 10 meters are sometimes visible where they are in sharp contrast with their surroundings (e.g. bridges over water or dirt roads passing through dark brush). Like all the images in this book, this one is a false color infrared.

Procedure

Familiarize yourself with the San Francisco Bay area by checking conventional maps or atlases and other source materials and use the following information to explore the image with your students.

Urban development, which is indicated by gray to blue-gray, is prominent in this view and reveals several well known cities: San Francisco, on the northern tip of the peninsula; Oakland, across the straits from San Francisco; and San Jose, at the southern tip of the Bay. The Golden Gate Bridge connects the Presidio in San Francisco with the Marin Headlands to the North. At least three other bridges are visible in the image: the Richmond-San Rafael Bridge across the San Pablo Strait; the San Francisco - Oakland Bay Bridge (which partly collapsed in the earthquake of October, 1989) that also connects with Treasure Island ; and the San Mateo Bridge across the southern Bay. Landfills and salt evaporation pans show up emerald green in the south part of the Bay and at least three airports, including the NASA base at Moffett Field, are also visible.

The scale of this image can be estimated by taking a measurement of an object of known size and then using it to calculate the scale. Once the scale is known, it is equally possible to determine the approximate size of objects in the image. For example, using the Golden Gate Bridge as a yardstick (a six-lane highway, 2,824 meters or 3,089 yards long), measure the size of various features. (e.g., How long are the other bridges? What is the area of this image? How long is Golden Gate Park?)

The region includes a diversity of farm products, including lettuce, tomatoes and grapes in the Santa Clara, Salinas and Great Valleys. The Sacramento Valley is used almost entirely for rice, cotton, barley and other cash crops. Since this image was recorded, this area has suffered a terrible drought beginning in 1986. Knowing this, how would this image be different if taken today?

Geologically, the area contains the Calaveras and San Andreas faults. The infamous San Andreas fault can be seen south of San Francisco where the long, linear reservoirs highlight it at the base of the Santa Cruz mountains. Also evident are the intricately folded coastal mountains with their many watersheds. The Sacramento River enters the Bay in the northeast corner of the image. The bay also contains several easily identifiable islands. Can your students find Angel Island, Treasure Island, or notorious Alcatraz? Just north of the Golden Gate Bridge lies Muir Woods, named for the famous naturalist; a national monument protecting the Redwood Forest. The Santa Cruz mountains contain the southern-most Redwood forest, indicated by the deep reds, along the California coast. The hills to the north, south and east of the Bay area support California Oaks and Evergreens, mixed with Chaparral in places. Recent fires in the Chaparral have caused the loss of many homes.

The Presidio, San Francisco, California

(image source: Eros Data Center)

Description

This final image is a color infrared (CIR) photograph taken from an aircraft flying at an altitude of 20, 000 feet in June of 1987. It shows a very detailed view of the northern area of San Francisco and the Golden Gate Bridge. Such aerial photographs reveal an enormous amount of detail about a very limited area. Similar color infrared photos are available for all of the United States, including the area where you live, and are suggested for use with this handbook.

Procedure

At this resolution and scale, buildings, cars on the streets and parking lots, ships in the bay, and individual trees in the parks are clearly visible. Can your students identify Fort Point, at the base of the Golden Gate Bridge? Can they pick out the Presidio Army Golf course? How can they tell it is a golf course? The San Francisco Palace of Fine Arts is a large crescent shaped building. Have the students locate it on the image.

Ask the students to become very specific about what they can see. For example, using the Golden Gate Bridge (2,824 m. long) as a measuring stick to determine scale, ask your students to estimate the area of Alcatraz Island and the lengths of some of the ships in the image. How many kilometers to the east of the Golden Gate Bridge is Fisherman's Wharf (at the eastern edge of the image). The streets are very evenly spaced, so what are the dimensions of a city block in the city of San Francisco? What proportion of the city is made up of parks and green spaces? Can they make out baseball diamonds or football fields? What keys can they use to determine these features? The University of San Francisco is on the image—can they find it? What cues did they use? It is possible to estimate the time of day at which the photo was taken from shadows of tall objects, such as buildings or the Golden Gate Bridge. What can your students tell about wave conditions and the direction the wind was blowing when this photo was taken?

To the North of the Golden Gate Bridge is the Marin Peninsula and the Muir Woods National Monument. Do the areas of San Francisco and the Marin Headlands appear to be flat or mountainous? Ask your students to compare the woods with the vegetation visible within the city. Can they tell the difference between dense forests and grassy areas? Have them compare the golf courses with parks of the city and the National Park. Based on the information given in "A Note About the Colors", have your students explain the differences in color on the image, especially the different shades of red and pink. What might explain these differences? Remember that California has been experiencing a prolonged drought. On sheets of acetate, have the students outline areas of different terrain, vegetation, urban areas, and major highway corridors. Given their knowledge of San Francisco based on these images, where would your students like to live?

Handbook Cover

Turkey Point and the Everglades, Florida

(image source: ERIM)

Description

The striking image on the front and back cover of this Handbook is a Landsat image showing the Turkey Point area, south of Miami, and a portion of the Everglades. The scene was recorded by an electronic sensor known as the Thematic Mapper (TM) on board Landsat 5, at an altitude of 700 km (435 miles), with a resolution of 30 meters (98 feet). Note the difference in resolution between this Landsat TM image and the Landsat MSS image of the San Francisco Bay area.

Exploring the Image

Use this image with your students to explore an area very different from that of the San Francisco Bay area. Ask them to use the skills they have developed to interpret this striking image. What conclusions can they draw about the nature of city development and natural systems in this area? What would be the consequences of a radiation leak at the Turkey Point nuclear power plant to the residents of the area? What effect will further road building and development have on the Everglades? What effect would rising sea levels, associated with global warming, have on these communities?

This area of Florida encompasses climates, vegetative habitats, and economic pursuits not found elsewhere in the continental United States. Most of the land surface is at or near sea level, reflecting its youthful age in terms of its emergence from the seas that once covered all of mainland Florida.

This image contains a number of interesting natural and artificial features for your students to examine. In the Everglades, for example, vast expanses of sawgrass (the darker colored areas) are interspersed with hammocks ("tree islands") - slightly higher land covered with hardwood trees. The splotches of intense red occurring in long, arcing patterns represent the hammocks and show the natural flow of water through the Everglades. Mangrove swamps are confined to the coastal areas and show up brilliant red against the dark blue of the ocean waters. Note, too, the light blue streaks that delineate the great coral reef that is part of the Florida Keys. Key Largo is the red island off the coast.

The image clearly shows how humans are encroaching on the Everglades: the many dark blue inland areas, surrounded by white, are gravel pits which provide landfill and construction materials for new developments. The regular patchwork of red, gray and white is the development of new areas south of Miami. The grid of canals forming the cooling system for the Turkey Point nuclear power plant on Biscayne Bay is strikingly apparent, as are the runways of Homestead Air Force Base to its northwest.

Evaluation

Before you leave the color images, have your students go back to the previous images and report whether they can now find more detail in the satellite images than they had found during their first investigations. As a writing exercise, ask the students to answer the questions: 1) How does comparing between images of different scales and resolutions add to your ability to interpret all of the images? 2) How would being able to ground truth the sites on the image affect your ability to correctly interpret the images?

Conclusion

These images are beautiful and fun to look at, but so what? Why is remote sensing important?

Remote sensing provides a unique tool for the study of both the Earth as a whole and its respective parts. The applications are almost limitless, as almost every field and every discipline can potentially benefit from its use. For example, in Earth Science, one can identify and study drainage patterns, glaciers, volcanoes and their impacts, and map surface and tectonic features. In Environmental Studies, one can identify and map categories of land use, study human impacts on the environment, and observe change over time. In Social and Urban Studies, remote sensing can be used to study urban size and function, urban form and structure, significant social issues, historical and political events, and economic activities.

A vast amount of information is already available for your locality using this technology. It is certainly possible for you and your students to study and track many aspects of your area; development, habitat, population increase, agricultural seasons, etc., just to name a few. Similar data exists for almost every other point on Earth. This allows you to make the connection from local conditions to regional and global perspectives. It also makes discussion of environmental issues far more meaningful; i.e. studying a satellite image of rainforest deforestation.

For more information about the many applications of remote sensing, please refer to the “Image Application Chart,” the “Bibliography of Suggested Reading,” and the “Sources of Remote Sensing Imagery” found in the back of this handbook. For assistance in obtaining images for your class, please contact AGCI directly, or consult the “Sources of Remote Sensing Imagery” mentioned above.

Ground Truthing Your Image

Age
Grades 4 -12

Subjects
Geography, Science, Math

Duration
Two or more class periods combined with field trips

Skills
analysis, image interpretation, soil and plant identification

Vocabulary
botanical names, clues, cues, keys, vegetative cover

Objectives
The students will be able to: 1) demonstrate an understanding of how resolution affects information content on remotely sensed images; 2) relate their digitizing activity to the information content of the satellite image; 3) interpret remotely sense images and verify them using ground truthing techniques; 4) relate remote sensor resolution (pixel size) to information content; and 5) gain an understanding of the information content of different kinds of remote sensing imagery.

Method
First, the students examine aerial or satellite images of your school area in much the same way that they analyzed the digital faces they created. How many pixels? How many tonal values? What kinds of questions can be answered from the images at the given resolutions? What kinds of questions would require greater resolution? Less resolution? What resolution is needed for what studies?

Second, students use the image of the area surrounding your school to identify features as specifically as possible (i.e., the school playing fields, a stand of pine and oak trees near the school or individual trees, a pond in a neighborhood park, grocery store parking lot with how many cars, dirt or paved roads, etc.)

Third, the students take field trips to "ground truth" their interpretation of the images. During these field trips, students will classify as specifically as possible the areas they visit. For example, they should identify the structure and species of trees in a wood, or the amount of bare soil and grass on the playing field, or whether a parking lot is asphalt or concrete.

Finally, the students will mark out pixels on the ground which correspond to the sizes of actual image pixels. They will also compare their view of the pixel and the image the satellite scanner or aircraft camera records (bird's eye view).

Materials
Aerial photos of the vicinity of the school; satellite images of Earth, preferably including the area of the school (the images provided with this handbook provide good starting examples of different views of the same area); magnifying glasses (2x, 5x and 10x); photographs, magazine and newspaper pictures. For the field trips, bring plant identification books (or a local naturalist), some long tape measures (100 meters if possible), and journals or notebooks to record the observations.

Procedure

1. Look at aerial photos of the area surrounding your school. Aerial photos are another kind of remote sensing, taken closer to the subject than satellite images. Identify neighborhoods, the school and grounds, bodies of water, highways and other landmarks. Students may wish to compare a current aerial photo with one taken many years ago. Observe natural and human-caused changes in the landscape and discuss these changes. Do the same with satellite images. How do the two images differ?

2. Look at all three types of images you now have before you: the student digitized images, the aerial photos, and the satellite images. What are the visual "keys", "clues" or "cues" that you use to help interpret the images?—Keys unlock things; clues are bits of evidence that help solve a puzzle; cues are information that prompt understanding. You may notice that eyes are a key in recognizing a face, bodies of water are keys in aerial photos of a landscape, and bodies of land and water are keys in satellite images. Students should identify as many features as they can and be specific about what these features represent (i.e., park, duck pond, the shopping mall at 43rd Street with parking for 5000 cars, a little league baseball diamond, etc.). Students can "read" the images and discuss what helps them understand and interpret what they are seeing.

3. Use the magnifying glasses to compare regular photographs to magazine and newspaper photos under different magnifications. At between 5x and 10x students should start to see the dots of the newspaper and magazine images. These are similar to the pixels of the digital satellite images. Is the printed page higher or lower resolution than a photograph? Compare some color prints using the same magnifications as above. You will see much less graininess. Photography relies on minute chemical crystals which react to different wavelengths of light. Faster speed films (such as ASA 400 or more) are visibly more grainy than films which need more light (ASA 25).

4. Take a field trip to some of the sites identified on your images. Ask the students to describe as exactly as possible the features which they had identified on the images. Have them examine the structure of objects, such as the composition of a forest, meadow or park. Have them identify some plants to genus or species level and ask if this could be determined from their images. How accurate were they? Ask them to compare what they see while standing on the ground with what the satellite or aircraft viewed. How important is "ground truthing" to accurately interpreting an image?

5. While outside on the field trip, have your students use the measuring tapes to map out "real" life-sized pixels on the ground which correspond to pixel sizes from satellite images:

SATELLITE	SENSOR	RESOLUTION
SPOT	panchromatic (black and white)	10 m x 10 m
SPOT	multi-spectral	20 m x 20 m
Landsat	Thematic Mapper (TM)	30 m x 30 m
Landsat	Multi-Spectral Scanner (MSS)	80 m x 80 m
NOAA	Advanced Very High Resolution Radiometer (AVHRR)	1 km x 1 km

6. Have the students digitize a number of these different sized pixels according to the most common component of each pixel, just as they did in part I of this activity. They will have to decide what is the most common reflective surface in the Pixel. What information can still be gained from a pixel of 10, 20, 30, 80, or 1000 m^2. What information would be lost when averaging the reflected light from the pixel groups your students identified?

Investigating the Invisible

Objectives

Students will be able to: 1) discuss the existence of invisible phenomena; 2) develop ways of verifying and measuring their existence.

Methods

Students will discuss and research different invisible phenomena. They will then test and verify the existence of selected invisible phenomena by using measurement or detection devices and track them on a regular, long-term basis.

Background

Many phenomena which are remotely sensed are not visible — examples include ozone concentrations in the upper atmosphere, temperature, and ultraviolet radiation. Students can use this activity to learn about the tools for sensing such phenomena in their own environment, and to consider the significance of such measurements.

Students should also use this exercise to contemplate how they define "invisible." For example, if an organism or object is too small to be seen with the eye, but can be seen with the aid of a microscope, is it invisible? Some things are visible from one perspective or scale, but not another—like Earth's atmosphere, which can be seen from space, but not from the surface. Water can be invisible in its vapor phase, but visible in its liquid phase. Temperature, which is easily felt, is visible only indirectly, as in its effect on a thermometer, or ice forming on a pond.

Age

Grades 4 - 12 , adapted for each grade level

Subjects

Science, Social Studies, Math, Language Arts

Duration

Approximately two class sessions, plus a few minutes each day to measure and record data

Skills

building, charting, collecting and recording data, computing, crafting experiments, graphing, measuring, observation, planning, research, word derivation

Key Vocabulary

concentration, evidence, invisible, long-term, measurement, ppm (parts per million), seasonal, sensor, short-term; prefixes such as micro, tele, thermo; and suffixes such as meter, scope

Materials

Research library; instruments such as a thermometer, an ultraviolet sensor, infrared film, a light meter, gas sensors, filters, anemometer, decibel meter, radon-detecting test kit, microscope, and telescope, graph paper, paper, pencils.

Procedure

1. Ask your students to think and talk about what "invisible" means. For example, how do they know that something exists if they cannot see it. Have your students form small groups to choose one "invisible" phenomenon. These groups should then research and figure out how they can verify its existence.

2. Students examine the measurement tools and consider what they are called. This provides a good lesson in language and root words. Roots such as meter and scope are paired with thermo, tele, micro, etc. When students learn some of the basic meanings, they can figure out for themselves what related, but unfamiliar, words mean.

3. The groups should use their tools to measure their invisible phenomenon every day for a designated period of time, preferably long-term. Have them chart and/or graph their data and post it in a special place in the classroom designated for the "Daily Invisible Data Set."

4. In some cases, the students may be collecting the only daily information on a particular subject and it may be of interest to the wider community. For example, if students measure ultraviolet-B, they could issue UV-B alerts the way weather reporters issue smog alerts. They could warn fellow students or even the entire community (via school newspapers, public access cable, local newspapers, etc.) of an increased need for hats, sunscreens and sunglasses on high UV-B days. They could visit tanning salons and measure the UV-B output of the machinery to determine if it falls within federal guidelines.

5. Students studying radon could test radon levels in the school basement, in their classroom and in their homes. They could read recently published information about radon and the controversy surrounding its relative danger.

Discussion

Bring the different groups together to discuss their experiences and share their data. Let them present their measuring devices to the other groups and explain how their device functions and how it verifies the existence of the phenomenon they are measuring. Bring up the topic of the nature of "invisible" phenomenon and discuss how their perception has changed.

Extension

1. Students collect their "Daily Invisible Data Set" and enter it into a computer which is networked (through EcoNet or other computer network) with other schools around the country or the world. The students compare their data with that coming from other areas, gaining a larger perspective on invisible phenomena. A forum for making, testing and sharing data from an inexpensive ozonometer is available on EcoNet. Plans for making a low cost UVB meter are available in the "Amateur Scientist" section of the August 1990 issue of *Scientific American*.

