Nonlinear forced change and nonergodicity: The case of ENSO-Indian monsoon and global precipitation teleconnections

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UNIT OF EXCELLENCE MARÍA DE MAEZTU

Motivation

- ENSO and Indian monsoon: important teleconnection

- In the MPI Grand Ensemble, Bódai et al. (2020) found
  - increasing teleconnection strength on the long term,
  - a slight drop after 2000

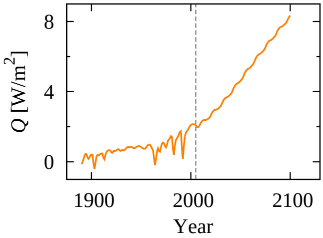
  between traditional ENSO indices and the all-Indian summer monsoon rainfall (AISMR)

- Are the findings robust? Spatial aspects?

Model, ensemble, forcing scenario

Max Planck Institute Earth System Model, MPI Grand Ensemble: 63 members from 1880

(we discard 37 members out of 100 due to incomplete spin-up, and 30 years from 1850 to lose correlations between members $\rightarrow$ natural probability measure of a snapshot/pullback attractor (Bódai and Tél, 2012; Drótos et al., 2015; 2017; Ghil et al., 2008; Chekroun et al., 2011; Romeiras et al., 1990))



Q: radiative forcing, historical+RCP8.5 (Meinshausen et al., 2011)

Fields

- ENSO: JJA mean sea surface temperature
- Indian monsoon: JJAS mean precipitation

In each year and each ensemble member

Pearson's correlation coefficient $r(\Phi, \Psi)$ evaluated

- in each year
- with respect to the ensemble

between Φ (ENSO-side quantity) and Ψ (IM-side quantity)

Characterising the teleconnection

Φ	Ψ
Niño3	AISMR
Niño3.4	AISMR
PC of EOF1	AISMR
PC of EOF1	PC of EOF1
PC of MCA1	PC of MCA1
PC of CCA1	PC of CCA1
PC of EOF2	AISMR
PC of EOF2	PC of EOF2
PC of MCA2	PC of MCA2
PC of CCA2	PC of CCA2
PC of single CCA mode with AISMR	AISMR

where . . .

. . . where

- PC: principal component
- EOFn: nth empirical orthogonal function
- MCAn: nth mode of maximum covariance analysis
- CCAn: nth mode of canonical correlation analysis

Everything evaluated with respect to the ensemble! (With a little smoothing, such that a conservative estimate results for r.)

Characterising the teleconnection

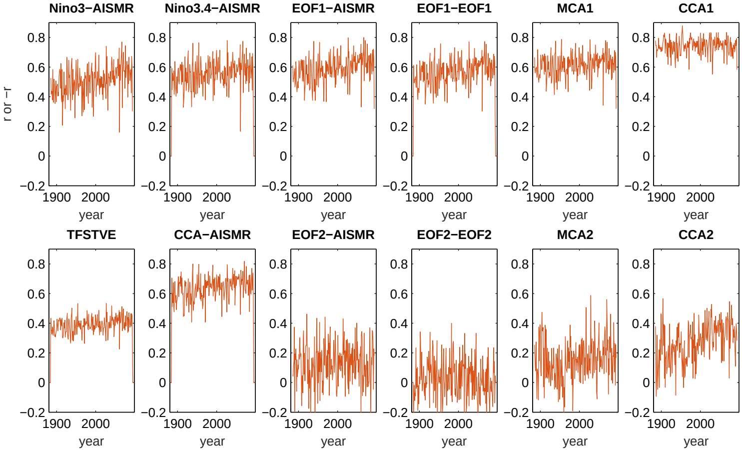
Beyond $r(\Phi, \Psi)$: TFSTVE: total fraction of spatio-temporal IM variability explained by the PCs of the Pacific-side MCA modes:

$$\mathrm{TFSTVE} = \frac{\sum_{n=1}^{N} \sigma_n^2 r_n^2}{\sum_{n=1}^{N} \sigma_n^2},$$

where

- r_n is evaluated between the PCs of MCAn
- σ_n^2 is the variance of the PC of MCAn on the IM side
- N is the number of MCA modes

