CLIMATE CHANGE / GLOBAL WARMING: SOURCES AND IMPACTS

PRESENTED TO THE HEARTWOOD CHAPTER OF THE TEXAS MASTER NATURALIST SOCIETY – Oct 7, 2020

Presented By
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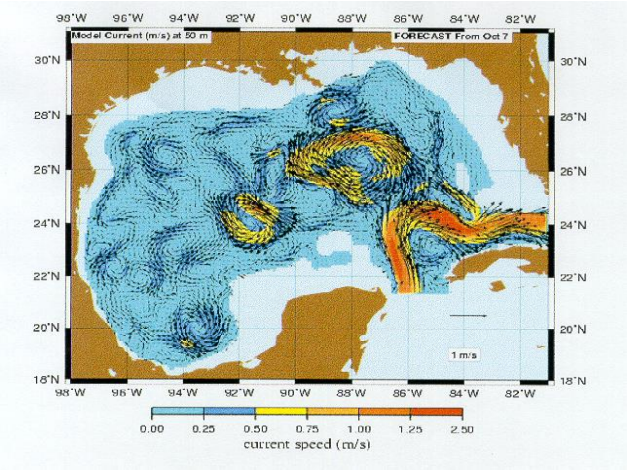
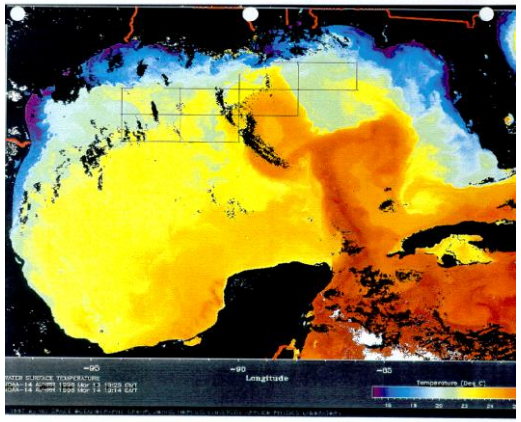
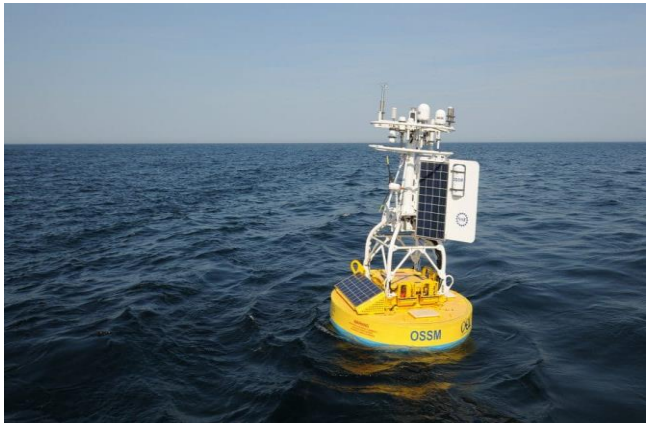


Numerical Modeling

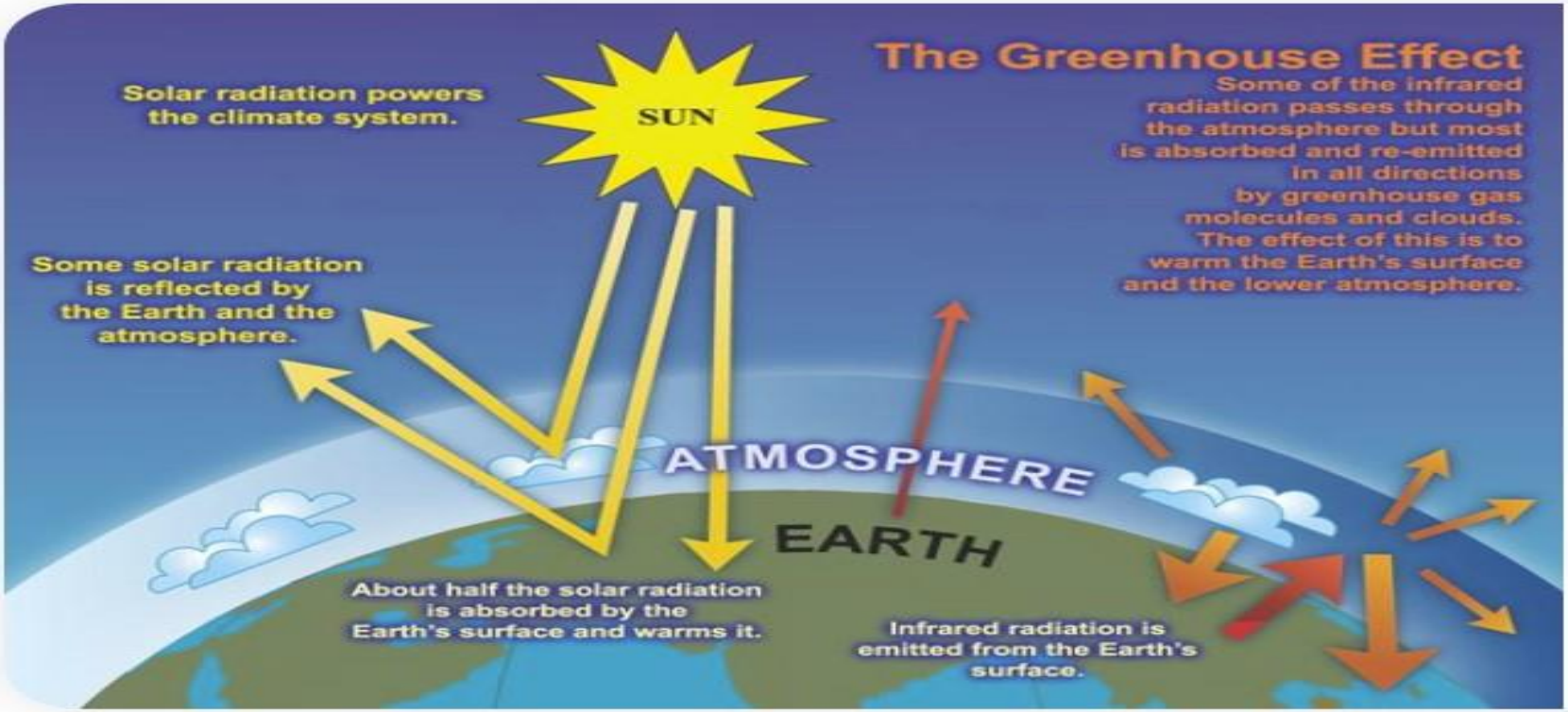


Remote Sensing



In-Situ Data Gathering

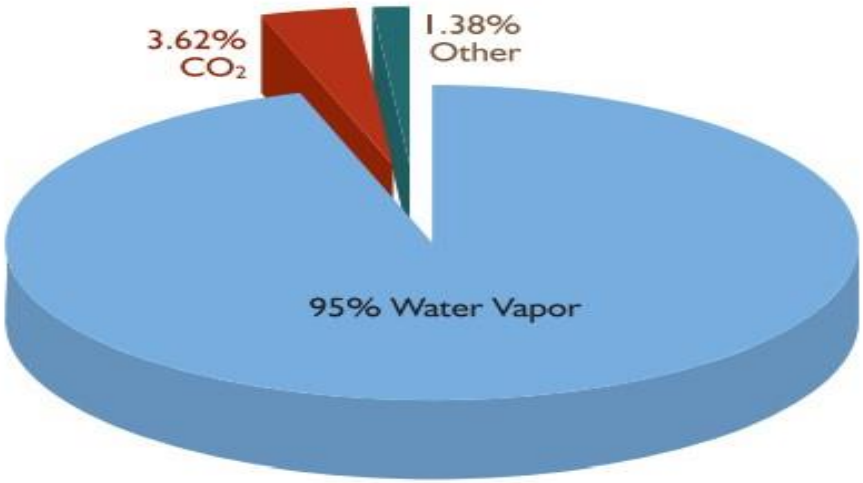
WHAT IS THE CAUSE OF GLOBAL WARMING AND RESULTING CLIMATE CHANGE?



IPCC Download – FAQ1.3, Fig 1

The natural Greenhouse Gas (GHG) effect is critical to life on earth. Otherwise the average temperature would be ~-20^{0}C

WHAT IS THE MOST ABUNDANT GREENHOUSE GAS?

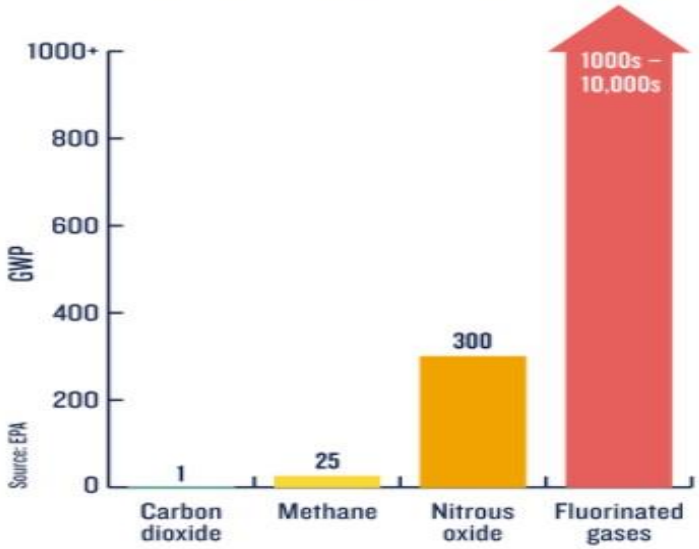


National Center For Policy Analysis – A Global Warming Primer

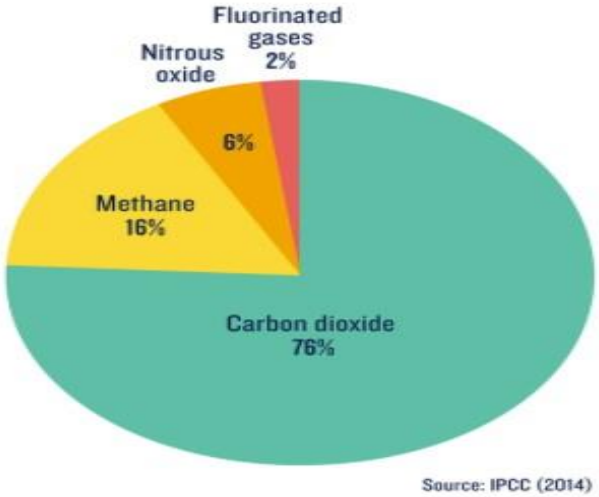
- Water vapor is by far the most abundant GHG, and the only one that is condensable. Water vapor and clouds contribute ~60% of the warming.
- It responds rapidly to temperature changes through evaporation, condensation (clouds) and precipitation, so residence time is short / highly variable.
- Clouds also reflect the suns energy, an indirect cooling effect (~65% coverage on average). Total impact widely debated.
- The non-condensable, long lived GHG's are controlling the changes in the Greenhouse Effect, leading to increases in water vapor.

