Phase Coherence between Precipitation in South America and Rossby Waves

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Joint work with Niklas Boers and Jürgen Kurths

Based on M. Gelbrecht, N. Boers, J. Kurths: "Phase coherence between precipitation in South America and Rossby Waves", Science Advances Vol. 4, no. 12, eaau3191, DOI: 10.1126/sciadv.aau3191

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Photo: Nacho Doce/Reuters /Landov

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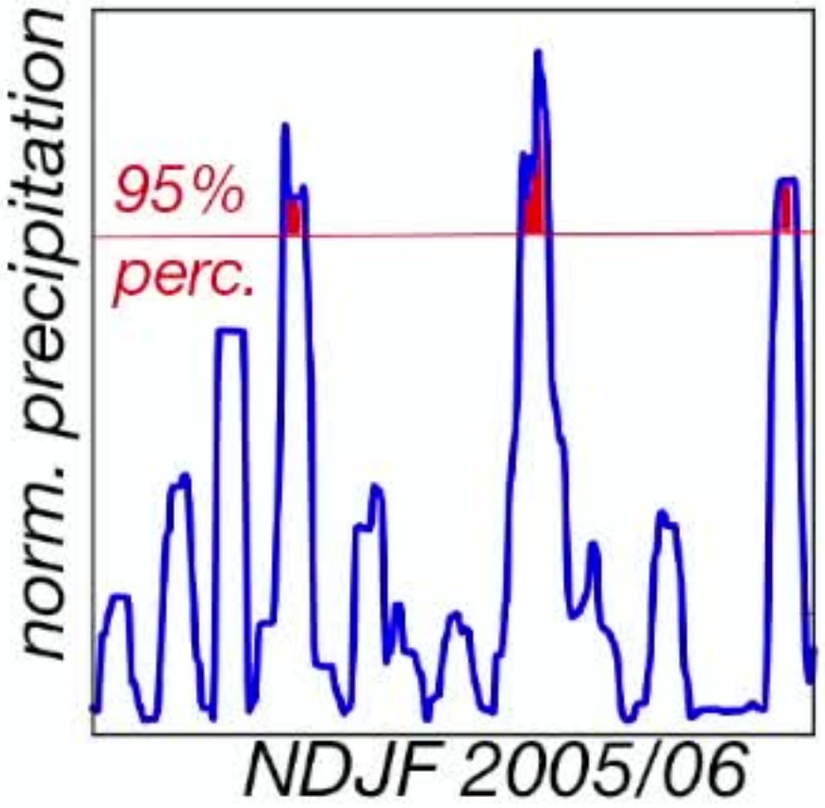
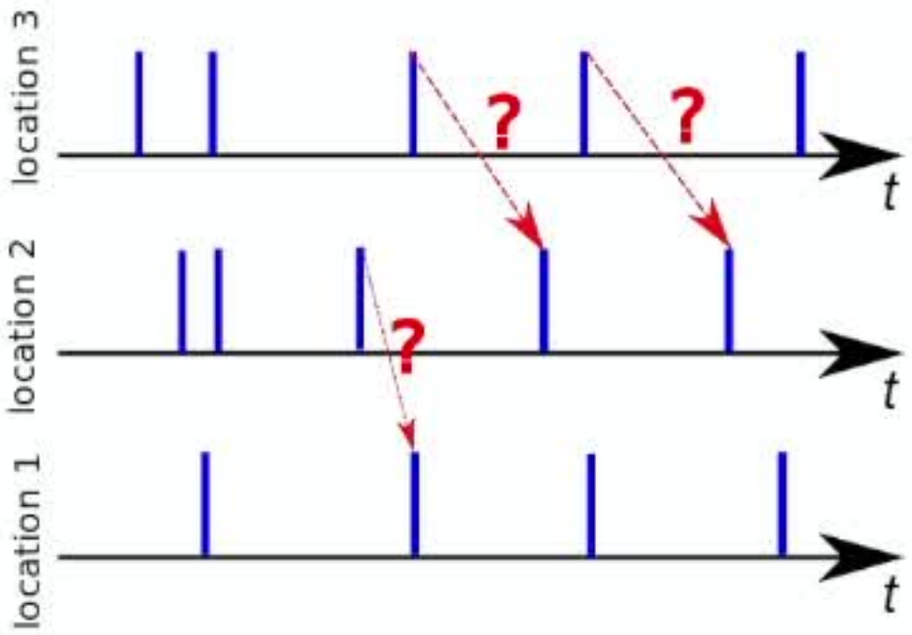
SAMS

- **Climate Networks (CN)** excel in visualizing these moisture paths
- e.g. Boers, 2014 (Event Synchronization); Ciemer, 2018 (Precipitation Correlation Networks); Gelbrecht, 2017 (Wind Flow Networks)
- CNs can tell where to look further



