Tipping point analysis of atmospheric oxygen concentration

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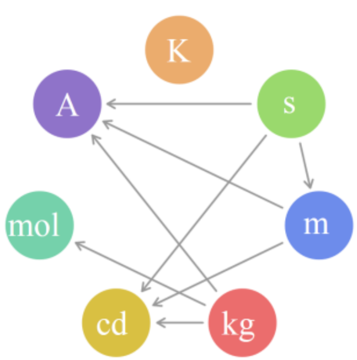
National Physical Laboratory, UK

APO meeting, 19th September 2015

UK national metrological institute

- Interface between business, academia and government
- Science with impact: ensure that measurements are comparable and traceable to the same standard units of the System International (SI)
- 700 staff



Magna Carta - 1215

"There is to be one measure of wine and ale and corn within the realm, namely the London quarter, and one breadth of cloth, and it is to be the same with weights."

BSI

CDSB
Climate Disclosure Standards Board

Coventry University

Department of Energy & Climate Change

BAE SYSTEMS

e·on

GREATERLONDONAUTHORITY

Imperial College London

bp

BENTLEY

Thames Gateway
Institute for Sustainability

Knowledge Transfer Network
Energy Generation and Supply

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logica

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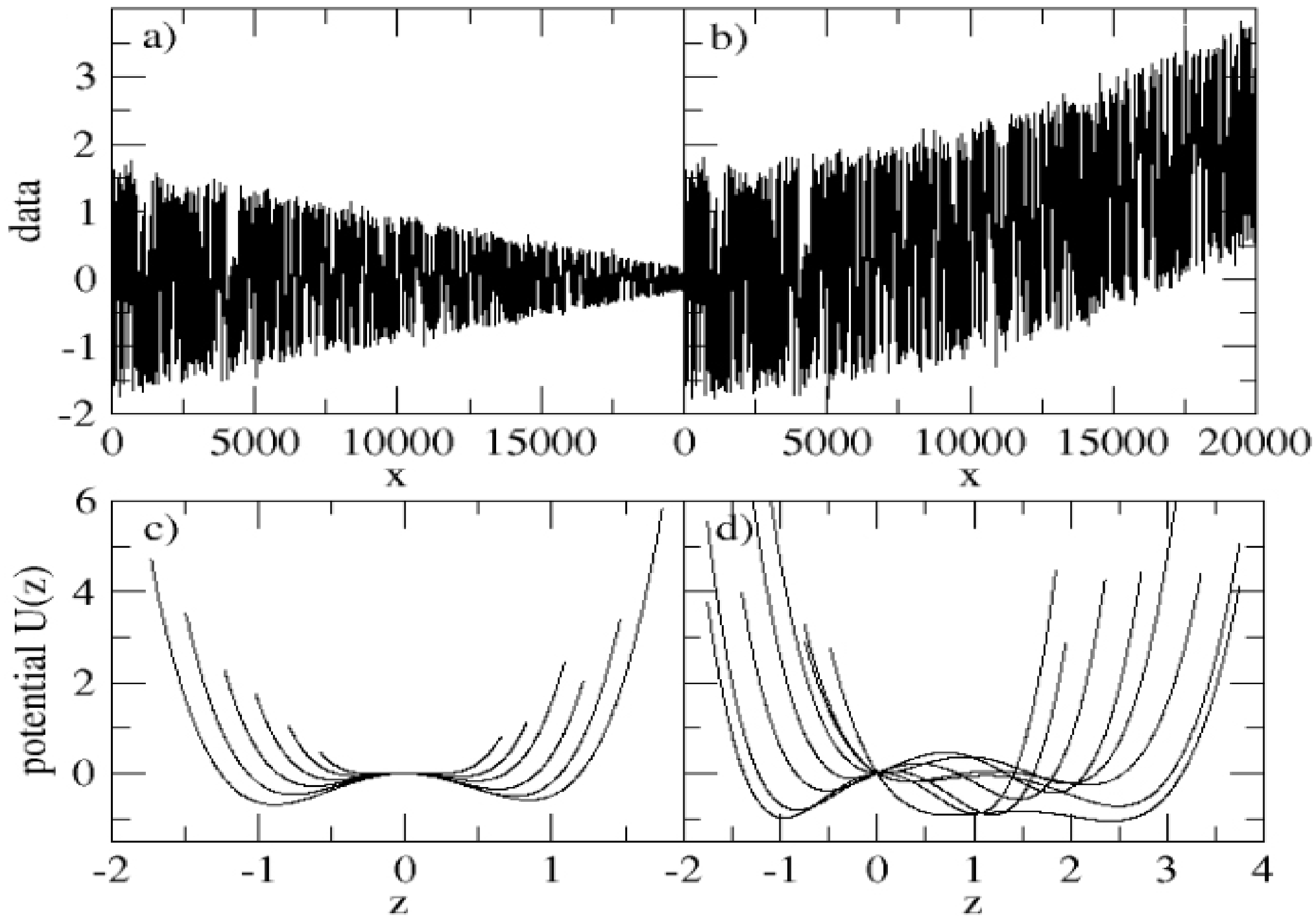
Tipping points:

bifurcations and transitions in time series

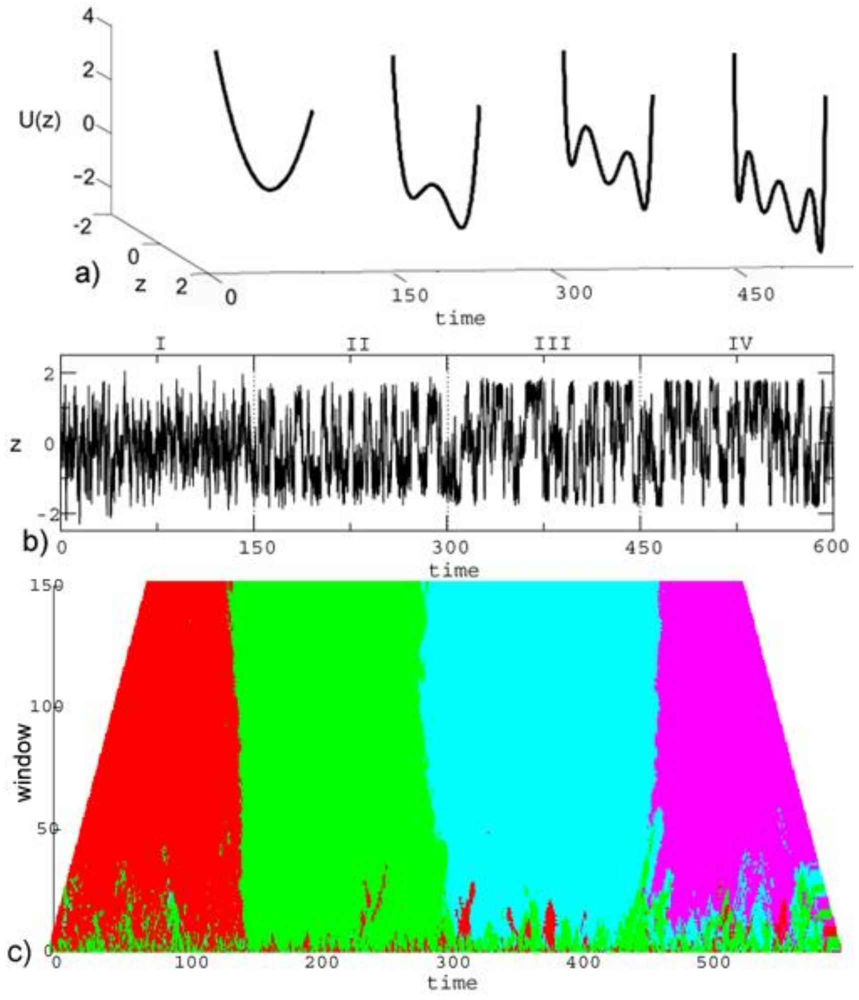
changes in system states



Tipping point toolbox (being developed since 2007)

- Anticipating (pre-tipping): early warning signals of tipping points
- Detecting (tipping): potential analysis
- Forecasting (post-tipping): PDF & potential analysis, recently added bayesian techniques

