A self-organized lecture prepared amid the COVID-19 pandemic
School of Civil Engineering, National Technical University of Athens
20 July 2020

A voyage in climate, hydrology and life on a 4.5-billion-years old planet

Demetris Koutsoyiannis
Department of Water Resources and Environmental Engineering
School of Civil Engineering, National Technical University of Athens

Available online: http://www.itia.ntua.gr/2036/

Parts of the presentation

Prologue

1. Introduction: My wandering in climate and hydrology
2. Weather and climate: Definitions, meaning and historical background
3. Climate of the past
4. Climate of the present
5. Basics of climate theory and the spring of change
6. The energy cycle
7. The carbon cycle
8. The hydrological cycle and its alleged intensification
9. The alleged intensification of hydrological extremes
10. Dealing with the future of climate and water

Epilogue

Why revelation of climate misinformation is important for Greeks, the world champions in climate scare

Pew Research Center

Global Attitudes & Trends

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FEBRUARY 10, 2019

Climate Change Still Seen as the Top Global Threat, but Cyberattacks a Rising Concern

https://www.pewresearch.org/global/2019/02/10/climate-change-still-seen-as-the-top-global-threat-but-cyberattacks-a-rising-concern/

Note: Greeks ranked first in climate scare also in earlier polls:
https://www.pewresearch.org/global/2013/06/24/climate-change-and-financial-instability-seen-as-top-global-threats/
https://news.gallup.com/poll/147203/Fewer-Americans-Europeans-View-Global-Warming-Threat.aspx

TOP FOUR

Country	Global climate change	The Islamic militant group known as ISIS	Cyberattacks from other countries	North Korea's nuclear program	The condition of the global economy	U.S. power and influence	Russia's power and influence
+ Greece	90%	69%	63%	63%	88%	48%	33%
+ South Korea	86%	63%	81%	67%	74%	67%	44%
+ France	83%	87%	67%	55%	46%	49%	40%
+ Spain	81%	75%	59%	59%	57%	42%	41%

MIDDLE FOUR

Country	Global climate change	The Islamic militant group known as ISIS	Cyberattacks from other countries	North Korea's nuclear program	The condition of the global economy	U.S. power and influence	Russia's power and influence
+ Netherlands	70%	67%	72%	39%	28%	37%	42%
+ Sweden	69%	61%	55%	41%	27%	34%	40%
+ Philippines	67%	79%	69%	61%	48%	29%	38%
+ Canada	66%	54%	57%	47%	41%	46%	32%

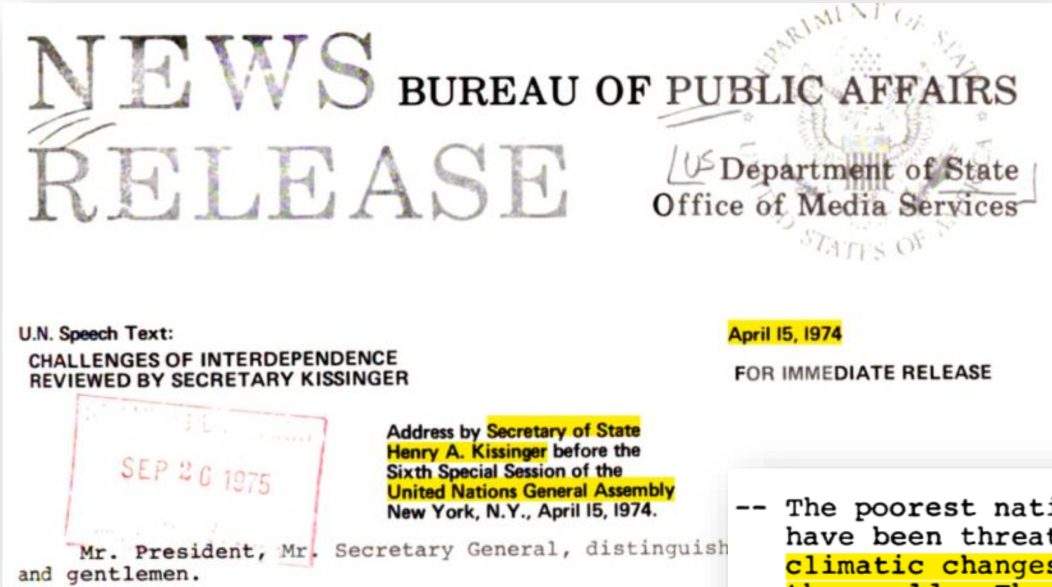
BOTTOM FOUR

Country	Global climate change	The Islamic militant group known as ISIS	Cyberattacks from other countries	North Korea's nuclear program	The condition of the global economy	U.S. power and influence	Russia's power and influence
+ Poland	55%	59%	53%	53%	23%	18%	65%
+ Russia	43%	62%	36%	30%	40%	43%	*
+ Nigeria	41%	61%	47%	41%	49%	39%	33%
+ Israel	38%	47%	42%	36%	35%	15%	28%

Prologue:
Connection with the previous lecture:
The political origin of the climate change agenda (Athens, 14 April 2020)

Despite the heavy disguise in a scientific garb, climate change is a political issue, rooted in American political elites (Rockefellers, Kissinger et al.)

Kissinger's Labour ④: Launching the Climate Change Agenda



NEWS RELEASE

BUREAU OF PUBLIC AFFAIRS

Department of State
Office of Media Services

U.N. Speech Text:
CHALLENGES OF INTERDEPENDENCE REVIEWED BY SECRETARY KISSINGER

April 15, 1974

FOR IMMEDIATE RELEASE

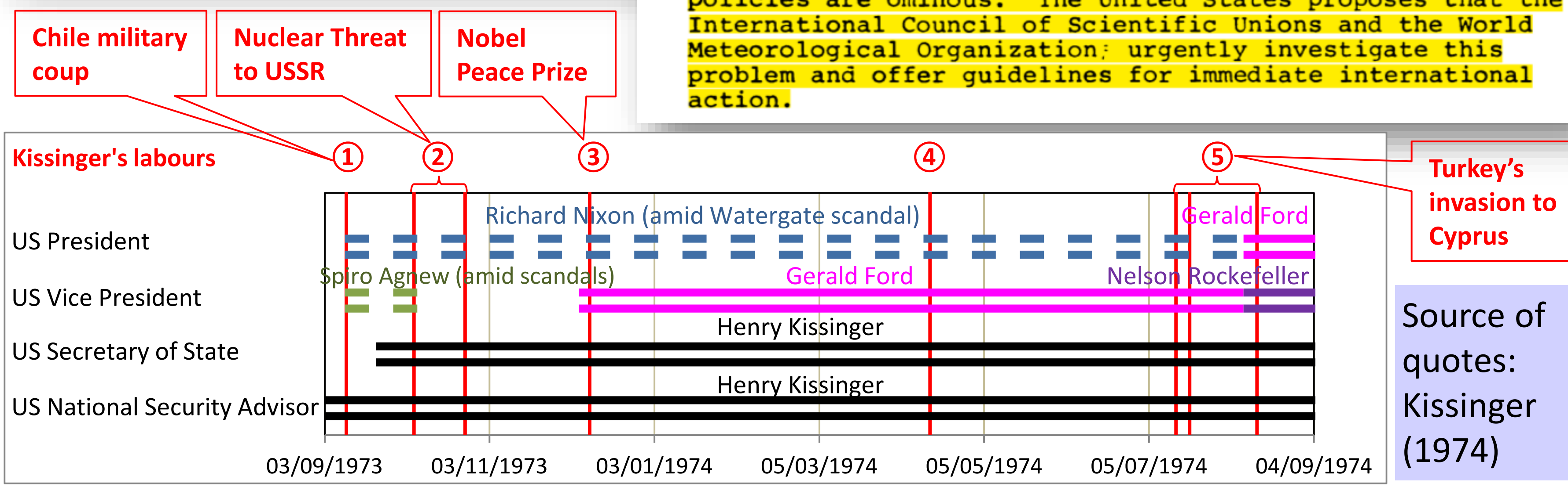
SEP 26 1975

Address by Secretary of State Henry A. Kissinger before the Sixth Special Session of the United Nations General Assembly New York, N.Y., April 15, 1974.

Mr. President, Mr. Secretary General, distinguish
and gentlemen.

- Labours ①, ②, ③ and ⑤ triggered hatred by the left-oriented groups.
- **Labour ④ would be loved by left-wing, green and activist groups**, which soon took over its promotion.
- Hence, it is the **most successful**.

-- The poorest nations, already beset by man-made disasters, have been threatened by a natural one: the possibility of climatic changes in the monsoon belt and perhaps throughout the world. The implications for global food and population policies are ominous. The United States proposes that the International Council of Scientific Unions and the World Meteorological Organization urgently investigate this problem and offer guidelines for immediate international action.



Source of quotes: Kissinger (1974)

Immediate reaction by WMO, May 1974

Distr.: RESTRICTED

WORLD METEOROLOGICAL ORGANIZATION

EC-XXVI/Doc. 70
(23.V.1974)

EXECUTIVE COMMITTEE

ITEM 5.6 (3)

TWENTY-SIXTH SESSION, GENEVA, 1974

Original: ENGLISH

ENVIRONMENTAL POLLUTION AND OTHER ENVIRONMENTAL QUESTIONS

Implications of possible climatic changes

(Presented by the Secretary-General)

Summary

This document conveys to the Executive Committee a request from the Government of the United States of America to consider the problem of the implications of possible climatic changes on the well-being of man. The present WMO activities in this field are reviewed and it is suggested that the Committee may wish to establish a Panel of Experts as the focal point within WMO on the subject of climatic changes.

References:
1. Resolution 7 (CAS-VI) - Working Group on Problems of Climatic Fluctuation
2. Resolution 15 (CoSAMC-VI) - Working Group on Climatic Fluctuations and Man
3. EC-XXVI/Doc. 14, Add. 1 - Report of the president of the Commissio[n] for Agricultural Meteorology
4. EC-XXVI/Doc. 51 - United Nations Environment Programme
5. EC-XXVI/Doc. 66 - WMO drought project.

Implications of possible climatic changes

5.6.25 The Executive Committee discussed a request from the Government of the United States of America to consider certain problems of climatic change in relation to the current and planned activities of WMO. This request had stemmed from a statement made by the Secretary-of-State at the sixth special session of the United Nations General Assembly in which he had called attention to the possibility of climatic changes which could have serious implications for global food and population policies. In this connexion, the Committee also noted the decision of the second session of the Governing Council of UNEP that the Executive Director should continue his activities relating to "outer limits", particularly climatic change.

5.6.26 The Committee agreed that the question of climatic change was of great importance and that WMO should take the initiative in formulating a coherent programme for international action in this field. This programme could include studies of the following items:

(a) The probabilities of occurence of various types of climatic change;

(b) The implications of such possible climatic changes on world food production, taking into account the meteorological aspects;

(c) The causes of climatic changes;

(d) The systematic observations of meteorological and other geophysical parameters which are necessary for detecting climatic changes;

(e) The possibilities of predicting climatic changes on various time scales;

(f) The effects of man's activities on the climate.

Lewin (2017)

WMO (1974)

Immediate reaction by CIA, August 1974 (a global cooling alert)

A Study of Climatological Research as it Pertains to Intelligence Problems

AUGUST 1974

Approved for Release: 2015/10/28 C06464613

CIA (1974)

PREFACE

This document was originally prepared as a classified working paper, and to make it available to interested persons without the proper clearances, certain portions have been edited. An attempt has been made not to diminish the document's technical content.

SUMMARY

The western world's leading climatologists have confirmed recent reports of a detrimental global climatic change. The stability of most nations is based upon a dependable source of food, but this stability will not be possible under the new climatic era. A forecast by the University of Wisconsin projects that the earth's climate is returning to that of the neo-boreal era (1600-1850)—an era of drought, famine, and political unrest in the western world.

As an example, Europe presently, with an annual mean temperature of 12°C. (about 53°F.), supports three persons per arable hectare. If, however, the temperature declines 1°C. only a little over two persons per hectare could be supported and more than 20 percent of the population could not be fed from domestic sources. China now supports over seven persons per arable hectare; a shift of 1°C. would mean it could only support four persons per hectare—a drop of over 43 percent.

A unique aspect of the Wisconsin analysis was their estimate of the duration of this climatic change. An analysis by Dr. J. E. Kutzbach (Wisconsin) on the rate of climatic changes during the preceding 1600 years indicates an ominous consistency in the rate of which the change takes place. The maximum temperature drop normally occurred within 40 years of inception. The earliest return occurred within 70 years. (Figure 8). The longest period noted was 180 years.

Immediate reaction by scientists: NOAA, October 1974

Photo: Carl Purcell, AID

CLIMATE: A KEY TO THE WORLD'S FOOD SUPPLY

BY PATRICK HUGHES

"The poorest nations, already beset by man-made disasters, have been threatened by a natural one: the possibility of climatic changes in the monsoon belt and perhaps throughout the world. The implications for global food and population policies are ominous. . . ."

HENRY KISSINGER, Address before the UN General Assembly, April 15, 1974

Hughes (1974)

- Was the climate alert about **global cooling or global warming**?
- The answer was not categorical and in fact did not matter.
- **What did matter was the alert per se**.

Both the Little Ice Age and our own climatic era are relatively minor variations superimposed on long-term fluctuations between cold, glacial and warm, relatively brief, interglacial periods of the ice age in which we are now living. For most of the Earth's history our planet had no permanent ice cover. For more than two million years now, however, we have had permanent ice fields which alternately expand and contract. The last major glacial period ended about 10,000 years ago. Some climatologists think that the present cooling trend may be the start of a slide into another period of major glaciation, popularly called an "ice age."

Many other scientists disagree. J. Murray Mitchell, Jr., of the Environmental Data Service, a world authority on climatic change, comments, "We observe these trends, and we know they are real. But we can't find the central tendency, we just don't know how long they will last." Mitchell himself suspects that the present cooling trend will reverse itself rather soon.

Part 1:
Introduction: My wandering in climate and hydrology

The last slide of my previous talk

Till now I have received zero funding for my climate research 😢😢😢

Any sponsoring offers? 😹😹😹

My first "official" contact with climate models (2000)

Carpenter and Georgakakos (2001)

ELSEVIER

Journal of Hydrology 249 (2001) 148–175

Journal of Hydrology

www.elsevier.com/locate/jhydrol

Assessment of Folsom lake response to historical and potential future climate scenarios: 1. Forecasting

Theresa M. Carpenter[a], Konstantine P. Georgakakos[a,b,*]

[a]*Hydrologic Research Center, 12780 High Bluff Drive, Suite 250, San Diego, CA 92130, USA*
[b]*Scripps Institution of Oceanography, UCSD, La Jolla, CA 92093-0224, USA*

Received 28 July 2000; revised 20 March 2001; accepted 26 March 2001

and the closest nodes of CGCM1. Significant scale bias exists and the variability of the mean areal precipitation is substantially different from that of CGCM1 nodes, with a cross-correlation coefficient that is less than 0.45 accounting for less than 20% of the observed precipitation variance. It is not necessary, however, that low skill in reproducing regional precipitation is an index of the utility of GCM information for systems acting as low-pass filters, such as the hydrologic and reservoir systems are.

The manuscript (2000)

drainage and the few closest nodes of CGCM1. Significant scale bias exists and the variability of the mean areal precipitation is substantially different from that of CGCM1 nodes, with a cross-correlation coefficient that is less than 0.45 accounting for less than 20 percent of the observed precipitation variance.

My review comment (I was a reviewer)

In p. 12, last paragraph: The cross-correlation of observed and simulated flows and the percent of variance explained does not suffice for a quantitative assessment of the hydrologic model performance. Please give indication of bias in reproduction of mean and variance. The variance is very important if the model outputs are to be used in a reservoir simulation study.

My first paper on climate

Hydrological Sciences–Journal–des Sciences Hydrologiques, **48**(1) February 2003 3

Koutsoyiannis (2003)

Climate change, the Hurst phenomenon, and hydrological statistics

DEMETRIS KOUTSOYIANNIS

Department of Water Resources, School of Civil Engineering, National Technical University, Athens Heroon Polytechneiou 5, GR-157 80 Zographou, Greece

dk@itia.ntua.gr

Abstract The intensive research of recent years on climate change has led to the strong conclusion that climate has always, throughout the Earth's history, changed irregularly on all time scales. Climate changes are closely related to the Hurst phenomenon, which has been detected in many long hydroclimatic time series and is stochastically equivalent to a simple scaling behaviour of climate variability over time scale. The climate variability, anthropogenic or natural, increases the uncertainty of the hydrological processes. It is shown that hydrological statistics, the branch of hydrology that deals with uncertainty, in its current state is not consistent with the varying character of climate. Typical statistics used in hydrology such as means, variances, cross- and auto-correlations and Hurst coefficients, and the variability thereof, are revisited under the hypothesis of a varying climate following a simple scaling law, and new estimators are studied which, in many cases, differ dramatically from the classical ones. The new statistical framework is applied to real-world examples for typical tasks such as estimation and hypothesis testing where, again, the results depart significantly from those of the classical statistics.

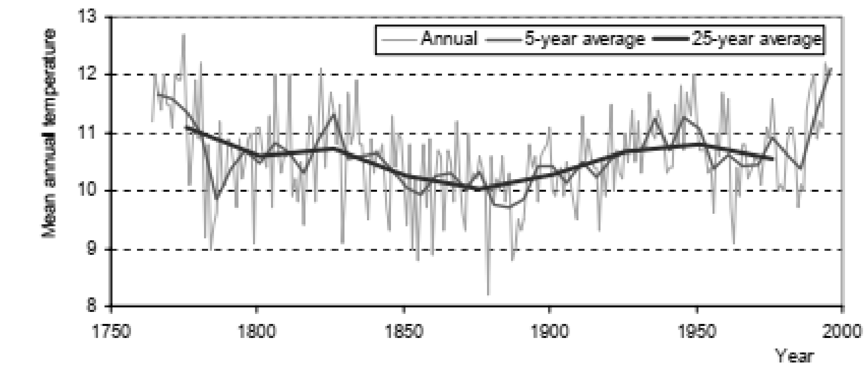


Fig. 2 Plot of the time series of mean annual temperature at Paris/Le Bourget.

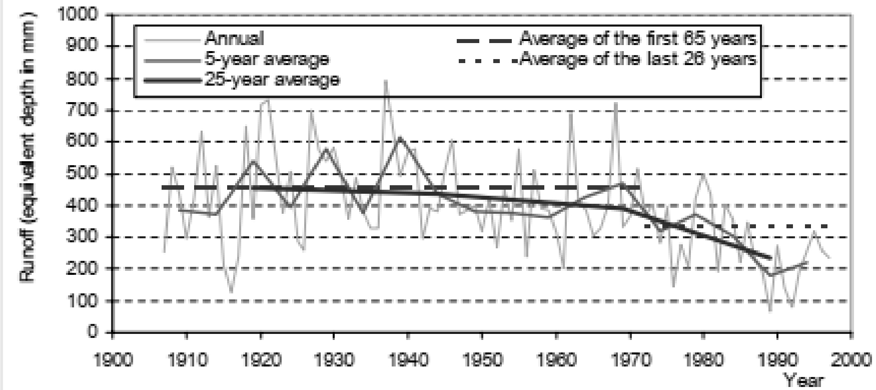


Fig. 3 Plot of the time series of the equivalent runoff depth of the Boeotikos Kephisos River basin, Greece.

- The paper proposed a stochastic methodology for dealing with changing climate.
- The methodology was inspired by the long-lasting and intense drought that shook Athens for seven years (starting in the late 1980s).
- It does not rely on climate models and was successfully used and for the management of the Athens water supply system; it is still in use, after further developments.

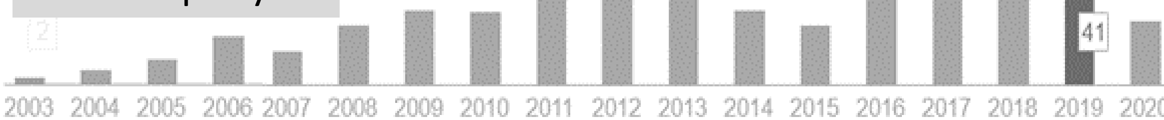
My first paper on climate: Backstage

- The paper was rejected twice by *Water Resources Research*.
- It was accepted by *Hydrological Sciences Journal*, whose Editor, Zbigniew W. Kundzewicz, has been, at the same time, the IPCC leader for hydrology (Chairing Lead Author of the IPCC freshwater chapter in IPCC AR4 and Review Editor in IPCC AR5 & AR6).
- Later Kundzewicz, who appreciates diversity of opinion, invited me to jointly lead the Journal, which we did for more than a decade.
- The paper has now has almost 400 citations.

Hydrological Sciences–Journal–des Sciences Hydrologiques, **48**(1) February 2003

Climate change, the Hurst phenomenon, and hydrological statistics

Citations per year



Sources of images: https://scholar.google.com/citations?user=OPA_BScAAAAJ, https://iahs.info/Publications-News/Hydrological-Sciences-Journal.do

Former Editors

Zbigniew W. Kundzewicz 1997-2015

Demetris Koutsoyiannis 2006-2017

Influence of my first paper on "Naturally trendy"

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L23402, doi:10.1029/2005GL024476, 2005

Cohn and Lins (2005)

Nature's style: Naturally trendy

Timothy A. Cohn and Harry F. Lins
U.S. Geological Survey, Reston, Virginia, USA

Received 29 August 2005; revised 29 September 2005; accepted 12 October 2005; publish

[1] Hydroclimatological time series often exhibit trends. While trend *magnitude* can be determined with little ambiguity, the corresponding *statistical significance*, partitioned stochastic *al.*, 2004]

GEOPHYSICAL RESEARCH LETTERS, VOL. ?

The manuscript

Nature's Style: Trendy and Insignificant

Timothy A. Cohn and Harry F. Lins
U.S. Geological Survey MS:415, Reston VA 20192

Hydroclimatological time series often exhibit trends. While trend *magnitude* can be determined with little ambiguity, the corresponding *statistical significance*, sometimes where t $(1, 2, \ldots,$ efficient (

My review (I was a reviewer)

Reviewer's report

Journal:	Geophysical Research Letters
Journal's Ref.:	2005GL024476
Reviewer's Ref.:	DK-134
Title:	Nature's Style: Trendy and Insignificant
Authors:	Timothy Cohn, Harry Lins (USA)
Reviewer:	Demetris Koutsoyiannis
Date:	29/8/2005

Reviewer's assertion: It is my opinion that a shift from anonymous to eponymous (signed) reviewing would help the scientific community to be more cooperative, democratic, equitable, ethical, productive and responsible. Therefore, it is my choice to sign my reviews.

Science category: 1

Presentation category: A

What is noteworthy about this manuscript

(a) Shows that classical statistical trend tests that fail to consider long term persistence greatly overstate the statistical significance of observed trends. (b) Proposes a modified test that establishes the validity of significance testing of trends. (c) Using a long record of air temperature in the northern hemisphere, demonstrates that significance of temperature trend varies extraordinary depending on the test used. (d) Discusses implications in hydrometeorological practices and beyond.

4. I am not sure about how successful the title "Nature's Style: Trendy and Insignificant" is. Although I think I understand what the authors mean (and I like the reference to Nature's style), I also think that one may read it as if Nature's style were insignificant (unless this impression is due to my poor English). My interpretation of the paper's

Bloggers' reaction on "Naturally trendy"

Naturally trendy?

Filed under: Climate modelling Climate Science Greenhouse gases — rasmus @ 16 December 2005

From time to time, there is discussion about whether the recent warming trend is due just to chance. We have heard arguments that so-called 'random walk' can produce similar hikes in temperature (any reason why the global mean temperature should behave like the displacement of a molecule in Brownian motion?). The latest in this category of discussions was provided by Cohn and Lins (2005), who in essence pitch statistics against physics. They observe that tests for trends are sensitive to the expectations, or the choice of the *null-hypothesis* .

84 Demetris Koutsoyiannis says:
31 Dec 2005 at 11:51 AM

A few points on the response to #82 by rasmus, which I appreciate:

1. "Statistical questions demand, essentially, statistical answers". (Here I have quoted Karl Poppers' second thesis on quantum physics interpretation – from his book "Quantum Theory and the Schism in Physics"). The question whether "The GCMs [...] give a good description of our climate's main features" (quoted from the rasmus's response) or not is, in my opinion, a statistical question as it implies comparisons of real data with model simulations. A lot of similar questions (e.g., Which of

The orthodox RealClimate
http://www.realclimate.org/index.php/archives/2005/12/naturally-trendy/
The heretic ClimateAudit
https://climateaudit.org/2006/01/05/demetris-koutsoyannis/

« To Browsing Undergraduates   Trenberth on Statistics »

Demetris Koutsoyannis

Stephen McIntyre
Jan 5, 2006 at 8:50 AM

I mentioned a few days ago that a serious discussion had threatened to break out at realclimate, where Demetris Koutsoyannis had posted up some astute commentary. He has recently dropped in here as well. I was unfamiliar with his work prior to this recent introduction. He has written extensively on climate, much of which has been from a statistical viewpoint much more advanced than poor old Rasmus.I began writing a commentary on his realclimate post, but instead have simply reproduced it below as it deserves to be read in its entirety, following some short introductory comments.

You can consult a list of his publications here . He emailed me the following two articles not posted up his website, which may interest others. (They are more accessible to non-statisticians than some of the other articles on the website): Koutsoyiannis, D., Climate change, the Hurst phenomenon, and hydrological statistics, Hydrological Sciences Journal, 48(1), 3-24, 2003. Koutsoyiannis, D., The Hurst phenomenon and fractional Gaussian noise made

Follow up on hydroclimatic stochastics

WATER RESOURCES RESEARCH, VOL. 43, W05429, doi:10.1029/2006WR005592, 2007

Click Here for Full Article

Koutsoyiannis and Montanari (2007)

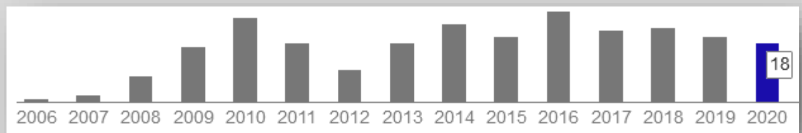
Statistical analysis of hydroclimatic time series: Uncertainty and insights

Demetris Koutsoyiannis[1] and Alberto Montanari[2]

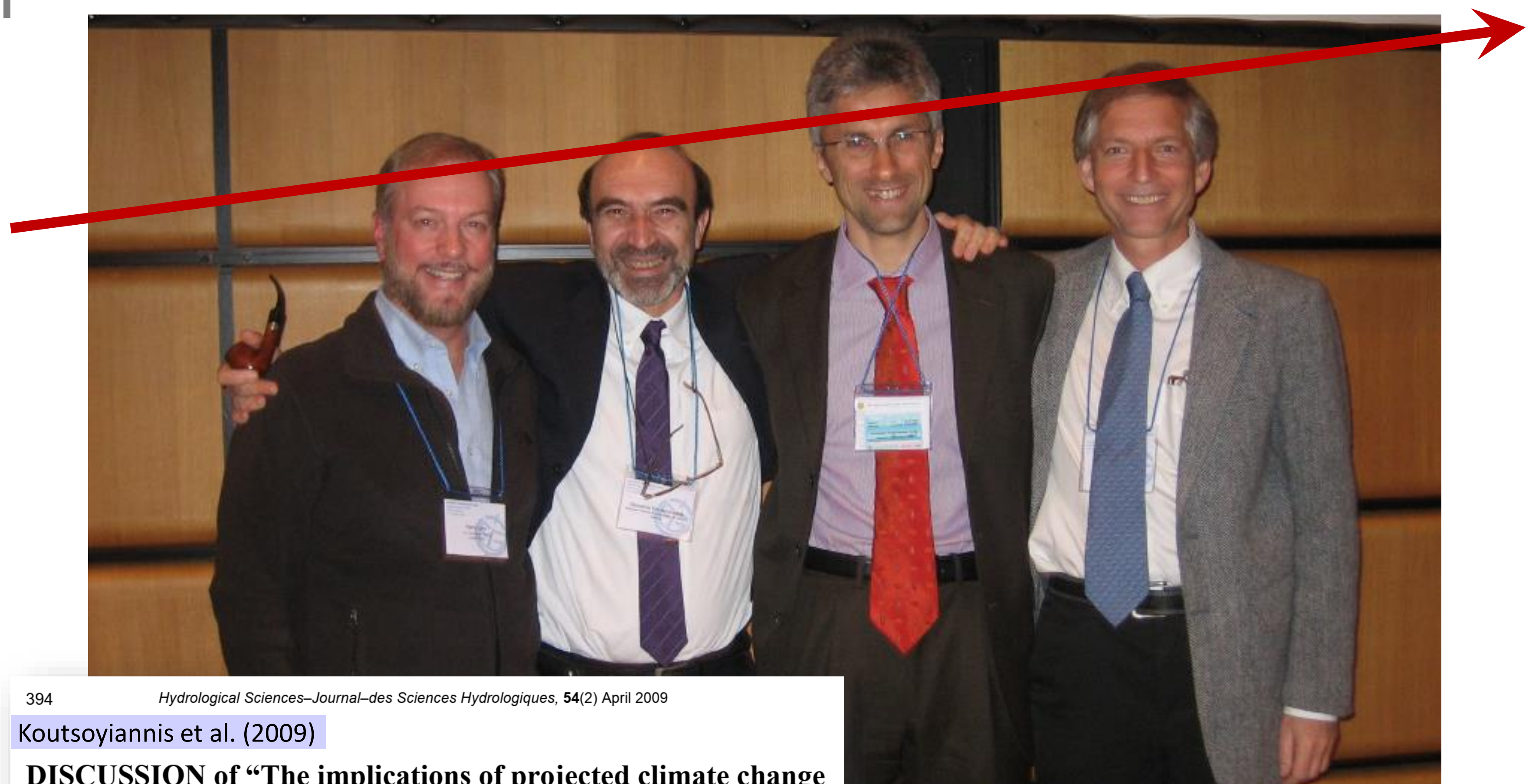
Received 4 October 2006; revised 19 December 2006; accepted 2 January 2007; published 22 May 2007.

[1] Today, hydrologic research and modeling depends largely on climatological inputs, whose physical and statistical behavior are the subject of many debates in the scientific community. A relevant ongoing discussion is focused on long-term persistence (LTP), a natural behavior identified in several studies of instrumental and proxy hydroclimatic time series, which, nevertheless, is neglected in some climatological studies. LTP may reflect a long-term variability of several factors and thus can support a more complete physical understanding and uncertainty characterization of climate. The implications of LTP in hydroclimatic research, especially in statistical questions and problems, may be substantial but appear to be not fully understood or recognized. To offer insights on these

The paper was rejected twice by *Geophysical Research Letters* and has now ~250 cites.



Naturally trendy…



394 *Hydrological Sciences–Journal–des Sciences Hydrologiques,* **54**(2) April 2009

Koutsoyiannis et al. (2009)

DISCUSSION of "The implications of projected climate change for freshwater resources and their management"*

Climate, hydrology and freshwater: towards an interactive incorporation of hydrological experience into climate research

DEMETRIS KOUTSOYIANNIS[1], ALBERTO MONTANARI[2], HARRY F. LINS[3] & TIMOTHY A. COHN[3]

Harry Lins, Demetris Koutsoyiannis, Alberto Montanari, Tim Cohn†; EGU, Vienna, 2009

† 1957–2017
https://eos.org/articles/timothy-a-cohn-1957-2017

Stochastic vs. climate model approaches

VOLUME 8 JOURNAL OF HYDROMETEOROLOGY JUNE 2007

Koutsoyiannis et al. (2007)

Uncertainty Assessment of Future Hydroclimatic Predictions: A Comparison of Probabilistic and Scenario-Based Approaches

D. KOUTSOYIANNIS* AND A. EFSTRATIADIS

Department of Water Resources, National Technical University of Athens, Athens, Greece

K. P. GEORGAKAKOS+

Hydrologic Research Center, San Diego, California

(Manuscript received 21 December 2005, in final form 1 September 2006)

ABSTRACT

During the last decade, numerous studies have been carried out to predict future climate based on climatic models run on the global scale and fed by plausible scenarios about anthropogenic forcing to climate. Based on climatic model output, hydrologic models attempt then to predict future hydrologic regimes at regional scales. Much less systematic work has been done to estimate climatic uncertainty and

My first direct research contact with climate models was a disappointing experience. Stationary stochastic modelling proved far superior.

Systematic testing of climate model outputs against observations

Hydrological Sciences–Journal–des Sciences Hydrologiqu

Koutsoyiannis et al. (2008)

RAPID COMMUNICATION

On the credibility of climate predictions

D. KOUTSOYIANNIS, A. EFSTRATIADIS, N. MAM

Department of Water Resources, Faculty of Civil Engineering, National Tec
Heroon Polytechneiou 5, GR-157 80 Zographou, Greece
dk@itia.ntua.gr

Abstract Geographically dis
widely used in hydrology and
compare the output of various
long (over 100 years) records
climatic (30-year) scale. Thus
models can perform better at l

1334 *Hydrological Sciences Journal – Journal des Sciences Hydrologiques*, **56**(7) 2011

REPLY

Koutsoyiannis et al. (2011)

Scientific dialogue on climate: is it giving black eyes or opening closed eyes?

Reply to "A black eye for the *Hydrological Sciences Journal*" by D. Huard

D. Koutsoyiannis[1], A. Christofides[1*], A. Efstratiadis[1], G. G. Anagnostopoul...

A comparison of local and aggregated climate model outputs with observed data

Anagnostopoulos et al. (2010)

G. G. Anagnostopoulos, D. Koutsoyiannis, A. Christofides, A. Efstratiadis & N. Mamassis

Department of Water Resources, Faculty of Civil Engineering, National Technical University of Athens, Heroon Polytechneiou 5, GR 157 80 Zographou, Greece
a.christofides@itia.ntua.gr

Received 10 April 2009; accepted 10 May 2010; open for discussion until 1 April 2011

Citation Anagnostopoulos, G. G., Koutsoyiannis, D., Christofides, A., Efstratiadis, A. & Mamassis, N. (2010) A comparison of local and aggregated climate model outputs with observed data. *Hydrol. Sci. J.* **55**(7), 1094–1110.

Abstract We compare the output of various climate models to temperature and precipitation observations at 55 points around the globe. We also spatially aggregate model output and observations over the contiguous USA using data from 70 stations, and we perform comparison at several temporal scales, including a climatic (30-year) scale. Besides confirming the findings of a previous assessment study that model projections at point scale are poor, results show that the spatially integrated projections are also poor.

The climatic models proved irrelevant with reality.

From 2010 to 2020

Surv Geophys (2013) 34:181–207
DOI 10.1007/s10712-012-9208-9

Markonis and Koutsoyiannis (2013)

Climatic Variability Over Time Scales Spanning Nine Orders of Magnitude: Connecting Milankovitch Cycles with Hurst–Kolmogorov Dynamics

Yannis Markonis · Demetris Koutsoyiannis

1174 *Hydrological Sciences Journal – Journal des Sciences Hydrologiques*, 60 (7–8) 2015
http://dx.doi.org/10.1080/02626667.2014.959959
Special issue: *Modelling Temporally-variable Catchments*

Koutsoyiannis and Montanari (2015)

Negligent killing of scientific concepts: the stationarity case

Demetris Koutsoyiannis[1] and Alberto Montanari[2]

Journal of Hydrology 588 (2020) 125005

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Iliopoulou and Koutsoyiannis (2020)

Projecting the future of rainfall extremes: Better classic than trendy

Theano Iliopoulou*, Demetris Koutsoyiannis

Department of Water Resources, Faculty of Civil Engineering, National Technical University of Athens, Heroon Polytechneiou 5, GR-157 80 Zografou, Greece

A R T I C L E I N F O

This manuscript was handled by A. Bardossy, Editor-in-Chief, with the assistance of Felix Frances, Associate Editor

Keywords:
Trends
Rainfall extremes
Probability dry
Out-of-sample validation
Predictive performance
Rainfall projections

A B S T R A C T

Non-stationarity approaches have been increasingly popular in hydrology, reflecting scientific concerns regarding intensification of the water cycle due to global warming. A considerable share of relevant studies is dominated by the practice of identifying linear trends in data through in-sample analysis. In this work, we reframe the problem of trend identification using the out-of-sample predictive performance of trends as a reference point. We devise a systematic methodological framework in which linear trends are compared to simpler mean models, based on their performance in predicting climatic-scale (30-year) annual rainfall indices, i.e. maxima, totals, wet-day average and probability dry, from long-term daily records. The models are calibrated in two different schemes: block-moving, i.e. fitted on the recent 30 years of data, obtaining the local trend and local mean, and global-moving, i.e. fitted on the whole period known to an observer moving in time, thus obtaining the global trend and global mean. The investigation of empirical records spanning over 150 years of daily data

Clim Dyn (2014) 42:2867–2883
DOI 10.1007/s00382-013-1804-y

A Bayesian statistical model for deriving the predictive distribution of hydroclimatic variables

Hristos Tyralis · Demetris Koutsoyiannis

Tyralis and Koutsoyiannis (2014)

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Abstract Recent publications have provided evidence that hydrological processes exhibit a scaling behaviour,

1 Introduction

HYDROLOGICAL SCIENCES JOURNAL – JOURNAL DES SCIENCES HYDROLOGIQUES, 2017
VOL. 62, NO. 13, 2083–2102
https://doi.org/10.1080/02626667.2017.1361535

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Tyralis and Koutsoyiannis (2017)

On the prediction of persistent processes using the output of deterministic models

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ABSTRACT

ARTICLE HISTORY

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Hydrology and Earth System Sciences
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Discussions
EGU

Koutsoyiannis (2020; in press)

Revisiting global hydrological cycle: Is it intensifying?