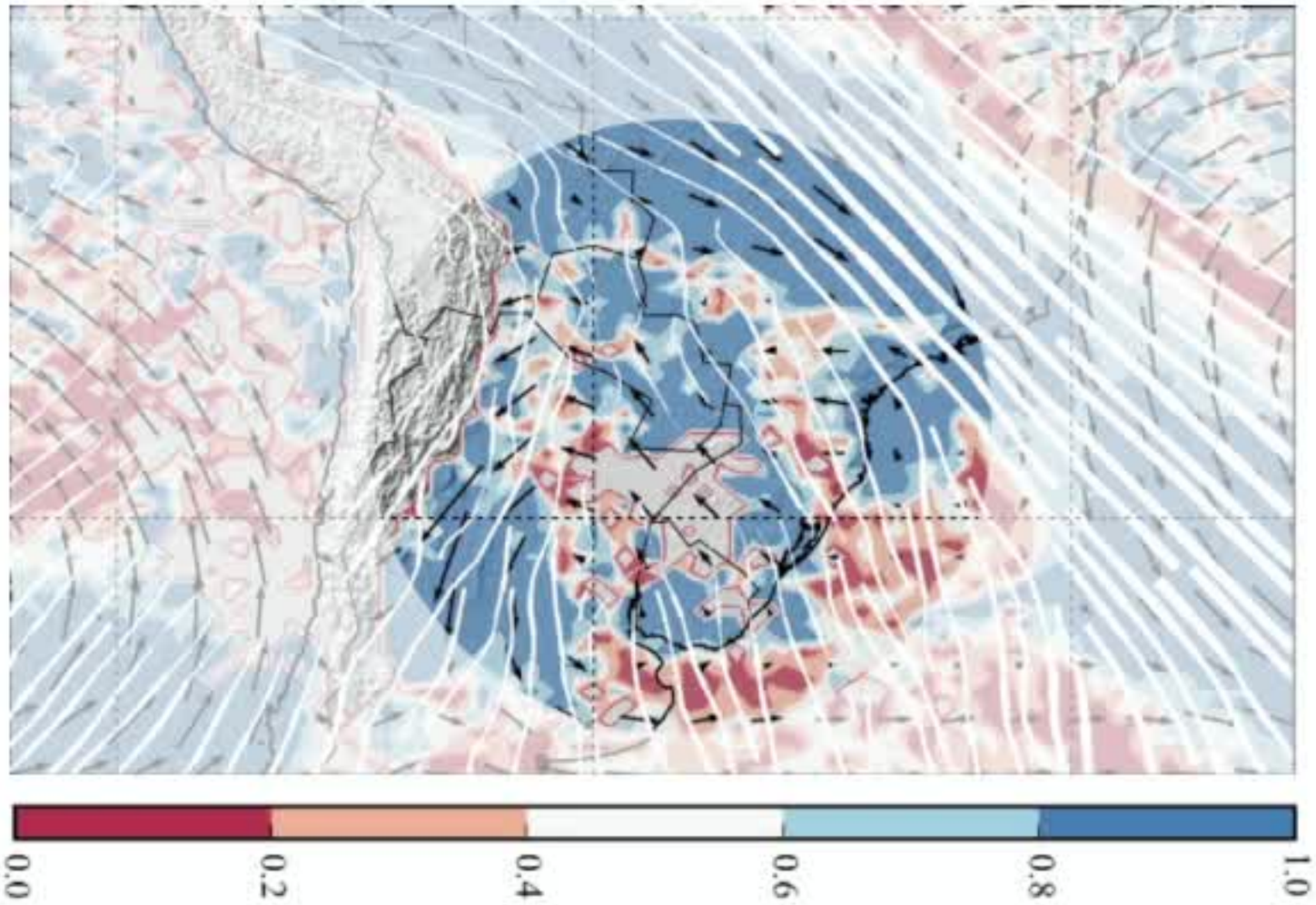
Event Synchronization

- Threshold precipitation time series to event time series
- Spatiotemporal data → Event Synchronization (ES)
- ES References: Quiroga et. al. 2002,
  - for Climate: Malik et al. 2010, Boers et al 2014, many more



