GEOG2016

Introduction to Greenhouse
Global Carbon Analysis Exercise

Instructions

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CRC for Greenhouse Accounting

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A. Introduction

This global carbon analysis exercise runs over three weeks in the G1 computer lab. The exercise is conducted in this lab because of the need to access the GIS software.

The aims of this exercise are to:

1. Illustrate how climate influences net primary productivity and carbon accumulation in ecosystems;
2. Examine how human land use activity affects ecosystem carbon stocks; and
3. Generate data and information that will form the basis of the practical assignment, which is detailed in Appendix 1.

The analyses that follow are to be undertaken over a three-week period (i.e. the practical sessions for weeks 5, 6 and 7 of the semester). The exercise is designed to be self-guided. Thus, students can proceed through the exercise at their own pace. Expert tutors will be available to answer questions and assist with any difficulties.

The analyses will be undertaken using the ESRI ArcView GIS Software. The exercises assume no previous GIS experience.

Appendix 2 provides an introduction to GIS for students who have no prior experience with GIS. It explains the basic operations you will need to perform to undertake the GIS exercise. If you have previously studied any GIS units, you can probably skip reading it. However, GIS-literate students may still find the appendix a useful “re-fresher” of some basic concepts.
**B. Getting Started in G1**

NB: For the purposes of these instructions:
SLMC = single left mouse click
DLMC = double left mouse click
SRMC = single right mouse click
DRMC = double right mouse click

First, you need to load into your folders the data sets you will be analysing.

On the Desktop screen, DLMC on “My Computer”; then DLMC on F:, go to geog – geog2016, then DLMC on FileSetupIII; this will automatically copy across the required data into H:\geog2016; when the program is finished, go to “My Computer” again, and DLMC H:\geog2016 to see your data folders and files.

On the Desktop screen, DLMC on “My Computer”; then DLMC on H: - geog2016; go File – New folder; name this folder “projects”; this is the folder where you will store the projects you create in ArcView. An ArcView project is a set of related files.

**C. GIS tasks**

This section provides an overview of the main GIS tasks involved in the global carbon exercise. All the data files you need have been provided as ArcView themes.

**Task 1. Estimate global Net Primary Productivity**

Previous research has revealed there is a strong empirical relationship between net primary productivity (NPP) and climate. Recall that Net Primary Productivity is the rate at which plants and microorganisms manufacture biomass (and remember, approximately half of all biomass is carbon). The units of NPP that you will use are grams of carbon manufactured, per 1m x 1m area of land, per year (i.e. gC m$^2$ yr$^{-1}$).

There is a published mathematical expression that describes the relationship between temperature and NPP and rainfall and NPP. In this exercise you will use the map calculator function within ArcView to calculate global NPP using two mathematical expression that quantifies these relationships. The result will be a global surface of NPP values.
We are using relationships between climate and NPP developed by Helmut Lieth (Lieth 1975).

Lieth’s NPP models are illustrated in Figures 1 and 2. The circles represent real world observations of NPP and climate. The equations in each figure describe the curve of best fit through these data. In Figure 1, NPP is shown as a function of annual precipitation. In Figure 2, NPP is shown as a function of annual mean temperature.

The equation from Figure 1 to calculate temperature-limited NPP is:

\[
NPP_t = \left(\frac{3000}{1 + e^{1.315 - 0.119 \times AMT}}\right) \times 0.5 \quad \text{equation (1)}
\]

where \( NPP_t \) is temperature-limited NPP, AMT is annual mean temperature in degrees Celsius, and 0.5 converts biomass to carbon. Units are gC m\(^2\) yr\(^{-1}\).

The equation from Figure 2 to calculate precipitation-limited NPP is:

\[
NPP_p = \left(3000 \times (1 - e^{-0.000664 \times P})\right) \times 0.5 \quad \text{equation (2)}
\]

where \( NPP_p \) is precipitation limited NPP, \( P \) is annual precipitation, and 0.5 converts biomass to carbon. Units are gC m\(^2\) yr\(^{-1}\).

In the ArcView GIS we have provided two data files that contain estimates on a 0.5\(^\circ\) resolution grid of annual precipitation and annual mean temperature. By using the map calculator function, you can apply equations 1 and 2 (given above) to these two data files, thereby generating gridded estimates of NPP as a function of temperature, and NPP as a function of precipitation.

