Invited Seminar

WasserCluster Lunz – Biologische Station GmbH
Lunz am See, Austria

Saving the world from climate threats *vs.* dispelling climate myths and fears

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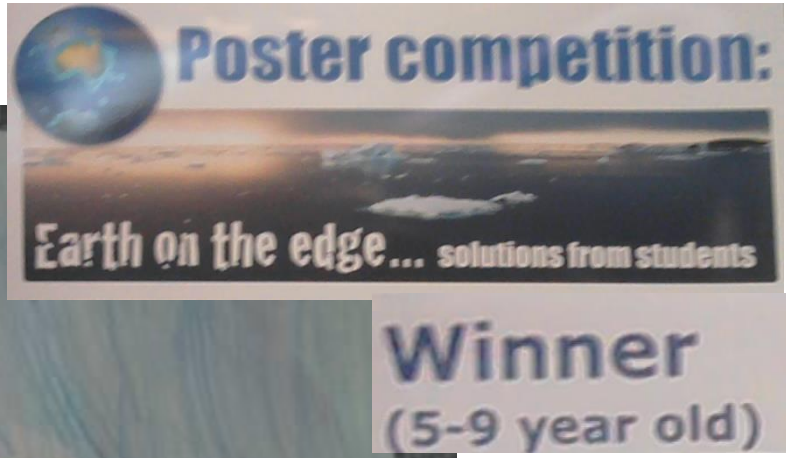
Presentation available online: http://itia.ntua.gr/1706/

The 1333 flood in Florence

- 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 dilemma" and debate would have been ***on whether the flood occurred for anthropogenic climate change or for natural causes***.

http://www.anamericaninitaly.com/2014/02/11/acqua-alta-high-water-marks/

A culture promoting fear: from God's punishment to Earth's punishment



First prize in a poster competition for kids in the frame of the IUGG 2011 in Melbourne (Photo: D. Koutsoyiannis)

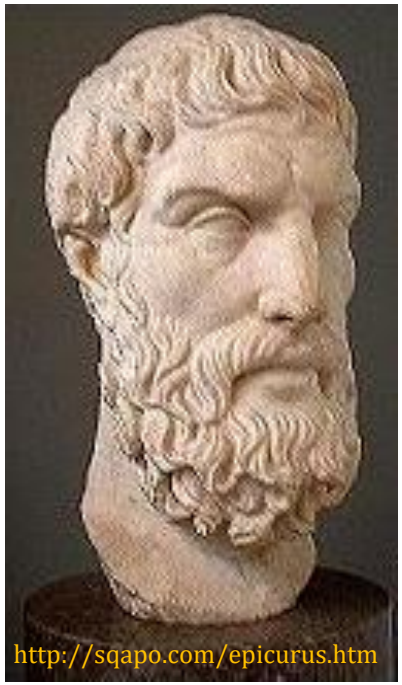
Epicurus's contribution in "attribution dilemmas": the aim of science in dispelling fears and myths, and the role of scientists

- *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).

- ***Παρρησία*** *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

Modern fears promoted by the political and climate orthodoxy

- *If political leaders have one duty above all others, it is to protect the security of their people. Thus it was, according to the prime minister,* ***to protect Britain's security against Saddam Hussein's weapons of mass destruction that this country went to war in Iraq****. And yet our long-term security is threatened by* ***a problem at least as dangerous as chemical, nuclear or biological weapons, or indeed international terrorism: human-induced climate change****.*
- *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"****.*

Houghton (2003)

Weapons of mass destruction continued: Are Syria's conflict and Brexit caused by climate change?

- *The devastating **civil war that began in Syria in March 2011** is the result of complex interrelated factors. The focus of the conflict is regime change, but the triggers include a broad set of religious and sociopolitical factors, … and challenges **associated with climate variability and change** and the availability and use of freshwater* (Gleick, 2014).
- *There is evidence that the 2007–2010 drought contributed to the conflict in Syria. … anthropogenic forcing has increased the probability of severe and persistent droughts in this region, and made the occurrence of a 3-year drought as severe as that of 2007–2010 2 to 3 times more likely than by natural variability alone. We conclude that **human influences on the climate system are implicated in the current Syrian conflict*** (Kelley et al., 2015).
- *There's already some really interesting work — not definitive but powerful — showing that **the droughts that happened in Syria** contributed to the unrest and **the Syrian civil war*** (Obama, 2016).
- The **"principal" cause of the Syrian Civil War had been the worst drought in 900 years**… The resulting war brought more refugees into Europe, causing political instability and **helping convince some in the UK to vote to leave the European Union** (Gore, 2017).

Scientists predicted lots of catastrophes in the past, God laughed... (we too may laugh now)

- **1970:** ***Civilization will end within 15 or 30 years unless immediate action is taken against problems facing mankind.***
  George Wald, Harvard Biologist, share of the 1967 Nobel Prize in Physiology or Medicine (quoted in Looney, 2011, p. 390, and Dudley, 2001, p. 26) .
- **1970:** *Demographers agree almost unanimously on the following grim timetable: by 1975 widespread famines will begin in India; these will spread by 1990 to include all of India, Pakistan, China and the Near East, Africa. …* ***By the year 2000, thirty years from now, the entire world, with the exception of Western Europe, North America, and Australia, will be in famine.***
  Peter Gunter, professor, North Texas State University (quoted in Looney, 2001, p. 389).
- **1970:** ***The world has been chilling*** *sharply for about twenty years... If present trends continue, the world will be about four degrees colder for the global mean temperature in 1990, but* ***eleven degrees colder in the year 2000. This is about twice what it would take to put us into an ice age.***

  Also: *We have about five more years at the outside to do something.*
  Kenneth E. W. Watt, Ecologist and Professor of University of California, Davis (Environmental Action, 1970, pp. 14-15).

The Club of Rome predicted catastrophes, God laughed... (we too may laugh now)

Table 4 NONRENEWABLE NATURAL RESOURCES

1	2	3	4			5	6
Resource	*Known Global Reserves* [a]	*Static Index (years)* [b]	*Projected Rate of Growth (% per Year)* [c]			*Exponential Index (years)* [d]	*Exponential Index Calculated Using 5 Times Known Reserves (years)* [e]
			High	*Av.*	*Low*		
Aluminum	1.17×10^9 tons [f]	100	7.7	6.4	5.1	31	55
Copper	308×10^6 tons	36	5.8	4.6	3.4	21	48
Gold	353×10^6 troy oz	11	4.8	4.1	3.4 [f]	9	29
Lead	91×10^6 tons	26	2.4	2.0	1.7	21	64
Mercury	3.34×10^6 flasks	13	3.1	2.6	2.2	13	41

In **1972**, the report by Meadows et al. (1972), written for the Club of Rome warned that the world would run out of gold by 1981, mercury (and silver by 1985, tin by 1987 and petroleum, copper, lead and natural gas by 1992.

If you have cruel heart, there is abundance of predicted catastrophes for your amusement; the above citations, as well as Bailey (2000, 2015), Bratby (2008), provide a guide to start.

Ecologists predict catastrophes, God laughs... (some of us laugh, too)

- On the occasion of the first Earth Day, "celebrated" 47 years ago (on 22 April **1970**) several predictions of ecological catastrophes were issued. Senator Gaylord Nelson wrote in *Look*, "*Dr. S. Dillon Ripley, secretary of the Smithsonian Institute, believes that* ***in 25 years****, somewhere between* ***75 and 80 percent of all the species of living animals will be extinct***" (from Bailey, 2000, 2015).
- In 1975 Paul and Anne Ehrlich predicted that "*since more than nine-tenths of the original tropical rainforests will be removed in most areas* ***within the next 30 years*** *or so, it is expected that* ***half of the organisms in these areas will vanish*** *with it*" (from Bailey, 2000, 2015).
- In 2002 Edward O. Wilson wrote. "***Now we are no longer counting extinctions in the past but instead commitments to extinction in the near future*** *... [I]t is safe to say that at least a fifth of the species of plants and animals would be gone or committed to early* ***extinction*** *by 2030, and* ***half by the end of the century****. If, on the other hand, an all-out effort is made to save the biologically richest parts of the natural world, the amount of loss can be cut by at least half*" (Wilson, 2002).
- In 2007 in its Fourth Assessment Report (AR4), IPCC predicted that "*There is medium confidence that* ***approximately 20-30% of species assessed*** *so far are likely to be at increased risk of extinction if increases in global average warming exceed 1.5-2.5 °C (relative to 1980-1999). As global average temperature increase exceeds about 3.5 °C, model projections suggest significant extinctions (****40-70% of species assessed****) around the globe*"(IPCC, 2007).

Ecologists alleviate their predictions for catastrophes, God laughs... (some of us laugh, too)

- While in its Fourth Assessment Report (AR4) in 2007, IPCC gave rough quantitative predictions on species extinction (from 20-30% to 40-70% depending on the temperature increase), in its Fifth Assessment Report (AR5) in 2014 downsized its predictions and made them fuzzier.
- From the Synthesis Report, Summary for Policymakers (IPCC, 2014)
  - "*A **large fraction of species** faces increased **extinction risk** due to **climate change during and beyond the 21st century**, especially as climate change interacts with other stressors (high confidence).*"
  - "*The risks associated with temperatures at or **above 4°C include substantial species extinction**, global and regional food insecurity, … (high confidence)*"
- From IPCC Ch. 4 — Terrestrial and Inland Water Systems (Settele et al., 2014)
  - "*Models project that the risk of species extinctions will increase in the future owing to climate change, but **there is low agreement concerning the fraction of species at increased risk**, the regional and taxonomic focus for such extinctions and the time frame over which extinctions could occur.*"
  - "*Modeling studies and syntheses since the AR4 **broadly confirm that a large proportion of species are projected to be at increased risk of extinction** at all but the lowest levels of climate warming.*"

Who will save us from saviors?

- In 17 November 2011, several email exchanges of protagonists in the “climate change research” leaked and the “Climategate” scandal broke out.
- Featured excerpts from emails:
  - *“If anything, I would like to see the climate change happen, so the science could be proved right, regardless of the consequences.”*
  - *“I tried hard to balance the needs of the science and the IPCC , which were not always the same.”*

Climate Science: Roger Pielke Sr.

HOME MAIN CONCLUSIONS MESSAGE FROM R.A. PIELKE SR.

Pielke Research Group: News and Commentary

NOVEMBER 24, 2009 · 7:00 AM

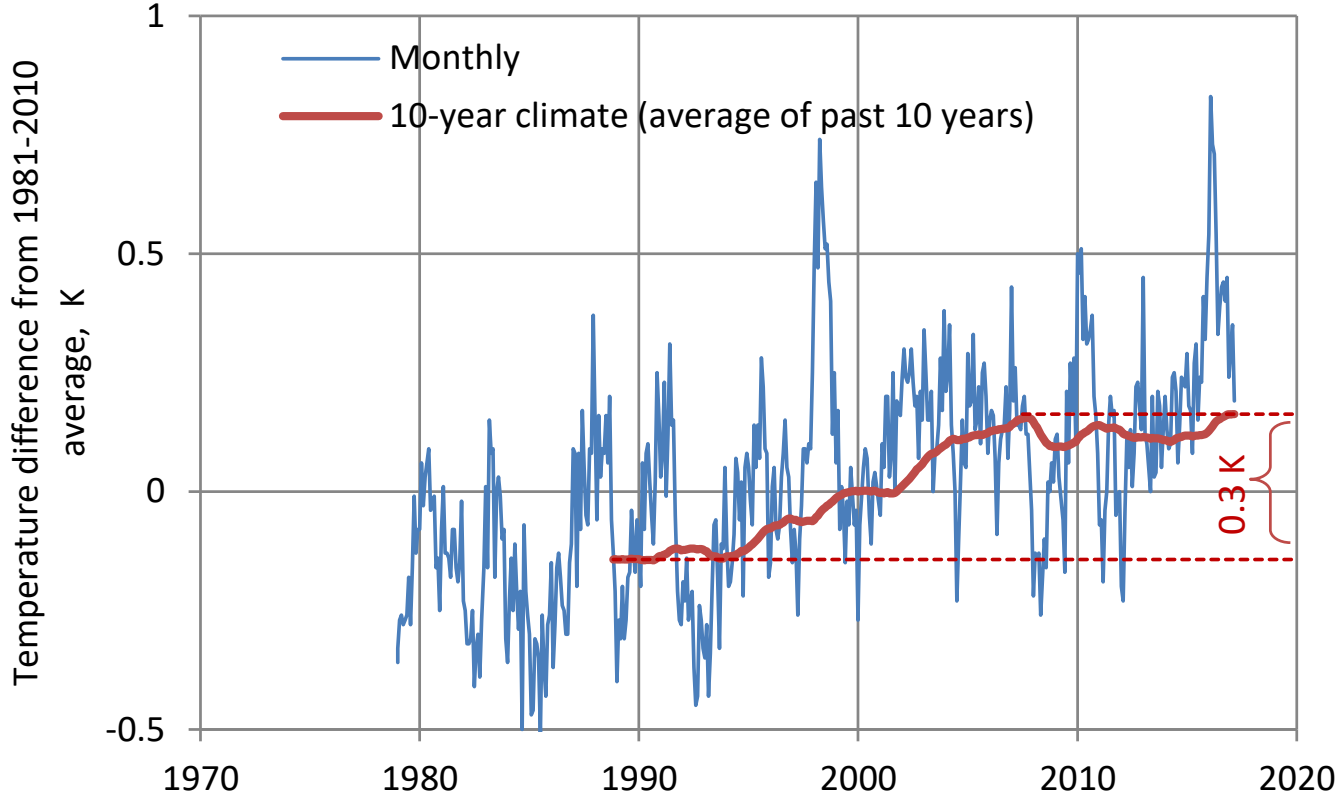
Beware Saviors! By Demetris Koutsoyiannis

