Climate change science: the IPCC process

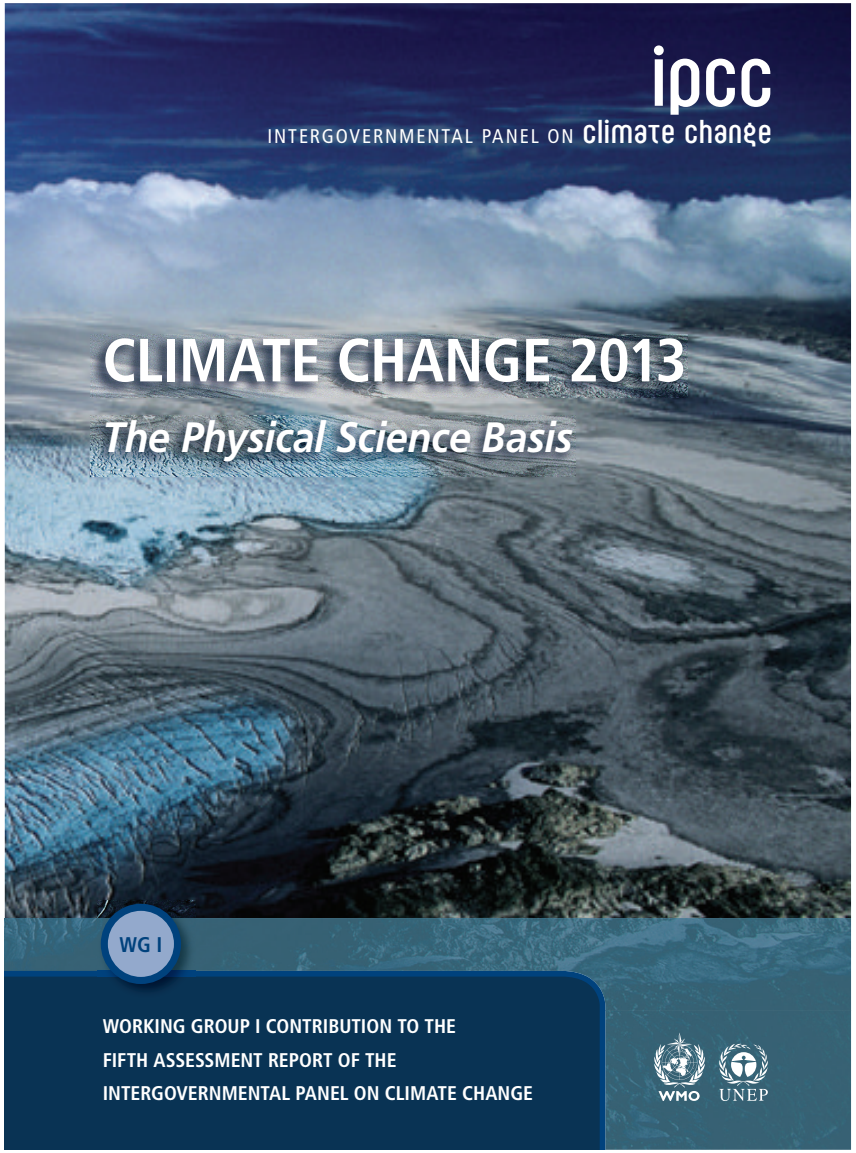
http://www.ipcc.ch

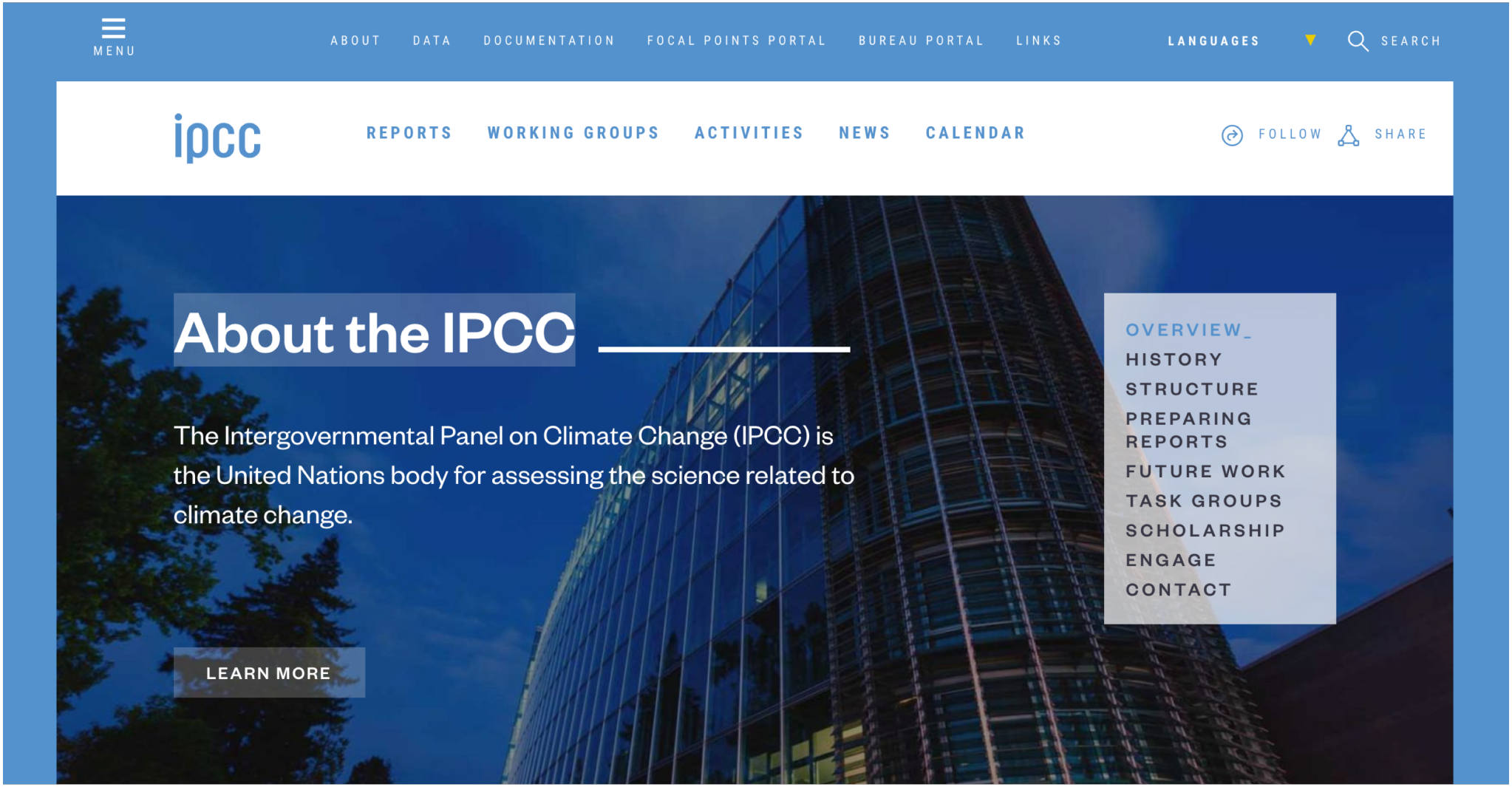
SIO87 Freshman Seminar

Winter 2019

L. D. Talley, SIO

January 23, 2019 (Week 2: heat and water)

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About the IPCC
The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.
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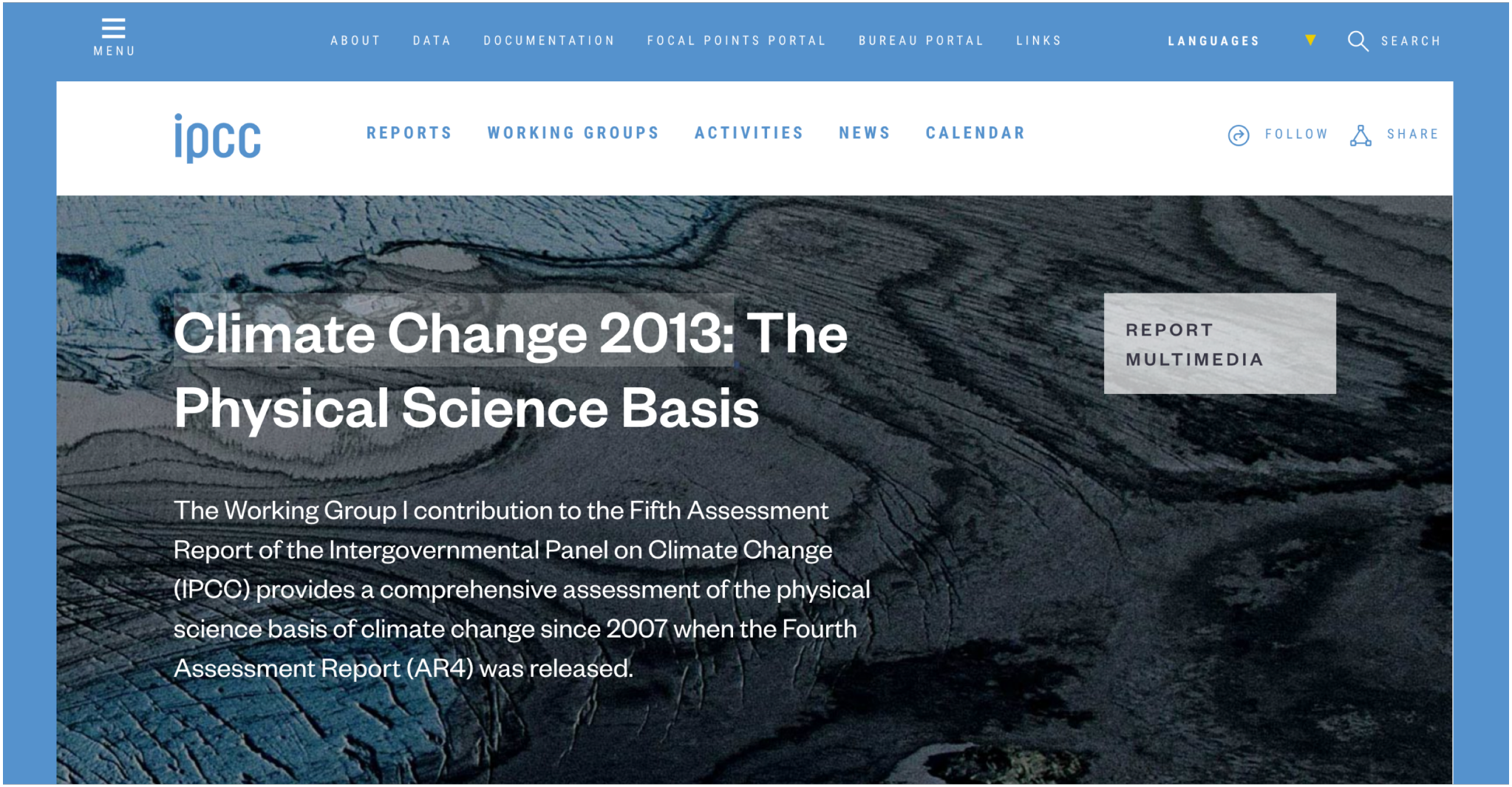
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Climate Change 2013: The Physical Science Basis
REPORT
MULTIMEDIA
The Working Group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provides a comprehensive assessment of the physical science basis of climate change since 2007 when the Fourth Assessment Report (AR4) was released.

IPCC AR5 WG1
Headline statements
distilled

Warming of the climate system is unequivocal.

Human influence on the climate system is clear.

Continued GHG emissions will cause further warming.

Limiting climate change will require substantial and sustained reductions of GHG emissions.

IPCC AR5 WG1
Headline statements
distilled

Warming of the climate system is unequivocal.

2017 is the warmest year on record

NASA Global Climate Change website
http://climate.nasa.gov/

GLOBAL CLIMATE CHANGE
Vital Signs of the Planet

FACTS ARTICLES SOLUTIONS EXPLORE RESOURCES NASA SCIENCE

Global Temperature

LATEST ANNUAL AVERAGE ANOMALY: 2017

0.9 °C

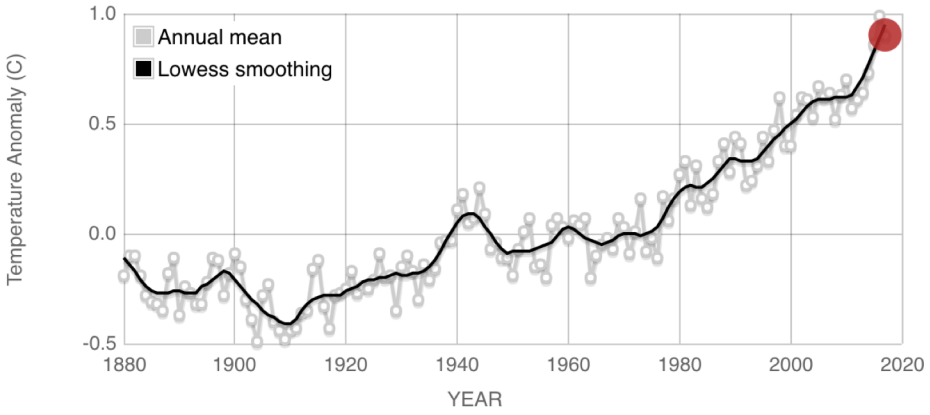
DOWNLOAD DATA

This graph illustrates the change in global surface temperature relative to 1951-1980 average temperatures. Seventeen of the 18 warmest years in the 136-year record all have occurred since 2001, with the exception of 1998. The year 2016 ranks as the warmest on record. (Source: NASA/GISS). This research is broadly consistent with similar constructions prepared by the Climatic Research Unit and the National Oceanic and Atmospheric Administration.

The time series below shows the five-year average variation of global surface temperatures. Dark blue indicates areas cooler than average. Dark red indicates areas warmer than average.