Then, applying Leibig’s “law of the minimum” (see http://www.microsoil.com/liebigs_law_of_the_minimum.htm), it is possible to calculate for each grid cell, the lower of these two values. The resulting grid is the best estimate of NPP.
Figure 1. Precipitation-limited NPP relationship from Lieth (1975). \( n = 52 \).

Figure 2. Temperature limited NPP relationship from Lieth (1975). \( n = 52 \).

Now you are ready to run the GIS software system called ArcView 3.2.

NB: the Geographical Information System you are using for this exercise is called “ArcView 3.2”. In ArcView terminology, a “theme” refers to a spatial data set. In these instructions we sometime also refer to themes as grids.
in the Start menu at the bottom left of the computer screen, open Arcview 3.2

a dialogue box will appear – click Cancel

go to the top left hand menu; File – Extensions; click the button next to Spatial Analyst; make this your default

now go File – New Project; a Project control box will appear; click View and then New; a View box will appear; this is where you can store and view spatial data sets

now go File – Set Working_Directory; enter “H:\geog2016\projects”; this is the folder where all your data will be stored

now go File – Save Project; enter a file name in your projects folder; e.g. “H:\geog2016\projects\proj1”

From now on when you open Arcview 3.2, you will “open an existing project”; and then open “proj1” (or whatever you call your project file) in “H:\geog2016\projects”.

You now can import the data files.

go View – Add theme; make sure Data source type is grid data source; then, go to the H:\geog2016 folder, and DLMC on the file called “annualprecip”; a legend for this new data file will appear in the top of the View box. Click the small square button at the top left of the legend to display the file. Repeat this sequence and import the file called “annualtemp”.

The units for “annualprecip” are mm, and the units for “annualtemp” are degrees Celsius.

You are now ready to undertake your first analysis: calculating global estimates of NPP.

Go Analysis – Map Calculator; a “dialogue box” will appear; cut and paste the following into the blank space in the dialogue box;

(3000.AsGrid / (1.AsGrid + (1.315.AsGrid - (0.119.AsGrid * [annualtemp])).Exp)) * 0.5

NB: this is the same equation discussed above in Figure 1.

click the Evaluate button.
A new grid will be produced and automatically appear in your View. This is a grid of predicted global temperature limited NPP.

*click* on the legend button to highlight this new theme

*go Theme – properties;* and rename the theme something like “temp_limited_NPP”; *click OK*

Repeat the above process for the following equation:

\[(3000.\text{AsGrid} \times (1.\text{AsGrid} - (-0.000664.\text{AsGrid}*[\text{annualprecip}].\text{Exp})) \times 0.5.\text{AsGrid}\]

**NB:** This is the same equation discussed above in Figure 2.

This will produce a grid of predicted global precipitation-limited NPP. Rename this file “precip_limited_NPP”

*The next step is to find, for each grid cell, the lowest value of NPP*

in the View box, holding down the “shift” key, SLMC the legend for “temp_limited_NPP” and then “precip_limited_NPP”

*go Analysis – Cell statistics – Minimum - ok*

A new theme will be produced and the legend will appear on your View box; *click the legend button to display the new theme.*

Click on the legend to the new grid to make sure it is “highlighted”, then *go Theme – Properties;* rename the new theme “NPP”.

*Evaluating NPP by country and biome*

Now that you have generated a global grid of NPP, it is possible to intersect this theme with additional global data. Specifically, we want you to intersect your grid of NPP with (i) a data set of all countries and (ii) a data set of the world’s biomes (i.e. major terrestrial ecosystems).

*You first need to import these two additional data files.* Follow the same sequence of instructions noted above for importing the “annualprecip” and “annualtemp” files. The two new files you need to import are called:

*“countries”* (note that the grid cells for each country are assigned a unique numeric label, e.g. Australia = 10); and

*“biomes”* (where the grid cells for each biome are assigned a unique numeric label)
The country and biome names associated with the numeric labels are given in Appendix 3. Note that it is convenient to replace these numeric codes with the actual names in the theme legends and in the summary tables (rather than having to continually refer back to the numeric codes to work out which number refers to what country). The instructions for doing this are given in Appendix 3.

**Now, you can creating “intersection” tables.**
The next step is to create two tables that summarises the NPP values for each country and each biome.

nb: these *Tables* will be listed in your *Projects* control box, along with your *Views*.

in the *View* box, SLMC the “countries” theme; then go *Analysis – Summarize Zones*; select the global NPP theme you have created; the result will be a new table of values summarising NPP for all countries; the table should appear on the screen; each column represents a different statistic; at the top of the table are various function buttons, SLMC the column for *mean* and then SLMC the button for “descending”; this will re-order the countries by their mean NPP value.

