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Lesson 7 - Projected Climate Changes, part 1

The links below provide an outline of the material for this lesson. Be sure to carefully read through the entire lesson before returning to Canvas to submit your assignments.

Introduction

About Lesson 7

With plausible greenhouse gas emissions scenarios now in hand, we are ready to begin looking at future climate change projections. We will start out by looking at the basic attributes of the projections—changes in surface temperature, atmospheric and oceanic circulation changes, patterns of rainfall and drought, and the climate mechanisms that may influence climate changes at regional spatial scales.

What will we learn in Lesson 7?

By the end of Lesson 7, you should be able to:

- assess the impact of hypothetical pathways of future greenhouse gas emissions on global temperatures in the context of the estimated uncertainties; and
- assess potential impacts of projected climate changes on patterns of rainfall and drought patterns, ocean and atmospheric circulation, and modes of climate variability.

What will be due for Lesson 7?

Please refer to the Syllabus for specific time frames and due dates.

The following is an overview of the *required activities* for Lesson 7. Detailed directions and submission instructions are located within this lesson.

- Take Quiz #2.
- Read:
  - IPCC Fifth Assessment Report, Working Group 1 [1]
  - Summary for Policy Makers [2], Future Global and Regional Climate Change
    - E.1 Atmosphere: Temperature: p. 20
    - E.2 Atmosphere: Water Cycle: p. 20-23
    - E.3 Atmosphere: Air Quality: p. 24
  - Dire Predictions, v.2: p. 98-103

Questions?

If you have any questions, please post them to our *Questions?* discussion forum (not e-mail) located under Home tab in Canvas. The instructor will check that discussion forum daily to respond. Also, please feel free to post your own responses if you can help with any of the posted questions.

Surface Temperature Changes

When it comes to climate change projections, the most obvious first thing to look at is the increases in global mean temperature projected by the climate models. When we do that, we are immediately confronted with two major uncertainties each of a fundamentally different nature.

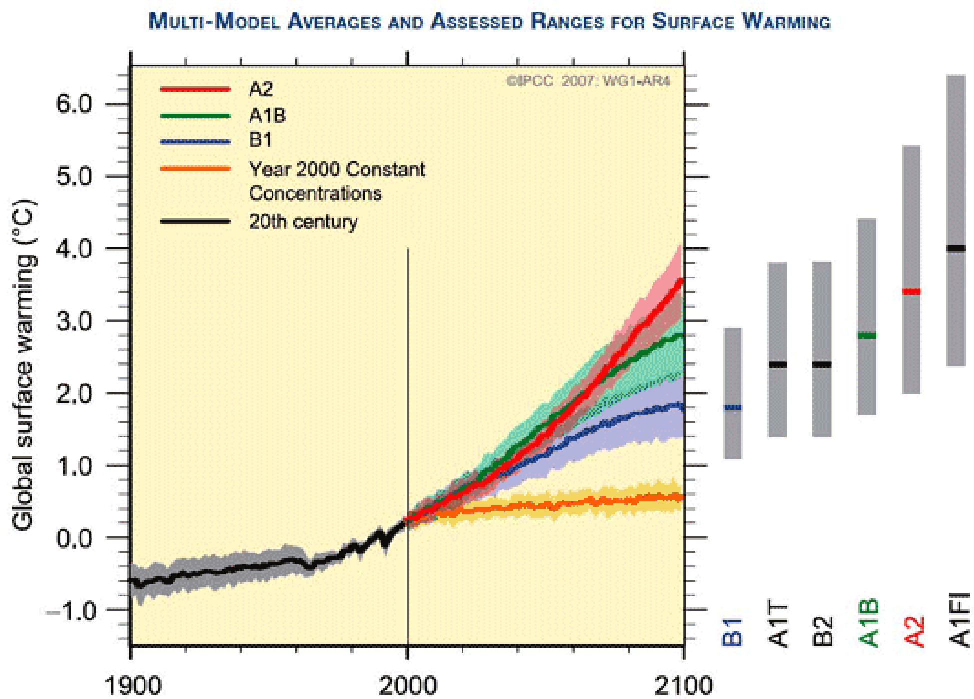

Figure 7.1: Model Projections of Future Warming Under Various Emissions Scenarios.
Credit: IPCC, 2007

The first of the two uncertainties is the *scenario uncertainty*, and is represented by the different families of color-shaded regions in the graph below. It corresponds to the uncertainty in what pathway of future behavior *we* will follow. That uncertainty, in a crude sense, is spanned by the various SRES scenarios explored in the previous lesson. In reality, this set of scenarios alone implies greater constraint on the true spread of potential future pathways of anthropogenic activity, since there are numerous wild-cards, including (i) future anthropogenic aerosol emissions and (ii) potential carbon cycle feedbacks which may accelerate the rate at which the airborne fraction of $\mathrm{CO_2}$ increases with future emissions. That having been said, it is likely that a lower bound corresponding to fixed $\mathrm{CO_2}$ concentrations and an upper bound specified by the A1FI scenario, reasonably brackets the range of future emissions pathways that human civilization will choose to follow.

The second of the two uncertainties is the *physical uncertainty*, and it corresponds to the width of each of the shaded regions (the width of the shading indicates the one standard error range among the 20+ models used in the IPCC assessment; the wider gray bars shown on the right indicate the full range of warming over all 20+ models). Much of this uncertainty comes from the previously discussed uncertainty in cloud radiative feedbacks. On average, as we know from our previous lesson, cloud radiative feedbacks are estimated to be negative. The uncertainty, however, is huge. Among the 20+ models used in the IPCC assessment, the cloud radiative feedback for $\mathrm{CO_2}$ doubling varies anywhere from around $-2W/m^2$ (offsetting roughly half of the direct radiative forcing by the $\mathrm{CO_2}$ increase) to nearly $+2W/m^2$ (adding nearly half of the radiative forcing due to the $\mathrm{CO_2}$ increase alone).