How When Affects What: Part I

When You Look, Where You Look

Age
Grades 7 -12

Subjects
Science, Social Studies, Math

Duration
One class period to prepare, several days of "out of class" data acquisition, one class period for discussion

Skills
analysis, calculating, data interpretation, observation, pattern recognition

Key Vocabulary
climate, data, data set, natural variability, pattern, variability, weather, window

Objectives
Students will be able to: 1) gather and record visual and written data from their surroundings; 2) show how the specific time of data collection, or the sampling window, chosen for examination can affect an outcome, sometimes resulting in false conclusions.

Method
Students will photograph and/or count the number of people in the public areas of the school, such as hallways, the cafeteria, the gymnasium, etc. They will also consider various "windows" or periods of time within which to examine data. They will discuss what conclusions might be drawn from their data sets and why these conclusions might not be accurate. In part two of this exercise, students will then examine global change data, a graph of global temperatures, and extend their understanding of how time of data collection and window of the data set affects conclusions. **Variation:** It may also be suggested to the students that they measure and compare daily temperatures instead.

This activity should be followed up with **Part II,** and with **Part III.**

Background
In global change research, as in any scientific research, the timing and duration of data collection, and the window of the data set are of critical importance in reaching accurate conclusions. This is best illustrated by seeing how "truth" can easily be distorted by isolating a part of the complete data set or by collecting data at a particular time. Issues such as natural variability often come into play, and it is important to evaluate cause and effect.

Materials
Camera and film (preferably Polaroid or video camera for instant results), paper, graph paper, pencils and pens.

Procedure

1. Explain the purpose of this activity to your students and have them choose a public area of the school (hallways, cafeteria, gymnasium) as their subject of study. They should photograph (or count the people) in these areas from above (from a window, high up in a nearby building, etc.) at various times of day—say 8 am, lunchtime, and on different days of the week—and count the students that appear at each time. They can choose some special times to collect data.

2. The students should then graph their data and describe what they have learned about the phenomenon they measured—such as average number of students counted—based on when the observations were made.

Discussion

Ask your students to examine their data and pose questions that can be answered by evaluating that data. How would someone interpret the data if they did not know where and when it had been collected? What kinds of conclusions can be drawn from the information collected? How did the time of collection affect the answers to the questions posed? How did the window selected affect the outcomes? How might the data be interpreted or misinterpreted? Students can come up with conclusions they know are false, but which can be supported by their data sets. Have your students discuss ways in which information might be unintentionally misread or intentionally manipulated.

Extension

1. Ask the students to design a sampling schedule which would help avoid gross distortions of reality, but which do not require continuous sampling.

2. Have students bring in examples from articles in the press which demonstrate the effect that how and when data is collected has an impact on the conclusions drawn.

How When Affects What: Part II

Is it Getting Hot or Not?

Age
Grades 7-12

Subjects
Math, Science, Social Studies

Duration
One or two class periods

Skills
analysis, data interpretation, forecasting

Key Vocabulary
long and short term observations, sample size, trend, window of observation

Objective
Students will be able to: 1) critically interpret graphical data; 2) evaluate and discuss the difficulties inherent in interpreting and forecasting long and short term trends.

Method
Students will extend the understanding gained in the first part of this activity (counting students in the school) to global mean temperature change. They will see how the sample or window they choose to examine effects the outcome of their study.

Background
During the past 20 years, much attention has been given to the potential climatic effects of increasing concentrations of atmospheric greenhouse gases. Much work has been performed during this period and researchers have gained important new insights from these studies. The graphs on the following pages show that there was little trend towards increasing or decreasing temperature during the 19th century, a marked increase of about 0.5^{o} C from about 1910 to 1940, followed by a period of very erratic and dramatic temperature fluctuations from 1940 to 1970, and followed again by a sharp increase in temperatures to the present. The 1980s were a decade of unprecedented warmth, with 1990 the warmest year since comparable records began in the middle of the 19th century. All six of the warmest years in the global record have now occurred since 1980, and after corrections for the influence of El Niño (a warm current in the Pacific ocean which has a powerful influence on the world's climate), every year since 1985 has shown an increase in temperature.

Some scientists see a trend of increasing global temperatures in this data. James Hansen and Sergij Lebedeff, of NASA's Goddard Space Flight Center, reported in 1988 that the global surface air temperature in the 1980s were the warmest in the history of meteorological records and that the four warmest years on record were all in the 1980s. Other scientists emphasize the large amount of variability in the global temperature record, and argue that the globe has not warmed as much as predicted by climate modelers, and thus there is no evidence of global warming. Against this backdrop of high annual temperature variation and inconclusive trends, government policy makers must decide whether to take action to reduce greenhouse gas emissions or not. Some policy makers oppose any specific timetables for combating global warming, citing lack of agreement among scientists on the problem. Others call for the establishment of specific targets for cutting the pollution that causes greenhouse gases (principally carbon dioxide and methane).

This exercise is an opportunity for your students to view

the data, discuss the issue, and draw their own conclusions using the actual data which is the basis of the controversy. This data was compiled by P.D. Jones, T.M.L. Wigley and P. B. Wright from the Climatic Research Unit of the University of East Anglia in England.

Materials

Four graphs of global mean temperatures: the first from 1882 to 1894; the second from 1944 to 1956; the third from 1978 to 1990; and the fourth from 1854 to 1990, presented on following pages.

Procedure

1. Divide the class into four groups, or subsets of four groups. The groups should be kept separate so they cannot share data and gain information from the graphs of other groups. Give each group (or subgroup) a copy of one of the four temperature graphs. Students will study their sample of global mean temperatures and observe how readings fluctuate from year to year, over two to several to many decades. By looking at their samples, they should theorize whether there is evidence that global temperature was rising, falling, or remaining constant. They should be able to back up their conclusions with the data from their sample graph.

2. After the students have spent some time studying their graphs, ask them to project what global surface air temperature will be 10, 20 and 50 years into the future.

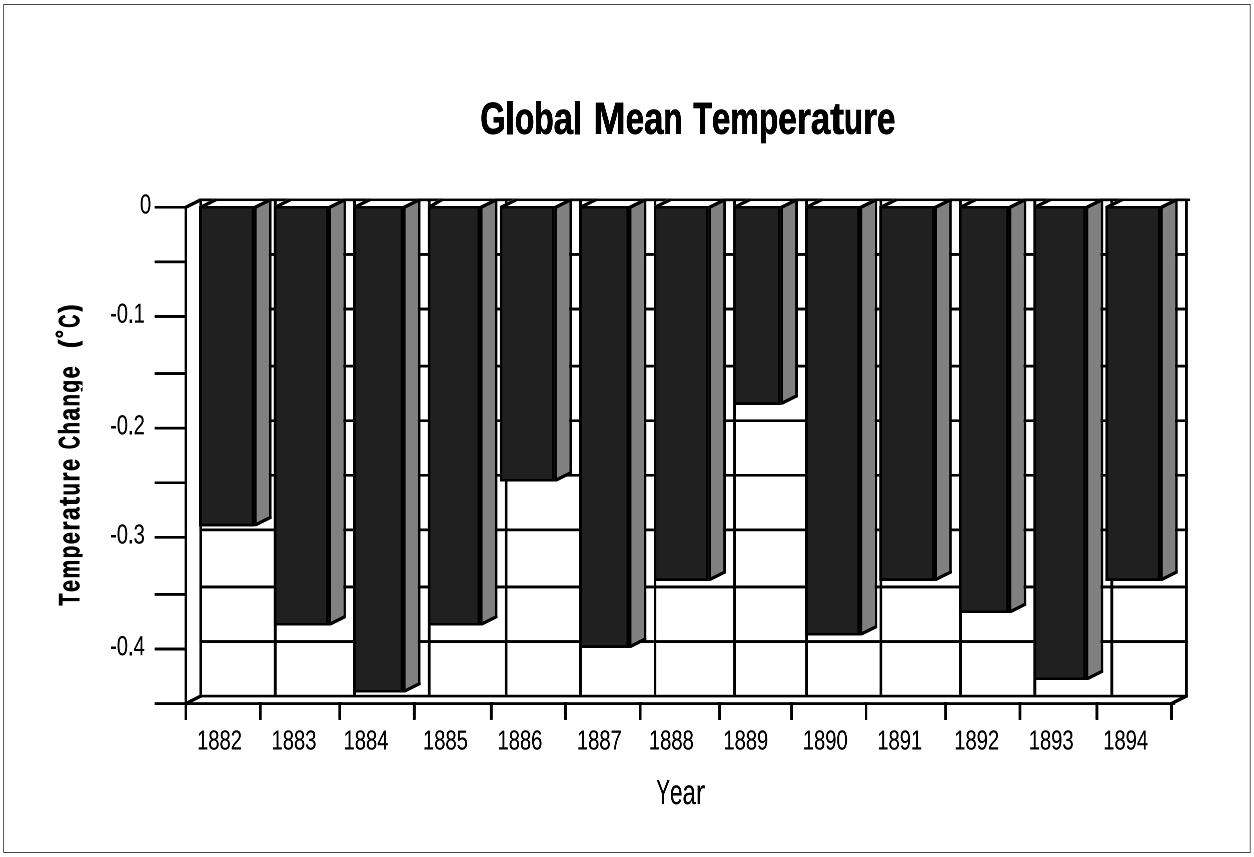
3. Have each group, beginning with the first temperature chart (1882 to 1894), present their predictions for average global temperatures 10, 20 and 50 years in the future. The last group to report should be the one with the 138 year chart.

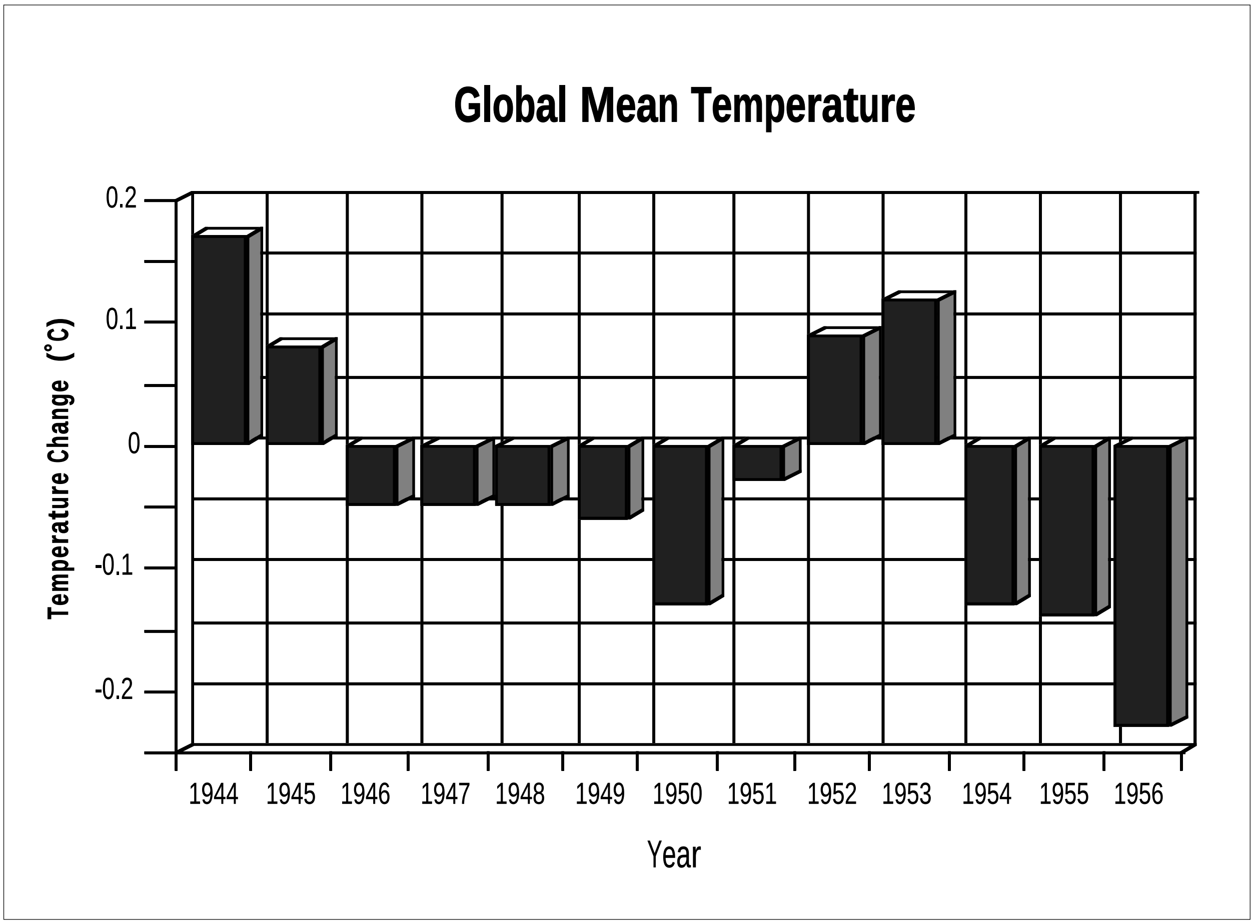
4. With the 1854 - 1992 graph, let the students from the first three groups compare their estimates with the longer term graph.