AD with four potentials



Potential contour plot at different time scales

We generate artificial data using Euler scheme

$$x_{t+\Delta t} \approx x_t - \left.\frac{dU}{dx}\right|_t \cdot \Delta t + (W_{t+\Delta t} - W_t)$$

W is a Wiener process

Potentials:

$$U(z) = z^2$$

$$U(z) = z^4 - 2z^2$$

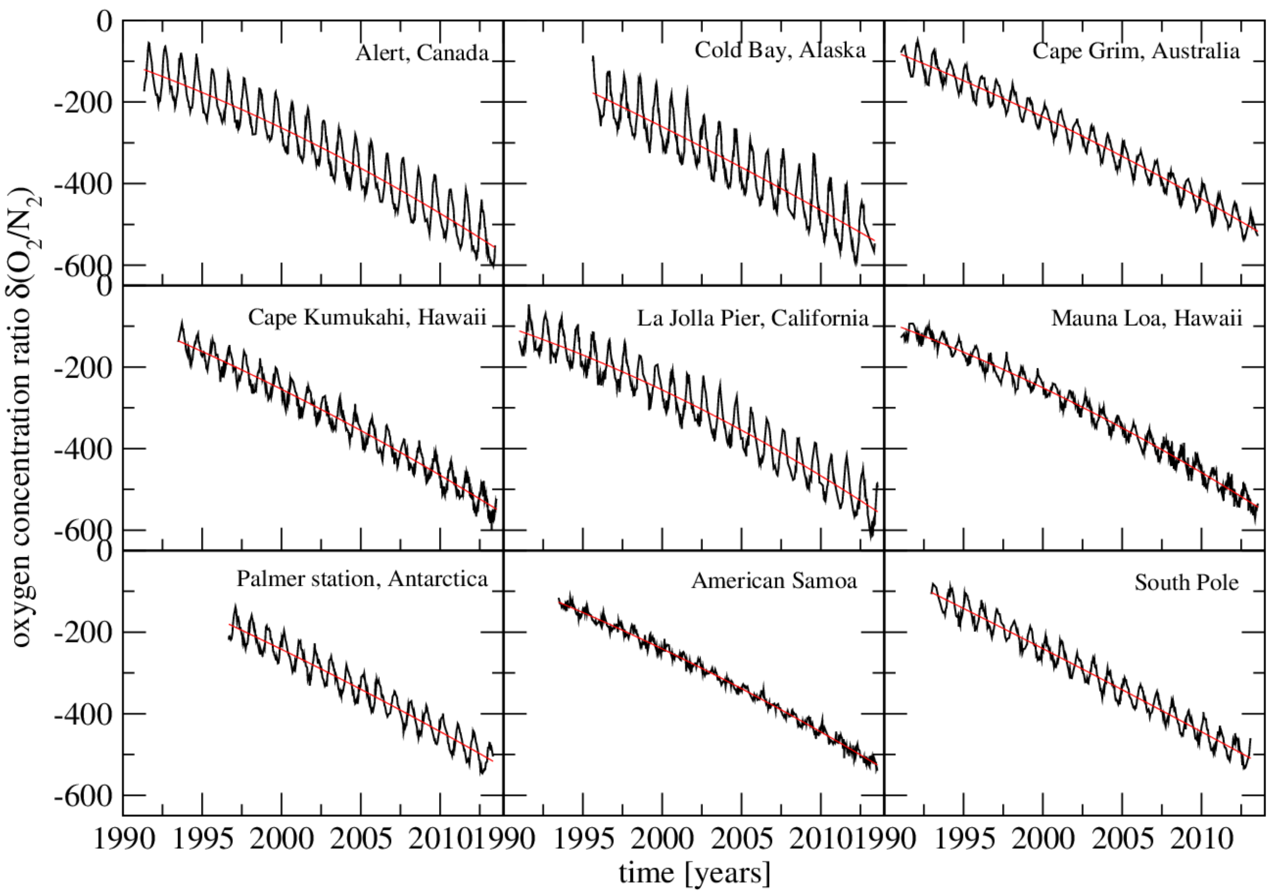
$$U(z) = z^6 - 4.5z^4 + 5z^2$$

$$U(z) = z^8 - 6.5z^6 + 13z^4 - 8z^2$$

Atmospheric oxygen concentration

Paper: V.Livina, T.Vaz, A.Forbes, *Chaos*, 2015

Atmospheric oxygen raw data



Unit is the change of $\frac{O_2}{N_2}$ ratio in *per meg*, 0.0001% of decline of oxygen concentration,

reference is based on tanks of air pumped in the mid-1980s stored in the US lab

Model to test tipping

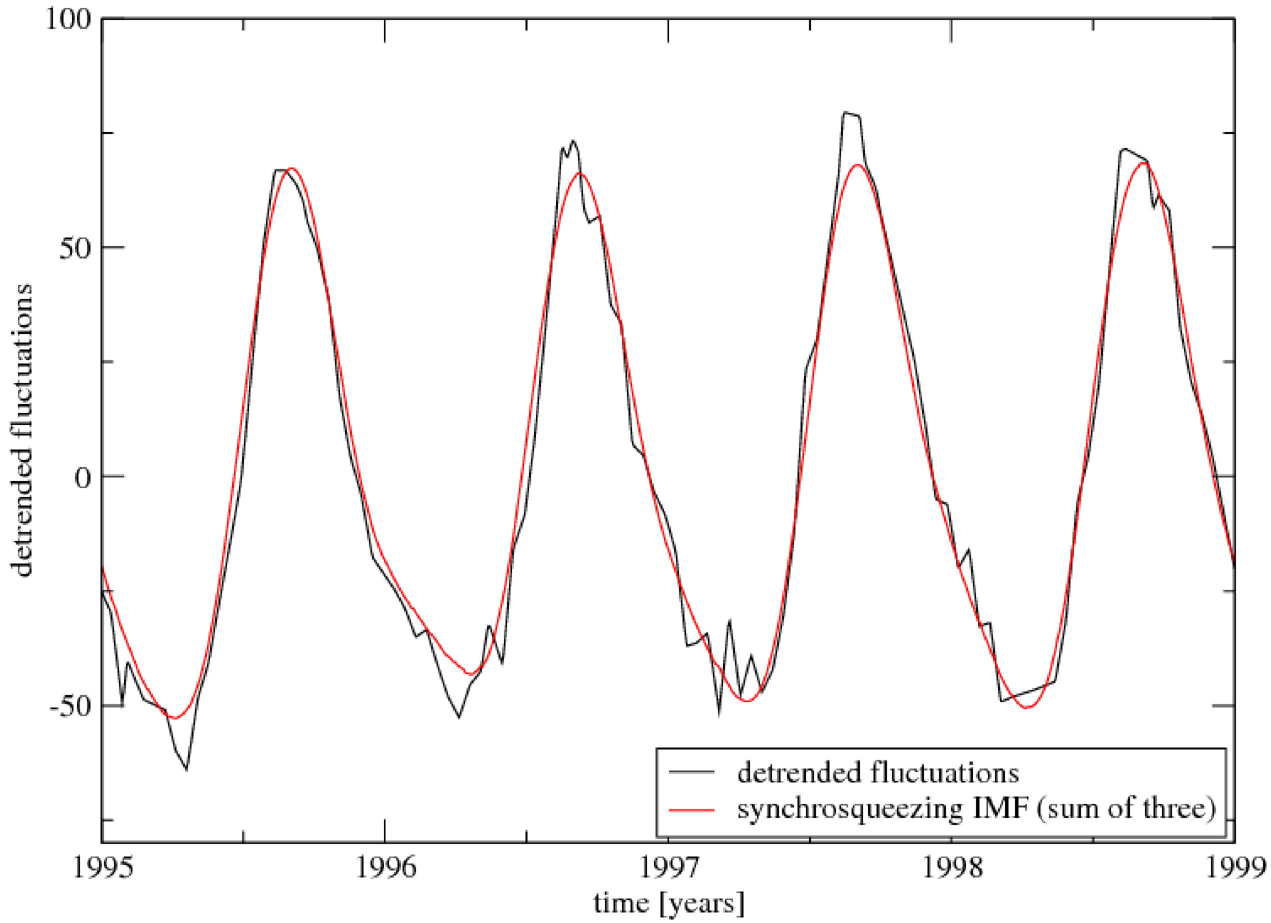
Data = global trend + seasonality + fluctuations

What kind of trend?

