1

1) Within this country lies a picturesque desert, located at the bottom right of the image. This desert was home to a group of enigmatic ancient people who were known for their skill and resourcefulness. Their capital is a UNESCO World Heritage Site. *Name the desert and the given name of the people.*

The Rum Desert or Wadi Rum, and the people are the Nabateans.

2) The wavy lines that cross the middle of the image are natural geologic features that often carry descriptive names of their location. *What is the native word used to accurately describe these features?*

The native word is the Arabic word for valley: Wadi.

3) The name of the body of water at the bottom of the image is actually a misnomer. The nearby hills that protect the landscape from weather fronts also enable a “rain shadow,” thus contributing to the surrounding aridity. *What is the name of the body of water?*

The body of water is the Dead Sea.

4) At the bottom left, small city developments are visible. One of those cities came was developed at the beginning of the 20th century. It now accounts for 50 percent of the industrial output of the country. *Name the city.*

The city is Zarqa.

5) The landscape dominating most of the image is an extension of a much

larger, natural feature. This feature is home to a very limited floristic diversity and to a number of critical and endangered species—though there are no formally protected areas. *Name this feature.*

It is the Arabian Desert.

6) *Name the country that fills most of the area in this image.*

Jordan.

Nearly 250 people from around the world responded before the deadline. Individuals who answered all questions correctly are listed below in the order in which responses were received. The prize winners are indicated by an asterisk. Well done to all and thank you for participating!

1. James Mackie, Fort Collins, CO *
2. Philip Bedggood, Melbourne, Australia *
3. Roel Duijnhouwer, Oud-Beijerland, The Netherlands *
4. Britt Smith, Madison, WI
5. Kristin Poinar, Seattle, WA
6. Pam Stewart, Eugene, OR
7. Tyler Rundel, Topanga
8. John Thomas, Oakland, IA
9. Ivan P Anderson, Ditton, Kent, England
10. Jonathan Frishtick, Norwich, VT

Exam Schedule

Lecture 16 March 1 **Take Home Midterm (2nd Midterm) Released**

Urban Chapter 13, 10

Heat islands

Impervious surfaces and hydrology

High spatial resolution satellites

Landscape mixtures

subpixel mixing

pan sharpening

Lecture 17 March 6 **Midterm due before start of class**

Feb. 27, 2012 Climate Change

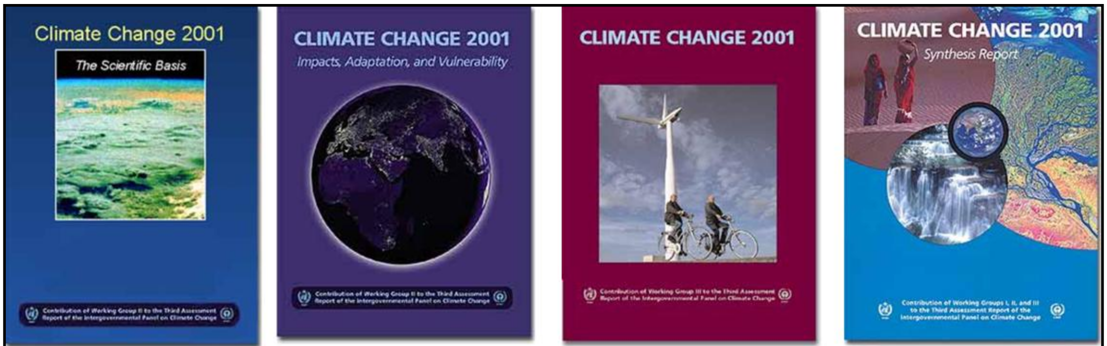
Handouts:
IPCC 4th Assessment, 2007, Working Group I: Physical Science Basis, Summary for Policy Makers

California AB32 Fact Sheet, 2006

Our Changing Climate: Assessing Risks to California, biennial report, 2007
2009 CA Action Team Draft Report

Lecture:
Greenhouse gases and energy budget
Biogeochemical cycles
Climate warming

The Intergovernmental Panel on Climate Change (IPCC), is a group of scientists from around the world brought together by the United Nations, evaluates our current understanding and the potential impacts of climate change.



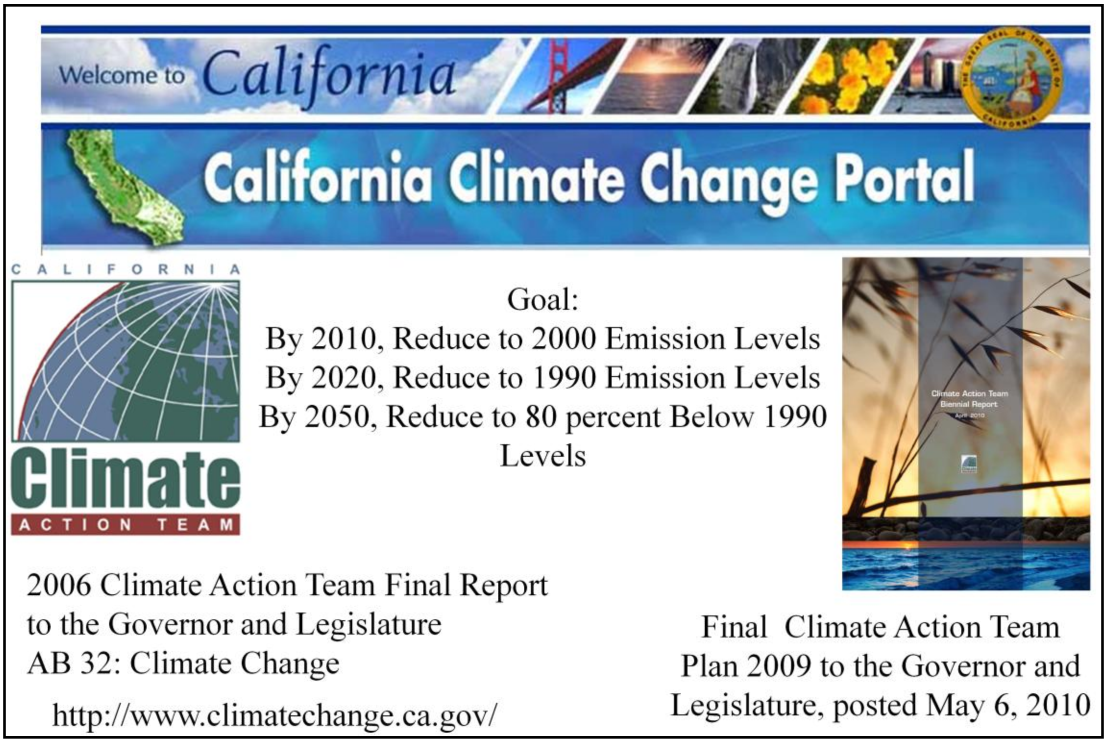
IPCC Third Assessment Report – Climate Change 2001
IPCC Fourth Assessment Report – Climate Change 2007

The **Intergovernmental Panel on Climate Change (IPCC)** was established by WMO and UNEP to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. It is open to all Members of the UN and of WMO.

http://www.ipcc.ch/

The UN Intergovernmental Panel on Climate Change (IPCC), produces a **concensus report** by committees of international scientists, who evaluate current understanding and potential impacts of climate change.

Current findings, conclude surface air temperature has increased an average of 0.6°C during the 20th Century.



Climate Action Team & Climate Action Initiative

Governor Schwarzenegger signed Executive Order # S-3-05 on June 1, 2005. The Executive Order established greenhouse gas targets:

By 2010, Reduce to 2000 Emission Levels

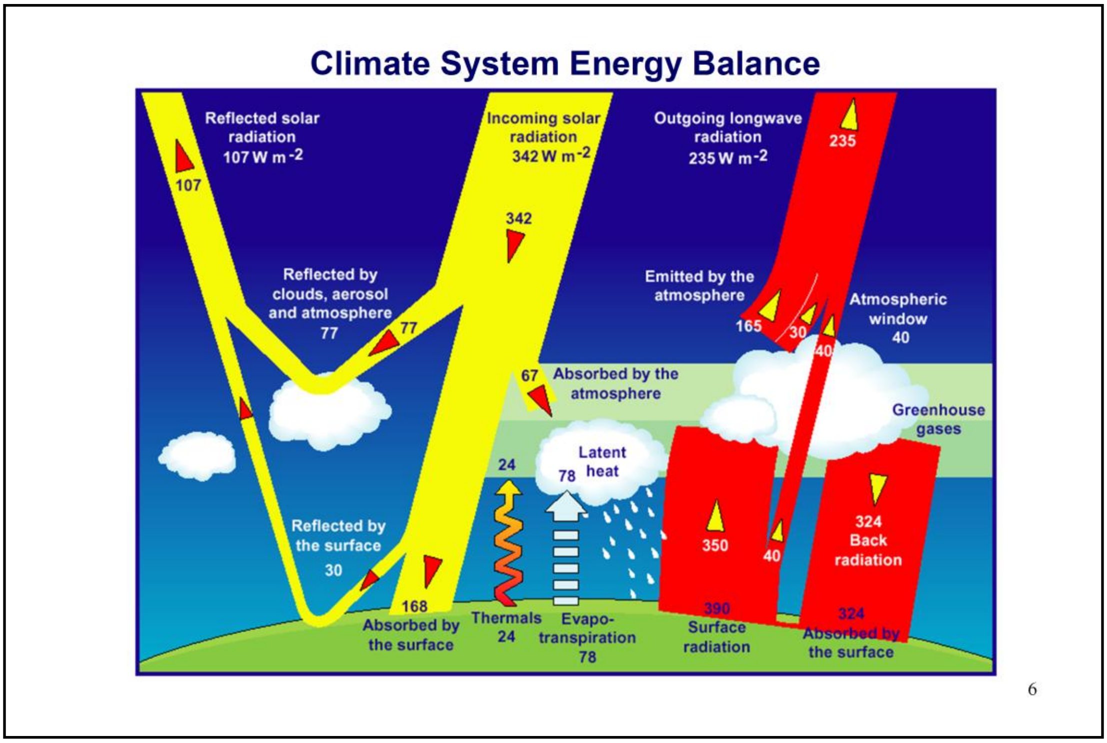
By 2020, Reduce to 1990 Emission Levels

By 2050, Reduce to 80 percent Below 1990 Levels

To meet the targets, the Governor directed the Secretary of the California Environmental Protection Agency to coordinate with the Secretary of the Business, Transportation and Housing Agency, Secretary of the Department of Food and Agriculture, Secretary of the Resources Agency, Chairperson of the Air Resources Board, Chairperson of the Energy Commission and President of the Public Utilities Commission .

The Secretary of CalEPA will lead a **Climate Action Team** made up of representatives from the agencies listed above to implement global warming emission reduction programs and report on the progress made toward meeting the statewide greenhouse gas targets that were established in the executive order.

Per the Executive Order, the first report to the Governor and the Legislature was released in March 2006 and will be issued bi-annually thereafter.



According to the IPCC current findings, the world's surface air temperature has increased an average of 0.6°C (1.0 °F) during the 20th Century. One degree of change may not sound like very much, but it affects the Earth's climate, oceans, and biosphere. Below are some effects of climate change that we see happening now.

Sea level is rising. During the 20th century, sea level rose 10-20 cm (4-8 inches) due to melting glacier ice and expansion of warmer seawater. Models predict that sea level may rise as much as 85 cm (33 inches) during the 21st century. This is a threat to coastal communities, wetlands and coral reefs.

Arctic sea ice is melting. The summer thickness of sea ice is about half of what it was in 1950. Melting Arctic sea ice may eventually lead to global changes in water circulation and melting ice speeds up warming of the Arctic because water absorbs much more heat than the ice did.

Sea-surface temperatures are warming. This has contributed to the death of about a quarter of the world's coral reefs in the last few decades. Many of the coral animals died after weakened by coral bleaching, a process tied directly to warmed waters.

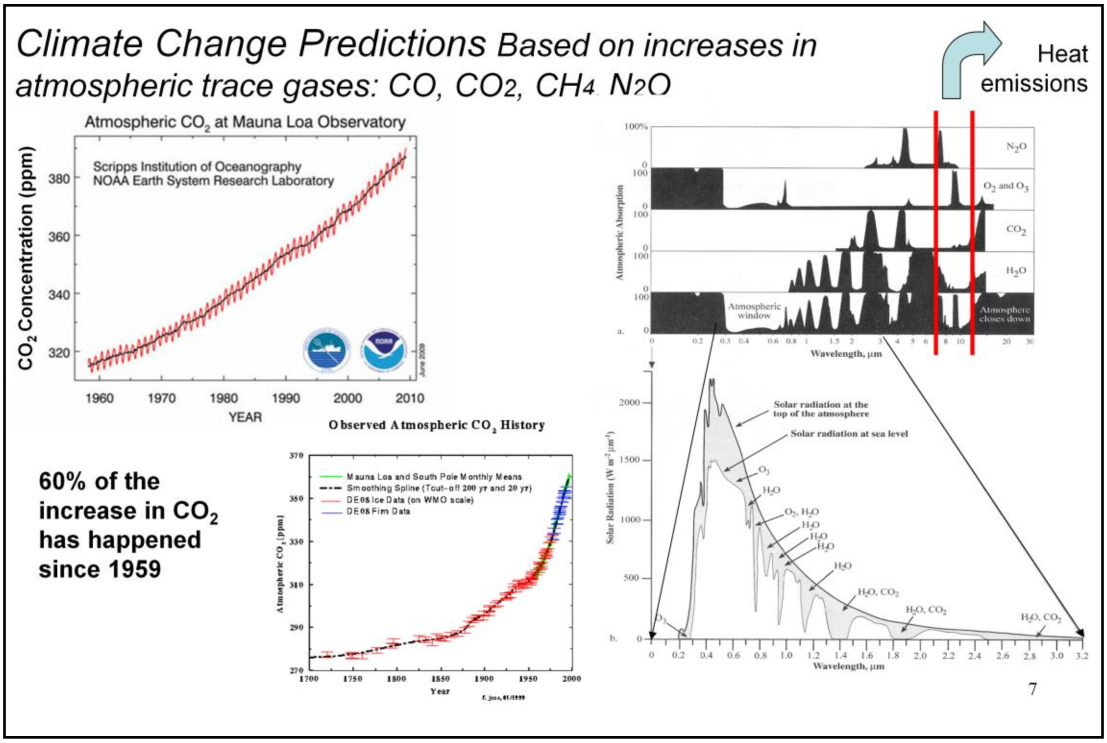
Heavier rainfall causes flooding in many regions as warmer temperatures speed up the water cycle. There has been a 5-10% increase in precipitation over the past century. In the last ten years, floods have caused almost 300 billion US dollars of damage, that's three to six times the amount of damage caused by floods in previous decades.

Changes in agriculture affect regions of the globe: As regional climates warm, some mid-latitude places, like Europe, receive a longer growing season, while some tropical places are becoming too hot and dry to grow crops.

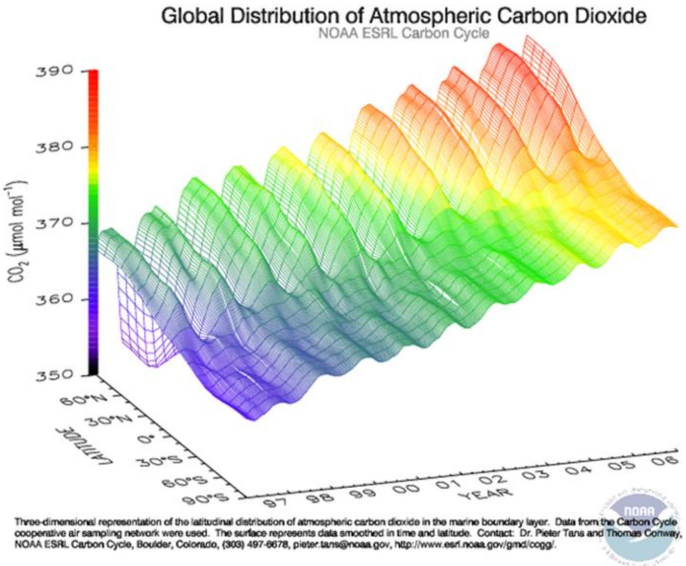
The amount of drought may be increasing. Higher temperatures lead to a high rate of evaporation and drought in some areas of the world. Researchers are not sure if drought has increased as a result of current warming.

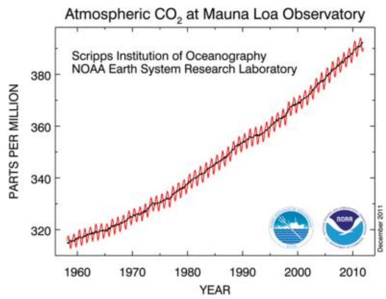
Ecosystems are changing. As temperatures warm, species may either migrate to a cooler, more suitable habitat or die. Species that are particularly vulnerable include endangered species, coral reefs, and polar animals such as penguins, polar bears and seals.

Severe weather events may be more common and stronger. Some researchers say that the number and strength of hurricanes, tornadoes, and other events has increased over the last 15–20 years. However, there is not enough evidence to be certain that climate is the cause.

