Educational Product	
Teachers	Grades 5–12

National Aeronautics and
Space Administration
**Office of Mission to
Planet Earth**

LOOKING AT EARTH FROM SPACE

TEACHER'S GUIDE WITH ACTIVITIES FOR EARTH AND SPACE SCIENCE

About This Publication

The Maryland Pilot Earth Science and Technology Education Network (MAPS-NET) project was sponsored by NASA to enrich teacher preparation and classroom learning in the area of Earth system science. Teachers who participated in MAPS-NET completed a graduate-level course and developed activities that incorporate satellite imagery and encourage the hands-on study of Earth.

This publication includes the *Teacher's Guide* that replicates much of the material taught during the graduate-level course and *Activities* developed by the teachers. Both are important elements in the series, Looking at Earth from Space, developed to provide teachers with a comprehensive approach to using satellite imagery to enhance science education.

The *Teacher's Guide* will enable teachers (and students) to expand their knowledge of the atmosphere, common weather patterns, and remote sensing. Because the Guide is designed to expand teachers' knowledge, it is divided into topical chapters rather than by grade-level. The *Activities* are listed by suggested grade level.

ACKNOWLEDGMENTS

Teacher's Guide Acknowledgments

The *Teacher's Guide* was developed for the MAPS-NET project graduate course, *Atmospheric Observations from Space*, conducted at the University of Maryland, College Park, Department of Meteorology. It is a collaborative effort of NASA's MAPS-NET project; the Department of Meteorology, University of Maryland, College Park; and Maryland precollege teachers, with additional contributions noted. Special thanks to Dr. Gerald Soffen, Director, Goddard Space Flight Center for nurturing this project and series of publications. Special thanks to Ms. Theresa Schwerin, WT Chen & Company, who developed and directed the MAPS-NET concept. Special thanks to Dr. Robert Hudson, Chairman and Professor, Department of Meteorology, University of Maryland, College Park for his commitment to and active involvement in enhancing science education.

Editor, Writer, Illustrator, Ms. Colleen Steele, MAPS-NET Project Manager,
WT Chen & Company

Weather Systems and Satellite Imagery Chapter, and additional material
Mr. William F. Ryan, Department of Meteorology, University of Maryland, College Park

Graphic Design, NASA Printing and Design

We gratefully acknowledge the generous contributions of the following people in preparing this document: Dr. Philip Ardanuy, Research and Data Systems Corporation; Mr. William Bandeen, Hughes STX Corporation: Mr. Kevin Boone, Southern High School; Mr. Louis Caudill, NASA Headquarters; Mr. Austin Conaty, University of Maryland, College Park; Mr. Bill Davis, DuVal High School; Mr. Charles Davis, Dallas Remote Imaging Group; Ms. Claudia Dauksys, WT Chen & Company; Mr. John Entwistle, Damascus High School; Mr. Richard Farrar, Northern High School; Mr. Ron Gird, National Weather Service; Dr. George Huffman, Science Systems and Applications, Inc.; Dr. Nahid Khazenie, NASA Goddard Space Flight Center; Mr. Greg Helms, NASA Goddard Space Flight Center: Ms. Mary Hughes, NOAA NESDIS; Mr. Loren Johnson, Satellite Data Systems, Inc.; Dr. Jack Kaye, NASA Headquarters; Dr. David F. McGinnis, NOAA NESDIS; Captain David Miller, United States Air Force; Mr. Terry Nixon, Maryland Science Center; Ms. Carolyn Ossont, DuVal High School; Ms. Lisa Ostendorf, NASA Headquarters; Ms. EllaJay Parfitt, Southeast Middle School; Mr. Dale Peters, Linganore High School; Dr. Robert Price, NASA Goddard Space Flight Center; Mr. Martin Ruzek, Universities Space Research Association; Mr. Buzz Sellman, Dexter, Michigan; Dr. Owen Thompson, University of Maryland, College Park; Dr. Shelby Tilford, Institute for Global Environmental Strategies; Mr. John Tillery, Fairfax County Public Schools; Dr. Jeff Wallach, Dallas Remote Imaging Group; Ms. Linda Webb, Jarrettsville Elementary School; Mr. Allen White, New Market Middle School; and Mr. Tom Wrublewski, NOAA.

Satellite images courtesy of: Professor G.W.K. Moore, University of Toronto, Toronto, Ontario; Dr. Mohan K. Ramamurthy, University of Illinois, Urbana/Champaign; Space Science and Engineering Center (SSEC), University of Wisconsin, Madison; and Mr. David Tetreault, University of Rhode Island, Kingston, Rhode Island.

December 1994

Activities Acknowledgments

The *Activities* were developed by teachers participating in the Maryland Pilot Earth Science and Technology Education Network (MAPS-NET) project: Mr. Donald Allen, Hancock High School, Hancock, MD; Ms. Mary Ann Bailey, Crossland High School, Temple Hills, MD; Ms. Angeline Black, Kenmoor Middle School, Landover, MD; Mr. Russ Burroughs, Harford Day School, Bel Air, MD; Mr. Stu Chapman, Southampton Middle School, Bel Air, MD; Ms. Sarah Clemmitt, Montgomery Blair High School, Silver Spring, MD; Mr. Bill Davis, DuVal High School, Lanham, MD; Mr. Edward Earle, Norwood School, Bethesda, MD; Mr. John Entwistle, Damascus High School, Damascus, MD; Ms. Gayle Farrar, Southern Middle School, Oakland, MD; Ms. Renee Henderson, Forestville High School, Forestville, MD; Mr. Onyema Isigwe, Dunbar High School, Washington, DC; Ms. Eileen Killoran, Glenelg Country Day School, Glenelg, MD; Mr. Tony Marcino, Margaret Brent Middle School, Helen, MD; Ms. Karen Mattson, Ballenger Creek Middle School, Frederick, MD; Ms. Sue McDonald, Canton Middle School, Baltimore, MD; Mr. Bob Mishev, DuVal High School, Lanham, MD; Ms. Stacey Mounts, Ballenger Creek Middle School, Frederick, MD; Mr. Terrence Nixon, Maryland Science Center, Baltimore, MD; Ms. Carolyn Ossont, DuVal High School, Lanham, MD; Mr. Dale E. Peters, Linganore High School, Frederick, MD; Mr. Wayne Rinehart, North Hagerstown High School, Hagerstown, MD; Ms. Lonita Robinson, Suitland High School, District Heights, MD; Ms. Sandra Steele, Pikesville High School, Baltimore, MD; Mr. Hans Steffen, DuVal High School, Lanham, MD; Ms. Sushmita Vargo, Washington International School, Washington, DC; Ms. Linda Webb, Jarrettsville Elementary School, Jarrettsville, MD; Mr. John Webber, Aberdeen High School, Aberdeen, MD; Mr. Allen White, New Market Middle School, New Market, MD; Ms. Nancy Wilkerson, Prince George's County Public Schools.

Editor and Illustrator, Colleen Steele, WT Chen & Company

Meteorology Background and Terms, Mr. William Ryan, University of Maryland

Graphic design, NASA Printing and Design

Special thanks to Dr. Gerald Soffen, Director, Office of University Programs, Goddard Space Flight Center for nurturing this series of publications.

We gratefully acknowledge the generous contributions of the following people in preparing this document: Mr. Louis Caudill, NASA Headquarters; Ms. Claudia Dauksys, WT Chen & Company; Dr. Robert Hudson, University of Maryland; Dr. George Huffman, Science Systems and Applications, Inc.; Dr. Jack Kaye, NASA Headquarters; Dr. Nahid Khazenie, NASA Goddard Space Flight Center; Captain David Miller, United States Air Force; Ms. Theresa Schwerin, WT Chen & Company; and Mr. John Tillery, Fairfax Public Schools.

Satellite images courtesy of: Mr. Geoff Chester, Smithsonian Institution, Albert Einstein Planetarium, Washington, DC; Mr. Charles Davis, Dallas Remote Imaging Group, Hampstead, MD; Mr. Dale Peters, Linganore High School, Frederick, MD; Dr. Mohan K. Ramamurthy, University of Illinois, Urbana/Champaign, IL.; Space Science and Engineering Center, University of Wisconsin, Madison; and Mr. David Tetreault, University of Rhode Island, Kingston, Rhode Island.

Table of Contents

Matrix, National Science Education Standards 1

Looking at Earth from Space 2

NASA's Mission to Planet Earth 3

Sample Uses for Direct Readout Images and Data in Earth Science Study 5

Weather Systems and Satellite Imagery 7

Introduction to Mid-Latitude Weather Systems 9
geosynchronous and polar-orbiting satellite views of Earth
GOES image of wave pattern
the comma cloud

Wave Motion and the General Circulation 17
differential heating of Earth
Intertropical Convergence Zone
Ferrel and Hadley cells
Coriolis effect and general circulation
baroclinic stability/instability

Cyclonic Disturbances and Baroclinic Instability 24
polar front theory
baroclinic theory
jet streams, jet streak
divergence
upper air information and charts

Clouds 44
saturation pressure of an air parcel
dew point temperature, relative humidity
advection
adiabatic assumption
adiabatic cloud formation
cloud identification

Additional Common Weather Patterns 55
coastal storm development
Mesoscale Convective Systems
hurricanes

Satellite Images and the Internet 61
obtaining images and data via the internet
sources of meteorological images

Environmental Satellites 65

Orbits 105

Ground Station Set-up 117

Resources 123
Bulletin Boards
Federal Agencies and Programs
National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration
Organizations
Vendors
Weather Forecast Office Locations
Internet

Activities 147

Using the Activities 149

Imagery from Environmental Satellites 150

Activities

Grade Level

4-6 Using Weather Symbols 151

4-6 Forecasting the Weather: Satellite Images & Weather Maps 161

6-8 Cloud Families 171

6-8 Cloud Identification 183

5-8 Classification of Cloud Types Through Infrared APT Imagery 190
Background: Clouds

8 Comparison of Visible and Infrared Imagery
Background: APT Imagery 213

8 Right Down the Line: Cold Fronts 223

8 To Ski or not to Ski (Imagery as a Decision-Making Tool) 229

9 Infrared and Visible Satellite Images
The Electromagnetic Spectrum 233

9 Understanding a Thunderstorm 242

7-12 Animation Creation (Looping Satellite Images) 255

7-12 Wherefore Art Thou, Romeo? (Studying Hurricanes) 257
Background: U.S. Geostationary Environmental Satellites
Background: Hurricanes

9-12 A Cold Front Passes 265

9-12 Will There be a Rain Delay? (Forecasting) 272

9-12 Seasonal Migration of the ITCZ 280
Background: Intertropical Convergence Zone (ITCZ)

9-12 Using Weather Satellite Images to Enhance a Study of
the Chesapeake Bay 288

Glossary 309

Bibliography 327

Index 335

SCIENCE CONTENT STANDARDS

This publication responds to the following content standards proposed in the *Draft National Science Education Standards*[1]. Note that this is not a comprehensive list of the standards, and includes only those relevant to this publication.

Content Standards, Grades 5-8

Science as inquiry	Physical science	Life science	Earth and space science	Science and technology	Science in personal and social perspectives	History and nature of science	Unifying concepts and processes
Abilities related to scientific inquiry Understanding about scientific inquiry	Properties and changes of properties in matter Motions and forces Transforma-tions of energy	Populations and ecosystems Diversity and adaptations of organisims	Structure of the Earth system Earth in the solar system	Understanding about science and technology	Populations, resources and environments Natural hazards Risks and benefits Science and technology in society	Science as a human endeavor Nature of science	Order and organization Evidence, models, and explanation Change, constancy, and measurement

Content Standards, Grades 9-12

Science as inquiry	Physical science	Life science	Earth and space science	Science and technology	Science in personal and social perspectives	History and nature of science	Unifying concepts and processes
Abilities related to scientific inquiry Understanding about scientific inquiry	Chemical reactions Forces and motions Interactions of energy and matter	The interdepen-dence of organisms	Energy in the Earth system	Understanding about science and technology	Personal and community health Natural resources Environmental quality Natural and human-induced hazards Science and technology in local, national, and global challenges	Science as a human endeavor Nature of scientific knowledge	Order and organization Evidence, models, and explanation Change, constancy, and measurement

[1] ***Draft*** *National Science Education Standards,* National Research Council (National Academy Press, November 1994), V-14,15.

Looking at Earth from Space

The launch of the first environmental satellite by the United States on April 1, 1960, dramatically changed the way we observe Earth and the frequency of those observations. Looking at Earth from space meant that monitoring the atmosphere was transformed into a global capability and perspective. Isolated local information became a component in a worldwide view of the atmosphere. The polar ice caps and the large areas of Earth's surface covered by water could remain inaccessible to ground observers, but that did not preclude information from being obtained by remote sensors.

Sophisticated technology enables and challenges us to:

- observe the changing Earth system,
- identify the changes caused by nature and those effected by humans,
- understand those interactions,
- assess the impact of those changes, and
- eventually, predict change.

Technology provides constantly improving tools for conducting this task, but scientific knowledge, observation, assessment, and prediction are the objectives that drive it forward.

Remote sensing is the ability to acquire information about an object or phenomena by a device that is not in physical contact with that object. Direct readout is the capability to acquire information directly from environmental satellites. Users of ground station equipment can obtain real-time data from environmental satellites. Data can be displayed on a personal-computer screen as images of Earth (similar to those seen on television weather forecasts). This exciting capability is impacting the way many students now study Earth, and providing many with experience using first-hand satellite data.

The practical utilization of technology has real merit in preparing students for future careers. But more importantly, direct readout technology transforms them into explorers. This experience can spark interest in science and math, further understanding of our planet, and provide a clearer perspective of our individual and collective responsibilities as caretakers of Earth. It underscores the importance of international cooperation for observing Earth and developing strategies to preserve it.

This *Teacher's Guide* was developed by the NASA-sponsored Maryland Pilot Earth Science and Technology Education Network (MAPS-NET) project. MAPS-NET, in partnership with the University of Maryland, College Park, Department of Meteorology, implemented a science-based utilization of direct readout to study Earth. The MAPS-NET materials enhance both teacher preparation and existing school curriculum. Participating Maryland precollege teachers developed activities and contributed to both the course content and the development of this *Teacher's Guide*. Their emphasis on curriculum relevancy and classroom implementation was the leading influence in shaping the information presented in this manual.

This Guide was designed for teachers (as background, for training, or for classroom application) and focuses on the study of meteorology, with application to satellite imagery. Segments on topics such as environmental satellites, orbital prediction, and setting-up environmental satellite ground stations are included. Each chapter may have independent classroom application, as well as contributing to a comprehensive understanding of looking at Earth from space.

NASA'S Mission to Planet Earth

The perspective from space is a unique one, providing a global view that is available in no other way. While scientists of the past were limited by the types of observations available, today's scientists use measurements collected from a number of perspectives. Data from space-based instruments have become an integral tool for studying our global environment. For example, remotely-sensed data indicating ocean temperature helps explain changes in polar ice, ocean vegetation, and global weather patterns. Global ozone measurements from space were the key to discovering the ozone hole. Studies of ocean color provide information about ocean vegetation, pollution, changes in ocean chemistry, and subtle changes in climate.

NASA's Mission to Planet Earth (MTPE) has evolved from international concern about our environment and the need to mount a global effort to study the causes of climate change. This program is dedicated to understanding the Earth system — how the land, water, air, and life interact and how humans are affecting this system. MTPE is pioneering the study of global climate change and is laying the foundation for long-term environmental and climate modeling and prediction. MTPE is focusing on climate changes—those changes that could occur on time scales of decades to centuries—and possibly within our lifetimes.

This effort involves gathering long-term global measurements of the Earth system using spacecraft, aircraft, balloons, and ground-based observations. The gathered data is used to build complex computer models that simulate the processes governing the Earth system. These models will ultimately serve as prediction tools for future global changes, providing information necessary for making informed decisions about the environment.

A number of MTPE satellites are collecting data. Two major research satellites are the Upper Atmospheric Research Satellite (UARS) and the Ocean Topography Experiment (TOPEX/ POSEIDON). UARS, launched September 1991, is investigating the Earth's upper atmosphere and the effects of human activities on stratospheric ozone levels.

Understanding the dynamics of ocean circulation and its role in climate change is the main goal of TOPEX/POSEIDON, a joint effort between NASA and the French Space Agency, launched in August 1992. Oceanographers are using data from TOPEX/ POSEIDON to study climatic phenomenon such as El Niño, a recurring event that brings devastating weather to several global regions, including heavy rains and flooding to California, colder than normal winters across the United States, and severe droughts and dust storms to Australia. Insights gained from the TOPEX/POSEIDON investigation will not only advance our basic science knowledge, but will also aid in mitigation of economic and environmental impacts related to climate.

The centerpiece of MTPE is the Earth Observing System (EOS). EOS will consist of a series of small- to intermediate-sized spacecraft, planned for launch beginning in 1998. These satellites will provide global measurements over an eighteen-year period. Measurements for this period or longer are needed to assess the impact of natural changes (e.g., El Niño events and the solar cycle) versus human-caused changes (e.g., pollution, urbanization). EOS satellites will carry a suite of instruments designed to study global climate change, focusing on the following key research areas:

1. The role of clouds, radiation, water vapor and precipitation.
2. The primary productivity of the oceans, their circulation, and air-sea exchange.
3. The sources and sinks of greenhouse gases and their atmospheric transformations.
4. Changes in land use, land cover, primary productivity, and the water cycle.
5. The role of polar ice sheets and sea level.
6. The coupling of ozone chemistry with climate and the biosphere.
7. The role of volcanoes in climate change.

In addition to EOS and research satellites such as UARS and TOPEX, MTPE will include Earth Probes — discipline-specific satellites with instruments that will gather observations before the launch of the EOS platforms. Earth Probes will include the Tropical Rainfall Measuring Mission (TRMM), Sea-Viewing Wide Field Sensor (SeaWiFS), which will measure ocean vegetation, reflights of the Total Ozone Mapping Spectrometer (TOMS), and a NASA scatterometer designed to measure ocean surface winds (NSCAT).

Data from these missions will be complemented by other datasets. Space Shuttle experiments; Landsat data; data from U.S., European, and Japanese-operated polar and geostationary environmental satellites; and ground-based observations from ships, buoys, and surface instruments all contribute to MTPE.

MTPE Information is not only critical for scientific research, but can also play an important role in science education. Through educational materials such as *Looking at Earth from Space,* NASA encourages teachers to use a space perspective to spark their students' imagination, and capture their interest in and knowledge of Earth system science.

SAMPLE USES FOR DIRECT READOUT IMAGES AND DATA IN EARTH SCIENCE STUDY

Biology and Agriculture

- use sea surface temperature to determine location of various species of fish
- determine probable crop production (cropics)
- land management
- correlate rainfall and vegetation vigor
- study effects of acid rain on vegetation

Geology

- identify land formations, coast lines, mountains, lakes
- determine areas of water sheds
- locate active volcanoes
- monitor Earth resources
- compare water and land temperatures
- identify renewable and non-renewable resources
- study how Earth evolves over time

Meteorology

- produce daily weather reports, monthly averages, annual comparisons
- develop weather forecasts
- track severe storms
- study upper air circulation and jet streams
- measure snow and ice areas
- compare Earth and satellite views of clouds
- develop cloud cover indexes for regions of the Earth
- compare seasonal changes of a specific region
- identify weather fronts

Oceanography

- study sea surface temperatures (currents)
- predict fish harvest based upon sea surface temperatures
- conduct time studies comparing erosion, land formations

Weather Systems and Satellite Imagery

This chapter provides a theoretical and technical discussion of how satellite images can be used to understand the most common weather pattern observed in the northern mid-latitudes of Earth.

This chapter was prepared by William F. Ryan, University of Maryland, College Park, Department of Meteorology.

Weather Systems and Satellite Imagery

Section 1 Introduction to Mid-Latitude Weather Systems 9
geosynchronous and polar-orbiting satellite views of Earth
GOES image of wave pattern
the comma cloud

Section 2 Wave Motion and the General Circulation 17
differential heating of Earth
Intertropical Convergence Zone
Ferrel and Hadley cells
Coriolis effect and general circulation
baroclinic stability/instability

Section 3 Cyclonic Disturbances and Baroclinic Instability 24
polar front theory
baroclinic theory
jet streams, jet streak
divergence
upper air information and charts

Section 4 Clouds 44
saturation pressure of an air parcel
dew point temperature, relative humidity
advection
adiabatic assumption
adiabatic cloud formation
cloud identification

Section 5 Additional Common Weather Patterns 55
coastal storm development
Mesoscale Convective Systems
hurricanes

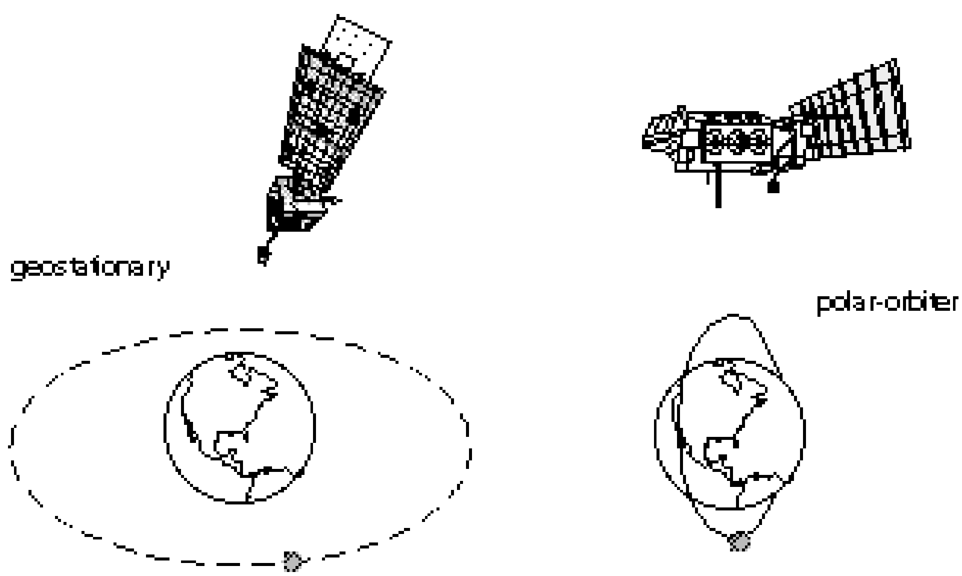
Section 6 Satellite Images and the Internet 61
obtaining images and data via the internet
sources of meteorological images

Introduction to Mid-Latitude Weather Systems

Section 1

One of the first applications of data and images supplied by satellites was to improve the understanding and prediction of weather. The object of this chapter is to use satellite images and meteorological concepts to describe the most common weather patterns of a portion of the Earth's atmosphere. In this chapter, we will concentrate on the northern mid-latitudes, the area of the Earth between 30 and 60 degrees north latitude, and the extratropical cyclone which brings the changes in weather that we experience in these latitudes.

In figure 1a (page 10), a full disc image of the Earth taken from the GOES* satellite is shown. The region of the mid-latitudes is distinguished by the wave-like structure of the clouds that are observed. The length, amplitude, and number of these waves have remarkable variation. In addition, the waves evolve over time and space. In figure 2 (page 12), a GOES image of the continental United States shows a close-up of one mid-latitude wave. An even closer view can be obtained from a polar-orbiting satellite.



* Two major types of meteorological satellites

Environmental (also known as meteorological or weather) satellites are unmanned spacecraft that carry a variety of sensors. They scan the Earth and electronically transmit acquired information back to Earth. Two types of meteorological satellite systems provide direct readout service. The satellite systems are geostationary and polar-orbiting, named for their orbit types. The satellite images in this chapter are from U.S. Geostationary Operational Environmental Satellites (GOES), and U.S. polar-orbiting satellites (NOAA-series). See the chapter on satellites for more information.

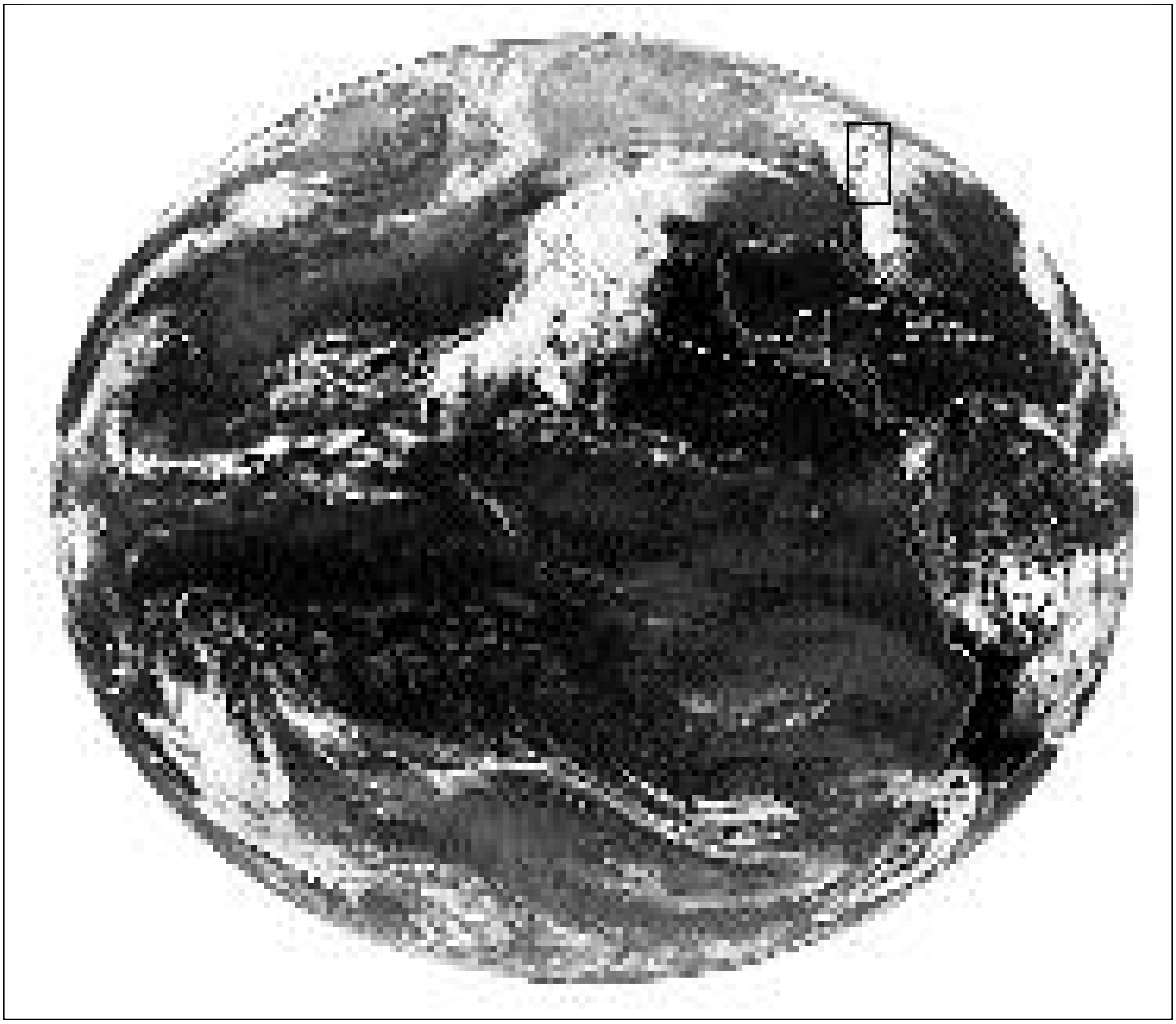


figure 1a. GOES 7 image, December 5, 1994, 1800
image courtesy of SSEC: University of Wisconsin-Madison
rectangle indicates location of polar-orbiter image in figure 1b

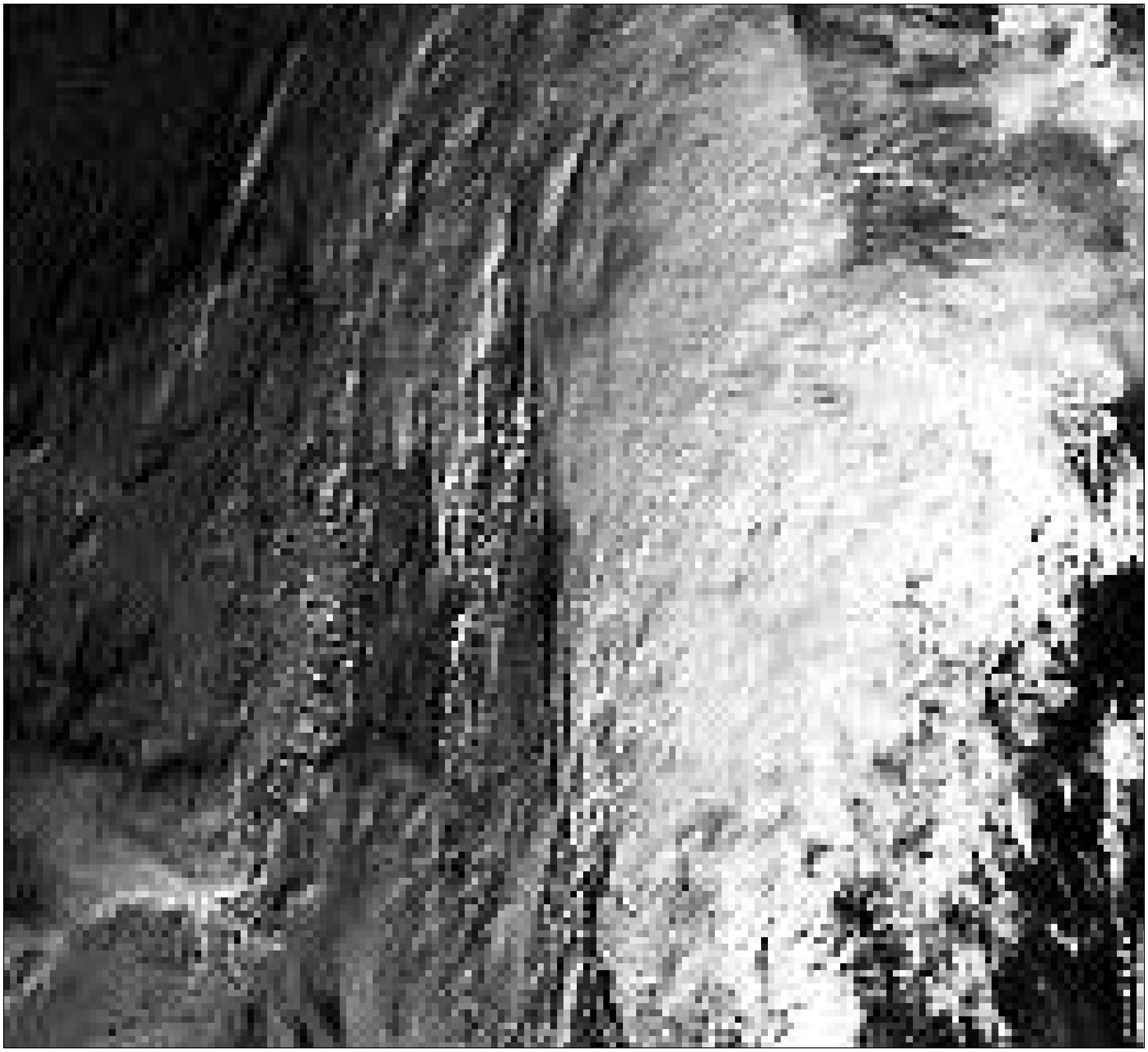


figure 1b. Polar-orbiting satellite image for December 5, 1994.
image courtesy of D. Tetreault, University of Rhode Island

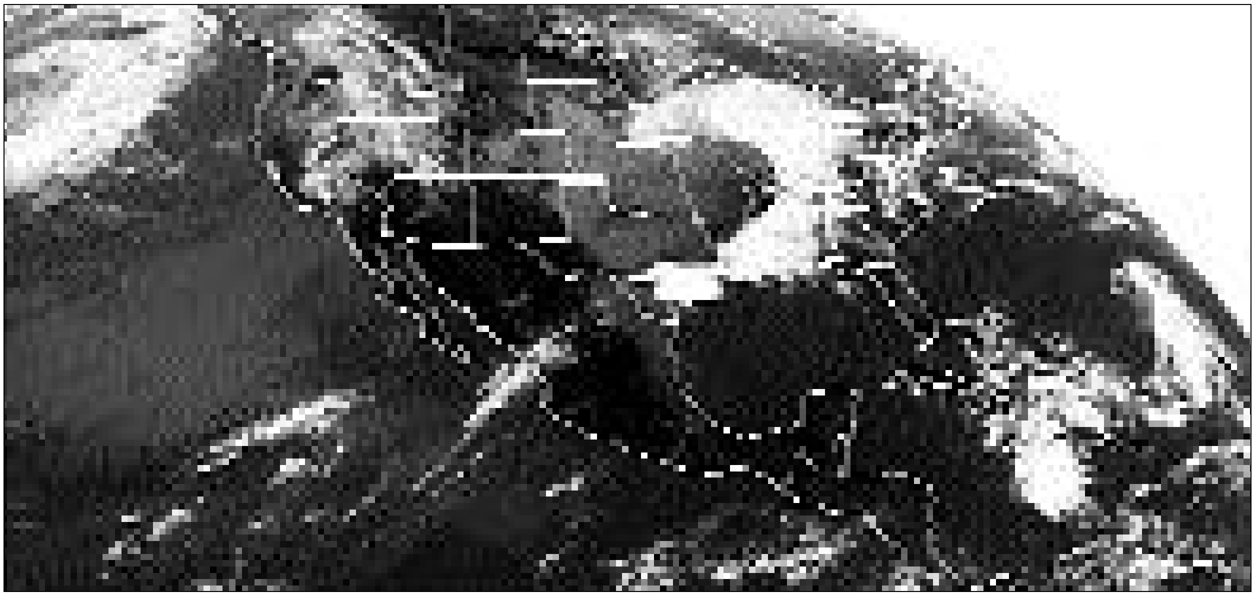


figure 2. GOES image of wave pattern in U.S. April 30, 1700 UTC.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

Because the GOES image has a very wide field of view, it is able to observe the extratropical cyclone in its entirety. The polar orbiter can often observe only a portion of the entire wave, although the resolution of individual clouds is much more precise in the polar-orbiter image. The greater frequency of the GOES image (once per hour) also provides the ability to closely observe the evolution of weather features. GOES images are now readily available on the Internet. Information about obtaining images electronically is included in Section 6 of this Chapter and in the Resources section.

Because wave motion is so important to weather prediction, meteorologists have devised standard terminology for discussing wave structure. An idealized wave is shown in figure 3. Waves tend to be quasi-horizontal. The top/northern-most extension of the wave is a **ridge**, the jagged line in figure 3 is the **ridge axis**. In general terms, weather conditions beneath the ridge axis are dry and storm free. The bottom/southern-most extension of the wave is the **trough**, it has a **trough axis** represented by the dashed line. As will be shown in section 3, the area just ahead (east) of the trough axis is the preferred location for storm development. The area to the west of the trough is usually cool and dry.

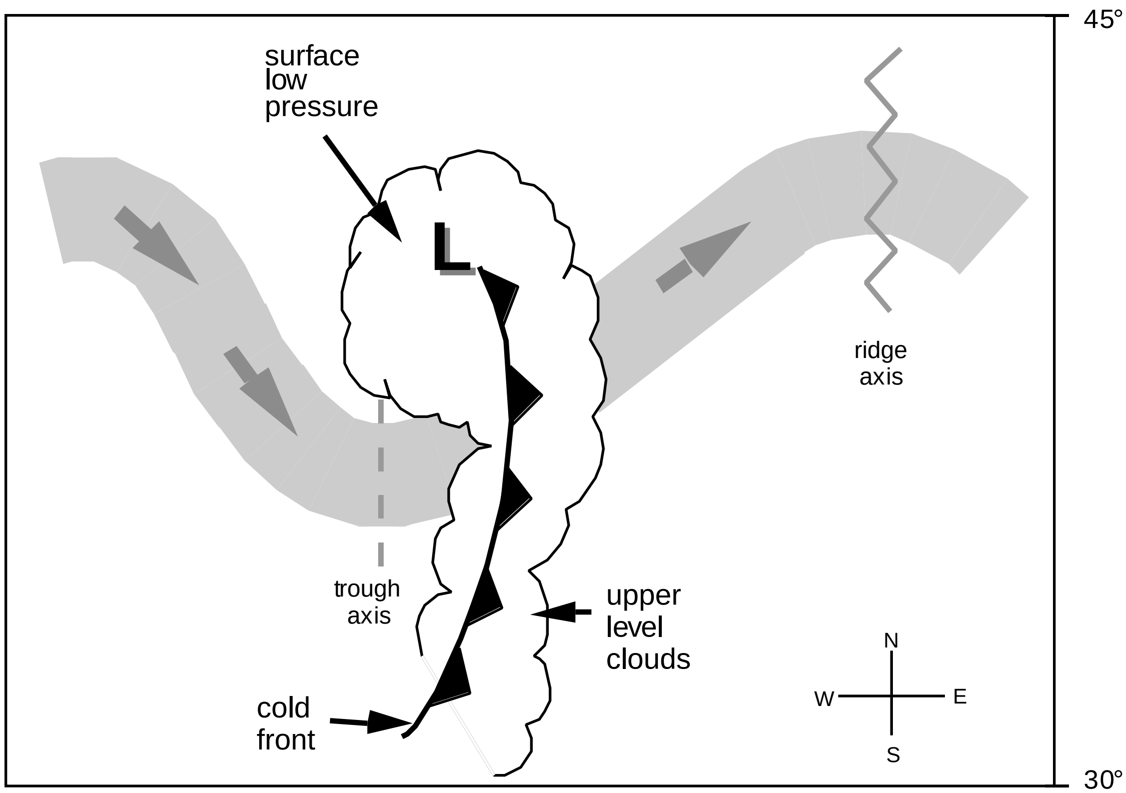


figure 3. common mid-latitude weather pattern: comma cloud

Weather disturbances in the vicinity of atmospheric waves, like ocean waves near the beach, have a life cycle in which they initiate, amplify, break, and then dissipate. As a mid-latitude cyclone moves through its life cycle, certain characteristic cloud shapes develop that can be observed from space. At the mature stage, when the weather associated with the wave is most intense, the satellite signature is the spiral-shaped **comma cloud** and the weather system associated with it is a cyclone or cyclonic disturbance (figure 4a).

There is often confusion associated with the term cyclone. **Cyclone** refers to large-scale closed circulations in the atmosphere whose direction of rotation is counter clockwise in the Northern Hemisphere. Cyclones in the tropics, such as hurricanes, are referred to as tropical cyclones. Cyclones in the upper latitudes are called **extratropical**, or mid-latitude, cyclones. In this chapter, cyclone, or cyclonic disturbance will be used solely to refer to extratropical weather disturbances, which are the characteristic weather developments in the mid-latitudes.

The length of the wave, which often contains a comma cloud as in figure 3, is usually several thousand kilometers. This is generally referred to as the **synoptic** scale. This scale of wave is common in the northern mid-latitudes. There are many important smaller scale events that can very usefully be observed by satellites, these will be discussed later. These smaller-scale events are generally termed **mesoscale** and include both hurricanes and the massive Great Plains thunderstorm systems that can spawn destructive tornadoes. For most of this section, we will look carefully at the larger synoptic scale waves and the extratropical cyclones associated with them.

synoptic scale
Scale of atmospheric motion that covers the range of hundreds of kilometers to several thousand kilometers in the horizontal. An example of synoptic scale meteorological phenomena are extratropical cyclones and high pressure systems.

mesoscale
Scale of atmospheric motion that covers the range from a few kilometers to several hundred kilometers—in the horizontal. Examples of meteorological effects that occur in the mesoscale are squall lines and sea breeze fronts.

If we see a comma cloud as in figure 4a (page 15), what can we say about the weather associated with it? If we watch or listen to broadcast meteorologists, we often hear about approaching cold or warm fronts which are displayed on the screen in blue and red lines (figure 4b, page 16). Commonly used weather symbols are shown in the glossary on page 322. In a general sense, the western edge of the tail of the comma marks the location of the cold front. A warm front is often associated with the head of the comma. Where the two fronts intersect is often the location of the area of lowest surface pressure—which marks the center of the cyclone. Around this center of low pressure, lines of equal pressure or isobars radiate outward. As we will see in more detail later, wind flow is generally parallel to the isobars and therefore circulate counter-clockwise about the center of low pressure.

We can make certain preliminary guesses about the current weather and the changes that will occur in the next few hours based solely on the comma cloud pattern. In this case, the area behind the cold front is relatively cold and dry with winds from the west or northwest. The area ahead of the cold front is usually moist and warm (the **warm sector**) with winds from the south and southwest. Along the frontal boundaries lie cloud bands which are associated with rainy conditions. The clouds along the cold front often contain isolated, vertically-developed clouds with thunderstorms and brief, heavy rain. Along the warm front are layered clouds at various altitudes with little vertical development. Surface conditions are overcast, perhaps with rain.

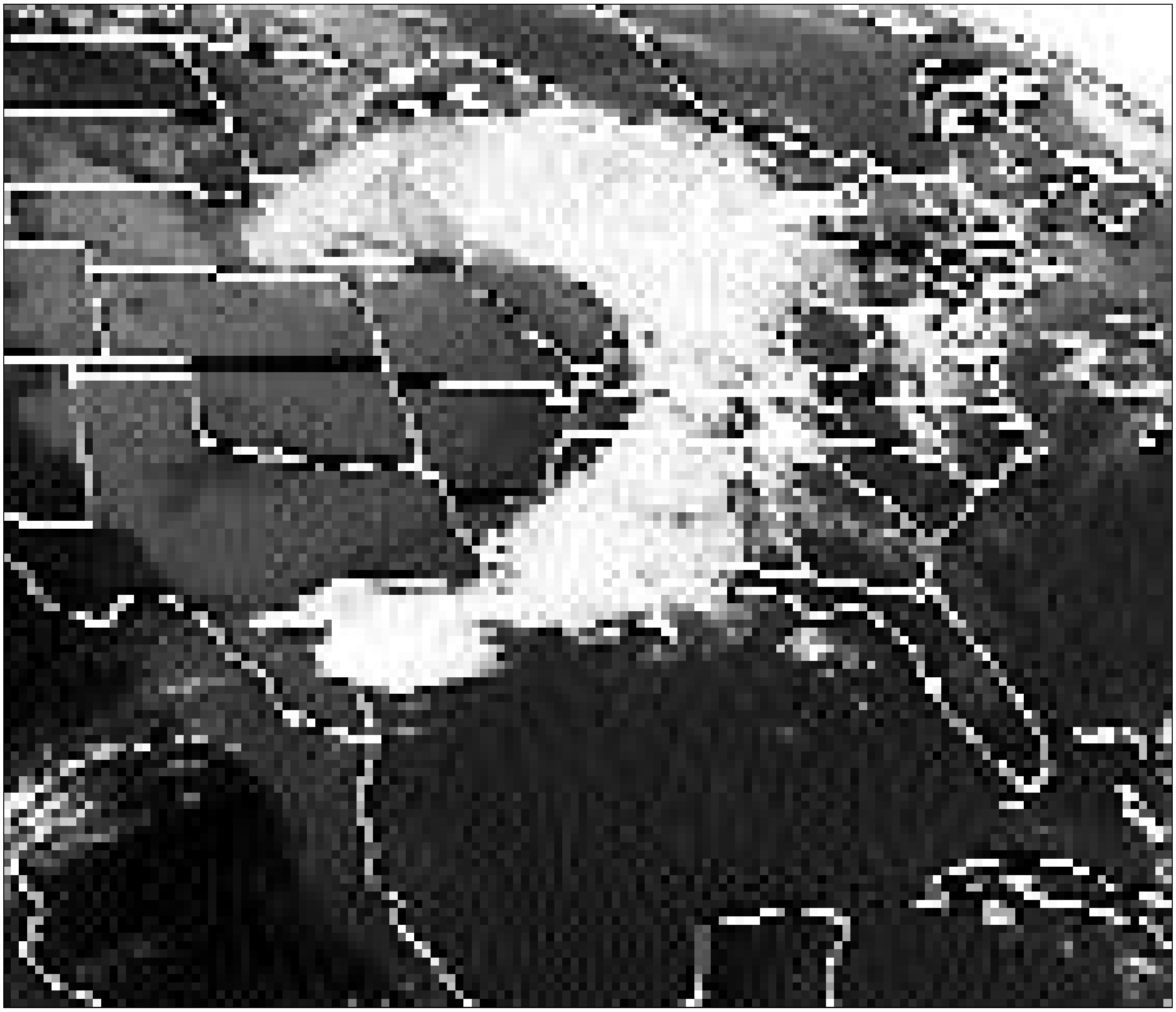


figure 4a. GOES image April 30, 1994 1200 CDT
image courtesy of M. Ramamurthy, University of Illinois,Urbana/Champaign
comma cloud system

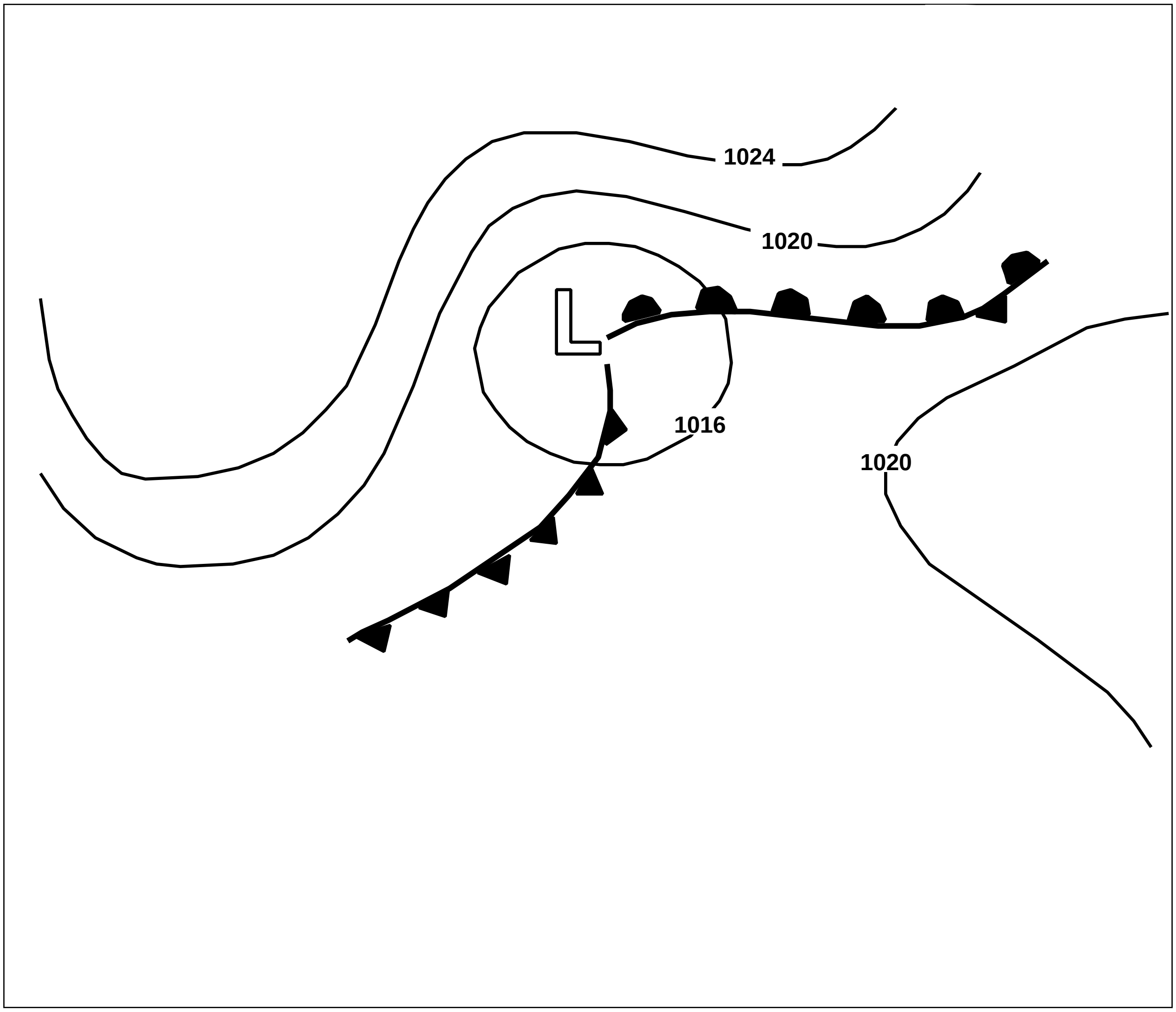


figure 4b. Surface pressure field and fronts
Can be copied onto a transparency and overlaid on figure 4a

In the next sections we will describe in qualitative terms how extratropical cyclones develop and the satellite signatures associated with them. A standard theoretical model will be used to answer questions about the initiation and development of these storms. Keep in mind that there are other weather phenomena that do not fit this model of extra-tropical cyclones yet do result in important weather effects. These phenomena are on a scale that can be readily observed by polar-orbiting satellites and will be discussed in section 5.

