Basic GAPS

A tool for investigating the dynamic and complex systems of the global environment.

GLOBE Program
Soil Characterization Team

Contact Information

Jeff Melkonian
1123 Bradfield Hall
Cornell University
Ithaca, NY 14853
USA
Phone: (607) 227-9172
Fax: (607) 255-2106
Email: jjm11@cornell.edu

Jessica Robin
Code 923
NASA Goddard Space Flight Center
Greenbelt, MD 20771
USA
Phone: (301) 614-6636
Fax: (301)614-6695
Email: jrobin@ltpmail.gsfc.nasa.gov

Table of Contents Page

List of Figures

Basic GAPS Manual, Version 1

1 Welcome for Teachers

Basic GAPS is a computer model for students that can simulate the cycles of water and energy between the atmosphere, soil, and vegetation. Students can easily obtain the required soil, vegetation, phenology, and climate data from sources such as the GLOBE program data archive and input the information through guided menus. Once the model simulation runs, the change in soil water content, evaporation, transpiration and other environmental parameters can be displayed so that students can observe how different parts of the system change and are affected by each other.

A major goal of the Basic GAPS model is to teach students that the Earth's ecosystems are the result of closely linked, dynamic interactions among many processes and many components. Basic GAPS enables students to study the interplay among these processes in a quantitative way. They can examine linkages within a particular biome, such as the sensitivity of soil moisture to seasonal changes in the overlying vegetation or the amount of evaporation and transpiration under certain types of soil or land use. Using Basic GAPS, students can also make up different scenarios (such as increasing the temperature, changing the pattern of precipitation, or modifying the soil properties or vegetation type) to make predictions about how the ecosystem may respond. In this way, students, just like scientists, can pose and address questions regarding the impact of climate, including global climate change, on the environment.

Schools that would like to use Basic GAPS do not have to collect all the required input data themselves. In fact, all the input data required for Basic GAPS is available from the GLOBE student data archive. In this way, students can use either their own data or data from GLOBE schools from all over the world to explore many interesting regional or global environmental questions using Basic GAPS. Figure 1 shows an example of the major biomes of the world each of which have data collected by GLOBE students.

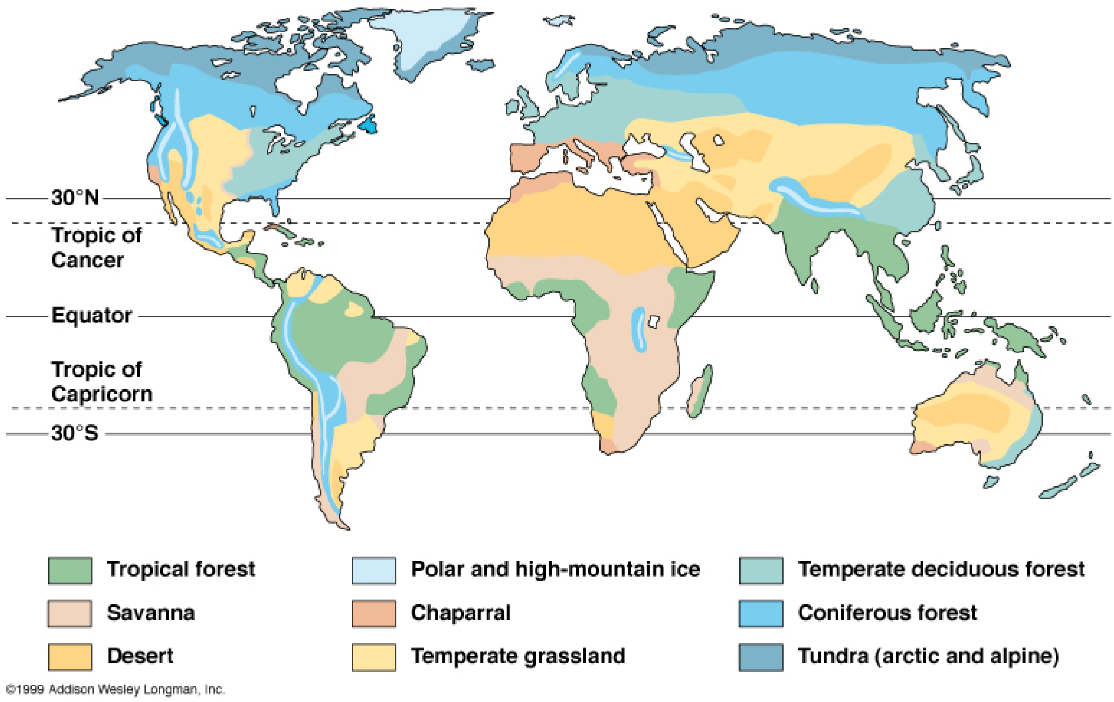


Figure 1. GLOBAL BIOMES. (Please note that, in MS Word, you can increase the size of this figure and the following figures using the zoom button on the tool bar above or by selecting 'zoom' under the 'View' pull down menu.)

We would, however, like to encourage schools that are interested in collecting data at their own sites to collect the whole range of measurements that are required for the Basic GAPS model (see Chapter 4: Summary of GLOBE data required for Basic GAPS). As more and more schools gather this information, we (GLOBE scientists and students) can work more closely together to explore important scientific questions related to the interaction of soils, vegetation and climate across the Earth's biomes. At the present time, Scientists from the GLOBE Soil Characterization Team at Cornell University and NASA are looking for schools to work with us to develop GAPS study sites all over the world. Working together, we will use the data collected with the GAPS model to understand more about the Earth's ecosystems and publish in scientific journals. We hope that you too will become part of this important project! Please look at Appendix C for more information on this, or contact us directly (Appendix B).

Sample Input (and Output) data

In order to work with Basic GAPS without downloading data, we have included sample soil, climate, phenology, and land cover input data with the Basic GAPS software. These are located on the worksheets labeled ‘SoilInput Example’ and ‘ClimateInput Example’. These data can be copied and pasted into the ‘SoilInput’ and ‘ClimateInput’ worksheets if you would like to try out the Basic GAPS model right away. Output from a model run using these data is shown in the ‘Output Example’ worksheet. This is meant to allow you to become familiar with the operation of Basic GAPS before you begin to enter and download your own data. Note that you can edit these data if you like (e.g. increasing or decreasing temperatures or precipitation) in order to explore how the model works.

2 Basic GAPS in Excel: System Requirements

Basic GAPS is written in a programming language called Visual Basic for Applications or VBA, and is used in Microsoft Excel. Basic GAPS was developed in Excel 2002 and has not been tested on earlier versions of Excel. If you have problems running the model on an earlier version of Excel, please contact us (Appendix B) and we will work with you to get the model running. We assume that the user has some experience with Excel; however it is by no means necessary that you be an ‘expert’ at Excel in order to use Basic GAPS.

VBA in Excel means that the model user interface, the model inputs, and the model outputs (graphs and tables) are separate worksheets in an Excel workbook (called ‘Basic GAPS’). The code for the input and output data, and for the model algorithms, was written in the VBA editor and lies “behind” the Excel worksheets. This code constitutes a VBA “Project” with structures for developing the user interfaces that you will use to enter data, run the model and examine model output. The basic approach of VBA is the manipulation of “objects” such as worksheets and cells in worksheets. This manipulation is accomplished by writing VBA code.

3 Introduction to Modeling and Basic GAPS

Basic GAPS is a *dynamic, deterministic simulation model* of the "soil-plant-atmosphere" system. The model describes, among other things, water uptake by plants, water and heat flux in soil, and the impact of climate on these processes.

What exactly is a dynamic, deterministic simulation model to a scientist?

When scientists talk about models, they are referring to a representation of a natural system such as the Earth's climate or soils. This representation or model is developed using the best knowledge available to scientists and is often expressed as a set of mathematical equations that describe individual processes such as water uptake by plants. These equations are linked together, usually with a computer program. These linked equations are what we refer to as a simulation model. A simulation model is *dynamic* if it predicts how processes change over time (e.g. hourly, daily, monthly). Each model simulation has input parameters that describe what the natural system (e.g. soil properties, vegetation type) looks like at the beginning of the simulation. Other inputs are used as "drivers", such as daily rainfall and temperatures, which constrain the model to certain conditions. The simulation model is then set to run with this input information until a set time limit is reached. At that time, the original properties of the system have changed based on the equations in the model and the drivers. Changes in the original properties constitute the output of the model and are analyzed by scientists. Basic GAPS is a particular type of dynamic simulation model called a *deterministic* simulation model. Basic GAPS is a *deterministic* model because it makes definite predictions about the changes in the properties of the natural system such as: "on Sept. 1, soil volumetric water content increased from 0.20 $m^3 m^{-3}$ to 0.25 $m^3 m^{-3}$".

Why do scientists construct simulation models and what do they use the models for?

Scientists construct simulation models for several different reasons. Most often, scientists use models to help in their research. Models provide a quantitative description of a particular system and allow scientists to test theories of how that system operates. Used cautiously, models can provide scientists with the capability to make predictions of future conditions and direct our research efforts in areas that require further investigation. For example, models are often used to help design better experiments by identifying the parts of a system that have the largest impact on something that is an output from that system. For example, a scientist may ask how air and soil temperature will affect bud burst timing. Models are available to help the scientist try out different possible scenarios that might occur before testing them in a field experiment. Results from these experiments can, in turn, be used to improve the model.

Scientists also use models to study large, complex systems such as soils and climate. Models integrate the different parts of these systems so that the scientists can examine the behavior of the system as a whole. This is exactly what both GLOBE scientists and, with Basic GAPS, students can begin to do. Models like GAPS are designed specifically for scientists and students to better understand the impact of these interactions on the environment.

The Basic GAPS model

GAPS stands for *G*eneral-Purpose *A*tmosphere-*P*lant-*S*oil Simulator. Professor Susan Riha at Cornell University, Ithaca, NY, USA, the GLOBE Co-Principal Investigator for Soil Characterization, and graduate students and staff members in her research program developed this model. GAPS has been used by a large number of scientists in many different research applications. GAPS uses climate, soils and plant inputs to describe soil and plant responses to changes in climate. GAPS represents soil, plant and atmospheric processes in several different ways so that the person using GAPS can select those processes that best fit with the input data and the purposes for which GAPS is being used. Basic GAPS is a student version of GAPS that contains the soil, plant and atmospheric processes that best fit with data like that collected by GLOBE students.

Both GAPS and Basic GAPS are "systems" models. They mathematically describe Earth system processes and components that are also represented in the GLOBE program: soil, atmosphere, hydrology, phenology and land cover. Both models can be used to predict how these processes and components will change under varying conditions. A critical attribute of these models, emphasized throughout this manual, is the capacity to *link* these components and processes. This allows us to examine the interactions among them that are so important to life on Earth. These include key components of the hydrologic cycle such as the relationship between precipitation, water flux from plants and soils, and runoff and drainage to ground- and surface water resources. Using models like GAPS and Basic GAPS, we can determine such things as how different soils and land covers can affect these key hydrologic cycle components.

The GAPS processes that we have included in Basic GAPS are:

- <u>Potential and actual water vapor loss from soil and vegetation surfaces</u>. Potential water vapor loss or "*potential evaporation"* directly from soil surfaces (PotEvap) and from vegetated surfaces through stomata (pores on the leaves of plants) or *"potential transpiration"* (PT) is usually referred to as "*potential evapotranspiration*" or PET. These losses are considered "potential" losses because they represent the maximum evaporation that can occur when the soil surface is completely wet and when stomata are fully open. As the soil dries out due to water losses to the atmosphere, there is less soil water available for evaporation or plant uptake and the rates of both evaporation and transpiration decrease below their potential values. When this occurs, these are referred to as "*actual evaporation*" (ActEvap) and *"actual transpiration"* (ActTrans). There are several ways to calculate PET. In Basic GAPS, PET is calculated from mean daily air temperature, mean daily dew point temperature (minimum daily temperature is used as an approximation), elevation and latitude.

- Plant water uptake. This variable is restricted to those sites that are partially or completely vegetated and to the times of year between green-up and green-down (see GLOBE Phenology protocols) when plants are capable of taking up water and transpiring it to the atmosphere. Plant water uptake is largely determined by PET and the plant-available water in the soil where there are roots present. When soil water is low, plant water uptake is reduced leading to the reductions in PT to ActTrans and, as the soil surface layer dries out, PotEvap to ActEvap as described above.