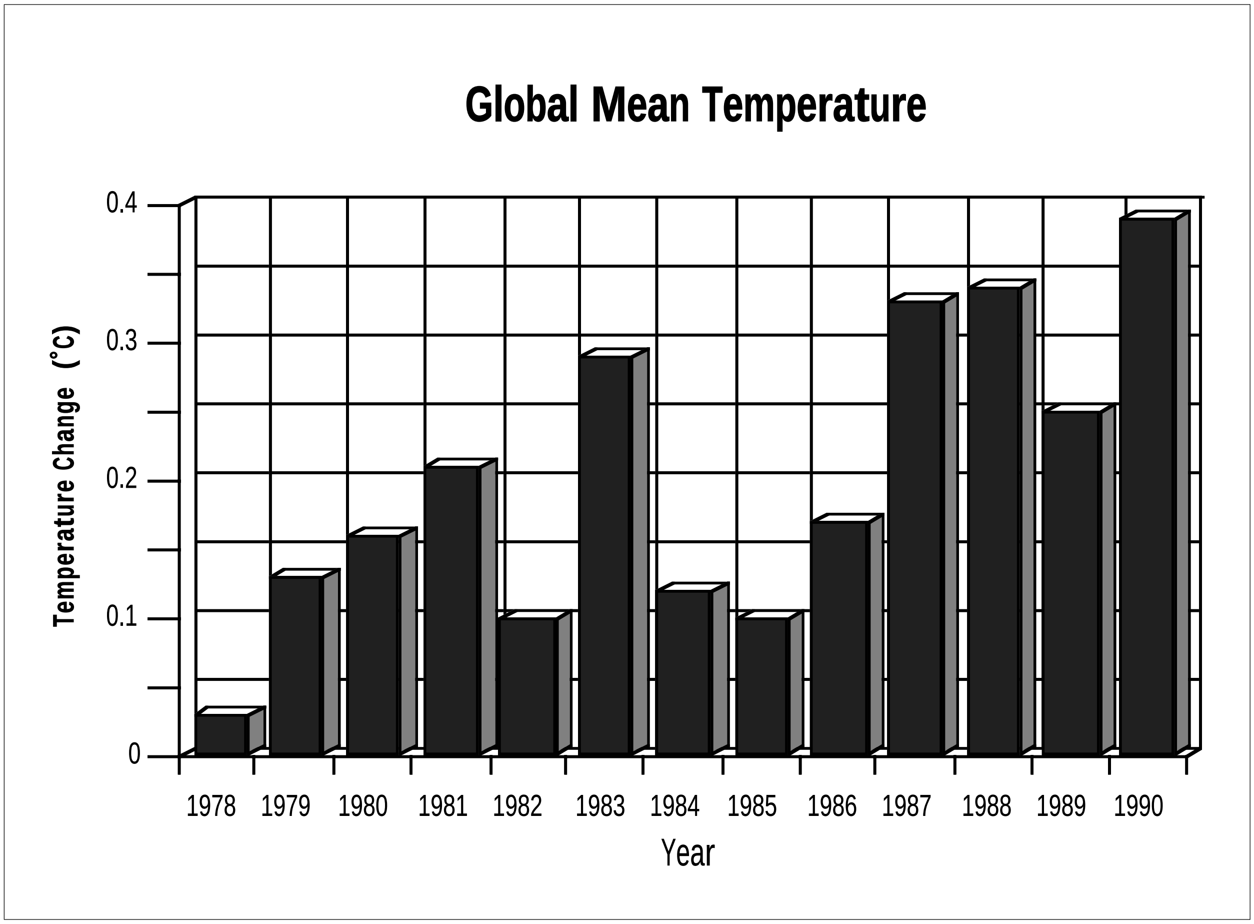
Discussion

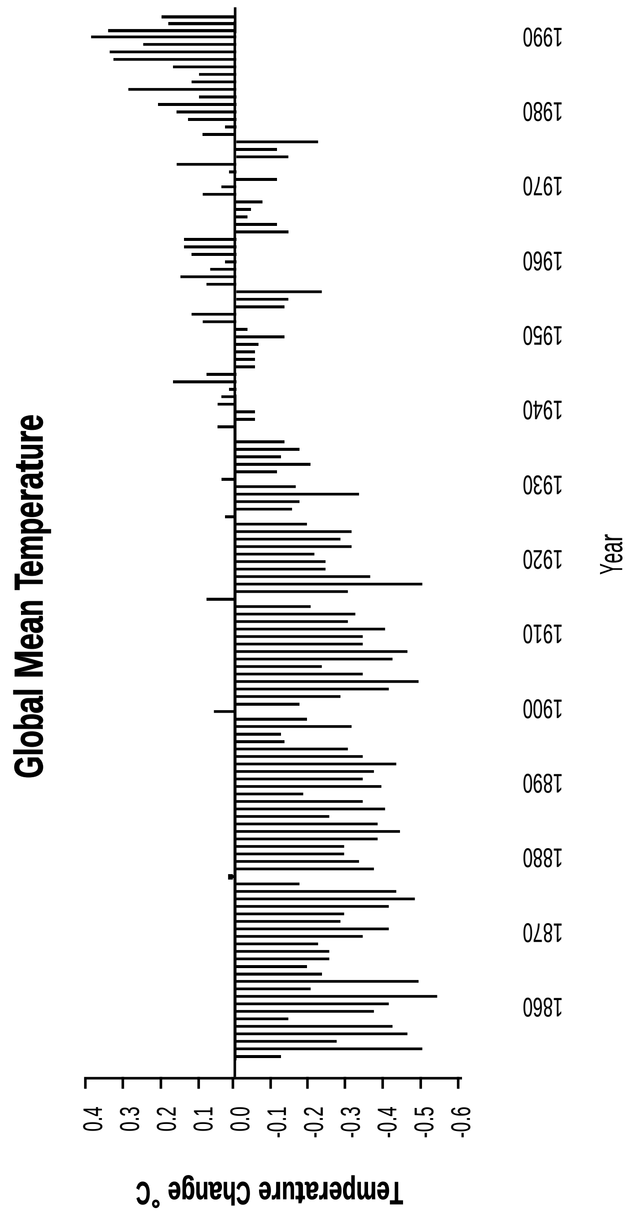
1. Compare the four sets of predictions and consider the reliability of each. Discuss the implications of basing conclusions on limited data and the patterns that could be inferred from considering each of these subsets. The pitfalls of basing conclusions on limited data sets should become obvious.

2. How much data is needed to make reliable predictions? Have students develop a list of things they would need to find out in order to prove that their projections were valid.


Global Mean Temperature
Temperature Change (°C)
0
-0.1
-0.2
-0.3
-0.4
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
Year


Global Mean Temperature
0.2
0.1
0
-0.1
-0.2
Temperature Change (°C)
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
Year


Global Mean Temperature
Temperature Change (°C)
0.4
0.3
0.2
0.1
0
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
Year


Global Mean Temperature
Temperature Change °C
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Year
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

Extension

Perhaps the 138 year sample that we called the “big picture” is but a blip on the larger time scale and is really too small a sample. Why might this statement be true or false for human purposes? What is the time scale of concern for human study? If the temperature rises or falls, is the Earth itself in peril or is human civilization as we know it in peril?

Discuss how much data is enough to be reliable while comparing the four different data sets, the 136 year graph, the 1,000 year temperature graph, the 10,000 year temperature graph and the 1,000,000 year temperature graph.

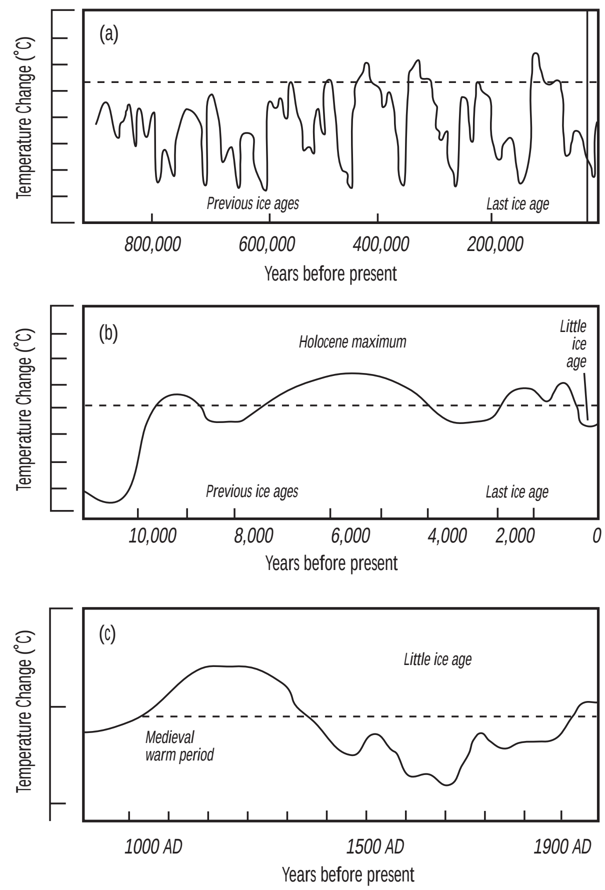


Figure 12: Schematic diagrams of global temperature variations since the Pleistocene on three time-scales; (a) the last million years, (b) the last ten thousand years, and (c) the last thousand years. The dotted line nominally represents conditions near the beginning of the twentieth century. From: 1989/90 UNEP Environmental Data Report.

How When Affects What: Part III

Local Temperatures, Global Changes

Age
Grades 7-12

Subjects
Science, Math, Social Studies

Duration
Two class periods to set up, followed by daily monitoring and weekly analysis

Skills
averaging, data recording, analysis and interpretation, graphing, temperature and weather monitoring

Key Vocabulary
anthropogenic, average and mean, degrees Celsius and Fahrenheit, global warming, temperature graph

Objectives
The students will be able to: 1) monitor daily temperatures and average daily minimums and maximums; 2) explain factors which affect the temperatures they take; 3) compare their temperature record with local weather station readings; 4) compare their data with that of the average global temperature used by scientists to monitor for global warming.

Method
Students will set up at least one temperature monitoring station at the school and take daily minimum and maximum temperature readings. The minimum and maximum daily measurements will be averaged to give a rough estimate of the mean (average) daily temperature. Daily temperatures should be averaged each week, and weekly temperatures averaged each month, and finally, monthly temperatures will be averaged each year. These data will be displayed on separate graphs showing the long term variations in temperature for your school. These local average temperatures can be compared to the global average temperatures for the period of 1854 to 1990 found in the appendix. Finally, updated monthly global and regional average temperatures can be obtained from the Aspen Global Change Institute, to make an up-to-date temperature graph of global temperatures as recorded by satellite. If available, a weather or data logging system could be used to automate the data collection process once the students have learned to carry out the procedures manually.

Background
During the last 20 years, much attention has been given to the potential climatic effects of increasing concentrations of atmospheric greenhouse gases (see the Global Change Primer). In order to isolate the "greenhouse signal", or that part of the climate change which indicates anthropogenic global warming, it is necessary to identify what temperature changes would have occurred naturally and which may be due to human activity. Fortunately, temperature records have been kept since about the middle of the last century. This historical data set is vital to identify whether or not human activities are causing global warming.

Taking the Earth's temperature, however, is a complex and difficult task and many methods have been used over the years. For example, one important source of information comes from sea surface temperatures taken by ships crossing the oceans. Much of the older data came from sea surface temperatures measured by hauling canvas buckets of water aboard ships. Later the canvas bucket were replaced by wooden buckets, and now sea temperatures are measured as water is brought on board to cool the ships' engines. These three techniques yield different

temperatures which must be accounted for. This activity is designed to give students an appreciation of this task of measuring average global temperatures. An excellent review of the process of analyzing global temperatures can be found in Global Warming Trends, by P.D. Jones and T.M.L. Wigley in Scientific American, August 1990. The Jones and Wigley data are presented in the appendix of this handbook for use by your students.

Materials

Minimum-maximum thermometer, hand-held thermometers, data sheets for recording time, date, minimum and maximum temperatures, weather conditions and other relevant data.

Procedure

1. Students should be given some background on the topic of global warming, as presented in the Global Change Primer. Older students should be encouraged to research the topic, especially how average global temperatures have been calculated.

2. Students should then be told that they will have an opportunity to measure local temperatures and compare them with the local newspaper, radio station, and weather station reports. They should decide where to place a maximum-minimum thermometer to get representative readings at the school. (Care must be taken to keep it out of direct sunlight and away from other areas which might artificially affect the temperatures.) If possible, multiple stations could be set up, including at the students' homes for comparison.

3. A list of student data recorders should be established, with student teams spending at least a week each monitoring the thermometers, recording the daily temperature ranges, calculating the daily average and graphing the results. Weekly and monthly, the data should be averaged and reported to the entire class.

4. A separate team of students should obtain daily or weekly data from your local weather service and graph this on the same graph, and in a similar manner (i.e. daily, weekly, monthly and annual) as the school recorders.

5. The data for the 1854 to 1990 global average temperature is listed in the appendix. Students should use this data as an exercise in graphing data. The results should be the same as in the temperature graph in How When Affects What: Part II. The students graphs of global mean temperatures should be displayed in a spot for the entire school to see and where they can be compared with the local temperature graphs.

Extensions

Monthly global temperature data recorded by the Microwave Sounder aboard the TIROS-N satellite, and compiled by Roy Spencer and John Christy, are now available. The satellite data record extends back to 1979 and represents the most comprehensive recent temperature record to date and provides quasi-global coverage each day. The satellite measures tropospheric temperatures to an accuracy of 0.01 ˚C. Current data and the annual averages for the northern and southern hemispheres, and for the globe as a whole, are available on InterNet or from the Aspen Global Change Institute. Please contact us if you would like to use this information with your class.

Dust Busters

Objectives
Students will be able to: 1) discuss and explain the presence of particulate matter in the air; 2) identify particles collected from the air around them; 3) explain what they are, where they come from, and what their effects are on the health of humans, wildlife and vegetation.

Method
Students will collect samples of particles in the air on simple slides they make themselves. They will classify, count and chart their findings, draw conclusions, make predictions, and compare their findings to other available data.

Background
The air around us is anything but "pure". The air we breathe contains many particles which can be readily sampled and identified. Some of these particles, such as plant pollen, can cause human discomfort in the form of allergies, or "Hay Fever". Other particles may be dust or lint, which may also cause allergies. The EPA has set standards for acceptable limits of dust pollution. Surprisingly, this is often worst in the winter as a result of sanding icy or snowy roads. In many cities, daily newspapers and radio and television stations announce pollen counts and allergy alerts. Allergists, medical doctors who treat allergies, have developed a simple, yet effective, method of measuring the presence of particulates in the air. This same method will be used here.

Age
Grades 4 -12

Subjects
Science, Social Studies, Math

Duration
One class period to set up, should run through year, graph against seasons

Skills
calculating, charting, classification, data collection, evaluation , prediction, research

Key Vocabulary
air quality, atmosphere, data, particles, particulates, pollution, prediction, sample, seasonal variation

Materials
Microscope slides, petroleum jelly or clear adhesive tape, magnifying glasses and microscope, Eosin, Methyln Blue or Iodine for staining the particles, paper and pencils, data on particulates in your area (available from your city air quality control office, or from an allergist).

Procedure

1. Students make "sticky slides" by coating them with petroleum jelly or wrapping the slides with clear, adhesive tape with the sticky side out. The slides should be placed in various locations around the classroom, school and grounds, or taken home to collect samples of particles in the air. In each location, place one slide vertically and another horizontally.

2. Collect and view the slides with a magnifying glass and microscope. The students should design a system to classify, count, and chart all visible particles. Shape, size, and composition are some of the elements students can use to classify the particles. Older students should be allowed to invent their own means of cataloging their data, while younger students (grade 4-6) should be assisted in setting up their charts. Students should check results seasonally, with varying temperature, before and after rain storms, and with other variables. Account for and discuss variations and reasons for them. Discuss all data collected and attempt to draw conclusions based on evidence.

Discussion

Bring in and discuss reports on pollen and dust from the newspaper, radio or television, and other available data on particulates in your area. Compare those results with those obtained by the class. Make predictions about trends such as increasing or decreasing numbers of certain particles. Discuss what factors might affect such trends and what impacts various types of particulates might have on humans, wildlife, and plant life in the environment.

Extension

1. Develop and graphically display a weekly or seasonal "particulate index" for your school.

Dead Right, Dead Wrong

Objectives
Students will be able to: 1) make informed decisions regarding the current global warming debate; 2) present evidence to support their views on the issue.

Method
Students will research and evaluate information about global warming, identify decision-making criteria for action or lack of action, and decide what level of certainty is sufficient to take action. They should debate the issue of when we know enough to act, based on the results of their research.

Background
A recurring question regarding society's handling of scientific problems is: how certain must we be of a bad outcome in order to take action to prevent it? How much evidence is enough to cause us to change our ways, especially if the changes are believed to be difficult and expensive?

Age
Grades 7-12

Subjects
Science, Social Studies, Math

Duration
Two or more class periods

Skills
critical thinking, debating, organizing, predicting, research

Key Vocabulary
criteria, prediction, probability, variability

One way of looking at it is to draw an analogy to buying insurance. Even though there is a very low probability that my house will burn down, I purchase fire insurance to protect myself and my family from being devastated if fire does strike. It costs money for this protection, and some might say that since the probability is so low, the money is wasted, but most prudent people do carry insurance.

Applying this logic to increasing global temperatures, even if we are not certain that it will occur (even, in fact, if the probability were low that it would occur), some people would consider it prudent to take action to prevent or reduce it, even if it cost something. This is especially true since the effects of global warming, if they occur, could be cataclysmic.

Another very significant factor in this debate is that if we wait for absolute certainty that there is a distinct warming trend, it would then be too late for our actions to make much of a difference. If we wait 50 years for an undeniable signal without changing our output of greenhouse gases, in the meantime carbon dioxide levels will have doubled, methane levels will have more than doubled, and we will be dead right or dead wrong—it won't matter.

Materials

A library with periodicals and reference books. Good sources include recent editions of the major encyclopedias, especially their annual updates, and science magazines such as American Scientist, New Scientist, Scientific American, and Science News. Newspapers and weekly news magazines are a good source of material concerning the political debate surrounding global warming, as well as other global change issues.

Procedure

1. Do we have enough evidence for global warming to take action to prevent or reduce it? Divide your class in three sections, with one smaller group of 5 to 7 students to act as judges and referees between the two other larger groups. The first large group will research and debate on behalf of taking immediate action to reduce greenhouse gas emissions. The second large group should state a case for waiting until there is scientific certainty. Students should use the library to research current information about global warming and then consider and debate the question.

Discussion

When is evidence sufficient to have confidence in the data set and take action based on it? When is a sample of a subset enough to have accurate results (as in taking a survey)? What are other issues that could impact the decision of whether or not to act (for example, might it be good to reduce use of fossil fuels for other reasons)?

Back to the Future

Objectives

Students will be able to: 1) describe the changes that have taken place in their regional environment during their lifetime; 2) explain how past choices have impacted their current environment and how their choices now will impact the future.

Method

Students will compare aerial photos of their area from the past with current photos, noting differences and then conducting ground truth investigations to determine what happened. Finally, students will use the information they gather about past changes to make predictions about the future.

Background

Encouraging today's students to understand and take responsibility for environmental changes may be the best hope we have for preserving Earth's natural resources into the future. In every region, choices made by past generations impact the environment their children live in. This activity offers students the opportunity to examine the impacts that past choices have had on their surroundings and to project the kinds of impacts their own choices will have on their children's environment.

Through this activity, students will become aware of their watershed, nearby park lands and natural areas, the impacts of recent development, resulting changes in human, animal and plant qualities of life, economic, civic, political, and historical issues that impact development, and the whole range of land use questions that exist for every region.

