

Causal maps versus correlation maps: visual analysis of tropical-extratropical atmospheric teleconnections using causal discovery

Giorgia Di Capua and Reik V. Donner

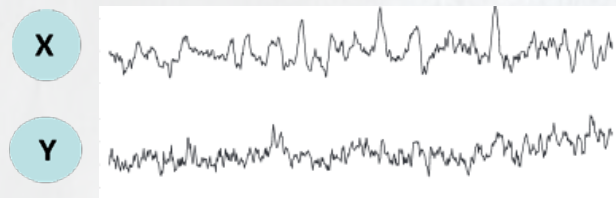
EGU General Assembly 2021 in session NP4.2

—
'Analysis of complex geoscientific time series: linear, nonlinear, and computer science perspectives'

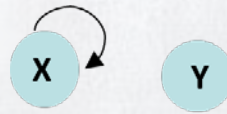
Scope of the study:

- Apply a **causal discovery tool** to remove **spurious correlation** in a 2D field
 - Causal effect networks → **causal maps**
- Practical example:
 - Identify main **modes of covariability** between **tropical convection** and **mid-latitude circulation** at intraseasonal timescales (weekly) in **reanalysis**
 - Assess what is the **causal effect** of these patterns **on surface conditions** and circulation features in the Northern Hemisphere
 - Do **seasonal forecasts** reproduce these causal links?

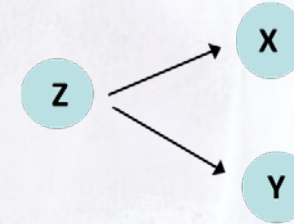
Does this mean X causes Y? Problems with Cross-Correlation



Auto-correlation



Common driver



Indirect link



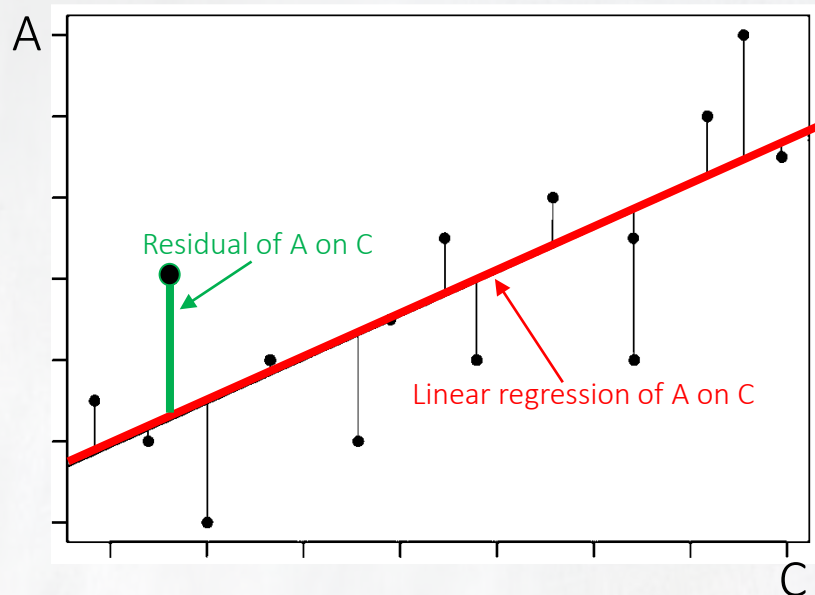
PCMCI: Modification of the Peter and Clark algorithm (Runge et al., 2014; Runge, 2018)

- Using **partial correlation** to assess causal links in a set of several 1D time series (*actors*)
- Identify the *causal parents* of each actors
- Represent the detected causal link with **causal effect networks (CEN)**

