Weather and Climate: How Does Everything Start?
From Solar Radiation to Air Circulation Patterns

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INTRODUCTION / UNIT SUMMARY AND TOPIC

This unit is intended for elementary fifth grade students who take a regular or magnet course in science. The subject of this unit contains the core concepts needed to understand why we have changing weather conditions and different climates on Earth, focusing mostly on the primary factors that generate them.

By means of this unit students will understand the importance of the Sun as the generator of all conditions that interplay in creating the various climates, Earth-Sun relations, and the main physical and geographical features of the planet that result in the wind and ocean circulation patterns on Earth.

OBJECTIVES

The unit will cover the following HISD objectives of the elementary 4th and 5th grade science curriculum:

SCI.4.2.05. Identify the Sun as the major source of energy for the Earth and understand its role in the water cycle.

SCI.4.4.02. Identify the Sun as the major source of energy for the Earth and understand its role in the creation of winds.

SCI.4.4.03. Summarize the effects of the oceans on land.

SCI.4.4.07. Identify and measure patterns of change in weather and recognize that the Sun's heat energy is responsible for weather patterns.

SCI.5.4.08. Explain that primary sources of energy, including solar, wind and water, are naturally available on Earth.

SCI.5.4.13. Identify events and describe changes that occur on a regular basis, such as in daily and seasonal cycles.

SCI.5.5.A. Describe cycles, structures, and processes found in a simple system.

SCI.5.5.B. Describe some interactions that occur in a simple system

SCI.5.6.A. Identify events and describe changes that occur on a regular basis, such as in daily and seasonal cycles.

SCI.5.12.C. Identify the physical characteristics of the Earth.

RATIONALE

Modern humans are impacting the environment in ways that were unthinkable a few generations ago. One of the most contentious and controversial issues is whether humans are indeed changing Earth's climate, the serious consequences of which would eventually manifest themselves on a global scale. It is of great importance that, within the framework of the science curriculum, the school teacher possesses enough information and teaching options in order to avail the younger generations of a satisfactory understanding of weather and climate and their origin. The key concepts and questions that are to be reviewed in this unit are:

- Solar energy.
  What is the solar energy?
  What constitutes the solar spectrum?
- Incoming Solar Radiation (Insolation).
  Does the Earth receive the same amount of solar energy everywhere?
  Does the Earth receive the same amount of solar energy at all times?
- Earth's tilt:
  Why do we have seasons?
- Earth's energy budget:
  Why doesn't Earth overheat or freeze?
- Albedo:
  Does the Earth's surface reflect the same amount of energy everywhere on the planet?
- Scattering, reflection and absorption:
  What happens to solar energy as it is intercepted by the Earth and its atmosphere?
- Heat transfer:
  How is heat "shared" between the soil and the layers of the atmosphere?
- Air pressure:
  Does air have weight?
- Pressure gradient force:
  How does wind originate?
- -Coriolis force:
  What is coriolis?
  Does the Earth's rotation affect wind circulation? How?
  Are winds the same near the ground and at high layers of the atmosphere?
- Friction force:
  How does the terrain affect the winds?
- Cyclonic movement:
  What are cyclones? How do they form?
- Anticyclonic movement:
  What are anticyclones? How do they form?
- Planetary wind model:
  Why do we have winds?
  Where do winds come from? Where do they go?
- Daily and seasonal wind shifts:
  Why does wind change direction?
- Ocean currents:
  Why do we have ocean currents? Where do they come from? Where do they go?

UNIT BACKGROUND

Here the basic vocabulary and concepts are presented, which will enable the teacher to explain core ideas in a simple, but still scientific way to elementary students.

Solar Radiation, Earth's Radiation Balance, and the Seasons

The Electromagnetic Spectrum and Insolation

Except for the internal heat from the Earth, practically all the energy that flows through the terrestrial environment comes from the Sun. This energy along with the presence of water on the planet is what ultimately creates the current climatic zones and allows the existence of life.

Solar energy is electromagnetic radiation and comes to Earth in different wave lengths (the wavelength is the distance between two crests in a wave). These wavelengths travel from the Sun through "empty" space to the Earth.

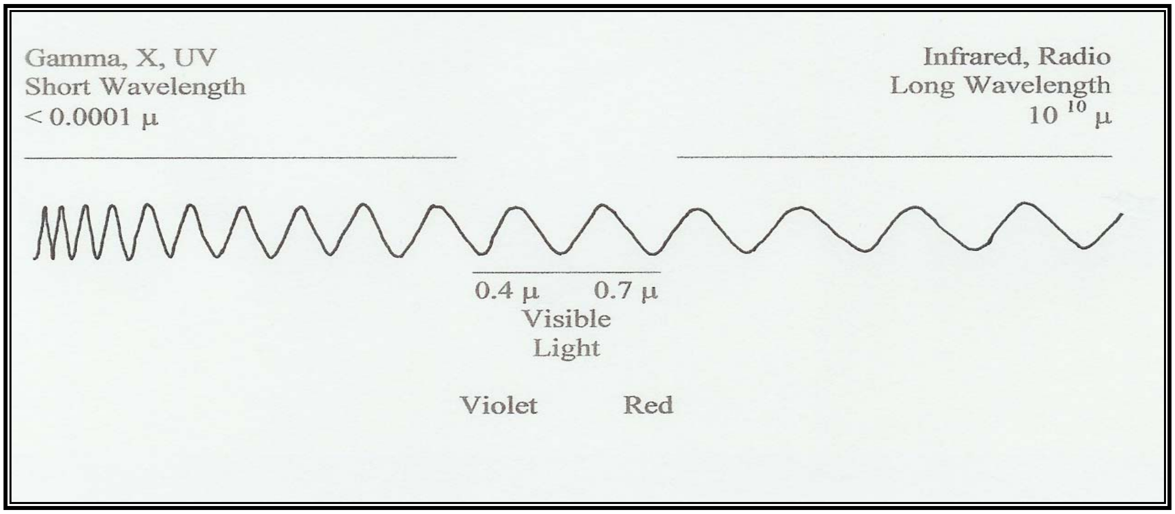

Figure 1. Electromagnetic radiation from the Sun.

The Solar Constant; Earth-Sun Relations; Intensity and Duration of Sunlight

The Sun, our energy source, provides an average amount of energy known as the solar constant. This solar constant is equal to two gram-calories per square centimeter per minute; a gram-calorie is the amount of heat necessary to raise the temperature of one gram of water by 1 degree Celsius (Barnhart 85; Rogers *et al*. 419). But not all this energy reaches the surface, nor with the same intensity, because of three factors:

1) Some energy is reflected back to space by the atmosphere or absorbed by it (Fig. 2), whereas some is reflected by the Earth's surface (the albedo) (Moyer *et. al*.182; Strahler and Strahler 40).

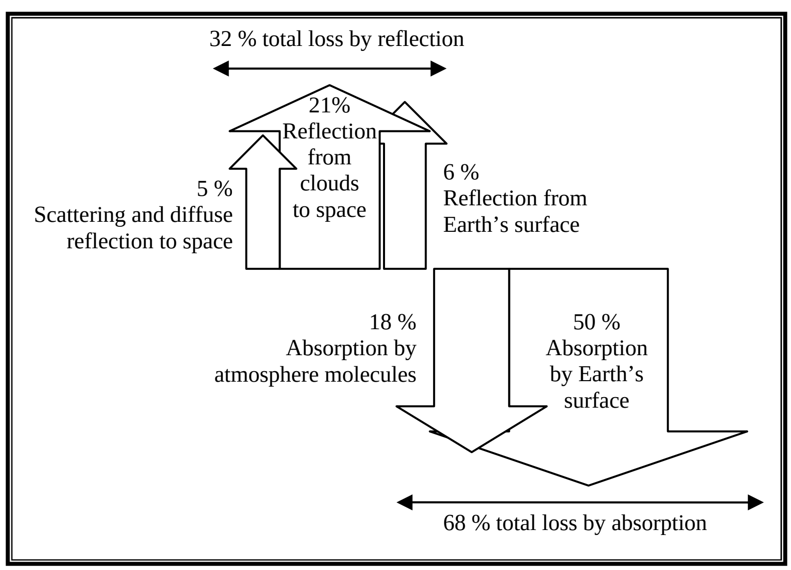

Figure 2. Radiation absorbed and reflected back to space.

