Climate Change:
Skeptics, Science, Causes, & Impacts

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Key questions

What is climate and climate change?

How is energy balance maintained?

Are there climate change deniers?

What are the causes of climate change?

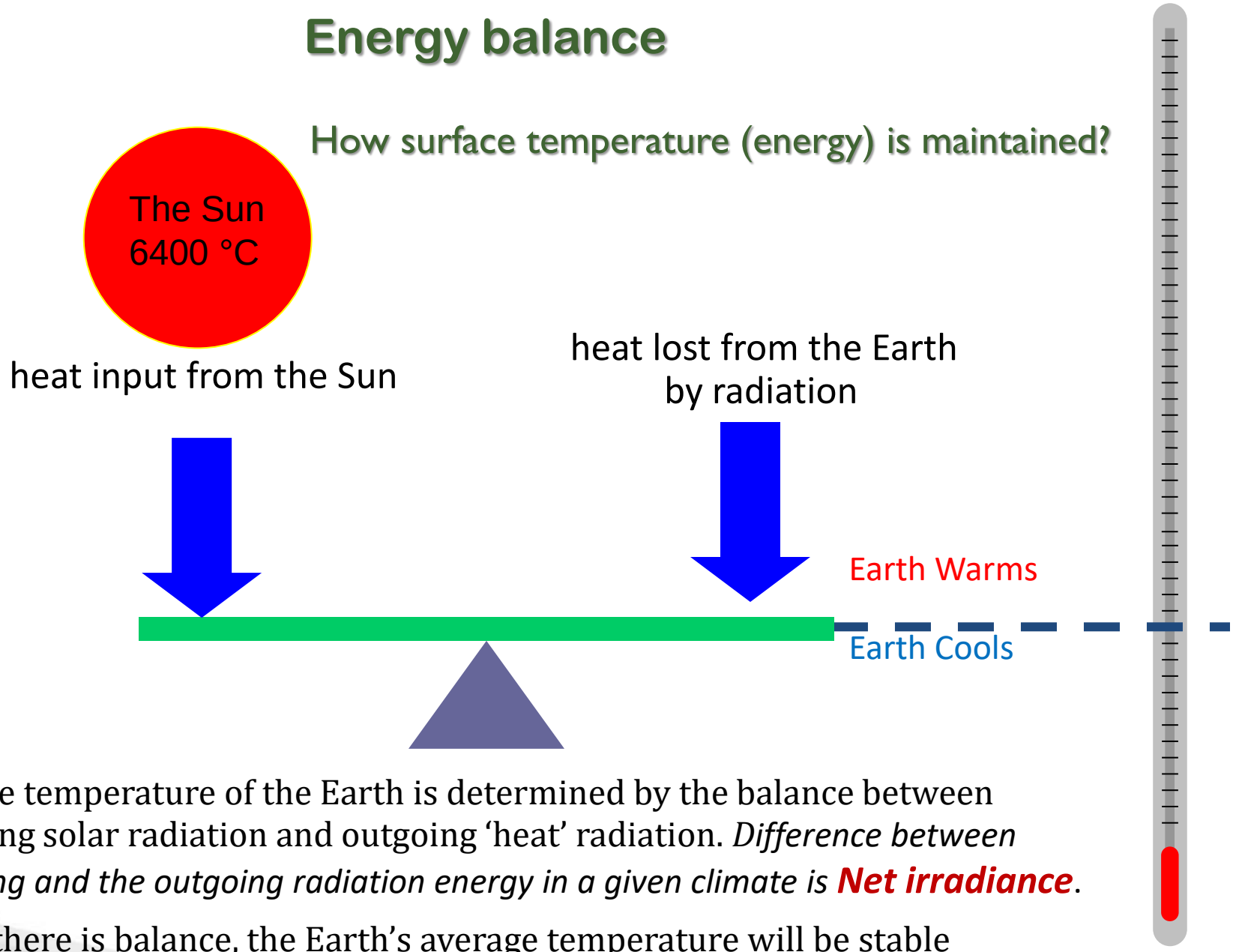
What are the impacts and associated risks of climate change?

Sir David Attenborough's Address to World Leaders at COP26

https://www.youtube.com/watch?v=qjq4VWdZhq8

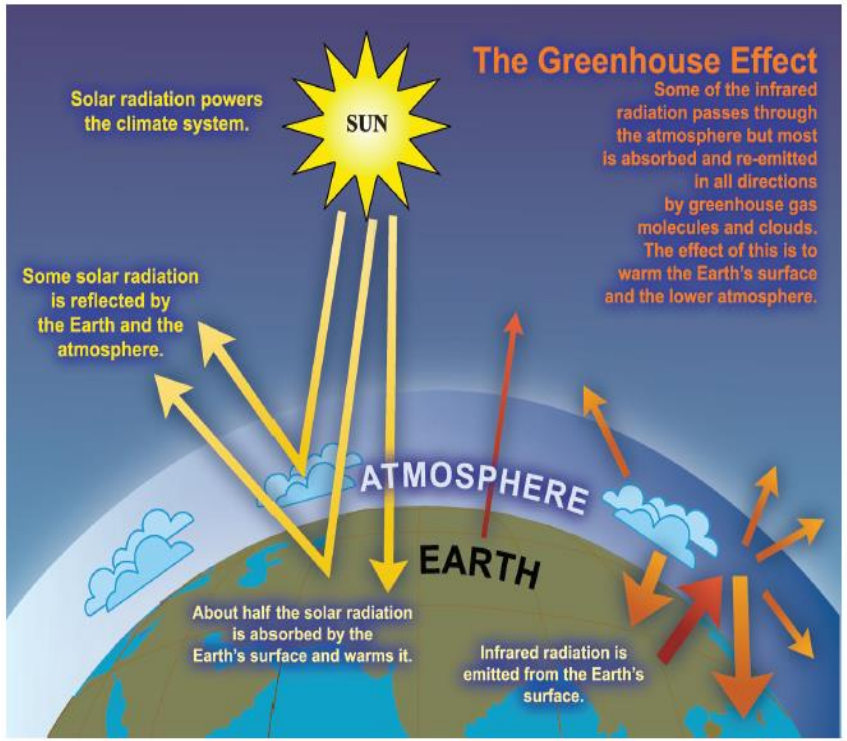
Energy balance

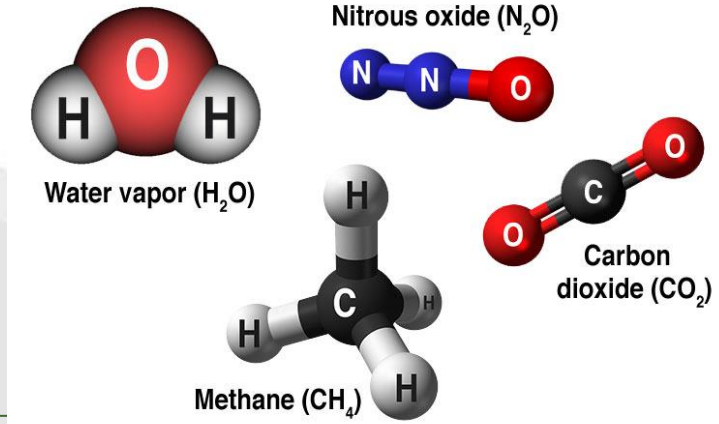
How surface temperature (energy) is maintained?

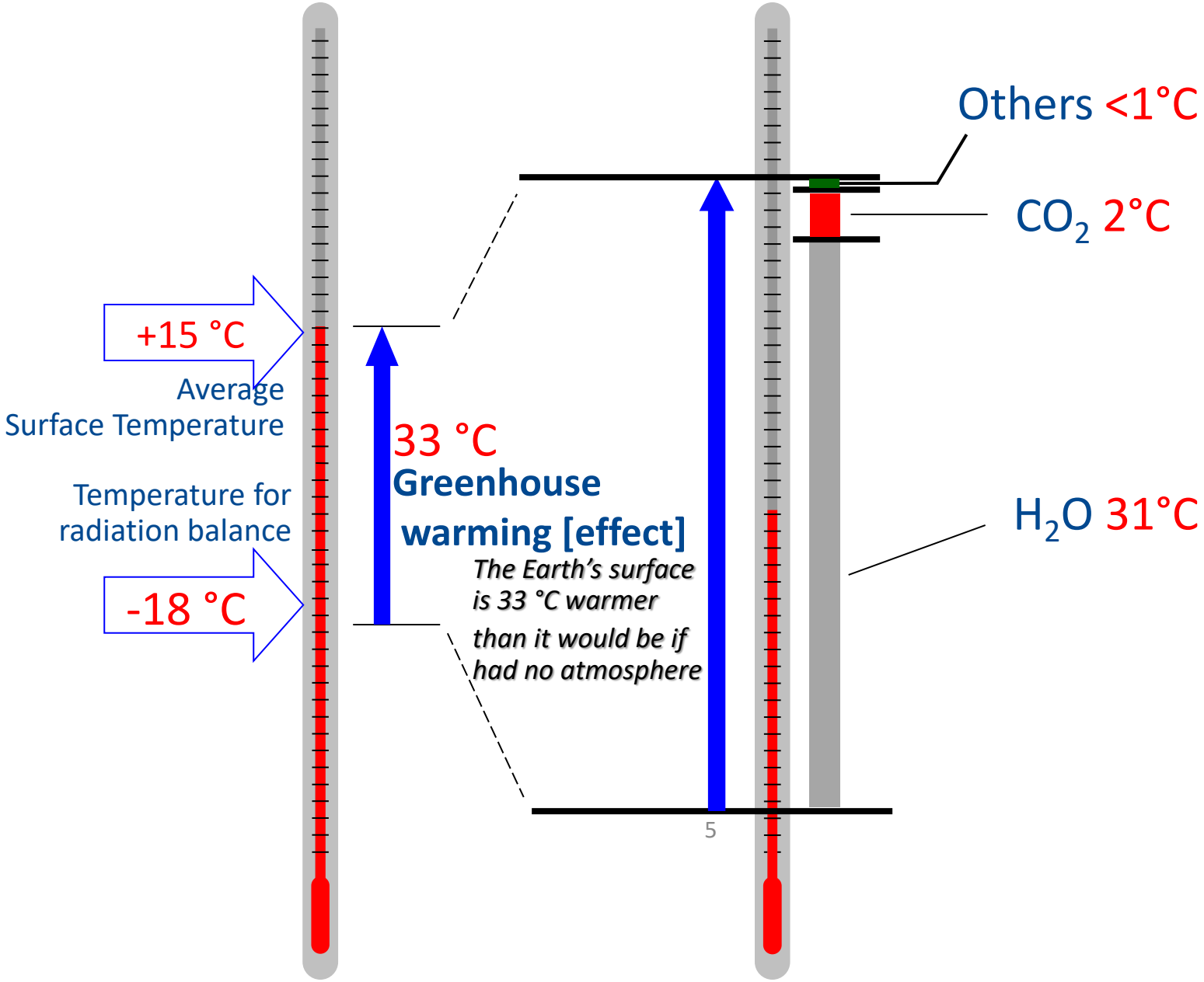


- Average temperature of the Earth is determined by the balance between incoming solar radiation and outgoing 'heat' radiation. *Difference between incoming and the outgoing radiation energy in a given climate is* ***Net irradiance***.
- When there is balance, the Earth's average temperature will be stable

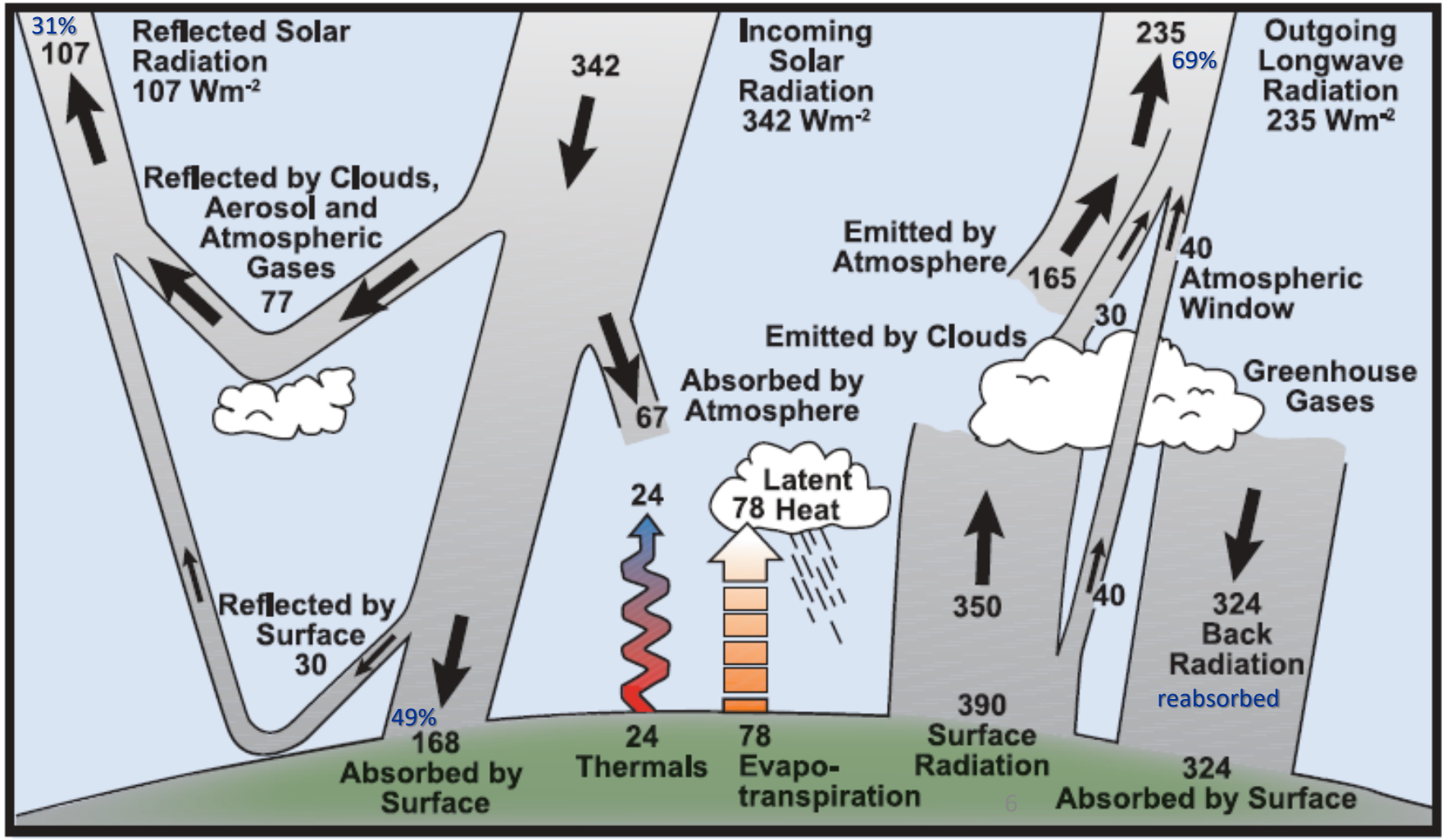
Greenhouse effect







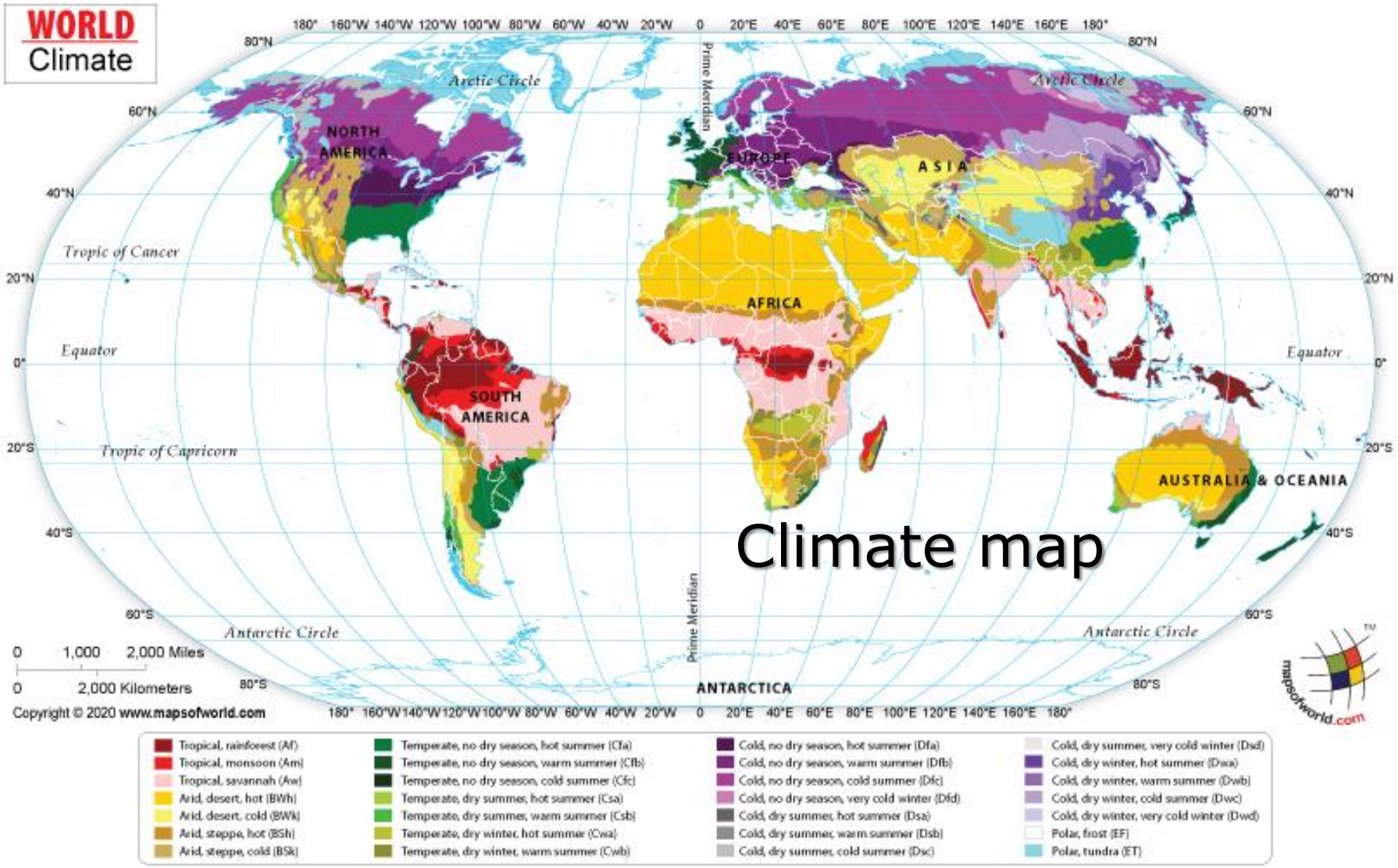
Radiance balance: Incoming and Outgoing radiation



FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Climate

– the “average weather”, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities (surface variables – temperature, precipitation, wind) over a period of time, classically 30 years, as defined by the WMO [IPCC]

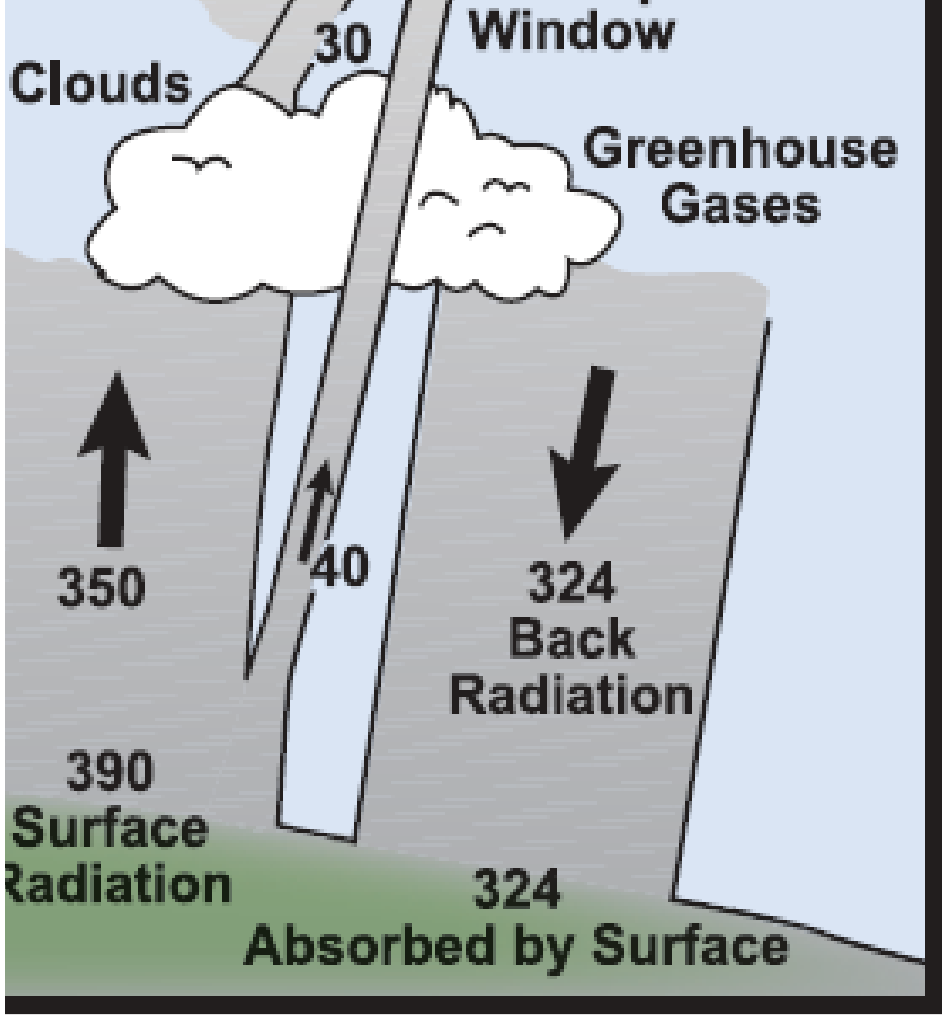


Climate Change

- a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
- 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' [UNFCCC]

Climate Variability

- Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the *climate system* (internal variability), or to variations in natural or *anthropogenic* external *forcing* (external variability).



Climate Change Skepticism

‘Climate change is a natural phenomenon’

“Climate change is a natural phenomenon that has occurred many times in the past”

“the warming.. is likely to do more good than harm.”

‘This has been the worst winter in years…and they talk about global warming!’

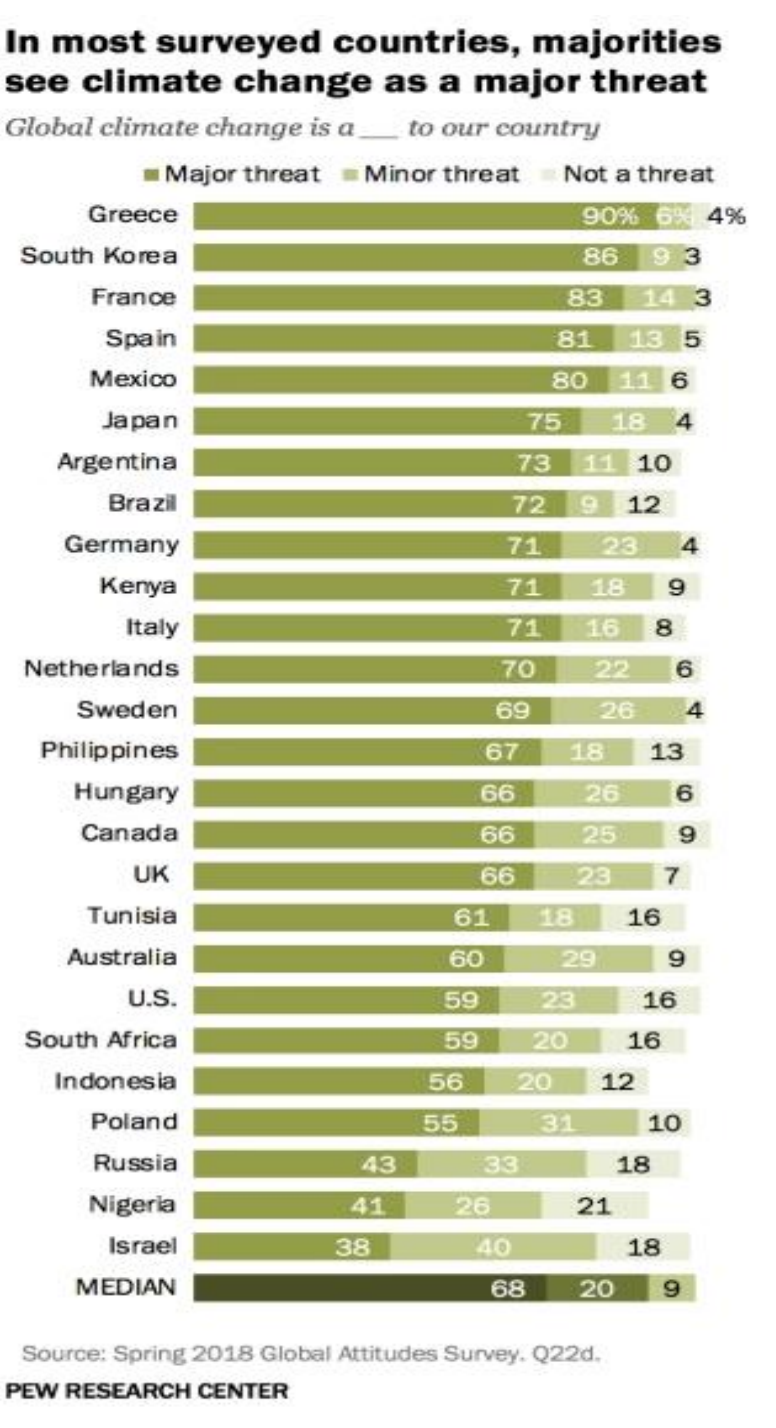
‘Our climate is very unpredictable’

‘Models are unreliable’

‘Humans are too insignificant to affect global climate’

‘CO_2 limits will harm the economy’

‘Future climate cannot be predicted by computers’



AIT

Climate change Skepticism is holding of doubts about climate change (due to humans)

Type of skepticism arguments

- Conspiracy theories
- Fake experts
- Impossible expectations
- Misrepresentations and logical fallacies
- Cherry picking

The types are either relating to doubts about

- the status of climate change as a scientific and physical phenomenon - **Epistemic skepticism** or
- the efficacy of action taken to address climate change - **Response skepticism.**

CNN politics

Two former Trump officials to be investigated for posting papers denying climate change

By Daniella Diaz, CNN

Updated 0021 GMT (0821 HKT) January 24, 2021

David Legates is pictured.

(CNN) — The Commerce Department's Office of Inspector General said it will investigate how two former Trump officials posted dubious papers questioning man-made climate change using government logos but without the approval of the Trump administration.

AIT

Science of Climate Change

1898: Swedish scientist Svante Ahrrenius warns carbon dioxide from coal and oil burning could warm the planet

1987: Montreal protocol, an environmental treaty (for CFCs)

1988: NASA scientist James Hansen tells U.S. Congress global warming "is already happening now"

Exceptional drought hits the USA

Creation of the IPCC [Inter-governmental Panel on Climate Change)

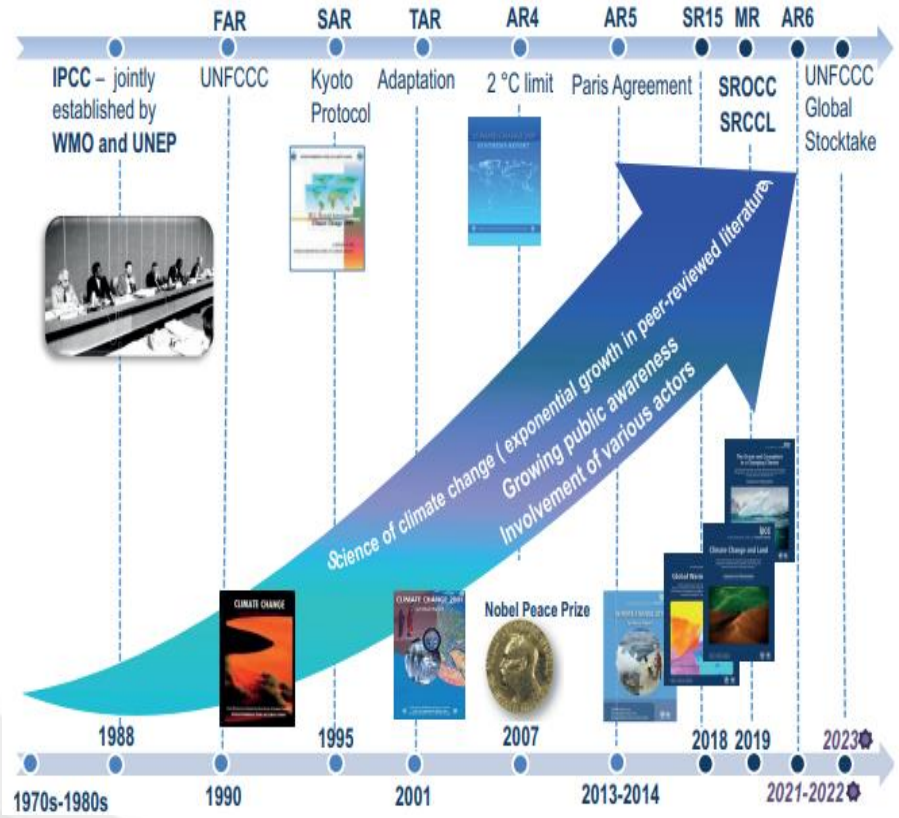
1992: UNFCCC aims at stabilising atmospheric concentrations of GHG

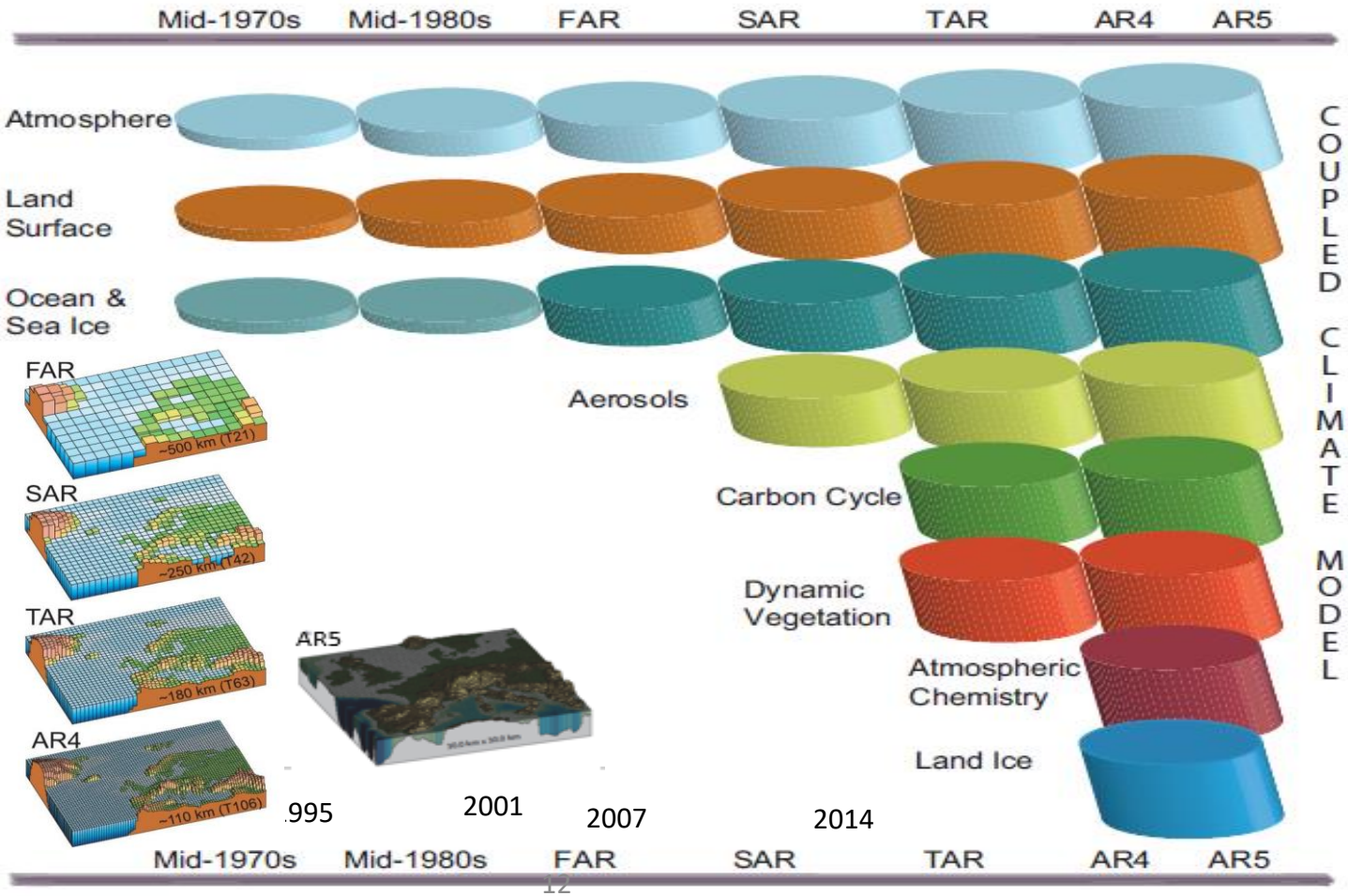
1997: Kyoto Protocol mandating emission cuts by industrial nations (took effect in 2005-2020)

2016: Paris Agreement

Warmest years (NOAA, 1880-2021): top 10 - 2016, 2020, 2019, 2015, 2017, 2021, 2018, 2014, 2010, 2013 (2013-2021, 9 continuous warmest years)

