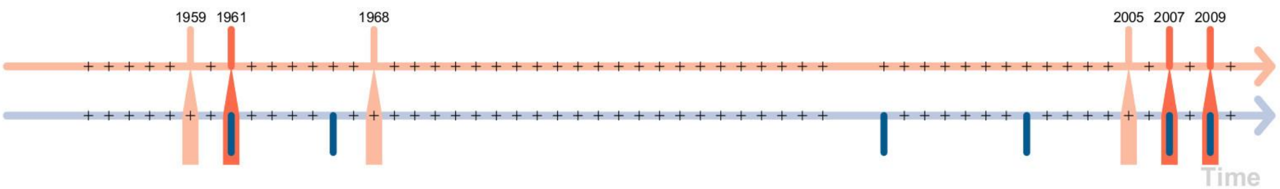
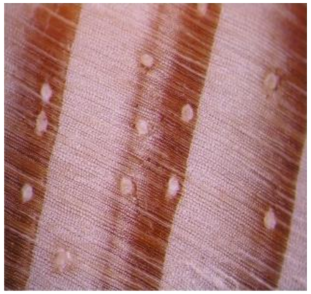
Potsdam Institute for Climate Impact Research

Event Coincidence Analysis

A simultaneity measure for event time series







Leibniz Gemeinschaft

Siegmund, J.F., Donner, R.V., Donges, J.F., Schleussner, C.-F.

http://cfe.uc.pt
www.aux.tv
www.sodahead.com
www.usgs.gov

Outline

- Motivation
- Conceptual Idea and Definition
- Examples
- The R Package `CoinCalc`

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Motivation

1. (Binary) event time series

storms,
bushfires,
volcanoes,
floods,
droughts,
……

2. Nonlinear relationships

Possibly nonlinear and nonstationary relationship between climate drivers and ecosystem responses

(e.g. impacts only appear after threshold exceedance)

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Images:
www.srw.de; www.nasa.gov
www.sueddeutsche.de
www.sodahead.com; www.usgs.gov

Motivation

- Climate impact studies so far mostly use linear methods (correlation, linear regression models)
- Few results on properties of extreme responses to climate extremes (existence, conditions, strength of interrelationships, etc.)
- Impact studies often call for establishing possible cause-effect relationships

Need for a method that

(i) can deal with event-like data

(ii) can distinguish between differently directed relations

(iii) is flexible and therefore suitable for various applications

(iv) is (conceptually) easy to understand

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Conceptual Idea and Definition

1. Two binary event sequences with N events
2. Count "coincidences" (K)
3. Calculate coincidence rate r = K/N

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Donges, J. Schleussner, C.F., Siegmund, J. and Donner, R. (2016): Event coincident analysis for quantifying statistical Interrelationships between event time series. EPJ.ST

Conceptual Idea and Definition

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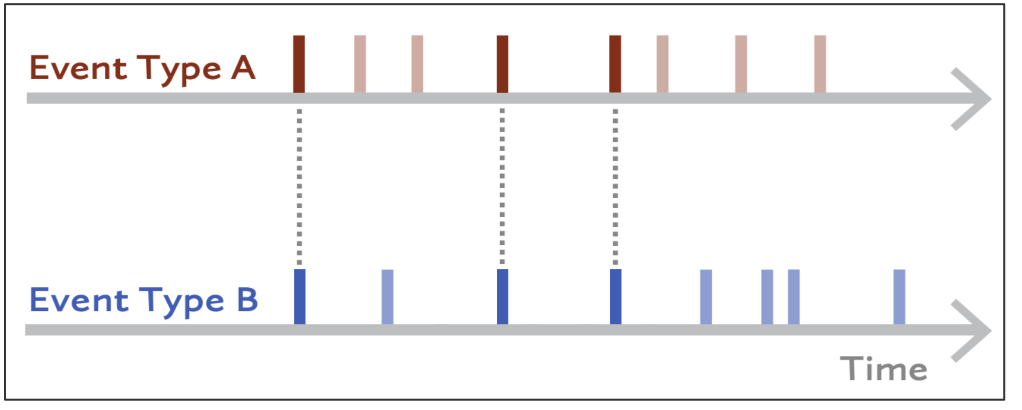
<u>**Case 1:**</u>

$N_A = N_B, \tau = 0, \Delta T = 0$

K = 3

N = 8

r = 0.375



Event B causes Event A

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Conceptual Idea and Definition

Case 2:

N_A != N_B, τ != 0, ΔT != 0

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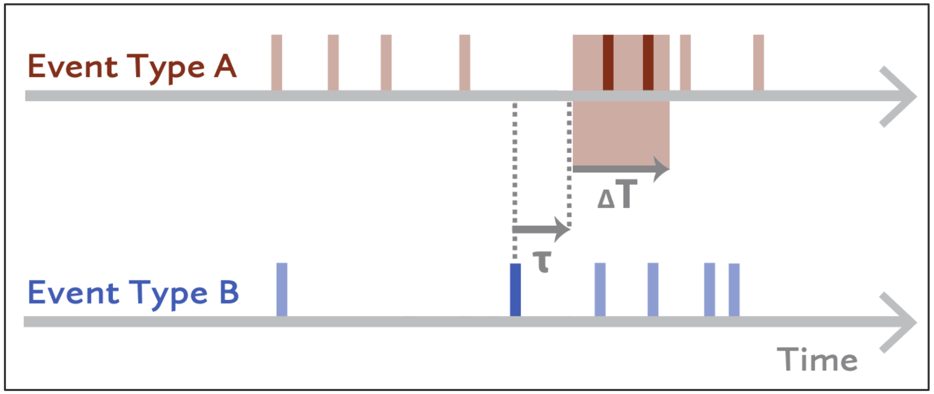

trigger coincidence rate

$$r_t(\Delta T,\tau) = \frac{1}{N_B}\sum_{j=1}^{N_B}\Theta[\sum_{i=1}^{N_A} 1_{[0,\Delta T[}((t_i^A-\tau)-t_j^B)]$$

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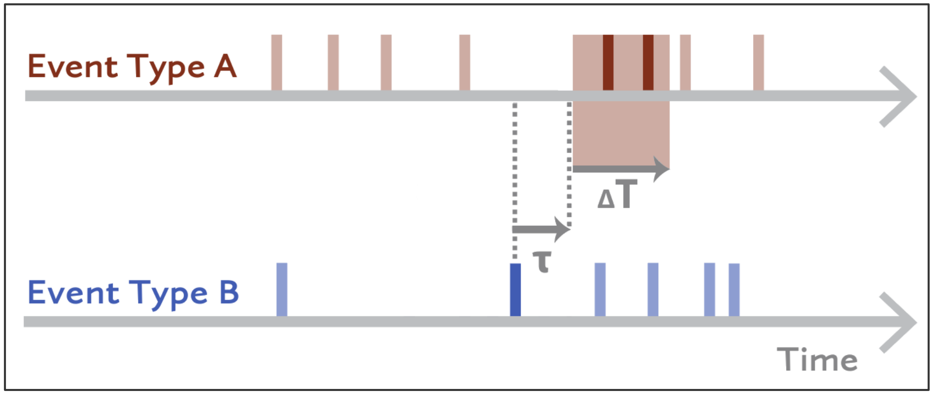
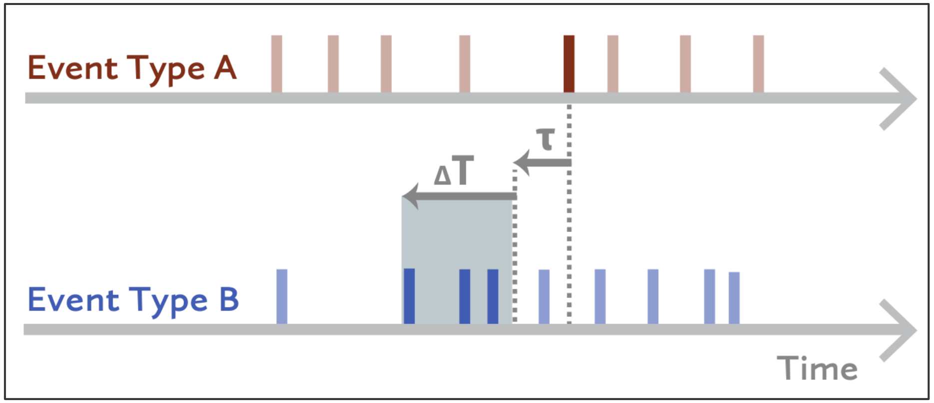


precursor coincidence rate

$$r_p(\Delta T,\tau) = \frac{1}{N_A}\sum_{i=1}^{N_A}\Theta[\sum_{j=1}^{N_B} 1_{[0,\Delta T[}((t_i^A-\tau)-t_j^B)],$$



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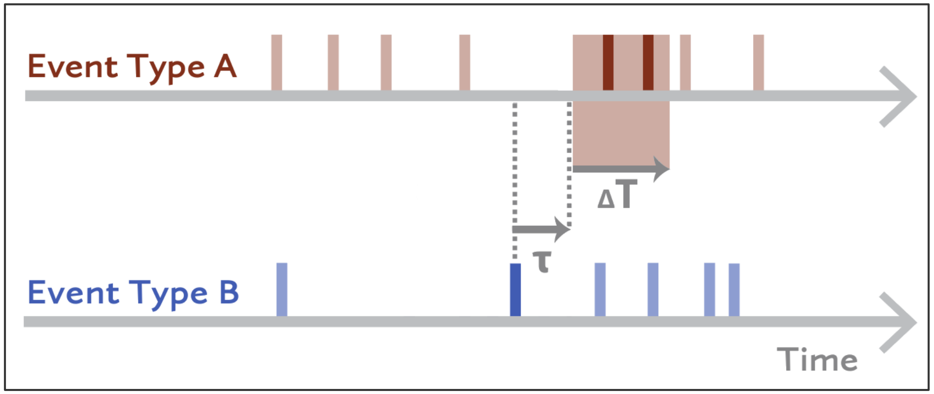

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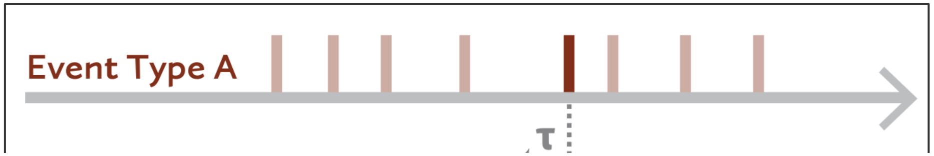

Note: Tolerance window can also be defined symmetrically (Siegmund et al. 2016, under rev.)

