

200 Years of Climate Science

from physics to a transdisciplinary research field

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Agenda

1. 19th century: In the beginning there was physics
2. 20th century: Evidence of human influence on climate change
3. 21st century: How to escape the crisis in the human-nature relationship?
 - Technical change
 - Cultural change
 - A short remark on “follow the science”

19th Century: In the beginning there was physics

1824: Jean-Baptiste Joseph Fourier discovered the greenhouse effect

- He could show that the atmosphere transformed short-waved sunlight into long-waved thermal radiation and formulated the concept of sunlight being absorbed by the atmosphere.
 - “So the temperature rises just by putting the atmosphere in between, since heat in luminous form [i. e. solar radiation] penetrates air more easily than once it is in the form of "**chaleur obscure**" [i. e. infrared radiation].”
- But **what** in the atmosphere causes this greenhouse effect?



© Portraits et Histoire des Hommes Utiles via Wikimedia Commons; Portrait created by Julien Léopold Boilly (1796)

<https://scienceblogs.de/primaklima/2009/06/25/geschichte-des-treibhauseffekts-von-herschel-zu-fourier/>

19th Century: In the beginning there was physics

1856 Eunice Newton Foote

discovered that CO₂ is responsible for the greenhouse effect

... and was forgotten....

- Her work "Circumstances affecting the Heat of the Sun's Rays" (two pages) was accidentally rediscovered in 2010.
- *Experimental setup: She had filled normal air into a glass flask, while only CO₂ was in a second glass flask. The subsequent measurement showed a clear temperature difference.*



shutterstock.com - 771809017

More on E. Foote (in German):

<https://taz.de/Entdeckerin-des-Treibhauseffekts/!5646043/>

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On the Heat in the Sun's Rays.

ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays;*
by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

MY investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Several results have been obtained.

First. The action increases with the density of the air, and is diminished as it becomes more rarified.

The experiments were made with an air-pump and two cylindrical receivers of the same size, about four inches in diameter and thirty in length. In each were placed two thermometers, and the air was exhausted from one and condensed in the other. After both had acquired the same temperature they were placed in the sun, side by side, and while the action of the sun's rays rose to 110° in the condensed tube, it attained only 88° in the other. I had no means at hand of measuring the degree of condensation or rarefaction.

The observations taken once in two or three minutes, were as follows:

Exhausted Tube		Condensed Tube.	
In shade.	In sun.	In shade.	In sun.
75	80	75	80
76	82	78	95
80	82	80	100
83	86	82	105
84	88	85	110

This circumstance must affect the power of the sun's rays in different places, and contribute to produce their feeble action on the summits of lofty mountains.

Secondly. The action of the sun's rays was found to be greater in moist than in dry air.

In one of the receivers the air was saturated with moisture—in the other it was dried by the use of chlorid of calcium.

Both were placed in the sun as before and the result was as follows:

First page of E. Foote's pioneering work

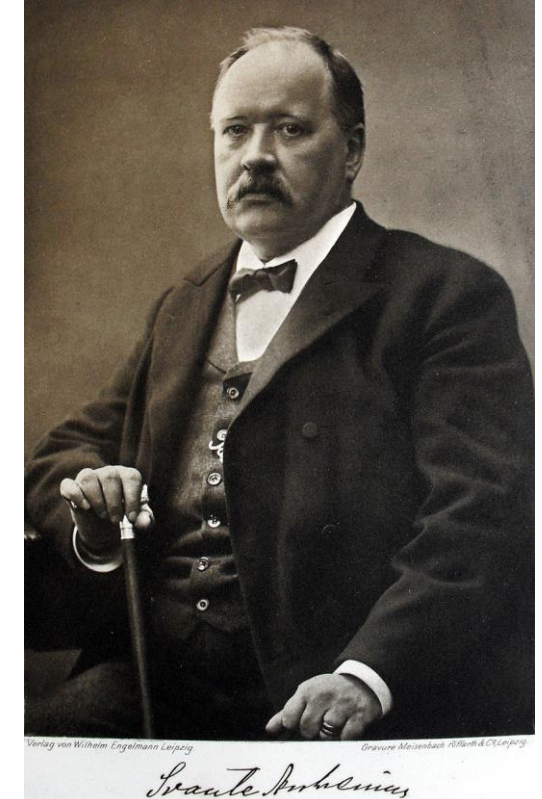
19th Century: In the beginning there was physics

1895 Svante Arrhenius

calculates for the first time the extent of warming supposing CO₂ increases

1. He establishes the theory of the **greenhouse effect** by drawing up the first radiation balance.
2. For the first time, he determines **climate sensitivity** (= measure of how many degrees Celsius the atmosphere would warm up if the CO₂ concentration doubled):
 - His result: a doubling of the CO₂ concentration from around 280 ppm at that time to 560 ppm would correspond to a temperature increase of 4-5 °C
 - Calculating climate sensitivity today:
IPCC, WG1, 2021: 2-5 °C → best estimate: 3 °C

