Blair's Model Inter-comparison Project (BMIP-5)

Introduction

The goal of this project is to compare the performance of four climate models from the **AR5 Climate Model Mapper**. These models were selected because they have a wide range of climate sensitivity, and they support both Cloud Fraction and Precipitation in the Variable list. The models are:

CCSM4	US National Centre for Atmospheric Research
CSIRO-Mk3.6.0	Queensland Climate Change Centre of Excellence, Australia
GISS-E2-H	NASA Goddard Institute for Space Studies, USA
NorESM1-M	Norwegian Climate Centre

Methodology

I will first compare how successfully the models were able to simulate the changes in annual average temperature during the 20th century. We have the great advantage of knowing how the climate turned out, so we can test the results against reality. I will use the **CLIMATE TIME SERIES Browser** to do some of this verification.

Next I examine the temperature predictions for the models in the 21st century, using the high end RCP 8.5 scenario. This time we do not know the answers, so all we can look at is consistency between models.

Finally, I look at predictions for precipitation in the 21st century. Then I try to see if I can detect any relationship between cloud fraction and the climate sensitivity of the models.

Philosophy

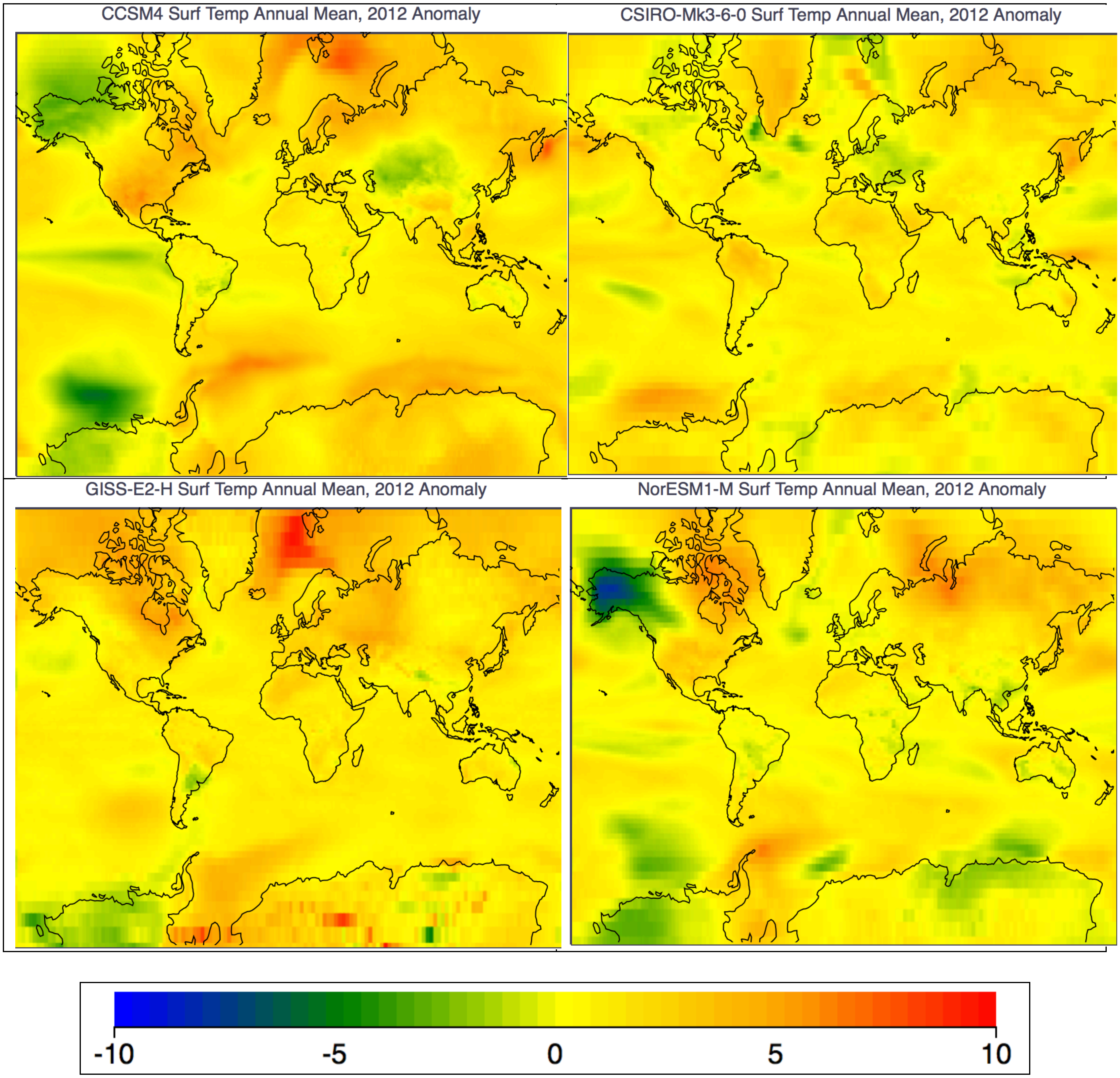
I am mainly working with images of world maps produced by the climate models. Therefore I have to use visual inspection rather than hard numbers. My expertise in the subject is of course limited, which is why I am taking this course. Therefore any conclusions I reach in this "BMIP-5" project are mostly subjective. The real CMIP-5 model comparison project is considerably more sophisticated.

