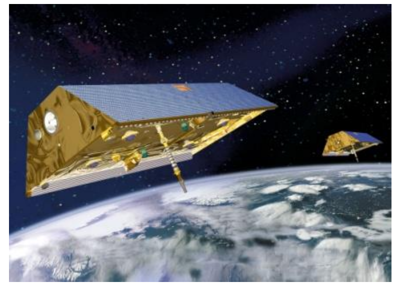
Title:	Using GRACE to evaluate change in Greenland's ice sheet
	Part I: Download, import and map GRACE data
	Part II: View and animate seasonal ice sheet mass changes
	Part III: Calculate and visualize annual ice sheet mass changes
	Part IV: Calculate annual mass loss rate
Product Type:	Curriculum
Developer:	Helen Cox (Professor, Geography, California State University, Northridge): helen.m.cox@csun.edu Laura Yetter (Research Asst., Institute for Sustainability, California State University, Northridge)
Target audience:	Undergraduate/Graduate
Format:	Tutorial (pdf document)
Software requirements*:	ArcMap 9 or higher (ArcGIS Desktop) (Parts I, II, III, IV), ArcGIS Spatial Analyst (Parts III, IV)
Data:	All data required are obtained within the exercise.
Estimated time to complete:	All parts: 5.5 hrs
	Part I: 2 hrs.
	Part II: 0.5 hrs.
	Part III: 1.5 hrs. - 2 hrs.
	Part IV: 1 hr.
Alternative Implementations:	• Part I provides a standalone exercise producing a map of ice sheet mass • Parts I and II together provide a standalone exercise producing an animation of seasonal change in ice sheet volume • Parts I, II and III together provide a standalone exercise to produce animations of seasonal and annual ice sheet volume changes • Completing all parts (I through IV) include calculations of the total decadal mass change and corresponding sea level rise
Learning objectives:	Part I: • Understand the GRACE satellites and how they measure gravity • Understand the application of GRACE to measure ice sheet volume • Download, import and map GRACE data
	Part II: • View GRACE data in ArcGIS • Create an animation of seasonal ice sheet changes
	Part III: • Create an animation of annual ice sheet volume • Generate images to show annual changes in ice sheet mass • Calculate change in ice sheet mass over past decade
	Part IV: • Compute annual and decadal ice sheet mass change • Compute sea level rise

*Tutorials may work with earlier versions of software but have not been tested on them

Using GRACE to evaluate change in Greenland's ice sheet
Part III: Calculate and visualize annual ice sheet mass changes



Objectives:

- Create an animation of annual ice sheet volume
- Generate images to show annual changes in ice sheet mass
- Calculate change in ice sheet mass over past decade

In this exercise you will create an animation of the annual changes in Greenland's ice sheet over the past decade allowing you to view the changes that have occurred. You will also generate difference images showing the year to year changes in ice mass and mapping where on the continent these changes are occurring. Some parts of Greenland may be gaining ice mass and others losing it (the effects of climate change are not geographically uniform throughout the world or even within a single continent).

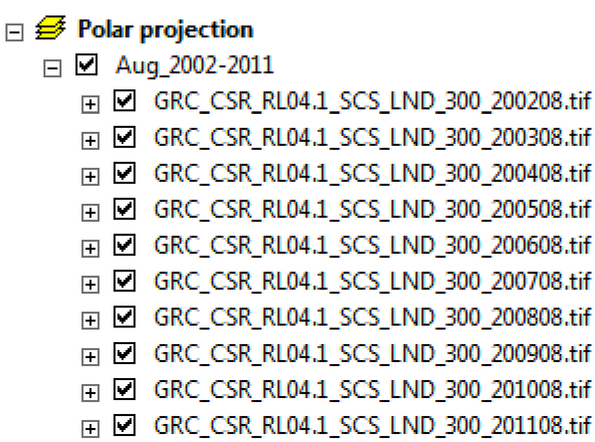
To see how the ice sheet has changed through the past decade we will display the year to year change for the same month from 2004 to 2011 on a map and quantify it. Let's use August as our minimum month and examine how ice in August has changed over the years.

Why should we just choose a single month for the analysis?

