Special Workshop “New Statistical Tools in Hydrology”

IHP 2008 Capri Symposium:
“The Role of Hydrology in Water Resources Management”
UNESCO & IAHS
Isle of Capri, Italy, 13-16 October 2008

# From climate certainties to climate stochastics

Demetris Koutsoyiannis

Department of Water Resources and Environmental Engineering
Faculty of Civil Engineering
National Technical University of Athens, Greece (dk@itia.ntua.gr)

Presentation available online: http://www.itia.ntua.gr/en/docinfo/880

# 1. Should hydrologists study climate?

# Element 1: Hydrologists as impact assessors

- Climate modellers predict the future climate.
- Hydrologists should:
  - Adopt the climate models outputs;
  - Downscale them at a catchment scale;
  - Feed their hydrological models with downscaled climatic projections;
  - Run their models to assess the impacts on freshwater quantity and quality.
- Is this pathetic, one-way role of hydrologists useful for the scientific progress?

**Impacts Research Seen As Next Climate Frontier**

**Scientists hope the next U.S. president will devote more of the billion-dollar climate change research program to impacts**

Marine ecologist Jane Lubchenco was among the first scientists to study how weighed in on the need to better understand the regional consequences of global warm- CCS acros

From **SCIENCE**
10 Oct 2008 Vol. 322 p. 182
www.sciencemag.org

# Element 2: Hydrologists and politicians

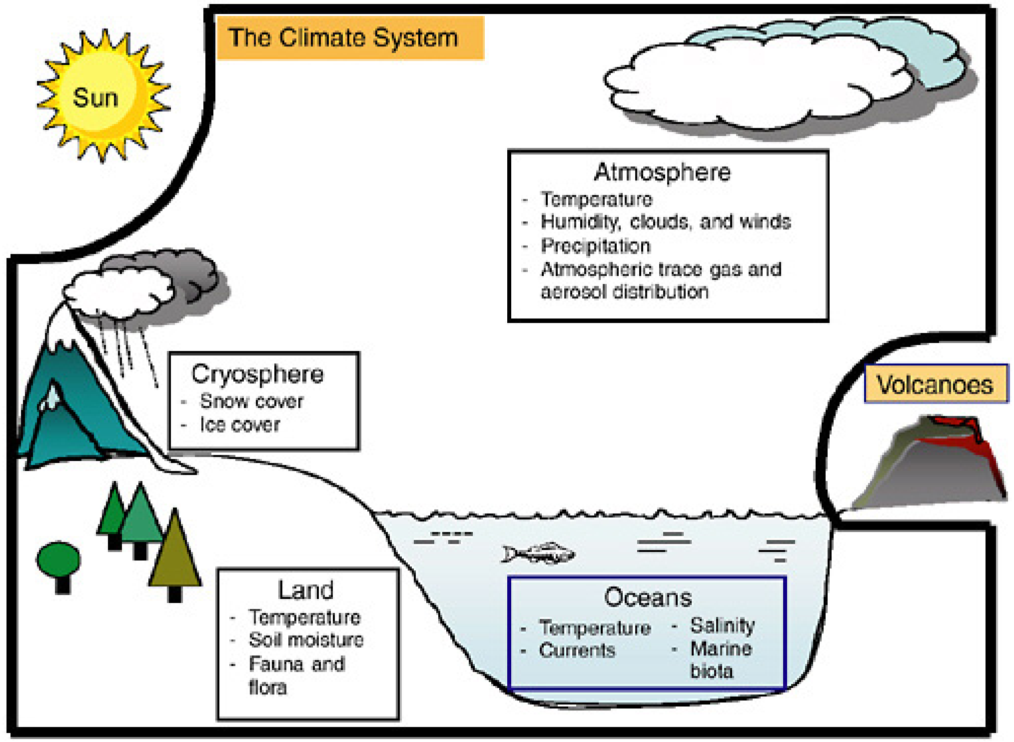
- "Climate change" is more a political/economical enterprise than a scientific area.
  - "***Tony Blair** is due to take his post-prime ministerial earnings to more than £7m this year following his appointment to a six-figure-salary job with Zurich Insurance, **the Swiss financial firm, advising it on climate change**. The company, which could pay out tens of millions of pounds for claims from businesses and householders over **floods, hurricanes and droughts caused by global warming, is taking Blair on to advise it on the implications of climate change**.*" (The Guardian). [www.guardian.co.uk/politics/2008/jan/29/uk.tonyblair]
- Politicians claim that they know the scientific truth.
  - "***The inconvenient truth***" (film & book by Al Gore, 2006).
- Yet they need scientists for sustaining alarmism and shaping and backing catastrophic scenarios.
- The role of hydrologists is not negligible because some of the most prominent predicted catastrophes are related to water shortage and extreme floods.
- Is this pathetic role of hydrologists useful for the scientific progress?

# Element 3: Hydrologists and climate modellers

- Climate is too serious a matter to entrust to climate modellers.
  [Paraphrasing: "*War is too serious a matter to entrust to military men*", Georges Clemenceau]
- Traditionally hydrologists have some skills perhaps less encountered in the climatological community:
  - Pragmatism, related to the engineering background;
  - Expertise in supporting decision making under uncertainty;
  - Familiarity with long term predictions (for the design of major works), and particularly their infeasibility using deterministic approaches.
- Hydrological research has provided breakthrough contributions in stochastics (Hurst, Mandelbrot, Hosking) whereas climatologists still use simplistic and unrealistic stochastic representations (Markov/AR(1) model; classical statistics based on independent identically distributed – IID – variables).

# Element 4: Hydrology and nature of the climate system

The climate system, consisting of the atmosphere, oceans, land, and cryosphere, with the Sun and volcanic emissions considered as external agents
[From Fig. 1-1 of US NRC, 2005; books.nap.edu/openbook.php?record_id=11175&page=12]




- Climate, despite being the state of the atmosphere (similar to weather) at long time scales, cannot be described based on solely the atmospheric processes (in contrast to weather). Additional natural processes should be taken into account.
- Water is a key factor, the regulator of the entire climate system.
- From the prevailing definitions of hydrology (e.g., Ad Hoc Panel on Hydrology, 1962; US Committee on Opportunities in the Hydrological Sciences, 1992; Dingman, 1994) which emphasize its involvement on the terrestrial, oceanic and atmospheric compartments, and the physical and chemical processes accompanying the movement of water, we may easily infer hydrology’s key role in all these components of the climate system and their mutual interaction.

# 2. What is climate and climate change?

# Common definition of "climate"

- "***Climate:*** *The* ***average*** *of weather over at least a 30-year period. Note that the climate taken over different periods of time (30 years, 1000 years) may be different. The old saying is climate is what we expect and weather is what we get.*" (Authoritative answer given in NOAA's glossary) [http://www.cpc.noaa.gov/products/outreach/glossary.shtml]
- Observation 1: By definition, climate is a statistical concept (*average*).
- Observation 2: Why "*at least a 30-year period*"? Is there anything special with 30 years?
  - Tacit reply: It has been generally believed that 30 years are enough to smooth out "random" weather components and establish a constant mean. **Such belief is incorrect.**
- Observation 3: Why the climate taken over 30 or 1000 years is different?
  - Obvious reply: Because different 30-year periods have different climate (which contradicts the tacit belief of constancy).
- Observation 4: Is the saying "*climate is what we expect and weather is what we get*" scientifically meaningful?
  - Reply: No (to be discussed later).
- **Arguably, the entire definition is not scientific.**

# Common definition of "climate change"

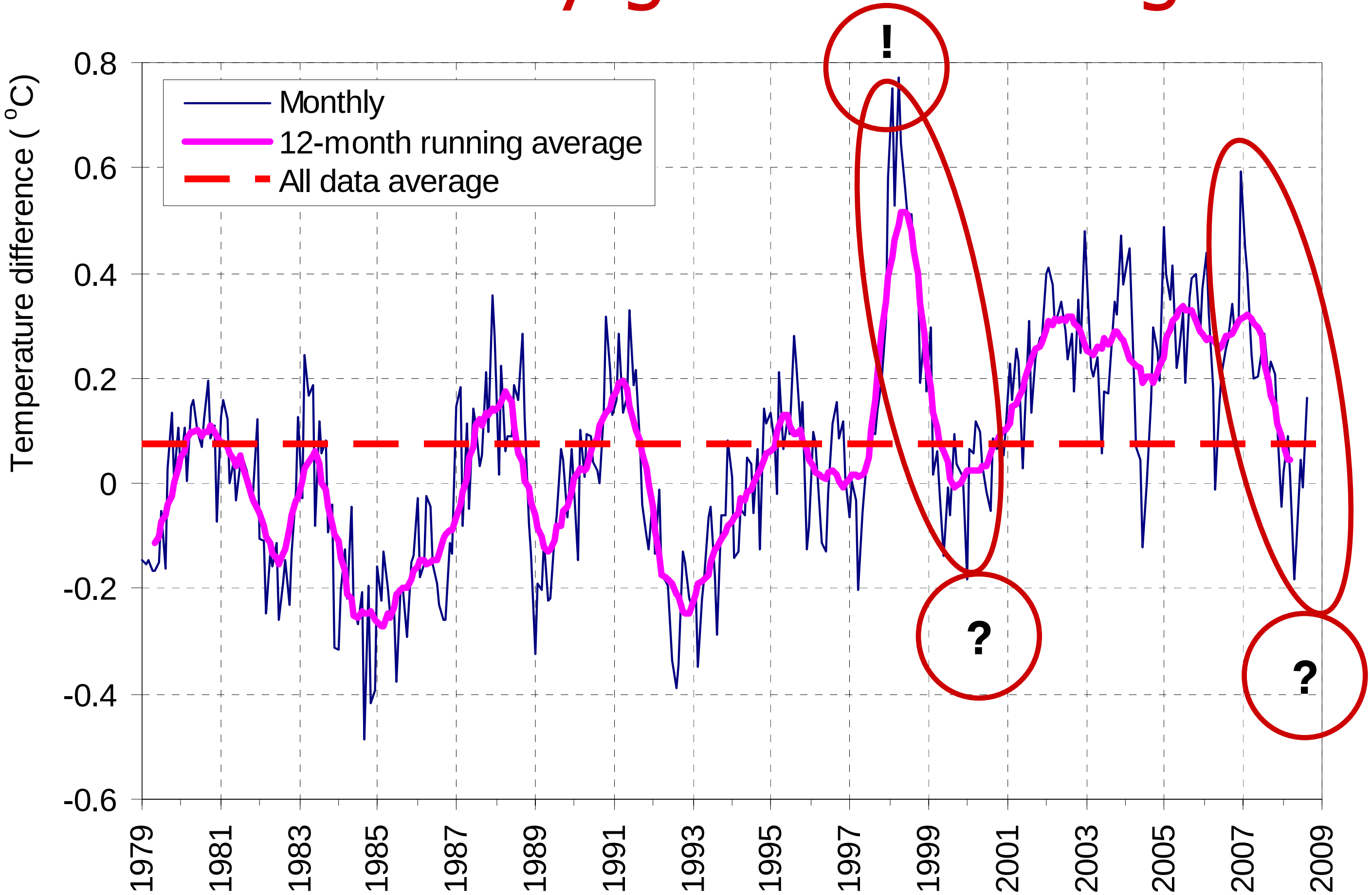
- "***Climate Change:*** *A* ***non-random*** *change in climate that is measured over several decades or longer. The change may be due to natural or human-induced causes.*" (Authoritative answer given in the same NOAA's glossary) [http://www.cpc.noaa.gov/products/outreach/glossary.shtml]
- Observation 1: What is the meaning of "*non-random*"?
  - Reply 1: It is just a manifestation of confusion between **natural processes** on the one hand and the **modeling convenience** we use and our **ability to explain** the change (attribute it to some causative mechanism) on the other hand.
  - Reply 2: It is just a manifestation of a logical inconsistency of the definition: If a change in climate is random (we cannot explain it), isn't it a "climate change"?
- Observation 2: Is the term "climate change" meaningful and useful?
  - Reply 1: In a scientific context **No**, because by definition the climate changes. The introduction of the term into the scientific vocabulary just indicates a **false perception of a static climate**.
  - Reply 2: In a political context **Perhaps**, because of the implied link of "*climate change*" with "*human-induced causes*".
- **Arguably, the definition is not scientific – and the term redundant.**

# 3. Advertized climate “certainties” (or elements of consensus) – and some question marks

# A trick to convert any observed event into climate certainty

- "*Global **warming** can mean **colder**, it can mean **drier**, it can mean **wetter**.*" (Stephen Guilbeault, Greenpeace, 2005; Telegraph). [www.telegraph.co.uk/opinion/main.jhtml?xml=/opinion/2005/12/06/do0602.xml]
- We can blame it for any negative sign we see:
  - Hot summers;
  - Cold winters;
  - Floods, typhoons, cyclones, hurricanes;
  - Droughts, desertification.
- We can predict every conceivable catastrophe for the future:
  - All above will worsen, and even …
  - … the Earth can end up like Venus with temperature rises of several hundreds degrees and sulfuric acid rain (Stephen Hawking).