WHY IS THE GLOBAL WARMING POTENTIAL OF GHG'S SO IMPORTANT?

HOW GREENHOUSE GASES WARM OUR PLANET



The global warming potential (GWP) of human-generated greenhouse gases is a measure of how much heat each gas traps in the atmosphere, relative to carbon dioxide.



How much each human-caused greenhouse gas contributes to total emissions around the globe.

Natural Resources Defense Council

WHY IS GHG RESIDENCE TIME IN THE ATMOSPHERE SUCH AN IMPORTANT ISSUE?

NASA Earth Observatory

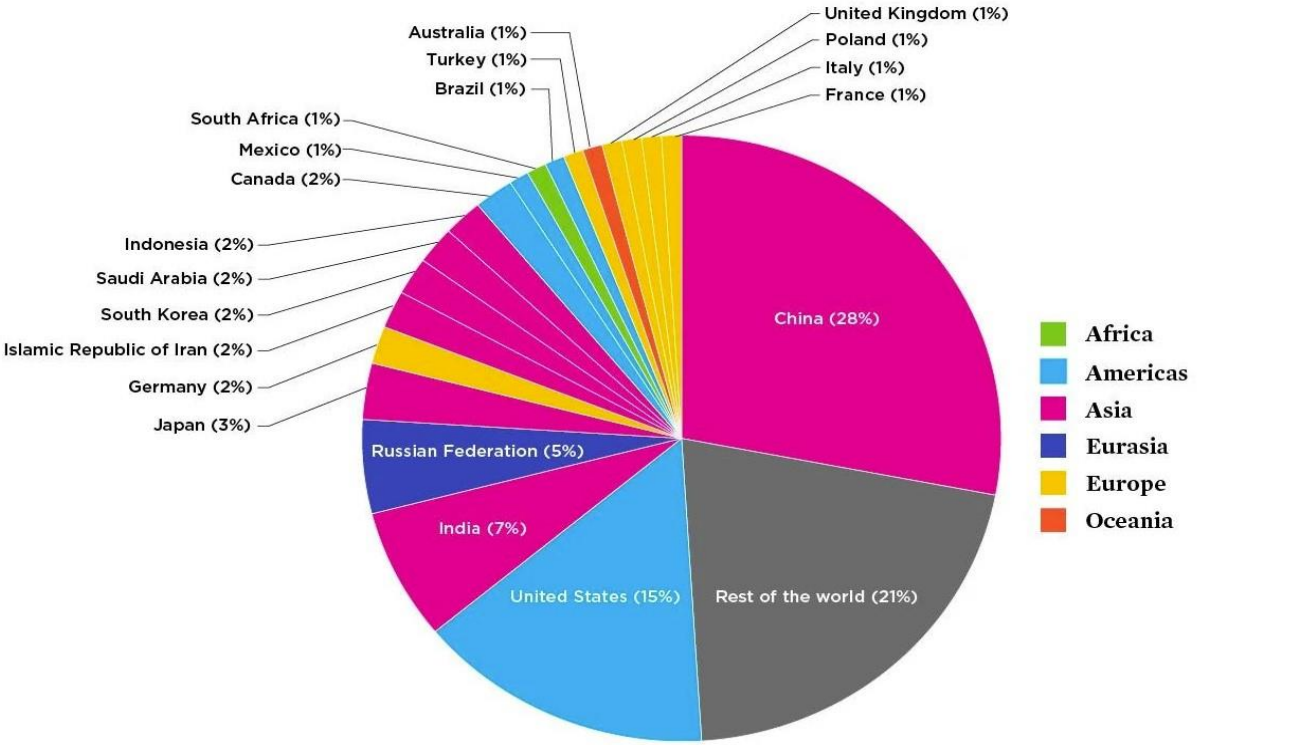
Carbon Dioxide (CO_2): 40 percent still remains after 100 years, 20 percent after 1,000 years, and 10 percent as long as 10,000 years.

Methane (CH_4): Persists in the atmosphere for about a decade.

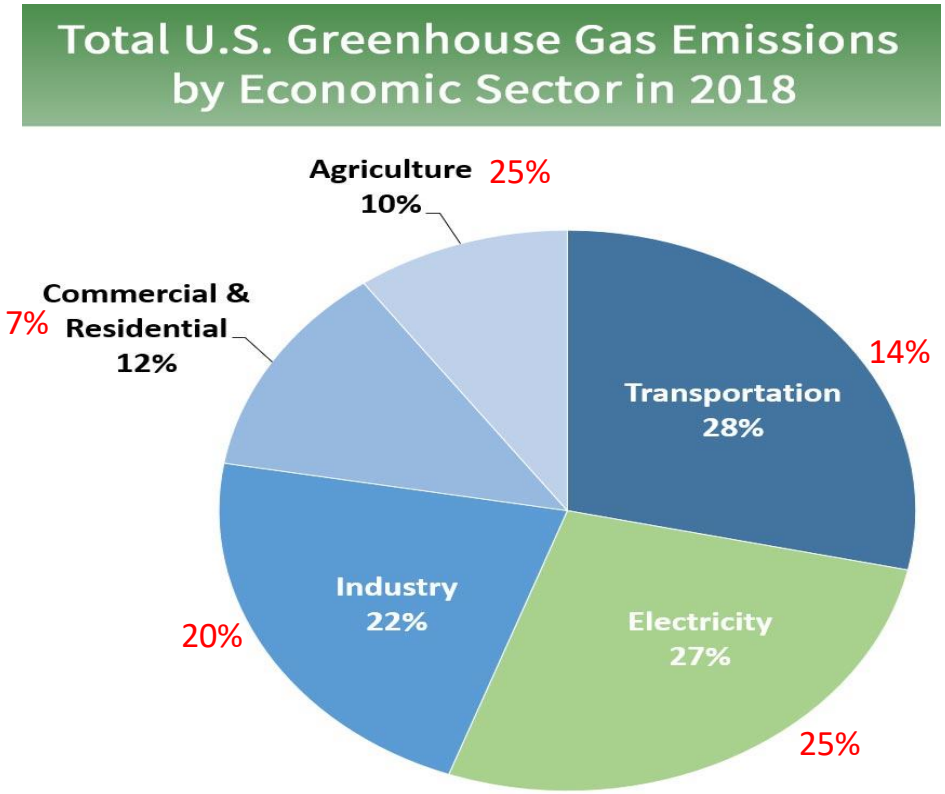
Nitrous Oxide (N_2O): Persists a little more than 100 years.

Fluorinated Gases: (Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), nitrogen trifluoride (NF_3). Man made. In some cases 10's of thousands of years.

GLOBALLY WHERE DO MOST OF THE GREEHOUSE GAS EMISSIONS ORIGINATE?



WHAT ECONOMIC SECTORS ARE THE SOURCE FOR MOST OF THE EMISSIONS IN THE U.S. AND GLOBALLY?



U.S. Environmental Protection Agency (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018

Electricity and Heat Production
The burning fossil fuels. Mainly CO_2 (some CH4 and N20).

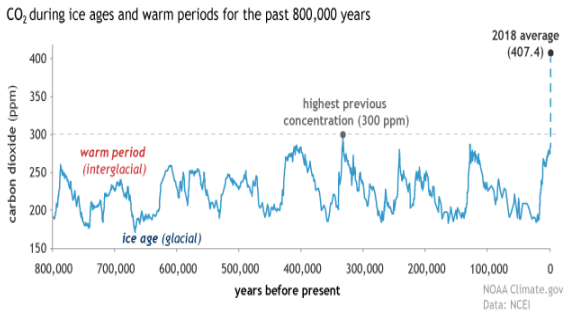
Agriculture and Land Use Changes
Such as deforestation, raising of livestock and crops for food (fertilizers). Mainly CH_4 and N_2O.

Industry
Manufacturing of goods and raw materials, extraction, refining, chemical processing, food processing, and construction. Mainly CO_2 (some CH_4, N_20 & fluorinated gases).

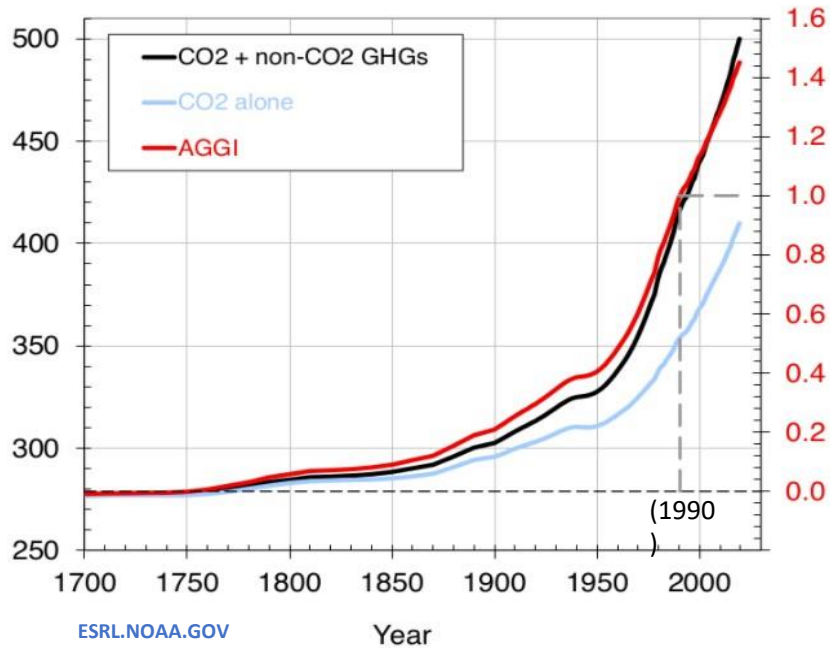
Transportation
The burning of petroleum-based fuels (cars, jets, ships, etc). Mainly CO_2 (some CH_4, N_20 & fluorinated gases).

Commercial and Residential
Homes and businesses burn fossil fuels for heating and cooking. Use of A/C systems, refrigeration, waste and wastewater disposal. Mainly CO_2, CH_4 and Fluorinated gases.

