Lecture Twelve

Structure and Behavior of Atmospheres

Scope: The air we breathe is a vital component of most life on Earth. Nowhere else in the solar system can one find the same gases in abundance, and atmospheric pressure elsewhere varies from hundreds of times down to about a billionth of Earth's. The major similarity among atmospheres is the structure of overlying thermal layers where temperatures can both increase and decrease with altitude. The clouds of other planets can be composed not just of water vapor, but also of carbon dioxide, methane, ammonia, and sulfuric acid. Winds can be gentle, with a single global circulation pattern, or they can be many times beyond hurricane speed and show a multitude of turbulent bands wrapping around a planet. In the Venusian atmosphere, one finds a cautionary tale: The small greenhouse effect that warms Earth has become a runaway process that produces hellish conditions on Venus.

Outline

I. Atmospheres across the solar system are diverse in composition and thickness yet similar in structure.

- **A.** Earth's atmosphere is a very thin layer above its surface, roughly 100 kilometers thick on a planet that is nearly 13,000 kilometers across.
  1. Earth's atmosphere is about 77% nitrogen, 21% oxygen, 1% water vapor, and 1% argon.
  2. While oxygen is the component we emphasize for breathing, nitrogen is much more abundant.
  3. Carbon dioxide plays an important role as a greenhouse gas, yet it is less than 1/30 of 1% of the atmosphere.
- **B.** The other rocky planet atmospheres are markedly different.
  1. Venus's heavy atmosphere is 96% carbon dioxide and has a pressure about 100 times that of Earth's.
  2. Mars also has a carbon dioxide atmosphere (95%), but it is remarkably thin.

- **C.** The vertical structure of Earth's atmosphere has four levels.
  1. The lowest level, the troposphere, is dominated by heat absorbed and reradiated by the ground.
  2. Above 15 kilometers, in the stratosphere, ozone molecules absorb ultraviolet light, and the atmosphere gets warmer with altitude.
  3. Thermal inversions also occur at the boundaries of the mesosphere (50 kilometers) and the troposphere (85 kilometers), where temperatures decrease and increase, respectively, with altitude.
  4. The commonly quoted height of the atmosphere, 100 kilometers, does not have a scientific basis and is just an approximate round number that marks the boundary between aeronautics and astronautics.
- **D.** The atmospheres of Venus and Mars, though of vastly different pressures, show similar vertical structure and extent.
- **E.** Saturn's moon Titan has an atmosphere that is a bit thicker than Earth's, and which is predominantly nitrogen, with a few percent methane.
- **F.** Tenuous atmospheres are found on Io, Triton, and Pluto.
- **G.** The giant planets have deep atmospheres of hydrogen and helium.
  1. Lacking a surface, their heights are not strictly defined, but they span several thousand kilometers and contribute a significant percentage of the mass of the giant planets.
  2. The upper atmospheres are cold, hundreds of degrees below zero, with generally only a single thermal inversion.

II. Clouds, the dominant feature of many atmospheres, are generally condensates of minor constituents.

- **A.** Jupiter and Saturn's clouds are condensations of ammonia, ammonium hydrosulfide, and water, each at distinct layers in their atmospheres.
- **B.** Uranus and Neptune have temperatures cold enough to form methane clouds.
- **C.** Earth's water vapor clouds appear in several varieties at several characteristic heights in the atmosphere.
- **D.** Mars's thin clouds are made of water or carbon dioxide.
- **E.** Venus has thick cloud layers composed of sulfuric acid droplets.

III. Wind patterns on the planets are well organized, though not completely understood.

A. Winds on Earth and Venus show relatively simple thermal circulation.

1. Venus provides an excellent example of Hadley cell circulation that transports energy from the equator to the poles.

2. Earth's faster rotation produces three Hadley cells per hemisphere.

3. The trade winds and jet stream are examples of sustained circulatory patterns on Earth.

4. Wind speeds on Earth can reach 200 kilometers per hour, but that merely equals the speed of the constant upper jet stream on Venus.

B. The fast rotation of the giant planets leads to a large number of zonal winds.

1. Lighter regions are called zones, while darker regions are called bands.

2. The colors of the zones and bands have been observed to change significantly over a period of months.

3. Wind speeds on the giant planets are strong and stable, ranging up to about 1100 kilometers per hour on Saturn.

4. Saturn shows a remarkable hexagon feature at its pole.

5. The winds on Uranus and Neptune are less well studied but show strong winds with only a few zones and bands.

IV. The composition of the atmosphere can play a critical role in determining surface temperature.

A. The greenhouse effect is the trapping of heat within the atmosphere by gases such as water vapor, carbon dioxide, and methane.

B. Earth and Venus show the benefits and drawbacks of warming of the atmosphere.

1. On Earth, a small warming effect keeps the average temperature at the surface above the freezing point of water.

2. On Venus, a runaway warming pushed the temperature and pressure at the surface beyond the melting point of lead.

3. Earth has about the same amount of carbon dioxide as Venus, but most of it is in rocks.

C. Human behaviors are affecting Earth's atmosphere and climate, with potential for long-term consequences.

1. Since the industrial age, the amount of carbon dioxide in Earth's atmosphere has risen dramatically.

2. The amount of sea ice at the North Pole is visibly shrinking.

3. The scientific evidence for climate change is clear, but how we respond to that evidence is a social and political issue.

Suggested Readings:

Beatty, Petersen, and Chaikin, *The New Solar System*, chaps. 13, 15.

Bennett, Donahue, Schneider, and Voit, *The Cosmic Perspective*, chaps. 10–11.

De Pater and Lissauer, *Planetary Sciences*, chap. 4.

Dessler and Parson, *The Science and Politics of Global Climate Change*.

McFadden, Weissman, and Johnson, *Encyclopedia of the Solar System*, chaps. 7, 9, 15, 20, 25.

Shu, *The Physical Universe*, chap. 17.

Questions to Consider:

1. What are the factors that determine whether or not a planet or moon has an atmosphere?

2. Watching from outside, we can see the banded wind patterns on the giant planets. As there is no surface, how and where would a probe carried along in the atmosphere be able to detect these winds?

3. Could global warming on Mars make its atmosphere hospitable to life?