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Abstract. As a result of technological advances in monitoring atmosphere, hydrosphere, cryosphere and biosphere, as well as in data management and processing, several data bases have become freely available. These can be exploited in revisiting

General impression from my publication experience

It has been hard to publish papers challenging climate orthodoxy—rejection has been frequent
😢😢😢

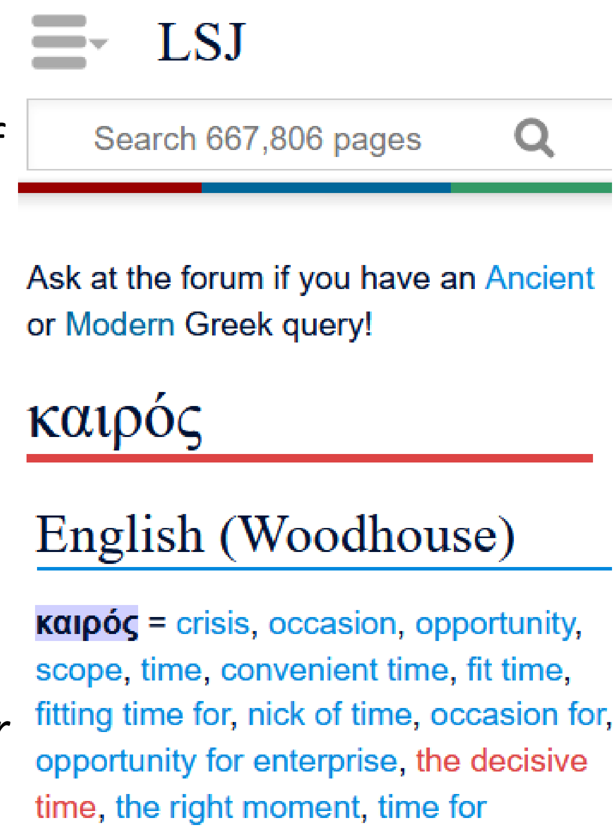
Later my papers have been cited—even by IPCC
😁😁😁

Till now none of my papers has been found erring
😀😀😀

Part 2
Weather and climate: Definitions, meaning and historical background

Weather – Tempus – Καιρός

- Weather is the state of the atmosphere in terms of a combination of meteorological variables: e.g., pressure, temperature, humidity, precipitation, cloudiness, visibility and wind[1].
- It is more a popular notion, often used with respect to its effects upon life and human activities[2], rather than a rigour scientific term.
- In Greek and Romance (Neo-Latin) languages the term has also the meaning of *time*.
- In English and Greek (not in all languages), *weather* refers to short-scale (min to d) variations in the atmosphere and is distinguished from *climate*.

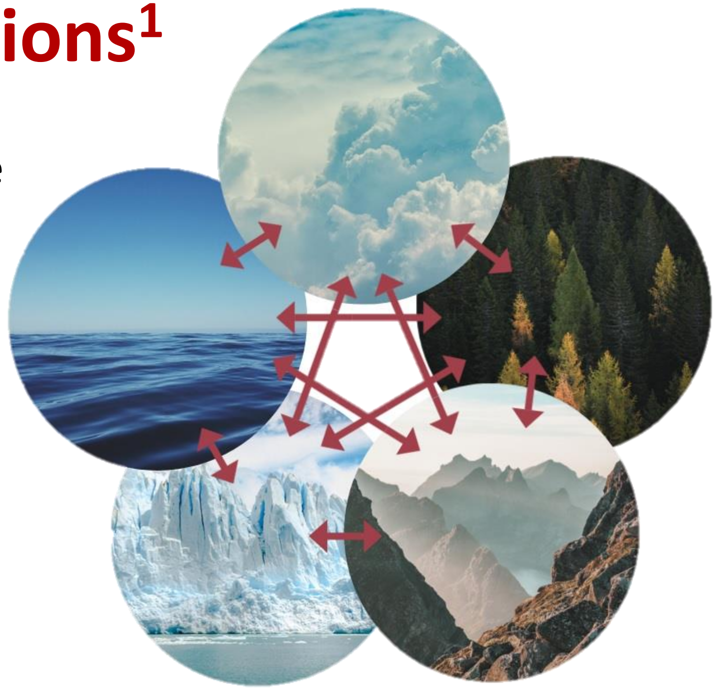


Greek	Καιρός
Italian	Tempo
French	Temps, Météo
Spanish	Tiempo, Clima
Portuguese	Tempo, Clima

[1] My definition (Koutsoyiannis, 2021) is based on the glossary of the NOAA's National Weather Service: https://w1.weather.gov/glossary/index.php?letter=w.
[2] Cf. the glossary of the American Meteorological Society, http://glossary.ametsoc.org/wiki/Weather
[3] For example the IPCC (2013) glossary does not include a definition of weather.

Climate < Clima < Κλίμα: Definitions[1]

- **Climate system** is the system consisting of the atmosphere, hydrosphere, cryosphere, lithosphere and biosphere, which mutually interact and respond to external influences.
- **Climatic processes** are the physical, chemical and biological processes, which are produced by the interactions and responses of the climate system components through flows of energy and mass, and chemical and biological reactions.
- **Climate** is the multiscale stochastic characterization of the climatic processes.
- The term *process* means *change* (Kolmogorov, 1931). Thus, climate is changing by definition.
- The term *stochastic* means random (i.e., unpredictable, unknowable in deterministic terms) and the term *stochastic process* means a family of stochastic (random) variables $\underline{x}(t)$ indexed by time t.
- The terms *stochastic characterization* and *stochastics* collectively refer to the scientific areas of *probability*, *statistics* and *stochastic processes*.
- The term *hydroclimatic* is used to give more emphasis on the hydrological processes.

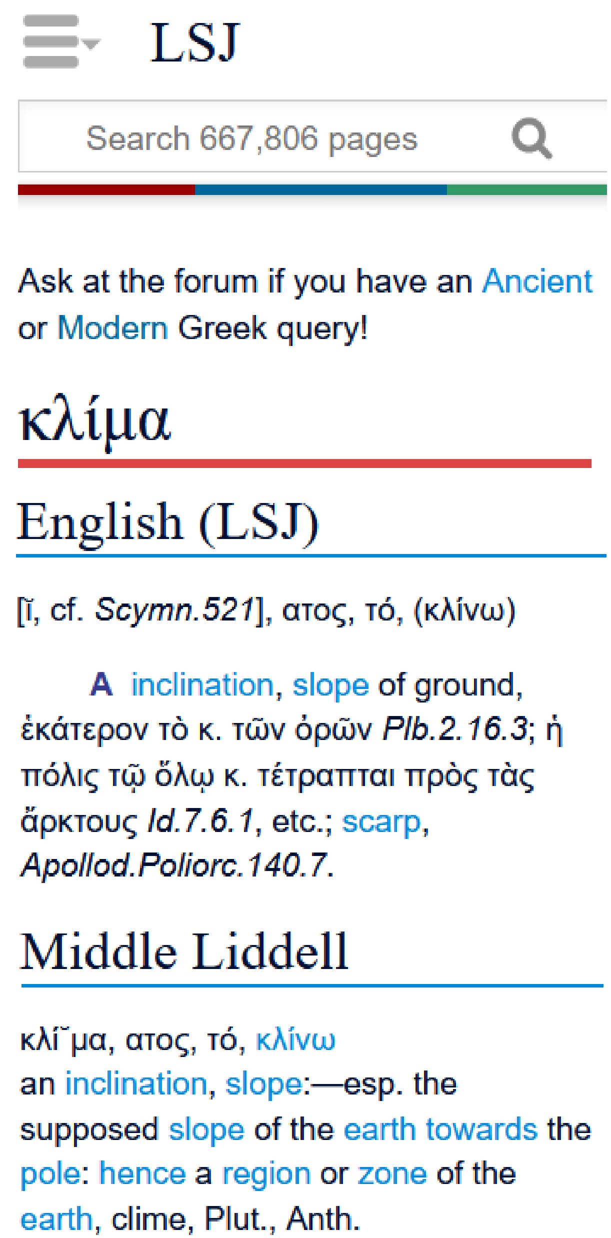


Source: https://en.wikipedia.org/wiki/Climate_system

[1] My definitions (Koutsoyiannis, 2021) are based on, but are not identical to, common ones in the literature (see next slides).

Climate < Clima < Κλίμα: History

- Aristotle (384–322 BC) in his *Meteorologica* describes the climates on Earth in connection with latitude but he does not use the term *climate*. Instead, he uses the term *crasis* (*κρᾶσις*, literally meaning mixing, blending, temperament; cf. *εὔκρατος*, *εὐκρασία*).
- The term *climate* (*κλίμα*, plural *κλίματα*) was coined as a geographical term by the astronomer Hipparchus (190 –120 BC; founder of trigonometry). It originates from the verb *κλίνειν*, meaning 'to incline' and denoted the angle of inclination of the celestial sphere and the terrestrial latitude characterized by this angle.
- Hipparchus's Table of Climates is described by Stabo the Geographer (63 BC – AD 24), from whom it becomes clear that the *Climata* of that Table are just latitudes of several cities, from 16° to 58°N (see Shcheglov, 2007, for a reconstruction of the Table).
- Furthermore Strabo, defined the five climatic zones, *torrid* (*διακεκαυμένη*), two *temperate* (*εὔκρατοι*) and two *frigid* (*κατεψυγμέναι*), as we use them to date.


LSJ

Search 667,806 pages

Ask at the forum if you have an Ancient or Modern Greek query!

κλίμα

English (LSJ)

[ῐ, cf. *Scymn.521*], ατος, τό, (κλίνω)

A inclination, slope of ground, ἑκάτερον τὸ κ. τῶν ὀρῶν *Plb.2.16.3*; ἡ πόλις τῷ ὅλῳ κ. τέτραπται πρὸς τὰς ἄρκτους *Id.7.6.1*, etc.; scarp, *Apollod.Poliorc.140.7*.

Middle Liddell

κλῐ˜μα, ατος, τό, κλίνω
an inclination, slope:—esp. the supposed slope of the earth towards the pole: hence a region or zone of the earth, clime, Plut., Anth.

Climate < Clima < Κλίμα: Contemporary history

- The term *climate* was used with the ancient Greek geographical meaning until at least 1700. The term *climatology* appears after 1800.
- With the increasing collection of meteorological measurements, the term *climate* acquires a statistical character as the average weather. Indeed, the geographer A.J. Herbertson (1907) in his book entitled "*Outlines of Physiography, an Introduction to the Study of the Earth*", gave the following definition of climate, based on weather (but also distinguishing it from weather):

  > *By climate we mean the average weather as ascertained by many years' observations. Climate also takes into account the extreme weather experienced during that period. Climate is what on an average we may expect, weather is what we actually get.*

- Herbertson also defined climatic regions of the world based on statistics of temperature and rainfall distribution.
- Herbertson's work was influential for the famous and most widely used Köppen (1918) climate classification; this includes six main zones and eleven climates which are on the same general scale as Herbertson's (Stamp, 1957).

Climate < Clima < Κλίμα: Some modern definitions

- Definition by the USA National Weather Service, Climate Prediction Center (https://www.cpc.ncep.noaa.gov/products/outreach/glossary.shtml#C):

  Climate – The average of weather over at least a 30-year period. Note that the climate taken over different periods of time (30 years, 1000 years) may be different. The old saying is climate is what we expect and weather is what we get.

- Definition by the American Meteorological Society (http://glossary.ametsoc.org/wiki/Climate):

  Climate – The slowly varying aspects of the atmosphere–hydrosphere–land surface system. It is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities. Climatic classifications include the spatial variation of these time-averaged variables. Beginning with the view of local climate as little more than the annual course of long-term averages of surface temperature and precipitation, the concept of climate has broadened and evolved in recent decades in response to the increased understanding of the underlying processes that determine climate and its variability.

- Definition by the IPCC (2013)

  Climate – Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Some remarks on climate’s modern definitions

- Why “*at least a 30-year period*”? Is there anything special with the 30 years?
  - This reflects a historical belief that 30 years are enough to smooth out “random” weather components and establish a constant mean. In turn, this reflects a perception of a constant climate—and a hope that 30 years would be enough for a climatic quantity to get stabilized to a constant value. It can be conjectured that the number 30 stems from the central limit theorem and in particular the common (albeit wrong) belief that the sampling distribution of the mean is normal for sample sizes over 30 (e.g. Hoffman, 2015). Such a perception roughly harmonizes with classical statistics of independent events.
  - This perception is further reflected in the term anomaly (from the Greek ανωμαλία, meaning abnormality), commonly used in climatology to express the difference from the mean.
  - Thus, the dominant idea is that a constant climate would be the norm and a deviation from the norm would be an abnormality, perhaps caused by an external agent.
  - The entire line of thought is incorrect.
- Why “*climate taken over different periods of time (30 years, 1000 years)* [is] *different*”?
  - The obvious reply is: Because different 30-year periods have different climate. This contradicts the tacit belief of constancy and harmonizes with the perception of an ever-changing climate.
- Is Herbertson’s idea, “*climate is what we expect, weather is what we get*”, correct?
  - **No**. A correct reformulation would be “*weather is what we get immediately, climate is what we get if we keep expecting for a long time*” (Koutsoyiannis, 2011a).

The meaning of “climate change”

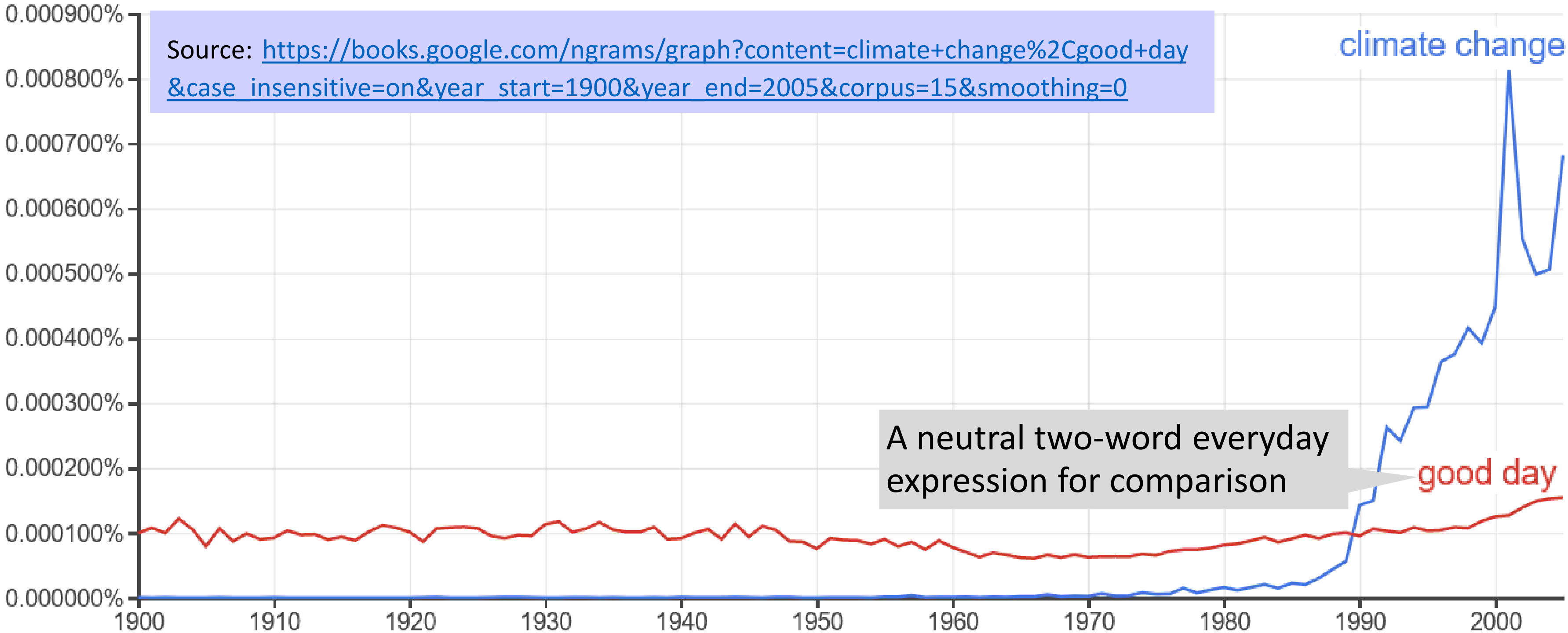
- In scientific terms, the content of the term *climate change* is almost equivalent to that of *weather change* or even *time change* (climate is changing as is weather and time).
- Thus, “*the term 'climate change' is a misleading popular slogan*” (Vit Klemes[†]) and serves political aims. It is not a scientific term.
- Even according to the IPPC’s (2013) definition, its meaning is ambiguous:

  Climate change refers to 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. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

  Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: ‘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’. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

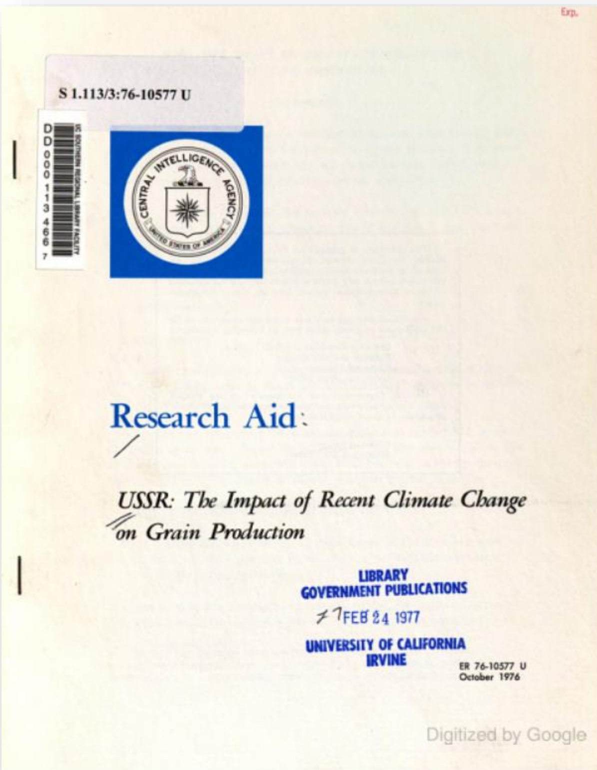
[†] 1932-2010; https://motls.blogspot.com/2011/03/vit-klemes-1932-2010.html

Evolution of the use of the term "climate change"



- The graph shows the evolution of the frequency of appearance of the term "climate change" in the millions of books archived by Google Books. The neutral term "good day" is used as a reference for comparison.
- The term appeared in the 1970s.
- It looks that after 1990 climate change became more important than good day.

The first book with a title containing “climate change”



CIA (1976)

A cold-war report in which climate change is the **cooling** of the Northern Hemisphere since 1940.

Introduction

8. The world's climate and the possible effect of a change in climate on food production is receiving increased attention. In particular, the drought and subsequent famine in the Sahelian zone of North Africa during the late 1960s and early 1970s has focused world attention on the implications of climate change. According to evidence gathered by climatologists, the Northern Hemisphere has been cooling since the mid-1940s. This cooling may have been responsible for the widespread failure during the 1960s of the rain-producing monsoons in the grain-growing regions that lie south of the tropical deserts.

9. In the USSR, a grain crop shortfall in 1972 and subsequent massive imports drew attention to the potentially precarious situation some grain-producing countries in the North Temperate Zone might face because of climate fluctuations. Bounded to the north by cold temperatures and to the south by deserts, the grain-growing region of the USSR has a high potential for disastrous weather should the boundaries of these unfavorable climates shift.

10. Little has been done to evaluate the effect that this climate change has had on food production in the temperate latitudes. This report (1) discusses the nature of climate and climate change, (2) uses detailed meteorological data to measure changes in the climate in the USSR grain belt, and (3) estimates the impact of the climate change on grain production since 1962.

USSR: Average Annual Change in All Grain Production, 1962-74

	Grain Area[1] (Million Hectares)	Average Increase in All Grain Production (Million Metric Tons/Year)	Caused by Climate Change (Million Metric Tons/Year)
Total	**112.0**	**6.84**	**3.50**
Baltics	2.2	0.28	0.05
Belorussia	2.8	0.42	0.01
Ukraine	16.7	1.62	0.94
Moldavia	0.9	0.11	0.03
RSFSR	71.3	3.49	1.71
Kazakhstan	18.1	0.92	0.76

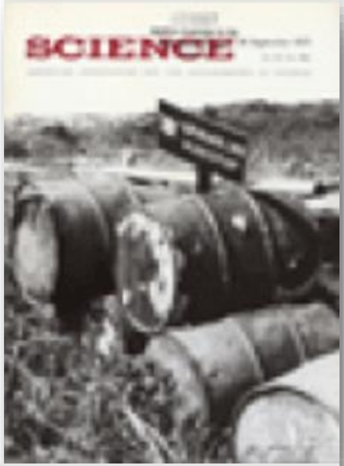
The first appearance of "climate change" in *Science*

Article by Rasool and Schneider (1971) and Comment by Gast (1971).

Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate

Abstract. *Effects on the global temperature of large increases in carbon dioxide and aerosol densities in the atmosphere of Earth have been computed. It is found that, although the addition of carbon dioxide in the atmosphere does increase the surface temperature, the rate of temperature increase diminishes with increasing carbon dioxide in the atmosphere. For aerosols, however, the net effect of increase in density is to reduce the surface temperature of Earth. Because of the exponential dependence of the backscattering, the rate of temperature decrease is augmented with increasing aerosol content. An increase by only a factor of 4 in global aerosol background concentration may be sufficient to reduce the surface temperature by as much as 3.5°K. If sustained over a period of several years, such a temperature decrease over the whole globe is believed to be sufficient to trigger an ice age.*

S. I. RASOOL
S. H. SCHNEIDER
Institute for Space Studies, Goddard Space Flight Center, National Aeronautics and Space Administration, New York 10025



Science
Vol 173, Issue 4001
10 September 1971

Science
Vol 173, Issue 3992
09 July 1971

Climate Change

The report by Rasool and Schneider (9 July, p. 138) presents quantitative relationships between atmospheric carbon dioxide and aerosol concentrations which may be useful. However, two

Inadvertent and purposeful climate change

27 December 1974, Volume 186, Number 4170

SCIENCE

Climate Stabilization: For Better or for Worse?

Even if we could predict the future of our climate, climate control would be a hazardous venture.

W. W. Kellogg and S. H. Schneider

Causes of Climate Change

Given a fixed input such as solar radiation, the system that determines climate, on a regional or global scale,

3) What if we could trace climatic cause and effect linkages? Accusations would abound.

4) What if one nation perceived climatic cause and effect linkages? Could this be used as an excuse for hostility?

fied a complete quantitative description.

flict scenarios. This is the first step. In any case, the object of understanding and anticipating natural, inadvertent, or purposeful climate change and its consequences for society must, in our view, continue to be a major interdisciplinary goal. While it is essential to

Kellogg and Schneider (1974)

Politics and conceit in *Science* in the cradle of climate change agenda.

Climate change and fear

- Stephen H. Schneider, founder and past editor of the journal *Climatic Change* and Coordinating Lead Author of Impacts Assessment Working Group II (WG2) of the Intergovernmental Panel on Climate Change's (IPCC) Third Assessment Report, has stated (Schneider, 1996):

  So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of any doubts we might have. This 'double ethical bind' we frequently find ourselves in cannot be solved by any formula. Each of us has to decide what the right balance is between being effective and being honest.

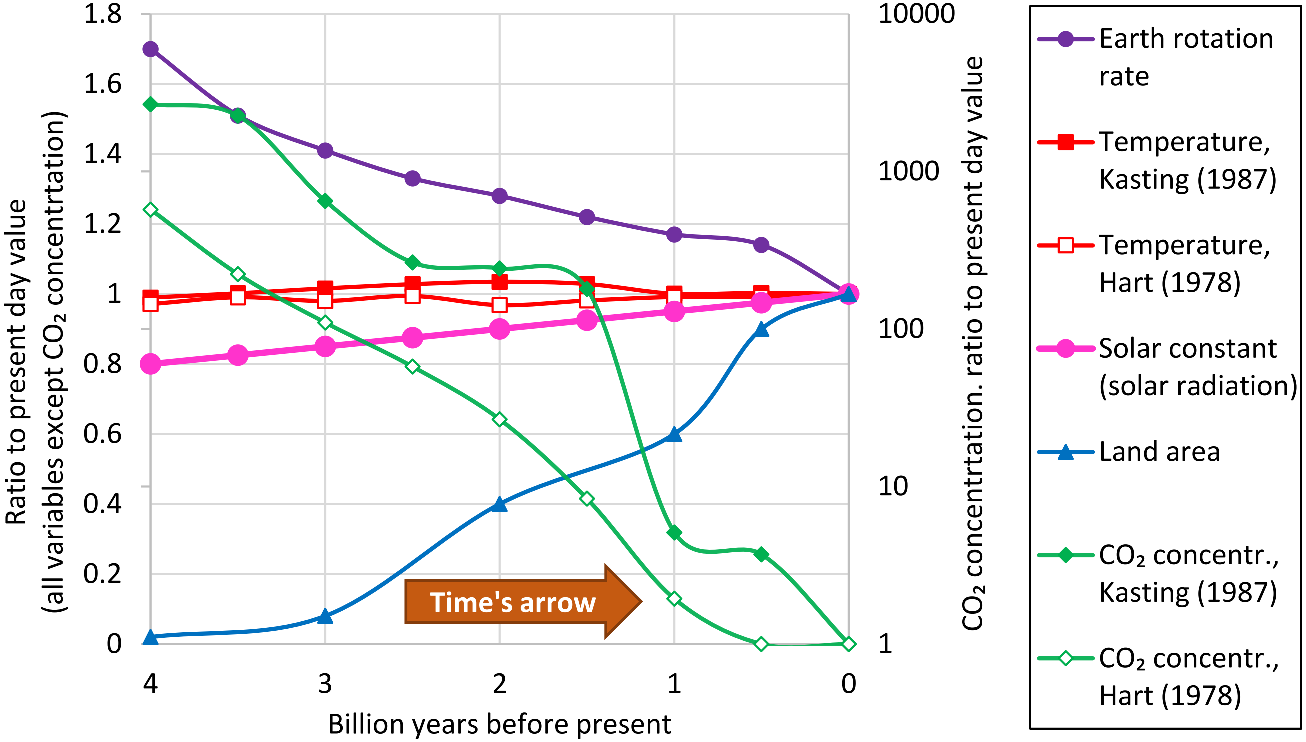
- John Houghton, co-chair of IPCC's Scientific Assessment Working Group (WG1) and lead editor of the first three IPCC reports, in an article with title "*Global warming is now a weapon of mass destruction*" and subtitle "*It kills more people than terrorism, yet Blair and Bush do nothing*" had written (Houghton, 2003):

  As a climate scientist who has worked on this issue for several decades, first as head of the Met Office, and then as co-chair of scientific assessment for the UN intergovernmental panel on climate change, the impacts of global warming are such that I have no hesitation in describing it as a "weapon of mass destruction".

- Sadly, both IPCC leaders and 'Climate Warriors' passed away (rather ingloriously—not killed by that specific *"weapon of mass destruction"*: Schneider died of heart attack on an —allegedly climate-damaging— airplane flight on 19 July 2010 at age 65; Houghton died of Covid-19 on 15 April 2020 at age 88).

Part 3
Climate of the past

"Πάντα ρεῖ"[1] & "Μεταβάλλει τῷ χρόνῳ πάντα"[2] Changes on Earth since the appearance of earliest life, 4 billion years ago



The graph has been constructed from estimates by Kuhn et al. (1989). Temperature is expressed in K and corresponds to 35° latitude; a change in the temperature ratio by 0.01 corresponds to ~2.9 K.

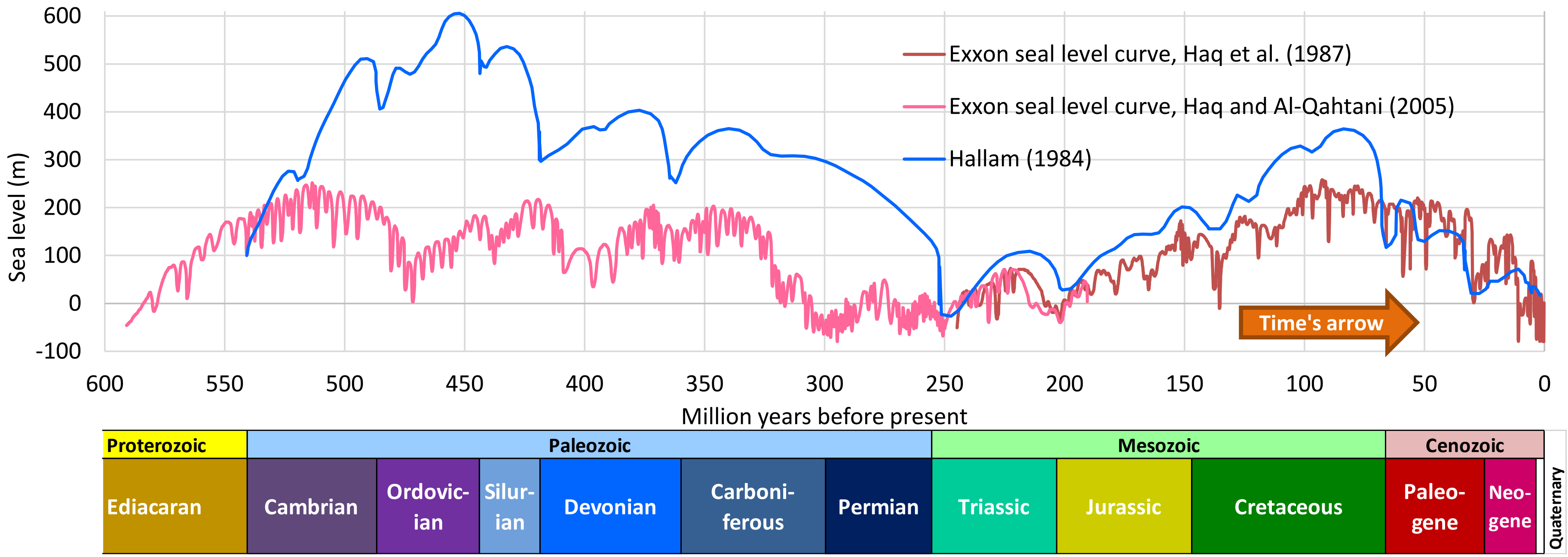
Although the estimates are dated and uncertain, evidence shows existence of liquid water on Earth even in the early period, when the solar activity was smaller by 20-25%. This is known as the faint young Sun problem (Feulner, 2012).

______

[1] "Everything flows" Heraclitus, quoted in Plato's Cratylus, 339-340

[2] "Everything changes in course of time", Aristotle, *Meteorologica*, I.14, 353a 16

Sea level during the Phanerozoic



Phanerozoic = Paleozoic + Mesozoic + Cenozoic. High sea level suggests high temperature.

Digitized data sources:

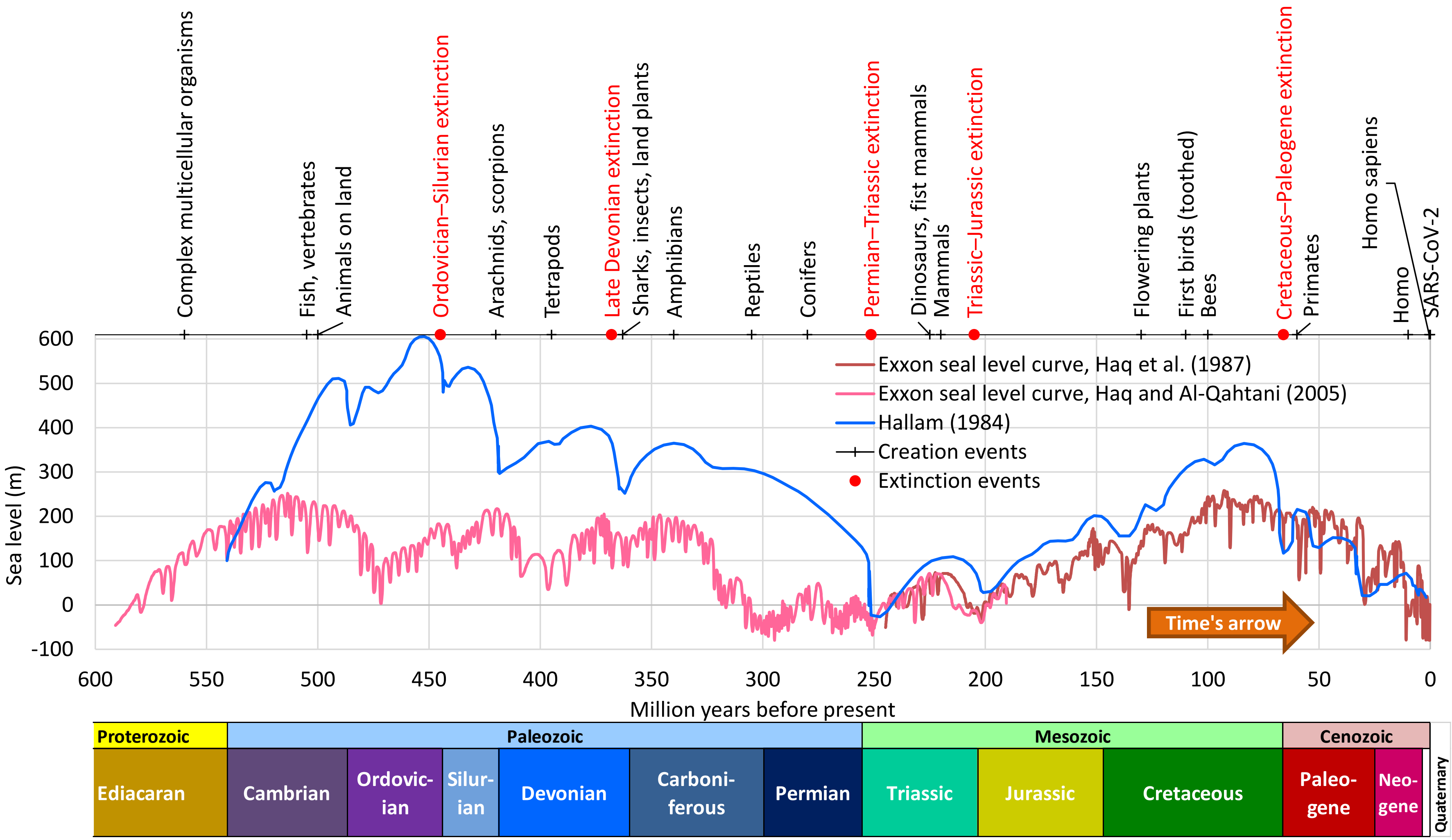
For Haq et al. (1987): https://figshare.com/articles/Haq_sea_level_curve/1005016.

For Haq and Al-Qahtani (2005):
https://web.archive.org/web/20080720140054/http://hydro.geosc.psu.edu/Sed_html/exxon.sea;
Note though that it has discrepancies from the graph in Miller et al. (2005).

For Hallam (1984) data were digitized in this study using chronologies of geologic eras from the International Commission on Stratigraphy, https://stratigraphy.org/chart.

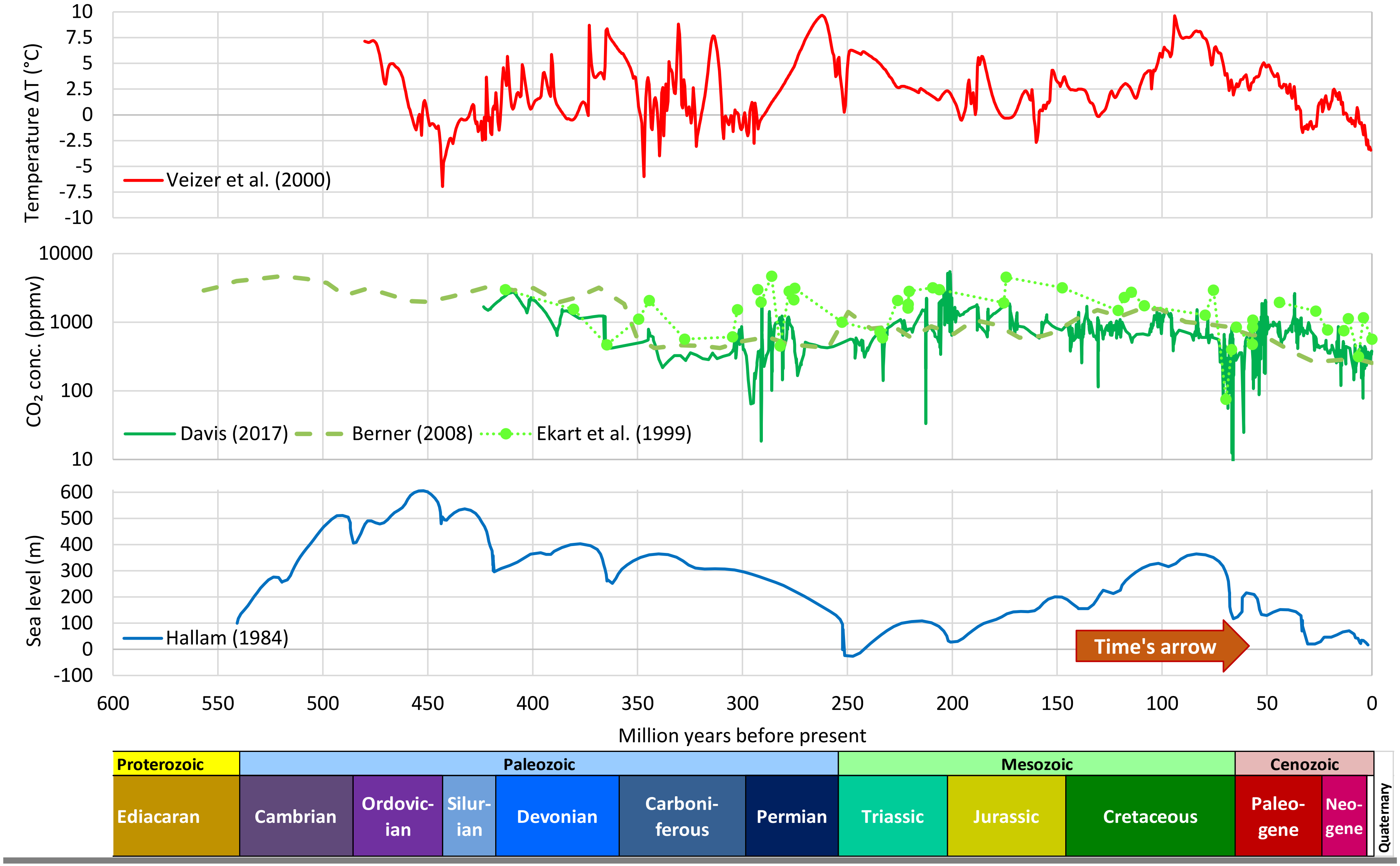
For other reconstructions see van der Meer (2017).