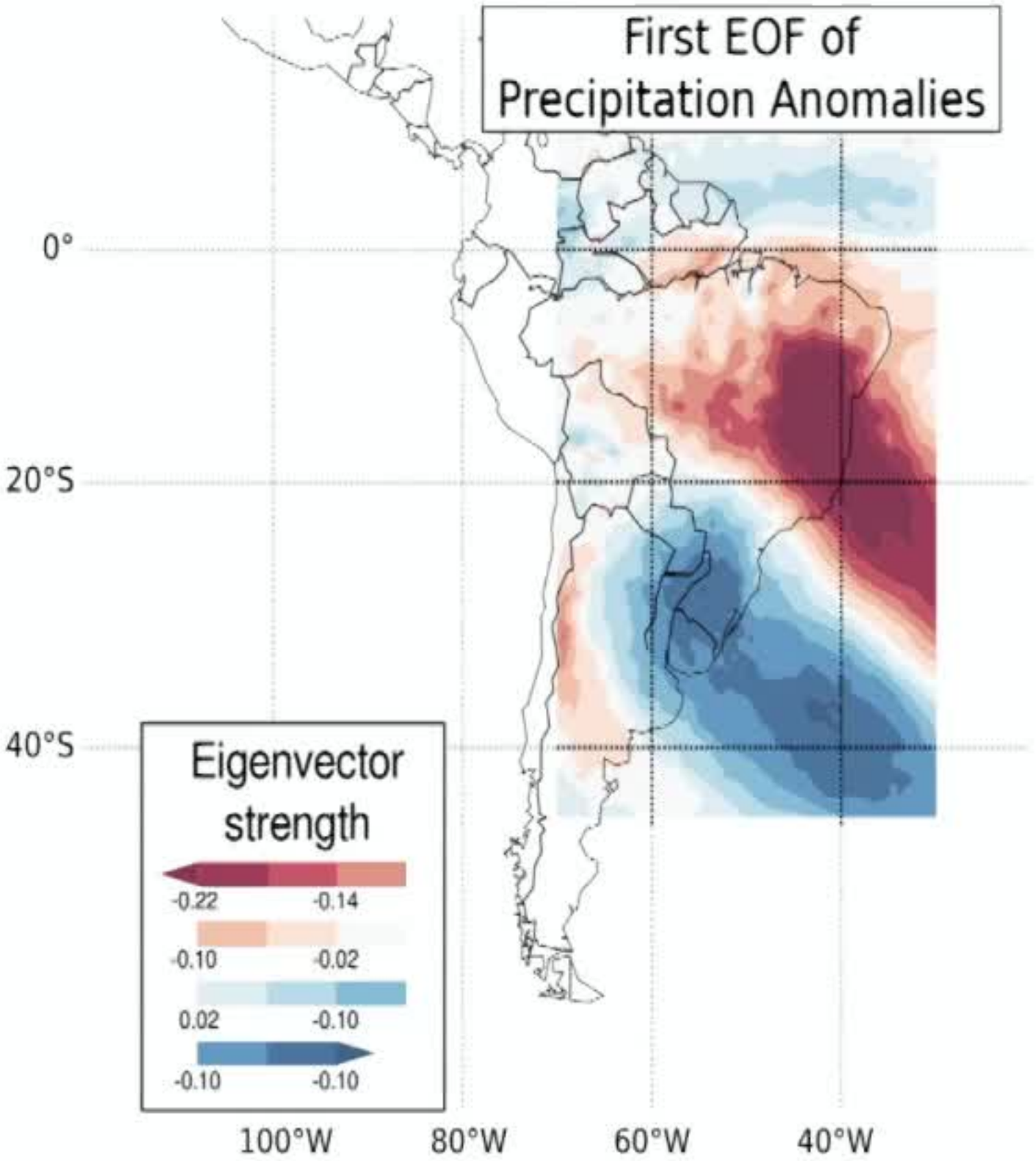
Climate Networks

Figure from Boers et al. 2014, Geophysical Research Letters



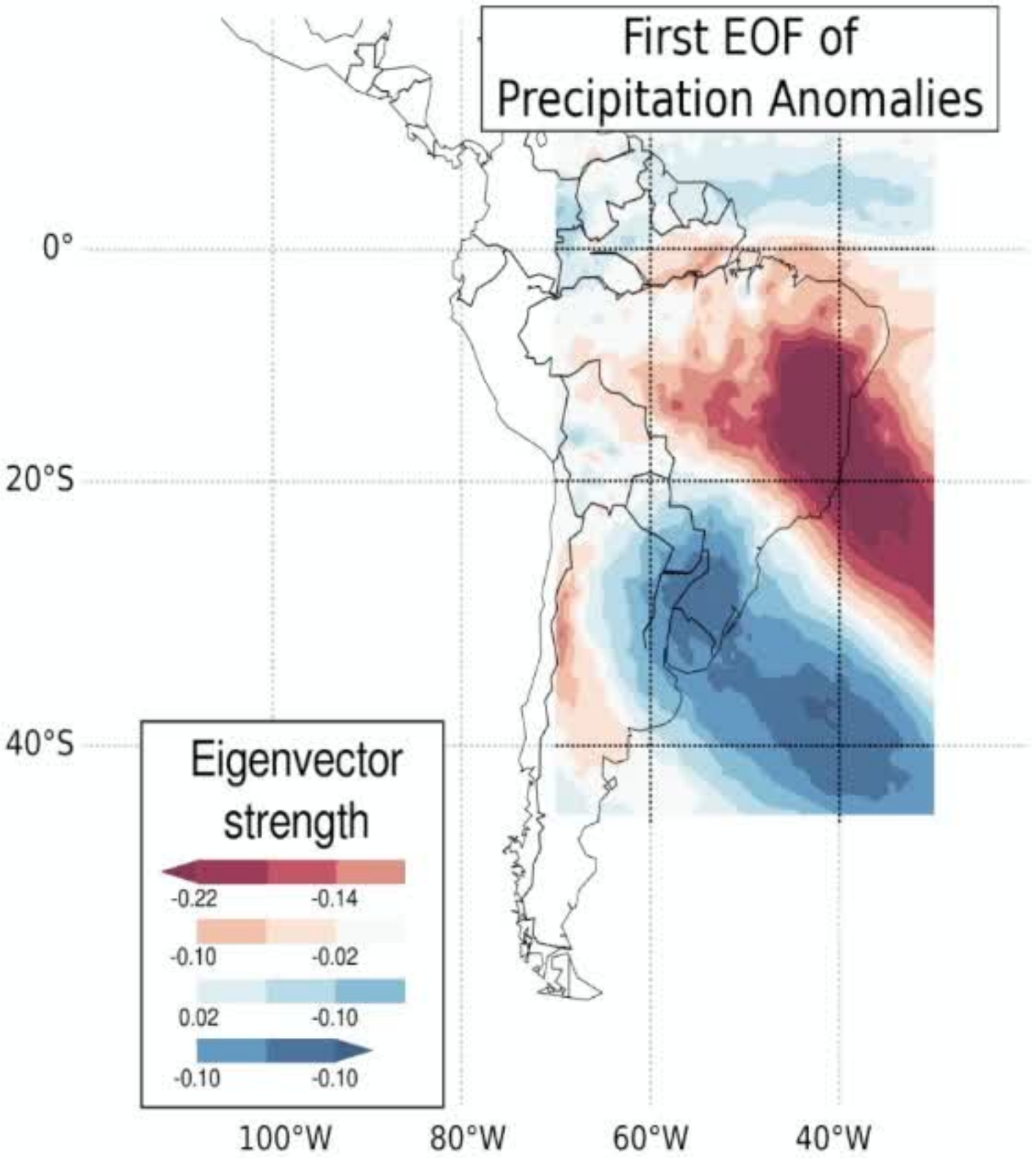
scalar product of direction of event synchronization and wind direction

