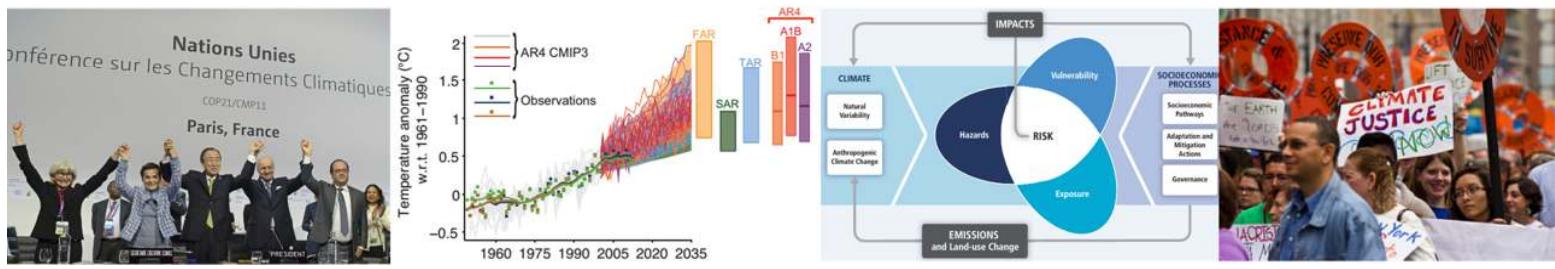




Energy Systems & Climate Change



Climate: Science and Policy

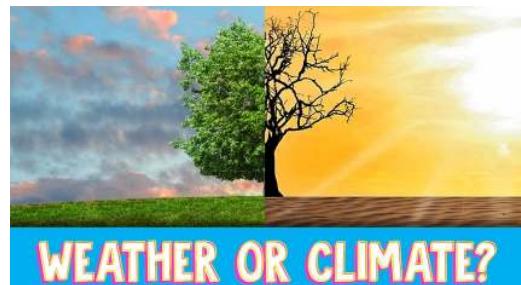
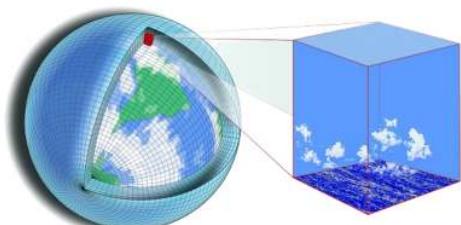
MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.1

Topic 3: Climate – Science and Policy

Material covered in this Topic:

- What is climate?
- Modelling earth's climate
- The global response: UNFCCC, IPCC, and the Paris Agreement



What do we mean by climate?

Consider first a regional or national climate: what metrics are appropriate for describing regional climate?



Average temperature?



Temperature range?



Annual rainfall?



Storm frequency?

What time scale is appropriate?



Year?



Decade?



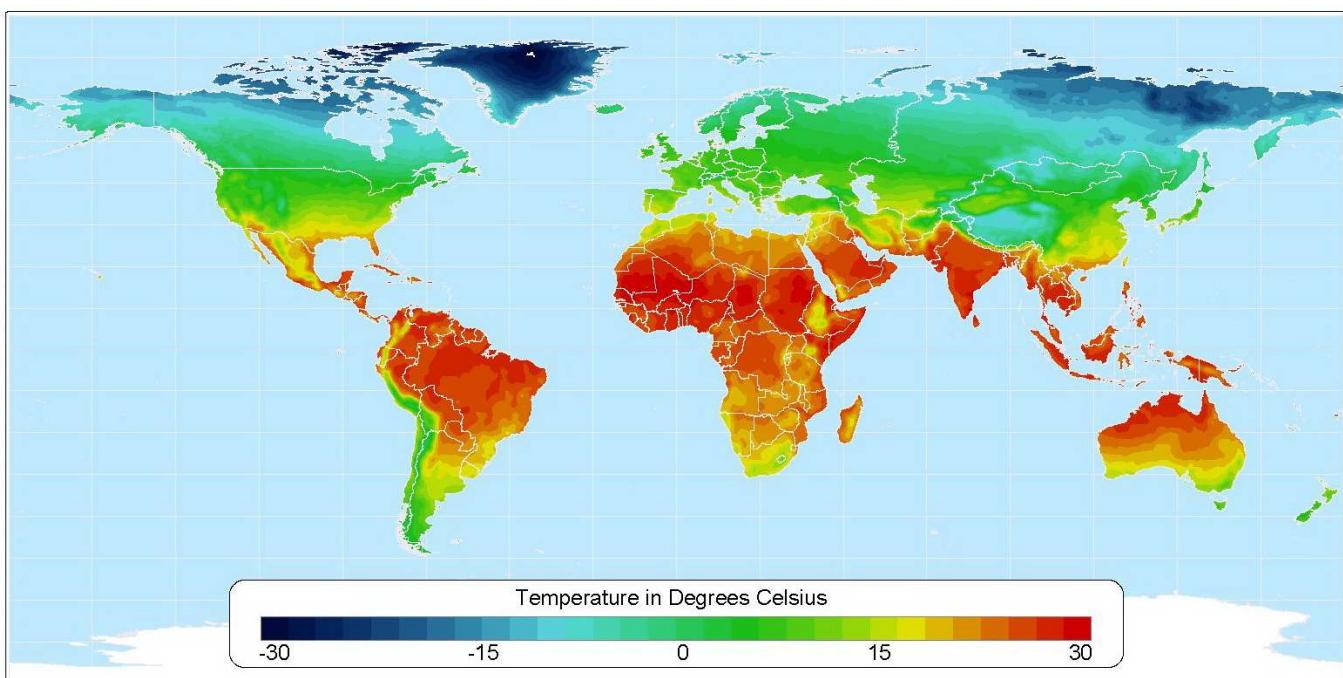
Century?



What do we mean by climate?

Image source: https://nelson.wisc.edu/sage/data-and-models/atlas/maps/avganntemp_atl_avganntemp.jpg

How do we define the global climate? What does "global climate" mean?

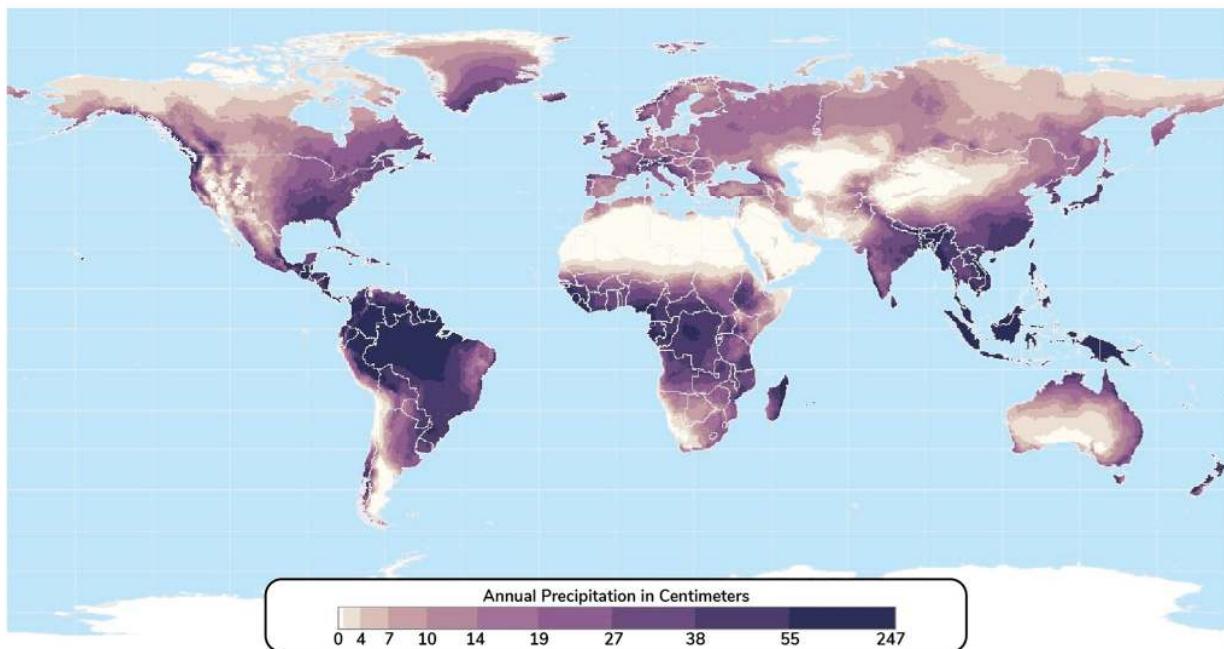


What do we mean by climate?

Image source: https://nelson.wisc.edu/sage/data-and-models/atlas/maps/anntotprecip/atl_anntotprecip.jpg

How do we define the global climate? What does "global climate" mean?

Annual Global Precipitation

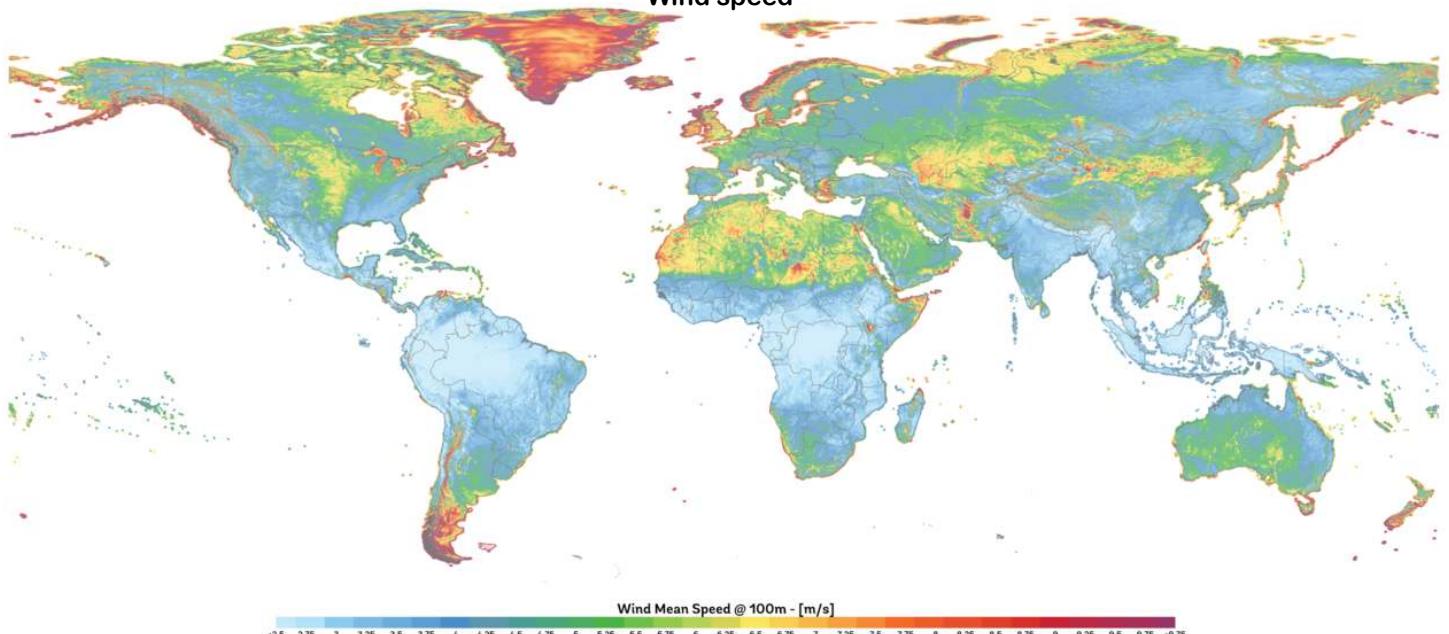


What do we mean by climate?

Image source: https://commons.wikimedia.org/wiki/File:Global_Map_of_Wind_Speed.png

How do we define the global climate? What does "global climate" mean?

