# Climate in the Future
# AOSC 200

## Tim Canty

**Class Web Site: http://www.atmos.umd.edu/~tcanty/aosc200**

**Topics for today:**

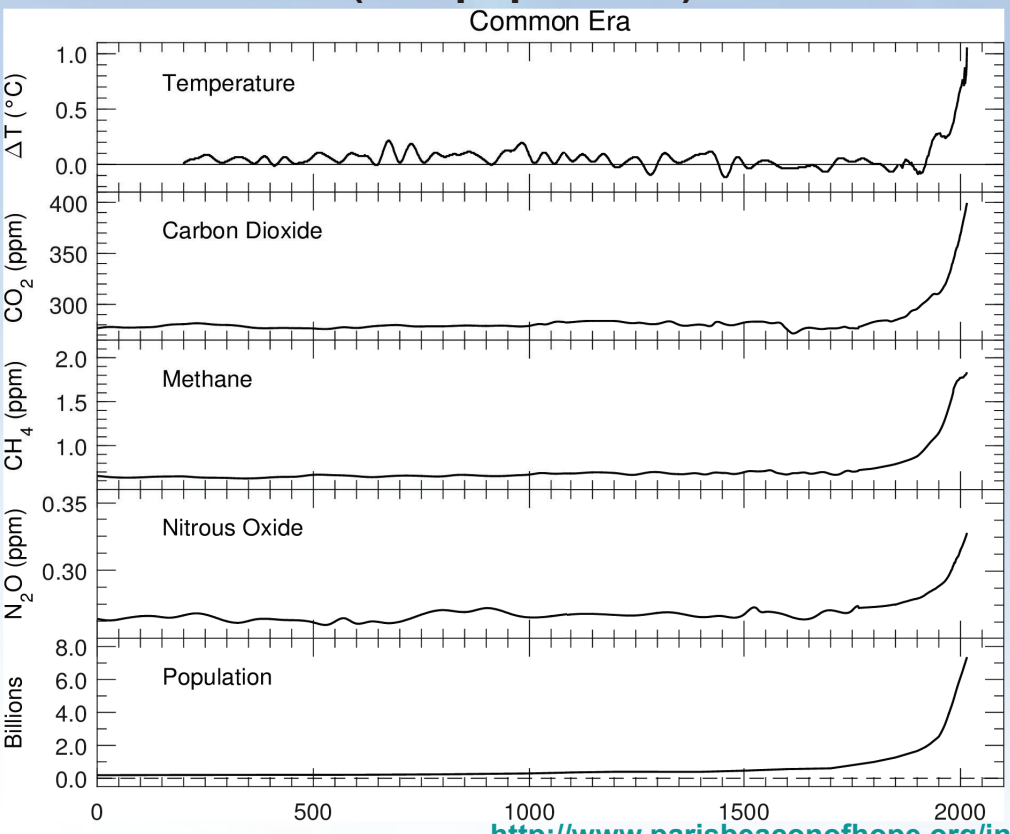
**Evidence of a changing climate**
**Possible issues associated with a changing climate**

**Lecture 28**
**Dec 5 2019**





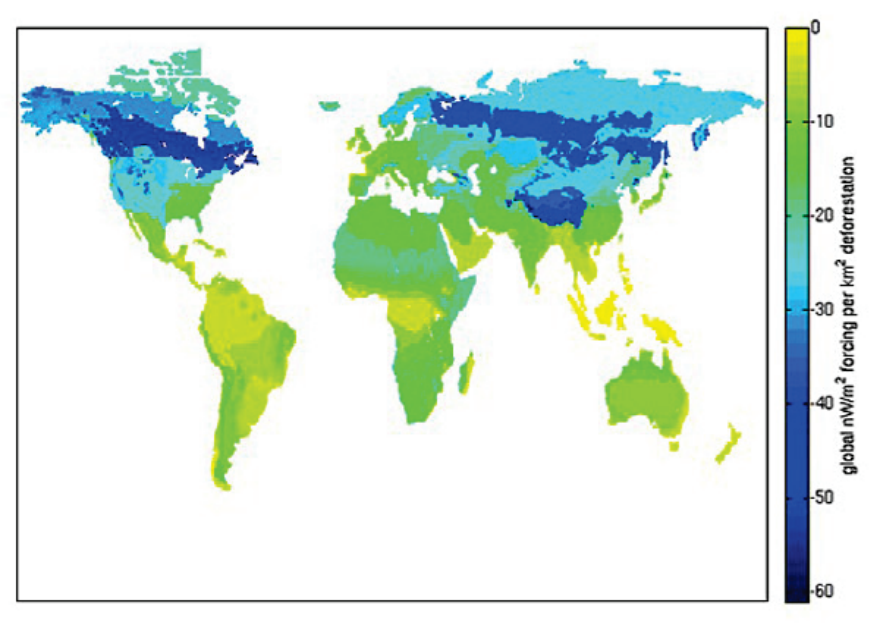
# Increase in temperature is correlated with increase in GHGs (and population)




http://www.parisbeaconofhope.org/index.htm

# Land use change

**Converting forests to land for agriculture may decrease radiative forcing (cooling). Albedo increases as snow on the ground is more reflective than snow on trees.**




http://esd.lbl.gov/radiative-forcing-albedo-in-land-use-scenarios/





# Aerosol: Direct Climate Effect

**Aerosols are often brighter than the surface and reflect incoming solar radiation. This leads to cooling.**

# Aerosol: Direct Climate Effect

**Some aerosols are darker and lead to regional warming. May explain retreat of Himalayan glaciers.**

http://www.nature.com/climate/2007/0709/full/climate.2007.41.html





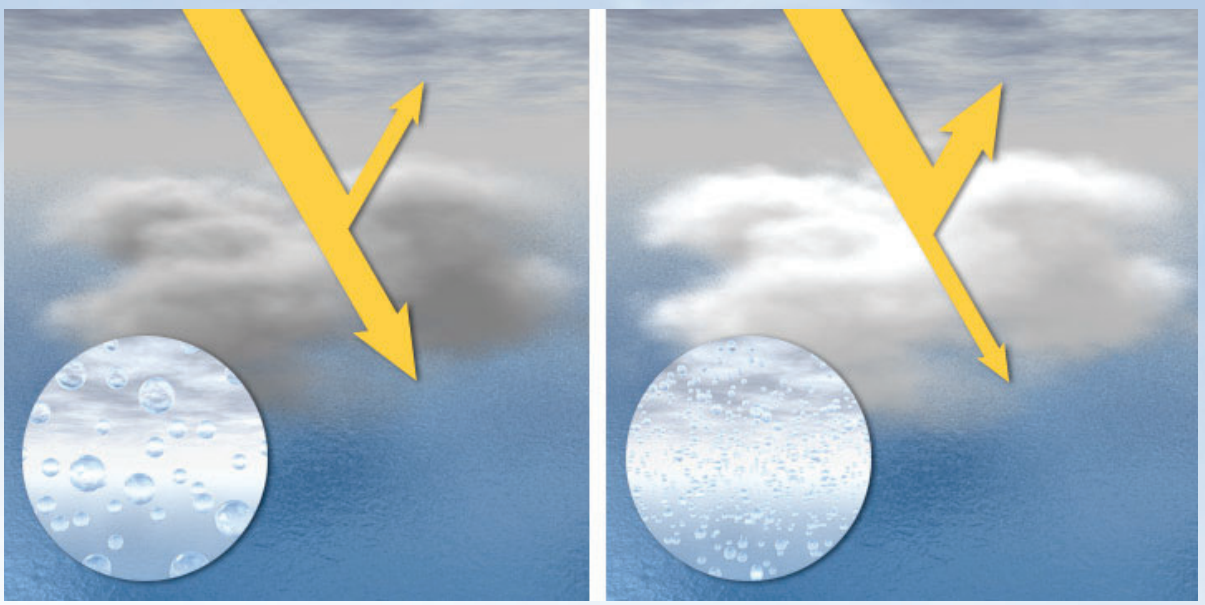
# Aerosol: Direct Climate Effect

**Dark aerosols on snow will decrease albedo and lead to increased absorption of solar energy and snow melt.**

http://earthobservatory.nasa.gov/Features/Aerosols/page3.php

# Aerosol: Indirect Climate Effect

**Aerosols = cloud condensation nuclei**



**Clean air: clouds made of fewer, larger drops. Cloud is darker**

**Dirty air: clouds made of many smaller drops. Cloud is brighter**





# Influences on Climate

**To try and predict future climate, we need to understand past climate**

**Understanding past climate allows us to separate natural changes in climate from human-made (anthropogenic)**

**Need to understand how changing climate can lead to further changes (feedback mechanisms)**

# Climate Feedback

**A climate feedback mechanism is a climate response to an initial change**

***Positive Feedback*: amplifies the initial change**

***Negative Feedback*: diminishes the initial change**

**Feedback mechanisms are one of the big "unknowns" in climate research**

**Understanding climate feedbacks vital to predicting climate trends.**




# Ice-Albedo Feedback

**A rise in temperature, caused by increasing greenhouse gases like $CO_2$, will cause a further increase in temperature**

**How will this affect ice?**

# Ice-Albedo Feedback

**Initial Action:**
**Humans Release $CO_2$**

→

**Initial Response:**
**$T_{SURFACE}$ and $T_{OCEAN}$ Rise**

↓

**Secondary Response:**
**Ice Melts**

↓

**Consequence:**
**Albedo Falls**

↓

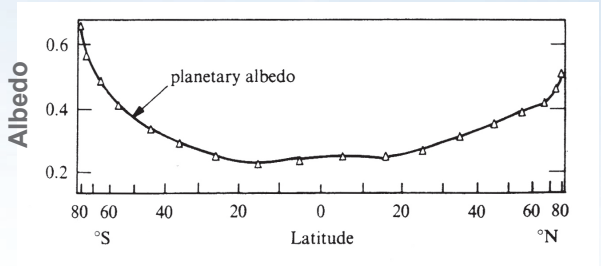
**Response to Consequence:**
**⇨ $T_{SURFACE}$ Increases**

↺

**2. Albedos of selected surfaces on Earth**

| surface | albedo |
|---|---|
| snow | 0.7 ± 0.2 |
| sand | 0.25 ± 0.05 |
| grasslands | 0.23 ± 0.03 |
| bare soil | 0.2 ± 0.05 |
| forest | 0.15 ± 0.1 |
| water (highly dependent on surface roughness and incident angle of sunlight) | 0.2 + 0.6 − 0.2 |

Harte, *Consider a Spherical Cow: A Course in Environmental Problem Solving*, 1988.




Houghton, *The Physics of Atmospheres*, 1991.

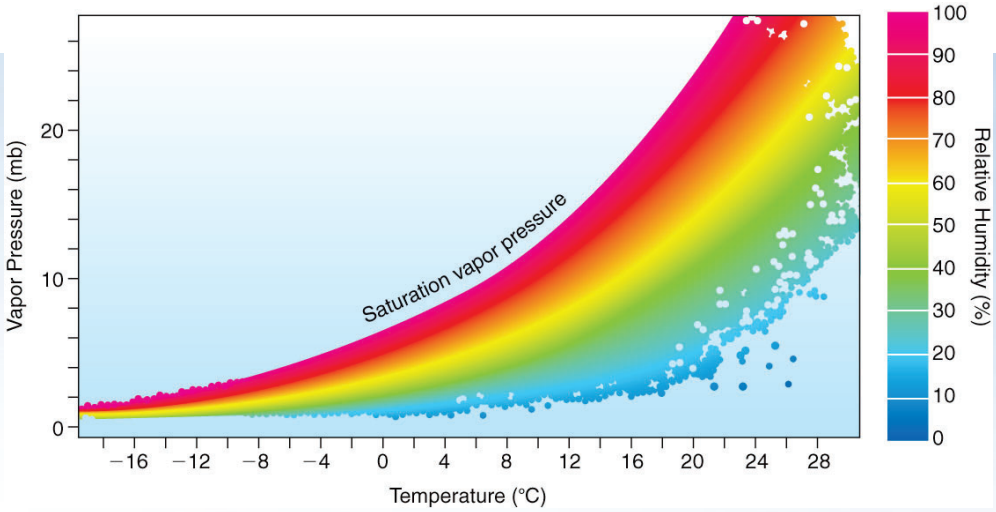




# Water Vapor Feedback

**A rise in temperature caused by increasing greenhouse gases, like $CO_2$, will cause an increase in temperature**

**How will this affect $H_2O$ vapor?**



# Water Vapor Feedback

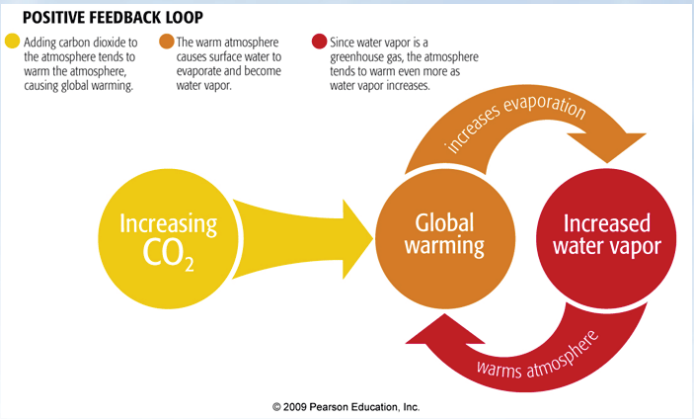
**Initial Action:**
**Humans Release $CO_2$**