Guest weblog by Demetris Koutsoyiannis (http://www.itia.ntua.gr/dk/)

Hydrological engineering is my scientific field and it is closely related to climate. In the last decade, I have been concerned about the state of research in climate and its detrimental influence on hydrology. Also, I should note up front that I try to be a skeptic; for a Greek, this is a positive quality (skeptic is etymologized from skepsis = thought). In

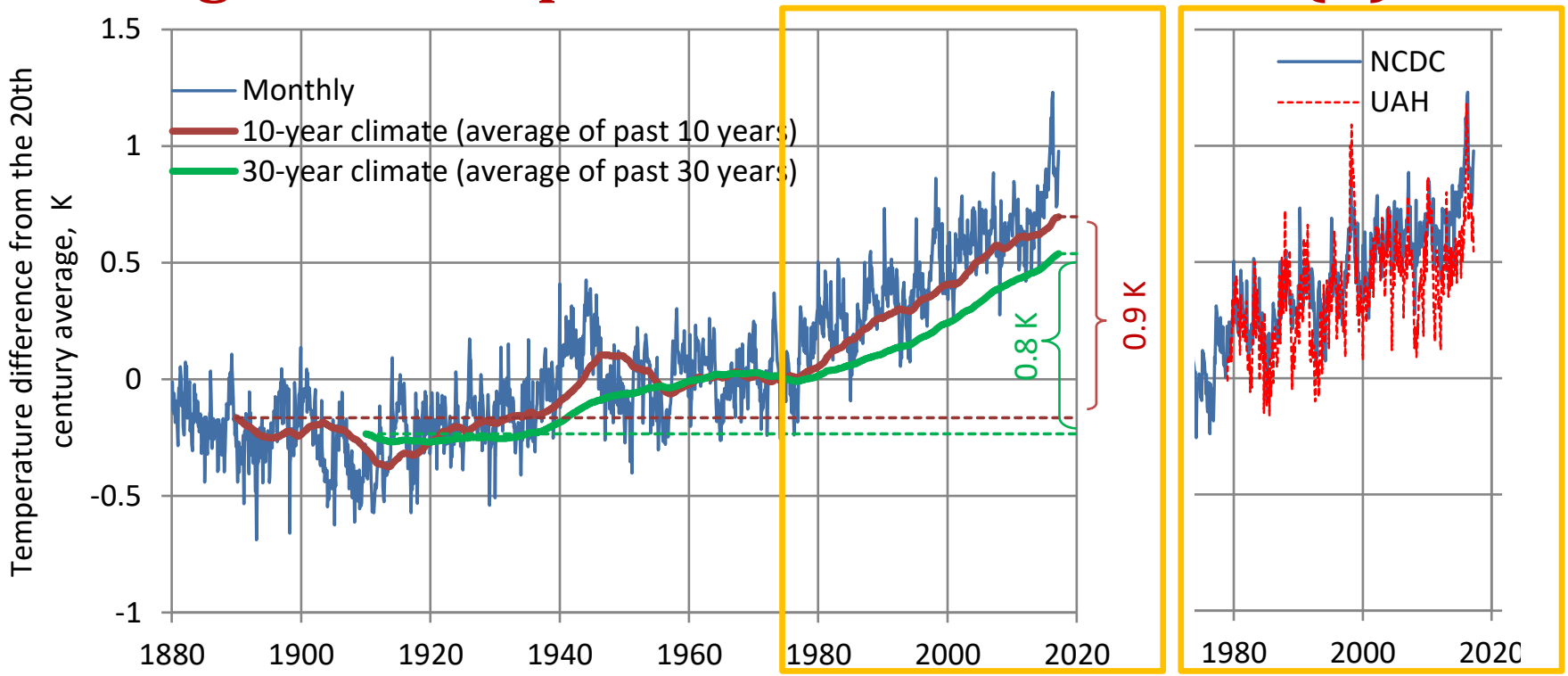
Source: pielkeclimatesci.wordpress.com/2009/11/24/beware-saviors

Facts: global temperature has increased



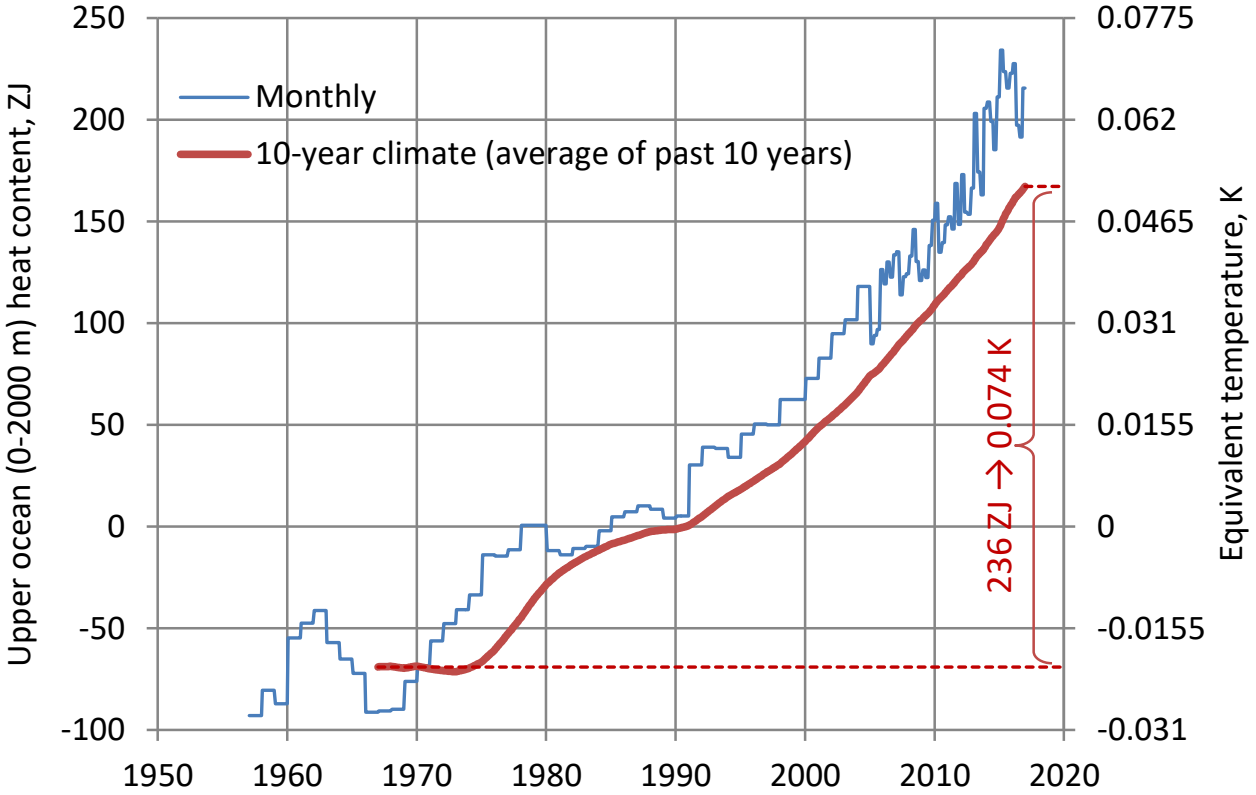
- **Data**: UAH satellite data for the lower troposphere (global average) gathered by advanced microwave sounding units on NOAA and NASA satellites (http://www.nsstc.uah.edu/data/msu/v6.0/tlt/uahncdc_lt_6.0.txt).
- **Fact**: From 1995 to 2007 there has been an increase of 0.3 K in the globally averaged 10-year climatic temperature; the data indicate no temperature change at the 10-year climatic scale before and after that period (**increase 0.11 K/decade**).

Facts: global temperature has increased (2)



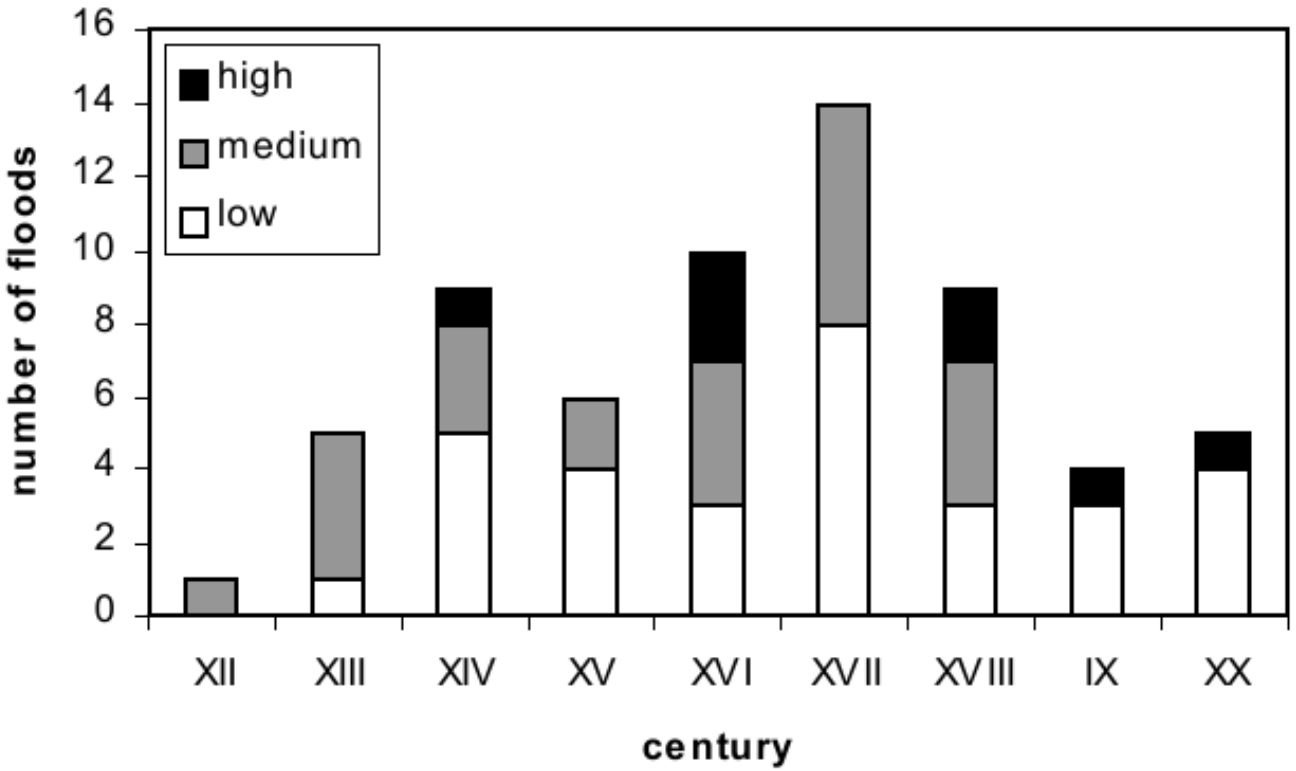
- **Data**: NCDC/NOAA global temperature data (http://climexp.knmi.nl/data/incdc_gl.dat).
- **Note 1**: These data are being repeatedly revised and each new version usually boosts the observed temperature increase (see comparison with UAH data).
- **Note 2**: According to the latest version of the data, from 1940 to date there has been an increase of 0.9 K in the globally averaged 10-year climatic temperature or 0.8 K in the globally averaged 30-year climatic temperature; the data indicate climatic fluctuations before that period (average **increase 0.07 K/decade**).

Facts: Ocean heat content has increased (but how much?)



