Weather and Climate 85.141

Professor Lori Weeden

- Text: get it.
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- Blackboard: Get an account. We will use this for all homework assignments.
Chapter 1: Introduction to the Atmosphere
Definitions

- **Atmosphere** – the shell of gases around the Earth that gravitationally bound to it.
- **Meteorology** - the scientific study of the atmosphere.
- **Weather** - the state of the atmosphere at a given time and place.
- **Climate** - the sum of the statistical weather information that helps describe the atmosphere in a given place or region.

*****Climate data cannot be used to predict the weather.
Remember: Climate data cannot predict the weather!
Temperature data for New York

Note: because this graph describes the average temperatures and the record temperature for a specific place, it is considered climatological data.
The Elements that describe weather:

1. Temperature of the air
2. Humidity of the air
3. Type and amount of cloudiness
4. Type and amount of precipitation
5. Pressure exerted by the air
6. Speed and direction of the wind
Newspaper weather map
Atmospheric Hazards

1. Floods
2. Lightning
3. Tornadoes
4. Hurricanes
5. Heat waves
6. Droughts
Weather-related disasters From 1980 to 2010
### TABLE 1-1 Billion-Dollar Weather Events 2002–2007

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Damage/Costs $</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought-Great Plains and East</td>
<td>Entire year 2007</td>
<td>$5 billion</td>
<td>Unknown</td>
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<tr>
<td>Western Wildfires (drought and high winds)</td>
<td>Summer-Fall 2007</td>
<td>$1 billion</td>
<td>12</td>
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<tr>
<td>Severe Freeze in East and Midwest</td>
<td>April 2007</td>
<td>$2 billion</td>
<td>0</td>
</tr>
<tr>
<td>Severe Storms and Tornadoes in East and South</td>
<td>April 2007</td>
<td>$1.5 billion</td>
<td>9</td>
</tr>
<tr>
<td>California Freeze</td>
<td>January 2007</td>
<td>$1.4 billion</td>
<td>1</td>
</tr>
<tr>
<td>Wildfires-Western states and Florida</td>
<td>Entire year 2006</td>
<td>$1 billion</td>
<td>28</td>
</tr>
<tr>
<td>Widespread Drought</td>
<td>Spring-Summer 2006</td>
<td>$6.2 billion</td>
<td>unknown</td>
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<tr>
<td>Northeast Floods</td>
<td>June 2006</td>
<td>$1 billion</td>
<td>20</td>
</tr>
<tr>
<td>Midwest/Southeast Tornadoes</td>
<td>April 2006</td>
<td>$1.5 billion</td>
<td>10</td>
</tr>
<tr>
<td>Midwest/Ohio Valley Tornadoes</td>
<td>April 2006</td>
<td>$1.1 billion</td>
<td>27</td>
</tr>
<tr>
<td>Severe Storms/Tornadoes in South/Southern Great Plains</td>
<td>March 2006</td>
<td>$1 billion</td>
<td>10</td>
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<tr>
<td>Hurricane Wilma</td>
<td>October 2005</td>
<td>$17.1 billion</td>
<td>35</td>
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<tr>
<td>Hurricane Rita</td>
<td>September 2005</td>
<td>$17.1 billion</td>
<td>19</td>
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<td>Hurricane Katrina</td>
<td>August 2005</td>
<td>$134 billion</td>
<td>1833</td>
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<tr>
<td>Hurricane Dennis</td>
<td>July 2005</td>
<td>$2.1 billion</td>
<td>15</td>
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<tr>
<td>Midwest Drought</td>
<td>Spring-Summer 2005</td>
<td>$1.1 billion</td>
<td>0</td>
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<td>Hurricane Jeanne</td>
<td>September 2004</td>
<td>$7.7 billion</td>
<td>28</td>
</tr>
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<td>Hurricane Ivan</td>
<td>September 2004</td>
<td>$15.4 billion</td>
<td>57</td>
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<td>Hurricane Frances</td>
<td>September 2004</td>
<td>$9.9 billion</td>
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<td>Hurricane Charley</td>
<td>August 2004</td>
<td>$16.5 billion</td>
<td>35</td>
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<td>Southern California Wildfires (drought and winds)</td>
<td>October–November 2003</td>
<td>$2.8 billion</td>
<td>22</td>
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<td>Hurricane Isabel</td>
<td>September 2003</td>
<td>$5.6 billion</td>
<td>55</td>
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<td>Severe Storms and Tornadoes in Midwest and South</td>
<td>May 2003</td>
<td>$3.4 billion</td>
<td>51</td>
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<td>Severe Storms and Hail in Midwest and South</td>
<td>April 2003</td>
<td>$1.6 billion</td>
<td>3</td>
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<tr>
<td>Drought in 30 states</td>
<td>Spring-Fall 2002</td>
<td>$10 billion</td>
<td>0</td>
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<tr>
<td>Western Fire Season (drought and winds)</td>
<td>Summer 2002</td>
<td>$2 billion</td>
<td>21</td>
</tr>
</tbody>
</table>

† To allow for more accurate comparison, dollar amounts are normalized to 2007.