→ **Initial Response:**
**$T_{SURFACE}$ rises**

↓ **Secondary Response:**
**Surface water evaporates**

↓ **Consequence:**
**Increased water vapor**

↓ **Response to Consequence:**
**⇨ $T_{SURFACE}$ Increases**








# $CO_2$ Feedback: Plants

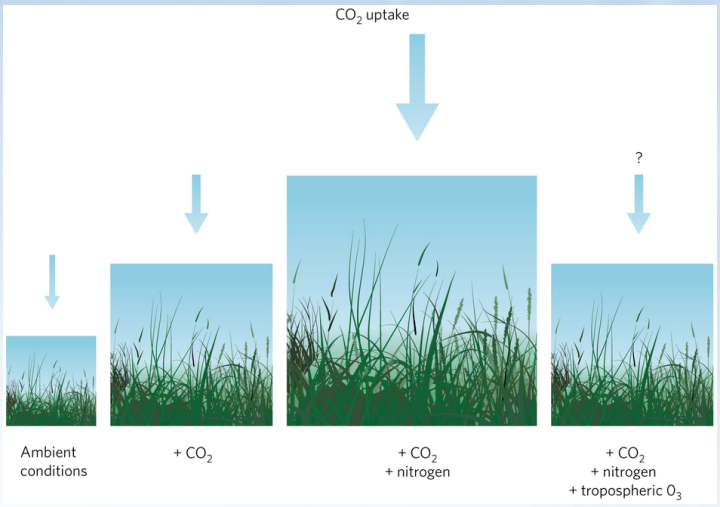
**Initial Action:**
**Humans Release $CO_2$**

→ **Initial Response:**
**$T_{SURFACE}$ rises**

↓ **Secondary Response:**
**Increased plant growth due to more $CO_2$**

↓ **Consequence:**
**$CO_2$ decreases**

↓ **Response to Consequence:**
**⇨ $T_{SURFACE}$ decreases**




**This is a negative feedback**

http://www.nature.com/nclimate/journal/v3/n3/full/nclimate1841.html

# Cloud Feedback

**Increased temperatures can increase the amount of water vapor which, in turn, can lead to an increase in clouds**

**How will clouds affect temperatures?**





# Cloud Feedback

**Increased temperatures can increase the amount of water vapor which, in turn, can lead to an increase in clouds**

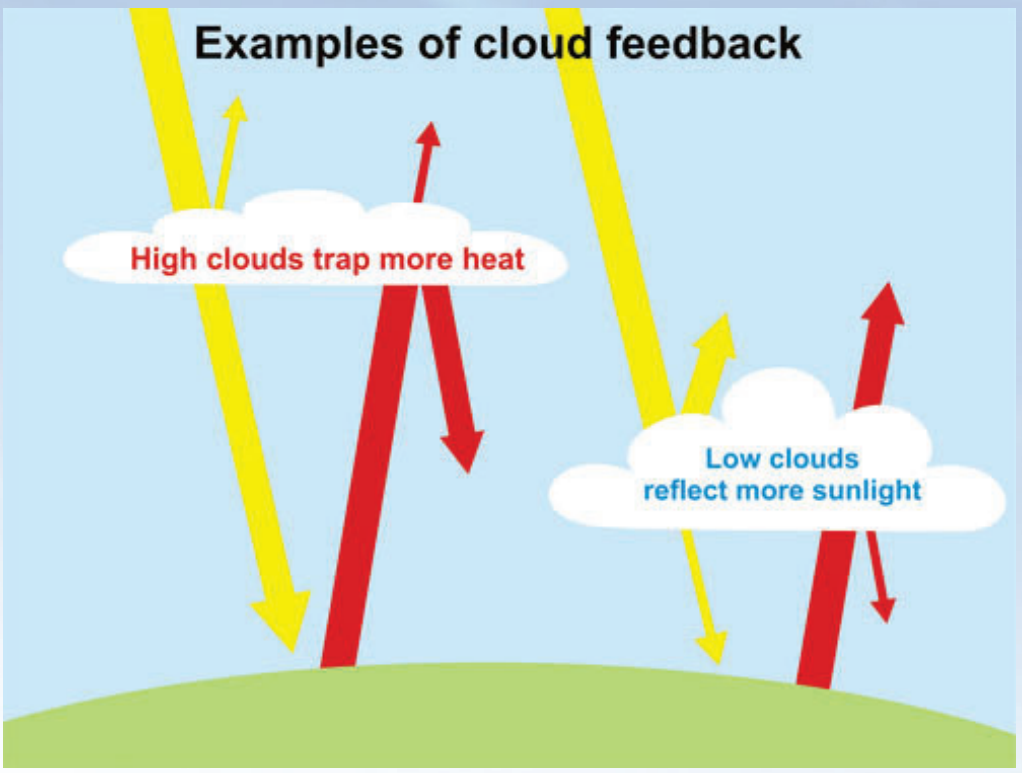
**How will clouds affect temperatures?**

**This one's tricky?**

**Clouds can either lead to more warming or more cooling**

**Cloud feedback is one of the largest uncertainties in climate science**

# Cloud Feedback








# Climate Change

## What is Climate Change?

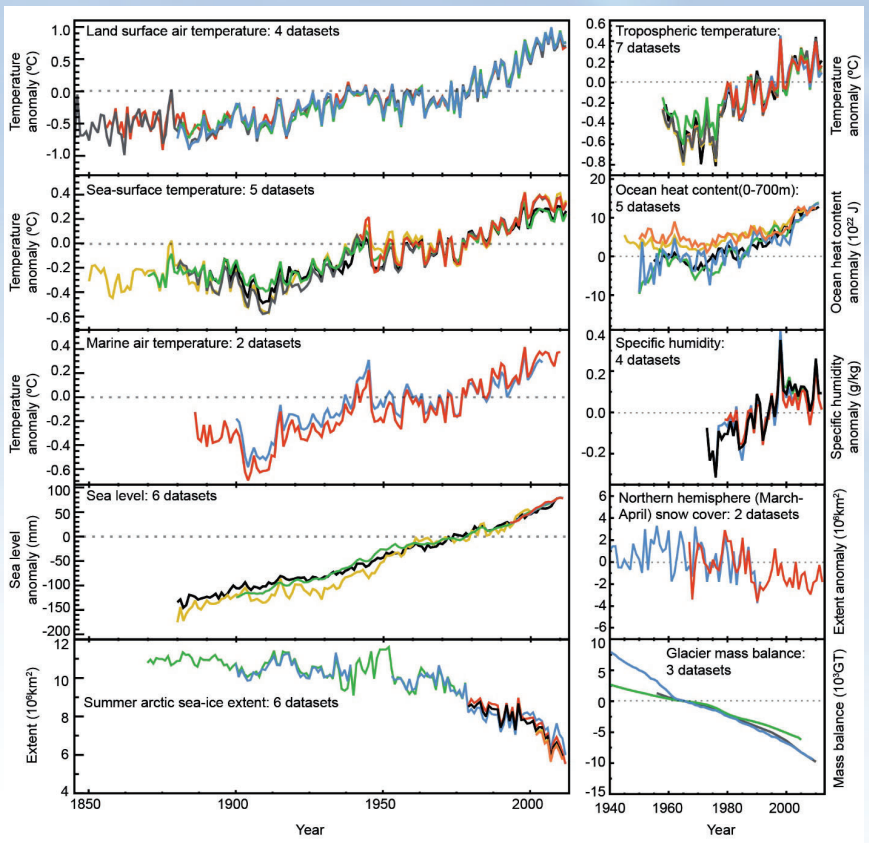
**"Any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer."**