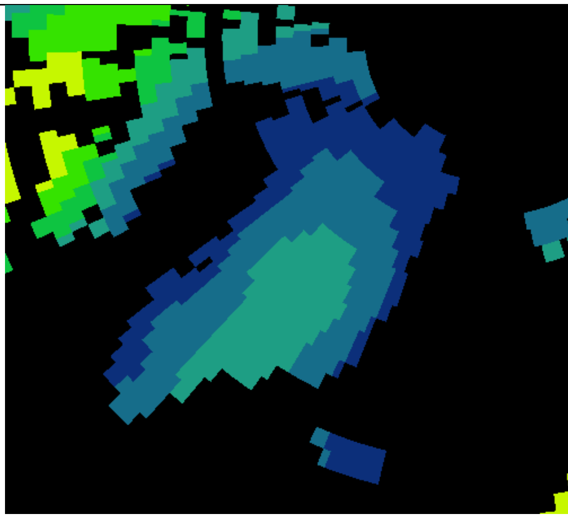
Why is August a good choice for this?

1. Download, and display the August image for all available years (2004 -2011). Download data from the same website ftp://podaac-ftp.jpl.nasa.gov/allData/tellus/L3/land_mass/RL05/geotiff/ as described in Pt I.

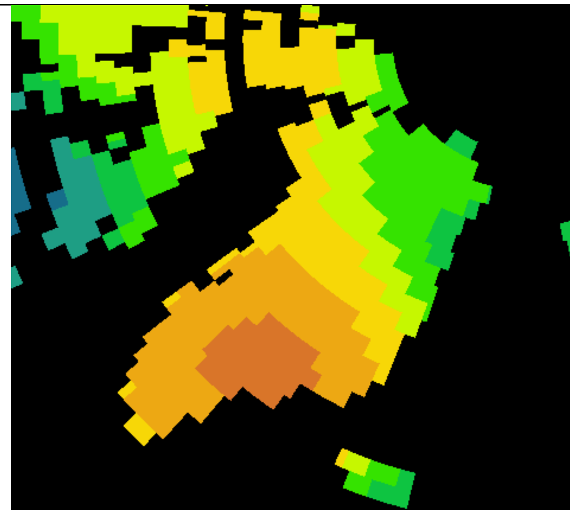
2. Give the layers the same symbology, and clip to shape as described in Pt I and II. Group as described in Pt II using an appropriate group name (like Aug_2004-2011):



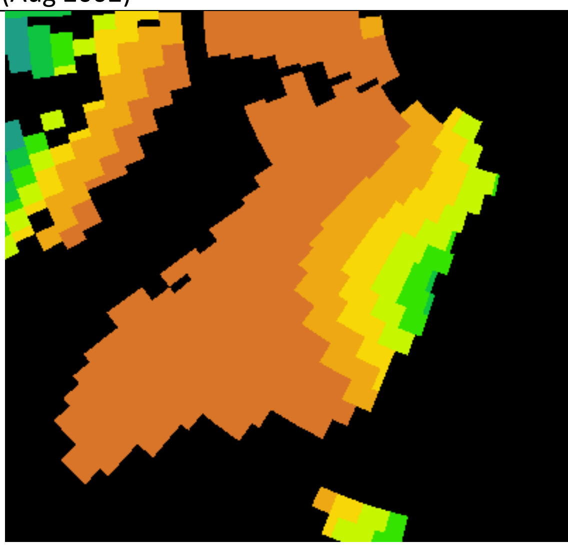
3. Create an animation through these as you did in Pt II for the months. What do you observe?



(Aug 2002)



(Aug 2007)



(Aug 2011)

- -99.99900055
- -99.99900054 - -13.77394159
- -13.77394158 - -7.58098155
- -7.580981549 - -3.76992922
- -3.769929219 - -0.911639973
- -0.911639973 - 1.470267733
- 1.470267734 - 3.85217544
- 3.852175441 - 6.710464687
- 6.710464688 - 11.4742801
- 11.47428011 - 21.47829247

The observed changes in gravity are caused by changes in mass. The mass changes can be thought of as equivalent to a very thin layer of water concentrated at the surface whose thickness changes. In reality, *much* of the change in gravity is indeed caused by changes in water storage in hydrologic reservoirs, by moving ocean, atmospheric and cryospheric masses, and by exchanges among these reservoirs. Some changes in gravity are caused by mass redistribution in the 'solid' Earth, such as that following a large earthquake, or that due to glacial isostatic adjustment; in those cases the concept of 'equivalent water thickness' does not apply, even though it is possible to compute the quantity. The mass of the atmosphere is removed during processing using ECMWF (weather data) fields, so the data shown do not reflect atmospheric variability over land or continental ice (Greenland, Antarctica), except for uncertainties in ECMWF.

