

## Lab Overviews

(Title of each is “overview course topic for week --- lab name”. Brief description follows, along with itemized list of proposed/possible activities)

### 1) History of Universe/Earth/Life – Measuring temperatures and uncertainties

*Overview of measurement, uncertainty estimation, and statistics, using temperature measurements and full class data.*

Equipment: Thermometers (IR, glass, ?); computers (for data sharing and analysis); things to measure temperature of (ice / room temp/ boiling water, hotplate, ?)

Activities:

- Multiple measurements of same object with same instrument type (IR thermometer, glass). Repeat for other objects, instrument
- Measure temperature of multiple humans (maybe distributions for two groups?)
- Some simple statistical analysis: calculating average and std dev; histograms of data (overlap or not?); how to state the uncertainty.

### 2) Contemporary Climate Change – Constructing a global temperature average

Understanding the meaning and method of taking a global temperature average, along with its uncertainties and confounding factors.

Equipment: Computer (for analysis); Thermometers (brought home to make measurements over prior week);

Activities:

- Have class measure and record outdoor temperature all week; also the sky temperature (w/ IR thermometer).
- Plot all class data on temperature from prior week.

- Plot approach to average of multiple measurements
- Gather worldwide data from online weather database, try to construct average for two years separated by decades.
- Calculate anomaly for temperatures. Estimate uncertainty.
- Use ideas from NASA's [Global Temperature Average](#) and JPL's Graphing Global Temperature Trends.
- Addressing heat islands.

### 3) Energy and Equilibrium – Leaky buckets

*Using analogy of conserved water, understand how the rates (of input/output) influence the establishment of an energy equilibrium.*

Equipment: Graduated cylinders (with and without holes, multiple types); Beverage dispenser with adjustable spigot; aquarium pumps (for water return); stopwatch

#### Activities:

- Measure flow rates for different spigot positions
- For multiple flow rates, and then multiple graduated cylinders (w/different hole numbers, widths, hole heights), find the equilibrium level of water.
- Why is there a rate-dependent equilibrium level? Observe outflow carefully.
- Use [Seeley tutorial](#)

### 4) EM and Blackbody Radiation – All the light you cannot see

*Explore the emission of light at various frequencies and the transparency of materials to light at different frequencies.*

Equipment: Thermal imaging cameras; Near IR cameras (security/trail cameras); IR LEDs for Near-IR; Near UV cameras; Silica and glass (and other things) for transparency demonstration

#### Activities:

- Identify where on EM spectrum different sources will have BB radiation; area estimates to look at SB law?

- Explore with Thermal imaging camera, and other cameras (humans, in the dark, boiling water, ice water, stretched rubber band, incandescent vs led vs fluorescent lightbulbs, water on carpet, ...)
- Near-IR camera with and without IR LED
- Leslie cube and emissivity
- See Toffaletti et al ([AJP 2023](#))

#### 5) The atmosphere and Greenhouse Effect I – Heating by radiation

Observe the approach to equilibrium of an object (e.g., metal plate or bottle of water) and estimate the rate of energy input. Can be done outside or with incandescent lamp.

Equipment: Apparatus for heating block (e.g., see [UArizona site](#));

Activities:

- Heat block and measure temperature over time; plot and find the region of constant increase; estimate  $DT/Dt$ .
- Observe moonshine?

#### 6) The atmosphere and Greenhouse Effect II – Absorption and blanketing

Observe the absorption/transmission of light of different frequencies when encountering matter.

Equipment: Broad-spectrum LED flashlights; red/blue/green filters; tank of water; food coloring

Activities:

- Similar experiment to prior week, but with bottle of water with and without a “space blanket”
- Toffaletti et al ([AJP 2023](#)) experiment with red/blue/green light and red/blue/green lights.

