Prof. Dr. Ir. Henri A. MASSON

Analysis of complex systems and associated signals (time series)

Bijeenkomst over oorzaken van klimaatverandering
8 december 2012
Planetarium Museum/Johannes Post School
Rijksstraatweg 101, 2988 BB Ridderkerk–Rijsoord

Scope

- Limitation of linear analysis
- Some usual signal patterns and their signature
- An example of chaotic signals
- Advanced non linear signal analysis
- The Earth Climate case: analysis of temperature time series
- Predictability of Earth Climate

CLASSICAL ANALYSIS OF TIME SERIES & THEIR LIMITATIONS

Classical methods for time series analysis

- ***Moving average***

$$X_{t+1} = \frac{1}{n}\sum_{i=0}^{n-1} \omega_i X_{t-i}$$

- ***Exponential smoothing***

$$X_{t+1}^{*} \stackrel{\text{def}}{=} \alpha X_t + (1-\alpha)X_t^{*}$$

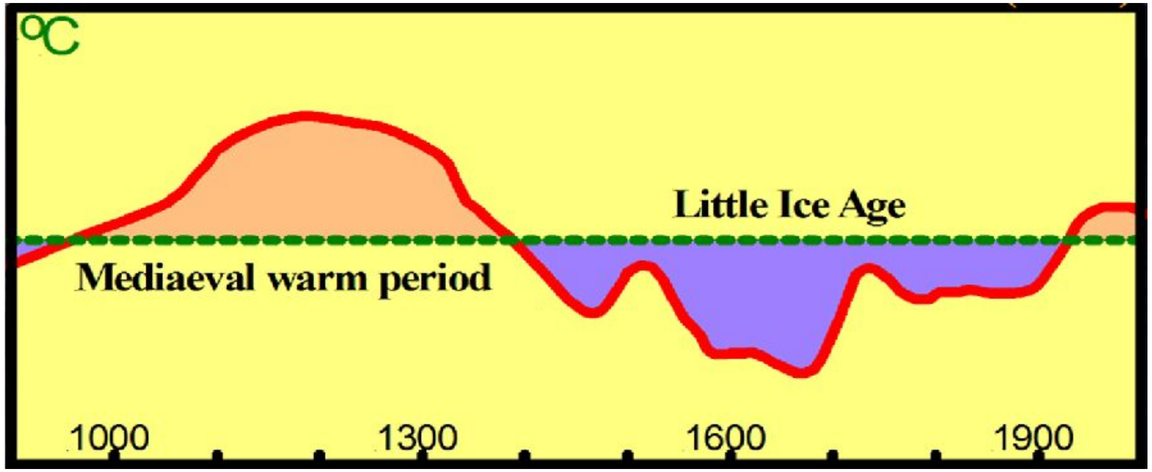
α is a tuning parameter $(0 \leq \alpha \leq 1)$
X_t^{*} is the predicted value of the indicator X at time t
X_t is the actual value observed for the indicator X at time t

- ***Regression (least squares)***
  - Linear
  - Polynomial
  - Exponnetial, logarithmic, hyperbolic, etc.

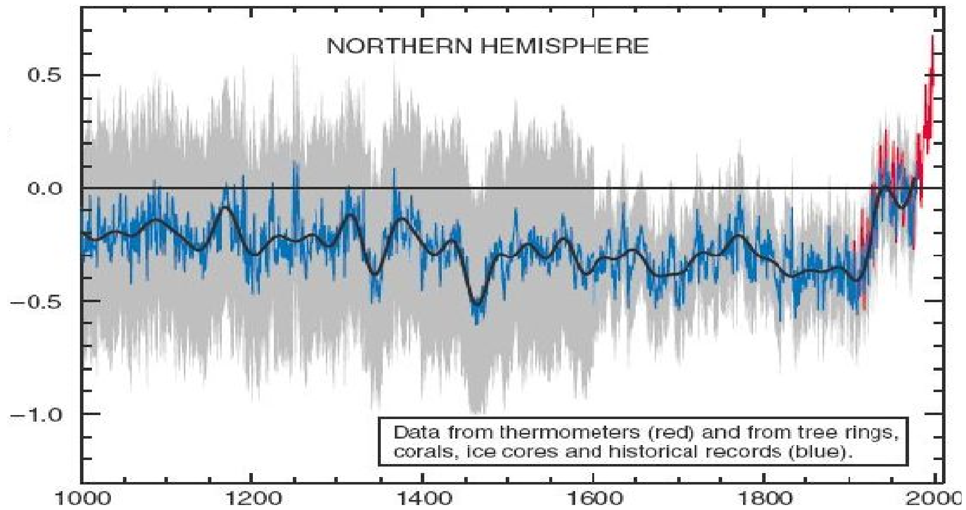
- ***Seasonal effects***

- **Factor analysis**
  - variable Z (normal « reduced »)
  - Co-variance matrix
  - Eigen values and vectors (diagonalisation)
  - Representation of reduced variables in this new axis system.
- **Hockey stick (Mann)**
  - Higher confidence in recent measurements made by thermometers than by proxies
  - Centering of variables on the mean value of most recent data only
  - **=> Error when calculating co-variance matrix (and eigen values + vectors)**
  - **=> bias** => hockey stick
  - Random data generate also a hockey stick when submitted to the same treatment.

Which data to believe??



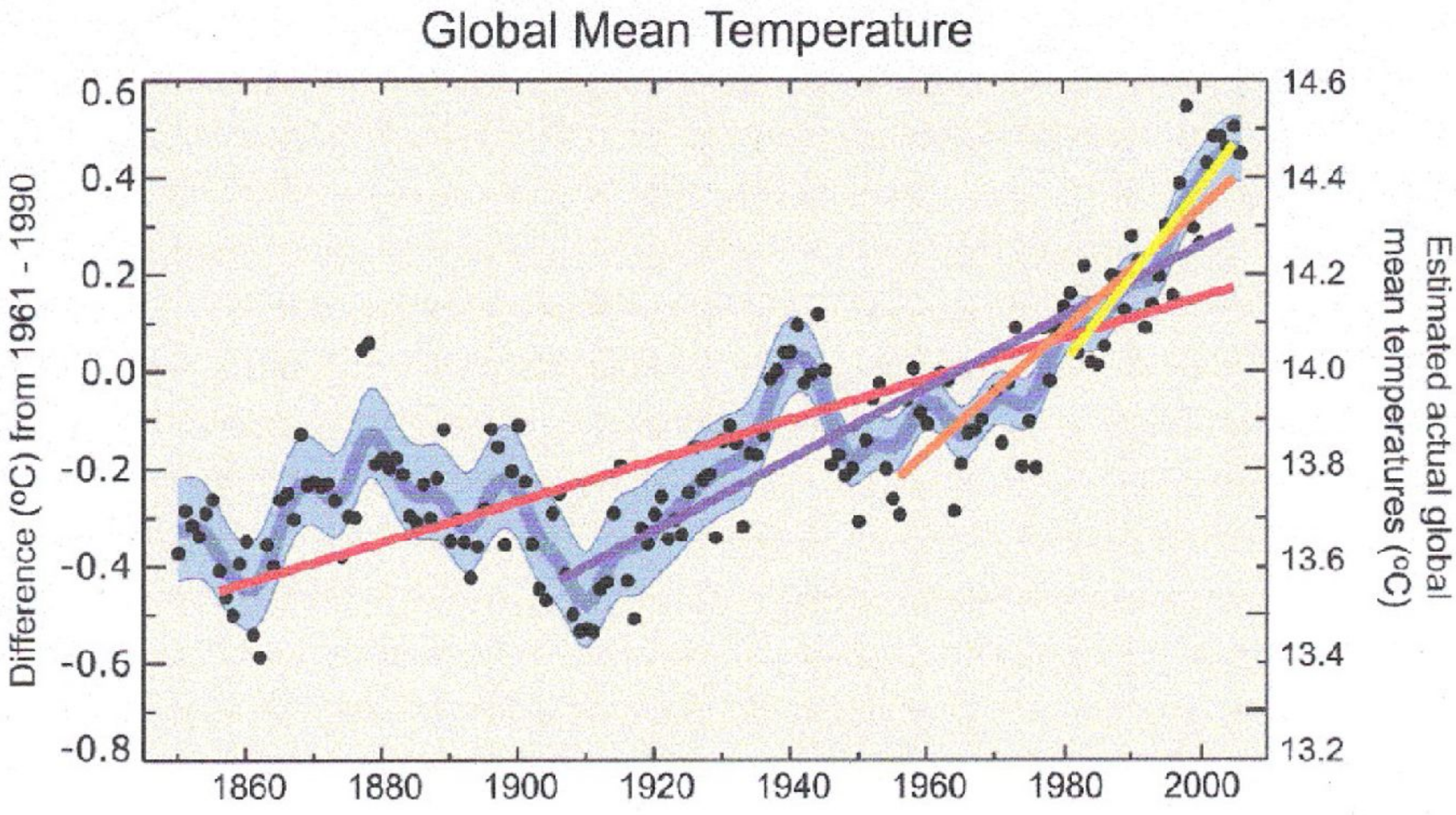
Original IPCC 1990 figure, confirmed by several recent experimental evidences (i.e; Bifra, 2009)



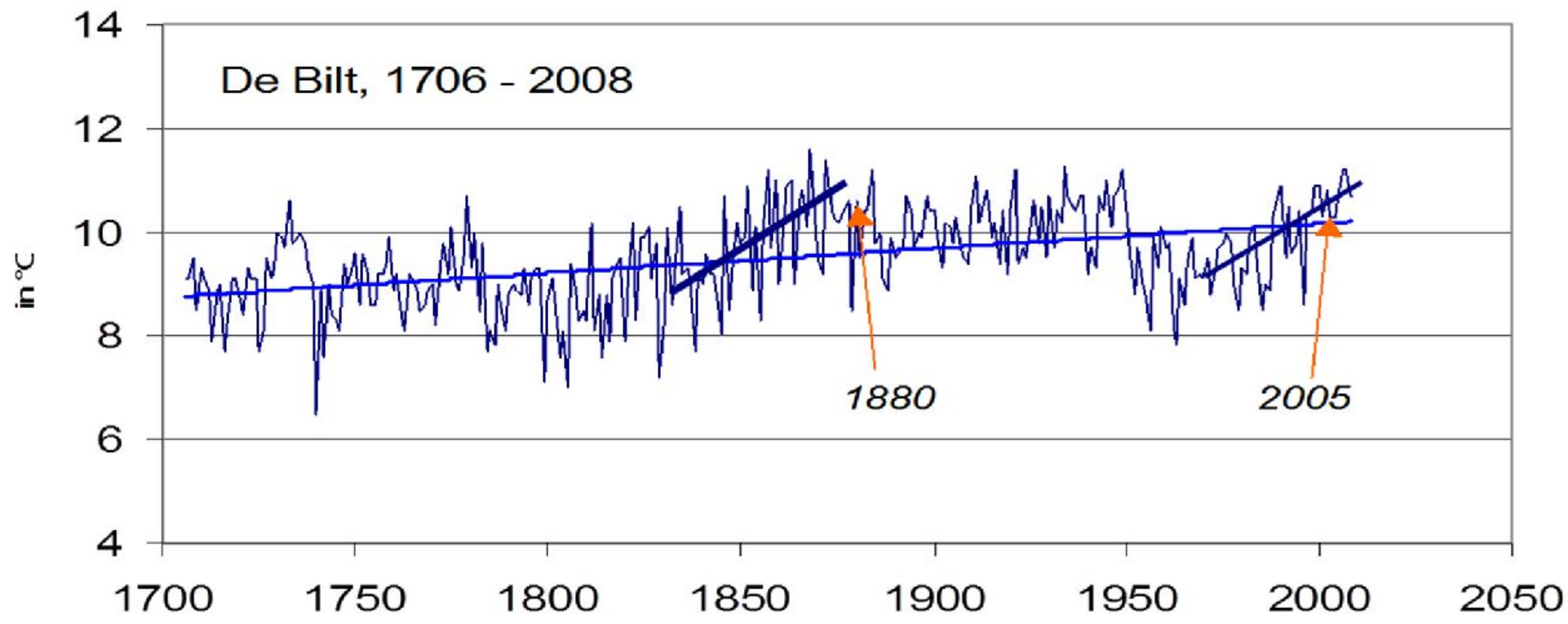
IPCC 2001 From M. Mann, the famous "hockey stick" curve!

IPCC 2007 & linear time series

Effect of the time window considered on the trend line

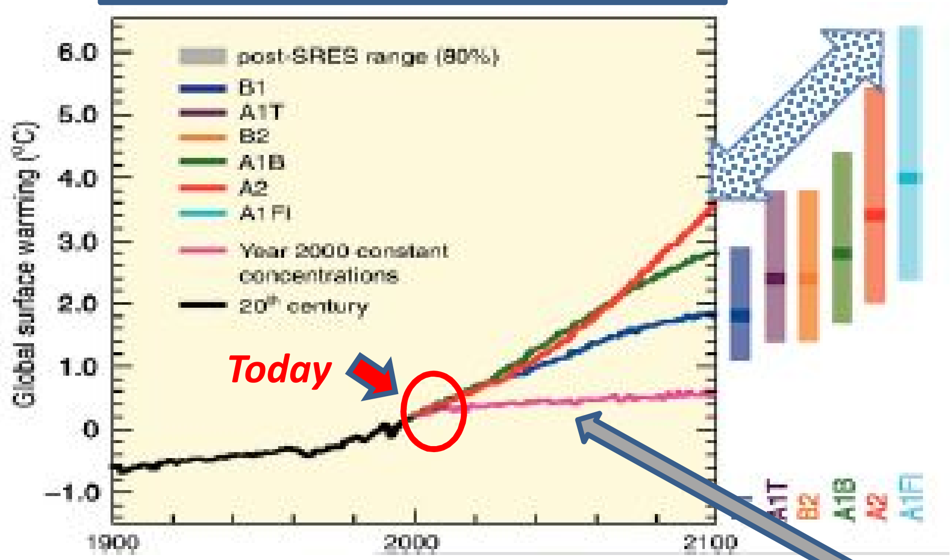


Is T° increasing faster those days than during early 19th century?



Evolution of the global temperature on Earth

IPCC MODELS PREDICTIONS



Key climate indicator for IPCC

Global temperature remains ***constant since 16 years*** **(***UK MET DBase Hadcrust 4, november 2012 update)*

Cannot be explained by IPCC models

(<u>Rem</u>: best fit so far: no increase in CO2 => no effect of CO2? => flaw in model?)

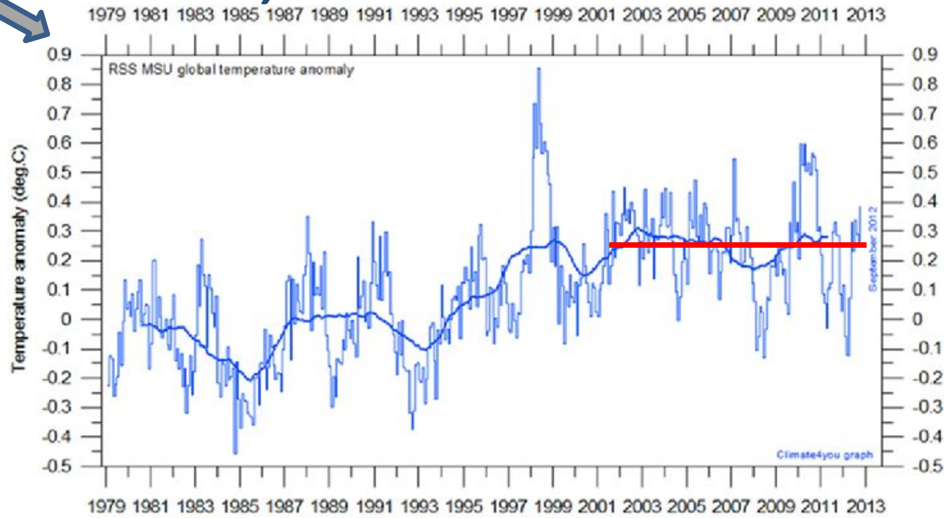
<u>IPCC approach</u>

Calibration over existing data (=> 1995)

After smoothing the data (by moving average) and eliminating « rogue points » (volcanoes eruptions, El Nino, etc.)

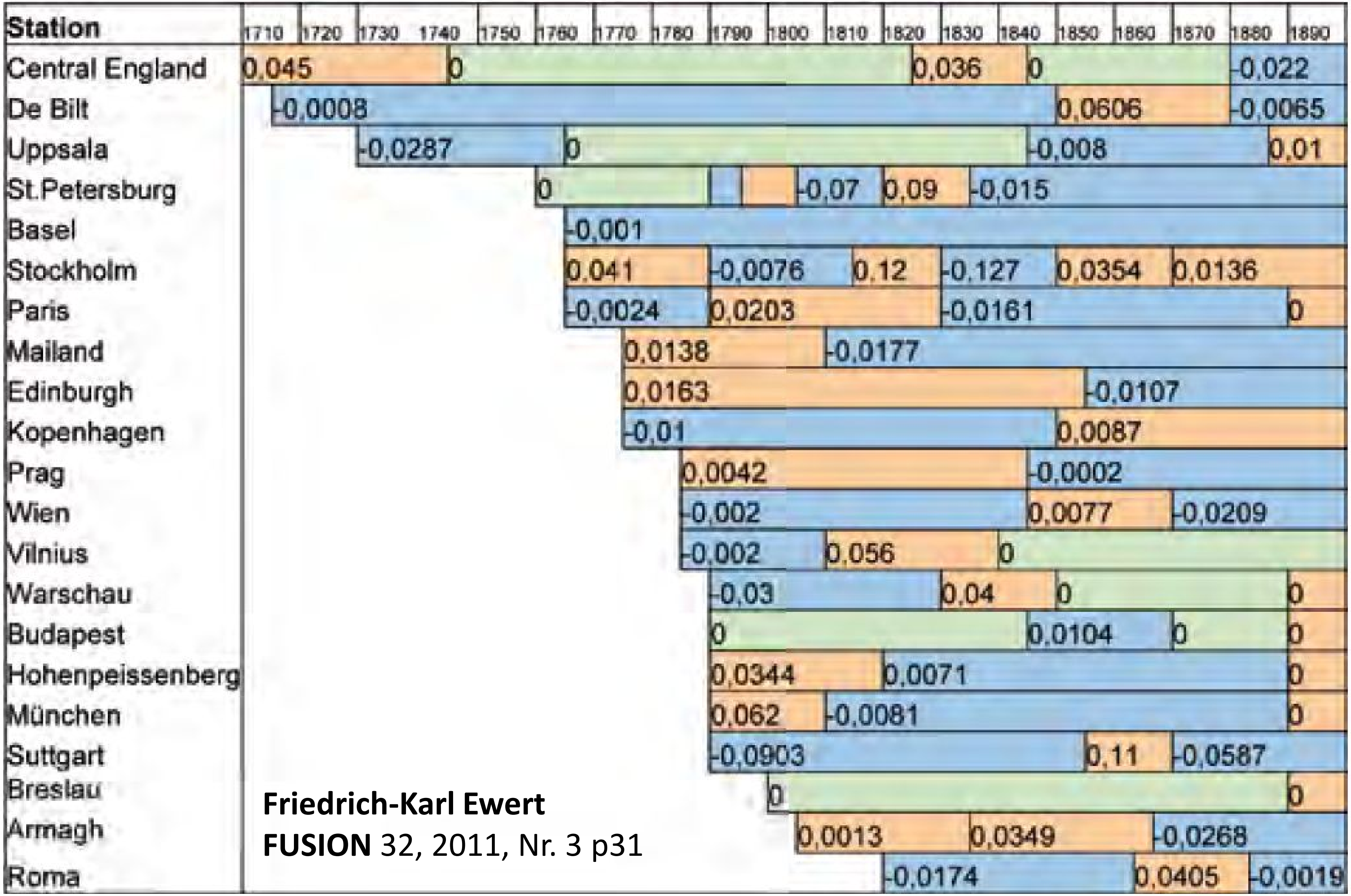
<u>But</u> periodic components are also eliminated.

What if natural cycles are significant?

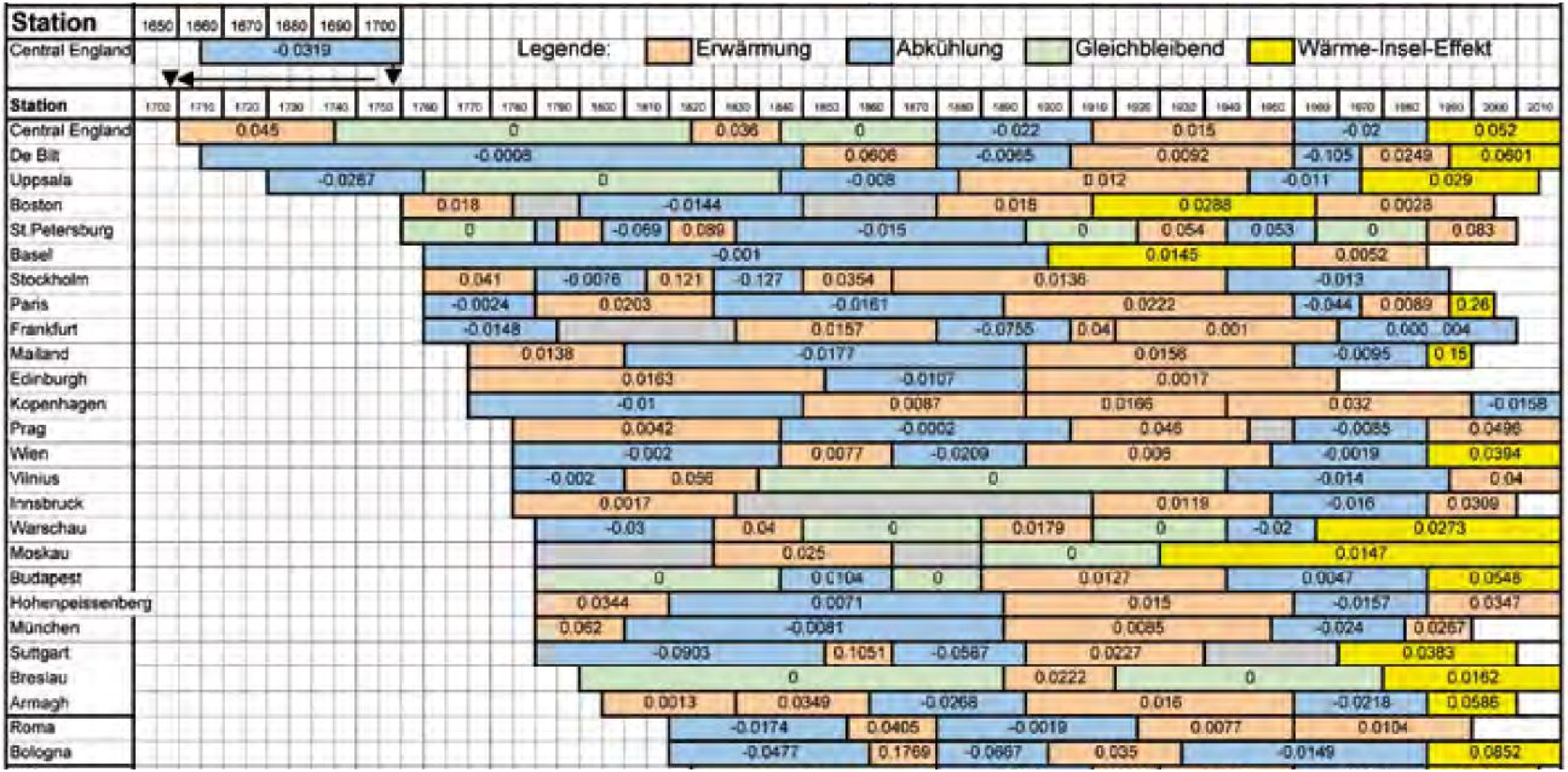


SOME EVIDENCES OF PERIODIC COMPONENTS IN CLIMATIC DATA

Oscillations in local temperature anomalies



Friedrich-Karl Ewert
FUSION 32, 2011, Nr. 3 p31


Station
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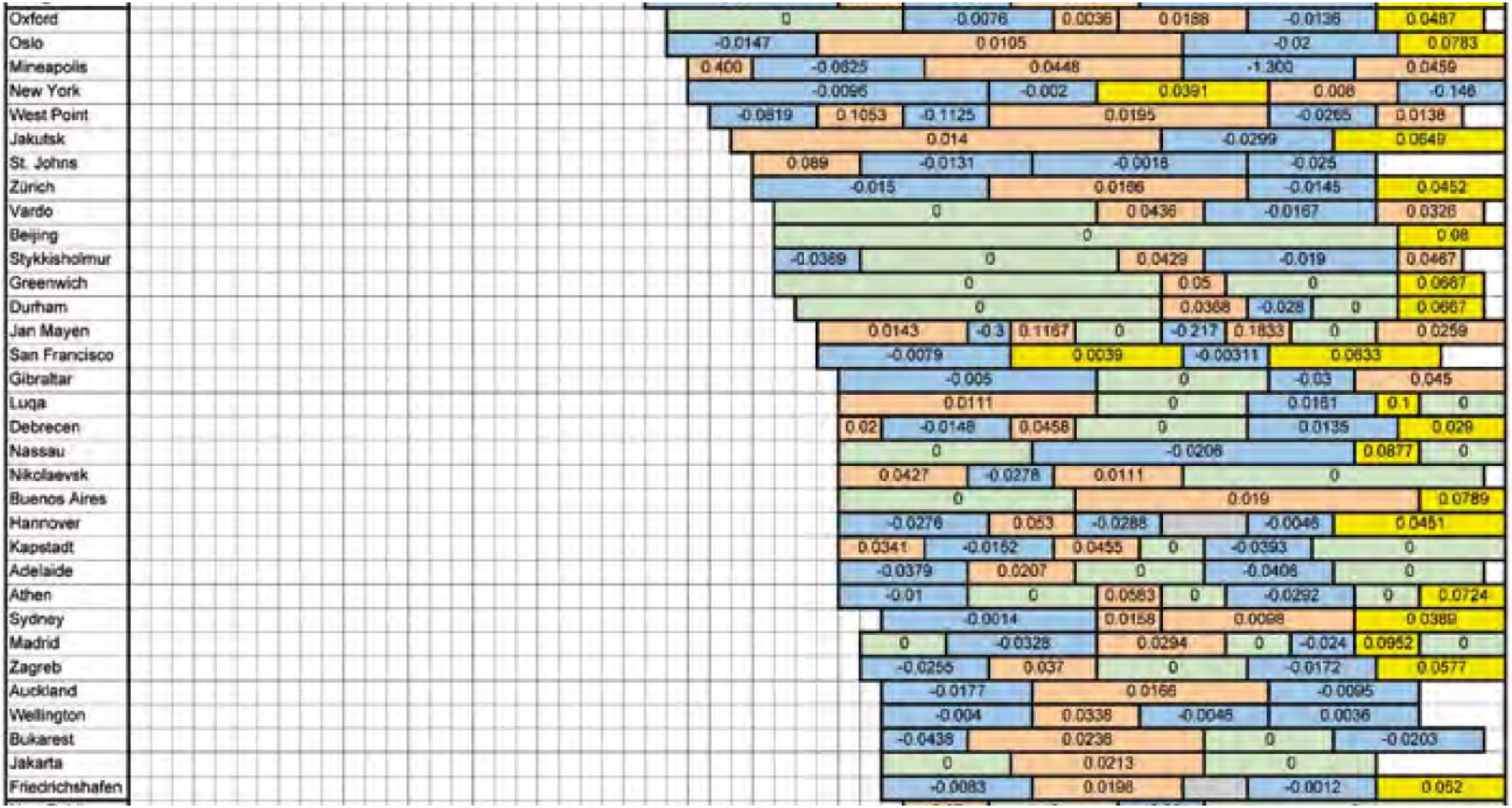