GLOBAL LAND-OCEAN TEMPERATURE INDEX

Data source: NASA's Goddard Institute for Space Studies (GISS).
Credit: NASA/GISS



Click+drag to zoom RESET

Get Data: HTTP | Snapshot: PNG

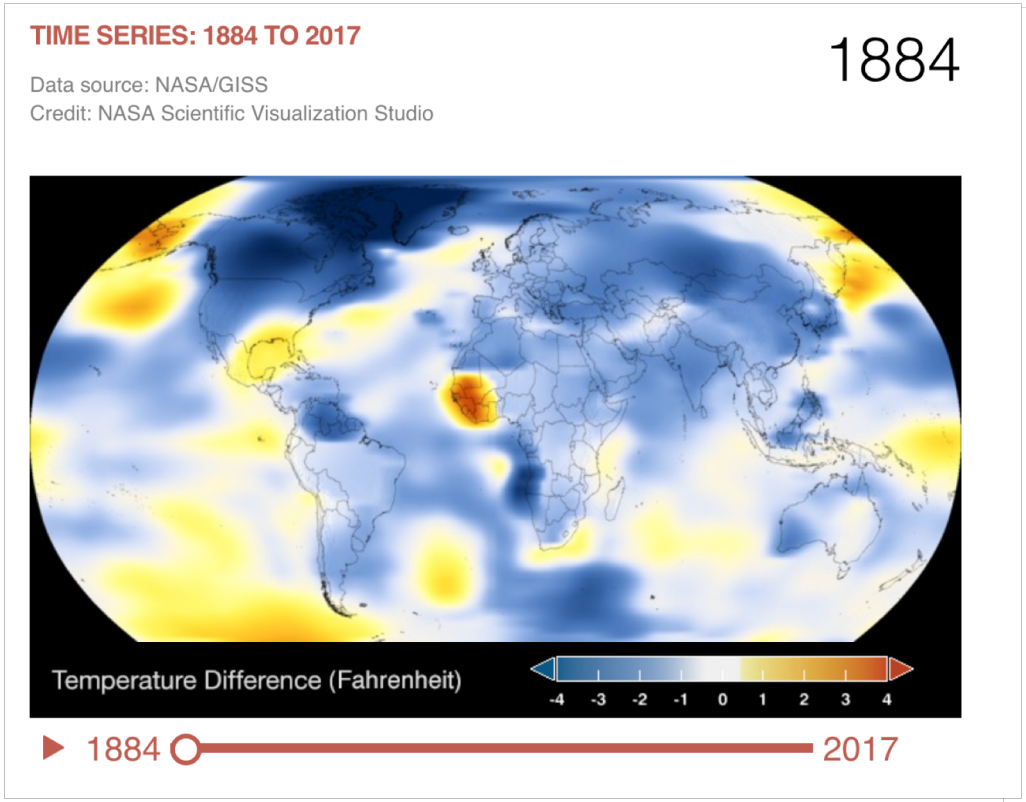
TIME SERIES: 1884 TO 2017

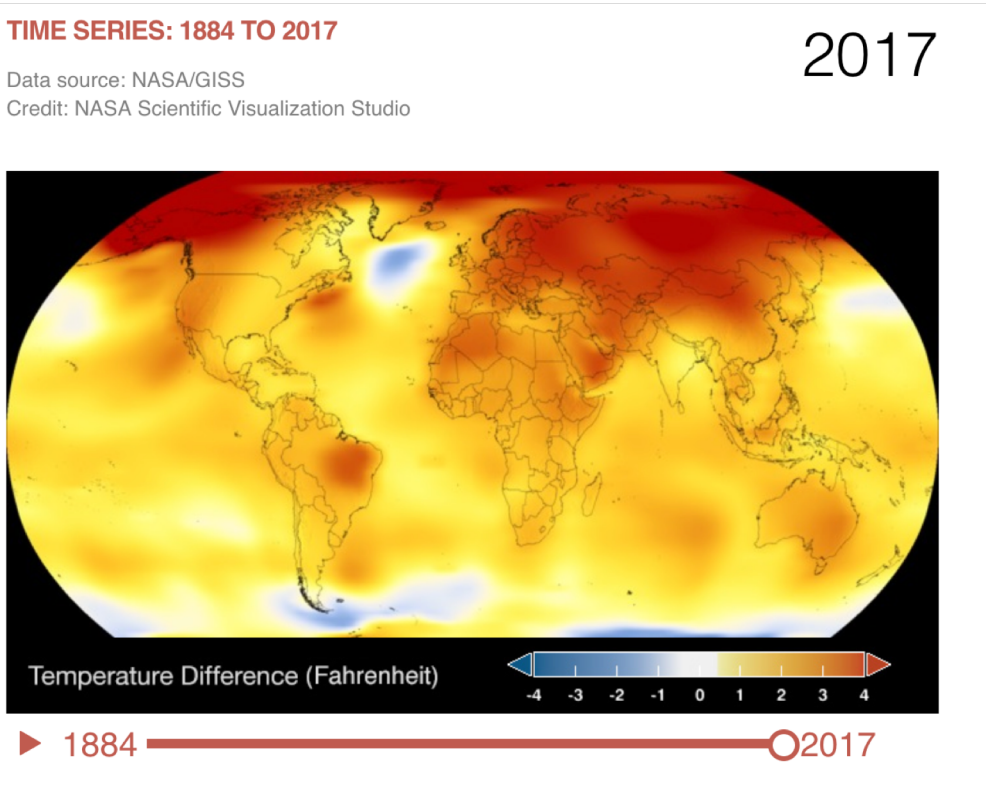
Data source: NASA/GISS
Credit: NASA Scientific Visualization Studio

1884

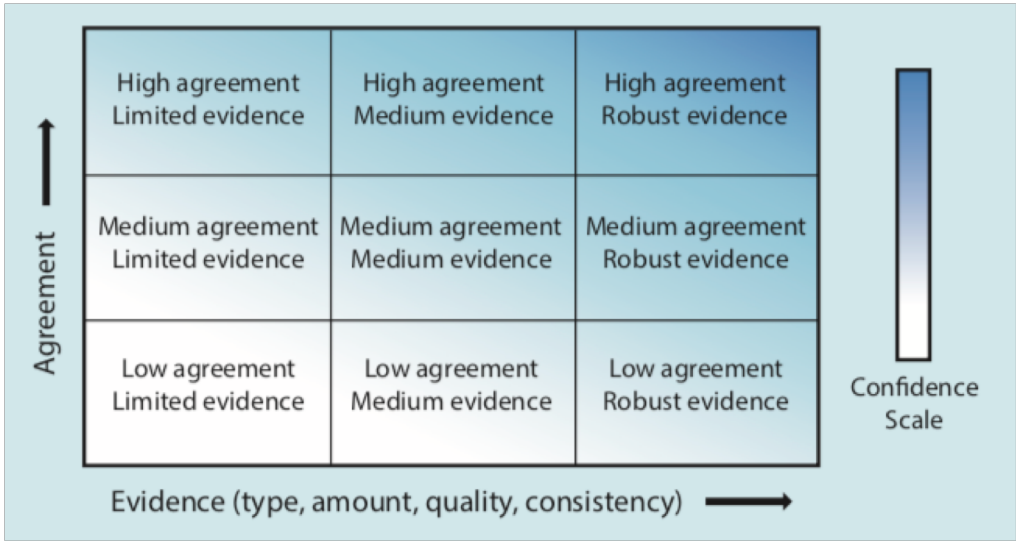
2017 is the warmest year on record

NASA Global Climate Change website
http://climate.nasa.gov/





IPCC AR5
Uncertainty language



The following terms have been used to indicate the assessed likelihood, and typeset in italics:

Term*	**Likelihood of the outcome**
Virtually certain	99–100% probability
Very likely	90–100% probability
Likely	66–100% probability
About as likely as not	33–66% probability
Unlikely	0–33% probability
Very unlikely	0–10% probability
Exceptionally unlikely	0–1% probability

IPCC AR5 WG1

Headline Statements

Headline Statements from the Summary for Policymakers *

Observed Changes in the Climate System

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years *(medium confidence)*.

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 *(high confidence)*. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971.

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent *(high confidence)*.

The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia *(high confidence)*. Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.

The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

Drivers of Climate Change

Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750.

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WMO UNEP

Understanding the Climate System and its Recent Changes

Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.

Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions *(very high confidence)*.

Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing.

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

Future Global and Regional Climate Change

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.

Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation.

It is *very likely* that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease.

Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.

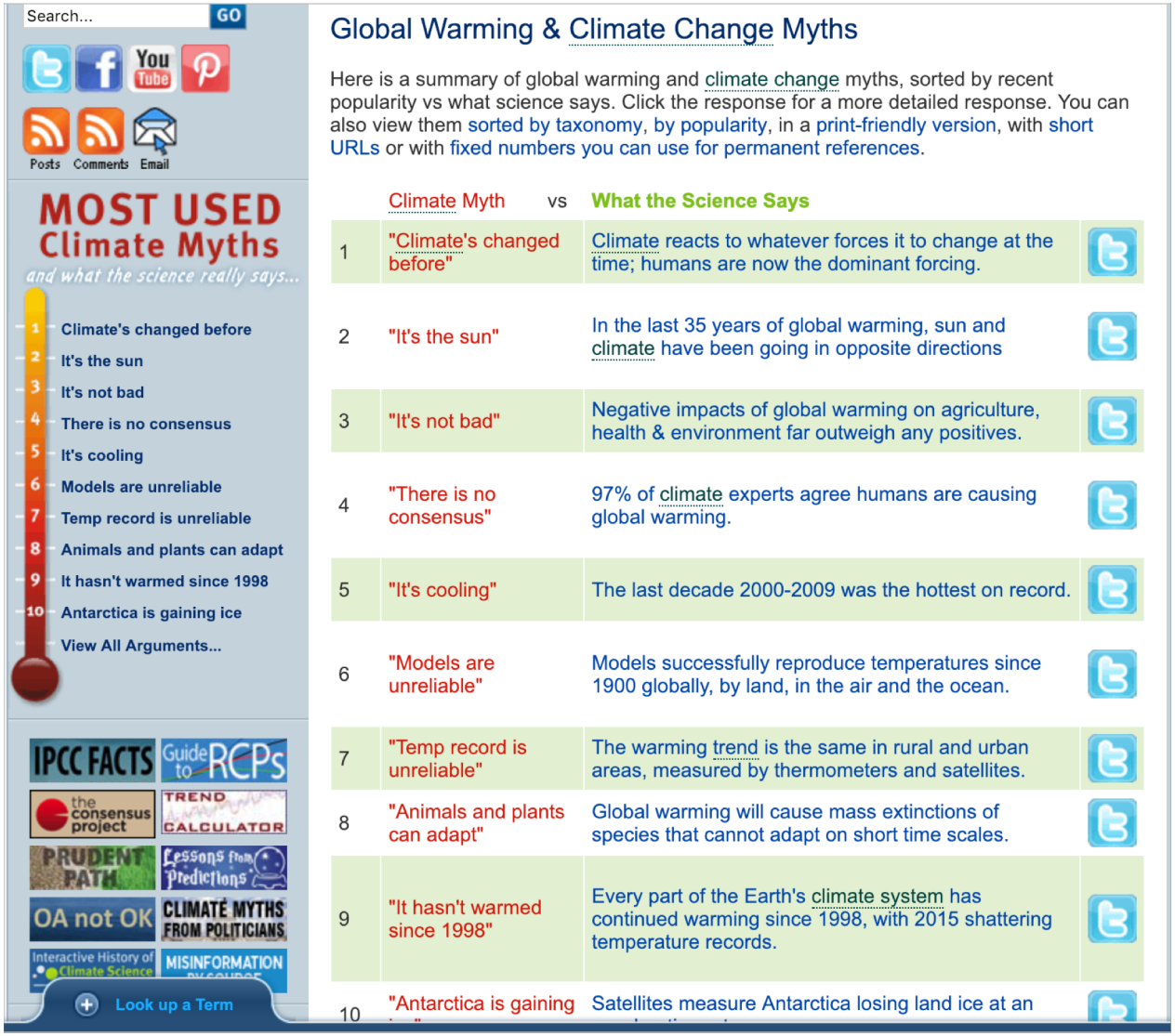
Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere *(high confidence)*. Further uptake of carbon by the ocean will increase ocean acidification.

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2.

* Headline statements are the overarching highlighted conclusions of the approved Summary for Policymakers which, taken together, provide a concise narrative. The four statements in boxes here are those summarizing the assessment in the Summary for Policymakers, sections B-E.

