Multiscale event synchronization measure for unraveling climate process: A wavelet-based approach

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Background and Motivation

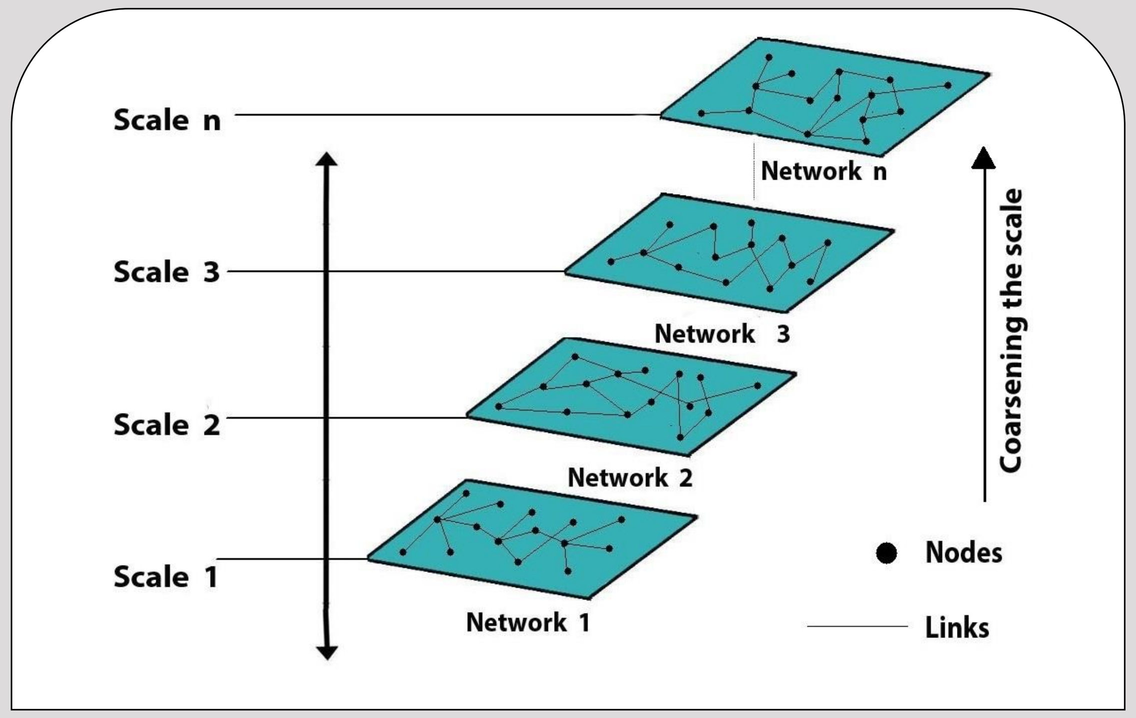
Multi-timescale Process

- ❑ The temporal dynamics of natural processes (climatic/hydrological) are spread across different time scales
- ❑ The study of these processes only at a given scale would not reveal all the underlying governing processes spanning over different scales.
- ❑ Hence, it is vital to investigate such processes at various time-scales. (Rathinasamy et al., 2014)

Wavelet Transform

- ❑ Used extensively to comprehend the multiscale process and appeared to be exceptionally reliable in understanding the dynamics of the process across various time scales as these evolves in time. (T&C 1998; Torrance and Webster 1999)

Multi-timescale Network



Current Research State

- ❑ At present, the event synchronization, analyses the relationship (synchronize/ time lag) at single scale. (Stolbova et al., 2014)
- ❑ Network measure such as (ES/Correlation) provide an overall integrated idea about the process, no insight into the scales at which that process dominates.
- ❑ Single scale measure may underestimate or overestimate the performance of the network.

