GEOG2016

Introduction to Greenhouse

Global Carbon Analysis Exercise Instructions

Dr Brendan Mackey (SRES/Science/ANU) and Dr Stephen Roxburgh (RSBS/ANU)
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 a 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 instruction:
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 DLCM 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:

$$NPP_t = (3000 / [1+e^{1.315-0.119*AMT}]) * 0.5 \qquad \textbf{equation (1)}$$

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:

$$NPP_p = (3000 * (1-e^{-0.000664*P})) * 0.5 \qquad \textbf{equation (2)}$$

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 0.5^0 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.

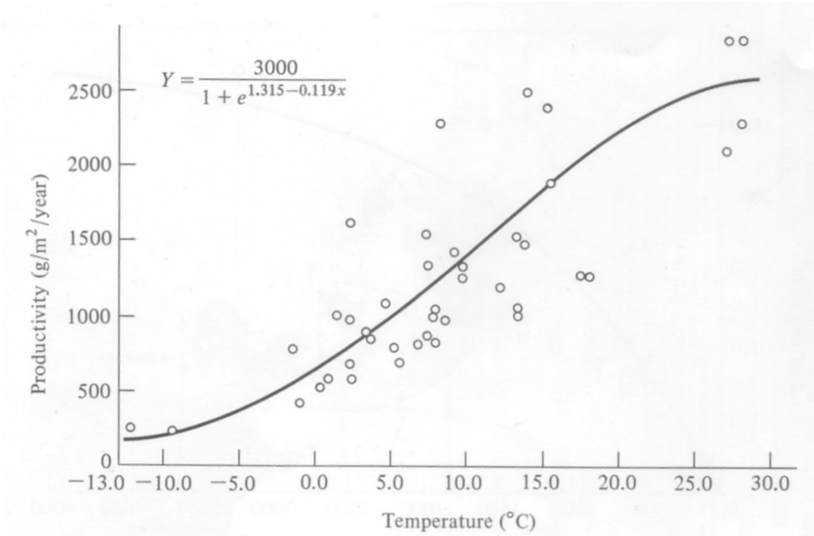

Figure 1. *Precipitation-limited NPP relationship from Lieth (1975). n = 52.*

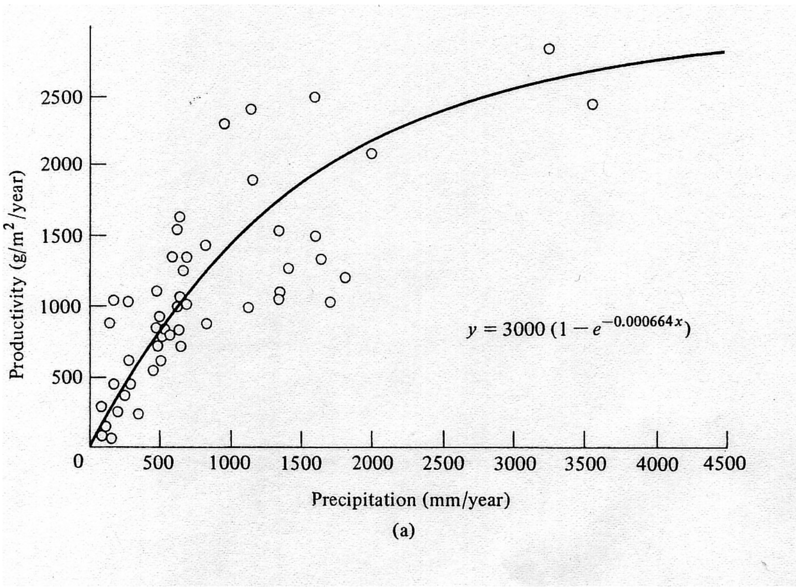

Figure 2. *Temperature limited NPP relationship from Lieth (1975). n = 52.*

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 f*older, 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.AsGrid * (1.AsGrid - (-0.000664.AsGrid*[annualprecip]).Exp)) * 0.5.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 *Anaysis – 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: *Start – Programs - Microsoft Office – Microsoft Excel – ope*n *.txt file – select "*delimited*" – select "*comma*" – open file.

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 cabon 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.

