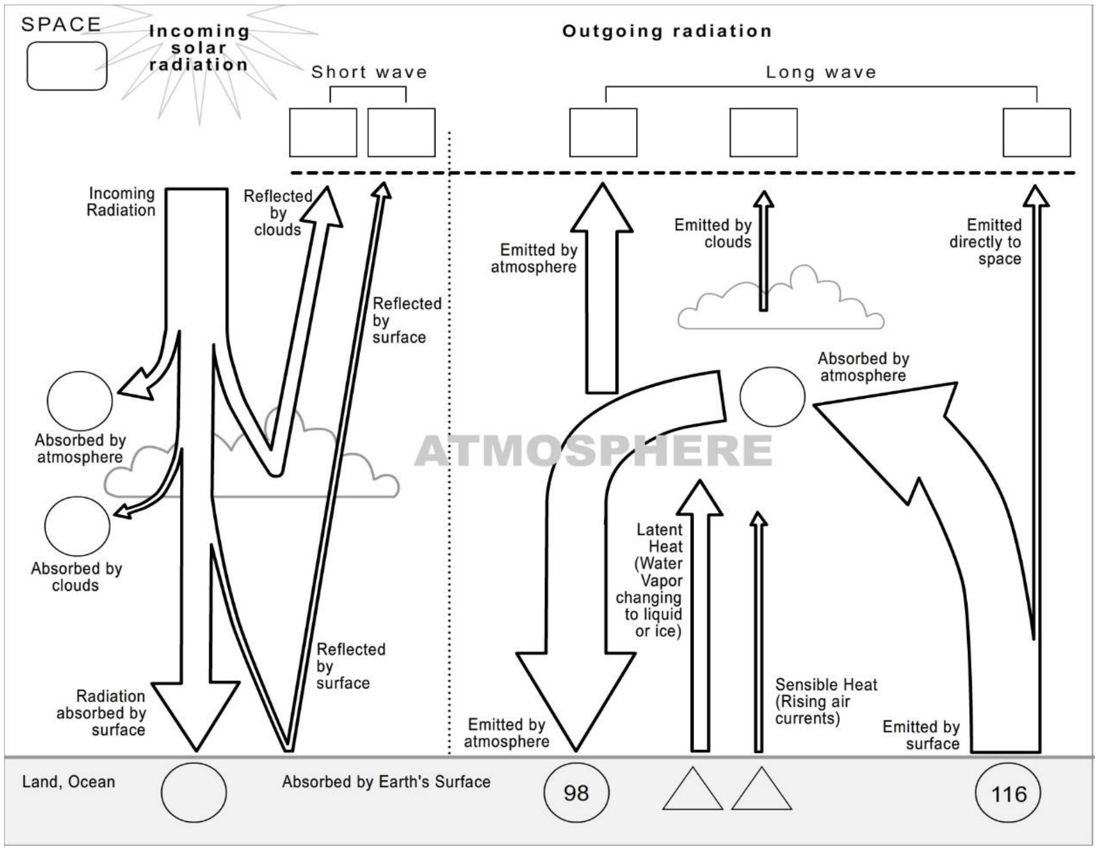
Earth's Energy Budget

Instructions:

In the following activity you will use pennies to illustrate the text and graphics describing Earth's energy budget. You will read each section of text, and then stack objects to "account" for Earth's energy budget. You will need 100 pennies, a recording sheet, red, blue, and orange colored pencils, and a pen or pencil to complete this activity. After you have completed your accounting, you can check your work with your instructor.



Original source: *https://d32ogoqmya1dw8.cloudfront.net/files/eslabs/weather/energy_balance_instructions.pdf*

Earth's Energy Budget: Introduction

Earth's heat engine does more than simply move heat from one part of the surface to another; it also moves heat from the Earth's surface and lower atmosphere back to space. This flow of incoming and outgoing energy is Earth's energy budget. For Earth's temperature to be stable over long periods of time, incoming energy and outgoing energy have to be equal. In other words, the energy budget at the top of the atmosphere must balance. This means that for every 100 units of energy into the system there must be 100 units of energy out of the system. This state of balance is called global radiative equilibrium.

