Project Atmosphere Canada

MODULE 13

Weather Satellites

Teacher's guide

Canadian Meteorological and Oceanographic Society
La Société Canadienne de Météorologie et d'Océanographie

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Project Atmosphere Canada

Project Atmosphere Canada (PAC) is a collaborative initiative of Environment Canada and the Canadian Meteorological and Oceanographic Society (CMOS) directed towards teachers in the primary and secondary schools across Canada. It is designed to promote an interest in meteorology amongst young people, and to encourage and foster the teaching of the atmospheric sciences and related topics in Canada in grades K-12.

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Eldon J. Oja
Project Leader Project Atmosphere Canada
On behalf of
Environment Canada and the Canadian Meteorological and Oceanographic Society

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INTRODUCTION

Our everyday view of the atmosphere is from the bottom looking up and around. Our field of view is limited since most of us can see only a few kilometres in any direction. At the same time, the systems that dominate our weather can be hundreds or even thousands of kilometres across. Weather maps and radar have extended our views, but it is the weather satellite that gives us a completely different perspective on weather. Orbiting satellites are platforms from which the atmosphere and surfaces below can be observed from the outside.

By looking down on weather, we can see that fair and stormy weather are somehow related. Clear areas and giant swirls of clouds fit together. In the continually changing atmosphere we can observe evidence of predictability through the order and evolution of weather systems.

With the launch of TIROS-1 in 1960, we gained our first total views of the cloud patterns that accompany low pressure systems and fronts. Areas of high pressure and fair weather also became apparent by their general lack of clouds. The launch of TIROS culminated a long march of technological advance in electronics and space exploration. The use of electronics for the sensors, information storage, and transmissions to Earth depended upon the newest transistor technology.

The sensors themselves depended upon television research for their images. Later sensors were outgrowths of this and went on to solid-state extensions where heat radiation, as well as light, from the Earth could be measured.

Finally, the signals that are measured electrically, are converted to digital values for storage and are later transmitted down to Earth. There, the visual images we are familiar with, are produced. This last step is highly dependent on computer technology for the assembly, organization, and interpretation of the data.

We now have two basic types of satellite systems. The descendants of TIROS are known as polar-orbiting satellites. They revolve around the Earth at relatively low altitudes, 800 kilometres (500 miles) or so, passing over the polar regions as the Earth rotates underneath. Such an orbit takes about 100 minutes to complete. Most places are scanned twice a day, once in daylight and once in darkness. Large-scale views are made from composites of several orbital strips that are about 1,900 kilometres (1,200 miles) in width.

The satellite pictures most often displayed on television and in the newspapers are taken by geostationary orbiters known as Geostationary Operational Environmental Satellites (GOES). Today's images are commonly from GOES-8 and GOES-10 and on May 17, 2000, the first images from GOES-11 were received. At 35,800 kilometres (22,300 miles) above the equator, such satellites will make one revolution in 24 hours. Because this is the same time as one Earth rotation, and the satellite revolves in the same direction the Earth is turning, such a satellite remains over the same equatorial surface location. Successive views from the same geostationary satellite can be provided to observe development of storm systems. They do not picture details as well as the closer polar-orbiting type of satellite, but they do provide more frequent views, every half hour, of the same Earth surfaces.

The sensors onboard the satellites react to two basic types of radiant energy. Visible light is produced by the sun and reflected off Earth surfaces and clouds, back up to the satellite. These images appear the same as black-and-white television pictures. All clouds look white to the sensor as they do to our eyes. Darker ground surfaces and water bodies in clear areas reflect little sunlight back up to space and therefore appear dark, gray or black. Visible images from the current geostationary weather satellites can resolve objects such as clouds that are as small as one kilometre in width.

The second main type of sensor detects infrared or heat energy given off by surfaces with temperatures in the range of the Earth's land and water surfaces and cloud tops. The intensity of the infrared energy is related to the specific temperature of the emitting surface. In this way, infrared (IR) images are temperature maps of the Earth view. Because the Earth and atmosphere emit heat day and night, infrared images are always available. The infrared sensor on the geostationary weather satellites can distinguish areas as small as four kilometres in width.

