



UNDERSTANDING THE ROLE AND FINDINGS OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

ALLISON SERAKOS

DR. JIM BOWYER

DR. JEFF HOWE

DR. ED PEPKE

DR. STEVE BRATKOVICH

MATT FRANK

KATHRYN FERNHOLZ

14 MAY 2014

DOVETAIL PARTNERS INC.

A Trusted Source of Environmental Information



Understanding the Role and Findings of the Intergovernmental Panel on Climate Change (IPCC)

Introduction

The effects of climate change are being experienced firsthand. Changes in the Earth's atmosphere, oceans, and lands are having environmental, social and economic effects. One of the world's leading organizations dedicated to understanding climate systems and impacts is the Intergovernmental Panel on Climate Change (IPCC). This report examines the work of the IPCC over the past 23 years, and the anticipated fifth IPCC report that will be released later this year. This report also describes some of the primary scientific mechanisms of climate science that are key to understanding the work of the IPCC.

Background

The Intergovernmental Panel on Climate Change (IPCC) is dedicated to the assessment of climate change. It was formed in 1988 and organized through the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO).¹ The IPCC does not conduct research of its own; rather, it reviews and analyzes scientific and socio-economic information in order to report on climate change. Policymakers utilize IPCC reports to inform climate change policy and decision-making.

The IPCC has produced four full reports within the last 23 years. Each report consists of three sub-reports produced by three respective working groups (Table 1). Working Group I focuses on the science and processes of climate change; Working Group II focuses on the socio-economic effects and impacts due to climate change and subsequent adaptation and mitigation; and Working Group III focuses on mitigation techniques.

Table 1. IPCC Working Groups and Areas of Focus

IPCC Working Group	Area of Focus and Reporting
Working Group I	Science and Processes of Climate Change
Working Group II	Socio-Economic Effect and Impacts due to Climate Change; Adaptation and Mitigation
Working Group III	Mitigation Techniques

The most recent completed sub-report produced by Working Group I, "*Climate Change 2013: The Physical Science Basis*", was presented to the public in September 2013 and is part of the upcoming IPCC Fifth Assessment Report (AR5). In March 2014 Working Group II released a preliminary report (pending copy editing) called "*Climate Change 2014: Impacts, Adaptation, and Vulnerability*." The IPCC's full report, including all three sub-reports and a synthesis, will be released in October 2014.

The Science of Climate Change

In order to understand the IPCC reports, some of the scientific mechanisms of climate science must be summarized. The key scientific mechanisms include the greenhouse effect, climate feedback systems, radiative forcing, the carbon cycle, atmospheric circulation, and ocean circulation, among others.

The Greenhouse Effect

One of the fundamental climate science and global warming concepts is the greenhouse effect (Figure 1)ⁱⁱ. The most common greenhouse gases are: carbon dioxide (CO₂), methane (CH₄), water vapor (H₂O) and nitrous oxide (N₂O). These gases influence the Earth's global energy budget¹ (or energy balance). The solar intensity and the quantity and type of greenhouse gases in the atmosphere affect this balance.

A majority of the energy that affects the earth's climate comes from the sun. As the sun heats up the earth (solar radiation) the earth radiates some of this energy back into space as invisible "infrared radiation (IR)." The difference between the amount of energy absorbed and that radiated back into space determines the average temperature. The atmosphere and greenhouse gases absorb and reflect back to earth some of the IR, making the earth's average temperature higher than it otherwise would be. Without greenhouse gases the earth would average a chilly -18 °C (0 °F) versus an actual average of about 15°C (59 °F) over the past few millennia.ⁱⁱⁱ Thus, the greenhouse effect is essential to life, as we know it on the earth.

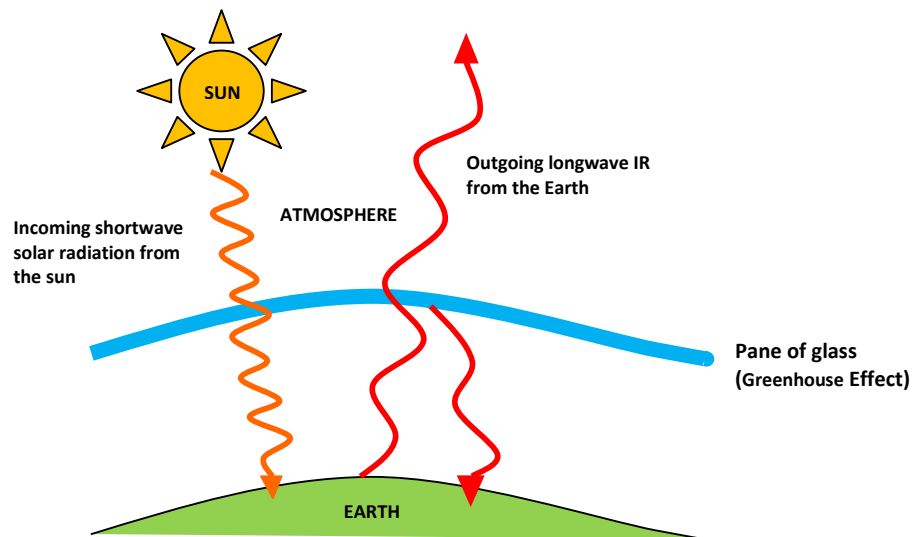


Figure 1. The Greenhouse Effect. Visible light from the sun is allowed in through the pane of glass while infrared radiation (IR) from the Earth is either absorbed by the greenhouse gases in the pane of glass and emitted back towards Earth or dispersed out to space. This is dependent on the vibration frequencies of the gases and the light.

David Archer, professor of geophysical science at the University of Chicago, explains the greenhouse effect with a pane of glass analogy illustrated in Figure 1.^{iv} The glass, representing the earth's atmosphere, suspended above the Earth's surface, allows for a portion of incoming sunlight to pass through and heat the Earth's surface. However, when the Earth emits IR, some of the gases (e.g. greenhouse gases) absorb the energy and emit it in multiple directions, including both out into space and back toward the Earth's surface.^v Each greenhouse gas absorbs IR at different frequencies and reemits the energy in different directions at different temperatures.^{vi} As the quantity of greenhouse gases in the atmosphere increases, the amount of outgoing (cooling) IR from the Earth decreases. When this decrease in IR occurs, the temperature at which the IR is emitted increases to compensate

¹ The Earth's energy budget is the net flow of incoming shortwave solar radiation and the outgoing longwave infrared radiation from the Earth's surface that keeps the earth in balance.

for the loss in outgoing IR, which balances the Earth's energy budget back to its initial amount of outgoing IR.^{vii} In this situation the Earth eventually reaches equilibrium, but the average global temperature (i.e. what we feel from the earth due to IR) is now higher.