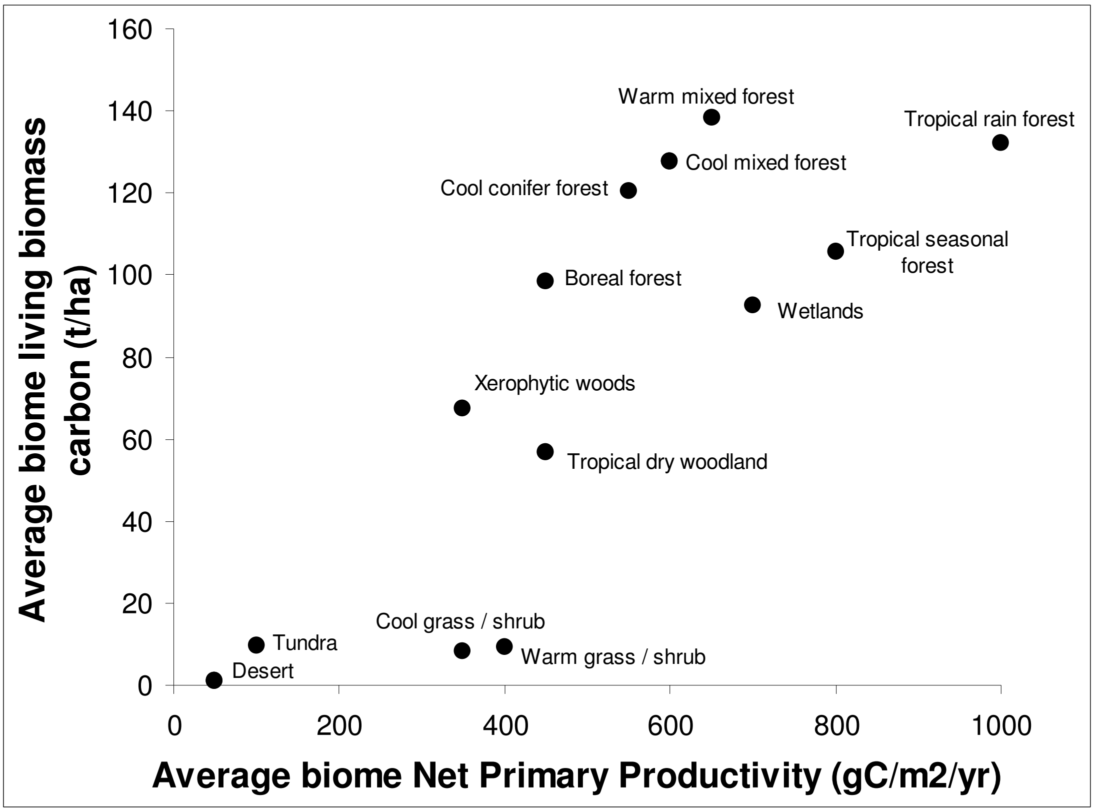

Figure 3. Average NPP and biomass across major biomes

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

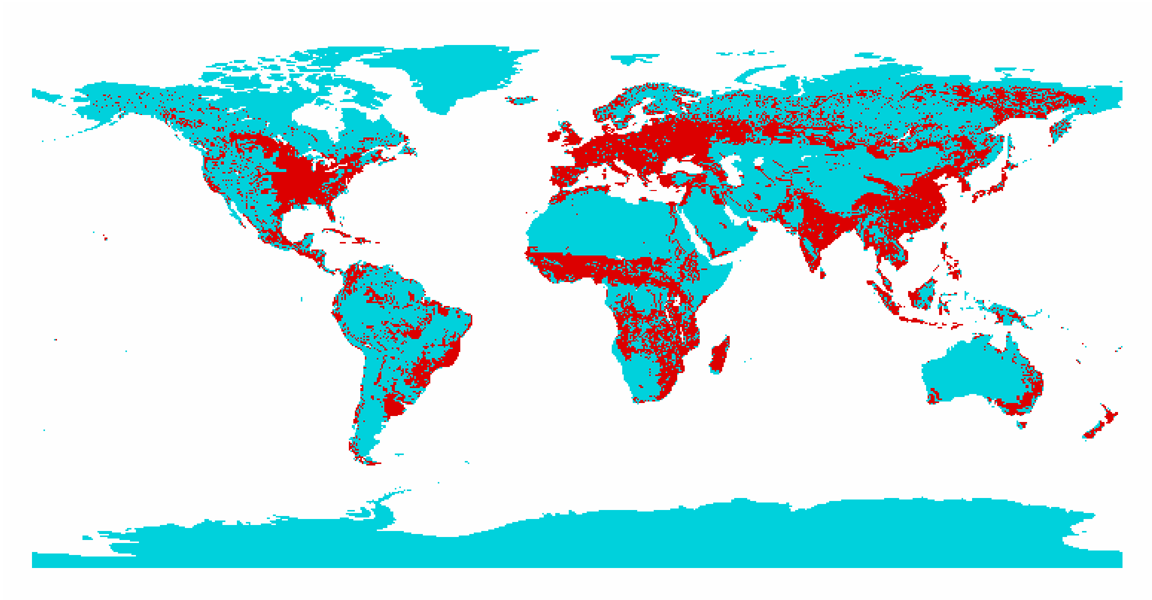

Figure 4. The extent of global land clearing.