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New York
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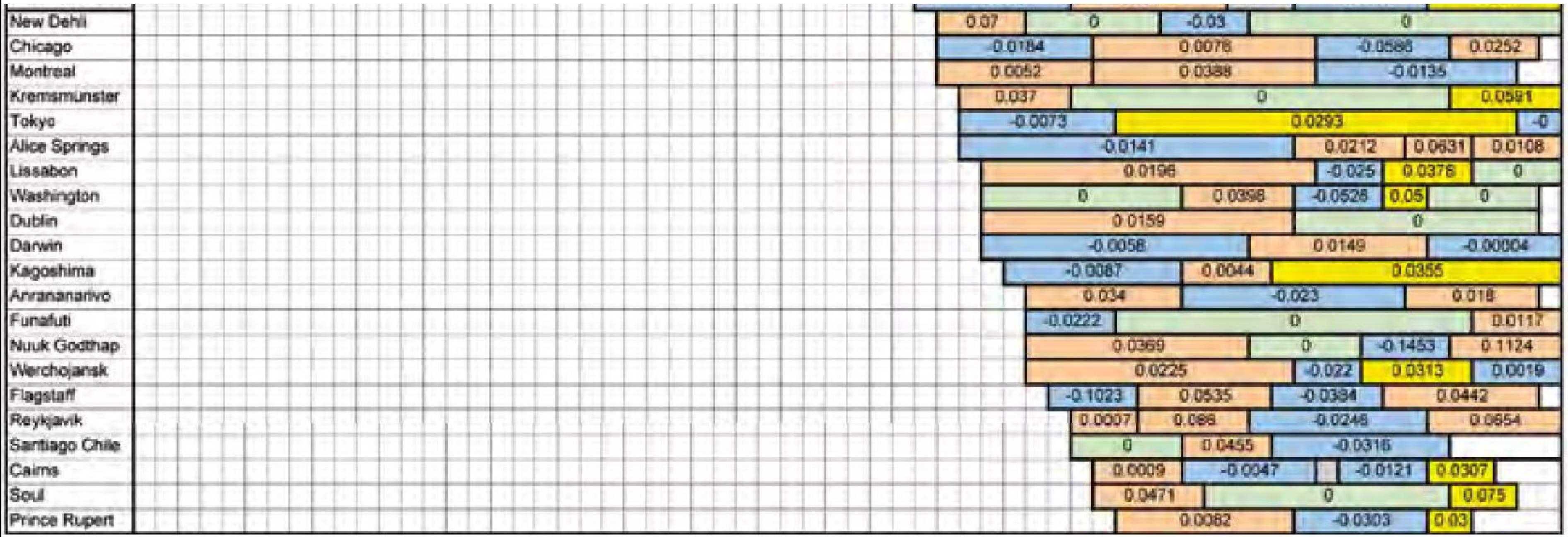
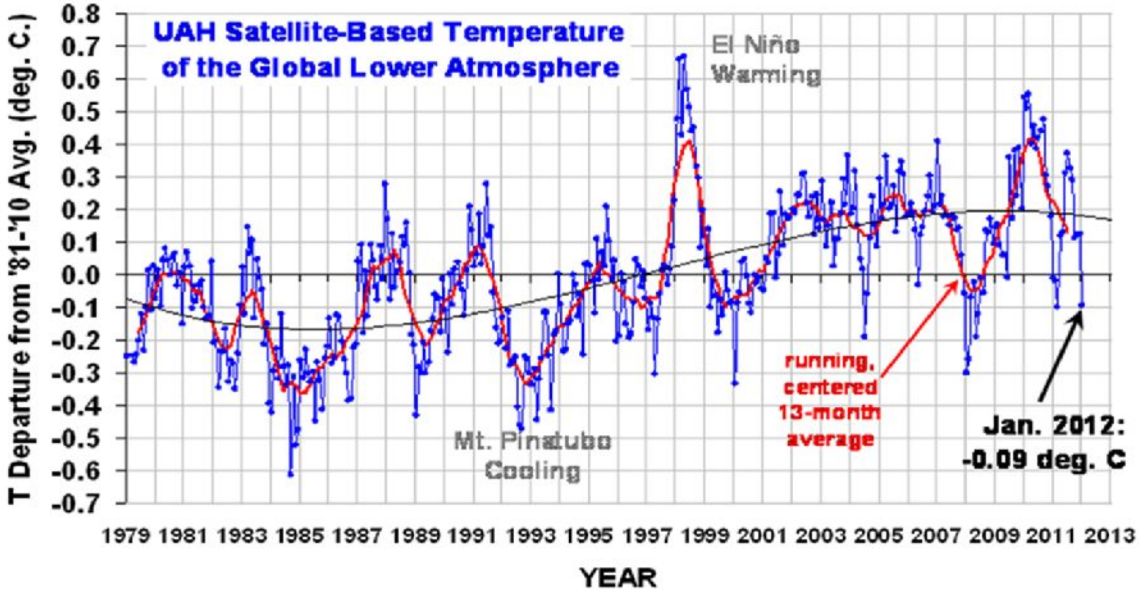


At every point around the world, temperature increases, stays stagnant, decreases for rather lng periods of time, in an *oscillating* but NOT *exactly periodic* way.

Global temperature anomalies measured from satellites.

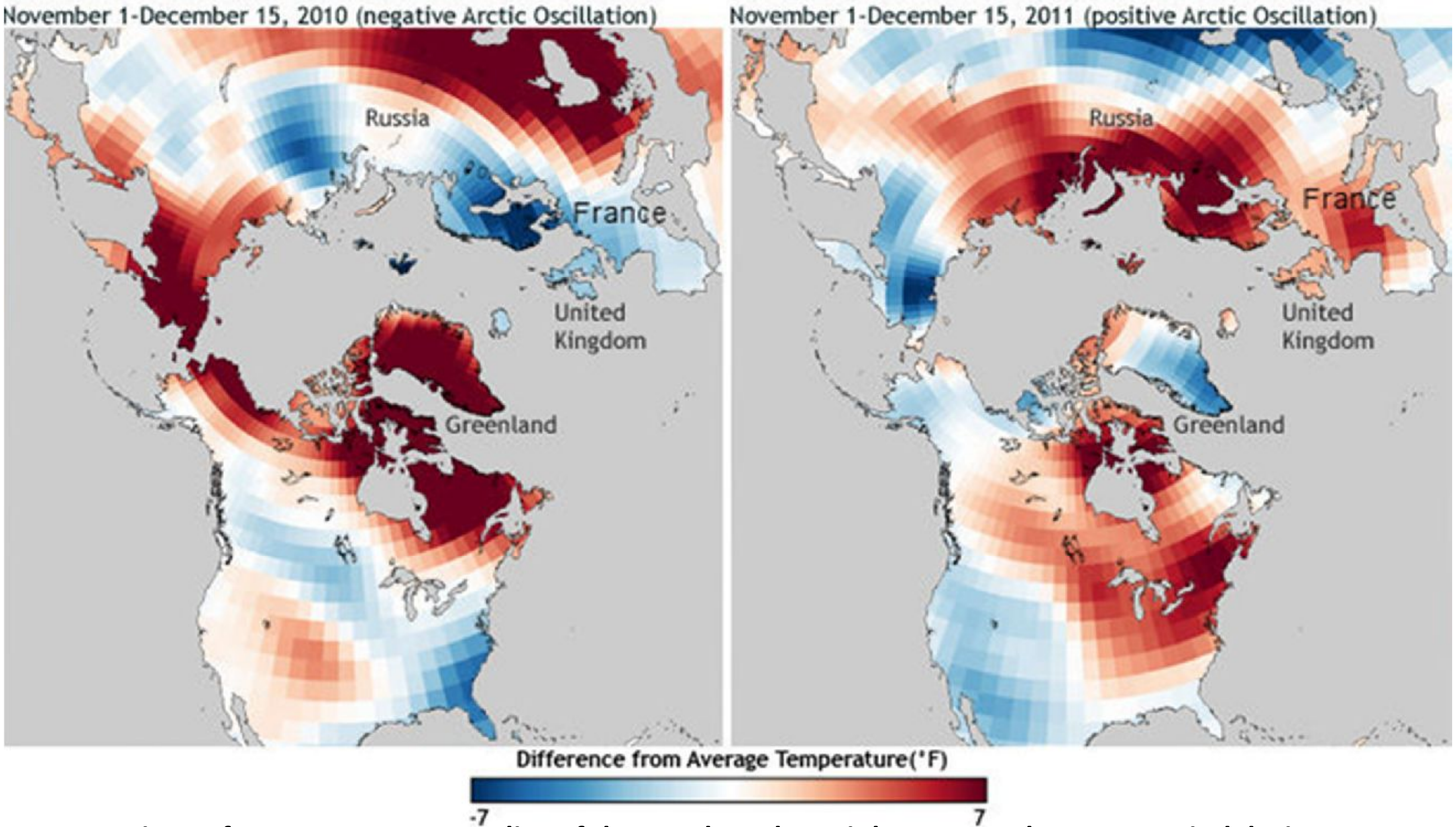


Temperature anomalies in the (very) low atmosphere as measured by satellites (<u>over 33 years only</u>) (*<u>source</u> : figure by Spencer & Curry, redispatched by Hans Labohm, Dagelijkse Standaard, 3 februari, 2012)*

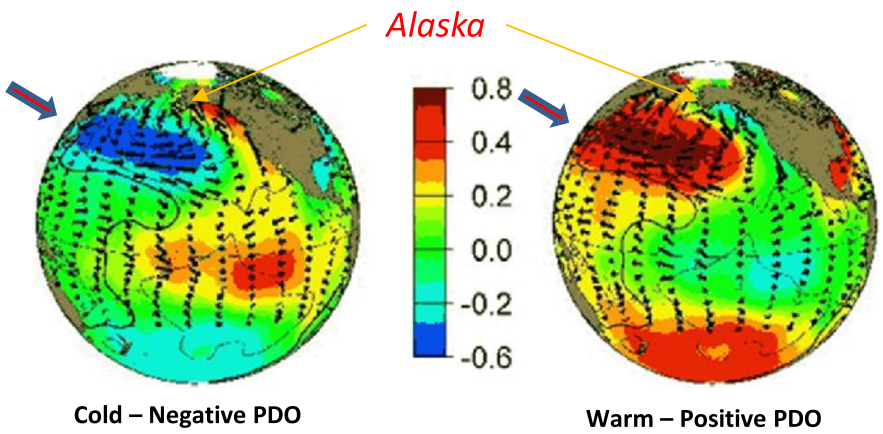
- **<u>Evidence</u>: sensitive tool (natural « accidents » perfectly detected)**
- **<u>Evidence</u>: no (positive) trend observed**
- **<u>Evidence</u>: superposition of multi-periodic signals**

More oscillations of temperature anomalies

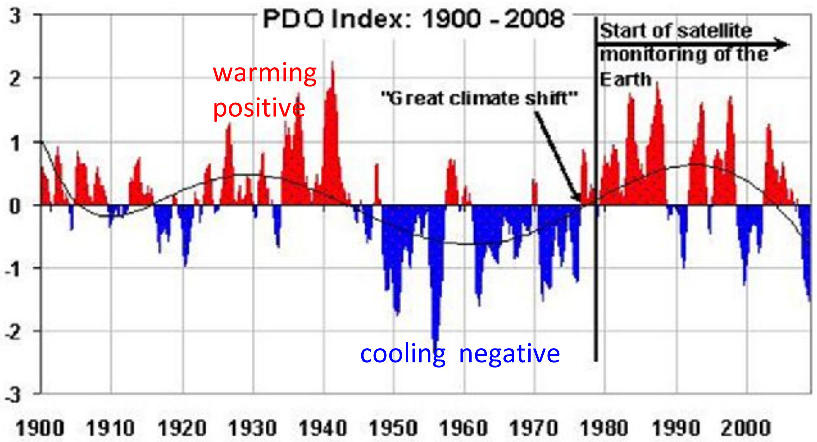
(Systematic inversion in almost all locations)



Comparaison of temperature anomalies of the Northern hemsiphere, over the same period during two successive years *(source: NOAA Climate Service).* **on the left side:** from 1st of November to 15th of December 2010. Under *Negative* Artic oscillations conditions (AO-) ; **On the right side:** from 1st of November to 15th of December 2011. Under *positive* Artic Oscillation conditions (AO+). *Note : anomalies given in Fahrenheit temperature scale. °C = 5/9*(°F-32)*. For temperature anomalies, the conversion factor is *5/9 (anomalies are temperature differences: actual temperature – local average over 30 years[1960-1990])*



Source of diagram: jisao.washington.edu



Source of diagram: Spencer (2012)

The **driving mechanism** of the PDO COULD be of the astronomical-physical type, involving *in-line gravitational interaction of Jupiter, Saturn and Sun affecting Pacific tidal activity* (Scafetta, 2010).

Pacific Decadal Oscillation

PDO measures the *difference in atmospheric pressure between Japan and Alaska*. It is said to *affect strongly US weather conditions*

Mainly in the **North Pacific** two different oceanic and atmospheric circulation patterns alternate every *20-30 yrs* with a cyclicity of *40-60 yrs*, causing changes in areas of warm and cold surface waters.

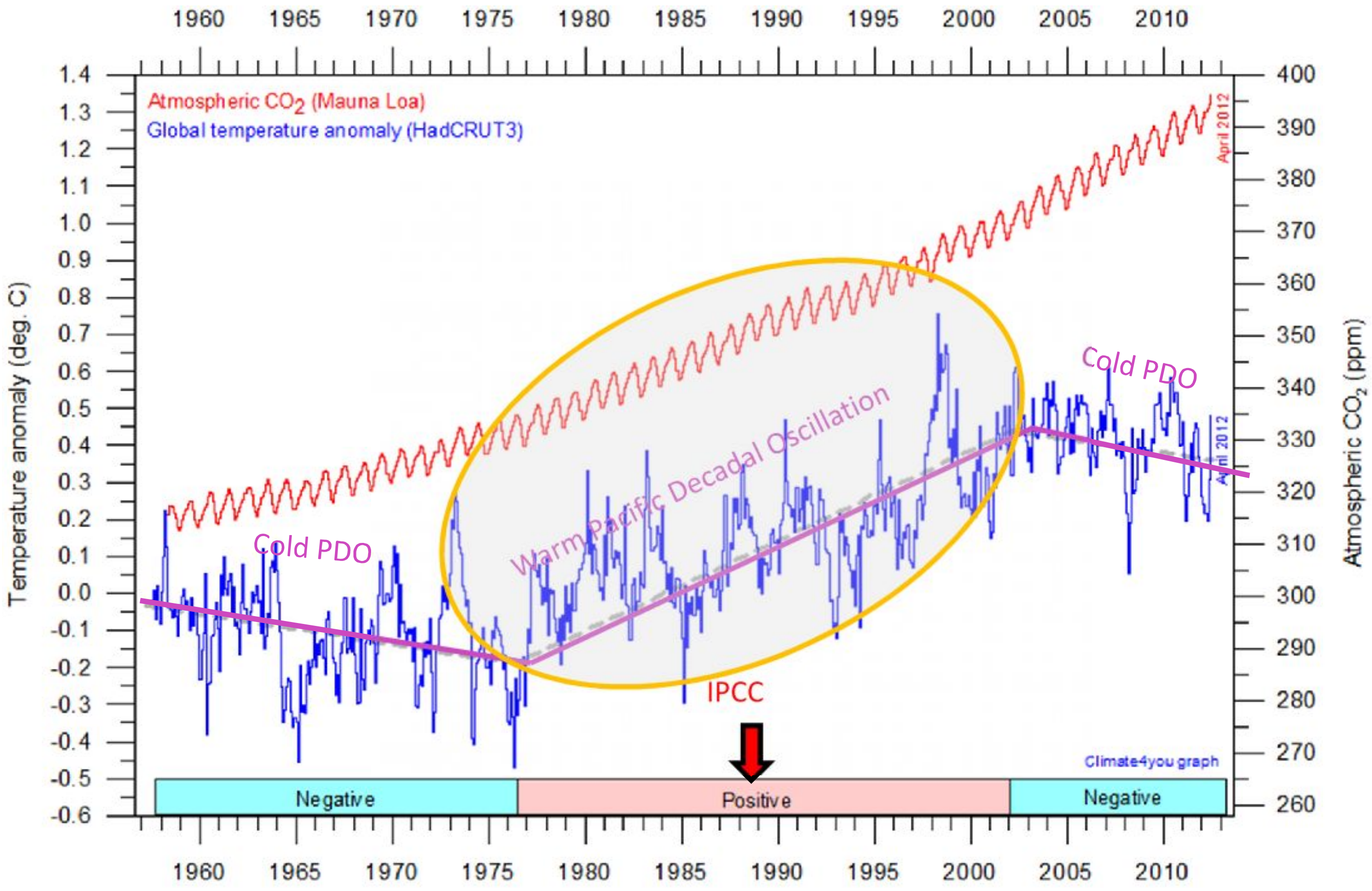
A clear PDO/temperature relationship does exist.

Modeling and satellite data show that the ***cloud cover of oceans*** decreases slightly during positive PDO phases but increases slightly during negative PDO phases. This affects *the Earth's Albedo* and, by radiative forcing, the climate (Spencer, 2008).

Recently the PDO entered a new negative phase, thus contributing to the present decline of global average temperatures.

GCM models neglect PDO effects

Since 1958 global surface air temperature and atmospheric CO_2 concentrations correlate only partly while there is a striking correlation between the Pacific Decadal Oscillation and temperature.

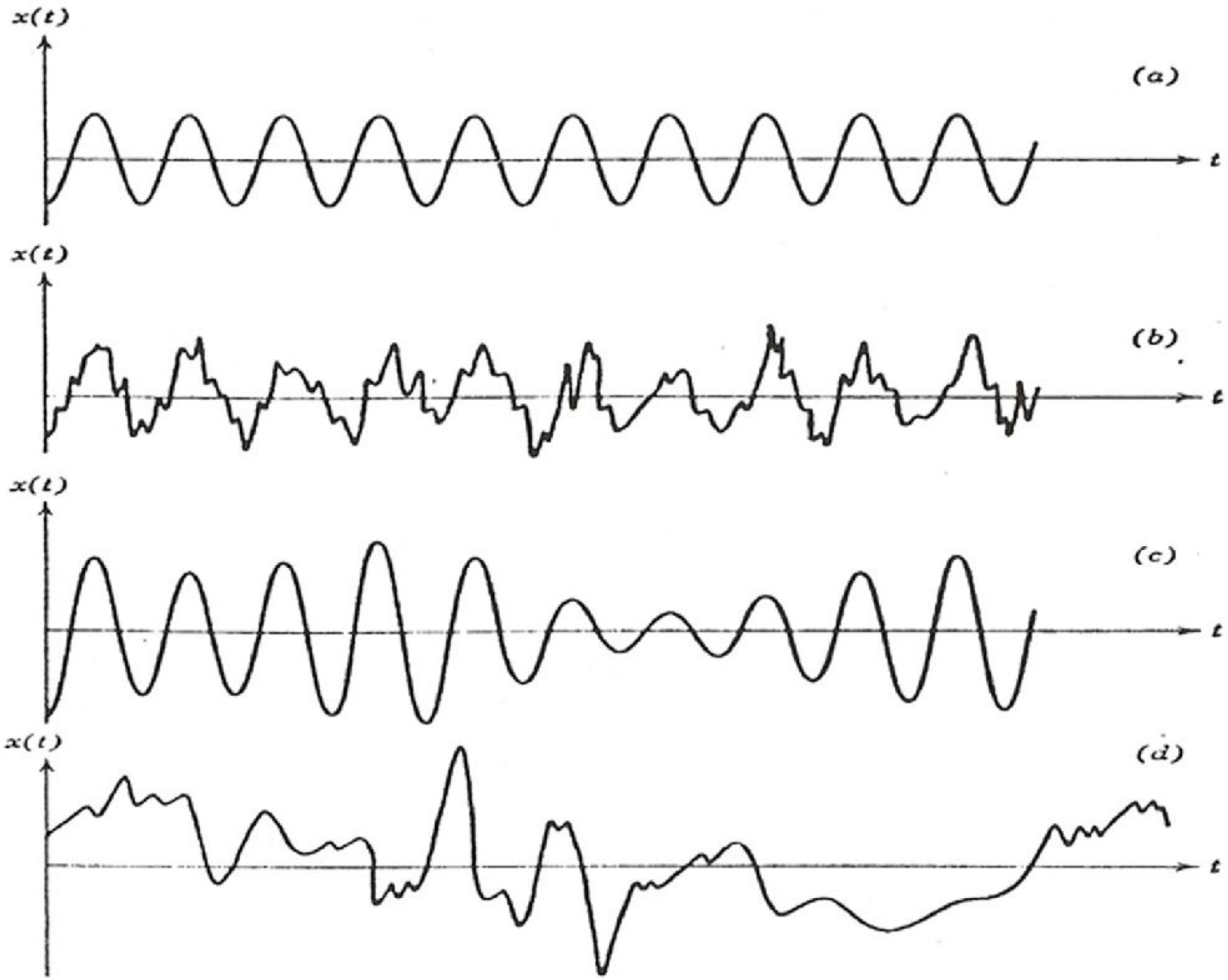


Source: Climate4you Greenhouse Gases

Similar to the HadCrut3 temperature curve, the NCDC, GISS, RSS MSU and UAH MSU curves show the same **ABSENCE** of temperature relationship to atmospheric CO_2 concentrations, *over the last 50 years*

(Note: red arrows shows the 1988 start-up of IPCC and the Anthropogenic Global Warming Scare, *based EXCCLUSIVELY on the 1978-2002 time window*)

SOME COMMON SIGNAL PATTERNS



Four special time histories. (*a*) Sine wave. (*b*) Sine wave plus random noise. (*c*) Narrow-band random noise. (*d*) Wide-band random noise.

Two kinds of noises

Random Noise

- Mean value is zero
- Gaussian distribution (bell shaped)
  - Complely defined by mean value and variance
  - Statisitcal parametric methods are appliable
  - Error on mean value diminishes as sqrt (1/(N-1))

Chaotic (Dynamical) Noise

- Deterministic non-linear equations
- **Extremely** sensitive to initial conditions and value of parameters

  => ***Practically non-predicitble on the medium or long term***.
- Amplitude distribution is ***NOT gaussian***. Points fluctuate in the vicinity of several « ***strange attractors*** » around which they fluctuate in an approximative periodic way.

  ⇒ **Mean value** is **meaningless**, as the probability that points are in its vicinity is very low.

  ⇒ **The mean value is NOT longer representative of the signal**

NON LINEAR ANALYSIS OF SIGNALS

Non linear analysis of signals

What to measure?

- Amplitude distribution
- Time recurrence (or its inverse the frequency)
- Predictibility

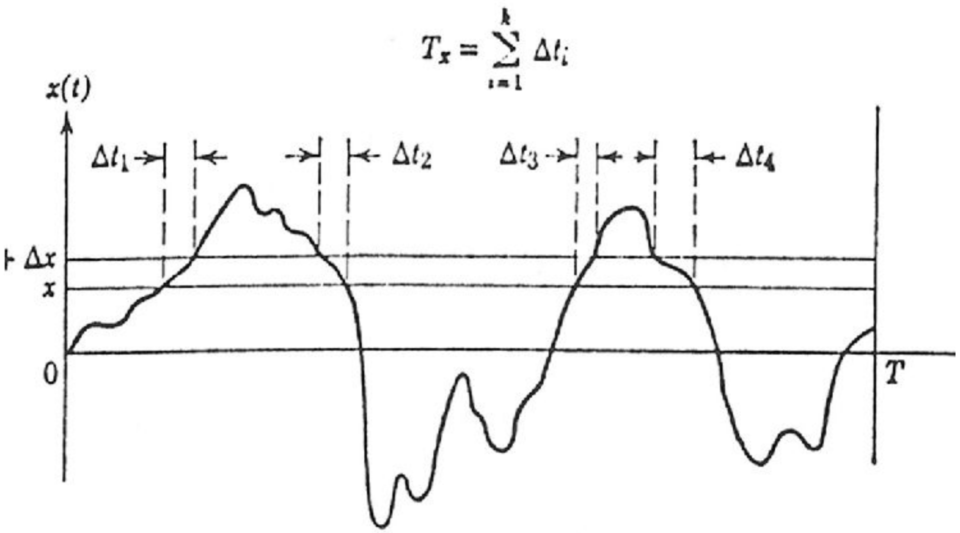
What to detect?

- Trends (shifts)
- Periodicities
- Chaotic signature
- Differentiating chaotic from random noise

Which toolbox?