http://glossary.ametsoc.org/wiki/Climate_change

**We've focused on temperature.**

**Are there other indications of a changing climate?**

# Evidence that climate is changing?



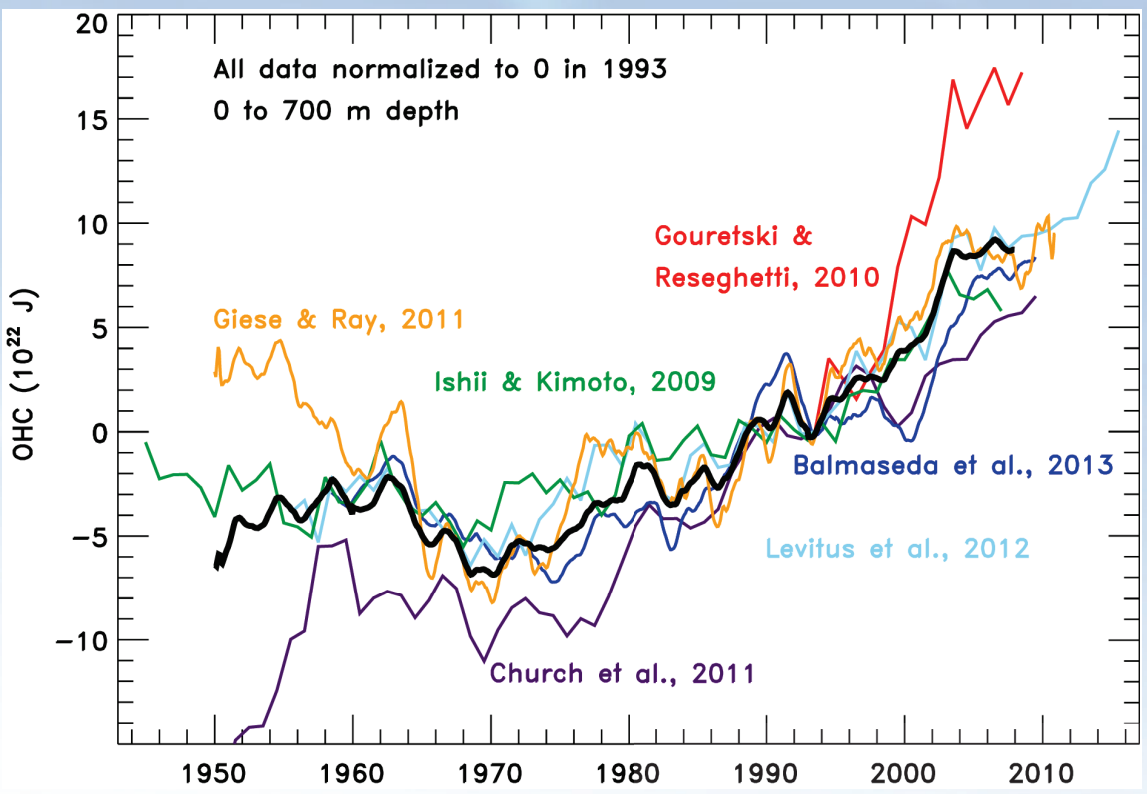

**Numerous data sets indicate long term changes in the Earth system.**

http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf



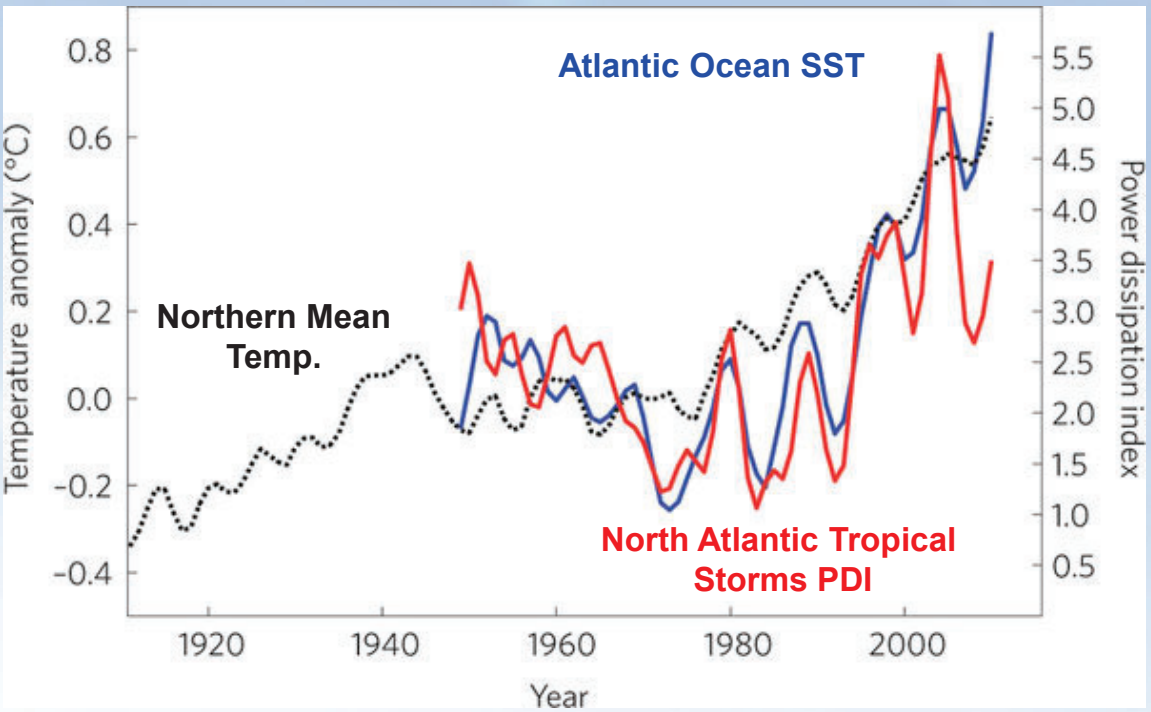


# Increase in Energy in Oceans since 1970




http://www.parisbeaconofhope.org/index.htm

# Atlantic Tropical Storms

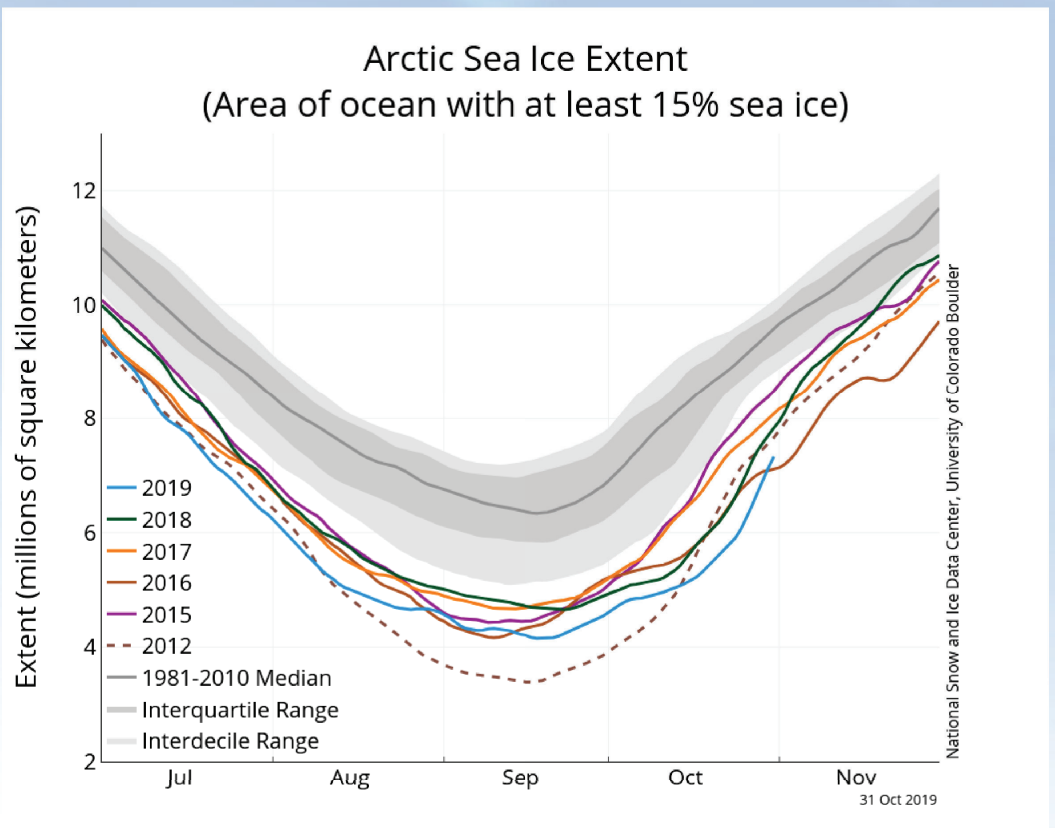



**Since the 1950's, the amount of energy (power dissipation) in tropical storms has been closely correlated with Atlantic Ocean temperature**

http://www.nature.com/nclimate/journal/v2/n7/full/nclimate1452.html?WT.ec_id=NCLIMATE-201207

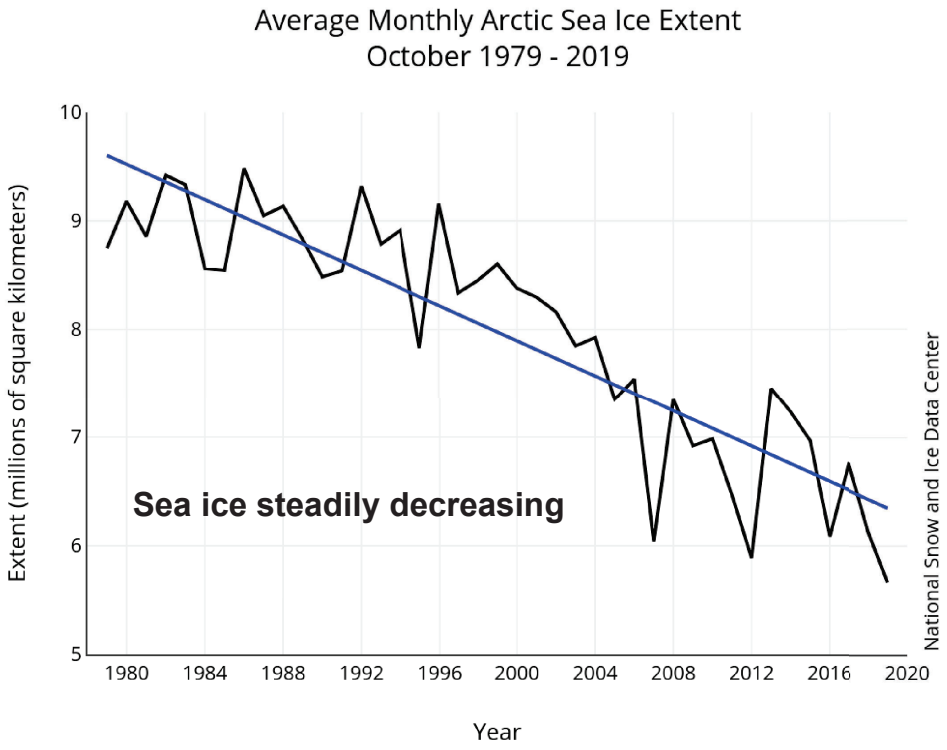


# Arctic Sea Ice Loss




https://nsidc.org/arcticseaicenews/

# Arctic Sea Ice Loss

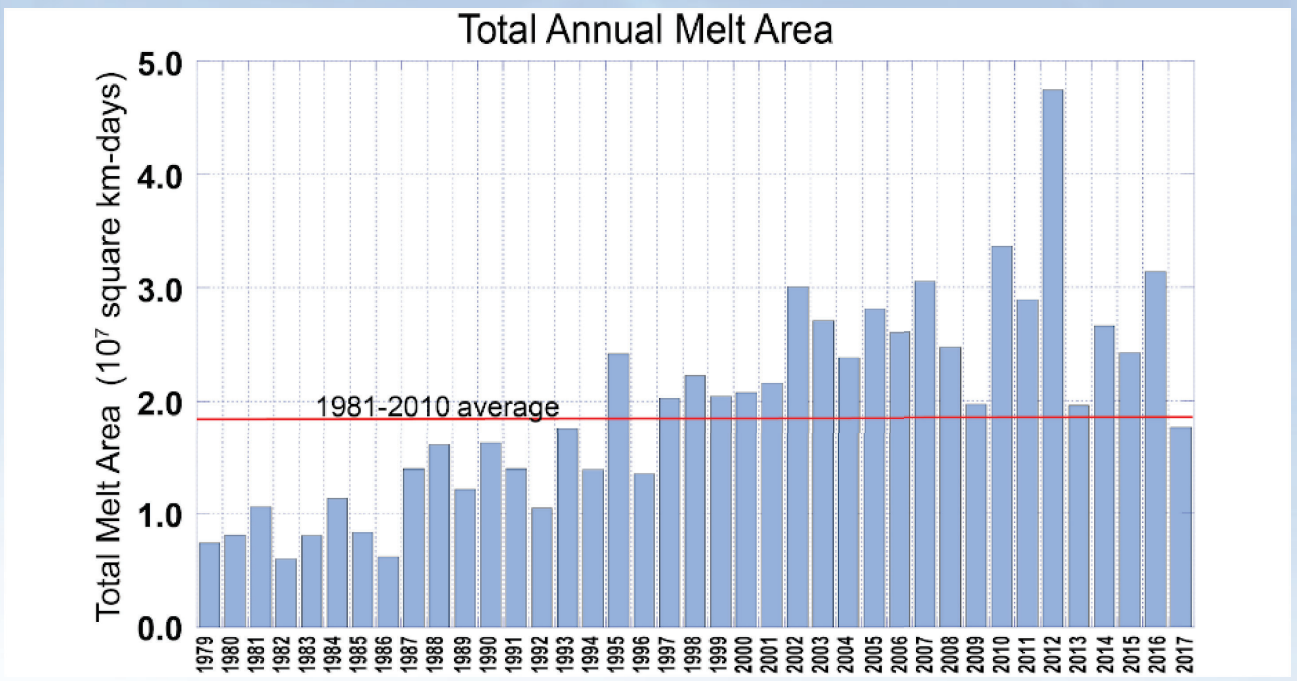



https://nsidc.org/arcticseaicenews/





# Greenland is melting…




https://nsidc.org/greenland-today/

# Greenland is melting…faster

www.sciencemag.org/news/2017/02/great-greenland-meltdown

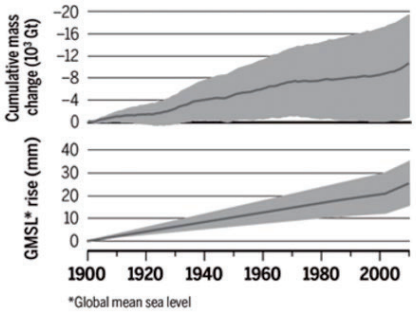
og in chicago | Emissions Inventory | Extreme Weather | Na | National WeatherAssn

## The great Greenland meltdown

By **Eli Kintisch** | Feb. 23, 2017 , 8:00 AM

From a helicopter clattering over Greenland's interior on a bright July day, the ice sheet below tells a tale of disintegration. Long, roughly parallel cracks score the surface, formed by water and pressure; impossibly blue lakes of meltwater fill depressions; and veiny networks of azure streams meander west, flowing to the edge of the ice sheet and eventually out to sea.

Cumulative mass loss has risen in recent years, along with Greenland's contribution to sea level rise.



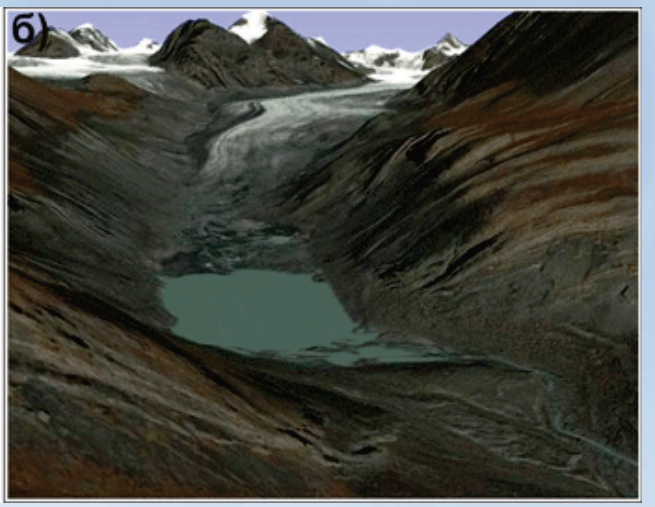

(Graphic) G. Grullón/*Science*; (Data) Kjeldsen et al., *Nature* (17 December 2015)