Life evolution and sea level during the Phanerozoic



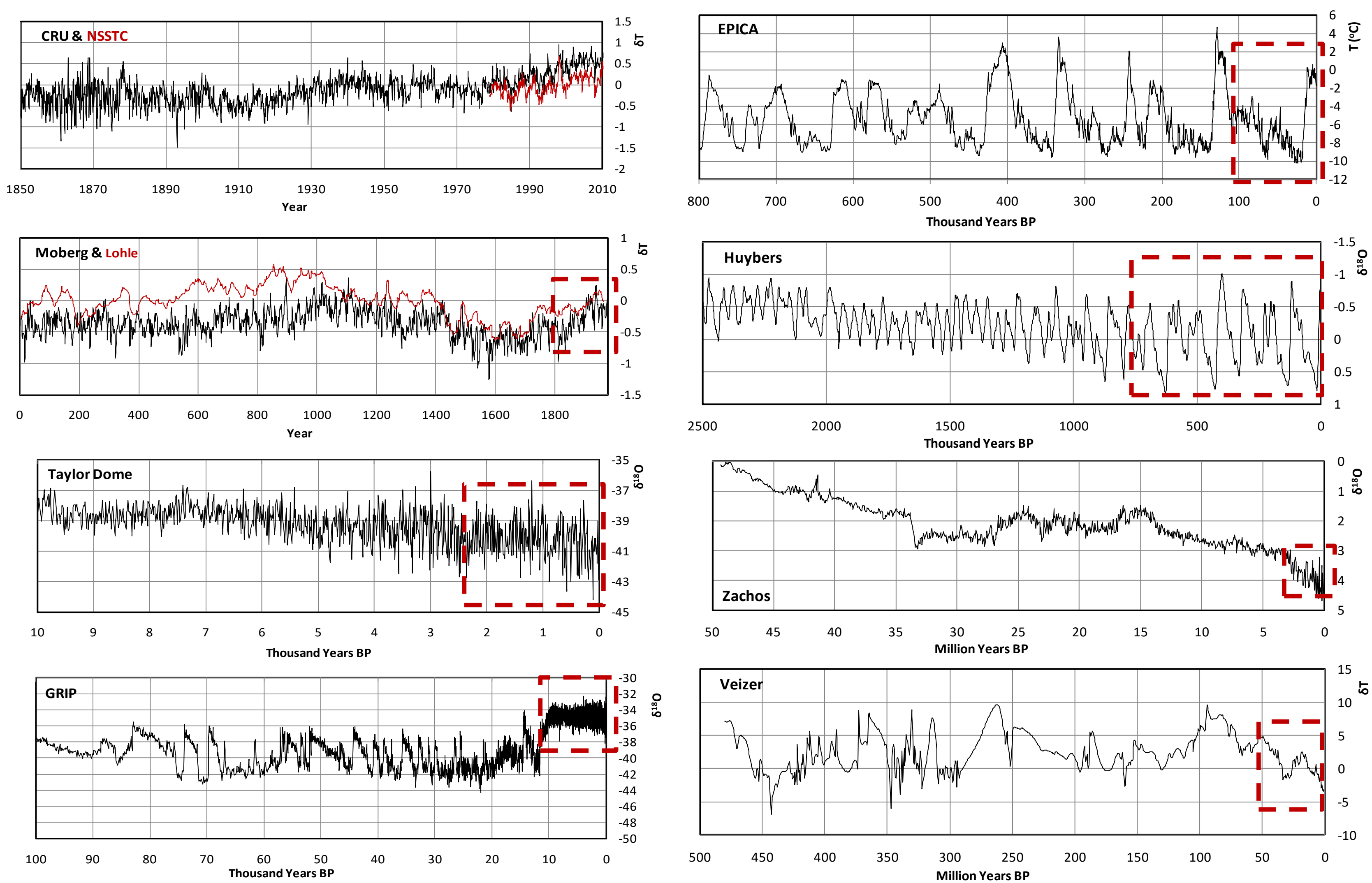
- Q: When did extinction happen? On temperature rise or fall?

Co-evolution of temperature, CO_2 concentration and sea level in the Phanerozoic

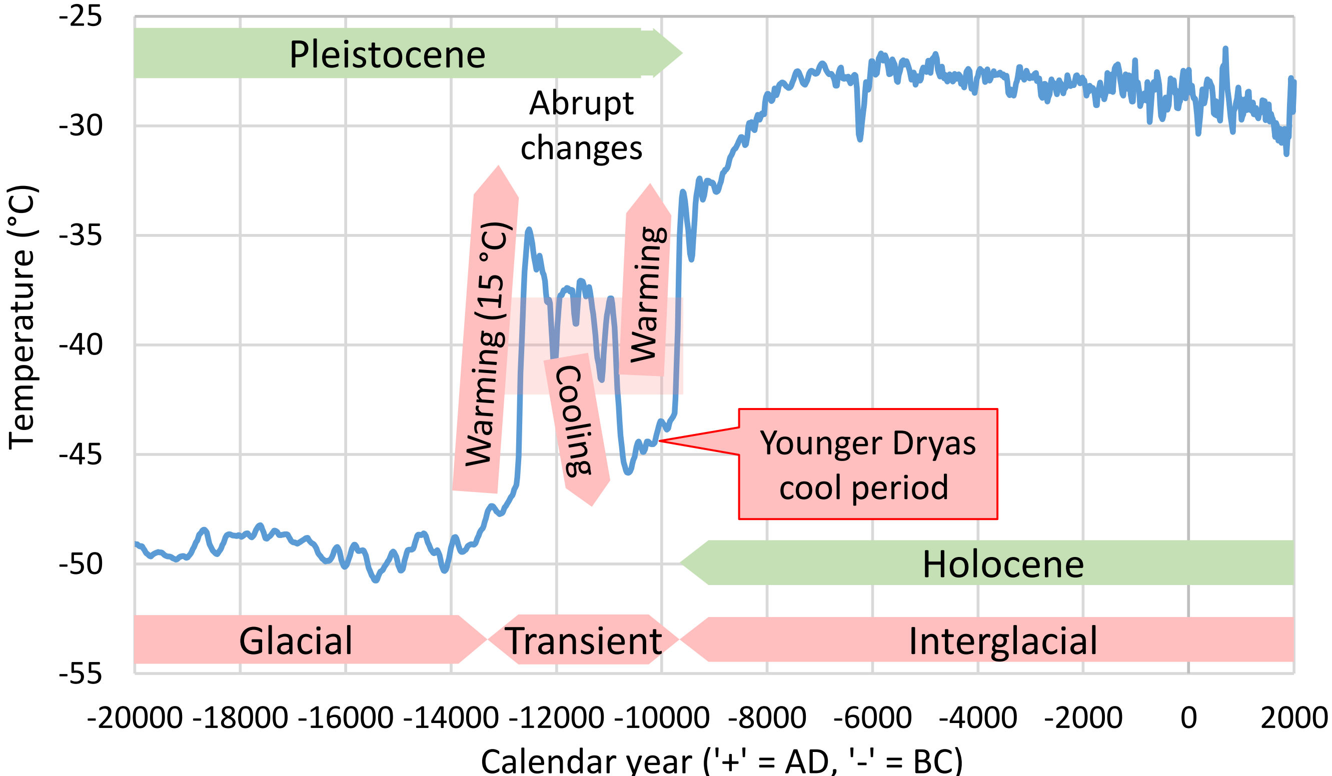


Temperature change in different time windows from observations and proxies

Markonis and Koutsoyiannis (2013)



Focus on the last deglaciation: temperature



Experimental drilling on the Greenland Ice Cap in 2005, https://earthobservatory.nasa.gov/features/Paleoclimatology_IceCores

Noticeable facts:

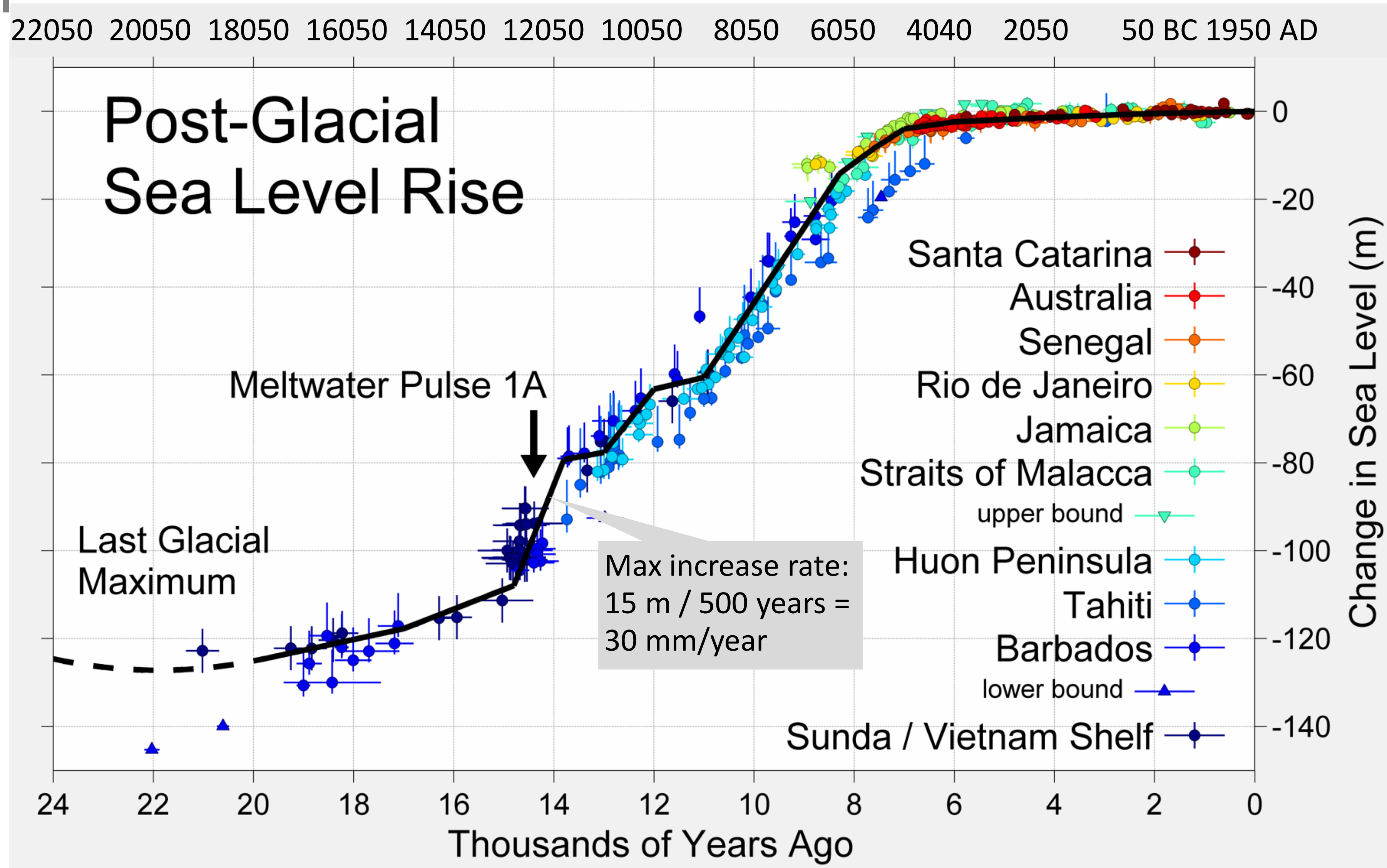
(1) The difference of the interglacial from glacial temperature is > 20 °C.

(2) In periods of temperature increase, the maximum rate of change has been 8.5 °C/century.

(3) In periods of decrease, the maximum rate has been -4.3 °C/century.

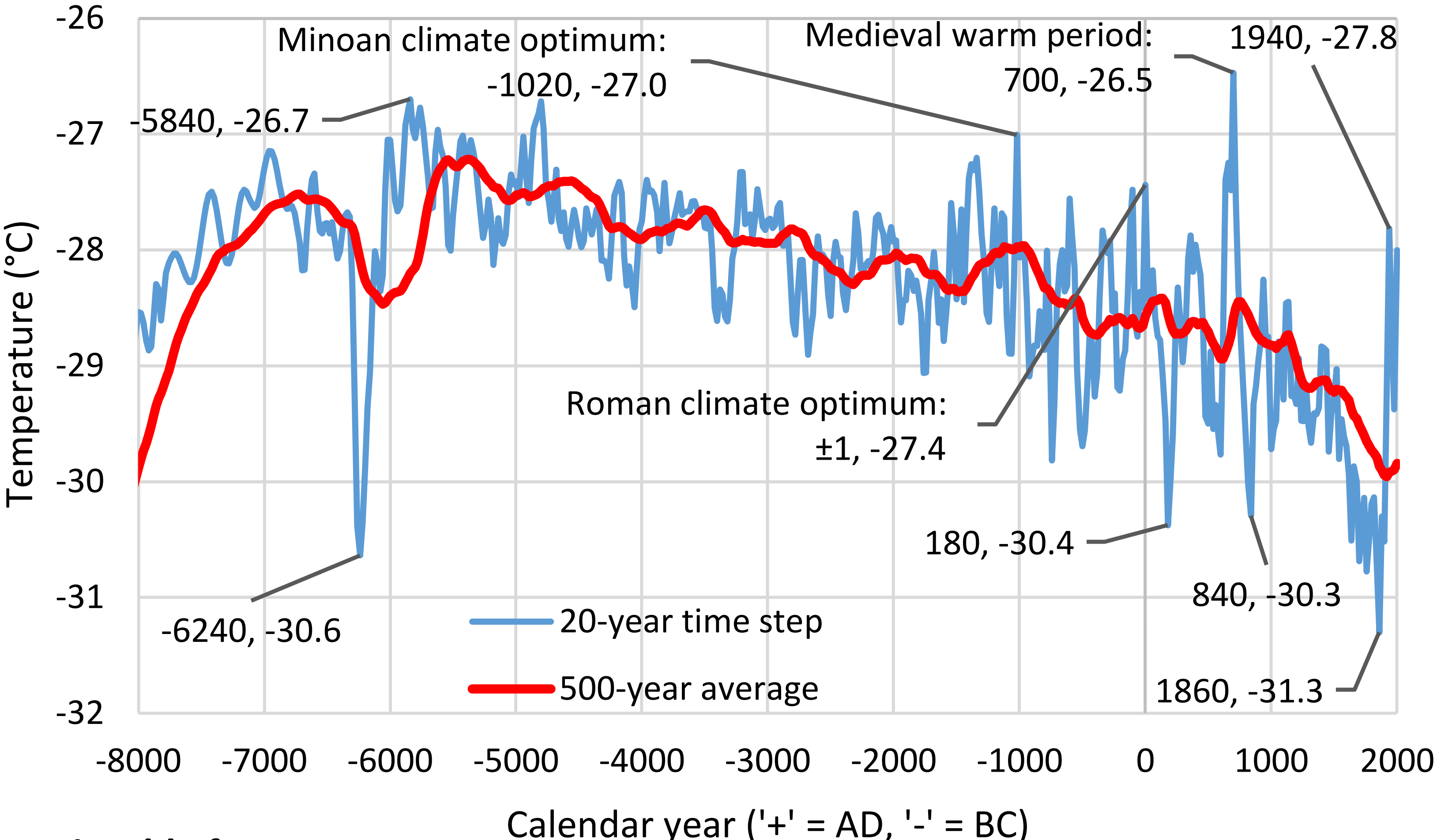
Data: Temperature reconstruction from Greenland ice cores; averages from GISP2, NGRIP and NEEM Ice Drilling locations as given by Buizert et al. (2018) for a 20-year time step (available from https://www.ncdc.noaa.gov/paleo-search/study/23430).

Focus on the last deglaciation: sea level



Source: https://commons.wikimedia.org/wiki/File:Post-Glacial_Sea_Level.png

Focus on the last 10 thousand years: temperature

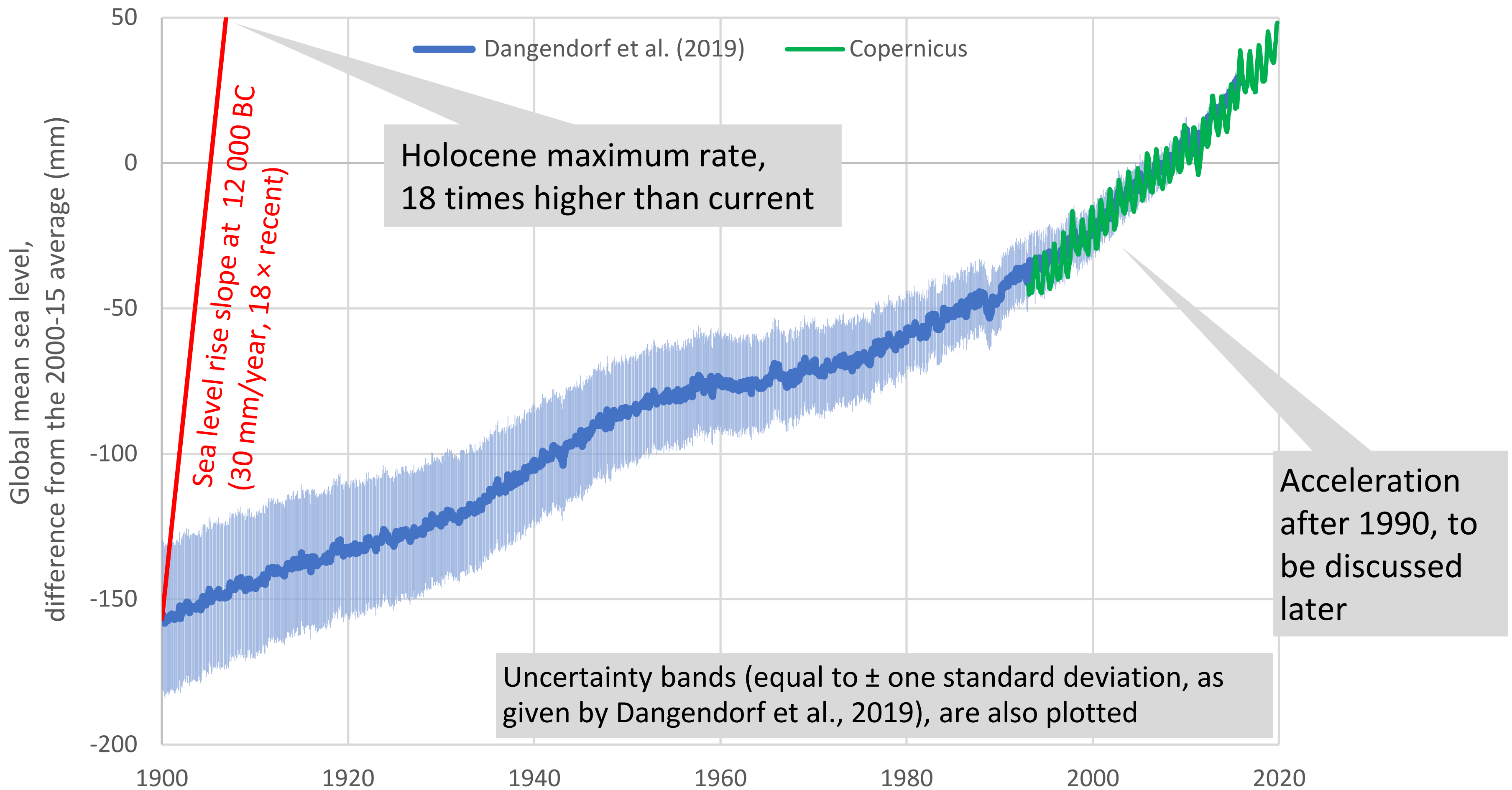


Noticeable facts:
(1) 1940 was warmer than present. (2) The warmest period was around 700 AD. (3) There has been a dominant cooling trend for more than 7000 years.

Data: Greenland ice cores as in a previous slide.

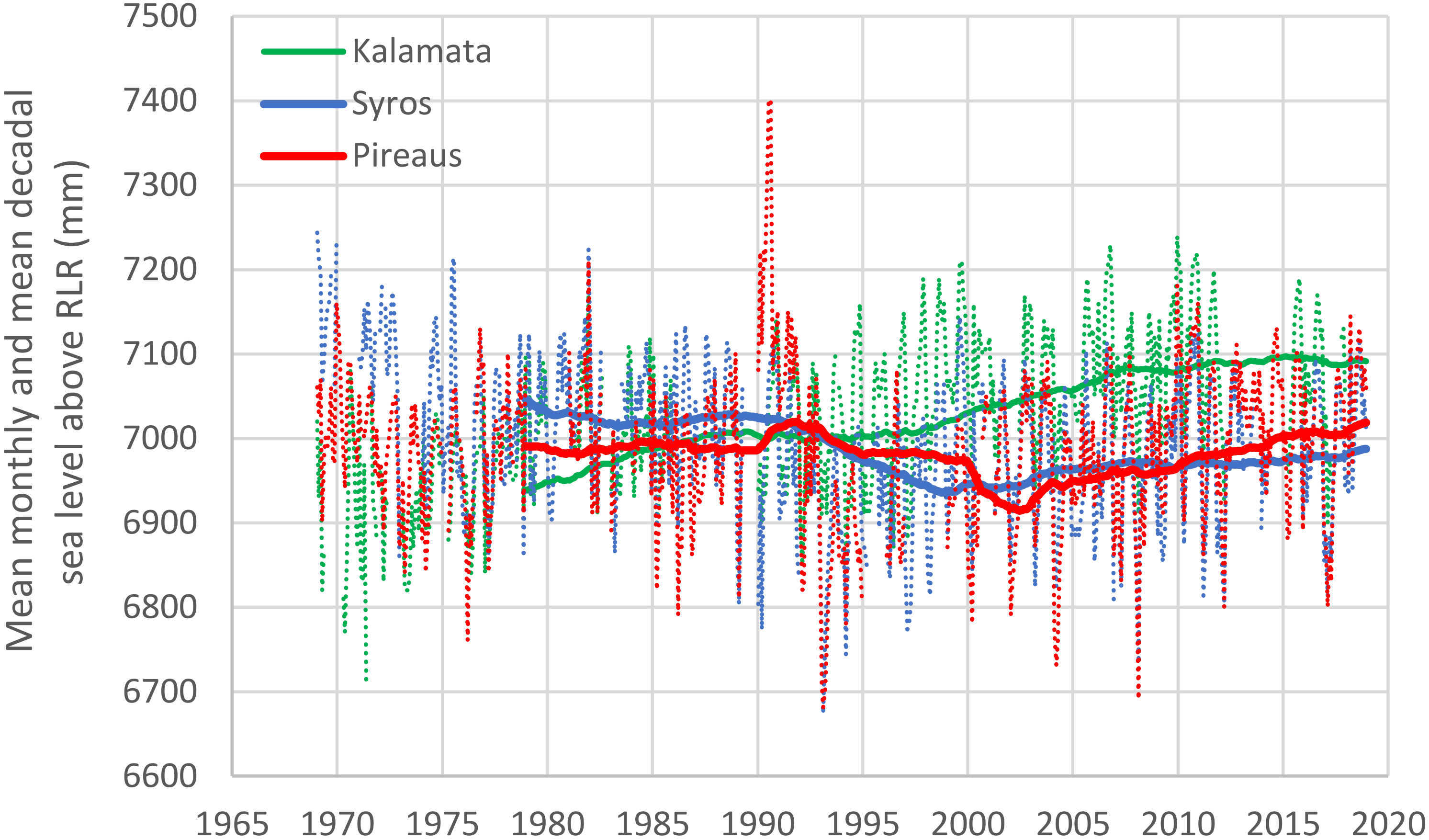
Part 4
Climate of the present

Recent global sea-level rise



Data:
(1) Dangendorf et al (2019): Synthesis of satellite altimetry with 479 tide-gauge records (https://static-content.springer.com/esm/art%3A10.1038%2Fs41558-019-0531-8/MediaObjects/41558_2019_531_MOESM2_ESM.txt)
(2) Copernicus: satellite altimetry for the global ocean from 1993 to present (http://climexp.climexp-knmi.surf-hosted.nl/getindices.cgi?WMO=CDSData/global_copernicus_sla&STATION=global_sla_C3S&TYPE=i&id=someone@somewhere)

Recent sea-level record in Greece



Dashed thin lines: monthly values

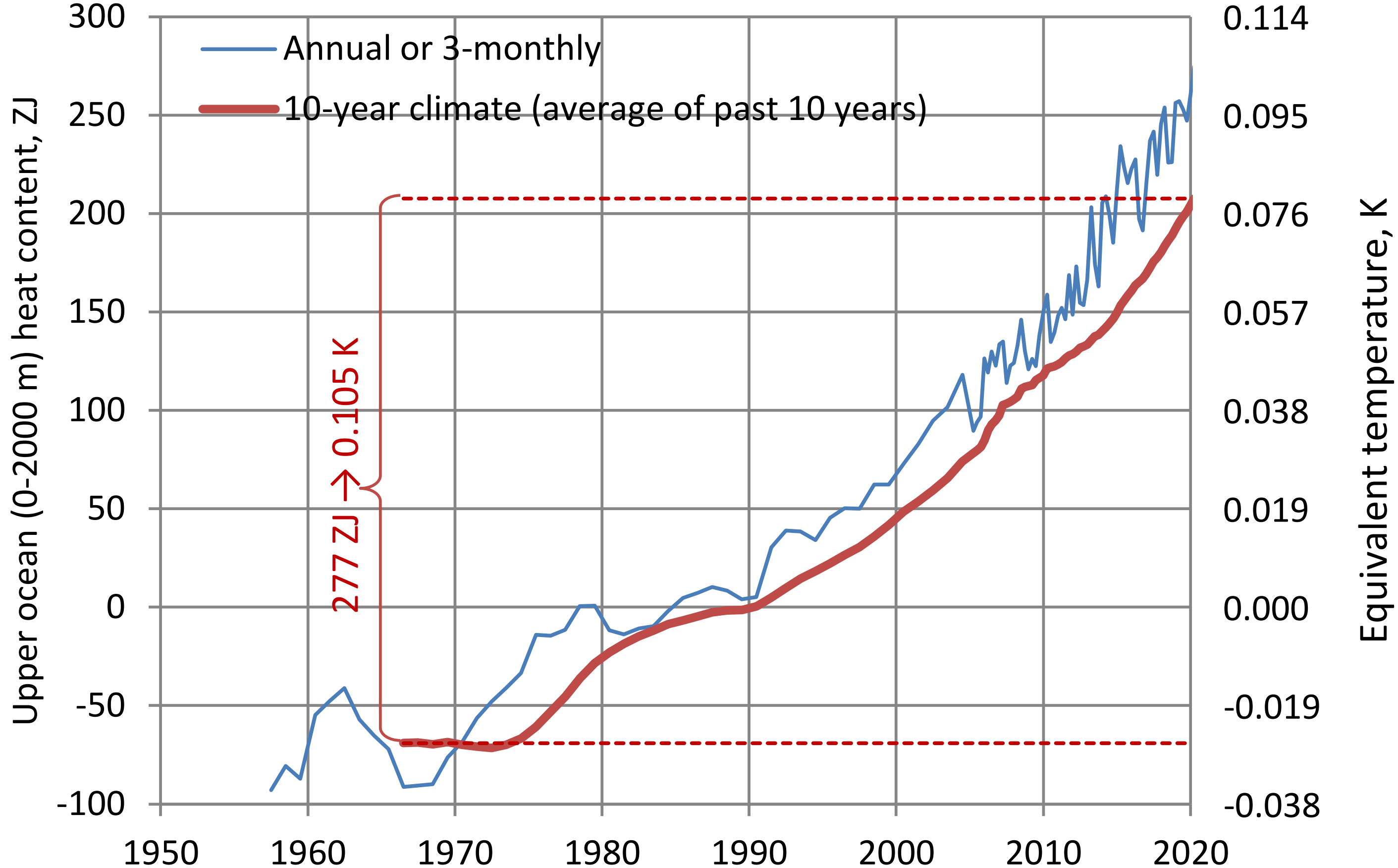
Continuous thick lines of same colour: 10-year running averages (right aligned)

Note: RLR stands for Revised Local Reference and is a datum at each station defined to be approximately 7000 mm below mean sea level, with this arbitrary choice made to avoid negative numbers in the resulting values.

Noticeable fact: Fluctuation – no monotonic trend (rise or fall).

Tide-gauge observational data: Holgate et al. (2013) through the Permanent Service for Mean Sea Level (PSMSL) (http://www.psmsl.org/data/obtaining/). Stations are maintained by the Greek Hydrographic Service.

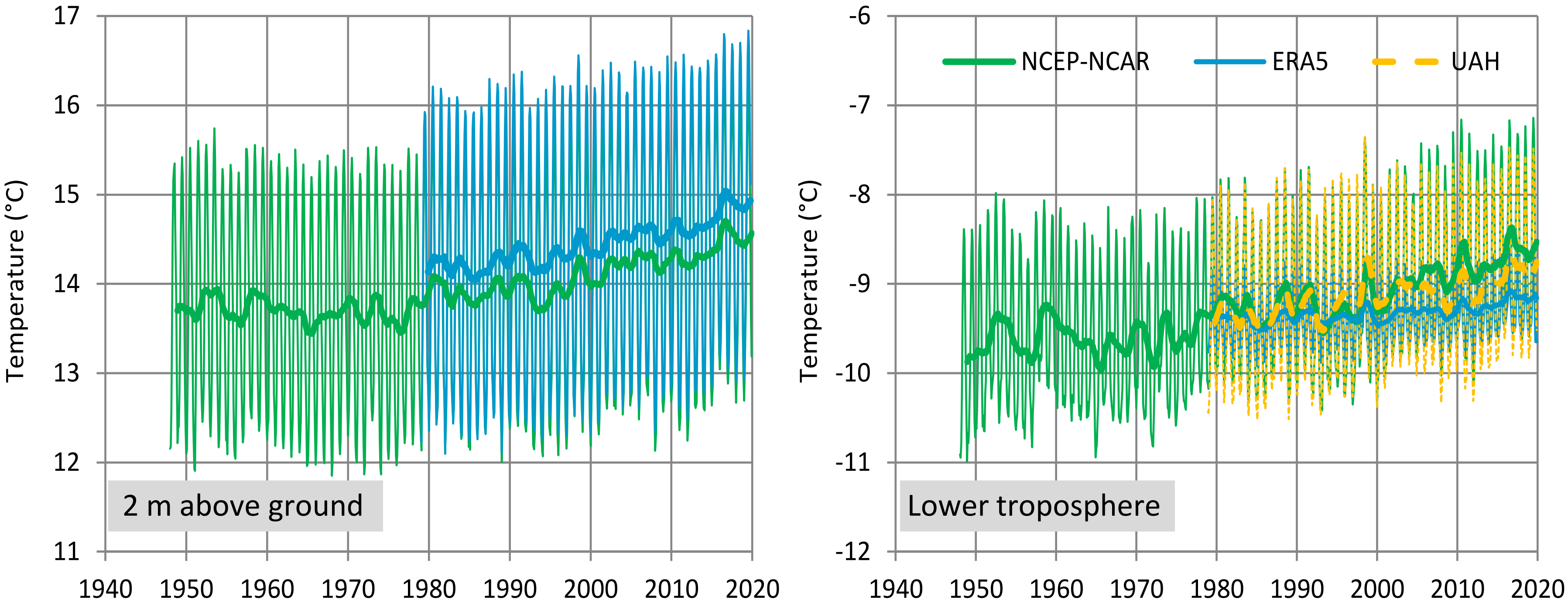
Ocean heat content



Noticeable fact: During the 54-year period 1966 -2020 the upper ocean heat content has increased by 277 ZJ, averaged globally at a 10-year climatic scale; this corresponds to a temperature increase of 0.105 K (average rate <2 hundredths of a °C per decade).

Data: NODC upper ocean (0-2000 m) heat content (from https://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/basin_data.html; conversion into equivalent temperature using data from http://climexp.knmi.nl/selectindex.cgi resulting in a conversion factor of 2640 ZJ/K).

Atmospheric temperature averaged over the globe



Noticeable fact: During the recent years, climatic temperature increases at a rate of:

- 0.19 °C/decade at the ground level, or
- 0.13 °C/decade at the lower troposphere.

Compare with the rate 0.85 °C/decade in the distant past.

Source of graph: Koutsoyiannis (2020); data: (1) NCEP/NCAR R1 reanalysis; (2) ERA5 reanalysis by ECMWF; and (3) UAH satellite data for the lower troposphere gathered by advanced microwave sounding units on NOAA and NASA satellites (see Koutsoyiannis, 2020 for the data access sites).

Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Part 5
Basics of climate theory and the spring of change

Dominant theory: CO_2 and Svante Arrhenius

continuously. Conversations with my friend and colleague Professor Högbom, together with the discussions above referred to, led me to make a preliminary estimate of the probable effect of a variation of the atmospheric carbonic acid on the temperature of the earth. As this estimation led to the belief that one might in this way probably find an explanation for temperature variations of 5°–10° C., I worked out the calculation more in detail, and lay it now before the public and the critics.

Arrhenius (1896)

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

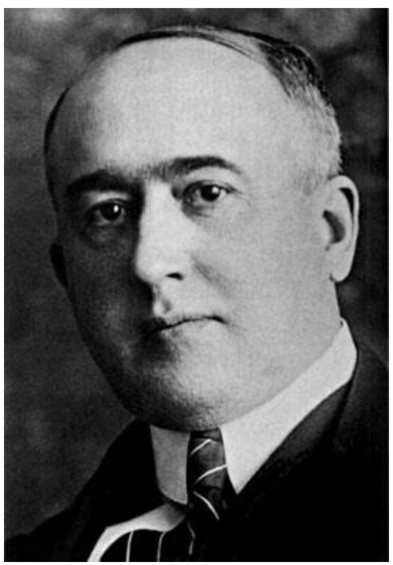
APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

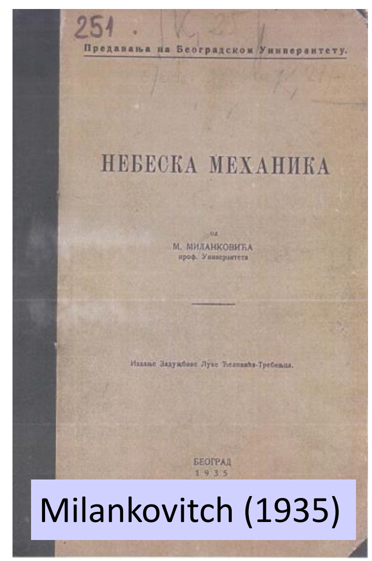
- Arrhenius regards CO_2 (which he calls carbonic acid) as the cause of temperature changes of the past.
- In his calculations, he underestimates by a factor of 7 the relative importance of atmospheric water (in fact, 4 times stronger than CO_2 in greenhouse effect).
- Following the Italian meteorologist De Marchi (1895), he rejects the orbital changes of the Earth as possible causes of the glacial periods.
- He does not explain what causes the changes in the CO_2 concentration in the atmosphere.

Astronomical theory and Milutin Milankovitch

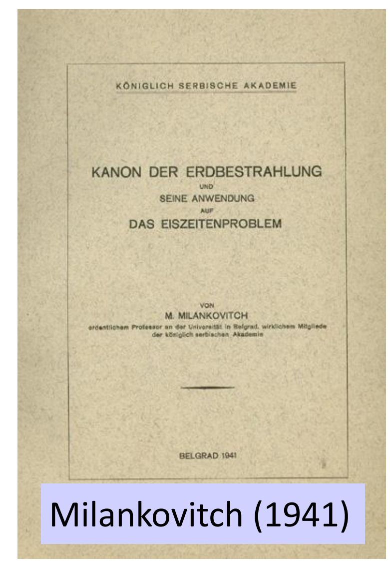
- Milutin Milankovitch (Милутин Миланковић; 1879 – 1958) was a Serbian civil engineer (by basic studies and PhD, as well as work in the design of dams, bridges, aqueducts and other reinforced concrete structures). He is also known as mathematician, astronomer, climatologist and geophysicist.
- He characterized the climates of all the planets of the Solar system.
- He provided an astronomical explanation of Earth's long-term climate changes caused by Earth’s orbital changes.
- He proposed the Milankovitch calendar (revising the Julian calendar) in 1923, which in May 1923 was adopted by a congress of some Eastern Orthodox churches, including the Ecumenic Patriarchate of Constantinople and the Greek church. It is more accurate than the Gregorian (but the difference is small, now 0 to become +1 day in 2800).