HOW MUCH HAVE GHG CONCENTRATIONS INCREASED FROM THE HISTORICAL BASE LEVELS?



GHG Concentration (ppm)

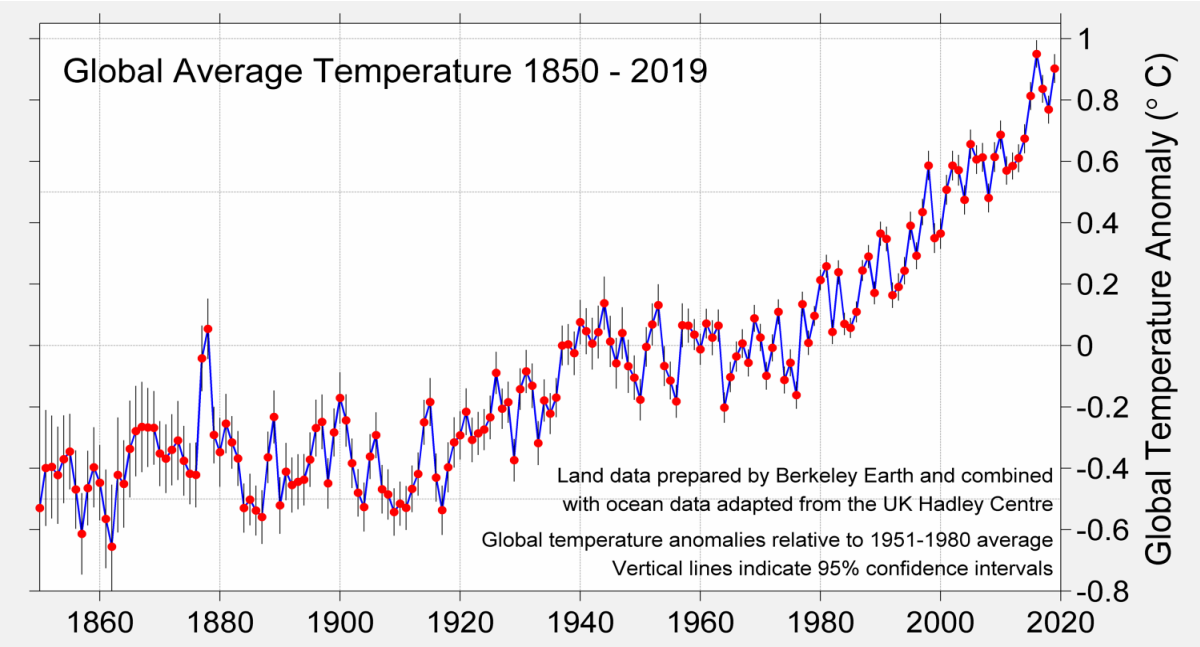


Annual GHG Index

ESRL.NOAA.GOV

Estimates are that 78% of increase since 1970 is anthropogenic.

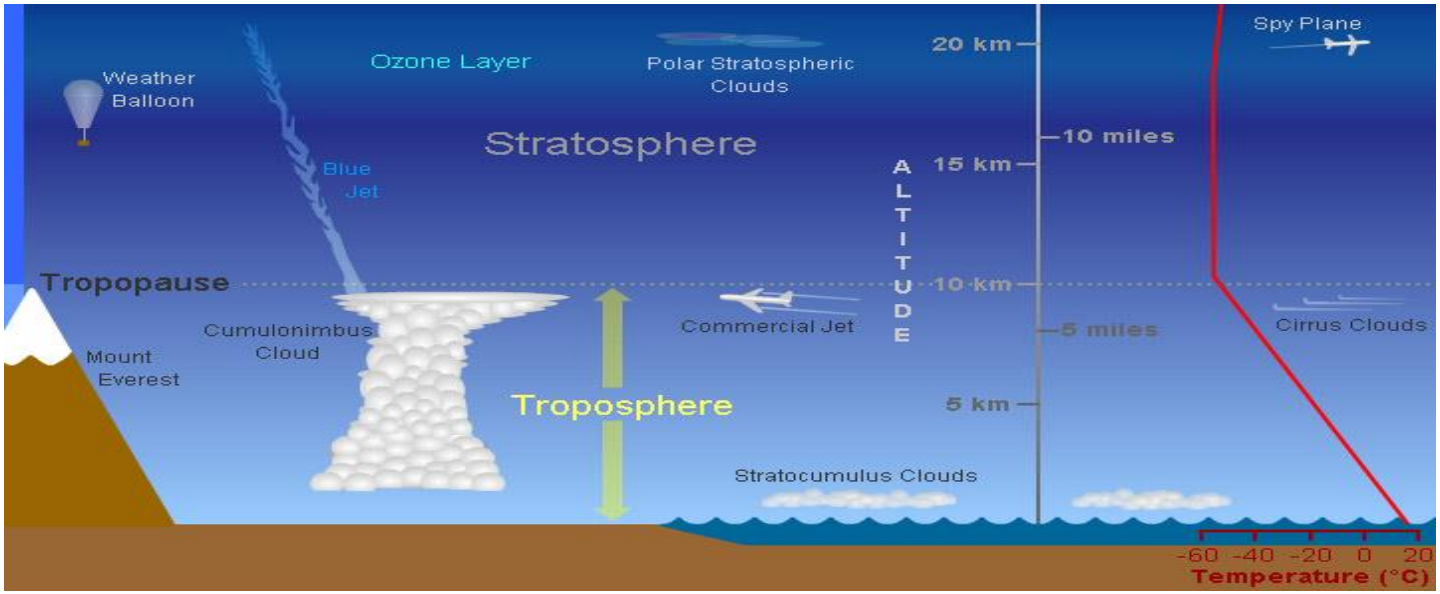
HOW MUCH HAS THE GLOBAL AVERAGE TEMPERATURE INCREASED SINCE 1850?



Rank	Year	Anomaly °C	Anomaly °F
1	2016	0.94	1.69
2	2019	0.93	1.67
3	2015	0.90	1.62
4	2017	0.84	1.51
5	2018	0.77	1.39
6	2014	0.74	1.33
7	2010	0.70	1.26
8	2013	0.66	1.19
9	2005	0.65	1.17
10	2009	0.64	1.15

- **Average rate of increase has doubled from 0.8^{O}C per century to 1.9^{O}C per century.**
- **The warming over the northern continents is largest in the mid to high (polar) latitudes in the winter-spring. Notably smaller in the summer-autumn.**
- **Can't ignore natural climate variability.**
- **Recent estimates range between 72 and 100+% of the observed global warming since 1950 was caused by anthropogenic based GHG emissions.**

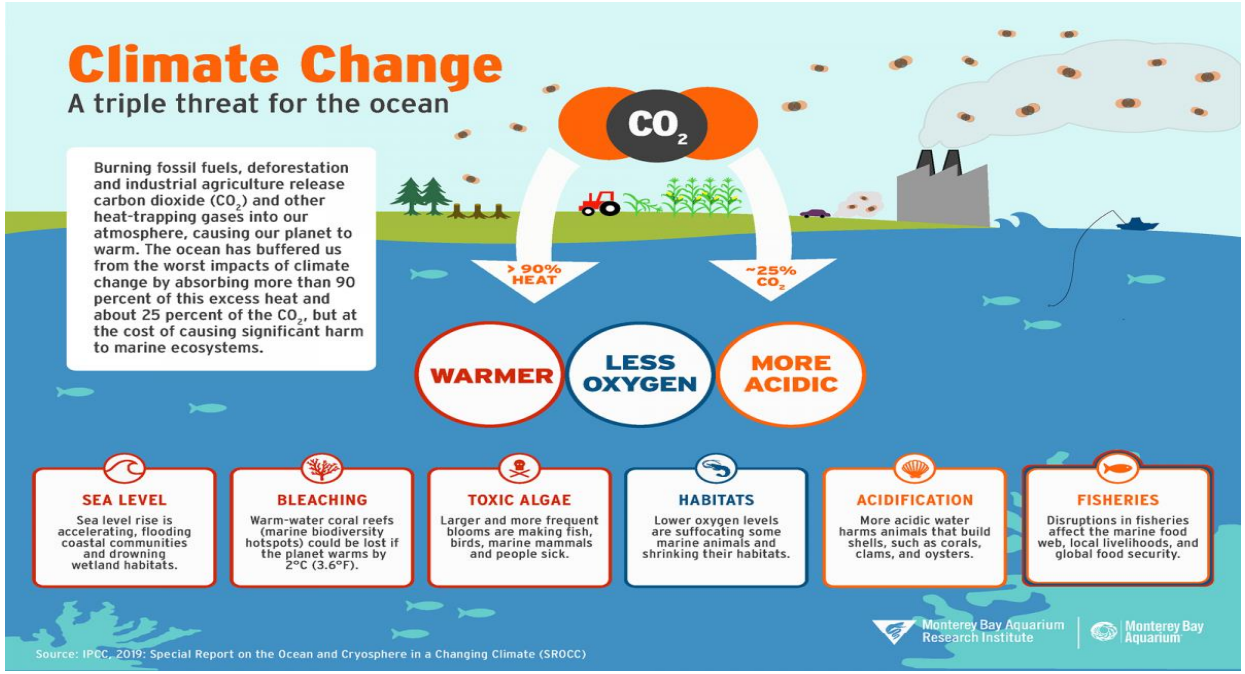
WHAT IS THE IMPACT OF GLOBAL WARMING ON THE TROPOSPHERE AND STRATOSPHERE?



