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12.003 Atmosphere, Ocean and Climate Dynamics
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Assignment I

The Earth's Radiation Budget

1. I. Introduction

The global energy balance is important for Earth's climate. When visible radiation from the Sun reaches the Earth, some of it is reflected or scattered directly back into space as shortwave radiation (the percent reflected is known as albedo) and some of it is absorbed. In the absence of clouds, absorption happens mainly at the surface. The absorbed energy warms the Earth's surface, which, in turn, emits this energy at a longer wavelength (infrared rather than visible light).

The purpose of this assignment is to get you thinking about the Earth's radiation budget and the sorts of phenomena which may influence that budget. The description of the datasets is taken from a class taught by Schlosser, Pfirman and Ting at Columbia University.

A. How the data were collected

The Earth Radiation Budget Experiment (ERBE) was designed to collect information about sunlight reaching the Earth, sunlight reflected by the Earth, and heat released by the Earth into space. Since October 1984, ERBE employed three satellites to carry the instruments which collected this information: ERBS, NOAA-9, and NOAA-10. Each satellite was equipped with special instruments (scanners) that measured radiation along the satellite track and from space. Radiation is measured in three wavelength bands:

- * Total: radiation in the 0.2 to 50 micron wavelength band.
- * Longwave: radiation in the 5 to 50 micron wavelength band.
- * Shortwave: radiation in the 0.2 to 5 micron wavelength band.

Technical information about the scanners and other information about the experiment can be found in the following NASA web sites.

1. The Earth Radiation Budget Experiment website.
2. The NASA Educational Resources website - the Trading Card page (click on radiation budget).
3. JPL Quick-Look at ERBS website.

4. [A NASA Fact Online ERBE page](#).

B. The structure of the ERBE dataset, and how to access it

The ERBE data available from the [IRI/LDEO Climate Data Library](#) contains information from all three ERB satellites and their combinations (for the period when the satellite provided overlapping observations). The data are organized by satellite, and by variable.

Open the [ERBE dataset](#). (Note that you just opened a new browser window. Please move that browser aside so you can continue to access it later).

As indicated above, the ERBE data include shortwave (solar) radiation reflected by the Earth's surface and longwave radiation emitted by the Earth. These data are processed by month for the duration of the satellite flight, and are provided on a grid of latitude and longitude lines. On this grid, longitude varies from 1.25°E to 1.25°W by intervals of 2.5°, and latitude varies from 88.75°N to 88.75°S by intervals of 2.5°. Thus, there are 144 grid points on each latitude and 72 latitudes overall. You can read the information on the time and space grids when you click on a satellite name in the viewer. For example, in the ERBE dataset page you opened earlier, click on the link **Climatology**. This is a time averaged set created by using data from the NOAA 9 and NOAA 10 satellites. Each calendar month was averaged for four full years of available data (February 1985 to January 1989).

The **Climatology** dataset is divided again into three data types (as are all other ERBE datasets as well):

- * **clear-sky**: Satellite measured radiation averaged only from satellite views that were free of clouds.
- * **cloud-forcing**: The difference between clear-sky and cloudy-sky radiation, showing how radiation at the top of the atmosphere differs in the presence or absence of clouds.
- * **total**: Satellite measured radiation averaged over an entire month regardless of sky cloud coverage.

For each of these data types, the "data tree" branches off further, as you can see by clicking on their links. For example, on the NASA ERBE Climatology page, click on **clear-sky**. Now you can see the different variables measured by the satellites, and provided by NASA in the ERBE dataset:

- * **albedo**: The ratio between the shortwave radiation reflected from Earth and what is coming in from space (this is a unit-less number expressed in percent).
- * **longwave radiation**: The longwave radiative flux emitted from Earth (in W/m^2).
- * **shortwave radiation**: The shortwave radiative flux reflected from Earth (in W/m^2).
- * **net radiation**: The difference between the shortwave radiative flux absorbed by the Earth climate system and the longwave radiation emitted into space (in W/m^2).

Also on this page (titled NASA ERBE Climatology clear-sky), under the section Grids, you can find the Latitude and Longitude grid information described above. Note that the Time grid

for this dataset is the period of overlap between the two satellites, NOAA 9 and NOAA 10.

More information about the ERBE dataset can be accessed by clicking on the "NASA ERBE documentation" link in the blue IRI box in the upper left corner of the browser window.

Click on **albedo**. Notice that the page no longer contains dataset links. You are now ready to access the actual albedo data month by month and to view them using the different buttons on the page.

The same set of variables is given in the **total** dataset. The variable list under **cloud-forcing** is somewhat different, but we will not use it.

Click on the **Views** link to access the **NASA ERBE Climatology clear-sky albedo** data.

2. II. Assignment

A. Clear-Sky Albedo

The instructions below assume you arrived at the radiation budget data web site following the instructions above.