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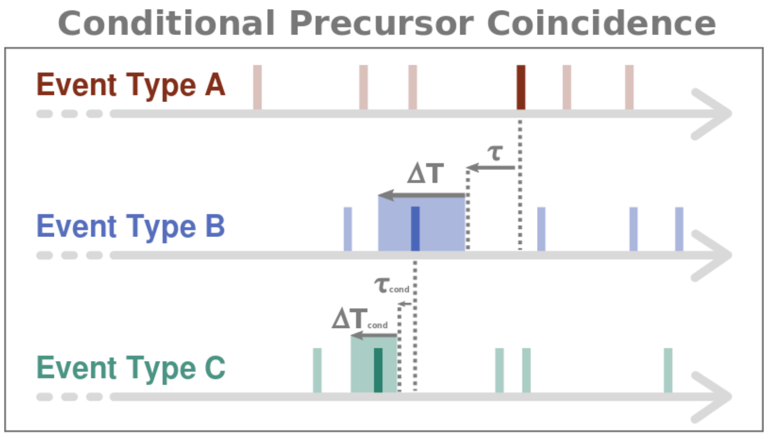
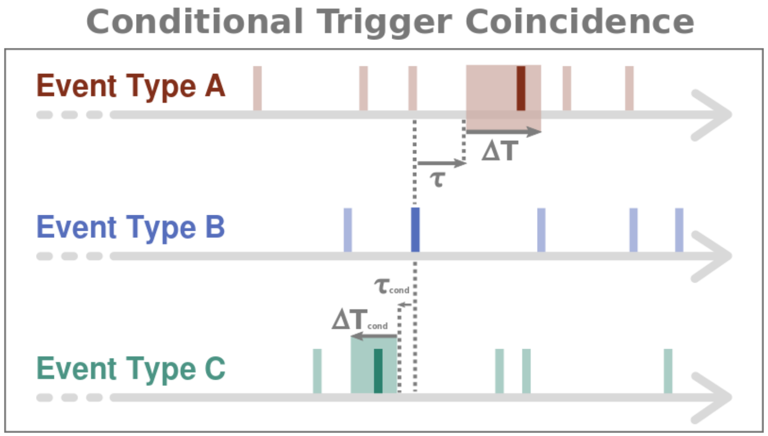
Conceptual Idea and Definition

Case 3: Conditional Event Coincidence

Possible conditioning of events in B by events in C

For $\Delta T_{cond} = 0$ and $\tau_{cond} = 0$: Joint Event Coincidence





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Siegmund JF, Sanders TGM, Heinrich I, van der Maaten E, Simard S, Helle G and Donner RV (2016) Meteorological Drivers of Extremes in Daily Stem Radius Variations of Beech, Oak, and Pine in Northeastern Germany: An Event Coincidence Analysis. *Front. Plant Sci.* 7:733

Conceptual Idea and Definition

4. Testing for significance of the coincidence rate (r_t and r_p)

a) Analytical test: independent Poisson processes as null model

$$P(K \geq K_e) = \sum_{K^*=K_e}^{N_A} P(K^*; N_A, 1-(1-p)^{N_B})$$

with

$$P(K; N_A, 1-(1-p)^{N_B}) = \binom{N_A}{K} \left(1-\left(1-\frac{\Delta T}{T-\tau}\right)^{N_B}\right)^{K} \left(\left(1-\frac{\Delta T}{T-\tau}\right)^{N_B}\right)^{N_A-K}$$

If conditions (events are rare and distributed independently and uniformly) for this approximation do not hold: numerical approximation of test statistics → surrogate tests

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Conceptual Idea and Definition

4. Testing for significance of the coincidence rate (r_t and r_p)

b) Shuffling/Resampling Test

create a large ensemble of artificial time series

→ perform ECA on the ensemble

→ **distribution of r for independent event sequences**

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Conceptual Idea and Definition

