

## **Agronomy 541 : Lesson 7a**

# **Dew and Plant Diseases**

### **Introduction**

Developed by E. Taylor and D. Todey

It is suggested that you watch Video 7A and complete the exercise in the video before continuing with the lesson.

[Podcast Version](#) **Full Podcast List**

An important aspect of our environment is the formation of dew. It is common thing to find morning dew on lawns in the Midwest during the summer because of clear windless nights and high humidities. It is not so common in the Mountain West, where clear skies are prevalent but relative humidity is very low. As discussed in lesson 5, dew is a form of precipitation. More important in humid climates is its persistence, which can lead to the development and transfer of disease.

### **What You Will Learn in This Lesson:**

- How dew is related to moisture measurement.
- How dew is formed.
- About the implications of dew on plant disease.

### **Reading Assignments:**

- pg. 109-110—Aguado and Burt

## Agronomy 541 : Lesson 7a

# Dew and Plant Diseases

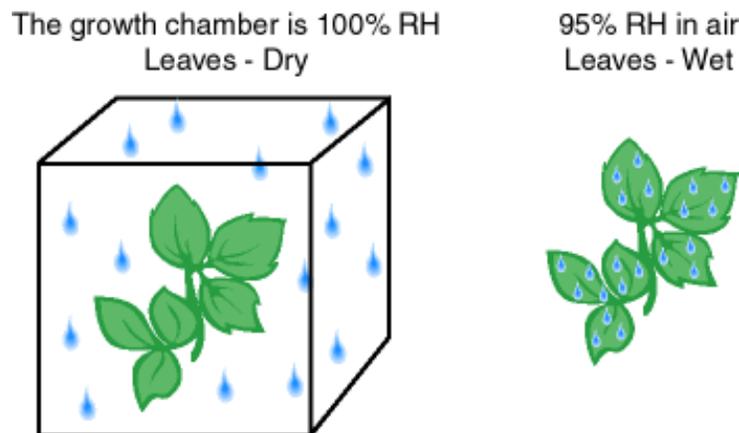
## Dew Point

By definition, dew is the moisture that gathers on objects when temperature falls to the dew point. We have already talked about the concept of the dew point (**Lesson 5**) in regard to forming clouds. Cooling air at a specific moisture content (no change in moisture) will at some temperature produce dew as the air will reach the point where it can no longer hold as much water vapor. This is the temperature where relative humidity equals 100% or the air is saturated, holding all the water it can.

**Dew Point = Temperature when RH = 100%**

Because air holds less water when cooler, something will happen when relative humidity is at 100%. Fog will form, dew will form, or a "super saturated" condition will exist. Sometimes the air temperature does not reach a humidity of 100%, yet dew is observed. Air temperature does not need to drop to the dewpoint because objects may become cooler than the air around them. This is important to the concept of dew formation. It may be assumed that dew is "usually" present at night when the relative humidity exceeds 95% in the atmosphere.

The atmosphere at 95% relative humidity does not produce fog (Fig. 7.1). But dew will form if temperatures of items are enough colder than the air surrounding them that they are at the dew point.



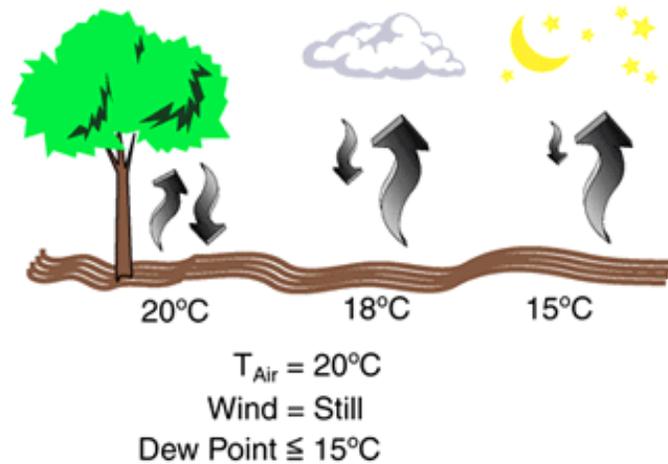
**Fig. 7.1 Wetness (dew) will form on leaves at 95% relative humidity in the air.**

On clear, cool, and still nights radiative frost (if temperatures drop below freezing) or dew is possible. Under mid-level to low cloud cover, dew is not likely. When wind blows, dew is not likely. With light wind, however, fog is possible. In addition, some source of moisture is needed. When relative humidity levels are high, on a clear, still, cool night fog is likely. If the relative humidity is not quite as high, but the ground provides moisture from a wet soil, growing plants or moist vegetation for some reason, heavy dew is probable.

The concept of dew formation is rather old. **Dew** is mentioned as an ecological factor in the Old Testament. It may have been necessary for occurrence of manna (Exodus 13:16). The factors causing dew have been observed well back into history. The logic and conditions for dew formation became apparent to people. Mathematical models followed after a hundred years of observation. There are some rather interesting aspects to relative humidity and soil conditions. Several factors necessary for dew formation are:

## Lack of Cloud Cover

The night sky cover (cloud amount) must be less than 50% and preferably 100% clear. If more than half the sky is obscured with clouds, dew will not likely form. The clouds must be mid- or low-level clouds. High clouds do not re-radiate enough energy back toward the surface to keep the surface warmer than dew point (Fig. 7.2).



**Fig. 7.2 Dew formation occurs on clear windless nights, trees and cloud cover emit longwave radiation and keep temperatures above the dew point while cloudless skies will allow sufficient heat loss for the temperature to fall to the dew point.**

## Air Flow

A weak pressure gradient must exist. The dew forecaster looks at the weather maps to determine pressure differences identifying a front coming in, if the air mass is going to change, or if there will be substantial winds overnight. A weak pressure gradient will likely not have substantial winds. If there is a wind of over 7 mph, the assumption is that dew will not form. Air moving by an object that is warmer (or cooler) than the air gains (or loses) heat from the object while lowering (or raising) the temperature of the object.

## Moist Conditions

Enough moisture near the surface must exist to create relatively humid conditions. The relative humidity by midnight needs to be 85% or greater. If the relative humidity is at 85% by midnight, it is likely that dew will develop.

## FYI : Dew

"In a clear, quiet night, the grass radiates heat into free space, whence no heat returns...The grass cools and vapor condenses upon it...A cloudy sky hinders...by returning heat...Winds carry heat to the cool objects..."William Charles Wells 1814

[Close Window](#)

## Agronomy 541 : Lesson 7a

# Dew and Plant Diseases

## Moisture

The source of moisture for the dew is usually very near the plant. Very seldom does the dew arrive from somewhere far distant. It almost always arrives from the immediate vicinity of the plants, usually from the soil right around them or from other vegetation (Fig. 7.3). If the soil is wet because it has rained in the last day or two, much heavier dew may form than if the soil is dry. The plant itself may exude moisture. While appearing similar to dew, this occurrence is actually termed guttation. It is different since the moisture source is the plant itself and not external to the plant.

The Source of Moisture is  
Usually Soil or Plant Material  
in the Local Area

Dry Soil --- Dew Light or No Dew

Fig. 7.3 Moisture for dew is usually evaporated or transpired locally.

The dew forming on farms in Iowa is probably moisture evaporating from the soil in the immediate vicinity of the plants. A couple of things are going to happen then. Because there is a source of moisture at the surface, the relative humidity will be much greater than higher in the sky. The leaves are cooled below the dew point in this vicinity, and so dew begins to form on the leaves, and the leaves become wet.

All of these conditions (clear sky, low air movement, and moist air) are considered in forecasting or anticipating if dew will form. Here in Iowa, the night sky cover and the wind are the usual controlling factors. The humidity in the summer, when dew is of concern, is almost always greater than 85% in the evening well before midnight. Most morning air temperatures are near the dew point. Therefore, most mornings in Iowa during the growing season have relative humidity at or near 100%.

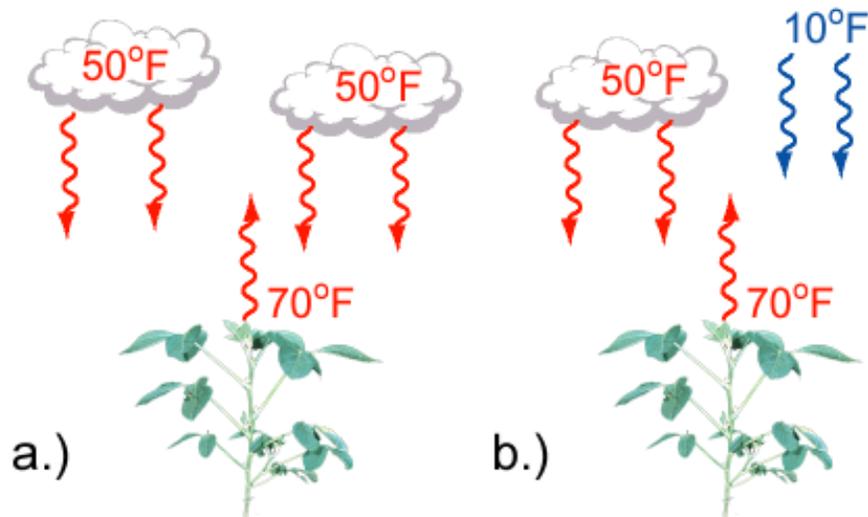
The rate of heat loss by radiation is expressed by the **Stefan—Boltzmann Law**. The law simply states that when radiation is the only method of heat transfer, an object will cool until it radiates the same amount of energy it receives (or heat until it balances as the case may be).

## Physical Causes

What is the physical reason why these conditions produce dew? First consider the cloud cover. The clouds, which affect dew, are generally **low clouds**. For example, these clouds may have a temperature of 50°F (10°C) (Fig. 7.5a). The temperature of the air above the clouds and out into space will be much colder. Refer back to the **atmospheric temperature profile** for estimates of cloud temperatures at various levels. The temperatures from high clouds or clear space may be 10°F (-12.2°C) or below (Fig. 7.5b). This is much cooler than the low clouds. With significant cloud cover overhead, the leaf at the surface is exposed to a 50°F (10°C) radiation environment. If there are no clouds, it is exposed to a 10°F (-12.2°C) radiation environment. Less heat is emitted from an object at 10°F compared with an object at 50°F. The difference is striking when calculating the **energy emitted from an object**, which is related to the fourth power of temperature. The leaf may be at 70°F (21.3°C), giving off heat, and absorbing energy from the clouds. If the clouds are not there, very little heat is coming back. Rather than a 20°F (11.1°C) difference between the radiating bodies, there is a

60°F (33.3°C) difference between the radiating bodies, and the leaf will become much colder than the air.