2) The intensity of the energy reaching the ground depends upon the angle of incidence, or the angle at which the sunlight hits the surface, being most intense at the places perpendicular to the sunrays and less intense at the places oblique to the sunrays (Fig. 3) (Aguado and Burt 47; Strahler and Strahler 34).

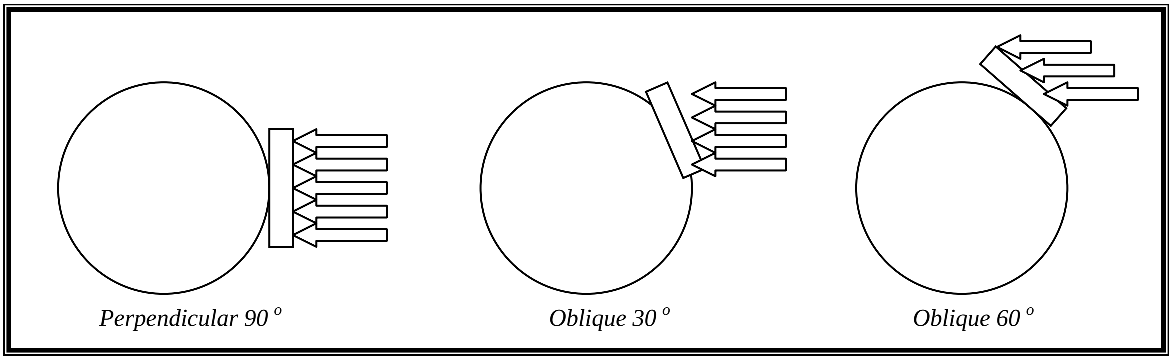

Figure 3. Angle of incidence of the sunlight at different locations on Earth.

The time that a certain area is exposed to sunlight (day length or period of daylight) depends on the position of the Earth at different places in its orbit around the Sun. The Earth's inclination on its axis, or tilt, explains why the days are shorter in winter than in summer in the northern hemisphere and vice versa in the Southern hemisphere (Fig. 4) (Aguado and Burt 46; Moyer *et al* 100). In modern times (the last few millennia), the tilt has been 23.5.

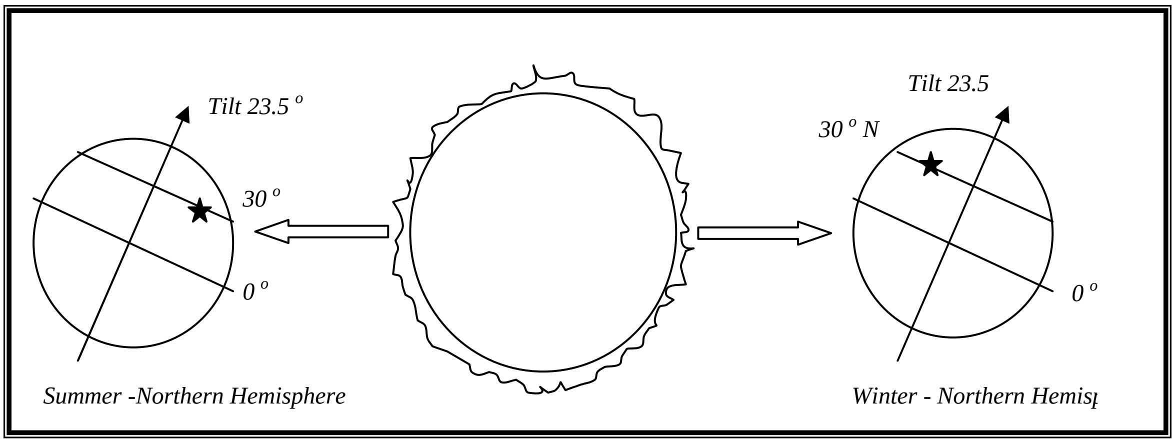

Figure 4. Tilt of the axis of the Earth and length of the day throughout the year.

The combination of these three factors on the one hand works to create the seasons and on the other hand gives the whole Earth its average annual temperature throughout the year. These factors in turn affect the planet in a way that prevents it from either overheating, which would happen if the Earth keeps more heat than it sends back to space, or freezing, which would happen if the Earth loses more heat than it receives. This is known as the Earth's radiation balance, which makes possible the existence of life on the planet.

Differential Patterns of Heat on Earth

Earth's Energy Budget

A number of factors interact over the Earth's surface and atmosphere, all of which determine the local weather and climate. The first thing to consider is the fate of solar energy as it travels through the atmosphere.

What Happens to the Solar Radiation? As soon as the solar radiation enters the atmosphere, some 6% is sent back to space as diffuse reflection by solid particles or as scattering by atmospheric gases. Under clear skies a further 14% is absorbed by air molecules and dust, and a final 80% of energy reaches the ground. Under cloudy conditions on the other hand, clouds can reflect between 30 % and 60%, and absorb between 5 % and 20 % of solar energy, thus allowing between 45 % and 0 % of solar energy to reach the ground (Fig. 5) (Strahler and Strahler 39).

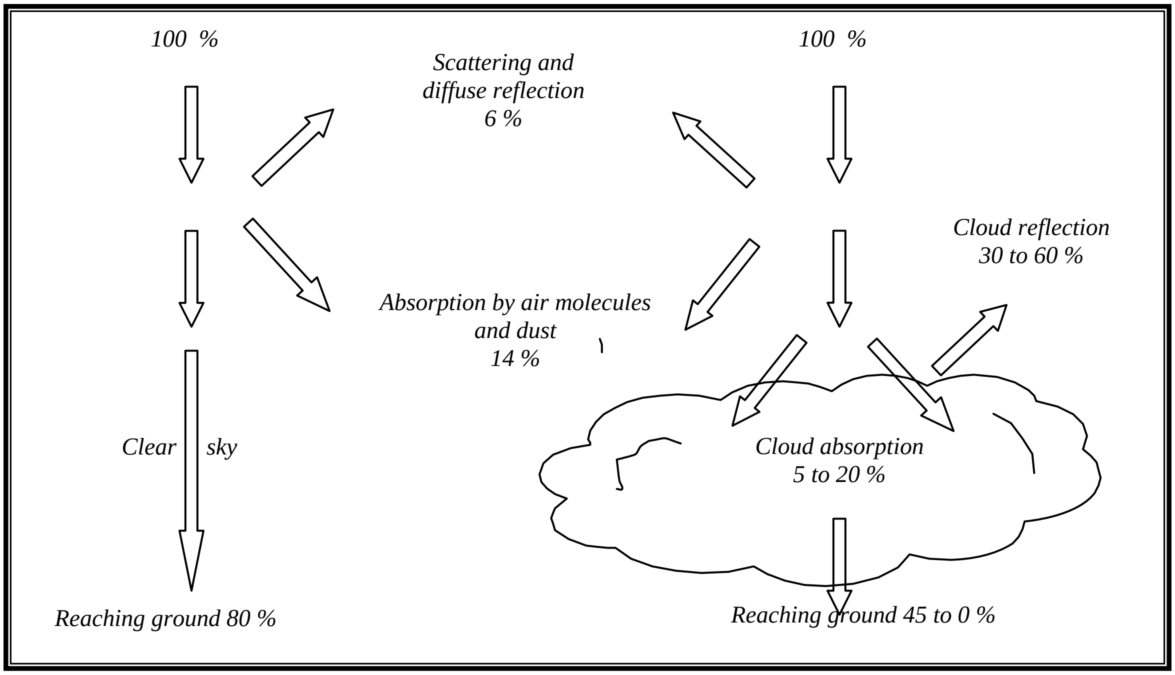

Figure 5. Amount of solar energy that reaches the ground through clear and cloudy skies.

