CLIMATE CHANGE:

ANALYSES
RISKS
OPPORTUNITIES

1

MUDELSEE

1970


ABI '81
ABI 81

HERR MANFRED MUDELSEE

geboren am 6.10.1962 in HEIDELBERG

hat sich am 1.6.1990

der Diplomprüfung im Studiengang Physik

an der Universität Heidelberg unterzogen

und in den einzelnen Prüfungsfächern folgende Urteile erhalten:

1. Experimentalphysik	SEHR GUT-GUT	PROF. K.O. MÜNNICH
2. Theoretische Physik	SEHR GUT	PROF. H.A. WEIDENMÜLLER
3. Wahlfach (Physik)	SEHR GUT-GUT	PROF. W. ROEDEL
4. CHEMIE	SEHR GUT-GUT	PROF. G. WOLF
5. Diplomarbeit	SEHR GUT	PROF. K.O. MÜNNICH PROF. U. PLATT

Das Thema der Diplomarbeit lautete:

ESR-DATIERUNG KARBONATHALTIGER, QUARTÄRER TIEFSEESEDIMENTE

1992

1997

PERGAMON

Computers & Geosciences 26 (2000) 293–307

COMPUTERS & GEOSCIENCES

Ramp function regression: a tool for quantifying climate transitions ☆

Manfred Mudelsee*

Institute of Mathematics and Statistics, University of Kent, Canterbury CT2 7NF, UK

Received 16 March 1999; received in revised form 15 September 1999; accepted 15 September 1999

2003

letters to nature

No upward trends in the occurrence of extreme floods in central Europe

Manfred Mudelsee[1]*, Michael Börngen[1], Gerd Tetzlaff[1] & Uwe Grünewald[2]

[1]*Institute of Meteorology, University of Leipzig, Stephanstrasse 3, 04103 Leipzig, Germany*

[2]*Institute of Hydrology, Technical University Cottbus, PF 101344, 03103 Cottbus, Germany*

* Present address: Department of Earth Sciences, Boston University, 685 Commonwealth Avenue, Boston, Massachusetts 02215, USA

2024

Journal of
Water & Climate Change

Journal of Water and Climate Change Vol 15 No 3, 1300 doi: 10.2166/wcc.2024.587

Are extreme floods on the Danube River becoming more frequent? A case study of Bratislava station

Igor Leščešen [a], Biljana Basarin [a], Dragoslav Pavić [a], Manfred Mudelsee [b,c,d,e], Pavla Pekarova [f] and Minučer Mesaroš [a,*]

[a] Department of Geography, Tourism and Hotel Management, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, Novi Sad, Serbia
[b] Climate Risk Analysis, Kreuzstrasse 27, 37581 Bad Gandersheim, Germany
[c] Advanced Climate Risk Education gUG, Kreuzstrasse 27, 37581 Bad Gandersheim, Germany
[d] Institute of Geosciences, University of Potsdam, Karl-Liebknecht-Str. 24–25, 14476 Potsdam, Germany
[e] Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Klußmannstr. 3, 27570 Bremerhaven, Germany
[f] Institute of Hydrology, Slovak Academy of Sciences, Dubravska cesta 9, 841 04 Bratislava, Slovakia
*Corresponding author. E-mail: minucer.mesaros@dgt.uns.ac.rs


Atmospheric and Oceanographic Sciences Library 51
Manfred Mudelsee
Climate Time Series Analysis
Classical Statistical and Bootstrap Methods
Second Edition
Springer
51st Online Course
20–24 January 2025
www.climate-risk-analysis.com

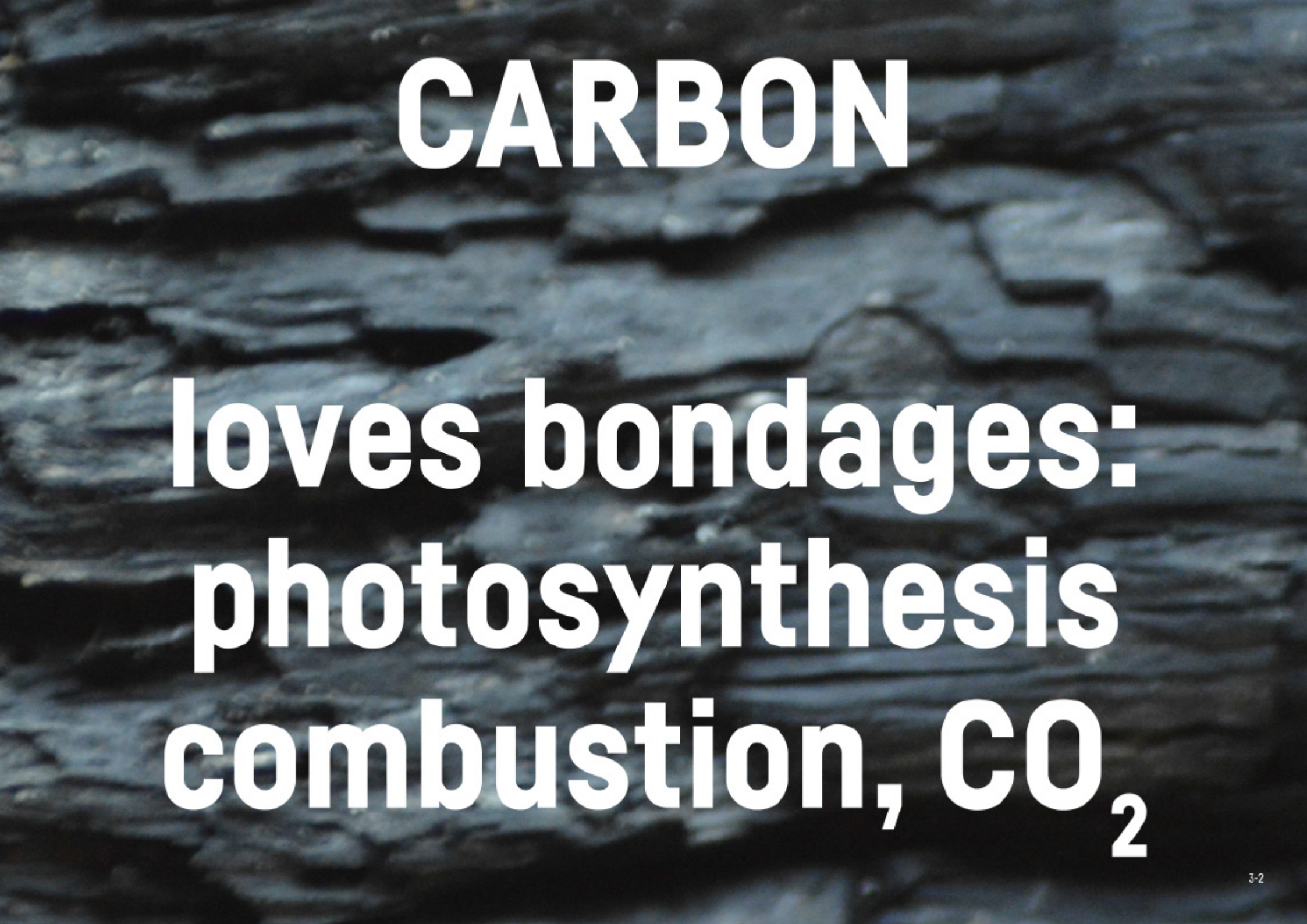

2
MESSAGE

CLIMATE MITIGATION REMAINS IMPORTANT.

ADAPTATION BECOMES MORE IMPORTANT.

3

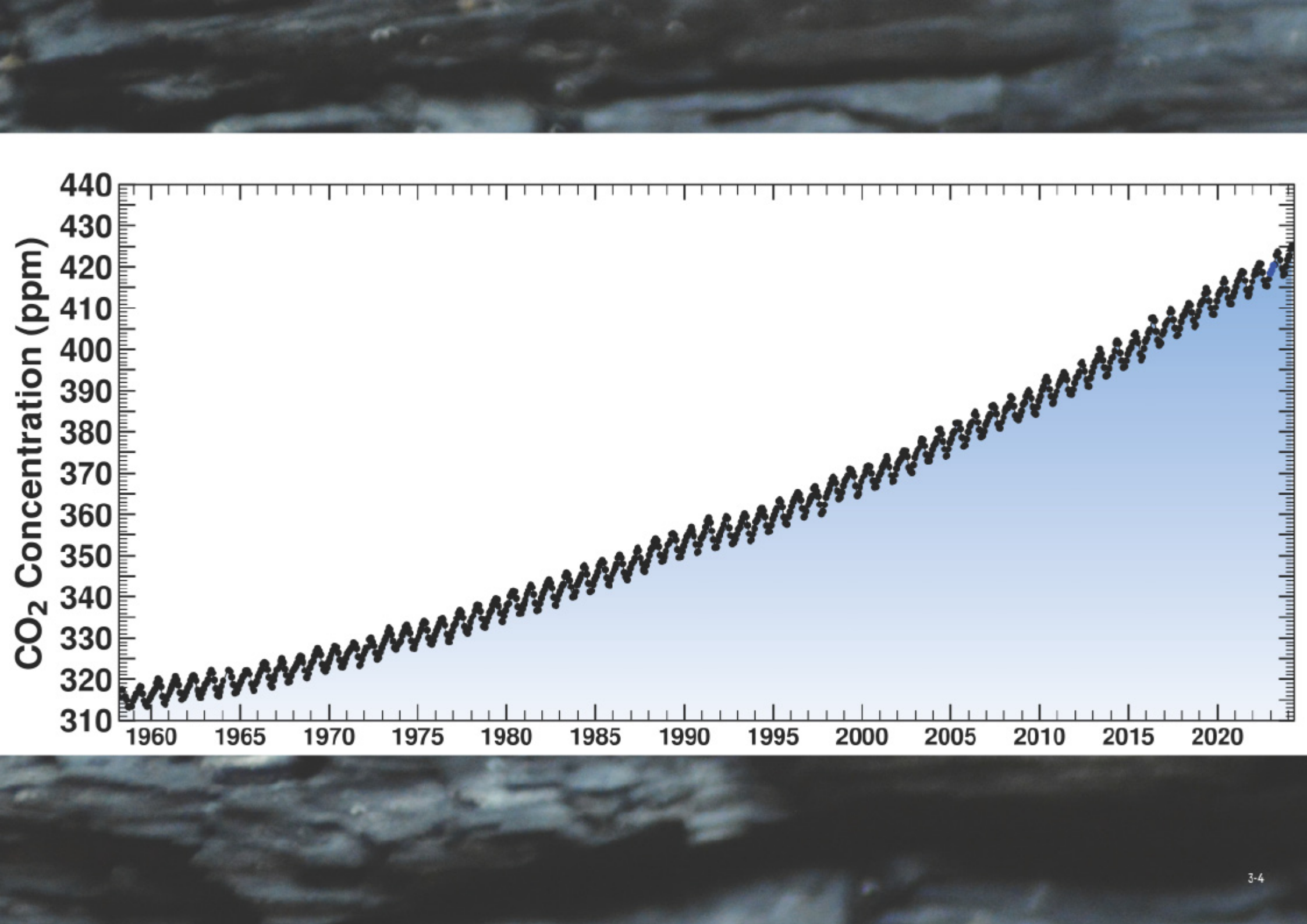
CARBON DIOXIDE

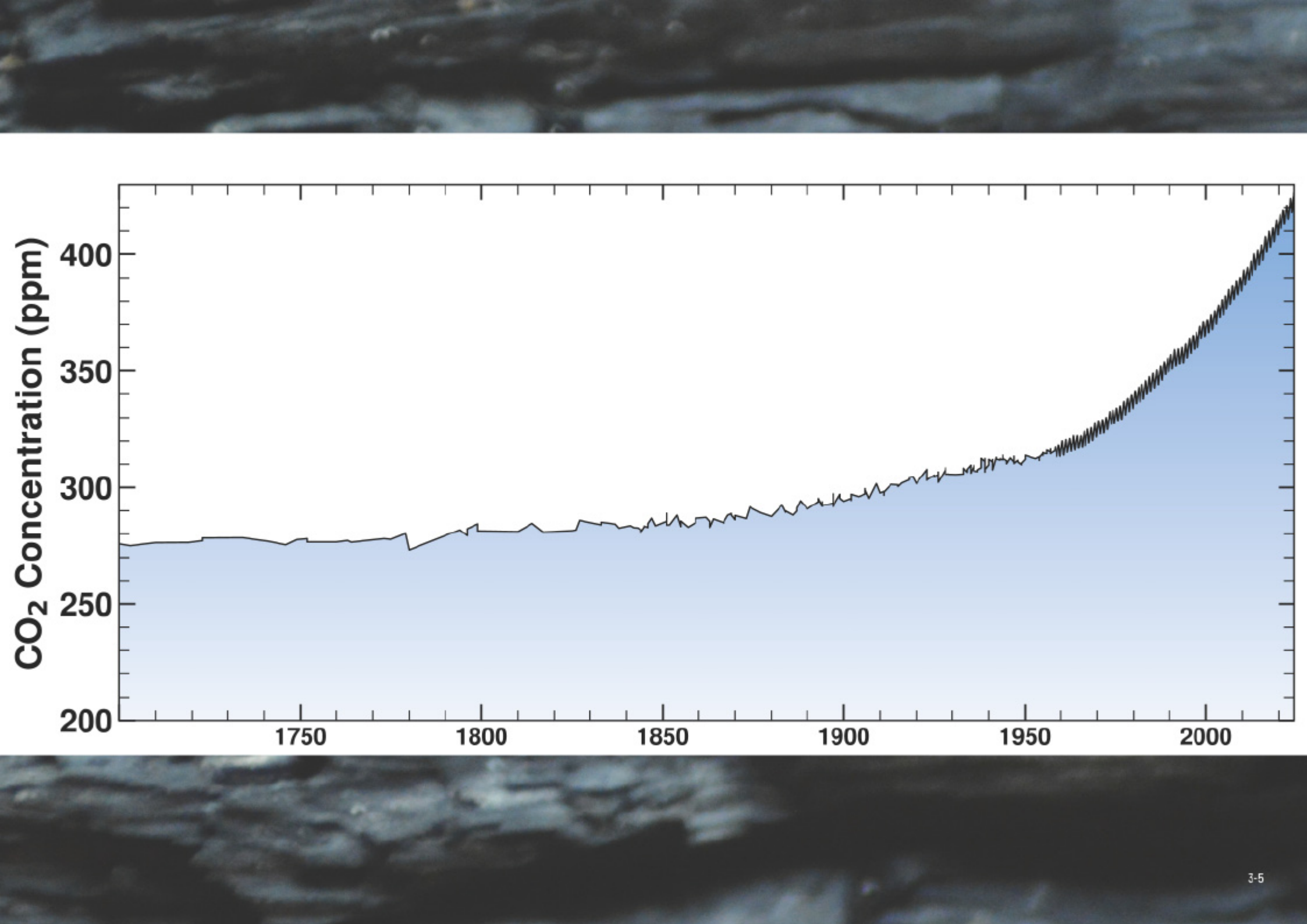

CARBON
loves bondages:
photosynthesis
combustion, CO_2

carbon dioxide = CO_2

The atmospheric concentration shows

annual variations (biology)
and
decadal upwards trend (fossil fuels)


CO_2 Concentration (ppm)
440
430
420
410
400
390
380
370
360
350
340
330
320
310
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


CO_2 Concentration (ppm)
400
350
300
250
200
1750
1800
1850
1900
1950
2000

ppm = parts per million

429 ppm (April 2024):

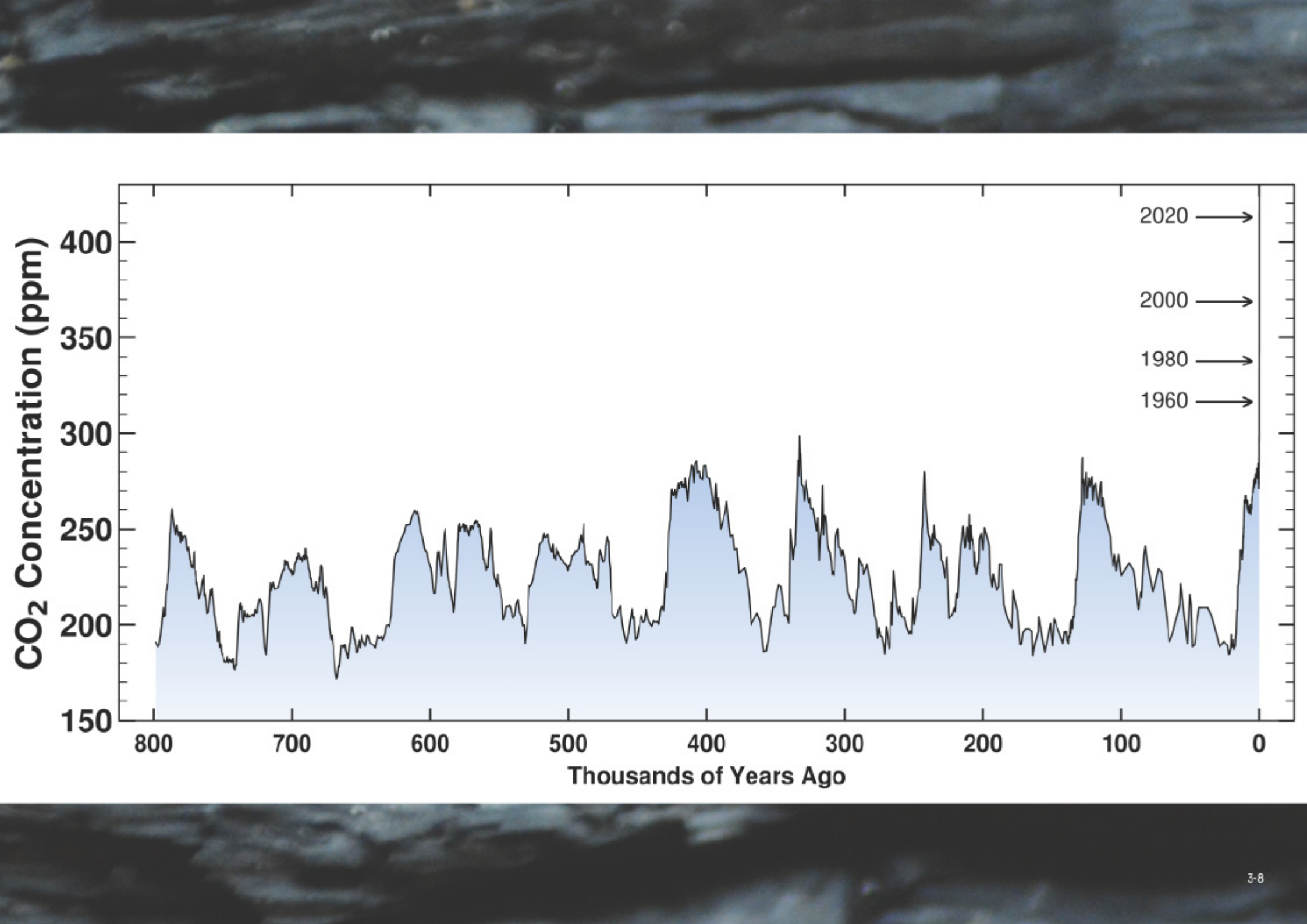
out of 1 million air particles (N_2, O_2, Ar, CO_2, ...)