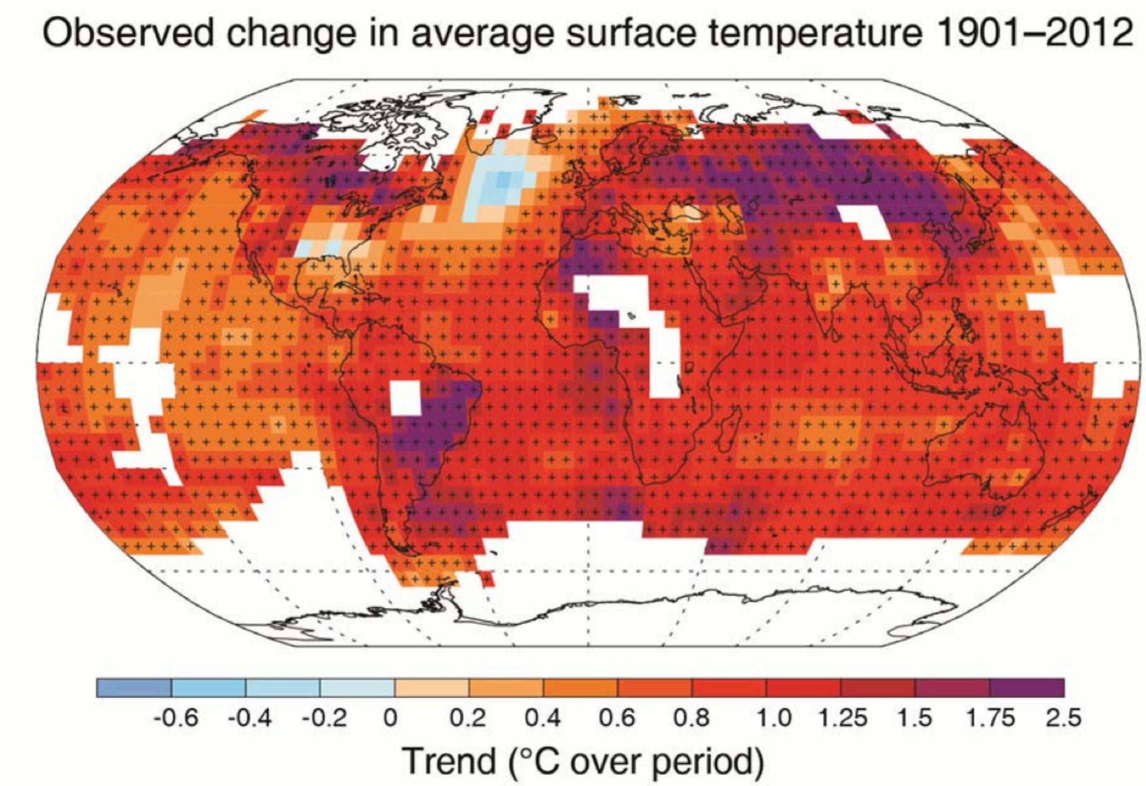
The difficulty with any study, especially one as subjective as this one, is the preconceptions and bias of the author. I am testing the models against what I expect them to achieve. My knowledge of climate theory leads me to expect more warming over land than the ocean, and more warming in the Polar Regions than the Tropics. I also expect some, but not perfect, consistency between models. These expectations probably affect my results.

In summary, this paper is more of an exploration than a conclusive investigation.

Temperature Changes in the Twentieth Century

Here I look at how well the four climate models are able to reproduce the climate of the 20th century. I compare the change in surface temperatures between 1900 and 2012, and verify them against the real world results on the next page. The results here do not really show the expected warming of continental interiors compared to the oceans. Increased warming in the Polar Regions is only weakly visible. Regional differences between models include Alaska (10 degrees cooling in NorESM1!), West Antarctica (3 models show cooling, CSIRO strong warming), and the ocean between Greenland and Europe (CCSM4 and GISS appear to have a stronger Gulf Stream).





Now I look at how well the model results compare with the real world. The map is taken from figure SPM.1 (b) in the Summary for Policy Makers of the IPCC AR5 report. Continental interiors clearly show more warming than the oceans, which was not so evident in the models. Polar amplification does not show up in this real world picture because the Polar Regions have no data.

