What's the difference between weather and climate?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

That's a good question! Sometimes the words get used almost synonymously, but there's a real difference. And we can illustrate the difference with a pack of M&Ms.

Necessary materials:

- Bags of M&M candy, "fun size", or:
- Beads of a mix of colors and/or shapes

Other types of candy will work as well, of course. You just need a little bag of candy with many—but not too many—different kinds of candy in the bag. If you choose not to use candy, beads make a very nice substitute.

Theory

Weather is what it is doing *right now*. It might be raining, it might be sunny.

Climate is a bit harder to define. Here are a couple of characteristics:

- Climate describes the range of what you might expect in a given location—the limits of what the weather might be. In Fort Collins, where we are, it might be cold in March or it might be hot. It might be 25°F or it might be 75°F. But it's never 0°F or 100°F in March.
- Climate describes average weather. On any given day, it might be hot in Denver and cool in Miami, but, on most days, it's hotter in Miami than it is in Denver.
- Climate describes long-term trends. If it's cold for a few days, that's weather. If it's an ice age, that's climate.

The expected range of M&Ms in the bag is the climate. What actually comes out is the weather.

In Colorado, our weather is pretty changeable. It might be rainy one minute and sunny the next. But our climate is pretty stable. It's warm in the summer, cool in the winter, and, overall, pretty dry.

Doing the Experiment

This is a pretty quick experiment. It's more of a demonstration, but one that is interactive and informative, and one that has a candy treat at the end.

Define a different type of weather for each color of candy. Orange might be cool and cloudy, blue hot and sunny. Use your imagination!

Give each group a bag of candy. Each bag will represent the weather in Colorado (or wherever you are!) for a series of days in March for a particular year. You might even assign years—one bag represents 1996, one 2000...

Ask each group to tear open a corner of their bags, and tip out one piece of candy. That's the weather on March 1. Now, ask each group what they got. In some groups (that is, in some years...) the M&M is orange (March 1 was cool and cloudy); in others, it's blue (March 1 was hot and sunny.) That's weather. On a given day in a given year, you just can't predict what the weather will be.

Now, have each group pour out all of their candy and count: How many orange? How many blue? You'll find that there are some differences between groups, but the differences are reasonably small. Some groups may get a larger percentage orange candy, others will get more blue. But no one will get all orange or all blue! If you look at the weather over a longer period of time, patterns start to emerge. You are starting to pin down the climate....

Now, compute an average number for each color in all of the bags. This is climate, the average weather, what you expect. If you give someone a fresh bag, you can't predict the weather—whether the next candy out of the bag will be blue or orange—but you can predict *trends* in the weather. You can say, with confidence, that there won't be 10 orange candies in a row. That would be very unlikely!

If you want a nice extension, you can compare different types of candy. Give some of your groups M&Ms, some of them another kind of candy. That would correspond to different climates.

When you are done, ask your students the question we started with: What is the difference between weather and climate?

Summing Up

This is really a demonstration, but we have found it helpful in demonstrating the difference between the unpredictable fluctuations of the weather and the long-term predictable average of the climate.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

What is a “model”?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

The physics of how the atmosphere works is quite simple, described with some very straightforward equations. The behavior of the atmosphere itself, though, is quite complex, and can’t be expressed in a series of simple equations. Building up from the very simple concept of a physical theory to the complicated behavior of a real physical system is the job of a *model*. The best way to learn what a model is is simple to create one, which we will do in this exercise.

Necessary materials:

- Chips or tokens
- 4 copies of the Heat Exchange Model sheet

Students will work in groups of four for this activity, one student representing each “cell” in the model.

Theory

Climate models start with physical theories: How air moves, how water behaves, how radiation transports energy. They then break the earth’s atmosphere down into pieces—cells—and then compute what happens in each cell based on these physical theories. Cells exchange energy and matter with each other based on the physics of the transfer of matter and energy. The net result is a simulation of what the actual atmosphere might do. We can illustrate this idea by doing a very, very simple model for a piece of the atmosphere, as described below.

The design of the CMMAP logo tells us something about the model being developed by the center.

Doing the Experiment

See detailed instructions below. Start with a simple simulation:

- Have each element start with tokens in the bold outlined squares—for example the temperature of Earth is 19.
- Now run the model for 4 turns. How do the temperatures change?
- Now, continue the simulation; keep running it, having students keep track of the temperature.