Time evolution

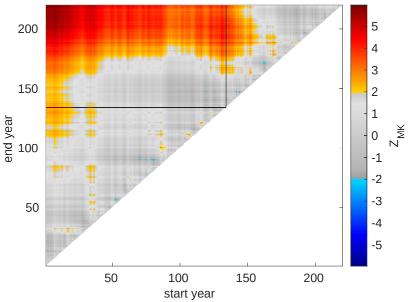


- Teleconnection: mainly between the first modes
- Trends are difficult to see

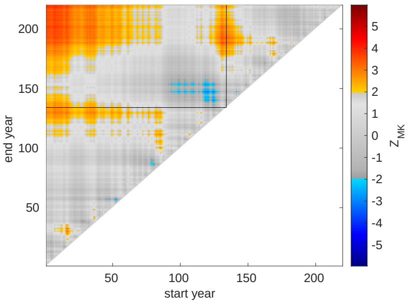
Testing for trends

Mann–Kendall test for each subinterval: H0: no monotonic trend
$\rightarrow$ colour: significant trend (5%) in the given subinterval

Niño3–AISMR



Niño3.4–AISMR



Testing for trends

Mann–Kendall test for each subinterval: H0: no monotonic trend
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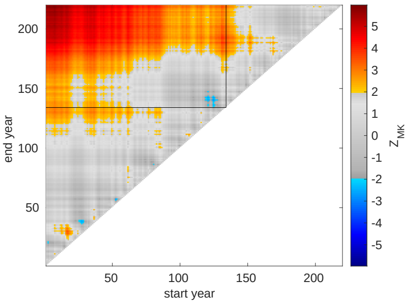
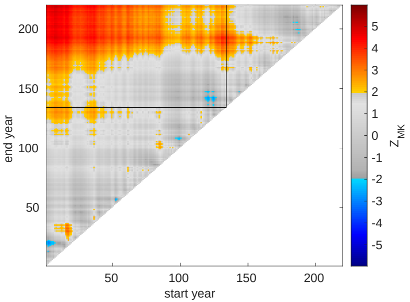
EOF1–AISMR



EOF1–EOF1



Mann–Kendall test for each subinterval: H0: no monotonic trend
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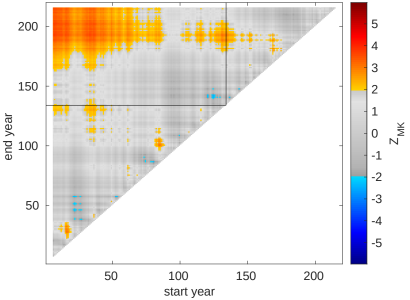
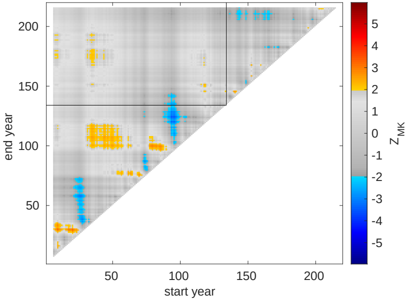
MCA1



CCA1



Testing for trends

Mann–Kendall test for each subinterval: H0: no monotonic trend
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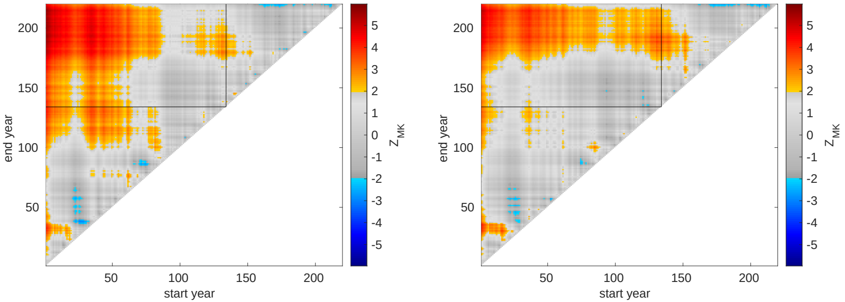
TFSTVE CCA-AISMR



- Long-term increase in strength confirmed
- Nontrivial further details, including a drop after 2000, but see Wilks (2016)