### Radiation effect of clouds

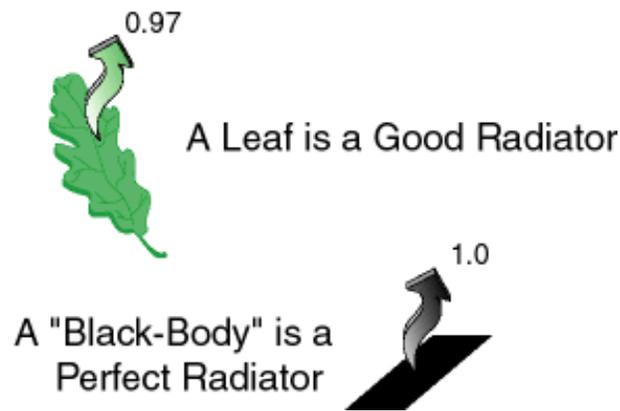


**Fig. 7.5a** The radiation being emitted by the leaf in part a is being balanced mainly by clouds emitting radiation at 50°F. Because the radiation received is near the amount lost, the leaf will cool only slightly below air temperature.

**Fig. 7.5b** Little cloud effect is seen. Less radiation comes from 10° F clouds or space to balance that given off by the leaf. Thus, the leaf will attain a "cooler" temperature.

The important point is that the energy imbalance on the leaf will cause the leaf to become much colder than the air. Radiation can cause things to get colder than the air. Cooling of air is caused by contact with something that is colder than the air. Car windows, grass, leaves of crops, and buildings cool below air temperature. Essentially everything cools below the air temperature. As soon as the sun stops warming the earth's surfaces, they begin to cool. If they are fairly well insulated surfaces, they cool off quite rapidly and fall below air temperature in a short period of time. Consequently, the air next to them begins to cool. This is called radiational cooling of objects.

A leaf is a good radiator (Fig. 7.6). It will cool quickly after it stops absorbing solar radiation. If we could look at the air flow from a leaf in the daytime when there is sun on the leaf, there will be warm air rising from the surface. A little circulation of the air may be seen if there is some smoke or some dust in the air, rising off that leaf. At night the leaf will be colder than the air around it and because it is colder, you will see air sinking off the leaf, pouring toward the floor. As the air pours off the leaf and sinks toward the floor, you have the effect of both cooling the atmosphere, making it more dense, and the radiative effect making the leaf colder than the air.



**Fig. 7.6 Leaf radiates very effectively. Thus, it will cool quickly at night when it stops absorbing solar radiation.**

In a very dry environment, such as in Idaho, Utah or Nevada, the measured leaf temperature might be 15°F (8.3°C) below the air temperature; in a moist area, the leaf would be just 2 or 3°F (1.8-2.7°C) below the air temperature. In Iowa, the 2-3°F difference would be more common for two reasons:

(1) Skies are not as clear and dry as they are in arid climates of Utah, Idaho and Wyoming. More moisture at higher altitudes in the Midwest radiates some heat back to the surface.

(2) The low level relative humidity and dew point are higher. These act as a base for minimum overnight temperatures (note the temperature and dewpoint temperature trace in Fig. 7.7). As soon as the leaf temperature reaches the dew point, it will not cool very much more. It will begin forming dew and will not cool very much more as long as the dew is forming. In fact, it is difficult for the air temperature to get very much below the dew point. The reason for that is that while dew or fog is forming, water condenses, giving off a great deal of heat. The water gives off that heat to the air, keeping the air from cooling more. Cooling has to overcome the condensation of the moisture.

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**Try This!**

[Click here to view interaction between dew point and relative humidity \(Fig. 7.7\).](#)

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**Study Question 7.1**

Using the In Detail above, when would the peak relative humidity occur?

- 6 PM
- 6 AM
- relative humidity wouldn't change

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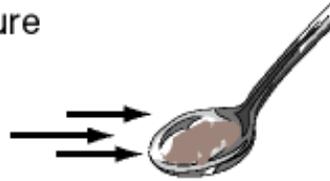
**Discussion Topic 7.1**

[How would clouds change the temperature and relative humidity trace from Figure 7.7? Why does](#)

the dewpoint vary slightly from day to night?

Wind is an additional consideration for dew formation. The pressure gradient indicator was mentioned in the previous section. Pressure gradient is the force that drives wind. When conditions are windy objects are kept near the ambient air temperature (Fig. 7.8). The wind can also mix colder air near the surface with warmer air aloft.

Wind Keeps Objects Near  
Air Temperature



Grandmother:  
"Blow on soup to cool,  
on ice-cream to warm."

Fig. 7.8 Air flow keeps objects near air temperature

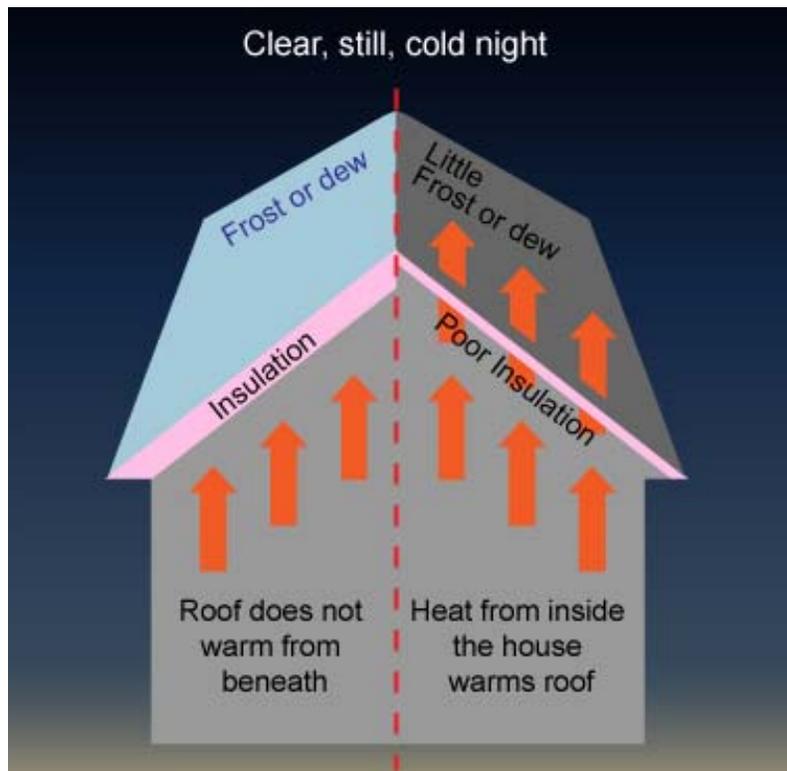


Fig. 7.9

## Agronomy 541 : Lesson 7a

# Dew and Plant Diseases

### Historical Example

Radiative cooling has several other applications than just the formation of dew. Two stories illustrate these.

Transcription of audio on [radiative cooling story](#).



Radiative cooling is a real physical process. Not only can ice freeze on a night that is not particularly cold because of radiative cooling, but leaves also cool off and they condense dew. Sometimes frost occurs at temperatures as high as 40°F (3.6°C). Quite often a little bit of frost can collect on a leaf or two with temperatures of 39° or 40°F when very dry, very clear air is in the area. All of these things contribute to the formation of dew.

### Camping Trip Example

Transcription of audio on [camping trip example](#).

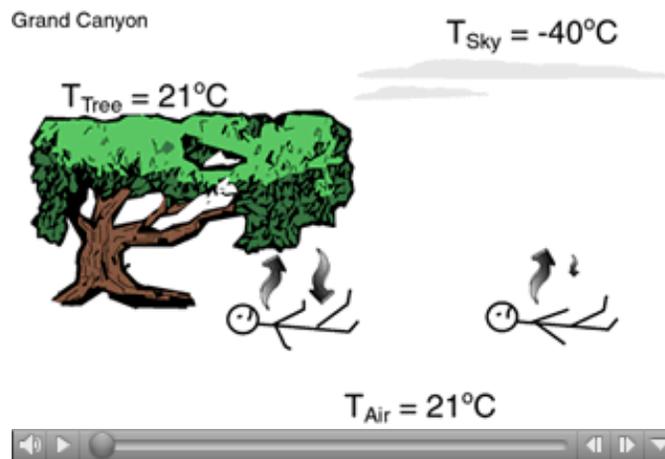


Fig. 7.9 Radiation emitted by a tree at 21°C helps to keep someone warmer sleeping underneath it whereas, someone sleeping in the open with radiation emitted by the sky at - 40°C will feel much colder.

## FYI : Transcription of Audio

Ice can be stored in insulated ice houses all through the summer in Iowa and in Egypt. Ancient ice houses have been identified from Egypt to Iran. The question is, where did they get the ice? Did they haul it in during the winter? It does not freeze in Egypt. How did they get it? It is said, they made it back in the time of the pharaohs. They say, "Well the sky is clear, and all that we have to do to make ice is make a little hole in the ground, fill it with reeds to insulate it, put in a clay dish which was maybe 2 feet across, put about 1/10 inch of water in there, and let it sit all night. Before the sun comes up in the morning, go pick up your clay dish and dump the layer of ice out of it." They collected ice from all of the clay dishes. They carried the little pile of ice that they would have ended up with in one clay dish. Maybe they collected 2 or 3 inches of ice since all of these little layers are maybe an eighth of an inch thick. Put them all together, take them to the ice house, and add it to the ice collection.

That was a little bit hard to believe. I took an ice chest and put a dish in the bottom of it with an eighth of an inch of water in it and set it out in the back yard on a clear, still night in the state of Utah. The air temperature that night never did go below 45°F (7.2°C). In the morning, there was ice in the chest. The water was all frozen. I could have created a deeper layer. You can freeze ice at 45°F (7.2°C) in an open styrofoam chest. I guess it worked in Egypt. At least I guess they made enough ice to put some ice in the pharaoh's beverage, whatever the pharaoh drank in those days.

[Close Window](#)

## FYI : Transcription of Audio

I took a group of Boy Scouts down to the bottom of the Grand Canyon on one occasion. We knew the temperature in the bottom of the Grand Canyon would not fall below 70° at night. The guys said, "Well, we would not have to take any sleeping bags or anything." And, in the bottom of the Grand Canyon, without any sleeping bags or anything, I found a little oak tree and made my place to sleep under the oak tree, and all of the Boy Scouts were out in the open. The Grand Canyon had almost 0 relative humidity, a perfectly clear night, still air. At about 2 a.m, I started waking up noticing the boys were moving. In fact, they had all gathered under my tree. They had figured out that I was warm and they were cold. Why? Because there was a tree radiating to me like a warm thing at 70°, and there was space radiating to these guys out there at -10°F (Fig. 7.9). So it was like sleeping in front of an open refrigerator door to be out from under the tree. Radiative cooling is an important ingredient of dew formation.

