

A decorative network diagram in the top-left corner of the slide. It consists of a series of interconnected nodes and edges. The nodes are represented by small circles, some of which are solid blue, some are solid grey, and some are hollow with a blue outline. The edges are thin grey lines connecting the nodes. The overall shape is roughly triangular, pointing towards the top-left.

An Efficient Method for Estimating Seismic Hazards Using Big Data Analysis

Denis M. Filatov^{1, 2} & Alexey A. Lyubushin²

¹ Sceptica Scientific Ltd (Stockport, UK)

² Institute of Physics of the Earth (Moscow, Russia)

A decorative network diagram in the bottom-right corner of the slide. It is similar to the one in the top-left, featuring interconnected nodes and edges. The nodes are small circles, some solid blue, some solid grey, and some hollow with a blue outline. The edges are thin grey lines. The shape is roughly triangular, pointing towards the bottom-right.

Introduction

There are two different approaches to analyse stochastic dynamical systems:

Mathematical

(via the solution of the equations of motion)

$$\ddot{x} = F(x, \dot{x}, \alpha, \beta, \gamma, \dots?)$$

- adequate equations of motion are often unknown ($F = ?$)
- the equations of motion are often incomplete ($\alpha, \beta, \gamma, \dots?$)
- to get the parameters' precise values is a great challenge ($\alpha, \beta, \gamma = ?$)

Statistical

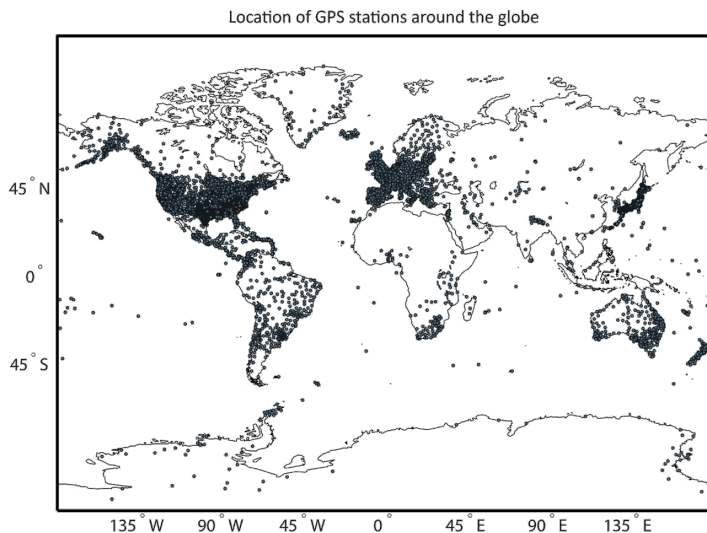
(via the analysis of the systems' big data)

$$\{\Delta x_k\}$$

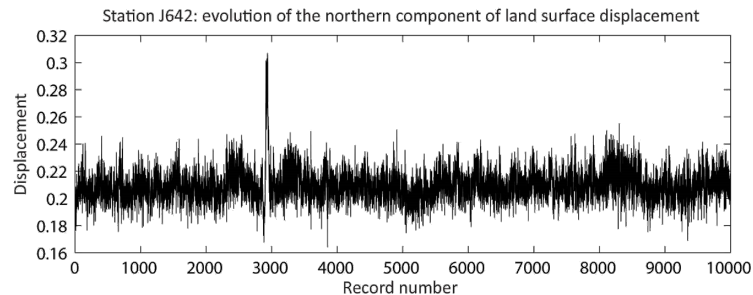
- the amount of available big data is constantly growing
- lack of model-related subjectivism (the data 'speak for themselves')

Statistical Approach | Big Data

Currently there are over 11,000 GPS stations around the globe



The stations' data are time series of land surface displacements northward (N), eastward (E) and upward (Z) sampled at $\Delta t = 5$ minutes