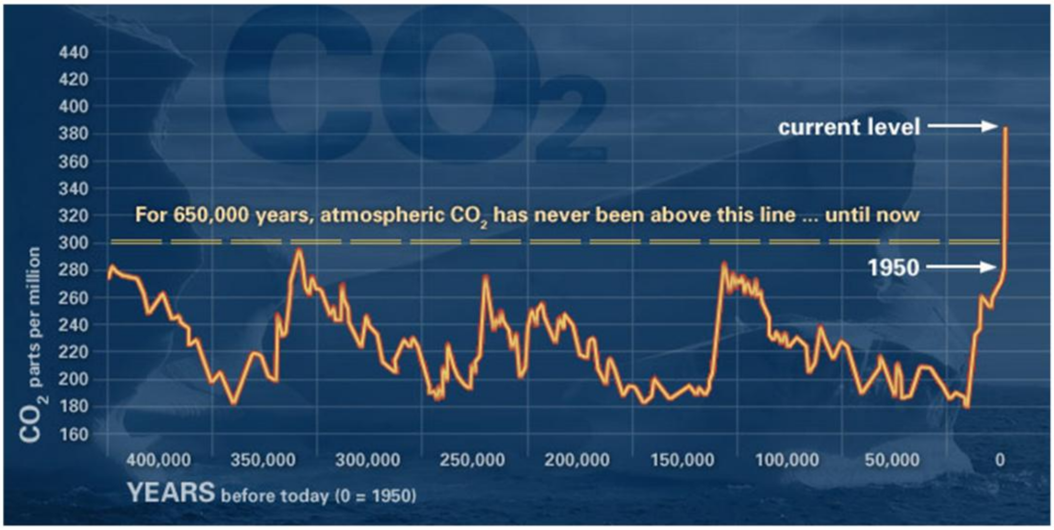


through "Trends Online," from the Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory. This is referred to as the "single best source" of information on fossil fuels use, CO2 and temperature trends.

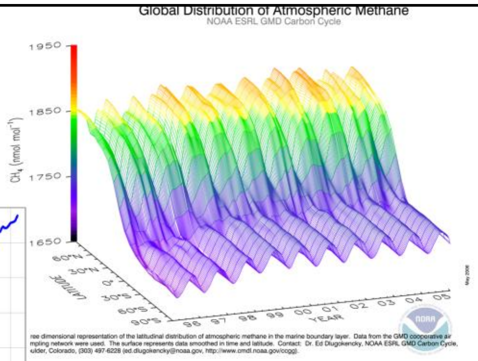

Global Distribution of Atmospheric Carbon Dioxide
NOAA ESRL Carbon Cycle
390
380
370
360
350
CO_2 (μmol mol^{-1})
60°N
30°N
0
30°S
60°S
90°S
LATITUDE
97 98 99 00 01 02 03 04 05 06
YEAR
Three-dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the Carbon Cycle cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Contact: Dr. Pieter Tans and Thomas Conway, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

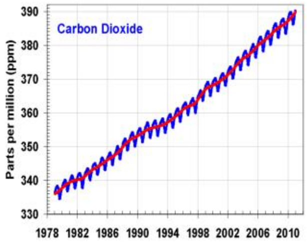

Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
December 2011

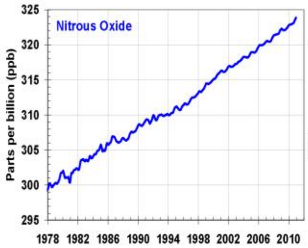

National Aeronautics and Space Administration
NASA
subscribe

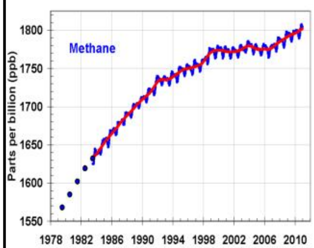

CO2
current level
For 650,000 years, atmospheric CO2 has never been above this line ... until now
1950
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
CO2 parts per million
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
YEARS before today (0 = 1950)

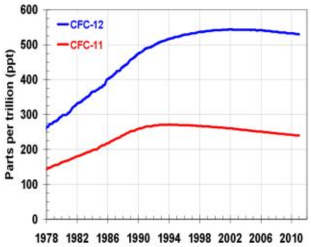
Atmospheric Trace Gasses Are Increasing



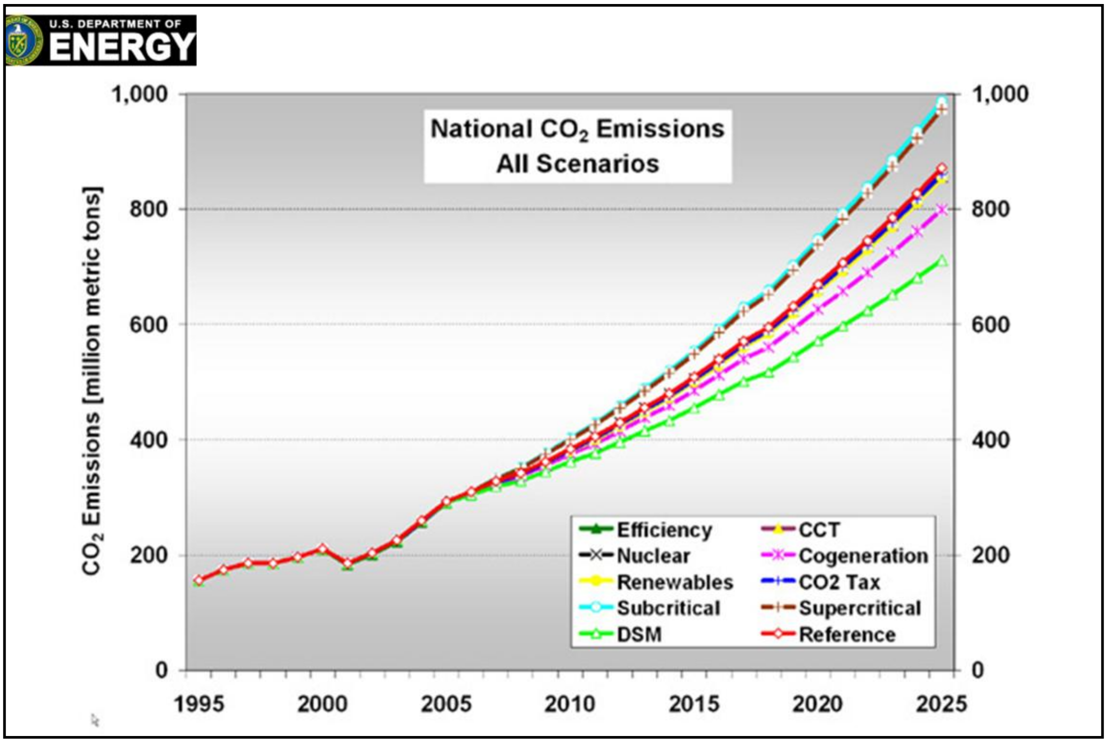








CH_4 has 23x effect CO_2



U.S. DEPARTMENT OF
ENERGY
National CO_2 Emissions
All Scenarios
CO_2 Emissions [million metric tons]
1,000
800
600
400
200
0
1995
2000
2005
2010
2015
2020
2025
Efficiency
Nuclear
Renewables
Subcritical
DSM
CCT
Cogeneration
CO2 Tax
Supercritical
Reference

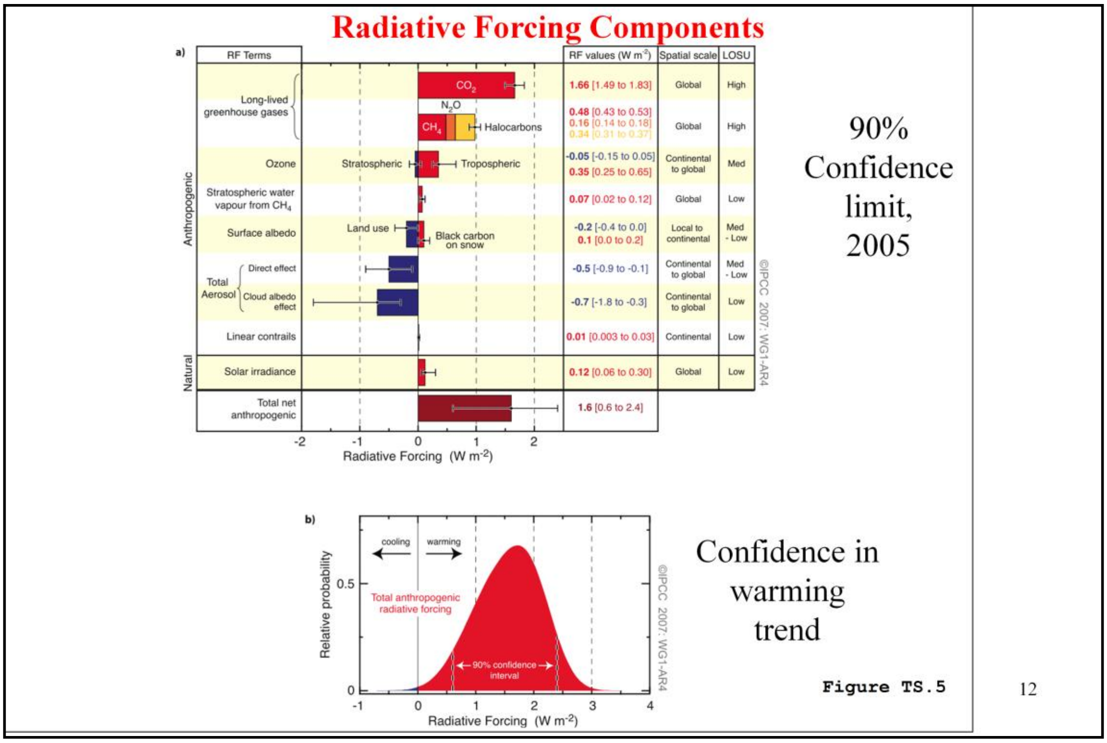
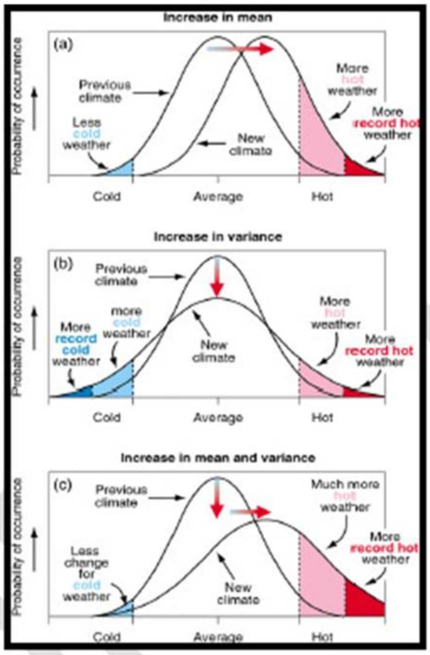


Figure TS.5. (a) Global mean radiative forcings (RF) and their 90% confidence intervals in 2005 for various agents and mechanisms. Columns on the right-hand side specify best estimates and confidence intervals (RF values); typical geographical extent of the forcing (Spatial scale); and level of scientific understanding (LOSU) indicating the scientific confidence level as explained in Section 2.9. Errors for CH_4, N_2O and halocarbons have been combined. The net anthropogenic radiative forcing and its range are also shown. Best estimates and uncertainty ranges can not be obtained by direct addition of individual terms due to the asymmetric uncertainty ranges for some factors; the values given here were obtained from a Monte Carlo technique as discussed in Section 2.9. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional form of natural forcing but are not included due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness. (b) Probability distribution of the global mean combined radiative forcing from all anthropogenic agents shown in (a). The distribution is calculated by combining the best estimates and uncertainties of each component. The spread in the distribution is increased significantly by the negative forcing terms, which have larger uncertainties than the positive terms. {2.9.1, 2.9.2; Figure 2.20}

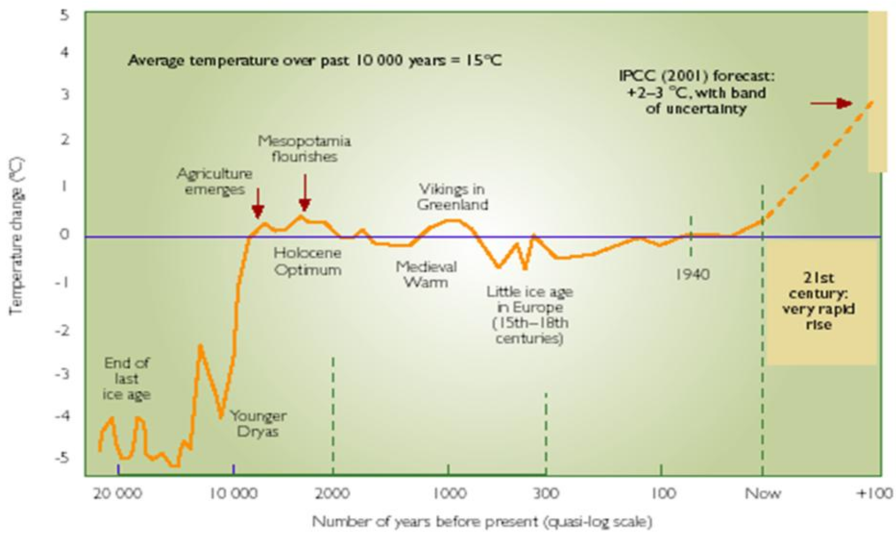


Why do we experience extreme weather (often cold!) patterns if there is a warming trend?

Trend includes changes in mean temperature and in the variance of temperature

Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution.

Figure 1.1. Variations in Earth's average surface temperature, over the past 20,000 years



14

The IPCC (2001) has estimated that the global average temperature will rise by several degrees centigrade during this century. There is unavoidable uncertainty in the estimate, since the intricacies of the climate system are not fully understood, and humankind's developmental future cannot be foretold with certainty.

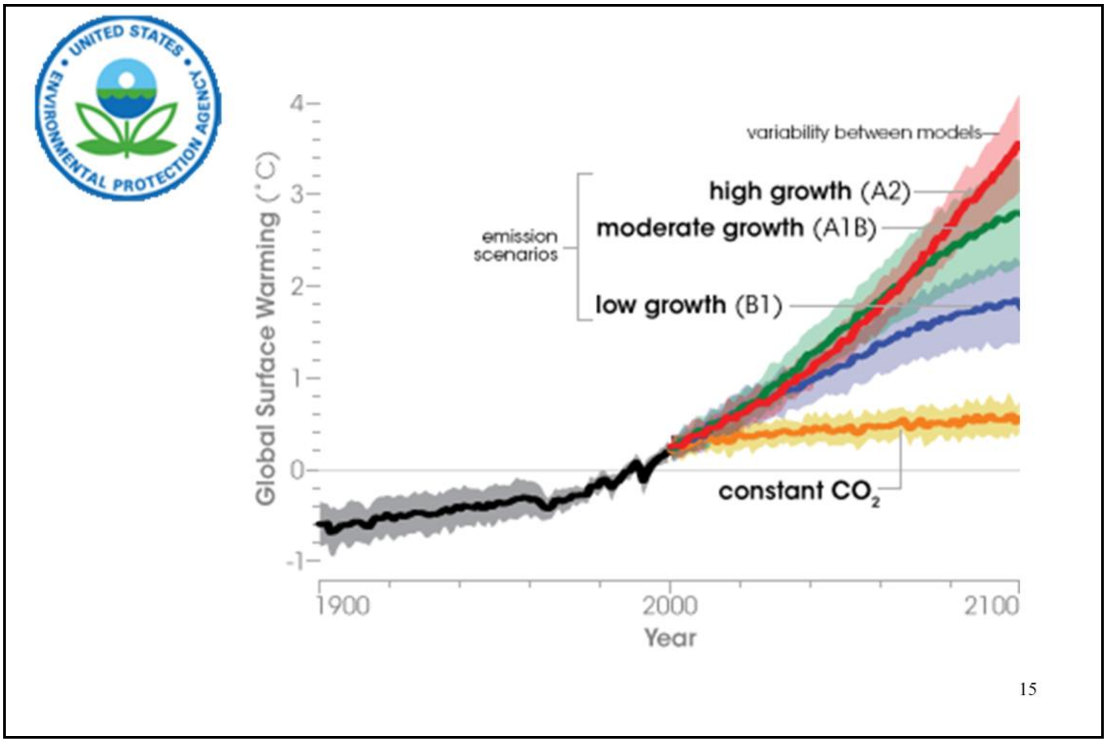


Figure 1: *Temperature projections to the year 2100, based on a range of emission scenarios and global climate models. Scenarios that assume the highest growth in greenhouse gas emissions provide the estimates in the top end of the temperature range. The orange line ("constant CO2") projects global temperatures with greenhouse gas concentrations stabilized at year 2000 levels. Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007)*

Temperature Change Projections

Due to uncertainties about future emissions and concentrations of greenhouse gases, their net warming effect in the atmosphere, and the response of the climate system, estimates of future temperature change are uncertain. With these caveats in mind, the IPCC made the following projections of future warming (IPCC, 2007):

The average surface temperature of the Earth is likely to increase by 2 to 11.5°F (1.1-6.4°C) by the end of the 21st century, relative to 1980-1990, with a best estimate of 3.2 to 7.2°F (1.8-4.0°C) (see Figure 1). The average rate of warming over each inhabited continent is very likely to be at least twice as large as that experienced during the 20th century.