At some point, the model will stabilize; all of the elements will remain at the same temperature for each turn. How long does it take to reach this point? This is the final temperature profile that the model predicts for the atmosphere. Just as for the real atmosphere, the earth is warmer than the lower atmosphere and the temperature drops as you go higher.

The model breaks down at the high end, though: In fact, the stratosphere is hotter than the lower atmosphere. That's because the stratosphere is heated by the sun, something our model doesn't consider. But we can fix this! You should try "tweaking" the model a bit to get a more realistic result. You could add another layer to the atmosphere, and then have space give some energy to the highest level each turn—say 3 tokens to earth and 1 token to the upper atmosphere.

- How does this alter the predicted temperature profile?

You could also do an open-ended discussion of how this model could be made more realistic. What elements would you add?

Summing Up

This is a very simple model, but it captures the key elements of what a model is and does. And it can be made more complex.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

Setting up and Running the Model

Setting up the Model

Four people are needed to run the model. Each person represents one segment of the model: One is the earth, one is the lower atmosphere, one is the upper atmosphere and one is space. The four people sit in a row, in order, just as the different segments appear in relation to each other:

Earth	Lower Atmosphere	Upper Atmosphere	Space

Each element can exchange energy to the adjacent element:

- The earth exchanges energy with the lower atmosphere.
- The lower atmosphere exchanges energy with the earth and with the upper atmosphere.
- The upper atmosphere exchanges energy with the lower atmosphere and with space.
- Space exchanges energy with the upper atmosphere.

In addition, the earth gets energy directly from space.

How much energy is exchanged depends on the temperature: If an element is hotter, it gives off more energy.

On the lower atmosphere and upper atmosphere are two columns of the number of transfer chips, original and revised. Original represents the current amount of CO_2 in the atmosphere. Revised represents a higher amount of CO_2 in the atmosphere than the current levels. Run the model first using the original model then try the revised version to see the differences.

Running the Model

During each "turn" each element exchanges energy with other elements using the transfer cups. The energy transferred depends on the temperature of each element.

The earth, lower atmosphere and upper atmosphere each get some tokens via the transfer cups. Each person puts his or her tokens on the model sheet, a copy of the following page, in order from the bottom. The first uncovered square gives the temperature and the energy to be transferred.

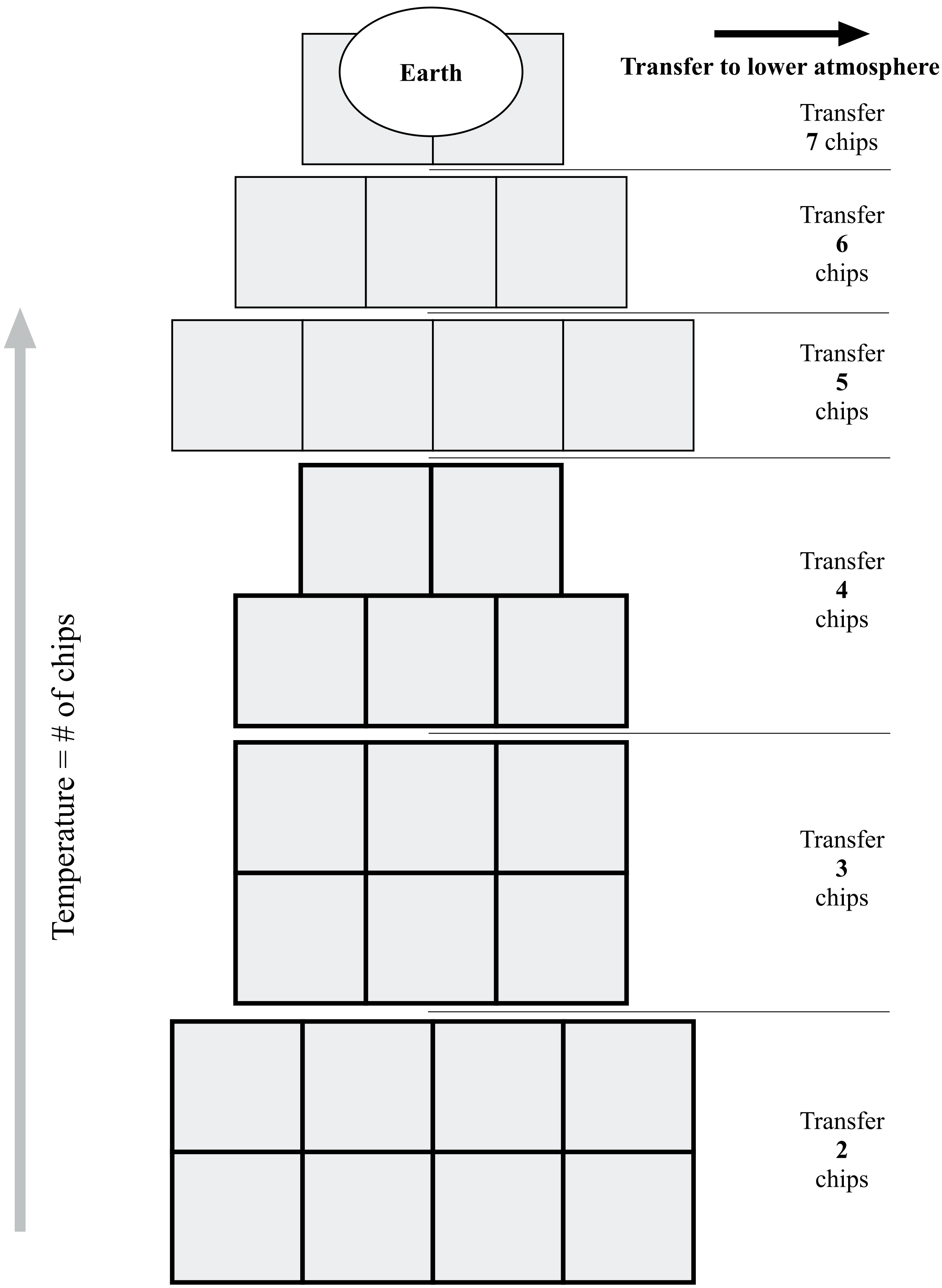
During one "turn", each element exchanges energy with the other elements:

- The earth exchanges energy with the lower atmosphere via the transfer cup. The amount transferred is determined by the temperature of the earth. If the temperature is 19, then 4 tokens are transferred to the lower atmosphere.
- The lower atmosphere exchanges energy with the earth and with the upper atmosphere. If the temperature is 19, then 3 tokens are transferred to earth and 3 are transferred to the upper atmosphere.
- The upper atmosphere exchanges energy with the lower atmosphere and with space. If the temperature is 8, then 1 token are transferred to the lower atmosphere and 1 are transferred to space.
- Space gives 3 tokens to the earth—because energy from the sun heats the earth directly.

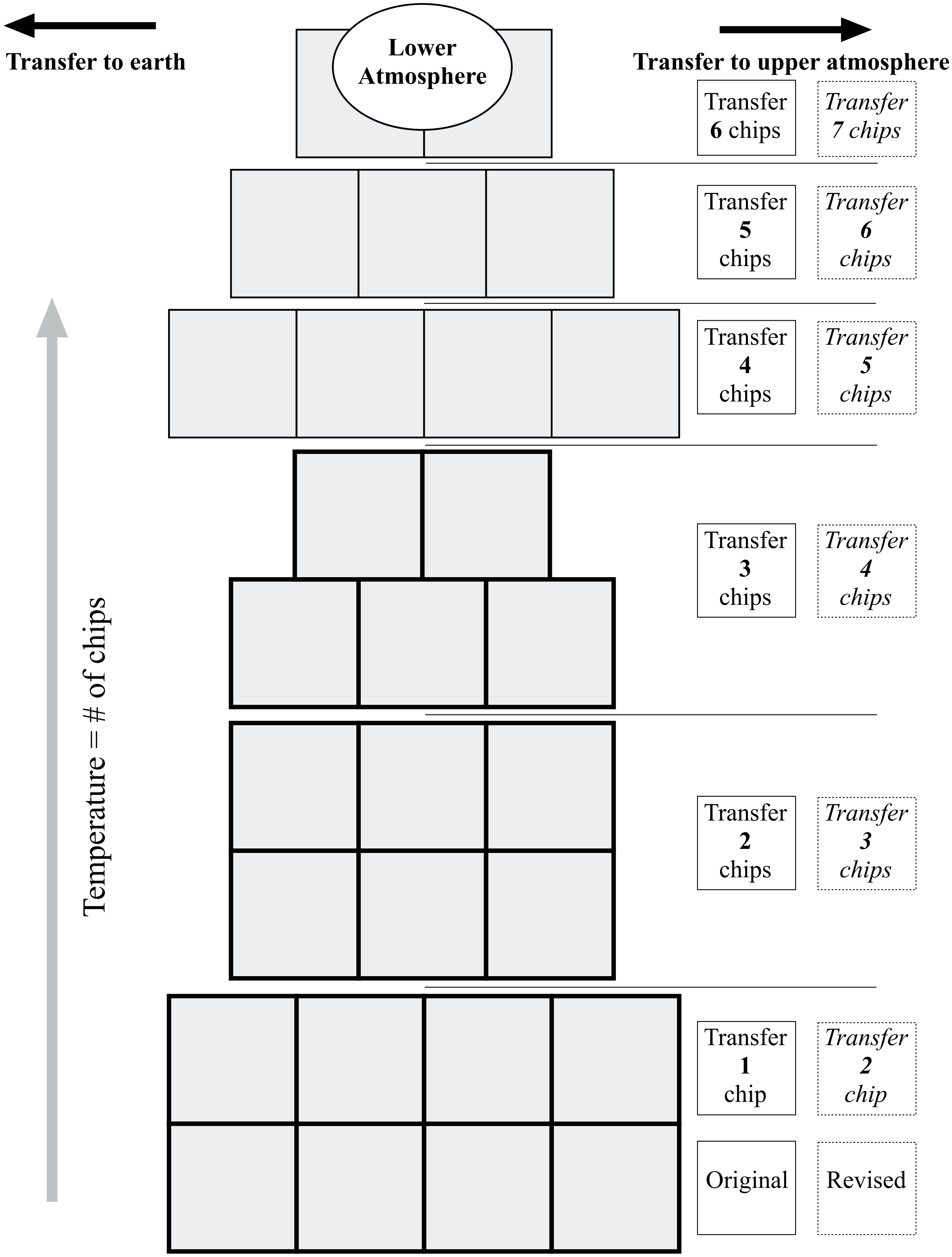
Each element places the newly received tokens and then determines the new temperature. This temperature is used for determining the energy transferred during the next "turn."

Take 4 turns of daylight, the sun transferring energy to the Earth, and 4 turns of nighttime, no transfer of energy from the sun.

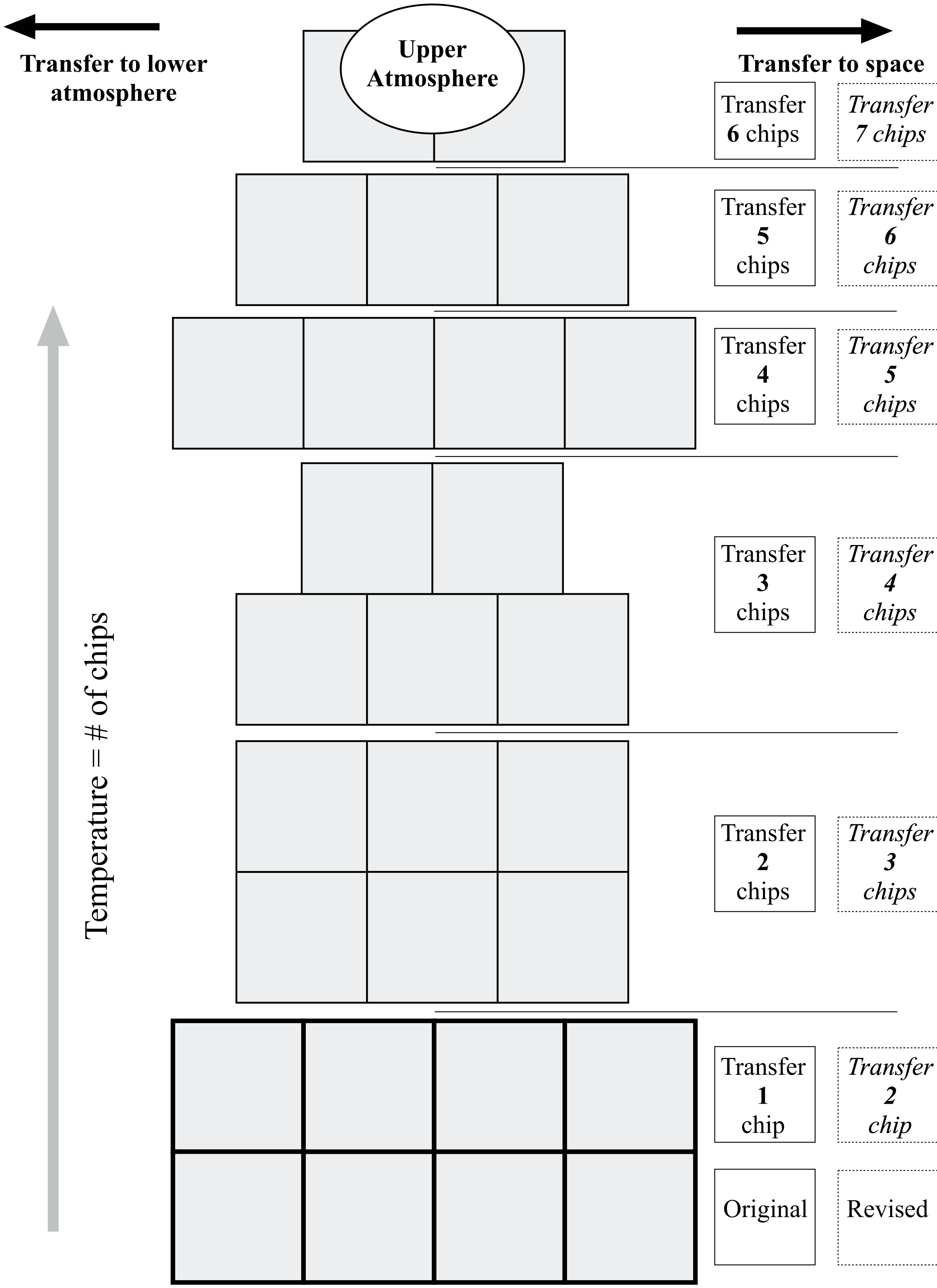
Then take 4 turns of daylight and 4 turns of nighttime with the revised amount of CO_2 in the atmosphere.