- Soil water flow. Precipitation is used to "refill" the soil when the soil is dry which is when the amount of water in the soil is below its maximum capacity to hold water. The precipitation, or water, enters the first layer or horizon of soil (defined in the Soil Input section below). If more water enters than the" water holding" capacity of that horizon can hold, the water is transferred to the next horizon. This process is repeated from horizon to horizon. Any water moving out of the bottom horizon (after all horizons are at their water holding capacity) is referred to as "drainage". This is a particularly important variable for soil scientists, hydrologists and environmental scientists because of its importance for maintaining water flow into lakes, streams and underground aquifers. In addition, this water may contain chemicals such as pesticides or nitrates that are "leached" out of the soil layers containing plant roots. In the model, precipitation that falls on soil whose water content is approaching saturation or on soil which is frozen flows directly off the soil into rivers, lakes or other drainage basins. The flow of water off the soil also depends on the slope of the land and the land cover. This flow of water is referred to as "*runoff*".

- "Mass balance" check. The model also performs a "mass balance" check for water. With a mass balance check, a calculation is made to make sure that all the precipitation can be accounted for as output (runoff, drainage, ActTrans, and ActEvap) or storage (change in soil water content). This is one way that errors in data or in the model equations can be checked for.

- Outputs of the model (for example soil water contents) are put into columns in the 'Output' worksheet of the Basic GAPS workbook. These can be viewed directly or selected outputs can be displayed in graphical form as charts by clicking on the appropriate button on the 'User Interface' worksheet.

A complete description of these processes and the entire GAPS model is located at: http://www.geo.cornell.edu/eas/index.html, click on "faculty", click on "Susan Riha" and follow the links to GAPS.

4 Summary of the GLOBE data required by Basic GAPS

GLOBE Protocol	GLOBE Data	Input Data for Basic GAPS *Worksheet*/Data name
Atmosphere/Climate:		*ClimateInput:*
1) Air Temp.	Daily max and min temp.	Max and Min Temp, C
2) Automated Air & Soil Temp	Daily max and min temp	Max and Min Temp, C
3) Digital Multi-Day Max/Min/	Daily max and min temp	Max and Min Temp, C
4) Precipitation	Daily rainfall	Rain, mm
	Daily snow (rain equivalent)	Snow, mm
Soil:		*SoilInput:*
1) Soil Characterization	Horizon number	Horizon
	Root estimate	Rel. Root Density
	Depth to top of horizon	Thickness, m
	Depth to bottom of horizon	Thickness,m
	Slope of site	Slope
	Horizon texture (field)*	Horizon texture
2) Soil Particle Size Distribution	Horizon texture (lab, USDA)*	Horizon texture

* If available, use the horizon texture data determined in the laboratory, as this data is more accurate than the field data. If those data are not available, use the horizon texture determined in the field.

GLOBE Protocol	GLOBE Data	Input Data for Basic GAPS *Worksheet*/Data name
Phenology:		*ClimateInput:*
1) Green-up	Budburst date	Budbreak Date
	Date of max leaf size	Full Leaf Date
2) Green-down	Leaves start change color	Start Sen. Date
	Leaves fall off	End Sen. Date
	Latitude	Latitude
3) Budburst*	Budburst date	Budbreak Date

* If the budburst data is not in the Green-up protocol.

GLOBE Protocol	GLOBE Data	Input Data for Basic GAPS *Worksheet*/Data name
Land cover:		*ClimateInput:*
1) Land cover/Biometry	Canopy cover (under Tree Biometry)	Fractional Land Cover
	Total ground cover (under Grass Biometry)	

5 Summary Instructions for Running Basic GAPS

The following is a summary of the instructions for running Basic GAPS. Please read the previous background and descriptions of Basic GAPS before proceeding. You should have climate, soils, phenology and land cover data ready either from your own GLOBE investigations, by downloading these data from the GLOBE website, or by using the sample input data included with Basic GAPS (SoilInput Example and ClimateInput Example worksheets). Downloading the climate data requires more steps than the soils, phenology, and land cover data. Follow the instructions in Chapter 7 (**Basic GAPS Model Inputs**) for downloading climate data.

Running Basic GAPS

1) Open the Basic GAPS workbook. A dialog box will appear indicating that the workbook contains macros. These macros are legitimate macros that contain the equations for the model simulations. You need to enable these macros for the model to run.

2) Insert the climate data you have downloaded in the proper location in the 'ClimateInput' worksheet. If this worksheet is not visible, it can be made visible ("active") by clicking on the command button labeled 'Climate Data' on the 'User Interface' worksheet or by clicking on the worksheet tab labeled 'ClimateInput' at the base of the Excel screen.

3) Go to the 'User Interface' worksheet by clicking on the worksheet tab labeled 'User Interface' at the base of the Excel screen. The 'User Interface' worksheet should appear (Fig. 2).

4) Click on the "Soils Data" command button under the 'Enter Inputs' heading on the 'User Interface' worksheet and enter the soils data following the screen instructions. You will return to the 'User Interface' worksheet after clicking "Done" on the soils dialog box, entering data in the runoff dialog boxes, and "OK" on the dialog box that contain cautions for data checking.

5) Click on the "Phenology/Land cover Data" command button, also under the 'Enter Inputs' heading on the 'User Interface' worksheet, and enter the phenology and land cover data. Clicking on "Done" and, after checking your data, clicking on "OK" on the data checking dialog box caution will return you to the 'User Interface' worksheet.

6) Click on the "Run Model" command button on the 'User Interface' worksheet.

7) There are two options for viewing model output: Excel charts (graphs) or Excel worksheet (table). These can be selected by clicking on the appropriate command button under 'View Results' on the 'User Interface' worksheet. Output

can be viewed as graphs by clicking on the “View Graphs” command button. There are two options for viewing graphs: dynamically or static. Dynamic graphs actually show the data being plotted day-by-day while the static graphs show the data after the plotting is complete. Output can also be viewed as a table in an Excel worksheet by clicking on the “View Table” command button. This Excel worksheet can also be viewed by clicking on the ‘Output’ worksheet tab at the bottom of the Excel workbook.

6 Basic GAPS Excel Workbook: The 'User Interface' worksheet.

Basic GAPS is designed so that users access the model through worksheets in an Excel workbook called "Basic GAPS". When the workbook is brought up, the main *"user interface"* menu to input data, run the model and view output from the model is displayed on the active worksheet. Additional worksheets for each of these tasks are labeled 'User Interface', 'SoilInput', 'ClimateInput', and 'Output' and appear on tabs at the bottom of the screen. Each worksheet can be made visible ("active") by clicking on its tab. Prior to the main *user interface* menu appearing, there will be a dialog box indicating that the workbook contains macros. These macros are legitimate macros that contain the equations for the model simulations. <u>You need to enable these macros for the model to run</u>. The 'User Interface' worksheet is briefly described below. The remaining worksheets will be described in the following sections as we go through the inputs and output of the Basic GAPS model.

The "Basic GAPS" workbook also contains example worksheets labeled 'SoilInput Example', 'ClimateInput Example' and 'Output Example'. The tabs with these worksheet names are also visible at the bottom of the workbook. As mentioned above, data from the 'SoilInput Example' and,'ClimateInput Example' worksheets can be copied and pasted into the 'SoilInput' and 'ClimateInput' worksheets if you would like to try out the model right away. Output from a model run using these data is shown in the 'Output Example' worksheet. This allows you to familiarize yourself with the operation of Basic GAPS before entering and downloading your own data.

'User Interface' Worksheet

The 'User Interface' worksheet is the start of the program. It is shown in Figure 2A. This is referred to as the "user interface" because all model operations are done from this worksheet. This worksheet has three sections.

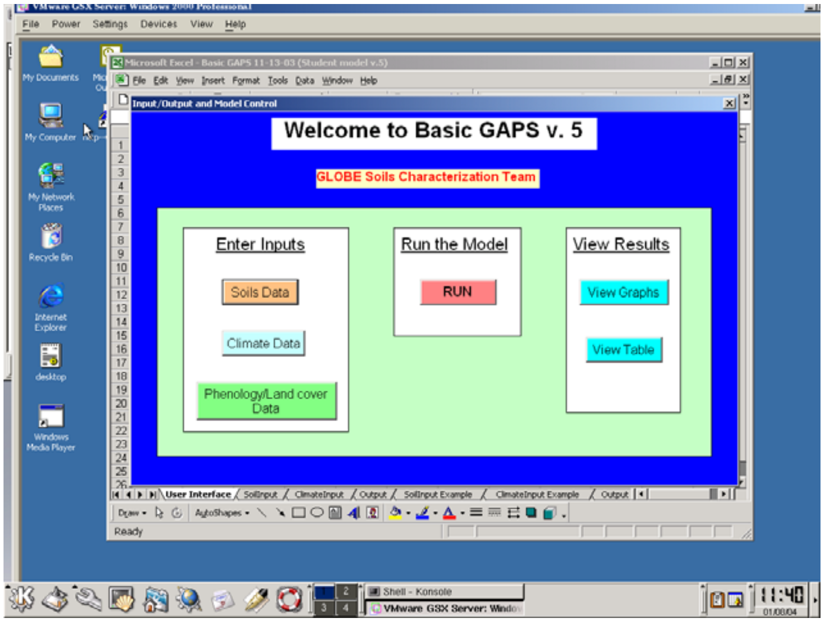


Figure 2. User Interface*.* This worksheet is the user interface for Basic GAPS and will be visible (active) when the Basic GAPS workbook is opened. The 'User Interface' worksheet contains the dialog boxes for inputting soils, climate, phenology, and land cover data, running the model, and viewing model output.

The first section ('Enter Inputs') has three command buttons: "Soils Data", "Climate Data", and "Phenology/Land cover Data". When these command buttons are clicked, forms will appear for entering soils, climate or phenology/land cover data. These are explained in detail in Chapter 7 (**Basic GAPS Model Inputs**). Climate inputs are entered directly into the 'ClimateInput' worksheet that is activated when the "Climate Data" command button is clicked. Soils, phenology, and land cover data are entered via dialog boxes that appear when you click on the "Soils Data" and "Phenology/Land cover Data" command buttons. These dialog boxes will prompt you for the soils, phenology, and land cover data.

The second section ('Run the Model') has one command button, "Run". This is clicked when all the input data has been entered and the model is ready to start the simulations.

The third section ('View Results') has two command buttons, "View Graphs" and "View Table". These allow the user to view the data as a graph or as table. The Basic GAPS inputs and output are described in more detail in Chapters 7 (inputs) and 9 (output).

7 Basic GAPS Model Inputs

Considering Data Quality and Accuracy of Results

One of the goals of the GLOBE program is to educate students about the linkages between different parts of the natural system: soils, plants, climate, hydrology, and the atmosphere. The user-friendly software of Basic GAPS is an excellent tool for examining natural systems and the linkages between them. It is critical to recognize, though, that the output of Basic GAPS is only as good as the input data. This is generally not a problem if you are collecting all the data you need for Basic GAPS at your GLOBE site and have followed the instructions provided by the GLOBE protocols. However, if you are downloading data from the GLOBE website to use in Basic GAPS, we suggest several guidelines to maintain the quality of your input data and, therefore, the quality of the model output:

- Make sure that the soils, climate, phenology, and land cover data are collected from the same general location (latitude, elevation, physiographic region/land classification). Why? Because, as mentioned above, there are linkages between the components of the natural system. For example, if you are interested in modeling a particular location near your GLOBE site you should try to get all input data for Basic GAPS from that area. You do not want to use soils data from a site that is very different from the site where the phenology, land cover, and/or climate data was collected from because soil has a significant impact on plants and this impact varies in a complex way with climate.

- We also recommend that you check the “Site Info” section under the Search Results for the GLOBE site data that you want to download. Look at the soils, climate, phenology, and land cover site descriptions and check whether they are at similar geographic areas and elevations. If it wasn’t, the soil data may not represent the area where the climate, phenology, and land cover data were collected. This could lead to model outputs that do not represent (within the limits of the Basic GAPS model) the system you are interested in modeling (e.g. a local forest). Please contact us if you have any questions. Check for anything unusual that may affect the quality of the input data.