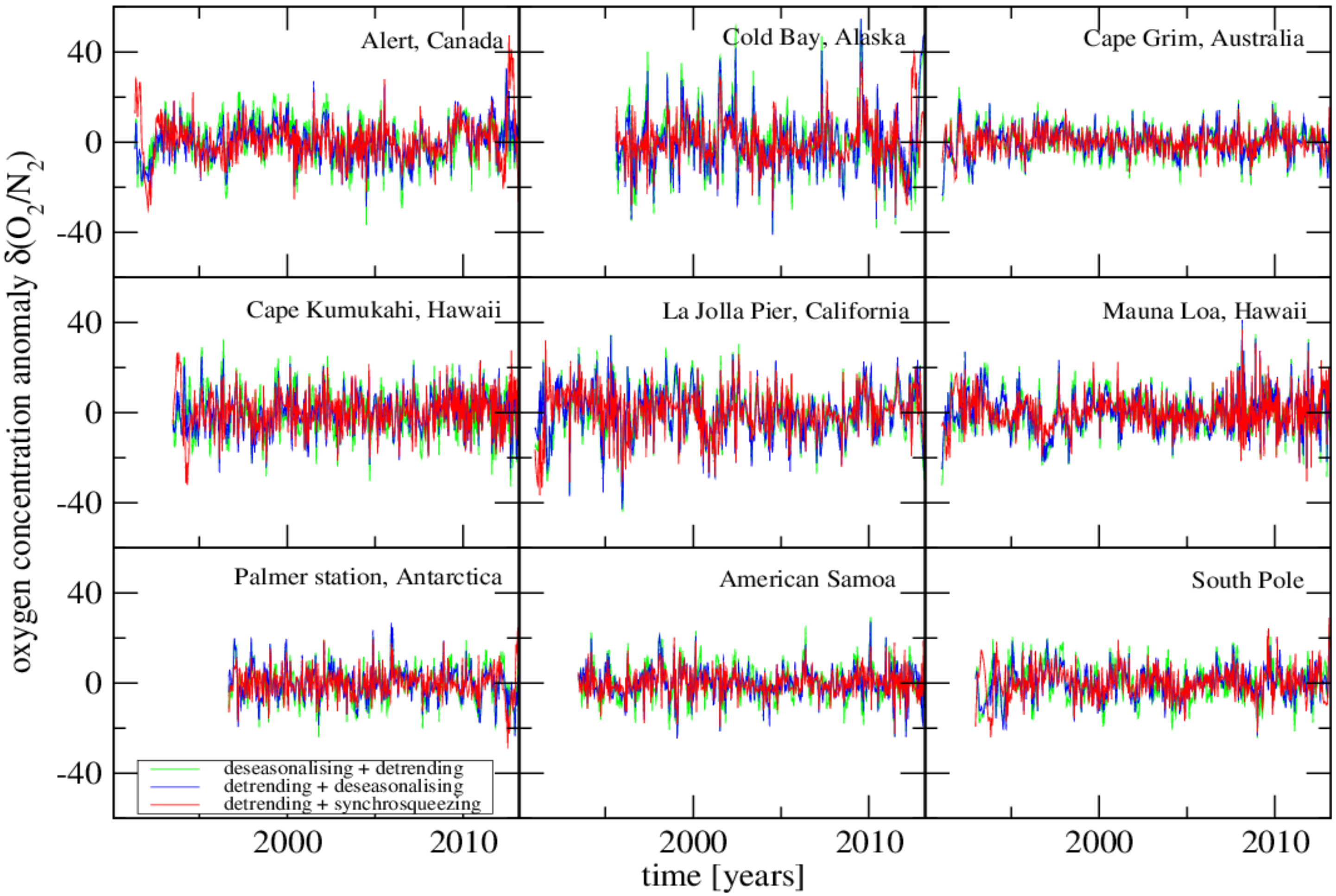
Is seasonality stable?

Are fluctuations stable?

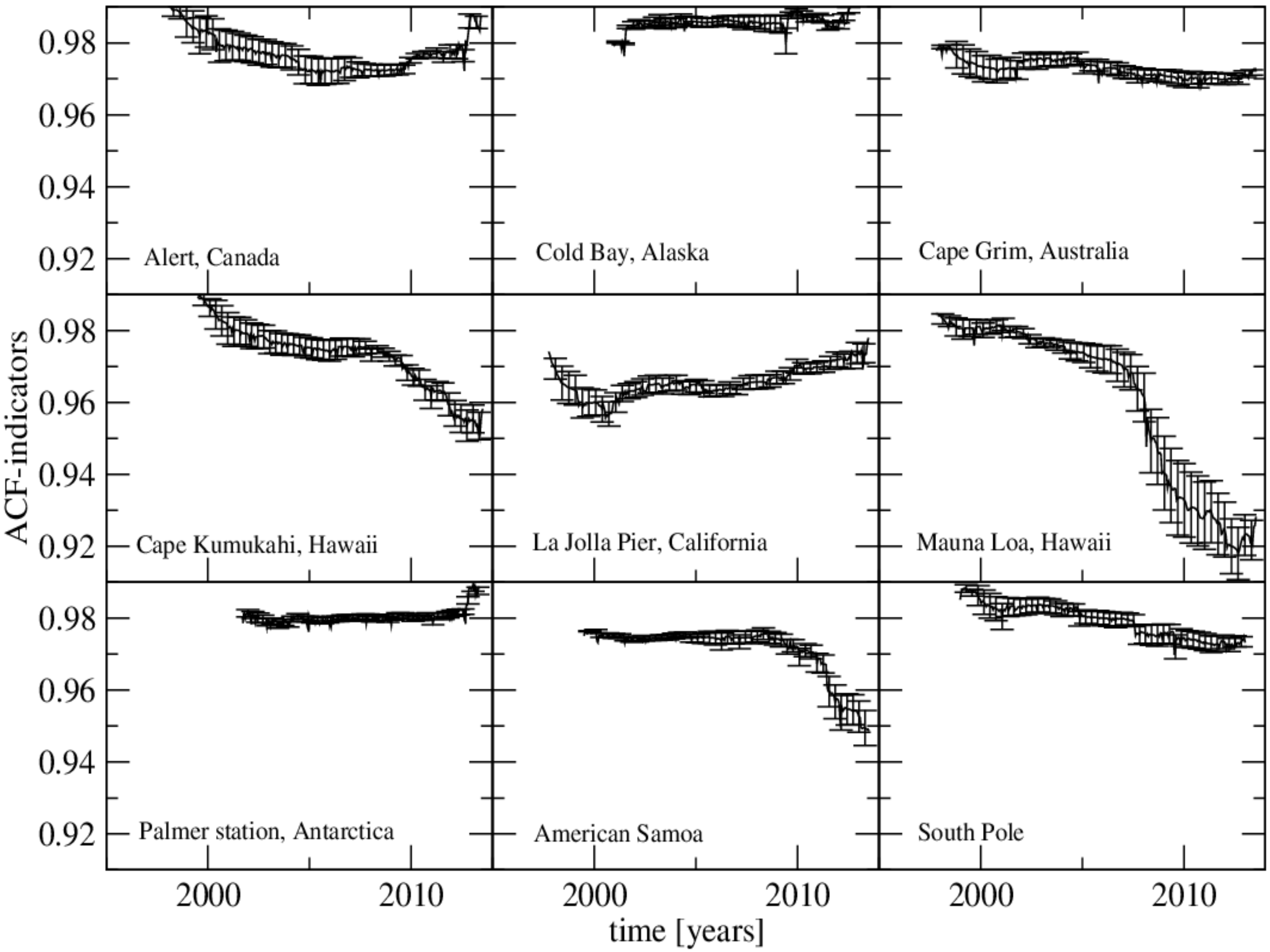
Synchrosqueezing:
wavelet-based seasonal trend