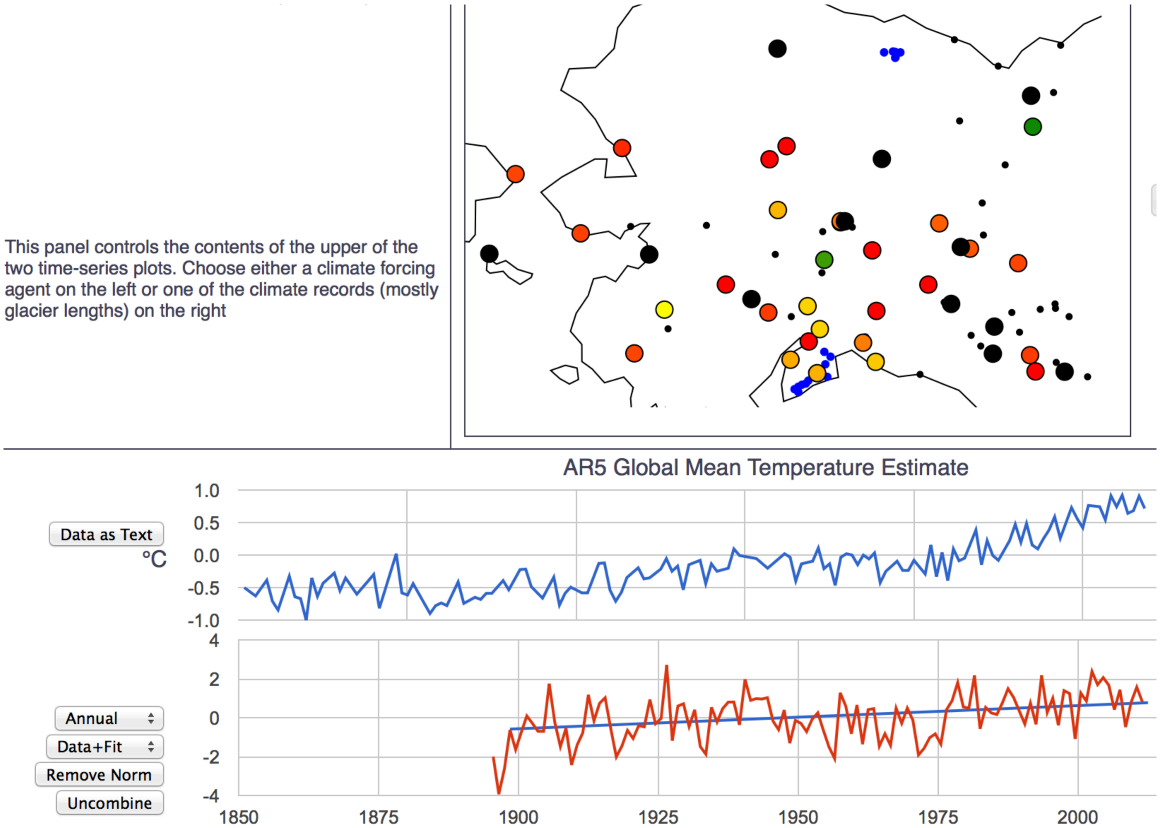
The table below rates the four models compared to the real world. Each model is rated from 1 to 10, with 10 being perfect. I rated each region by looking at the pictures and making a judgment. I picked six regions that had the most interesting results, but I could not rate West Antarctica. GISS performed a little better than the others, but I doubt this result is significant. The models all seem to perform poorly, getting no better than 32 out of 60, but that result is probably biased by choosing of regions with the greatest anomalies instead of a random selection.

	CCSM	**CSIRO**	**GISS**	**NorESM1**
Alaska	3	5	7	1
West Antarctica	Cool	Warm	Cool	Cool
Gulf Stream	3	8	2	7
Western Europe	7	2	8	4
Eastern Europe	7	1	8	5
Asia Interior	1	4	6	6
Eastern South America	3	6	1	3
TOTAL	**24**	**26**	**32**	**26**

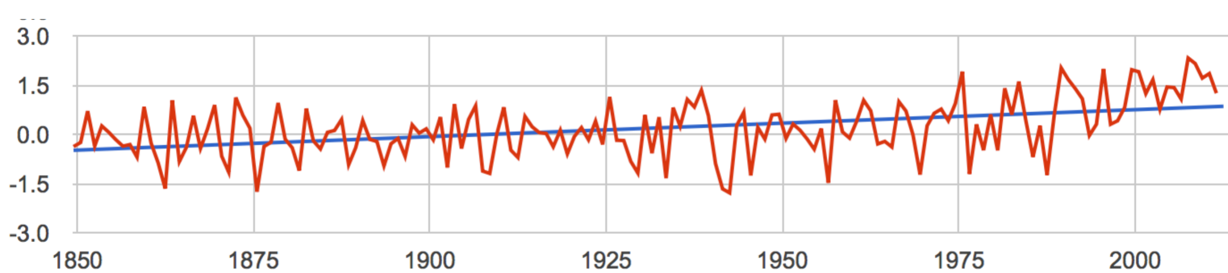
I conclude that the models get the big picture right, but there are problems with regional projections, even though the right answer is known in advance. We do not have that advantage when trying to project the future.

I now look at the temperature trend between 1900 and 2012 for three of the above regions, using the **CLIMATE TIME SERIES Browser**. I zoomed in on the region in question and selected all the stations.