Visible light images, when containing a portion of the daylight half of the globe, show clouds to be uniformly white whether they are at low, middle, or high levels in the atmosphere. Earth surface details are usually dark. In contrast, infrared images can provide continuous information, day and night, because heat is constantly being emitted from all surfaces, day and night. Land and water surfaces are usually warm and therefore shown as dark. Cooler surfaces are typically displayed as grey with decreasing temperatures having lighter shading. In this way, low, warm clouds will be contrasted with high, cold ones. Temperature variations between warmer land and cooler water surfaces can be seen, as can the temperature cycle on land where daytime warming changes to night-time cooling.

The variation in temperature across land and water surfaces is a major factor in the development of weather systems. These temperature variations are also displayed in cloud features associated with severe weather situations. Therefore, it has been useful to enhance or process infrared images to accentuate the temperature variations by displaying differing shades of gray or by the use of colour coding. The 24-hour availability and the colour-coding make the enhanced infrared imagery ideally suited to display on television weathercasts as successive views are looped into movies of cloud motions.

The solid and liquid water found in clouds is very well monitored by the visible and infrared images of weather satellites. The existence of water vapour in the atmosphere is much more difficult to detect. A knowledge of water vapour patterns is very important to understanding weather systems. Water vapour is the supply material for the creation of clouds and precipitation, but it is invisible to the eye and only measured by instruments at widely separated locations. Fortunately, a specific range of infrared energy wavelengths interacts with water vapour. This finely tuned infrared sensor on the geostationary satellites can provide images, and sequences, of cloud locations and the regions of large water vapour content in cloud-free areas at altitudes between 3 and 7 km. Current water vapour imagery can resolve areas down to widths of eight kilometres. Water vapour images are especially helpful in detecting the atmospheric circulation patterns that lead to later cyclone formation and their associated cloud shapes.

The combination of satellite types provides much valuable information about the Earth below. In addition to monitoring weather systems, the satellites provide other data, including vertical temperature profiles and moisture measurements.

To view the latest satellite imagery, you can go to the Environment Canada Web Site:

http://weatheroffice.ec.gc.ca

Navigate to the Satellite page. The menu offers a number of choices, such as:

GOES-East - Eastern Canada
IR (infra-red: 10.7 µm)
Visible & Topography
IR + Visible

NOTE: 10.70 µm (micron) is an infrared (IR) image where 10.70 microns simply refers to the infrared wavelength being used for this specific image.

BASIC UNDERSTANDINGS

Weather Satellite Characteristics

1. Weather satellites are orbiting platforms from which onboard instruments can sense light and heat energy from the atmosphere and underlying surfaces.
2. Because weather satellites can view a large area at one time, anywhere on Earth, they provide meteorological information over the oceans and sparsely populated land regions.
3. Weather satellite pictures are received as composites of tiny blocks (called pixels) of varying energy intensities, often shown in shades of grey or in colour. The area each block covers determines how detailed the image can be. The smaller the block, the greater the detail in a satellite image.
4. In addition to sending back pictures of Earth, weather satellites can determine the temperature and water vapour content at different heights in the atmosphere. They can also monitor the ozone layer and detect energetic particles in the space environment.

Polar Orbiting Weather Satellites

5. One type of weather satellite orbit passes near the Earth's poles making north and south journeys at an altitude of about 800 kilometres.
6. Polar orbiting satellites scan a strip of Earth, taking less than 2 hours to complete an orbit. With each pass, they survey a strip approximately 1900 km wide that is further west because of the Earth's eastward rotation. Many hours elapse between passes over the same mid or low latitude location.
7. These satellites provide us with information on the condition of the ozone "hole" and composite pictures of snow cover and ocean surface temperatures.