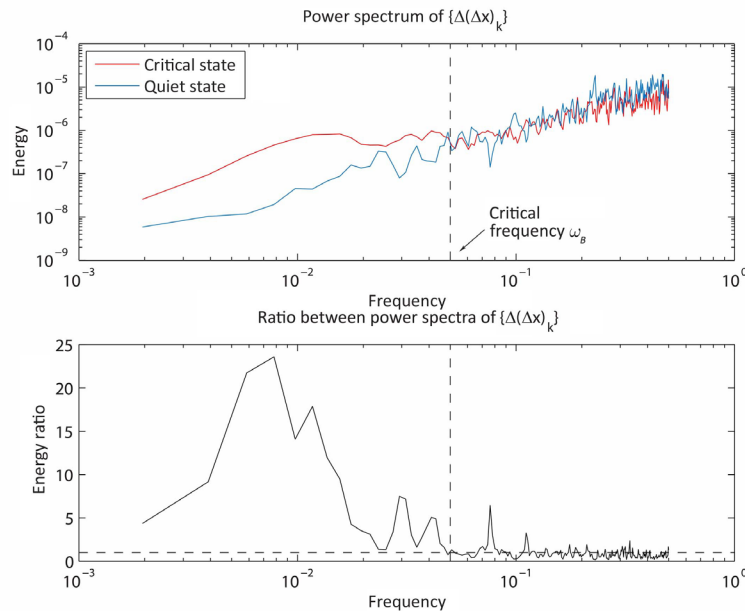
Source: Nevada Geodetic Laboratory (<http://geodesy.unr.edu>)

Statistical Approach | Main Idea

A system's transition from a quiet into a critical state results in a growth of energies at the low frequencies

As a result, the system's chaoticity decays¹⁻²

Hence, in order to differentiate the system's critical and quiet states, an adequate **measure of chaoticity** has to be developed



¹ H. Haken, *Information and Self-Organization*, Springer, Berlin, 2000

² Yu.L. Klimontovich, *Turbulent Motion and the Structure of Chaos*, Nauka, Moscow, 1990

Statistical Approach | Measures of Chaoticity

The lack of a single mechanism exhibited in all extreme seismic events suggests that a number of diverse quantitative measures has to be developed

Our methods include¹⁻⁶:

- fractal critical exponents
- width of the multifractal singularity spectrum
- multivariate canonical correlations and coherences
- principal components of Fourier-aggregate time series
- among others

¹ A.A. Lyubushin, *Izv. Phys. Solid Earth*, 45 (2009) 381-394

² A.A. Lyubushin, *Nat. Sci.*, 4 (2012) 659-666

³ A.A. Lyubushin and P.V. Yakovlev, *SpringerPlus*, 3 (2014) 364-370

⁴ D.M. Filatov and A.A. Lyubushin, *Phys. A*, 469 (2017) 718-730

⁵ D.M. Filatov and A.A. Lyubushin, *Phys. A*, 527 (2019) 121309

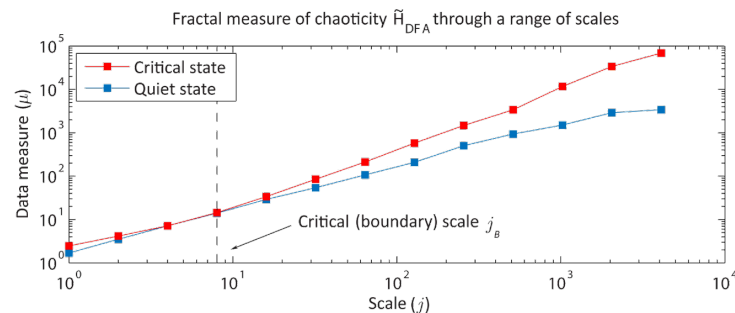
⁶ D.M. Filatov and A.A. Lyubushin, *Pure Appl. Geophys.*, 177 (2020) 509-530

Statistical Approach | Critical Exponent

An example of the measures of chaoticity is the critical exponent $\tilde{H}_{DFA}$:

Analysis of the big data $\{\Delta x_k\}$ through a range of scales j allows to quantify¹ critical and quiet states by different values of the slope $\log \mu_{\Delta x}(j)$ vs. $\log j$

$$\tilde{H}_{DFA} \equiv \frac{\log \mu_{\Delta x}(j + \Delta j) - \log \mu_{\Delta x}(j)}{\log (j + \Delta j) - \log j}$$

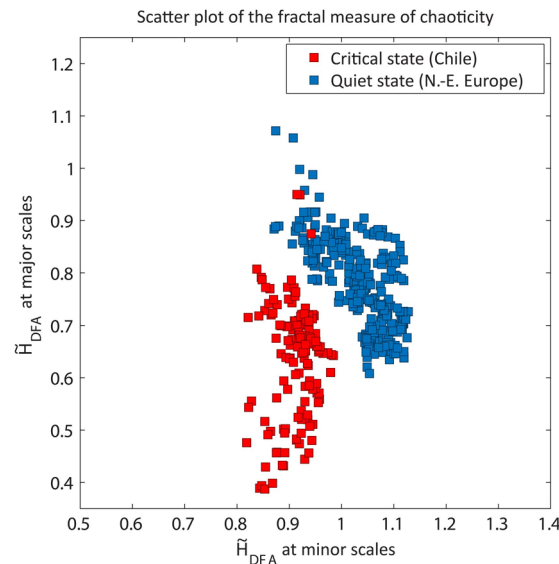


¹ D.M. Filatov, *J. Stat. Phys.*, 165 (2016) 681-692

Statistical Approach | How It Works

Different values of the exponent $\tilde{H}_{DFA}$ at both sides of the boundary scale j_B for the two analysed regions group in two separated clusters

The separated clusters clearly **discriminate the critical and quiet states** of the Earth's crust

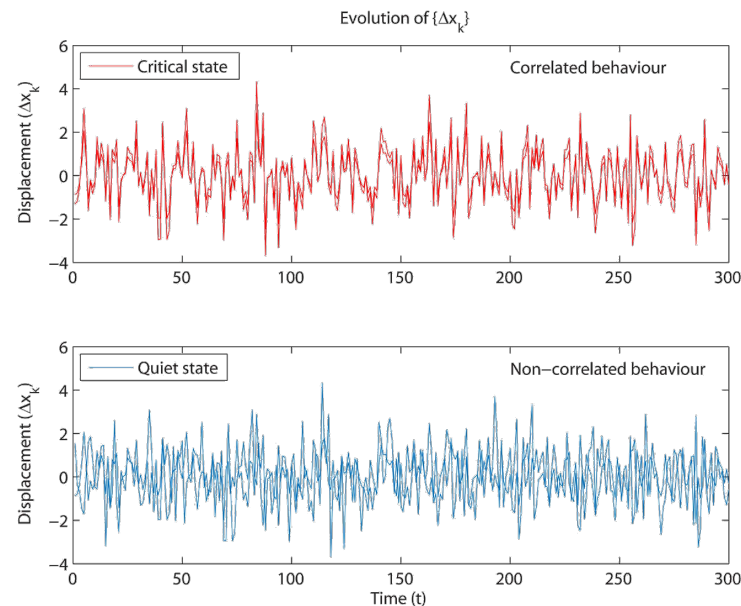


Statistical Approach | Pair-Wise Correlations

Another example of the measures of chaoticity is the mean squared cross-correlation:

$$C \equiv \sqrt{\frac{1}{M} \sum_{i \neq j}^M \text{corr}^2(\{\Delta x_k^{(i)}\}, \{\Delta x_k^{(j)}\})}$$