Wind speed



What do we mean by climate?

How do we define the global climate? What does "global climate" mean?

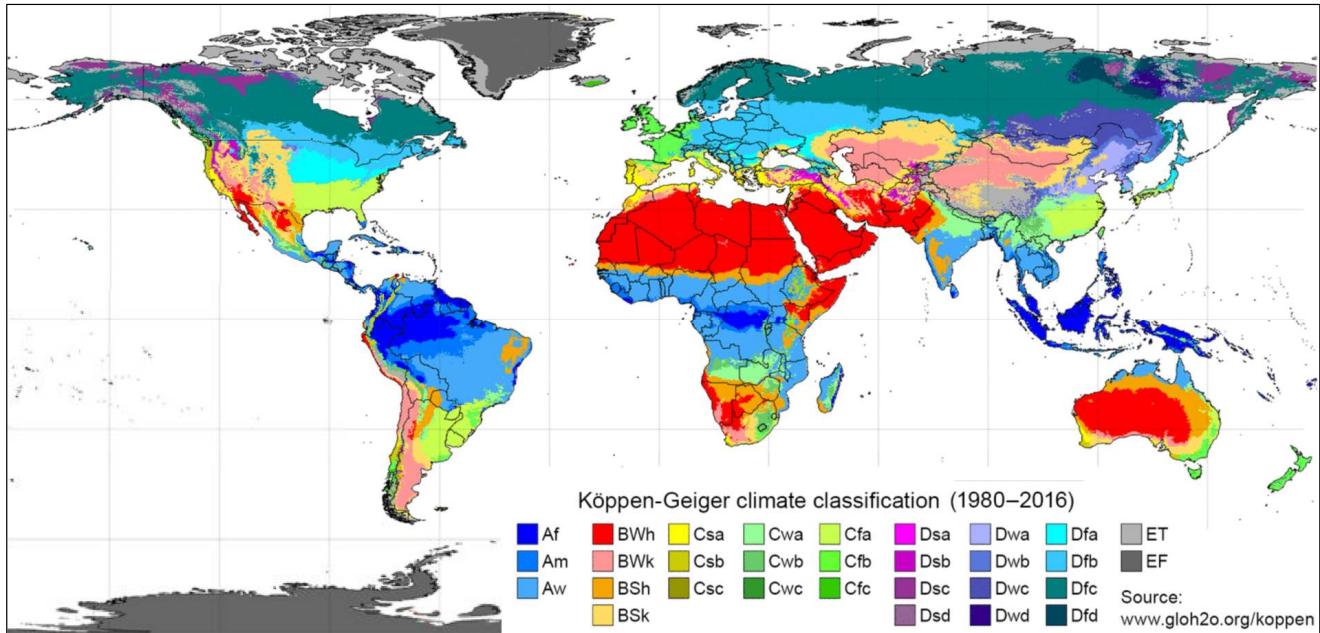


Image source: [https://commons.wikimedia.org/wiki/File:K%C3%B6ppen-Geiger_Climate_Classification_Map.png#/media/File:K%C3%B6ppen-Geiger_climate_classification_\(1980-2016\).png](https://commons.wikimedia.org/wiki/File:K%C3%B6ppen-Geiger_Climate_Classification_Map.png#/media/File:K%C3%B6ppen-Geiger_climate_classification_(1980-2016).png)



What do we mean by climate?

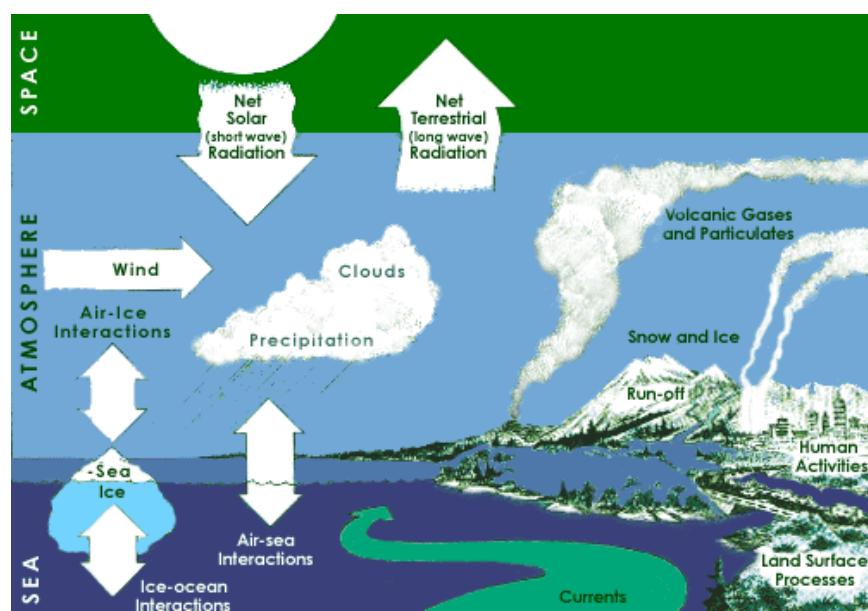
The earth is not a billiard ball...

Radiation, convection and conduction

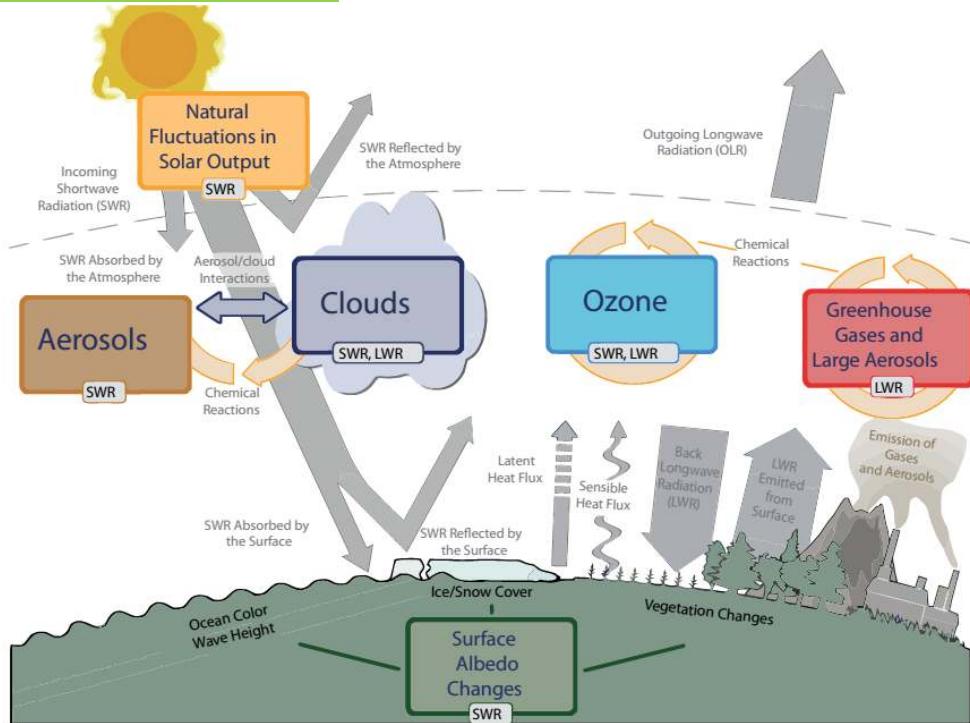
The global hydrological cycle – phase change

Dynamically, a chaotic system

- Sahara versus Bahamas and Northern India
- Ireland versus Newfoundland, etc.



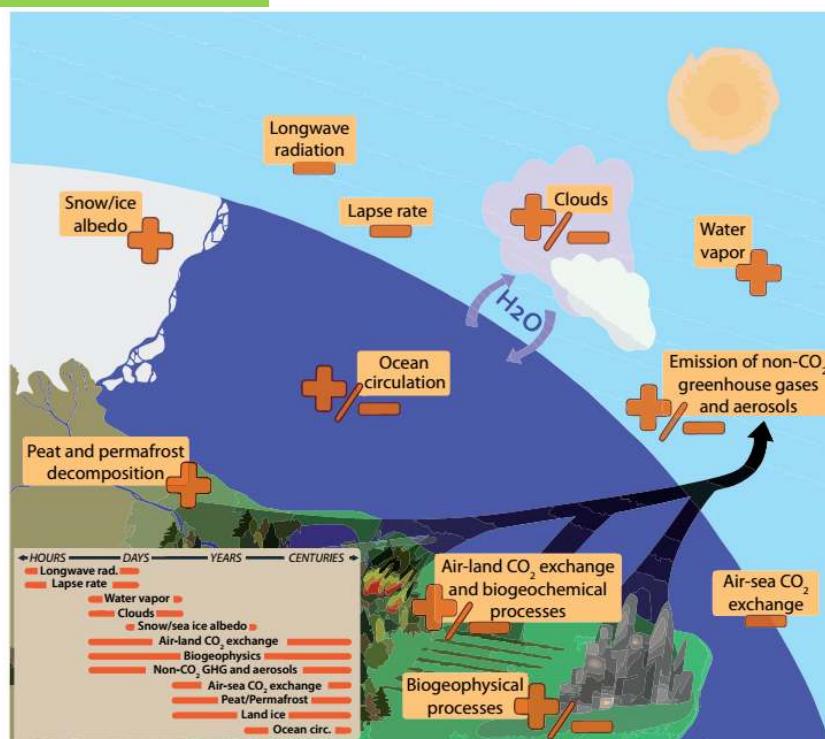
What do we mean by climate?



*Source: Figure 1.1, AR5 WG1 The Physical Science Basis. IPCC (2014)



What do we mean by climate?



*Source: Figure 1.2, AR5 WG1 The Physical Science Basis. IPCC (2014)



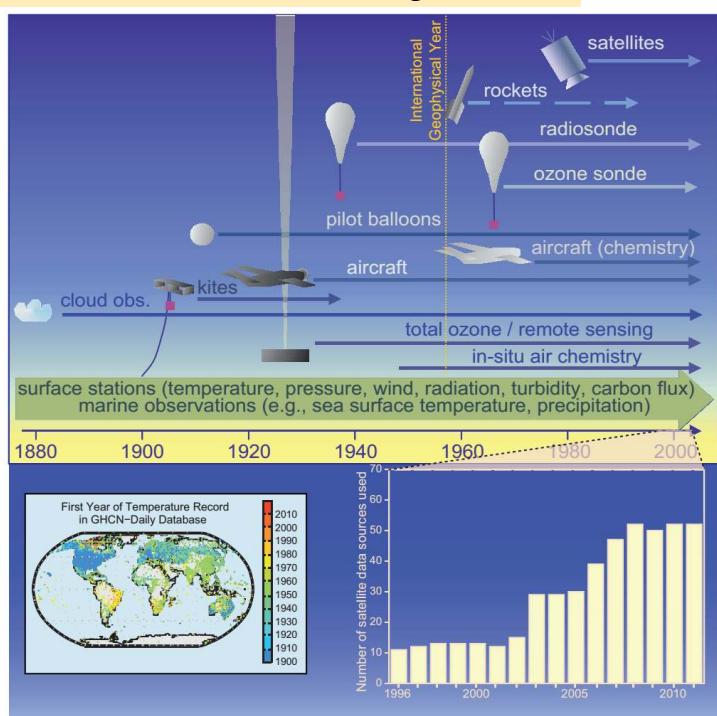
Observations of climate change

The quality of our temperature measurements depends on:

- Spatial coverage
- Length of record
- Accuracy of data
- Choice of variable (TLT, "surface" temperature, "ocean" temperature, etc.)
- Measurement discrimination (e.g. UHI effect)
- ...etc.



Observations of climate change



Source: Figure 1.12, AR5 WG1 The Physical Science Basis. IPCC (2014)

Records of "recent" temperature come from 2 main sources:

- Direct measurements of air or seawater temperature (since about 1850);
- Air temperatures inferred by satellites from upwelling radiation signals (since 1979);

Records of pre-industrial temperature are inferred from "proxies", such as tree-ring thickness, oxygen-isotope ratio, etc.