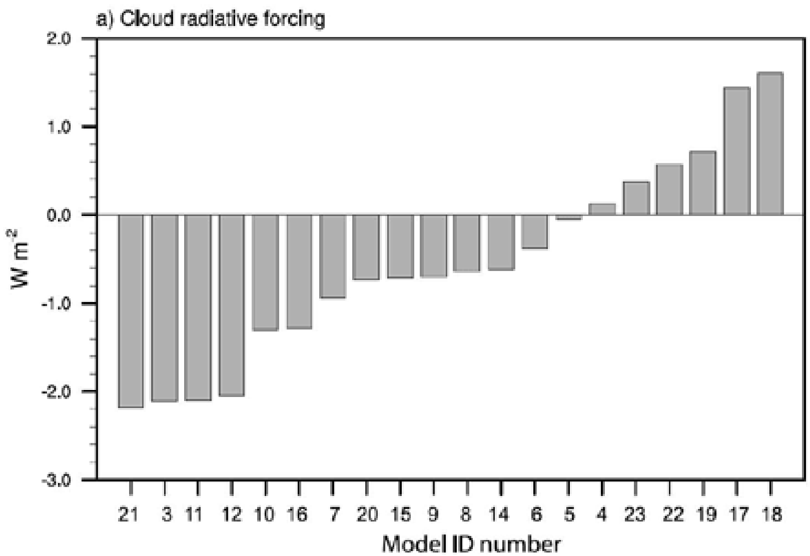

Figure 7.2: Cloud Radiative Forcing for Various IPCC Models.
Credit: IPCC, 2007

Collectively, the various scenarios and their physical uncertainty ranges span a very large spread of projected warming for the next century. In the most optimistic of scenarios—indeed, an arguably unrealistic scenario—where we could manage to keep $\mathrm{CO_2}$ fixed at the year 2000 concentration (this would require immediate cession of all activities—including fossil fuel burning, deforestation, etc.—contributing to anthropogenic $\mathrm{CO_2}$ emissions), warming nonetheless persists for decades owing to the "commitment to warming" we investigated in the previous lesson in our EdGCM experiments. This is warming already in the pipeline but not yet realized because of the delayed response of ocean warming to greenhouse gas concentration increases that have already taken place. The additional warming by 2100 might be anywhere between 0.2 and 0.6°C depending on the precise sensitivity of the climate, with most likely warming of 0.4°C. At the upper end of the scenarios is the A1FI scenario, which yields anywhere from 2.5 to 6.5°C additional warming (with the most likely warming of about 4°C) depending, again, on the sensitivity of the climate. Interestingly, we find that the *scenario uncertainty* and *physical uncertainty* are, in a sense, of nearly the same magnitude. While the most likely warming (i.e., the central estimates for each scenario) ranges from 0.4 to 4°C, i.e., just under a range of 4°C, the range for any one scenario (i.e., A1FI, which ranges from 2.5 to 6.5°C warming) also corresponds roughly to a maximum 4°C range. In this sense, roughly half the spread shown in the various projections of future warming is under our control, i.e., it depends on choices *we* make about future emissions.

There is so much focus on climate projections through 2100 that it is easy to lose sight of the fact that the climate does not magically stop changing at 2100 in the emissions scenarios we have been exploring—indeed, there is, in many cases, significant additional warming and associated changes in climate for several more centuries.

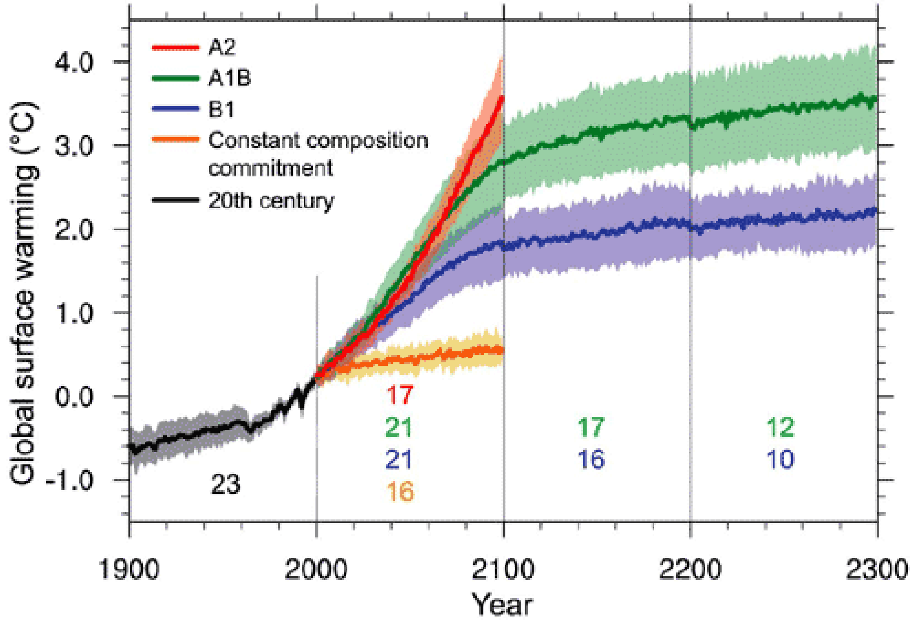

Figure 7.3: Extended Model Projections of Future Warming Under Two IPCC Emissions Scenarios.
Credit: IPCC, 2007

We already discussed that global warming is not predicted to be uniform. High northern latitudes are expected to warm more and faster due, in large part, to the positive ice-albedo feedback, which becomes very strong as Arctic sea ice melts. Land regions are expected to warm faster than ocean regions owing to the ocean's delaying thermal inertia. Some regions will warm more than others, and some may even cool slightly, due to changing atmospheric and oceanic circulation patterns.

Can we see this effects in the actual spatial temperature patterns projected by a state-of-the-art climate model? Let us take a look—we are going to examine the yearly average spatial patterns of surface temperature change in a simulation of the GFDL CM2.1 coupled model (one of the models that contributes to the 20+ member IPCC model ensemble we have been looking at), subjected to the A1B scenario, as it evolves over the entire course of the 21st century.

As you watch the animation below, take note of the overall pattern of warming. Note the latitudinal breakdown of the warming shown to the right of the map. What patterns do you see—are they what you expect? Take note of the variability, both spatially and temporally. Do you see events that resemble El Niño events? Are there any particularly conspicuous, persistent anomalies that emerge over time which you did not expect? You might want to restart the video several times so you can absorb all of the information contained in the animation.

Think About It!

One anomaly you may have noted is the cooling in a small region of the North Atlantic south of Greenland. Any idea what might be responsible for that?

Click for answer.

How much did the model warm in the global mean from 2000 to 2100? How does this compare to the overall spread of projected warming for the A1B scenario shown earlier? If you had to make an educated guess, what "model number" might you suspect this is, looking at the figure comparing cloud radiative forcing for the different IPCC models? Why?

Click for answer.

Surface temperature changes are of course just one of a myriad effects of anthropogenic climate change. Equally if not more important, in terms of its impact on civilization and our environment, are the shifts in rainfall and drought patterns. What do the models have to say about this?