WAVE MOTION AND THE GENERAL CIRCULATION

Section 2

The weather patterns that we experience in the northern midlatitudes are driven by the unequal heating of the Earth's surface. The tropical latitudes (23°S - 23°N) receive more energy input than the higher latitudes. Because the amount of heat energy reradiated by Earth back into space is approximately the same anywhere on the globe, the energy imbalance is mainly due to two factors (figure 5).

- First, the Sun's rays are nearly perpendicular to the surface near the equator. As a result, they travel a shorter distance through the dense lower atmosphere and are less likely to be reflected or dissipated.
- Second, the tropical regions receive more of the Sun's energy per unit area due to the curvature of the Earth.

The presence of waves and weather disturbances in our latitudes is a result of the Earth-atmosphere system attempting to restore balance to the system by transporting excess energy from the south to the north.

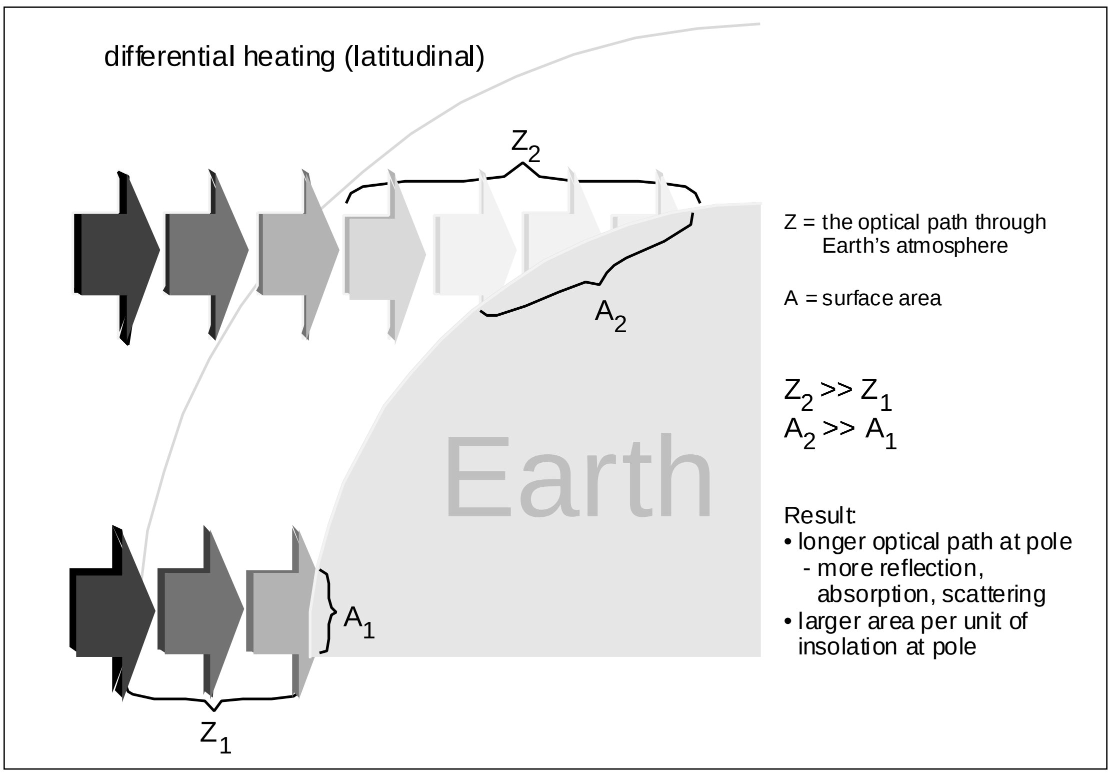


figure 5.

The general circulation of the atmosphere—the average motion of the winds around the globe—is also driven by the differential heating of the Earth. In the simplest terms, excess heating near the equator causes the air to expand or swell over the equatorial regions. Upward motion associated with this heating is typically concentrated in a relatively narrow band named the **Inter-Tropical Convergence Zone** (ITCZ). The satellite signature of the ITCZ is a band of clouds, usually tall thunderstorms (cumulonimbus), that circles the oceans near the equator (figure 6). The position of the ITCZ varies seasonally, moving northward during the northern summer and moving south during the northern winter. The ITCZ forms as a result of moist air rising under the influence of strong surface heating. Upward motion along the ITCZ is limited to approximately 15 kilometers by the presence of the stratosphere. The stratosphere, which is kept very warm by its abundance of ozone efficiently absorbing solar radiation, acts as a lid on the lowest portion of the atmosphere—the troposphere (figure 7, page 19). For practical purposes, all the weather that we experience occurs in the troposphere .

figure 6. ITCZ: Full disc GOES image with 10°N-10°S indicated.
image courtesy of the SSEC: University of Wisconsin-Madison

The air that rises in the vicinity of the ITCZ must spread out, or diverge, at the top of the troposphere. In the simplest case (figure 8b, page 20), we could assume that the Earth has a one-cell circulation in which the air lifted at the ITCZ travels north until it reaches the cold polar regions and then sinks. This would be a direct way to restore the system to balance. However, due to complex effects, the circulation associated with the differential heating of the atmosphere is not a simple one-cell circulation from equator to pole. Instead, a more complex multi-cell structure acts to transport heat energy from the equator to the poles.

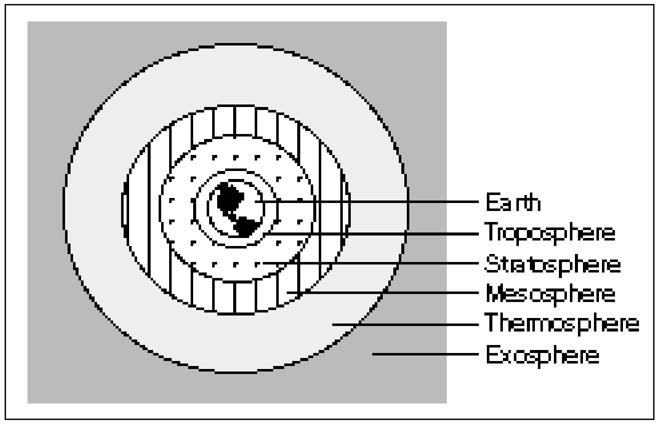
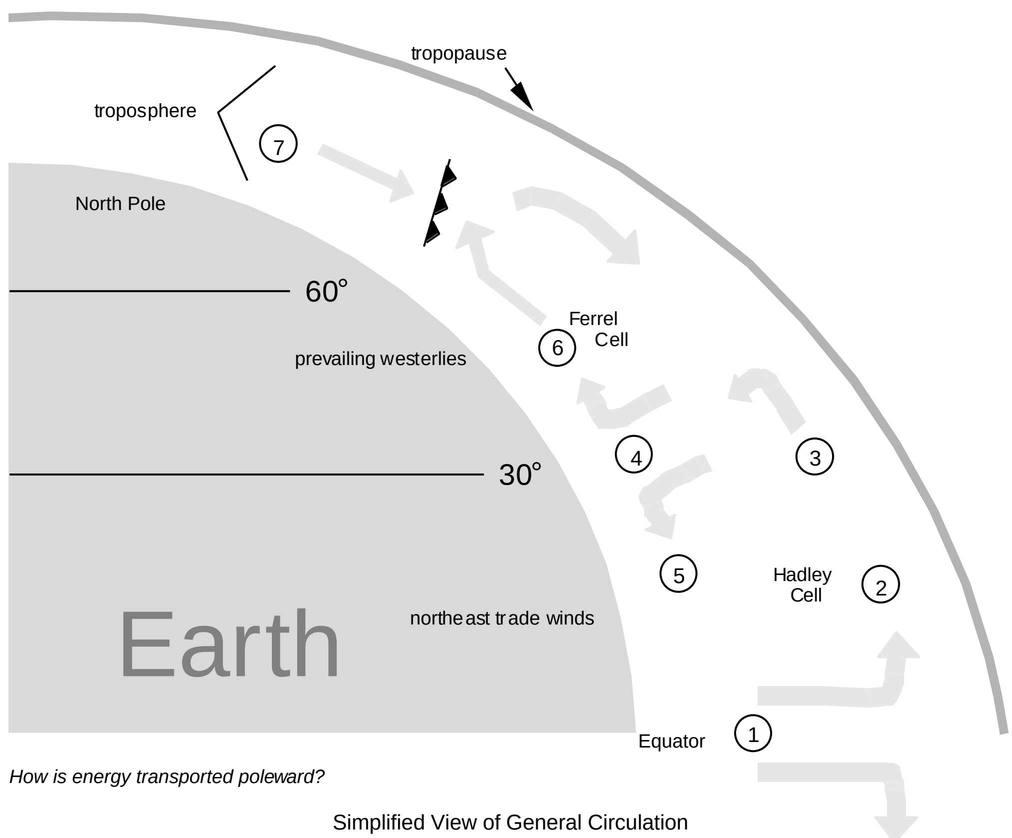


figure 7.



How is energy transported poleward?

Simplified View of General Circulation

The rising air near the ITCZ (1) diverges at the top of the troposphere and some portion travels north (2). As the air moves north it radiates energy into space and cools. As it cools it becomes more dense and sinks (3). The area of sinking motion, or subsidence, occurs near 30°N. A region with strong subsidence is typically very clear and warm with light winds. The subsiding air reaches the surface and branches outward (4) with the northern branch traveling north (6) and the southern branch traveling south to complete Hadley cell circulation (5). The northern branch collides with cold, dense polar air moving south (7). This area, marked by the cold front symbol (▲▲▲) is often the location of frontal zones and cyclonic disturbances.

figure 8a. Simplified View of General Circulation

In figure 8a (page 19), a simplified description of the general circulation of the atmosphere in the Northern Hemisphere is given. The area of interest for this section is the northern latitudes where the northward branch of the Ferrel cell (point 6) interacts with polar air moving south (point 7). Instabilities associated with the coexistence of these warm and cold air masses are responsible for the wave motion that is characteristic of the weather in mid-latitudes. The general circulation shown in figure 8a has several distinct circulation regions, or cells. The horizontal air motion associated with these cells, however, is not directly north-to-south **(meridional flow)** because the air is flowing over a rotating sphere (see figure 8b).

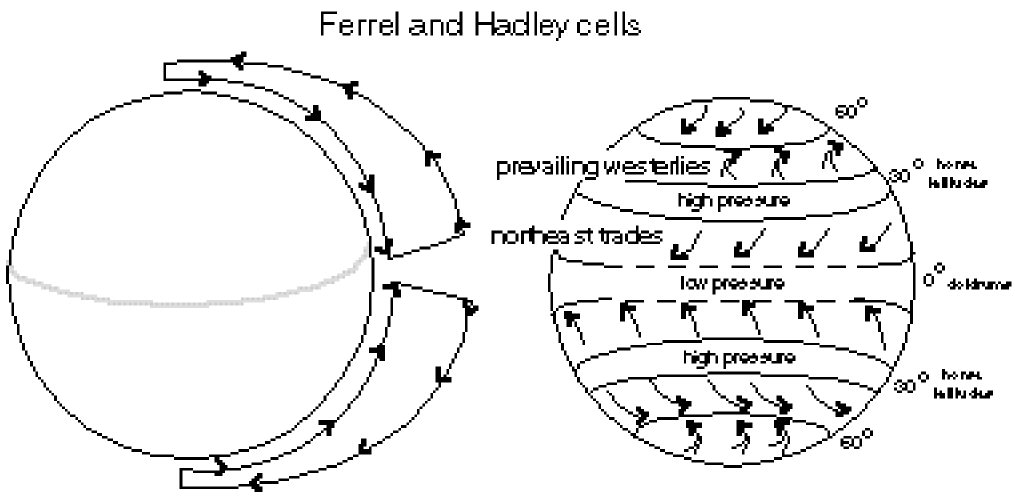


figure 8b.

Hadley cell

Single-cell model of circulation that assumes Earth is uniformly covered with water, that the Sun is always directly over the equator, and that the Earth does not rotate. Circulation consists of a closed loop with rising air over the equator and sinking air over the poles. Named after 18th century meteorologist, George Hadley.

Ferrel cell

Each hemisphere of the rotating Earth has three cells to redistribute energy. The middle cell, named for American meteorologist William Ferrel, is completed when surface air from the horse latitudes flows poleward toward the polar front.

Surface high pressure is located at the poles and near 30° latitude, low pressure exists over the equator and 60° latitude.

Because the Earth is rotating, our point of view about local motions—our frame of reference—is rotating as well (figure 9, page 21). Although this motion is imperceptible to us, if we observe Earth from a vantage point in space, the Earth rotates beneath us from right to left (counterclockwise). As an example of the effect of the Earth's rotation on relative motion, figure 9 shows a baseball (or parcel of air) moving northward at high speed from point A to B, If the length of the trip is long enough, the Earth will rotate under the baseball (or parcel of air). Although the baseball continues moving north relative to our geostationary point of view, when the path of the baseball (or air parcel) is traced on the Earth's surface, it appears to have curved to the right. The apparent force which accounts for such curved motion in a rotating frame of reference is called the Coriolis effect. The Coriolis effect accounts for the large scale horizontal winds that are driven by the general circulation of the atmosphere.

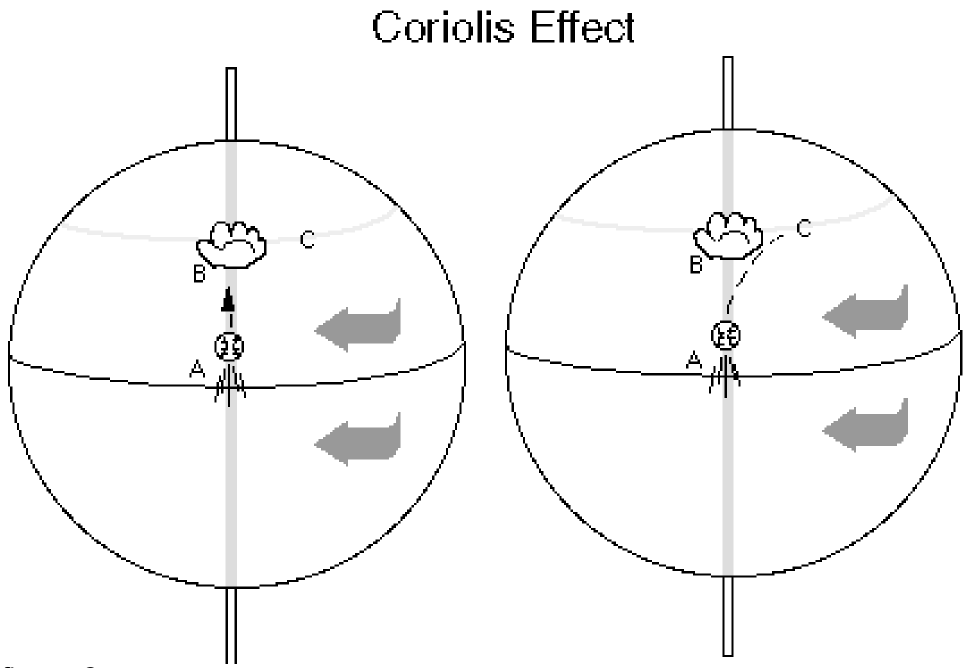


figure 9.

The Coriolis effect has several important characteristics.

1. The Coriolis effect is a deflecting force. It acts at right angles to wind direction but does not affect wind speed.
2. The strength of the Coriolis effect is proportional to wind speed.
3. The Coriolis effect deflects winds to the right in the Northern Hemisphere. Thus northerly moving winds are bent eastward and southerly moving winds are bent westward. The reverse is true in the Southern Hemisphere (winds are deflected to the left, meaning northerly moving winds are bent westward and southerly moving winds are bent eastward.)
4. There is no effect at the equator.

The influence of the Coriolis effect on general circulation gives us the prevailing wind regimes that were observed by sailors centuries ago. For example, the winds that move from north to south from the lower latitudes into the ITCZ are deflected to the right (westward) and produce the northeast **trade winds**, observed in the Caribbean and Hawaii (figure 10, page 22). The winds that move south-to-north in the midlatitudes are deflected to the right and form the prevailing westerlies in this area.

Now that we understand the overall circulation patterns of the atmosphere, we can return to the energy balance issue; the transport of heat from the equator to the poles. The southernmost cells of the general circulation (Hadley and Ferrel) are fairly efficient in transferring heat directly from the tropical regions. In the mid-latitudes, the general circulation and the Coriolis effect combine to produce conditions less favorable to energy transfer. The mid-latitude, westerly winds are opposed by easterly winds produced by polar air sliding southward (figure 10). Due to differences in density, the two air masses do not readily mix and the transfer of warm air poleward is retarded. How then is heat transported poleward across the mid-latitudes to restore balance to the system?

The mechanism which transports energy poleward in the mid-latitudes is the cyclonic disturbance. On satellite images, the distinct **comma cloud** pattern associated with these storms indicates the energy transfer. The process by which the transfer of warm air poleward occurs is summarized in qualitative terms in figure 11 (page 23). The process begins with the transport of warm air to the mid-latitudes. As noted above, this air mass does not readily mix with denser polar air. Over time, the west winds in the mid-latitudes continue to absorb heat transported northward and a strong latitudinal **temperature gradient** develops with increasingly warm air bordering on cold polar air. As the gradient becomes progressively stronger, a small disturbance, which is often associated with the movement of smaller scale waves and the structure of the jet stream, begins to amplify. Over time, a large wave develops which sweeps warm air poleward and finally heat is exchanged. The latitudinal temperature gradient decreases and stable conditions return.

Earth's weather patterns are a result of the unequal heating of the Earth's surface. The tropical latitudes receive more energy from the Sun than the higher latitudes.

Averaged over Earth, incoming radiation from the Sun approximately equals outgoing Earth radiation. However, this energy balance is not maintained in all latitudes—the tropics experience a net gain, the polar regions a net loss.

The Earth-atmosphere system attempts to restore balance to the system by transporting excess energy from the equatorial regions to the poles.

Differences in pressure within the atmosphere cause air to move—wind to blow.

General atmospheric circulation represents average air flow around the world. Actual winds at any location may vary considerably from this average.

Wind direction is given as the direction from which the wind is blowing, i.e., a north wind blows from north to south.

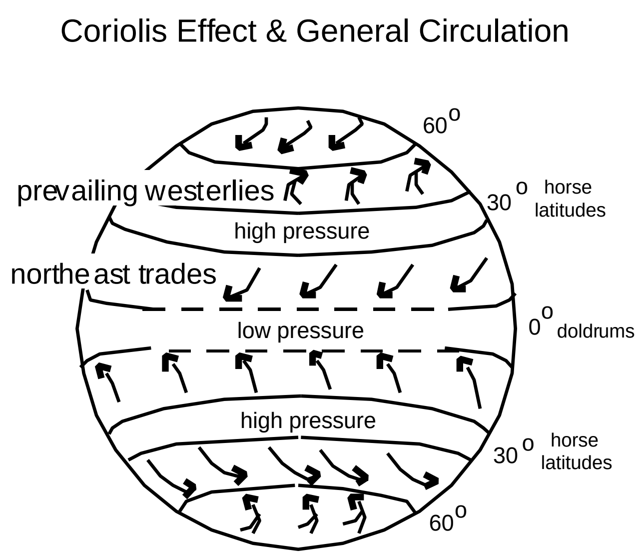


figure 10.

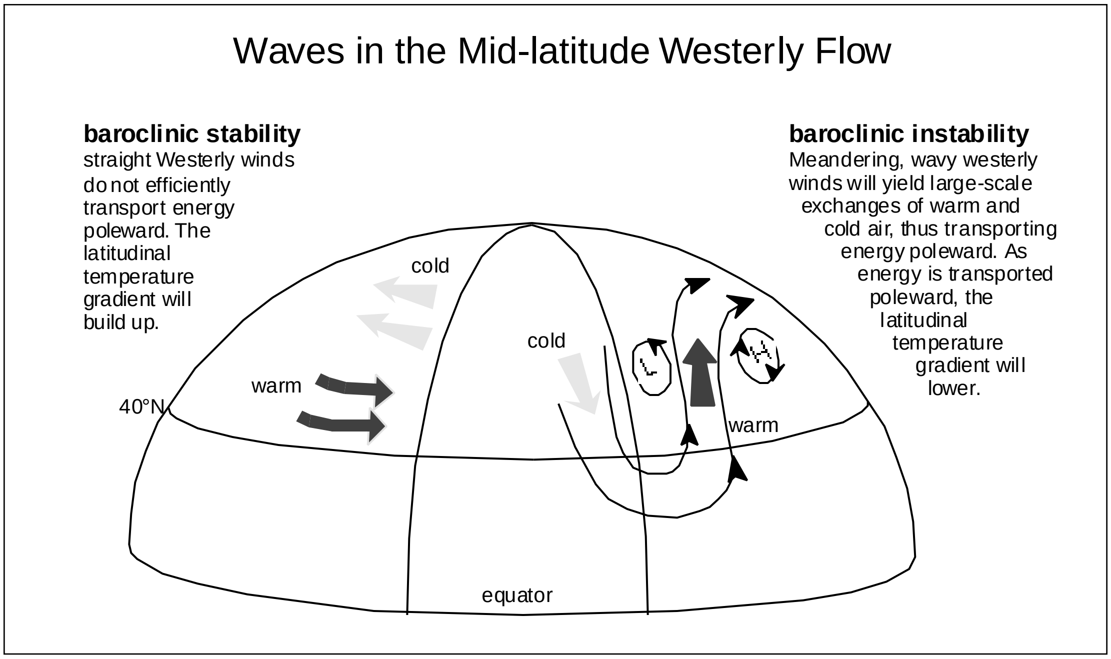
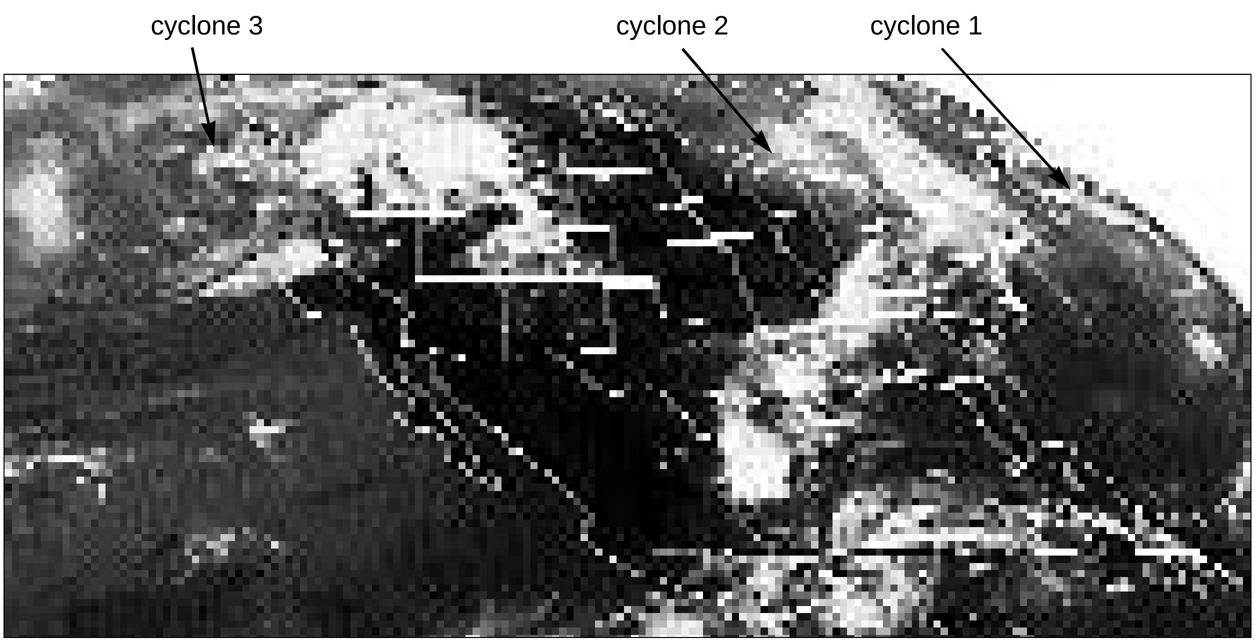


figure 11. adapted from the course materials of Dr. Owen Thompson, University of Maryland

The cycle shown in figure 11 is idealized and occurs in many different permutations with a variety of regional effects. At any given time, several examples of the process can be observed on GOES images (figure 12).

figure 12. GOES image, May 15, 1994, containing several cyclones, image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign



Cyclonic Disturbances and Baroclinic Instability

Section 3

In this section, the wave motion that is characteristic of the weather in the mid-latitudes is investigated in more detail. A pattern of regular storms in the mid-latitudes has been known for many years (see historical note on page 25). However, the first modern paradigm for describing the development of mid-latitude disturbances did not appear until the time of World War I. At that time, Vilhelm Bjerknes— a noted hydrodynamicist, his son Jacob, and other Norwegian scientists set up a research facility in Bergen, Norway. Because of the war, all sources of weather data were cut off. To prepare local forecasts, the group—later known as the Bergen School, set up a dense observational network across Norway. The data collected from this network was used to develop what has come to be known as the polar front theory. This theory postulated the existence of the now-familiar warm and cold fronts, as well as the three-dimensional motions associated with them. Although many of the concepts associated with the polar front theory had already existed or been hinted at, the scientists of the Bergen School created a complete and coherent three-dimensional picture of the life cycle of extra-tropical cyclones.

The data upon which this theory was based was primarily a network of surface observations, supplemented by limited upper air data. The polar front theory predates many observing systems in use today including the global upper air observation network, radar, and satellites. However, the basic insights contained in this paradigm still form part of the current understanding of extratropical cyclone development and are a useful place to begin to understand what we see on the satellite images.

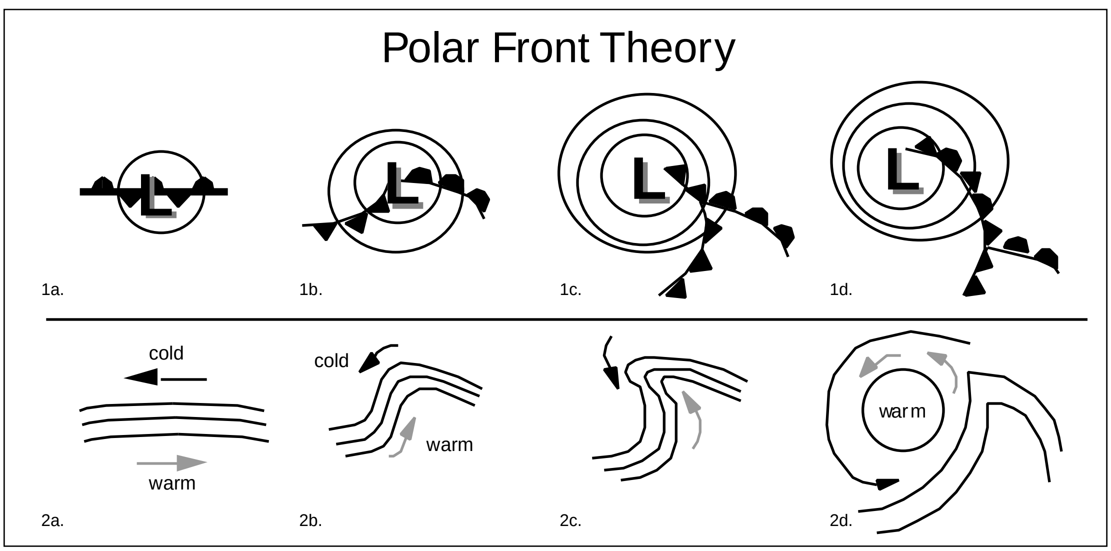


figure 13. panel 1, a-d four-stage pressure and front fields
panel 2, a-d four-stage wind and temperature field

The evolution of the wave as described by the polar front theory is shown in figure 13. The symbols for fronts are shown in the *Glossary* under **weather symbols**. The wave passes through several distinct stages with characteristic surface weather phenomena associated with each stage.

- In stage 1a. and 1b., a stationary polar front exists in a region of locally lower pressure (pressure trough) between two air masses. Cool polar air is to the north and warmer tropical air to the south. This is a local expression of the stable condition shown in figure 11 (page 23) regarding the general circulation.

- A kink or open wave forms in stage b with low pressure at the center of the wave. The inverted V-shape in stage b now contains the familiar cold and warm fronts. The cold front moves faster and eventually catches up to warm front.

- The top of the inverted V becomes closed in stage c. This is the **occlusion stage** of a mature system, the storm is now intense with a distinct comma shaped cloud pattern associated with it.

- As the occlusion progresses in stage d, the main area of warm, moist air becomes isolated from its source. The storm will spin about itself and slowly dissipate. This isolated area of warm air (warm **eddy**) in stage d is an example of the poleward transfer of heat that acts to restore the Earth system to balance.

Historical Note

Advances in the field of meteorology have paralleled general technological advances. The invention of the telegraph in 1845 allowed, for the first time, the rapid communication of weather data and the ability to create timely weather maps. The day-to-day weather motions revealed by these charts provided the ability to provide short-term forecasts. The first regular storm warnings were issued in the Netherlands in 1860. As the network of surface observations increased, and theoretical understanding improved, the first general theory of wave development, the polar front theory, was introduced in the early 20th century (1917–1922).

The shortcoming of weather analysis up to the early 1920's was the dearth of observations of upper air conditions. However, advances in radio technology and associated improvements in storage battery technology made possible the invention of the radio meteorograph (radiosonde). Inexpensive radiosondes were the key to the development, during the period from 1920–1950, of a global network of regular upper air observations. The data from this network stimulated theoretical investigations of the physics of the atmosphere culminating, just after the Second World War, in the work of Jule Charney and Arnt Eliassen. These scientists, working independently, adapted the general equations of hydrodynamics to provide the possibility of a mathematically manageable description of three-dimensional atmospheric motion.

The problem with theoretical investigations of atmospheric motion was the inability to carry out the immense number of calculations involved in solving the equations of motion. The advent of the general purpose (programmable) computer in the early 1950's finally surmounted this problem and allowed rapid and significant advances in meteorology. In fact, the first peacetime use of a multipurpose electronic digital computing machine (the Electronic Numerical Integrator and Computer or ENIAC) was to predict weather. In the following years, advances in semi-conductor technology has made computers more powerful and able to solve more complex forecast problems.

However, any computer forecast is dependent upon the data used as input. While a dense network of observations existed over the land areas of the Northern Hemisphere, many remote areas of the globe—particularly the oceans—were not routinely observed. The satellite era, beginning in the early 1960's, provided the capability for global weather observations. These observations further improved computer forecasts.

In the future, advances in observations, computing technology, and remote sensing will continue to drive advances in forecast meteorology, particularly in the areas of longer range (greater than 6 day) forecasts and local, severe weather forecasts. The information now becoming available from Doppler radars and the new generation of geosynchronous satellites will also improve the theoretical understanding of the atmosphere.

The polar front theory gained general acceptance by World War II because it was able to explain the observed weather associated with mid-latitude disturbances. In figure 14a, vertical cross-sections through the cold and warm fronts are shown. The cloud patterns that are associated with the different regions of the disturbance are a function of the vertical structure of the atmosphere at each location. The cold front is characterized by cool, dense air which burrows under warm, moist air. As we will see in more detail later, rapid lifting and cooling of moist air produces the thunderstorms that frequently accompany frontal passages, and are often large enough to be fully detected by satellite images. Conversely, the warm front consists of warm air rising gradually over slightly cooler air. This slowly rising air produces layered, or stratiform, clouds.

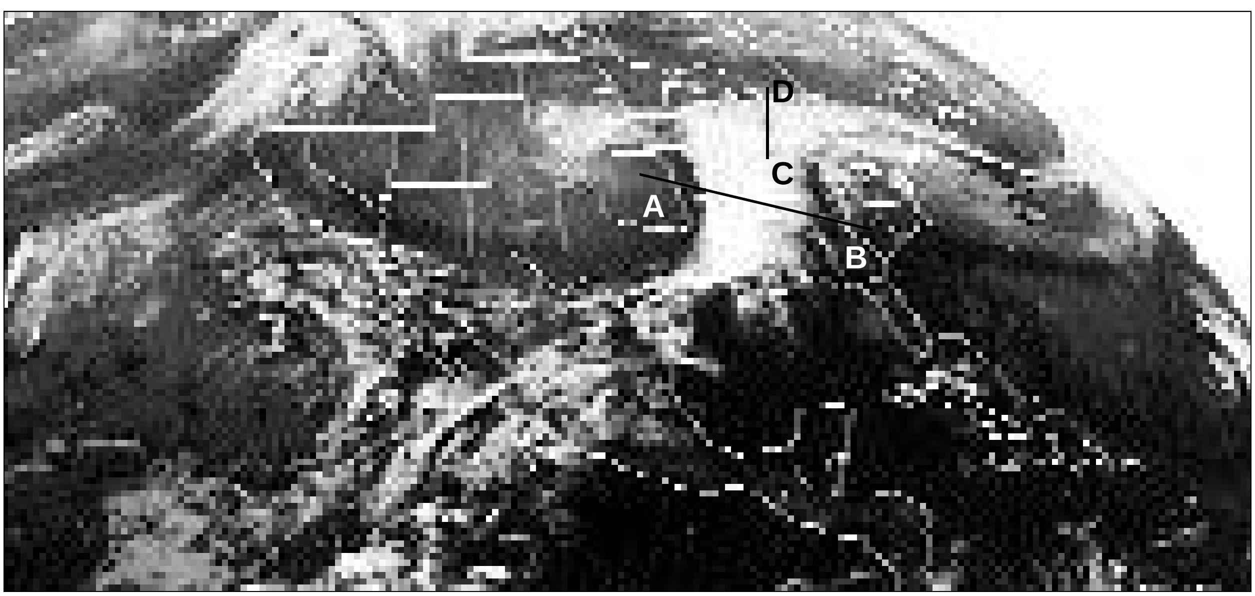


figure 14a. GOES image of cyclone, April 12, 1994 0100 CDT.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign
Cross sections are A-B (cold front) and C-D (warm front).

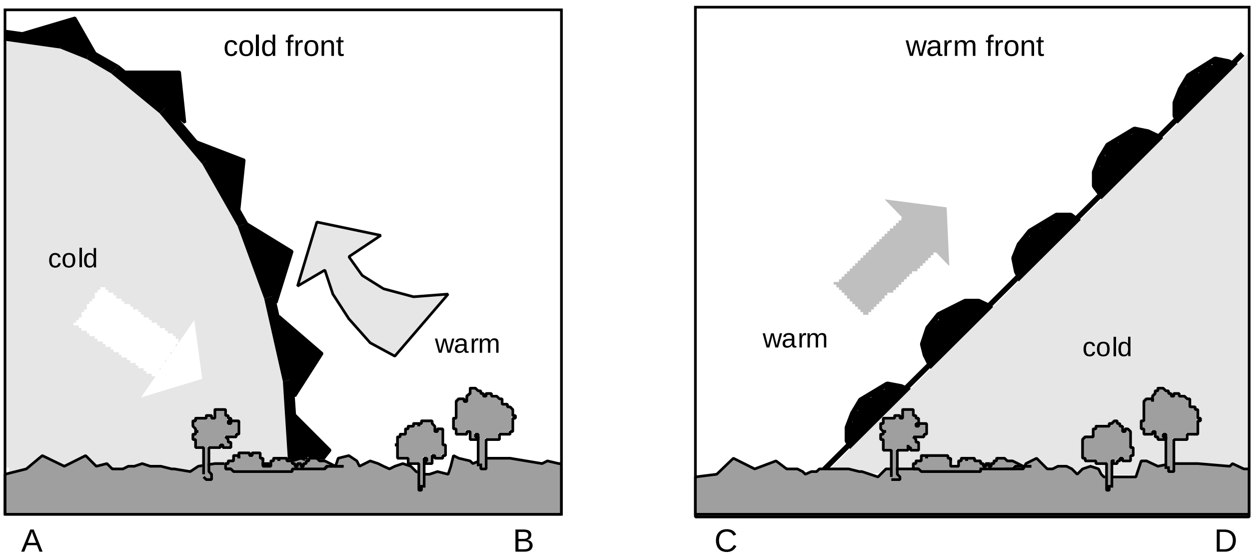


figure 14b. Panels are cross sections of A- B and C-D, in figure 14a.

The most striking aspects of the development of extratropical cyclones, as explained by the polar front theory, are the rapid lowering of pressure and the counter-clockwise rotation of winds about the center of low pressure. This distinct air motion is reflected in the comma cloud system that we observe from satellites, and is produced by four basic forces:

1. pressure gradient force (PGF),
2. Coriolis effect,
3. centrifugal force, and
4. friction.

In general, the motion of wind is from high pressure to low pressure. The center of the mid-latitude cyclone is an area of low pressure. As a result, air at the surface converges toward that location. The Coriolis effect, as discussed in section 2, deflects the incoming wind to the right (in the Northern Hemisphere), to produce a counterclockwise rotation (figure 15, page 28). If the area of low pressure is roughly circular, the rotation will be counterclockwise.

At distances of greater than 1 kilometer from the surface, the PGF and Coriolis effect are in balance for relatively straight-line flow (in curved flow, the centrifugal force must also be considered). The PGF, a constant force, initially accelerates a parcel of air toward lower pressure (figure 15a). As the parcel's speed increases, the Coriolis effect deflects it to the right in proportion to the speed of the parcel. The parcel eventually reaches a velocity in which balance is achieved and no net force is exerted on the parcel. At this point, there is no further acceleration and the velocity of the parcel is constant. The air flow is parallel to the isobars (lines of equal pressure-15b). This balance of PGF and Coriolis forces is called the geostrophic wind (Vg) assumption. Above the Earth's surface, where frictional effects are negligible, this assumption is a valid approximation.

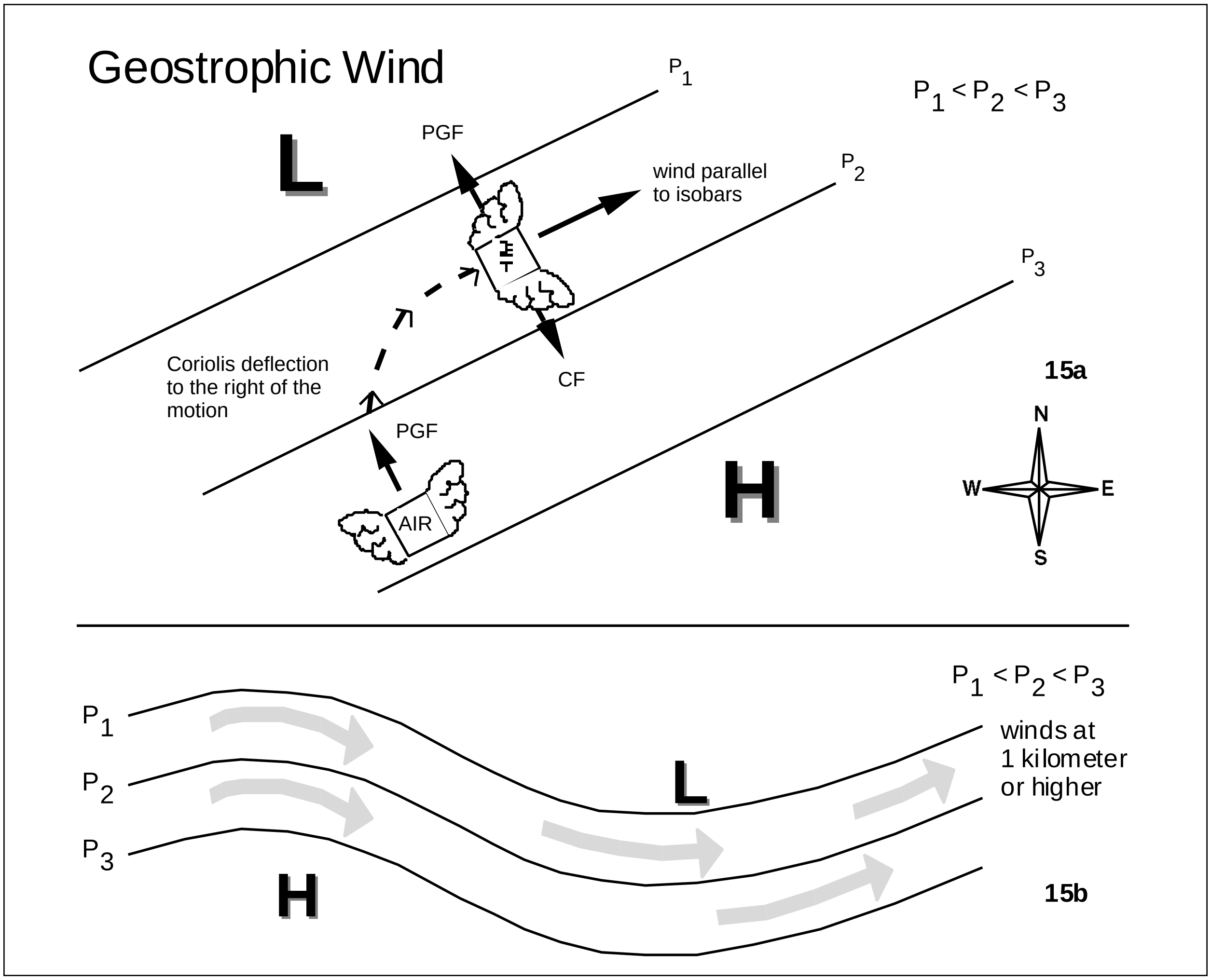


figure 15.

In sharply curved flow, the geostrophic assumption is no longer completely valid. It is observed that air flow around curved ridges and troughs is still geostrophic in direction (parallel to lines of equal pressure). But the observed wind speeds are not equal to that predicted by the geostrophic assumption. Wind speed around a low pressure trough is slower than predicted by the geostrophic assumption and winds around a high pressure ridge are stronger than predicted by the geostrophic assumption. To explain this difference in speed but not direction, we must consider centrifugal force. Centrifugal force is, like the Coriolis effect, an apparent force that is used so that Newton's laws can be applied in a rotating frame of reference. An example is shown in figure 16. A block of wood is tied to the center of a rotating platform. To an observer outside the rotating platform, the block moves in a circle with force provided by the tension on the line (T in the figure). However, to an observer on the platform, the block is at rest. To account for the tension on the string, an apparent outward force— called the centrifugal force (Ce)—must be introduced.

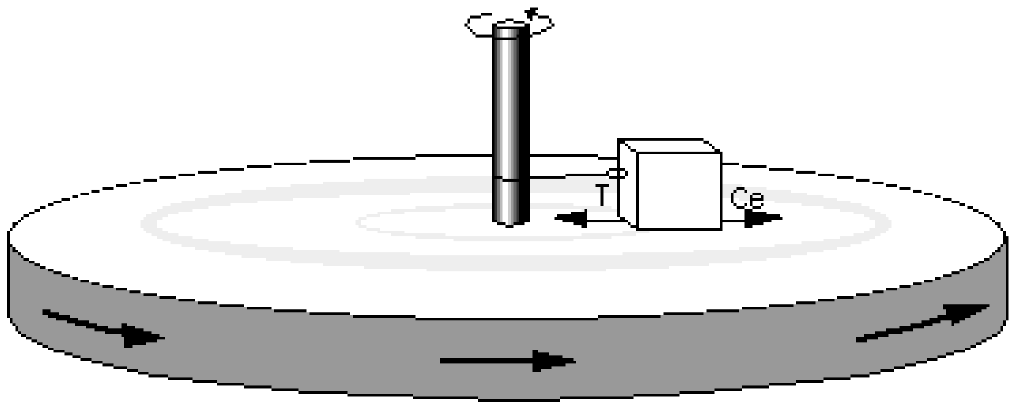


figure 16.

The effect of the centrifugal force on winds that curve around high and low pressure centers is shown in figure 17 (page 30) and provides a clue to the most likely location for the development of cyclonic disturbances. The centrifugal force is directed outward from the center of the curved motion. Near the center of low pressure, the centrifugal force (Ce) opposes the PGF in this region and in order for the air parcel to continue moving parallel to the isobars, the Coriolis effect (Co) must be reduced. Because the Coriolis effect is proportional to wind speed, the speed of the air parcel is less than it would be for straight flow. The flow around a low pressure center is slower than expected or sub-geostrophic. The reverse effect occurs at the top of the ridge. Here the centrifugal force reinforces the PGF and requires a stronger Coriolis effect, and stronger winds, to balance. The flow here is faster than would be expected for straight flow (supergeostrophic). As a result, an air parcel accelerates as it moves from the base of the trough to the top of ridge. This acceleration creates an area of horizontal divergence ahead of (east of) the trough. That is, air is leaving the shaded area (in figure 18, page 30) faster that it enters, so that the mass of air within the shaded area decreases. This reduction in mass is an area of horizontal divergence. Areas of divergence lead to vertical motion and are a key region for development of mid-latitude cyclones (figure 3, page 13).

Near the surface, a different sort of balance occurs. Here the winds do not flow parallel to lines of equal pressure (isobars) but tend to cross the isobars at an angle slightly toward lower pressure (figure 19, page 31). This is a result of friction acting on the parcel of air. Friction decreases velocity so that the Coriolis effect (Co), which is proportional to velocity, decreases. The PGF, which is a constant force, becomes more dominant relative to the Coriolis effect, and air is drawn toward the center of low pressure. This flow across isobars accounts for the tight spiral near the heart of the comma cloud. It also accounts for converging air near the center of the cyclonic disturbance.

The polar front theory was able to account for the wind fields we have just discussed as well as provide a mechanism for the transfer of heat toward the pole. The polar front theory, based on surface observations, had shortcomings which became clearer as new observational techniques were developed. As upper air soundings became more widespread and frequent, it was observed that frontal zones could exist for long periods of time without becoming unstable and that strong cyclonic disturbances could occur without preexisting frontal zones.