Climate skeptic questions vs. science

https://www.skepticalscience.com/



IPCC AR5 WG1

Heat

Observed Changes in the Climate System

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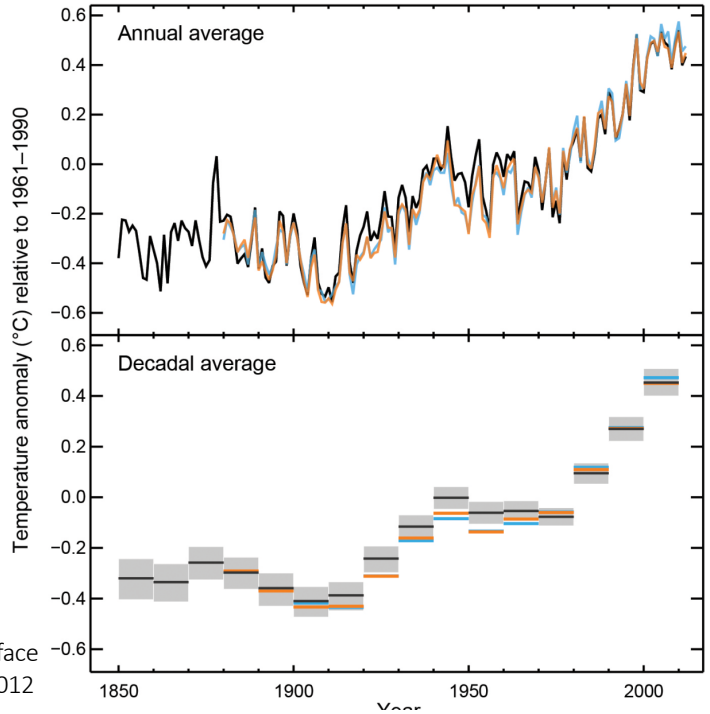


Figure SPM.1a
Observed globally averaged combined land and ocean surface temperature anomaly 1850-2012

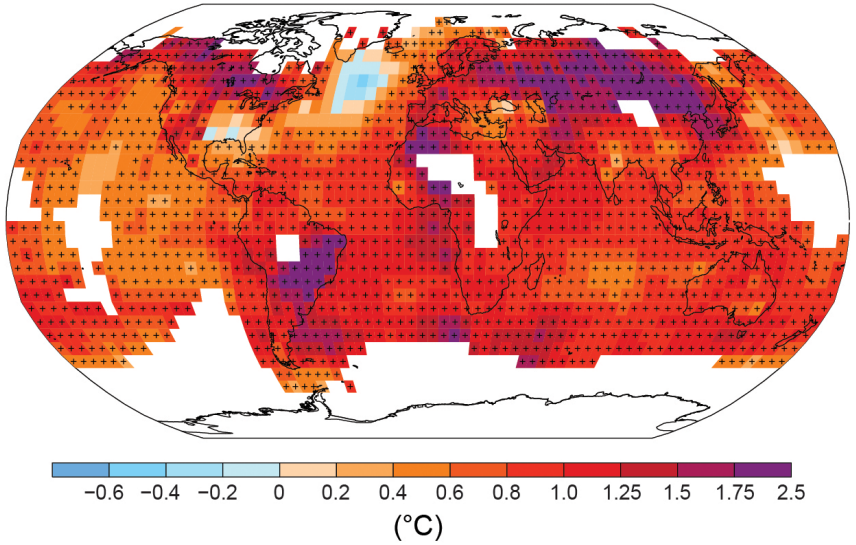


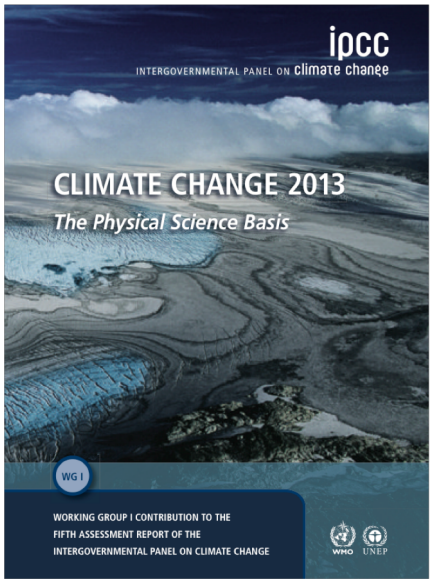
Figure SPM.1b
Observed change in surface temperature 1901-2012

IPCC AR5 WG1

Ocean Heat

IPCC AR5 summary statements:

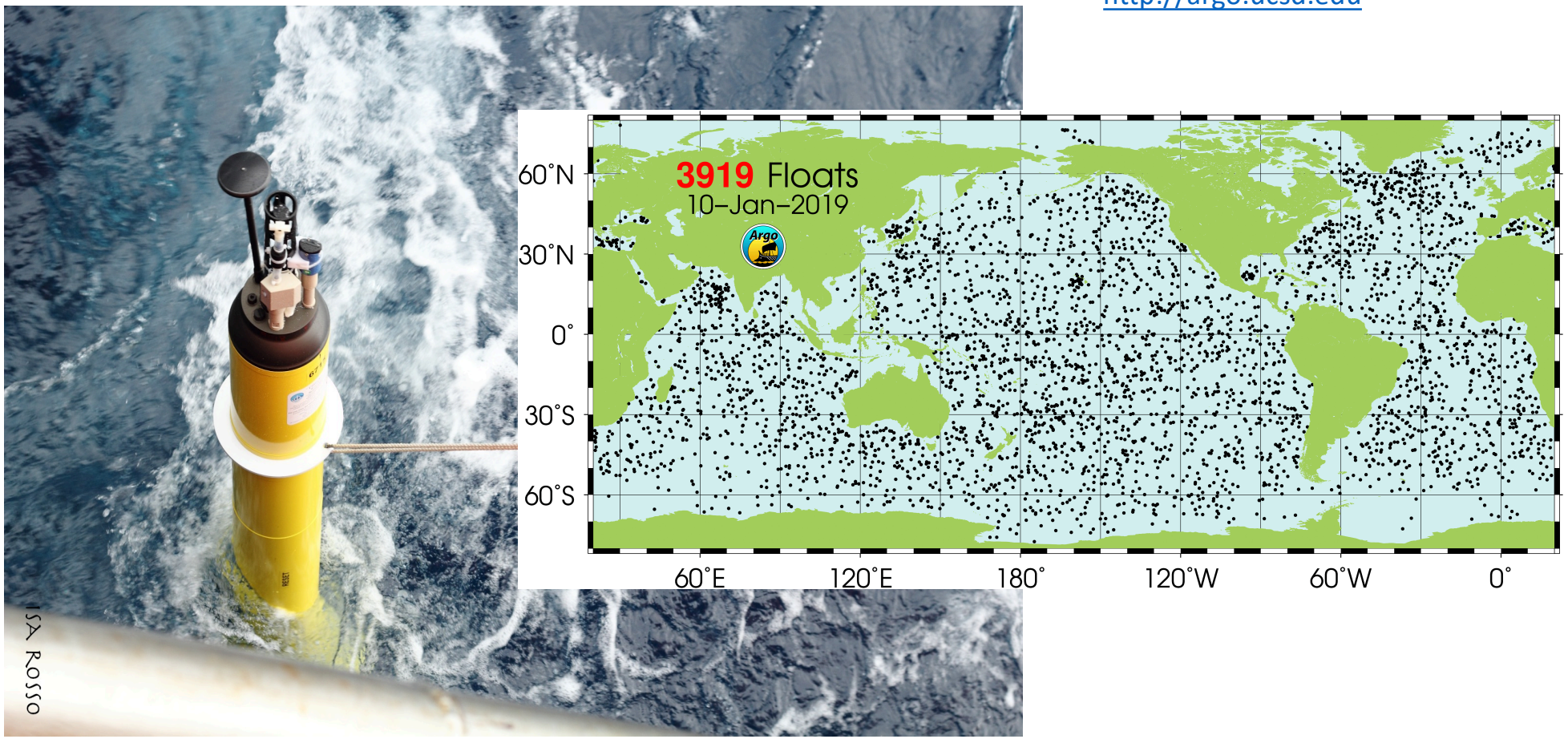
•Ocean warming dominates the increase in energy stored in the climate system, …>90%.. between 1971 and 2010



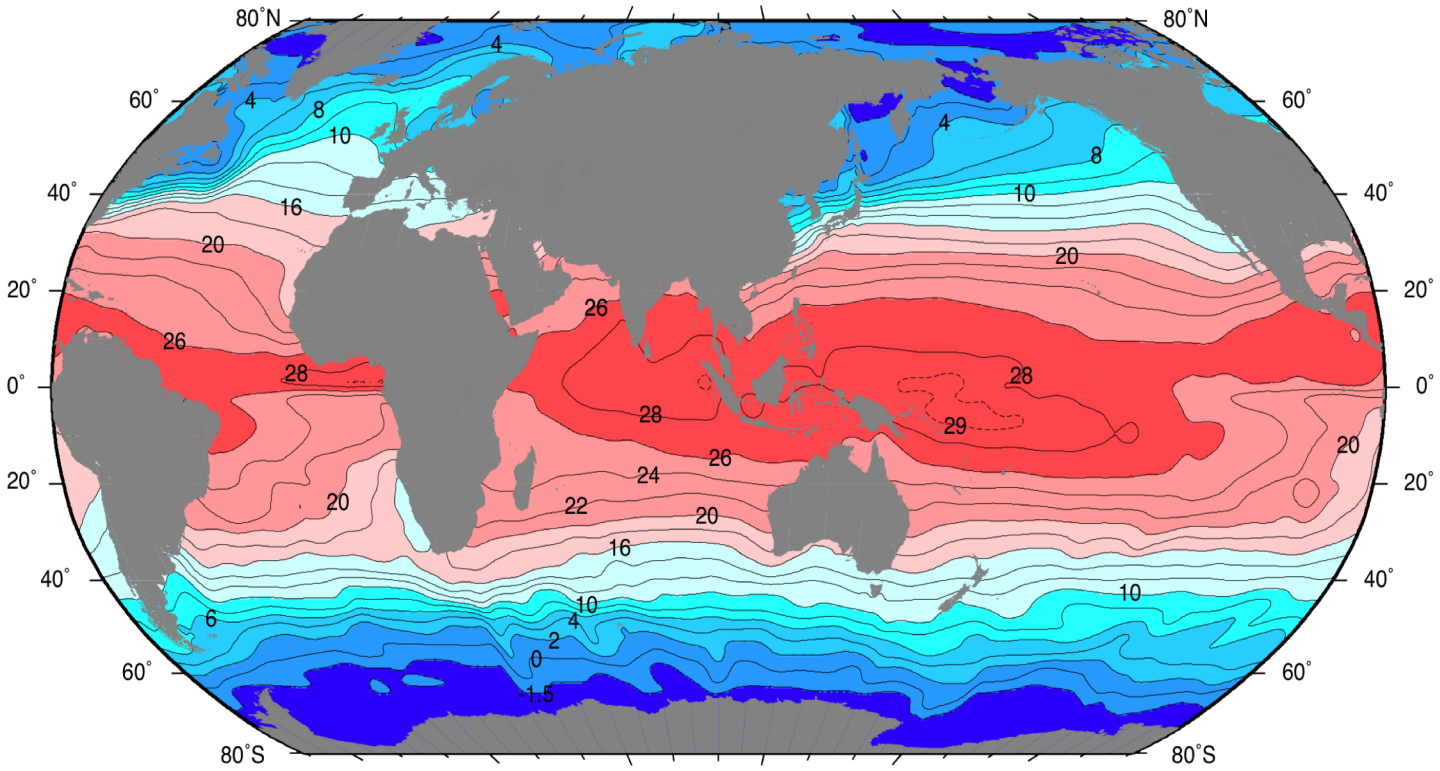
Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 *(high confidence)*. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971.

Observing the upper ocean using profiling floats: “Argo”

http://argo.ucsd.edu

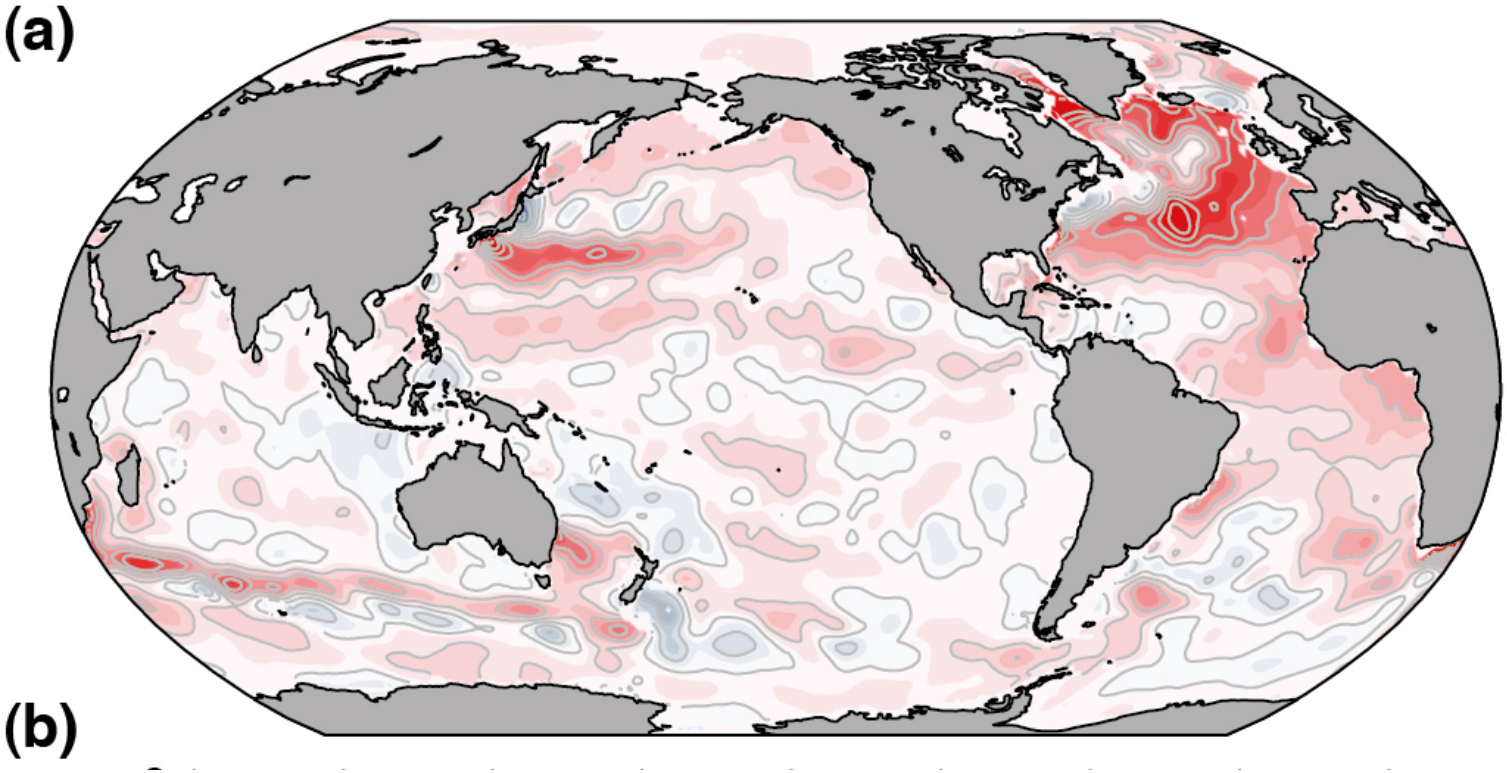


Surface temperature (° C)



