HIC 2018

13TH INTERNATIONAL HYDROINFORMATICS CONFERENCE HIC 2018

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Climate change impacts on hydrological science

How the climate change agenda has lowered the scientific level of hydrology

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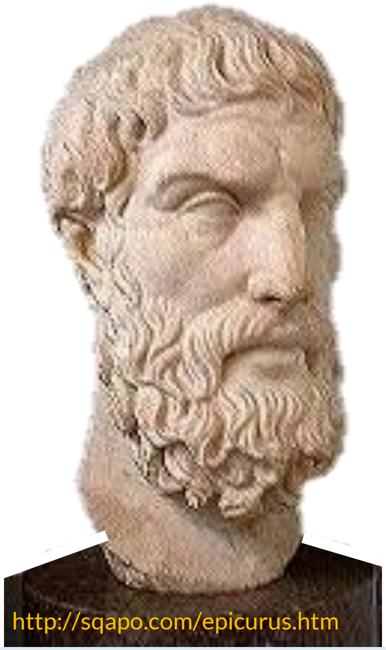
Presentation available online: http://itia.ntua.gr/1847/

Prologue: setting the scene



Epicurus
341–270 BC

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

As I study nature, ***I would prefer to speak 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.*

(Epicurus, Vatican Sayings, 29)

Bring' vor, was wahr ist;
Schreib' so, dass es klar ist
Und verficht's, bis es dir gar ist!

Put forward what is ***true****;*
So write that it may be ***clear***
Fight for it to the end!

DK's variant:
"what is true" →
what I believe is true

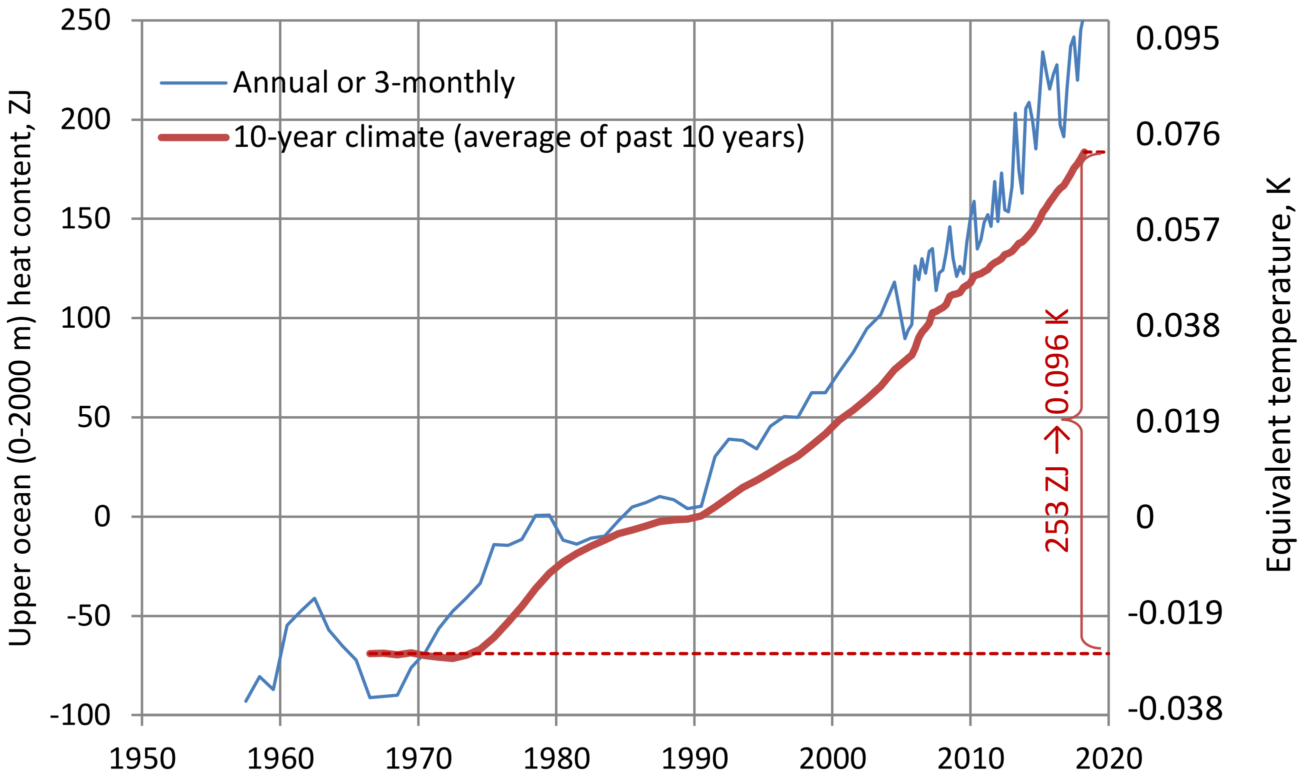
(Ludwig Boltzmann, *Vorlesungen über die Principe der Mechanik*, 1897)

Ludwig Boltzmann
1844 – 1906

Part 1
Some (soft*) facts about recent climate with particular emphasis on processes relevant to hydrology

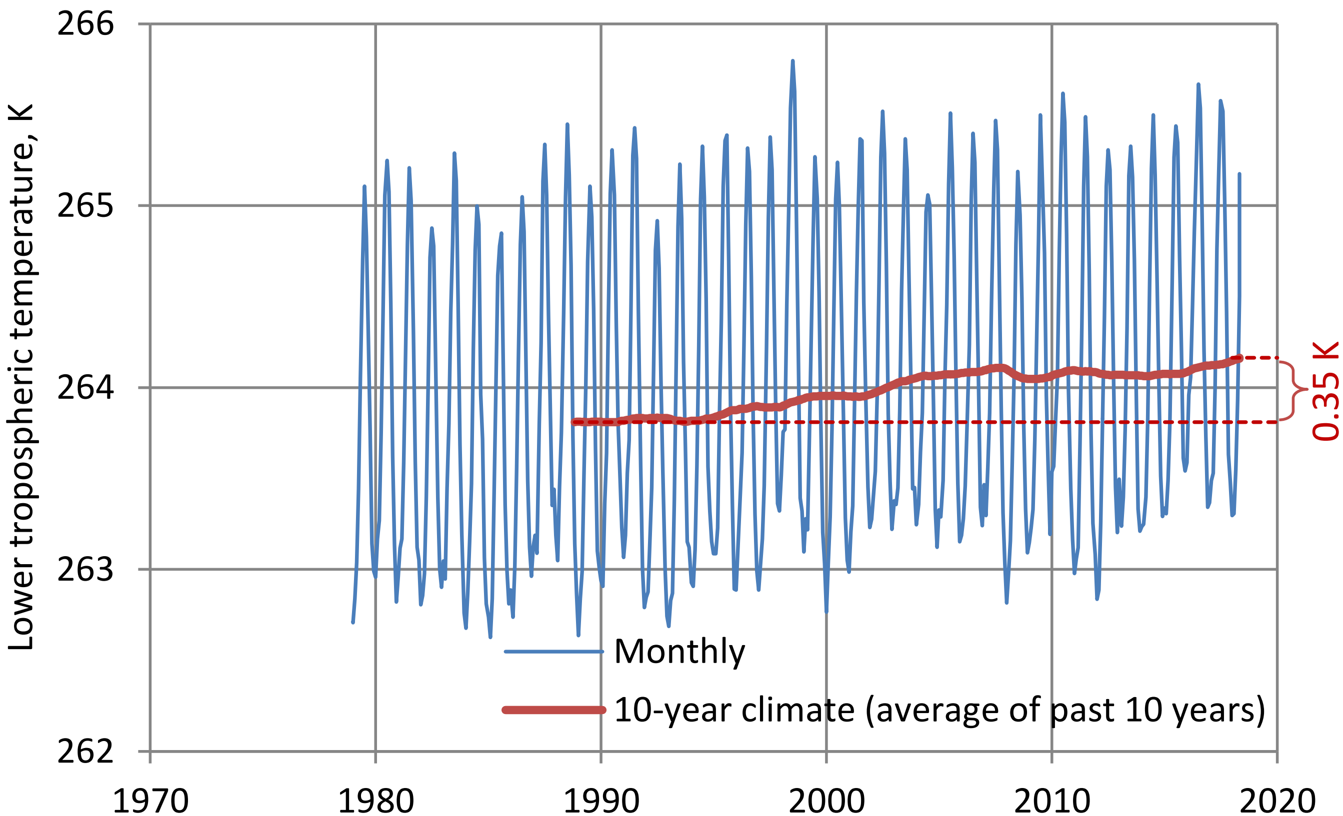
*results from analyses of complex data sets or from other studies

Ocean heat content has been increased



- **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, somewhat lower than in Koutsoyiannis, 2017).
- **Result**: During the 50-year period 1968 -2018 there has been an increase of 253 ZJ in the upper ocean heat content averaged globally at a 10-year climatic scale; this corresponds to a temperature increase of 0.096 K (average rate 0.018 K/decade).

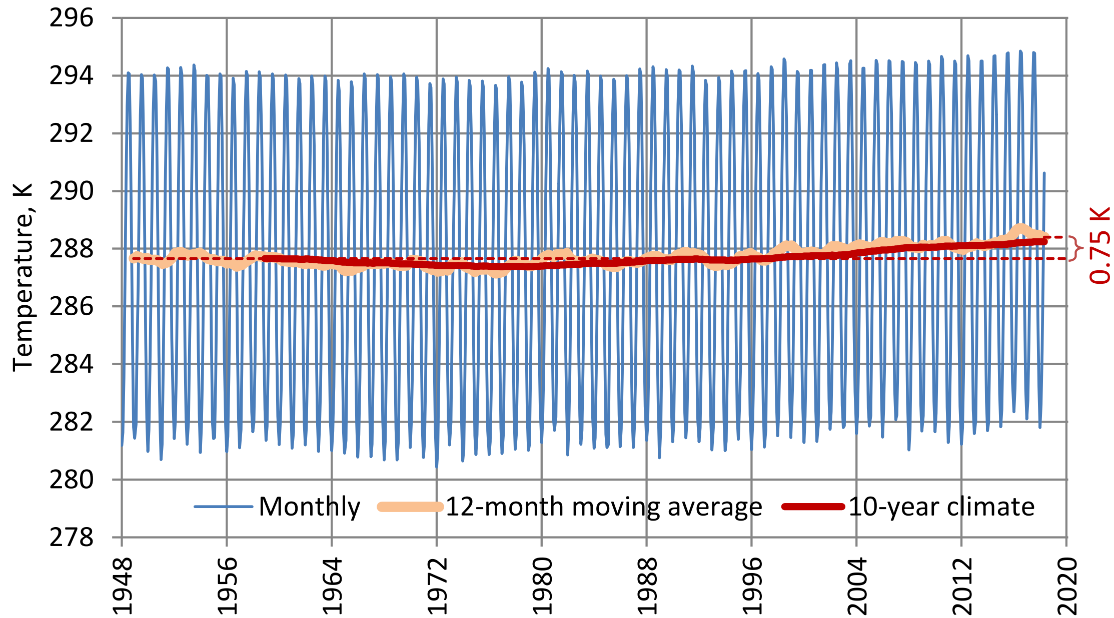
Temperature of the lower troposphere has been increased

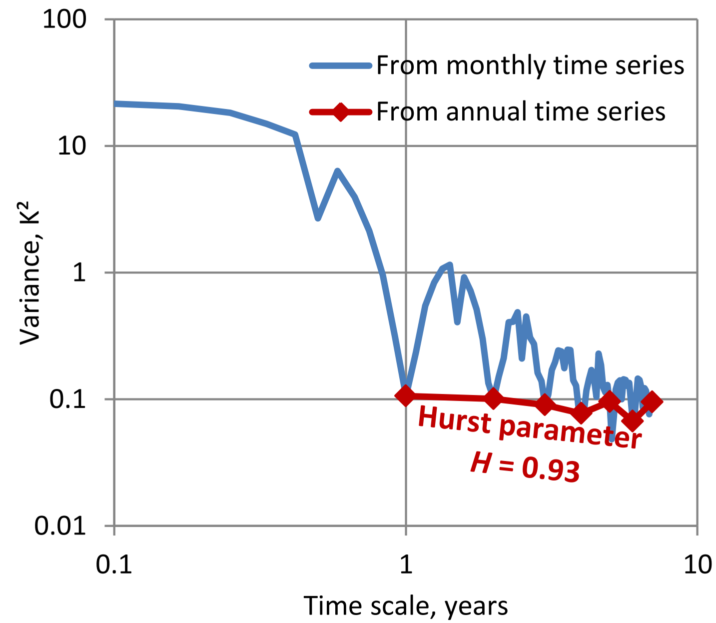


Updated with data of June 2018

- **Data**: UAH satellite data for the lower troposphere (global average) gathered by advanced microwave sounding units on NOAA and NASA satellites (from http://www.nsstc.uah.edu/data/msu/v6.0/tlt/uahncdc_lt_6.0.txt with monthly averages from http://www.drroyspencer.com/2016/03/uah-v6-lt-global-temperatures-with-annual-cycle/).
- **Result**: During the 30-year period 1988 – 2018 there has been an increase of 0.35 K in the globally averaged 10-year climatic temperature (**increase 0.11 K/decade**).

Earth surface temperature has been increased

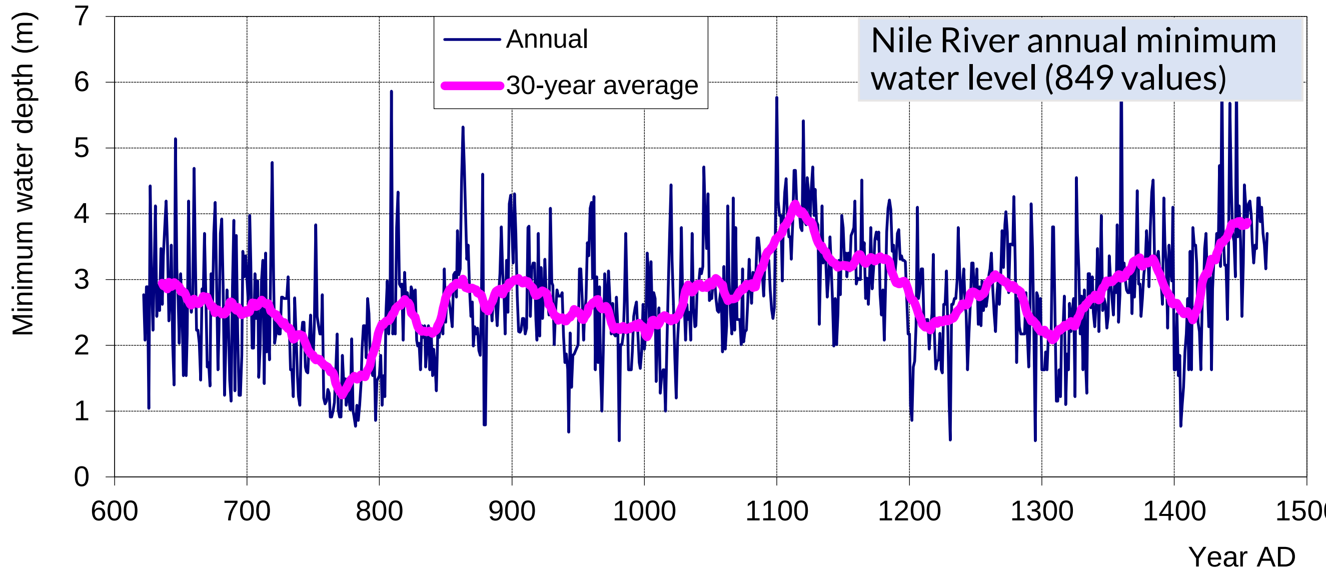




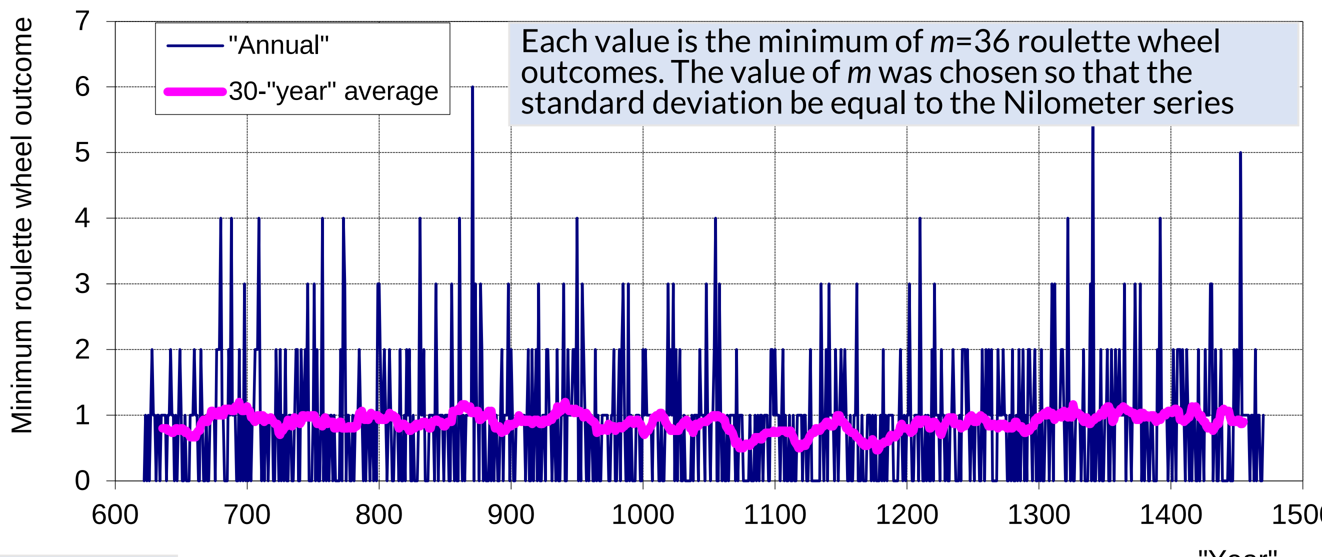
- **Data**: Monthly NCEP/NCAR R1 2m air temperature (K) averaged over the globe (from NCEP-NCAR Reanalysis 1, retrieved through KNMI Climate Explorer, http://climexp.knmi.nl/data/inlhtfl_0-360E_-90-90N_n.dat)
- **Result 1**: During the 60-year period 1958 – 2018 there has been an increase of 0.75 K in the globally averaged 10-year climatic temperature (**increase 0.13 K/decade**).
- **Result 2**: The climatic temperature has been fluctuating, slightly dropping before 1978 and then increasing. The fluctuation is consistent with the **Hurst-Kolmogorov dynamics** (long-term changes) with a high Hurst parameter, H = 0.93.