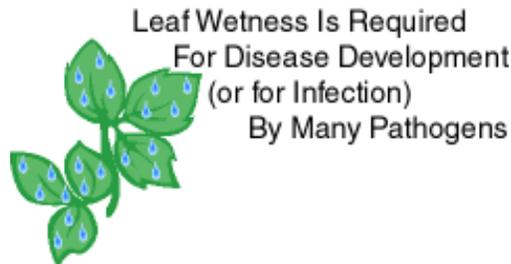
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## Agronomy 541 : Lesson 7a

# Dew and Plant Diseases

### Dew Impacts

As mentioned earlier, dew can be a significant moisture source in some arid areas. In the Midwest, it is not since other water sources are dominant. Some effects of dew can be noted. The presence of dew on a plant reduces the amount of transpiration from the plant. Water on the plant's surface will evaporate before transpiration will begin. The evaporation serves to cool the leaf, also. Some species of plants can actually absorb some of the water on the leaf surface. The most important impact in the Midwest is that many pathogens of crops are dependent on free water on the plant surface. For some pathogens, dew is a suitable "free water medium" for the development of the diseases (Fig. 7.10). Wet plants are then a necessity for transfer of the pathogen from plant to plant. Soybean seed growers always have a concern about the September temperatures and the hours that the vegetation is wet, particularly when rain has fallen. Diseases on the soybean pods can move into the seed and reduce the quality sufficiently that the beans must be used as grain rather than for soybean seed production.



**Fig. 7.10 Dew importance to disease formation.**

Extended periods of wet corn are prime conditions for corn leaf spot (Fig. 7.11). Periods of wet humid conditions with overnight temperatures above 70°F (21.3 C) are conducive to leaf spot development.



**Fig. 7.11. Corn leaf spot**

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[The Great Potato Famine](#) in Ireland was related to a dew, rainfall and temperature combination that created widespread disease and potato blight. A similar situation exists causing the rust of White Pine trees in the Mountains West of the United States and with early blight and late blight of tomatoes in Iowa (Fig. 7.12). It is

similar to the one that forms on potatoes because potatoes and tomatoes are closely related. Potatoes, tomatoes, tobacco, and nightshade, being closely related in the nightshade family, are all fairly subject to the blight. There is some question whether the weeds are subject to blight. But the vegetables are quite sensitive to moisture on the leaves.



**Fig. 7.12 Blight on tomato plant leaves**

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## Agronomy 541 : Lesson 7a

# Dew and Plant Diseases

## Dew Measurement

Several ways exist to determine dew formation. To measure the effect of dew, there needs to be some method for determining when dew has occurred. Directly observing is the best method but requires intensive observation and is not practical for remote sites. Modeling, using measures of meteorological parameters, is another possible method, but will not be discussed here.

### Measuring Leaf Wetness

a. Direct observation  
(touch with tissue)



b. Sensor (implied)



c. Model

$$\frac{k(e_a - e_L)}{\Gamma_b}$$

Fig. 7.13 Dew may be measured using one of three methods: a) feeling for wetness, b) using a dew sensor, or c) model it using measured weather parameters.

There are some instruments for measuring the occurrence of dew. One of them, the Hughes and Davis Dew Sensor, is pictured in Figure 7.14. This instrument was developed by scientists with the National Weather Service in Georgia 25 to 30 years ago. It has become sort of the world's standard for dew sensing. The device is a shiny piece of circuit board, such as in a transistor radio, which has gold on it. The gold is in lines, connected at one end and interlaced like fingers in clasped hands which are not touching each other. When a drop of dew forms on this plate, the drop will complete a circuit and conduct electricity between the wires and ends. Measuring the conduction of electricity determines if there is moisture on the plate.

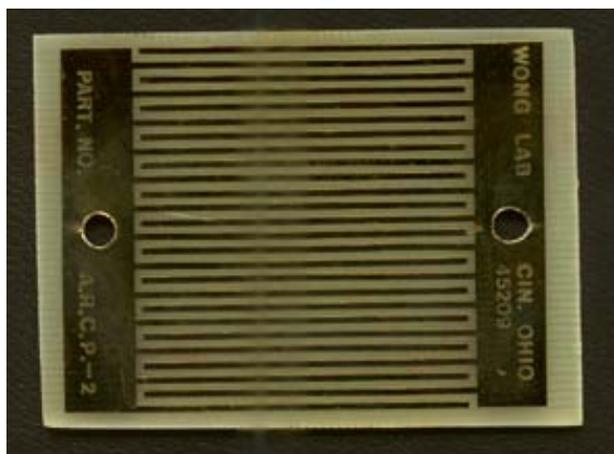


Fig. 7.14 Hughes and Davis dew sensor. Note the interlocking fingers of dew sensor. Dew is detected

**when a drop of water completes the circuit between  
the two wires.**

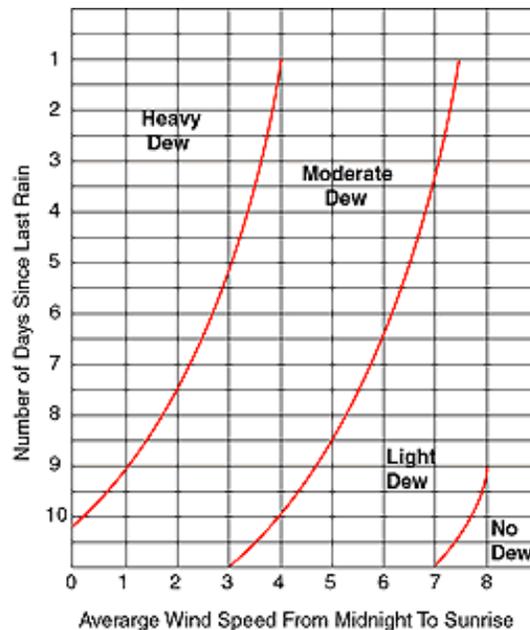
If the plate is perfectly clean and the dew is perfectly clean, it will not conduct electricity. To make sure the plate is not perfectly clean it is painted with latex paint. This covers the sensor, but does not insulate it because latex paint is not a very good insulator. In fact, the paint does a good job of evaluating the water on a surface. It simulates a real leaf. The sensor is set out in the field oriented about the same way the leaves are oriented. It is about the size of a soybean leaflet and mimics its quantity and timing of when dew forms on this plate. Measuring stations for dew are not common since dew is not a regularly measured meteorological parameter. Five dew recording sites in the state of Iowa operate regularly. None of these stations consistently operate year after year.

## Agronomy 541 : Lesson 7a

# Dew and Plant Diseases

## Dew Forecasting

To take preventive measures against damage or disease by dew, knowing when dew will form is useful. Two methods are discussed here. A "rule-of-thumb" oriented model (Fig. 7.15) will place some of the principles in perspective. Wind speeds are indicated across the bottom from 0 to 8 mph. If the wind is greater than 7 mph, dew is not expected to form. As mentioned, a moist soil will have some effect on dew formation. This is measured by the number of days since last rain. If rain has fallen recently, if no wind is blowing, and the sky is less than half covered by clouds, expect to have heavy dew. If it has not rained in a week and there is a wind of 3 mph, expect moderate dew. If the wind is 5 mph, still moderate dew. But if it has been 9 days without rain, only light dew will occur. Two forecasting methods, one based on the number of days since the last rain and the other on soil moisture, are depicted in Figure 7.15.



**Fig 7.15a Dew forecasting chart based on wind speed and length of dry period.**

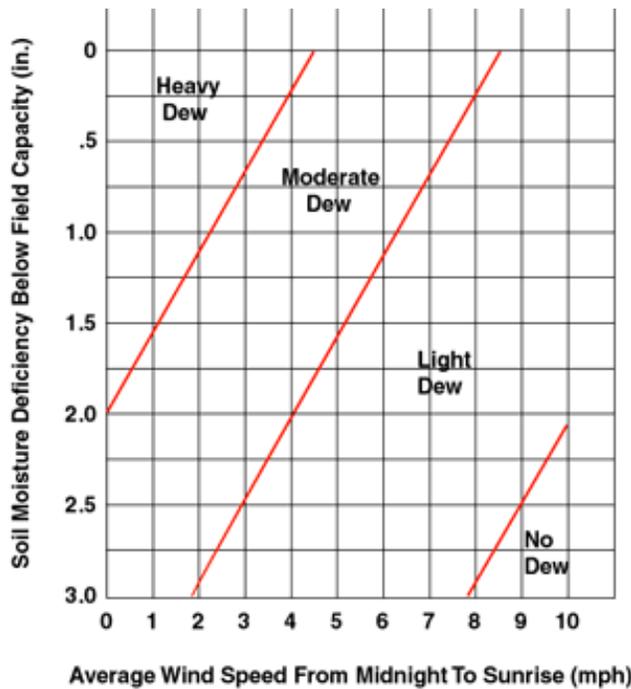


Fig 7.15b Chart based on soil moisture and wind speed.

Study Question 7.2

If the average wind speed is 3 mph and rain occurred 6 days ago, what amount of dew is expected?

- none
- light
- moderate
- heavy

Check Answer

Study Question 7.3

If soil moisture is 2.5" below field capacity with a wind speed of 7 mph, what type of dew conditions would be expected?

- none
- light
- moderate
- heavy

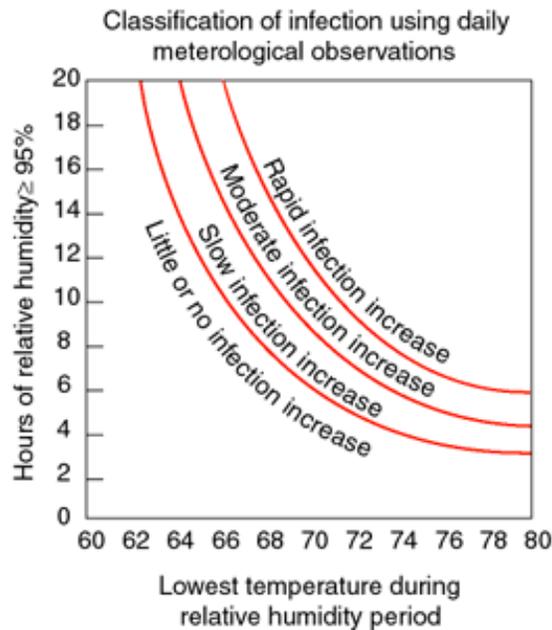
Check Answer

A case where dew is very significant agriculturally is with peanut leaf spot. A study on peanut leaf spot was one of the early studies done (this one conducted in 1966) on the influence of dew on crop disease. Significant leaf spot on peanuts will greatly reduce the peanut harvest. Peanut growers would prefer not to spend all of their finances on spraying the peanuts. This method of control is environmentally unsound as well. Therefore, the peanut leaf spot is of great concern.