- You may want to review the GLOBE protocols for each of the sets of input data (soils, climate, phenology, land cover) that you download from the GLOBE website. This information may help you to understand how these data were collected and why they were collected so that you can be a better judge of the quality of the data. The protocols can be accessed from the GLOBE main page. Under ‘Science + Education’, click on ‘Protocols’. For example, if you are downloading soils data then you will want to look at the Soil Characterization protocol under “Soils”. If you are using soil textures determined in the lab (“TXU” on the Soil Characterization data table; see below), you may also want to check the ‘Particle Size Distribution’ Protocol that describes the laboratory procedure for determining soil texture more accurately. Follow a similar procedure for any climate, phenology, or land cover data you may be downloading.

Instructions for downloading GLOBE data, entering into the Basic GAPS input worksheets, and detailed descriptions of the input worksheets

The following sections describe the input data required for Basic GAPS, and give instructions on how to download data (soils, climate, phenology, land cover) from a GLOBE website and how to enter these data into specific worksheets. One important point to remember: <u>You must always recheck your data for errors after entering it, whether it is soils, climate, phenology, or land cover data. This “error checking” is an important part of science. Putting in the time to catch errors before doing an analysis saves time later.</u>

<u>Soils Data</u>

You will need the following GLOBE soil characterization data as inputs to Basic GAPS:

- Horizon number;
- Top and bottom depths (cm) of each horizon;
- Root estimate in each horizon (if the site has plants);
- Field or lab texture of each horizon (lab texture is preferred);
- Site slope;

If you do not have these data, you will either need to collect them, following the GLOBE Soil Characterization and Particle Size Distribution (for laboratory determinations of soil texture) Protocols, or you will need to select another GLOBE site (following the recommendations at the beginning of this section) and download these data.

<u>*Downloading GLOBE soils data from the GLOBE website*</u>

- Access the GLOBE homepage.
- Click on ‘Enter the GLOBE site’.
- Click on ‘Schools’ (under ‘GLOBE Partners’).
- Select the country/school where you want to get the climate data from:
- Click on ‘Data’ under the school information.
- Select the ‘Soil Characterization’ option button and click the ‘Get the data now!’ button at the bottom of the menu.
- The soil characterization data should appear in table form. First check to make sure there are either field texture and/or USDA texture descriptions, and

root estimates data (if the site has vegetation). These two data sets are required by Basic GAPS.

- Check the latitude, longitude and elevation to make sure it matches with the approximate location and elevation of the climate, phenology, and land cover data you will be using in Basic GAPS.

- The following headings in the soil characterization table identify input data necessary for Basic GAPS:

- NBR: Soil horizon number.
- TOP: Depth (cm) from the soil surface to the top of the horizon.
- BOT: Depth (cm) from the soil surface to the bottom of the horizon.
- TXF: Field soil texture. The numbers are a code that corresponds to different soil texture classes. This code and the texture classes are given in the table legend. Note that the texture determined in the laboratory (USDA texture, see TXU below), if reported, should be used in place of TXF.
- ROT: Root estimate. 1: no roots; 2: few roots; 3: many roots.
- SLOPE: slope of the site, in degrees.

We recommend that you look at the site comments (‘SITE-COMMENTS’ at the far right of the Soil Characterization table). Check to make sure there is nothing unusual about the site. If you are satisfied with the data, it can be copied directly off the screen or printed out and used as inputs entered via the ‘Enter Soils Data’ dialog box described below.

Entering soils data into the ‘SoilInput’ worksheet

The soils data is entered into the ‘SoilInput’ worksheet by clicking on the “Soils Data” command button on the ‘User Interface’ worksheet. After clicking on this button, a dialog box will appear (‘Enter Soils Data’). This is shown in Figure 3A. Note that the ‘SoilInput’ worksheet is now active (visible). This allows you to check your inputs to make sure they are correct. Procedures for re-entering data to correct mistakes are described below.

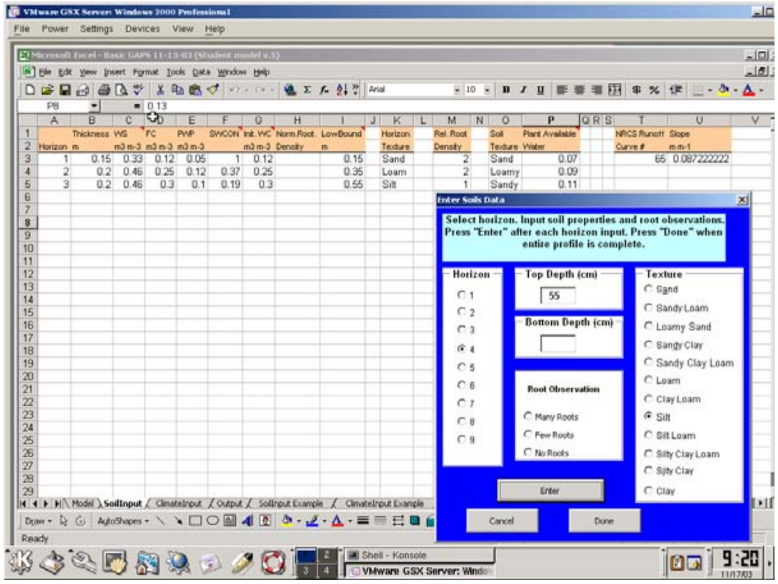


Figure 3A. Soils input dialog box. Dialog box for entering soils data in the 'SoilInput' worksheet in Basic GAPS.

Soils data is entered in the same way that it is recorded in the GLOBE Soils protocol:

- Select a horizon by clicking on a Horizon option button.
- Enter the depth to the top of the horizon (cm) (0 if it is the first horizon).
- Enter the depth to the bottom of the horizon (cm).
- Select the texture for the horizon by clicking on a Texture option button.
- Click on the option button under Root Observations that best describes the number of roots in the horizon.
- Click on 'Enter' to enter the data for that horizon.
- Repeat these instructions for all remaining horizons.

- Click "Done" when you have finished entering the soil horizon data.

After clicking "Done", two additional message boxes will appear. The first ('Runoff', Fig. 3B) will ask if you have information regarding the site vegetation cover type (used to select an "NRCS Runoff Curve #"; this is described below) and site slope (in degrees) for the surface runoff simulation. If you have one or both of these data, click "OK". If you don't have these data, click "Cancel" and default values for the runoff curve # and slope will be entered.

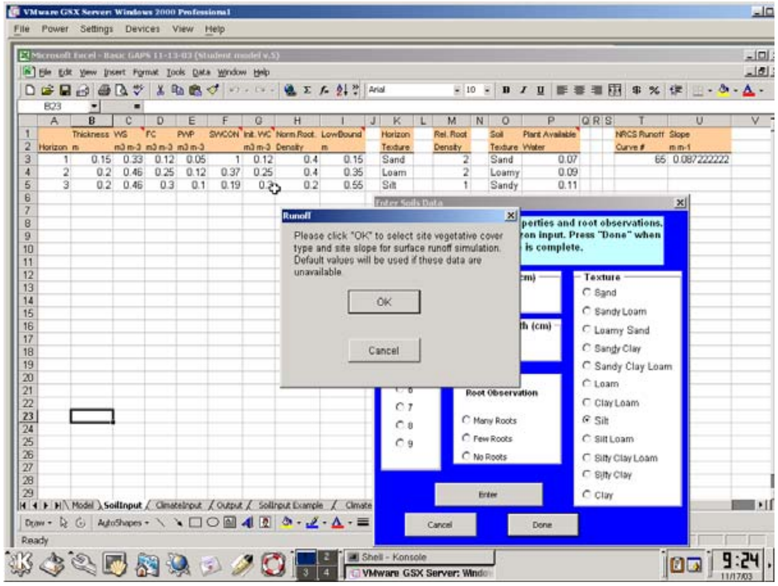


Figure 3B. Runoff message box. Message box requesting whether the user has the information necessary for the runoff simulation in Basic GAPS.

If you clicked "OK", another message box ('Runoff Information') will appear (Fig. 3C) asking you to check the option button that best describes the vegetation cover of your site. There will also be an input box to enter the slope of the site. If you only have the slope but not vegetation cover or vice versa, enter the data you do have and the default will be used for the other.

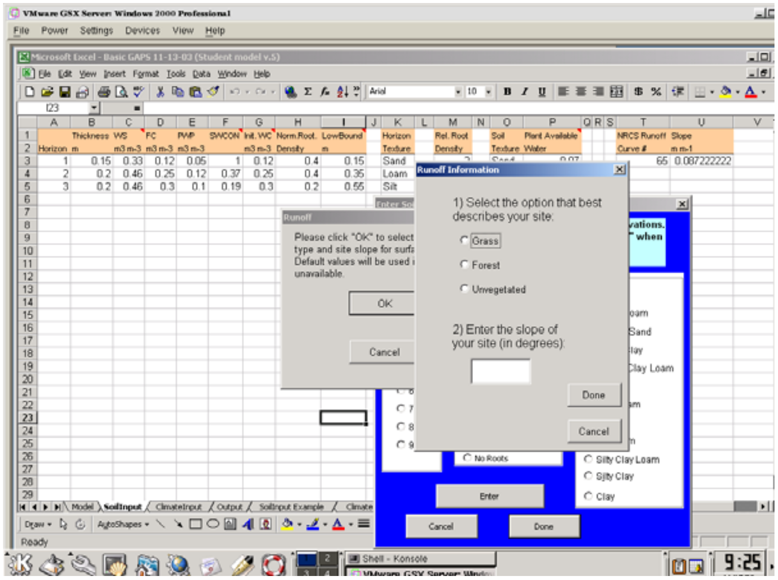


Figure 3C. Runoff information dialog box. Message box for entering land cover information and the site slope necessary for the runoff simulation in Basic GAPS.

When you are finished, the soil input data necessary to run Basic GAPS can be seen by looking at the 'SoilInput' worksheet (Figure 4).

'SoilInput' Worksheet: List of inputs

When you are finished entering soils data, a 'SoilInput' worksheet similar to the one show in Figure 4 will be created. This worksheet contains the soils data that you entered using the dialog box that appears when the "Soils Data" command button is clicked under 'Enter Inputs' on the 'User Interface' worksheet.

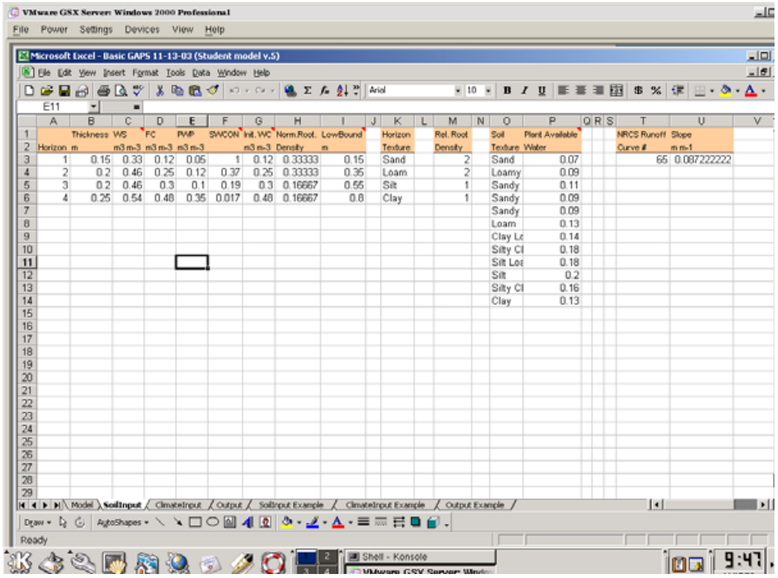


Figure 4. Sample 'SoilInput' worksheet.

You will notice that there are a number of values that you did not enter in the 'Enter Soils Data' dialog box. These inputs were obtained either from equations in the model (for example, "thickness" was calculated by subtracting the top depth from the bottom depth of each horizon) or from a soils data base using the soil texture information that you entered in the 'Enter Soils Data' dialog box as a key.