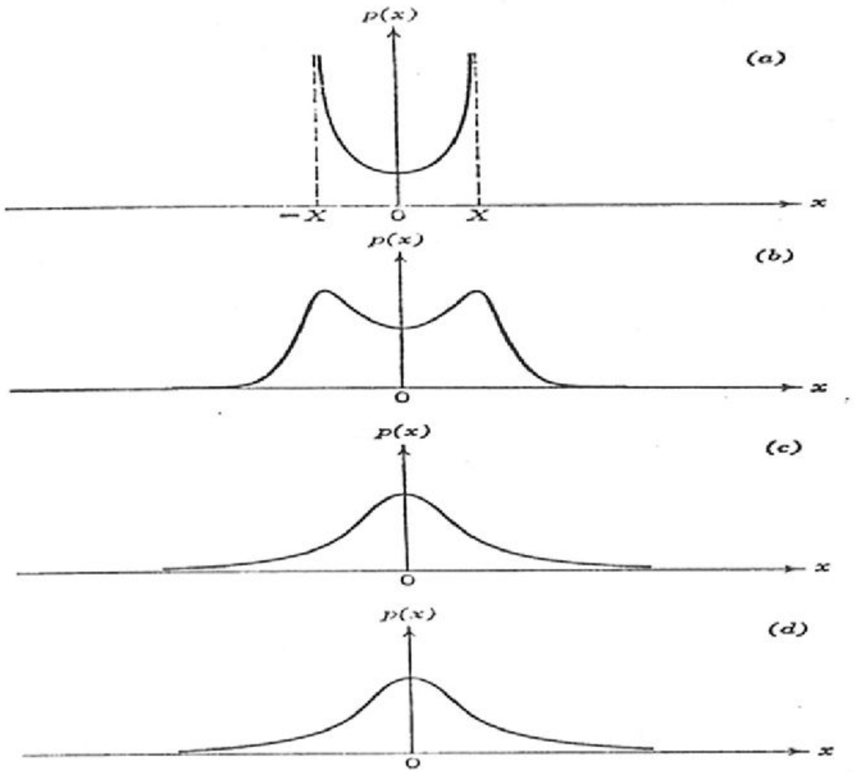
- Amplitude analysis
- Autocorrelation
- Fourier analysis
- Power spectrum
- Phase diagrams
- Recurrences + toolbox
- (non parametric predictibility of time series)
- Wavelets

Amplitude Analysis



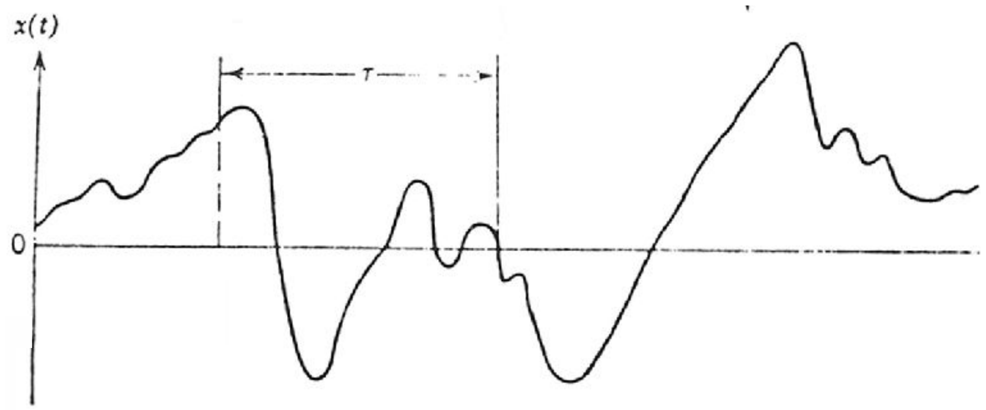
Probability measurement.

Examples of Amplitude Distributions



Probability density function plots. (a) Sine wave. (b) Sine wave plus random noise. (c) Narrow-band random noise. (d) Wide-band random noise.

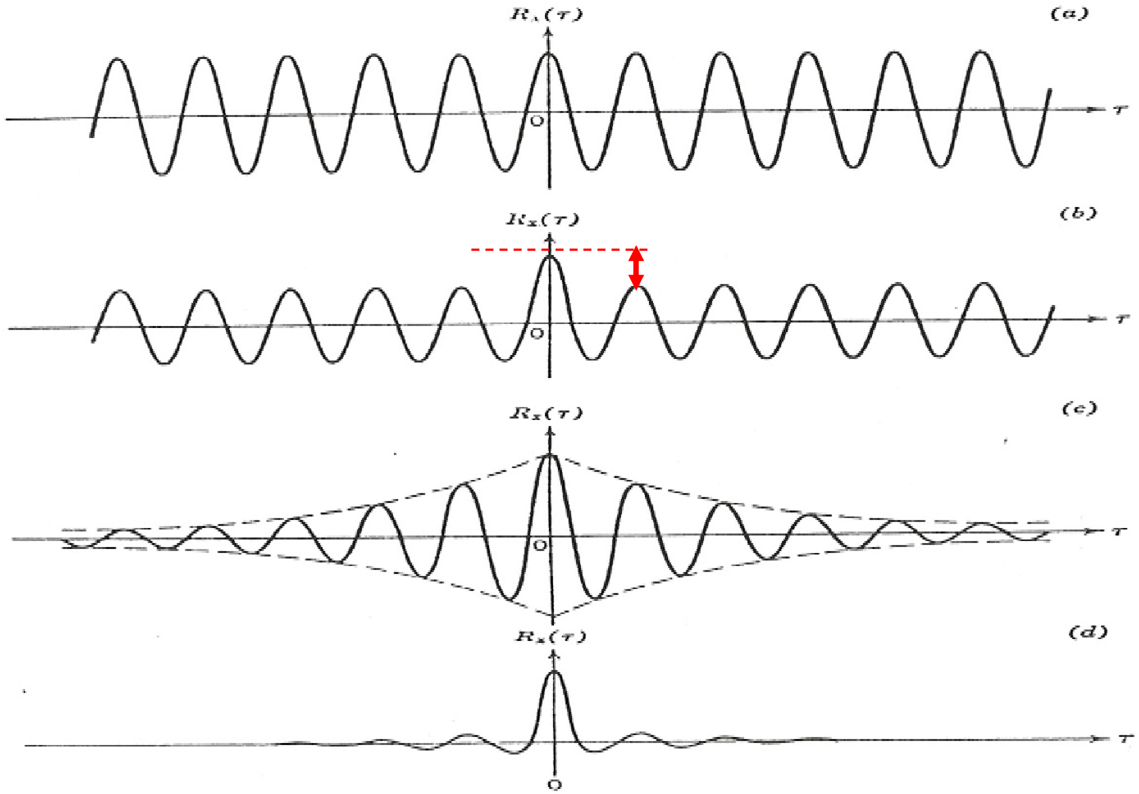
Time auto-correlation



$$\rho\,(\tau) \stackrel{\text{def}}{=} \frac{1}{n}\sum_{i=1}^{n} X_i\, X_{i+\tau}$$

Autocorrelation measurement.

Examples of autocorrelation functions



Autocorrelation function plots (autocorrelograms). (a) Sine wave. (b) Sine wave plus random noise. (c) Narrow-band random noise. (d) Wide-band random noise.

Power Spectrum

- Fourier Transform of the auto-correlation function

$$P(f) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} \rho(\tau) e^{-i2\pi f\tau}\, d\tau$$

- *IMPORTANT*: ***Shannon sampling theorem***
  - Max frequency detectable = ½ sampling frequency (⇔ smallest period detectable = 2 times time interval between samples
  - Information lost when averaging from hour to day to month to quarter to year to decade to century to millenium, etc.

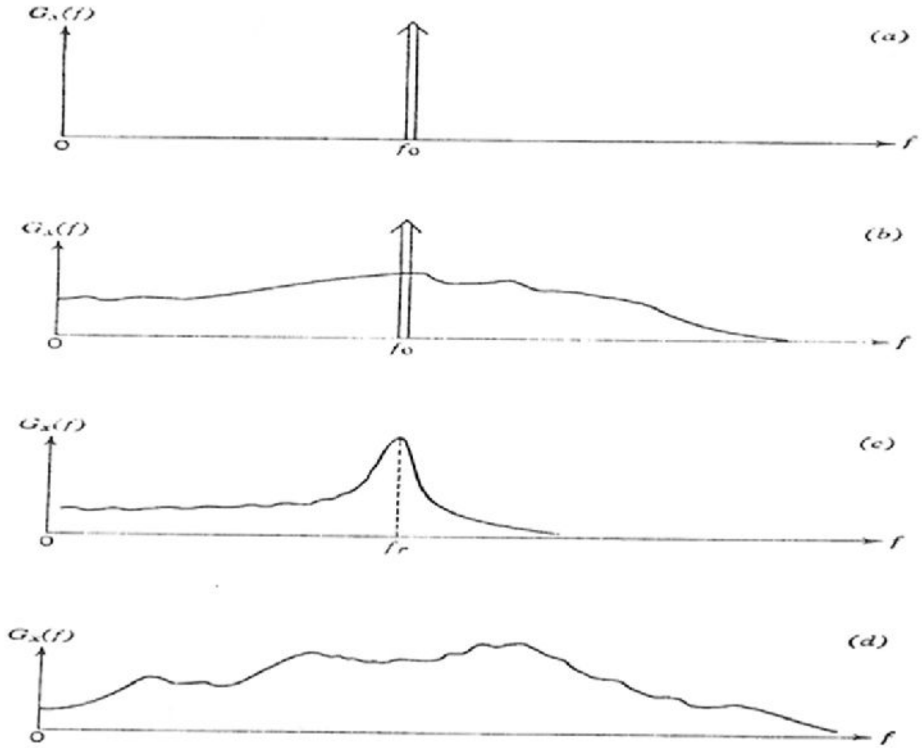
- *IMPORTANT:* ***end effects***: maximum period detectable ~ 1/3 of time window of the time series

- "Reconstruction" is possible by Inverse Fourier Transform

$$X(t) = a_0 + \sum_{i=1}^{\infty} (a_i \cos(\omega_i + \varphi_i)t + b_i \sin(\omega_i + \varphi_i)\, t)$$

Provides a physical meaning: the amplitude, frequencies and phases of a set of sinusoids (and cosninusoids) giving the best fit to the time series (or signal)

Examples of Power Spectra



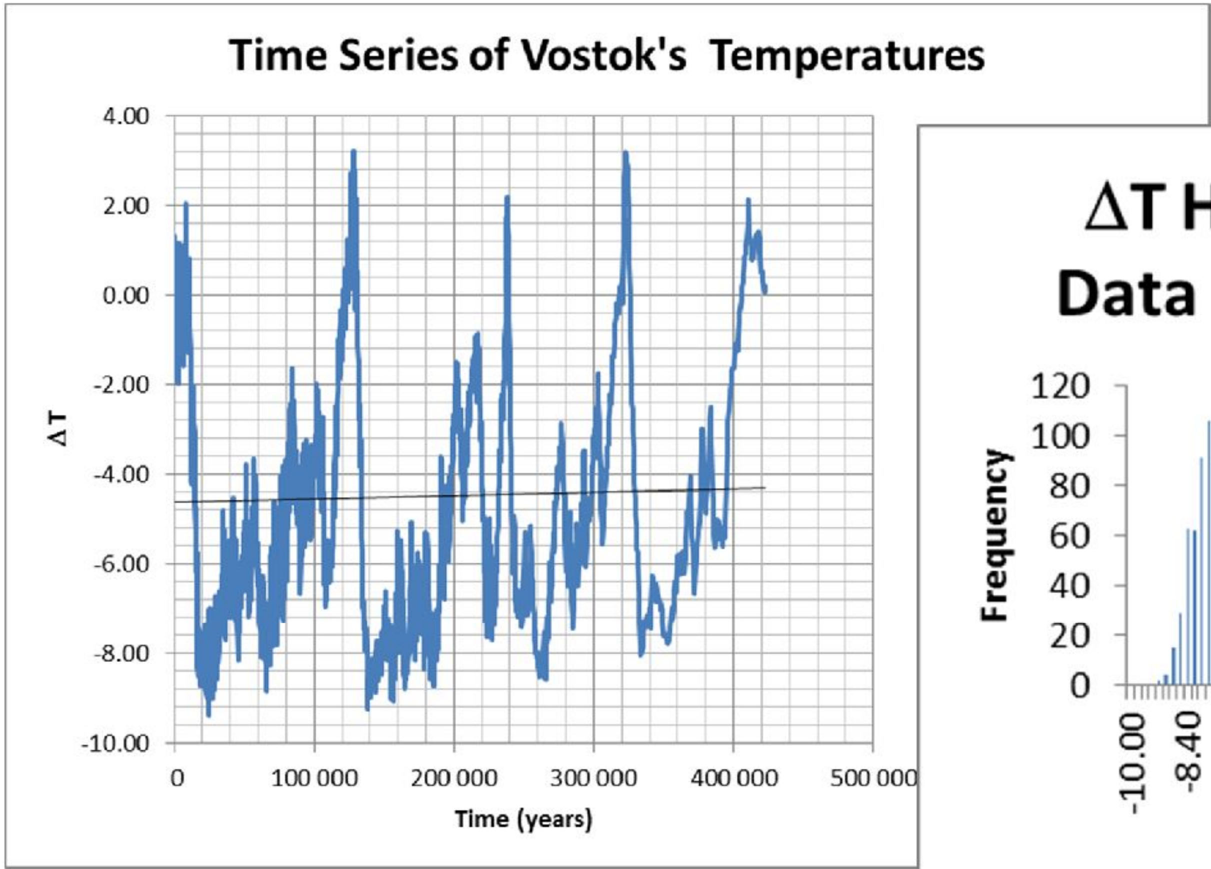
Power spectral density plots (power spectra). (a) Sine wave. (b) Sine wave plus random noise. (c) Narrow-band random noise. (d) Wide-band random noise.

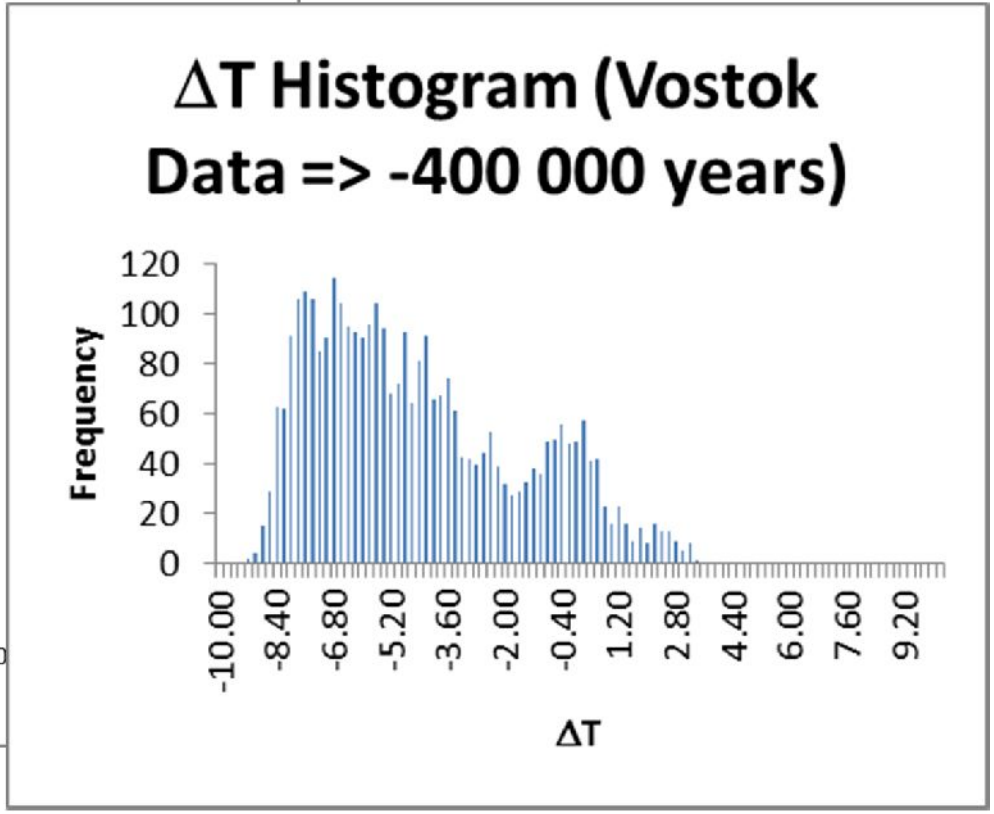
Vostök (from isotopic analysis of ice rods & included bubbles)

Spatial Averaged temperatures 30-60°N

Local temperatures Uccle Meteo station (Brussels, Belgium)

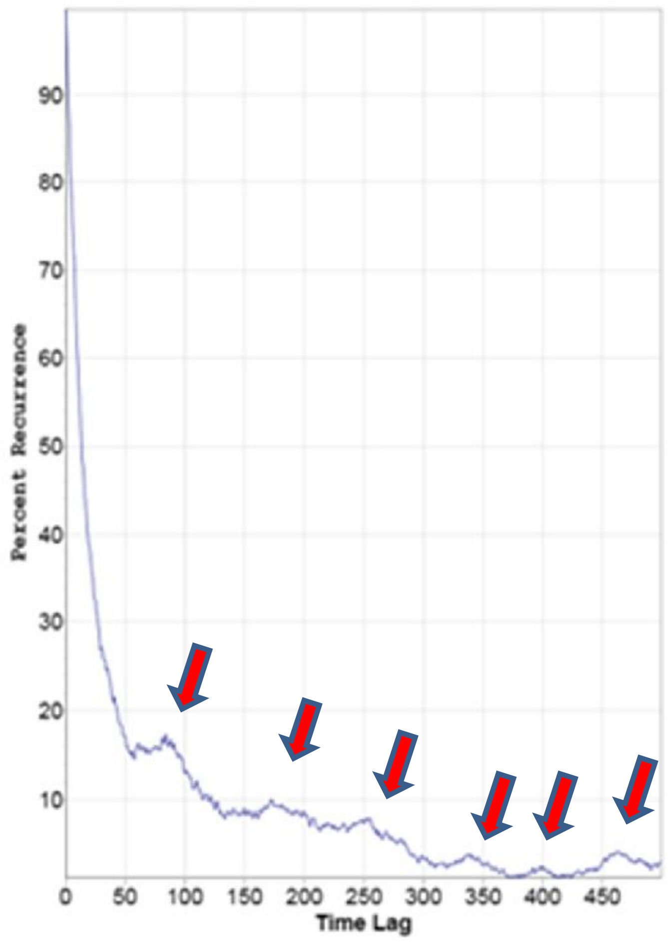
APPLICATION TO LAND TEMPERATURE MEASUREMENTS.





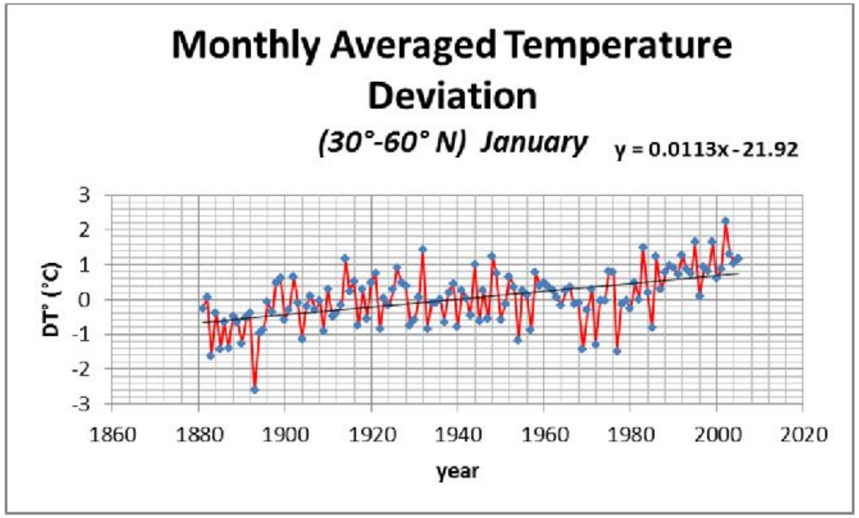
Amplitude analysis of temperature anomalies estimated from ice rods at Vostök. The amplitude distribution is *NOT gaussian but bimodal*. The main mode corresponds to glaciation conditions (6 to 8°C lower than presentlly (with amode at -6.8°C). A secundary peak corresponds to a « temperate » climate, fluctuating around the a-present temperatures (with a mode 0.4°R lower) as the one prevailing presently. The temperature never exceeded over 400 000 years the present temperature by more than 3.2°C.

Autocorrelation of Vostök data. The horizontal axis refers to the order of the sample in the sime series? Unfortunately, the time interval between successive data is not totally constant, but the scale is *approximatively* expressed as Kyears. The periodicities detected (local maxima in the curve) are thus only approximative. Points are expressed as anomalies towards the temperature averaged over the 20th century. The important peak at origin corresponds to the sum of the square of the mean value (corresponding to a bias in the data) and the variance of the signal. Periodicities have been linked to the Planets' ***Milankovitch cycles*** (Berger et all, 1988).



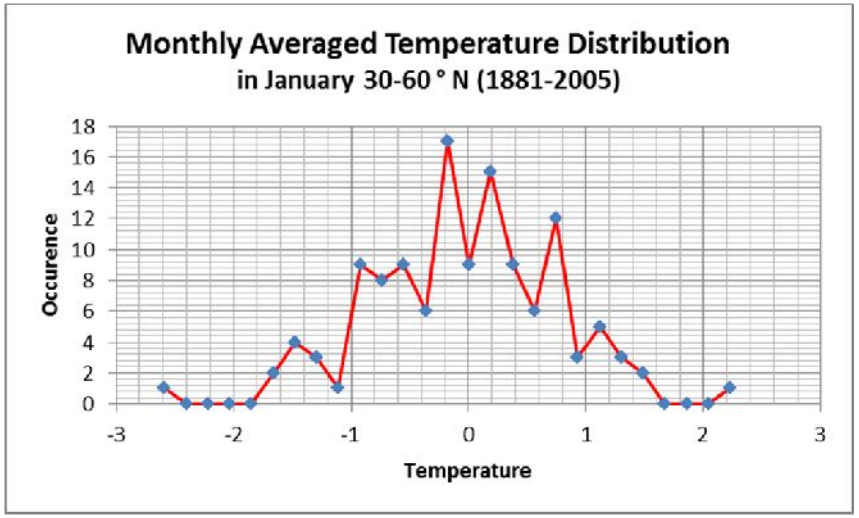
Analysis of spatially averaged temperatures

Time series



125 Data points

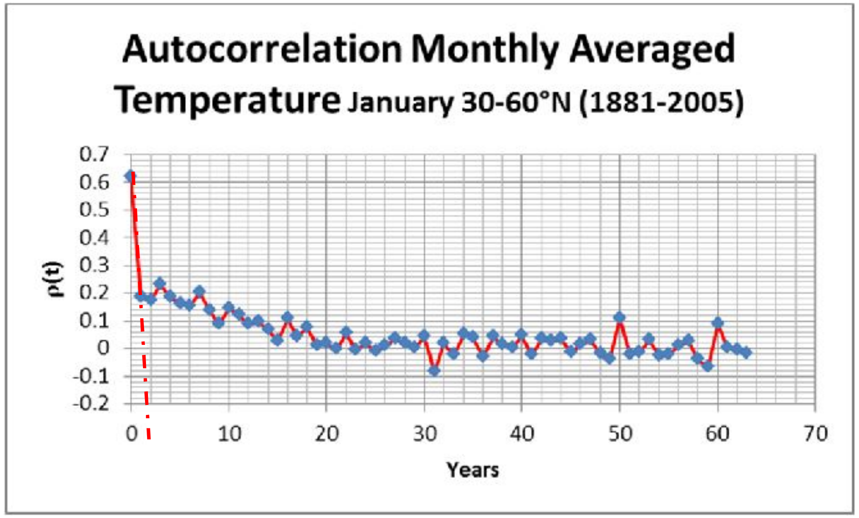
Amplitude distribution



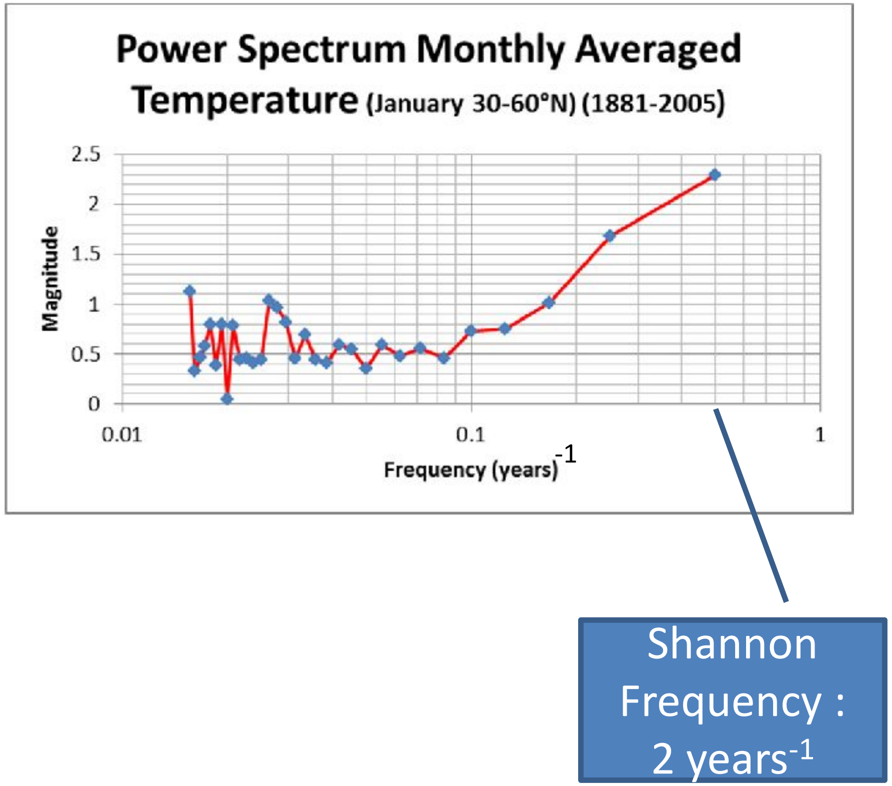
The amplitude distribution is ***not gaussian*** (as can be tested with a χ square test). Strictly speaking, *usual statistics (i.e. regression lines) may not be applied.*

Analysis of Temperature

Time autocorrelation



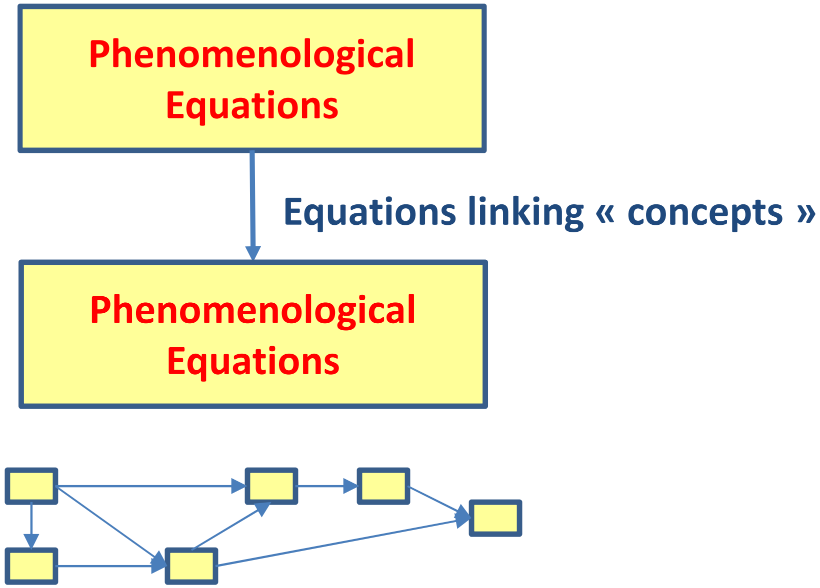
Power spectrum



TEMPERATURE RECONSTRUCTIONS USING FOURIER ANALYSIS

Two different approaches

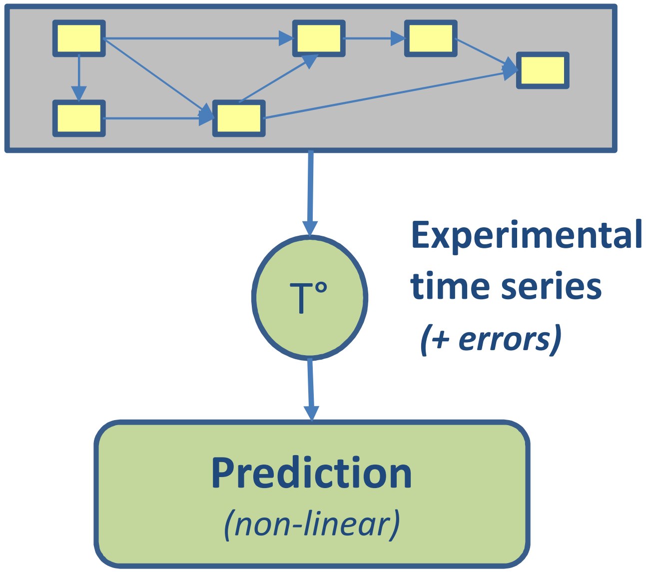
IPCC – Descriptive model



If the algorithm contains an equation stating that temperature increases when anthropogeniic carbon emissions increases, the results will show such a pattern. THIS IS NOT A PROOF…

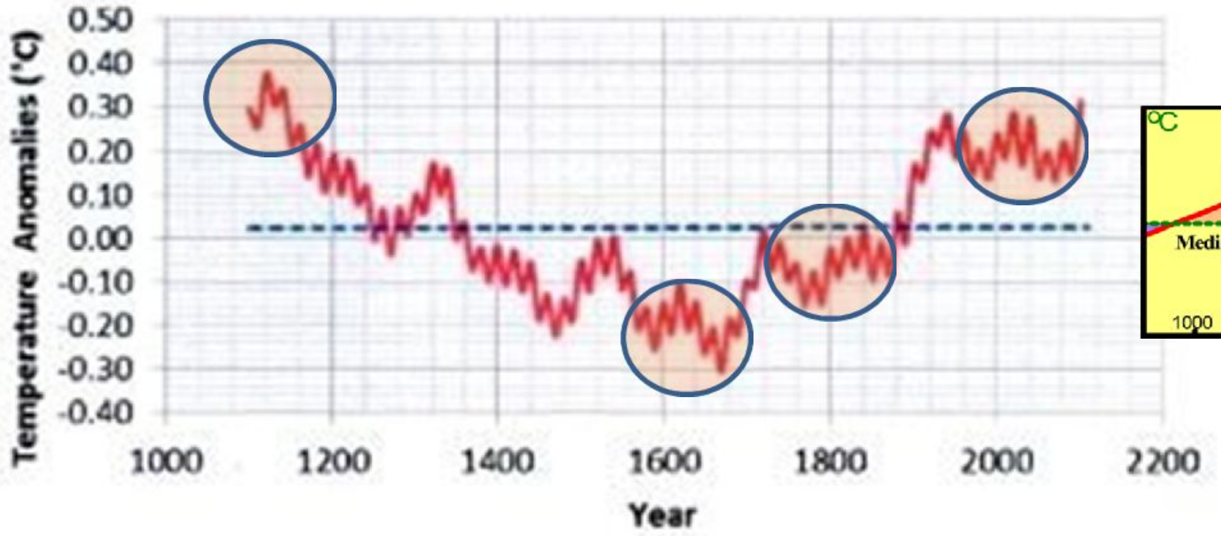
What if one concept has been forgotten ?
What if one of the links has been forgotten?
What if one of the links has been wrongly formulated?