**Fig 7.16 Late leaf spot on peanut.**

Two important factors when forecasting peanut leaf spot are high relative humidity and high minimum temperatures since both contribute to leaf spot transmission. A method for determining the rate of infection for peanut leaf spot using these factors is displayed in Figure 7.17. The chart combines the hours of relative humidity, which are greater than 95%, with the lowest temperature during a time of high relative humidity. For example 14 hours of leaf wetness and a low temperature of 74°F (23.3°C) would indicate a "rapid infection rate". Knowing the hours of dew and the overnight low temperature indicates "no infection" because it was either too dry or too cold, "high infection rate" or a condition somewhere in between. These levels are usually given a score of 4, 3, 2, 1 or 3, 2, 1, 0 or something similar. When the score for a certain number of nights sums to a particular value, such as "6", people are advised that they need to treat their plants if they want to save them for their intended purpose. It would be economically feasible to treat them and prevent the diseases that are likely developing because of the hours of wetness and the temperature in combination. Those are the things to look for in evaluating plant disease as influenced by wetting or by dew.



**Fig. 7.17 Possible infection rate caused by number of hours of dew exposure.**

**Study Question 7.4**

If you had consecutive nights of conditions listed below, would treating peanuts for disease be necessary?

	Night 1	Night 2	Night 3
Minimum Temperature	72	66	78

Hours of 95% relative humidity | 8 | 4 | 10 |

- yes
- no

Check Answer

The lower atmosphere temperature and humidity conditions necessary for the formation of dew can be summarized in Figure 7.18.

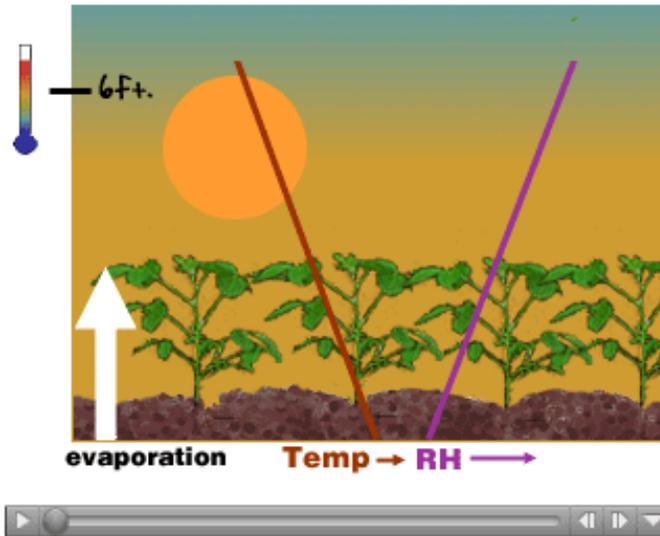


Fig. 7.18 Low-level temperature and humidity conditions which lead to dew formation.

What is the significance of 95% relative humidity? That is assumed to be the condition for dew formation if dew observations are not available. If dew cannot be measured directly, by having a Hughes and Davis dew sensor for instance, how can dew be estimated? Many more places than have dew sensors have hygrometers to measure the amount of humidity in the air as well as the temperature. A trace of one of these can be seen in Figure 7.19. Hygrothermographs simultaneously measure the temperature and relative humidity on a continuous trace. Any time the humidity trace goes above 95%, dew is assumed to have formed or precipitation has fallen.

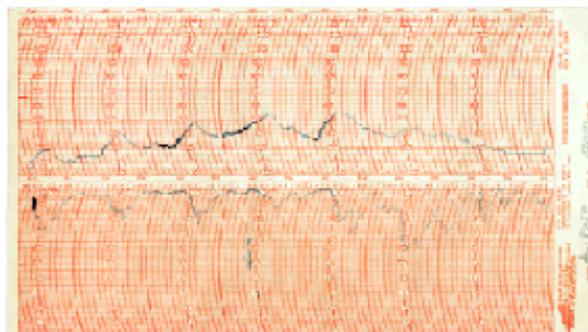


Fig 7.19 Hygrothermograph trace for detecting relative humidity of 95% occurrence. Click the image above for a better view.

Temperatures are depicted in the top chart with humidities on the bottom. Notice how the humidity level raises as temperatures fall at night. The top of the humidity chart indicates 100% relative humidity.

How can there be dew at 95%? First, the humidity is probably measured at 5-6 feet above the ground. Temperatures will likely be colder near the ground producing a higher relative humidity. Second, the humidity will be a little bit higher near the ground because of evaporation from the ground and transpiration from plants. Third, the leaves at night are usually colder than the air. A relative humidity of 95% will likely cause the formation of dew. It has almost become a "rule of thumb" that a relative humidity of 95% will likely be associated with dew. This value is used by horticulturalists, crop protection people, and people who grow especially high value crops such as tomatoes and other things which are very sensitive to diseases and the amount of dew.

## **Agronomy 541 : Lesson 7b**

# **Orbits and Climate**

### **Introduction**

Developed by E. Taylor and D. Todey

It is suggested that you watch Video 7B and complete the exercise in the video before continuing with the lesson.

[Podcast Version](#) **Full Podcast List**

The Earth has numerous planetary motions which affect our weather and climate in various ways. The two primary earth motions that influence the weather are the revolution of the earth in an orbit around the sun every 365 days, and the rotation of the earth on its axis every 24 hours. The effect of these two motions is to produce a daily cycle (often called a diurnal cycle) and an annual cycle in our weather. A number of other cycles exist because of various motions of the earth. The effects of these are less apparent because of their lengthy time-scale. But when viewed over thousands of years of climatic reconstructions, they become very apparent.

### **What You Will Learn in This Lesson:**

- About some changes in the Earth's orbit and alignment with regard to the sun.
- How orbital circulations affect the climate of the globe.
- About the general circulation and its affect on climate.

### **Reading Assignments:**

- pg. 39-50—Aguado and Burt
- pg. 210-206—Aguado and Burt

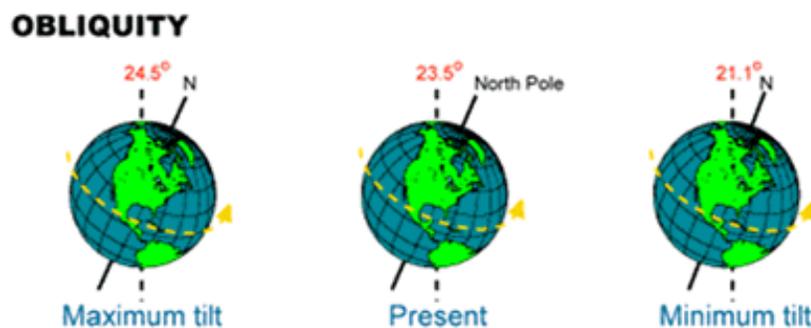
## Agronomy 541 : Lesson 7b

# Orbits and Climate

### Axis Tilt (Obliquity)

The most apparent and repetitive cycle of the earth's weather is the rising and setting of the sun caused by the rotation of the earth on its axis. The Earth's **axis of rotation** is not perpendicular to the plane of rotation. The axis is tilted  $23.5^\circ$  from the vertical (Fig. 7.20). This axis angle varies, from  $24.5^\circ$  to  $22.1^\circ$  over a 41,000 year period. This tilt is perhaps the most significant long-term effect on our climate and short-term weather as well. The fact, not that it changes, but that the poles are not straight up and down is the real short-term effect on the weather, because tilting the Earth toward or away from the Sun results in summer and winter seasons.

The axis tilt of the Earth defines the "tropics", the "tropic" being the low latitude where the Sun is directly overhead for any day of the year. At present this is at  $23^\circ 26' 22''$  and is decreasing. This will result in a less well-defined difference between summer and winter over a span of a few thousand years. During the past 100 years the tropics have become about 2 km narrower. Observers in Taiwan have placed monuments at the "line of return" or the latitude of the tropic. The oldest surviving dates to 1908 and is more than 1 km from the present latitude of the tropic.



**Fig. 7.20 Earth is tilted  $23\frac{1}{2}^\circ$  from the perpendicular to the plane of the Earth's orbit (or tilted  $66\frac{1}{2}^\circ$ ) from the plane of orbit. The tilt change has a 41,000 year cycle.**

### Wobble (Precession)

The wobble of the axis of the Earth was noticed before people discovered that the Earth rotated or that the Earth was in an orbit around the Sun. Discerned 125 years before the time of Christ, the wobble was the first thing that was really well documented and understood. The wobbling has an interesting effect on climate and on navigation. Eleven thousand years ago, the North Star was Vega (Fig. 7.21a); currently, the North Star is Polaris (Fig. 7.21b). The North Star has changed over the past 11,000 years, and in another 11,000 years it will switch back to Vega again. The North Star changes because of precession and is slightly influenced by the change in the angle of the Earth's tilt.

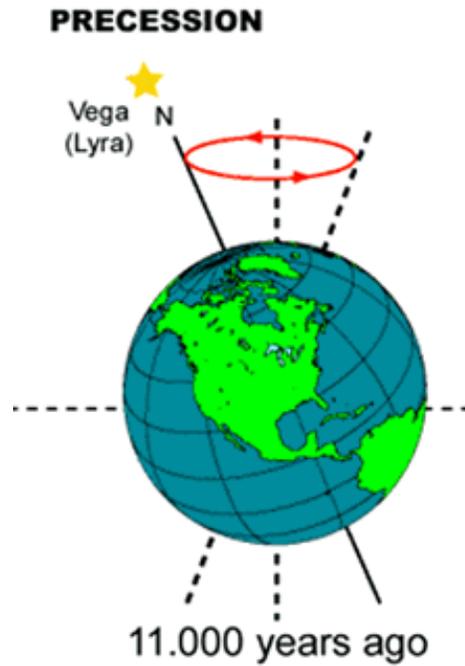


Fig. 7.21a.



Fig. 7.21b An 11,000 year wobble in the tilt of the Earth's axis changes which star is the "North Star"

## The North Star Changes

The following excerpt is taken from [http://www.wikipedia.org/wiki/North\\_Star](http://www.wikipedia.org/wiki/North_Star) (Verified 10 August 2011)

Due to the precession of the equinoxes the direction of the Earth's axis is very slowly but continuously changing, and as the projection of the Earth's axis moves around the celestial sphere over the millennia, the role of the North Star passes from one star to another. Since the precession of equinoxes is so slow, taking about 26,000 years to complete a cycle, a single star

typically holds that title for many centuries.

In 3000 BCE the faint star Thuban in the constellation Draco was the North Star. At magnitude 3.67 (fourth magnitude) it is only one-fifth as bright as Polaris, the current North Star.