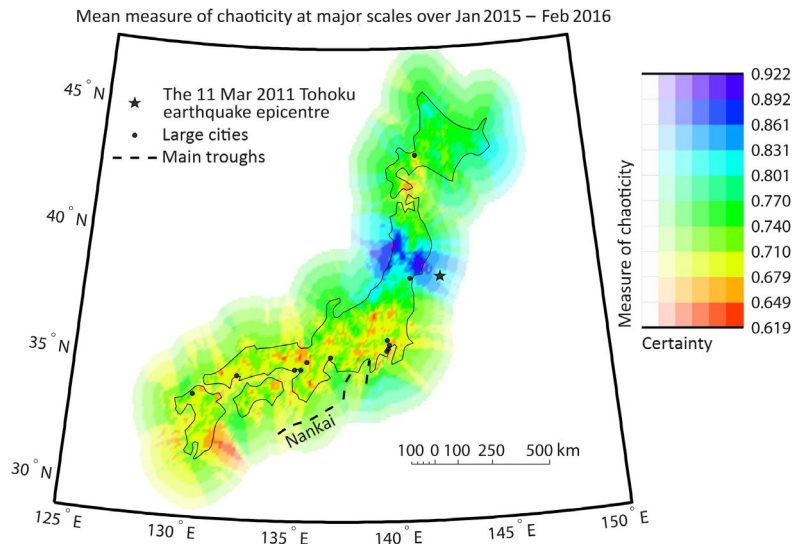
The squared pair-wise correlations allow to **distinguish critical and quiet states** via highlighting the areas of higher collective behaviour



Case Studies | Japanese Islands

Analysis of the northern component of the land surface displacements highlights an **anomalous area in the Tohoku region**, for which $\tilde{H}_{DFA} > 0.85$, where a large earthquake is most likely to occur in the future

Our results are consistent with those obtained by other authors¹⁻³



¹ K. Mogi, *Earth, Planets and Space*, 56 (2004) li-lxvi

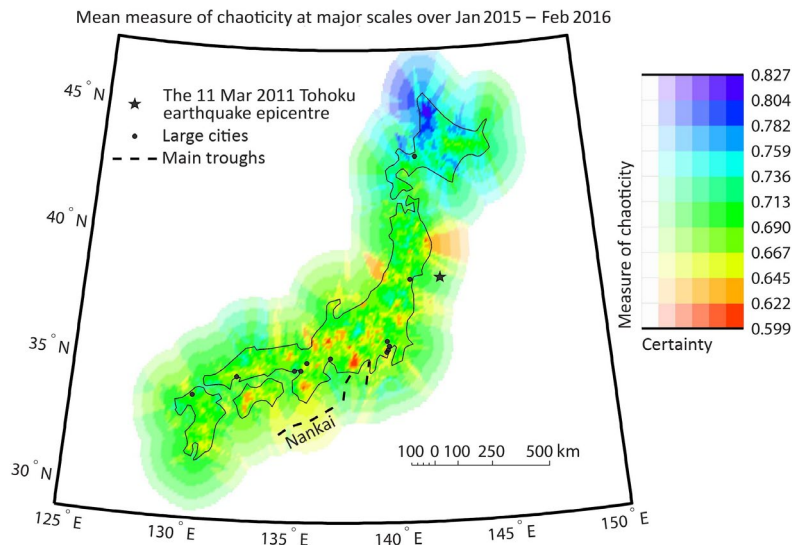
² T. Rikitake, *Earth, Planets and Space*, 51 (1999) 147-157

³ M. Simons et al., *Science*, 332 (2011) 1421-1425

Case Studies | Japanese Islands

Analysis of the upward component of the land surface displacements also highlights an **anomaly in the Tohoku region** and another one **near the Nankai trough**, for both of which $\tilde{H}_{DFA} < 0.65$