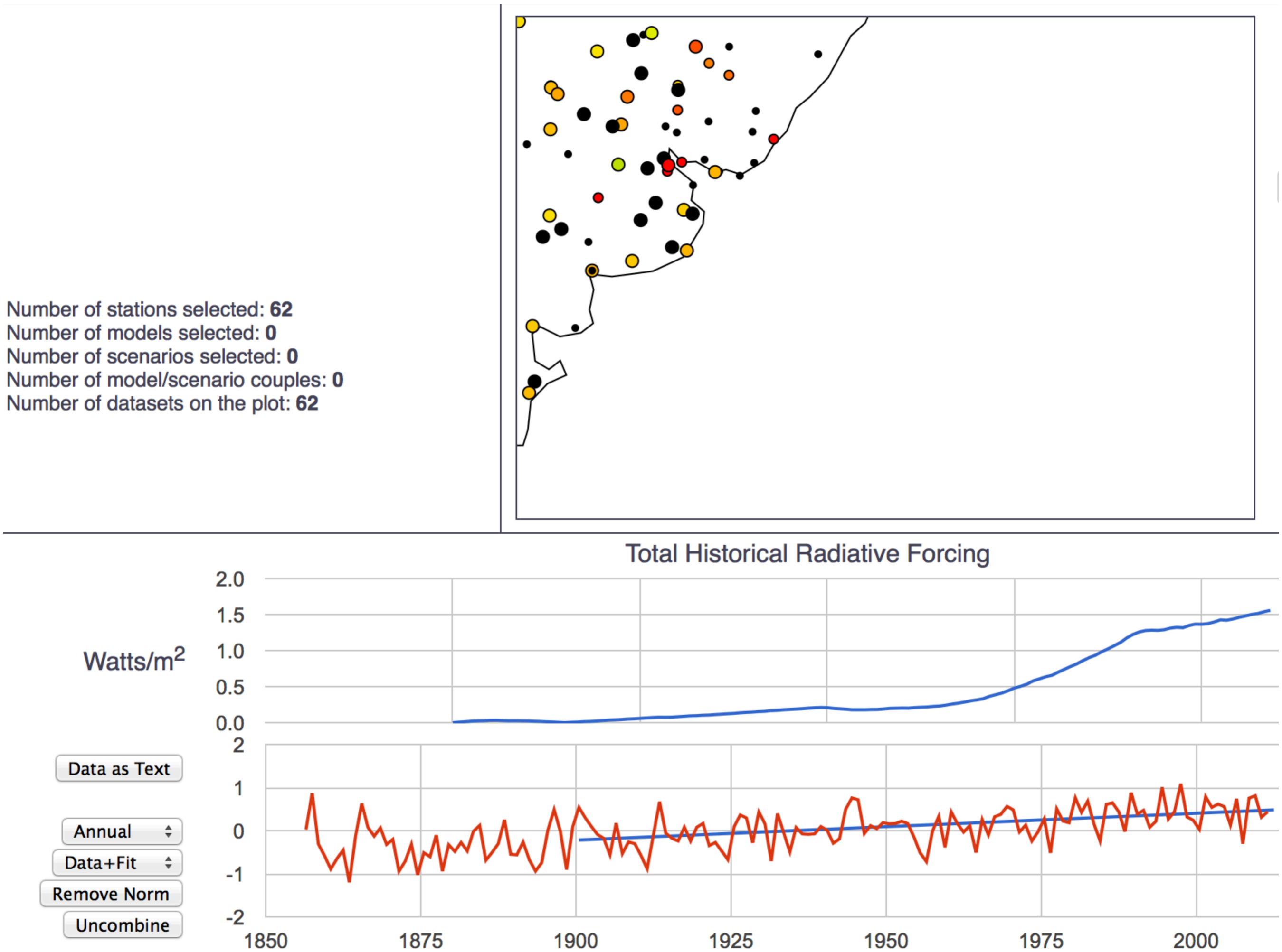
Alaska shows a clear warming trend, consistent with the real world results on the previous page, and in contrast to CCSM4 and NorESM1.



Below is the temperature trend for the region of **Eastern Europe** between the Black and Baltic seas, based on selecting 99 stations. Again we have a warming trend, in strong contrast to the CSIRO model.