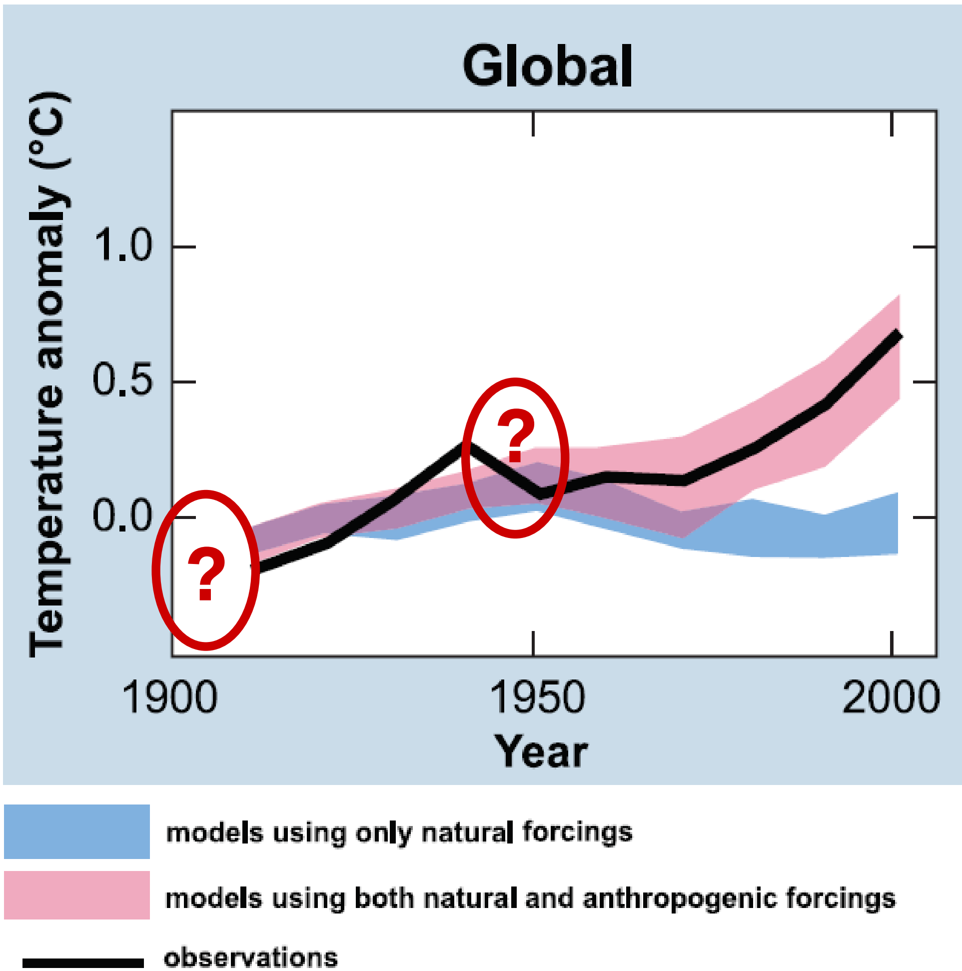
# Climate “certainty” 1: The current period is characterized by global warming




In the last ten years, alarmism about global warming has burgeoned. Is there global warming in this period? Or a slight cooling?

Satellite-derived temperature of lower troposphere; Data from the US National Space and Technology Center (Monthly means of lower troposphere lt5.2**)**
[vortex.nsstc.uah.edu/; vortex.nsstc.uah.edu/public/msu/t2lt/tltglhmam_5.2]

# Climate "certainty" 2: The recent warming is anthropogenic



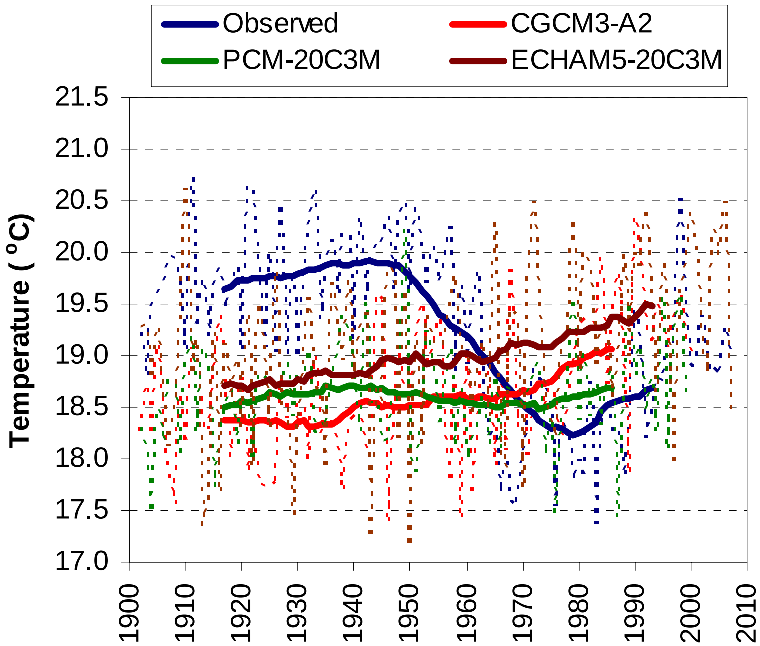

IPCC (2007; Figure SPM.4 partly reproduced) has concluded that it is likely that there has been significant anthropogenic warming over the past 50 years. The observed patterns of warming, are only simulated by models that include anthropogenic forcing.

Are models good enough to support such a conclusion? They did not capture the cooling trend in 1940s; perhaps for the same reason the first decade of 1900, which had a cooling trend, has been deleted from the figure. Further, is such a conclusion supported by statistical testing?

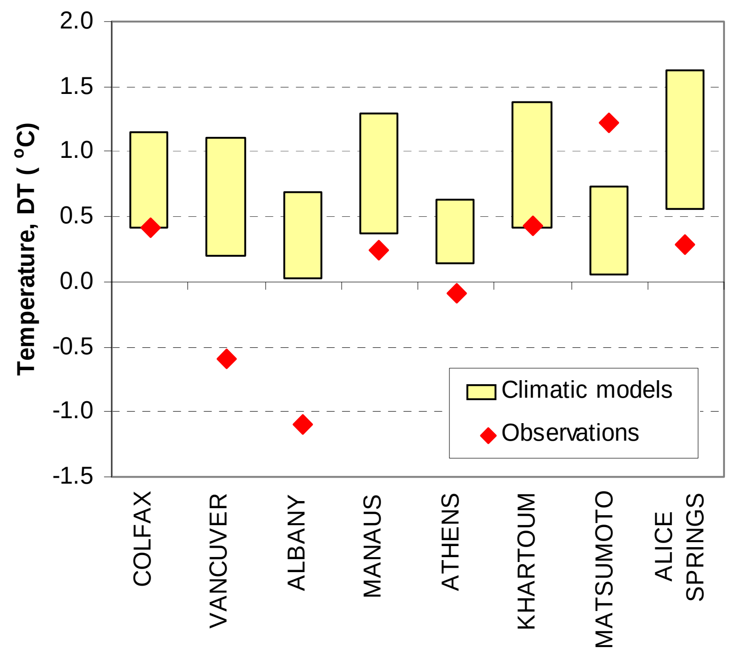
# Climate "certainty" 3: Climate models are able to predict the climate in 2050 or 2100

Koutsoyiannis *et al.* (2008) tested retrodictions of three IPCC AR4 and three TAR climatic models at 8 test sites worldwide that had long (> 100 years) temperature and precipitation series of observations. They found that model outputs are irrelevant with reality.

Comparisons of observed temperature at Albany, Georgia, USA, and modelled temperature by three AR4 models

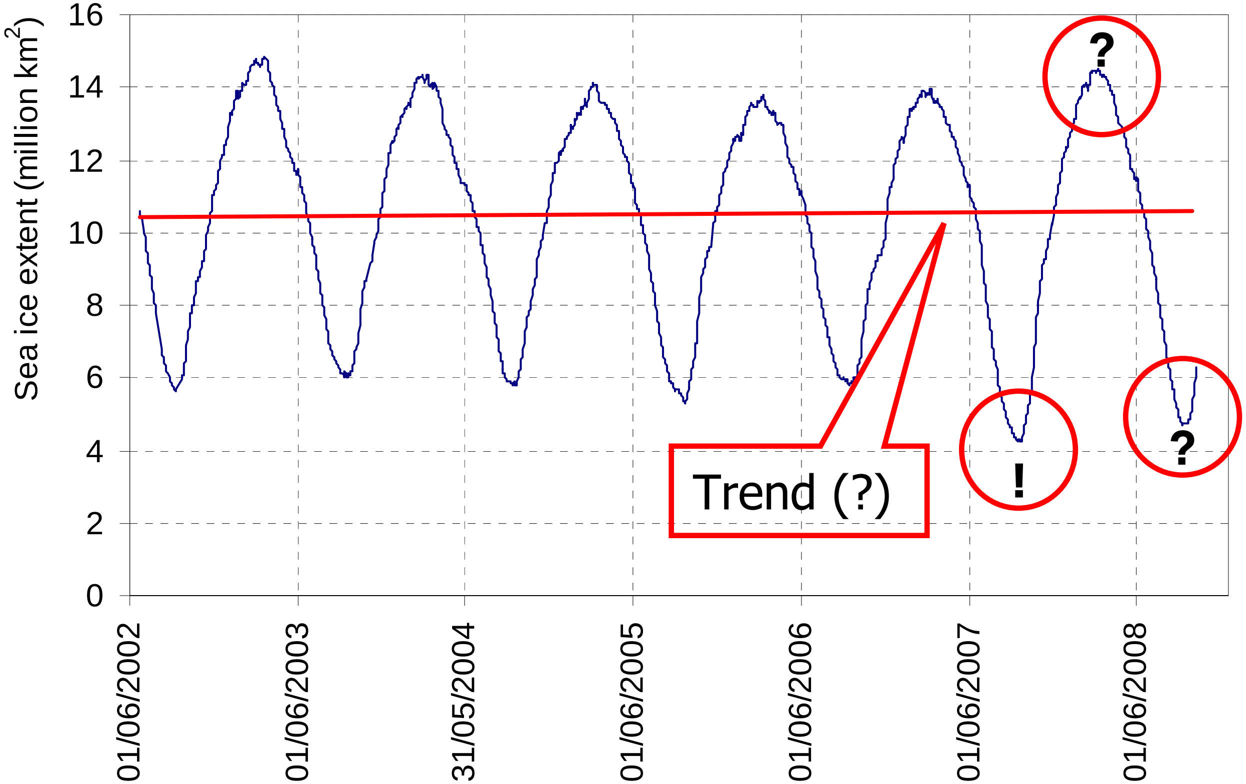



Change of climatic (30-year moving average) temperature (in the 20th century: models vs. reality




Models cannot reproduce past climate. How can then predict future climate?

# Climate "certainty" 4: Arctic sea ice is melting

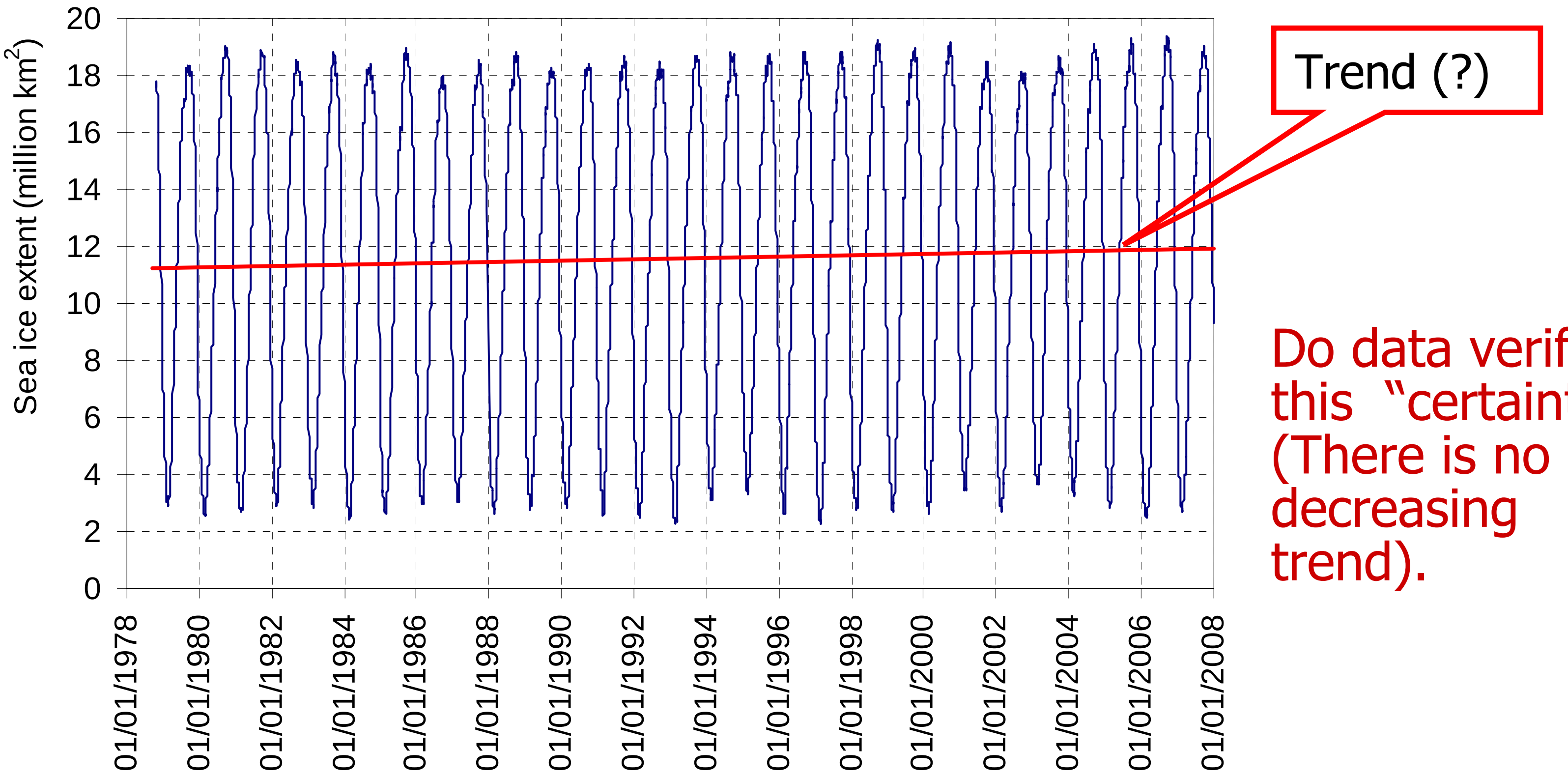



Climate modellers expect that the North and South Poles will show the most dramatic effects of global warming. In June 2008 there were predictions of an ice-free North Pole for first time in history during the summer of 2008 (Mehta, 2008).