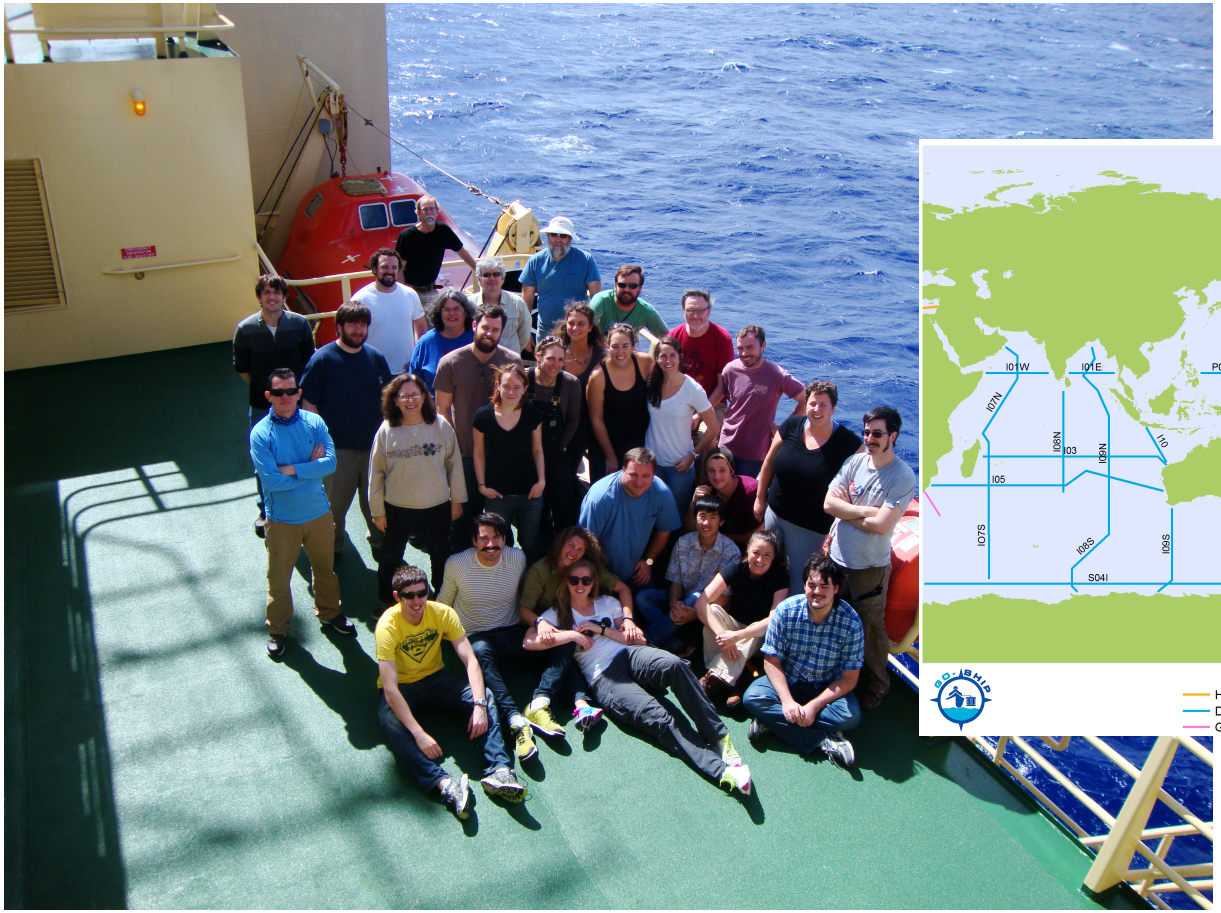
DPO Figure 4.1: Winter data from Levitus and Boyer (1994)

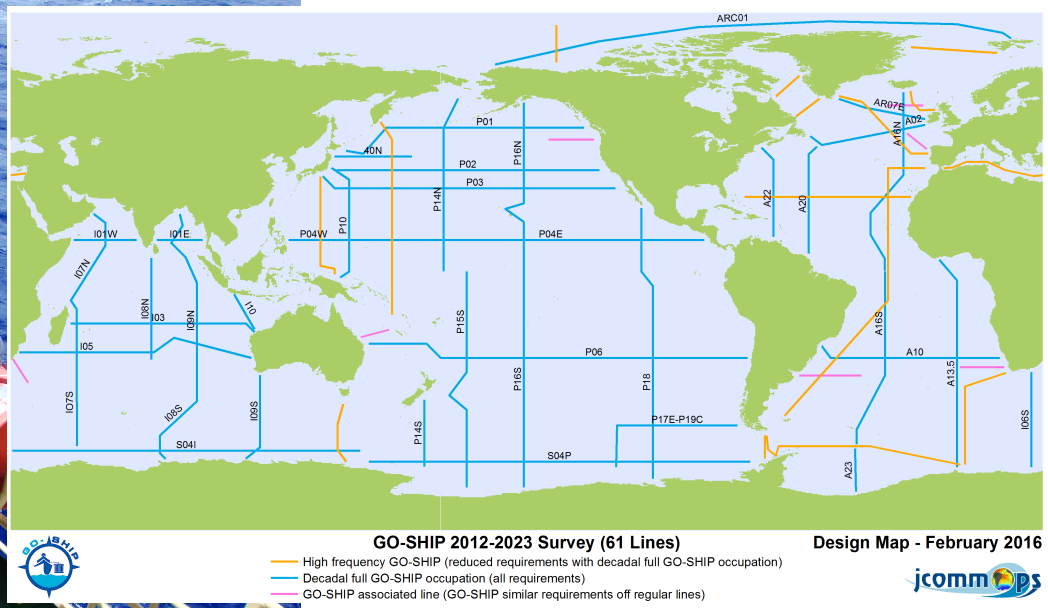
Is ocean temperature changing? Yes



0.3°C increase in the upper 700 m since 1950

Observing the deep ocean from ships





GO-SHIP 2012-2023 Survey (61 Lines)

Design Map - February 2016

High frequency GO-SHIP (reduced requirements with decadal full GO-SHIP occupation)

Decadal full GO-SHIP occupation (all requirements)

GO-SHIP associated line (GO-SHIP similar requirements off regular lines)

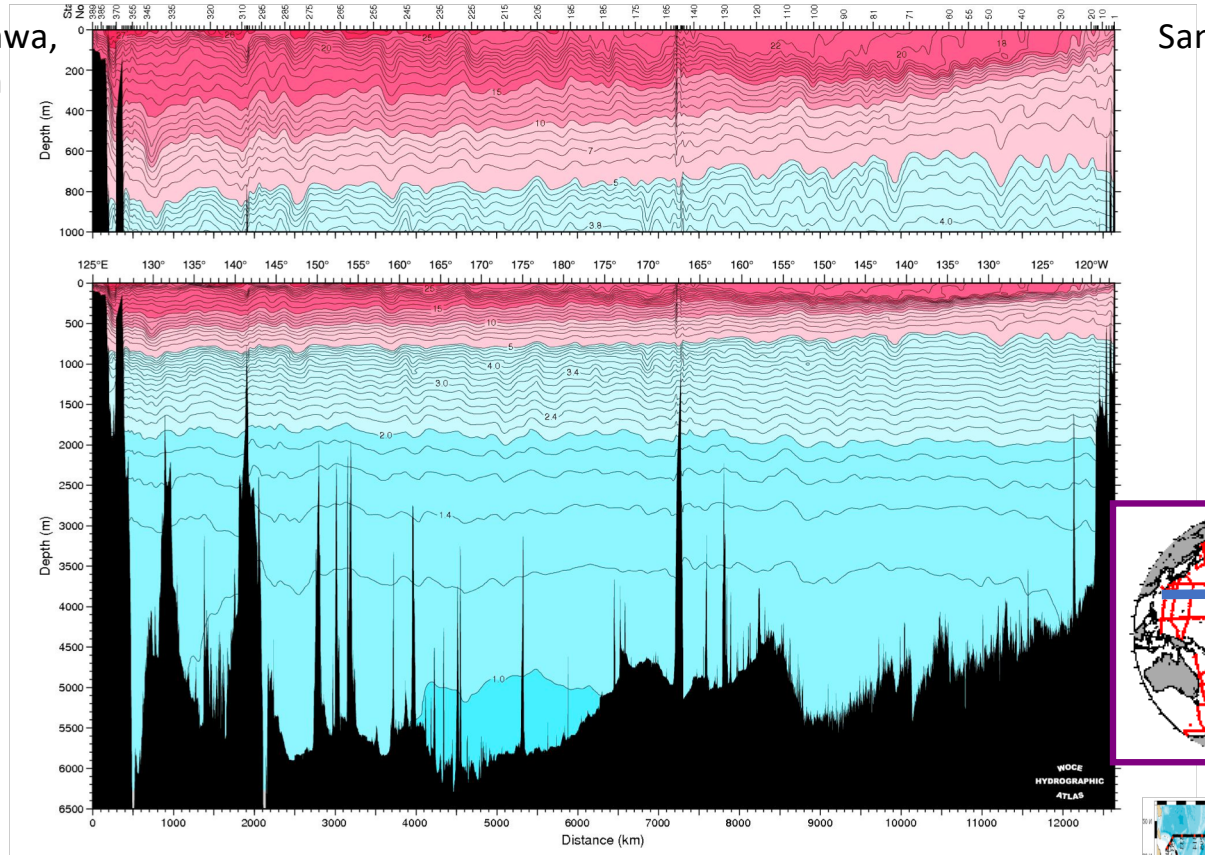
jcommops

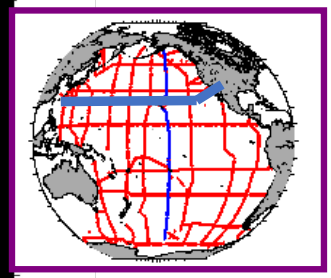
Pacific potential temperature section

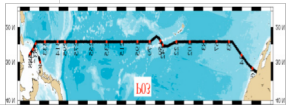
Hawaii

Okinawa, Japan

San Diego

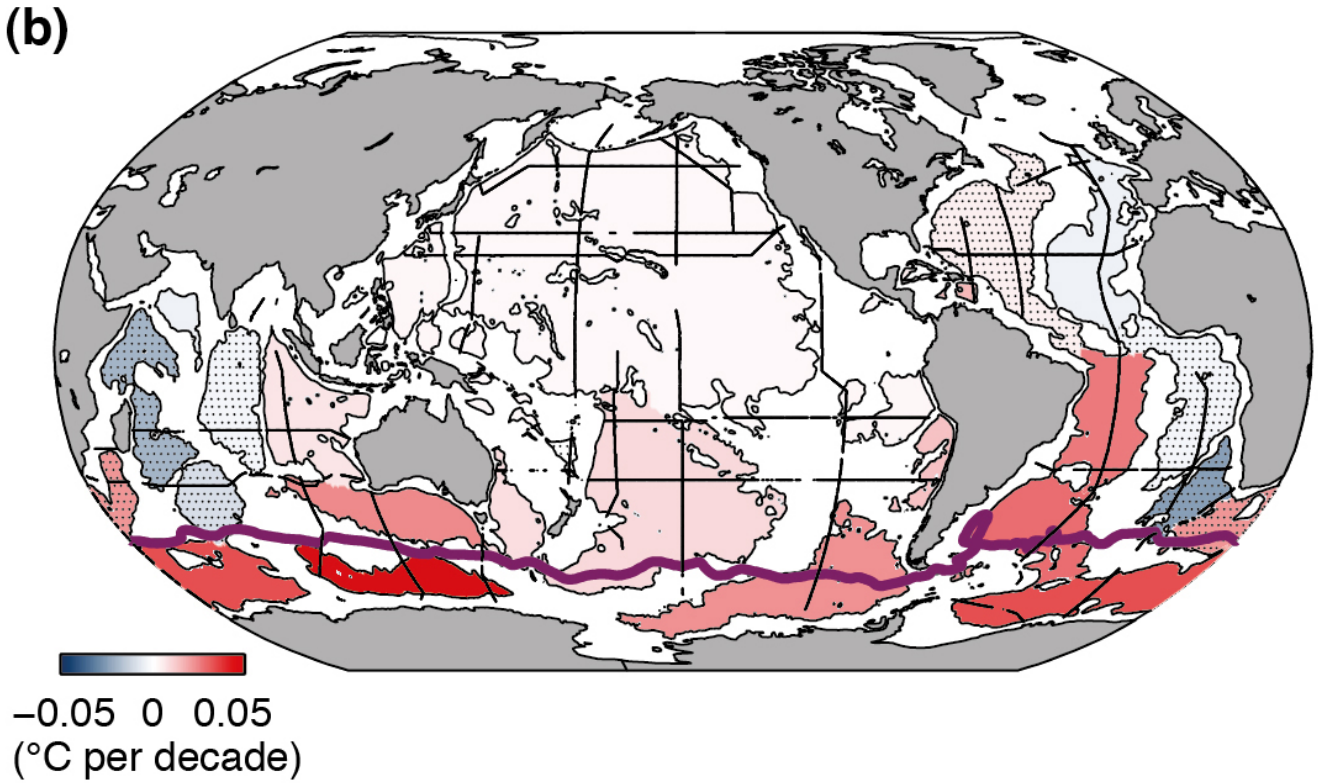






From an Atlas of Pacific Ocean water properties (Talley, 2007)
http://www-pord.ucsd.edu/whp_atlas/pacific_index.html