429 are CO_2

The atmospheric concentration shows on long timescales (past 800 thousand years)

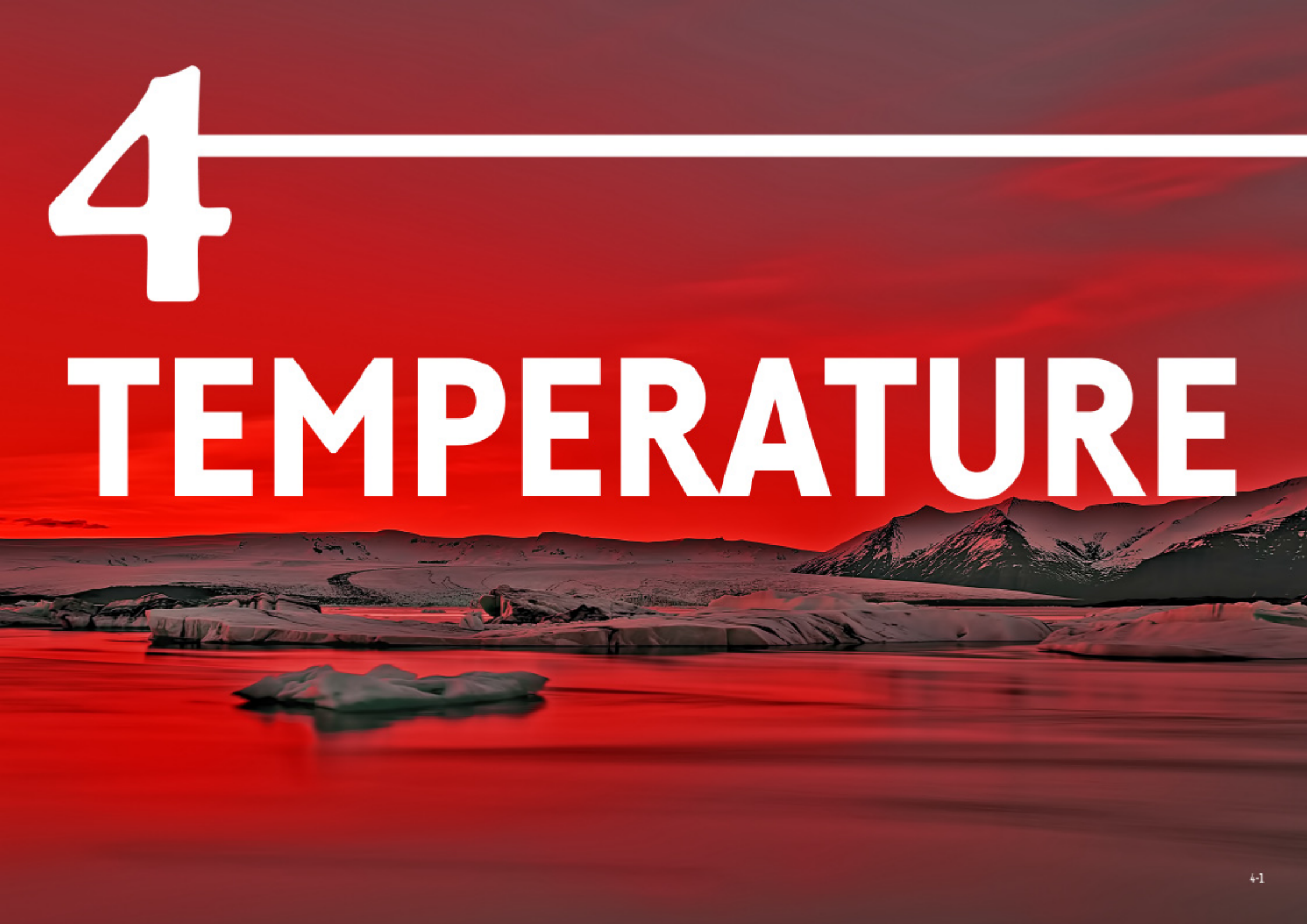
climatic variations (ice ages) and also that

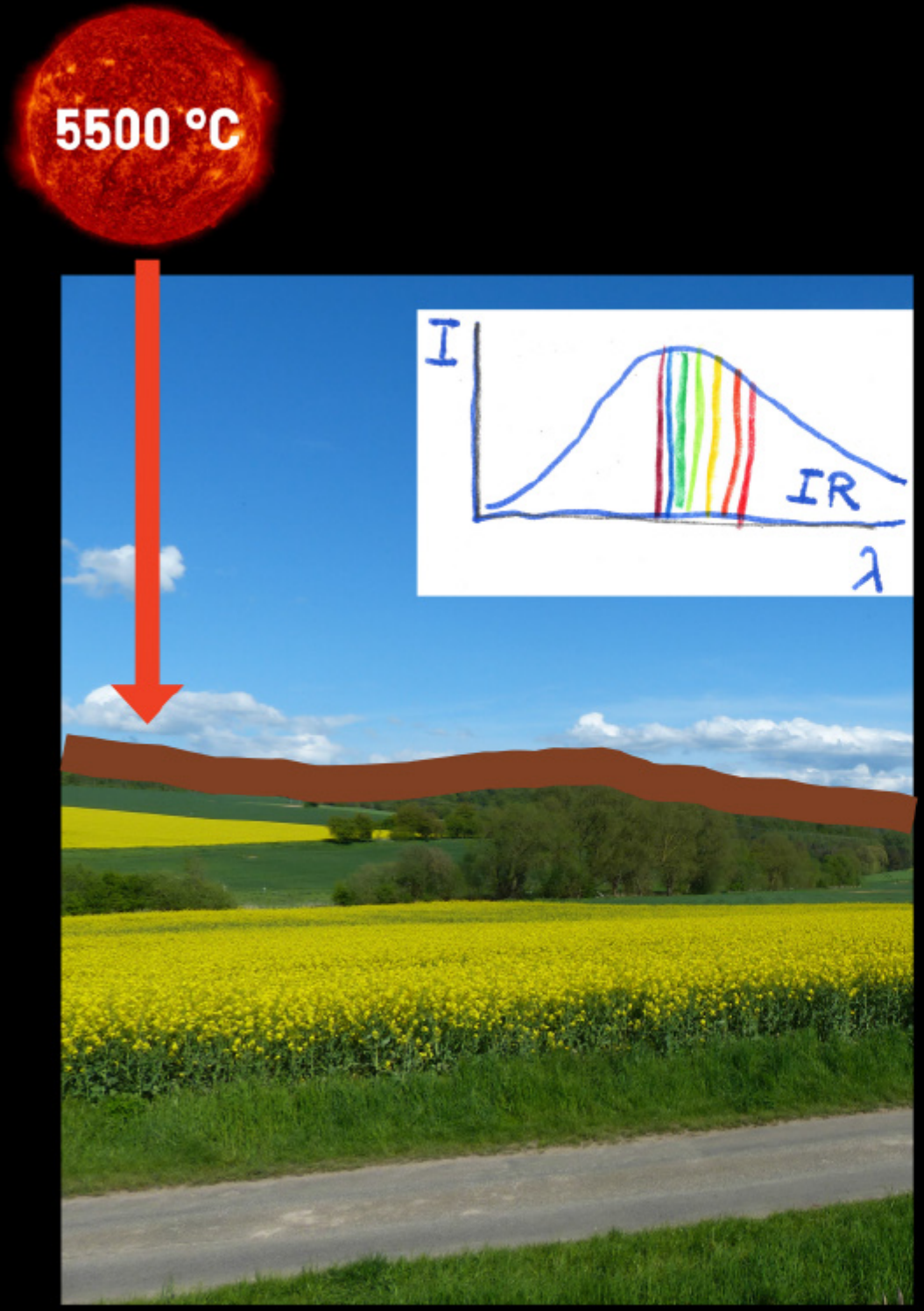
the current value of 429 ppm has by no means ever been reached before.


CO_2 Concentration (ppm)
400
350
300
250
200
150
800
700
600
500
400
300
200
100
0
Thousands of Years Ago
2020
2000
1980
1960