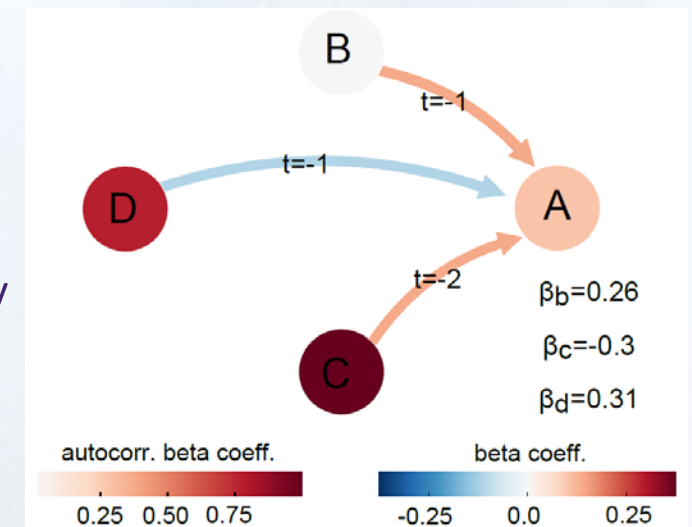
Runge, J., Petoukhov, V., & Kurths, J. (2014). Quantifying the strength and delay of climatic interactions: The ambiguities of cross correlation and a novel measure based on graphical models. *Journal of Climate*

Runge, J. (2018). Causal network reconstruction from time series : From theoretical assumptions to practical estimation. *Chaos*

- **Simple corr.** between $A_{t=0}$ and $B_{t=-1}$: $\rho(A_{t=0}, B_{t=-1})$
- **Partial corr.** between $A_{t=0}$ and $B_{t=-1}$ conditioning on $C_{t=-1}$: $\rho(A_{t=0}, B_{t=-1} | C_{t=-1}) = \rho(\text{res}(A_{t=0}), \text{res}(B_{t=-1}))$
- **Linear regression** of both A and B on C
- If $\rho(A_{t=0}, B_{t=-1} | C_{t=-1})$ still significant then A and B are said to be **conditionally dependent**, if not **conditionally independent**



- We can condition on a set of n variables
- Causal links are visualized as a **network**:
- Direction of arrow → **direction of causality**
 - Color → **strength of link** (β /path coeff.)

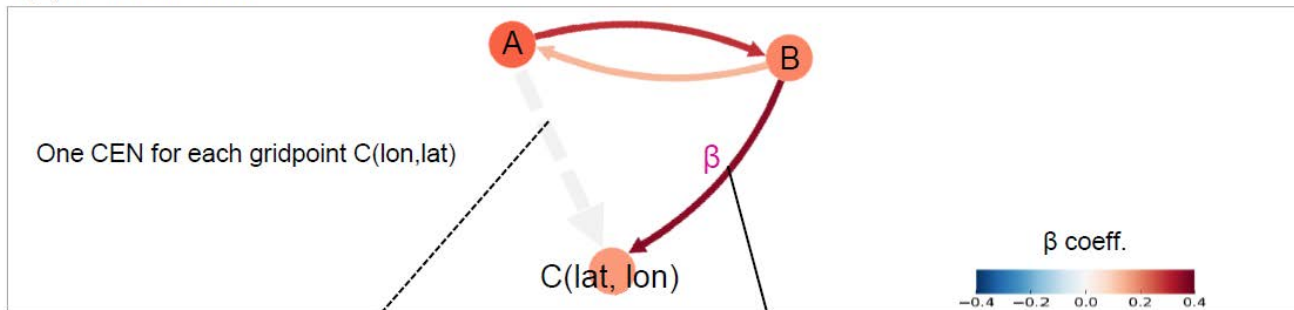


Causal parents of A: $P^A = \{B_{t=-1}, C_{t=-2}, D_{t=-1}\}$ Strength of link: $A_{t=0} = a_0 + \beta_b * B_{t=-1} + \beta_c * C_{t=-2} + \beta_d * D_{t=-1}$