Radiation Balance of the Earth

When the solar energy reaches the atmosphere and the ground as shortwave radiation, it is either absorbed or re-radiated as longer wavelengths. Long wavelength radiation (LW) is thermal radiation or heat. On average, terrestrial radiation from the Earth consists of wavelengths that are 20 times longer than those of solar radiation (Strahler and Strahler 33). In the process, the radiation balance for the atmosphere is negative. In contrast, the radiation balance for the ground is positive in the same magnitude, which ultimately results in a radiation balance for the Earth (Fig. 6) (Aguado and Burt 64).

Heat Transfer Mechanisms

Analyzing the Earth’s radiation balance merely tells us that the energy deficit for the atmosphere is equal to the energy surplus for the ground; but how is it that the ground does not overheat and the air does not overcool? Several mechanisms of heat transfer account for this thermal equilibrium, namely conduction, free convection and forced convection (Aguado and Burt 64-65; UCAR 2000-2001).

Conduction of heat occurs in a thin layer of the air that is only a few millimeters thick adjacent to the ground. This layer heats up due to direct contact with the much hotter surface. A temperature gradient exists in this layer. The heat in this layer is transferred to the upper atmosphere by convection processes. Free convection is the process by which the warmer air, being less dense by expansion than colder air, rises to upper layers of the atmosphere carrying with it its heat. Forced convection is also known as mechanical turbulence and is the process by which warm air is forced to mix both horizontally and vertically by wind currents.

Convection (free and forced) transfers two types of heat, namely sensible and latent heat. Sensible heat travels by conduction and is simply the energy added to a substance. In simpler terms, this is hot air mixed with cooler air (in other words, adding heat directly to the air). Latent heat is the energy needed to change the phase of a substance, and for weather and climate, the heat needed to melt ice, to evaporate water, or vice-versa (Aguado and Burt 66). A simple example of latent heat is the traditional way to make ice-cream: by adding salt to the water in the container outside the ice-cream bucket, the liquid inside the last "lends" heat to the surrounding water in order to dissolve the salt, or conversely, the water outside "borrows" heat from the ice-cream water in order to dissolve the salt. These processes of sensible and latent heat transfer are important in our understanding of meteorological and climatologic phenomena involving water masses (oceanic currents) and the water cycle.

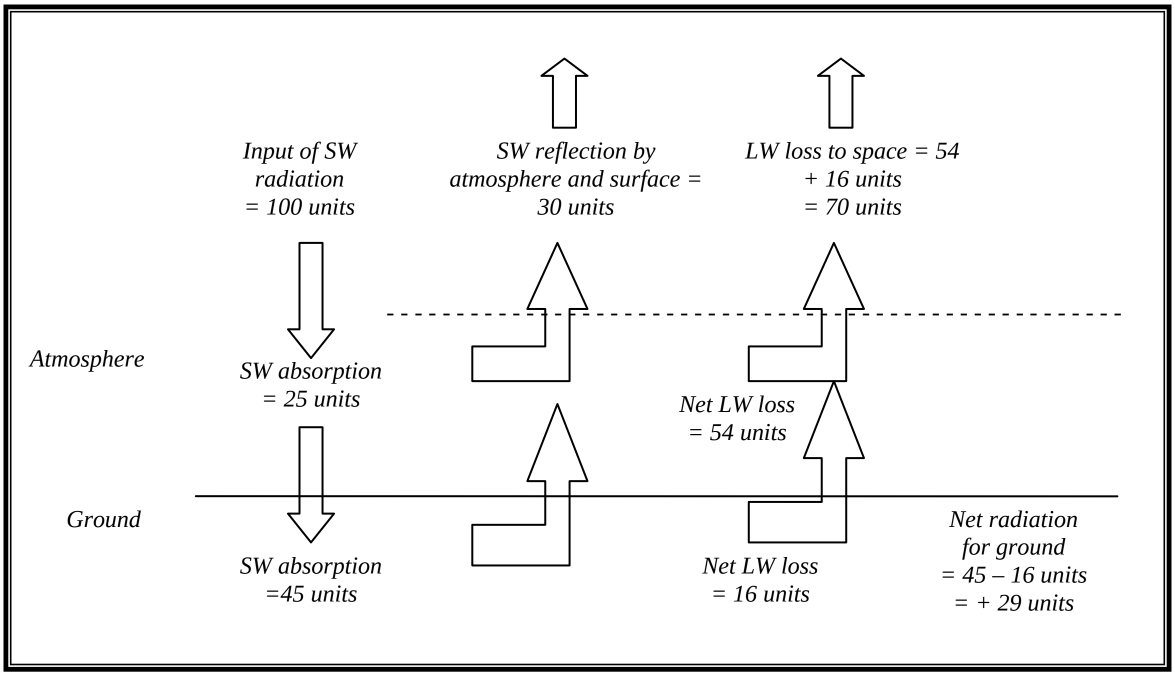

Figure 6. Radiation balance for the Earth

The Effects of Latitude and Continental Position on the Radiation Balance

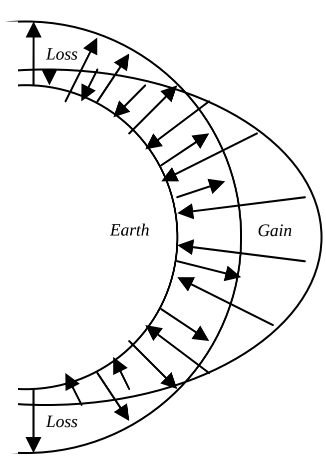

Figure 7. Net loss and net gain of energy depending on latitude

As earlier established, latitude helps to determine the amount of energy that a certain place receives (Figures 3 and 4). The amount of energy radiated by a spherical body is rather equal at any given point, and inasmuch as the Earth is quite spherical, the planet follows this simple pattern. This results in a net gain of radiation between 38 degrees north and south latitudes and a net loss of energy poleward of these latitudes. Thus, equatoward of 38 degrees there is a heat surplus, and poleward of the same latitude there is a heat deficit (Fig. 7).

Again, an imbalance in the global temperature difference is prevented because the global wind systems and the ocean currents transfer heat from the low to the high latitudes horizontally, which is known as advection or meridional transport (because the heat travels along a meridional direction). Of all the heat transferred in this way, 75 % is transferred by winds and 25 % is transferred by oceanic currents (Aguado and Burt 68).

Ocean currents play a direct role in local climates because, on the one hand, warm water masses transfer more heat than cooler water masses to the overlying atmosphere which blows over land, and on the other hand, water has smaller temperature fluctuations than land because water has a specific heat five times that of land (Aguado and Burt 73); therefore, land areas closer to water masses show smaller temperature variations through the year, whereas land areas far from the water masses show greater temperature variations throughout the year. The latter is known as the effect of continentality.

If we observe an Earth globe, it becomes clear that around 40 % is land in the northern hemisphere, whereas approximately only a 20% is land in the southern hemisphere, i.e. the northern hemisphere contains twice the land mass of the southern hemisphere. This unequal distribution of land masses also plays a role in the effect of continentality. Thus the northern hemisphere land areas experience hotter summer temperatures and colder winter temperatures.