Do data justify the fears and verify this "certainty"? (The melting in 2008 was lower than in 2007).

Satellite-derived sea ice extent in the Arctic Ocean. Data from the FIARC-JAXA Information System (IJIS) of the International Arctic Research Center in corporation with the Japan Aerospace Exploration Agency and the Advanced Earth Science and Technology Organization of Japan [http://www.ijis.iarc.uaf.edu/en/home/seaice_extent.htm]

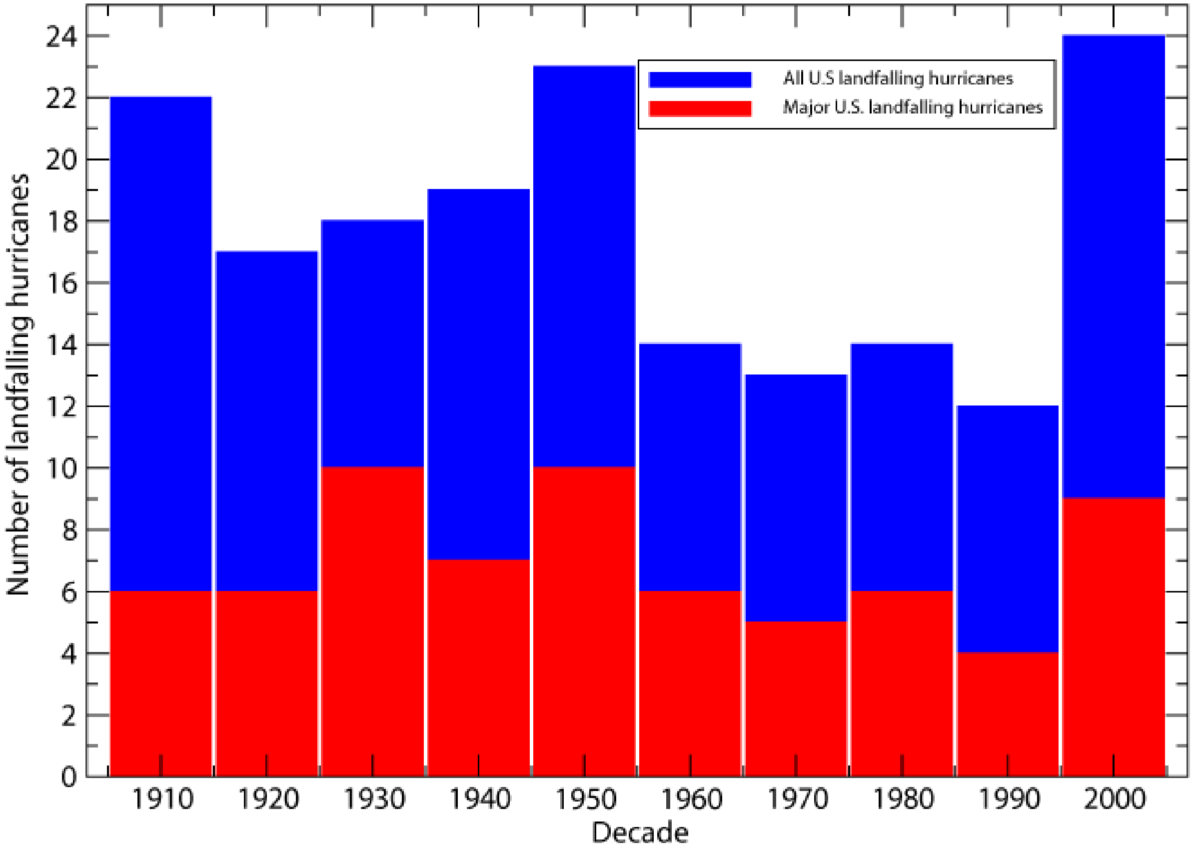
# Climate “certainty” 5: Antarctic sea ice is melting




Do data verify this “certainty”? (There is no decreasing trend).

Satellite-derived sea ice extent in Antarctica. Data from the US National Snow and Ice Data Center [nsidc.org/data/smmr_ssmi_ancillary/area_extent.html; sidads.colorado.edu/DATASETS/seaice/polar-stereo/trends-climatologies/ice-extent/nasateam/gsfc.nasateam.daily.extent.1978-2007.s]

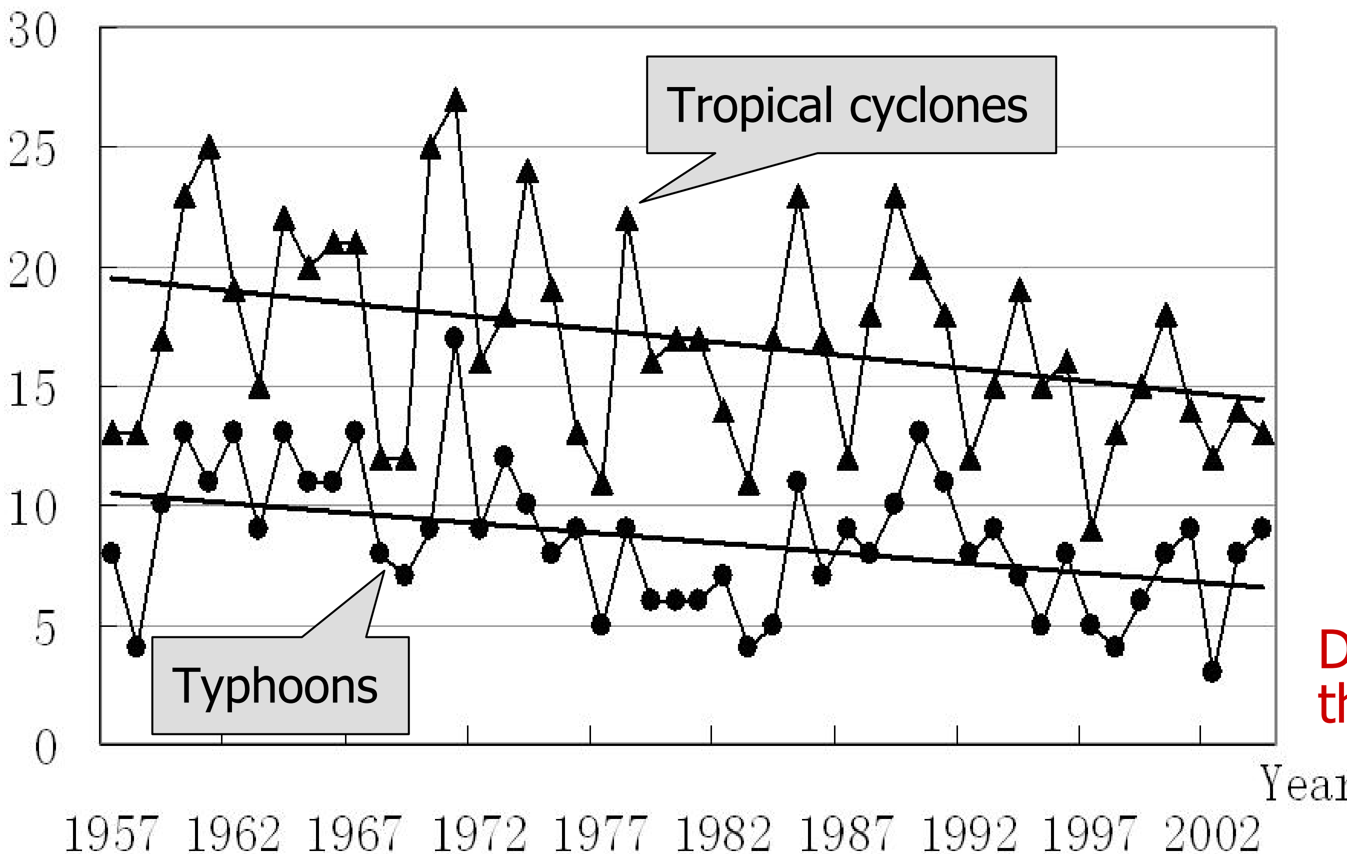
# Climate "certainty" 6: Extreme weather phenomena are becoming more frequent




Do data verify this "certainty"?

Frequency of hurricanes and major hurricanes (categories 3-5) landfalling in the USA (by decade, 1906-2005)
[www.ncdc.noaa.gov/oa/climate/research/hurricane-climatology.html]

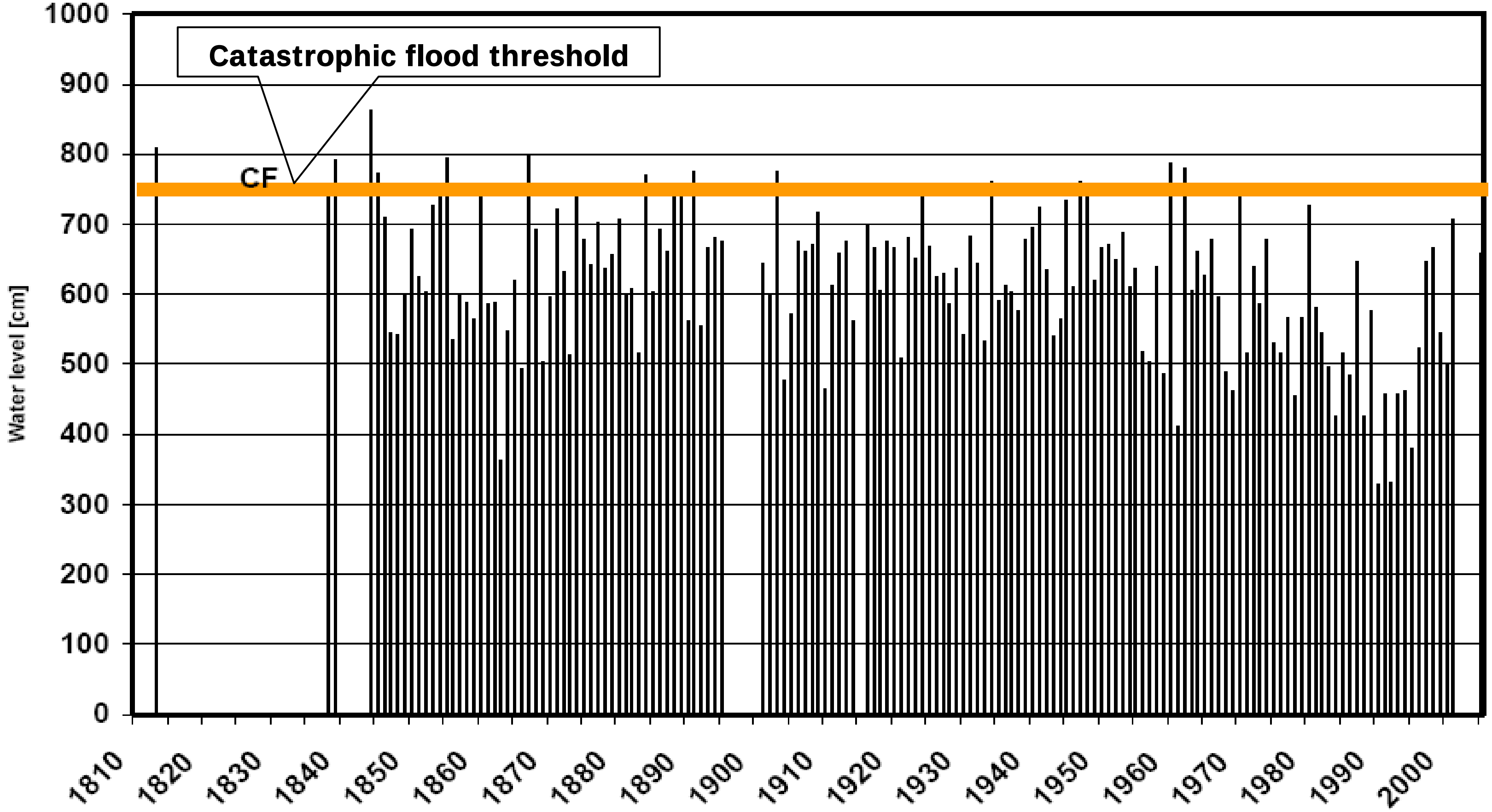
# Climate certainty 6 (cont.): Extreme weather phenomena are becoming more frequent




Do data verify this "certainty"?