*“Rising CO₂ will allow future humans to live under a warmer sky.”
S. Arrhenius positive conclusion of the prospect of a warmer world*



Svante Arrhenius (1859 – 1927)

Swedish scientist, Nobel Prize in
Chemistry, 1903

Source: Photogravure Meisenbach
Riffarth & Co. Leipzig. - Zeitschrift für
Physikalische Chemie, Volume 69, from 1909

19th Century: In the beginning there was physics

Interim conclusion

The basic physical principles of global warming are understood in the 19th century

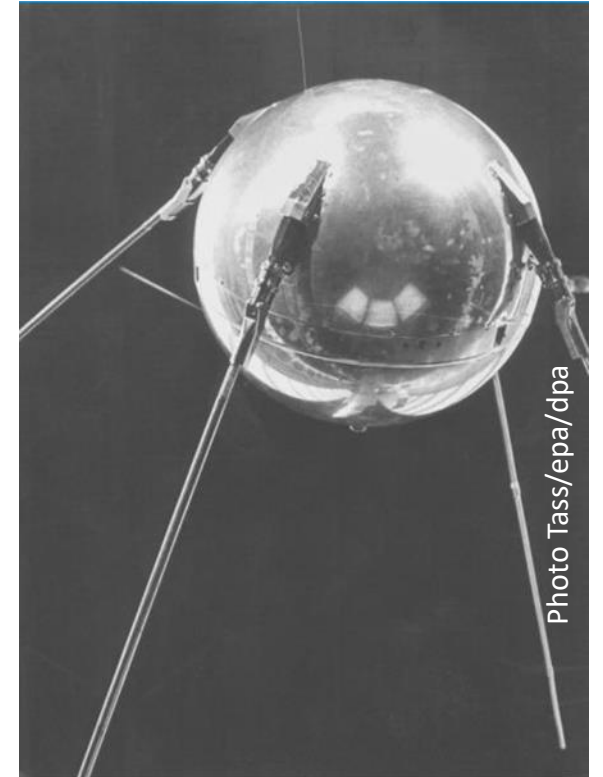
- **The world is "infinite"** Natural science works to **unravel** the world ("God's clockwork") - and makes ground-breaking discoveries
 - Jean-Baptiste Fourier: Greenhouse effect
 - Svante Arrhenius: Climate sensitivity
 - Charles Darwin: Evolution theory
 - Alfred Wegener: Continental drift theory
 - and others ...
- That humans could dominate the geological processes is inconceivable at that time - or at best a **thought experiment** that one imagines rather positively (“... living under a warmer sky....”)



20th century: Proving human-made climate change undoubtedly.

The research questions:

1. Can we **MEASURE** in the real world what we have found out and calculated in laboratory tests?
2. What does this mean for the future?
3. Is it **REALLY** humankind?



1957

First satellite "Sputnik 1"

In the 50s: There is increasing evidence that humans have already changed the concentration of CO₂ in the atmosphere

Quelle: <https://www.aip.org/history/climate/xRevelle.htm>



1957 Roger Revelle, together with Hans Suess, proves that the oceans will not completely absorb the CO₂ produced by humans.

Roger Revelle researches the increase in CO₂ in the atmosphere and lays the foundation for the global measurement of greenhouse gases in Hawaii.

As early as 1957, he warned:

“Humans are currently conducting a large-scale geophysical experiment that could not have happened in the past, nor can it be repeated in the future.”

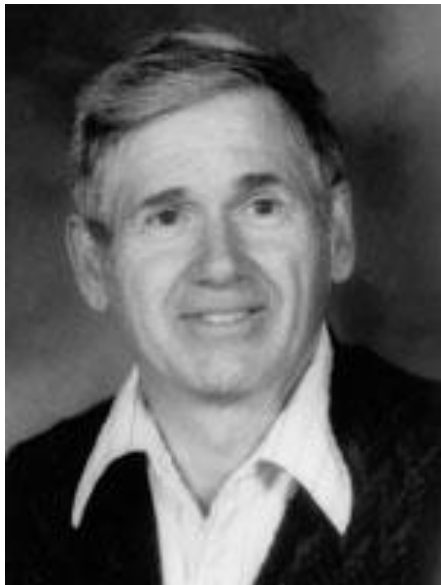
1957 in the "New York Times"

