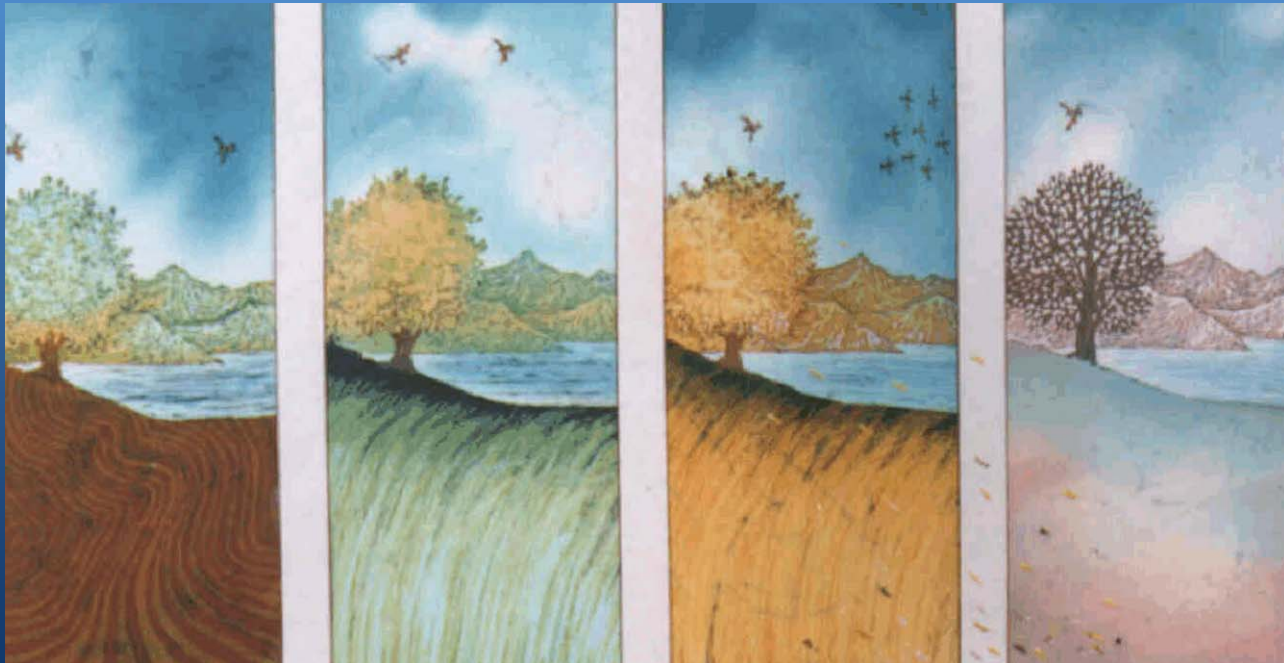


THE HEAT BUDGET OF THE EARTH: A HANDS-ON INVESTIGATION

- Roy Plotnick and Gene Harris,
University of Illinois at Chicago



Context of the Laboratory

- Taught in introductory earth science and physical science courses
- Audience: nearly all non-majors; in physical science, pre-service elementary teachers
- Assumed knowledge of material: minimal
- Assumed skills: basic algebra; some geometry
- About 20-23 students per lab section, taught by a teaching assistant
- Separate lab, lecture, discussion times
- Replaces earlier pencil and paper lab

Goals of the Laboratory

- Following completion of the lab, students:
 - ▶ Will have an intuitive understanding of inverse-square laws
 - ▶ Be able to describe how solar radiation changes as a function of
 - Distance from the sun
 - Latitude
 - Season
 - ▶ Will be able to predict how different surfaces are warmed by the sun
 - ▶ Interpret differences in climate related to proximity to a body of water
- These concepts are tied in to a conceptual climate model developed in lecture