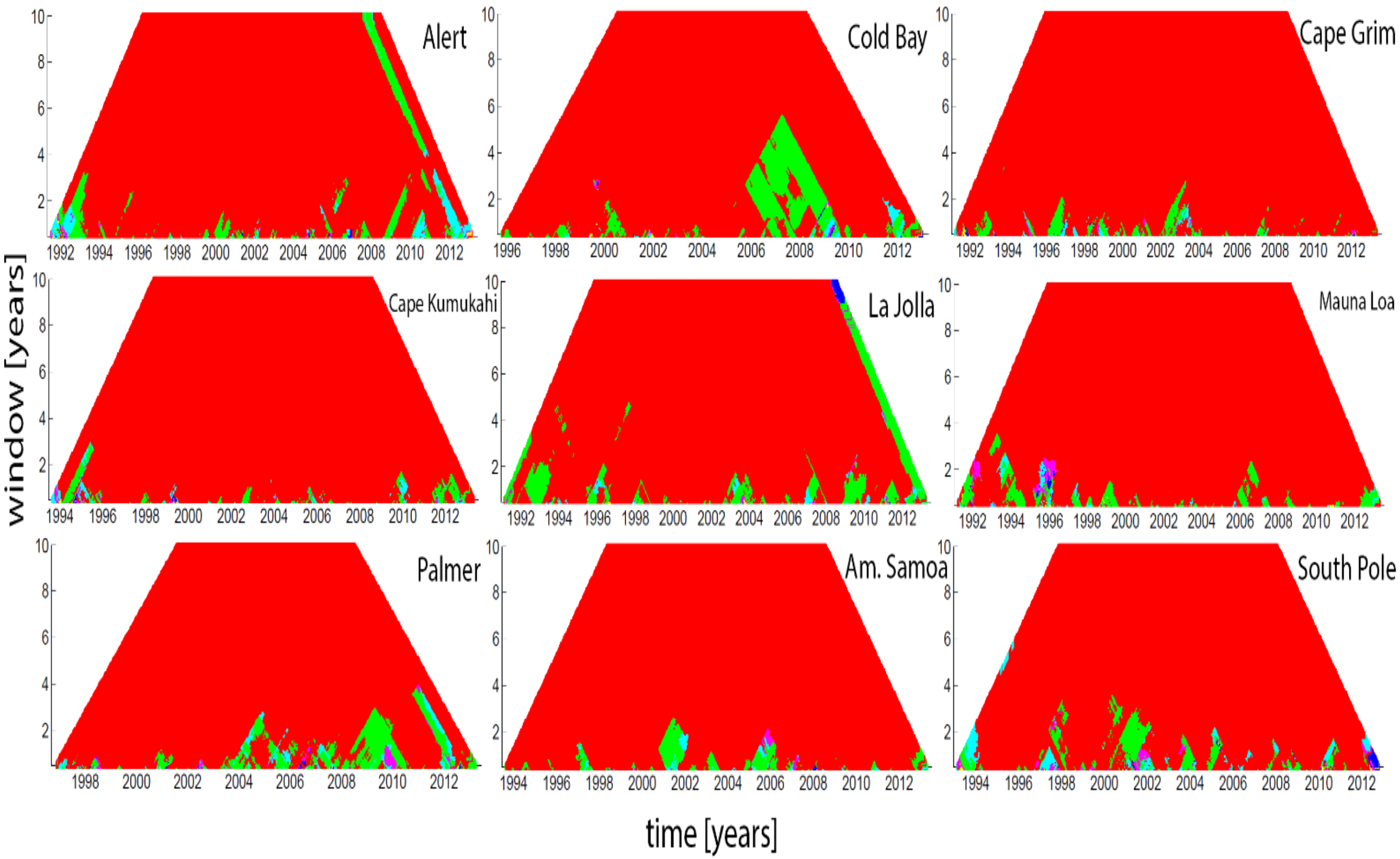
Detrended data: fluctuations



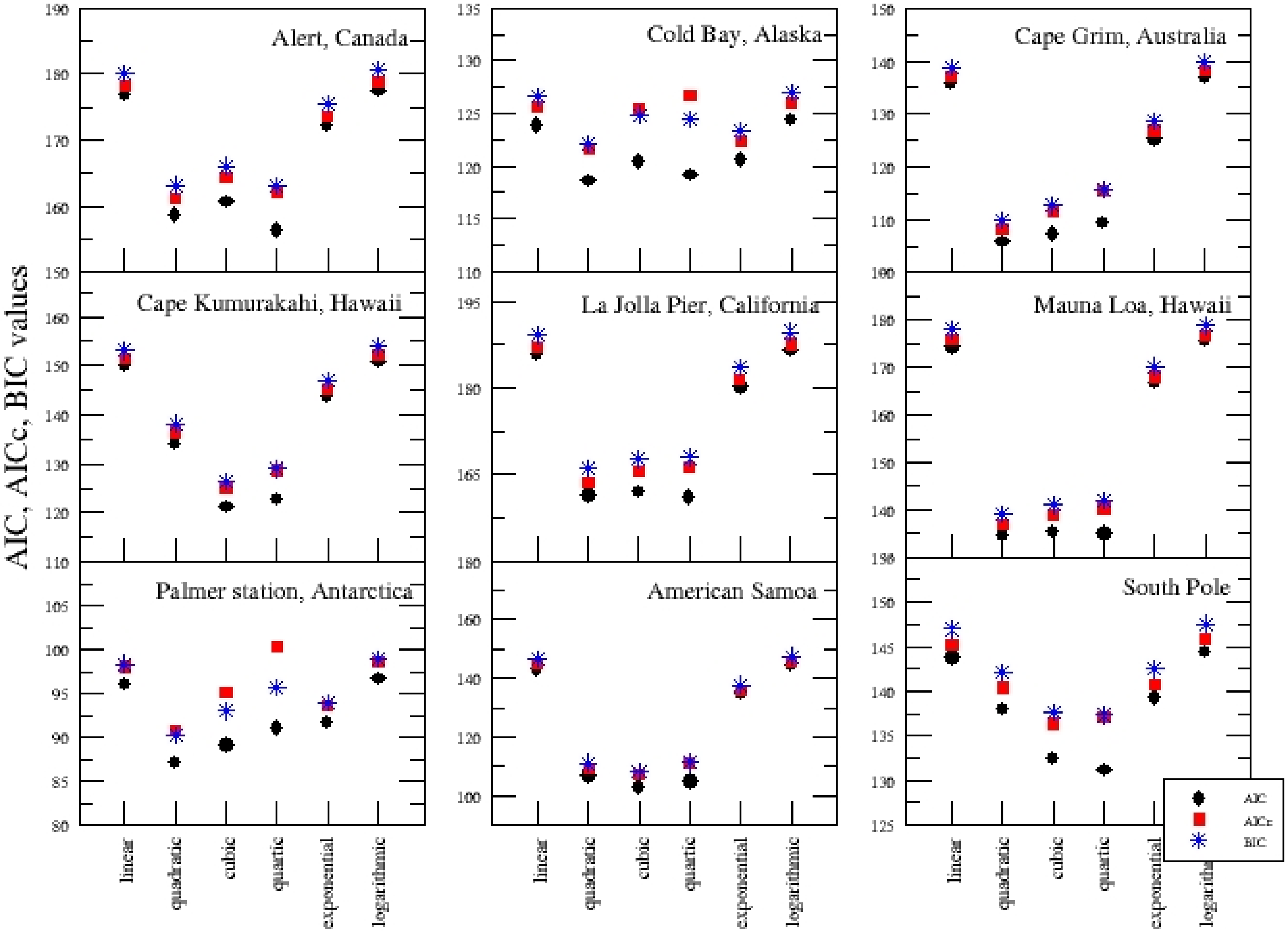
Early warning indicators