Climate Feedback Systems

The Earth's climate is made up of many internal feedback systems that can have both a positive (climate change amplifier) and negative (climate stabilizer) affect. The ice albedo effect is an example of a positive effect. This effect refers to the reflectivity of snow and ice on the surface, and ice particles in the atmosphere. The ice albedo effect causes a portion of the incoming solar radiation to reflect off these surfaces back to the atmosphere rather than being absorbed by the Earth through exposed, rocky surfaces. An increase in greenhouse gases raises the Earth's temperature, melting ice and causing additional rocky surface to be exposed and absorb more solar radiation. This in turn further raises the temperature, melting more ice and so on in a reinforcing pattern; thus creating the positive feedback loop.

Water vapor is believed to be the dominant greenhouse gas, although the role of atmospheric water in climate change is complex. Water vapor provides positive feedback, to such an extent that Andrew Dessler of Texas A&M states "we now think that water vapor feedback is extraordinarily strong, capable of doubling the warming due to carbon dioxide alone."^{viii} When temperature increases, more water evaporates into the atmosphere. Since water vapor is a greenhouse gas, more of it in the atmosphere leads to an increase in temperature and higher humidity and the positive feedback loop continues. However, this effect is moderated when water vapor reaches a cooler temperature in the high atmosphere where it condenses and precipitates. In this case, the loss of water vapor provides a negative feedback effect because it stabilizes the amount of water vapor in the atmosphere.

At any given time, about 70 percent of the Earth's surface is covered by clouds.^{ix} Clouds contribute to both positive and negative feedback systems depending on the type of cloud, its thickness, and its position in the atmosphere. Currently, it is believed that clouds combine to create a net cooling effect on the atmosphere. However, their net impact on future climate change is less certain. There are three main types of clouds in the atmosphere: cirrus (high, thin clouds), cumulus (low, storm clouds), and stratus (low, thick clouds). Cirrus clouds are relatively thin clouds that absorb and emit IR from the Earth due to their position in the high, cold atmosphere. However, because they are thin, solar energy is able to pass through them to the Earth more easily. Therefore, cirrus clouds contribute to positive feedback systems. Clouds that are positioned lower in the atmosphere, including stratus and cumulus, contribute differently to the global energy budget. They tend to have a weaker influence on warming due to their low position in the atmosphere. Their density also provides them with a high albedo effect, thus causing a cooling or negative feedback. In general, high atmospheric clouds warm the Earth, and low ones cool the Earth. In the overall net energy budget, low clouds cause a greater contribution and therefore the cooling effect dominates.

Radiative Forcing

The rate at which the Earth's energy balance changes is called "radiative" or climatic "forcing" and can be quantified per specific factor affecting the change (e.g., CO_2). Radiative forcing is a measure of the amount of energy change per unit area of the globe as measured at the top of the atmosphere. Factors such as ozone, greenhouse gases, aerosols, albedo, and solar fluxes each have their own radiative forcing value in watts per meter squared (W/m^2) (Figure 2). A negative radiative forcing value represents a net cooling, while a positive value represents a net warming. These values help scientists develop estimates of relative degrees of climate impact from different factors.

The Carbon Cycle

An important climate science concept is the carbon cycle. There are four main carbon reservoirs, ordered here in decreasing size: (1) the solid Earth, where carbon is stored in sedimentary rocks; (2) the oceans, where carbon is stored as dissolved carbonates; (3) the biosphere, where carbon is stored in living species of plants and animals; and (4) the atmosphere, where carbon is stored as carbon dioxide (CO_2). In general, the carbon cycle tempers climate change (provides negative feedback). However, a significant increase in atmospheric CO_2 may result in development of positive feedback systems.

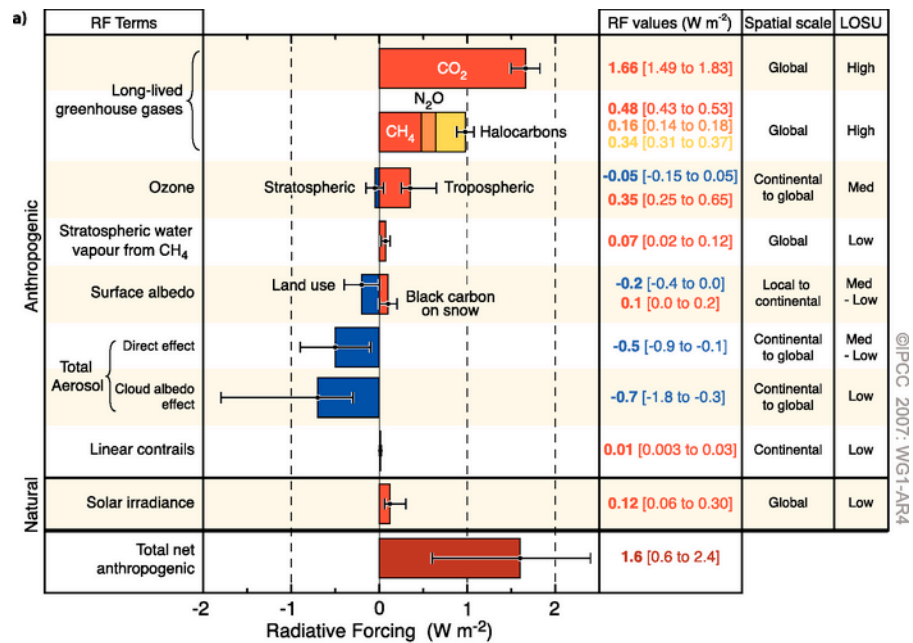


Figure 2. Global averages of radiative forcing values and their 90% confidence intervals for different mechanisms in 2005. AR4: Working Group I of IPCC, *Global Mean Radiative Forcing*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-ts-5.html.