http://www.sciencemag.org/news/2017/02/great-greenland-meltdown

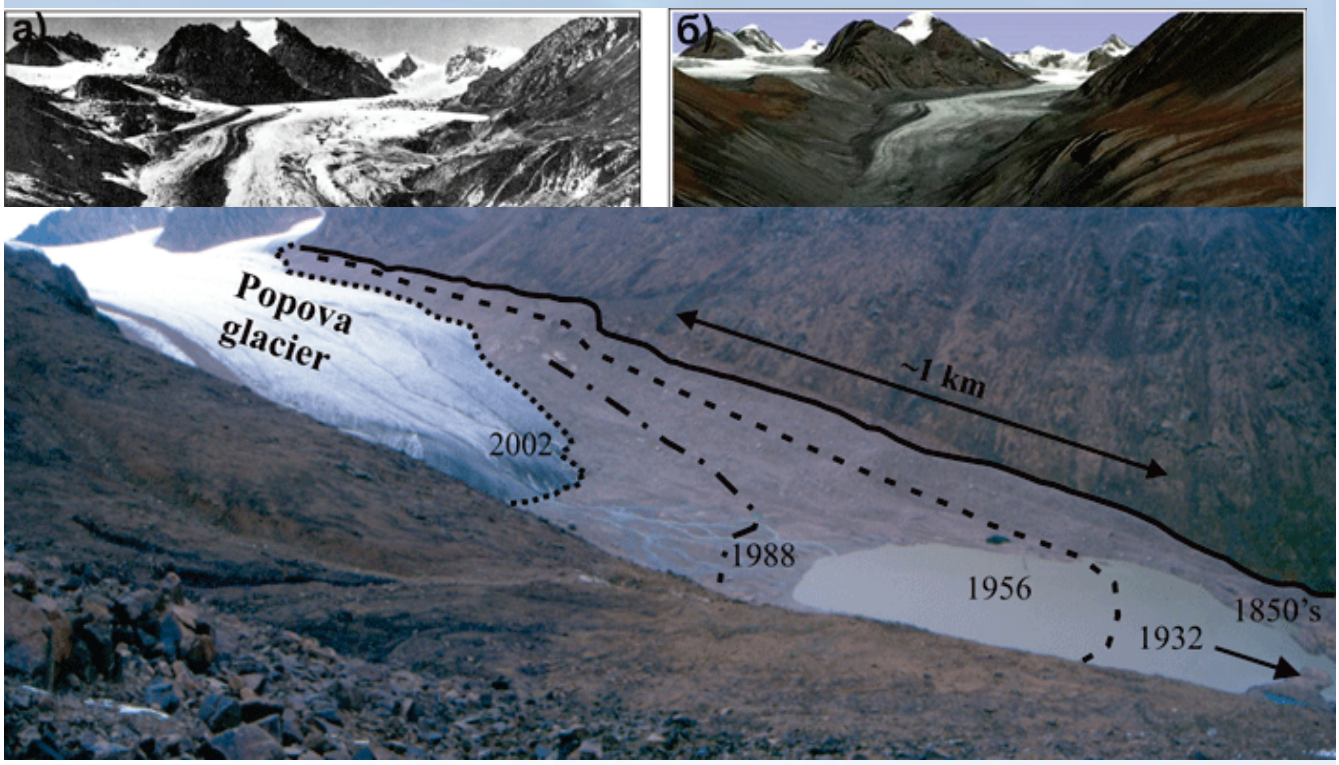




# Glacial Retreat

# Glacial Retreat





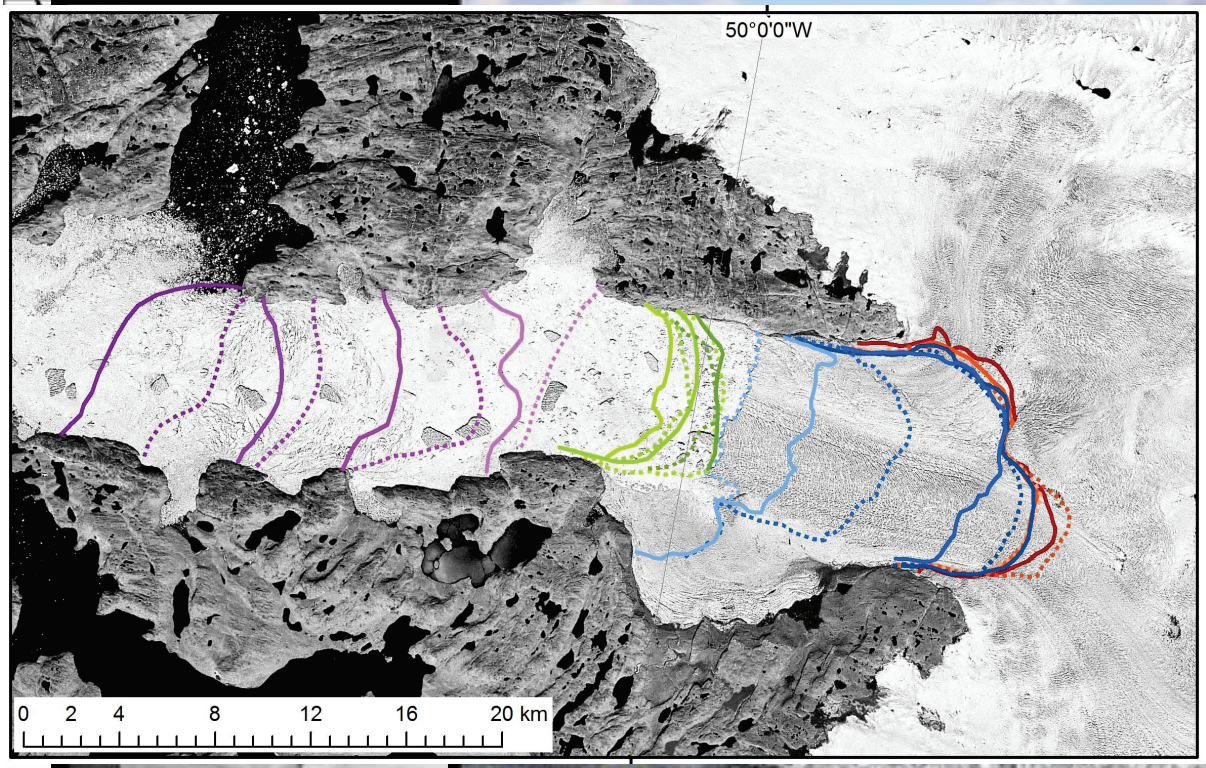



# Muir and Riggs Glaciers






# Muir and Riggs Glaciers



# Glacial Retreat (?)






# Shrinking glaciers are indicated in red
# Blue represents the glaciers that are increasing

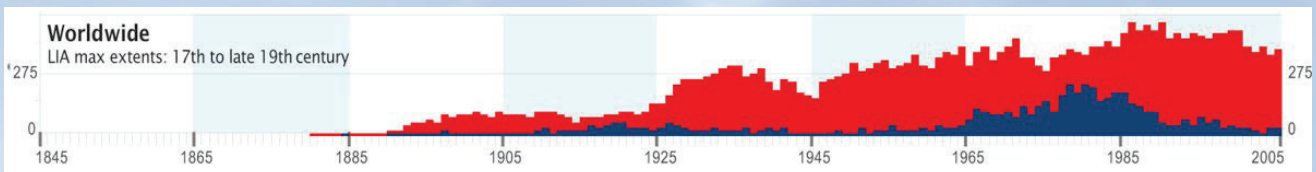


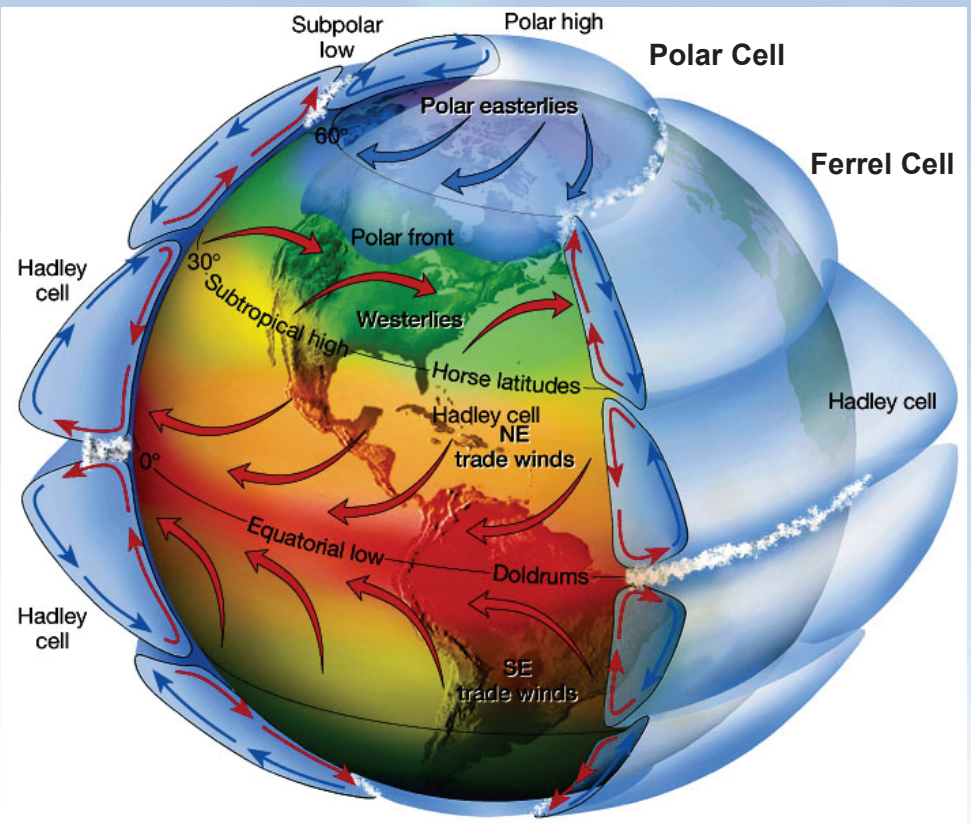

**Fig. 5.1 Glacier length changes** - Temporal overview on short-term glacier length changes. The number of advancing (blue) and retreating (red) glaciers are plotted as stacked columns in the corresponding survey year. This figure shows 30 420 length change observations with a time range of less than 4 years (between survey and reference year). This corresponds to almost 85 per cent of the reported data which in addition include observations covering a longer time scale and/or stationary conditions. The time period of glacier LIA maximum extents is given according to the regional information in Chapter 6. Note that the scaling of the number of glaciers on the y-axis changes between the regions. Source: figure based on data analysis by R. Prinz, University of Innsbruck, Austria; data from WGMS..

**This figure shows the number of glaciers that are growing in blue and the number of glaciers that are shrinking in red.**

**If temperatures are warming, how can some glaciers be growing? Warmer air carries more moisture. As long as temperatures are cold enough, this can fall as snow and cause some glaciers to grow.**

**http://www.livescience.com/48256-asia-karakoram-glaciers-stability.html**

# Conceptual Model




http://www.ux1.eiu.edu/~cfjps/1400/circulation.html





# Movement of the Sub-tropical Jet

**From 1979– 2010, the subtropical jet moved poleward by:**

**3.7° in the Northern Hemisphere**
**6.5° in the Southern Hemisphere**

## The tropics are expanding.

**Storms that follow the path of the jet stream will move poleward as well.**

**Hudson, *ACP*, 2012**

# Climate Change and Health

**Warmer temperatures promote the spread of warm climate diseases.**

**- Dengue Fever (Maurens and Fauci, JAMA, 2008)**

- **fever, severe muscle and joint pain, may last week or more**
- **Affect millions each year**
- **Carried by mosquito, currently at Texas/Mexico border**

**- Chikungunya Fever**

- **Symptoms similar to dengue fever, pain persists for weeks-months**
- **Higher rates of death than dengue fever**
- **Carried by mosquito, first cases in Italy, 2007 came from Africa**

**- Zika Virus**

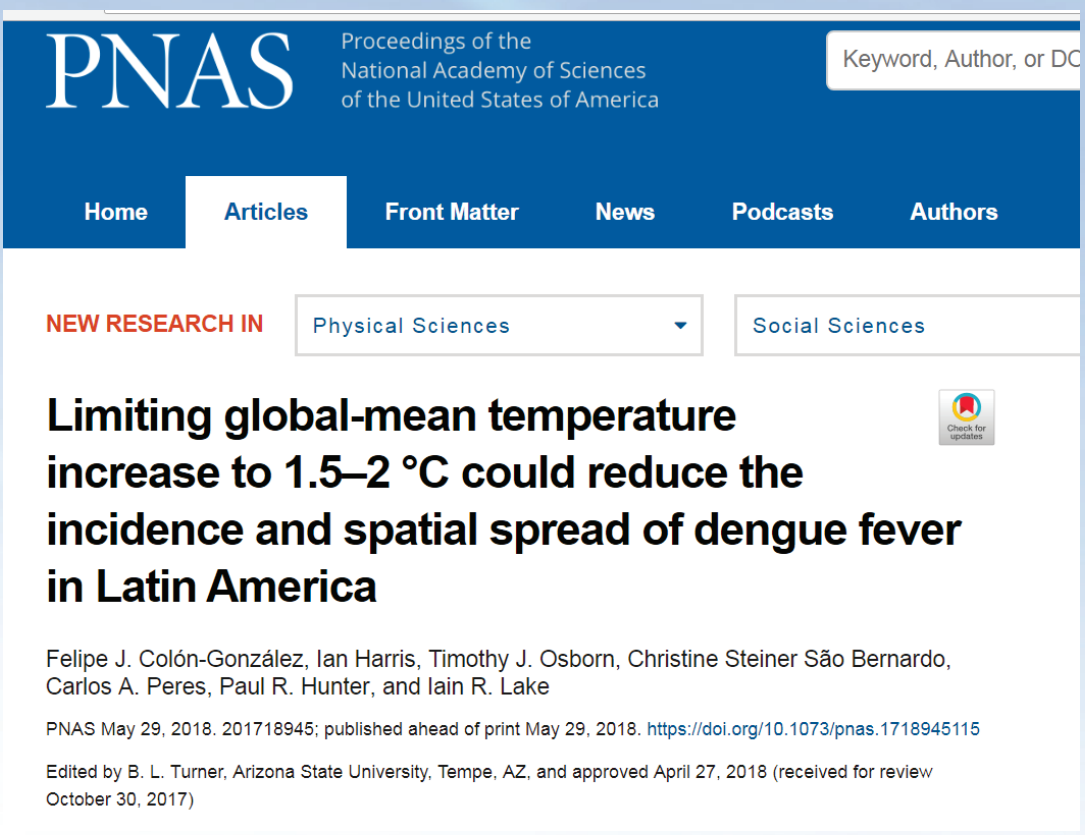
- **fever, rash, joint pain, or conjunctivitis (red eyes)**
- **Usually mild with symptoms lasting for several days to a week**
- **Remains in the blood of an infected person for about a week**
- **Infection during pregnancy can cause microcephaly and other severe brain defects**