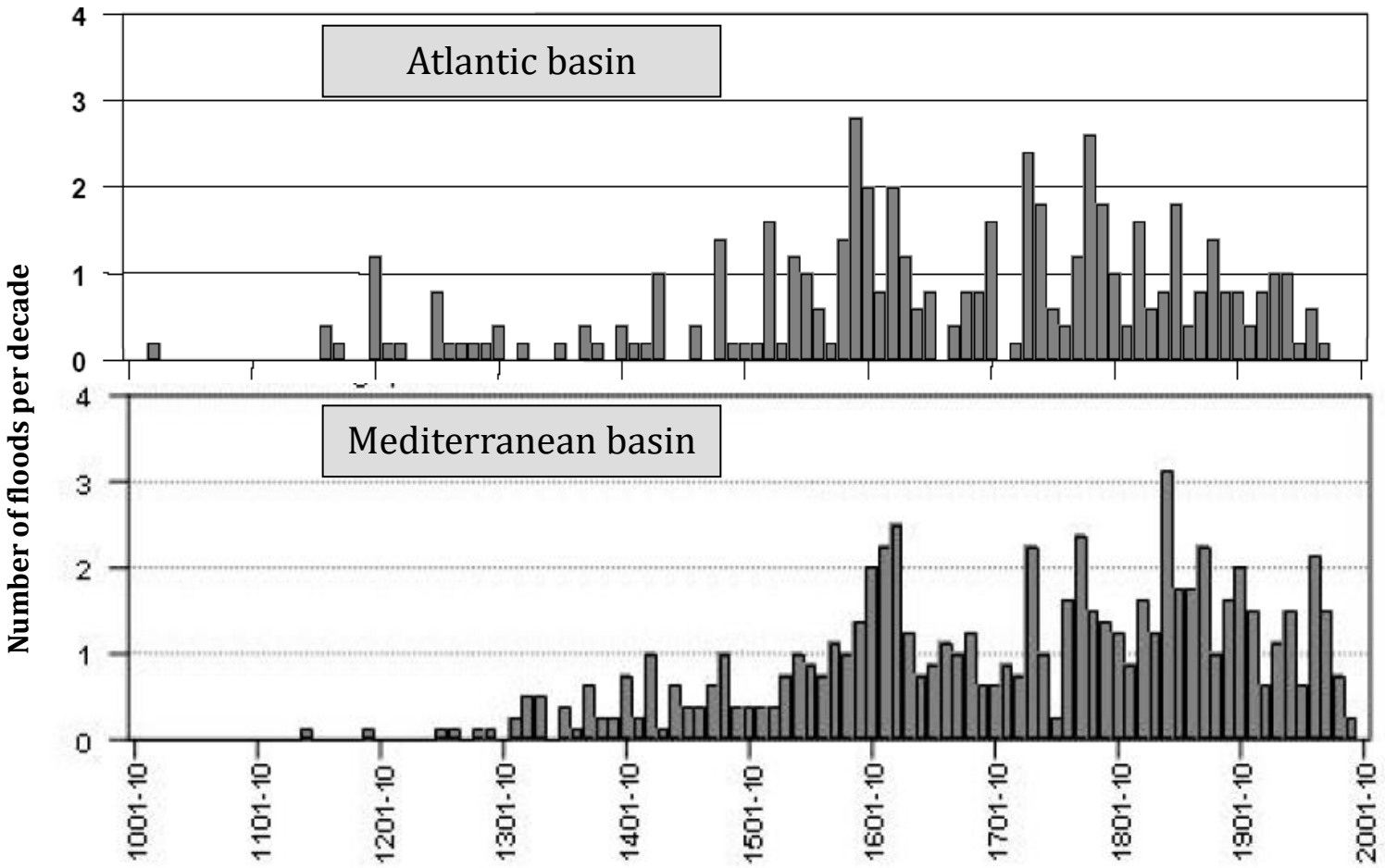
- **Data**: NODC upper ocean (0-2000 m) heat content (http://climexp.knmi.nl/data/iheat2000_global.dat); conversion into equivalent temperature using information from Kennish (2001) and Menard & Smith (1966).
- **Fact**: From 1975 to date there has been an increase of 236 ZJ in the upper ocean heat content averaged globally at a 10-year climatic scale; this corresponds to a temperature increase of 0.074 K (average rate 0.015 K/decade = **0.15 K/century**).

Facts: Floods have not increased through the centuries



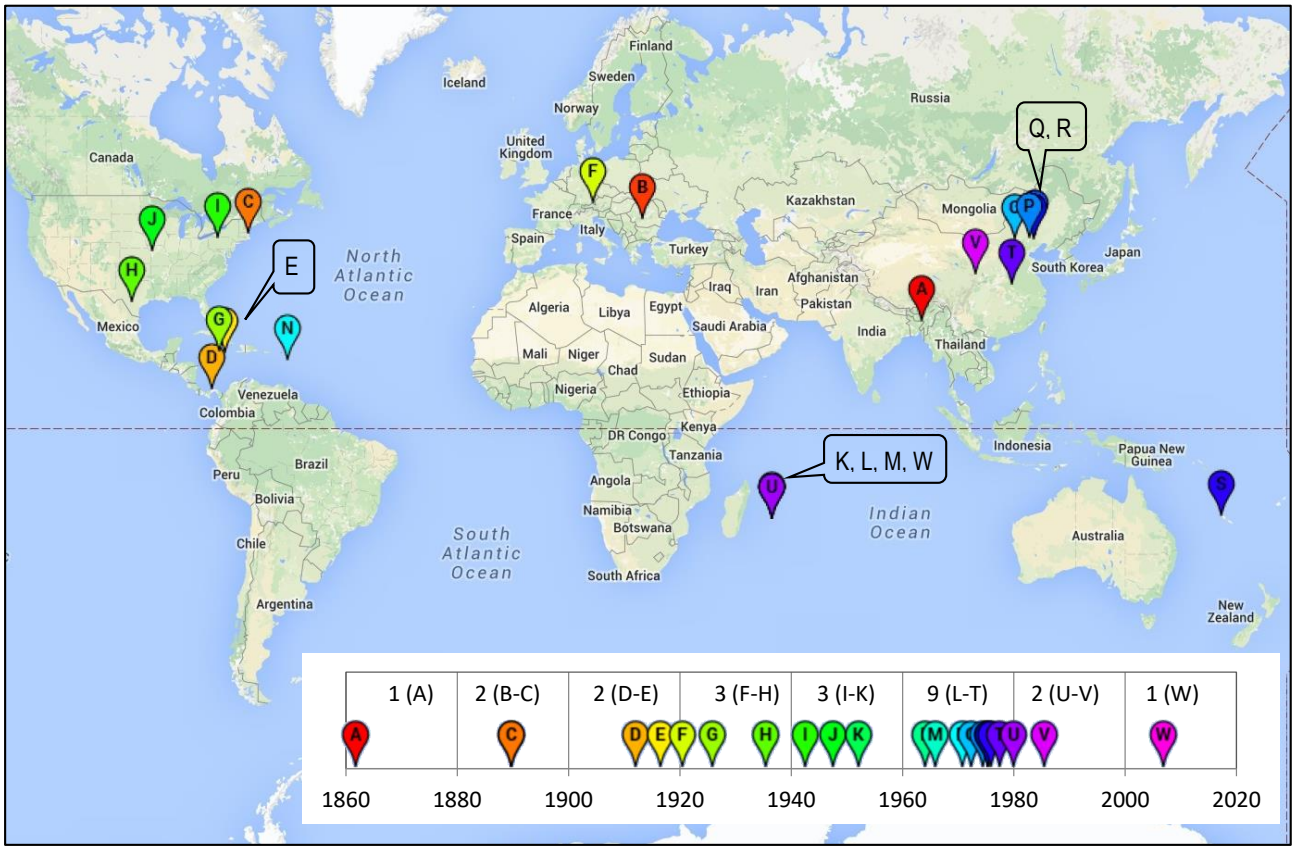
- **Data**: Number of flood events, distributed by intensity, of the Arno River, which caused damage in Florence between the 12th and 20th centuries (Caporali et al., 2005).
- **Note 1**: Fewer floods in the 20th century than in most other centuries.
- **Note 2**: Fewer high- and medium-intensity floods in the 20th century than in all but one other centuries.

Facts: Floods have not increased through the centuries (2)



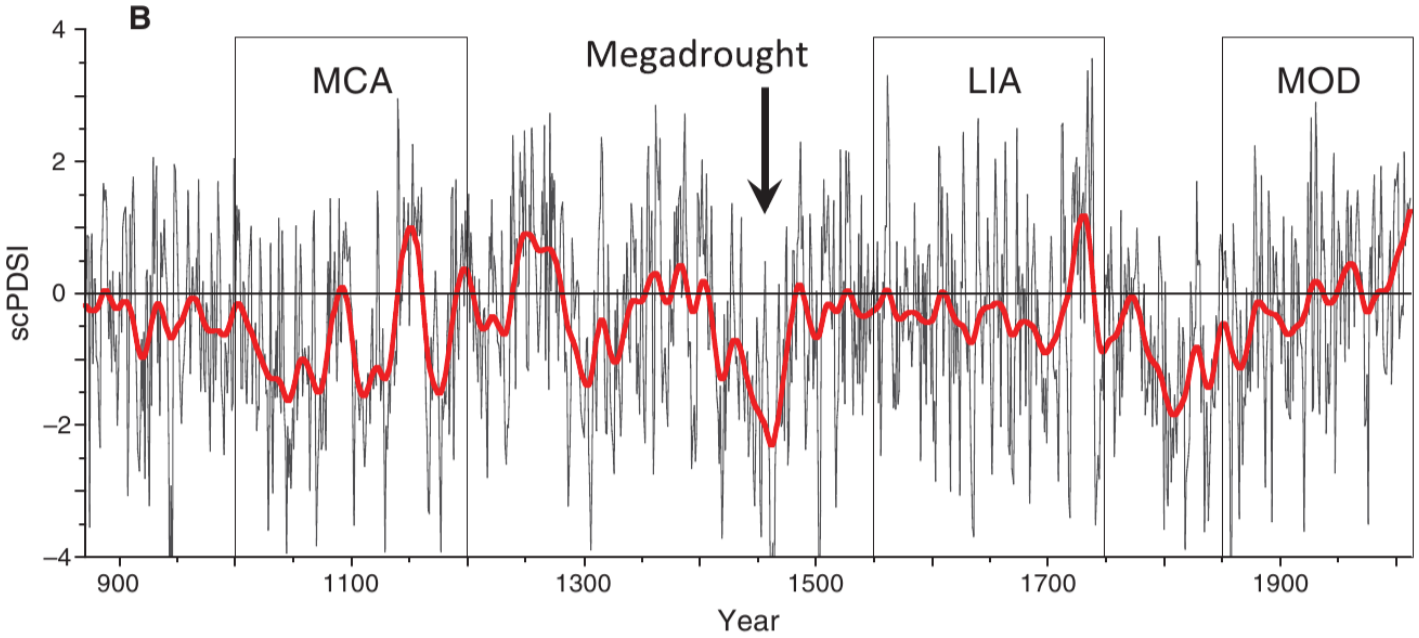
- **Data**: Flood frequency, estimated from documents and archives in Spain for the last millennium (Barriendos et al., 2006).
- **Note**: Fewer floods in the 20th century than in 17th-19th centuries.

Facts: 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 it decreased substantially.