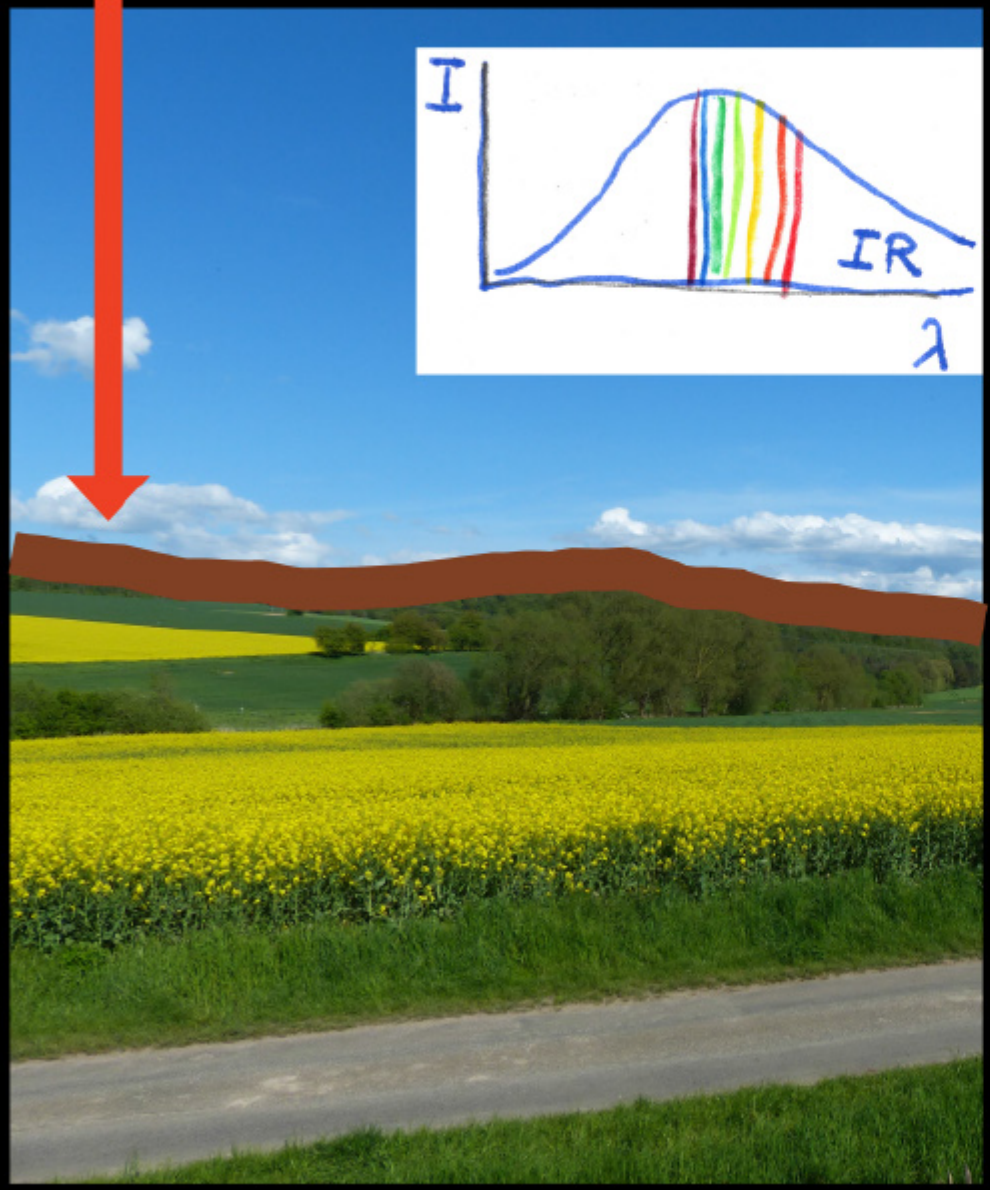
4

TEMPERATURE

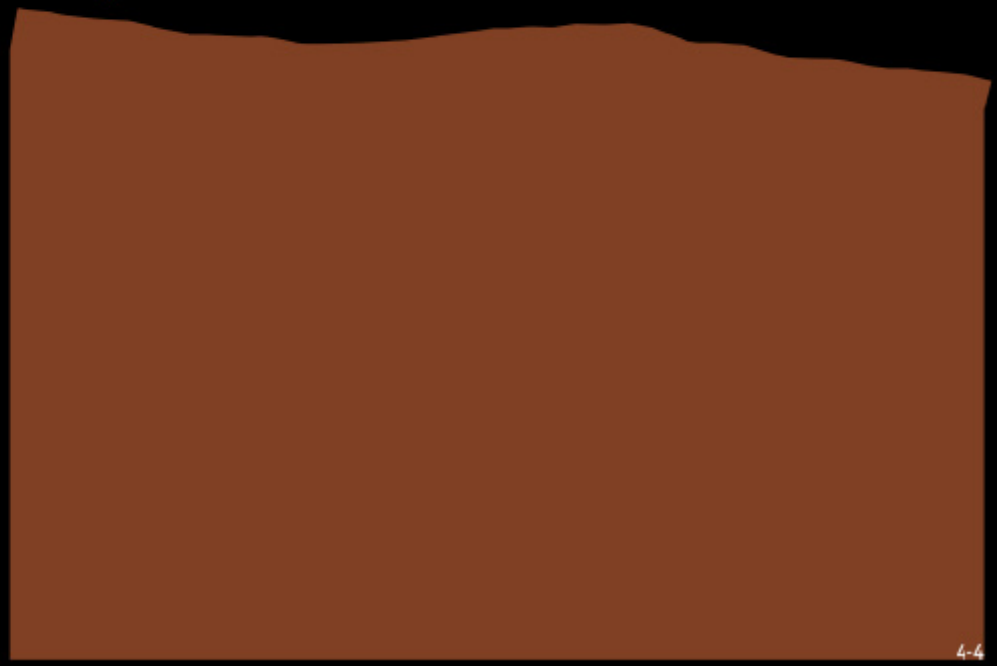


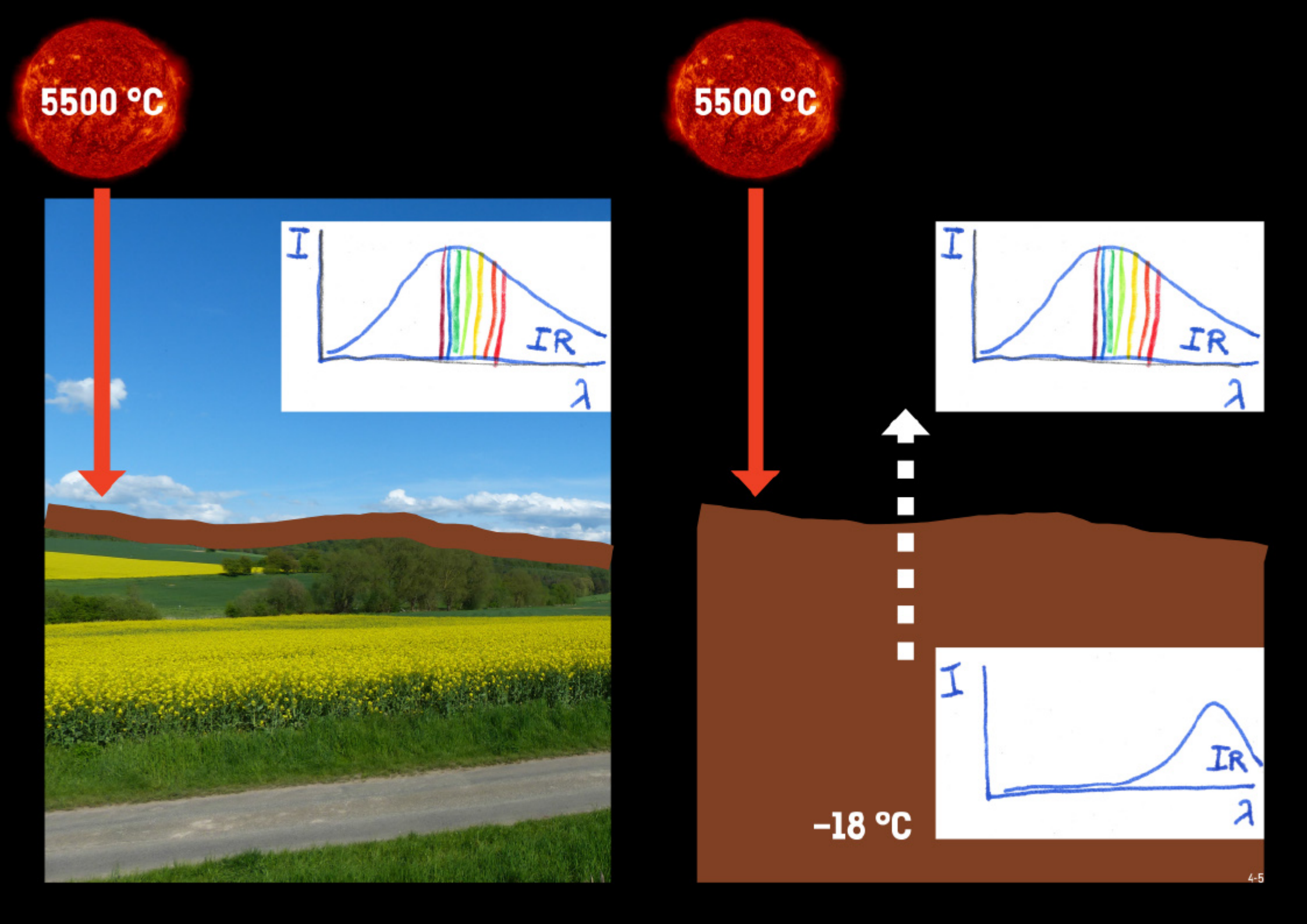

5500 °C
I
IR
λ

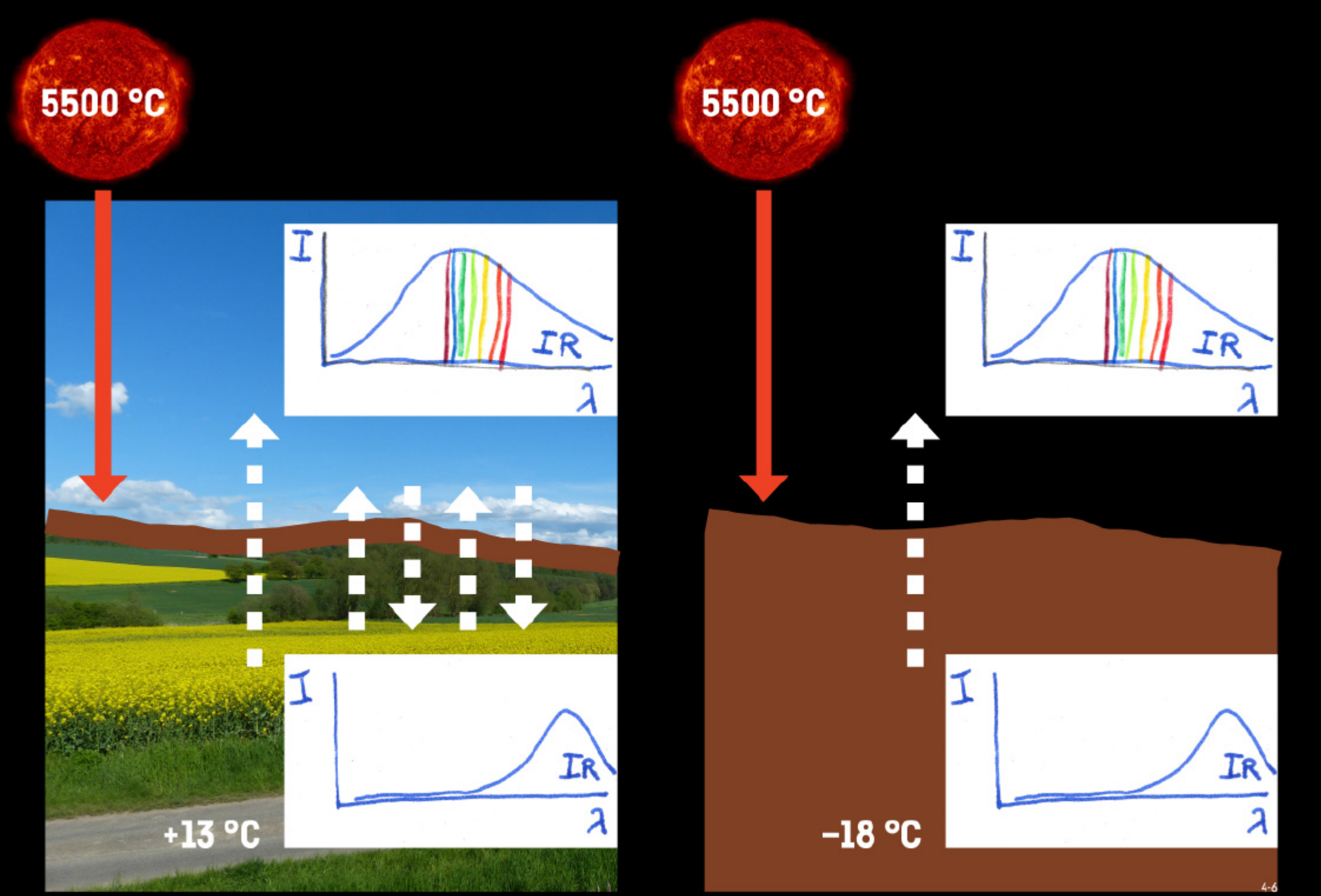
5500 °C



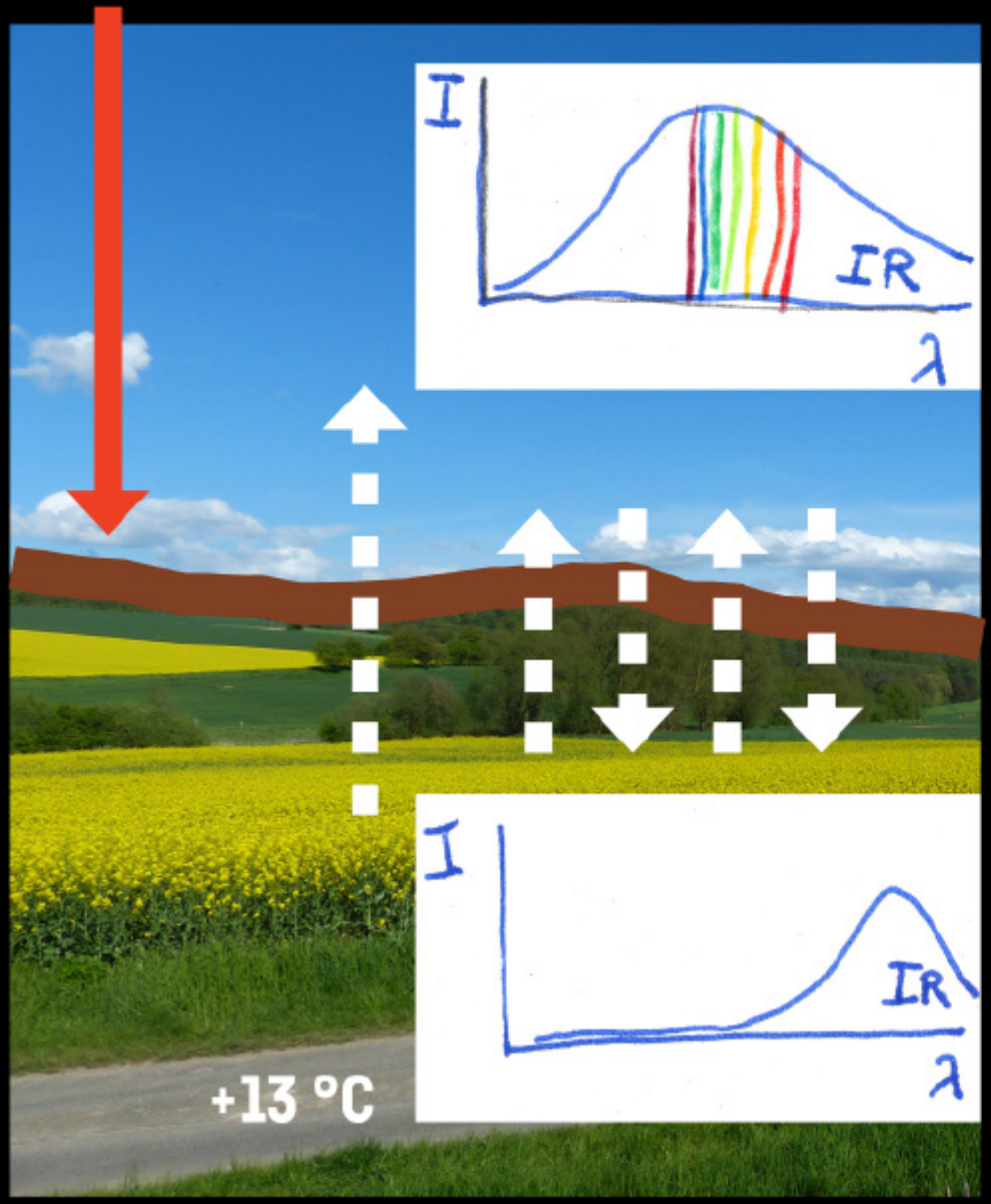
5500 °C

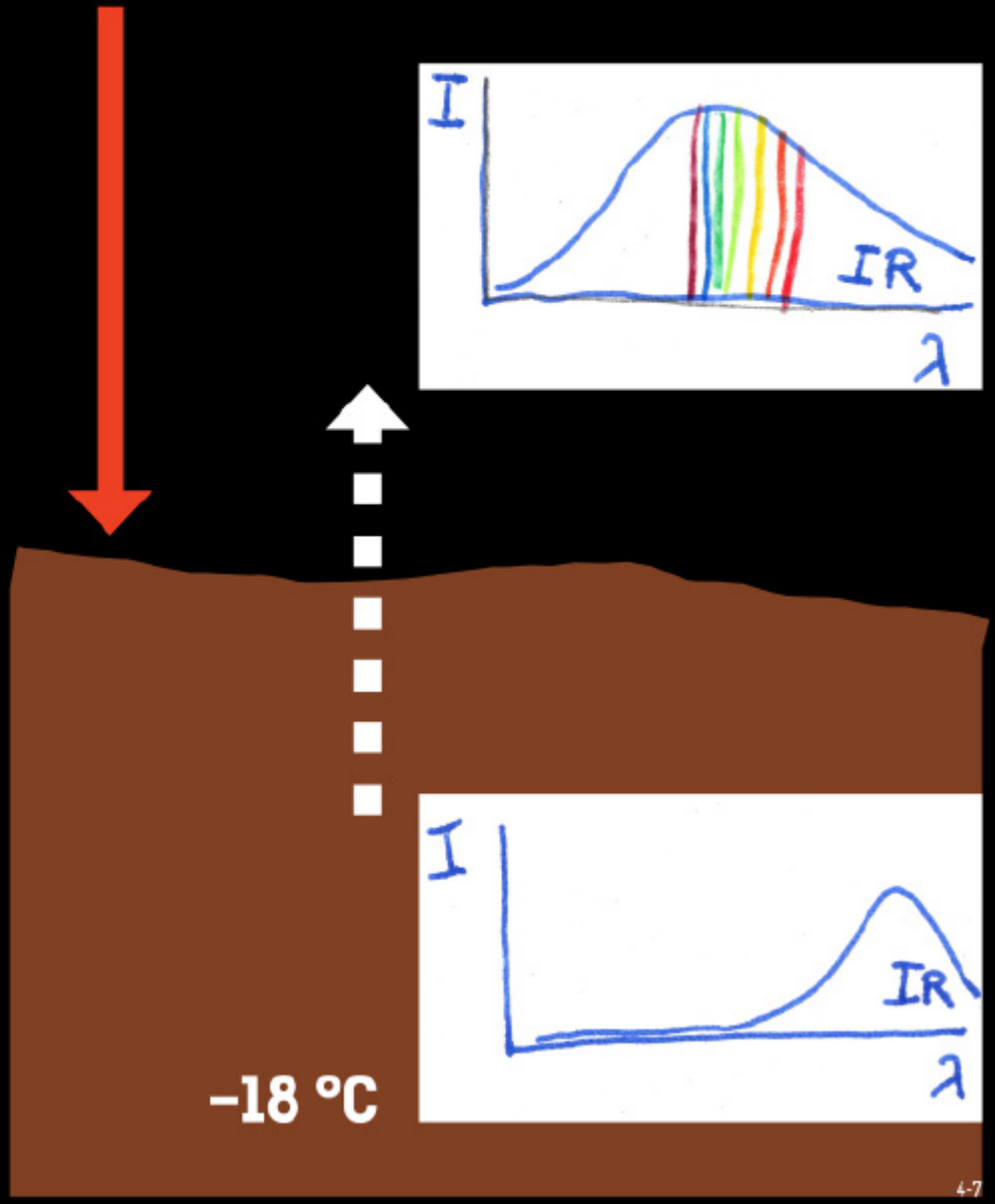



5500 °C
I
IR
λ
5500 °C
I
IR
λ
I
IR
λ
–18 °C
4-5


5500 °C
I
IR
λ
+13 °C
5500 °C
I
IR
λ
I
IR
λ
−18 °C
4-6

NATURAL GREENHOUSE EFFECT





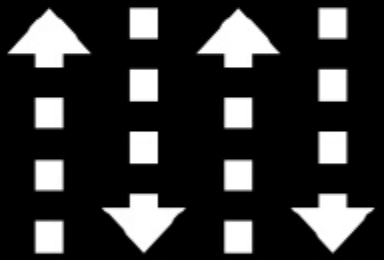
NATURAL GREENHOUSE EFFECT

Greenhouse gases (H_2O, CO_2, CH_4, ...),

transparent to visible light,

barely transparent to infrared,

lead to

increased back-and-forth radiation 

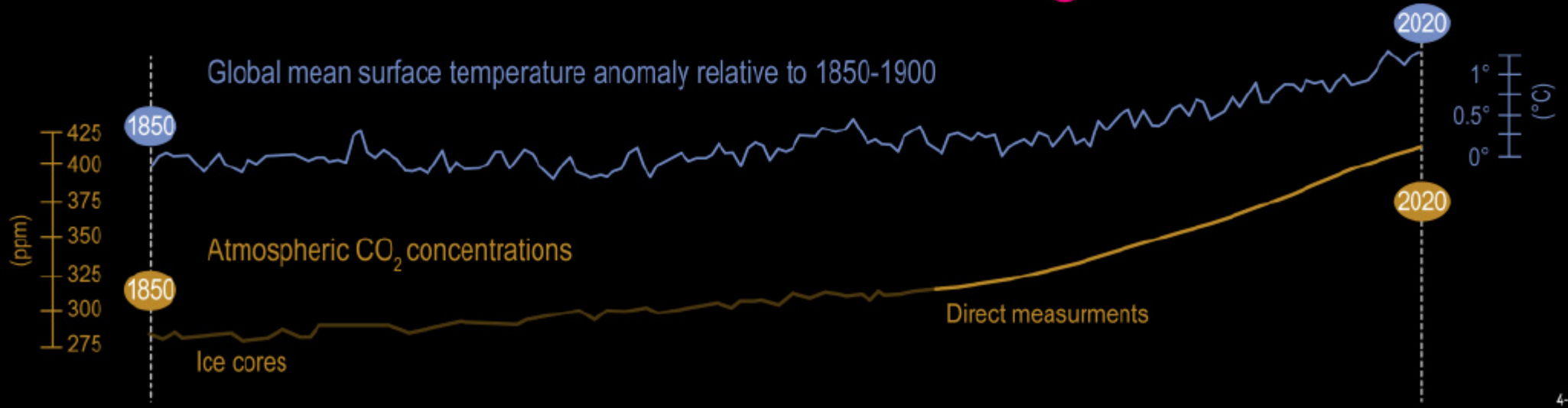
(i.e., an increase in the surface-air temperature),

until a steady state (net zero) is reached.

ANTHROPOGENIC GREENHOUSE EFFECT

Additional, greenhouse gas concentrations (CO_2, CH_4, ...), which have increased since industrialization, lead to

additional warming.



COMMUNITY

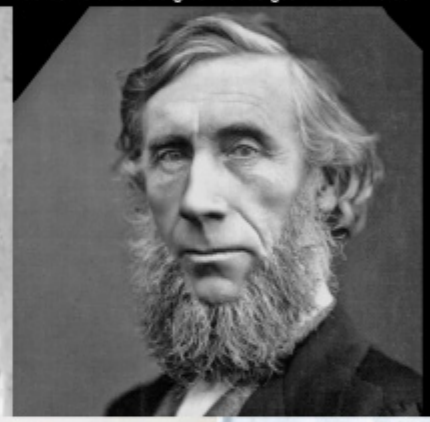
Isaac Newton 1643–1727
Light, Spectrum

Friedrich Wilhelm Herschel 1738–1822
Infrared light

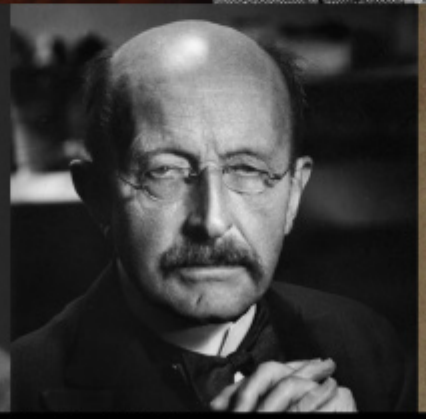
Joseph Fourier 1768–1830
Greenhouse analogy, Radiation balance

Eunice Newton Foote 1819–1888
Carbon dioxide is a greenhouse gas

John Tyndall 1820–1893
Carbon dioxide is a greenhouse gas in the infrared



James Clerk Maxwell 1831–1879
Electrodynamics



Max Planck 1858–1947
Radiation law

Svante Arrhenius 1859–1927
Calculations of climate sensitivity, Ice ages

Guy Stewart Callendar 1898–1964
Measurements of climate sensitivity, Prediction

Valerie Masson-Delmotte 1971-
IPCC, Prediction


ipcc
Climate Change 2021
The Physical Science Basis
Volume 1
CAMBRIDGE
ipcc
Climate Change 2021
The Physical Science Basis
Volume 2
CAMBRIDGE
CLIMATE CHANGE 2013
The Physical Science Basis
CAMBRIDGE
CLIMATE CHANGE 2007
THE PHYSICAL SCIENCE BASIS
CAMBRIDGE
CLIMATE CHANGE 2001
The Scientific Basis
CAMBRIDGE
CLIMATE CHANGE 1995
The Science of Climate Change
CAMBRIDGE

IPCC

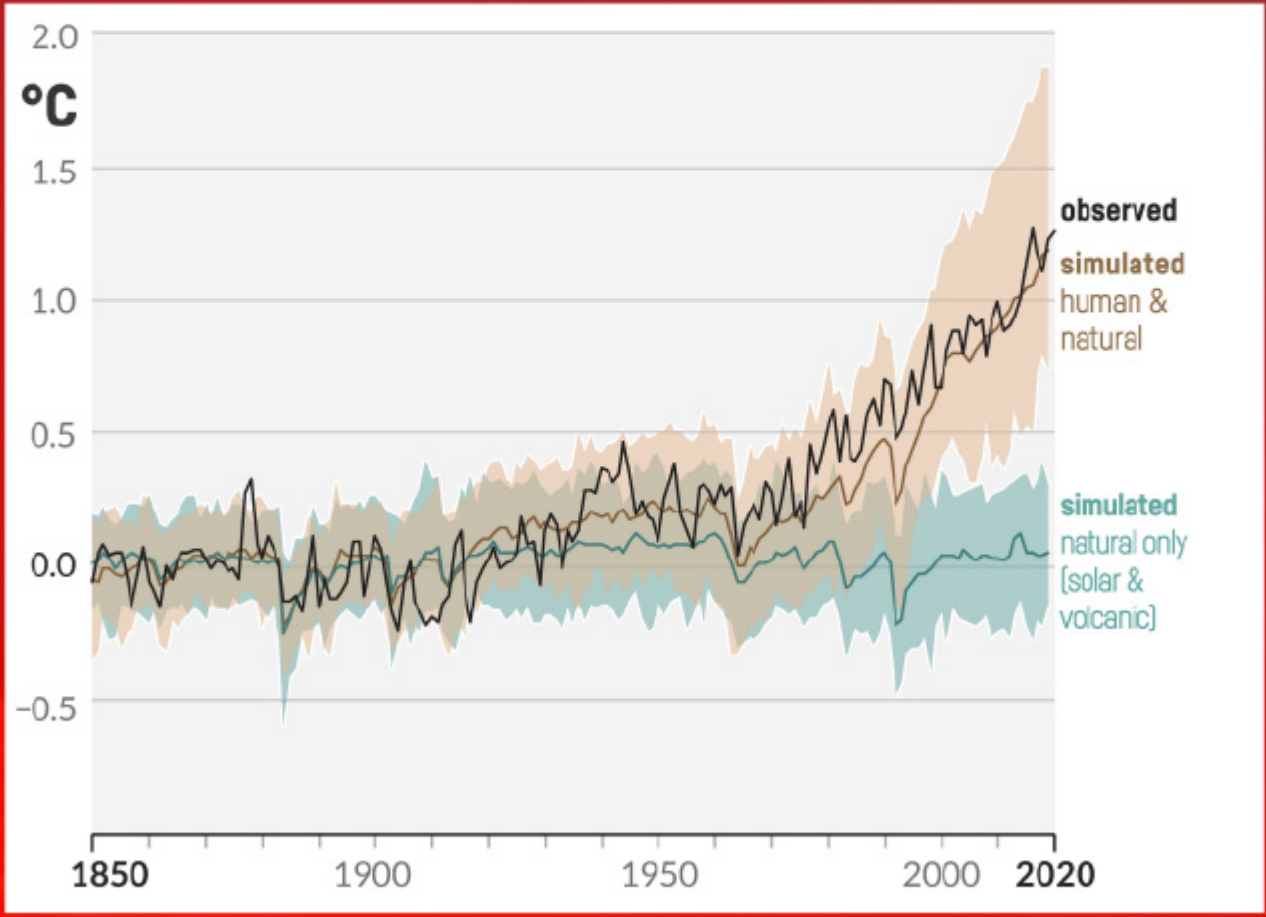
GLOBAL WARMING

THERE ARE FURTHER NATURAL TEMPERATURE CHANGES:

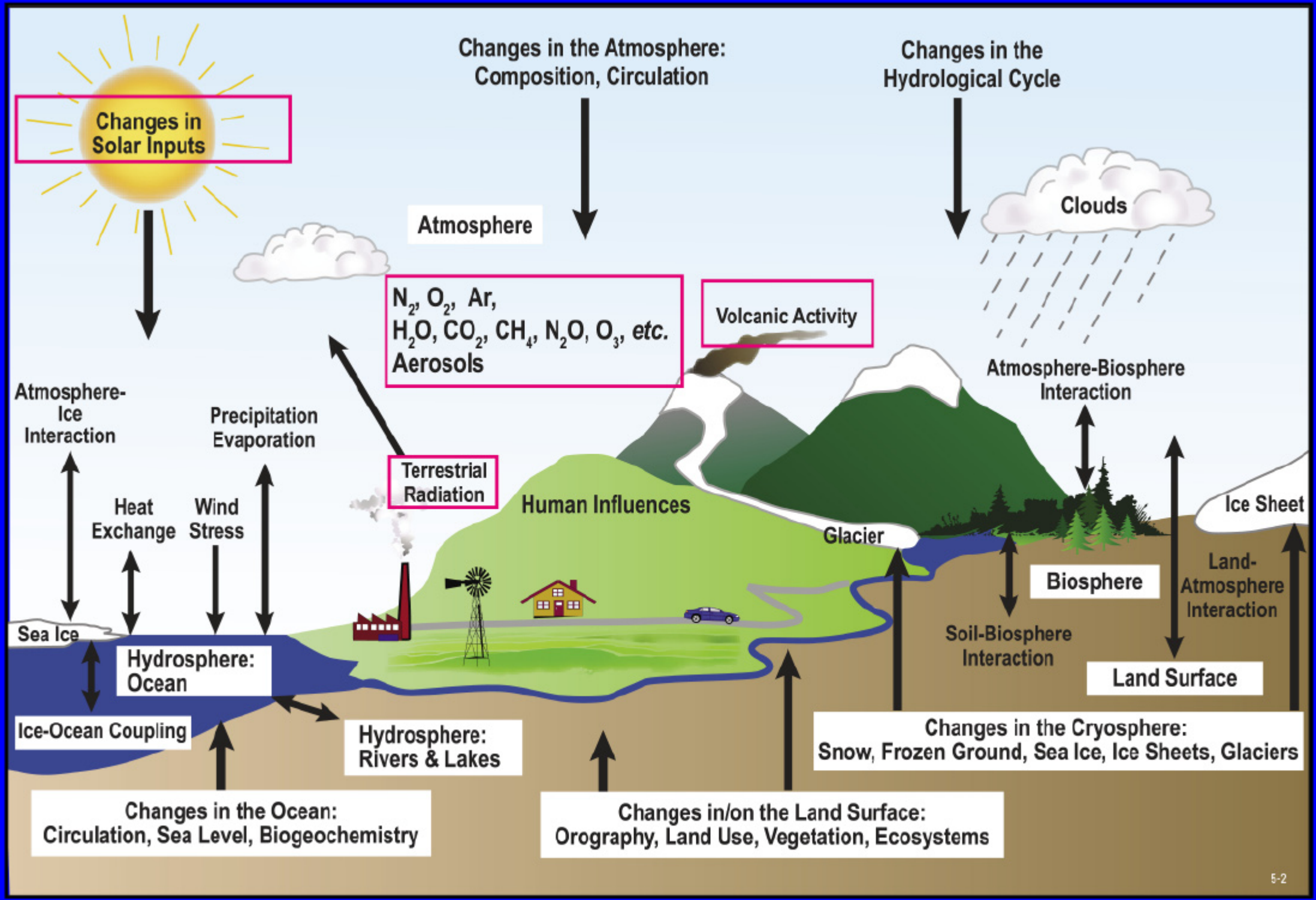
solar insolation
volcanic activity
internal variations

GLOBAL WARMING

Global mean surface air temperature anomaly relative to 1850–1900



5 CLIMATE CHANGE


Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
N_2, O_2, Ar,
H_2O, CO_2, CH_4, N_2O, O_3, *etc.*
Aerosols
Volcanic Activity
Atmosphere-Biosphere Interaction
Atmosphere-Ice Interaction
Precipitation Evaporation
Heat Exchange
Wind Stress
Terrestrial Radiation
Human Influences
Glacier
Ice Sheet
Biosphere
Land-Atmosphere Interaction
Soil-Biosphere Interaction
Land Surface
Sea Ice
Hydrosphere: Ocean
Ice-Ocean Coupling
Hydrosphere: Rivers & Lakes
Changes in the Cryosphere: Snow, Frozen Ground, Sea Ice, Ice Sheets, Glaciers
Changes in the Ocean: Circulation, Sea Level, Biogeochemistry
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems
5-2

MODERN VIEW (CLIMATE)

SYSTEM (NOT JUST ATMOSPHERE)

Climate variables: CO_2, Temperature,
Precipitation,
Wind speed,
Runoff, ...