Warming will not be evenly distributed around the globe (see Figure 2):

Land areas will warm more than oceans in part due to water's ability to store heat.

High latitudes will warm more than low latitudes in part due to positive feedback effects from melting ice (as discussed above).

Most of North America; all of Africa, Europe, northern and central Asia; and most of Central and South America are likely to warm more than the global average. Projections suggest that the warming will be close to the global average in south Asia, Australia and New Zealand, and southern South America.

The warming will differ by season, with winters warming more than summers in most areas.

For additional explanatory information about some of the projected spatial and seasonal differences in warming, see the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) fact sheet "Patterns of Global Warming" (PDF, 1 pp., 15 KB, About PDF)

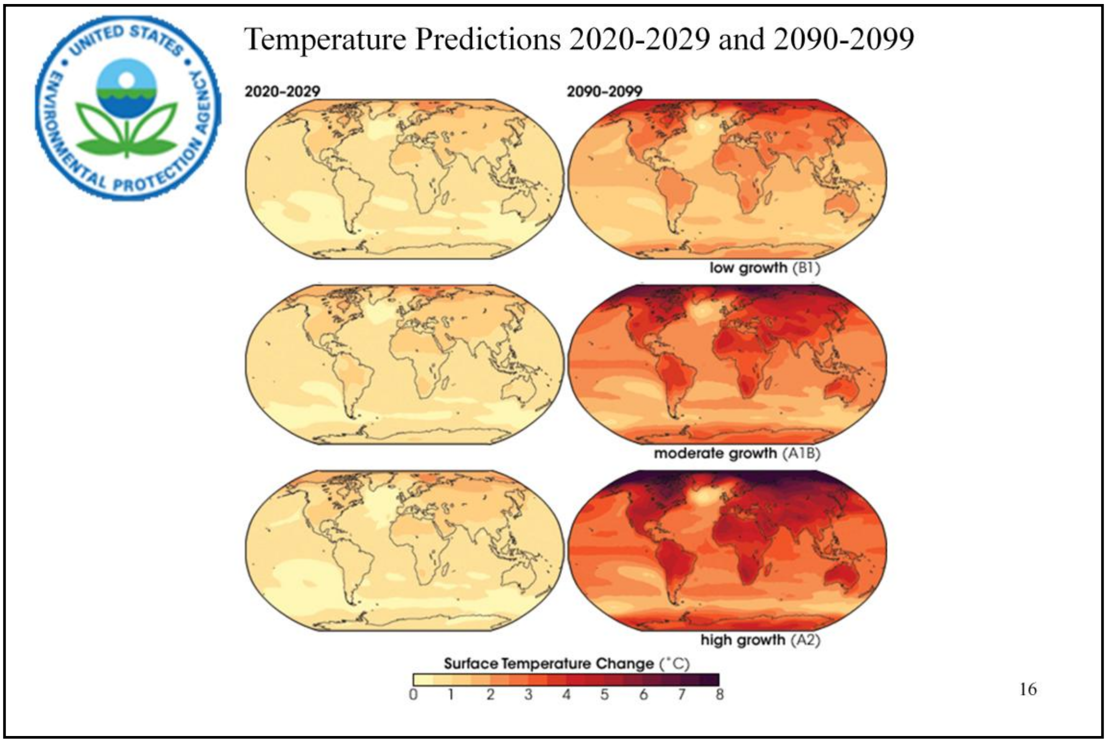


Figure 2: *Projected future regional patterns of warming based on three emissions scenarios (low, medium, and high growth). Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007)*

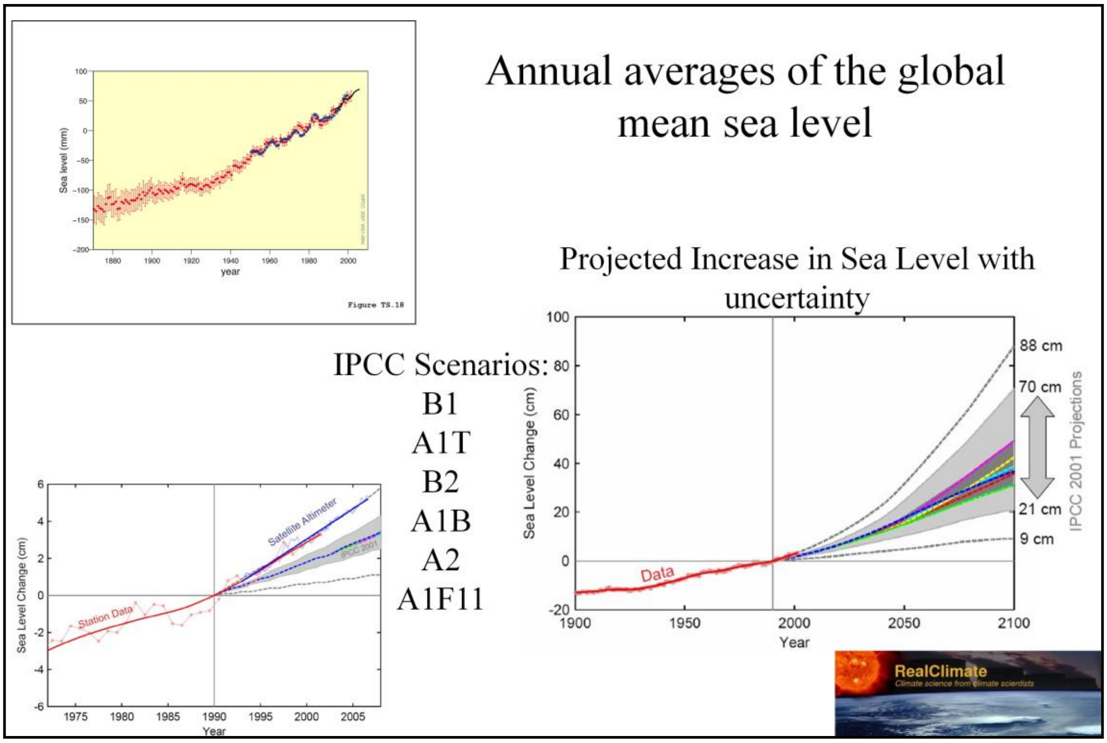


Figure TS.18 (upper left). Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals. {Figure 5.13}

(LOWER LEFT) OVERLAP PERIOD. Comparison of the 2001 IPCC sea-level scenarios (starting in 1990) and observed data: the Church and White (2006) data based primarily on tide gauges (annual, red) and the satellite altimeter data (updated from Cazenave and Nerem 2004, 3-month data spacing, blue, up to mid-2006) are shown with their trend lines. Note that the observed sea level rise tends to follow the uppermost dashed line of the IPCC scenarios, namely the one "including land ice uncertainty", see first Figure.

(lower Right). Sea level rise as observed (from Church and White 2006) shown in red up to the year 2001, together with the IPCC (2001) scenarios for 1990-2100. See second figure below for a zoom into the period of overlap.

Let us have a look at how these numbers were derived. They are made up of four components: thermal expansion, glaciers and ice caps (those exclude the

Greenland and Antarctic ice sheets), ice sheet surface mass balance, and ice sheet dynamical imbalance.

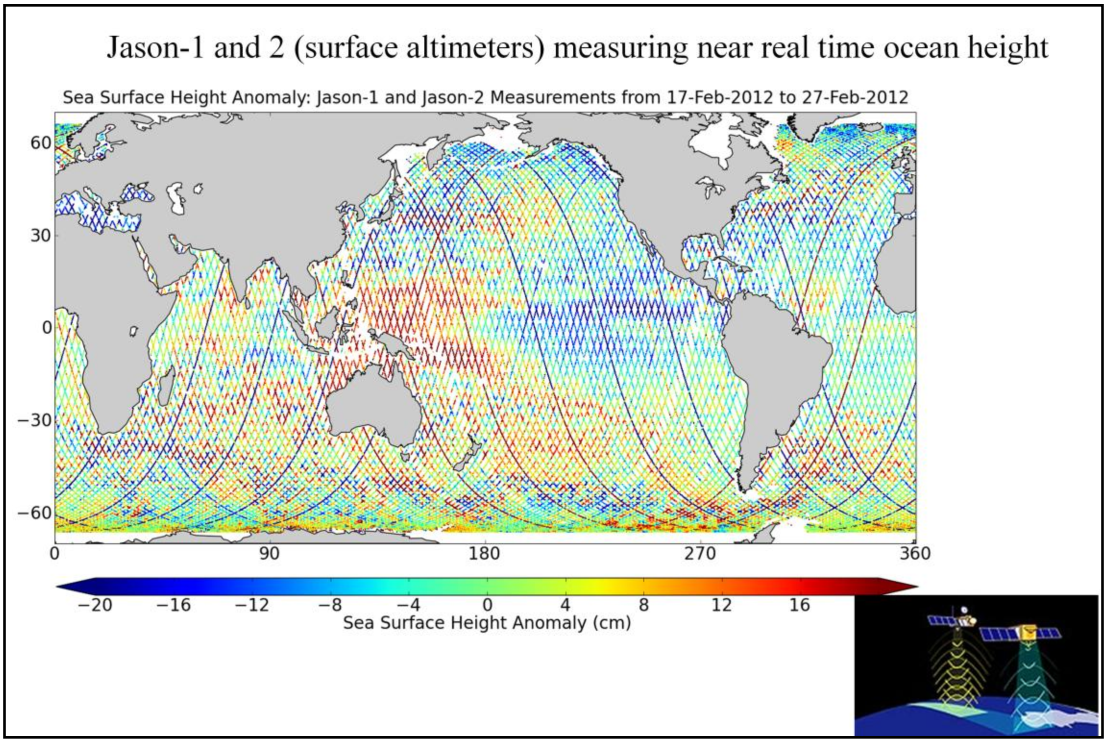
1. Thermal expansion (warmer ocean water takes up more space) is computed from coupled climate models. These include ocean circulation models and can thus estimate where and how fast the surface warming penetrates into the ocean depths.

2. The contribution from glaciers and ice caps (not including Greenland and Antarctica), on the other hand, is computed from a simple empirical formula linking global mean temperature to mass loss (equivalent to a rate of sea level rise), based on observed data from 1963 to 2003. This takes into account that glaciers slowly disappear and therefore stop contributing – the total amount of glacier ice left is actually only enough to raise sea level by 15-37 cm.

3. The contribution from the two major ice sheets is split into two parts. What is called surface mass balance refers simply to snowfall minus surface ablation (ablation is melting plus sublimation). This is computed from an ice sheet surface mass balance model, with the snowfall amounts and temperatures derived from a high-resolution atmospheric circulation model. This is not the same as the coupled models used for the IPCC temperature projections, so results from this model are scaled to mimic different coupled models and different climate scenarios. (A fine point: this surface mass balance does include some "slow" changes in ice flow, but this is a minor contribution.)

4. Finally, there is another way how ice sheets can contribute to sea level rise: rather than melting at the surface, they can start to flow more rapidly. This is in fact increasingly observed around the edges of Greenland and Antarctica in recent years: outlet glaciers and ice streams that drain the ice sheets have greatly accelerated their flow. Numerous processes contribute to this, including the removal of buttressing ice shelves (i.e., ice tongues floating on water but in places anchored on islands or underwater rocks) or the lubrication of the ice sheet base by meltwater trickling down from the surface through cracks. These processes cannot yet be properly modelled, but observations suggest that they have contributed 0 – 0.7 mm/year to sea level rise during the period 1993-2003. The projections in the table given above assume that this contribution simply remains constant until the end of this century.

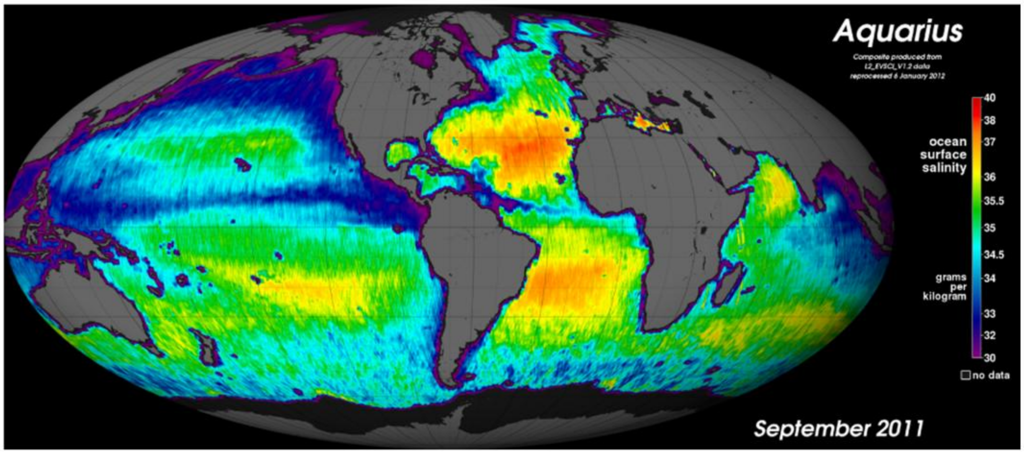
As an example, take the A1FI scenario – this is the warmest and therefore defines the upper limits of the sea level range. The "best" estimates for this scenario are 28 cm for thermal expansion, 12 cm for glaciers and -3 cm for the ice sheet mass balance – note the IPCC still assumes that Antarctica gains more mass in this manner than Greenland loses. Added to this is a term according to (4) simply based on the assumption that the accelerated ice flow observed 1993-2003 remains constant ever after, adding another 3 cm by the year 2095. In total, this adds up to 40 cm, with an ice sheet contribution of zero. (Another fine point: This is slightly less than the central estimate of 43 cm for the A1FI scenario that was reported in the media, taken from earlier drafts of the SPM, because those 43 cm was not the sum of the individual best estimates for the different contributing factors, but rather it was the mid-point of the uncertainty range, which is slightly higher as some uncertainties are skewed towards high values.)



These maps show a daily sample of the along-track near-real-time (NRT) sea surface height anomaly (SSHA) measurements from the Jason-1 and Jason-2 (launched 2001 and 2008, respectively) satellite altimeter missions. The seasonal cycle and trend have not been removed. Each map is generated from a 10-day window of SSHA measurements. The NRT SSHA measurements from these missions are typically available within 5 to 7 hours of real time. These measurements can be used for meteorological applications (i.e. weather), marine operations (i.e. fishing, boating, offshore operations), and other applications where knowledge of current ocean conditions are relevant.

To access the data files please see:

1St Monthly Map of Salinity from Aquarius for Sept., 2001

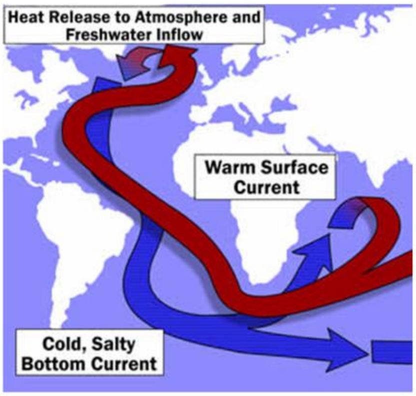


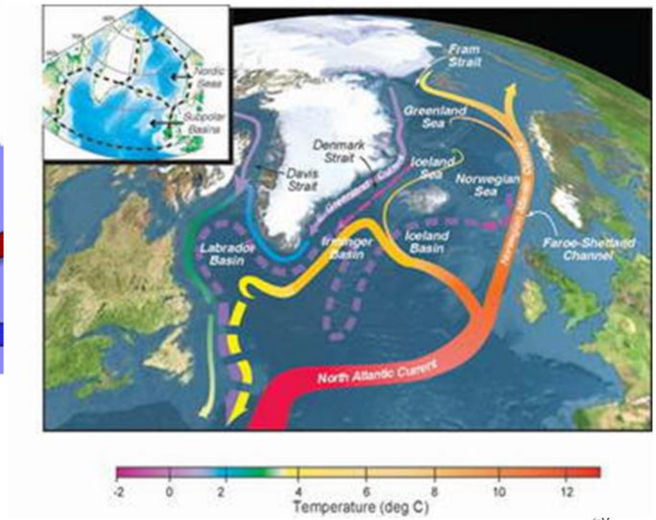
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NEO NASA Earth Observation

Aquarius is a focused effort to measure Sea Surface Salinity and will provide the global view of salinity variability needed for climate studies. The mission is a collaboration between NASA and the Space Agency of Argentina (Comisión Nacional de Actividades Espaciales, (CONAE)). It is a set of three radiometers that are sensitive to salinity (1.413 GHz; L-band) and a scatterometer that corrects for the ocean's surface roughness. The spacecraft was contributed by CONAE. It was launched from California's Vandenberg Air Force Base on June 10, 2011.

Aquarius has produced its first monthly maps of global ocean salinity for September - December 2011. These preliminary (Version 1.2) data contain uncertainties and, over time, will be updated as further calibration and validation work are completed.





Large regions of the North Atlantic Ocean have been growing fresher since the late 1960s as melting glaciers and increased precipitation, both associated with greenhouse warming, have enhanced continental runoff into the Arctic and sub-Arctic seas. Over the same time period, salinity records show that large pulses of extra sea ice and fresh water from the Arctic have flowed into the North Atlantic. But, until now, the actual amounts and rates of fresh water accumulation have not been explicitly known.