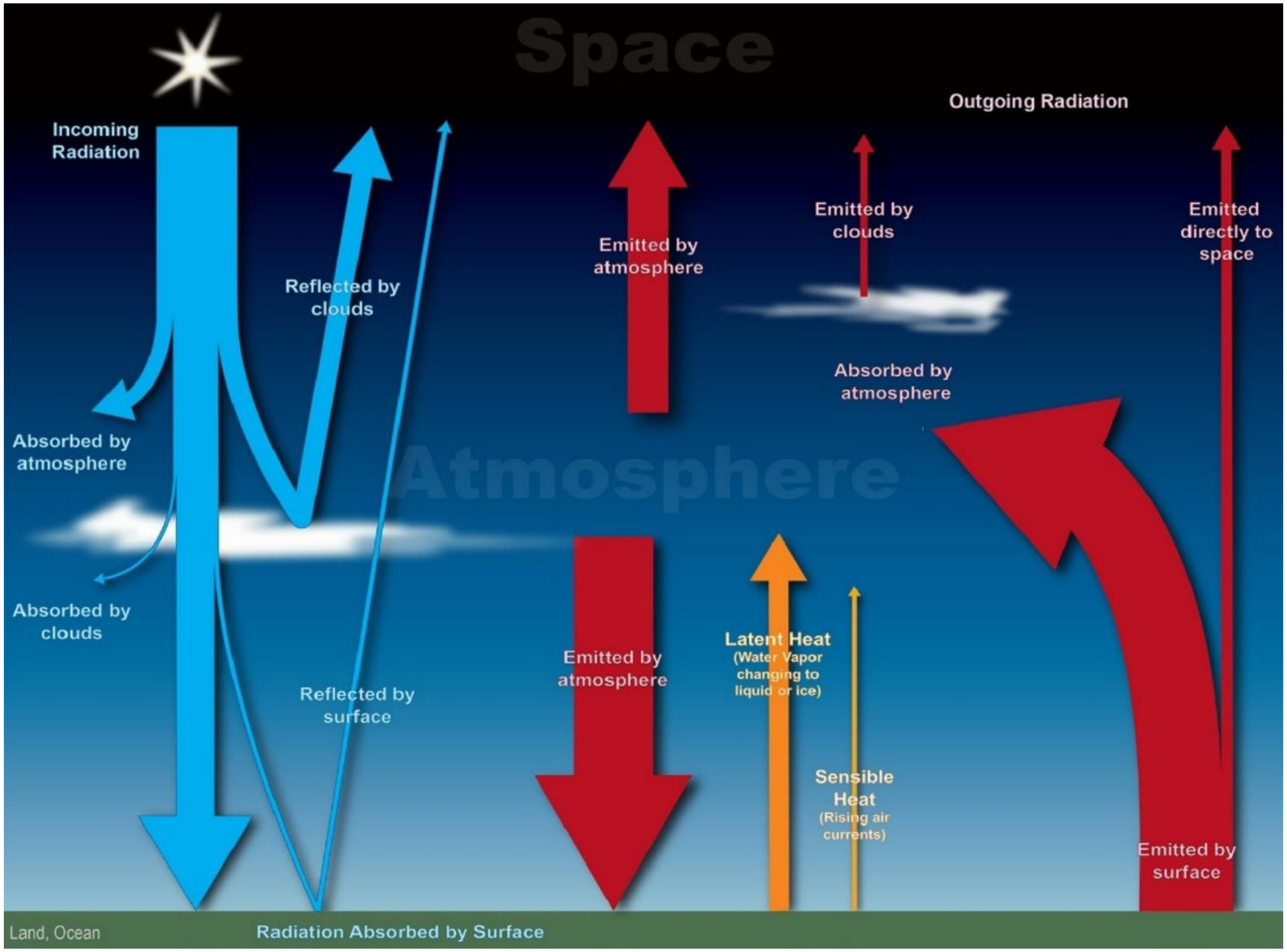
To understand how the Earth's climate system balances the energy budget, we have to consider processes occurring at three levels: the surface of the Earth, where most solar heating takes place; the top edge of Earth's atmosphere, where sunlight enters the system; and the atmosphere in between. At each level, the amount of incoming and outgoing energy, or net flux, must be equal.

Earth's energy balance is complex, and includes many concurrent processes. In this activity, you will break these processes into three steps in order to simplify the processes and understand how it all fits together.

Overview of Energy Pathways:

Begin this activity by gaining an overview of the energy pathways. Using the graphic shown below, identify the incoming solar radiation.

On your printed version of the graphic, color the incoming radiation blue. Next, color the arrows representing outgoing radiation red, and the latent and sensible heat arrows orange.



Part 1: Incoming Solar Radiation

Solar energy is constantly moving through space and bathing our planet and its atmosphere. The energy that arrives at the top of the atmosphere is either reflected or absorbed.

About 30% of the solar energy that arrives at the top of the atmosphere is reflected back to space by clouds, atmospheric particles, or bright ground surfaces like sea ice and snow. This energy plays no role in Earth's climate system.

Meanwhile, about 23% of incoming solar energy is absorbed in the atmosphere by water vapor, dust, and ozone, and 47% passes through the atmosphere and is absorbed by Earth's surface. Thus, about 70% of the total incoming solar energy is absorbed by the Earth system.

Part 1 (continued)

Acquire 100 pennies to represent the energy units. These pennies represent all of the solar energy reaching the top of the atmosphere from the sun, or 100%. Start at the upper-left of the energy balance diagram. Fill in the box next to the sun with the number 100.

Then, stack the pennies on the diagram according to what happens to each unit of energy as it travels through the atmosphere on its way to Earth's surface.