*Source: National Climatic Data Center/NOAA.*
The Nature of Scientific Inquiry

• Observations lead to an hypothesis that can be tested.
• Successful hypotheses become theories.
• To be a scientific theory, the theory must successfully predict something that was not used to develop the theory.
• Theories cannot be proved - they can only be disproved.
Gathering Data
Thermoscope

- See Wikipedia.
- You are no longer permitted to say “I don’t know”.
- Google “thermoscope wiki”
Observing the Atmosphere

- **Radiosondes** - package of instruments fitted with radio transmitters and flown on a balloon. Measurements of temperature, pressure and relative humidity radioed back to the weather station. Flown twice a day.
- **Weather radar** - familiar from TV
- **Weather satellites** provide wide area coverage. Can deduce pressure patterns from the clouds.
Weather Balloons
Aircraft reconnaissance
Radar Images
Monitoring Earth from Space

• Tropical Rainfall Weather Mission (TRMM) from NASA.
• Provides rainfall and heat release associated with rainfall for tropical regions.
• Much of Earth's rain falls over the tropical oceans (no ground-based observations).
Earth's Four Spheres

- Atmosphere: shell of gases around the Earth, and gravitationally bound to it. It allows life, protects us from the Sun, and gives us weather.
- Geosphere: solid Earth = core + mantle + crust.

The Earth System
Four Spheres - 2

- **Hydrosphere** - our water (oceans, lakes, rivers, glaciers, underground)
  *(Cryosphere: “honorary sphere”, part of the hydrosphere – all the ice in the world)*

- **Biosphere** - all life on the Earth
Distribution of Earth's Water

- Oceans: 97.2%
- Hydrosphere: 2.8%
- Glaciers: 2.15%
- Groundwater: 0.62%
- Nonocean Component (% of total hydrosphere)

- Freshwater lakes: 0.009%
- Saline lakes and inland seas: 0.008%
- Soil moisture: 0.005%
- Atmosphere: 0.001%
- Stream channels: 0.0001%

Stream channel

Glaciers

Groundwater (spring)
The Earth as a System

• The Earth's four spheres plus the solid Earth behave as a System.

• A System is a group of interacting or interdependent parts that form a complex whole. - e.g., a motor vehicle
The Earth as a System

- Have *Open* and *Closed* systems

- Systems can be controlled by *Feedback*

- *Negative feedback* systems work to maintain the system as it is. *(It counters any change to the system.)*

- *Positive feedback* drives changes in the system. *(It reinforces any change to the system.)*
Debris flow – water and solid Earth interacting
Hydrologic Cycle
Energy of the Earth

- The *Energy* required to drive the Earth as a system comes from

1. The Sun - drives all processes that occur on or above the Earth's surface

2. From within the Earth - primordial heat and radioactive decay (small %)
Composition of a *Dry Atmosphere*

1. Nitrogen - 78%
2. Oxygen - 21%
3. Argon - 1% (from radioactive decay)
4. Carbon dioxide - 0.04% (influences heating of the atmosphere)
5. We are ignoring water here ("dry")
The Dry Atmosphere

- Nitrogen (78.084%)
- Oxygen (20.946%)
- Argon (0.934%)
- Carbon dioxide (0.0391% or 391 ppm)
- All others

Concentration in parts per million (ppm):
- Neon (Ne) 18.2
- Helium (He) 5.24
- Methane (CH₄) 1.5
- Krypton (Kr) 1.14
- Hydrogen (H₂) 0.5
So, what are today’s atmospheric CO$_2$ levels?
Evolution of Earth’s Atmosphere

1. Early Earth was very hot and molten.

2. As it cooled, gases dissolved in the molten rocks escaped - Outgassing.

3. Gases were mostly water vapor, carbon dioxide and nitrogen.
Evolution of Earth’s Atmosphere continued…

1. Water led to very heavy rains that cooled the Earth down, and absorbed most of the CO$_2$. Nitrogen was left.

2. Once plants began to grow, they emitted oxygen as a by-product of photosynthesis. Allowed plants and then animals to exist.
Oxygen is produced by photosynthesis in green plants.