Hurst-Kolmogorov dynamics—Or: Earth's perpetual change

A real-world process as seen in the longest instrumental record



A "roulette" process



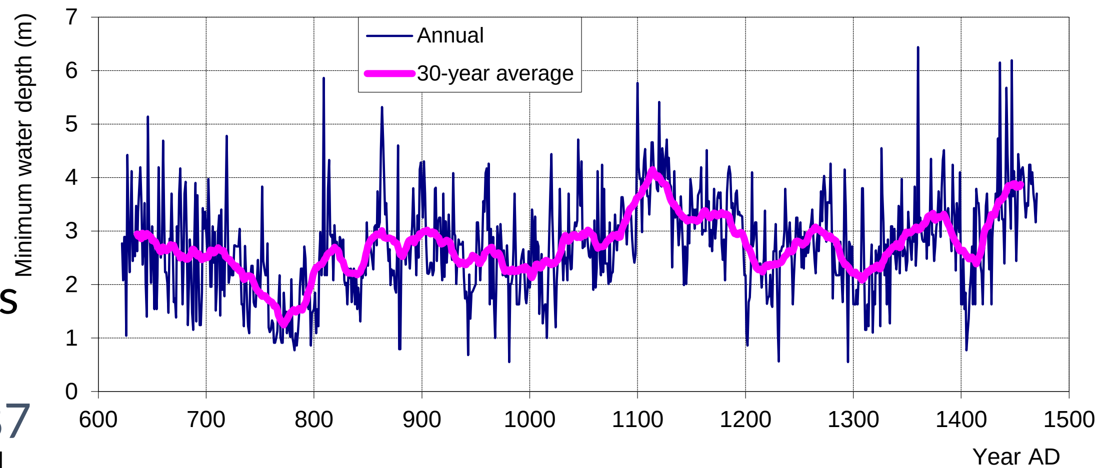
Nilometer data: Koutsoyiannis (2013)

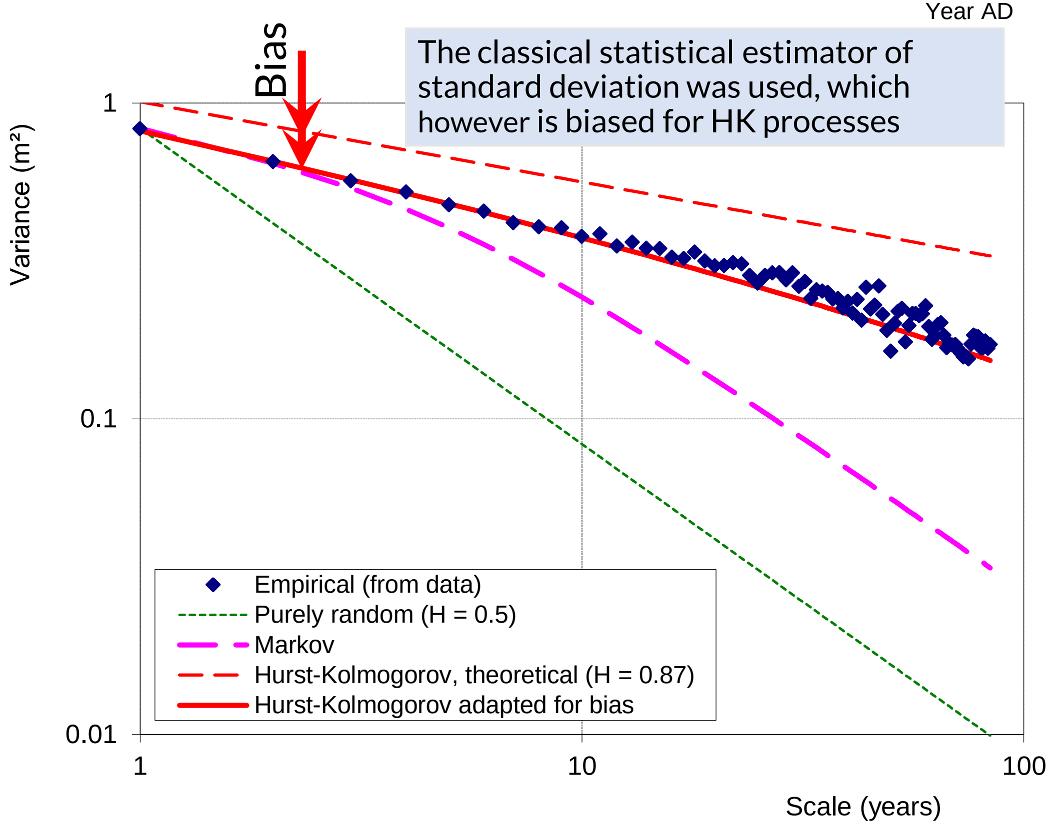
The climacogram: A simple statistical tool to quantify change across time scales

- Take the Nilometer time series, $x_1, x_2, ..., x_{849}$, 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):
  $x^{(2)}{}_1 := (x_1 + x_2)/2, x^{(2)}{}_2 := (x_3 + x_4)/2, ..., x^{(2)}{}_{424} := (x_{847} + x_{848})/2$
  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 $\gamma^{(3)}, \gamma^{(4)},\dots \gamma^{(84)}$.
- The **climacogram** is a logarithmic plot of the variance $\gamma^{(\kappa)}$ (or alternatively the standard deviation $\sigma^{(\kappa)}$) *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 coefficient ($0 < H < 1$).
- 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.

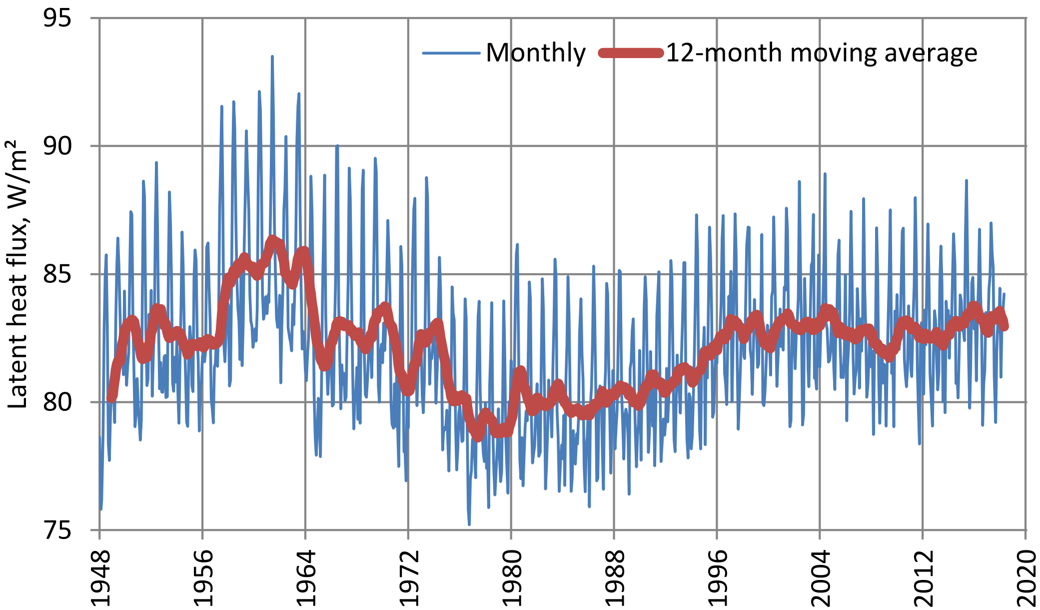
The climacogram of the Nilometer time series

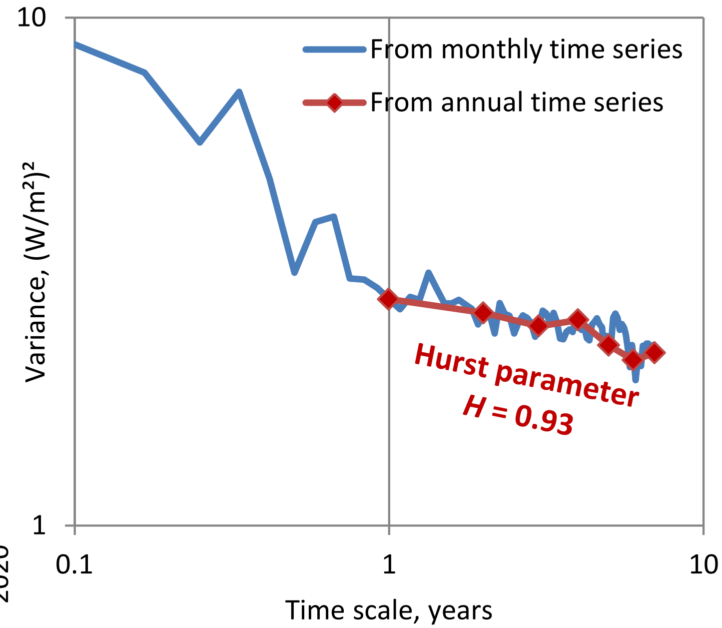
- The Hurst-Kolmogorov process seems consistent with reality.
- The Hurst coefficient is $H = 0.87$ (Similar H values are estimated from the simultaneous record of maximum water levels and from the modern, 131-year, flow record of the Nile flows at Aswan).
- The Hurst-Kolmogorov behaviour, seen in the 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.





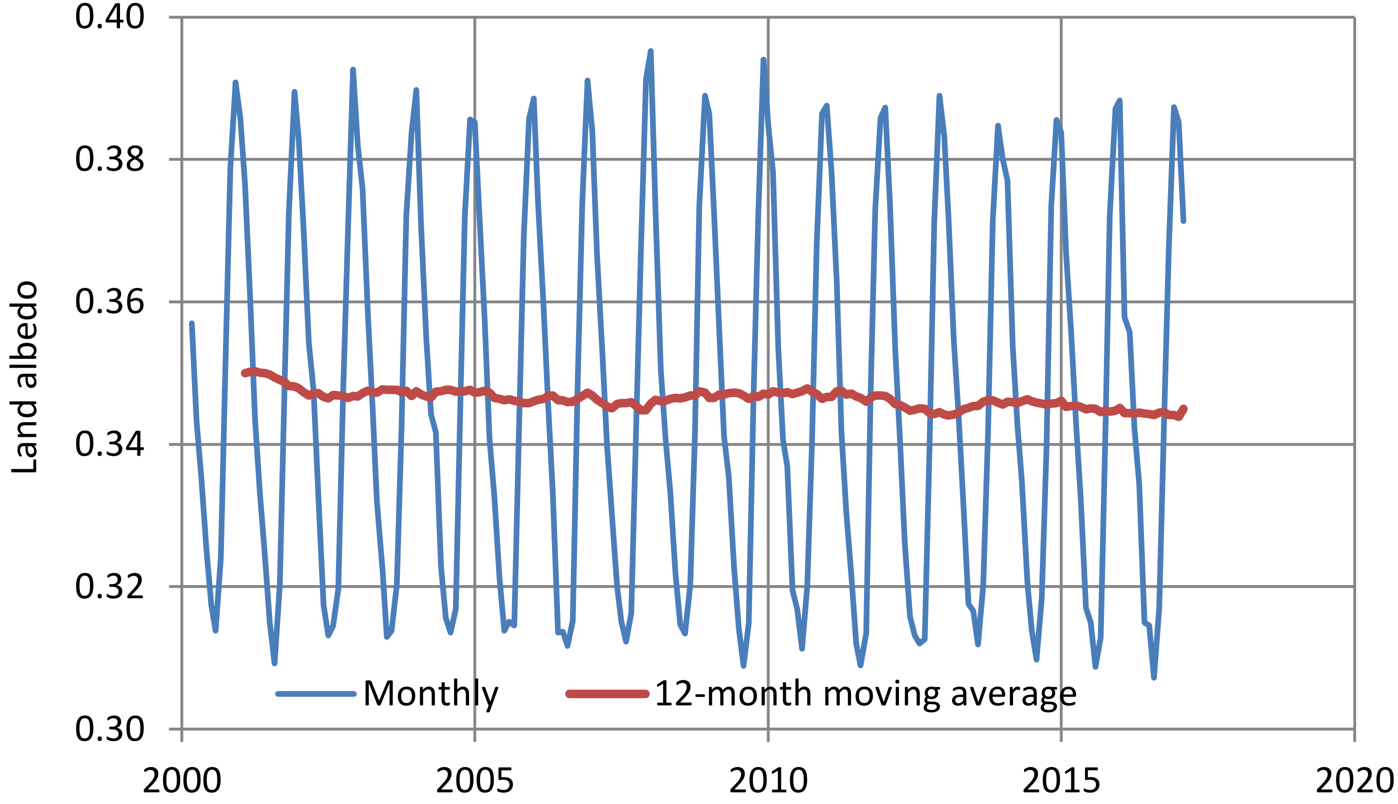
Latent heat net flux is fluctuating





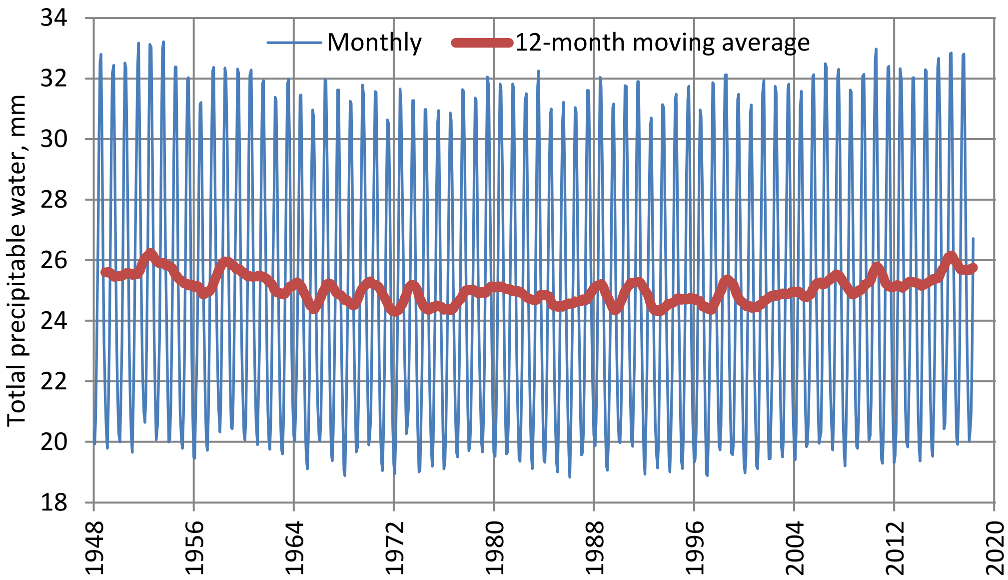
- **Data**: Monthly mean of latent heat net flux averaged over the globe (from NCEP-NCAR Reanalysis 1, retrieved through KNMI Climate Explorer, http://climexp.knmi.nl/data/inlhtfl_0-360E_-90-90N_n.dat Monthly).
- **Result**: The latent heat net flux has been fluctuating and nothing unprecedented is currently experienced. The fluctuation is consistent with the Hurst-Kolmogorov dynamics with a high Hurst parameter, $H = 0.93$.

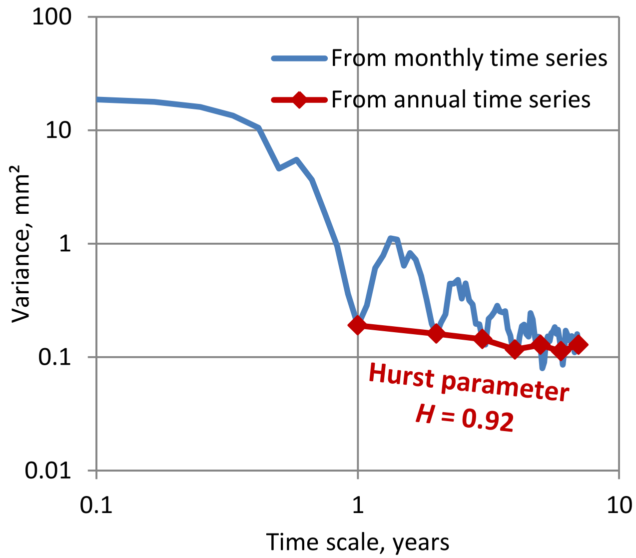
Land albedo is (slightly) fluctuating



- **Data**: Monthly albedo averaged over land (from Clouds and the Earth's Radiant Energy System—CERES, subset over land and kindly provided by Willis Eschenbach).
- **Result**: The land albedo has been fluctuating showing a downward trend in the 21st century, which is consistent with the upward trend of temperature. The data availability is too short to make any conclusions about the long-term behaviour.

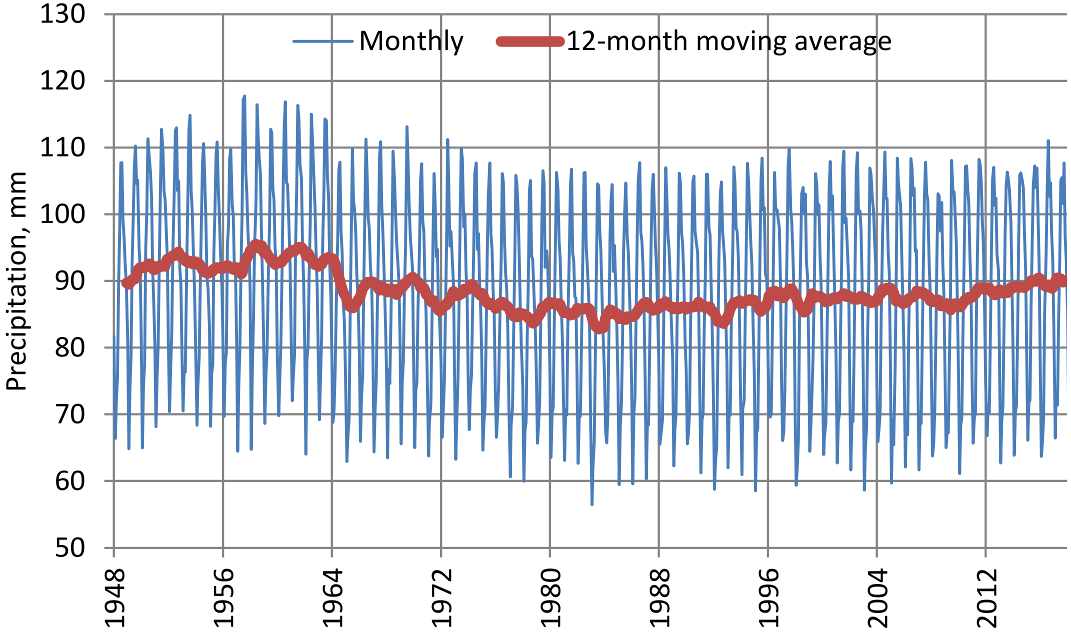
Precipitable water is fluctuating

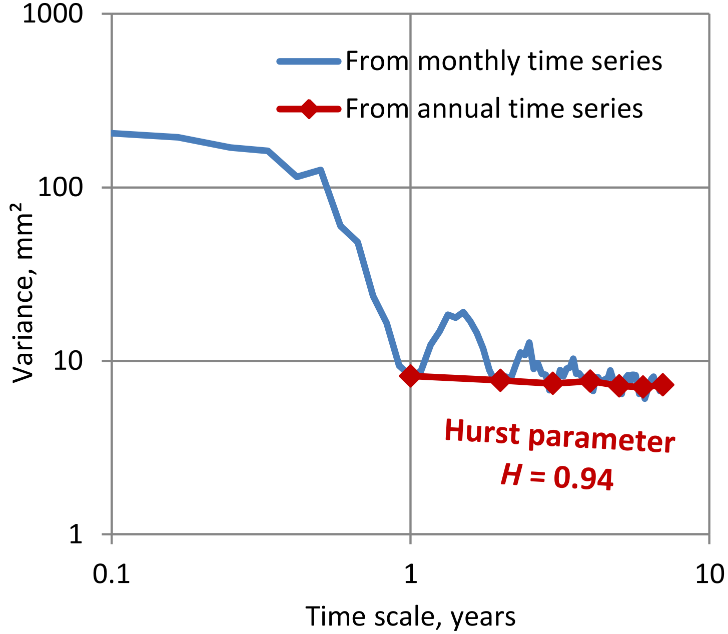




- **Data**: NCEP/NCAR R1 precipitable water averaged over the globe (from NCEP-NCAR Reanalysis 1, retrieved from NOAA, http://www.esrl.noaa.gov/psd/cgi-bin/data/testdap/timeseries.pl).
- **Result**: The precipitable water over the globe has been fluctuating with lowest values during the 1980s and highest values during the 1950s and 2010s. The fluctuation is consistent with the Hurst-Kolmogorov dynamics with a high Hurst parameter, H = 0.92.

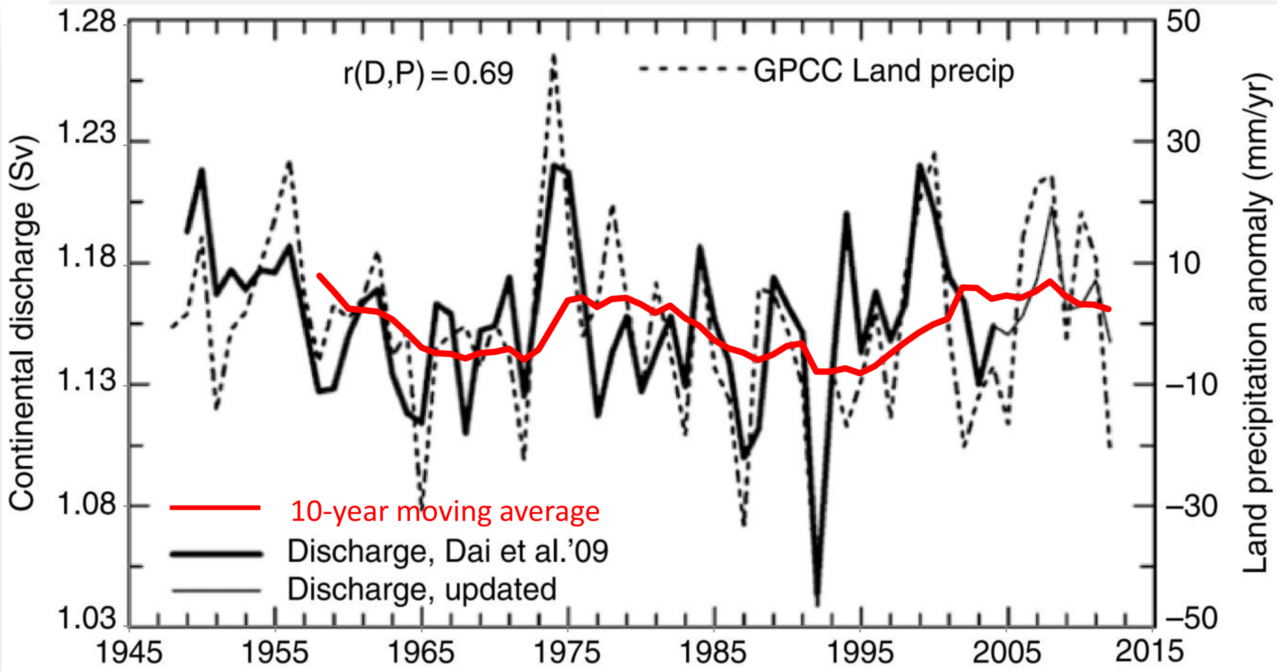
Precipitation is fluctuating

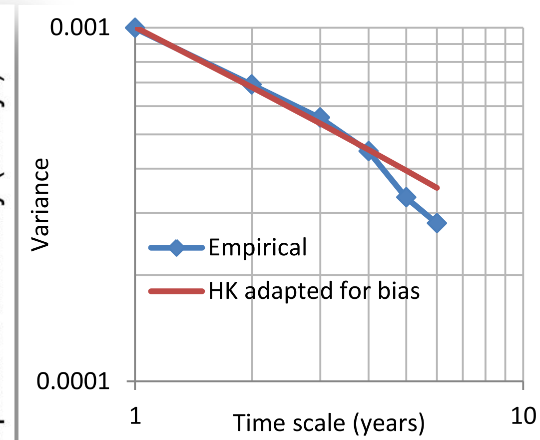




- **Data**: NCEP/NCAR R1 precipitation averaged over the globe (from NCEP-NCAR Reanalysis 1, retrieved from NOAA, http://www.esrl.noaa.gov/psd/cgi-bin/data/testdap/timeseries.pl).
- **Result**: Precipitation has been fluctuating and nothing unprecedented is currently experienced at the global scale. Lowest values have occurred during the 1980s and highest values during the 1960s and 2010s. The fluctuation is consistent with the Hurst-Kolmogorov dynamics with a high Hurst parameter, H = 0.94.