Is the deep ocean temperature changing? Yes – mostly warming

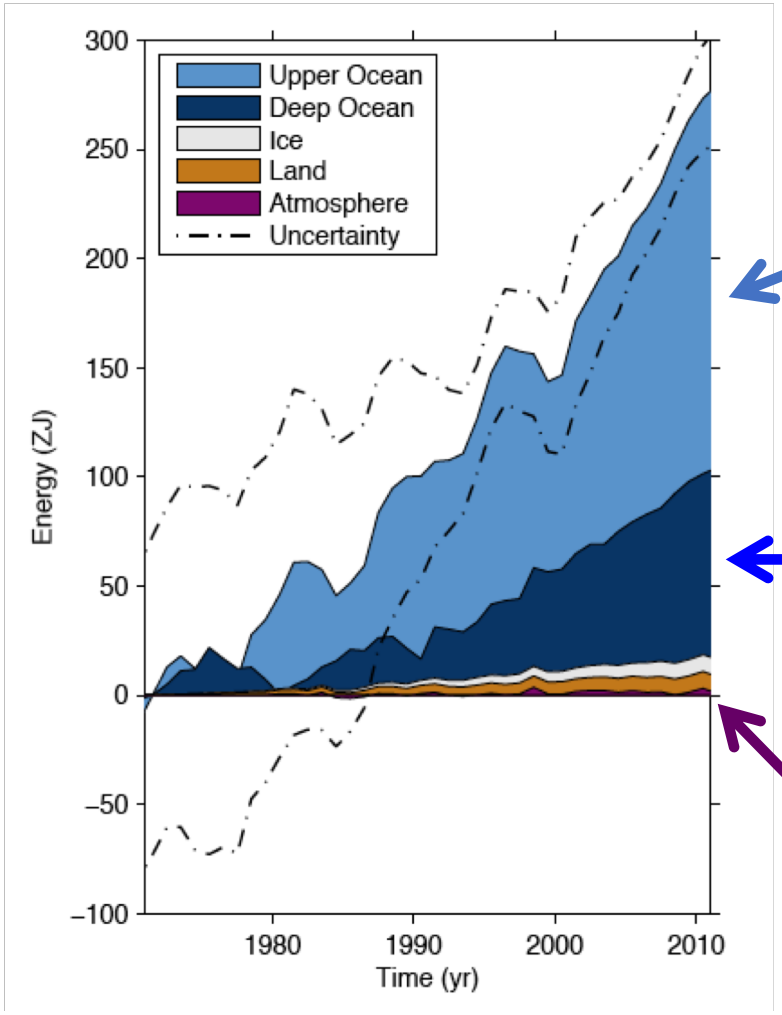


Warming below 4000 m (1992-2005)

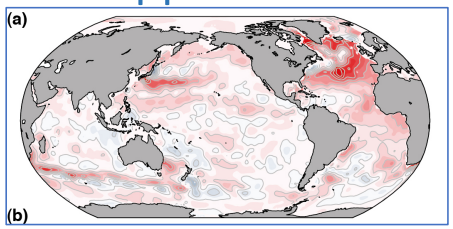
Mostly in the Antarctic!

Global warming is ocean warming

IPCC AR5 (2013) WGI Chapter 3
(ocean observations)



Upper ocean

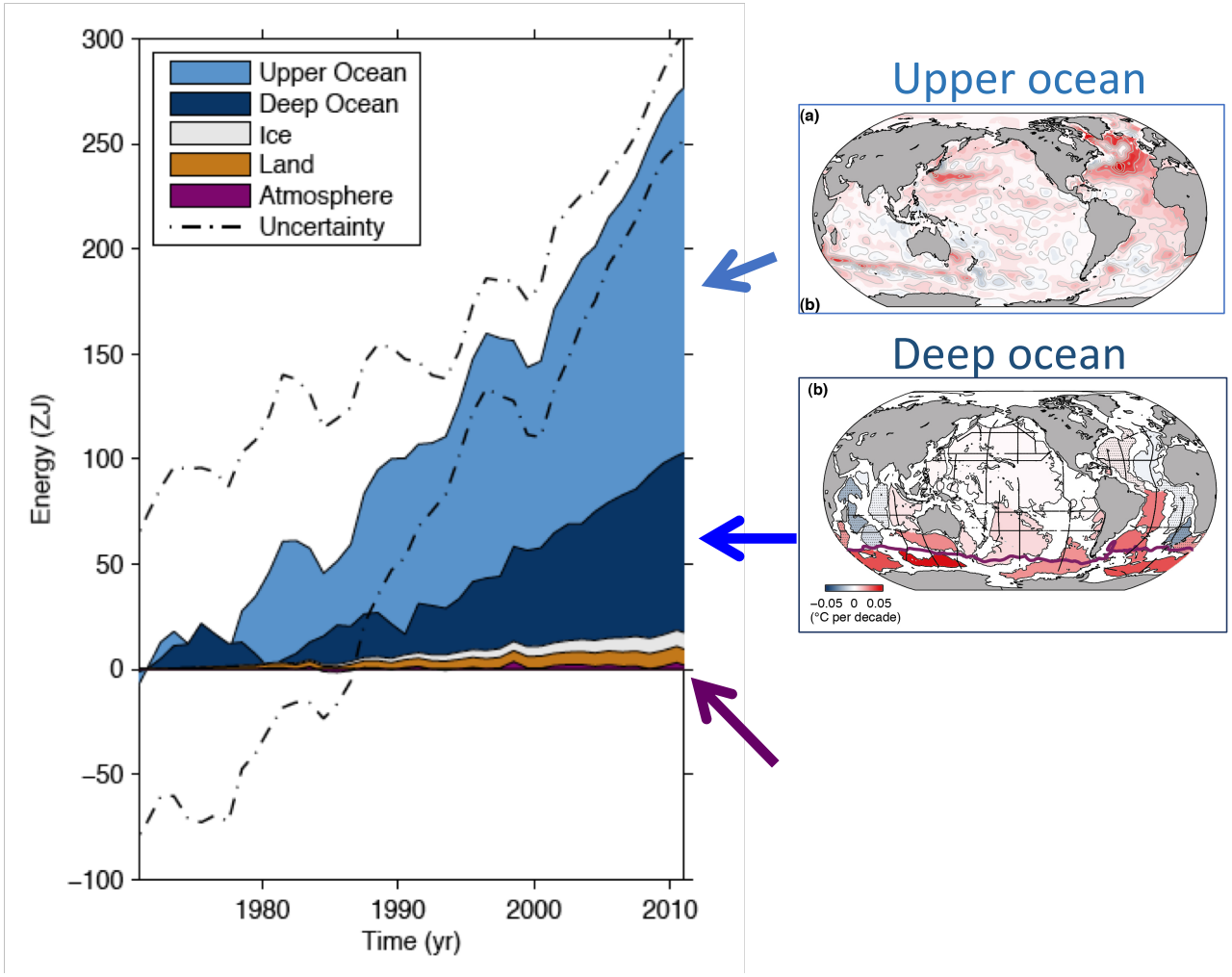


93% of the global energy excess is in the ocean

Temperature change is much bigger in the atmosphere (1°C) (because it's a gas)

Global warming is ocean warming

IPCC AR5 (2013) WGI Chapter 3
(ocean observations)



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IPCC AR5 (2013) WGI Chapter 3
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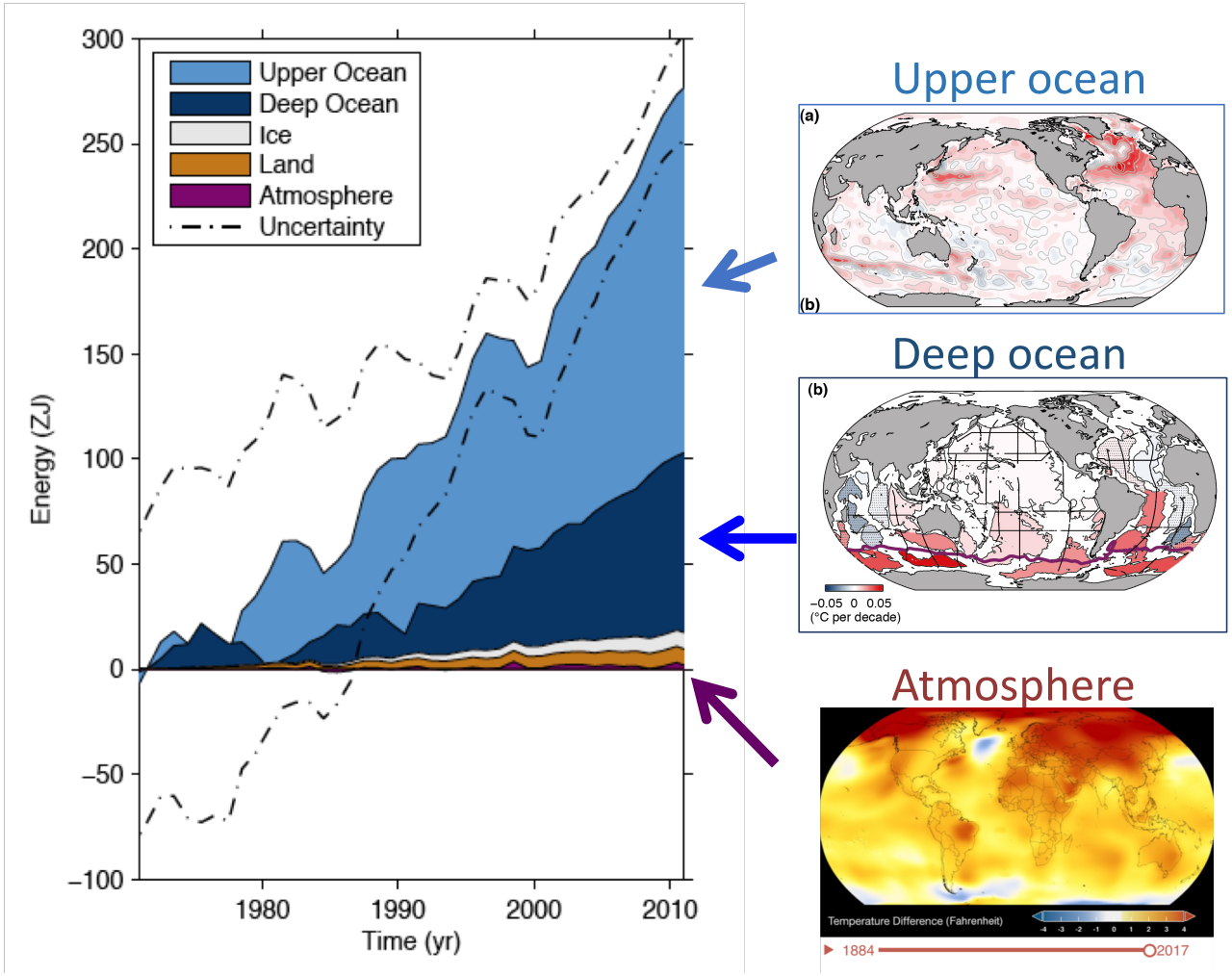


Upper ocean

Deep ocean

Atmosphere

93% of the global energy excess is in the ocean

Temperature change is much bigger in the atmosphere (1°C) (because it's a gas)

NY Times headline this week:

Ocean Warming Is Accelerating Faster Than Thought, New Research Finds

New paper in Science

CLIMATE CHANGE

How fast are the oceans warming?

Observational records of ocean heat content show that ocean warming is accelerat

By Lijing Cheng[1], John Abraham[2], Zeke Hausfather[3], Kevin E. Trenberth[4]

Climate change from human activities mainly results from the energy imbalance in Earth's climate system caused by rising concentrations of heat-trapping gases. About 93% of the energy imbalance accumulates in the ocean as increased ocean heat content (OHC). The ocean record of this imbalance is much less affected by internal variability and is thus better suited for detecting and attributing human influences (*1*) than more commonly used surface temperature records. Recent observation-based estimates show rapid warming of Earth's oceans over the past few decades (see the figure) (*1*, *2*). This warming has contributed to increases in rainfall intensity, rising sea levels, the destruction of coral reefs, declining ocean oxygen levels, and declines in ice sheets; glaciers; and ice caps in the polar regions (*3*, *4*). Recent estimates of observed warming resemble those seen in models, indicating that models reliably project changes in OHC.

The Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5), published in 2013 (*4*), featured five different time series of historical global OHC for the upper 700 m of the ocean. These time series are based on different

Since then, the research community has made substantial progress in improving long-term OHC records and has identified several sources of uncertainty in prior measurements and analyses (*2*, *6*–*8*). In AR5, all OHC time series were corrected for biases in expendable bathythermograph (XBT) data that had not been accounted for in the previous report (AR4). But these correction methods relied on very different assumptions of the error sources and led to substantial differences among correction schemes. Since AR5, the main factors influencing the errors have been identified (*2*), helping to better account for systematic errors in XBT data and their analysis.

Scientists deploy an Argo float. For over a decade, more than 3000 floats have provided near-global data coverage for the upper 2000 m of the ocean.