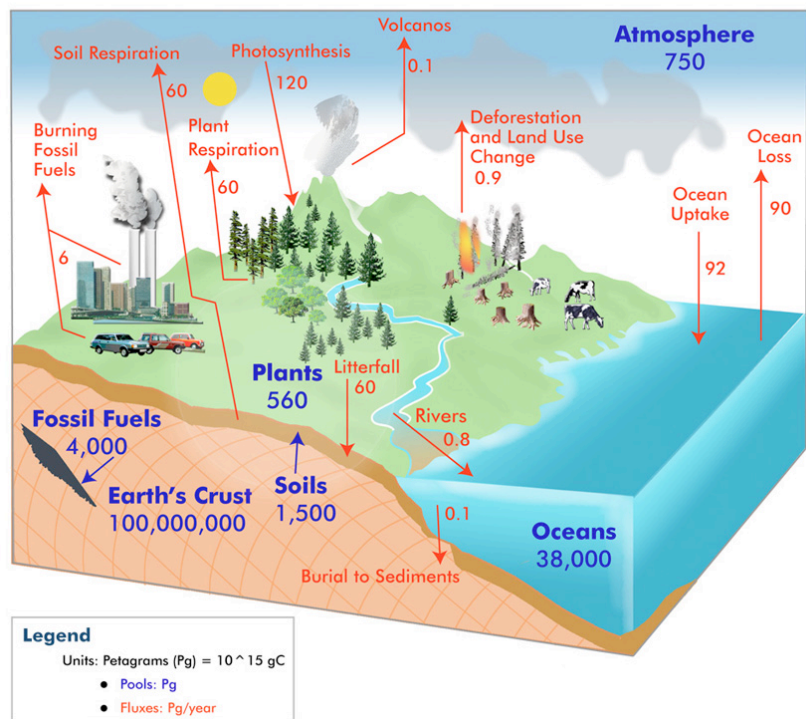


Figure 3. The Global Carbon Cycle. The arrows indicate the direction of carbon flow. The red indicate the amount of carbon being transmitted by different environmental systems and stresses per year in petagrams. The blue represents the carbon pools and how much carbon (in petagrams) is stored in each pool. GLOBE Carbon Cycle, 2007, <http://globecarboncycle.unh.edu/CarbonCycleActivities.shtml>.

Carbon moves through its core cycle through a process of chemical weathering. For example, CO_2 from the atmosphere reacts with water to form carbonic acid in rain. This carbonic acid dissolves rocks and releases ions, including calcium ions, from the rocks that eventually flow into rivers and oceans where the calcium ions react with bicarbonate ions to form calcium carbonate (CaCO_3). This formation of CaCO_3 , combined with the CaCO_3 from the shells of decaying organisms and plankton, form limestone. The carbon that is stored in limestone may be stored for billions of years. The carbon is released back to the atmosphere in the form of volcanic degassing. This chemical weathering is considered a negative feedback system. Chemical weathering depends on rainfall, which depends on temperature, which in turn is affected by atmospheric CO_2 levels. As CO_2 levels increase there may be an increase in chemical weathering.

In terms of the biosphere, carbon is exchanged with the atmosphere by means of photosynthesis and respiration. In photosynthesis, plants use the CO_2 in the atmosphere along with H_2O and sunlight to produce sugars ($\text{C}_6\text{H}_{12}\text{O}_6$) and oxygen. Animals breathe oxygen and respire CO_2 back into the atmosphere while plant decay allows for carbon to be passed into the soil.

The Carbon Cycle & Fossil Fuels

The increased amount of CO_2 expelled into the atmosphere from the burning of fossil fuels has been a significant and relatively recent change to the carbon cycle that has occurred since the beginning of the Industrial Revolution.

Coal is the largest fossil fuel reserve on Earth. It was formed from dead plants and animals that were deposited in thick layers of organic matter at the bottom of swamps and bogs. These layers are then compressed and heated for millions of years to form coal. The coal that has been heated the longest has the purest carbon. Coal from plants deposited in seawater swamps contain more sulfur due to the sulfate dissolved in seawater. This sulfate forms sulfate aerosols when burned and in turn contributes to acid rain. Coal that contains sulfur also has mercury, which when burned, is also released into the atmosphere.

Petroleum, another fossil fuel, results from the photosynthesis of phytoplankton in oceans that creates organic carbon. Phytoplankton and zooplankton (small animals that eat phytoplankton) decay on the deep ocean floor and eventually break down into oil source rocks² formed near continents and oxygen depleted waters. These materials are covered with sediment over millions of years and the heat and pressure over time creates petroleum..

The third common fossil fuel is natural gas. Natural gas is formed in conjunction with petroleum and coal, most commonly when oil is overheated resulting in the formation of methane. Methane is the most reduced form of carbon and therefore has more energy per carbon molecule than other sources of carbon-based energy. Methane freezes with water to form methane hydrates that are located in mid-deep ocean sediments and permafrost soils. Chemical reactions occur slowly to form a buildup of methane in these regions. Methane hydrates are also scattered throughout the Earth's bedrock. Hydraulic fracturing or "fracking" is a technique used to extract natural gas from bedrock using pressurized injections of water and chemicals.

² Rocks that have high levels of organic matter if heated to a certain degree will produce oil or gas.

Atmospheric Circulation

Atmospheric circulation systems have a large effect on climates. The Hadley Cell Circulation (Figure 4) is an atmospheric circulation system in the tropics that in combination with the Coriolis effect produces both the trade winds and tropical easterlies. This atmospheric circulation is dependent on the temperature and air pressure around different latitudes of the Earth. Warm air heated by the sun at the equator rises creating an area of low pressure at the surface and higher pressure in the upper atmosphere. This rising air expands and as it reaches the troposphere it condenses as temperature decreases. This causes water in the warm air to precipitate out along the equator. During this process, the now warm, dry air in the upper atmosphere deflects away from the equator toward both poles due to the relative pressure gradient force at that height.

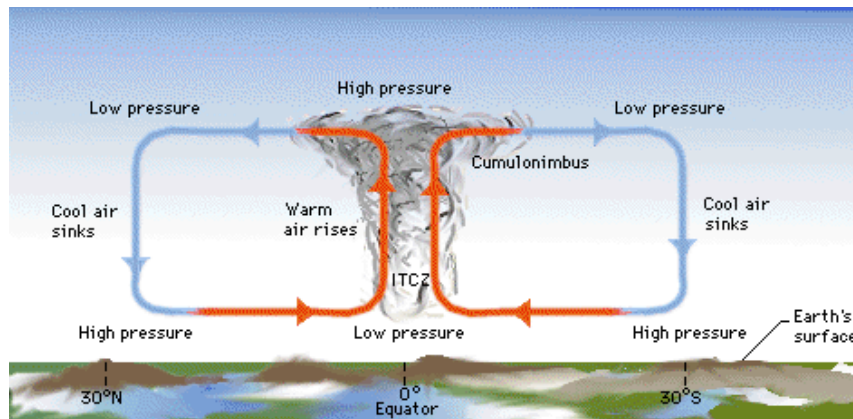


Figure 4. Hadley Cell Circulation. Global Warming, “Suggestions of “Strong Negative Cloud Feedbacks” in a Warmer Climate,” 2009, <http://hernadi-key.blogspot.com/2009/06/suggestions-of-strong-negative-cloud.html>.