Age

Grades 4 -12, customized for each level

Subjects

Geography, Science, Social Studies, Math

Duration

Several one hour class periods, plus outside work by students

Skills

analysis, considering responsible action, determining trends, image interpretation, prediction

Key Vocabulary

data, ground truth, land use, prediction, remote sensing, vegetation, watershed

Materials

Regional maps and aerial or satellite images from 10 to 15 years ago and recent photos (this is an ideal interval because it approximates the lifetime of the students so far, but if these are not available, use whatever interval you can get. See the appendices for information on obtaining RS images), graph paper, paper and pens, straight edge, access to a local research library and other sources of local statistical data such as the Public Service Company or the County Zoning Authority.

Procedure

1. Give small groups of students regional aerial or satellite images from 10-15 years ago and today. Have them study and compare the photos, looking for differences between them. The photos may not have been taken at approximately the same time of year, and students should check for the existence of any extraordinary circumstances, such as seasonal variations or a major drought, that could account for differences.

2. Students should make two identical grids [offer guidance on grid size here] and lay them over the two images. Let them study the images to locate 10 sites which are the same and 10 sites which are different in the corresponding grid boxes on the old and new photos. Students should make predictions about what the differences indicate. With the aid of a local map, students can locate the actual areas which correspond to the grid boxes in which the differences occur. Then they should plan and embark on a "ground truth" investigation. On the ground truth investigation, the students should record their observations of crops, trees, vegetation, developed areas, etc., and compare these observations with their hypotheses about the differences they observed between the two images.

Alternate Procedure

1. If only a recent image is available, students should learn as much as they can from the current image and using this information, make predictions about the future. Their predictions can use the grid overlay as a method of creating a map of the future. (Pretend you are a remote sensing scientist in orbit about Earth, and have the assignment of projecting the future trends of the area covered by the aerial photo in this activity.)

2. Tie the activity into current issues, e.g.. planned highways, dams, housing projects, greenbelts. Give 4-5 groups the same assignment, compare their results and discuss the decisions they made.

Extension

1. Based on the results of their study, have your students make a representation of what they project the region will look like 10-15 years in the future. To make their predictions more accurate and meaningful, they should collect statistical information such as lists of all the towns and cities in the region and their populations 10-15 years ago and today. In addition, they should collect data on current rates of population growth, numbers of dirt roads which have been paved, changes in total traffic miles driven, and similar information that would assist the process of preparing a prediction of what the area will look like in 15 years.

2. In preparing this prediction, students should determine and extend forward any discernible trends that have formed over the past 10-15 years, using relevant information on rates of change that they discover. Students need not attempt to provide an unbiased assessment of what they would like to see happen or what they fear could happen, etc. After making and sketching their prediction, students can then go on to sketch pictures of alternative futures, including what they would consider to be the ideal future and a worst case scenario. Have your students discuss what they can do to turn around negative aspects and preserve what they would like to see protected.

Map Your Watershed

Objectives

Students will be able to: 1) identify, describe and outline watersheds on a topographic map; 2) determine the direction of water flow; 3) discuss and explain the size and importance of watersheds.

Method

The students will learn to identify watersheds on topographic maps by learning how to interpret contour lines and distinguish adjacent watersheds by the ridge line between them.

Background

A watershed is the whole region from which a river receives its supply of water. Watersheds may be identified on topographic maps by the contour lines which represent different elevations, or heights, of the land surface. Because water flows downhill, adjacent watersheds are separated by areas of higher ground. This high ground is called a ridge line, and is represented by the contour line of highest elevation between two watercourses on a topographic map. The area of a watershed can be outlined by tracing the ridge line or contour line of highest elevation enclosing it. Contour lines represent surface relief by connecting the points having the same elevations. Contour lines represent a difference of 40 feet in elevation on a 7.5 minute series map from the United States Geological Survey (USGS), but may represent different elevations on maps of different scales, and this "Contour Interval" is printed on each topographic map.

A single contour line always forms a closed figure. Contour lines on a map never intersect because each point on the surface has only one elevation. Closely spaced contour lines represent steep land because the elevation changes rapidly in a short horizontal distance.

Age

Grades 7 - 12

Subjects

Geography, Geology, Math

Duration

One or two class periods, depending on the detail

Skills

map interpretation

Key Vocabulary

contour line, gradient, ridge line, topographic map, topography, watercourse, watershed

Widely spaced contour lines represent flatter terrain in which elevation changes little across long horizontal distances. The ratio of change in elevation to change in horizontal distance is called the gradient or slope of the land.

Materials

Laminated 7.5 topographic maps of your city and the local watershed for each pair or small group of students, grease pencils. Topographic maps may be obtained from libraries, map stores, some book stores or wilderness outfitters, and the United States Geological Survey.

Procedure

1. Introduce the topographic maps as the two-dimensional representation of the physical features of an area. Some of your students may be familiar with "Topo Maps". Ask them to help explain them to the class. Ask the groups to locate your town and a local stream or river on their map.

2. With reference to the topographic map key, ask your students to locate contour lines on their maps and to determine the elevation difference which they represent. Introduce the concept that contour lines each lie along a particular elevation. Discuss what kinds of land forms widely spaced or closely spaced contour lines represent. Locate the contour lines representing the lowest and highest elevations on the topographic map.

3. Because water flows downhill, it is possible to determine which land area drains into the stream or river under study. Locate the contour line of highest elevation that encloses the stream or river, and mark it with a grease pencil. This indicates a ridge line; on one side of the ridge, water will flow into your stream or river, and on the other side of the ridge it will flow into the neighboring watershed.

4. Have your students trace where the water they use (like drinking and washing water) comes from and where it goes after they are finished with it. Was their water used by someone else upstream? Will it be used by someone else further downstream? How is the water quality affected by this use and reuse?

Discussion

Organize a discussion with your students by asking the following questions:

- How do the contour lines appear on this map and what do they show?
- Do the contours make a V-shape up or down stream? In what direction does the stream or river flow? How can they tell?
- About how many feet does the stream or river fall as it crosses the area on the map?
- What is the average width of the stream or river you are examining and what is the approximate area of your watershed?
- What land forms do crowded contour lines represent and what land forms do widely spaced contour lines represent?

Extension

1. Use the Plane-Table and T-Stick mapping techniques mentioned in the extension of "Sandboxes and Satellites" activity to make a contour map of the school grounds or a local park. This would be best carried out in an area with considerable topographic variation.

2. Using the topographic map, ask the students to determine the approximate length and area of land which would be flooded if a dam was built on the stream over the river near a town, what would be its length, and what would be the approximate area of the lake behind the dam?

Evaluation

1. Locate and describe the following features on a topographic map: watercourse, contour line, and ridge line.

2. Trace the ridge line between two adjacent watersheds on a topographic map.

Land Cover Mapping

Objectives

Students will be able to: l) recognize and explain the differences between satellite images and topographic maps; 2) identify different land cover types on satellite images and relate them to the corresponding areas on the topographic maps; 3) explain the relationship between cover types, water flow, and water quality.

Method

Students will use remotely sensed images and topographic maps to classify land cover types in their watershed. A field trip to specific sites will allow the students to “ground truth” cover types found on the remotely sensed images and extrapolate that information to other sites not visited. If possible, a second field trip will allow students to test their interpretive skills with reality, by visiting new sites for which they were asked to determine the land cover solely from a remotely sensed image.

Age

Grades 7 - 12

Subjects

Biology, Geography, Geology, Science, Social Studies

Duration

One or two class period and one or two field trips.

Skills

image interpretation, mapping, plant identification, scale

Key Vocabulary

false-color, infiltration, riparian zone, runoff, scale, sediment, turbidity, spectral reflectance

Background

Land cover, in remote sensing, refers to the primary reflective or emitting surface detected by sensors. Land cover differs from forest or vegetative cover in that it is all inclusive and includes everything detected by the sensors: Trees, fields, houses, lawns, lakes, roads and parking lots, etc. Land cover significantly influences water flow and water quality. Because vegetation intercepts precipitation with its many surfaces, it slows and decreases runoff (the flow of water across the land surface). Runoff is faster and greater on bare ground or paved surfaces. Vegetation cover permits more infiltration, or soaking of precipitation into the ground, because root channels keep the soil loose and decaying organic material, or humus, acts as a sponge. Impermeable paved surfaces do not allow infiltration for recharge of the soil moisture and groundwater reserves.

Because land cover influences water flow across a watershed, it directly impacts water quality in the watercourse. If vegetation is removed, precipitation hits the soil surface more energetically and runs off more quickly, carrying with it greater amounts of soil and plant nutrients. This results in increased erosion, watercourse turbidity, and decreased water quality. Eventually, the suspended soil particles settle to the bottom of the watercourse as sediment, perhaps suffocating riverbed organisms or filling in reservoirs behind dams. On the other hand, sediments may settle during receding seasonal floods, renewing the fertility of riverside agricultural fields. Runoff may enter a

watercourse at a temperature quite different than the water already there. A temperature change may benefit some organisms living in the water while making it less suitable for others. For example, trout require cold water, but catfish prefer warmer water. Runoff may bring bacteria, pesticides, or toxic chemicals from the land into watercourses, thus decreasing water quality.

Mining, road construction, housing developments, industrial expansion, and the conversion of forests to cropland all decrease the amount of vegetative land cover. Reforestation, mine reclamation, residential landscaping laws, soil conservation ordinances, the creation of parklands, and the cultivation of perennial instead of annual crops all increase vegetative land cover. Conversion of land cover in the riparian zone bordering a watercourse can directly affect water quality. The removal of trees shading a watercourse will increase water temperature while the planting of trees will decrease water temperature, wind speed, and evaporation in the riparian zone.

The purpose of this activity is to teach students how information gained from a small sample of sites can be used to interpret remotely sensed images and to make educated guesses as to the extent of similar types of land cover within their watershed. Maps are generalizations of reality, often containing numerical or alphabetical information as well as selected and adjusted graphic detail.

Within limits, different objects, such as areas of different land cover, can be distinguished on remotely sensed images because they each have a unique spectral signature. That is, each type of vegetation or material covering the land reflects or emits a unique radiation pattern that is sensed and recorded. To a certain degree, then, it is possible to differentiate between different types of land cover. Thus corn fields, pine forests, open water and concrete buildings may all appear differently on remotely sensed images.

There are limitations to what can be interpreted from any remotely sensed image. While it will almost always be possible to tell a paved parking lot from an agricultural field, it may not be possible to tell a gravel or dirt parking lot from fallow (unplanted) agricultural field, to determine whether a field contains corn, barley, wheat or rye, or to distinguish a marsh from a rice field without more information than is available in one satellite photo.

Materials

Topographic maps and aerial or satellite images of your watershed that have been laminated or have acetate covers; grease pencils or tracing paper, pencils and rulers.

Procedure

1. Ask your students to locate their watershed on both their map and satellite image.
2. Introduce the concept of spectral reflectance. Each type of vegetation or material covering the land reflects or emits a unique electromagnetic signature that is recorded by the satellite sensor and appears as a uniquely colored entity on the satellite image. With a grease pencil on the laminated satellite image, or with a pencil on tracing paper, outline ten areas in your watershed that appear distinctly different on the image, indicating different land covers.
3. On the basis of their knowledge of the area, your students should record what might be the ground cover on each of several areas which are close enough to the school for a field trip to test their accuracy.

4. Take your students on a field trip to a few of the representative sites. Bring along the maps, images, and outlines as you visit the various parts of the watershed. Your students should record the cover in each of the areas that they outlined. Have them compare their predictions of land cover to what is actually there.
5. Back in the classroom, have your students reconsider the accuracy of their predictions on the basis of the evidence from their ground truthing.

Discussion

Organize a discussion with your students by asking the following questions:

- What vegetation symbols appear on the map and how do they compare with the remotely sensed images?
- Which is older, the map or the satellite image? What indicates that one is older than the other, other than the dates printed on the map and image?
- How does the appearance of towns and cities differ between the map and satellite image?
- If the contour lines on the map were erased, what clues would you have about the location of high land? The remotely sensed image has no contour lines—can the students find clues as to the outline of the watershed?
- What indicates the deeper and more fertile soils? Are they on the low or high land?
- How would your students describe the texture of the different different classes of cover that you see on the satellite image?
- What percentage of the local watershed is covered by forest, by grasslands, by agriculture, by human settlements, etc.?

Extension

Have your students work in groups to make additional land cover maps using satellite images. Compare the percentages of land cover types in the local watershed with those in a similar ecosystem in another country. Compare the percentages of land cover types in the local watershed with those in a watershed in a different ecosystem. Discuss how human activities may account for the differences in amounts of various land covers, and any indications of differing water quality.

Evaluation

1. Describe several ways in which satellite images are different from topographic maps.
2. Locate and name all the land cover types you can find on the satellite image.
3. Locate and name all the land cover types you can find on the topographic map.
4. Explain how different types of land cover affect runoff and infiltration.
5. Describe several human activities that change land cover and thereby decrease water quality. Explain the impacts.
6. Suggest some possible changes in land cover that humans could make in the watershed to increase water quality.

A Changing Watershed

Objectives

Students will be able to: 1) relate changes that have occurred to the local watershed to local history and development; 2) describe how these changes have had positive or negative impacts on water quality in the watershed.

Method

Students will examine two satellite images of their local watershed taken at different points in time and use this data to learn about changes in the watershed, particularly in land cover. As an alternative, or if you are short of images from different times, students should interview family, neighbors and “old-timers” and use old and recent photos to develop a “then and now” theme.

Age

Grades 7 - 12

Subjects

Social Studies, Language Arts, Geography, Science

Duration

Two class periods

Skills

image interpretation, mapping

Key Vocabulary

Land cover

Background

The purpose of this activity is to increase your students’ awareness of change as both ecological and social phenomena of a watershed. Changes, particularly land cover changes, occur in watersheds through time as a result of both natural forces and human actions, and these changes, in turn, affect water quality in steams and rivers. This activity closely parallels the activity, **Back to the Future**, but has its main emphasis on features which directly impact water quality in your watershed. Ask the students to look at positive as well as negative impacts. It is easy to forget or overlook positive measures which have been taken to protect or restore water quality in many areas. Since public awareness and action on water quality issues began in the late ’60s, there will have been many local success stories about rivers being “brought back to life” through the actions of aware and concerned citizens, often students such as yours.

Since 1972, Landsat has been remotely sensing nearly the entire earth every 18 days. Sometimes clouds obstruct the view of the sensors; this happens more often in some regions than others. Despite the vagaries of weather, at least two clear Landsat images exist for most locations. Two or more satellite images of an area form a time series that can be used to assess changes in the watershed, particularly changes in land cover.

On images from temperate zones, changes in the appearance of vegetation, or the extent of snow cover, will help distinguish seasons. The lush growth of summer will contrast with the barrenness of winter. Evergreen trees that are difficult to distinguish in mixed forests will contrast sharply with the leafless deciduous trees in winter images. In summer scenes, the same crop will often have the same texture even if in a different stage of

growth; this assists in determining if a field has been planted with the same or different crops in successive years.

On images from other climate zones, the lushness of vegetation may indicate wet or dry seasons. Rivers or other water bodies may increase their size in flood, and may decrease in size seasonally or in unusual droughts. Even without standing crops, cultivated land may often be distinguished from natural vegetation by the regular pattern of the fields.

At the edges of cities and towns, or along roads, rivers, or beaches, the expansion of residential or industrial areas may be evident. At the boundaries between land cover types, conversion from one type to another may be discerned. In addition to incremental changes like these, there may be catastrophic changes in vegetative cover caused by forest clear cutting, windstorms, fires, landslides, or volcanic eruptions.

Materials

At least two satellite images of the local watershed from different points in time (as used in the activity **Back to the Future**), topographic maps. Have the satellite images laminated or protected with clear acetate.

Procedure

1. Ask your students to study the pairs of images, carefully noting differences in land cover (as described in the previous activity) which would have direct impacts on the watershed. These might include new tracts of housing, shopping centers and roads, or areas newly designated as parks or green-ways. List and describe the differences found. Locate the areas of change on a topographic map and suggest why these land cover changes may have occurred, given what is known about these areas.
2. Can your students detect any differences in the width, color, or flow path of the stream or river? Ask them to explain these changes in the river in relation to the land cover changes found.
3. Determine the size of the area converted from one land cover to another over the time period represented by the satellite images. Calculations may include the following areas: total area converted from one land cover to another; expansion or contraction of human settlements, natural vegetation, or agriculture; conversion of one agricultural land cover to another; conversion attributable to windstorms, fire, land-slides, or volcanic eruption. Present these calculations in the form of a graph. Predict the land cover in the watershed ten or twenty years from now if the trends in the time interval represented by the satellite images continue.
4. Propose ways in which information about local cover changes that appear in satellite images could be used to plan desired changes and to monitor undesired changes in the watershed or water quality in the future.