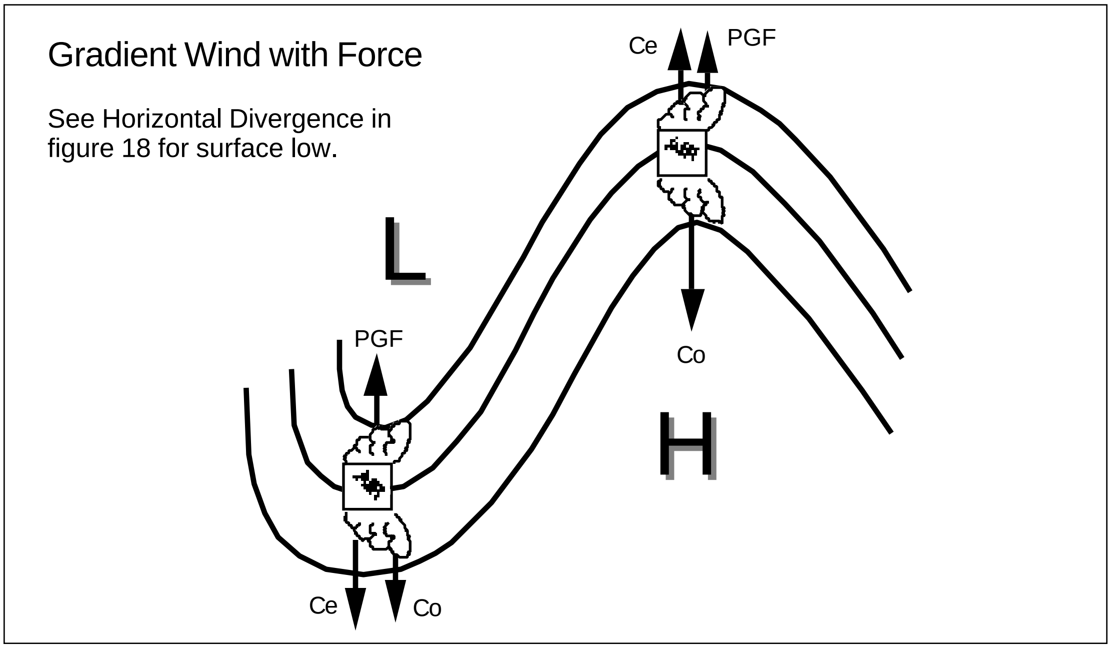
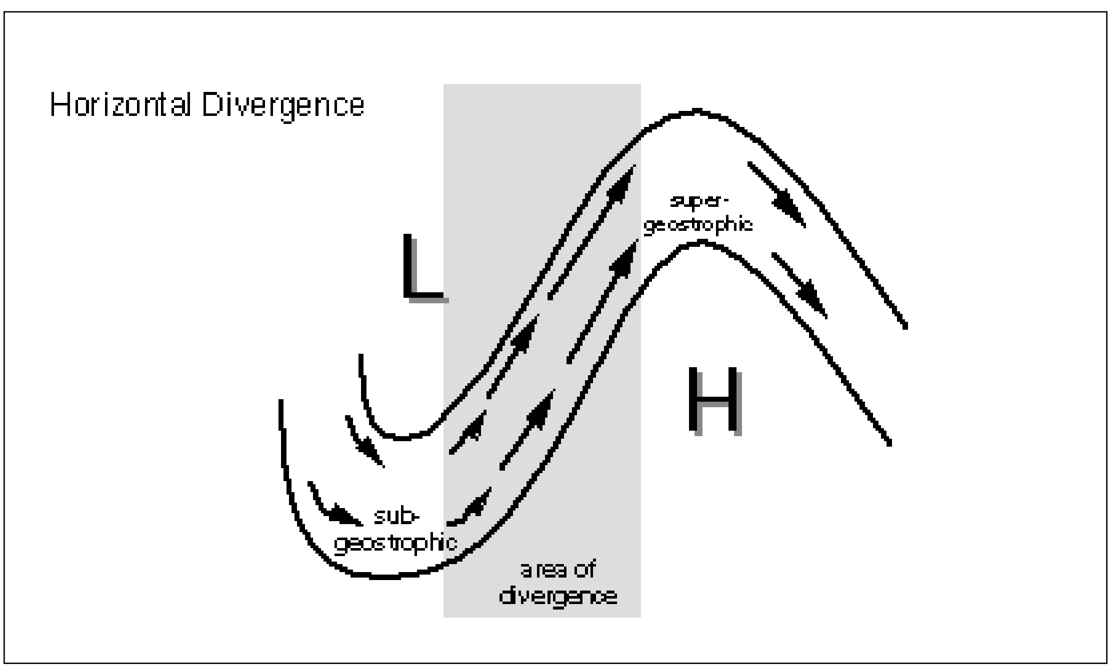


figure 17. centrifugal force affects wind around high pressure and low pressure differently

figure 18. mid-latitude cyclones tend to develop in the shaded area



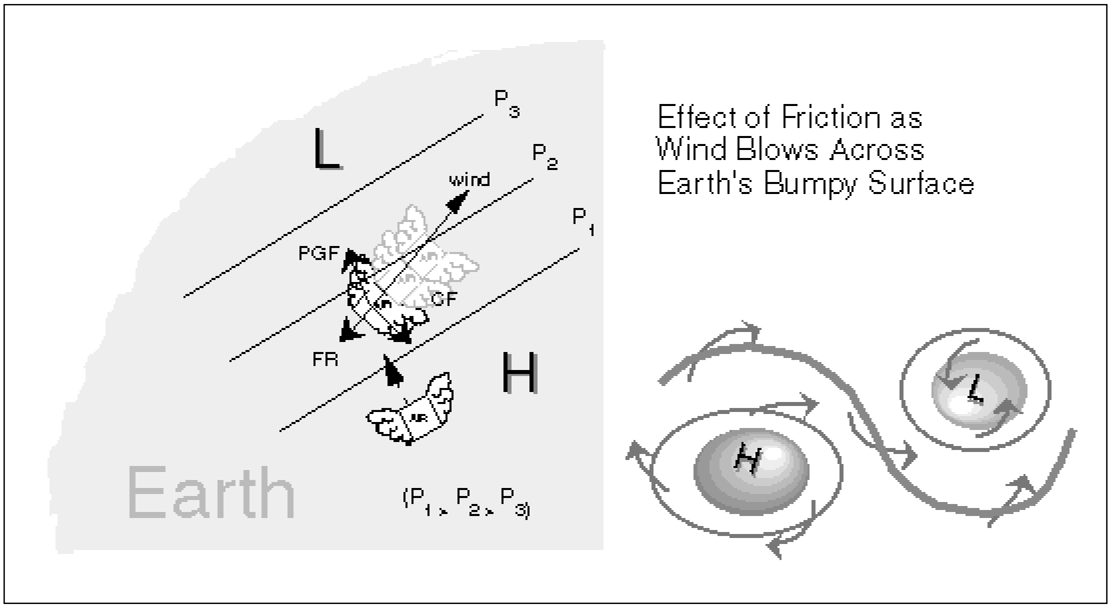


figure 19.   surface winds and friction

The theoretical explanation of the development of cyclones that succeeded the polar front theory was first introduced in the 1940's. This theory, termed the **baroclinic theory,** identified instabilities in the upper level westerlies as the key to cyclone development. The baroclinic theory is better able than the polar front theory to predict when and where mid-latitude cyclones will develop. With the advent of satellite observations in the 1960's, the basic insights of the baroclinic theory were confirmed although, as will be explained in section 5, satellites have also identified large weather-making systems that are not fully explained by baroclinic processes.

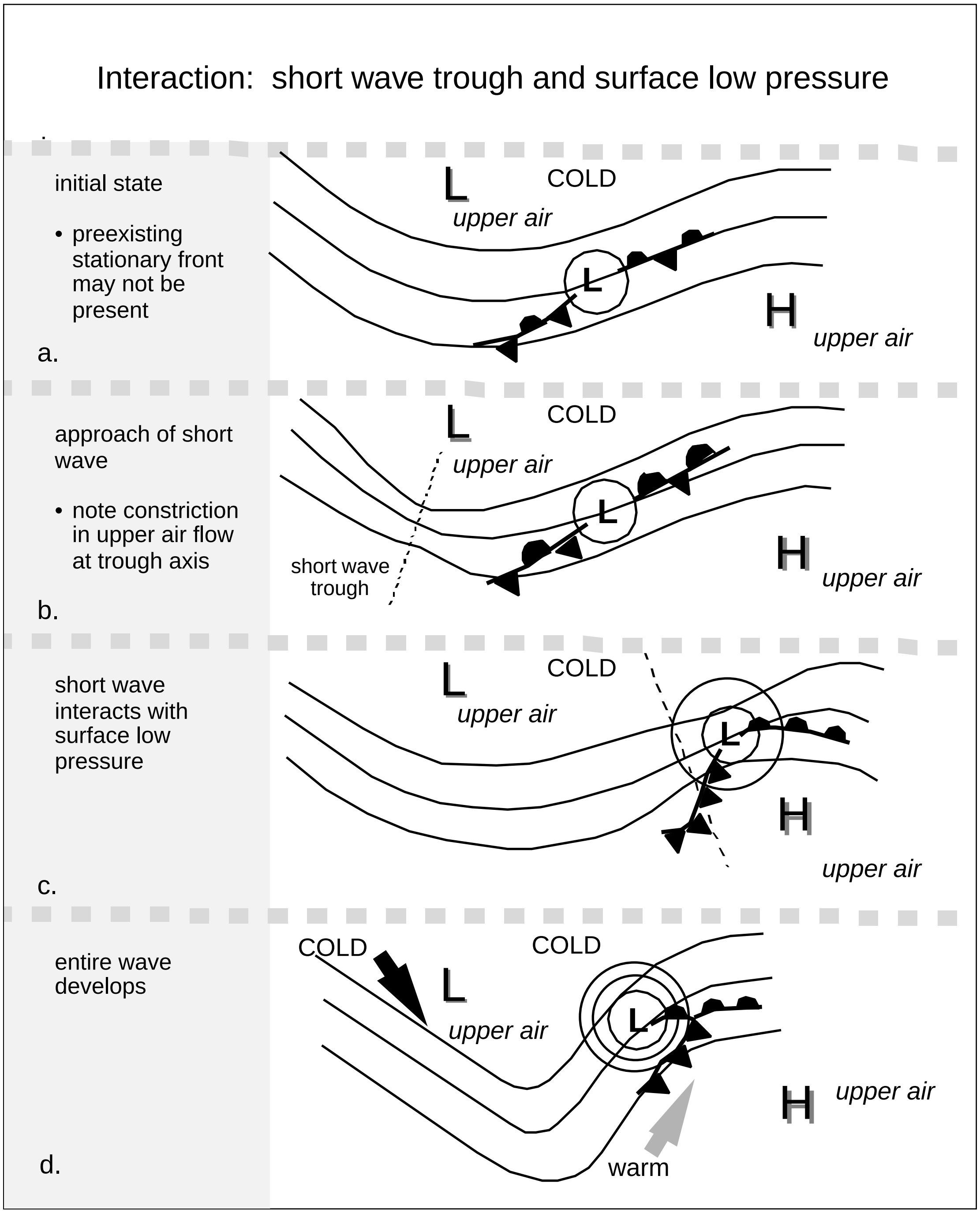
While the baroclinic theory is quite complex and cannot be fully described here, we can point to the key factors that result in extra-tropical cyclone development and the manner in which they interact. Through satellite images and surface and upper air charts (all now routinely available on the Internet), these factors can be identified and tracked so that simple, but often accurate, forecasts of cyclone development can be made.

Historical Background

Serial ascents of balloon-borne **meteorographs** in the late 1920's and early 1930's were able to provide clues regarding the upper-air conditions associated with cyclonic disturbances. These showed the vertical extent of the frontal zones - rather than abrupt discontinuities between air masses - and some indication of upper level wave structure. After the Second World War, a **radiosonde** network that spanned the globe was set up which allowed for daily analysis of upper air patterns. This allowed, for the first time, routine observation of the strength and extent of the polar jet stream.

With the advent of routine upper air observations, it was found that cyclonic disturbances tend to occur just ahead (east) of the base of the trough (figure 3) and that these upper air waves—which are quasi-horizontal—amplify along with the developing storm. With higher resolution observations, it was found that the amplifications in the wave were associated with the movement of small scale disturbances (short waves) within the troughs. When these short waves, which appear as constrictions in the longer wave (figure 20), approach an area of surface low pressure, rapid development of the cyclonic disturbance occurs.

figure 20.

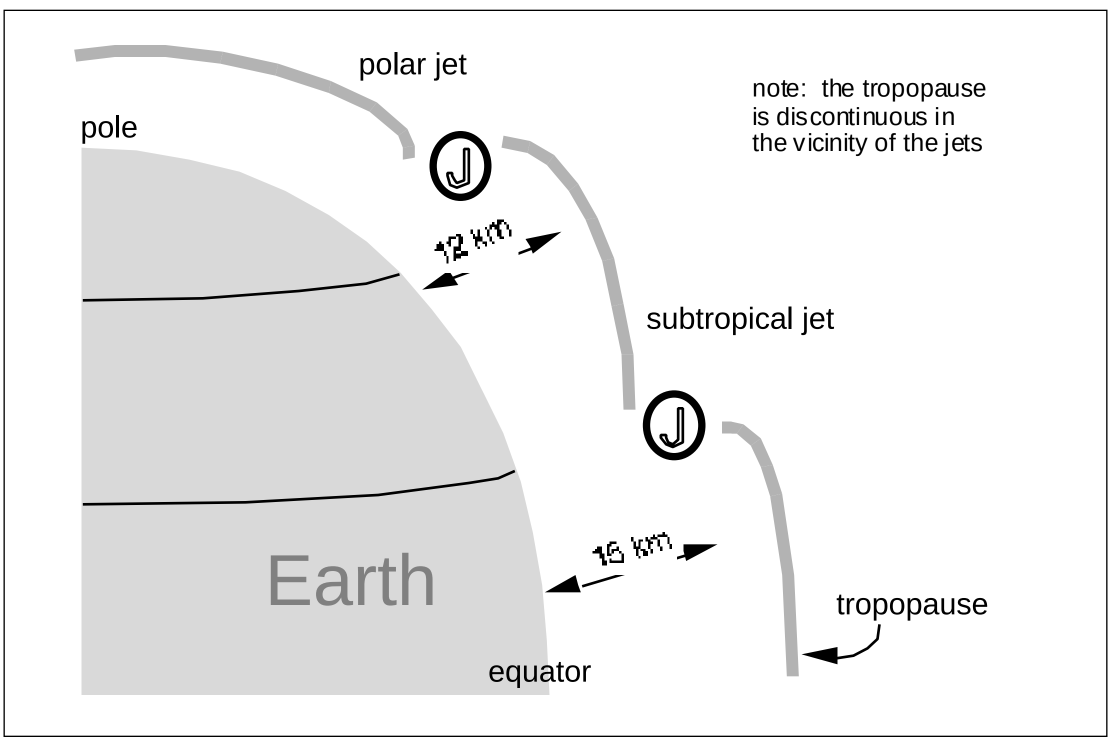


The interaction of the short wave trough with the surface low pressure center is shown in figure 20 (page 32). In figure 20a, the initial state is drawn. In this situation, there may or may not be a stationary front present. Often there is only an area with latitudinal temperature gradient present in the region shown by a stationary front in figure 20a. The short wave begins circulating through the longer wave pattern in figure 20b. The short wave is identified by a kink, or constriction, within the overall, large scale, wave. As will be discussed below, upper air charts at 500mb (~ 5km above ground) or 700 mb (~ 3km) will typically show the location of any short wave troughs. In figure 20c, the short wave travels into the area with either a stationary front or latitudinal temperature gradient. At this point, the surface pressure falls quickly and the classic wave form (compare figure 13) is present. The interaction of the short wave with the surface low pressure center causes the large scale wave to amplify rapidly (figure 20d). The short wave trough thus acts to energize the entire wave train and heat transfer, as discussed in section 2.

Large scale instabilities, or waves, in the westerly flow in the mid-latitudes which are triggered by the passage of the mid-tropospheric short wave troughs through a region of strong temperature gradients can be further enhanced by circulations resulting from accelerations in the jet stream at the top of the troposphere.

The jet stream is a semi-continuous belt of strong upper level winds that encircle the globe with wave-like meanders. The jet stream can best be described as a ribbon of high speed winds located at the top of the troposphere (10–15 km). At this height, the tropopause marks the limit of the troposphere and the beginning of the stratosphere. The jet is not continuous but has segments that are thousands of kilometers in length, hundreds of kilometers in width, but only one to five kilometers deep.

figure 21.



On the average, there are two jet streams present in the Northern Hemisphere (figure 21, page 33). The polar jet is found in latitudes 30°-60°N. The subtropical jet is located between 20-40° N and has a distinct cloud signature which is evident on satellite images (figure 22). An important characteristic of jet streams is that wind speed is not uniform within the jet. There exists a jet core or streak which contains the maximum winds. The location and movement of the jet streak is a key factor in cyclone development.

The jet streak moves along the jet stream in a manner similar to the way a short wave trough moves through the long wave pattern. Jet streaks move slowly relative to the wind parcels that travel along the jet stream. Jet streaks are analogous to constricted areas in a river. A parcel of air traveling along the jet stream will overtake the jet streak and be temporarily accelerated before exiting the region.

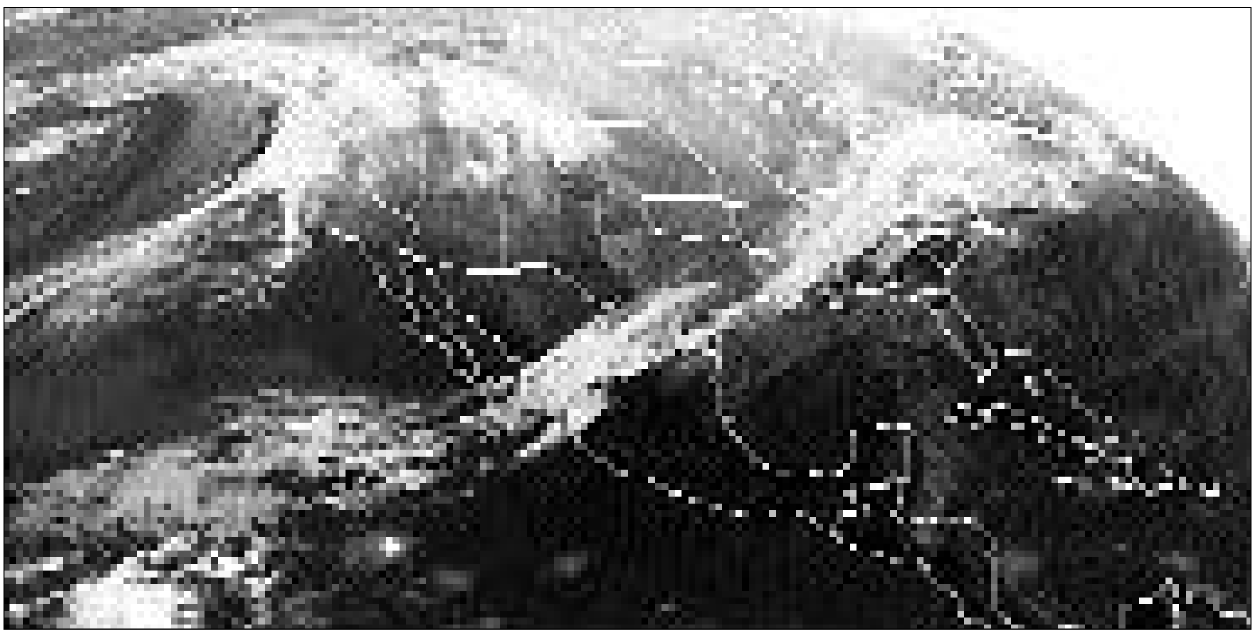


figure 22. GOES image, January 7, 1994, 1100 CST
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

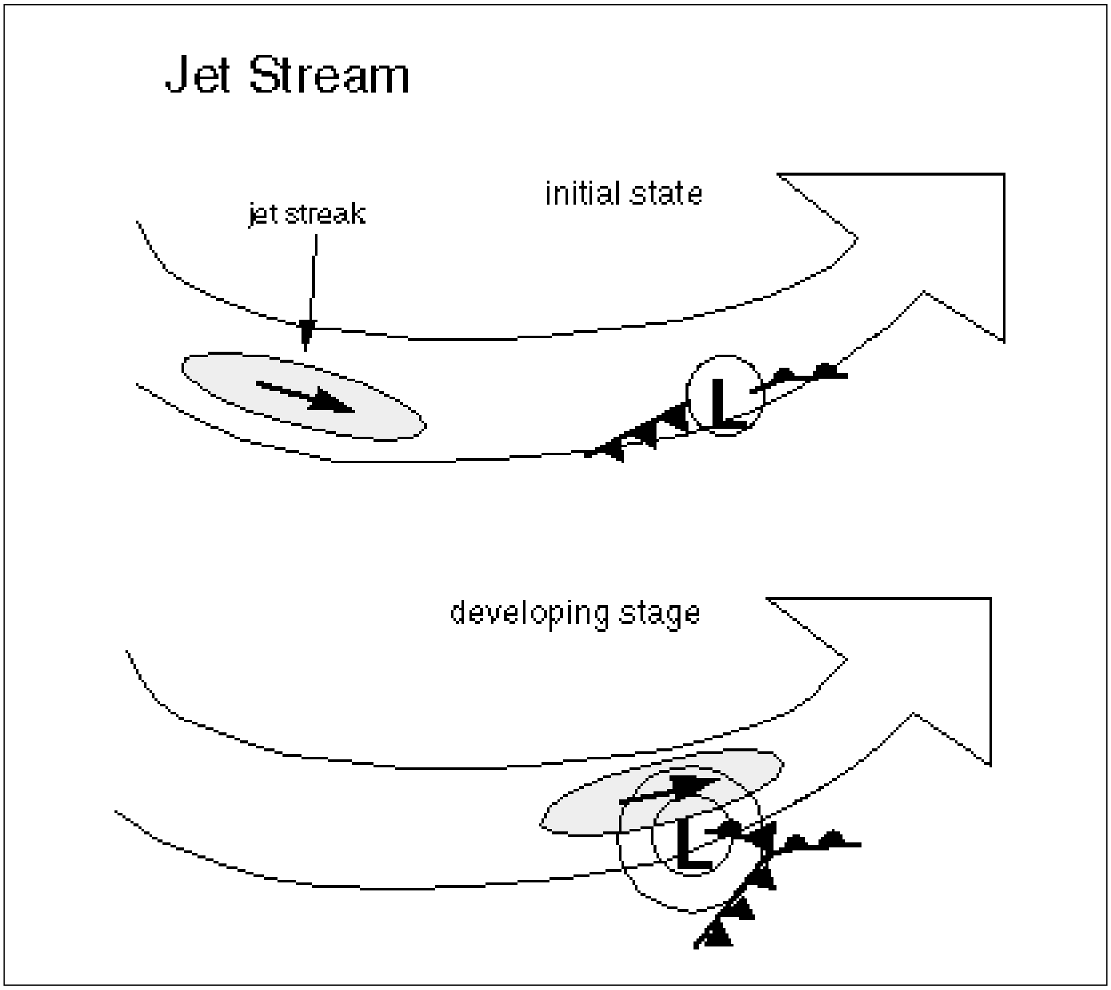


figure 23.

When the surface jet streak is near the surface low pressure center, the surface pressure rapidly decreases

The accelerations within the jet streak act to increase upward air motions. Because upward motion is limited at the top of the troposphere, the air then moves outward (or diverges) similar to the tropopause's effect on convection at the ITCZ. The net result of this upward motion in the vicinity of the jet streak is to decrease the mass of air beneath it. This results in lower surface pressure. When the jet streak moves close to a region with a developing surface cyclone, the effect is to further decrease pressure and enhance the cyclonic circulation (figure 23).

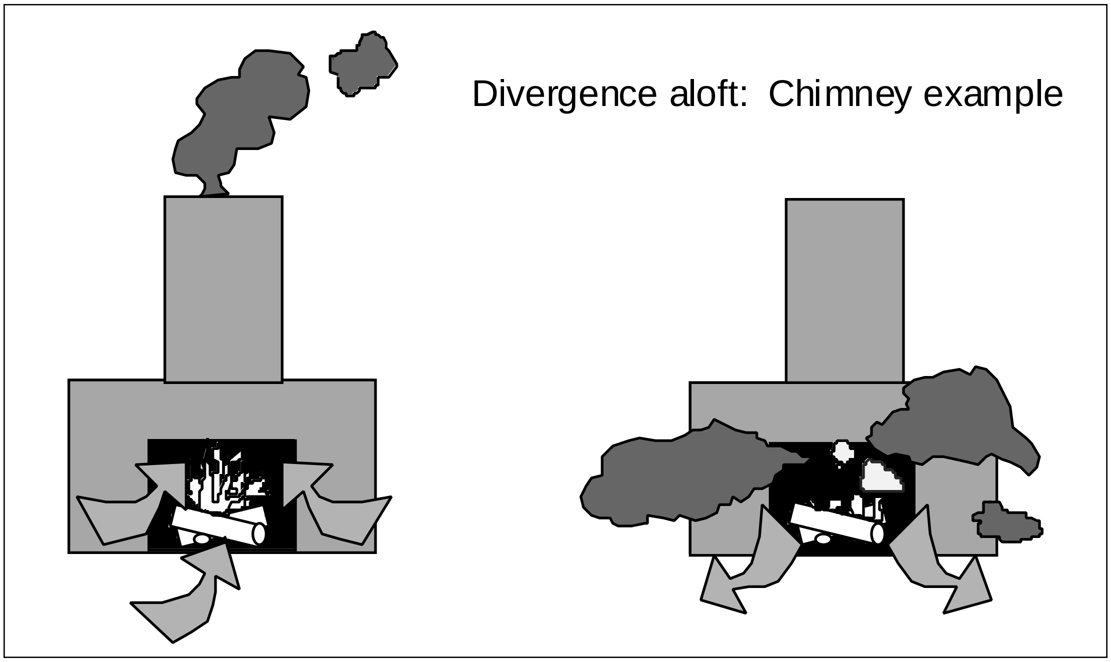
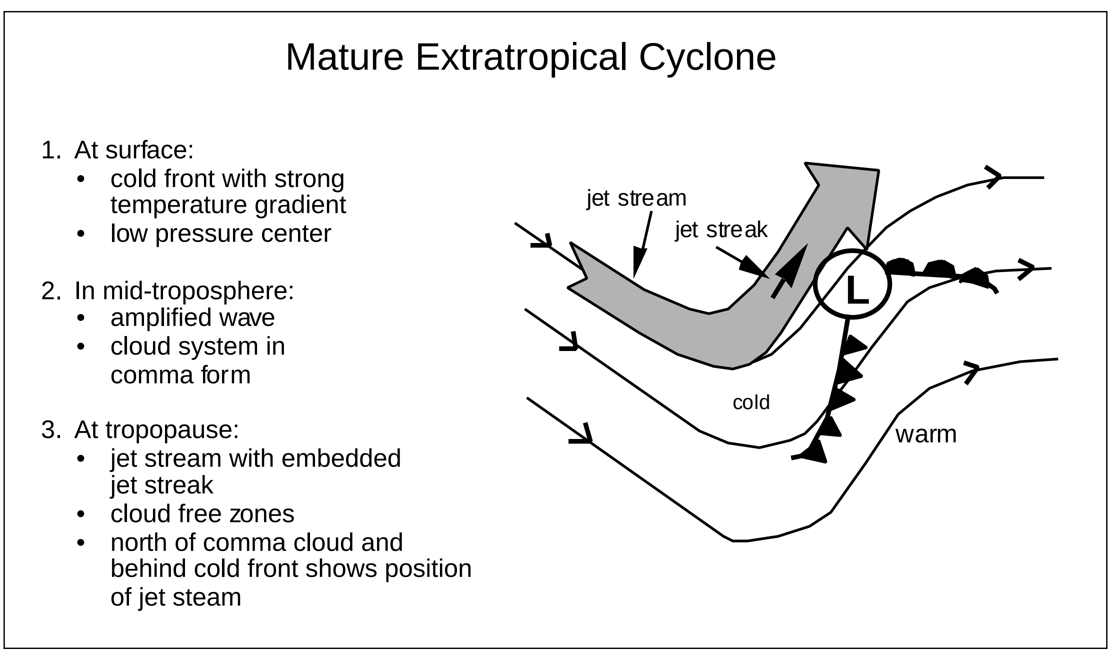


figure 24.

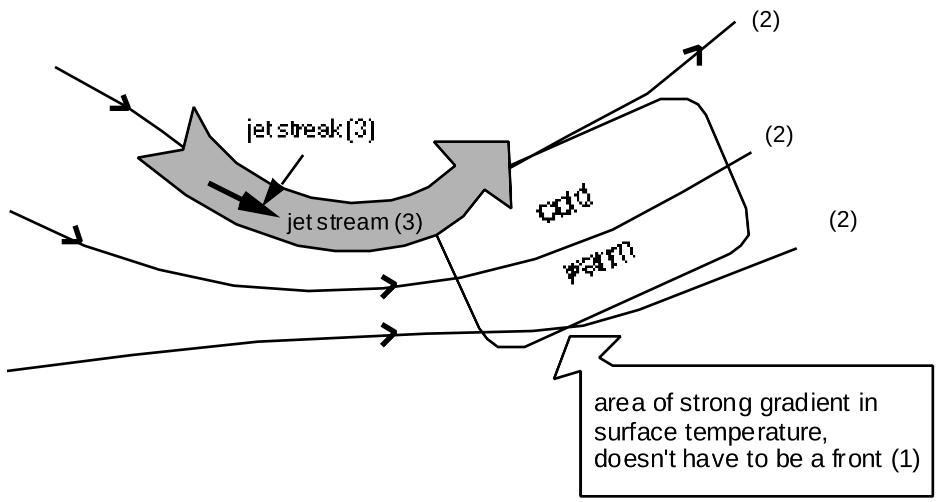
Divergence associated with jet streak circulations can be compared to a chimney. If the chimney flue is open, smoke escapes and more air is drawn in to feed the fire. If the flue is closed, smoke backs up into the fireplace and no new air feeds the fire. As a fire needs an open flue to grow, a deepening low pressure system must contain a deep region of divergence (figure 24).

figure 25.



For understanding satellite images and the current and future weather associated with them, the factors discussed above point to information that is helpful to a full analysis. The cloud patterns from a GOES image, or series of GOES images, will show the longer wave pattern with troughs and ridges, as well as any pre-existing cyclones. A surface map will show the existence of low pressure centers, surface cold and warm fronts, as well as any stationary fronts or regions with strong temperature gradients. A chart of the mid-troposphere (500 or 700 mb) will show the location of short wave troughs that may be embedded in the large scale flow. Finally, an upper air chart (200 or 300 mb) will show the location of the jet stream and any jet streaks that are present. With this information, the presence of a mature extratropical system is easily recognized (figure 25) and areas conducive to new cyclone formation can be identified (figure 26).

Possible Cyclone Development



1. At surface
   - region of strong temperature gradient (often a stationary front)
2. In mid-troposphere
   - long wave trough just upstream (west) of area of strong surface temperature gradient
   - short wave trough embedded in larger-scale wave
3. At tropopause
   - jet stream advances from west with embedded jet streak

figure 26.

A sequence involving several extratropical cyclones is shown in figures 27 a–f (pages 38–43). In figure *a*, a mature cyclone, centered in central Quebec, was exiting North America on April 10, 1994. The cold front associated with it is moved into northern New England. The front was fairly weak at this stage in its evolution; as it trailed into the central United States it became nearly stationary. Along the stationary front in Oklahoma, Nebraska and Missouri, a slight curvature was present in the cloud shield. This curvature was the first sign of the development of the next cyclone in the series.

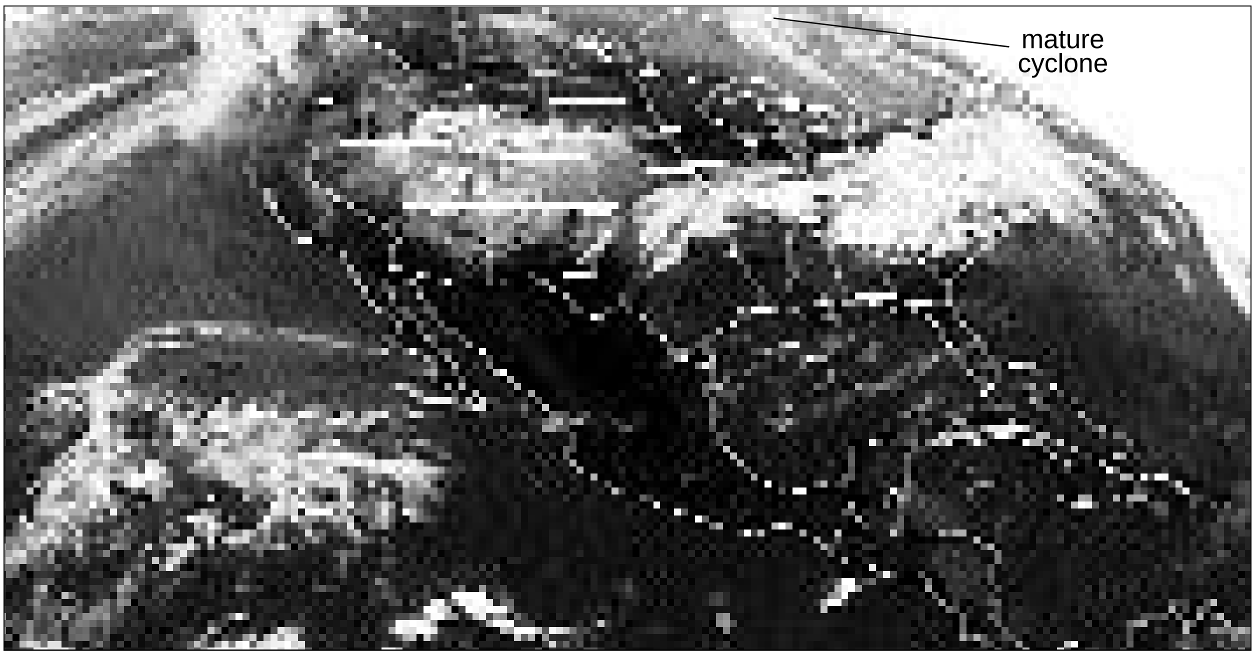


figure 27a. GOES image, April 10, 1994, 1200 CDT
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

In figure *b*, a polar-orbiter image from April 11th showed the front passing through the mid-Atlantic states and moving out to sea. Note that the cloud deck along the front is not well-developed, a sign that the front is weakening. To the west, however, a considerable amount of cirrus was present suggesting thunderstorms and significant convective activity.

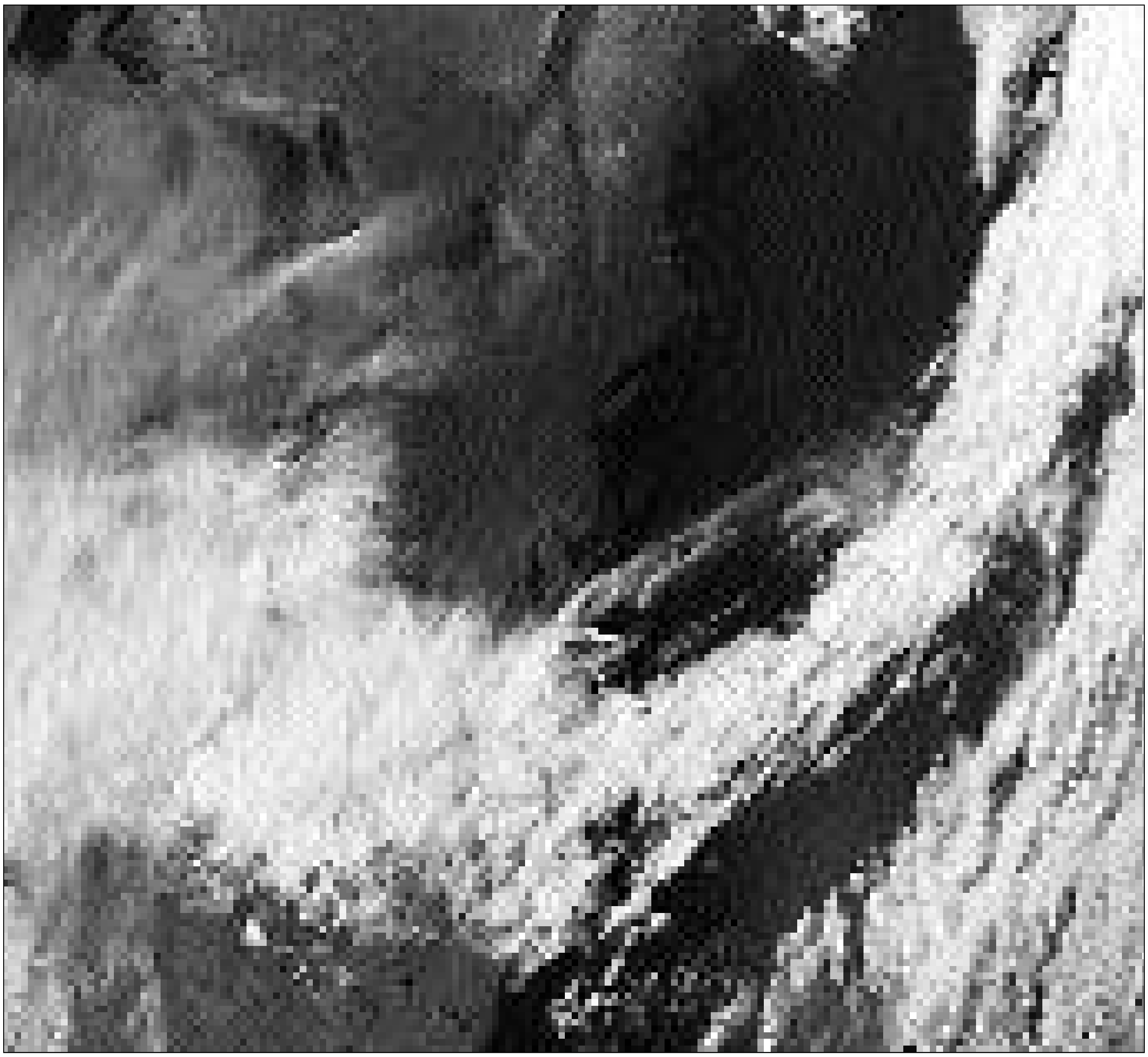


figure 27b. NOAA 10 (AM) image, April 11, 1994
image courtesy of D. Tetreault, University of Rhode Island

In figure *c*, the beginning comma cloud circulation is seen in a GOES IR image from April 11th. This circulation, centered roughly over Kansas, began in the curved area noted the previous day. The cloud shield associated with this circulation is extensive.

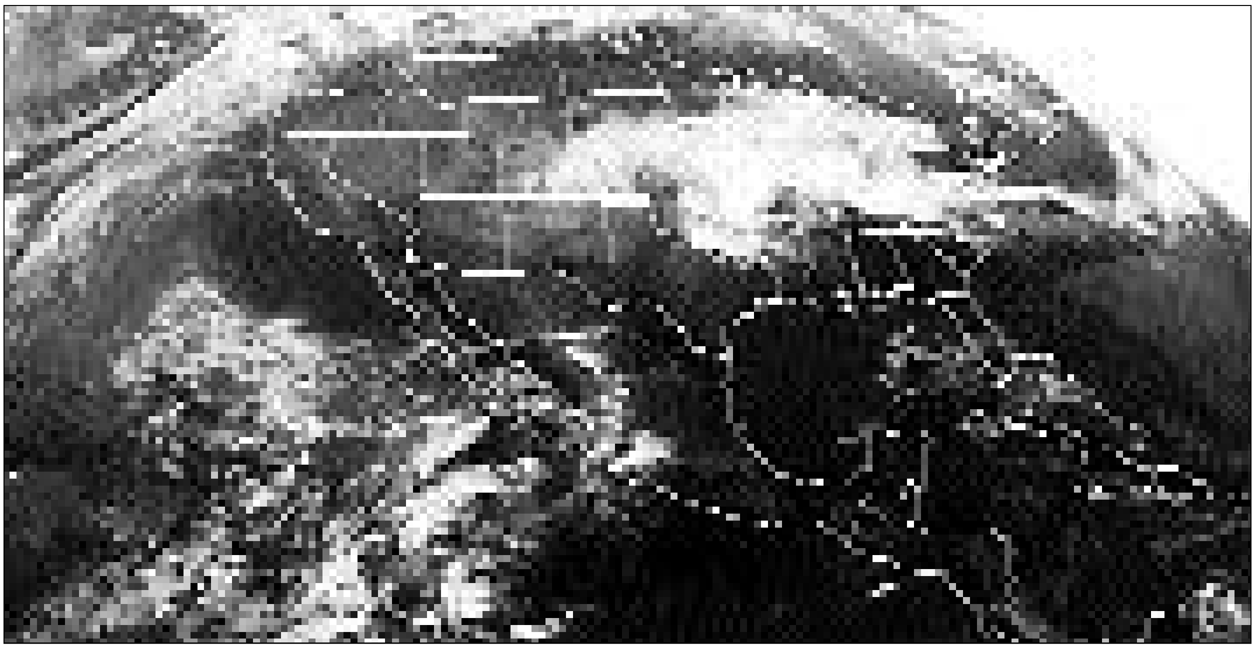


figure 27c. GOES image, April 11, 1994, 0900 CDT
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

On the following day, figure *d*, the comma cloud was fully formed. The cloud stretches from Iowa through eastern Texas. The head of the comma is less distinct although it is visible over Kansas and Nebraska.

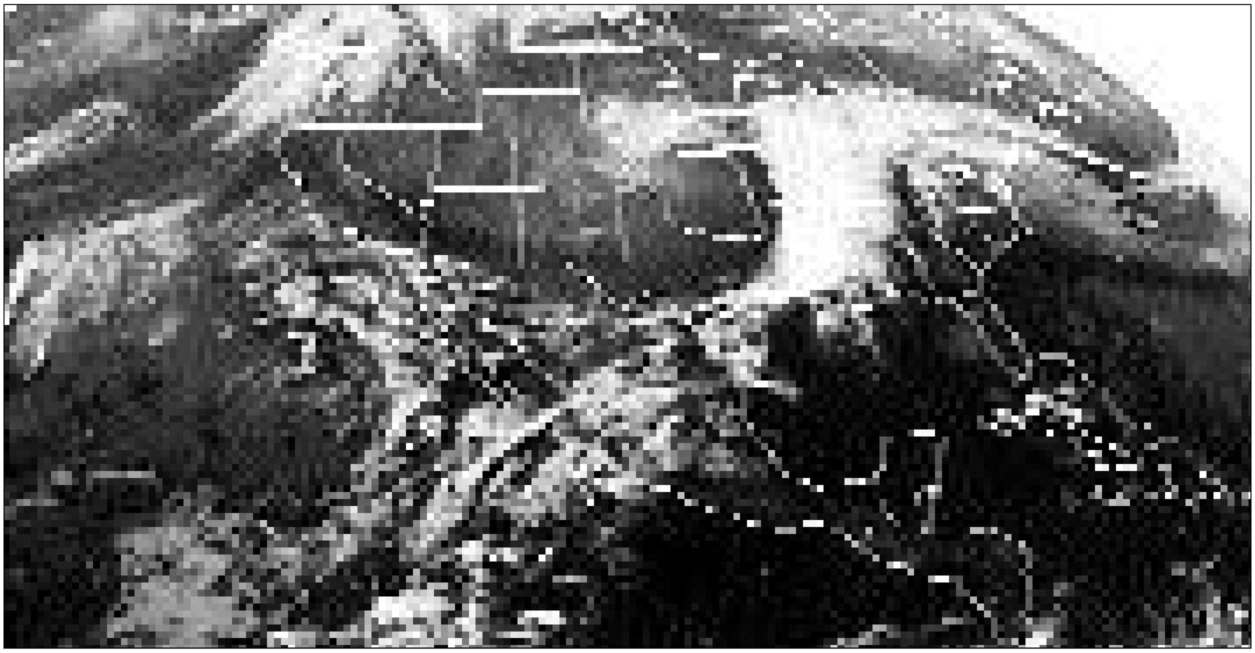


figure 27d. GOES image, April 12, 1994, 1AM CDT
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

Two days later, on April 14th, this cyclone followed its predecessor and moved into the Atlantic Ocean. The polar orbiter image (figure *e*) shows the location of the front. Note that the cloud features are better resolved (sharper, more detailed) in the polar-orbiter images than in the corresponding GOES image in figure *27f*. Images from the newest GOES satellites will be higher resolution and will provide more detailed images. See the *Satellites* chapter for more information.

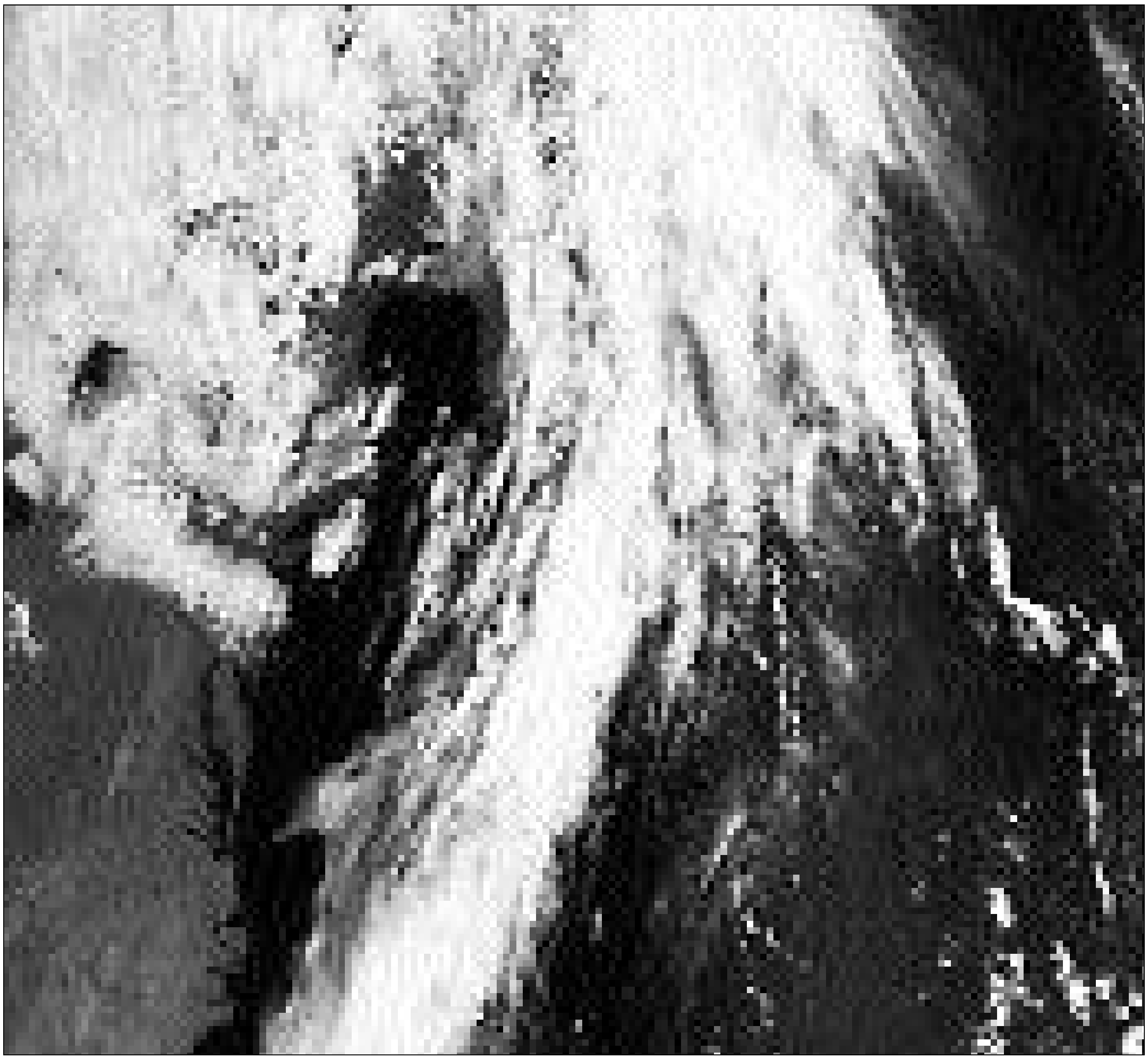


figure 27e. NOAA 10 (AM) image April 14, 1994
image courtesy of D. Tetreault, University of Rhode Island

This sequence of several cyclones following each other is fairly common. As the initial cyclone weakens, the trailing (western) portion of its cold front will become stationary. This stationary front is a region of strong temperature gradients. The appearance of the next upper air wave and jet streak is often sufficient to start the cyclone formation process again.