Objectives

Research questions

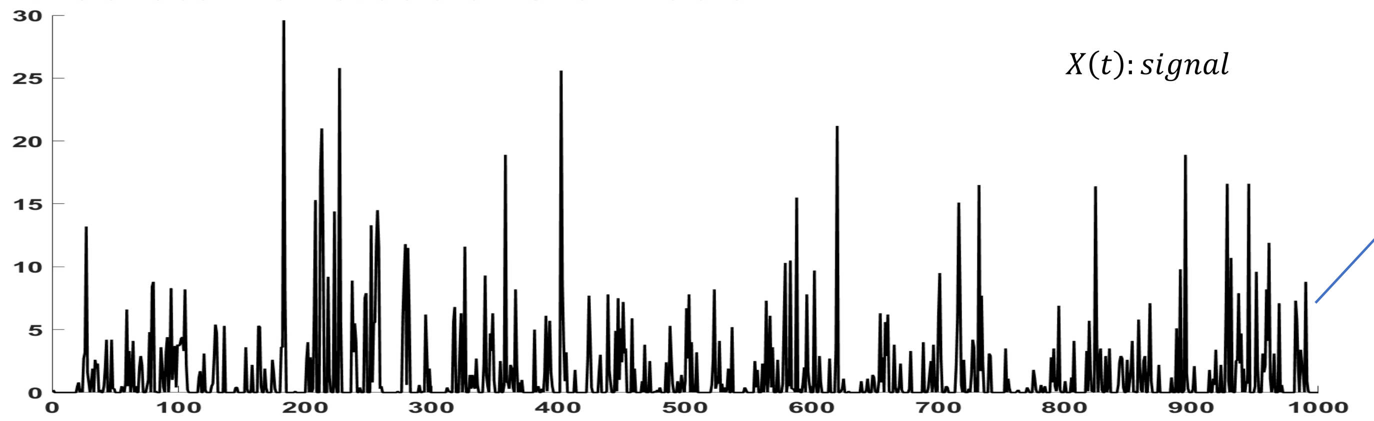
Can ES be used in a multiscale system where processes occur at different time scales?

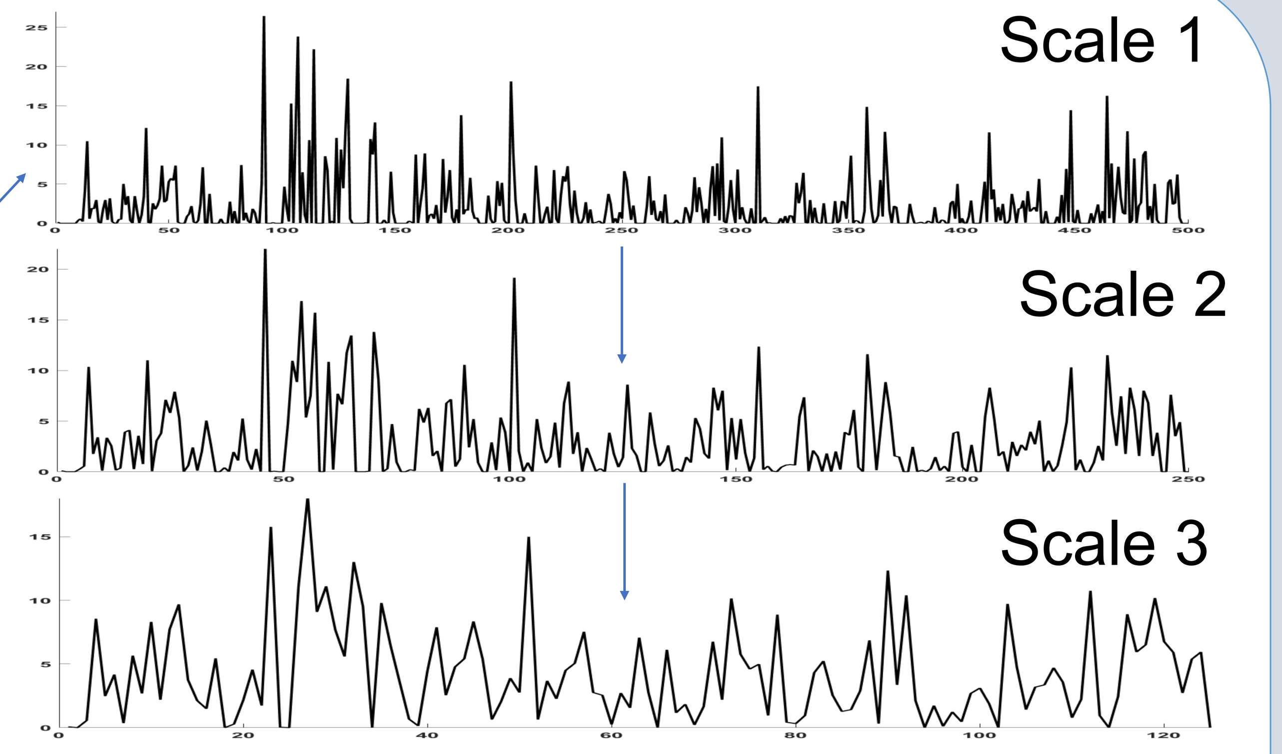
How does the dependency based on ES measure evolve at different timescales between any two given processes?