Increasing understanding of complexity of climate system



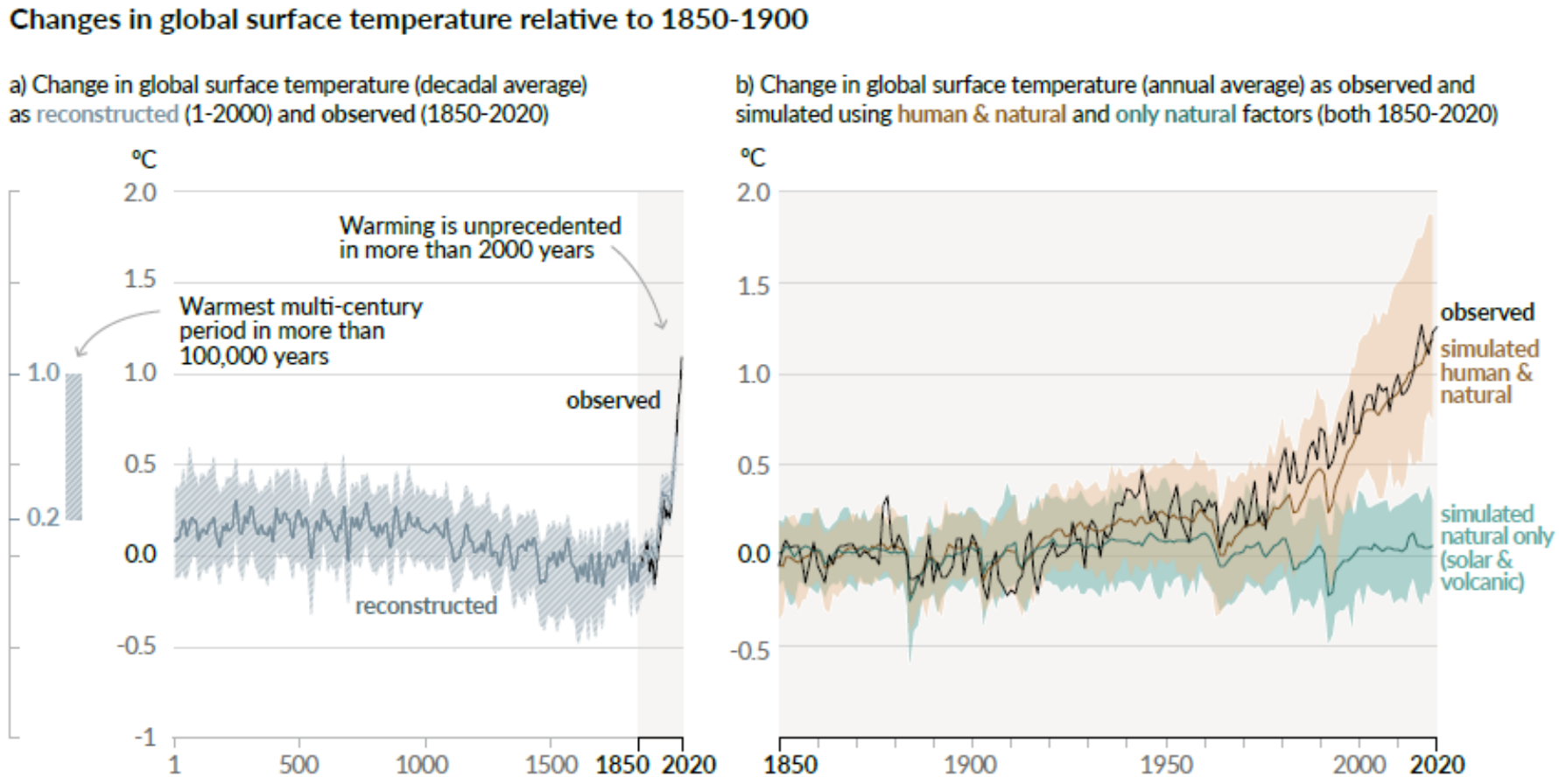


Special Reports (SR): Methodology Report - Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (MR), Global Warming of 1.5ºC (SR15); Climate Change and Land (SRCCL), Ocean and Cryosphere in a Changing Climate (SROCC

Figure 1.13 | The development of climate models over the last 35 years showing how the different components were coupled into comprehensive climate models o each aspect (e.g., the atmosphere, which comprises a wide range of atmospheric processes) the complexity and range of processes has increased over time (illustrated cylinders). Note that during the same time the horizontal and vertical resolution has increased considerably e.g., for spectral models from T21L9 (roughly 500 km horizo tion and 9 vertical levels) in the 1970s to T95L95 (roughly 100 km horizontal resolution and 95 vertical levels) at present, and that now ensembles with at least three ir experiments can be considered as standard.

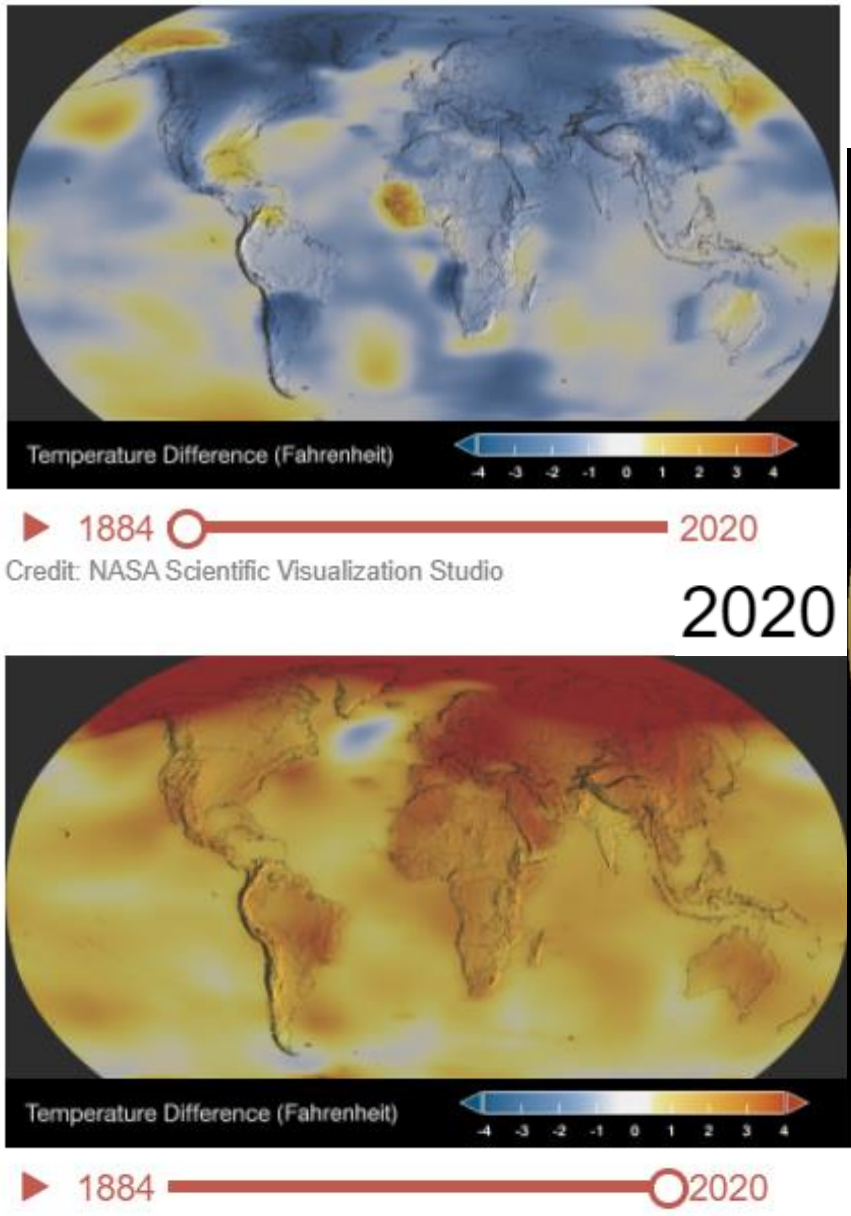
All Figures © IPCC 2013

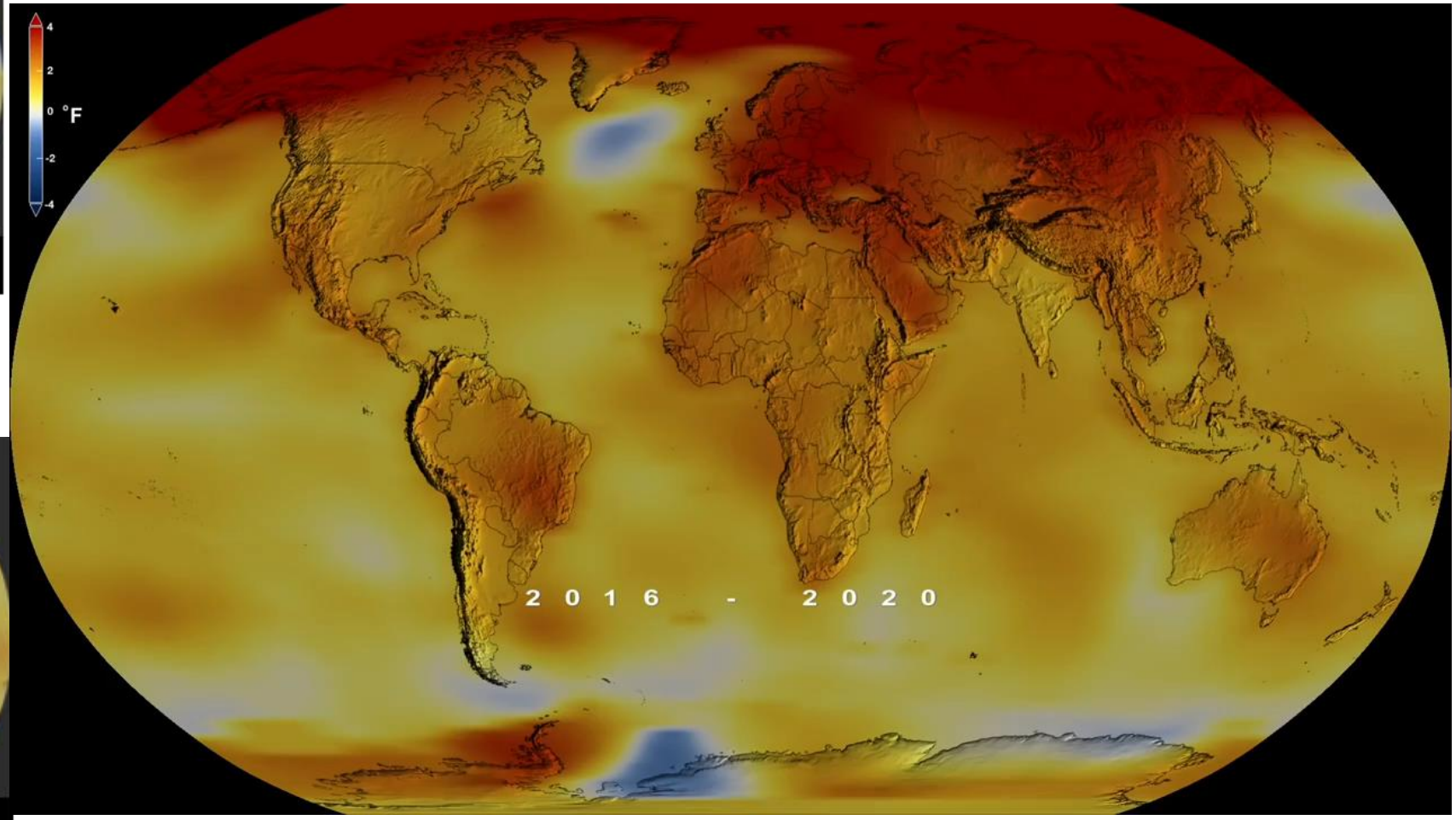
Climate warming at unprecedented rate in at least the last 2000 years due to human influence



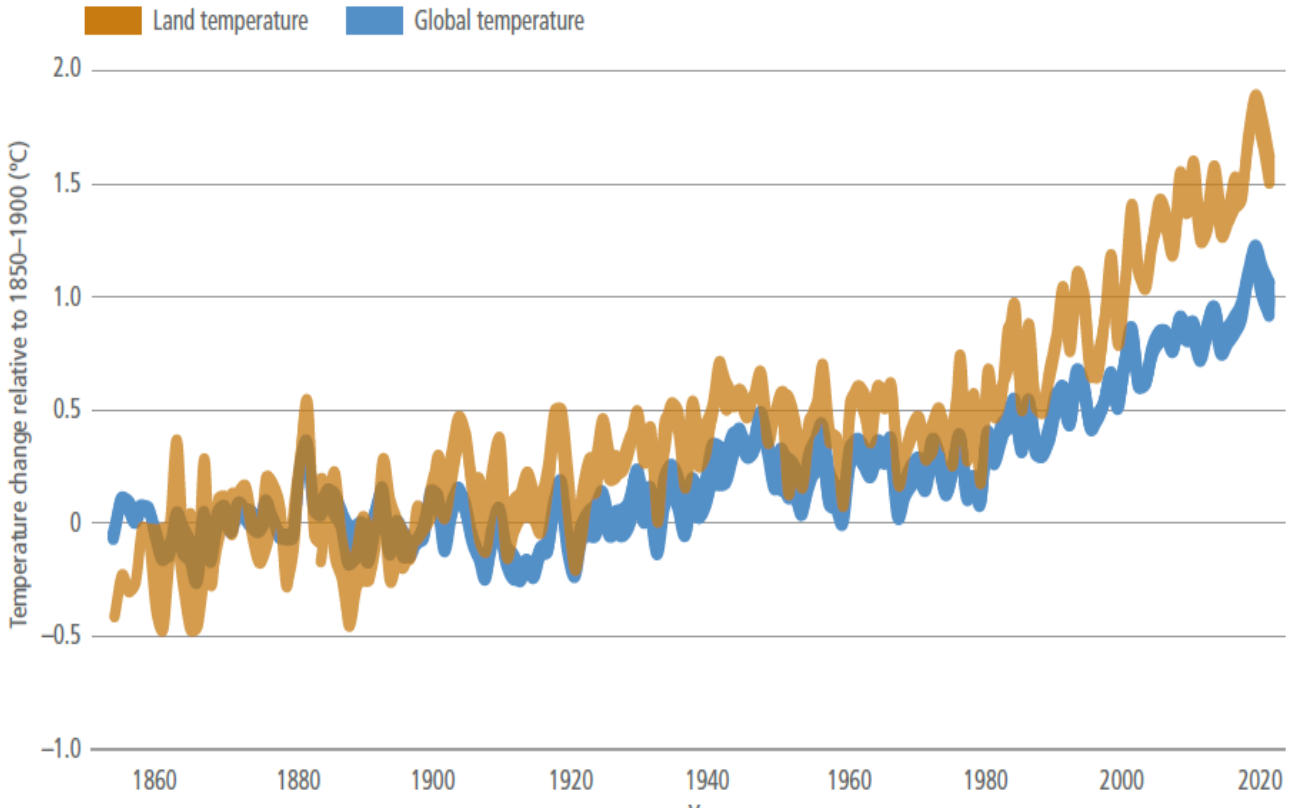
https://www.ipcc.ch/report/ar6/wg1/#FullReport

Global Temperature Trend
[1880-2020]



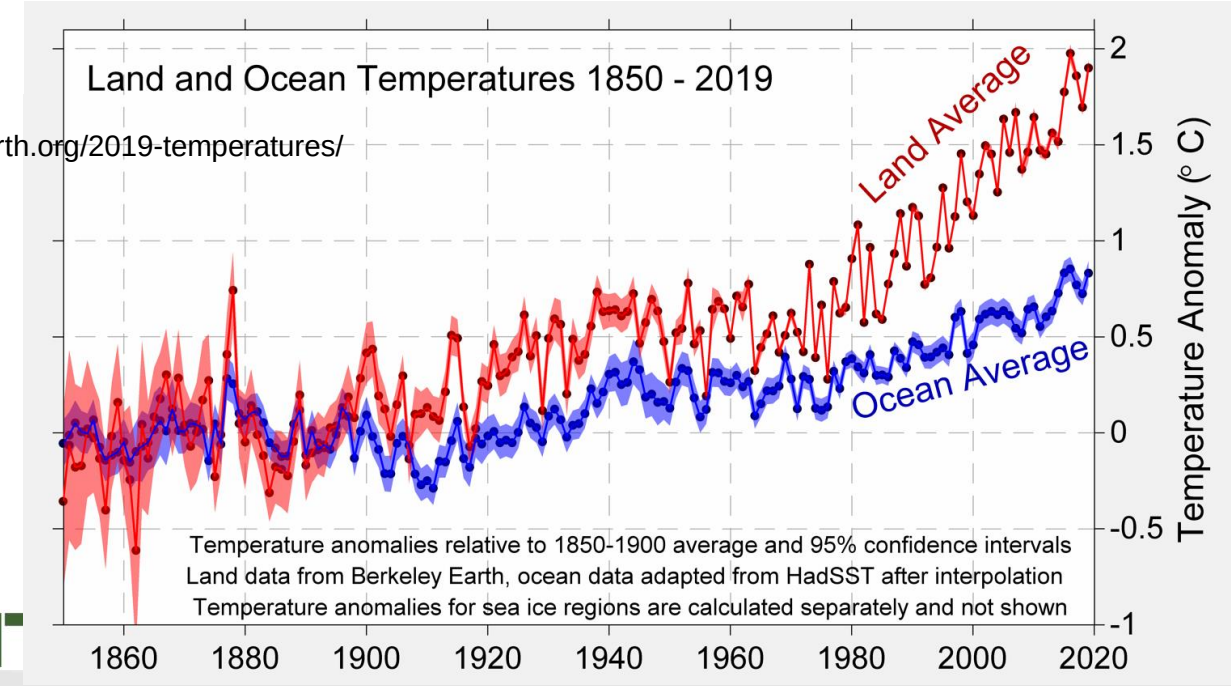


https://mashable.com/video/nasa-video-climate-change, released Jan 2021



Globally averaged LSAT has risen faster (1.53°C) than the global mean surface temperature (0.87°C) from the preindustrial period (1850–1900) to the present day (1999–2018).

http://berkeleyearth.org/2019-temperatures/



Evolution of land surface air temperature (LSAT), Global mean surface temperature (GMST), and Ocean average