Potential analysis



Information criteria for model fit of annually averaged data



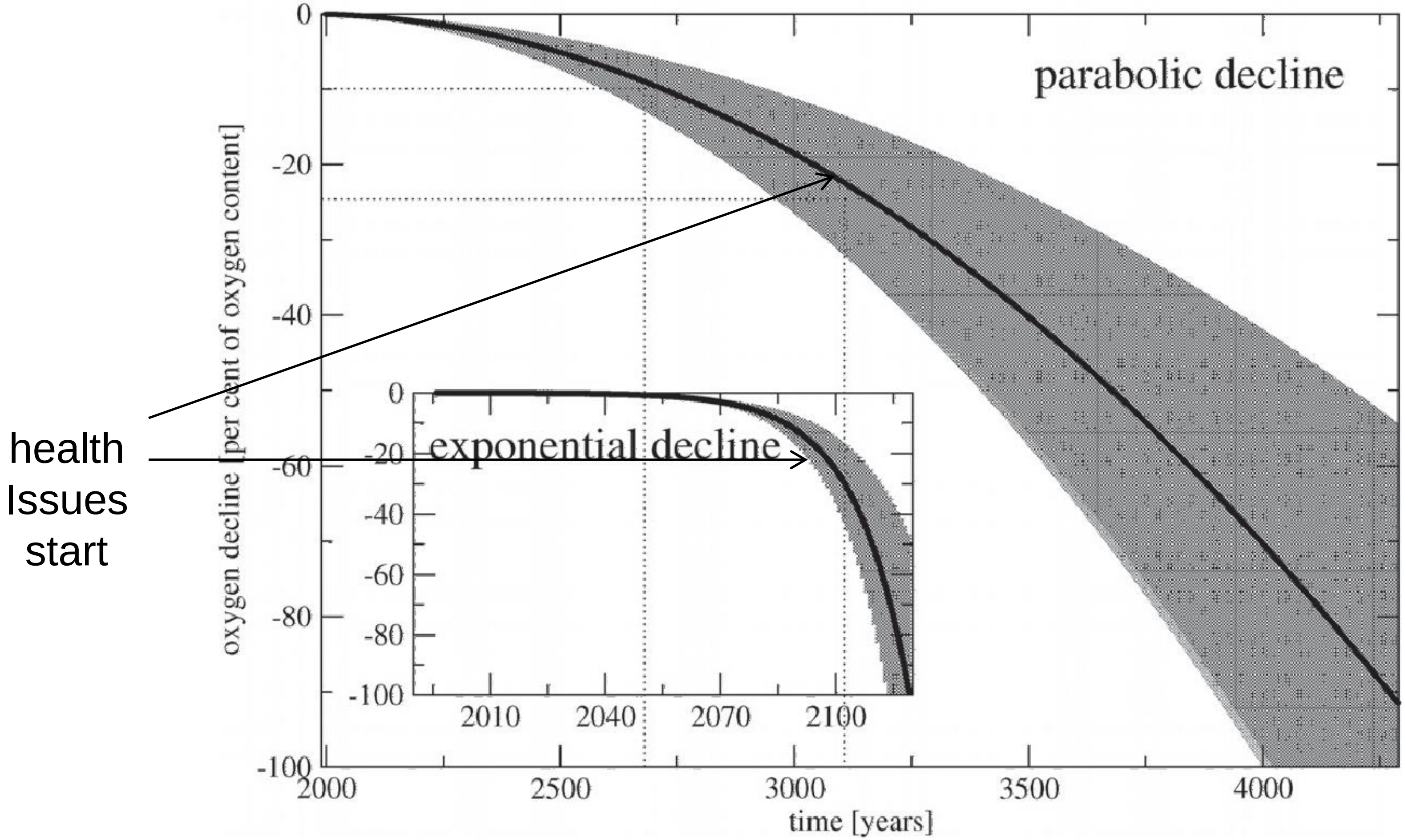
Likely:

Seasonality is stable

Fluctuations are stable

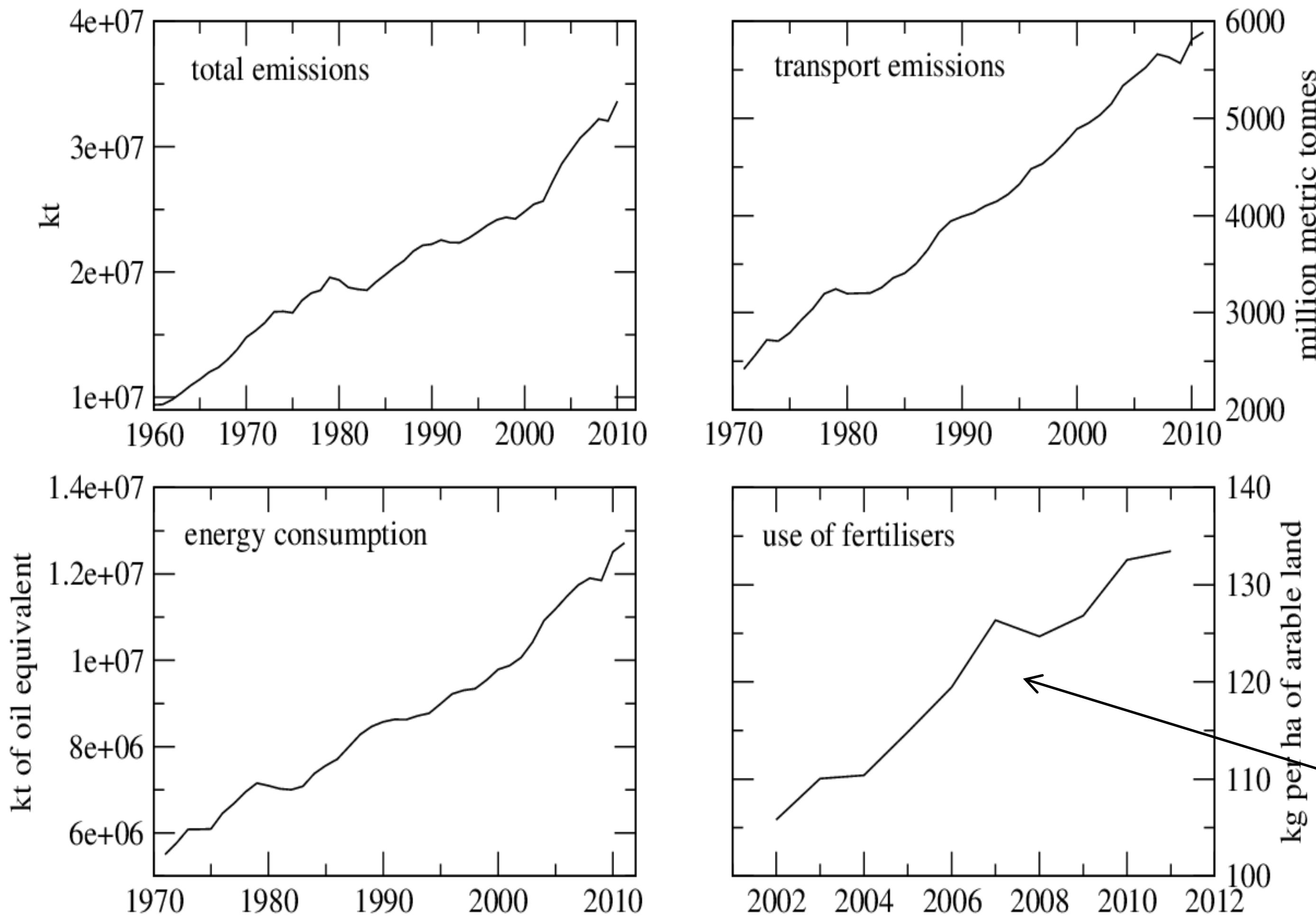
Trend is parabolic

Projection of oxygen decline



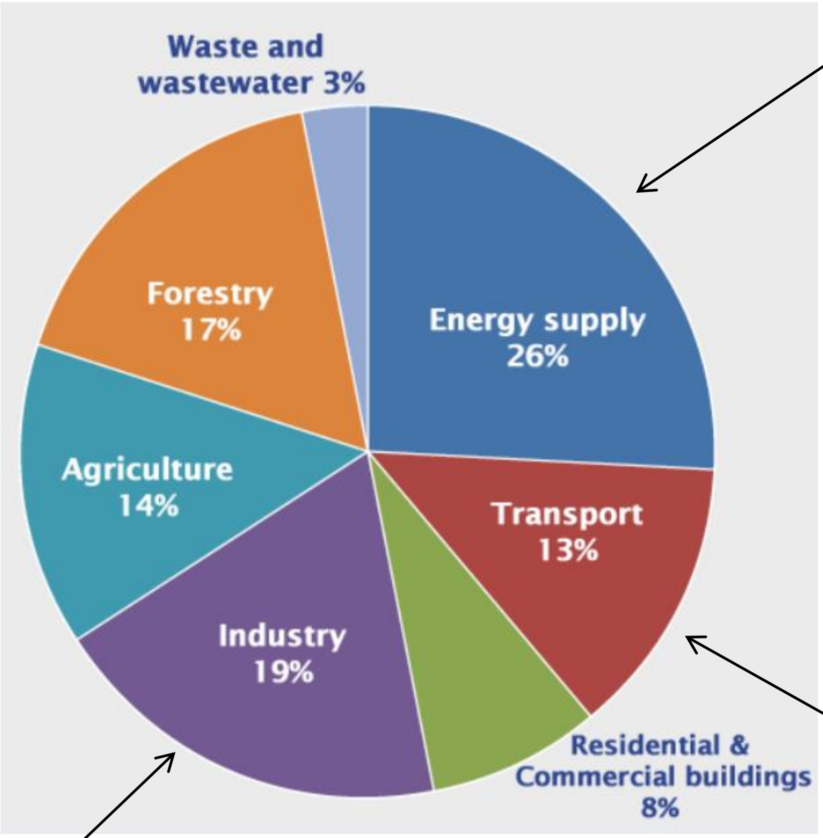
Uncertainties: modelling and technological

Resources utilisation (World Bank)



Alarming increase in fertilisation - oxygen sink (Haber-Bosch) and soil depletion

Global GHG emissions

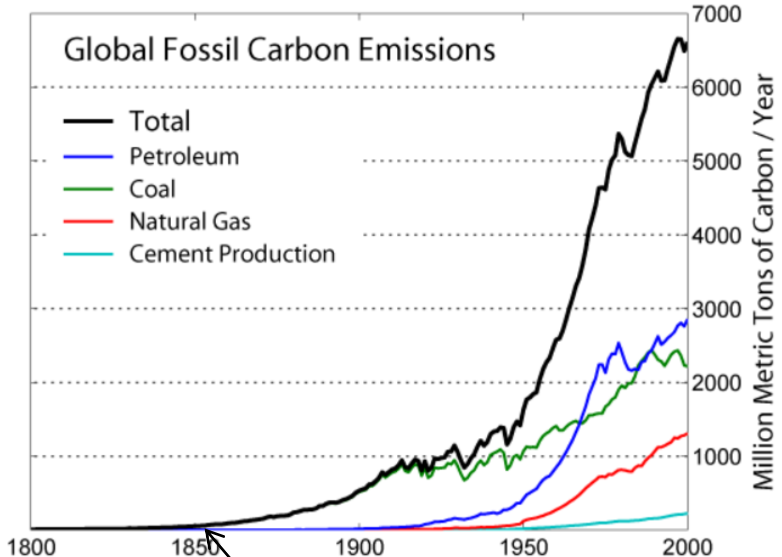


oxygen sink

oxygen sink

oxygen sink

IPCC



tipping point

Hydrogen cars: dual-fuel BMW 7

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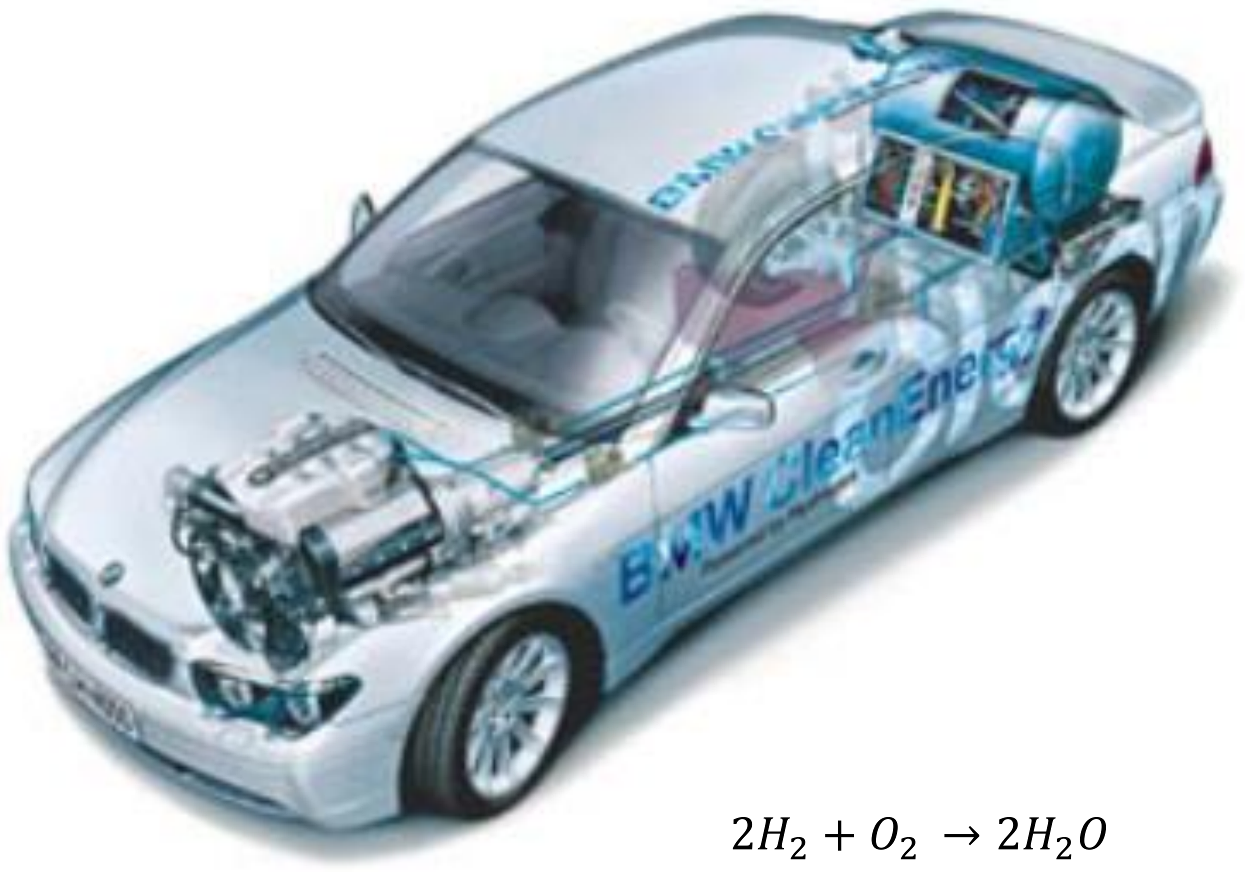