At or near 30° north and south latitudes the warm, dry air cools, and sinks to the surface creating a subtropical region of high pressure at the surface and contributing to drier and even desert climates in that area. Scientists speculate that Hadley Cell Circulation will become more intense as the climate warms, causing more intense precipitation at the equator and more intense dry air at the 30° north and south latitudes.^x

The Coriolis Effect is another fundamental atmospheric circulation system. Surface winds move from the subtropical areas of high pressure to areas of low pressure. Because of this, winds move toward both the equator and the sub-polar latitudes at 60° north and south where there is low pressure. If the Earth did not rotate these winds would move in a straight line toward low-pressure systems. However, since the Earth rotates, the winds are deflected (Figure 5). For example, in the Northern Hemisphere, as the trade winds move south towards the equator the rotation of the Earth causes the winds to deflect slightly toward the west (the “trade winds”). The opposite effect occurs with the “westerlies” (winds between 30°N and 60°N latitude). Since the region between 30°N and 60°N latitude is not a band of low pressure like the equator, the winds blowing northward are deflected toward the east.³

Jet streams are also an important component of atmospheric circulation. Jet streams consist of high velocity bands of winds in the upper troposphere that form where two air masses of different temperatures come together. The greater the temperature difference and the deeper the troposphere layer the higher the wind speeds. In the northern hemisphere, the polar jet stream lies around 60°N latitude where aloft winds are diverging, and the subtropical jet stream lies around 30°N latitude where

³ Winds are labeled based on where they come from. Thus winds blowing toward the east are called Westerlies.

aloft winds are converging. Both jet streams blow toward the east. In the high atmosphere winds deflect in the opposite direction than they do along the surface. Therefore, winds deflect away from the equator at 0° latitude toward the subtropical high systems at 30° north and south latitude.

Additional atmospheric circulation processes that impact climate patterns include:

- Teleconnections – “recurring and persistent, large scale pattern of pressure and circulation anomalies that span vast geographic areas.”^{xi}
- The Monsoonal effect – strong seasonal shift in wind patterns from continental (land/dry) to maritime (sea/wet) winds over many parts of the world; and
- Cyclones and Anticyclones – very large seasonal weather systems such as hurricanes, tropical storms, wave cyclones and tornadoes

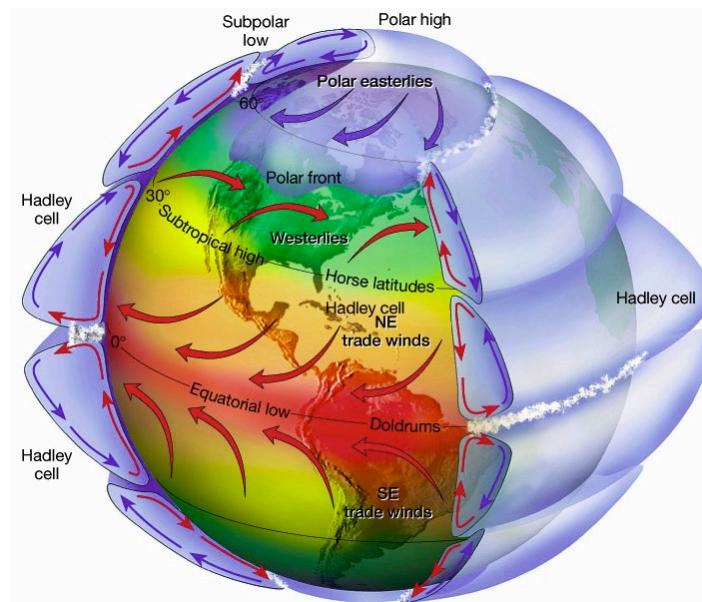


Figure 5. General Global Air Circulation. Arrows that lay along the Earth are deflected due to Coriolis winds and the rotation of the Earth. Hadley circulation is depicted in the atmosphere. Scioly.org, “Meteorology/Everyday Weather: Coriolis Effect and the Three Cell Model,” 2010, http://scioly.org/wiki/index.php/Meteorology/Everyday_Weather.

Oceanic Circulation

Oceanic circulation, similar to atmospheric circulation, has an impact on climate. In general, winds drive surface circulation (down to 2000 meters) and sinking of cold water in Polar Regions drives deep-water circulation. A mixture of surface wind systems and the Coriolis Effect cause gyres, or circular patterns, in oceanic surface currents and include major currents such as the Gulf Stream in the Atlantic Ocean. In the Northern Hemisphere gyres move in a clockwise motion, while in the Southern Hemisphere they move in a counterclockwise motion. This provides for a mixing of warm water from the equator with cold water near the poles (Figure 6).

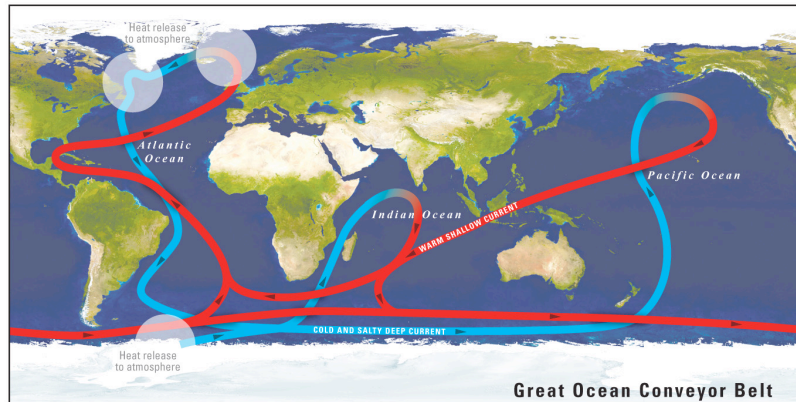


Figure 6. The Ocean Conveyor System. Red indicates warm, shallow currents while blue indicates cold, deep currents (thermohaline circulation). When currents reach the poles, they sink due to the cold water's density. Where the currents change depth indicates upwelling and downwelling circulation. Broecker, "Chapter A-2 (Figure 31)," 1991, <http://pubs.usgs.gov/pp/p1386a/gallery2-fig31.html>.

The El Niño-Southern Oscillation (ENSO) and La Niña contribute to oceanic circulation (Figure 7). The El Niño effect is characterized by unusually warm water temperatures in the equatorial Pacific and La Niña by unusually cool ones. Trade winds along the coast of South America near Peru push warm surface water westward towards the Pacific Ocean basin near Indonesia. Here warm air, due to the warm water, rises and precipitates. This surface water shift to the west allows for upwelling of colder water along the coast of Peru. During an El Niño event, trade winds decrease off the western coast of South America, which causes a decrease in flow of warm water toward Indonesia. Therefore, warmer water suppresses the upwelling of cold water near the South American coast. The weakening of trade winds also causes low pressure systems, which often form near Indonesia, to shift eastward causing drier conditions in the western tropical Pacific Ocean.

A La Niña event has the opposite effect of El Niño. In the case of La Niña, trade winds are amplified causing more cold water to surface along the western coast of South America and more precipitation in the western tropical Pacific Ocean.