MODERN VIEW (CLIMATE)

SEPARATION WEATHER-CLIMATE (30 YEARS) ARBITRARY/IRRELEVANT

MODERN VIEW (CLIMATE)

VARIATIONS AT ALL SCALES

Space: global, regional, local
Time: deep time (back to 4.55 billion years)
instrumental period (since 1659)
future
Indices: average, extremes, ...

6

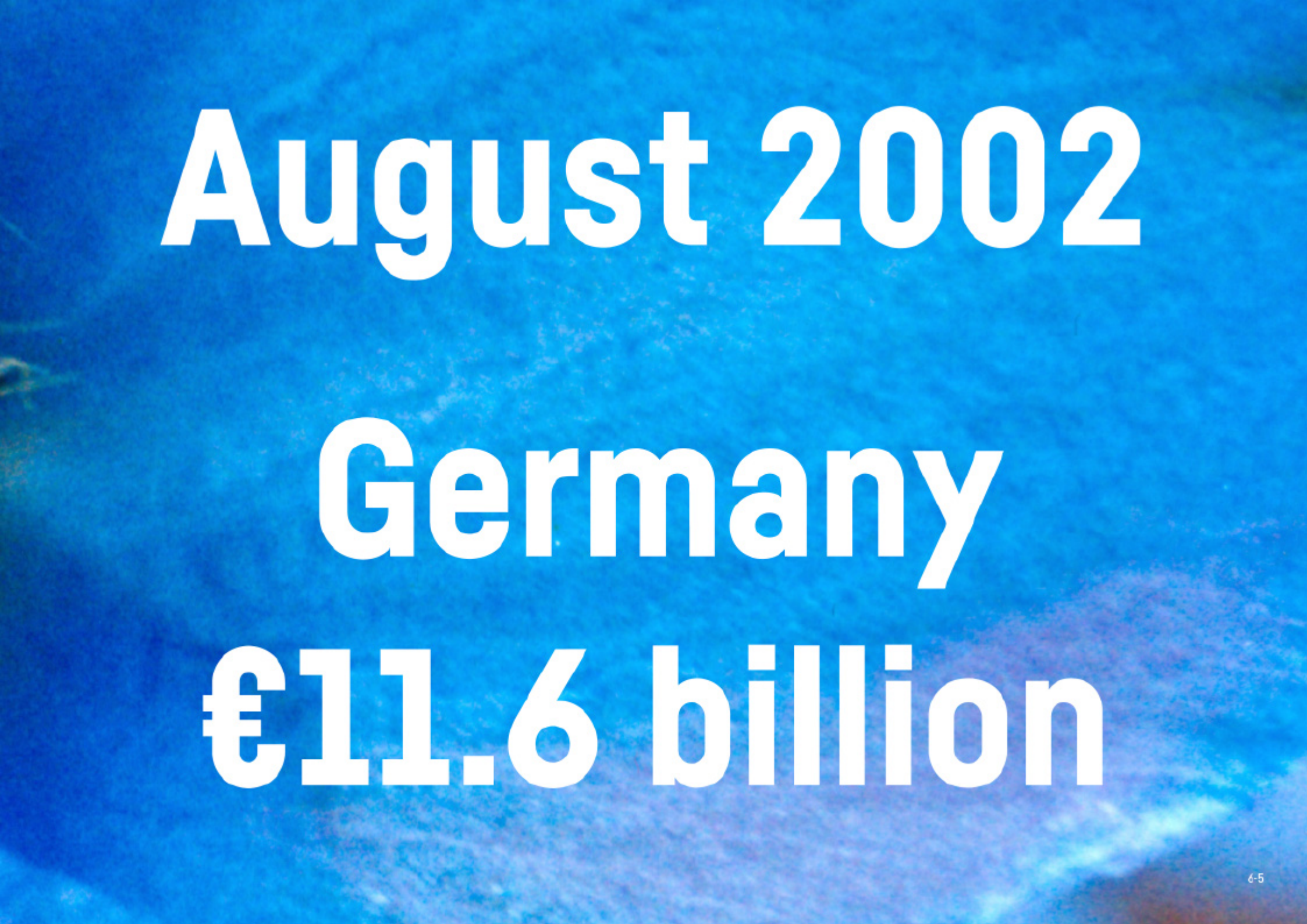
ANALYSIS I FLOODS

17 August 2002

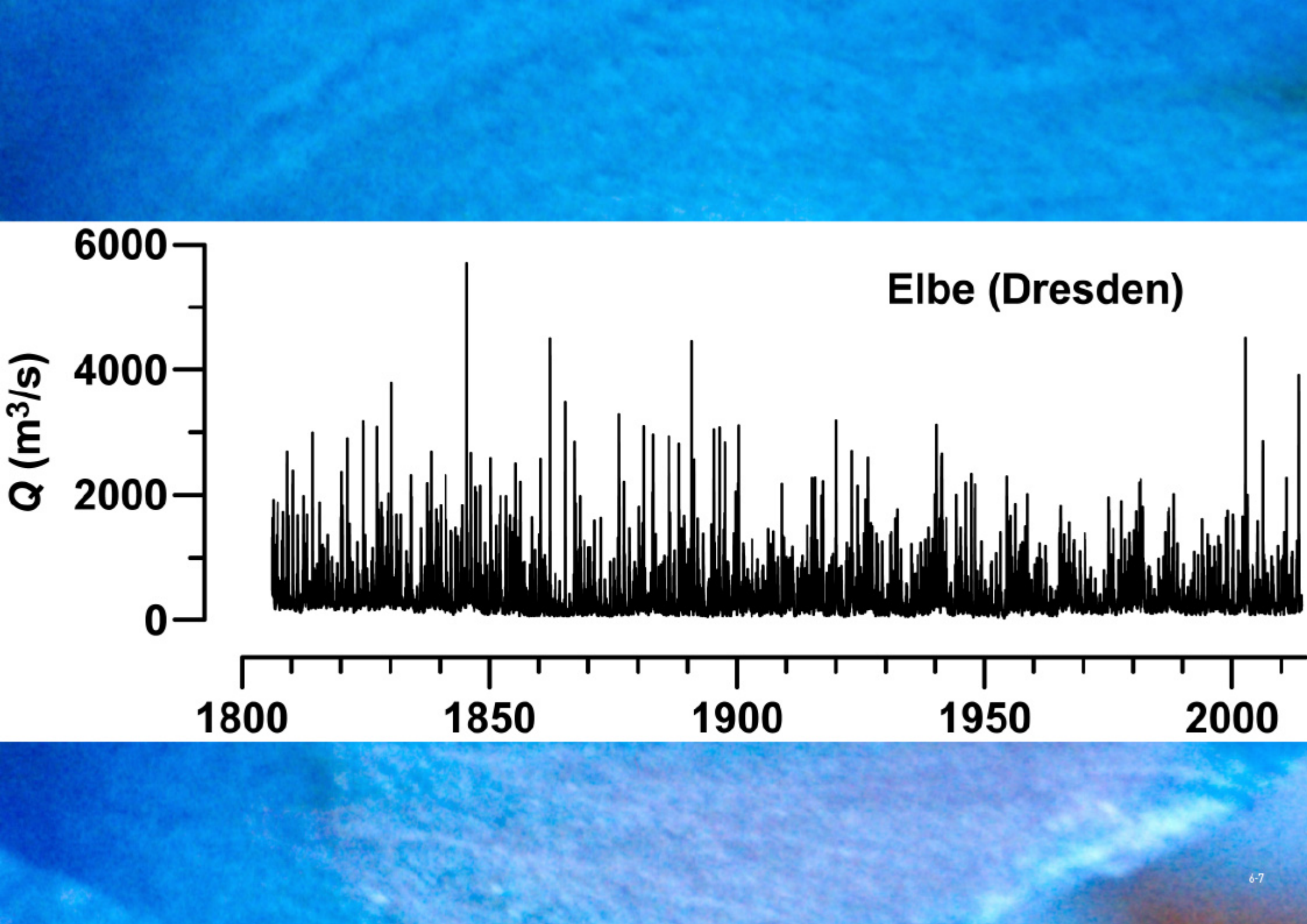
17 August 2002

Dresden, Elbe

$Q = 4500\ m^3/s$


August 2002
Germany
€11.6 billion


North Sea
Brunsbüttel
Cuxhaven
Hamburg
Schwerin
Waren (Müritz)
Oste
Sude
Elde
Elbe
Lüneburg
Wittenberge
Rhin
Havel
BERLIN
Spree
Potsdam
Ohre
Havel
Magdeburg
Wittenberg
Bode
Cottbus
Saale
Dessau-
Roßlau
Schw. Elster
Mulde
Elbe
Halle (Saale)
Leipzig
Unstrut
Erfurt
Dresden
Gera
Ilm
Weiße Elster
Zwickau
Ústí nad Labem
(Aussig)
Saale
Ohře
Litoměřice


Elbe (Dresden)
Q (m³/s)
6000
4000
2000
0
1800
1850
1900
1950
2000

How was is like further back in the past?

Historical climate documents

Anno 1342 vor Maria und Madalena tag haben sich
wasser so ser ergossen das die Brückh zu Nurmberg
so gross gewesen ist das das wasser biß zum Rathauß
ist gangen welches zu vor nie geschehen ist

1784 & 28. - 29. Febr. & Meißen & Elbe: Eisgang u. Überschwemmung & & 1 & I, 5: 370 (2934)

Elbe. 28. Febr. 11 Uhr abends brach das Eis und trieb anfänglich bey zwar ziemlich heranwachsendem Wasser, welches am folgenden Tag [= 29. Febr.] früh schon hier und da in die Stadt trat, ganz ruhig, obgleich sehr gedrange fort, ..., bis um 9 Uhr, um welche Zeit auf einmal die reissende Fluth mit dem Eise, und was sie sonst bei sich führte, durch die Vorstadt zum Fleischer- und Jüdenthore in die Stadt hinein brach, und so über den kleinen Markt durch die Gassen, ..., rauschte. Diese traurige Periode hielt zunehmend bis um 11 Uhr des Vormittags an, in welcher Zeit die großen Eisschollen auch schon der Brücke, ..., dermaßen zusezten. Der Wasserwuchs dieser wüthenden Fluth dauerte, wie gesagt, bis 11 Uhr, alsdann fiel solcher wieder, bis des Nachmittags um 4 Uhr 1 Elle 12 Zoll, aber in einer Stunde darauf stellte sie sich von neuem, und fast noch schneller ein, ... Das Wasser stund aller Orten 3, 4, 5-6 Ellen hoch. Beyde Vorstädte, sowohl vor dem Fleischer- und Jüden- als vor dem Wasserthore, die Wasserburg und die Fischergasse, ..., stunden völlig, ..., zu 4-6 Ellen hoch unter Wasser ..., der Fleischersteg genannt, über die Triebisch, ward bald von der wilden Fluth eingestürzt. Die Stadt selbst stund außer dem großen Markte, der Burggasse und der Rosengasse bey der Stadtkirche, völlig eben so hoch unter Wasser. Das Jüdenthor bedeckte es völlig, und wenigstens noch eine Elle darüber. [9 Personen ertrunken]. Größte Höhe der Fluth: 12 Ellen 10 Zoll. Das Wasser stand in der Kirche 1 reichliche Elle höher als drittehalbe Ellen.

(C. G. Poetzsch 1784 "Chronolog. Geschichte d. großen Wasserfluthen d. Elbstroms etc." S. 150/53 u. 159.)

1784 & 28. - 29. Febr. & Dresden & Elbe: Eisgang u. Hochwasser & & 1 & I, 5: 370 (2935)

Elbe. Vormittags rührte sich auch das Eis hinter der Brücke und schob sich sehr ruhig, bis unter die Stadt hinunter; allein oberhalb derselben blieb es noch unbeweglich stehen. Des Nachmittags fiel sogar das Wasser wieder 9 Zoll, folglich bis an 1 Elle 15 Zoll herunter. 9 Uhr abends erfolgte der Aufbruch. Dieser gewaltige Aufbruch mit einem fast unglaublich schnellen Anwuchse des Wassers war erschrecklich.

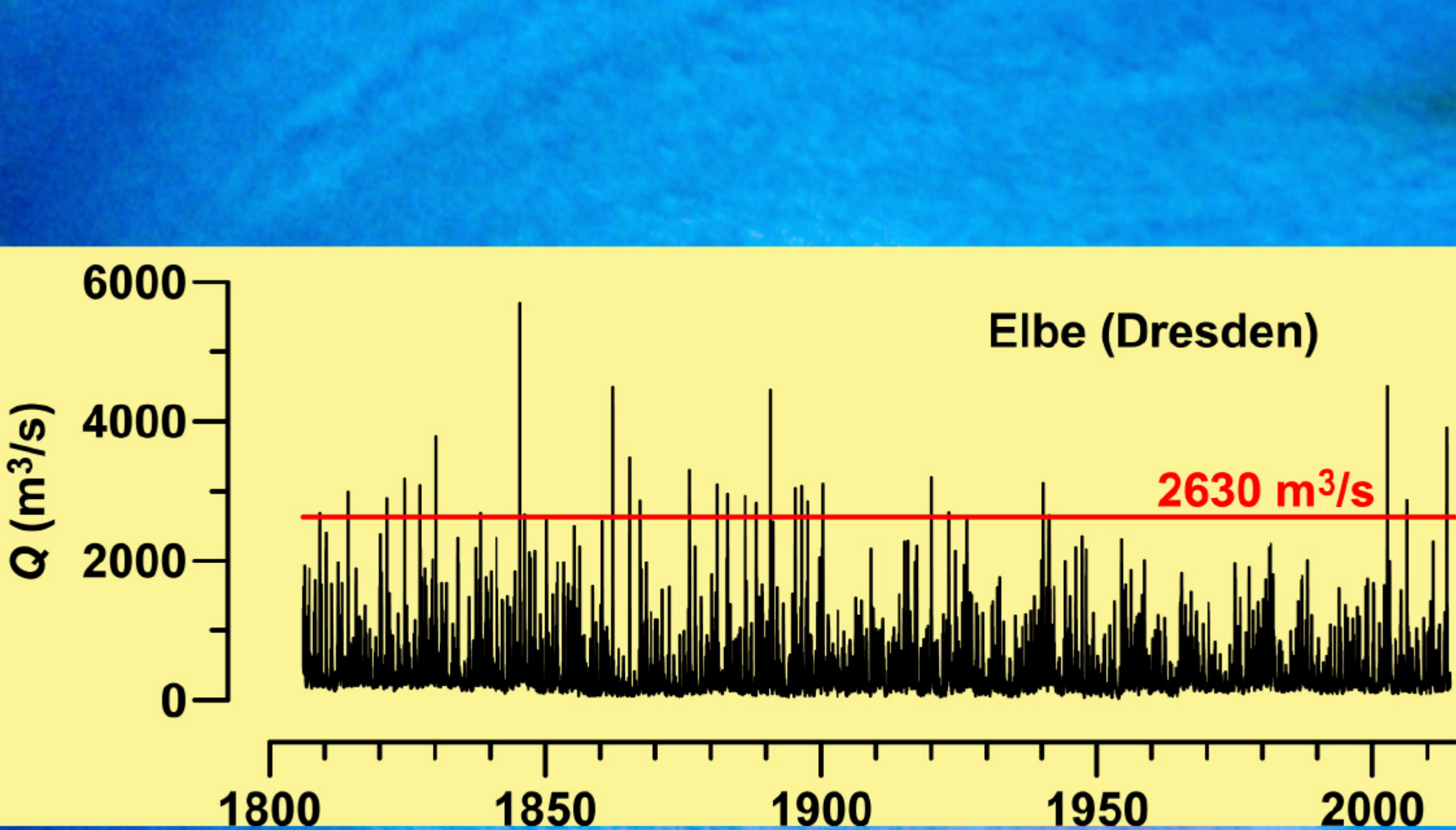
(C. G. Poetzsch 1784 "Chronolog. Geschichte d. großen Wasserfluthen d. Elbstroms etc." S. 117 u. 136.)

1784 & 28. - 29. Febr. & Dresden & Elbe: Eisgang u. Hochwasser & & 2 & I, 5: 370 (2936)

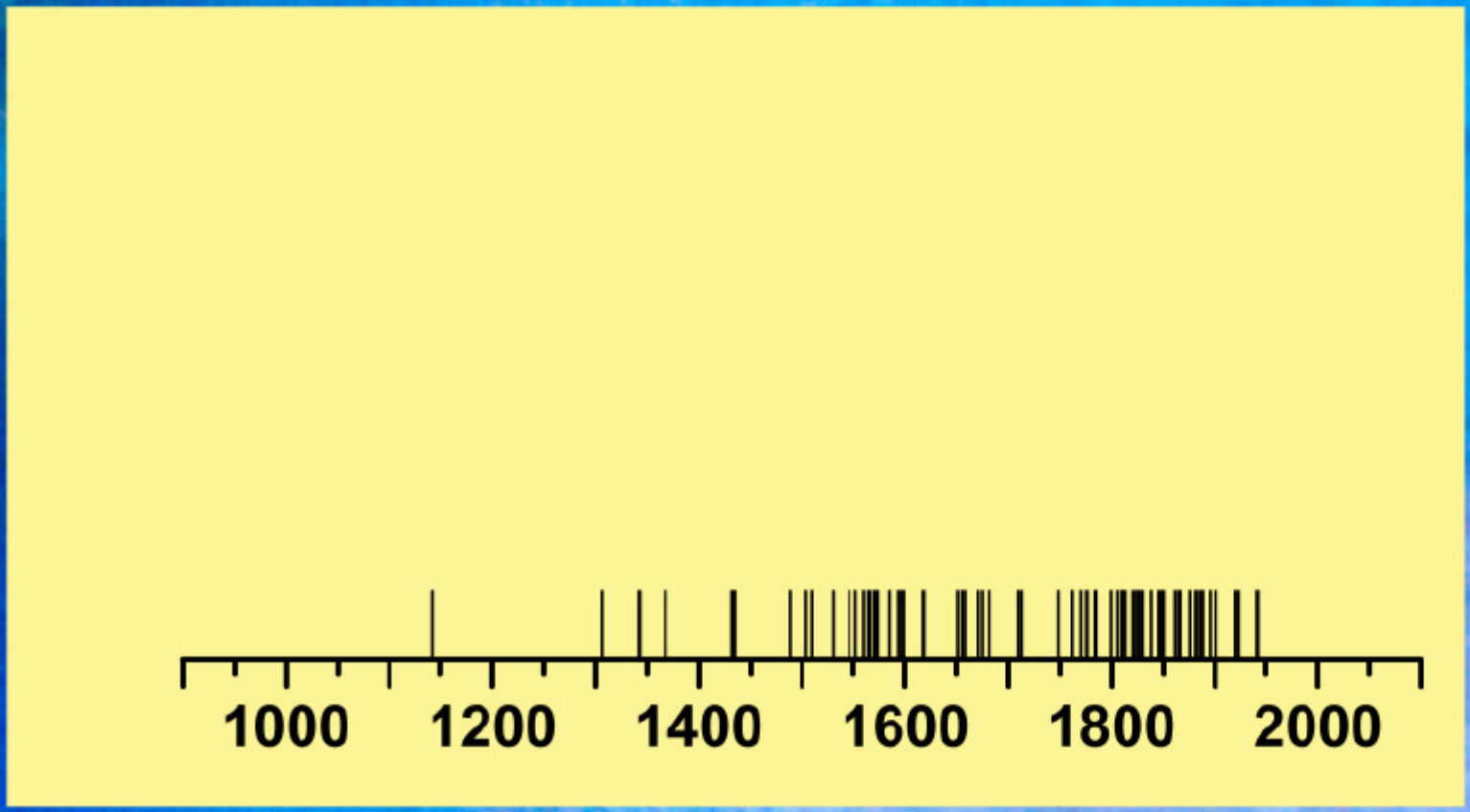
Es bricht die Elbe auf und wächst von 3 auf 9 Ellen Höhe mit unbegreiflicher Schnelligkeit.