Are the relationships preserved at different time scales or do they depend on the scale of analysis?

Decomposition of signal

Discrete wavelet transformation





$\phi_{\lambda,q}(t) = 2^{-\frac{\lambda}{2}}\phi(2^{-\lambda}t - q)$ ∀ scaling function (Addison, 2002)

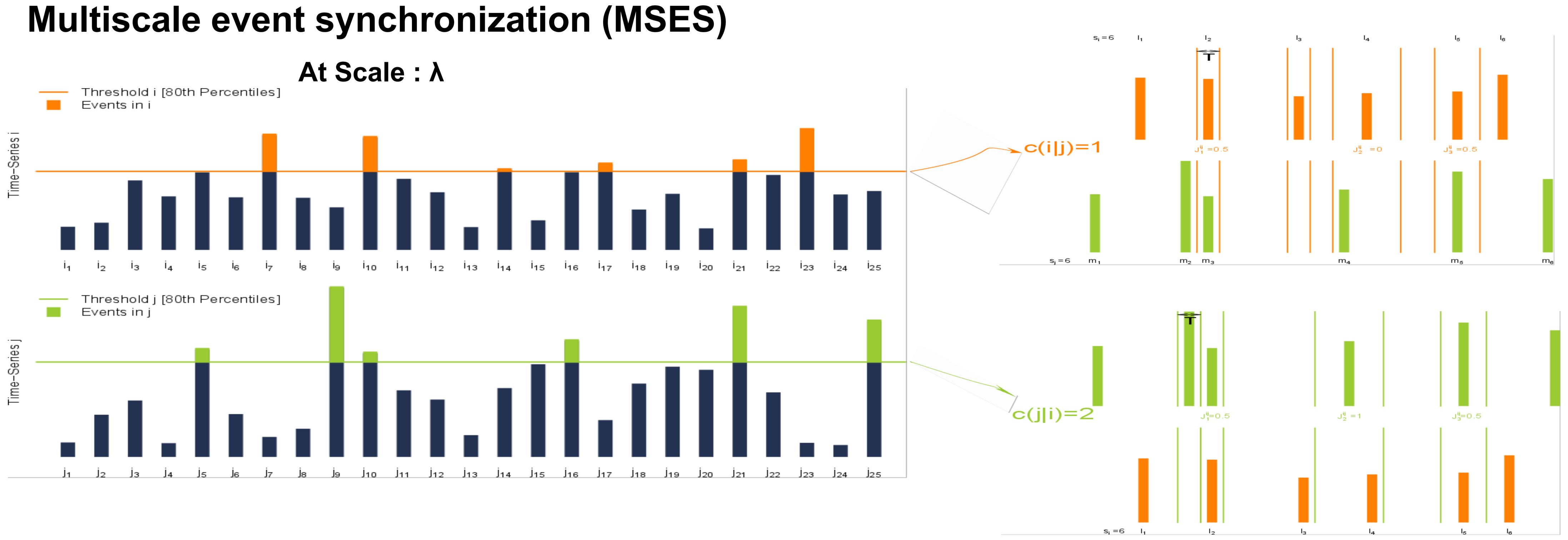
λ, q : scale-location grid index; ∀ λ=1,2,3…….up to scale λ