Earth
Transfer to lower atmosphere
Transfer 7 chips
Transfer 6 chips
Transfer 5 chips
Transfer 4 chips
Transfer 3 chips
Transfer 2 chips
Temperature = # of chips



Transfer to earth
Lower Atmosphere
Transfer to upper atmosphere
Transfer 6 chips
Transfer 7 chips
Transfer 5 chips
Transfer 6 chips
Transfer 4 chips
Transfer 5 chips
Transfer 3 chips
Transfer 4 chips
Transfer 2 chips
Transfer 3 chips
Transfer 1 chip
Transfer 2 chip
Original
Revised
Temperature = # of chips



Transfer to lower atmosphere
Upper Atmosphere
Transfer to space
Transfer 6 chips
Transfer 7 chips
Transfer 5 chips
Transfer 6 chips
Transfer 4 chips
Transfer 5 chips
Transfer 3 chips
Transfer 4 chips
Transfer 2 chips
Transfer 3 chips
Transfer 1 chip
Transfer 2 chip
Original
Revised
Temperature = # of chips

Efficiency & Conservation

Increased efficiency of cars

GOAL

All cars in the world by must have a minimum fuel efficiency of 60 miles per gallon.

COSTS

This will require much more efficient engines and lighter weight vehicles.

Efficiency & Conservation

Reducing miles traveled by cars

GOAL

Reduce the yearly number of miles traveled of every car in the world by half.

COSTS

This will require better urban planning, increased use of telecommunication, and more use of mass transit.

Efficiency & Conservation

Increased efficiency of buildings

GOAL

Increase (by 25%) efficiency of the space heating and cooling, water heating, lighting, and electric appliances in all new and existing residential and commercial buildings.

COSTS

This will require a dramatic increase in the efficiency of the buildings through insulation and other conservation measures.

Efficiency & Conservation

Increased efficiency of electricity production

GOAL

Double the efficiency of every coal plant in the world. (Coal is singled out because it is used to produce more electricity than any other fuel, and it releases more carbon per unit of energy.)

COSTS

A doubling of efficiency will require dramatic changes to the way coal is used to generate electricity.

Fossil Fuel Based

Fuel switching

GOAL

Retrofit 1400 coal-fired power plants to run on natural gas.

COSTS

This uses existing technology. Combined-cycle gas power plants produce much more energy per kilogram of carbon than coal plants. Nonetheless, this would be a major effort, and would increase costs.

Fossil Fuel Based

Carbon capture & storage (CCS)

GOAL

Capture all of the emissions of 800 coal or 1600 natural gas power plants and store the carbon dioxide underground.