Global river flow is fluctuating





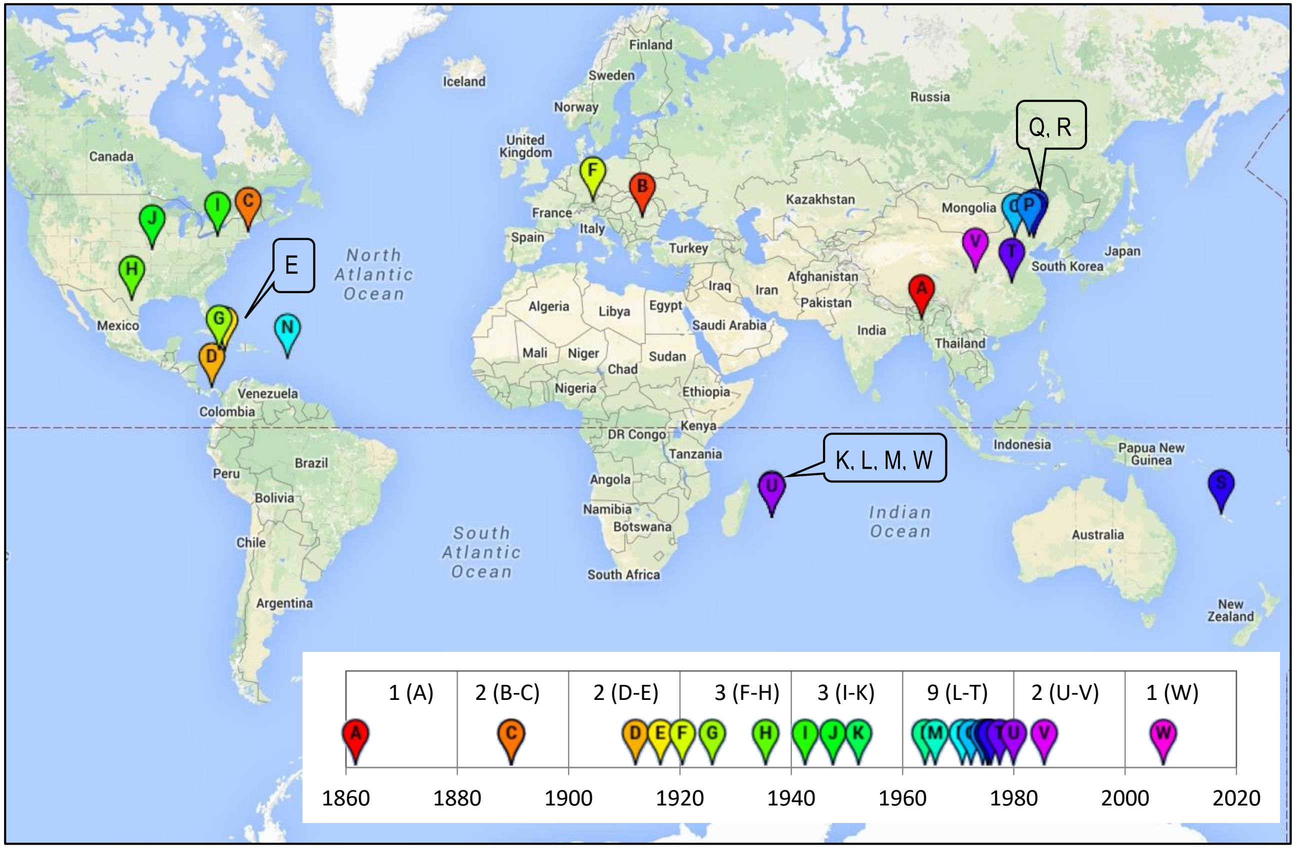
- **Source of graph**: Dai (2016); the red line (10-year climate) and the climacogram on the right have been produced after digitizing the original graph on the left.
- **Result 1**: River flow has been fluctuating and nothing unprecedented is currently experienced at the global scale. The fluctuation is consistent with the Hurst-Kolmogorov dynamics with a Hurst parameter $H = 0.75$.
- **Result 2**: River flow fluctuation is in phase with precipitation fluctuation; note though that the precipitation time series has large differences from that of the previous slide.

River flow trends are alternating

	Total	Stations with trends				Slopes of trends	
		Positive		Negative		Positive	Negative
	#stations	#stations	%	#stations	%	hm^3/year	hm^3/year
North America	190	7	3.7	12	6.3	5.6	-10.7
South America	206	12	5.8	2	1.0	5.3	-19.6
Europe	186	6	3.2	6	3.2	2.0	-0.6
Asia	167	7	4.2	21	12.6	24.5	-8.9
Africa	83	0	0.0	18	21.7	-	-7.6
Oceania	84	2	2.4	16	19.0	2.1	-3.2
Total	916	34	3.7	75	8.2	9.1	-7.2

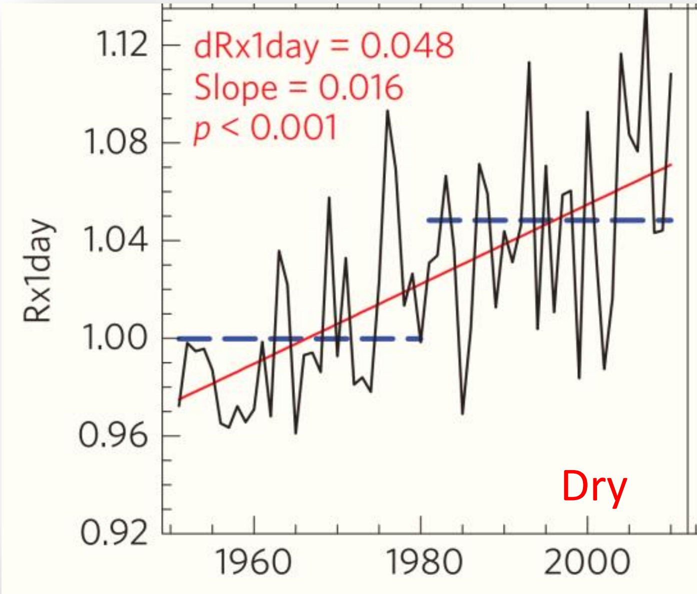
- **Source of table**: Su et al. (2018); among results for different assumptions contained in the paper, those taking account of long-term persistence are reproduced here.
- **Result**: River flow at world's largest rivers show some positive and negative trends. Negative trends are more common than positive in number, but have slightly lower slopes, so that eventually overall the positive slopes surpass the negative ones (9.1 vs -7.2 hm^3/year).

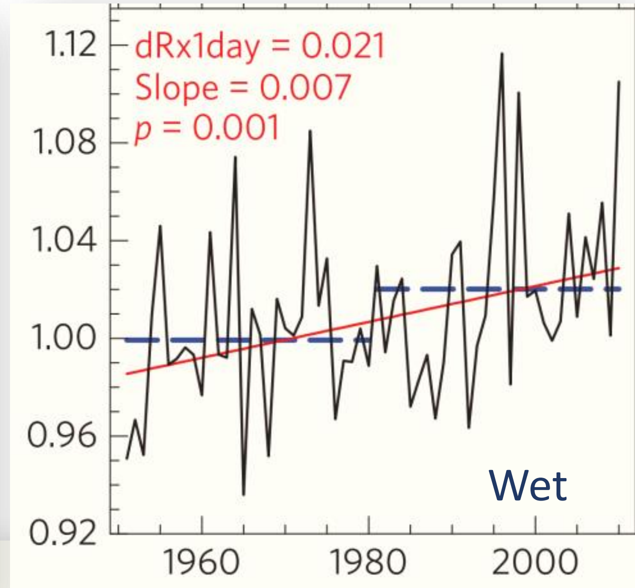
Record rainfall is not increasing

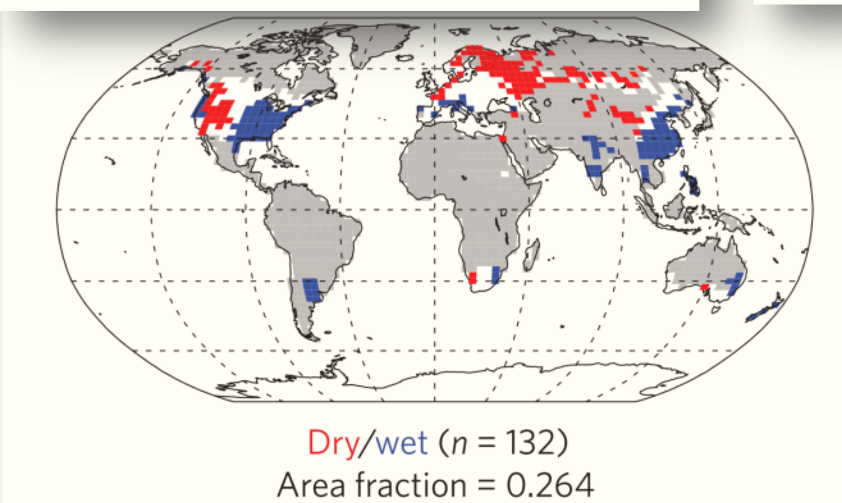


- **Data**: World record point precipitation measurements compiled in Koutsoyiannis and Papalexiou (2017) for various time scales (durations) ranging from 1 min to 2 years; locations and time stamps of the events producing record rainfall are shown.
- **Fact**: Highest frequency of record rainfall events occurred in the period 1960-80; later the frequency was decreased substantially.

Annual maximum rainfall has been (slightly) increased in some areas







- **Source of graphs:** Donat et al. (2016); Rx1day denotes the annual-maximum daily precipitation
- **Result**: The climatic value of annual maximum daily rainfall of the 30-year period 1980 – 2010, compared to that of 1960-80, is greater by 5% for dry areas and by 2% for wet areas.

Increasing trends on annual maximum daily rainfall have been more frequent than decreasing ones

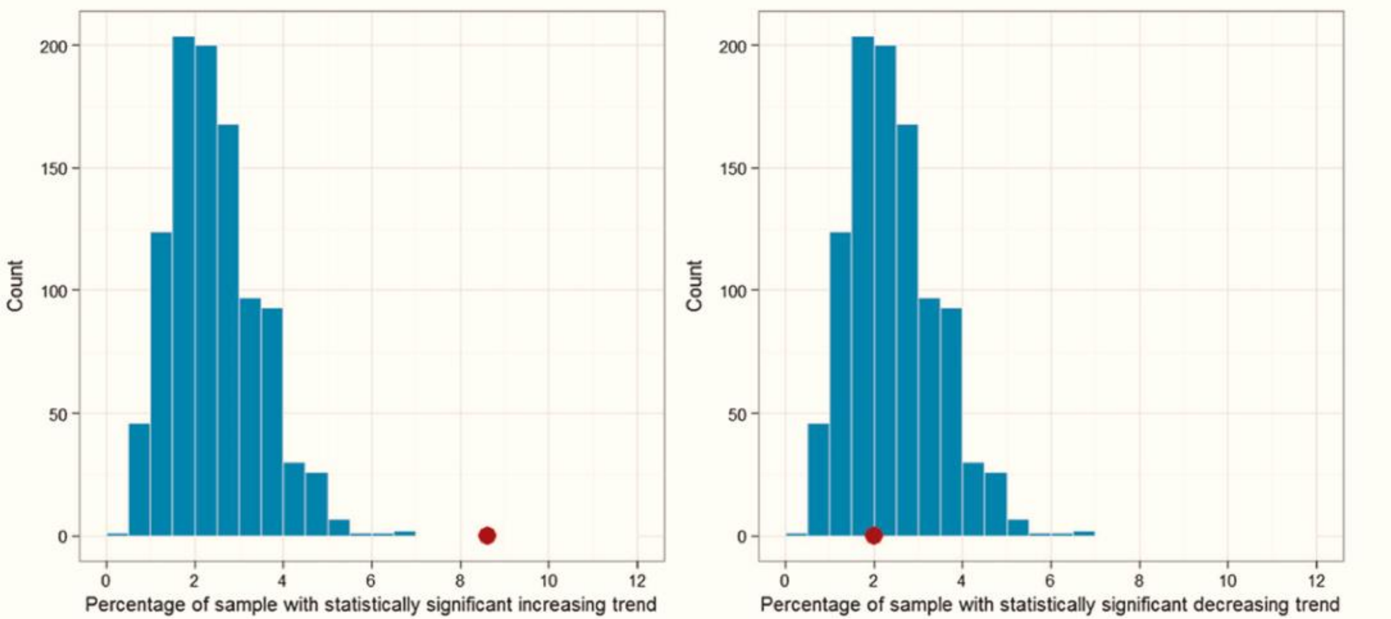
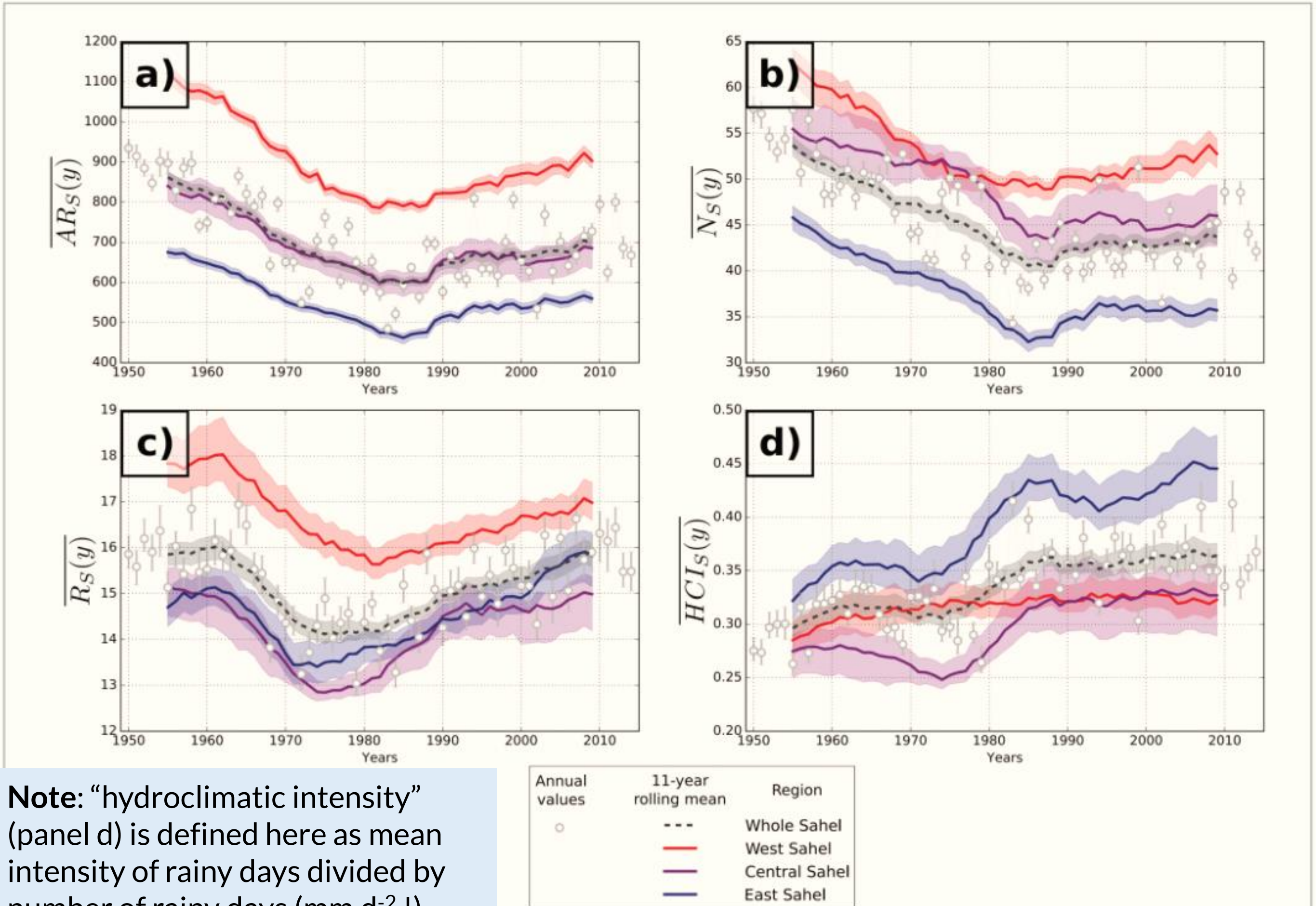


FIG. 3. Percentage of stations showing statistically significant (left) increasing and (right) decreasing trends based on the Mann–Kendall test. The histogram represents the distribution of results from 1000 bootstrap realizations of the global annual maximum rainfall data, and the red dot represents the value from the observed data.

- **Source of graphs:** Westra et al. (2013); 8326 stations with more than 30 years of data over the period from 1900 to 2009 (the average record length is 53 years).
- **Result**: Using the Mann-Kendall test, 8.5% were found with positive trends and 2% with negative, against an expected (for the specific test) 2.5% for each direction.
- **Note**: The test was done assuming independence while an assumption of HK dependence would give lower percentages (perhaps adding to 5%).

Data on “rainfall intensification” (sic) do not show unprecedented conditions of rainfall regime



Note: “hydroclimatic intensity” (panel d) is defined here as mean intensity of rainy days divided by number of rainy days (mm d^{-2} !)