Thermohaline circulation occurs when cold, salty water in Polar Regions sinks and is carried along the ocean floor, driving deep ocean currents. The deep ocean conveyor system provides a framework for net ocean current circulation as well as oxygen and energy transportation around the planet. It also plays an important role in the mixing of surface water and deep water.

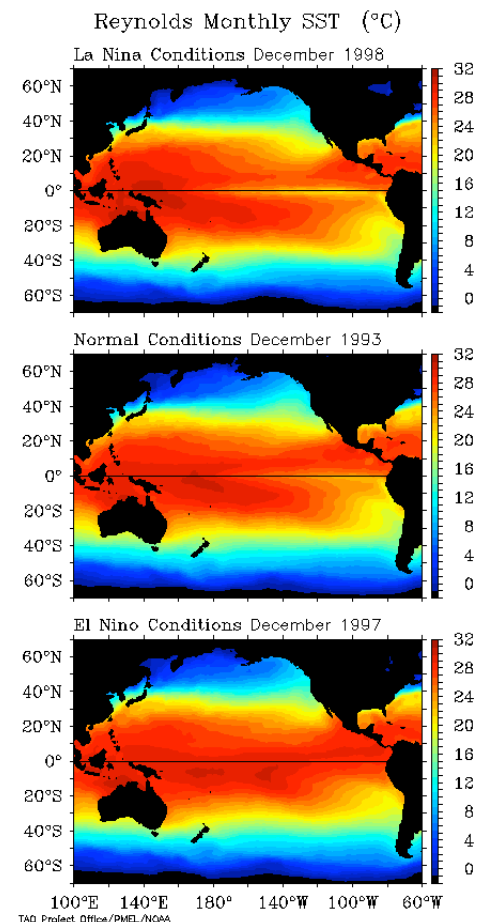


Figure 7. El Niño, La Niña, and Normal Conditions. The top chart shows a La Niña event with cooling equatorial currents, the middle chart shows a normal equatorial current event and the bottom chart shows an El Niño event with warming equatorial currents. National Oceanic and Atmospheric Administration (NOAA), <http://www.pmel.noaa.gov/tao/elnino/la-nina.html>.

IPCC's Fifth Assessment Report (AR5)

IPCC reports consider a series of scenarios. In previous reports, the IPCC evaluated and approved various climate change scenarios based on greenhouse gas and aerosol emissions.^{xii} The IPCC's Fifth Assessment Report (AR5) focuses on radiative forcing intensity of emitted greenhouse gas compounds as well as socio-economic conditions. As previously described, radiative forcing is the quantified net change in irradiance of the earth, under certain conditions, based on a specific factor or forcing agent affecting the climate change. The AR5 includes new scenarios approved by research communities rather than the full intergovernmental panel. The new scenarios used in the AR5 are described as Representative Concentration Pathways (RCP).

There are four RCPs in the AR5: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (Table 2). Each RCP was modeled and formulated by a different institution in order to incorporate details from scientists around the world. Figure 8 illustrates the radiative forcing predictions for each RCP. Scientists are able to use these predictions to further project coastal erosion rates and natural disaster occurrence, which in turn allows for predictions regarding climate change effects on urban populations and food production, among other impacts.

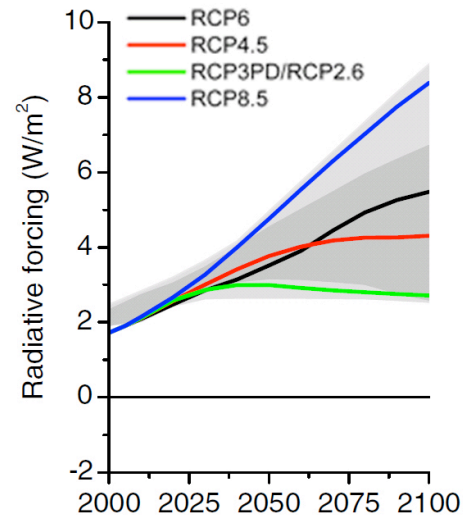


Figure 8. Radiative Forcing Predictions for the Representative Concentration Pathways (RCP). Van Vuuren et al, *The Representative Concentration Pathways: An Overview*. *Climatic Change*, 2011, 109 (1-2), 5-31.

Table 2. AR5 Representative Concentration Pathways (RCPs)

RCP	Model Team	Institution	Country of Origin	Representation
2.6	IMAGE	Netherlands Environmental Assessment Agency	Netherlands	Emission stabilization mid-century, decreases by year 2100
4.5	MiniCAM	Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI)	USA	Emission stabilization by the year 2100
6.0	AIM	National Institute for Environmental Studies	Japan	Emission stabilization after year 2100
8.5	MESSAGE and IIASA Integrated Assessment Framework	International Institute for Applied System Analysis (IIASA)	Austria	Increasing emissions and high concentration levels well after year 2100

Areas of Noticeable Effects in the IPCC Reporting

The impacts of a changing climate can be observed, measured, and monitored in several specific ways, including impacts to ice and permafrost, coastal regions and islands, and production systems such as agriculture and forestry.

Ice and Permafrost

The earth's cryosphere encompasses ice caps, continental ice sheets and floating ice shelves, mountain top glaciers, seasonal snow cover on land; sea, lake and river ice; and frozen ground. In general, according to IPCC research, elements of the cryosphere are shrinking.⁴ Currently, a retreat in mountain top glaciers is causing an increase in snow melt runoff, which is increasing erosion, stream and river discharge rates, and flooding in mountainous regions including the Alps, Himalayas, and the Andes.^{xiii} In permafrost regions, climate warmth is causing typical seasonally frozen ground to thaw, which is causing an increase in ground water, an increase in arctic wetlands, and new colonization of plants and animals in these regions.^{xiv} Climate warmth is also causing sea ice to melt leading to ocean freshening. This freshening may cause changes in oceanic circulation due to its density difference compared to salty ocean water. Ocean freshening is also causing ecosystem changes and population fluctuations in species.^{xv}

Coastal Regions and Islands

As sea levels increase coastal areas are more prone to high-energy waves and erosion, including the East Coast of the United States where inlet splits and tidal engineering structures are common.^{xvi} Impacts have included loss of development and displacement of commercial and residential neighborhoods. Areas such as the United Kingdom are experiencing erosion problems due to rising sea levels affecting coastal development as well as wetland changes.^{xvii} Wetland habitats in Normandy, France are expanding into lake habitats due to an increased sea level as well.^{xviii}

Another area of concern is coral reefs. An increase in atmospheric CO₂ results in more oceanic CO₂, which raises oceanic pH and acidity levels. Coral reefs are being depleted due to coral bleaching - the removal of symbiotic algae (zooxanthellae) resulting in the coral turning white and potentially dying. There is a direct correlation between an increase⁵ in ocean temperature and an increase in coral bleaching.^{xix}

The elevation of sea level relative to islands also makes them highly susceptible to natural disasters. Climate change may have a great effect on the weather systems of island nations such as Indonesia and the Philippines, and could significantly change the climate of these nations.^{xx} Natural disaster impacts to coastal regions and islands may increase the population of refugees or displaced persons. Scientist Norman Myers predicts there will be 200 million climate-induced refugees by the year 2050^{xxi} while the International Organization for Migration (IOM) predicts there will be between 25 million and 1 billion refugees migrating due to environmental effects by the year 2050.^{xxii} Areas such as Bangladesh, Venice, New Orleans, Sub-Saharan Africa, and the Maldives are at risk of inundation. The Republic of Maldives is working with the nations of Australia, India, and Sri Lanka for environmentally induced migration evacuation plans.^{xxiii}

⁴ There is an increase in some regions due to an increase in snowfall.