Precipitation and Drought

As we alluded to earlier in the course, climate change is projected to lead to a poleward expansion of the Hadley Cell circulation pattern, which results in an expansion of the zone of subsiding, dry air well out of the subtropics into middle latitudes. This is particularly true in the summer when the ITCZ, jet stream, and polar front shift furthest poleward. As a result, we see decreased rainfall over the large parts of the subtropics through the mid-latitudes, including large parts of North America and Europe. Rainfall increases in the deep tropics where more water vapor is available to be squeezed out of the air and turned into rainfall as it rises within the ITCZ, which migrates north and south of the equator over the course of the year. Large rainfall increases are also seen in sub-polar latitudes owing to a combination of (a) the poleward shift of the jet stream and polar front, bringing this secondary band of rising atmospheric motion further toward the pole and (b) the effect of increased atmospheric moisture, meaning that where it rains, there will be more of it.

In comparing the spatial pattern of precipitation changes (panel *a) Precipitation*) with that of soil moisture (panel *b) Soil moisture*), we might initially be somewhat surprised. The pattern of soil moisture suggests decreases in soil moisture over most of the continents of the world, even in those regions (e.g., the high boreal regions of North America and Eurasia) which see substantial projected *increases* in precipitation. This might seem like a paradox. Is it?

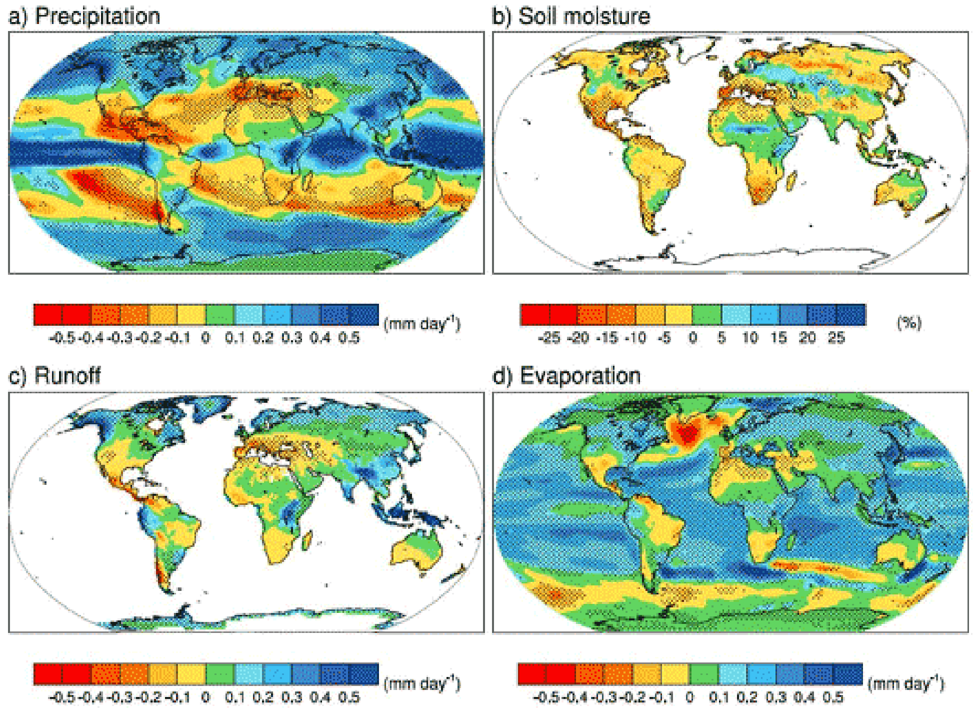

Figure 7.4: Model Projections of Hydrological Changes by end of 21st Century in A1B Emissions Scenario (based on average over all IPCC models). Stippling indicates where there is a consensus among models.
Credit: IPCC, 2007

In fact, there is no paradox here at all. Keep in mind that soil moisture reflects a balance between the water coming in (in the form of precipitation, and runoff) and the water leaving the soil (in the form of evaporation/evapotranspiration). Evaporation is projected to increase over most of the continents, including many regions that are projected to see an increase in precipitation. So, what is actually happening is that even in many areas where rainfall is increasing, soil moisture nonetheless is projected to decrease, and drought thereby worsen, because warmer soils are evaporating water into the atmosphere at a faster rate than water is accumulating at the surface from rainfall or snowfall, even when precipitation is projected to increase. As we will see later, a further complication is the distribution of the rainfall—it is projected to come in fewer, but heavier rainfall events—which, seemingly paradoxically, means that both flooding and drought can become problematic for the very same regions. We will discuss this issue later in our treatment of climate change *impacts*.

Certain projected changes in precipitation are robust, with a fair degree of consensus among models (e.g., much of Canada and Europe). For other regions however (much of the U.S., and much of tropical and subtropical North Africa) there is no clear agreement among models—meaning that the projected changes are highly uncertain. Much of this uncertainty comes from the fact that many of the projected changes in rainfall patterns are related to projected shifts in atmospheric circulation, and these shifts themselves are often quite uncertain. Let us look at this in greater detail.

Atmospheric Circulation Change

We already saw the pattern of projected change in rainfall. It is especially useful to look at this pattern averaged zonally, i.e., by latitude bands, which provides a simpler picture of how rainfall is projected to change as a function of latitude. When we do that, we see a fairly clear latitudinal pattern emerge.