Discussion

Organize a discussion with your students by asking the following questions:

- In which season of the year were the images taken? Is it possible to tell this from the image alone? Would it be possible to tell which year (perhaps a specific event is occurring)? What day of the week?
- What indications are there on the images that some areas once had a different land cover than they do now? For instance, what indications are there that some areas were once forested, or were once beaches, and are not now?
- What is the average width of the stream or river at the same point on the two satellite images? What explains the similar or different average width?
- What might be some reasons for the location of the towns? In what ways are the towns and cities growing or shrinking? How is the area covered by the towns and cities affecting the river?
- What forms of land cover change are occurring most rapidly, and which are occurring most slowly in the watershed? What are some explanations for these different rates of land cover conversion?
- What are the advantages and disadvantages of these land cover changes for the people living in the watershed?
- What are the impacts of these land cover changes on the quality of water in the stream or river?

Extension

Compare the rates of land cover conversion in the local watershed to their counterparts for the state or the country. This data can be found in yearbooks, almanacs, and government publications. Explain how these state or national land cover conversion rates could be determined or verified using satellite images. What are the implications of the land cover changes over larger areas for the water quality of streams and rivers in the state and the county? Propose possible explanations for the similarities and differences found in the land cover conversion rates in the local watershed, the state, and the country.

Your Watershed's Story

Objectives

Students will be able to: 1) devise and carry out interviews within the community; 2) name several natural and human activities that have changed the local watershed in living history; 3) describe the interaction between the river, its quality and the lives of people in the watershed.

Method

Students will design a questionnaire, interview local people, and compile the oral histories collected to establish the recent history of a river and its watershed. Students must have a firm grasp of the meaning of watershed in order to be able to interview other people.

Background

Anthropologists and ethnographers use interviewing as a research technique to collect oral histories: accounts of places and events that are not written, but passed on from one generation to the next verbally. Oral histories are usually the re-telling of the personal, daily lives of ordinary people, in their own words. Collecting oral histories provides students with an exciting way to forge links with people of various ages and to accumulate the wisdom of experience. The purpose of this activity is for students to gain an appreciation for the rich information contained in oral histories, and the complex ways in which watershed changes affect people's lives. Learners more easily establish the connections between events and the context in which they occur because interviewing makes history more personal.

Materials

Writing materials, tape recorders, blank tapes, aerial or satellite images, topographic maps or watershed model of the local watershed.

Age

Grades 7 - 12

Subjects

Social Studies, Sociology, Anthropology, Science, Language Arts

Duration

At least two class periods plus time outside of class for conducting interviews

Skills

compiling information, designing questionnaires, interviewing

Key Vocabulary

anthropology, ethnography, meander, oral history, political boundary, raw materials, value judgement

Procedure

1. To prepare to interview older members of the community to find out what various parts of the watershed were like in years gone by, divide the learners into small groups to generate questions to be asked during interviews. Compile all questions suggested. As a large group, decide which questions to place on a questionnaire to insure that a minimum standard of similar information is sought with each interview. Interview questions might include:

- How long have you lived in the area?
- What were the river and the surrounding watershed like when you were my age?
- What are the different uses of the river that you have witnessed?

- How has the land in the watershed been used during the years that you have lived here?
- What do you think has caused changes in the river or watershed?
- How do you feel about the changes that you have witnessed?
- What do you think this watershed and river will be like in the next ten to twenty years?

2. Have the students rehearse their interviews by role-play with fellow students prior to the actual interviews with community members. Practice drawing out specific examples when people make general statements.

3. Each student or group should contact older relatives, historical society members, or senior citizens to arrange interviews. The students should inform each interviewee of the purpose of the interview, how long it will last, how the interview results will be used, and what the questions might be.

4. At the beginning of the interview, students should ask permission to take notes or tape record the interview conversation, and abide by the wishes of the interviewee concerning making records of the conversation.

5. Ask each of the questions on the questionnaire. Encourage specific examples whenever the person interviewed makes general statements. Ask the person to indicate on the satellite image, map or watershed model, the places in the watershed that they describe. Note the natural and human forces of change to which they attribute changes in the watershed. Listen for value judgements that they attach to the changes that they have witnessed. Enquire about the changes they think will happen in the future and their attitudes about these changes.

6. Each student should prepare a written report of the interview findings in the form of a feature article for a newspaper, or a chapter in a biography. Ask learners to illustrate their report with pictures of the watershed as it appeared in the past, or with a cover map of the watershed in the past.

7. All of the interview reports should be compiled into a booklet. Find old photographs to complement the text. Perhaps the persons interviewed, the historical society, or the local newspaper have photos that they would allow to be used as illustrations.

Discussion

Organize a discussion with your students by asking the following questions:

- How has the river or stream been affected by the human use of raw materials available in the watershed?
- Does any part of the river correspond to a political boundary? If so, how might this give rise to difficulties?
- Why are some areas of river meanders built on and others are not?
- What reduces or increases a river's usefulness for transport?
- What are the major economic uses of the river?
- How would the satellite image or map have looked fifty or one hundred years ago?
- How may the satellite image, map, or watershed model appear ten to twenty years from now?
- How might different attitudes toward change affect how the watershed appears then?

Extensions

1. A small group of learners may prepare questions and arrange for three or four interviewees to gather for a television talk show type program titled "Your Changing Watershed" before a live audience of the whole group of learners. This program may be videotaped for presentation later to younger learners or to a 'family night' audience.
2. Write a story as if the local stream or river could talk. Include the changes that the river has noticed in the past 100 years, the river's opinion of its water quality, and its opinion of the future of the watershed. What is the river's reaction when it finds out that Landsat records its appearance on a satellite image every eighteen days, and that such images can be used for planning or monitoring changes in watersheds and water quality? If the river could speak for one hour, who would it like to talk to, and what would it say? What questions would the river like to ask? Illustrate the story with drawings, paintings, photos, or collages.
3. Make a timeline of the river's history and the use of the land surrounding it. Illustrate the timeline with photos or drawings of how the various parts of the watershed looked in the past. Display this timeline in the school, a mall, library, city hall, or other place where people in the community may learn from it.

Evaluation

1. Name several natural forces and several human activities that have changed the watershed in living memory.
2. Describe some of the most important ways in which the river has historically affected the lives of people in the watershed.
3. Describe the relationship between changes in the watershed and river water quality, and people's attitudes toward those changes.

Make a Watershed Model

Objectives

Students will be able to: 1) describe the topography of the watershed as a three-dimensional model; 2) locate corresponding features on topographic maps and a three-dimensional model; 3) describe the interactions between the watershed and human activities.

Method

A three-dimensional watershed model will be created and used to trace the flow of water across the land and down a stream or river. Students will create the model from a two-dimensional topographic map. They will use the model to trace the path that a water droplet takes across the watershed and into the watercourse, and will describe the relationship between the physical features of the watershed and the location of human activities.

Age

Grades 7 - 12

Subjects

Geology, Geography,
Social Studies, Language Arts, Science

Duration

3-4 hours

Skills

physical modelling

Key Vocabulary

floodplain, levee, watercourse

Background

Students are often familiar with only a small portion of the watersheds within which they live. Building a watershed model and tracing the flow of water in the watershed can assist them in understanding the relationship between the different features of the watershed, and the interdependence of the human activities in the watershed. This watershed model can be used as an important instructional aid for many activities about the watershed.

Many human activities are influenced by the flow of water across different land forms in a watershed. People locate their farms and towns along watercourses to have a water supply for their homes, their crops and animals, and their industries. People live near watercourses to have transportation for the things they need or produce. People have observed the hazards of flood plains and employed the relative safety of natural levees for their building activities. Where rivers impede transportation, bridges have been built. Bridges are often placed where the watercourse is narrow, where the banks on either side are the same height, and where the water is not too swift. Trains cannot travel on steep slopes like cars, trucks, and buses, so railroads are found in flatter areas of the watershed, while roads may exist in even the steepest areas. Airports require large flat areas for their runways and even larger areas without tall obstructions, so they are often located on the ridge lines or in wide valleys of the watershed.

Sometimes humans change the shape of a watershed or the flow of water across it for their own needs. Farm fields may be terraced, made to look like stairs with retaining walls, to slow the flow of water downhill. Dams may be built across watercourses to provide water deep enough for navigation, to generate electricity, or to create

drinking water reservoirs. Valleys may be filled or hills cut away for the building of railroads or highways.

Materials

Topographic map of your watershed, tracing paper, tempera paints, paint brushes, cutting knife or saw, plaster of Paris or paper maché, plasticene or other waterproofing, and corrugated cardboard, plywood or other media from which to cut layers representing each of the contour intervals in your watershed.

Procedure

1. Use one piece of your layering material as a base. Trace the lowest elevation contour on tracing paper and then cut away all of the area below this contour elevation. Use this as a pattern to cut this contour interval from your layering material. Attach the layer at the proper position to the base. Repeat this tracing, layer cutting, and layer attaching process for each of the successively higher elevation contours. The result is a three-dimensional model of your watershed.

Plaster of Paris or paper maché can be used to smooth the edges of the various layers. Use tempera paints to indicate the watercourses, beaches, rock outcrops, forests, buildings, roads, towns, or other features in your watershed.

2. Place the model in a sink or outdoors where water running off of it will not cause any problems. Place an eye dropper full or a spoonful of water on the model and watch where it flows. Try placing water at several different points on the model simultaneously to determine how the water flows during a rainstorm or spring snow melt.

Discussion

Organize a discussion with your students by asking the following questions:

- Do the roads or railroads appear to respond to relief — meaning, do they follow the grade up and down or simply plow through without responding to the existing terrain? Why are the railroad cuttings, tunnels, or bridges where they are?
- Which landforms correspond to closely spaced contour lines and which ones correspond to widely spaced contour lines? Which river in the watershed has the steepest-sided valley?
- What are some possible reasons for the location of particular facilities, such as sewage treatment plants, an airport, or industrial plants, within the watershed? What path would you suggest for a walking path, a biking path, a motor vehicle path, and a flight path across the watershed?
- Where would you recommend building new houses or industry in the watershed? At which locations in the watershed would you ban further building?

Extensions

1. Divide the learners into groups to make more than one model. Make a model of the watershed as it was ten years or one-hundred years ago, or as it was before the last Ice Age. What sorts of changes occur at the different time scales? How have human activities changed the shape of the watershed?

2. If the local stream or river is a tributary of another watercourse, make a model of the larger watershed. What are the similarities and differences in the two different scale watersheds?
3. Make a model of a watershed in another part of the state, country, or world. Compare it with the local watershed. What features might be common to all watersheds? How do the relationships between the physical features and the humans in the two watersheds compare?

Evaluation

1. Locate several natural physical features and several human-made features on the topographic map, and locate their corresponding position on the watershed model.
2. Describe a few important ways in which the physical features of a watershed influence the location of human activities.
3. Describe ways in which human activities change the shape of the watershed, and consequently, the path along which water will flow.

River Walk

Objectives

Students will be able to: 1) describe how local land uses influence river water quality; 2) use both visual and olfactory stimuli as indicators of water quality; 3) pose pertinent questions concerning aspects of the river that require action or further investigation.

Method

Through a field trip along a local water course students will conduct a visual survey to discover information about local land use and water quality. They will document their findings with mapping and compilation of a river profile and use this initial reconnaissance to raise questions about local land use or river water quality that require investigation.

Background

Many factors can affect the quality of a river system. The conditions of a river can fluctuate. What is high quality in one area may be low quality in another, while some factors, such as pollutants, are a hazard to any watershed. Cold water that is good for trout may be fatal for catfish or bass, and vice versa, but discharges of industrial or agricultural wastes will be detrimental for all life in the water. Water quality monitoring can begin with one's visual and olfactory senses (Refer to the activity: **Learning to Look, Looking to See**); it does not require sophisticated equipment. Common constituents and pollutants in water have characteristic appearances and smells that can be observed for an initial determination of water quality. Field observations increase one's ability to conceptualize links between land use and water quality.

Age

Grades 7 - 12

Subjects

Biology, Geography, Social Studies, Language Arts, Science, Math

Duration

Three hour field trip

Skills

field observations, flow & current, mapping

Key Vocabulary

algae, erosion, olfactory, point source, runoff, sedimentation, tannin

Materials

Clip board, pencils, data sheets, local map, aerial or satellite images and the watershed and land cover maps that were created earlier.

Procedure

1. Ideally, small groups of students should walk and survey designated stream or river segments appearing on the watershed map which they made earlier. If watershed maps were not made, local topographic maps encompassing the stream or river can be used, and are helpful in any case for showing roads and other reference points. Accessibility and safety are two criteria for designating these segments. Each segment should be bound by conspicuous reference points: bridges, monuments, roads, or distinctive natural features. An appropriate length for each segment is site-specific, but l km segments are suggested. Familiarize everyone with safety procedures before beginning the walk.
2. Stream or river segments may be coded or labeled to abbreviate the river's name and to indicate the relative position of the segment along the stream or river. For example, the segment at the mouth of the Arkansas River, USA, might be labeled AR1, the next segment upstream AR2, etc.
3. During their walk each group completes a data sheet. The group also records its observations on a stream map. As each group walks their stream segment, bordering land uses should be noted: urban, industrial, residential, agricultural, woodlands, swamp, and others. Tributaries and point sources of pollutants, such as discharge pipes, open sewers, and ditches should also be shown on the map as well as the direction of flow. Your students may decide to use topographic symbols or symbols of their own choosing to denote land uses and human-made structures.
4. Each student should write a personal narrative account of the walk. Encourage richness of detail about uses bordering the watercourse, colors and odors, human usage of the river, suspected pollution sources, and the students' perceptions of and reflections on being at the river. Unique or significant features could be referenced to the small group's map.
5. Assemble the maps according to their relative positions along the stream. Exchange data sheets among all small groups. Look for similarities, differences, and patterns among the observed characteristics of the segments.

Discussion

Organize a discussion with your students by asking the following questions:

- What type of water appearance was recorded most often and what does this indicate about the water quality of the stream or river? What might be the source of material creating this appearance? How does the appearance of the water change from upstream to downstream?
- Which human uses of the river were found with which land covers? If two land cover types were reversed in their order along the stream or river, what changes might this make in the appearance of the river?
- What kinds of habitats were observed to be most extensive along the river or stream? If one of the most extensive habitats along the river or stream was eliminated, what effect might it have on wildlife? What effect might it have on human uses of the river?
- What is the total number of barriers found in the segments investigated? Were the majority of the barriers naturally occurring or human-made? What are some reasons humans have created barriers?
- What do the odors noticed along the river indicate about the water quality? How could the weather on the day of the walk and the day before the walk have influenced the water quality?
- As you exchanged narratives with a partner, which river characteristics did you both mention, and which characteristics did just one of you mention? Why might your perceptions vary? What implications do differing perceptions among people in the watershed have for choosing land uses, and for solutions to water quality problems?

Extension

1. Bring your students atop a high place from which the whole segment of the river walk is visible. On the watershed map or land cover map, sketch in the boundaries of landform or land use subdivisions that are apparent from the high vantage point. Write a description of the area to accompany the map. Try to place the river segment in context in the watershed and between other segments. Begin by stating the location of the segment and its length and breadth in miles. If fairly uniform, give the general altitude of the area. Describe distinguishing landforms, including waterfronts, drainage pattern, vegetation types, minerals, and cultural features such as communication or transport systems and their responses to relief and drainage, land use and land cover, occupations in the area and so on. Distinguish between what is actually seen and what is surmised. The written descriptions of the river segments and their surroundings, along with corresponding sketch maps, could be compiled into a travelogue booklet.

Evaluation

1. Describe the relationship between visual and olfactory indicators and water quality.

2. Pose several questions about the river's water quality that require further investigation.

Regulatory Agencies on the River

Objectives

Students will be able to: 1) list and identify functions and jurisdiction of at least three governmental agencies charged with safeguarding water quality; 2) explain the concern over water quality; 3) explain how citizens can have a role in the action of governmental agencies.

Method

Learners will identify existing government agencies charged with safeguarding water quality, their geographic jurisdiction, and their subjects of concern, such as water quality laws, information, testing, and enforcement. They will explain the role of citizen action in these agencies, and locate the names, telephone numbers, and addresses that citizens may use to contact the agencies.