Our results are consistent with those obtained by other authors¹⁻³



¹ K. Mogi, *Earth, Planets and Space*, 56 (2004) li-lxvi

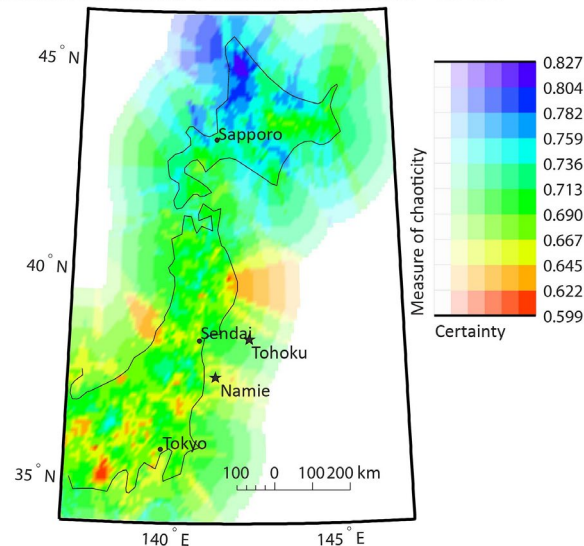
² T. Rikitake, *Earth, Planets and Space*, 51 (1999) 147-157

³ M. Simons et al., *Science*, 332 (2011) 1421-1425

Case Studies | Japanese Islands

The recent earthquake on 21 Nov 2016 near Namie town, Fukushima, Japan, post factum **confirmed the adequacy of our estimates** of the current seismic hazards of the Japanese islands¹

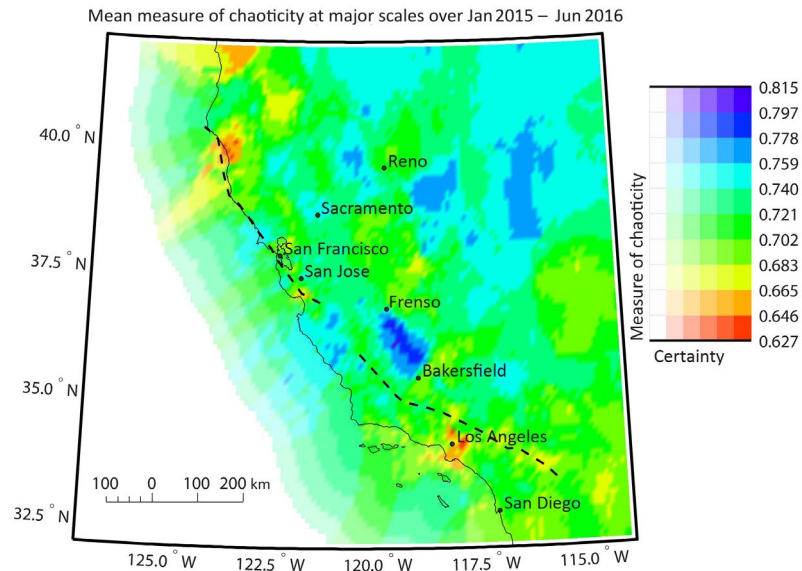
Mean measure of chaoticity at major scales over Jan 2015 – Feb 2016



¹ D.M. Filatov and A.A. Lyubushin, *Phys. A*, 469 (2017) 718-730

Case Studies | West Coast of the USA

Two obvious anomalies highlighted by $\tilde{H}_{DFA} < 0.65$, one around Los Angeles and the other near Cape Mendocino, are detected using the upward GPS data