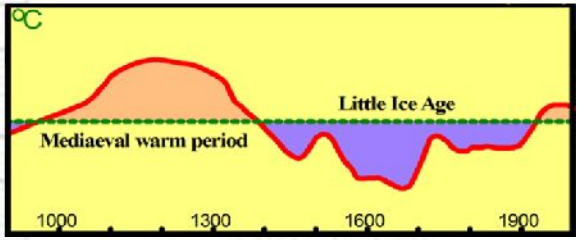
Black box – predictive model



Exclusively based on experimental data (unfortunately non perfect)
Requires limited computer facilities => easier to assess
Better adjustment than descriptive models?
Predictabiliy horizon (& error margin)?

Simulation of Temperature Anomalies



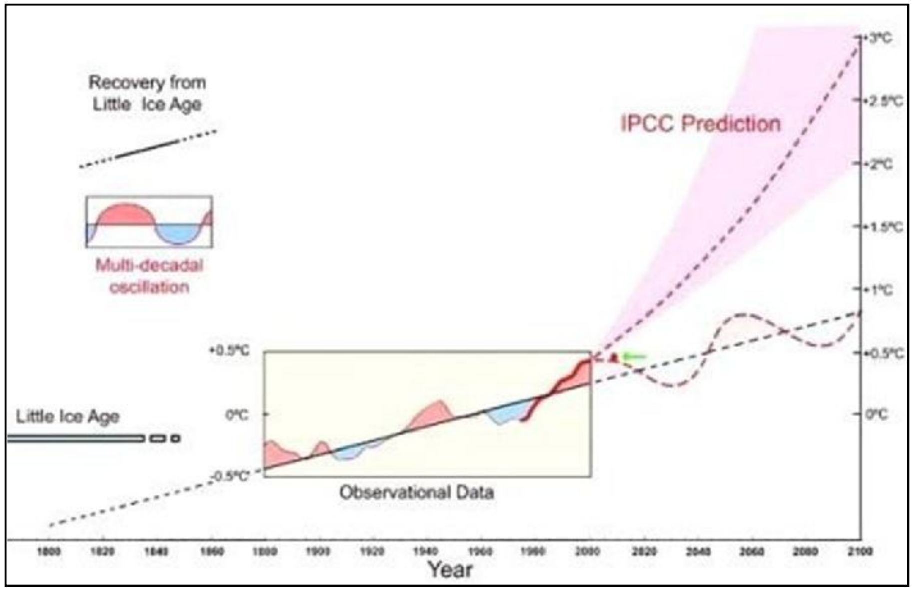


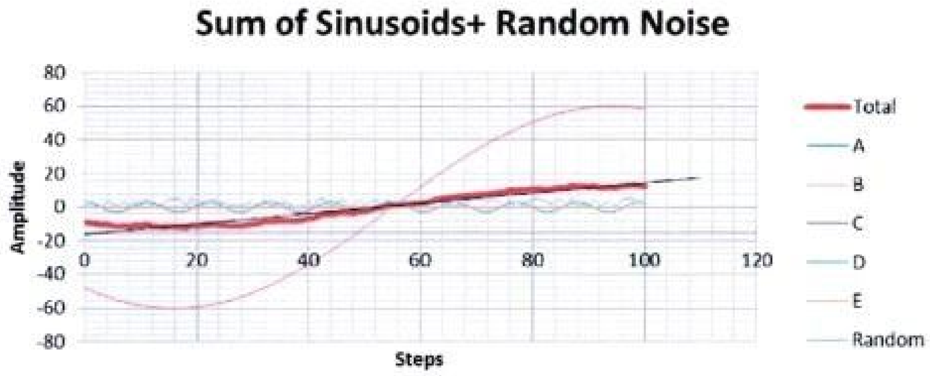
$y = 0.0021x - 3.6766$

	Amplitude	Period (in N steps)	Pulsation	Frequency	Phase (degres)
Curve A	6	2	3.142	0.500	50
Curve B	5	10	0.628	0.100	0
Curve C	6	20	0.314	0.050	20
Curve D	3	50	0.126	0.020	140
Curve E	20	99	0.063	0.010	90
Random	4				

Calibration Ox Time scale		Calibration Oy Temperature (Anomalies)	
	year		
Initial date	1100	°C/unit	0.05
increment	10		
N of steps	100		
Final date	2100		

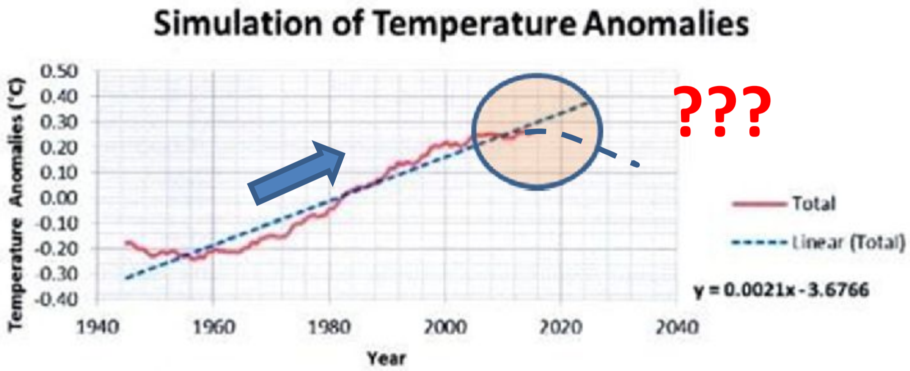
- A simple approximation by Fourier series (sum of sinusoids)
- A « black box » approach. Predicitng does not require modeling. (i.e. best model for tides prediction is a black box model….and this remains the best predicitive tool for more than a century….)





Superposition of two sinusoids & random noise (*<u>sinusoid A</u>: amplitude: 3; period: 11; initial phase: 86<u>°; sinusoid B</u>: amplitude: 60; period: 156; initial phase: 233°; white random noise amplitude: 5)*

The figure shows that the **linear trend** between 1880 and 2000 is a **continuation of recovery from the LIA**. It shows also the predicted temperature rise by the IPCC after 2000. Another possibility is also shown, in which the recovery from the LIA would continue to 2100, together with the **superposed multi-decadal oscillation**. This possible progress beyond the peak of an oscillation *<u>could explain the halting of the warming after 2000</u>*. The observed temperature in 2008 is shown by a red dot with a green arrow. (source : Akasofu, 2009)



Same figure recalibrated *(Ox: initial year : 1945 ; step: 0.7; number of steps: 100 ; final year :2010 . Axe Oy : 0.02 °C/unit)*

***<u>But</u>*: The « linear trend » is best replaced by a centennial wave (+ some noise)**

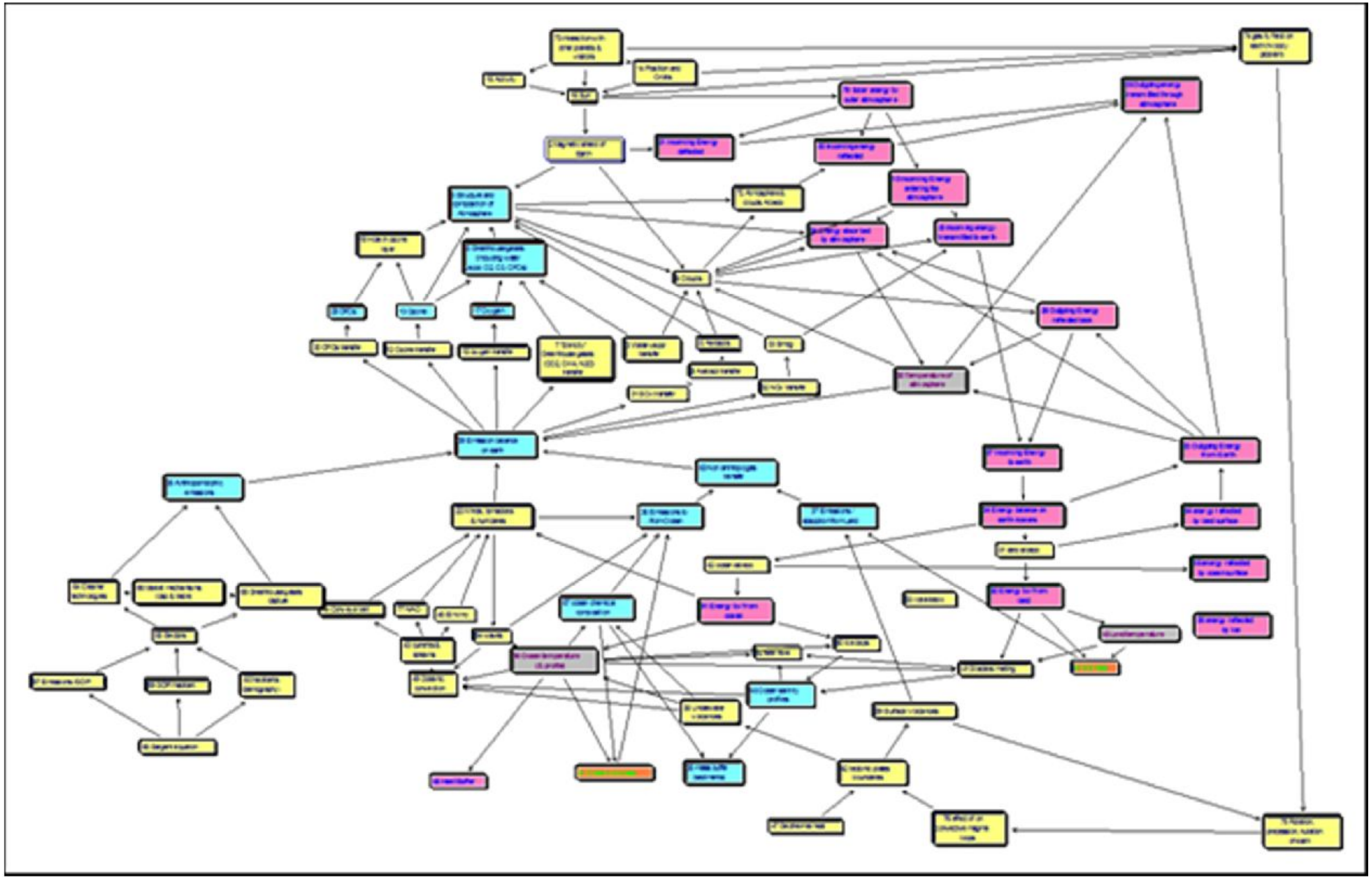
The climate system is extremely complex

Synchronisation mechanisms

Where is the master clock?

SYNCHRONISATION IN COMPLEX SYSTEMS

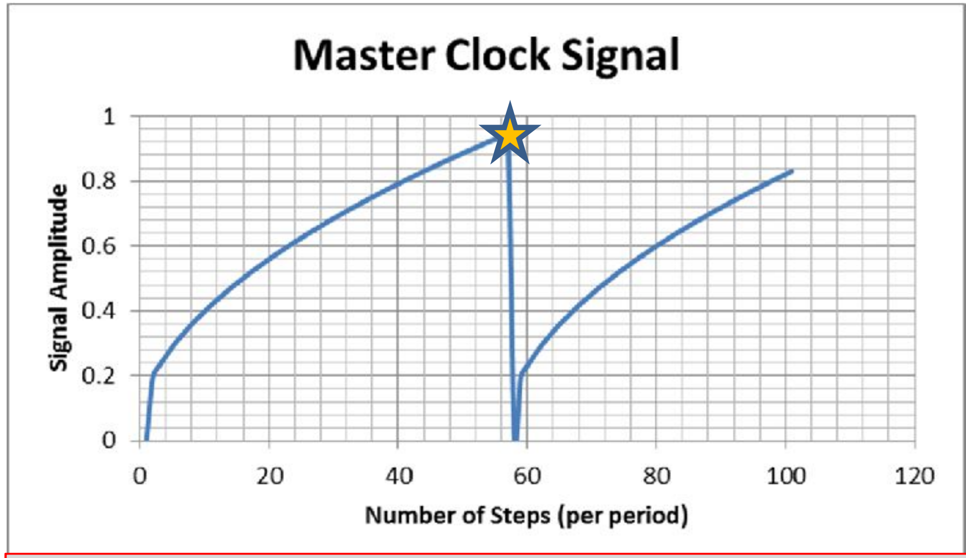
Complexity of the Climate System



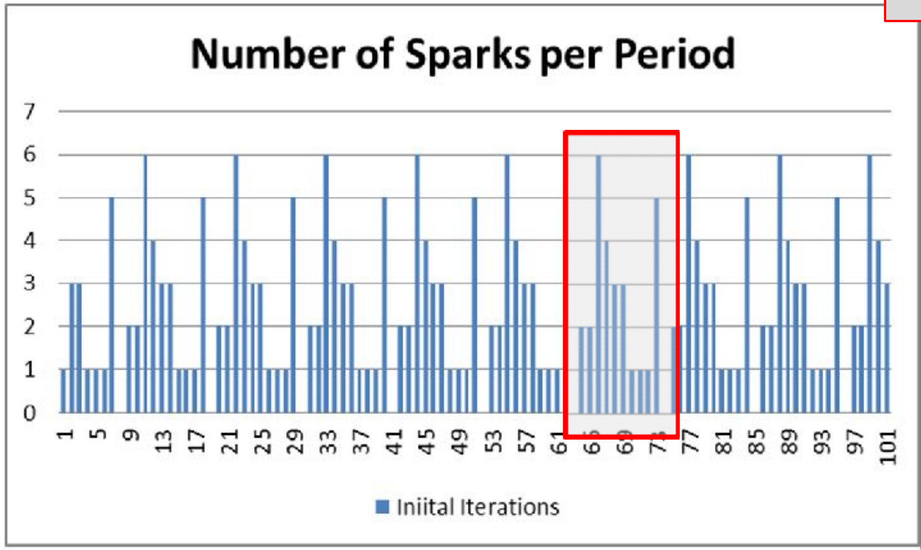
Synchronisation of complex systems

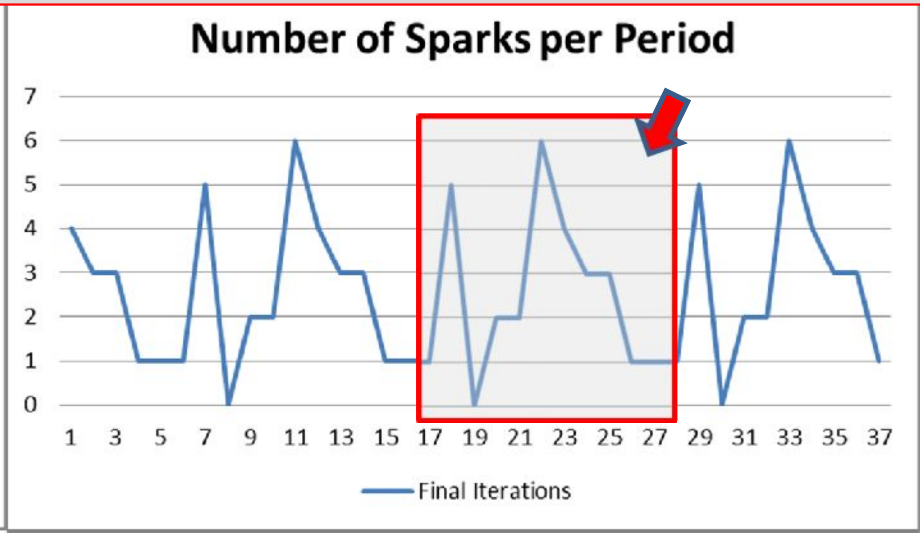
Legion synchronisation

- A « *master clock* »
  - Corresponding to an « ***accumulator*** » (⇔electrical capacity)
  - (adjustable) load curve (stepwize)
  - at (adjustable) threshold level: a « flash » followed by instantaneous discharge
  - Provides initial « flash »
- N « *slave* » oscillators
  - Receive a load « quantum » when any other oscillator « flashes »
  - « Flash » & Send a load « quantum » to every other oscillator when they reach their own threshold level



Rather quickly the phases of the oscillators become locked. A characteristic pattern is repeated.





Where is the master clock ?

- Solar or planet conjunction cycles?
- Complex systems also exhibit **synchronisations**
  - No strict causality link but discontinuous mutual influence
  - Each concept send « flashes » to the other concepts when it reaches a certain threshold level (Legion effect)
  - Does Exist in nature
    - Pendula synchronisation in a same room
    - Crickets; light worms
    - Josephson diodes, etc.

- **CAUTION: Approximative Synchronism is NOT Causality but Intermittent mutual influence through (eventually complex & indirect) feedbacks**

Centennial gravity interactions

Decandole (2003) computations over the 1800-2032 period

Number of conjunctions	Concerned planets	Cycle length (years)
14	Jupiter & Neptune	178.95
13	Jupiter & Uranus	179.55
9	Jupiter & Saturne	178.73
5	Saturne & Neptune	179.35
4	Saturne & Uranus	181.14
1	Uranus & Neptune	171.44

There is clearly a **179 years periodicity**,
Or more exactly several 179 years cycles, that are phase shifted

Such cycles do interfer with ***solar activity*** (by changing the ***angular momentum*** of the sun towards the gravity centre of the solar system, generating solar « *hot spots » and eruptions*, modifying ***the magnetic field of the Sun and the Earth***. Also the ***rotation axis of the Earth and its trajectory*** could be affected

Some well known solar cycles

« Classical » cycles

Duration (years)	Name	Latest cold period	Next cold period
11	Schwabe		
22	Hale		
24-29			
60			
87-90	Gleissberg	1996	2030
180	Harmonic 2 of Gleissberg cycle?		
208-210	Suess	1898	2210
232		1876	2038
~ 1 000			
2 300	Halstadt		
6 000	(Xapsos & Burke)		

Milankovitch cycles (1922)

- 40 **K**years
- 100
- Etc.

Cycles Identified usng C^{14} (Damon & Sornett ,1991)

- 105 years
- 131
- 232
- 385
- 504
- 805
- 1500
- 2241

CHAOTIC SYSTEMS

A Simple Chaotic Function:

The Logistic (Quadratic) Equation

For this purpose, one best looks at one of the simplest dynamical systems: the one where a single positive and negative feedback try to balance each other (*logistic equation*, also known as quadratic or *Verhulst equation*):

$$\boldsymbol{X_{t+1} = \alpha X_t(1 - X_t)} \qquad [1]$$

Where $\boldsymbol{\alpha}$ is a parameter

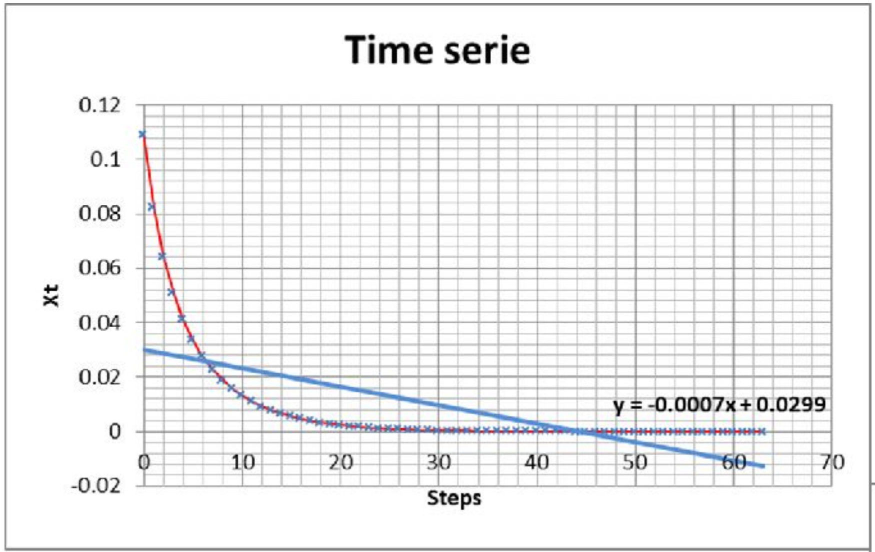
- If 0< a <4, the value of X_i remains between 0 and 1; the function presents a maximum for $X = \frac{\alpha}{4}$

For an initial value $X_0 = 0.6876$, and increasing values of a, X_i :

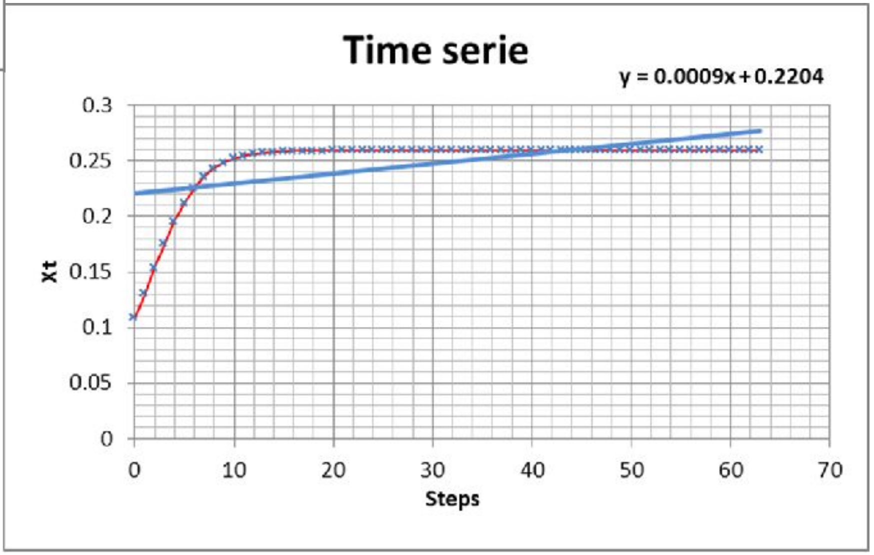
- goes asymptotically to zero (extinction) for $0 \leq \alpha \leq 1$
- goes asymptotically to an asymptotic value $L = 1 - \frac{1}{\alpha}$ for $1 < \alpha \leq 2$
- goes to the same equilibrium value, but from both side (damped oscillations) for $2 < \alpha \leq 3$
- quits progressively the equilibrium value and starts to oscillate between two values, for $\alpha = 3.2$

Logistic equation

Extinction or asymptotic saturation



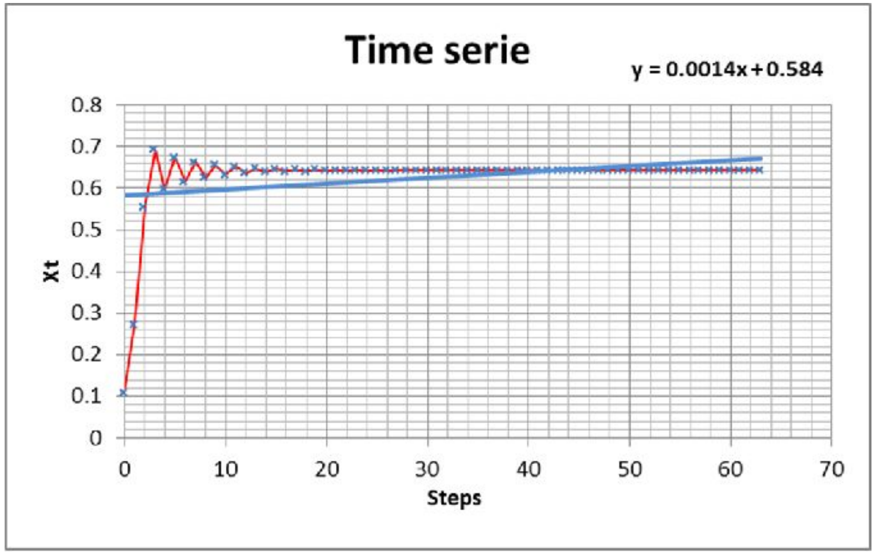
$X_0 = 0.109$
$\alpha = 0.85$



$X_0 = 0.109$
$\alpha = 1.35$

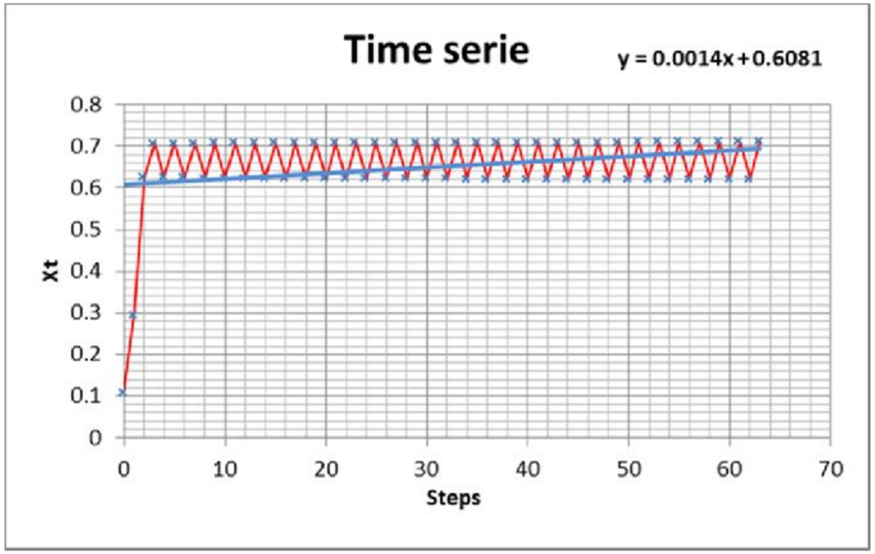
Logistic equation

Oscillating behaviour (damped or stabilized)