UCAR Center For Science and Education

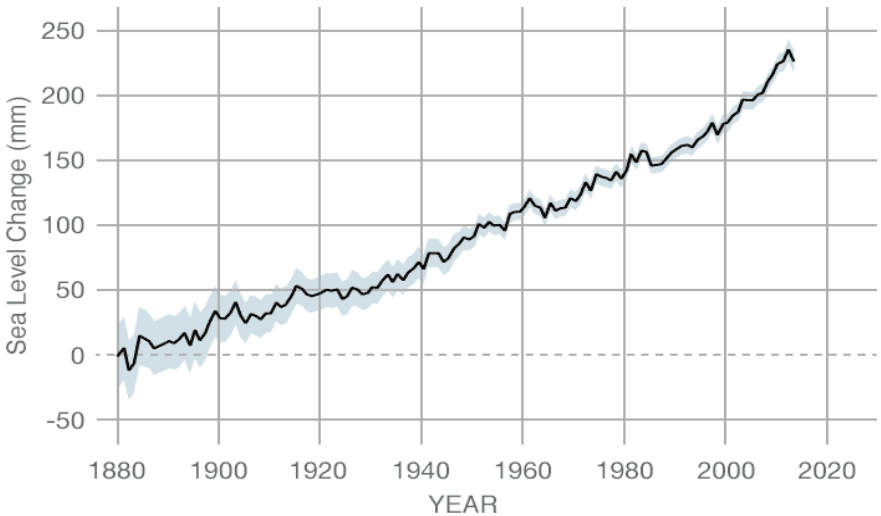
- The troposphere has warmed as well allowing the air to hold more water vapor which feeds back into increased precipitation potential.
- Meanwhile the stratosphere is cooling mainly due to ozone depletion and the impact of GHG warming in the troposphere.
- There are likely other mechanisms contributing to stratospheric cooling that are not completely understood.
- Nevertheless initial indications are that further stratospheric cooling would lead to increased ozone depletion.

HOW HAVE THE OCEANS BEEN IMPACTED?



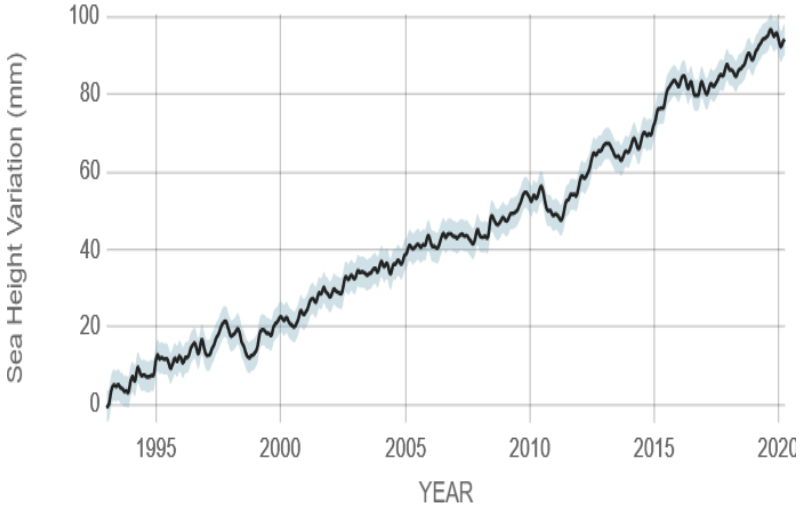
- **Warmed through absorption of excess heat from the warming atmosphere. $1^{O}C$ per century in the surface/upper subsurface layers.**
- **More acidic due to absorption of CO_2 (25% - 0.1 pH decrease over the last century). Some cooling trends limited to small areas.**
- **Surface warming has lead to reduced oxygen levels.**
- **These factors have already lead to an acute near-term threat to many marine ecosystems and marine life.**

HOW HAS GLOBAL WARMING IMPACTED SEA LEVEL?



climate.nasa.gov

Coastal Tide Gauge Records: 1.7mm/yr
(For 1993 to 2017: 3.1mm/yr)

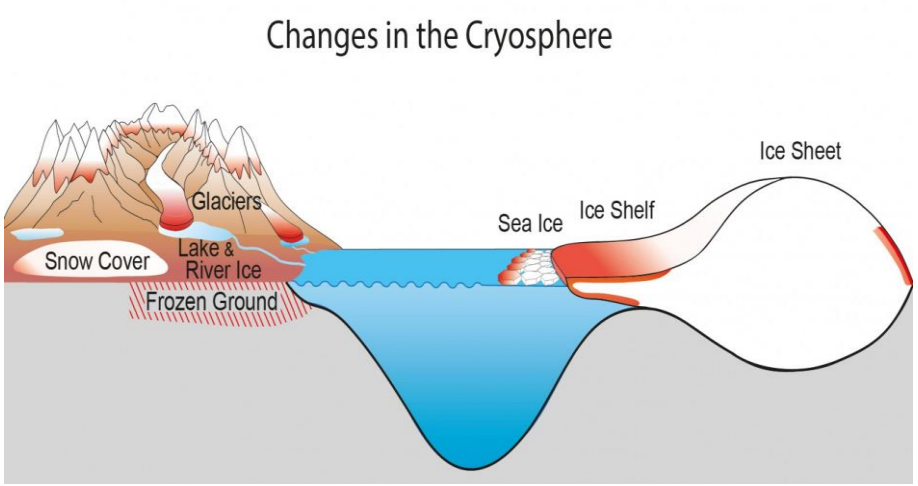


Source: climate.nasa.gov

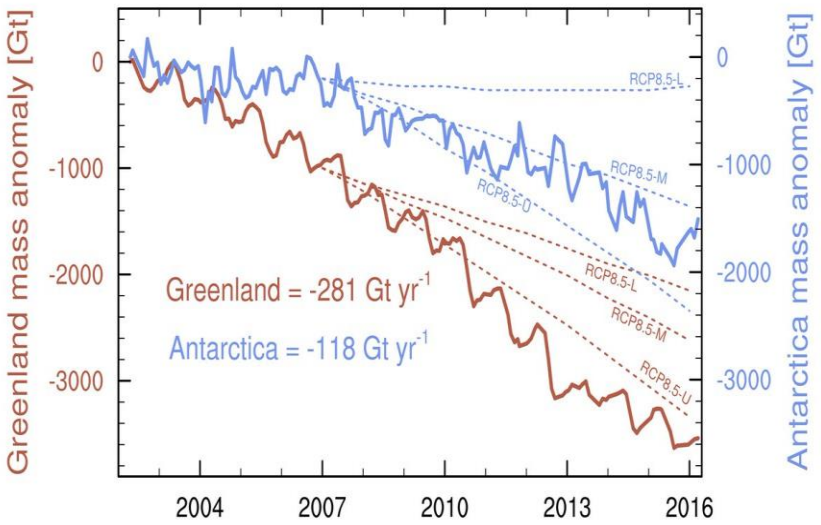
Satellite Data: 3.3mm/yr

- **Complex issues related to measurement technology and link to global warming.**
- **Sea level rise is caused primarily by global warming induced water column expansion and melting of ice sheets and glaciers.**
- **Average rate is about 3mm per year since 1993. This is enough to have already impacted some coastal communities and small island nations.**

HOW HAS GLOBAL WARMING IMPACTED THE CRYOSPHERE?



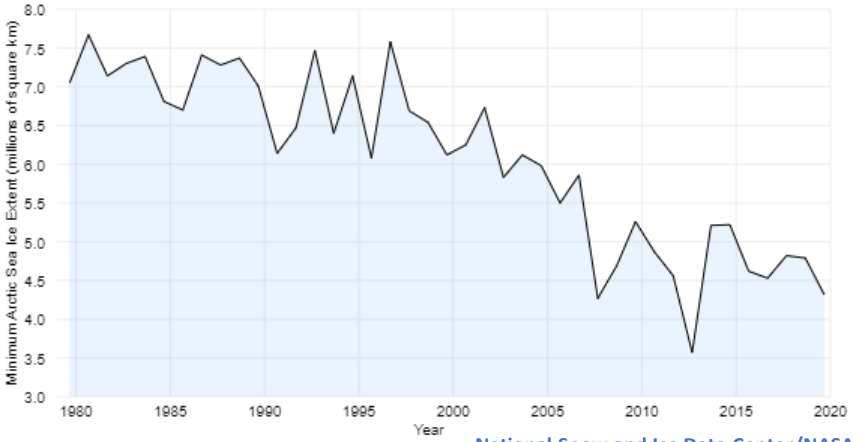
European Geosciences Union



NASA Earth Observing System

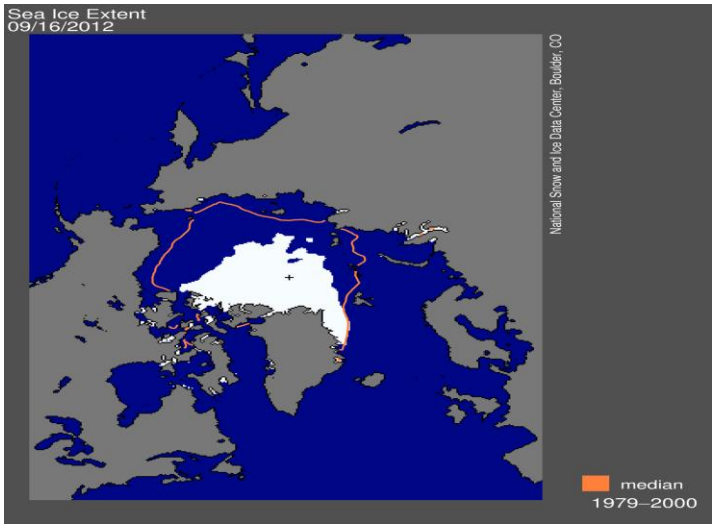
- Satellite measurements from 2002-2016 reveal sea level rise from loss in ice sheet mass on Greenland and Antarctica of order 0.75 and 0.33mm /yr.
- The contribution from Greenland is triple the previous decade.
- For alpine glaciers the global trend in the mass balance over the last century is about 1mm/yr of sea level rise.
- The loss of average seasonal snow and ice cover impacts solar radiation absorption and freshwater storage (A critical factor for the western U.S.)

HOW HAS GLOBAL WARMING IMPACTED THE ARCTIC OCEAN SEA ICE SHEET - SUMMER MINIMUM?



National Snow and Ice Data Center/NASA

A decline of about 50% over 4 decades or about 13% per decade.