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 instructons 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:

CSD = CCC – 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 Phillipes:
CCC = 7 050 Mt
CCS = 5 040 Mt
CSD = 2 010 Mt
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 10.1Mt / 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

<u>Proportion of total course assessment</u>: 15%
<u>Length</u>: 800-900 words + figures, tables etc.
<u>Due date</u>: 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 <u>not</u> 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 you 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 0.5^0 of longitude x 0.5^0 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 $55km^2$ in area.

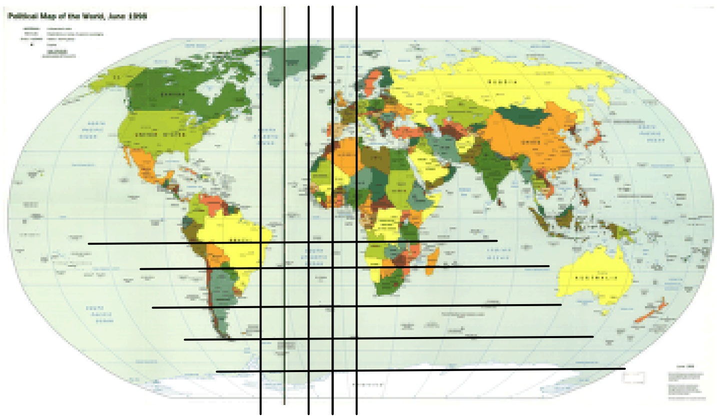

Figure 1. Illustration of how in a GIS, Earth's surface is delineated by a regular grid of cells as a way of spatially referencing the distribution of environmental parameters.

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.

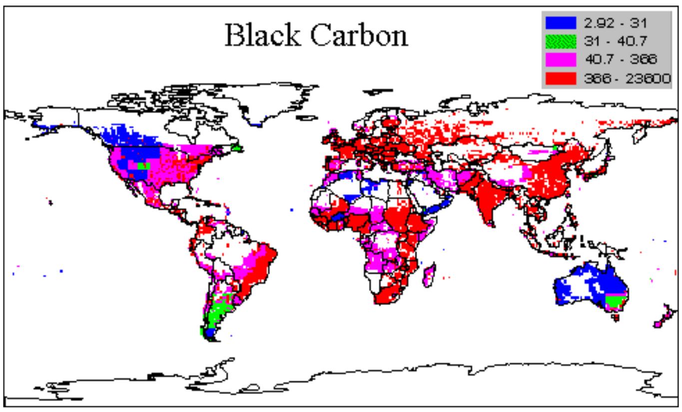

Figure 2. Gridded surface of fossil fuel carbon emissions for an unspecified year. Grid resolution is 0.5^0.

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 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).

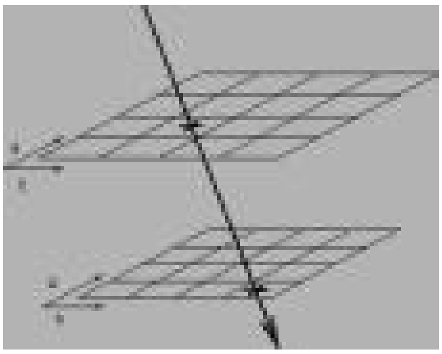

Figure 3. In a GIS it is possible to overlay two surfaces and perform mathematical operations on the values in the corresponding grid cells.