When complete, the 'SoilInput' worksheet will contain the following data:

Column	Input	Description
A	Horizon	Number of soil horizons for which you have data.
B	Thickness	Difference (m) between the top and bottom depths of a horizon.
C	WC	The saturated volumetric water content ($m^3\ m^{-3}$)of the horizon. This is the soil volumetric water content when all the pores in the soil are filled with water. Calculated from soil texture.
D	FC	The "field capacity" volumetric water content ($m^3\ m^{-3}$) of the horizon. This is the soil volumetric water content after free drainage of water from saturated soil has occurred. Calculated from soil texture.
E	PWP	The "permanent wilting point" volumetric water content ($m^3\ m^{-3}$) of the horizon. This is approximately

		the soil volumetric water content where plants can no longer extract water from the soil. The difference between FC and PWP is referred to as the "plant available" volumetric water content. Calculated from soil texture.
F	SWCON	A measure of the capacity of a horizon (soil) to allow water movement. Calculated from soil texture.
G	Init. WC	The initial water content (m^3 m^{-3}) of the soil in the horizon. This is set equal to FC at the beginning of each model run.
H	Norm. Root Density	The "normalized" root density. The model assigns a value of 2 for 'Many Roots', 1 for 'Few Roots' and 0 for 'No Roots'. The model adds up the total for all the horizons then normalizes the root value for each horizon so that the sum of the normalized root densities across horizons equals 1.
I	Lowbound	The lower depth (m) of each horizon.
K	Horizon Texture	Texture for the horizon that was selected by the user on the 'Enter Soils Data' dialog box.
M	Rel. Root Density	The model assigns a value of 2 for 'Many Roots', 1 for 'Few Roots' and 0 for 'No Roots' where 'Many Roots', 'Few Roots' and 'No Roots' are the options under "Root Observations" in the 'Enter Soils Data' dialog box.
O,P	Soil Texture/ Plant Available Water	The soil textures and associated plant available water volumetric water contents <u>at field capacity</u> for all the soil types currently in the Basic GAPS soils database. These data are used to create a graph ("Maximum Plant Available Water by Texture", one of the graphing options available from the "Graphs" dialog box when the 'Graphs' command button is selected on the 'User Interface' worksheet.)
T	NRCS Runoff Curve #	NRCS stands for Natural Resources Conservation Service. It is a unit within the United States Department of Agriculture that is responsible for, among other things, maintaining the database on the physical properties of the soil types in the United States. One of these physical properties is the

		potential for runoff. Runoff is calculated by using both the slope (see below) and a parameter called the "runoff curve number" (NRCS Runoff Curve #; USDA-Soil Conservation Service. 1972. National Engineering Handbook, Hydrology. Washington: USDA-SCS). This number represents the effects of vegetation type and land management on runoff potential; we use it in the runoff simulation in Basic GAPS. The NRCS has assigned runoff curve numbers for almost all the soils classified in the US. We estimate the runoff curve value based on information you provide in the runoff dialogue boxes (under soil data input).
U	Slope	The approximate slope ($m\ m^{-1}$) of the location being modeled. The slope is entered in degrees and is internally converted to $m\ m^{-1}$. Slope represents the incline of an area based on the number of meters the area goes up (vertical) over a certain number of meters across (horizontal). Site slope measurements are part of several GLOBE protocols, including the Soil Characterization protocol.

Climate data

You can use climate data for Basic GAPS from your own GLOBE site or you can download climate data from the GLOBE website. These data are then pasted into the "ClimateInput" worksheet. GLOBE climate data required to run the Basic GAPS model include: maximum temperature (C), minimum temperature (C), liquid precipitation (rain, mm), and solid precipitation (snow, mm). It is important that you have a relatively complete data set if you want to run the model. These data sets must contain at least one year's data and may contain more than one year. Basic GAPS can keep track of multiple years but you will need corresponding phenology and land cover data for the additional years. For small gaps (3 – 4 days) in the climate data set, you can interpolate temperature data over the missing time period. For example, if the maximum daily temperature before a gap of three days is 25^{o} C and the maximum daily temperature after the gap is 18^{o} C, the maximum temperatures for the three days of missing data would be something like: 23,21,19. A similar approach would be used for the minimum daily temperature. No precipitation should be entered over the small gaps. If the GLOBE climate data set that you have has gaps of more than a few days at a time, you will either need to look for another school that has more complete data or look for nearby schools with climate data (and that are at similar elevations and site locations) to fill in the gaps in your data set (see below: *Downloading GLOBE climate data from the GLOBE website*, Sections 2 and 3).

<u>Downloading GLOBE climate data from the GLOBE website</u>

There are several ways to download climate data:

1) Your school (or the school site you are interested in) has a relatively complete climate data set for the needed time period. This section describes how to download data from one school site.

2) Your school (or the school site you are interested in) has a large block of missing data in the climate file. This section describes how to search nearby GLOBE schools to fill in the missing data.

3) Your school (or the school site you are interested in) has a large block of missing data in the climate file and there are no nearby GLOBE schools with climate data for the needed time period. This section describes how to search nearby non-GLOBE sites to fill in the missing data.

4) You know the geographic area where you would like to have climate data but do not know a specific GLOBE school that has climate data in that area. This section describes how to search for climate data by country, latitude/longitude and elevation.

5) Instructions for when you are unable to locate any climate data for the geographic area you are interested in, or you have a GLOBE climate data set with missing data and you cannot fill in the missing data with nearby sites. This section describes how to search for climate data by distance.

1*) Your school (or the school you're interested in) contains a complete climate data set that you would like to use as inputs to Basic GAPS*.

- Access the GLOBE homepage.
- Click on 'Enter the GLOBE site'.
- Click on 'Schools' (under 'GLOBE Partners').
- Select the country/school where you want to get the climate data from:
- Click on 'Data' under the school information.
- Select the 'Atmosphere' option button.
- - Under 'Atmosphere', select the following check boxes:
    - o Air Temperature
    - o Rainfall
    - o Solid precipitation

<u>Note the elevation, longitude and latitude of the site at this time.</u> Latitude is a required input for Basic GAPS and is entered from the Phenology dialog box described below. Elevation, longitude and latitude may also be used to search for other GLOBE sites as described below.

- At the bottom of the menu, enter the 'Start' and 'End' dates for the time intervals that you want climate data for.
- Under 'Output format', select: "Download tab-delimited results to disk".

- Click on ‘More Options’
- Under ‘Date format’ select:
- YYYY-MM-DD
- De-select ‘Show table legend’.
- Click on ‘Select specific fields’.
- Check the following boxes:
- Maximum temperature
- Minimum temperature
- Rainfall
- New snow rain equivalent
- De-select all other check boxes.
- Go to the bottom of the page and click on ‘Get the data now!’.

****** A message box will appear asking if you would like to open the file or save it to your computer. Select ‘Save’. A ‘Save as’ message box will appear. Save the file using a name that you can readily identify (eg, ‘School 2003 climate data’) and select the directory you would like to save the file in.

Close the GLOBE web page.

Open Excel.

- Under ‘File’, select ‘Open’.
- Enter the directory that contains the GLOBE climate data file. Once you are in the proper directory, make sure to select all files, not just Excel files since the climate file is not yet an Excel file. To do this, scroll down ‘Files of type’ at the bottom of the file open page and select ‘All files’.
- Find your GLOBE climate file, select that file and click ‘Open’.
- A message box called ‘Text Import Wizard’ will appear.
- Click ‘Next’
- Click ‘Finish’
- The climate data should appear in an Excel spread sheet with the column headings: DATE, TMAX, TMIN, Rain, SFLE. (SFLE is the rain equivalent of snow).
- Select the entire DATE column.
- Go to the ‘Format’ pull down menu at the top of the screen.
- Click on ‘Cells’.
- Select the ‘Number’ tab if it is not already selected.
- Under ‘Category’, select ‘Date’.
- Under ‘type’, select ‘MM/DD/YY’ format (this is shown as ‘03/14/01’).
- Click ‘OK’.
- Save your climate data file.

This is a good time to check the completeness of the data set. This can be done several ways. One option is to select all the data for a defined time period (year, for example) and check to see if the total number of entries is correct (e.g.365 for one year's data or 366 for a leap year). If the data is complete, continue as described below. If there are small gaps (3 – 4 days) with missing data, follow the instructions for filling in the temperature data as described in the first paragraph of Climate data. If there is a larger block of data missing, follow the instructions in section 2. Sometimes GLOBE climate data contains more than 365 (or, for leap years, 366) entries for a year due to duplicate entries for the same day. If this occurs, check the number of days in each month to track down the duplicates.

If the data set is complete, paste the data under the proper column headings in the ClimateInput worksheet. For example, date data under 'Day', maximum temperature under 'Max T, C', minimum temperatures under 'Min T, C', rain under 'Rain, mm or kg m^{-2}' and new snow rain equivalent under 'Snow, mm'. See Fig. 5 to view sample climate input data.

2) *There is a large block of missing data in the climate file of the school whose climate data you would like to use in Basic GAPS.*

The strategy in this case is to first try to fill in your missing climate data with climate data from a nearby GLOBE school (at a similar elevation and, if possible, similar geography). In order to do this, you will need to go back to the GLOBE website and go through the steps to get to the school site from which you originally got the climate data. Once there:

- Click on 'Other Nearby data'

******* A dialog box called 'Advanced School Search' will appear at the bottom of the page.

  - Under 'SITE SEARCH', click on the 'Atmosphere' button.
  - Under 'SCHOOL ELEVATION' set the upper and lower elevations approximately 100 – 200 m above and below the elevation of the original school site. (There is a change in temperature with elevation. At a given latitude, the temperature change is assumed to be about 6.4 C per 1000 m change in elevation.)
  - Under 'NUMBER OF DATA REPORTS', select the Start and End dates for the data you are interested in.
  - Click 'Start Search'.

If one or more schools appear, start checking the schools to see if they have data to fill in the missing data in your current climate file. To do this:

- ********Identify a school and click on 'Data'
- Put a check in the check box for 'Air Temperature', 'Rainfall', and 'Solid Precipitation'.
- Select the appropriate Start and End dates for the data file then click on 'Get the data now'.

- View the results in the browser. If it contains data that you can use to fill in the missing climate data from the original school, then go to the ***** (Section 1) instruction above and proceed from there. Once the data is downloaded and converted to an Excel file, cut and paste blocks from the data to fill in the missing climate data from the first school. If you are unable to fill in the missing climate data, try another school (go back to step ******** (this section)). If there are no nearby GLOBE schools with the necessary data, go to Section 3 below.

If the data set is complete, paste the data under the proper column headings in the 'ClimateInput' worksheet (i.e., date data under 'Day', maximum temperature under 'Max T, C', minimum temperatures under 'Min T, C', rain under 'Rain, mm or kg m^{-2}' and new snow rain equivalent under 'Snow, mm'. See Figure 5 to view sample climate input data.

3) *The GLOBE school has some climate data but not a complete set and you are unable to fill in the missing data with data from other, nearby GLOBE schools.*

The strategy in this case is to fill in your missing climate data with climate data from a nearby non-GLOBE site (at a similar elevation and, if possible, similar landscape). In order to do this, you will need to go back to the GLOBE website and go through the steps to get to the school site from which you originally got the climate data. Once you are at the 'Search Results' page for that school:

- Click on 'Other Nearby data'
- A dialog box called 'Advanced School Search' will appear at the bottom of the page.
- Under 'DATABASE SEARCH' at the bottom of the page, select the 'Other Weather Stations' option button.
- Under 'SITE SEARCH', click on the 'Atmosphere' button.
- Under 'SCHOOL ELEVATION' set the upper and lower elevations approximately 100 – 200 m above and below the elevation of the original school site as described above.
- Under 'NUMBER OF DATA REPORTS', select the Start and End dates for the data you are interested in.
- Click 'Start Search'.

Any sites that meet the criteria (elevation, atmosphere data) will appear in a similar fashion to the school listings. Pick a site and click on the 'Graph' button. Once the graph appears:

- Select the dates over which you want data (at bottom of the dialog box).
- Under 'Currently Selected Datasets', depress the 'Control' key on your keyboard and select Maximum Temperature, Minimum Temperature, Rainfall, and New Snow Rain Equivalent. Release the 'Control' key.
- Go to the 'Other Options' box near the bottom of the page and, under 'Select Option', select 'Show Table'.