Years AD (dates from 1 Mar to 28/29 Feb)	Milankovitch – Gregorian
1 –200	0
…	
1500 – 1600	−1
1600 – 2800	0
2800 – 2900	+1
…	
10 000 – 10 100	+3

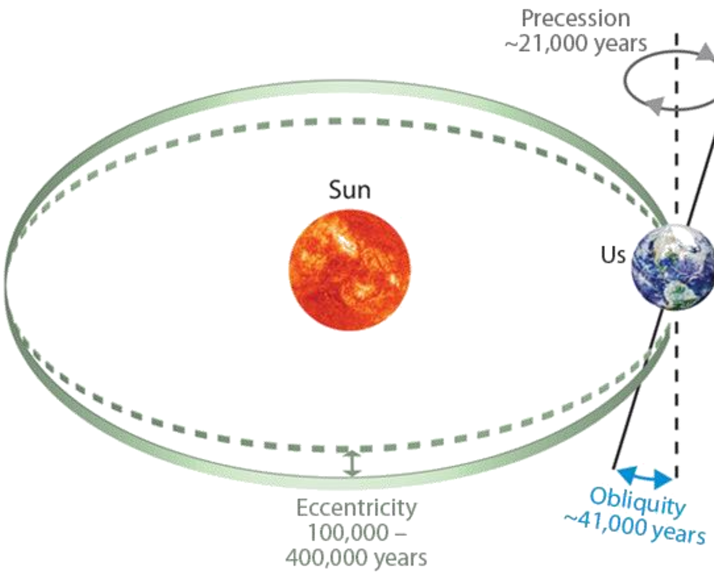


Milankovitch (1935)



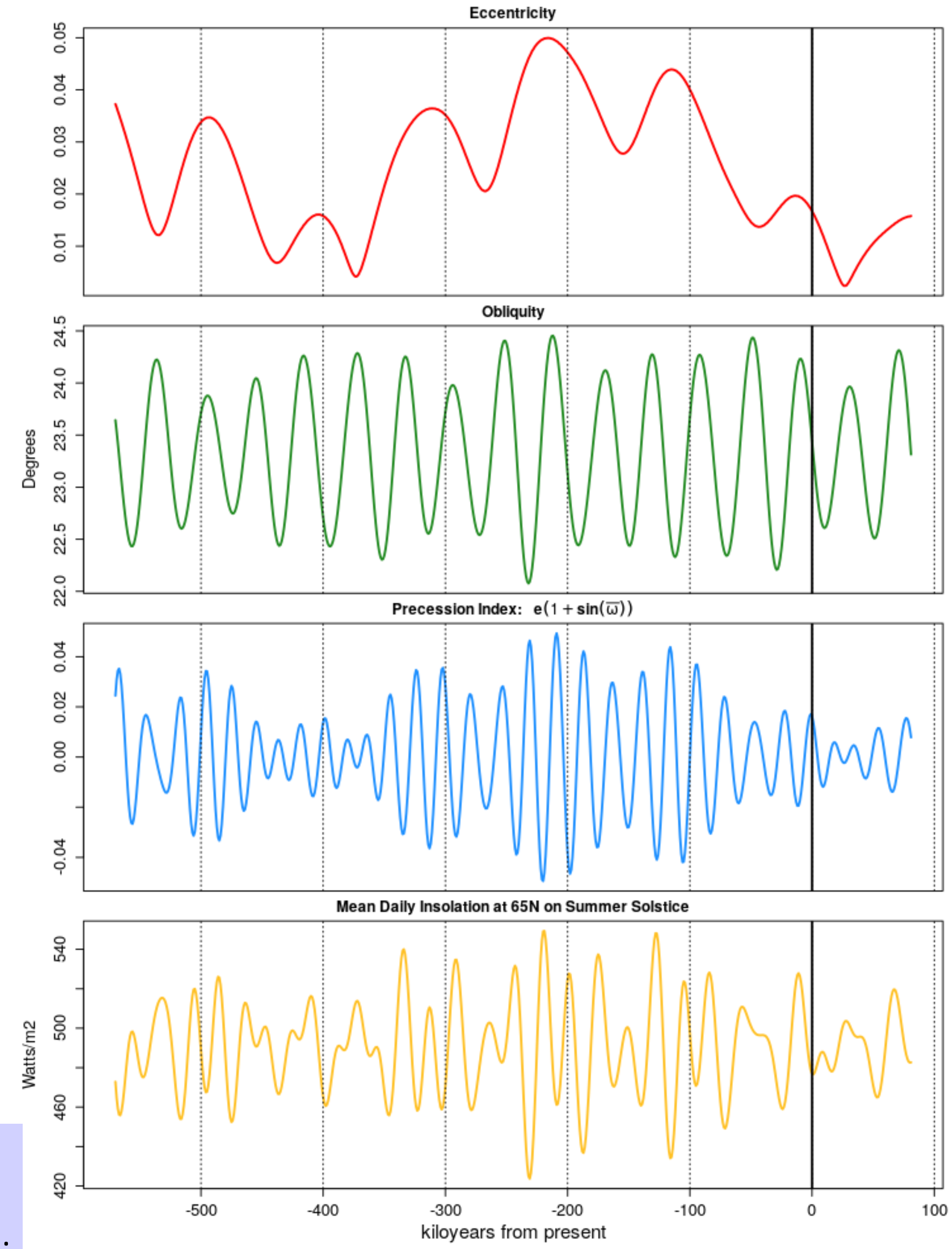
Milankovitch (1941)

Milankovitch cycles



- Astronomical changes (already known):
  - Eccentricity (ἐκκεντρότης);
  - Obliquity (λόξωσις);
  - Precession (μετάπτωσις, first calculated by Hipparchus);
- Milankovitch calculated the insolation at latitude 65°N, which he regarded most sensitive to the change of thermal balance of Earth.

Source of figures and calculations: https://biocycle.atmos.colostate.edu/shiny/Milankovitch/ based on the solutions of equations by Laskar et al. (2004).



Recent confirmation of Milankovitch theory

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L24703, doi:10.1

Click Here for Full Article

Roe (2006)

In defense of Milankovitch

Gerard Roe[1]

Received 9 August 2006; accepted 3 November 2006; published 21 December 2006.

[1] The Milankovitch hypothesis is widely held to be one of the cornerstones of climate science. Surprisingly, the hypothesis remains not clearly defined despite an extensive body of research on the link between global ice volume and spheric CO_2 and tr important role in *Lea*, 2004], (2) c changes relative to

- Roe (2006) confirmed Milankovitch' theory by comparing the insolation at latitude 65°N with changes of global ice volume ($\mathrm{d}V/\mathrm{d}t$).
- He also observed that variations in ice melting precede variations in atmospheric CO_2, which implies a secondary role for CO_2.
- However, Milankovitch theory does not explain every change, thus highlighting the need for a stochastic theory.

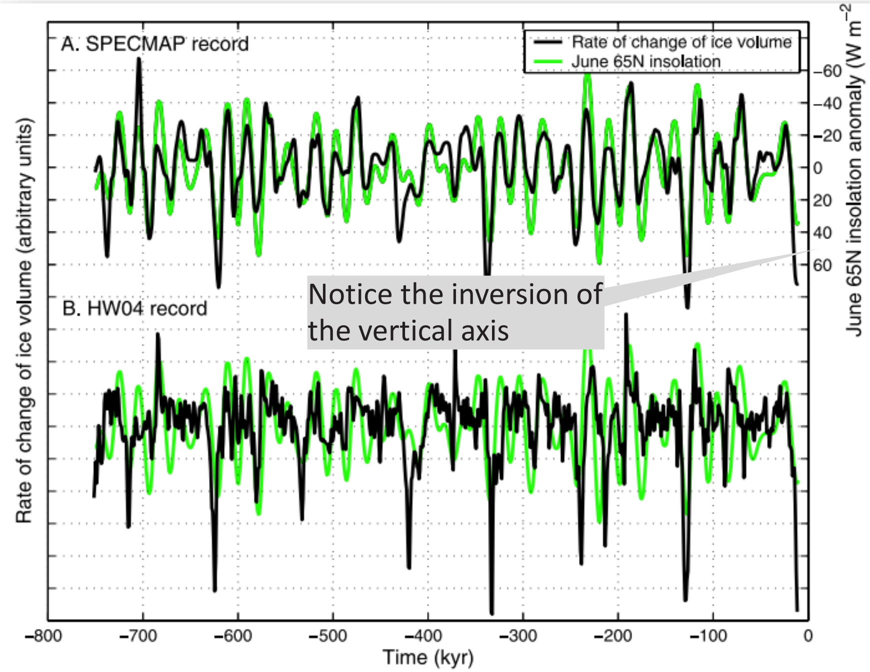
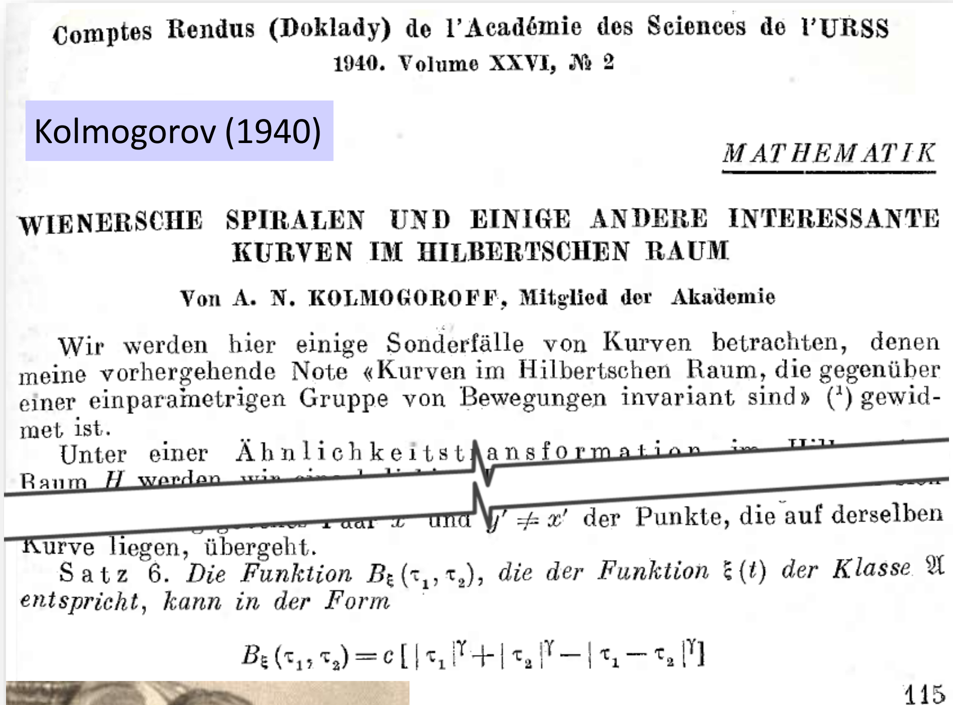


Figure 2. As for Figure 1, but comparing June 65N insolation anomaly with the time rate of change of global ice volume (dV/dt). The SPECMAP record has zero lag and HW04 record is lagged by only 1 kyr, in order to show the maximum lag correlation with the insolation time series of −0.8 and −0.4, respectively. Autocorrelation estimates suggest that the SPECMAP and HW04 time series of dV/dt have 106 and 123 degrees of freedom respectively. Therefore, in both cases the correlations are significant at well above the 99% confidence level. If the HW04 record is smoothed in the same manner as SPECMAP (using a nine-point Gaussian filter [*Imbrie et al.*, 1984]), the maximum lag correlation does not increase. Convention for units is as for Figure 1.

Climate stochastics: Kolmogorov, Hurst and the Nile



Comptes Rendus (Doklady) de l'Académie des Sciences de l'URSS
1940. Volume XXVI, № 2

Kolmogorov (1940)

MATHEMATIK

WIENERSCHE SPIRALEN UND EINIGE ANDERE INTERESSANTE KURVEN IM HILBERTSCHEN RAUM

Von A. N. KOLMOGOROFF, Mitglied der Akademie

Wir werden hier einige Sonderfälle von Kurven betrachten, denen meine vorhergehende Note «Kurven im Hilbertschen Raum, die gegenüber einer einparametrigen Gruppe von Bewegungen invariant sind» (1) gewidmet ist.

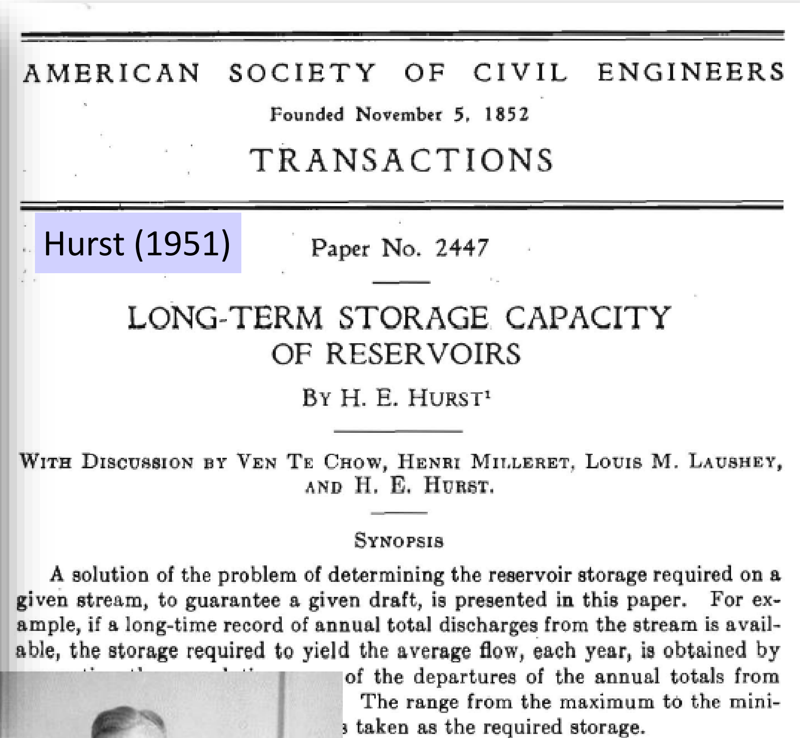
Unter einer Ähnlichkeitstransformation ...
Raum H werden ...

... und $y' \neq x'$ der Punkte, die auf derselben Kurve liegen, übergeht.

Satz 6. *Die Funktion* $B_\xi(\tau_1, \tau_2)$, *die der Funktion* $\xi(t)$ *der Klasse* $\mathfrak{A}$ *entspricht, kann in der Form*

$$B_\xi(\tau_1, \tau_2) = c\,[\,|\tau_1|^\gamma + |\tau_2|^\gamma - |\tau_1 - \tau_2|^\gamma\,]$$

115



AMERICAN SOCIETY OF CIVIL ENGINEERS
Founded November 5, 1852
TRANSACTIONS

Hurst (1951)

Paper No. 2447

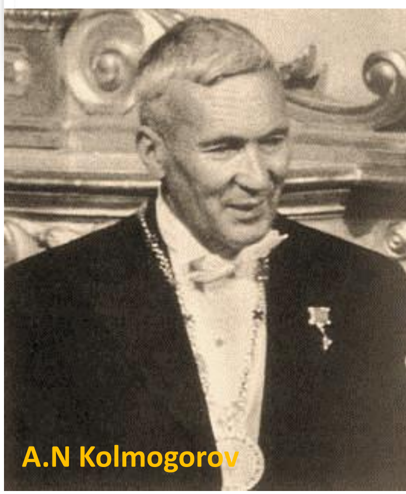
LONG-TERM STORAGE CAPACITY OF RESERVOIRS

By H. E. Hurst[1]

With Discussion by Ven Te Chow, Henri Milleret, Louis M. Laushey, and H. E. Hurst.

Synopsis

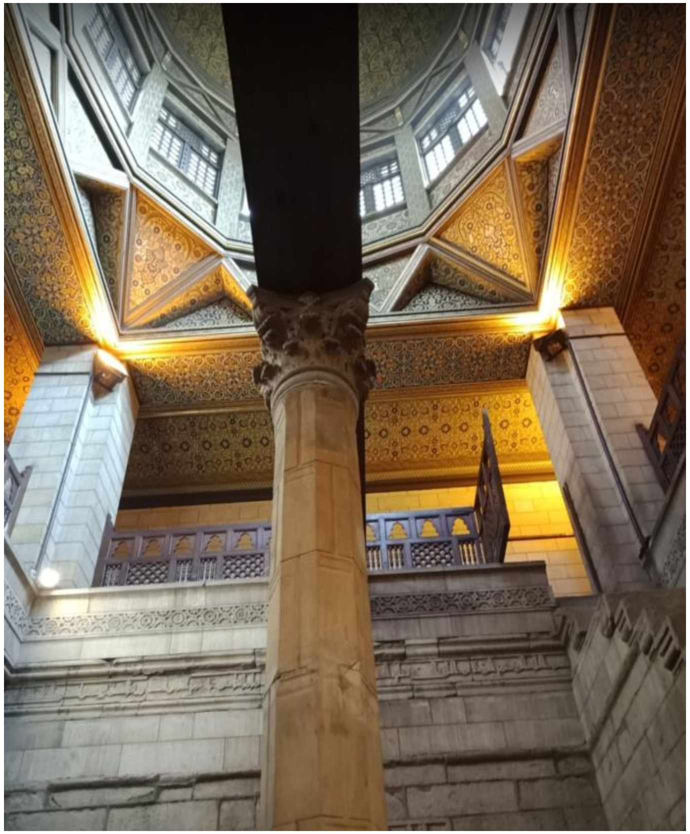
A solution of the problem of determining the reservoir storage required on a given stream, to guarantee a given draft, is presented in this paper. For example, if a long-time record of annual total discharges from the stream is available, the storage required to yield the average flow, each year, is obtained by ... of the departures of the annual totals from ... The range from the maximum to the mini- ... taken as the required storage.

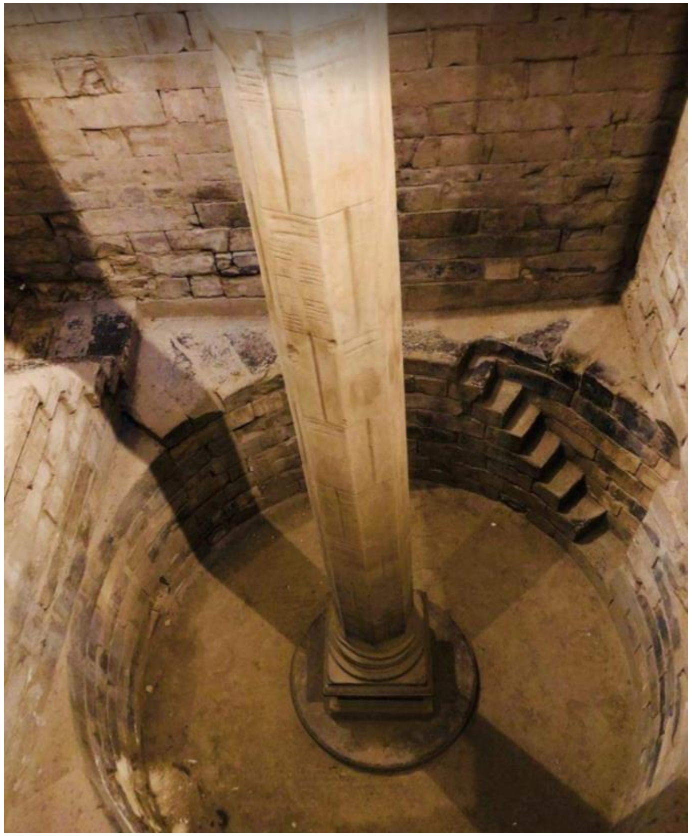


Kolmogorov proposed a stochastic process that describes a behaviour unknown at that time. It was discovered a decade later in geophysics by Hurst.

"Although in random events groups of high or low values do occur, their tendency to occur in natural events is greater. This is the main difference between natural and random events."

The Roda Nilometer and the longest instrumental record on Earth



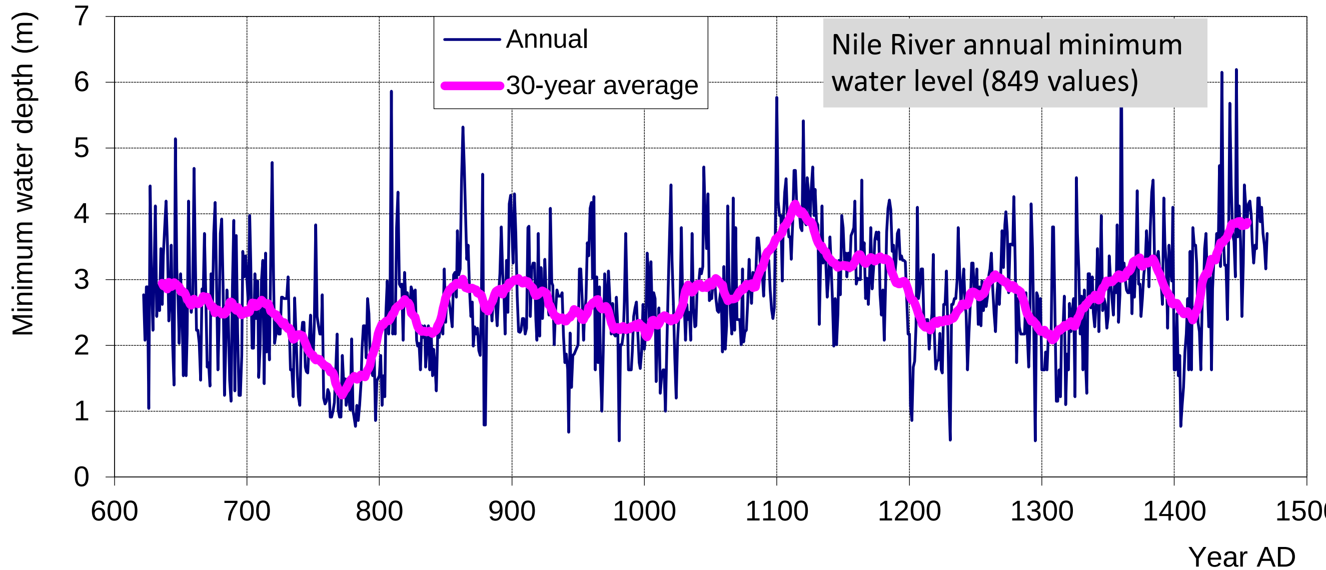


Photos by Loai Samen and Mohamd Mubarak; Google maps, https://goo.gl/maps/T8NUgoDAorK2 and https://goo.gl/maps/dsdJHJYVv572.

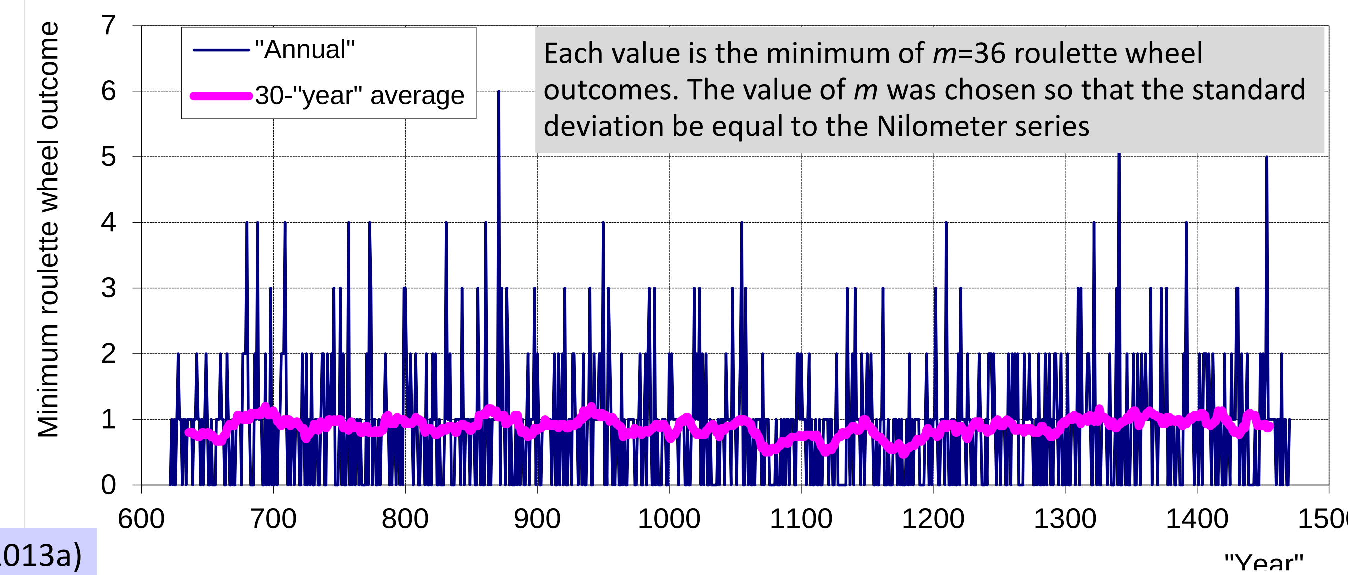
The Roda Nilometer, near Cairo. Water entered through three tunnels and filled the Nilometer chamber up to river level. The measurements were taken on the marble octagonal column (with a Corinthian crown) standing in the centre of the chamber; the column is graded and divided into 19 cubits (each slightly more than 0.5 m) and could measure floods up to about 9.2 m. A maximum level below the 16th mark could portend drought and famine and a level above the 19th mark meant catastrophic flood.

Hurst-Kolmogorov (HK) dynamics and the perpetual change of Earth's climate

A hydroclimatic process as seen in the longest instrumental record



A "roulette" process



Nilometer data: Koutsoyiannis (2013a)

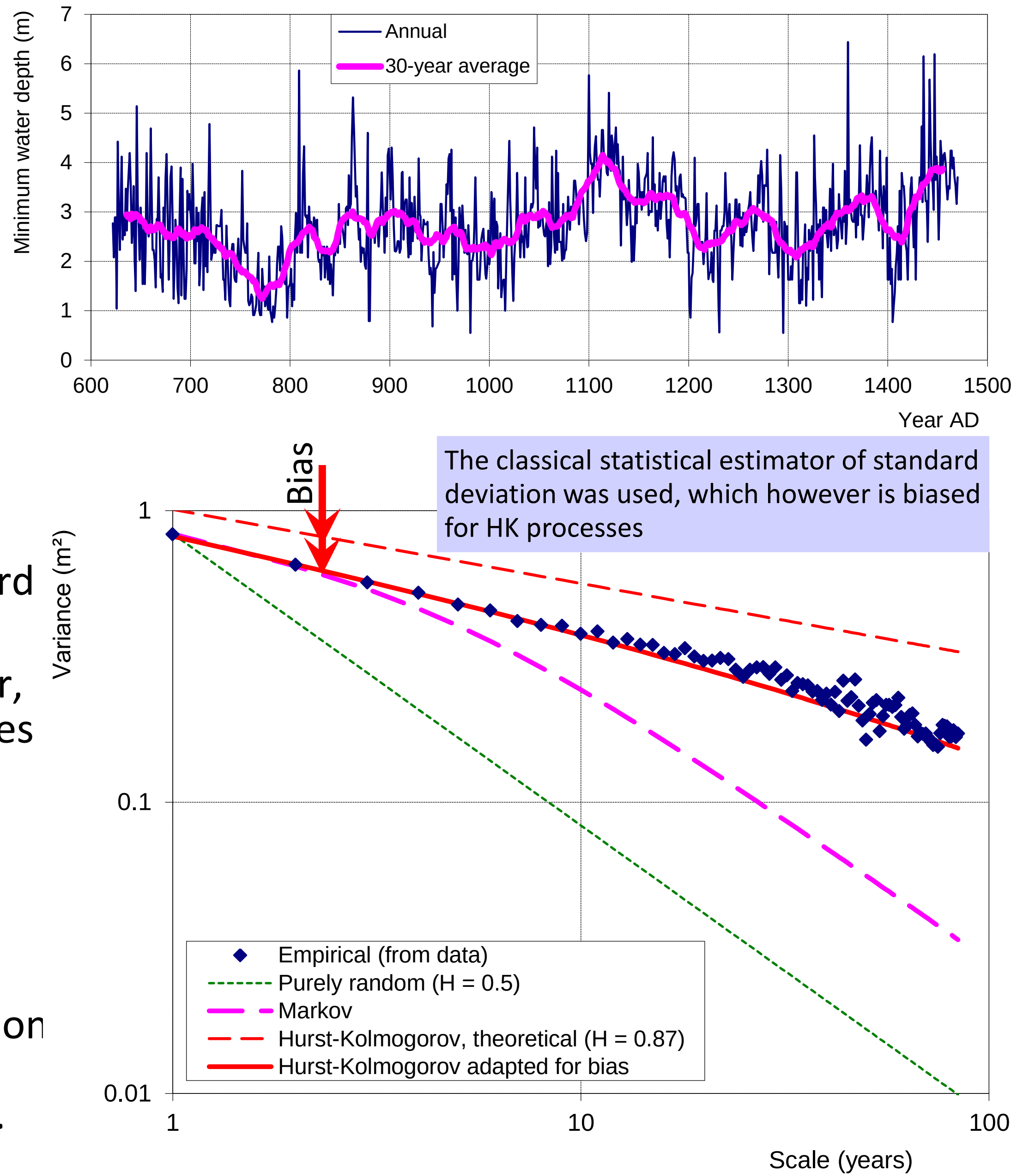
The climacogram: A simple statistical tool to quantify change across time scales

- Take the Nilometer time series, $x_1, x_2, \ldots, x_{849}$, and calculate the sample estimate of variance $\gamma(1)$, where the superscript (1) indicates time scale (1 year).
- Form a time series at time scale 2 (years):
  $x_1^{(2)} := (x_1 + x_2)/2, x_2^{(2)} := (x_3 + x_4)/2, \ldots, x_{424}^{(2)} := (x_{847} + x_{848})/2$
  and calculate the sample estimate of the variance $\gamma(2)$.
- Repeat the same procedure and form a time series at time scale 3, 4, … (years), up to scale 84 (1/10 of the record length) and calculate the variances $\gamma(3), \gamma(4), \ldots \gamma(84)$.
- The **climacogram** is a logarithmic plot of the variance $\gamma(\kappa)$ *vs*. scale κ.
- If the time series x_i represented a pure random process, the climacogram would be a straight line with slope -1 (the proof is very easy).
- In real world processes, the slope is different from -1, designated as $2H - 2$, where H is the so-called Hurst parameter ($0 < H < 1$).
- The scaling law $\gamma(\kappa) = \gamma(1) / \kappa^{2-2H}$ defines the **Hurst-Kolmogorov (HK) process**.
- High values of H (> 0.5) indicate **enhanced change** at large scales, else known as **long-term persistence**, or strong **clustering** (grouping) of similar values.

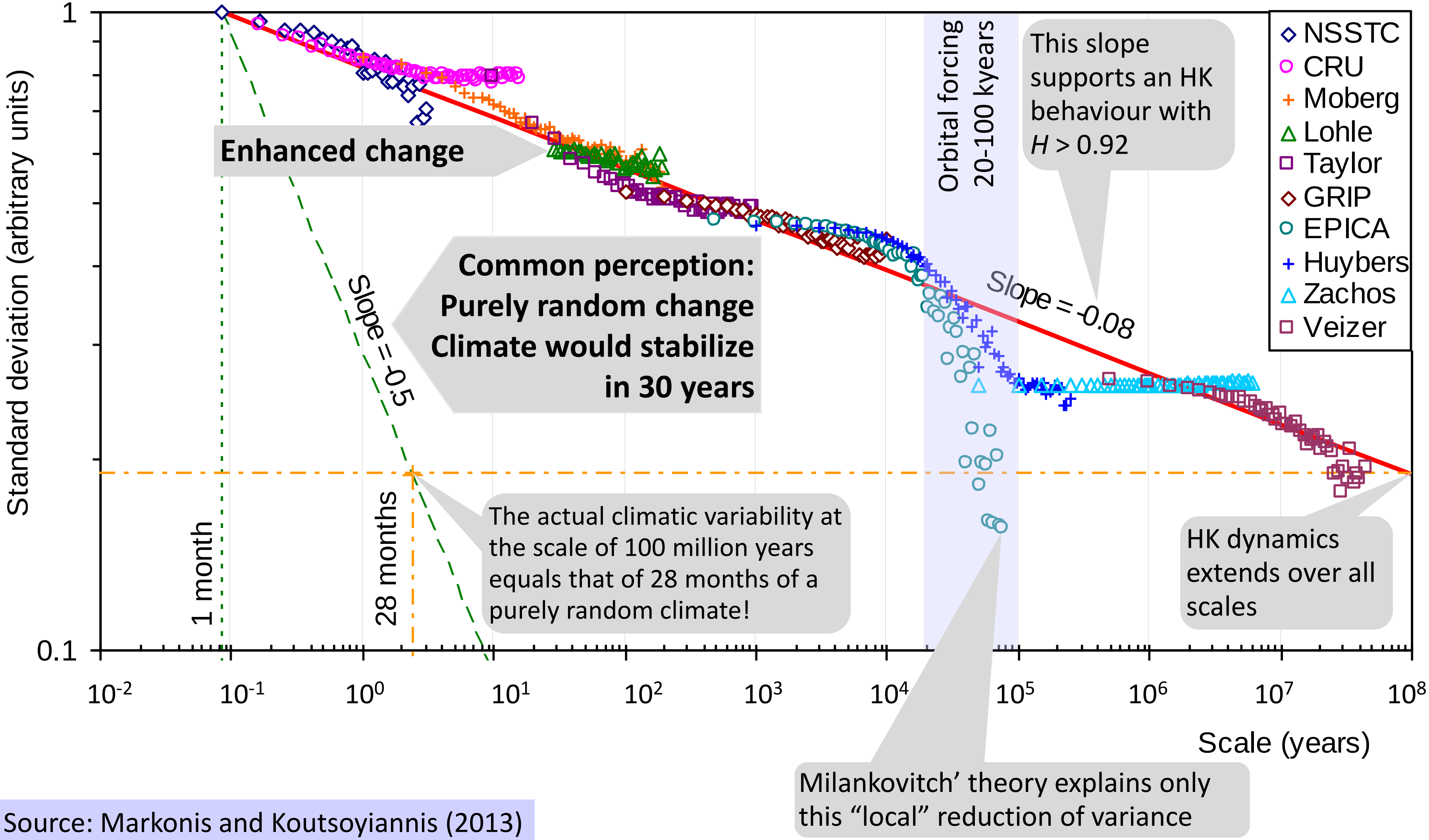
Koutsoyiannis (2010, 2013a, 2016)

The climacogram of the Nilometer time series

- The Hurst-Kolmogorov process seems consistent with reality.
- The Hurst coefficient is H = 0.87. (Similar H values are estimated from the simultaneous record of maximum water levels and from the modern, 131-year, flow record of the Nile flows at Aswan).
- The Hurst-Kolmogorov behaviour, seen in the climacogram, indicates that:
  - (a) long-term changes are more frequent and intense than commonly perceived, and
  - (b) future states are much more uncertain and unpredictable on long time horizons than implied by pure randomness.



A combined climacogram of temperature observations and proxies (Hurst-Kolmogorov + Milankovitch)



Source: Markonis and Koutsoyiannis (2013)

The spring of change: © Peter Atkins

ENTROPY

THE SPRING OF CHANGE

THE GREAT IDEA

All change is the consequence of the purposeless collapse of energy and matter into disorder

Not knowing the Second Law of thermodynamics is like never having read a work of Shakespeare[1]

C. P. SNOW

Atkins (2004)

- Laws of physics generally express conditions of conservation (of mass, momentum, energy, etc.)
- Conservation does not produce change.
- The 2nd law, which is a variational law, explains change and time's arrow.

timents. The second law is of central importance in the whole of science, and hence in our rational understanding of the universe, because it provides a foundation for understanding why *any* change occurs. Thus, not only is it a basis for understanding why engines run and chemical reactions occur, but it is also a foundation for understanding those most exquisite consequences of chemical reactions, the acts of literary, artistic, and musical creativity that enhance our culture.

Atkins (2007)

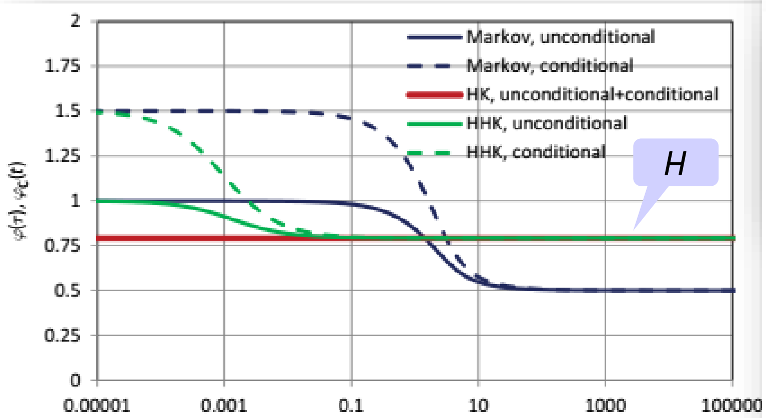
Entropy ≡ Uncertainty quantified

- Historically entropy was introduced in thermodynamics but later it was given a rigorous definition within probability theory (owing to Boltzmann, Gibbs and Shannon).
- Thermodynamic and probabilistic entropy are essentially the same thing (Koutsoyiannis, 2010, 2013b, 2014a, 2017; but others have different opinion).
- Entropy acquires its importance from the **principle of maximum entropy** (Jaynes, 1957), which postulates that the entropy of a random variable should be at maximum, under the conditions (constraints) which incorporate the available information about this variable.
- The tendency of entropy to become maximal explains a spectrum of phenomena from the random outcomes of dice to the 2nd Law of thermodynamics as the driving force of natural change.
- Entropy is a dimensionless measure of uncertainty:

Discrete random variable $\underline{x}$	**Continuous random variable $\underline{x}$**
$\Phi[\underline{x}] := \mathrm{E}[-\ln P(\underline{x})] = -\sum_{j=1}^{w} P_j \ln P_j$ where $P_j := P\{\underline{x} = x_j\}$ (probability)	$\Phi[\underline{x}] := \mathrm{E}\left[-\ln \frac{f(\underline{x})}{\beta(\underline{x})}\right] = -\int_{-\infty}^{\infty} \ln \frac{f(x)}{\beta(x)} f(x) dx$ where $f(x)$ is probability density and $\beta(x)$ is the density of a background measure

Maximum entropy production and the emergence of HK dynamics

- At large time scales, maximization of entropy entails HK dynamics.
- The Hurst parameter is none other than the entropy production in logarithmic time.