Facts: Droughts have not increased



- **Data**: 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. 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 (Cook et al., 2015).
- **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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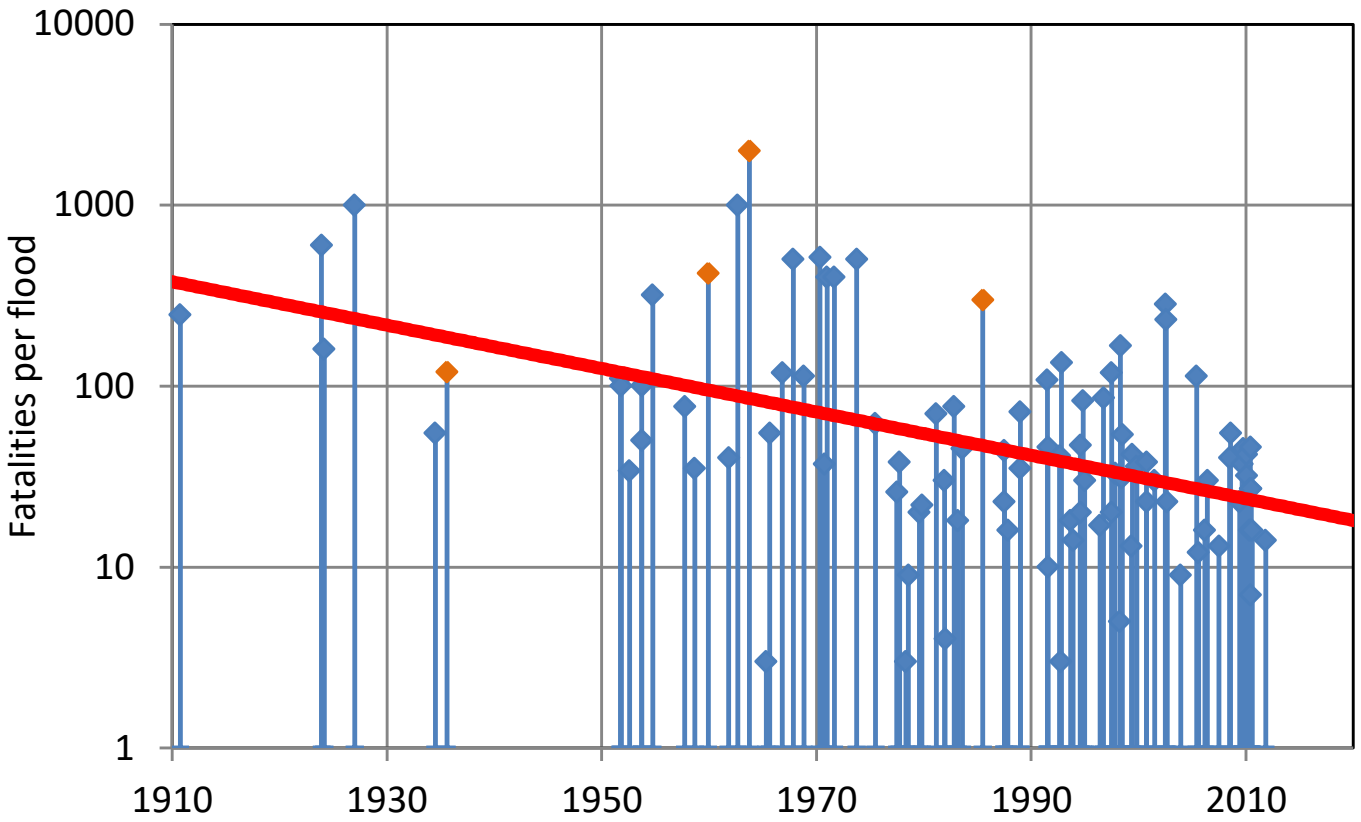
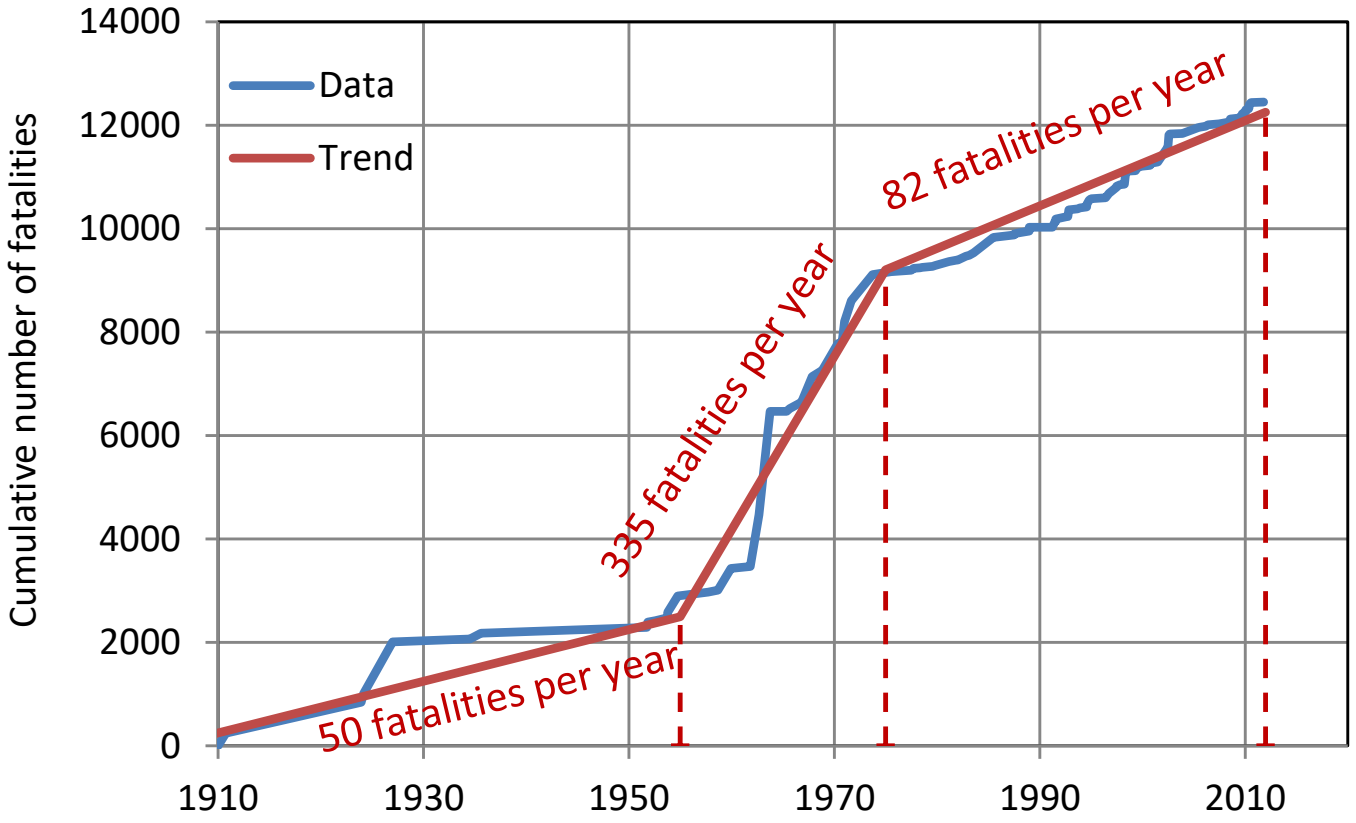
Facts: Floods in Europe are not becoming more severe

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).
- **Fact**: Severity of floods, in terms of fatalities it causes, is decreasing.

Facts: 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.

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

Period	Area	Fatalities (million)	Fatalities (% of world population)
1876-79	India	10	
	China	20	
	Brazil	1	
	Africa	?	
	Total	>30	>2.2%
1896-1902	India	20	
	China	10	
	Brazil	?	
	Total	>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%

- Long-lasting droughts of large extent are intrinsic to climate (Hurst-Kolmogorov dynamics; see below).
- Such droughts may have dramatic consequences to human lives, as shown in the table, which refers to drought-related historical famines.
- As shown in table, famines and their consequences have been alleviated through the years owing to:
  - improved large-scale water infrastructure (multi-year regulation of flows), and
  - international collaboration.

Source: Koutsoyiannis (2011)

Future-telling industries: From Delphi and Pythia to modern climate predictions

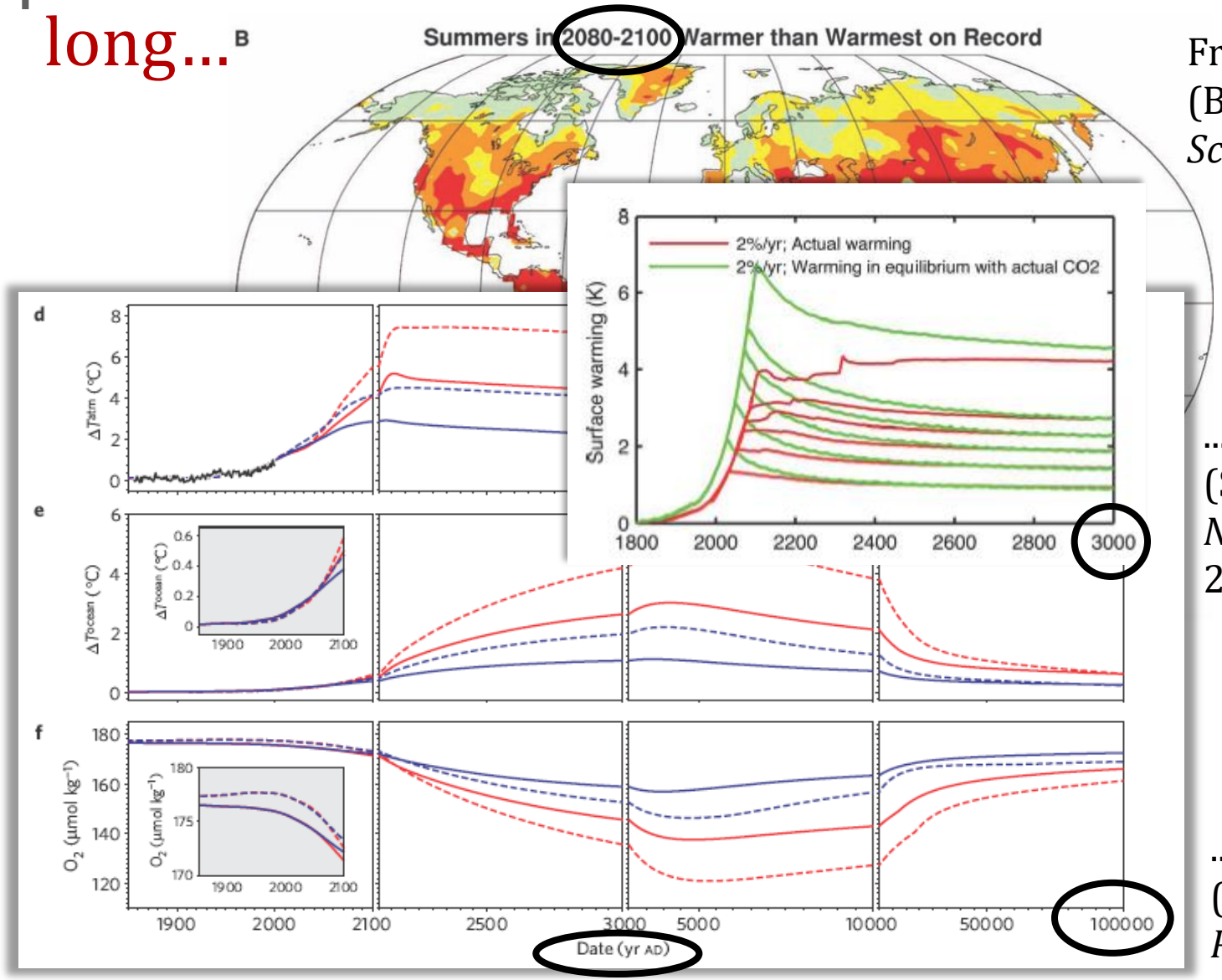
- Pythia's power relied on ambiguous predictions:

  "*ἤξεις ἀφήξεις οὐ θνήξεις ἐν πολέμω*" or "*you will go you will come not in the war you will die*" (put a comma before or after "not").
- Modern climate predictions (or "projections") owe their success to the distant time horizon to which they refer (e.g. 2080, 2100, etc.); this makes them (temporarily) resistant to falsifiability.

Pythia inspired by *pneuma* rising from below (from wikipedia)

Climate model outputs

Indeed, time horizons of climate predictions are long…

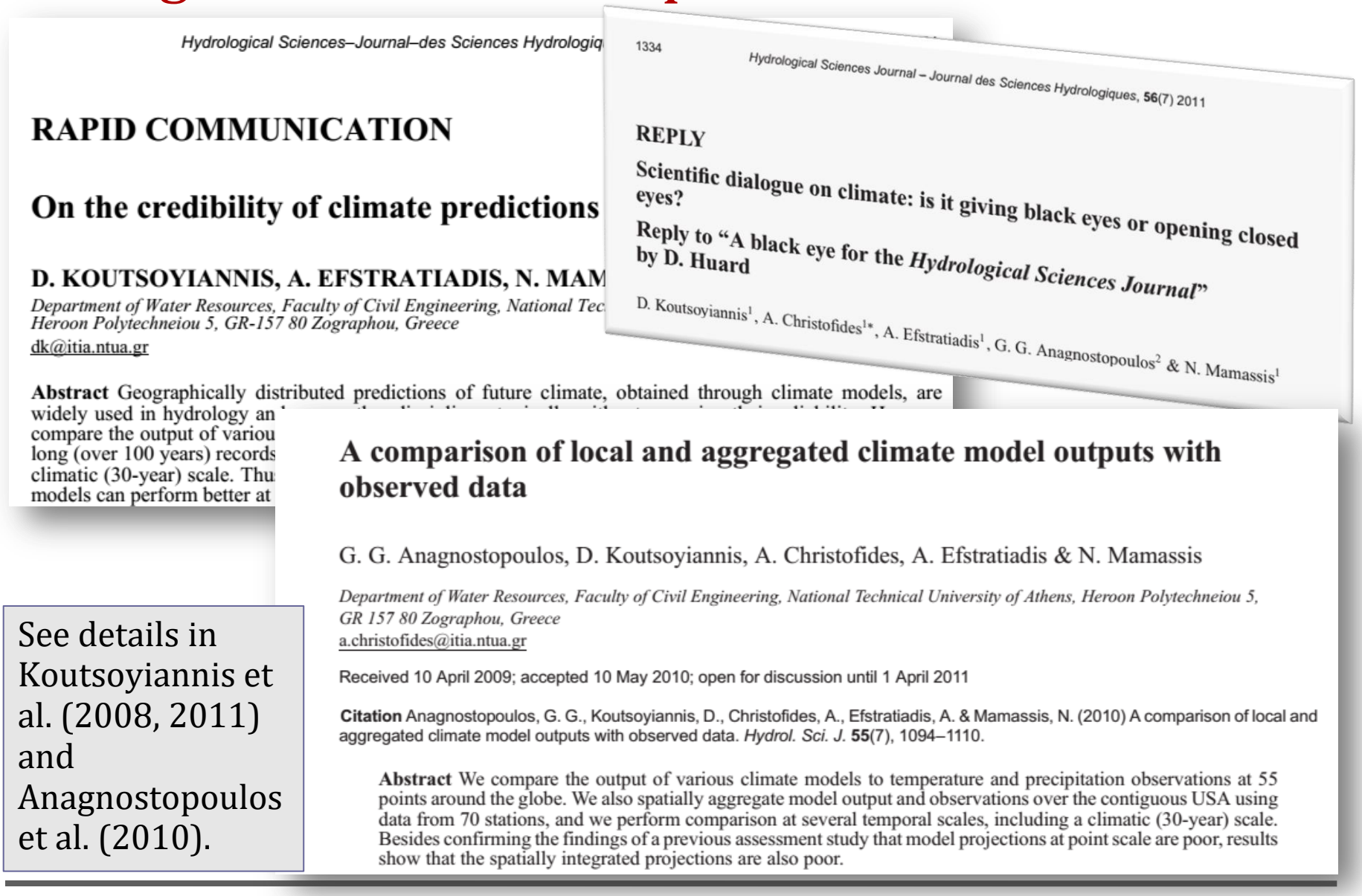


From 2100 AD (Battisti and Naylor, *Science*, 2009)...