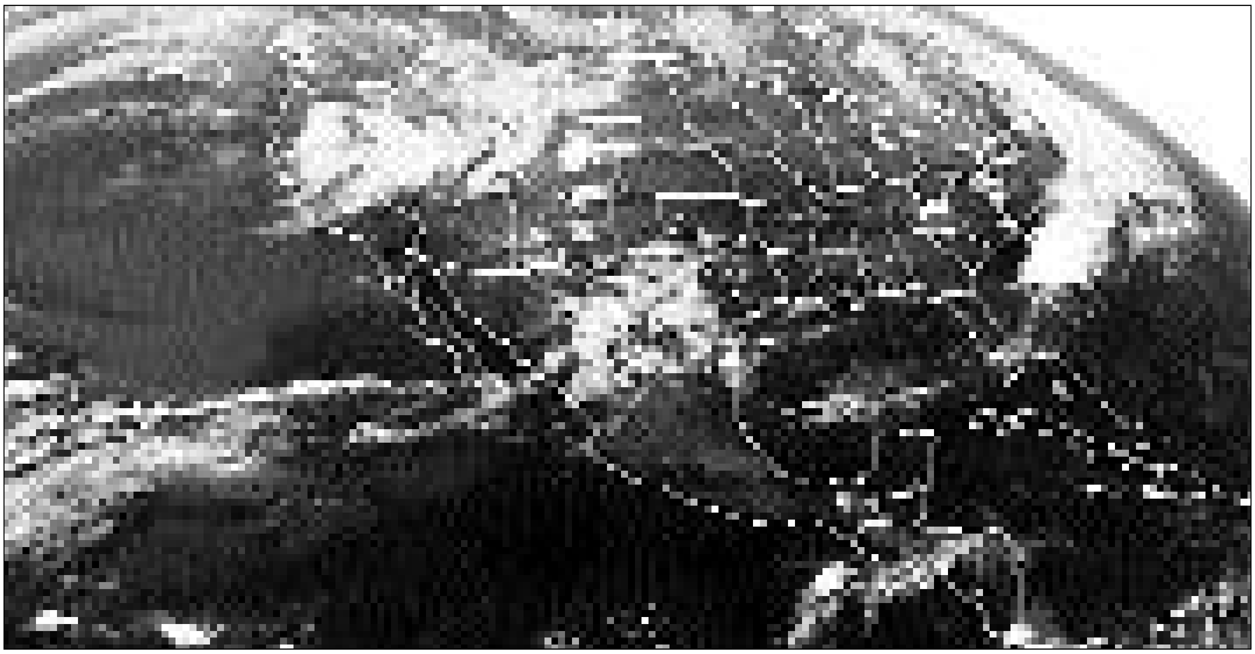


figure 27f. GOES image, April 14, 0600 CDT
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

Clouds

Section 4

In this section, cloud formation is explained and typical clouds types that are associated with midlatitude cyclones are described. The cloud features within a mature cyclonic disturbance are typically organized in a **comma** form. Specific cloud types can be identified with polar orbiter images and, to a lesser extent, GOES images.

Air is comprised mainly of nitrogen and oxygen, but also contains a small amount of water vapor. Clouds form when a parcel of air is cooled until the water vapor that it contains condenses to liquid form. Another way of saying this is that condensation (clouds) occur when an air parcel is **saturated** with water vapor.

The amount of moisture in a parcel of air is expressed in a variety of ways. The standard scientific measure is the partial pressure of water vapor. Partial pressure simply refers to the pressure exerted by only the water vapor part of the air parcel. The standard unit of measurement is **millibars** (mb) and is typically a small fraction of total atmospheric pressure. The water vapor content can also be expressed as a mass mixing ratio, that is, the mass of water vapor per total mass of air. Mixing ratio is usually expressed as grams H_20 per kilograms air.

The partial pressure of water vapor at the point of condensation is termed the saturation pressure (e_s). The saturation pressure of any air parcel is proportional to temperature and is described by the Clausius-Clapeyron equation, figure 28.

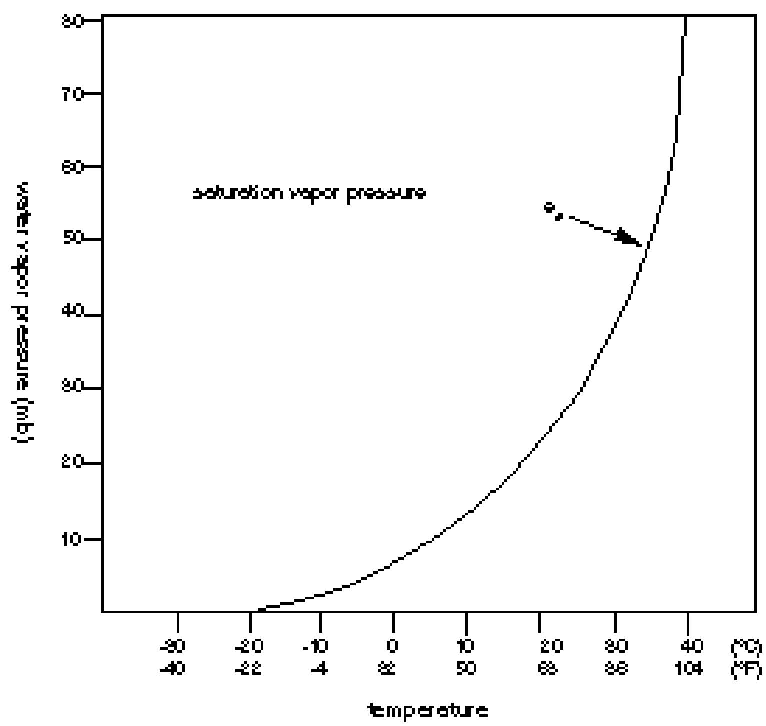


figure 28. Clausius-Clapeyron Equation indicates the dependence of saturation vapor pressure on temperature. It is derived from the first law of thermodynamics.

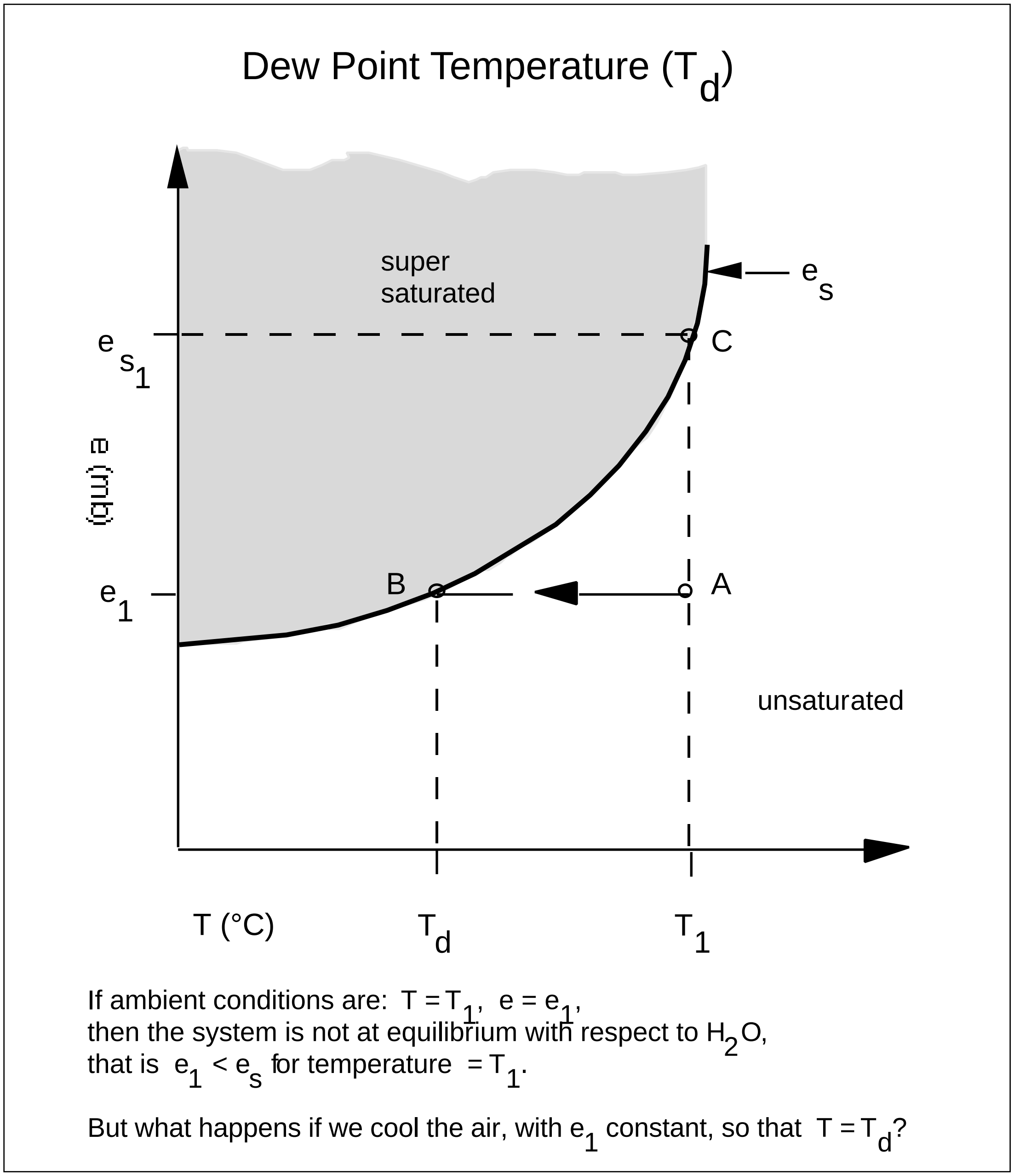


figure 29.

An example illustrating cloud formation is given in figure 29. The starting point for the parcel of air is Point A. At this temperature (T_1) and water vapor pressure (e_1), the parcel of air is not saturated with respect to water vapor. That is, it is positioned below and to the right of the saturation line (e_s). If the parcel is cooled with no change in moisture, it will move along the line A-B. When it reaches point B, its vapor pressure (e_1) is equal to the saturation vapor pressure (e_s) for that temperature (T_d) and condensation occurs. The temperature at point B is known as the dew point temperature or dew point.

The ratio of the vapor pressure at Point A to the saturation vapor pressure for the initial temperature (Point C)— expressed in percent — is the relative humidity. As the parcel cools along the line A-B, its relative humidity increases. When temperatures cool in the evening, with little change in local moisture levels, relative humidity increases and reaches a peak just before sunrise.

For a given temperature (T_1):

$$\frac{\text{vapor pressure at Point A}}{\text{saturation vapor pressure for Point C}} = \text{relative humidity (\%)}$$

Clouds may occur when air is cooled to near its dew point. There are three ways to cool air to its dew point:

1. advection of warm air over a cold surface
2. mixing air parcels of different temperature and moisture
3. lifting of air to higher levels

advection
The horizontal transfer of any atmospheric property by the wind.

- First, horizontal motion (**advection**) of warm and moist air over a cool surface will cause the air parcel to cool and condensation to occur. This is how advection fog forms.

- Mixing parcels of different temperature and moisture can also result in cloud formation. The mixing cloud is another application of the Clausius-Clapeyron equation (figure 30). Parcels A and B are both in the unsaturated region of the graph. Parcel A is warm and moist and Parcel B is cool and dry. When they are equally mixed, the final parcel has a vapor pressure equal to the saturation vapor pressure (e_S) and condensation occurs. Jet aircraft contrails are an example of this type of cloud.

- A third way to cool air to its dew point is by lifting. Because pressure and accordingly, temperature, decrease rapidly with height, a rising parcel of air will cool rapidly.

Mixing Clouds

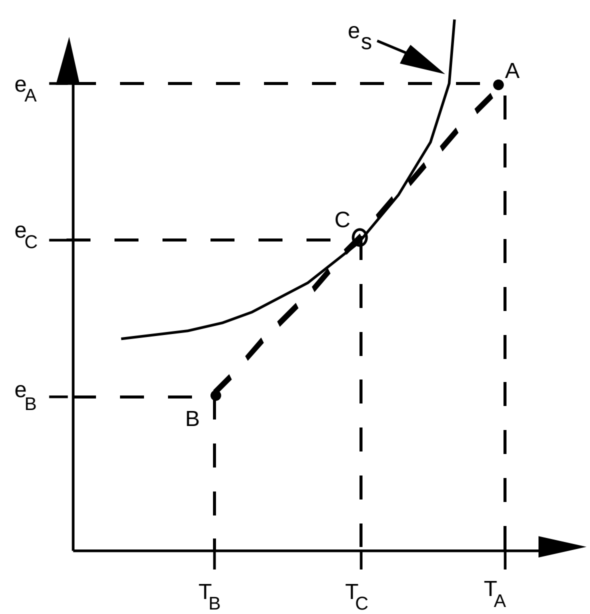


figure 30.

Cloud Condensation Nuclei

In the atmosphere, clouds can form at relative humidities of less that 100%. This is due to the presence of minute (0.1 - 2 micrometers in radius) water-attracting (hygroscopic) particles. Water vapor will stick to, and condense on, these particles to form clouds—hence the particles are termed cloud condensation nuclei (CCN).

CCN occur naturally in the atmosphere. Major sources of CCN are:

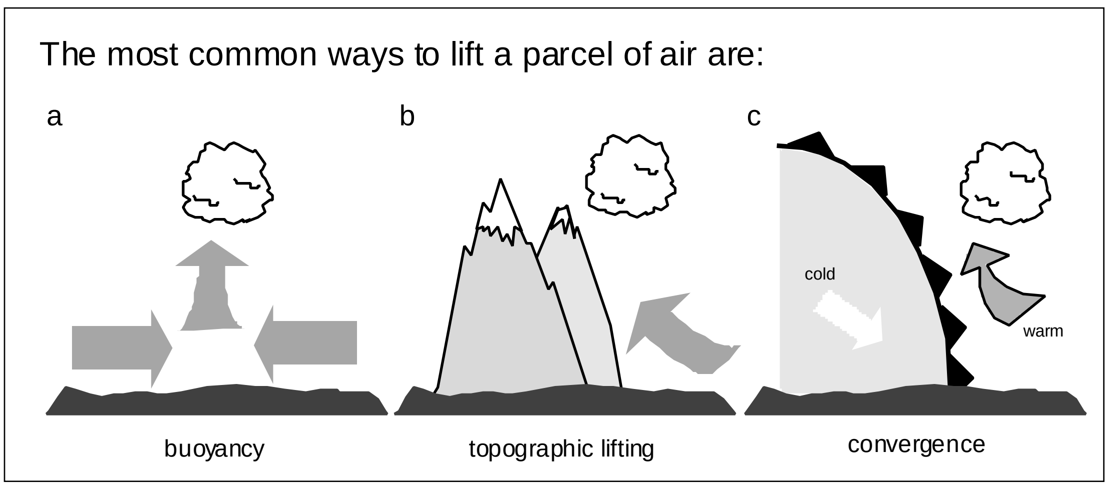
- volcanoes - dust and sulfate particles
- oceans - sea salt particles
- phytoplankton - sulfate particles
- wildfires - soot and dust

CCN can also result from man's activities. In particular, CCN occur as a byproduct of any combustion process. This includes motor vehicles emissions, industrial activity, and controlled fires (*slash and burn agriculture*).

The effect on CCN concentrations on climate is an area of continuing research. For example, if greenhouse-gas-induced-global warming occurs, sea surface temperature (SST) will increase. Will this result in increased emission of sulfates from phytoplankton? If so, will this significantly affect CCN concentrations over the oceans? Will increases in CCN concentrations result in increased cloud cover? Will this in turn lead to a cooling effect that will modulate the warming trend?

The most common ways to lift a parcel of air are: buoyancy, topographic lifting, and convergence. Buoyant lifting results from surface heating. This is a common manner of cloud formation in the summer. Buoyancy lifting is also called convection and occurs when local warm areas heat the air near the surface (figure 31a). The warm air is less dense than the surrounding air and rises. The rising air will eventually cool to its dew point and form a fair-weather cumulus cloud.

figure 31.



Air that is forced into, or over, a topographic barrier will also rise and cool to form clouds (figure 31b). This occurs near mountain ranges. For example, warm and moist air from the Gulf of Mexico can be pushed northwestward and up the eastern slope of the Rockies to form extensive cloud decks.

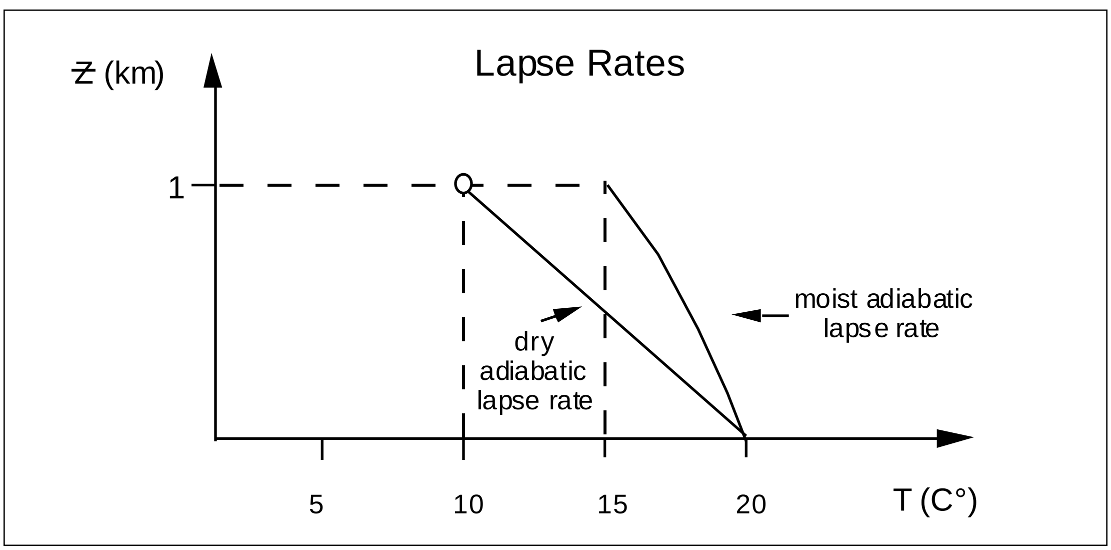
Finally, lifting occurs where there is large scale convergence of air (figure 27c, page 40). Cold fronts are a location of strong convergence as cold, dense southward moving air displaces warmer air. Convergence can also occur on smaller scales along the leading edge of the sea or bay breeze boundaries.

The formation of clouds is an application of the First Law of Thermodynamics. According to the First Law, a change in the internal energy of a system can be due to the addition (or loss) of heat or to the work done on (or by) the system. In the atmosphere system, the change of internal energy is measured as a change in temperature and the work done is manifested as a change in pressure. Because air is a relatively poor conductor of heat energy, the assumption is made that the parcel of air upon which work is being done is insulated from the surrounding environment. This is the **adiabatic** assumption. For a rising air parcel, the change in internal energy is therefore due entirely to pressure work with no addition or loss of heat to the surrounding environment. A simple relationship for temperature change for a rising parcel of air can then be determined. This change of temperature with height is the dry adiabatic lapse rate of -9.8°C per kilometer.

> **adiabatic**
> The process without transfer of heat, compression results in warming, expansion results in cooling.

Air is, of course, not entirely dry and always contains some water vapor which can condense as the air parcel rises and cools. Condensation creates clouds and affects the temperature and vertical motion of the parcel. During condensation, heat is released

figure 32.



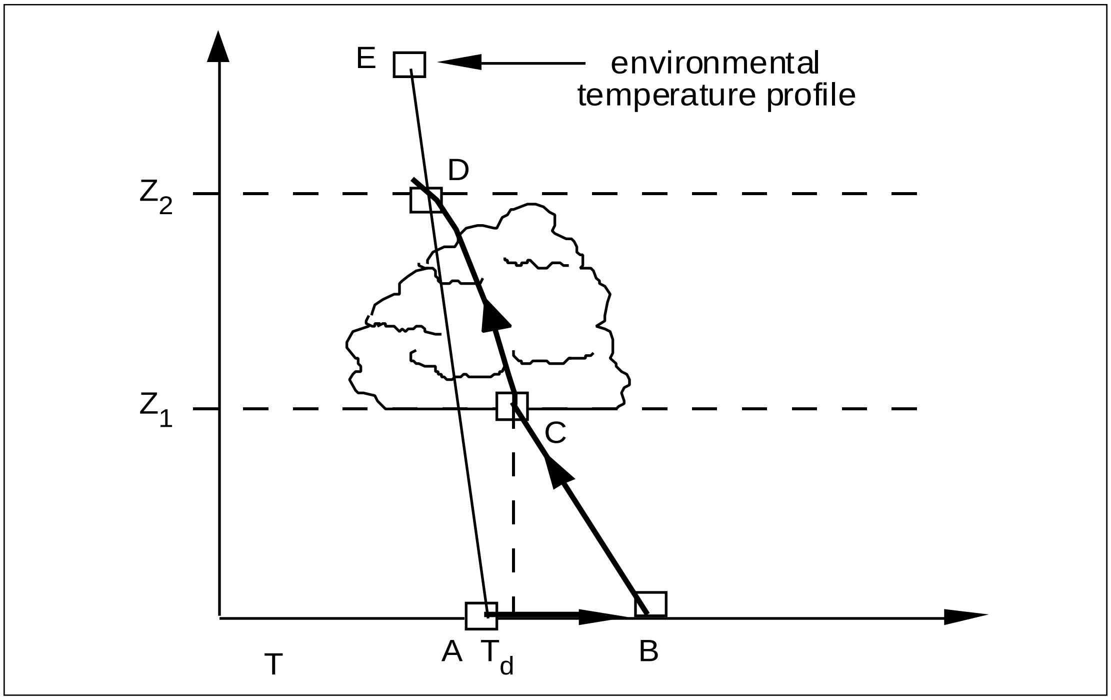


figure 33.

(latent heat of condensation). This addition of heat to the system violates the adiabatic assumption. The rate of cooling of an ascending air parcel undergoing condensation is, therefore, less than for dry air. The lapse rate for air under these conditions is the moist adiabatic lapse rate and is approximately -5° C per kilometer (figure 32).

The process by which clouds are formed adiabatically can be summarized using buoyancy clouds as an example. In figure 33, a parcel of air (point A) is heated by the surface and its temperature increases (point B). Because it is warmer than the surrounding measured air temperature, the air parcel cools dry adiabatically as it rises (line BC). At the height (Z_1) at which the parcel cools to its dew point (T_d) temperature, condensation occurs and heat is released. Because the parcel remains warmer than the environment temperature (line AE) it continues to rise but cools at a slightly slower rate (moist adiabatic lapse rate). The parcel will continue to rise until its temperature is less than the measured air temperature that surrounds it (Z_2). At this point, vertical motion ceases and the cloud top height (Z_2) is attained.

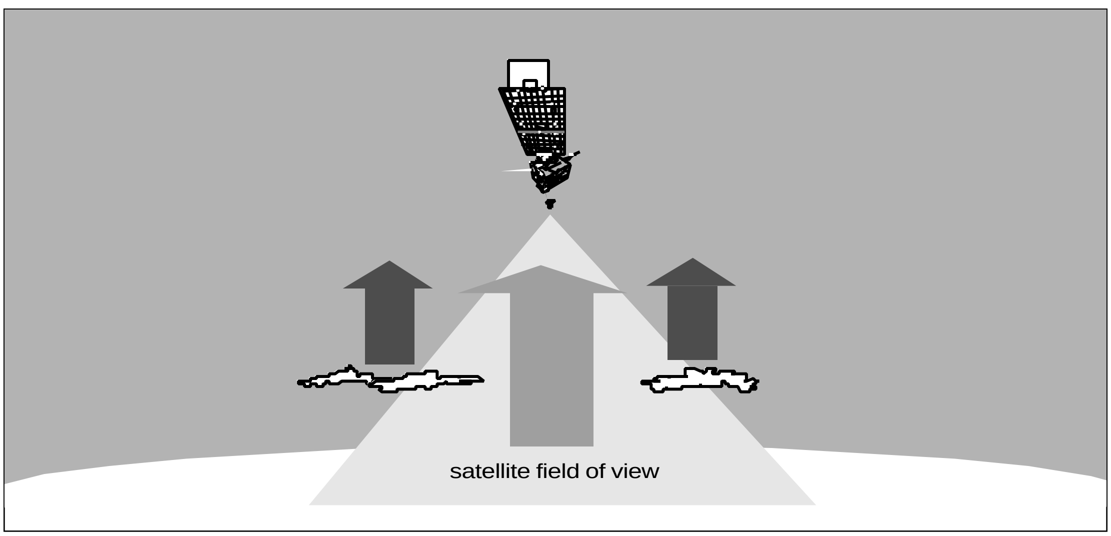
Many of the clouds formed by the processes noted above can be observed by satellite. The mid-latitude cyclones that are the focus of this chapter contain a subset of cloud types. These clouds are organized into common patterns which are described below.

Clouds are initially classified into types based on their height. They are then subclassified based on their shape. While the shape of a given cloud type can often be adequately observed by satellite, determination of cloud height can be difficult. In order to fully determine cloud shape and height, both visible and infrared satellite images are useful. Shape or appearance of clouds can be determined from a visible image, but temperature—and, by inference, height—are best determined by infrared images.

As noted in the Satellites chapter, GOES and polar orbiting satellites return both visible and infrared (IR) images. Visible images are created by sunlight reflected from cloud tops. Smooth cloud tops will give a much different reflected signal than clouds that are irregularly shaped. However, two layers of smooth, thick clouds will reflect sunlight in a similar manner making relative height determination difficult. In some cases, if the layers overlap and the sun angle is aligned properly, shadows will reveal the height differences. In most cases, the best way to determine cloud top height is by the use of infrared imagery. Infrared sensors detect the radiation emitted by clouds. Because temperature decreases with height in the troposphere, higher clouds will appear colder (or whiter) on the satellite images. If image enhancement software is available, the differences can be accentuated.

Some types of clouds are not observed well by satellites. Small clouds, such as fair weather cumulus, are simply too small to be resolved by the satellite sensors. Clouds which are thin or scattered also may not be observed well (figure 34). For a thin or scattered cloud, a GOES infrared detector will receive infrared radiation from both the colder cloud fragments, and in the clear spaces—from the warmer Earth. When the total radiation is averaged, the satellite will *see* clouds that appear warmer due to this heterogeneous field of view.

figure 34.



Prior to looking at images it is important to be familiar with the clouds. Clouds most often associated with mid-latitude cyclones are listed below and discussed in the following paragraphs.

Upper Level Clouds (6–12 km): Cirrus (Ci), Cirrostratus (Cs), Cirrocumulus (Cc), Cumulonimbus (Cb)

Mid Level Clouds (2–6 km): Altostratus (As), Altocumlus (Ac)

Low Level clouds: Stratus (St), Stratocumulus (Sc), Cumulus (Cu)

The highest clouds are cirroform clouds. These clouds are made up of ice crystals and are found at 6–12 km. This group includes cirrus clouds, which are observed from the surface as thin hooks and strands. While cirrus clouds are easily observed from the surface, they are usually so thin that they are difficult to detect by satellite. In strong thunderstorms, however, strands of thicker cirrus clouds are often visible as outflow at the top of the thunderstorm (as in figure 27b). Cirrus clouds are very helpful in determining the direction of upper-level winds. The cloud strands, when visible, are oriented parallel to the upper level winds. Dense cirrus decks can be observed in visible images as streaks or bands and can be distinguished from lower clouds by the shadow they cast below. In the infrared image (27b), the denser cirrus are very bright because of their cold temperature, but can be subject to the effects of a heterogeneous field of view.

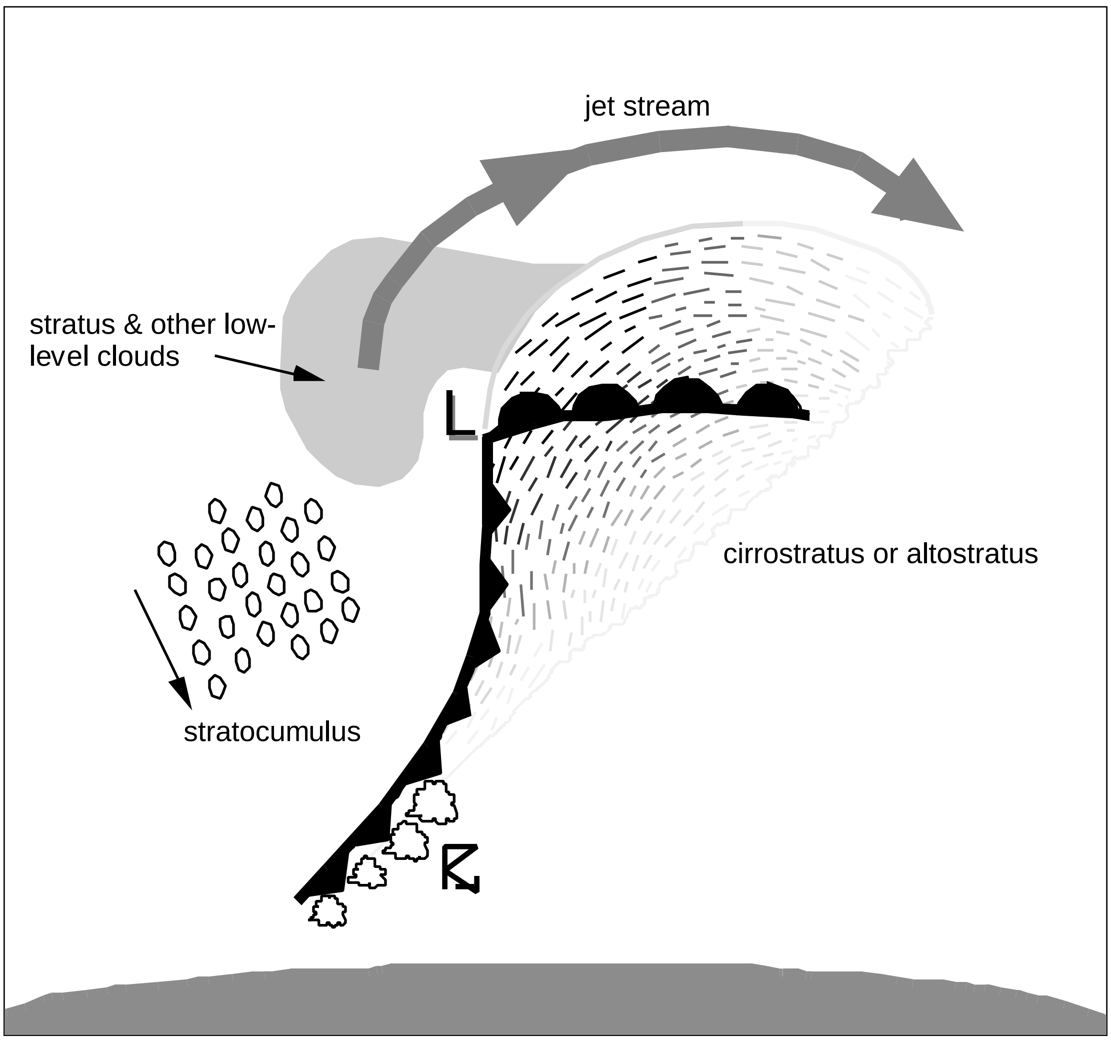


figure 35. Clouds Associated with Extratropical Cyclones

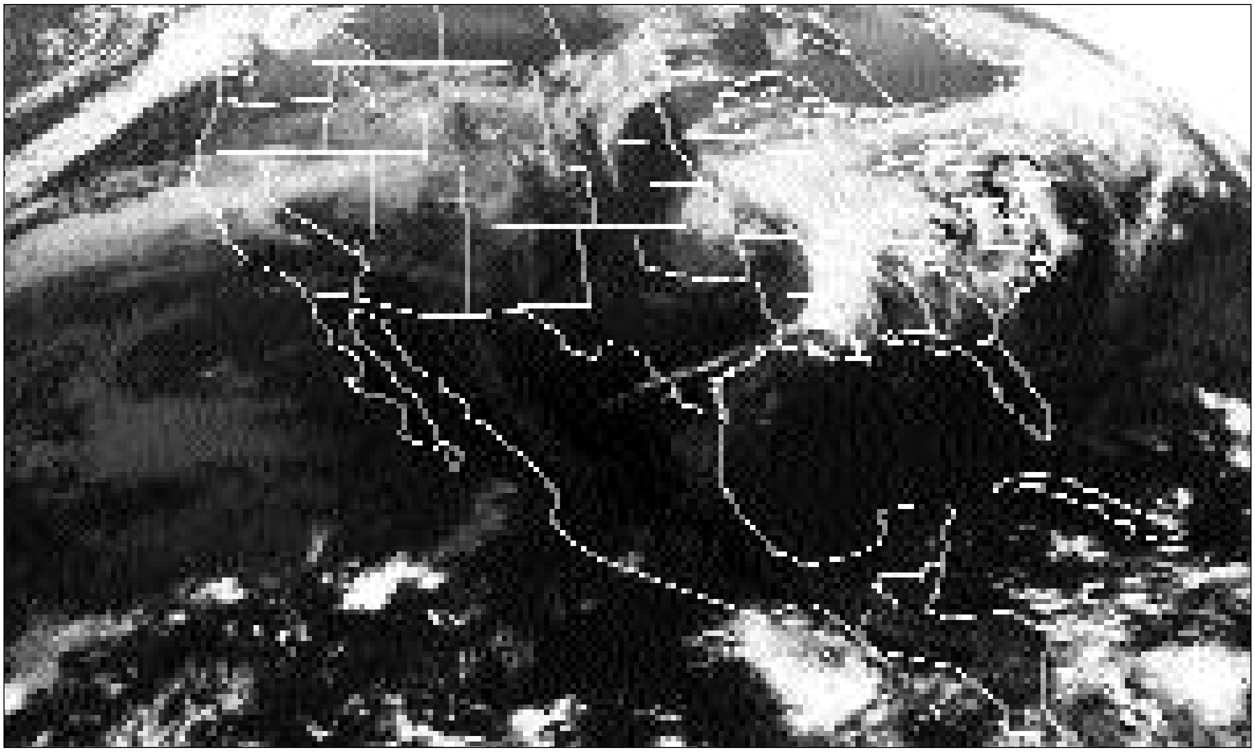


figure 36a. GOES infrared image, November 5, 1994
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

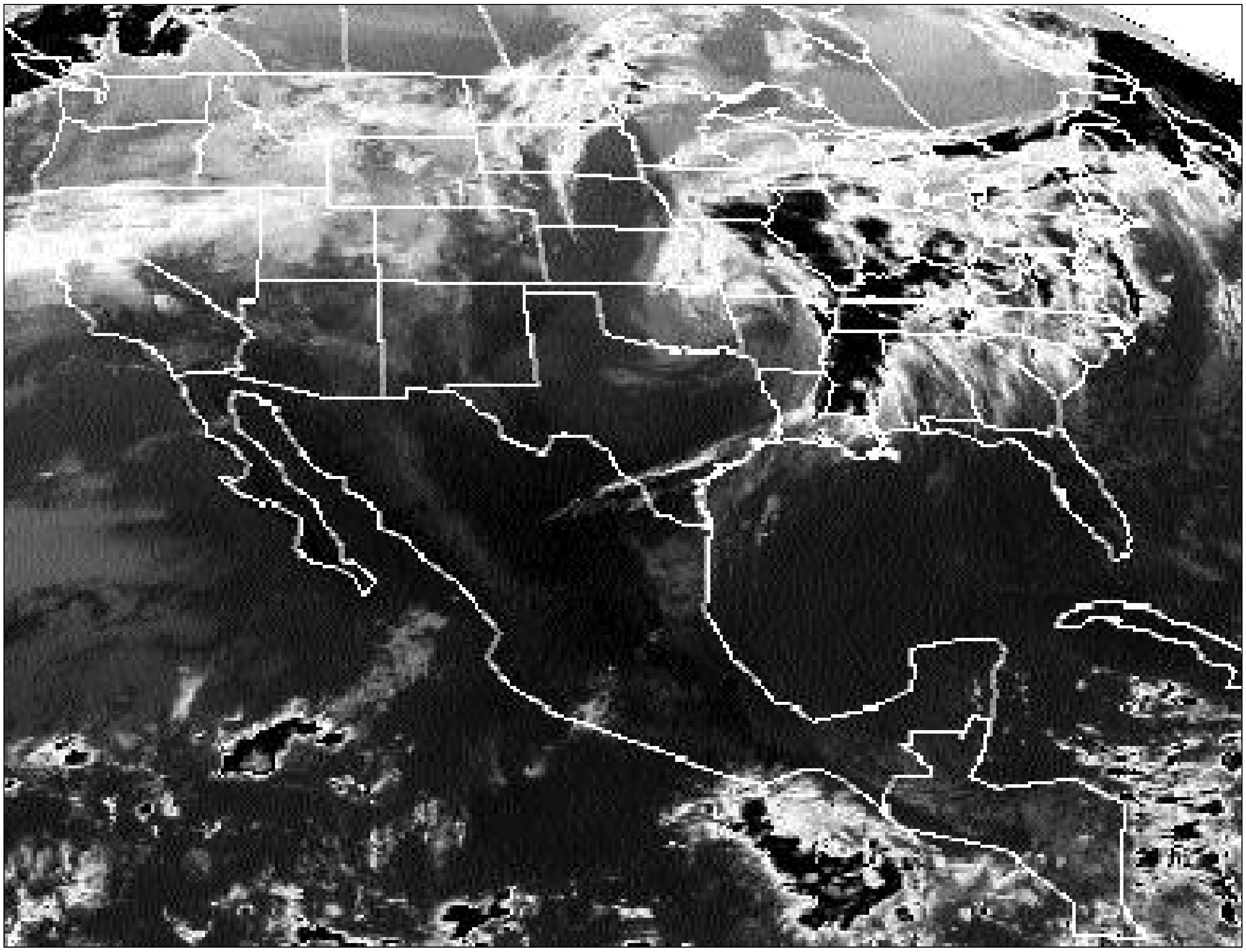


figure 36b. enhanced GOES infrared image, November 5, 1994
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

The clouds typically associated with extratropical cyclones are illustrated in figure 35. Clouds that make up the bulk of the comma cloud seen in satellite images are the cirrostratus clouds. As shown in figure 35, the mature comma cloud has an extensive deck of cirrostratus clouds. The GOES IR image in figure 36a is an example of the illustration in figure 35. The western limit of the cirrostratus deck typically marks the position of the surface cold front. In this case, it is found in Missouri, eastern Arkansas, and central Louisiana. The northern limit of the cirrostratus typically marks the southern edge of the jet stream. This is found across Minnesota and Lake Superior. In figure 36b, the IR image is enhanced to show the cirrostratus cloud region in black. Note that there are whiter regions embedded within the cirrostratus deck, particularly in central Alabama. These are very high cirrus clouds associated with cumulonimbus clouds that have formed along the cold front.

The final form of upper level clouds are cirrocumulus. These small puffy clouds are usually too small to be resolved by the satellite or subject to contamination effect. If the cirrocumulus are large and extensive enough, they are distinguished from cirrostratus by a lumpy texture.

Mid-level clouds, which are found at heights of 2–6 km, frequently resemble the upper level clouds although they tend to be composed of liquid water droplets rather than ice. Altostratus clouds, like cirrostratus, are usually found in association with midlatitude cyclones. Often the only way to distinguish mid-level from upper level clouds is by using software to enhance infrared images, as in figure 36b. In the visible, altostratus is quite similar to higher or lower stratiform clouds and may only be distinguished if shadows are present. Altocumulus clouds also accompany midlatitude disturbances but are typically covered, as are altostratus, by higher clouds. The altocumulus clouds are often found in association with altostratus decks and can be distinguished by a lumpier appearance.

The lowest level clouds also contain cumuloform and stratiform variants. Fair weather cumulus, the "popcorn" clouds seen on fair days, are often below the resolution of regional satellite images. When the cumulus clouds grow into towering cumulus or thunderstorms (cumulonimbus), their high tops and isolated rounded shape are easily identifiable. Cumulonimbus often form along the leading edge of the cold fronts that are associated with cyclones. Stratocumulus forms by the spreading out of cumulus clouds or breaking up of stratus decks. Large decks of stratocumulus are often found off the West Coast of the United States. Stratocumulus cloud lines often form off the East Coast of the United States after the passage of a cold front. Stratus clouds are low-based clouds with uniform features and are difficult to distinguish in the visible from altostratus.

Fog, the lowest of all clouds, can often be observed from satellites. On visible images, fog is relatively featureless and difficult to distinguish from higher stratus clouds. If the fog is located over land, either along the coast or in mountain valleys, it can sometimes be detected by the manner in which it follows ground contours. For example, the fog bank may follow the contours of a bay or harbor, or branch into mountain valleys. The branching effect is a good way to distinguish mountain fog from snow cover. Fog can be difficult to observe in infrared images because its temperature is often very close to ground temperature. It can, at times, be even warmer!

Additional Common Weather Patterns

Section 5

Cyclonic weather disturbances are the most common mid-latitude weather pattern. This type of disturbance occurs in all seasons, although they are more vigorous in the late fall to early spring. Examples of the mid-latitude cyclone cloud shield were given in figures 2 (page 12), 4a (page 15), 14a (page 26), 27d (page 41), and 36a (page 52). The development of these systems can be explained by the interaction of low-level temperature gradients with disturbances in upper level winds and accelerations in the jet stream. Other weather-making systems that can be observed by satellite in the mid-latitudes are of an entirely different scale and form. These non-standard events have geographic and season patterns that make them useful for study during the school year.

In the fall and winter months, strong cyclonic storms develop rapidly off the East Coast of the United States. These coastal storms, often called northeasters, are a peculiar type of cyclonic disturbance. They occur most often in the winter months and are associated with heavy snowfall events along the East Coast. These storms initially develop as a small wave in the eastern Gulf of Mexico or along the southeastern coast of the United States. Like other cyclonic disturbances, these coastal storms are associated with low level temperature gradients as well as disturbances in upper level winds and accelerations in the jet stream. What is peculiar about these storms is the speed with which they develop. In figures 37–39 (pages 55 and 56), the development of a strong coastal storm is shown over a 24 hour period. Note that the circulation around the center of the storm is very intense. Note also the presence of a mature extratropical cyclone off the northwest coast of the United States.