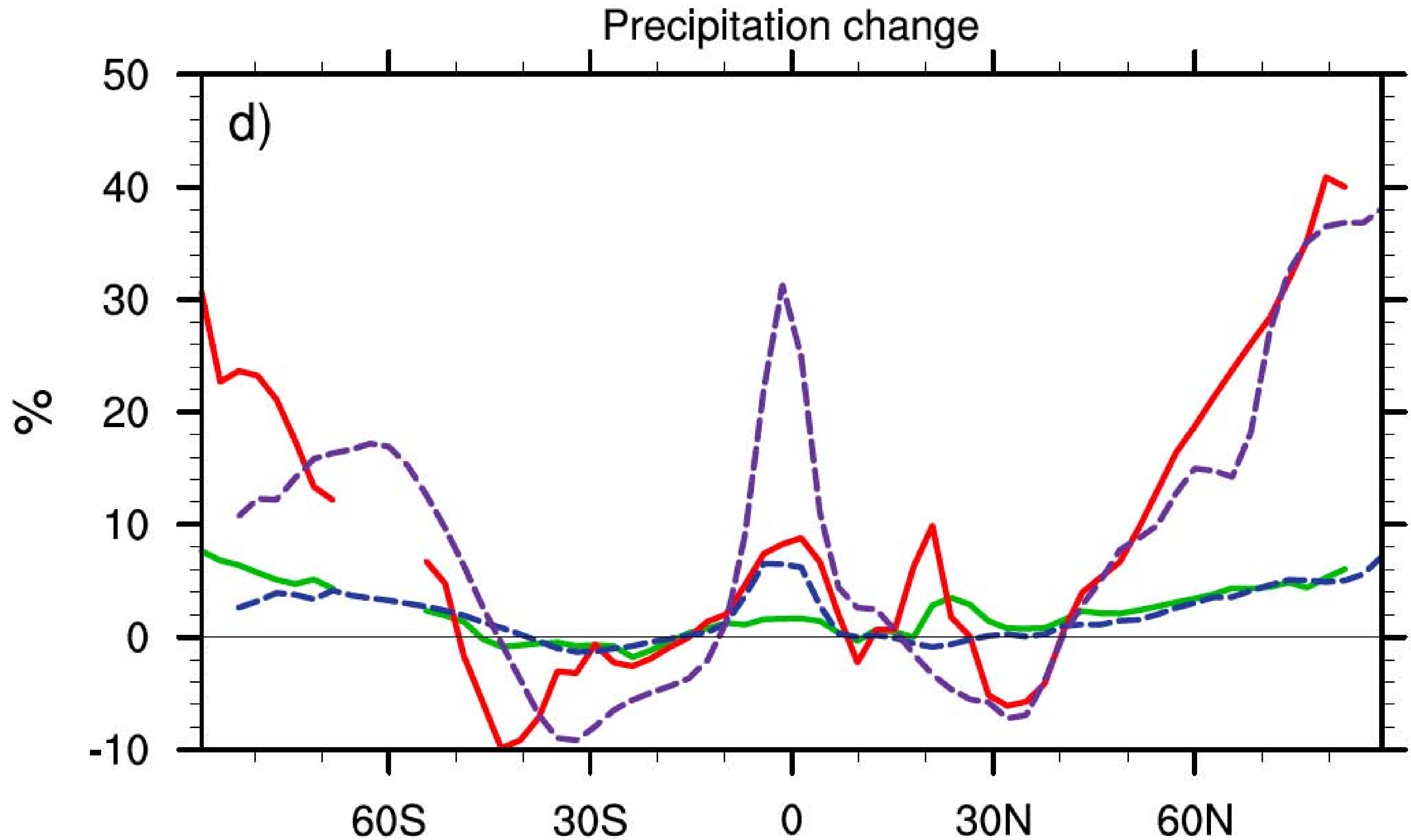

Figure 7.5: Model Projections of Rainfall Changes Over 21st Century in A2 (red and blue) and Constant 2000 CO_2 commitment (purple and green) Scenarios (dashed curves are ocean only; solid curves are land only/ results based on average over all IPCC models).
Credit: IPCC, 2007

Here we see the increase in precipitation near the equator where the ITCZ lies, decreases from the sub-tropics through the mid-latitudes as the Hadley Cell expands poleward, and increases again in sub-polar latitudes where the polar front migrates poleward. In short, we are seeing the effect of the poleward shifting of the zones of rising and descending motion that we reviewed during the overview [3] of atmospheric circulation in our very first lesson.

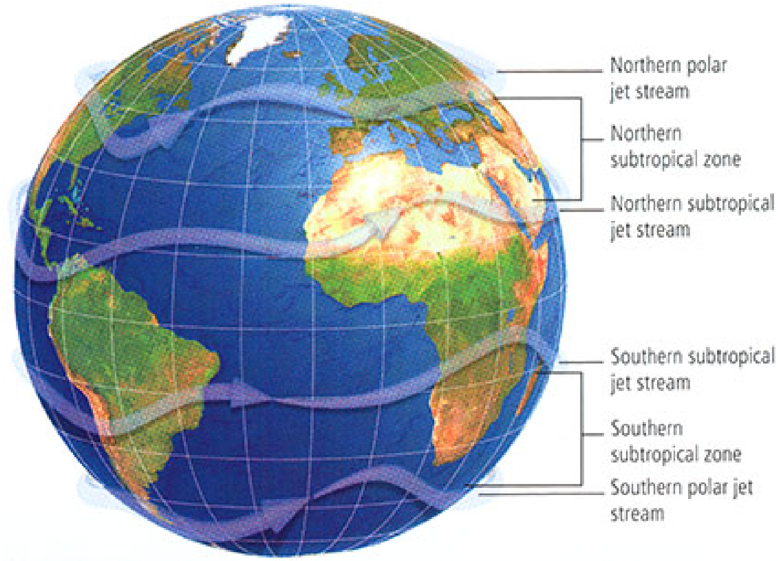

Figure 7.6: Subtropical Zone Expansion.
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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We first encountered the notion of a potential poleward migration of the jet stream in our previous discussion of the 2003 European heat wave [4], which was a possible harbinger of climate change impacts to come. In this particular case, the sub-tropical jet stream (which lies above the descending limb of the Hadley Circulation in the subtropics, and is associated with the subsidence of warm, dry air in the subtropics) shifted well north of its usual summer location over the northern Sahara desert and southern Mediterranean, well into the middle and even sub-polar latitudes of Europe. That single event encapsulated a pattern that is expected to become more prevalent with future climate change, as the various atmospheric bands, including the Hadley Circulation, and polar front, expand poleward.

It is worth looking more closely, in this context, at one particular metric of the latitudinal shift of the polar front and jet stream, the North Atlantic Oscillation (NAO; we introduced this concept briefly in our discussion of factors influencing Atlantic tropical cyclone activity [5] in Lesson 3). The NAO is a measure of the poleward extent of the Northern Hemisphere jet stream and polar front during northern winter over the North Atlantic ocean. A positive NAO reflects a stronger than usual sub-polar *Icelandic low* surface pressure center and stronger than usual subtropical *Bermuda/Azores high* surface pressure center during the northern winter. It is associated with a strengthened and more northerly storm track. It is associated with warmer and wetter than usual conditions in Europe. By contrast, the negative phase of the NAO is associated with a weaker than normal jet stream, cooler, dryer winters in Europe, and wet winters in the Mediterranean and near/middle east.