... to 3000 AD (Solomon et al., *Nature Geoscience*, 2009)

...to 100 000 AD (Shaffer et al., *PNAS*, 2009)

How good have climate predictions been so far?



Hydrological Sciences–Journal–des Sciences Hydrologiq

RAPID COMMUNICATION

On the credibility of climate predictions

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Abstract Geographically distributed predictions of future climate, obtained through climate models, are 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

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] & N. Mamassis[1]

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

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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.

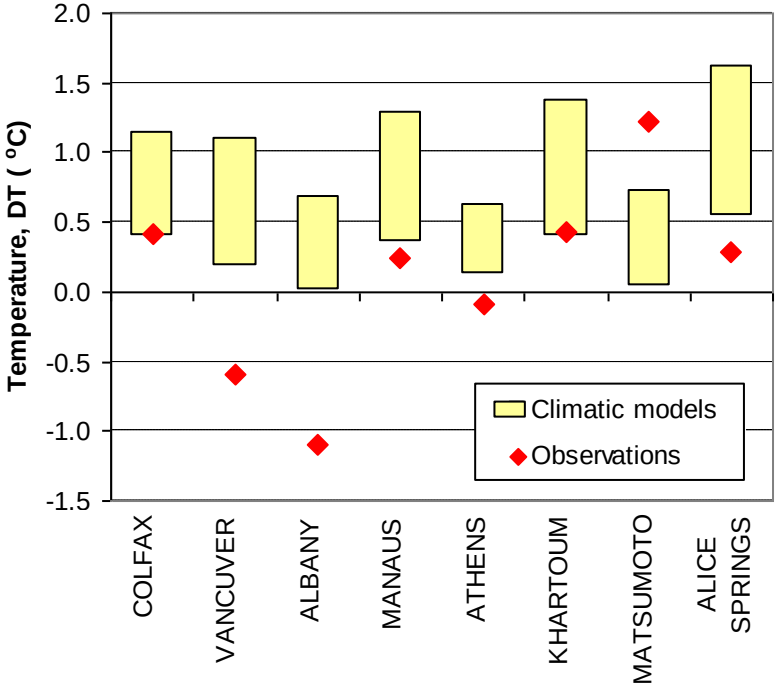
Abstract We compare the output of various climate models to temperature and precipitation observations at 55 points around the globe. We also spatially aggregate model output and observations over the contiguous USA using data from 70 stations, and we perform comparison at several temporal scales, including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

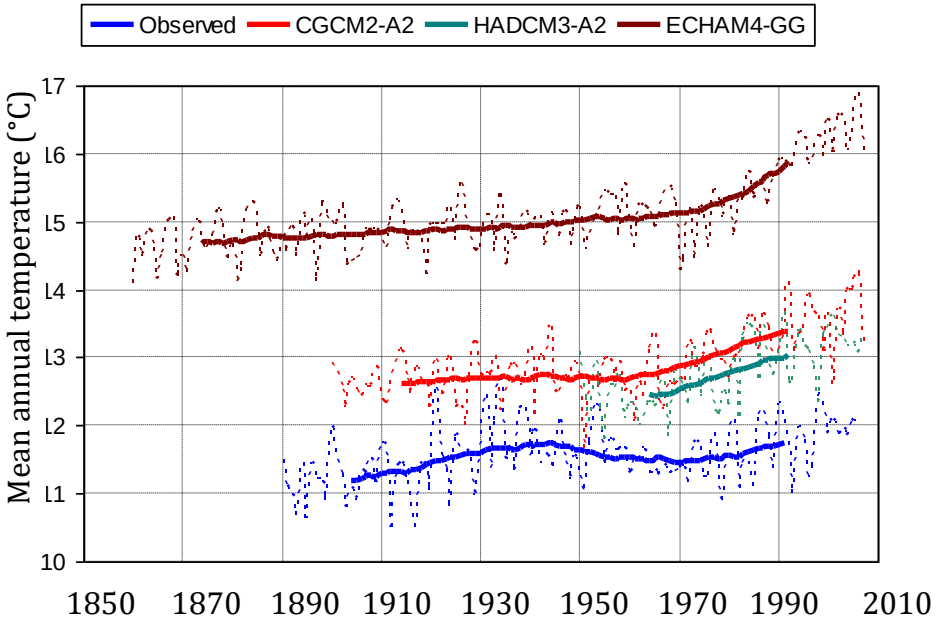
Do climate models reproduce real-world temperature?

- 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.

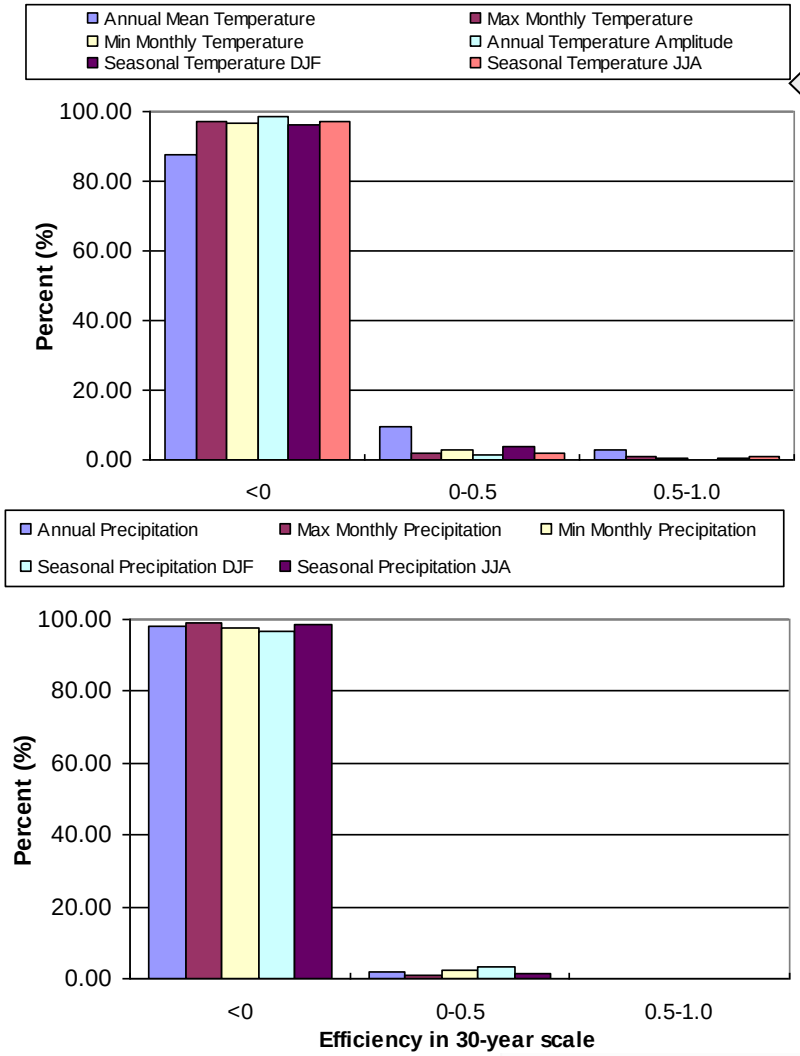
Change of climatic (30-year moving average) temperature in the 20th century: models vs. reality (Koutsoyiannis et al., 2008)



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

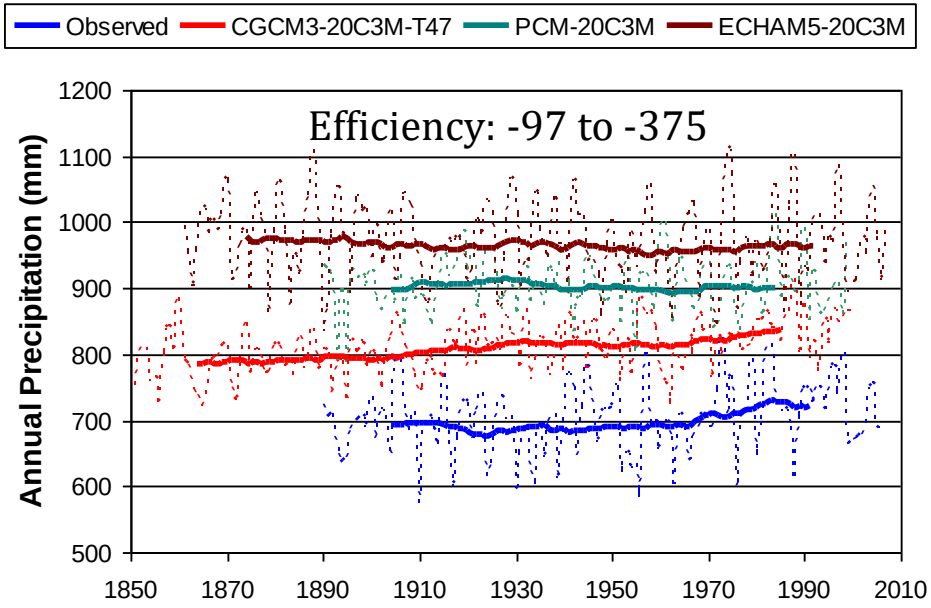


Do climate models reproduce real-world rainfall?



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)



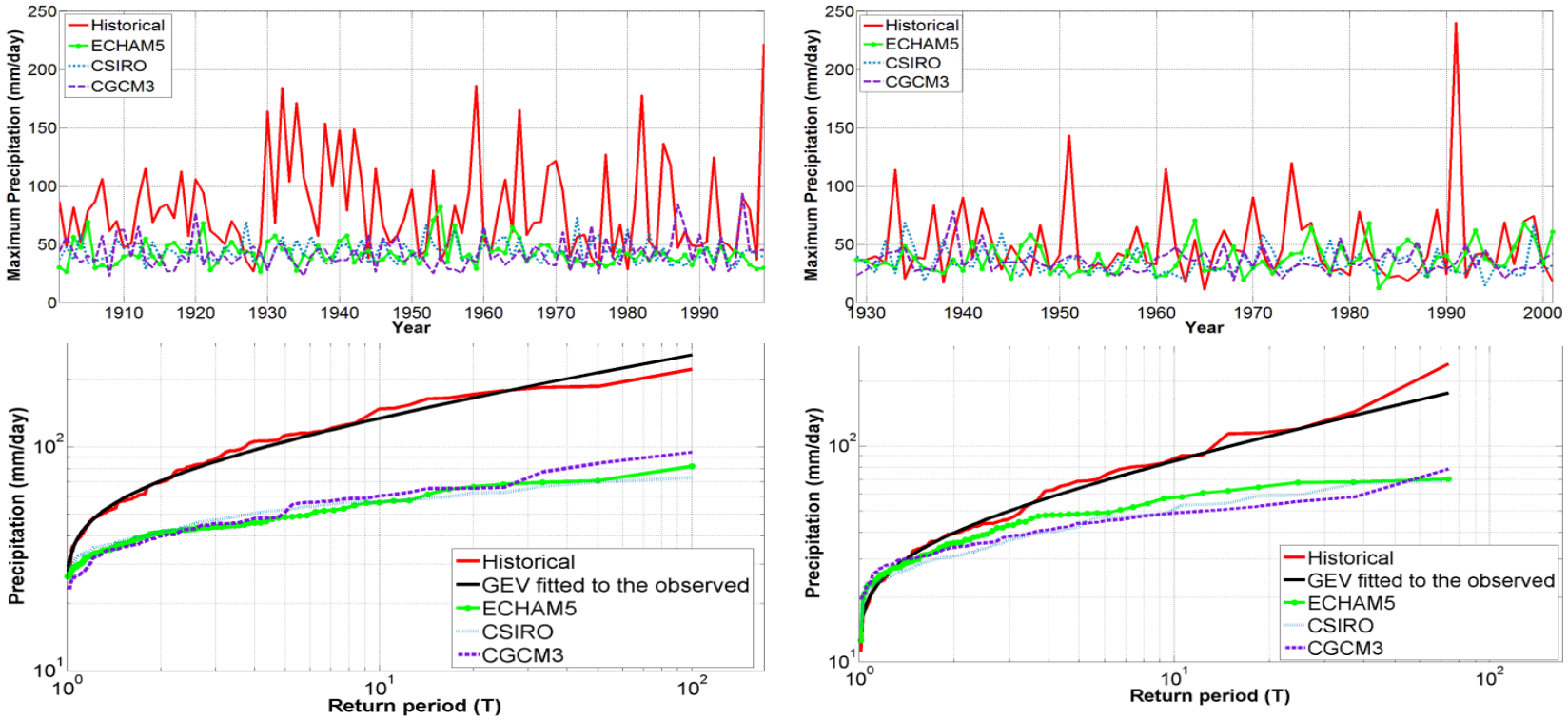
Source: Anagnostopoulos, *et al.* (2009).