Observations of climate change

1. Direct measurements of temperature

- How are they made?
- How are they used to establish a global mean temperature?
- What are the challenges for interpreting the data?



Observations of climate change

Measurements on land

Stevenson screen:

- Box is 1.25 m above ground level
- Painted white
- Protected from rain, snow, leaves, animals, etc.
- Louvres protect from wind, but permit ventilation



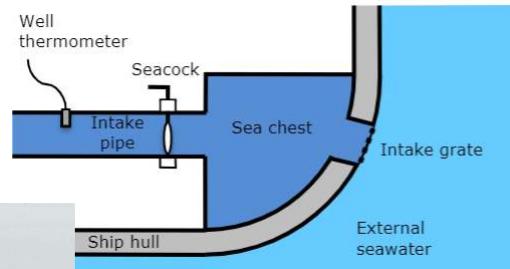
Traditionally recorded manually, once or twice per day; more recent versions transmit automatically.



Observations of climate change

Measurements at sea

- Buckets.....(~1850 – ~1940)
- Ship engine cooling water intake..... (~1940 – 2000)
- Moored and drifting buoys (~1970 – now)
- “Argo” floats..... (2010 – now)



Climate: Science and Policy

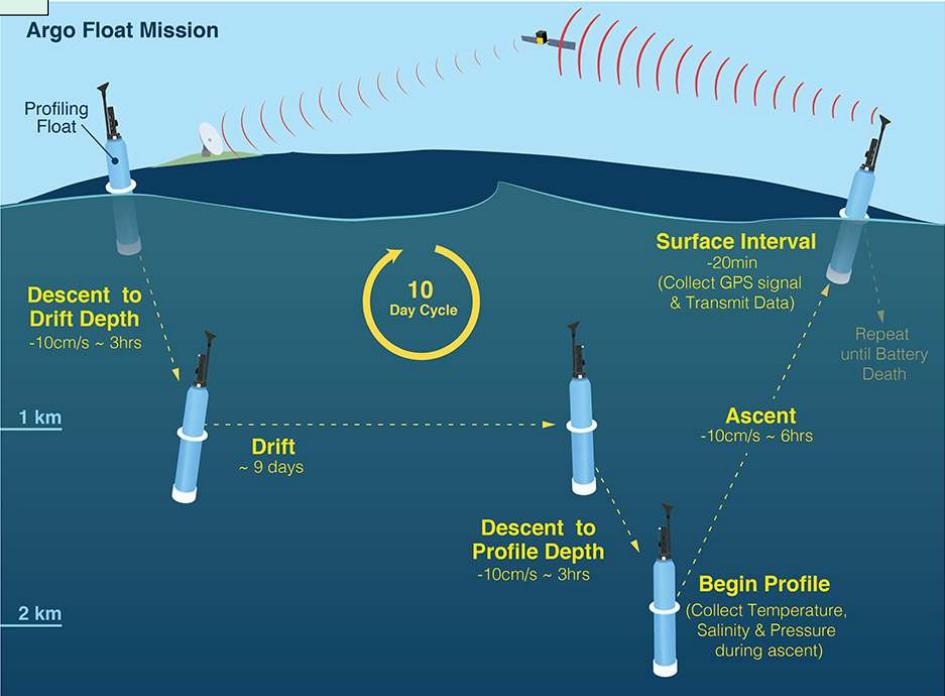
MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.15

Observations of climate change

Measurements at sea – Argo floats

- International program
- Fleet of robotic instruments that drift with the ocean currents and move up and down between the surface and a mid-water level.
- Each instrument (float) spends almost all its life below the surface.
- <https://argo.ucsd.edu/>



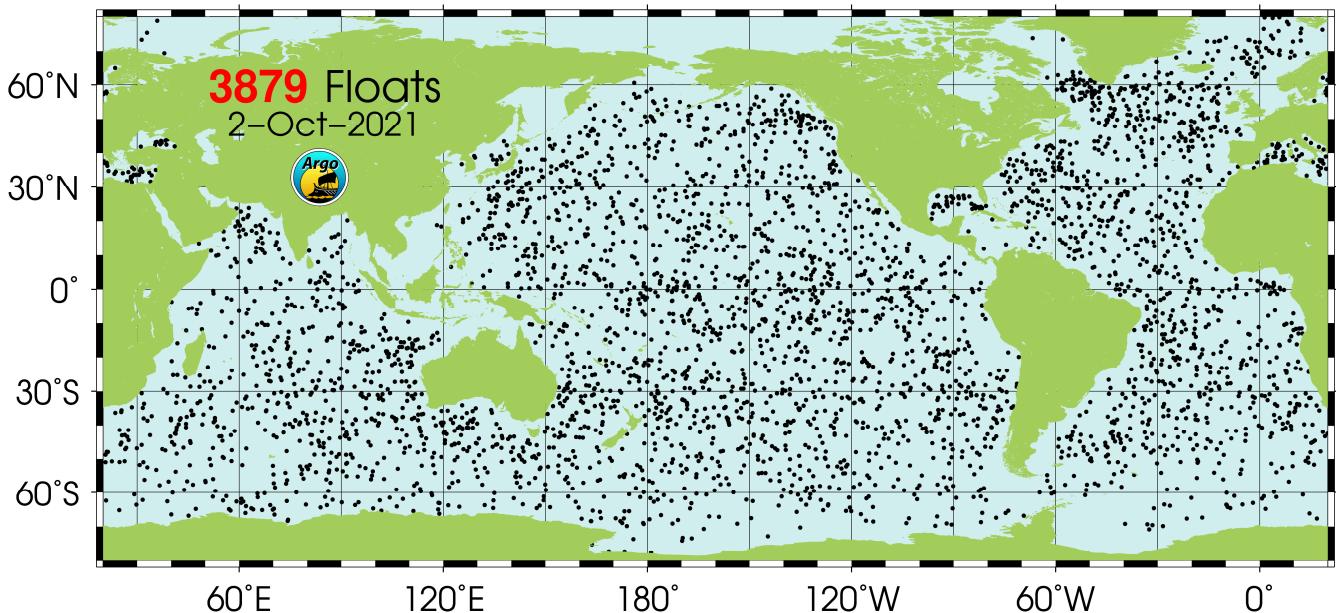
Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.16

Observations of climate change

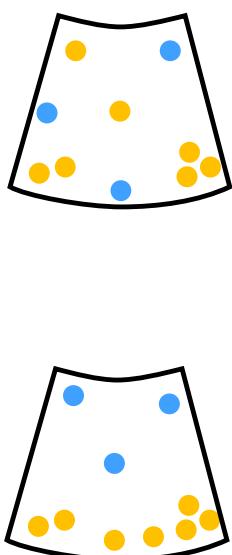
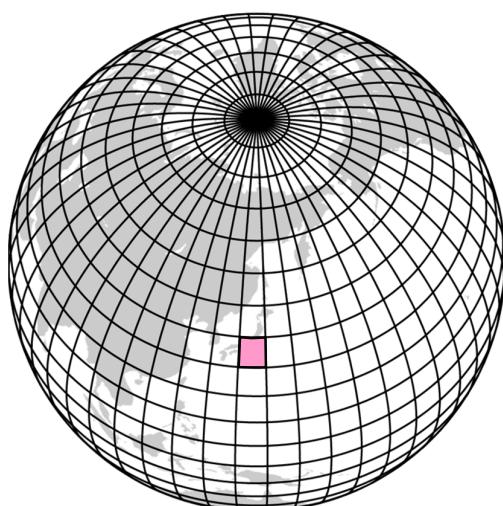
Measurements at sea – Argo floats



Observations of climate change

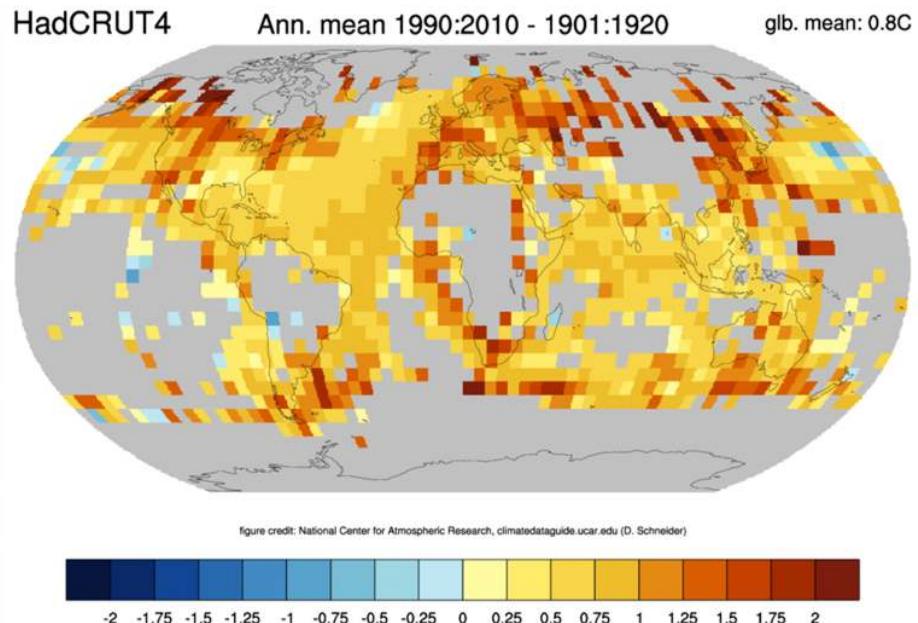
Deriving a global temperature from point measurements

- Homogenisation
(within a 5 deg. x 5 deg. cell)



Observations of climate change

Deriving a global temperature from point measurements



Observations of climate change

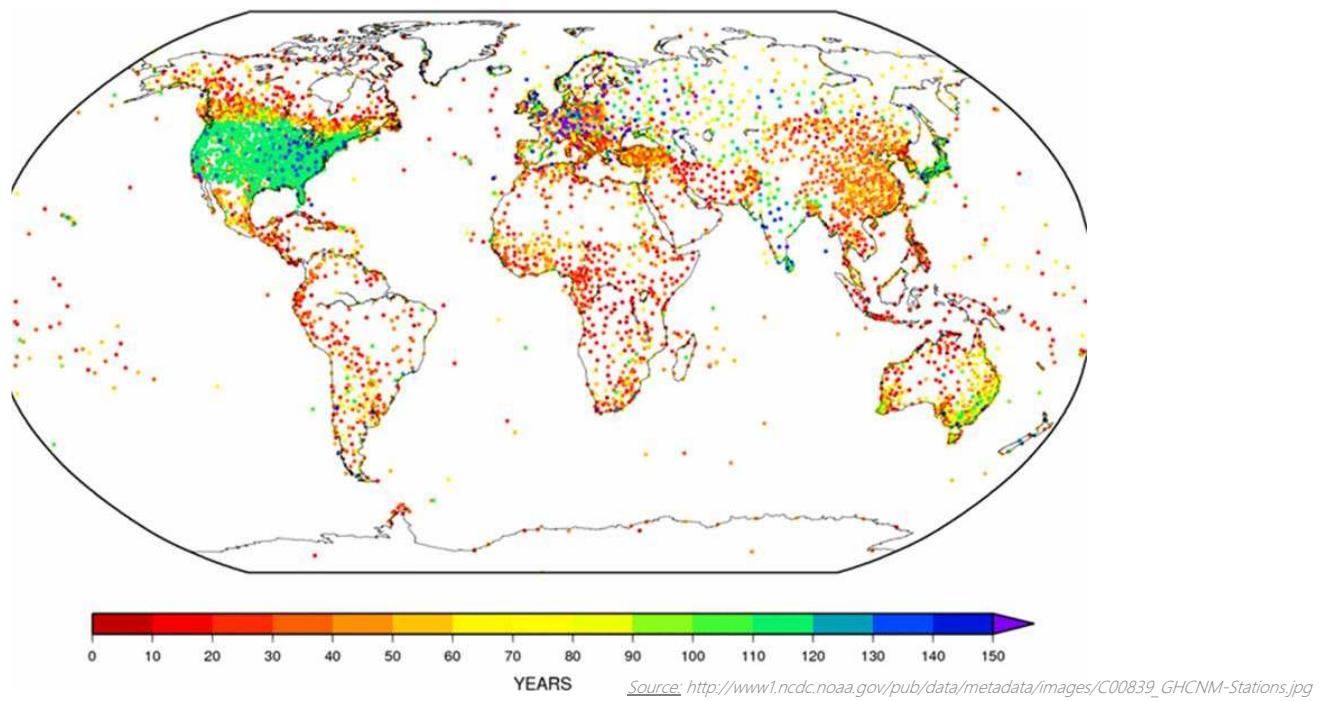
Challenges with interpreting direct measurements

- Age of station (length of record)
- Distribution of measurement locations
- Density of measurement locations
- Calibration, consistency, and accuracy
- Urban Heat Island (UHI)
- ...etc.