Repeat the above instructions and create table that intersects the “biomes” theme with your global NPP grid.

You will be using the information in these intersection tables in your Assignment. You can also save each table as a text file (*.txt) or a database file (*.dbf). This is useful because either of these formats can be loaded into e.g. Microsoft Excel for further analysis, generating graphs, etc. To export a table, first make sure it is open, and then go *File – Export* and select either *delimited text* or *Dbase*. Either of these formats can be loaded straight into Excel. Save the file to *H:\geog2016\projects*.

To enter the exported table file (in text format) into Excel go:

Note that Excel files can be saved on diskette on the “a:" drive.
Task 2. Calculating CCC and CCS

Carbon Carrying Capacity (CCC) is the total organic carbon stocks of an ecosystem when it has reached equilibrium with the prevailing climatic conditions. A system is in equilibrium when the sum of all forces acting on the system is zero.

While NPP results in biomass being accumulated (and carbon being sequestered from the atmosphere), decomposition results in biomass being decayed and carbon released back into the atmosphere. The difference between NPP and decomposition is the carbon stock stored in a landscape ecosystem. CCC can be most easily thought of as the carbon stocks when the ecosystem has reached maturity.

Carbon Stock Deficit (CSD) is the difference between the current stocks of organic carbon (CCS) and the carbon carrying capacity (CCC). This deficit reflects the impact of human activity through land clearing and deforestation.

CCC is not easily calculated. We have produced grids (themes) of CCC based on simulation models and existing data (Goldewijk et al. 1994, Batjes 1996).

As discussed in the lectures, it is critical to keep in mind that organic carbon is stored in and fluxes between various pools in a terrestrial ecosystem. The two main pools are (i) above ground biomass (including living and dead plant material) and (ii) below ground carbon (soil organic carbon and carbon in plant roots). We have provided two data files of global above ground and below ground carbon. These files are called:

- “abovegc”
- “belowgc”

Import them into ArcView as per the instructions above for the other files.

“abovegc” and “belowgc” are in units of Giga tonnes (i.e. 1 x 10^9). However, for you analyses it will be more convenient if they are in units of Mega tonnes (i.e. 1 x 10^6). This can be achieved by multiplying each data grid by 1000.
go Analysis - Map Calculator; DLMC on "abovegc", then the multiply symbol (*), then 1000, then Evaluate. Rename the new theme "abovegc_M". Repeat this calculation for "belowgc", renaming the new file "belowgc_M"

**Relationship between NPP and carbon stocks**

CCC is intimately related to NPP. Recall that NPP is a rate – the rate at which carbon in a mature ecosystem is sequestered from the atmosphere by plants (and photosynthesising microorganisms such as bacteria) and stored as biomass. CCC is the amount of organic carbon stored in an ecosystem at equilibrium. Figure 3 shows an empirical relationship between global NPP and CCC for the world’s major biomes. This suggests that places that have higher rates of NPP will tend to have larger CCC (i.e. larger carbon stocks at equilibrium). However, note that Figure 3 does not include values for soil carbon.

![Figure 3. Average NPP and biomass across major biomes](image-url)
Combining carbon grids to produce a grid of CCC

The next step is to generate a theme that equates with the global Carbon Carrying Capacity, i.e. the sum of total above- and below-ground carbon at equilibrium (maturity).

go Analysis – Map calculator; DLMC the “abovegc_M” theme, the SLMC the “+” (i.e. addition) button, then DLMC the “belowgc_M” theme, then Evaluate.

The new grid produced will be show global total carbon (call this file “totalc”).

Produce intersection tables

Now, following the instructions above, produce three tables, intersecting the “countries” theme:

1. “totalc” (total carbon);
2. “abovegc_M” (above ground carbon); and
3. “belowgc_M” (below ground carbon).

For each table, rank the countries by their SUM carbon values.

Now, you are ready to calculate the Current Carbon Stock (CCS)

The Current Carbon Stock (CCS) represents the carbon that currently exists in the world’s ecosystems, i.e. it is the Carbon Carrying Capacity minus the carbon lost primarily as the result of deforestation for agriculture. This difference between the carbon carrying capacity and the current carbon stock is what we call the Carbon Stock Deficit (CSD), and will be calculated in the next section.

