

## Chapter 3

# Climate and the General Circulation

### 1. Climate Defined

#### 1.1. *Weather and Climate*

When we talk about the **weather**, we are talking about the condition of the atmosphere at any particular time and place. Weather—which is always changing—is comprised of the elements of:

- |                    |                  |
|--------------------|------------------|
| 1. air temperature | 5. precipitation |
| 2. air pressure    | 6. visibility    |
| 3. humidity        | 7. wind          |
| 4. clouds          |                  |

If we measure and observe these **weather elements** over a specified interval of time, say, for many years, we would obtain the “average weather” or the **climate** of a particular region. Climate, therefore, represents the accumulation of daily and seasonal weather events over a long period of time. The concept of climate is much more than this for it also includes the extremes of weather—the heat waves of summer and the cold spells of winter—that occur in a particular region. The *frequency* of these extremes is what helps us distinguish among climates that have similar averages.

If we were able to watch the earth for many thousands of years, even the climate would change. We would see rivers of ice moving down stream-cut valleys and huge glaciers—sheets of moving snow and ice—spreading their icy fingers over large portions of North America. Advancing slowly from Canada, a single glacier might extend as far south as Kansas and Illinois, with ice several thousands of meters thick covering the region now occupied by Chicago. Over an interval of 2 million years or so, we would see the ice advance and retreat several times. Of course, for this phenomenon to happen, the aver-

age temperature of North America would have to decrease and then rise in a cyclic manner.

Suppose we could photograph the earth once every thousand years for many hundreds of millions of years. In time-lapse film sequence, these photos would show that not only is the climate altering, but the whole earth itself is changing as well: mountains would rise up only to be torn down by erosion; isolated puffs of smoke and steam would appear as volcanoes spew hot gases and fine dust into the atmosphere; and the entire surface of the earth would undergo a gradual transformation as some ocean basins widen and others shrink.

In summary, the earth and its atmosphere are dynamic systems that are constantly changing. While major transformations of the earth’s surface are completed only after long spans of time, the state of the atmosphere can change in a matter of minutes. Hence, a watchful eye turned skyward will be able to observe many of these changes.

#### 1.2. *Climate Controls*

Many factors work together to shape the climate of any locality. Controls of climate consist of (1) latitude, (2) elevation, (3) topography, (4) proximity to large bodies of water, and (5) prevailing atmospheric circulation. For all practical purposes, the first four controls are fixed and so exert a regular and predictable influence on climate. Seasonal changes in incoming solar radiation, as well as length of day, vary with latitude. Elevation also influences air temperature and whether precipitation falls in the form of rain or snow. Topography can affect the distribution of cloud and precipitation patterns. For example, windward slopes of high mountain barriers are wetter than the leeward slopes. The great thermal inertia of large bodies of water moderates the temperature of downwind localities, reducing the seasonal tempera-

ture contrast and lengthening the growing season.

The fifth climatic control, atmospheric circulation, encompasses the combined influence of all weather systems. Although strongly influenced by the other climate controls, atmospheric circulation is considerably less regular and, consequently, less predictable than the others. This variability is especially evident in synoptic- and subsynoptic-scale weather systems. Planetary-scale circulation systems, such as the prevailing wind belts, the subtropical anticyclones, and the intertropical convergence zone (ITCZ), exert a somewhat more systematic impact on climate. How these and other controls interact to shape the climates of the continents will become clearer as we describe the Earth's major climate groups.

### 1.3. Global Patterns of Climate

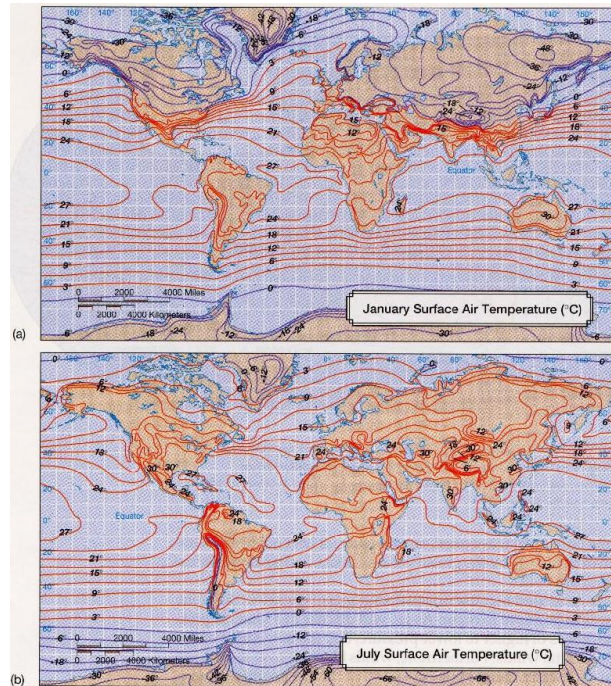
Viewed globally, climate exhibits some regular patterns. As we describe these patterns, keep in mind that they may be significantly altered by local and regional climate controls.