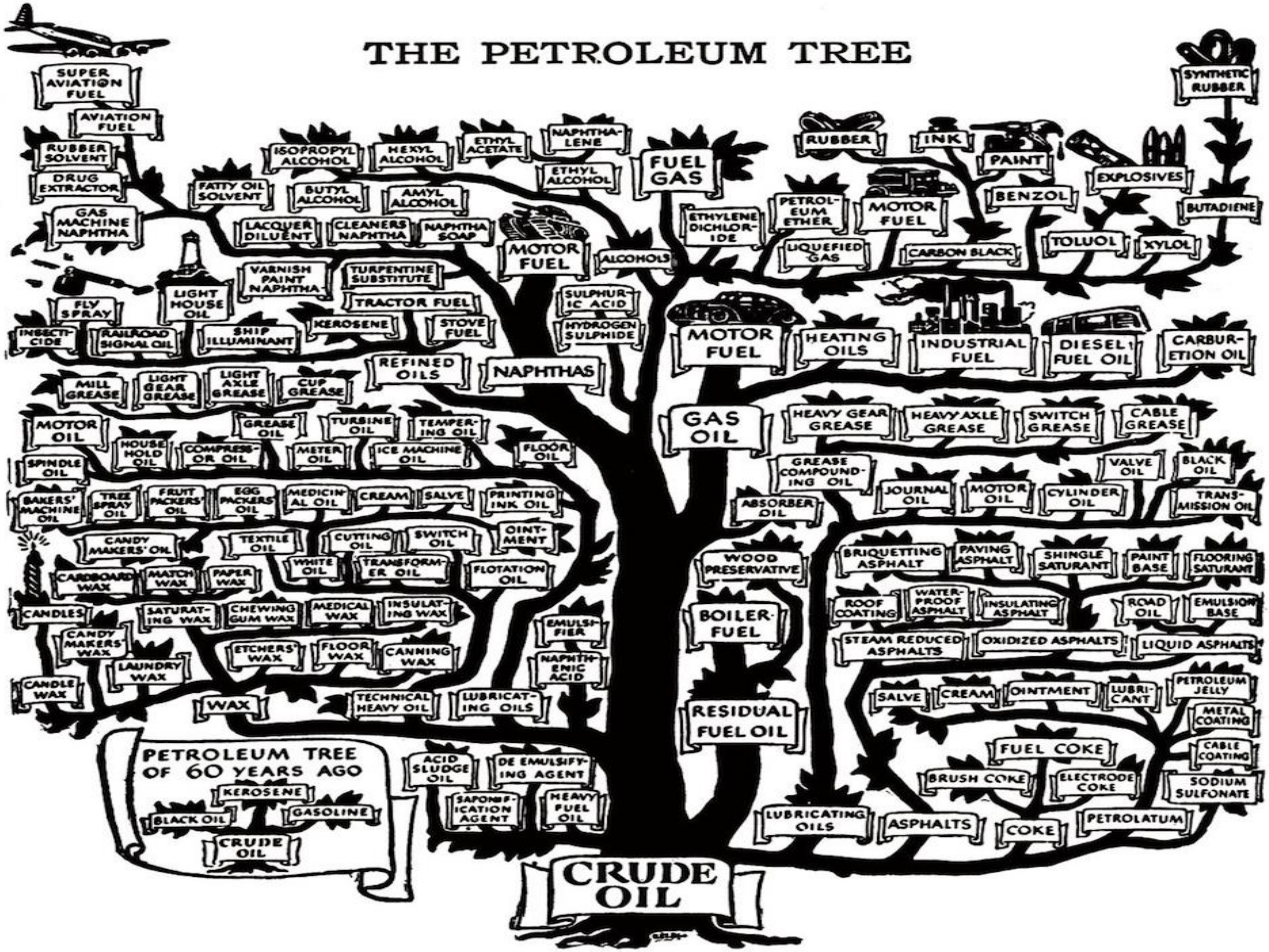
$$2H_2 + O_2 \rightarrow 2H_2O$$

Technology with double sink of oxygen

Two fuel tanks
170 litres of liquid hydrogen: driving range 200 km;
73 litres of petrol: driving range 480 km

This technology uses about 2.7 times less volume of oxygen for combustion in hydrogen mode than in petrol mode.

Most of modern hydrogen generation is not green!
(steam reforming of hydrocarbons at high temperature; also hydrolysis)



Even when oil and gas will not be used for energy, they will be used for materials synthesis

Possible collaboration in a publishing project

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- To engage experts from various fields: geochemistry, physiology, wildfires and combustion
- To assess the oxygen decline time scale and impact

“The future of the atmospheric oxygen” ?

Topics to address

- Measurement techniques and standardisation
- Derivation of long-term trend of oxygen from GCMs (100-200 years)
- Physiological impact of oxygen decline
- Long-term projections of oxygen under various scenarios of demographics and consumption development
- Assessment of impact of modern industrial technologies
- Raising social awareness of the oxygen decline

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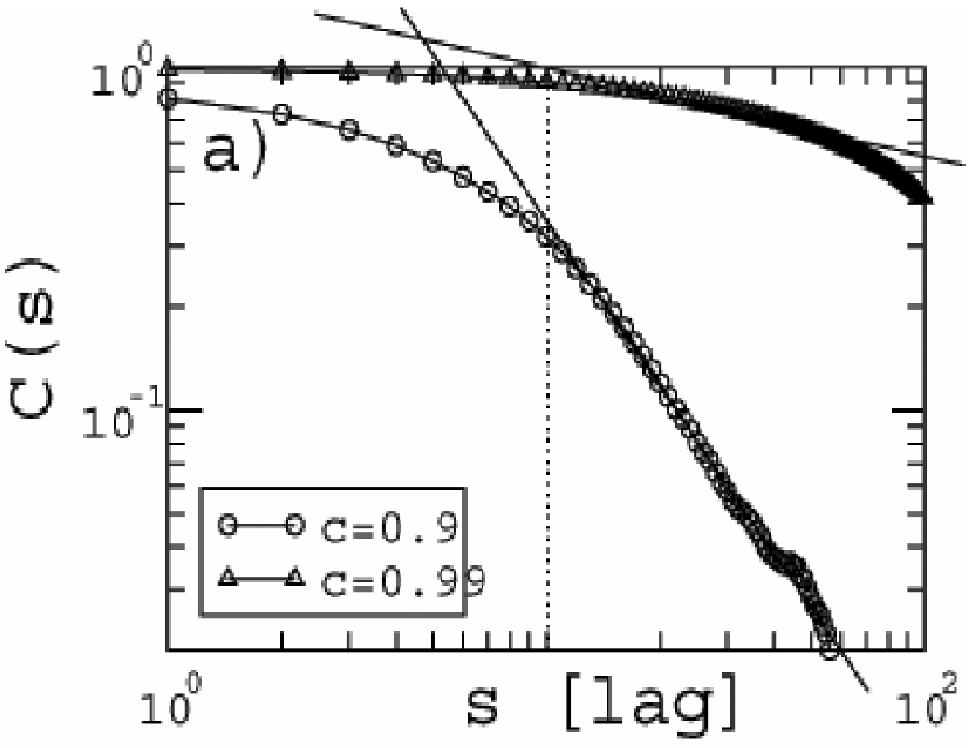
The idea needs communal effort and support!

Thank you

Early warning signal model



Livina & Lenton, GRL 2007

Series is approximated by an AR(1) process, and exponential decay of the auto-correlation function (ACF) is estimated. Thus ACF-indicator c is defined; its gradual trend towards value 1 indicates critical behaviour.