⁵ Although large decreases in ocean temperature have been known to cause bleaching as well.

Agriculture and Forestry

Climate change also affects agriculture and crop yields around the world. With 40% of the Earth's surface occupied by cropland and pastures, a shifting climate may alter agricultural locations, techniques, crop choices and yields.^{xxiv} IPPC reports predict that climate change will bring drier conditions to already dry areas while bringing more precipitation to temperate and tropical areas.^{xxv} An increase in atmospheric CO₂ and temperature may have positive effects for one crop, while having negative effects on others. Scientists have shown that with an increase in atmospheric CO₂, there will be an increase in corn crop yields from an increase in net CO₂ assimilation by corn plants.^{xxvi} However, an increase in atmospheric CO₂ may cause a decrease in yields in grains such as rice and wheat.^{xxvii}

With respect to forestry, according to the Working Group II sub-report of the AR4, timber production is expected to increase globally due to climate change.^{xxviii} This increase varies depending on region; in some regions there will be a decrease while in others there will be an increase. In North America, growing seasons are lengthening in forests, which are causing an increase in carbon intake through photosynthesis. Along with an increased growing season, geographic ranges of many species will shift northwards in North America, which will form different landscapes and habitats for species.^{xxix} A predicted drought in some areas as well as a precipitation increase in others is likely to alter forest ecosystems further.^{xxx}

Climate Change Economics

The global measure of economic markets is gross domestic product (GDP), a measure of the total value of goods and services produced within the borders of a nation.

$$\text{GDP} = \text{consumer spending} + \text{industry investments} + (\text{exports} - \text{imports}) + \text{government spending}$$

The world's GDP may alter as a result of the indirect change on a country or economic system due to a changing climate.

Both climate scientists and economists are predicting changes in economic activity due to climate change. According to *The Economics of Climate Change: The Stern Review*, under a business as usual scenario, there will be a 5-10% decrease in GDP due to the indirect effects of climate change.^{xxxi} Poor nations near coastal and dry environments will experience negative effects on economic growth as a result of increased temperatures. It is estimated that this will be influenced, in part, by a decrease in crop yields.^{xxxii} Scientists at the National Bureau of Economic Research hypothesize that a one-degree annual Celsius temperature increase will result in a 1.1% decrease in economic activity in poor nations.^{xxxiii} A decrease in GDP will decrease a country's economic growth, which may lead to a host of negative impacts, including inflation, unemployment, a rise in black markets, and political or governmental instability.

Economists tend to view the world in terms of current dollars, applying discount rates to costs or income that will be realized in the future. As a result, some economists argue that since costs that might result from climate change will occur at some point in the future, only modest investments aimed at avoiding or reducing these future costs are justified in the present. Naturally, the effects of change are long-term. Markets will not generally support long-term decisions and industries will have trouble investing for the future if they do not see benefits in the short-term. Moreover, because it is difficult to predict the rate at which climate change will occur, the question of how much to invest versus how much to spend now is even more difficult to address. Some economists are advising to do little to nothing at present other than maintain a healthy economy and reserve so that future generations

will have enough money to live well despite expected degradation of living conditions. Others, like Nicholas Stern, advise that investments in climate change avoidance and mitigation should be made now. He states in *The Economics of Climate Change: The Stern Review* that 1% of global GDP should be invested to combat climate change, with the view that if “business as usual” continues to be practiced, there will be a 20% reduction of GDP every year.^{xxxiv} The AR4 suggests that each country should base its mitigation discount rate on the opportunity cost of capital. For developed countries, rates between 4-6% are recommended, while for developing countries, rates around 10-12% are recommended.^{xxxv}

Climate Research, Modeling and Variability

It is difficult for scientists to draw conclusions about changing climate systems with very limited data sets. In particular it has proven difficult for scientists to make predictions and draw conclusions about the Polar Regions due to their remote locations and harsh environments. The influence of climate change on the occurrence of tropical cyclones and hurricanes has also proven difficult to predict. The use of satellites to study these hurricanes and tropical cyclones has proven useful; however, satellites still do not provide accurate information about cloud cover and the storm’s center location.^{xxxvi} Scientific records of hurricanes and tropical cyclones date back to the mid-1800s, though these storms have only been seriously studied since the mid-1900s.^{xxxvii} This lack of historical data limits scientists in drawing conclusions about future hurricane and tropical cyclone activity.

Climate models allow scientists to input different weather and climate patterns in order to simulate what may occur under certain conditions. Two major types of climate models are used, general circulation models (GCMs) and regional climate models (RCMs). GCMs take into account land, oceanic, and the atmospheric interactions on a global scale. The data from GCMs may be imputed into RCMs to look at regional effects of climate change. The largest areas of uncertainty in climate models are scales and resolution, clouds, pollution particles, and natural variability.^{xxxviii}

In terms of natural variability, it is difficult to forecast future circumstances based on present climate variability. Past data from tree rings and ice cores provide information regarding general trends, but they are not accurate enough to base conclusions on more particular trends. These areas of uncertainty cause differing models to compute different scenarios and projections even though they all consider similar factors.

The Global Warming Hiatus

Over the past 15 years there has been a much smaller increase in the linear trend of an increasing global mean surface temperature (GMST) than in the decades prior, a change that has raised questions among scientists and policy makers. From 1998-2012 the warming trend was 0.04°C/annum, whereas the trend for the longer period 1951-2012 is 0.11°C/annum.⁶ This “global warming hiatus” raises questions about the cause of the trend and whether existing climate models are able to reproduce the effect. IPCC states two possible reasons why this hiatus may be occurring: the effects of internal climate variability and incorrect radiative forcing assumptions.