20th Century: Evidence of human influence

1958

The measurement of the global CO₂ concentration begins

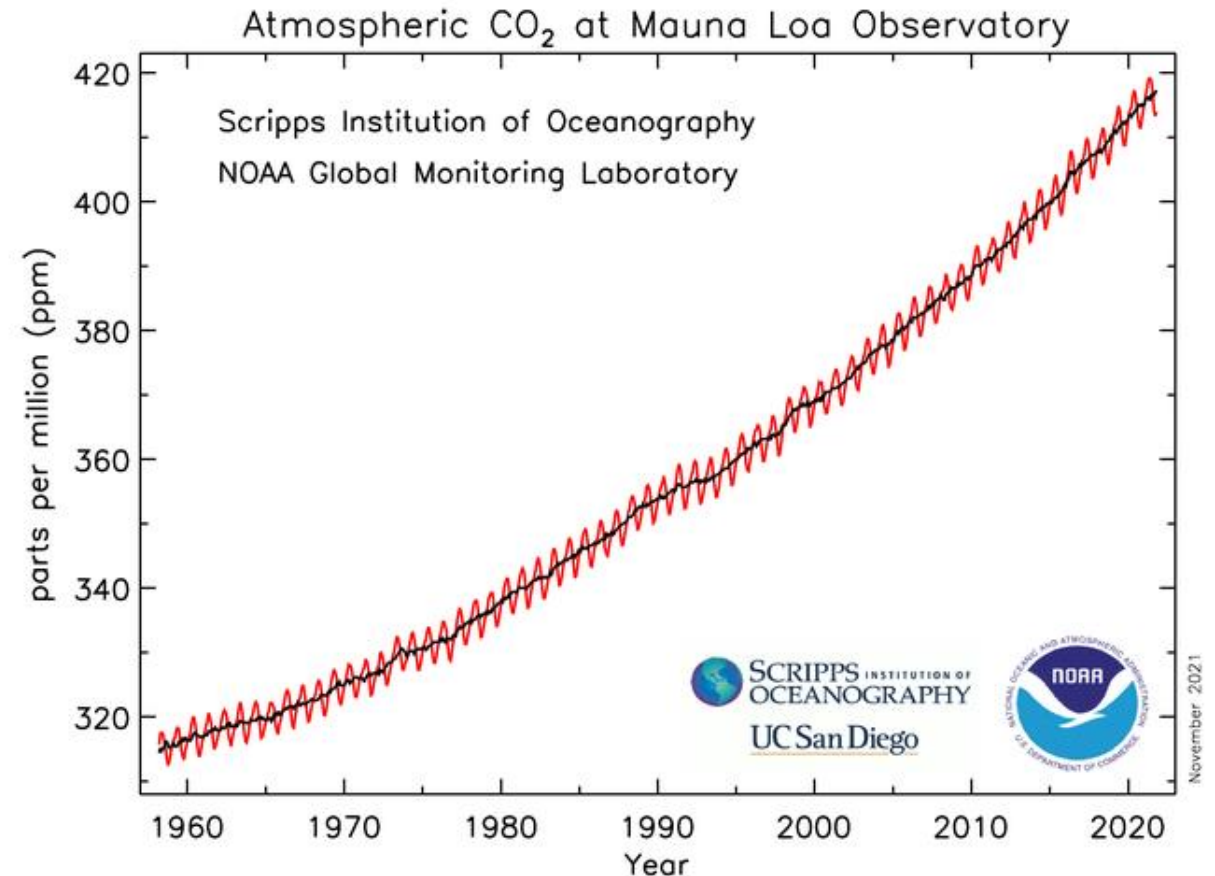
The "Keeling Curve"



Charles Keeling



More on the global measurement of CO₂ on Mauna Loa, Hawaii:
<https://www.noaa.gov/>



Is it really human influence - or just natural variability?

1979 Klaus Hasselmann describes how to recognize human fingerprint in the background noise of weather variability

In 1988, Hasselmann warned:

“In 30 to 100 years, depending on how much fossil fuel we consume, we will face a very significant climate change. Climate zones will shift, precipitation will be distributed differently ...”

1988 in the "Stuttgarter Nachrichten"

In 2021 Hasselmann was awarded with the Nobel Prize in Physics together with Syukuro Manabe and Giorgio Parisi.



Klaus Hasselmann, German climate researcher, founding director of the Max-Planck-Institute of Meteorology in Hamburg oceanologist and meteorologist, at the computer in his office in Hamburg, Germany in 1990. © Source: picture alliance / United Archives