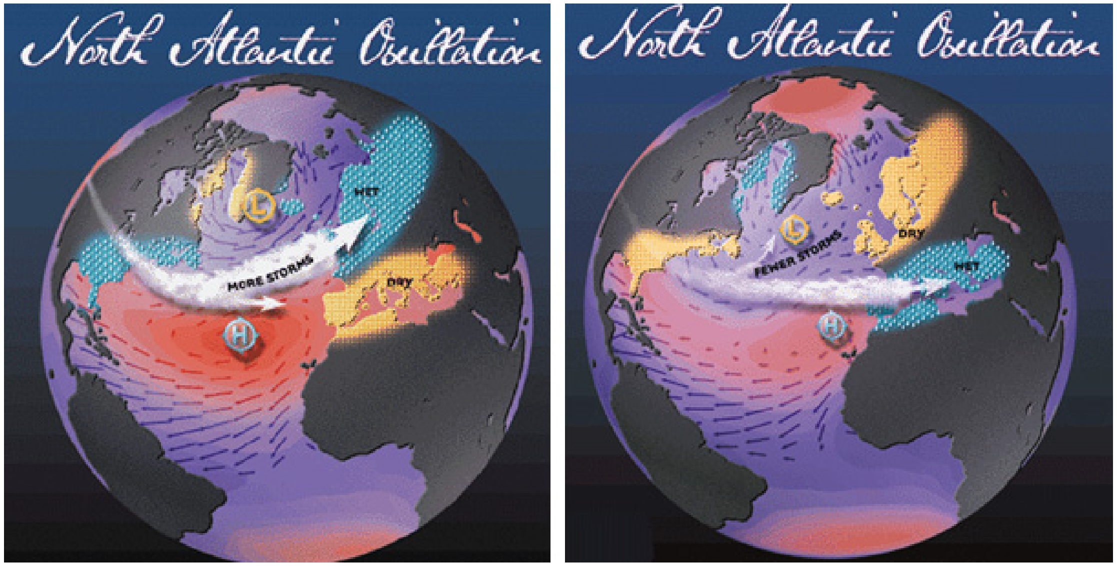

Figure 7.7: Pattern of Climate Influence of the Positive (left) and Negative (right) phases of the NAO.
Credit: Lamont Doherty Earth Observatory [6], Columbia University

Often the NAO is associated with a more hemispherically-symmetric mode of atmospheric variability known as the Arctic Oscillation (AO) or Northern Annular Mode (NAM), which reflects a deeper than usual surface low pressure area throughout the sub-polar belt of the Northern hemisphere, and a deeper than usual surface high-pressure area throughout the sub-tropical belt of the Northern hemisphere. The positive mode of the AO/NAM is associated with a stronger northern hemisphere winter jet stream, while the negative phase is associated with a weakened jet stream.

Climate models project a trend towards a more positive winter NAO/AO/NAM as a result of anthropogenic climate change, due to the changing vertical and latitudinal patterns of temperature (as you may recall from our introductory readings [3], it is the vertical and latitudinal gradients in atmospheric temperatures which drive the jet stream in the first place). This implies a stronger winter jet stream in the Northern Hemisphere (similar changes are projected for the Southern Hemisphere), and stronger surface westerlies in middle latitudes. The stronger westerly winds at the surface further warm winter temperatures over land regions by spreading heat from the relatively warm oceans over the relatively cold continents. A more positive NAO also leads to a relative increase in winter rainfall in the southeastern U.S. and Northern Europe, and dryer conditions in the near and middle east and southern Mediterranean. Given that these regions are currently stressed for their limited available water supply, this projected climate change response could represent a substantial threat to water security in these regions.

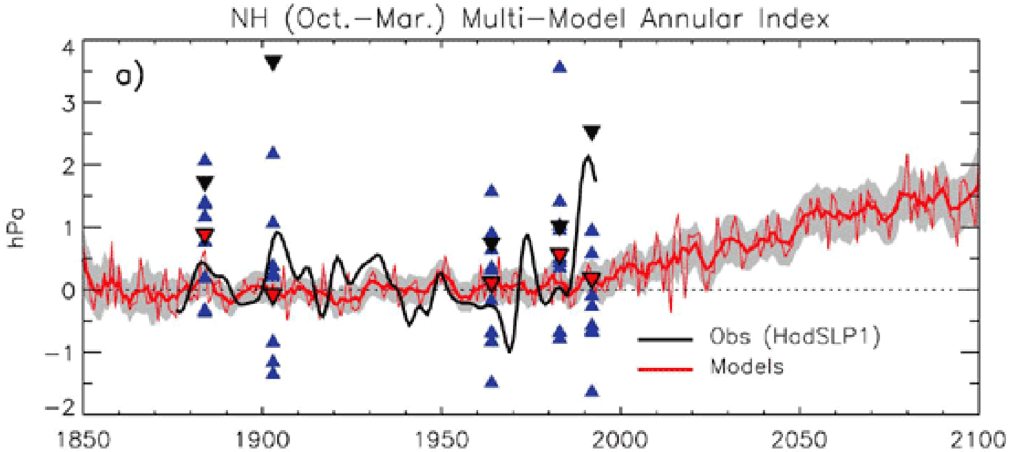

Figure 7.8: Model Projections of the NAO/AO/NAM based on an Average Over all IPCC Models (A1B Emissions Scenario) Compared Against Historical Observations.
Credit: IPCC, 2007

Monsoonal circulation patterns may also change. The most prominent of the monsoons is the South Asian Summer monsoon, which is the source of much of the annual rainfall in heavily-populated regions such as India. The monsoon is driven primarily by the contrast in heating of the oceans and land. The land responds more strongly to summer heating than the oceans, leading to a tendency for a very large-scale thermally-driven circulation cell, similar in some respects to the Hadley Circulation. There is rising motion inland over the Tibetan plateau and sinking motion over the Indian Ocean, so moist warm air over the Indian Ocean is drawn in toward the land, where it rises and condenses out water vapor. This circulation pattern can be influenced by a number of factors, each of which may be altered by anthropogenic climate change. For example, the differential heating of land relative to ocean, projected over the next century, could drive a stronger monsoonal circulation. On the other hand, increased atmospheric stability in South Asia due to latent heating of the atmosphere arising from condensing water vapor in the rising limb of the monsoon could stabilize the vertical temperature profile, inhibiting the Monsoonal circulation. In state of the art models such as those assessed by the IPCC, this latter factor tends to dominate, and the South Asian Summer monsoon is projected to weaken. Seemingly paradoxically, however, the monsoonal precipitation is projected to remain either stable or even increase. In the face of a weakening Monsoonal circulation this has to do with the fact that even though the circulation may be weakened, there will be greater water vapor content in a warmed atmosphere, leading to the potential for greater amounts of rainfall for a given circulation strength. There is still quite a bit of uncertainty on this, however, and a wide spread in projected behavior is seen among the models assessed by the IPCC.