4. Testing for significance of the coincidence rate (r_t and r_p)

b) Shuffling/Resampling Test

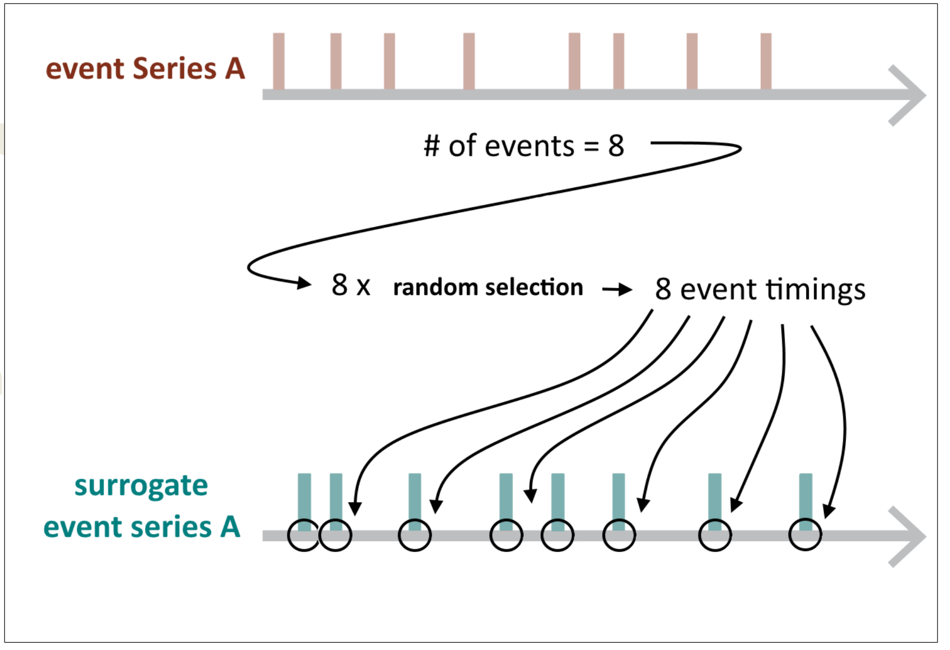
Creates e.g. 1000 surrogate t

→ 1000x ECA

→ distribution of 1000 r

→ „normal“ r under random

Monte Carlo Surrogates



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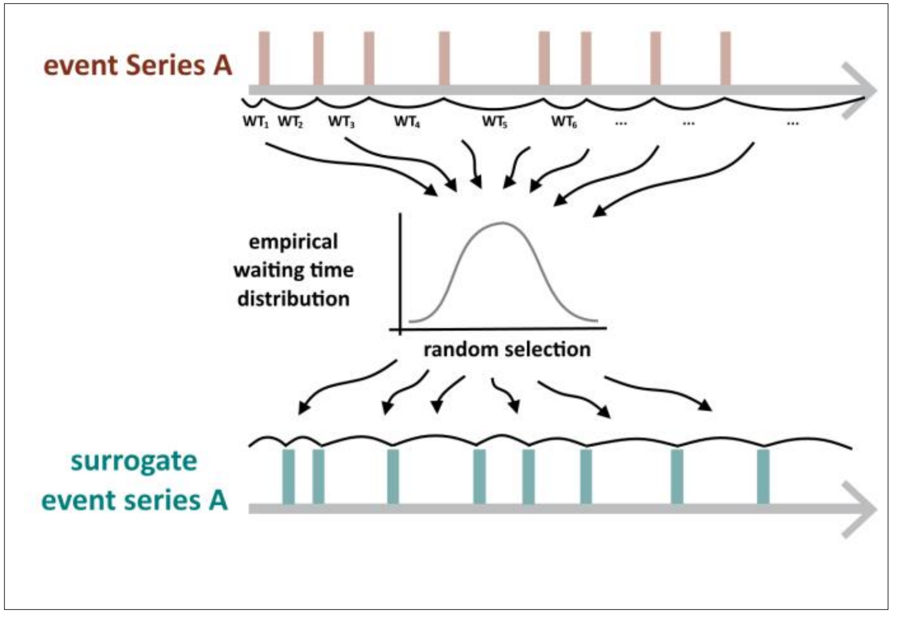
Waiting Time Surrogates



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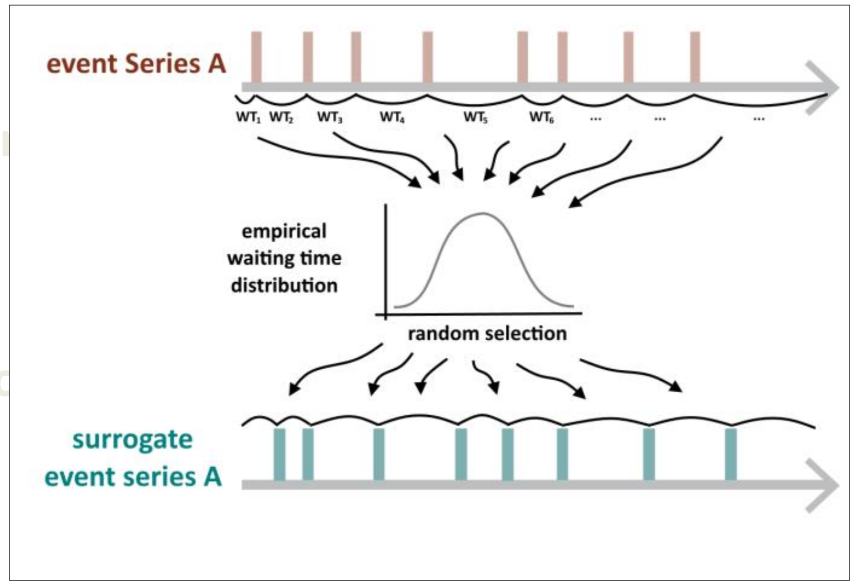