Gamma Cephei (also known as Alrai, situated 45 light-years away) will become closer to the northern celestial pole than Polaris around 3000 CE, and be at its closest approach around 4000 CE. The title of the North Star then will pass to Iota Cephei (Iota Cephei, situated 115 light-years away) some time around 5200 CE. The first magnitude star Vega (26 light-years away) will then become the North Star by 14000 CE.

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### **Was Draco ever the North Star?**

The following excerpt is taken from <http://www.astronomical.org/oldsite/portal/modules/wfsection/article.php?articleid=34> (which is no longer active).

Draco, the Dragon, used to hold special significance as the location of the pole star, but due to the Earth's precession, the pole has shifted to Polaris in Ursa Minor. The Dragon is usually associated with guardian's of the temples and treasures. Draco was important as it was the guardian of the star that never moves, the celestial pole. The celestial pole in ancient times was the doorway between the mortal world and the eternity.

In Greek mythology the dragon is Ladon, the guardian of the 'golden apples' of immortality which grew in the garden of Hesperides, beyond the River of Time, in the land of death. It is Ladon which Hercules kills in his 11th labor to get the golden apples.

To learn more about if the North Star ever moves, check out this site: <http://www.earthsky.org/faq/north-star-movement>

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## Agronomy 541 : Lesson 7b

### Orbits and Climate

#### Earth-Sun Orbit (Eccentricity)

The motion of the Earth around the Sun is a very important motion. Some early Greek philosophers initially decided that the earth was in orbit around the sun, but they could not solve the mathematics. Deciding that they could not make the arithmetic fit, they stated that the Sun revolved around the Earth. Simply because they could not make mathematics describe the motion of the Earth around the Sun, the Sun must be in orbit around the Earth. Because they could write a formula for the Sun's orbit around the Earth explaining the action of shadows, people were convinced for a long time that the Sun must be in orbit around the Earth.

The reason the arithmetic could not be solved is that the Earth is not rotating around the Sun. The Sun does not rotate around the Earth, and the Earth does not rotate around the sun. Neither theory was completely correct. Newton finally solved the problem around 1666. It required his understanding of gravity to realize that the Earth is not traveling around the Sun. The Earth and Sun act as a system. Imagine the Earth and Sun hooked together by a weightless strong rod. Where would it balance? Because the Sun is much heavier than the Earth, the system would balance near, but not at, the center of the Sun. The Earth and the Sun are traveling around a common center of mass, or the common center of gravity of the Earth-Sun system (Figure 7.22).

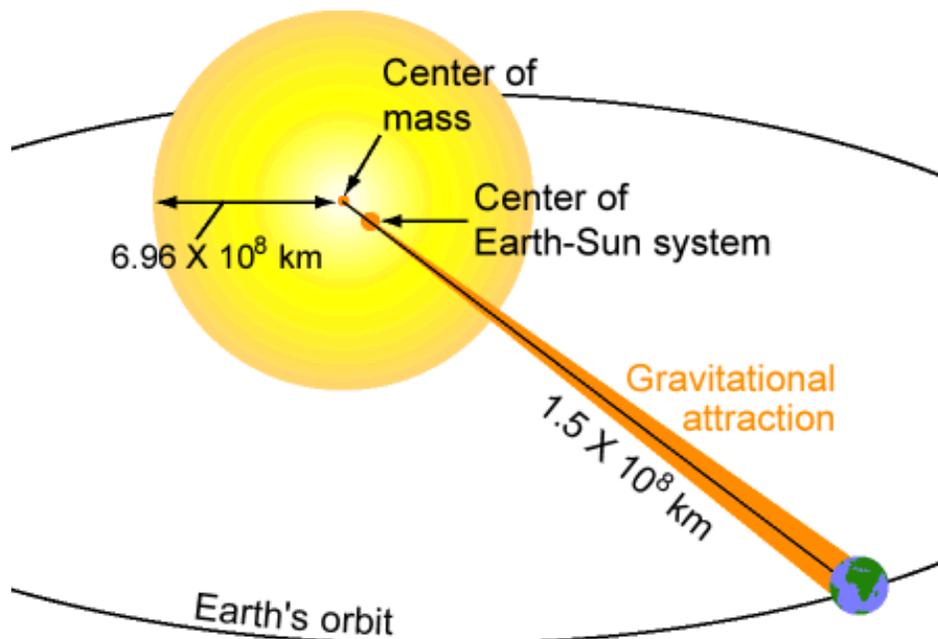
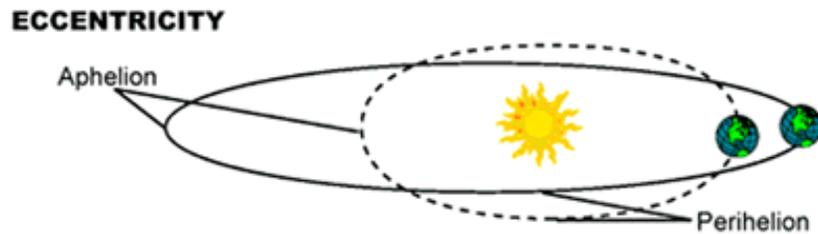


Fig 7.22 Center of the Earth-Sun system, around which the system revolves, is not at the center of mass of the Sun, although very close to it.

Some apparent irregularities occur because of the Earth-Sun connection. One irregularity would appear to some who thought the planet was going around the Sun. The irregularity is called the retrograde movement of the Sun, which occurs about every 176 years (Shirley, 1988). A shadow can actually reverse itself and can be seen if you are watching a sundial during that period of time. It does not really go backwards, but it elongates when it should be shortening. The way it occurs is explained clearly by this rotation around something other than the center of the Sun. Once, what Newton calls his "**theory of gravity**" was explained, the mathematics of

planetary motion could be described. It describes the orbit of the Earth and the Sun with sufficient accuracy that travel from the Earth to the Moon and other planets by spacecraft can occur.

Gravity affects the orbit of the Earth by producing an orbit, which is not a circle. The orbit is slightly elongated into something more eccentric (termed an ellipse) than a perfect circle. At times the Earth is closer to the Sun than at others (Fig. 7.23). The orbital variation is not as extreme as depicted in this picture, but it is something other than a circle. This elliptical orbit actually has the Earth closer to the Sun during the Northern Hemisphere winter. The change is very small, amounting to a slight increase in radiation during the winter. This eccentricity changes over thousands of years, also. This is a cycle of about 100,000 years. The shifting center of mass for the solar system might make the Sun appear to wobble if viewed from some distinct point. Astronomers infer the existence of planets in other solar systems from observed wobbling of stars.



**Fig 7.23 Eccentricity of the Earth's orbit causes the Earth to be slightly closer or farther from the sun during the year. Eccentricity varies over a 100,000 year cycle.**

## FYI : Theory of Gravity

It is called a "theory" of gravity because there is no "law" of gravity. Newton came up with the theory of gravity by observing the tides of the ocean and the moon. He saw that they were obviously connected and worked on the mathematics to illustrate this. To do the mathematics he had to develop calculus (most students have hated him ever since!). But with the development of calculus he came up with the theory of gravity to describe the motion of the Earth and other planets in the solar system and of the Moon with respect to the Earth and the Sun. But it was wrong or at least incomplete. The planet motions did not agree exactly with Newton's analysis. He knew the period of the Moon was 18.6 years and was determined to confirm his observations at the next Lunar cycle.

So he left the manuscript of the theory of gravity sitting on his desk for 18 years until he could make the measurements again when the moon was back in exactly the same relationship to the sun and earth that it had been before. He made his measurements again; they were still the same. He let the manuscript sit there another year but still could not find the mistake in it. Finally, one of his friends said that this was still a contribution, mistake or no mistake in the theory of gravity.

It was published, acknowledging that there was a mistake in the theory of gravity. Every great physicist ever since has tried to correct the mistake in the theory of gravity. Maxwell worked on it. Planck worked on it. Einstein worked on it. Einstein came the closest to correcting the flaw in the theory of gravity. Einstein's correction is known as the theory of relativity. Most people would accept the theory of relativity as the correction to make the theory of gravity correct except for Einstein's statement that there is a mistake in the theory of relativity. The error in the theory of gravity is not solved, yet. But the theory is sufficient for space travel and to explain the retrograde movement of the sun.

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## Agronomy 541 : Lesson 7b

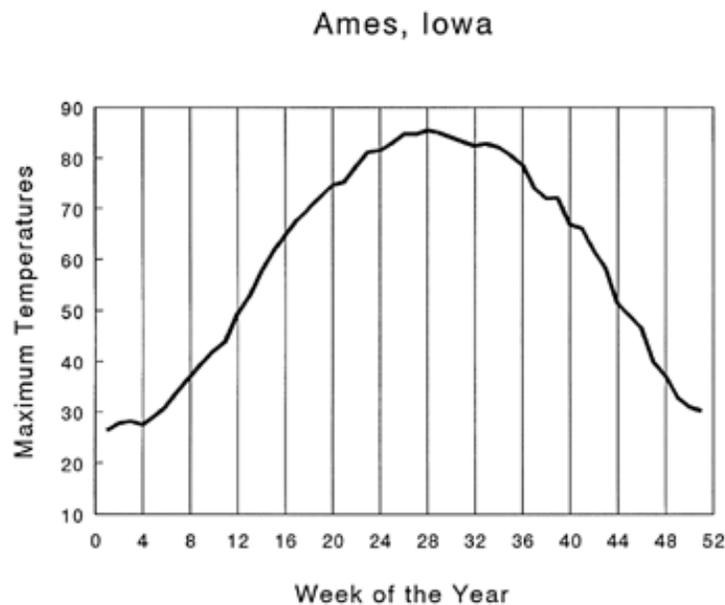
# Orbits and Climate

## Seasonal Changes

Combining the tilting of the Earth on its axis and movement of the Earth in its orbit around the sun produces the main and most basic climatic change in the atmosphere, the seasons. At summer solstice (June 21) the North Pole is tilted toward the sun. It stays daylight at the North Pole for 24 hours a day; it stays dark at the South Pole for 24 hours a day as the earth rotates. The Northern Hemisphere has more than 12 hours of daylight, while the Southern Hemisphere has less than 12. At the equinoxes, no part of the Earth is tilting toward the sun. All places on the Earth have days, 12 hours in length.

In the middle of the Northern Hemisphere winter (22nd of December) the South Pole is toward the sun and the North Pole is away from it. Hence, our seasons change as the Earth travels around the sun. The result of the tilt is to enhance the difference in extremes of the seasons. The part of the Earth tilted toward the sun is heated the most while that tilted away heats the least. This heating imbalance produces weather.

The seasons discussed here are universally recognized seasons. They may be termed astronomical seasons. Climatologists often adapt the season concept slightly. As most people who live in the Midwest recognize, cold temperatures occur in November, well before the winter begins on December 21. Warm temperatures occur before astronomical summer begins. Average Maximum temperatures for each week of the year for Ames, IA are displayed in Figure 7.24. The astronomical summer starts in week 25.