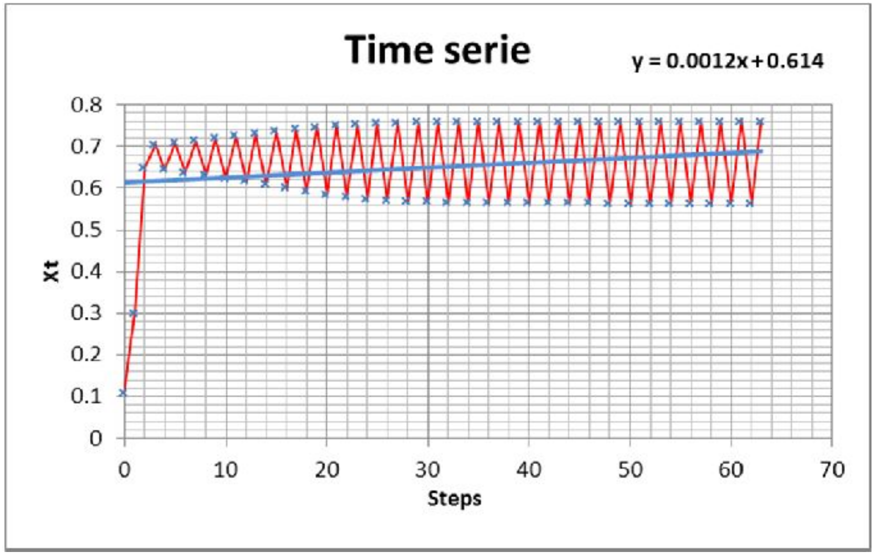
$X_0 = 0.109$
$\alpha = 2.8$

$X_0 = 0.109$
$\alpha = 3.01886$



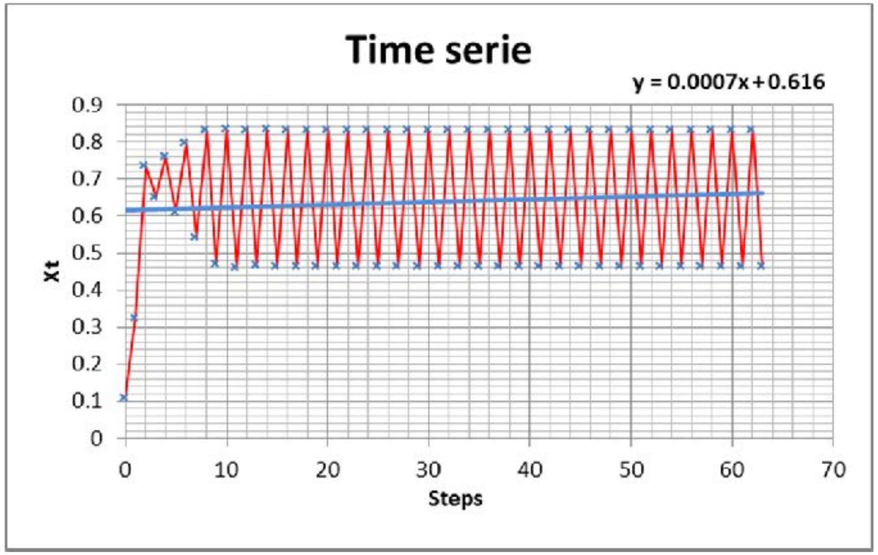
Logistic equation

Oscillating behaviour (divergent)



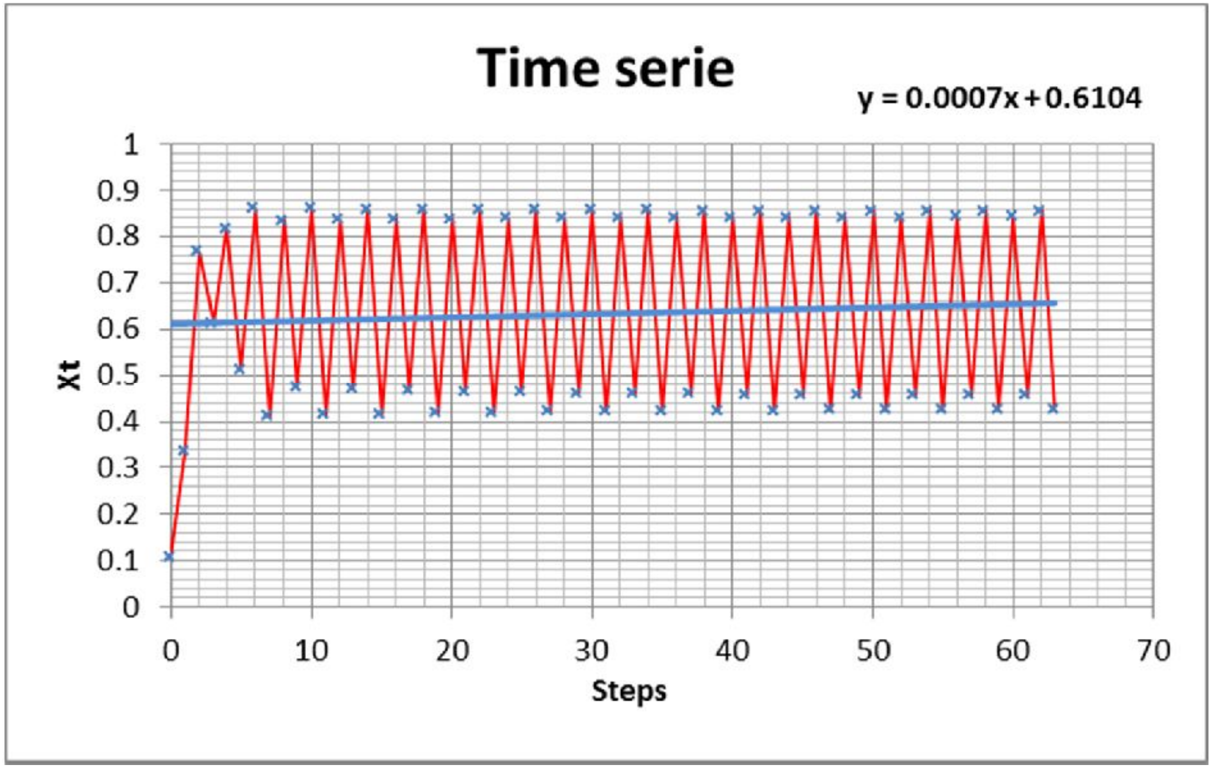
$X_0 = 0.109$
$\alpha = 3.09$

$X_0 = 0.109$
$\alpha = 3.35$



Logistic equation

slightly chaotic signal

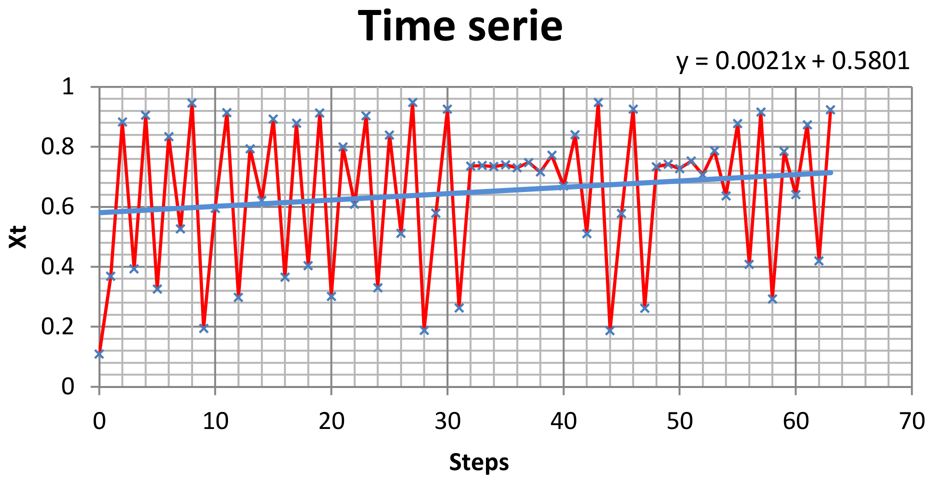


X_0 = 0.6, α =3.45

*The periodic signal has split in two components (**bifurcation**)*

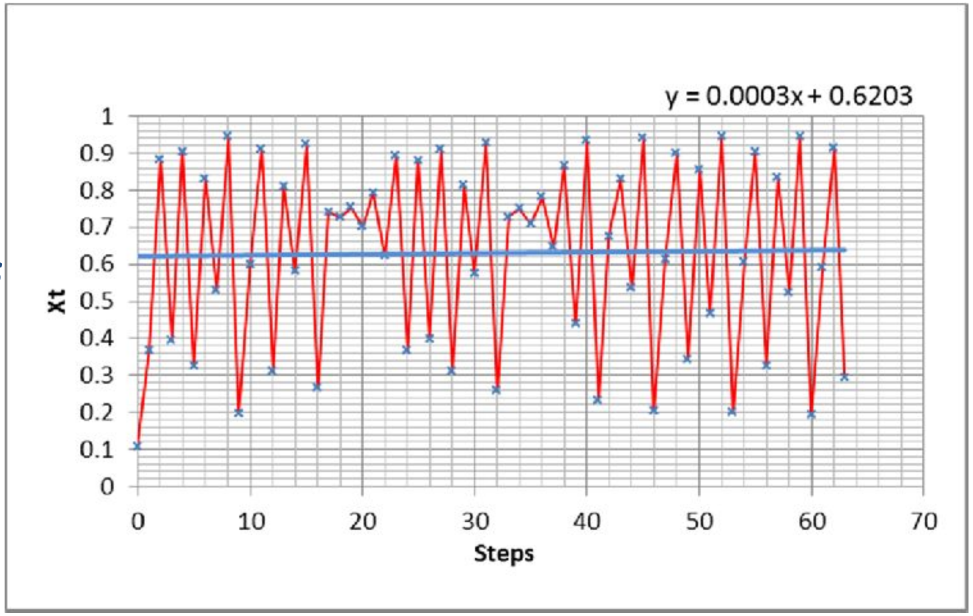
Logistic equation

Evolution towards a more chaotic state



*Logistic equation (X_0 =0.109; **a = 3.793<u>04</u>**) showing a <u>slight positive</u> trend versus time.*

*Logistic equation (X_0 = 0.109; **a = 3.793<u>54</u>**) showing almost <u>no trend</u> versus time*



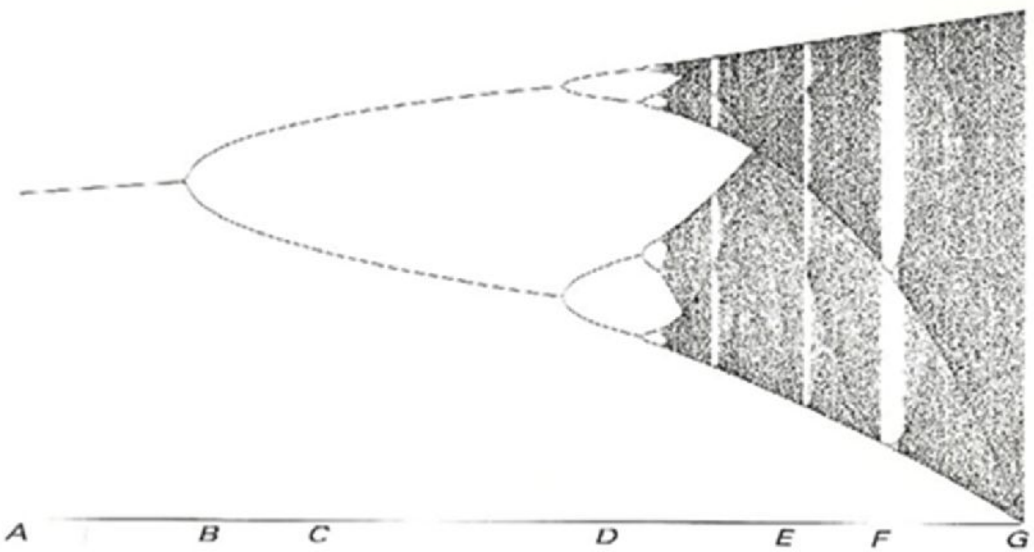
Whatch out:

- ***Tiny difference in value of the parameters***
- ***Periods of relative stability***

Purely deterministic equation
but Predicitability from time series?
Meaning of the regression line?

Sensitivity to parametre α

- When the parameter α is increased, the signal becomes oscillating,
- then the frequencies split in more and more (sub)harmonics, at some BIFURCATION points
- Chaos corresponds to a very large number of harmonics
- Some stable windows exist between very chaotic situations.



Order and chaos in the model of restricted growth $x \rightarrow ax(1-x)$

A	$a = 2.9$	single limit point
B	$a = 3.0$	transition to 2-cycle
C	$a = 3.2$	2-cycle
D	$a = 3.5$	4-cycle
E	$a = 3.74$	5-cycle
F	$a = 3.83$	3-cycle
G	$a = 4.0$	complete chaos

It is possible to detect the "signature" of a <u>system evolving progressively towards a chaotic state</u> by identifying the occurrence of bifurcation points

Phase Plan

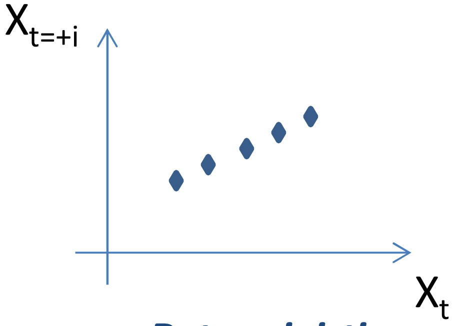
- Based on ***Tokens*** Theorem:
  - Phase plan (Comweb graph) can be constructed from time series

$$\mathbf{X_{t+i} = f(X_t)}$$

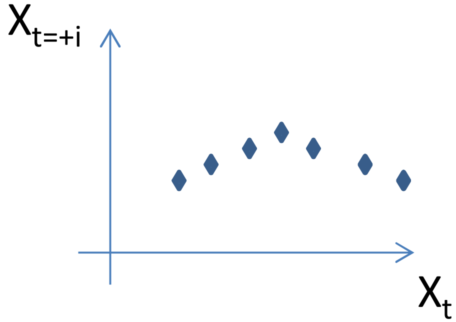
- **i = embedding dimension**: a way to analyse the predictability of the signal
- Can be extrapolated to 3, 4, etc. dimensions

Interpretation of phase plan

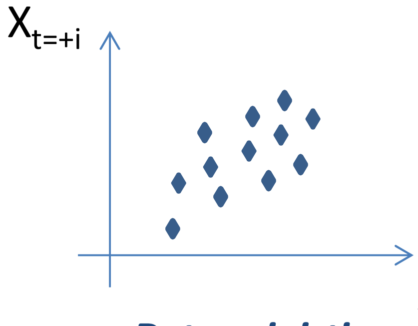
Predictable signals



Deterministic (monotonic)

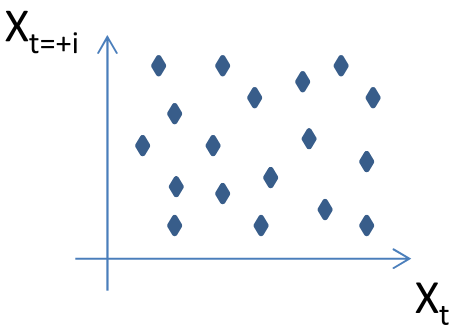


Deterministic (Non monotonic)

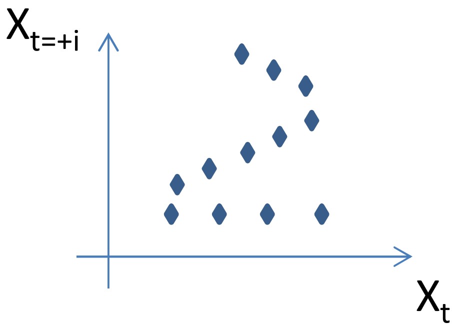


Deterministic+ some noise

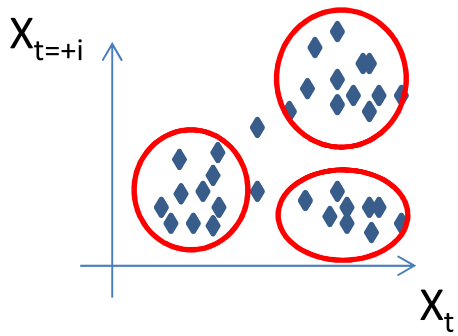
Non-Predictable signals



Random noise



Non linear (multiple outcomes)



Chaotic signal (& "strange" attractors)

Phase Plan Analysis of the Logistic Equation (# embeddings)

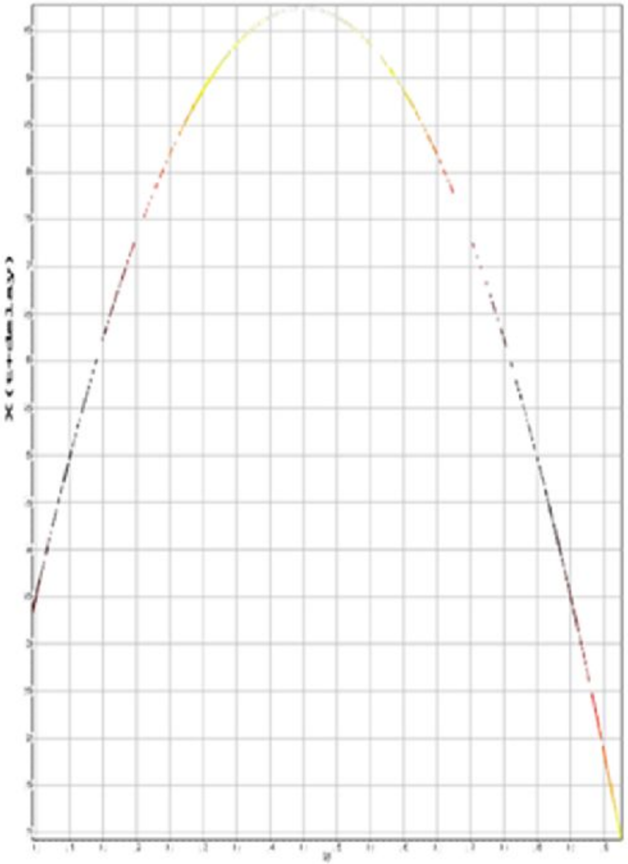


Fig 6a. Phase plot of the Logisitc equation. Embedding 01

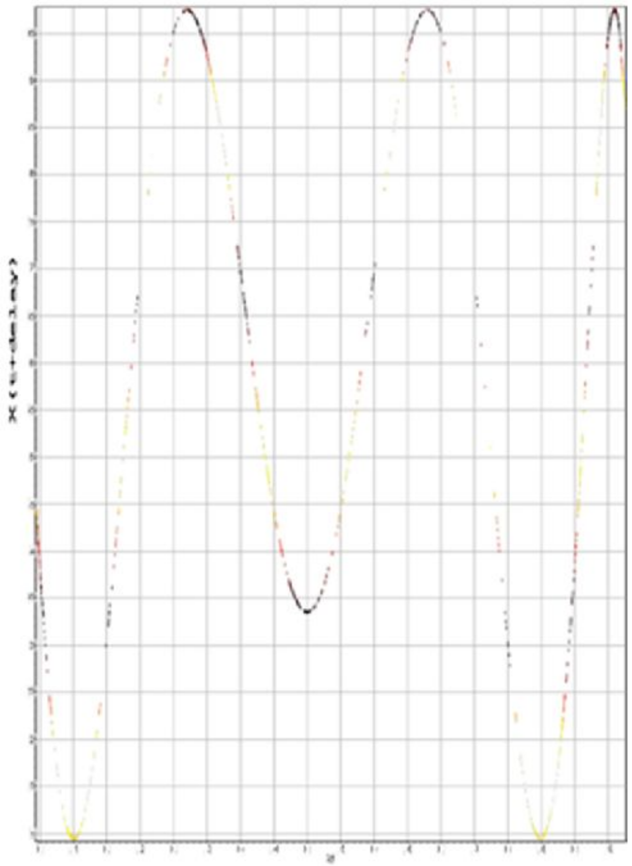


Fig 6b. Phase plot of the Logisitc equation. Embedding 03

Phase Plan Analysis of the Logistic Equation (# embeddings) (ctnd)

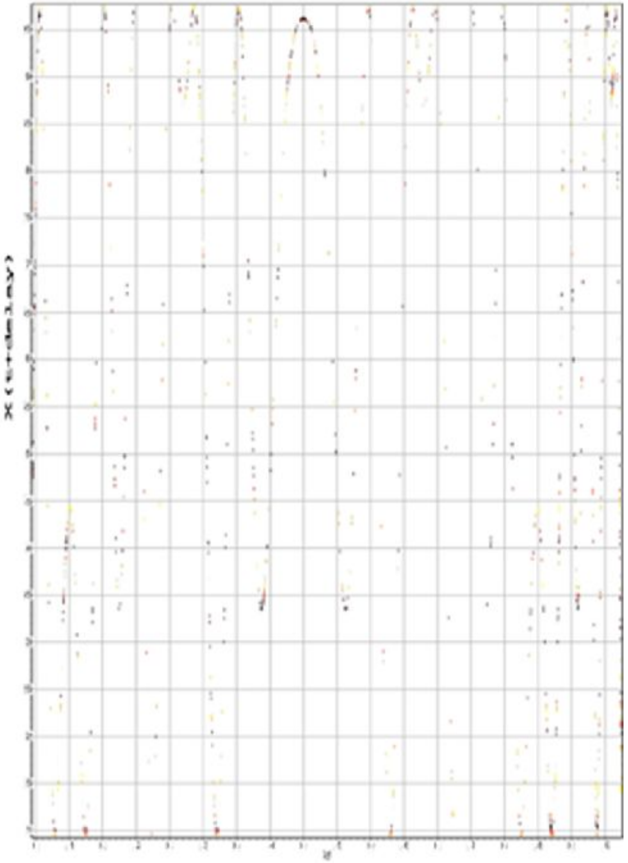


Fig 6c. Phase plot of the Logisitc equation. Embedding 06

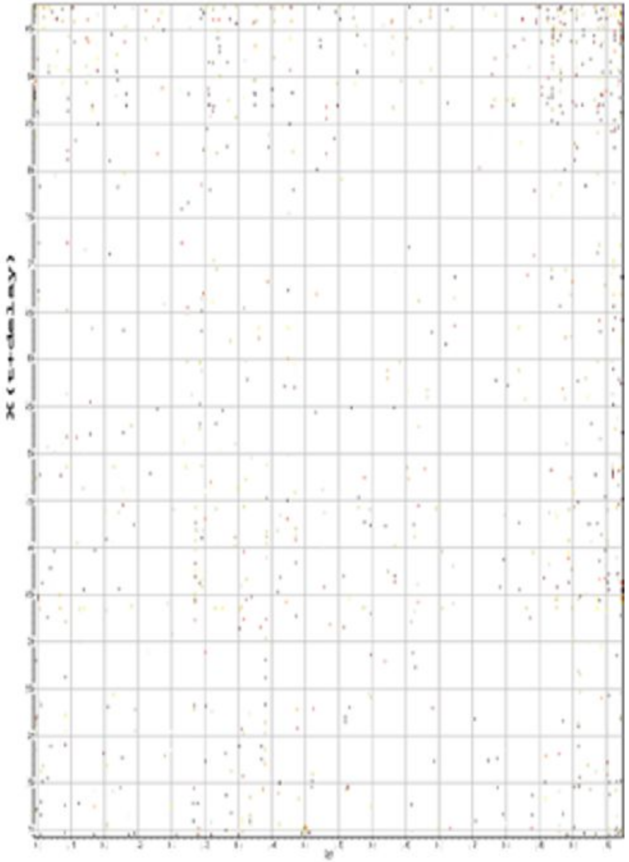
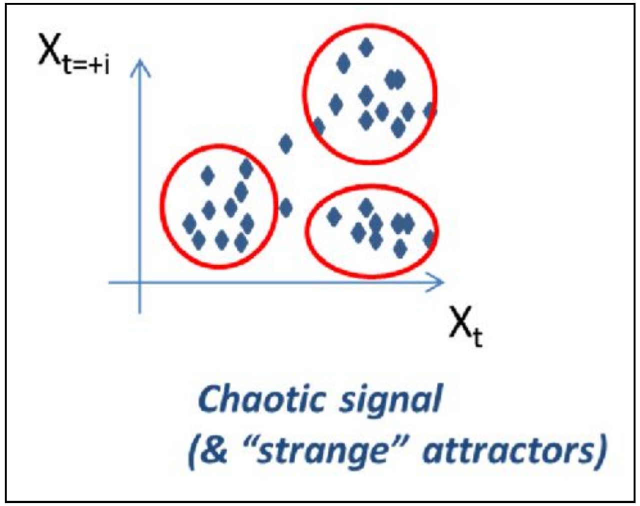