Berlin, 19.06.2023

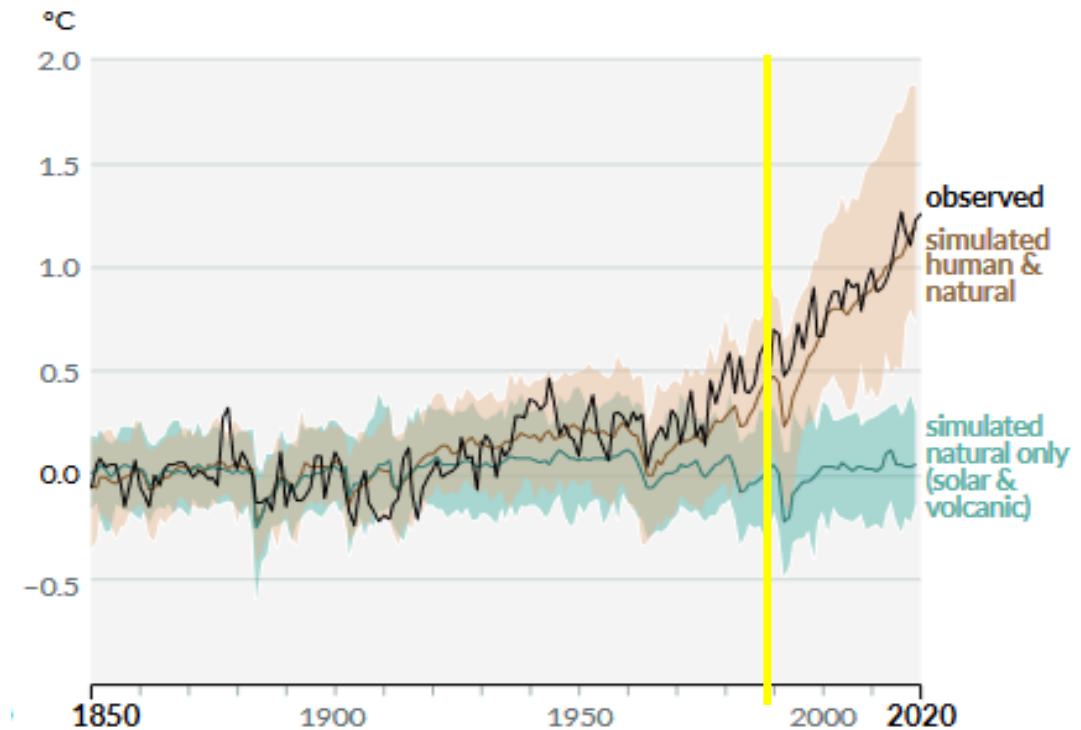
Hasselmann's trick

... to identify anthropogenic climate change

According to his thesis, one would have to simulate one world with the human contribution and a second world in which only natural causes such as volcanic eruptions or solar activity are included; one could then compare both simulations with the actual observations. If one recognizes the change pattern of the first simulation in the observation data, then the human fingerprint would be identified. Hasselmann was able to implement his idea and prove human influence only in the 1990s.

One of many lines of evidence that the cause of the observed climate change is human activity: **the observed surface warming can be reproduced only by simulations that take into account human influencing factors as well as natural ones.**

(b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850–2020)



The comparison of the observed course (black line) and the simulated change (a) with inclusion of man-made emissions (brown) and (b) under exclusively natural conditions (green) proves the human influence on the climate.

What was it like in Earth's history?

In the 70s: paleoclimatology is picking up speed

- Paleontological data from cores (ice cores, sediment cores...) since the 1950s and more intensively from the 1970s.
- Researchers analyse the "fossil air" in the ice cores from Greenland and Antarctica - and find out that CO₂-concentration has not been that high for at least 800.000 years.

Film recommendation: "Between Heaven and Ice" - about the life's work of the glaciologist Claude Lorius.



© NASA's Goddard Space Flight Center/Ludovic Brucker



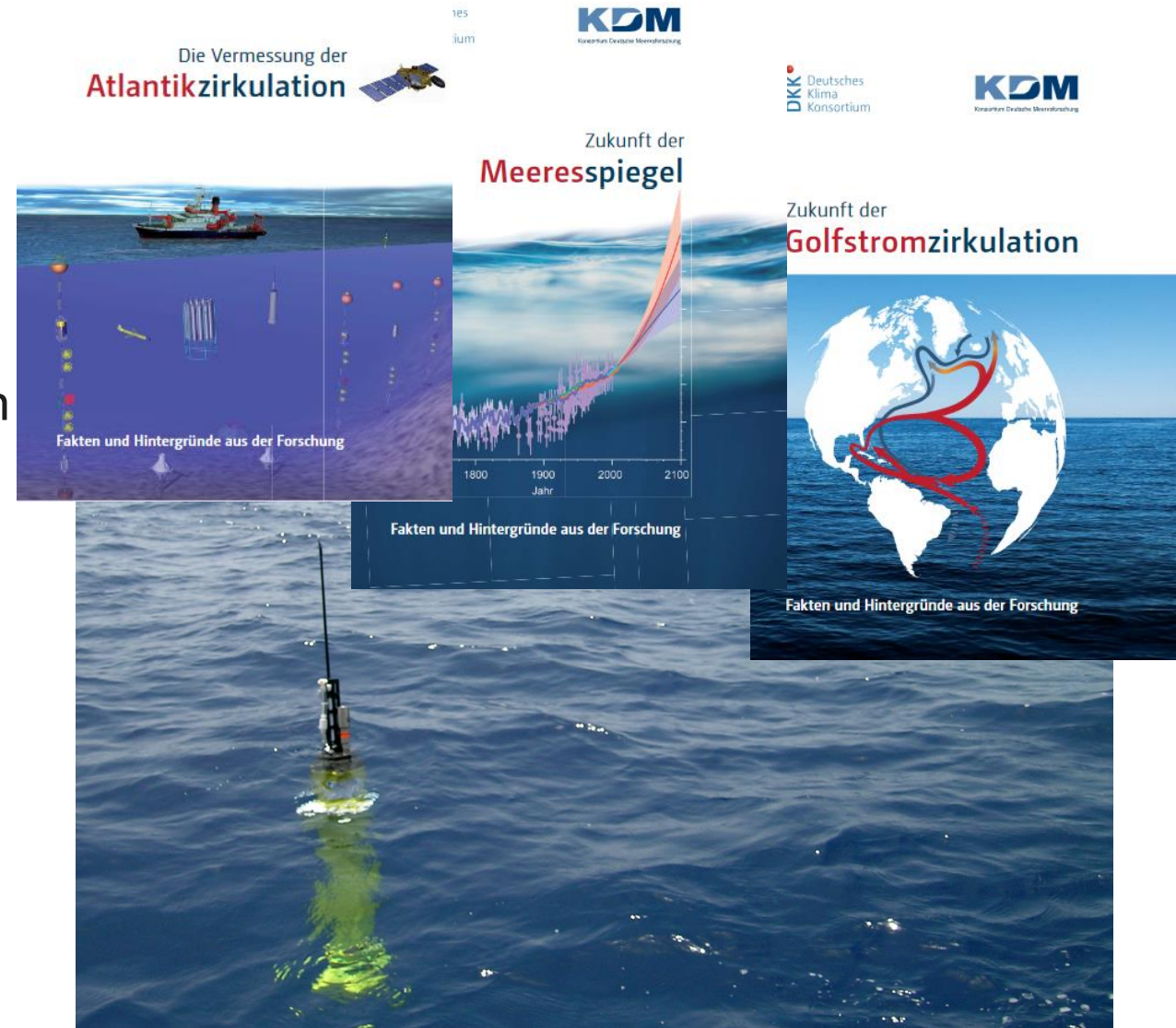
© Alfred Wegener Institute (picture section)