Air Circulation Patterns

Air Pressure, Winds and Pressure Gradient Force

The atmosphere, by its gaseous nature, is dynamic and constantly in motion. The lowest layer of the atmosphere is the troposphere, where weather changes occur and the air moves in different directions and at different speeds. Horizontal movements are called local breezes or winds; when such horizontal movements cover extensive areas they are known as air masses. Air masses moving vertically are called currents.

Basically, air moves because of differences in pressure from one location to another. The air moves horizontally, flowing out from an area of higher pressure (much like maple syrup falling on a pancake) into an area of lower pressure (like air converging into an aspirator tube), obeying a pressure gradient force. This atmospheric pressure is represented in charts as concentric lines with numbers, which indicate the atmospheric pressure in millibars along all their length; these lines are called isobars. Subsequent lines indicate locations of higher or lower pressure. Centers of high pressure represent areas of surplus air (a "ridge" of high pressure) whereas centers of low pressure are zones of relatively less air (a "through" of low pressure). These surpluses and deficits may be illustrated by a map of isobars (Fig. 8).

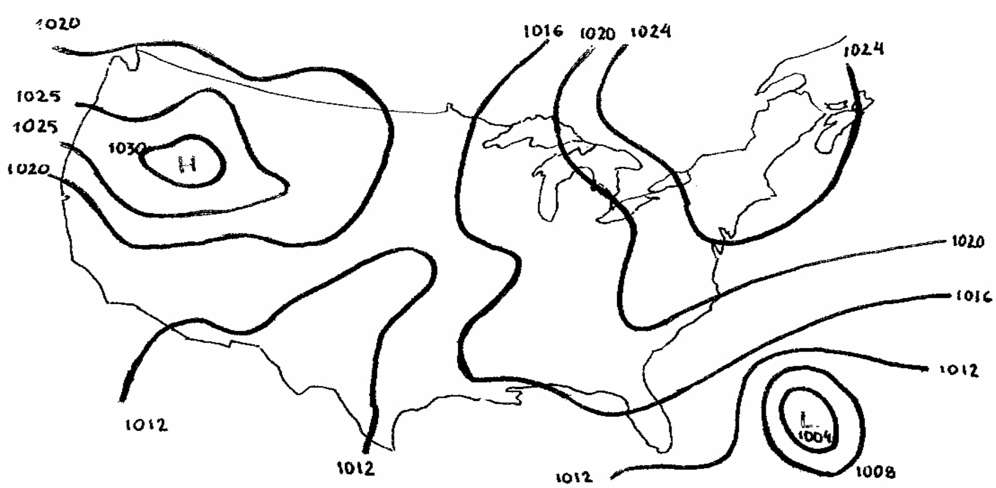

Figure 8. Map of isobars or lines of equal atmospheric pressure. (Adapted from Kellman et al, 2005)

Coriolis and Friction Forces

Logic tells us that wind flowing from one high pressure zone to a lower pressure zone would follow the shortest path, crossing the isobar lines at right angles, but this is not so. Instead, in the northern hemisphere the air flowing out from a high pressure zone "whirls" clockwise, whereas the air flowing into a low pressure zone "whirls" counterclockwise (Fig. 9). This is the result of coriolis force, which is the effect that the rotation of the Earth has on the wind. Accordingly, wings are deflected to the right in the northern hemisphere and to the left in the southern hemisphere (Moyer *et al* 138; Navarra 145; UCAR 2000-2001).

The Earth rotates from west to east; it has a greater linear velocity (tangential velocity) at the equator than it does at higher latitudes because the equator has a larger perimeter than a polar circle. In other words, a point on the equator describes a longer circumference in twenty-four hours (a complete rotation). This location goes faster (covers more) at the equator than points on higher latitudes during the same twenty-four hours (the geographical pole does not travel at all; it only spins on the same spot).

The above-mentioned difference in velocity affects air parcels or masses that move latitudinally towards the poles. An air parcel at the equator, which is stationary over a specific location, has the highest possible tangential velocity. When it moves poleward, it enters latitudes with a relative lower tangential velocity at ground level (it enters a smaller circumference). In addition to the poleward movement, this mass of air exhibits a higher west-to-east velocity than the ground, or higher angular momentum (because of its greater tangential velocity); thus, it gradually leaps "forward" and is simultaneously deflected to the east.

Conversely, air masses moving from higher latitudes toward the equator begin with a lower relative tangential velocity, and, by entering a zone with a higher tangential velocity at ground level, they experience a smaller angular momentum. This means that they lag behind and are gradually deflected westward as they gravitate toward the equator (Fig. 9).

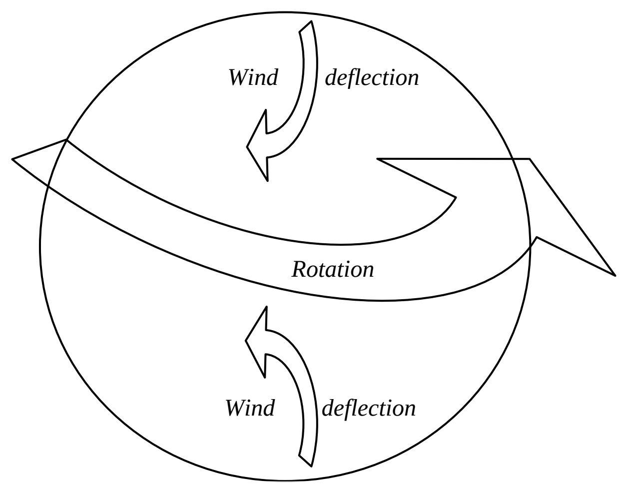

Figure 9. Coriolis effect in the Northern Hemisphere

Together with differential pressure and coriolis, friction force is a third factor influencing air mass movements. Friction is determined by the contact of the air mass with the surface. Friction force works in opposition to the direction of the wind.

Obviously, friction is greater when the wind blows over rough surfaces, like mountainous terrain, than when it blows over smooth surfaces like water. As seen above, the wind flows at an angle across the surface isobars; this angle is bigger as the friction increases and smaller as the friction decreases, which results in an average angle of 30 degrees between the surface isobars and the wind over land and an average angle of 10 degrees between the surface isobars and the wind over water (Navarra 146-147). This angle between the surface isobars and the wind also decreases with height, because the farther the wind is from the ground, the lower the friction force. This ultimately results in wind flowing parallel to the surface isobars at heights of about thousand meters (3000 feet). At that altitude friction force is negligible (Navarra 149).

Cyclonic and Anticyclonic Air Movements

Throughout the world the relative positions of cyclones and anticyclones control our weather. A cyclone is a system of low pressure into which wind flows and converges in a counterclockwise direction in the northern hemisphere. On the other hand, an anticyclone is a system of high pressure from which wind moves and diverges in a clockwise direction (Fig. 10). In the southern hemisphere the direction of the cyclonic and anticyclonic rotation is reversed (Navarra 150; "Cyclonic Anticyclonic Rotation").

In the northern hemisphere, when high and low pressure zones interact closely enough, they are said to be coupled. In this state, a convection system is formed at ground level. The high pressure zone "expels" clockwise-turning divergent winds. The low pressure area in turn receives and "aspires" these air masses that converge in a counterclockwise motion. The area/size of a cyclone or anticyclone can vary from 200 to 2000 in diameter.

In the high pressure zone, the descending or subsiding air mass is subject to increasing pressure and thus compresses and warms up, as does a bicycle tire when it is inflated; this is an adiabatic heat gain, meaning the temperature rises because of pressure and not because of the addition of heat from an external (or diabatic) source. As this air mass heats up its moisture capacity increases, and thus it can hold more water vapor as it subsides. Accordingly, anticyclones bring drier, fairer weather with brilliant sunlight, blue skies, and low wind speeds.