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

Theme code	Label
0	Oceans
1	Afghanistan
2	Albania
3	Algeria
4	Andorra
5	Angola
6	Antarctica
7	Antigua and Barbuda
8	Argentina
9	Armenia
10	Australia
11	Austria
12	Azerbaijan
13	Bahamas
14	Bahrain
15	Bangladesh
16	Barbados
17	Belgium
18	Belize
19	Benin
20	Bermuda
21	Bhutan
22	Bolivia
23	Bosnia-Hercegovina
24	Botswana
25	Brazil
26	Brunei
27	Bulgaria
28	Burkina Faso
29	Burundi
30	Byelorussia
31	Cambodia
32	Cameroon
33	Canada
34	Cape Verde
35	Central African Republic
36	Chad
37	Chile
38	China
39	Columbia
40	Comoros
41	Congo
42	Costa Rica
43	Croatia
44	Cuba
45	Cypress
46	Czechoslovakia
47	Denmark
48	Djibouti
49	Dominica
50	Dominican Republic
51	Ecuador
52	Egypt
53	El Salvador
54	Equatorial Guinea
55	Estonia
56	Ethiopia
57	Falkland Islands (Malvinas)
58	Faroe Islands
59	Fiji
60	Finland
61	France
62	French Guiana
63	French Polynesia
64	Gabon
65	Gambia
66	Gaza Strip
67	Georgia
68	Germany
69	Ghana
70	Greece
71	Greenland
72	Grenada
73	Guadeloupe
74	Guatemala
75	Guinea
76	Guinea-Bissau
77	Guyana
78	Haiti
79	Honduras
80	Hong Kong
81	Hungary
82	Iceland
83	India
84	Indonesia
85	Iran
86	Iraq-Saudi Arabia
87	Ireland
88	Isle of Man
89	Israel
90	Italy
91	Ivory Coast
92	Jamaica
93	Jan Mayen (Island)
94	Japan
95	Jordan
96	Kazakhastan
97	Kenya

98	Kerguelen
99	Kiribati
100	Korea
101	Korea
102	Kuwait
103	Kyrgyzstan
104	Laos
105	Latvia
106	Lebanon
107	Lesotho
108	Liberia
109	Libya
110	Liechenstein
111	Lithuania
112	Luxembourg
113	Macau
114	Madagascar
115	Malawi
116	Malaysia
117	Maldives
118	Mali
119	Malta
120	Martinique
121	Mauritania
122	Mauritius
123	Mexico
124	Moldova
125	Monaco
126	Mongolia
127	Morocco
128	Mozambique
129	Myanmar
130	Namibia
131	Nepal
132	Netherlands
133	New Caledonia
134	New Zealand
135	Nicaragua
136	Niger
137	Nigeria
138	Nothern Mariana Islands
139	Norway
140	Oman
141	Pakistan
142	Panama
143	Papua New Guinea
144	Paraguay
145	Peru
146	Philippines
147	Poland
148	Portugal
149	Puerto Rico
150	Qatar
151	Reunion
152	Romania
153	Russia
154	Rwanda
155	San Marina
156	Sao Tome and Principe
157	Saudi Arabia
158	Senegal
159	Seychelles
160	Sierra Leone
161	Singapore
162	Slovenia
163	Solomon Islands
164	Somalia
165	South Africa
166	Spain
167	Sri Lanka
168	St. Christopher-Nevis
169	St. Lucia
170	St. Vincent and the Grenadines
171	Sudan
172	Surinam
173	Svalbard
174	Swaziland
175	Sweden
176	Switzerland
177	Syria
178	Taiwan
179	Tajikistan
180	Tanzania
181	Thailand
182	Togo
183	Tonga
184	Trinidad and Tobago
185	Tunisia
186	Turkey
187	Turkmenistan
188	Turks and Caicos Islands
189	Uganda
190	Ukraine
191	United Arab Emirates
192	United Kingdom
193	United States
194	Uruguay
195	Uzbekistan
196	Vanuatu
197	Venezuela
198	Vietnam
199	Western Sahara
200	Western Samoa
201	Yemen
202	Yugoslavia
203	Zaire
204	Zambia
205	Zimbabwe
206	Iraq

Biome codes

Theme code	Label
0	Water
1	Agricultural land
2	Ice
3	Cool semidesert
4	Hot desert
5	Tundra
6	Cool Grass Shrub
7	Warm Grass Shrub
8	Xerophytic woods
9	Taiga
10	Cool Conifer Forest
11	Cool Mixed Forest
12	Temperate Deciduous Forest
13	Warm Mixed Forest
14	Tropical Dry Woodland & Savanna
15	Tropical Seasonal Forest
16	Tropical Rain Forest
17	Wetlands

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:\geog\geog2016* and paste into *H:\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 nemeric 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 colum 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 C1
Document: CO2.txt Andres et al. (1995) Global Biogeochemical Cycles (in prep.)
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^{o} x 1^{o}) 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^{o} x 1^{o} data sets of political units and human population density to create the new 1^{o} x 1^{o} 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^{o} x 1^{o} 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.

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