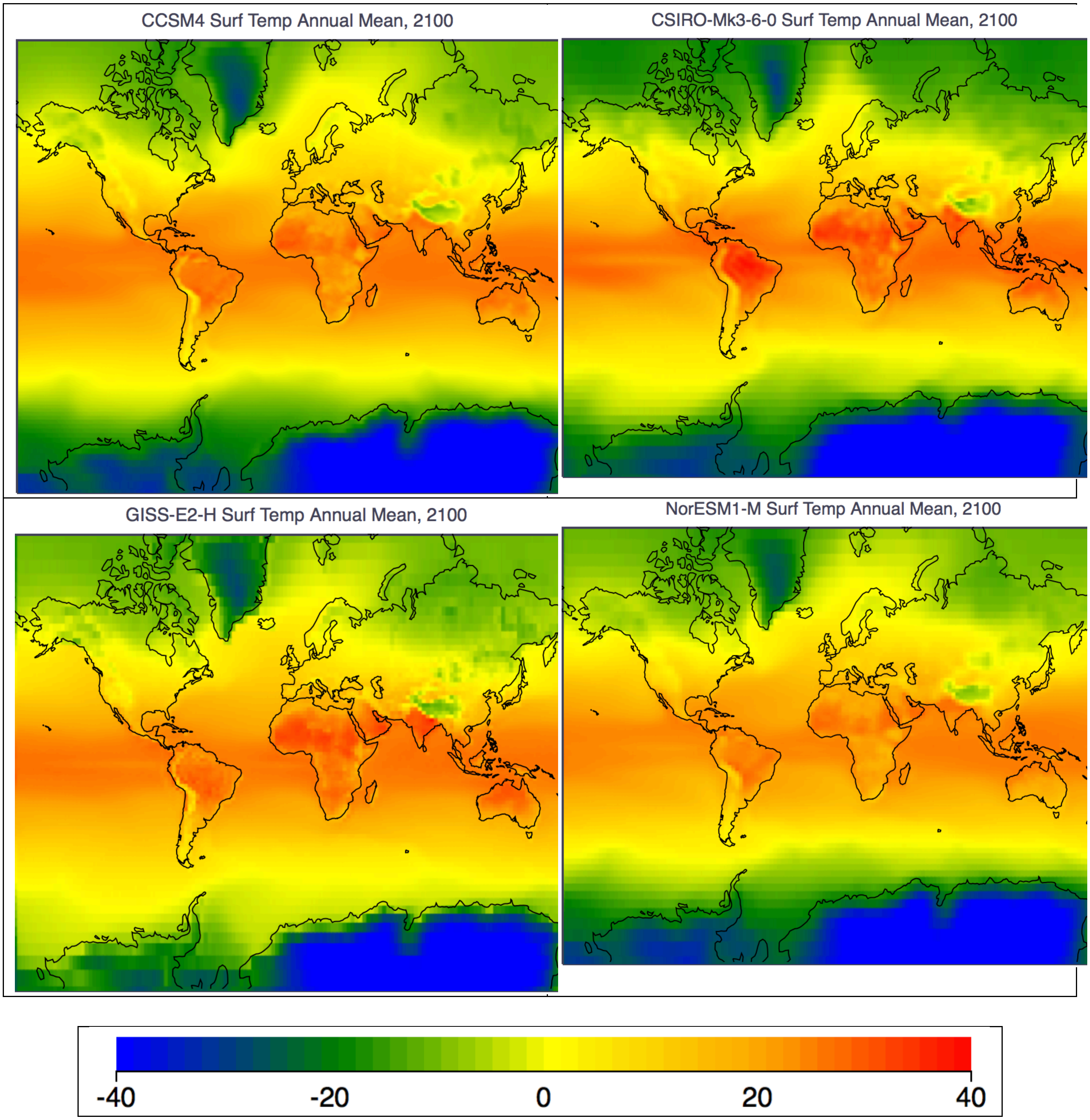


Eastern South America also shows no cooling trend, in contrast to the GISS projection.

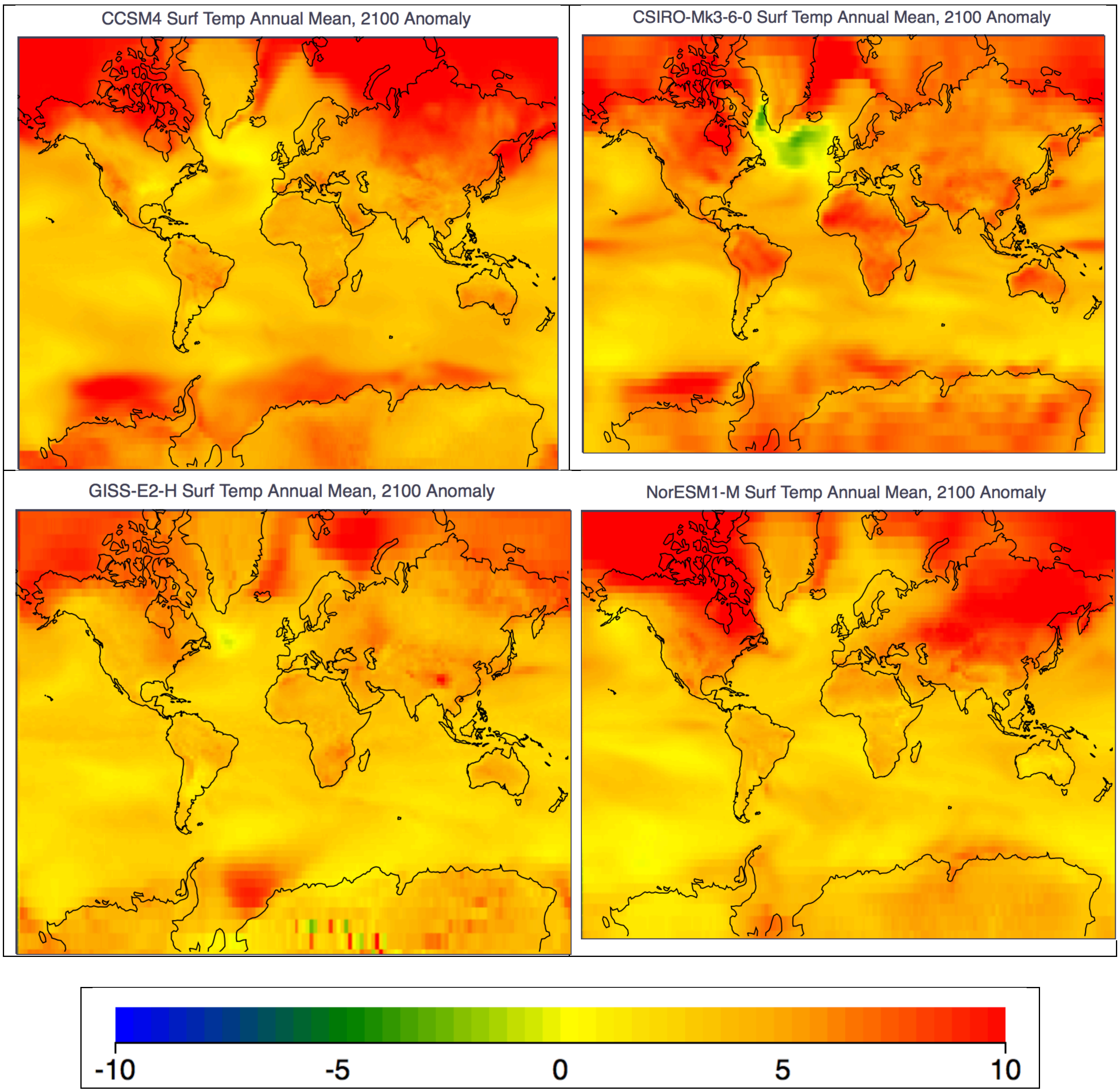


Evaluating Twenty First Century Temperature Projections

Now I look at the projections for the mean average surface temperature at the end of the 21st century. All such projections in this project are based on the high end RCP 8.5 scenario. We can see that all models produce the same general pattern, which is not very different than today except warmer. CSIRO has a colder Arctic, while GISS has a warmer Antarctic. CSIRO and GISS show warmer tropics. Paleoclimate studies of warmer climates tend to show less tropical warming and more polar warming than these models (especially CSIRO and GISS) predict. But see Appendix A for a discussion about models and paleoclimate.