We have produced from published data (Loh et al. 1998, Olson et al. 1983) a theme that maps the areas of land that have been cleared of their natural ecosystems by human activity. Most of this land has been cleared for agriculture (Figure 4). By combining the themes of carbon carrying capacity (total, above ground, below ground) with this new theme of cleared land, it is possible to calculate global CCS.
Following land clearing, the proportion of carbon that is rapidly lost back to the atmosphere differs between above and below ground carbon. The figures are actually highly variable and uncertain. For this exercise we assume that 10% of all below-ground carbon is lost from below-ground following clearing and 70% above ground. These estimates are conservative, in the sense that actual losses are likely to have been higher. You need to import the following two data files:

- “abovegclear”
- “belowgclear”

Import these files into ArcView (you should know how to do this by now!), and display the files in your View. The “abovegclear” theme has values of 1.0 for non-cleared land, and 0.3 for cleared land (reflecting the 70% loss of carbon following clearing). Similarly, the “belowgclear” theme has values of 1.0 for non-cleared land, and 0.9 for cleared land (reflecting the 10% loss of carbon following clearing).

Now, Current Carbon Stocks (CCS) can be calculated by multiplying the grids of “abovgc_M” and “belowgc_M by the equivalent cleared land files;

go Analysis – Map Calculator

and perform multiplication on the grids thus:
“abovegc_M * abovegclear”, and then

“belowgc_M * belowgclear”

Call these new grids “aboveCCS” and “belowCCS” To obtain an estimate of total CCS, add these two grids together using the Map Calculator, calling the output “totalCCS”.

Using the Analysis – Summarize zone function (as per instructions above), calculate three tables showing for each country the above ground carbon CCS, the below ground carbon CCS, and the total CCS.
Task 3. Calculating the Carbon Stock Deficit (CSD)

CSD is the Carbon Stock Deficit. It is the difference between how much organic carbon an ecosystem can potentially store at climatic equilibrium, and how much it currently stores given land use history. Conversely, the CSD can be interpreted as the amount of carbon that could be sequestered from the atmosphere into biomass and soil if cleared land was allowed to naturally regenerate back to the original ecosystems.

The Carbon Stock Deficit (CSD) is the difference between Carbon Carrying Capacity (CCC) and Current Carbon Stocks (CCS), i.e. in general terms:

\[ \text{CSD} = \text{CCC} - \text{CCS} \]

Now, calculate CSD using the *Map Calculator*.

Note that you can calculate:

1. “total_CSD” = “totalc – totalCCS”
2. “aboveground_CSD” = “abovegc_M – aboveCCS”
3. “belowground_CSD” = “belowgc_M – belowCCS”

Using *Analysis – Summarize zone*, create tables showing these CSD for all countries.
**Task 4. Analysing Fossil Carbon emissions**

We have generated from published data gridded estimates of carbon emitted from fossil fuel use during the period 1945-1995. This data file is called “fossilc”. Add this theme to your project. The sources of these data are detailed in Appendix 4. Also, add the theme called “fossilc1990”. This theme contains grid cells values for fossil carbon emissions in the year 1990. The units for both themes are Mt C.

Using the *Analysis – Summarize Zones* function, create a table for the countries that summarizes their “fossilc” emissions, and rank by their SUM to see who have been the biggest emitters over the last 50 years.

**A potential relationship between CSD and fossil carbon emissions?**

You can undertake further analyses to explore some of the possible interactions between CCC, CSD and fossil carbon emissions. These calculations do not require any GIS based analyses. You simply need the figures you have already calculated in the tables and a calculator (which is found by going *Start – Programs – Accessories – Calculator*).

Let us assume that it takes, on average, 200 years for a landscape that has been cleared to naturally regenerate and recover its CSD (Carbon Stock Deficit) and reach its CCC (i.e. maximum potential Carbon Carrying Capacity). Based on this assumption, it is possible to calculate for a given country the average annual amount of carbon that could be sequestered each year and how this relates to the amount of fossil fuel emitted by that country.

e.g for the US:
- **CCC = 237 000 Mt**;
- **CCS = 199 000 Mt**;
- **CSD = 38 000 Mt**

**Current (1990) emissions = 1305 Mt / yr.**

If the USA were to allow the regeneration (or replanting) of all their forested lands, and if it took 200 years for the forests to reach CCC, than over that period the average accumulation would be 190Mt / year (i.e. 38 000 / 200), which is annually about 16% of their current (1990) annual fossil fuel emissions.
To give another example, let us take the Philippines:

\[
\begin{align*}
\text{CCC} & = 7050 \text{ Mt} \\
\text{CCS} & = 5040 \text{ Mt} \\
\text{CSD} & = 2010 \text{ Mt}
\end{align*}
\]

Current (1990) emissions = 8.18 Mt /yr.