Observed warming is driven by emissions from human activities

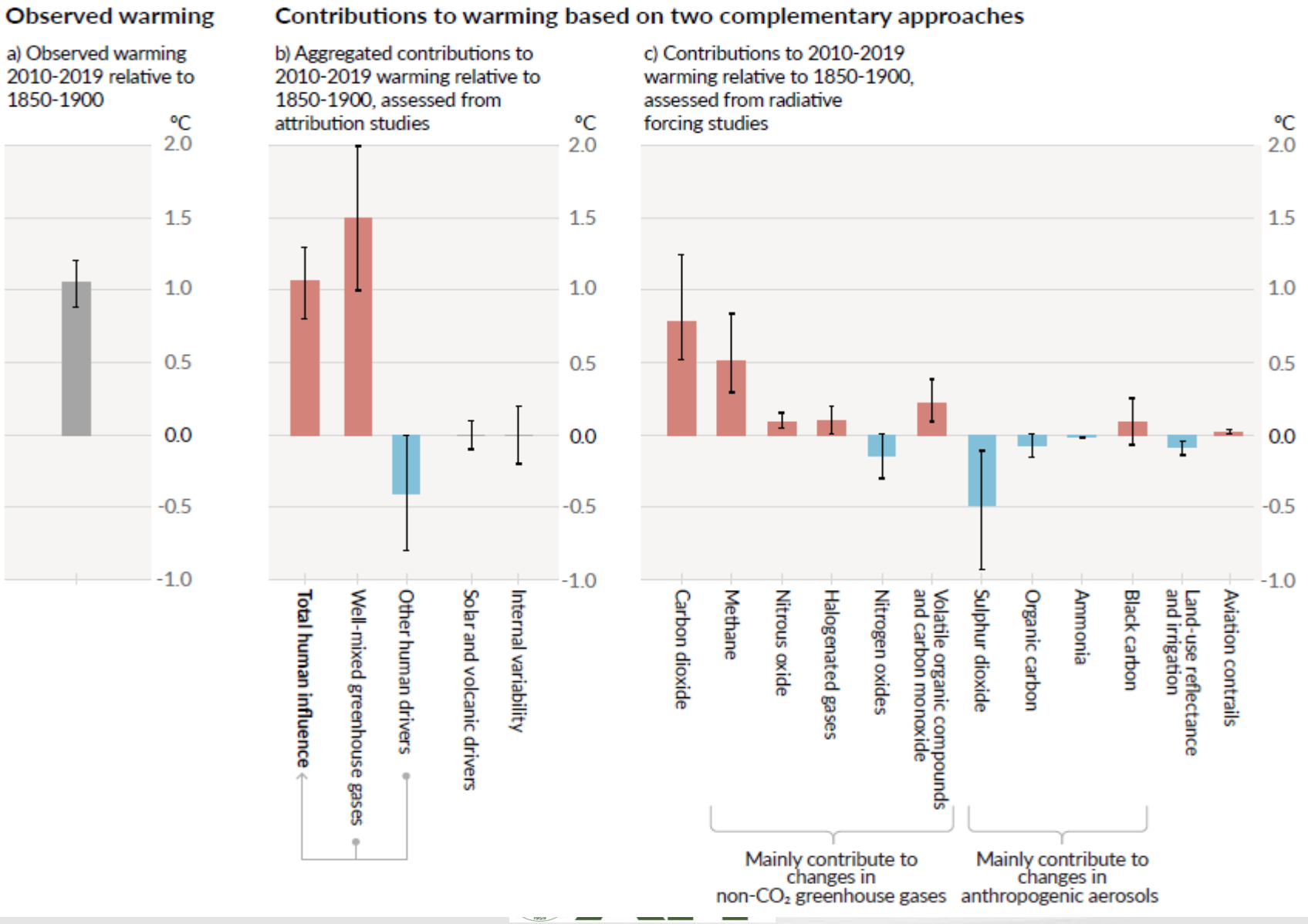
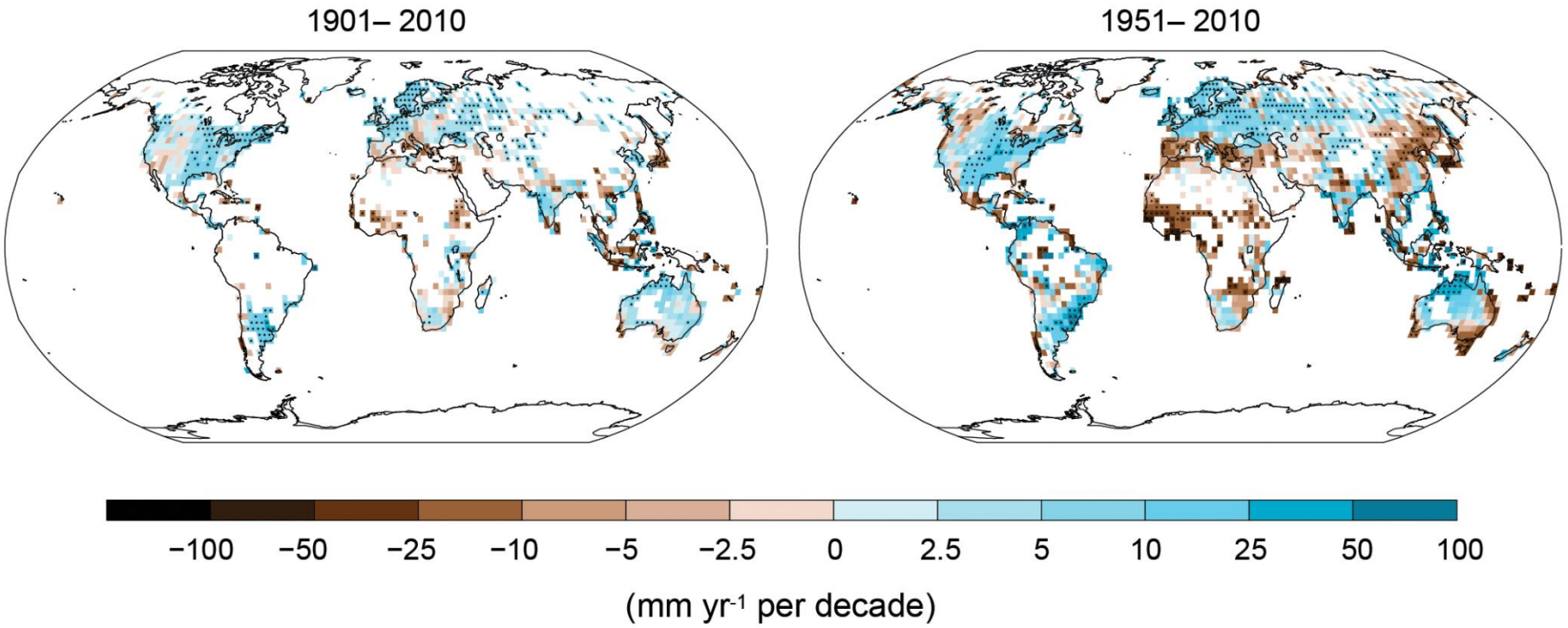


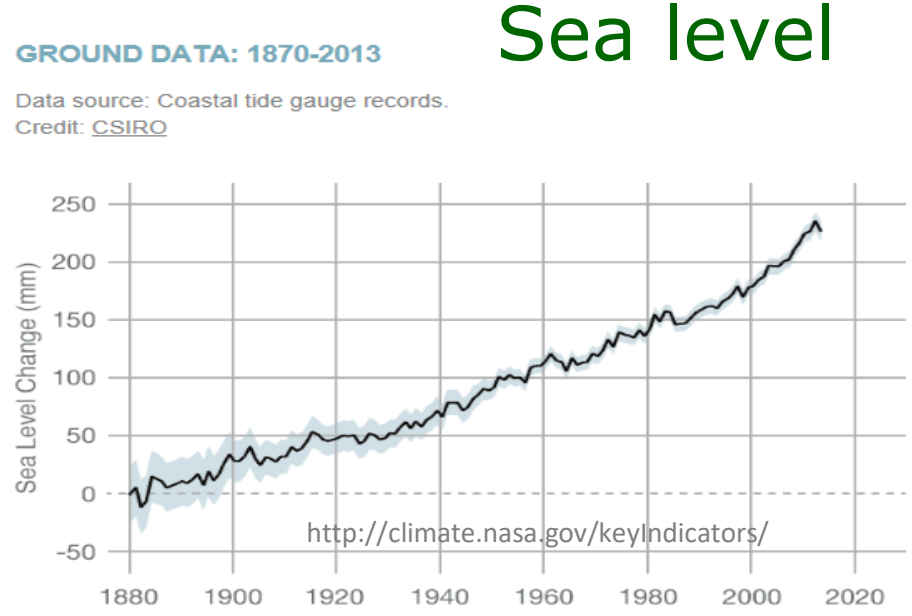
Figure SPM.2

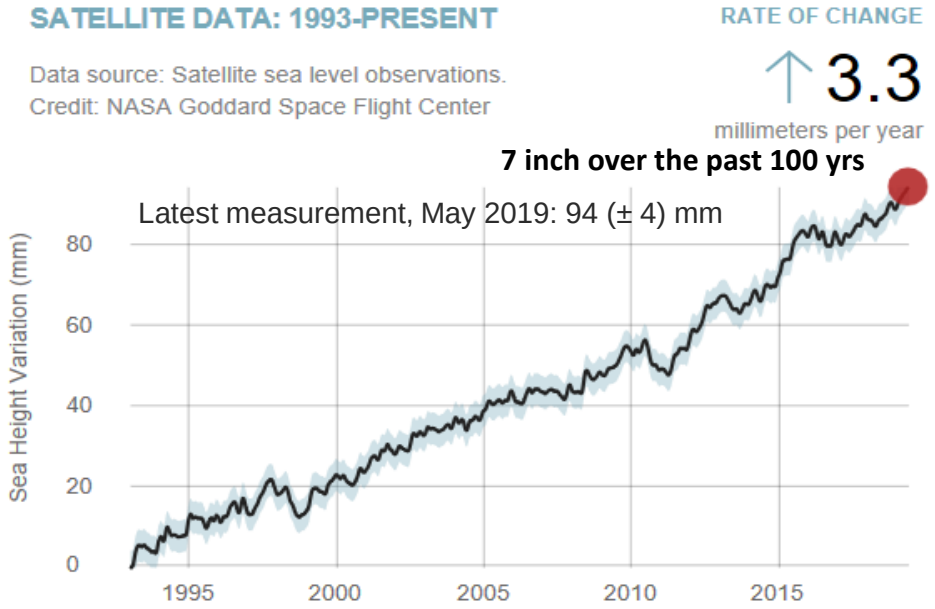
Observed change in annual precipitation over land

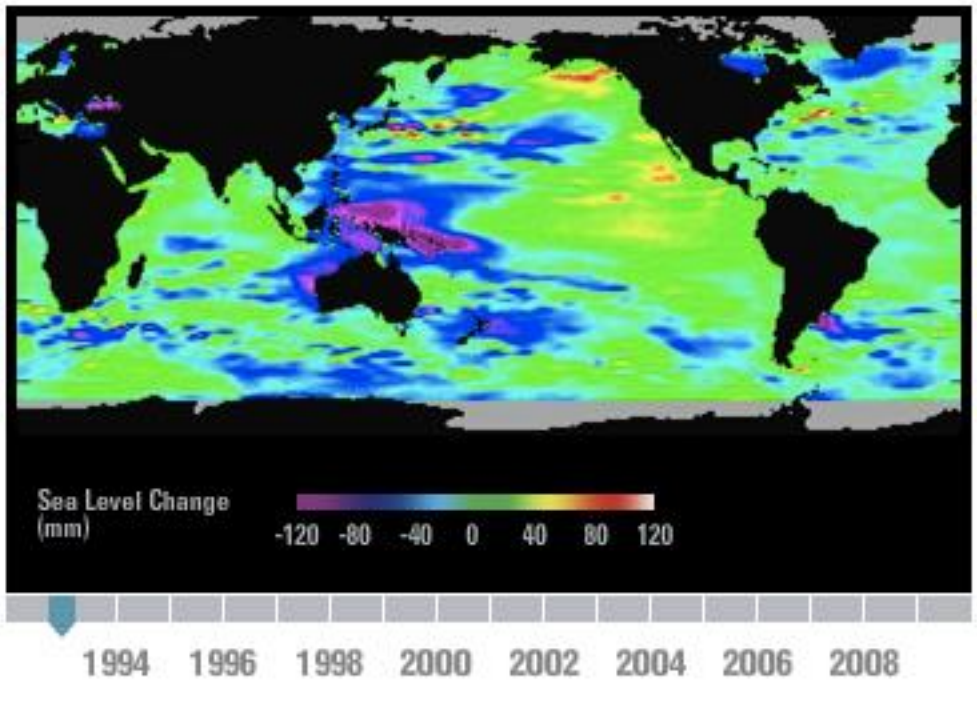
All Figures © IPCC 2013

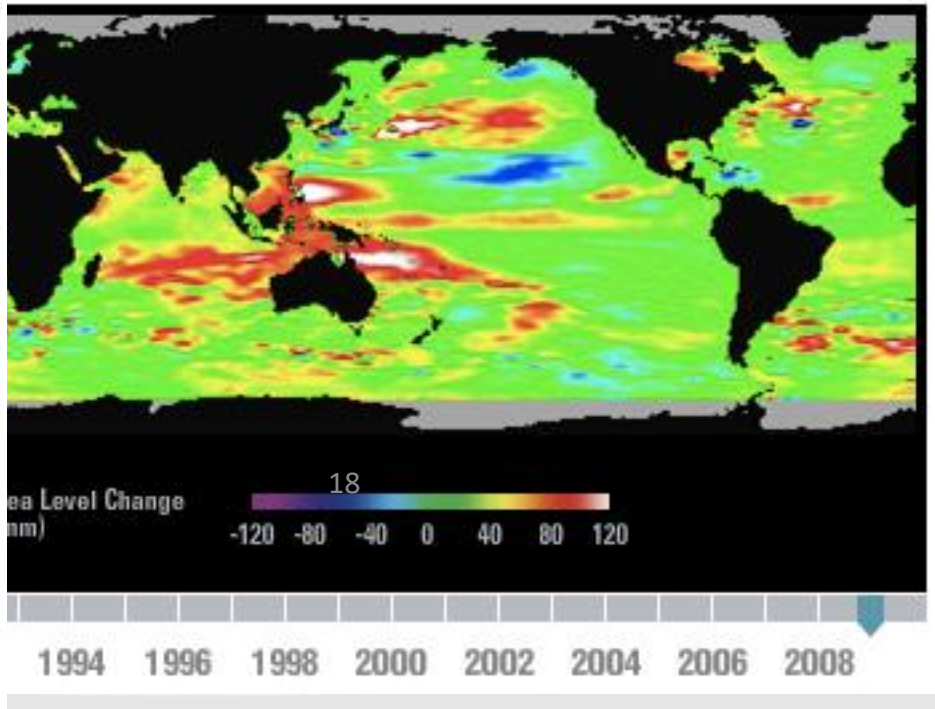


Sea level

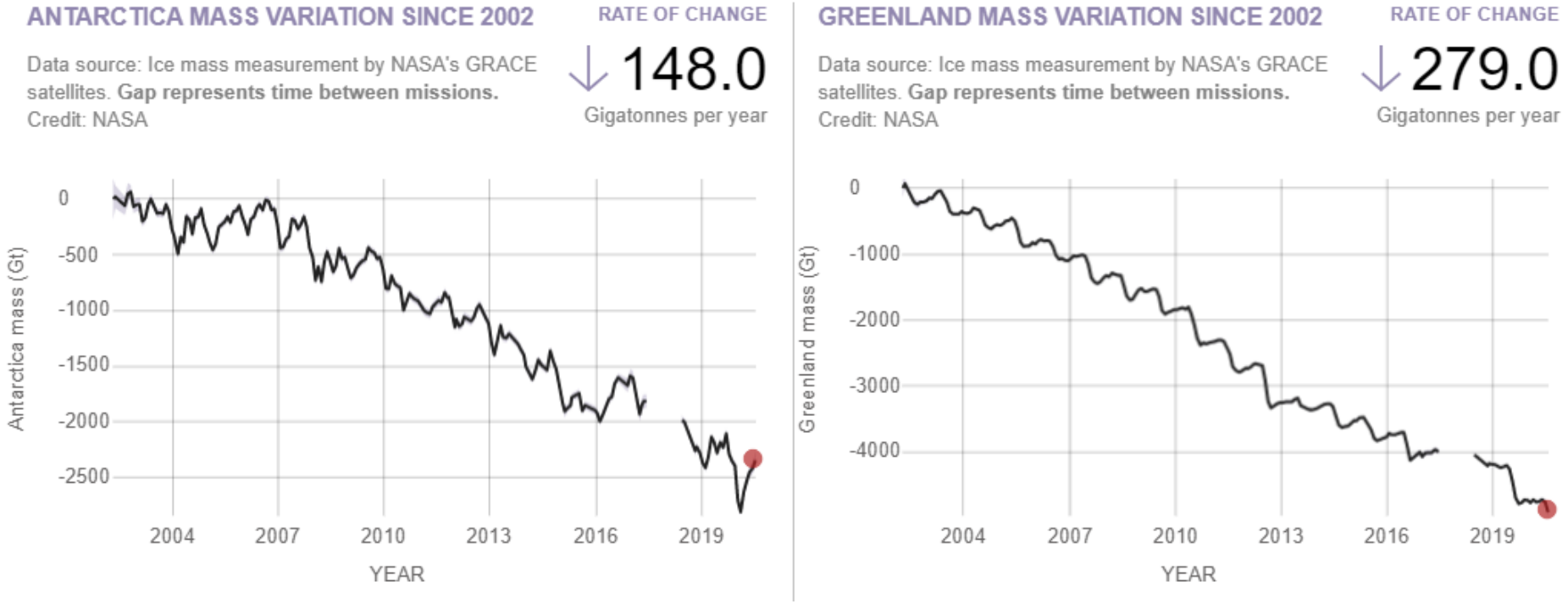

GROUND DATA: 1870-2013
Data source: Coastal tide gauge records.
Credit: CSIRO
Sea Level Change (mm)
250
200
150
100
50
0
-50
1880
1900
1920
1940
1960
1980
2000
2020
http://climate.nasa.gov/keyIndicators/


SATELLITE DATA: 1993-PRESENT
Data source: Satellite sea level observations.
Credit: NASA Goddard Space Flight Center
RATE OF CHANGE
3.3
millimeters per year
7 inch over the past 100 yrs
Latest measurement, May 2019: 94 (± 4) mm
Sea Height Variation (mm)
80
60
40
20
0
1995
2000
2005
2010
2015