- Boers et al. 2014 found extreme events that propagate against the direction of the wind
- How can we understand this?
- Frontal systems propagating from the south possibly play a role



Precipitation

- Precipitation Regimes possibly connected with the **Rossby waves**, the meandering upper-level athmosphere Jet Stream
- Classic method to analyze spatial variability patterns: **Principial Component Analysis (PCA)** of the Covariance Matrix that yield **Empirical Orthogonal Functions (EOFs)**
- Precipitation Dipole



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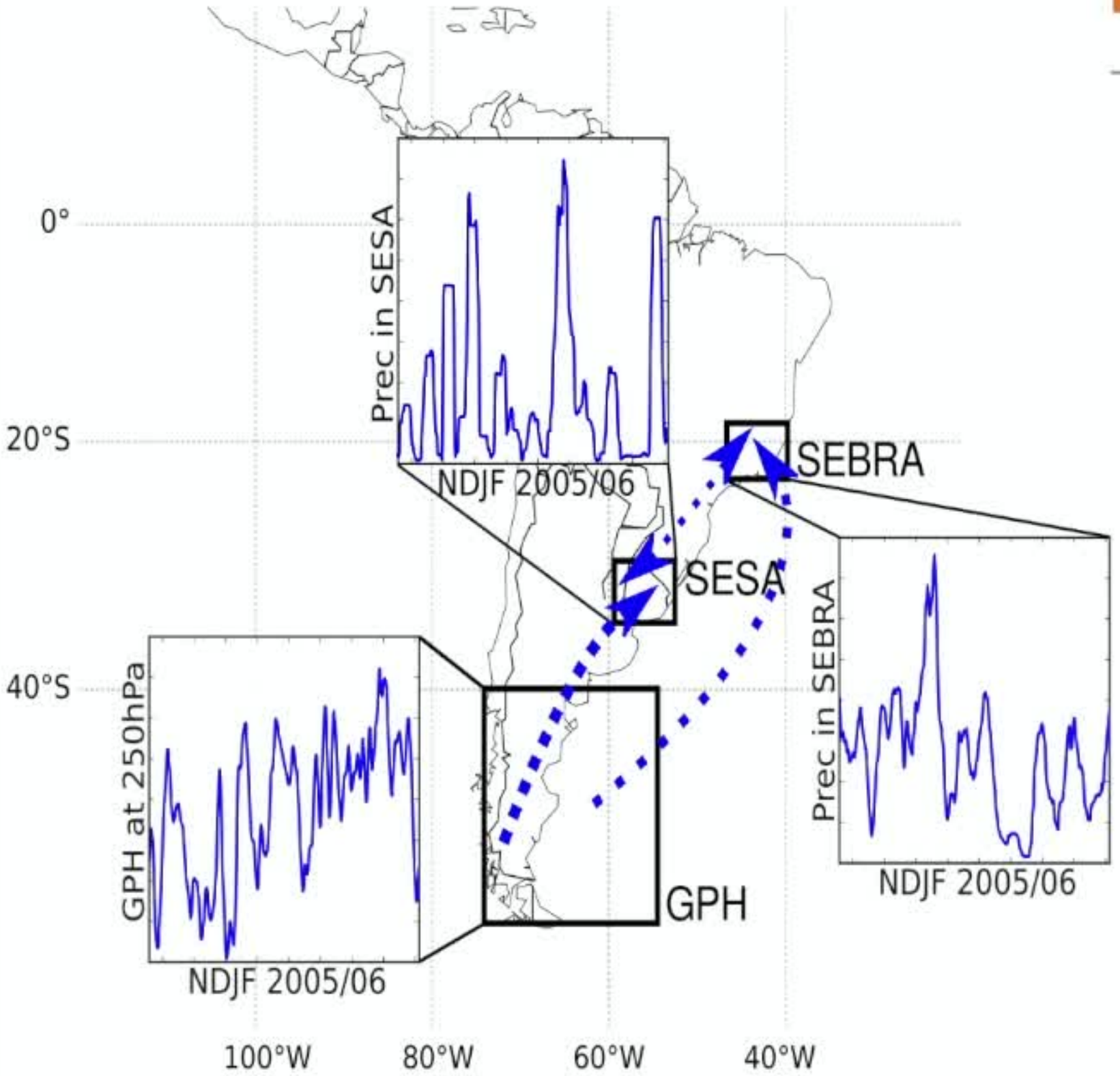
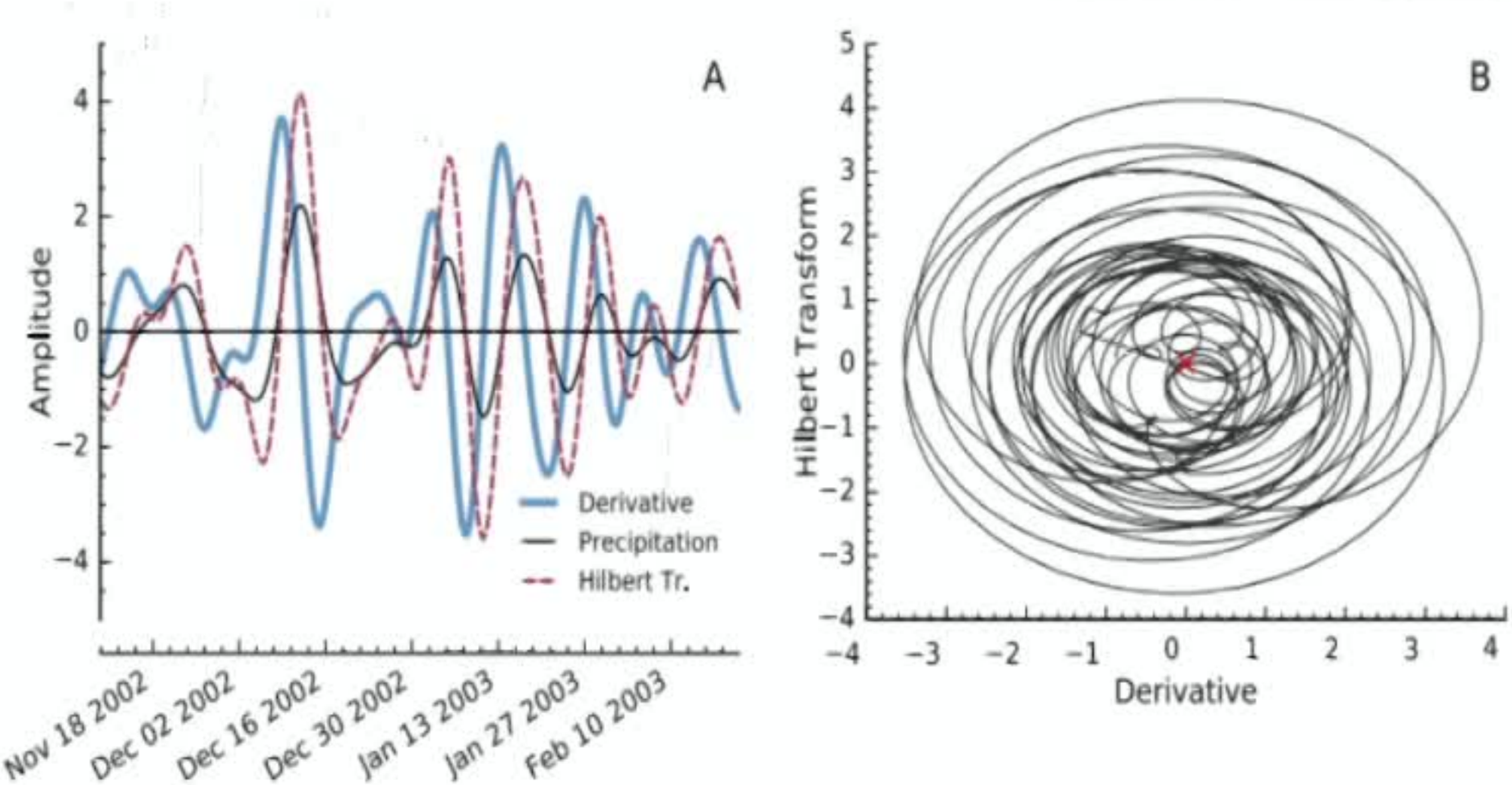
Methods

- Investigate coupling / link between SESA, SEBRA and GPH
- First: **Data-driven phase analysis**
- Investigate Oscillations → show phase coherence
- Second: **Conceptual Model**