Age

Grades 7-12

Subjects

Social Studies, Science

Duration

Four class periods, plus independent research

Skills

research

Key Vocabulary

jurisdiction, regulation

Background

Regulatory agencies at all levels of government have certain responsibilities and authority to protect public safety and water quality on rivers and other bodies of water. Regulations are principles, rules, or laws to govern behavior. Water resource regulations have been created and are enforced because some people are inconsiderate of others, some aspects of river and waterways (such as floods) are unpredictable, and some services (such as water treatment) are more efficient when provided on a larger scale. The purpose of this activity is to increase learners' understanding of regulatory agencies charged with water resources management, how citizens have input into these agencies, and to increase skills in locating sources of political, social, economic, and legal information about regulatory agencies and citizens' organizations.

Human behavior may be changed by means other than regulation. Education can alert people to the unknown hazards of building on flood plains. Economic incentives can encourage industries to reuse their by-products rather than to discharge effluents into a river. Peer pressure or philosophical reasoning can persuade people to be more considerate when fishing, or to avoid littering in and near the river.

Agencies at all levels of government in the United States have been charged with water resources management. They include, but are not limited to the following:

- International agencies like the International Joint Commission which resolves mutual border problems between Canada and the United States.
- Federal agencies such as the Soil Conservation Service (SCS) which works with farmers to try to minimize erosion, or the Environmental Protection

Agency (EPA) which sets water quality standards. Most federal agencies with water concerns are under the jurisdiction of the U.S. Department of the Interior.
- State agencies such as a Department of Natural Resources are charged with protection and management of water resources along with forests, wildlife, minerals, etc.
- County agencies like the Public Health Department monitor the safety of drinking water and of bathing beaches.
- Local agencies like the Department of Water Supply and the Department of Wastewater Management provide services to individual clients in the city or district.
- Private water quality testing firms are often an excellent source of information on local water quality issues, even though they are not regulatory agencies themselves.

Materials

List of regulatory agencies at different levels of government which have primary water resource responsibilities, phone book, writing materials, envelopes, pens, postage, access to a telephone.

Procedure

1. Each small group of students should choose one agency to investigate. Tell them that they will be responsible for informing the rest of the class about their particular choice. They will be the experts on their agency. Through library research, phone calls, letters and even visits to the respective offices, students should determine the laws, standards, enforcement, and penalties for which their particular water resources agency is responsible. Obtain the address and phone number of the agency's nearest office, and the name of someone to contact in that agency concerning its water resources work.

2. After determining which agencies would find the data useful or which would address the kinds of concerns identified during the river walk, make appointments with agency staff members to present the group's observations, discuss the water quality problems identified, and possible solutions generated.

3. Each group should report back to the class on their agency and the results should be posted in graphic form so that the students can see how each agency interacts with or compliments the others.

Discussion

Organize a discussion with your students by asking the following questions:
- What are the names and responsibilities of the regional, federal, state, county, and local agencies which have primary water resource responsibilities in the local area?
- Why are regulations associated with water resources necessary to protect public health and safety?
- What measures other than regulations may be used to maintain the health and safety of water resources?
- What are some difficulties encountered by water resources agency staff in creating and enforcing regulations? How might these difficulties be overcome?

Extensions

1. Record water meter readings at the beginning of a day and at the end of a day at home to check the accuracy of water consumption figures used by water resources agencies. Discuss why the home meter readings may differ from the agency consumption figures.

2. Tour a water or wastewater treatment plant. If possible, videotape or tape record the tour for later reference. If the treatment plant needs upgrading to meet EPA standards, how might this be accomplished?

3. Conduct a Delphi study, a technique used by some regulatory agencies, to determine the consequences of proposed water resources rules. A Delphi study consists of the following steps:

- As a small group, brainstorm a list of the consequences of one proposed water resources rule. Devise a scale on which to rate the importance or magnitude of each consequence.
- Determine the probability of each consequence occurring.
- Calculate the overall effect of each consequence by multiplying the importance rating by the probability of occurrence.
- As a large group, discuss the overall effects of each consequence and the reasoning used by each small group in making a determination.
- Discuss the advantages and disadvantages of using a Delphi study to consider the consequences of proposed water resources regulations.

4. If it is not possible to visit regulators or others associated with water resources use and regulation at their place of work, invite them to visit the group. Ask them to illustrate or demonstrate their work. Persons to invite include: county health specialist, county naturalist, county sanitarian, commercial water quality tester, well driller. Discuss the water resources regulations important in their jobs.

5. Take on the role of law makers. Write five rules to protect water quality, or public health and safety associated with water resources. Write to legislators concerning the existence, future existence, or nonexistence of the rules proposed.

Evaluation

1. Identify the area of geographical jurisdiction for at least three government agencies charged with safeguarding water quality.

2. Identify and explain the subjects of concern for at least three government agencies charged with safeguarding water quality in the local area.

3. Explain how citizens can have a role in the actions of at least three water resources agencies.

Appendices

- Global Temperature Data Set
- Glossary
- Evaluation Forms
- Image Applications
- Sources of Remote Sensing Imagery
- Reading and Resources

Global Temperature Data Set

These data are global average temperature anomalies (variations) from a global average temperature of 15˚C (59˚F) which was calculated from a reference period of temperatures taken between 1950 and 1979 (the values listed are *not* corrected for the influences of El Nino/Southern Oscillation (ENSO)). These data were compiled by PD Jones and TML Wigley of the Climatic Research Unit at the University of East Anglia in England. For a comprehensive review of how the data were gathered, and corrected for errors, read Jones & Wigley's article in the August 1990 issue of *Scientific American.*

For more of the data in this set see: Jones, PD, TML Wigley, and KR Briffa. 1994. Global and hemispheric temperature anomalies-land and marine instrumental records. pp. 603-608. In TA Boden, DP Kaiser, RJ Sepanski, and FW Stoss (eds.), *Trends '93: A Compendium of Data on Global Change.* ORNL.CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., USA. To obtain data from CDIAC electronically contact the following internet address: DCP@ORNL.GOV. Their homepage is *http://cdiac.esd.ornl.gov:80/cdiac/*

Year & Global Average Temperature Anomalies based on 1950-1979 Reference

Year	Global Temperature Variation	Year	Global Temperature Variation	Year	Global Temperature Variation
1854	-0.12	1872	-0.28	1890	-0.40
1855	-0.43	1873	-0.30	1891	-0.34
1856	-0.28	1874	-0.39	1892	-0.38
1857	-0.47	1875	-0.44	1893	-0.43
1858	-0.38	1876	-0.40	1894	-0.35
1859	-0.18	1877	-0.12	1895	-0.31
1860	-0.38	1878	0.02	1896	-0.14
1861	-0.45	1879	-0.35	1897	-0.10
1862	-0.58	1880	-0.32	1898	-0.31
1863	-0.23	1881	-0.29	1899	-0.18
1864	-0.46	1882	-0.30	1900	-0.05
1865	-0.23	1883	-0.35	1901	-0.14
1866	-0.20	1884	-0.44	1902	-0.25
1867	-0.23	1885	-0.38	1903	-0.38
1868	-0.27	1886	-0.27	1904	-0.47
1869	-0.21	1887	-0.40	1905	-0.31
1870	-0.31	1888	-0.31	1906	-0.22
1871	-0.37	1889	-0.17	1907	-0.41

Global Temperature Data Set (continued)

Year	Global Temperature Variation	Year	Global Temperature Variation	Year	Global Temperature Variation
1908	-0.44	1939	-0.03	1970	0.05
1909	-0.36	1940	0.03	1971	-0.08
1910	-0.35	1941	0.04	1972	0.02
1911	-0.40	1942	0.05	1973	0.14
1912	-0.31	1943	0.00	1974	-0.10
1913	-0.33	1944	0.16	1975	-0.09
1914	-0.16	1945	0.05	1976	-0.22
1915	-0.05	1946	-0.06	1977	0.11
1916	-0.29	1947	-0.04	1978	0.04
1917	-0.47	1948	-0.05	1979	0.10
1918	-0.35	1949	-0.08	1980	0.19
1919	-0.25	1950	-0.14	1981	0.27
1920	-0.23	1951	-0.02	1982	0.09
1921	-0.20	1952	0.08	1983	0.30
1922	-0.28	1953	0.13	1984	0.12
1923	-0.25	1954	-0.11	1985	0.09
1924	-0.29	1955	-0.14	1986	0.17
1925	-0.17	1956	-0.22	1987	0.30
1926	0.00	1957	0.09	1988	0.34
1927	-0.13	1958	0.11	1989	0.25
1928	-0.14	1959	0.05	1990	0.39
1929	-0.32	1960	-0.02	1991	0.35
1930	-0.14	1961	0.12	1992	0.17
1931	-0.04	1962	0.11	1993	0.21
1932	-0.11	1963	0.13		
1933	-0.22	1964	-0.18		
1934	-0.11	1965	-0.12		
1935	-0.16	1966	-0.04		
1936	-0.13	1967	-0.01		
1937	0.01	1968	-0.06		
1938	0.08	1969	0.06		

Glossary

Acid Deposition
is precipitation (rain, snow, etc.) made acidic by the introduction of sulfur dioxide and nitrogen oxides into the atmosphere as a result of fossil fuel burning. Automobile exhaust and emissions from coal-fired power plants are two of the primary causes of acid deposition. In severe cases, acid precipitation kills fish and other aquatic life and damages and destroys trees and crops. In some instances, it has rendered entire lakes and forests nearly lifeless.

Advection
the predominantly horizontal large-scale movement of air that causes changes in temperature or other physical properties. In oceanography, advection is the horizontal or vertical flow of sea water as a current. ■

Aerial Photo
a 9" X 9" photograph taken vertically downward from the air on 10" roll film. Aerial photo images may be in the form of paper prints or transparent film. ▲

Air Mass
a widespread body of the ***atmosphere*** that gains certain meteorological or polluted characteristics while set in one location. The characteristics can change as it moves away. ■

Albedo
the fraction of the total solar radiation incident on a body that is reflected by it (i.e., reflected sunlight). ■

Analog
information stored and processed as signal intensity or other measurement of a continuous physical variable. Analog information processing translates and represents slight increments in data easily and conveys information by relative position without relying on the numeric value necessary to convey the same information digitally. For example, you can tell time on an analog watch even if it has no numbers on the face and a thermometer that displays temperature using a needle or liquid can indicate fractions of a degree, as well as provide information about relative warmth by the position of the dial or height of the liquid. On the other hand, this continuous analog information is harder to copy, store, manipulate, and reproduce dependably. Anyone who has listened to a copy of a copy of a copy of a cassette tape has first-hand knowledge of analog information degradation. For this reason, much analog information (video, audio, or field and laboratory measurements of temperature, pressure, voltage, radiation, etc.) is converted to its digital equivalent. (See also ***Digital, Digitizer***) ▲

Anthropogenic
man made. Usually used in the context of emissions that are produced as the result of human activities. ■

Atmosphere
the envelope of air surrounding the Earth and bound to it by the Earth's gravitational attraction. Studies of the chemical properties, dynamic motions, and physical processes of this system constitute the field of meteorology. ■

AVHR
Advanced Very High Resolution Radiometer - imagery produced by ***NOAA*** satellites. ▲

CAD
Computer Aided Design. CAD originated on larger, dedicated workstations and minicomputers and has now migrated to microcomputers. In its simplest sense, CAD is used for computerized drafting. Many CAD systems also provide more advanced features like solid modeling and simulation. ▲

Climate
the statistical collection and representation of the weather conditions for a specified area during a specified time interval, usually decades, together with a description of the state of the external system or boundary conditions.
The properties that characterize the climate are thermal (temperatures of the surface air, water, land, and ice), kinetic (wind and ocean currents, together with associated vertical motions and the motions of ***air masses***, aqueous humidity, cloudiness and cloud water content, ground-water, lakes, and water content of snow on land and sea ice), and static (pressure and density of the atmosphere and ocean, composition of the dry air, salinity of the oceans, and the geometric boundaries and physical constants of the system). These properties are interconnected by the various physical processes such as ***precipitation, evapotranspiration, infrared radiation, convection, advection***, and ***turbulence***. ■

Cloud Albedo
reflectivity that varies from less than 10 to more than 90% of the ***insolation*** and depends on drop sizes, liquid water content, water vapor content, thickness of the cloud, and the sun's zenith angle. The smaller the drops and the greater the liquid water content, the greater the cloud albedo, if all the other factors are the same. ■

Cloud Feedback
the coupling between cloudiness and surface air temperature in which a change in surface temperature could lead to a change in clouds, which could then amplify or diminish the initial temperature perturbation. For example, an increase in surface air temperature could increase the evaporation; this in turn might increase the extent of cloud cover. Increased cloud cover would reduce the solar radiation reaching the Earth's surface, thereby lowering the surface temperature. This is an example of negative feedback and does not include the effects of ***longwave radiation*** or ***advection*** in the oceans and the atmosphere, which must also be considered in the overall relationship of the climate system. ■

Cloud
a visible mass of condensed water vapor particles or ice suspended above the Earth's surface. Clouds may be classified on their visual appearance, height, or form. ■

Color Composite
as associated with Landsat, a 24.1 cm (9.5 in.) color transparency or print generated from black and white triplet sets usually using ***multispectral scanner*** bands 4,5, and 7. The resulting colors are arbitrarily derived, hence the expression "false color." ●

Color-Infrared (CIR)
color-infrared images may be collected by an electronic scanner or a camera that uses special film. Infrared film records

the photographic infrared radiation just beyond the range of human vision as red. Normal red from the scene becomes green, and green becomes blue. Normal blue in the scene is filtered out and is not recorded. Any physical or biological damage to growing plants which begins to cause a deterioration in their vigor (their water and/or chlorophyll content) causes a rapid decrease in their red reflectance. CIR photographs show these changes much sooner and more dramatically than normal photographs or human eyesight. Healthy, green vegetation appears in bright red, while damaged, diseased, or dying vegetation appears in shades of pink, tan, and yellow. This knowledge was first used in the Second World War when color-infrared film was called camouflage detection film. It provided pre-visual detection of the changes in vegetation cut or damaged by military activity and could very easily separate color-camouflage materials (like olive-green canvas) from live foliage. ▲

Convection

atmospheric or oceanic motions that are predominantly vertical and that result in vertical transport and mixing of atmospheric or oceanic properties (i.e., heat and cold). Because the most striking meteorological features result if atmospheric convective motion occurs in conjunction with the rising current of air (i.e., updrafts), convection is sometimes used to imply only upward vertical motion. ■

Coregistration

the condition in which associated ***raster*** and/or ***vector*** objects overlay each other with correct orientation and geometry so that corresponding internal features align. ▲

Data

a magnitude, figure or relation supposed to be given, drawn, or known in a mathematical investigation from which other magnitudes, figures or relations are to be deduced. ❖

Digital

information stored and processed with numerical digits, often in base 2. Digital information processing is constrained by the finite set of numbers a system uses, such that every data value is forced into its nearest representation. For example, a digital temperature sign at the local bank has no way to deal with fractions of a degree: it can show 75° or 76°, but not 75 and 2/3°. At some point, every digital system faces the same kind of limit in accuracy. On the other hand, digital information is easy to copy, store, manipulate, and reproduce dependably.
(See also ***Analog***) ▲

Digitize

convert analog data into a digital form; also, more specifically, use a digitizing tablet to convert data to digital form. ▲

Digitizer

a device that converts an analog signal or representation to a digital one. (See also ***Video Digitizing Board, X-Y Digitizing Tablet, and Scanner)*** ▲

Electromagnetic Spectrum

"the entire spectrum, considered as a continuum of all kinds of electric, magnetic, and visible radiation, from gamma rays

having a wavelength of 0.001 angstrom to long waves having a wavelength of more than 1 million km" (Random House). Remote sensing devices typically record electromagnetic bands in the region of optical light and may include the near infrared. (See also ***Spectral Band***) ▲

Evapotranspiration

discharge of water from the Earth's surface to the atmosphere by evaporation from bodies of water, or other surfaces, and by ***transpiration*** from plants.