**Fig. 7.24** Variation of weekly average maximum temperatures for Ames, IA.

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### Study Question 7.5

What week would you place the start and end of a climatological summer?

Start: week  End: week

The sun has progressed to its northern extreme (the North Pole is pointed most directly toward the sun) on June 22. On that day the Northern Hemisphere receives the most solar radiation because of the long day length and the sun being oriented nearly directly down on the surface. However, that day is not often the warmest of the year climatologically (Fig. 7.25 for an example in Iowa). The average warmest days of the year in the Midwest occur about 30 days later. Even though the earth has been heating up throughout the late winter and spring, it continues heating while the amount of solar radiation absorbed is decreasing. The incoming solar radiation still exceeds the outgoing longwave radiation (Fig. 7.25). Thus, the Midwest continues to heat until late July. After that date, the average daily temperatures begin to cool off. (For an example of the energy budget involved, do the Try This.) After our longest day and most solar radiation of the year, the average hottest day of the year is still a month away.

Try This!

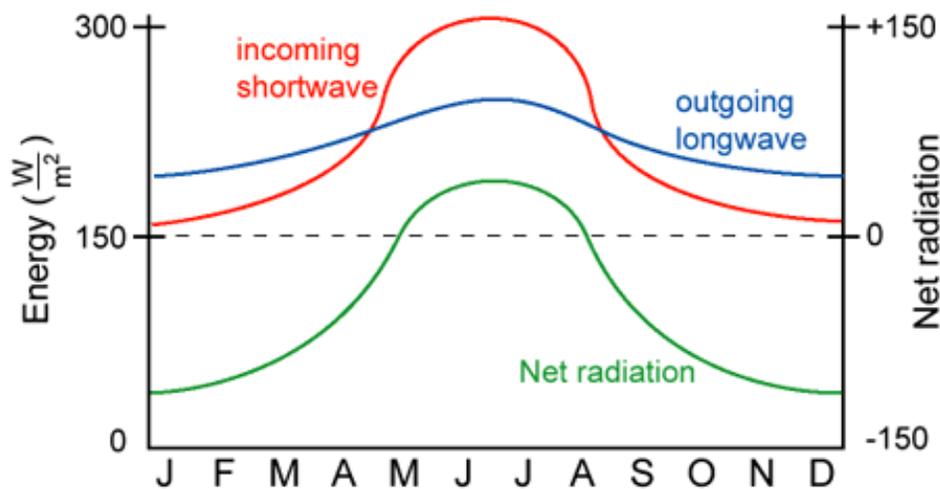


Fig. 7.25 Click the figure for the activity.

Discussion Topic 7.2

What kind of seasons would we have if the Earth did not tilt? What if the earth was tilted on its side?

## Agronomy 541 : Lesson 7b

# Orbits and Climate

## General Circulation

The orientation of the Earth with respect to the Sun produces a semi-regular circulation pattern of the winds around the globe. The large-scale wind patterns produced are called the general circulation. Large-scale air movement helps to produce the climate of areas. The patterns are generally similar in the Northern and Southern Hemispheres with some slight differences. The driving force for the winds is the Sun. Heating differences produce heat imbalances which produce wind. Since the Sun is nearly overhead every day of the year, the area near the equator is very warm. Warm air tends to rise. But that air is going to go somewhere. It does not just rise out into space. It moves toward the North Pole or the South Pole, attempting to balance the heat difference between the Equator and Poles. If the Earth did not rotate, this air would flow directly to the North Pole or South Pole. Sinking at the poles, the cold air would flow back to the Equator, and complete the circulation cell (Fig. 7.26). This type of circulation is called the "**Hadley Circulation**" or the circulation that the Earth would have if it were not rotating, named after the meteorologist who theorized it.

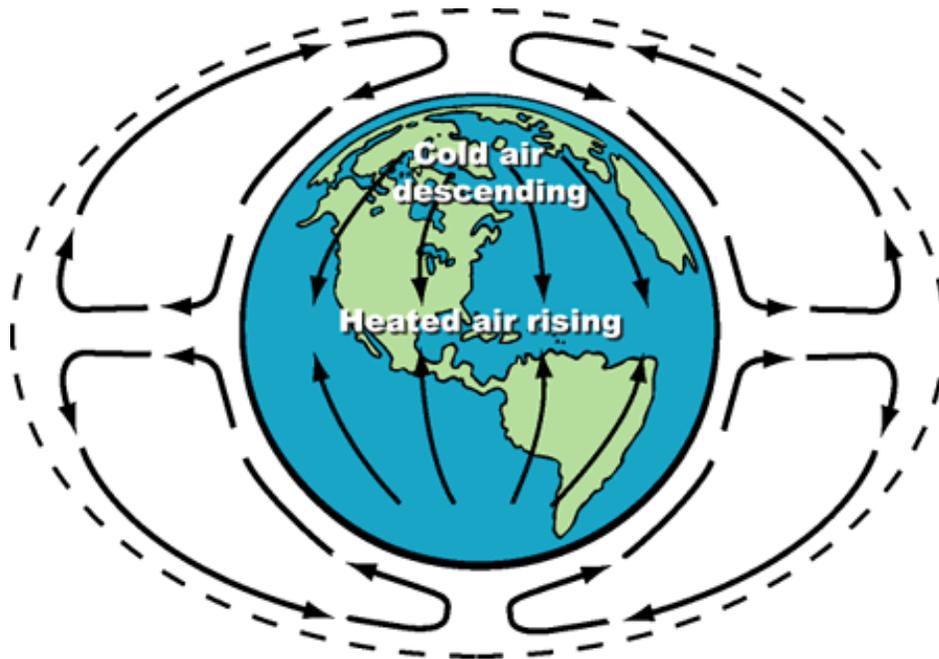
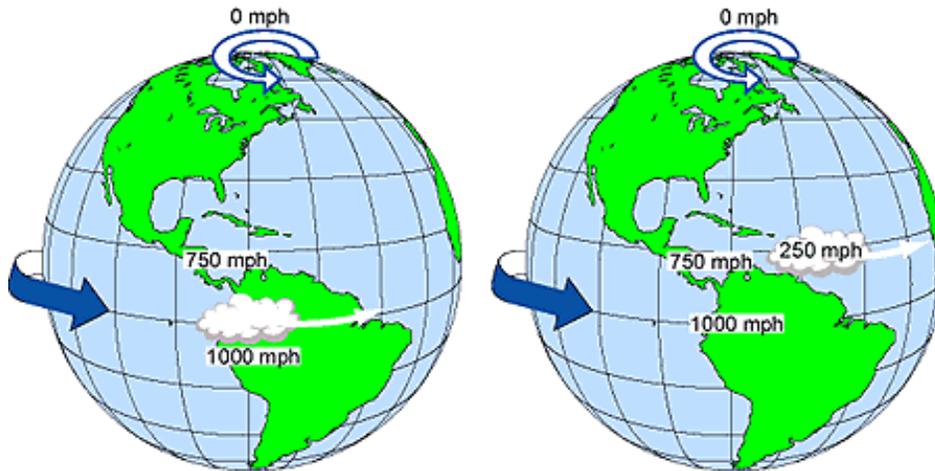


Fig. 7.26 On a non-rotating planet, heated air from the equator would rise and move toward the poles, cool, and sink. The cold air from the poles would then flow toward the equator completing the circulation.

Since the **Earth does rotate**, it has a more complicated circulation caused by that rotation. To describe this effect, imagine yourself sitting in a chair on the earth at the equator. You sit still in your chair for 24 hours. Where have you gone? The Earth has made one complete circle, about 24,400 miles (40,000 km) around, in 24 hours. You are traveling about 1,000 mph (1600 kph) just sitting in a chair with the Earth rotating on its axis. Imagine a cloud sitting over your head. That cloud has to be moving the same speed you are to stay overhead. So the cloud is moving at about 1,000 mph just like you are.

Now, imagine yourself sitting in a chair at the North Pole. In 24 hours you make one slow turn, moving no distance in circling the Pole. Your translational speed is 0 mph (0 kph) at the pole while it was 1,000 mph (1600

kph) at the Equator. Places in between move at speeds between these two values, based on their distance from the axis of rotation (the closer you are to the axis, the slower you go). The Earth in Iowa is only traveling about 750 mph (1200 kph). In the southern United States it is traveling 850 mph (1360 kph) and in Canada it is going only 600 mph (Fig. 7.27).



**Fig. 7.27** A cloud moving northward from the Equator maintains its speed of 1000 mph. As it moves over slower moving latitudes away from the Equator, it appears to move east in the Northern Hemisphere.

The cloud is moving the same speed as the ground under it. If the cloud from the Equator were to move over Iowa, how fast would the cloud be moving? It is still going 1,000 mph (1600 kph), just like it was at the Equator. The cloud is still going 1,000 mph toward the east, while the Earth underneath it is only going 750 mph (1200 kph). The cloud overhead goes off toward the east at 250 mph (400 kph) (Fig. 7.27). This is called the Coriolis effect, or the Coriolis force (although it is not really a force). It is just an effect describing the fact that because of the rotation of the Earth, something moving from north to south, or with any north or south component at all to it, will appear to curve because the Earth underneath it will be moving. While the cloud, for instance, moves northward at a certain speed, the Earth beneath it is moving at a slower speed. The cloud (and air in general) will appear to be deflected toward the right in the Northern Hemisphere. Something moving in the Southern Hemisphere will appear to be deflected towards the left of its path of motion. This is the same effect discussed in Lesson 4a regarding the deflection of wind on smaller scales.

Clouds and air from the Equator do not make it to Iowa. Air from the Equator only moves to about 30°N or 30° S. Getting only that far north, most of the air then begins to sink back down to the Earth. When it sinks to the surface, it forms high pressure regions at the surface. Regions around the Earth at about 30° North and 30° South tend to be deserts since the sinking air keeps clouds from forming.

High pressure is nothing more or less than a great pile of air on the ground. So when you see high pressure indicated on a weather map, the air from above is coming down and making a heap of air on the ground. Just like a pile of corn or soybeans on the ground, it spreads out in all directions. This air from the high pressure spreads out in all directions controlling the general winds blowing on our planet. The air rising from the Equator cools and most of the moisture in the air is condensed and produces rain, losing most of its moisture. Sinking air is dry. Deserts are found at about 30° North and 30° South except where there is an ocean and land patterns cause a disruption. The Sahara Desert, the American Desert, and deserts in Asia exist at about where these high pressures form (Fig. 7.28). A pile of air tries to get back toward the equator. The air blowing out from high pressure toward the Equator is influenced by the Coriolis effect producing easterly winds at the surface, more commonly called the "trade winds". This produces **a closed circulation**.