<u>**ECA Output:**</u> r_t, r_p, p_t, p_p

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Examples

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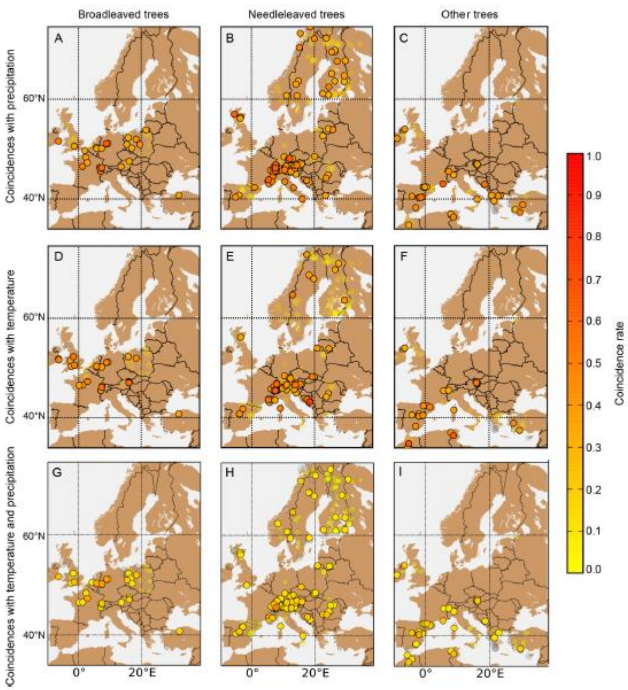
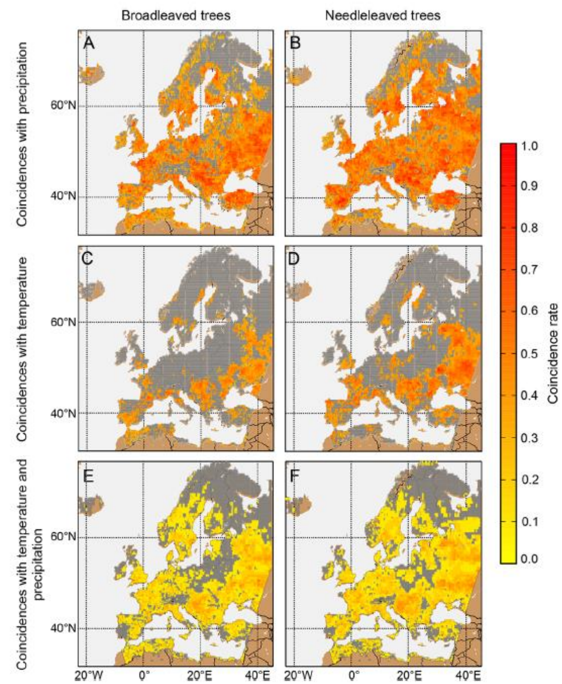
Examples

Tree Ring widths and model output

Rammig, A. et al. (2015)