⁶ These trends were predicted from the HadCRUT4 model from the Working Group I of the AR5. Flato, Gregory, Marotzke, Jochem, “Chapter 9: Evaluation of Climate Models in Climate Change 2013: Working Group I: The Physical Science”, 2013, http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf

Internal climate variability refers to natural climate systems. One area scientists are keeping a close eye on is the deep ocean and its heat-uptake. Working Group I of the AR5 has concluded that as a result of sampling limitations, it is uncertain that there has been sub-surface ocean heat up-take; however, they also state that from 1998-2010 it is very likely that the climate system, including the deep ocean (below 700m), was storing energy.⁷ Another area that scientists are reexamining is shifting atmospheric oscillation events. The Interdecadal Pacific Oscillation (IPO) in particular has shown positive and negative shifts from the year 2000.^{xxxix} However, scientists have doubts about the reality of observed shifts because of inconsistency between models.

The reduction of radiative forcing is said to be from natural forcing, or natural variations due to radiative forcing. Changes in solar forcing went from relative maximum values in 2000 to relative minimum values in 2009.^{xi} Furthermore, after the year 2000 a small series of volcanic eruptions occurred causing an increase in stratospheric aerosols and thus causing a negative feedback system and a cooling effect. Although these factors may be contributing to the warming hiatus, scientists provide low certainty levels in IPCC reports due to lack of consistency between models.

Criticisms of IPCC

Many criticisms have been leveled at IPCC reports. One of the biggest criticisms is in regard to discrepancy between climate change models and observational data. It is difficult to draw conclusions about temperature and sea level rise projections when a lack of consistency between the different instruments exists. A current IPCC goal is to close the uncertainty gap between models and observations as much as possible.

Another criticism of IPCC relates to incorporation of incorrect data within some of the reports. In the Working Group II sub-report of the AR4, an error was made about the rate by which glaciers in the Himalayan Mountains were receding. The report concluded, “Glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high”.^{xli} Scientists argued that this statement was incorrect and that assumptions such as this can not be made due to a lack of sufficient glacial observations within the Himalayan Mountains. IPCC has also admitted to producing a false statement in the Working Group II sub-report of the AR4 concerning the Netherlands, stating that, “55% of its territory is below sea level”.^{xlii} The statement should say, “55% of the country is at risk of flooding,” according to the Netherlands Environmental Assessment Agency (PBL).^{xliii}

The ‘Theory’ of Climate Change

According to most individuals, a theory is an idea that is not yet proven to be true.^{xliv} However, in the scientific world a theory is defined as “*a coherent group of tested propositions, commonly regarded as correct, that can be used as principles of explanation for a class of phenomena.*”⁸ A theory is scientific when its hypotheses or propositions can be tested, observed, and able to make falsifiable predictions. The theories of gravity, relativity, evolution, and plate tectonics are examples of scientific theories. Scientific theories provide a basis for scientific knowledge, allow for technological innovation and progression, and provide answers to many questions, such as how to cure some diseases.

⁷ Flato, Gregory, Marotzke, Jochem, “Chapter 9: Evaluation of Climate Models in Climate Change 2013: Working Group I: The Physical Science”, 2013, http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf

⁸ <http://dictionary.reference.com/browse/theory>

Climate change is an example of a scientific theory. There are many different propositions as to why changes in climate are occurring. One of the significant hypotheses being debated is human influence on climate change. There is evidence that supports this hypothesis, but there is also evidence supporting others, such as increases in natural solar radiation and warming cycles of the Earth. The theory of gravity, as well as other scientific theories, has undergone intense scientific experimentation for centuries, which allows it to sit high on the scientific theory spectrum, closer to proven fact. Climate change, on the other hand, is a relatively new scientific theory and thus does not have the same level of intense experimentation as the theory of gravity. As technology develops and research expands, scientists will be able to develop more accurate explanatory climate change theories.

Conclusion

The Earth's atmospheric, oceanic, and land processes are complex and susceptible to disturbance. The rhythmic balance of biotic systems is dictated by the equilibrium of abiotic processes. The impacts of climate change can be seen in many areas of the world, including economic effects and natural disasters. Organizations, such as the IPCC, provide a basis for policy makers to access the science and effects of climate variability and use this information to inform policy development and decision-making.

ⁱ Intergovernmental Panel on Climate Change, "Organization", *IPCC- Intergovernmental Panel on Climate Change*, 2014, <http://www.ipcc.ch/organization/organization.shtml#.UpOvtLYiSo>.

ⁱⁱ Serakos, Allison, Dovetail Partners, Inc., 2014.

ⁱⁱⁱ <https://www.acs.org/content/acs/en/climatescience/climatesciencenarratives/what-is-the-greenhouse-effect.html>

^{iv} Archer, David, "Chapter 3: The Layer Model with Greenhouse Effect," in *Global Warming: Understanding the Forecast 2nd Edition*, (USA: John Wiley & Sons, Inc. 2012), 19-28.

^v Archer, David, "Chapter 4: Greenhouse Gases," in *Global Warming: Understanding the Forecast 2nd Edition*, (USA: John Wiley & Sons, Inc. 2012), 29-42.

^{vi} Ibid.

^{vii} Ibid.

^{viii} http://www.nasa.gov/topics/earth/features/vapor_warming.html

^{ix} http://www.nsf.gov/news/special_reports/clouds/question.jsp

^x Archer, David, "Chapter 12: Potential Climate Impacts," in *Global Warming: Understanding the Forecast 2nd Edition*, (USA: John Wiley & Sons, Inc., 2012), 153-172.

^{xi} <http://www.cpc.ncep.noaa.gov/data/teledoc/teleintro.shtml>

^{xii} The previous systems included the 1990 IPCC Scenario A (SA90) in the First Assessment Report (FAR), the 1992 IPCC Scenarios (IS92) that appeared in the Third Assessment Report (TAR), and the Special Report on Emission Scenarios (SRES) used in the Fourth Assessment Report (AR4) as well as the TAR. IPCC-Intergovernmental Panel on Climate Change, "Scenario Process for AR5: The IPCC and Scenario Development", *IPCC-Intergovernmental Panel on Climate Change*, 17 June 2013, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/ipcc_scenarios.html.

^{xiii} Kundzewicz, Zbigniew W, Mata, Luis José, "1.3.1.1 Observed effects due to changes in the cryosphere in Climate Change 2007: Working Group II: Impacts, Adaptations, Vulnerability", *IPCC- Intergovernmental Panel on Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch1s1-3-1-1.html.

^{xiv} Ibid.

^{xv} Ibid.

^{xvi} Rosenzweig, Cynthia, Casassa, Gino, “1.3.3.1 Changes in coastal geomorphology in Climate Change 2007: Working Group II: Impacts, Adaptations, Vulnerability”, *IPCC-Intergovernmental Panel on Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch1s1-3-3-1.html.

^{xvii} Ibid.

^{xviii} Ibid.