Observations of climate change

The GHCN station network, coloured by age of station



Observations of climate change

Urban Heat Island (UHI) effect

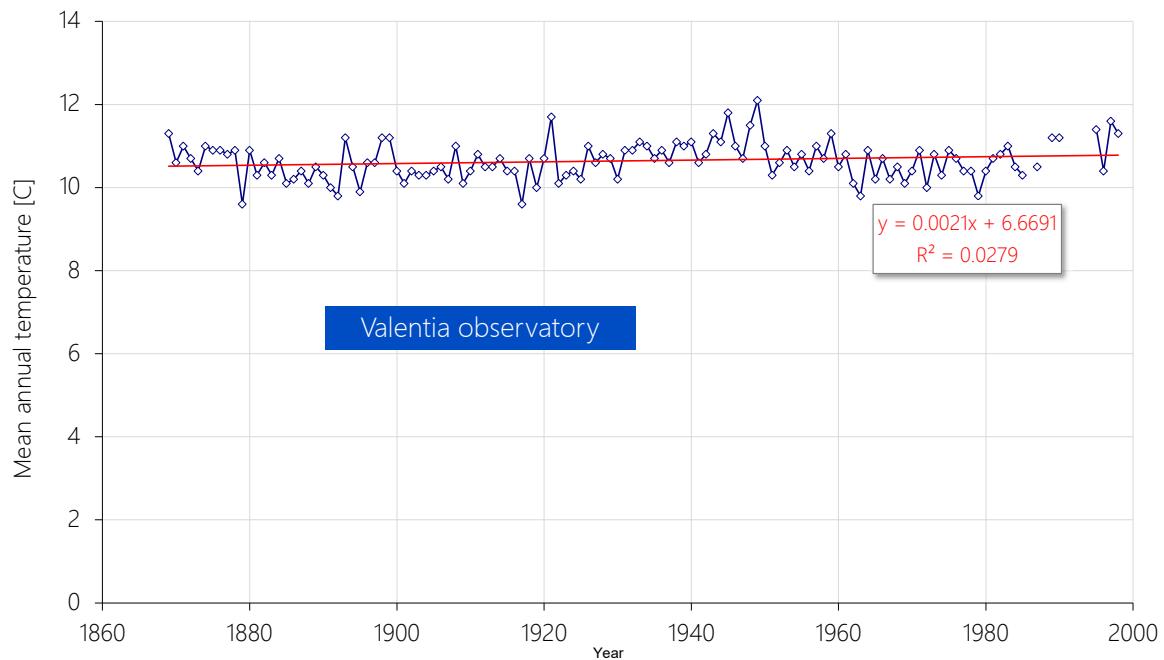


Dublin airport

Valentia observatory



Observations of climate change



Raw data: <http://dss.ucar.edu/datasets/ds570.0/>

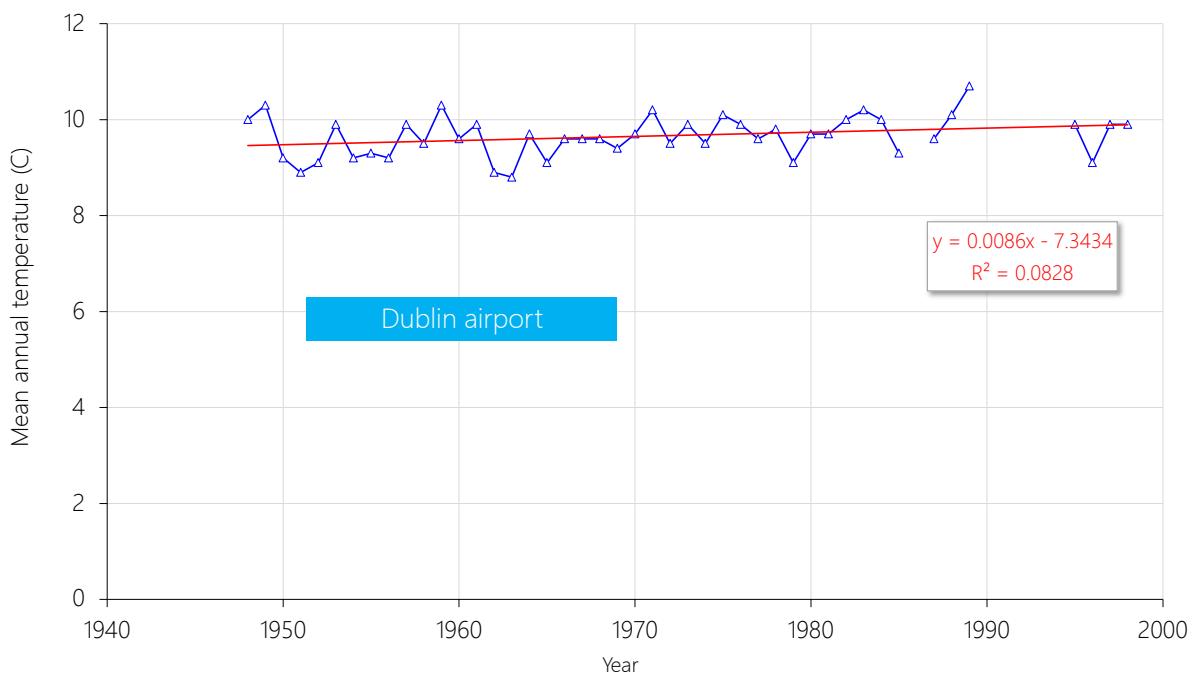


Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.23

Observations of climate change



Raw data: <http://dss.ucar.edu/datasets/ds570.0/>

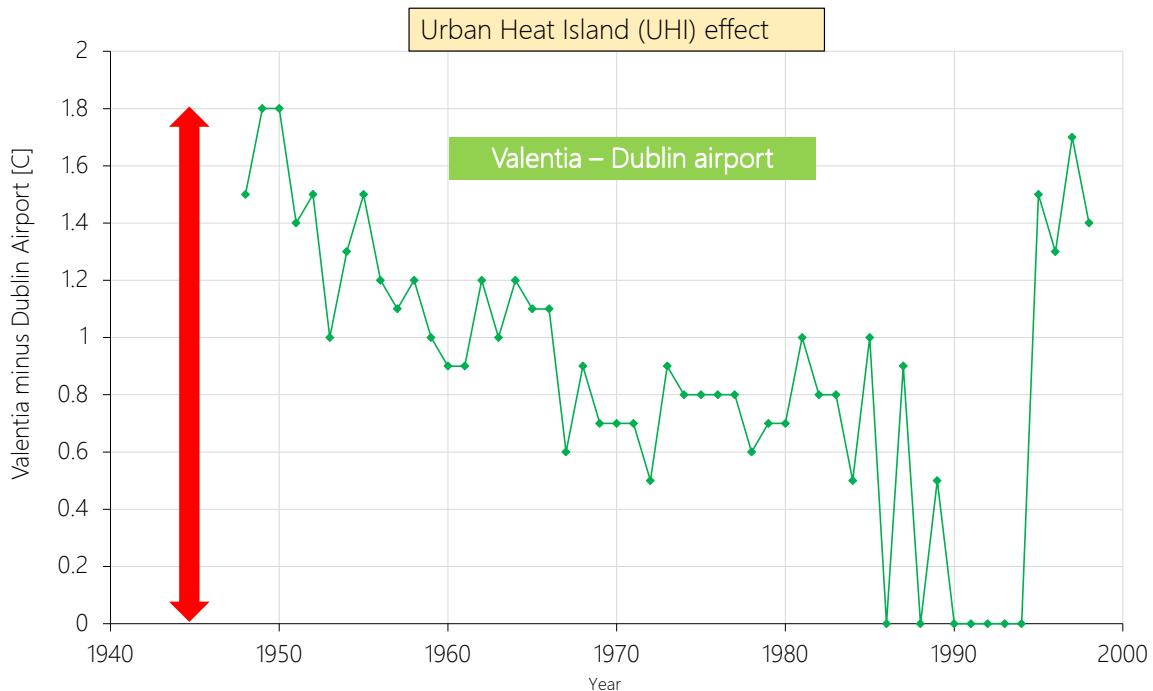


Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.24

Observations of climate change

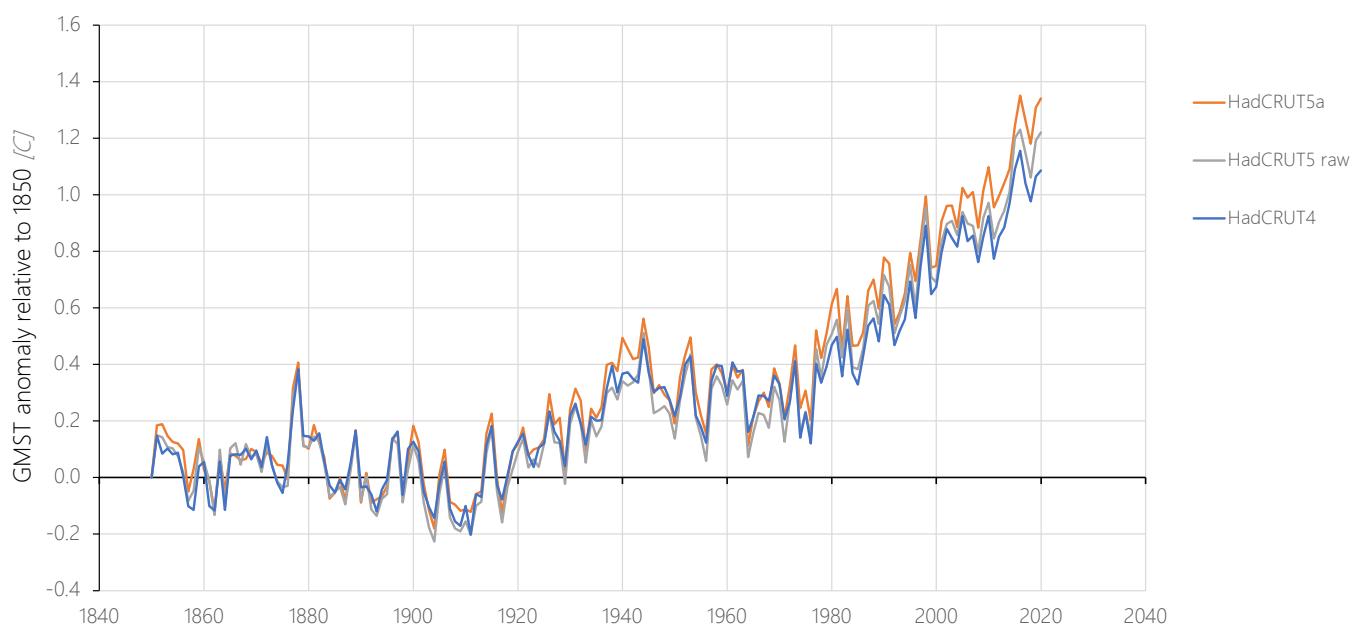


Raw data: <http://dss.ucar.edu/datasets/ds570.0/>

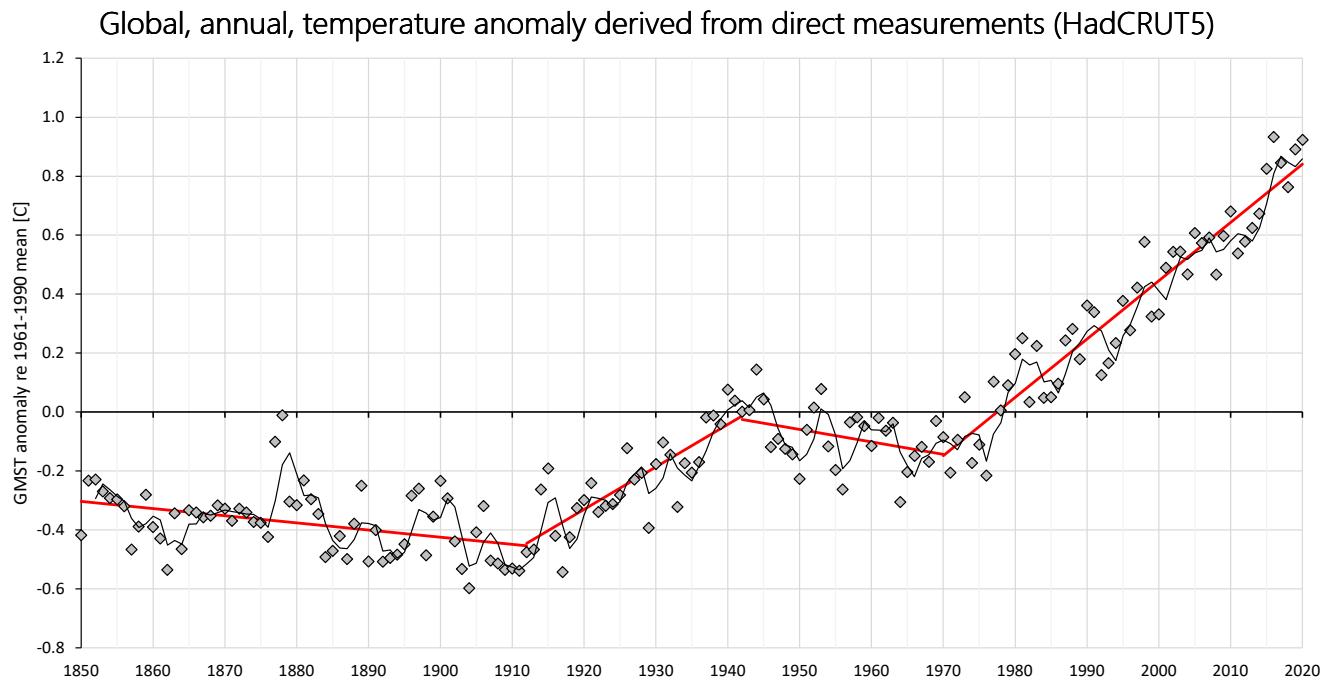


Observations of climate change

Global, annual, temperature anomaly derived from direct measurements (HadCRUT)



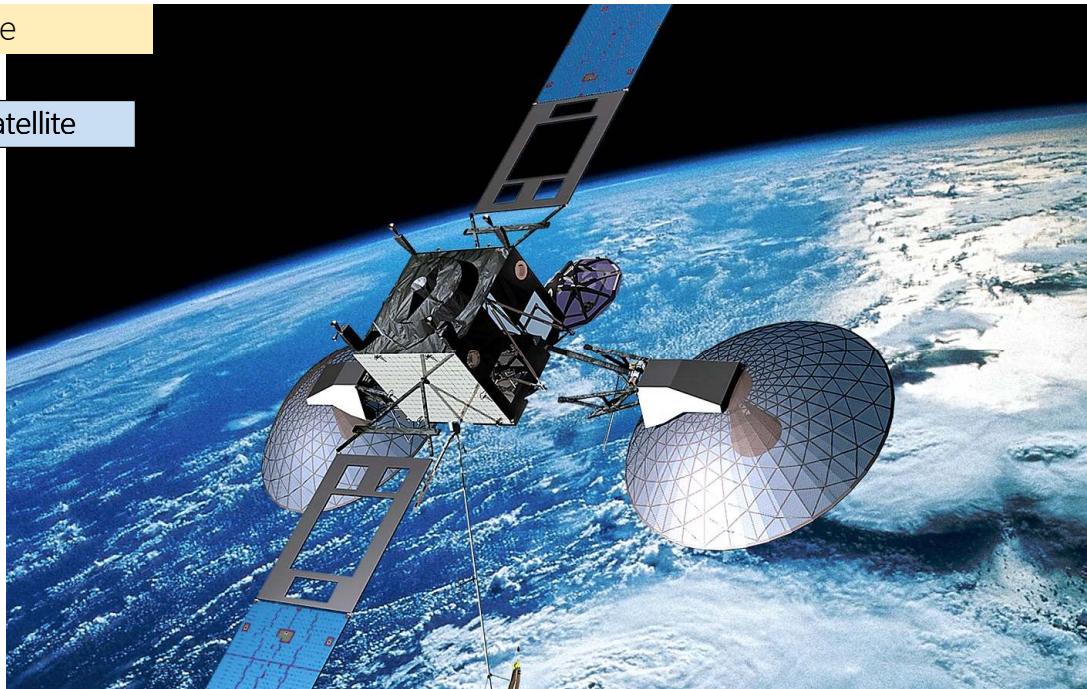
Observations of climate change



Observations of climate change

2. Indirect measurements by satellite

