Simulation of hydrologic data using fractals to investigate climate change

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California Department of Water Resources
Sacramento, April 15, 2016

Outline

- The fractal-multifractal method
- Encoding rainfall
- Simulating and downscaling rainfall
- Encoding streamflow
- Classifying and predicting streamflow
- Downscaling streamflow
- Conclusions and potential collaboration
- Encoding temperature

Outline

- **The fractal-multifractal method**
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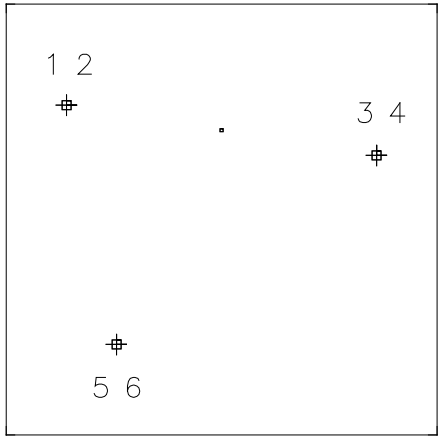
- Encoding temperature

The chaos game



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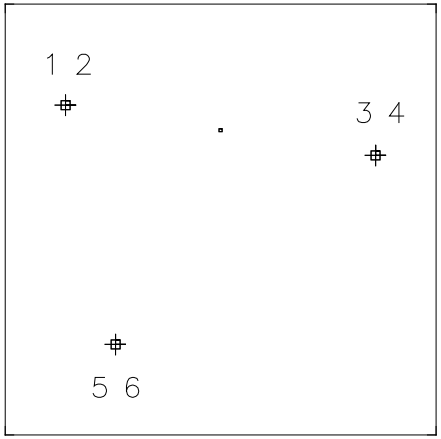

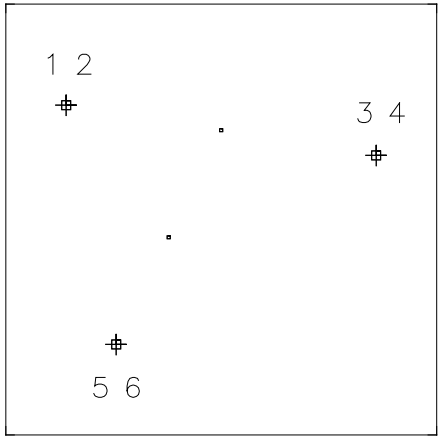

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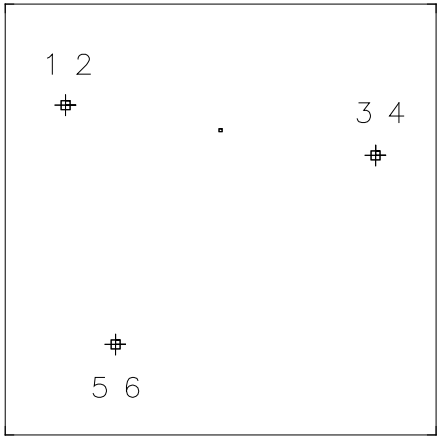

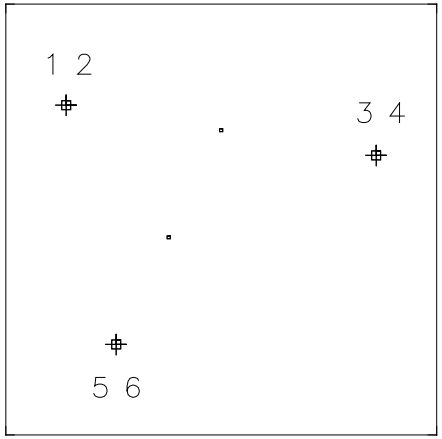

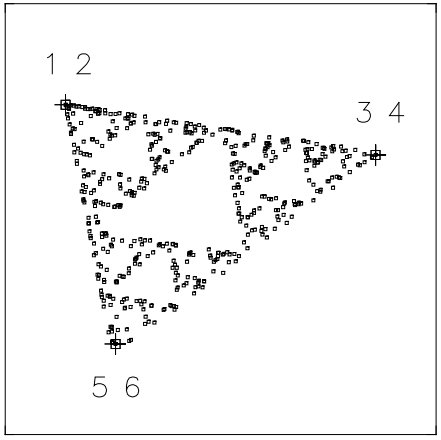

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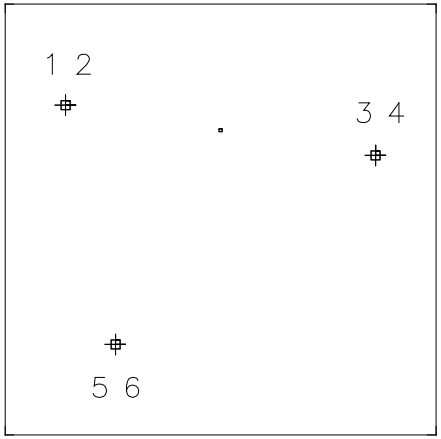
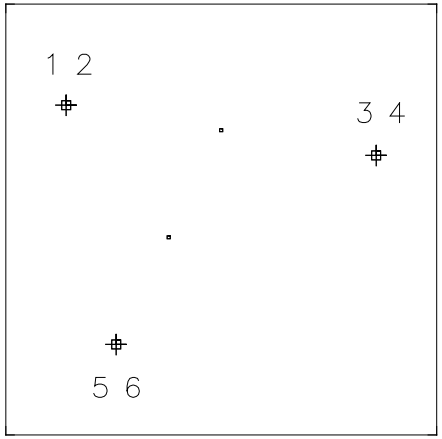
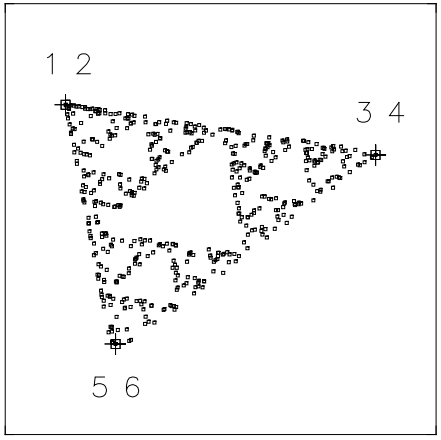
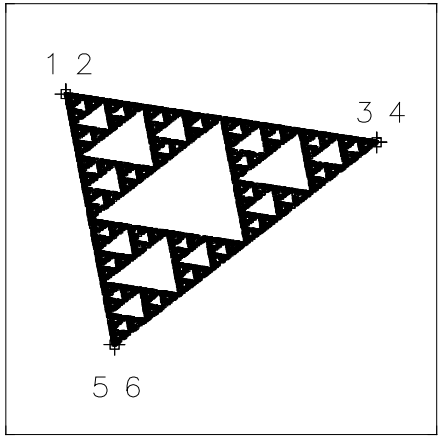








a fractal

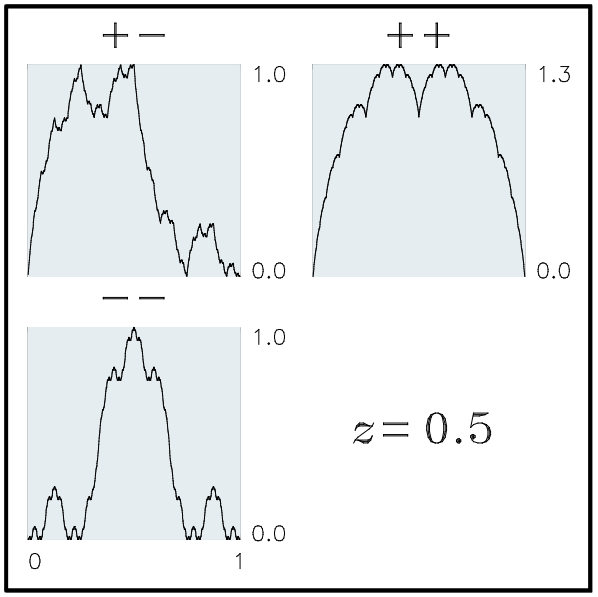
With other rules and a coin

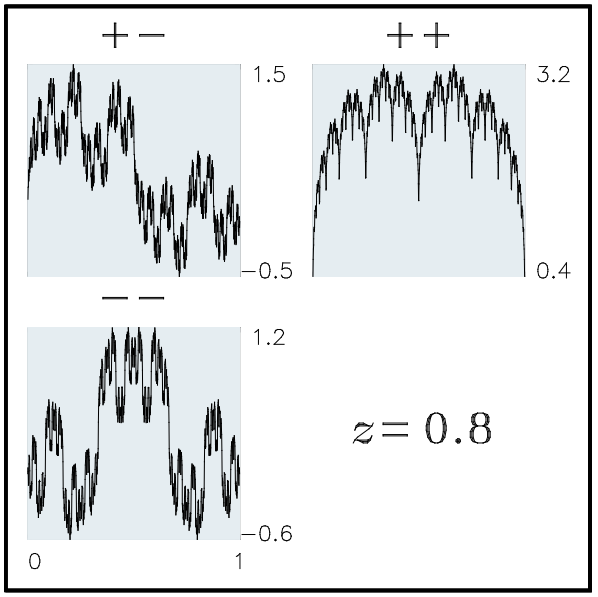
$$w_1(x,y) = \left(\frac{x}{2}, x + d_1 \cdot y\right),\ w_2(x,y) = \left(\frac{x}{2} + \frac{1}{2}, 1 - x + d_2 \cdot y\right)$$

With other rules and a coin

$$w_1(x,y) = \left(\frac{x}{2}, x + d_1 \cdot y\right),\ w_2(x,y) = \left(\frac{x}{2} + \frac{1}{2}, 1 - x + d_2 \cdot y\right)$$

$$z = |d_1| = |d_2|$$

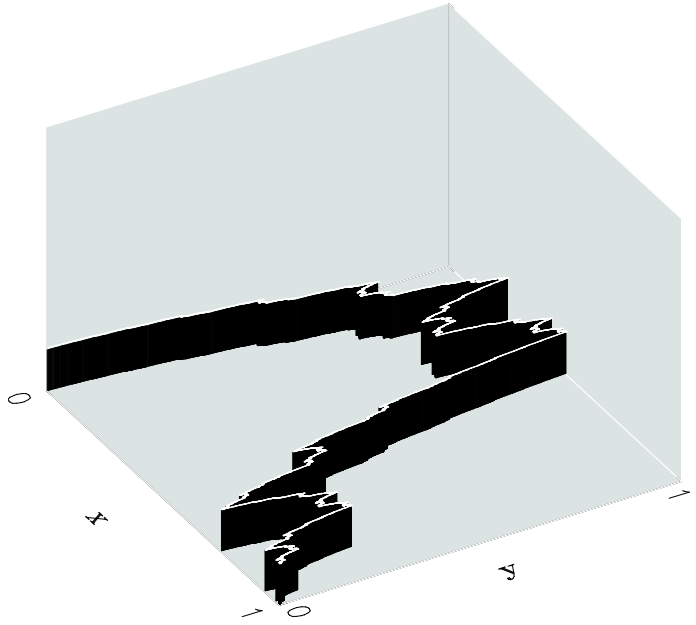




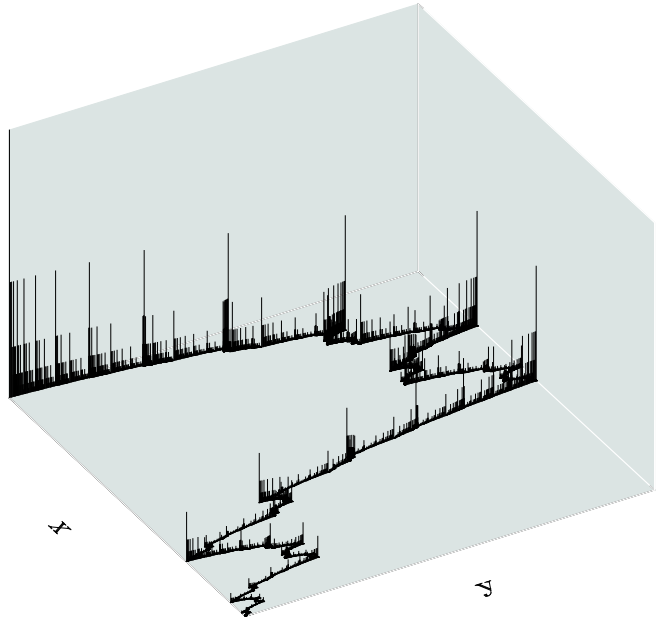
more fractals…

Using fair or biased coins

50-50



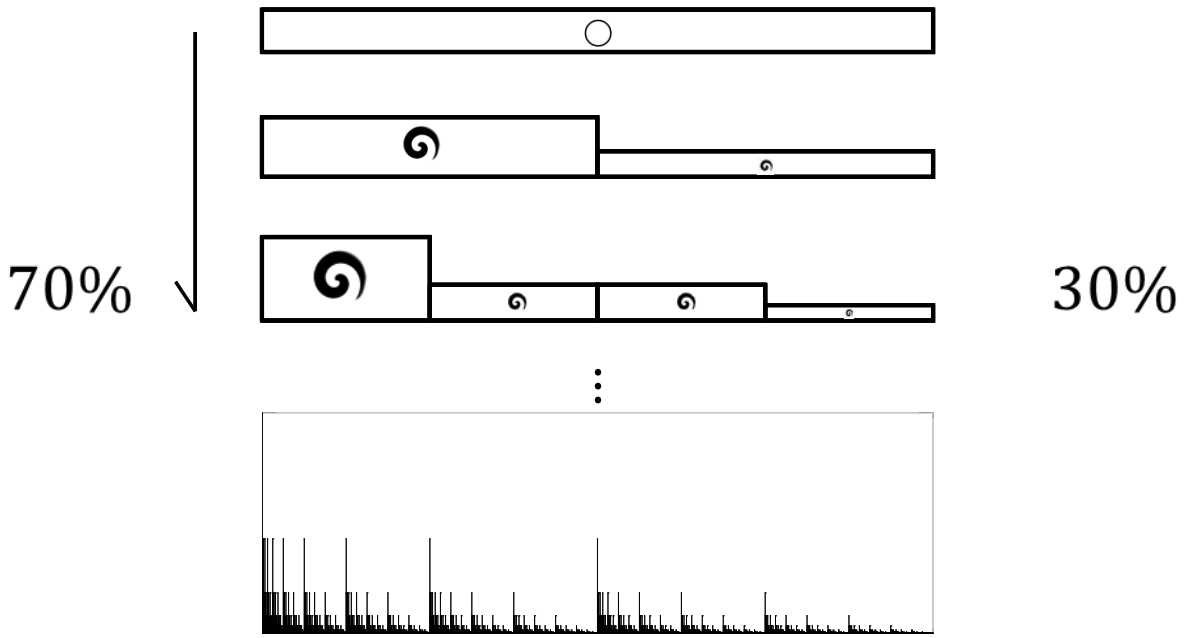
70-30



different textures over the same “wire”