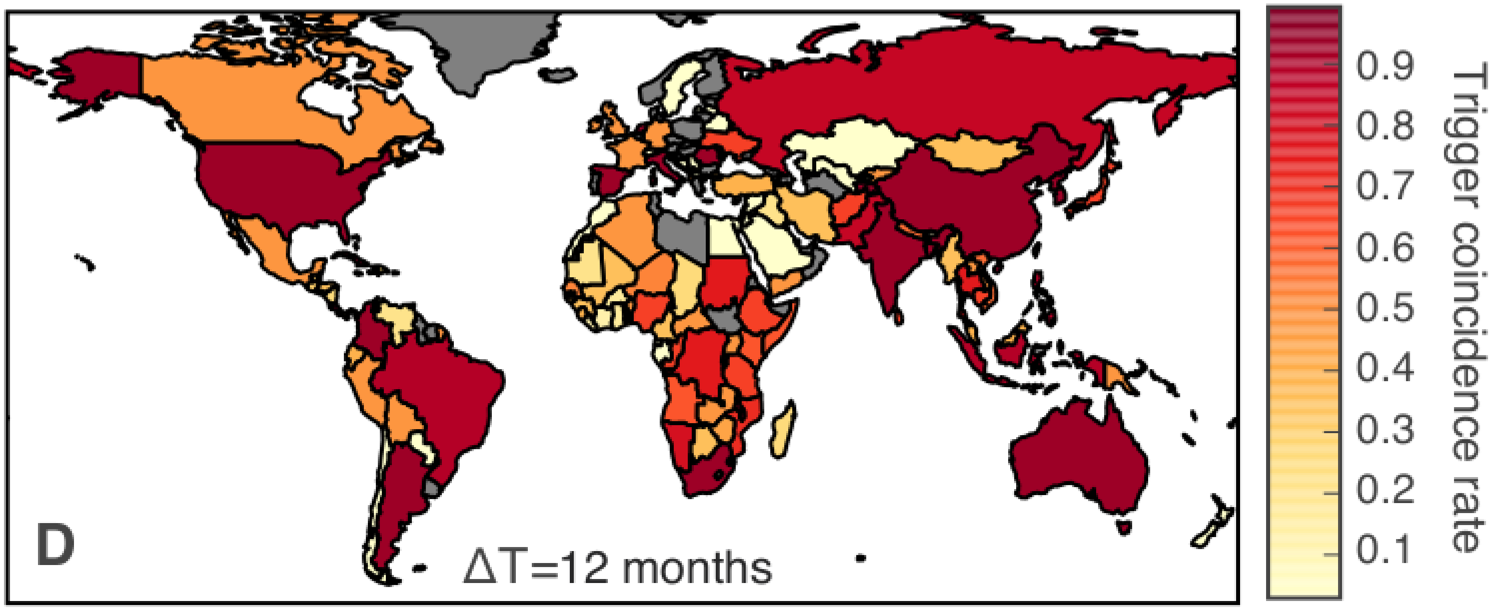




Examples

Flood events vs. epidemics

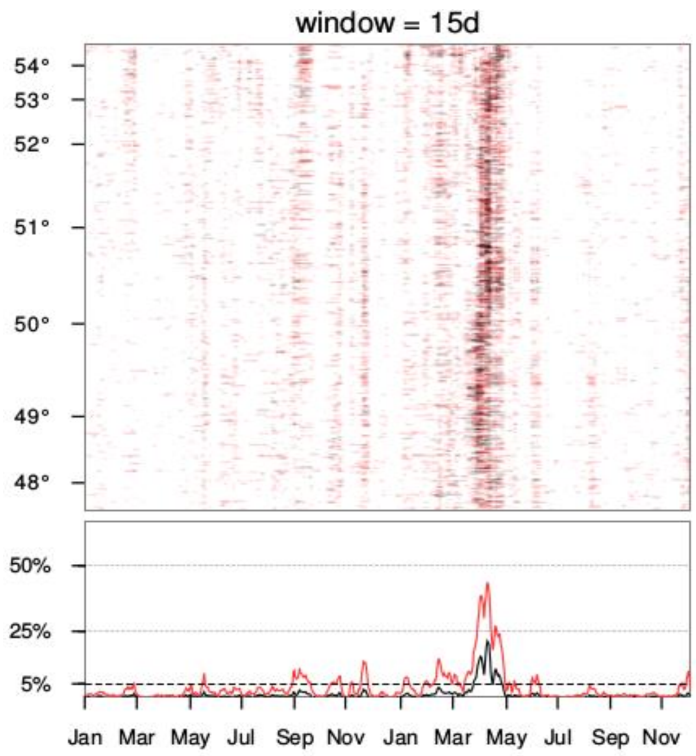
Donges, J. et al. (2016)



Examples

Flowering dates vs. extreme temperature

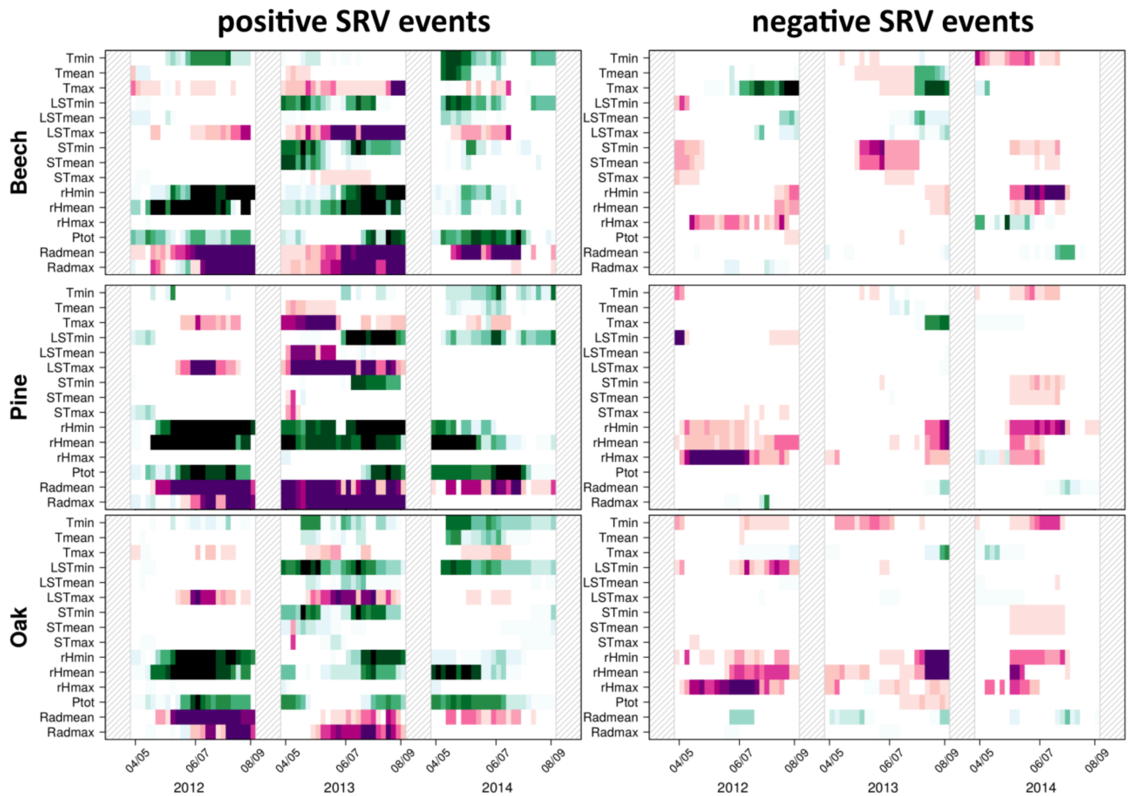
Siegmund, J. et al. (2015)