In the northern hemisphere, as air flows into a low pressure zone it is "sucked" upward in a counterclockwise motion; as the air mass rises, it decompresses with altitude and cools down because of an adiabatic loss of heat, which promotes the condensation of its water vapor and induces subsequent precipitation. Cyclones are thus characterized by cloudy, stormy weather. Low pressure air mass ascending from the Earth's surface in a counterclockwise motion begins to change the direction of its rotation at approximately ten thousand feet of altitude. At twenty thousand feet it turns clockwise in a diverging movement, which is known as the layer of divergence of the low pressure system.

In turn, this cold air at the twenty thousand foot elevation is fed into the high pressure zone in a counterclockwise movement. At the layer of convergence of the high pressure system, it eventually subsides and changes gradually the sense of its rotation toward clockwise again at around ten thousand feet, and continues the convection system (Fig. 10) (Navarra 150, 151). In every case, the direction of these layers of convergence and divergence is reversed in the southern hemisphere.

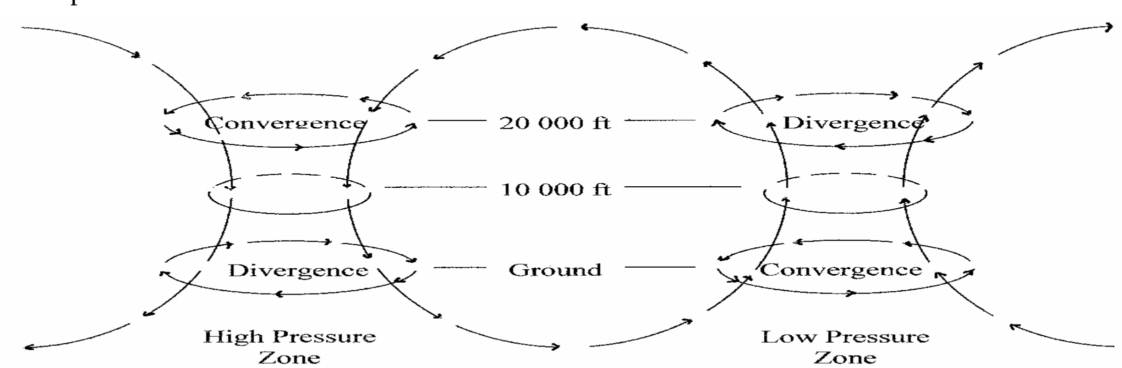

Figure 10. High and low pressure systems coupled, forming a convection system (Northern Hemisphere rotation pattern represented). (Adapted from Navarra, 1979)

The Planetary Pressure and Winds Model

Because the Earth is basically a sphere, it receives varying amounts of insolation at different latitudes (Fig. 7). Under uniform geographical conditions, the pressure zones would tend to follow a global pattern of high and low pressure zones distributed as alternating belts. This pattern is referred to as the three-cell wind circulation pattern model in which the individual cells are known as Hadley cells (Fig. 11) (Navarra 227; UCAR 2000-2001).

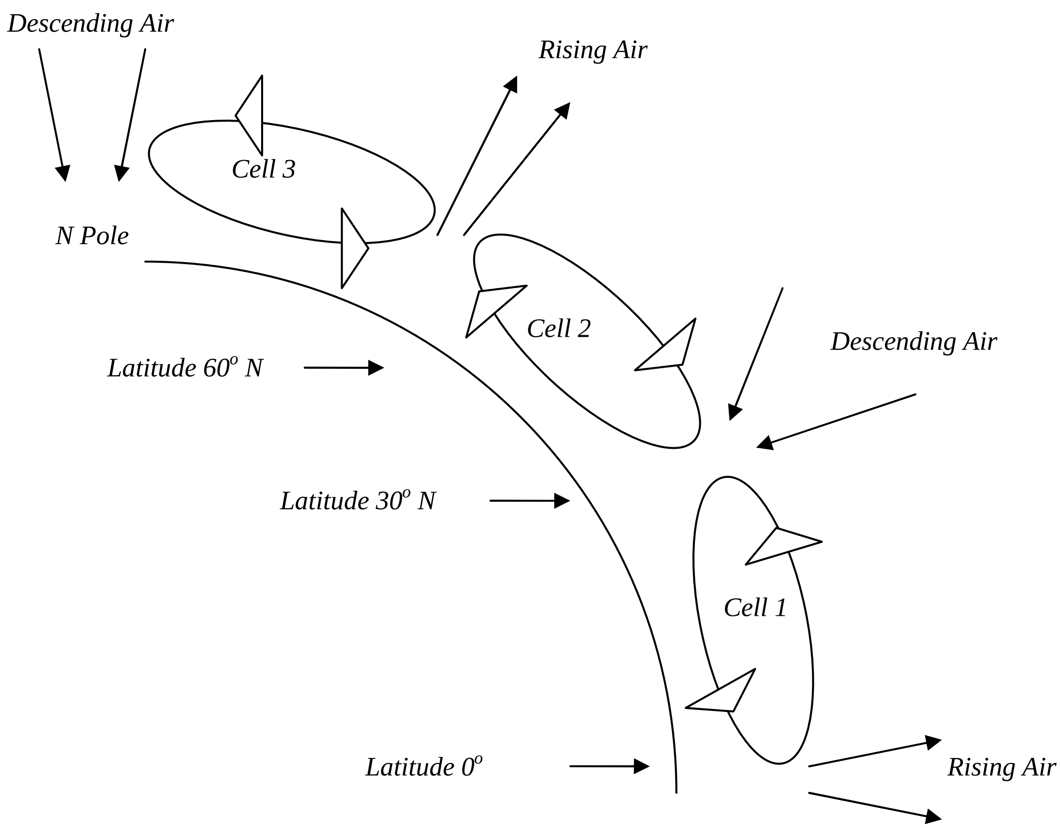

Figure 11. Three cell circulation pattern.

The model presents (for each hemisphere) a first equatorial cell where air rises to high altitude, moves poleward and subsides at the 30th parallel, from which it returns to the equator at ground level. Cell two starts with subsiding air at latitude 30 degrees, from which it moves poleward at ground level. It gradually rises to high layers of the atmosphere at latitude 60 degrees and returns equatoward to its point of departure (latitude 30 degrees). Cell three begins at latitude 60 degrees with air rising to high altitude as it moves poleward and subsides at latitude 90 degrees. It then returns to the latitude 60th parallel at ground level. This model, despite deviations in wind flow because of Earth's geographical heterogeneity, helps us to understand many of the features of the global wind circulation pattern.

By adding the effect of coriolis into the model, we create a dynamic picture of the three zones of prevailing surface winds (represented by arrows). These zones are named for the latitude at which they originate or the direction from which the wind blows on the Earth's surface. In contrast, the zones of subsidence or ascendance of the air masses between the prevailing winds (represented without arrows) are named for their high or low pressure system and their latitude (Fig. 12) (Moyer et al 138; Navarra 233).