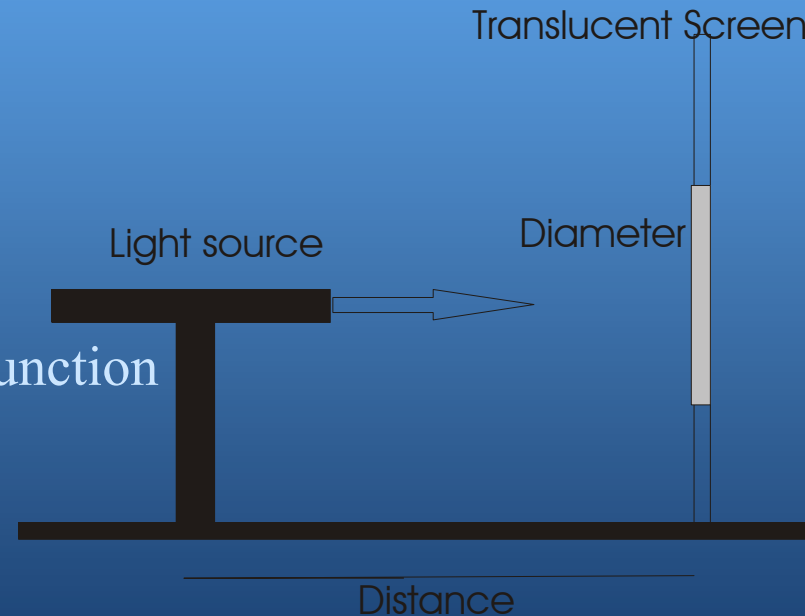
Part I: Effect of Changing Distance From the Sun

- **Leading Question:** How would the amount of energy reaching the earth's surface change if the earth were a different distance from the sun?
- **Scientific concept:** The amount of radiation decreases proportional to $1/\text{distance}^2$
- **Students observe:**
 - ▶ how light spreads out from its source and
 - ▶ how the intensity of light changes with distance from the source.

Part I: Effect of Changing Distance From the Sun

- How light spreads from its source

- Apparatus:
 - ▶ Microscope lamp which projects a narrow beam of light
 - ▶ translucent screen
 - ▶ Rulers.
- Procedure. At different distances:
 - ▶ Measure diameter image on screen
 - ▶ Calculate area covered by image and plot as function distance
 - ▶ Qualitatively assess changes in brightness
- What they should observe:
 - ▶ Spot areas go up as distance²
 - ▶ Light intensity declines



Part I: Effect of Changing Distance From the Sun

- Measuring the Effect of Distance on Intensity



Part I: Effect of Changing Distance From the Sun

- Measuring the Effect of Distance on Intensity

■ Apparatus:

- ▶ Microscope lamp
- ▶ Solar cell, cover removed
- ▶ Ammeter, set to measure current in microamperes
- ▶ Ruler



Part I: Effect of Changing Distance From the Sun

- Measuring the Effect of Distance on Intensity

■ Procedure:

- ▶ solar cell and ammeter 100 cm. from the light source = 1 *Distance Unit* (DU)

- ▶ How much electricity is the cell generating? = 1 *Energy Unit*.

- ▶ Predict how much electricity at 0.5 and 2 DU. -most students predict linear relationship

- ▶ Measure how much electricity at 0.25, 0.5, 1.5, and 2 DU

- ▶ Graph prediction and measurement

■ What they should observe:

- ▶ Energy is not a linear function of distance

Part I: Effect of Changing Distance From the Sun

- Mathematical Foundations: Revising the Prediction

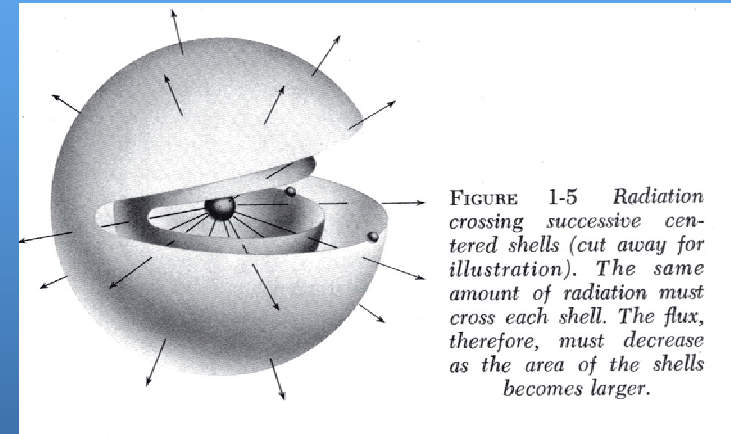
- The total energy E from the sun is spread out over the surface of a sphere whose radius is the earth- sun distance = 1 astronomical unit or 1 AU

- The solar flux SF (radiation/unit area) = total energy/surface area of the sphere = $E / (4\pi \text{ AU}^2)$

- What if the earth were 2 AU's from the sun? In that case the equation would be: $SF = E / (4 (2\text{AU})^2) = E / (16 \pi \text{ AU}^2)$ or 1/4 as much

- Geometry thus forces a simple rule: as distance from the sun changes, the energy the planet receives varies by $1/\text{distance}^2$.