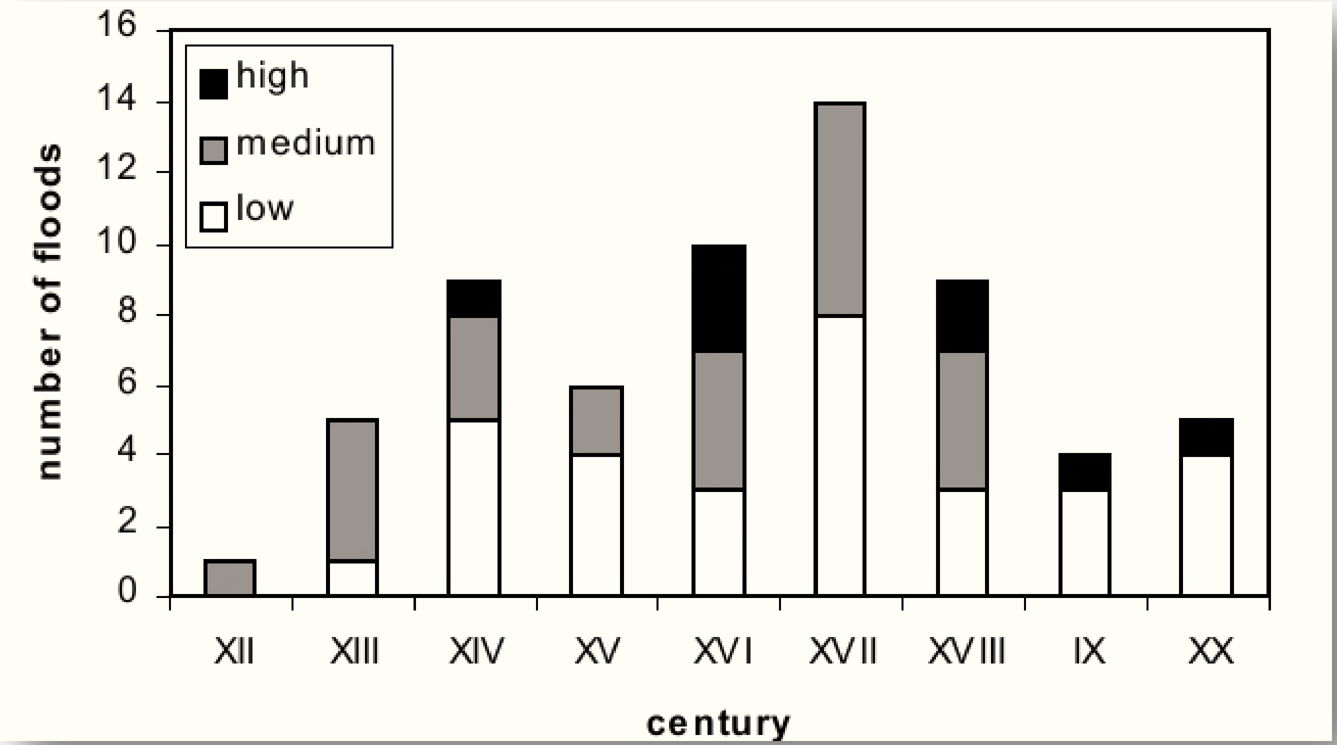
Figure 2. Evolution of (*a*) the mean annual rainfall totals (mm yr^{-1}), (*b*) the mean number of rainy days (*d*), (*c*) the mean intensity of rainy days (mm d^{-1}), and (*d*) the mean hydro-climatic intensity (mm d^{-2}); over the whole Sahel and sub-domains (West, Central and East Sahel). Error bars (resp. shaded area) delineate 80% confidence intervals for annual values (resp. 11 year rolling mean).

Source of graph: Panthou et al. (2018), entitled “*Rainfall intensification in tropical semi-arid regions: the Sahelian case*”

From abstract: “*The analysis of the daily data leads to the assertion that a hydro-climatic intensification is actually taking place in the Sahel, with an increasing mean intensity of rainy days associated with a higher frequency of heavy rainfall.*”

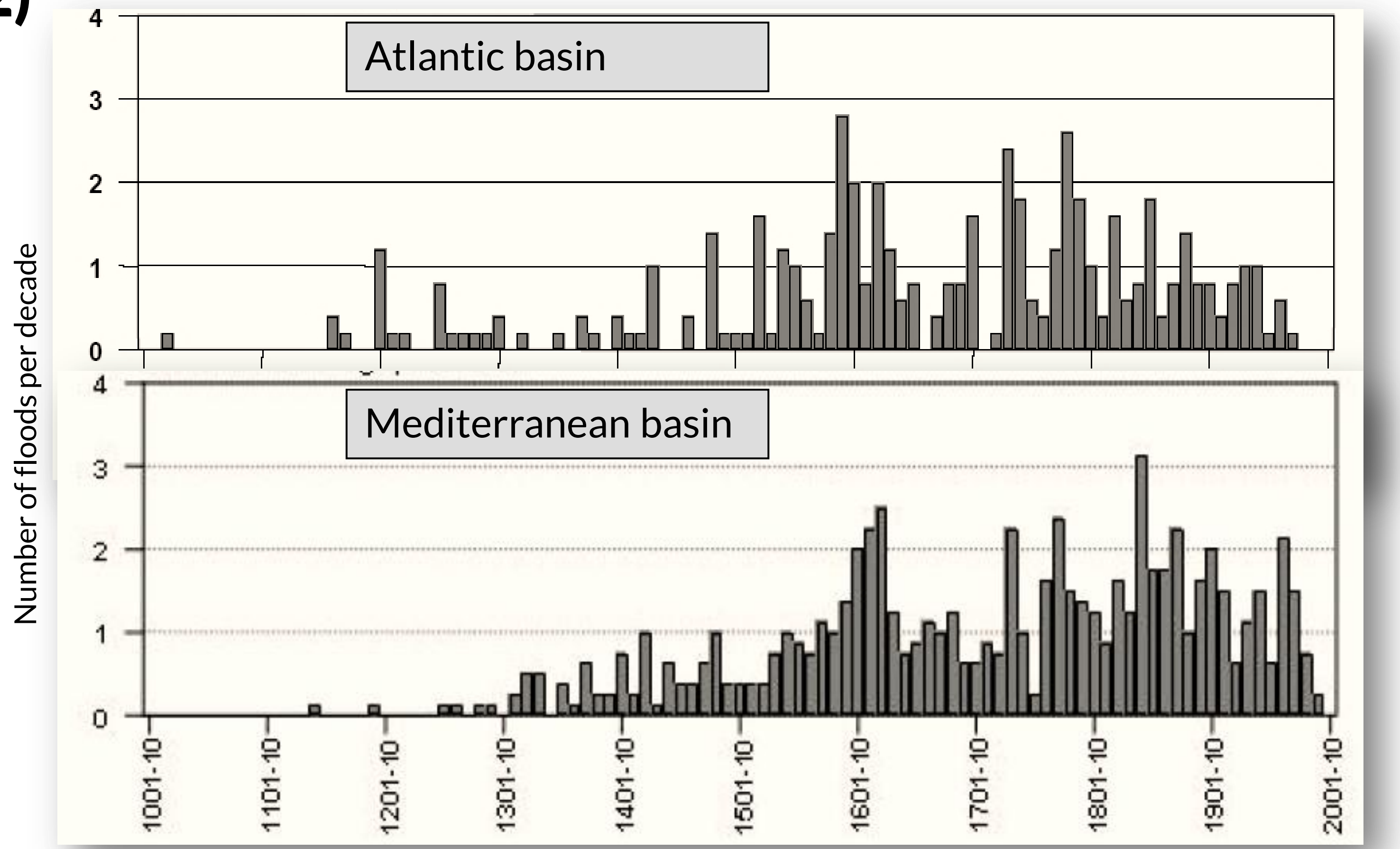
Question: Is it intensification or fluctuation?

Flood occurrences have been fluctuating through the centuries (1)



- **Source of graph**: Caporali et al. (2005): Number of flood events, distributed by intensity, of the Arno River, which caused damage in Florence between the 12th and 20th centuries.
- **Result 1**: There is prominent fluctuation with fewer floods in the 20th century than in most other centuries.
- **Result 2**: Fewer high- and medium-intensity floods occured in the 20th century than in all but one other centuries.

Flood occurrences have been fluctuating through the centuries (2)



- **Source of graph**: Barriendos et al. (2006): Flood frequency, estimated from documents and archives in Spain for the last millennium.
- **Result**: Number of floods fluctuates, with most floods occurring in the 17th and the 19th centuries—not in the 20th century.

Flood occurrences have been fluctuating globally

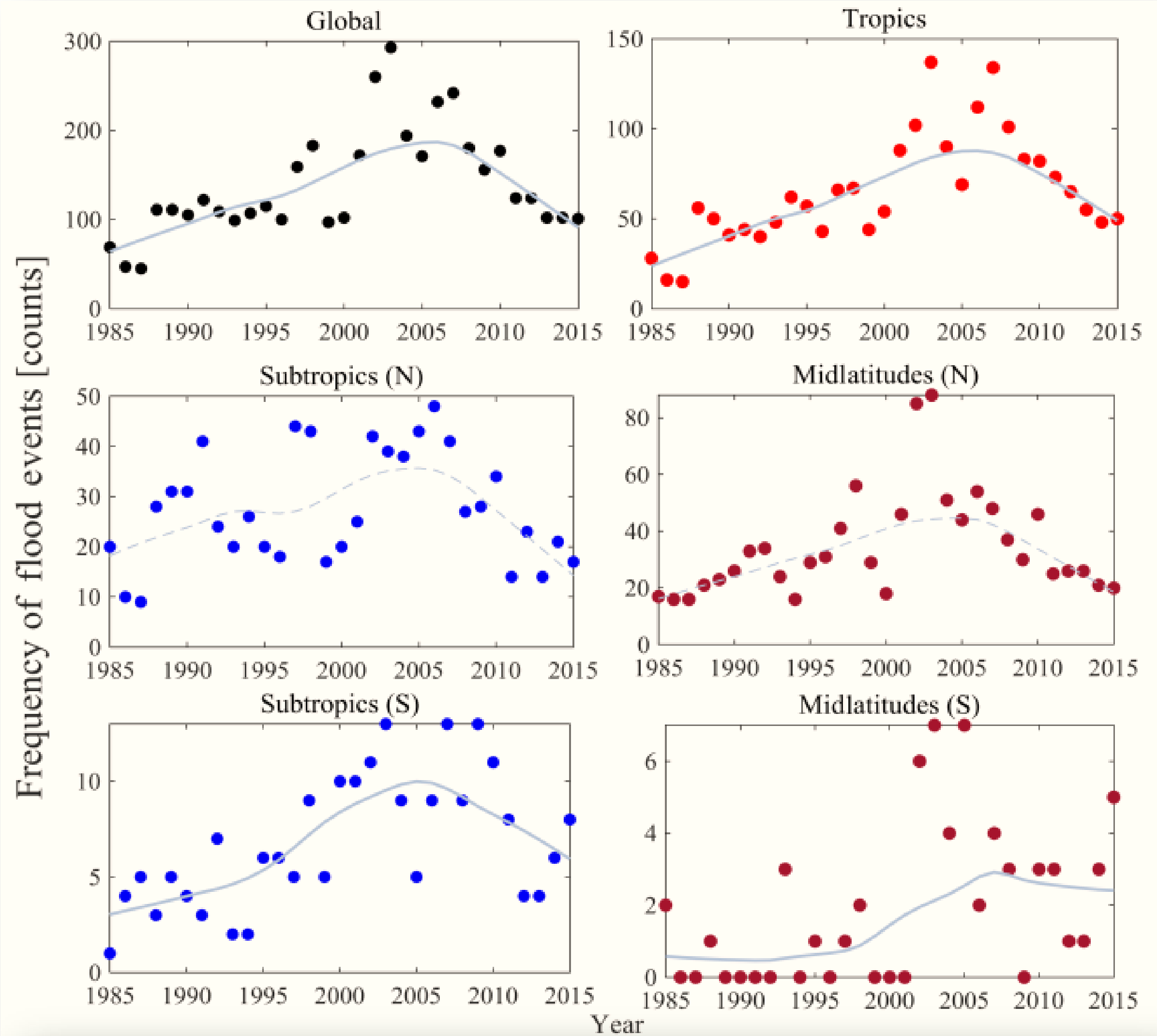


Figure 2. Frequency of flood events at the global scale and the latitudinal scales (i.e., tropics, subtropics – N, subtropics – S, midlatitudes – N, and midlatitudes – S); a LOESS curve fitting is shown (solid line) for the time series in which a significant trend in the number of flood events is observed (Mann–Kendall test with significance level $\alpha = 0.05$). A dashed line indicates the LOESS curve for the regions with insignificant trends.

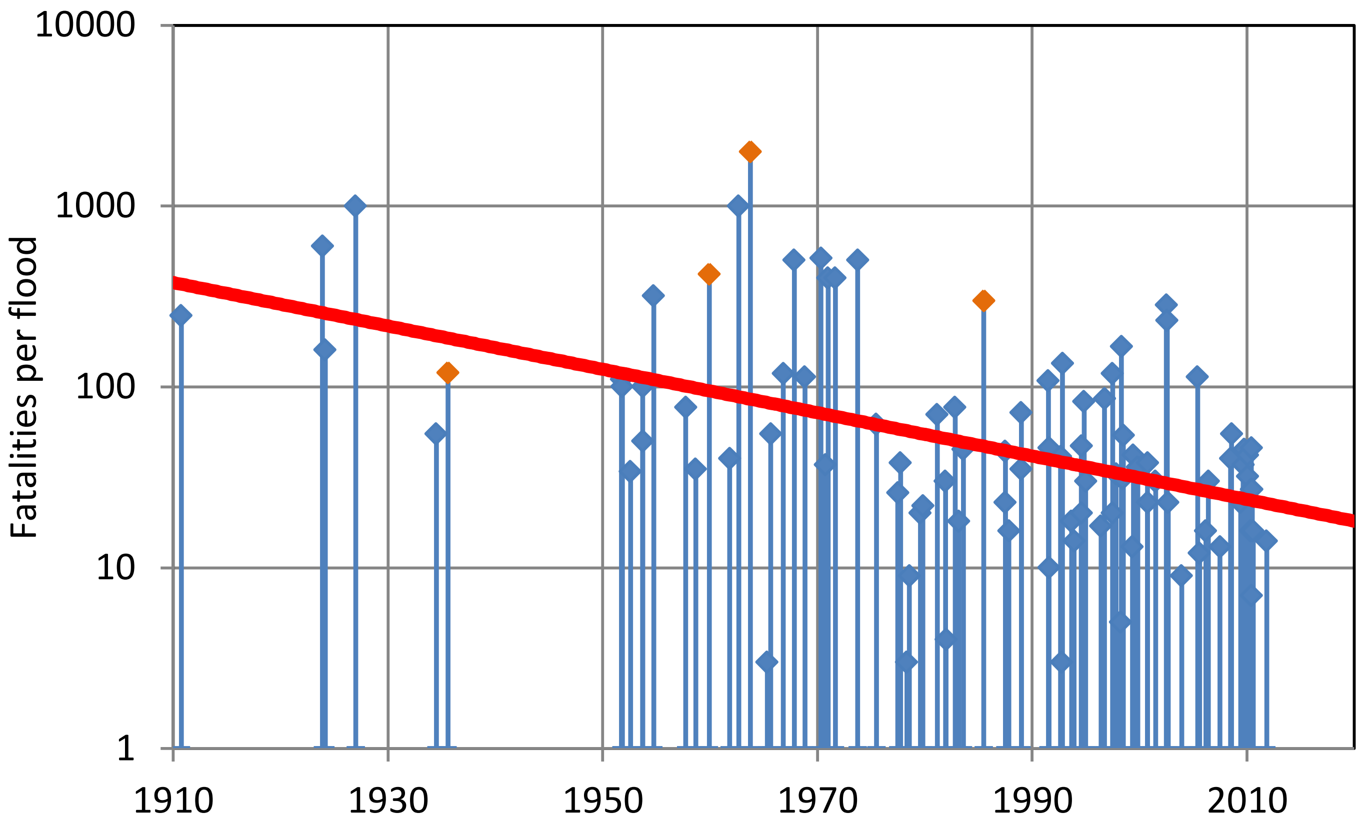
Source of graph: Najibi and Devineni (2018).

From abstract: "*It was verified here that the frequency of floods increased at the global scale, tropics, subtropics (S), and midlatitudes (S).*"

Question: Is it a monotonic increase or a fluctuation?

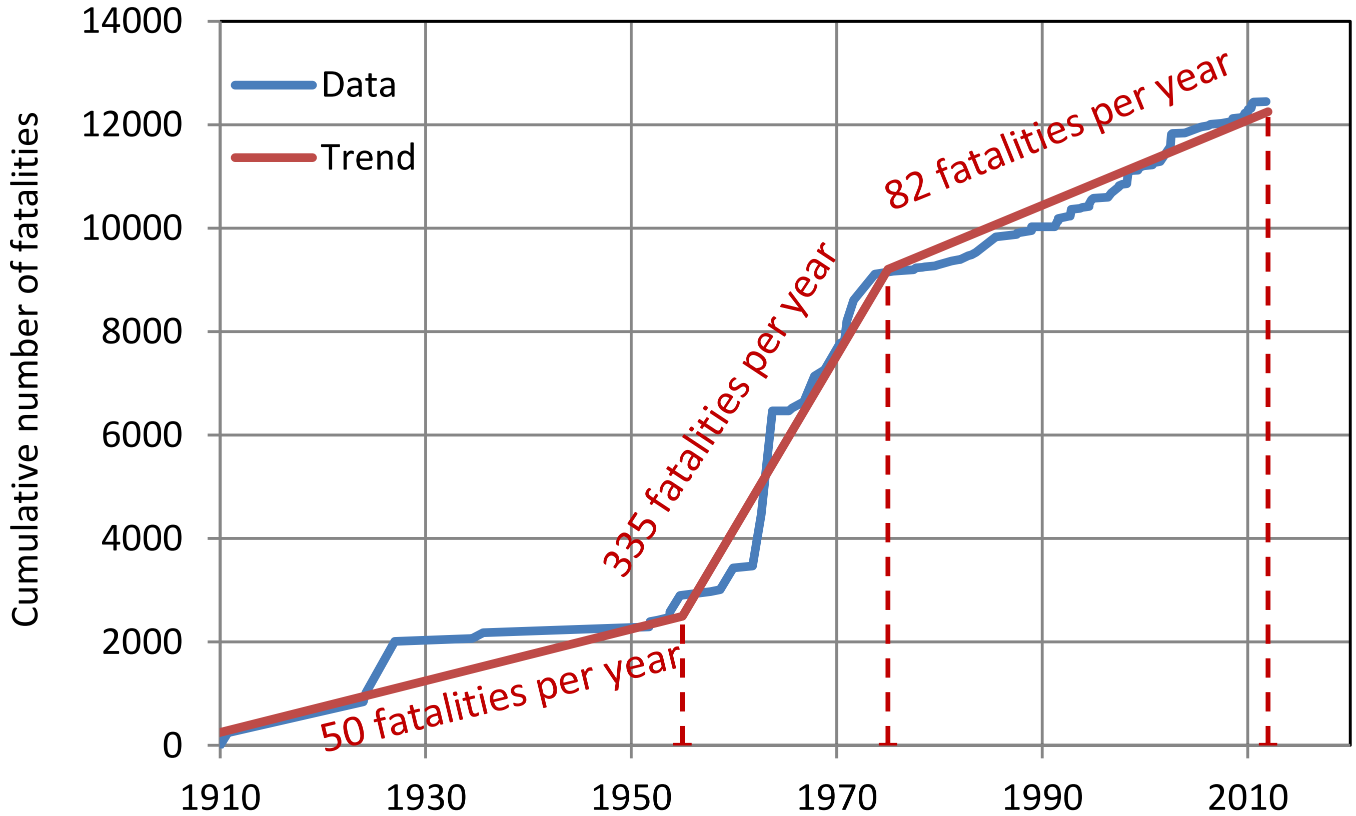
Floods in Europe are not becoming more severe

Red line depicts a negative exponential trend. Data points in brown indicate events with dam damages.



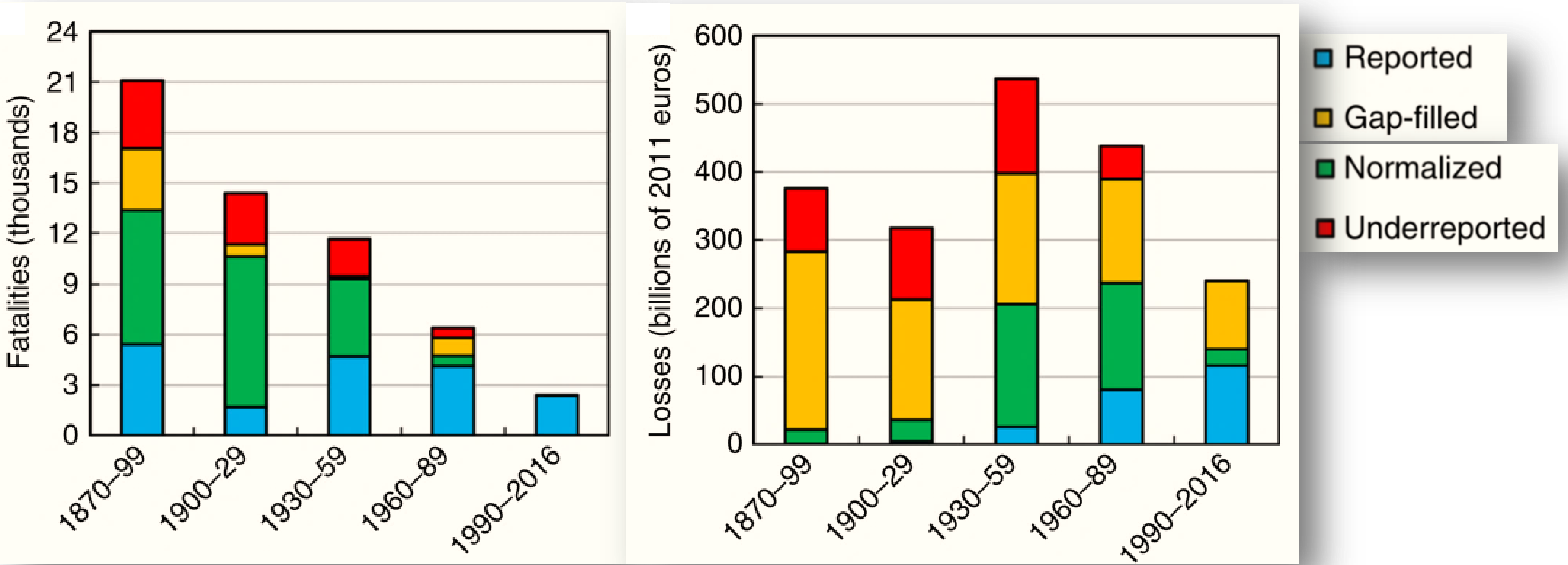
- **Data**: Catalogue of large floods in Europe in the last 100 years from Table 5 of Choryński, et al. (2012) in Kundzewicz (2012). Conditions of inclusion: number of fatalities greater than or equal to 20, or total material damage greater than or equal to 1 billion US$ (inflation-adjusted).
- **Result**: Severity of floods, in terms of fatalities caused, is decreasing.