If the Philippines were to allow the regeneration (or replanting) of all their once-forested lands, and if it took 200 years for the forests to approach CCC, than over that period the average accumulation would be 10.1 Mt / year, which is annually about 23% more than their current annual fossil fuel emissions.

Calculate these statistics for your country.

NB: For a given country, not all the land that has been cleared is necessarily now available for regeneration. In many cases, the current land use will have to be closed down before regeneration could occur. For example, if the land has been cleared for agriculture, then that agricultural production would need to now cease before regeneration could occur. Strategies based on cessation of current land use to allow regeneration are likely in many cases to have dramatic social, political and economic consequences.
Appendix 1. Practical Assignment 1. Global Carbon Accounting

Proportion of total course assessment: 15%
Length: 800-900 words + figures, tables etc.
Due date: any time up to 3.00pm Friday 20 September.

Assignment

In the context of the UN Framework Convention on Climate Change and related Protocols, discuss the significance of Carbon Carrying Capacity, Current Carbon Stocks, and Carbon Stock Deficit.

Additional Comments

1. You are not expected to print off and make use of any GIS maps for inclusion in this report. However, you are expected to make use of the tabular data generated in the GIS practical.

2. In your discussion you may wish to consider some of the following questions:
   - For your country, which climatic variable most limits NPP?
   - Does your country have a rich or poor endowment of natural productivity?
   - What are the implications of high/low NPP mean for your country’s agricultural potential?
   - Where in the world do you find the most below ground carbon? Why is this?
   - Where in the world do you find the most above ground carbon? Why is this?
   - Does your country have more above ground or below ground carbon? Why?
   - Is your country relatively endowed with high or low CCC?
   - What is your country’s total carbon stock deficit?
   - Has your country lost more above ground or below ground carbon as the result of land clearing?
   - Does your country’s CSD provide options for making use of proposed Kyoto flexibility mechanisms?

3. You are not limited to data generated in the G1 practical. Thus, you may draw upon additional carbon accounting data from other reputable sources.
Appendix 2. Some basic concepts in GIS

GIS data
In these GIS exercises, the global distributions of environmental parameters are presented as data values on a regular grid with a resolution (or grid spacing) of $0.5^\circ$ of longitude x $0.5^\circ$ of latitude. Thus, Earth’s surface is divided into a regular grid of cells as is crudely illustrated in Figure 1. Note that as one minute of arc equals about 1.85km, it follows that, on average, each grid cell is about $55\text{km}^2$ in area.

![Figure 1. Illustration of how in a GIS, Earth’s surface is delineated by a regular grid of cells as a way of spatially referencing the distribution of environmental parameters.](image)

In the GIS data base developed for this exercise, a separate grid is generated for each environmental parameter (such as temperature or land cover). The spatial distributions of these environmental data are represented by numeric values in each grid cell as illustrated in Figure 2.

![Figure 2. Gridded surface of fossil fuel carbon emissions for an unspecified year. Grid resolution is $0.5^\circ$.](image)
Cleary, with a half degree (30 minutes) grid resolution, each cell in Figure 2 covers a substantial area of Earth’s surface (keep in mind that Goulburn is about 70km from Canberra). Thus, the values for the environmental parameters represent only very average conditions.

Note that in GIS terminology, a regular grid of environmental values is called a “surface” (hence the figure caption for Figure 2) or a “theme”.

**Spatial analysis – map calculator**

The numeric values recorded in each grid cell can be of two basic data types:

1. numbers that indicate a class or category; for example, a forest type such as “tropical forest”; and

2. numbers that indicate a quantitative amount of something; for example, the annual mean temperature in degrees Celsius.

Note also that it is possible in a GIS to classify values that represent quantitative amounts. For example, values of carbon stocks could be grouped into three classes where:

- 1 = large carbon stocks
- 2 = medium carbon stocks
- 3 = low carbon stocks.

It is important to understand the difference between the two data types as they affect the kinds of analyses that can be undertaken in a GIS.

For example, take two surfaces. If the values of both surfaces represent quantitative amounts, then the grid values can be in effect overlaid and mathematical operations performed on the corresponding grid values (see Figure 3).