Drivers of changes

Linear regression model:

$$\Psi = a\Phi + \xi,$$

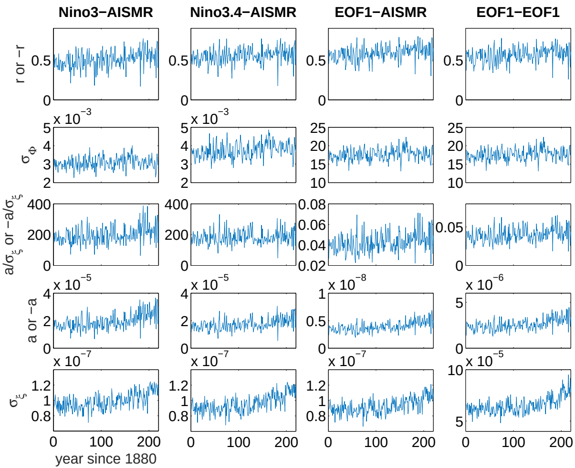
where ξ is random noise

$\rightarrow$

$$r = \frac{1}{\sqrt{1 + \frac{1}{\left((a/\sigma_\xi)\sigma_\Phi\right)^2}}},$$

where σ denotes standard deviation

Time evolution

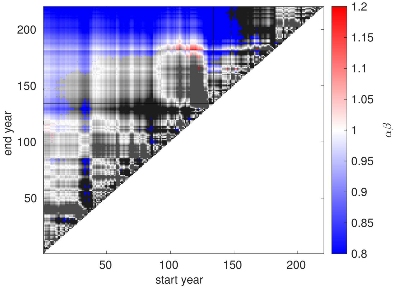


- Increase in a/σ_ξ and mostly in σ_Φ (exception: late 21st c.)
- An increase in a outcompetes that in σ_ξ

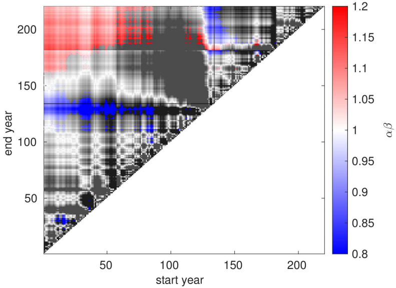
Time evolution

Blue ($\alpha\beta < 1$):
the increase in a/σ_ξ is more important than that in σ_Φ

Niño3–AISMR

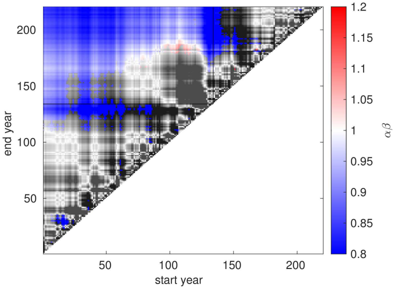


Niño3.4–AISMR

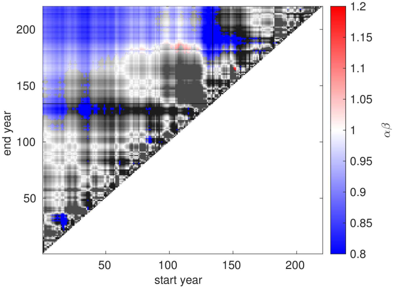


Blue ($\alpha\beta < 1$):
the increase in a/σ_ξ is more important than that in σ_Φ

EOF1–AISMR



EOF1–EOF1

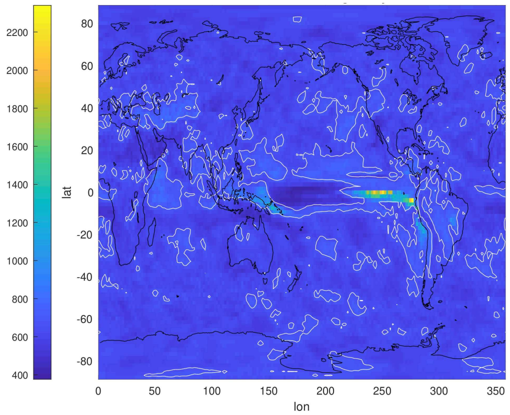


Summary: main driver: coupling strength a

Nonlinearity, nonergodicity

Nonlinearity (as observed as a drop in the teleconnection strength) implies nonergodicity (a nonzero expected difference between the correlation coefficients evaluated with respect to time and the ensemble) (but not the other way around!).
→ Can we explicitly detect nonergodicity gridpoint-wise over the globe?

Results for an ad hoc test statistic: contour lines: significant nonergodicity (5%)



Conclusions

ENSO–Indian monsoon teleconnection strength in the MPI-GE:

- long-term increase
- a drop after 2000
- nonlinearity

Main driver: coupling strength

Nonergodicity over the globe

Confidence thanks to the ensemble, but in a model

See more in Bódai et al., Front. Earth Sci. 8, 599785 (2021)

Cf. EGU21-3904

Further references

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