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2
\]
A lot of the oxygen produced in the Precambrian era reacted with elements like iron to produce rocks like these.
Variable Components of the Atmosphere

1. **Water Vapor** - between 0 and 4% by volume
2. **Aerosols** - are solid or liquid particles suspended within the atmosphere. Water condenses on their surfaces, and they absorb/reflect solar radiation—up to 20µm in size.
3. **Ozone** – O₃ formed at altitudes of 10 to 50 km (stratosphere)
Dust causes red sunsets
Temperature structure of the atmosphere

Height & Structure of the Atmosphere

1. Atmospheric pressure = weight of column of atmosphere above per square meter
2. Average atmospheric pressure at surface of Earth is 1000 millibars (1 bar)
3. One half of the atmosphere lies below 5.6 km. Pressure drops by half.
4. Atmosphere thins out with increasing height
5. The atmosphere has no real edge
Temperature Changes

1. **Troposphere**. Bottom layer. Where we live. About 12 km thick. Atmospheric components are very well mixed.

2. Temperature decreases with increasing altitude (**environmental lapse rate**). Average is 6.5 degrees C per km (called the **normal lapse rate**).

3. Sun heats the Earth. As altitude increases, get further away from heat source.
Temperature Changes - 2

1. Temperature stops decreasing at the *Tropopause*, which is at altitudes between 9 and 18 km, depending on latitude.

2. Temperature then increases in the *Stratosphere*, up to the *Stratopause* at 50 km.

3. Increase arises from heat generated when UV light creates the ozone.
Temperature Changes - 3

1. Temperature then decreases in the **Mesosphere**, up to the **Mesopause** at 80 km.
2. Temperature then increases in the **Thermosphere** to very high values (1000°C).
3. Increase arises when O and N absorb the longer wavelength UV radiation, and give out heat.
4. Temperature is a measure of the speed of the individual atoms.
Vertical Variations in Composition

• Based on composition
• The atmosphere is divided into two layers:
  • Homosphere - up to about 80 km, composition is constant because of mixing
  • Heterosphere - above 80 km. Gases are arranged in shells. $N_2$, O, He, H.
• $N_2$ is the heaviest, hydrogen the lightest
Ozone

1. Formation - UV light from the Sun breaks down an oxygen molecule \((O_2)\) into O and O. The Os can then combine with \(O_2\) to form \(O_3\).
2. Protects us from UV light from the Sun.
3. Depleted by man-made CFCs. At very high altitudes, CFCs are broken down by the UV light from the Sun, liberating chlorine gas, which combines with and destroys the \(O_3\).
the sun

oxygen molecules (O₂)
Step one in formation of stratospheric ozone

Oxygen molecule + Ultraviolet rays → Atomic oxygen

Step two

Atomic oxygen + Oxygen molecule → Ozone
Step 2

Ozone molecule + Ultraviolet rays → Oxygen \((O_2)\) + Single atom of oxygen

Single atom of oxygen + Oxygen \((O_2)\) → Ozone molecule
Chlorine (Cl) + Ozone molecule → Chlorine monoxide (ClO) + Oxygen (O₂)

Chlorine monoxide (ClO) + Single atom of oxygen → Chlorine (Cl) + Oxygen (O₂)
The Ionosphere

1. Lies at altitudes between about 80 and 500 km (and higher)
2. Caused by photoionization of atoms or molecules of the atmosphere by UV and EUV light from the Sun
3. Photoionization - the energy of the light from the Sun is absorbed by an electron in an atom, allowing it to escape from its atom.
The Ionosphere - 2

1. Result of (photo)ionization is a mixture of positively charged ions and negatively charged electrons.

2. It is the light electrons that are interesting. Ions are relatively heavy.

3. The ionosphere has a vertical structure because the Sun's radiation is not monochromatic, and different atoms or molecules are ionized. Layers called D, E, F. (E = electrical; others from alphabet)
1. D region absorbs radio waves, especially at low frequencies. D & E layers disappear at night.

2. Electrons in ionosphere slow radio waves down, and thus affect the accuracy of locations determined by using the GPS satellites.
End Chapter 1

Chapter 1 homework assignment: Problems: 1, 2, 6, 7
Due in one week.