$A_{\lambda,q} = \int_{-\infty}^{\infty} x(t)\phi_{\lambda,q}(t).dt$: approx. Coeff. of the signal x(t) at scale λ

Daubechies et al., 1992, T&C, 1998, Rathinasamy et al., 2014

Methodology

Multiscale event synchronization (MSES)



$$\tau_{l,m}^{x_\lambda,y_\lambda} = min\{t_{l+1}^{x_\lambda} - t_l^{x_\lambda},\ t_l^{x_\lambda} - t_{l-1}^{x_\lambda}, t_{m+1}^{y_\lambda} - t_m^{y_\lambda},\ t_m^{y_\lambda} - t_{m-1}^{y_\lambda}\}/2$$

$$J^{x_\lambda,y_\lambda} = \begin{cases} 1 & \text{if } 0 < t_l^{x_\lambda} - t_m^{y_\lambda} < \tau_{l,m}^{x_\lambda,y_\lambda} \\ \frac{1}{2} & \text{if } t_l^{x_\lambda} = t_m^{y_\lambda} \\ 0 & \text{else} \end{cases}$$

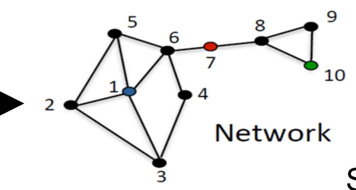
$$C(x_\lambda|y_\lambda) = \sum_{l=1}^{S^{x_\lambda}} \sum_{m=1}^{S^{y_\lambda}} J^{x_\lambda,y_\lambda}$$

Here J^{x_λ,y_λ} is an event that happens in the $y(t)$ after an event in the time series $x(t)$ within the time lag $\tau_{l,m}^{x_\lambda,y_\lambda}$

We define the strength of synchronization

$$Q^{x_\lambda,y_\lambda} = \frac{C(x_\lambda|y_\lambda) + C(y_\lambda|x_\lambda)}{\sqrt{(S_{x_\lambda} - 2)(S_{y_\lambda} - 2)}}$$

Adjacency Matrix →



Network at Scale λ

Stolbova et al., 2014

Artificial data for method test

Nonstationary dataset

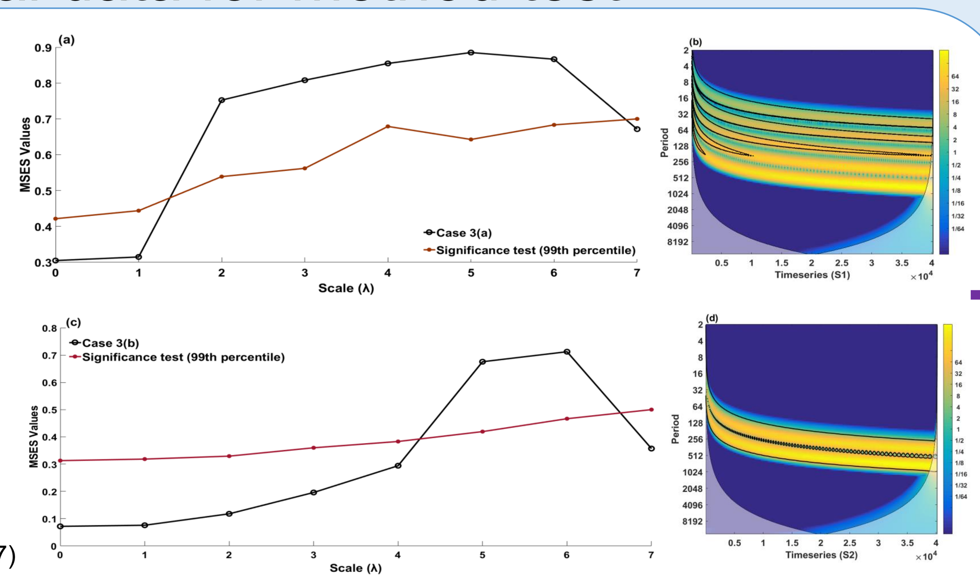
(a)=Z1+Z2+Z3+Z4+Z5+random noise
(b)=Z4+Z5+random noise