From x: a turbulent cascade

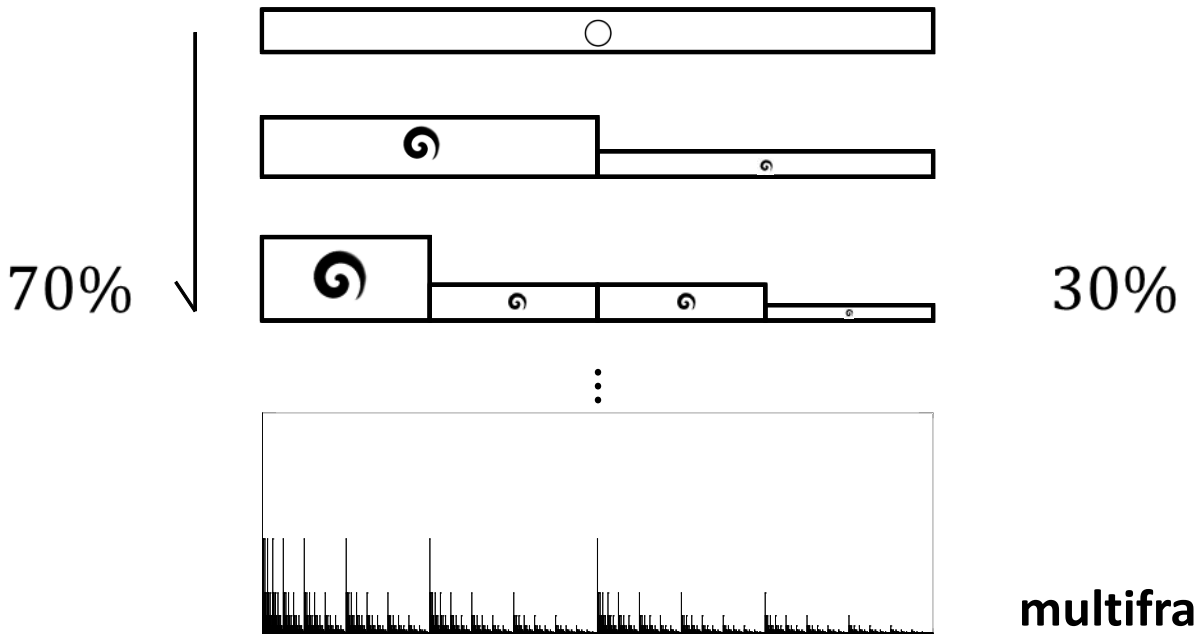
(Meneveau and Sreenivasan, 1987)



a sequence of **eddies** that divide the energy **universally**

From x: a turbulent cascade

(Meneveau and Sreenivasan, 1987)



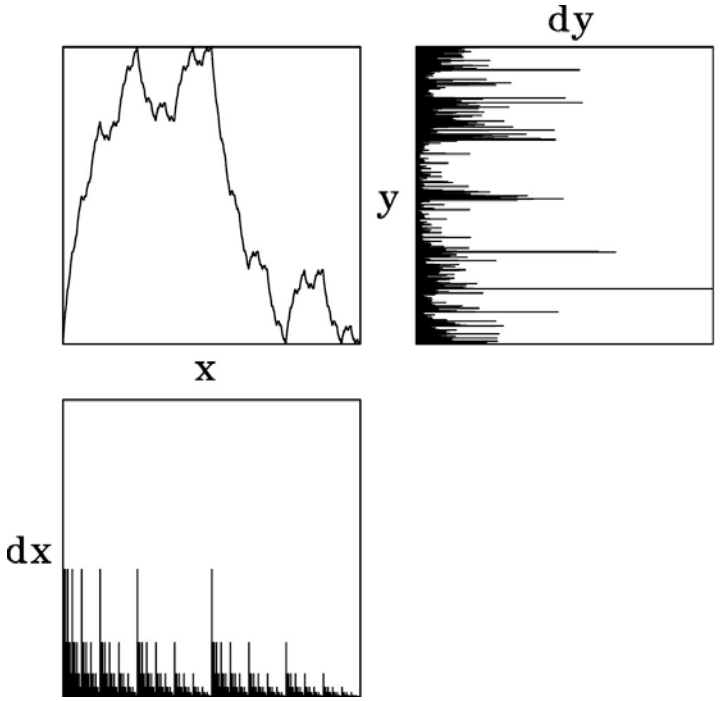
multifractal

a sequence of **eddies** that divide the energy **universally**

a collection of intertwined **thorns** with **dusty** supports

From y: a Platonic vision to complexity

(Puente, 1992, 1994)



fractal-multifractal, FM

dx is the "illumination" of the **wire** and dy is its **derived** projection

From y: a Platonic vision to complexity

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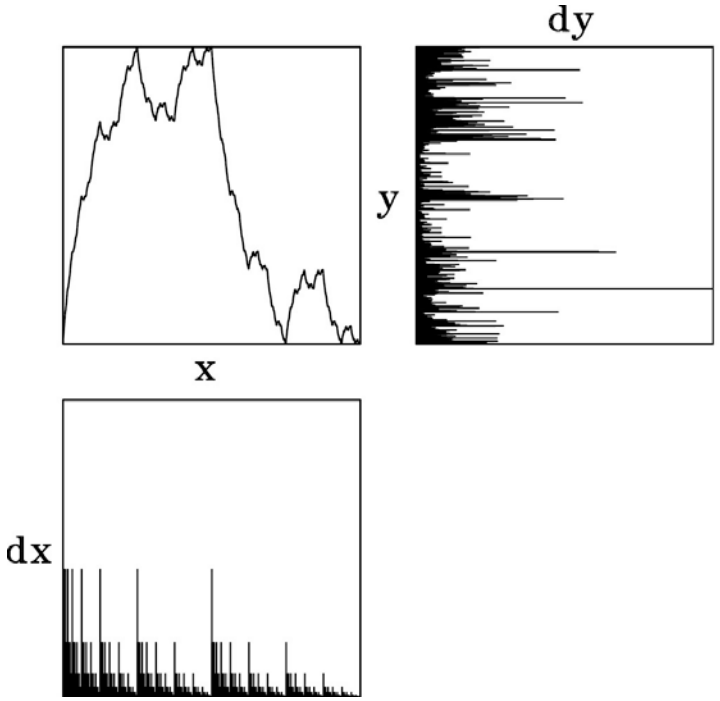

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dx is the "illumination" of the **wire** and dy is its **derived** projection

dy is a **transformation** of turbulence, a non-trivial **physical** cascade

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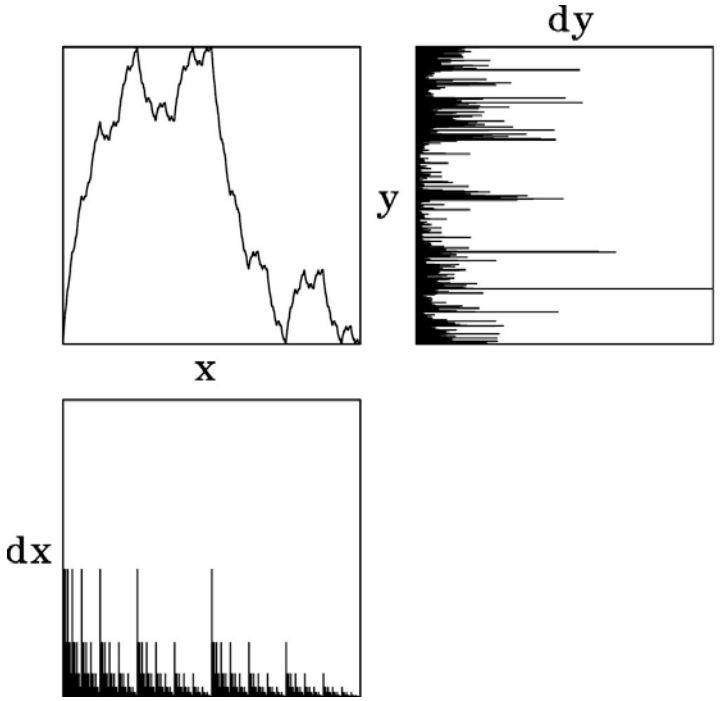


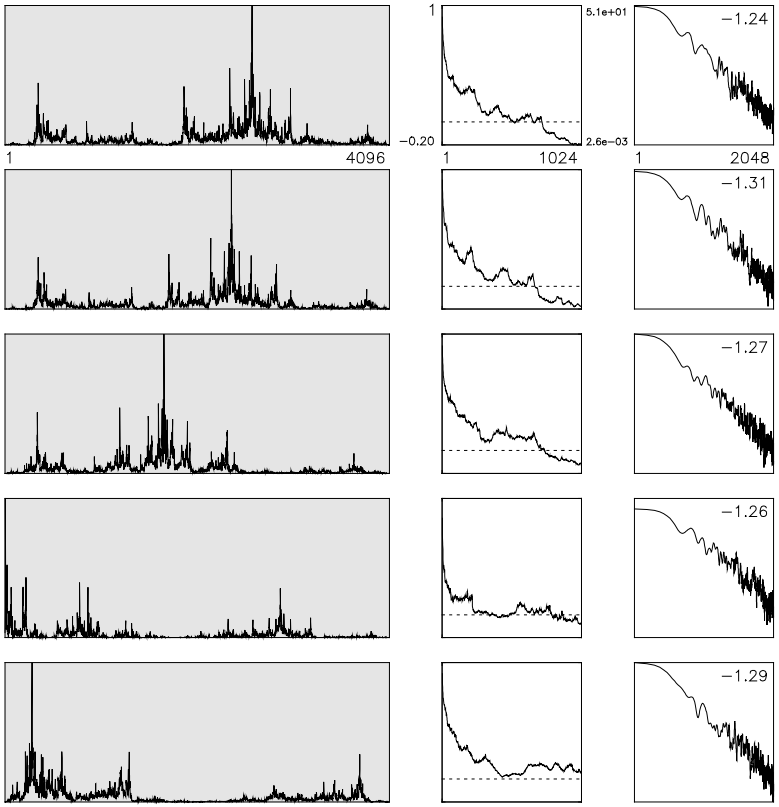
fractal-multifractal, FM

dx is the "illumination" of the **wire** and dy is its **derived** projection

dy is a **transformation** of turbulence, a non-trivial **physical** cascade

the "shadow" dy appears to be **random**, but it is not

Projections galore



complex data sets are thought of as distributions

varying FM parameters yields similar statistics as **natural** sets

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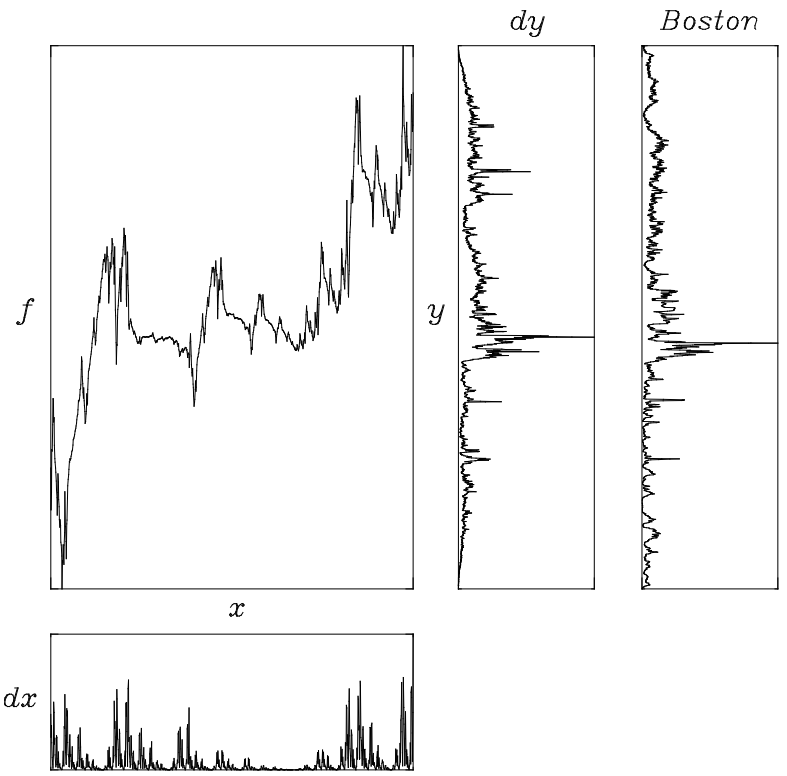
Encoding a rainfall storm in Boston

(Puente and Obregón, 1996)

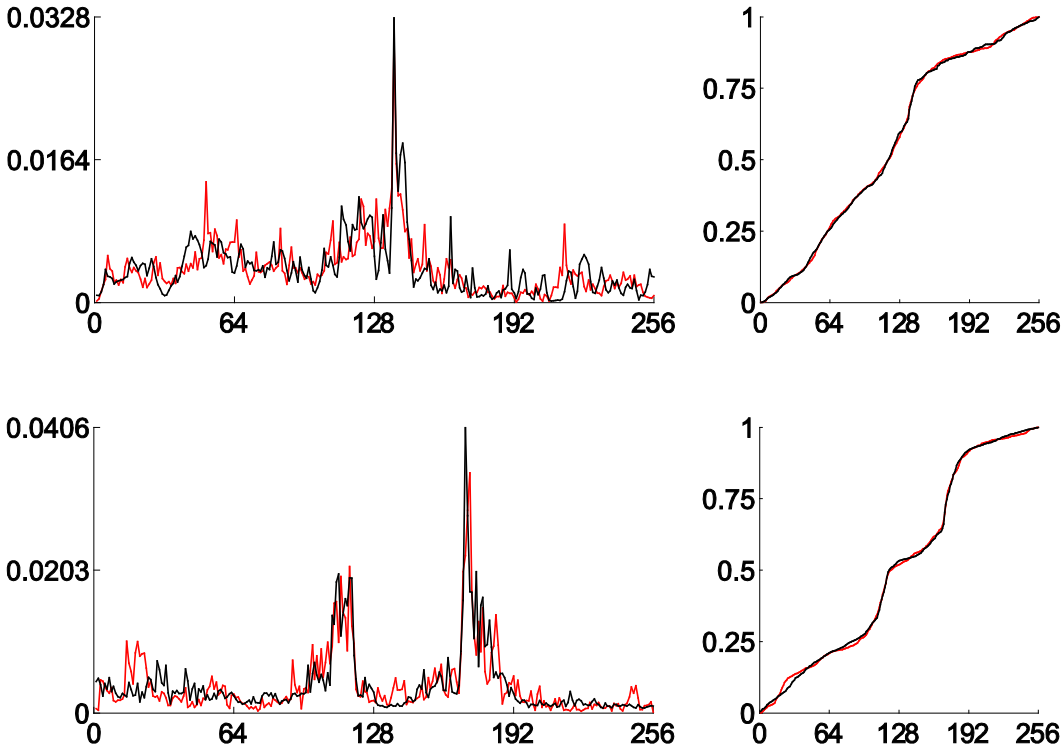


a model (center) of real data (right)

the model preserves **statistical** and **chaotic** characteristics

Encoding storms in Boston and Iowa City

(Puente et al., 2010)