Separate the pennies into five columns and place them on the paper as follows:

- **23 units – reflected by the clouds and atmosphere**
- **7 units – reflected by the Earth's surface**
- **19 units – absorbed by the atmosphere (ozone, aerosols, dust)**
- **4 units – absorbed by clouds**
- **47 units – absorbed by the Earth surfaces (primarily ocean)**

Part 2: Surface Energy Budget

In Part 1 you saw that about 30% of incoming sunlight is reflected back to space by particles in the atmosphere or bright ground surfaces, which leaves about 70% to be absorbed by the atmosphere (23%) and Earth's surface (47%) including the ocean. For the energy budget at Earth's surface to balance, processes on the surface must transfer and transform the 47% of incoming solar energy that the ocean and land surfaces absorbed back into the atmosphere and eventually space. Energy leaves the surface through three key processes: evaporation, convection, and emission of thermal infrared (IR) energy.

About 24% of incoming solar energy leaves the surface through evaporation and sublimation. Liquid water molecules absorb incoming solar energy, and they change phase from liquid to gas. The heat energy that it took to evaporate the water is latent (or hidden) in the random motions of the water vapor molecules as they spread through the atmosphere. When the water vapor molecules condense back into clouds, the latent heat is released to the surrounding atmosphere. Evaporation from tropical oceans and the subsequent release of latent heat are the primary drivers of the atmospheric heat engine.

Part 2: Surface Energy Budget (continued)

An additional 5% of incoming solar energy leaves the surface through convection. Air in direct contact with the sun---warmed ground becomes warm and buoyant. In general, the atmosphere is warmer near the surface and colder at higher altitudes, and under these conditions, warm air rises, shuttling heat away from the surface.

Finally, a net of about 18% of incoming solar energy leaves the surface as thermal infrared energy (heat) radiated by atoms and molecules on the surface. This net upward emission results from two large but opposing fluxes: heat flowing upward from the Earth's surface to the atmosphere (116%) and heat flowing downward from the atmosphere to the ground (98%).

The energy, which had been absorbed by the surface of the Earth, will now be transferred to back to the atmosphere and space via several processes.

To represent these processes, move the 47 pennies from the radiation absorbed by the surface to four *new* locations on the energy balance diagram as follows.

- **24 – Latent heat: energy that is used in evaporation, transpiration, and condensation**
- **5 – Sensible heat: energy that becomes convection**
- **12 – Emitted from Earth directly back to space**
- **6 – Net radiation amount absorbed by atmosphere**

Note: this is the long---wave energy that is emitted by Earth to the atmosphere (116), minus the energy that is directly transferred to space (12) combined with that which re--radiated back to Earth by the atmosphere (98). [116 - (12 + 98)] = 6

Part 3: The Atmosphere's Energy Budget

Just as the incoming and outgoing energy at the Earth's surface must balance, the flow of energy into the atmosphere must be balanced by an equal flow of energy out of the atmosphere and back to space. Satellite measurements, taken at the top of the atmosphere, indicate that the atmosphere radiates thermal infrared energy equivalent to 58% of the incoming solar energy. If the atmosphere is radiating this much, it must be absorbing that much. Where does that energy come from?

Recall from Part 1, that clouds, aerosols, water vapor, and ozone directly absorb 23% of incoming solar energy. In Part 2, you saw that evaporation and convection transfer another 24 and 5% of incoming solar energy from the surface to the atmosphere, which then moves the energy back to space. These three processes transfer the equivalent of 52% of the incoming solar energy to the atmosphere. If total inflow of energy must match the outgoing thermal infrared observed at the top of the atmosphere, where does the remaining fraction (about 6%) come from? The remaining energy comes from the portion that was absorbed by the atmosphere and not re-emitted back to Earth.

Part 3 (continued)

Move the energy from to the atmosphere back to space, through the following steps.

1. **Collect the 19 and 4 pennies, which were absorbed by the atmosphere and clouds.**
2. **Collect the 24 and 5 pennies that were transferred to the atmosphere via latent and sensible heat.**
3. **Collect the 6 pennies that remained in the atmosphere.**
4. **Move these 58 pennies to two remaining locations in the following amounts**
    a. **49 emitted by the atmosphere**
    b. **9 emitted by clouds**

Look at the three boxes labeled "Long wave" at the top-right of your diagram. These are units of infrared (longer wavelength) energy transferred by the atmosphere back into space. Draw plus signs between these three numbers on the diagram (as seen below) and then add them up. <u>Record your answer in the margin to the right on your diagram</u>.

_____ + _____ + _____ = _______	← *DO NOT WRITE ANYTHING HERE.*

This amount of energy, when combined with the amount of energy that was reflected in Part 1, should equal 100%. In other words, all the incoming solar energy has been returned to space, and your energy budget is now in balance.

Check your work:

Earth's energy balance is complex, however once you have simplified the processes it becomes clear how the parts relate to the whole. Use this diagram to check your work.