Flood fatalities in Europe are not increasing



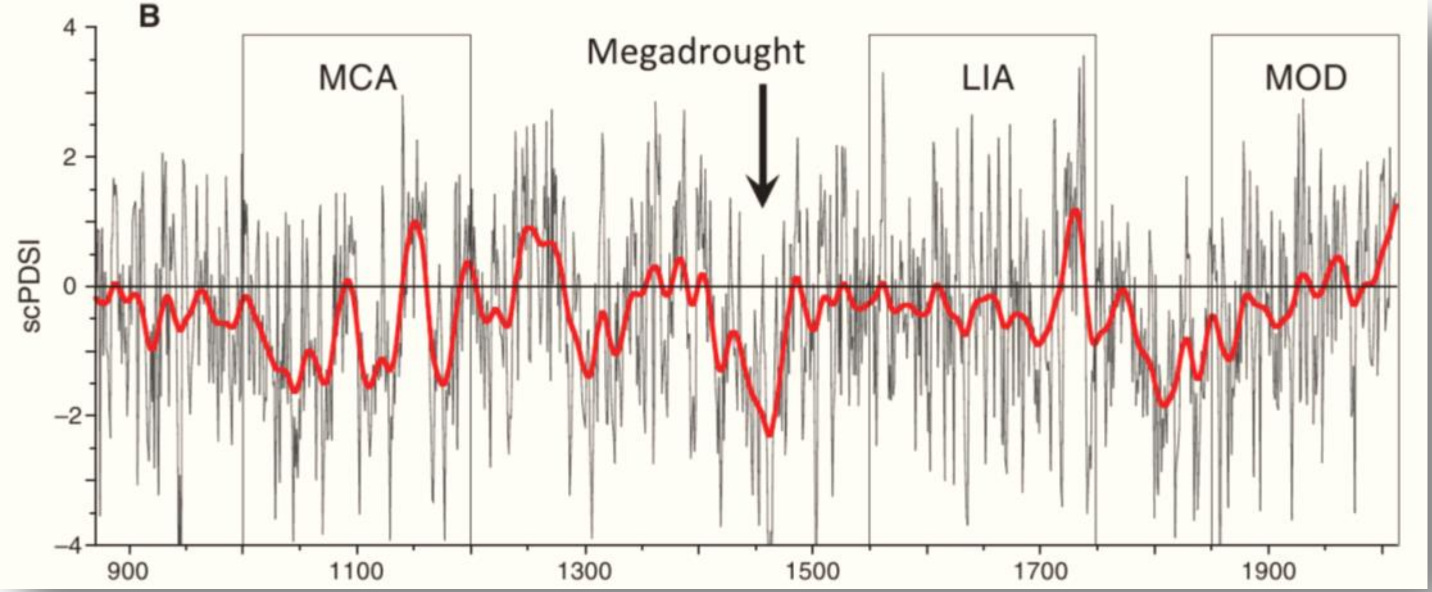
- **Data**: Catalogue of large floods in Europe in the last 100 years from Table 5 of Choryński, et al. (2012) in Kundzewicz (2012), as in previous slide.
- **Fact**: After 1975, the average number of all flood fatalities in Europe was decreased fourfold.

Flood fatalities and losses in Europe have been decreased in the last decades



- **Source of graph**: Paprotny at al. (2018), entitled "*Trends in flood losses in Europe over the past 150 years*".
- **Result**: Flood fatalities (left graph) have been spectacularly decreased; financial value of losses with normalization by GDP (right graph) were also decreased.
- **Note**: Engineering means must have had a substantial contribution in lowering the flood impacts.

Droughts in Europe have not been increased



Long-lasting droughts are intrinsic to climate and are consistent with Hurst-Kolmogorov dynamics.

- **Source of graph**: Cook et al. (2015); average of reconstructions of a self-calibrating Palmer Drought Severity Index (scPDSI) for Central Europe based on the "Old World Drought Atlas" (OWDA) project which used tree-ring data.
- **Result:** The graph indicates drier conditions during the "Medieval Climate Anomaly" (MCA) period, in ~1300, and in ~1800, and also shows an extraordinary megadrought in the mid-15th century.
- **Quote**: "*Megadroughts reconstructed over north-central Europe in the 11th and mid-15th centuries reinforce other evidence from North America and Asia that* ***droughts were more severe, extensive, and prolonged over Northern Hemisphere land areas before the 20th century****, with an inadequate understanding of their causes.*"

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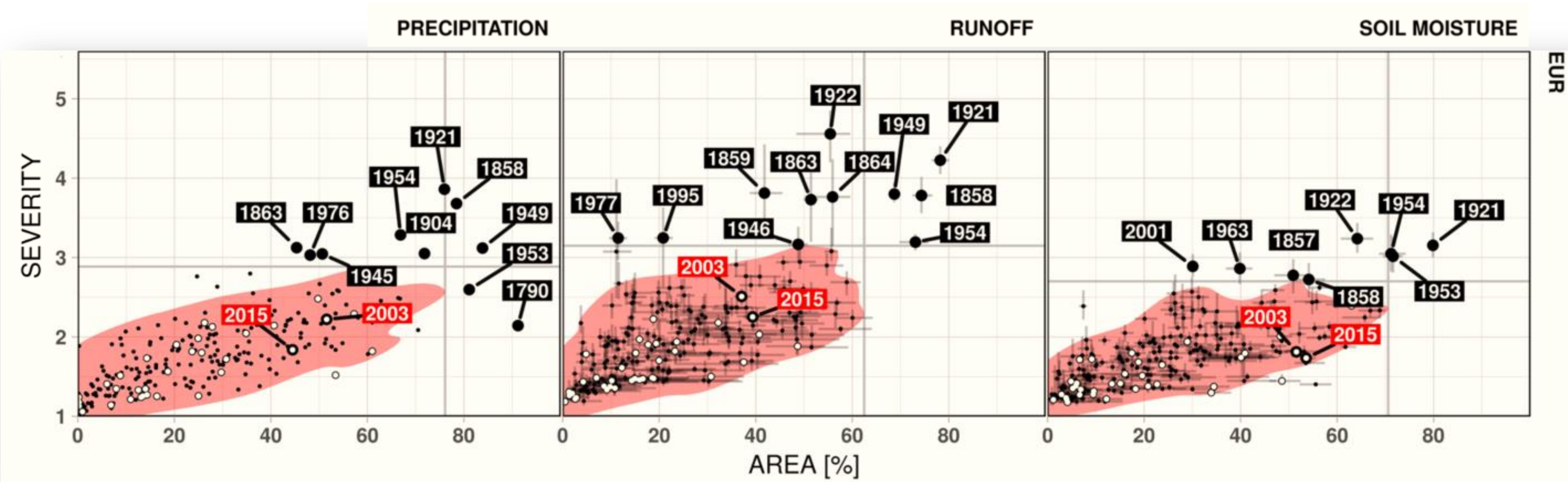
Recent droughts in Europe are less severe than earlier ones



- **Source of graph**: Hanel et al. (2018), entitled "*Revisiting the recent European droughts from a long-term perspective*"; reconstructed droughts over the last 250 years
- **Result**: Even though 21st-century droughts in Europe have been broadly regarded as exceptionally severe, the study shows that they were much milder in severity and areal extent in comparison to many other extensive drought events in Europe.

Impacts of droughts ("food availability decline" or famines) have been substantially decreased

Period	Area	Fatalities (million)	Fatalities (% of world population)
1876-79	India China Brazil Africa Total	10 20 1 ? >30	>2.2%
1896-1902	India China Brazil Total	20 10 ? >30	>1.9%
1921-22	Soviet Union	9	0.5%
1929	China	2	0.1%
1942	India	1.5	0.06%
1943	Bangladesh	1.9	0.07%
1965	India	1.5	0.04%
1973	Ethiopia	0.1	0.003%
1981	Mozambique	0.1	0.002%
1983	Ethiopia	0.3	0.006%
1983	Sudan	0.15	0.003%

- **Source of table**: Koutsoyiannis (2011a); it refers to drought-related historical famines.
- **Result**: Droughts may have dramatic consequences to human lives. Famines and their consequences have been alleviated through the years owing to:
  - improved large-scale water infrastructure for multi-year regulation of flows, and
  - international collaboration and aid for suffering people.

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Part 2
Detrimental impacts of climate change agenda on science in general
(Impacts G1-G4)

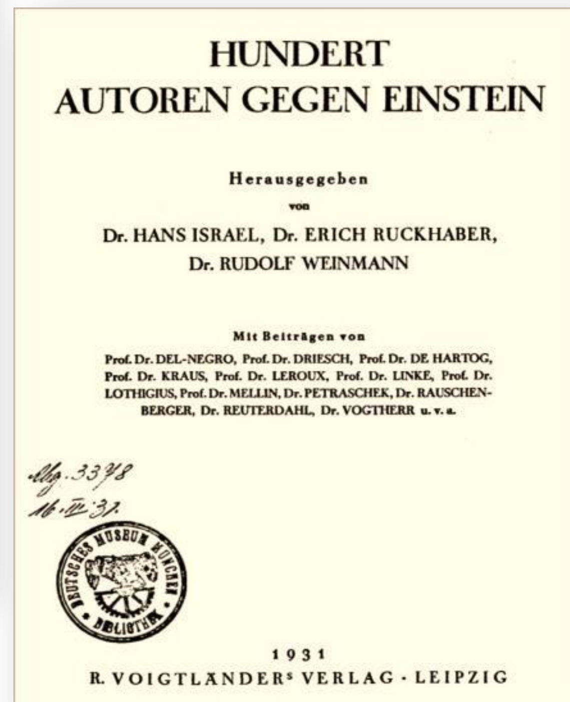
G1. Resurrection of medieval ideas: *consensus science* and *heretics**

*currently called "deniers"

Image from: http://climate.nasa.gov/blog/938/

Related story: The *Hundred Authors Against Einstein* (book cover shown below).

Einstein' response: *"Why 100? If I were wrong, one would have been enough.*



HUNDERT
AUTOREN GEGEN EINSTEIN

Herausgegeben
von
Dr. HANS ISRAEL, Dr. ERICH RUCKHABER,
Dr. RUDOLF WEINMANN

Mit Beiträgen von
Prof. Dr. DEL-NEGRO, Prof. Dr. DRIESCH, Prof. Dr. DE HARTOG, Prof. Dr. KRAUS, Prof. Dr. LEROUX, Prof. Dr. LINKE, Prof. Dr. LOTHIGIUS, Prof. Dr. MELLIN, Dr. PETRASCHEK, Dr. RAUSCHENBERGER, Dr. REUTERDAHL, Dr. VOGTHERR u. v. a.

1931
R. VOIGTLÄNDERS VERLAG · LEIPZIG

G1. *Consensus science* and *heretics* (2)

- What would modern **physics** be if:
  - **Copernicus, Kepler, Galileo** and **Newton** followed the *consensus* view of a **geocentric universe**?
  - **Ludwig Boltzmann** complied with *consensus* ideas and did not insist on the **reality of atoms** and on **statistical mechanics**?
  - **Albert Einstein** complied with the *Hundred Authors Against Einstein*?
- What would modern **geophysics** be if **Alfred Wegener** renounced his **continental drift theory** to comply with *consensus* views?
- What would modern **biology** be if **Louis Pasteur** and **Robert Koch** had followed then *universally accepted* "spontaneous generation theory" of the origin of life and **had rejected the existence of micro-organisms**?
- What would modern **mathematics** be if:
  - **Kurt Gödel** followed the *consensus* view, i.e. Hilbert's doctrine "*Wir müssen wissen, wir werden wissen* (*We must know, we will know*) and Hilbert's quest for a set of axioms sufficient for all mathematics, instead of **formulating and proving the Incompleteness Theorem**?
  - **Andrey Kolmogorov** and **Vladimir Arnold** accepted Hilbert's conjecture (on his thirteenth problem) rather than *disproving* it in their **Superposition Theorem**?

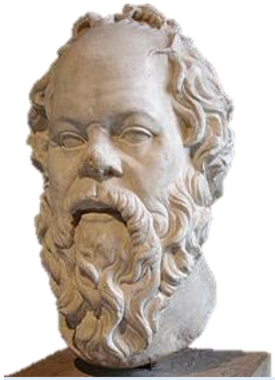
G2: Mixing up of science with politics

- A personal memory from EGU 2010, Great Debate on Climate Change: The climate-orthodoxy representative replied my comment about mixing up science with politics: "*Thank God!*".
- Reflections on mixing up science and politics from the history of Soviet Union:
  - **Trofim Lysenko**: Politically induced fake genetic theories ("environmentally acquired inheritance") whose opponents were dismissed from their posts, imprisoned or even sentenced to death as "enemies of the state".
  - **Nikolai Luzin** (father of the mathematical School of Moscow): Use of politics (notably, by his great students, Aleksandroff, Khinchin, Kolmogorov) to annihilate him as an "enemy under the mask of a Soviet citizen" (Kutateladze, 2007).
- Political pressures on science are real even without the Soviet Union: "*Political pressures often set the agenda for what is to be (or not to be) predicted, and sometimes even try to impose the prediction result thus transforming prediction into prescription*" (**Vit Klemes**, 2008).

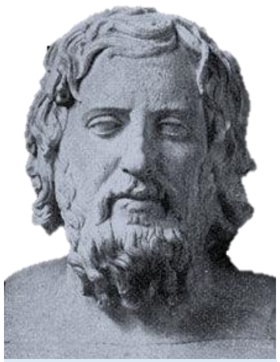
G3: Mixing up of science with ideology (in particular the world saviour ideology and activism)

- Some personal experiences from EGU conferences:
  - EGU 2017: Delegates (including participants in the Hydrology Journals Editors Meeting) participating in "*March for Science*" with pride.
  - EGU 2018, session *History of Hydrology*: Speaker stating (with pride) *We are all scientists and we are all activists.*
- The so-called "**Climategate**" scandal (which broke out in 17 November 2011, when several email exchanges of protagonists in the climate change research leaked) showed that the **world saviour attitude is mostly hypocritical**.
- While in some cases this ideology expresses **honest beliefs**, in other cases it reflects **personal or group interests related to fame and money.**
- In other cases the world saviour ideology reminds religious practices (cf. a modern indulgence, termed "carbon emission offset" and issued by airline companies, EGU —http://www.egu.eu/news/399/— etc.; Christofides and Koutsoyiannis, 2011).
- From the time of **Aristotle**, **science (επιστήμη)** is meant to be thoroughly explored knowledge that we seek for the satisfaction which it carries with itself.
- Ancient Greek philosophers distinguished **science** from **religion** as well as from **sophistry**, i.e. knowledge serving other interests or abusing reasoning making trade of unreal wisdom (cf. Taylor, 1919; Horrigan, 2007; Papastephanou, 2015).

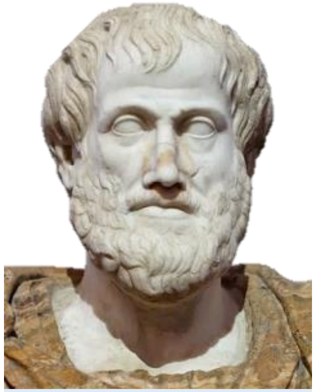
Science (= pursuit of the truth) vs. sophistry



Socrates
(470 – 399 BC)



Xenophon
(430 – 354 BC)



Aristotle
(384 – 322 BC)

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, prostitutors of wisdom (Xenophon, Memorabilia, 1.6.13, quoting Socrates)

G4. Loss of balance, and elevation of catastrophism and fear

- A recent example from hydrology: "*if the trends revealed in this paper persist, and their connection with global warming is confirmed, then the Sahel is at risk of becoming a very hostile region for mankind.*" (from Panthou et al. 2018).
- Climate change is almost **always described as catastrophic and dramatic**, sometimes even as apocalyptic—**never as favourable, positive and beneficial** (Koutsoyiannis, 2013).
- The inverse is also true: **Any disaster** or negative development is commonly attributed to global warming, the ***global scapegoat*** (cf. Koutsoyiannis, 2008).
- There is no short of imagination in connecting climate change with any negative effect, e.g., **kidney stones** (Koutsoyiannis, 2008), **civil war in Syria** and **Brexit** (Koutsoyiannis, 2017).
- Even conflicting extremes are alike connected to anthropogenic climate change (dry and wet, hot and cold; Koutsoyiannis, 2008).
- The history of environmental ("green") movement is **full of predictions of catastrophes, which did not come true and have become laughable** by now (Koutsoyiannis, 2017).
- All these are detrimental to science as they have created imbalance, oversimplification and **distraction of the study of the real causes**.
- There are also contrary to the ethical value of **science in fighting fear** (cf. Epicurus).

Climate orthodoxy: modern sophistry or modern religion?

- Are faith, belief, apocalypticism, saviour ideology, dividing people into orthodox and heretics (deniers), and connection with power and politics, inconsistent with religion?
- The following example relevant to hydrology and medieval religion may be illustrative.
- The great flood of the Arno River in Florence in November 1333 (the first recorded) killed more than 3 000 people.
- As was chronicled by Giovanni Villani (Cronica, Tomo III, Libro XII, II), "*D'una grande questione fatta in Firenze se 'l detto diluvio venne per iudicio di Dio o per corso naturale ...*"— "***the great debate in Florence was on whether the flood occurred for God's will or for natural causes***".
- In November 1966, a somewhat bigger flood occurred, killing ~100 people.
- Had these occurred after 2000, the attribution debate would have been ***on whether the flood occurred for anthropogenic climate change or for natural causes***.

Part 3
Detrimental impacts of climate change agenda on hydrology
(Impacts H1-H5)

Hydrology or “Climate-impactology”?

Searched phrase →	“Hydrologic model” OR “Hydrological model”	"climate change impacts" + hydrology OR water
Total number of articles with the phrase	683 000 (of which ~1% in title)	280 000 (of which ~1% in title)
Number of articles since 2014	43 000	48 000
Total number of citations of the most cited 1800 articles	223 000	674 000
Largest number of citations for a single article	4 729	12 585
Most cited article	D.N. Moriasi et al. (2007): Model evaluation guidelines for systematic quantification of accuracy in watershed simulations	N. Stern (2008): The economics of climate change
H-index	232	407

Data from Google Scholar as of 2018-06-25; data processing: Publish or Perish software

The situation could be worse…

Fundamental disagreement about climate change

External forcing:
CO_2 as climate 'control knob'

- 20th -21st century climate change is explained by external forcing (primarily from CO_2)
- Forcing is amplified by positive **feedbacks** (water vapor, clouds)
- Climate driven by solar – thermal energy balance top of atmosphere

Response: climate chaos is 'noise' that averages out

Atmospheric physicists & chemists
Paleoclimatologists
Climate impacts (ecologists, public health . . .)

Climate chaos:
no simple cause and effect

- **Highly complex system:** globally coupled, spatio-temporal chaotic, resonant system.
- Climate change occurs as discrete **shifts** in the system
- Equilibrium is fleeting.