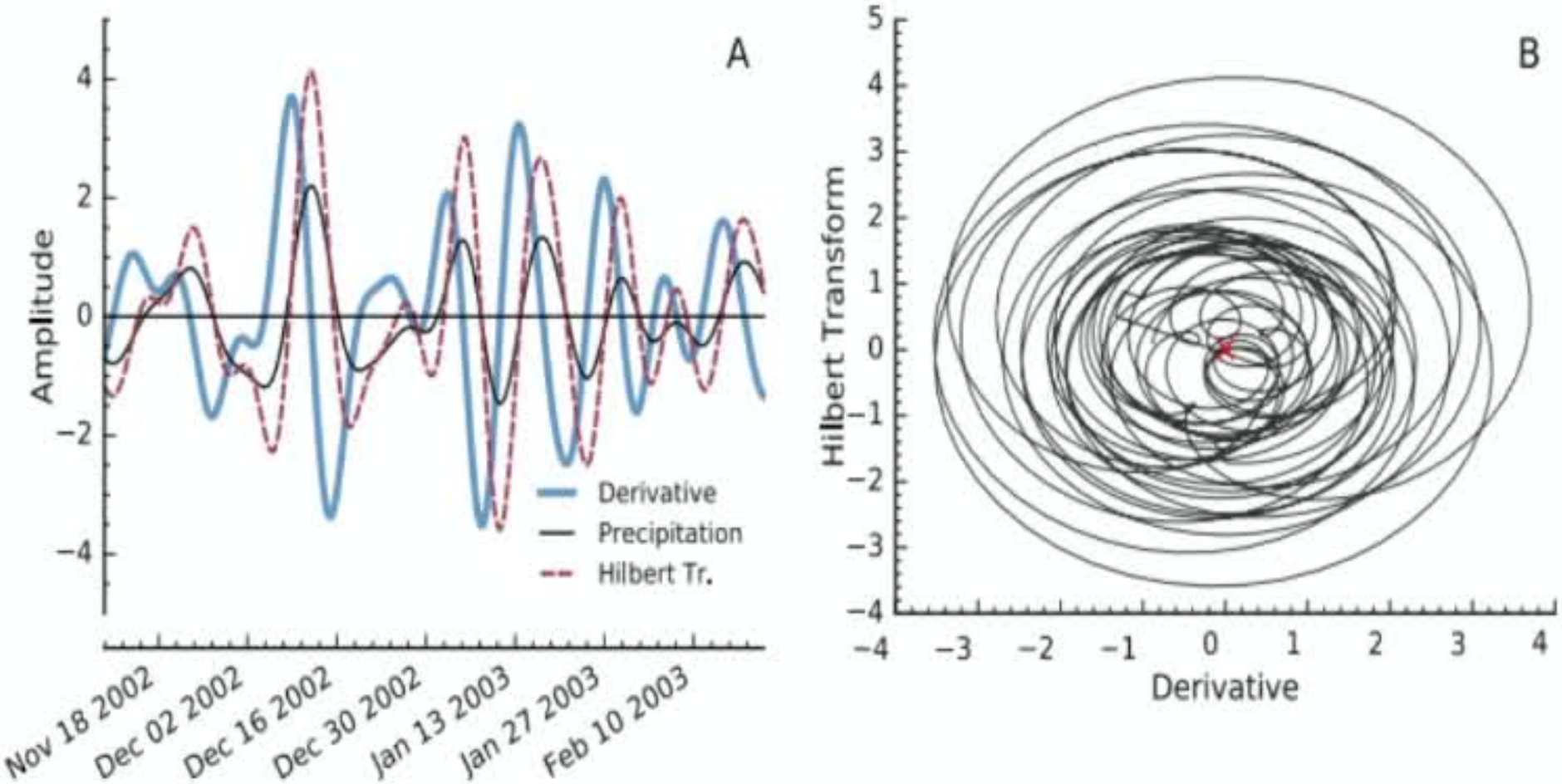


Phase Analysis



- Embed time series via a Hilbert transform, use derivative (Osipov et al 2003, PRL)
- Endpoint matching for seasonal data
- Phase computed via $\phi(t) = \arctan \frac{\mathcal{H}\{\dot{x}\}(t)}{\dot{x}(t)}$ for all three time series