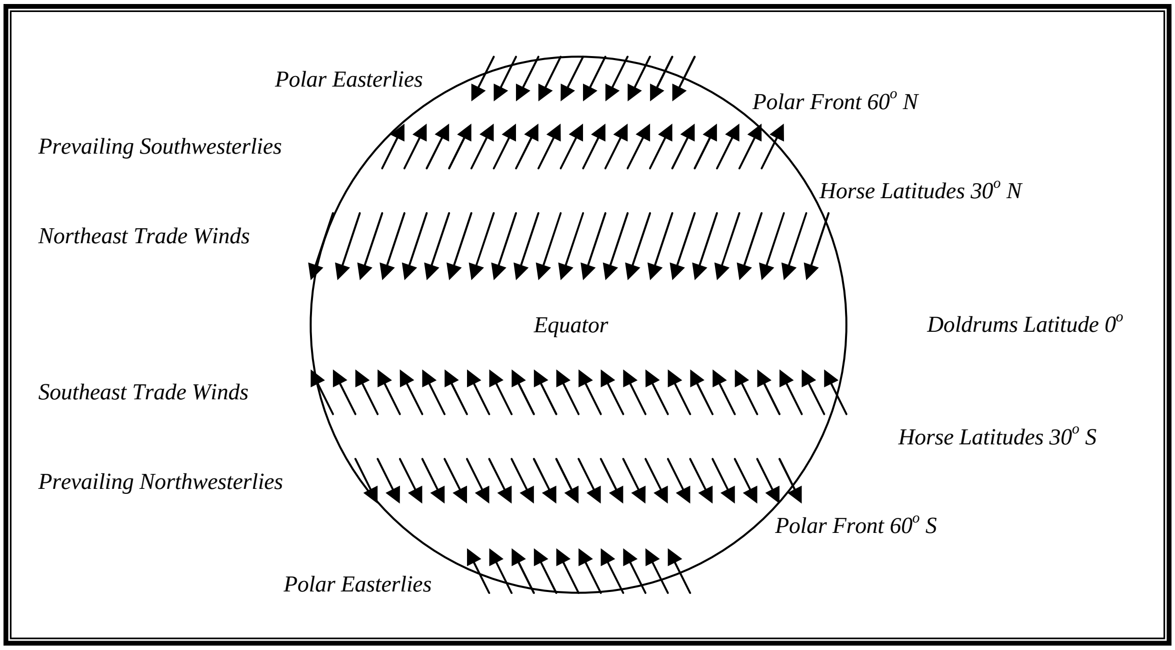

Figure 12. The three zones of prevailing surface winds on Earth: Polar Easterlies, Prevailing Westerlies and Trade Winds. Intermediate zones: Polar Front, Horse Latitudes and Doldrums. Note that in the Southern hemisphere the winds pattern is the mirror image.

Seasonal and Daily Shifts of Winds

The global circulation pattern is not absolute. Because of variations of features like mountains, valleys, plains, or the proximity of water bodies, the wind and pressure patterns change on a seasonal or daily basis at a regional and local scale.

Well known seasonal variations at the regional scale are the monsoonal circulation patterns that occur where extensive landmasses and oceans meet. Obvious examples are the north coast of Australia, the Iberian Peninsula, the sub-Saharan Sahel region of Africa, and most notoriously around the Indian subcontinent.

Monsoon winds occur during summer and during winter. Summer monsoons occur when the landmass warms up at a higher and faster rate than the neighboring ocean. Water, a fluid, has a higher specific heat than solid land. Water thus warms and cools at a slower rate. The air mass over land starts rising to higher atmosphere layers generating a low pressure system and pulling moist air from above the seas, which in turn becomes a higher pressure system. As these moist air masses flow inland, they rise as well and cool adiabatically, generating abundant rainfall (Fig. 13) (Navarra 237-240).

Conversely, the winter monsoon occurs because the land masses cool down rapidly, whereas the ocean waters release their heat at a lower rate (again, because of the high specific heat of water), staying relatively warm and forming a low pressure system. Land in turn becomes a focus of high pressure. The difference of winter monsoons as compared to summer monsoons is that during winter the air that flows from the land is typically dry (Fig. 13) (Navarra 237-240).

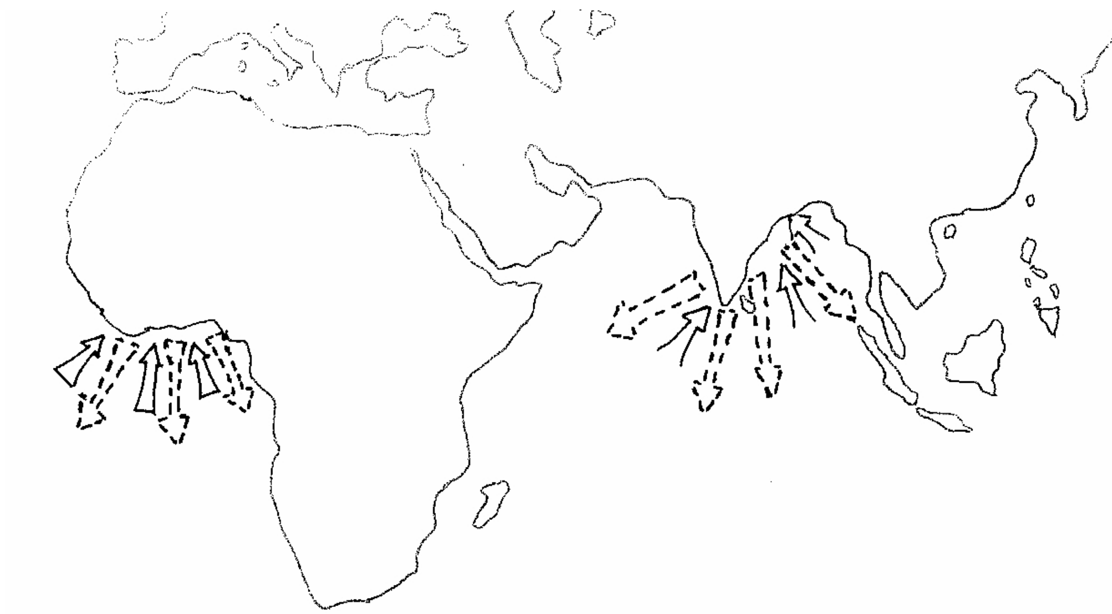

Figure 13. Summer (solid arrows) and winter (dotted arrows) monsoon winds at the Sahel and Indian regions. (Adapted from Navarra, 1979)

On a much smaller scale, local shifts of winds occur on a daily basis because of insolation and subsequent differential temperature between two adjacent areas. These are the land-sea breezes on the one hand and the mountain and valley breezes on the other.

Like the monsoon, sea breezes occur when the adjacent land warms up at a higher rate during daytime, generating a zone of rising air and low pressure, thus pulling winds from the sea. During night the situation reverses and the sea, which has a higher specific heat and therefore a lower heat loss rate, generates rising air and a lower pressure zone. The land in turn becomes relatively cooler and "sends" wind toward the warmer sea.

In mountainous areas, as the sun warms up a side of a hill, the air above it rises, "pulling" a valley breeze from the cooler, lower elevations. At night, the air on the side of the mountain cools more rapidly than the air within the valley because it is less exposed to the wind chill effect. The hillside air gradually becomes colder and denser and flows down the valley because of the pull of gravity, becoming a mountain breeze (Kellman *et al* 102, 117; Moyer 137; Navarra 152,153).

Ocean Currents

Ocean currents flow because winds blow and cause friction across the water surface. Without the presence of landmasses, ocean currents would possibly mirror the global prevailing winds model, but the location and shape of the continents pose obvious constraints to ocean currents' paths. There are basically deep and surface currents, flowing respectively at depths below or above 1000 feet (304.8 m) (Rogers *et al* 188).

Deep currents are colder, denser waters flowing from the poles toward the equator, sinking under warmer surface waters. As these currents approach the equator they gradually become warmer and less dense, until they rise toward the surface because of their lower density. These surface currents move toward the poles, completing a water circulation pattern. Surface currents, in broad terms, move along with the prevailing winds, greatly influencing the regional climate by transporting heat and moisture along their path, transferring it to the atmosphere.

Generally, currents on the western flank of a large water body, such as an ocean, are warm and flow poleward. Their eastern-flank counterparts, in contrast, are relatively cold and flow equatoward (Fig. 14). Ocean waters can only partially follow such a pattern because of the existence of landmasses of diverse shapes and locations.