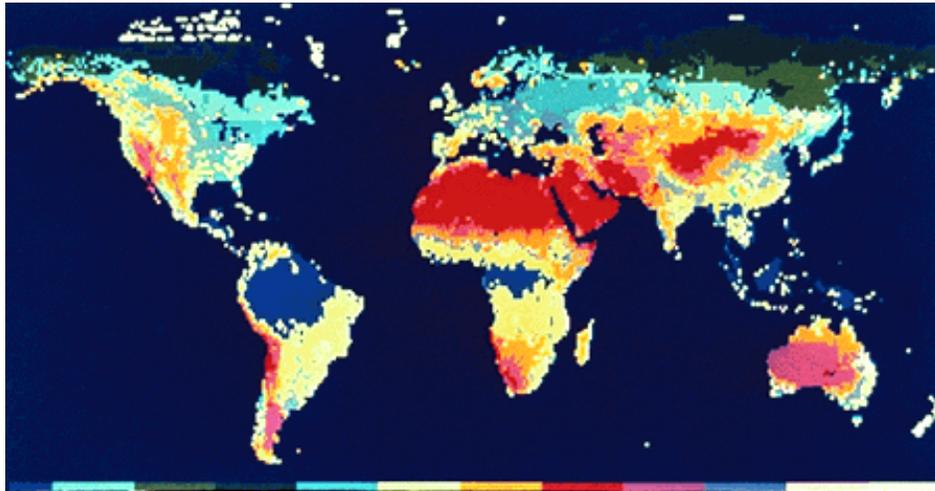


Fig. 7.28 **Global vegetation** from the satellite measurements. Pinks and reds are low vegetation areas (deserts). Note that they form at nearly the same latitude. All form at roughly 30° N or 30° S. Dark colors indicate heavier vegetation, which occurs in wetter areas. Lighter blues are moderately vegetated.

Another cell is caused by sinking air over each pole (Fig. 7.29). The high pressure produced at the surface blows away from the pole producing polar easterlies. In between the Hadley cell near the Equator and the polar cell, a third cell (Ferrell) is produced. Sinking air near 30° N and 30° S flows toward the poles also. This air is deflected by the Coriolis effect, producing westerly surface winds in the latitude band between 30° and 60°. The surface air from this cell and the polar cell collide to create an area of rising motion, cloudiness, and precipitation near 60° North and 60° South called the polar front. The vertical motion of the three cells is shown in Fig. 7.29.

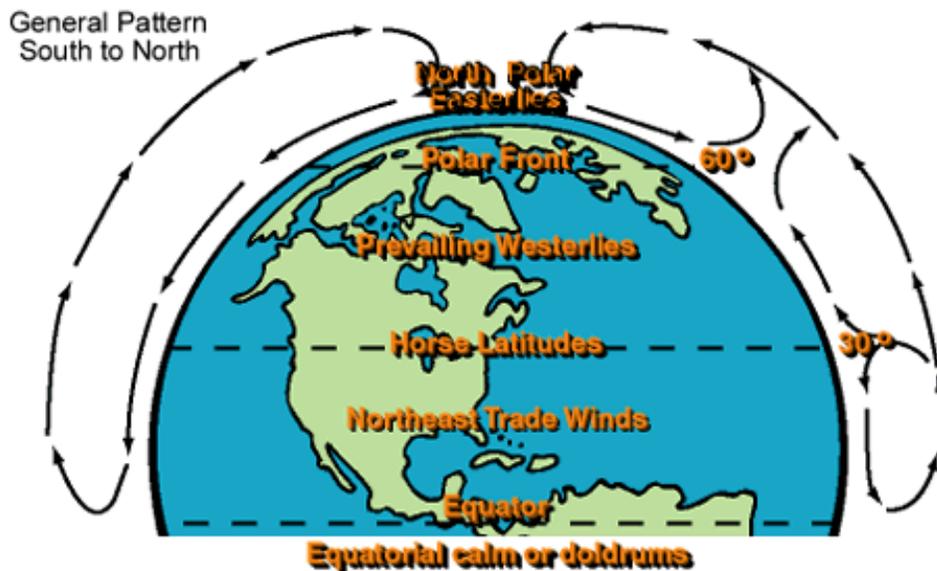
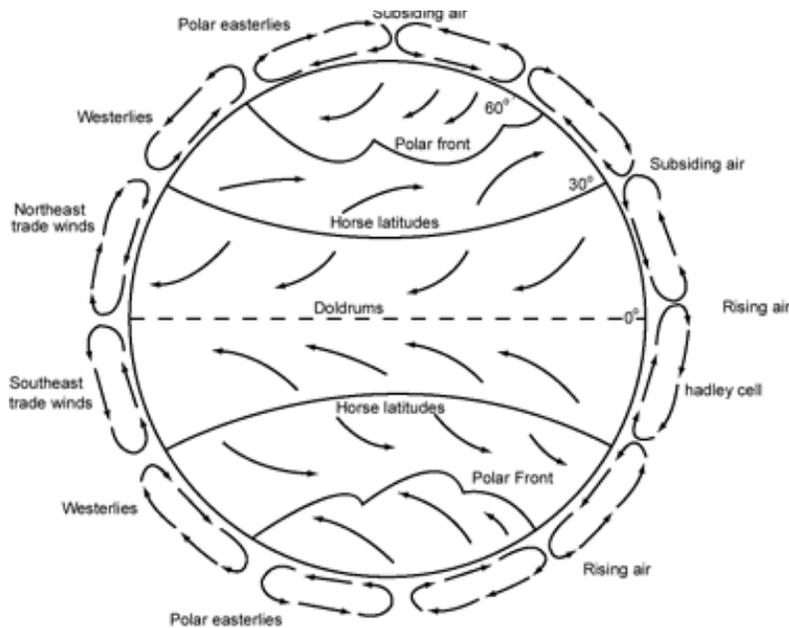


Fig. 7.29 Side view of the general circulation. Rising air and precipitation will be common near the equator and along the polar front. Sinking air will be found over the pole and around 30° N.



**Fig. 7.30 Turning of winds near the surface by the Coriolis effect causes the winds depicted in each of the latitude bands.**

These large areas of sinking and rising motion profoundly influence the climate of these bands. In review, on a non-rotating earth, warm air would rise at the equator, go to the poles, sink to the surface, and flow back to the equator. But because the earth rotates, air is deflected from this path. Air rising at the equator only gets about 30° N and sinks back down to the earth, making the Hadley cell. There is another cell where air is sinking at the North Pole. Polar outflow is deflected a little bit producing the polar easterlies. This flow collides with the mid-latitude westerlies creating a rainy area at about 60° N, somewhere around Hudson Bay in the summertime. This pattern delivers water to the lakes in the Boundary Waters area of our continent.

Thus, there is a dry band around 30° and two wet bands, one over the equator and one about 60° N (Fig. 7.30). The total picture of the earth's winds is slightly complex because it has the doldrums at the equator where the air is rising. It is difficult to cross the equator in a sailing ship because of the lack of horizontal winds. Weather tends to be rainy with calm winds, hence the name "doldrums". The air descending at about 30° N is called the horse latitudes. Sinking air and high pressure create little wind here also. Sailing ships caught in this area for a long period of time were forced to throw horses overboard or eat them (so it is said).

Westerlies and polar easterlies collide, producing an area of unsettled weather. The theoretical area is near 60° N. In reality this area varies significantly, affecting much of North America throughout the year. This area of colliding masses produces variable and sometimes violent weather throughout the year. It is the same at the tip of South America for the Southern Hemisphere as well. Another dry area is considered to be near the North Pole and the South Pole. If temperatures were hot there, it would be a desert because the poles receive less than 10 inches precipitation per year. It really is a desert area as far as the amount of precipitation is concerned, but the cold conditions cause much of the scant precipitation to accumulate.

#### Study Question 7.6

What type of vertical motion would be expected over Australia?

- Rising
- Sinking

Check Answer

## **FYI : Global Vegetation**

Global vegetation is a good measure of the wetness of the area. The band structure discussed in the general circulation works relatively well. Other climate controls such as mountains, proximity to oceans, and the temperature of the oceans, have a role in the moistness of climates.

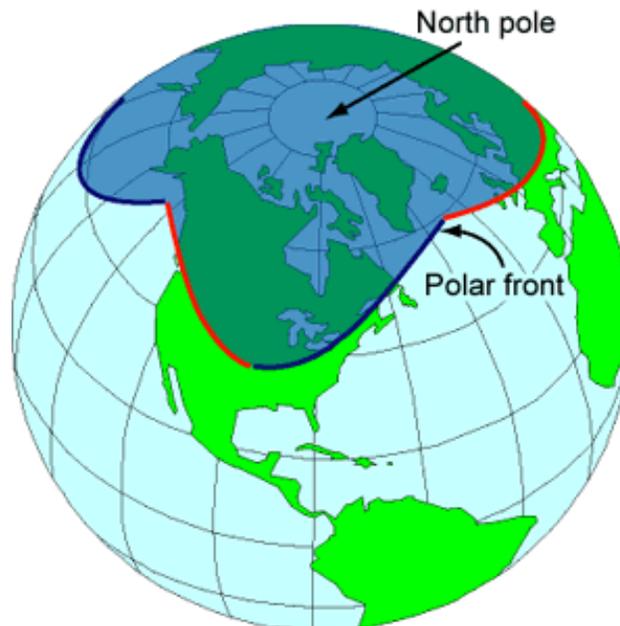
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## Agronomy 541 : Lesson 7b

# Orbits and Climate

## Circulation Effect on Weather

How do these circulations cause our weather? Now, as we look at the effect of these circulations, the polar air has some farthest extent to the south that it travels, called the polar front. At the polar front, the air begins to rise again. Sometimes lowa is south of the polar front, and sometimes north of it. This boundary of polar air would not be a perfect circle. It is a circle that has nodes, more like a 3-5 leaf clover (Fig. 7.31). These lobes or nodes have low pressure areas associated with them. In between them are relative high pressure areas (Fig. 7.32). With low pressure and high pressure, we start to see a pattern that looks familiar. As all of these long wave troughs (lows) and ridges (highs) progress toward the east, the whole pattern slowly migrates toward the east. When a long wave ridge is over us, we are under high cold pressure. As this slowly moves to the east, we get on the back side of the warm front. Then we will move from cold and dry high pressure to perhaps a lower pressure and warmer and moister air. The winds turn to a southerly direction (Fig. 7.33). As the low passes over us, we will be behind the cold front (Fig. 7.34). The weather will be cold and back to the northeasterly wind and dry again. Most of our weather patterns from lowa northward originate with these undulations, or perturbations, of the arctic front. The arctic front varies by season. In the winter it expands and moves down over lowa. In the summer it contracts and moves up around Hudson Bay.