Phase Analysis



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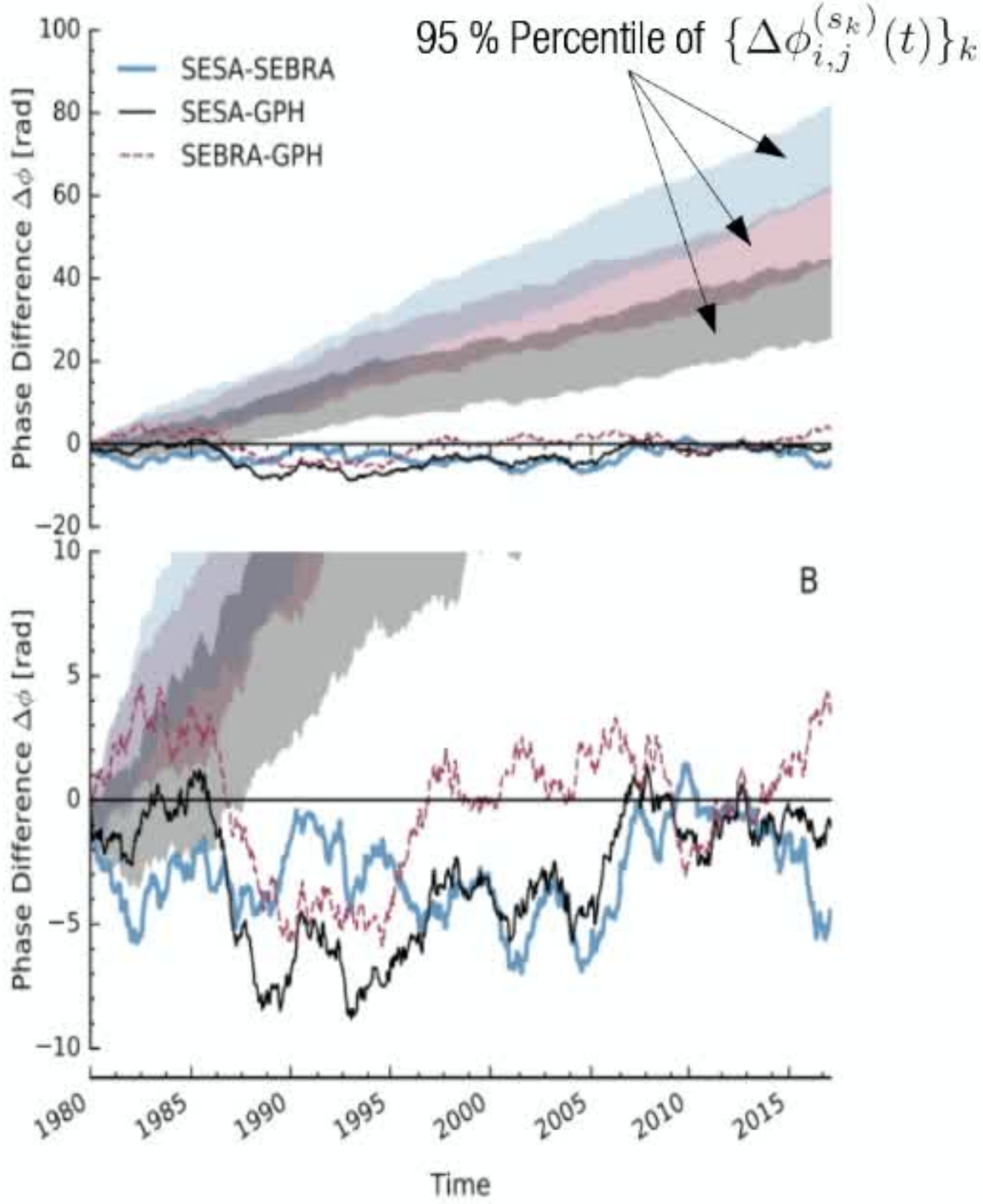
Phase Differences



- Investigate phase differences between the three proxies

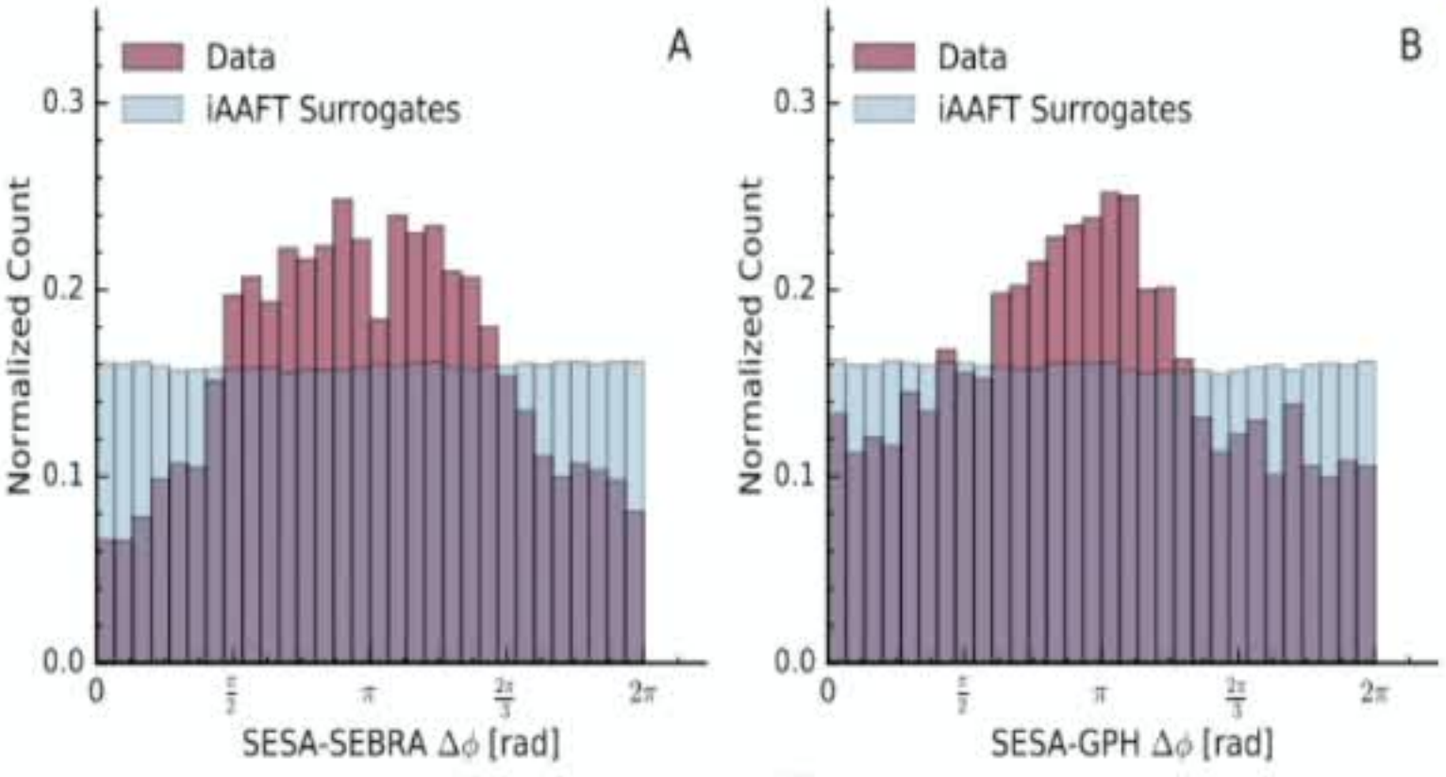
$$\Delta\phi_{i,j}(t) = \phi_i(t) - \phi_j(t)$$