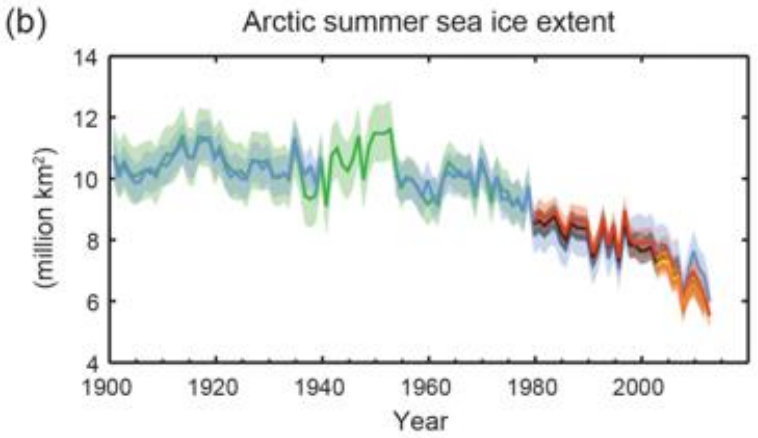

Sea Level Change
(mm)
-120 -80 -40 0 40 80 120
1994 1996 1998 2000 2002 2004 2006 2008

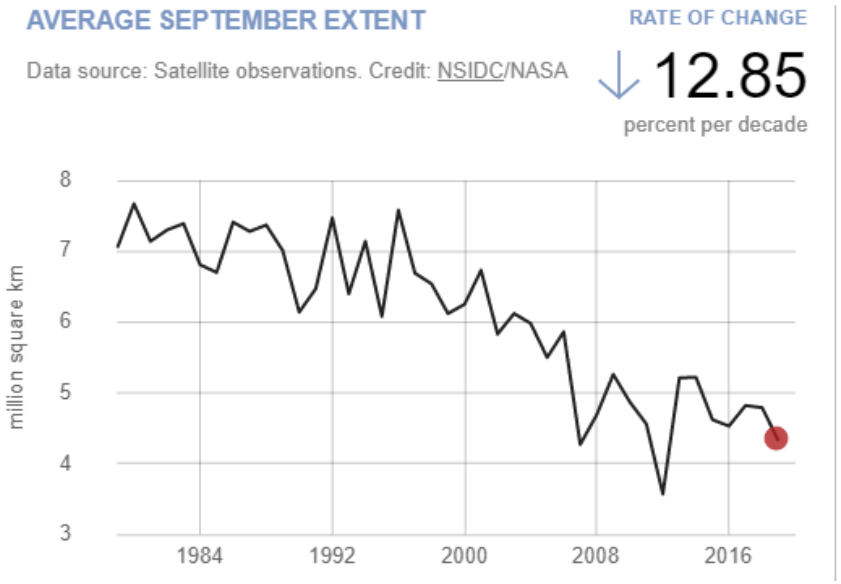

ea Level Change
nm)
-120 -80 -40 0 40 80 120
1994 1996 1998 2000 2002 2004 2006 2008

Ice Sheets


ANTARCTICA MASS VARIATION SINCE 2002
RATE OF CHANGE
Data source: Ice mass measurement by NASA's GRACE satellites. Gap represents time between missions.
Credit: NASA
148.0
Gigatonnes per year
Antarctica mass (Gt)
0
-500
-1000
-1500
-2000
-2500
2004
2007
2010
2013
2016
2019
YEAR
GREENLAND MASS VARIATION SINCE 2002
RATE OF CHANGE
Data source: Ice mass measurement by NASA's GRACE satellites. Gap represents time between missions.
Credit: NASA
279.0
Gigatonnes per year
Greenland mass (Gt)
0
-1000
-2000
-3000
-4000
2004
2007
2010
2013
2016
2019
YEAR

Arctic Sea Ice

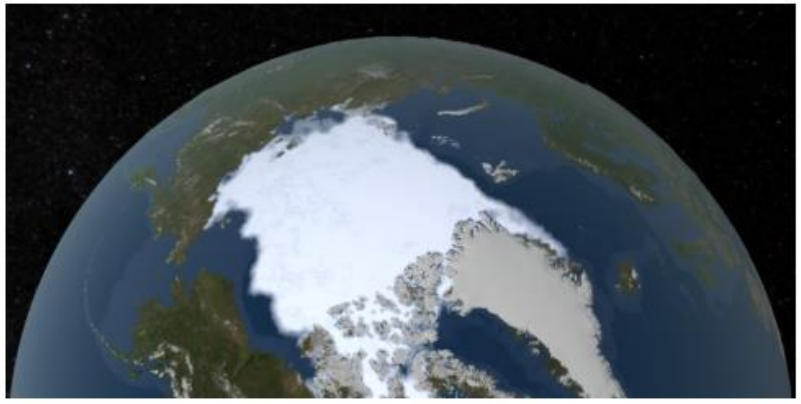




TIME SERIES: 1979-2019

Data source: Satellite observations.
Credit: NASA Scientific Visualization Studio

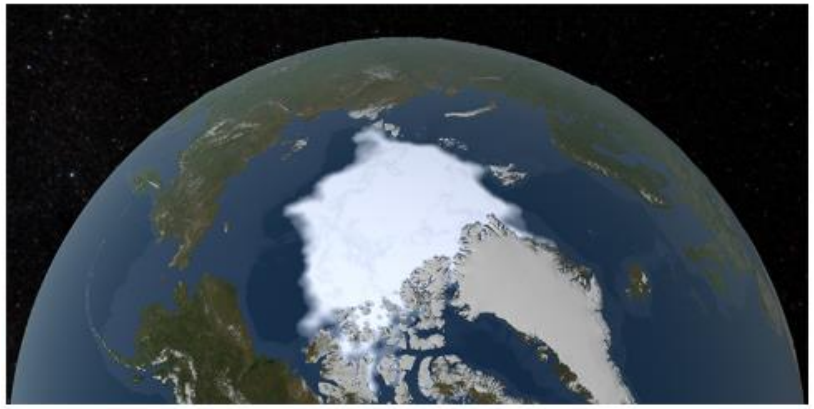
1979



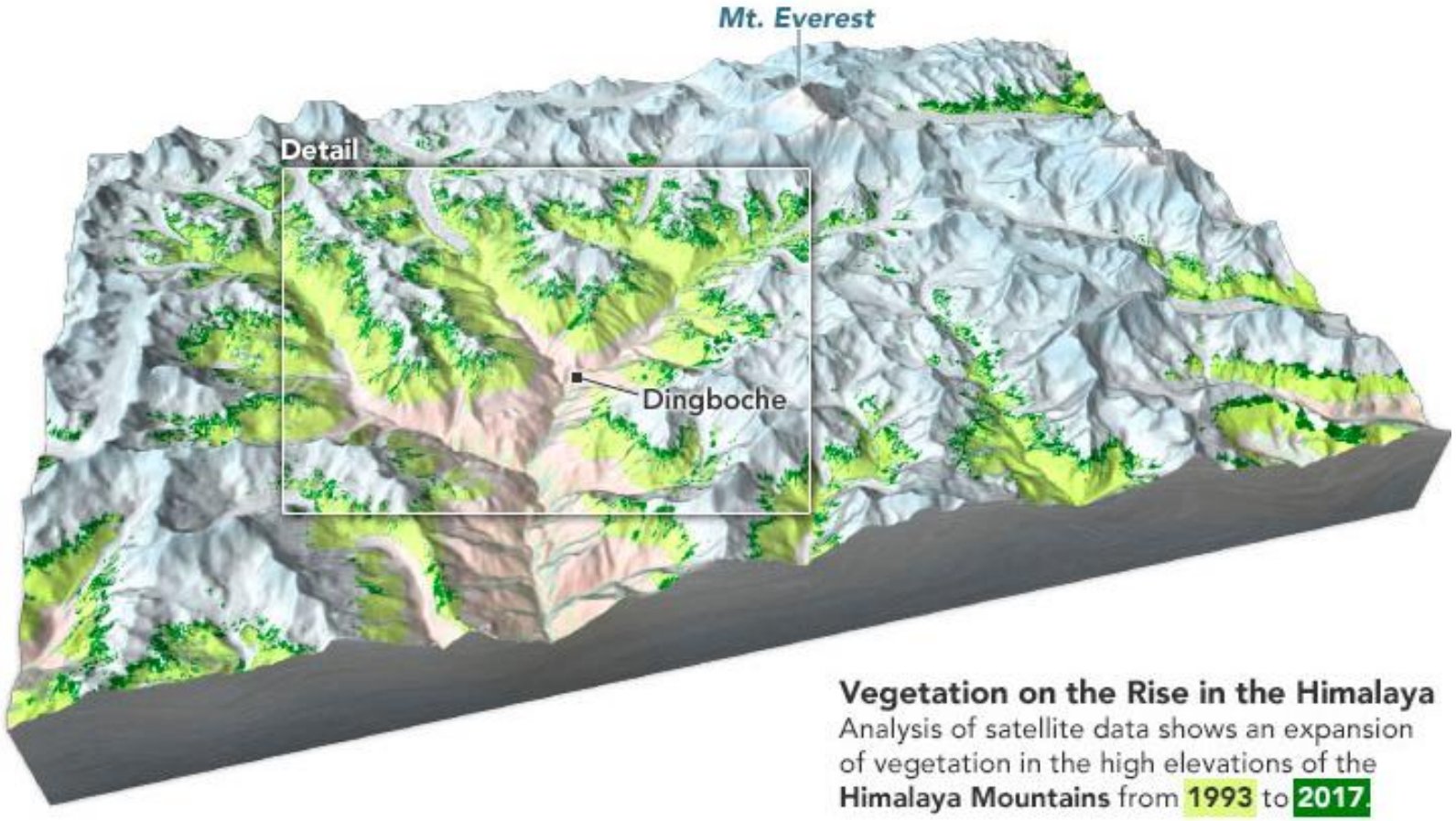
TIME SERIES: 1979-2019

Data source: Satellite observations.
Credit: NASA Scientific Visualization Studio

2019



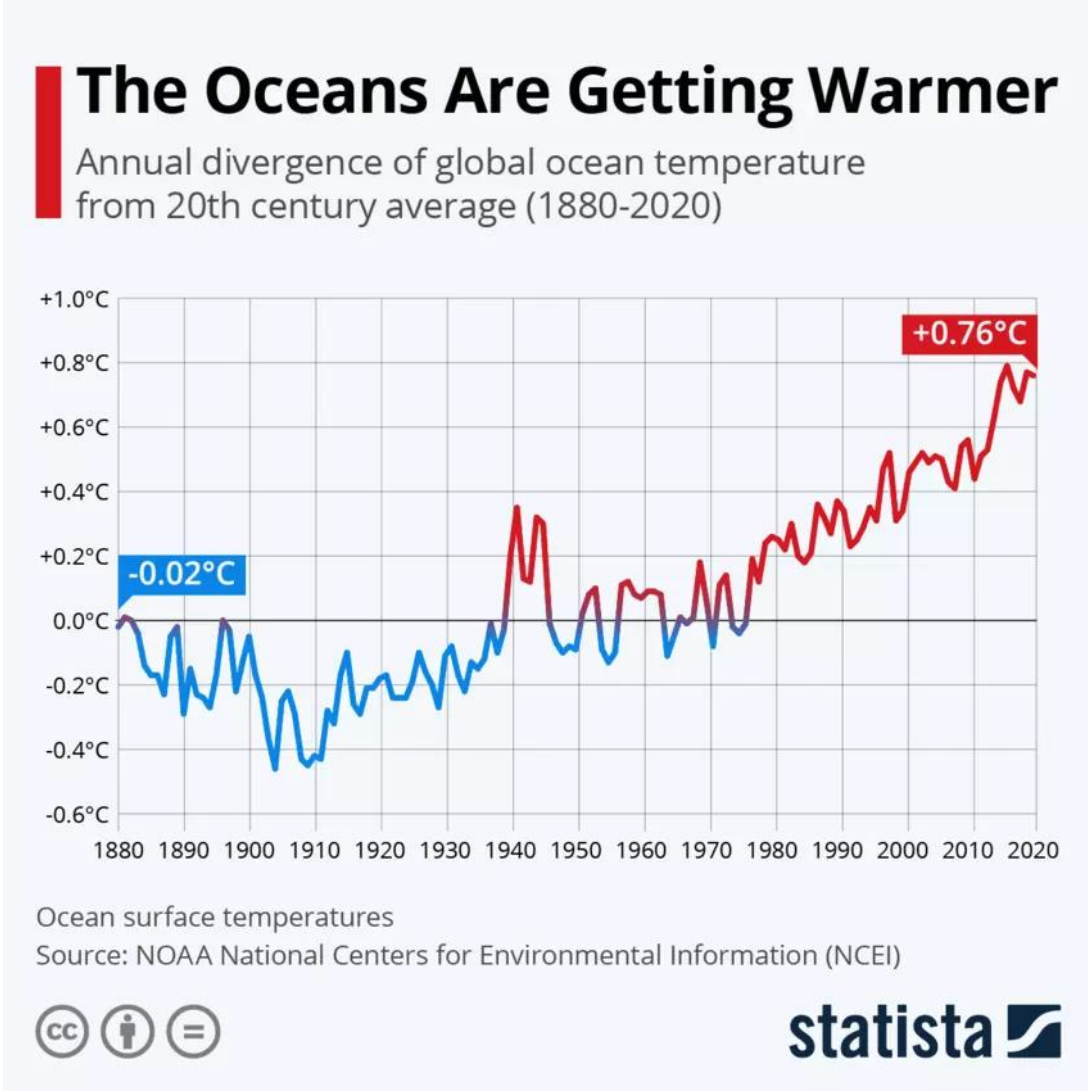
Ice melting and plant life spreads



https://earthobservatory.nasa.gov/images/149312/everest-area-plant-life-spreads?src=eoa-iotd; 12 Dec 2022

Warming of Oceans

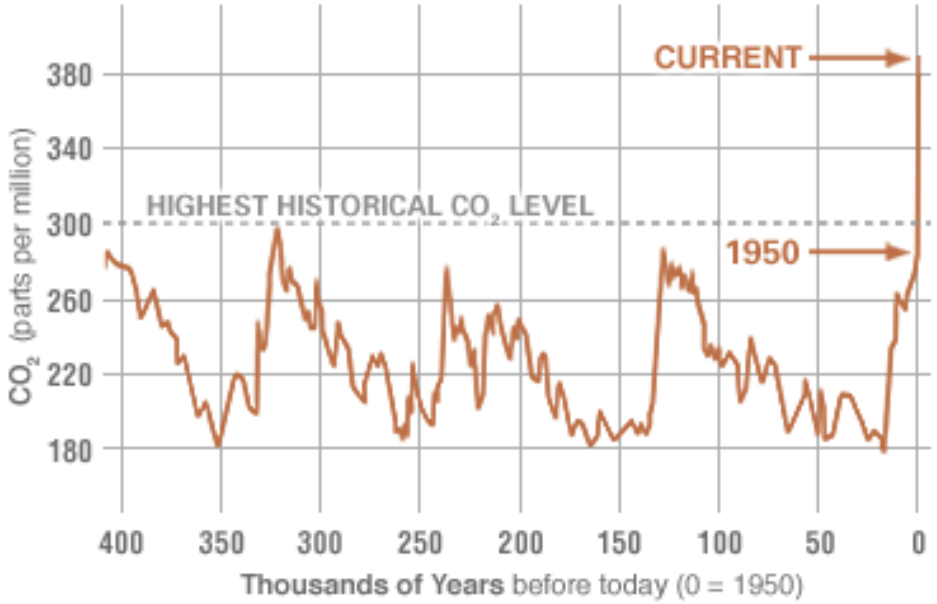
- Ocean warming by 0.302^0 F of top 700 m ocean since 1969
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010.