Examples

Extreme tree stem radius changes vs. climate extremes

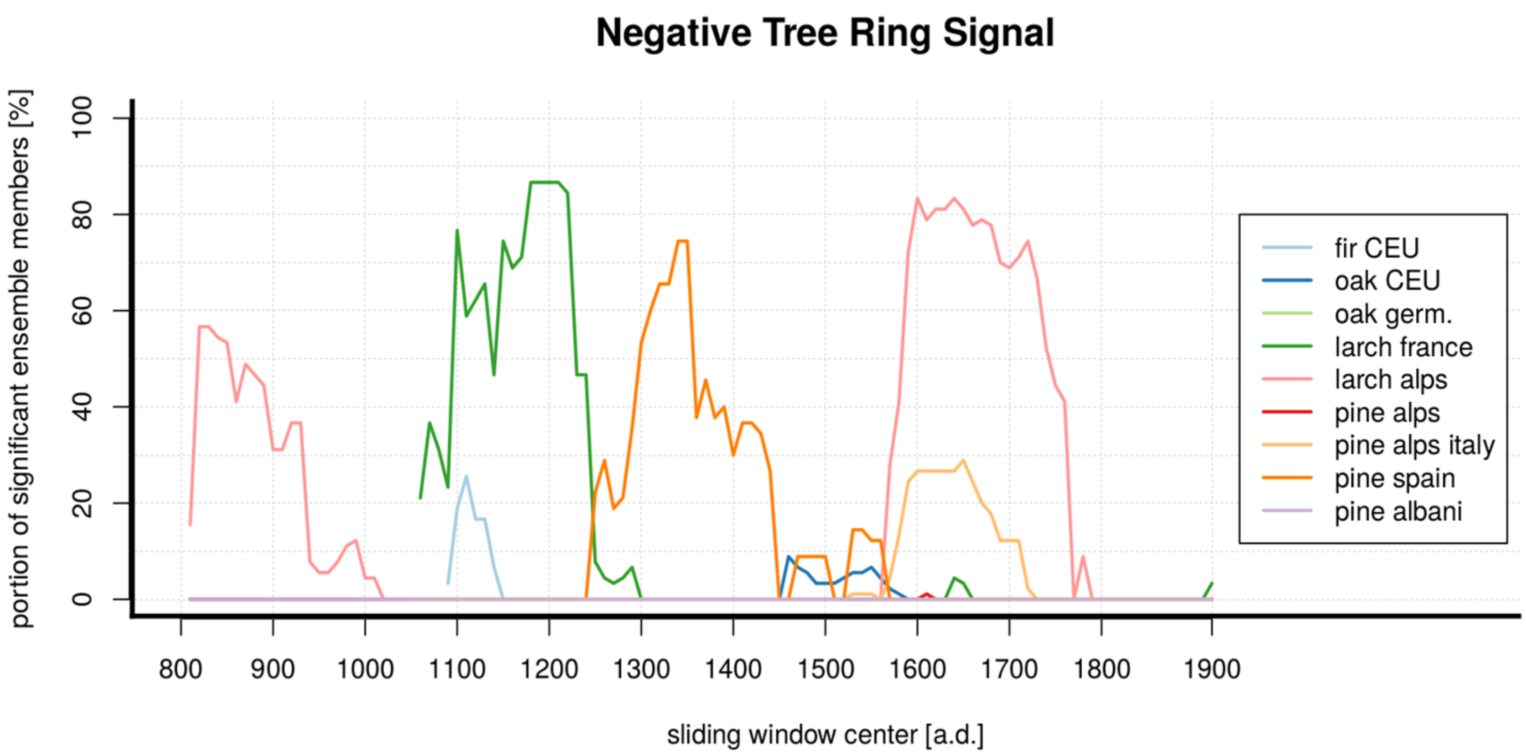
Siegmund, J. et al. (2016)