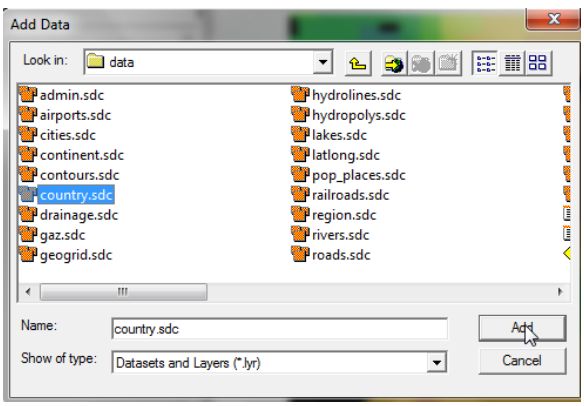
What are the units of the displayed data? Explain the units. (Refer to: http://grace.jpl.nasa.gov/data/gracemonthlymassgridsland/ if necessary.)

4. Add Greenland continent to the map. Now let's quantify the change that we observed and try to answer questions for the continent such as: How much ice mass has been lost over the 7 years between 2004 and 2011?

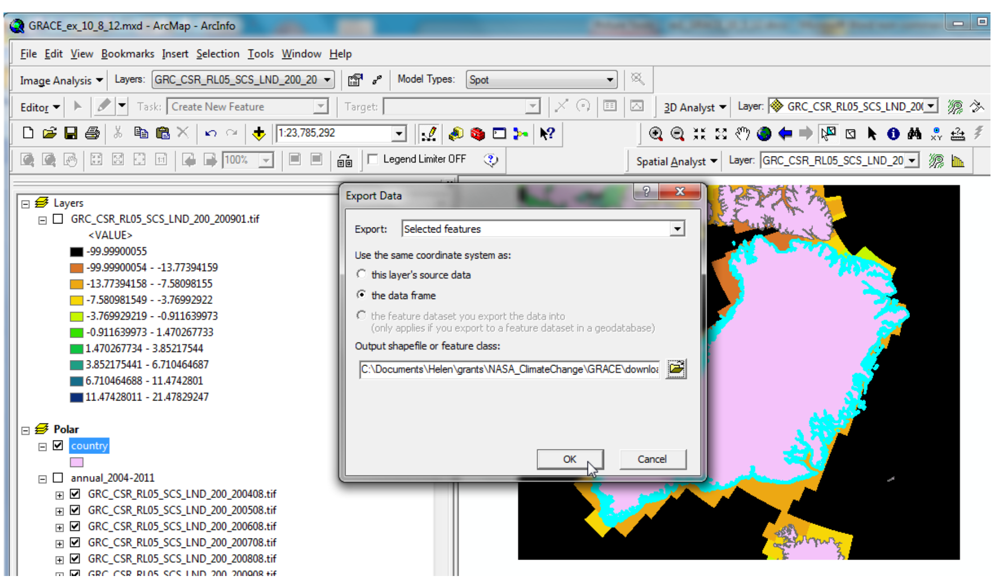
The mass of the Greenland ice sheet is derived from the gravitational pull that GRACE senses. The change in mass over the last 7 years can be calculated by finding the value of the cells that cover Greenland and knowing the size of Greenland.