#### TEMPERATURE

If we ignore the influence of mountainous terrain on air temperature, then mean annual isotherms roughly parallel latitude circles, underscoring the importance of solar radiation and solar altitude as climate controls. Interestingly, the latitude of highest mean annual temperature, the so-called **heat equator**, is located about 10 degrees north of the geographical equator. Mean annual isotherms are symmetrical with respect to the heat equator and decline in magnitude toward the poles.

The heat equator is in the Northern Hemisphere because, overall, that hemisphere is warmer than the Southern Hemisphere. Several factors contribute to this hemispheric temperature contrast. For one, the polar regions of the two hemispheres have different radiational characteristics. Most of the Antarctic continent is submerged under a massive glacial ice sheet, so the surface has a very high albedo for solar radiation and is the site of intense radiational cooling, especially during the long polar night. In contrast, the Northern Hemisphere polar region is mostly ocean. Although the Arctic Ocean is usually ice cov-

ered, patches of open water develop in summer and lower the overall surface albedo. Hence, differences in radiational characteristics mean that the Arctic is warmer than the Antarctic.



**Figure 3.1:** Distribution of mean January (a) and July (b) surface air temperatures.

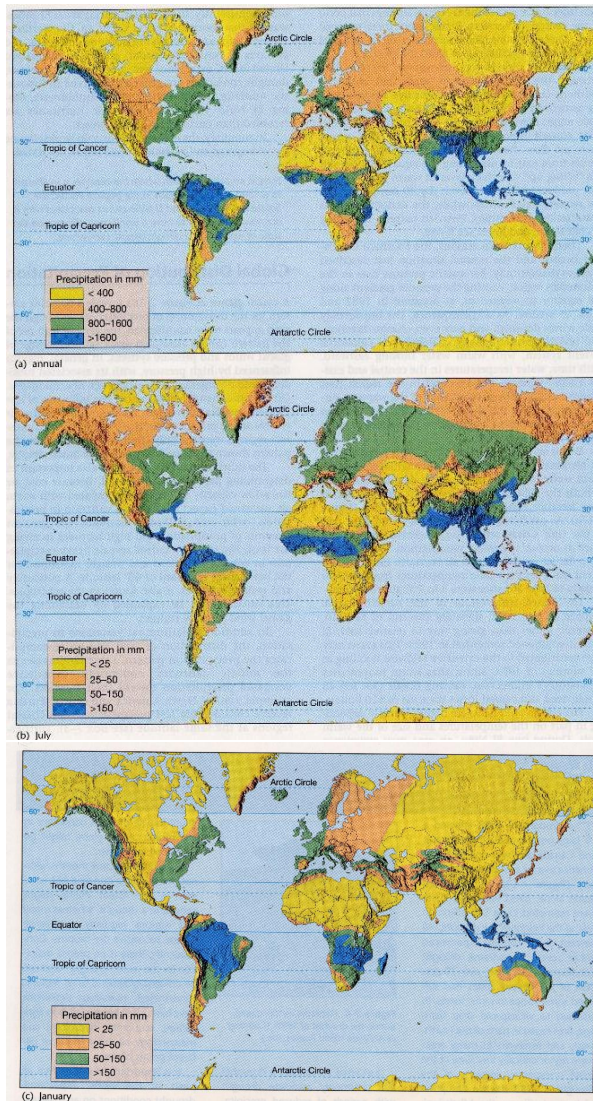
A second factor contributing to the relative warmth of the Northern Hemisphere is that hemisphere's greater fraction of land in tropical latitudes. Because land surfaces warm up more than water surfaces in response to the same insolation, tropical latitudes are warmer in the Northern Hemisphere than in the Southern Hemisphere. A third contributing factor is ocean circulation. Apparently, ocean currents transport more warm water to the Northern Hemisphere than to the Southern Hemisphere.

Systematic patterns also appear when we consider the worldwide distribution of mean January temperature (Figure 3.1a) and mean July temperature (Figure 3.1b); January and July are usually the coldest and warmest months of the year. If we neglect the influence of topography on air temperature, isotherms tend to parallel latitude circles. However, monthly isotherms exhibit some notable north-to-south bends, primarily because of land/sea contrasts and the influence of ocean currents.