Frequency of tropical cyclones and typhoons (with maximum sustained wind speed > 32.7 m/s) in China; source: Ren *et al.* (2006)

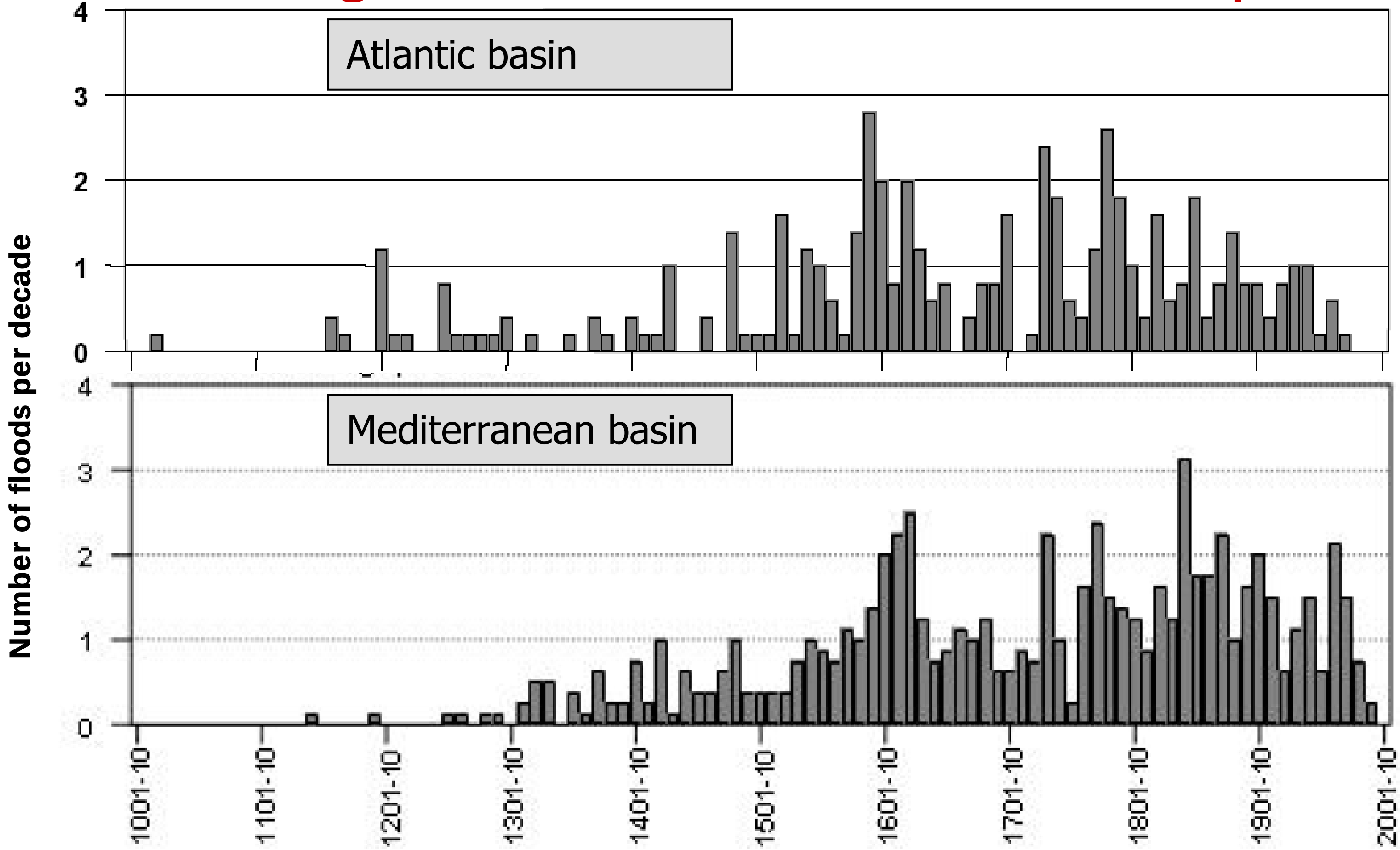
# Climate "certainty" 7: Catastrophic floods are becoming more intense and more frequent




Annual maximum water level of the Vistula River in Warsaw, 1813-2005 (Cyberski *et al.*, 2006)

Do data verify this "certainty"?

# Climate "certainty" 7 (cont.): Catastrophic floods are becoming more intense and more frequent



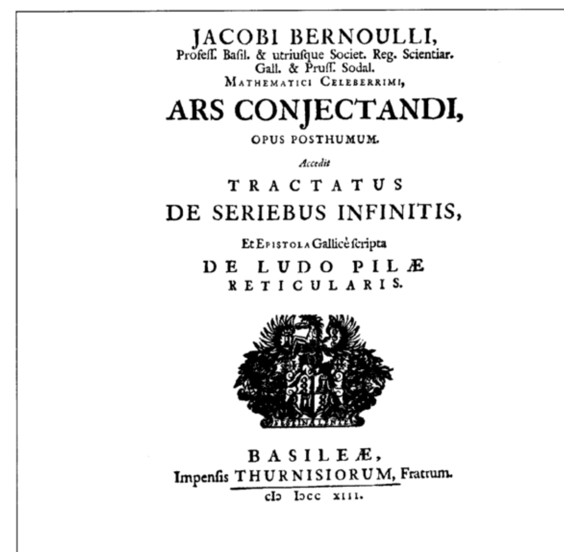

Historical evidence for flood frequency in Spain in the last millennium from documents and archives (Barriendos *et al.*, 2006)

Do data verify this "certainty"?

# 4. Climate stochastics

# What is *Stochastics*?

- "***To predict something is to measure its probability***. *The Science of Prediction or **Stochastics** is therefore defined as the science of measuring as exactly as possible the probabilities of events so that in our decisions and actions we can always choose or follow that which seems to be better, more satisfactory, safer and more considered. In this alone consists all the wisdom of the Philosopher and the prudence of the Statesman.*"
  [Jakob Bernoulli, Ars Conjectandi, 1684-1689, published in 1713; quoted from von Collani, 2005, 2006]
- The modern meaning of "stochastics" points to a mathematically based science, the subject of which is chance and uncertainty. It comprises probability theory, mathematical statistics and stochastic processes, as well as their applications.



JACOBI BERNOULLI,
Profess. Basil. & utriusque Societ. Reg. Scientiar.
Gall. & Pruss. Sodal.
MATHEMATICI CELEBERRIMI,

ARS CONJECTANDI,

OPUS POSTHUMUM.

*Accedit*

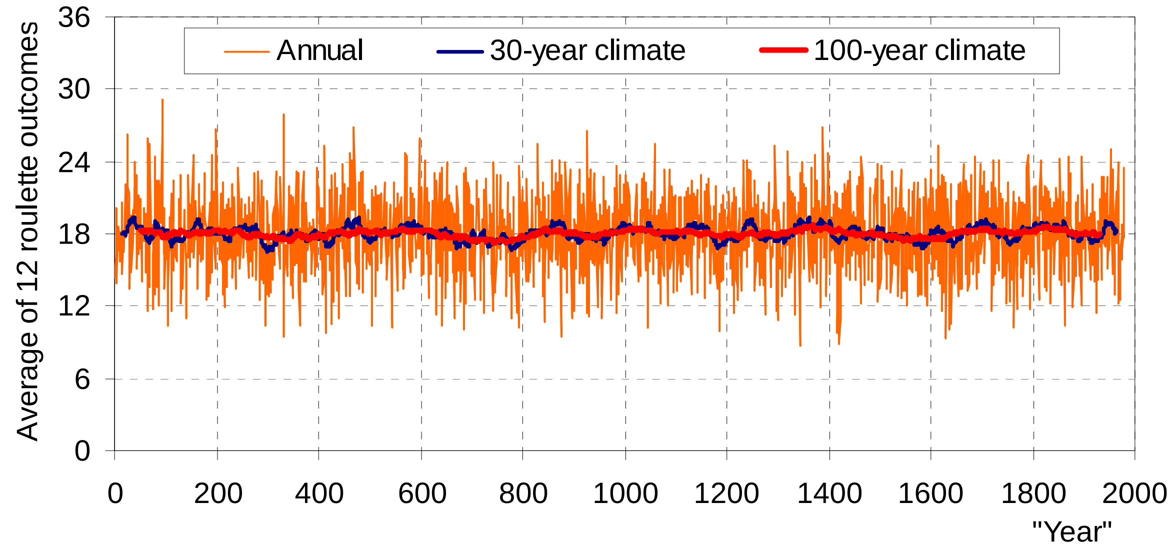
TRACTATUS
DE SERIEBUS INFINITIS,

Et EPISTOLA Gallicè scripta
DE LUDO PILÆ
RETICULARIS.

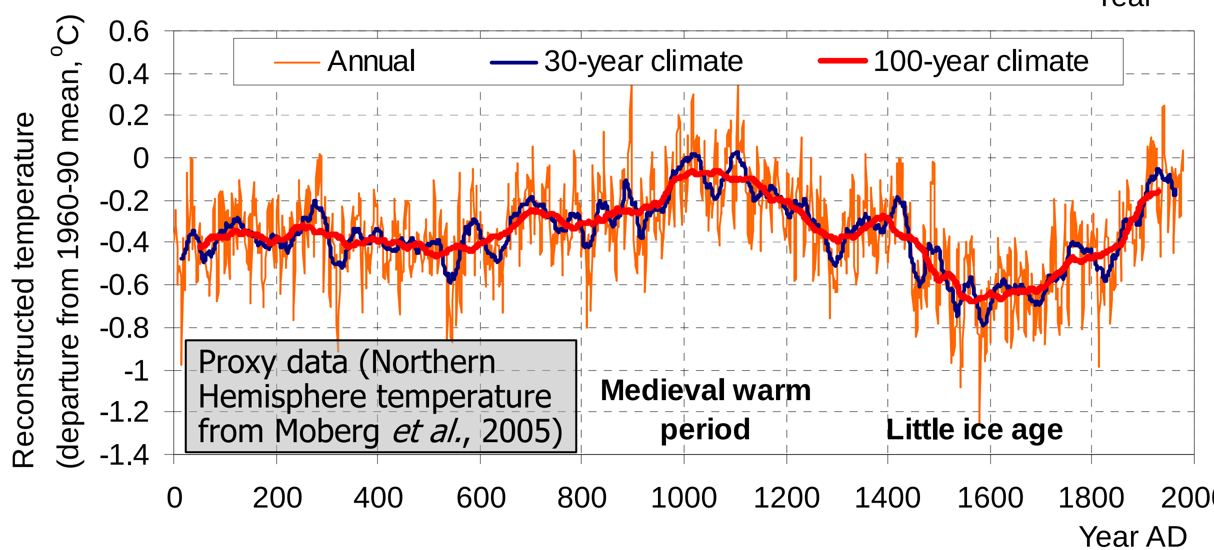
BASILEÆ,
Impensis THURNISIORUM, Fratrum.
clɔ Iɔcc XIII.

# Simplified random processes are insufficient for climatic processes

"Roulette climate"




Real-world or "Hurst-Kolmogorov" climate



# The Hurst-Kolmogorov (HK) pragmaticity

The recognition that real world processes behave differently from an ideal roulette wheel (where the differences mainly rely on long excursions of local averages from the global mean) has been termed the Hurst-Kolmogorov pragmaticity (Koutsoyiannis and Cohn, 2008)

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

TRANSACTIONS

Paper No. 2447

LONG-TERM STORAGE CAPACITY OF RESERVOIRS

BY H. E. HURST[1]

WITH DISCUSSION BY VEN TE CHOW, HENRI MILLERET, LOUIS M. LAUSHEY, AND H. E. HURST.

SYNOPSIS

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

Hurst (1950) studied numerous geophysical time series and observed that: "*Although in random events groups of high or low values do occur, their tendency to occur in natural events is greater. This is the main difference between natural and random events.*"

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

*MATHEMATIK*

WIENERSCHE SPIRALEN UND EINIGE ANDERE INTERESSANTE KURVEN IM HILBERTSCHEN RAUM

Von A. N. KOLMOGOROFF, Mitglied der Akademie

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

Unter einer Ähnlichkeitstransformation im Hilbertschen Raum $H$ werden wir eine beliebige ...