False Color Composite

see ***color composite.*** ●

Frame Grabbing

Background: composite video and U.S. standard broadcasts repeat each ***field*** (see definition) every 1/60 of a second. Two interlaced fields, each containing alternate lines of the image make up one video frame that lasts 1/30 of a second. A video frame-grabber is a microcomputer interface board that accepts a video input signal and passes it to a color monitor. A program signals the video frame-grabber to both freeze and digitize one video frame. Digitizing a video frame may transform each picture element (**Pixel)** in the frame to a single byte in the board's memory. More commonly, it simultaneously captures, digitizes, and stores the video's separate red, green, and blue color values. Some frame-grabbers can be set to grab only a single field to avoid the relative movement between a frame's two fields. If the video comes from a camera that has high-speed electronic shuttering (like 1/1000 of a second), movement in the 1/30 of a second between the primary field and the secondary field causes saw-toothed edges on alternate lines in straight features like road edges, and vertical poles. (See also ***Video Digitizing Board***) ▲

Frame or Video Frame

a complete video image which consists of two interlaced ***fields***. Odd lines of the frame are contained in the ***primary field*** which is alternated with the ***secondary field*** that contains the even lines. The primary field lasts 1/60 of a second in standard broadcast video. The secondary field follows in the next 1/60 of a second. The entire frame takes 1/30 of a second to display. There is a difference of 1/60 of a second between alternate lines in the image. ▲

Global Change

refers to environmental change caused by the aggregate of interactive linkages among major Earth systems — ***climate*** and ***hydrologic systems***, ***biogeochemical dynamics***, ***ecological systems*** and dynamics, ***solid earth processes***, ***solar influences***, and human interactions with these systems.

Global Warming

is a term used to describe the warming of Earth's climate due to an increased ***Greenhouse Effect*** (see below) caused by human beings introducing large amounts of carbon dioxide, methane, and other greenhouse gases into the atmosphere. It is believed that Earth's climate could warm as much as 5 ˚C (9 ˚F) as early as the middle of the next century—a rate of climate change tens of times faster than the average rate of natural change.

Greenhouse Effect

is a phrase used to describe the increased warming of the Earth's surface and lower atmosphere due to carbon dioxide and other atmospheric gases that, like the glass panels in a greenhouse, let the sun's energy in, but block the ***long wave radiation*** emitted by the earth's surface after being heated by the incoming solar energy. Were it not for the existence of the Greenhouse Effect, Earth's surface temperatures would be about 33 ˚C (60 ˚F) colder than they are and life as we know it would not exist.

Ground Resolution

the limit of detail clarity in an image of the Earth's surface collected by some remote sensing device, usually measured in meters. An image with a ground resolution of 10 meters shows no ground features smaller than 10 X 10 meters. Each data cell (or ***Pixel***) in such an image contains one averaged value for a distinct 10 X 10 meter surface area. ▲

Ground Truth

information collected at the same site and at the same time that a remote sensing system collects data. Ground Truth data are used to interpret and calibrate remotely sensed observations. ▲

Landsat

is the name given to a group of 5 satellites which collect remotely sensed data about Earth. Landsat 1, originally called Earth Resources Technology Satellite or ERTS-1, was launched in 1972 to apply remote sensing techniques to the inventory, monitoring, and management of Earth's natural resources. There are currently two sensors for the Landsat system — ***multispectral scanner (MSS)*** and ***thematic mapper (TM)***. The resolution of MSS data is 80 meters by 80 meters; it acquires black and white images in 4 spectral bands in the visible and near-infrared portions of the electromagnetic spectrum. The resolution of TM is 30 meters by 30 meters with sensing in 7 spectral bands.

Longwave Radiation

the radiation emitted in the spectral wavelength greater than 4 angstrom corresponding to the radiation emitted from the Earth and atmosphere. It is sometimes referred to as "terrestrial radiation" or "infrared radiation," although somewhat imprecisely. ■

Modeling

an investigative technique that uses a mathematical or physical representation of a system or theory that accounts for some or all of its known properties. Models are often used to test the effects of changes of system components on the overall performance of the system. ■

MSS

Multi-Spectral Scanner. A sensing device on the Landsat satellite that collects simultaneous images over multiple ranges of the spectrum. MSS has a pixel resolution of 80 meters. ▲

Multiband or Multispectral
images optically acquired in more than one ***spectral*** or ***wavelength interval.*** Each individual image is usually of the same physical area and scale, but of a different ***spectral band***. The ***MSS*** and ***TM*** sensors aboard the ***Landsat*** satellite both collect simultaneous multispectral images. The TM sensor scans and stores seven individual images in spectral bands ranging from the blue wavelengths up to those in the thermal ***infrared***. ▲

Multisensor Images
coregistered images with the same cell size collected by different sensing devices. For example, a 10-meter ***SPOT panchromatic image*** can be coregistered with a resampled ***Landsat TM*** image so that their cells correctly match. This combination is called a multisensor image. ▲

NAPP Airphotos
National Aerial Photography Program airphotos. USGS CIR high altitude airphotos. The NAPP series replaces the NHAP series. (See also NHAP). ▲

NHAP Airphotos
National High Altitude Program. NHAP is underwritten by the ***USGS*** and provides a publicly available collection of ***CIR*** airphotos covering the United States in print or transparency format. ▲

NOAA Satellite
refers to the National Oceanic and Atmospheric Administration's TIROS Polar Orbiting satellite which obtains images with the ***Advanced Very High Resolution Radiometer (AVHRR)*** or the GOES Geostationary satellite with the ***Visible-Infrared Spin-Scan Radiometer (VISSR)***. These images, used for weather prediction and other purposes, are available from NOAA.

Ozone Depletion
refers to the thinning of the stratospheric ozone layer which protects Earth and its inhabitants from excess ultraviolet radiation from the sun. Human-made chemicals, chlorofluorocarbons or CFC's, are primarily responsible for the ozone depletion which is now proceeding at an alarming rate. Ozone concentrations over the U.S. may have fallen as much as 5% in the last decade and there is a measurable thinning of the ozone layer over both poles, particularly over the South Pole in the early Spring. (The issue of stratospheric ozone depletion is not to be confused with the problem of ground level or tropospheric ozone which is a pollutant in the lower atmosphere.)

Panchromatic Image
an image collected in the broad visual wavelength range, but rendered in black and white. The term has historically referred to a black and white photograph of a color scene. Since the ***SPOT*** satellite 10-meter images are collected over this broad visual spectral band and are usually rendered in black and white, these images are called panchromatic ▲

Pixel or Picture Element
refers to a single sample of data in a digital image. The word pixel is a contraction of “picture element.”

Pollution
harmful substances deposited in the air, land or water, leading to a state of dirtiness, impurity, unhealthiness, or hazard. ✶

Precipitation
any or all forms of liquid or solid water particles that fall from the atmosphere and reach the Earth’s surface. It includes drizzle, rain, snow, snow pellets, snow grains, ice crystals, ice pellets, and hail. The ratio of precipitation to evaporation is the most important factor in the distribution of vegetation zones. Precipitation is also defined as a measure of the quantity, expressed in centimeters or milliliters of liquid water depth, of the water substance that has fallen at a given location in a specified amount of time. ■

Range
the space or extent included, covered, or used. ❖

Raster Cell
one value in a raster that corresponds to a specific area on the ground. A raster cell value may be the elevation above sea level at one position in a survey site or the intensity of red radiation for a pixel in a video image. For convenience, a raster is usually thought of as square or rectangular, although many image collection devices actually measure circular or elliptical areas. ▲

Raster
a single, related, two-dimensionally grouped, set of numbers of a single data type. Each number represents the value of some parameter. Its position in the group represents its relative position to the other values ▲

Remote Sensing
acquisition of information about objects or phenomena on the Earth (including land, oceans, and atmosphere) through the use of sensory devices at positions separated from (remotely situated) the subject under study. Examples of remote sensors include aircraft, satellites, and human eyesight, hearing, and smell. Obtaining information from a distance. ●

Resolution
the level of object detail or sharpness determined by how many picture elements (***Pixels***) compose an area of a display or corresponding ***raster***. Resolution may refer to sensors, raster objects, or displays. Low resolution display devices produce images with a grainy visual texture. High resolution display use such small picture elements (***Pixels***) that they can produce a near-photographic quality image. (See also ***Ground Resolution***) ▲

Riparian
located or living along or near a stream, river, or body of water.

Satellites
here referring to human-made objects that orbit celestial bodies. In the Ground Truth Studies Project, we will be primarily concerned with those that orbit the Earth and collect remotely sensed data of Earth's surface. These include: Landsat (***MSS*** and ***TM***), ***SPOT***, and ***NOAA***.

Scale
an indication of the relationship between the distances on a map, chart, or image and the corresponding actual distances.

Scanner
a digitizer that produces an image (raster object) from flat input material such as photographs, maps, and drawings. ▲

Spectral Band or Spectral Region
a well-defined, continuous wavelength range in the spectrum of reflected or radiated electromagnetic energy. Red, green, and blue are each spectral regions within the small portion of the spectrum that is visible to humans as light. Color-infrared images are composed of red, green, and a spectral region commonly called the photo infrared, which is not in the visible portion of the electromagnetic spectrum. (See also ***Electromagnetic Spectrum***, ***Color-Infrared***) ▲

SPOT
the French Satellite Pour l'Observation de la Terre. There are two SPOT satellites: one collects images with 10-meter ***ground resolution*** in a single ***panchromatic spectral region***; the other collects 20-meter images in the three spectral regions used for ***color-infrared*** maps. SPOT satellites may be pointed at an angle off-axis or off-nadir to collect forward and rearward images: a techniques that yields stereoscopic image pairs from which accurate elevation ***rasters*** can be computed. ▲

TM
Thematic Mapper. A sensing device on the ***Landsat*** satellite that scans and stores 7 individual images in ***spectral bands*** ranging from the blue wavelengths up to those in the thermal infrared. TM has a pixel resolution of about 30 meters. ▲

Topographic Map
a map that uses colors and symbolic patterns to represent the general surface features of the Earth, such as grassland, forest, marsh, agricultural, urban, and barren rock. ▲

Topography
the features of the actual surface of the Earth, considered collectively according to their form (grassland, cultivated, desert, forest, swamp, etc.) A single feature, such as one mountain or one valley, is called a topographic feature. ▲

Transpiration
the process in plants by which water is taken up by the roots and released as water vapor by the leaves. The term can also be applied to the quantity of water thus dissipated. ■

Turbid
opaque with suspended matter, such as of a sediment-laden stream flowing into a lake. ●

USGS
United States Geological Survey. ▲

Vector
a data structure for representing point and line data by means of 2- or 3-dimensional geometric (Cartesian x, y or x, y, z) coordinates. In connection with ***GIS*** and computer graphics, "vector" can refer to a set of line segments joined end to end to make a curved line in space. ▲

Verification
is establishing the accuracy of data by checking it against an independent means of collecting information; confirmation, validation. Often ***ground truth*** observations and measurements are verification for remotely sensed data.

Video Digitizing Board
a video interface circuit board that samples or frame-grabs a video frame and constructs a digital image. Video digitizing boards are slower than video capture boards, but can be used for non-standard, higher resolution video sources. (See also ***Frame-Grabbing***) ▲

Watershed Seed Point
the point at the base of a watershed into which all points in the watershed drain; often taken as the mouth of a stream or river. ▲

Watershed
the entire area above a given point (called the watershed "seed") that drains into that point. ▲

X-Y Digitizing Table
a peripheral device for manually translating line and point data (like engineering and technical drawings) into some computer format (usually vector or CAD). The drawing is secured to the tablet, and the operator positions the device's cursor (which may look like a pen or a computer mouse with a crosshair lens) over lines and other elements, clicking a button or pressing a key to record a coordinate. ▲

■ *Glossary: Carbon Dioxide and Climate*, ORNL/CDIAC-39, Oak Ridge National Library, Oak Ridge, Tennessee (1990)

● *Glossary of Technical Terms*, Mission to Earth: Landsat Views the World. Scientific and Technical Information Office, National Aeronautics and Space Administration, Washington, D.C. (1976 and 1978)

▲ *Glossary*, A Guide to Map and Image Processing, MicroImages, Inc., Lincoln, Nebraska (1991)

✶ *Glossary*, Project WILD: Secondary Activity Guide, Project WILD, Boulder, Colorado (1983)

❖ *Webster's Third New International Dictionary*, G. & C. Merriam Company, Publishers, Springfield, Massachusetts (1971)

Uncited definitions by Aspen Global Change Institute.

Image Application Chart

Soils and Land Use information to use as environmental education content

	Airplane platform	Satellite platform
Inventory and mapping of resources	Identify beach cliff erosion, landslides on hillsides and ground displacements Map soil units and delineate soil boundaries Map land use and land use intensities Map annual extent of fires Map faults and folds	Map large-scale degradation Space shuttle imaging radar maps ancient drainage patterns and potential present-day sources of near-surface water Classify dune fields and identify rock types
Quantifying the environment	Determine soil temperature with thermal infrared images Delineate extent of erosion, desertification, and encroachment of sand Indicate land potential Measure soil moisture	LANDSAT indicates extent of area burned by fire ERTS assists soil temperature measurement
Describe flow of matter and energy	Suggest the design of rural access networks Study dynamics of soil salinization	LANDSAT 5 and 6 TM provide soil moisture data for more intensive development such as resettlement EOS detects tectonic plate motion Space shuttle detects dust storms in arid lands
Evaluate change and alternate solutions for management of ecosystems	Record sequential land use as with gravel pits Indicate amount of replacement of one land use by another Compare the relative productivity of various combinations of crop and grazing land Record changes during the year because of tillage, crop rotation, crop growth, and conservation measures	Document large-scale degradation: wind erosion, salinization, and flooding Monitor surface mining and reclamation LANDSAT TM indicates conversion of forest to cropland LANDSAT updates knowledge of gross land-use changes

Aquatic Ecosystems information to use as environmental education content

	Airplane platform	Satellite platform
Inventory and mapping of resources	Map watersheds, surface water bodies, water temperature distributions and coastal features and reefs Detect and map wetlands and floodplains Identify potential recharge zones for groundwater Identify hazardous substances in water Identify and map aquatic vegetation	ERTS watershed, floodplain, wetlands, and inundation mapping Meteorological satellite cloud type identification Map the circulation patterns in large water bodies and the spread of phreatophytes in intermittent streams Inventory sewage and industrial outfalls
Quantifying the environment	Estimate wetlands biomass Indicate extent of floods or snow cover Indicate extent of lake eutrophication Measure snow depth Measure stream length and channel development Measure sea-surface wind direction and velocity	LANDSAT wetland biomass estimation and coastal primary productivity measurement Meteorological satellite indicates amount of cloud cover and sea-surface temperature Measure extent and character of sea-ice Estimate oceanic biologic activity
Describe flow of matter and energy	Study turbidity, transparency, thermal stratification and surface thermal patterns investigate pollution concentrations assess ocean wave pattern and size detect freshwater upwellings in coastal zones and current patterns	ERTS assists water quality assessment with data about water depth variations, sediments, and pollution concentrations detect ice flows assess amount, direction, and movement rate of floating algae, foam, and suspended matter in coastal morphology study ocean currents with thermal scanning
Evaluate change and alternate solutions for management of ecosystems	monitor biological and chemical changes in waters used predict and monitor floods monitor seasonal extent of change in surface water coverage, aquatic vegetation abundance, and degree of turbidity monitor the impact of large impoundments	LANDSAT documents drainage, reclamation, and polderizaton of land LANDSAT monitors chlorophyll, particulate, and suspended solids in aquatic environs LANDSAT detects oil slicks and seepage in coastal areas determine coastline erosion or accretion

Wildlife information to use as environmental education content

	Airplane platform	Satellite platform
Inventory and mapping of resources	locate grazing animals map migration and nomadic movements map forage vegetation and damage by animals thermal location of animals at night zoophenological mapping	LANDSAT MSS mapping of woody country preferred by grey kangaroos locate the conditions for locust outbreaks ERTS characterization of staging and resting
Quantifying the environment	create permanent records for later analysis and counting determine number and status of grazers census wild and domestic species such as Beluga whales, snow, blue, and Canada geese, nesting pairs of gannets, kulan, caribou, and seabirds	LANDSAT MSS estimate of Australian grey kangaroos observe North Sea seals and Australian dugong
Describe flow of matter and energy	follow migratory herds and nomads correlate macro, meso, and micro events affecting animal distribution determine distribution of animals during migration and after calving	track locust swarms track dugong off Australian coast
Evaluate change and alternate solutions for management of ecosystems	evaluate and monitor animal or wildfowl habitat detect changes in the numbers or seasonal and longer-term distribution check the efficacy of management strategies and policies	ERTS evaluation of fish schools

Population Ecology principles that may be illustrated with remotely sensed images