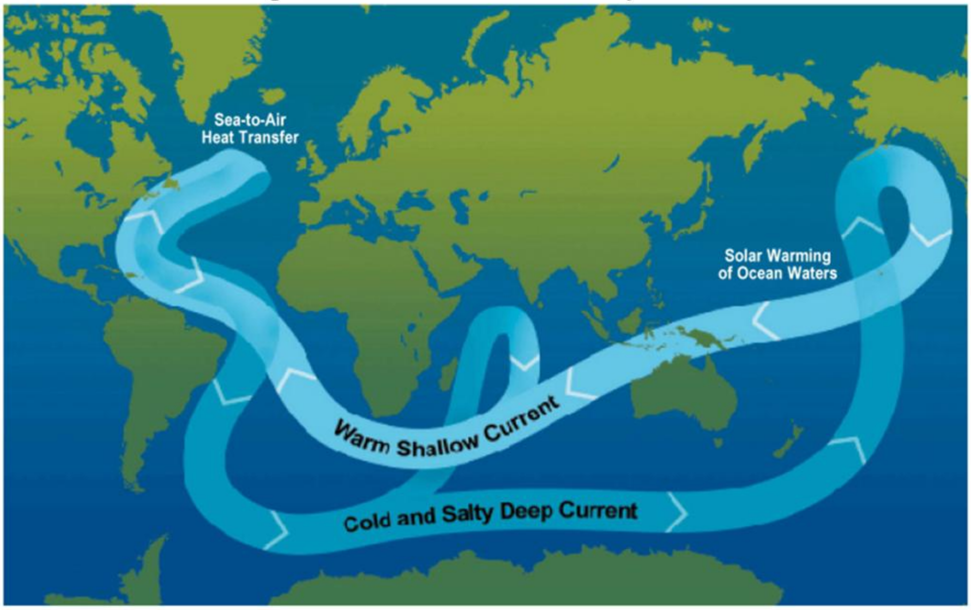
The warm, salty, surface waters of the Gulf Stream move up the eastern coast of North America and then east to the European coast. From here, the heat absorbed by the water at the equator is released and carried into Europe by westerly onshore winds. As the surface water cools, it becomes denser and sinks to a depth of about 1 mile, traveling back across the Atlantic and then southward toward the equator again. The climates of Europe and North America rely heavily on the heat released from the Gulf Stream.

New Revelations:
Over the past 30 years, the North Atlantic has been receiving huge inflows of cold freshwater. There is mounting evidence that the resulting cool-down of the North Atlantic could give rise to a mini ice age. Scientists cannot say that these huge inflows come from the glaciers melting in the Arctic, but they are

certainly the prime suspect.

The new mass of relatively fresh water sits on top of the ocean’s saltier water like a thermal blanket. This may cause a weakening or even halting water circulation. As glaciers continue to melt and precipitation in higher latitudes increases, greater inflows of cold freshwater are going to rapidly drop salinity and temperatures of the North Atlantic and adjoining seas.

Deep Ocean Circulation Conveyor Belt

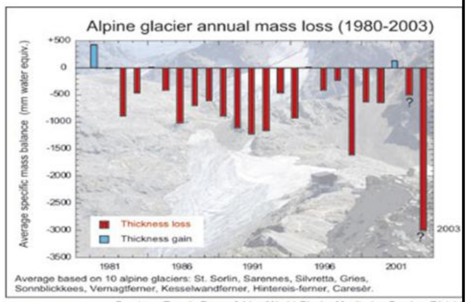


The ocean plays a major role in the distribution of the planet's heat through deep sea circulation. This simplified illustration shows this "conveyor belt" circulation which is driven by differences in heat and salinity. Records of past climate suggest that there is some chance that this circulation could be altered by the changes projected in many climate models, with impacts to climate throughout lands bordering the North Atlantic.

Scientists are concerned that the point at which the current Conveyor begins to slow may be near. Other current research shows the Gulf Stream is not the prime moderator of European temperature (westerly winds play a larger role). Yet climate in Europe and NE North America could chill if the ocean current slows dramatically.

Glacier Bay, Alaska

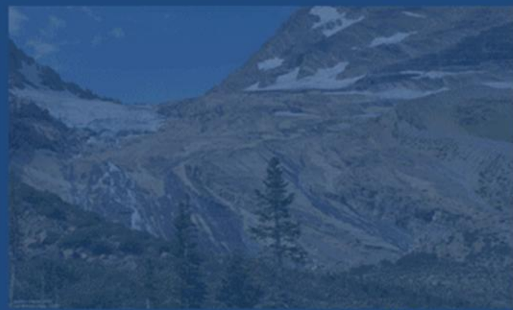
Effects of climate change seen today:



Courtesy: Regula Frauenfelder (World Glacier Monitoring Service, Zürich)

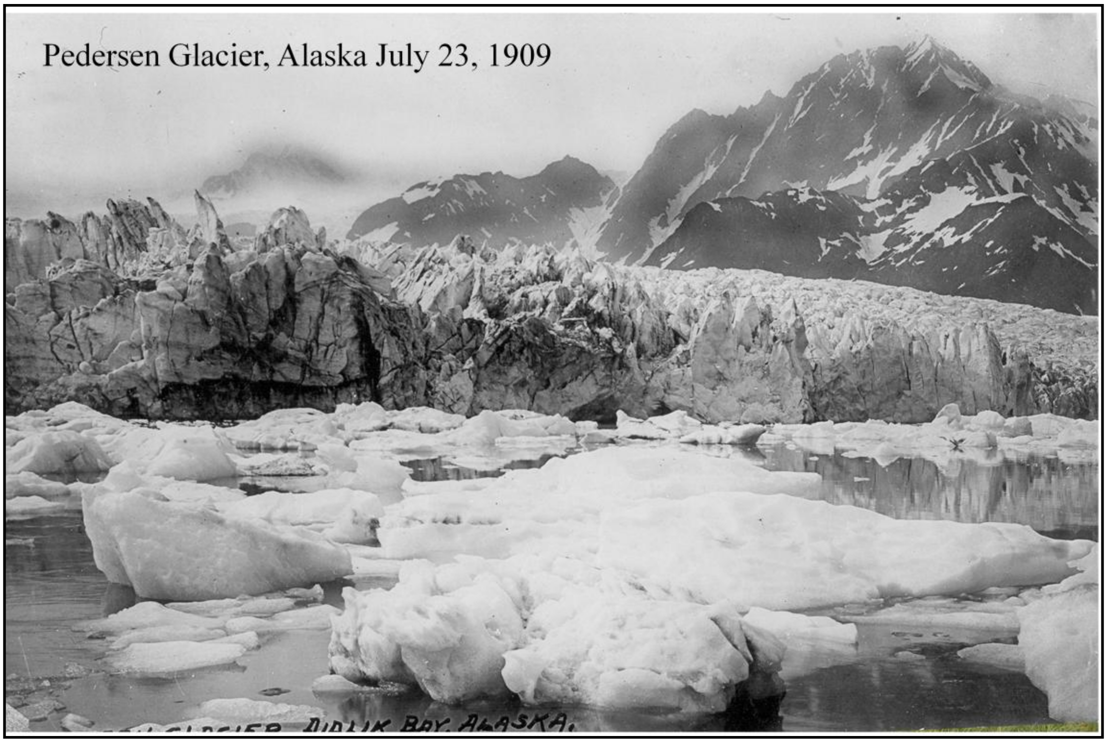
USGS
science for a changing world

1911 Morton Elrod photo
Courtesy of K. Ross Toole Archives, UM



2009 Lisa McKeon photo
USGS

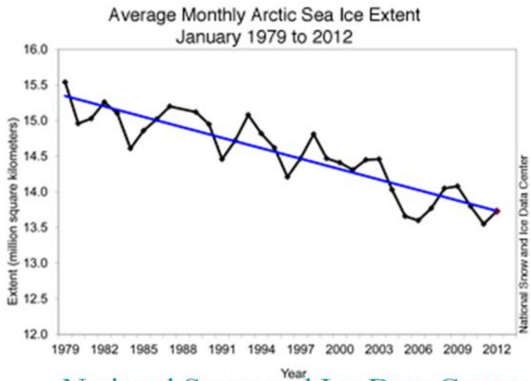
At the time this historic photograph was taken in 1911, Blackfoot Glacier encompassed the current Jackson Glacier. By 1939, Blackfoot Glacier's recession had resulted in two distinct glaciers, Jackson and Blackfoot. This photo pair shows glacial recession and successive vegetation growth along Jackson Glacier's terminus.

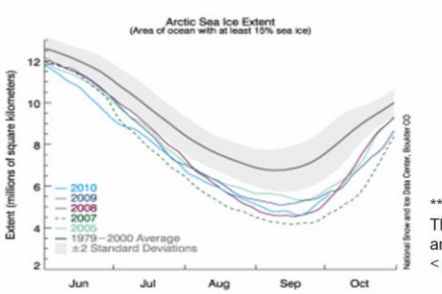

Pedersen Glacier, Alaska July 23, 1909


Pedersen Glacier, Alaska, August 13, 2004

Effects of climate change seen today:

•**Arctic sea ice is melting**. The summer thickness of sea ice is ~ half that in 1950. Melting Arctic sea ice may lead to global changes in water circulation. Melting ice speeds up warming of the Arctic because water absorbs more heat than the ice.





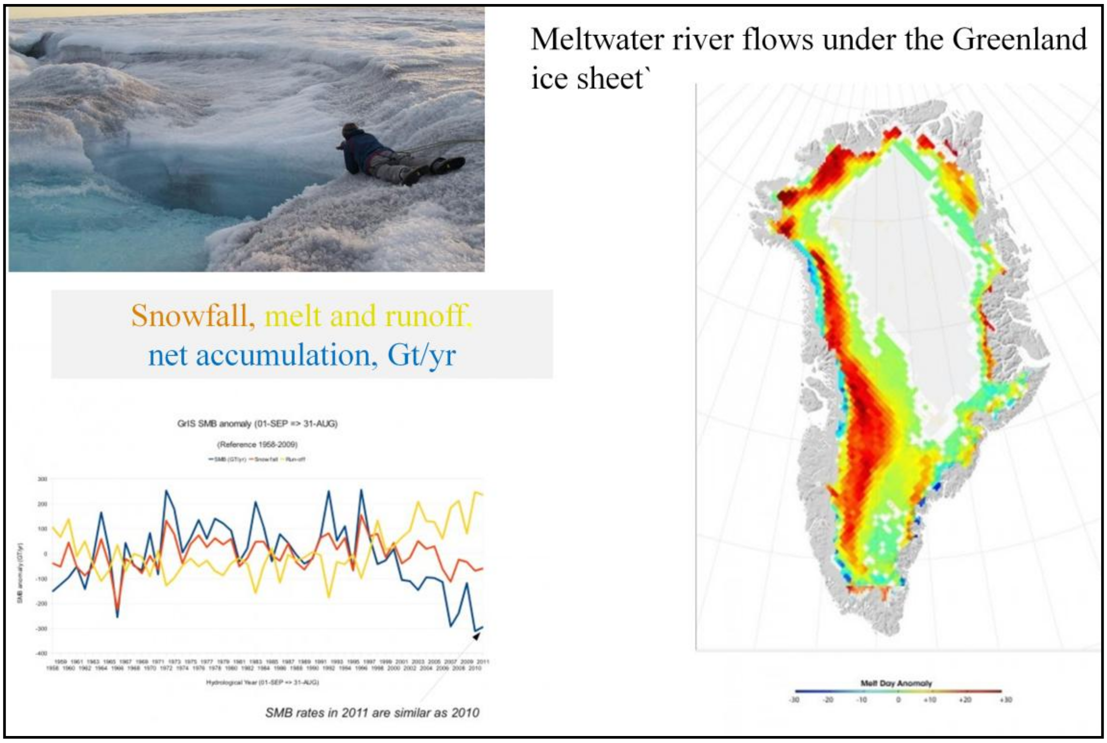
National Snow and Ice Data Center

** Melting Arctic link to UK snows **
The progressive shrinking of Arctic sea ice is bringing colder, snowier winters to the UK and other parts of the Northern Hemisphere, scientists show.
< http://www.bbc.co.uk/go/em/fr/-/news/science-environment-17143269 >

26

Arctic sea ice extent for January 2012 was the fourth lowest in the satellite record. Including the year 2012, the linear rate of decline for January ice extent over the satellite record is 3.2% per decade.

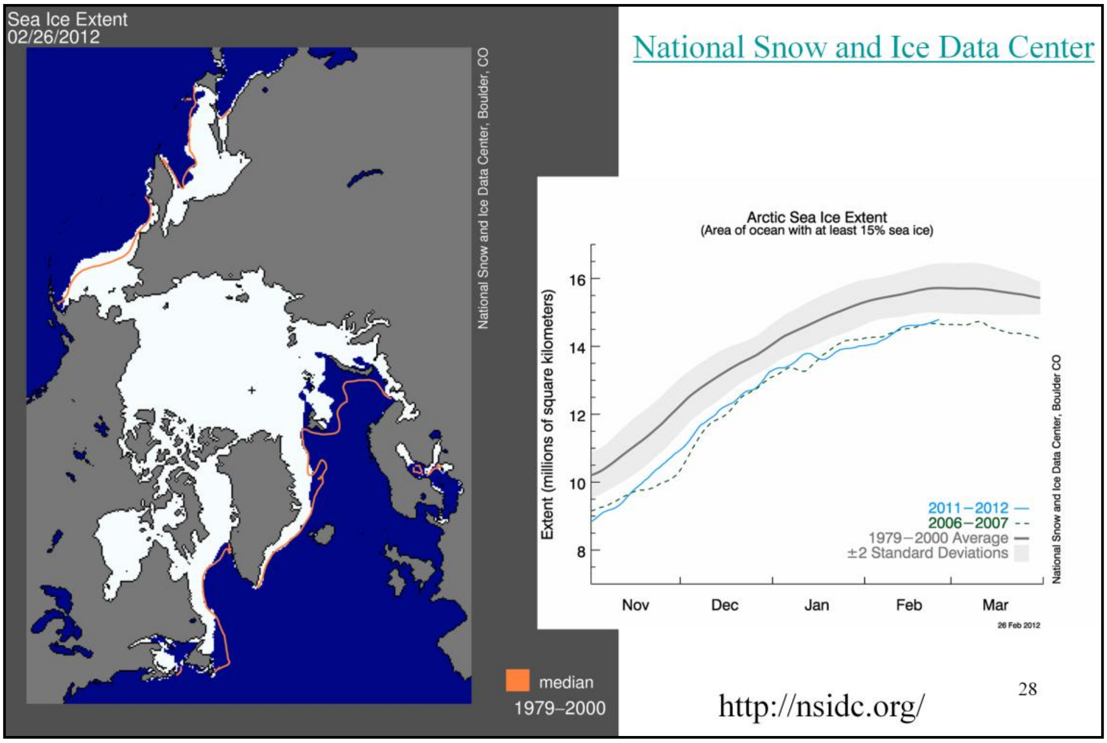
Based on the satellite record, before 2005 average January ice extent had never been lower than 14 million square kilometers (5.41 million square miles). January ice extent has now fallen below that mark six out of the last seven years.



After a record-breaking 2010 in terms of surface melt area in Greenland Tedesco et al, 2011, numbers from 2011 have been eagerly awaited. Marco Tedseco and his group have now just reported their results. This is unrelated to other Greenland meltdown this week that occurred at the launch of the new Times Atlas. (The Times Comprehensive Atlas of the World shows Greenland as having lost around 15% of its ice cover between the 1999 10th edition (left) and 2011 13th edition (right). Scientists argue the depiction is wrong. According to the researchers, the volume of ice contained in the Greenland ice sheet is approximately 2.9m cubic kilometres and the current rate whereby ice is lost is roughly 200 cubic kilometres per year – a decrease of about 0.1% by volume over 12 years.) *Regional model-based estimates of snowfall (orange), surface melt and runoff (yellow) and the net accumulation (Gt/yr) (blue) since 1958.* Photograph: Times Comprehensive Atlas of the World

Regional model-based estimates of snowfall (orange), surface melt and runoff (yellow) and the net accumulation (Gt/yr) (blue) since 1958. The melt index anomaly is the number of days with detectable surface melt compared to the baseline period of 1979-2010. The higher the number, the more melt days there were. While this did not match the record 2010 levels, depending on the analysis 2011 was either the 3rd or 6th year in the rankings.

Analysis of the surface mass balance via regional modelling demonstrates that there has been an increasing imbalance between snowfall and runoff over recent years, leading to a lowering of ice elevation, even in the absence of dynamical ice effects (which are also occurring, mostly near the ice sheet edge).



Sea ice data updated daily, with one-day lag. Orange line in extent image (left) and gray line in time series (right) indicate 1979 to 2000 average extent for the day shown. Overall, Arctic sea ice extent remained lower than average in January. However, in the Bering Sea, ice extent was much greater than normal. The heavy ice cover caused problems for fishermen and made for an arduous late-season resupply mission to Nome, Alaska. The Arctic Oscillation, which had been in its positive phase most of the winter so far, switched to a negative mode, bringing cold weather to Europe and changing the direction of sea ice movement. Arctic sea ice extent in January 2012 averaged 13.73 million square kilometers (5.30 million square miles). This is the fourth-lowest January ice extent in the 1979 to 2012 satellite data record, 1.10 million square kilometers (425,000 square miles) below the 1979 to 2000 average extent.