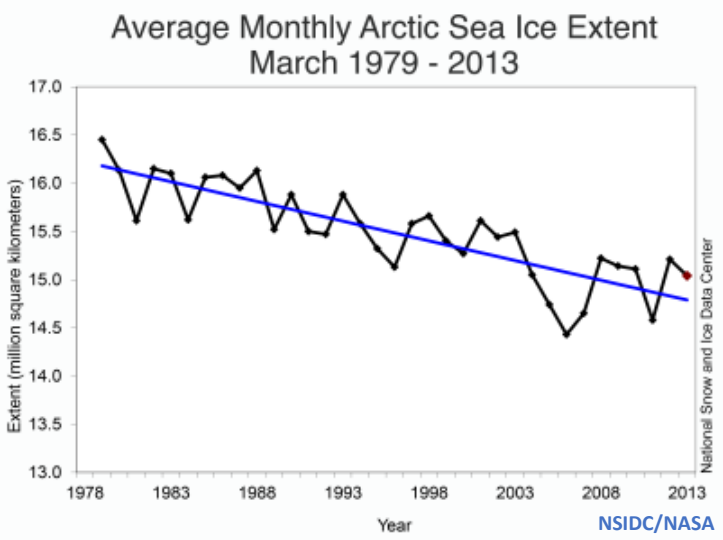


National Snow and Ice Data Center/NASA

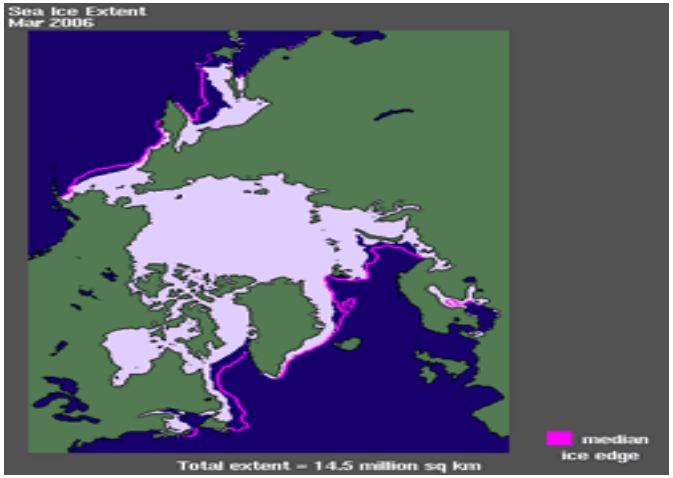
The record 2012 minimum

- As of Sep 2019 the 13 lowest summer minimum ice years have occurred in the last 13 years.
- Multiyear ice has declined dramatically. In 1987, 57 percent was 5+ years old, declining to 7 percent by 2007.
- Sea ice regulates exchanges of heat, moisture and salinity of the polar oceans. Much more important is summer.
- Arctic mammals, fish, birds, etc. depend on sea ice for their habitat. Already seeing dramatic impact.

HOW HAS GLOBAL WARMING IMPACTED THE ARCTIC OCEAN SEA ICE SHEET – WINTER MAXIMUM?



A decline of about 10% over 3.5 decades

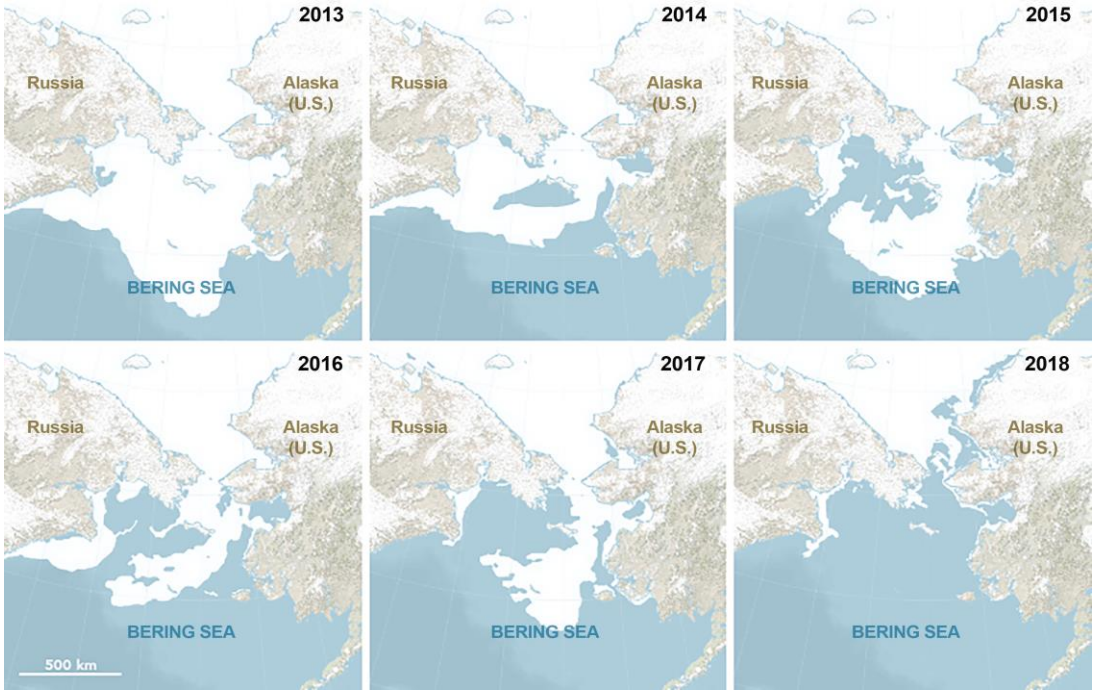


National Snow and Ice Data Center/NASA

The record 2006 minimum

- The winter recovery trend is not as striking as the sea ice minimum trend.
- Changes in the sea ice maximum extent are much less important.
- Submarine records show a decrease in average winter level ice thickness from 3.64m in 1980 to 1.89m in 2008. Feeds back to minimum.

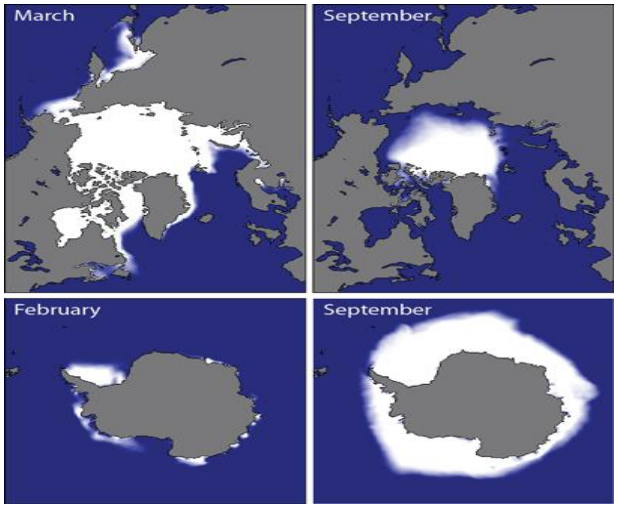
HOW HAS GLOBAL WARMING IMPACTED THE BERING SEA ICE SHEET?



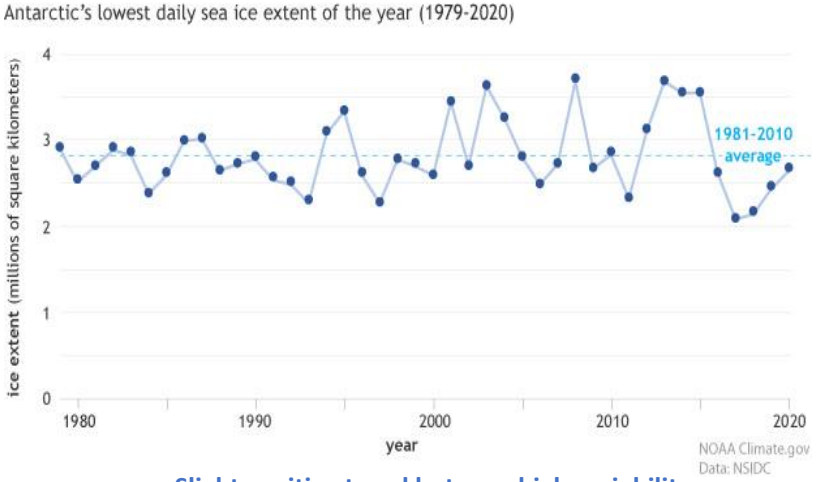
climate.nasa.gov

- The maximum ice extent in the Bering Sea during April for the years 2013 through 2018.
- The year 2018 set the record for the least amount of sea ice dating back to 1850. (NASA Earth Observatory, Joshua Stevens)

HOW HAS GLOBAL WARMING IMPACTED THE ANTACRTIC SEA ICE SHEET?



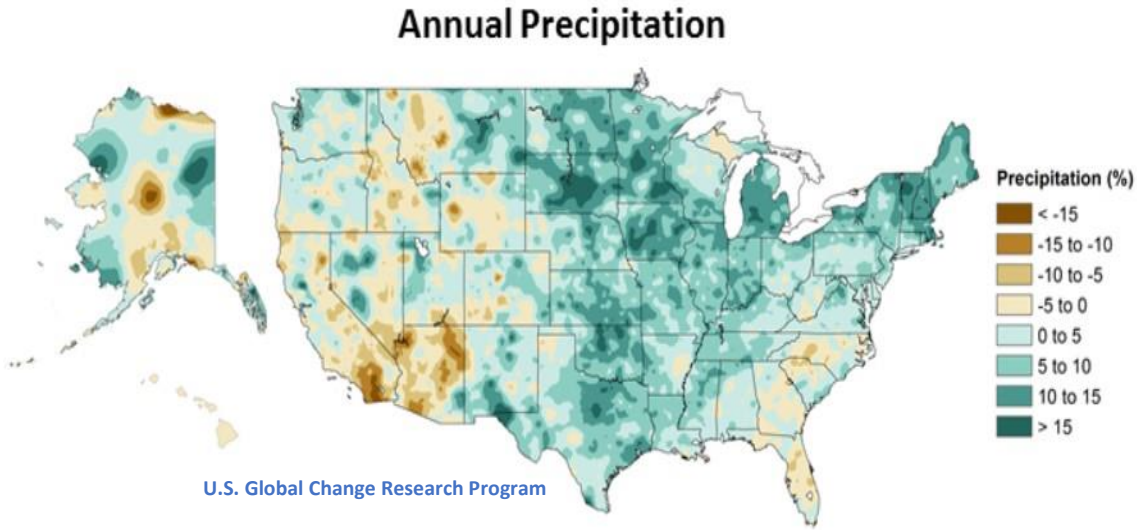
NSIDC/NASA



Slight positive trend but very high variability

- The differences in seasonal extremes are due to basic geography.
- Since the sea ice forms at lower, warmer latitudes, less Antarctic sea ice survives the summer.
- Also, large-scale upwelling of colder deep waters in the Southern Ocean, which limit the effects of surface warming.

HOW IS GLOBAL WARMING IMPACTING PRECIPITATION?



U.S. Global Change Research Program

*Average for 1986-2015 minus average for 1901-1960

*Alaska and Hawaii: 1925-1960

- A warmer atmosphere holds more water vapor (precipitable water) – 7% for every ^{O}C of warming.
- Globally - Increasing over the northern hemisphere middle and high latitudes – especially in autumn.
- Heavy precipitation events have steadily increased in frequency and intensity since 1900– especially in the northeast.
- Drylands are increasing in area due to both warmer temperatures and lower precipitation.
- While average trends are clear, the fraction attributable to human activity is difficult to quantify on a regional scale.