20th Century: Evidence of human influence

The Oceans

... unknown land

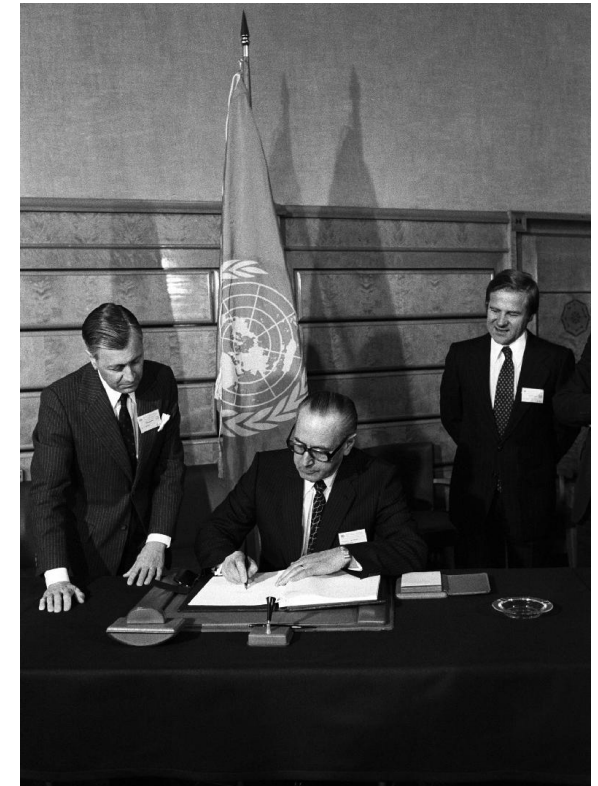
- The oceans cover 2/3 of the planet
- They are the "elephant" in the climate system
- Observations start in the 1970s; major technical challenges
- Insights into the "deep ocean" started only in this century
- **Argo observation system since 2007:** provides data on the climatic development of the oceans via mobile systems and has revolutionized ocean observation



1979: The first world climate conference

... takes place under the umbrella of the WMO (World Meteorological Organization) in Geneva

- Impetus for establishing the IPCC ("Intergovernmental Panel on Climate Change")
- Adoption of a declaration: "The nations of the world must do everything possible **to prevent man-made climate change** that could endanger the well-being of mankind."
- This was followed by:
 - Establishment of a UN climate secretariat in Bonn
 - Formation of the IPCC in 1988
 - Implementation of the first Conference of the Parties (COP) in Berlin in 1995