The growth rate for Arctic sea ice in January was the slowest in the satellite record. After growing relatively quickly early in January, ice extent declined briefly in the middle of the month, and then grew more slowly than normal for the rest of the month. The slow growth likely stemmed from winds from the south and west that compressed the sea ice in the Barents Sea, and above-average temperatures and winds that limited ice growth in the Sea of Okhotsk.

Overall, the Arctic gained 765,000 square kilometers (295,000 square miles) of ice during the month. This was 545,000 square kilometers (210,000 square miles) less than the average ice growth rate for January 1979 to 2000.

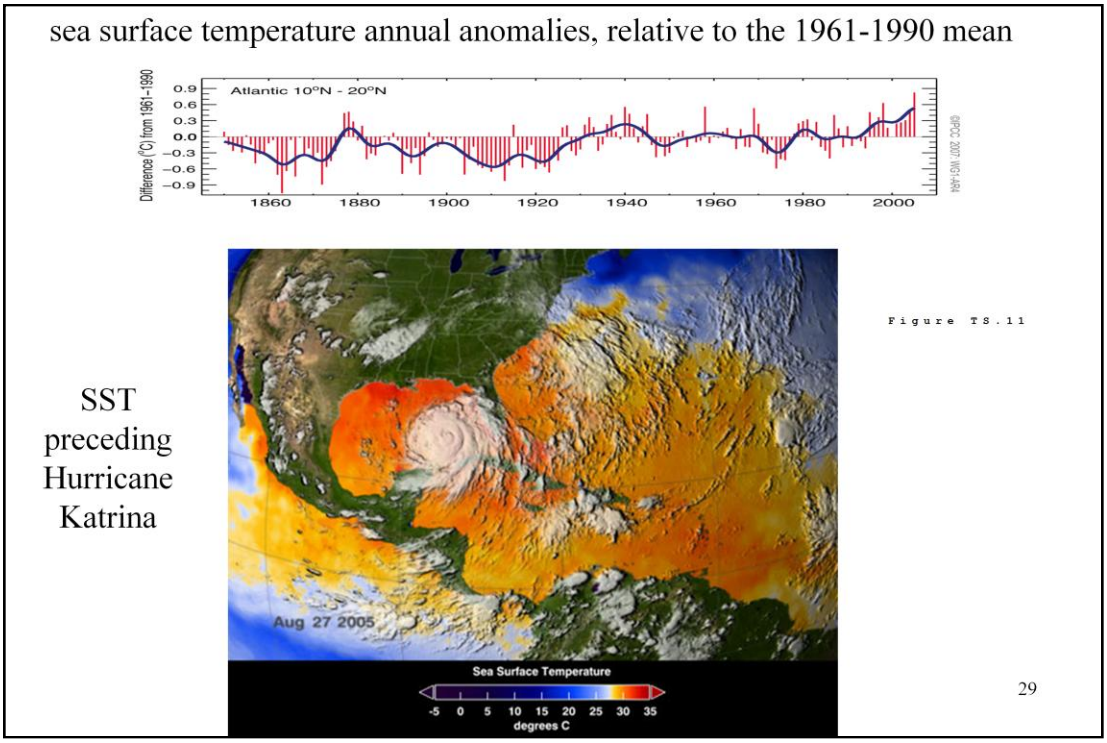
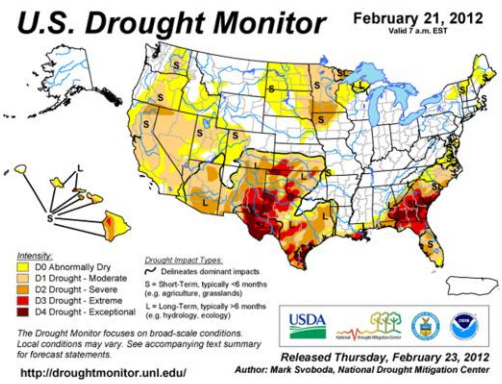
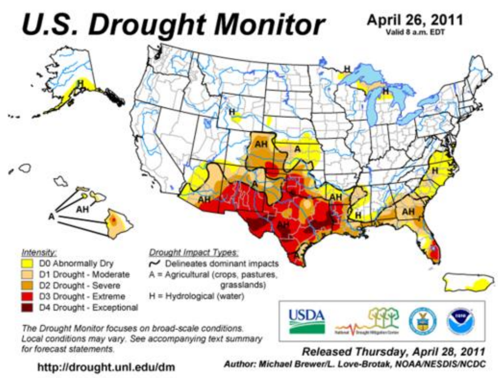


Figure TS.11. Tropical Atlantic (10°N–20°N) sea surface temperature annual anomalies (°C) in the region of Atlantic hurricane formation, relative to the 1961 to 1990 mean. {Figure 3.33}

Effects of climate change seen today:

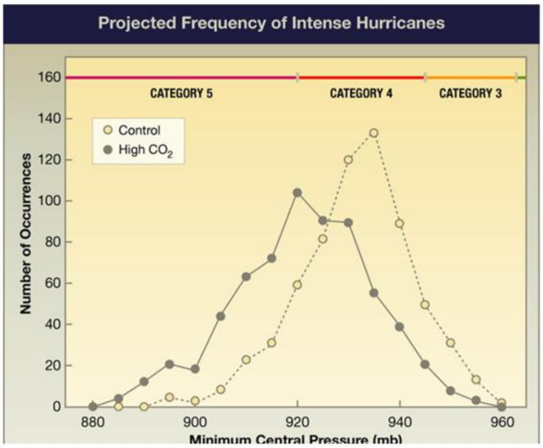
Drought frequency, intensity may be increasing. Higher temperatures lead to a high rate of evaporation and drought. It is not clear whether drought has increased as a result of current warming.





Effects of climate change seen today:

• **Severe weather events may be more common and stronger**. Some researchers say that the number and strength of hurricanes and tornados, and other severe weather events has increased over the last 15–20 years.

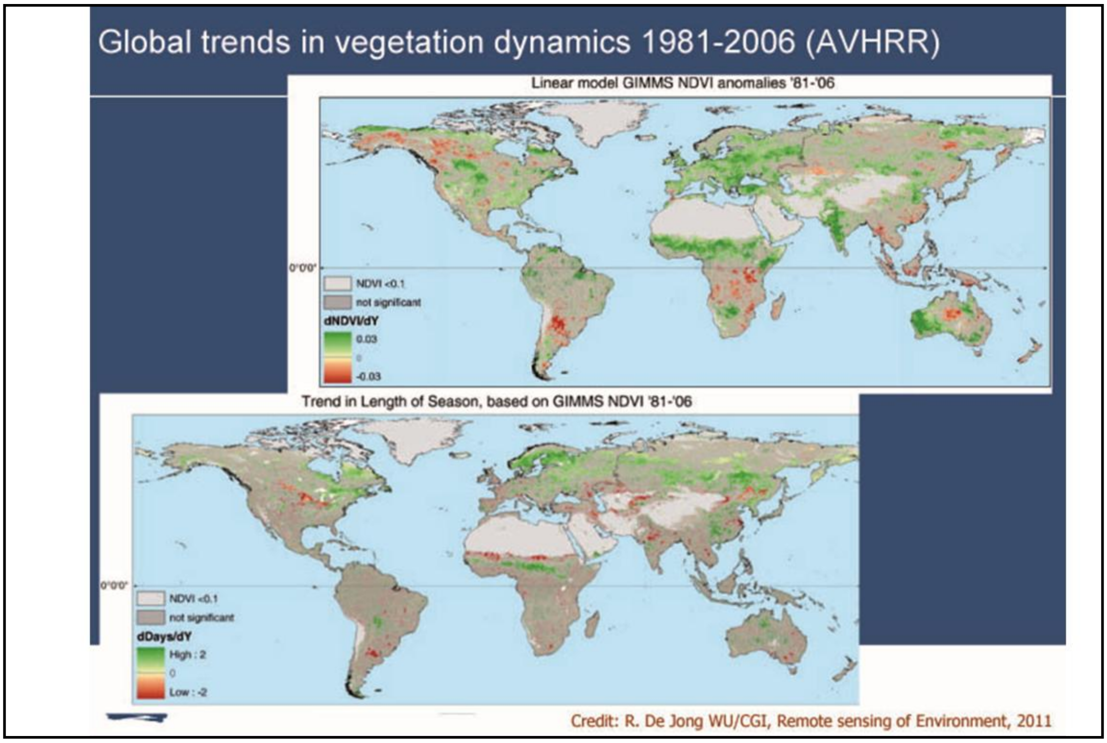


US had 1,897 tornadoes (1,688 confirmed) in 2011, 6 EF5 and enough total reports to eclipse the 1,817 tornadoes in 2004, the current record year for total number

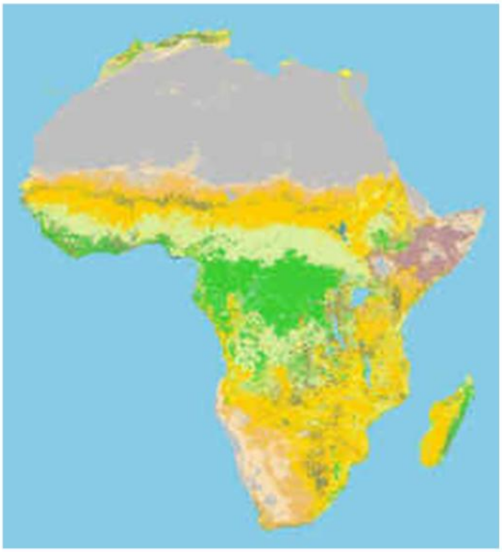
However, the evidence for direct climate cause is not clear.

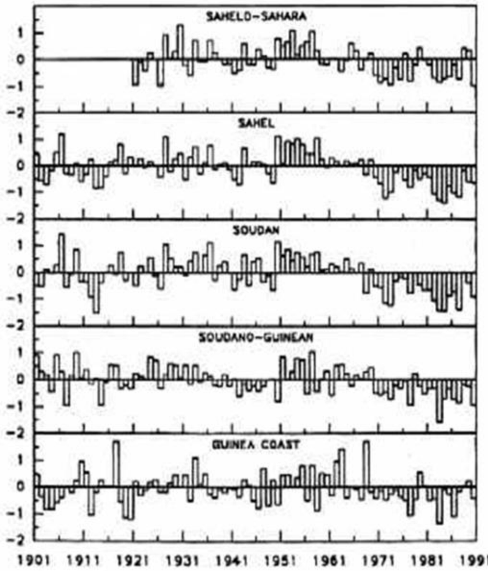
Effects of climate change seen today:

•**Ecosystems are changing**. As temperatures warm, species may migrate or die. Extinctions are increasing. Particularly vulnerable are endangered species, coral reefs, and polar animals such as penguins, polar bears and seals.


Global trends in vegetation dynamics 1981-2006 (AVHRR)
Linear model GIMMS NDVI anomalies '81-'06
0°0'0"
NDVI <0.1
not significant
dNDVI/dY
0.03
0
-0.03
Trend in Length of Season, based on GIMMS NDVI '81-'06
0°0'0"
NDVI <0.1
not significant
dDays/dY
High : 2
0
Low : -2
Credit: R. De Jong WU/CGI, Remote sensing of Environment, 2011

West Africa has experienced significant changes in land cover





Significant droughts during the last few decades

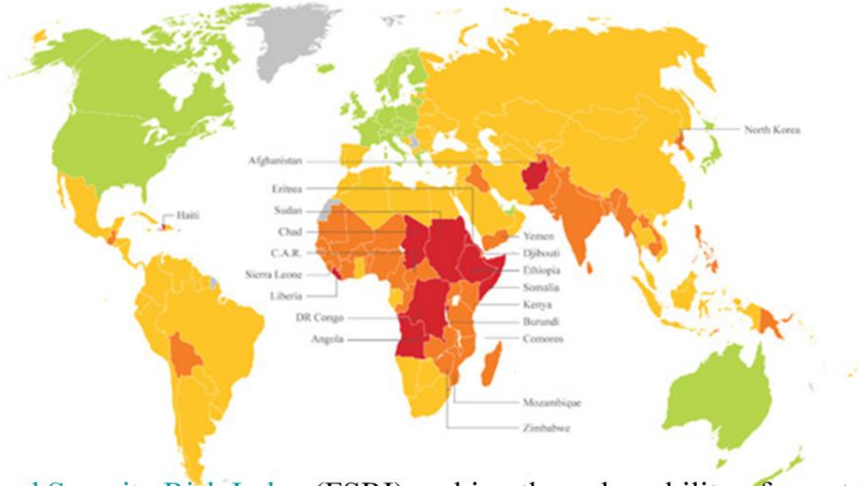
34

The region of West Africa has experienced significant changes in land cover during this century, ranging from deforestation near the Atlantic coast to desertification near the border with the Sahara desert.

The same region has been experiencing a significant drought during the last few decades, with below normal levels of rainfall observed almost everywhere within West Africa. This drought has been associated with weakening of the monsoon circulation.

Effects of climate change seen today:

•**Changes in agriculture affect some regions:** As regional climates warm, some mid-latitudes, like Europe, receive a longer growing season, while some tropical places are becoming too hot and dry to grow crops.



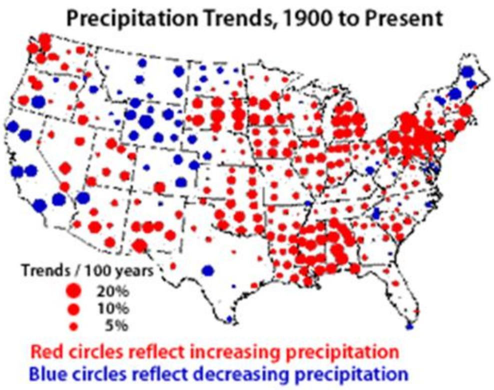
FAO's Food Security Risk Index (FSRI) ranking the vulnerability of countries to food insecurity. 08/31/2011

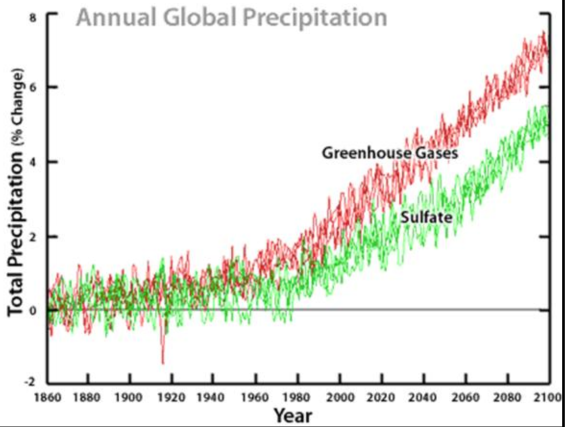
35

In California spring snowmelt runoff decreased 12 %

Effects of climate change seen today:

•**Heavier rainfall causes flooding** in many regions as warmer temperatures speed up the water cycle. There has been a 5-10% increase in precipitation over the past century. In the last 10 years, floods have caused almost 300 billion US dollars of damage, 3 to 6 times the damage caused by floods in previous decades.





In the last 100 years, precipitation has increased by an average of about 1% over all the land surfaces on Earth. Across the United States, alone, precipitation has increased by an average of about 5% in the last 100 years. Note that this is an average. Some areas of the United States have experienced as much as a 20% increase in precipitation over the last 100 years (see figure above). While other areas have experienced a 20% decrease in precipitation. Map courtesy of the United States Environmental Protection Agency.

There are many reasons for changes in precipitation. The leading cause is a change in temperature. Many scientists believe an increase in temperature could lead to a more intense water cycle. The rates of evaporation from soils and water, as well as transpiration from plants, could increase. The amount of precipitation could also increase.

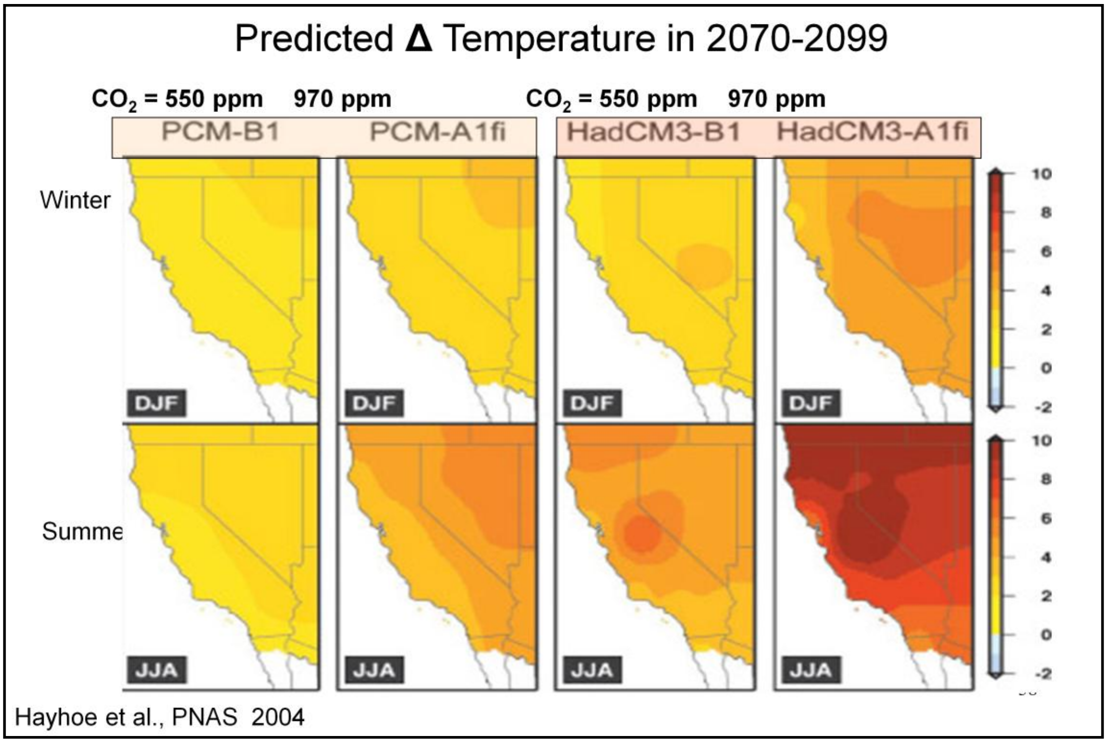
Predicted changes in the water cycle differ according to the region of the planet being examined. Many scientists believe rates of evaporation will be greater than precipitation in the middle latitudes such as the United States. This could result in drier summers in these regions.