**Fig. 7.31 Typical position of polar front and warm and cold fronts along it.**

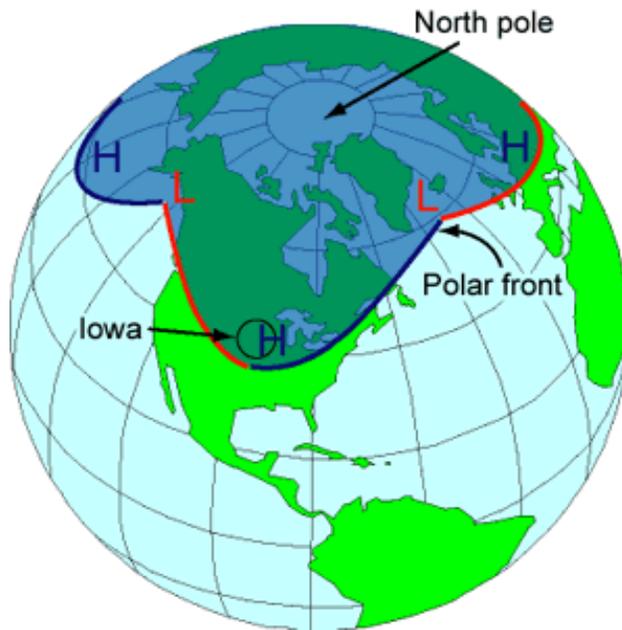


Fig. 7.32.

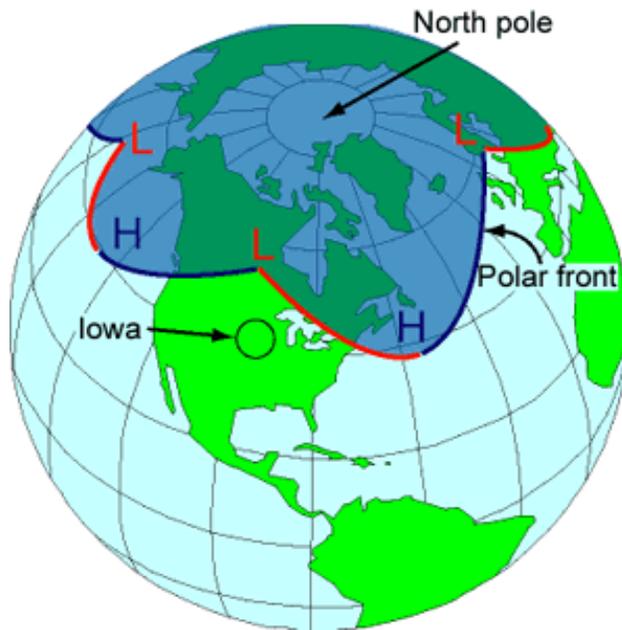


Fig. 7.33.

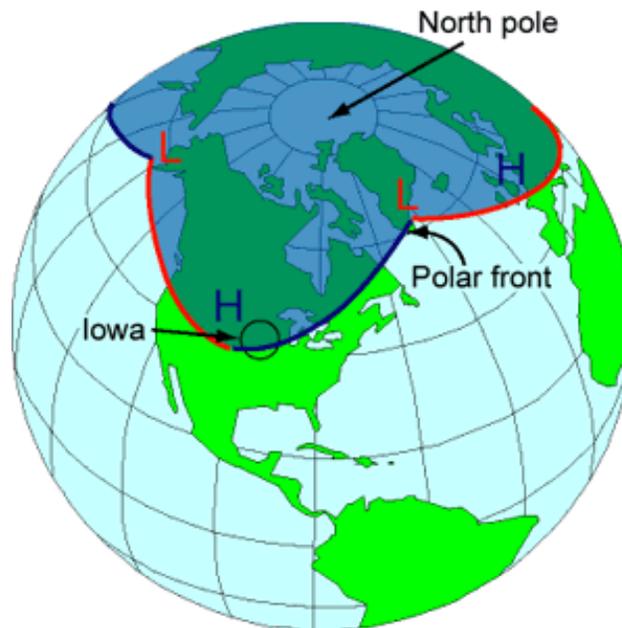


Fig. 7.34.

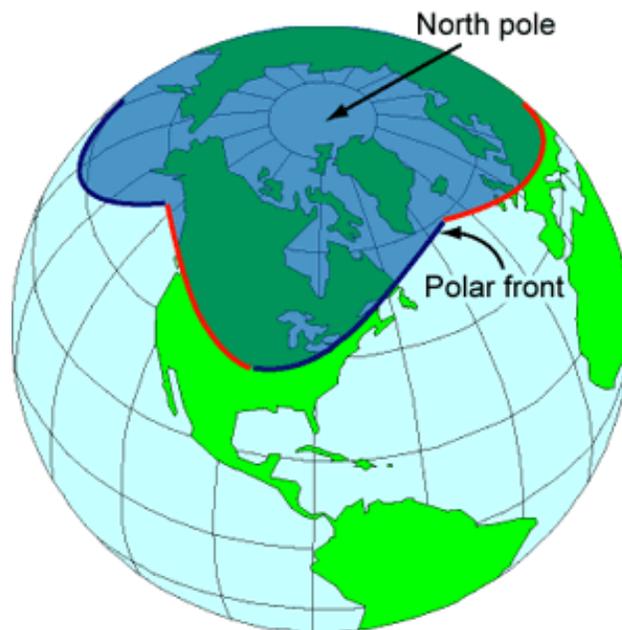


Fig. 7.35.

In the next lesson we will get into some of the major weather patterns and the influences that this effect has on them. The complete circulation can be seen in Figure 7.36. This loop shows cloud formation and movement in the latitude bands.

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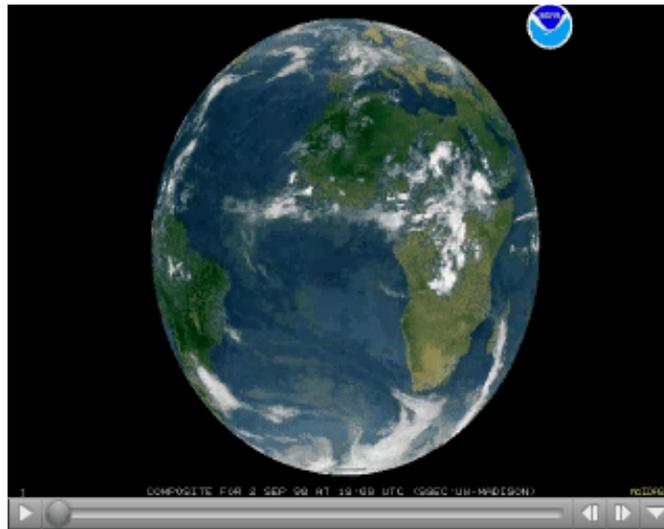


Fig. 7.36 Satellite loop depicting cloud movement.

The various sections can be seen in the picture. The rising motion in the tropics is apparent as is the cloudiness associated with mid-latitude cyclones near the polar front. The dry sub-tropical areas are very obvious with large cloud-free zones poleward of the tropics.

Since the tropics contain such large amounts of heat compared to the polar areas, some method of heat transfer must be occurring to balance the heat imbalance. This significant heat transfer is apparent (Fig. 7.37). This partially explains the weather activity experienced in the mid-latitudes. Cold and warm air masses alternately flow across the area transporting heat and creating the impressive storm systems experienced there.

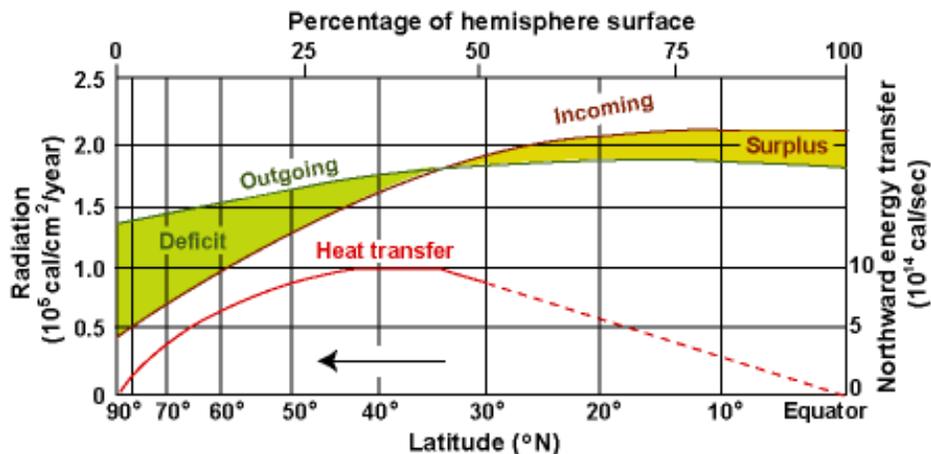


Fig. 7.37 Radiation balance and heat transfer across latitudes.

The poles emit more radiation than they absorb during the year. The Equator has the opposite situation. Thus, to attempt to balance the situation, heat is transferred from the Equator toward the poles as depicted by the red line.

As we have discussed in this lesson, the amount of radiation received is directly related to the amount of sunlight. But the amount of radiation emitted is based on the temperature of the emitting surface. The radiation balance is then depicted by the two lines (Fig. 7.37).

## Assignment 7.1

[Click here for Assignment 7.1](#)

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### Lesson 7 Reflection

#### [Why reflect?](#)

Submit your answers to the following questions in the **Student Notebook System**.

1. In your own words, write a short summary (< 150 words) for this lesson.
  2. What is the most valuable concept that you learned from the lesson? Why is this concept valuable to you?
  3. What concepts in the lesson are still unclear/the least clear to you?
  4. What learning strategies did you use in this lesson?
-

## **Agronomy 541 : Lesson 7b**

# **Orbits and Climate**

### **References**

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## **Agronomy 541 : Lesson 7a**

# **Dew and Plant Diseases**

### **Introduction**

Developed by E. Taylor and D. Todey

It is suggested that you watch Video 7A and complete the exercise in the video before continuing with the lesson.

[Podcast Version](#) **Full Podcast List**

An important aspect of our environment is the formation of dew. It is common thing to find morning dew on lawns in the Midwest during the summer because of clear windless nights and high humidities. It is not so common in the Mountain West, where clear skies are prevalent but relative humidity is very low. As discussed in lesson 5, dew is a form of precipitation. More important in humid climates is its persistence, which can lead to the development and transfer of disease.

### **What You Will Learn in This Lesson:**

- How dew is related to moisture measurement.
- How dew is formed.
- About the implications of dew on plant disease.

### **Reading Assignments:**

- pg. 109-110—Aguado and Burt