Another pattern of atmospheric circulation that may potentially change as result of anthropogenic climate change is the Walker Circulation, which we discussed in our introduction [7] to the ENSO phenomenon. We will defer any discussion of the uncertain potential changes in this atmospheric circulation pattern to a later section discussing potential change in modes of atmospheric-ocean variability.

Of course, it is not only the atmosphere which is projected to change in its circulation patterns as a result of anthropogenic climate change, but also the ocean.

Oceanic Circulation Changes

By far, the most critical issue regarding climate change impacts on ocean circulation patterns involves the thermohaline/conveyor belt /meridional overturning circulation which we discussed earlier in the course (e.g., Ocean Circulation page of Lesson 1 [8] and the Oceans page of Lesson 3 [9]). As we discussed earlier, it was once thought that global warming could paradoxically lead to cooling over a wide region of the globe by sending large amounts of fresh water into the high-latitudes of the North Atlantic, where it would freshen the surface waters and inhibit the formation of dense surface waters whose sinking in the sub-polar North Atlantic constitutes the descending limb of the conveyor belt circulation. Since this ocean current system is a substantial contributor to the transport of heat to the high latitudes of the North Atlantic, such an occurrence could lead to widespread cooling of the North Atlantic and neighboring continental regions. Indeed, scientists believe this happened during the Younger Dryas event [10] toward the end of the last ice age, between 13,000 and 12,000 years ago as the climate was warming during the initial phase of deglaciation.

Of course, as noted during our earlier discussion of the Younger Dryas event, the two situations are quite different in many respects. Toward the end of the last ice age, there was much ice to melt, and far greater potential to flood the North Atlantic with extremely large amounts of fresh water. Today, however, the ice sheets are much diminished, and there is less snow and ice available to melt. Nonetheless, certain simple climate models, such as the CLIMBER model used by the Potsdam Institute for Climate Change Impacts, suggest that global warming could lead to a substantial weakening of the thermohaline circulation and a fairly dramatic cooling of the North Atlantic and neighboring regions.

Model Projections of the NAO/AO/NAM based on an Average Over all IPCC Models (A1B Emissions Scenario) Compared Against Historical Observations.
Credit: Potsdam Institute for Climate Impacts Research [11]

We have seen that current state-of-the-art climate models show only a weak semblance of this effect, however. Earlier in this lesson [12], we saw that the GFDL CM2.1 coupled model produces a very moderate cooling over a small region of the North Atlantic in response to anthropogenic warming, in part due to a slight weakening of the thermohaline circulation due to the mechanisms discussed before.

In fact, this model exhibits a larger response than most of the 20+ models used in the most recent IPCC assessment. If we look at the average pattern of surface temperature change over the next century in the A1B scenario, averaged over all 20+ models, we see only the vaguest hint of the effect. Nowhere in the North Atlantic do we see any cooling. Instead, we see a small region in the North Atlantic, south of Greenland and

Iceland, where there is less warming than in most other regions. Western Europe also sees somewhat less warming than most other regions due to the downstream effects. So if we take the composite response of the IPCC models as our best current assessment, we are led to conclude that the very, very small grain of truth to the *Day After Tomorrow* [13] scenario, is that global warming may lead to a bit less warming in some parts of the North Atlantic and neighboring regions, owing to a slowing of the oceanic thermohaline circulation.

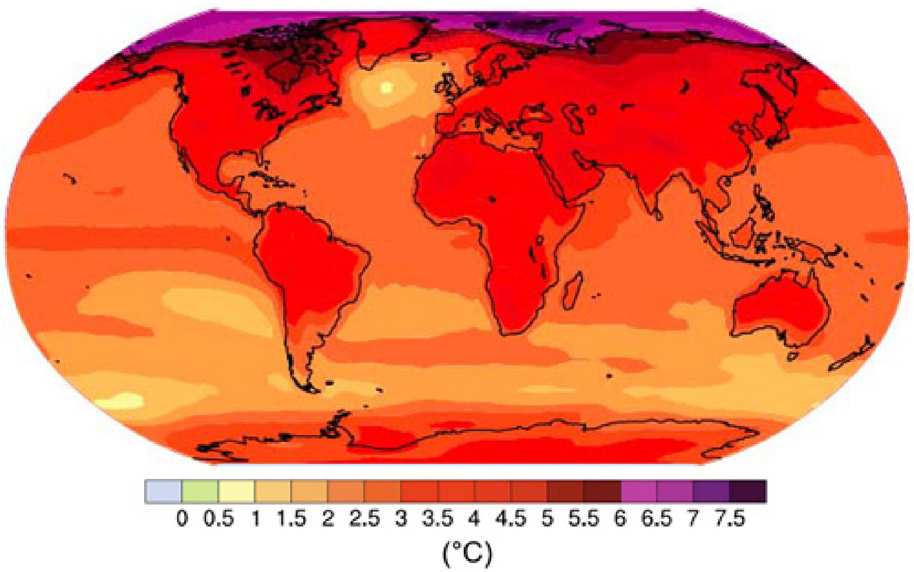

Figure 7.9: Model projections of surface temperature changes by end of 21st Century in A1B Emissions Scenario (based on average over all IPCC models).
Credit: IPCC, 2007

If we look at a more direct measure of the thermohaline circulation in the models, namely the intensity of the northward current associated with the meridional overturning component of the ocean circulation and thermohaline circulation, we see that in very few models does it actually collapse. In some models, it does weaken substantially, but in most models, it weakens only very modestly; and in some models, it marches along at near its current intensity, as if nothing happened at all! Why is this? More elaborate climate models, which contain detailed three-dimensional representations of ocean components that finely resolve boundary currents and even the eddies in these currents, tend to show far more robustness of the MOC than the simpler models, which ignore lateral ocean currents, eddies, etc. The state-of-the-art models have more *degrees of freedom*, i.e., more ways to circulate and transport water, heat, and salinity, and it is, therefore, much harder to cut off the poleward transport of heat by the ocean circulation, as there are multiple components of the oceanic circulation that can deliver heat poleward. These models typically, for related reasons, have a far more stable thermohaline circulation than simpler, earlier ocean models.