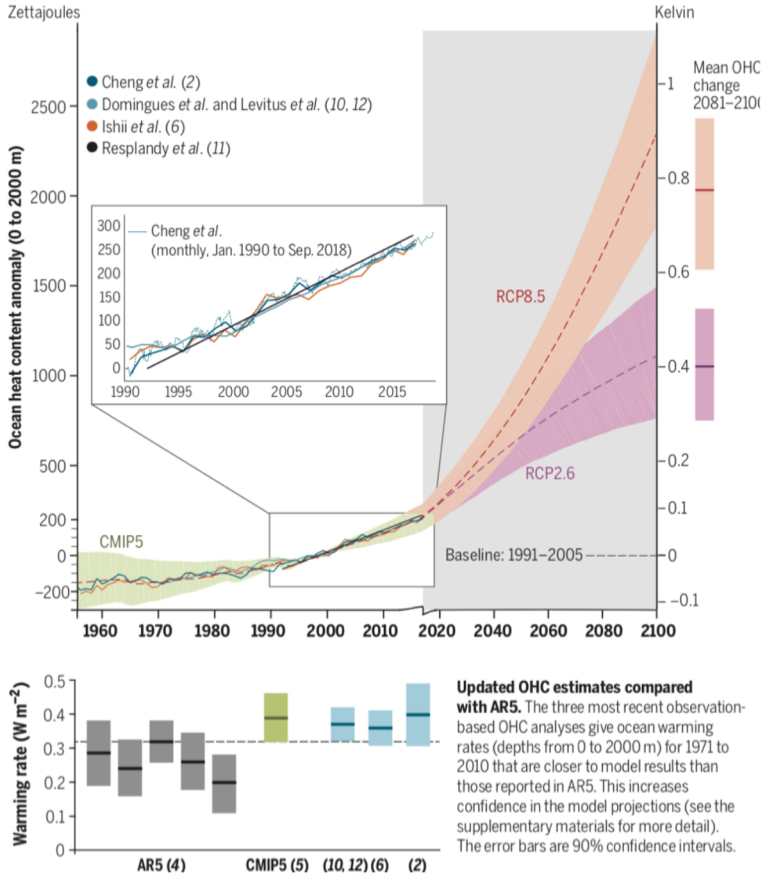
for the upper 2000 m since 1
al. (*6*) completed a major revi
estimate in 2017 to account fo
ous underestimation and also e
analysis down to 2000 m and b
Resplandy *et al.* (*11*) used ocea
outgassing of O_2 and CO_2, wh
isolated from the direct effects
pogenic emissions and CO_2 sink
pendently estimate changes in
time after 1991.

These recent observation-bas
estimates show highly consistent
since the late 1950s (see the figu
warming is larger over the 1971–
riod than reported in AR5. The OH
for the upper 2000 m
ranged from 0.20 to
m^{-2} during this peri
The three more conten
estimates that cover th
time period suggest a wa
rate of 0.36 ± 0.05 (*6*),
0.04 (*10*), and 0.39 ± 0.
W m^{-2}. [Note that the an
in Domingues *et al.* (*10*) is
bined with that in Levitus
(*12*) for 700 to 2000 m to
duce a 0 to 2000 m time se
All four recent studies (*2*, *6*
11) show that the rate of oc
warming for the upper 200
has accelerated in the deca
after 1991 to 0.55 to 0.68 W
(calculations provided in
supplementary materials).

Multiple lines of eviden
from four independent gro

Past and future ocean heat content changes

Annual observational OHC changes are consistent with each other and consistent with the ensemble means of the CMIP5 models for historical simulations pre-2005 and projections from 2005–2017, giving confidence in future projections to 2100 (RCP2.6 and RCP8.5) (see the supplementary materials). The mean projected OHC changes and their 90% confidence intervals between 2081 and 2100 are shown in bars at the right. The inset depicts the detailed OHC changes after January 1990, using the monthly OHC changes updated to September 2018 [Cheng *et al.* (*2*)], along with the other annual observed values superposed.



Updated OHC estimates compared with AR5. The three most recent observation-based OHC analyses give ocean warming rates (depths from 0 to 2000 m) for 1971 to 2010 that are closer to model results than those reported in AR5. This increases confidence in the model projections (see the supplementary materials for more detail). The error bars are 90% confidence intervals.

IPCC AR WG1

Heat

Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing.

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

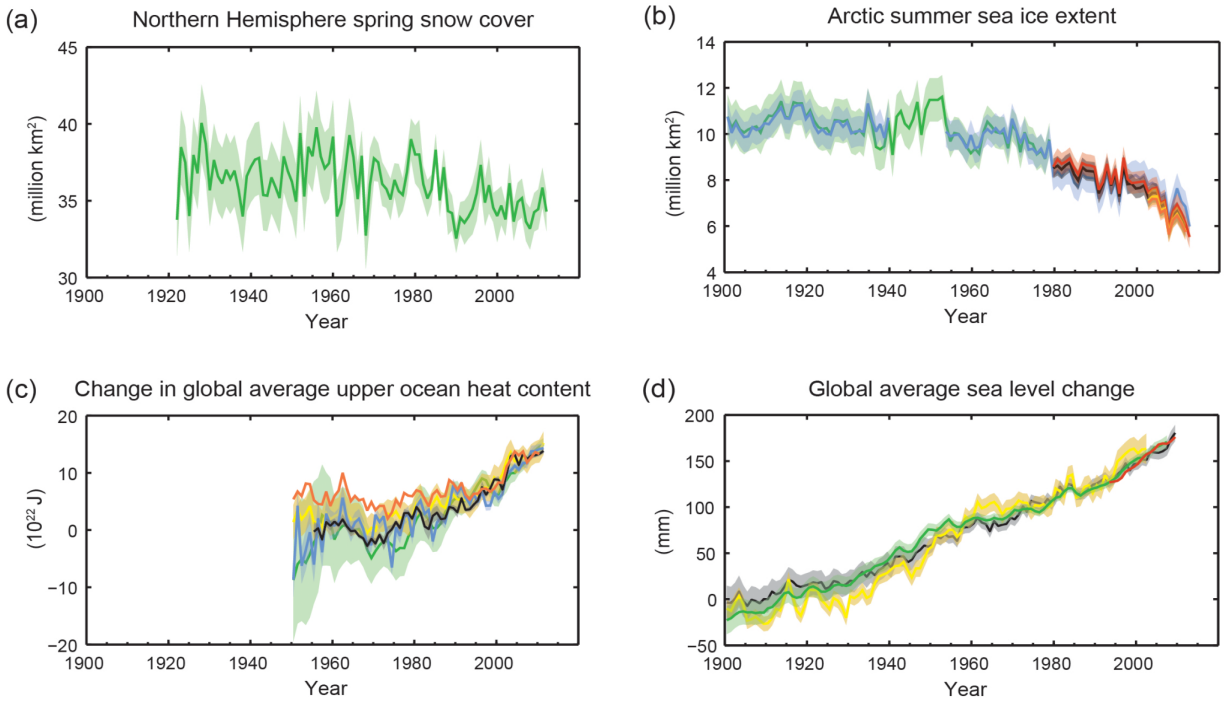


Figure SPM.3
Multiple observed indicators of a changing global climate

The UN Environmental Program's Intergovernmental Panel on Climate Change (IPCC)

http://www.ipcc.ch

IPCC AR5 WG1

Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.

Future Heat

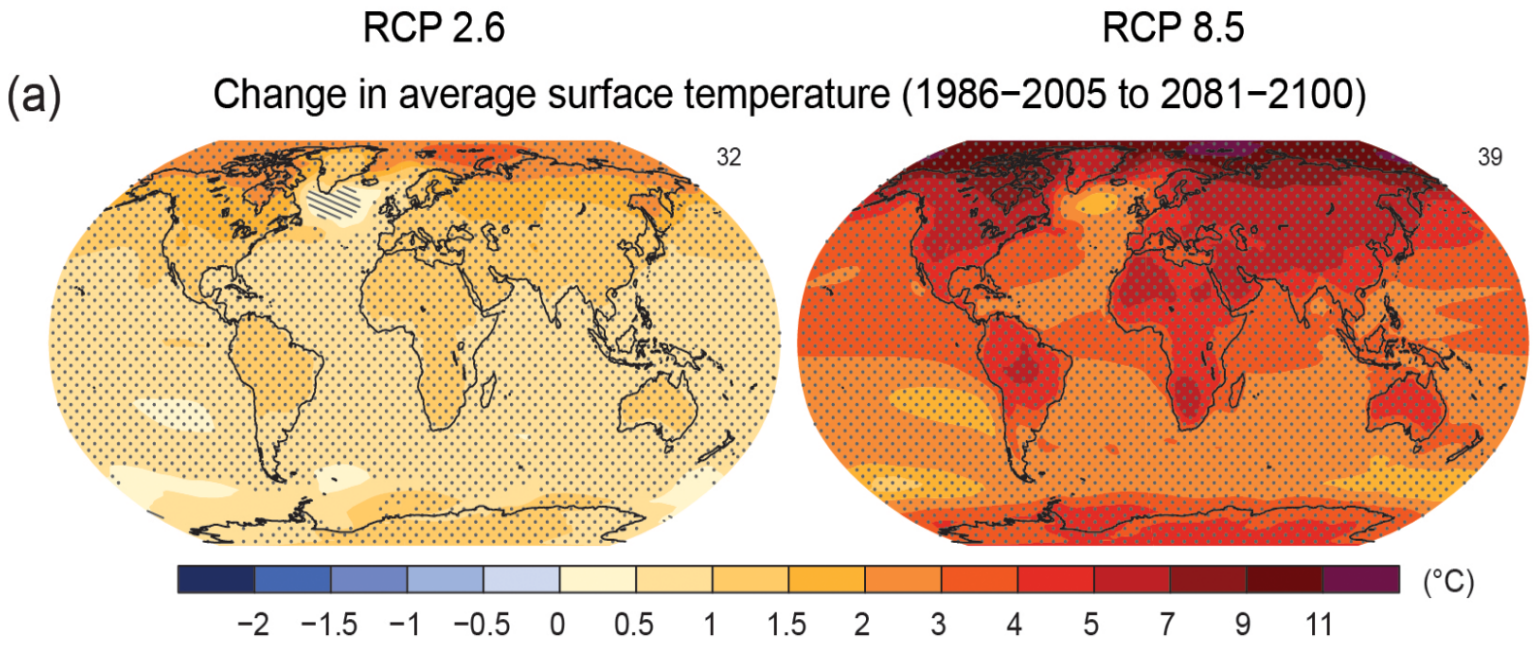


Figure SPM.8a,b
Maps of CMIP5 multi-model mean results

What is an RCP? (Representative Concentration Pathway): level of radiative forcing

Figure 7: Changes in radiative forcing relative to pre-industrial conditions. *Bold coloured lines show the four RCPs; thin lines show individual scenarios from approximately 30 candidate RCP scenarios that provide information on all key factors affecting radiative forcing… (Moss et.al., 2010)*

RCP2.6 assumes that through drastic policy intervention, greenhouse gas emissions are reduced almost immediately, leading to a slight reduction on today's levels by 2100.

RCP8.5 - assumes more or less unabated emissions.