- Check the table to see if the site has data that can be used to fill in the missing data of the original climate file. If so, go to ‘Select Option’ and select ‘Download Data’ then click ‘Go’. If it doesn’t, try another site (if there is one). If no other site has the necessary data or there is no other site, go to Section 5. If the site has the data:
- Go to the top of the page that appears, find ‘Follow this link to download data’ and click on it.
- In the dialog box that appears, select the following option buttons:
- ‘Save to file on disk’
- ‘Print column headers’
- ‘Tab’
- ‘YYYY/MM/DD’ (under ‘Date format’). The data file should contain the Date, Maximum Temperature, Minimum Temperature, Rain, and Snow Rain Equivalent.
- Click on ‘Create a data file’ at the top of the box.

Follow the instructions in Section 1, from the section marked ****** onwards. If the data set is complete, paste the data under the proper column headings in the ‘ClimateInput’ worksheet (e.g. date data under ‘Day’, maximum temperature under ‘Max T, C’, minimum temperatures under ‘Min T, C’, rain under ‘Rain, mm or kg m^{-2}’ and new snow rain equivalent under ‘Snow, mm’. See Figure 6 to view sample climate input data.

4) *You know the geographic area where you would like to have climate data but do not know a specific GLOBE school that has climate data.*

- Access the GLOBE homepage.
- Click on ‘Enter the GLOBE site’.
- Click on ‘Schools’ (under ‘GLOBE Partners’).
- Click on ‘Advanced Search’.
- Under ‘SCHOOL SELECTION’, select the country where you would like to get climate data. Skip this step if you don’t know the country but do know the approximate longitude and latitude of the location you want climate data from.
- If you know the exact latitude and longitude that you want to search around, select the ‘Lat/Lon Point Search’. If you only know the approximate latitude and longitude, you can select the ‘Lat/Lon Regional Search’. (Note that there are other options for searching a geographic area.)
- Under ‘SITE SEARCH’, click on the ‘Atmosphere’ button.
- If you want to restrict the search for climate data to a certain range of elevation then, under ‘SCHOOL ELEVATION’, set the upper and lower elevations approximately 100 – 200 m above and below the midpoint of the elevation range you are interested in.

- Under ‘NUMBER OF DATA REPORTS’, select the Start and End dates for the data you are interested in.
- Under ‘DATABASE SEARCH’ at the bottom of the page, select the ‘Both’ option button. This will select both potential GLOBE and non-GLOBE sources for the climate data.
- Click ‘Start Search’ and, depending on what data is available, go to the directions in one of the other sections.

If the data set you download in this way is complete, paste the data under the proper column headings in the ClimateInput worksheet (e.g. date data under ‘Day’, maximum temperature under ‘Max T, C’, minimum temperatures under ‘Min T, C’, rain under ‘Rain, mm or kg m^{-2}’ and new snow rain equivalent under ‘Snow, mm’. See Fig   to view sample climate input data.

5) *You are unable to locate any climate data for the geographic area you are interested in, or you have a climate data set with missing data and you cannot fill in the missing data with nearby sites.*

You can expand your original search (Section 2, starting at *******). To do this, go to ‘SCHOOL SELECTION’ near the top of the ‘Advanced School Search’ dialog box. Under ‘Point Search’:

- Pull down the menu and select a100 km search radius

or

- Increase the latitude and/or longitude of the search.

After doing this, follow the instructions from Section 2, from ******* onwards.

You must be cautious when using these options. You can quickly move outside the climatic or ecological zone for which you want to run the model. Contact us (Appendix B) if you aren’t sure what to do or you can’t find the climate data you would like.

Entering climate data into the ‘ClimateInput’ worksheet

Once downloaded, you can enter the climate data into the ‘ClimateInput’ worksheet by transferring the dates, daily maximum, daily minimum, daily rainfall and daily snow (rain equivalent) data to that worksheet. If you downloaded the data from the GLOBE website, or if your GLOBE site climate data is already in a spreadsheet in the computer, all you will need to do is cut or copy and paste the data into the ‘ClimateInput’ worksheet. If not you will have to enter the data manually.

‘ClimateInput’ Worksheet: List of inputs

The list of inputs for the ‘ClimateInput’ worksheet will be listed following the section on phenology and land cover data since these data also entered into the ‘ClimateInput’ worksheet.

Phenology and Land Cover Data

Phenology data describes the start and end dates of “green-up” and “green-down” of vegetation (See the GLOBE Green-up, Green-down, and Budburst protocols under the ‘Phenology’ heading for a complete description of these terms.) These dates define when the vegetation is active and can take up and transpire water from the soil to the atmosphere, and when vegetation is either dormant, or has no leaves, and cannot take up water and transpire. We can then determine the proportion of evapotranspiration (water leaving the soil and leaf surfaces into the atmosphere) that is from evaporation (from the soil surface) and from transpiration (from the plant). When vegetation is active, most evapotranspiration is transpiration and when vegetation is not active, most is evaporation. It is important to know how evapotranspiration is partitioned because different processes control transpiration and evaporation.

Basic GAPS also requires data on the fractional land cover of the site. This is a value between 0 and 1 that indicates how much of the site is covered with vegetation. For Basic GAPS, we consider both tree canopies and low-lying vegetation (e.g. grass). This value is also used to determine how much of evapotranspiration is transpiration and how much is evaporation. A value of 0 would indicate no vegetation at the site. Therefore, all evapotranspiration would come from evaporation. A value of 1 would indicate complete vegetation at the site. Therefore, when the vegetation is active, most of the evapotranspiration would come from transpiration. You can obtain this value from the canopy cover and total ground cover measurements in the Tree and Grass Biometry Protocols (see Land Cover/Biology Protocols). If you have not taken these measurements yet, and plan to do so, please also calculate the percent of canopy **and** total ground cover and use that value for fractional land cover input. If you have already taken these measurements and/or are downloading data from the web site, please use the higher value of the two for the fractional land cover input.

Note that it is very important that the phenology and land cover data are collected in a similar location as the climate data since plant phenology is closely tied to climate. If you do not have your own climate and/or phenology and/or land cover data and are downloading those data from the GLOBE website, make sure that all the data you input to the model are from similar locations (latitude, elevation, and physiographic location) For example, don’t use coastal phenology and land cover data, and climate data from a site 500 km inland, even if the site with the climate data is at approximately the same latitude and elevation as the coastal site with the phenology data. Please contact us (Appendix B) if you have any questions concerning your phenology, land cover and climate data inputs to the model.

The phenology and land cover data required for each year of climate data are budbreak date, full leaf date, green down start date, green down end date, the latitude of the site, year the data was collected, and the fractional land cover. These are all explained in detail in the following sections.

Downloading GLOBE phenology data from the GLOBE website

- Access the GLOBE homepage.
- Click on ‘Enter the GLOBE site’.
- Click on ‘Schools’ (under ‘GLOBE Partners’).
- Select the country/school where you want to get the climate data from:
- Click on ‘Data’ under the school information.
- Select the ‘Green-up/Green-down’ option button.
- Click on ‘Get the data now!’ The Green-up/Green-down table will appear but you will need more information before you can use these data.
- Go to the bottom of the page. There will be a table with a list of information related to the green-up and green-down data. Near the bottom of the table, check the following check boxes: ‘Green-up comments’, ‘Green-down comments’, Genus’, ‘Species’, ‘Common Name’ and ‘MetaData Comments’.
- Click on ‘Get the data now!’. Now the Green-up/Green-down table will (hopefully) contain the data you need for the phenology inputs to Basic GAPS.
- Make sure elevation, latitude, and longitude are approximately the same as your climate and soils data sites.
- Check the dates. Are there phenology data for the years of climate data you would like to use in Basic GAPS? If not, you will have to restrict the climate data to those years where phenology data is available.
- Check the genus (GEN4) and species (SPEC) columns. It is important that the phenology data be collected from the same species at a location. You should not have green-up data from one species or location and green-down data from another species or location. Similarly, if you have more than one year’s of climate data you want to run, the phenology data for each year should be from the same site and on the same species. If the phenology data are from different species from year to year, you should do separate runs of Basic GAPS for each year.
- You will need the following data from the Green-up/Green-down table:
    - Budbreak data: Look under the heading ‘GS’ (greening state). Note the date when ‘B’ (budburst) first appears. This date is the budbreak date for that year and will be inputted to the ‘ClimateInput’ worksheet as ‘Budbreak Date’, described below.
      If there is Green-up/Green-down data but no ‘B’ for budburst, go back to the GLOBE Data Access page and check the ‘Phenology-Budburst’ option button. Click on ‘Get the data now!’ In the table that appears, check the year, latitude, longitude, elevation, site, genus and species. Make sure that they match the Green-up/Green-down table data. If so, use the ‘BBAVG’ (average budburst date) as the ‘Budbreak Date’.

- Full leaf date. This is the date when the leaves have grown to their largest size. Determining this data from the Green-up/Green-down table will require some judgment. First, check to see if there are several leaves (LS) in the table legend. If so make sure to follow the same leaf when looking at changes in leaf length with time. Under LL (leaf length), check the increase in leaf length for a given leaf. As the values increase, there will be a date where the values start to 'bounce' around a mean; that is, there will be increases or decreases of 5 – 10 mm but no net, long-term change. In this case use the first date when this begins to occur as the 'Full Leaf Date' for that year. For example, suppose you see the following leaf length data for a given leaf:

  10
  30
  50
  70
  90
  110
  130*
  135
  130
  135
  140
  130

  In this case, the 'bouncing' begins when 130 (*) is first recorded. We would call the date when this was measured the 'Full Leaf Date'.
- Green down start date. For this, you need to check the column LS (leaf state). Use the date when 'C' (for color change) is first recorded as the 'Green Down Start Date' (see below).
- Green down end date. In the LS column, use the date when 'F' (leaf has fallen) is first recorded as the 'Green Down End Date' (see below).
- Latitude of the site. This is recorded as 'Latitude' (see below).
- The year that a set of phenology data was obtained. This is recorded as 'Year of data collection' (see below). Please note that, in some areas all the phenology data for a given season may not occur in the same calendar year (see the section below). If this is the case, please contact us (Appendix B) for assistance.

In some cases, obtaining phenology data for Basic GAPS from the GLOBE website may be difficult. Please contact us for help if you are having trouble.

Downloading GLOBE land cover data from the GLOBE website

- Access the GLOBE homepage.
- Click on ‘Enter the GLOBE site’.
- Click on ‘Schools’ (under ‘GLOBE Partners’).
- Select the country/school where you want to get the land cover data from:
- Click on ‘Data’ under the school information.
- Select the ‘Land cover/Biology’ option button.
- Go to the bottom of the page and select ‘Select special fields.’
- Under Tree Biometry select ‘canopy cover’ and under Grass Biometry select ‘total ground cover’.
- Click on ‘Get the data now!’
- The Land cover/Biology table will appear. Compare the numbers from canopy cover (CV) and the total ground cover (TGC) columns for the designated site. Note that these are the percent values. You will need to convert them to the decimal values (e.g. divide the percentages by 100) for the Fractional Land Cover input. Use the higher number of the two for the Fractional Land Cover input.

<u>Entering phenology and land cover data into the ‘ClimateInput’ worksheet</u>

The phenology and land cover data are entered by clicking on the “Enter Phenology/Land cover Data” command button on the ‘Model’ worksheet. The dialog box (‘Green Up/Green Down and Fractional Land Cover’) shown in Figure 5 will appear for entering the phenology data.

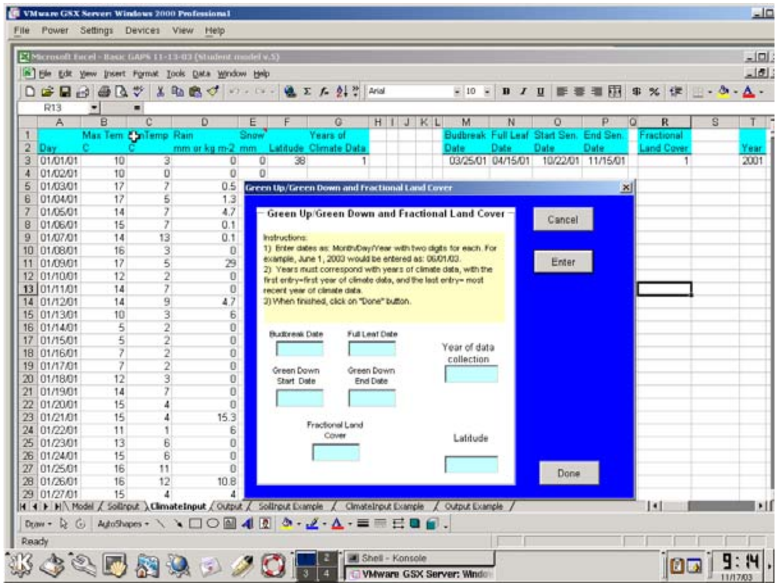


Figure 5. Green Up/Green Down and Fractional Land Cover Dialog Box.