See review of papers testing climate model skills in Pielke Sr. (2017)

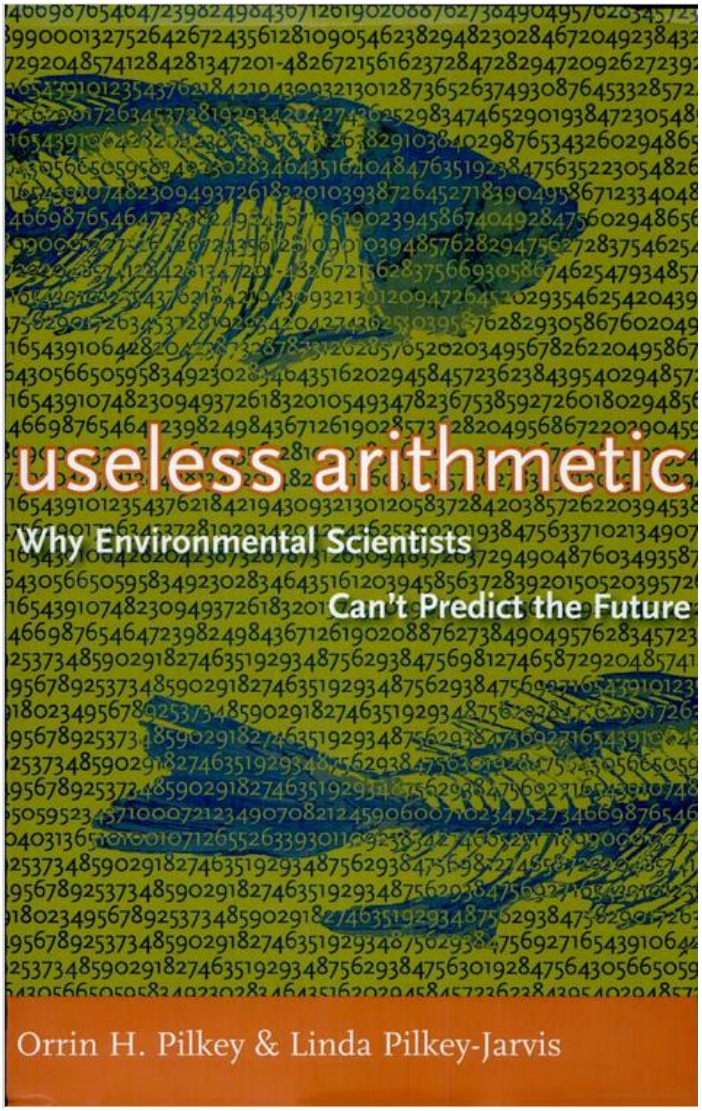
Do GCMs simulate the real phenomenon, i.e. rainfall?

- 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)



Arithmetic simply useless? Or dangerous?

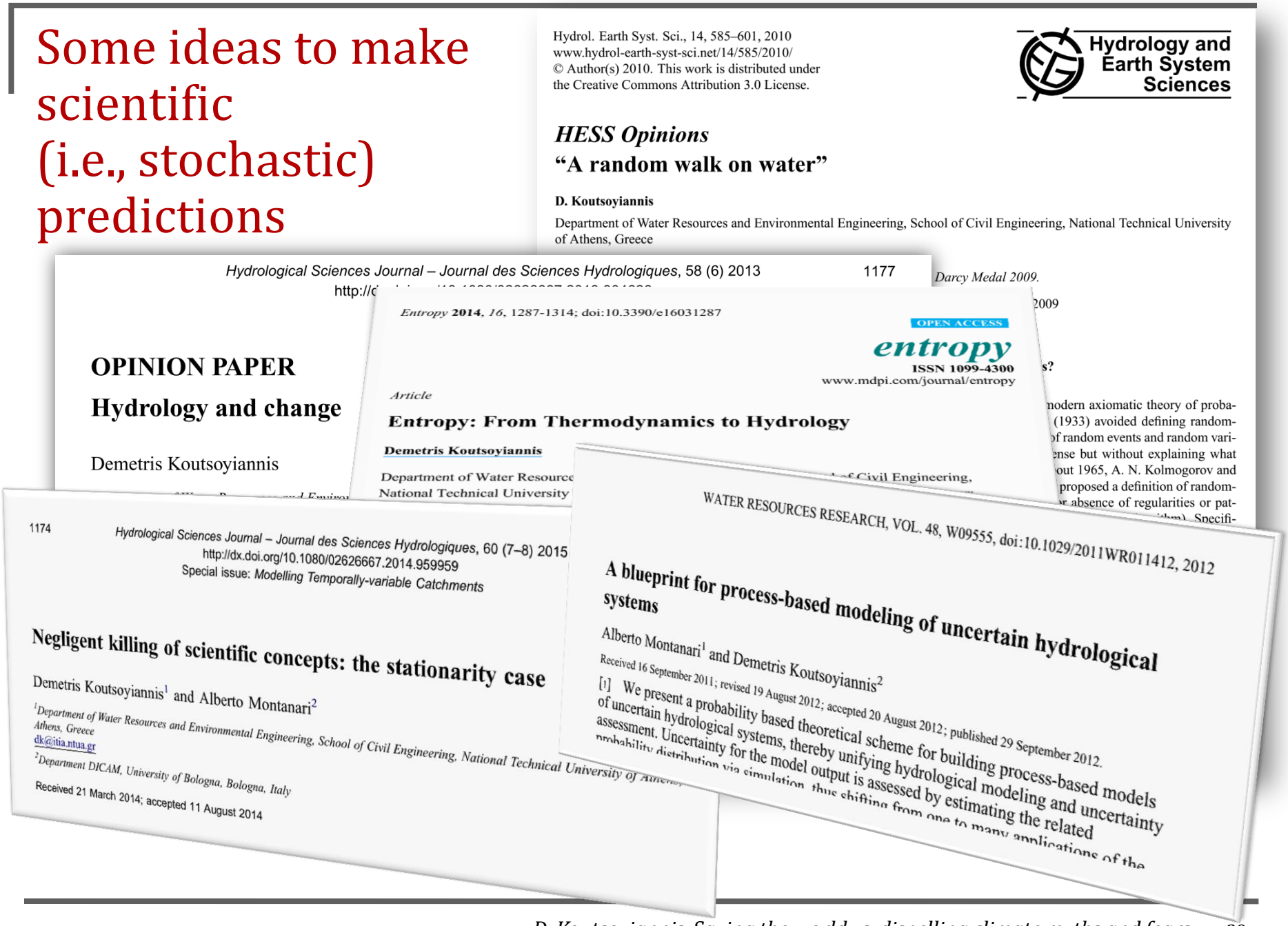


Excerpts from the book:

- *A reviewer of a paper I wrote condemning beach models penned the following criticism, which is very typical of the responses that model critics receive:* "Everyone, even the engineers, realizes that models have shortcomings, some serious ones, but **that is all that they have at this time**. They are constantly working on improving them. Instead of continuing to tear down the existing ones, the discipline would be much better served by offering better alternatives".
- *My response (had I been given a chance to respond) would have been this: One should not use bad models for any reason. If you know that there are problems, shame on you and your fellow modelers for not saying so when you apply the model and give the results to the public.* ***Because of the complexity of beaches, rest assured that nothing better is coming along.*** *They can never be quantitatively modeled with sufficient accuracy for engineering purposes.*

(Pilkey and Pilkey-Jarvis, 2007, p. 136)

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



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Hydrology and Earth System Sciences

HESS Opinions

"A random walk on water"

D. Koutsoyiannis

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

Hydrological Sciences Journal – Journal des Sciences Hydrologiques, 58 (6) 2013 1177

OPINION PAPER

Hydrology and change

Demetris Koutsoyiannis

Darcy Medal 2009.

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

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Article

Entropy: From Thermodynamics to Hydrology

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*

Negligent killing of scientific concepts: the stationarity case

Demetris Koutsoyiannis[1] and Alberto Montanari[2]

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A blueprint for process-based modeling of uncertain hydrological systems

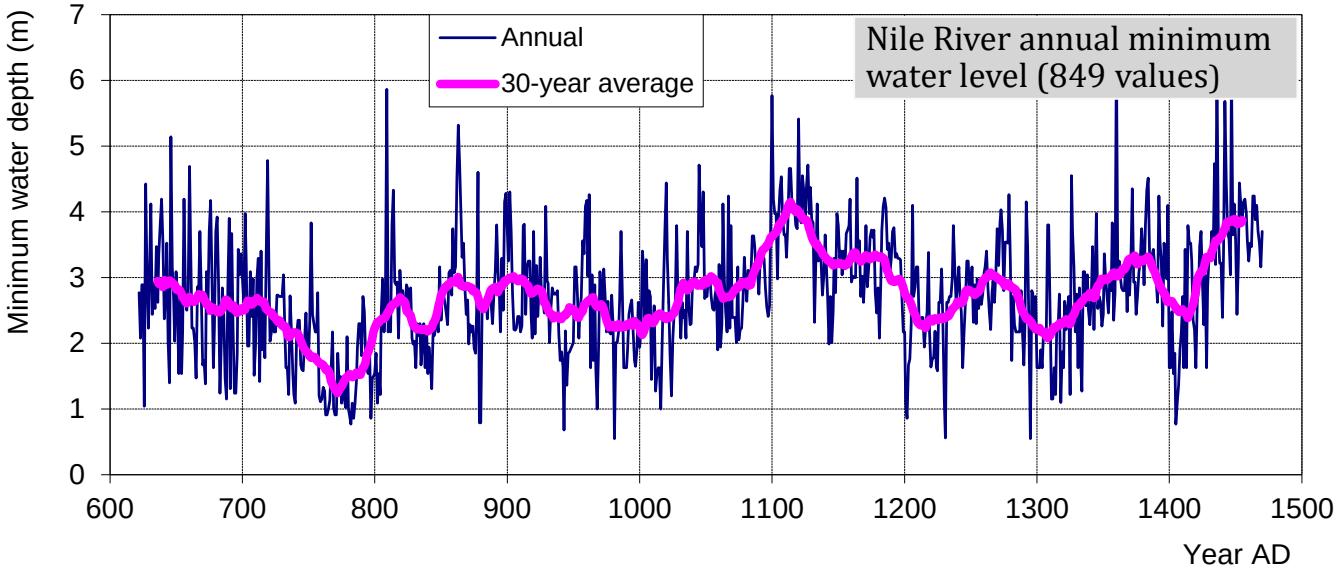
Alberto Montanari[1] and Demetris Koutsoyiannis[2]

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

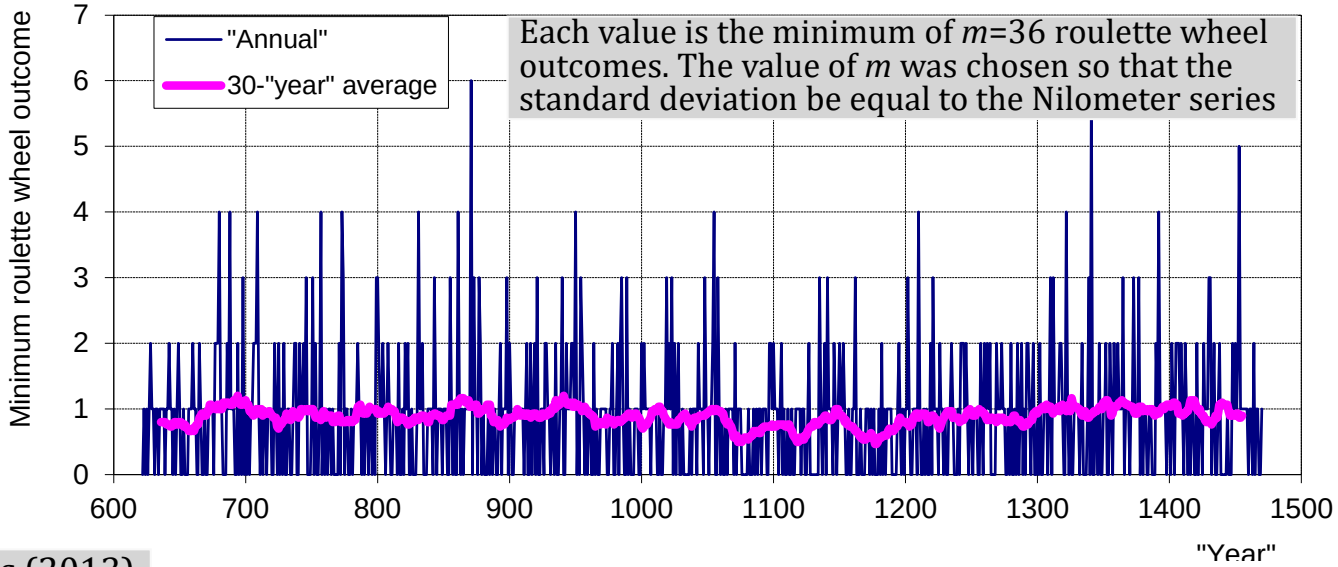
[1] We present a probability based theoretical scheme for building process-based models of uncertain hydrological systems, thereby unifying hydrological modeling and uncertainty assessment. Uncertainty for the model output is assessed by estimating the related