- Students now compare this with their experimental results



From: Goody & Walker. 1972. *Atmospheres*.

Part I: Effect of Changing Distance From the Sun

- Perihelion and Aphelion

- The ratio between the energy per unit area received at two different distances d_1 and d_2 :
 - ▶ $SF_1/SF_2 = (d_2/d_1)^2$
- On Jan. 4, perihelion, Sun-Earth distance is 147.5×10^6 km; on July 4, aphelion, distance is 152.6×10^6 km
- How much radiation is received at aphelion compared to that received at perihelion?
 - ▶ 93.5 %
 - ▶ So why do we have summer in Chicago????

Part II: The Role of Solar Angle

- **Leading Question:** How does the amount of energy reaching the earth's surface change as a function of the angle of the sun relative to the surface?
- **Scientific concept:** The decrease in amount of radiation as a function of angle is much greater than that of distance
- **Students will observe:**
 - ▶ How angle of radiation changes because the Earth is sphere
 - ▶ How the intensity of light changes with angle

Part II: The Role of Solar Angle

- Changing Angles

- Equipment:

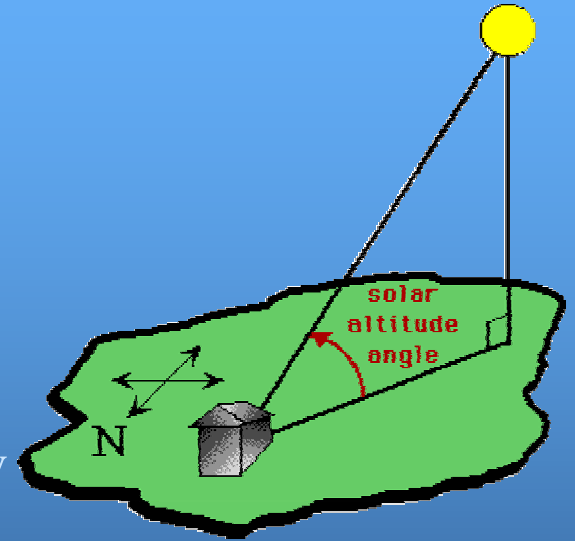
- Globe
- Light source

- Procedure

- Orient globe relative to light source at the correct orientations for the equinoxes and solstices
- At each orientation, locate Chicago on the globe. How close is the "sun" to being directly overhead?

- Students are given:

- The angle of the sun relative to the surface at Chicago at noon at the equinoxes is approximately 48.5° .
- The angle of the sun at the summer solstice in Chicago is approximately 71° .
- The angle of the sun at the winter solstice in Chicago is approximately 25° .