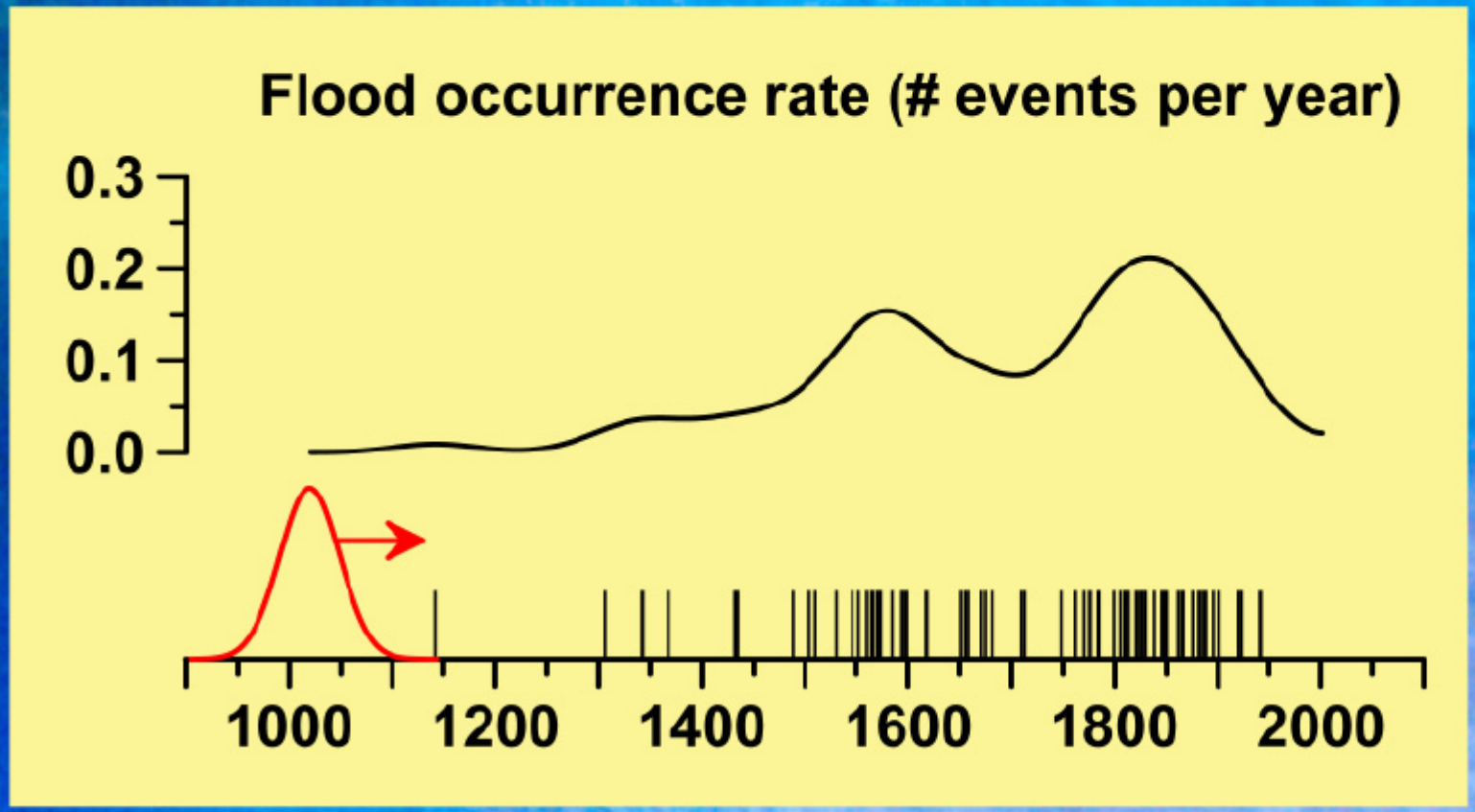
(Dr. G. Klemm "Chronik d. etc. Residenzstadt Dresden", edid. P. G. Hilscher 1837. II. S. 513.)

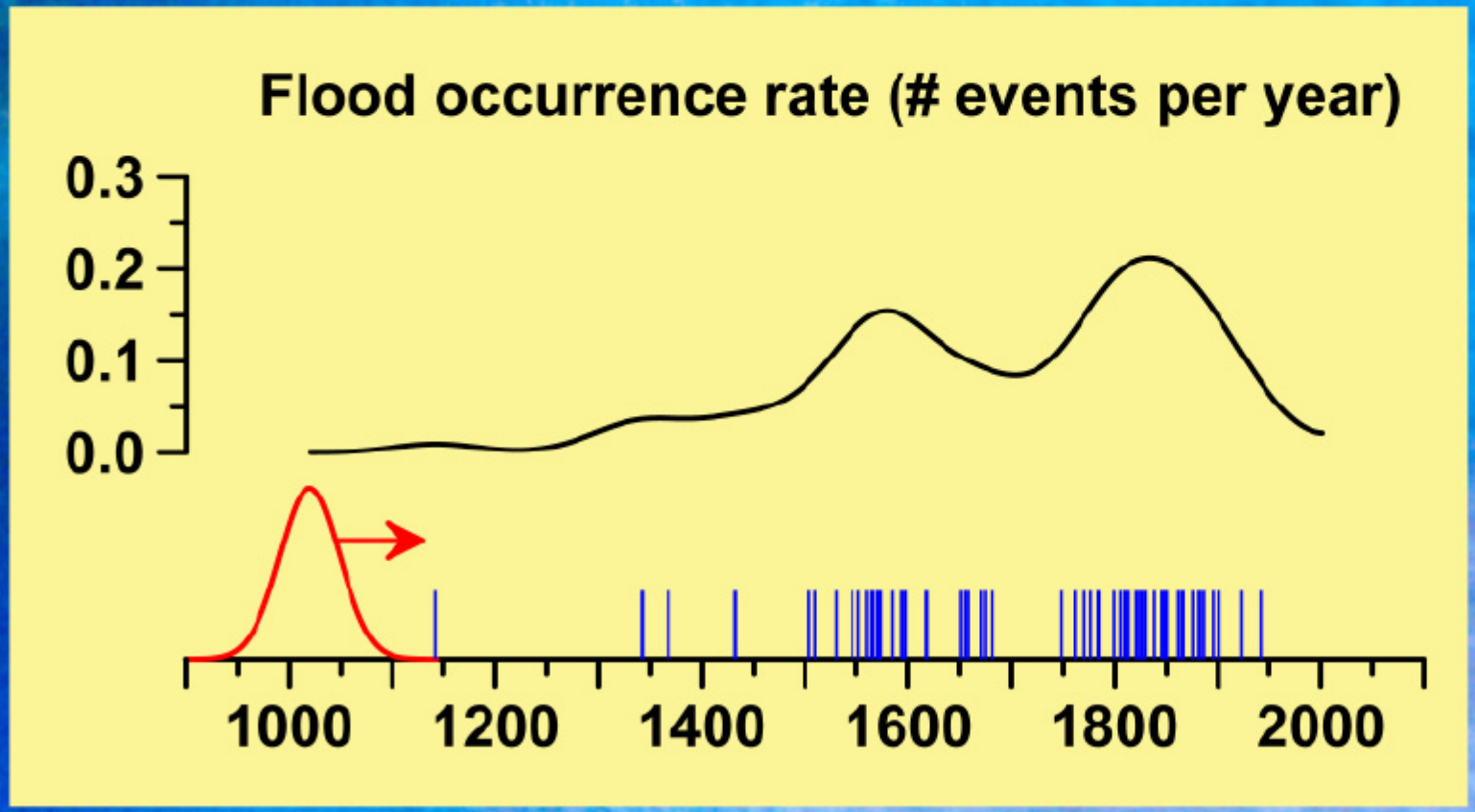
(Fr. W. Pohle 1886 "Chronik von Loschwitz" S. 77. u. S. 79.)

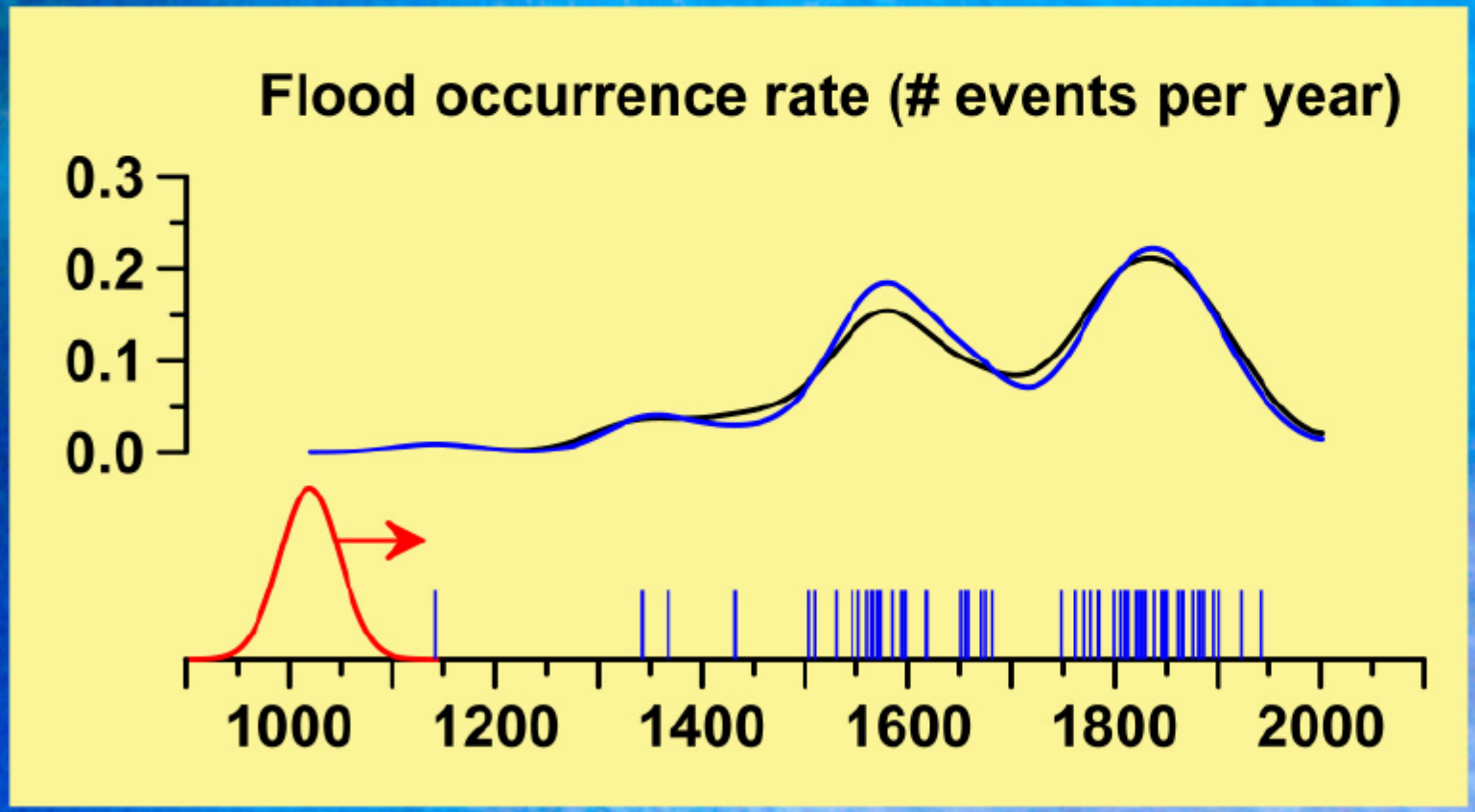

Elbe (Dresden)
2630 m³/s
Q (m³/s)
6000
4000
2000
0
1800
1850
1900
1950
2000

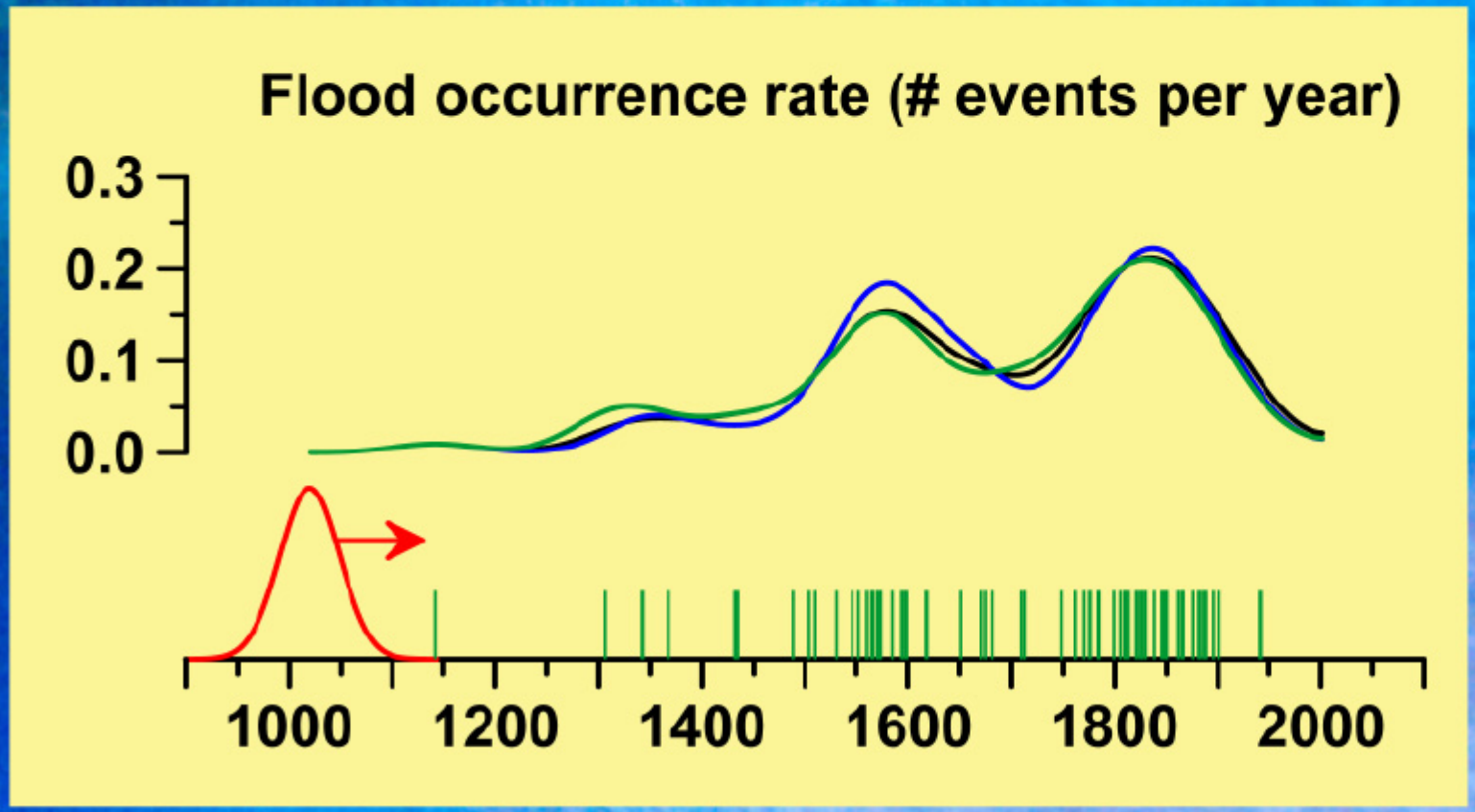
Middle Elbe
Heavy floods (above 2630 m^3/s)
Winter (November to April)

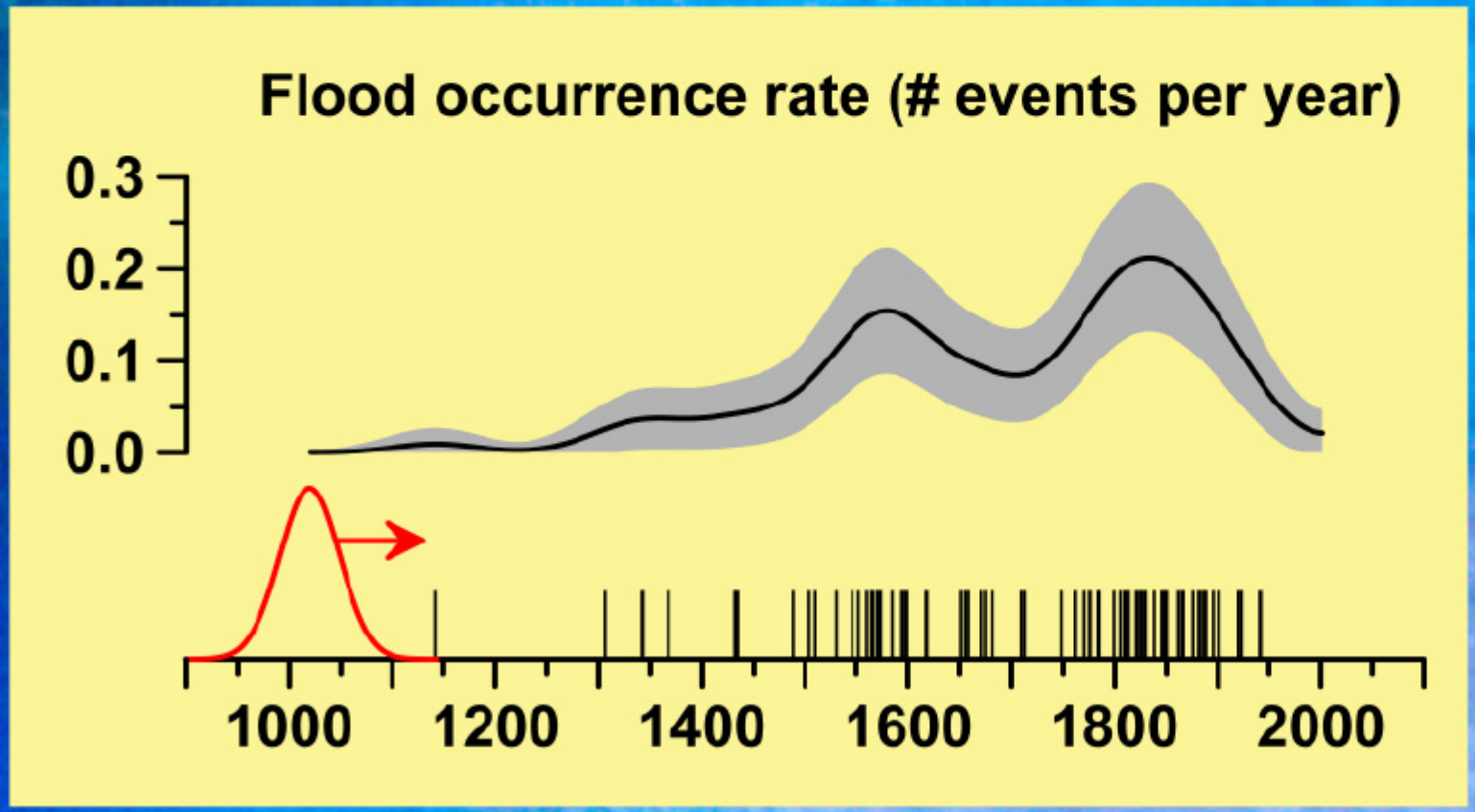



Flood occurrence rate (# events per year)
0.3
0.2
0.1
0.0
1000
1200
1400
1600
1800
2000