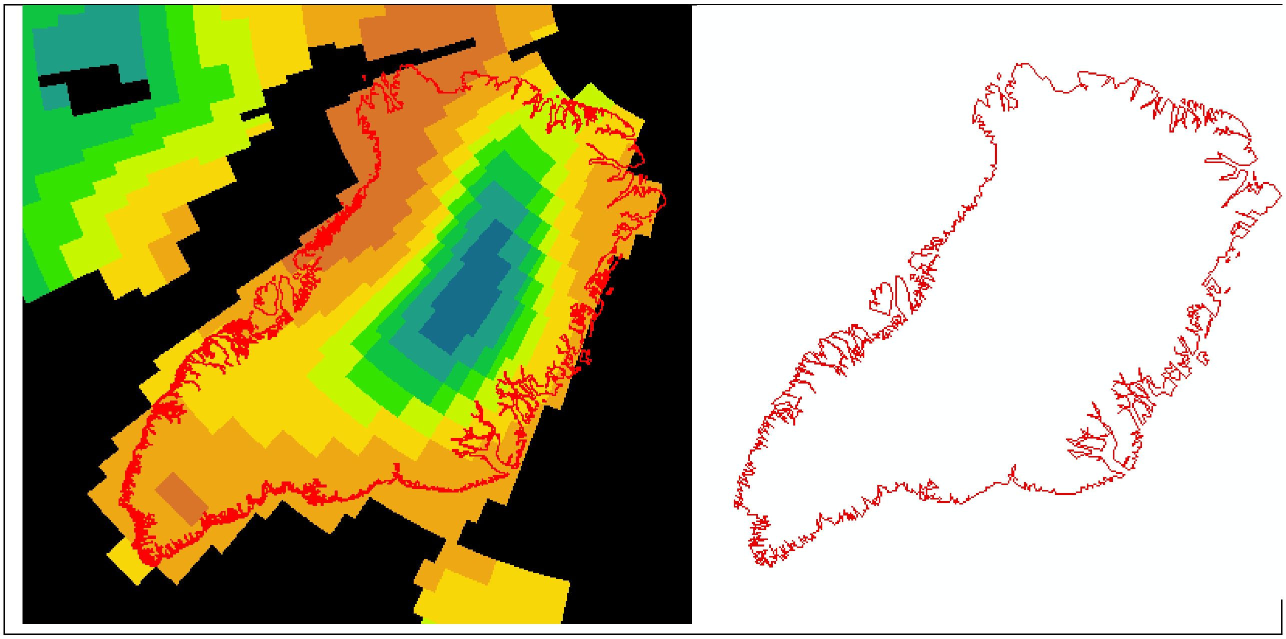
Let's look at the cells that fall within Greenland.

First, bring up an outline of the countries and make a shapefile of just Greenland. You can do this using ESRI's data under Add Data -> Data from ArcGIS online -> World Countries (in ArcGIS 9 this is under the File menu), or you may be able to find it under the department's GIS data (geogserver3\GIS_Data\ESRI Data 2010\DataMaps10\world) or just search online. Since ESRI changes their maps from time to time, the name of the data may be different.



Select just Greenland on the map and Export to its own shapefile. Display just the outline.