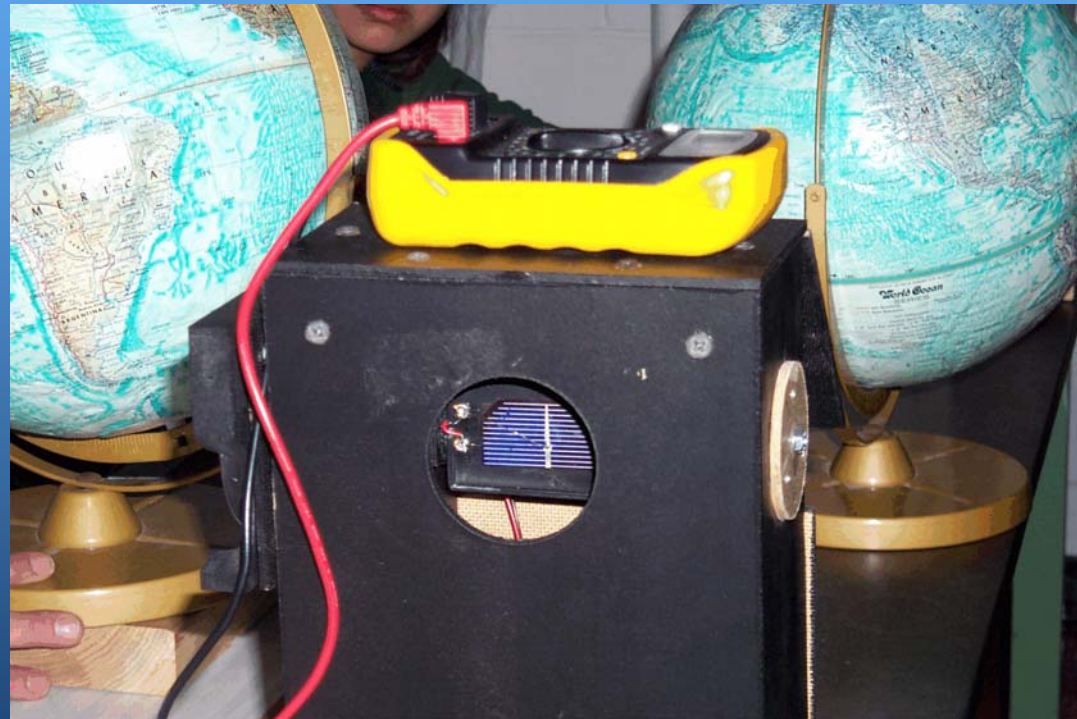
<http://www.susdesign.com/sunangle>

Part II: The Role of Solar Angle

- Measuring the Effect of Angle

■ Equipment:

- ▶ Solar cells, mounted to allow angle relative to light to change
- ▶ Light source
- ▶ Ammeter



Part II: The Role of Solar Angle

- Measuring the Effect of Angle

■ Procedure:

- ▶ Set the angles of the solar cell corresponding to the positions of the Sun for Chicago in summer, winter, fall, and spring. How do the output values change? Compare to aphelion to perihelion change

- ▶ Set the angles of the solar cell corresponding to different latitudes. How do the output values change?

■ What they should discover:

- ▶ Effect angle >> effect distance.
- ▶ Why there are seasons!
- ▶ Pole-equator differential heating

Part III: Albedo

- **Leading Question:** How does the amount of heating depend on the nature of the surface?
- **Scientific concept:** The amount of heating of a surface depends on how much radiation it reflects, its albedo
- **Students observe:** Light colored surfaces heat more slowly than dark colored surfaces

Part III: Albedo

Equipment:

- ▶ Floodlamp
- ▶ Flat black and flat white surfaces. Glued on each surface is a thermometer that measures its temperature.
- ▶ Solar cell mounted to measure the amount of radiation reaching the surface from the bulb and then the amount reflected back.



Part III: Albedo

- Procedure:
 - Measure the starting temperature of each surface.
 - Turn the floodlamp on
 - Using the solar cell setup, measure the amount of energy reaching and reflected from each surface
 - After 10 minutes, measure the temperature of each surface
- What they should discover:
 - White surface reflects more light and heats less than the black surface
 - How different parts of the Earth should heat differently; effect of clouds

Part IV: Heat Capacity

- Leading question: How do different materials, such as water and land, heat up and cool down?
- Scientific concept: Heat capacity of water is much greater than that of solid materials
- Students observe: how rapidly sand and water change temperature when heated

Part IV: Heat Capacity

- **Equipment:**
 - Heat lamp -initially off
 - beaker filled w/sand, the second beaker w/ equal weight water at room temperature
- **Procedure:**
 - Turn the heat lamp on. Measure the temperature of each beaker every minute for 5 minutes
 - turn the heat lamp off. Measure the temperatures once every minute for the next 5 minutes
- **What they should discover:**
 - Water heats more slowly and cools off faster than sand
 - Why continents and oceans differ in climate



Lessons Learned?

- The Climate of the Earth
 - Solar heating of the Earth depends on distance from the Sun - decreases by $1/\text{distance}^2$
 - The equator is heated more than the poles
 - Seasonal changes in solar angle are much more important than changes in the Sun-Earth distance
 - Parts of the Earth's surface that are darker should heat more rapidly
 - Land surfaces heat up and cool down far more rapidly than the oceans