Koutsoyiannis (2011b, 2016, 2017)

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Hurst–Kolmogorov dynamics as a result of extremal entropy production

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HYDROLOGICAL SCIENCES JOURNAL – JOURNAL DES SCIENCES HYDROLOGIQUES, 2016
VOL. 61, NO. 2, 225–244
http://dx.doi.org/10.1080/02626667.2015.1016950

IAHS AISH Taylor & Francis

Generic and parsimonious stochastic modelling for hydrology and beyond

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ABSTRACT
The old principle of parsimonious modelling of natural processes has regained its importance in the last few years. The inevitability of uncertainty and risk, and the value of stochastic modelling in dealing with them, are also again appreciated, after a period of growing hopes for radical

ARTICLE HISTORY
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entropy

MDPI

Article

Entropy Production in Stochastics

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Received: 14 September 2017; Accepted: 23 October 2017; Published: 30 October 2017

Abstract: While the modern definition of entropy is genuinely probabilistic, in entropy production the classical thermodynamic definition, as in heat transfer, is typically used. Here we explore the concept of entropy production within stochastics and, particularly, two forms of entropy

Part 6
The energy cycle

Global energy flows and energy balance

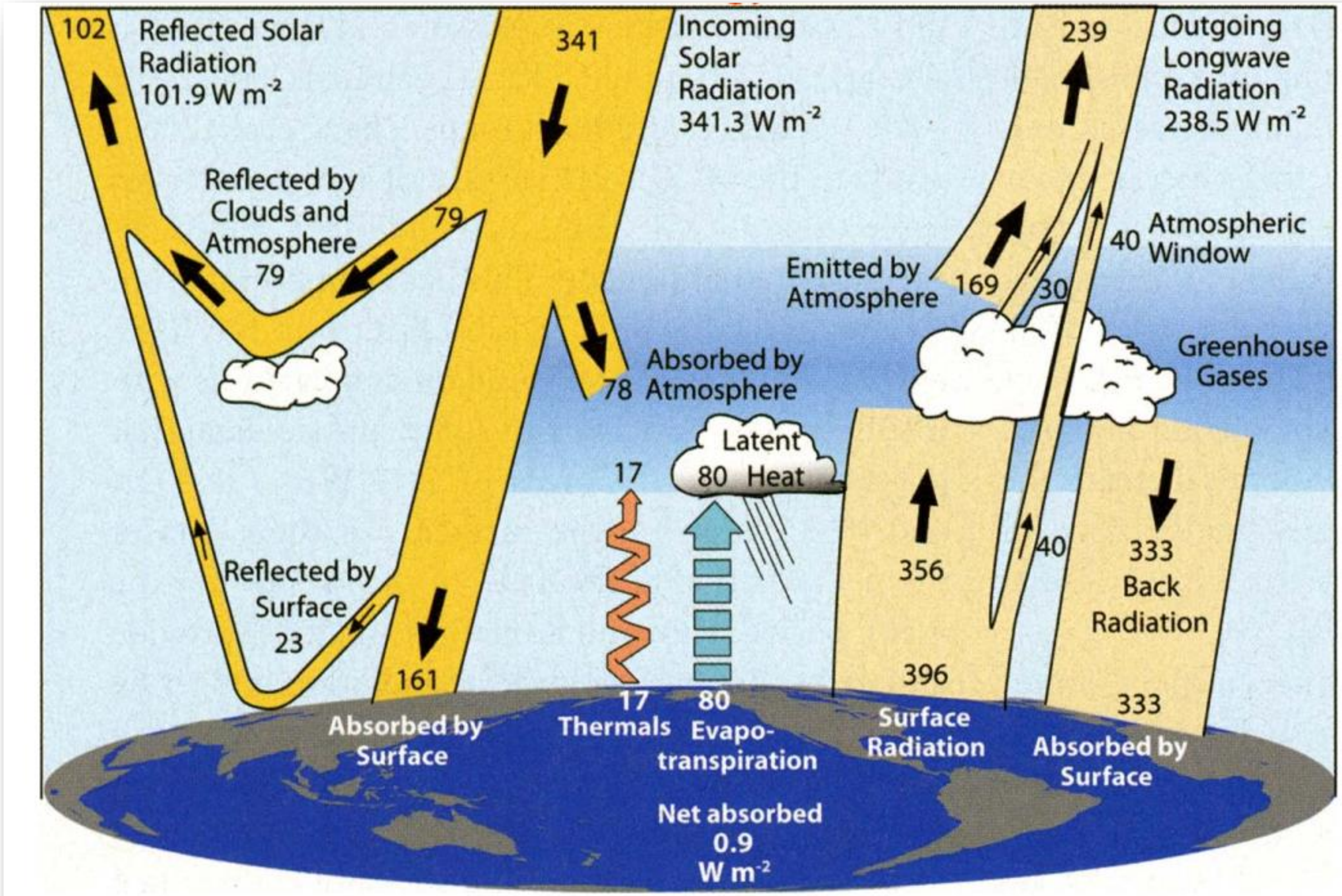


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Trenberth et al. (2009)

Comparison of human and natural locomotives (not to scale)

Human locomotive

All human energy production (2014): 170 000 TWh/year $= 0.612 \times 10^{21}$ J/year = 0.612 ZJ/year (Mamassis et al., 2020)

Natural locomotive

Power density (for evaporating water): 80 W/m^2

For earth's area 5.101×10^{14} m^2:

4.08×10^{16} W = 40.8 PW

Annual energy: 1.290×10^{24} J/year = 1290 ZJ/year.

Image from http://4-designer.com/2014/03/Cartoon-steam-train-vector-material/

Koutsoyiannis (2020)

Comparison of human and natural locomotives (to scale)

All human energy production

Human locomotive
0.612 ZJ/year

Natural locomotive
1290 ZJ/year
(2100 times higher than all human energy production)

Image from http://4-designer.com/2014/03/Cartoon-steam-train-vector-material/

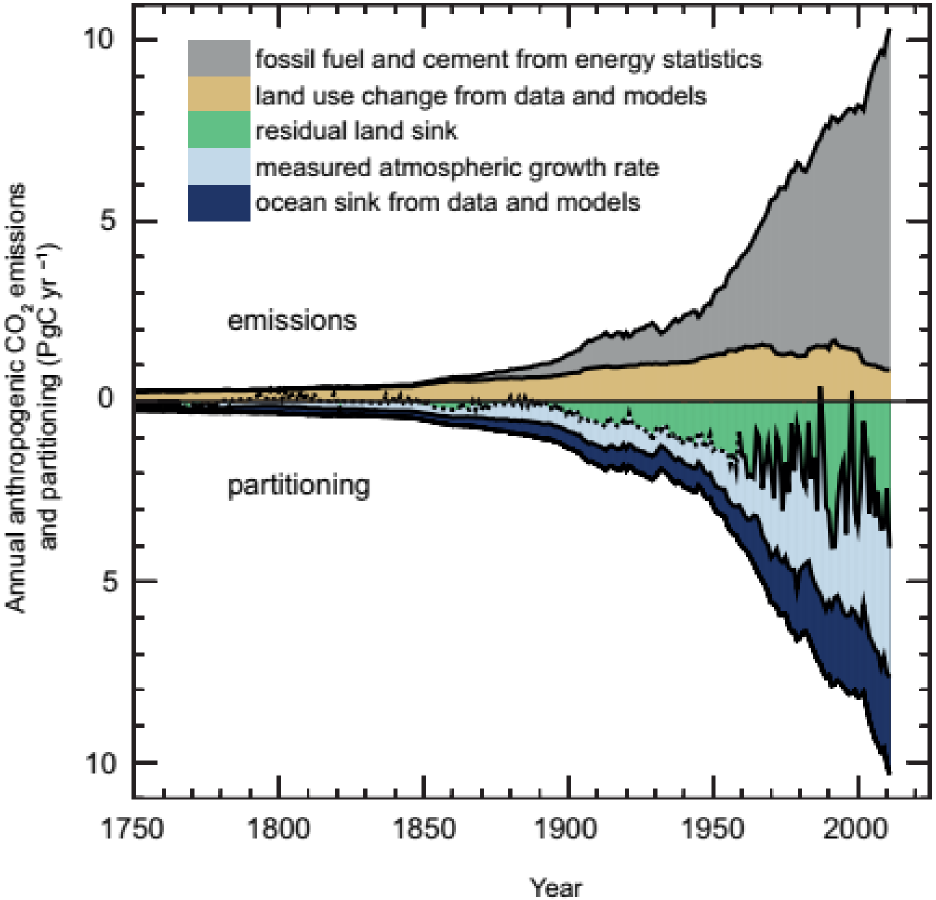
Koutsoyiannis (2020)

Part 7
The carbon cycle

Anthropogenic changes in atmospheric carbon according to IPCC (2013)

Questions:

1. Does the measured atmospheric growth rate (cyan in the lower part of the figure) originate from anthropogenic emissions as implied by the figure?
2. What percentage of the total carbon flow to the atmosphere do anthropogenic emissions represent?
3. Is the net human effect on land use increasing the emissions, as implied by the figure?

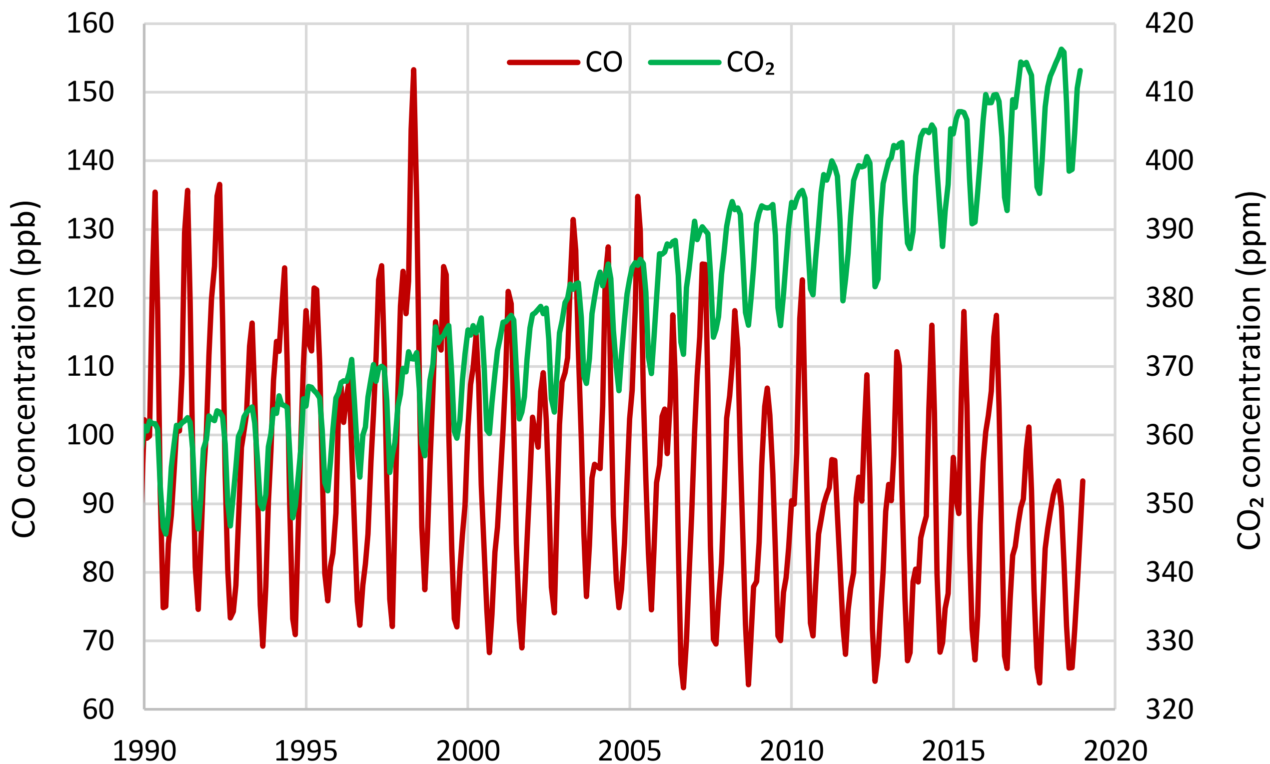


From the original figure caption
Figure TS.4 | Annual anthropogenic CO_2 emissions and their partitioning among the atmosphere, land and ocean (Gt / year; 1 Gt = 1 Pg) from 1750 to 2011. […]. CO_2 emissions from net land use change, mainly deforestation, are based on land cover change data. […]

On question 1: Atmospheric carbon monoxide (CO)

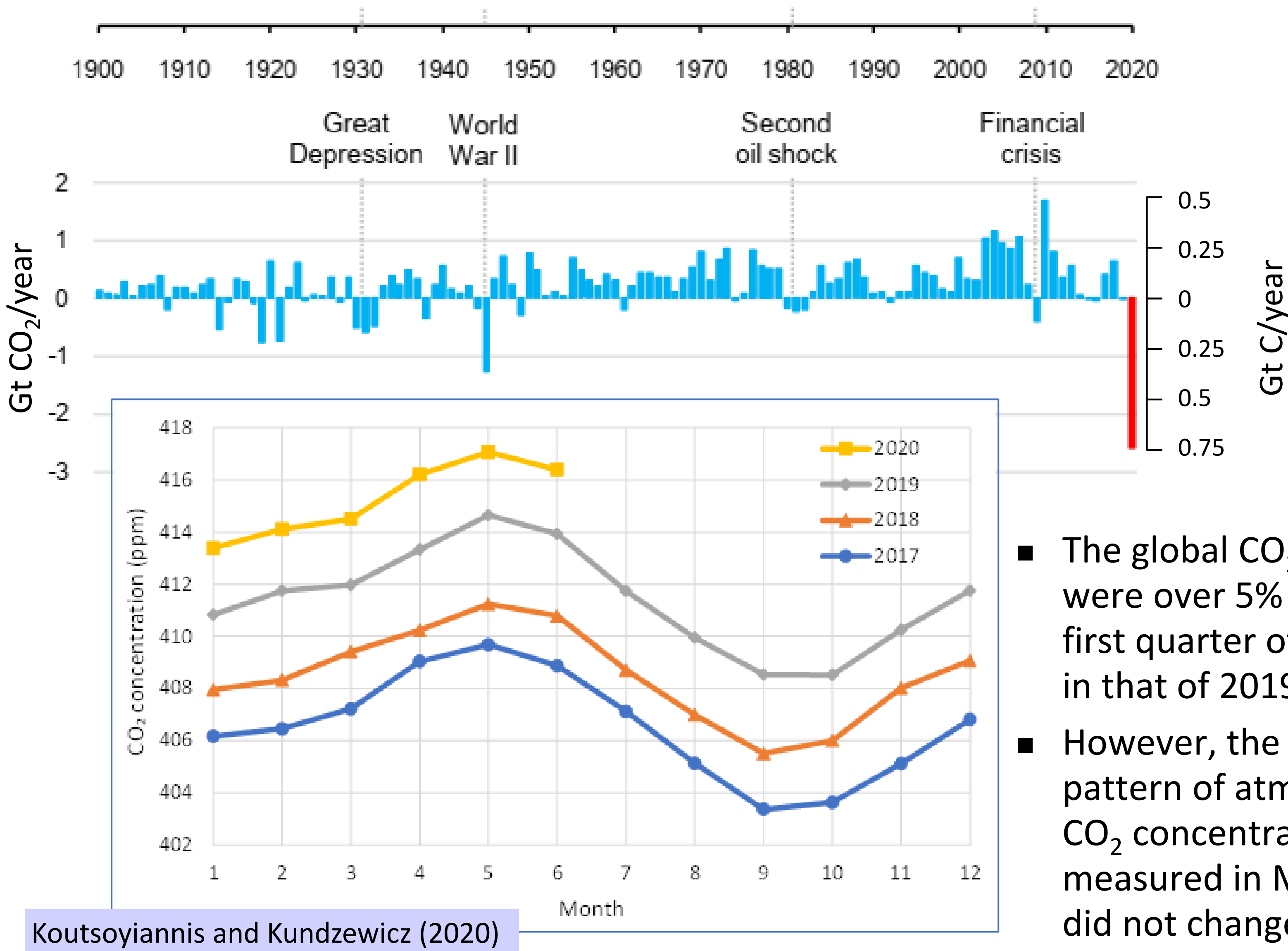
- While CO_2 can enter the atmosphere by several processes, natural and anthropogenic, CO is mainly produced by combustion—fossil fuel and biomass burning.
- The major quantities of CO are human-produced (e.g. automobile emissions).
- Hence, CO has been investigated as a possible quantitative tracer for fossil-fuel CO_2 (Gamnitzer et al. 2006).

The Mauna Loa Observatory, Hawaii, the most famous for its measurements of atmospheric CO_2, also measures the atmospheric CO.
The graph shows that while concentration of CO_2 increases, that of CO does not.



Data source: http://climexp.knmi.nl, https://www.esrl.noaa.gov/gmd/dv/data/index.php?parameter_name=Carbon%2BMonoxide&site=MLO

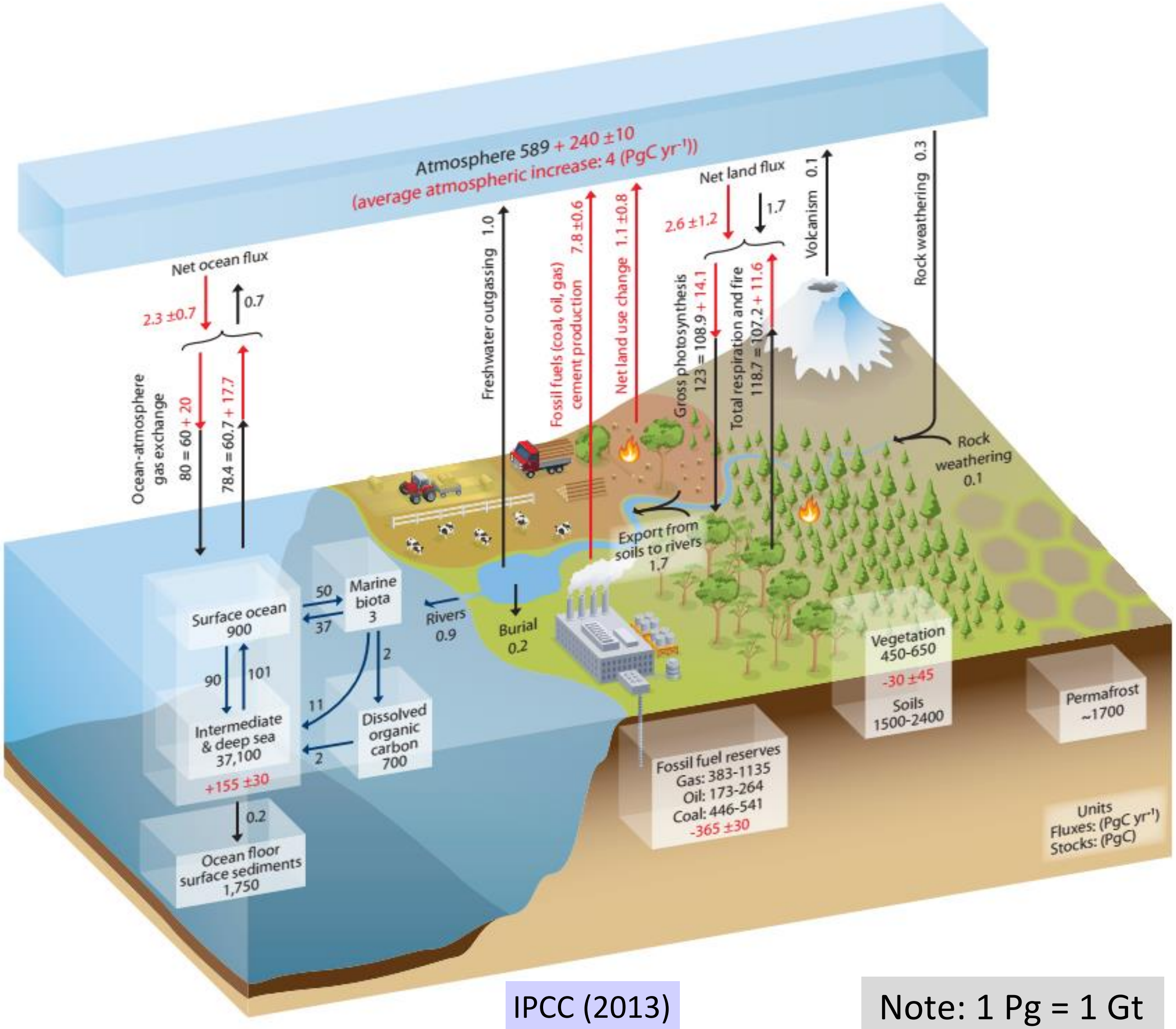
On Question 1: Covid-19 and an unfortunate experiment



Koutsoyiannis and Kundzewicz (2020)

- The global CO_2 emissions were over 5% lower in the first quarter of 2020 than in that of 2019 (IEA, 2020).
- However, the increasing pattern of atmospheric CO_2 concentration, as measured in Mauna Loa, did not change.

The global carbon cycle according to IPCC (AR5)



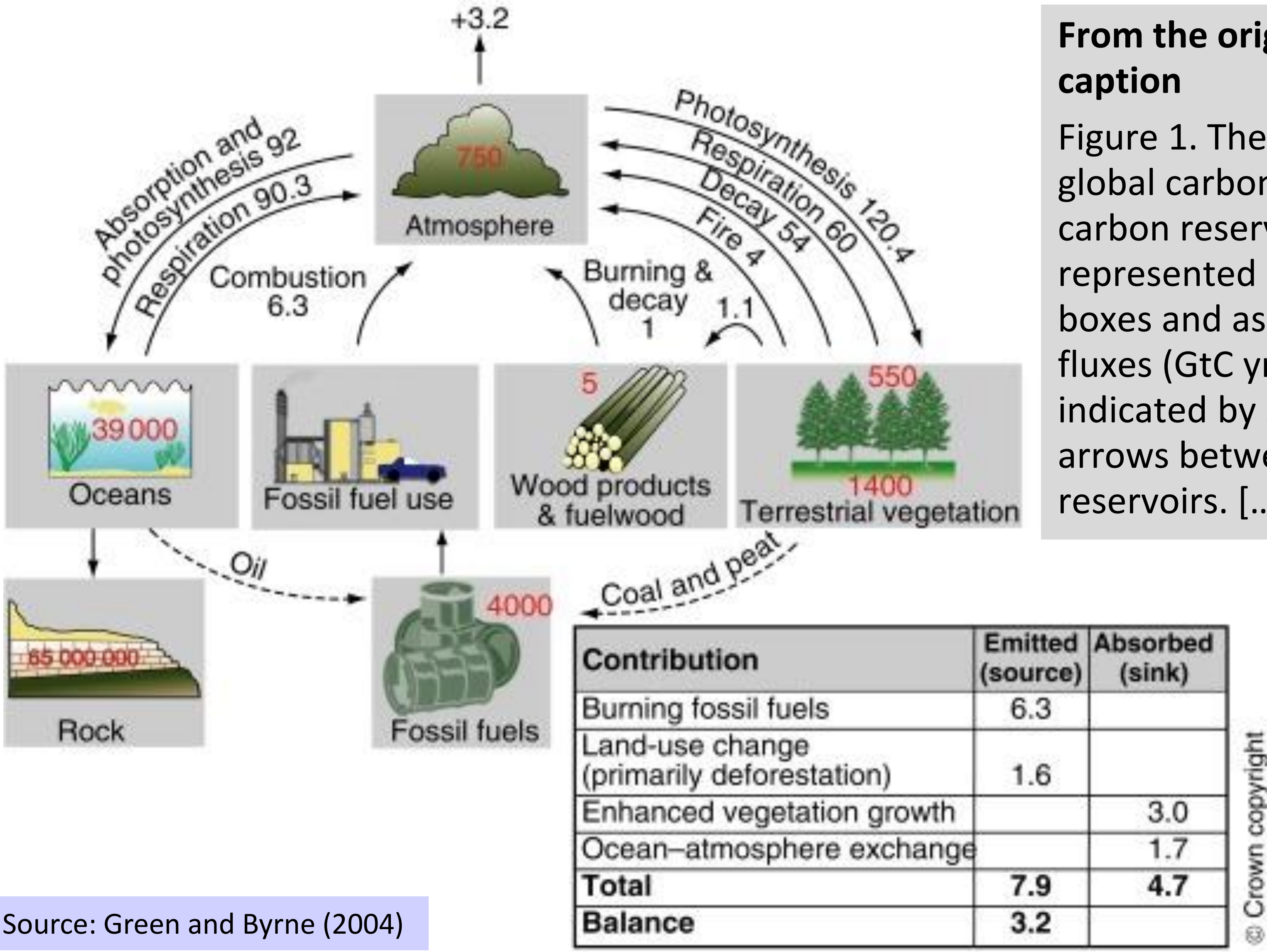
IPCC (2013)

Note: 1 Pg = 1 Gt

From the original figure caption

Figure 6.1 | Simplified schematic of the global carbon cycle. Numbers represent reservoir mass, also called 'carbon stocks' in PgC (1 PgC = 10^{15} gC) and annual carbon exchange fluxes (in PgC yr^{-1}). Black numbers and arrows indicate reservoir mass and exchange fluxes estimated for the time prior to the Industrial Era, about 1750 […] Red arrows and numbers indicate annual 'anthropogenic' fluxes averaged over the 2000–2009 time period. […]

The global carbon cycle according to another source



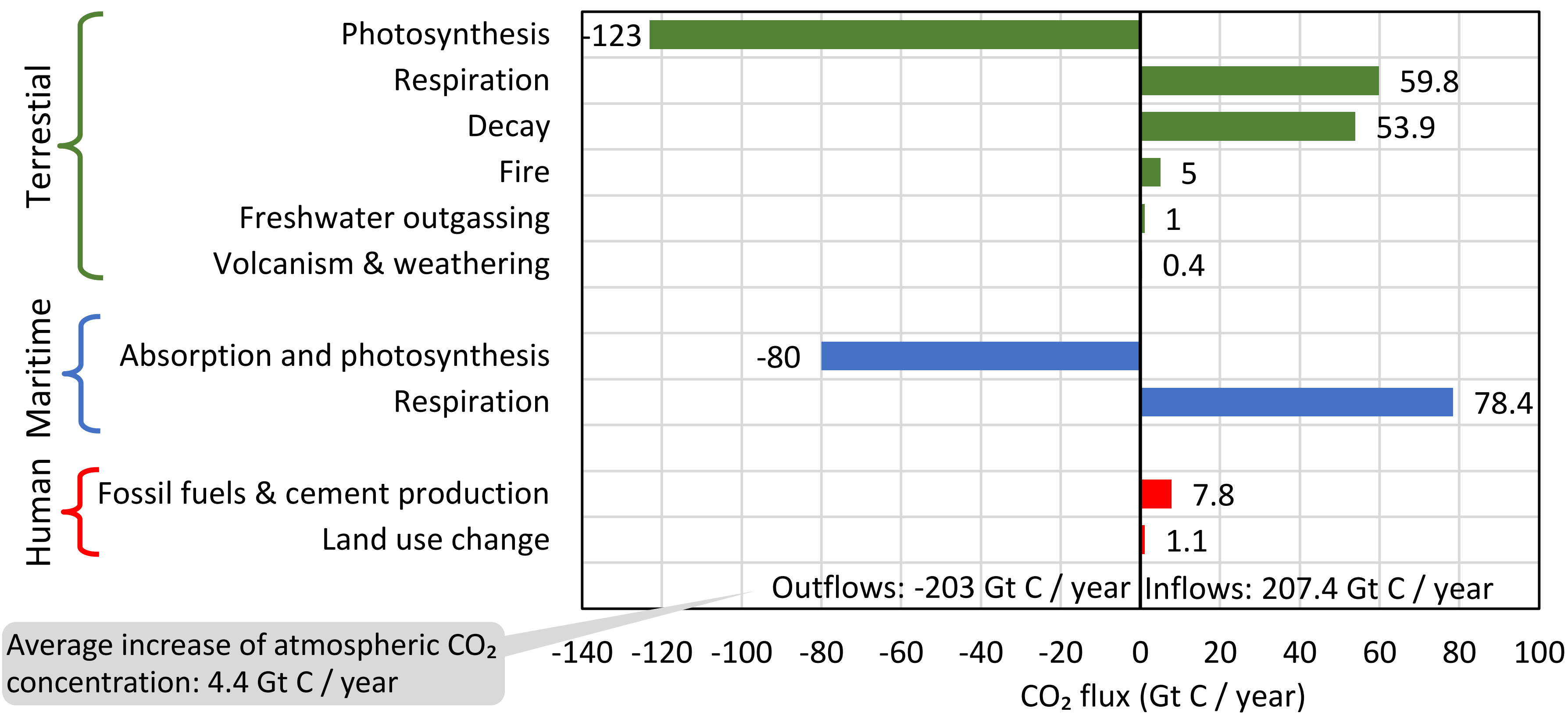
Contribution	Emitted (source)	Absorbed (sink)
Burning fossil fuels	6.3	
Land-use change (primarily deforestation)	1.6	
Enhanced vegetation growth		3.0
Ocean–atmosphere exchange		1.7
Total	**7.9**	**4.7**
Balance	**3.2**	

From the original figure caption

Figure 1. The simplified global carbon cycle; carbon reservoirs (GtC) represented within the boxes and associated fluxes (GtC yr^{-1}) indicated by solid arrows between the reservoirs. […]

Source: Green and Byrne (2004)

Synthesis of the atmospheric carbon balance from the two sources (with totals according to IPCC, 2013)



On question 2: Percentage of the anthropogenic emissions on total carbon flux to the atmosphere

Human CO_2 emissions (fossil fuels and cement production): **3.8%**

Natural CO_2 emissions (respiration, decay, etc., in land and sea): **96.2%**

Images from: https://www.whitehorse.vic.gov.au/dust-smoke-fumes-and-odour-nuisance
https://www.wallpapers13.com/tropical-landscape-marine-animal-underwater-world-sea-dolphin-colorful-sea-fish-corals-land-coast-palm-trees-scarlet-birds-sunrise-art-wallpaper-hd-1920x1200/

On question 3:
Is Earth browning or greening?

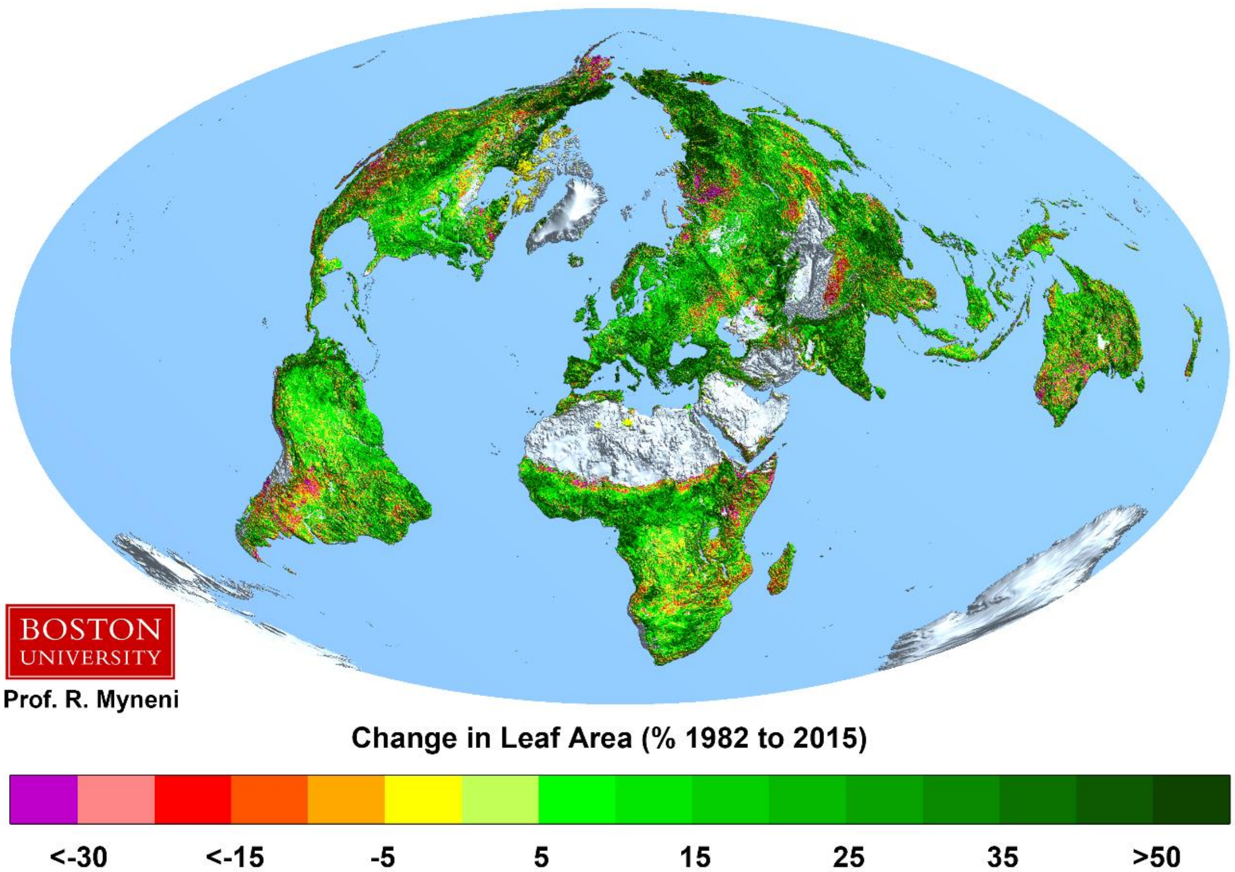


Image source: http://sites.bu.edu/cliveg/files/2016/04/LAI-Change.png

Quoting **Zhu et al. (2016)**:
"We show a persistent and widespread increase of growing season integrated LAI [Leaf Area Index] *(greening) over 25% to 50% of the global vegetated area, whereas less than 4% of the globe shows decreasing LAI (browning). Factorial simulations with multiple global ecosystem models suggest that CO_2 fertilization effects explain 70% of the observed greening trend, followed by nitrogen deposition (9%), climate change (8%) and land cover change (LCC) (4%). CO_2 fertilization effects explain most of the greening trends in the tropics* [...]"

On question 3: Are human activities browning or greening the Earth?

Source: Chen et al. (2019)

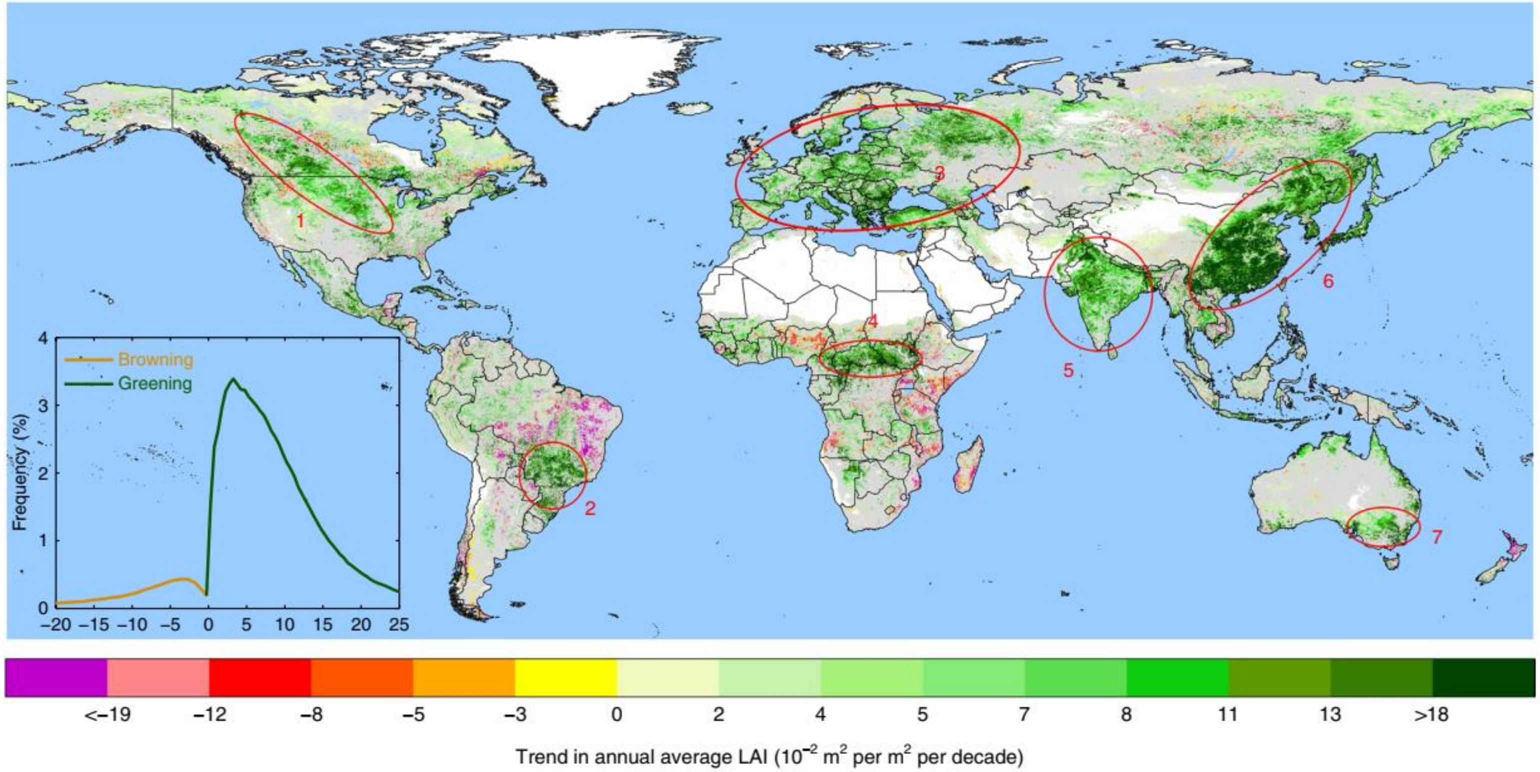
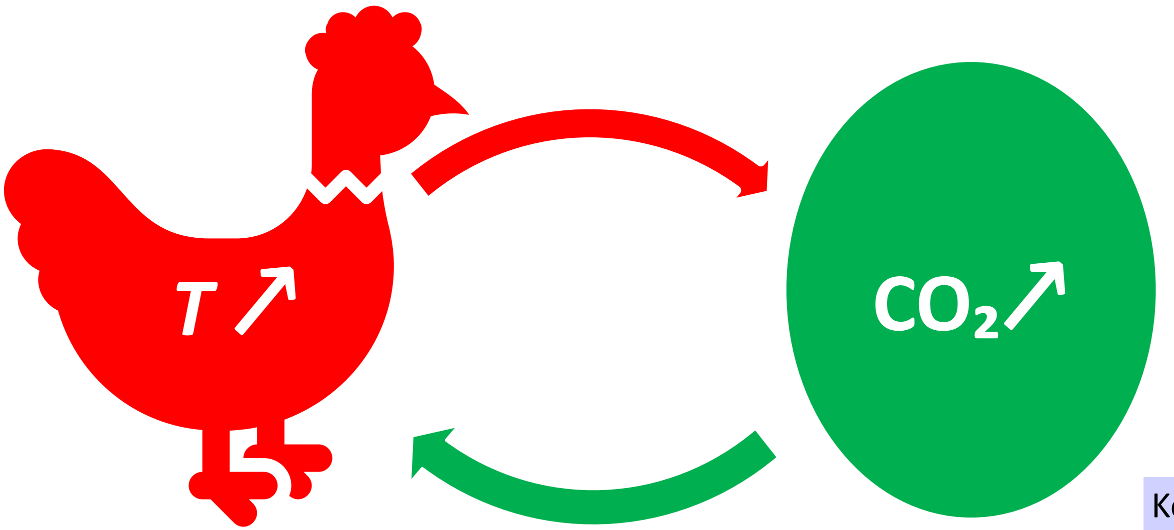


Fig. 1 | Map of trends in annual average MODIS LAI for 2000–2017. Statistically significant trends (Mann–Kendall test, $P \leq 0.1$) are colour-coded. Grey areas show vegetated land with statistically insignificant trends. White areas depict barren lands, permanent ice-covered areas, permanent wetlands and built-up areas. Blue areas represent water. The inset shows the frequency distribution of statistically significant trends. The highlighted greening areas in red circles mostly overlap with croplands, with the exception of circle number 4. Similar patterns are seen at $P \leq 0.05$ and the seven greening clusters are visible even at $P \leq 0.01$.