*Figure 3. In a GIS it is possible to overlay two surfaces and perform mathematical operations on the values in the corresponding grid cells.*

In *ArcView*, mathematical operations can be readily performed on the corresponding values in surfaces by a function called a *Map*
Calculator. This function enables the user to specify the surfaces to be analysed, and then the mathematical operations to be performed on the corresponding grid cells. These operations can range from simple addition, subtraction, multiplication and division, through to complex algorithms such as a regression equation. The result is a new grid (i.e. surface or theme) of values representing the output of the calculation.
## Appendix 3. Country and Biome Codes

### Country codes

<p>| Theme code | Label                        | 45   | 46   | 47   | 48   | 49   | 50            | 51   | 52   | 53   | 54   | 55   | 56   | 57                            | 58   | 59   | 60   | 61   | 62   | 63   | 64   | 65   | 66   | 67   | 68   | 69   | 70   | 71   | 72   | 73   | 74   | 75   | 76   | 77   | 78   | 79   | 80   | 81   | 82   | 83   | 84   | 85   | 86   | 87   | 88   | 89   | 90   | 91   | 92   | 93   | 94   | 95   | 96   | 97   |
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<th>Russia</th>
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Biome codes

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<tr>
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<td>Wetlands</td>
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Linking the above codes to theme legends and summary tables

It is often convenient to be able to click on a theme and have returned to you the country or biome name, rather than the underlying code associated with it. Similarly, it is convenient to have these names attached to the theme legend, so you can see at a glance which colour refers to what country or biome, without having to interpret the codes from the above tables. The instructions for doing this are given below.

You need to first copy from $F:\text{geog}\text{geog2016}$ and paste into $H:\text{geog2016}$ the following four files
- biomes.avl
- Biomes.dbf
- countries.avl
- Countries.dbf

To add labels to the theme legend:
1. Open the legend editor by a DLMC on the themes legend.
2. Press the ‘load’ button, and load in the file ‘Biomes.avl’ or ‘Countries.avl’, depending on the theme you have opened.
3. Press the ‘Apply’ buton.

To link labels with the theme:
1. Select the ‘Tables’ option on the projects main window, and press ‘add’
4. Load in either ‘Biomes.dbf’ or ‘Countries.dbf’, depending on the theme you want to add labels to.
2. Select the theme you wish to add labels to by a SLMC on the legend.
3. Click the button on the main menu to open that themes attribute table.
4. Now position the windows so you can see simultaneously the themes attribute table, and the *.dbf table you opened under step 1.
5. In the *.dbf file select the ‘Attribute’ column by a SLMC on the grey ‘Attribute’ button.
6. In the themes attribute table select the ‘Value’ column in the same way.
7. Now link the two together by pressing the button. A SLMC on the image should now return both the numeric code as well as the label.

To add a column of countries or biomes to a table generated by the ‘Summarize zones’ command, in step 3 above select the summary table of choice rather than the themes attribute table, and proceed as above. The list of countries (or biomes) will be appended in the last column of the table.
Appendix 4. Fossil Carbon Emission Data
http://weather.engin.umich.edu/geia/emits/co2.html#Documentation
GEIA Inventory CO250yr1.1a 07 Mar 95
CO2 1950 annual 10^6 metric tonnes C
Contact: Robert Andres, Institute of Northern Engineering,
University of Alaska Fairbanks, Fairbanks, AK 99775-5900 USA
FAX: 907-474-6087, Phone: 907-474-7856 e-mail: ffrja@aurora.alaska.edu
Values: minimum: 0 maximum: 30.9859 sum: 1587.941 million tonnes C
The format of the data is FORTRAN (2(I3),1x,E10.5,1x).
The data is at best good to 4 significant digits, although more are reported.
This data is for anthropogenic CO2 emissions from fossil fuel consumption.

Abstract. One degree latitude by one degree longitude (1° x 1°)
data sets of carbon dioxide emissions from fossil fuel consumption
and cement manufacture were produced for 1950, 1960, 1970,
1980, and 1990. National estimates of carbon emissions were
combined with 1° x 1° data sets of political units and human
population density to create the new 1° x 1° carbon emissions data
sets. The human population density data set has an effective
resolution of the country/state level. This resolution translates to
the 1° x 1° carbon emissions data set. Latitudinal distribution of
emissions have also been calculated. The data show continual
growth with time over most of the world, with increased growth
rates in major urban areas. A slow southerly shift in the bulk of the
emissions is apparent as Asian countries increase their energy
consumption to support their growing economies and populations.
The digital data sets are available by anonymous ftp.
References