- How are the measurements made?
- How are they used to establish a global mean temperature?
- What are the challenges for interpreting the data?



Observations of climate change

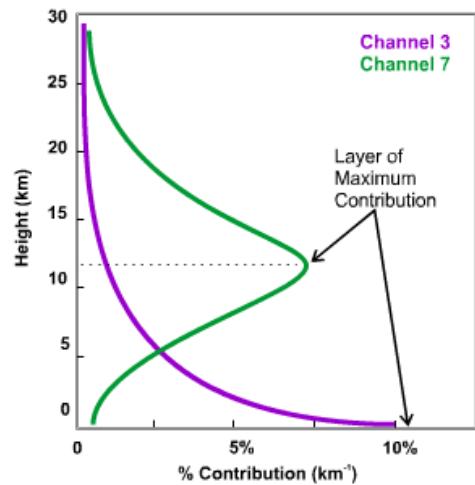
Advanced Microwave Sounding Unit (AMSU)

- Senses microwave radiation emitted by molecular oxygen.
- Molecular oxygen absorbs strongly at some frequencies, but not as strongly at others, e.g.:

Satellites – how are the measurements made?

Channel 3:

- Weak absorption at 50.3 GHz (channel 3);
- Radiation emitted from O₂ near the surface passes through the atmosphere without much absorption.
- Most of the 50.3 GHz radiation that reaches the satellite comes from the earth's surface (that's where most of the O₂ is).



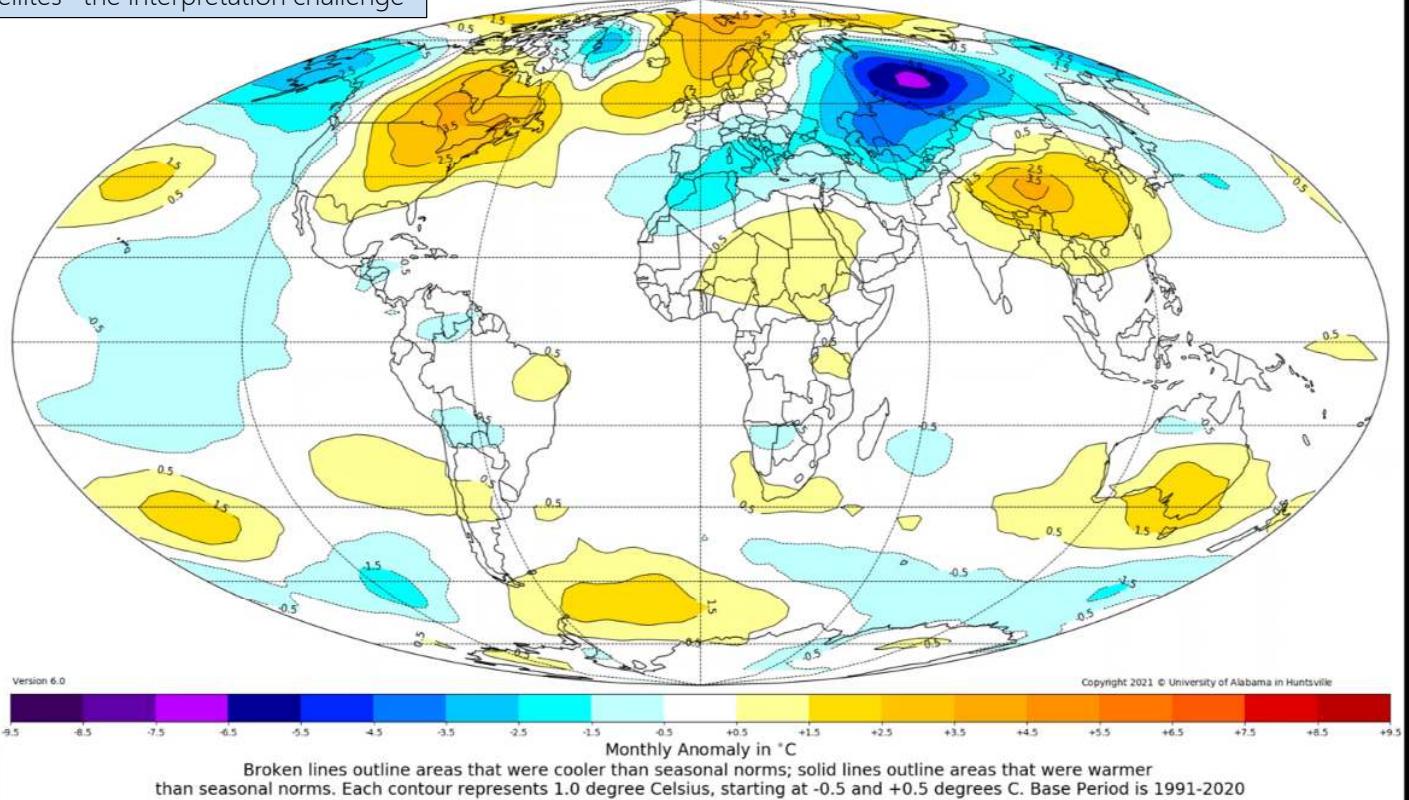
Channel 7:

- Strong absorption at 54.9 GHz (channel 7);
- Radiation emitted from O₂ near the surface is mostly absorbed;
- Most of the 54.9 GHz radiation that reaches the satellite comes from ~12 km above earth's surface.