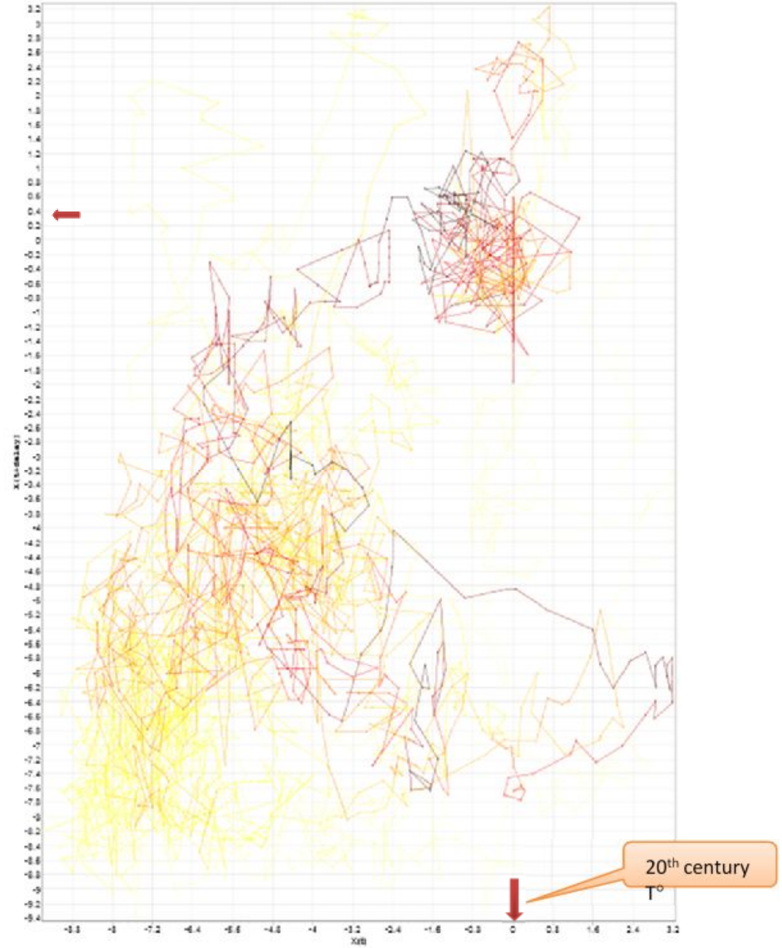
Fig 6d. Phase plot of the Logisitc equation. Embedding 10

It is impossible to predict the outcome of the logistic equation 10 steps ahead, only based on the corresponding time series (when one ignores the equation & value of parameters and initial conditions)

Phase diagram of the Vostök data

- The chaotic signature is obvious
- Predictability is very limited





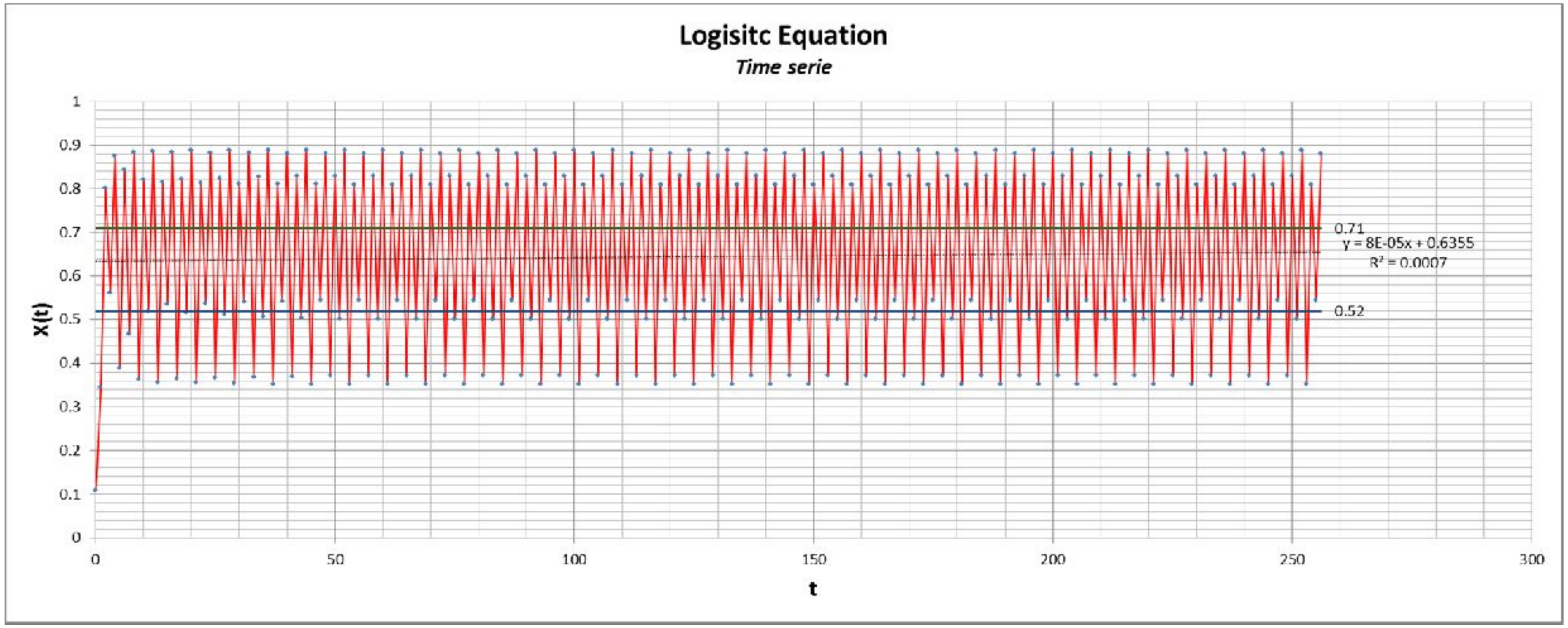
Quantitative Analysis of Phase Space

- **Embedding dimension (ED)**: the value of the time shift **i** in $X_{t+i} = f(X_t)$ (=> analysis of predictability)
- **Correlation Dimension (CD)**
  - C(ε) = probability that 2 points differ by less than ε in the phase space

$$\lim_{\varepsilon \to 0} \lim_{C \to \infty} \left(\frac{log(C)}{log(\varepsilon)} \right)$$

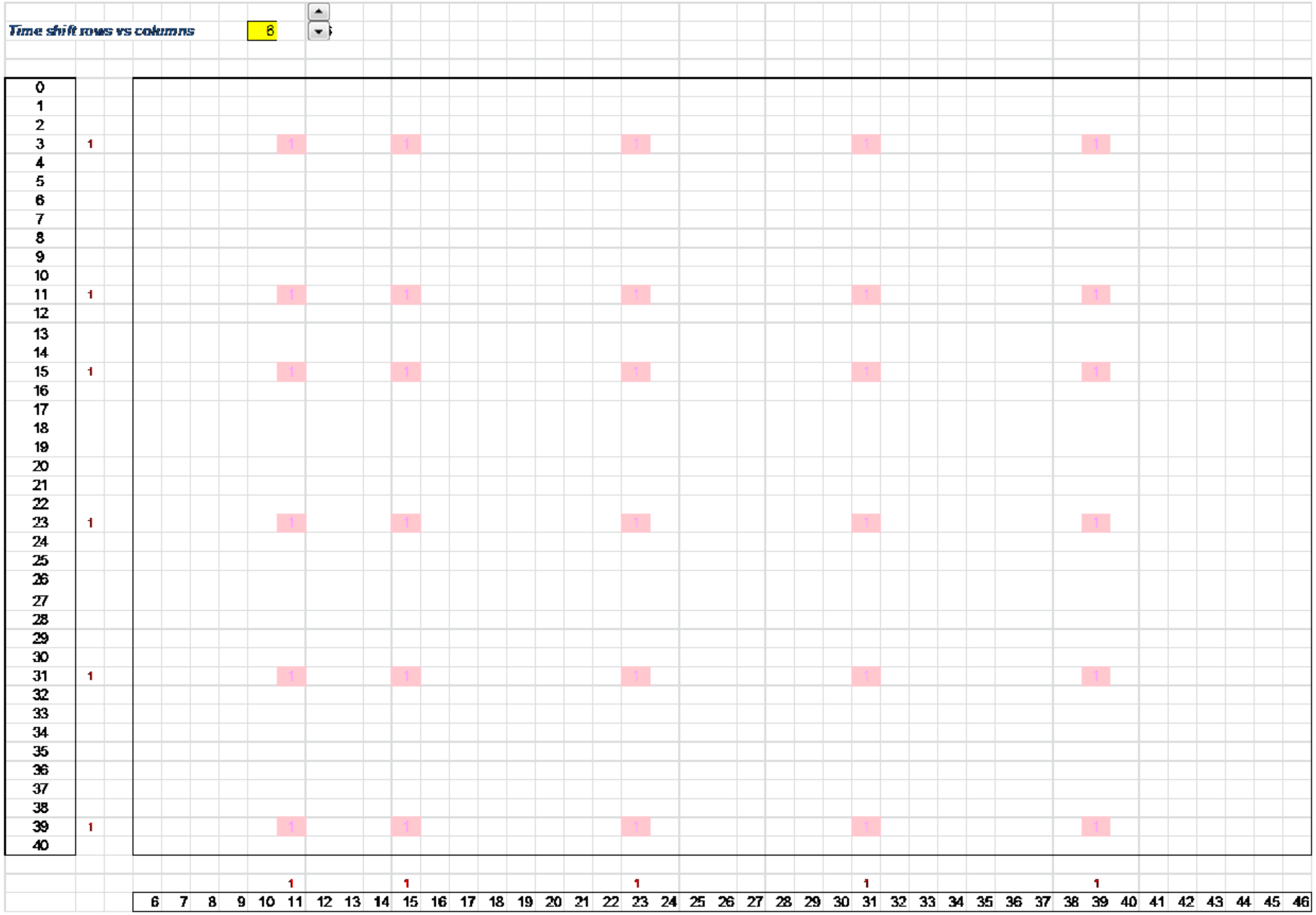
  - On Diagonal in graph CD versus ED (embedding dimension) if signal is random
  - Reaches some saturation for periodic or chaotic functions
  - If # integer: indication of a **fractal** dimension
- **False Nearest Neighbour**
  - Stays around 50% if signal is random
  - First minimum gives estimation of most interesting embedding dimension for random & periodic signals
- **Noise reduction** (# algorithms do exist)
- **Non parametric time series predictions** (without having to make an hypothesis on the shape of the relation)
- And many others (***Hurst*** coefficients, ***Lyapounov*** exponents, ….)

Recurrence Plot: Principle

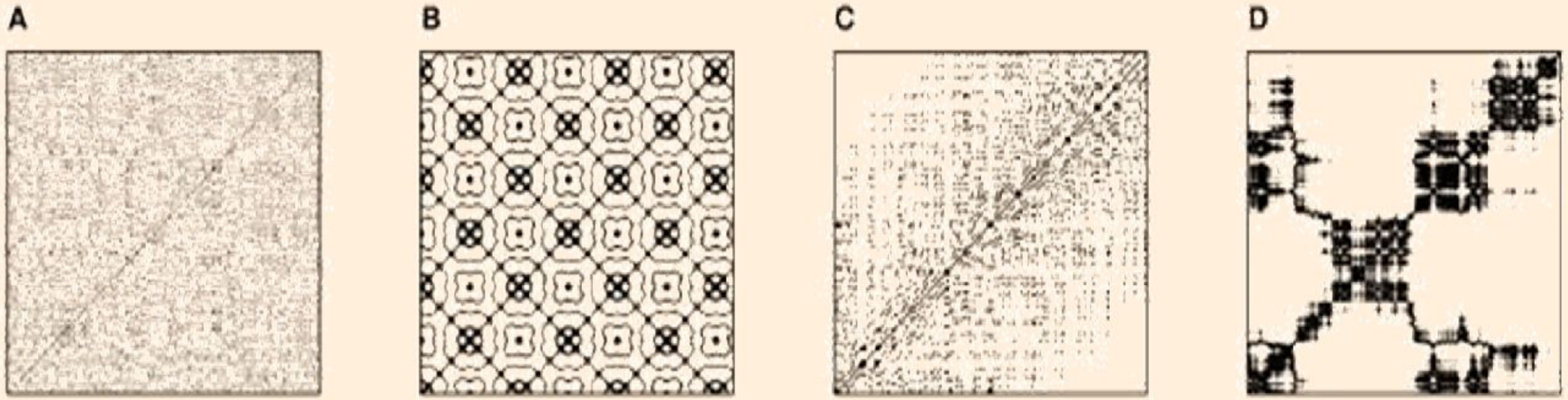


- Checks when the signal falls in a given amplitude window
- Time series is cut in strips of length **L**
- Each "strip is shifted towards the preceding one by **n**
- Strips are juxtaposed & the "*distances*" between neighbouring points are computed
- Different "distance windows" are superposed using colour coding
- Eventually: *Vectors of points* (spaced each other along the time series by the embedding dimension) are considered & the "distance" between the vectors is calculated
- Pattern recognition is applied
- Patterns are analysed ***qualitatively (visually) & quantitatively***

Recurrence Plot (one window)



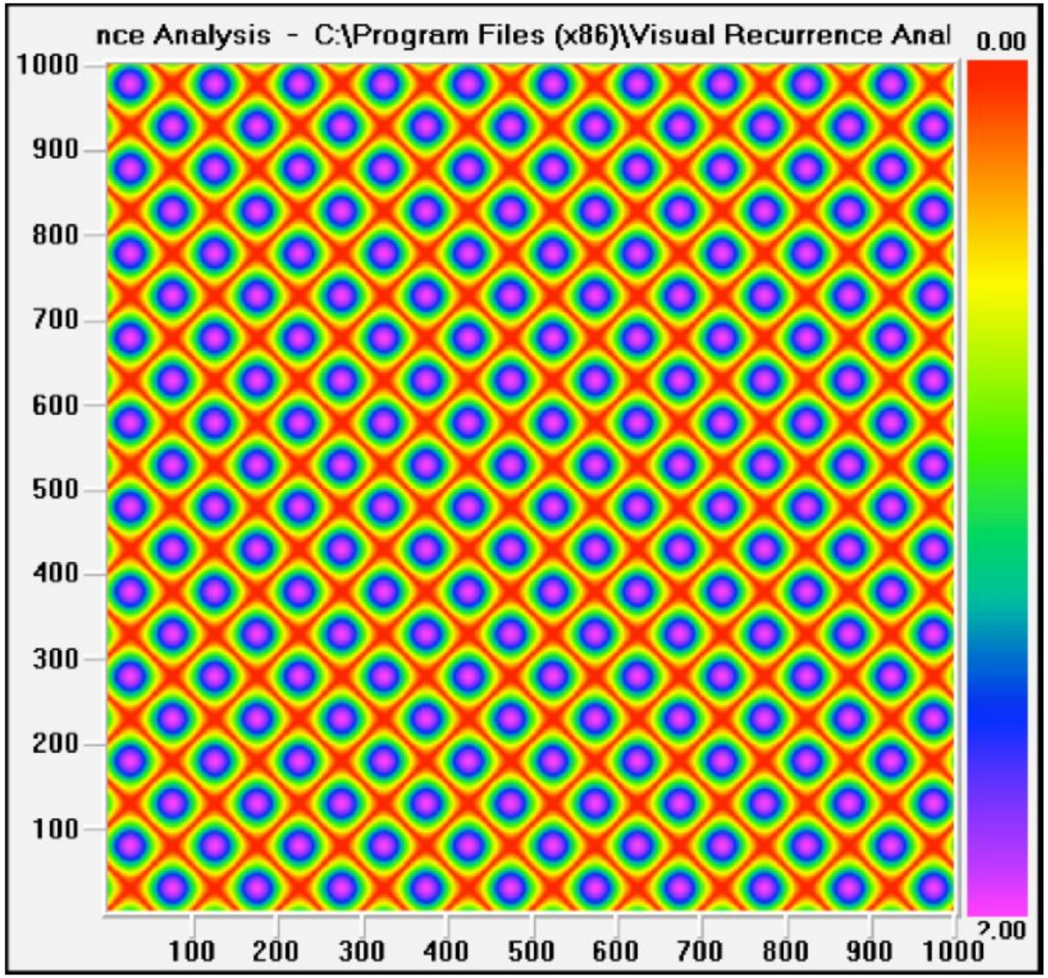
Recurrence Plot Signatures



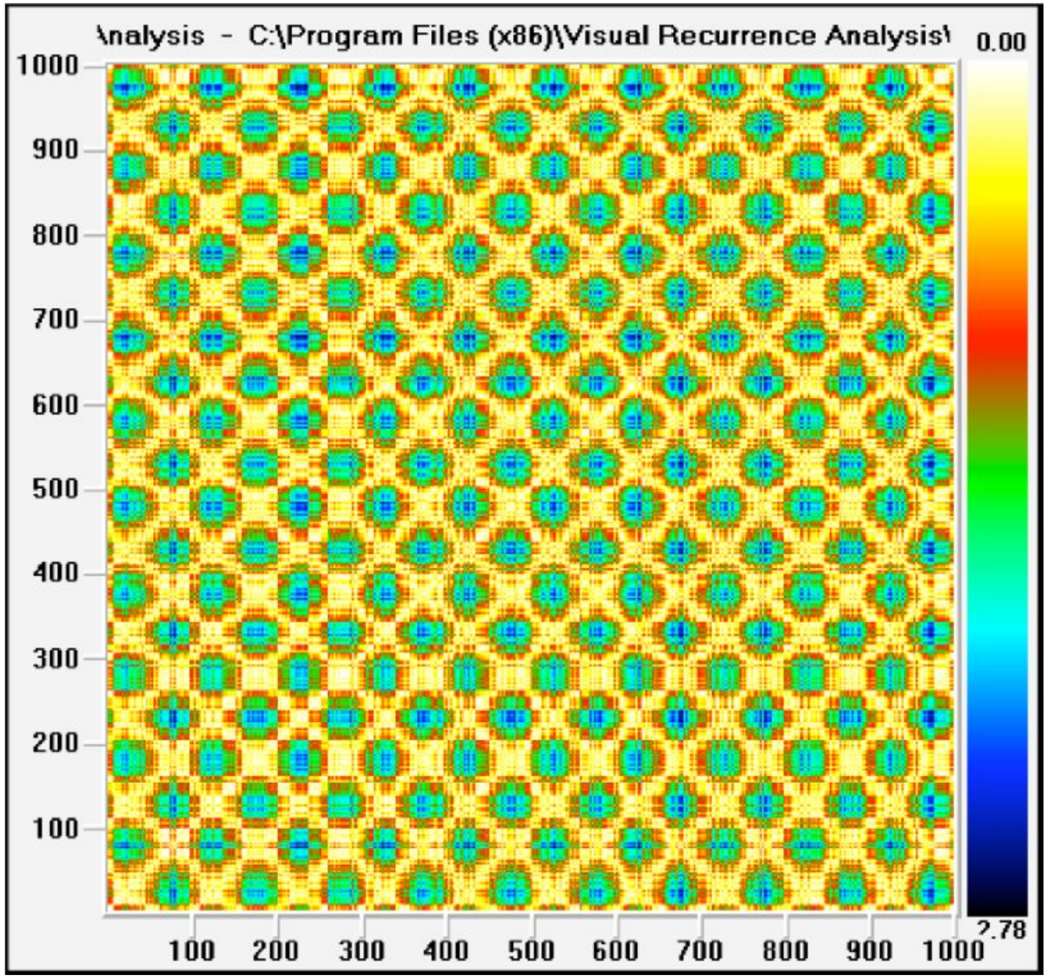
Characteristic typology of recurrence plots: (A) homogeneous (uniformly distributed noise), (B) periodic (super-positioned harmonic oscillations), (C) drift (logistic map corrupted with a linearly increasing term) and (D) disrupted (Brownian motion). These examples illustrate how different RPs can be. The used data have the length 400 (A, B, D) and 150 (C), respectively; no embeddings are used; the thresholds are ε=0.2 (A, C, D) and ε=0.4 (B).

A vertical-horizontal cross through the diagram = some exceptional event.