Examples

Volcanic eruptions vs. tree ring widths

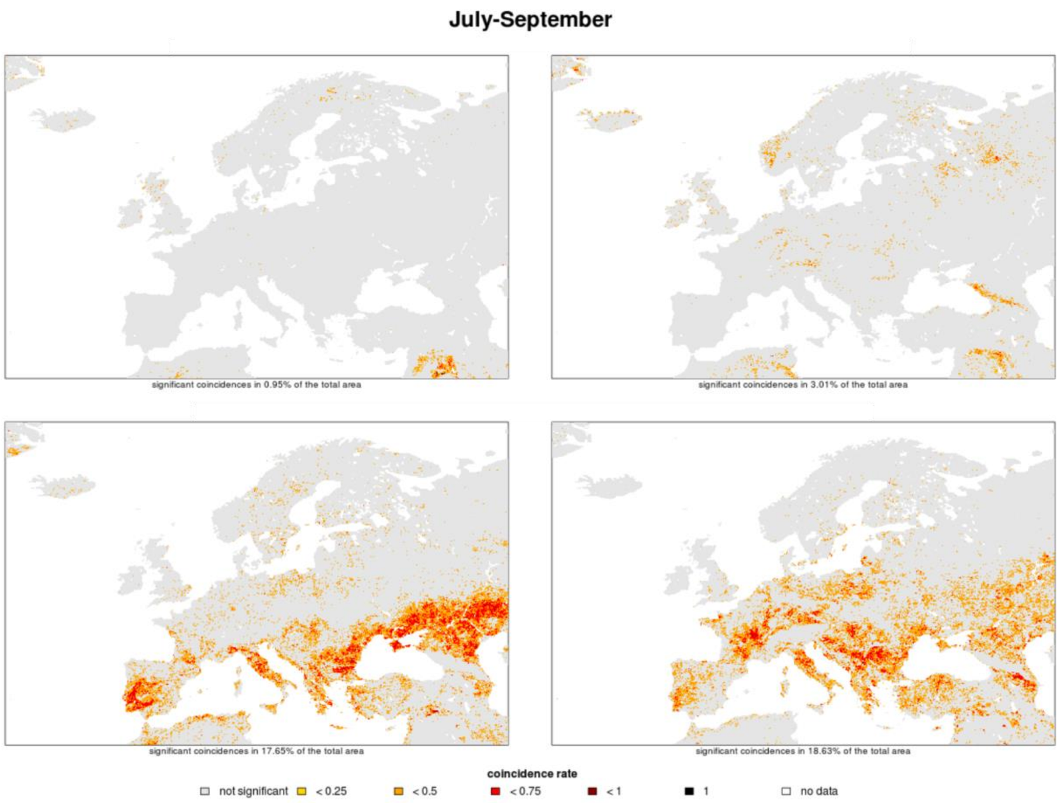
Pieper, H. et al., in prep.



Examples

Remote sensing: terrestrial productivity and climate extremes

Baumbach, L. et al, in prep.



The R package CoinCalc

R implementation of event coincidence analysis

<u>version 1.02 (available, beta-tested)</u>

- variable ΔT, τ, tolerance window type, ...
- time series binarization
- plot function
- three different significance tests
- some small data sets with example calculations

<u>version 1.4 (available upon request, not beta-tested)</u>

- multivariate/conditional ECA
- ECA for spatial data sets

github.com/JonatanSiegmund/CoinCalc

siegmund@pik-potsdam.de

Siegmund, J., Siegmund, N. and Donner, R. (2016): CoinCalc: An R package for quantifying simultaneities of events in two time series. Computers and Geosciences, under review.

Summary

Event Coincidence Analysis

Classical statistical methods are insufficient to quantify interdependencies between event sequences in a general context

- ECA is
  - a new tool to quantify simultaneities between event time series
  - important addition to classical linear methods (e.g. correlation, …)

- ready-to-use R-package `CoinCalc`

Literature

Donges, JF. Schleussner, C.F., Siegmund, JF. and Donner, RV. (2016): Event coincident analysis for quantifying statistical Interrelationships between event time series. EPJ.ST

Donges, J., Donner, R., Trauth, M., Marwan, N., Schellnhuber, H.-J., and Kurths, J. (2011). Nonlinear detection of paleoclimate-variability transitions possibly related to human evolution. Proceedings of the National Academy of Sciences of the USA 108, 20422–20427

Rammig, A., M. Wiedermann, J.F. Donges, F. Babst, W. von Bloh, D. Frank, K. Thonicke, M.D. Mahecha: Tree-ring responses to extreme climate events as benchmarks for terrestrial dynamic vegetation models. Biogeosciences 12, 373-385 (2015)

Siegmund JF, Sanders TGM, Heinrich I, van der Maaten E, Simard S, Helle G and Donner RV (2016) Meteorological Drivers of Extremes in Daily Stem Radius Variations of Beech, Oak, and Pine in Northeastern Germany: An Event Coincidence Analysis. *Front. Plant Sci*. 7:733

Siegmund, J. F., Wiedermann, M., Donges, J. F., and Donner, R. V. (2015): Impact of climate extremes on wildlife plant flowering over Germany. In: Biogeosciences Discuss., 12, 18389-18423