Response: CO_2 is small 'wedge' that projects onto these modes

Meteorologists, Geologists, Hydrologists, Physical Oceanographers, Solar Physicists, Engineers

Source of slide: Blog post by Judith Curry (30 May 2018), entitled "*Fundamental disagreement about climate change*"

http://judithcurry.com/2018/05/30/fundamental-disagreement-about-climate-change/

Impacted hydrological practices

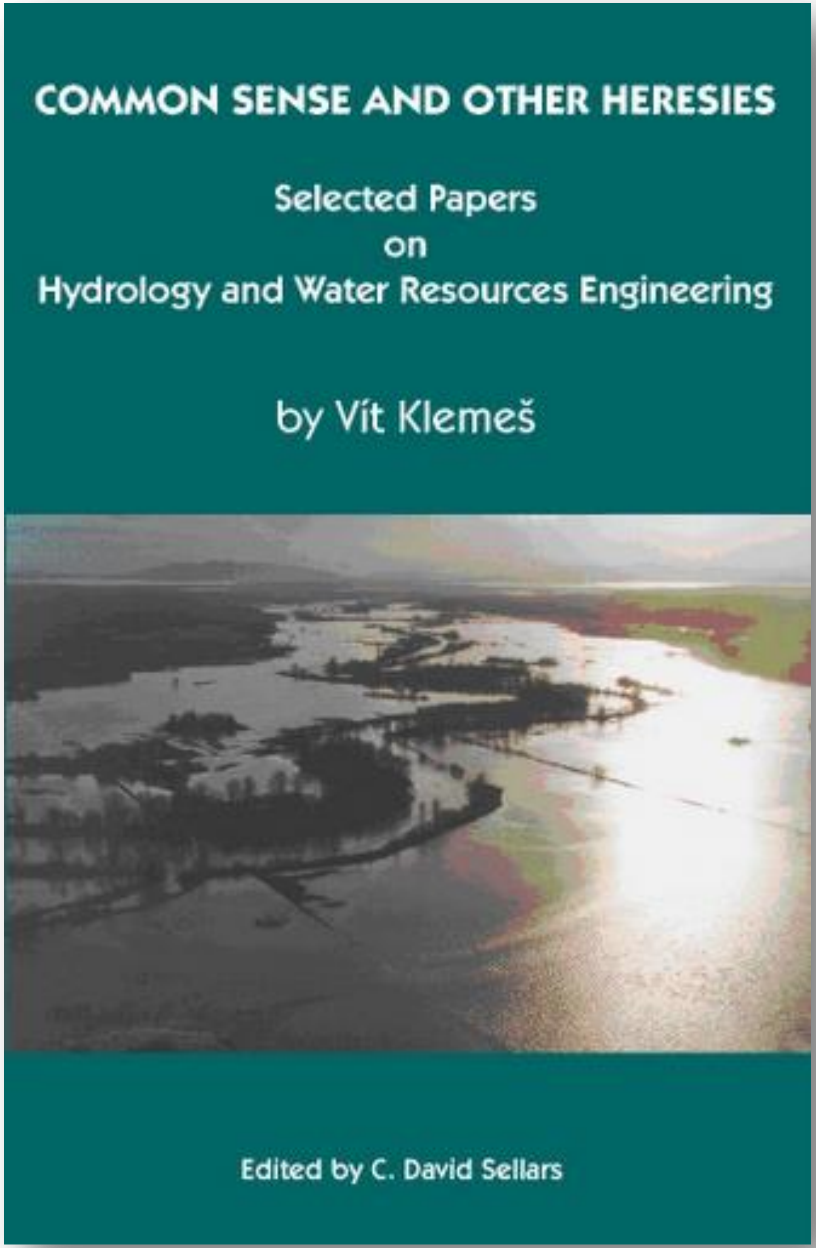
H1. Use of common sense

H2. Focus on real-world problems

H3. More trust on observations (real-world data) than on model outputs

H4. Model validation

H5. Uncertainty characterization using stochastics and quantification based on proximity to observations



Impacted hydrological practice H4: Model validation (the practice of not using non-validated or invalidated models)

12 -Split-sample technique

This gave me an opportunity to apply in practice the split-sample technique which I had advocated already more than 20 years ago[7].

Hydrological Sciences – Journal – des Sciences Hydrologiques, 31, 1, 3/1986

Operational testing of hydrological simulation models

V. KLEMEŠ
National Hydrology Research Institute, Environment Canada, Ottawa, Ontario, Canada K1A OE7

ABSTRACT A hierarchical scheme for the systematic testing of hydrological simulation models is proposed which ties the nature of the test to the difficulty of the modelling task. The testing is referred to as operational, since its aim is merely to assess the performance of a model in situations as close as possible to those in which it is supposed to be used in practice; in other words, to assess its operational adequacy. The measure of the quality of performance is the degree of agreement of the simulation result with observation. Hence, the power of the tests being proposed is rather modest, and even a fully successful result can be seen only as a necessary, rather than a sufficient, condition for model adequacy vis-à-vis the specific modelling objective. The scheme contains no new and original ideas; it is merely an attempt to present an organized methodology based on standard techniques, a methodology that can be viewed as a generalization of the routine split-sample test. Its main aim is to accommodate the possibility of testing model transposability, both of the

Klemes (2007) referring (in a funny way) to Klemes (1986) and WMO (1975).

(1a) *Split-sample test* The available record should be split into two segments one of which should be used for calibration and the other for validation. If the available record is sufficiently long so that one half of it may suffice for adequate calibration, it should be split into two equal parts, each of them should be used in turn for calibration and validation, and results from both arrangements compared. The model should be judged acceptable only if the two results are similar and the errors in both validation runs acceptable. If the available record is not long enough for a 50/50

Impacted hydrological practice H5: Uncertainty characterization using stochastics and quantification based on proximity to observations (not on proximity to outputs of other models)

HYDROLOGICAL PROCESSES, VOL. 6, 279–298 (1992)

THE FUTURE OF DISTRIBUTED MODELS: MODEL CALIBRATION AND UNCERTAINTY PREDICTION

KEITH BEVEN AND ANDREW BINLEY

Journal of Hydrology (2006) 330, 368–381

available at www.sciencedirect.com

ScienceDirect

ELSEVIER

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

Hydrological forecasting uncertainty assessment: Incoherence of the GLUE methodology

Pietro Mantovan [a], Ezio Todini [b,*]

Beven and Binley (1992) and critique by Mantovan and Todini (2006)

Krzysztofowicz (2002)

ELSEVIER

Journal of Hydrology 268 (2002) 16–40

Journal of Hydrology

www.elsevier.com/locate/jhydrol

Bayesian system for probabilistic river stage forecasting

Roman Krzysztofowicz*

Hydrol. Earth Syst. Sci., 14, 585–601, 2010
www.hydrol-earth-syst-sci.net/14/585/2010/
© Author(s) 2010. This work is distributed under
the Creative Commons Attribution 3.0 License.

Hydrology and Earth System Sciences

HESS Opinions
"A random walk on water"

D. Koutsoyiannis

Koutsoyiannis (2010)

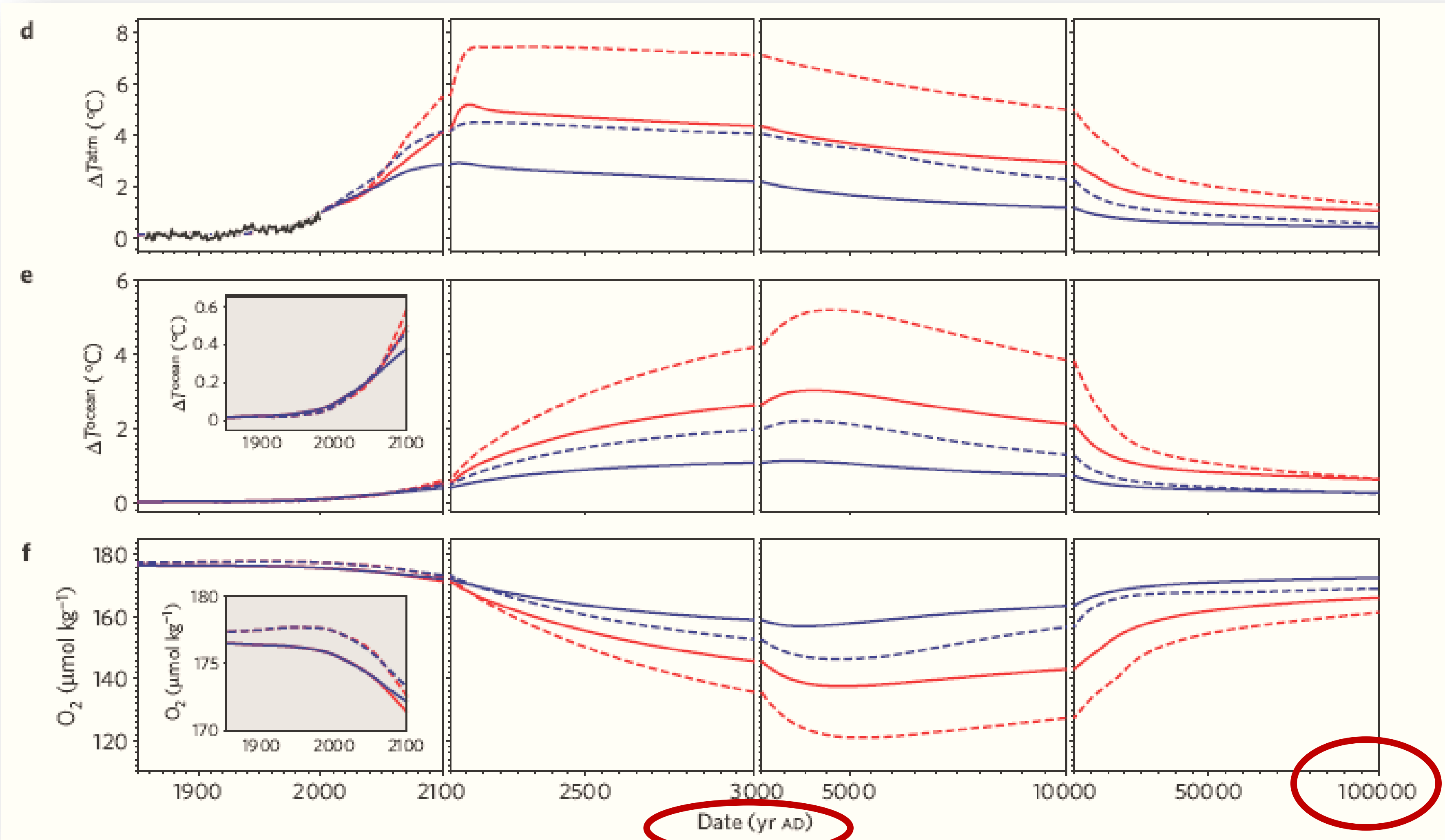
Montanari and Koutsoyiannis (2012)

WATER RESOURCES RESEARCH, VOL. 48, W09555, doi:10.1029/2011WR011412, 2012

A blueprint for process-based modeling of uncertain hydrological systems

Alberto Montanari[1] and Demetris Koutsoyiannis[2]

Example of violation of common sense



Climate prediction for 100 000 AD (Shaffer et al., 2009)

Example of mixing up predictions with reality & comparing models to each other

nature climate change

LETTERS

PUBLISHED ONLINE: 16 JANUARY 2017 | DOI: 10.1038/NCLIMATE3201

Future increases in extreme precipitation exceed observed scaling rates

- From Bao et al. (2017) *“Models and physical reasoning predict that extreme precipitation will increase in a warmer climate due to increased atmospheric humidity.* […] *Projections from the same model show future daily extremes increasing at rates faster than those inferred from observed scaling.”*
- From Panthou et al. (2018): “*The detection of long term changes in the rainfall regimes of tropical regions from observations is both challenging and necessary* ***since models often do not agree on this issue.***”

Example of mixing up predictions with reality and treating model outputs as if they were observed data

Source of graph and table: Quintero et al. (2018).

Question: What is the epistemological basis of performing Mann-Kendall tests for future trends and calculating p-values of model projections?

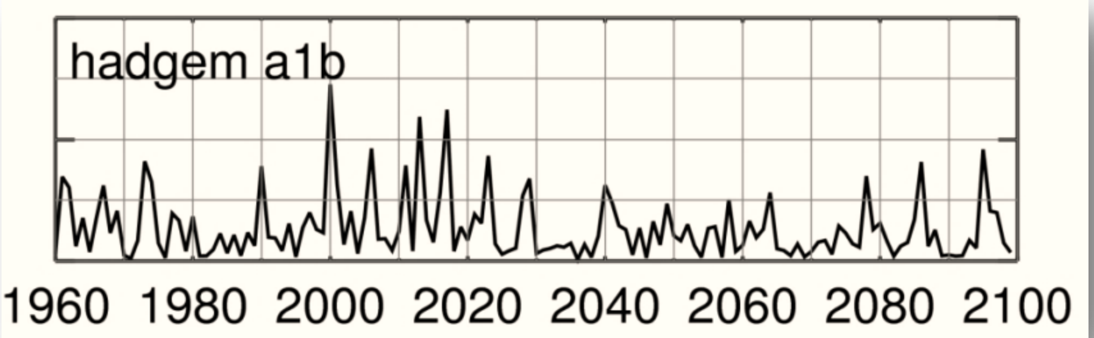


Table 3. Parameters obtained after a Mann-Kendall test with alpha = 0.05 for detection of trends in the projected annual peak flows in the bridge of US 151 in Cedar River at Cedar Rapids.

Model and Scenario	Mann-Kendall's *Tau*	*p*-Value	*p*-Value < 0.05
CCSM A1FI	0.278	1.07×10^{-6}	true
CCSM A2	0.273	1.79×10^{-6}	true
CGCM3T47 A1B	0.129	0.024	true
CGCM3T47 A2	0.183	0.0013	true
CGCM3T63 A1B	0.031	0.58	false
CGCM3T63 A2	0.095	0.095	true
CNRM A1B	0.300	1.19×10^{-7}	true
CNRM A2	0.242	2.37×10^{-5}	true
ECHAM5 A1B	0.131	0.021	true
ECHAM5 A2	0.205	0.00033	true
ECHO A1B	0.124	0.029	true
ECHO A2	0.059	0.30	false
GFDL A1FI	0.053	0.35	false
GFDL A2	0.120	0.035	true
HADCM3 A1B	0.091	0.11	false
HADCM3 A1FI	0.224	9.18×10^{-5}	true
HADCM3 A2	−0.003	0.96	false
HADGEM A1B	−0.017	0.77	false
HADGEM A2	−0.017	0.77	false

Example of determining uncertainty by comparing models to each other

Some quotes from Melsen et al. (2018), entitled "*Mapping (dis)agreement in hydrologic projections*":

- "*We show that in the majority of the basins,* ***the sign of change*** *in average annual runoff and discharge timing for the period 2070–2100 compared to 1985–2008* ***differs among combinations of climate models, hydrologic models,*** *and parameters.* ***Mapping the results revealed that different sources*** *of uncertainty dominate in different regions*".
- "*In our results, GCM forcing was the main source of uncertainty, followed by the hydrologic model structure and the parameters of the hydrologic model.*"
- "*The constrained hydrologic models were forced with statistically down-scaled and bias-corrected GCM output.*"

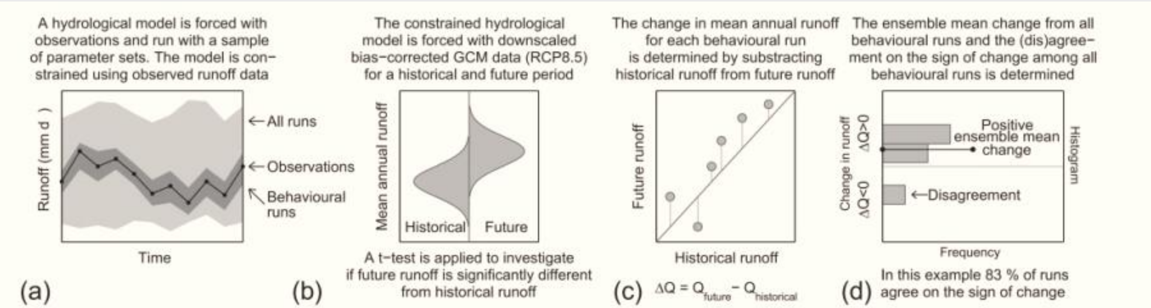


Figure 1. Overview of the conducted procedure, demonstrated for the mean runoff metric. For the discharge timing metric, the same procedure was employed. This procedure was repeated for 15 combinations of three hydrologic models and five general circulation models (GCMs) using Representative Concentration Pathway (RCP) 8.5. **(a)** The hydrologic model was run with a sample of parameter sets for the period 1985–2008. The model was forced with observed Daymet data (Thornton et al., 2012). The size of the parameter sample differed per model, from 1600 to 1900 (see Sect. 2). Behavioural runs were identified based on 23 years of daily observed discharge data. **(b)** The constrained models, i.e. the behavioural parameter sets, were forced with GCM data for the historical period 1985–2008 and future period 2070–2100. For each run, the mean annual runoff was determined for both periods. **(c)** The change is defined as the difference in mean annual runoff between the historical and future periods, and is determined per run. **(d)** Histogram showing the distribution of the change for the different model runs as shown in **(c)**. The sign of the ensemble mean change is determined, as well as the agreement among the different parameter sets on the sign of the ensemble mean change. The agreement is defined as the percentage of runs that project the same sign of change (positive change = increasing mean annual runoff; negative change = decreasing mean annual runoff) as the ensemble mean change. Finally, the sign of the ensemble mean change is compared for different combinations of hydrologic models and GCMs.

Some questions regarding key concepts and terminology in climate impact literature

- If a model is irrelevant to reality, can the average difference of the model to reality be called "*bias*" or "*systematic error*"?
  (What about "*not-even-error*", in accord to the expression "*not even wrong!*"?)
- Can the "lifting" of model outputs, so as to approach reality, be called "*bias correction*" (cf. Ehret et al., 2012) or "*downscaling*"?
  (What about "*cosmetic reformation*"?)
- Can the disagreement among models be called "*uncertainty*"?
  (What about "*model resistance to confirmation bias*"?) (cf. Essex and Tsonis, 2018.)
  Note: If models agreed to each other, would uncertainty disappear?
- By what premise could a "trend" located in data be called "*nonstationarity*", particularly when the change resulted from the "trend" is far lower than "*bias correction*"?
  (What about "*non-nonstationarity*"?)

The horrible passion of stationarity

A quote from Salas et al. (2018):

However, […] some hydrologists strongly questioned the assumption of stationarity and suggested that

- *“Stationarity is dead – whither water management?” (Milly et al. 2008)*

and that alternative methods should be developed based on nonstationary concepts for more realistic design, evaluation, and planning and management of infrastructure. While the referred paper received major attention, […] many others reacted with opposite positions and opinions, as exemplified by the titles of some of the published articles, such as:

- *“Stationarity: wanted dead or alive?” (Lins and Cohn 2011),*
- *“Comment on the announced death of stationarity” (Matalas 2012),*
- *“Negligent killing of scientific concepts: the stationary case” (Koutsoyiannis and Montanari 2014),*
- *“Modeling and mitigating natural hazards: stationarity is immortal!” (Montanari and Koutsoyiannis 2014), and*
- *“Stationarity is undead: uncertainty dominates the distribution of extremes” (Serinaldi and Kilsby 2015).*

Cautionary note on the asymmetry among referenced papers: The Milly et al. paper has about 2881 citations while none of the others exceeds ~100 citations.

A last moment addition: According to Serinaldi and Kilsby (2018), also the temperature extremes (in USA) “*are still consistent with stationary correlated random processes.*”

Examples of trendy modelling of hydrological maxima using linear functions of time

Source: Sarhadi and Soulis (2017)

"The present study outlines a framework for fully time varying IDF curves to incorporate the impact of climate change in the new generation of engineering planning and infrastructure designs."

$$\mu(t) = \mu_0 + \mu_1 t$$

$$\sigma(t) = \sigma_0 + \sigma_1 t$$

Different views

Source: Ganguli and Coulibaly (2017)

"Despite apparent signals of nonstationarity in precipitation extremes […], the stationary vs. non-stationary models do not exhibit any significant differences in the design storm intensity […]"

Source: Koutsoyiannis (2011b)

Linear trends can only be local; otherwise there is risk of deriving negative values or heading to ±∞; HK-dynamics offers a better alternative.