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

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

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

115

Kolmogorov (1940) studied the stochastic process that describes this behaviour 10 years earlier than Hurst.

# Multi-scale stochastic properties of a HK process

A natural process usually evolves in continuous time $t$: $X(t)$

… but we observe or study it in discrete time, averaging it over a fixed time scale $k$ and using discrete time steps $i = 1, 2, …$

$$X_i^{(k)} := \frac{1}{k} \int_{(i-1)k}^{ik} X(t)\, dt$$

| Properties of the HK process | At an arbitrary observation scale $k = 1$ (e.g. annual) | At any scale $k$ |
|---|---|---|
| Standard deviation | $\sigma \equiv \sigma^{(1)}$ | $\sigma^{(k)} = k^{H-1}\sigma$ (can serve as a definition of the HK process; $H$ is the Hurst coefficient; $0.5 < H < 1$) |
| Autocorrelation function (for lag $j$) | $\rho_j \equiv \rho_j^{(1)} = \rho_j^{(k)} \approx H(2H-1)\, \lvert j \rvert^{2H-2}$ | |
| Power spectrum (for frequency $\omega$) | $s(\omega) \equiv s^{(1)}(\omega) \approx 4(1-H)\,\sigma^2\,(2\omega)^{1-2H}$ | $s^{(k)}(\omega) \approx 4(1-H)\,\sigma^2\,k^{2H-2}\,(2\omega)^{1-2H}$ |

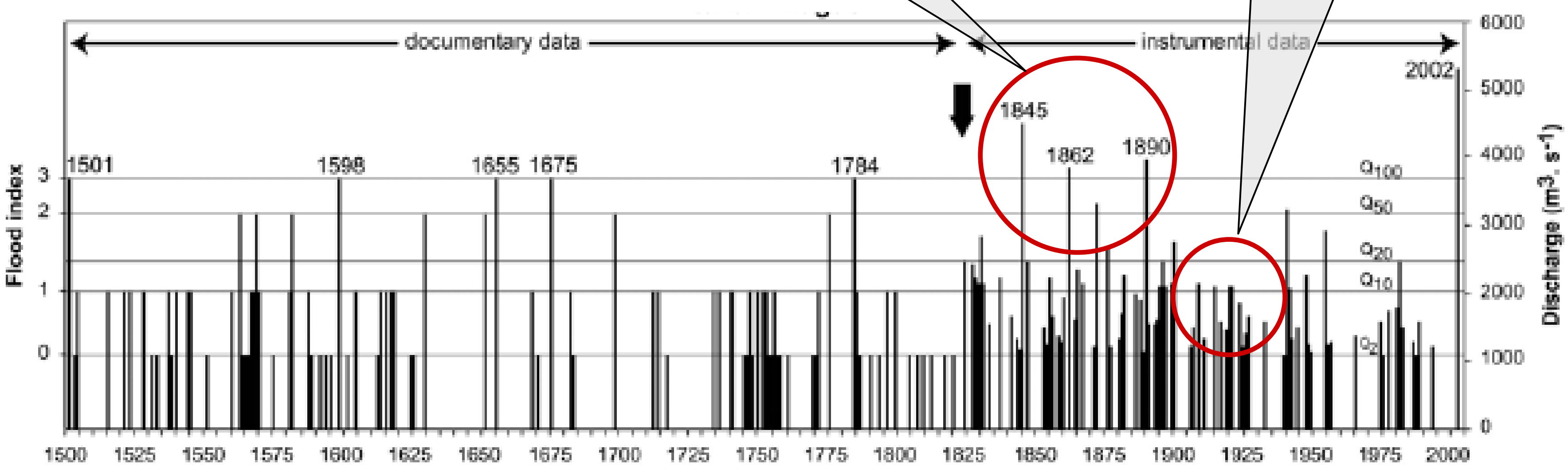
In classical statistics $\sigma^{(k)} = \sigma/\sqrt{k}$

All equations are power laws of scale $k$, lag $j$, frequency $\omega$

# Example 1: Tendency of grouping of floods

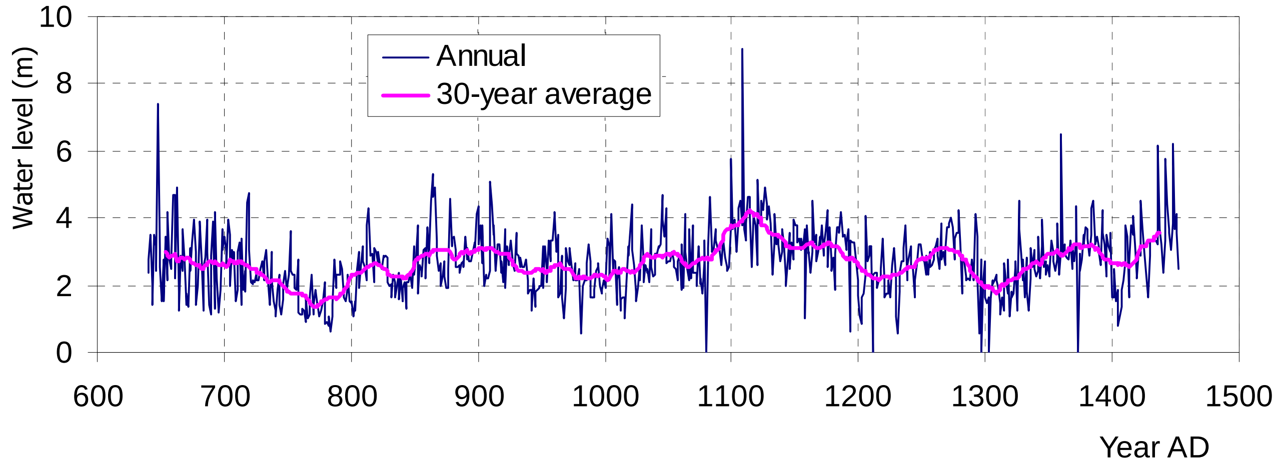
1845-90: Three flood events greater than the 100-year flood in 45 years

1900-45: No flood event greater than the 10-year flood in 40 years




Flood discharges of the Vltava River in Prague during the last 5 centuries (Brázdil *et al.*, 2006).

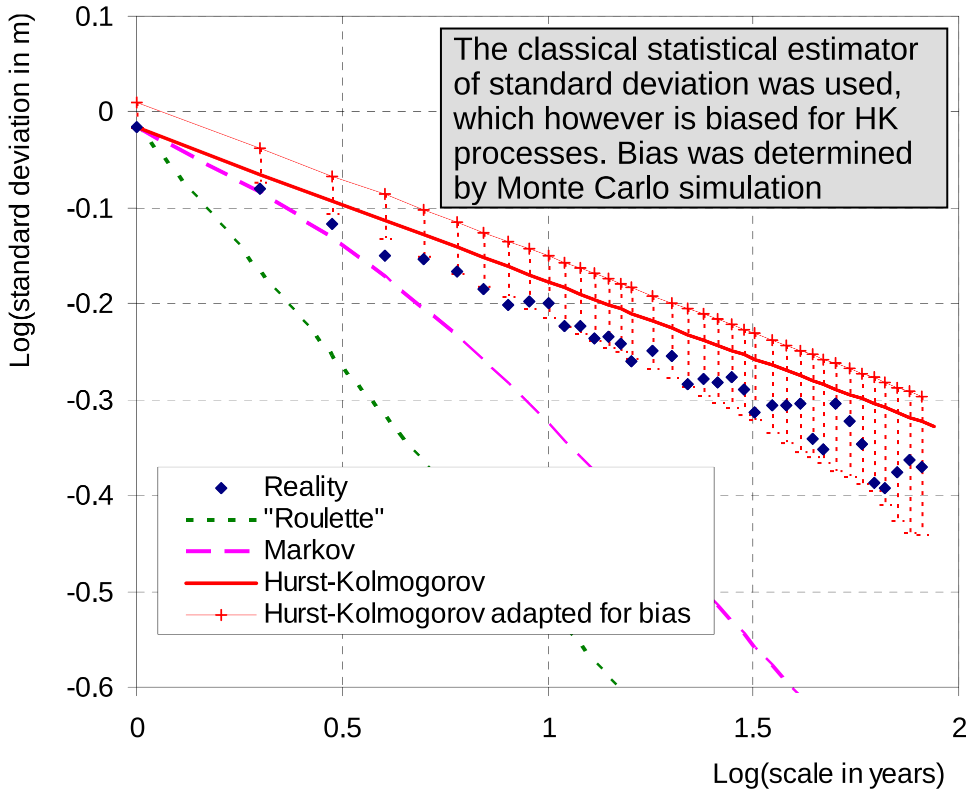
# Example 2: Annual minimum water levels of the Nile



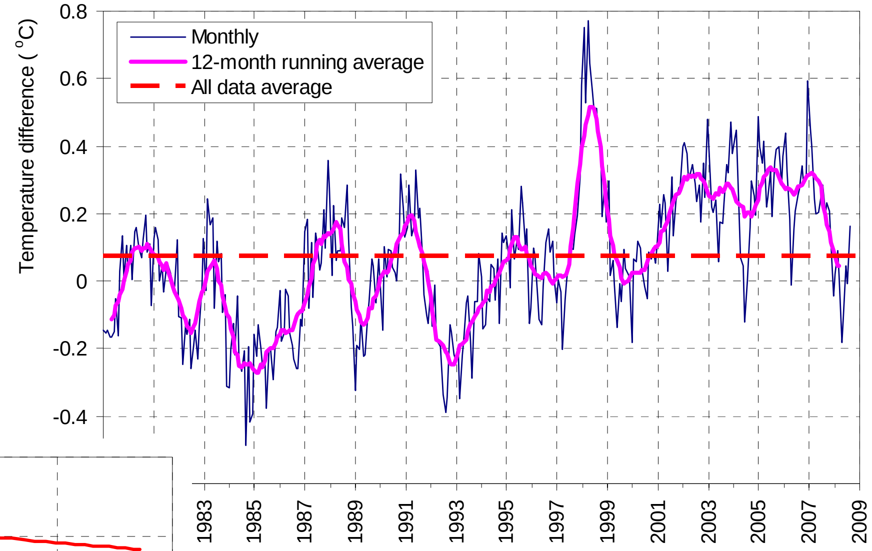


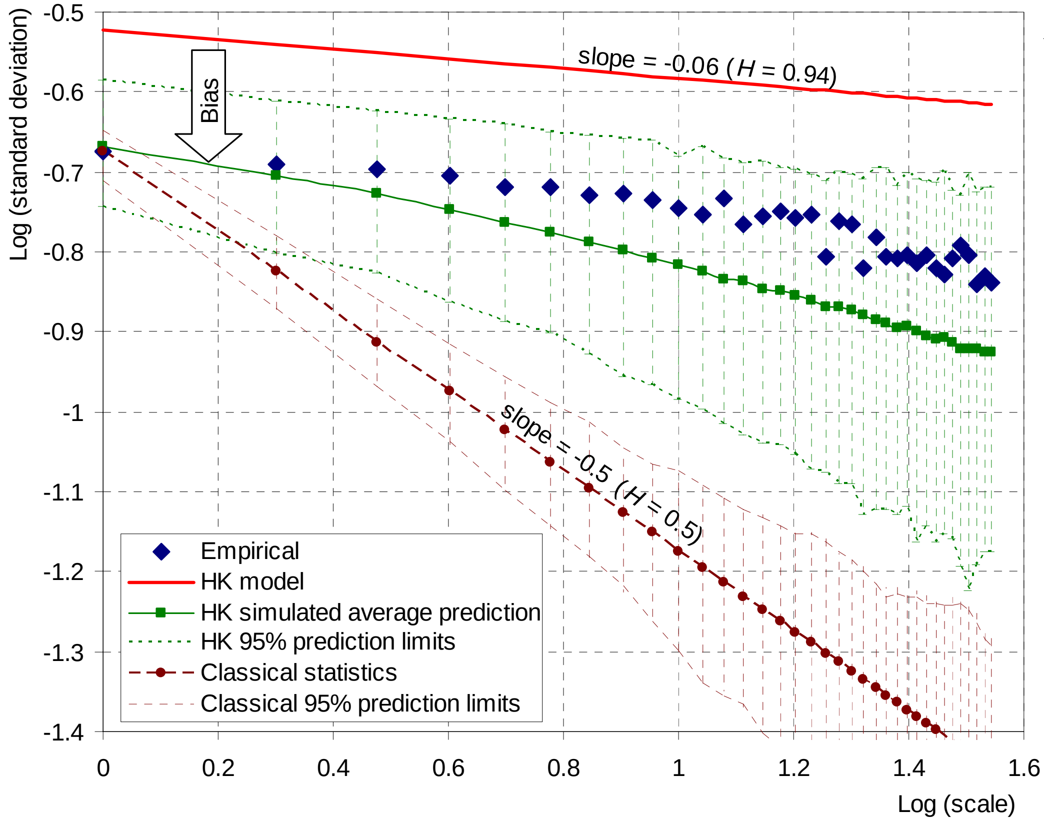
Roda Nilometer

- The longest available instrumental hydroclimatic data set (813 years).
- Hurst coefficient *H* = 0.84.
- The same *H* is estimated from the simultaneous record of maximum water levels and from the modern record (131 years) of the Nile flows at Aswan.