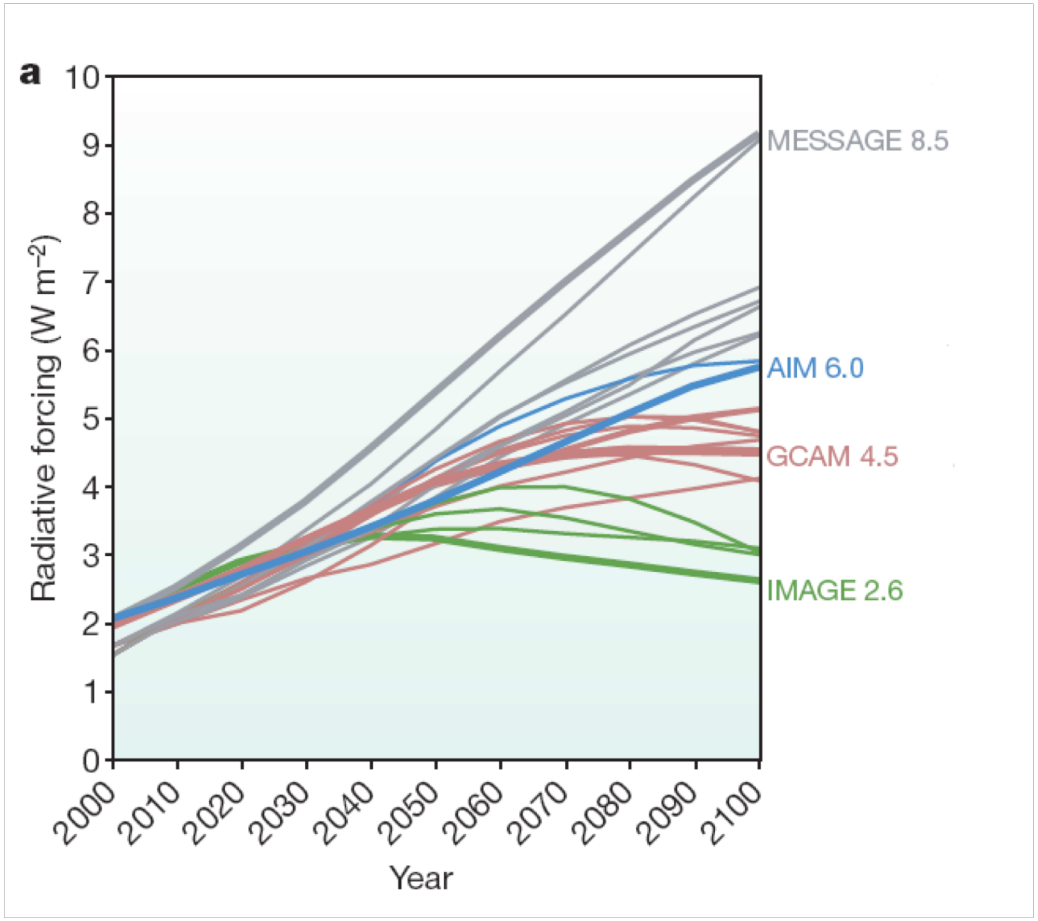


Figure SPM.7a
Global average surface temperature change

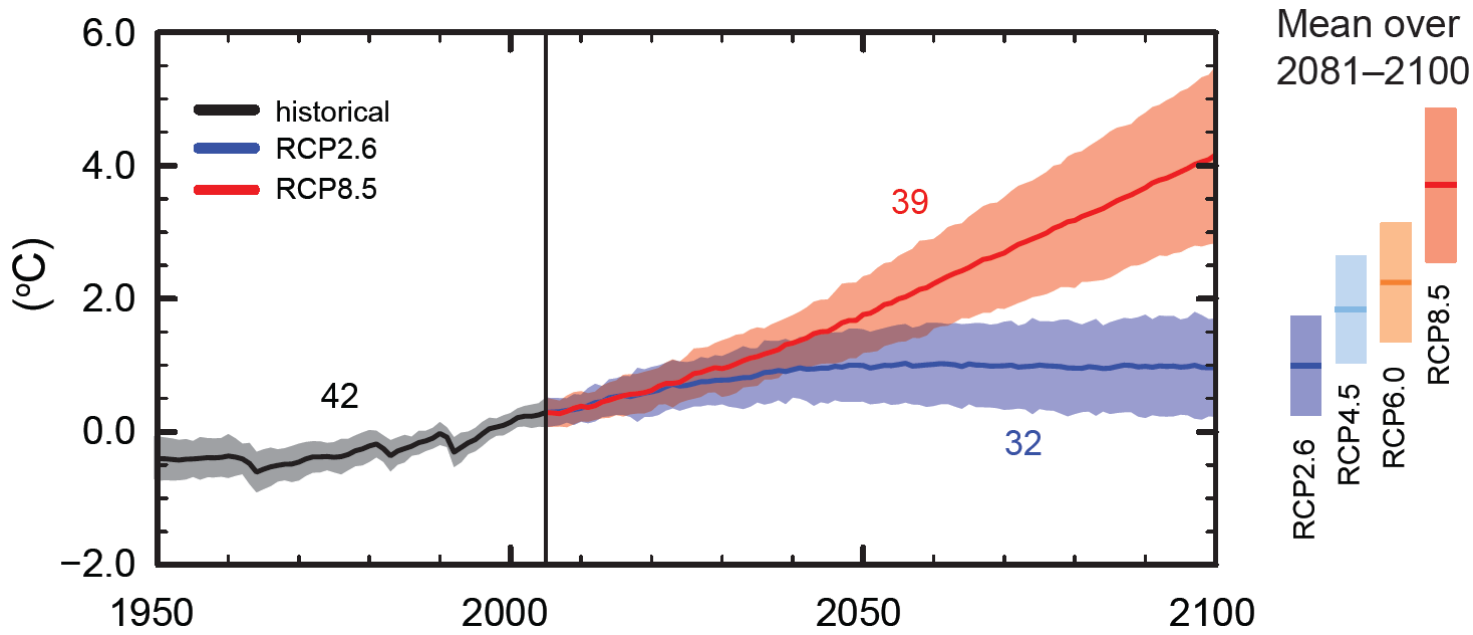
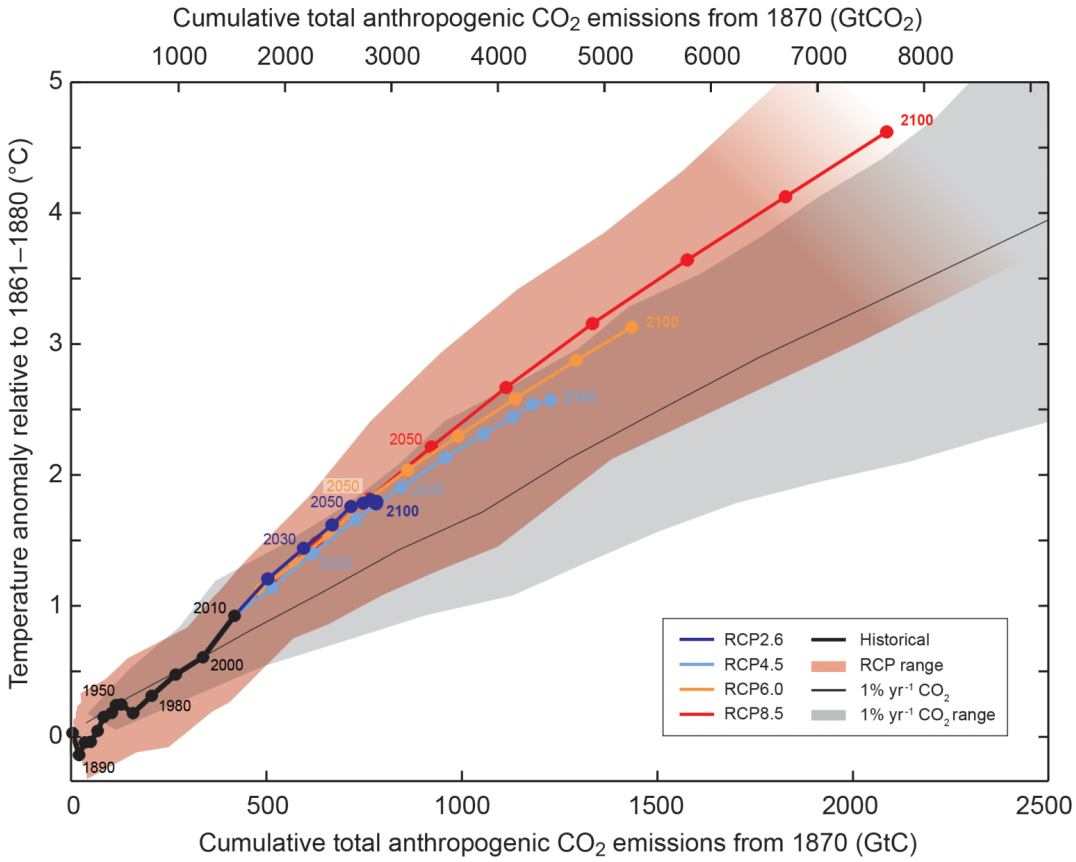


Figure SPM.10

Temperature increase and cumulative carbon emissions



IPCC AR5 WG1

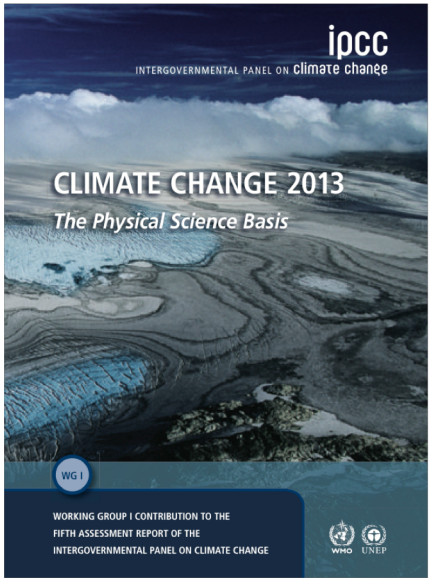
Water: rain, drought, ocean salinity ?

IPCC AR5 WGI statements:

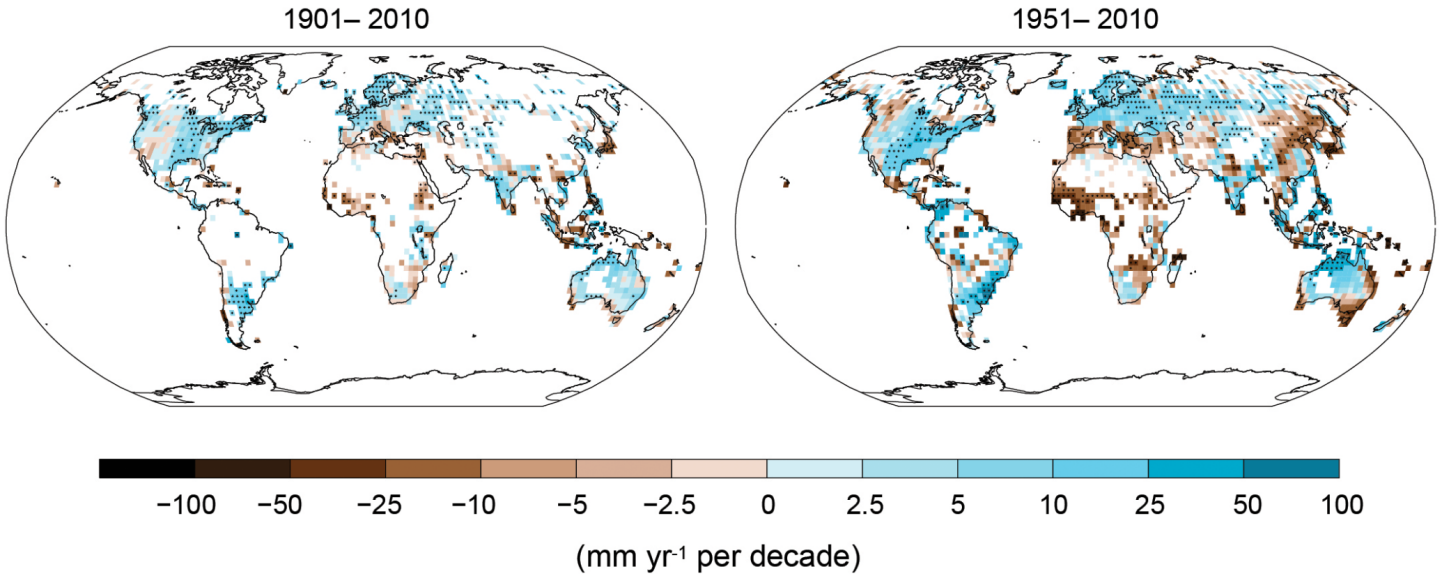
•Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

•..since the 1950s: ..saline surface waters ..have become more saline, while relatively fresh surface waters .. have become fresher

•..the pattern of evaporation minus precipitation over the oceans has been enhanced since the 1950s"



Has precipitation changed? Yes

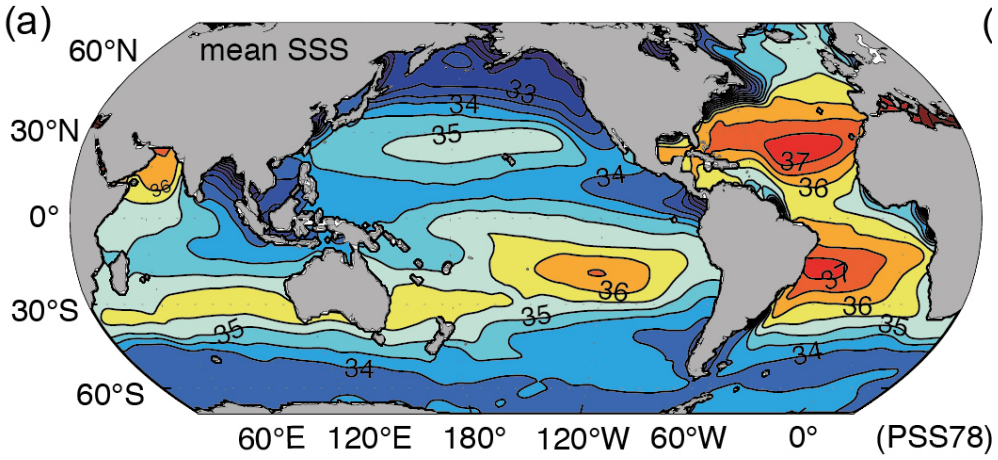


Dry areas ~ becoming drier
Wet areas ~ becoming wetter

Notice that we can only measure long-term changes OVER LAND.
Salinity is the global rain gauge.