**Cold temperatures kill off the mosquito species that carry these diseases**

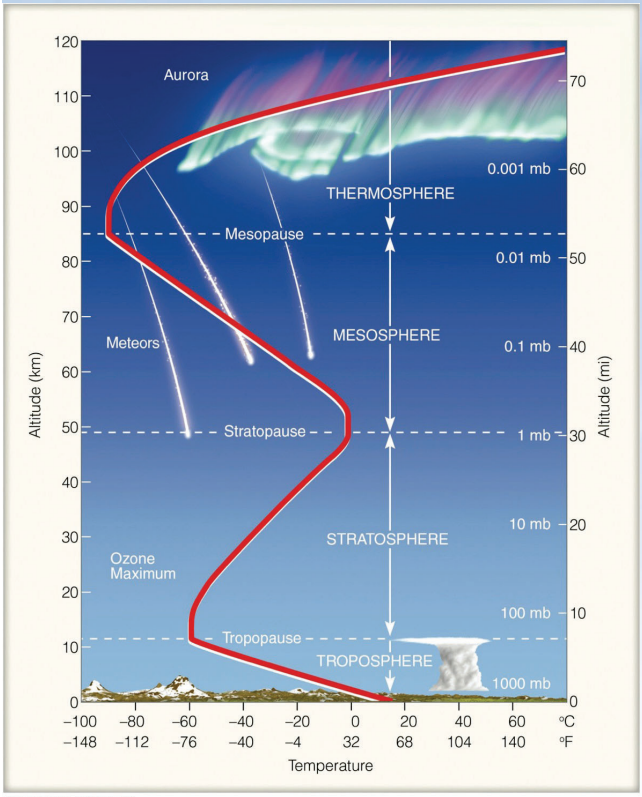




# Poleward shift in the Tropics can impact human health



# Have temperatures in other parts of the atmosphere exhibited changes?






**The Sun provides the energy that warms the planet.**

**The rise in surface temperature must be caused by more heat at the surface**

**Some people say that increasing solar output is causing the rise in surface temperature**

**If this is the case then the entire atmosphere should be warming**

**Is this the case?**





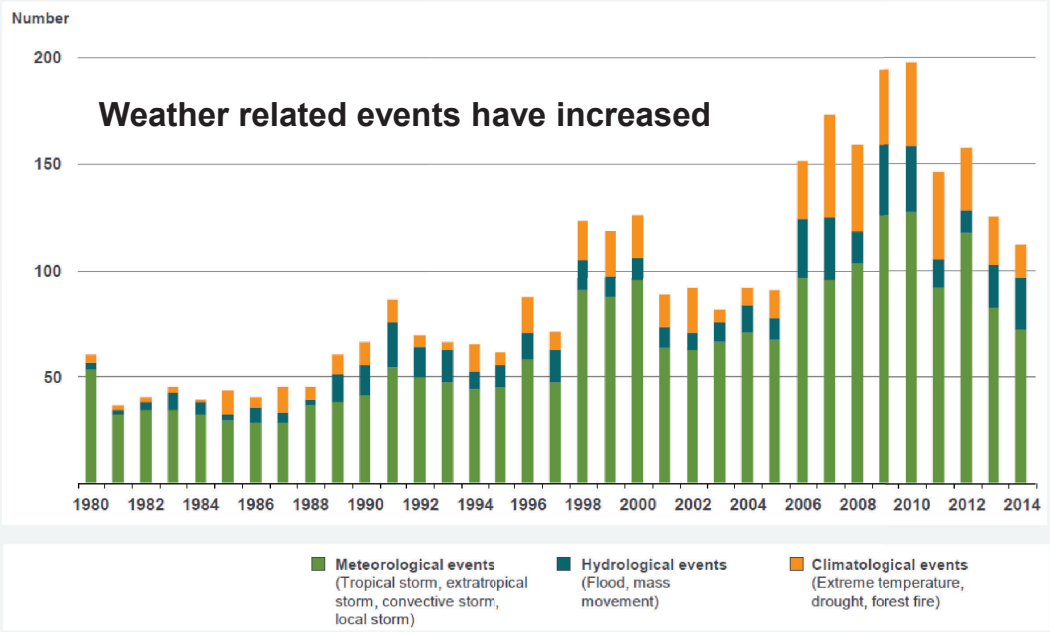
# Are extreme weather events getting more frequent?

NatCatSERVICE

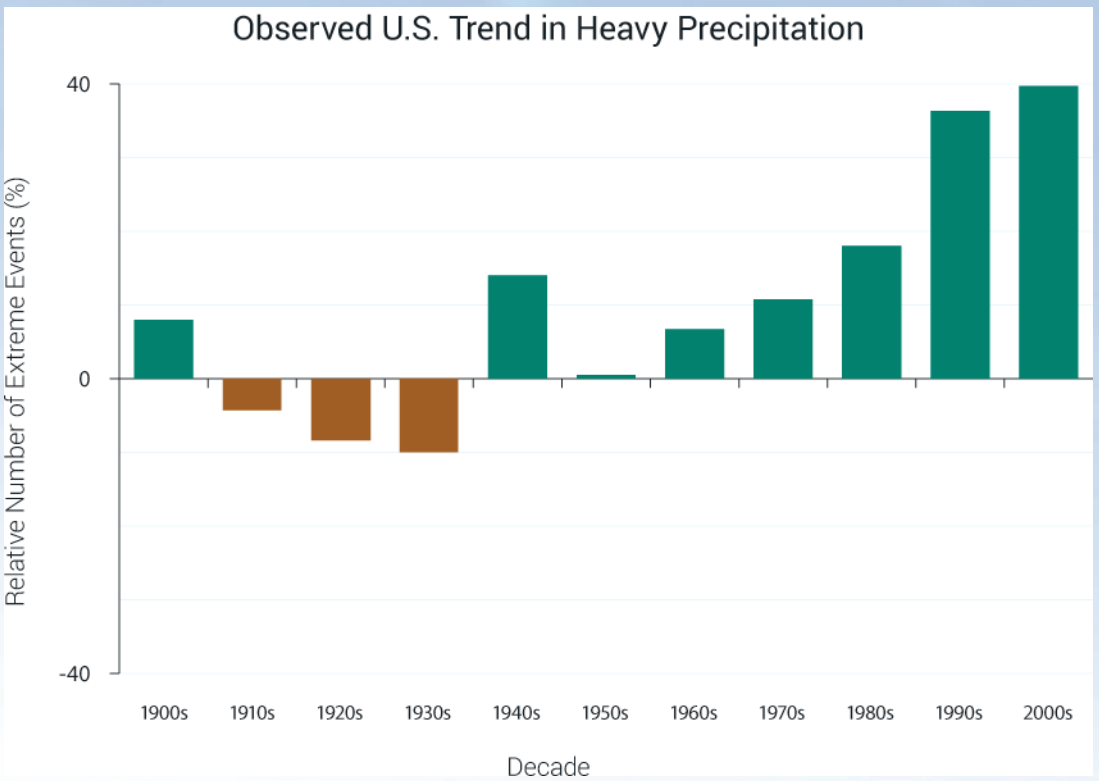
Weather-related loss events in the U.S. 1980 – 2014

Number of events

Munich RE



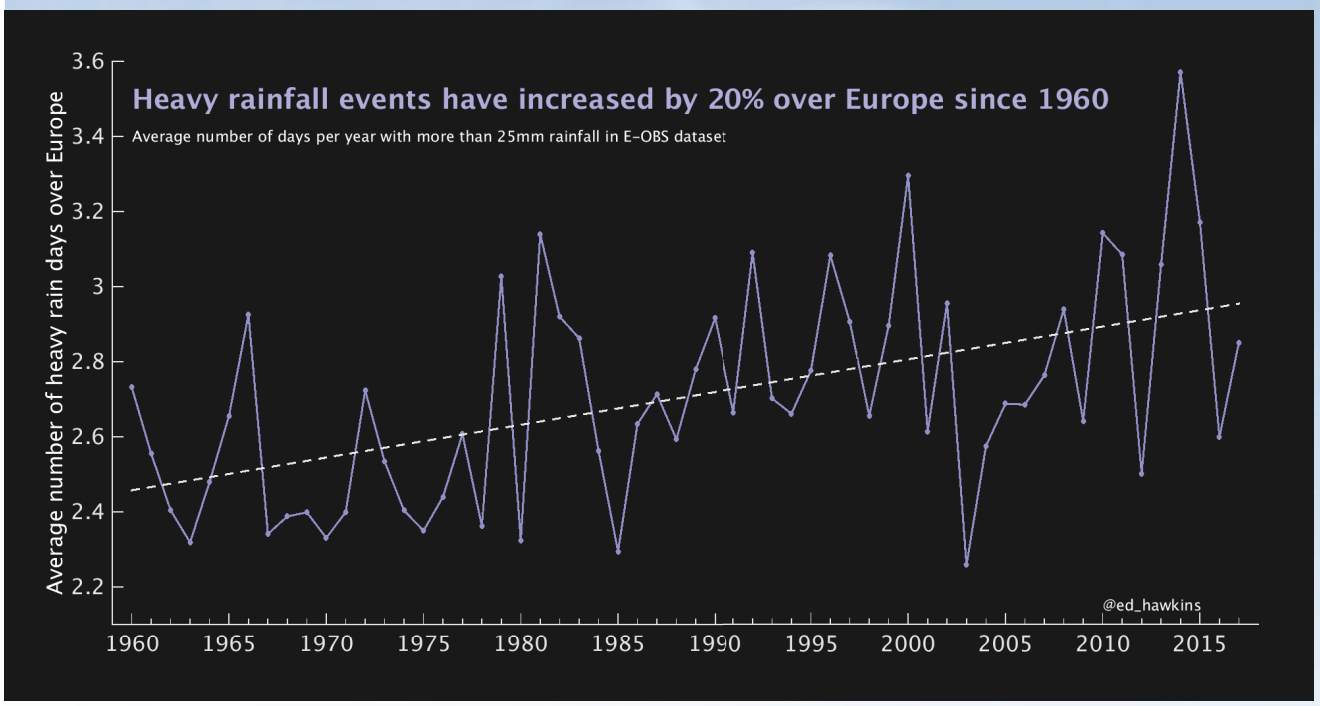
## In the United States, the number of extreme precipitation events has increased




http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather#intro-section



## Heavy rainfall events in Europe are increasing




https://www.climate-lab-book.ac.uk/author/ehawkins/

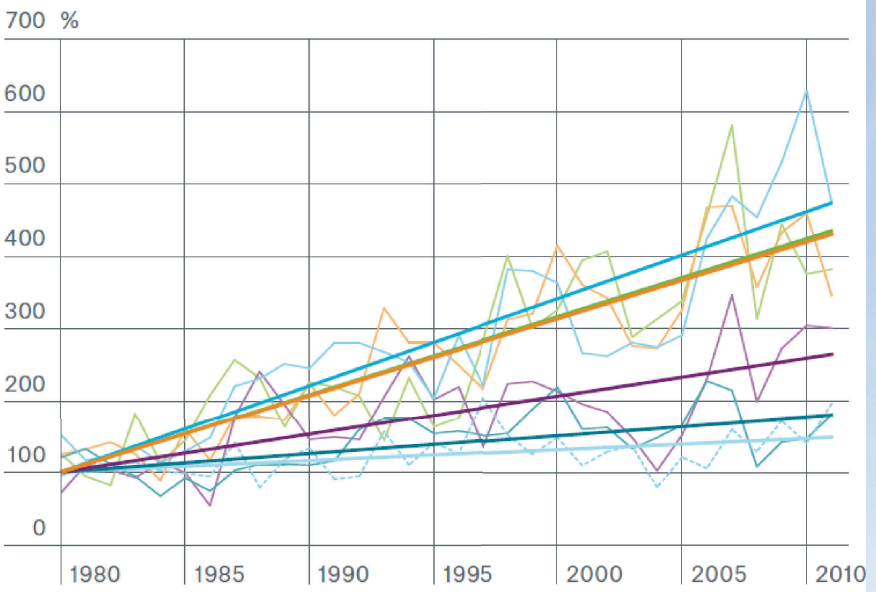
# Globally, severe weather has increased

**Upward trends in weather-related loss events per continent, 1980–2011**

Remark: This analysis considers events in the United States, Canada, the Caribbean and Central America.

- North America
- Australia/Oceania
- Asia
- Africa
- Europe
- South America

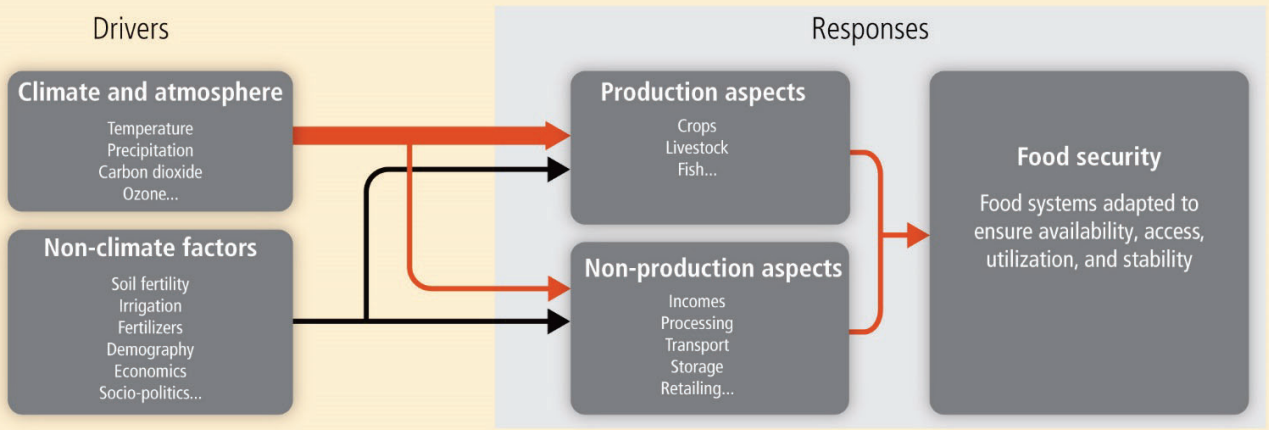
Source: Munich Re, NatCatSERVICE




Some regions of the world have experienced a greater increase in severe weather events