# Example 3: The lower tropospheric temperature

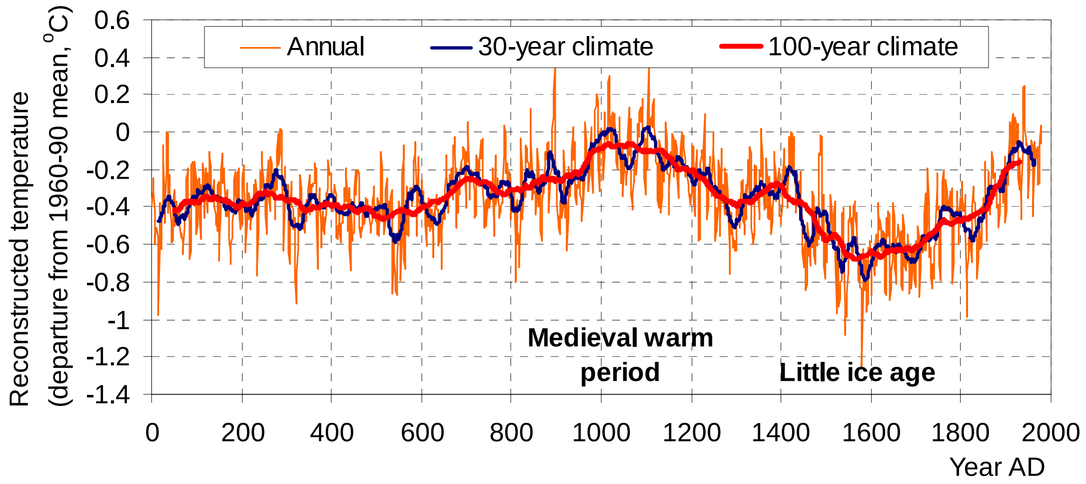


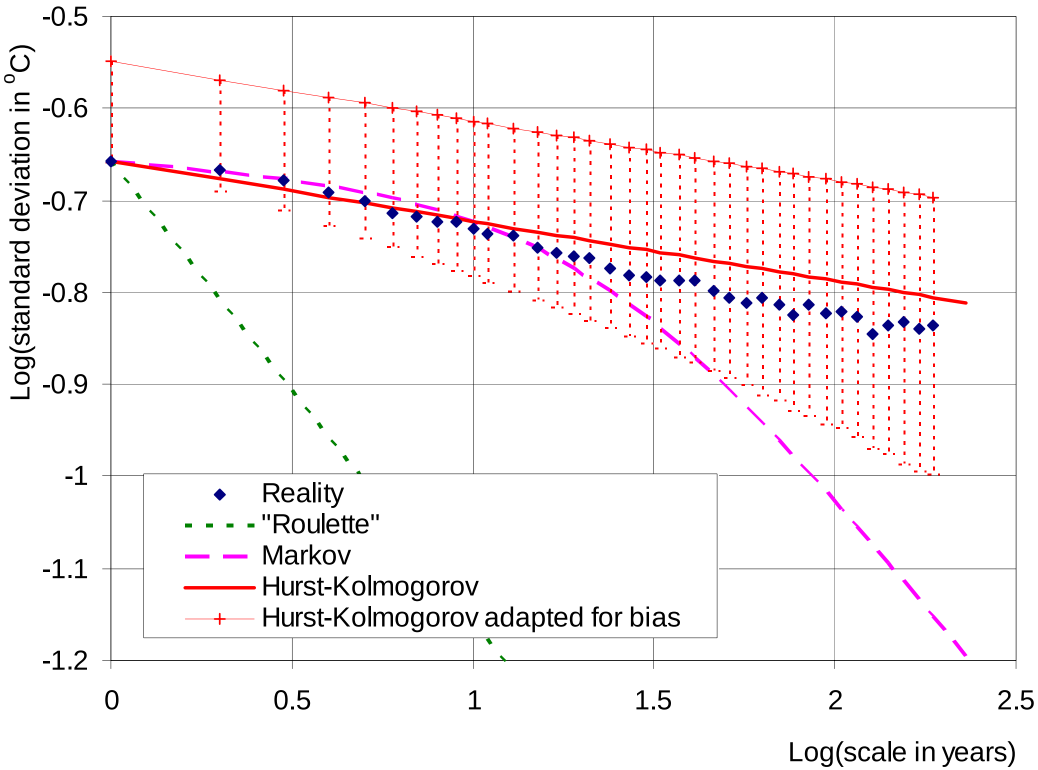




Suggests an HK behaviour with a very high Hurst coefficient: $H = 0.94$

Estimation bias and 95% prediction limits were determined by Monte Carlo simulation (200 simulations with length equal to the historical series)

# Example 4: The Moberg *et al.* proxy series of the Northern Hemisphere temperature

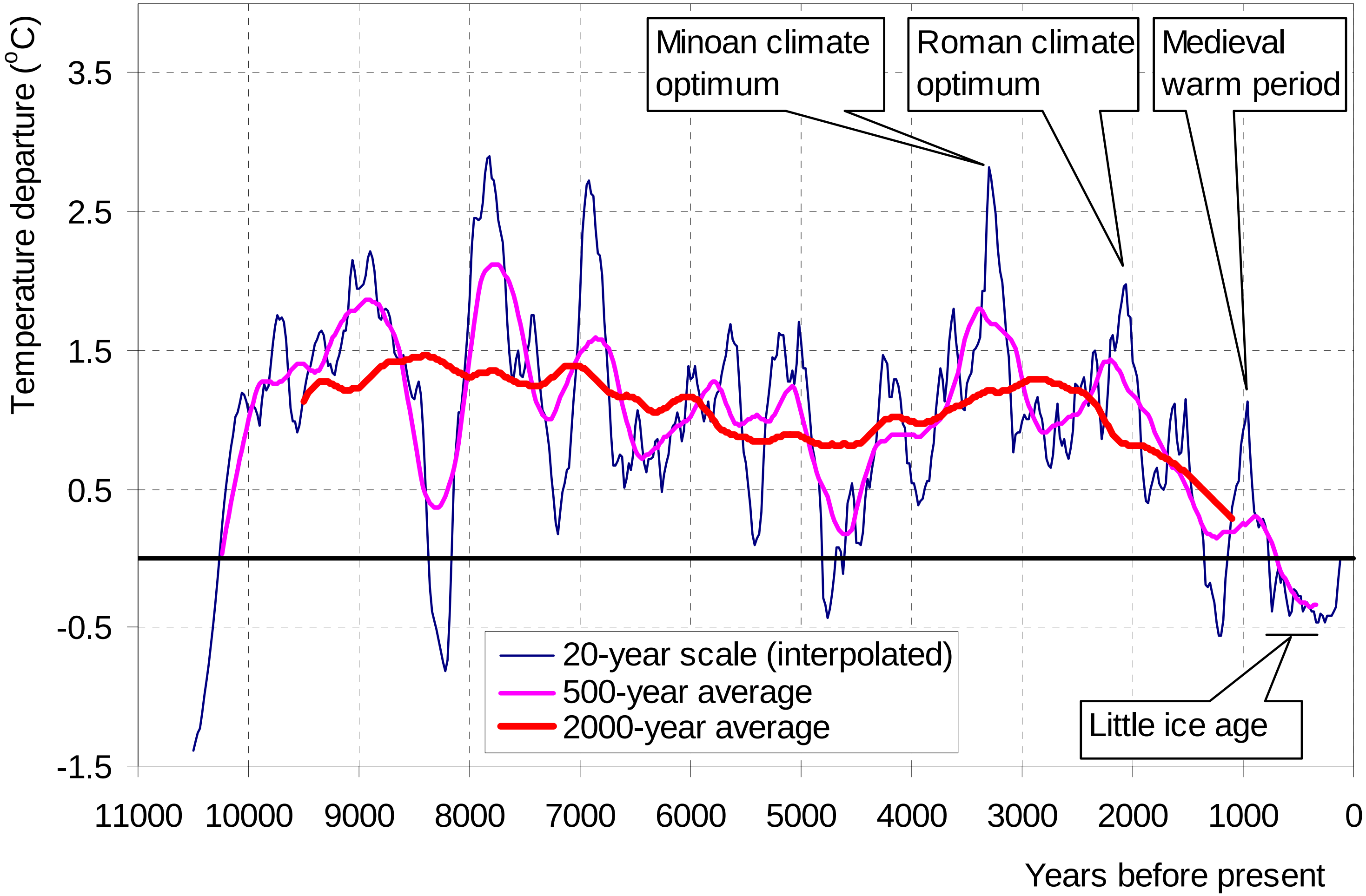



Suggests an HK behaviour with a very high Hurst coefficient: $H = 0.94$

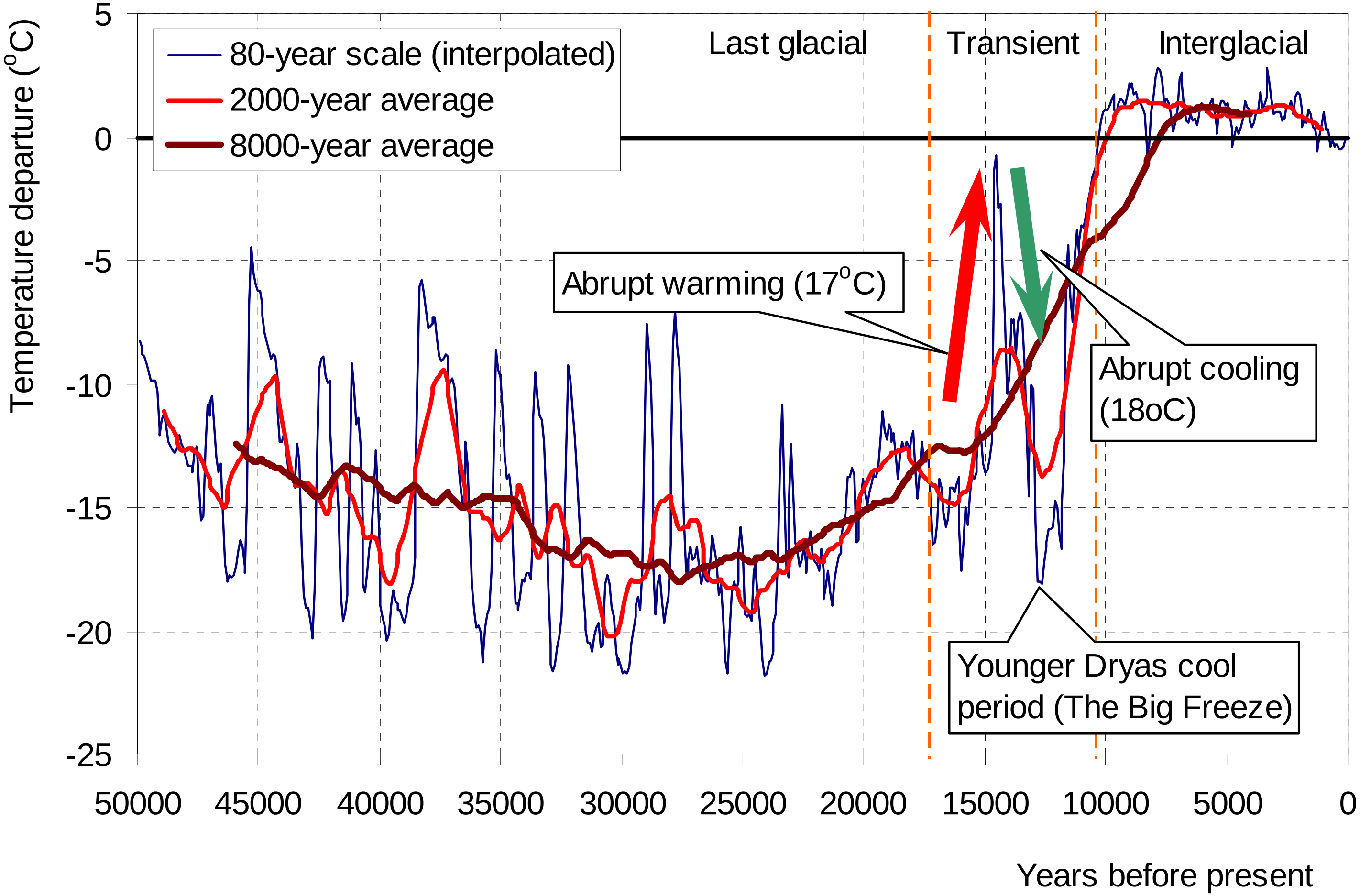
Estimation bias was determined by Monte Carlo simulation (200 simulations with length equal to the historical series)