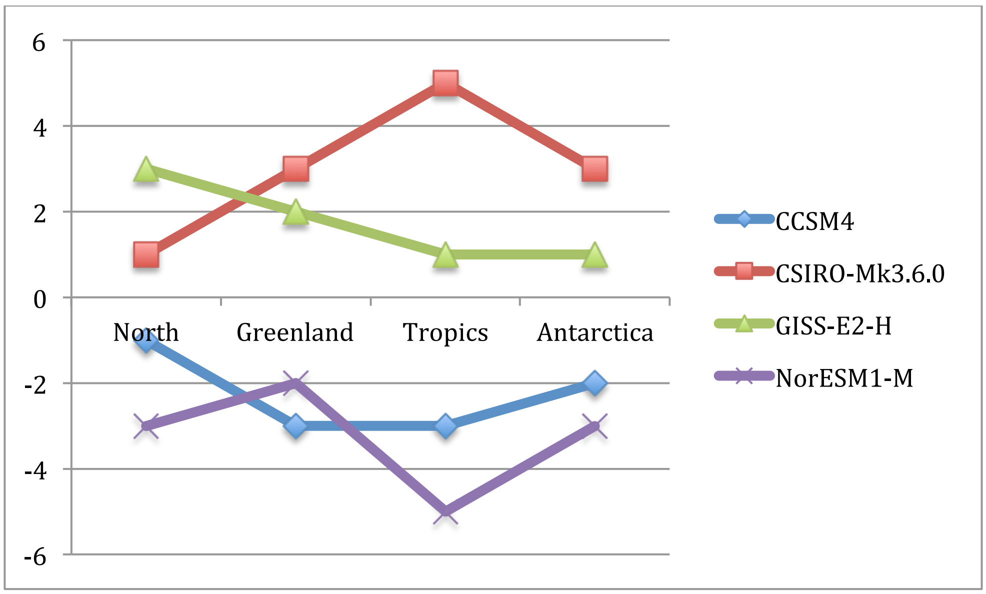


Now we make the same comparison using the calculated anomalies between the 2100 and 2000 results from each model. Note that the year 2000 starting point is the result of the models running from much earlier. That means each model has a different starting point, therefore the anomaly results below sometimes differ from absolute results above. The striking feature is strong cooling in the North Atlantic in the CSIRO model, even after a century of high end warming. CCSM4 and NorESM1 both seem to project a stronger Gulf Stream than the other two models. All project strong Arctic warming, but distribute it differently. CSIRO shows warmer tropics than the other models. The tropical warming seen in the GISS model above does not show up here.



Here I attempt to quantify the differences between the models, by visually inspecting the anomaly charts above. I divided the world into four regions. Greenland behaved so differently that I chose to make it a separate region. I assigned the temperature differences on a scale of -3 to +3, except for the tropics, which are -5 to +5 to account for their larger area. The table at the bottom shows the Equilibrium Climate Sensitivity for all four models, obtained from the IPCC AR5 report. CSIRO has the highest sensitivity, which agrees with the warmer temperature differences on the graph.

	North	Greenland	Tropics	Antarctica
CCSM4	-1	-3	-3	-2
CSIRO-Mk3.6.0	1	3	5	3
GISS-E2-H	3	2	1	1
NorESM1-M	-3	-2	-5	-3