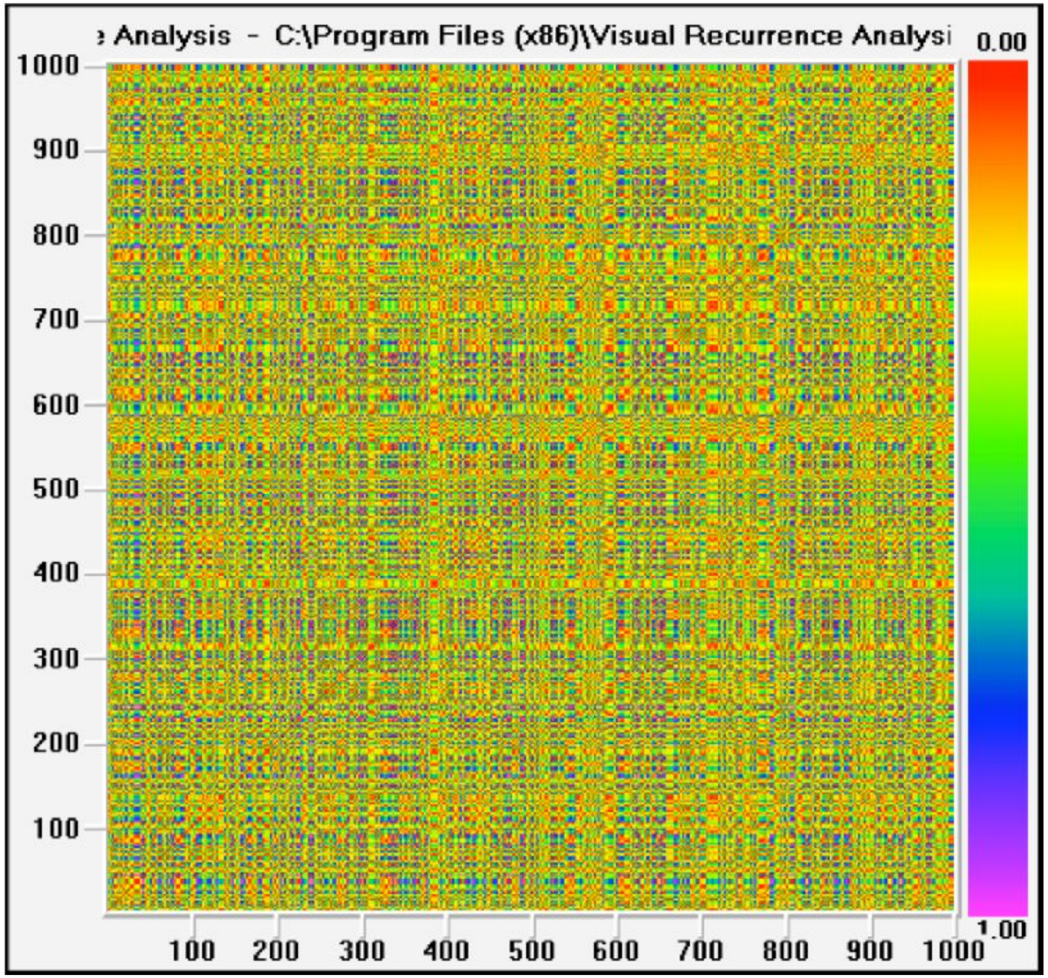
R.P. for a sinusoid



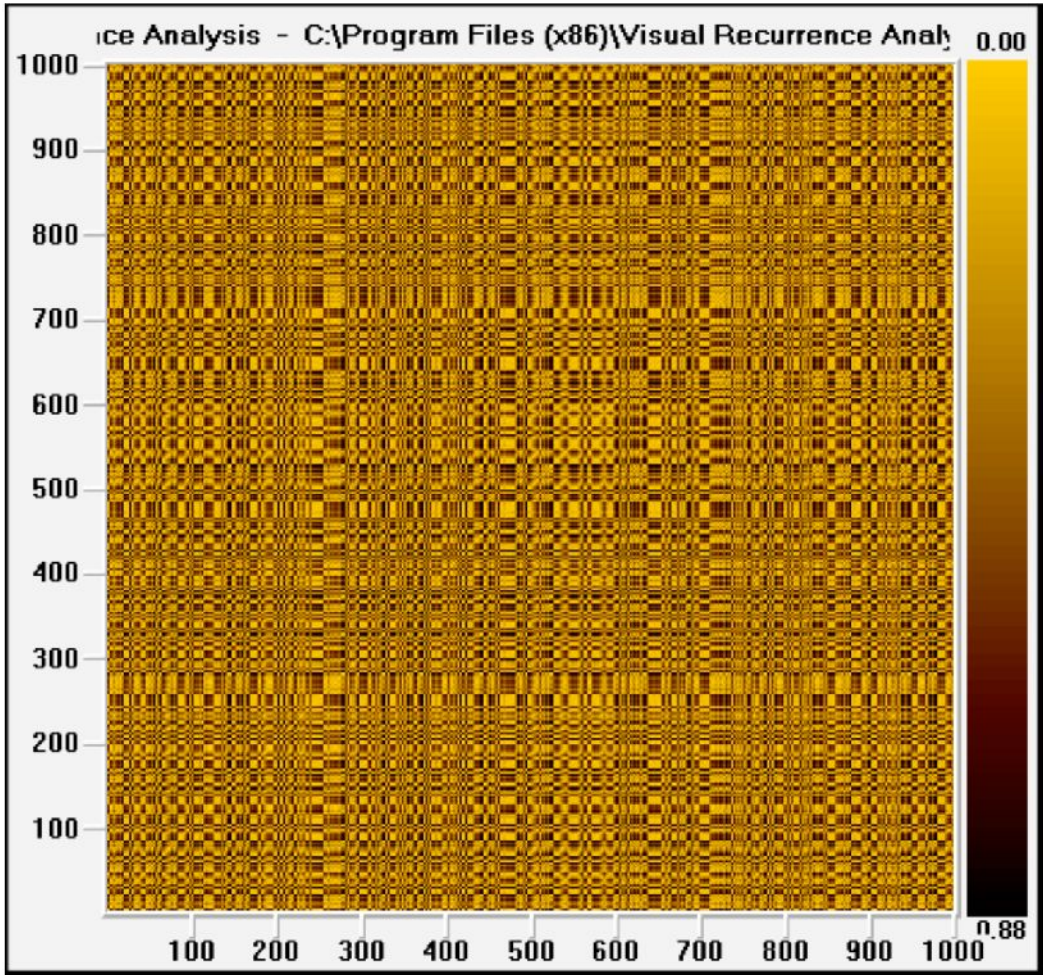
R.P. for Sinusoid + noise



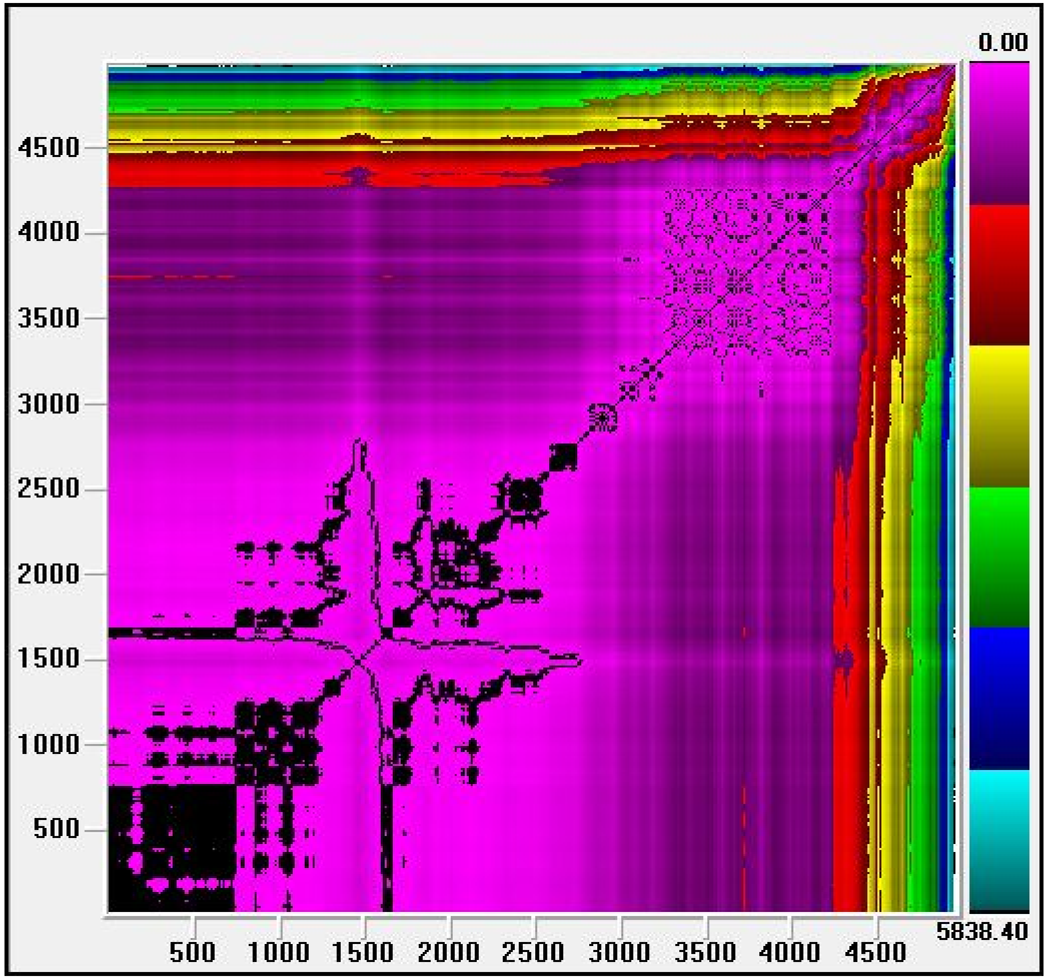
R. P. for a Random Signal



RP for the Logistic Curve

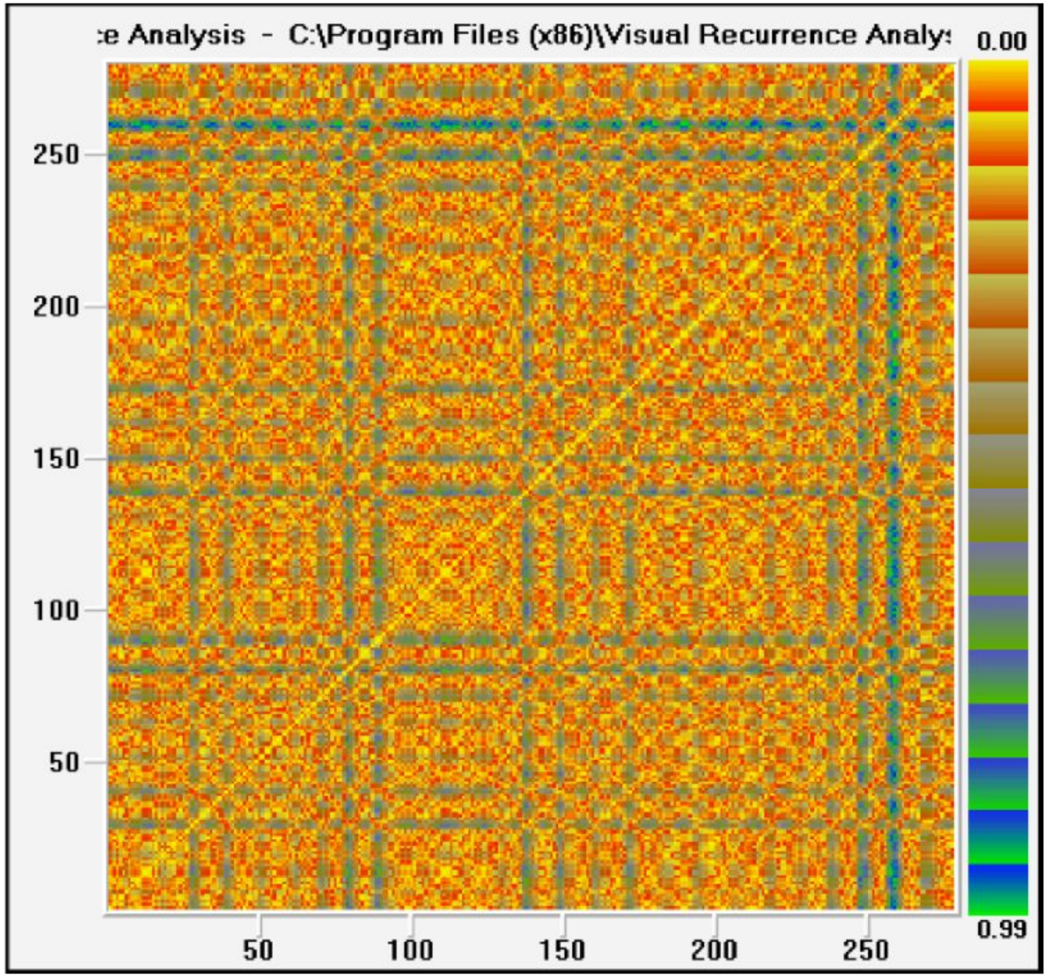


R.P. for Dow Jones

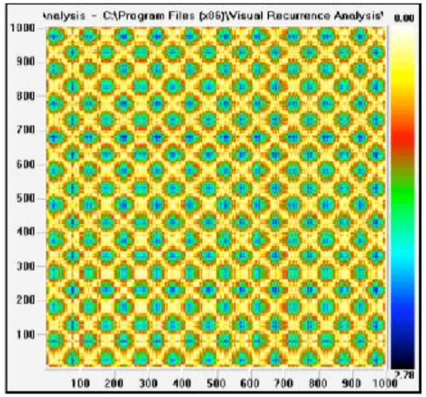


A trend line in time series => "structures" at two ends of the diagonal

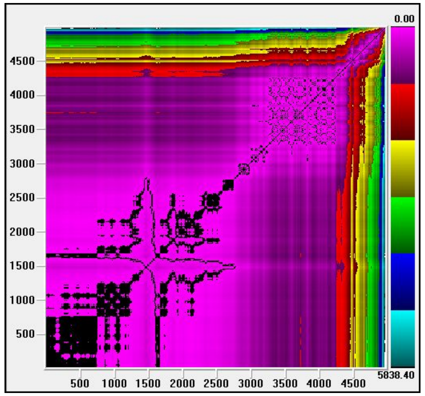
R.P for
Sun Spots Number



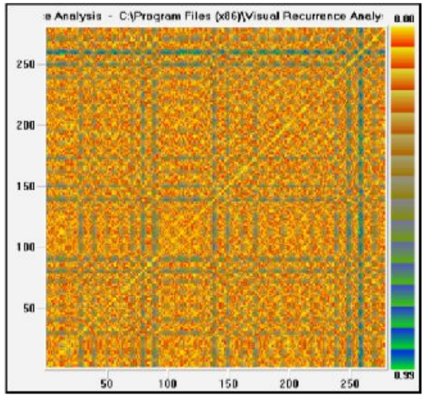
R.P. for Local Temperature Time Series



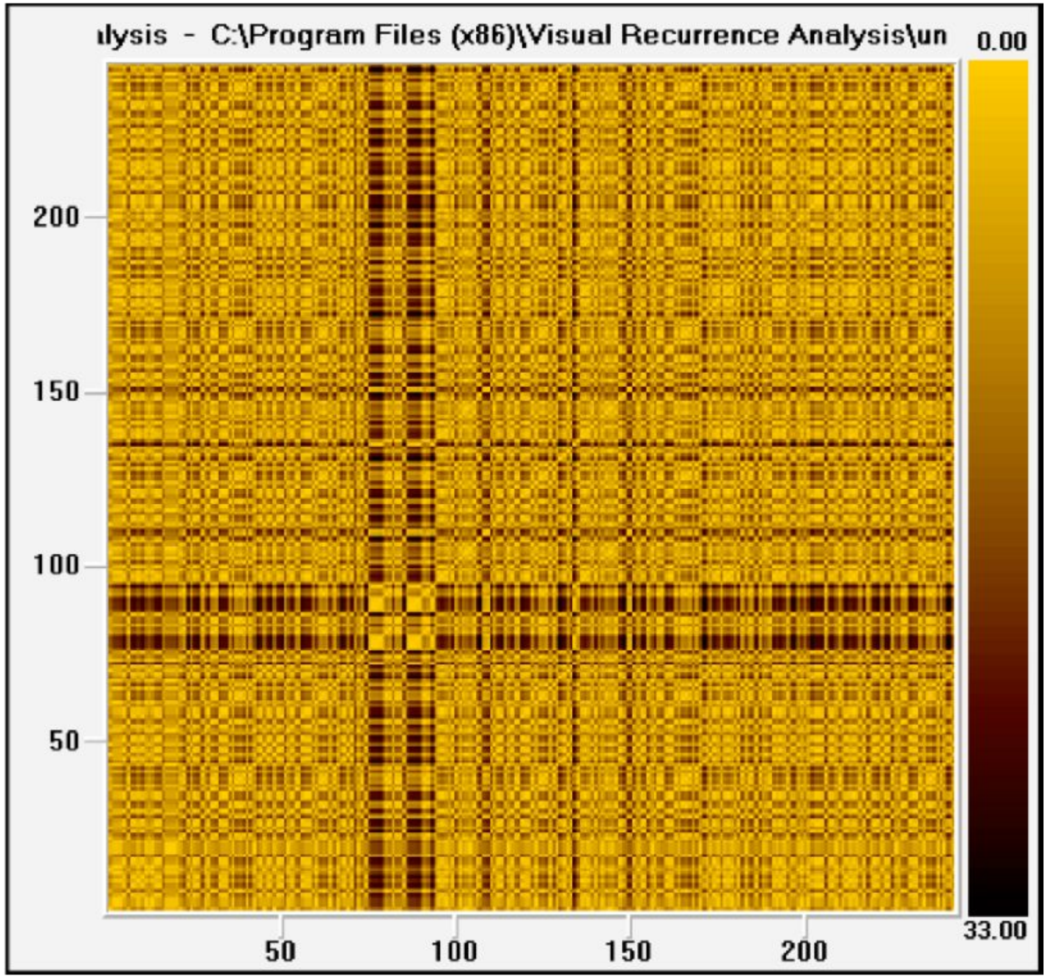
Sinusoid
+ noise



Trend
line



Number
of sun
spots
(chaotic)

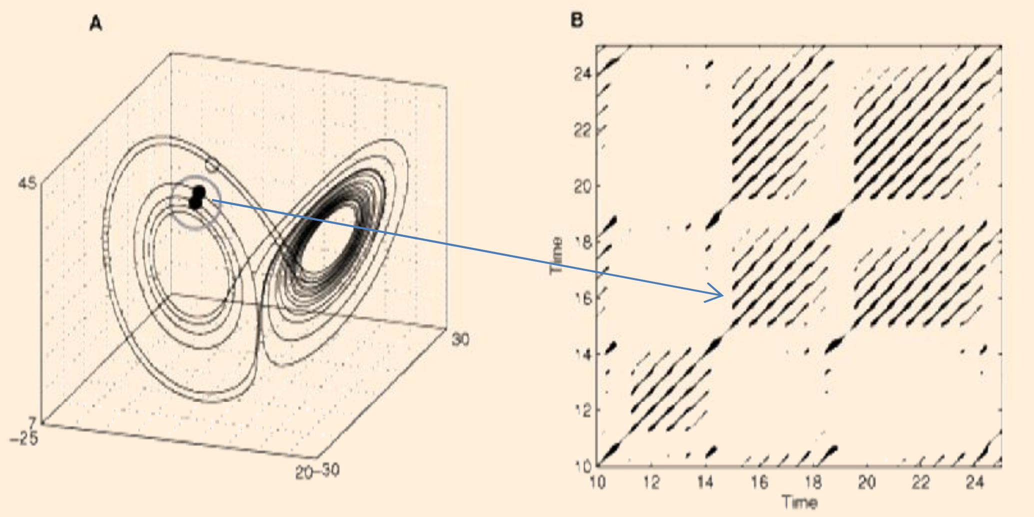


Daily Averaged Temperature in Brussels since 1830 (30 000 points)….**NO TREND….similar to R.P. for sun spots….Chaotic signature**

Quantitative Analysis of Recurrence Plots

- ***Length of vertical signals***: persistence
- ***Regular patterns & oblique lines***: periodic signal spaces by 1/4th of a period
- ***Length of interrupted oblique lines***: extended of corruption of a periodic signal by noise
- ***Size & extend of chaotic patterns & blanks***
- Etc.

Link between Phase Space and Recurrence Plot



(A) Segment of the phase space trajectory of the Lorenz system (for standard parameters $r=28$, $\sigma=10$, $b=8/3$; Lorenz, 1963) by using its three components and (B) its corresponding recurrence plot. A point of the trajectory at j which falls into the neighbourhood (gray circle in (A)) of a given point at i is considered as a recurrence point (black point on the trajectory in (A)). This is marked with a black point in the RP at the location (i, j). A point outside the neighbourhood (small circle in (A)) causes a white point in the RP. The radius of the neighbourhood for the RP is $\varepsilon=5$.

WAVELETS ANALYSIS

Principle of Wavelets Analysis
(spectrograms, scalograms, …)

- Adapted from *voice recognition* methods
- A signal filetring technique aimed to represent
  - As function of *time* (horizontal axis)
  - The contribution of different *frequencies* (vertical axis) to the *power* of the signal (colour coded third dimension of the graph)

- ⇔ ***evolution over time of a Power Spectrum*** (already described).

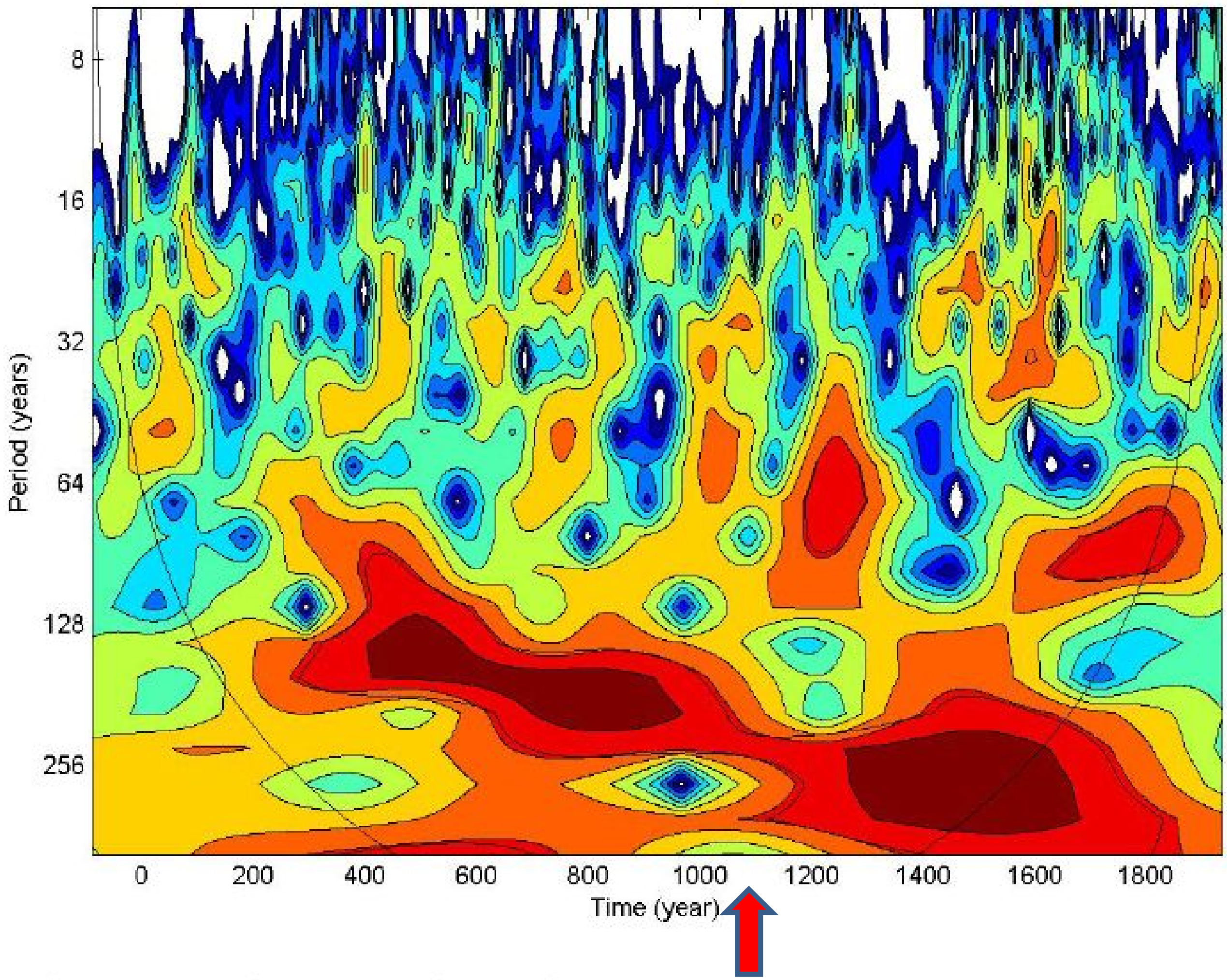
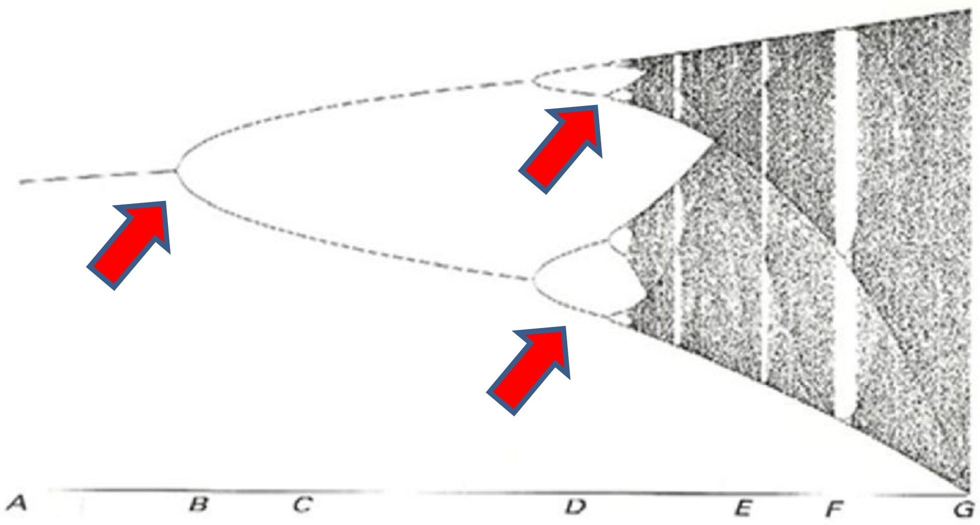


Fig. 4. *(color online) Wavelet (Morlet) spectrum [18] of the interpolated SPA record from -90 until 1935 AD. The solid black line from the left to the right top of the Figure is the cone of influence (below the coi the results are not significant). The spectrum shows that the power density between the period of 128 and 256 years is moving with increasing time to lower frequencies. This area is only badly resolved in M6 (see Fig. 3, left panel)*

H-J. Ludecke, A. Hempelmann, and C. O. Weiss (2012)

Bifurcations are a signature for chaotic signals

(recall of the bifurcation diagram for the logisitc equation)



Order and chaos in the model of restricted growth $x \rightarrow ax(1-x)$

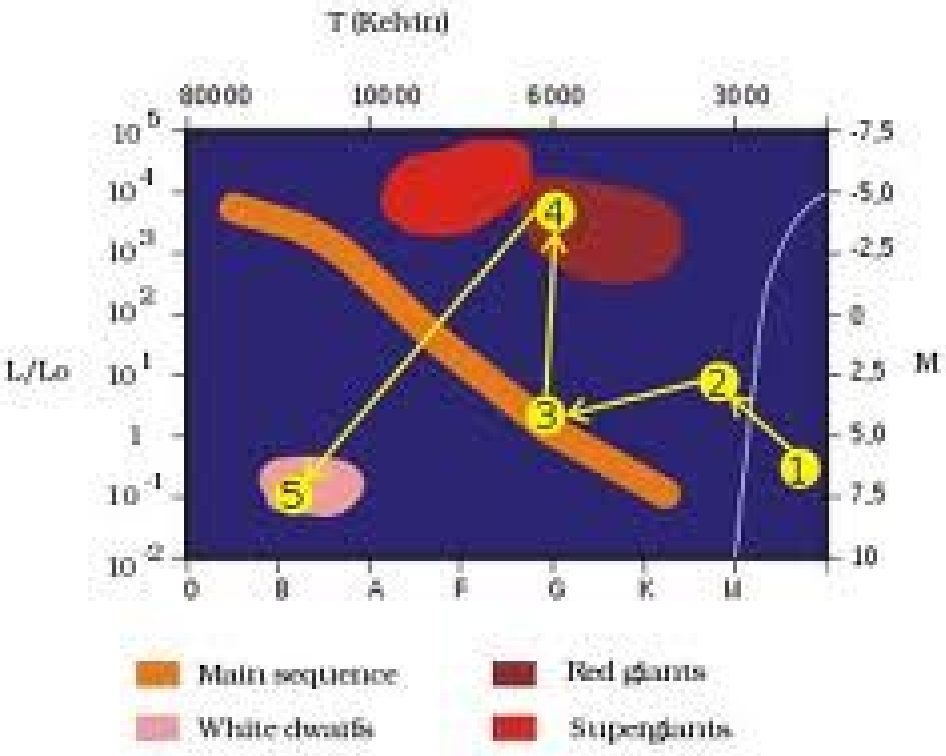
A	$a = 2.9$	single limit point
B	$a = 3.0$	transition to 2-cycle
C	$a = 3.2$	2-cycle
D	$a = 3.5$	4-cycle
E	$a = 3.74$	5-cycle
F	$a = 3.83$	3-cycle
G	$a = 4.0$	complete chaos

The data of Ludecke et all, obtained from measurements made on stalactites in a Bavarian cave *show the progressive (and slow) move of the climate system towards a (less and less predictable) Chaotic State.*

A significant bifurcation happened around year 1000.

This is probably due to some astrophysical event (explosion of giant star becoming a supernovae in the crab constellation?)…. but ***surely not due to anthropogenic carbon***

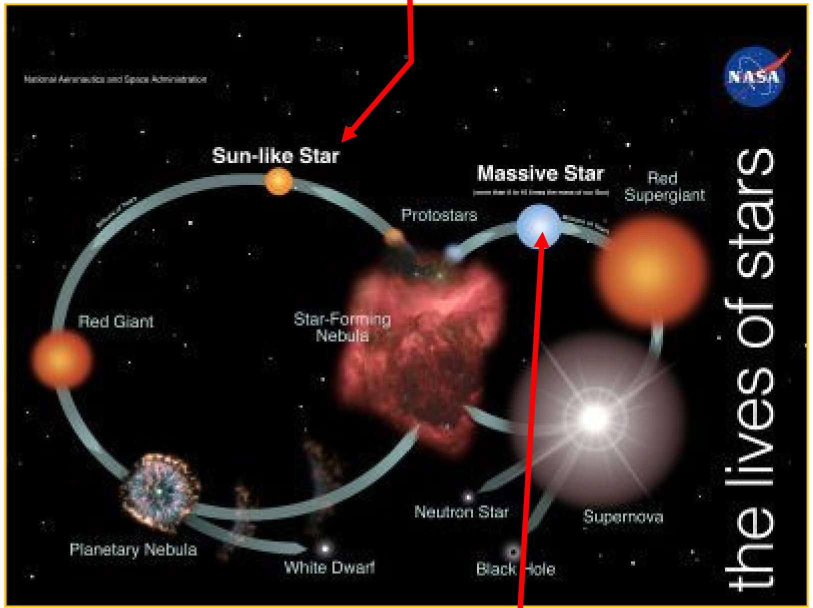
In brief: The fate of stars……



Evolution of stars in a graph (Log) Relative Irradiance (present Sun =1) versus temperature (°K) .

The Sun (small star) is presently in *phase 3* (irradiance =1) & will evolve towards a red giant (4) before exploding into a Nebula in …..millions of years(?) before becoming a white dwarf (5)

Small star (Sun) => Giant red => nebula => white dwarf (sequence 1 to 5 , on the left figure)



Massive star => hyper-giant red star => supernova=> Neutronic star + black hole

Size of the Universe....

- Mass of the Sun = 330 000 *earth mass
- Mass Jupiter = 2.5* Σ (mass of all other planets in solar system)
- Etc...

(www.cosmonline.co.uk)

Neither significant electro-magnetic nor significant gravitational influence on:

- ***earth rotation speed?***
- ***Position of rotation axis?***
- ***Magnetosphere?***
- ***Stresses in magma and tectonic plates (= vulcanism)?***
- ***Movement of oceans***
- ***Movement of anticyclones & barometric depressions zones??***

10 –Crab Nebula= Results from the Explosion of a giant star in Supernova during year 1054
(observed by Chinese astronoms)

MORE GENERAL CONSIDERATIONS & CONCLUSIONS

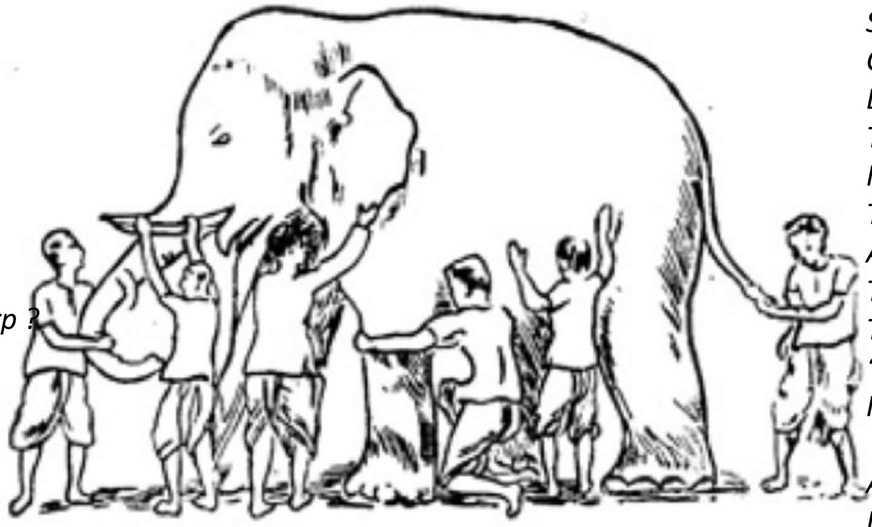
“ The Blind Men and the Elephant ”

an Hindu fable

It was six men of Hindustan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind

.