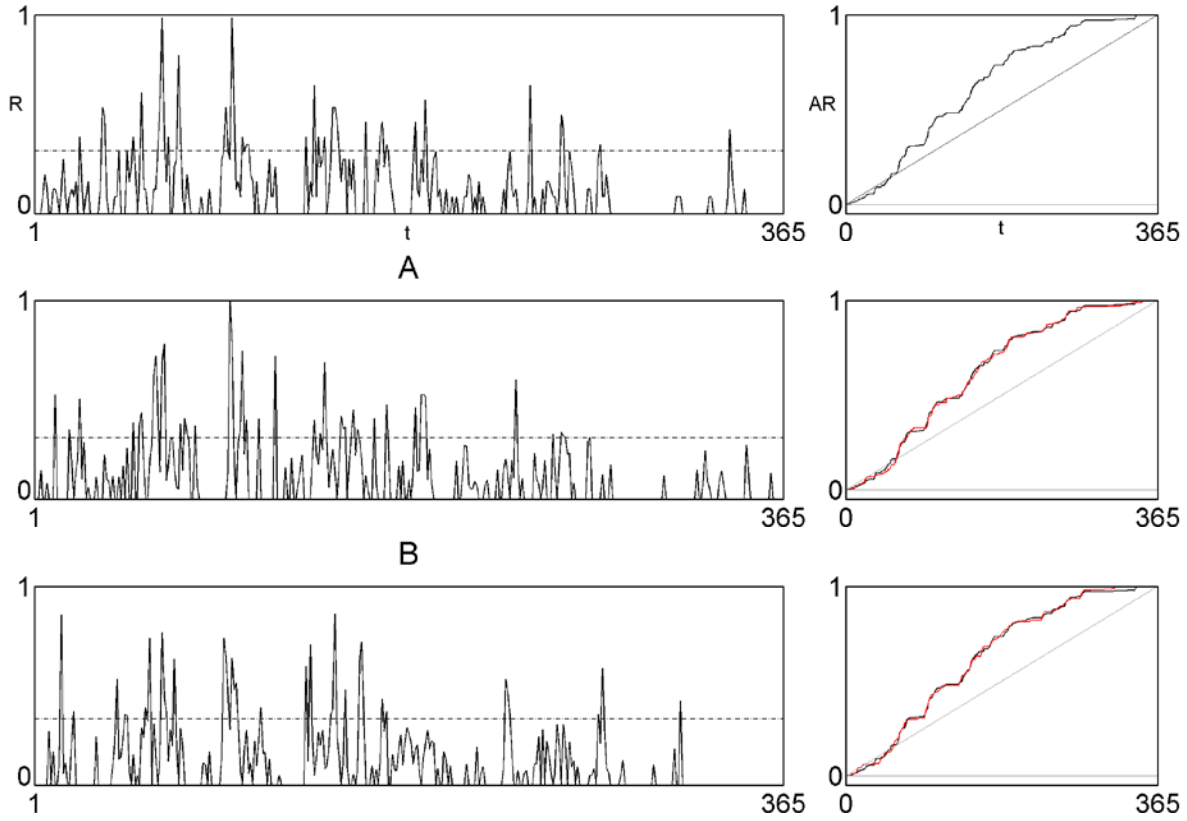


RMSEAR 0.7, 1.0%; MAXEAR 1.8, 2.1%

compressions greater than 350:1

Encoding rainfall in Tinkham, WA

(Maskey et al., 2015)



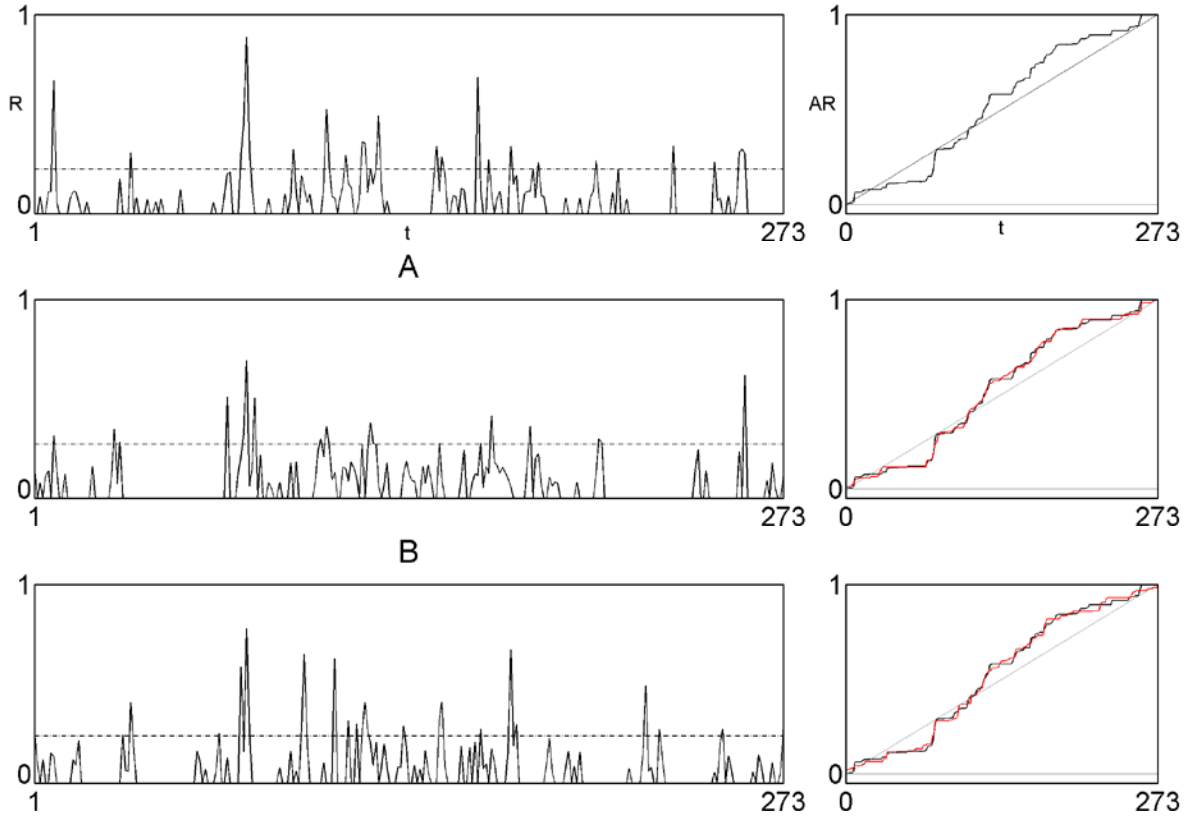
Cantorian input plus threshold

RMSEAR 1.1, 1.2%; MAXEAR 3.1, 2.7%

compressions 33:1

Encoding rainfall in Laikakota, Bolivia

(Maskey et al., 2015)



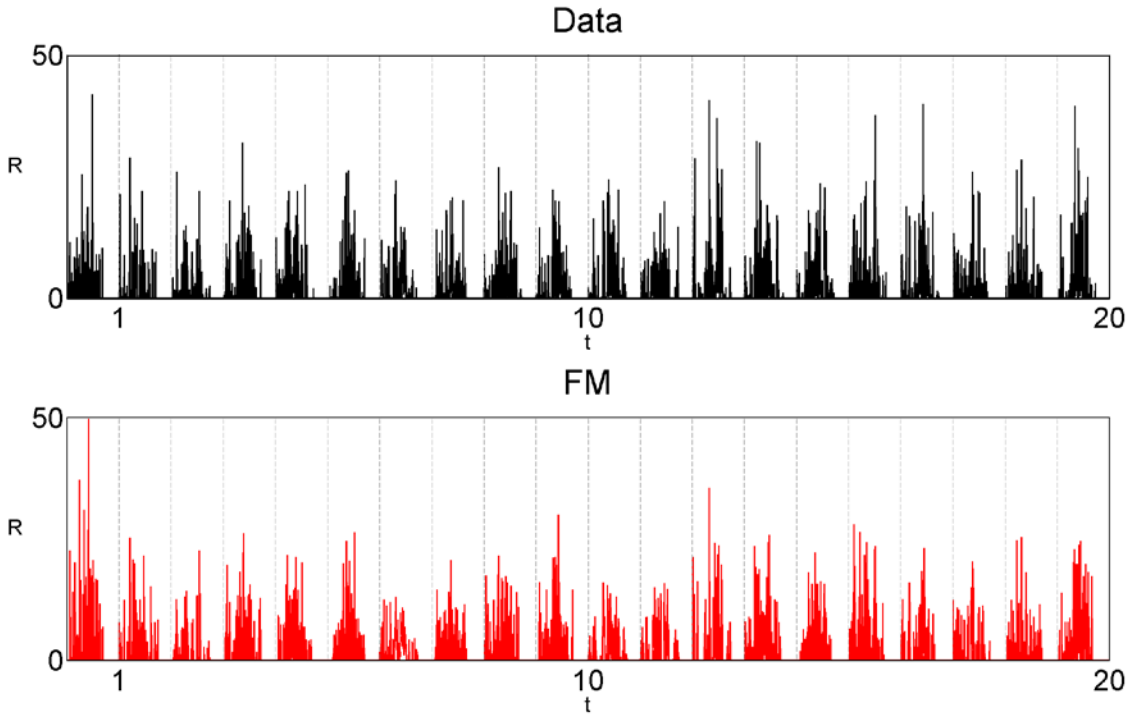
Cantorian input plus threshold

RMSEAR 1.4, 1.8%; MAXEAR 4.4, 3.5%

compressions 25:1

Encoding rainfall in Laikakota, Bolivia

(Maskey et al., 2015)



Cantorian input plus threshold

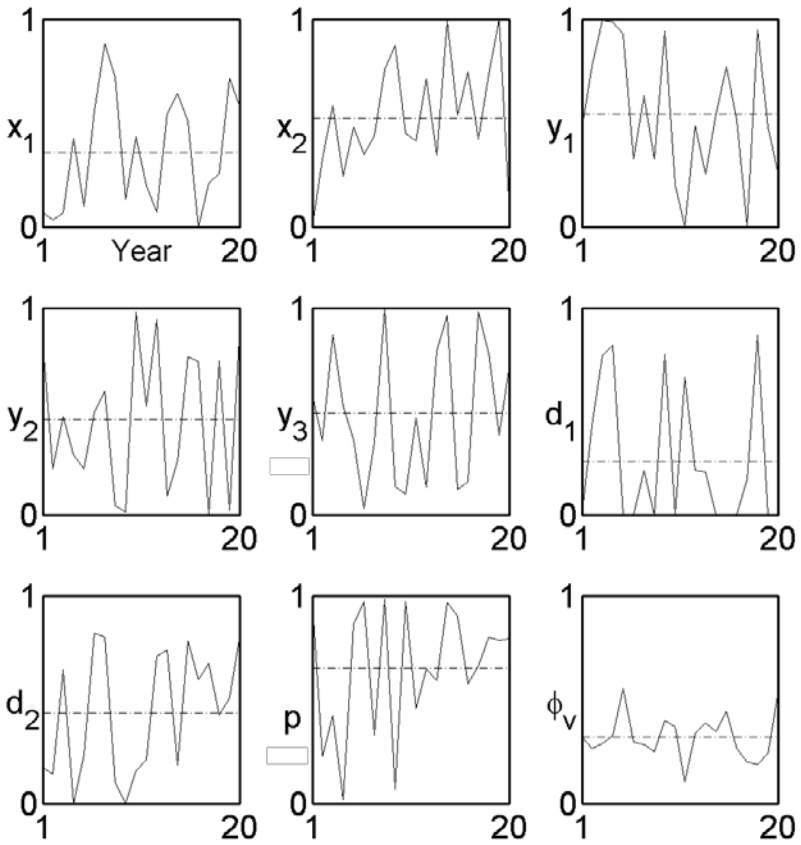
scale in mm/day

RMSEAR 1.8 ± 0.3%; MAXEAR 5.6 ± 1.3%

compressions 25:1

Dynamics of rainfall in Laikakota, Bolivia

(Maskey et al., 2015)



to assess rainfall complexity and climate change, also temperature…

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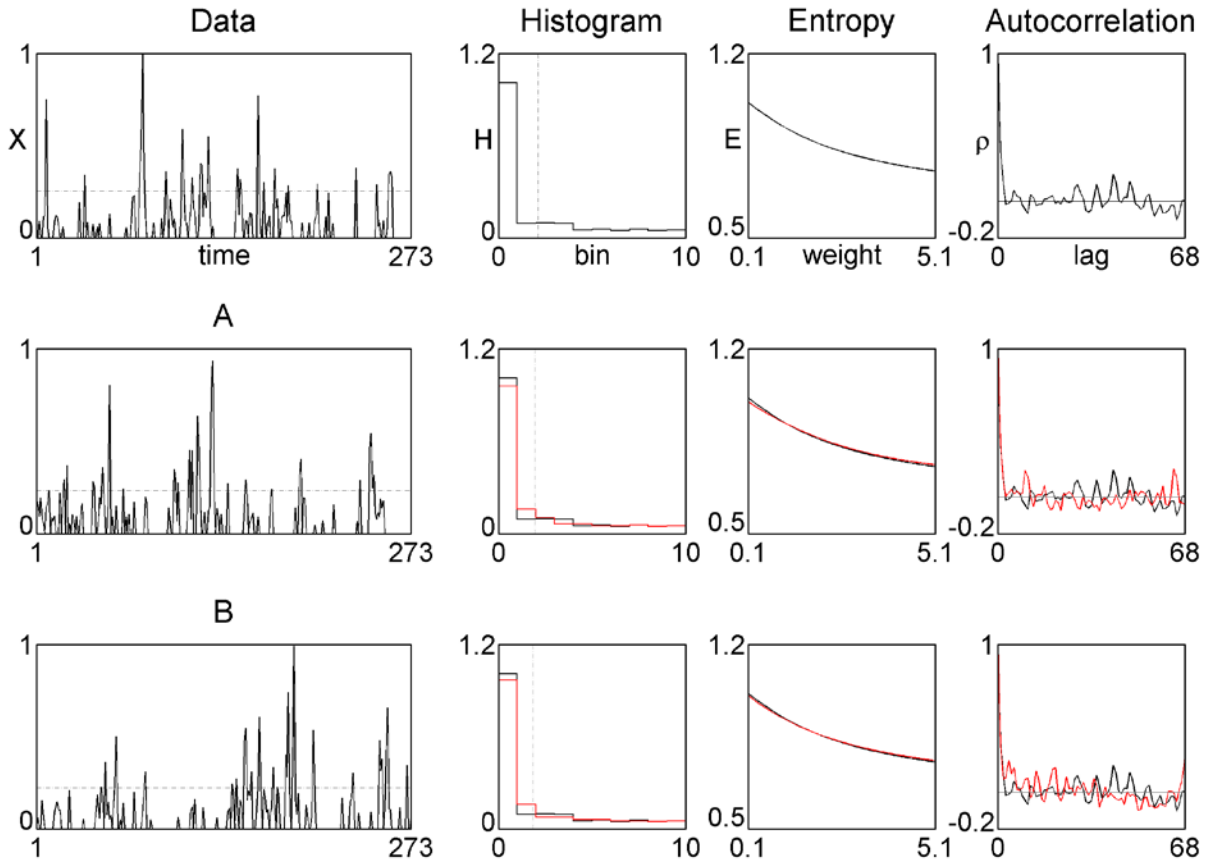
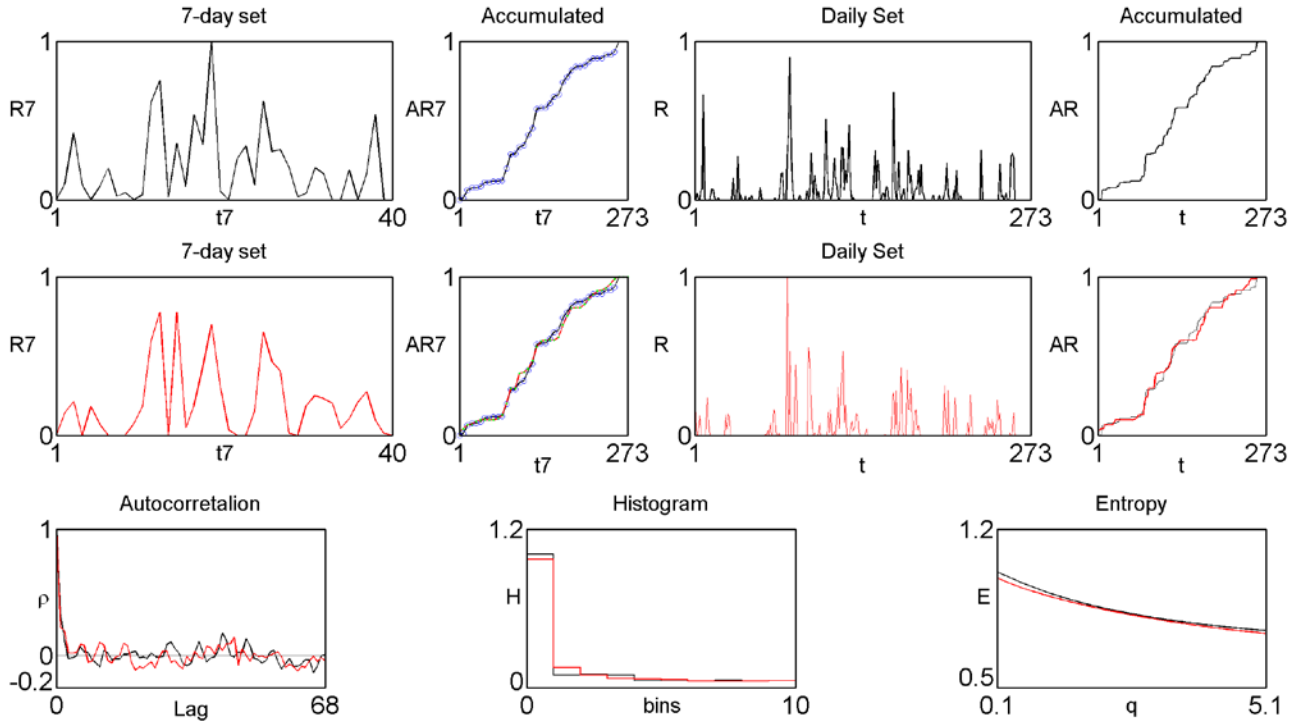
Simulating rainfall in Laikakota, Bolivia

