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European Water
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10th WORLD CONGRESS on Water Resources and Environment
“Panta Rhei”

‘Panta Rhei’ and its relationship with uncertainty

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Presentation available online: http://itia.ntua.gr/1724/

‘Panta Rhei’ in Water Resources and Environment

‘Panta Rhei’ in Hydrology: The scientific decade of IAHS 2013-2022

IAHS AISH

Panta Rhei
Everything Flows
Change in Hydrology and Society

PANTA RHEI LIBRARY

PANTA RHEI

CHANGE IN HYDROLOGY AND SOCIETY

The new scientific decade 2013–2022 of IAHS, entitled “Panta Rhei – Everything Flows”, is dedicated to research activities on change in hydrology and society. The purpose of Panta Rhei is to reach an improved interpretation of the processes governing the water cycle by focusing on their changing dynamics in connection with rapidly changing human systems. Panta Rhei is presented by Montanari et al., Panta Rhei—Everything Flows”:Change in hydrology and society—The IAHS Scientific Decade 2013–2022, Hydrological Sciences Journal, 58:6, 1256-1275, DOI:10.1080/02626667.2013.809088. The practical aim is to improve our capability to make predictions of water resources dynamics to support sustainable societal development in a changing environment. The concept implies a focus on hydrological systems as a changing interface between environment and society, whose dynamics are essential to determine water security, human safety and development, and to set priorities for environmental management. The Scientific Decade 2013–2022 will devise innovative theoretical blueprints for the representation of processes including change and will focus on advanced monitoring and data analysis techniques. Interdisciplinarity will be sought by increased efforts to bridge with the socio–economic sciences and geosciences in general.

Concepts of Panta Rhei

http://iahs.info/Commissions--W-Groups/Working-Groups/Panta-Rhei.do

‘Panta Rhei’: © Heraclitus
Change and randomness

Πάντα ῥεῖ
Everything flows
(Heraclitus; quoted in Plato’s Cratylus, 339-340)

Αἰών παῖς ἐστι παίζων πεσσεύων
Time is a child playing, throwing dice
(Heraclitus; Fragment 52)

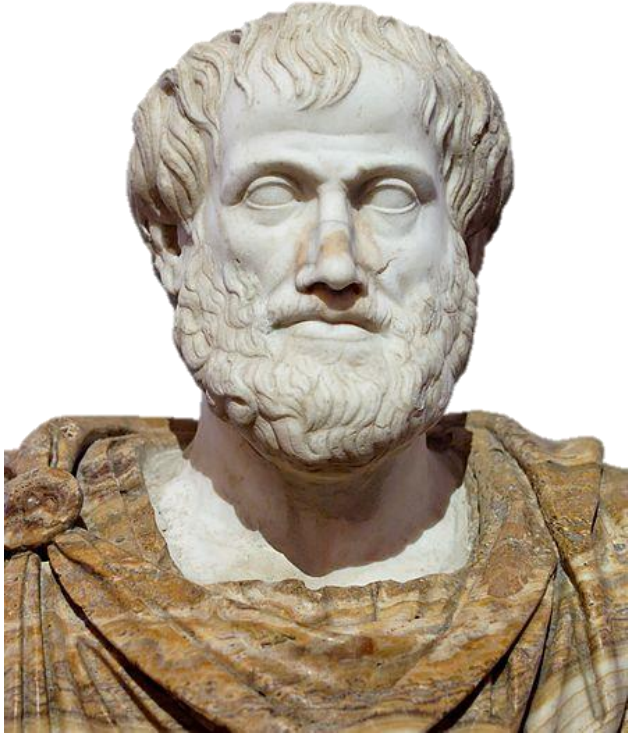
Heraclitus
ca. 540-480 BC

Change, logic, precision: © Aristotle

Μεταβάλλει τῷ χρόνῳ πάντα
All is changing in the course of time
(Aristotle; Meteorologica, I.14, 353a 16)