Flood occurrence rate (# events per year)
0.3
0.2
0.1
0.0
1000
1200
1400
1600
1800
2000

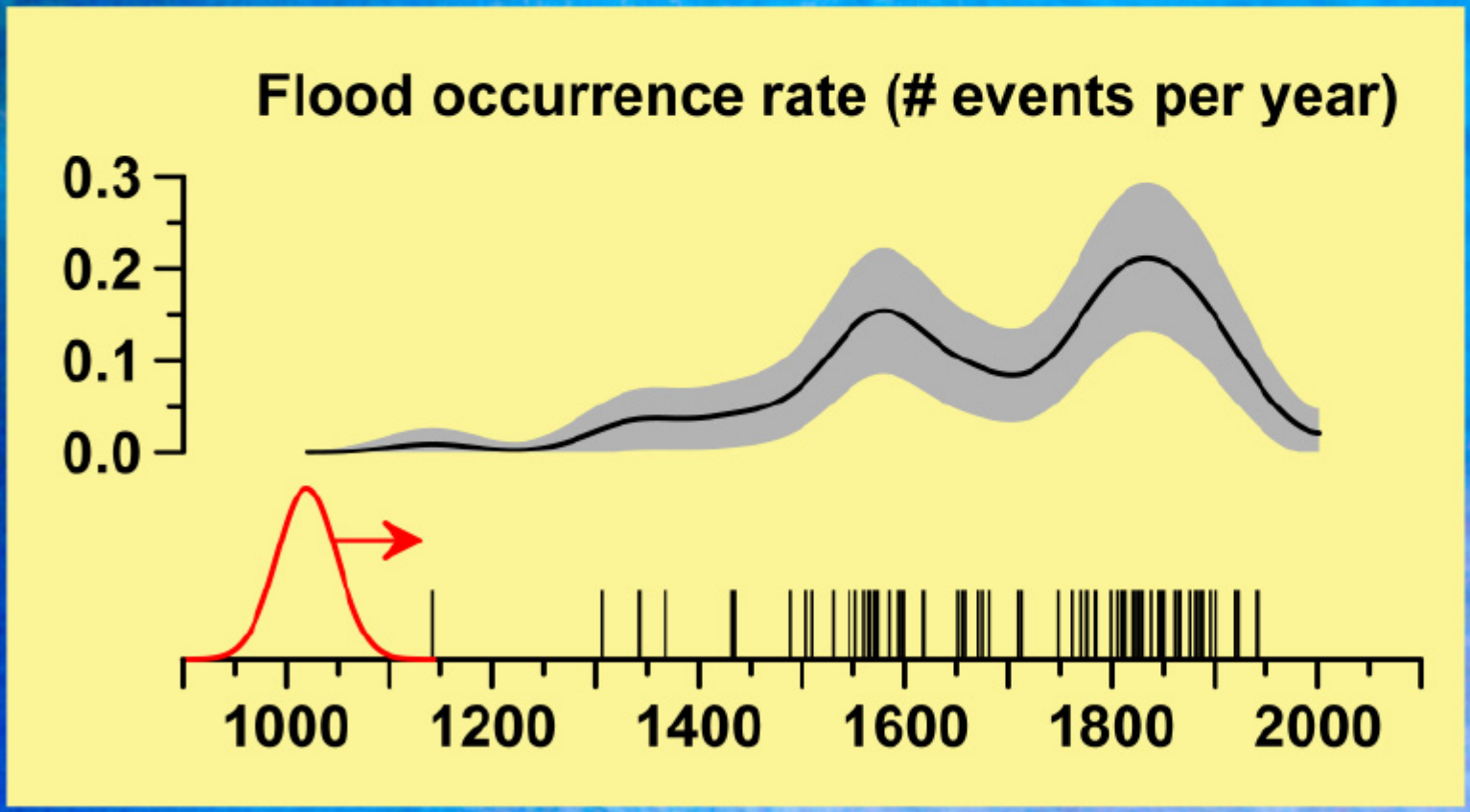

Flood occurrence rate (# events per year)
0.3
0.2
0.1
0.0
1000
1200
1400
1600
1800
2000


Flood occurrence rate (# events per year)
0.3
0.2
0.1
0.0
1000
1200
1400
1600
1800
2000

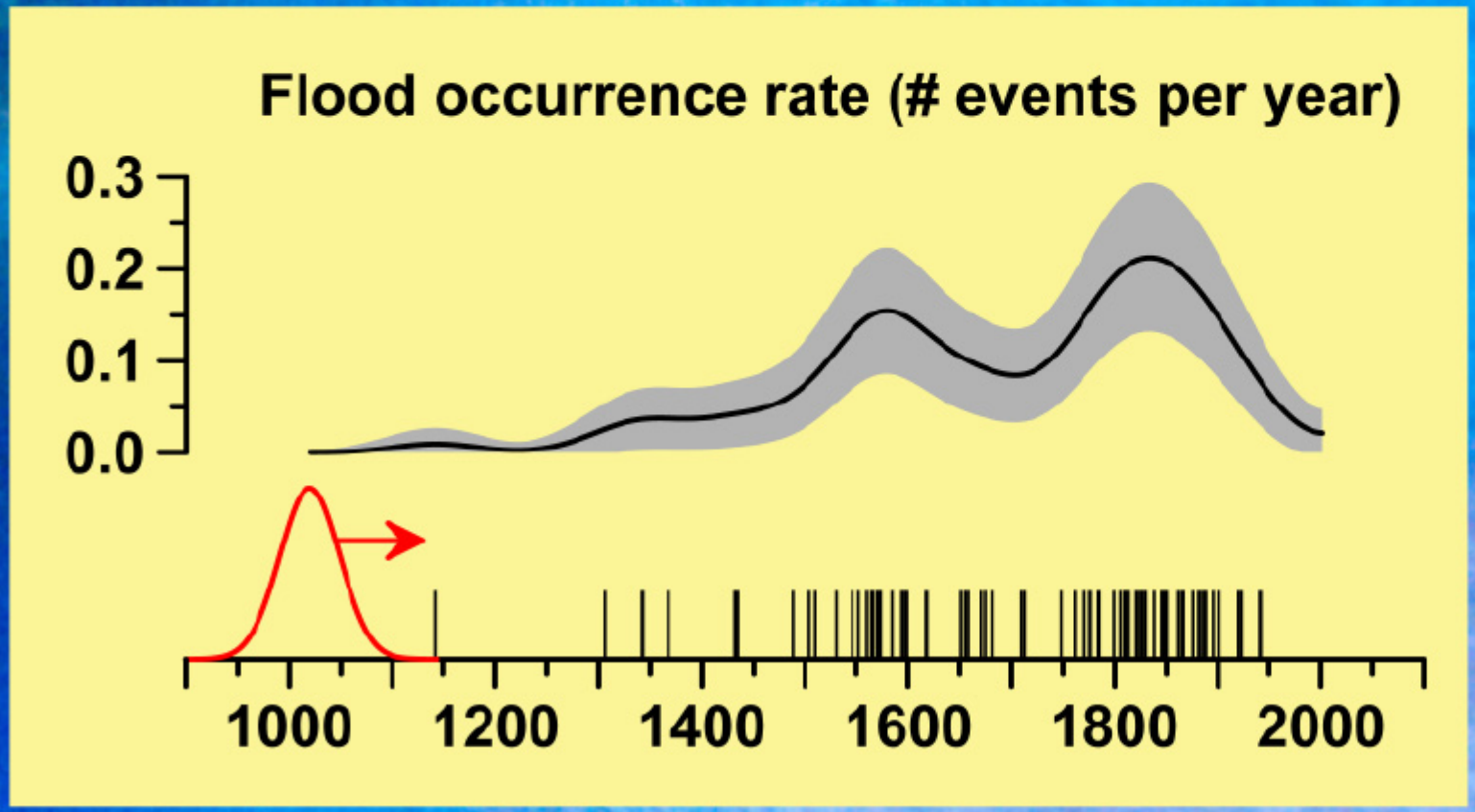

Flood occurrence rate (# events per year)
0.3
0.2
0.1
0.0
1000
1200
1400
1600
1800
2000

Statistical estimation

Computer simulations to determine estimation uncertainties



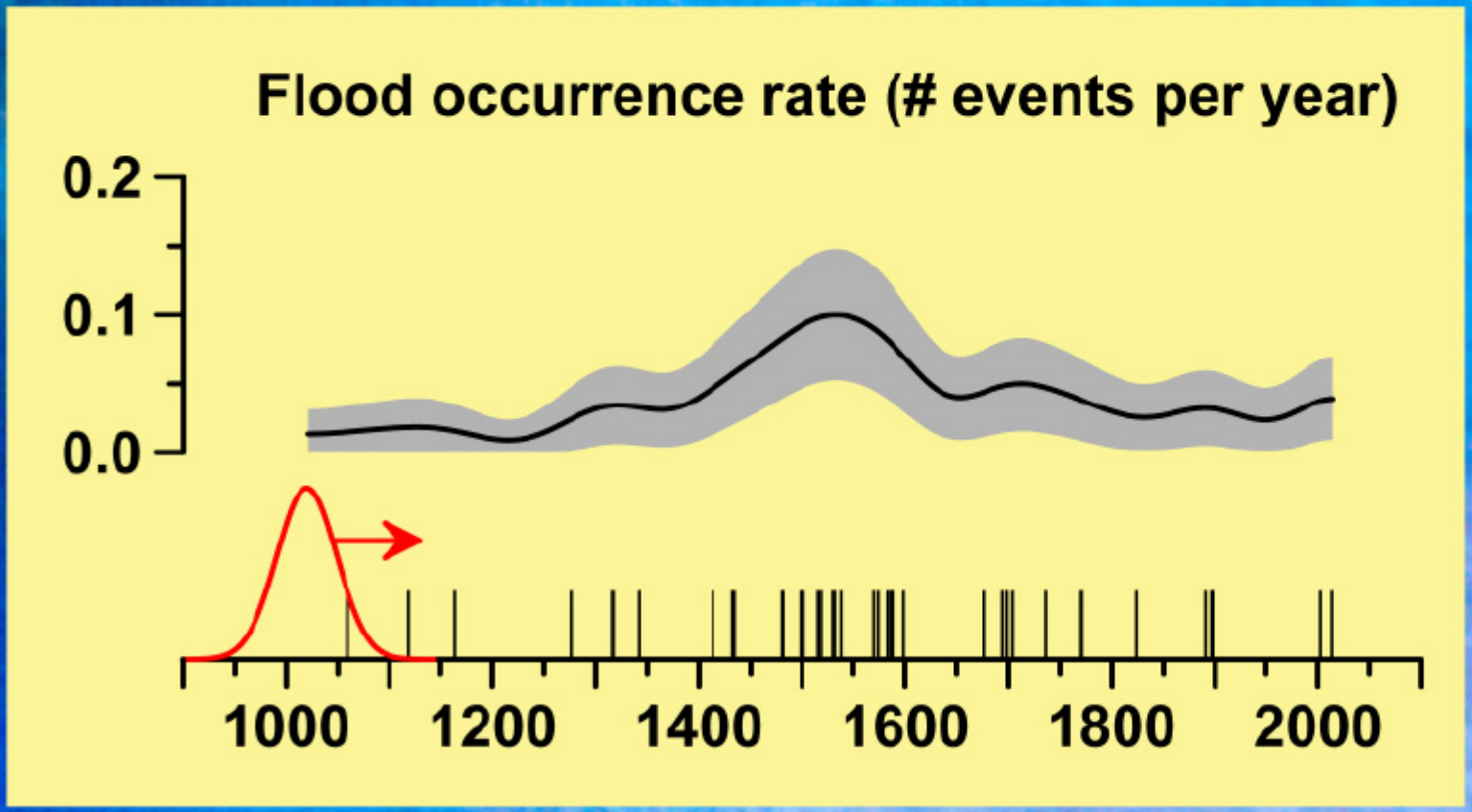
Heavy Elbe winter floods: downwards trend since about 1820 fewer freezing events (warming)



"Opportunity"

Heavy Elbe summer floods: no clear trend since about 1650

increased water vapour absortion (warming) not yet proven



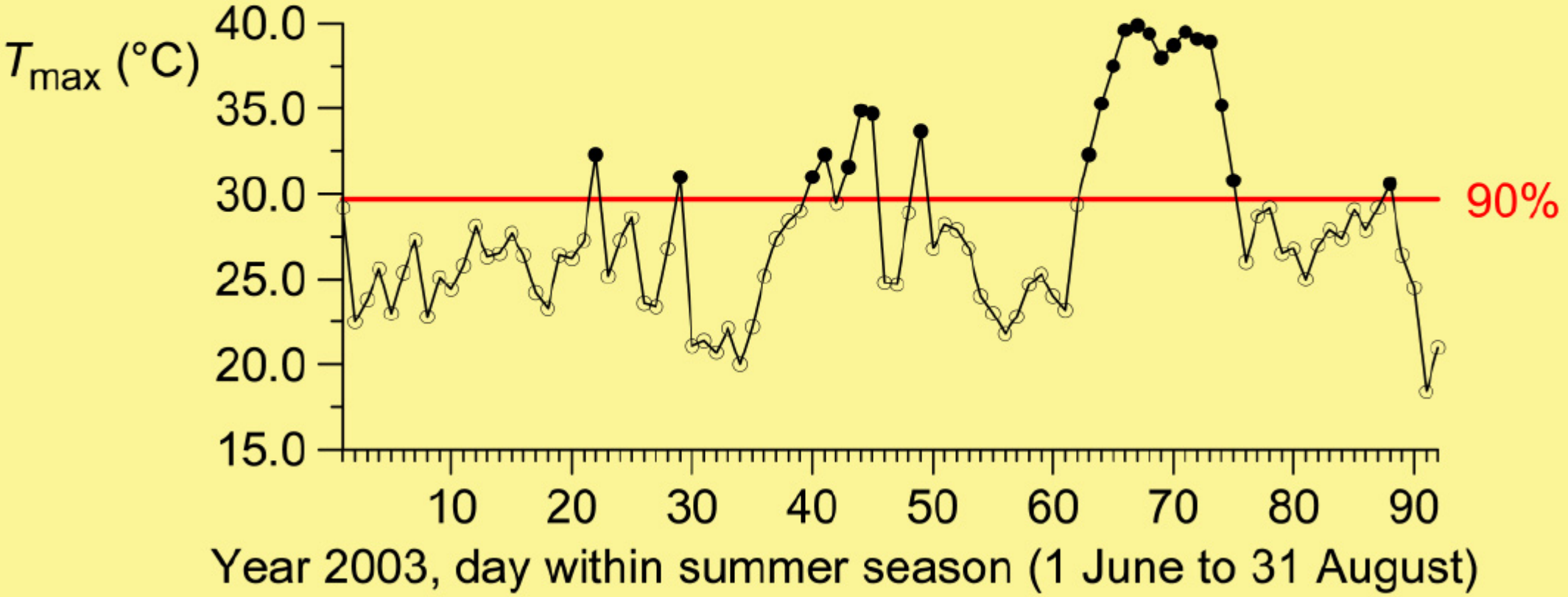
"Risk"?

7

ANALYSIS II HEATWAVES

Orléans

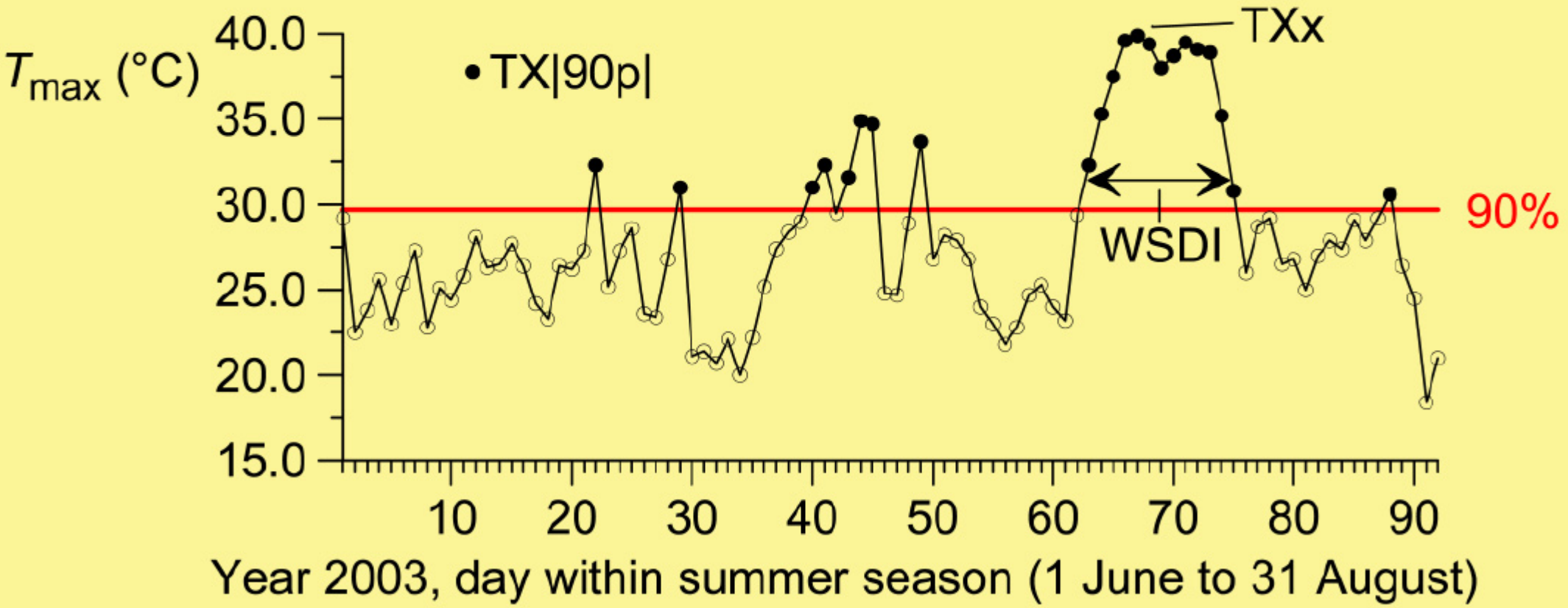
Orléans


T_{max} (°C)
40.0
35.0
30.0
25.0
20.0
15.0
90%
10
20
30
40
50
60
70
80
90
Year 2003, day within summer season (1 June to 31 August)