Based on histogram, entropy and consecutive zeroes



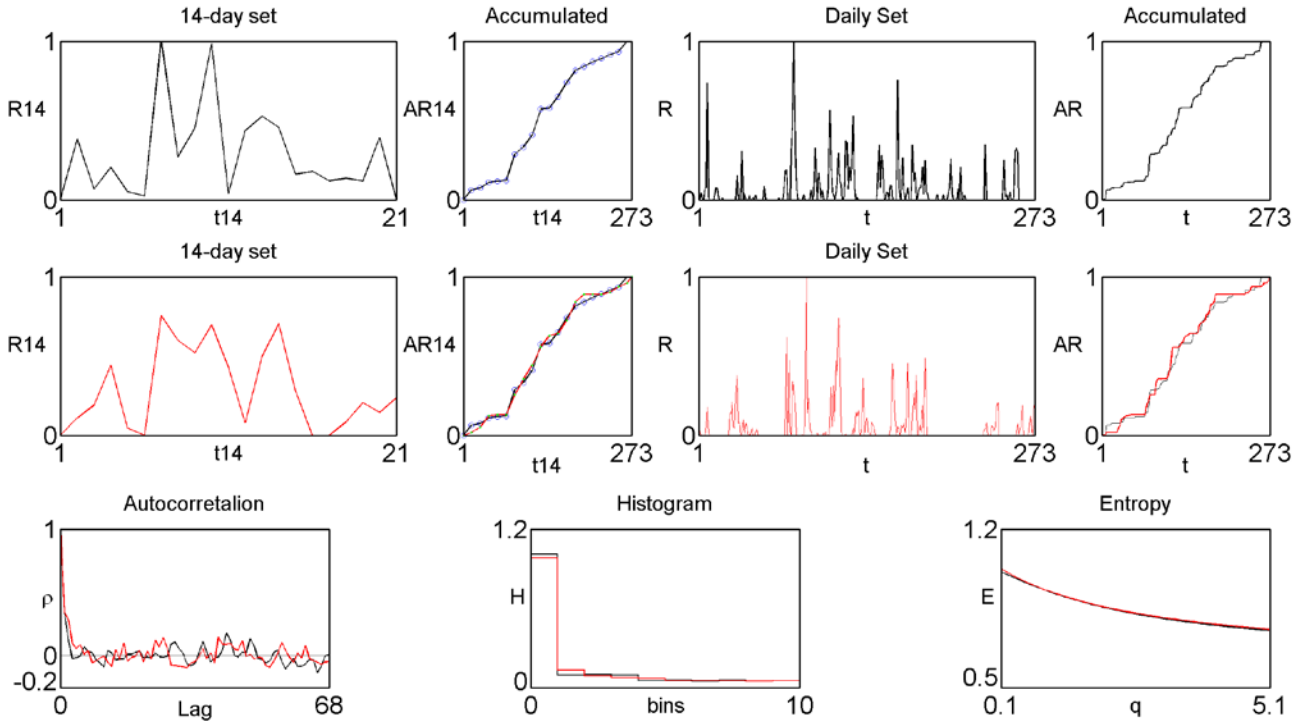
Downscaling rainfall in Laikakota, Bolivia

Based on cumulative set every 7 days



Downscaling rainfall in Laikakota, Bolivia

Based on cumulative set every 14 days



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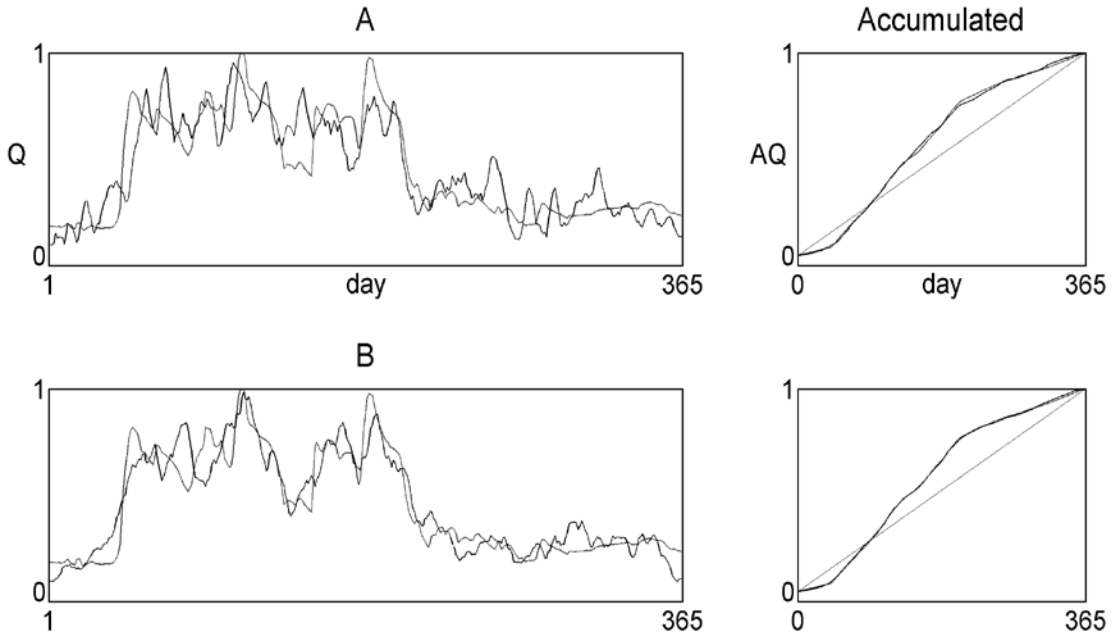
Encoding streamflow in Sacramento