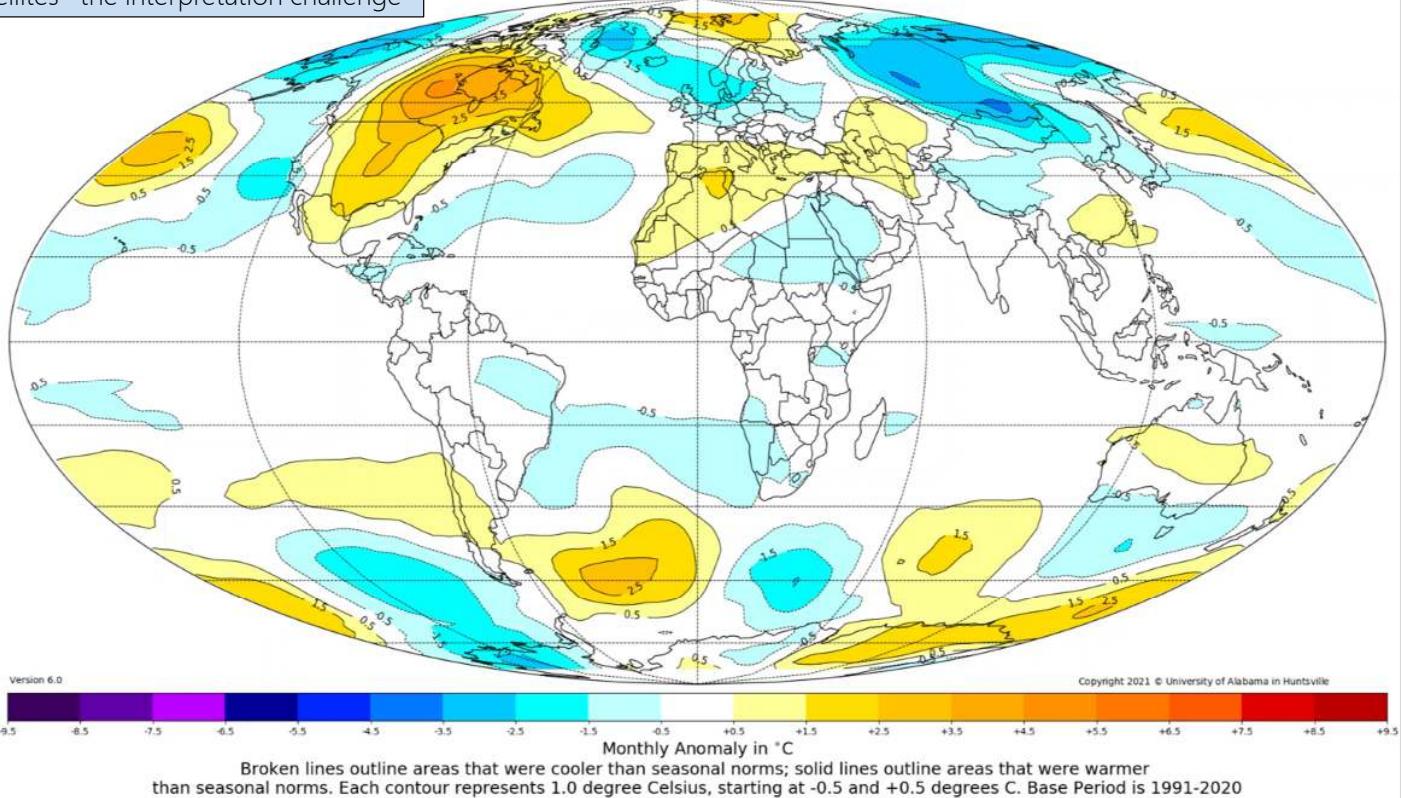
Satellites –the interpretation challenge

JANUARY 2006
LAYER = LT LOWER TROPOSPHERE



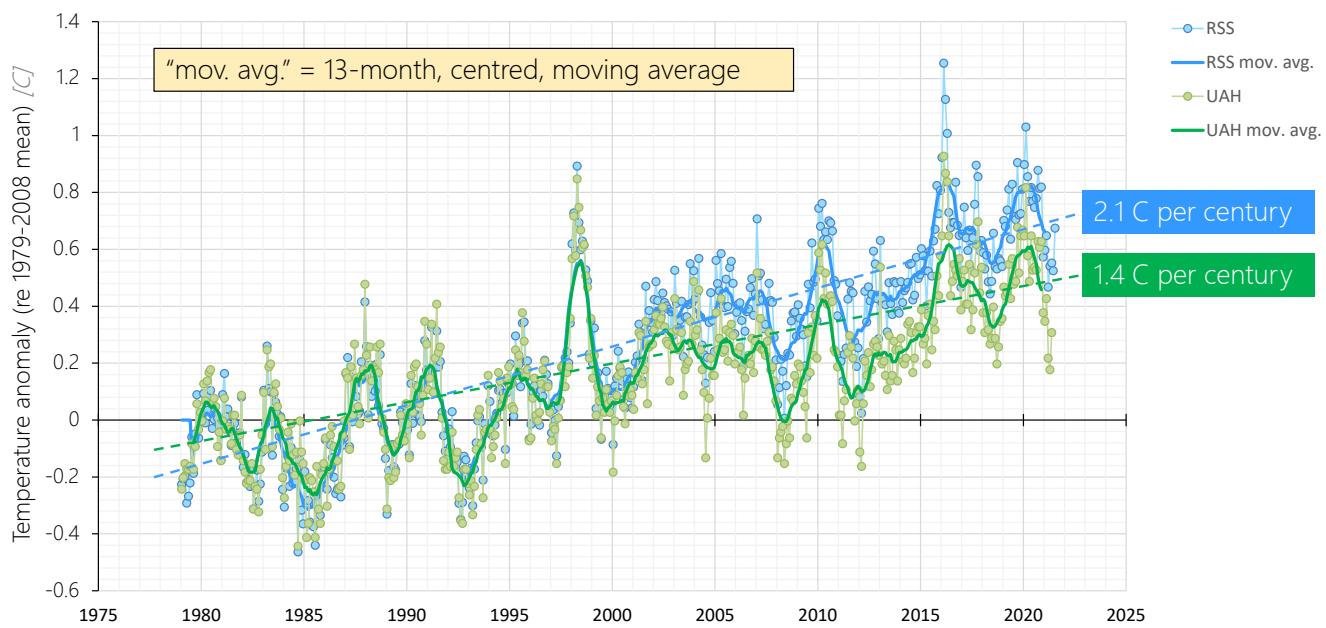
Satellites –the interpretation challenge

APRIL 2006
LAYER = LT LOWER TROPOSPHERE



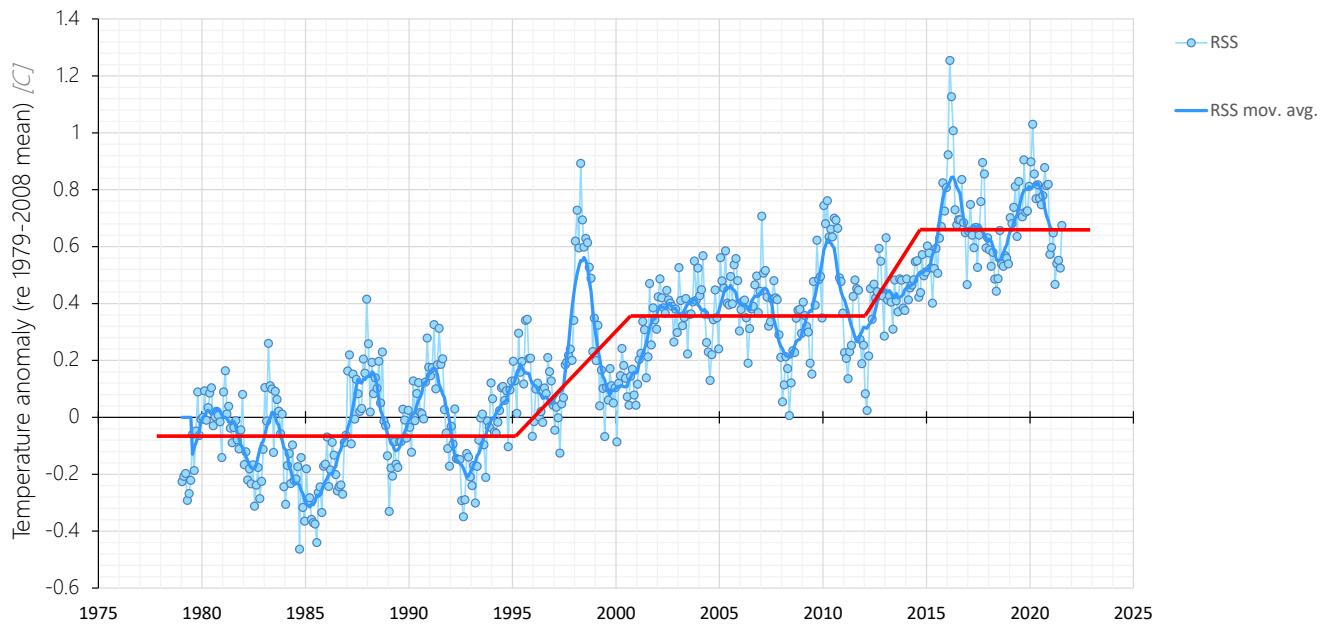
Observations of climate change

Satellite-based temperature data compared



Observations of climate change

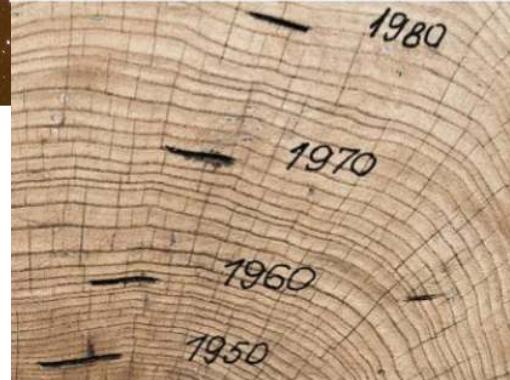
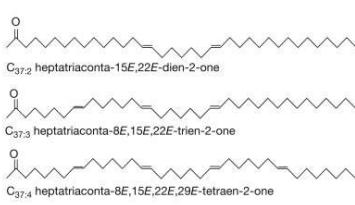
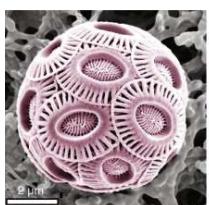
Interpretation of satellite-based temperature data



Observations of climate change

3. Indirect measurements using proxies

- How are they made?
- How are they used to establish a global mean temperature?
- What are the challenges for interpreting the data?



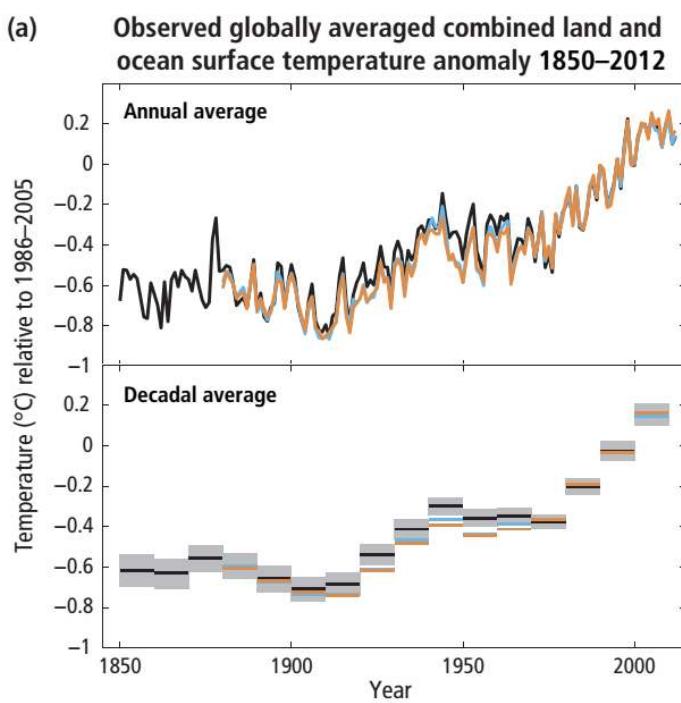
Observations of climate change

Temperature measurements – interim summary

1. Determining the current global average temperature is difficult.
2. Determining recent global average temperature, even during the satellite era, is even more difficult.
3. Determining global average temperature, back to 1850, is more difficult still.
4. Determining global average temperature, before 1850, has pretty wide uncertainty bars.