Quoting Chen et al. (2019): *"recent satellite data (2000–2017) reveal a greening pattern that is strikingly prominent in China and India and overlaps with croplands world-wide."*

Causation between CO_2 and temperature: "ὄρνις ἢ ᾠὸν;" ("hen or egg?")[1]



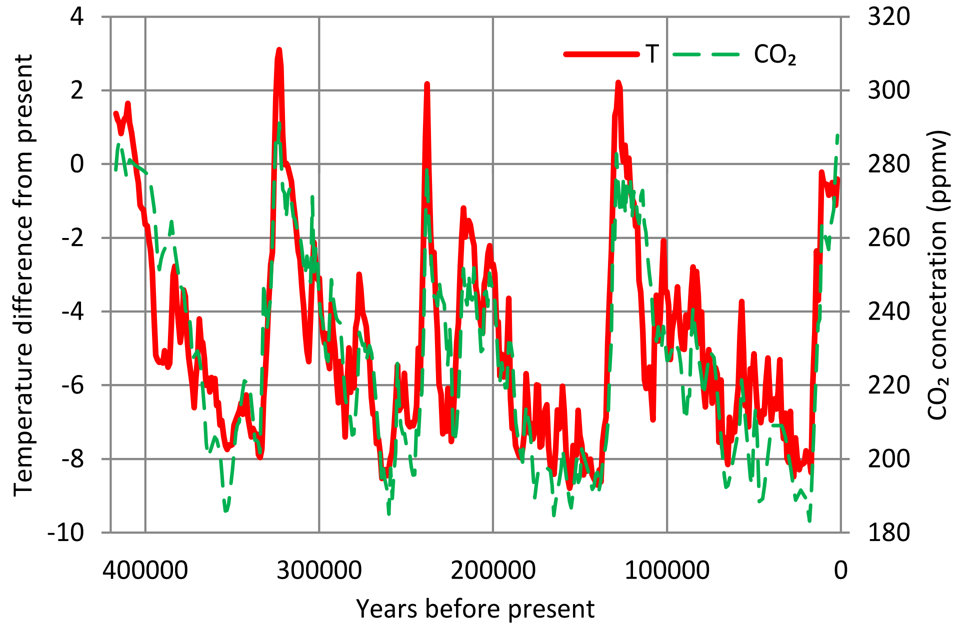
Koutsoyiannis and Kundzewicz (2020)

Koutsoyiannis and Kundzewicz (2020) postulate that the link between CO_2 and temperature classifies as a "hen-or-egg" causality problem, as it is not clear which of two is the cause and which the effect.

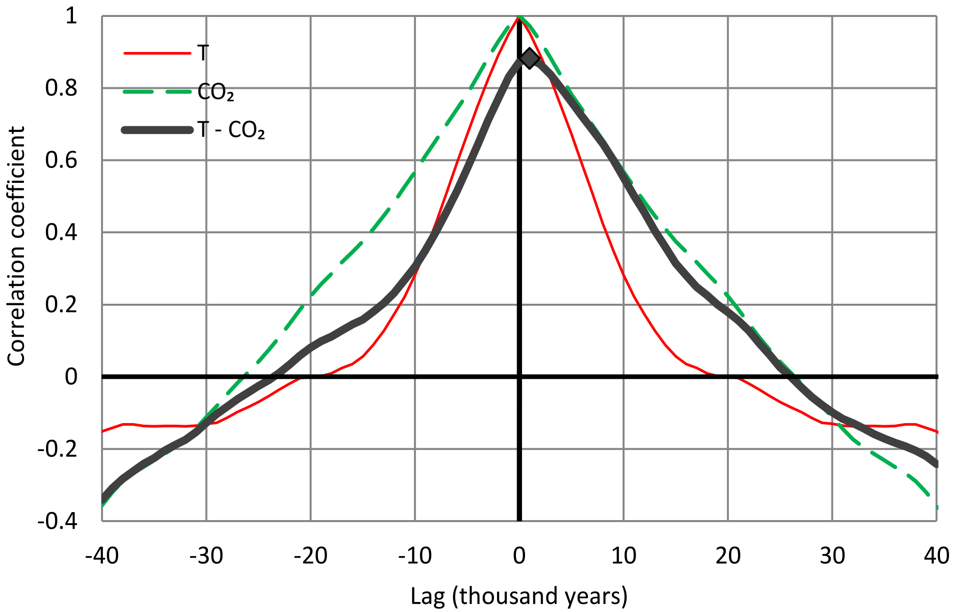
[1] Plutarch first posed this type of causality as a philosophical problem using the example of the hen and the egg: "*Πότερον ἡ ὄρνις πρότερον ἢ τὸ ᾠὸν ἐγένετο*" (Πλούταρχος, Ηθικά, Συμποσιακὰ Β, Πρόβλημα Γ) —Which of the two came first, the hen or the egg? (Plutarch, Moralia, Quaestiones convivales, B, Question III).

Palaeoclimatic data in search of causality

Time series of temperature and CO_2 concentration from the Vostok ice core, covering part of the Quaternary (420 000 years) with time step of 1000 years.



Auto- and cross-correlograms of the two time series. The maximum value of the cross-correlation coefficient is 0.88 and appears at lag 1 thousand years.

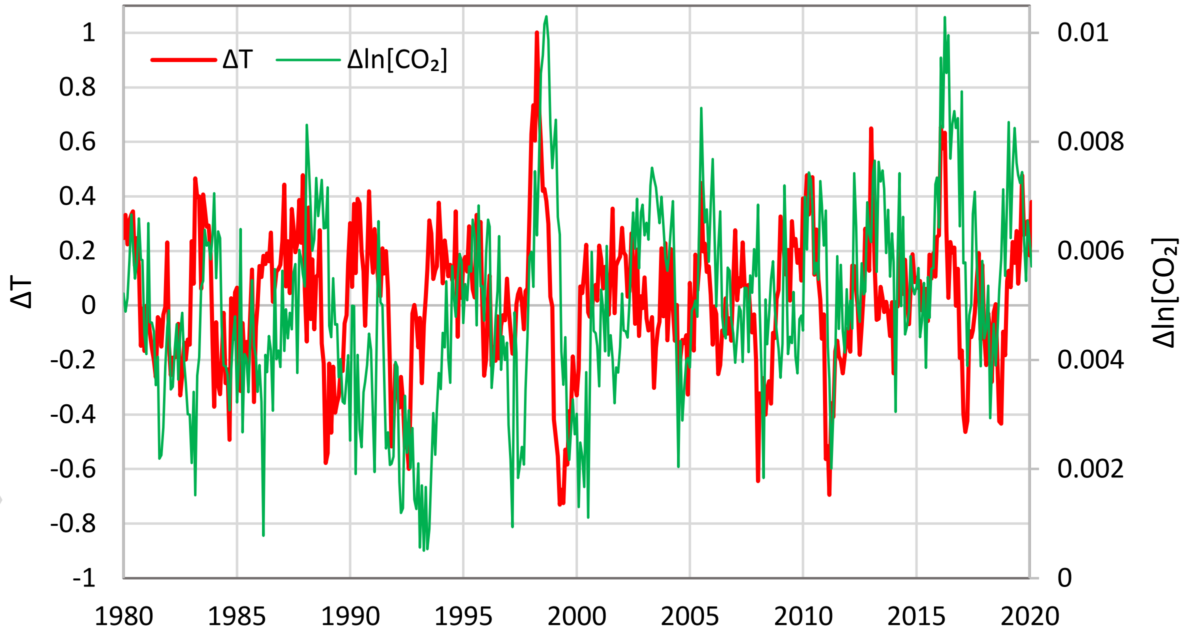


This suggests that the dominant causality direction is $T \rightarrow CO_2$ and that Milankovitch, rather than Arrhenius, is right.

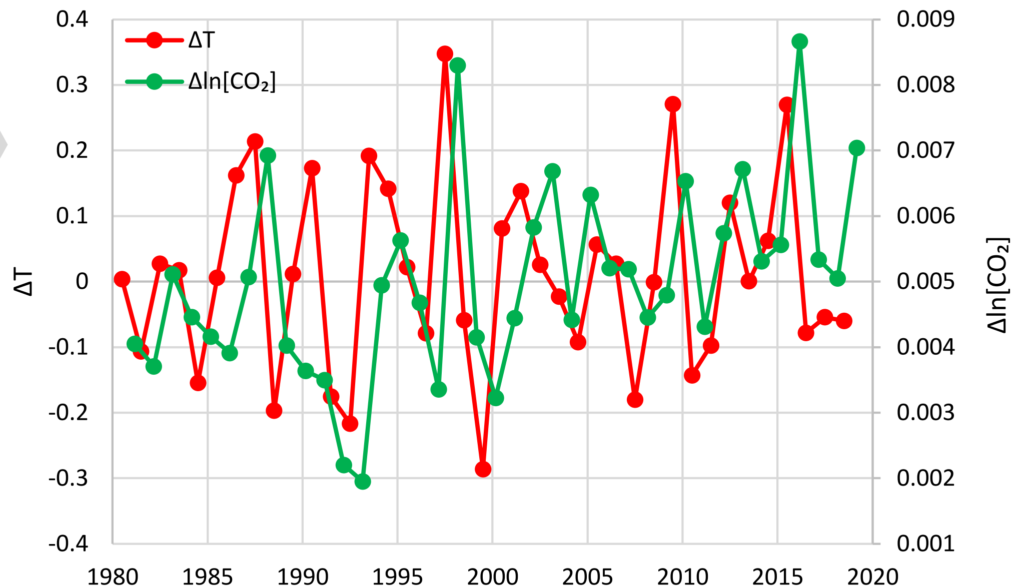
Adapted from Koutsoyiannis (2019)

Recent instrumental temperature and CO_2 data

Differenced monthly time series of global temperature (UAH) and logarithm of CO_2 concentration (Mauna Loa)



Annually averaged time series of differenced temperatures (UAH) and logarithm of CO_2 concentration (Mauna Loa). Each dot represents the average of a one-year duration ending at the time of its abscissa.



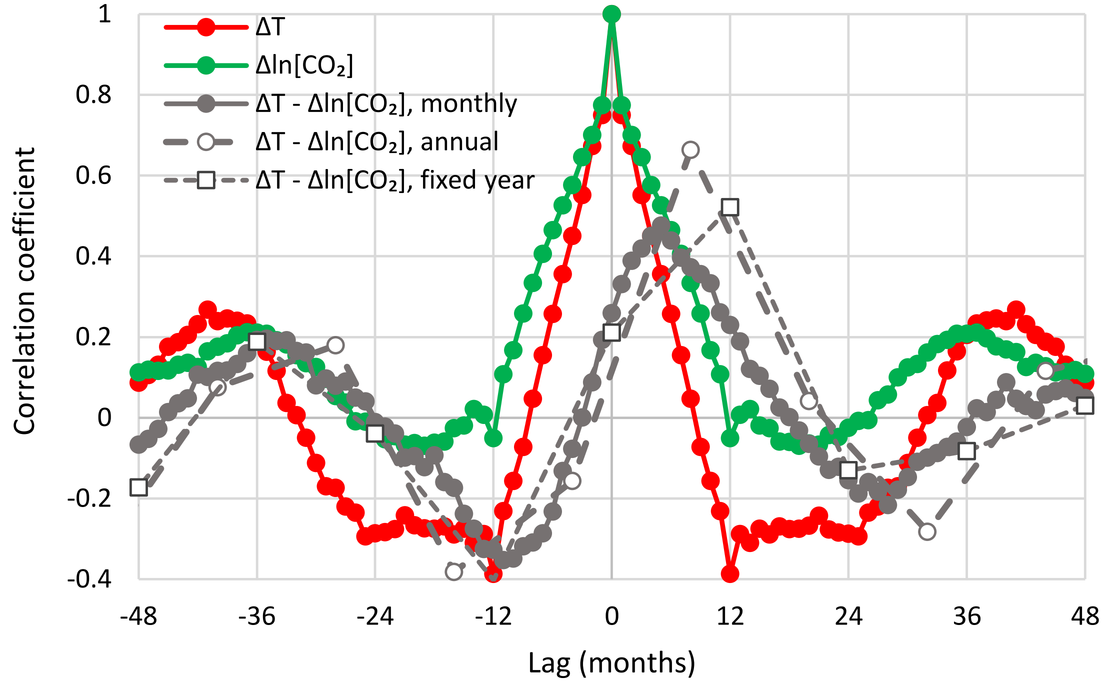
Which is the cause and which the effect?

Koutsoyiannis and Kundzewicz (2020); notice that logarithms of CO_2 concentration are used for linear equivalence with temperature.

Changes in CO_2 follow changes in global temperature

Auto- and cross-correlograms of the differenced time series of temperature (UAH) and logarithm of CO_2 concentration (Mauna Loa)

Which is the cause and which the effect?



Maximum cross-correlation coefficient (MCCC) and corresponding time lag in months						
	Monthly time series		Annual time series – sliding annual window		Annual time series – fixed annual window	
Temperature - CO_2 series	MCCC	Lag	MCCC	Lag	MCCC	Lag
UAH – Mauna Loa	0.47	5	0.66	8	0.52	12
UAH – Barrow	0.31	11	0.70	14	0.59	12
UAH – South Pole	0.37	6	0.54	10	0.38	12
UAH – Global	0.47	6	0.60	11	0.60	12
CRUTEM4 – Mauna Loa	0.31	5	0.55	10	0.52	12
CRUTEM4 – Global	0.33	9	0.55	12	0.55	12

Koutsoyiannis and Kundzewicz (2020)

Towards a physical explanation for causality direction

- We start from the Arrhenius equation for the rate of chemical reactions, which is:

$$k = A \exp\left(-\frac{E}{RT}\right)$$

where *k* is the rate constant of the chemical reaction, *T* is the absolute temperature (in kelvins), *A* is a constant, *E* is the activation energy and *R* is the universal gas constant.

- Assuming $T = T_0 + \Delta T$ for some $T_0 > 0$ for which $k = k_0$ and for $\Delta T \ll T_0$, we can write:

$$\frac{k}{k_0} = \exp\left(-\frac{E}{R(T_0 + \Delta T)} + \frac{E}{RT_0}\right) = \exp\left(-\frac{E}{R(T_0 + \Delta T)} \frac{\Delta T}{T_0}\right) \approx \exp\left(-\frac{E}{RT_0} \frac{\Delta T}{T_0}\right)$$

- Hence:

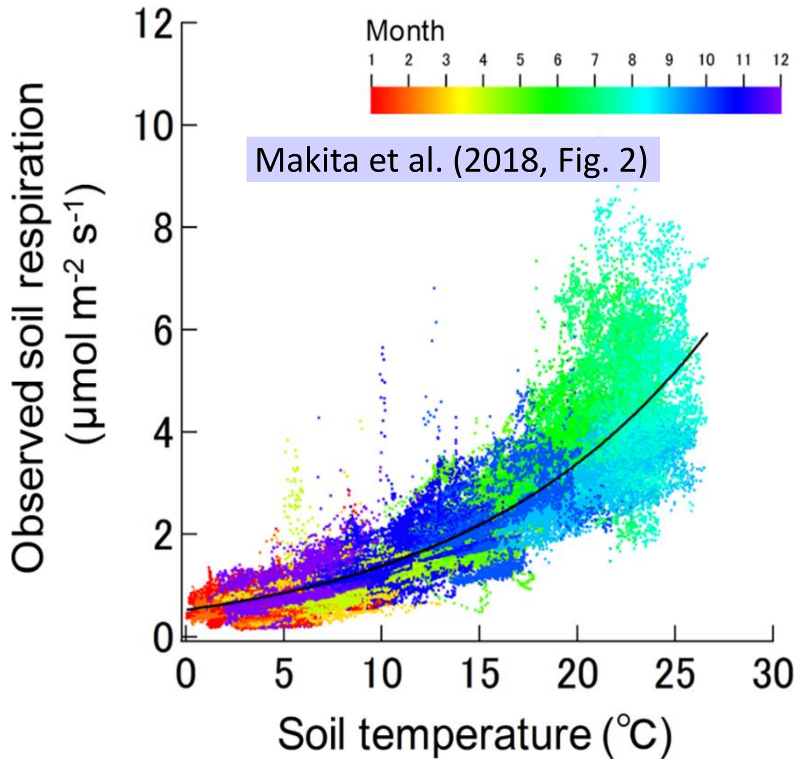
$$k \approx k_0 \left(\frac{A}{k_0}\right)^{\frac{\Delta T}{T_0}} = k_0 B^{\Delta T}$$

which is a exponential relationship in terms of ΔT, where:

$$B := \left(\frac{A}{k_0}\right)^{\frac{1}{T_0}}$$

Physical explanation of the T → CO_2 causality

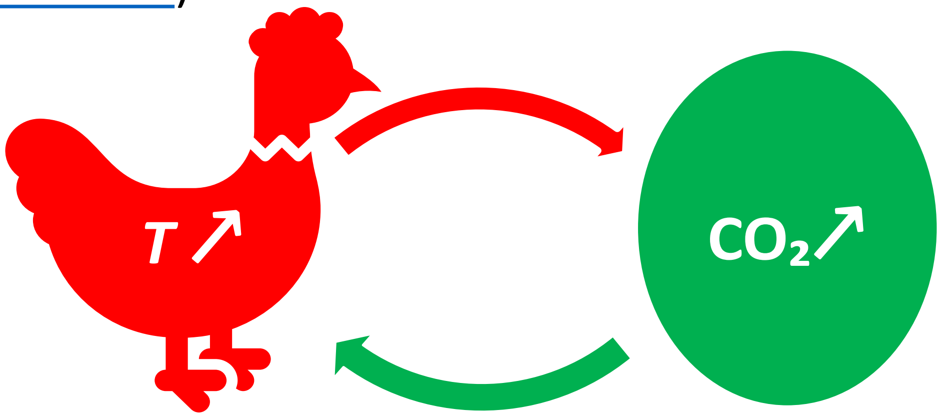
- The approximation of the Arrhenius equation for the rate of chemical reactions, i.e.:
$$k \approx k_0 B^{\Delta T}$$
remains valid for biochemical and biological processes (for typical temperature ranges).
- Thus, the graph on the right for the respiration rate R_s (emission of CO_2 from plants and microorganisms) of a coniferous forest can be modelled as
$$R_s = 2.18\,(1.09)^{T-15}$$
- This entails a 9% increase of respiration for an increase of temperature by 1 °C (= 1 K).
- Also, it has been known since 70 years ago (Pomeroy and Bowlus, 1946) that the metabolic rate (activity of microorganisms) in sewer networks follows similar dynamics, i.e.:
$$[\mathrm{EBOD}] = [\mathrm{BOD}]\,(1.07)^{T-20}$$
where BOD stands for biochemical oxygen demand and EBOD for effective BOD.
- The latter equation, which is routinely used in engineering design even today, suggests a 7% increase of metabolic rate for temperature increase of 1 °C.



Graph reproduced from Makita et al. (2018) showing the relationship between soil respiration and temperature during 2005-10 in a temperate evergreen coniferous forest area in Japan. The best-fit model is shown by the solid black line.

How does the natural increase of respiration compare to human emissions?

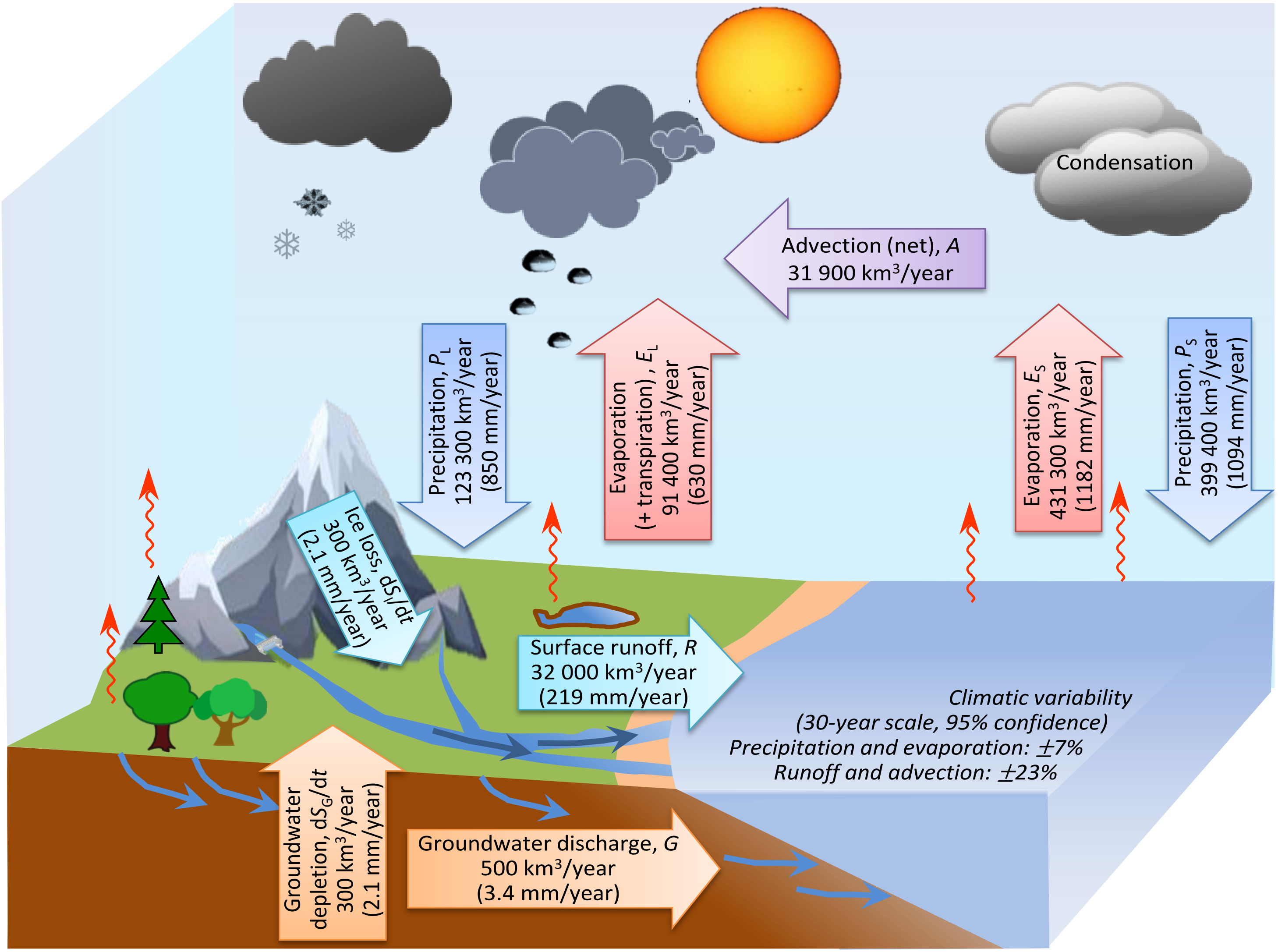
- The soil respiration, assumed to be the sum of respiration (plants) and decay (microbes) is 113.7 Gt C/year (see graph of atmospheric carbon balance).
- According to Koutsoyiannis (2020, Table 2), in the last 30 years the land temperature has been increasing by 0.29 °C/decade corresponding to an increase in temperature over land of 1.16 °C for the 40-year period 1980 – 2020.
- This means that between 1980 and 2020 there was an increase of annual respiration of 11% or 12 Gt C/year.
- This imbalance is by 50% higher than human emissions (7.8 Gt/year as shown in the graph of atmospheric carbon balance).
- We can expect that the sea respiration would have increased too, but at a lower rate as the sea temperature increase is much lower.



Part 8
The hydrological cycle
and its alleged intensification

The hydrological cycle: A recent quantification

Koutsoyiannis (2020)



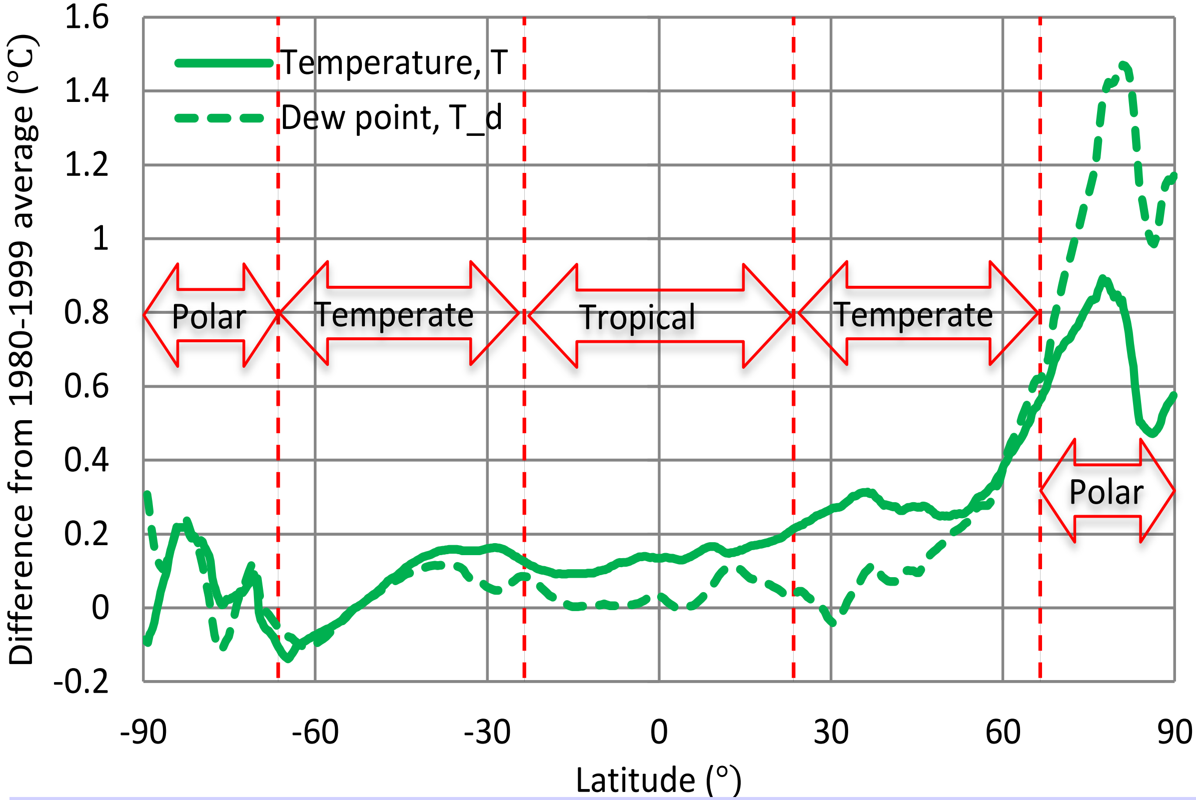
Notice the **groundwater depletion**, i.e., (unsustainable) over pumping beyond the rate of natural recharge.

This contributes 1/3 of the sea-level rise—the most significant anthropogenic effect on the hydrological cycle.

Another 1/3 is contributed by **ice loss** (not necessarily anthropogenic), while 1/3 is due to **thermal expansion**.

Dew point and its comparison to temperature

- The presence of water in the atmosphere (and hence hydrology) is affected more by the dew point, T_d, than the temperature, T.
- The dew point is defined as the temperature at which the air must be cooled to become saturated with water vapour; thus when the relative humidity is 100%, the dew point equals the temperature.



Zonal distribution of the difference of the earth temperature and dew point from their averages in the 20-year period 1980-99, from ERA5 **reanalysis data**. Note that the graph represents averages for the entire 40+ year period 1980-2019, rather than differences between two periods (the latter are about twice the former).

Notice the **zero change in the dew point in the tropics**, which are responsible for most part of evaporation.

Koutsoyiannis (2020); Reanalysis data access and processing through http://climexp.knmi.nl

Saturation vapour pressure and humidity

- The **saturation vapour pressure**, e, increases almost exponentially with temperature, T:

$$e = e(T) = e_0 \exp\left(\frac{\alpha}{RT_0}\left(1 - \frac{T_0}{T}\right)\right)\left(\frac{T_0}{T}\right)^{(c_L - c_p)/R}$$

$$= e_0 \exp\left(24.921\left(1 - \frac{T_0}{T}\right)\right)\left(\frac{T_0}{T}\right)^{5.06}$$

where (T_0, e_0) are the coordinates of the triple point of water, R is the specific gas constant of water vapour, c_p is the specific heat at constant pressure of the vapour and c_L is the specific heat of the liquid water.

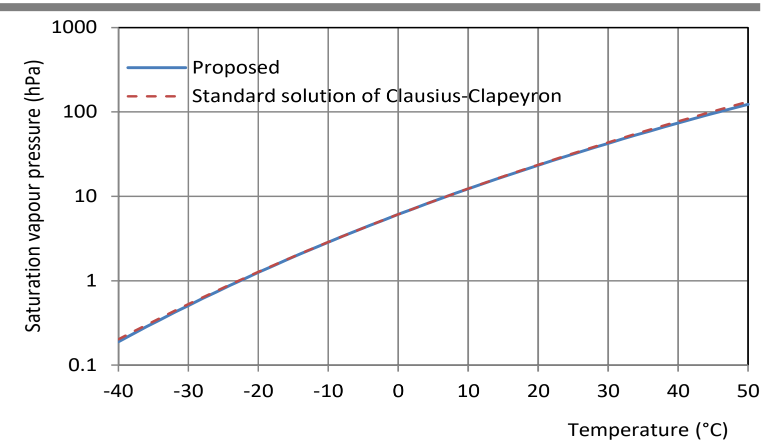
- The dew point is $T_d \coloneqq e_s^{-1}(e_A)$, where e_A is the actual vapour pressure, and the **relative humidity** is the ratio:

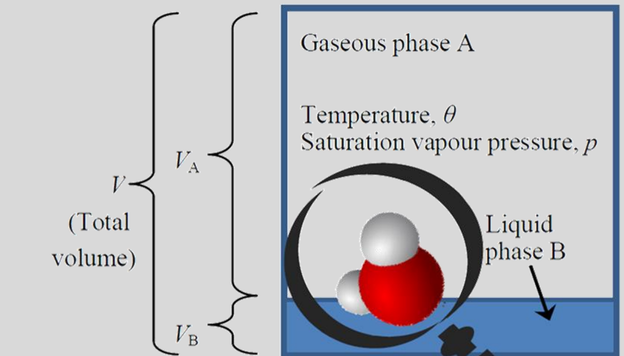
$$U \coloneqq \frac{e_A}{e(T)} = \frac{e(T_d)}{e(T)}$$

- The **specific humidity** is the ratio of the density of vapour ρ_v to the density of air $\rho_v + \rho_d$, where ρ_d is the density of dry air, and is related to vapour pressure by:

$$q \coloneqq \frac{\rho_v}{\rho_v + \rho_d} = \frac{\varepsilon e_A}{p - (1 - \varepsilon) e_A}$$

where ε =0.622 is the ratio of the molecular mass of water to that of the mixture of gases in the dry air.





The law was derived by studying a single molecule and maximizing the combined uncertainty of its state, i.e.:

(a) its phase (whether gaseous or liquid);
(b) its position in space; and
(c) its kinetic state, i.e., its velocity and other coordinates corresponding to its degrees of freedom and making up its thermal energy.

Koutsoyiannis (2012, 2014a)

Basic assumptions of IPCC on hydrological cycle

- As a result of increasing temperature, the saturation vapour pressure is increasing by 6%–7% per °C of warming.
  - This is a fact resulting from the Clausius–Clapeyron relationship and does not need observations to confirm.
- In a warming climate, atmospheric moisture is changing in a manner that the **relative humidity remains constant**, but **specific humidity increases** according to the Clausius–Clapeyron relationship. As a result, the established view is that the global atmospheric water vapour should increase by about 6%–7% per °C of warming.
  - This is a conjecture that needs to be tested by data.
- This gives rise to what has been called **intensification of hydrological cycle**.
  - Because of the alleged intensification, the role of hydrology becomes thus important in the climate agenda from a sociological point of view: some of the most prominent predicted catastrophes are related to water shortage and extreme floods (Koutsoyiannis, 2014b).
- The rate of increase of precipitation, necessarily accompanied by an equal rate of increase of evaporation, estimated from climate model simulations, is conjectured to be smaller, 1% to 3% per °C, with a typical estimate of 2.2% per °C (Kleidon and Renner, 2013).
  - Even accepting this IPCC assertion and the celebrated target of 2 °C of global warming, which translates in 2-6% increase of rainfall, the change is negligible.

Decadal change as seen in a long daily precipitation record

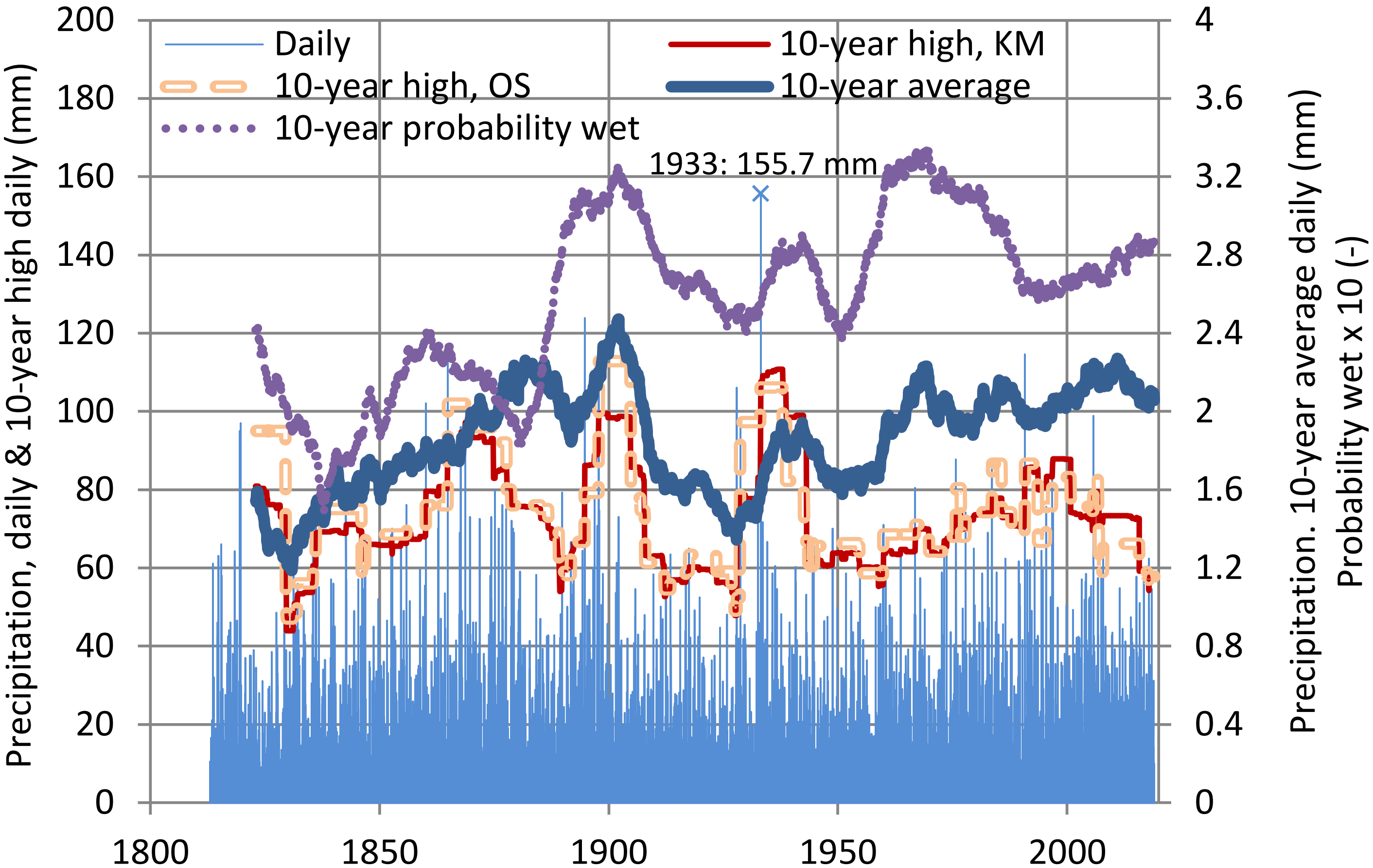
All 10-year **climatic indices** have varied substantially and irregularly:

The average by **100%** (from 1.2 to 2.4 mm).

The probability wet by **120%** (from 0.15 to 0.33).

The high daily precipitation by **150%** (from 44 to 110 mm/d).