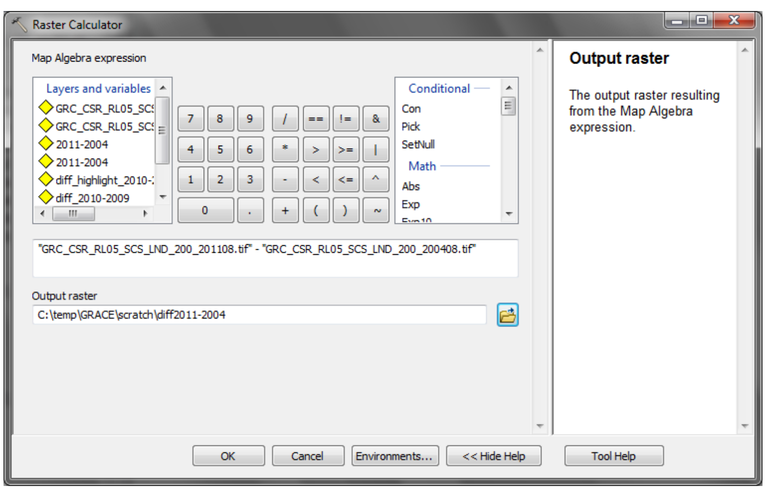




5. Calculate total mass loss of Greenland ice sheet between 2004 and 2011.

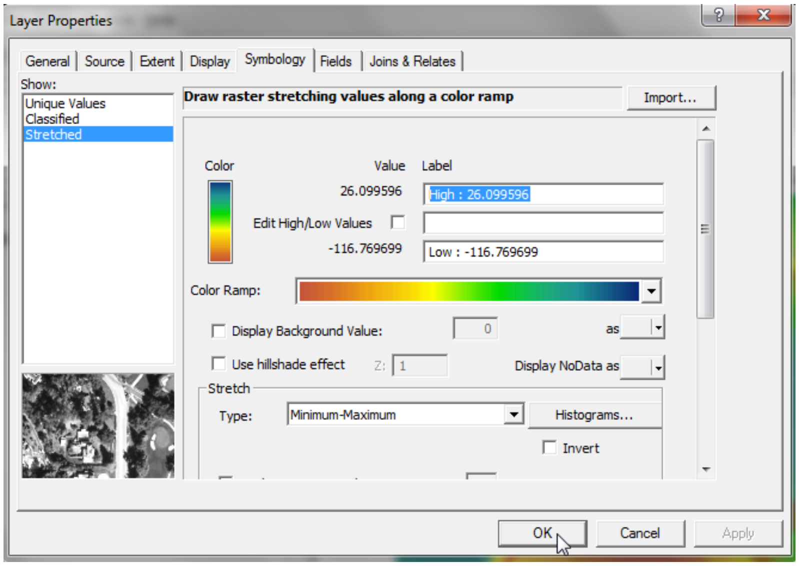
We will calculate the change in ice thickness by using the Raster Calculator within ArcMap.

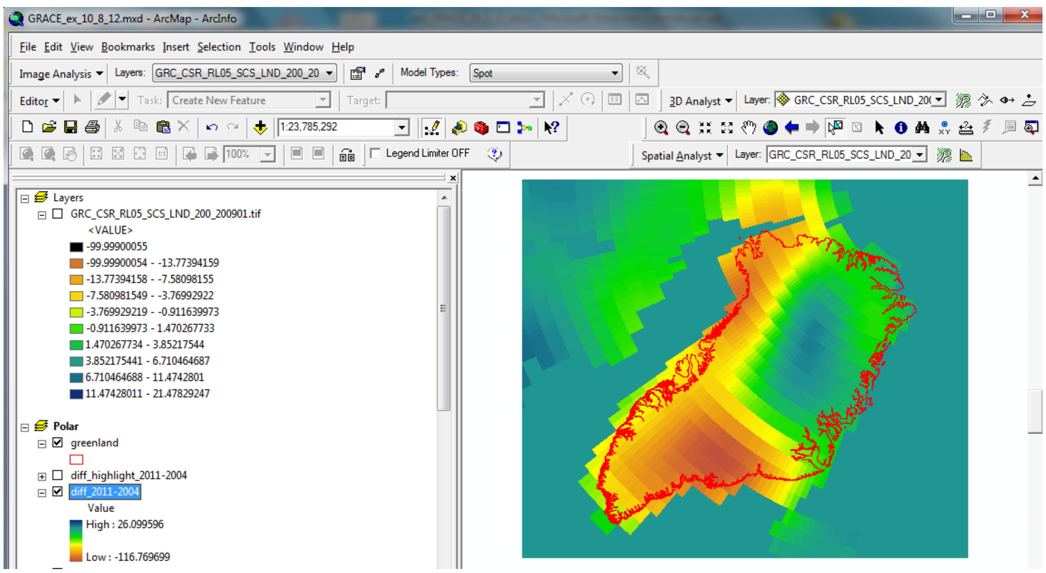
In ArcMap 10, go to Spatial Analyst > Map Algebra> Raster Calculator. (In ArcMap 9 the Raster Calculator can be found under the Spatial Analyst toolbar not in the toolbox.) Select the 2 images you want to compare (ex. 201108 and 200408) and generate a difference image for Aug 2011 relative to Aug 2004. Your equation should look like this.



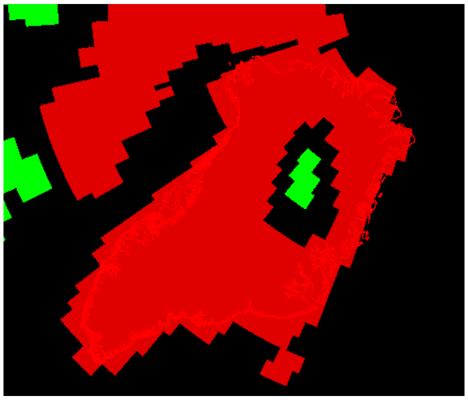
6. Display difference image for 2011 relative to 2004.