Report to Governor and Legislature: Dec. 8, 2005

Model	Sensitivity	Scenario B1 PPM CO2	Scenario A1f1 PPM CO2	Period
NCAR/DOE Parallel Climate Model (PCM)	low	550	970	2100
UK Met Office Hadley HADCM3	medium	550	970	2100

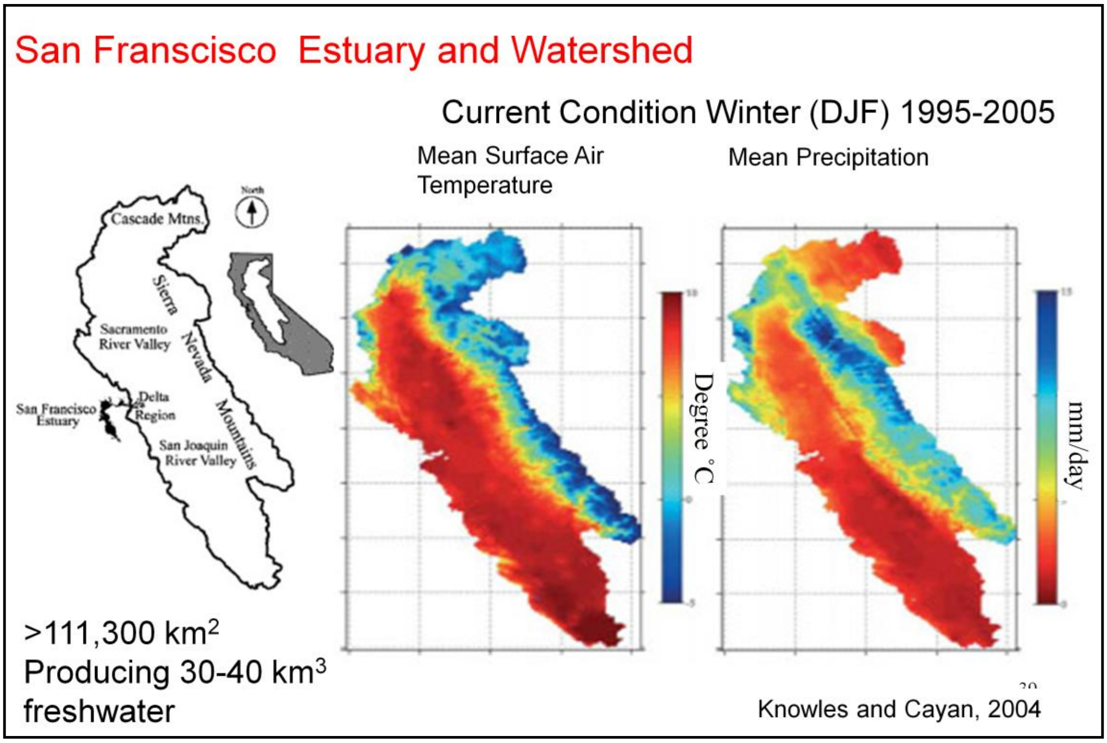
By 2100:

- Loss of 30-90% California's Snowpack
- Mean Temperature increase 4.4-5.8C → O_3 exposure increases 25-35%; → Increased heat related deaths
- Sea level rise by 10-80 cm
- Increased winter flood risk → Threat to levee system; salinity in delta; coastal erosion;
- Threat to agriculture → $68B Industry; h alf US Fruits+Veg
- Loss native biodiversity; Pest infestation; Invasive species
- Wildfires → air pollution



Modeled at 150km resolution (1/8deg).

Stewart et al. (2005) J. Climate report tree ring record suggests that spring temperatures over western NA in past 50 years are higher than the previous 900 years. This is consistent with retreat of snow cover extent and glaciers over the Northern Hemisphere.



SF watershed: **3rd largest in US**; Generates 3-40 km^3 of freshwater runoff from rain and snow. Snowmelt accounts for 40% annual discharge; starting after April 1 (Roos, 1989) Reservoir storage is ~35km^3 or ~runoff.

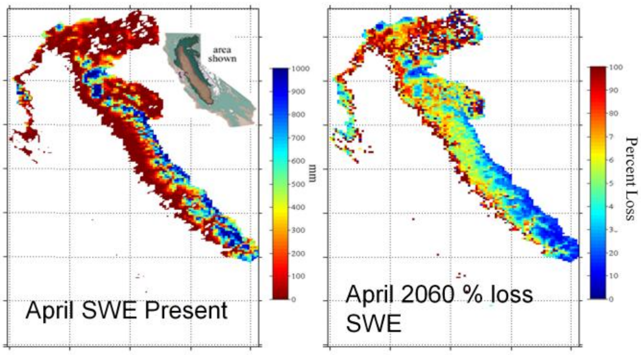
Effects for climate warming: reduced snowpack storage; higher flood peaks in winter; reduced summer-fall flows limiting freshwater supply.

Hydrologic reductions will increase salinities and contamination by salinity intrusion

Snowpack reductions would primarily impact mid altitudes in Sierra's: low elevation have little snow and highest elevations would have less impact of moderate warming.

	B1	A1f1	B1	A1f1
Δ April 1 %SWE snowpack	-29	-73	-72	-89
Δ Annual %reservoir inflow	12	-29	-24	-30
Δ Water year flow Centroid, days	-7	-14	-23	-32

Hayhoe et al., PNAS 2004



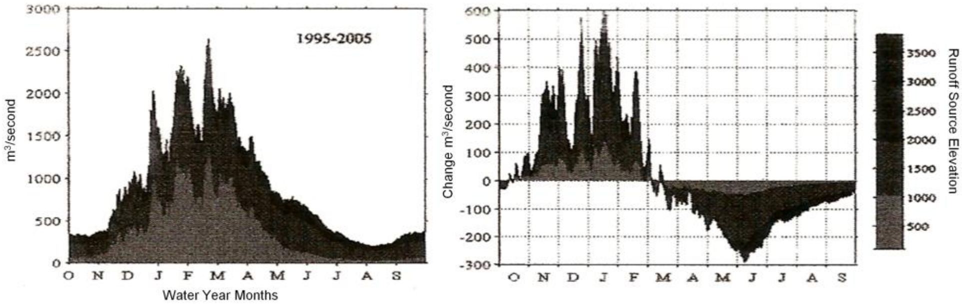
Knowles and Cayan, 2004

40

SWE=snow water equivalent

Reference 1990-1999; 7 dams Sac/San Joaquin Rivers: Shasta, Oroville, Folsom, New Melones, New Don Pedro, Lake McClure, Pine Flat

Freshwater Inflow into Delta Today and 2060



Consequences:

Winter floods; levee failures

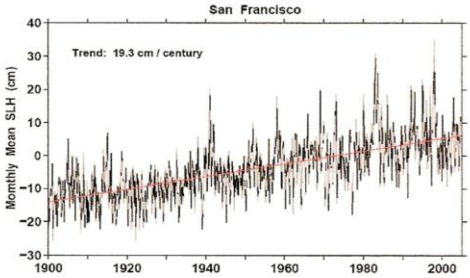
Summer drought; wildfires

Inadequate freshwater, electricity

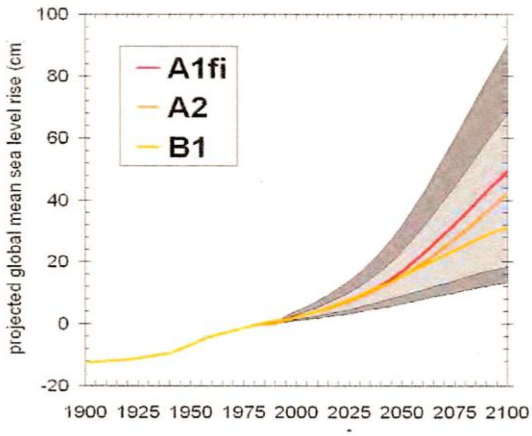
Delta salinity; loss of wetlands

Knowles and Cayan, Climatic Change, 2004

Observed Sea Level Rise in
San Francisco Bay

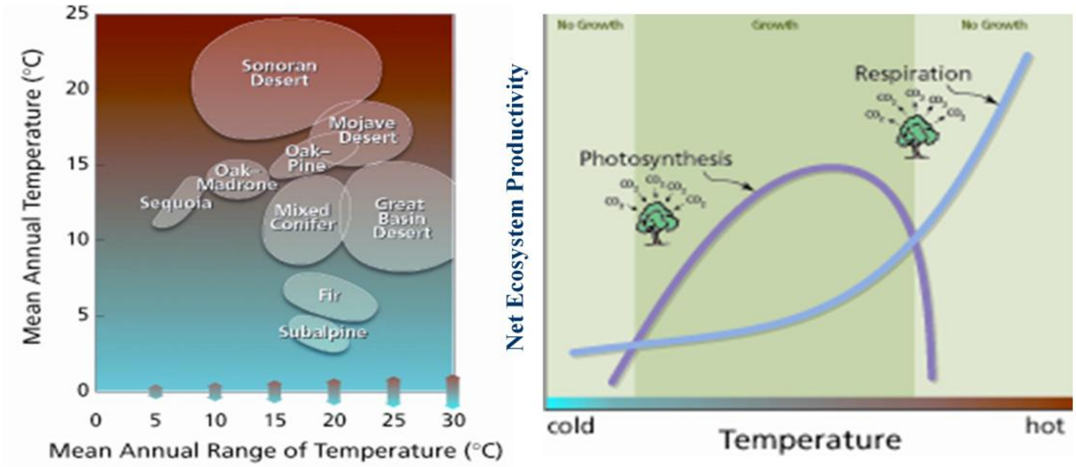


Predicted Global Sea Level Rise



Source: Cayan et al., in review

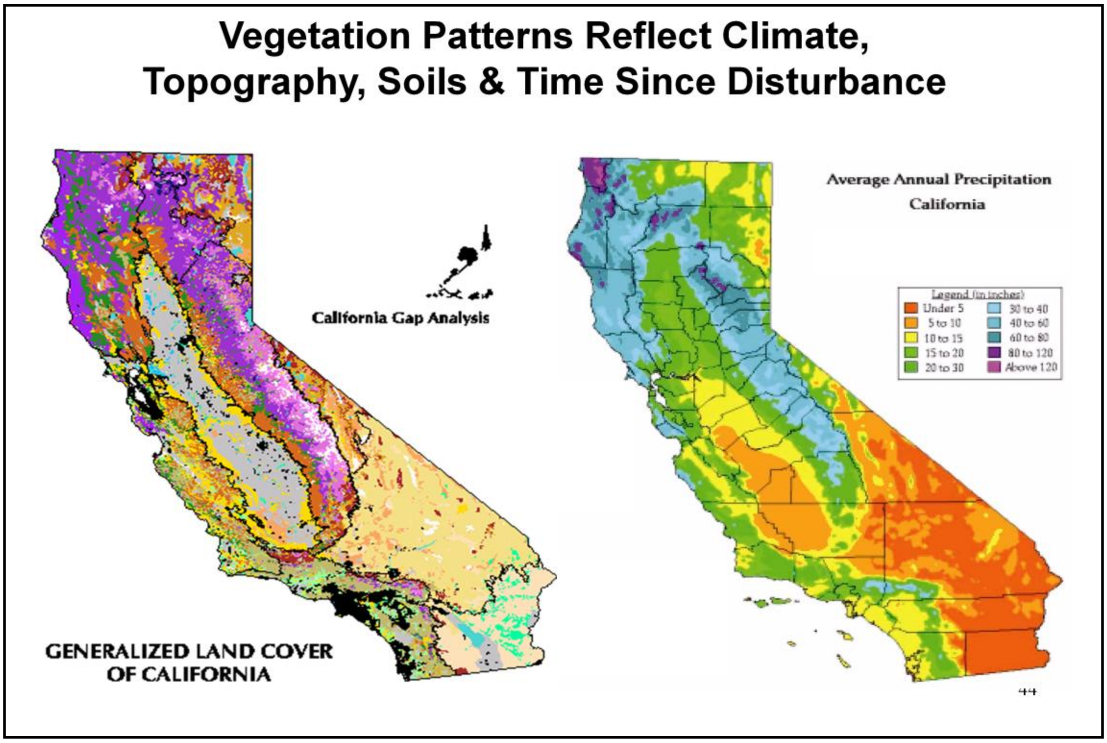
Response of California Vegetation Types to Temperatures and Temperature Ranges



Higher temperatures increase water demand

California's Changing Climate. Union of Concerned Scientists. 2001. (www.ucusa.org/environment/gw.calclimate.html), Chris Field, Chair.

California's Changing Climate. Union of Concerned Scientists. 2001. (www.ucusa.org/environment/gw.calclimate.html), Chris Field, Chair.

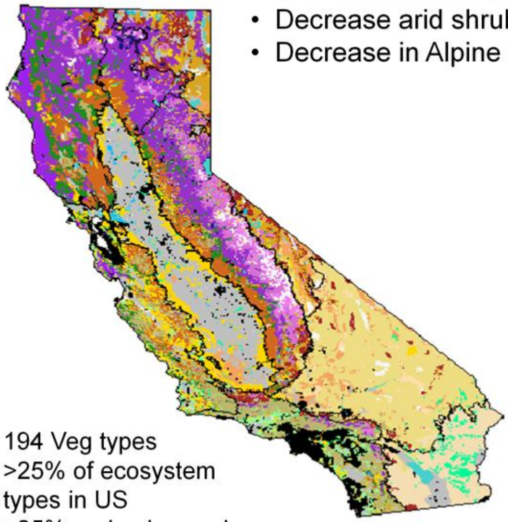


The Potential Consequences of Climate Variability and Change for California: The California Regional Assessment. June 2002. Robert Wilkinson, lead author.