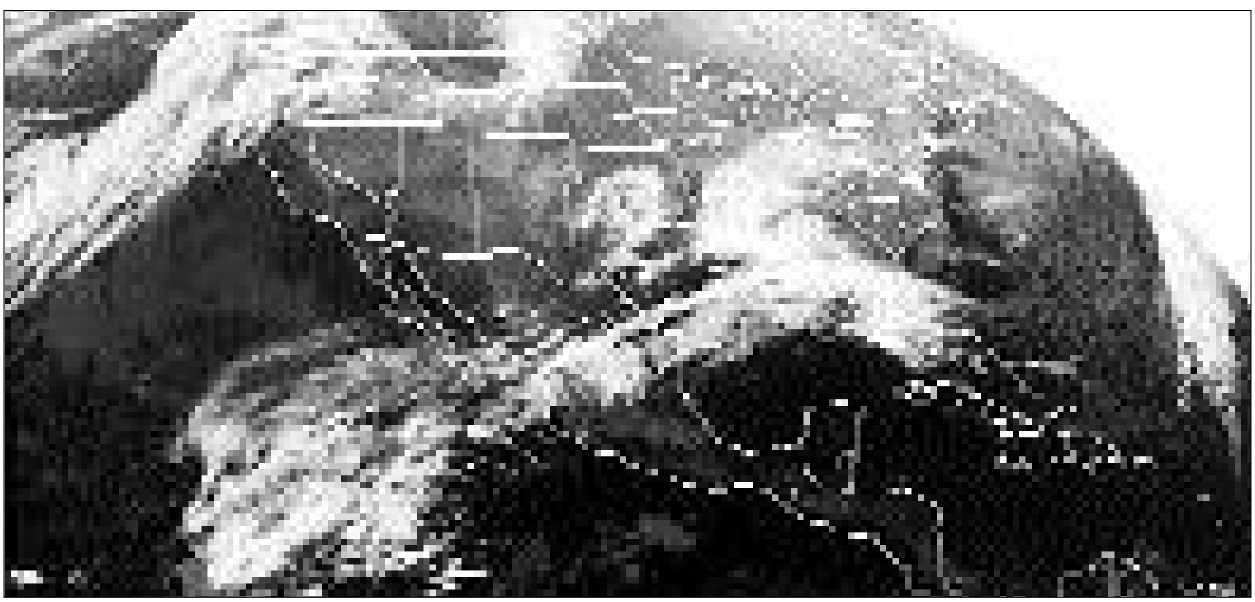


figure 37. Time series of coastal storm development.
GOES image, March 1, 1994, 0300 CST
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

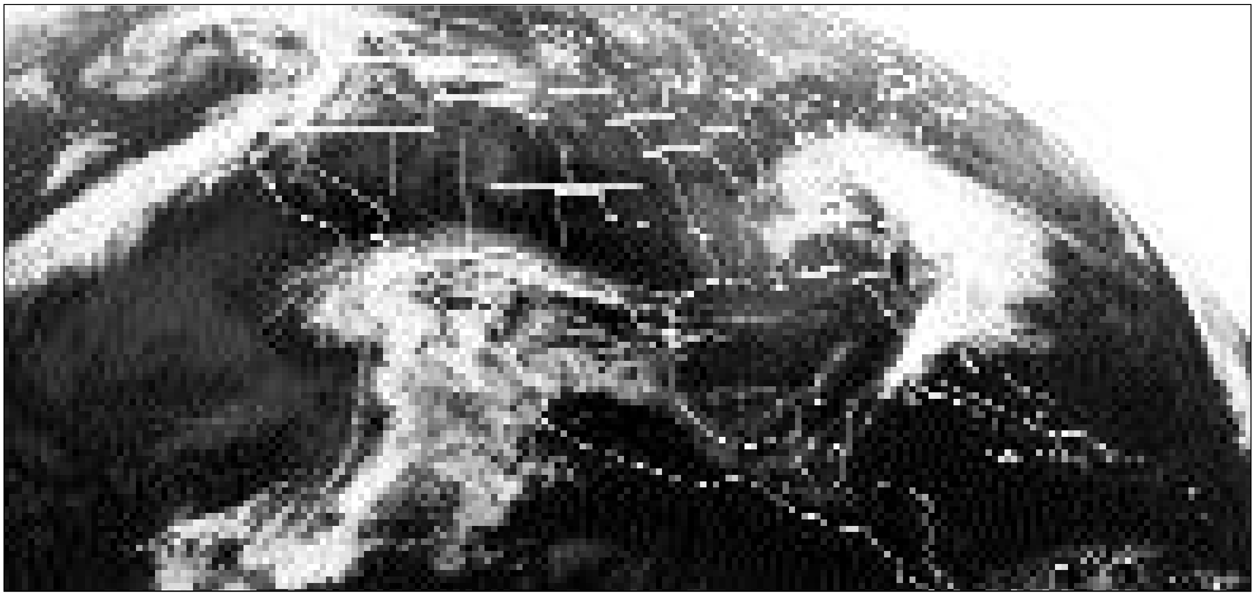


figure 38. Time series of coastal storm development.
GOES image, March 2, 1994, 1100 CST.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

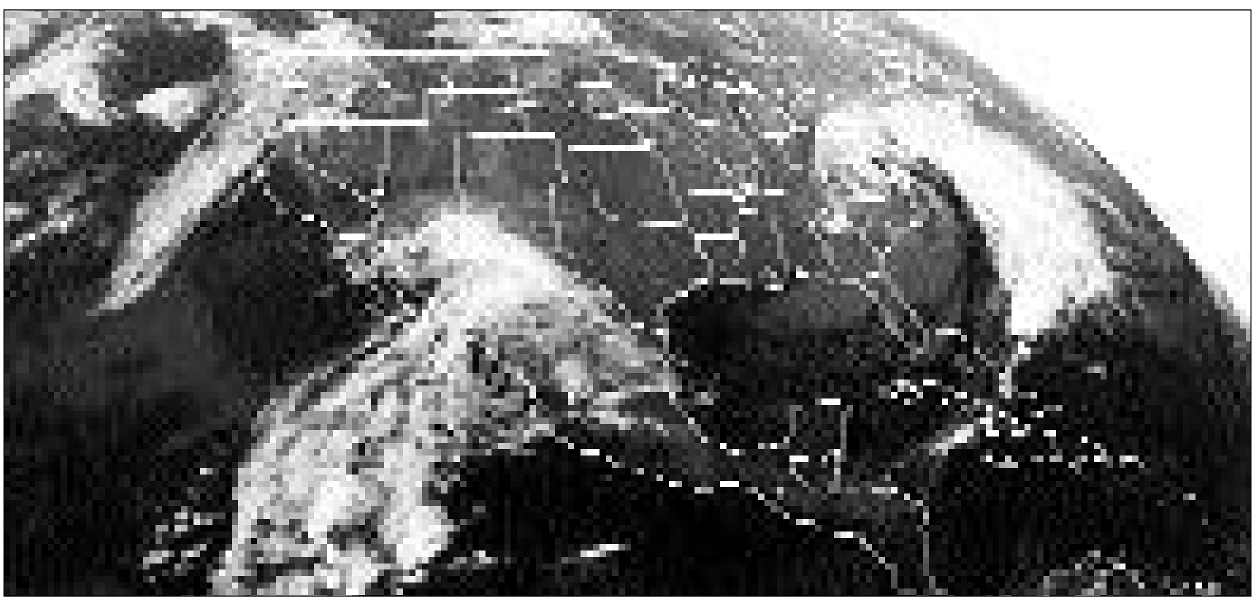


figure 39. Time series of coastal storm development.
GOES image, March 3, 1994, 0300 CST.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

Another remarkable aspect of these storms, in addition to their rapid development, is the extent of snowfall associated with them. These heavy snowfalls are made possible by the collision of very warm, moist, maritime air with very cold and dry air of continental origin. The coastal storms usually develop after a very intense cold front has crossed the eastern United States leaving cold Canadian air along the eastern seaboard. This cold dense air can be trapped, or "dammed," between the coast and the Appalachian Mountains to the west and remain in place for several days. The coastal storm, which often begins as a wave along the remnants of the original cold front, moves up the coast parallel to the offshore Gulf Stream. Because the wind field around the storm is counterclockwise (cyclonic), warm, moist Gulf Stream air is driven into and, being less dense, over the cold air dammed along the coast. The moisture wrung out of the ascending air passes through the colder layer below and creates the mixture of rain, snow, sleet and freezing rain that is typical of these storms. Along the coast, the cold air layer is thinner, if present at all, and the precipitation falls as rain. Further inland, the cold air may be thick enough to freeze the precipitation as it hits the ground (freezing rain) or as it falls toward the ground (sleet). As the ground rises into the Appalachians, the precipitation will be mainly snow.

The forecasting of these coastal storms has improved over the last several years with advances in computing power and improvements in weather forecast models. As a rough guide, any time a strong Canadian cold front crosses the East Coast during the winter months and becomes stationary across the northern Gulf of Mexico, there is a possibility for this coastal storm development.

During the spring months, the focus for severe and unusual weather shifts to the central United States. This is the season of tornadoes in the Great Plains. Again there is a clash of air masses. In this case, warm air from the Gulf of Mexico advances northward where it collides with southward moving cold polar air. While the systems that produce severe weather in this season are generally variations on the classic comma cloud cyclonic disturbance, there are also smaller scale (mesoscale) systems that produce heavy rainfall and severe weather. These systems, called **Mesoscale Convective Systems** (MCS), come in various shapes—from the familiar line squall to the nearly circular **Mesoscale Convective Complex** (MCC). The latter system has a unique satellite signature and is very common over the Great Plains in the spring and early summer. During the Flood of 1993, a considerable number of MCSs occurred in the Midwest.

Several MCCs are shown In figures 40a and b (page 58). The MCC is an organized group of thunderstorms that initiates late in the afternoon from a localized area and develops throughout the night before dissipating late the next morning. In figure a, taken at 0100 CDT, two mesoscale systems are present over Iowa and Nebraska. Note the size of the cloud shield associated with each system. These systems initiated late the previous afternoon from a small group of thunderstorms. These MCC's persist throughout the early morning or even through the next night and (figure b) can migrate considerable distances before dissipating.

These systems often recur over several days and can account for significant local rainfall. During the flood of 1993, mesoscale systems occurred frequently during the summer months. A great deal of research continues regarding the organization and development of these systems. For example, figure 40c (page 59) shows another large MCC occurring the night after the storms in figures 40a and b.

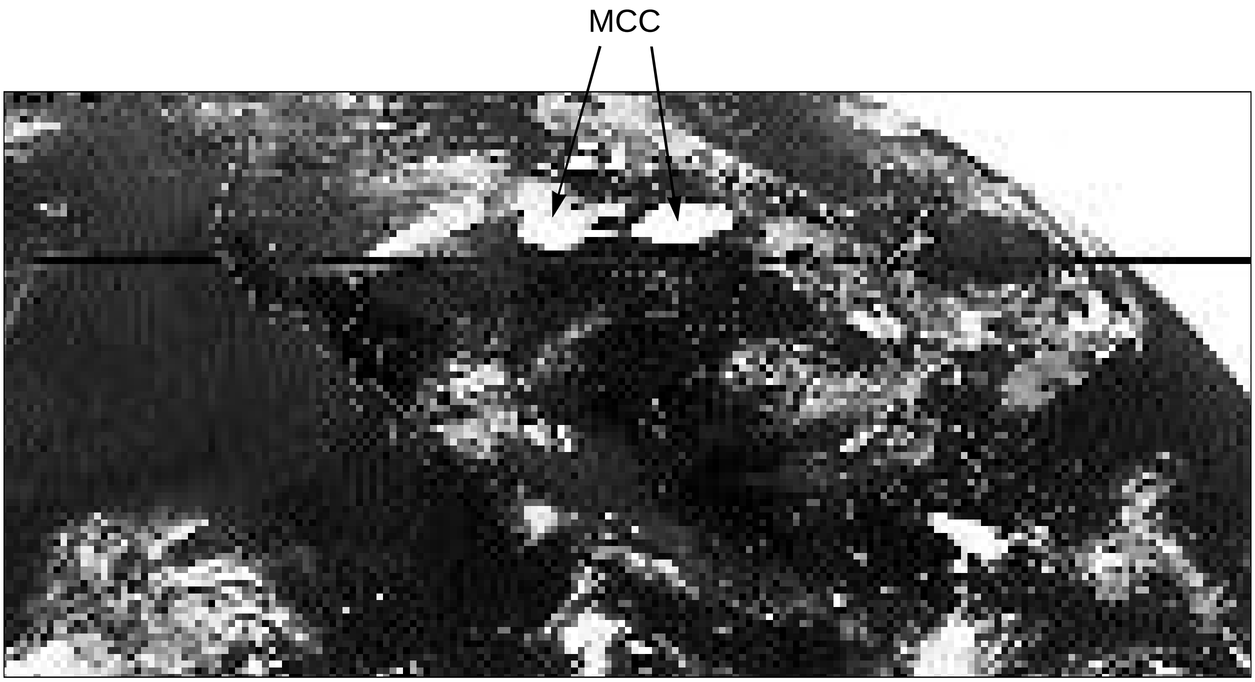


figure 40a. MCC
GOES 7, IR. July 24, 1993–0100 CDT.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

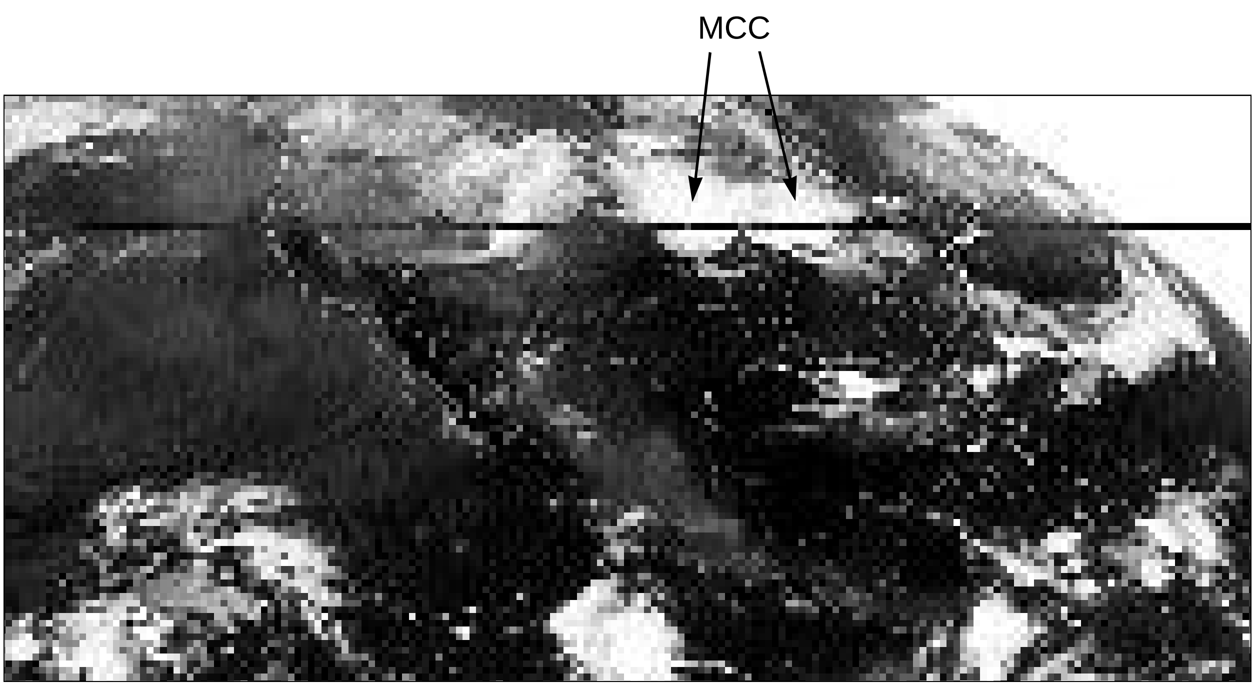


figure 40b. MCC
GOES 7, IR. July 24, 1993–0700 CDT.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

MCC

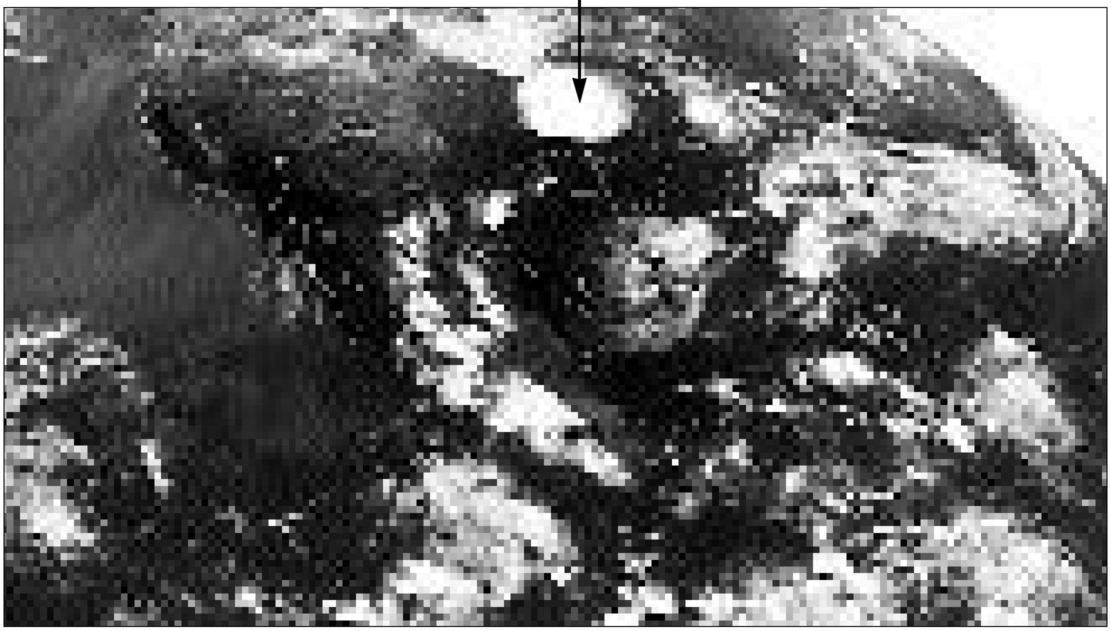


figure 40c. MCC
GOES 7, IR. July 25, 1993–2200 CDT.
image courtesy of M. Ramamurthy, University of Illinois, Urbana/Champaign

During summer and fall months, the most arresting weather developments are tropical hurricanes. Because hurricanes travel long distances during their lifetimes, the best way to observe them is through a series of GOES images. Hurricanes are observed in the eastern Pacific in the summer months and become frequent in the Atlantic during the late summer and early fall. The strongest Atlantic hurricanes typically develop from waves in the easterly trade-wind-flow off the coast of Africa. Clusters of convective clouds with cold tops can be seen in GOES IR images and can then be tracked across the Atlantic. As the hurricane moves closer to land, polar-orbiter images can be used to resolve the finer scale of the hurricane, including the bands of clouds that circle around the core (*eye*) of the hurricane. In figure 41 (page 60), a polar orbiter image of Hurricane Emily is shown off the coast of North Carolina.

noise

Reception of satellite images is often affected by local sources of interference—noise. Common sources of interference are household appliances, motors (heating and cooling, vacuum cleaners, etc.), radio and aircraft transmissions, automobiles, and fluorescent lights. The higher the frequency, the less susceptible the receiving equipment is to noise (geostationary reception is less affected than polar-orbiting satellite reception). On satellite images, interference typically appears as horizontal stripes. Examples of noise appear in figures 40a and 40b.

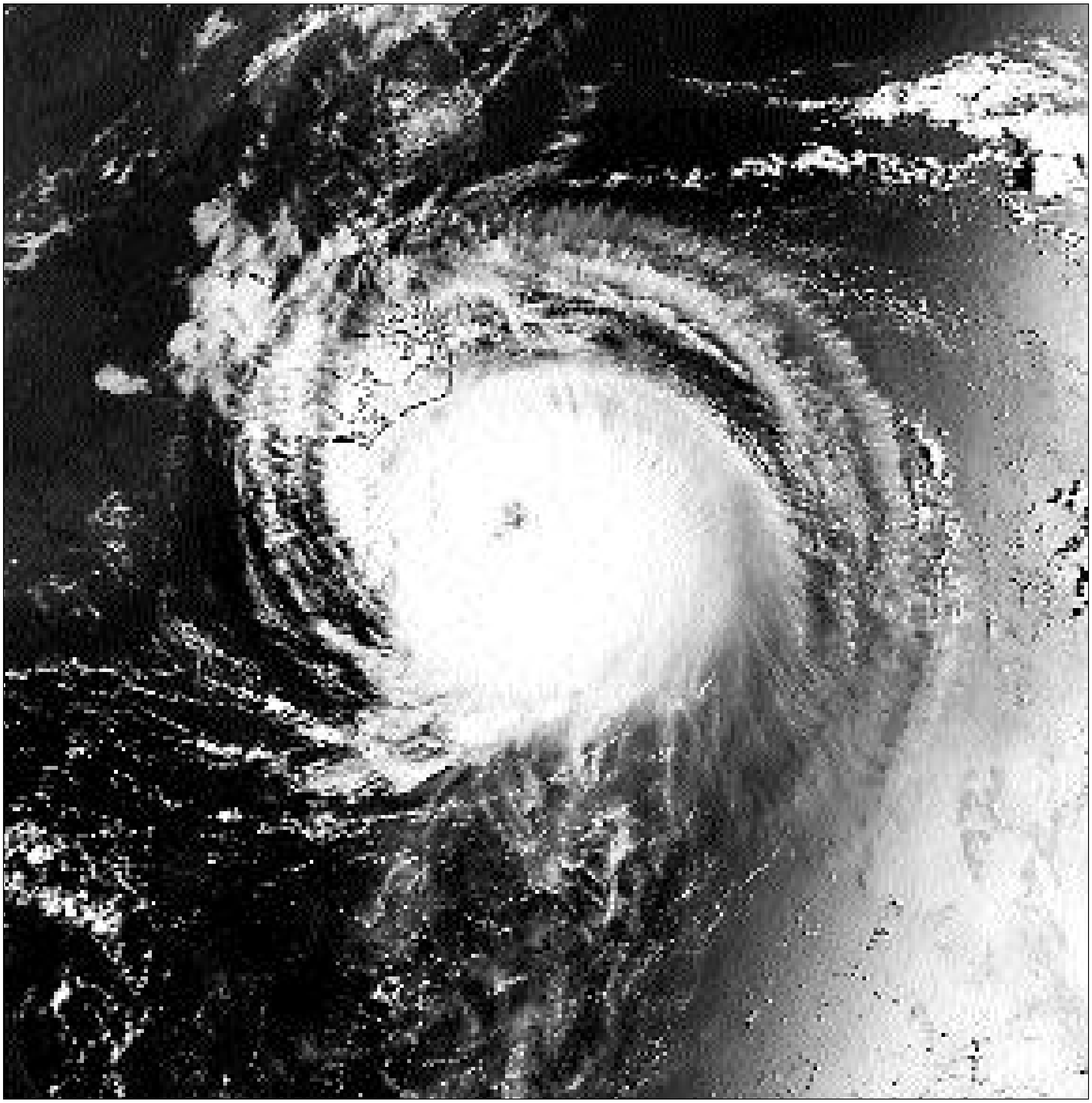


figure 41. Hurricane Emily
HRPT image courtesy of Professor G.W.K. Moore, University of Toronto

SATELLITE IMAGES AND THE INTERNET

Section 6

Obtaining Images and Data via the Internet

Listed below are a sequence of commands that will allow you to get the most recent copy of a document that lists weather data and satellite images available on the Internet. Methods and access to satellite imagery are changing rapidly so this information may not be applicable to all users and/or may be outdated in the near future. Before you begin, you must be able to access your account at a local university or other site via modem and access the Internet from that account. In addition, you must have the ability to store files temporarily on your university account. Finally, you will need to determine your complete Internet address. With these tasks accomplished, dial in to your account and enter these commands after the prompt:

ftp vmd.cso.uiuc.edu

The initial command "ftp" simply means "file transfer protocol." ftp is a standard form of communicating within Internet. The remainder of this command is simply the address of a computer that is on the Internet.

If the network isn't busy, you will be greeted with a prompt to login. The best time to access the Internet is before 10 am or after 3 pm. For Internet transfers of the type we will be discussing here (called "anonymous ftp"), your login is always "anonymous." Your password is always your full address. Your address is typically your login name followed by the address of your home account. For example, John Doe who works at the University of Maryland may have an address like jdoe@atmos.umd.edu.

login: anonymous
password: your address

Once you have been logged in at vmd.cso.uiuc.edu, you will need to move from your starting point to the directory that has the weather data information. You will do this by changing directories. Most locations on the Internet use the UNIX system. The command to change directories in UNIX is "cd".

cd wx

Then list all the files in the "wx" directory:

ls

You can use the wildcard "*" to list only those files with certain characters. For example to see all files with the extension "doc", enter the command below:

ls *.doc

Before downloading, check the size of each file with the command:

ls -l

Now download the file “sources.doc” which contains the most recent listing of weather data and images available via Internet. This is done using the “get” command followed by the name of the file at the Internet location and the name you wish to give the file when it arrives at your location. The file names below are the same though they need not be.

get sources.doc sources.doc

You will be sent a line confirming the transfer. Now leave the Internet:

bye

At this point, check your account to see if the file has arrived. To bring the file over the phone line to your school or house, use the communication software that is recommended, or often supplied for free, by the university. You now have a resource file that will give you information on weather data on the Internet along with further details on Internet usage.

There are a number of other commands that are commonly used on the Internet. A few critical ones are listed below.

binary

Many files are stored in unusual formats. These include Word Perfect files as well as files that are compressed for ease of storage and transfer. The standard naming convention for compressed files is the extension “.Z.” In the example above, the file would be “sources.doc.Z.” Before these types of files can be transferred over the Internet (i.e., before issuing the “get” command), you must notify the Internet that you will be sending a non-standard file format. This is done by entering the “binary” command.

prompt
mget ci0717*.gif

You may wish to transfer more than one file at a time. This is accomplished by first telling the Internet that multiple files will be sent together (the “prompt” command) and then using the multiple get command (“mget”) followed by the list of files. In the example above, all infrared images from July 17th are sent. Because there may be many files with a common extension, be very careful with the “mget” command. To check how many files would be transferred, list the files before transferring with the command:

ls ci0717*.gif

Finally, if you have downloaded a compressed file (e.g., “sources.doc.Z”) you will need to issue the UNIX command to uncompress the file before bringing it from the university to your home computer. The command for this is “uncompress” and the usage is given below. The uncompressed file will have the same name although without the “.Z” extension.

uncompress sources.doc.Z

Sources of Meteorological Images

GOES Image or ***Loop***

A GOES image provides the context for the detailed polar-orbiter image. The wide field of view of the GOES image provides information on the current position of active cyclones and a rough idea of the long wave trough and ridge pattern. A loop of GOES images shows the recent development and movement of large scale features. Wave patterns are much easier to identify in time lapse loops than from an image or group of images. GOES loops can be taped from television weather broadcasts and shown in the classroom.

Source of GOES Images

Downloading GOES images from the Internet or other source, and animating the images in the classroom may prove to be overly cumbersome. The simplest method for displaying GOES loops is television videotapes. A compact and comprehensive weather discussion, complete with GOES loops, is provided each morning by “AM Weather” on PBS. Other sources are local weather broadcasts as well as “The Weather Channel.”

Upper Air Information

The identification of wave patterns as well as jet stream and jet streak position is best done using standard meteorological upper air charts. These are available from several sources using the Internet. Many television broadcasts show the position of the jet stream which, in most cases, is parallel to the upper air flow pattern. The location of jet streaks is not a standard broadcast item and can only be obtained via upper air charts.

Upper Air Charts

Upper air charts are available on the Internet at the same location as satellite images. They are usually identified by filename “uwxxyyzz.gif” [w is the level identifier, xx is the month, yy is the day of the month, and zz is the time—Greenwich Mean Time). Upper air charts are given for several levels in the atmosphere: 850 millibars (mb), 700 millibars, 500 millibars, 300 millibars. A chart for conditions at 850mb at 1200 GMT, on June 14 would have the file name 061412.gif. All upper air charts are plotted on a constant pressure surface. For example, the 850 mb chart is created from observations made as a radiosonde reaches a pressure of 850 mb. The altitude at this point varies from place to place. Near low pressure centers, the altitude corresponding to 850 mb will be much lower than the altitude corresponding to 850 mb near high pressure. Therefore, low pressure areas are depicted on upper air charts as areas of lower height. This can be a source of confusion. The jet stream is usually found around 300 mb or 200 mb. The location of short wave disturbances is best seen at the 500 mb level. Temperature gradient information is best seen at 850 mb.

Surface Information

Surface data provides an idea of low-level temperature gradients, fronts, and the location of low pressure centers. These are often available in the local newspaper as well as on the Internet and TV broadcasts.

Environmental Satellites

This section provides background information about environmental satellites, covering types of satellites, hardware specifications, and the kinds of information they obtain. It concludes with review or test materials.

U.S. geostationary and polar-orbiting satellites are discussed in some detail, supplemented with information about other nations' satellites. Note that the descriptions of the satellites and sensors are accurate at printing, but they are a *snapshot* taken during a continuing process of enhancement.

It should become obvious that there is a continuing need for international cooperation in using satellites—not only to study atmospheric conditions and provide warning of hazardous conditions, but also to study Earth as a whole.

Remote sensing, the acquiring of data and information about an object or phenomena by a device that is not in physical contact with it, plays a critical role in the use of environmental satellites. A variety of sophisticated remote-sensing instruments onboard satellites gather regional and global measurements of Earth. That information describes current conditions, allows us to predict severe weather, and monitor long-term change in the system (such as climate or ocean temperature). Such knowledge enables effective global policy-making and resource management.

Understanding the electromagnetic spectrum will help with understanding how satellite sensors and other remote-sensing tools work.

THE SATELLITES

Section 1 Looking at Earth 67
Remote Sensing and the Electromagnetic Spectrum
Radio Frequency Spectrum

Section 2 Types of Environmental Satellites and Orbits 72

Section 3 U.S. Operational Meteorological Satellite Program 73
GOES Geostationary Satellite
NOAA GOES Geostationary Satellite (diagram)
GOES Satellite Elements
GOES Primary Sensors
NOAA GOES 8 Geostationary Satellite (diagram)
GOES 8 Satellite Elements
GOES 8 Primary Systems
Geostationary Satellite Coverage
Polar-orbiting Satellites
Advanced TIROS-N (diagram)
TIROS-N Satellite Elements
TIROS-N Primary Systems
Polar-orbiter Coverage
U.S. Meteorological Satellite Systems, Comparison Chart

Section 4 Direct Readout from Environmental Satellites 92
Sample Uses for Direct Readout in the Classroom
Direct Readout from NOAA Polar-orbiting Satellites
Environmental Satellite Frequencies

Section 5 Forecast 97
Satellite-Delivered Weather
Weather Forecast Impact

Section 6 Environmental Satellites of Other Nations 99

Section 7 Review 100
Satellite Review Questions
Comparative Review of Satellites
Suggested Answers for Review Questions
Answers, Comparative Review of the Satellites

Looking At Earth

Section 1

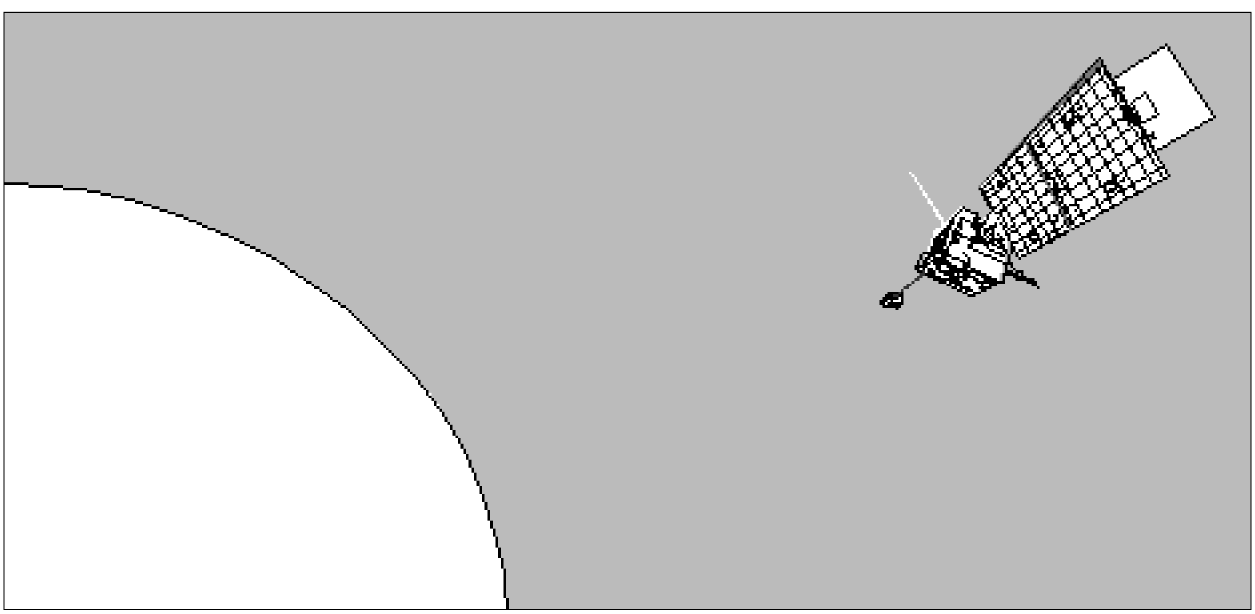
Humans have engaged in weather observation for centuries, aware of the impact of inclement weather on everything from agriculture to whaling. Galileo is credited with developing the first thermometer in 1592—over four hundred years later, we're still interested in what the temperature is. Gods who controlled thunder, lightning, and the wind are abundant in ancient mythology. Adages such as *red sky in the morning, sailors take warning, red sky at night, sailors' delight* influenced daily decisions. Observations of animal behavior, such as how large a food stockpile squirrels accrued, were considered indicators of the harshness of an oncoming winter.

Ben Franklin was the first American to suggest that weather could be forecast, having deduced from newspaper articles that storms generally travel from west to east. He further deduced that weather observers could notify those ahead of a storm that it was coming. Shortly after the telegraph was invented in 1837, Franklin's ideas were implemented by a series of observers sending information in Morse code to a central office where a national weather map was created.

A seemingly separate purpose was enabled by the invention of the camera in 1839. Beginning in 1858, cameras were flown on balloons for topographic mapping. Cameras mounted on both kites and pigeons were later used to obtain photographs from higher altitudes, encompassing larger areas. Wilbur Wright topped that by taking the first recorded photographs from an airplane in 1909.

Research during World War II, motivated by both the desire for security and superiority, produced infrared detectors and other thermal sensors. Information could be obtained about a subject, as with the camera, without being in physical contact with it. The term *remote sensing* is now commonly used in conjunction with electromagnetic techniques for acquiring information.

figure 42.



One hundred and two years after cameras were first flown on balloons to get a better look at Earth, the U.S. launched the first weather satellite, the Television and Infrared Observation Satellite (TIROS-1). TIROS-1 made it possible for the first time to monitor weather conditions over most of the world regularly, including the approximately 70% of the Earth covered by water (where weather observations had been sparse or non-existent). That first launch on April 1, 1960 was the beginning of what is now a sophisticated network of international environmental satellites monitoring Earth. Regional, national, and global observations provide information with immediate impact—such as identifying hurricanes or winter storms—and providing data for climatic and global change studies—such as changes in polar ice or mean sea level.

Satellites are now operated to fulfill a variety of objectives (e.g., communications, Earth observation, planetary exploration). However, the focus of this publication is on environmental (also called meteorological or weather) satellites, and their unique capability to provide direct readout—that is, they provide data that can be obtained directly from the satellite by a ground station user.

Remote Sensing and the Electromagnetic Spectrum

Sensors onboard environmental satellites measure a vast array of information. In order to understand how they work, and more generally, how/why remote sensing works, it is important to understand electromagnetic radiation and the electromagnetic spectrum.

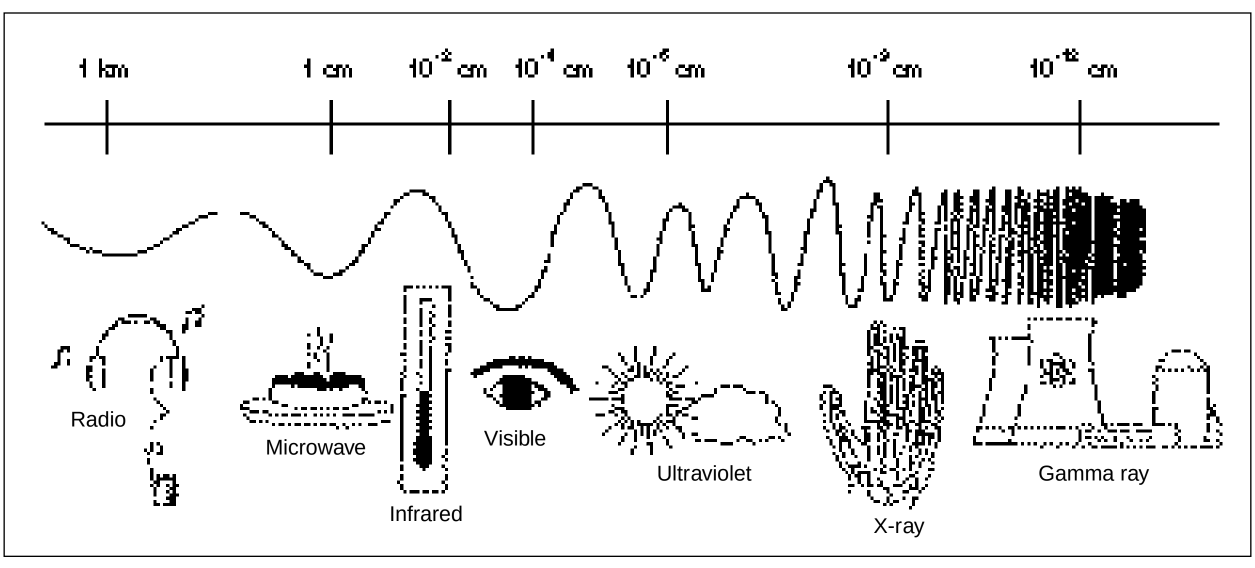
Electromagnetic radiation is composed of electric and magnetic fields that are generated by the oscillation of electrons in atoms or in a conducting material.

All matter, unless it has a temperature of absolute zero, emits electromagnetic radiant energy or radiation. This radiation travels in electromagnetic waves—a coupled electric and magnetic force field—that release energy when absorbed by another object. The waves propagate through space at the speed of light. The full range of wave frequencies—usually divided into seven spectral regions or bands—is the electromagnetic spectrum. Note that the spectrum has *ranges* rather that precise divisions. As shown in the diagram, visible and ultraviolet are examples of electromagnetic radiation, differing in their wavelengths (frequencies).

Most materials possess unique radiation properties or signatures, from which they can be identified. In general, their emissivity (the rate at which they give out radiant energy) is determined by characteristics such as chemical composition, crystal structure, grain size, surface roughness, etc.

In free space, electric and magnetic fields are at right angles to each other and maintain their relative positions during wave transmission. Radiation from some sources, such as the Sun, doesn't have any clearly defined polarization (electrical or magnetic alignment)—meaning the electrical field assumes different directions at random. However, waves can be polarized or aligned. Polarized paper, sunglasses, or camera lens will demonstrate how effectively parallel slits filter light. Hold the filtering medium horizontally up to a light source (light bulb, flashlight, projector) and note the passage of light. Turn the medium vertically or add a second filter held vertically and see the light disappear.

figure 43.



The ability to selectively examine portions of the spectrum enables satellite sensors to perform specific tasks, such as providing visual images, monitoring temperatures, and detecting reflected or emitted radiation.

Sensors monitor or *sense* 1.) natural radiation coming from the Earth or 2.) reflected radiation resulting from having sent energy to Earth that is reflected back to the satellite. Sensors are categorized as either active or passive instrumentation. Active instruments transmit their own radiation to detect an object or area for observation and receive the reflected or transmitted radiation. Active instruments include both imaging and non-imaging sensors. Imaging sensors include real and synthetic aperture radars; non-imaging sensors include altimeters and scatter-ometers. Active altimeters use either radar pulses or lasers for measuring altitude. Scatterometers use radar to determine wind speed and direction.

Passive instruments sense only radiation emitted by the object or reflected by the object from another source. The two types of passive sensors are imagers and sounders. Imagers measure and map sea-surface temperature, cloud temperature, and land temperature. Imager data are converted into pictures. Sounders are a special type of radiometer (instrument that quantitatively measure electro-magnetic radiation) which measure changes in atmospheric radiation relative to height (ground processing of this information produces temperature information), and changes in water vapor content of the air at various levels.

The Radio Frequency Spectrum

Radio frequency signals are electromagnetic waves that generally include frequencies above 10 KHz. The waves are usually generated by periodic currents of electric charges in wires, electron beams, or antenna surfaces. Radio and TV transmissions (collectively referred to as radio signals) work on a line-of-sight basis. Signal transmission and reception is dependent upon an unobstructed straight line that connects transmitters and receivers. Radio frequencies represent the different channels or stations that are broadcast—higher channels correspond to higher radio frequencies.

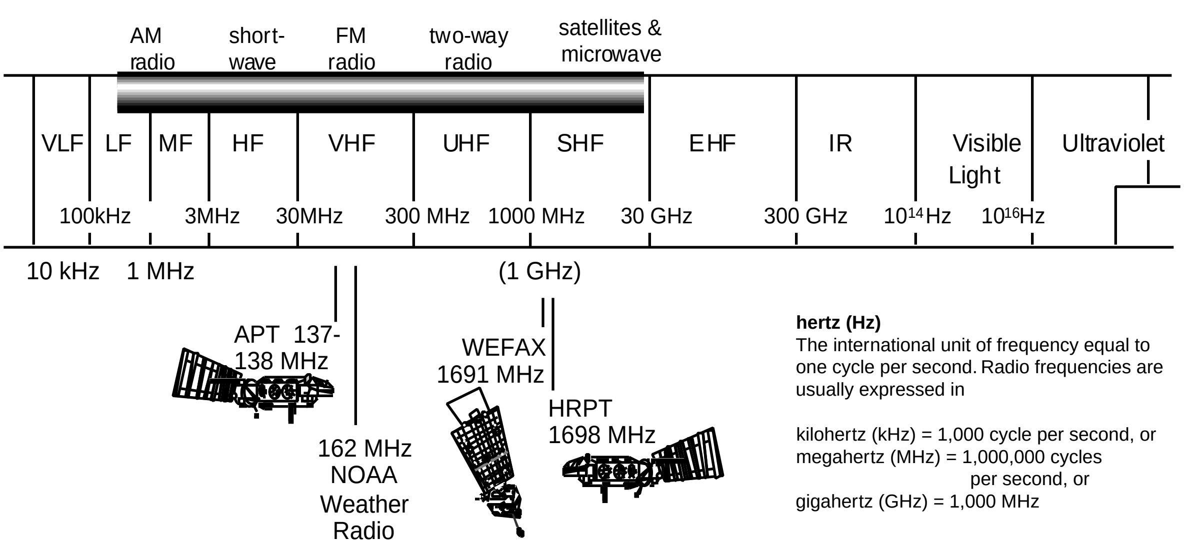
The waves most often received from satellites are in the range of 30 MHz up to 30 GHz. Those frequencies include the electromagnetic spectrum from Very High Frequency (VHF) to Super High Frequency (SHF).

U.S. polar-orbiting satellites broadcast Automatic Picture Transmission (APT) at 137 MHz, and GOES geostationary satellite Weather Facsimile (WEFAX) at 1691 MHz (see pages 92, 96).

The tracking and ranging capabilities of radio systems were known as early as 1889, when Heinrich Hertz showed that solid objects reflect radio waves. Bouncing signals off the ionosphere (upper atmosphere) increased the signal area, but the erratic atmosphere relayed signals of varying clarity. The radio signal area was also expanded by using series of transmitting towers, 31 to 50 miles apart. Oceans, deserts, and lack of towers all limited the relay.

In the early 1950s, U.S. army engineers unsuccessfully tried bouncing radio signals off the moon (resulting signals were diffused and unfocused). In 1960 NASA launched a satellite named Echo I to reflect radio signals. Since that first NASA launch, satellites have graduated from being passive reflectors to actively relaying signals and carrying sensors that obtain and relay additional information.

figure 44.



hertz (Hz)
The international unit of frequency equal to one cycle per second. Radio frequencies are usually expressed in

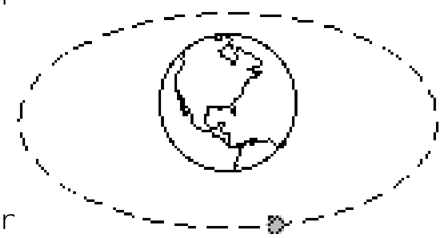
kilohertz (kHz) = 1,000 cycle per second, or
megahertz (MHz) = 1,000,000 cycles per second, or
gigahertz (GHz) = 1,000 MHz

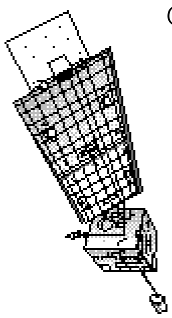
Types of Environmental Satellites and Orbits

Section 2

Environmental satellites operate in two types or orbits, geostationary and polar-orbiting.

A geostationary (GEO = geosynchronous) orbit is or in which the satellite is always in the same position with respect to the rotating Earth. The satellite orbits at an elevation of approximately 35,790 kilometers (22,240 statute miles) because that produces an orbital period equal to the period of rotation of the Earth (actually 23 hours, 56 minutes, 04.09 seconds). By orbiting at the same rate, ir the same direction as Earth, the satellite appears stationary (synchronous with respect to the rotation of the Earth).





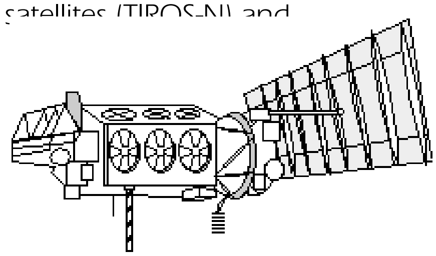
Geostationary satellites provide a "big picture" view, enabling coverage of weather events, especially useful for monitoring severe local storms and tropical cyclones. Examples of geostationary satellites are the U.S. GOES, European METEOSAT, and the Japanese GMS.

Because a geostationary orbit must be in the same plane as the Earth's rotation, that is the equatorial plane, it provides distorted images of the polar regions with poor spatial resolution. As you continue reading, note how the capabilities of the geostationary and polar-orbiting systems provide comprehensive coverage of Earth.

Polar-orbiting satellites provide a more global view of Earth, circling at near-polar inclination (a true polar orbit has an inclination of 90°). Orbiting at an altitude of 700 to 800 km, these satellites cover best the parts of the world most difficult to cover in situ (on site). For example, McMurdo, Antarctica can receive 11 or 12 of the 14 daily NOAA polar-orbiter passes.

The satellites operate in a sun-synchronous orbit, providing continuous Sun-lighting of the Earth-scan view. The satellite passes the equator and each latitude at the same time each day, meaning the satellite passes overhead at essentially the same solar time throughout all seasons of the year. This feature enables regular data collection at consistent times as well as long-term comparisons. The orbital plane of a sun-synchronous orbit must also rotate approximately one degree per day to keep pace with the Earth's surface.

Examples of polar-orbiting satellites are the U.S. NOAA satellites (TIROS-N) and the NASA Upper Atmosphere Research Satellite (UARS).



The U.S. Operational Meteorological Satellites (METSAT) Program

Section 3

Two Federal Agencies are responsible for the U. S. meteorological satellites (also known as environmental or weather satellites).

Roles and Responsibilities*

National Oceanic and Atmospheric Administration (NOAA)

- Establish observational requirements
- Provide funding for program implementation
- Operate and maintain operational satellites
- Acquire, process, and distribute data products

National Aeronautics and Space Administration (NASA)

- Prepare program implementation plans
- Design, engineer, and procure spacecraft and instruments
- Launch the spacecraft
- Conduct on-orbit check-out before handover to NOAA

** As defined in the 1973 Department of Commerce, NASA Basic Agreement*

Organizational Assignments

NOAA

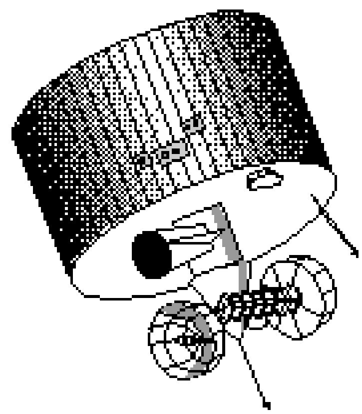
- NOAA is part of the Department of Commerce

- Within NOAA, the National Environmental Satellite, Data, and Information Service (NESDIS) is responsible for the U.S. civil operational weather satellites and uses data from other programs such as the Defense Meteorological Satellite Program (DMSP).

NASA

- NASA Goddard Space Flight Center (GSFC) is responsible for program implementation.