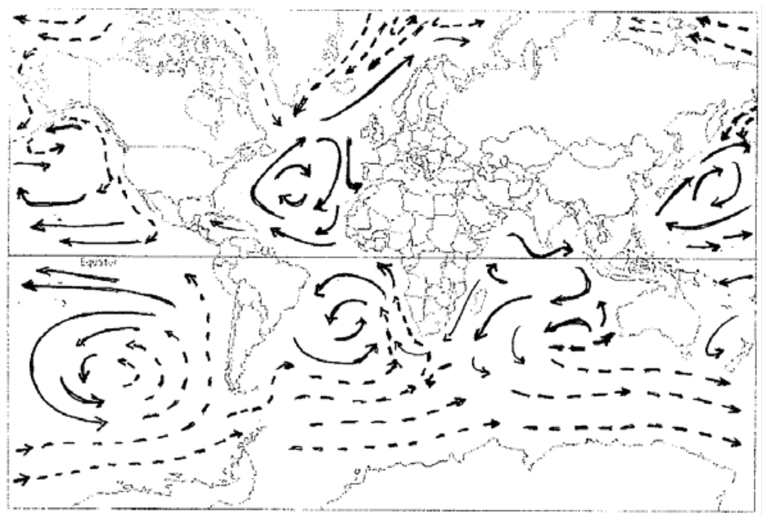

Figure 14. Circulation pattern of ocean currents. Solid-line arrows = warm currents; broken-line arrows = cold currents. (Adapted from Kellman et al, 2005)

Together with the atmospheric circulation patterns, the patterns of oceanic circulation contribute mightily to the world's weather and climate by mixing the heat and cold of the equatorial and polar zones respectively. Without this synergistic and dynamic process, areas poleward of the mid-latitudes (33-35 degrees) would be perpetually frozen, and areas equatoward of the same would be hot beyond levels of human endurance.

LESSON PLANS

Lesson One: Atmospheric Pressure (45 – 50 minutes)

Objectives

SCI.4.2.02. Identify the Sun as the major source of energy for the Earth and understand its role in the creation of winds.

SCI.4.4.07 Identify and measure patterns of change in weather and recognize that the Sun's radiant energy is responsible for weather patterns.

SCI.5.5.A. Describe cycles, structures and processes found in a simple system.

SCI.5.5.B. Describe some interactions that occur in a simple system

Introduction

Air is a fluid and as such it flows. At ground level it moves from zones of high atmospheric pressure toward zones of low atmospheric pressure, creating horizontal movements of air masses, called winds. The purpose of this lesson is to represent by means of a model how high and low atmospheric pressures "look," how pressure zones are represented by means of isobars, and how winds originate.

Notes: This model will help the student to visualize, and therefore to better understand, the existence of high and low pressure zones, the isobar concept, and wind formation.

Concept Development / Key Questions

Does air have weight?

How does wind originate?

Are surface winds the same as those that blow higher in the atmosphere?

What are cyclones? How do they form?

What are anticyclones? How do they form?

Where do winds come from? Where do they go?

Notes: The vocabulary utilized in this lesson is defined and explained in the background section Air Pressure, Pressure Gradient, and Winds of this unit.

Instruction: Explain and demonstrate by using a vacuum machine and a hair dryer (as described below in the Student Practice section) that the atmosphere has zones of high pressure pushing air downward on the one hand and zones of low pressure lifting or “sucking” air upward, which creates horizontal winds that travel from high to low pressure cells.

Student Practice

Clear a rectangle of approximately 4 ft long by 3 ft wide (a laboratory table can be used for this purpose), and using masking tape, mark an H at 1 1/2 ft distance from one end and an L at 1 1/2 ft distance from the other end of the rectangle centered widthwise.

Encircle the H and L letters with masking tape; each will mark the center of the high and low pressure zones respectively. Mark with masking tape segments of circle, spaced about four inches from one another, departing from both centers of pressure and going towards the opposite center; eventually the lines will coincide in a central line, midway between both pressure zones. These lines model the isobars or lines that mark points with the same atmospheric pressure.

On the central line write the average atmospheric pressure equal to 1013 millibars; write decreasing pressure figures at four millibar intervals each line towards the center of low pressure L and increasing pressure figures at four millibar intervals on each line towards the center of high pressure H. This models the pressure or isobaric map for the purposes of the demonstration.

On the map, spread confetti sized Styrofoam pieces, particularly on the H and L zones. Have one student to hold an aspirator hose or tube (turned off at this time) approximately ten inches above the L and have another student to hold a hair dryer (turned off as well) at a similar distance above the H (It is convenient to slightly tilt both, the aspirator and dryer “mouths” toward each other in order to get a better directed flow of air).

Have two more students to **simultaneously** turn on the aspirator and the dryer, so that the high pressure current sends away the foam pieces, whereas the low pressure current pulls them.

Notes: The model illustrates only the movement of wind at the surface; explain that at higher layers of the troposphere a flow of air occurs in the opposite direction, completing in such a case the circular movement of air in a convection cell.

Assessment

The students must make a drawing of the isobaric map model and the wind flow depending of the difference of pressure and explain in writing:

- what are high and low pressure zones.
- how the air currents move upwards and downwards in such zones.
- what are isobars?

The students also must be able to recognize in a newspaper weather report, the features shown in the model.

Closure

Explain to the students that high and low pressure zones occur at the same time in different places of the world and that at a certain extent they shift their position gradually from one location to another. Definitely much of the weather a specific location has is due to the pressure zone in place at a certain moment.

Notes: An important addition to this lecture would be to mention that rain occurs in the low pressure whereas the weather is usually good in the high pressure zones.

Resources

An area of 4 ft by 3 ft clear (it could be the top of a laboratory table).

Masking tape.

Styrofoam chips cut into confetti size

Vacuum cleaner or other kind of aspirator and hair dryer.

Lesson Two: Latitudinal Effect (45 – 50 minutes)

Objectives

SCI.5.4.08. Explain the primary sources of energy, including solar.

SCI.5.4.13. Identify events and changes that occur on a regular basis such as in daily… and seasonal cycles.

SCI.5.12.C. Identify the physical characteristics of the Earth.

Introduction

The spherical shape of the earth plays a role in the amount of solar energy received at different latitudes, just because the Earth's surface is increasingly less perpendicular as we go from the Equator to the Poles. As obvious as this appears, it is often novel information for an elementary student. This physical feature of the Earth that influences the climate at different latitudes will be explained by this activity.

Notes: This difference in angle with respect to the incoming solar rays is related to the occurrence of seasons when combined with the tilt of the terrestrial axis and the orbit around the Sun.

Concept Development / Key Questions

How does the shape of the Earth affect the amount of energy received from the Sun?

Does the Earth receive the same amount of solar energy everywhere?

Does the Earth receive the same amount of solar energy at all times?

Why do we have seasons?

Instruction: Demonstrate by using an Earth model, thermometers and a desk lamp, that the spherical shape of the planet has a strong influence in the intensity of sunlight that different latitudes receive.

Notes: It is important to place the lamp relatively close to the Earth model, otherwise the difference in heat received will be jeopardized by the distance of the model from the heat source (the lamp).

Student Practice

Tape five thermometers to the Earth model: one at the Equator, which will be in vertical position, two between the Equator and each pole, which, therefore, will be positioned at an angle of forty five degrees approximately, and a one thermometer each on top of the North and South poles. The polar thermometers will be positioned horizontally.

Place a desk lamp ten inches to one foot from the Earth **at the level of the Equator**, and turn it on. After ten minutes read the temperature recorded by each of the thermometers and note them in a table.

Notes: It is a good idea to do this demonstration first with the Earth model standing on a vertical position, and then repeat the measurements with the model tilted at 23.4 degrees, as it is in reality. This will help to explain the role of the Earth's axis tilt and will allow a further explanation of the seasons if time permits.