COSTS

This is a technology that is still being developed. There are 3 pilot plants in the world. The technology would need to be scaled up and implemented very widely.

Fossil Fuel Based

Coal synfuels with CCS

GOAL

Produce liquid fuels for transport from coal, and capture the carbon dioxide released in the process. 180 plants would be needed.

COSTS

This is a technology that is still being developed. New technologies will need to be developed, scaled up, and implemented.

Fossil Fuel Based

Fossil-based hydrogen fuel with CCS

GOAL

Produce hydrogen fuel from fossil fuels, and capture and store all carbon dioxide. Currently, hydrogen is generally produced from natural gas. The scale of this production will need to increase by a factor of 10, and all carbon will need to be captured.

COSTS

We can produce hydrogen, but we need to develop reliable ways to transport it and safely use it to fuel cars.

Nuclear Energy

Nuclear electricity

GOAL

Triple the world production of nuclear energy.

COSTS

This is a proven technology, but it has risks associated with waste storage and the possibility of the diversion of fuel or waste to weapons production.

Renewable Energy & Biostorage

Solar electricity

GOAL

Increase worldwide solar electric power capacity by a factor of 700 and displace a corresponding amount of coal-fired power plants.

COSTS

The area required for the solar cells would be approximately the size of New Jersey. Solar cells are cheap to operate, but they require huge up-front costs.

Renewable Energy & Biostorage

Wind-generated hydrogen fuel for cars

GOAL

Install 4 millions windmills to produce hydrogen from water and use it to power vehicles.

COSTS

The area required for the windmills would be approximately the size of France. This would require changes to cars, fueling systems, and the development of new networks for distributing hydrogen fuel.

Renewable Energy & Biostorage

Biofuels

GOAL

Increase the worldwide production of ethanol for vehicles by a factor of 30.

COSTS

The cropland required would be approximately the size of India. This would have dramatic effects on world food production.

Renewable Energy & Biostorage

Forest storage

GOAL

Halt all reduction in forest cover worldwide.

COSTS

The countries where deforestation is taking place would need to be compensated.

Renewable Energy & Biostorage

Soil storage

GOAL

All cropland in the world would be managed to reduce carbon production.

COSTS

This would be quite difficult to implement.

Renewable Energy & Biostorage

Wind-generated electricity

GOAL

Increase worldwide wind power capacity by a factor of 30 and displace a corresponding amount of coal-fired power plants.

COSTS

The area required for the windmills would be approximately the size of Germany. Wind turbines are cheap to operate, but they require huge up-front costs.

Reducing Your Carbon Footprint

Each year, every person in the United States adds about 40,000 pounds of carbon dioxide to the atmosphere.

Suppose you wish to reduce your carbon footprint by 10%—you need to make changes to eliminate 4,000 pounds of carbon dioxide.

What changes do you make?

The following activities or products each contribute about 1 pound of carbon dioxide to the atmosphere. So, think: What changes would you make?

One pound of carbon dioxide corresponds to:

Electricity: One pound of carbon dioxide corresponds to approximately 1 kW-hr of electricity, enough for:

- 100 hours of laptop use (low power MacBook air)
- 10 hours of TV use (HDTV)
- 15 minutes of electric clothes dryer use

Travel: One pound of carbon dioxide will get you:

- 1 mile on an airplane
- 2 miles in a car

Heating and cooling: One pound of carbon dioxide buys you:

- 15 minutes of air conditioning
- 6 minutes of heating with a gas forced air furnace
- 2 minutes of a hot shower

Food and beverages: It takes one pound of carbon dioxide to produce and deliver to you:

- 1/2 oz. of beef
- 1 pound of dry beans
- 1 pint of milk
- 1 bottle of Fat Tire

Consumer goods: Producing and delivering clothing and other goods costs energy, which means carbon in the atmosphere. One pound of carbon dioxide gets you:

- 1/100 of a pair of boots
- 1/50 of a lightweight jacket or shirt
- 1/25 of a pair of flip-flops

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Food and beverages: It takes one pound of carbon dioxide to produce and deliver to you:

- 1/2 oz. of beef
- 1 pound of dry beans
- 1 pint of milk
- 100 local apples or 10 domestic apples or 1 imported apple

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- 1/100 of a pair of boots
- 1/50 of a lightweight jacket or shirt
- 1/25 of a pair of flip-flops