# What drives food production?

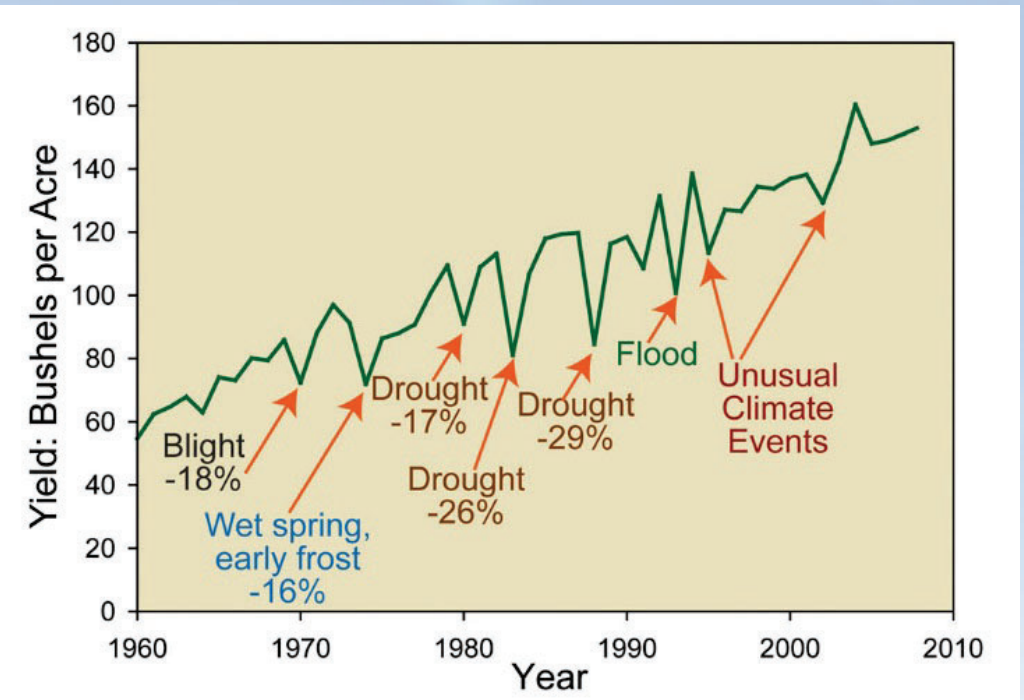



Food security: the supply of food and people's access to it.

Food security is driven by climate and non-climate factors and all must be accounted for.

https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap7_FINAL.pdf

# Too much rain or not enough will affect crop yields



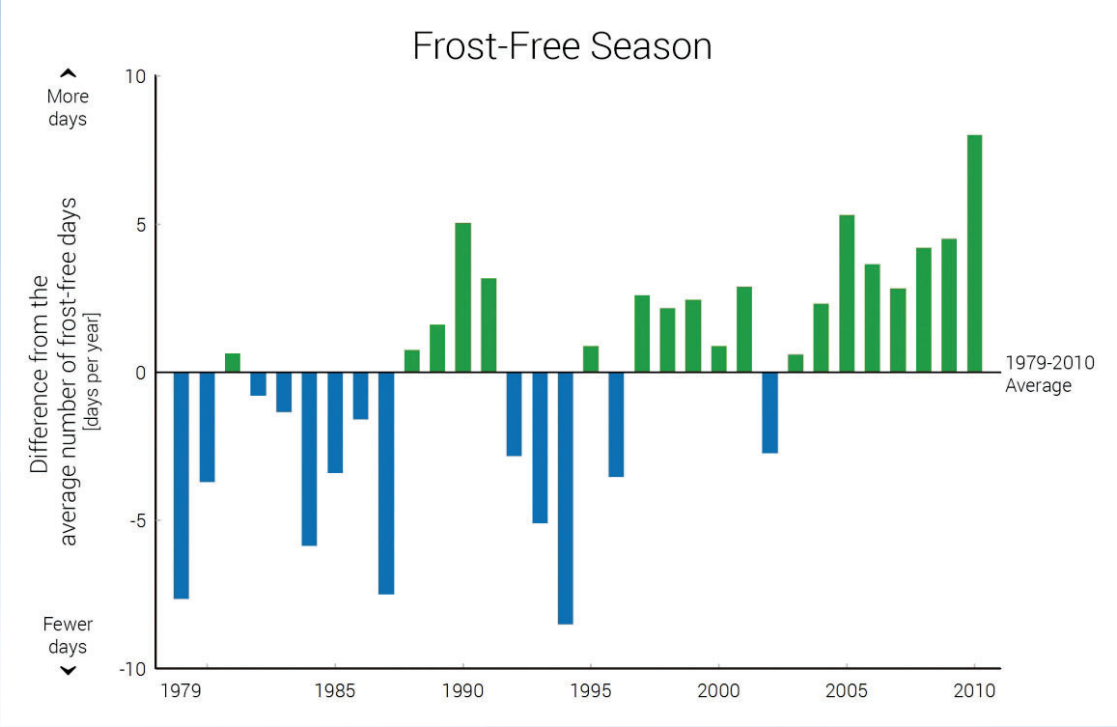

Crop yields have been increasing due to better farming practices but nature can play a negative role at times.

http://www3.epa.gov/climatechange/impacts/agriculture.html#impactscrops





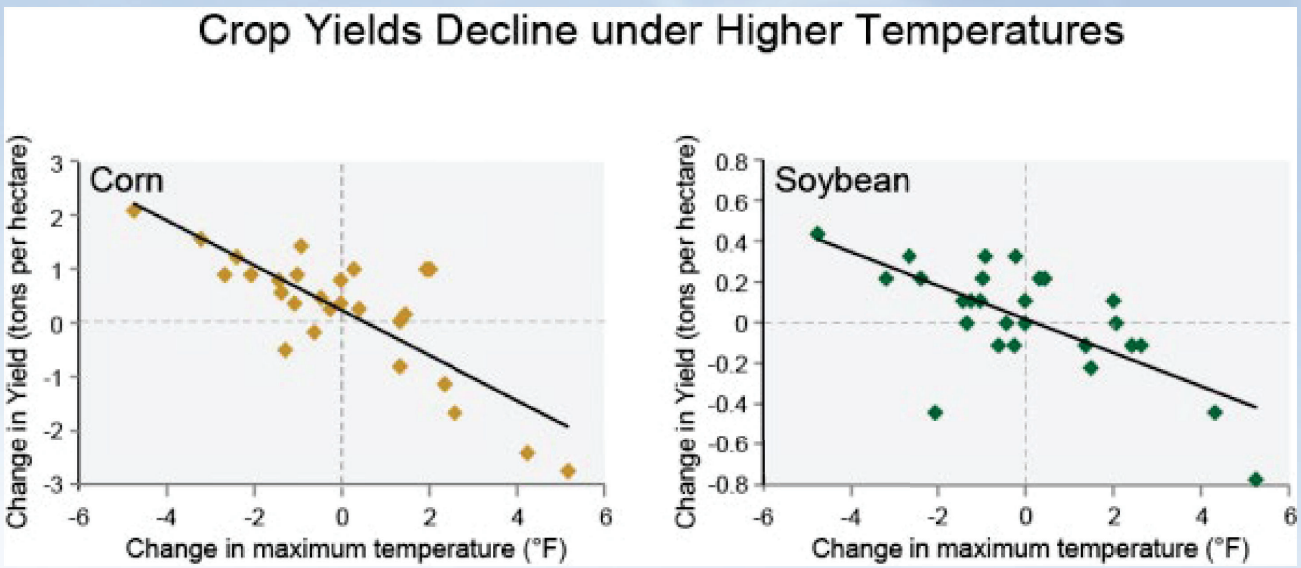
# Less frost means a longer growing season but …




The number of frost free days has been increasing

http://www.globalchange.gov/browse/indicators/indicator-frost-free-season

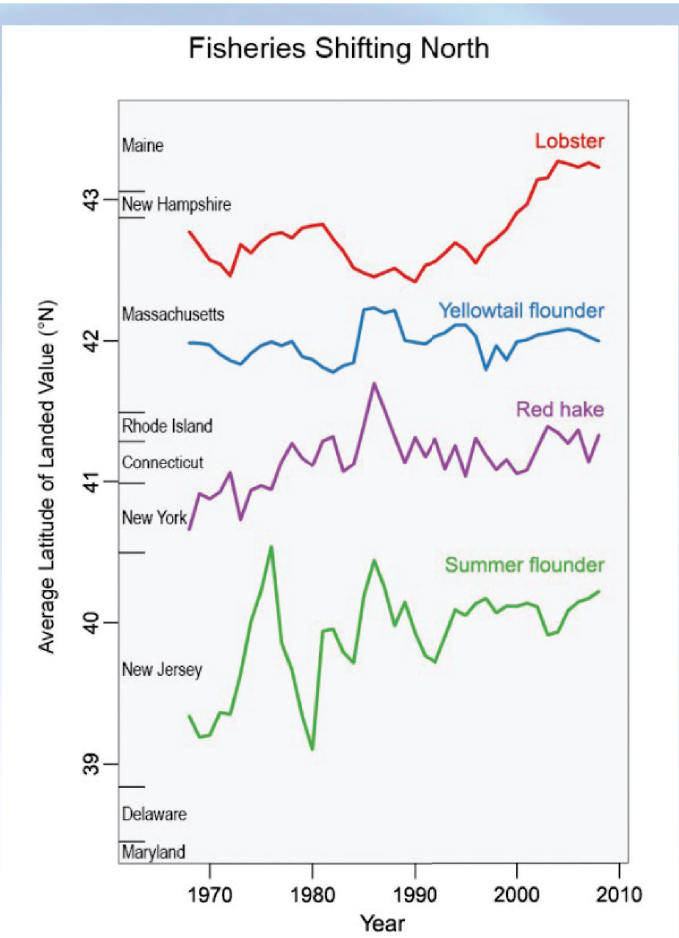
# …warmer temperatures can harm crop yields




http://www.globalchange.gov/browse/multimedia/crop-yields-decline-under-higher-temperatures








**As ocean waters warm, species move northward to stay in waters that are more comfortable for them.**

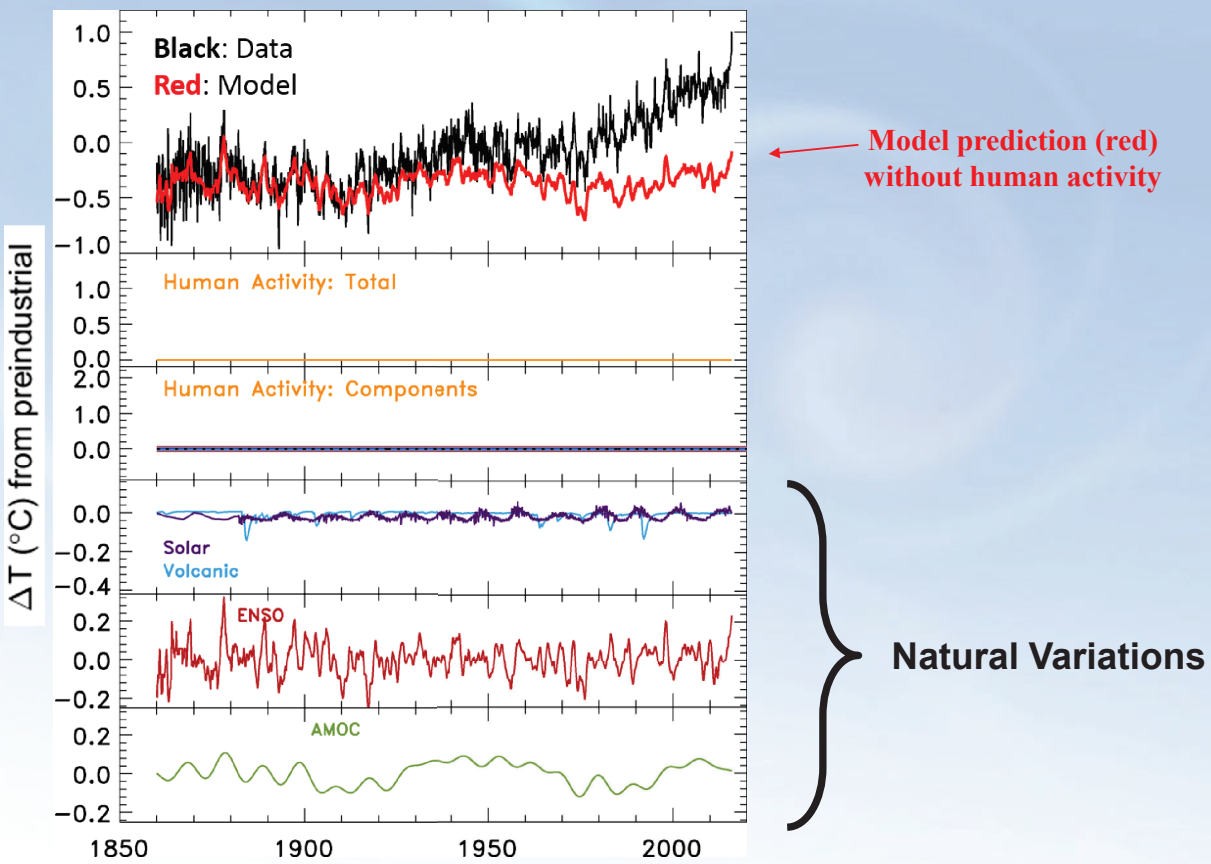
**This means that species more accustomed to warmer waters will move into the area.**