HOW IS GLOBAL WARMING IMPACTING TROPICAL CYCLONES?

- The number and intensity of Atlantic hurricanes have both increased since the early 1980s.
- There is little trend or even a decrease in the number tropical cyclones in other ocean basins.
- Globally, there is clear evidence that ocean warming is providing more energy to make tropical cyclones more intense.

HOW IS GLOBAL WARMING IMPACTING WINTERTIME EXTRATROPICAL CYCLONES?

National Weather Service/NOAA

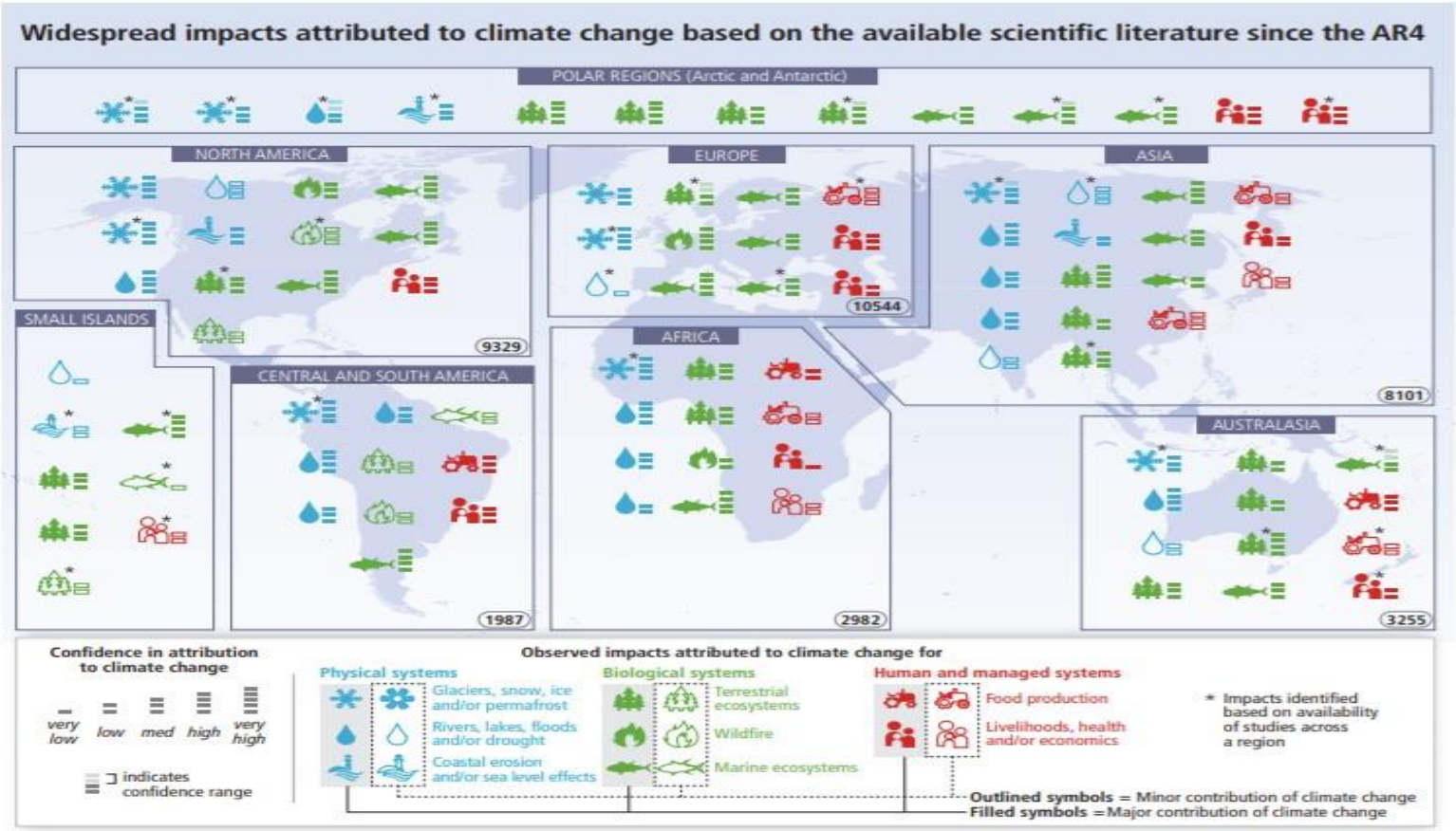
- **Changes in the extremes of extratropical cyclones with climate warming are less clear.**
- **Their energy source may be decreasing in strength, but too early to be certain.**
- **The largest detected changes are in the total precipitation, where a significant increase is seen along the tracks of these storms.**
- **Potentially very large regional changes in precipitation could be seen if major storm tracks are impacted in a warmer climate.**

HAS GLOBAL WARMING IMPACTED TORNADO ACTIVITY?

NOAA.Gov

- There is no clear evidence pointing to an increase in the most violent U.S. tornadoes.
- However, tornado activity has become more variable since the 1970s.
- The high natural variability of tornadoes, severe thunderstorms, etc. make it difficult to detect anthropogenic induced impacts, if any.

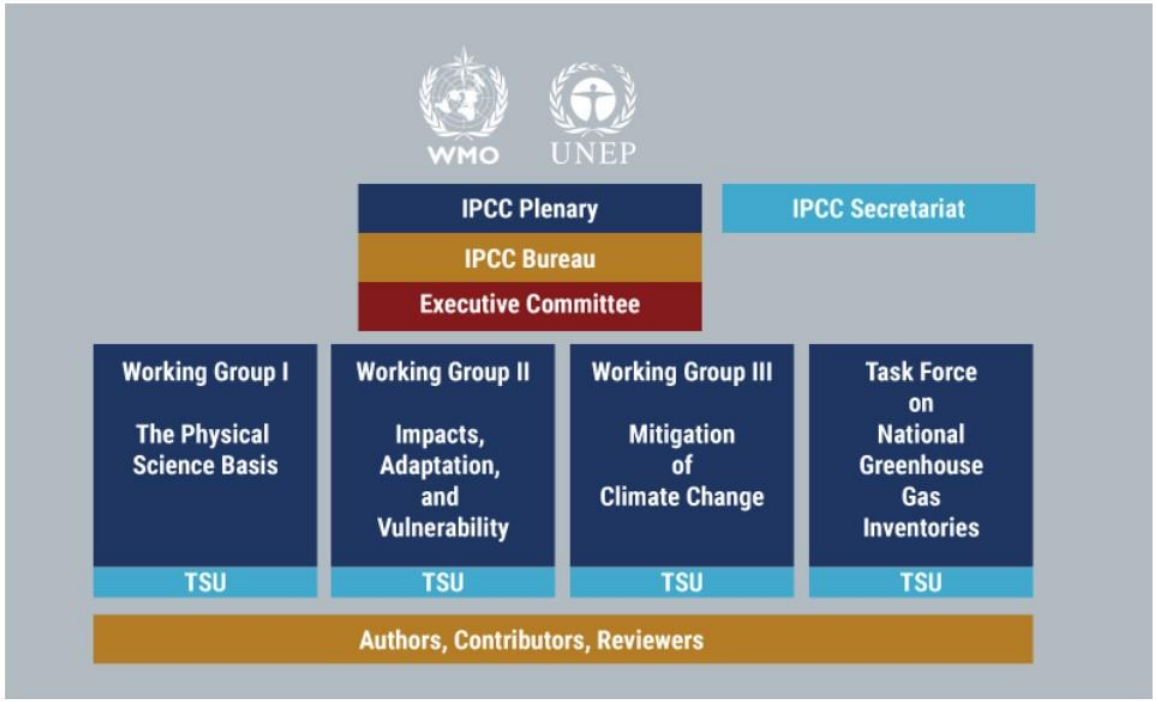
HOW HAS WARMING / CLIMATE CHANGE AFFECTED PHYSICAL, BIOLOGICAL AND HUMAN SYSTEMS?



IPCC AR5 Synthesis Report

WHAT IS THE INTERGOVERMENTAL PANEL ON CLIMATE CHANGE (IPCC)?

The following graphic depicts the structure of the IPCC:



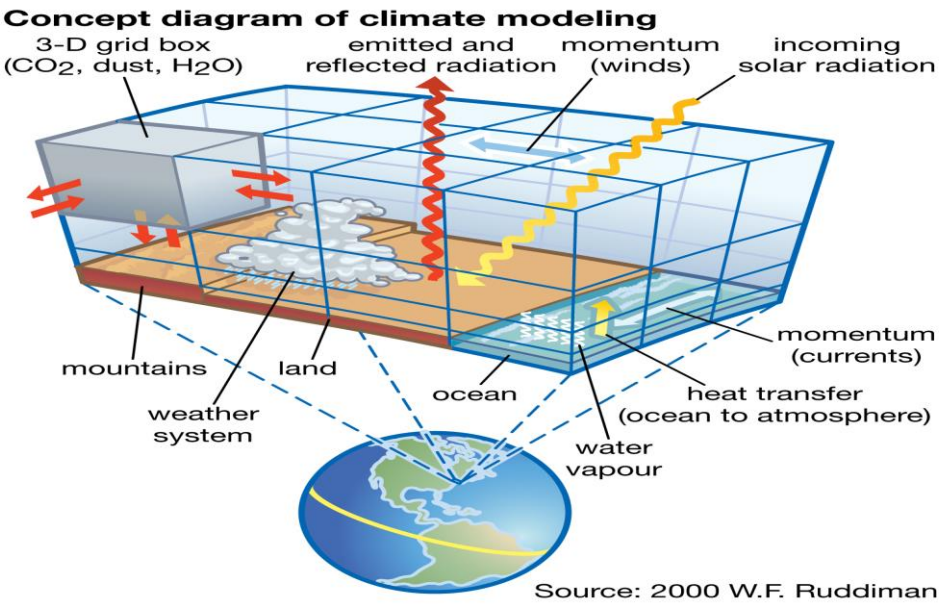
ipcc.ch/about/structure

Framework for governments, scientists and IPCC staff to deliver the most authoritative scientific assessments of climate change.

Regular assessments of the scientific basis of climate change, its impacts future risks and options for mitigation and adaption.

The 5 major assessments (1990, 1996, 2001, 2007 & 2014) have also included global climate modeling as part of the input to decision making.

HOW IS CLIMATE CHANGE PROJECTED INTO THE FUTURE?