As the year progresses from January to July and to January again, isotherms in both hemispheres shift

north and south in tandem. The latitudinal (north-south) shift in isotherms is greater over the continents than over the oceans. That is, the annual range in air temperature is greater over land than over the sea. Furthermore, the meridional temperature gradient is steeper in the winter hemisphere than in the summer hemisphere.

## PRECIPITATION



**Figure 3.2:** Global distribution of precipitation: (a) annual, (b) July, and (c) January.

The global pattern of mean annual precipitation (rain plus melted snow) exhibits great spatial variability (Figure 3.2). Some of this variability can be attributed to topography and the distribution of land

and sea, but the planetary-scale circulation is also important. The ITCZ, subtropical anticyclones, and the prevailing wind belts impose a roughly zonal pattern on precipitation distribution. In addition, the regular shifts of these circulation features through the year cause the seasonality of precipitation that is typical of many localities.

At low latitudes near the equator, convective activity associated with the trade wind convergence triggers abundant rainfall year-round. In the adjacent belt poleward to about 20 degrees latitude, rainfall depends on seasonal shifts of the ITCZ and the subtropical anticyclones. Poleward shifts of the ITCZ cause summer rains, whereas the equatorward shift of the subtropical highs brings winter drought.

Poleward of this belt, from about 20 to 35 °N and °S, subtropical anticyclones dominate the climate, all year. Subsiding dry air on the anticyclones' eastern flanks is responsible for the Earth's major subtropical deserts. On the other hand, unstable humid air that characterizes the western flanks of subtropical anticyclones causes relatively moist conditions.

Between about 35 to 40° latitude, precipitation is governed by the prevailing westerlies and subtropical anticyclones. Typically, on the western side of continents, winter cyclones migrating with the westerlies bring moist weather, but in summer, westerlies shift poleward and the area lies under the dry eastern flank of a subtropical anticyclone. Hence, summers are dry. At the same latitudes, but on the eastern side of continents, the climate is dominated by westerlies in winter and the moist airflow on the western flank of a subtropical anticyclone in summer. Thus, rainfall is triggered by cyclonic activity in winter and by convection in summer and shows little seasonal variability.

Poleward of about 40° latitude, precipitation generally declines as lower temperatures reduce the mean saturation vapor pressure. Although precipitation is generally not seasonal, the tendency in the continental interiors is for more precipitation in summer. This is a result of higher air temperatures and more vigorous convection in summer and lower air temperatures and more frequent anticyclones in winter.

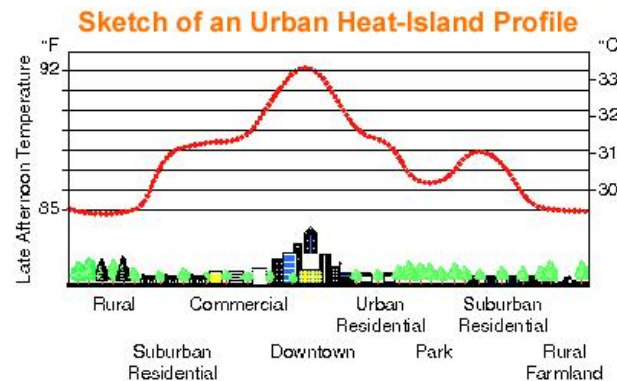
Our description of annual global precipitation is somewhat idealistic and requires some qualification. Land/sea distribution and topography add

complexity to the zonal distribution of precipitation. More rain falls over the oceans than over the continents, and north-to-south-oriented mountain ranges induce wet windward slopes and extensive leeward rain shadows. Furthermore, annual precipitation totals fail to convey some other important aspects of precipitation, including the average amount of rainfall per day and the season-to-season and year-to-year reliability of precipitation. As a rule, rainfall is most reliable in maritime climates, less reliable in continental localities, and least reliable in arid regions. However, drought is possible anywhere, even in maritime climates.

## 2. Urban Climatology

Urban and rural environments differ substantially in their micro-climate. These climatic differences are primarily caused by the alteration of the Earth's surface by human construction and the release of artificially created energy into the environment.