$$Z1 = \cos\left(500\pi\left(\frac{x}{1000}\right)^{.5}\right), Z2 = \cos\left(250\pi\left(\frac{x}{1000}\right)^{.5}\right),$$

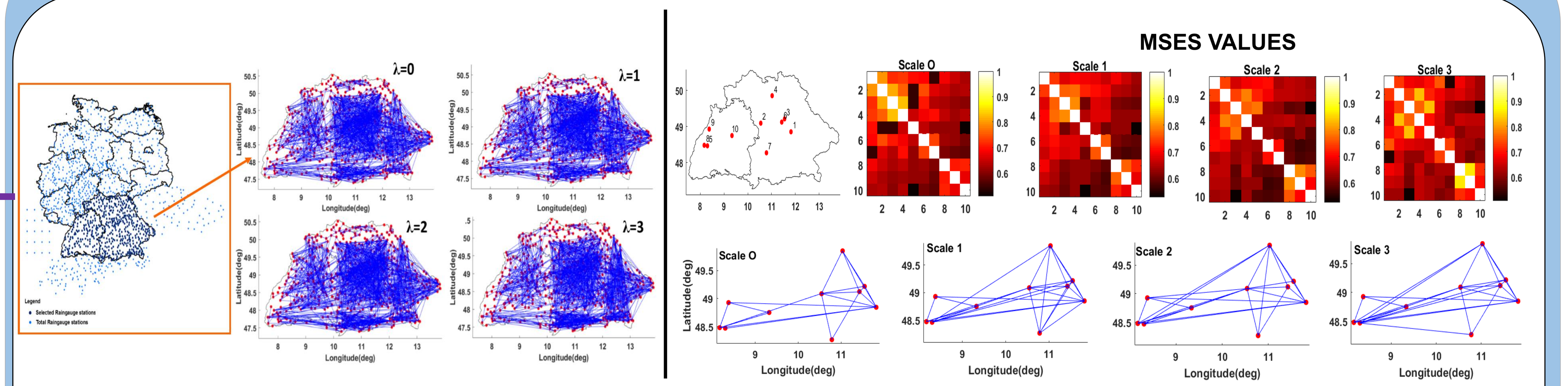
$$Z3 = \cos\left(125\pi\left(\frac{x}{1000}\right)^{.5}\right), Z4 = \cos\left(62.5\pi\left(\frac{x}{1000}\right)^{.5}\right),$$

$$Z5 = \cos\left(31.25\pi\left(\frac{x}{1000}\right)^{.5}\right),$$

(Hu and Si 2016; Yan and Gao 2007)



Real data for application



Conclusions

- ❑ Single scale measures only provide an overall integrated idea about the process, however, they do not provide any insight into the time scale at which that process dominates.
- ❑ The proposed methodology is well suited for evaluating the performance of climatic processes in terms of capturing extreme events. Further, it can be used for studying the scale dependent relationship of the complex system at different scales.
- ❑ The proposed measure is able to provide more information (scale dependency, features present in the signal, dominant scale of process, nonstationarity etc.) about the interaction between the processes.
- ❑ The wavelet transform can potentially convert a nonstationary timeseries into stationary component, this may further help in analyzing the nonstationary signal.

Suggestions welcome!!

Reference:

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