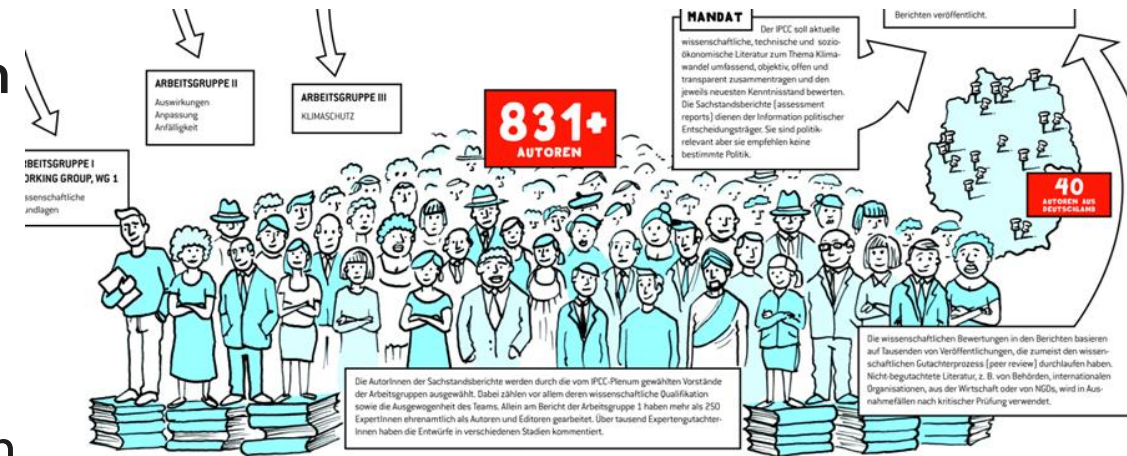
© picture alliance / KEYSTONE

Berlin, 19.06.2023

1988: Foundation of the IPCC by the UNEP and WMO

IPCC - Intergovernmental Panel on Climate Change

- **Mandate:** Reliable and comprehensive information for political decision-makers: "policy-relevant but not policy prescriptive"
- In the reports, **several hundred lead authors** from all over the world **evaluate** current climate research every seven to eight years.
- **195 governments** recognize the "Summary for Policymakers" of the IPCC in a joint final meeting.



Recommendation: Poster on the workings of the IPCC and the core statements of the first volume "Scientific Foundations" of the current IPCC Report 2021 are available at https://www.deutsches-klima-konsortium.de/fileadmin/user_upload/pdfs/Publikationen_DKK/ipcc-poster-en-2021.pdf

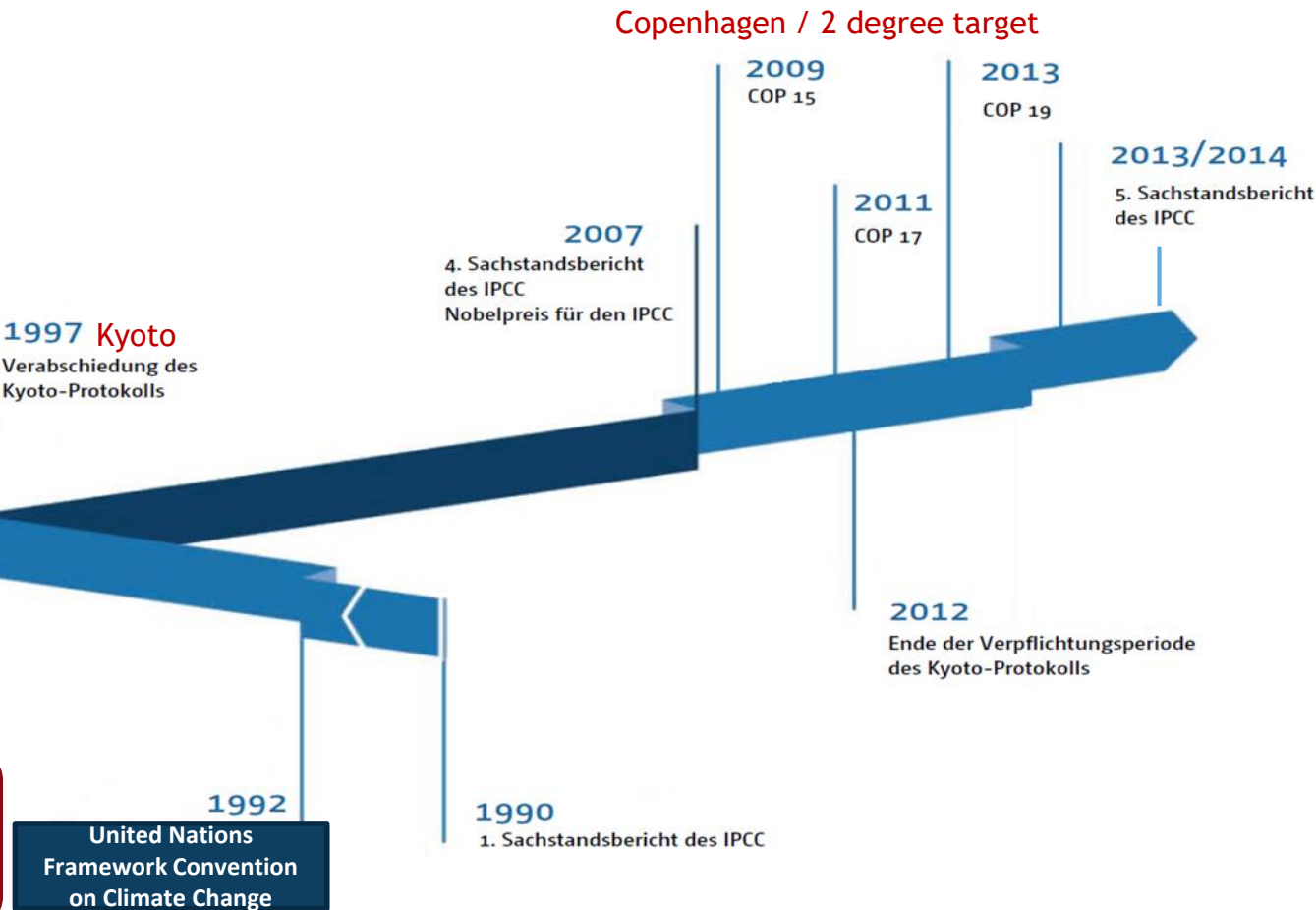
1992: The Rio Conference - and thereafter ...