Water year 1973-74



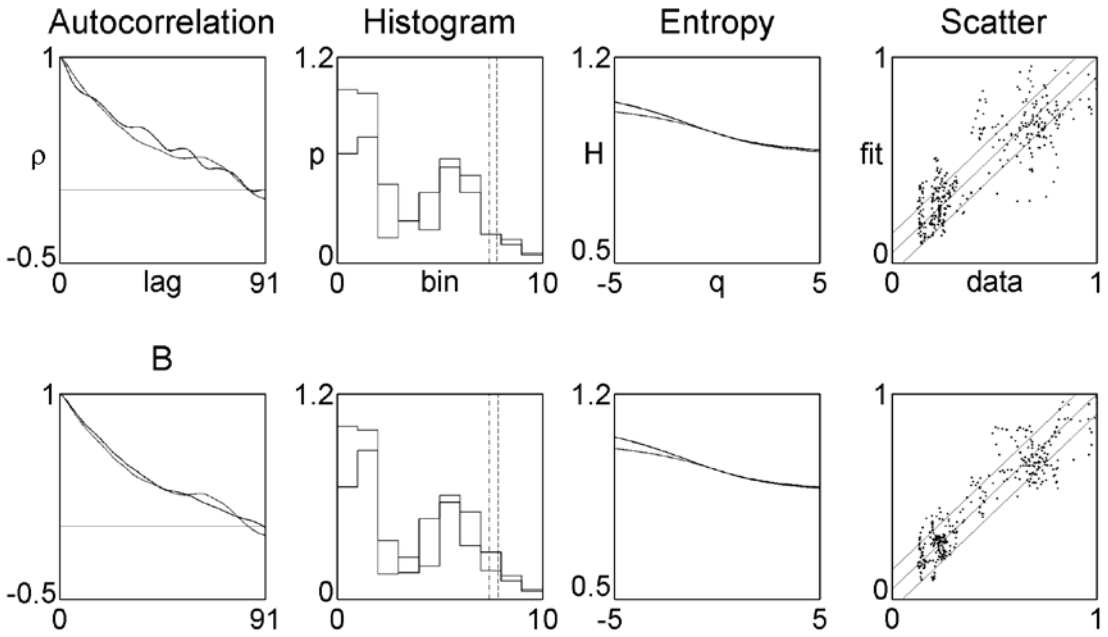
A: wire 2 maps, B: wire 3 maps

RMSEAR 1.0%, 0.5%; MAXEAR 2.3%, 1.1%

compressions greater than 40:1

Encoding streamflow in Sacramento

Water year 1973-74

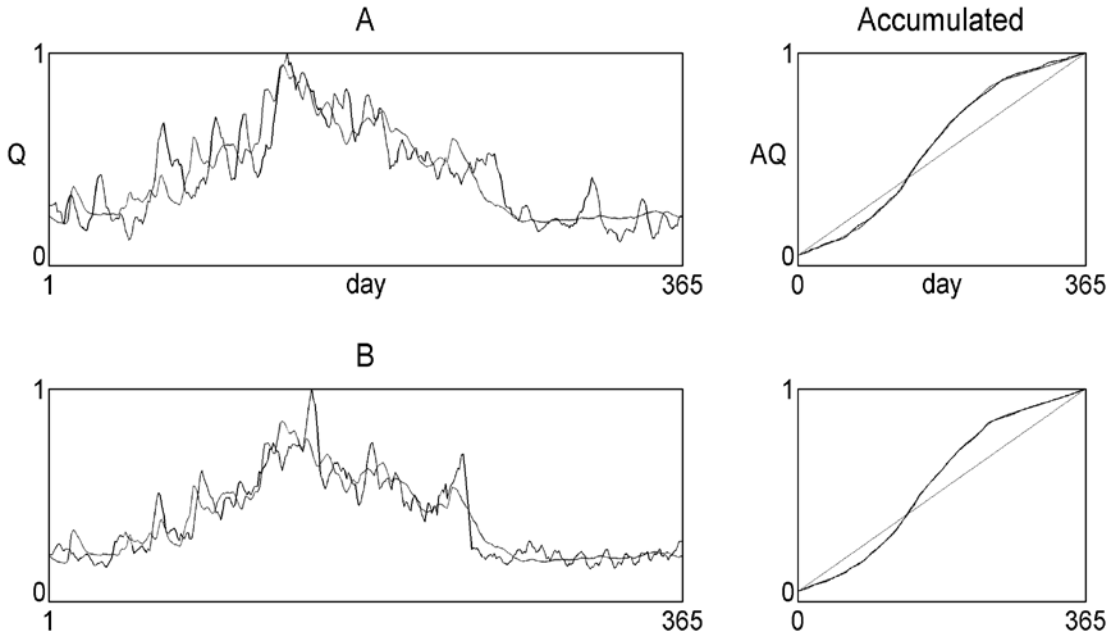


A: wire 2 maps, B: wire 3 maps

NSD 73.3%, 85.0%; NSA 95.7%, 98.1%; NSE 93.9%, 92.8%

Encoding streamflow in Sacramento

Water decade 1956-65



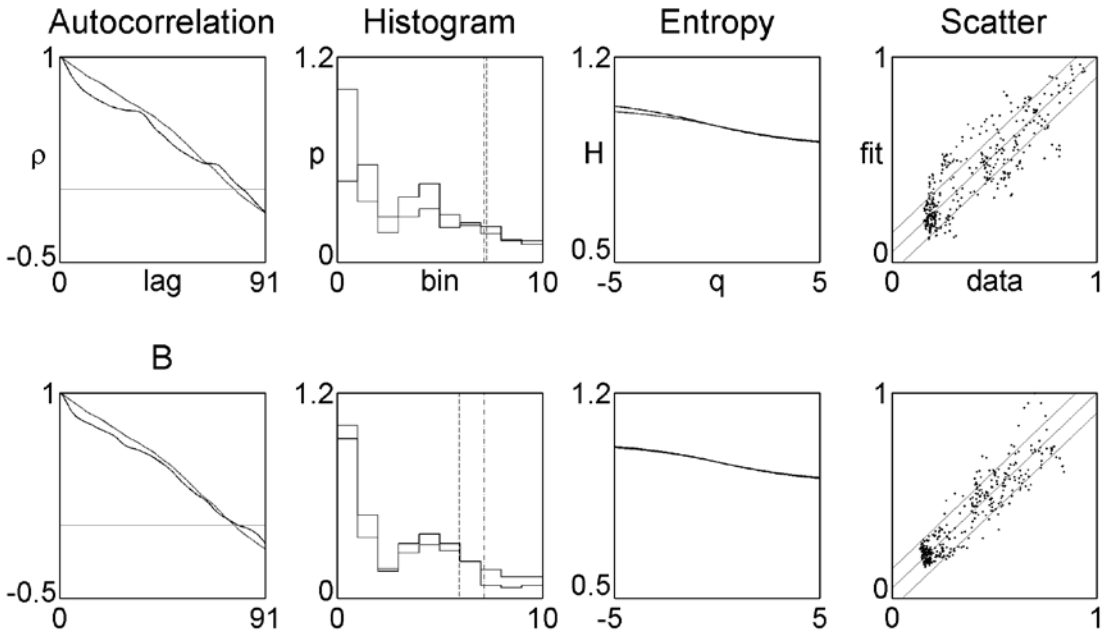
A: wire 2 maps, B: wire 3 maps

RMSEAR 0.7%, 0.3%; MAXEAR 1.5%, 0.7%

compressions greater than 40:1

Encoding streamflow in Sacramento

Water decade 1956-65

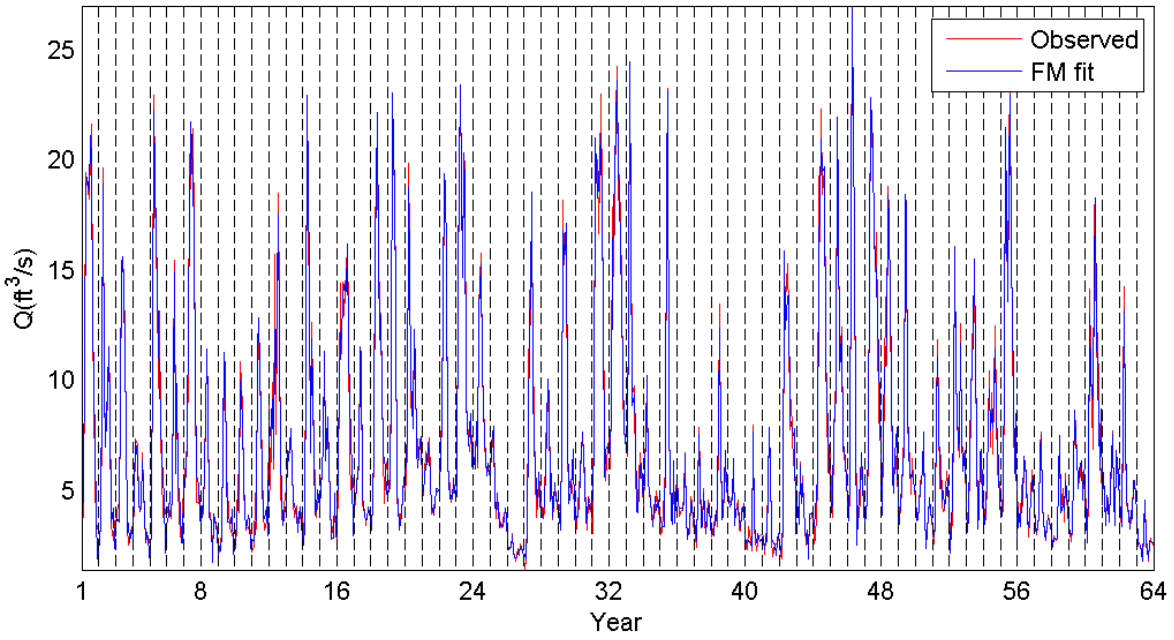


A: wire 2 maps, B: wire 3 maps

NSD 72.9%, 84.0%; NSA 92.4%, 96.9%; NSE 96.1%, 99.6%

Encoding streamflow in Sacramento

By year 1950-2014

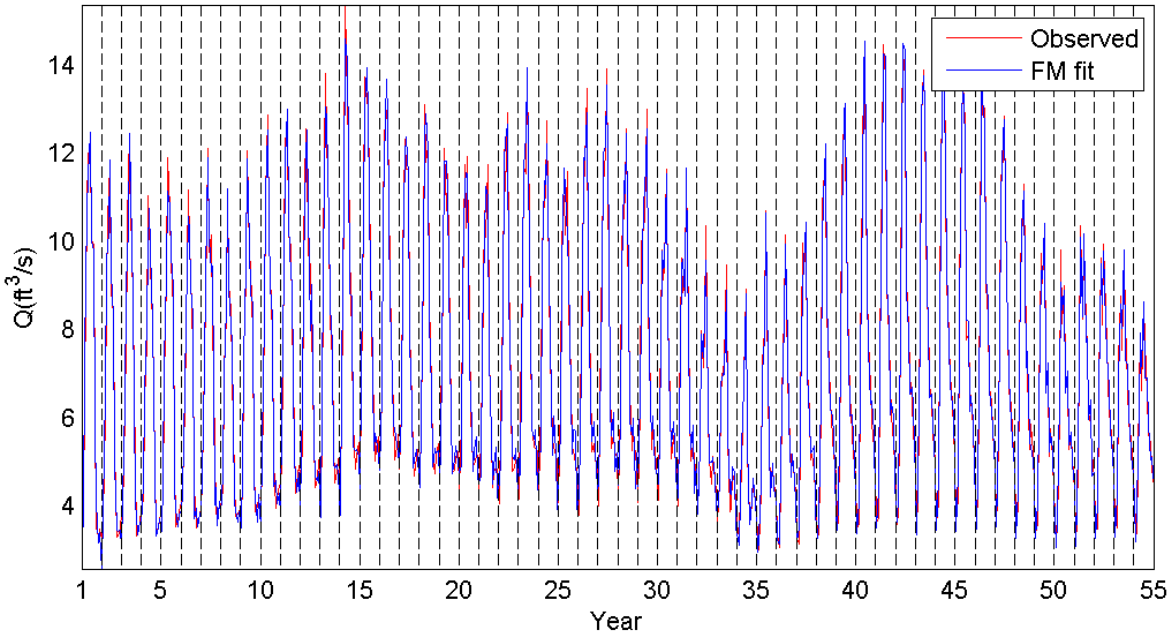


wire 3 maps, scale in 10^4 x cfs

RMSEAR 0.8 $\pm$ 0.3%; MAXEAR 1.8 $\pm$ 0.5%; NSD 63.9 $\pm$ 19.0%

Encoding streamflow in Sacramento

By decade 1959-2014

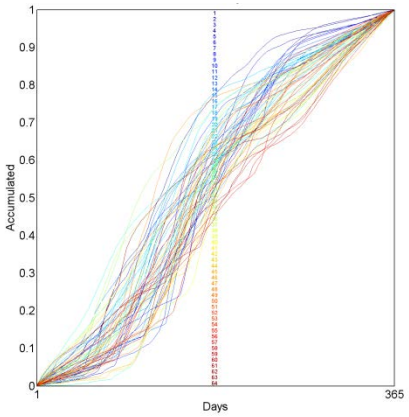


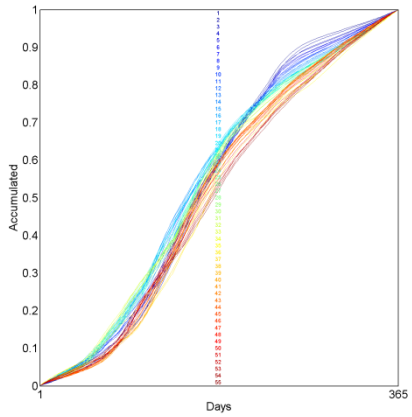
wire 3 maps, scale in 10^4 x cfs

RMSEAR 1.8 $\pm$ 0.4%; MAXEAR 3.6 $\pm$ 0.7%; NSD 92.2 $\pm$ 12.5%

Encoding streamflow in Sacramento

Accumulated by year and by decade





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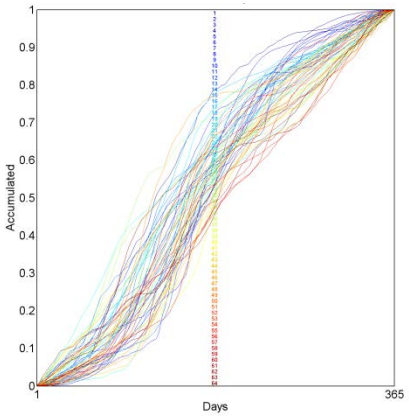
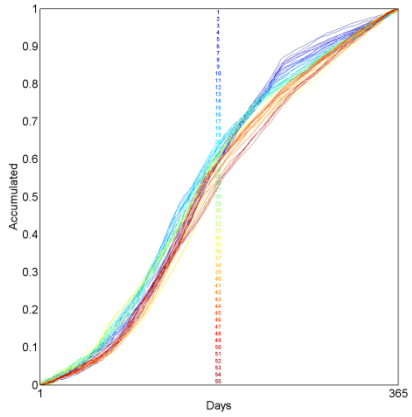
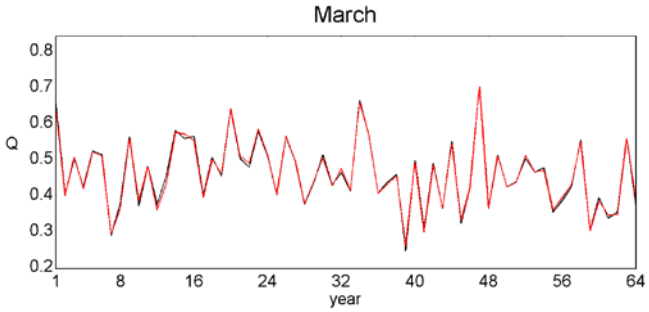