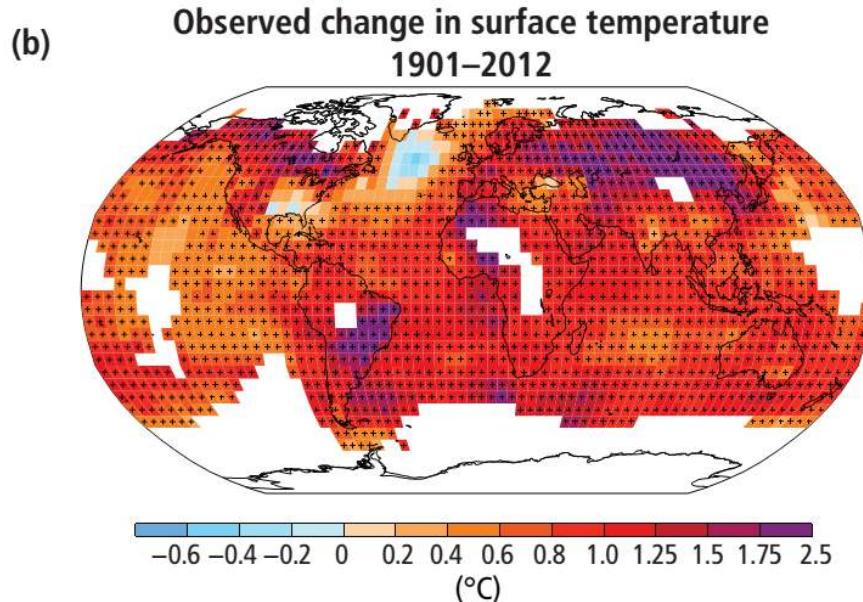
Observations of climate change



Source: Figure 1.1, AR5 Synthesis Report. IPCC (2014)



Observations of climate change



"Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850."

(AR5 Synthesis Report p40. IPCC (2014))

Source: Figure 1.1, AR5 Synthesis Report. IPCC (2014)

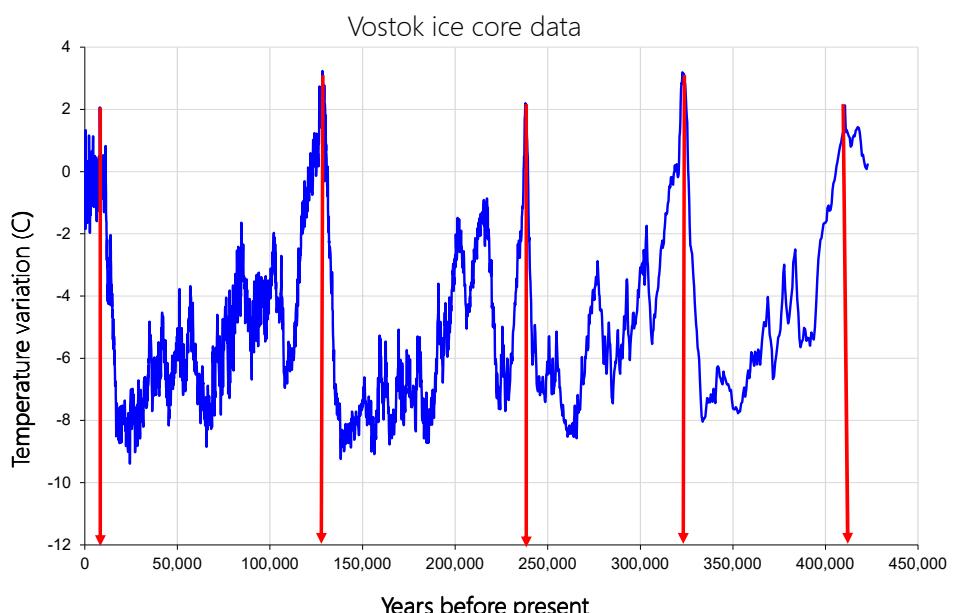


Observations of climate change

Temperature is not constant

"Periodic" temperature swings of 10-12 C have occurred.

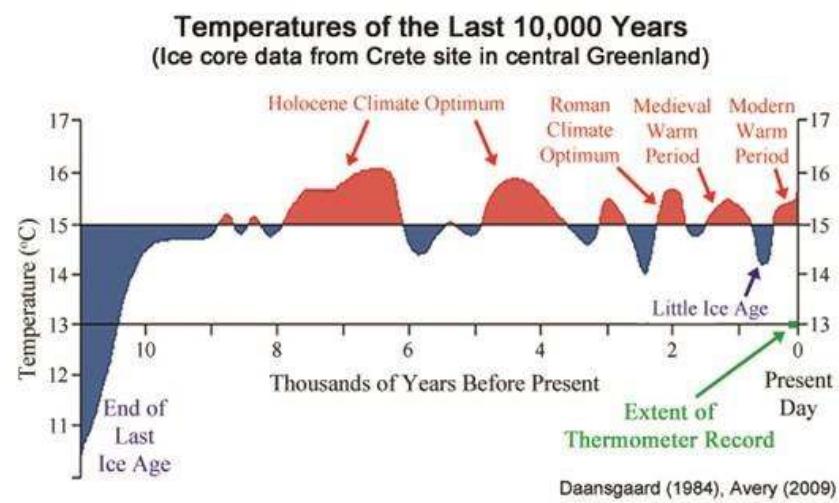
Current absolute temperature levels are not unprecedented.



Source: http://cdiac.esd.ornl.gov/ftp/trends/temp/vostok/vostok_1999.temp.dat



Observations of climate change



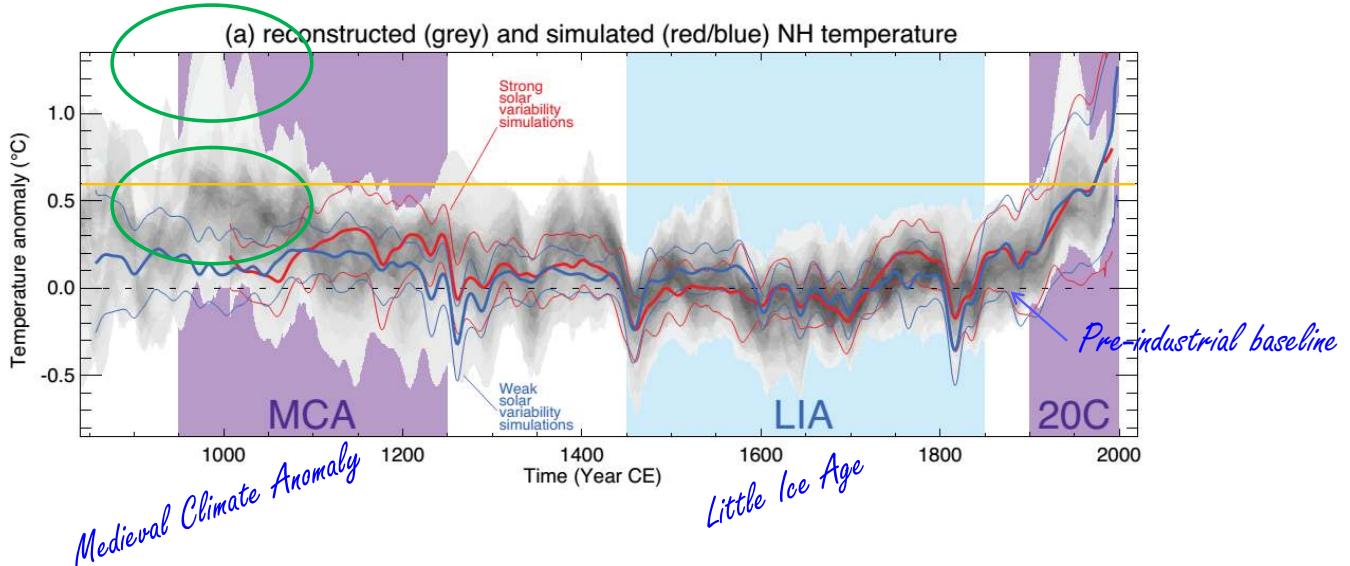
Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.39

Observations of climate change

Steve McIntyre's discussion (<https://climateaudit.org/>) of temperature reconstructions used to inform AR6 are disconcerting.



Source: Figure 5.8, AR5 WG1 The Physical Science Basis. IPCC (2014)



Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.40

Observations of climate change

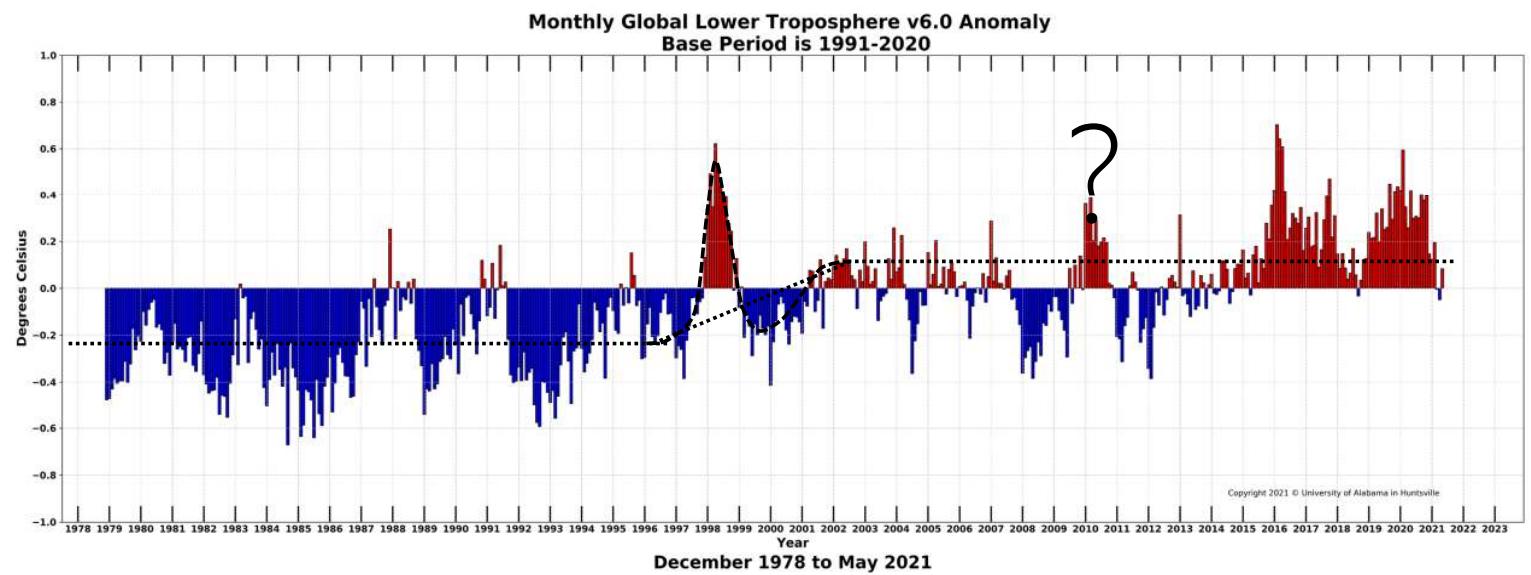


Chart source: https://www.nsstc.uah.edu/climate/2020/september/202009_bar.png

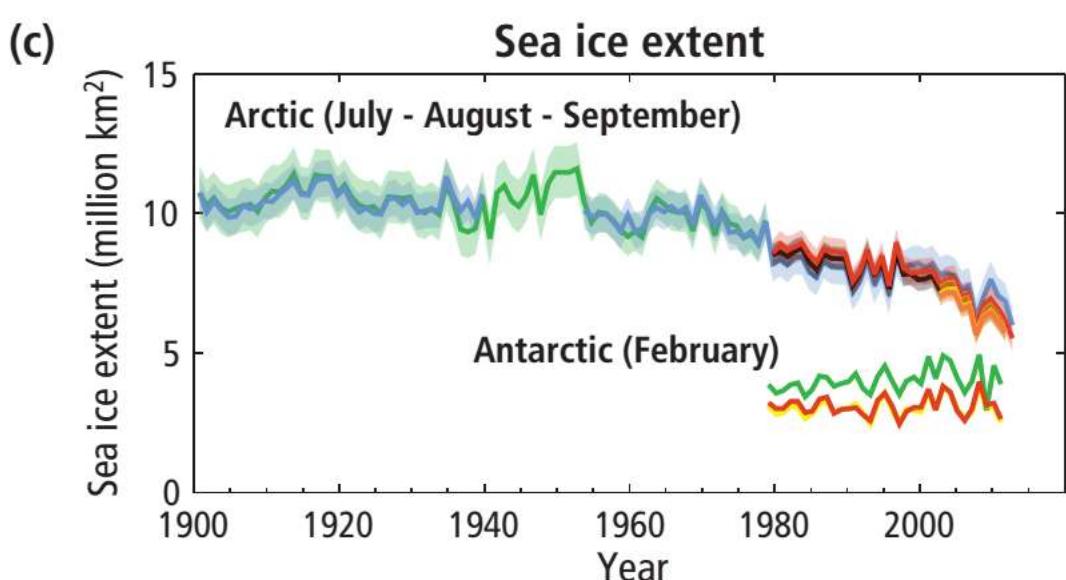


Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.41

Observations of climate change



Source: Figure 1.1, AR5 Synthesis Report. IPCC (2014)

