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Guide to the Science of Climate Change in the 21st Century

Chapter 7
Global Circulation of the Atmosphere

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Table of Contents

List of Figures

7.0 Global Circulation of the Atmosphere

7.1 Introduction

Global circulation of Earth's air mass, the atmosphere, together with ocean currents, are responsible for the movement and redistribution of solar energy received by the Earth that is not immediately reflected or absorbed and emitted back into space. It is responsible for the mixing of air masses, the movement of water evaporated from the surface of the oceans and the land surfaces and the manner with which it is precipitated back to the Earth's surface. Global circulation of the atmosphere together with topographic and local photosynthesizing effects determine weather and climate. As well, it is responsible for the mixing, storage and redistribution of greenhouse gases, airborne particulate matter and pollution that enters the atmosphere. Global circulation of the atmosphere ultimately determines the climate and quality of the air mass over of all regions of the Earth's surface.

7.2 Characteristics of the atmosphere

Global circulation of the atmosphere is a result of the convective and advective energy transfer between earth's surface and the atmosphere, particularly the troposphere. The troposphere is the layer of the atmosphere next to the surface of the Earth (See Figure 7.1). Most of the mixing of the atmosphere and weather occurs in the troposphere. The temperature of the atmosphere steadily decreases with elevation. The layer of air above the troposphere is the stratosphere. The temperature of air in the stratosphere starts to increase with elevation. The troposphere and the stratosphere are separated by a comparatively thin layer of atmosphere known as the tropopause. The thickness of the troposphere is greatest at the equator gradually thinning out to the poles.

7.3 Early perception of global circulation of the atmosphere

An early perception of global circulation is illustrated in Figure 7.2 where the circulation in the northern and southern hemispheres did not cross the equator; that is, there was very little if any mixing of the respective air masses. This view of atmospheric circulation has changed dramatically since the mid twentieth century with increased information on the characteristics of the various air masses within the atmosphere and has evolved to the more complex and accurate view as illustrated in Figure 7.3. An important take-away from Figure 7.3 is that air masses, everywhere on the planet, affect each other and intermingle.

Tropopause – boundary between troposphere and stratosphere.

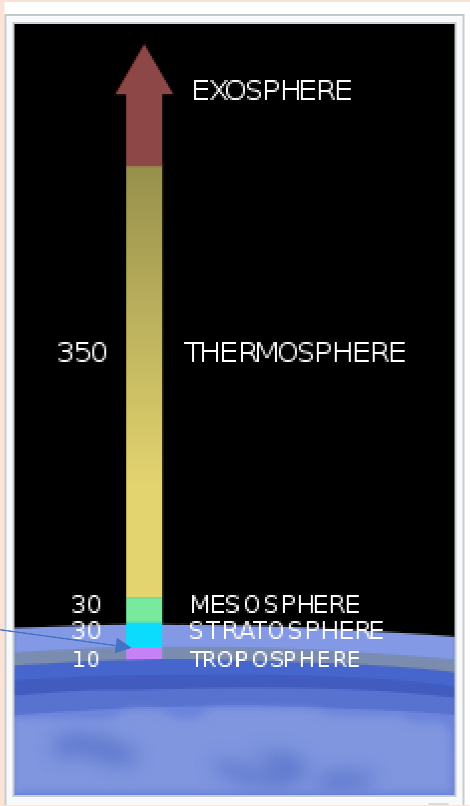


Figure 7.1 Schematic showing different layers of the atmosphere (not to scale).

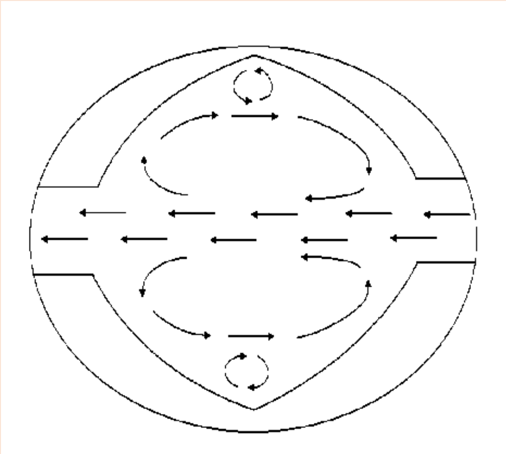


Figure 7.2 Early perception of global circulation of the atmosphere.