Ecologic Principle	*General description of remotely sensed image to use*	*Specific images recommended in particular biosphere reserves*
age structure	photo showing how a group of organisms is divided	photo of an elephant herd or of a timber plantation into individuals at different stages in the life cycle
density	aerial photo recording the random, uniform, or clumped distribution of a population within a unit of space	color aerial photo of flamingos in tidal marsh, whales in shallow water, or mopane trees on the African savanna
ecological niche	color photo documenting an animal's profession, what it does	photo series of warbler species feeding in each one's region of a tree
habitat	aerial photo of mountain showing zones of vegetation varying with altitude	color aerial photo of mountain valley showing hardwoods at warmer lower elevations and confers at cooler higher elevations
predation	color photo of predator eating prey	photo of lions eating a wildebeest
migration	color photo of seasonal movement of groups of animals in spring	aerial photo of caribou moving north across the tundra
intraspecific competition	photo of an animal marking its territory	color photo of male red-winged blackbirds perched on vegetation in the center of each one's nesting territory
interspecific competition	aerial photo demonstrating that two species are seeking the same resource	aerial black and white photo of aromatic shrubs invading annual grassland by exuding biochemical inhibitors

Community Ecology principles that may be illustrated with remotely sensed images

Ecologic principle	*General description of remotely sensed image to use*	*Specific images recommended in particular biosphere reserves*
ecotone	photo of area where two major communities meet and blend together	black and white or color photo of western coniferous forests meeting short grass prairie in mountain foothills
primary succession	image showing the initial establishment and development of an ecosystem	aerial photo series showing lichens spreading over a rock surface
secondary succession	images depicting re-establishment of an ecosystem image of one community giving way to another	aerial photo series of eutrophying lake showing yearly successional stages in center with open water and widening later successional stages at the shoreline
human communities	aerial photos of different kinds of dwelling arrangements and their surroundings	aerial photo of the bhoma of Sahelian pastoralists, the village among Javanese sawah fields, or a hamlet in the Himalayas
microenvironment	close-up of a localized distribution of organisms within a community because of micro-differences in moisture, light, or other factors	photo of a hemlock stand within an oak-maple forest or of sedges and frogs in a prairie pothole in spring

Ecosystem Ecology principles that may be illustrated with remotely sensed images

Ecologic Principle	General description of remotely sensed image to use	Specific images recommended in particular biosphere reserves
energy flow	thermal image recording a temperature gradient	aerial thermal infrared image of water surface temperature in an estuary
materials flow	image series showing the movement of matter	satellite color photos of ocean eddies
productivity	image series documenting the amount of increase of organic matter per unit of time	satellite infrared images of the greening of arid lands after the rainy season
biome	images distinguishing dominant vegetation types in different places	aerial photos or satellite infrared images recording the vegetation of the tundra, temperate deciduous forests, or Mediterranean scrub
systems analysis	satellite images of global patterns	color photo of the Earth from Skylab

Sources for Remote Sensing Imagery

As a service for participating teachers, AGCI will provide assistance and centralized ordering.
To order images directly, contact the resources listed below.

Topographic Maps

Topographic maps are also available from local hiking/camping/outfitting shops.

order from:

Map Distribution, USGS
Box 25286
Federal Center,
Denver, CO 80225
allow 2 weeks cost: $2.50 each

Map Express
P.O. Box 280445,
Lakewood, CO, 80228
1-800-MAP-0039
same day service cost: $4.50 each

Aerial Photographs ❖

Government Sources, United States

Nearly every federal agency involved with land preservation, planning, or management maintains collections of aerial photographs that span the nation from picture-perfect coast to picture-perfect coast.

U.S. Geological Survey, Aerial Photography Summary Record System, established in 1976 as the first Earth Science Information Center data base, catalogs the in-progress and completed aerial photographs for the U.S. to assist in locating a desired photograph. The USGS, through its ESIC offices, can sell prints from photography from a number of federal agencies, such as the Bureau of Reclamation, the U.S. Navy, and the Environmental Protection Agency. A pamphlet, *How to Obtain Aerial Photographs,* available from the USGS, may be helpful in obtaining aerial photos(User Services Section, EROS Data Center, U.S. Geological Survey, Sioux Falls, SD 57198; 605-594-6151) or (Earth Science Information Center, 507 National Center, 12201 Sunrise Valley Dr., Reston, VA 22092; 703-860-6045).

U.S. Department of Agriculture, Aerial Photography Field Office in Salt Lake City, part of the Agricultural Stabilization and Conservation Service (Aerial Photography Field Office, P.O. Box 30010, Salt Lake City, UT 84130; 801-524-5856), has thousands of aerial photographs covering most of the nation's major cropland. USDA's National Forest Service has aerial photographs of the nation's forests.

Department of Commerce, National Ocean Service (Distribution Branch, (N/CG33), National Ocean Service, Riverdale, MD 20737; 301-436-6990) has aerial photographs of the nation's coastline.

Landsat Images ❖

Landsat images are available for the 50 states and for most of the Earth's land surface outside the U.S. There are several products available for any given location, including:

- Single black-and-white images, available as film negatives, film positives, or paper prints.
- Complete sets of four black-and-white images and a false-color composite.
  All false-color composites are available as film positives or paper prints.
- Computer tapes containing digital data.

Each Landsat image covers about 8 million acres. Images do not reveal outlines of small areas, like houses or small towns and villages, but provide views of broad areas and large features, such as mountain ranges and the outlines of major cities.

Landsat images within the past two years (very expensive— $2,750) are available through EOSAT offices located at the EROS Data Center (USGS-Department of Interior, EROS Data Center, Sioux Falls, SD, 57198;
605-594-6151), where orders are processed. For images over two years old (much cheaper - $200), order directly from EROS. When ordering, it is important to describe the exact area in which you are interested, including, if possible, the geographic coordinates or a map marked with the specific area. You should also indicate:

- The type of product (black-and-white, false-color, or digital tape);
- The minimum image quality acceptable;
- The maximum percent of acceptable cloud cover (10 percent to 90 percent); and
- The preferred time of the year.

A useful brochure, "Landsat Products and Services" is available from the EROS Data Center. This brochure includes a price list, order form, inquiry form, reference aids, and other information. To order specific images of the 48 contiguous United States, you can use the form *Selected Landsat Coverage* (NOAA Form 34-1205, available free from EROS and USGS Earth Science Information Centers), which includes a map of the U.S. showing the locations of individual Landsat

images selected for their clarity and lack of cloud cover. USGS has also prepared a number of photomaps, mosaics, and other images produced from Landsat, SPOT, and other imagery, including an impressive view of the entire U.S. Prices for most of these range from $2.50 to $6, not including postage and handling charges for mail orders.

SPOT Images ❖

SPOT's images may be obtained directly from SPOT Image Corp. (1897 Preston White Drive, Reston, VA 22091; 703-620-2200), the wholly-owned subsidiary of the French company created to market SPOT's services. SPOT data are available as digital information in computer-compatible tapes and as black-and-white or color prints and transparencies. Prices depend on several factors, including which of the three types of radiation that SPOT records (two bands of visible light and one of near-infrared radiation) is desired, resolution quality (either 20-meter resolution or the sharper 10-meter resolution), and the size of the print or transparency. For example, a 9 1/2" square black-and-white transparency showing all three bands at a scale of 1:400,000 and 10-meter resolution is $2,450 - a color transparency at a scale of 1:400,000 (corrected for distortion to the point that it can be used to overlay on a printed map with high accuracy) and 20-meter resolution is $1,300. Prints are a bit less pricey ($250 each, black-and-white or color), but must accompany a tape or transparency order. At such prices, SPOT images, however spectacular, are not intended for mere decoration.

Satellite-Image Maps ❖

USGS has published satellite-image maps for selected areas in the U.S. and such areas as Antarctica, the Bahamas, and Iceland from multispectral (MSS) scanner, thematic mapper (TM), and SPOT imagery. Most of these image maps are printed in false-color infrared. Notable examples are "Denali National Park, Alaska," at a scale of 1:250,000 with a standard topographic map on the reverse side ($7); "Washington, D.C." at a 1:50,000 scale ($5.50); and "Point Loma, California," at a scale of 1:24,000 with a standard quadrangle map on the reverse side ($4). An order form listing these maps is available from USGS ESIC offices nationwide or from the Distribution Center in Denver, Colorado (Denver-ESIC 169 Federal Bldg., 1961 Stout Street, Denver, CO 80294; 303-844-4169 to order or for local office address and phone #).

NOAA Images

Advanced Very High Resolution Radiometer (AVHRR) images ($20-$100), including mosaics of the United States, hurricanes, and selected international locations, from NOAA weather satellites are available from the EROS Data Center (USGS-Department of Interior, EROS Data Center, Sioux Falls, SD, 57198; 605-594-6151).

Commercial Sources ❖

Geoscience Resources (2990 Anthony Road, P.O. Box 2096, Burlington, NC 27216; 919-227-8300; 800-742-2677) distributes many USGS satellite-image maps, many with topographic maps on the reverse side. Most titles it distributes portray areas of geological interest.

National Air Survey Center Corp. (4321 Baltimore Ave., Bladensburg, MD 20710; 301-927-7177) sells a variety of satellite photography including mosaics of U.S. states, many cities, and several countries. Prices range from $25 to $250 for color prints, and $60 to $350 for color transparencies. A brochure, "Satellite Photography - Space Portrait USA," is available.

Spaceshots Inc. (11111 Santa Monica Blvd., Ste. 210, Los Angeles, CA 90025; 310-792-5692; 800-272-2779) produces prints of satellite images of the Earth. More than 20 images are available for areas in North America. Print size and area covered varies; prints are available on paper or laminated; prices range from $12.95 to $21.95.

❖ *The Map Catalog*, Second Edition, A Tilden Press Book, Vintage Books, A division of Random House, Inc., New York, NY (1990).

Suggested Reading and Resources

Internet Homepages

A partial list of Internet Homepages with information about global change.

Aspen Global Change Institute (AGCI)
http://www.agci.org
AGCI global change science and education programs

U.S. Global Change Research Information Office (GCRIO)
http://www.gcrio.org/
access to global change data and information

NASA SpaceLink
http://spacelink.msfc.nasa.gov/
access to NASAs educational programs and information

Carbon Dioxide Information Analysis Center (CDIAC),
http://cdiac.esd.ornl.gov:80/cdiac/
global change data sets and information

The GLOBE Program
http://www.globe.gov
international education program of student environmental data

Global Warming

"The Changing Climate," by Stephen Schneider, *Scientific American,* September 1989 (9). pp. 70-79.

"Endless Summer: Living with the Greenhouse Effect," *Discover,* October, 1988.

"Global Climatic Change," by R. A. Houghton and G. M. Woodwell, *Scientific American,* April 1989 Volume 260 (4).

"Global Warming," 4-page pamphlet, 1989, printed and distributed by: The Sierra Club, Public Affairs, 730 Polk Street, San Francisco, CA 94109.

"Global Warming Trends," Phillip D. Jones and Tom M. L. Wigley, *Scientific American,* August 1990, pp. 84-91.

"The Great Climate Debate," by Robert M. White, *Scientific American*, July 1990, pp. 36-43.

The Climate Crisis: Greenhouse Effect and Ozone Layer, John Becklane and Franklin Watts, New York, London, Toronto, Sydney, 1989.

CO_2 Diet for a Greenhouse Planet: A Citizen's Guide for Slowing Global Warming, DeCicco, John, Audubon Policy Reports 1990. 75 p.

The Co-Evolution of Climate and Life, Schneider, Stephen and Londer, Randi S., Sierra Club Books, San Francisco, CA 1984. 563 p.

Global Climate Change and Life on Earth, Wyman, Richard L., editor, Routledge, Chapman and Hall, New York, NY, 1991. 282 p.

Global Climate Change: Human and Natural Influences, Singer, S. Fred, editor, Paragon House Publishers, New York, NY 1989. 424 p.

Global Warming and The Greenhouse Effect: Teacher's Guide (grades 7-10), Hocking, Colin, et. al., Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California at Berkeley, Berkeley, CA 1990.

Global Warming: Are We Entering the Greenhouse Century?, Schneider, Stephen H., Sierra Club Books, Random House 1989. 317 p.

Global Warming, Assessing the Greenhouse Threat, Pringle, Laurence, Arcade Publishing: Little, Brown and Company, New York, NY, 1990.

The Greenhouse Effect, Hare, Tony (part of the "Save Our Earth" series), Gloucester Press, New York, London, Toronto, Sydney, 1990.

The Greenhouse Effect: Life on a Warmer Planet, Johnson, Rebecca L., Lerner Publications Company, Minneapolis, MN, 1990.

Our Global Greenhouse, April Koral and Franklin Watts, New York, London, Toronto, Sydney, 1989.

Potential Effects of Global Climate Change on the United States, Smith, Joel B. and Tirpak, Dennis A., editors, Hemisphere Publishing Corporation, New York, NY 1990. 689 p.

Population Growth

"The Growing Human Population," by N. Keyfitz, *Scientific American* 261(3):119-126, September 1989.

The Population Explosion, Ehrlich, Paul R. and Anne H., Simon and Schuster, New York, NY (1990). 320 p.

Ozone Depletion

"Ozone Breakdown," by Michael D. Lemonick, *Time Magazine,* February 17, 1992, pp. 60-68.

Ominous Future Under the Ozone Hole: Assessing Biological Impacts in Antarctica, Voytek, Mary A., Environmental Defense Fund, Wildlife Program, Washington, DC (1989). 69 p.

Ozone Diplomacy: New Directions in Safeguarding the Planet, Benedick, Richard Elliot, Harvard University Press, Cambridge, MA (1991). 300 p.

The Ozone Hole: A Selected Bibliography, Lockerby, Robert W., Vance Bibliographies, Monticello, IL (1989). 12 p.

Biological Diversity

Keeping Options Alive: The Scientific Basis for Conserving Biodiversity, Reid, Walter V. and Miller, Kenton R., World Resources Institute, Washington, DC (1989). 128 p.

Lessons from the Rainforest: Essays by Norman Myers, Randall Hayes, Francis Moore Lappé, and others, Head, Suzanne and Heinzman, Robert, editors, Sierra Club Books, San Francisco, CA 1990.

National Forum on Biodiversity, Wilson, E. O. editor, National Academy Press, Washington, DC (1988). 521 p.

Remote Sensing

A Guide to Remote Sensing: Interpreting Images of the Earth, Drury, S. A., Oxford University Press, 1990. 199 p.

Educators Guide for Mission to Earth: Landsat Views the World, Tindal, Margaret A., Goddard Space Flight Center 1978. 58 p.

Exploring Earth From Space, Erickson, Jon, Blue Ridge Summit: TAB Books 1989. 192 p.

The Home Planet, Kelley, Kevin W., Addison-Wesley Publishing Company, New York, NY (1988). 176 p.

Introduction to Remote Sensing, Campbell, James B., Guilford Press 1987. 551 p.

The Map Catalog: Every Kind of Map and Chart on Earth and Even Some Above It, Makower, Joel, editor., (2nd ed.) Tilden Press 1990. 364 p.

Mission to Earth: Landsat Views the World, Short, Nicholas M. II., U.S. Government Printing Office 1976. 459 p.

Principles of Remote Sensing, Curran, Paul J., Longman 1985. 282 p.

Remote Sensing and Image Interpretation, Lillesand, Thomas M. & Ralph Kiefer., (2nd ed.) Wiley 1987. 721 p.

Remote Sensing: Methods and Applications Hord, R. Michael, Wiley 1986. 362 p.

Remote Sensing: Principles and Interpretation, Sabins, Floyd F., (2nd ed.) Freeman 1987. 449 p.

General / Comprehensive

"Managing Planet Earth," *Scientific American*, Volume 261, Number 3, September, 1989.

Earth in the Balance, Gore, Senator Al, Houghton Mifflin Company, Boston, New York, London (1992). 407 p.

50 Simple Things You Can Do to Save the Earth, EarthWorks Group. EarthWorks Press, Berkeley, CA (1989).

One Earth, One Future: Our Changing Global Environment, Silver, Cheryl Simon, National Academy Press, Washington, DC 1990. 196 p.

State of the World 1984-1992, (published each year) Brown, Lester R. et. al., W. W. Norton & Company, New York, London.

Videotapes

Should We Believe Climate Prediction? Presented by Dr. Richard Somerville at the Scripps Institution of Oceanography. Distributed by Aspen Global Change Institute.

An Introduction to Remote Sensing, (Presented by Ed Sheffner - NASA/AMES TGS Technologies), distributed by Aspen Global Change Institute (100 East Francis, Aspen, CO 81611; 303-925-7376).

Our Planet Earth, Bullfrog Films, Inc. (P.O. Box 149, Oley, PA 19547; 800-543-FROG or 215-779-8226).

The Films of Charles & Ray Eames, Volume 1, Powers of Ten, Pyramid Film & Video (2801 Colorado Avenue, Santa Monica, CA 90404; 800-421-2304).

Spaceship Earth: Our Global Environment, WorldLink (3629 Sacramento Street, San Francisco, CA 94118).