August 2003
France

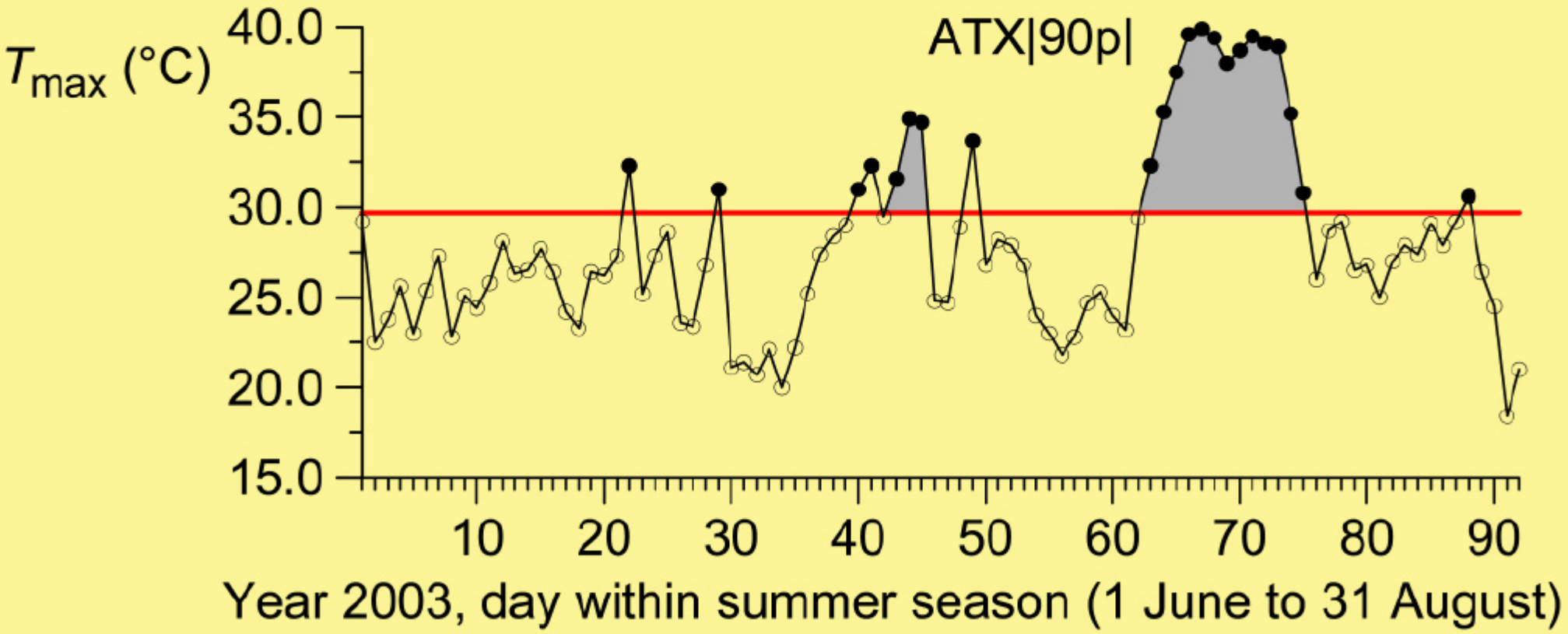
Excess mortality:
15000 deaths

Orléans



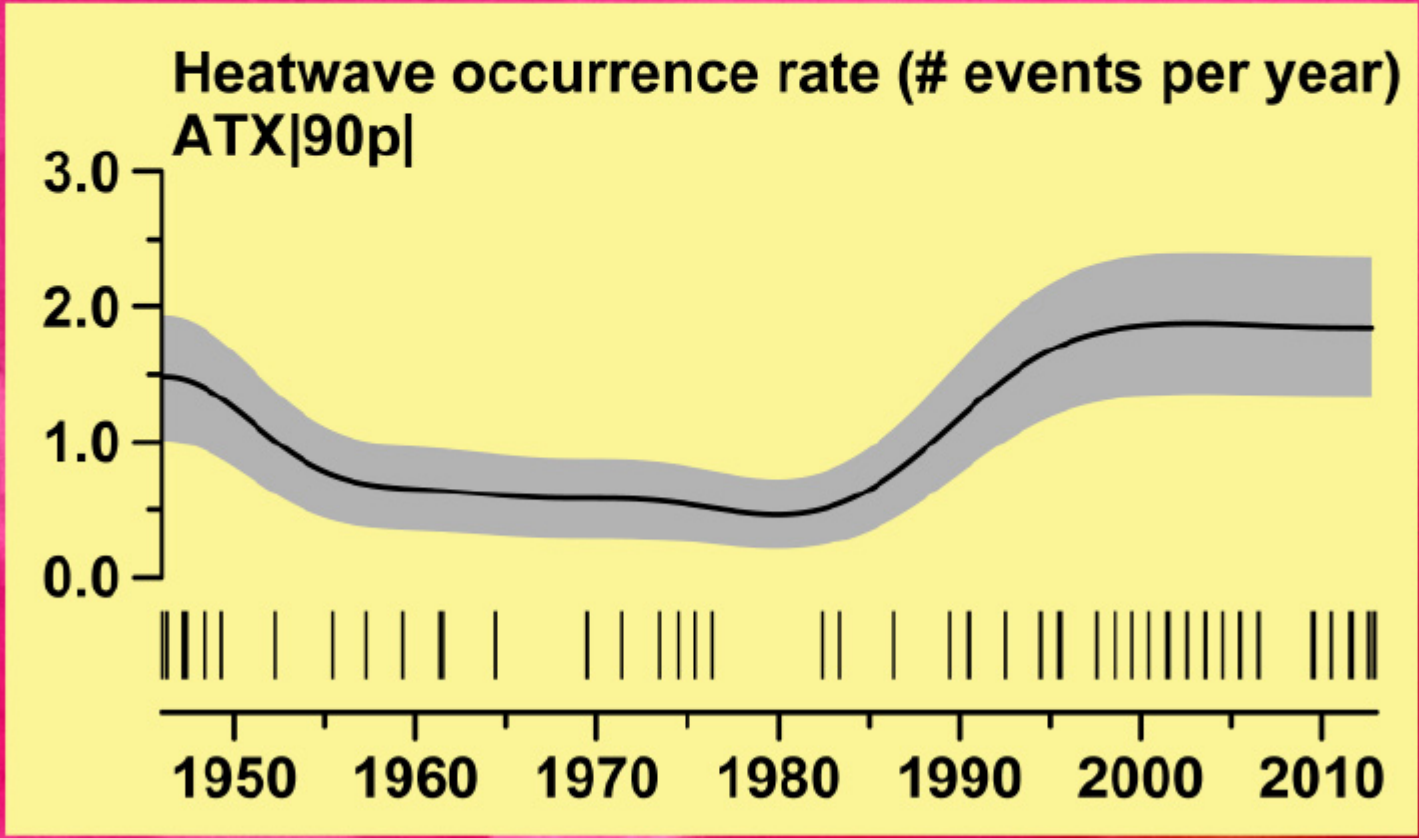
T_{max}: maximum daily temperature;
TX|90p|: number of days within summer season with T_{max} > 90% percentile;
TXx: maximum of T_{max} within summer season;
WSDI: number of days within summer season with T_{max} > 90% percentile on at least 6 consecutive days

Orléans

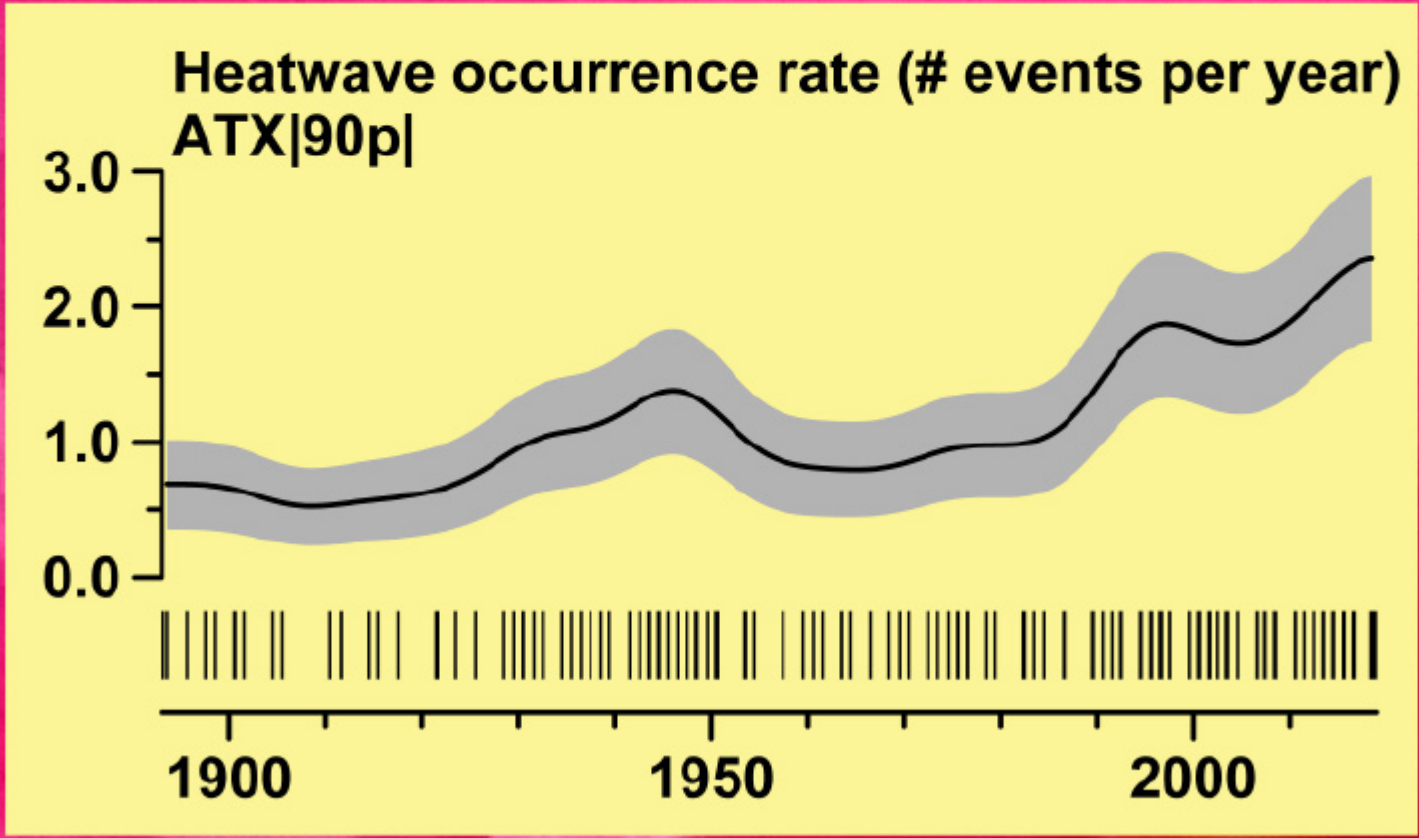


T_{max}, ATX|90p|: maximum daily temperature; integral of exceedance (T_{max} – 90% percentile) on at least 3 consecutive days

Orléans


Heatwave occurrence rate (# events per year)
ATX|90p|
3.0
2.0
1.0
0.0
1950
1960
1970
1980
1990
2000
2010

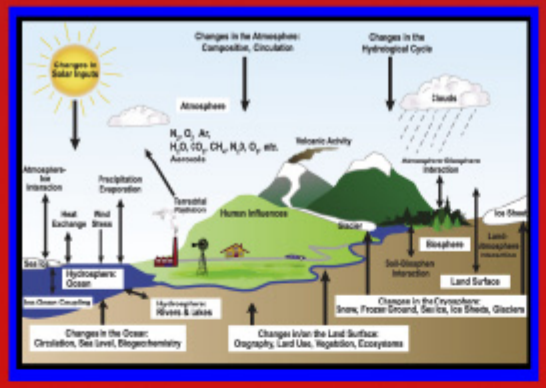
Potsdam


Heatwave occurrence rate (# events per year)
ATX|90p|
3.0
2.0
1.0
0.0
1900
1950
2000

8

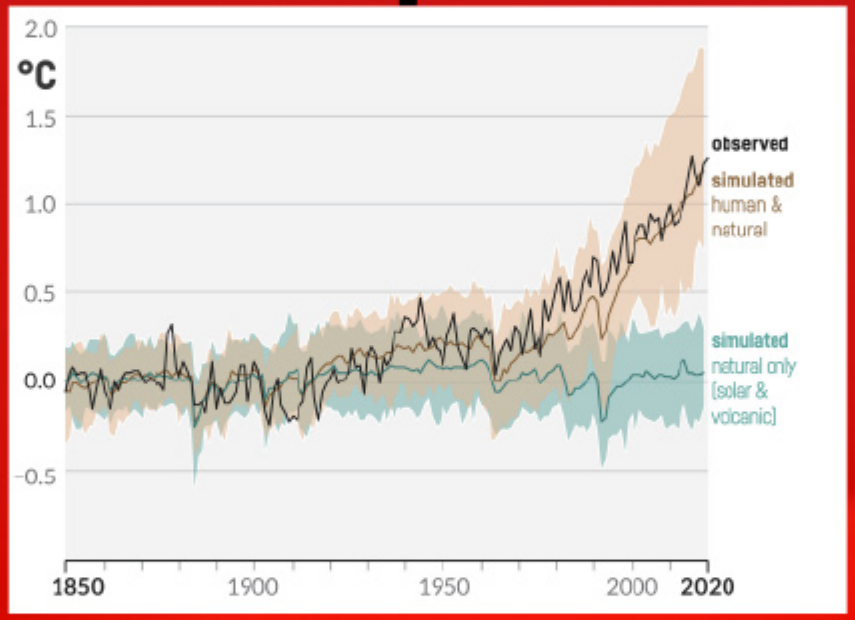
ASSESSMENT

Climate Change: Analyses, Risiks, Opportunities

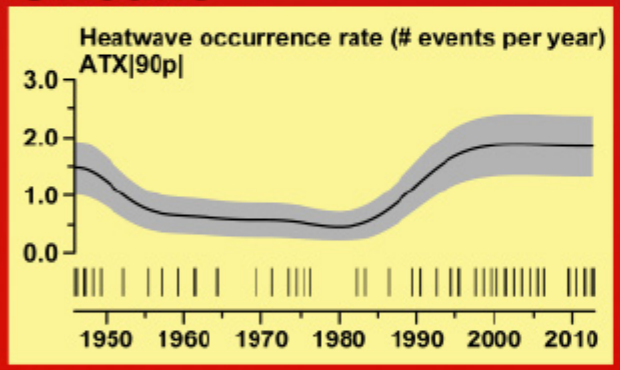


Climate system

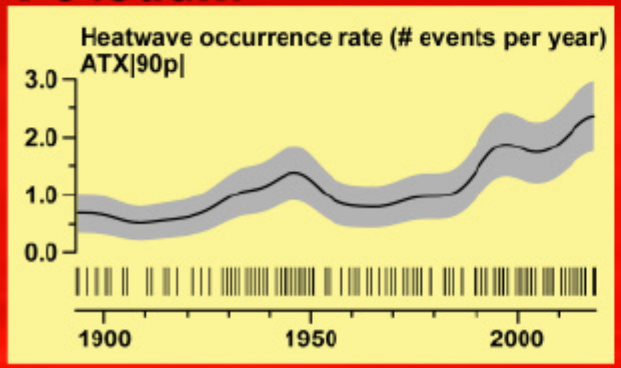
Temperature



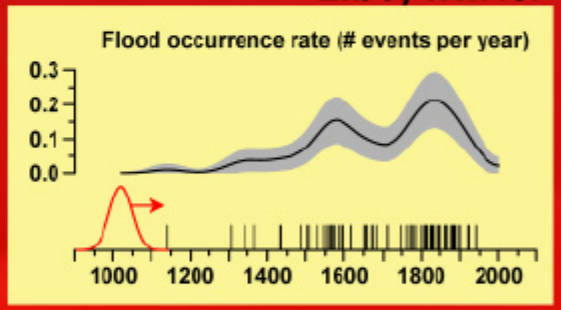
Orléans



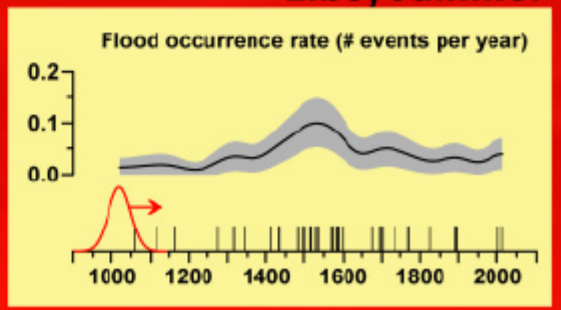
Potsdam



Elbe, winter



Elbe, summer



TEMPERATURE RISKS

easier to detect, since "closer to CO_2"

heatwaves

temperature records

coral bleaching

4th global event February 2023 to April 2024

PRECIPITATION RISKS

"further away from CO_2"

higher spatial variability than temperature

floods

extreme rainfall events

droughts

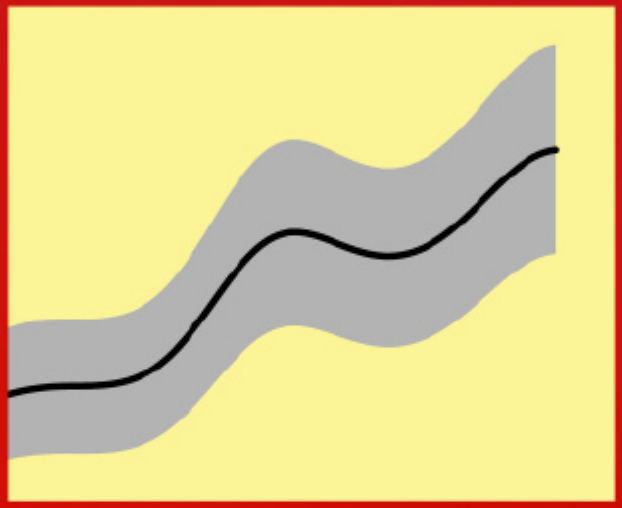
often difficult/not detectable

UNCERTAINTIES

Error bars

Confidence bands

***P*-Values**



Communication is a must!

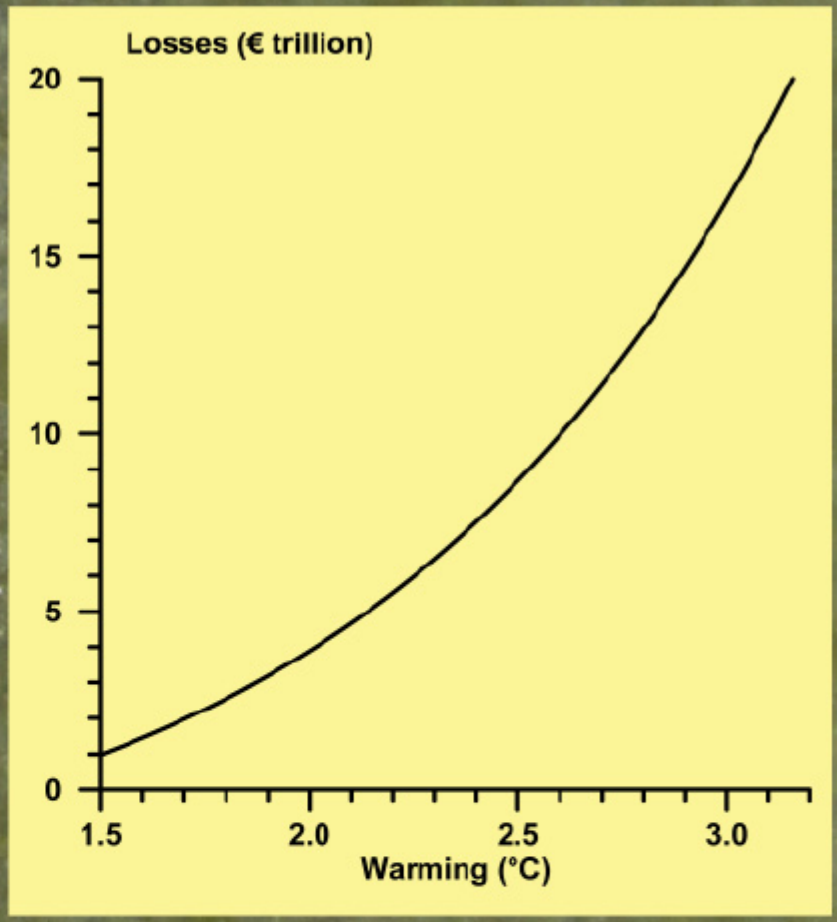
9

OPTIONS FOR ACTION

"I thought knowledge leads to action" (M. Latif)

Focus on Germany (M. M.)