Source: Serago and Vogel (2018)

$$\mu_{y/w} = \mu_y + \beta(w - \mu_w)$$

$$\sigma^2_{y/w} = \sigma^2_\varepsilon = \sigma^2_y(1 - \rho^2)$$

$$w = time$$

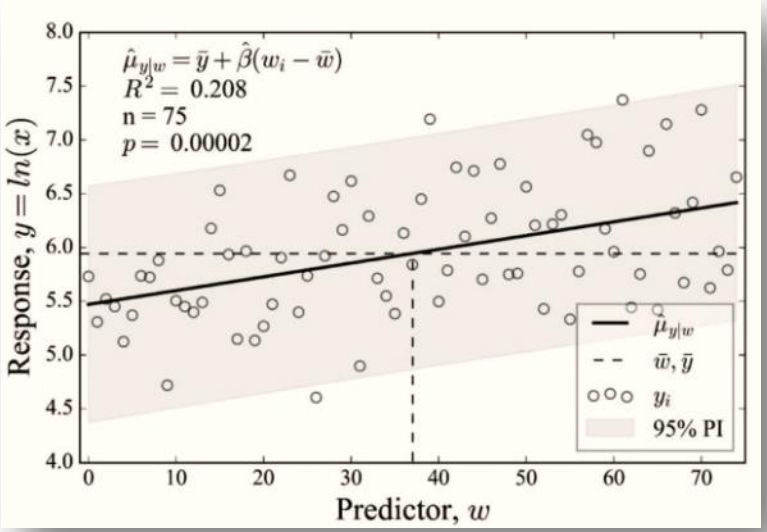
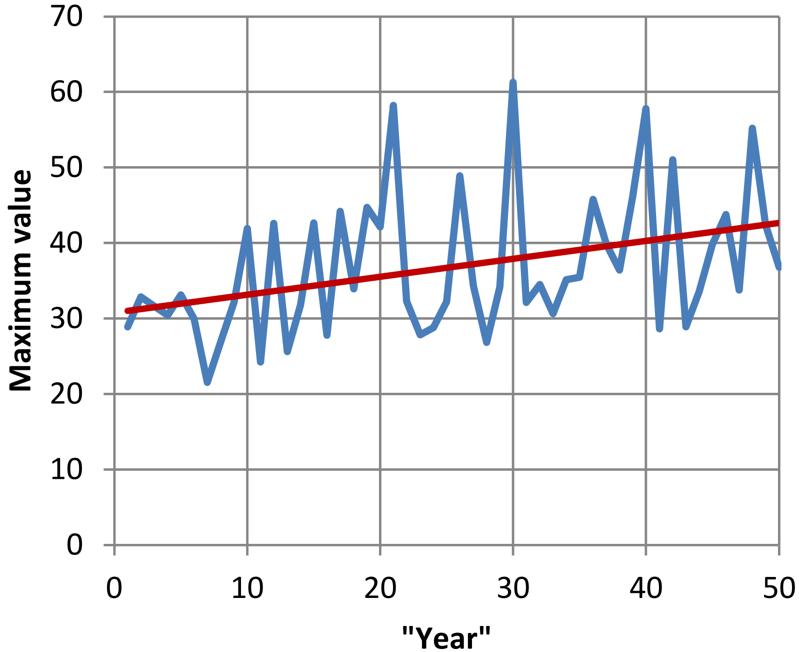
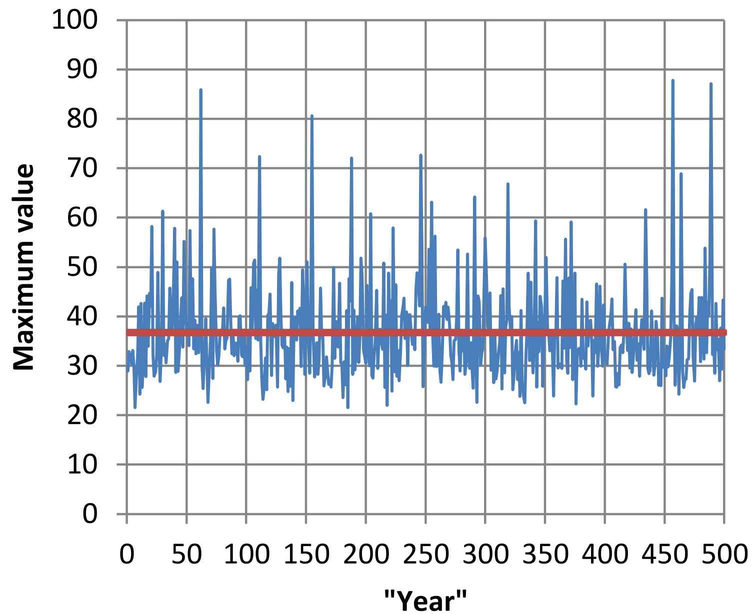


Fig. 1. Natural logarithm y, of annual maximum streamflow x of the Aberjona River at Winchester, MA, 1940–2014 versus w = *time* in years. Solid line is a bivariate linear regression which represents the conditional mean of $y = \ln(x)$ as a function of w, denoted $\hat{\mu}_{y|w}$. Shaded region is the estimated 95% prediction interval for future values of $y = \ln(x)$.

Nature's style is naturally trendy*, yet it can be modelled as stationary

*Cohn and Lins (2005)





- The graph on the left shows 50 "years" of simulated (artificial) maxima of a process that is by construction stationary. The parent process is an exponentiated HK process with Hurst exponent H = 0.7 and the maxima are taken at scale 128.
- The first 50 values show a "clear" upward trend. A classical statistical test for a linear trend rejects the stationarity hypothesis (i.e. makes a type-I error) at a *p*-value of 8.7×10^{-6}!
- The trend disappears if more terms are viewed, thus revealing the stationarity of the entire model and setting.

Nonstationarity would be justified if we had good deterministic predictions for future climate, but do we?

Hydrological Sciences–Journal–des Sciences Hydrologiq

RAPID COMMUNICATION

On the credibility of climate predictions

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dk@itia.ntua.gr

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

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

REPLY

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. Anagnostopoulos[2] ...

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

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
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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.

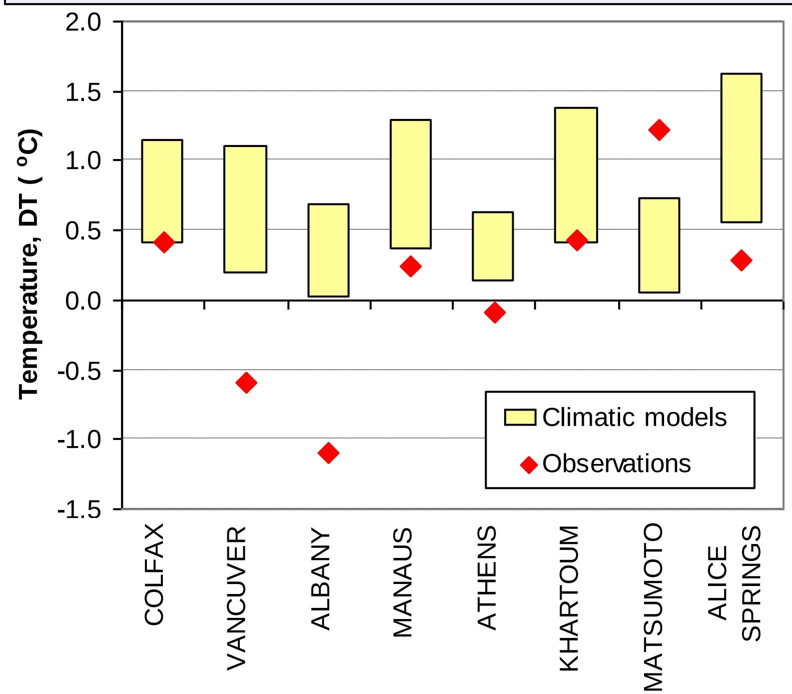
Abstract We compare the output of various climate models to temperature and precipitation observations at 55 points around the globe. We also spatially aggregate model output and observations over the contiguous USA using data from 70 stations, and we perform comparison at several temporal scales, including 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.

See details in Koutsoyiannis et al. (2008, 2011) and Anagnostopoulos et al. (2010).

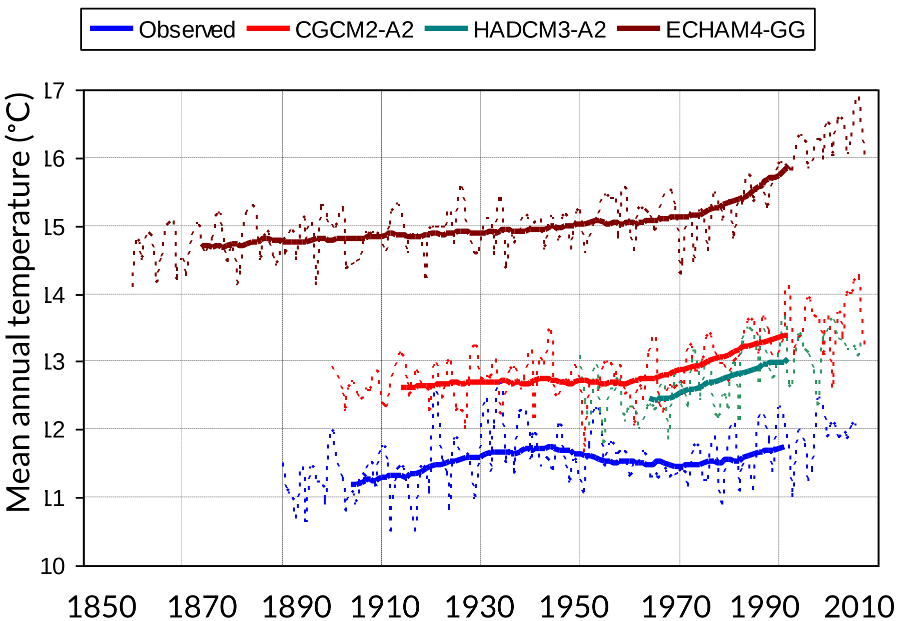
Do climate models reproduce real-world temperature?

- Koutsoyiannis *et al.* (2008) tested hindcasts of three IPCC AR4 and three TAR climatic models at 8 test sites that had long (> 100 years) temperature and precipitation series of observations.
- Anagnostopoulos et al. (2010) extended the exploration in 55 additional test sites, and also compared model results with reality over the contiguous USA.
- Both studies found that model outputs do not correlate well with reality, particularly at climatic scales and at large spatial scales.

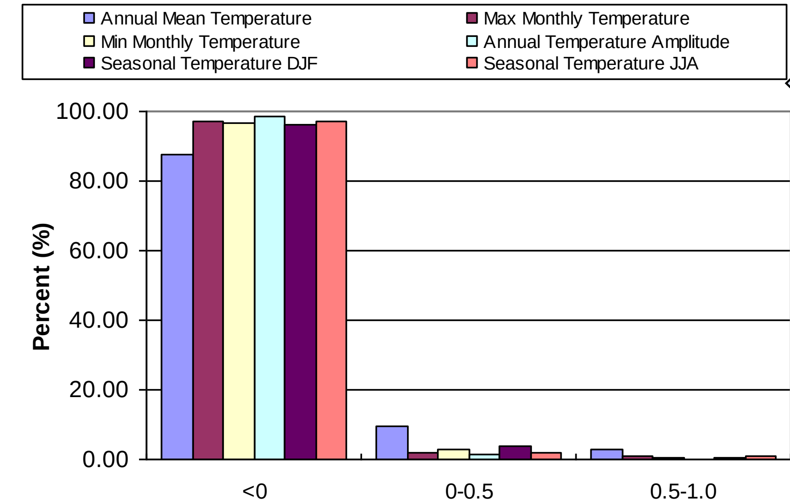
Change of climatic (30-year moving average) temperature in the 20th century: models vs. reality (Koutsoyiannis et al., 2008)



Average temperature at the contiguous USA: models vs. reality (Anagnostopoulos et al., 2010)

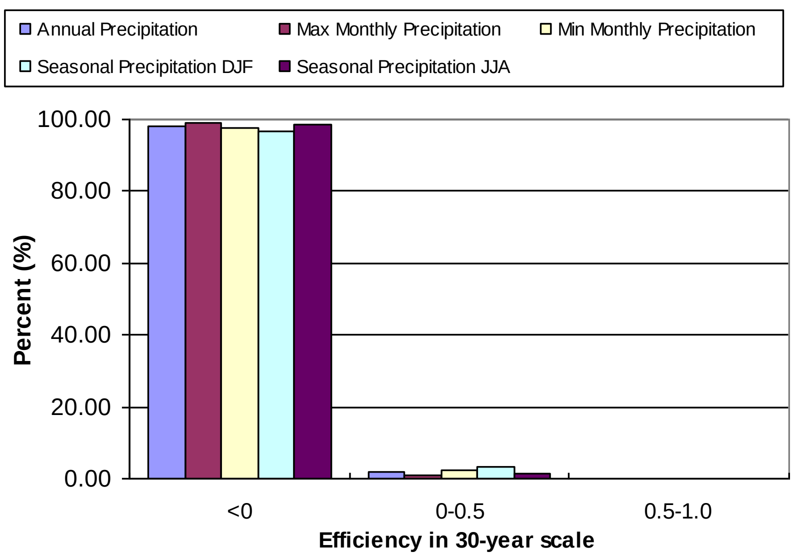


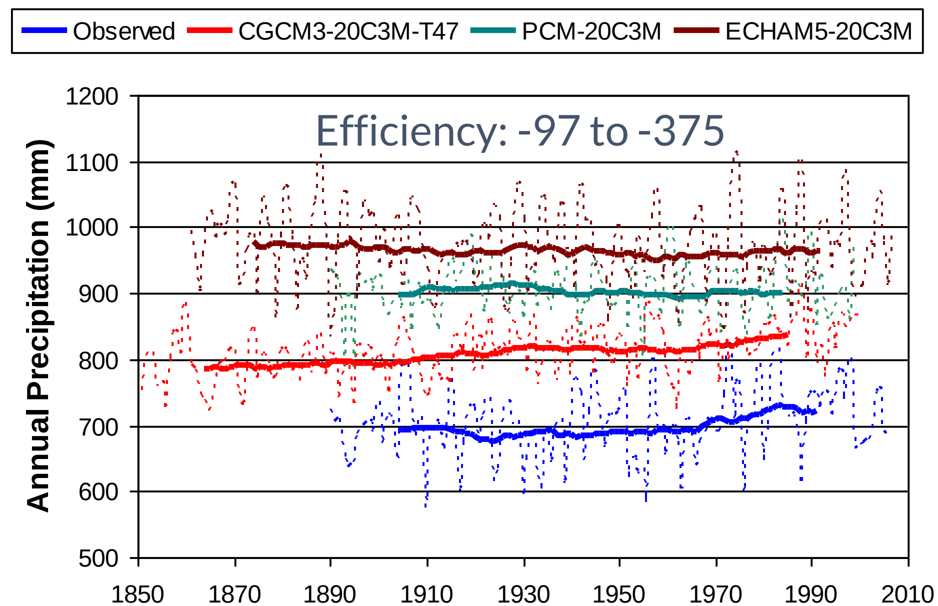
Do climate models reproduce real-world rainfall?



Comparison of 3 IPCC TAR and 3 IPCC AR4 climate models with historical series of more than 100 years length in 55 stations worldwide

Comparison of 3 IPCC AR4 climate models with reality in sub-continental scale (contiguous USA)



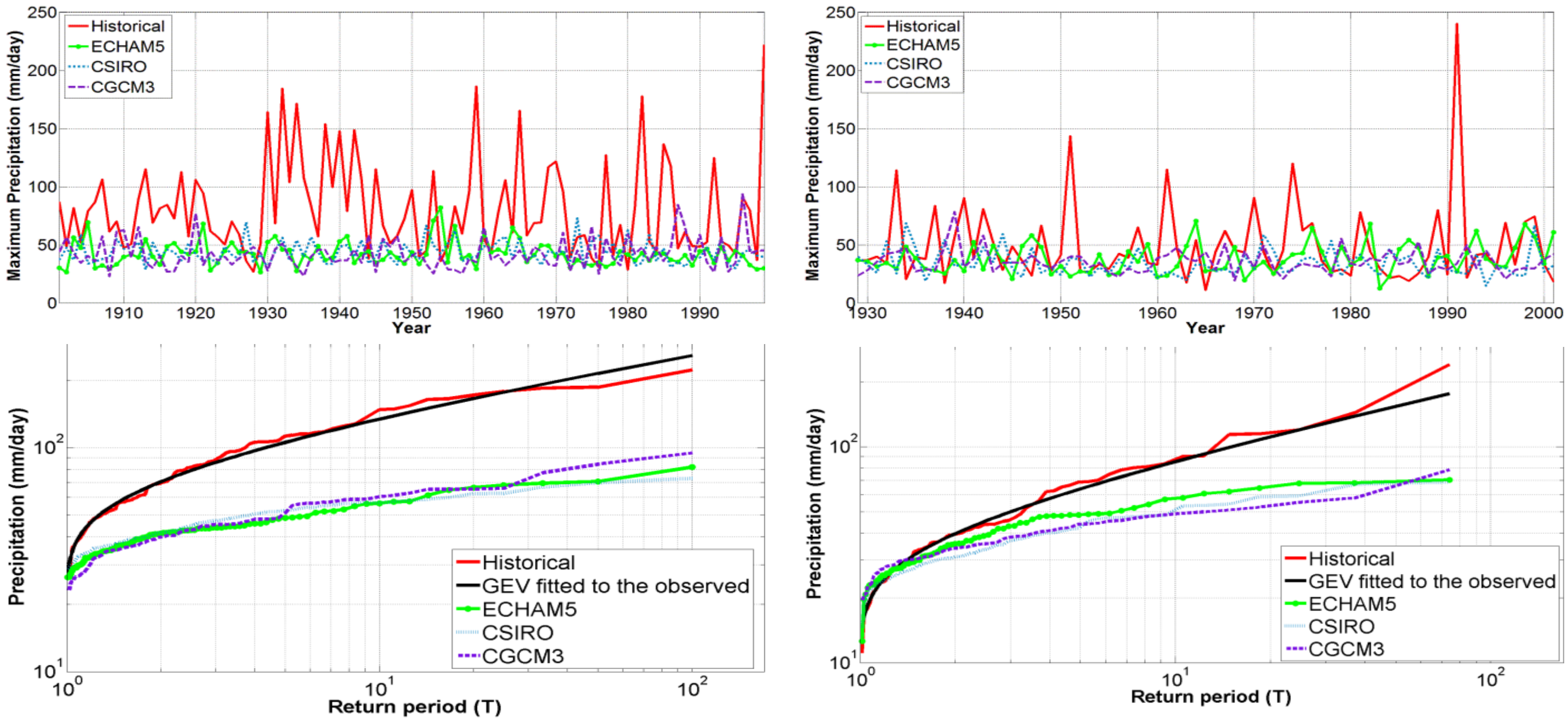


Source: Anagnostopoulos, et al. (2010).
See also reviews by Pielke Sr. (2017) and Essex and Tsonis (2018)

Do GCMs simulate the real phenomenon, i.e., rainfall?

- Tsaknias et al. (2016—**multirejected paper**) tested the reproduction of extreme events by three climate models of the IPCC AR4 at 8 test sites in the Mediterranean which had long time series of temperature and precipitation.
- They concluded that model results are irrelevant to reality as they seriously underestimate the size of extreme events.

Upper row: Daily annual maximum precipitation at Perpignan and Torrevieja; Lower row: empirical distribution functions of the data in upper row (Tsaknias et al., 2017)



Do hydroclimatic models reproduce real-world runoff?

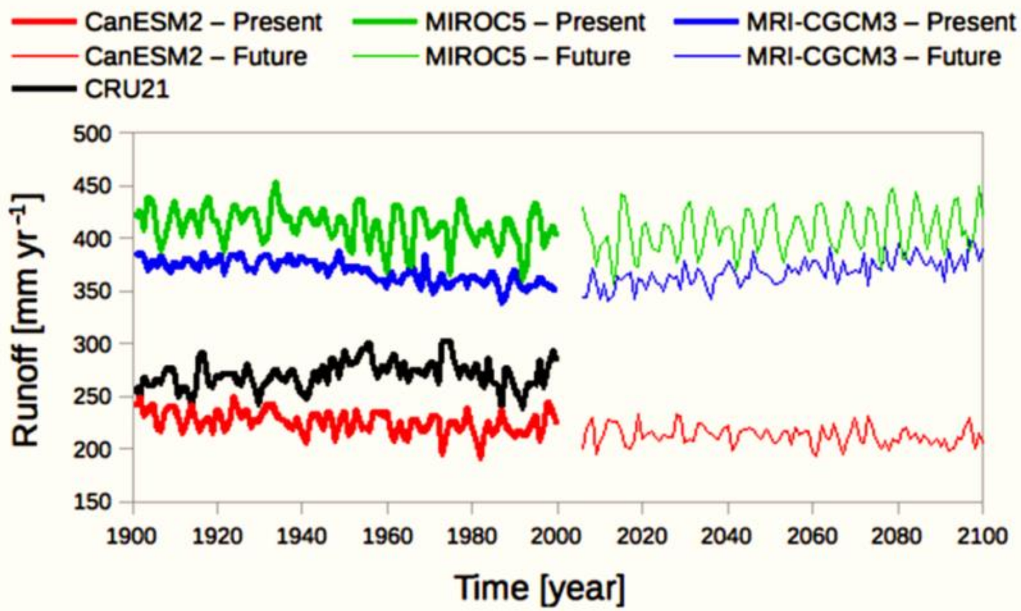


Figure 1. Annual estimates from GCM simulations under present and projected future conditions in contrast with observed climate forcings from the Climate Research Units, University of East Anglia.