Phenology and land cover data should be entered as follows:

- Input the Budbreak, Full Leaf, Green Down Start and Green Down End dates. These dates are explained in the Green Up/Green Down section of the GLOBE Phenology protocols. The dates need to be inputted as described in the Instructions (MM/DD/YY format).
- Input the Fractional Land Cover.
- Input the year that the Budbreak, Full Leaf, Green Down Start and Green Down End dates were collected.
- Input the Latitude of the location.
- Input the year that the phenology and land cover data were collected (e.g. 2001). Make sure that you have phenology data for each year of climate data. <u>If you live in a location where, for a given season, the green up/full leaf dates occur in one calendar year, and the begin and end senescence dates occur in the next calendar year, contact us (Appendix B) for how 'Year' should be inputted.</u>
- Click the 'Enter' button.

Repeat this for each year that you wish to have the model run (equal to the number of years for which you have climate, phenology and land cover data). Note that your phenology dates will probably vary from year to year. Plant phenology is closely tied to climate and climate often varies somewhat from year to year.

‘ClimateInput’ Worksheet: List of inputs

Figure 6 shows a sample ‘ClimateInput’ worksheet after both climate and phenology input data have been entered. Your ‘ClimateInput’ sheet should look like this after following the instructions above for obtaining and entering climate and phenology data.

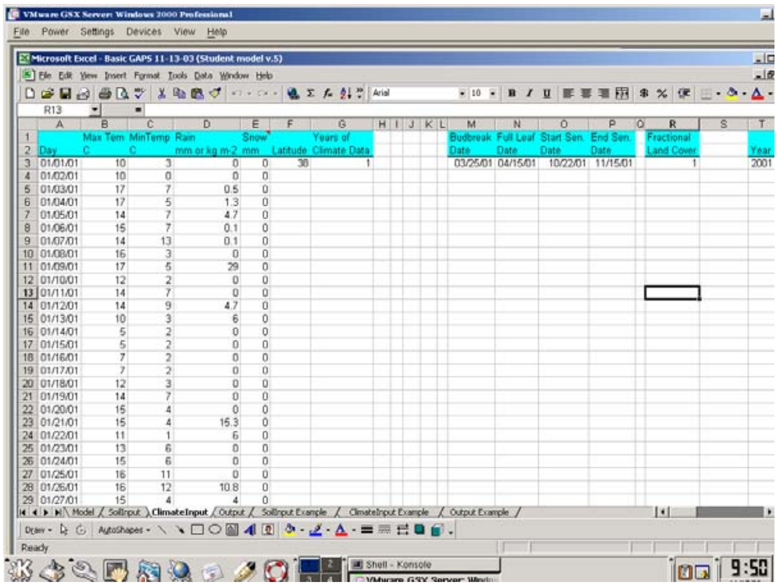


Figure 6. Sample ‘ClimateInput’ worksheet.

When complete, the ‘ClimateInput’ worksheet will contain the following data:

Column	Input	Description
A	Day	Days (MM/DD/YY) for which you have climate data.
B	Max Temp	Daily maximum temperature (C).
C	Min Temp	Daily minimum temperature (C).
D	Rain	Daily liquid precipitation (mm).
E	Snow	Daily new snow rain equivalent (mm).
F	Latitude	Latitude (decimal form) of the site where the climate, phenology and land cover data were collected
G	Years of Climate Data	Number of years of climate data (at least 1 year’s data is strongly recommended).

M	Budbreak Date	Budbreak date is defined in the GLOBE phenology protocol and is the start of “green-up” of the vegetation at the GLOBE site, either following a winter, or, in warmer locations, a prolonged dry season.
N	Full Leaf Date	Full leaf data, also defined in the GLOBE phenology protocol, is the date when the leaves of the vegetation at the GLOBE site have reached their maximum size.
O	Start Sen. Date	Start Sen. (senescence) date, defined in the GLOBE phenology protocol, is the date when the vegetation at the GLOBE site begins the process (senescence) that leads to leaf fall either due to cold weather (cool climates) or the onset of a dry season (some warmer climates). Senescence starts when leaves begin to either die or change color (as the plant begins to breakdown chlorophyll and other valuable chemical compounds in leaves and store the components for the next growing season).
P	End Sen. Date	End Sen. (senescence) date, defined in the GLOBE phenology protocol, is the date senescence is complete at the GLOBE site, resulting in leaf fall either due to cold weather (cool climates) or the onset of a dry season (some warmer climates).
R	Fractional Land Cover	Fractional land cover: fraction of area (0 – 1) with vegetative cover in the site you are modeling.
T	Year	Enter the year (YYYY) that the phenology data was collected. There should be one year of phenology data for each year of climate data.

8 Running Basic GAPS

After entering the necessary input data, you will click the “Run” command button under “Run the Model” on the ‘User Interface’ worksheet (Figure 2). When this happens, the model begins to process the input data. The climate data “drives” the model; that is, values in the climate data (maximum and minimum temperature, rain, and snow) that change day-to-day are responsible for changing the other components of the system we are modeling such as soil water content, transpiration, and evaporation. How much these components are affected by the daily climate changes is modified by other inputs to the model such as soil texture, soil depth, latitude, and phonological data. However, the key point is that the model is controlled or “driven” by daily climate data and, therefore, we say that the model runs on a “daily time step”. In the same way, the output data, described below, are daily values such as daily changes in soil water content for horizon 1, etc. The model also calculates annual totals by summing the daily values for certain variables. These are described below in the “Basic GAPS Model Output” section.

9 Basic GAPS Model Outputs

After running, the Basic GAPS model output can be viewed either as a table or as a graph. These options are selected by clicking on either the "View Table" or "View Graphs" command button under 'View Results' on the 'User Interface' worksheet. Note that, when you look at the output, you will see that it consists of daily values. That is because Basic GAPS runs on a daily time step as described above: there is one model run for each day of climate data.

"View Table"

If the "View Table" command button is clicked after running the model, the 'Output' worksheet will be active (visible). A sample of the 'Output' worksheets is shown in Figures 7A-D. It contains the output from the model. Your 'Output' worksheet should look similar to this although, of course, the individual numbers will be different.

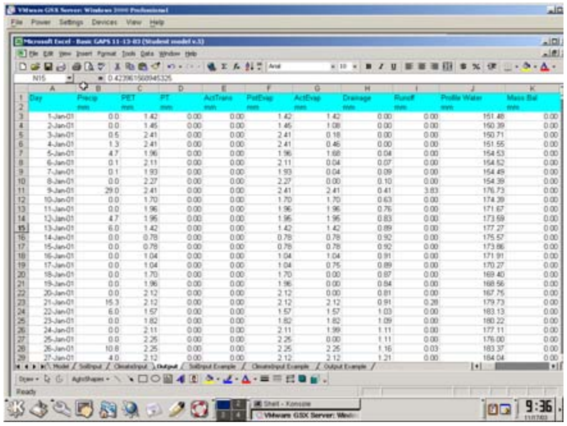


Figure 7A

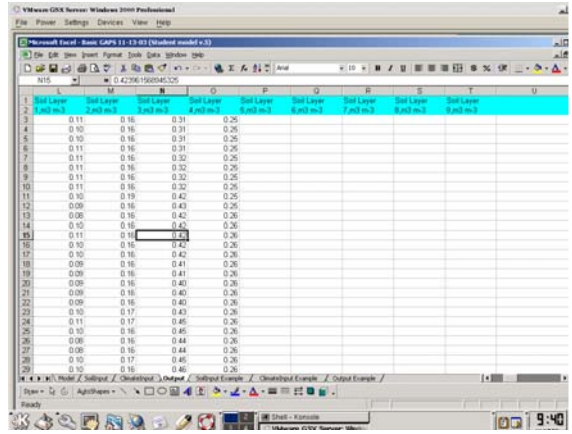


Figure 7B

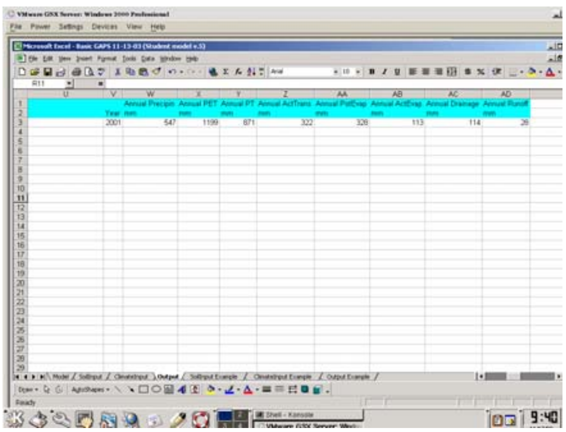


Figure 7C

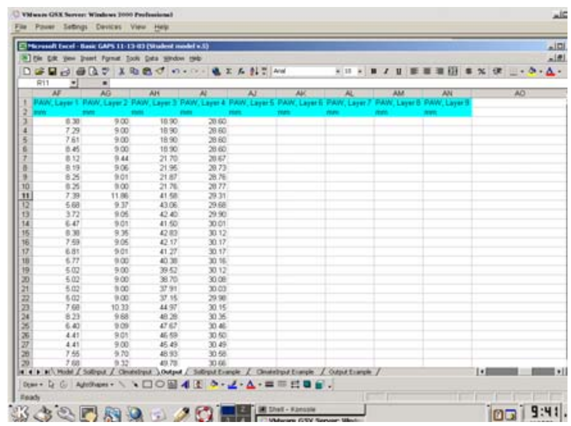


Figure 7D

Figure 7A-D. Sample 'Output' Worksheet. **A:** The first set of columns on the Output worksheet, contains daily simulated transpiration and evaporation parameters, drainage, runoff, and total amount of water in the horizons specified in the Soils data input dialog box (Inputs section) and displayed in Fig. 3A. **B:** The next set of columns on the Output worksheet, contains the soil volumetric water contents for the soil horizons. **C:** This contains the annual summaries of key data related to the flux of water in the system: precipitation, potential and actual transpiration and evaporation, drainage and runoff. **D:** The last columns in the Output worksheet contain daily, simulated changes in plant available water (PAW) for each soil horizon.

The outputs in each of the columns are as follows:

Column	Output	Description
A	Day	Date (DD-Month-YY).

B	Precip*	Precipitation (mm) for the day.
C	PET**	Potential Evapotranspiration (mm): the potential rate at which water can evaporate from the soil and can be transpired from plants. “Potential” means that the soil water content is not low enough to restrict evaporation or transpiration.
D	PT**	Potential Transpiration (mm): the potential transpiration component of PET.
E	ActTrans**	Actual Transpiration (mm): the transpiration rate that includes any restriction on transpiration due to low soil water content (e.g. drought).
F	PotEvap**	Potential Evaporation (mm): the potential evaporation component of PET.
G	ActEvap**	Actual Evaporation (mm): the evaporation rate that includes any restriction on evaporation due to low soil water content (i.e., drought).
H	Drainage**	Water (mm) moving into the soil horizon below the last horizon listed in the SoilInput worksheet
I	Runoff**	Water (precipitation, mm) that doesn’t enter the soil.
J	Profile** Water	Total water (mm) in all the soil horizons.
K	Mass Balance	Internal model check to make sure water. inputs – outputs – (change in water stored) = 0.
L	Soil Layer 1	Volumetric water content (m^3 m^{-3}) of horizon 1.
M	Soil Layer 2	Volumetric water content (m^3 m^{-3}) of horizon 2.
N	Soil Layer 3	Volumetric water content (m^3 m^{-3}) of horizon 3.
O	Soil Layer 4	Volumetric water content (m^3 m^{-3}) of horizon 4.
P	Soil Layer 5	Volumetric water content (m^3 m^{-3}) of horizon 5.
Q	Soil Layer 6	Volumetric water content (m^3 m^{-3}) of horizon 6.
R	Soil Layer 7	Volumetric water content (m^3 m^{-3}) of horizon 7.
S	Soil Layer 8	Volumetric water content (m^3 m^{-3}) of horizon 8.
T	Soil Layer 9	Volumetric water content (m^3 m^{-3}) of horizon 9.
U	(empty)	
V	Year	Years of climate data. Year 1 in first row, year 2 in second row, etc.