Climate Change Predictions

Geographic Shifts in ecosystems:

- Increase grasslands
- Increase woodlands & forests
- Decrease arid shrublands
- Decrease in Alpine vegetation



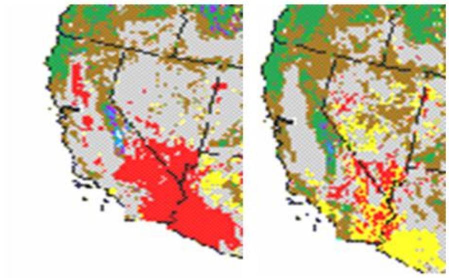
194 Veg types
>25% of ecosystem types in US
>25% endemic species

Davis et al., 1998

Tundra
Taiga/Tundra
Conifer Forest
Northeast Mixed Forest
Temperate Deciduous Forest
Southeast Mixed Forest
Tropical Broadleaf Forest
Savanna/Woodland
Shrub/Woodland
Grassland
Arid Lands

Current Vegetation

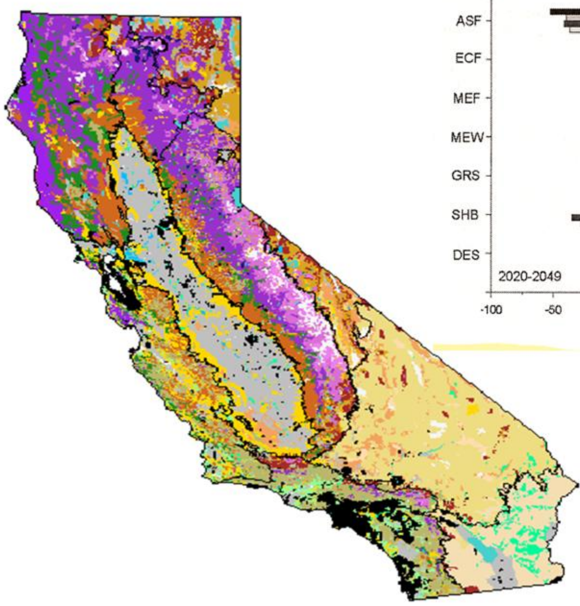
Predicted Vegetation 2070-2099

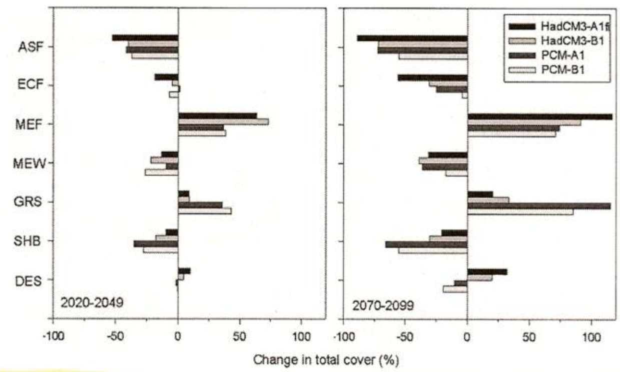


MAPPS Dynamic Vegetation Model

Biological Diversity in California

2020 - 2049 2070 - 2099



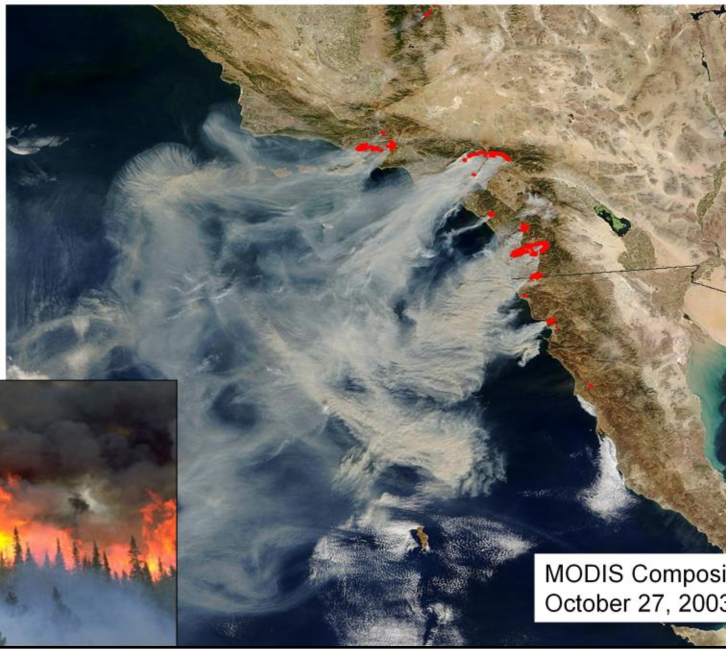


Predicted Changes in Cover of Major Vegetation Types

Davis et al., 1998

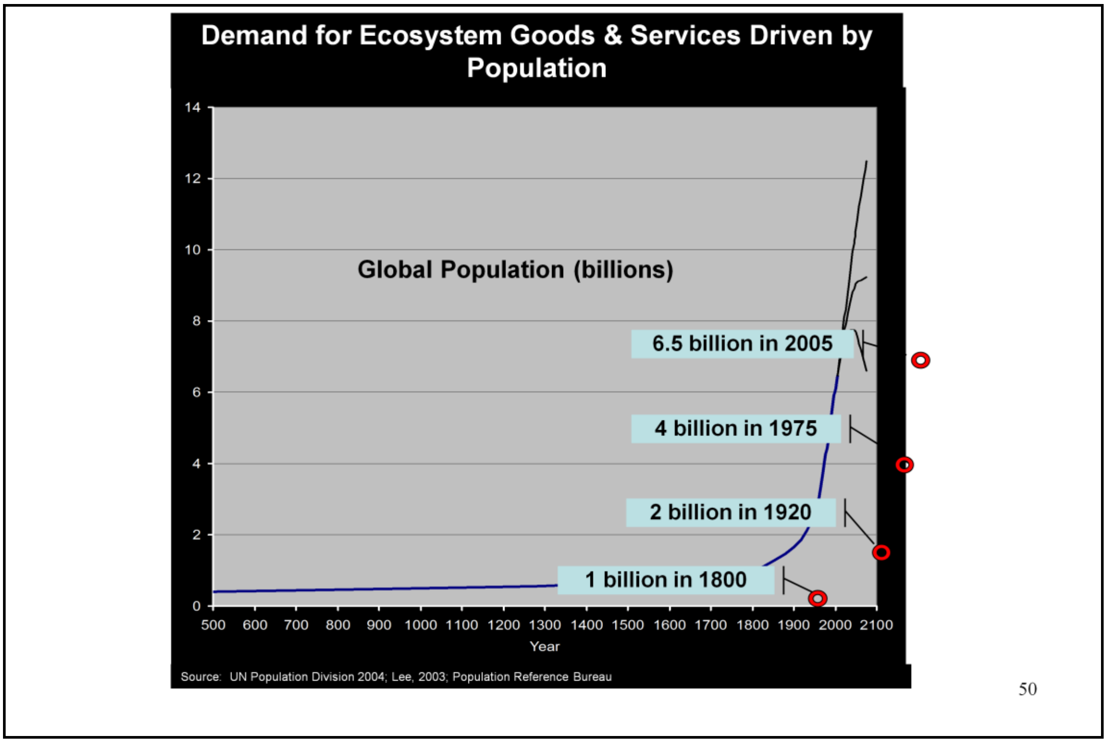
Loss of Freshwater Wetlands in California

Extended Summer Drought will increase frequency and intensity of wildfires



MODIS Composite Image
October 27, 2003


Of 20 Largest CA fires:
10 occurred since 2000
3 in 1990-1999
2 in 1980-1889
3 in 1970-1979
2 between 1932-1970
5 year Average 2006-2011
Acres Burned 218,447
Cost $100,223,017
Seen from ISS on 11/26/05 San Bernardino National Forest, Lake Arrowhead, left, and Silverwood Lake, right.



The UN's Millennium Assessment (MA) focused on population growth in last 50 years. From MA Synthesis: "Between 1960 and 2000, the demand for ecosystem services grew significantly as world population doubled to 6 billion people ..." This figure (not from the MA) illustrates that recent growth but in the context of the longer term trends. Sources are listed below.

1 billion in about 1804, 2 billion in 1927 (123 years to double), 4 billion in 1974 (54 yrs to double); 6.5 billion in July 2005. In the last 45 years (since 1960) more people have been added to the planet (3.4 billion) than lived on the planet in 1960.

Source (1950 to 2050): Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision, http://esa.un.org/unpp, 06 July 2005; 1:30:16 PM.

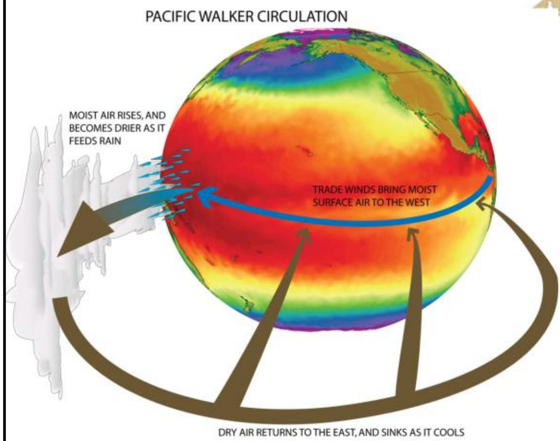
Source (1700-1900): Ronald Lee, "The Demographic Transition: Three Centuries of Fundamental Change", Journal of Economics Perspectives, Volume 17, Number 4—Fall 2003—Pages 167–190.

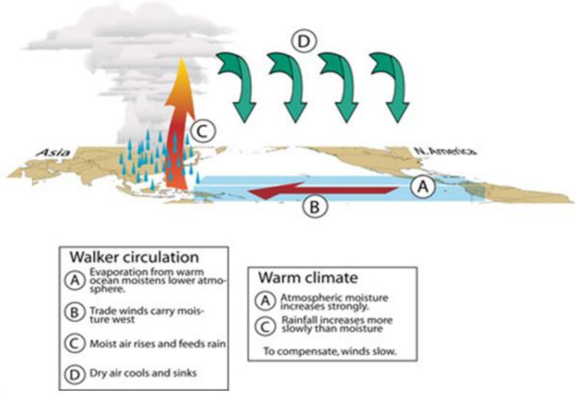
Source (pre 1700): Population Reference Bureau: "World population expanded to about 300 million by A.D. 1 and continued to grow at a moderate rate. But after the start of the Industrial Revolution in the 18th century, living standards rose and widespread famines and epidemics diminished in some regions. Population growth accelerated. The population climbed to about 760 million in 1750 and reached 1 billion around 1800"

Lecture 15: Climate Change: What you should know

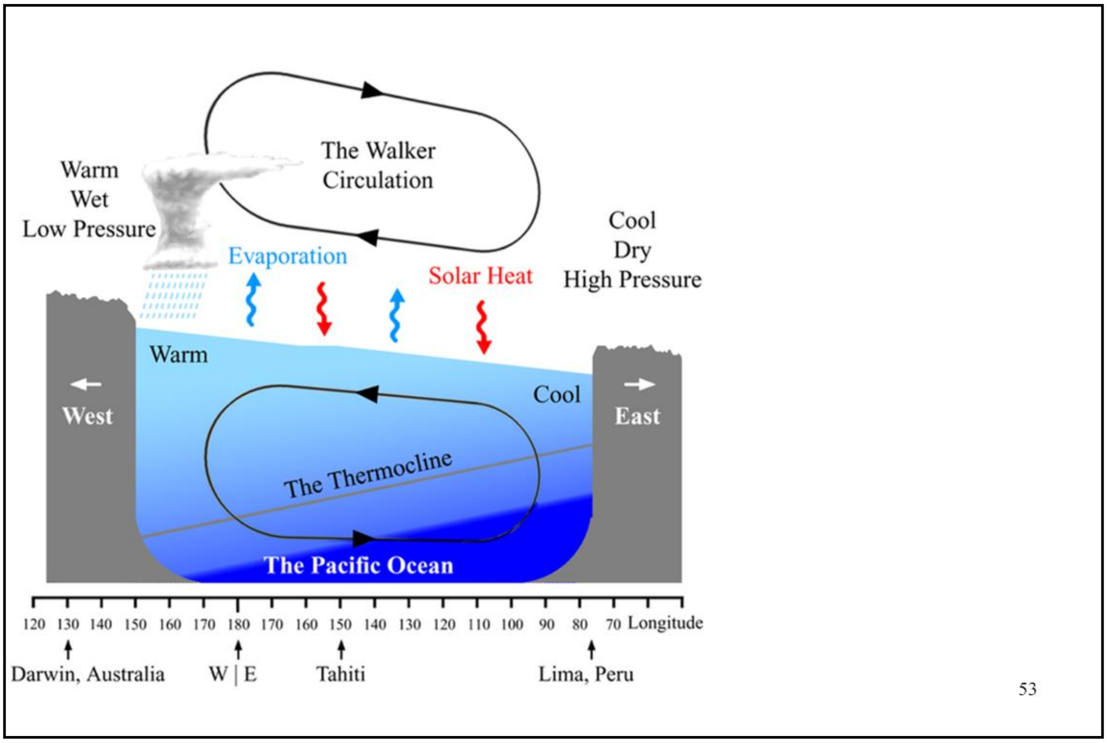
1. What is the IPCC and what authority do they have to issue conclusions about climate change?
2. What physical factors are driving climate variability?
3. What is the evidence for increased CO2 and other trace gases in the atmosphere?
4. What is the evidence for temperature increases?
5. Examples of current evidence for climate change? Sea level rise, pathogen outbreaks, melting of polar ice, loss of glaciers, changes in precipitation patterns, changes in biodiversity, etc.
6. Why has California adopted a low emissions program?
7. What vulnerability does California have from climate change?
8. Changes in cycles e.g., el Nino, PDO, North American Monsoon

Walker Circulation

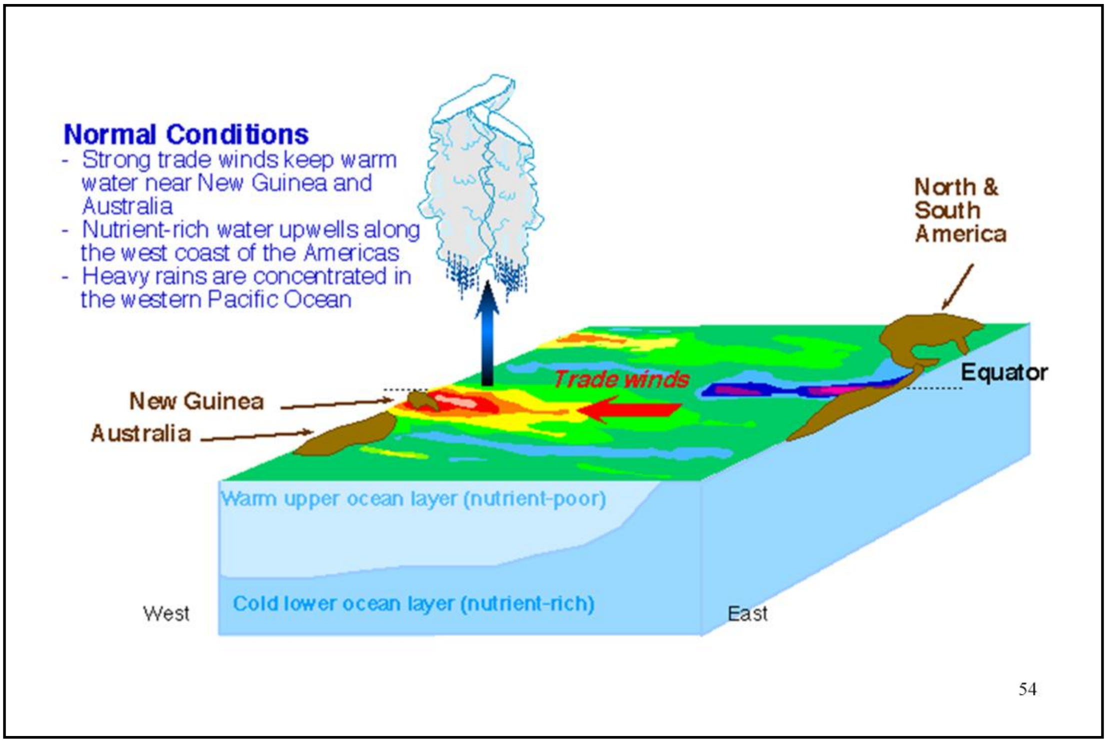




The Walker Circulation is seen at the surface as easterly trade winds that move water and warm air towards the west. This creates ocean upwelling off the coasts of Peru and Ecuador that brings nutrient-rich cold water to the surface. The western side of the equatorial Pacific is characterized by warm, wet low pressure weather as the collected moisture is released in the form of typhoons and thunderstorms. The ocean is some 60 cm higher in the western Pacific as the result of this motion.



The characteristic Walker circulation produces a trade wind behavior that produces the “normal” climate.



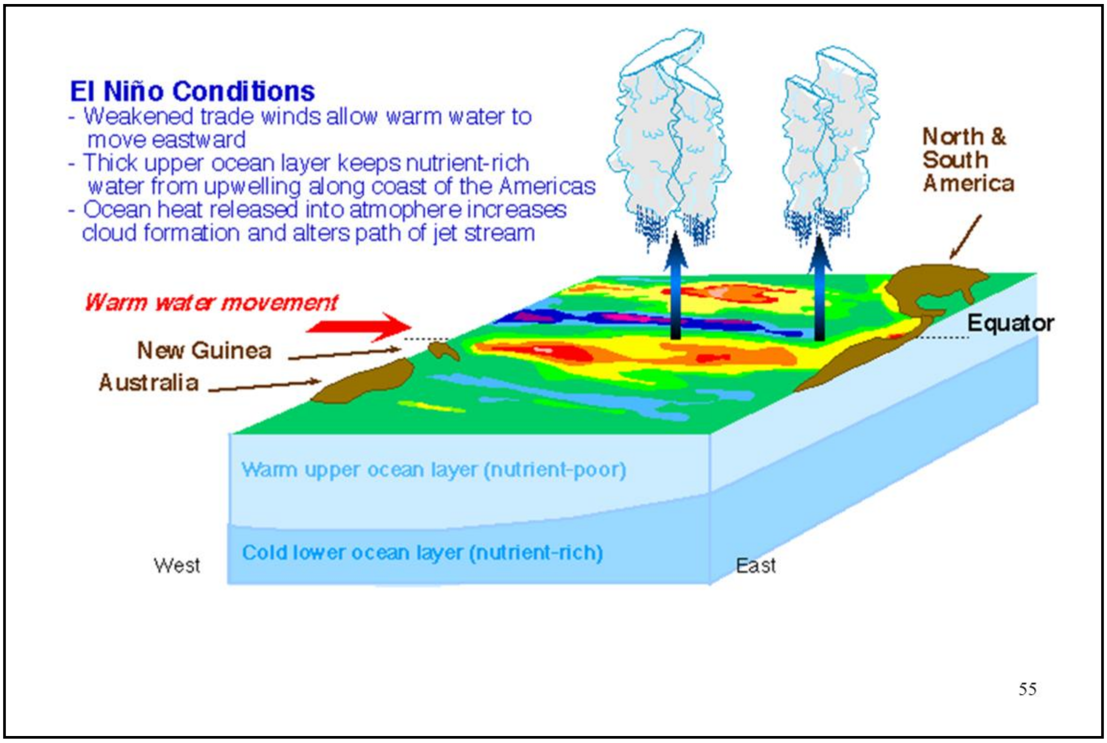
Normal Pacific Ocean Conditions 3-dimensional graphic showing the area around the Pacific Ocean. It diagrams how the Trade Winds interact with sea surface height, ocean layers, and heavy concentrations of rain.