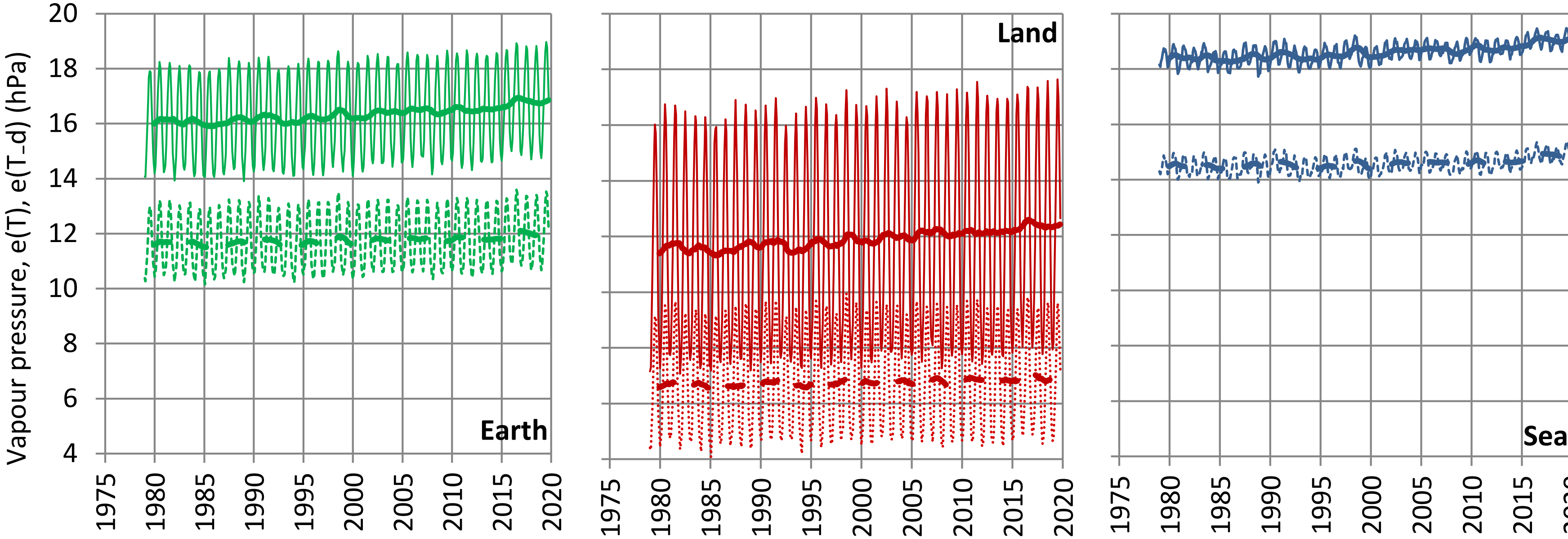
Why hydrologists have given so much energy in studying impacts a priori framed within **2-6%**?



Bologna, Italy (44.50°N, 11.35°E, +53.0 m). Available from the Global Historical Climatology Network (GHCN) – Daily (https://climexp.knmi.nl/gdcnprcp.cgi?WMO=ITE00100550). Uninterrupted for the period 1813-2007: 195 years. For the period 2008-2018, daily data are provided by the repository Dext3r of ARPA Emilia Romagna. **Total length: 206 years.**

Saturation vs. actual water vapour pressure

- The graph shows the variation of the water vapour pressure, saturation, $e(T)$, (continuous lines) and actual, $e(T_d)$, (dashed lines) for the average temperature T and dew point T_d.
- Clearly, the increase in $e(T_d)$ is smaller than that in $e(T_d)$, thus falsifying the constant relative humidity conjecture of IPCC.
- In particular, in land, where hydrological processes mostly occur, there is no increase in $e(T_d)$, while there is in $e(T)$.

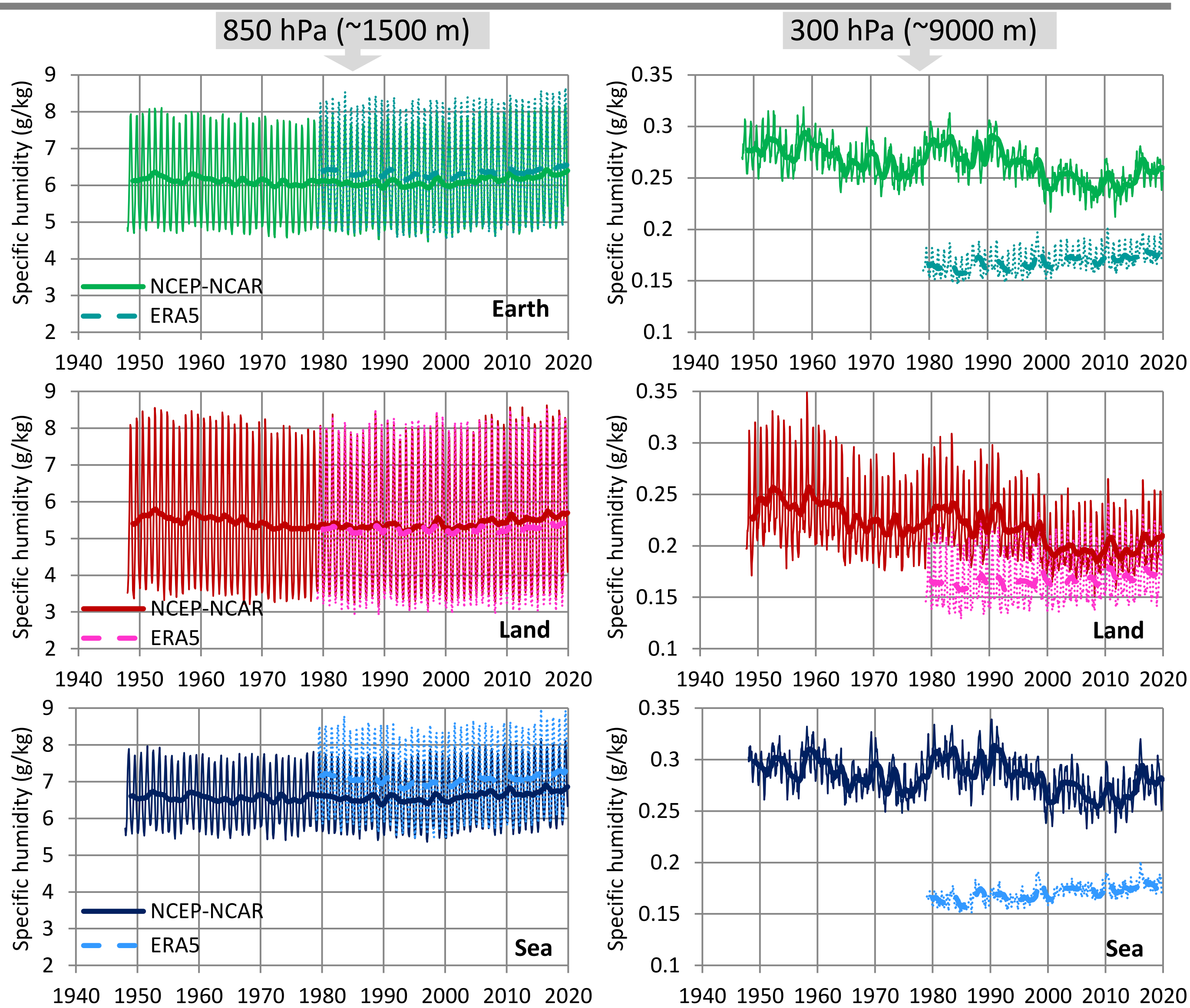


Source of graph: Koutsoyiannis (2020); source of data: ERA5 reanalysis, http://climexp.knmi.nl

Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Specific humidity: Does it increase?

- The specific humidity is fluctuating—not increasing monotonically.
- Hence, the IPCC conjecture is falsified.
- Interestingly, in the NCEP-NCAR reanalysis at the 300 hPa, the specific humidity is decreasing.



Source of graph: Koutsoyiannis (2020); data: NCEP-NCAR & ERA5 reanalysis, http://climexp.knmi.nl

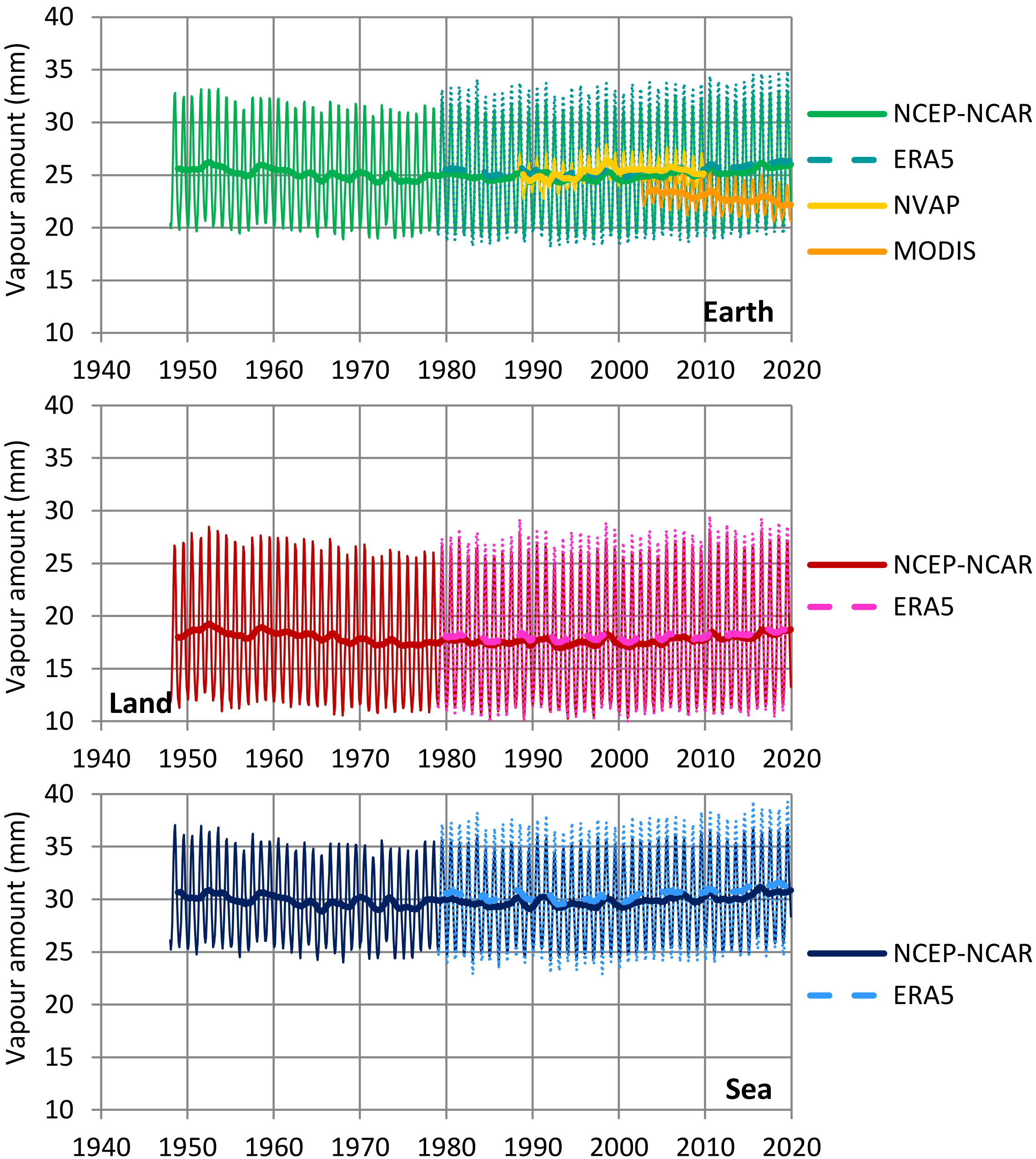
Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Water vapour amount: Does it increase?

- The water vapour amount in the atmosphere (most often misnamed as *precipitable water*) is fluctuating—not increasing monotonically.
- Hence, the IPCC conjecture is falsified.
- Interestingly, the satellite data (mostly MODIS) show a decreasing vapour amount.

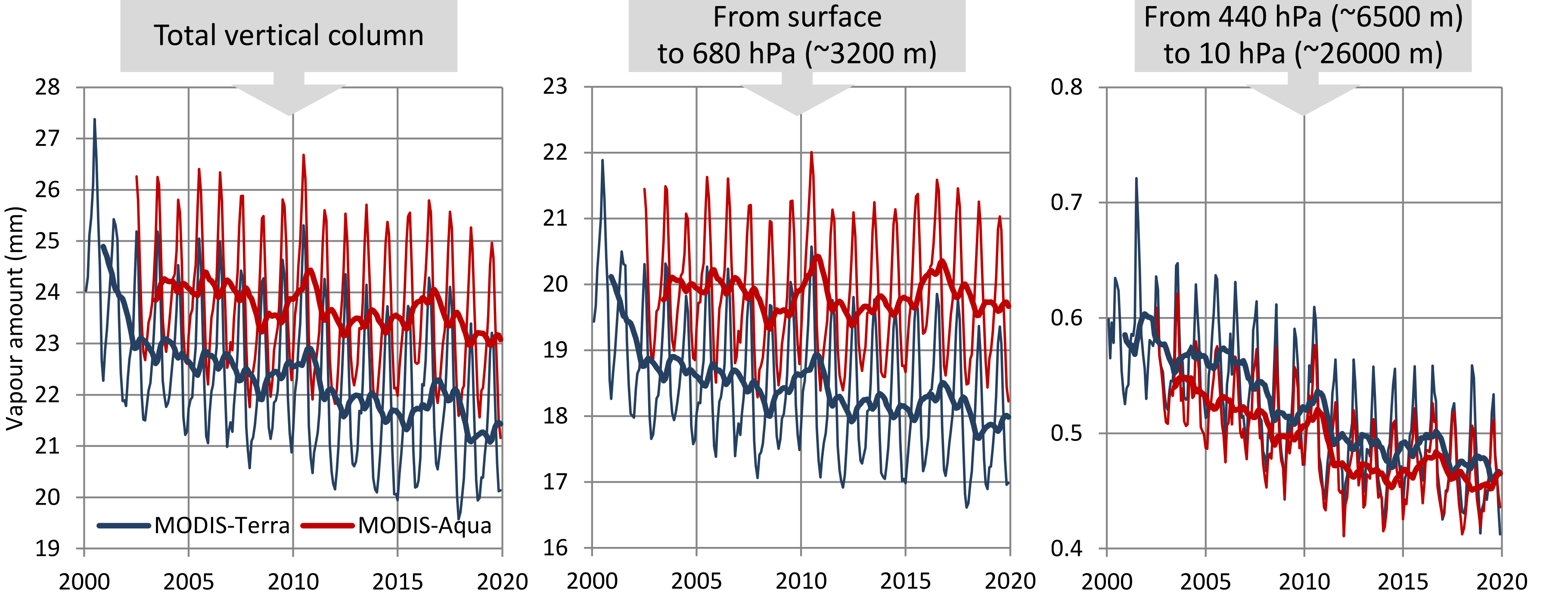
Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Source of graph: Koutsoyiannis (2020); reanalysis data (NCEP-NCAR & ERA5): http://climexp.knmi.nl; satellite data, NVAP: Vonder Haar et al. (2012) (Figure 4c, after digitization); satellite data, MODIS: https://giovanni.gsfc.nasa.gov/giovanni/; averages from Terra and Aqua platforms.



Satellite data of the 21st century for water vapour amount: Is there an increasing trend?

- Both Terra and Aqua satellite platforms for all atmospheric levels suggest decreasing trends.
- Hence, the data are opposite to the IPCC conjecture.

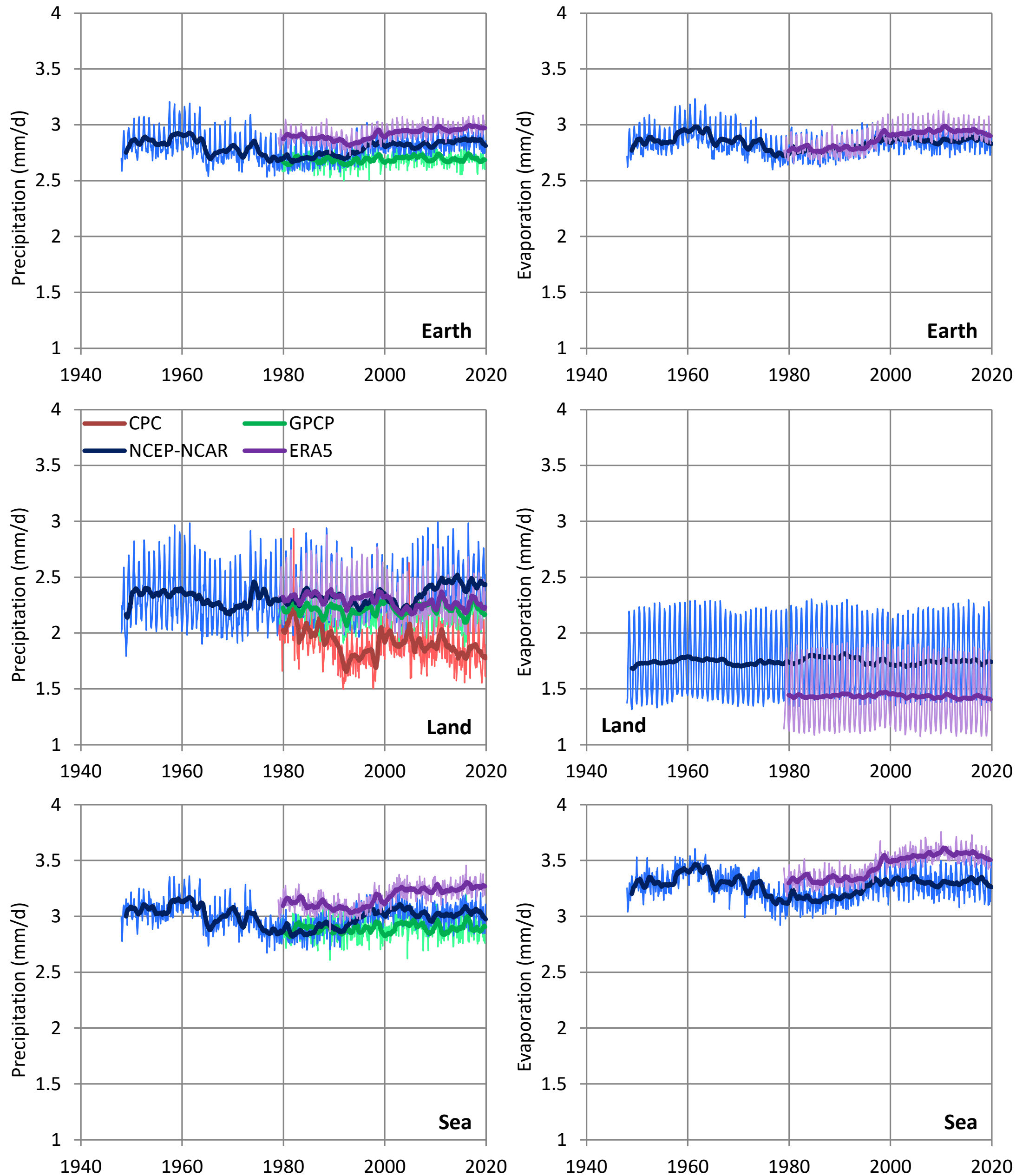


Source of graph: Koutsoyiannis (2020); MODIS data: https://giovanni.gsfc.nasa.gov/giovanni/

Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Precipitation and evaporation: Do they increase?

- Both precipitation and evaporation are fluctuating—not increasing monotonically.
- Hence, the IPCC conjecture is falsified.

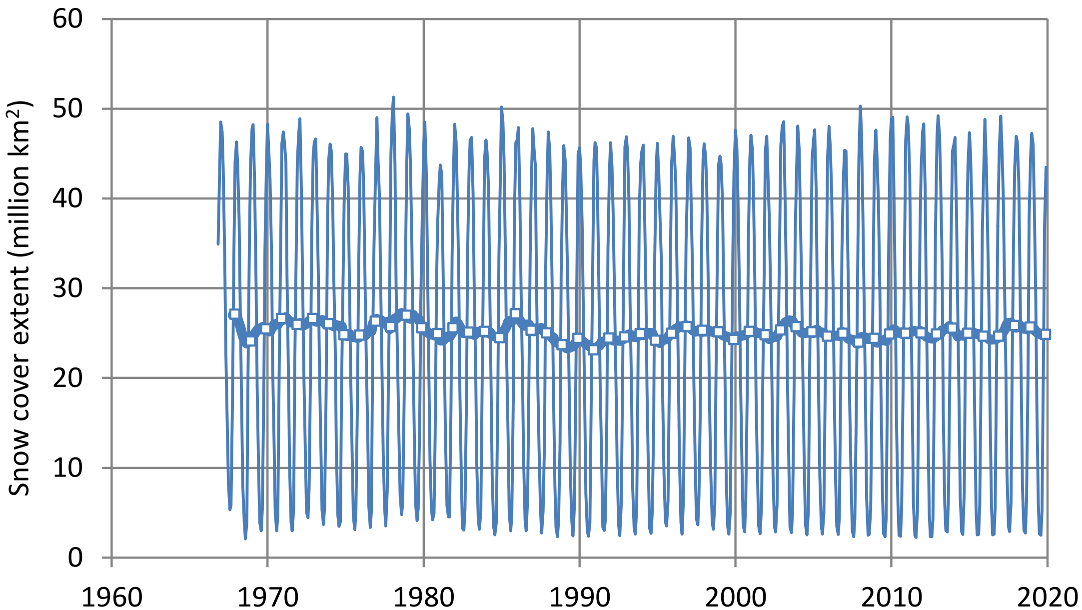


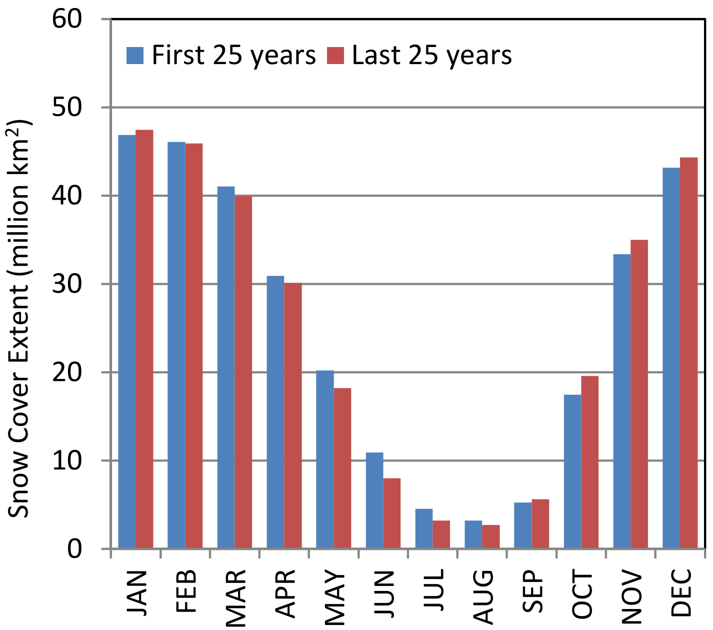
Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Source of graph: Koutsoyiannis (2020); reanalysis data (NCEP-NCAR & ERA5, gauge-based precipitation data gridded over land (CPC), and combined gauge and satellite precipitation data over a global grid (GPCP):http://climexp.knmi.nl

Snow: Does it tend to disappear?

- The snow part of precipitation is interesting to examine, as snow is more directly related to temperature and also affects Earth's albedo.
- Systematic satellite observations of snow cover extent exist only for the northern hemisphere.
- Despite temperature increase, no noticeable change appears on the annual basis.
- However, there are perceptible changes in the seasonal variation (right panel): in the most recent period the snow cover has decreased during the summer months and increased during the autumn and winter months.





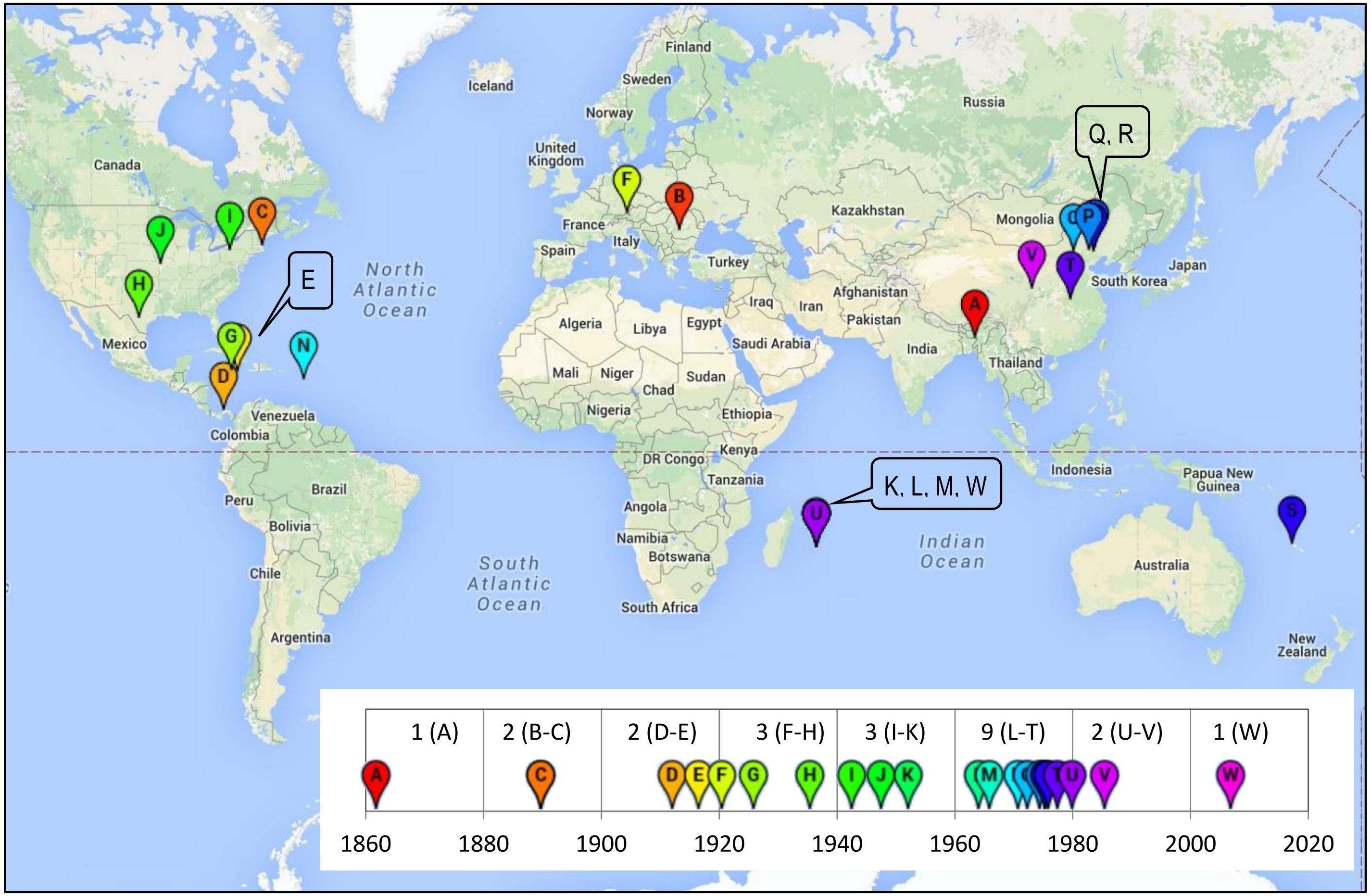
Source of graph: Koutsoyiannis (2020); source of snow cover data: Global Snow Laboratory (GSL), https://climate.rutgers.edu/snowcover/table_area.php

Thin and thick lines represent monthly values and running annual averages (right aligned), respectively. Squares are annual averages aligned at December of each year.

Part 9
The alleged intensification of the hydrological extremes

Point rainfall data: When did world records in rainfall occur?

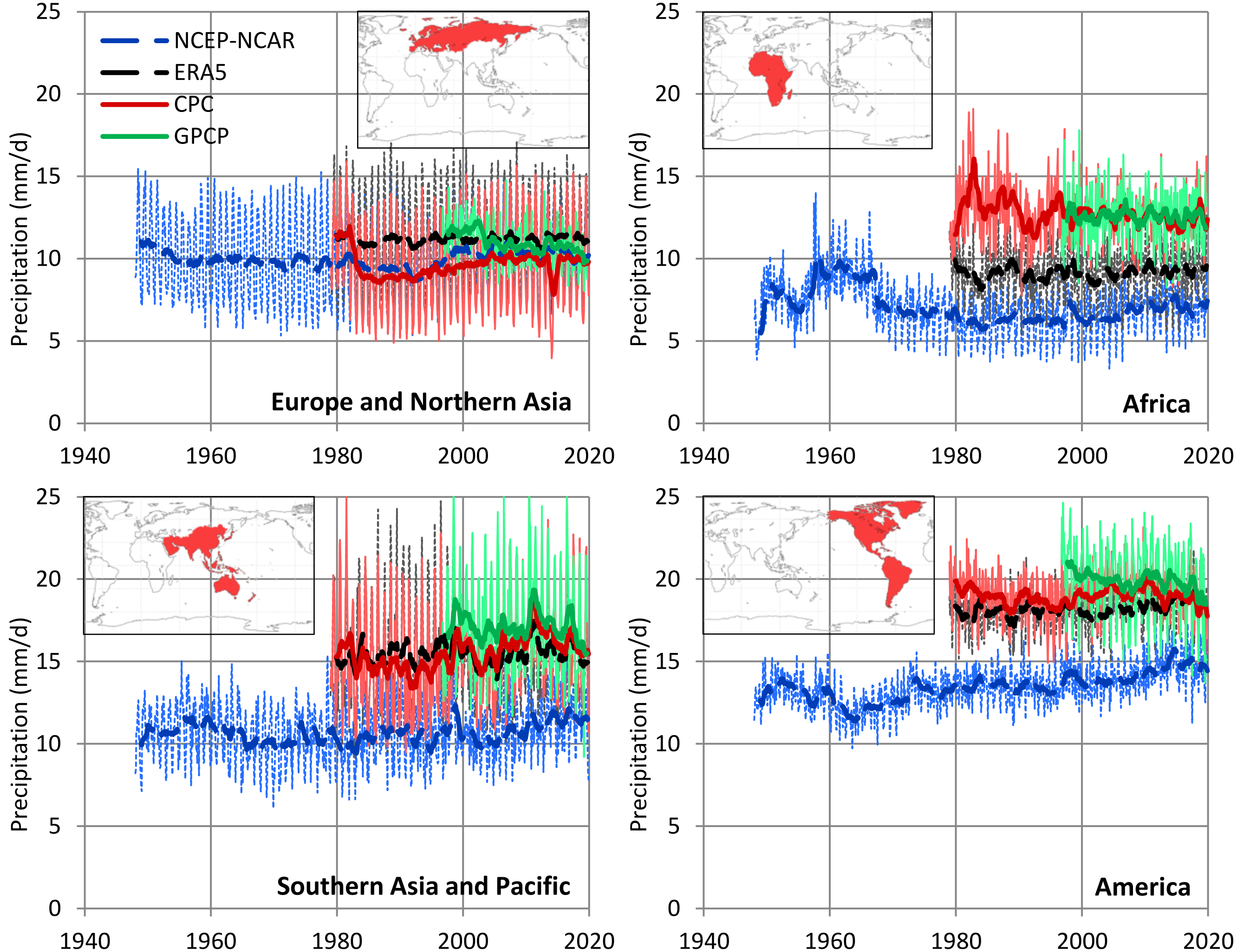
Data: World record point precipitation measurements for time scales ranging from 1 min to 2 years, compiled in Koutsoyiannis and Papalexiou (2017).



- The graph shows the locations and time stamps of the events producing record rainfall for various time scales ranging from 1 min to 2 years.
- The highest frequency of record rainfall events occurred in the period 1960-80; later the frequency was decreased substantially.

Monthly maximum daily precipitation: Is it increasing?

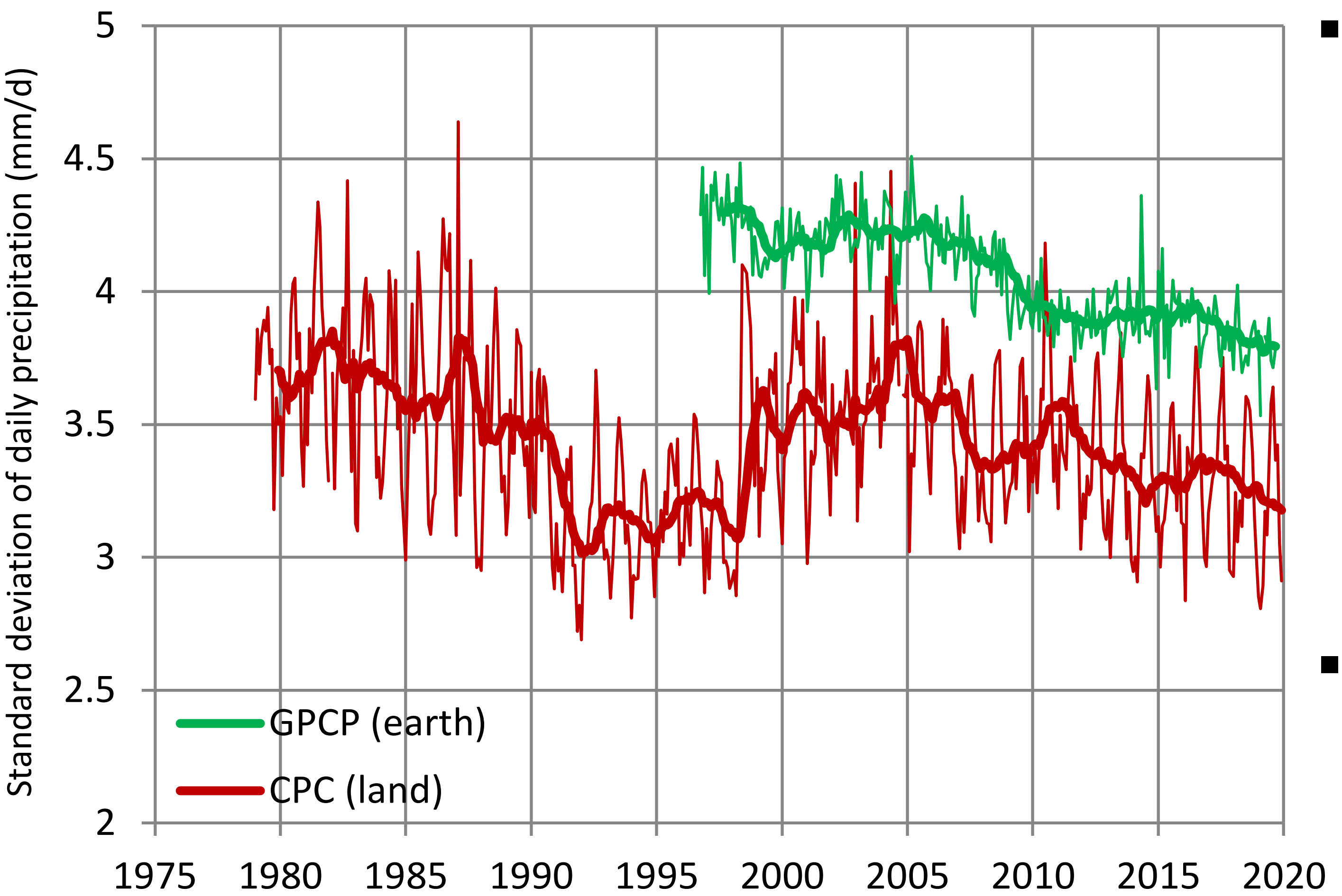
- The graphs show the variation of the monthly maximum daily precipitation areally averaged over the continents.
- In all continents, the monthly maximum daily precipitation is fluctuating—not increasing monotonically.
- In particular, the satellite observations show decreasing, rather than increasing trends in the 21st century.



Source of graph: Koutsoyiannis (2020); reanalysis data (NCEP-NCAR & ERA5, gauge-based precipitation data gridded over land (CPC), and combined gauge and satellite precipitation data over a global grid (GPCP): http://climexp.knmi.nl

Thin and thick lines represent monthly values and running annual averages (right aligned).

Daily precipitation variability: Is it increasing?



- The standard deviation of daily rainfall, areally averaged, as seen both from CPC and GPCP observational data, decreases, thus signifying deintensification of extremes in the 21st century.
- Again, it will be more prudent to speak about fluctuations rather than deintensification.

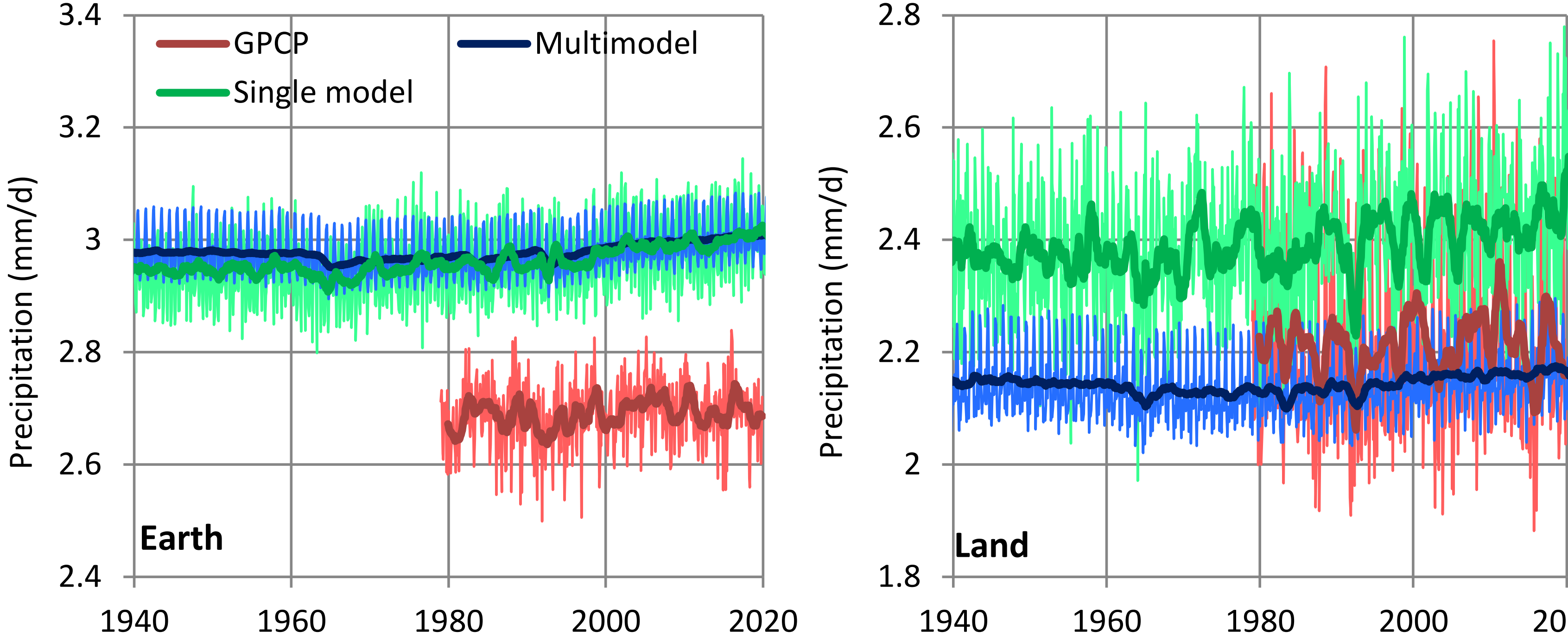
Source of graph: Koutsoyiannis (2020); gauge-based precipitation data gridded over land (CPC), and combined gauge and satellite precipitation data over the entire Earth (GPCP): http://climexp.knmi.nl

Thin and thick lines of the same colour represent monthly values and running annual averages (right aligned), respectively.