The following columns (W – AD) are annual totals for each year listed in column V.

W	Annual Precip*	Total precipitation (mm) for the year.
X	Annual PET**	Total PET (mm) for the year.
Y	Annual PT**	Total PT (mm) for the year.
Z	Annual ActTrans**	Total actual transpiration (mm) for the year.
AA	Annual	Total potential evaporation (mm) for the year.

	PotEvap**	
AB	Annual ActEvap**	Total actual evaporation (mm) for the year.
AC	Annual Drainage**	Total drainage (mm) out of the bottommost soil horizon.
AD	Annual Runoff**	Total surface runoff (mm) off the soil surface.
AE	(empty)	
AF	PAW*, Layer 1	Plant available water (mm) in horizon 1.
AG	PAW*, Layer 2	Plant available water (mm) in horizon 2.
AH	PAW*, Layer 3	Plant available water (mm) in horizon 3.
AI	PAW*, Layer 4	Plant available water (mm) in horizon 4.
AJ	PAW*, Layer 5	Plant available water (mm) in horizon 5.
AK	PAW*, Layer 6	Plant available water (mm) in horizon 6.
AL	PAW*, Layer 7	Plant available water (mm) in horizon 7.
AM	PAW*, Layer 8	Plant available water (mm) in horizon 8.
AN	PAW*, Layer 9	Plant available water (mm) in horizon 9.

* The units for these outputs are given as mm, which is equivalent to mm^3 [water] mm^{-2} [ground area].
** These outputs, PET, PT, PotEvap, ActTrans, ActEvap, Drainage, and Runoff, also have mm as their units. However, unlike the * outputs, these outputs are fluxes. A flux is defined as the amount of material (mm^3 [water]) moving across a given area (mm^{-2} [ground area]) per unit time. Since Basic GAPS operates on a daily time step, the time unit is day (d). Therefore, the complete description of the units for these fluxes is mm^3 [water]) mm^{-2} [ground area] d^{-1}. This unit is typically shortened (divided through) to mm d^{-1} or mm when the time step of the model is assumed and not explicitly stated. This unit also applies to the annual fluxes of these outputs except that the time unit is year not day.

"View Graphs"

Output from the model, as well as daily precipitation, and daily minimum and maximum temperatures, can be viewed as graphs by clicking on the "View Graphs" command button under 'View Results' on the 'User Interface' worksheet. All the graphs, except for the "Maximum Plant Available Water by Texture" selection, show the daily changes in the model outputs over the time period of the model run (e.g. the total number of days of climate data).

When the “View Graphs” button is clicked, the following dialog box for selecting output graphs appears (Figure 8):

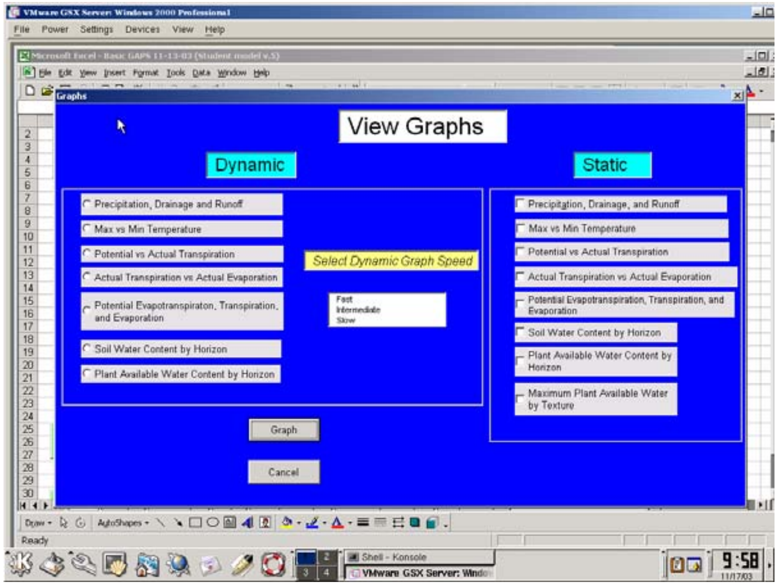


Figure 8. Graphs dialog box.

There are two options for viewing graphs: dynamically or static. Dynamic graphs actually show the data being plotted day-by-day while the static graphs show the data after the plotting is complete. Instructions for graphing output data using the ‘Graphs’ dialog box are as follows:

Dynamic Graphs.

1) Click the option button of the graph you wish to view dynamically (left side of ‘View Graphs’ dialog box shown in Figure 7). Note that you can only select and view one dynamic graph at a time. Once you view the graph dynamically, a static graph of the same output data is created. These static graphs are on separate worksheets (‘chart sheets’) labeled with the graph name.

The following output data can be viewed as dynamic graphs:

- Daily precipitation, drainage and runoff (‘Precipitation, Drainage and Runoff’ option button).
- Daily maximum and minimum temperature (‘Max vs Min Temperature’ option button).
- Daily potential and actual transpiration (‘Potential vs Actual Transpiration’ option button).

- Daily actual transpiration and evaporation (‘Actual Transpiration vs Actual Evaporation’ option button).

- Daily potential evapotranspiration and its components: daily transpiration and evaporation (‘Potential Evapotranspiration, Transpiration and Evaporation’ option button).

- Daily soil volumetric water content (m^3 m^{-3}) by horizon (‘Soil Water Content by Horizon’ option button).

- Daily plant available water (mm) by horizon (‘Plant Available Water Content by Horizon’ option button).

2) Select a dynamic graph speed by clicking on the speed you would like. There are three options for graph speed:

- Fast
- Intermediate
- Slow

3) Click the ‘Graph’ button at the bottom of the dialog box.

Static Graphs.

1) Click on the check boxes of the static graphs you would like (right side of “View Graphs” dialog box shown in Figure 8). Note that, unlike the dynamic graphs, you can select any number of static graphs to view, from one up to the total number of static graph options.

You can view all the dynamic graphs as static graphs as well as one additional graph (‘Maximum Plant Available Water by Texture’). This is a bar graph, which shows field capacity plant available water by soil texture class. These data are also displayed in columns O and P in the ‘SoilInput’ worksheet and were obtained from: Saxton et al., 1986. Estimating generalized soil-water characteristics from soil texture. Soil Science Society of America Journal. 50(4):1031-1036.

2) Click the ‘Graph’ button at the bottom of the dialog box.

Each static graph you select will be on a separate chart sheet labeled with the static graph’s name.

10 Suggested Learning Activities

Below are a few possibilities for student investigations using Basic GAPS and GLOBE data. Any one of these could be developed into inquiry-based lessons/labs for science and math teachers.

Impact of vegetation on soil water balance

For a given GLOBE site or sites and using a constant climate:

- How does the depth of rooting affect the amount of water in the soil?

  Systematically vary the rooting depth (depth of horizons containing roots) and determine the impact this has on ActTrans/PET and drainage. The ActTrans/PET ratio is sometimes used as an indicator when drought stress is developing in a crop, forest or natural ecosystem. When this ratio falls below 1, it means that there is not sufficient soil water to meet the atmospheric “demand” for moisture as represented by PET.

- Does varying the time when vegetation is actively taking up water have an impact on the annual soil water balance? How do changes in phenology and fractional land cover affect the partitioning of evapotranspiration between evaporation and transpiration for a given year?

  Vary phenology and land cover input data (Budbreak, Full Leaf, Green Down Start and Green Down End dates; Fractional land cover) and determine the impact on annual soil water balance.

Importance of soil characterization and soil texture

- How do differences in soil texture affect the amount of water in the soil?

  Vary soil type (texture) and determine the impact on soil water parameters. For example, compare soil horizons composed of soil types with lower plant available water capacity (e.g. sand, loamy sand or sandy clay) with soil horizons composed of soil types with higher plant available water capacity (e.g. silt). The maximum plant available water capacities of different soil types can be seen on the ‘SoilInput’ worksheet. Run the model with the different soil types and look at ActTrans, ActEvap, and drainage. Some possible questions to ask are: Why do these parameters change with soil type? Why do soils with sand have less water holding capacity than soils with a finer texture (silts)? We can help you with educational materials to answer questions like these.

Impacts of global climate change

- How would a change in precipitation amount or timing affect soil water and evapotranspiration?

  For a given GLOBE site or sites, maintain the same plant and soil parameters. Maintain the same total annual precipitation but systematically vary the timing that this precipitation occurs. For example: 1) 'deliver' the precipitation in fewer but heavier rainfalls and compare this with 'delivering' the precipitation in many small rainfalls; 2) Change around the time of year that most of the precipitation occurs. For each of these exercises, how the examine the model output (e.g. soil water parameters and ActTrans/PET) change and explore possible reasons for why these parameters change the way they do. This learning activity could lead to further explorations with the model. This type of analysis is an important use of dynamic simulation models: to stimulate thought and identify areas where we need more information.

- How would an increase in air temperature affect soil water, evapotranspiration, and timing of green-up and green-down?

  For a given GLOBE site or sites, increase the daily maximum temperature by two or three degrees and observe the impact these changes have on soil water parameters and ActTrans/PET. (Raising the maximum temperature will increase both PET and PotEvap.) This learning activity could be part of a larger project examining the effects of increasing annual average temperature on phenology. GLOBE has a protocol for collecting data on lilac bud break and flower appearance as a means of tracking possible long-term effects of temperature on plant phenology.

Appendix A Glossary

Actual evaporation (ActEvap): The actual water vapor flux from the soil surface to the atmosphere. ActEvap is equal to potential evaporation (PotEvap, see below) when the resistance to that flux is at a minimum. This occurs when the surface layer of the soil is at field capacity. As the surface layer of the soil dries out, the resistance to the water vapor flux from the soil increases and ActEvap decreases below PotEvap.

Actual transpiration (ActTrans): The actual water vapor flux from vegetative surfaces to the atmosphere. When the resistance to that flux is at a minimum (stomatal pores on the leaf surface are completely open; see “Stomate” below), ActTrans is equal to potential transpiration (PT, see below). As soil water content in the root zone decreases, the stomatal pores begin to close and ActTrans decreases below PT. We do not directly simulate the opening and closing of these stomatal pores in response to soil water content in Basic GAPS. In Basic GAPS, ActTrans decreases below PT when, on a given day or days, the total amount of water available to plants (“Plant Available Water, see below) in the soil layers containing roots is less than the demand for that water represented by PT.

Algorithm: A step-by-step mathematical procedure for arriving at a solution to a problem.

Aquifer: A below-ground water-bearing permeable rock, gravel or sand formation.

Atmospheric demand: The difference in the energy potential of water between the inside of a leaf or surface soil layers and the surrounding air. This energy potential difference driving water movement between the leaf or soil surface to the atmosphere is generally much larger than the energy potential differences that drive water movement from the soil into plant roots and then to the leaves of the plant. Therefore, atmospheric demand is said to drive transpiration and evaporation.

Biome: A major ecosystem type (e.g. savanna, where savanna is one of several grassland biomes).

Deterministic: In reference to simulation models, model outputs that are definite with no probability associated with the outputs.

Dew point: The temperature to which air must be cooled (with no change in air pressure or moisture content) for saturation to occur (100% relative humidity).

Drainage: Water movement through soil horizons to ground or surface waters. This typically occurs in soils that are wet and the rates of evaporation and transpiration are low.

Drivers: In reference to simulation models, dynamic inputs (e.g. precipitation) that, in turn, cause dynamic changes in other model inputs producing model output (e.g. soil water content).

Dynamic: Changing with time.

Field Capacity (FC): The amount of water remaining in a given soil horizon or horizons after the soil has been saturated (all soil air spaces filled with water) and the free (drainable) water has been allowed to drain away (usually one to two days). Field capacity varies with soil texture because the texture affects how much drainage will occur from a saturated soil.

Flux: The amount of a material that crosses some area in some unit time. For example, we refer to the flux of water vapor from a soil or plant surface as mm^3 [water] mm^{-2} [surface area] s^{-1} [per second].

Inputs: Data provided to simulation models that (a) define the initial state of the system being modeled; (b) 'drive' the model algorithms that change the original properties of the system (see 'Drivers' above).