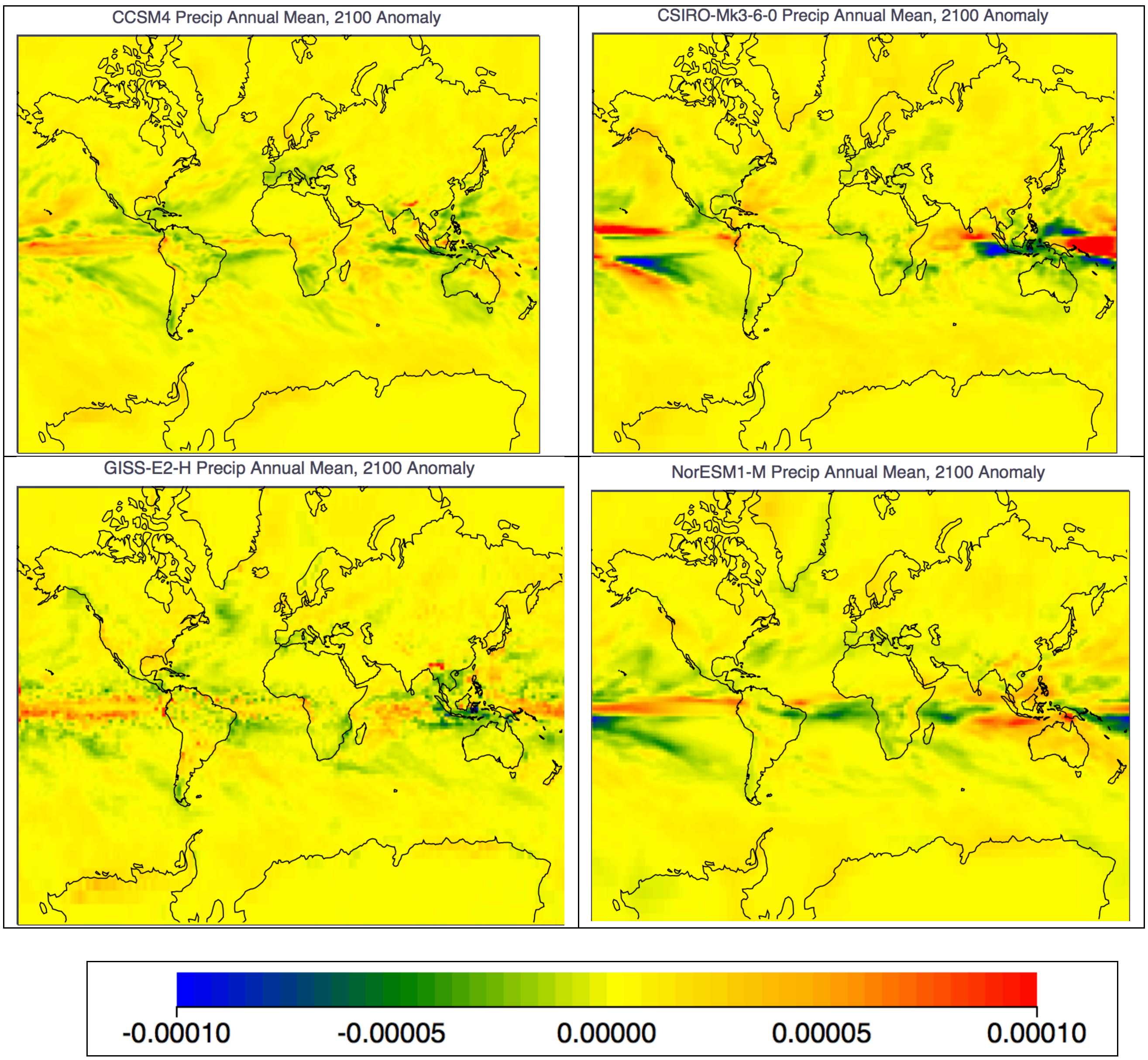
Results from IPCC AR5 WG1, Table 9.5

	Radiative Forcing Fixed SST	Regression	Climate Sensitivity Equilibrium	Transient	Cloud Feedback
CCSM4	4.4	3.6	2.9	1.8	-0.4
CSIRO-Mk3.6.0	3.1	2.6	4.1	1.8	
GISS-E2-H		3.8	2.3	1.7	
NorESM1-M		3.1	2.8	1.4	0.3

Precipitation

The primary effect of increasing greenhouse gases in the atmosphere is to raise global temperatures. Models are able to simulate this effect reasonably well, with some problems at regional scales. Precipitation is a secondary effect of rising temperatures, and is therefore much more difficult to model. This is evident in the precipitation anomaly charts below. Most precipitation happens near the equator, and this is where the strongest effects in the models are observed. We mainly see a small shifting of precipitation bands.

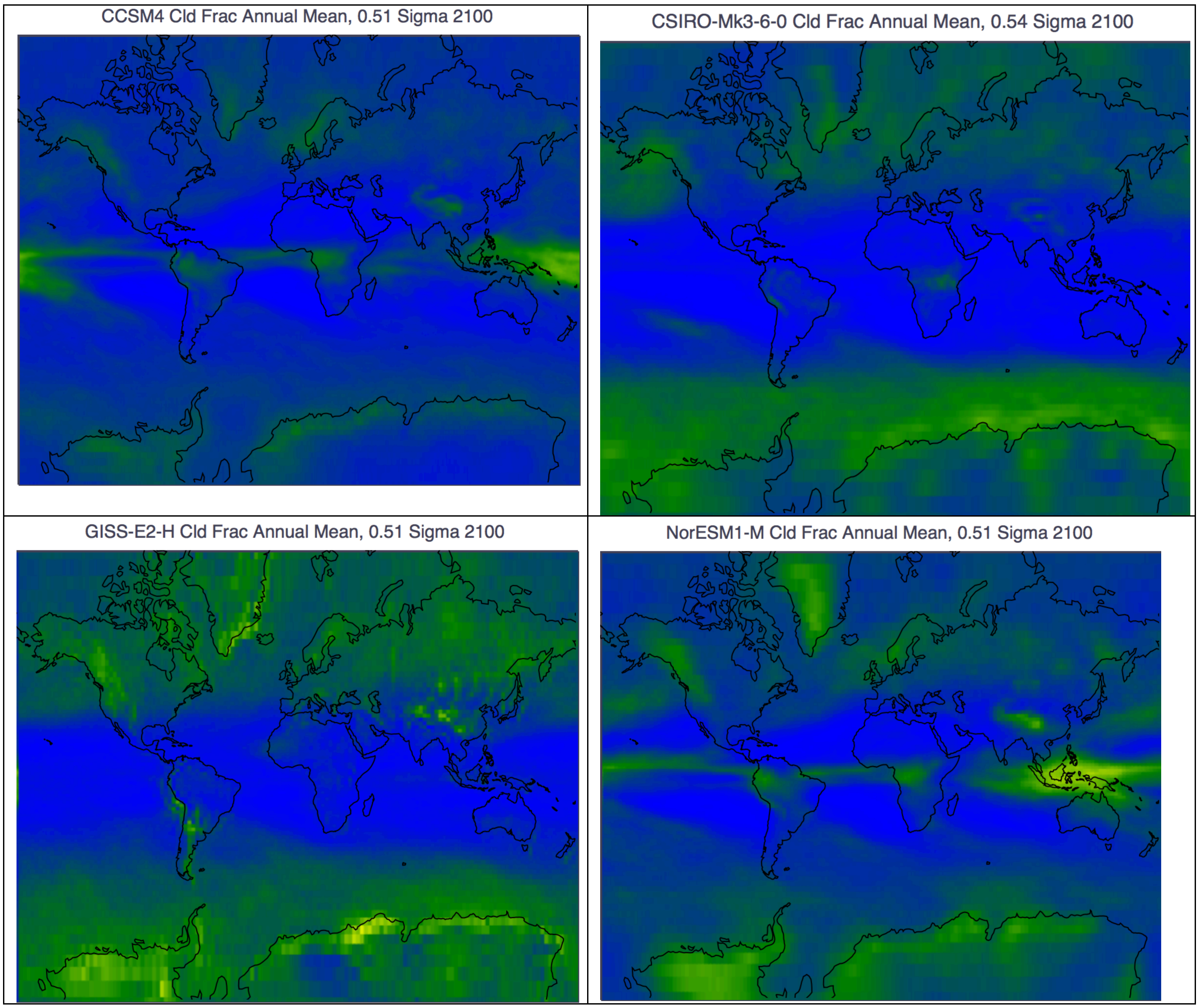
The most basic theoretical effect of rising temperatures should be the shifting of climate zones toward the poles. This is not very evident, except perhaps in western Mexico and southern Europe. Other than that, the precipitation patterns look rather random, and are not consistent between models. I think we can conclude that outside the tropics the models are not yet up to the job of predicting changes in precipitation, other than the high chance that it will change one way or another in a warmer climate.