GOES A-H Geostationary Satellite



Background
- Alphabet label before launch (GOES-A, GOES-B)
- Numerical label after geostationary orbit achieved (GOES-6, GOES-7)

Weight
- Liftoff: 840 kg (1851 lbs)
- On orbit: 503 kg (1108 lbs)
- End of Life (EOL), spacecraft dry weight: 400 kg (881 lbs)

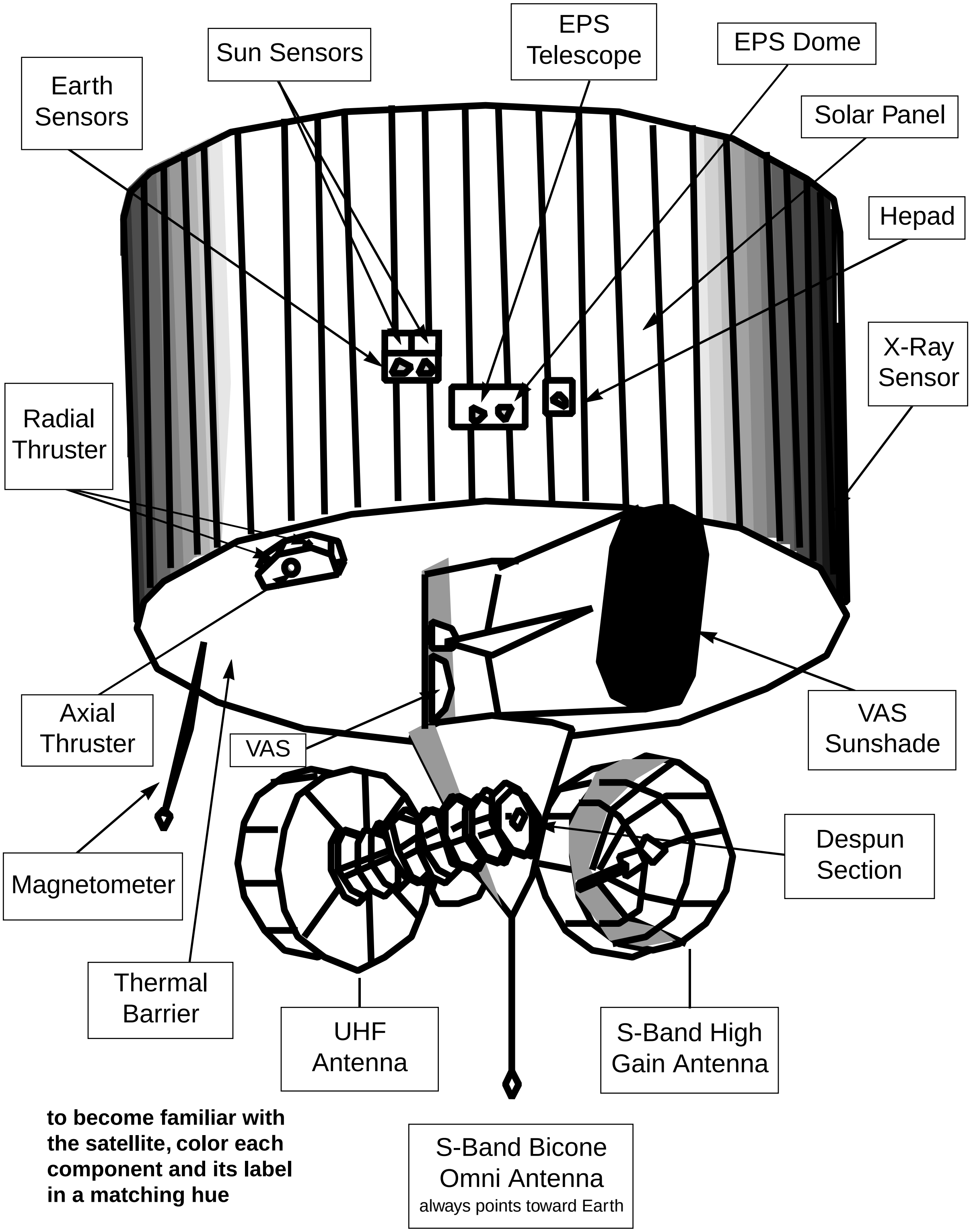
Size
- Main body: 1.5 m (4.8 ft) height
  2.1 m (7.0 ft) diameter
- Despun section: 2.0 m (6.7 ft) height [section that does not spin]

Orbit
- Equatorial, Earth-synchronous orbit

Uses
- Provides continuous day and night weather observations
- Monitors weather patterns and events such as hurricanes and other severe storms
- Relays environmental data from surface collection points to a processing center
- Performs facsimile transmission of processed weather data to users (WEFAX)
- Provides low-cost direct readout services; the low resolution version is called weather facsimile (WEFAX)
- Monitors the Earth's magnetic field, the energetic particle flux in the vicinity of the satellite, and x-ray emissions from the sun

Weather Facsimile (WEFAX) Description
- Uses the GOES spacecraft to relay low-resolution satellite imagery and meteorological charts to properly equipped ground stations in the Western Hemisphere
- Uses a transmission frequency (1691 MHz) in common with that of the European Space Agency's METEOSAT and Japan's GMS spacecraft
- Formatted in a 240 line/minute transmission rate, WEFAX transmissions occur 24 hours a day

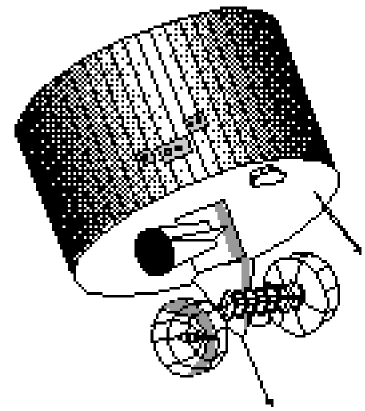
NOAA GOES A-H Satellite



to become familiar with the satellite, color each component and its label in a matching hue

figure 45.

GOES 7 Satellite Elements



Axial Thruster

Used for positioning and station acquisition maneuvers, and maybe used for orbit control

Despun Section

Earth-oriented, helix dish antenna assemblies in section that does not spin

Earth sensors

Used for attitude determination during the transfer orbit and synchronous orbit, provides pitch, yaw, and roll information to maintain Earth-pointing

EPS dome

Covers the Energetic Particle Sensor

EPS telescope

Energetic Particle Sensor, measures low and medium-charged particles

High Energy Proton and Alpha Particle Detector (HEPAD)

Monitors protons in four energy ranges above 370 MeV (rest mass in electron-volts), and alpha particles in two energy ranges above 640 MeV/nucleon

Magnetometer

Measures the magnitude and field direction of energetic charged particles within the Earth's magnetosphere (within a specified range)

Radial Thrusters

Used for spin-rate control, range of 110-80 rpm

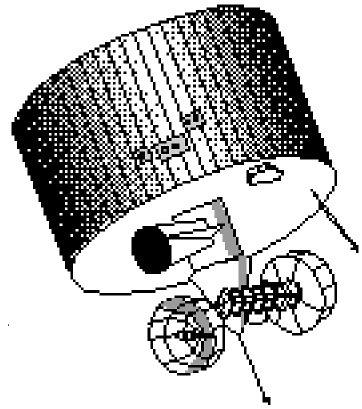
S-Band Bicone Omni Antenna

Part of telemetry and command subsystem

S-Band High Gain Antenna

Part of telemetry and command subsystem

Solar Panel



Primary source of spacecraft electrical power, designed so that normal satellite day light operation, plus required battery charging power can last for approximately seven years

Sun Sensors

Provides information on spacecraft spin rate and attitude with respect to the sun line, and provides reference pulses the VAS system

Thermal Barrier

Assists in thermal control, which is accomplished by using passive energy balance techniques

Ultra High Frequency (UHF) Antenna

Used to receive Earth-based data

VISSR Atmospheric Sounder (VAS)

See next page

VAS Sunshade

Shades the VISSR Atmospheric Sounder

X-Ray Sensor (XRS)

Uses ion chamber detectors to measure ionospheric effects associated with solar flares

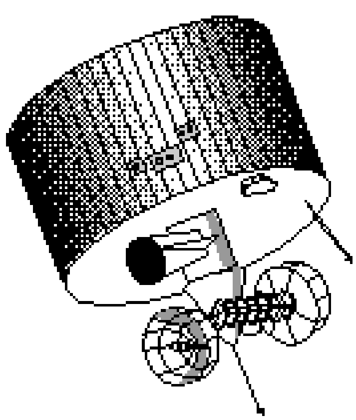
GOES 7 Geostationary Satellites

Primary Systems

- Visible-infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS)
  provides visible, infrared, and sounding measurement of the Earth, including the presence of water vapor. Primary data from this instrument are used to estimate cloud top temperatures, sea surface temperatures, and precipitation; determine the vertical structure of the atmosphere; study weather systems; and observe severe weather outbreaks. VISSR allows for both day and night cloud cover imagery. Imaging in the visible portion of the spectrum has a resolution of 0.9 km, and in the infrared (IR) portion a resolution of 6.9 km. These images, together with images received from polar-orbiting satellites, are processed on the ground and then radioed back up to GOES for broadcast in graphic form as WEFAX. The VAS instrument can produce full-Earth disk images every 30 minutes, 24 hours a day.

- Space Environment Monitor (SEM)
  measures the condition of the Earth's magnetic field, solar activity and radiation around the spacecraft, and transmits these data to a central processing facility. SEM instruments measure the ambient magnetic field vector, solar X-ray flux, and the charged particle population. SEM sensors are designed to provide direct measurement of the effects of solar activity in such a manner that data will be available in real time for use in the generation of advisory or warning messages, and for forecasting and operational research.

- Data Collection System (DCS)
  gathers and relays environmental data made by sensors placed on various objects (both mobile and stationary at various locations). Examples of environmental data obtained from these sites include precipitation, river heights, ocean currents and temperatures, water pH, wind speed and direction, and barometric pressure.



NOAA GOES I-M Satellites

to become familiar with
the satellite, color each
component and its label
in a matching hue

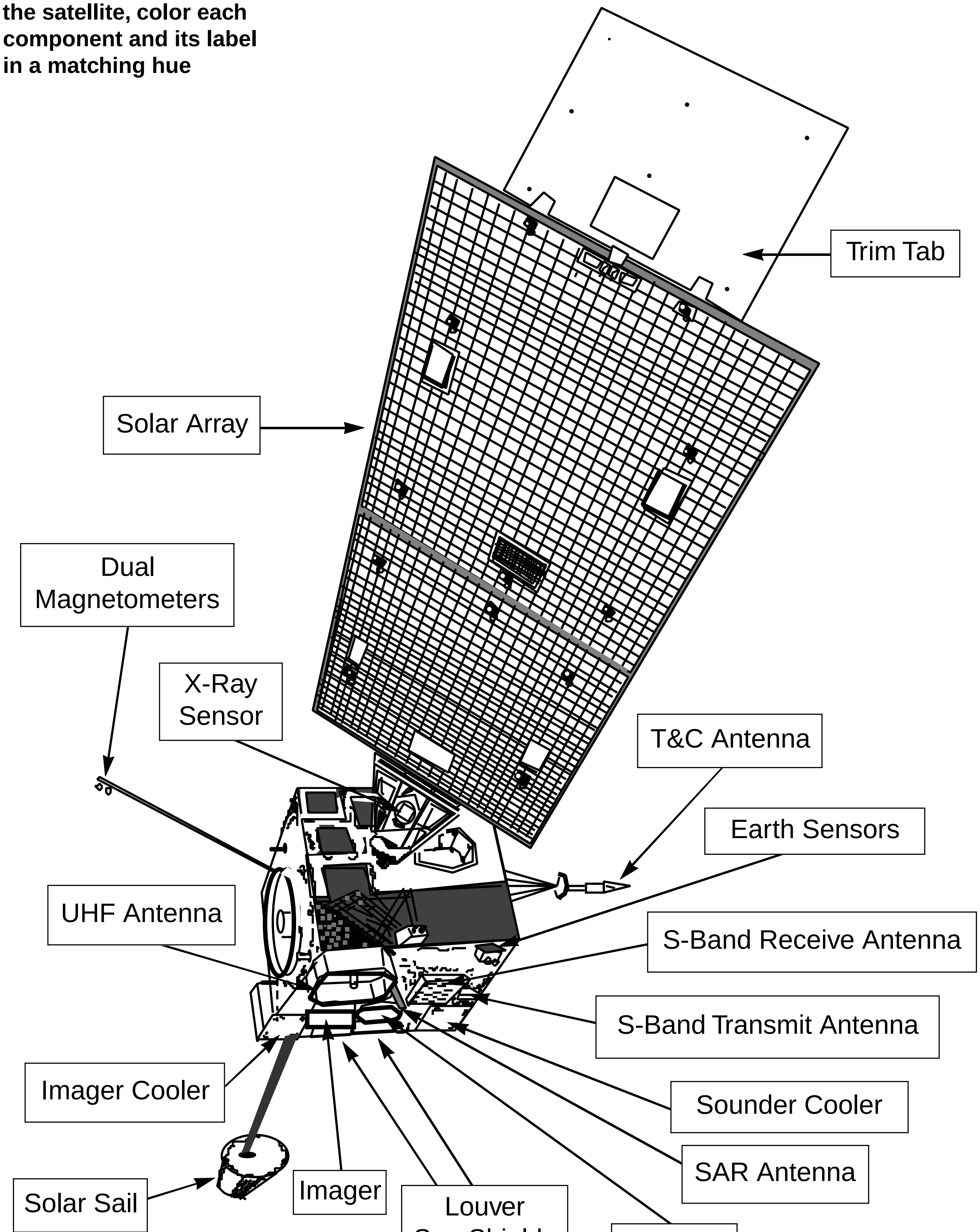
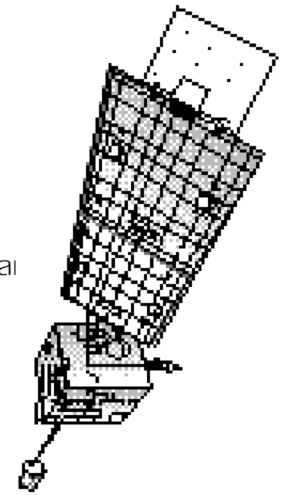


figure 46.

GOES I-M Satellite Elements



Earth Sensors

Detects Earth's horizon (Earth location).

Imager

Five-channel (one visible, four infrared) imaging radiometer designed to sense radiant and solar reflected energy from Earth. Provides full Earth scan to mesoscale area scans. Also provides star sensing capability.

Imager Cooler

Protects the imager from direct sunlight and contamination.

Louver Sun Shields

Passive louver assembly provides cooling during the direct sunlight portion of the orbit. A sun shield is installed on the Earth-end of the louver system to reduce incident radiation.

Magnetometers

Three-axis magnetometers for measuring the geomagnetic field; only one magnetometer can be powered at any time.

SAR Antenna

Search and Rescue Antenna detects distress signals broadcast by transmitters carried on general aviation aircraft and beacons aboard some marine vessels. It relays the distress signal (but cannot pinpoint the location of the signal) to a ground station that dispatches assistance.

S-Band Receive Antenna

Full Earth coverage beamwidth, it receives uplink data collection and Weather Facsimile (WEFAX) transmissions.

S-Band Transmit Antenna

Full Earth coverage beamwidth, it transmits data to the ground segment.

Solar Array

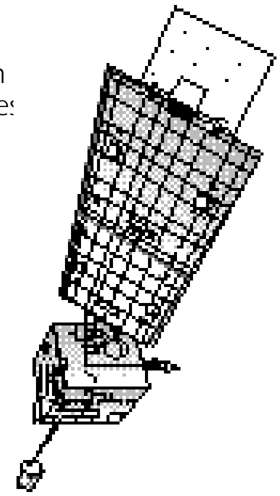
Two panel array that continuously rotates to track the sun during orbital motion, providing primary power for the satellite.

Solar Sail

Conical-shaped sail mounted on a 17 meter (58 foot) boom balances the torque caused by solar radiation pressure on the solar array.

Sounder

19-channel discrete-filter radiometer that senses specific radiation computing atmospheric vertical temperature and moisture profiles surface and cloud top temperature, and ozone distribution.



Sounder Cooler

Protects the sounder from direct sunlight and contamination.

Telemetry and Command Antenna

(T&C Antenna) Provides near omnidirectional coverage, enables functional interface between GOES satellite and ground command.

Trim Tab

Provides fine balance control for the solar radiation pressure

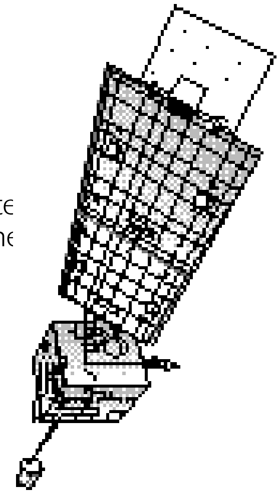
UHF Antenna

Dipole antenna with full Earth coverage beamwidth that receives data and search and rescue (SAR) signals, and transmits data collection signals.

X-Ray Sensor

X-ray telescope that measures solar X-ray flux in two spectral channels (short and long sun channels) in real-time.

GOES L-M



Primary Systems

- **Imager**
  is a five-channel (one visible, four infrared) imaging radiomete that senses radiant energy and reflected solar energy from the Earth's surface and the atmosphere. Position and size of an area scan are controlled by command, so the instrument is capable of full-Earth imagery and various area scan sizes within the Earth scene. The Imager also provides a star-sensing capability, used for image navigation and registration purposes.

- **Sounder**
  is a 19-channel discrete-filter radiometer that senses specific radiant energy for vertical atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution. As does the Imager, the Sounder can provide full-Earth imagery, sector imagery, or local region scans.

- **Communications Subsystem**
  Includes Weather Facsimile (WEFAX) transmission and the Search and Rescue (SAR) transponder. Low-resolution WEFAX transmission includes satellite imagery from GOES and polar-orbiting satellites and meteorological charts uplinked from the Command and Data Acquisition (ground) Station. The SAR subsystem detects the presence of distress signals broadcast by Emergency Locator Transmitters carried on general aviation aircraft and by Emergency Position Indicating Radio Beacons aboard some classes of marine vessels. GOES relays the distress signals to a SAR Satellite-Aided Tracking ground station within the field-of-view of the spacecraft. Help is dispatched to downed aircraft or ship in distress.

- **Space Environment Monitor (SEM)**
  consists of a magnetometer, and X-ray sensor, a high-energy proton and alpha detector, and an energetic particles sensor, all used for in-situ surveying of the near-Earth space environment. The real-time data is provided to the Space Environment Services Center—the nation's space weather service—which receives, monitors, and interprets solar-terrestrial data and forecasts special events such as solar flares or geomagnetic storms. That information is important to the operation of military and civilian radio wave and satellite communication and navigation systems, as well as electric power networks, Space Shuttle astronauts, high-altitude aviators, and scientific researchers.

Geostationary Satellite Coverage

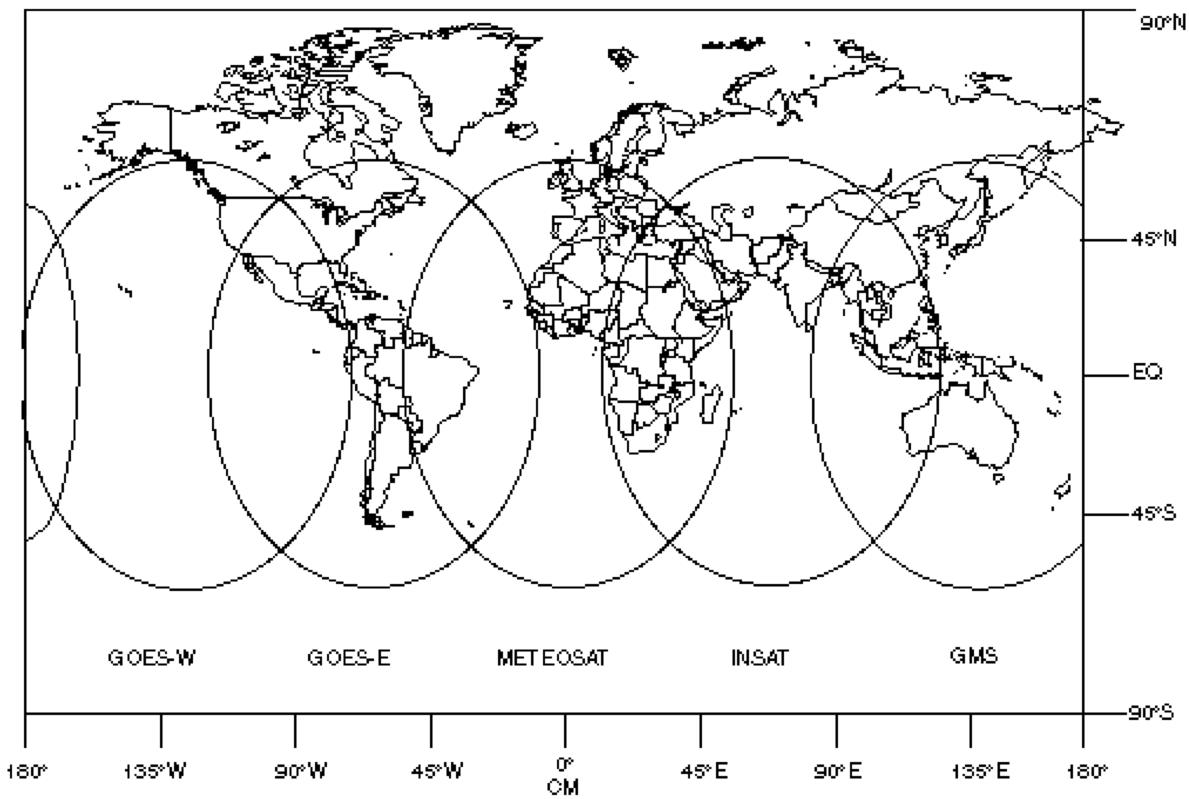


figure 47.

Polar-orbiting Satellites

TIROS-N

Designation

- Alphabet label before launch (NOAA-I, NOAA-J),
- Numerical label after launch(NOAA-13, NOAA-14)

Weight

- Range 2000–4000 lbs

Size

- Main body: 4.2 m (13.7 ft) length
  1.9 m (6.2 ft) diameter
- Solar array: 2.4 x 4.9 m (7.8 x 16.1 ft)

Payload Weight

- 854 lbs (386 kg)

Attitude Control

- Three-axis stabilized

Uses

- Provide operational coverage of entire Earth two times per day per satellite (morning and afternoon equator crossings), including the 70 percent of the Earth covered by water—where weather data are sparse

- Measure temperature and humidity in the Earth's atmosphere, sea-surface temperature, cloud cover, water-ice boundaries, snow cover, vegetation, ozone concentrations, energy budget parameters, and proton and electron flux near the Earth

- Receive, process, and retransmit data from buoys and remote automatic stations distributed around the globe

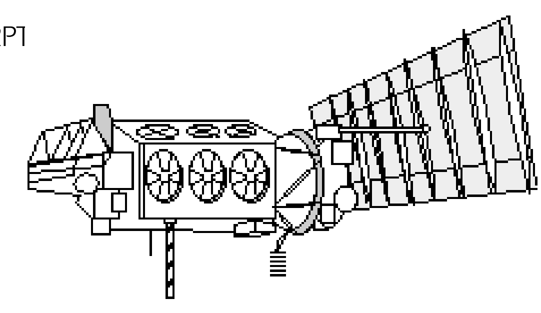
- Provide rapid relay of distress signals to rescue centers

Direct Data Readout Provided Via:

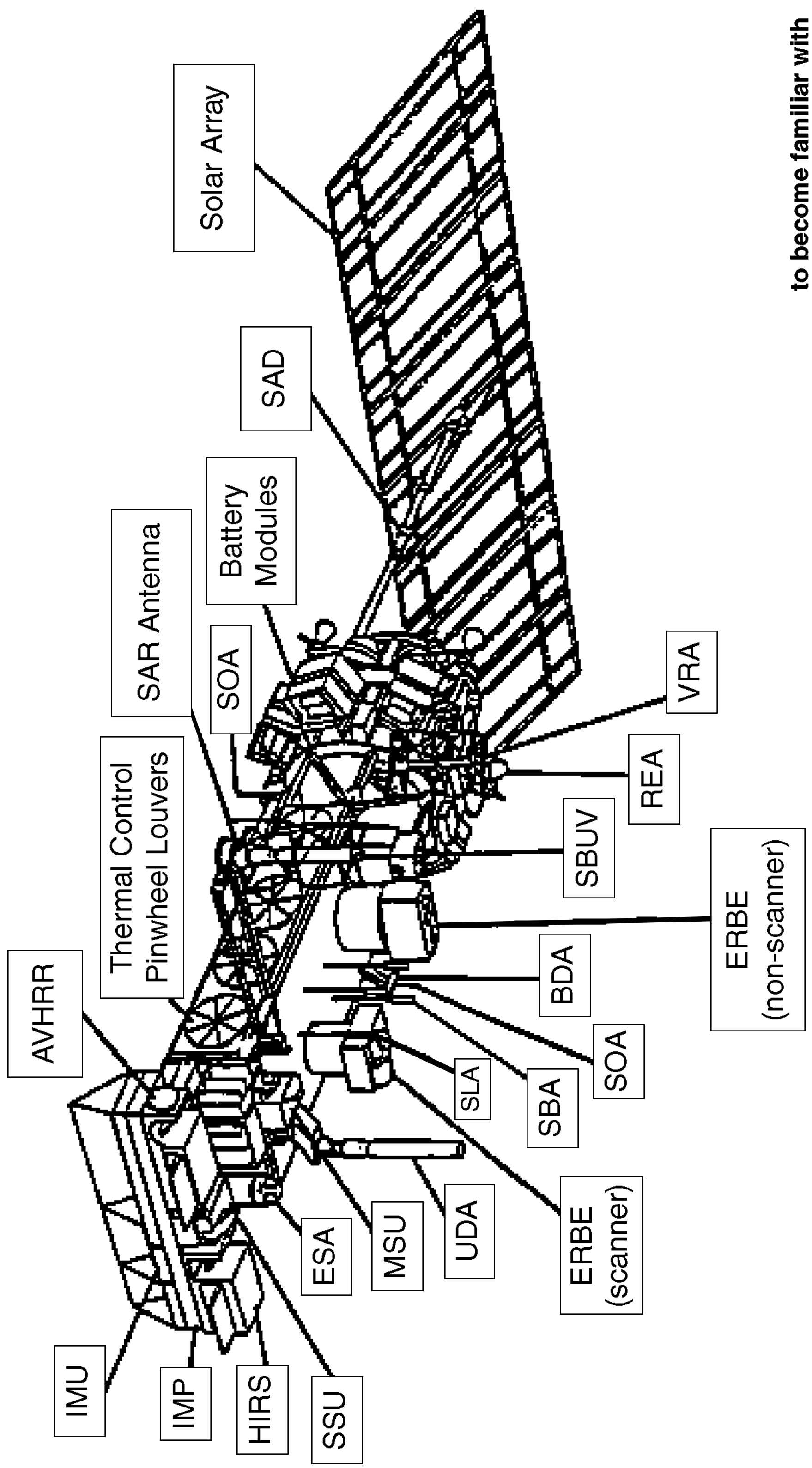
- High Resolution Picture Transmission (HRPT

- Automatic Picture Transmission (APT)

- Direct Sounder Broadcast (DBS)



ADVANCED TIROS-N (ATN)



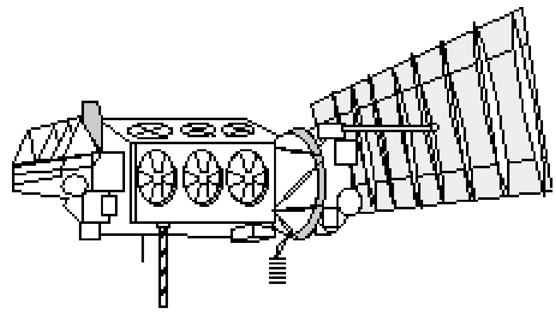
to become familiar with the satellite, color each component and its label in a matching hue

figure 48.

TIROS-N Satellite Elements

Advanced Very High Resolution Radiometer (AVHRR)

A radiation-detection imager used for remotely determining ice, snow, and cloud cover information, and day and night sea surface temperature (has an accuracy of 0.5 degrees Celsius)



Array Drive Electronics

An electronics box containing all the electronics required for operation of the solar array drive

Battery Modules

Six, located around casing of second stage solid fuel motor

Beacon/Command Antenna (BDA)

Dual-use antenna for receiving commands from ground stations and transmitting telemetry to ground stations

Earth Sensor Assembly (ESA)

A static, infrared, horizon sensor which provides spacecraft pitch and roll data to the on-board attitude determination and control subsystem

Equipment Support Module

Contains computers, transmitters, tape recorders, preprocessors, etc.

High Energy Proton and Alpha Particle Detector (HEPAD)

Senses protons and alpha particles in the 379 to 850 keV (thousand electron volts) range

High Resolution Infrared Radiation Sounder (HIRS)

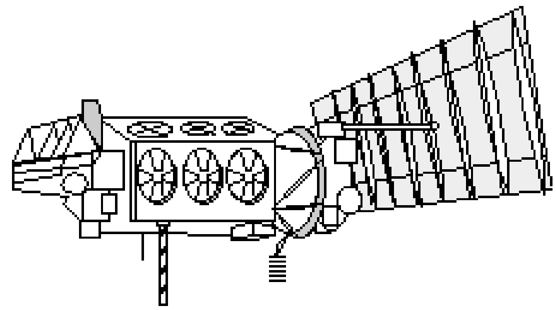
Detects and measures energy emitted in the atmosphere to construct a vertical temperature profile from the Earth's surface to an altitude of 50 km. It measures incident radiation in 19 spectral regions of the IR spectrum and one visible region. Total ozone, and water vapor at three levels in the troposphere are measured

Hydrazine Tank

The spacecraft has two tanks containing hydrazine, which is used for thrusting

Inertial Measurement Unit (IMU)

Contains gyros and accelerometers to provide information for determining spacecraft attitude and position



Instrument Mounting Platform (IMP)

Highly stable structure used to hold some instruments and level with Earth to accuracy of 0.2 degrees

Instrument Mounting Platform Sunshade

Shading to protect instruments from the Sun

Medium Energy Proton and Electron Detector (MEPED)

Senses protons, electrons, and ions with energies from 30 keV (thousand electron volts) to several tens of MeV (million electron volts)

Microwave Sounding Unit (MSU)

A passive scanning microwave spectrometer with four frequency channels that measures the energy from the troposphere to construct a vertical temperature profile to an altitude of 20 km, and measures precipitation

Nitrogen Tank

Used for thrusting and to provide ullage (fills the tank the amount that the hydrazine propellant lacks being full to ensure proper flow) pressurant for the hydrazine propellant tanks. The spacecraft has two tanks containing nitrogen

Reaction System Support Structure

Second-stage motor, batteries, and fuel

Rocket Engine Assembly (REA)

Used for thrusting, the spacecraft has four hydrazine engines

S-Band Real-time Antenna

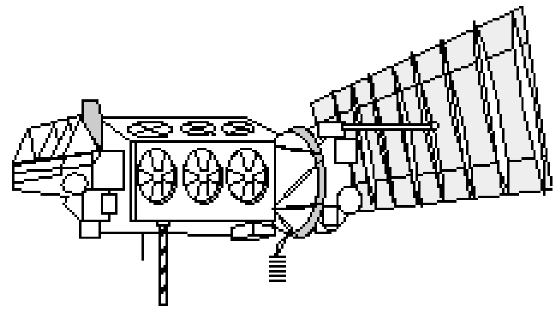
Transmission at 665.4 kilobits per second

S-Band Omni Antenna (SOA)

Broadcasts relatively low-frequency microwave bands for transmitting instrument and spacecraft data to ground stations during boost phase and during on-orbit emergencies

Solar Array

Silicon solar cells, produce 340 watts of power for direct use or for storage in batteries (with excess radiated into space as heat)



Solar Array Drive Motor (SAD)

The drive motor is used to rotate the solar array so that the array continuously faces the Sun

Stratospheric Sounding Unit (SSU)

A step-scanned spectrometer which measures temperature in the upper stratosphere. It senses energy in the 15 micrometer carbon dioxide absorption portion of the infrared spectrum, allowing for a study of the energy budget at the top of the atmosphere

Sun Sensor Detector (SSD)

A part of the Sun Sensor Assembly (SSA) which provides the Sun's position with respect to the spacecraft. The sun sensor is used to reinitialize the spacecraft yaw-attitude calculation once per orbit. (Yaw is the swinging on a vertical axis to the right or left above nadir, nadir is the point on Earth directly beneath a satellite)

Thermal Control Pinwheel Louvers

Three on each of four sides for TIROS-N thru NOAA-D. Four louvers per side for NOAA-E and newer satellites.

UHF Data Collection System Antenna (UDA)

Antenna used to receive Earth-based platform and balloon System Antenna data, and to receive search and rescue data

VHF Real-Time Antenna (VRA)

Transmission at 2 kiloHertz per second

TIROS-N
POLAR-ORBITING SATELLITES

Primary Systems

- Advanced Very High Resolution Radiometer (AVHRR)
  five-channel scanning radiometer sensitive in the visible, near-infrared, and infrared parts of the spectrum. Examples of its temperature-sensing include land, sea, and cloud-top temperature. It stores measurements on tape, and plays them back to NOAA's command and data acquisition stations. Provides the primary imaging system for both the High Resolution Picture Transmission (HRPT, 1.1 km resolution) and the Automatic Picture Transmission (APT, 4 km resolution) images that are transmitted by the spacecraft.

- TIROS Operational Vertical Sounder (TOVS)
  combines data from three complementary instrument units (HIRS, MSU, and SSU to provide the following atmospheric data: temperature profile of the Earth's atmosphere from the surface to 10 millibars, water content, ozone content, carbon dioxide content, and oxygen content of the Earth's atmosphere.

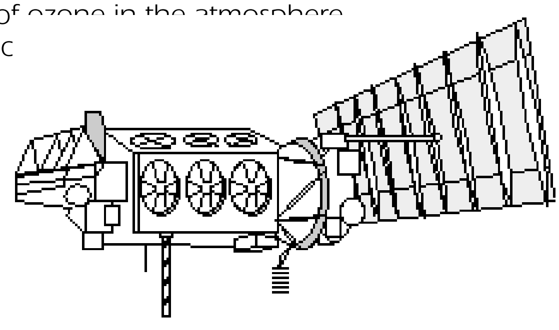
- ARGOS Data Collection and Platform Location System
  French-provided system collects data from sensors on fixed and moving platforms and transmits various environmental parameters. Provides for the receipt, processing, and storage of data (temperature, pressure, altitude, etc.), and for the location of the moving platforms for later transmission to a central processing facility.

- Space Environment Monitor (SEM)
  detects radiation at various energy levels in space, measuring energetic particles emitted by the Sun over essentially the full range of energies and magnetic field variations in the Earth's near-space environment. It measures the proton, alpha, and electron flux activity near the Earth.

- Search and Rescue (SAR)
  equipment receives emergency distress signals and transmits the signals to ground receiving stations in the U.S. and overseas. Signals are forwarded to the nearest rescue coordination center.

- Earth Radiation Budget Experiment (ERBE)
  radiometer that measures all radiation striking and leaving the Earth - enabling scientists to measure the loss or gain of terrestrial energy to space (NOAA 9 & 10 experiment).

- Solar Backscatter Ultraviolet Experiment (SBUV)
  makes measurements (afternoon satellites only) from which total ozone concentration and vertical distribution of ozone in the atmosphere can be determined; measures solar spec
  to 400 nanometers.



POLAR-ORBITING SATELLITE COVERAGE

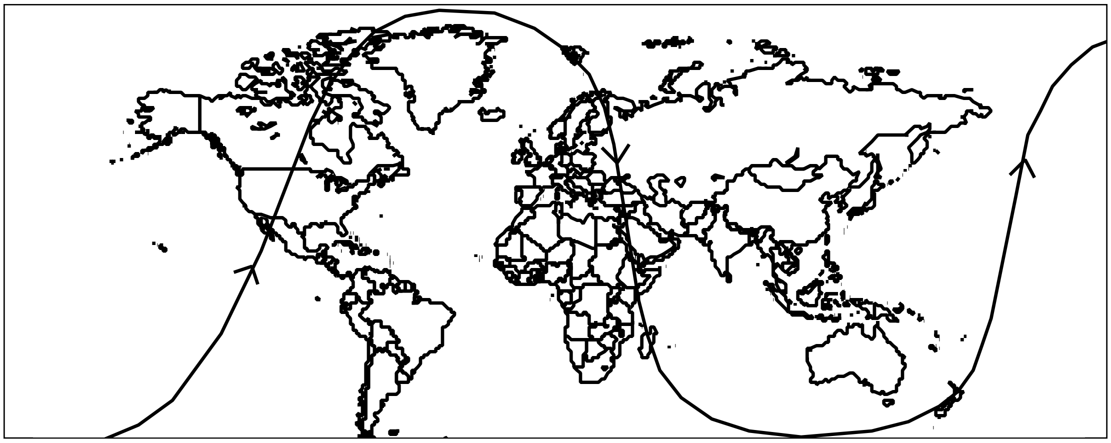


figure 49a. Single pass of a polar-orbiting satellite (on a globe, the satellite would orbit almost over the poles).

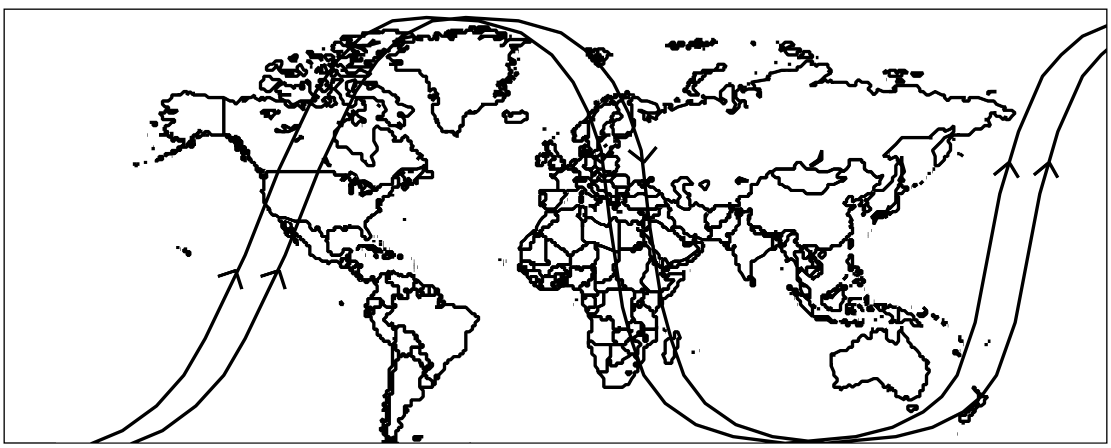


figure 49b. Two consecutive passes of a single polar-orbiting satellite.

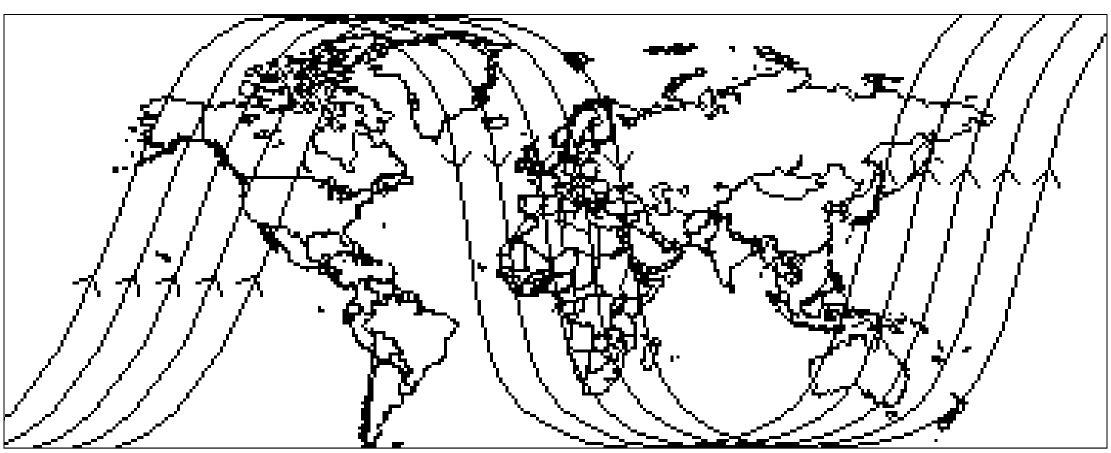
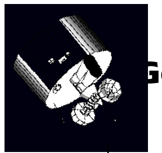
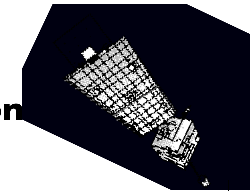
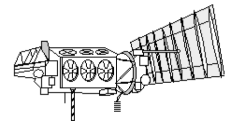


figure 49c. Five consecutive passes of a single polar-orbiting satellite show the ability to provide global coverage.

U.S. Meteorological Satellite Systems
Satellite Comparison

	Geostation	Polar Orbiter
	Geostationary Operational Environmental Satellite, (GOES)	Television Infrared Observation Satellite, (TIROS)
Basic Operation	Two satellite system covers area from North to South America, from Pacific to Atlantic locations	Maintains two satellites in Polar orbit at all times: N to S (morning satellite) S to N (afternoon satellite)
Coverage	Hemisphere/Quadrants	1,700 mile wide swath per pass
Major Missions	1. Earth Imaging & Data Collection 2. Space Environment Monitoring 3. Data Collection 4. WEFAX Transmissions *Primary Systems Include:* VISSR Visible Infrared Spin Scan Radiometer VAS Atmospheric Sounder SEM Space Environment Monitor DCS Data Collection System	1. AVHRR Advanced Very High Resolution Radiometer SAR 2. TOVS TIROS Operational Vertical Sounder 3. DCS Data Collection System 4. SEM Space Environment Monitor 5. Search & Rescue 6. ERBE Earth Radiation Budget Experiment 7. SBUV Solar Backscatter Ultra Violet Radiometer
Orbit		
Altitude	35,790 km (22,240 miles)	833 km (518 miles) AM orbit, southbound 870 km (541 miles) PM orbit, northbound
Location	Clarke Belt* over Equator GOES East, 75° West GOES West, 135° West	9–11°, N to S, S to N, Sun-synchronous
Velocity	6,800 mph (24 hour period)	17,000 mph (101 minute period)
Direct Readout Data	WEFAX Weather Facsimile Transmission 8 km resolution, visible 4 km resolution, infrared	APT Automatic Picture Transmission 4 km resolution HRPT High Resolution Picture Transmission 1.1 km resolution
Image Timeliness	Near Real Time	Real Time Transmission
Reception antenna	Dish (4 feet +)	Omnidirectional or quadrifilar helix antenna
RF Signal	1691 + MHz (to down converter)	137–138 MHz
Processed Data Rate	240 lines/minute - 4 lines/second	120 lines/minute - 2 lines/second APT
Schedule	WEFAX guide	by prediction
Signal Availability	Scheduled per 24 hours	two satellites cover entire Earth at least four times daily

*See Glossary

chart courtesy of John Tillery

Direct Readout from Environmental Satellites

Section 4

What is direct readout?

Direct readout is the capability to acquire information directly from environmental (also called meteorological or weather) satellites.

Data can be acquired from U.S. satellites developed by NASA and operated by NOAA, as well as from other nations' satellites.

How do I get direct readout?

By setting up a personal computer-based ground (Earth) station to receive satellite signals. See a station configuration in the Ground Station Set-up chapter on page 119. The electronic satellite signals received by the ground station are displayed as images on the computer screen.

Imagery can be obtained from both geostationary and polar-orbiting satellites. The low-resolution images (obtainable with the relatively inexpensive ground station equipment) from U.S. satellites are:

- Weather Facsimile or WEFAX images, transmitted by GOES satellites. WEFAX transmissions are not real-time: the images are first transmitted to NOAA for initial processing and then relayed back to the satellite for transmission to ground stations. The slight delay enables the inclusion of latitude and longitude gridding, geopolitical boundaries, weather forecast maps, temperature summaries, cloud analyses, polar-orbiter imagery, etc. WEFAX has a resolution* of 8 kilometers for visible images and 4 kilometers for infrared images. WEFAX images are broadcast on a fixed schedule, 24 hours a day.

- Automatic Picture Transmission or APT is available from polar-orbiting satellites. APT is real-time transmission, providing both visible and infrared imagery. The image obtained during a normal 14 minute reception period covers a swath approximately 1700 miles long. For example, a ground station in Baltimore will acquire an Eastern U.S. image bordered by Cuba (S), Quebec (N), Minnesota (W), and the Atlantic Ocean (E) from a typical satellite pass.

*Resolution indicates the area represented by each picture element–pixel–in an image. The lower the number, the higher the resolution or detail. For example, the two maps in figure 50 represent images on a computer screen, each one with an equal number of pixels. However each pixel in the map on top might represent 100 miles, each pixel in the world map at bottom might have to represent 500 miles. So, the lower number (the fewer meters, acres, miles, etc.) represented by a single pixel, the higher the resolution.

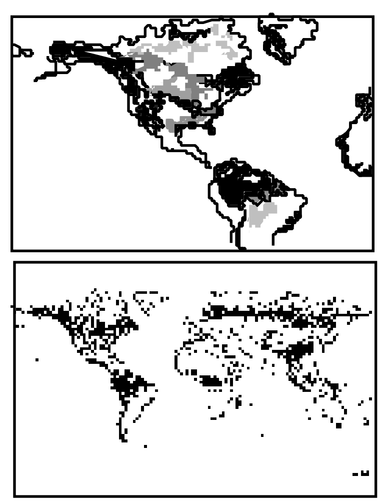
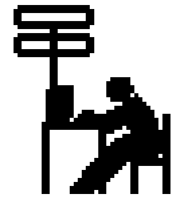


figure 50.

Sample Uses for Direct Readout in the Classroom



Basic Skills

1. world geography
2. universal coordinated time
3. latitude and longitude
4. map reading
5. remote sensing

Biology/Agriculture

1. use images for land management, land use decision-making
2. monitor flooding and changes in river systems
3 monitor crops and vegetative coverage, production
4. correlate rainfall and vegetation vigor
5. monitor forest fires and slash burning
6. monitor the impact of environmental disasters (oil spills, earthquakes, wars)

Geology

1. identify land formations, coast lines, and bodies of water
2. determine watersheds
3. locate and monitor volcanic activity and its affect on the atmosphere
4. compare land and water temperatures

Meteorology

1. observe and compare Earth and satellite views of Earth and clouds
2. observe clouds
3. develop cloud cover indexes for a specific region
4. identify fronts and characteristic associated patterns
5. develop weather forecasts
6. study upper air circulation and jet streams
7. compare seasonal changes in a specific region
8. track severe storms
9. produce monthly and annual weather comparisons

Oceanography

1. use IR images to study currents and sea surface temperatures
2. monitor ice coverage and compare seasonal changes
3. monitor moderating effects of oceans on land and meteorological effects

Direct Readout from NOAA Polar-orbiting Satellites

The Advanced Very High Resolution Radiometer (AVHRR) on U.S. polar-orbiting satellites provides the primary imaging system for both High Resolution Picture Transmission (HRPT) and Automatic Picture Transmission (APT) direct readout.

The AVHRR scans with a mirror rotating at 360 rpm. With each rotation, deep space, Earth, and a part of the instrument housing are observed. The radiant energy collected by the mirror is passed through five separate optical sub-assemblies to five spectral windows (detectors). Each of the five detectors is sensitive to radiant energy within specific spectral regions. All five channels and telemetry data are transmitted at high speed as digital data for HRPT.

AVHRR data signals are combined, and pre-processed to achieve both bandwidth reduction and geometric correction before being transmitted as APT.

The analog APT system was designed to produce real time imagery on low-cost ground stations. The FM signal from the satellites contains a subcarrier, the video image itself, as a 2400 Hz tone which is amplitude modulated (AM) to correspond to the observed light and dark areas of an image.

The louder portion of the tone represents lighter portions of the image, low volumes represent the darkest areas of the image, and intermediate volumes represent shades of gray (middle tones).

channel	HRPT / APT*		
	spectral range**	wave length	application
1	0.58 to 0.68	visible	cloud delineation, snow & ice monitoring, weather
2	0.725 to 1.0	near infrared	sea surface temperature, locate bodies of water, in combination with channel 1—vegetation assessment
3	3.55 to 3.93	thermal infrared	landmark extraction, forest fire monitoring, volcanic activity, sea surface temperature (nighttime)
4	10.3 to 11.3	thermal infrared	sea surface temperature, weather, soil, moisture, volcanic eruptions
5	11.4 to 12.4	thermal infrared	sea surface temperature, weather

* Any two AVHRR channels can be chosen by ground command for APT transmission.
** In micrometers (µm)

figure 51.

Satellite imagery is produced by sensors that detect electromagnetic waves emitted or reflected by a surface and measure their intensity in different parts of the spectrum. Because all substances absorb and reflect light differently, varying light and temperature are recorded as black, white, and shades of gray in a image. APT imagery is available from the visible or infrared segments of the electromagnetic spectrum.