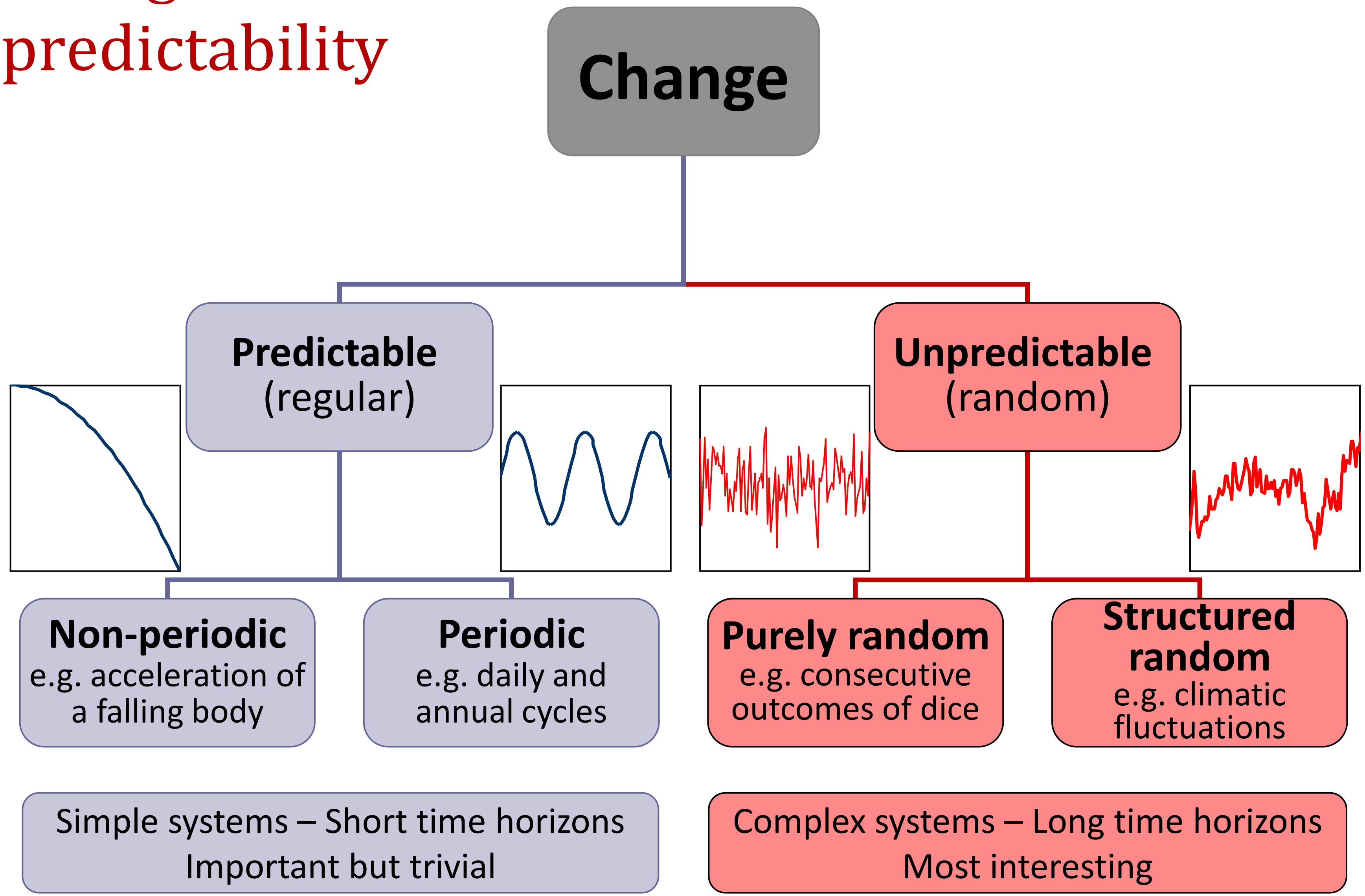
Λογική, συλλογισμός, επαγωγή
Logic, deduction, induction
(Aristotle, Organon)

…τοσοῦτον τἀκριβὲς ἐπιζητεῖν καθ᾽ ἕκαστον γένος, ἐφ᾽ ὅσον ἡ τοῦ πράγματος φύσις ἐπιδέχεται
… look for precision in each class of things just so far as the nature of the subject admits
(Aristotle, Nicomachean Ethics 1094b)



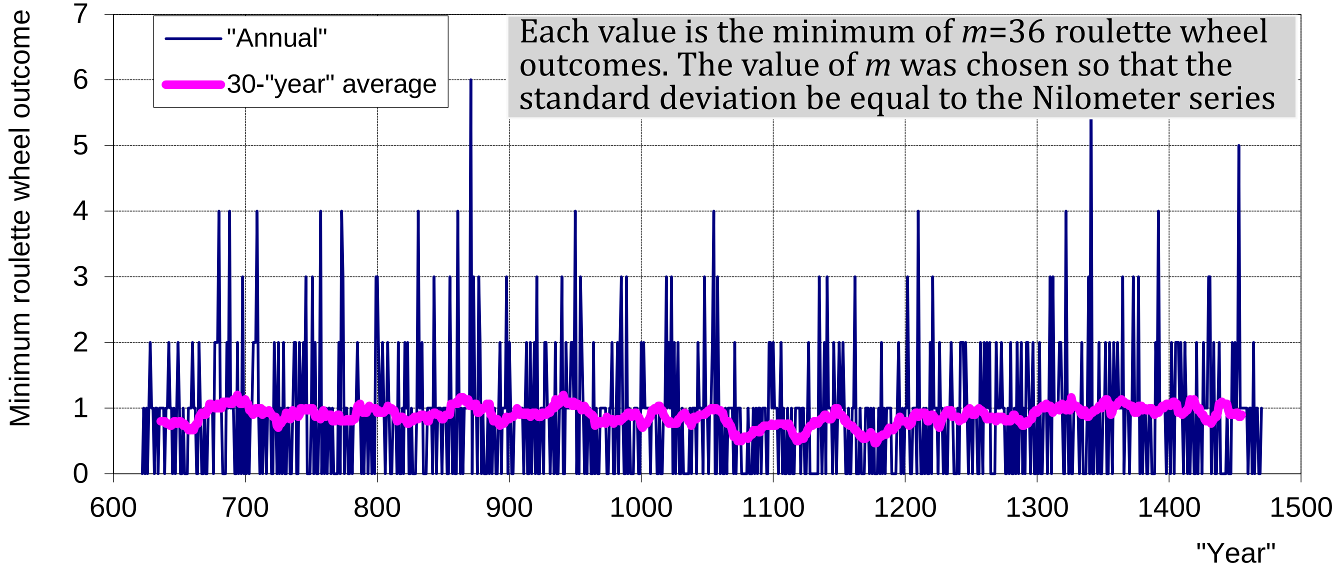
Aristotle
384 – 322 BC
(wikipedia)