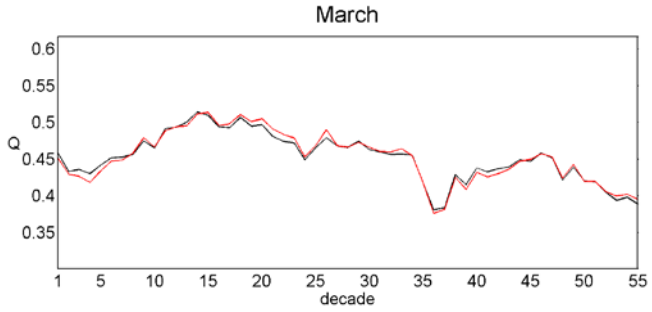


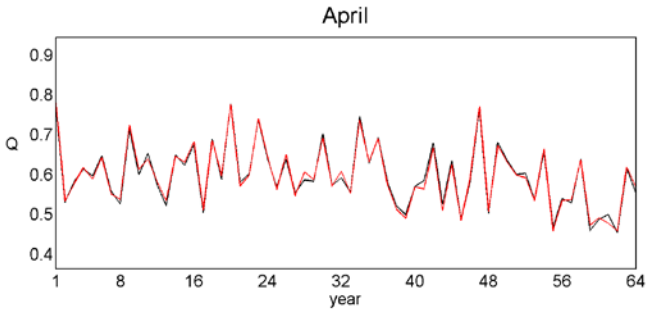
FM fit

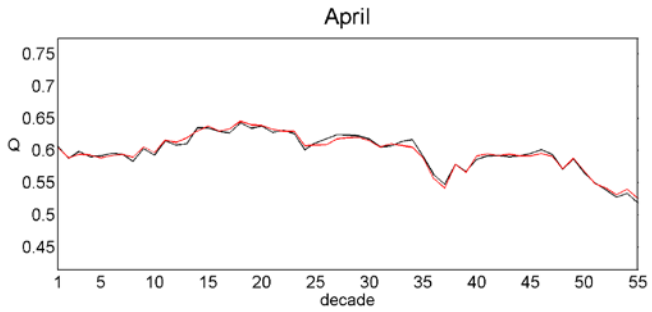
Encoding streamflow in Sacramento

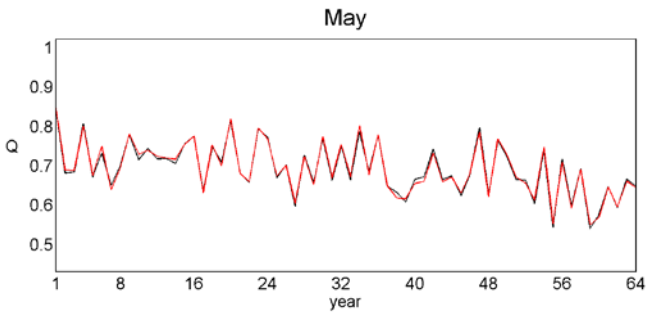
Spring flows by year and by decade

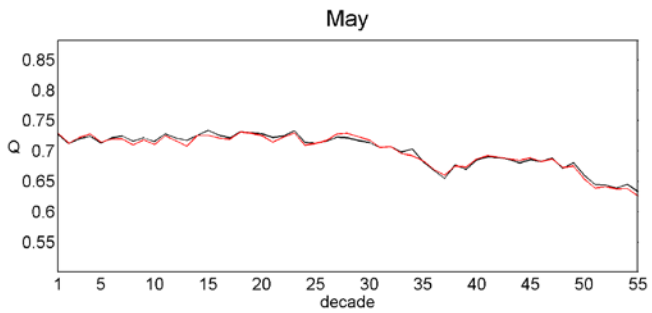






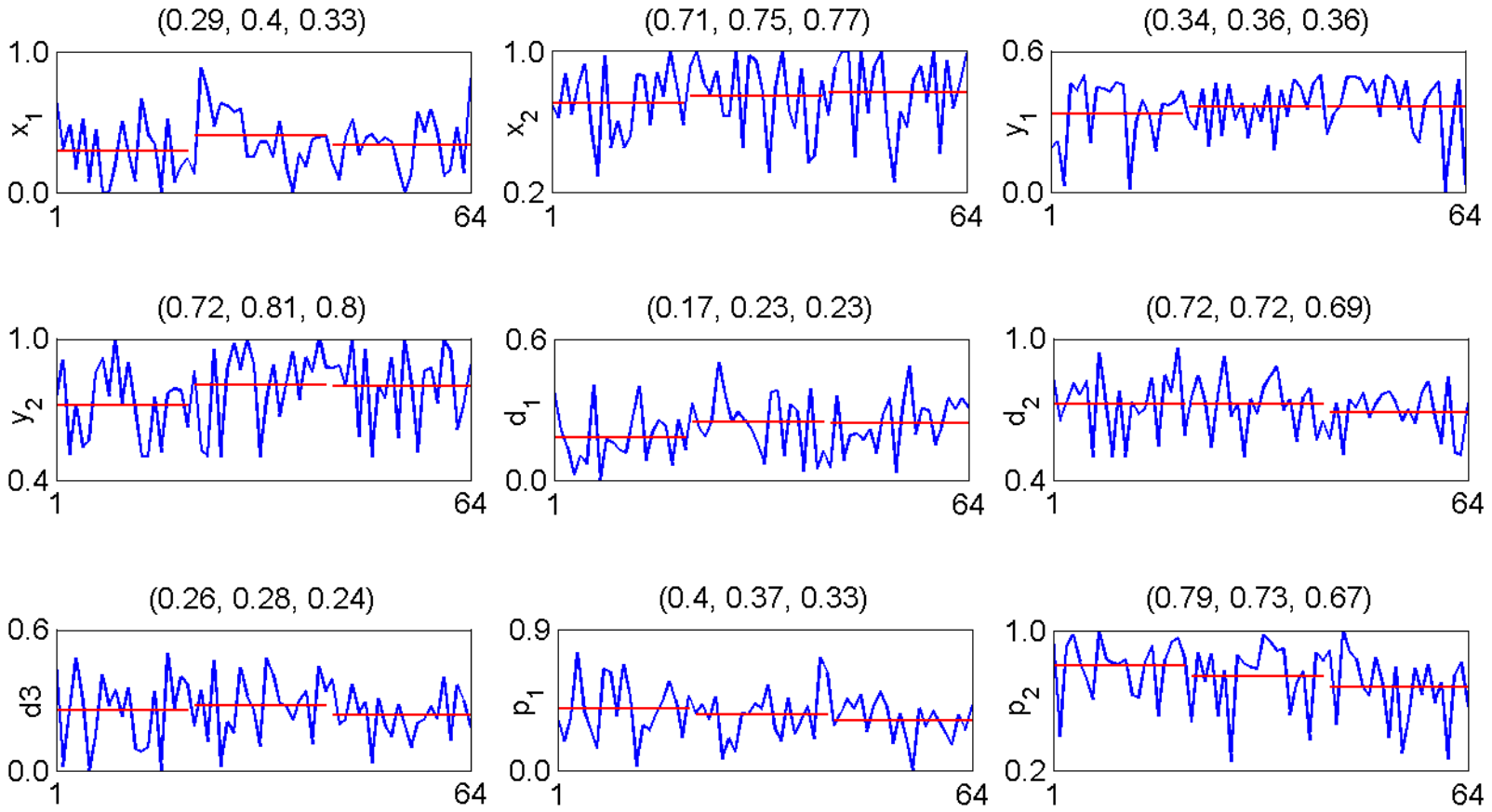






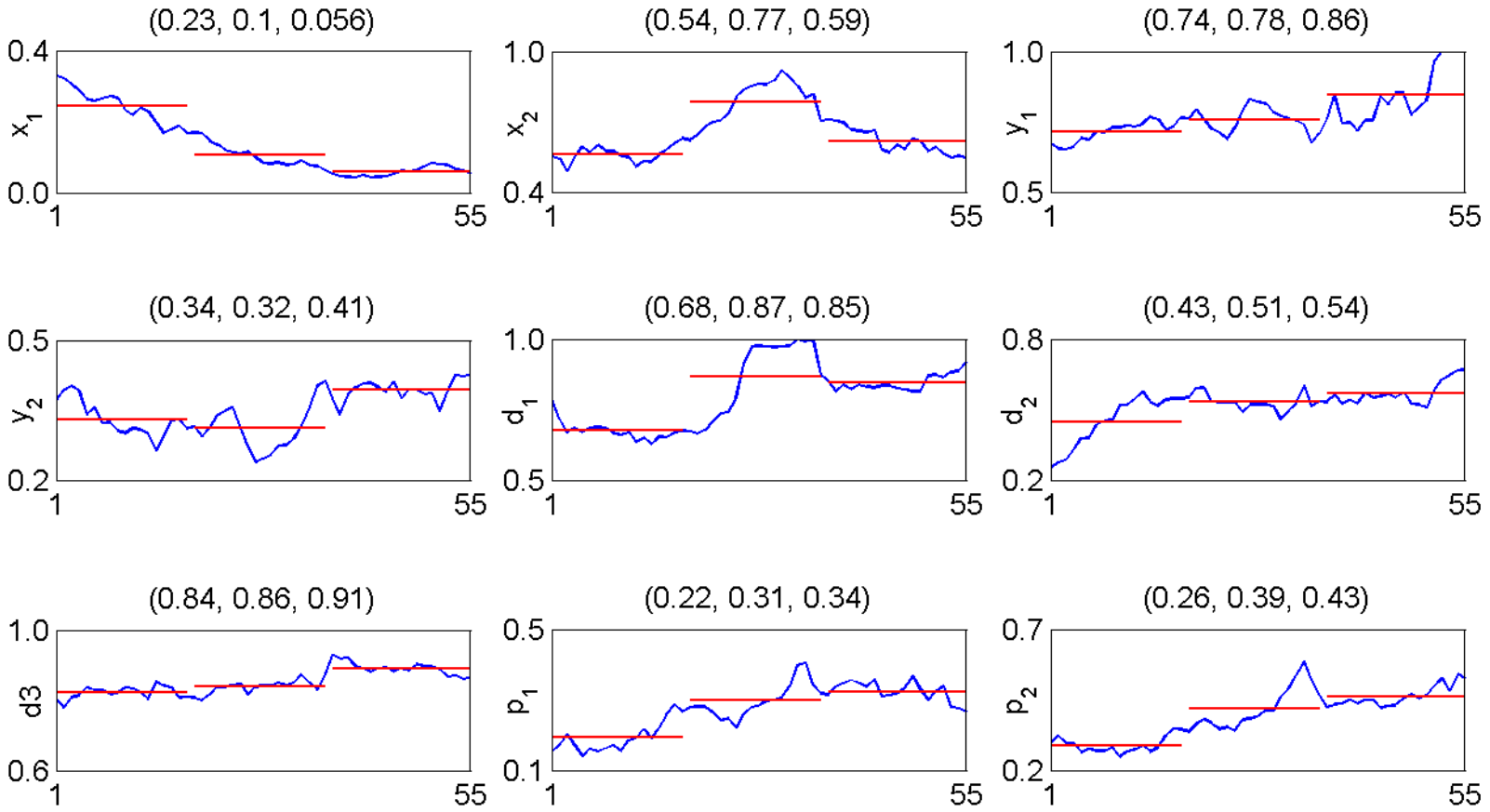
Dynamics of streamflow in Sacramento

By year 1950 - 2014



Dynamics of streamflow in Sacramento

By decade 1959 - 2014



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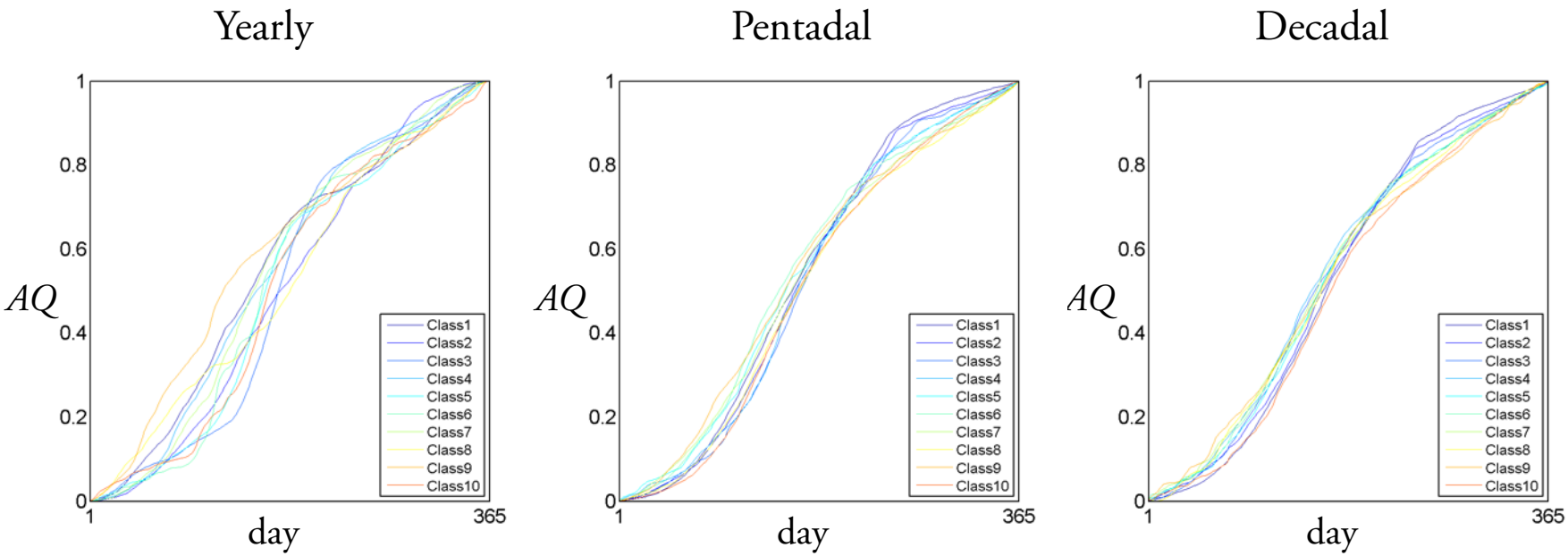
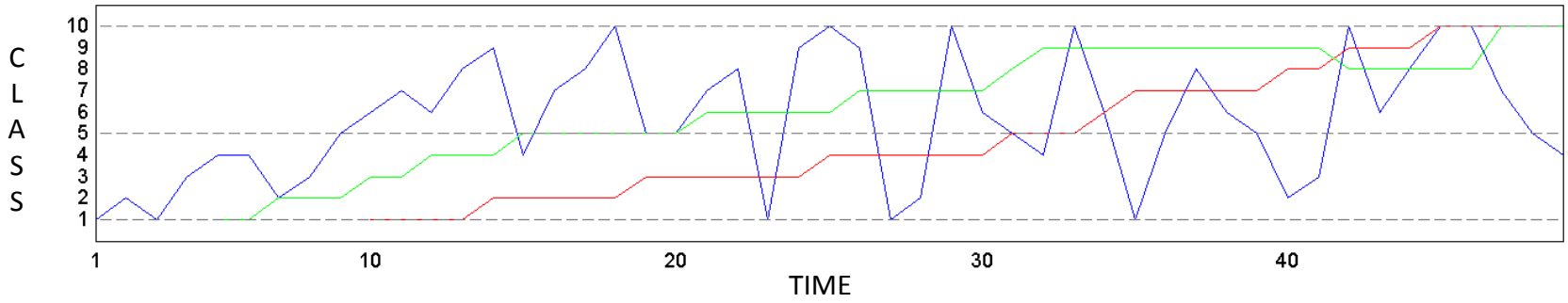
Classifying streamflow in Sacramento

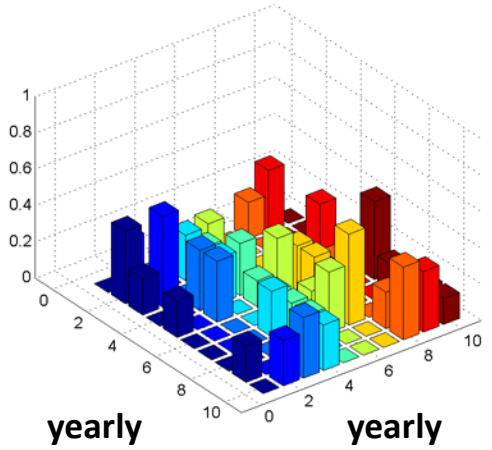
Based on FM parameters and k-means clustering