# Example 5: The Greenland temperature proxy during the Holocene



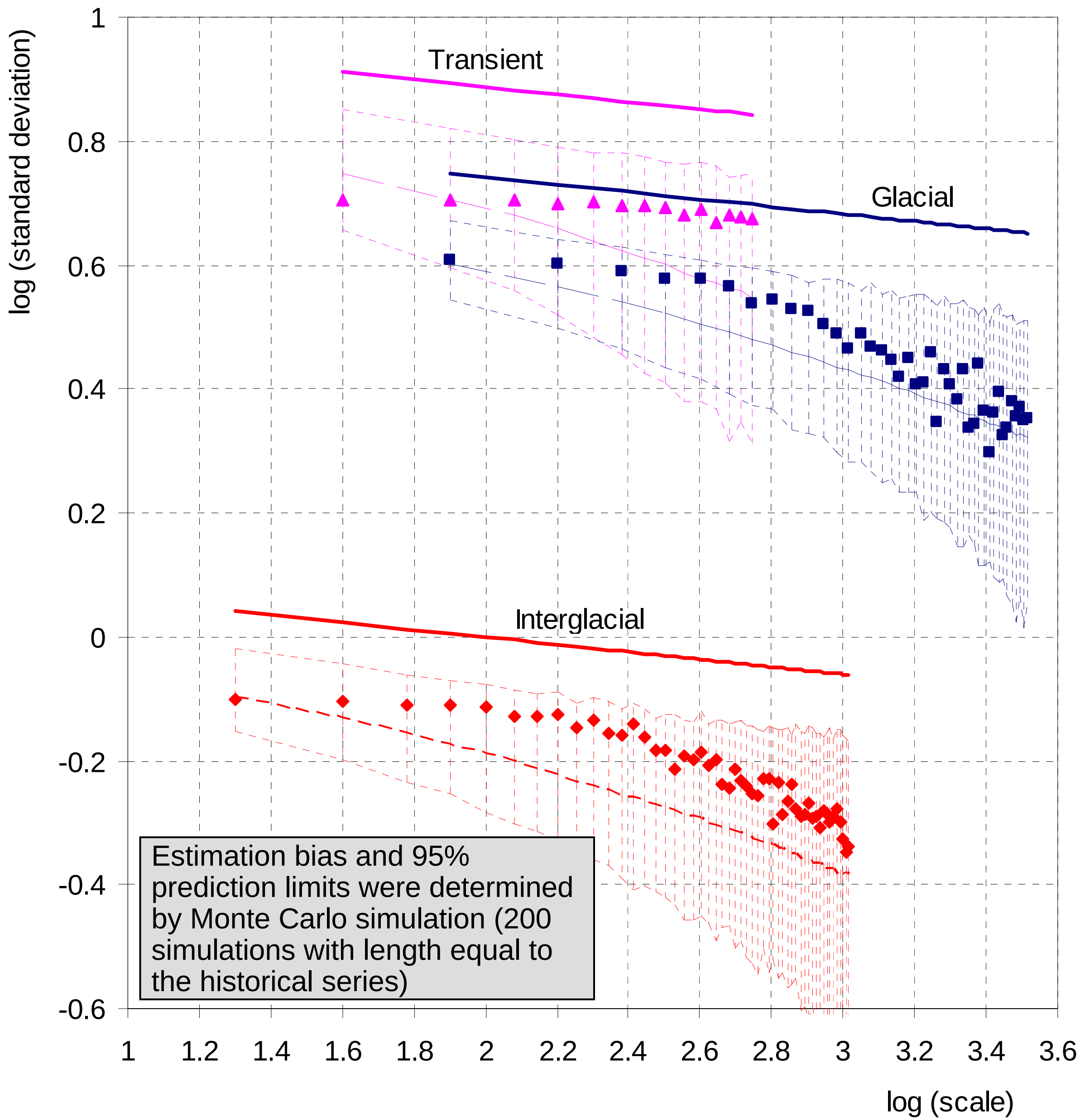

Reconstructed from the GISP2 Ice Core (Alley, 2000, 2004). Data from: ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt

# Example 5 (cont.): The Greenland temperature proxy on multi-millennial time scales




Reconstructed from the GISP2 Ice Core (Alley, 2000, 2004). Data from:
ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt

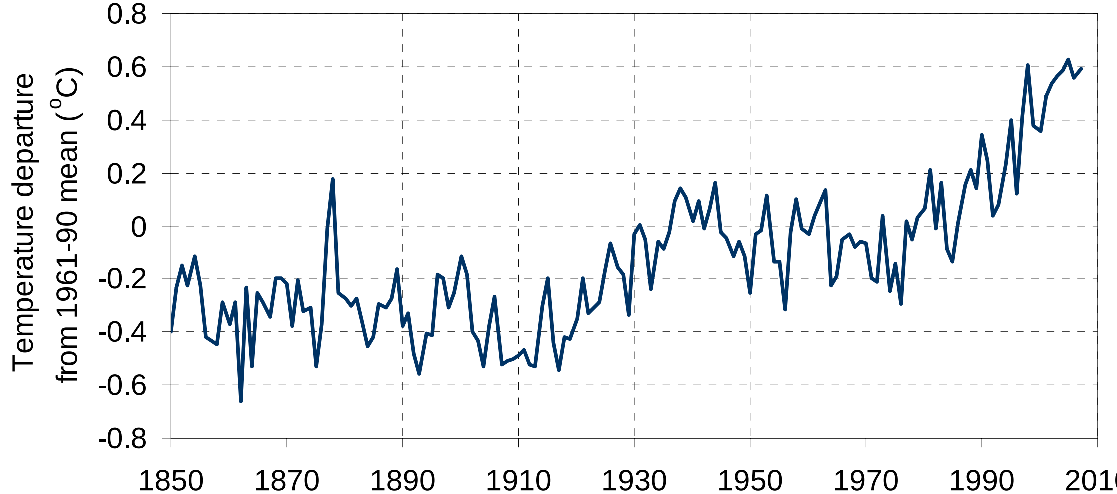
# Example 5 (cont.): The Greenland temperature proxy on all scales

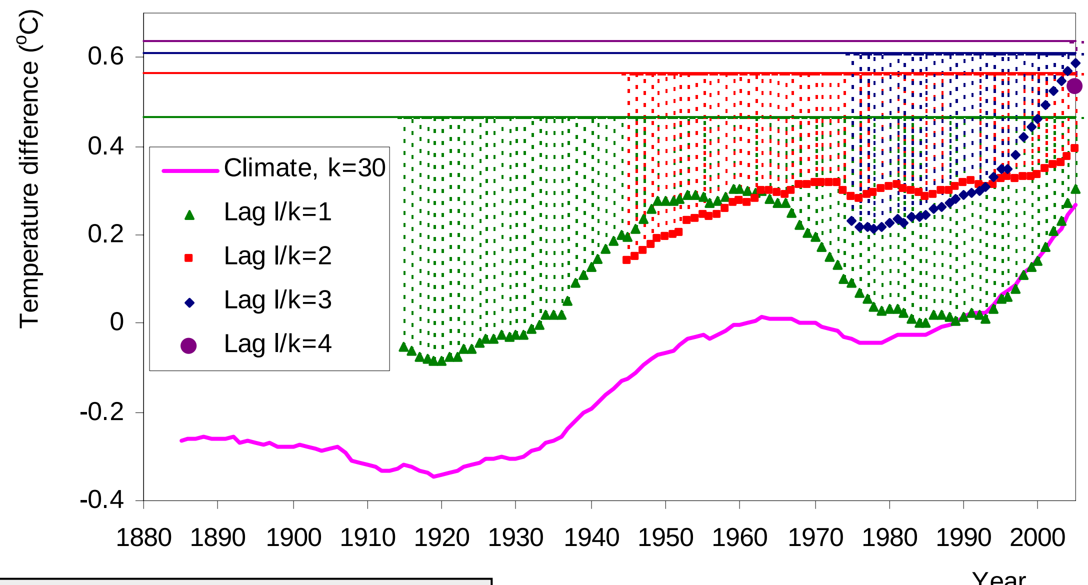



All three periods suggest an HK behaviour with a very high Hurst coefficient: $H \approx 0.94$

# Application 1: Significance testing of temperature changes

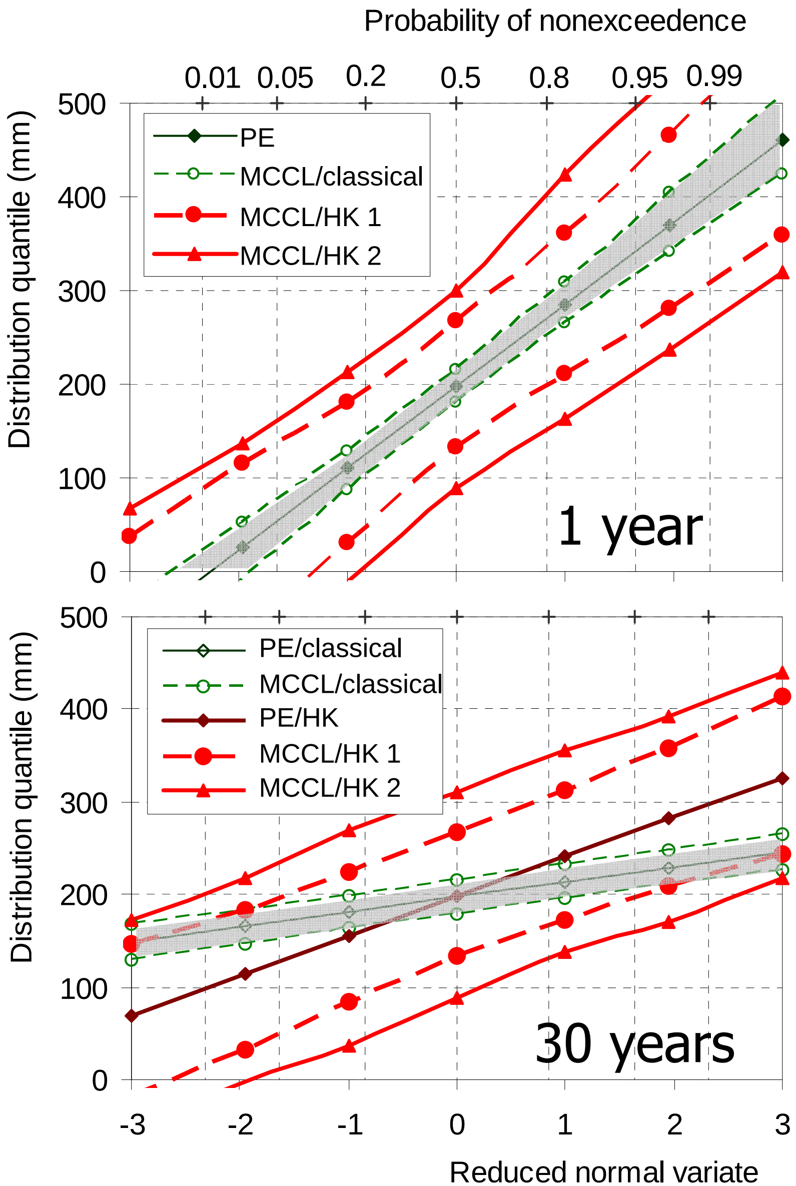
- Koutsoyiannis and Montanari (2007) developed a statistical "pseudo-test" **on an analytical basis** for detection of changes assuming HK climatic behaviour; this gives a lower bound of the significance level.
- Application of the test on the CRU series of the Northern Hemisphere temperature did not reject the null hypothesis of no change.
- A real test (instead of the pseudo-test) would even less likely reject the null hypothesis of no change.
- This result agrees with Cohn and Lins (2005) who developed a test based on **Monte Carlo** simulation.