Change and predictability

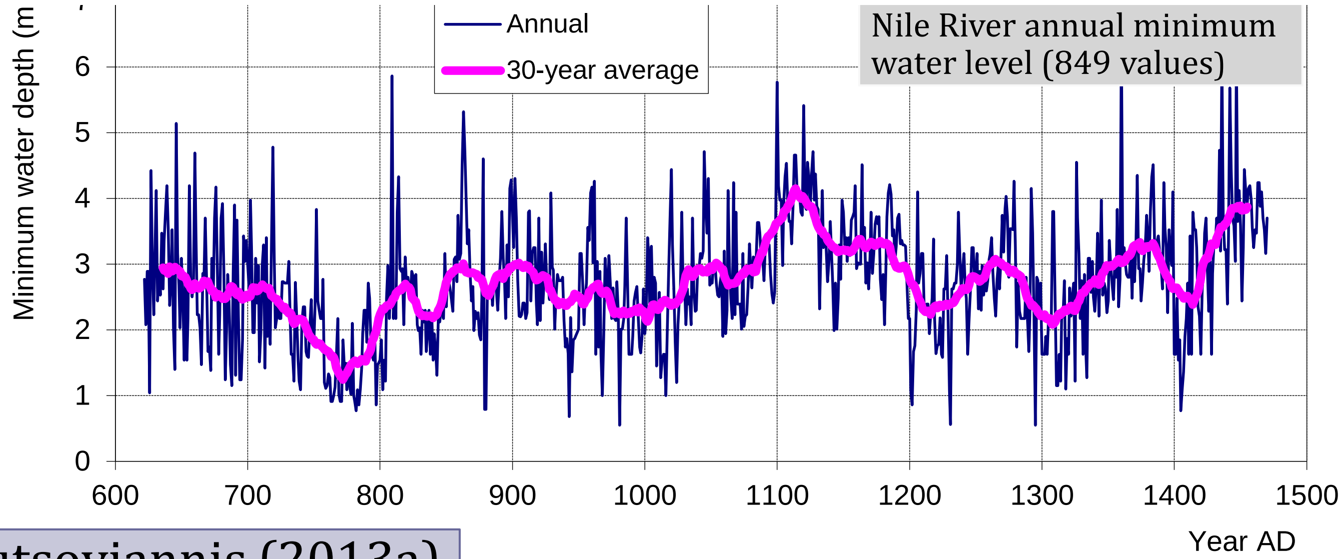


Perpetual change as seen in the Nilometer record

Purely random



Structured random



Nilometer data: Koutsoyiannis (2013a)

Change, stationarity and nonstationarity

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of w throughout the developed world l been designed and operated unde assumption of stationarity. Stationarity– idea that natural systems fluctuate withi unchanging envelope of variability– foundational concept that permeates trai and practice in water-resource engineerir implies that any variable (e.g., annual stre flow or annual flood peak) has a time-in ant (or 1-year–periodic) probability der function (pdf), whose properties can be mated from the instrument record. Under tionarity, pdf estimation errors are ackn edged, but have been assumed to be redu by additional observations, more effic estimators, or regional or paleohydrol data. The pdfs, in turn, are used to eval and manage risks to water supplies, w works, and floodplains; annual global invest-