Source: Fekete et al. (2016).

Quote: "*Our paper demonstrates core deficiencies in GCM based water resources assessments and articulates the need for improved Earth system monitoring that is essential not only for water managers, but to aid the improvements of GCMs in the future.*"

Do climate models represent key changes in the atmosphere and the hydrological cycle?

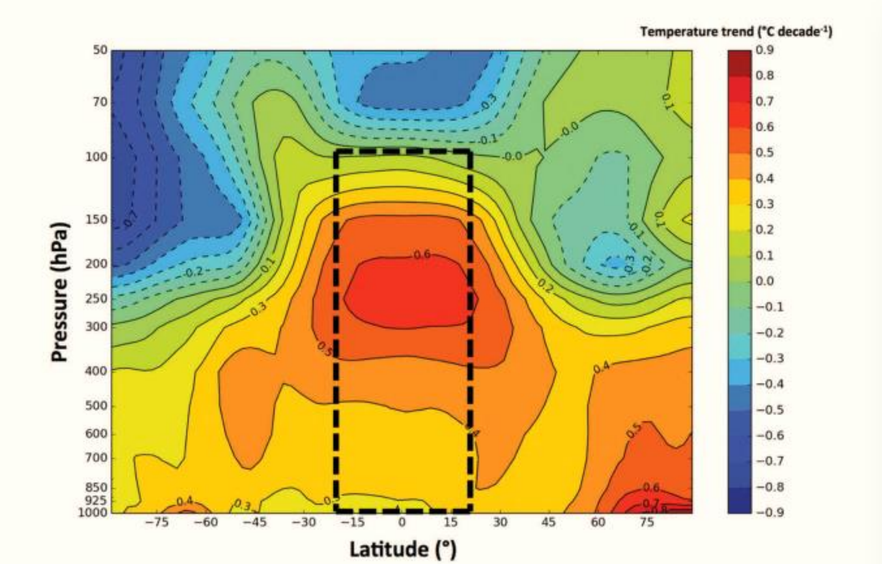


Figure 1. Latitude – Altitude cross-section of 38-year temperature trends (°C decade^{-1}) from the Canadian Climate Model Run 3. The tropical tropospheric section is in the outlined box.

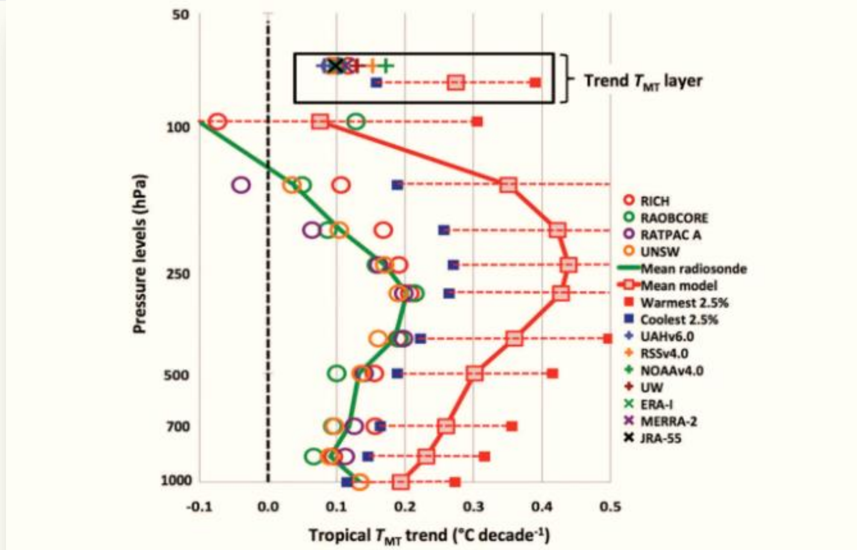


Figure 18. Trend magnitudes (°C decade^{-1}) from radiosonde and CMIP-5 climate model simulations over the period 1979–2016. In the upper box are the trend magnitudes of the T_{MT} layer as calculated by the various datasets defined in Table 2 and in this paper.

Source of graph: Christy et al. (2018).

Quotes: *"the troposphere (the air from the surface to the stratosphere, or about 85% by mass), is an especially informative layer because it is anticipated to show the most pronounced bulk temperature response to greenhouse forcing."*

"Because the model trends are on average highly significantly more positive and with a pattern in which their warmest feature appears in the latent-heat release region of the atmosphere, we would hypothesize that a ***misrepresentation*** *of the basic model physics of the* ***tropical hydrologic cycle*** *(i.e. water vapour, precipitation physics and cloud feedbacks) is a likely candidate."*

Part 4
Some ideas to make scientific (i.e., stochastic) predictions

Some papers presenting such ideas

Hydrol. Earth Syst. Sci., 14, 585–601, 2010
www.hydrol-earth-syst-sci.net/14/585/2010/
© Author(s) 2010. This work is distributed under the Creative Commons Attribution 3.0 License.

Hydrology and Earth System Sciences

HESS Opinions
"A random walk on water"

D. Koutsoyiannis
…hool of Civil Engineering, National Technical University

Hydrological Sciences Journal – Journal des Sciences Hydrologiques, 58 (6) 2013 1177
http://dx.doi.org/10.1080/02626667.2013.804626

OPINION PAPER

Hydrology and change

Demetris Koutsoyiannis

Entropy **2014**, *16*, 1287-1314; doi:10.3390/e16031287

OPEN ACCESS
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ISSN 1099-4300
www.mdpi.com/journal/entropy

Article

Entropy: From Thermodynamics to Hydrology

Demetris Koutsoyiannis

…odern axiomatic theory of proba- (1933) avoided defining random- …f random events and random vari- …nse but without explaining what … A. N. Kolmogorov and

1174 Hydrological Sciences Journal – Journal des Sciences Hydrologiques, 60 (7–8) 201…
http://dx.doi.org/10.1080/02626667.2014.959959
Special issue: *Modelling Temporally-variable Catchments*

Negligent killing of scientific concepts: the stationarity case

Demetris Koutsoyiannis[1] and Alberto Montanari[2]

WATER RESOURCES RESEARCH, VOL. 48, W09555, doi:10.1029/2011WR011412, 2012

A blueprint for process-based modeling of uncertain hydrological systems

Alberto Montanari[1] and Demetris Koutsoyiannis[2]

Received 16 September 2011; revised 19 August 2012; accepted 20 August 2012; published 29 September 2012.

…present a probability based theoretical scheme for building process-based models …tain hydrological systems, thereby unifying hydrological modeling and uncertainty …ent. Uncertainty for the model output is assessed by estimating the related …

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

Hristos Tyralis and Demetris Koutsoyiannis

Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Zographou, Greece

ABSTRACT
A problem frequently met in engineering hydrology is the forecasting of hydrological variables conditional on their historical observations and the hindcasts and forecasts of a deterministic …

ARTICLE HISTORY
Received 4 April 2017
Accepted 10 July 2017

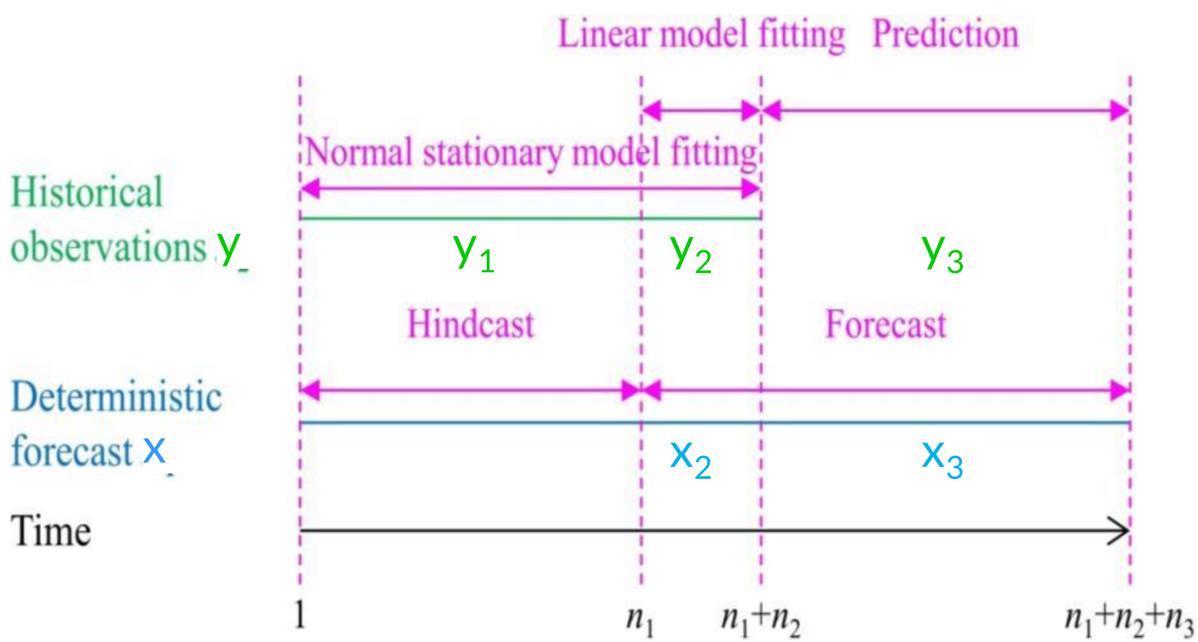
Can we convert deterministic modeling into stochastic?

- **Yes**—we can and we should.
- **Method 1**: By perturbing input data, parameters and model output (the latter by adding random outcomes from the population of the model error): see the blueprint by Montanari and Koutsoyiannis (2012).
- **Method 2**: By incorporating one or many deterministic forecasts into an initially independent stochastic model: Tyralis and Koutsoyiannis (2017).

- 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

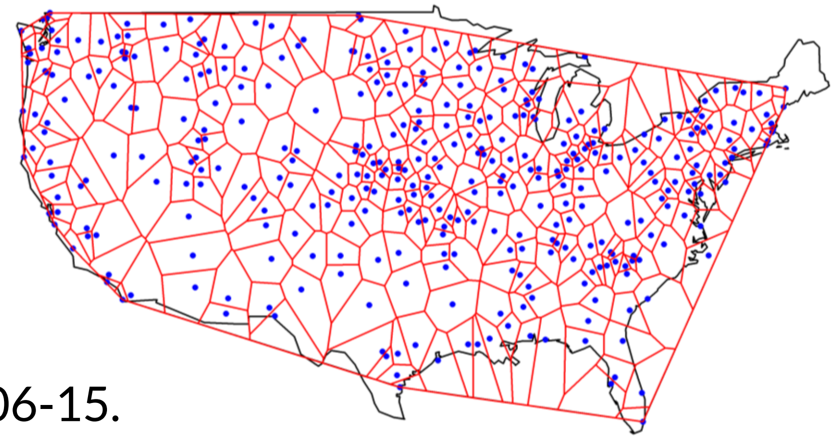
  $h(\boldsymbol{y}_3|\boldsymbol{y}_1, \boldsymbol{y}_2, \boldsymbol{x}_2, \boldsymbol{x}_3)$
  $\propto f(\boldsymbol{x}_3|\boldsymbol{y}_3)\, g(\boldsymbol{y}_3|\boldsymbol{y}_1, \boldsymbol{y}_2)$

  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.

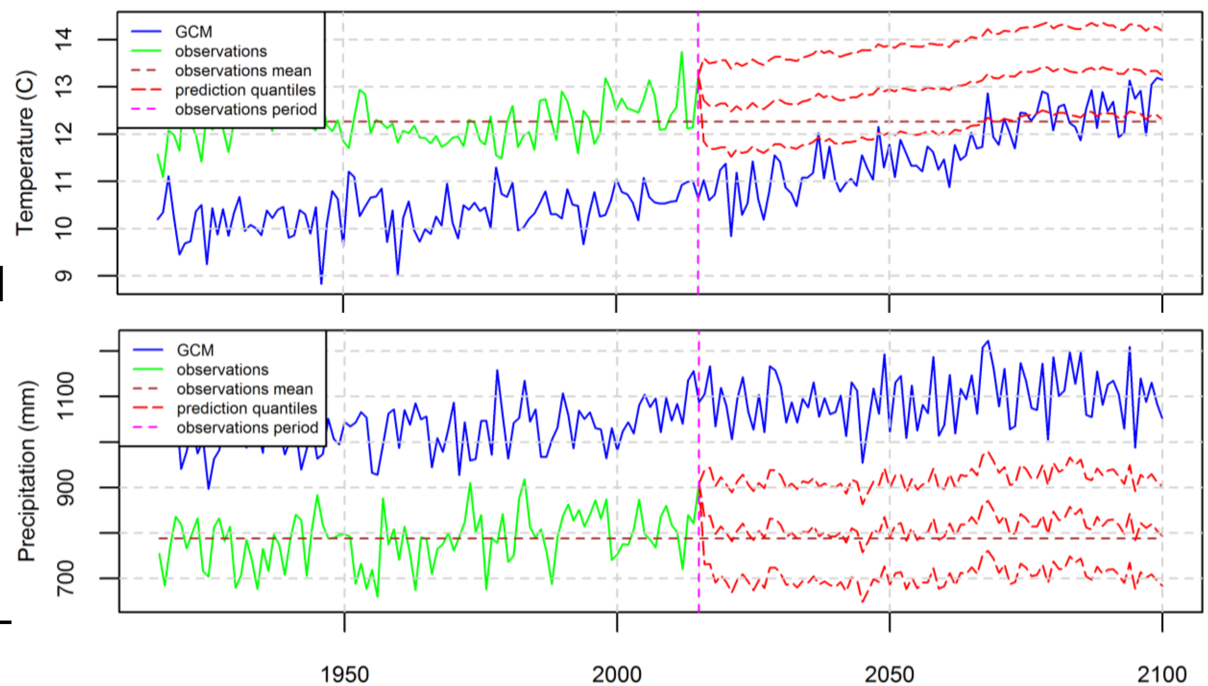


Application to the climate of the USA

- 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.



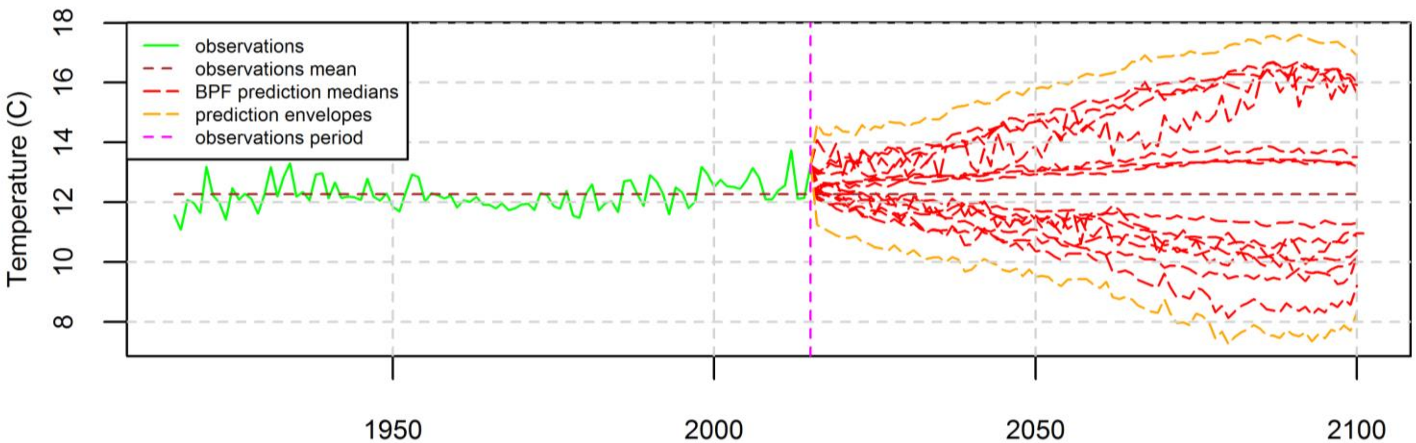
- The example on temperature (95% prediction intervals) shows a slight increase in annual temperature in the USA if conditioned on the output of MRI-CGCM3 climate model.
- The example on precipitation shows indifference despite conditioning on the GISS-E2-H climate model.



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**.

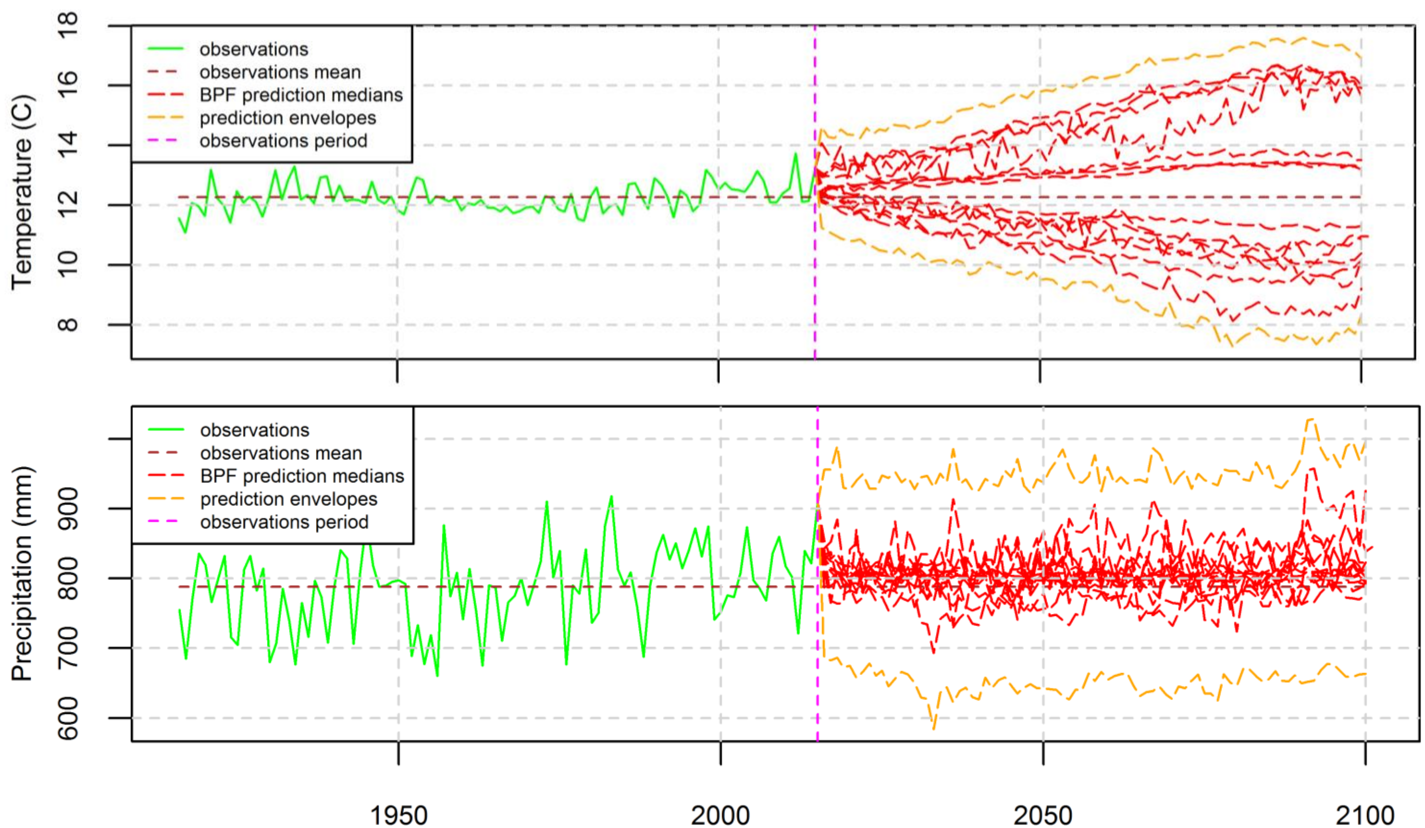
Caution: Envelops and spaghetti graphs are not stochastically sound, but have been popular in climatology communications.



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 K.
- 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.



Epilogue

- 2300+ years ago, **Epicurus** pronounced **science as the enemy of fear**.
- 130 years ago, **Ludwig Boltzmann** explained the concept of **entropy** in **probability** theoretic context and founded statistical physics.
- Yet today, climate and climate-impact research, including its hydrological branch, continue to scare people and interpret physics according to the "almighty determinism" of the 17th century.
- Fear is linked to the ideology of world saviour; but if we care about progress, we need to isolate science from **ideology**, and reestablish the link of **science** with **common sense**, **philosophy and technology**.
- In spite of zestful deterministic efforts, the future will remain unknown and uncertain.
- **Uncertainty** is **not** an **enemy**; rather this world is livable *because of it*.

> The quest for certainty blocks the search for meaning. Uncertainty is the very condition to impel man to unfold his powers.
>
> Erich Fromm

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