On the difference image, change the symbology to -> Stretched -> Stretch type: Minimum Maximum-> Color ramp (blue to red):



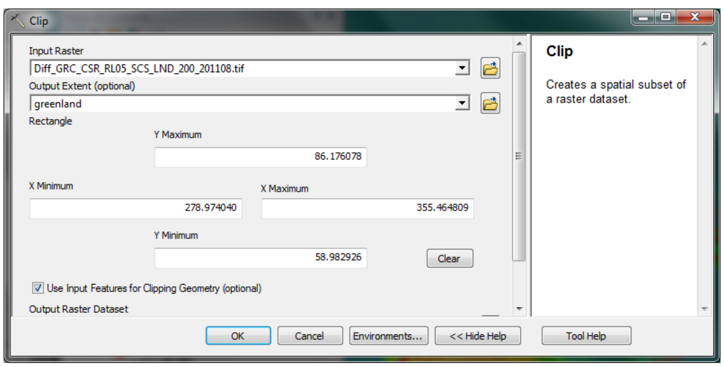


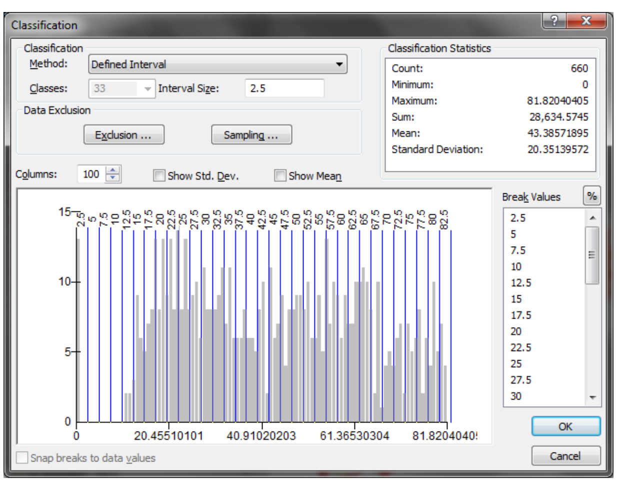
Quickly examine the highlights of where differences in ice mass are happening. Change the symbology to show where ice has decreased by 10% or more (set to color red), where it has increased by 10% or more (set color to green), and where there is no difference (set color to black). To do this change the symbology to Classified, number of classes 3, classify break values as -10, 0, highest value. Look at the highlights image:

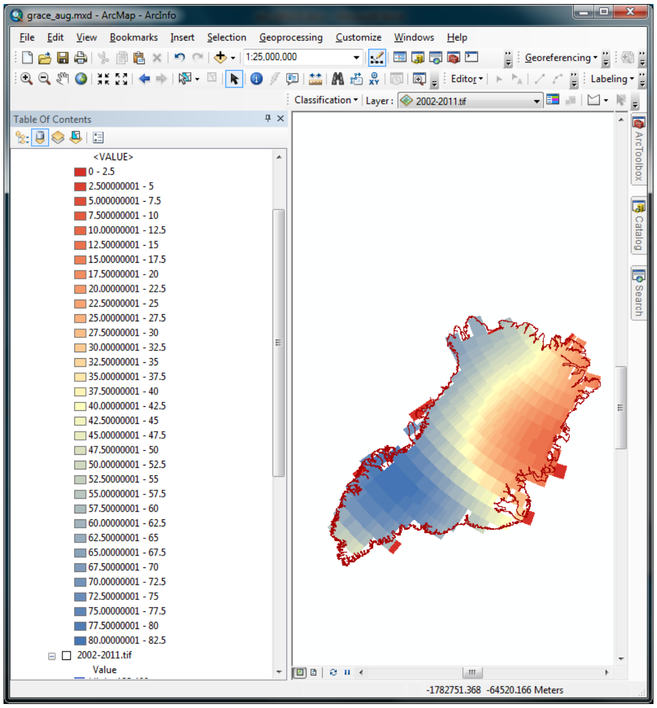


What does it tell you? Is Greenland gaining or losing mass? Is that true throughout the continent?

Change the symbology back to the difference stretched symbology. Clip the 2004-2011 difference layer to the Greenland shapefile (Data Management -> Raster -> Raster Processing -> Clip) and be sure to check the box 'Use input features for clipping geometry'. Change the symbology to classify with defined intervals of 2.5 (Classify-> define interval -> 2.5). You should see something like:







Now the map colors are easier to interpret.