recently demonstrated retrodictive skill of cli-

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

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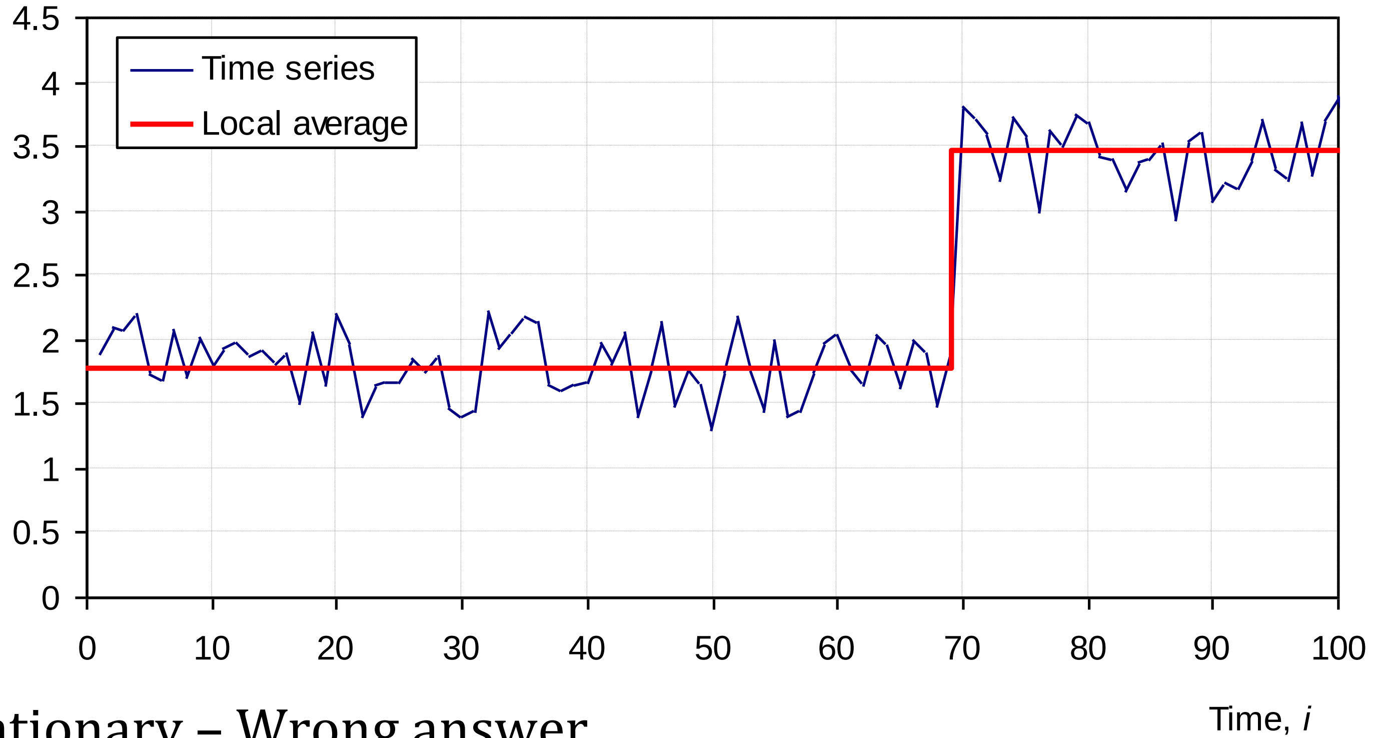
Abstract In scientific vocabulary, the term "process" is used to denote change in time. Even a stationary process describes a system changing in time, rather than a static one that keeps a constant state all the time. However, this is often missed, which has led to misuse of the term "nonstationarity" as a synonym of "change". A simple rule to avoid such misuse is to answer the question: can the change be predicted in deterministic terms? Only if the

Is this time series stationary or nonstationary?



- Answer 1: Stationary – Wrong answer
- Answer 2: Nonstationary – Wrong answer
- Answer 3: The question is wrong – Right answer

A time series cannot be stationary nor nonstationary.
These are properties of the process that generated the time series.
This series was generated by a stationary process (Koutsoyiannis, 2011).

Process, stochastic process, stationarity: © Kolmogorov

Andrey Kolmogorov (1903 –1987)

- Kolmogorov (1931)
  - clarified that the term *process* means *change of a certain system*;
  - introduced the term *stochastic process*;
  - used the term *stationary* to describe a process in probabilistic terms.
- Kolmogorov (1938) clarified:

  a *stationary stochastic process* [...] is a set of random variables x_t depending on the parameter t, $-\infty < t < +\infty$, such that the distributions of the systems

  $$(x_{t_1}, x_{t_2}, \ldots, x_{t_n}) \text{ and } (x_{t_1+\tau}, x_{t_2+\tau}, \ldots, x_{t_n+\tau})$$

  coincide for any n, t_1, t_2, … , t_n, and τ.
- Note: *nonstationary* processes are those whose statistical properties change in time in a **deterministic** manner.