IPCC AR5, 2013

Ocean surface salinity as rain gauge

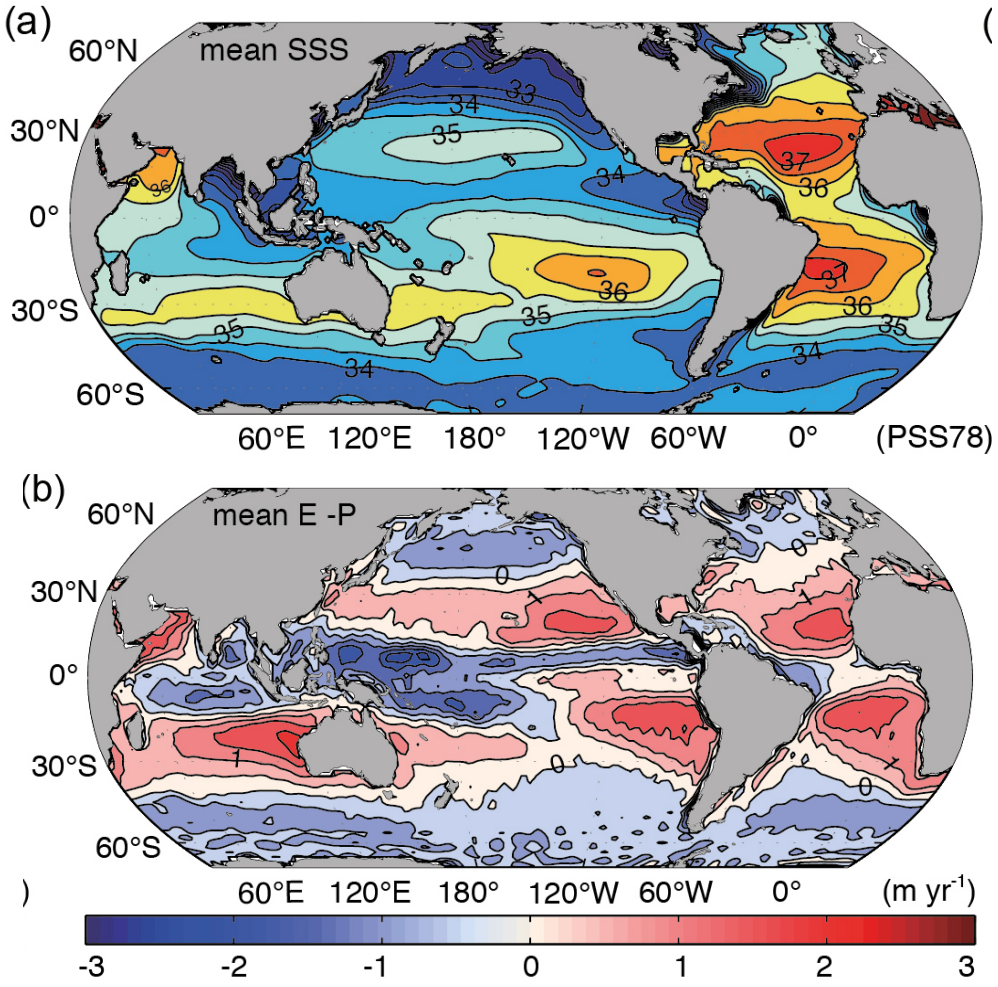


Surface salinity

Orange is salty

Blue is fresh

Ocean surface salinity as rain gauge



Surface salinity

Orange is salty

Blue is fresh

Evaporation

minus

Precipitation

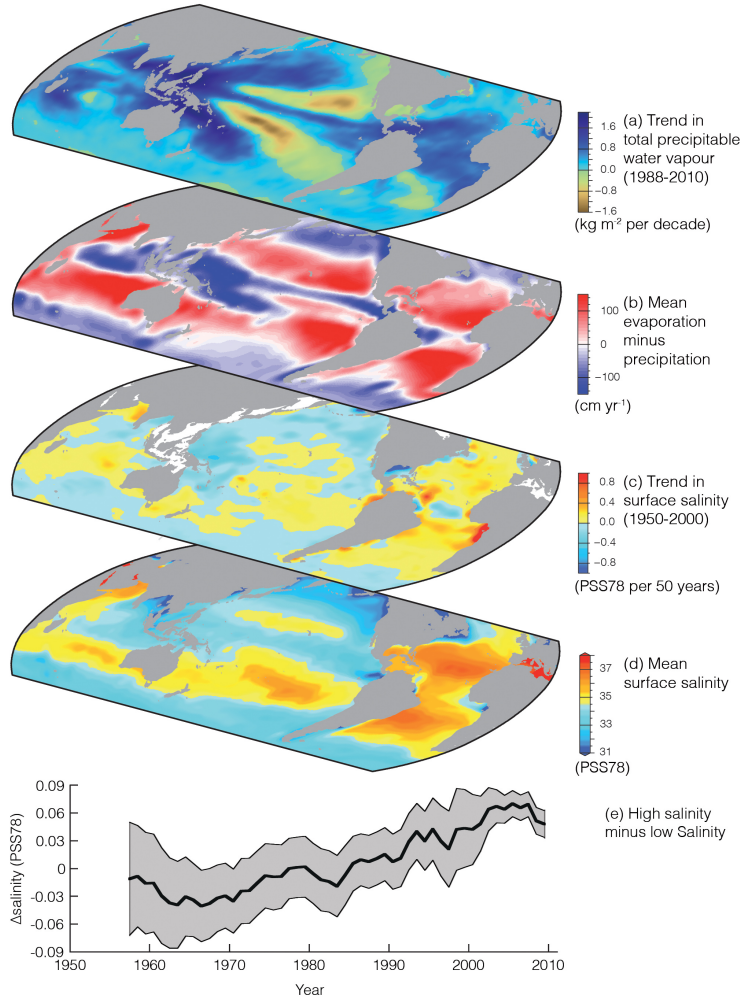
Red evaporates

Blue rains

Salty areas are getting saltier; fresh areas are getting fresher

Evaporation - precipitation

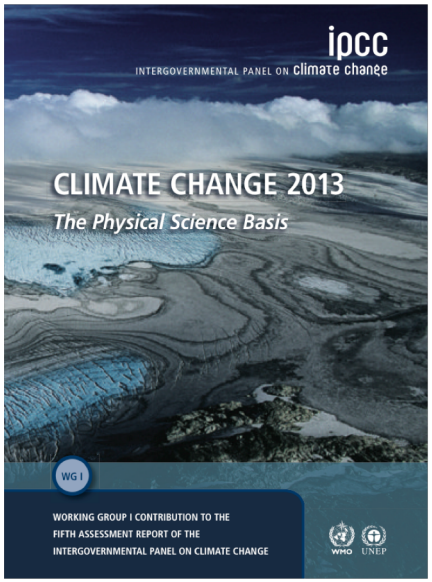
Salinity



Changes in salinity

Orange is saltier

Blue is fresher

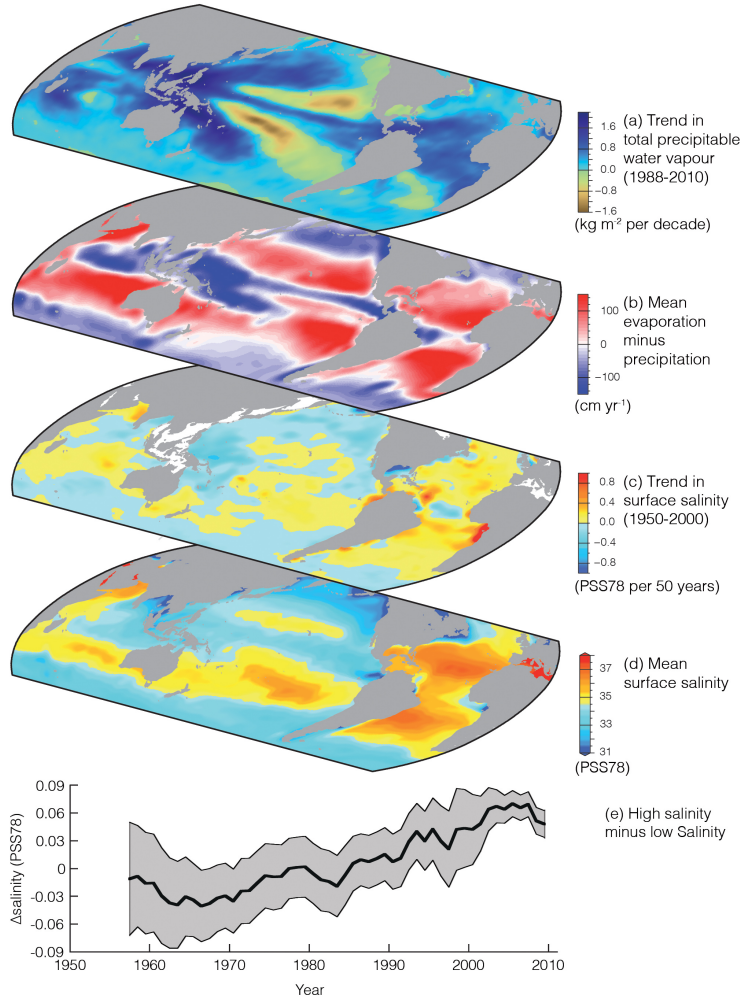


IPCC AR5 (2013)

Salty areas are getting saltier; fresh areas are getting fresher

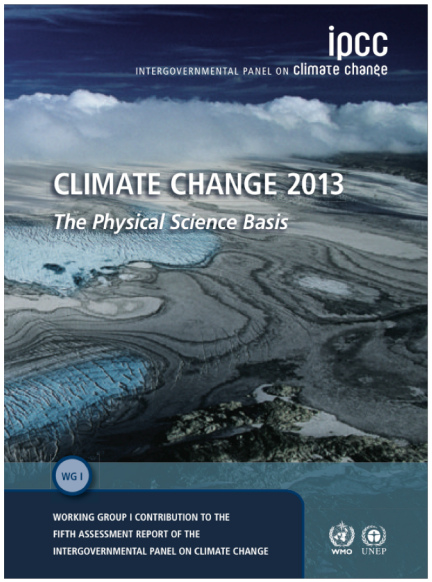
Evaporation - precipitation

Salinity



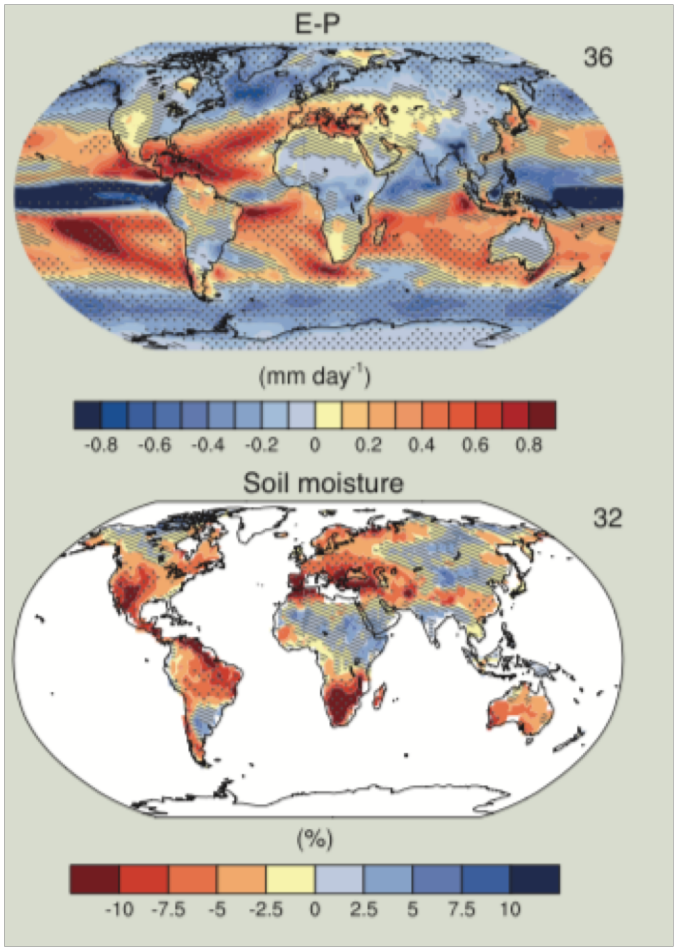
Trend in water vapor in atmosphere: mostly wetter (because air is warmer)

Changes in salinity
Orange is saltier
Blue is fresher



IPCC AR5 (2013)

Water cycle projection for 90 years from now



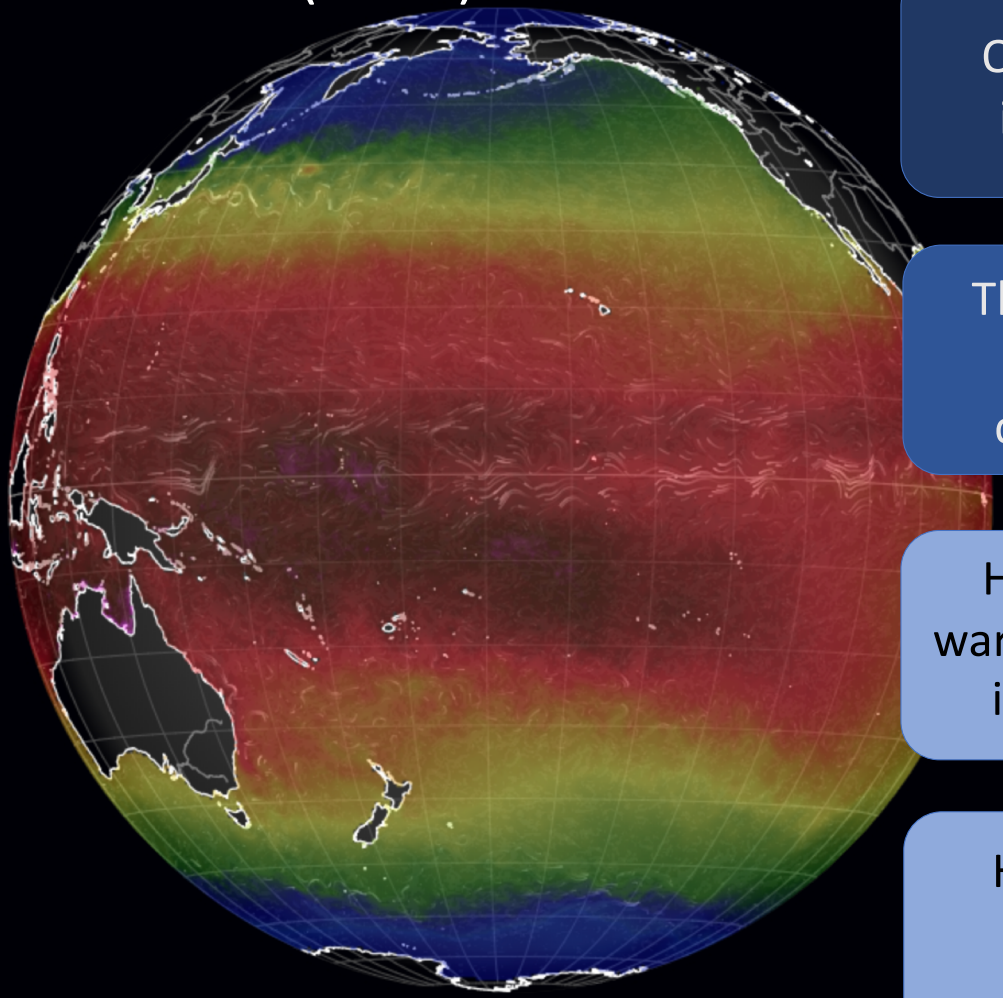
Dry areas become drier

Wet areas become wetter

Annual mean hydrological cycle change (RCP8.5: 2081-2100)

IPCC AR5, 2013

IPCC AR5 WG1 (2013) Oceans



Ocean warming dominates the increase in energy stored in the climate system

The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle,…

Heat has penetrated from the surface to the deep ocean and is affecting ocean circulation.

Visit next week to Argo float lab
argo.ucsd.edu
(measuring temperature and salinity over the global ocean: 4000 floats now and celebration of 2,000,000 profiles)