*The **First** approached the Elephant,*
And happening to fall
*Against his **broad and sturdy side**,*
At once began to bawl :
“ God bless me ! – but the Elephant
*Is very like a **wall !** ”*
*The **Second**, feeling of **the tusk**,*
Cried : “ Ho ! – what have we here
So very round and smooth and sharp ?
To me ‘t is mighty clear
This wonder of an Elephant
*Is very like a **spear** ! ”*
*The **Third** approached the animal,*
And happening to take
*The squirming **trunk** within his hands,*
Thus boldly up and spake :
“ I see, ” quoth he, “ the Elephant
*Is very like a **snake** ! ”*
*The **Fourth** reached out his eager hand,*
*And felt about the **knee**.*
“ What most this wondrous beast is like
Is mighty plain, ” quoth he ;
“ T is clear enough the Elephant
*Is very like **a tree** ! ”*



Importance of:

- Multidisciplinary Dialogue
- Reconstructing the complete picture (systemic thinking)

*The **Fifth**, who chanced to touch the **ear**,*
Said : “ E’en the blindest man
Can tell what this resembles most ;
Deny the fact who can,
This marvel of an Elephant
*Is very like **a fan** ! ”*
*The **Sixth** no sooner had begun*
About the beast to grope,
*Then, seizing on the swinging **tail***
That fell within his scope,
“ I see, ” quote he, “ the Elephant
*Is very like a **rope** ! ”*

And so these men of Hindustan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong !
So, oft in theologic wars
The disputants, I ween,
Rail on in utter ignorance
Of what each other mean,
And prate about an Elephant
Not one of them has seen !

« *The Science is Settled* »???

Some of the Key Near-term Science Challenges in Climate and Large Scale Dynamics

- *Modelling and prediction of organized tropical convection'*
- *Tropical-extratropical interactions; storm tracks and moisture transports*
- *Role of atmosphere-ocean interactions in intra-seasonal variability*
- *Systematic zonal flow variations: mechanisms and predictive implications*
- *Predictability of tropospheric wave guides and baroclinic wave packets*
- *Troposphere-stratosphere interactions; modelling and potential predictability*
- *Variability of climate modes beyond ENSO and MJO*
- *Effects of global ocean conditions, e.g. tropical Indian and Atlantic Oceans*
- *Effects of land surface processes*
- *Warm season climate system and its predictability*
- *Potential implications of climate change*

Attribution problems

- ***Type 1****: How do you disentangle natural variability of the climate/earth system from 'forced' change?*
- ***Type 2****: Given that the climate system is changing due to anthropogenic effects, how do you attribute particular events to the change? What are the conditionnal PDFs?*

Michael Morgan paper presented at UCAR (*University Corporation for Atmospheric Sciences*) Annual Member's Meeting (Boulder, USA, *November 2012*).

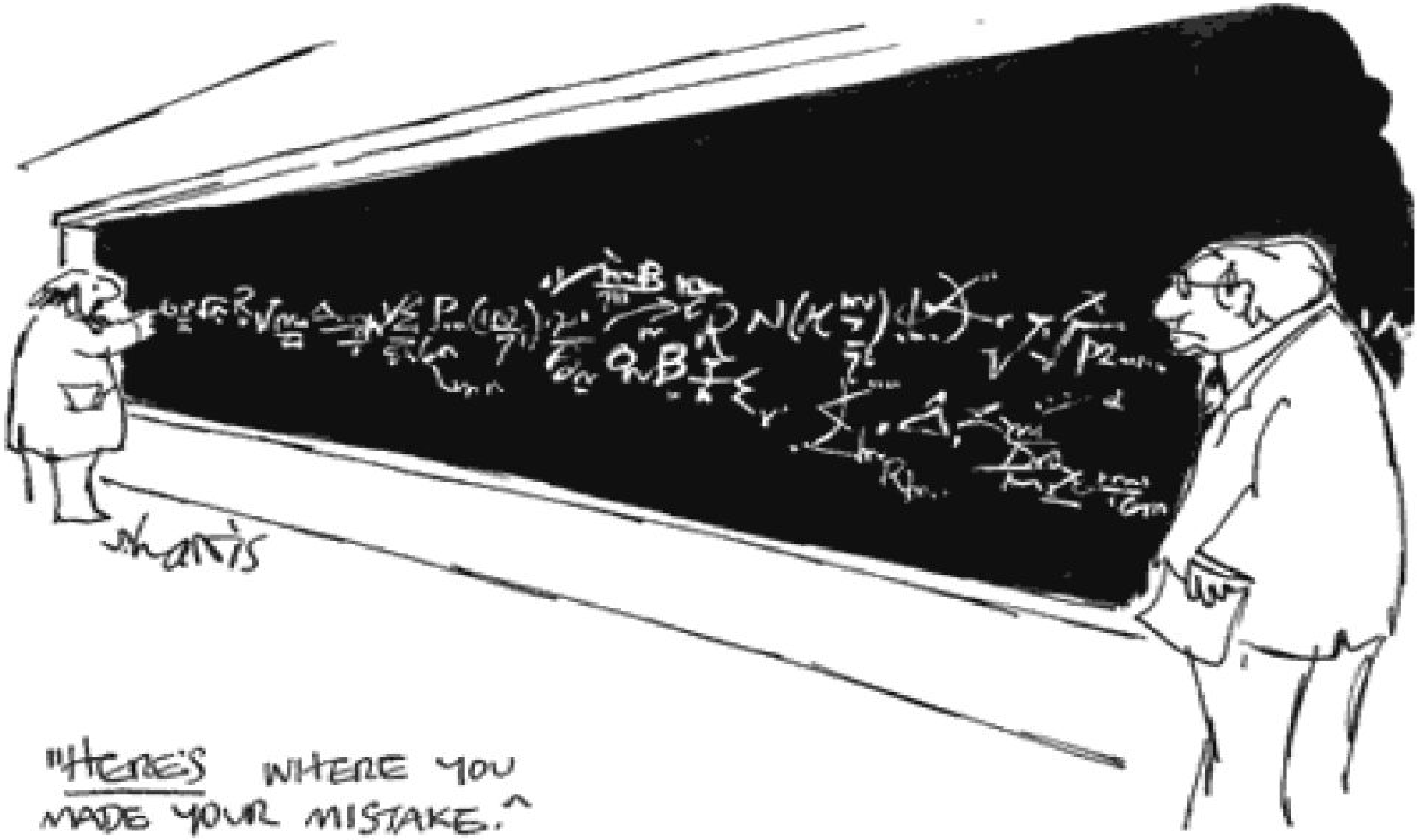
UCAR is the governing body of the National Centre for Atmospheric Research (NCAR).

Conclusions

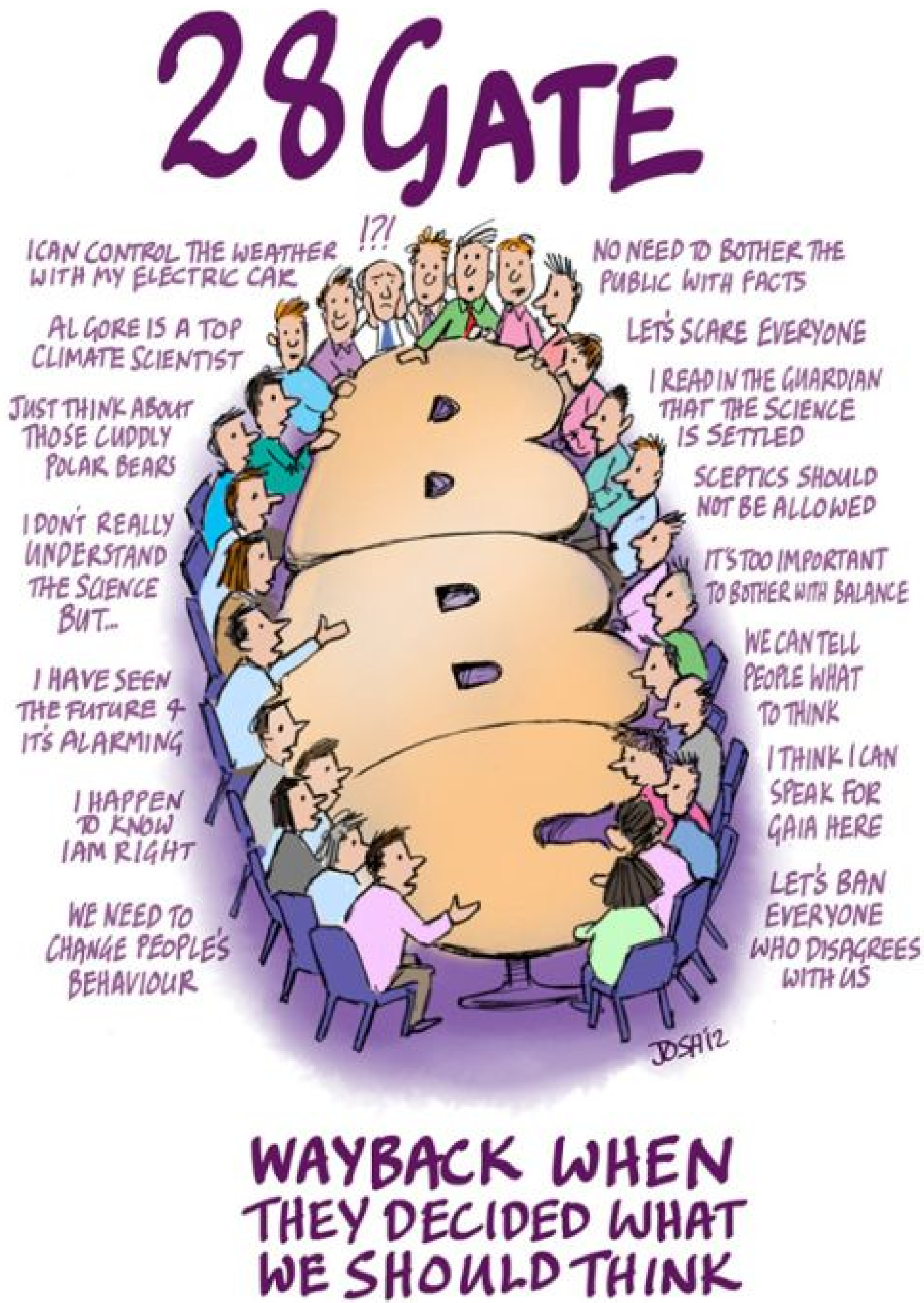
- **Linear analysis** of (climate) time series are affected by serious drawbacks, especially when the time window considered is too small and when data exhibit some oscillatory component.
- The climate system is slowly evolving with time towards **chaos**, which makes it *difficult to predict on the long term*
- As transition to chaos happens through bifurcations (creation of harmonics of a fundamental period), *the best possible forecasting method, on the short term is by Fourier analysis (sum of sinusoids)*
- This trend towards a chaotic state started many centuries *before anthropogenic carbon emissions became significant*
- The climate system is much more complicated than described by IPCC models, so far.
- Complex systems may create **synchronisation (or phase locking)** between oscillating phenomena, by **mutual** intermittent influence, but *without any formal causal (continuous) links between them*
- ***The master clock*** could be of *astrophysical origin (conjunction of planets, influence of supernovae, etc*.) & its signals are probably of *combined gravitational and magnetic nature*

THAT'S (QUITE) ALL FOLKS

Initially, something went wrong with the IPCC models



What happens in Doha?



It's that same old song…

INTERNATIONAL CLIMATE CHANGE NEGOTIATIONS
POZNAN
Come join the circus!
Where the hell was THAT?
What a joke that was!
COPENHAGEN
er–
Bolivia, go home!
CANCUN
DURBAN

"Dreaming of a White Christmas!"

Fortunately the science is not yet settled … and we have a lot of things to debate on…. And meet again

THANK YOU FOR YOUR ATTENTION

Source data

CLIMATIC INDICATORS

Climatic Indicators

PNA	***Pacific North American Index*:***From NOAA Climate Prediction Center (CPC)
EP/NP	***East Pacific/North Pacific Oscillation:***From NOAA Climate Prediction Center (CPC). This index replaces the old EP index which is no longer maintained by CPC.
WP	***Western Pacific Index**** From NOAA Climate Prediction Center (CPC)
NAO	***North Atlantic Oscillation**** From NOAA Climate Prediction Center (CPC)
NAO (Jones)	***North Atlantic Oscillation*** From CRU Hurrell, J.W., 1995: Decadal trends in the North Atlantic Oscillation and relationships to regional temperature and precipitation. Science 269, 676-679. Jones, P.D., Jónsson, T. and Wheeler, D., 1997: Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. Int. J. Climatol. 17, 1433-1450.
SOI*	***Southern Oscillation Index*** From NOAA Climate Prediction Center (CPC)
Nino 3*	***Eastern Tropical Pacific SST***(5N-5S,150W-90W) From NOAA Climate Prediction Center (CPC)
BEST* longer version	***Bivariate ENSO Timeseries*** Calculated from combining a standardized SOI and a standardized Nino3.4 SST timeseries. **Note that different SST dataset (Hadley SST) is now used to calculate Nino 3.4 timeseries. This replaces the GISST dataset. Most recent data is based on the NOAA OI V2 SST dataset.** PSD
TNA	***Tropical Northern Atlantic Index****Anomaly of the average of the monthly SST from 5.5N to 23.5N and 15W to 57.5W. GISST and NOAA OI 1x1 datasets are used to create index. Climatology is 1951-2000. Enfield, D.B., A.M. Mestas, D.A. Mayer, and L. Cid-Serrano, 1999: How ubiquitous is the dipole relationship in tropical Atlantic sea surface temperatures? JGR-O, 104, 7841-7848.AOML and PSD
TSA	***Tropical Southern Atlantic Index****Anomaly of the average of the monthly SST from Eq-20S and 10E-30W. GISST and NOAA OI 1x1 datasets are used to create index. Climatology is 1951-2000. Enfield, D.B., A.M. Mestas, D.A. Mayer, and L. Cid-Serrano, 1999: How ubiquitous is the dipole relationship in tropical Atlantic sea surface temperatures? JGR-O, 104, 7841-7848.AOMLand PSD
WHWP	***Western Hemisphere warm pool****Monthly anomaly of the ocean surface area warmer than 28.5°C in the Atlantic and eastern North Pacific. Climatology is 1951-2000. Wang, C., and D.B. Enfield, 2001: The tropical Western Hemisphere warm pool, Geophys. Res. Lett., 28, 1635-1638.AOML and PSD
ONI	***Oceanic Nino Index*** From NOAA Climate Prediction Center (CPC). Three month running mean of NOAA ERSST.v2 SST anomalies in the Nino 3.4 region (5N-5S, 120-170W), based on the 1971-2000 base period. Time Series is a newer version from source!
MEI	***Multivariate ENSO Index (MEI)**** From PSD. Time series is bimonthly so the Jan value represents the Dec-Jan value and is centered between the months. Details and current values are at Dr Wolter's website. Reference: Wolter, K., and M.S. Timlin, 1998: Measuring the strength of ENSO - how does 1997/98 rank? Weather, 53, 315-324.

Climatic Indicators (1)

MEI	***Multivariate ENSO Index (MEI)**** From PSD. Time series is bimonthly so the Jan value represents the Dec-Jan value and is centered between the months. Details and current values are at Dr Wolter's website. Reference: Wolter, K., and M.S. Timlin, 1998: Measuring the strength of ENSO - how does 1997/98 rank? Weather, 53, 315-324.
Nino 1+2	***Extreme Eastern Tropical Pacific SST*** *(0-10S, 90W-80W) From CPC
Nino 4	***Central Tropical Pacific SST*** *(5N-5S) (160E-150W) From CPC
Nino 3.4	***East Central Tropical Pacific SST****(5N-5S)(170-120W) From CPC
PDO	***Pacific Decadal Oscillation*** is the leading PC of monthly SST anomalies in the North Pacific Ocean.**UPDATED: Using data from 1948 to 2002.**Details and more information are available.
NOI	***Northern Oscillation Index*** is an index of climate variability based on the difference in SLP anomalies at the North Pacific High and near Darwin Australia. Schwing, F.B., T. Murphree, and P.M. Green. 2002. The Northern Oscillation Index (NOI): a new climate index for the northeast Pacific. Progress in Oceanography 53: 115-139.The time series and more information are available.
NP	***North Pacific pattern*** is the area-weighted sea level pressure over the region 30N-65N, 160E-140W. Time series source Trenberth and Hurrell (1994): Climate Dynamics 9:303-319.
TNI (Trans-Niño Index)	Indices of El Niño evolution: Kevin E. Trenberth and David P. Stepaniak: ***J. Climate***, **14**, 1697-1701. calculated at PSD. for longer tiumeseries, go to http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/TNI/
Trend	A linear time series (1,2,3,...). **NOT** the linear trend of the variable
Hurricane activity	**(Updated to 2003) Monthly totals Atlantic hurricanes and named tropical storms** Each month has the total number of hurricanes or named tropical storms in that month in the Atlantic region. These values are from Unisys at http://weather.unisys.com/hurricane/atlantic/ who obtained them from Colorado State/Tropical Prediction Center. **I** computed the number of hurricanes that begin in each month. Note that the hurricane might extend to the next month but won't be listed there. Their webpage should be read for a more complete description and attribution.
AO	Note, values are now from CPC as they update their data through the present From CPC: The loading pattern of AO (AAO) is defined as the first leading mode from the EOF analysis of monthly mean height anomalies at 1000-hPa (NH) or 700-hPa (SH). Note that year-round monthly mean anomaly data has been used to obtain the loading patterns. Since the AO and AAO have the largest variability during the cold sesaon (variance of AO/AAO), the loading patterns primarily capture characteristics of the cold season patterns. Daily and monthly AO (AAO) indices are constructed by projecting the daily and monthly mean 1000-hPa (700-hPa) height anomalies onto the leading EOF mode. Both time series are normalized by the standard deviation of the monthly index (1979-2000 base period). Since the loading pattern of AO (AAO) is obtained using the monthly mean height anomaly dataset, the index corresponding to each loading pattern becomes one when it is normalized by the standard deviation of the monthly index. Values and description

Climatic Indicators (2)

AAO	***Antarctic Oscillation.*** Values and references Data from CPC
Pacific Warmpool	***1st EOF of SST*** **(60e-170E, 15S-15N) SST EOF, all months** GISST 1948-1949 Reconstructed Reynolds 1950-1981 OI 1982-present Reference: Matin P. Hoerling (personal communication)
Tropical Pacific SST EOF	***1st EOF of SST*** 20N-20S, 120E-60W GISST 1948-1949 Reconstructed Reynolds 1950-1981 OI 1982-present Reference: Martin P. Hoerling, Arun Kumar, and Taiyi Xu, 2001: Robustness of the nonlinear climate response to ENSO's extreme phases. Journal of Climate, Vol.14, No.6, 1277-1293
Atlantic Tripole SST EOF	***1st EOF of SST*** 10N-70N, 0-80W GISST 1948-1949 Reconstructed Reynolds 1950-1981 OI 1982-present Deser, Clara, Michael S. Timlin, 1997: Atmosphere-Ocean Interaction on Weekly Timescales in the North Atlantic and Pacific. Journal of Climate: Vol. 10, No. 3, pp.393-408.
Atlantic multidecadal Oscillation Long Version	***AMO, unsmoothed*** Note: this index is newly computed from a new dataset. Please use it and note that it supersedes the old indices. The data is calculated from the Kalplan SST. See the AMO webpage for more details. Enfield, D.B., A. M. Mestas-Nunez and P.J. Trimble, 2001: The Atlantic multidecadal oscillation and it's relation to rainfall and river flows in the continental U.S.. Geophysical Research Letters, Vol. 28, 2077-2080.

Climatic Indicators (3)

Atlantic Meridional Mode	***AMM*** Note: this index is newly availablecomputed from a new dataset. See the AMM webpage for more details. 2004 Chiang, J. C. H., and D. J. Vimont: Analagous meridional modes of atmosphere-ocean variability in the tropical Pacific and tropical Atlantic. J. Climate,17(21), 4143-4158.
North Tropical Atlantic Index (NTA)	***NTA:North Tropical Atlantic SST Index*** (Definition slightly changed: old version available).The timeseries of SST anomalies averaged over 60W to 20W, 6N to 18N and 20W to 10W, 6N to 10N map. Data is obtained from the COADS dataset for 1951-1991 and NCEP afterwards. Anomalies were calculated relative to the 1951-2000 climatology, smoothed by three months running mean procedure and projected onto 20 leading EOFs. Month of data is the center of the 3 months that are smoothed. More information and the indexes forecasted values are available. Penland, C., and L. Matrosova, 1998: "Prediction of tropical Atlantic sea aurface temperatures using Linear Inverse Modeling," J. Climate, March, 483-496 pp.
Caribbean Index (CAR)	***CAR:Caribbean SST Index*** The timeseries of SST anomalies averaged over the the Caribbean. Data is obtained from the COADS dataset for 1951-1991 and NCEP after. Anomalies were calculated relative to the 1951-2000 climatology, smoothed by three months running mean procedure and projected onto 20 leading EOFs. More information and the indexes forecasted values are available. Penland, C., and L. Matrosova, 1998: "Prediction of tropical Atlantic sea surface temperatures using Linear Inverse Modeling," J. Climate, March, 483-496 pp.
Atlantic multidecadal Oscillation Long Version	***AMO, smoothed*** Note: this index is newly computed from a new dataset. Please use it and note that it supersedes the old indices. The data is calculated from the Kalplan SST. See the AMO webpage for more details. Enfield, D.B., A. M. Mestas-Nunez and P.J. Trimble, 2001: The Atlantic multidecadal oscillation and it's relation to rainfall and river flows in the continental U.S.. Geophysical Research Letters, Vol. 28, 2077-2080.
QBO	***Quasi-Biennial Oscillation****. Calculated at PSD (from the zonal average of the 30mb zonal wind at the equator as computed from the NCEP/NCAR Reanalysis).
Globally Integrated Angular Momentum	***Globally Integrated Angular Momentum**** Note that time series is scaled by 1e25. Values are 3-month running means except for the last month which is a 2-month average. Weickmann, K.M., W.A. Robinson and M.C. Penland, 2000: Stochastic and oscillatory forcing of global atmospheric angular momentum. ***J. Geophys. Res.***, **105**, D12, 15543-15557.

Climatic Indicators (4)

ENSO precipitation index	***ENSO precipitation index*** http://precip.gsfc.nasa.gov/ESPItable.html Please cite "ENSO Indices Based on Patterns of Satellite-Derived Precipitation" Curtis and Adler in ***J. of Climate***, 13,2786 (2000). Time series that uses rainfall data in the Tropical Pacific to describe ENSO events.
Central Indian Precipitation (core monsoon region)	***Central Indian Precipitation*** http://www.tropmet.res.in/ Please cite the Indian Institute of Tropical Meteorology. CORE-MONSOON INDIA RAINFALL (1871-1999) 7 SUB 776,942 SQ.KM.
Sahel rainfall	***Sahel Standardized Rainfall (20-8N, 20W-10E)*** http://jisao.washington.edu/data_sets/sahel/ From Mitchell: The averaging region is based on the rotated principal component analysis of average June through September African rainfall presented in Janowiak (1988, J. Climate, 1, 240-255). Stations within 20-8N, 20W-10E are obtained from the National Center for Atmospheric Research World Monthly Surface Station Climatology (WMSSC), and 14 retained which had complete or almost complete records for 1950-93. See link for stations.
SW Monsoon Region rainfall	***SahelArea averaged precipitation for Arizona and New Mexico*** Calculated using NCDC's climate division dataset. Monthly precipitation values for each of the climate divisions in Arizona and New Mexico are are averaged to produce a single monthly value. Reference: personal communication, Catherine Smith. Also, NCDC, 1994, Time Bias Corrected Divisional Temperature-Precipitation-Drought Index. Documentation for dataset TD-9640. Available from DBMB, NCDC, NOAA, Federal Building, 37 Battery Park Ave. Asheville, NC 28801-2733. 12pp.
Northeast Brazil Rainfall Anomaly	***Northeast Brazil Rainfall Anomaly*** http://jisao.washington.edu/data_sets/brazil/ From Mitchell: The northeast Brazil rainfall index is calculated from data for Fortaleza (3.7S, 38.5W) and Quixeramobim (5.3S, 39.3W) Brazil obtained from the NCAR World Monthly Surface Station Climatology. Climatological mean is for 1950-79.
Solar Flux (10.7cm)	***Solar Flux (10.7cm)**** http://www.ngdc.noaa.gov/nndc/struts/results?op_0=eq&v_0=Penticton_Observed&t=102827&s=4&d=8&d=22&d=9 For NGDC. t To cite, "The 10.7cm Solar Flux Data are provided as a service by the National Research Council of Canada". They would appreciate a preprint or at least a reference if you use the data (URL is http://www.drao.nrc.ca/index_eng.shtml.. Time series is ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_RADIO/FLUX/Penticton_Observed/monthly/MONTHLY.OBS.

Climatic Indicators (5)

Global Mean Lan/Ocean Temperature Index

Global Mean Lan/Ocean Temperature

Values change over time!

Data values are in the file http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt from NASA/GISS. Please read and refer to this web page plus the main web page describing various temperature indices at http://data.giss.nasa.gov/gistemp/. Note, the index is an **anomaly** index. They have comments in the datafile and the writeup on obtaining an absolute global mean temperatures. Please reference the papers:

Christy, J.R., R.W. Spencer, and W.D. Braswell 2000. J. Atmos. Oceanic Tech. 17, 1153.

Hansen, J., R. Ruedy, M. Sato and R. Reynolds 1996. Global surface air temperature in 1995: Return to pre-Pinatubo level. Geophys. Res. Lett. 23, 1665-1668.

Hansen, J., M. Sato, J. Glascoe and R. Ruedy 1998. A common-sense climate index: Is climate changing noticeably? Proc. Natl. Acad. Sci. 95, 4113-4120.

Hansen, J., R. Ruedy, J. Glascoe, and M. Sato 1999. GISS analysis of surface temperature change. J. Geophys. Res. 104, 30997-31022.

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Intergovernmental Panel on Climate Change 2001. Climate Change 2001 (J.T. Houghton et al., Eds.), Cambridge Univ. Press, New York.

National Research Council 2000. Reconciling Observations of Global Temperature Change. National Academy Press, Washington, DC, 85 pp.

Peterson, T.C., and R.S. Vose 1997. An overview of the Global Historical Climatology Network temperature database. Bull. Amer. Meteorol. Soc. 78, 2837-2849.

Rayner, N. 2000. HadISST1 Seaice and sea surface temperature files. Hadley Center, Bracknell, U.K.

Reynolds, R.W., N.A. Rayner, T.M. Smith, D.C. Stokes, and W. Wang 2002. An improved in situ and satellite SST analysis for climate. J. Climate 15, 1609-1625, doi:10.1175/1520-0442(2002)015<1609:AISAS>2.0.CO;2.

Reynolds, R.W., and T.M. Smith 1994. Improved global sea surface temperature analyses. J. Climate 7, 929-948, doi:10.1175/1520-0442(1994)007<0929:IGSSTA>2.0.CO;2

Smith, T.M., R.W. Reynolds, R.E. Livesay, and D.C. Stokes 1996. Reconstruction of historical sea surface temperature using empirical orthogonal functions. J. Climate 9, 1403-1420.

Source:

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research

NOAA

Earth System Research Laboratory

Physical Sciences Division