Carbon dioxide concentration

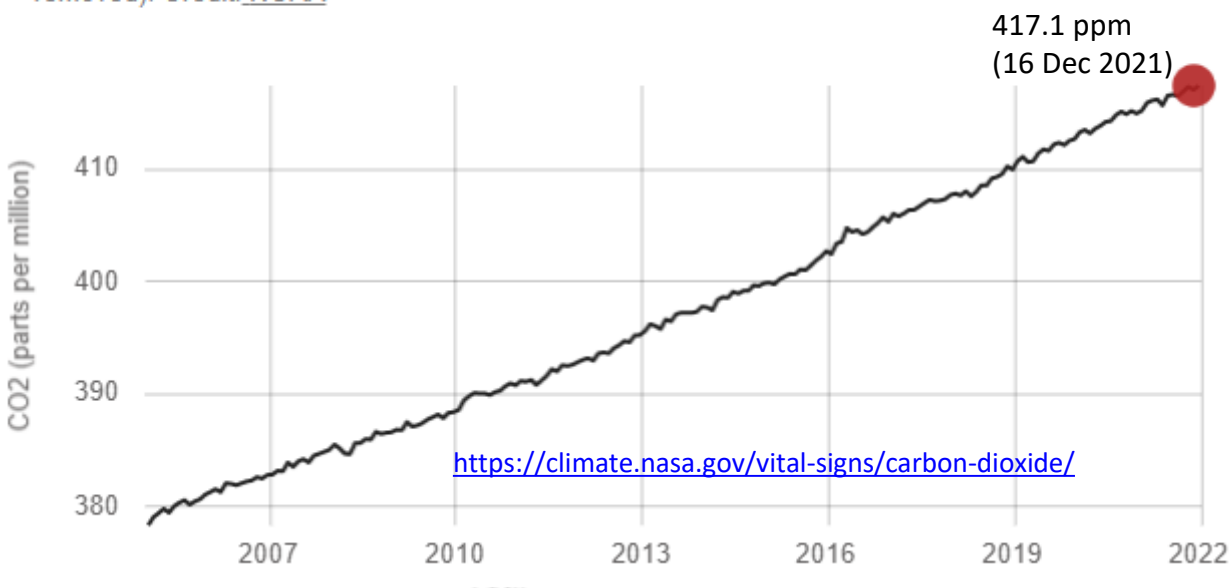
PROXY (INDIRECT) MEASUREMENTS

Data source: Reconstruction from ice cores.
Credit: NOAA



DIRECT MEASUREMENTS: 2005-PRESENT

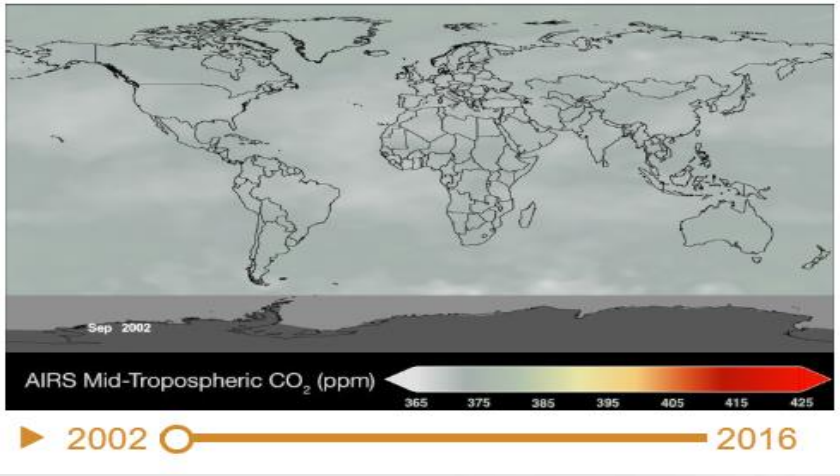
Data source: Monthly measurements (average seasonal cycle removed). Credit: NOAA



TIME SERIES: 2002-2016

Data source: Atmospheric Infrared Sounder (AIRS).
Credit: NASA

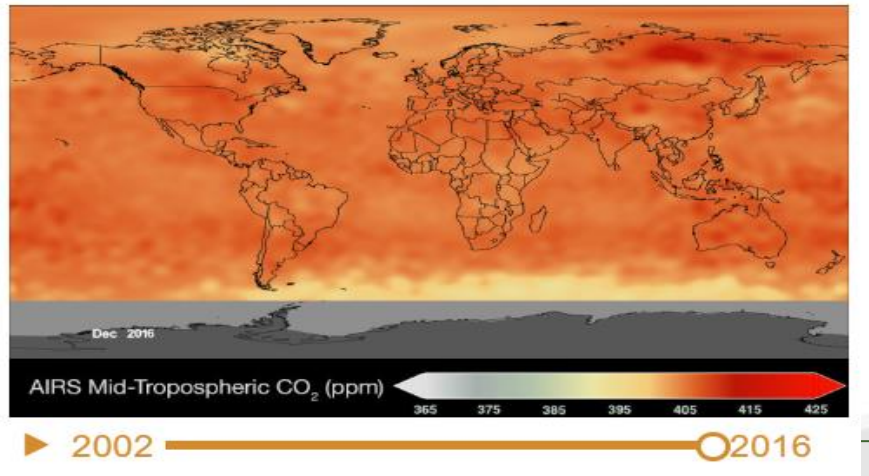
SEPTEMBER
2002



TIME SERIES: 2002-2016

Data source: Atmospheric Infrared Sounder (AIRS).
Credit: NASA

DECEMBER
2016

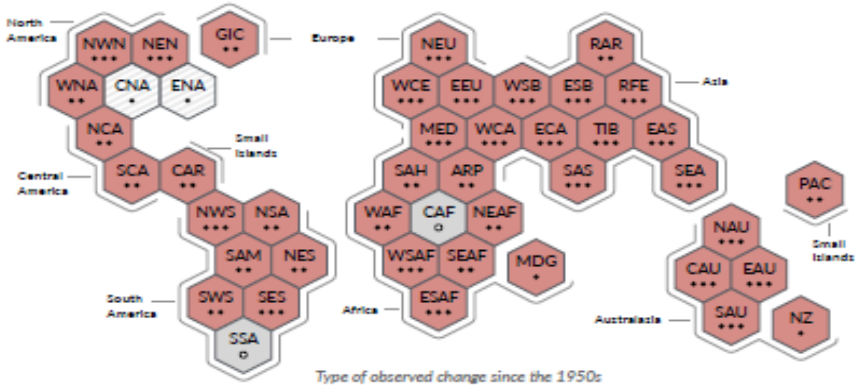


Observed changes in weather and climate extremes

a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in hot extremes
- Increase (41)
- Decrease (0)
- Low agreement in the type of change (2)
- Limited data and/or literature (2)

Confidence in human contribution to the observed change
- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

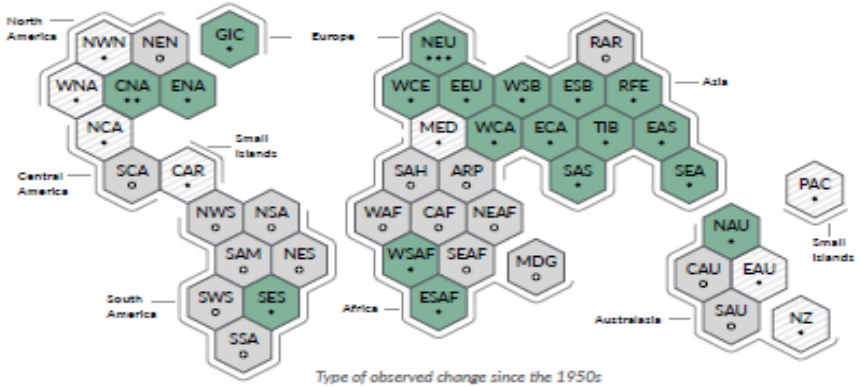


Type of observed change since the 1950s

b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in heavy precipitation
- Increase (19)
- Decrease (0)
- Low agreement in the type of change (8)
- Limited data and/or literature (18)

Confidence in human contribution to the observed change
- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

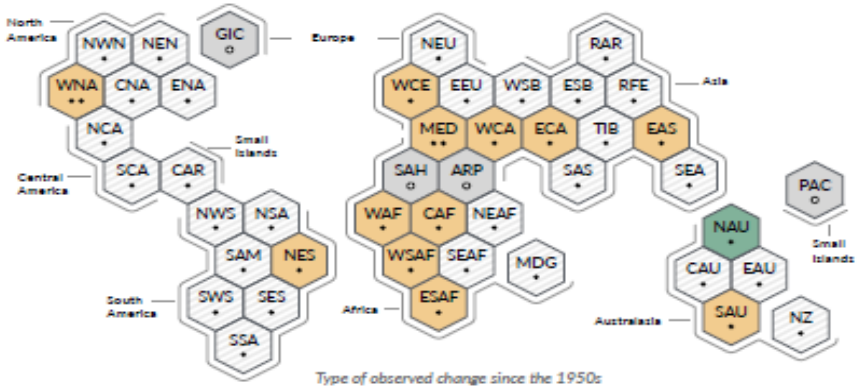


Type of observed change since the 1950s

c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in agricultural and ecological drought
- Increase (12)
- Decrease (1)
- Low agreement in the type of change (28)
- Limited data and/or literature (4)

Confidence in human contribution to the observed change
- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence



Type of observed change since the 1950s

Causes of climate change

1) Natural processes
   - Atmosphere-ocean interactions
   - Ocean currents
   - Volcanoes
   - Tidal forces
   - Continental drift
   - Sunspots and solar activity

2) Persistent Anthropogenic causes
   - AR6 WGI …*It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred*.
   - All 3 major GHGs have increased. Each of the last four decades has been successively warmer than any decade that preceded it since 1850.
   - Global surface temperature, in 2001-2020 was 0.99 [0.84-1.10] °C higher than in 1850-1900.
   - It was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C).
   - Globally averaged precipitation over land increased since 1950, with a faster rate of increase since the 1980s due to human influence.

Anthropogenic GHG emissions accelerate

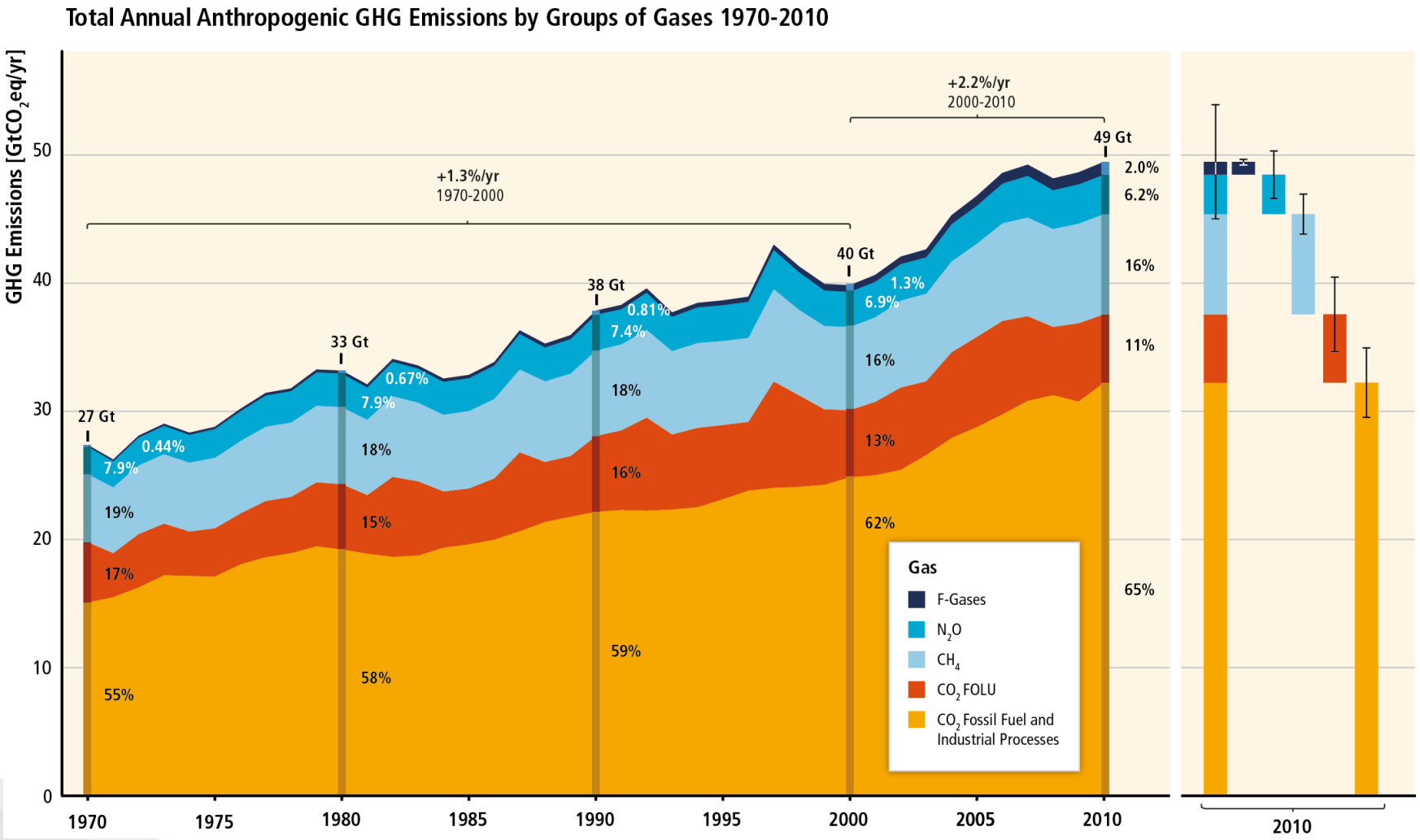
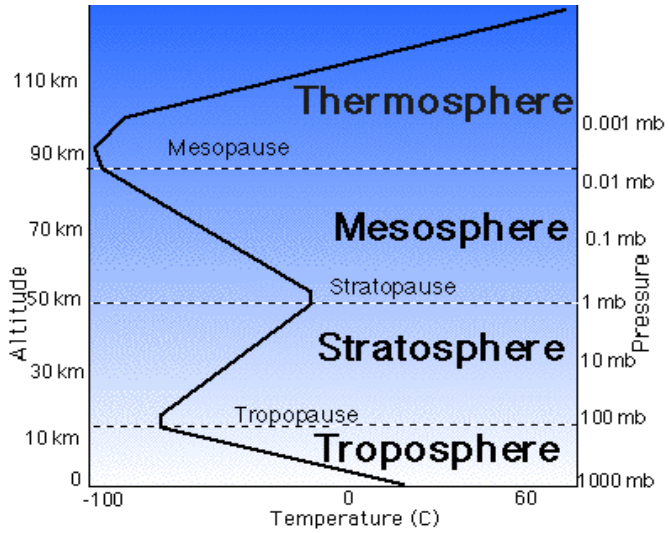


Figure SPM.5
Radiative forcing estimates in 2011 relative to 1750

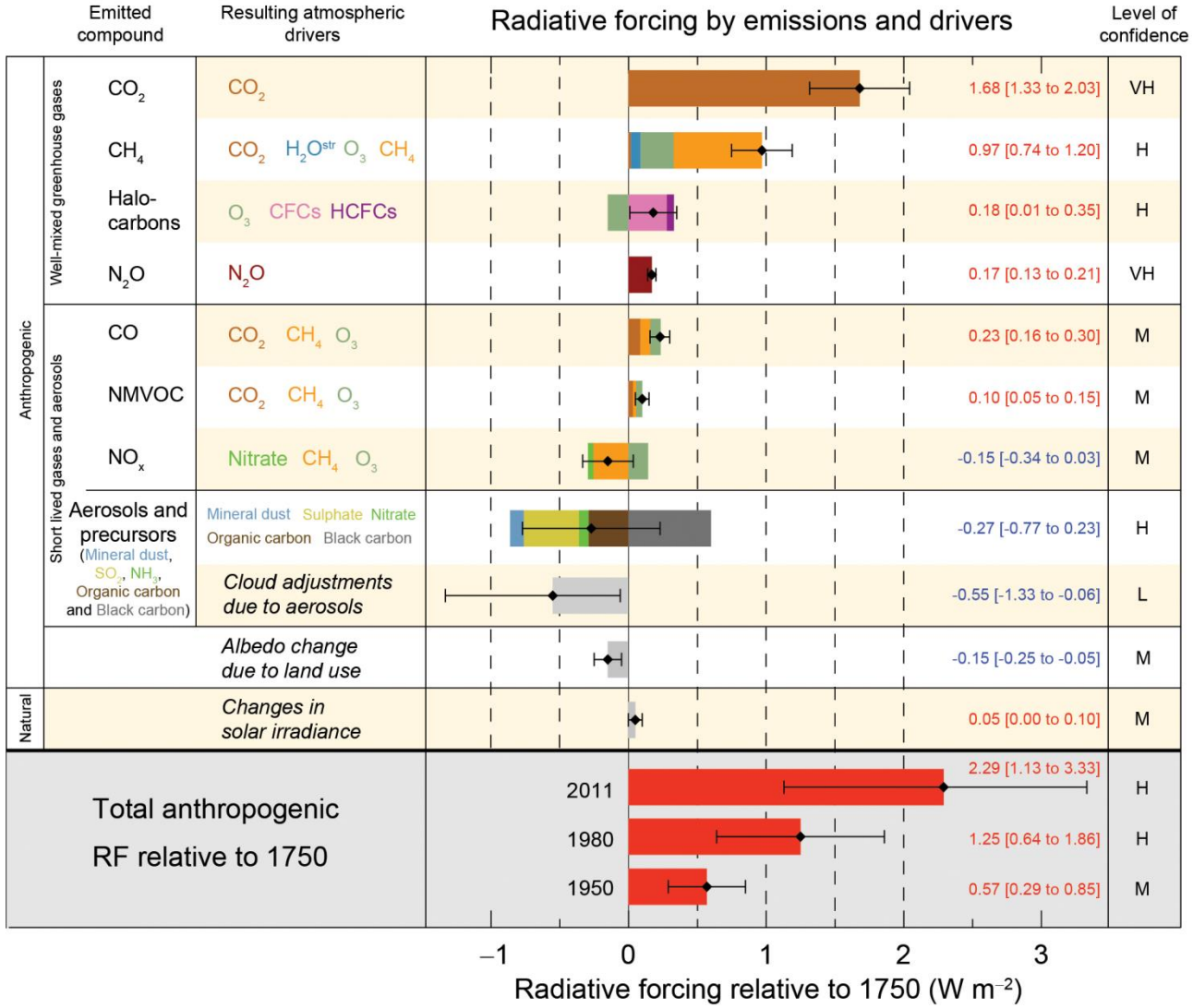
All Figures © IPCC 2013

Radiative Forcing

Change in net irradiance at the atmospheric boundary between the troposphere and the stratosphere (the tropopause)