The cause of change: © Peter Atkins

ENTROPY

THE SPRING OF CHANGE

THE GREAT IDEA

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

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

C. P. SNOW

Atkins, 2004

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

Atkins, 2007

Entropy ≡ Uncertainty quantified

- Historically entropy was introduced in thermodynamics but later it was given a rigorous definition within probability theory (owing to Boltzmann, Gibbs and Shannon).
- Thermodynamic and probabilistic entropy are essentially the same thing (Koutsoyiannis, 1010, 2013b, 2014; but others have different opinion).
- Entropy acquires its importance from the **principle of maximum entropy** (Jaynes, 1957), which postulates that the entropy of a random variable should be at maximum, under the conditions (constraints) which incorporate the available information about this variable.
- The tendency of entropy to become maximal explains a spectrum of phenomena from the random outcomes of dice to the 2nd Law of thermodynamics as the driving force of natural change.
- Entropy is a dimensionless measure of uncertainty:

Discrete random variable $\underline{z}$	Continuous random variable $\underline{z}$
$\Phi[\underline{z}] := \mathrm{E}[-\ln P(\underline{z})] = \sum_{j=1}^{W} P_j \ln P_j$ where $P_j := P\{\underline{z} = z_j\}$ (probability)	$\Phi[\underline{z}] := \left[-\ln \frac{f(\underline{z})}{h(\underline{z})}\right] = -\int_{-\infty}^{\infty} \ln \frac{f(z)}{h(z)} f(z) \mathrm{d}z$ where $f(z)$ is probability density and $h(\mathrm{z})$ is the density of a background measure

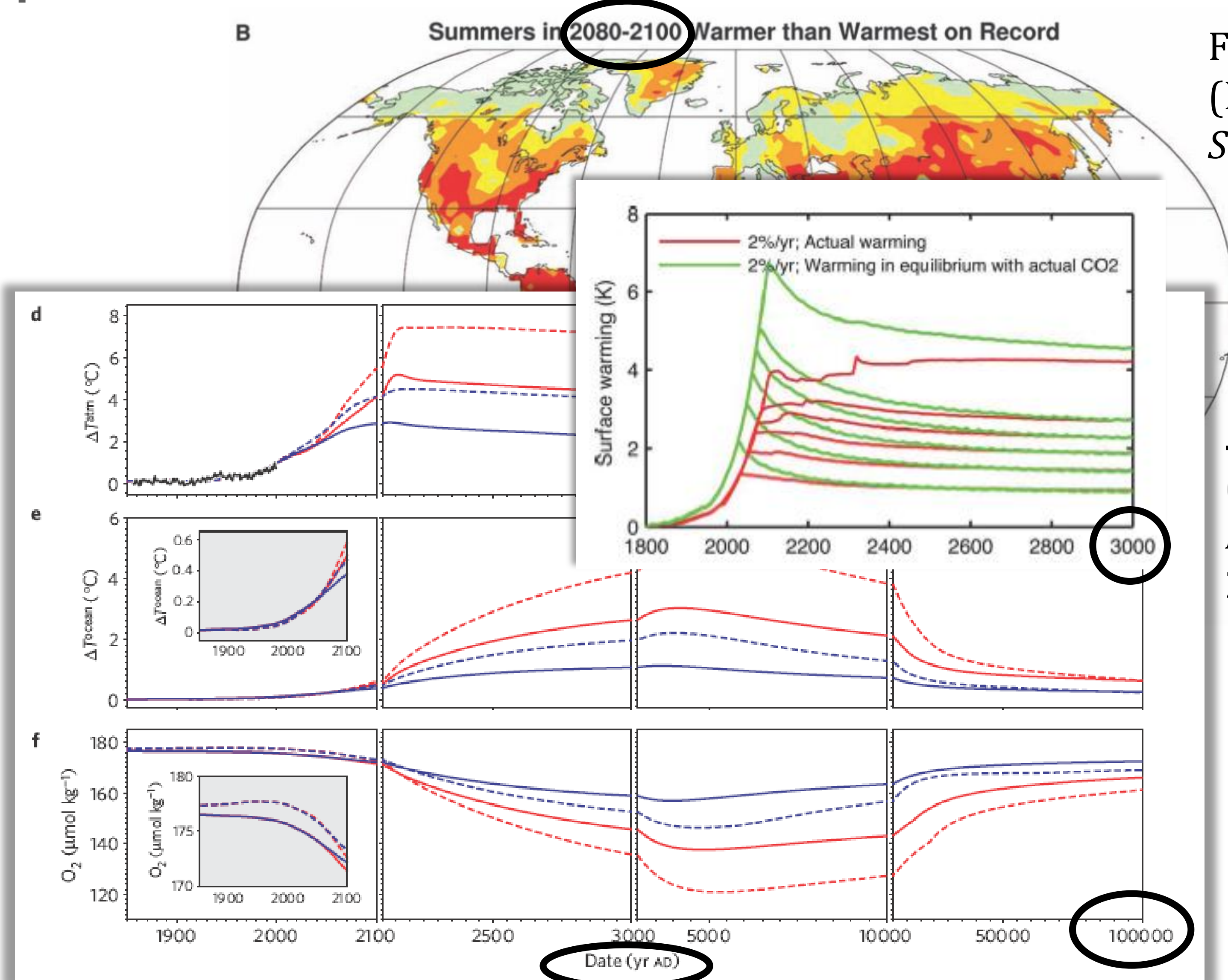
"It is difficult to make predictions, especially about the future": © Anonymous (Danish proverb, not Niels Bohr/Mark Twain)

[DK addition: but it is easy to laugh at predictions]

- **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, 30 years from now, the entire world, with the exception of W. Europe, N. 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).