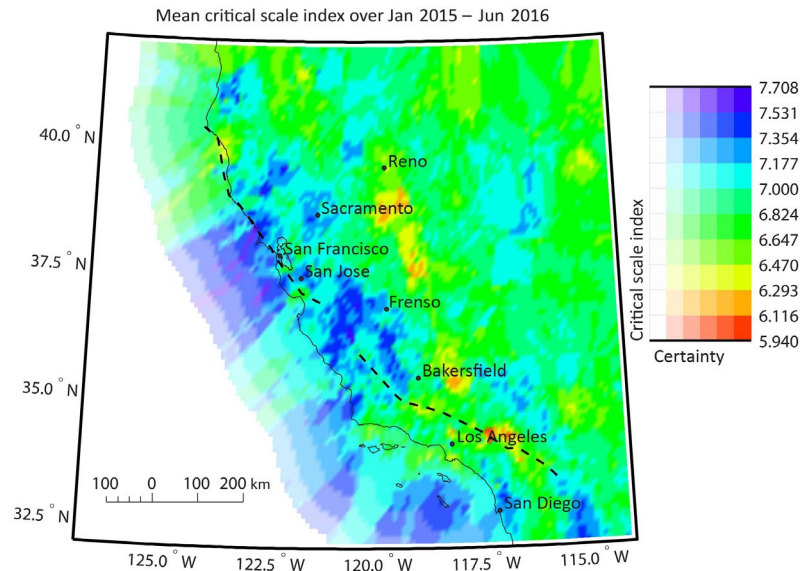


Case Studies | West Coast of the USA

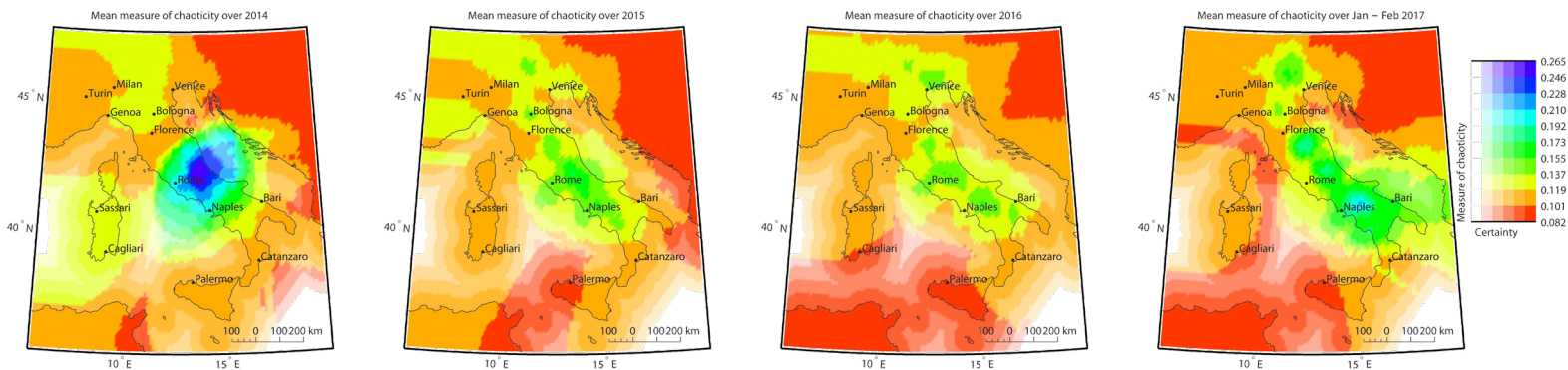
The mean value of the boundary scale j_B allows to estimate the typical period of time it takes the Earth's crust to transit from a quiet into a critical state:

$$i_B \approx 6.6 \dots 7.5, \quad j_B = N 2^{-(i_B+1)} \approx 22 \dots 41$$

$$T = 2j_B \Delta t \approx 220 \dots 410 \text{ min}$$



Case Studies | Italy



Regular monitoring and estimation of criticality permit to visualise the formation and development of the spots of hazard

This allows to identify areas exposed to a higher seismic risk in real time

Conclusion

- The statistical approach allows to objectively **recognise precatastrophic and quiet states** of the Earth's crust
- The use of various measures of chaoticity allows to **quantify a large variety of precursors** of the coming extreme seismic events
- The approach has shown to be an **efficient tool for early warning** of natural earthquakes, and it could be useful for fast detection of other disasters as well as man-made earthquakes (e.g., due to shale oil extraction)
- Regular quantification permits to **identify** the formation and development of **areas exposed to higher risks in real time**



Thanks!

For further information please visit our website:

www.sceptica.co.uk/?catastrophes

You are always welcome to contact us by e-mail:

Denis M. Filatov | **denis.filatov@sceptica.co.uk**

Alexey A. Lyubushin | **lyubushin@yandex.ru**