United Nations
Framework Convention on
Climate Change

Goal: “ ... to achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that prevents **dangerous anthropogenic interference** with the climate system.”

Agenda 21
–
Rio
Conference



2015
Paris Climate Agreement
“... well below 2 degrees ... 1.5 degrees ...”



Agenda 2030



Interim conclusion

Human influence on climate change has been proven.

- Basic convictions and optimism about progress begin to falter: the world is now "finite"; humankind becomes a "geo factor" (Anthropocene)
- Confrontation with the "unintended side effects of modernity" (Ulrich Beck, German sociologist)
- **Action is required**
- Climate change is changing from a scientific to a **political and social issue**. **Climate movements** who push for action arise as well as "climate (science) denial".
- The successes of climate policy fall well short of what would be required according to the **precautionary principle**

21st century: How to escape the crisis in the human-nature relationship

Transformation!

→ Research on the solution space

“The historically unique challenge in the forthcoming **transformation** to a low-carbon society is to push ahead with a comprehensive restructuring based on **insight, prudence and foresight.**”

Transformation as a research and educational project. → The role of science in society is changing.

Scientific Advisory Board of the Federal Government
Global environmental changes (WBGU), Berlin, 2011



Dealing with the crisis of the human-nature relationship

It is now about the "solution space".

Monitoring

- Measuring systems

Societal Climate Research:

- How to come from knowledge to action?
- What are drivers, what are obstacles for change?

Transformation of the energy systems

- Techniques: (sun, wind, geothermal ...)
- Economy (CO₂-price, climate dividend ...)

Health

- Heat
- Pollutants
- Vector-driven infectious diseases

CO₂-Removal

- natural: peatlands, forests
- technical: BECS, CCS, DAC ...

Attribution Science

Adaptation

- Cities
- Agriculture
- Forests
- Coast
- Security & civil protection...

Bio-diversity

New Materials

Recycling economy

Predictions

- downscaling to local level
- seamless prediction

2018/2019 Turnaround

From knowledge to action

- **Fridays for Future**
 - calls for **intergenerational justice**
- Politics: EU introduces burden sharing
 - Finding: NO climate policy costs money
- The long and hot Summer 2018
 - The abstract statistics of climate research materialize in the real world
- COVID-19 Pandemic
 - Physical realities are non-negotiable



21st century: How to escape the crisis in the human-nature relationship

The economy

The global race for "green" innovations has begun



ZUKUNFT DER AUTOINDUSTRIE

VW-Chef Diess: „Zugang zu elektrischer Mobilität wird einfach und günstig sein“



ller
. Von
zu

arbon2Chem Polit

on thyssenkrupp Steel tahl, frei von CO₂

duktion bei thyssenkrupp klimaneutral werden. Mit seiner
ie bisherigen Aktivitäten zur Emissionsreduzierung, steht für
die Übernahme gesellschaftlicher Verantwortung und bekennt sich zum Pariser Klimaschutzabkommen

Transformation: highly complex - and it must be done quickly

according to Uwe Schneidewind, 2019, modified

1. **Energy transition** → *sufficient - efficient - regenerative*
2. **Mobility turnaround** → *avoid - relocate - improve*
3. **Diet transition** → bringing health - nutrition - environment together
4. **Resource turnaround** → reduce resource backpack by a factor of 4
5. **Urban turn** → sustainability - participation - individuality
6. **Industrial turn** → make energy-intensive basic industry future-proof

Norms
and
values?

**Turnaround in prosperity
and consumption** →

- *clear out*
- *decelerate*
- *unbundle*
- *decommercialize*

Society

Cooperation, freedom, justice, long-term

Nobel Prize laureate Klaus Hasselmann on the problem of short-term logic:

“.... we are not used to solving a problem that has to be solved in 10, 20 or 30 years - we are used to solving a problem immediately. [...]