Perpetual change as seen in the Nilometer record

A real-world process



A "roulette" process



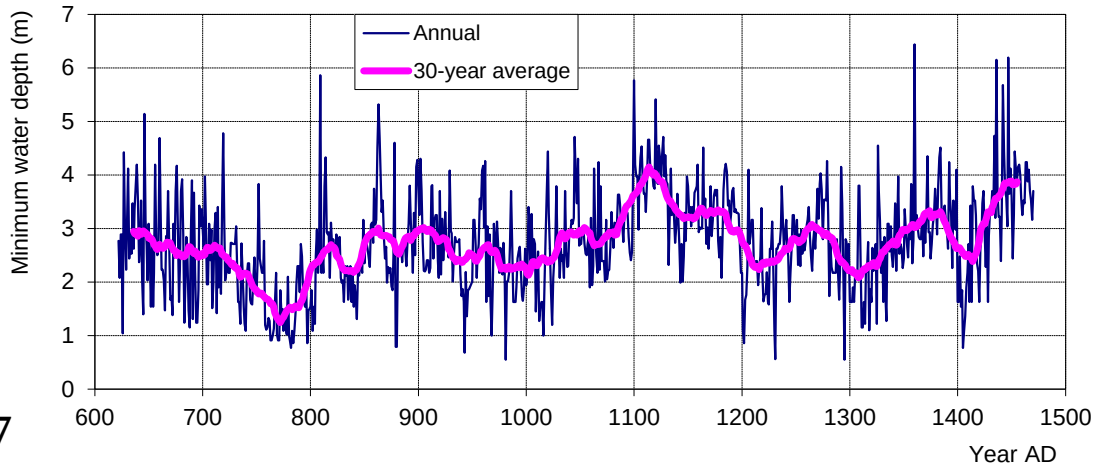
Nilometer data: Koutsoyiannis (2013)

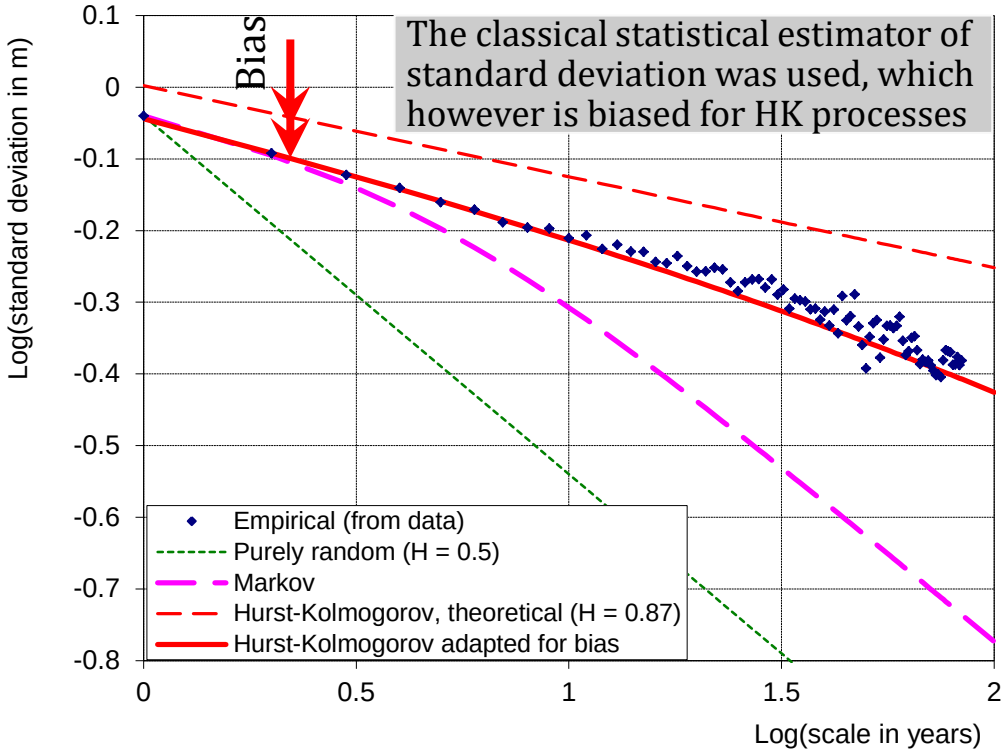
The climacogram: A simple statistical tool to quantify the change across time scales

- Take the Nilometer time series, $x_1, x_2, ..., x_{663}$, and calculate the sample estimate of standard deviation $\sigma^{(1)}$, 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 standard deviation $\sigma^{(2)}$.
- Form a time series at time scale 3 (years):
  $x^{(3)}_1 := (x_1 + x_2 + x_3)/3, ..., x^{(3)}_{283} := (x_{847} + x_{848} + x_{849})/3$
  and calculate the sample estimate of standard deviation $\sigma^{(3)}$.
- Repeat the same procedure up to scale 84 (1/10 of the record length) and calculate $\sigma^{(84)}$.
- The **climacogram** is a logarithmic plot of standard deviation $\sigma^{(k)}$ *vs*. scale k.
- If the time series x_i represented a pure random process, the climacogram would be a straight line with slope –0.5 (the proof is very easy).
- In real world processes, the slope is different from –0.5, designated as $H - 1$, where H is the so-called Hurst coefficient ($0 < H < 1$).
- The scaling law $\sigma^{(k)} = \sigma^{(1)} / k^{1-H}$ 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

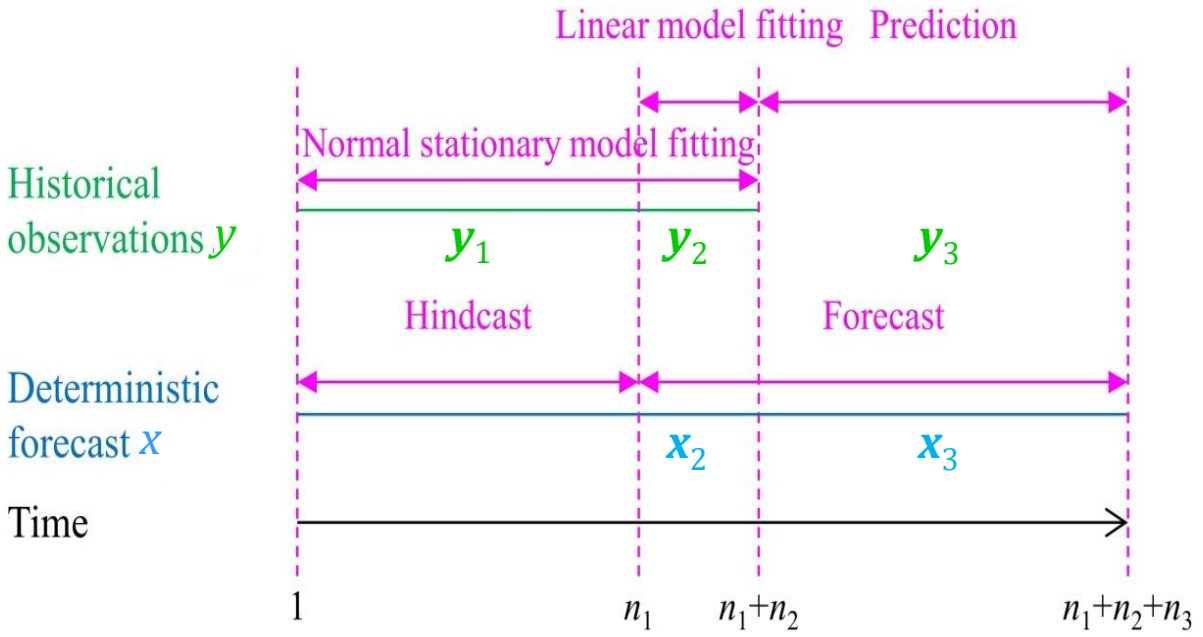
- The Hurst-Kolmogorov process seems consistent with reality.
- The Hurst coefficient is $H = 0.87$ (Similar H values are estimated from the simultaneous record of maximum water levels and from the modern, 131-year, flow record of the Nile flows at Aswan).
- The Hurst-Kolmogorov behaviour, seen in the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





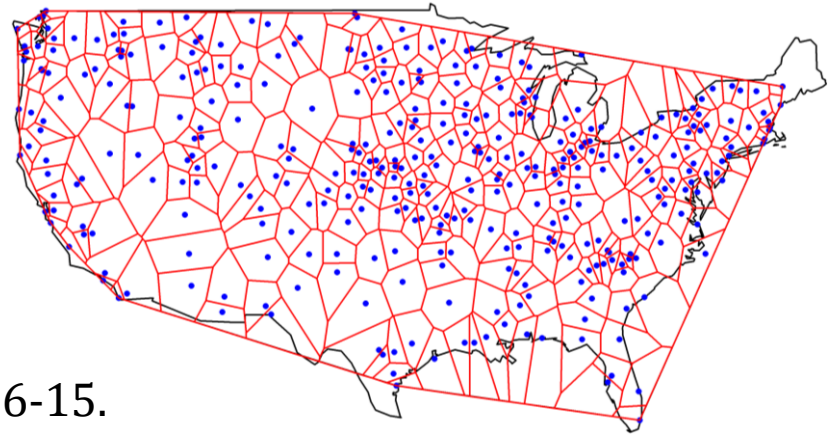
Can we convert deterministic modeling into stochastic?

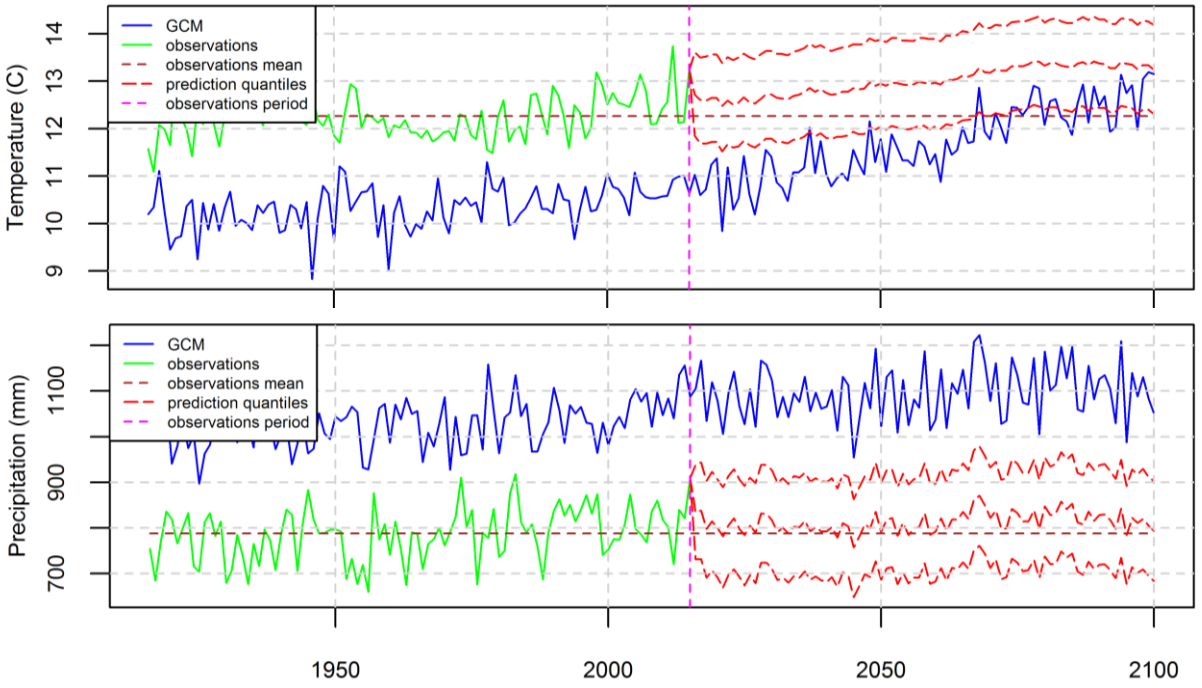
- Yes—we can and we should.
- Method 1: By perturbing input data, parameters and model output (the latter by adding random outcomes from the population of the model error): see the blueprint by Montanari and Koutsoyiannis (2012).
- Method 2: By incorporating one or many deterministic forecasts into an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



Application to the climate of the USA

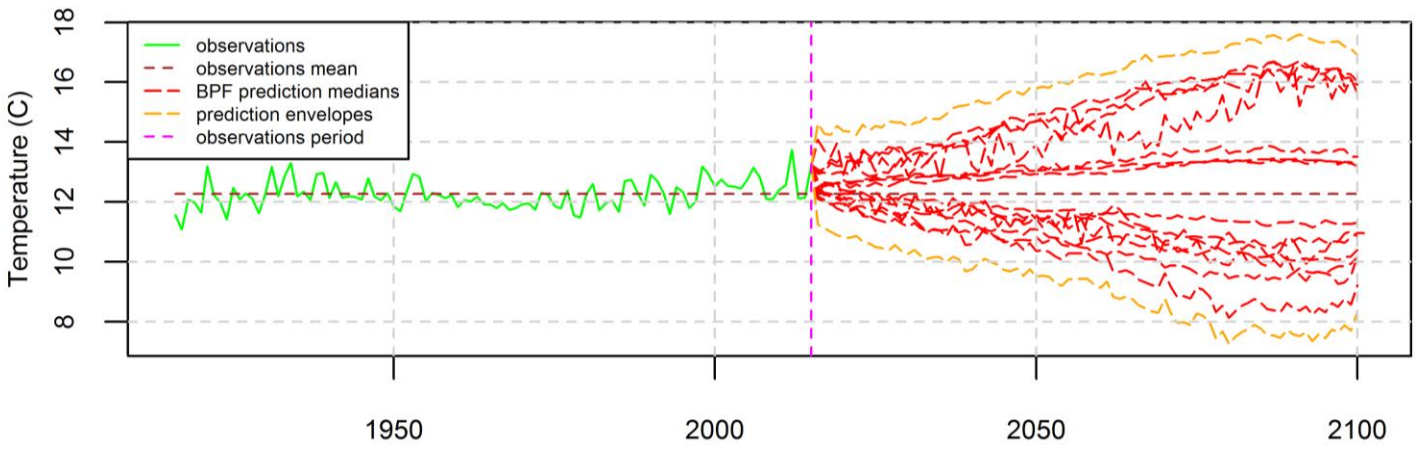
- Historical data for temperature and precipitation from 362 and 319 stations, respectively, have been used to estimate the areal averages (historical observations).
- Deterministic forecasts were taken from 14 different climate models. The model likelihood was evaluated in the period 2006-15.
- The 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.