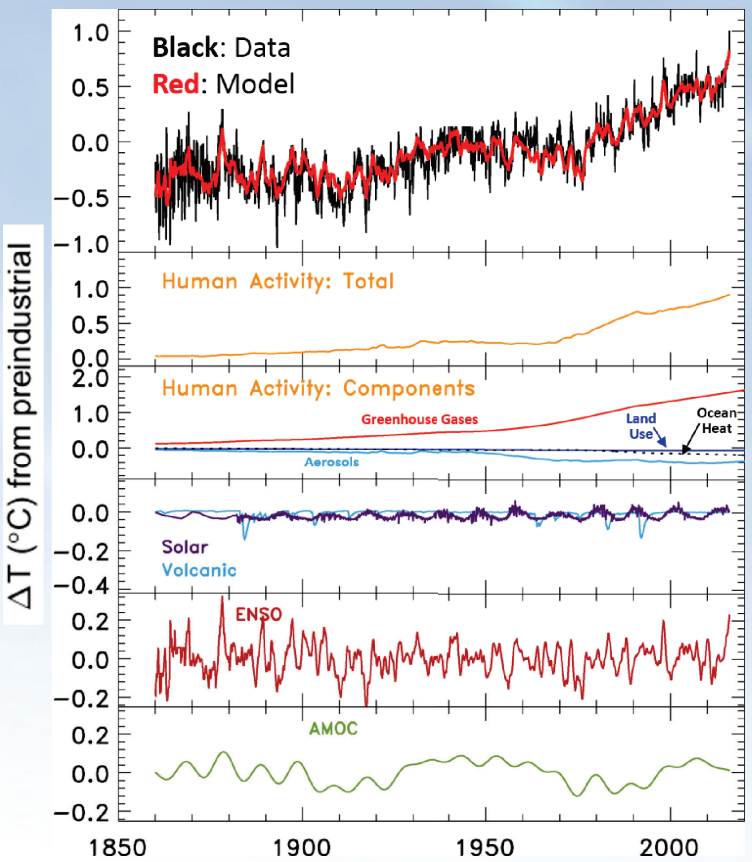
http://www.globalchange.gov/browse/multimedia/fisheries-shifting-north

# Future Predictions










Model prediction (red) with human activity

Human Activity



# Future Predictions

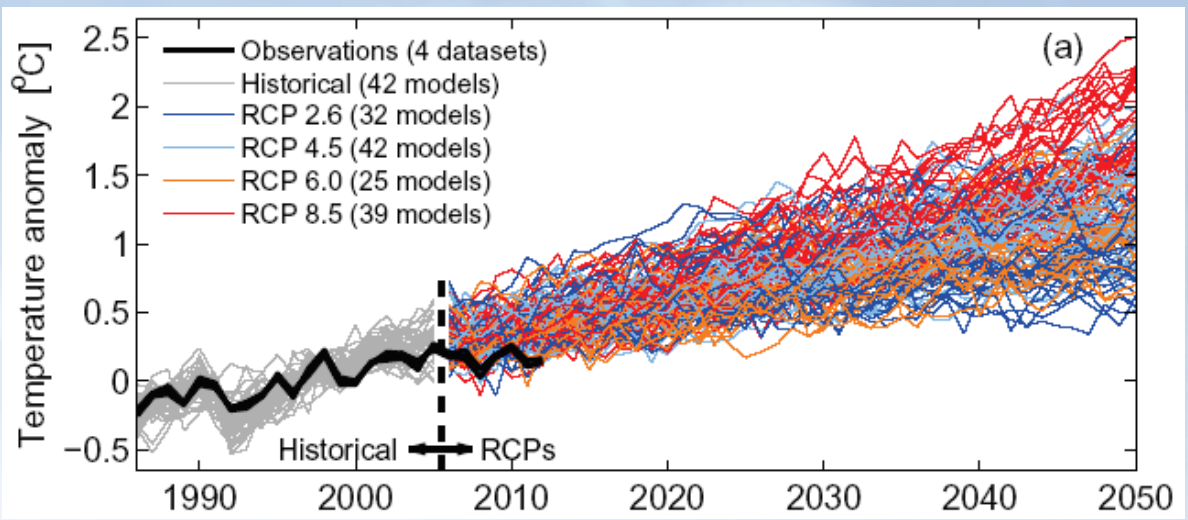
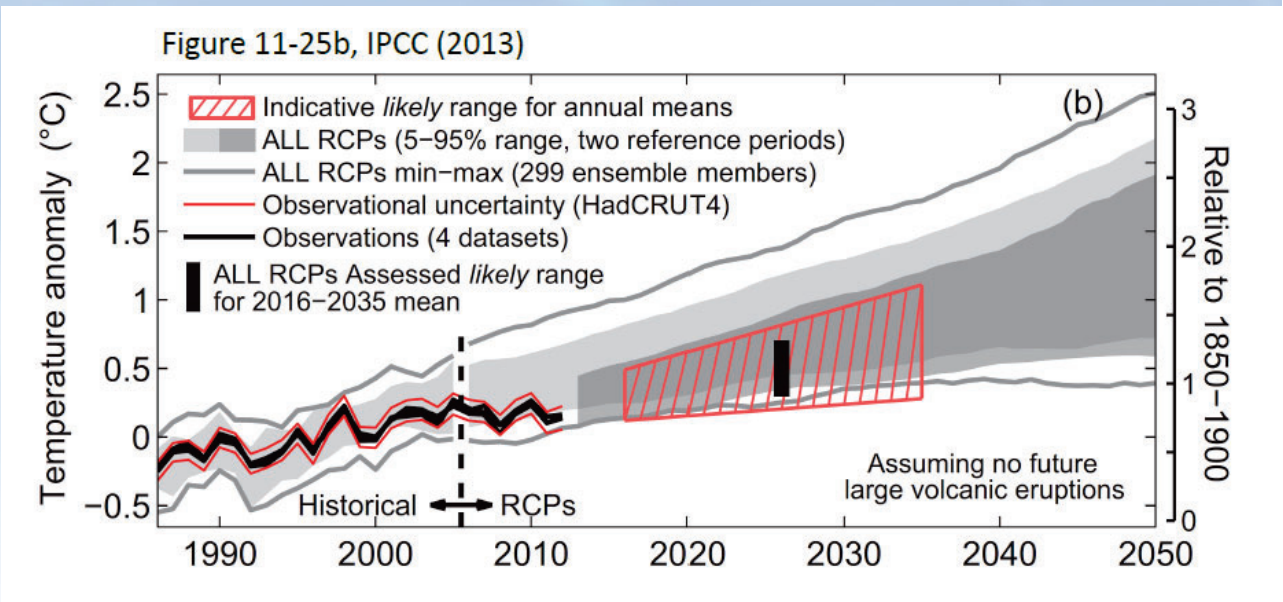


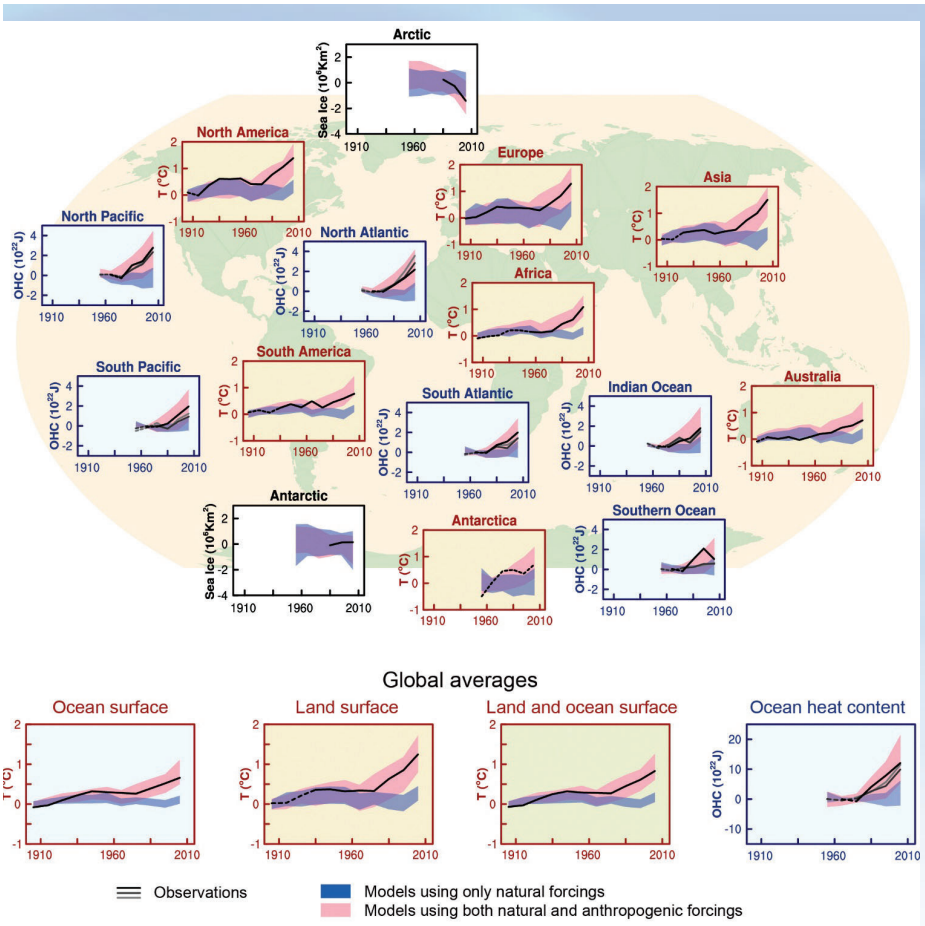

**Fig 11.25, IPCC 2013**

# Future Predictions: Corrected





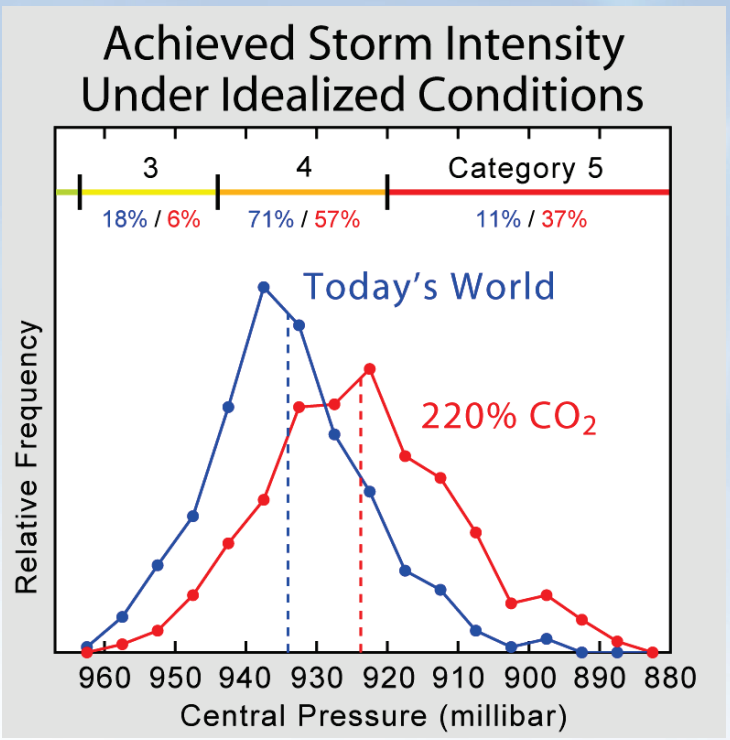



**In some areas, human activity plays a larger role than in other areas**

http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf

# Future Hurricanes




**Hurricane prediction is very difficult. It is expected that ocean waters will warm. It is also expected that wind shear will increase.**

**In Today's World, 90% of major hurricanes are category 3 or 4.**

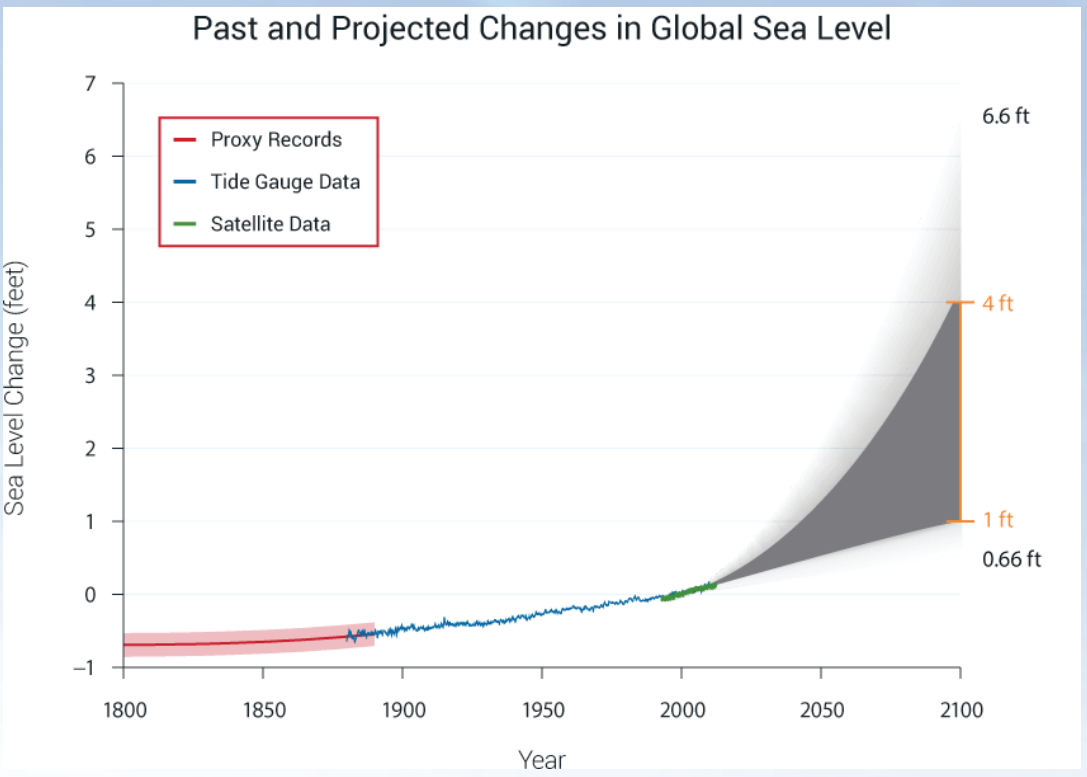
**Computer climate models that simulate a world where $CO_2$ is 220% greater than today and these results indicate over 90% of hurricanes will be category 4 or 5 but there will be fewer hurricanes overall.**