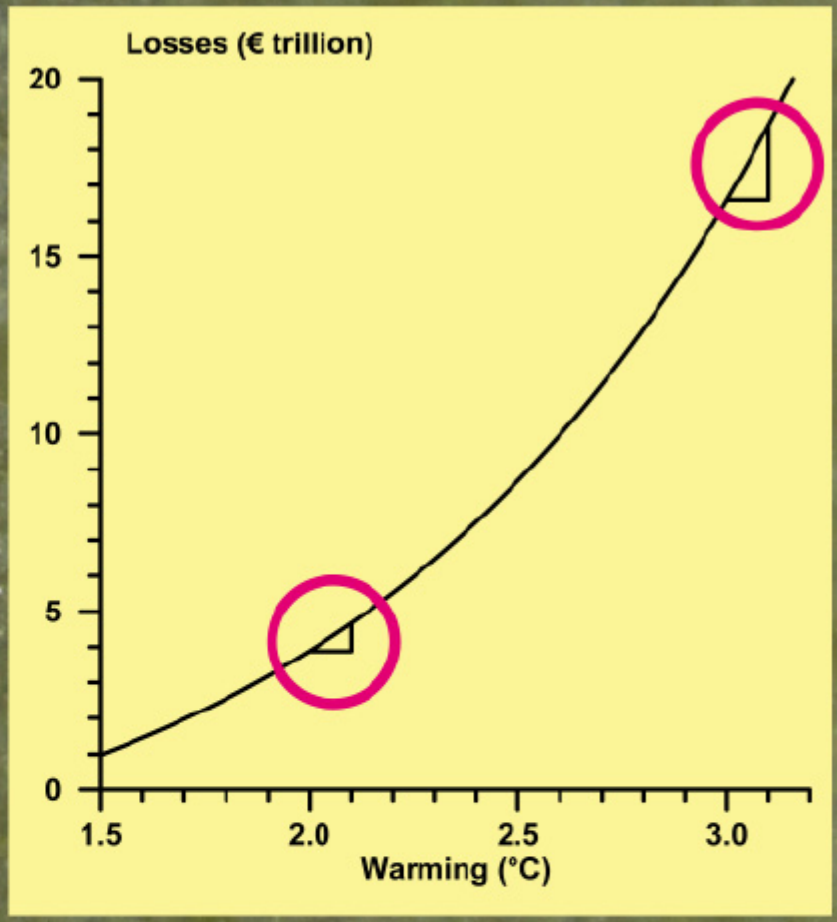
Option 1
Doing nothing



expensive

Total losses for Germany until 2100, estimate (educated guess)

Option 2
Climate mitigation



every tenth of a degree counts

Total losses for Germany until 2100, estimate (educated guess)

Option 2
Climate mitigation

nuclear power, speed limit,
Verbrenneraus

Option 2
Climate mitigation

carbon capture & storage, mirrors in outer space

Option 2
Climate mitigation

afforestation, rewetting of peatlands

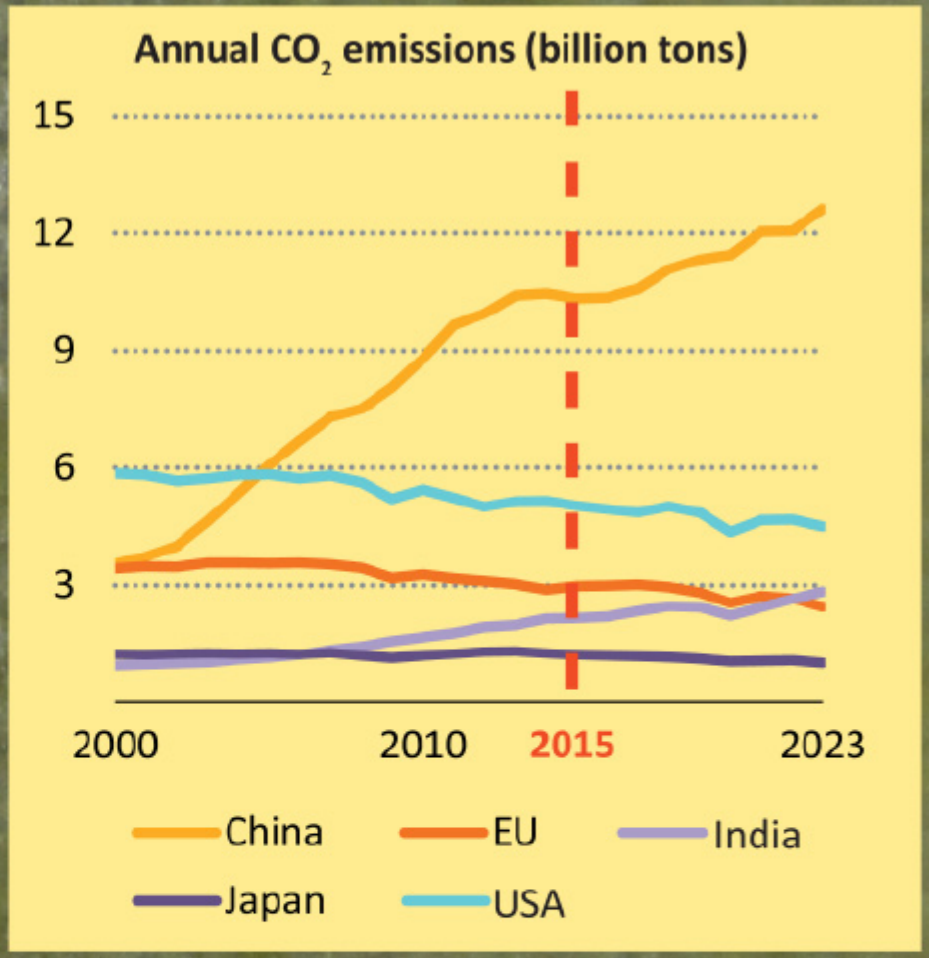
Option 2
Climate mitigation

(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

Paris, 12 December 2015

UN (2015) *Paris Agreement* (Article 2)

Option 2 Climate mitigation inertia



"The 1.5-degree target has failed." (J. Marotzke)

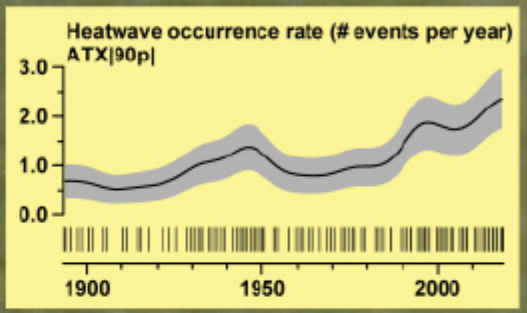
IEA (2024) *CO_2 Emissions in 2023*; Press Conference, *Extreme Weather Conference*, Hamburg, 27 September 2023

Option 3
Climate adaptation

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

Paris, 12 December 2015

Option 3
Climate adaptation



Analyses: minimize losses

It must pay off!

Nationally implementable

(still a role model).

CLIMATE MITIGATION REMAINS IMPORTANT.

ADAPTATION BECOMES MORE IMPORTANT.

A

ACKNOWLEDGEMENTS

The first time I gave this talk (in German) was at the Wiesloch Lions Club on 13 May 2024; I would like to thank President Armin Wolf for the invitation. The first time in English was as an invited keynote at the International Conference *Climate Change Adaptation in Rail Traffic Systems,* held online on 7 November 2024.

My colleague Scott St. George advised me on the question of how interested laypeople can be reached through creative means; and my colleague Han Dolman gave an online lecture on carbon dioxide in 2023, which I attended. I am very grateful to both of them for the insights they gave me.

I would like to thank the following people for allowing me to learn from them: my sister Steffi Soder; my primary school teacher Ruth Mack; at the gymnasium my teachers in physics Rudolf Löhken und in mathematics Hartmut Mackh; at the University of Heidelberg my diploma supervisor Augusto Mangini as well as Karl Otto Münnich and Walter Roedel; at the University of Kiel my doctoral supervisors Karl Stattegger and Michael Sarnthein-Lotichius as well as Pieter Grootes and Peter Stoffers; at the University of Kent at Canterbury my postdoctoral hosts Howell Tong and Qiwei Yao as well as my colleague Cees Diks; at the University of Leipzig my host Gerd Tetzlaff as well as my colleague Michael Börngen; at Boston University my host Maureen Raymo; as well as my numerous national and international colleagues, of whom here I would like to mention by name: Mersku Alkio, Gerald Haug, Gerrit Lohmann, Michael Schulz and Martin Trauth.

This presentation is a contribution to the GreenSCENT project, which has received funding from the EU's Horizon 2020 programme under the Grant Agreement No. 101036480. I would also like to thank the following organisations for their financial support of my research: British Antarctic Survey, Climate Service Center Germany, German Research Foundation, Heidelberg Academy of Sciences, Ministry of Science and Culture of Lower Saxony, Risk Prediction Initiative and Royal Society (London).

Bad Gandersheim, 7 November 2024 Manfred Mudelsee

B

NOTES

Image processing details (not specified):
Manfred Mudelsee

Image processing (others, in brackets):
Manfred Mudelsee

Picture credits (if not indicated):
Manfred Mudelsee

Image rights (external parties):
The rights associated with the individual images can be requested from the institutions and persons holding the rights indicated; in the case of the CC BY 4.0 licence, which is associated with extensive rights, this is indicated separately here. It is assumed that this presentation respects all image rights of external institutions and persons; any complaints should be addressed to Manfred Mudelsee (Appendix C).

Image rights (own):
This presentation is shown as a secured PDF file and can be downloaded from Manfred Mudelsee's academic website at the address https://www.manfredmudelsee.com (Appendix C). Insofar as it does not affect the image rights of external parties (see above), the licence CC BY-NC-ND (https://creativecommons.org/licenses/by-nc-nd/2.0/) plus an additional condition is linked to the file. With this licence, the work may be downloaded and distributed on condition that the author of the work is named; the additional condition is that a link is set to Manfred Mudelsee's academic website, https://www.manfredmudelsee.com. The work may not be edited, modified or used commercially.

Background image, page 0-1 (and further):
Dhwee/Getty Images
Font, page 0-1 (and further):
Fabrikat Kompakt by HvD Fonts

Font, page 1-1 (and further):
Livory by HvD Fonts

Background image, page 1-2 (and further):
Tom-Luis Künkler
Foto, page 1-2:
Rhein-Neckar-Zeitung
(image element highlighted)

Foto, page 1-3:
Presse-Foto Pfeifer
(image element highlighted)

Scan, page 1-4:
University of Heidelberg
(text elements highlighted)

Foto, page 1-5:
private
(image element highlighted)

Scan, page 1-6:
Mudelsee M (2000) Ramp function regression: A tool for quantifying climate transitions. Computers and Geosciences 26: 293–307
(text element highlighted)

Scan, page 1-7:
Mudelsee M, Börngen M, Tetzlaff G, Grünewald U (2003) No upward trends in the occurrence of extreme floods in central Europe. Nature 425: 166–169
(text elements highlighted)

Scan, page 1-8:
Leščešen I, Basarin B, Pavić D, Mudelsee M, Pekarova P, Mesaroš M (2024) Are extreme floods on the Danube River becoming more frequent? A case study of Bratislava station. Journal of Water and Climate Change 15: 1300 (doi:10.2166/wcc.2024.587)
(text element highlighted)

Book cover, page 1-9 :
Springer International Publishing
Foto, page 1-9:
Laura Brundrett

Background image, page 3-2 (and further):
Tom-Luis Künkler

Figure, page 3-4:
Scripps Institution of Oceanography, UC San Diego
Licence: CC BY 4.0
https://creativecommons.org/licenses/by/4.0/
Data, page 3-4:
doi.org/10.6075/J08W3BHW (26 April 2024)

Figure, page 3-5:
Scripps Institution of Oceanography, UC San Diego
Licence: CC BY 4.0
https://creativecommons.org/licenses/by/4.0/
Data, page 3-5:
doi.org/10.6075/J08W3BHW (26 April 2024),
doi.org/10.25919/5bfe29ff807f (26 April 2024)

Figure, page 3-8:
Scripps Institution of Oceanography, UC San Diego
Licence: CC BY 4.0
https://creativecommons.org/licenses/by/4.0/
Data, page 3-8:
doi.org/10.6075/J08W3BHW (26 April 2024),
doi.org/10.25919/5bfe29ff807fb (26 April 2024),
doi.org/10.1038/nature06949 (26 April 2024)

Foto, page 3-9:
Air bubbles in an Antarctic ice core: the ice is up to 24000 years old.
Bernhard Bereiter/Scripps Institution of Oceanography, UC San Diego/Empa/University of Bern

Foto (sun), page 4-3 (and further):
Courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.
https://sdo.gsfc.nasa.gov/assets/img/latest/latest_1024_0304.jpg
Licence: CC BY 4.0
https://creativecommons.org/licenses/by/4.0/

Figure, page 4-9:
Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Chen Y, Goldfarb L, Gomis MI, Matthews JBR, Berger S, Huang M, Yelekçi O, Yu R, Zhou B (2021) Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Vol. 1–2, Cambridge University Press, Cambridge, 2391 pp.
(therein Figure 1.6 centre)

Illustration, page 4-10 (Newton):
https://commons.wikimedia.org/wiki/File:Sir_Isaac_Newton._Line_engraving_by_A._M._Monsaldi_after_E._Wellcome_V0004274.jpg
Licence: CC BY 4.0
https://creativecommons.org/licenses/by/4.0/

Illustration, page 4-10 (Herschel):
https://commons.wikimedia.org/wiki/File:William_Herschel01.jpg

Illustration, page 4-10 (Fourier):
https://commons.wikimedia.org/wiki/File:Joseph_Fourier.jpg

Illustration, page 4-10 (Foote):
Alamy Limited

Illustration, page 4-10 (Tyndall):
https://commons.wikimedia.org/wiki/File:John_Tyndall_(scientist).jpg

Illustration, page 4-10 (Maxwell):
https://commons.wikimedia.org/wiki/File:James-Clerk-Maxwell-1831-1879.jpg

Illustration, page 4-10 (Planck):
Archive of the Max Planck Society, Berlin, VI. Abt., Rep. 1, Planck, Max I.1/25

Illustration, page 4-10 (Arrhenius):
https://commons.wikimedia.org/wiki/File:Svante_Arrhenius_01.jpg

Illustration, page 4-10 (Callendar):
G.S. Callendar Archive, University of East Anglia

Illustration, page 4-10 (Masson-Delmotte):
Bruno Levy/Divergence Images

Figure, page 4-13 (and further):
Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Chen Y, Goldfarb L, Gomis MI, Matthews JBR, Berger S, Huang M, Yelekçi O, Yu R, Zhou B (2021) Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Vol. 1–2, Cambridge University Press, Cambridge, 2391 pp.
(therein Figure SPM.1b)

Illustration, page 5-2 (and further):
Solomon S, Qin D, Manning M, Marquis M, Averyt K, Tignor MMB, Miller HLeR Jr, Chen Z (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 996 pp.
(therein Figure FAQ 1.2 on page 104; text elements highlighted)

Foto, page 6-3:
Brühl's Terrace Dresden
https://commons.wikimedia.org/wiki/File:20020817100NR_Dresden_Hochwasser_Br%C3%BChlsche_Terrasse.jpg
Licence: CC BY 4.0
https://creativecommons.org/licenses/by/4.0/

Illustration, page 6-6:
https://upload.wikimedia.org/wikipedia/commons/c/cb/Elbe_Einzugsgebiet.png
(three cities highlighted)

Data, pages 6-7 und 6-11:
Federal Waterways and Shipping Administration of Germany, WSV, provided by the Federal Institute of Hydrology, BfG

Illustration, page 6-9:
City archive Nuremberg, F/1/49

Text citations, page 6-10:
Weikinn C (2000) Quellentexte zur Witterungsgeschichte Europas von der Zeitwende bis zum Jahr 1850: Hydrographie, Teil 5 (1751–1800). Gebrüder Borntraeger, Berlin (edited by Michael Börngen and Gerd Tetzlaff), 674 pp.
(text elements highlighted)

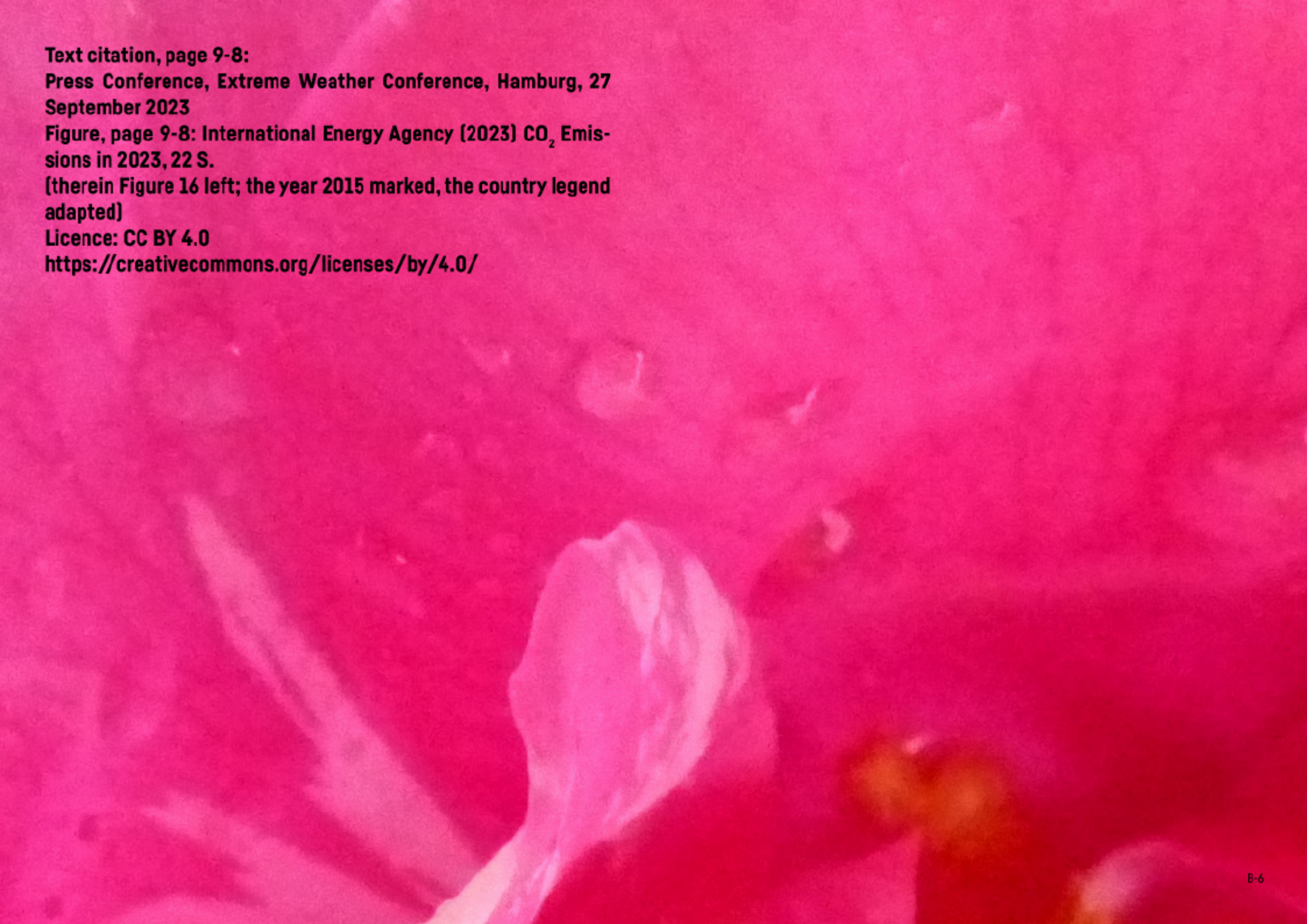
Foto, page 7-2:
https://commons.wikimedia.org/wiki/File:France_Orleans_panorama_01.jpg

Literature (excess mortality), page 7-4:
Fouillet A, Rey G, Laurent F, Pavillon G, Bellec S, Guihenneuc-Jouyaux C, Clavel J, Jougla E, Hémon D (2006) Excess mortality related to the August 2003 heat wave in France. International Archives of Occupational and Environmental Health 80: 16–24.

Background image, page 9-1 (and further):
Tom-Luis Künkler
Textzitat, page 9-1:
Die Zeit, 2 Mai 2024, page 38

Hint, figures, pages 9-2 und 9-3:
The loss figures are rough estimates.

Illustration, pages 9-7 und 9-9:
United Nations (2015) Paris Agreement (Article 2)
(text elements highlighted)



Text citation, page 9-8:
Press Conference, Extreme Weather Conference, Hamburg, 27 September 2023
Figure, page 9-8: International Energy Agency (2023) CO_2 Emissions in 2023, 22 S.
(therein Figure 16 left; the year 2015 marked, the country legend adapted)

C

CONTACT

Dr. Manfred Mudelsee
Climate Risk Analysis
Kreuzstrasse 27
Heckenbeck
37581 Bad Gandersheim
Germany

Telefon: +49 5563 9998140
E-Mail: mudelsee@climate-risk-analysis.com
URL: https://www.manfredmudelsee.com