Part 10
Dealing with the future of climate and water

Can climate models be used to deal with the future?

Short answer: **No**. They have not provided skill for the past. Notice: (1) the large error of the “Multimodel” ensemble in terms of the mean; (2) the increasing trend of climate model outputs after 1980, which did not appear in reality.

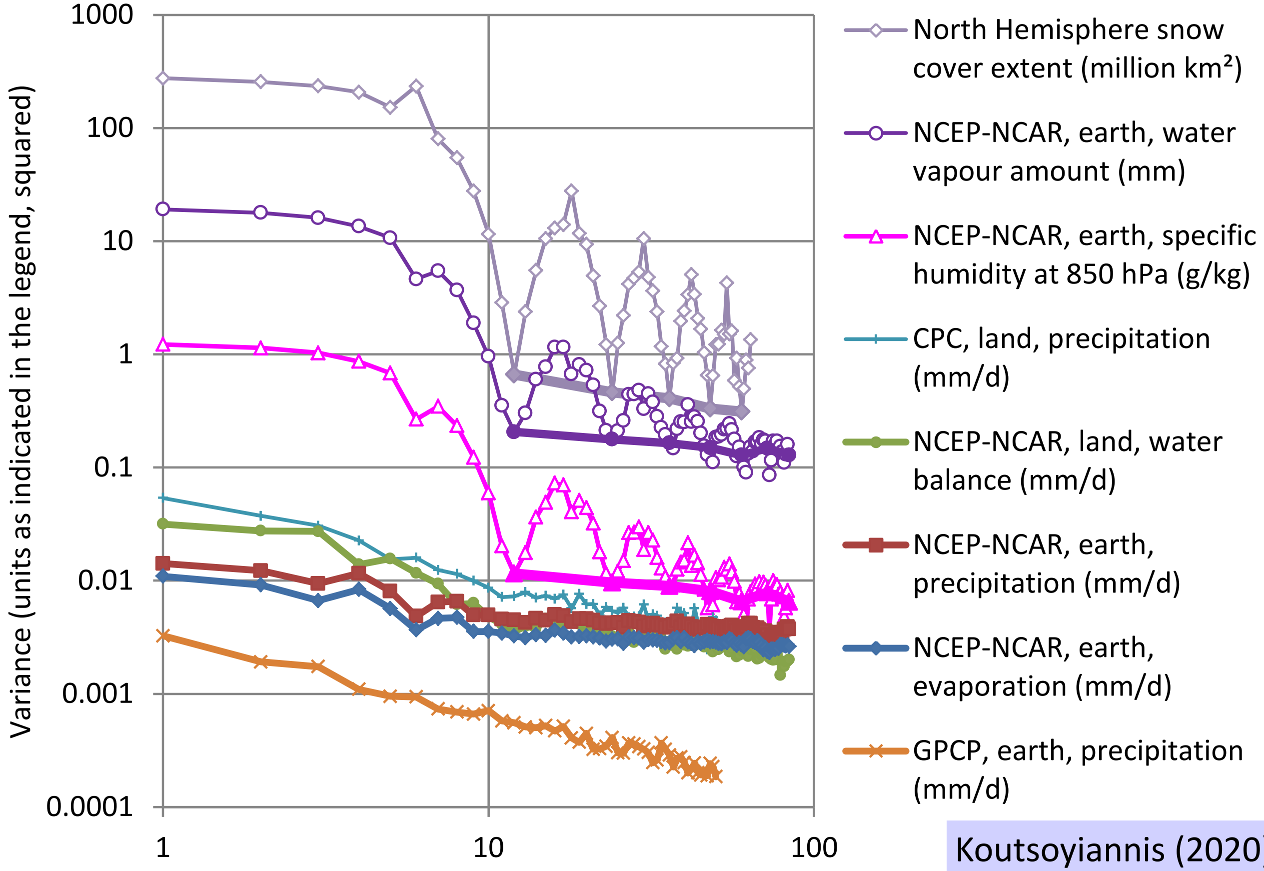


Source of graph: Koutsoyiannis (2020); observations come from the combined gauge and satellite precipitation data over a global grid (GPCP); climate model outputs are for the scenario “RCP8.5” (frequently referred to as “business as usual”); “Multimodel” refers to CMIP5 scenario runs (entries: CMIP5 mean – rcp85) and “Single model” refers to CCSM4 – rcp85 (ensemble member 0), where CCSM4 stands for Community Climate System Model version 4, released by NCAR. Data and model outputs are accessed through http://climexp.knmi.nl

Thin and thick lines represent monthly values and running annual averages (right aligned).

What is the scientific approach to deal with the future?

- Only stochastic approaches can provide means to deal with the future of non-trivial complex systems.
- Stochastics cannot make accurate predictions but can quantify uncertainty.
- Uncertainty is amplified because of the long-term fluctuations apparent in all processes.
- These can be modelled as Hurst-Kolmogorov dynamics.

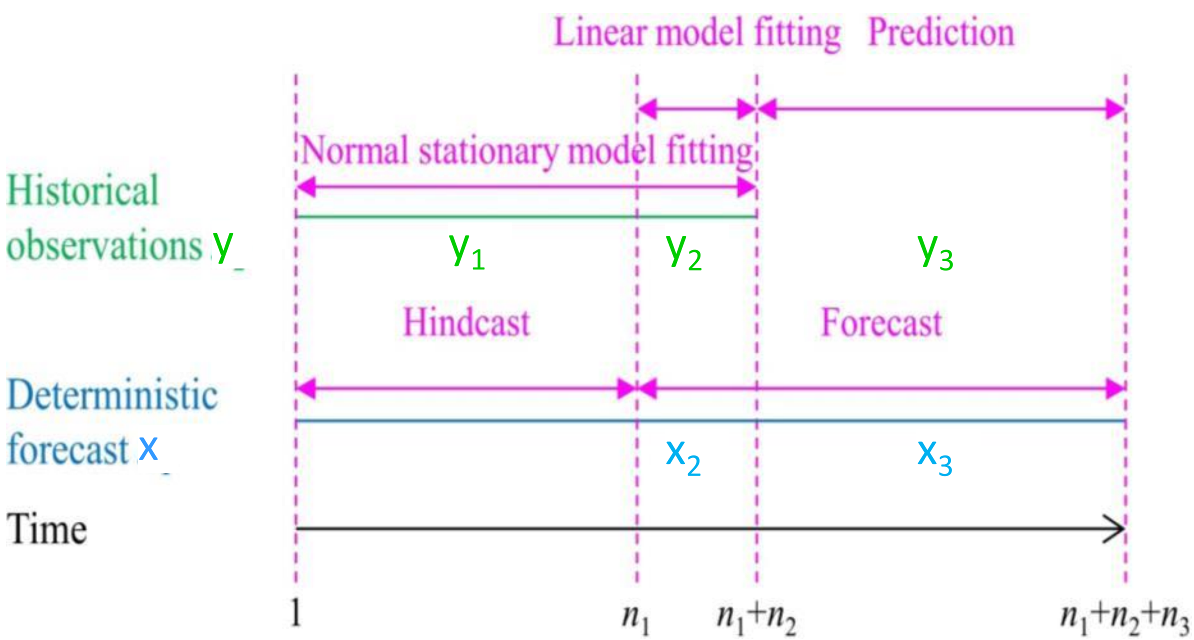


Koutsoyiannis (2020)

Climacograms of the indicated processes are calculated from monthly time series; for some series with prominent seasonality the climacograms from annual time series are also plotted with thicker lines of same colour. For time scales larger than annual, all slopes in the double logarithmic plots are close to –0.2, suggesting a Hurst parameter 0.90 or larger. Exceptions are the NH snow cover extent with a slope of –0.47, suggesting a Hurst parameter 0.76 and the GPCP precipitation series with a slope of –0.72, suggesting a Hurst parameter 0.64.

Last attempt to utilize climate models: Can we convert them to stochastic?

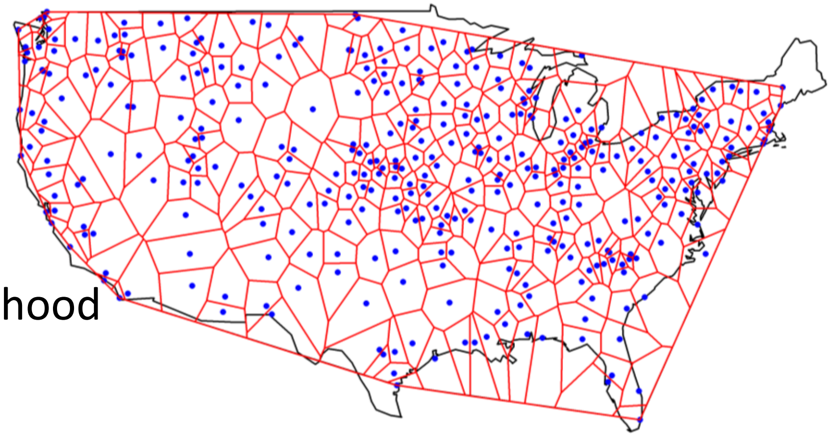
- Yes, we can: by incorporating one or many deterministic forecasts into an initially independent stochastic model in a Bayesian framework.
- If the climate model contains useful information, the stochastic framework will utilize it to improve the stochastic prediction; otherwise it will discard it.
- With reference to the sketch on the right, we simulate the unknown future $\boldsymbol{y}_3$ conditional on the known past $\boldsymbol{y}_1$, $\boldsymbol{y}_2$ and the deterministic model outputs $\boldsymbol{x}_2$, $\boldsymbol{x}_3$ by
  $h(\boldsymbol{y}_3 | \boldsymbol{y}_1, \boldsymbol{y}_2, \boldsymbol{x}_2, \boldsymbol{x}_3)$
  $\propto f(\boldsymbol{x}_3 | \boldsymbol{y}_3)\ g(\boldsymbol{y}_3 | \boldsymbol{y}_1, \boldsymbol{y}_2)$
  where $f(\boldsymbol{x}_3 | \boldsymbol{y}_3)$ is the model likelihood (evaluated from $\boldsymbol{x}_2$ and $\boldsymbol{y}_2$) and the other functions are conditional densities.



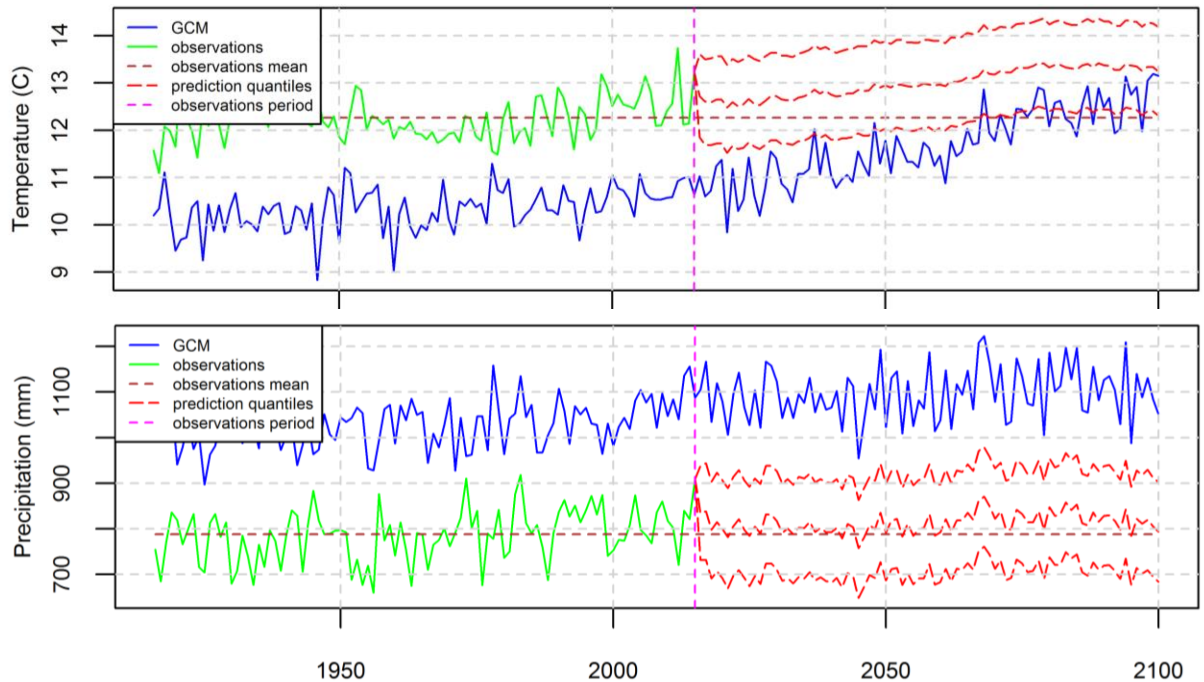
Tyralis and Koutsoyiannis (2017)

Application to the climate of the USA

Tyralis and Koutsoyiannis (2017)



- Historical data for temperature and precipitation from 362 and 319 stations, respectively, have been used to estimate the areal averages (historical observations).
- Deterministic forecasts were taken from 14 different climate models. The model likelihood was evaluated in the period 2006-15.
- The example on temperature (95% prediction intervals) shows a slight increase in annual temperature in the USA if conditioned on the output of MRI-CGCM3 climate model.
- The example on precipitation shows indifference despite conditioning on the GISS-E2-H climate model.

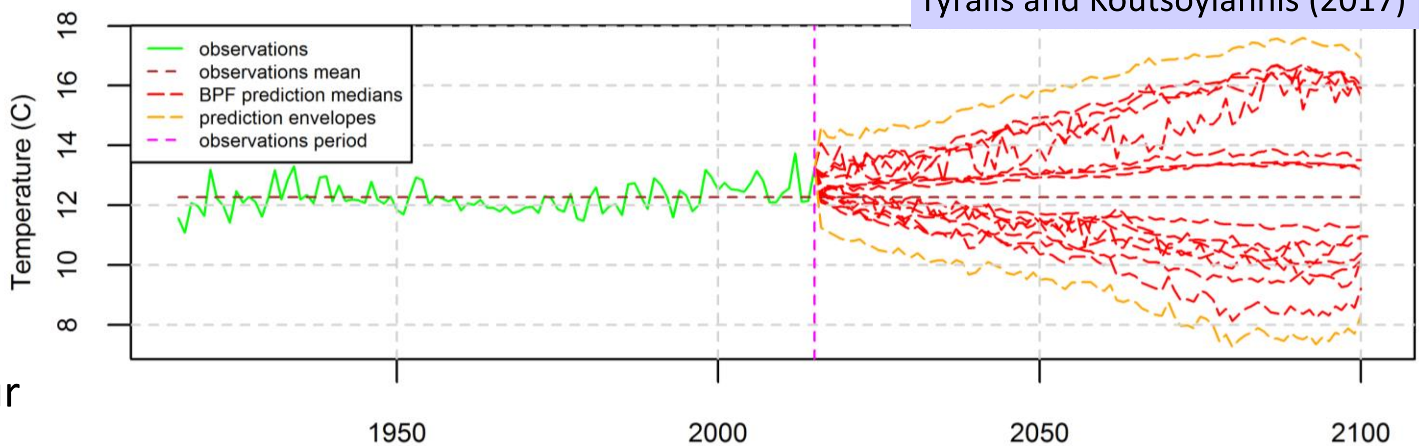


Multimodel approach: The Bayesian Thistle

- Some models have negative correlation with historical data.
- As a result, the predicted temperature rise turns into decline in the stochastic framework.
- In turn, this results in huge uncertainty if we take the envelope from many climate models conditioning our stochastic model.
- The resulting shape looks as a **thistle**.

Caution: Envelops and spaghetti graphs are not stochastically sound, but have been popular in climatology communications.

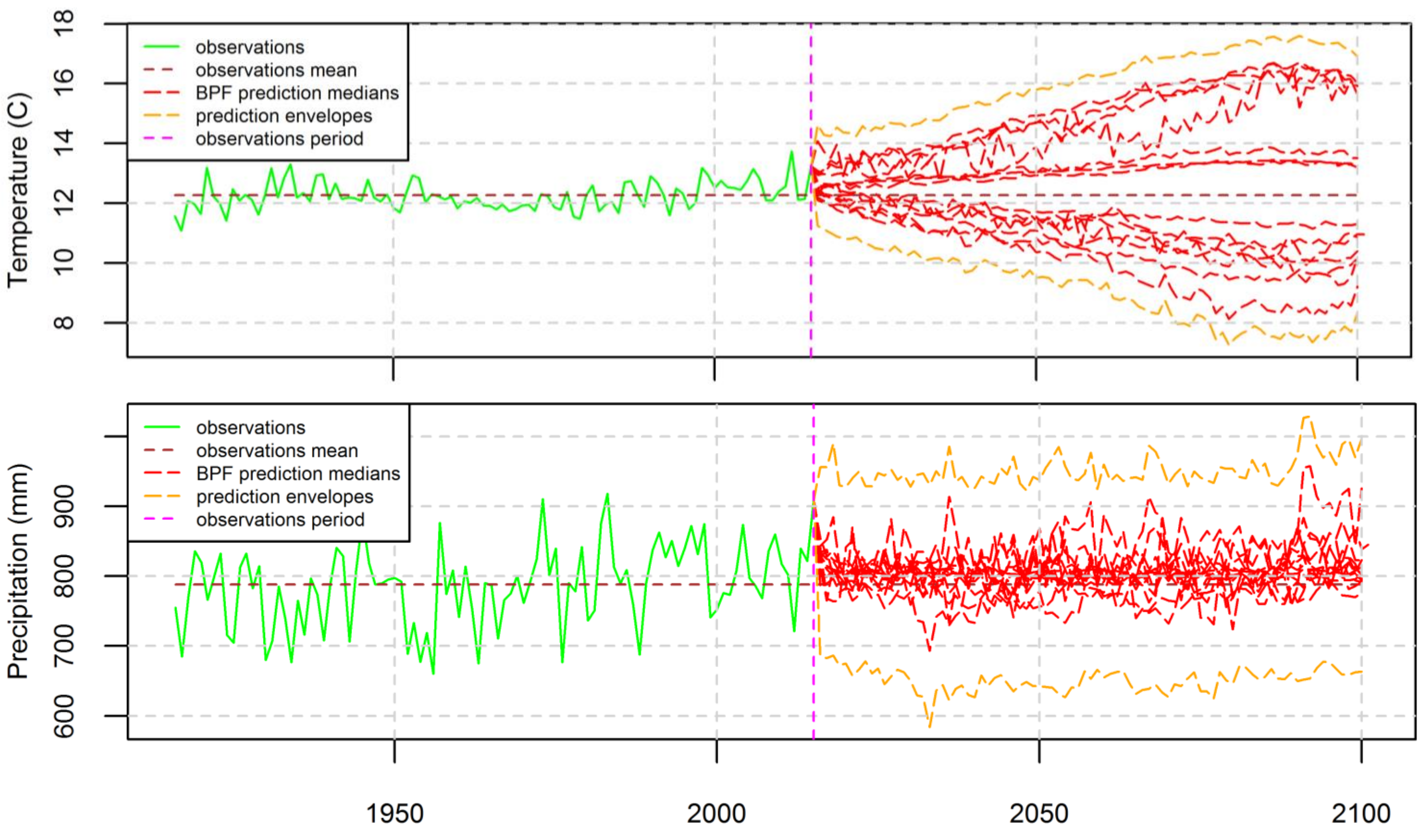
Tyralis and Koutsoyiannis (2017)



Final multimodel results for temperature and precipitation in the USA

- If all models are taken into account, the temperature change up to 2100 could be somewhere in the range −4 to 4 °C.
- Precipitation does not change by conditioning on all models. Only its uncertainty increases slightly (±50 mm, if compared to that without conditioning on models).

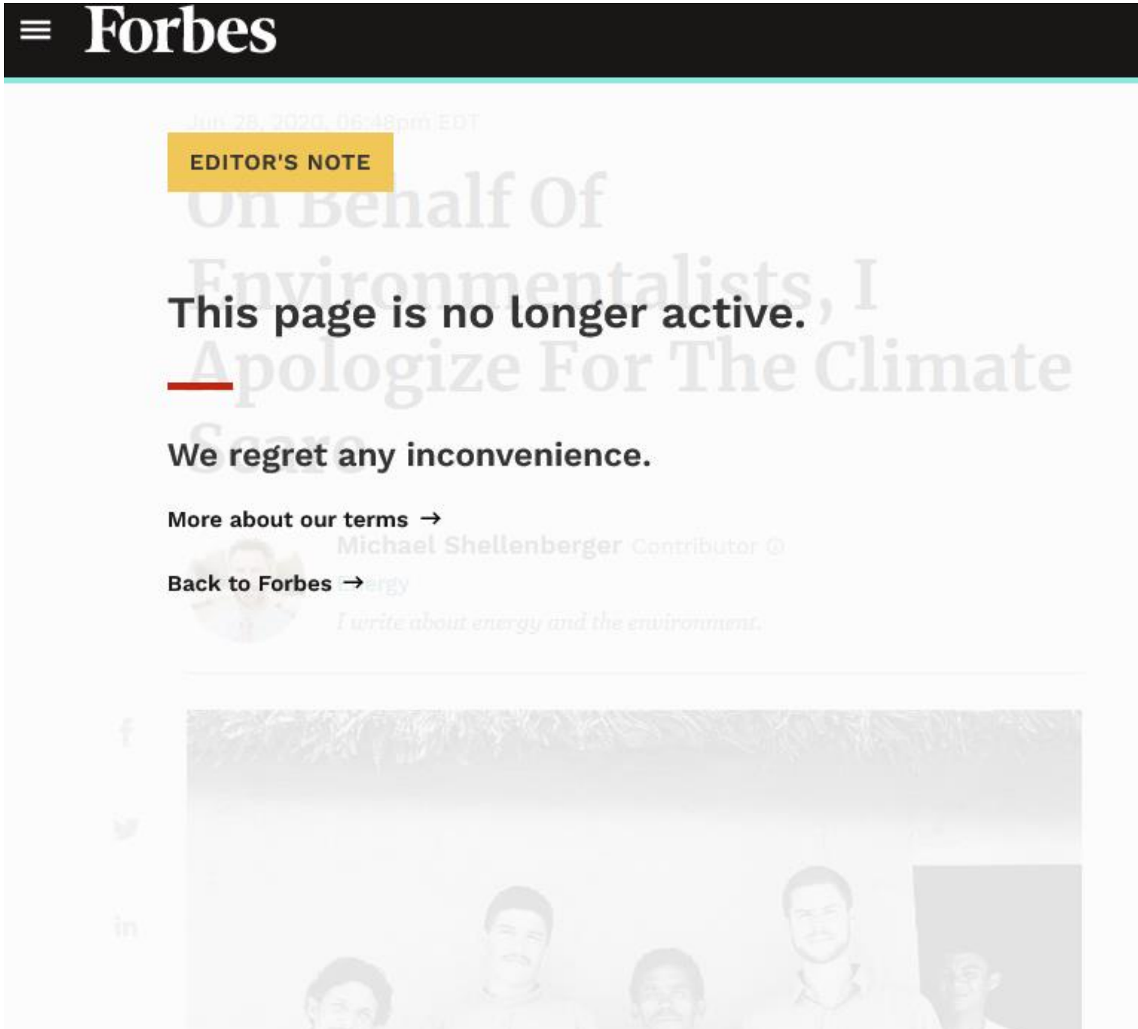
Caution: Same as in the previous slide.



Tyralis and Koutsoyiannis (2017)

Epilogue: Climate scare is real

Environmentalists’ apology for the climate scare



A simple trick to read the “no longer active” page

1. Go to the link given below.
2. Use the browser’s menu item “Save the page as …” and save the page as html.
3. Open the page with any html editor, e.g. Word.

https://www.forbes.com/sites/michaelshellenberger/2020/06/28/on-behalf-of-environmentalists-i-apologize-for-the-climate-scare/#1d966a951fa8

The recovered text of a brave apology – beginning

|Jun 28, 2020,06:48pm EDT

On Behalf Of Environmentalists, I Apologize For The Climate Scare

Michael Shellenberger Contributor

Energy

I write about energy and the environment.

On behalf of environmentalists everywhere, I would like to formally apologize for the climate scare we created over the last 30 years. Climate change is happening. It's just not the end of the world. It's not even our most serious environmental problem.

I may seem like a strange person to be saying all of this. I have been a climate activist for 20 years and an environmentalist for 30.

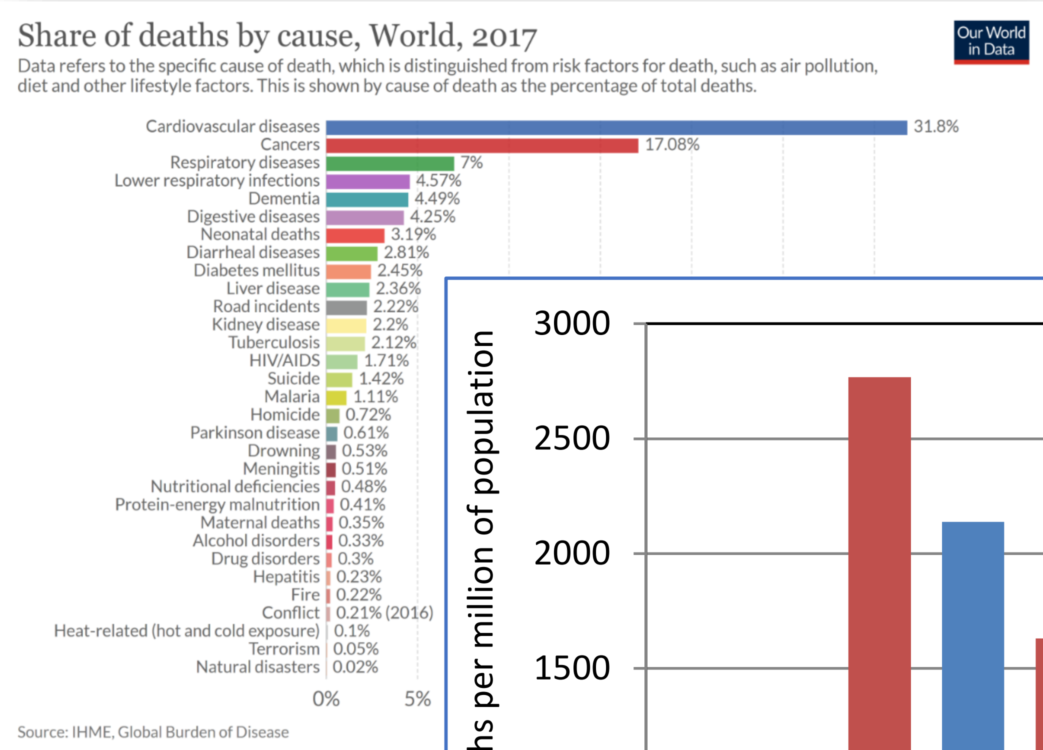
But as an energy expert asked by Congress to provide objective expert testimony, and invited by the Intergovernmental Panel on Climate Change (IPCC) to serve as Expert Reviewer of its next Assessment Report, I feel an obligation to apologize for how badly we environmentalists have misled the public.

The recovered text of a brave apology – continued

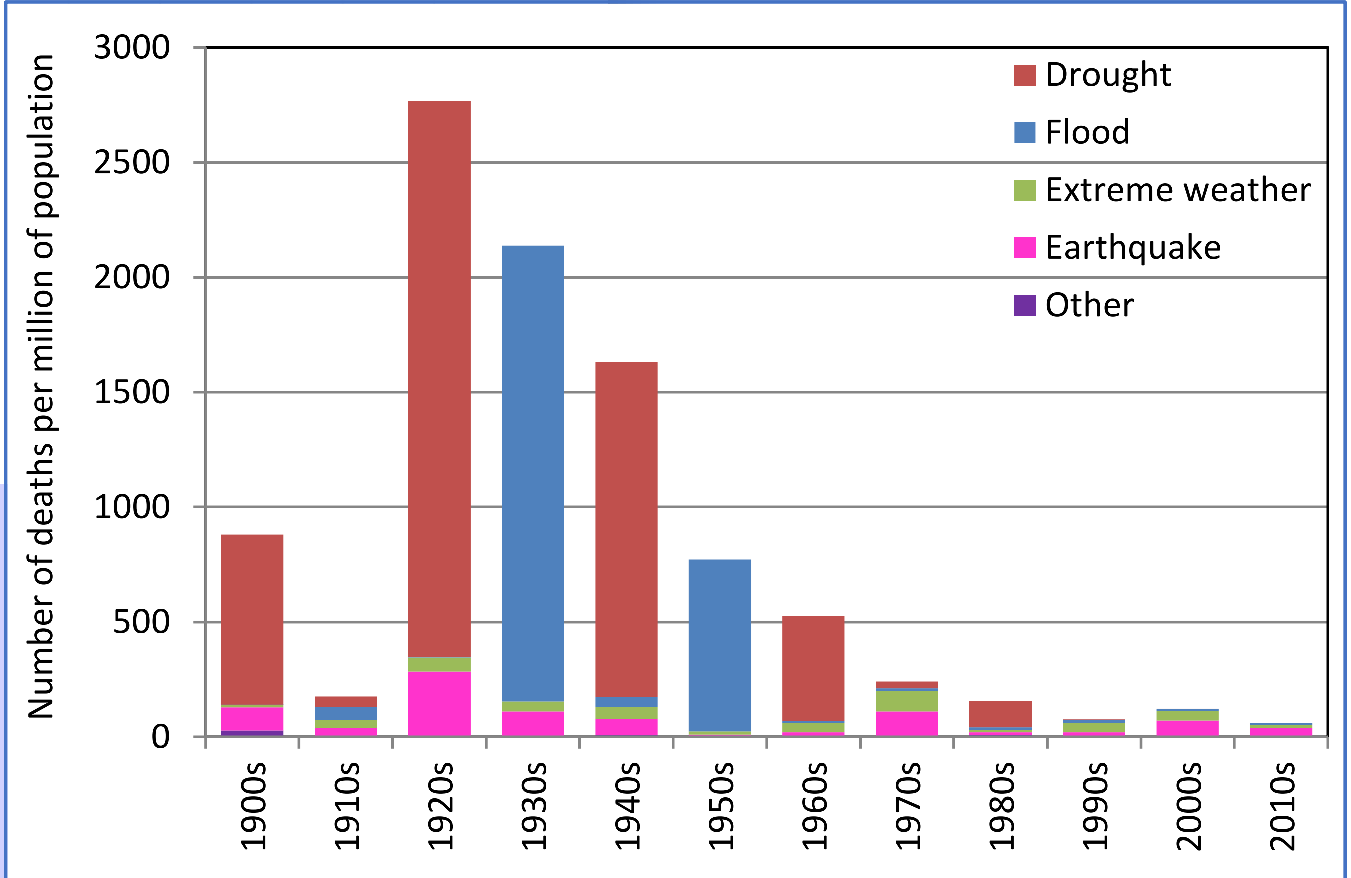
Here are some facts few people know:

- *Humans are not causing a "sixth mass extinction"*
- *The Amazon is not "the lungs of the world"*
- *Climate change is not making natural disasters worse*
- *Fires have declined 25% around the world since 2003*
- *The amount of land we use for meat — humankind's biggest use of land — has declined by an area nearly as large as Alaska*
- *The build-up of wood fuel and more houses near forests, not climate change, explain why there are more, and more dangerous, fires in Australia and California*
- *Carbon emissions have been declining in rich nations for decades and peaked in Britain, Germany and France in the mid-seventies*
- *Adapting to life below sea level made the Netherlands rich not poor*
- *We produce 25% more food than we need and food surpluses will continue to rise as the world gets hotter*
- *Habitat loss and the direct killing of wild animals are bigger threats to species than climate change*
- *Wood fuel is far worse for people and wildlife than fossil fuels*
- *Preventing future pandemics requires more not less "industrial" agriculture*

Engineers' epinicion on actual risk reduction



Instead of casting pessimistic prophesies about the future, engineers improved hydro-technology, water management, and risk assessment and reduction.



Upper graph: https://ourworldindata.org/grapher/share-of-deaths-by-cause?time=latest
Lower graph: Koutsoyiannis (2020); data from https://ourworldindata.org/world-population-growth; https://ourworldindata.org/ofdacred-international-disaster-data

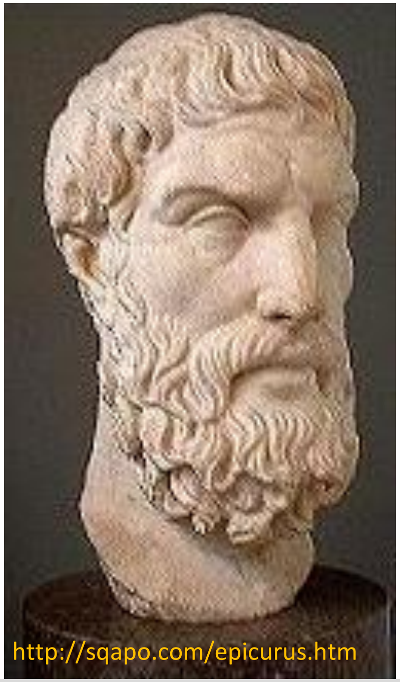
Epicurus's contribution in envisaging the aim of science in dispelling fears and myths, and the role of scientists

- *Οὐκ ἦν **τὸ φοβούμενον λύειν** ὑπὲρ τῶν κυριωτάτων μὴ κατειδότα τίς ἡ **τοῦ σύμπαντος φύσις**, ἀλλ᾽ ὑποπτεύοντά τι τῶν κατὰ τοὺς μύθους.*

  It is impossible for someone to dispel his fears about the most important matters if he doesn't know the nature of the universe but still gives credence to myths (Principal Doctrines, 12).

- *Παρρησίᾳ γὰρ ἔγωγε χρώμενος φυσιολογῶν χρησμωδεῖν τὰ συμφέροντα πᾶσιν ἀνθρώποις μᾶλλον ἂν βουλοίμιν, κἂν μηδεὶς μέλλῃ συνήσειν, ἤ συγκατατιθέμενος τοῖς δόξαις καρποῦσθαι τὸν πυκνὸν παραπίπτοντα παρὰ τὸν πολλῶν ἔπαινον.*

  As I study nature, I would prefer to speak all truth bravely about what is beneficial to all people, even though it be understood by none, rather than to conform to popular opinion and thus gain the constant praise of the many (Vatican Sayings, 29).



Epicurus
341–270 BC

Science (= pursuit of the truth) vs. sophistry

φίλος μέν Σωκράτης, ἀλλά φιλτάτη ή ἀλήθεια.
(Latin version: *Amicus Socrates, sed magis amica veritas.*)

Socrates is dear (friend), but truth is dearest.

(Ammonius, Life of Aristotle)

ἔστι γὰρ ἡ σοφιστικὴ φαινομένη σοφία οὖσα δ᾽ οὔ, καὶ ὁ σοφιστὴς χρηματιστὴς ἀπὸ φαινομένης σοφίας ἀλλ᾽ οὐκ οὔσης.

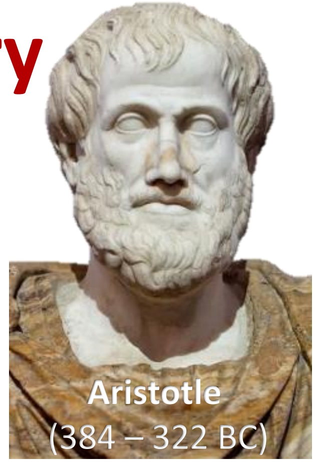
Sophistry is the semblance of wisdom without the reality, and the sophist is one who makes money from apparent but unreal wisdom.

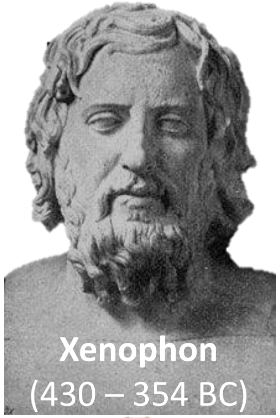
(Aristotle, On Sophistical Refutations, 165a21)

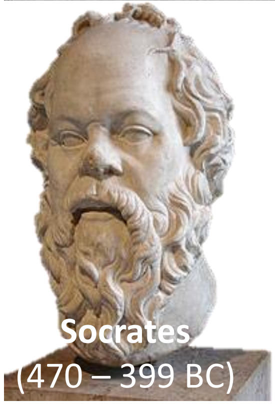
καὶ τὴν σοφίαν ὡσαύτως τοὺς μὲν ἀργυρίου τῷ βουλομένῳ πωλοῦντας σοφιστὰς ὥσπερ πόρνους ἀποκαλοῦσιν.

Those who offer wisdom to all comers for money are known as sophists, just like prostitutors.

(Xenophon, Memorabilia, 1.6.13, quoting Socrates)







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