Cloud Fraction

I was hoping to see if there was any connection between cloud fraction and climate sensitivity, based on the fact the clouds are the largest source of uncertainty in the models. The anomaly feature did not work, so I have to use the total cloud fraction. The results here look totally random. Two models have a band of clouds in the tropics (as one would expect) and two do not. GISS has the north and south parts of the world relatively cloudy, while CCSM4 does not.

There is some discussion in the scientific media about the importance of reporting negative results, and the bias that may result from not doing so. For example, failure to report inconclusive results from a drug trial will make the drug look better than it really is. In that spirit, I am reporting that I can make no sense out of the cloud fraction results from my selected models.



Conclusions

Climate models do a reasonable job of predicting the annual average temperatures for the 20th century. It seems that all the models have some difficulty getting regional temperatures right, even though the results were known in advance. This demonstrates that the models are not rigged to give the desired results; they really do attempt to model the physics, and do not always fully succeed.

One might expect that all the models would be initialized with the same real-world results for the starting year. Instead the models all start by simulating the entire 20th century. This means that the 21st century has a different starting point for each model. This makes a more rigorous test of model skill, but it makes comparing model results a little more difficult.

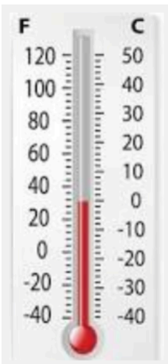
After applying a great deal of warming in the high end RCP 8.5 scenario, the model results for the 21st century produce the expected pattern of warmer continental interiors and polar amplification. The models show significant warming in the tropics, which I discuss in appendix A. There are still significant regional differences between the models. It is a bit hard to believe the CSIRO prediction that there will be 5 degrees of cooling in the North Atlantic after all this warming.

The precipitation predictions for the 21st century seem to be even more erratic except near the equator. I do not think we can have much confidence in these predictions. If a city planner were to ask how much precipitation can be expected in one hundred years, to plan the capacity of the drainage system, all we can say is that it might rain more, or maybe less. But there is a very good chance that it will be different than today.

I made an attempt to link cloud fraction with the climate sensitivity of the models, but I could make no sense out of the results I got.

Appendix A: Models and Paleoclimate Studies

Paleoclimate studies consistently show relatively little warming in the Tropics compared to the Polar Regions in warmer climates. One might be tempted to conclude that since the models contradict this data, the models must therefore be wrong. But first one should take a closer look where this "data" comes from. The short answer is "instruments". And these instruments are based on theories, which means that they are also models.



For example, a simple thermometer really only measures the expansion of a liquid in a tube. Our theory is the thermal molecular motion of the air molecules will be transferred to the liquid, causing it to expand. The number and the lines on the instrument are a model that converts the amount of that expansion into a temperature we can understand. This device has two different models, one for each temperature scale. If the sun shines directly on the thermometer, the temperature reading will be much higher than the actual air temperature. The model is wrong because it failed to take into account the effect of the sun's electromagnetic energy directly interacting with the liquid. Instruments need to be interpreted with care. The data they produce is sometimes not accurate.

Paleoclimate data consist of a set of temperatures measured at a specific location at a certain date in the past. The location information is probably reliable. Temperatures are measured using proxies, such a finding a certain type of pollen from a plant that grows only in certain climates. Such models are more much complex and error-prone than our simple thermometer. Similarly, the standard geological dating techniques, which tell us when those temperatures were supposed to have occurred, are also models, with their own problems.

Even if we trust the temperature, geological dating has a limited precision. This could be important if the climate is constantly changing because of the 22,000-year precession orbital cycle. If you think of the graph of the temperature as moving up and down like a wave, it is possible that our proxy pollen only shows up during the peak of those waves. But the dating may not be precise enough to tell where we are in the cycle, so we interpret the peak temperature as being the average temperature.

Perhaps more relevant for assessing climate models, the climates we measure in the past are probably in equilibrium. The climate that we are modeling is in a rapid transition. It is possible that on a time scale of one hundred years the tropics will warm, but in a thousand years some process will occur that transfers much of that warming to the poles. Thus our climate models and the paleoclimate measuring models could both be right, on the appropriate time scale. Or maybe they are both wrong for other reasons.

We have to accept some uncertainty when we are dealing with climate. But we should avoid assigning too much certainty to those model results that call themselves "data".