Predictions about the future climate abound



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 and many other disciplines, typically without assessing their reliability. Here we compare the output of various mo
long (over 100 years) records fro
climatic (30-year) scale. Thus loc
models can perform better at larg

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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] & N. Mamassis[1]

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

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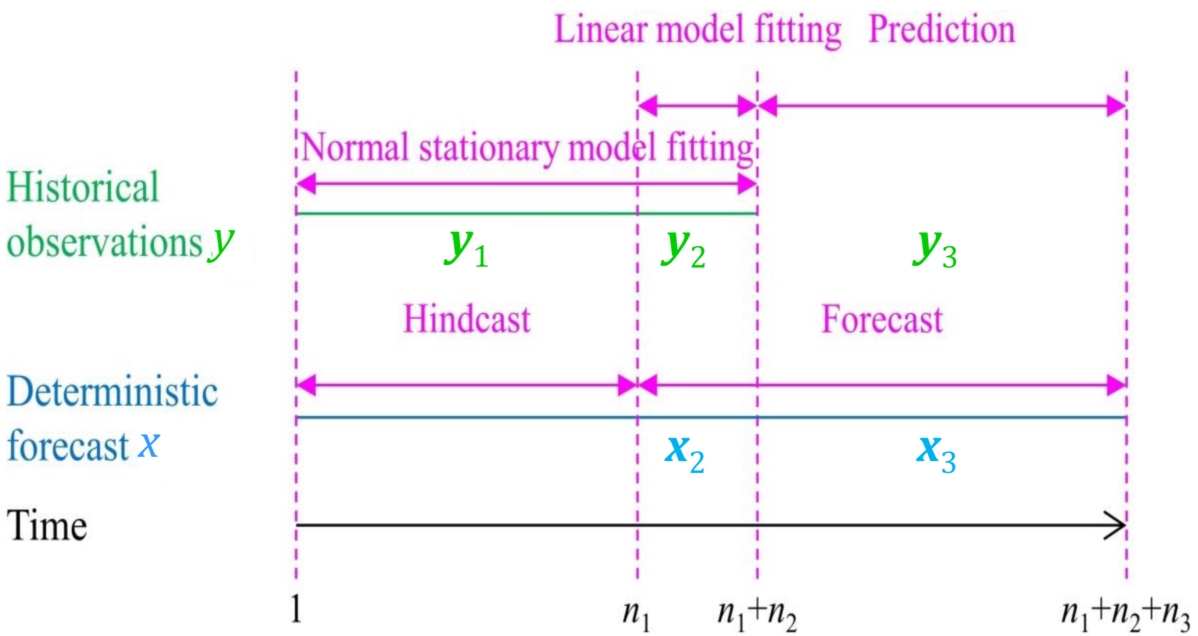
Abstract We compare the output of various climate models to temperature and precipitation observations at 55 points around the globe. We also spatially aggregate model output and observations over the contiguous USA using data from 70 stations, and we perform comparison at several temporal scales, including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

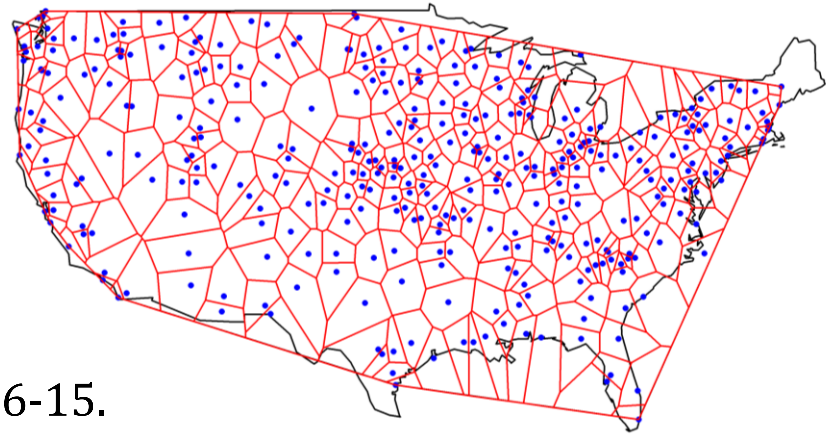
Answer: They are mostly irrelevant to reality; see details in Koutsoyiannis et al. (2008, 2011), Anagnostopoulos et al. (2010), Tsaknias et al. (2017).