Geostationary Weather Satellites

8. A second type of weather satellite orbit is located 35,800 kilometres directly over the equator. These satellites make one revolution, moving in the same direction as the Earth's rotation, in the time it takes Earth to make one rotation. This keeps them above the same spot on the equator, making them appear stationary, hence their name, Geostationary Operational Environmental Satellites (GOES).
9. Ordinarily, there are two geostationary satellites covering Canada and the United States, one for the eastern part and one for the west coast and Pacific Ocean. Each one has a field of view covering about one-third of the Earth's surface.
10. Each satellite's view remains the same, so sequential images may be viewed in rapid succession to show development and movement of weather systems.

Visible Satellite Images

11. Visible satellite images are views produced from reflected sunlight. Thus, these pictures look similar to pictures made with an ordinary camera.
12. On visible satellite imagery, clouds appear white and the ground and water surfaces are dark grey or black. Since this imagery is produced by sunlight, it is only available during daylight hours.
13. Low clouds and fog are usually distinguishable from nearby land surfaces. In addition, the hazy conditions associated with air pollution can be tracked.
14. The shadows of thunderstorm clouds can be seen cast on lower clouds in the late afternoon. Snow cover can be monitored because it does not move as clouds do. Land features, such as streams, can be visible.

Infrared Satellite Images

15. Infrared satellite images are produced by the infrared (heat) energy Earth radiates to space. Since Earth is always radiating heat, infrared images are available day and night.

16. On infrared images, warm land and water surfaces appear dark grey or black. The cold tops of high clouds are white and lower-level clouds, being warmer, are grey. Low clouds and fog are difficult to detect in the infrared when their temperatures are nearly the same as the nearby Earth surfaces.

17. An additional advantage of infrared imagery is that it can be processed to produce enhanced views. The data from the usual infrared pictures are specially treated to emphasize temperature details or structure by assigning contrasting shades of grey or colour to narrow temperature ranges. Such imagery, often seen colour-coded, appears regularly on television weathercasts and computer displays.

18. The enhanced images make it possible to keep track of land and oceanic surface temperatures. These surface temperatures play major roles in making and modifying weather. The high, cold clouds associated with severe weather are also easily monitored.

19. Enhanced imagery can be interpreted to produce rainfall rate estimates. This information is used in flash flood forecasting.

Water Vapour Images

20. Solid, liquid and vapour forms of water interact with specific ranges of infrared energy. Specially tuned geostationary weather satellite sensors can detect water vapour in the atmosphere, in addition to clouds.

21. The water vapour sensors aboard weather satellites reveal regions of high atmospheric water vapour concentration in the troposphere between altitudes of 3 and 7 km. These regions, sometimes resembling gigantic swirls or plumes, can be seen to flow within and through broad scale weather patterns.

22. Recent studies suggest that, at any one time, atmospheric water vapour may be found concentrated in several large flowing streams forming the equivalent of "rivers in the sky".

Weather Features in Satellite Imagery

23. Hurricanes look like pinwheels of clouds. More often than not, the beginnings of hurricanes are detected from satellite views, because they occur over broad expanses of oceans.

24. Large comma-shaped cloud shields give shape and form to mid-latitude low-pressure systems.

25. Clouds from which showers fall can look like grains of sand, especially on visible satellite pictures. Thunderstorms appear as "blobs" or "chains of blobs". Their high tops spread downwind from them as wispy cirrus clouds. They may have neighbouring lower clouds appearing as tiny curved "tails" to the southwest. Such "tails" can also be indicators of the possibility of tornadoes.

26. Movements of cloud patterns detected by viewing sequential satellite images, indicate the circulations of broad-scale weather systems. Wind speeds can be estimated at different levels and even upper-air jet streams can be identified.

27. Meteorologists use satellite images to determine cloud shapes, heights, and type. Changes in these cloud properties, along with cloud movement, provide valuable information to weather forecasters to determine what is happening and what is likely to happen to weather in the hours and days ahead.

28. Visible, infrared, and water vapour satellite imagery complement one another. There are weather features that can be clearly seen in one kind of image that are difficult to see in the others.