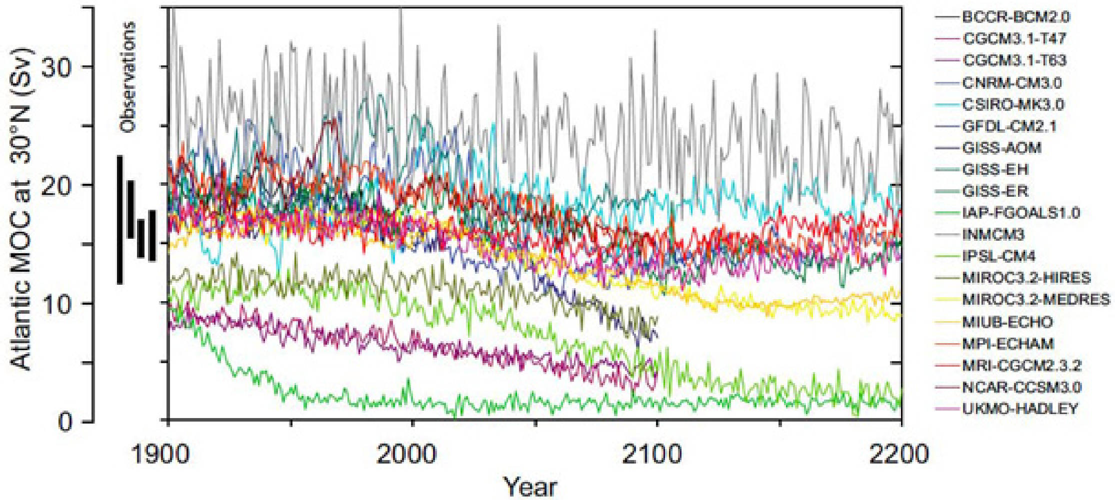

Figure 7.10: Model projections of the strength of the meridional overturning circulation (MOC) of the North Atlantic (measured in "Sverdrups" which is a million cubic meters of water transported poleward per second) in A1B Emissions Scenario (based on average over all IPCC models).
Credit: IPCC, 2007

Models of Climate Variability

We know that the ENSO phenomenon has a profound influence on climate on inter-annual timescales, leading to substantial regional alterations in temperature and rainfall patterns around the world, and influencing important phenomena, such as Atlantic hurricane activity. Needless to say, one key question of climate change is how the characteristics of ENSO might change in the future.

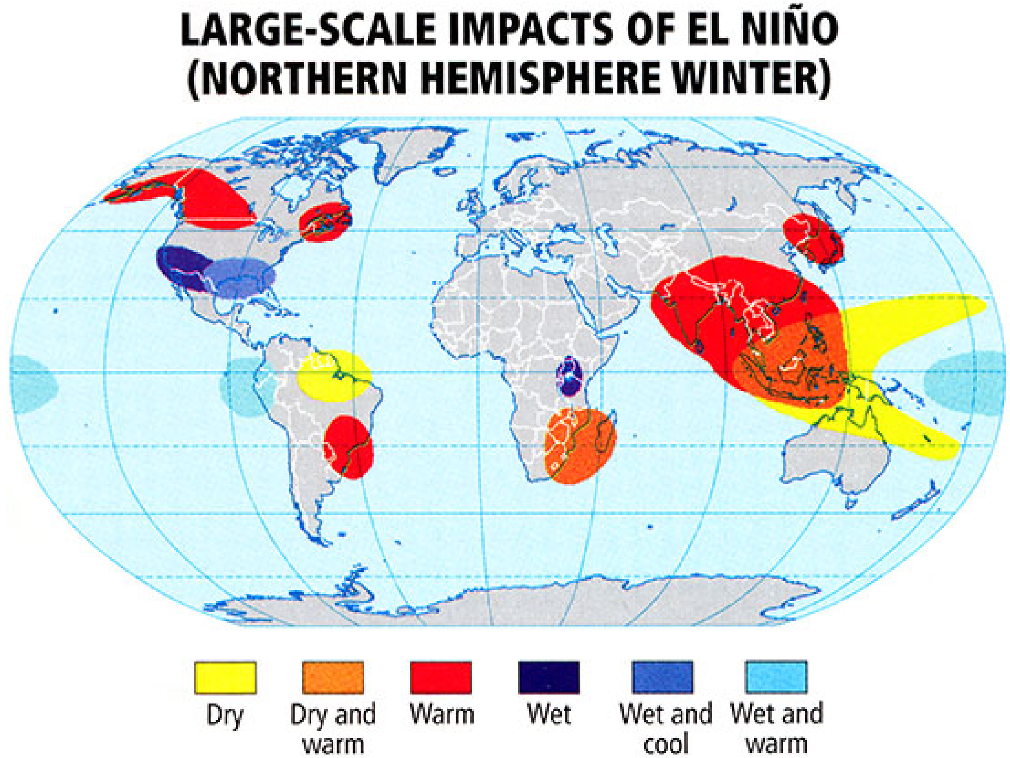

Figure 7.11: Large-scale impacts of El Niño.
Credit: Mann & Kump, *Dire Predictions: Understanding Climate Change, 2nd Edition*
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One of the great limitations in projecting future regional climate change is that we cannot yet confidently assess how ENSO will change in the future. The state-of-the-art models used in the most recent IPCC assessment do not show any clear consensus regarding how anthropogenic climate change will influence the characteristics of ENSO.

Most models (the models that fall in the right half of the plot below) project an overall more El Niño-like climate, that is to say, a weakened *Walker Circulation*, weakened trade winds and oceanic upwelling in the eastern and central tropical Pacific, and a surface temperature pattern wherein the eastern equatorial Pacific warms up more than the central and western equatorial Pacific ocean. However, a few state-of-the-art climate models (i.e., the three that fall in the left hand of the plot below) project the opposite, a more La Niña-like pattern. One might be tempted to go with the majority, the El Niño-trending models. However, paleoclimate evidence of the response of ENSO to past natural changes in radiative forcing (including research your course author has been involved in [14]) suggests the possibility that the minority of models (i.e., the La Niña-trending models) might be right. This issue has implications for how anthropogenic climate change might influence Atlantic hurricane activity (this is also an issue that your course author has done research on [15]). We will discuss climate change influences on tropical cyclone activity in more detail in our next lesson.

There is even greater uncertainty regarding the amplitude of ENSO variability, i.e., whether individual El Niño and La Niña events will become larger (models that fall in the upper half of the plot below) or smaller (models that fall in the lower half), with an equal split between the IPCC models with regard to which of the two possiblities is more likely. Since larger El Niño events have a greater impact on regional weather patterns, while smaller events have a lesser impact, this issue has significant implications for projected climate change impacts.