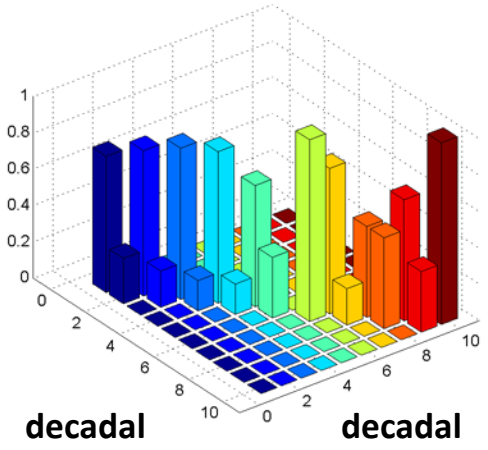


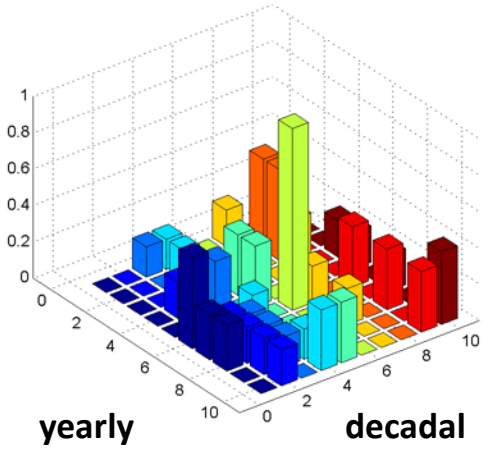
Classifying streamflow in Sacramento

Evolution by classes and transition matrices



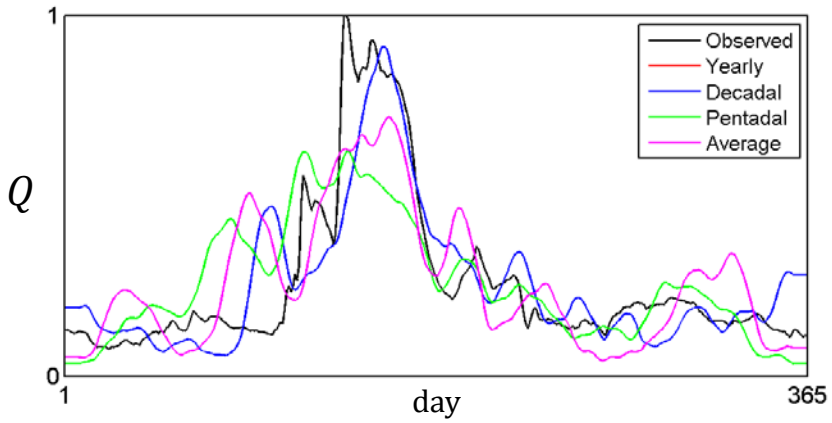


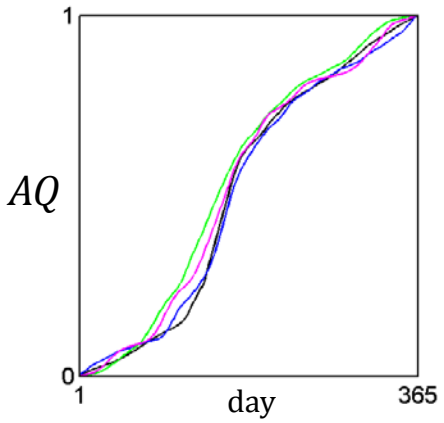


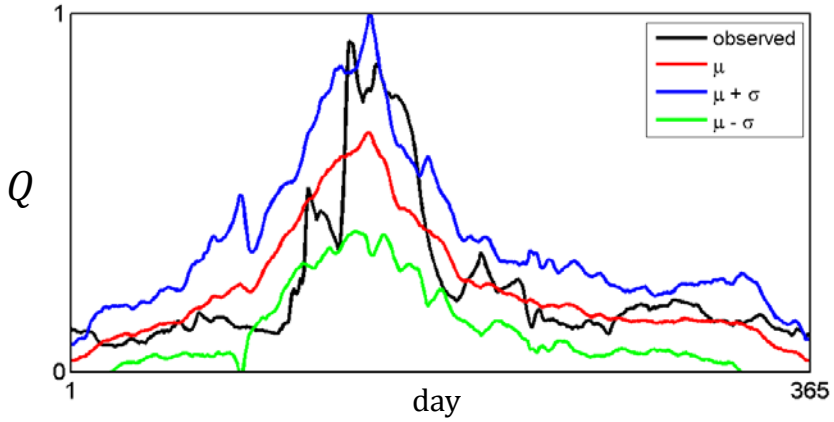


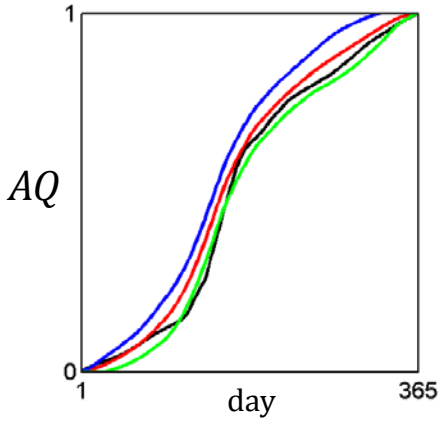
Predicting streamflow in Sacramento

A successful year, via trends and FM parameter sensitivity







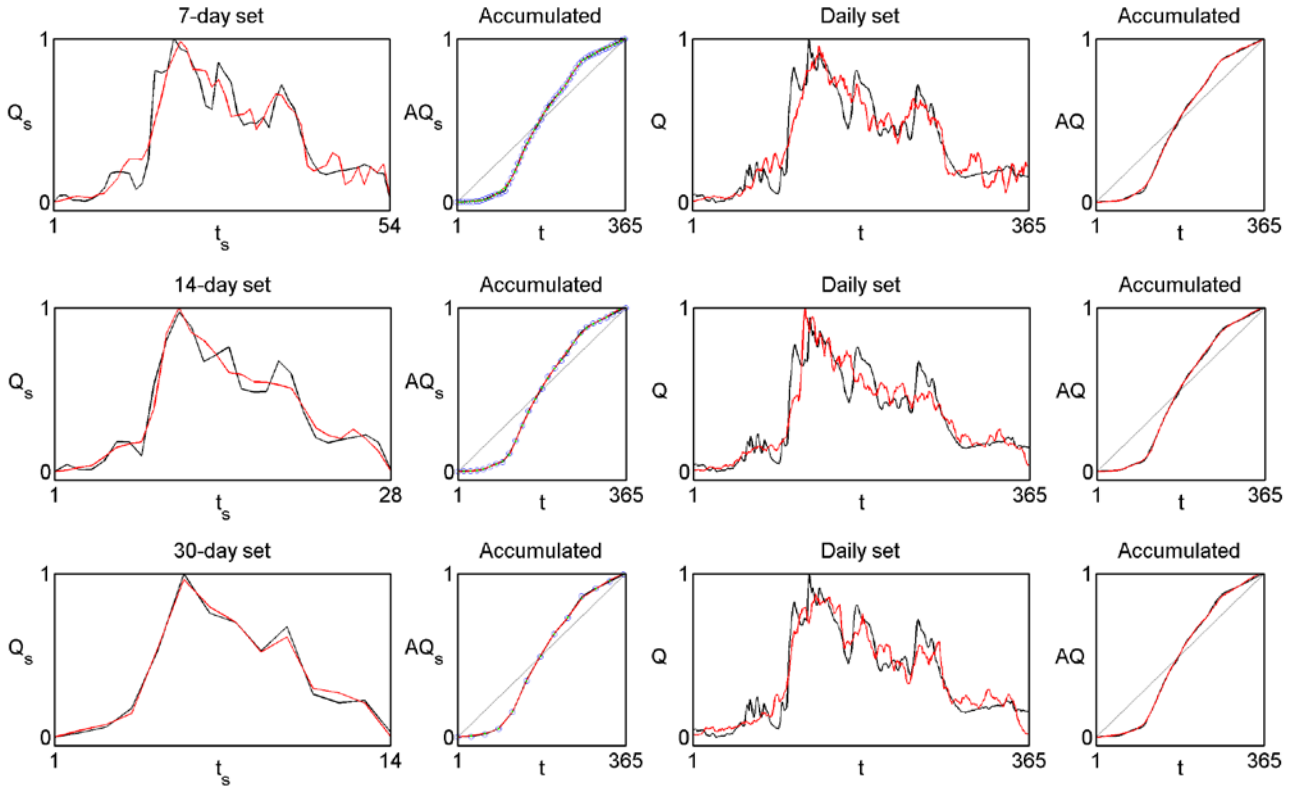


Outline

- The fractal-multifractal method
- Encoding rainfall
- Simulating and downscaling rainfall
- Encoding streamflow
- Classifying and predicting streamflow
- **Downscaling streamflow**
- Conclusions and potential collaboration
- Encoding temperature

Downscaling streamflow in Sacramento

Every 7, 14 and 30 days



Outline

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Outside the cave

- The platonic ideas may be used to model a variety of data sets, both in time and in space.
- The notions provide a compact deterministic language for some features of natural complexity.
- Perhaps the ideas may help classify patterns in different locations and also discern structural changes of qualifiers of climate change as a function of time.
- The notions may conceivably provide an alternative way to evaluate future scenarios if trends in geometric parameters may be established.

Potential collaboration

- Studying the dynamics of rainfall/streamflow/temperature at a few locations within the state and at various time resolutions, aiming at finding possible holistic predictions.

- Assessing the effects of climate change studying the structure of rainfall based on a FM geometric study at distinct locations and scales. Are distributions changing? Are those predictable?

- Analyzing distinct design scenarios generating FM synthetic rainfall/streamflow/temperature sets and/or downscales.

- Classifying and comparing the geometric structure of records to establish improved regional understanding. Can intensity-duration-frequency curves be parameterized via FM codes?

Outline

- The fractal-multifractal method
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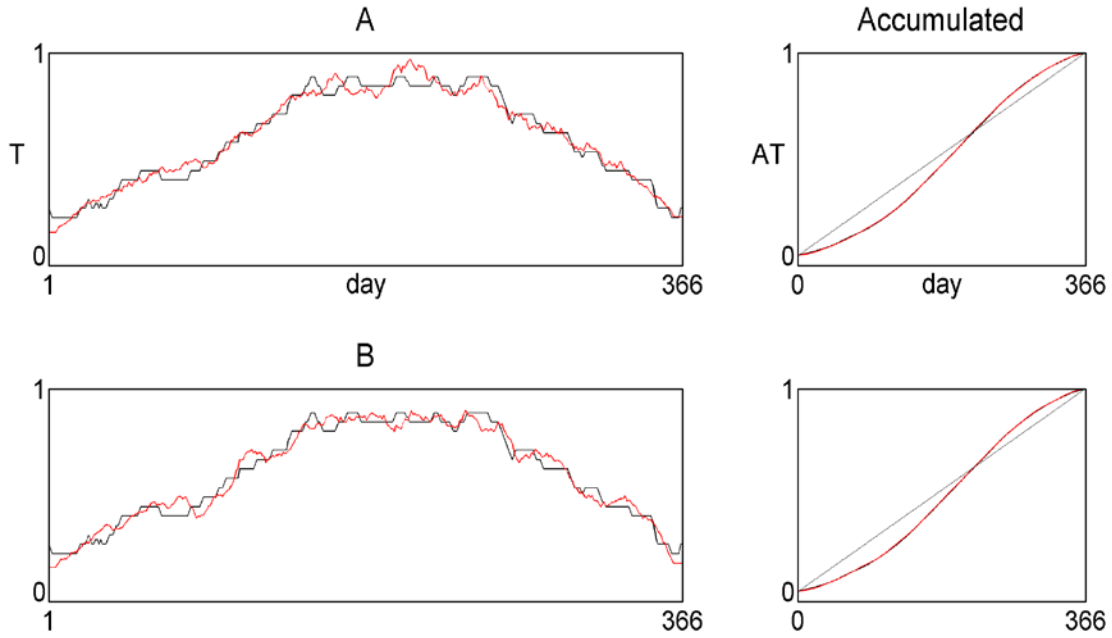
- **Encoding temperature**