*This difference between **short time scale** that is most people’s perspective and the **long time scale** of climate has always been the political problem of climate change.”*

Press conference in Hamburg to announce the award of the Nobel Prize on 5 October 2021



Klaus Hasselmann, founding director of the Max Planck Institute for Meteorology, Hamburg, and Jochem Marotzke, current director at the MPI-M at the press conference, 5 October 2021

Is it plausible that Germany will achieve its climate targets set in law? "Climate Futures Outlook" study by the University of Hamburg 2021

Result:

- From a purely technical and economic point of view, climate neutrality by 2050 is possible. However, politics underestimates the social component of the transformation.
- There is a gap between technical possibilities and **social rethinking**.



→ Complete decarbonization by 2050 currently not plausible

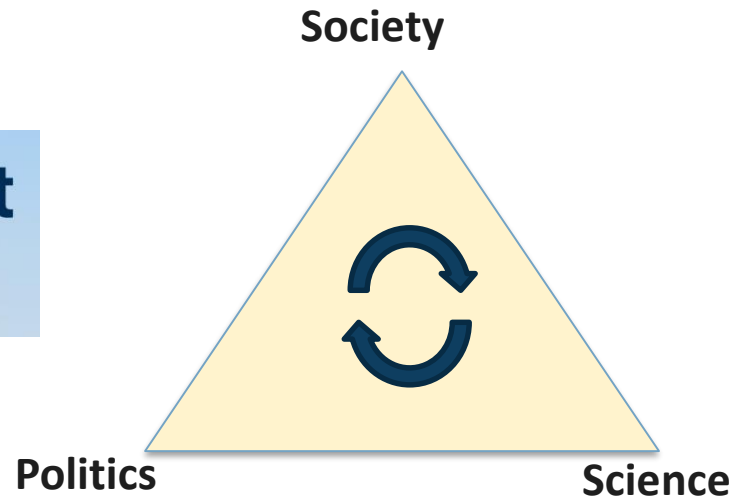
<https://www.cliccs.uni-hamburg.de/de/results/hamburg-climate-futures-outlook.html>

21st century: How to escape the crisis in the human-nature relationship

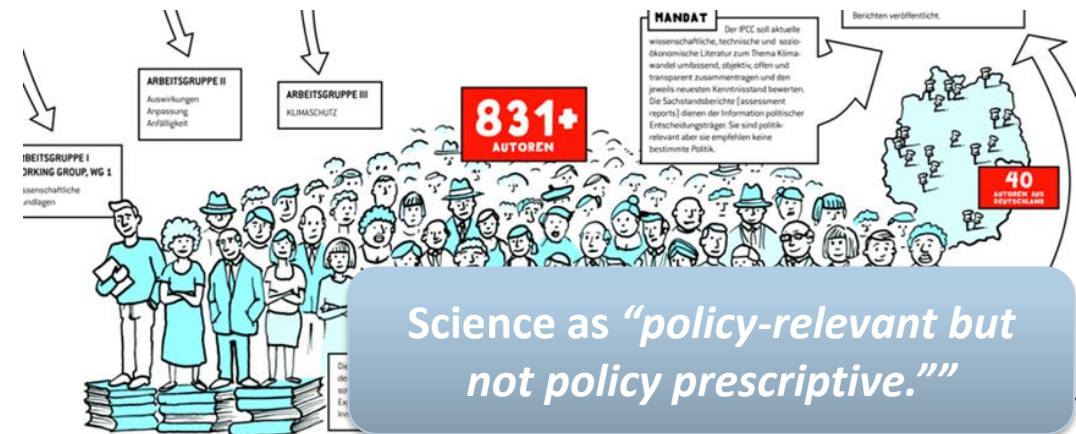
~~Listen to~~

~~Follow the Science!~~

The role of science



Climate science as a transdisciplinary science. Dialogue at eye level and participation of civil society.



Climate research in the 21st century...

- ... includes further **understanding of the climate system**, observing and exploring the **consequences of climate change** as well as investigating in technical, social and political **solutions** to limit climate change (mitigation) and to deal with the no longer avoidable climate impacts (adaptation).
- Other trends include:
 - Integration of the entire Earth system → **Earth system modelling, Earth system science**
 - Further differentiation in the **social sciences** and humanities, growing significance of basic research in these fields
 - **Interdisciplinary** association with more and more research fields. i. e. biodiversity, environment, risk & security, sustainability, agriculture, marine, energy etc.
 - New formats and methods that go beyond science: integrative or **transdisciplinary** research, co-design, co-production ...

Climate science is now a cross-sectoral research field, which is moving dynamically and cannot be defined conclusively.

Thank you!

Marie-Luise Beck

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Related links:

<https://www.deutsches-klima-konsortium.de/de/klima-themen/klimaforschung.html>

<https://zdfheute-stories-scroll.zdf.de/klimawandel-forschung-politik/index.html>

<https://scienceblogs.de/primaklima/2009/06/25/geschichte-des-treibhauseffekts-von-herschel-zu-fourier/>