^{xix} Rosenzweig, Cynthia, Casassa, Gino,, “1.3.4.1 Changes in coral reefs in Climate Change 2007: Working Group II: Impacts, Adaptations, and Vulnerability”, *IPCC-Intergovernmental Panel on Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch1s1-3-4-1.html.

^{xx} Mimura, Nobuo, Nurse, Leonard, “16.2.2 Climate and Weather in Climate Change 2007: Working Group II: Impacts, Adaptations, and Vulnerability”, *IPCC-Intergovernmental Panel on Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch16s16-2-2.html.

^{xxi} Meyers, Norman, “Environmental refugees : A growing phenomenon of the 21st century”, *The Royal Society*, 2001, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1692964/pdf/12028796.pdf>.

^{xxii} International Organization for Migration (IOM), “Migration and Climate Change: A Complex Nexus”, *International Organization for Migration*, <http://www.iom.int/cms/en/sites/iom/home/what-we-do/migration-and-climate-change/a-complex-nexus.html#estimates>.

^{xxiii} Brown, Oil, “Mitigation and Climate Change”, *International Organization for Migration*, 2007, http://publications.iom.int/bookstore/free/MRS-31_EN.pdf.

^{xxiv} Easterling, William, Aggarwal, Pramod, “5.1.1 Importance of agriculture, forestry and fisheries,” in *Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch5s5-1.html#5-1-1.

^{xxv} Collins, Matthew, Knutti, Reto, “Chapter 12: Long-Term Climate Change: Projections, Commitments and Irreversibility,” in *Climate Change 2013: Working Group I: The Physical Science*, 2013, http://www.climatechange2013.org/images/report/WG1AR5_Chapter12_FINAL.pdf.

^{xxvi} Leakey, A.D.B. et al, “Will photosynthesis of maize (*Zea mays*) in the US Corn Belt increase in future [CO₂] rich atmospheres? An analysis of diurnal courses of CO₂uptake under free-air concentration enrichment (FACE)” *Global Change Biology* 10 (2004): 951-962, <http://onlinelibrary.wiley.com/doi/10.1111/j.1529-8817.2003.00767.x/abstract>.

^{xxvii} Erda, Lin et al, “Climate change impacts on crop yield and quality with CO₂ fertilization in China”, *The Royal Society* 360 (2005): 2149-2154, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1569568/>.

^{xxviii} Easterling, William, Aggarwal, Pramod, “5.4.5.1 New findings since the TAR,” in *Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch5s5-4-5-1.html.

^{xxix} United States Environmental Protection Agency (EPA), “Climate Impacts on Forests”, *United States Environmental Protection Agency (EPA)*, 2013, <http://www.epa.gov/climatechange/impacts-adaptation/forests.html>.

^{xxx} United States Environmental Protection Agency (EPA), “Climate Impacts on Forests”, *United States Environmental Protection Agency (EPA)*, 2013, <http://www.epa.gov/climatechange/impacts-adaptation/forests.html>.

^{xxxi} Stern, Nicholas, “Executive Summary,” in *The Stern Review on the Economics of Climate Change*, (Cambridge, United Kingdom: Cambridge University Press, 2007), ix, http://webarchive.nationalarchives.gov.uk/20130129110402/http://www.hm-treasury.gov.uk/stern_review_report.htm.

^{xxxii} Nesvisky, Matt, “Climate change and economic growth over the last half century”, *The National Bureau of Economic Research*, <http://www.nber.org/digest/dec08/w14132.html>.

^{xxxiii} Ibid.

- ^{xxxiv} Stern, Nicholas, “Executive Summary,” in *The Stern Review on the Economics of Climate Change*, (Cambridge, United Kingdom: Cambridge University Press, 2007), ix, http://webarchive.nationalarchives.gov.uk/20130129110402/http://www.hm-treasury.gov.uk/stern_review_report.htm.
- ^{xxxv} Halsnaes, Kirsten, Shukla, Priyadarshi, “2.4.2.1 Discount Rates,” in *Climate Change 2007: Working Group III: Mitigation of Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch2s2-4-2-1.html.
- ^{xxxvi} Schmidt, Gavin, “Improving the Tropical Cyclone Record,” *Real Climate: Climate Science from Climate Scientists*, 2012, <http://www.realclimate.org/index.php/archives/2012/12/improving-the-tropical-cyclone-climate-record/>.
- ^{xxxvii} Vecchi, Gabriel A., Knutson, Thomas R., “Historical Changes in Atlantic Hurricane and Tropical Storms: How well do we know the historical cyclone record?,” *Geophysical Fluid Dynamics Laboratory at the National Oceanic and Atmospheric Administration (NOAA)*, <http://www.gfdl.noaa.gov/historical-atlantic-hurricane-and-tropical-storm-records>.
- ^{xxxviii} Lenart, Melanie, “Climate: Sources of Uncertainty in Global Models,” *The University of Arizona: Southwest Climate Change Network*, 2008, <http://www.southwestclimatechange.org/climate/modeling/uncertainty-global>.
- ^{xxxix} Ibid.
- ^{xl} Flato, Gregory, Marotzke, Jochem, “Chapter 9: Evaluation of Climate Models in Climate Change 2013: Working Group I: The Physical Science”, 2013, http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf.
- ^{xli} Cruz, Rex Victor et al, “10.6.2. The Himalayan Glaciers in Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability,” *IPCC-Intergovernmental Panel on Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-6-2.html.
- ^{xlii} Alcamo, Joseph, Moneno, José M., Nováky, Béla, “12.2.3 Current Adaptation and Adaptive Capacity in Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability,” *IPCC – Intergovernmental Panel on Climate Change*, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch12s12-2-3.html.
- ^{xliii} Netherlands Environmental Assessment Agency (PBL), “Chapter 8: Europe,” *Assessing the IPCC Assessment: An Analysis of Statements on projected Regional Impacts in the 2007 Report*, 2010, <http://www.pbl.nl/sites/default/files/cms/publicaties/500216002.pdf>.
- ^{xliv} Merriam-Webster Dictionary, “Theory,” *Merriam-Webster Dictionary*, <http://www.merriam-webster.com/dictionary/theory>.

This report was prepared by

DOVETAIL PARTNERS, INC.

Dovetail Partners is a 501(c)(3) nonprofit organization that provides authoritative information about the impacts and trade-offs of environmental decisions, including consumption choices, land use, and policy alternatives.

**FOR MORE INFORMATION OR TO REQUEST ADDITIONAL
COPIES OF THIS REPORT, CONTACT US AT:**

INFO@DOVETAILINC.ORG

WWW.DOVETAILINC.ORG

612-333-0430

© 2014 Dovetail Partners, Inc.



DOVETAIL PARTNERS, INC.

528 Hennepin Ave, Suite 703

Minneapolis, MN 55403

Phone: 612-333-0430

Fax: 612-333-0432

www.dovetailinc.org