Can we convert deterministic predictions into stochastic?

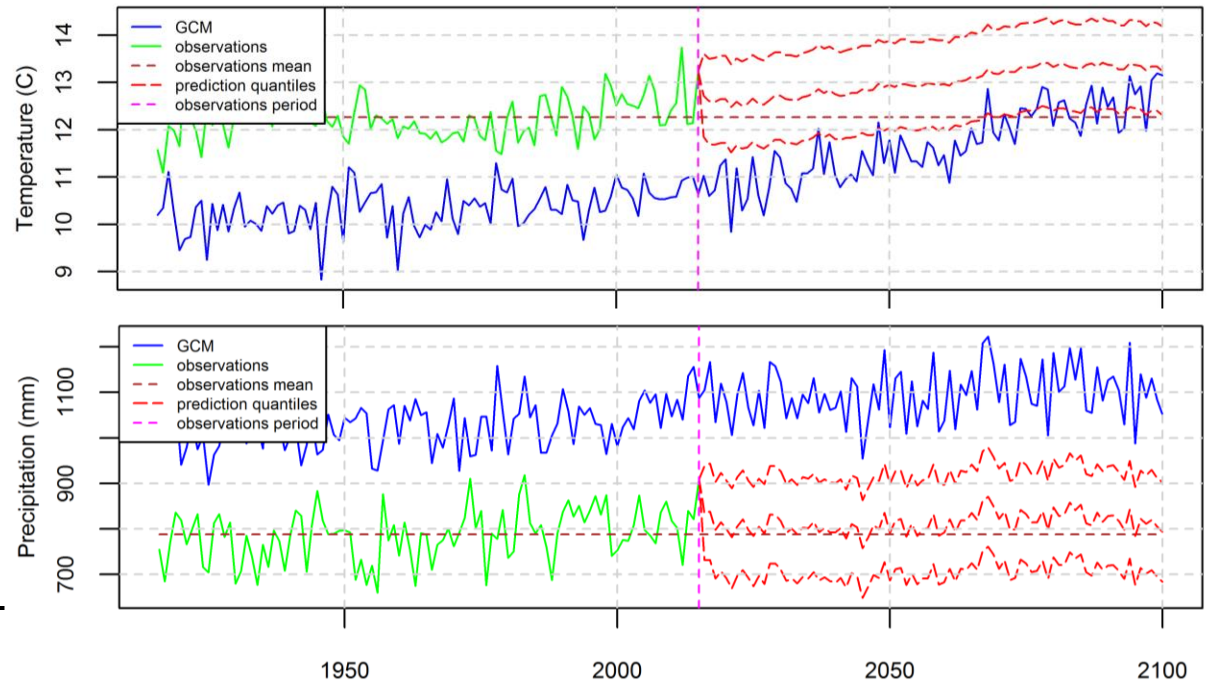
- Yes—we can and we should.
- Method 1: By perturbing input data, parameters and model output (the latter by adding random outcomes from the population of the model error): see the blueprint by Montanari and Koutsoyiannis (2012).
- Method 2: By incorporating one or many deterministic forecasts into an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

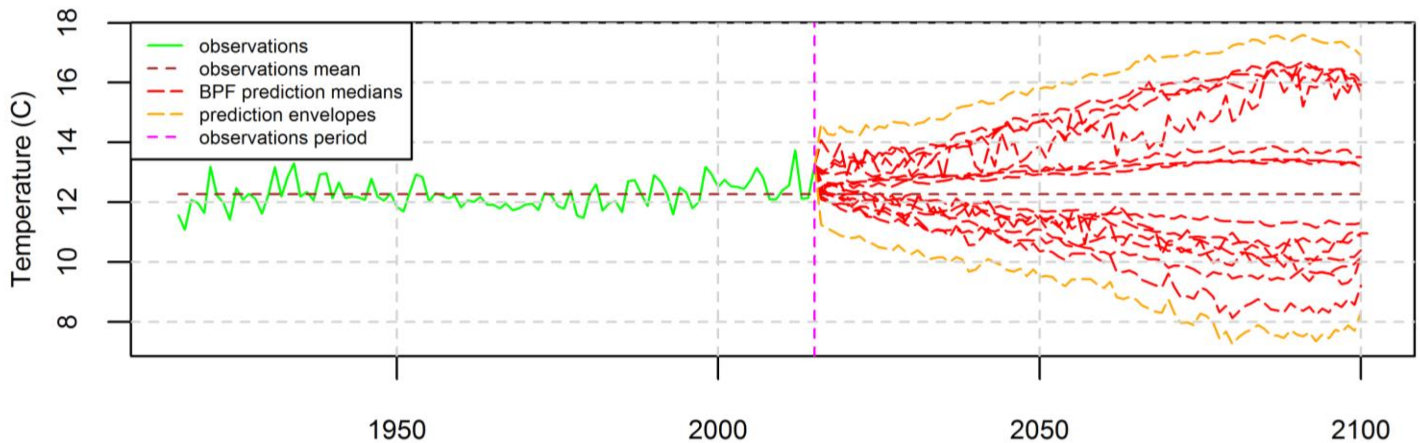


- Historical data for temperature and precipitation from 362 and 319 stations, respectively, have been used to estimate the areal averages (historical observations).
- Deterministic forecasts were taken from 14 different climate models. The model likelihood was evaluated in the period 2006-15.
- The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