All visible images of Earth record sun light (solar radiation) that is reflected by Earth—Earth does not emit visible light of its own. APT images show these differences in absorption and reflectivity (albedo) as different shades of gray. Subjects with highest albedo (greatest reflectivity) appear white in visible images, clouds show up as white or gray, outer space is black.

Infrared images are derived from two sources of infrared energy, thermal emissions (primary source) and reflected solar radiation. Thermal infrared emissions are the energies which are emitted from the Earth. Reflected solar infrared radiation is the energy which is given off by the sun and reflected from the Earth or clouds. Both of these types of energy are seen on an image as varying shades which correspond to particular temperatures. The warmer the temperature, the darker the shade in the image. The cooler the temperature, the lighter the shade. In an infrared image, the blackness of outer space (cold) is displayed as white. Hot spots, such as urban sprawl, appear as dark gray or black.

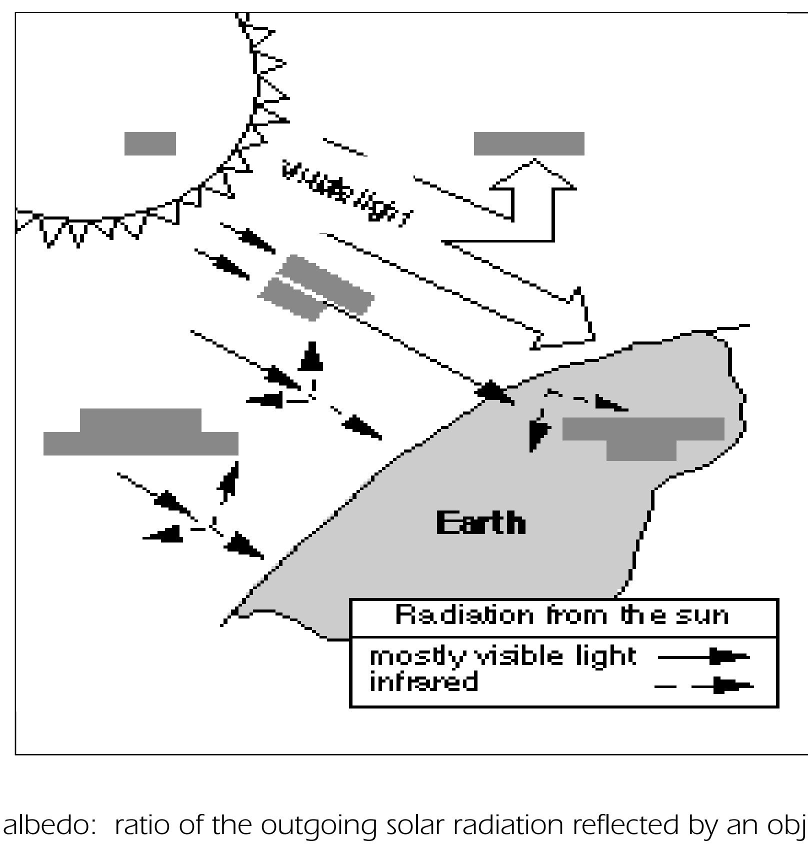
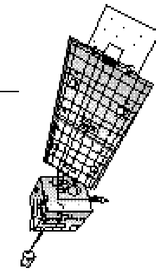
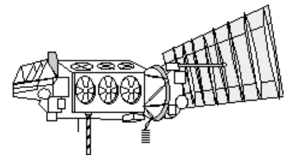


figure 52. albedo: ratio of the outgoing solar radiation reflected by an object to the incoming solar radiation incident upon it.

Environmental Satellite Frequencies



GOES	1691 MHz
NOAA 11* (afternoon) — APT	137.62 MHz
NOAA 12 (morning) — APT	137.5 MHz
NOAA HRPT	1698 MHz
METEOR (Russian)	137.85 137.4 137.3 MHz



U.S. polar-orbiting morning satellites generally transmit at 137.5 MHz, after-noon satellites transmit at 137.62 MHz. U.S. satellites are launched with the capability to transmit at both frequencies (2 APT and 2 HRPT frequencies are available for ground control to chose from on each polar orbiter). Note that the U.S. uses a two-polar-satellite system to provide complete Earth coverage; existing satellites in standby mode can be activated to replace the designated satellites if needed.

* pending successful instrument checkout, the recently launched NOAA 14 will replace NOAA 11 as the designated afternoon satellite.

NOAA Weather Radio	162.550 MHz 162.525 162.500 162.475 162.450 162.425 162.400

Hertz is the unit for measuring the frequency of any radiated signal.

- One Hertz equals one cycle per second
- One Kilohertz (kHz) equals 1,000 cycles per second
- One Megahertz (MHz) equals 1,000,000 cycles per second

Satellite-Delivered Weather

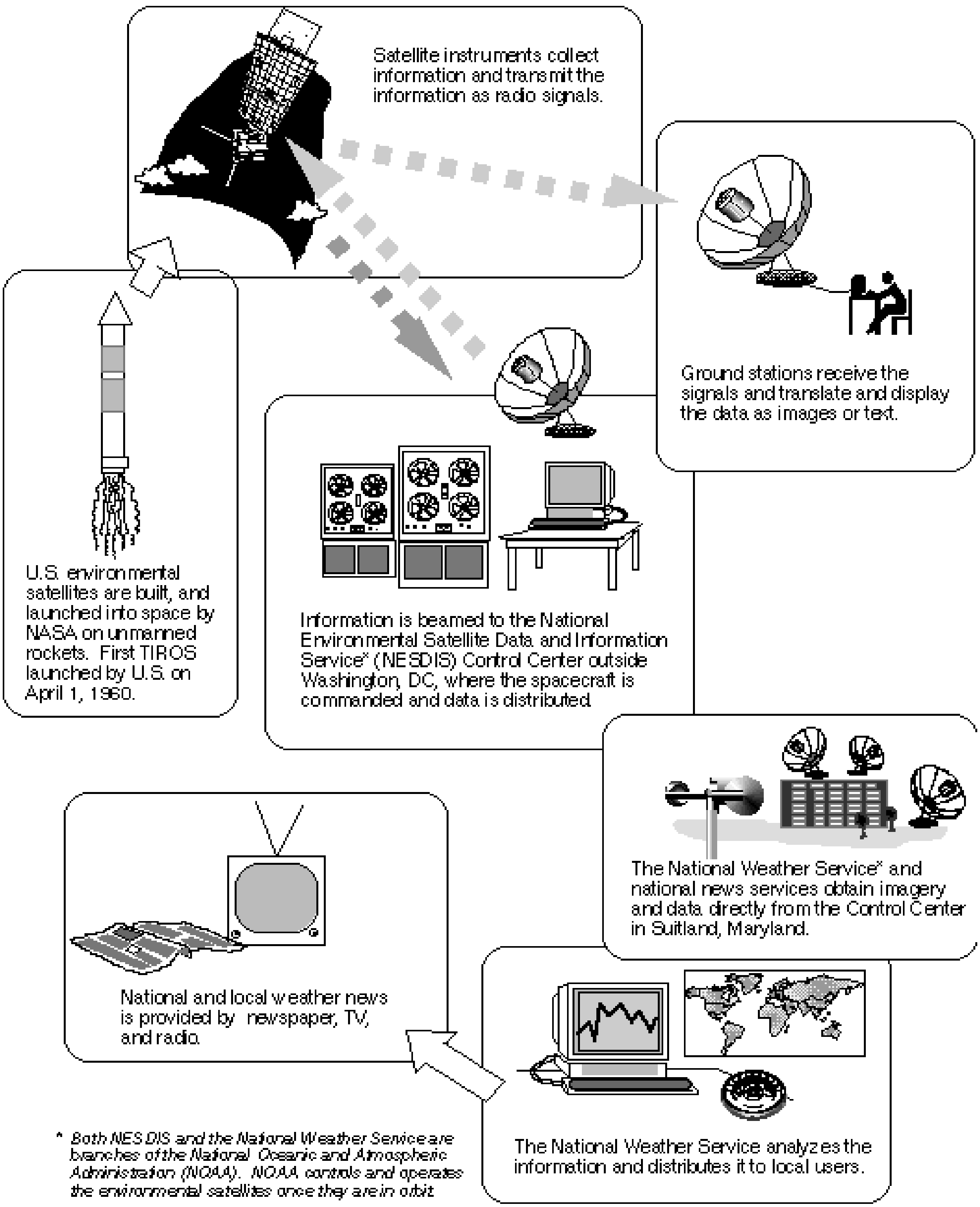


figure 53.

Weather Forecasts Impact...

Agriculture

- weed and pest control - cost to re-spray due to rain wash-off, $8– $10/acre
- harvesting - freezing, rainy, and excessively hot weather can damage harvest
- drought can generate large irrigation bills, damage harvest

Building Industry

- concrete pouring
- exterior painting
- roofing
- erecting steel structures
- material stockpiling
- excavation
- hurricanes and tornadoes can necessitate extensive rebuilding

Marine Industry

- erection or disassembly of off-shore oil platforms requires 3-5 days of reasonably calm waters
- fishing days regulated. Wrong choice of days reduces yield
- towing operations require 3-5 day forecast
- industry depends on 3-5 forecast for safe and efficient operations

Utilities Management

- electric companies use forecasts to anticipate peak loads. Poor forecasts and anticipation can result in brown-outs and total power loss at a high dollar penalty
- gas companies pay for guaranteed delivery and usage. If usage exceeds guarantee, they pay a large penalty
- customers pay for poor peak-load predictions

Other Industries

- transportation industries (airlines, bus, railroad trucking) affected by flooding, ice, blizzards
- professional sports, recreational businesses impacted by inclement weather
- forestry services, logging industry impacted by drought, fire, ice

Environmental Satellites of Other Nations

The world's environmental satellites provide an international network of global weather observations. Satellites of many countries provide data and services similar to those contributed by the United States, such as operational weather data, cloud cover, temperature profiles, real-time storm monitoring, and severe storm warnings. Their data contributes to the study of climate and the environment on both regional and global scales.

Geostationary satellites include:

Geostationary Meteorological Satellite (GMS), Japan

INSAT, India
Indian national satellite, satellite data not available.

METEOrological SATellite (METEOSAT), Europe
launched by the European Space Agency (sixteen member countries) and operated by Eumetsat (European Organization for the Exploitation of Meteorological Satellites), they send data on the same frequency as GOES (1691 MHz), as well as at 1694.5 MHz

Polar-orbiting satellites include:

METEOR Satellites, Russia
METEOR 2 satellites send a single picture (visible images at a rate of 120 lines/minute) as compared to the two (visible and infrared) that NOAA satellites send. The satellites are near-polar (not sun-synchronous) at an altitude of 900 km, with an inclination of 81.2 degrees.

The black and white bars that are visible along the edge of the Russian direct readout imagery are created by sync pulses and can be used to identify the particular satellite providing the imagery. The bars may also contain data on instrument characteristics and gray scale calibration. Images may display clouds in great detail, but land and water boundaries are difficult to distinguish without extreme video processing. Newer, METEOR 3-series satellites have an infrared imaging system.

SATELLITE REVIEW QUESTIONS

name ______________________

1. A satellite is a free-flying object that orbits:

   a. the Earth b. the Sun c. the other planets d. any of the above

2. What are the strengths of *remote sensing*?

3. A geosynchronous satellite appears stationary relative to ____________ .

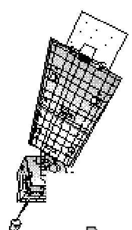
4. A polar-orbiting satellite transverses the ____________ and the ____________ .

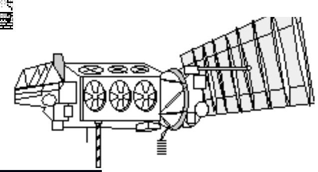
5. Match the satellites with their names and orbits

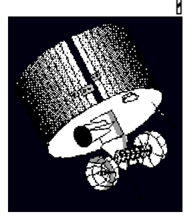
GOES 7

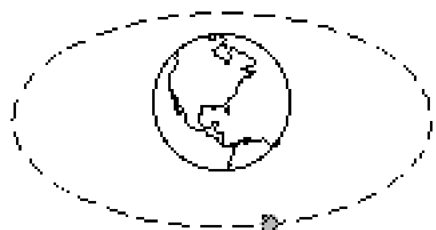
GOES I-M

TIROS-N









6. Compare the roles and responsibilities of the National Oceanic and Atmospheric Administration (NOAA) with the National Aeronautics and Space Administration (NASA) in the operation of the United States' Meteorological Satellite program.

7. Briefly discuss the type of data provided by the following systems on GOES satellites.

   a. Visible-Infrared Spin-Scan Radiometer (VISSR)

   b. Space Environment Monitor (SEM)

   c. Data Collection System (DCS)

Satellite Review Questions (continued)

8. Briefly discuss the type of data provided by the following systems on polar-orbiting satellites.

   a. Advanced Very High Resolution Radiometer (AVHRR)

   b. TIROS operational Vertical Sounder (TOVS)

   c. ARGOS Data Collection and Platform Location System

   d. Space Environment Monitor(SEM)

   e. Earth Radiation Budget Experiment (ERBE)

   f. Solar Backscatter Ultra-Violet Radiometer (SBUV)

9. You want to predict possible precipitation for the next four days. Which type of satellite images would be more helpful to you, GOES or POLAR? Explain your choice.

10. You want to study the seasonal surface temperatures of the Atlantic coast waters to assist commercial fishing operations. Which type of polar-orbiting satellite images (visible or infrared) would be most helpful to you? Explain why.

For Group Discussion

You and the state committee that you chair are given the responsibility for determining which types of hazardous weather are most likely to affect your state's parks and recreational activities. In addition to identifying threatening conditions, you must prioritize the use of state money allocated for prevention and recovery. What conditions most jeopardize your state and what measures will you take to minimize or recover from weather damage?

Comparative Review of Satellites

	Geostationary	Polar-orbiter
1. basic operation		
2. type of data received		
3. distance from the Earth		
4. orbit location		
5. spacecraft velocity		
6. reception		
7. RF signal		
8. processed data rate		
9. signal availability		
10. image format		

Suggested Answers for Review Questions (p 100–101)

1. d. any of the above

2. Remote sensing is the technology of acquiring data and information about an object or phenomena by a device that is not in physical contact with it. In other words, remote sensing refers to gathering information about the Earth and its environment from a distance. Using remote sensing enables measurement of inaccessible and/or accessible but too-costly-to-cover-subjects; it can provide a unique perspective (such as satellite images of the globe); and it can enable continuous monitoring of a subject .

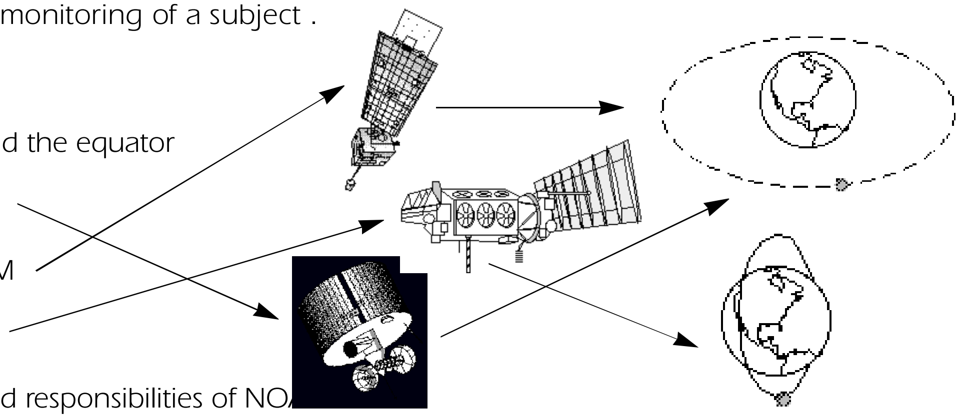
3. Earth

4. poles and the equator

5. GOES 7

   GOES I-M

   TIROS-N



6. Roles and responsibilities of NOAA
   - establish observational requirements
   - provide funding for program implementation
   - operate and maintain operational satellites
   - acquire, process, and distribute data products
   - responsible for U.S. civil, operational weather satellites

   Roles and responsibilities of NASA
   - prepare hardware implementation plans
   - design, engineer, and procure spacecraft and instruments
   - provide for launch of spacecraft
   - conduct on-orbit check-out before handover to NOAA
   - Goddard Space Flight Center responsible for implementation

7. See page 78 for data from VISSR, SEM, and DCS.

8. See page 89 for data from AVHRR, TOV, ARGOS, SEM, ERBE, and SBUV.

9. GOES Because the images provide greater coverage of the Earth (hemisphere/quadrants) and the signals are available 24 hours a day. You are able to see patterns of clouds over a much larger area than that provided by a polar satellite (a 1700 mile swath). GOES images will be more helpful in predicting fronts, cyclone paths, etc.

10. Infrared images would be more helpful because you would be able to determine the temperature of the water's surface with infrared images. Knowing the water temperature would be helpful in predicting where the fish would be concentrated along the coast for more efficient fishing.

Group Discussion: Students should determine the various terrain and types of recreational activities popular in their state, and the types of hazardous weather common to their state (hurricanes, tornadoes, blizzards, flooding, drought, etc.). Page 98 provides some background information for consideration.

Answer Key, Comparative Review of Satellites

	Geostationary	Polar-orbiter
1. basic operation	Two satellite system covers area from North to South America, from Pacific to Atlantic locations	Two satellites in Polar orbit at all times: N to S (morning satellite) S to N (afternoon satellite)
2. type of data received	visual and infrared	Day: visual and infrared Night: infrared
3. distance from the Earth	35,790km (22,240 miles)	833 km (518 miles) AM orbit, southbound 870 km (541 miles) PM orbit, northbound
4. orbit location	Clarke Belt over Equator GOES East, 75° West GOES West, 135° West	N>S, S>N, Sun-synchronous
5. spacecraft velocity	6800 MPH (24 hour period)	17,000 mph (101 minute period)
6. reception	Dish (4 meter +)	Omni directional or quadrifilar helix antenna
7. RF signal	1691 + MHz (to down converter)	137–138 MHz
8. processed data rate	240 lines/minute - 4 lines/second	120 lines/minute - 2 lines/second
9. signal availability	24 hours	101 to 102 minutes between accessibility, two satellites each view entire Earth at least twice daily
10. image format	24 hour period Hemisphere/Quadrants	1,700 Mile Swath

ORBITS

An orbit is the path in space along which an object moves around a primary body. In the case of environmental satellites, the satellite moves around the primary body Earth.

Bodies in space or low-Earth orbit are governed by laws of gravity and motion, just as life on Earth is. These laws make it possible to determine how, where, and why satellites will be. Orbital mechanics utilizes a standard set of reference points and terms that make it possible to pinpoint a body in space and describe its unique location and motion.

The ability to understand and predict the location of satellites is essential for obtaining direct readout from polar-orbiting environmental satellites. Geostationary orbits must also be located. However, because they remain in the same position relative to Earth, orbital information doesn't need to be regularly updated.

This section describes the basics of orbital mechanics, the Keplerian elements, procedures for tracking satellites, and resources for orbital data.

ORBITS

Section 1 Newton 107
Newton's Law of Universal Gravitation
Newton's Laws of Motions

Section 2 Kepler 109
Kepler's Laws of Motion
Keplerian Elements

Section 3 Orbital Data 112
Description of NASA Orbital Data
Obtaining NASA Orbital Data from NASA
Other Sources for Satellite Data

Section 4 Satellite Tracking Programs 116

SIR ISAAC NEWTON

Section 1

Sir Isaac Newton was born on Christmas day, 1642—the same year that Galileo Galilei died. His life-long intolerance of contradiction and controversy is attributed to an early, lengthy separation from his mother who was widowed shortly before Isaac's birth. She left Isaac in the care of his grandmother to remarry, live in the next town, and start a new family consisting of another son and two daughters.

As a teenager, Isaac's preoccupation with reading, experimentation, and observation was an irritant to his affluent, now twice-widowed mother who expected Isaac to become a gentlemen farmer. Apparently she was reluctant to have Isaac attend university, perhaps concerned about both the farm he had inherited and the cost of additional education. He entered Cambridge as a sizar (a student who waited on other students to pay his way), a step down from his social class and his mother's financial standing.

Newton's university studies were interrupted in 1665 and 1666 by the closure of Cambridge University because of bubonic plague. During this period, he left London and studied at home, doing extensive work in optics, laying the foundation for calculus—and perhaps his law of gravity. Experts disagree about the timing, some claiming another 13 years passed before Newton's ideas on gravity crystallized. In either case, Newton's achievements at this early age were substantial, although his undergraduate career was undistinguished.

Newton conducted research in theology and history with the same passion that he pursued science and alchemy throughout his life. Some consider him the culminating figure of the 17th century scientific revolution.

Newton's intense dedication to his intellectual pursuits took a toll on his physical and mental health, apparently causing at least two breakdowns during his life. He died in 1727 and is buried in the nave of Westminster Abbey.

Newton's Law of Universal Gravitation

The force of gravitational attraction between two point masses (m1 and m2) is proportional to the product of the masses divided by the square of the distance between them. In this equation, G is a constant of proportionality called the gravitational constant.

$$F = \frac{Gm_1 m_2}{r^2}$$

The closer two bodies are to each other, the greater their mutual attraction. As a result, to stay in orbit, a satellite needs more speed in lower orbit than in a higher orbit.

All orbits— Earth around the Sun, satellites around Earth, etc., follow the same laws of gravity and motion.

Newton's Laws of Motion

1. An object continues in a state of rest or uniform motion unless acted on by an external force.

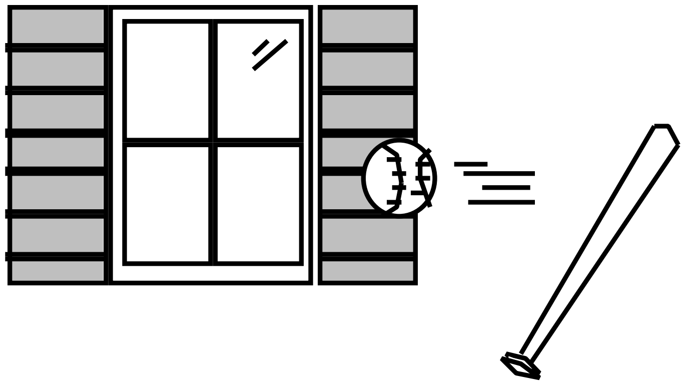


figure 54a.

2. The resultant force acting on an object is proportional to the rate of change of momentum of the object, the change of momentum being in the same direction as the force.

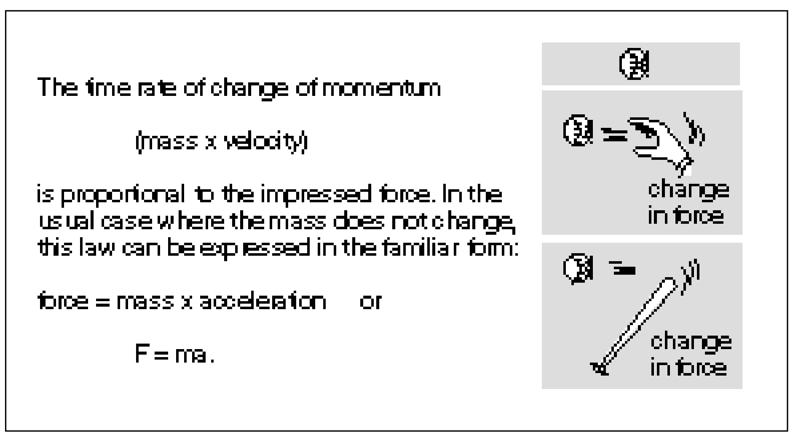


figure 54b.

3. To every force or action, there is an equal and opposite reaction.

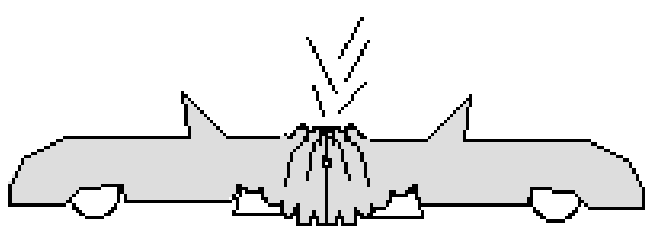


figure 54c.

JOHANNES KEPLER

Section 2

Johannes Kepler—German astronomer [1571-1630] derived three laws that describe the motions of the planets around our Sun, the moon around the Earth, or any spacecraft launched into orbit.

Early frail health seemed to destine Kepler for the life of a scholar. He was born into a dysfunctional, chaotic family and spent his lonely childhood with a variety of illnesses. He had myopia and multiple vision—unfortunate afflictions for the eyes of an astronomer.

Kepler intended to dedicate himself to the service of the Protestant church, but his independence, lack of orthodoxy, and disagreeableness led his university teachers to recommend him as a mathematics professor to a school some distance away. During this period, astronomy became an important focus.

Early writings of Kepler's attracted the attention of Tycho Brahe, the Danish astronomer. Kepler joined Brahe's staff in 1601. When Brahe died the following year, Kepler inherited Brahe's meticulous astronomical observations—considered critical to Kepler developing his first two laws of motion. Within days of Brahe's death, Kepler was appointed Brahe's successor as imperial mathematician of the Holy Roman Empire, a position Kepler held until his death.

Kepler was a transitional figure between ancient and modern science. Astrology often played an important, and sometimes dominant role in his life.

Kepler's laws stirred little interest for decades, only Newton seemed to realize their value. Kepler's laws describe how planets move. Newton's law of motion describes why the planets move according to Kepler's laws. Kepler himself never numbered these laws or specially distinguished them from his other discoveries. Kepler's laws apply not only to gravitational forces, but also to all other inverse-square law forces.

In the last decade of his life, Kepler wandered in search of a haven or a patron. In the fall of 1630, Kepler rode across half of Germany to collect pay and arrears due him. The exertion of the trip was responsible for Kepler's illness and death in Regensburg on November 15, 1630. He was buried outside the town walls. Subsequent conquest of the city decimated the cemetery and left the site of Kepler's grave unknown.

Kepler laws of motion

1. A planet moves about the Sun in an elliptic orbit, with one focus of the ellipse located at the Sun.

   An elliptical orbit is shown, the semi-major axis (a) determines its size and the eccentricity (e) its shape. Neither Kepler nor anyone else yet understood that a mass will continue to move in a straight line through space, so no force is needed to drive a body around its orbit— only a Sun-centered force to hold it in orbit (Newton) or a Sun-centered spacetime curvature (Einstein) (figure 55a).

2. A straight line from the Sun to the planet sweeps out equal areas in equal times. (figure 55b).

   The constant rate of sweeping out may be different for each orbit.

3. The time required for a planet to make one orbital circuit, when squared, is proportional to the cube of the major axis of the orbit (figure 55c).

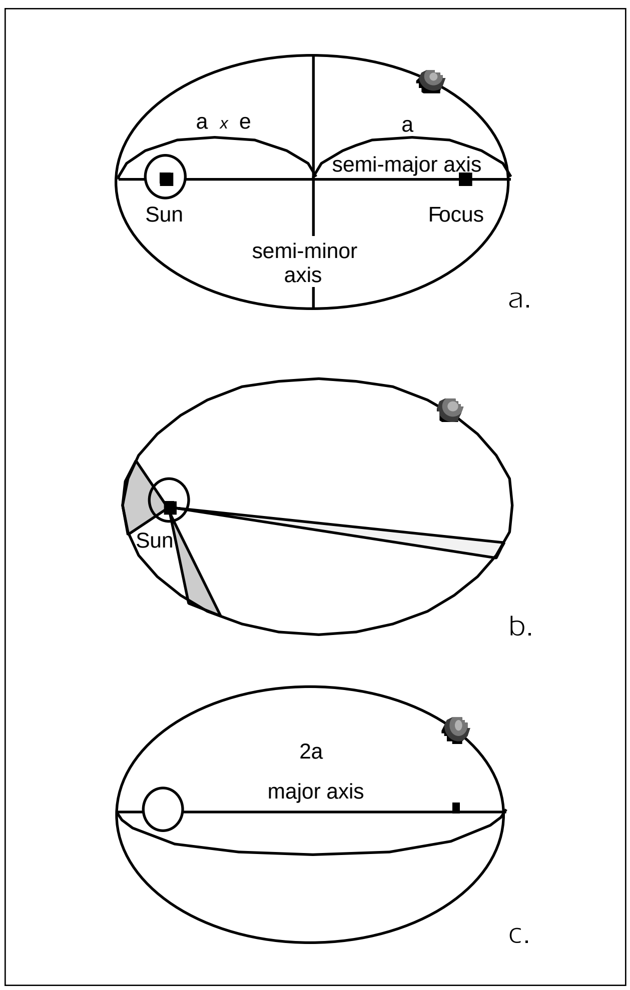


figure 55.

Keplerian elements

K eplerian elements

Also known as satellite orbital elements, Keplerian elements are the set of six independent constants which define an orbit—named for Johannes Kepler. The constants define the shape of an ellipse or hyperbola, orient it around its central body (in the case of environmental satellites the central body is Earth), and define the position of a satellite on the orbit. The classical orbital elements are:

Keplerian elements

a: semi-major axis, gives the size of the orbit,

e: eccentricity, gives the shape of the orbit,

i: inclination angle, gives the angle of the orbit plane to the central body's equator,

Ω: right ascension of the ascending node, which gives the rotation of the orbit plane from reference axis,

ω: argument of perigee is the angle from the ascending nodes to perigee point, measured along the orbit in the direction of the satellite's motion,

θ: true anomaly gives the location of the satellite on the orbit.

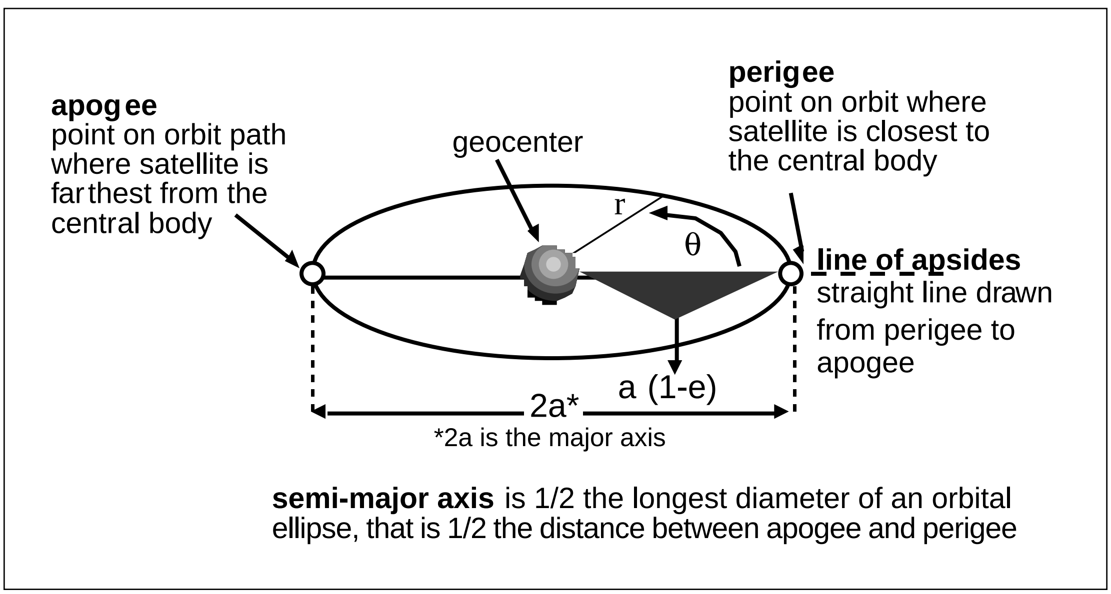


figure 56.

ORBITAL DATA

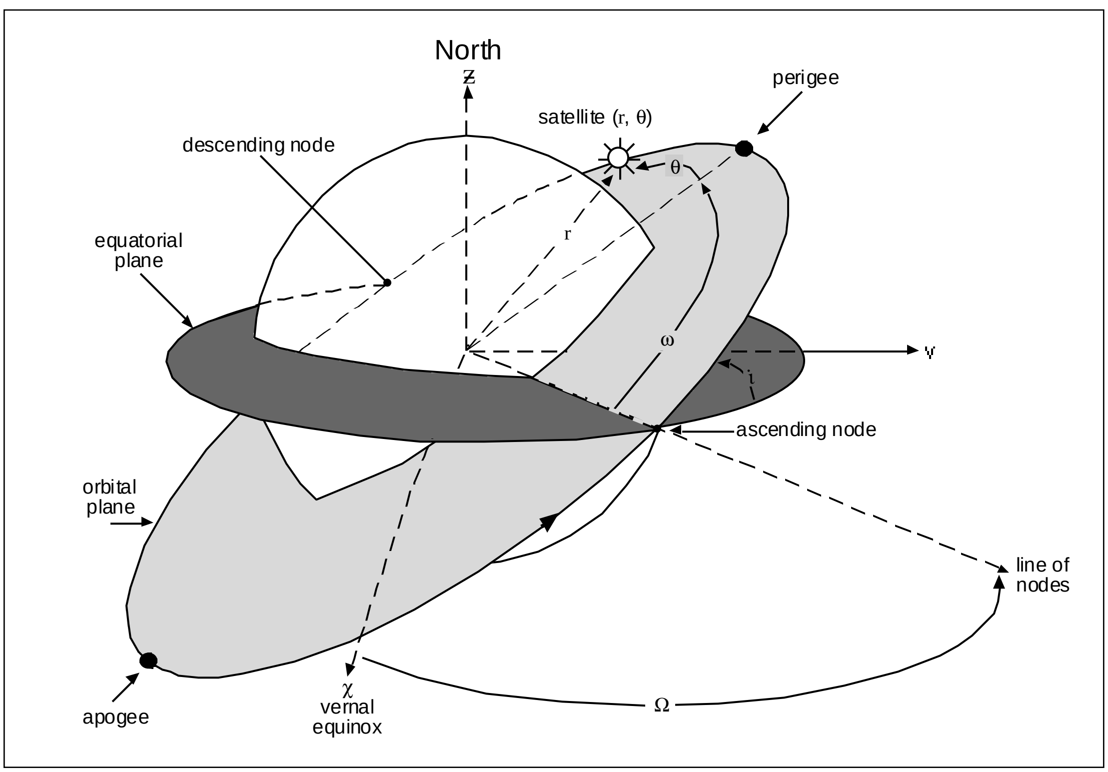
Section 3

Keplerian elements make it possible to describe a satellite's orbit and locate a satellite on its orbit at a particular time. In addition to furnishing a universal language for chronicling and pinpointing satellites, these elements provide the information necessary to predict the passage of specific satellites. That ability is essential to users of direct readout from polar-orbiting satellites.

NOAA and METEOR-series polar-orbiting environmental satellites continuously transmit low-resolution imagery of Earth as an AM signal corresponding to the reflected radiation of Earth as observed by sensors. This results in a strip of image as long as the transmission is received and as wide as the scanning instrument is designed to cover (typically 1700 miles in width). A normal reception period is approximately 14 minutes. However, not every one of a polar-orbiting satellite's 14 daily passes will be within reception range of a particular ground station; nor will every receivable pass be in optimal reception range. Limited reception occurs because, in order to provide global coverage, satellites in polar-orbits provide imagery in slightly-overlapping swaths (see satellite chapter for polar orbiter coverage). Ascending satellites move westward with each orbit, descending satellites move eastward with each orbit.

Ephemeris data (a collection of data showing the daily positions of satellites) is provided by NASA, NOAA, and electronic bulletin boards (pages 114–115). The data can be inserted into satellite tracking programs or used to manually calculate satellite positions. The next page describes the composition of the NASA two-line orbital elements.

figure 57.



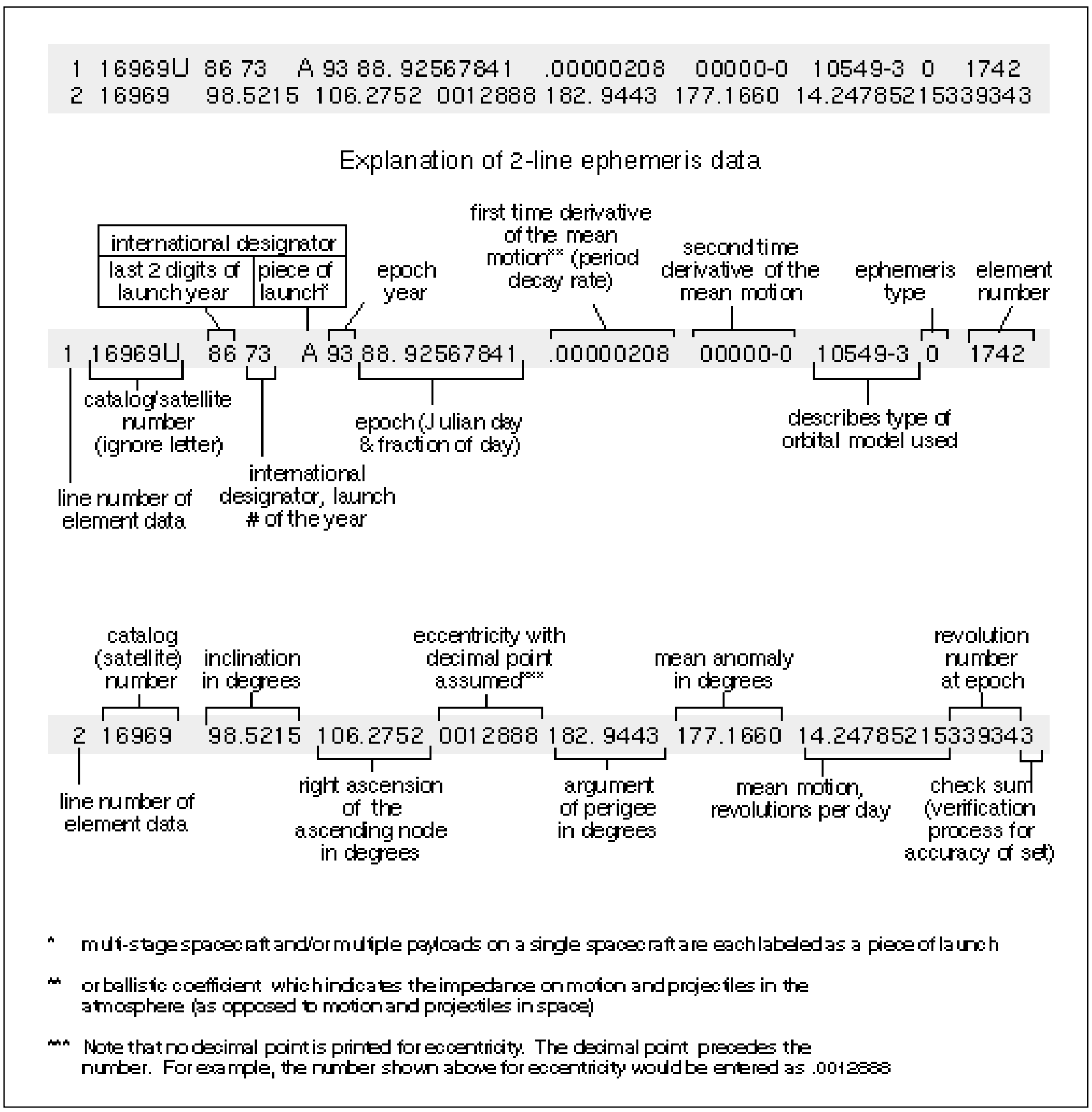
Description of NASA Orbital Data

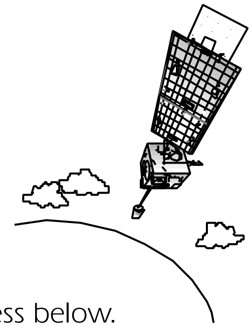
Ephemeris data is a tabulation of a series of points which define the position and motion of a satellite. This data, required by most tracking programs, is contained in the NASA two line orbital elements. These elements are part of the NASA prediction bulletin, which is published by NASA Goddard Space Flight Center and contains the latest orbital information for a particular satellite. The report provides information in three parts:

1. two line orbital elements
2. longitude of the South to North equatorial crossings
3. longitude and heights of the satellite crossings for other latitudes

The two line orbital elements look like this when you get them from NASA (this set is a description of NOAA 10).

figure 58. chart courtesy of Charles Davis





Obtaining NASA Orbital Data From NASA

NASA uses two methods to provide orbital data, mail and electronic distribution. Anyone interested in obtaining data through either method should contact the Goddard Space Flight Center at the address below. Requests for the more costly and less-timely mailed data sets should be restricted to users who are not equipped to obtain the information electronically.

A modem (14400/9600/2400/1200 baud) and computer software are required to electronically download the data sets.

Write and request electronic access and a password—or request mailed information—from the Orbital Information Group's (OIG) RAID* Bulletin Board System (RBBS) at:

NASA Goddard Space Flight Center
Project Operations Branch/513
Attn: Orbital Information Group
Greenbelt, Maryland 20771

You cannot log on without having received approval and a password from OIG.

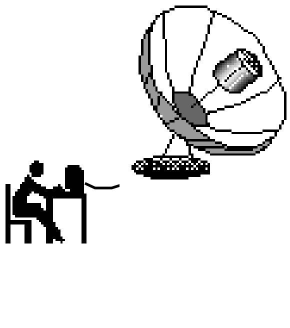
The RBBS provides access to the latest element sets twenty-four hours a day, from anywhere in the world. Two-line Orbital Elements (TLE's) are updated on the following schedule:

Monday	TLE's revised between 1200 GMT Friday and 1200 GMT Monday
Wednesday	TLE's revised between 1200 GMT Monday and 1200 GMT Wednesday
Friday	TLE's revised between 1200 GMT Wednesday and 1200 GMT Friday.

When a holiday falls on a scheduled update day, updating will be done on the next working day.

Data obtained from the RBBS is in a slightly different format from that required by tracking programs such as BIRD DOG, INSTANTRACK, STSORBIT, AND TRAKSAT. The data received from RBBS can't be used directly in these tracking programs without first filtering it with a computer program. The DRIG and Bordertech BBS's have posted programs to simplify conversion to the standard format. RBBS data may be manually entered into the INSTANTRACK program.

* Orbital Information Group's Report and Information Dissemination (RAID) section



Other Sources for Satellite Data

Keplerian elements can be obtained from the following electronic bulletin boards, with a modem, at no charge other than any long-distance telephone fees.

Celestial RCP/M
(205) 409-4280
Montgomery, Alabama
SYSOP: Dr. T.S. Kelso
24 hours
9600/2400/1200 baud
8 bit NO parity 1 stop
xmodem protocol only

BorderTech Bulletin Board
(410) 239-4247
Hampstead, Maryland
SYSOP: Charles A. Davis, Sr.
24 hours
14.400/9600/2400 baud
8 bit NO parity 1 stop

Datalink Remote Bulletin
Board System
(214) 394 - 7438
Carrollton, Texas
SYSOP: Dr. Jeff Wallach
24 hours
14.400/9600/2400 baud
8 bit NO parity 1 stop

Instructions for transferring the data directly from the source to your computer. These instructions apply only to the DRIG and BorderTech BBS's.

Dial the BBS and login.
After login, type "D" for download,
type "BULLET90" as the file to download, open a ZMODEM file transfer mode with your telecommunications software. (The file is always named BULLET90.)
After download, log out of the BBS.

Satellite Tracking Programs

Section 4

The tracking of polar-orbiting satellites by direct readout users is now commonly accomplished by computer—although it is possible to calculate the satellite's location rather than having the computer do the work.

One frequently used tracking program, entitled Bird Dog, is available on NASA Spacelink (see the *Resources* section for more information about NASA Spacelink), and the DRIG and Bordertech bulletin board systems. This software enables the tracking of environmental satellites, but it does require that current orbital data be inserted and that the orbital data be revised every two or three weeks. (Using old data makes it impossible for any software to accurately identify the current position of a satellite.) Instructions for using Bird Dog and updating the ephemeral data accompany the tracking program.

Ground Station Set-up

Environmental satellites, equipped with a variety of sensors, monitor Earth and transmit the information back to Earth electronically. These signals are received by a ground station, also known as an Earth station. The signals are displayed as images on a computer monitor that is a component of a ground station, see the diagram on page 119.

The NASA publication entitled *Direct Readout From Environmental Satellites, A Guide to Equipment and Vendors* (EP-301) describes ground station components and sources of the equipment. See the introduction to this *Training Manual* for more information about the *Guide*.

This section describes the procedure for placement and installation of a ground station to ensure optimal signal reception and system operation. The procedure outlined below is described in detail on the following pages.

- **Identify appropriate locations for the computer and antenna(s)*.**
- **Drill holes in the exterior wall for coaxial cable.**
- **Set-up the antenna(s) by attaching it to either the building or to a plywood base.**
- **(Geostationary system only) Attach feedhorn and down-converter to the parabolic dish.**
- **Connect the receiver and antenna with coaxial cable.**

Consult appropriate personnel to ensure compliance with local building and electrical codes.

Local amateur radio clubs may be able to assist with installation. To locate the club nearest you, contact:

American Radio Relay League
225 Main Street
Newington, Connecticut 18601

**** A system which receives both polar orbiter and geostationary images uses an antenna and a feedhorn, downconverter, and parabolic dish.***

GROUND STATION SET-UP

Section 1 Ground Station Configuration 119

Section 2 Setting-Up 120
Placing the System
Polar-Orbiter System Antenna
Geostationary System Antenna
Feedhorn
Downconverter
Antenna Feedline
System Safety

GROUND STATION CONFIGURATION

Section 1

Direct readout ground station components

polar-orbiting system	requires a personal computer and a receiver connected to an antenna by coaxial cable
geostationary system	requires a personal computer, a receiver, feedhorn, down-converter and a parabolic dish connected by coaxial cable
dual system	may require all of the above, although the basic set-up varies among manufacturers

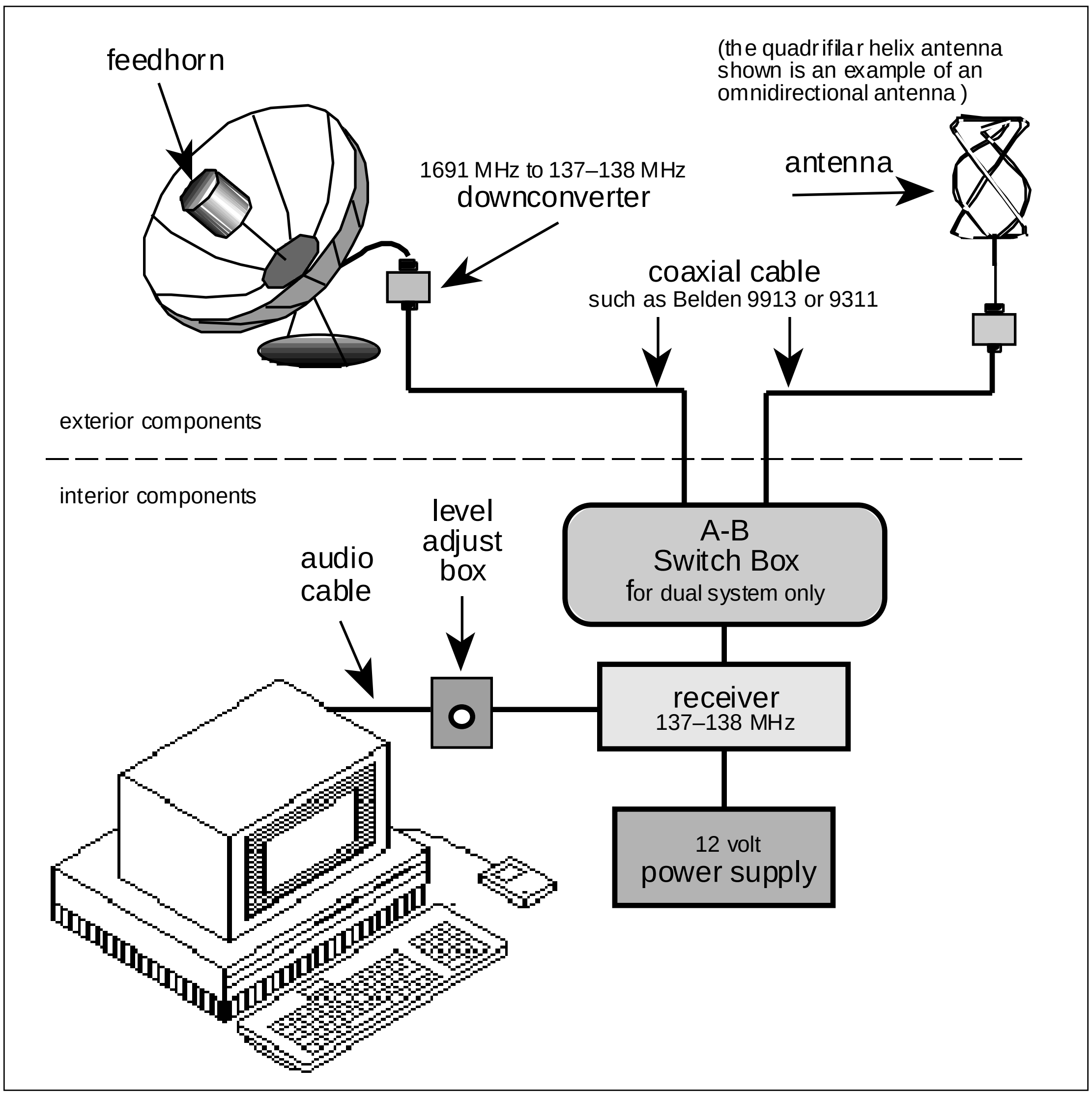


figure 59.