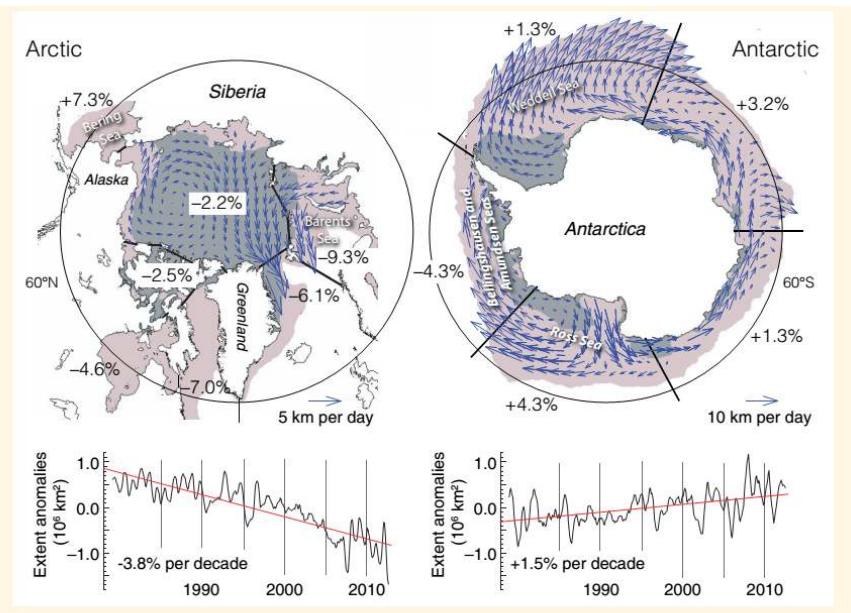


Climate: Science and Policy

MEEN 40090
Energy Systems & Climate Change

WJS Slide 3a.42

Observations of climate change



FAQ 4.1, Figure 1 | The mean circulation pattern of sea ice and the decadal trends (%) in annual anomalies in ice extent (i.e., after removal of the seasonal cycle), in different sectors of the Arctic and Antarctic. Arrows show the average direction and magnitude of ice drift. The average sea ice cover for the period 1979 through 2012, from satellite observations, at maximum (minimum) extent is shown as orange (grey) shading.

Source: FAQ 4.1, Figure 1, AR5 WG1 The Physical Science Basis. IPCC (2014)



Observations of climate change

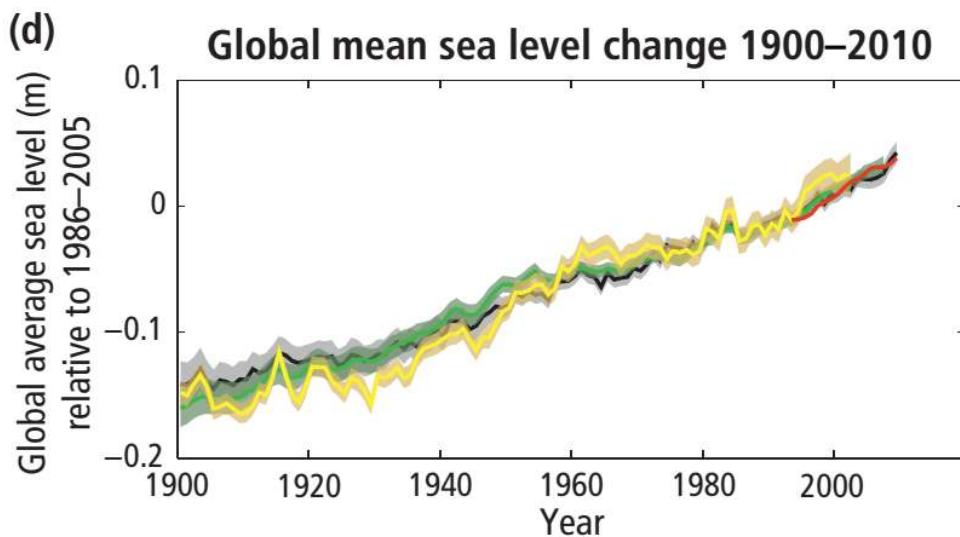
- “Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass (high confidence).”
- “Glaciers have continued to shrink almost worldwide (high confidence).”
- “Northern Hemisphere spring snow cover has continued to decrease in extent (high confidence).”
- “There is high confidence that there are strong regional differences in the trend in Antarctic sea ice extent, with a very likely increase in total extent.”



Source: AR5 Synthesis Report, p40. IPCC (2014)



Observations of climate change

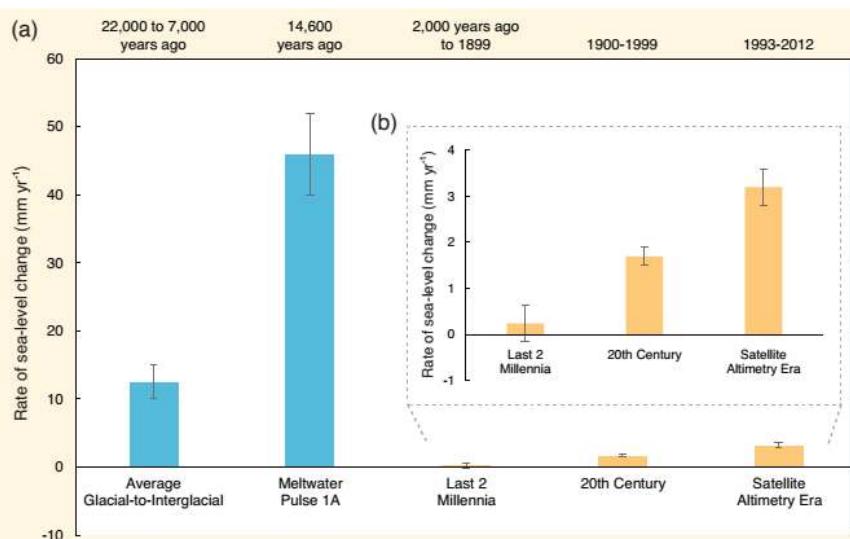


"Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m"

"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*)."

Source: Figure 1.1, AR5 Synthesis Report. IPCC (2014)

Observations of climate change

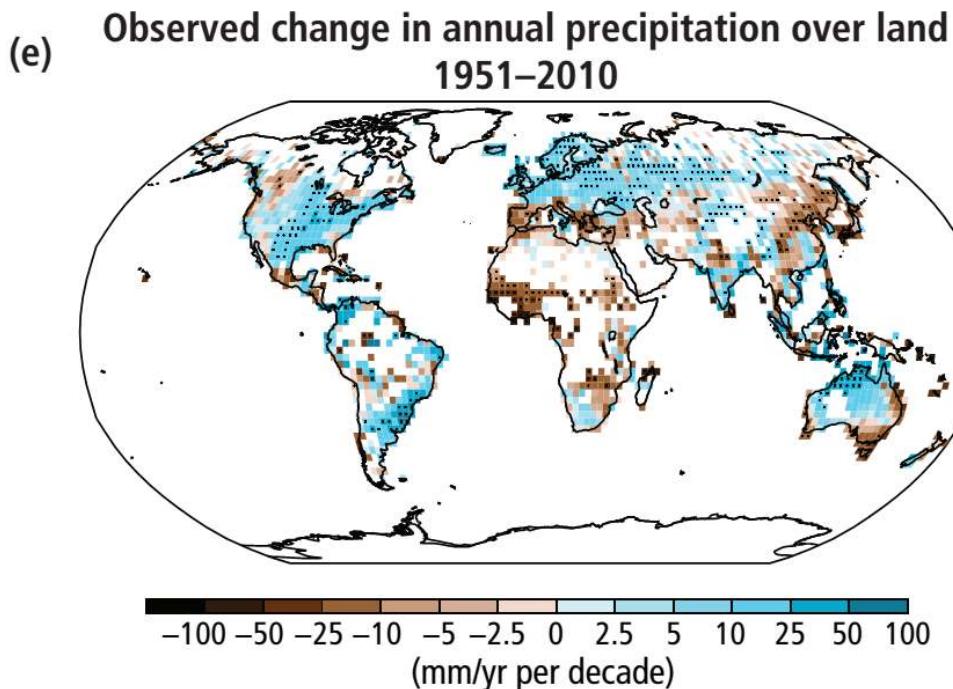


"Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m"

"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*)."

Source: FAQ 5.2, Figure 1, AR5 WG1 The Physical Science Basis. IPCC (2014)

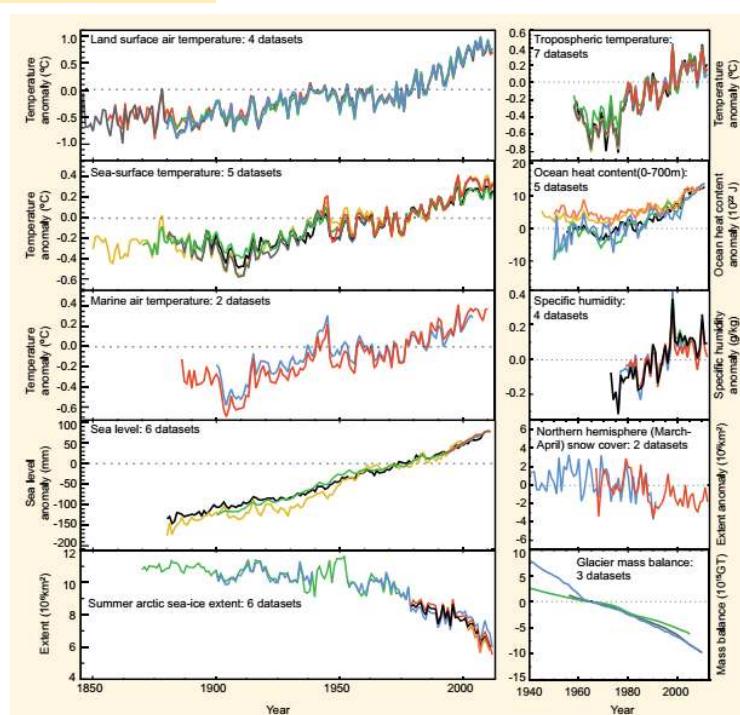
Observations of climate change



Source: Figure 1.1, AR5 Synthesis Report. IPCC (2014)



Observations of climate change



Source: FAQ 2.1 Figure 2, AR5 WG1 The Physical Science Basis. IPCC (2014)



Observations of climate change

1. The earth's climate is changing.... (but it always has, and it probably always will)
2. Globally averaged, it's probably getting warmer – but average global temperature is not a great metric, and different calculation assumptions yield different results.
3. Globally averaged, it's probably getting warmer – but there is no simple relationship between the amount of warming and atmospheric concentration of CO₂.
4. Regional climate changes (and impacts?) will be significantly larger – and more relevant – than the globally-averaged change.



Energy Systems & Climate Change