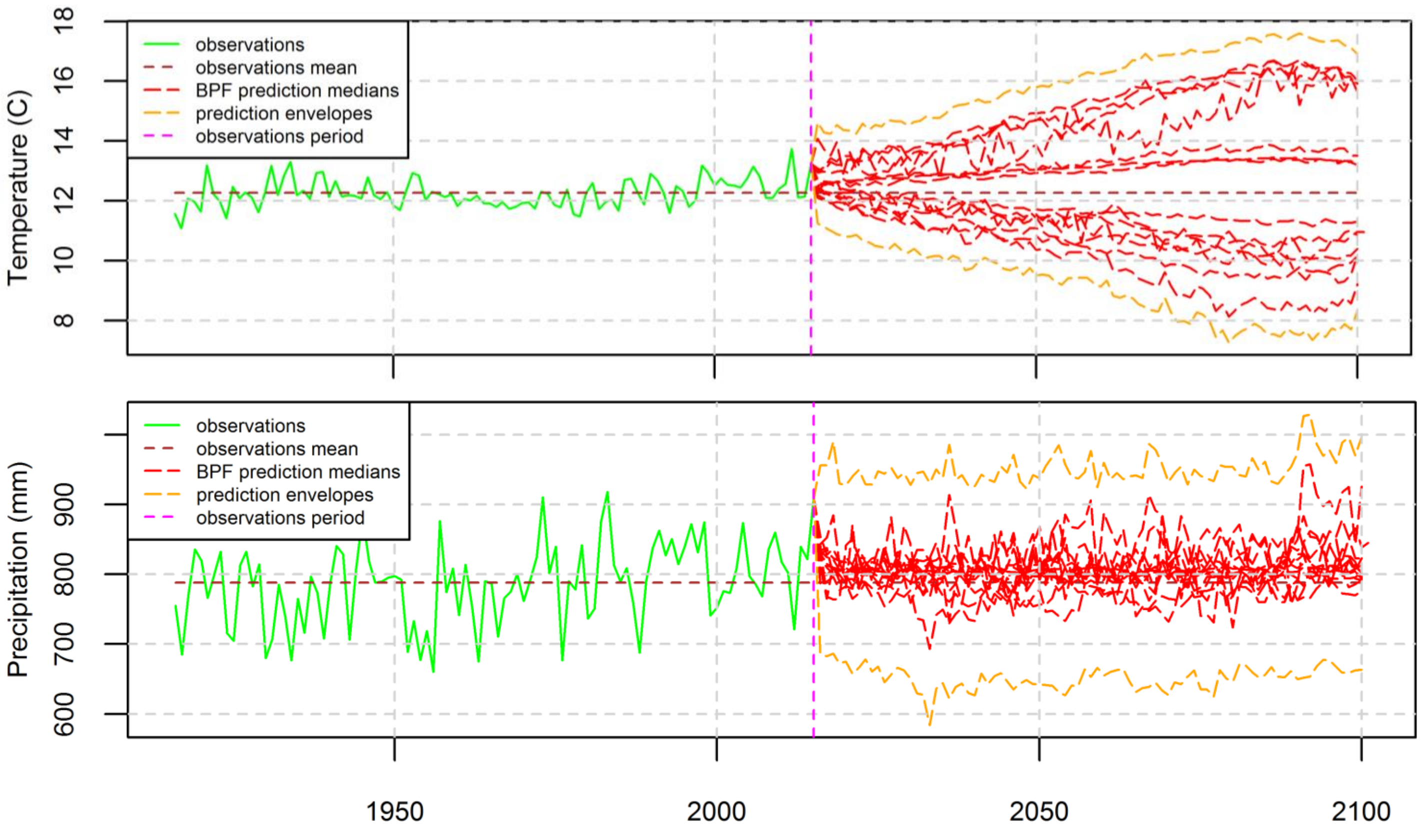
Multimodel approach: **The Bayesian Thistle**

- 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 conditioning on models).



Concluding remarks

- **Πάντα ῥεῖ** (or: Change is Nature's style).
- Change occurs at **all time scales**.
- A **process** is synonymous to **change**—even a stationarity process means change.
- Nonstationarity should not be confused with change, nor with dependence of a process in time.
- Change and uncertainty are **tightly connected** through (maximized) entropy.
- Change and uncertainty are **inevitable**.
- **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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