Interface: In reference to simulation models, the means by which a user interacts with the model to provide inputs, run the model, and view outputs.

Land cover: Characterization of a given land area according to the presence of vegetation. In GLOBE, land cover is classified using the Modified UNESCO Classification or MUC guide. See the GLOBE Land Cover Sample Site and Biometry protocols under the Land Cover/Biology heading for a more complete description and other related information.

Permanent Wilting Point (PWP): Approximate soil water content where plants can no longer take up water and, if this condition persists, will die. PWP soil water content will vary with soil texture because plants take up water as a function of energy gradients and not water content, and the soil energy status associated with permanent wilting occurs at different water contents for different soil textures.

Phenology: In reference to plants, climate-driven changes in a plant's life cycle. See the GLOBE protocols under the Phenology heading for a more complete description and other related information.

Physiographic: The exterior physical features of the landscape.

Plant Available Water (PAW): The water considered available for plant uptake. PAW is calculated as the mass or volume of water between the field capacity water content and permanent wilting point water content of the volume of soil in the root zone of the plant.

Potential Evaporation (PotEvap): Maximum evaporation that can occur when the soil surface is completely wet.

Potential Evapotranspiration (PET): The sum of potential evaporation (PotEvap) and potential transpiration (PT).

Potential Transpiration (PT): Water vapor flux from stomata on vegetative surfaces in response to atmospheric demand, where the stomatal pores are completely open and represent a minimum resistance to that flux.

Simulation Model: A set of linked mathematical algorithms that describe the behavior of a given system.

Soil Texture: The relative proportions of sand, silt and clay in a given soil.

Soil Volumetric Water Content: The ratio of the volume of water (m^3 or mm^3) in a soil horizon or horizons to the total bulk volume (m^3 or mm^3) of the soil horizon or horizons, i.e., the volume of water per unit volume of soil.

Stomate: A pair of specialized leaf epidermal cells called guard cells. When turgid, these cells curve and create an opening to form a *stomatal pore* through which carbon dioxide enters, and water vapor exits the leaf. Stomata, therefore, are critical control points in two major plant processes: photosynthesis and transpiration. Stomata open and close in response to external stimuli such as water vapor density, atmospheric carbon dioxide, and light. They also open and close with changes in leaf water status that can occur in response to changes in soil water content. For example, when the soil water content in the zone containing plant roots is low, plant can go into water stress. Under these conditions, guard cells lose turgidity and the stomata begin to close.

Workbook: A Microsoft Excel object that can contain any number of worksheets and chart sheets. Excel is a spreadsheet application for storing and manipulating data. Workbooks are a basic tool in this application.

Worksheet. Worksheets are the ‘spreadsheets’ where data is stored and manipulated in the workbook object. Worksheets can also contain embedded charts, graphic objects, pictures and embedded objects.

Appendix B Request for participation in GLOBE data collection for the data required by Basic GAPS.

Last year, we developed a request for GLOBE sites to adopt those GLOBE protocols that would provide the necessary input data for Basic GAPS. This request is given below:

<u>Help the Soil Characterization team: develop a GAPS site in your biome</u>

What is a biome?

Biomes differ in vegetation, phenology, soil, and land use. These differences are driven by the physical environment (climate, geography and geology) that are, in turn, influenced by biological activity. There are nine global terrestrial biomes on earth.

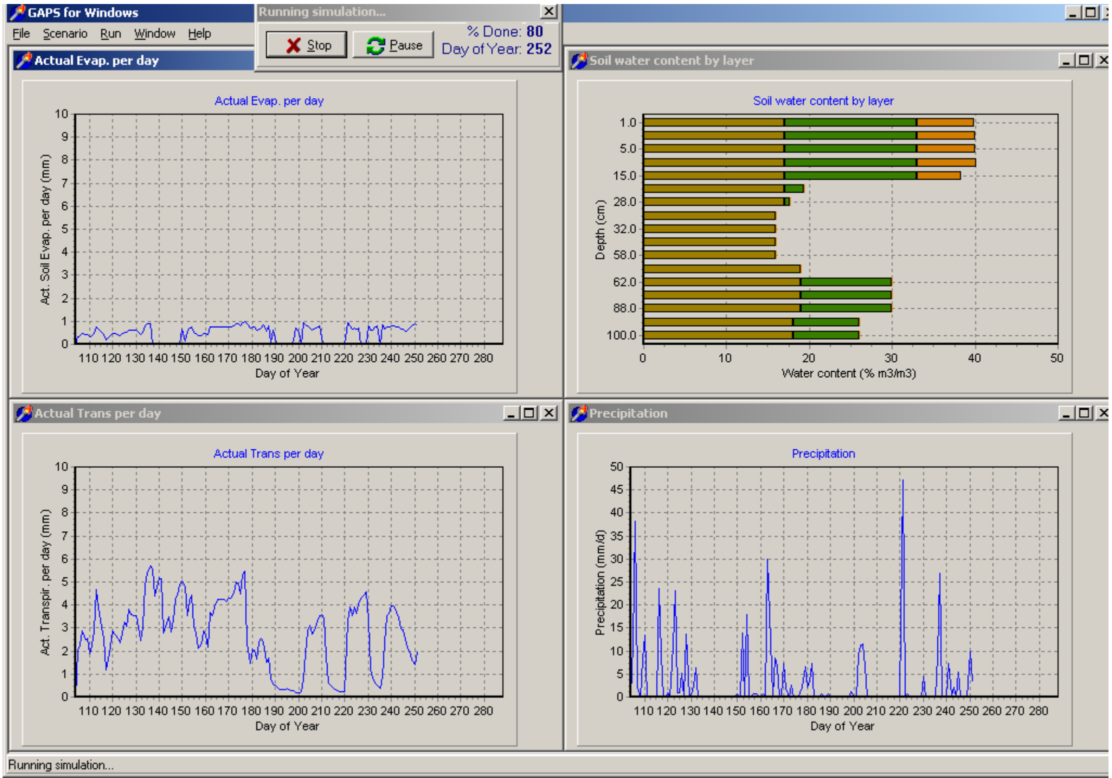
Why are biomes important and why do we want to study them?

The differences within each biome affect the linkages between the vegetation, soil, and climate, which in turn affect the susceptibility of the biome to climate change. Data collection by students, in conjunction with the GAPS initiative, will allow GLOBE scientists and students to better understand these differences and to predict the consequences of future changes in land use and climate within each biome.

What is GAPS?

GAPS is a menu driven computer model that utilizes soil, vegetation, phenology, and climate data to simulate different environmental processes such as soil water content, drainage, and phenology. The model simulates these processes on a daily basis and displays these changes as they are being simulated, thereby providing a dynamic visualization of the system.

Examples of GAPS visualizations



What is the purpose of the GAPS initiative in the GLOBE Soils program?

GAPS enables students and scientists to study the interplay among these processes in a quantitative way. Students and scientists can examine linkages within a particular biome, such as the sensitivity of soil moisture to seasonal changes in the overlying vegetation. Students and scientists can also predict how soil systems may respond to environmental changes and how these responses will impact the environment on local, regional and global levels. In this way, students and scientists can pose and address questions regarding the impact of future climate change on the environment.

How are student data used with the GAPS model?

Student data are used to define the specific conditions (type of soil, vegetation and climate) for each GAPS site. In addition, student data (soil moisture, soil temperature, and phenology) are used to validate model results. The Soils Characterization team will adapt GAPS (Basic GAPS) to allow easy input of data so that students can also display outputs of both measured and model results.

What is a GAPS site?

A GAPS site is an accessible and safe location near your school that has a uniform land cover. Ideally the site would be an undisturbed area such as a forest grove, wood lot or an open field. Within the GAPS site, a suite of GLOBE measurements are made by students. We are interested in the linkages within your biome so it is extremely important that you make your soil and phenology measurements at the same place. Climate measurements should be located in an open site, as described in the Atmosphere Investigation, within 100 meters of the other measurements being taken.

What GLOBE measurements are taken at each GAPS site?

Soil

- Soil Characterization Field Measurements Protocol
- Soil Characterization Lab Analysis Protocol
- Optional Soil Moisture Sensor Protocol
- Automated Soil and Air Temperature Monitoring Protocol

Atmosphere/Climate

- Maximum, Minimum and Current Temperature Protocol
- Precipitation Protocols (rainfall and snow equivalent in appropriate locations)

Phenology

- Green-up/Green-down Protocol

What if my school is interested in becoming a GAPS site but we're not sure we can take all the measurements?

We recognize that there are many measurements involved in this research project. But, one class does not have to tackle all these measurements. We recommend collaboration. Having a GAPS site is an ideal way to have different grades within a school work together on a science project. Each grade can be responsible for a specific set of measurements. And remember soil characterization field and lab protocols only have to be done once. Others, such as soil moisture, are daily measurements while the soil temperature is an automated measurement.

Why participate in the GAPS project?

GAPS is a great introduction for students and teachers to dynamic simulation models: increasingly important tools used by scientists to investigate complex systems like the Earth's environment. We expect to modify GAPS so that students will be able to run the model using their own data and/or archived GLOBE data from other schools. Using the GAPS model, students and teachers will be able to integrate and interpret GLOBE data collected from different protocol investigations in an Earth Systems Sciences approach. Scientists, students and teachers have a unique opportunity in the GLOBE/GAPS initiative to quantitatively examine the Earth's environment, as there are GLOBE schools in every major biome. Our goal is to have at least one GAPS site in each biome. Help us reach this goal.

Who do I contact for more information?

Interested schools should contact Jessica Robin (jrobin@ltpmail.gsfc.nasa.gov) or Jeff Melkonian (jjm11@cornell.edu).

Appendix C Copyright license agreement

Authors: Dr. Susan Riha and Jeffrey Melkonian

Software License Terms and Conditions

1. SOFTWARE shall mean Basic GAPS code or portions thereof contained in the file Basic GAPS.xls, or related documentation, described in Cornell Research Foundation, Inc. ("CRF") file D-3479. SOFTWARE includes, but is not limited to, Basic GAPS executable code.

2. CRF is a wholly owned subsidiary of Cornell University, is a fiduciary of Cornell University in intellectual property matters and holds all intellectual property rights in SOFTWARE.

3. LICENSEE means the party to this Agreement and the user of SOFTWARE. By using SOFTWARE, LICENSEE enters into this Agreement with CRF.

4. SOFTWARE is made available under this Agreement to allow certain non-commercial academic research and classroom use.

5. LICENSEE is hereby granted permission to download and execute SOFTWARE for non-commercial academic research or teaching purposes provided that this notice accompanies all copies of SOFTWARE.

6. LICENSEE agrees that the export of SOFTWARE from the United States may require approval from the U.S. government and failure to obtain such approval will result in the immediate termination of this license and may result in criminal liability under U.S. laws.

7. The work leading to the development of SOFTWARE was supported in part by various grants from an agency of the U.S. Government, and CRF is obligated to comply with U.S. OMB Circular A-124 and 37 CFR Part 401. This license is subject to the applicable terms of U.S. Government regulations concerning Government funded inventions.

8. CRF provides SOFTWARE on an "as is" basis. CRF does not warrant, guarantee, or make any representations regarding the use or results of SOFTWARE with respect to its correctness, accuracy, reliability or performance. The entire risk of the use and performance of SOFTWARE is assumed by LICENSEE. ALL WARRANTIES INCLUDING, WITHOUT LIMITATION, ANY WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE OR MERCHANTABILITY AND ANY WARRANTY OF NONINFRINGEMENT OF PATENTS, COPYRIGHTS, OR ANY OTHER

INTELLECTUAL PROPERTY RIGHT ARE HEREBY EXCLUDED.

9. LICENSEE understands and agrees that neither CRF nor Cornell University is under any obligation to provide maintenance, support or update services, notices of latent defects, correction of defects, or future versions for SOFTWARE.

10. Even if advised of the possibility of damages, under no circumstances shall CRF or Cornell University individually or jointly be liable to LICENSEE or any third party for damages of any character, including, without limitation, direct, indirect, incidental, consequential or special damages, loss of profits, loss of use, loss of goodwill, computer failure or malfunction. LICENSEE agrees to indemnify and hold harmless CRF and Cornell University for any and all liability CRF or Cornell University may incur as a result of use of SOFTWARE by LICENSEE.