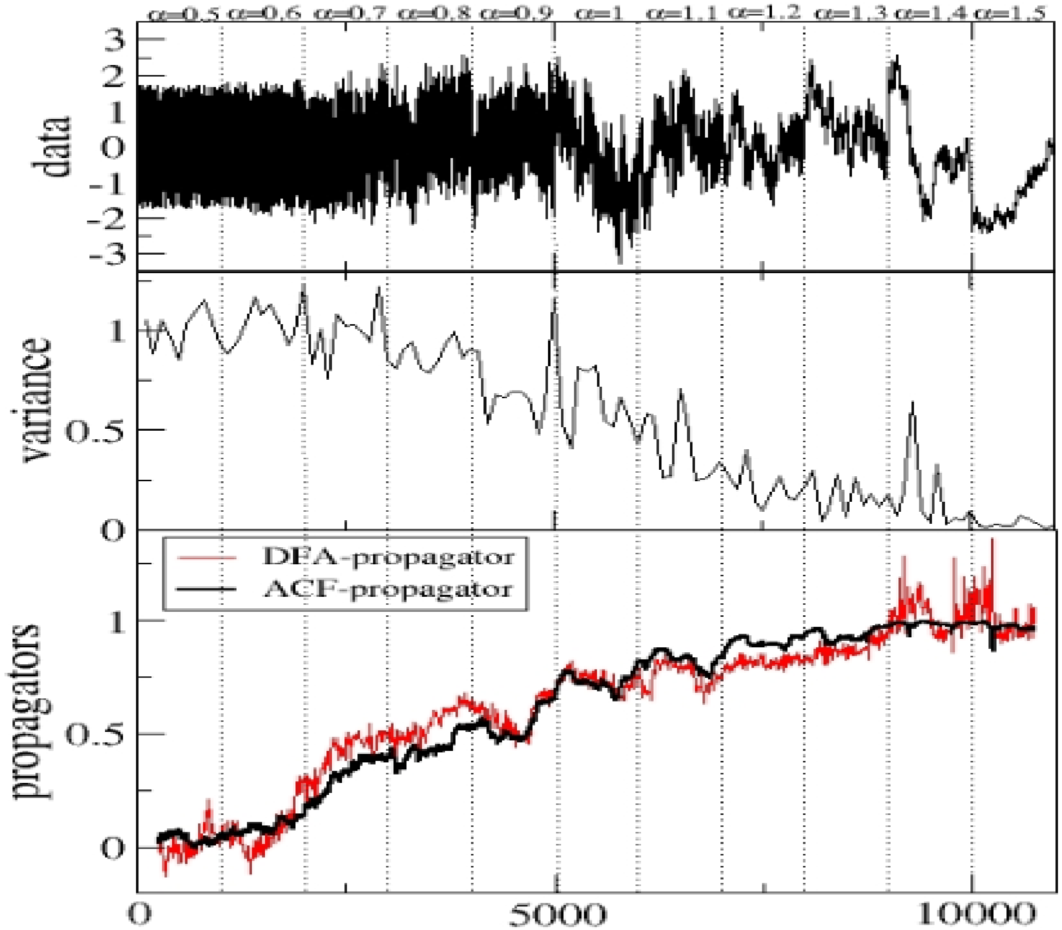
$$y_{n+1} = cy_n + \sigma\eta_n,$$

$$c = \exp(-\kappa\Delta t),\ \kappa \text{ is decay rate}$$

$$(\kappa = 0 \text{ when } c = 1)$$

Artificial data with increasing memory

Livina et al, Physica A, 2012



When ACF-indicator reaches critical value 1, DFA-indicator is still capable to reflect the variability in the variance

Potential analysis model

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$$\dot{z}(t) = -U'(z) + \sigma\eta$$

$$U(z) = a_4 z^4 + a_3 z^3 + a_2 z^2 + a_1 z$$

double-well potential

Kwasniok & Lohmann, Phys Rev E, 2009

Livina et al, Climate of the Past 2010

Potential vs Probability Density Function (PDF)

Fokker-Planck equation

$$\partial_t p(z,t) = \partial_z [U'(z)\, p(z,t)] + \frac{1}{2}\sigma^2 \partial_z^2 p(z,t)$$

$$p(z) \approx \exp[-2U(z)/\sigma^2]$$

If we assume that the considered subset of data is stationary, then

$$U = -\frac{\sigma^2}{2} \log p_d$$

bimodal histogram $\Longleftrightarrow$ double-well potential

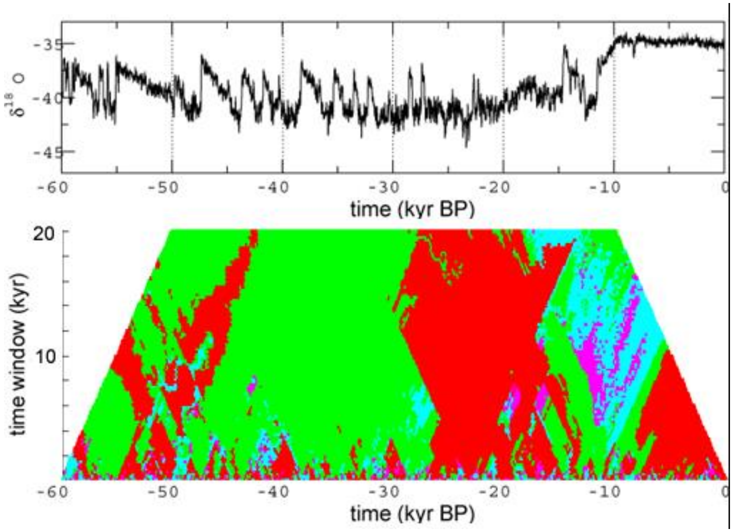
GRIP & NGRIP temperature proxies

National Physical Laboratory

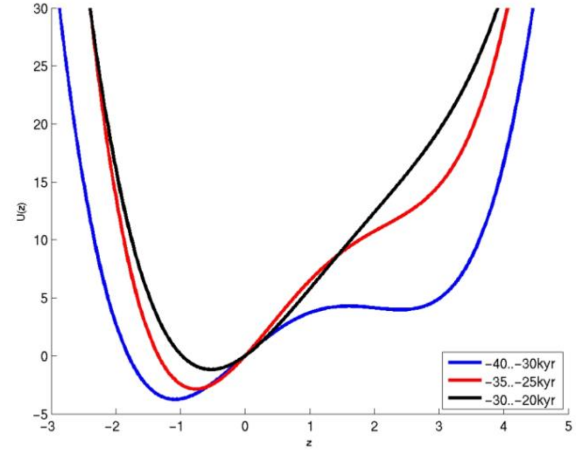
$\delta^{18}O$ data: bifurcation at 25-28 kyr BP

(Livina et al, Climate of the past, 2010)

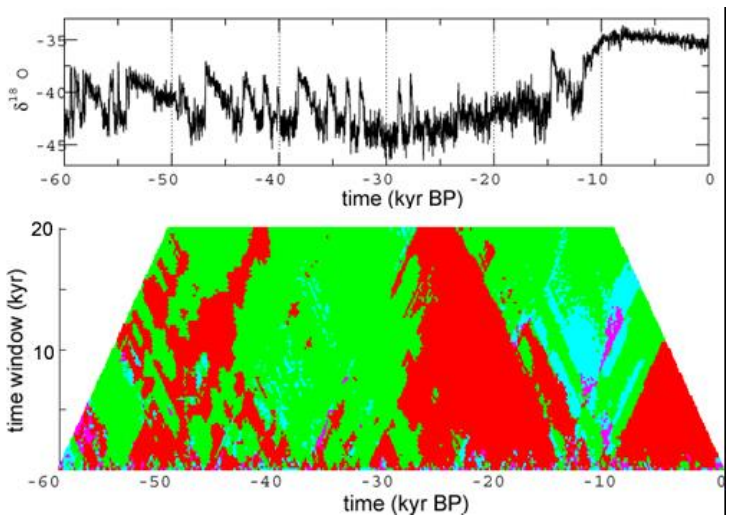
GRIP



GRIP

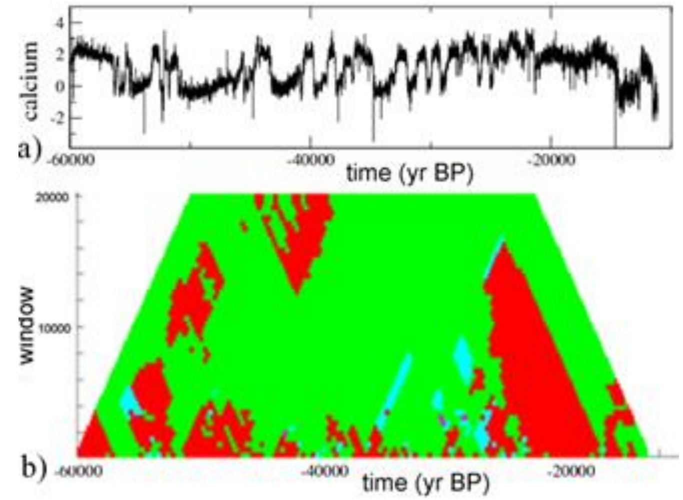


NGRIP



Calcium data: bifurcation at 27-28 kyr BP

GRIP



GICC05 time scale, resolution 20yr

Annual resolution

Potential forecast algorithm

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Livina et al, Physica A 2013

- Collect coefficients of Chebyshev approximation of PDF in sliding windows
- Extrapolate series of the coefficients
- Reconstruct forecast PDF
- Simulate time series from the obtained PDF (rejection sampling)
- Sort the series according to historic data (taking into account seasonality)

Oxygen period of observations is short, horizon forecast long: other techniques are necessary