SETTING-UP

Section 2

Placing the System

The computer equipment and antenna(s) should be placed as close to each other as possible to minimize radio signal loss and interference. The computer and receiver should be adjacent and easily accessible to an exterior wall and electrical outlet. Locate the equipment so that is protected from water, sinks, and gas jets. The equipment should be accessible to users but placed so that electrical and cable connections won't be disturbed.

The antenna(s) will be located on the roof, away from power lines, electric motors, and exhaust vents. The antennas should be grounded to a cold water pipe in order to drain atmospheric static charges and to protect the computer and receiving equiment.

Polar-orbiter System Antenna

Antennas for polar-orbiter systems should be located at the highest point on the building, away from surrounding objects such as air conditioning units. The antenna can be attached directly to the building or mounted on a weighted plywood base. Either technique requires a standard exterior TV antenna mast and associated mounting hardware. To mount the antenna, use a TV mast support tripod and bolt the tripod to a 4' x 4' x 3/4" sheet of exterior-grade plywood. Place at least three 50-pound bags of cement or gravel on the plywood sheet for stability. If using bags of cement, poke several small holes into the top of the bag to allow rain to wet the concrete and provide additional stabilization.

Geostationary System Antenna

Antennas for geostationary systems require an unobstructed, direct line-of-sight path to the satellite. A geostationary ground station typically uses a six foot parabolic reflector known as a satellite dish. (A TV satellite dish may be used but requires sophisticated modification.) The satellite dish should be located on a flat roof. Installation will be dictated by the desired mounting, but the mounting platform or structure for the dish must be secured to prevent the dish from moving in the wind. It should be weighted, as above.

A Yagi antenna may be used to receive geostationary images and should be installed according to the manufacturer's instructions.

Feedhorn

A feedhorn is a metallic cylinder which collects the radio signal reflected from the satellite dish. The feedhorn, available as either an open or closed cylinder, contains a probe which is the antenna. The closed feedhorn prevents birds from nesting and protects the antenna from snow and rain. The feedhorn is mounted on a strut(s) that positions it at a specified distance from the parabolic reflector.

Aim the feedhorn to face the parabolic reflector. With an open feedhorn, turn the open end (the other end is closed) toward the satellite dish. With a closed feedhorn, turn the plastic-covered end (the other end is metal) toward the dish.

Note that the antenna inside the feedhorn must be mounted in a vertical position for GOES (U.S.) satellite reception and in a horizontal position for METEOSAT (European) satellite reception. Enclosed feedhorns are marked horizontal and vertical. The placement of the antenna must be correct to receive the desired signal.

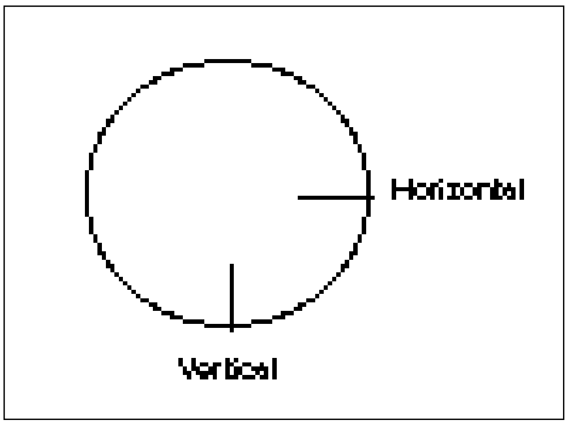


figure 60.

Downconverter

A downconverter is required to convert geostationary satellite signals to a form that can be used by the computer. Power is supplied to the downconverter by either a separate 12-volt source applied directly to the unit or by the receiver. The downconverter is housed in a weather-proof case with predrilled mounting holes and connected to the feedhorn with coaxial cable. Typically, the signal strength from a downconverter is high enough to permit the use of a smaller diameter cable between the downconverter and receiver. Cable runs of less than 200 feet may use a cable such as Belden 9311. Longer runs should use Belden 9913.

Antenna feedline

The antenna feedline is perhaps the most important component in a ground station. A good feedline will provide maximum signal while reducing stray radio frequency (RF) or man-made noise (interference). Coaxial cable is feedline whose center conductor has been encased in dielectric material with an outer braided shield. The shielding greatly reduces the introduction of RF or man-made noise into the receiving system. Avoid inexpensive cable that will not provide adequate shield or lasting construction.

Cable such as Belden 9913 and 9311 have a special foil wrap around the dielectric in addition to the copper braid. 9311 cable is approximately 1/4 inch in diameter and a good choice for cable runs of less than one hundred feet. 9913 is about 1/2 inch in diameter and will necessitate additional coaxial cable adapters if the antenna or receiver require a BNC-type connection. Support for the cable must be provided at BNC connection to av
mated connector on the receiver or

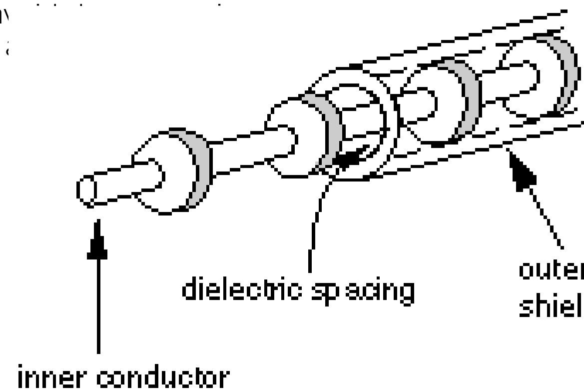


figure 61.

Never:
Run the antenna feedline next to power lines or electric cables
Bend the coaxial cable sharply
Run the cable through a window and shut the window on the cable
Use twist-on cable connectors
Pull or twist connectors installed on the cable
Allow cable to be walked on or crushed
Leave the antenna feedline connected to your receiver during electrical storms

Always:
Solder the shield of the coaxial cable to the connector
(not applicable for crimp connectors)
Ground the antenna to a cold water pipe or grounding rod, or both
Secure the antenna feedline so that the wind cannot sway it
Seal the antenna connection with electrical tape or non-conductive sealant
Purchase the best cable available
Replace worn or broken cables and ground connections immediately
Inspect the system at least once a year to reduce trouble-shooting time

System Safety

Once the system is set-up, always disconnect the antenna at the conclusion of use and during storms to prevent damage to the system.

Resources

A variety of resources are available to teachers, many of those listed have education materials available without charge. ***Please note the importance of making requests on school letterhead.***

Many excellent publications about, or organizations focusing on Earth system science, weather, remote-sensing technology, and space exist. Those appearing in the resource section were listed because of their relevancy to the use of environmental satellite imagery and their accessibility nation-wide.

Many additional resources are likely to be located in your area.

- Contact your local Red Cross or office of emergency preparedness for information about severe or hazardous weather;
- contact local science centers or museums for information related to global change, the atmosphere, satellites, etc.;
- utilize your school's, school system's, or county's experts to assist you with technology;
- contact nearby colleges and universities for assistance/collaboration on atmospheric studies, Earth observation, etc.;
- contact your local newspapers and television stations for information about how weather forecasts are prepared. All of these suggested sources are also potential providers of guest speakers.

Resources

Section 1 Bulletin Boards 125

Section 2 Federal Agencies and Programs 126

Section 3 NASA Educational Resources 128
- NASA Spacelink
- NASA Education Satellite Videoconference Series
- NASA Television
- NASA Teacher Resource Center Network
  - Regional Teacher Resource Center
  - NASA Core
  - General Information for Teachers and Students

Section 4 National Oceanic and Atmospheric Administration 132

Section 5 Organizations 134

Section 6 Vendors 136

Section 7 Weather Service Forecast Office Locations 137
- Weather Service River Forecast Centers

Section 8 Internet 140
- AskERIC
- Internet Society
- Anonymous File Transfer Protocol
- Gopher
- World Wide Web Servers
- Books, Articles, and Other Resources

Bulletin Boards

Section 1

Keplerian Elements

Keplerian Elements, or satellite orbital elements, are the group of numbers required to define a satellite orbit. The elements are a critical components of satellite tracking and essential to APT system-users for identifying optimal signal reception. Keplerian elements can be obtained by modem, at no charge other than the long distance phone fees, from the following electronic bulletin boards.

NASA Spacelink
205-895-0028
Huntsville, Alabama
24 hours
2400/1200/300 baud
8 bit NO parity 1 stop
or through Internet:
World Wide Web — http://spacelink.msfc.nasa.gov
Gopher — gopher://spacelink.msfc.nasa.gov
Anonymous FTP — ftp://spacelink.msfc.nasa.gov
Telnet — telnet://spacelink.msfc.nasa.gov

Two-line Keplerian elements are contained in the following directory of NASA Spacelink:
instructional materials/software/tracking elements

Celestial RCP/M
(205) 409-4280
Montgomery, Alabama
SYSOP: Dr. T.S. Kelso
24 hours
9600/2400/1200 baud
8 bit NO parity 1 stop

BorderTech Bulletin Board
410-239-4247
Hampstead, Maryland
SYSOP: Mr. Charlie Davis
24 hours
14400/9600/2400/300 baud
8 bit NO parity 1 stop

Datalink Remote Bulletin Board System
(Dallas Remote Imaging Group)
214-394-7438
Carrollton, Texas
SYSOP: Dr. Jeff Wallach
24 hours
9600/2400/1200 baud
8 bit NO parity 1 stop

For BorderTech Bulletin Board and Datalink RBB System:

Dial the BBS and login.
Type "D" for download,
Type "BULLET90" as the file to download,
Open a ZMODEM file transfer mode with your telecommunications software.
(The file name is always called BULLET90.)
This will transfer the NASA 2-line elements to a file on the users computer.
Log out of the BBS.

Federal Agencies and Programs

Section 2

The GLOBE Program
Thomas N. Pyke, Jr., Director
744 Jackson Place
Washington, DC 20503
(202) 395-7600
FAX (202) 395-7611

Global Learning and Observations to Benefit the Environment (GLOBE) is an international science and education program, which is establishing a network of K–12 students throughout the world making and sharing environmental observations.

National Air and Space Museum
Education Resource Center (ERC)
MRC 305, NASM
Washington, DC 20560
(202) 786-2109

For teachers of grades K–12, ERC offers educational materials about aviation, space exploration, and the Museum's collections, including curriculum packets, videotapes, slides, filmstrips, and computer software. Free newsletter published three times annually.

National Center for Atmospheric Research (NCAR)
PO Box 3000
Boulder, Colorado 80307-3000
(303) 497-1000

Educational materials, request ordering information.

U.S. Department of Agriculture
Soil Conservation Service
Public Information
PO Box 2890, Room 6110
Washington, DC 20013

Conservation education activities and technical information on soil, water, and other resources.

U.S. Department of Energy
National Energy Information Center EI-231
Room 1F-048, Forrestal Building
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-8800

Energy-related educational materials for primary and secondary students and educators, free or low cost.

U.S. Environmental Protection Agency
Public Information Center
401 M Street, SW
Washington, DC 20460
(202) 260-7751

Request list of publications, many of them free, and a sample copy of *EPA Journal*, a forum for the exchange of ideas in elementary-level environmental education.

U.S. Geological Survey
Geological Inquiries Group
907 National Center
Reston, VA 22092
(703) 648-4383

Teacher's packet of geologic materials and geologic teaching aids, information for ordering maps. Requests must be on school stationary and specify grade.

Hydrologic Information Unit
Water Resources Division
419 National Center
Reston, VA 22092

Free *Water Resources Div. Info Guide*, water fact sheets (Acid Rain, Regional Aquifer Systems of the U.S., Largest Rivers in the U.S., Hydrologic Hazards in Karst Terrain); leaflets (Groundwater: The Hydrologic Cycle).

U.S. Government Printing Office
Superintendent of Documents
Washington, DC 20402
(202) 783-3238

Request free *Subject Bibliography Index* that gives descriptions, prices, and ordering instructions.

University Corporation for Atmospheric Research (UCAR)
Office for Interdisciplinary Earth Studies
PO Box 3000
Boulder, Colorado 80307-3000
(303) 497-2692
FAX (303) 497-2699
Internet: oies@ncar.ucar.edu

Educational materials, including a series of three climate publications under the series Reports to the Nation On Our Changing Planet:
The Climate System (Winter 1991);
Our Ozone Shield (Fall 1992) ; and
El Niño and Climate Prediction (Spring 1994).

NASA Educational Resources

Section 3

NASA Spacelink: An Electronic Information System

NASA Spacelink is an electronic information system designed to provide current educational information to teachers, faculty, and students. Spacelink offers a wide range of materials (computer text files, software, and graphics) related to the space program. Documents on the system include: science, mathematics, engineering, and technology education lesson plans; historical information related to the space program; current status reports on NASA projects; news releases; information on NASA edcuational programs; NASA educational publications; and other materials such as computer software and images, chosen for their educational value and relevance to space education. The system may be accessed by computer through direct-dial modem or the Internet.

Spacelink's modem line is (205) 895-0028.
Data format 8-N-1, VT-100 terminal emulation required.
The Internet TCP/IP address is 192.149.89.61
Spacelink fully supports the following Internet services:

World Wide Web:	http://spacelink.msfc.nasa.gov
Gopher:	spacelink.msfc.nasa.gov
Anonymous FTP:	spacelink.msfc.nasa.gov
Telnet:	spacelink.msfc.nasa.gov (VT-100 terminal emulation required)

For more information contact:
Spacelink Administrator
Education Programs Office
Mail Code CL 01
NASA Marshall Space Flight Center
Huntsville, AL 35812-0001
Phone: (205) 554-6360

NASA Education Satellite Videoconference Series

The Education Satellite Videoconference Series for Teachers is offered as an inservice education program for educators through the school year. The content of each program varies, but includes aeronautics or space science topics of interest to elementary and secondary teachers. NASA program managers, scientists, astronauts, and education specialists are featured presenters. The videoconference series is free to registered educational institutions. To participate, the institution must have a C-band satellite receiving system, teacher release time, and an optional long distance telephone line for interaction. Arrangements may also be made to receive the satellite signal through the local cable television system. The programs may be videotaped and copied for later use. For more information, contact:

Videoconference Producer
NASA Teaching From Space Program
308 A CITD
Oklahoma State University
Stillwater, OK 74078-0422
E-Mail: nasaedutv@smtpgate.osu.hq.nasa.gov

NASA Television

NASA Television (TV) is the Agency's distribution system for live and taped programs. It offers the public a front-row seat for launches and missions, as well as informational and educational programming, historical documentaries, and updates on the latest developments in aeronautics and space science.

The educational programming is designed for classrooom use and is aimed at inspiring students to achieve–especially in science, mathematics, and technology. If your school's cable TV system carries NASA TV or if your school has access to a satellite dish, the programs may be downlinked and videotaped. Daily and monthly programming schedules for NASA TV are also available via NASA Spacelink. NASA Television is transmitted on Spacenet 2 (a C-band satellite) on transponder 5, channel 8, 69 degrees West with horizontal polarization, frequency 3880.0 Megahertz, audio on 6.8 megahertz. For more information contact:

NASA Headquarters
Technology and Evaluation Branch
Code FET
Washington, DC 20546-0001

NASA Teacher Resource Center Network

To make additional information available to the education community, the NASA Education Division has created the NASA Teacher Resource Center (TRC) network. TRCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Because each NASA Field Center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area. A list of the Centers and the geographic regions they serve starts on page 130.

Regional Teacher Resource Centers (RTRCs) offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as RTRCs in many states. Teachers may preview, copy, or receive NASA materials at these sites. A complete list of RTRCs is available through CORE.

NASA Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalogue of these materials and an order form by written request, on school letterhead to:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294

General Information for Teachers and Students

If You Live In:		Center Education Program Officer	Teacher Resource Center
Alaska Arizona California Hawaii Idaho Montana	Nevada Oregon Utah Washington Wyoming	Mr. Garth A. Hull Chief, Education Programs Branch Mail Stop 204-12 NASA Ames Research Center Moffett Field, CA 94035-1000 PHONE: (415) 604-5543	NASA Teacher Resource Center Mail Stop T12-A NASA Ames Research Center Moffett Field, CA 94035-1000 PHONE: (415) 604-3574
Connecticut Delaware DC Maine Maryland Massachusetts	New Hampshire New Jersey New York Pennsylvania Rhode Island Vermont	Mr. Richard Crone Educational Programs Code 130 NASA GSFC Greenbelt, MD 20771-0001 PHONE: (301) 286-7206	NASA Teacher Resource Lab. Mail Code 130.3 NASA GSFC Greenbelt, MD 20771-0001 PHONE: (301) 286-8570
Colorado Kansas Nebraska New Mexico	North Dakota Oklahoma South Dakota Texas	Dr. Robert W. Fitzmaurice Center Education Program Officer Education and Public Services Branch - AP2 NASA Johnson Space Center Houston, TX 77058-3696 PHONE: (713) 483-1257	NASA Teacher Resource Room Mail Code AP2 NASA Johnson Space Center Houston, TX 77058-3696 PHONE: (713) 483-8696
Florida Georgia Puerto Rico Virgin Islands		Dr. Steve Dutczak Chief, Education Services Branch Mail Code PA-ESB NASA Kennedy Space Center Kennedy Space Center, FL 32899-0001 PHONE: (407) 867-4444	NASA Educators Resource Lab. Mail Code ERL NASA Kennedy Space Center Kennedy Space Center, FL 32899-0001 PHONE: (407) 867-4090
Kentucky North Carolina South Carolina Virginia West Virginia		Ms. Marchelle Canright Center Education Program Officer Mail Stop 400 NASA Langley Research Center Hampton, VA 23681-0001 PHONE: (804) 864-3313	NASA Teacher Resource Center NASA Langley Research Center Virginia Air and Space Center 600 Settler's Landing Road Hampton, VA 23699-4033 PHONE: (804)727-0900 x 757
Illinois Indiana Michigan	Minnesota Ohio Wisconsin	Ms. Jo Ann Charleston Acting Chief, Office of Educational Programs Mail Stop 7-4 NASA Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135-3191 PHONE: (216) 433-2957	NASA Teacher Resource Center Mail Stop 8-1 NASA Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135-3191 PHONE: (216) 433-2017

If You Live In:	Center Education Program Officer	Teacher Resource Center
Alabama Arkansas Iowa Louisiana Missouri Tennessee	Mr. JD Horne Director, Education Programs Office Mail Stop CL 01 **NASA MSFC** Huntsville, AL 35812-0001 PHONE: (205) 544-8843	NASA Teacher Resource Center NASA MSFC U.S. Space and Rocket Center P.O. Box 070015 Huntsville, AL 35807-7015 PHONE: (205) 544-5812
Mississippi	Dr. David Powe Manager, Educational Programs Mail Stop MA00 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529-6000 PHONE: (601) 688-1107	NASA Teacher Resource Center Building 1200 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529-6000 PHONE: (601) 688-3338
The Jet Propulsion Laboratory (JPL) Center serves inquiries related to space and planetary exploration and other JPL activities.	Dr. Fred Shair Manager, Educational Affairs Office Mail Code 183-900 **NASA Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109-8099 PHONE: (818) 354-8251	NASA Teacher Resource JPL Educational Outreach Mail Stop CS-530 **NASA Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109-8099 PHONE: (818) 354-6916
California (mainly cities near Dryden Flight Research Facility)		NASA Teacher Resource Center Public Affairs Office (Trl. 42) **NASA Dryden Flight Research Facility** Edwards, CA 93523-0273 PHONE: (805) 258-3456
Virginia and Maryland's Eastern Shores		NASA Teacher Resource Lab NASA GSFC **Wallops Flight Facility** Education Complex - Visitor Center Building J-17 Wallops Island, VA 23337-5099 Phone: (804) 824-2297/2298

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

Section 4

Educational Affairs Division
Joan Maier McKean, Educational Affairs, E3
SSMC4, Room 1W225
1305 East West Highway
Silver Spring, Maryland 20910
(301) 713-1170
FAX (301) 713-1174

National Climatic Data Center
National Oceanic and Atmospheric Admin.
Federal Building
Asheville, NC 28801-2696

Archived, historical climate data.

National Environmental Satellite, Data, and Information Service (NESDIS)
Colby Hostetler
NESDIS Outreach Office
Federal Building 4, Room 1045
Suitland, Maryland 20233
(301) 763-4691
FAX (301) 763-4011

NESDIS primary education goal is to enable teachers to access and interpret satellite imagery as an Earth science education tool. Data can be accessed by direct readout from orbiting satellites or via the Internet.

National Marine Sanctuary Program and the
National Estuarine Research Reserve System
Lauri MacLaughlin, Education Coordinator
Sanctuaries and Reserves Division
SSMC4, Room 12409
1305 East West Highway
Silver Spring, Maryland 20910
(301) 713-3145
FAX (301) 713-0404

Identify, designate and manage areas of the marine environment of national significance. Thirteen sanctuaries have been established, visitor centers at these sites promote education activities

NOAA Public Affairs Office
Correspondence Unit
Room 317
1825 Connecticut Avenue NW
Washington, DC 20235

Limited number of publications suitable for classroom instruction that teachers can request by mail. Some of these titles are available on the Internet.

National Sea Grant College Program

Director, National Sea Grant College Program
SSMC3, Room 11843
1315 East West Highway
Silver Spring, Maryland 20910
(301) 713-2431
FAX (301) 713-0799

Develop and analyze U.S. marine resources. Office's divisions are: living resources, non-living resources, technology and commercial development, environmental studies and human resources

National Snow and Ice Data Center (NSIDC)

Box 449
Cires Campus
University of Colorado
Boulder, Colorado 80309
(303) 492-6197

National Weather Service (NWS)

Ron Gird
Office of Meteorology
SSMC2, Room 14110
1325 East West Highway
Silver Spring, Maryland 20910
(301) 713-1677
FAX (301) 713-1598

Supports educational programs developed by a variety of outside organizations such as American Meteorological Society and the Weather Channel. Provides a series of publications on severe weather and broadcasts NOAA weather radio to increase public awareness and responsibility in the event of severe weather.

Organizations

Section 5

American Meteorological Society
1701 K Street NW, Suite 300
Washington, DC 20006-1509

Request information about the Atmospheric Education Resource Agent (AERA) program and the AERAs in your state.

American Radio Relay League
225 Main Street
Newington, Connecticut 18601

Amateur club with local chapters, possible source of technical assistance with equipment.

American Weather Observer
401 Whitney Boulevard
Belvedere, Illinois 61008-3772

Weather interest group with publication.

Amsat
PO Box 27
Washington, DC 20044
(301) 589-6062
FAX (301) 608-3410

Non-profit organization, members are a potential source of local technical assistance to schools (e.g., direct readout ground station set-up), Amsat also publishes low-cost software.

AskEric
ERIC Clearinghouse on Information Resources
Center for Science and Technology
Syracuse University
Syracuse, New York 13244-4100
(315) 443-9114
(315) 443-5448
email: askeric@ericir.syr.edu

See ***The Internet,*** this section

Dallas Remote Imaging Group (DRIG) Information System
Dallas, Texas
SYSOP: Dr. Jeff Wallach
(214) 394-7438
24 hours
14.400/9600/2400 baud
8 bit NO parity 1 stop

International organization of professionals interested in image-processing techniques, tracking satellites, and telemetry analysis. DRIG's bulletin board system provides Keplerian elements free; fee to access other services.

Educational Center for Earth Observation Systems
School of Education
West Chester University
West Chester, Pennsylvania 19383
(215) 436-2393
FAX (215) 436-3102

Annual (March) Satellites and Education Conference, other educational information.

International Weather Watchers
PO Box 77442
Washington, DC 20013
American weather interest group with publication.

Internet Society
1895 Preston White Drive, Suite 100
Reston, Virginia 22091
(703) 648-9888
FAX(703) 620-0913
email: isoc@isoc.org

See ***The Internet,*** this section

The Weather Channel
Education Services
2690 Cumberland Parkway
Atlanta, Georgia 30339
(404) 801-2503

Televised weather documentaries, educational programming, educational materials for sale.

Vendors

Section 6

This is not an endorsement, recommendation, or guarantee for any person or product, nor does a listing here imply a connection with NASA or the MAPS-NET project. These vendors sell direct readout hardware, software, and/or services.

Amsat
PO Box 27
Washington, DC 20044
(301) 589-6062
FAX (301) 608-3410

Clear Choice Education Products
PO Box 745
Helen, Georgia 30545
800 533-5708
FAX (706) 865-7808

ERIM
Earth Observation Group
PO Box 134001
Ann Arbor, Michigan 48113
(313) 994-1200, ext 3350
FAX (313) 668-8957

Fisher Scientific
4901 West LeMoyne Street
Chicago, Illinois 60651
800 955-1177
FAX (312) 378-7174

GTI
1541 Fritz Valley Road
Lehighton, Pennsylvania 18235
(717) 386-4032
FAX (717) 386-5063

Lone Eagle Systems Inc.
5968 Wenninghoff Road
Omaha, Nebraska 68134
(402) 571-0102
FAX (402) 572-0745

Marisys Inc.
131 NW 43rd Street
Boca Raton, Florida 33431
(407) 361-0598
FAX (407) 361-0599

MultiFAX
143 Rollin Irish Road
Milton, Vermont 05468
(802) 893-7006
FAX (802) 893-6859

OFS Weatherfax
6404 Lakerest Court
Raleigh, North Carolina 27612
(919) 847-4545

Quorum Communications, Inc.
8304 Esters Boulevard
Suite 850
Irving, Texas 75063
800-982-9614
(214) 915-0256
FAX (214) 915-0270
BBS (214) 915-0346

Satellite Data Systems, Inc.
800 Broadway Street
PO Box 219
Cleveland, Minnesota 56017
(507) 931-4849
FAX same as voice number

Software Systems Consulting
615 S. El Camino Real
San Clemente, California 92672
(714) 498-5784
FAX (714) 498-0568

Tri-Space Inc.
PO Box 7166
McLean, Virginia 22106-7166
(703) 442-0666
FAX (703) 442-9677

U.S. Satellite Laboratory
8301 Ashford Blvd., Suite 717
Laurel, Maryland 20707
(301) 490-0962
FAX (301) 490-0963

Vanguard Electronic Labs
196-23 Jamaica Avenue
Hollis, New York 11423
(718) 468-2720

Weather Forecast Office Locations

Section 7

The following are Weather Forecast Office locations proposed under the National Weather Service modernization. Teachers are encouraged to contact their nearest office for information about local and hazardous weather.

WFO Name—Metropolitan Area	Proposed Office Location
Aberdeen, SD	Aberdeen Regional Airport
Albany, NY	State University of New York, Albany
Albuquerque, NM	Albuquerque International Airport
Amarillo, TX	Amarillo International Airport
Anchorage, AK	Anchorage International Airport
Atlanta, GA	Falcon Field, Peachtree City
Austin/San Antonio, TX	New Braunfels Municipal Airport
Baltimore, MD/Washington, DC	Sterling, VA
Billings, MT	Billings-Logan International Airport
Binghamton, NY	Binghamton Regional - Edwin LInk Field
Birmingham, AL	Shelby County Airport
Bismarck, ND	Bismarck Municipal Airport
Boise, ID	Boise Interagency Fire Center
Boston, MA	Taunton, MA
Brownsville, TX	Brownsville International Airport
Buffalo, NY	Greater Buffalo International Airport
Burlington, VT	Burlington International Airport
Central Illinois, IL	Logan County Airport
Central Pennsylvania, PA	State College, PA
Charleston, SC	Charleston International Airport
Charleston, WV	Ruthdale, WV
Cheyenne, WV	Cheyenne Municipal Airport
Chicago, IL	Lewis University Airport
Cincinnati, OH	Wilmington, OH
Cleveland, OH	Cleveland-Hopkins International Airport
Columbia, SC	Columbia Metropolitan Airport
Corpus Christi, TX	Corpus Christi International Airport
Dallas/Fort Worth, TX	Fort Worth, TX
Denver/Boulder CO	Boulder, CO
Des Moines, IA	Johnson, IA
Detroit, MI	Pontiac/Indian Springs Metropark
Dodge City, KS	Dodge City Regional Airport
Duluth, MN	Duluth, MN
Eastern North Dakota, ND	near University of North Dakota
El Paso, TX	Dona Ana County Airport at Santa Theresa, NM
Elko, NV	Elko, NV
Eureka, CA	Woodley Island, CA
Fairbanks, AK	University of Alaska, Fairbanks, AK
Flagstaff, AZ	Navajo Army Depot, Bellmont, AZ
Glasgow, MT	Glasgow City and County Int'l Airport
Goodland, KS	Goodland Municipal Airport

WFO Name—Metropolitan Area	Proposed Office Location
Grand Junction, CO	Walker Field, Grand Junction Airport
Grand Rapids, MI	Kent County International Airport
Great Falls, MT	near Great Falls International Airport
Green Bay, WI	Austin-Straubel Field
Greenville/Spartanburg, SC	Greenville/Spartanburg Airport
Hastings, NE	Hastings, NE
Honolulu, HI	University of Hawaii, Honolulu, HI
Houston/Galveston, TX	League City, TX
Indianapolis, IN	Indianapolis International Airport
Jackson, MS	Jackson Municipal Airport
Jacksonville, FL	Jacksonville International Airport
Juneau, AK	(not yet determined)
Kansas City/Pleasant Hill, MO	Pleasant Hill, MO
Knoxville/Tri Cities, TN	Morristown Airport Industrial District
La Crosse, WI	La Crosse Ridge, La Crosse, WI
Lake Charles, LA	Lake Charles Regional Airport
Las Vegas, NV	Las Vegas, NV
Little Rock, AR	North Little Rock Municipal Airport
Los Angeles, CA	Oxnard, CA
Louisville, KY	Louisville, KY
Lubbock, TX	Lubbock, TX
Marquette, MI	Marquette County Airport
Medford, OR	Medford-Jackson County Airport
Melbourne, FL	Melbourne Regional Airport
Memphis, TN	Agricenter International Complex
Miami, FL	Florida International University
Midland/Odessa, TX	Midland International Airport
Milwaukee, WI	Sullivan Township, Jefferson County
Minneapolis, MN	Chanhassen, MN
Missoula, MT	Missoula International Airport
Mobile, AL	Mobile Regional Airport
Morehead City, NC	Newport, NC
Nashville, TN	Old Hickory Mountain, TN
New Orleans/Baton Rouge, LA	Slidell Airport
New York City, NY	Brookhaven National Lab, Upton, NY
Norfolk/Richmond, VA	Wakefield, VA
North Central Lower Michigan	Passenheim Road, MI
North Platte, NE	North Platte Regional Airport
Oklahoma City, OK	University of Oklahoma Westheimer Airpark
Omaha, NE	Valley, NE
Paducah, KY	Barkley Regional Airport
Pendleton, OR	Pendleton Municipal Airport
Philadelphia, PA	Mt. Holly, NJ
Phoenix, AZ	Phoenix, AZ
Pittsburgh, PA	Coraopolis, PA
Pocatello/Idaho Falls, ID	Pocatello Regional Airport, ID
Portland, ME	Gray, ME

WFO Name—Metropolitan Area	Proposed Office Location
Portland, OR	near Portland International Airport
Pueblo, CO	Pueblo Municipal Airport
Quad Cities, IA	Davenport Municipal Airport
Raleigh/Durham, NC	NC State University, Raleigh, NC
Rapid City, SD	Rapid City, SD
Reno, NV	Reno, NV
Riverton, WY	Riverton Regional Airport
Roanoke, VA	Blacksburg, VA
Sacramento, CA	Sacramento, CA
Salt Lake City, UT	Salt Lake City International Airport
San Angelo, TX	Mathis Field
San Diego, CA	(not yet determined)
San Francisco Bay Area, CA	Monterey, CA
San Joaquin Valley, CA	Hanford Municipal Airport
San Juan, PR	Luis Munoz Marin Int'l Airport
Seattle/Tacoma, WA	NOAA Western Regional Center
Shreveport, LA	Shreveport Regional Airport
Sioux Falls, SD	Sioux Falls Municipal Airport
Spokane, WA	Rambo Road, Spokane, WA
Springfield, MO	Springfield Regional Airport
St. Louis, MO	Research Park, St. Charles County
Tallahassee, FL	Florida State University
Tampa Bay Area, FL	Ruskin, FL
Topeka, KS	Philip Billard Municipal Airport
Tucson, AZ	University of Arizona, Tucson, AZ
Tulsa, OK	Guaranty Bank Building
Wichita, KS	Wichita Mid-Continent Airport
Wilmington, NC	New Hanover International Airport

River Forecast Centers

River Forecast Center Name	Co-located Weather Forecast Office
Southeast RFC	Atlanta, GA
Lower Mississippi RFC	New Orleans/Baton Rouge, LA
Arkansas-Red Basin RFC	Tulsa, OK
West Gulf RFC	Dallas/Fort Worth, TX
Ohio RFC	Cincinnati, OH
Middle Atlantic RFC	Central Pennsylvania, PA
Northeast RFC	Boston, MA
Colorado Basin RFC	Salt Lake City, UT
California-Nevada RFC	Sacramento, CA
Northwest RFC	Portland, OR
North Central RFC	Minneapolis, MN
Missouri Basin RFC	Kansas City/Pleasant Hill, MO
Alaska RFC	Anchorage, AK

The Internet: Another Source of Imagery

Section 8

One of the fastest growing resources of information today is the Internet. Pick up a recent newspaper or magazine, turn on your television, and chances are you will read or hear about this powerful tool. A leading proponent of the Internet, Vice President Albert Gore recently set a goal for the year 2000 to connect every school and library in the United States to the "National Information Infrastructure."

The Internet contains text, images, and software on a broad range of topics. It is a computer network (commercial, government, research, and educational) which spans the globe and provides instant access to information and communication. Users can download text, images, and software for both IBM and Macintosh computers. Users can also participate in discussion groups and have instant access to experts worldwide.

For those who do not have access to an environmental satellite direct readout system, the Internet is an alternative source for up-to-date polar and geostationary environmental satellite images. Images downloaded from the Internet can be used with the environmental satellite lesson plans that have been developed as part of the Looking at Earth From Space series.

This listing of Internet sites where environmental satellite (polar and geostationary) imagery may be downloaded, also includes brief information describing some common Internet tools. In this section, resources are identified by their Uniform Resource Locator or URL. The following code is used:

ftp://host.name.domain/directory/(filename)	File Transfer Protocol (FTP) Site
http://host.name.domain/directory/(filename)	World Wide Web (WWW) Server
telnet://host.name.domain	Telnet Site
gopher://host.name.domain	Gopher Server

Check with local colleges for availability of no-cost access. Other possible sources are local libraries and dial-up services.

As you explore the Internet, please keep in mind that this is an ever-changing environment—some of the sites you use today may be gone tomorrow. The network services listed in this section have proven dependable. However, you will discover that some of these references have changed and that many new resources exist.

AskERIC

The Educational Resources Information Center (ERIC) is a federally-funded national information system that provides access to education-related literature at all education levels. AskERIC is an Internet-based question-answering service for teachers, library media specialists, and administrators. Anyone involved in K-12 education may send a question to AskERIC, whose policy is to respond to all questions within 48 hours.

AskERIC
ERIC Clearinghouse on Information Resources
Syracuse University — Center for Science and Technology
Syracuse, New York 13244-4100
(315) 443-9114; FAX (315) 443-5448
email: askeric@ericir.syr.edu

The Internet Society serves as the international organization for cooperation and collaboration.

Internet Society
1895 Preston White Drive, Suite 100
Reston, Virginia 22091
(703) 648-9888; FAX (703) 620-0913
email: isoc@isoc.org

Anonymous File Transfer Protocol (FTP)

File Transfer Protocol (FTP) allows the user to connect to another computer and copy files from that system to the user's computer. It also allows the user to upload files. Files may include ASCII text files, PostScript files, software, and images. Many computer systems also allow general public access to specific sections of their files through Anonymous FTP. The following Anonymous FTP sites contain polar and geostationary satellite images, in formats such as GIF that can be used on IBM and Macintosh computers. Note that these addresses are valid with World Wide Web browsers. If you are using FTP software, omit ftp:// from the following addresses.

Address:	Description:
ftp://ats.orst.edu/pub/weather/	Hurricane Andrew and Emily images
ftp://aurelie.soest.hawaii.edu/pub	University of Hawaii Satellite Oceanography Laboratory — Japanese Geostationary Meteorological Satellites (GMS), AVHRR data from HRPT stations, and public domain software for accessing data

Address:	Description:
ftp://early-bird.think.com/pub/weather/maps	Hourly GOES visible and IR (last few days)
ftp://earthsun.umd.edu/pub/jei/goes	Anonymous FTP site for the “Blizzard of 93” movie in .flc format
ftp://explorer.arc.nasa.gov/pub/weather	GOES and Japanese Geostationary Meteorological Satellite (GMS) images
ftp://ftp.colorado.edu/pub/	Includes satellite images for several U.S. cities and regions, as well as images of hurricanes Andrew and Emily in the subdirectory “hurricane.andrew.” Also included are radar summary map GIF and PICT files and surface maps.
ftp://ftp.ssec.wisc.edu/pub/images	University of Wisconsin FTP server
ftp://hurricane.ncdc.noaa.gov	NOAA climate archives
ftp://kestrel.umd.edu/pub/wx	Hourly GOES visible and IR (last few days)
ftp://photo1.si.edu/More.Smithsonian.Stuff/nasm.planetarium/weather.gif	NOAA and other satellite images
ftp://rainbow.physics.utoronto.ca/pub/sat_images	Images of Hurricane Emily
ftp://sumex-aim.stanford.edu/pub/info-mac/art/qt	Anonymous FTP site for Quicktime (for Macintosh) movie of the “Blizzard of 93”
ftp://thunder.atms.purdue.edu	Purdue University, “The Weather Processor” — current GOES visible and IR images and other weather information
ftp://unidata.ucar.edu/images/Images.gif	Images of hurricanes Emily, Hugo, Beryl, Kevin
ftp://wmaps.aoc.nrao.edu/pub/wx	Hourly GOES visible and IR (last few days)
ftp://wx.research.att.com/wx	Hourly GOES visible and IR (last few days)

Gopher

Gopher servers present information to users through a series of menus. By choosing menu items, the user is led to files or servers on the Internet. Gopher can also retrieve files because it has a built-in interface to FTP. Note that these addresses are valid for World Wide Web browsers. If you are using Gopher software, omit gopher:// from the following addresses.

Address:	Description:
gopher://cmits02.dow.on.doe.ca	Canadian Meteorological Centre server, GOES visible and IR images and other weather information
gopher://downwind.sprl.umich.edu	University of Michigan Weather Underground—current GOES visible and IR, climate and weather data, images of historic weather events (e.g., Blizzard of 93, hurricanes Andrew, Hugo, Emily, Elena)
gopher://gopher.esdim.noaa.gov	NOAA Environmental Satellite Information Service —includes GOES, Meteosat, and polar-orbiting satellite imagery
gopher://gopher.gsfc.nasa.gov	NASA Goddard Space Flight Center information server
gopher://gopher.ssec.wisc.edu	University of Wisconsin server — daily full-disk GOES image
gopher://informns.k12.mn.us	Gopher information related to grades K-12
gopher://metlab1.met.fsu.edu	Hourly GOES visible and IR (last few days)
gopher://thunder.atms.purdue.edu	Purdue University Gopher server containing meteorological satellite imagery and other information
gopher://unidata.ucar.edu	Images of hurricanes Emily, Hugo, Beryl, Kevin
gopher://wx.atmos.uiuc.edu	University of Illinois Weather Machine — includes GOES images — current and archived

World Wide Web (WWW) Servers

The WWW is a hypertext-based, distributed information system created by researchers in Switzerland. Users may create, edit, or browse hypertext documents. The WWW servers are interconnected to allow a user to travel the Web from any starting point.

Address:	Description:
http://cmits02.dow.on.doe.ca	Canadian Meteorological Centre — current GOES visible and infrared images in jpeg format (Text in English and French)
http://meawx1.nrrc.ncsu.edu	North Carolina State University server, includes latest visible and infrared satellite images, current regional and national weather maps, climatic data, tropical storm updates, and other weather-related information
http://vortex.plymouth.edu	Plymouth State College-Plymouth, New Hampshire Weather Center Server, includes current U.S. infrared satellite images and IR satellite loop (movie), surface analysis and radar/precipitation summary, historical weather events and other weather-related information
http://rs560.cl.msu.edu/weather	Michigan State University server containing current weather maps, images (GOES, Meteosat, and GMS), and movies
http://satftp.soest.hawaii.edu Laboratory server	University of Hawaii Satellite Oceanography
http://thunder.atms.purdue.edu	The Weather Processor at Purdue University — server containing GOES visible and IR satellite images and other weather and climate information
http://unidata.ucar.edu	Weather-related datasets, including satellite images, radar scan images, hourly observations from international weather reporting stations, etc.
http://www.atmos.uiuc.edu	University of Illinois Daily Planet, including weather and climate information, hypermedia instructional modules related to meteorology, and WWW version of the University of Illinois Weather Machine, which includes current and archived GOES images
http://www.esdim.noaa.gov	NOAA Environmental Satellite Information Services Home Page
http://www.met.fu-berlin.de/DataSources/MetIndex.html	The World Wide Web Virtual Library: Meteorology—produced by the University of Berlin, this server is categorized by subject.

http://www.ncdc.noaa.gov/ncdc.html	National Climatic Data Center Server
http://http.ucar.edu	NCAR server, includes current satellite image, weather maps, and movies
http://zebu.uoregon.edu/weather.html	University of Oregon current weather page, including latest IR and VIS images of the U.S., surface analysis map, and local weather information
http://www.usra.edu/esse/ESSE.html	Earth System Science Education Program server developed by the Universities Space Research Association. Contains current GOES VIS and IR images, surface analysis map, and information and materials related to Earth system science education.

Resources for Software

Name:	Description:
gopher://downwind.sprl.umich.edu ftp://madlab.sprl.umich.edu/pub/Blue-Skies	Sources for BLUE-SKIES, a unique weather display system developed for K-12 schools by the University of Michigan. BLUE-SKIES allows interactive access to weather and environmental images, animations, and other information. The program requires a TCP/IP network connection.
ftp://mac.archive.umich.edu	Anonymous FTP site for Macintosh software
ftp://ncsa.uiuc.edu	National Center for Supercomputing Applications' public domain software for image processing, data analysis, and visualization; applications are available for Macintosh, PC, UNIX platforms. NCSA is also the developer of Mosaic, a hypertext-based interface to the WWW, designed for Macintosh computers. A PPP or SLIP connection is required for running Mosaic.
ftp://sumex-aim.stanford.edu	Anonymous FTP site for Macintosh software
ftp://wuarchive.wustl.edu	Mirror site for many major FTP sites
ftp://spacelink.msfc.nasa.gov gopher://spacelink.msfc.nasa.gov telnet://spacelink.msfc.nasa.gov http://spacelink.msfc.nasa.gov	NASA Spacelink — source for public domain software related to satellite tracking and image-viewing programs, as well as many other NASA educational resources

BOOKS/ARTICLES/ OTHER RESOURCES

Experience the Power: Network Technology for Education Video released by the National Center for Educational Statistics. Contact: National Center for Education Statistics, 555 New Jersey Avenue, N.W. Room 410 C, Washington, DC 20208-5651, Phone: (202) 219-1364; FAX: (202) 219-1728; email: ncerinfo@inet.ed.gov.

FYI on Questions and Answers to Commonly Asked Primary and Secondary School Internet Users Questions by Jennifer Sellers of the NASA Internet School Networking Group, February 1994(Request for Comments [RFC] number 1578, FYI number 22,). Details on obtaining RFCs via FTP or EMAIL may be obtained by sending an EMAIL message to rfc-info@ISI.EDU with the message body —
help: ways_to_get_rfcs.

The Internet for Dummies by John Levine and Carol Baroudi, IDG Books Worldwide, 1993. An easy-to-understand and entertaining reference, which is written for the beginning Internet user. Covers IBM, Macintosh, and UNIX computers.

Global Quest: The Internet in the Classroom is a short video produced by the NASA National Research and Education Network (NREN) K-12 initiative. A copy can be ordered from NASA Central Operation of Resources for Educators (CORE). Teachers may also make a copy by bringing a blank tape into their local NASA Teacher Resource Center. Information on CORE and the TRCs is included in section 3 of this Chapter.

Internet World, Meckler Corporation, Westport, CT. A monthly magazine, which started publication in 1992.

Meteosat Images on CD-ROM, 1986-1991, Meteosat Data Service, European Space Agency, Robert Str.5, D6100 Darmstadt, Germany (price available on request). Contains one full-disk infrared image per day, one visible image on day 1 of each month (at the same time as the infrared image), one water vapor image on day 1 of each month of 1991. Also included are images of the Blizzard of 1993 over the east coast of the United States and images of Kuwait during the Gulf War.

Sources of Meteorological Data Frequently Asked Questions (FAQ), by Ilana Stern, 1993. Available through Anonymous FTP to rtfm.mit.edu, from the files weather/data/part 1 and weather/data/part 2 in the directory /pub/usenet/news.answers. If you can't use FTP, send an email to mail-server@rtfm.mit.edu with the following message as the text:
send/pub/usenet/news.answers/weather/data/part1 or
send/pub/usenet/news.answers/weather/data/part2 (note: send separate email messages for part 1 and part 2)

Zen and the Art of the Internet: A Beginner's Guide by Brendan P. Kehoe, TPR Prentice Hall, Englewood Cliffs, NJ, 1993.