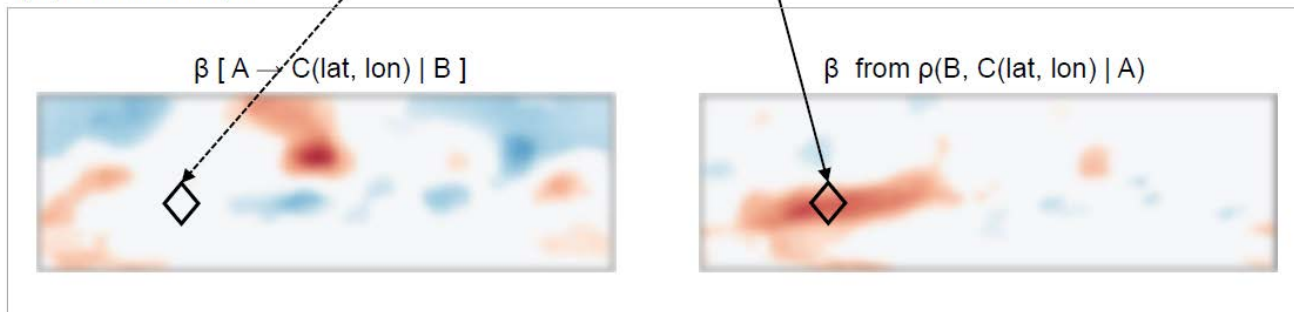
(a) Correlation maps



(b) PCMCI-CEN



(c) Causal maps



- $C(\text{lat}, \text{lon})$: 3D field
- A and B: two 1D time series
- A and B are correlated $\rightarrow$ produce similar correlation maps



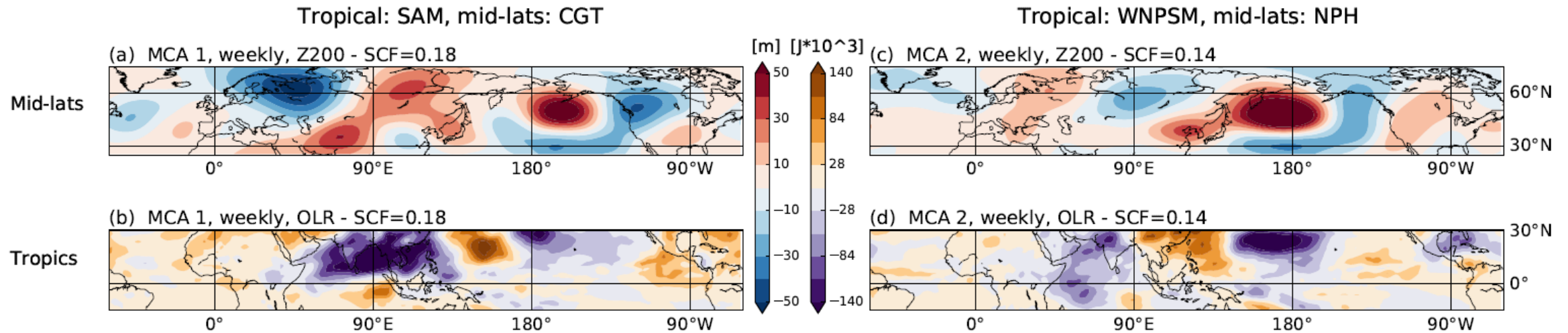
Scope of causal maps:

Disentangle causal and spurious links on a 2D map



- Calculate a causal effect network (CEN) for each grid point
- Plot only a specific link

Maximum covariance analysis between mid-latitude Z200 and tropical OLR



- Mid-latitudes: circumglobal teleconnection (CGT) pattern and North Pacific High (NPH)
- Tropics: South Asian monsoon (SAM) and western North Pacific summer monsoon (WNPSM)

OLR, Z200, weekly, ERA-I, 1979-2018

Di Capua et al. WCD 2020 <https://wcd.copernicus.org/articles/1/519/2020/>

Causal maps for SAM and CGT

Lag -1 (week)