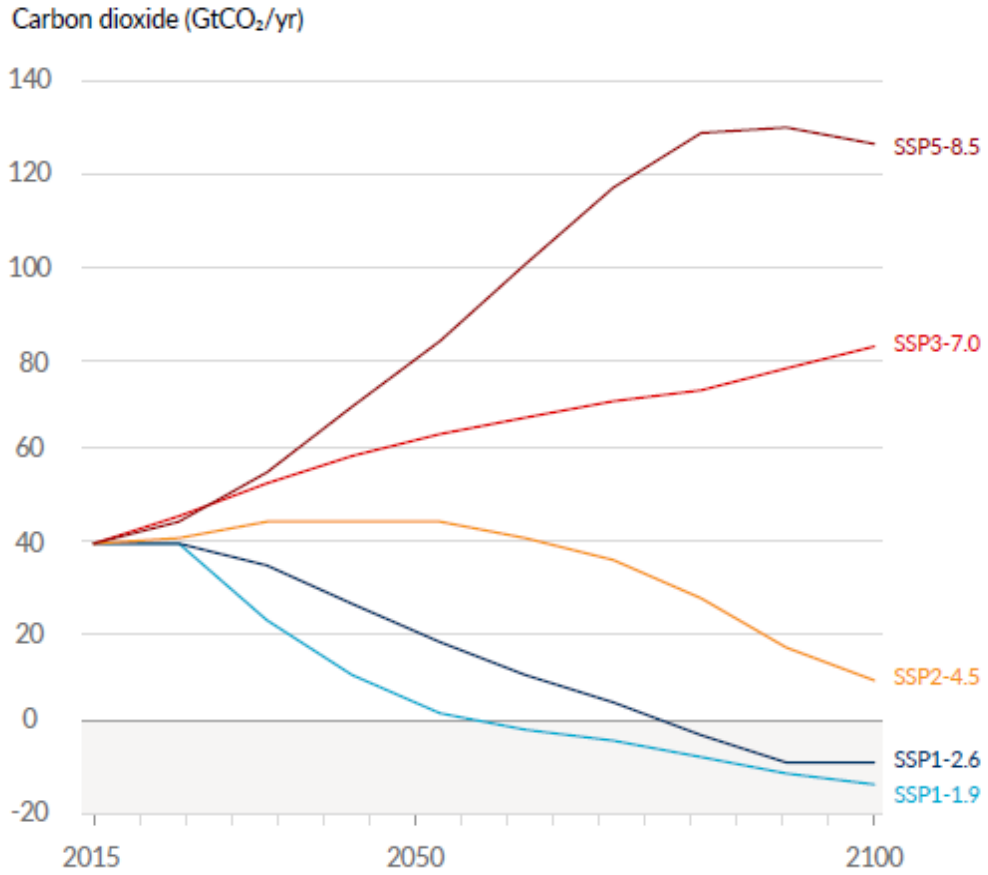


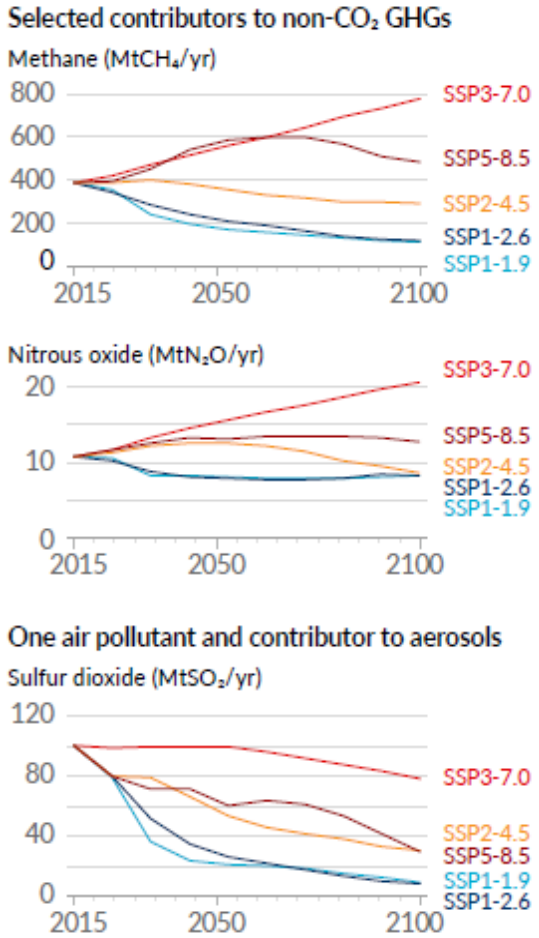
Radiative forcing due to anthropogenic cause



Future emissions cause future additional warming, with total warming dominated by past and future CO_2 emissions

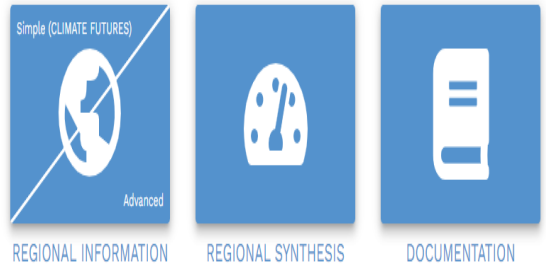
a) Future annual emissions of CO_2 (left) and of a subset of key non-CO_2 drivers (right), across five illustrative scenarios





IPCC Working Group I (WGI): Sixth Assessment Report

https://interactive-atlas.ipcc.ch/



GHG emissions from different sectors

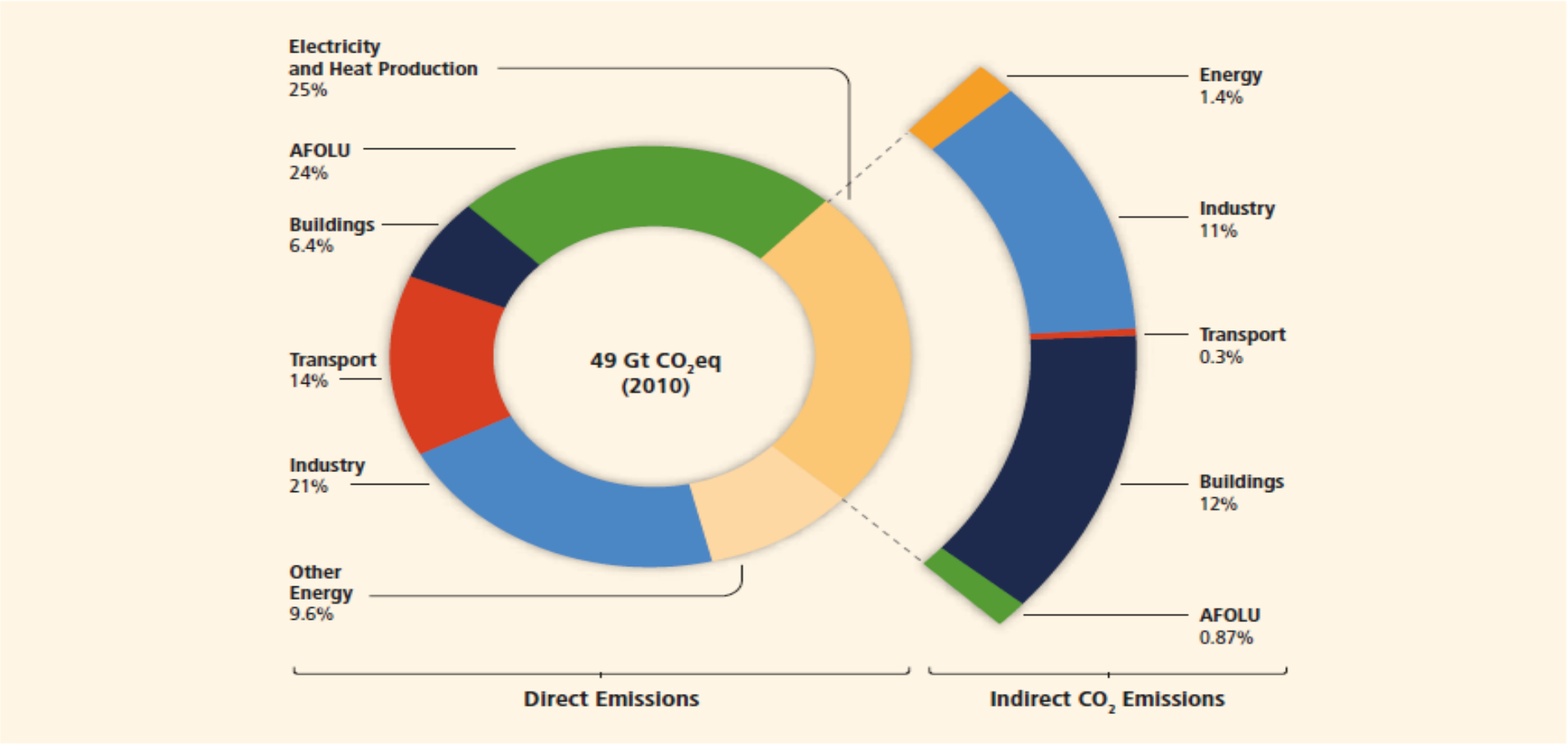


Figure SPM.2| Total anthropogenic GHG emissions ($GtCO_2eq/yr$) by economic sectors. Inner circle shows direct GHG emission shares (in % of total anthropogenic GHG emissions) of five economic sectors in 2010. Pull-out shows how indirect CO_2 emission shares (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. 'Other Energy' refers to all GHG emission sources in the energy sector as defined in Annex II other than electricity and heat production [A.II.9.1]. The emissions data from Agriculture, Forestry and Other Land Use (AFOLU) includes land-based CO_2 emissions from forest fires, peat fires and peat decay that approximate to net CO_2 flux from the Forestry and Other Land Use (FOLU) sub-sector as described in Chapter 11 of this report. Emissions are converted into CO_2-equivalents based on GWP_{100}[6] from the IPCC Second Assessment Report. Sector definitions are provided in Annex II.9. [Figure 1.3a, Figure TS.3 upper panel]

Emissions from country categories and sectors

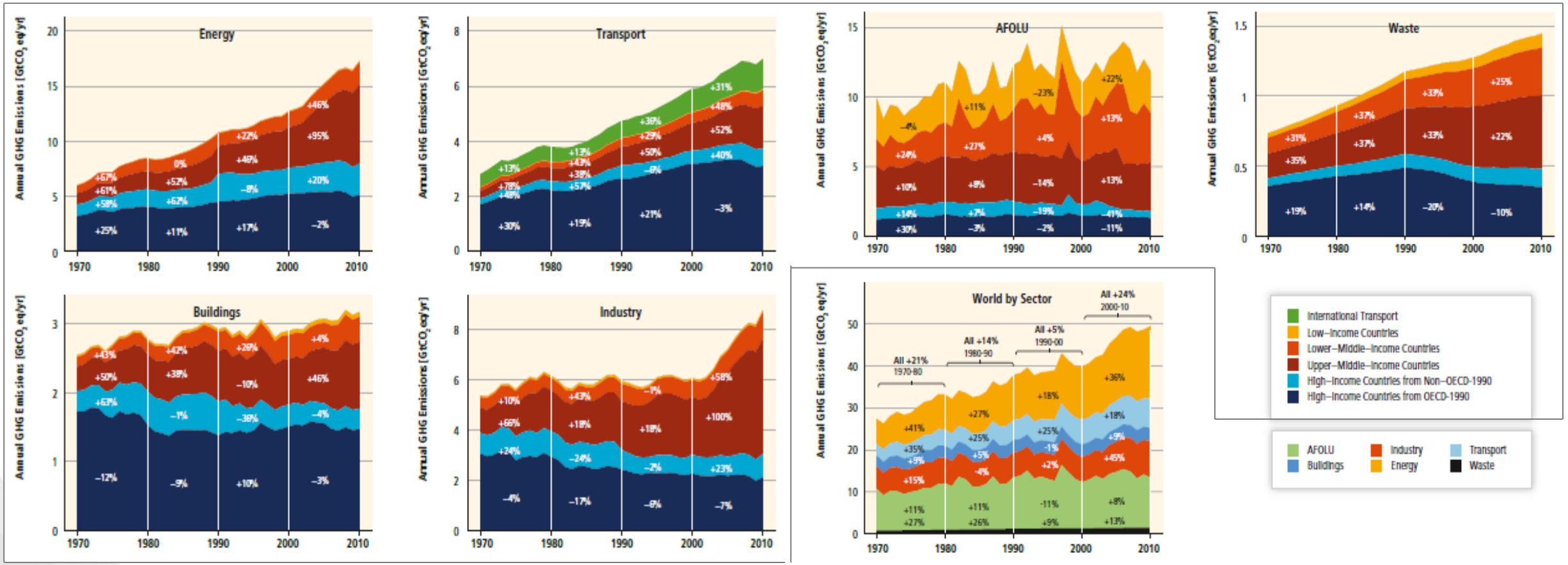
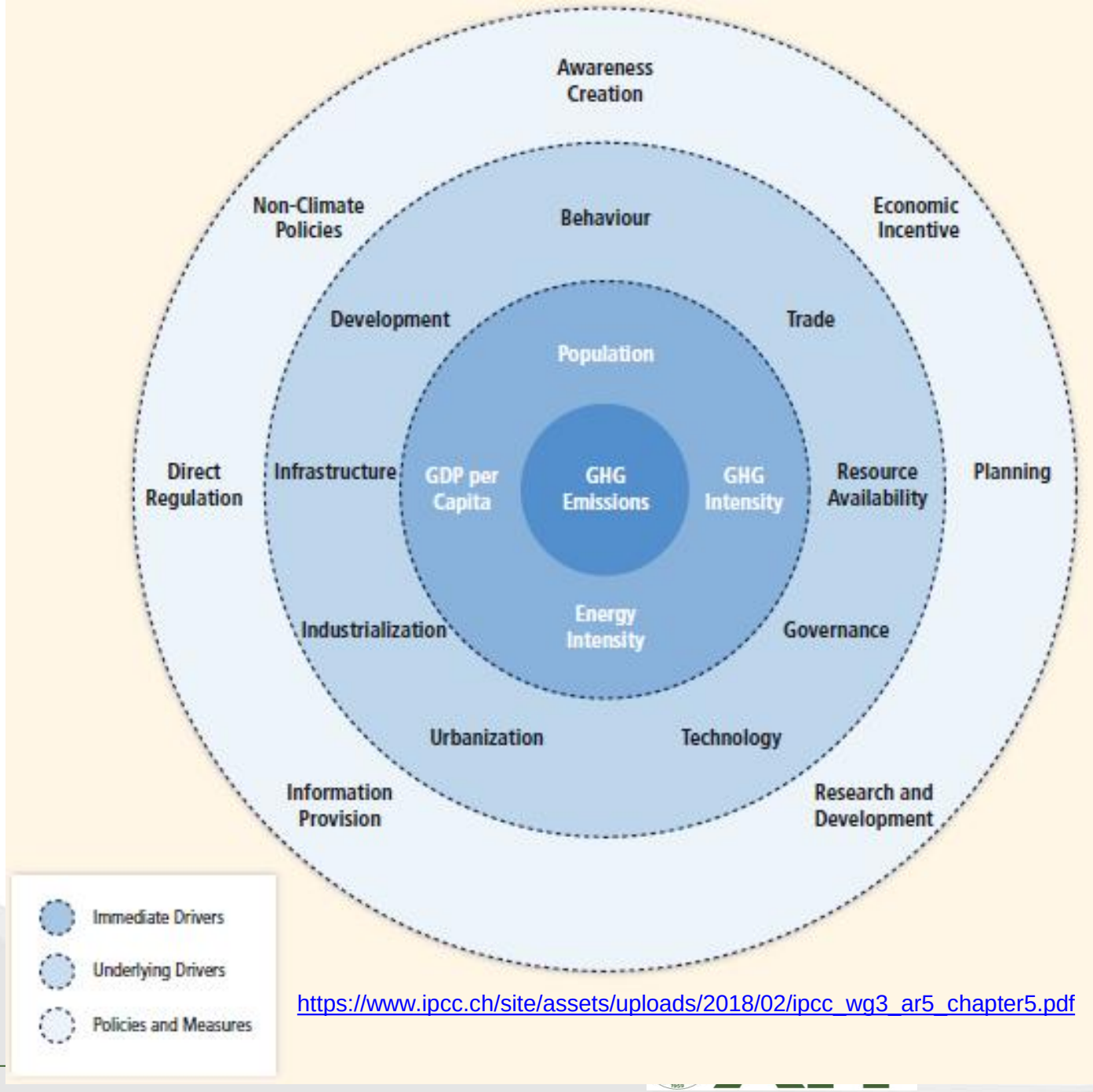


Figure 5.18 | Regional and sector distribution of GHG emission trends. Regions are defined in Annex II.2 | The figure shows annual GHG emissions for the six key sectors discussed in Sections 5.3.4 and 5.3.5 | The left-lower panel presents global sector emissions to assess the relative contribution. Decadal growth rates are projected on the charts for emissions exceeding 0.2 GtCO2eq / yr. The direct emission data from JRC / PBL (2013) and IEA (2012) (see Annex II.9) represents land-based CO2 emissions from forest and peat fires and decay that approximate to CO2 flux from anthopogenic emission sources in the Forestry and Other Land Use (FOLU) sub-sector. For a more detailed representation of Agriculture and FOLU (AFOLU) GHG flux see Section 11.2 and Figures 11.2 and 11.6. Chap 5, IPCC_WGIII_AR5