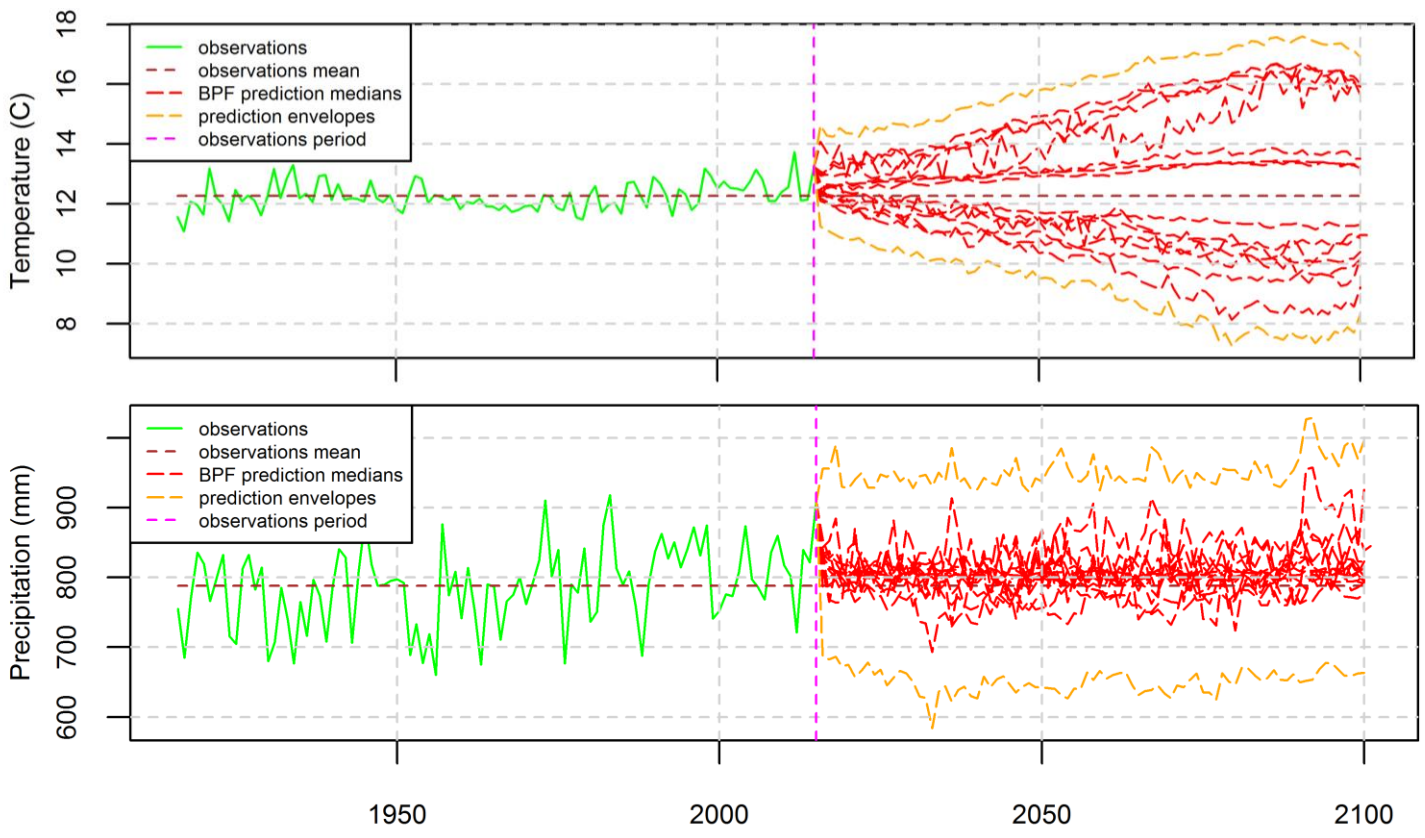
Multimodel approach: **The Bayesian Thistle**

- 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 many climate models are used in conditioning our stochastic model.
- The resulting shape looks as a **thistle**.



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 condition-ing on models).



Some philosophical reflections from Aristotle: Change, nature of precision, and sophistry

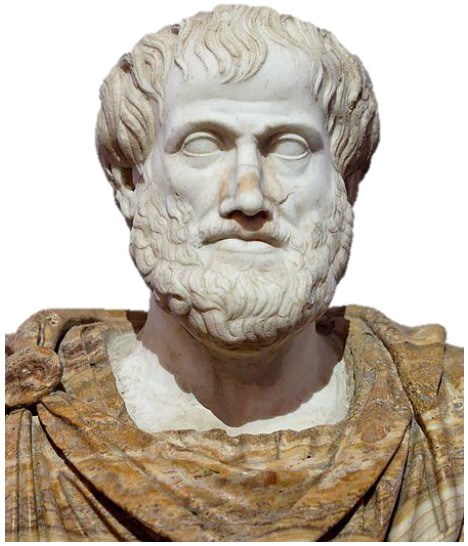
Μεταβάλλει τῷ χρόνῳ πάντα.
All is changing in the course of time.

Aristotle; Meteorologica, I.14, 353a 16

Πεπαιδευμένου γάρ ἐστιν ἐπὶ τοσοῦτον τάκριβὲς ἐπιζητεῖν καθ᾽ ἕκαστον γένος, ἐφ᾽ ὅσον ἡ τοῦ πράγματος φύσις ἐπιδέχεται.

It is the mark of an educated man to look for precision in each class of things just so far as the nature of the subject admits.

Aristotle, Nicomachean Ethics 1094b



Aristotle
(384 – 322 BC)

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.

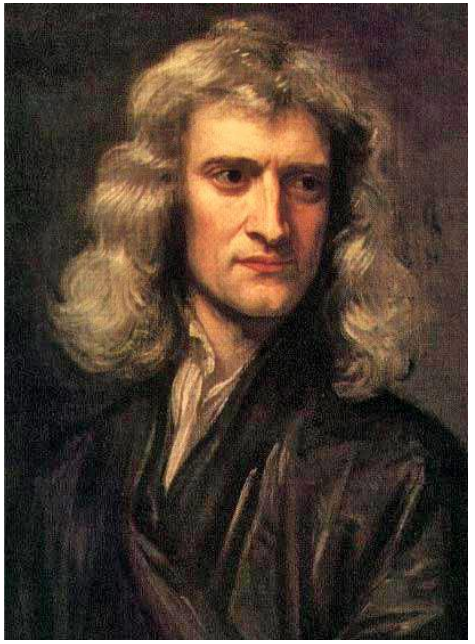
Aristotle, On Sophistical Refutations, 165a21

Modern determinism and the clockwise universe

- Johannes Kepler (1571-1630), Galileo Galilei (1564-1642) and René Descartes (1596-1650) introduced mathematical concepts to natural philosophy (i.e., science).
- They also introduced the idea of a clockwork universe, leading to the philosophical proposition of *determinism*, still widely accepted in science.
- It was perfected by the French mathematician and astronomer Pierre-Simon Laplace (1749-1827; cf. *Laplace's demon*).
- According to deterministic thinking, the roots of uncertainty about future are subjective, i.e. rely on the fact that we do not know exactly the present, or we do not have good enough methods and models. It is then a matter of time to eliminate uncertainty, with better data and better models.




Newton's awareness of the fragility of the universe (rejection of determinism)

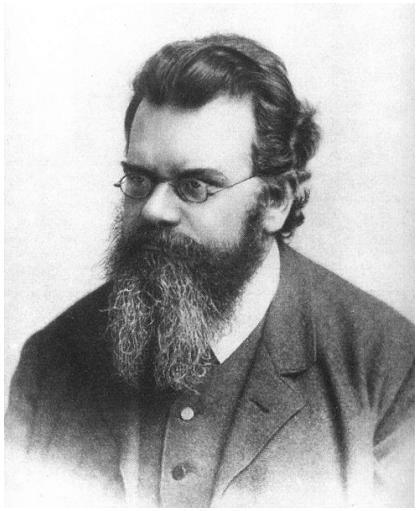


For while comets move in very eccentric orbs in all manner of positions, blind fate could never make all the planets move one and the same way in orbs concentric, some inconsiderable irregularities excepted which may have arisen from the mutual actions of comets and planets on one another, and which will be apt to increase, till this system wants a reformation (Newton, *Opticks*, Query 31).

- Newton regarded the complexity and fragility of the universe as proof of the existence of God.
- He rejected Leibniz' thesis that God would necessarily make a perfect world which requires no intervention from the creator.
- Newton simultaneously made an argument from design and for the necessity of intervention.

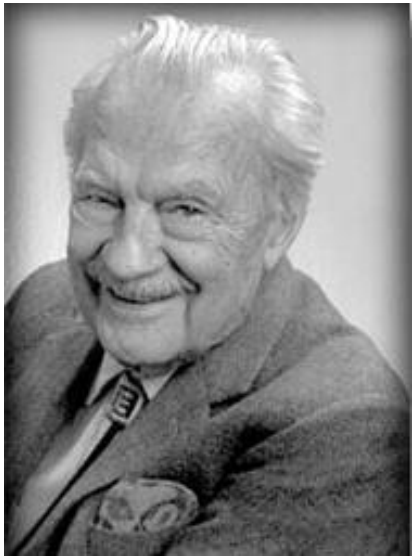
From the almighty determinism of the 17th century to the probabilistic world of the 20th century

- **Statistical physics** (cf. Boltzmann) used the probabilistic concept of entropy (which is nothing other than a quantified measure of uncertainty defined within the probability theory) to explain fundamental physical laws (most notably the Second Law of Thermodynamics), thus leading to a new understanding of natural behaviours and to powerful predictions of macroscopic phenomena.
- **Dynamical systems** theory (cf. Poincare) has shown that uncertainty can emerge even from pure, simple and fully known deterministic (chaotic) dynamics, and cannot be eliminated.
- **Quantum theory** (cf. Heisenberg) has emphasized the intrinsic character of uncertainty and the necessity of probability in the description of nature.



From the almighty determinism of the 17th century to the probabilistic world of the 20th century (2)

- Developments in **mathematical logic**, and particularly **Gödel's incompleteness theorem**, challenged the almightiness of deduction (inference by mathematical proof).
- Developments in **numerical mathematics** (cf. Metropolis) highlighted the effectiveness of stochastic methods in solving even purely deterministic problems, such as **numerical integration** in high-dimensional spaces and **global optimization** of non-convex functions (where stochastic techniques, e.g. evolutionary algorithms or simulated annealing, are in effect the only feasible solution in complex problems that involve many local optima).
- Advances in **evolutionary biology** emphasize the importance of stochasticity (e.g. in selection and mutation procedures and in environmental changes) as a driver of evolution.



Epilogue

- In 1927, **Werner Heisenberg** published his **uncertainty principle**, expressing the limitations of predictability in the quantum world.
- In 1930, **David Hilbert** pronounced his aphorism "*Wir müssen wissen, wir werden wissen*" ("***We must know, we will know***").
- Hilbert did not know that the day before, **Kurt Gödel** had announced his **incompleteness theorem** thus having killed Hilbert's dogma.
- Almost 90 years after, climate-change-ologists and climate-impact-ologists (including hydrologists) have advanced the Hilbert's dogma to "We must know, we know" (in particular, we know what the future ***will*** be: ***hell***).
- 2300+ years ago, Epicurus pronounced **science as the enemy of fear**.
- If we care about progress, we need to reestablish the link of **science** with **philosophy and technology**, and isolate science from **ideology**.
- **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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