http://www.globalwarmingart.com/wiki/File:Hurricane_Intensity_Shift_png



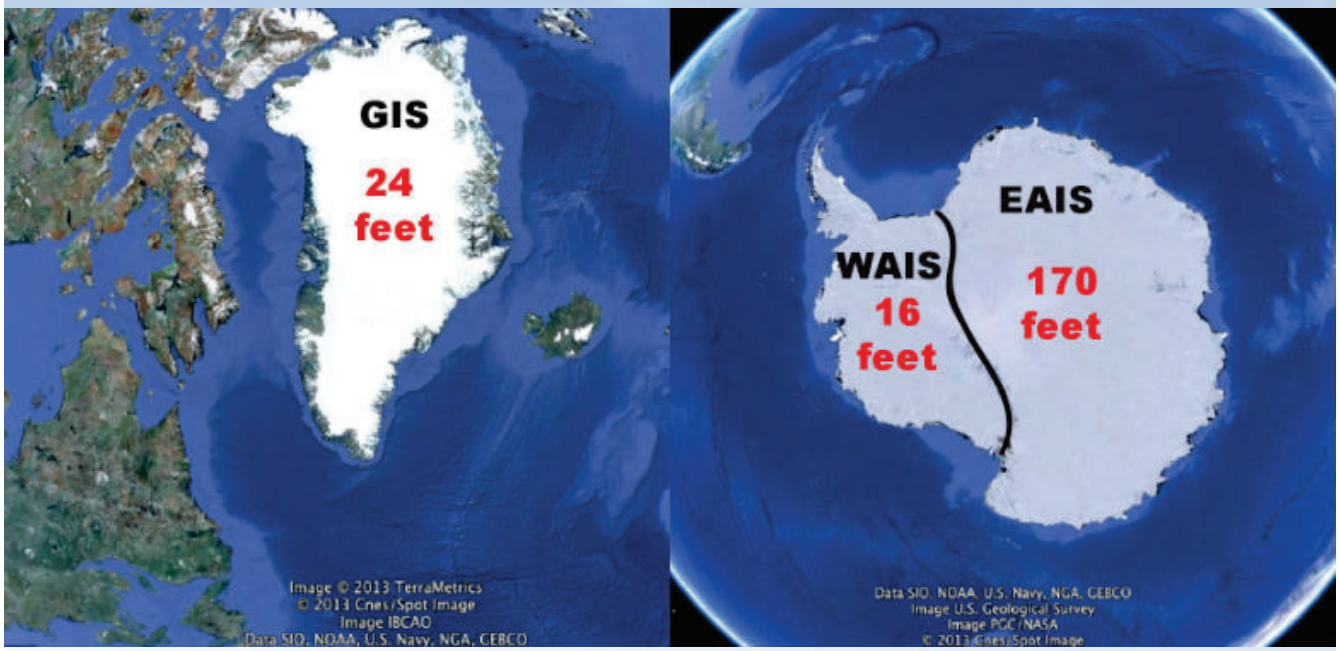


# Future Sea Level Rise




http://nca2014.globalchange.gov/highlights/report-findings/future-climate#graphic-20997

# How can melting ice sheets affect sea level?

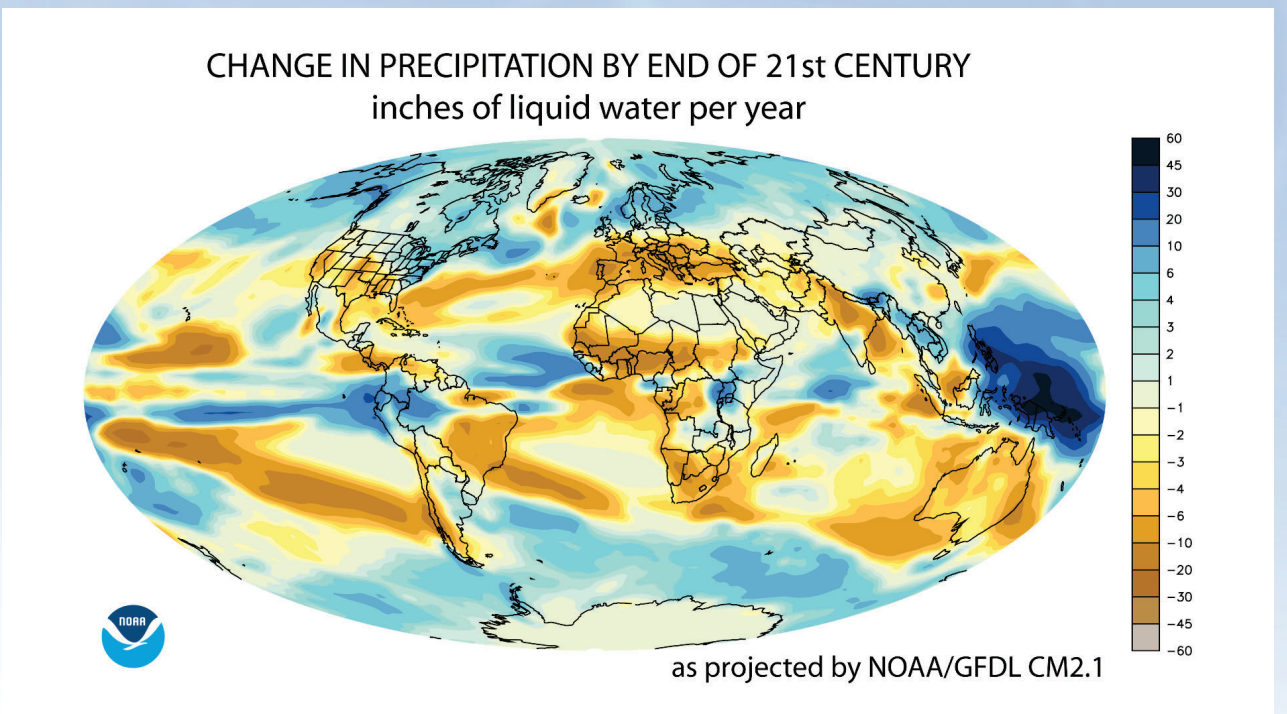



http://www.coastalreview.org/2013/06/rising-seas-come-with-rising-co2/





# The predictions are that dry areas will get drier and wet areas will get wetter




https://www.gfdl.noaa.gov/will-the-wet-get-wetter-and-the-dry-drier/#movies

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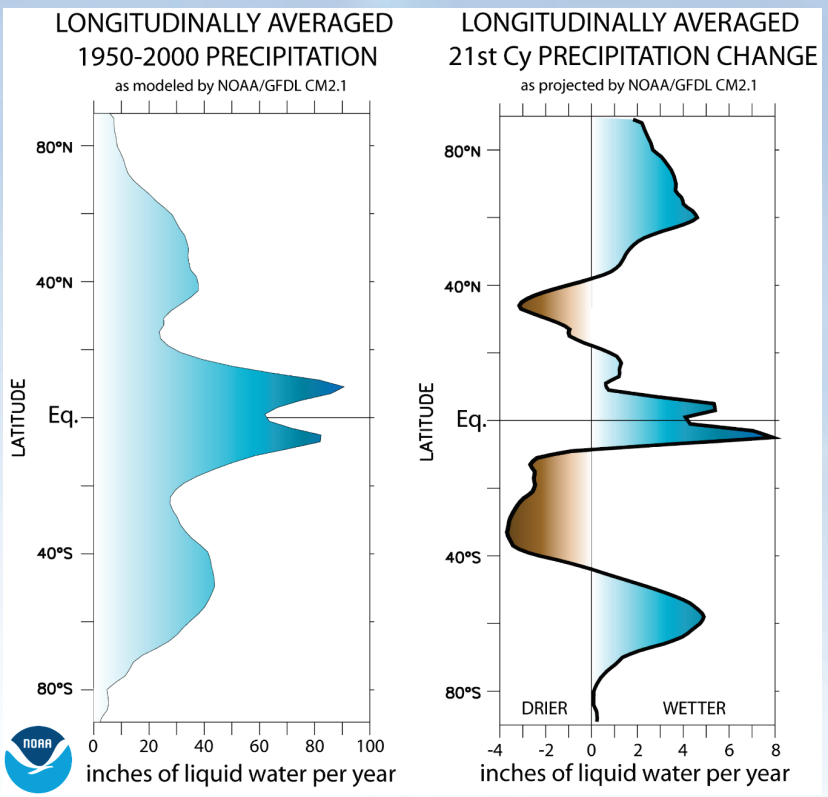
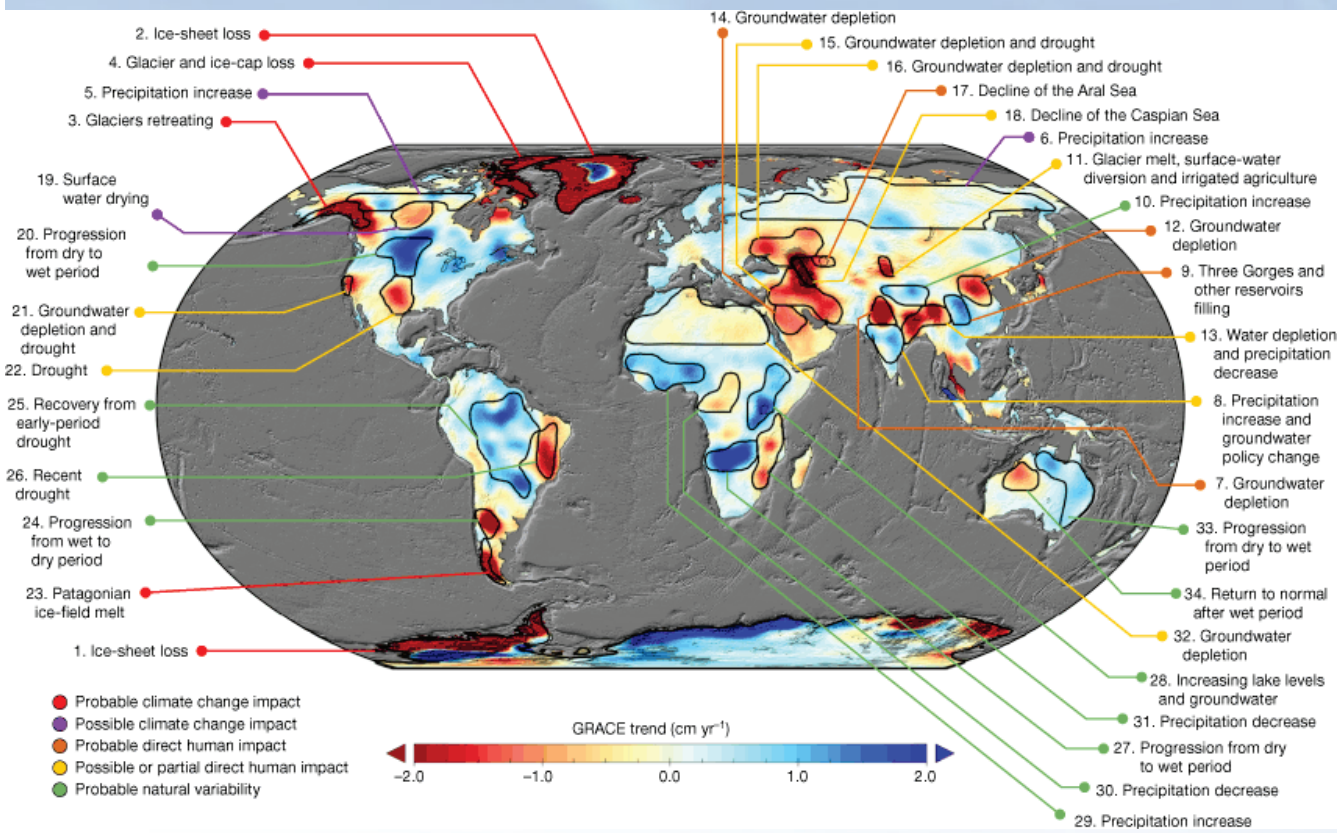



https://www.gfdl.noaa.gov/will-the-wet-get-wetter-and-the-dry-drier/#movies





## 15 years of satellite observations (GRACE) indicate this is happening now




Rodell et al., Nature 2018 https://www.nature.com/articles/s41586-018-0123-1#Fig1

## Analysis:

- Climate has warmed and most likely will continue to
- Recent warming due to human activity
- Warmer temperatures will affect weather
- Prediction is more extreme events; will cost more $$$, risk more lives
- Yes, it can still snow (all you need is below 32°F)

- *But*…climate models seem to be warming too quickly
- If correct, this gives us more time to fix the problem