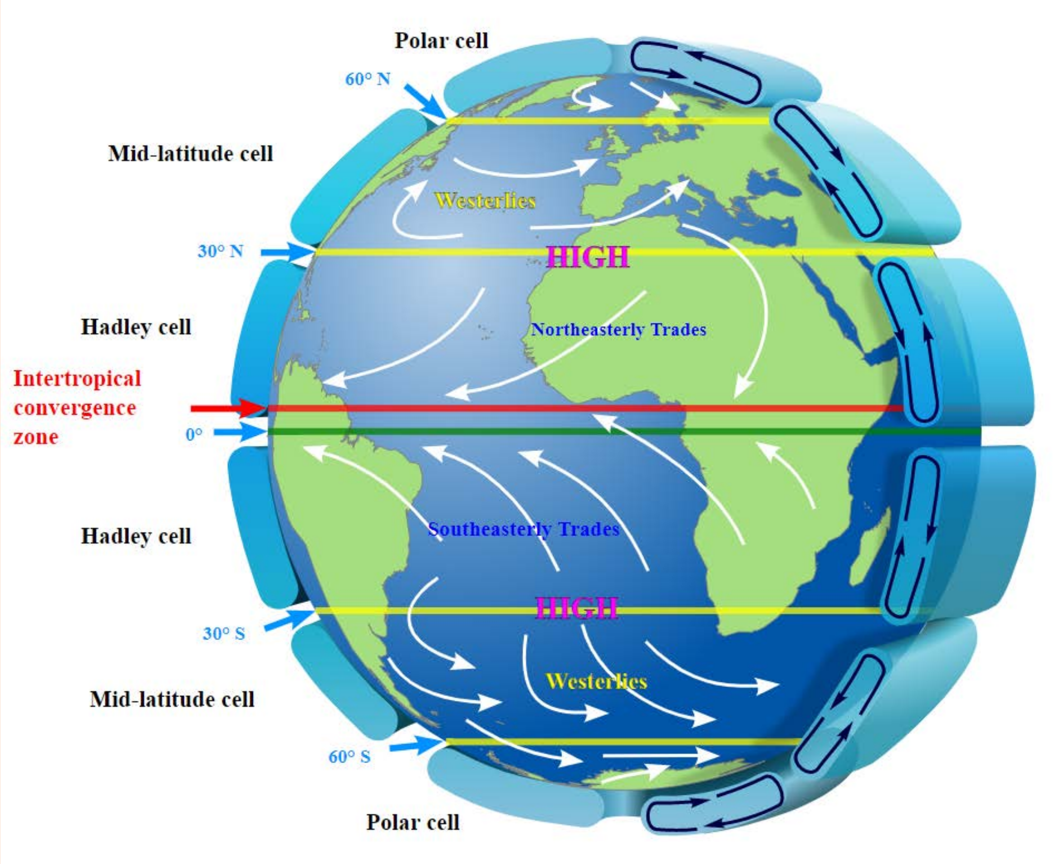
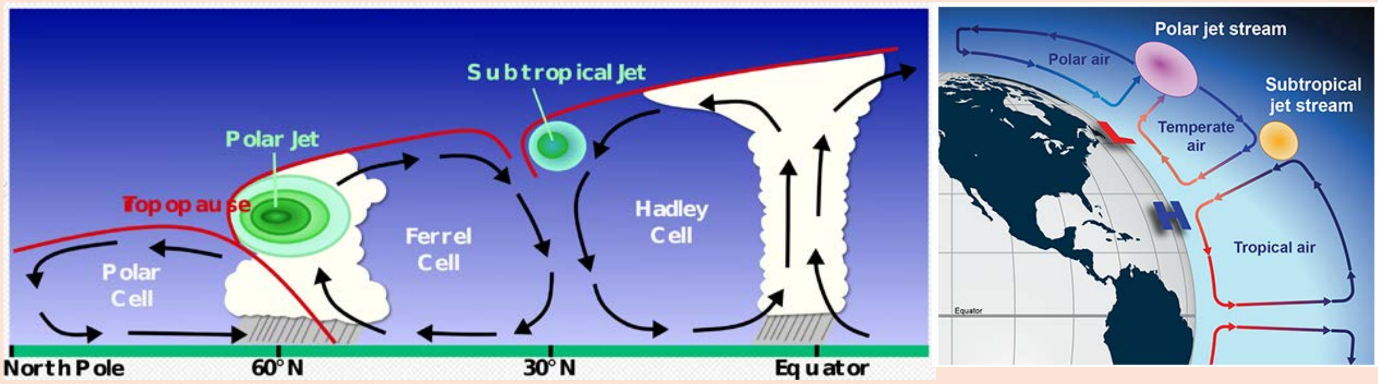


Figure 7.3 Actual global circulation of the atmosphere.

7.4 Actual global circulation of the atmosphere

There are three major circulations of the atmosphere north and south of the equator known as the Hadley cell, Mid-latitude or Ferrel cell and the Polar cell. Figure 7.2 and Figure 7.4 (a) and (b) illustrate the interaction between these cells. Warm air rises at the equator, falls at 30° and rises at 60°. The tropopause shown as the red line in Figure 7.4 (a) is the interface between the troposphere and the stratosphere. The atmosphere in the Hadley cell is the warmest so the thickness of the troposphere in the Hadley cells are the greatest and the atmosphere in the Polar cell is the coldest and the thickness of the troposphere in the Polar cells is the least.

As shown in Figure 7.3 the cells are actually very wide and contain all or parts of weather systems carried by the Westerlies or the Northeastern and Southeastern Trades. The weather systems themselves can be very large in diameter and overlap or move through cells. In this way air masses in both northern and southern hemispheres are well mixed both latitudinally and longitudinally.