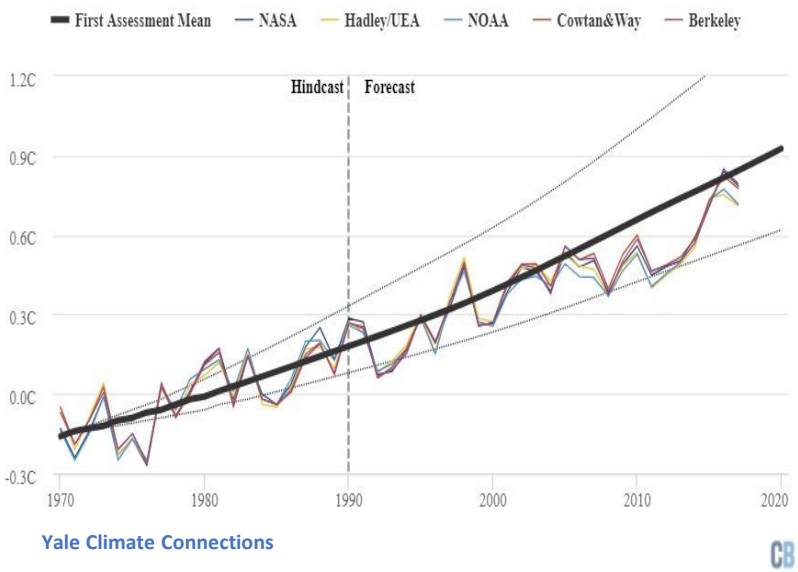
GLOBAL CIRCULATION MODEL

~150 to 600+ km horizontal resolution
~30 to 60 levels vertical resolution

- They have been shown to have skill in replicating the fundamental global processes (warming, sea level rise, etc.).
- Projections focus on the mean and extreme states of the atmosphere and ocean, averaged on the time scales of decades.
- Some crucial processes like clouds and convection, ocean eddies, tropical cyclones, and carbon cycle are crudely represented.
- Regional scale changes have to be addressed through downscaling until higher resolution climate models are reliable.

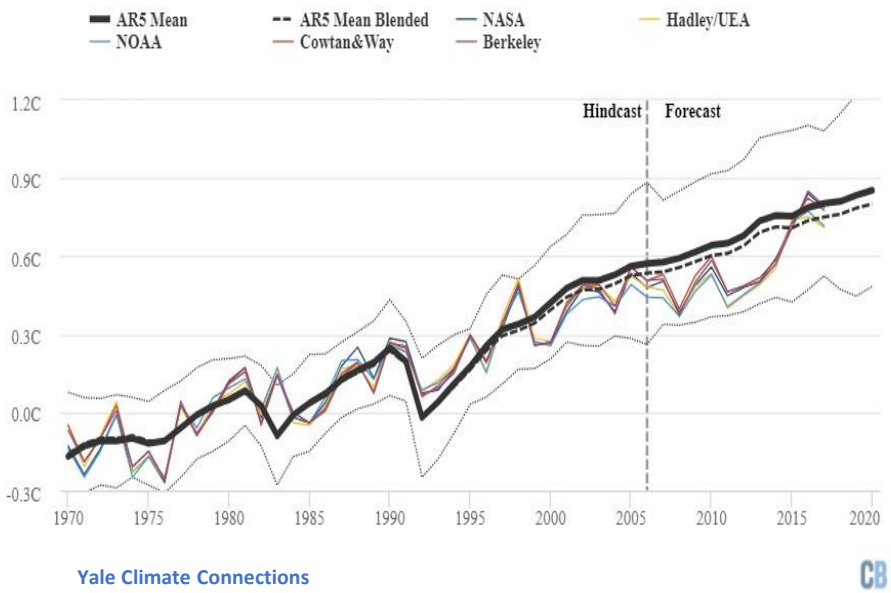
HOW WELL HAVE CLIMATE MODELS PREDICTED GLOBAL WARMING?

1990: IPCC First Assessment Report



Mean Forecast Warming Rate Vs Observations: +17%

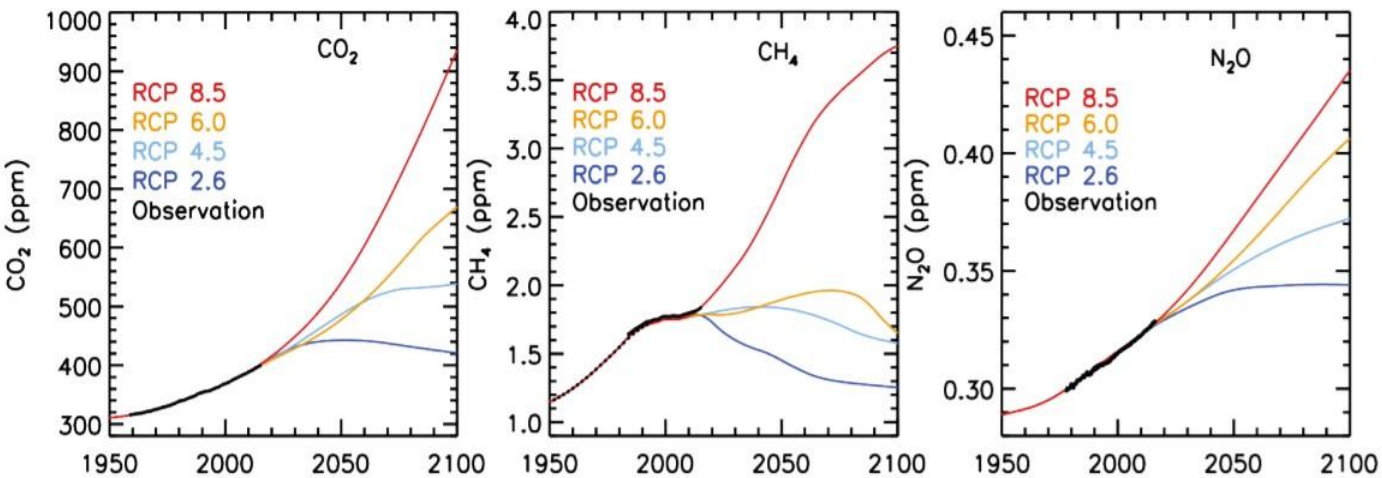
2013: IPCC Fifth Assessment Report



Mean Forecast Warming Rate Vs Observations: +10%

HOW ARE FUTURE GHG CONCENTRATIONS DETERMINED FOR USE IN CLIMATE MODELING?

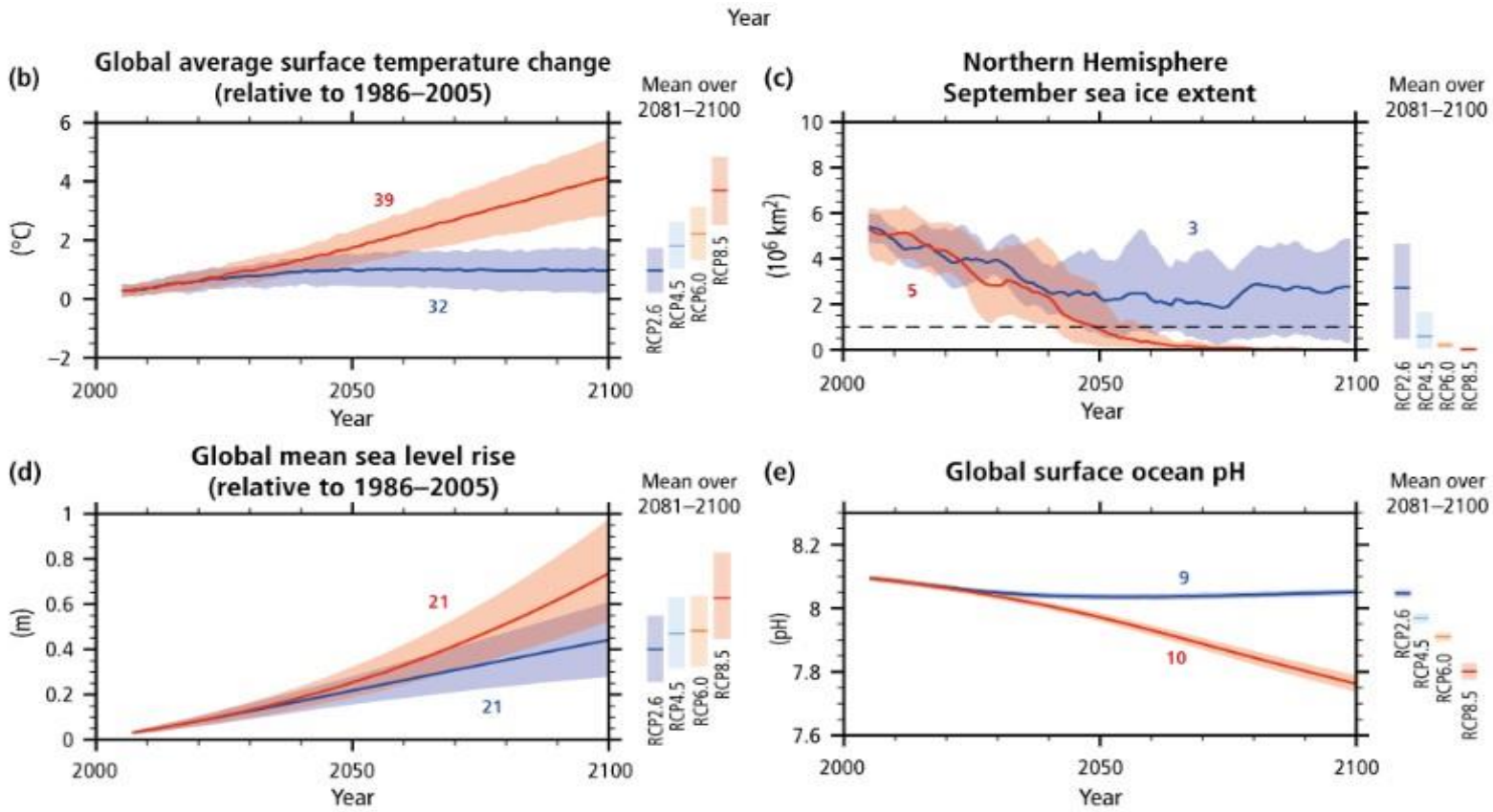
IPCC5 Representative Concentration Pathways (RCP)



Paris Climate Agreement: Beacon of Hope – Figure 2.1

- RCP's are based on 4 different scenarios describing future (2006+) anthropogenic based emissions from each of the economic sectors.
- A stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one with very high GHG emissions (RCP8.5)
- RCP2.6 is representative of a scenario that aims to keep global warming likely below $2^{O}C$ above pre-industrial temperatures.