The large uncertainties in projecting changes in ENSO likely result from a combination of factors, including the tendency for state-of-the-art climate models to produce an unrealistic *split ITCZ* in the eastern tropical Pacific, which biases the strength of the trade winds and equatorial upwelling; the still course resolution of the oceanic component of the models, which may lead to inaccuracies in the ocean wave disturbances that are important for El Niño and La Niña; and uncertainties in the behavior of marine stratocumulus clouds, which play an important role in equatorial Pacific radiation and heat budget.

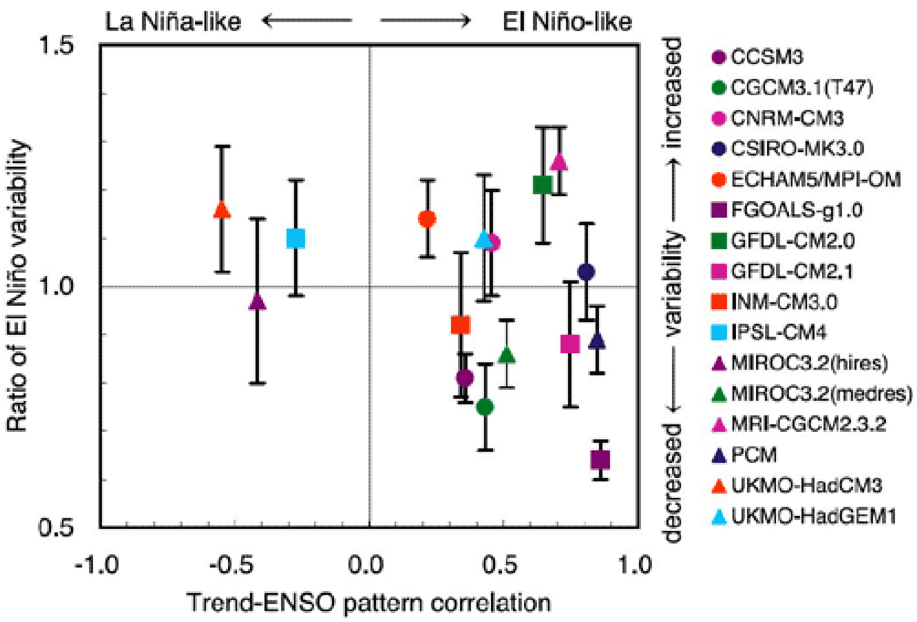

Figure 7.12: Model Projections of Changes in ENSO in Response to Doubling of CO_2 Concentrations.
Credit: IPCC, 2007

Lesson 7 Summary

In this lesson, we examined some of the key anthropogenic climate change projections. Some of the main findings were:

- climate models project anywhere from 0.2 to 7°C warming over the next century, depending on two critical variables: (1) what decisions society makes regarding future carbon emissions and (2) currently irreducible uncertainties regarding the sensitivity of the climate to greenhouse gas radiative forcing;
- the primary source of spread in projected warming is factor #1, the uncertainty in future emissions. Were we to freeze greenhouse gases at their current levels, the average projection among models is an additional warming of 0.5°C. This scenario is highly unlikely, as it is very

difficult to find a pathway to zero emissions in the near future. On the other hand, were we to pursue *business-as-usual* emissions scenario (e.g., continue on the A1FI scenario), the average projection among models is for an additional warming of 4°C;
- the impact of factor #2, the uncertainty in climate sensitivity, is nonetheless quite significant. In the A1FI scenario, the globe could warm anywhere from a lower bound of 2.5°C to an upper bound of 6.5°C, depending on which particular climate model is used;
- the variability in temperatures in both space and time is projected to be considerable. High latitudes warm more than low latitudes owing to positive feedbacks related to the melting of ice, and land warms more than oceans due in large part to the greater thermal inertia of the oceans. Even as the globe warms, there will continue to be cold periods over particular regions related to ENSO and other sources of natural variability;
- precipitation is projected to increase in the tropics and sub-polar latitudes, while decreases are projected for sub-tropical through mid-latitude regions. These changes reflect a combination of the effects of shifting storm tracks and the potential for a warmer atmosphere to hold more water vapor;
- continental drought becomes more widespread over much of the continents. This results from a tendency for increased evaporation to dry out soil, even in many regions that see an increase in precipitation;
- anthropogenic climate change leads to substantial changes in atmospheric circulation, including a poleward shift of the descending branch of the Hadley Circulation and of the jet streams, polar front, and storm tracks. These changes also include a weakening of monsoonal circulations, and possible, but uncertain, impacts on the Walker Circulation pattern associated with ENSO;
- the NAO/AO/NAM mode of variability, tied with variations in the position of the Northern Hemisphere winter jet stream, is projected to become more positive, associated with a northward displaced storm track and warmer, wetter winter conditions in regions such as Europe, but drier conditions in semi-arid regions such as the Mediterranean and Near and Middle East;
- a modest weakening is projected for the meridional overturning ocean circulation (variously referred to as the thermohaline circulation and conveyor belt circulation). State-of-the-art models, however, project a far weaker effect than what was once considered possible; rather than leading to cold conditions over the North Atlantic and neighboring regions, what is currently projected is only a moderate decrease of the warming in a small region in the North Atlantic ocean south of Greenland;
- projected changes in the character of the El Niño/Southern Oscillation are uncertain. Model projections are divided with respect to whether the future climate state will be more like El Niño or La Niña, and whether individual El Niño and La Niña events will be larger or smaller.

Reminder - Complete all of the lesson tasks!

You have finished Lesson 7. Double-check the list of requirements on the first page of this lesson [16] to make sure you have completed all of the activities listed there before beginning the next lesson.

Source URL: https://www.e-education.psu.edu/meteo469/node/149

Links
[1] https://www.ipcc.ch/report/ar5/wg1/
[2] https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf
[3] https://www.e-education.psu.edu/meteo469/node/203
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[6] http://www.ldeo.columbia.edu/res/pi/NAO/
[7] https://www.e-education.psu.edu/meteo469/node/211
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[11] http://www.pik-potsdam.de/%7Estefan/Movies/warming.mpg
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[13] http://www.imdb.com/title/tt0319262/

[14] http://live.psu.edu/story/43214
[15] http://www.nsf.gov/news/news_summ.jsp?cntn_id=115424&org=NSF&from=news
[16] https://www.e-education.psu.edu/meteo469/node/144