Data from: http://www.cru.uea.ac.uk/cru/data/temperature/hadcrut3nh.txt

# Application 2: Perception and quantification of uncertainty




Boeoticos Kephisos River runoff (close to Athens, Greece); $H = 0.84$;
from Koutsoyiannis *et al.* (2007)

| Statistical model | Total uncertainty in runoff (due to variability and parameter estimation) % of average | |
|---|---|---|
| | Annual scale | 30-year scale |
| Classical | 200 | 50 |
| HK | 270 | 200 |

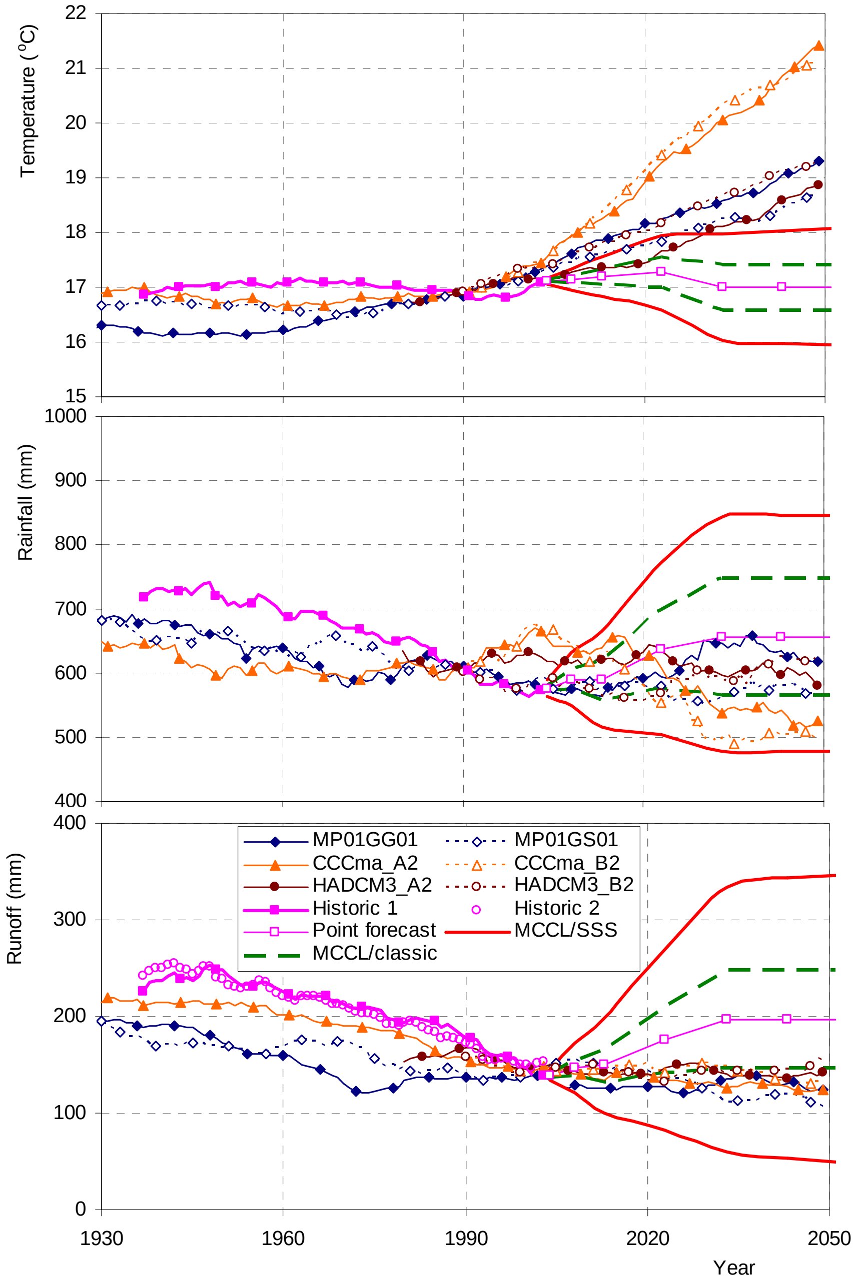
**Classical model (cf. common definition of climate)**
Climate is what we expect
Weather is what we get

**HK model**
Weather is what we get … immediately
Climate is what we get
… if you keep expecting for a long time

# Application 3: Comparison of GCM projections with HK climatic confidence limits

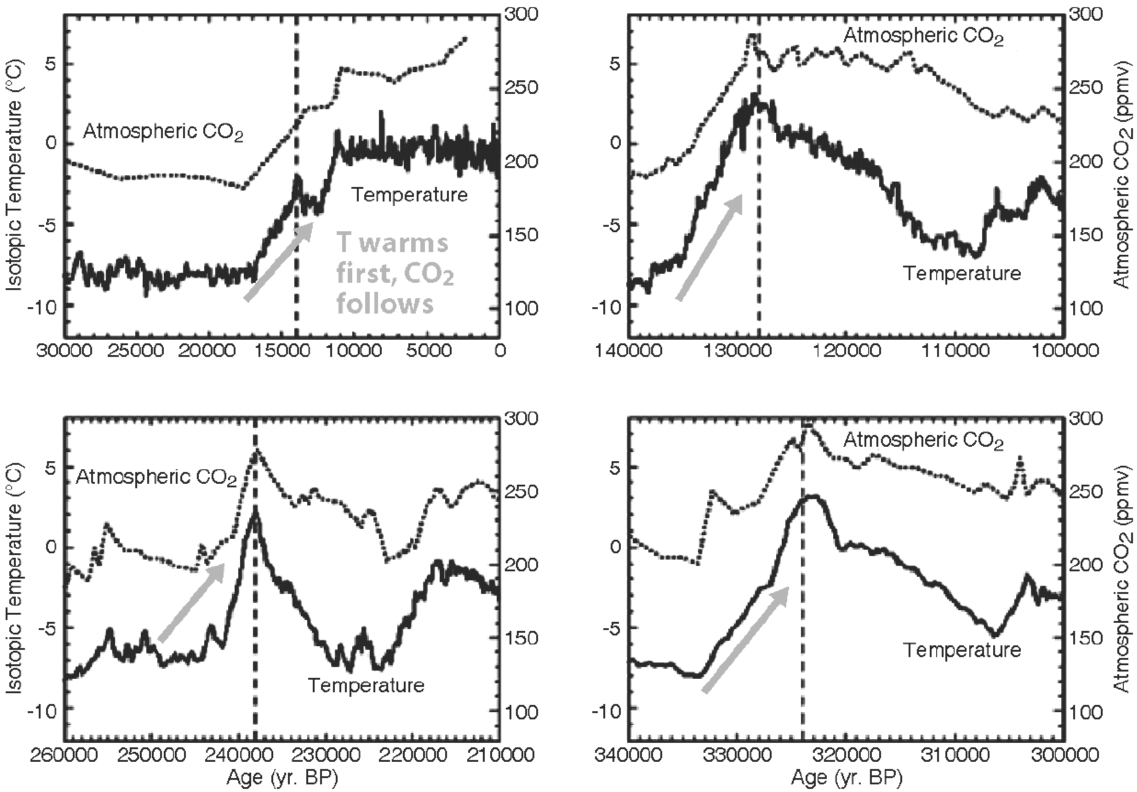
Boeoticos Kephisos catchment; temperature, precipitation and runoff; from Koutsoyiannis *et al.* (2007)

- Outputs from three GCMs for two scenarios were superimposed to confidence zones produced under the HK hypothesis with stationary conditions.
- For **the past**, despite adaptations performed to make GCM outputs consistent with reality (downscaling), the proximity of models with reality is not satisfactory.
- The GCM projected evolution of temperature for **the future** is too high and (for some models) has been already falsified by reality.
- The GCM projected trajectories of precipitation and runoff are too stable (in comparison to HK uncertainty zone) and their adoption increases risk.
- Conclusion: **It is dangerous to use GCM future predictions**.



# A future investigation

Vostok temperature and atmospheric $CO_2$ history for the past 420 thousand years, showing that Antarctic warming tends to lead the rise in $CO_2$ concentrations by several hundred years during the last deglaciations and that relatively high $CO_2$ levels can be sustained for thousands of years during glacial inception scenarios when the temperature has dropped significantly (from Soon, 2007).




- A stochastic relationship between atmospheric temperature and $CO_2$ concentration would enable a more realistic approach to current climate research targets.
- Proxy data would be very useful in establishing such a relationship.
- This task is not easy because even the direction of the causative relationship between temperature and $CO_2$ (which is the cause and which the effect), as well as the related time lags, are not clear.

# Concluding remarks

- Even the **explanation** of observed or estimated **present and past climate evolution**, based on hypothetical "sharp" causal mechanisms, and the reproduction by deterministic climatic models, encounter greatest difficulties.

> "*The infinite diversity which is manifest in the works of nature as well as in human activities and which constitutes the universe's extraordinary beauty cannot have any other source than the diverse combination, mixture and grouping of its parts. The set of entities which interact in generating a phenomenon or event is often so big and varied that the exploration of all ways that may lead or not lead to its combination or mixture encounters the greatest difficulties.*" (Jakob Bernoulli)
> [Ars Conjectandi, 1684-1689, published in 1713; quoted from von Collani, 2005, 2006]

- *A fortiori*, deterministic **predictions for the future** of the complex global climate system on long time horizons must be infeasible.
- Taking such predictions seriously and using them in decision making is **dangerous**: it underestimates uncertainty and thus increases the risk.
- A paradigm change is needed in climate:
  - From ambiguous terms and definitions to clear concepts;
  - Form **fallacious certainties** to recognition of **uncertainty**;
  - From deterministic approaches to **stochastics.**
- Hydrological experience in complex systems and contribution in stochastics justifies and qualifies a more active role of hydrologists in climate research.

# References


- Ad Hoc Panel on Hydrology, *Scientific Hydrology*, U.S. Federal Council for Science and Technology, Washington, D.C., 37 pp., 1962.
- Alley, R.B, The Younger Dryas cold interval as viewed from central Greenland, *Quaternary Science Reviews*, 19, 213-226. 2000.
- Alley, R.B., GISP2 Ice Core Temperature and Accumulation Data, IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2004-013, NOAA/NGDC Paleoclimatology Program, Boulder CO, USA, 2004.
- Barriendos, M., and F.S. Rodrigo, Study of historical flood events on Spanish rivers using documentary data, *Hydrological Sciences Journal*, 51(5), 765-783, 2006.
- Brázdil, P., Z.W. Kundzewicz and G. Benito, Historical hydrology for studying flood risk in Europe, *Hydrological Sciences Journal*,51(5), 739-764, 2006.
- Cyberski, J., M. Grześ, M. Gutry-Korycka, E. Nachlik and Z.W. Kundzewicz, History of floods on the River Vistula, *Hydrological Sciences Journal*, 51(5), 799-817, 2006.
- Cohn, T.A., and H.F. Lins, Nature's style: Naturally trendy, Geophysical Research Letters, 32(23), art. no. L23402, 2005.
- Dingman, S. L., Physical Hydrology, Prentice Hall, Englewood Cliffs, New Jersey, 1994.
- Gore, A., *An Inconvenient Truth*, Melcher Media, New York, 2006.
- Hurst, H.E., Long term storage capacities of reservoirs. *Trans. Am. Soc. Civil Engrs*, 116, 776–808, 1951 (Published in April 1950 as Proceedings Separate No. 11).
- IPCC (Intergovernmental Panel on Climate Change), Summary for Policymakers, In: *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report (AR4) of the IPCC (ed. by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller), Cambridge University Press, Cambridge, UK, 2007.
- Kolmogorov, A.N., Wienersche Spiralen und einige andere interessante Kurven in Hilbertschen Raum, *Dokl. Akad. Nauk URSS*, 26, 115–118, 1940.
- Koutsoyiannis, D., and T.A. Cohn, The Hurst phenomenon and climate, *European Geosciences Union General Assembly 2008, Geophysical Research Abstracts, Vol. 10*, Vienna, 11804, European Geosciences Union, 2008 (http://www.itia.ntua.gr/en/docinfo/849).
- Koutsoyiannis, D., and A. Montanari, Statistical analysis of hydroclimatic time series: Uncertainty and insights, *Water Resources Research*, 43 (5), W05429.1–9, 2007.
- Koutsoyiannis, D., A. Efstratiadis, and K. Georgakakos, Uncertainty assessment of future hydroclimatic predictions: A comparison of probabilistic and scenario-based approaches, *Journal of Hydrometeorology*, 8 (3), 261–281, 2007.
- Koutsoyiannis, D., A. Efstratiadis, N. Mamassis, and A. Christofides, On the credibility of climate predictions, *Hydrological Sciences Journal*, 53 (4), 671–684, 2008.
- Mehta, A., North Pole may be ice-free for first time this summer, National Geographic News, June 20, 2008 (http://news.nationalgeographic.com/news/2008/06/080620-north-pole.html).
- Moberg, A., D.M. Sonechkin, K. Holmgren, N.M. Datsenko, and W. Karlen, Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data, *Nature*, 433(7026), 613-617, 2005.
- Ren, F., G. Wu, W. Dong, X. Wang, Y. Wang, W. Ai, and W. Li, Changes in tropical cyclone precipitation over China, *Geophys. Res. Lett.*, 33, L20702, doi:10.1029/2006GL027951, 2006.
- Soon, W., Implications of the secondary role of carbon dioxide and methane forcing in climate change: past, present, and future. *Phys. Geogr.* **28**(2), 97–125, 2007.
- US Committee on Opportunities in the Hydrological Sciences, *Opportunities in the Hydrological Sciences*, edited by P. S. Eagleson, National Academy Press, Washington, D.C., 348 pp., 1992.
- US NRC (National Research Council), Radiative forcing of climate change: expanding the concept and addressing uncertainties. Committee on Radiative Forcing Effects on Climate Change, Climate Research Committee, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, The National Academies Press, Washington DC, USA, 2005.
- von Collani, E., 2005 - The Jakob Bernoulli Year, 350th Anniversary of Jakob's Birth and 300th Anniversary of Jakob's Death. Economic Quality Control 20, 155-169, 2005 (http://www.rcsd.org.cn/FCKeditor/userimages/rcsd-20051216011028.pdf).
- von Collani, E., Jacob Bernoulli Deciphered, Bernoulli News, 13 (2), 2006 (http://isi.cbs.nl/Bnews/06b/index.html).