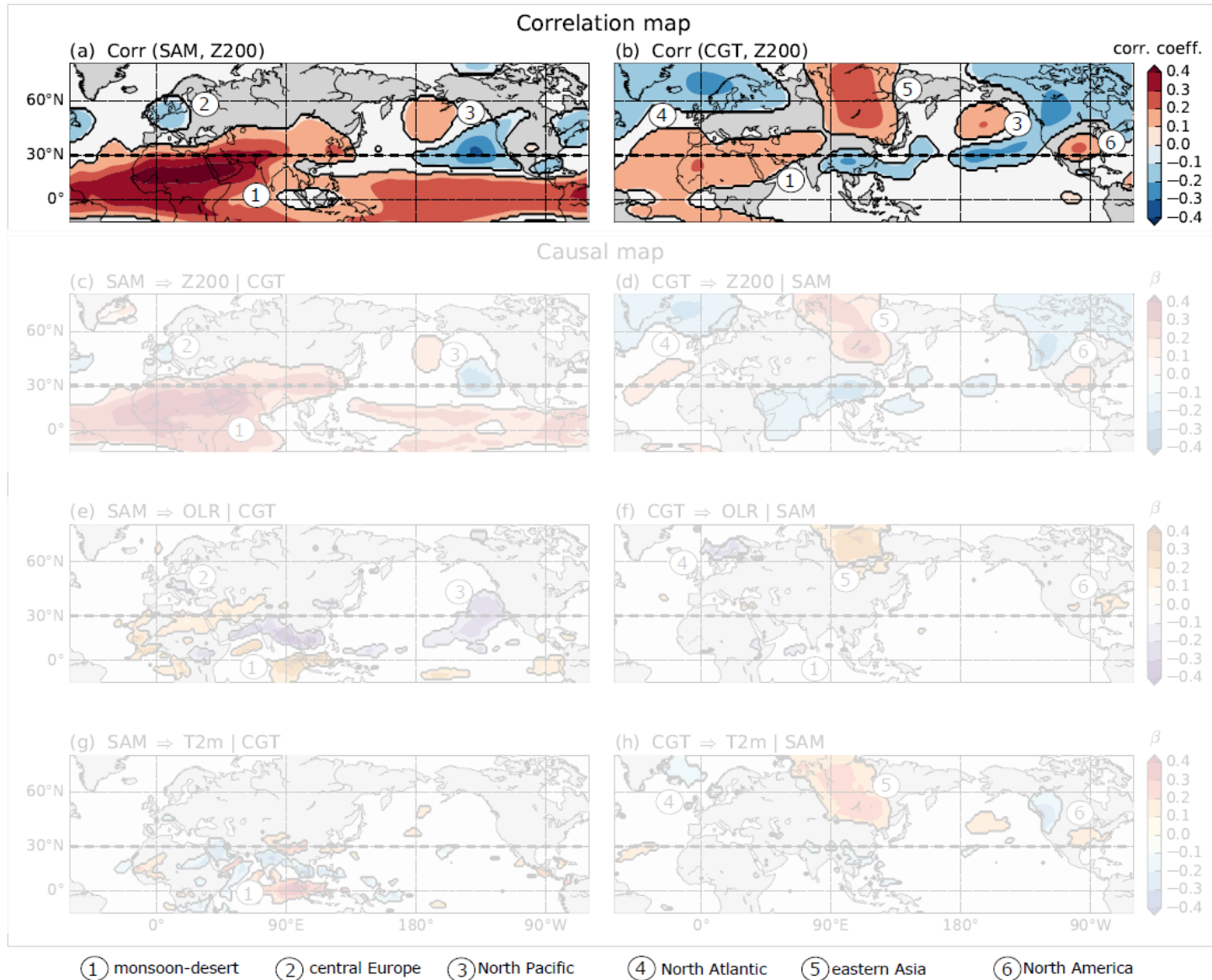
Corr. maps show strong similarity

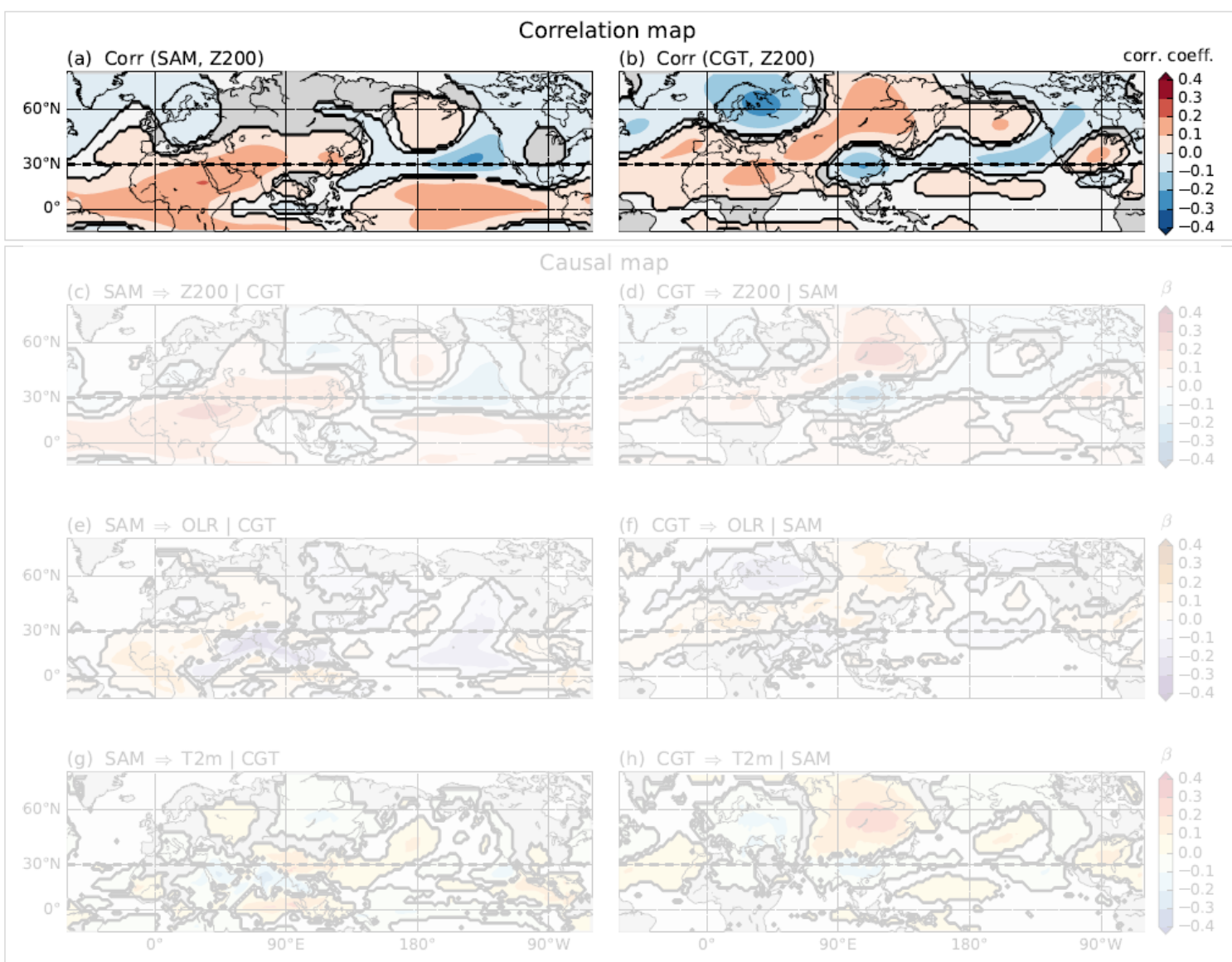
SAM

- Monsoon – desert mechanisms
- Some signal in the mid-latitudes

CGT

- Keeps its circumglobal character
- Most of signal in mid-latitudes
- North America, North Atlantic, North-east Asia





Causal maps for SEAS5

Lag -1 (week)

Corr. maps show strong similarity (~ERA-I)