### 2.1. Energy Characteristics of Urban Areas

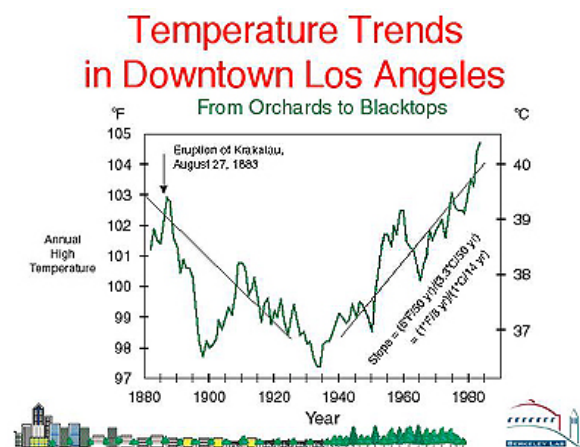


**Figure 3.3:** Temperatures in most cities are warmer than suburban rural areas. During the winter this is a small asset. However, during the summer the heat island causes discomfort, increased cooling use, and increased urban pollution.

In a city, concrete, asphalt, and glass replace natural vegetation, and vertical surfaces of buildings are added to the normally flat natural rural landscape. Urban surfaces generally have a lower albedo, greater heat conduction, and more heat storage than the surfaces they replaced. The geometry of city buildings causes the absorption of a greater quantity

of available incoming solar radiation and outgoing terrestrial infrared radiation. Even in early morning and late afternoon the urban areas are intercepting and absorbing radiation on their vertical surfaces. In urban areas, large amounts of heat energy are added to the local energy balance through transportation, industrial activity, and the heating of buildings.

In winter, the amount of heat generated from the burning of fossil fuels in New York City is 2.5 times greater than the heat absorbed from the sun. Finally, in rural areas, evaporation and transpiration from various natural surfaces act to cool the land surface and local atmosphere. In urban locations, drainage systems have been created to quickly remove surface water. Thus, little water is available for cooling.



**Figure 3.4:** The annual maximum temperatures in Los Angeles show a cooling trend from the 1880s to the 1930s, probably because of increased irrigation and rapidly expanding orchards around the city. Since the 1940s, the temperatures have increased by about 6°F (1°F per decade).

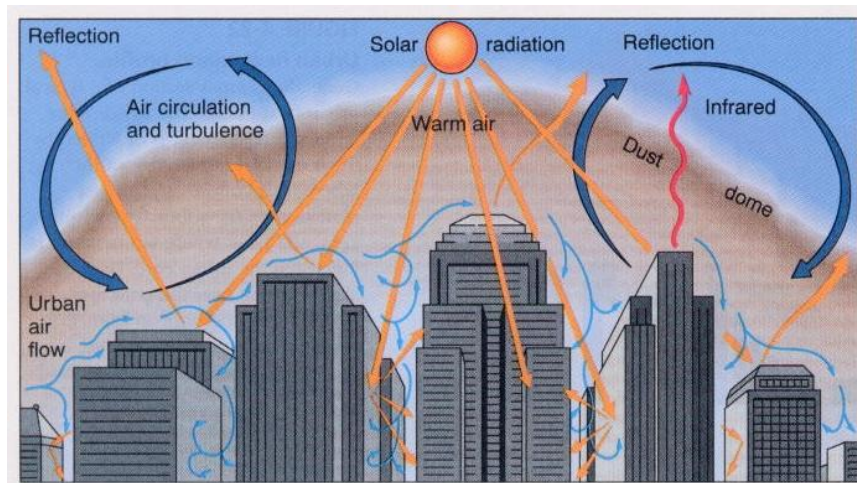
### 2.2. Observed Climate of Cities

Urban areas tend to be warmer than the surrounding countryside. These differences in temperature are best observed at night under stable conditions when atmospheric mixing is at a minimum. Climatologists call this phenomenon the urban heat island. The urban heat island is strongest at the city center where population densities are highest and industrial activity is at a maximum. The heat island effect has been

described in many cities around the world, and temperature differences between city and country can be as high as 6 degrees Celsius.

Wind in urban areas is generally calmer than those in rural areas. This reduction in velocity is due the frictional effects of the city's vertical surfaces. However, some street and building configurations within a city can channel the wind and increase its velocity through a venturi effect. Certain parts of downtown Chicago and Winnipeg are noted for their unusually high wind speeds.

Climatologists have measured about up to 10% more rainfall in urban areas. This increase may be due to the combined effect of particulate air pollution and increased convective uplift. Air pollution may enhance rainfall by increasing the number of condensation nuclei through the atmospheric addition of smoke and dust particles. The additional generation of heat within the city increases the number of convection currents over that surface. Convection is required to initiate the development of thunderstorms.



**Figure 3.5:** Insolation, wind movements, and dust dome in city environments.