Encoding water temperature in Sacramento

Calendar year 1968



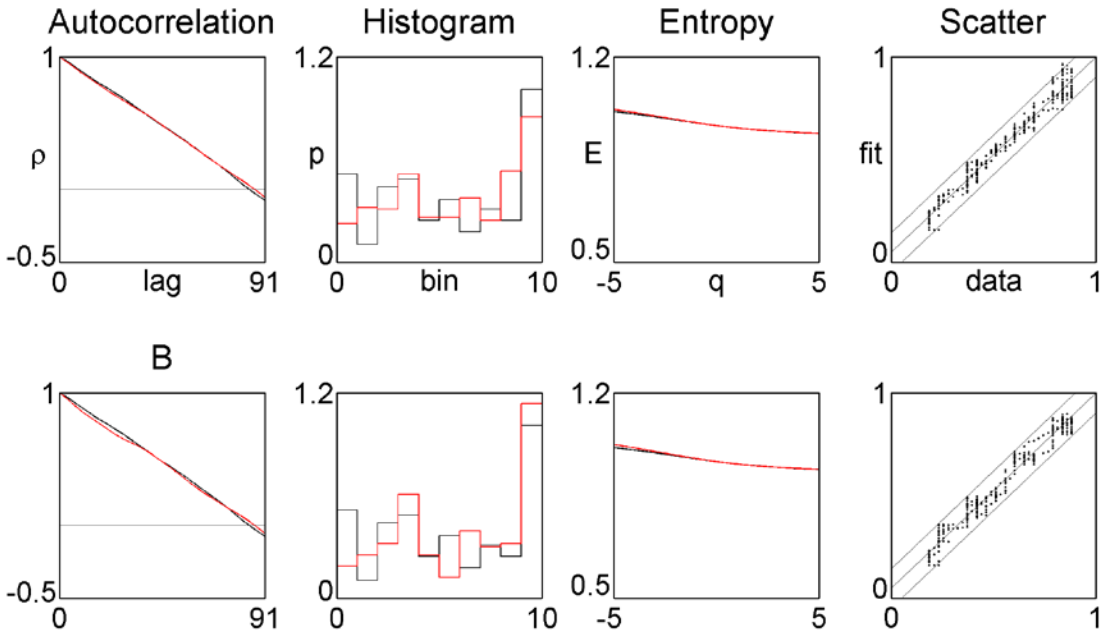
A: wire 2 maps, B: “leaf” 2 maps

RMSEAR 0.23%, 0.21%; MAXEAR 0.61%, 0.44%

compressions greater than 52:1

Encoding water temperature in Sacramento

Calendar year 1968

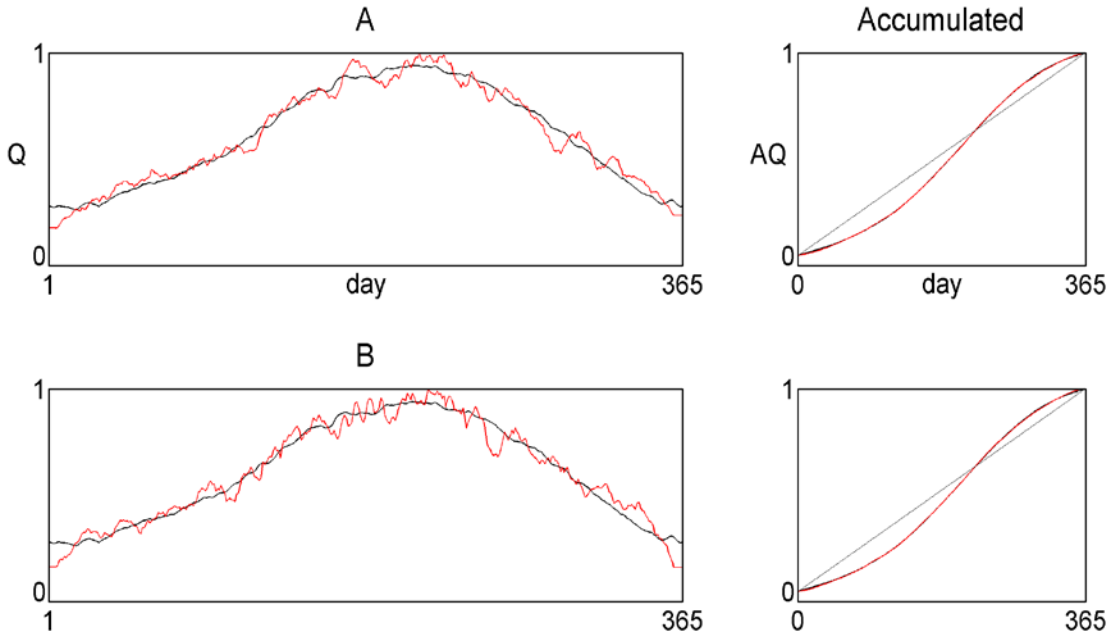


A: wire 2 maps, B: “leaf” 2 maps

NSD 96.7%, 96.4%; NSA 99.8%, 99.5%; NSE 99.1%, 98.0%

Encoding water temperature in Sacramento

Calendar decade 1972



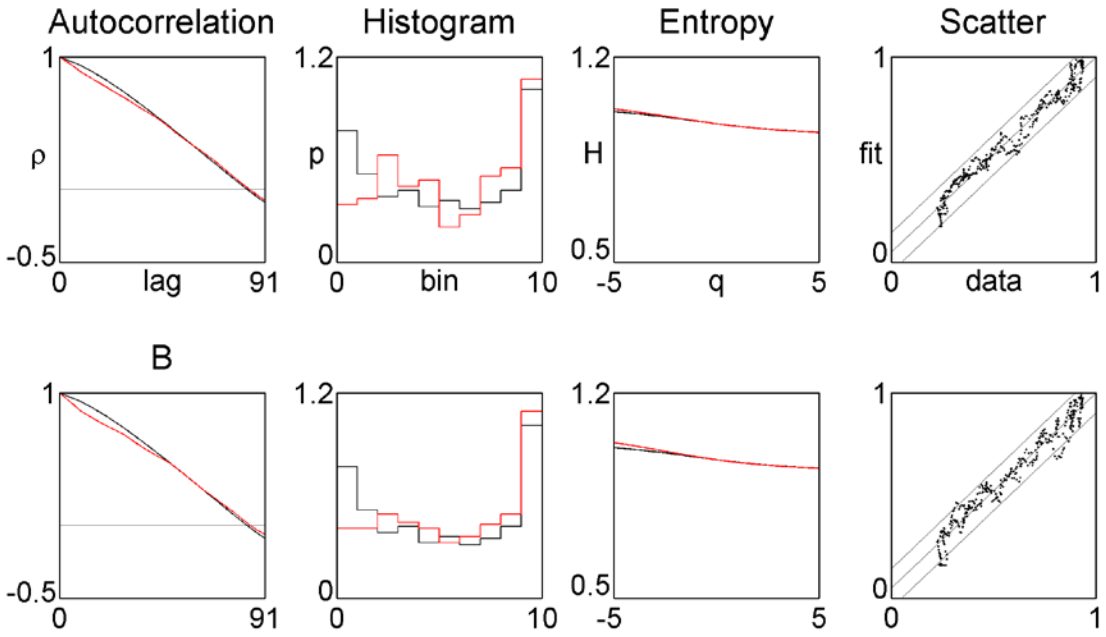
A: wire 2 maps, B: “leaf” 2 maps

RMSEAR 0.23%, 0.27%; MAXEAR 0.58%, 0.67%

compressions greater than 52:1

Encoding water temperature in Sacramento

Calendar decade 1972

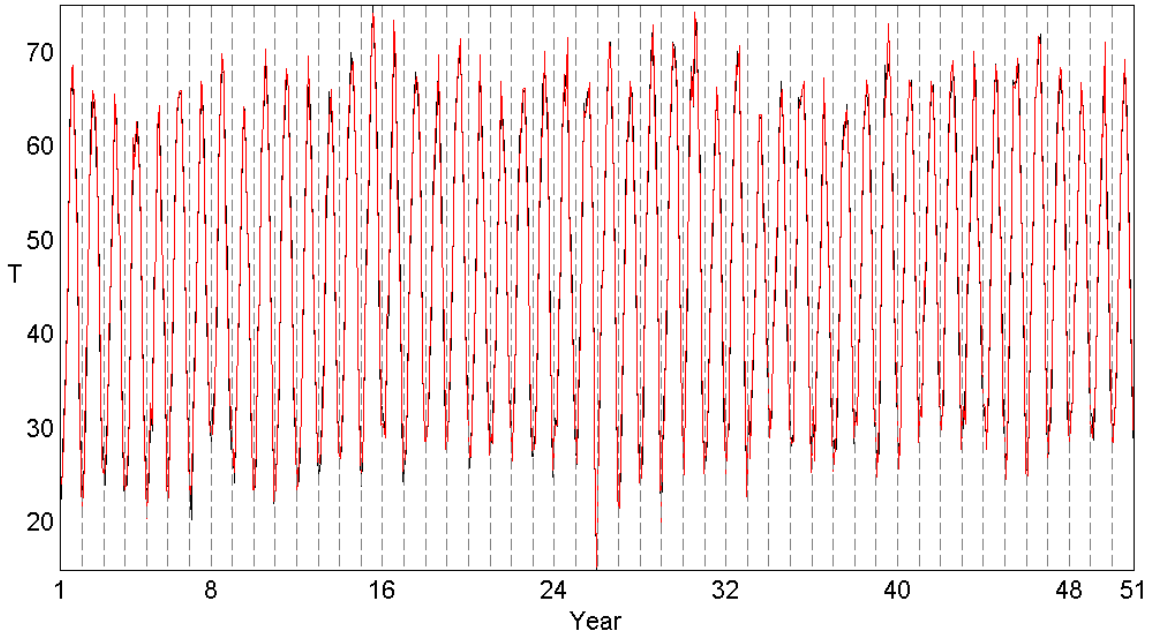


A: wire 2 maps, B: “leaf” 2 maps

NSD 96.7%, 95.3%; NSA 99.2%, 98.3%; NSE 98.4%, 94.8%

Encoding water temperature in Sacramento

By year 1962-2012

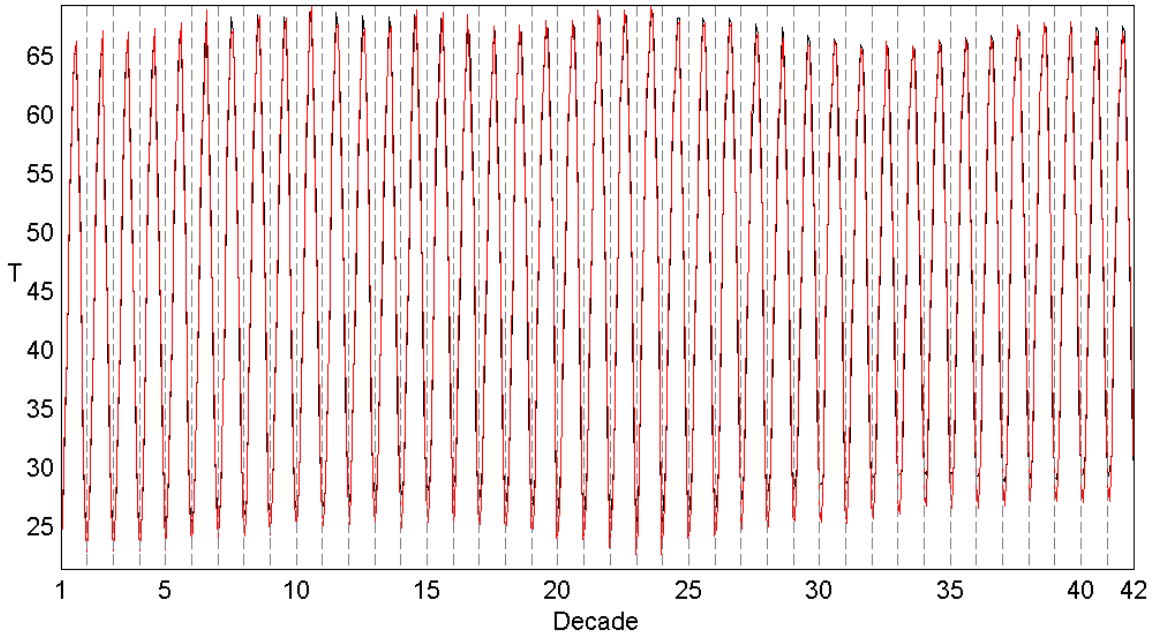


“leaf” 2 maps, scale in 10 x °C

RMSEAR 0.32 ± 0.07%; MAXEAR 0.72 ± 0.15%; NSD 92.1 ± 3.08%

Encoding water temperature in Sacramento

By decade 1971-2012

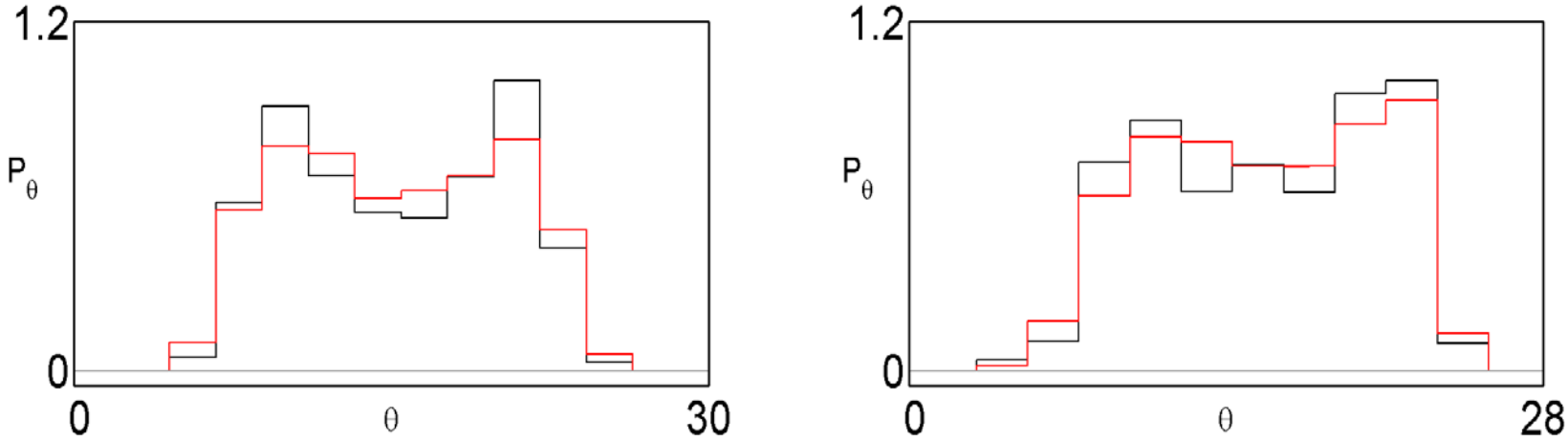


“leaf” 2 maps, scale in 10 x °C

RMSEAR 0.27± 0.05%; MAXEAR 0.56 ± 0.08%; NSD 96.01 ± 0.83%

Encoding water temperature in Sacramento

Two histograms 1962-2012

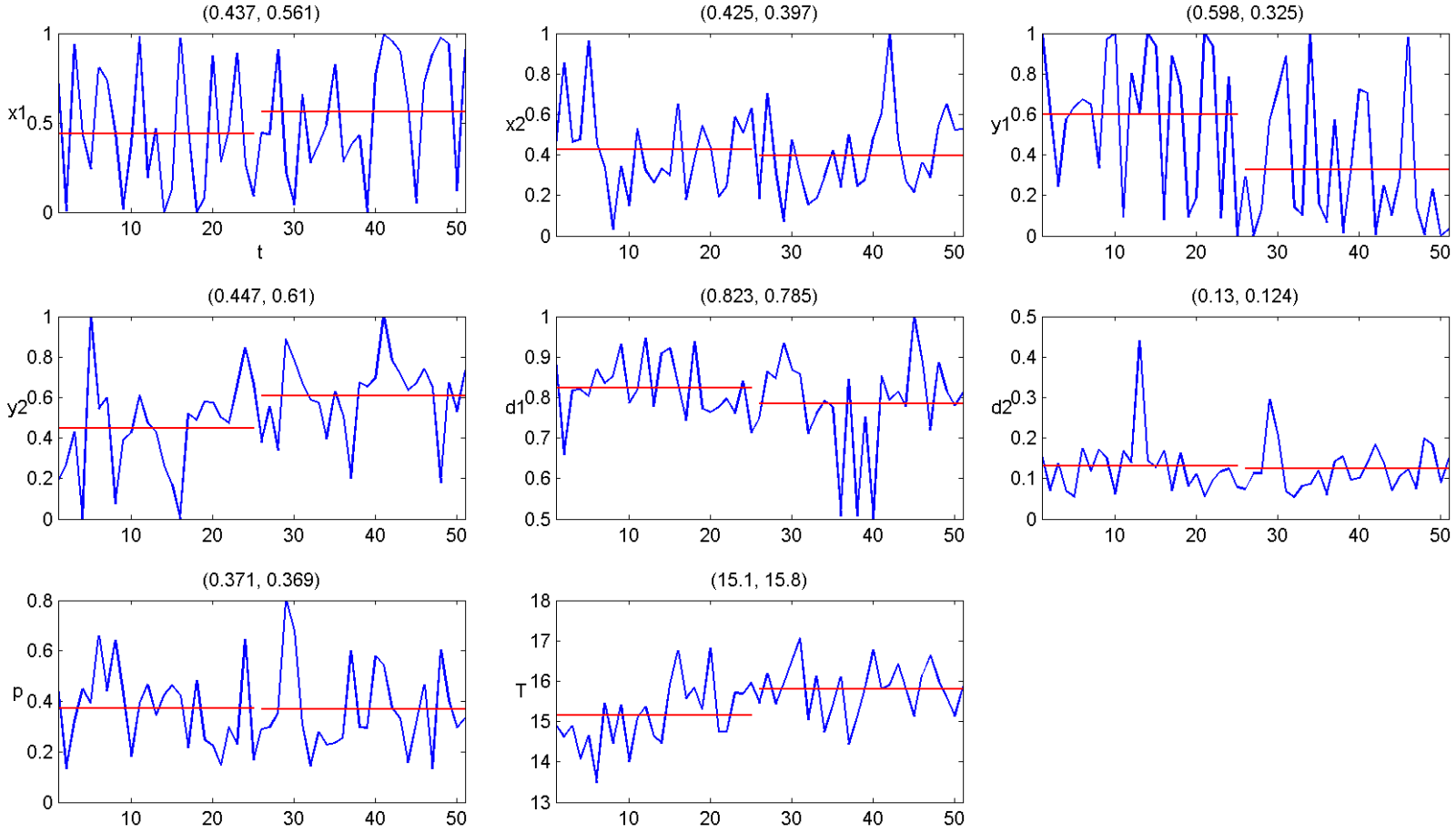


left: first 25 years, right: second 26 years

useful for climate change…

Dynamics of water temperature in Sacramento

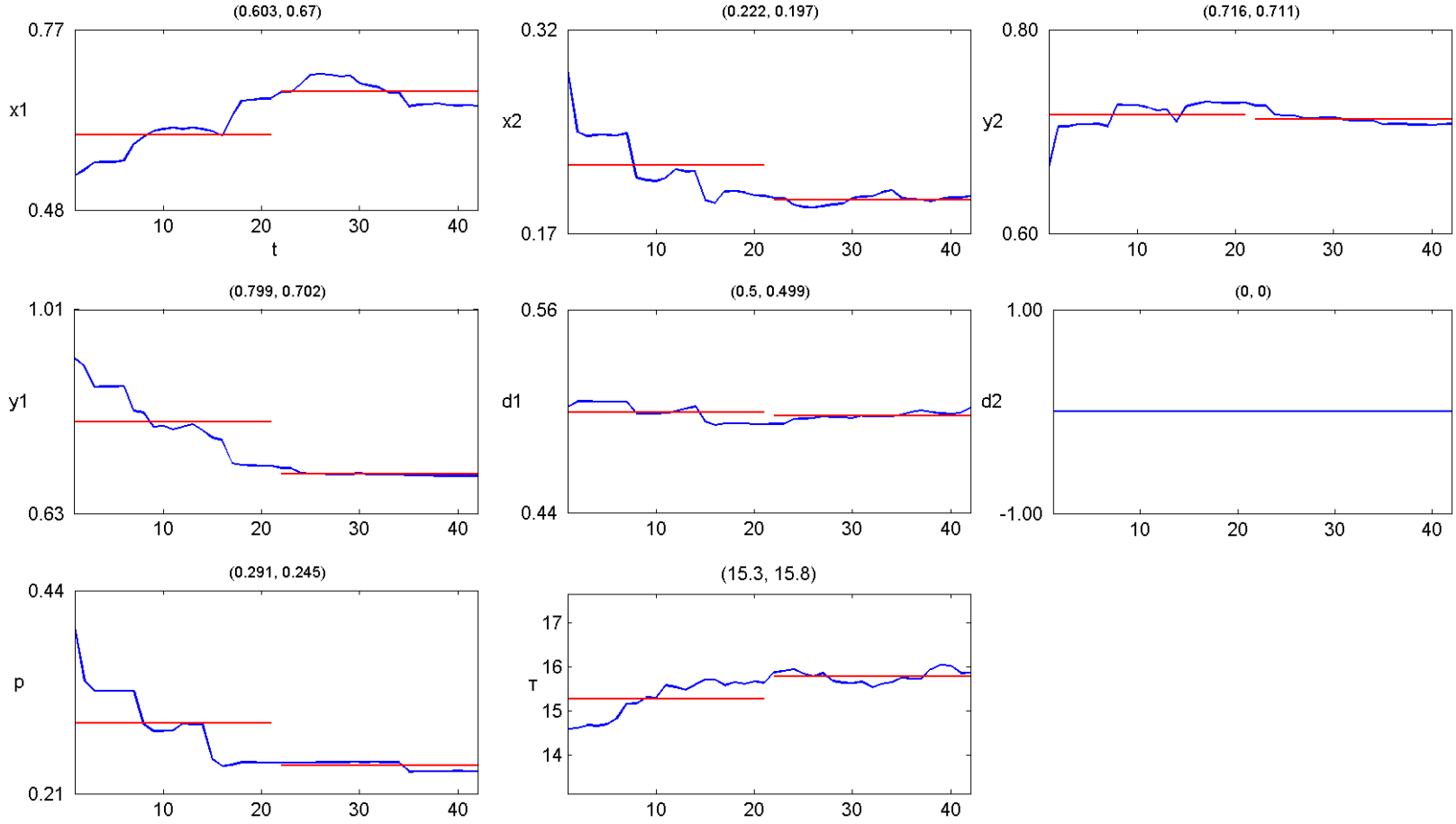
By year 1962-2012



inherent complexity in smooth temperature records…

Dynamics of water temperature in Sacramento

By decade 1971-2012



smoother evolution maybe useful to elucidate climate change…