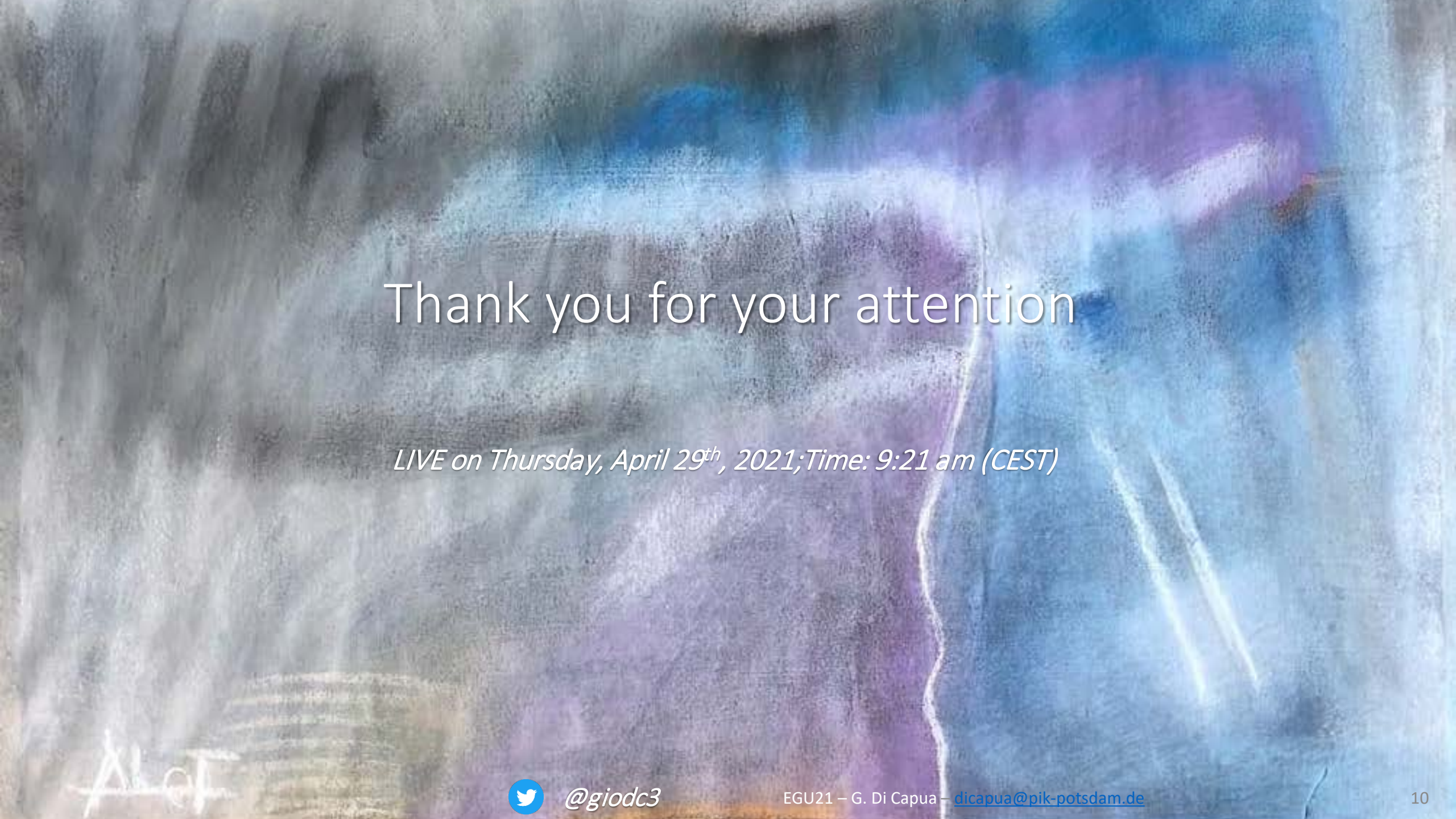
Comparison with ERA-I

- Clear two-way causal links between mid-latitudes and tropics
- Clear signal in the mid-latitudes
- Monsoon-desert mechanism is depicted
- The CGT has some signal on North Africa

Conclusions

- Causal maps help remove spurious links in a 2D field and thus represent an improved alternative to correlation maps
- The identified covariability patterns between tropical convection and mid-latitude circulation in reanalysis show:
 - the South Asia monsoon (SAM) paired with the circumglobal teleconnection pattern (CGT)
 - the western North Pacific summer monsoon (WNPSM) paired with the North Pacific High (NPH)
- At weekly timescale, a two-way causal link between tropical convection and mid-latitude circulation is found
- SEAS5 causal maps agree qualitatively but there are differences in the magnitude of the causal links





Thank you for your attention

LIVE on Thursday, April 29th, 2021; Time: 9:21 am (CEST)



@giodc3

EGU21 – G. Di Capua – dicapua@pik-potsdam.de