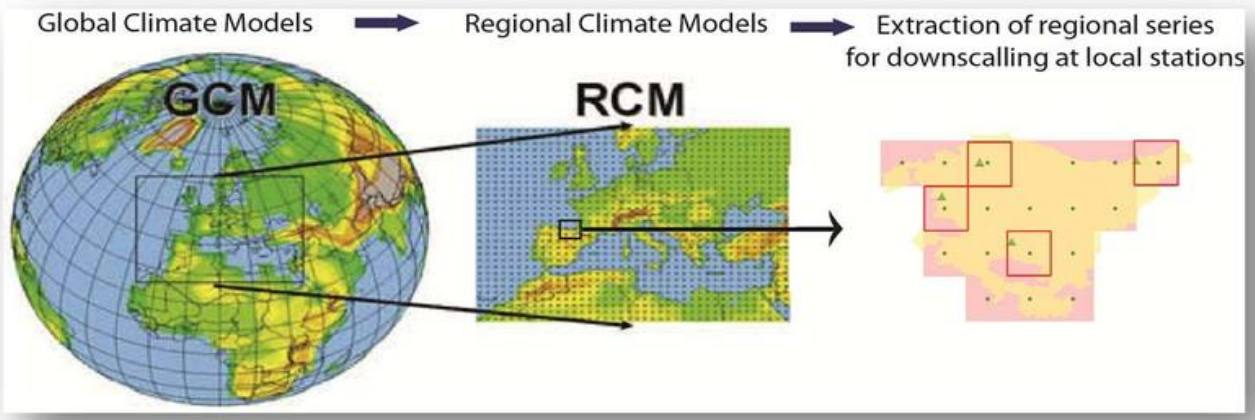
WHAT IS THE RANGE OF POTENTIAL FUTURE OUTCOMES INLCUDED IN IPCC-5?



IPCC AR5 Synthesis Report

HOW CAN GLOBAL CLIMATE MODELS BE USED TO LOOK AT MORE LOCALIZED REGIONS?

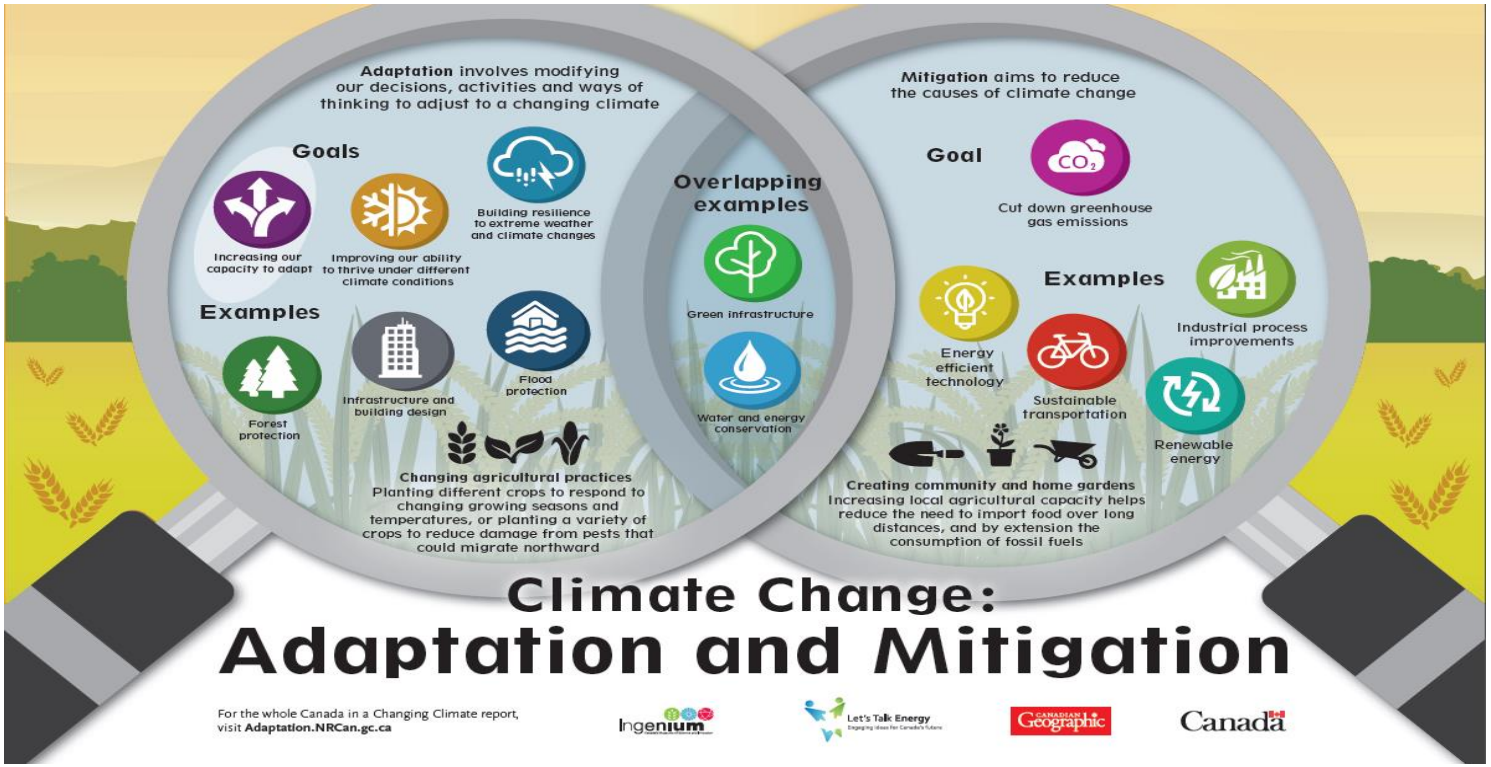
Dynamic Downscaling **Statistical Downscaling**



researchgate.net

- **Dynamical downscaling involves the use of much higher resolution regional numerical models embedded in the global model.**
- **Statistical downscaling can be easily applied, but it requires long-term, high-quality observations to establish robust statistics.**
- **Statistical downscaling can be applied from global to regional scales as well.**

HOW CAN WE ADAPT TO AND MITIGATE CLIMATE CHANGE?



- Adaptation refers to adjustments in ecological, social, or economic systems in response to climate stimuli. **There are limits to it's effectiveness.**
- Mitigation refers to limiting or preventing GHG emissions and enhancing activities that remove these gases from the atmosphere.

WHAT IS THE TASK FORCE ON NATIONAL GREENHOUSE GAS INVENTORIES?

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 [(1)]	CH_4	N_2O	HFCs	PFCs	SF_6	Unspecified mix of HFCs and PFCs	NF_3	Total
	CO_2 equivalent (kt)								
Total (net emissions)[(1)]	1245764.48	36099.86	22667.43	31776.63	3280.06	2165.76		1360.96	1343115.17
1. Energy	1250301.61	2484.74	6712.35						1259498.70
A. Fuel combustion (sectoral approach)	1249822.05	1667.77	6712.26						1258202.08
1. Energy industries	566643.99	293.16	2631.43						569568.59
2. Manufacturing industries and construction	338129.90	493.13	1854.26						340477.29
3. Transport	215803.65	169.55	1974.04						217947.24
4. Other sectors	129244.52	711.93	252.52						130208.96
5. Other	NO	NO	NO						NO
B. Fugitive emissions from fuels	479.56	816.97	0.09						1296.62
1. Solid fuels	0.49	533.12	NO,NE						533.61
2. Oil and natural gas	479.07	283.85	0.09						763.01
C. CO_2 transport and storage	NE,NO								NE,NO
2. Industrial processes and product use	46551.39	46.38	1748.15	31776.63	3280.06	2165.76		1360.96	86929.33
A. Mineral industry	35111.89								35111.89
B. Chemical industry	4757.48	28.13	1389.13	147.44	110.80	92.80		1229.80	7755.57
C. Metal industry	6300.60	18.26	NO	1.29	9.59	159.60			6489.34
D. Non-energy products from fuels and solvent use	299.09	NO	NO						299.09
E. Electronic Industry				111.61	1631.36	351.31		131.16	2225.44
F. Product uses as ODS substitutes				31516.29	1517.95				33034.24
G. Other product manufacture and use			359.02		10.36	1562.06			1931.44
H. Other	82.33	NO	NO						82.33
3. Agriculture	531.74	27958.38	11040.64						39530.76
A. Enteric fermentation		7400.57							7400.57
B. Manure management		2411.31	4543.48						6954.79
C. Rice cultivation		18077.30							18077.30
D. Agricultural soils		NO	6475.78						6475.78
E. Prescribed burning of savannas		NO	NO						NO
F. Field burning of agricultural residues		69.20	21.39						90.59
G. Liming	369.97								369.97
H. Urea application	161.77								161.77
I. Other carbon-containing fertilizers	NO								NO
J. Other		NO	NO						NO
4. Land use, land-use change and forestry[(1)]	-64926.94	57.79	209.36						-64659.80
A. Forest land	-68162.38	3.99	132.34						-68026.05
B. Cropland	3651.84	51.57	26.13						3729.54

IPCC: Example of Greenhouse Gas Emissions Inventory

Develops and refines an internationally-agreed methodology for the calculation and reporting of national GHG emissions and removals.

NASA Earth Observatory

CONCLUSIONS!

- **Human influence on climate change is clear and recent anthropogenic GHG emissions are highest in history, leading to atmospheric concentrations (CO_2, CH_4 & N_2O) that are unprecedented over 800k years.**
- **Resulting warming of the climate system is unequivocal. Since the 50's, observed changes are unprecedented over decades to millennia.**
- **These changes have already had widespread impacts on human and natural systems on all continents and oceans.**
- **Changes in many extreme weather and climate events (temperature and precipitation extremes, sea level rise, drought, etc.) have been observed since the 50's and linked to human influences.**
- **Continued GHG emissions under all assessed scenarios will cause further warming and long lasting changes over the 21st century.**
- **Many aspects of climate change and associated impacts will continue for centuries even if anthropogenic GHG emissions are stopped.**
- **Adaptation and mitigation are complementary strategies for reducing climate change risks and substantial progress needs to be made in both areas beyond what's in place today.**
- **Substantial emissions reductions (near zero for CO_2) will pose significant technological, economic and social challenges.**
- **Effective adaptation and mitigation response will depend on cooperative policies on international, regional, national and local levels.**