**ATMOSPHERIC CIRCULATION AND WIND**

The source of water for precipitation is the moisture laden air masses that circulate through the atmosphere. Atmospheric circulation is affected by the location on the earth, the season of the year, location of land and water and many other factors. The result of atmospheric circulation is the weather that we observe at a particular time and place. **Weather** is defined by Webster (1988) as the state of the atmosphere relative to heat or cold, wetness or dryness, calm or storms, clearness or cloudiness. The historical record or long term characteristics of weather at a particular location is **climate**. Climate is the most important factor affecting hydrologic processes and is used in the design of dams, bridges and other water control structures. However, weather data usually are used in daily operations of water control structures. This chapter is a brief discussion of climate, and meteorology and their effect on the hydrologic cycle.

**SOLAR AND TERRESTRIAL RADIATION**

The driving force behind atmospheric circulation, and indeed, the entire earth is solar energy. Incoming radiation covers an entire spectrum of visible and invisible radiation. **Wavelength** of radiation is measured in units of micrometers or Angstroms (\(A = 10^{-10} \text{m}\)). Most of the solar radiation is in the visible short-wave range (0.4 to 0.8 mm). Terrestrial radiation is primarily long wave of about 10 mm wavelength. The rate at which radiation is received on a surface perpendicular to the sun's rays at the upper limits of the atmosphere is termed the solar constant and equals 1.97 cal/cm² min or 1374 watts/m² = 82.46 kN/m² min (Linsley et al., 1982).

**SOLAR RADIATION AT THE EARTH'S SURFACE**

Much of the sun's radiation does not reach the surface of the earth because of scattering and absorption by the atmosphere and reflection by clouds. Scattering by molecules in the atmosphere is most effective in the shorter wavelengths which causes the blue color of the sky. The amount of reflected light is dependent on the **albedo**, which is defined as the ratio (in percent) of reflected light to the total incident light on a surface. Thus, surfaces that reflect much light such as newly fallen snow have a high albedo (80-95 percent) while dark, wet soils may have an albedo as low as five percent. The albedo of water is dependent on the amount of wind and the angle of the sun's rays but ranges from 2 to 40 percent (Linsley et al., 1982).

The variation of radiation and albedo with latitude is the cause of the large temperature variations between equatorial and polar regions on the earth. The sun's rays are nearly parallel to the earth's surface in the polar regions and nearly perpendicular to the earth's surface at the equator resulting in much more radiant energy per surface area at the equator. The albedo however, is much higher in the polar regions because of snow and the angle of the sun so there is more light reflected and less light absorbed. Both of these phenomena contribute to the wide variation in the mean annual temperature. Although we discuss the angle of the sun's rays striking the earth as if the earth were a smooth perfect sphere, this is not the case and it is rare when the sun is shining on a smooth horizontal surface.

**HEAT BALANCE**

The total radiant energy received by the earth is that which is incident on a circle the same diameter as the earth but the heat is spread over a sphere which has a surface
area four times that of a circle. Thus, the average energy received on the surface of the earth is one fourth of that which reaches the outer part of the atmosphere. The average radiation is therefore one fourth of the solar constant or about 0.5 langleys/min. About half of this energy ultimately is absorbed by the surface of the earth with the rest scattered, reflected, or absorbed by the atmosphere.

**THERMAL CIRCULATION**

The earth and sun radiate energy according to the **Stefan-Boltzmann law** for black-body radiation,

\[ W = \varepsilon \sigma T^4 \]

where \( W \) is emitted radiation, \( T \) is absolute temperature in Kelvins, \( \sigma \) is the Stefan-Boltzmann constant \( = 5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4 \), and \( \varepsilon \) is emissivity of the surface (Giancoli, 1984). The value of \( \varepsilon \) is 1 for a perfect radiator or black body. For complete equilibrium of the energy balance the outgoing radiation must be equal to the incoming radiation. However, if the black-body law is applied to the earth the average temperature should be about \(-40^\circ\text{C}\) while the actual average temperature is about \(15^\circ\text{C}\). The explanation is the so-called **“greenhouse” effect**, whereby much of the heat radiated from the \(15^\circ\text{C}\) surface is reflected back to the surface by the atmosphere. Carbon dioxide in the atmosphere has a large role to play in the greenhouse effect and many scientists think that increased carbon dioxide due to burning fossil fuels will increase the temperature of the earth several degrees over the next several decades. Such an increase could result in flooding of coastal areas due to melting of the polar icecaps as well as a change in the precipitation distribution over the earth.

![Figure 5-1 Thermal circulation model of a nonrotating sphere.](image)

A simple thermal circulation model of a nonrotating sphere is shown in Fig. (5-1). The high radiant energy at the equator would cause air to heat and rise with cooling and sinking occurring at the poles.

The actual circulation on the rotating earth more closely approximates a three cell model. As air moves away from the equator it usually cools and sinks by the time it reaches \(30^\circ\text{C}\) north or south. When reaching lower elevations the air flows both
north and south forming the prevailing **westerlies** and **trade winds** shown in Fig. (5-2).