Go to the open viewer window displaying the **NASA ERBE Climatology clear-sky albedo** data. Clear sky albedo is the light reflected back only from cloudless areas of the Earth's surface (this is calculated by ERBE scientists by identifying cloud-free regions during each satellite's observations and averaging their data separately). If the maps you are examining of clear sky albedo have white patches, these patches are areas so often covered by clouds that we do not have enough cloud-free observations to create a reliable average.

All ERBE data run through the calendar months from January to December so that annual variations in the measured variable can be appreciated. Use the drop-down menus and change "draw..." to "draw coasts", and "colors" to "colors | contours". Set the range of the albedo from 0 to 90. Click the redraw button (the circle arrow) and then click on "plot".

Task 1: Study the albedo data by concentrating on the months of January, March, July and September. Save images for each month with your browser.

1. Identify the latitudinal and longitudinal boundaries of those parts of the Earth's surface that are highly reflective and identify those that are not (implying they are strongly absorbing the solar radiation).

2. Describe how and why the albedo varies seasonally by comparing data for the four key calendar months. (Maximum two paragraphs)

3. Explain why there are variations of reflectivity from high to low latitudes and within continents such as Africa and North America. (Maximum one paragraph)

B. Short Wavelength Solar Radiation Reflected from the Earth

Reflected short wavelength radiation (SW) is a direct measurement of short wavelength radiative flux reflected from the Earth's surface and is expressed in watts per meter squared. Unlike albedo, this is an absolute measurement and not a ratio. Remember that:

$$\text{albedo} = (\text{reflected solar radiation}) / (\text{incoming solar radiation})$$

Thus, the albedo can be high where the actual reflected radiation is low. To appreciate the difference, compare the fields of Climatology clear-sky shortwave radiation for January with the albedo data for the same month that you have been studying earlier.

Task 2: As before, outline the continents, set colored contours, and set the short wavelength range from 0 to 400. Save images for January, March, July and September with your browser. Look at shortwave radiation and albedo over Antarctica and northern Europe, Asia and North America. These locations have high albedos but the clear-sky short wave radiation values there are very different. Why is this? (Maximum one paragraph)

C. Clear-Sky Long Wavelength Radiation

This last data set is for the radiation that the Earth emits in response to being warmed by the Sun. Since the Earth is much colder than the sun, its radiation to space peaks in the infrared (long wavelength) band of the electromagnetic spectrum. Because some components of Earth's atmosphere trap longwave radiation (the greenhouse effect), emission to space occurs not at Earth's surface, but at a higher level in the atmosphere which varies depending on the concentration of greenhouse gases (mainly water vapor) at that location.

Geographic variations in this data set are a result of differences in the effective temperature (the temperature at which the planet is emitting radiation to space) at various locations. Effective temperature depends both on the temperature at the surface, and on the concentrations and vertical profiles of greenhouse gases.

Task 3: Go to the **NASA ERBE Climatology** data page again and select the clear-sky longwave radiation data. Remember to "draw coasts", select "colors | contours," and click "Redraw." Study the data for January, March, July and September.

1. Write down the areas of each hemisphere that emit the least and most longwave radiation.
2. Use the Stefan Boltzmann relationship ($I = \sigma T^4$ where $\sigma = 5.67 \cdot 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$) to convert the minimum and maximum radiation values (for the northern and southern hemispheres in January and July) to temperatures first in Kelvin, then in Celsius ($^{\circ}\text{C} = \text{K} - 273.15$).
3. Describe the outstanding changes that occur as you move through the year.
(Maximum one

paragraph)

D. Emission Temperature of the Earth

Open a new browser window with the total longwave radiation dataset. We will now calculate the globally averaged amount of longwave radiation in the clear-sky case. To do that, click on the "expert mode" link in the upper right corner of the window. We will first average all the data over time to look at the annual average. In the expert mode window type the following line of text below the text which is already present in the window:

[T] average

Now click the "OK" button to the right of the expert window. This tells the software to average the data over all time slices. Each point in space is averaged separately. View this field to look at the annual average total longwave radiation. Now return to expert mode and continue typing underneath the first line you entered:

Y cosd mul

This multiplies every grid point in space by the cosine of the latitude angle (Y is the latitude angle in degrees, and cosd is a calculation of cosine when the angle is given in degrees). We need to do that so that our grid points will be properly weighted with respect to the geographical areas they represent as there are more grid points per unit area in the high latitudes than in the tropics. Then type:

[X Y] average

Click the "OK" button again. The viewer will return a single number just below the expert window (in bold letters). That number is the amount of longwave radiation averaged over the entire globe in W/m^2 .

Task 4: You can use the yearly average map of longwave radiation and the yearly and space average value of longwave radiation to compute the Earth's emission temperature.

1. Use the Stefan-Boltzmann equation to calculate the emission temperature averaged over the globe.
1. Use the Stefan-Boltzmann equation to calculate the

emission
temperature at
one of the areas
of maximum
longwave
radiation.