(a) (b)

Figure 7.4 (a) and (b) Cross section of the subtropical and polar jet streams by latitude**.**

Also shown in Figure 7.4 (a) and (b) are the jet streams. Jet streams are fast flowing, narrow, meandering air currents that occur at the interface of the Hadley cell and the Ferrel cell and at the interface of the Polar cell and the Hadley cell. The jets are known as the subtropical jet and polar jet respecitvely. The jet streams circle the Earth from west to east in an irregular pattern known as Rossby waves, as shown in Figure 7.5. The jet streams are driven by the circulation and difference in temperature of the air in the adjacent cells. Jet streams are also responsible for moving weather systems and associated air masses around the planet.

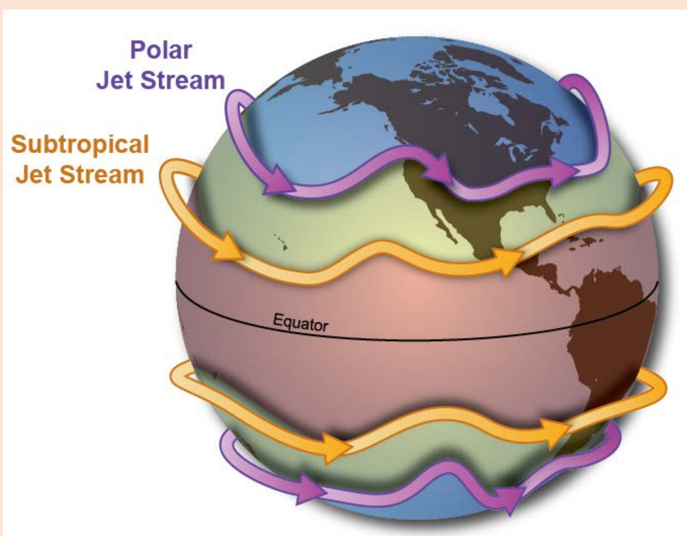


Figure 7.5 General configuration of the subtropical and polar jet streams by latitude.

Warming of air masses in the polar cell (Arctic) have the effect of weaking the polar jet stream. Cooling them (Antarctic ozone depletion) has an opposite effect.

Warming of air masses in the equatorial zone, Hadley cells, have the effect of strengthening the subtropical jet stream assuming the mid latitude zone, Ferrel cells, are not affected to a similar degree.

7.5 Ozone and the ozone hole

Regarding ozone: Ozone in the stratosphere absorbs ultraviolet light preventing it from reaching the Earth's surface and harming living organisms. Ozone forms in the atmosphere and is circulated upward into the stratosphere. While ozone is a strong greenhouse gas the quantity is so small as to have an insignificant effect on global warming.

Ozone in the stratosphere can be depleted as a result of reaction with ozone depleting chemicals such as compounds with chlorine and/ or fluorine attached to carbon, known as chlorofluorocarbons or CFCs. The Montreal Protocol, which was finalized in 1987, is a global agreement to protect the stratospheric ozone layer by phasing out the production and use of ozone depleting substances (including CFCs). The effect is most pronounced over Antarctica where the ozone may be completely depleted forming what is known as the ozone hole as shown in Figure 7.6.

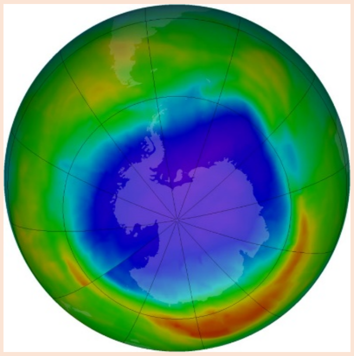


Figure 7.6 Ozone hole over Antarctica shown in blue.

Without the ozone the stratosphere over Antarctica cools resulting in faster winds near the pole. The impacts extend to the equator affecting tropical circulation and rainfall at lower latitudes.

The ozone hole does not cause global warming but does affect atmospheric circulation.

7.6 Information support

Key web sites:

1. Global atmospheric circulations. https://courses.lumenlearning.com/geophysical/chapter/global-atmospheric-circulations/

2. Weather systems and patterns. https://www.noaa.gov/education/resource-collections/weather-atmosphere/weather-systems-patterns

3. Global circulation patterns. https://www.metoffice.gov.uk/weather/learn-about/weather/atmosphere/global-circulation-patterns

4. Atmospheric circulation. https://www.globalsecurity.org/military/library/policy/navy/nrtc/14312_ch3.pdf

5. Jet stream. https://en.wikipedia.org/wiki/Jet_stream

6. The jet streams. https://www.weather.gov/jetstream/jet

7. Ozone hole and climate change. https://climate.nasa.gov/faq/15/is-the-ozone-hole-causing-climate-change/#:~:text=What%20scientists%20have%20uncovered%20recently,over%20the%20Southern%20Hemisphere%20colder.

8. Montreal Protocol 1988. https://www.mcgill.ca/iasl/files/iasl/montreal1988.pdf.