![Diagram](attachment:image.png)

**Figure 5-2** Westerlies and trade winds (Linsley et al., 1982)

As air moves north there is again a tendency to heat and rise. In polar regions there is cooling and sinking. This three cell circulation model is illustrated in Fig. (5-3).

The earth's rotation has a profound effect on the thermal model due to friction and the Coriolis acceleration. The **Coriolis effect** is due to the change in the velocity of the surface of the earth as one moves from the equator toward the poles. Thus, air particles accelerate as they move northward (in the northern hemisphere) and the resulting force causes a deflection of air particles to the right in the northern hemisphere and to the left in the southern hemisphere.
A particle of air begins to accelerate perpendicular to the isobars or lines of constant pressure, but in the northern hemisphere it is deflected to the right until it essentially follows the isobar. Thus, the circulation around the earth is in isobaric channels which results in **counterclockwise circulation around pressure lows in the northern hemisphere** and **clockwise circulation around pressure lows in the southern hemisphere**. The general atmospheric circulation and pressure distribution have a large effect on annual precipitation patterns throughout the earth. The low pressure and rising of moisture laden air at the equator result in cooling and in general high annual precipitation. At 30 degrees north and south high pressure regions exist with very dry air sinking and being heated resulting in very dry conditions in many areas at this latitude. Examples are the southwestern United States, the Sahara Desert, the Middle East, Australia, and the coast of Chile. Some areas at this latitude such as Florida, and southeast Asia are not dry but in such areas the general circulation is overwhelmed by the proximity of large water areas and the movement of moist air over the land.

**Figure 5-3  Three cell circulation model**

**JET STREAMS**

Jet streams are high altitude (9,000 to 15,000 m) undulating bands of air which flow from west to east at velocities of 100 to 250 km/h. These winds were unknown until World War II when Air Force pilots at high altitudes found that air speed was much faster when flying west to east than east to west. Meteorologists do not fully understand how the jet streams develop but it is known that they are a result of pressure gradients and the earth’s rotation. They have a large affect on weather especially in some locations. One of such locations is the western United States where the location of the jet stream determines whether Pacific storms move across the United States or whether they are diverted across Canada. The jet stream shifts south in winter and north in summer. The timing and location is important to the
location of storm paths and resulting precipitation patterns in the Pacific Northwest. In general the jet streams provide a mechanism for generating low-level pressure systems that determine the weather. The velocity distribution in the atmosphere in the northern hemisphere varies from north to south. The region of maximum velocity is called the core of the jet stream.

An excellent source of information about the jet stream and its effect on weather in the United States is the daily television weather forecast. Many television stations now use trained meteorologists to explain satellite weather maps. These people do an excellent job of showing the reasons for a particular type of weather.

EFFECT OF LAND AND WATER DISTRIBUTION

The idealized circulation previously discussed is changed considerably by the location and the difference in heat characteristics of land and water. In the northern hemisphere large land areas are dominated by low pressure systems in the summer and high pressure systems in the winter resulting in cold dry weather in the winter and wet conditions in the summer.

WIND

Wind is the result of pressure differences in the atmosphere and is a flow of air due to a pressure gradient or sometimes due to temperature differences. However, in an analysis of flow it is difficult to separate flow due to temperature differences from temperature effects on pressure and the resulting flow. As with all fluid flow problems a boundary layer occurs due to a fixed boundary (the earth) and within the boundary layer we observe a variation of velocity. All atmospheric flows are highly turbulent and the boundary layer is very thick (up to 600 m in thickness). Some winds are highly predictable. Many coastal areas typically have on-shore breezes during the daytime due to more rapid heating of land than water during the day and off-shore breezes at night due to the more rapid cooling of land than water at night. Such regular breezes also occur in mountainous areas due to air rising in the daytime and settling or flowing down hill at night and are called up-valley or down-valley breezes or up-slope, down-slope breezes. In mountainous areas these winds may move polluted air up and down the mountains such that the pollutants are not dispersed. This situation is especially common when there is a shallow inversion in a deep valley.

The general direction of wind in the United States is from west to east although there are often localized winds in other directions. Wind is important for precipitation because without wind there would be no mechanism for moving moisture laden air masses over the land. Wind velocities are measured with anemometers, which measure point velocities. Some of the equations, which will be used later for estimating evaporation require wind velocities at particular elevations so it is sometimes necessary to determine the wind velocity at one elevation when it is known at some other elevation. There are several equations, which can be used, but one of the more useful is the logarithmic equation in the form:

\[
\frac{v_2}{v_1} = \ln\left(\frac{Z_2}{Z_1}\right)
\]

(5-2)

where \(v_1\) is the velocity at elevation \(z_1\) and \(v_2\) is an unknown velocity at elevation \(z_2\). Most of the other equations require empirical coefficients, which may or may not be available for the particular location.
REFERENCES