Assessment

The student must make a table with temperatures of the Earth at different latitudes and explain this in writing.

Closure

The effect of latitude in the amount of insolation is due to the obliquity of the Earth's surface at different latitudes, because the solar beams are spread over a larger area as they reach a surface which is more inclined, as we move poleward. Conversely, at the Equator the solar rays are more "concentrated" because the Earth's surface is perpendicular to the Sun.

Notes: A follow up to this lesson can be the demonstration of the effect of the Earth's tilt, rotation, and revolution around the Sun in order to explain the seasons in both northern and southern hemispheres.

Resources

Per team:

One Earth model approximately the size of a basketball.

Five thermometers

Desk lamp

Notes: Instead of an Earth model, a basketball or a beach ball are useful.

Lesson Three: Coriolis Force (45 – 50 minutes)

Objectives

SCI 4.4.02 Identify the Sun as the major source of energy for the Earth and understand its role in the creation of winds.

SCI 5.5.A. Describe cycles, structures and processes found in a simple system.

SCI 5.5.B. Describe some interactions that occur in a simple system

SCI 5.12.C Identify the physical characteristics of the Earth.

Introduction

Coriolis is the effect that the rotation of the Earth has on the latitudinal movement of winds, deflecting them westward or eastward depending if the winds move poleward or equatoward respectively. The purpose of this lesson is to show by means of a model the effect of rotation on a moving fluid, namely the atmosphere.

Notes: The complete picture is rather complex for an elementary student, but this lesson is a simplification of the phenomenon in order to teach the core concept of coriolis.

Concept Development / Key Questions

Does the Earth rotation affect wind circulation? How?

Are surface winds the same as those high in the atmosphere?

What is coriolis?

Notes: The vocabulary utilized in this lesson is defined and explained in the background section Coriolis and Friction Force of this unit.

Instruction: Explain and demonstrate by using an Earth's model, as described in the Student Practice section, that the Earth rotates from west to east, and that all objects staying on the ground move with it. The speed at the Equator is higher than at other latitudes, both north and south of it, because of the smaller latitudinal circumferences traveled in one rotation; demonstrate it by attaching some paper stickers at different latitudes in the globe and make it rotate. This rotating movement has an effect on free moving objects, like rockets, airplanes or wind masses.

Student Practice

Form teams of students and give each team an Earth model, food coloring (which will model the winds), droppers (some food coloring is bottled already in dropper plastic bottles) and paper napkins.

To start, keeping the model stationary, drop some food coloring at a latitude between the Equator and the North Pole. Observe how -on a stationary planet, the winds move from the Pole to the Equator in a straight line.

Proceed to the second test, dropping some coloring on a rotating Earth. Whereas one student keeps the model with the axis vertical (and not tilted as they sit on the stand), another student makes the model spin with the hand, and a third student will carefully drop some food coloring at a latitude in between the Equator and the North Pole while the model is rotating. After some practice the students will be able to observe how the coloring drops run down towards the Equator describing a curve, or being deflected to the left **from the standpoint of the observer** the rotation of the model, illustrating the coriolis effect.

Notes: Explain that winds going from the Equator towards the poles will reverse its turning, "going forward" or describing a curve to the right **from the standpoint of the observer**, due again to the coriolis effect.

Assessment

The students must make a drawing of the coriolis demonstration and explain in writing:

- why the speed is higher as we move closer to the equator and vice-versa.
- what the coriolis effect is on the winds.
- why the winds are deflected.

Notes: You can decide on changing or adapting the questions according to your particular lecture.

Closure

Define coriolis as a force that affects any body moving on a rotating surface (Barnhart, 1986). Explain that coriolis is a determining factor in the global winds circulation pattern.

Notes: Clarify that the model is limited and only winds coming from the North Pole to the Equator could be observed, and explain the reverse movement when winds go in the opposite direction as well as when we consider the winds in the southern hemisphere.

Resources

The materials listed are per team.

Earth model (a small beach ball can be used too).

Food coloring (which will model the winds)

Droppers (some food coloring is already bottled in dropper-ready plastic containers)

Paper towels.

Lesson Four: Effect of Continentality (45 – 50 minutes)

Objectives

SCI.4.4.03. Summarize the effects of the oceans on land.

SCI.5.4.13. Identify events and describe changes that occur on a regular basis such as in daily…and seasonal cycles.

SCI.5.5.B. Describe some interactions that occur in a simple system.

SCI.5.6.A. Identify events and describe changes that occur on a regular basis such as in a daily … and seasonal cycles.

SCI.5.12.C Identify the physical characteristics of the Earth.

Introduction

The solar energy that arrives at the Earth's surface is the same at the same latitude; nevertheless, the rate at which land masses and water bodies gain and lose heat are different. Landmasses gain more heat and at a faster rate than water bodies during daytime and cool down faster at night. This occurs because water has a higher specific heat than rock and is more stable in face of temperature shifts.

The Earth's surface is 71 percent water. Wherever it exists in sufficient quantity, water plays a key role in the local weather and climate because during the daytime it keeps a relatively lower temperature than land, and during the night the same water masses don't cool as much as the land; thus, water serves as a thermal "buffer" for the planet. The larger the water mass is, the higher its thermal "buffer" capacity, and so an ocean is a stronger buffer than a lake.

Over the continent, as we go inland, the temperature fluctuations between day and night are greater because we are farther from the thermal "buffer" of the oceans. This is the effect of continentality. Naturally, in the depths of larger landmasses, the effect of continentality is stronger than in smaller continents. Continentality is weakest on small islands.

The effect of continentality over landmasses occurs not only on a daily basis, but also on a seasonal basis, making the winter and summer temperatures more extreme in the interior than they are near seas or oceans.

Concept Development / Key Questions

Is it equally hot on land and on the sea during daytime and night?

Is it equally cold on land and on the sea during night?

Is it equally hot on land and on the sea during summer and during winter?

Is it equally cold on land and on the sea during winter?

Why are the season's temperatures more extreme as we go farther form the coasts?

Instruction: Explain beforehand specific heat in a simple way as the amount of heat needed to raise the temperature of one gram of water, stone or any substance one degree Celsius. The specific heat of water is higher than that of stone because you need more heat, and, therefore, more solar energy, to heat up a gram of water than a gram of stone. But – as the saying goes – "easy come, easy go," the water, which takes more to warm up, will retain such heat longer, and will take longer to cool down, whereas land warms up easily and also loses its heat easily. The same principal applies on a large scale between oceans and landmasses.

Student Practice

Form teams of students and give them a plastic container (Tupperware™ will do) with several stones of medium size, (the size of small or medium-size potatoes). Place the stones together against one side of the container, which is modeling a continent. Pour water up to two inches deep in the container, which will represent the ocean (make sure that several stones rise above the water level). Insert one thermometer between the stones "above sea level" and put another thermometer in the water. Place a desk lamp, which will model the solar heat about ten inches directly above the plastic container.

Turn the lamp on and read the temperature increase in both "land" and "sea" at one minute intervals, up to twelve readings; record the temperatures in a table. Turn the lamp off and record the temperature decrease in both land and sea at one minute intervals up to twelve readings.

Assessment

The students must make a line graph of the temperature fluctuations on "land" and on "sea" during a period of twenty-four hours, showing the higher variation on land than on water, and explain in writing:

- where are the temperature variations greater, on land or on water?
- why are the temperature variations greater, on land or on water?

Closure

Remind the students that in the model we cannot appreciate very well the differences between areas near or far from the water, but that in the real situation, the distance from the sea plays an important role in both daily and seasonal temperature variations.

Resources

Per team:

One medium size plastic container (Tupperware®) and water up to two inches deep

Six to ten medium size stones

Desk lamp

Two thermometers and timer (students' wrist watches are useful, too)

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