This image represents normal conditions in the Equatorial Pacific Ocean in the Western Pacific (around New Guinea). Normally, "Trade Winds" blow steady from east-to-west and "pile up" warm ocean water at in the Western Pacific. The colors in the image correspond to sea surface height.

Under "normal" circumstances, the Trade Winds blow west along the Equator and allow nutrient-rich, colder bottom water

Normal Pacific pattern. Equatorial winds gather warm water pool toward west. Cold water upwells along South American coast. This provides good conditions for fish production.

During these times, heavy rains are tied to the warm water concentrated in the Western Pacific Ocean, near New Guinea and Australia.



El Niño Conditions in the Pacific Ocean 3-dimensional representation of El Niño conditions around the Pacific Ocean.

El Niño Conditions. Warm water pool approaches South American coast. Absence of cold upwelling increases warming.

"El Niño" is caused by the interaction between the Trade Winds and the ocean. A "minor" difference in sea surface height means a big difference in the where ocean heat is stored and where heavy rains and severe drought occur.

The name El Niño was coined by fishermen off of the west coast of Peru in reference to the warm currents that typically appear around Christmastime causing a decline in the fish population.

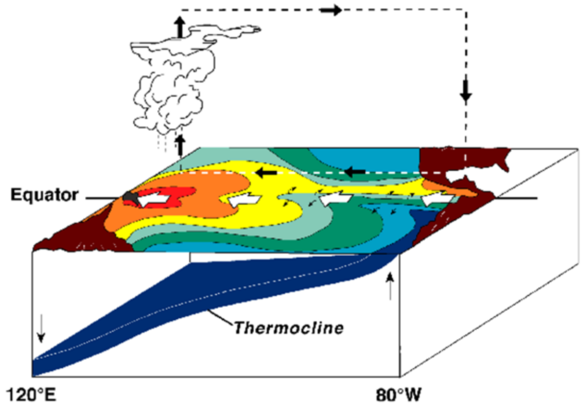
For decades, climatologists have assembled data to detect links to severe El Niño conditions. This includes dramatic shifts in conditions: drought in Australia, New Guinea, India, and Africa; mild winters in Canada; severe winters in California, Christmas Island (central Pacific), and Peru. Other, more subtle, evidence tied to severe El Niño conditions includes high pressure records in Australia, fishery production, patterns of marine life, changes in coral reefs, and few-degree increases in sea-surface temperature in the Pacific Ocean.

All of these conditions are tied to weakened Trade Winds that allow warm ocean surface water to travel eastward. This warm water brings heavy rains that disrupt normal atmospheric conditions. All of this is signaled by a rise in sea surface height of 18 cm! A good way to monitor this relatively small change in the sea level that has a huge impact is the Topex/Poseiden satellite.

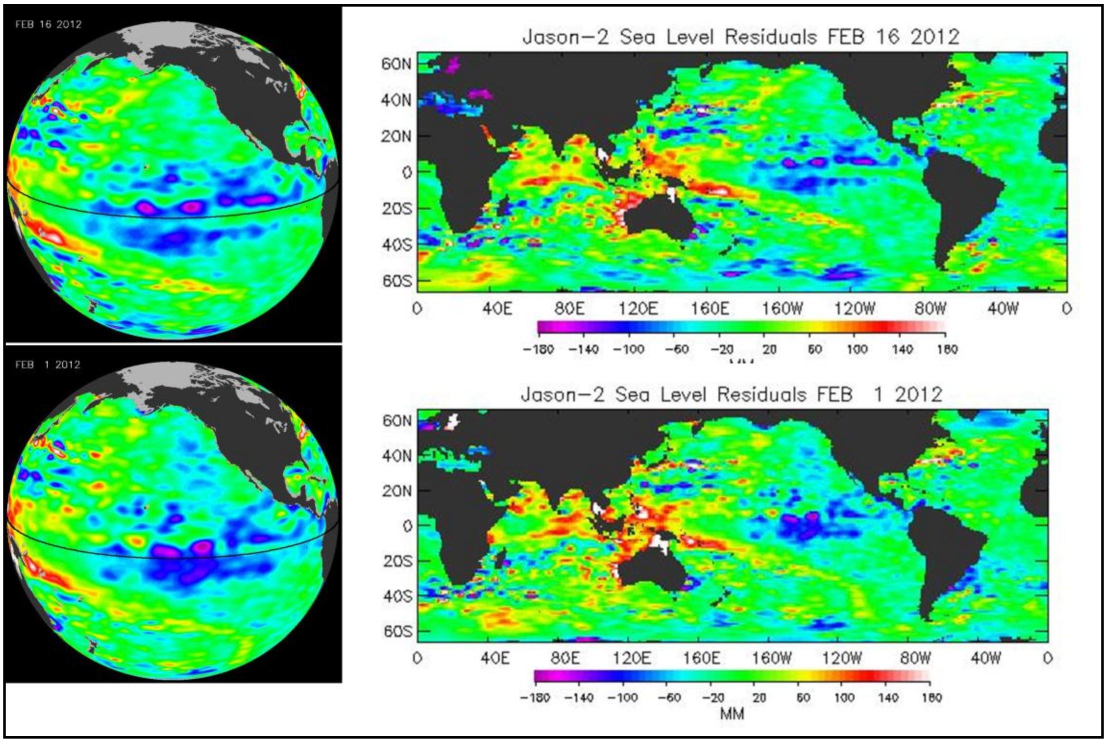
El Niño-Southern Oscillation (**ENSO**) is a global coupled ocean-atmosphere phenomenon. The Pacific ocean signatures, **El Niño** and **La Niña** are important temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. Their effect on climate in the southern hemisphere is profound. These effects were first described in 1923 by Sir Gilbert Thomas Walker from whom the Walker circulation, an important aspect of the Pacific ENSO phenomenon, takes its name. The atmospheric signature, the **Southern Oscillation** (**SO**) reflects the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. The most recent occurrence of El Niño started in September 2006 and lasted until early 2007.

ENSO is a set of interacting parts of a single global system of coupled ocean-atmosphere climate fluctuations that come about as a consequence of oceanic and atmospheric circulation. ENSO is the most prominent known source of inter-annual variability in weather and climate around the world (~3 to 8 years), though not all areas are affected. ENSO has signatures in the Pacific, Atlantic and Indian Oceans. El Ninio causes unusual weather patterns where it rains in specific places but not in others, this is one of many causes for the drought.

In the Pacific, during major warm events, El Niño warming extends over much of the tropical Pacific and becomes clearly linked to the SO intensity. While ENSO events are basically in phase between the Pacific and Indian Oceans, ENSO events in the Atlantic Ocean lag behind those in the Pacific by 12 to 18 months. Many of the countries most affected by ENSO events are developing countries within main continents (South America, Africa...), with economies that are largely dependent upon their agricultural and fishery sectors as a major source of food supply, employment, and foreign exchange. While ENSO is a global and natural part of the Earth's climate, whether its intensity or frequency may change as a result of global warming is an important concern. Low-frequency variability has been evidenced. Inter-decadal (ID) modulation of ENSO (e.g., from PDO) may explain the so-called protracted ENSO of the early 90s.



La Nina conditions



The data from the **Jason missions (altimeters)** helps understand the complex interactions between the oceans and the atmosphere that affect global weather and climate events. El Niño is one well-known example of this interaction.

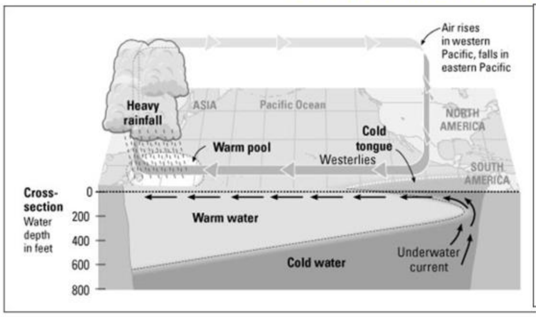
From its vantage point 1336 kilometers above the Earth, *Jason 1 and 2* can measure the height of the ocean surface directly underneath the satellite with an **accuracy of 4-5 centimeters** . Traveling in excess of 7 kilometers every second, provides repeat coverage of the global oceans every 10 days (the Jason 1 and 2 are offset by half the Earth so between them they provide 5 day coverage).

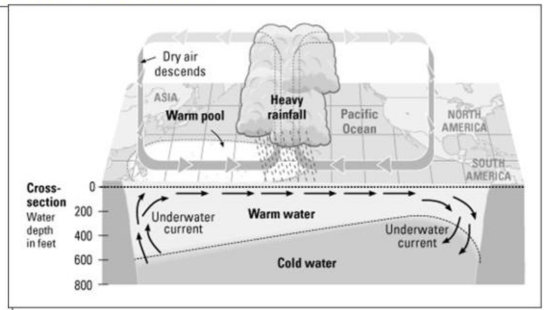
The accurate determination of the ocean height is made by first characterizing the precise height of the spacecraft above the center of the Earth. The baseline tracking system is the onboard *retroreflector array*, which serves as a target for 10-20 satellite *laser ranging* (SLR) stations that scattered over the Earth's surface. The CNES DORIS (*Doppler* Orbitography and Radio positioning Integrated by Satellite) system provides an important additional set of tracking data. Anchored by approximately 50 ground-based beacons, the DORIS receiver measures the Doppler shift of *microwave* signals. NASA's experimental GPS receiver onboard TOPEX/Poseidon provides precise, continuous tracking of the spacecraft by monitoring range and timing signals from up to 6 GPS spacecraft at the same time. In order to produce accurate estimates of the satellite orbital height, it combines the tracking information with accurate *models* of the forces (e.g., gravity, *aerodynamic drag*) that govern the satellite motion. For TOPEX/Poseidon, this process supports the determination of the satellite orbital height with an accuracy of 2-3 centimeters.

The second component of the ocean height measurement is the range from TOPEX/Poseidon to the ocean surface. The satellite carries two radar *altimeters* to provide this information: the NASA TOPEX instrument beams microwaves at 13.6 and 5.3 GHz; the CNES POSEIDON instrument, at 13.65 GHz. The onboard altimeter bounces microwave pulses off the ocean surface and measures the time it takes the pulses to return to the spacecraft. This measurement gives the range from the satellite to the ocean surface. After correction for atmospheric and instrumental effects, the TOPEX/Poseidon range measurements are accurate to 3-4 centimeters. The range measurements are subtracted from POD-derived estimates of the satellite orbital height, resulting in ocean height measurements that are good to 4-5 centimeters relative to the center of the Earth.

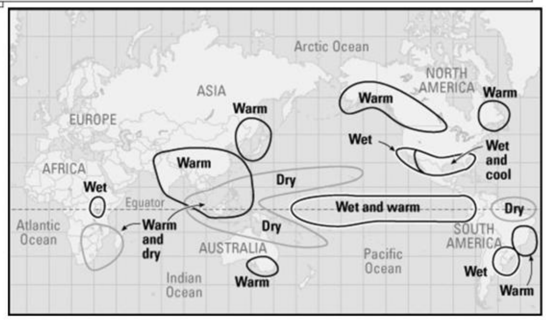
By averaging the few-hundred thousand measurements collected by the satellite in the time it takes to cover the global oceans (10 days), *global mean sea level* can be determined with a precision of several millimeters.

La Niña and El Niño Conditions





Atlantic tropical cyclone activity is generally enhanced during La Niña.



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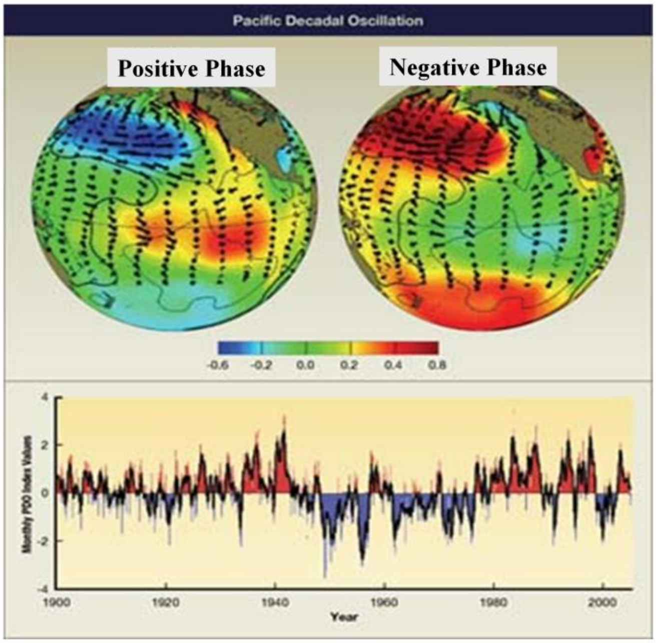
Similar to ENSO (El Nino-Southern Oscillation) normal state.

Warm water accumulates in far western Pacific.

Equatorial water is cooler than in the normal state.

Pacific Decadal Oscillation



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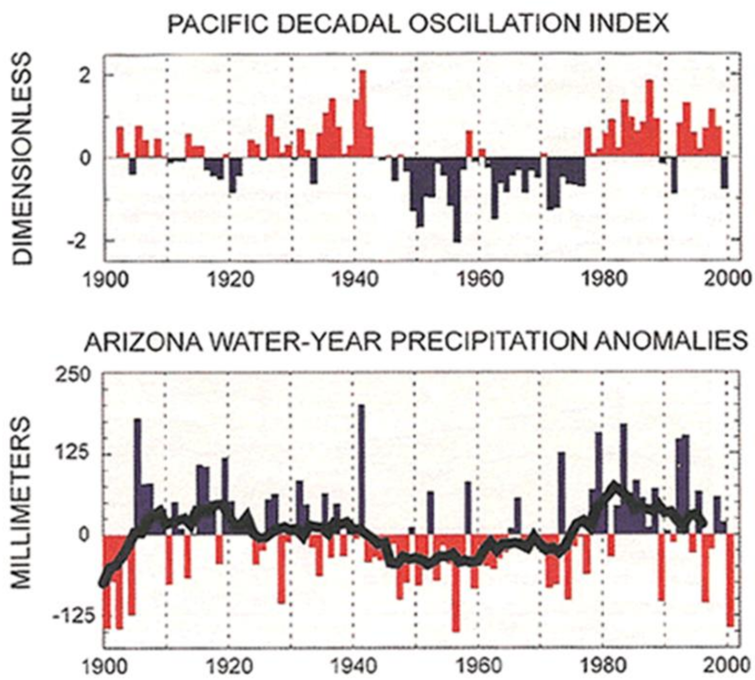
Winter sea surface temperature, wind pattern (arrows), and sea level pressure (contour) anomalies for the warm (left) and cool (right) phase of the Pacific Decadal Oscillation. (Courtesy of Nate Mantua, JISAO Univ. of Washington.)

One of the chief forcing agents on the world's oceans is weather. The Pacific Decadal Oscillation (PDO) is a climate feature that captures much of the variability in meteorological forcing over the Bering Sea and North Pacific Ocean. For example, the progressive change in ocean temperature is well described by the PDO. Phases seem to last a few tens of years, then change. Physical and biological features also track the PDO.

Two main characteristics distinguish the Pacific Decadal Oscillation (PDO) from the El Niño Southern Oscillation (ENSO). First, 20th century PDO "events" persisted for 20 to 30 years, while typical ENSO events persisted for 6 to 18 months. Second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics – but the opposite is true for ENSO. Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO. Even in the absence of a full theoretical understanding of the PDO, information about its phase can improve season-to-season and year-to-year climate forecasts for North America because of its strong tendency for multi-season and multi-year persistence. For the past several years, North Pacific sea surface temperature variations have not consistently correlated with either the warm or cool phases of the PDO pattern (see top panel). The PDO index has been highly variable. The 1900 to 2004 time series of the PDO index is shown in the bottom panel. Monthly updates of the PDO index are available online.

Pacific Decadal Oscillation. (top) Typical wintertime sea surface temperature (colors), sea level pressure (contours), and surface wind stress (arrows) anomaly patterns during positive and negative phases of the Pacific Decadal Oscillation (PDO), as derived from the TOPEX/Poseidon satellite plus other ocean/atmosphere data. Temperature anomalies (colors) are in degrees Celsius. (bottom) Monthly values for the PDO index, 1900-2004. Credit: S. Hare and N. Mantua, University of Washington.



The Pacific Decadal Oscillation (PDO) (above) and precipitation anomalies for Arizona (below). Arizona is typically in-phase with PDO. Jagged black line in the bottom graph is the smoothed out average of precipitation anomalies. Adapted from National Oceanic and Atmospheric Administration (NOAA)."Pacific Decadal Oscillation (PDO)." http://ww2.wrh.noaa.gov/climate_info/PDO_page.htm 5/5/03.

Polar Bear Is Made a Protected Species Under Endangered Species Act, May 15, 2008

Loss of sea ice threatens polar bear habitat. This loss of habitat puts polar bears at risk of extinction in the foreseeable future.
US Fish & Wildlife Service