#### 7) Water and Phase Transitions I – Evaporation and cloud formation

*Observe evaporation of water into air and formation of clouds.*

Equipment: Cloud chamber boxes (would like them to be invertible? alcohol more dense than air, water vapor less dense than air); Dry ice; hygrometers; humidifiers; bicycle pump

Activities:

- Measure the humidity (also have them do this over the course of the week with bring home hygrometers)
- Observe/Time the evaporation of a painted streak of water on surfaces of different temperature, and in a humid box.
- Create cloud with alcohol (alcohol sponge on top, dry ice on bottom) and with water vapor (vice versa?)
- Pressurized cloud with bicycle pump?
- Explore psychrometric charts by plotting temperature and humidity (what is required in different cities to reach comfort, see [Marrache-Kikuchi](#))

8) Water and Phase Transitions II – Something else (calorimetry?)

9) Paleoclimate perturbations of temperature – Precession & Paleo data analysis

*Explore orbital dynamical perturbations of earth around sun and effects on temperature on long time scales.*

Equipment: Something for showing precession/nutation; computer

Activities:

- Observe mechanical precession and relate to Earth spinning; identify the parts of the Milankovich cycles.
- Explore temperature record over past 1My and 5My (100ky cycles and 40 ky cycles). Fourier transform?
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10) Climate sensitivity (Changing temp from CO<sub>2</sub>) – IR spectroscopy and absorption

Precise measurement of blackbody curve in IR using thermopiles, and the absorption due to CO<sub>2</sub> and H<sub>2</sub>O vapor.

Equipment: Thermopiles (unfiltered, and then specifically filtered for gas detection purposes); Hotplate for IR source; “box” for CO<sub>2</sub>/H<sub>2</sub>O vapor in between

Activities:

- Measure the variation of thermopile voltage output with changing hotplate temperature.
- Use narrow-band thermopiles (and a calibration table) to plot BB spectrum of hotplate
- Repeat with intervening CO<sub>2</sub> and intervening H<sub>2</sub>O. (Looking for dip at lines).

#### 11) Timescales of Climate Change – Leaky buckets and Heating by radiation 2

Investigating how the rates and equilibrium levels lead to characteristic timescale of equilibration, and how forcing changes equilibrium levels and in what timescale.

Equipment: same as for (3) and (5)

Activities:

- Get the approach to equilibrium for a “leaky bucket” (level vs. time) and determine the rate. Compare to influx rate and equilibrium level
- Change influx rate in a “shock” and the approach to new equilibrium.
- Similar to bucket, but with the heating metal (change the brightness of the lamp, measure time of equilibration).
- Tutorial with IPCC data on timescales of CO<sub>2</sub> in atmosphere/ocean.

#### 12) Modeling Climate Change – Numerical modeling activity paired with discussion

## **Equipment**

- IR Thermometers (lots, let students use for semester, plus more for in-lab)
- Glass thermometers
- Graduated cylinders (multiple types)

- Beverage dispenser with spigot (or containers + spigots -> build)
- Aquarium pumps
- Thermal imaging cameras (we have two now, one for iPhone one; both were \$300? ; Sofia has a better one that is \$400); probably need at least 6?
- Near-IR cameras (like security/trail cameras, potentially with IR leds, or perhaps get IR leds separately)
- (near) IR LEDs?
- Near-UV cameras (apparently one can hack certain cameras, removing a filter?)
- (near) UV LEDs?
- Leslie cube (or build)
- LED flashlights and RGB filters, and food coloring
- Water tank (for RGB transmission)
- Hygrometers/Humidity meters (many, students bring home to make measurements)
- Dry Ice
- Humidifiers and box to humidify?
- Bicycle pump
- Thermopiles (broad and narrow for particular gas detection lines)

## Build

- Snip wires to lasers on IR thermometers
- Drilling holes in graduated cylinders
- Beverage dispenser from multiple-gallon water bottle and [stainless/plastic](#) spigots?
- [Leslie cube/cans](#)
- Cloud chamber boxes
- Thermopile “holder”... something to easily swap out thermopiles, opamp to amplify signal, and multimeter to measure output.
- Calibration of thermopiles
- “Box” for seeing CO<sub>2</sub>/H<sub>2</sub>O absorption of hotplate