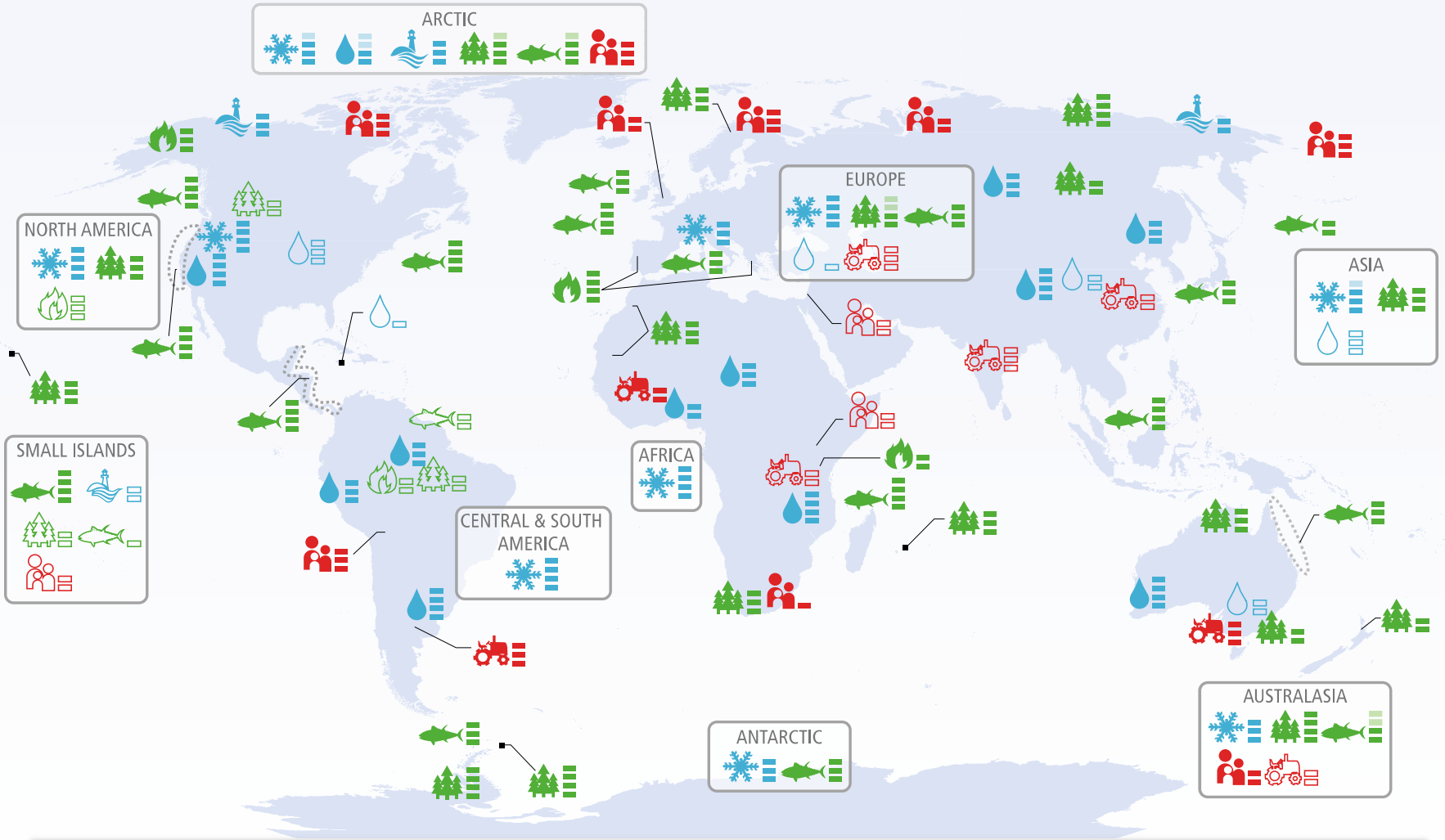
Drivers of GHG emission

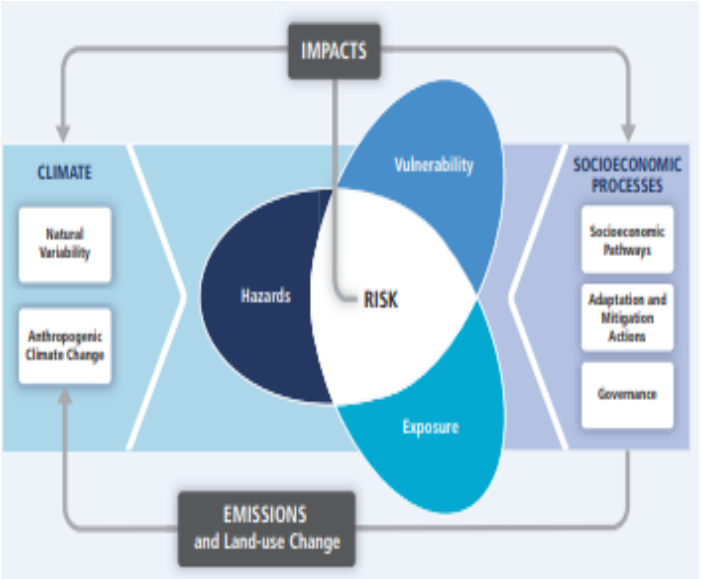


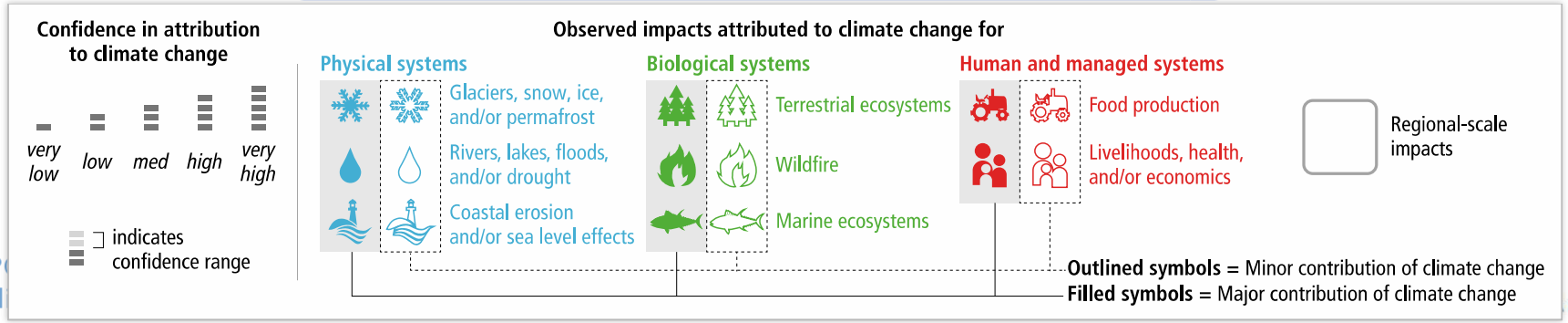
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter5.pdf

Figure 5.1 | Interconnections among GHG emissions, immediate drivers, underlying drivers, and policies and measures. Immediate drivers comprise the factors in the decomposition of emissions. Underlying drivers refer to the processes, mechanisms, and characteristics that influence emissions through the factors. Policies and measures affect the underlying drivers that, in turn, may change the factors. Immediate and underlying drivers may, in return, influence policies and measures.

Observed impacts

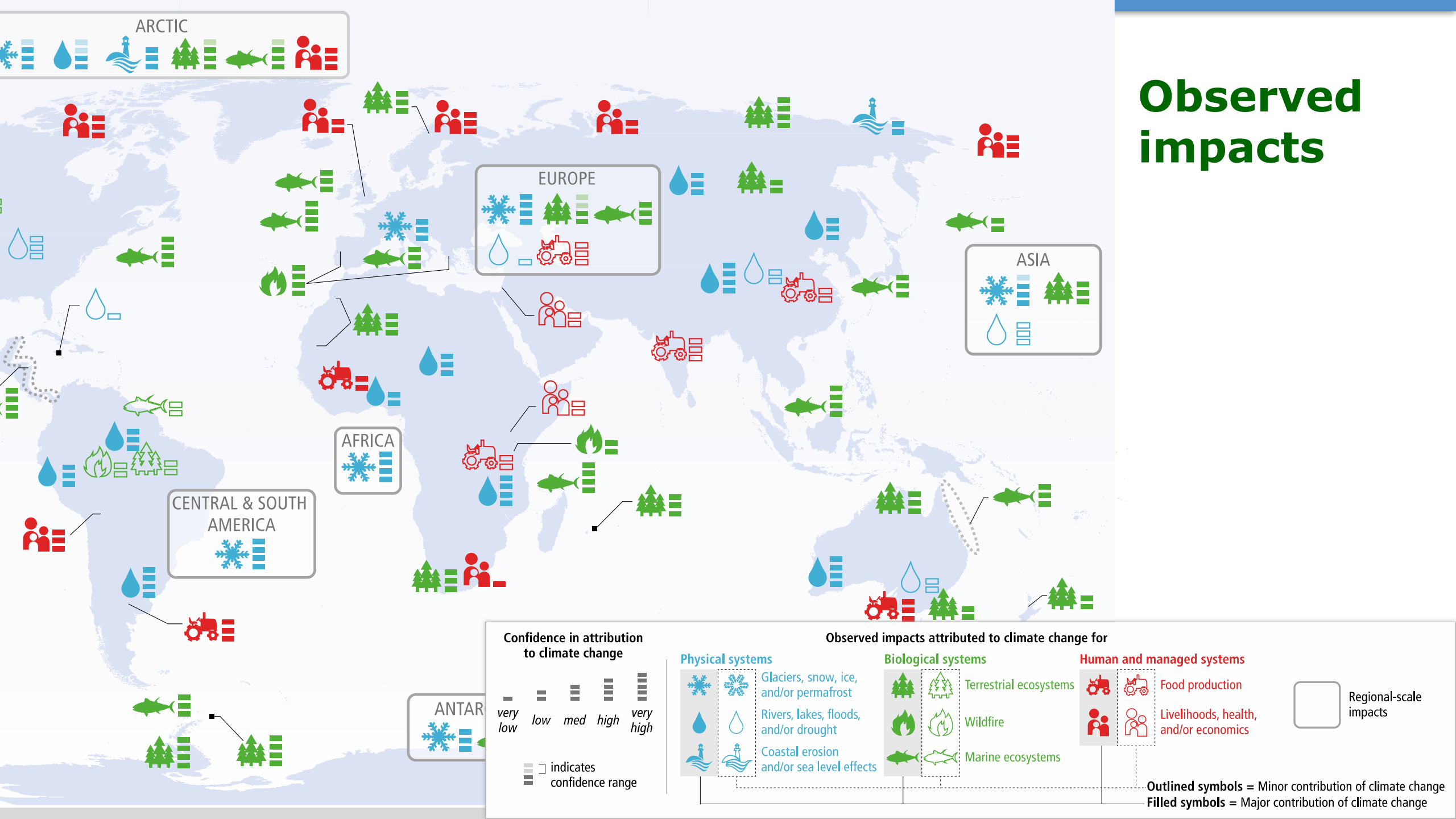




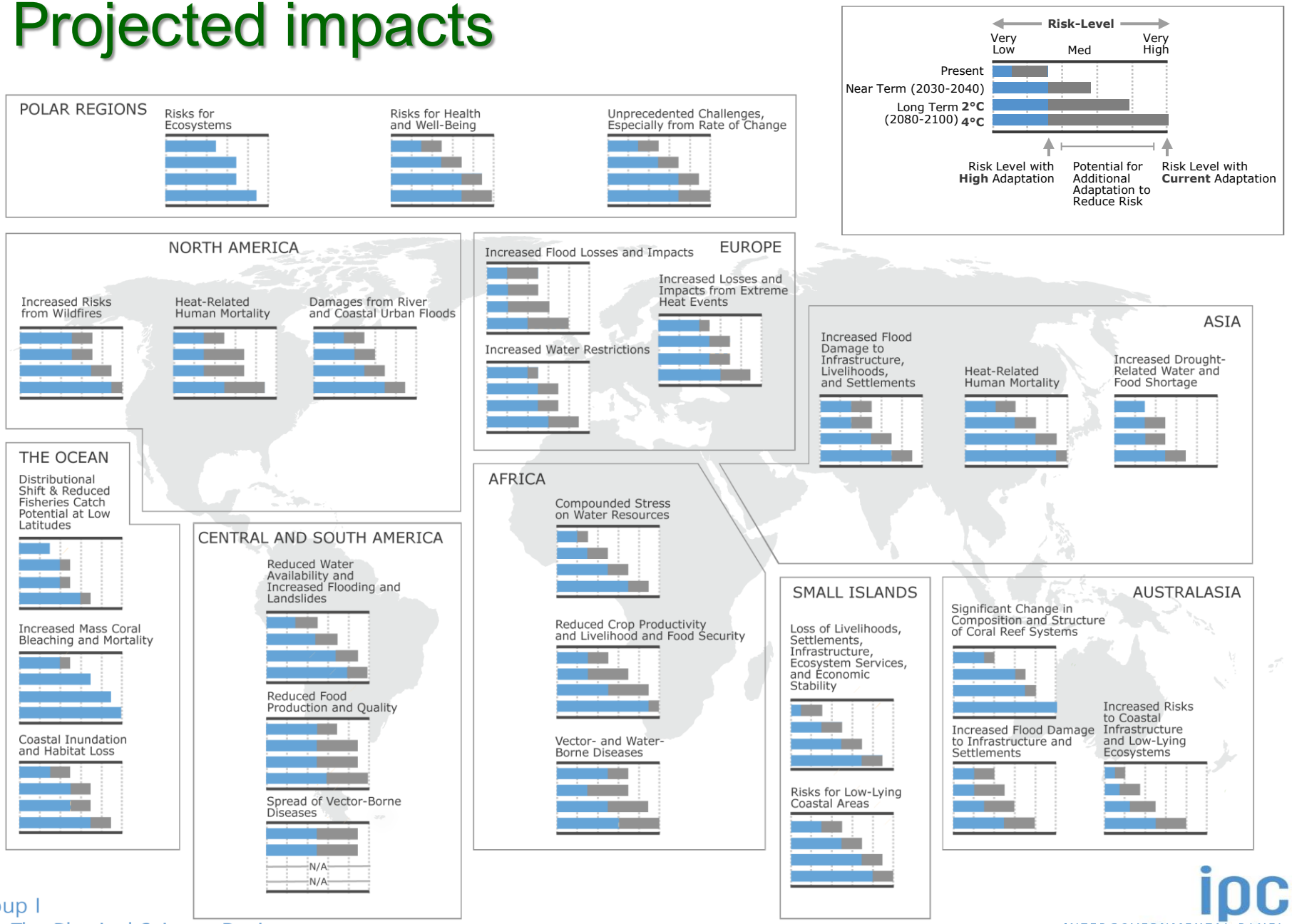


WG II, AR5

Observed impacts



Projected impacts



Climate Risk index

1999-2018

CRI 1999-2018 (1998-2017)	Country	CRI score	Death toll	Deaths per 100 000 inhabitants	Total losses in million US$ PPP	Losses per unit GDP in %	Number of events (total 1999–2018)
1 (1)	Puerto Rico	6.67	149.90	4.09	4 567.06	3.76	25
2 (3)	Myanmar	10.33	7 052.40	14.29	1 630.06	0.83	55
3 (4)	Haiti	13.83	274.15	2.81	388.93	2.38	78
4 (5)	Philippines	17.67	869.80	0.96	3 118.68	0.57	317
5 (8)	Pakistan	28.83	499.45	0.30	3 792.52	0.53	152
6 (9)	Vietnam	29.83	285.80	0.33	2 018.77	0.47	226
7 (7)	Bangladesh	30.00	577.45	0.39	1 686.33	0.41	191
8 (13)	Thailand	31.00	140.00	0.21	7 764.06	0.87	147
9 (11)	Nepal	31.50	228.00	0.87	225.86	0.40	180
10 (10)	Dominica	32.33	3.35	4.72	133.02	20.80	8

2018

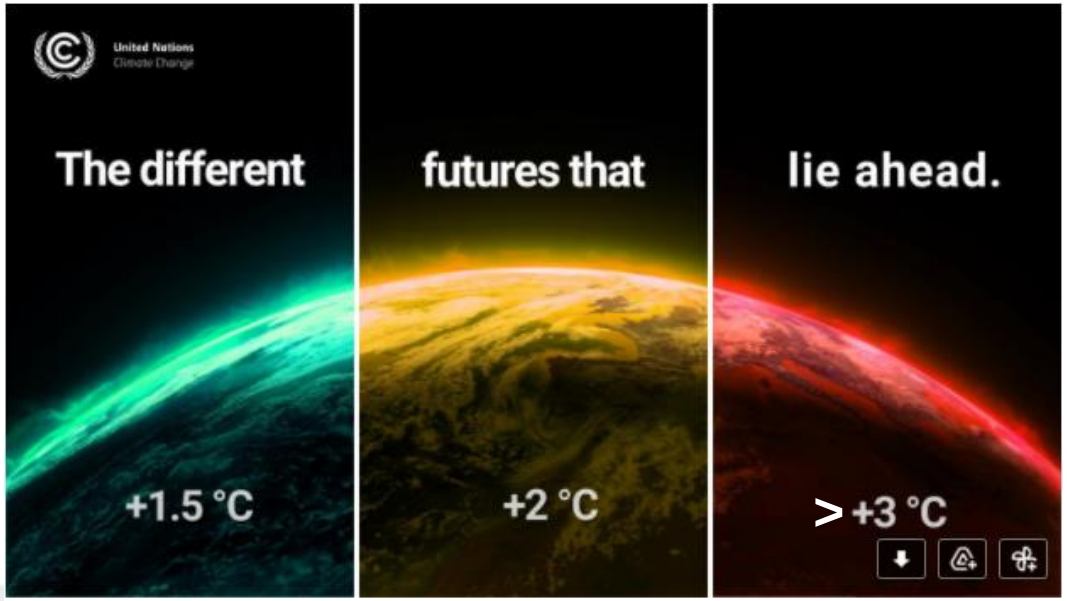
Ranking 2018 (2017)	Country	CRI score	Death toll	Deaths per 100 000 inhabitants	Absolute losses (in million US$ PPP)	Losses per unit GDP in %	Human Development Index 2018 Ranking[12]
1 (36)	Japan	5.50	1 282	1.01	35 839.34	0.64	19
2 (20)	Philippines	11.17	455	0.43	4 547.27	0.48	113
3 (40)	Germany	13.83	1 246	1.50	5 038.62	0.12	5
4 (7)	Madagascar	15.83	72	0.27	568.10	1.32	161
5 (14)	India	18.17	2 081	0.16	37 807.82	0.36	130
6 (2)	Sri Lanka	19.00	38	0.18	3 626.72	1.24	76
7 (45)	Kenya	19.67	113	0.24	708.39	0.40	142
8 (87)	Rwanda	21.17	88	0.73	93.21	0.34	158
9 (42)	Canada	21.83	103	0.28	2 282.17	0.12	12
10 (96)	Fiji	22.50	8	0.90	118.61	1.14	92

PPP = Purchasing Power Parities. GDP = Gross Domestic Product.

Eckstein et al, 2020. GLOBAL CLIMATE RISK INDEX 2020- Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2018 and 1999 to 2018. German Watch

Takeaway

- Science is very certain that climate change is happening with widespread impacts in climate system, environment, and ecosystem human system
- Anthropogenic cause as the major cause of climate change
- Degree of climate risk depends on socioeconomic development pathways and climate change responses we adopt



References

- Climate Change 2021: The Physical Science Basis (https://www.ipcc.ch/report/ar6/wg1/#FullReport
- Impacts of 1.5^0 C of Global Warming on Natural and Human Systems (https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf)
- Climate Change 2014: Impacts, Adaptation, and Vulnerability. (https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf)
- Climate data https://www.climate.gov/maps-data/climate-data-primer