- AR2 surrogates s_k as comparison

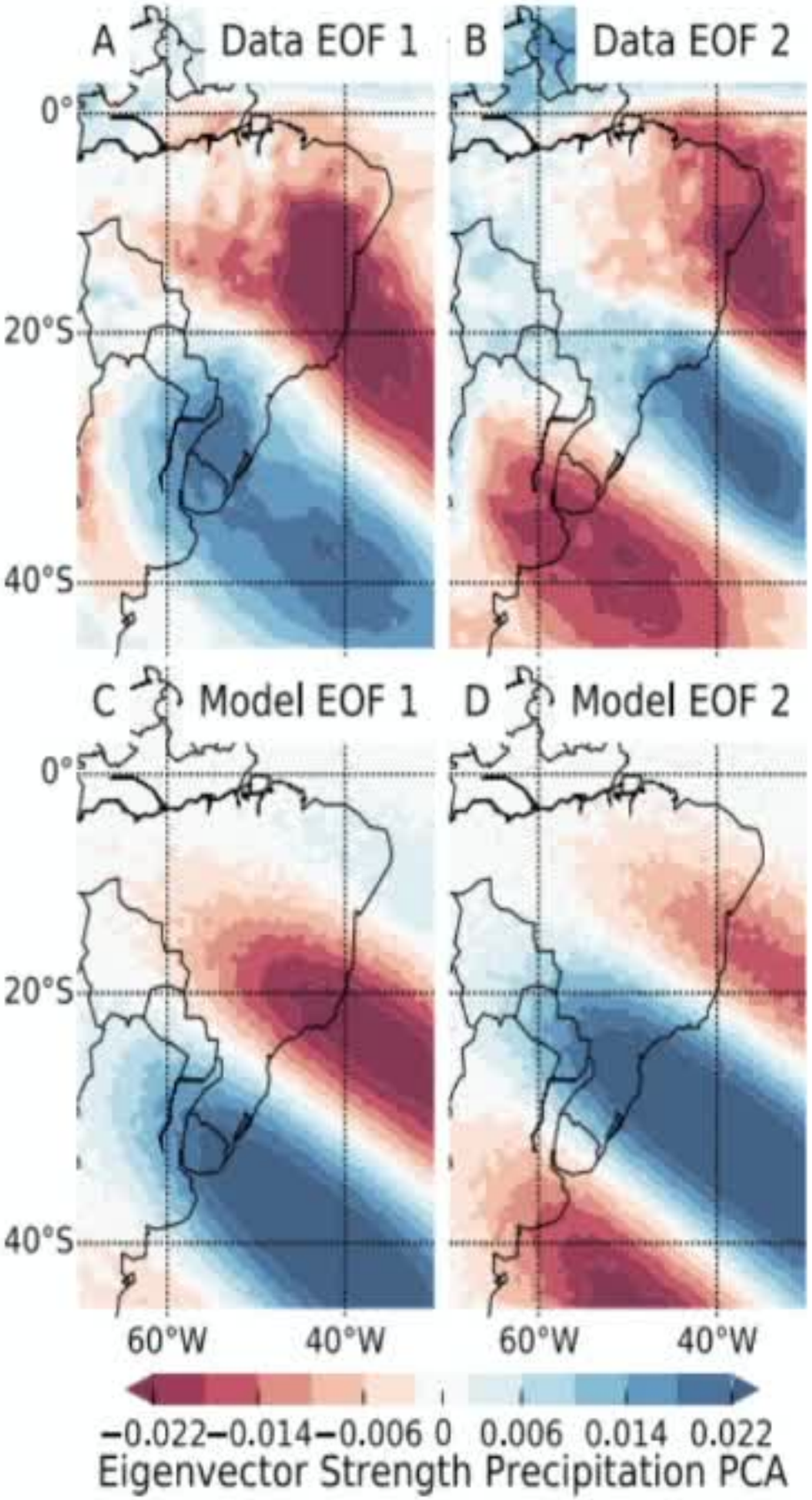
$$\Delta\phi_{i,j}^{(s_k)}(t) = \frac{1}{2}((\phi_i(t) - \phi_j^{(s_k)}(t) + (\phi_i^{(s_k)}(t) - \phi_j(t))$$

- Phase difference between all three proxies remain close to zero, much smaller than surrogates

Phase Differences



- Histograms of phase differences show distinctive peaks
- MLE fit to vonMises distribution
- Dispersion κ (width of the peaks) of the distribution an indicator of phase coherence
- Histograms and Phase Time Series show phase coherence
- Relate temporal evolution of dispersion back to extreme events?



Conceptual Model

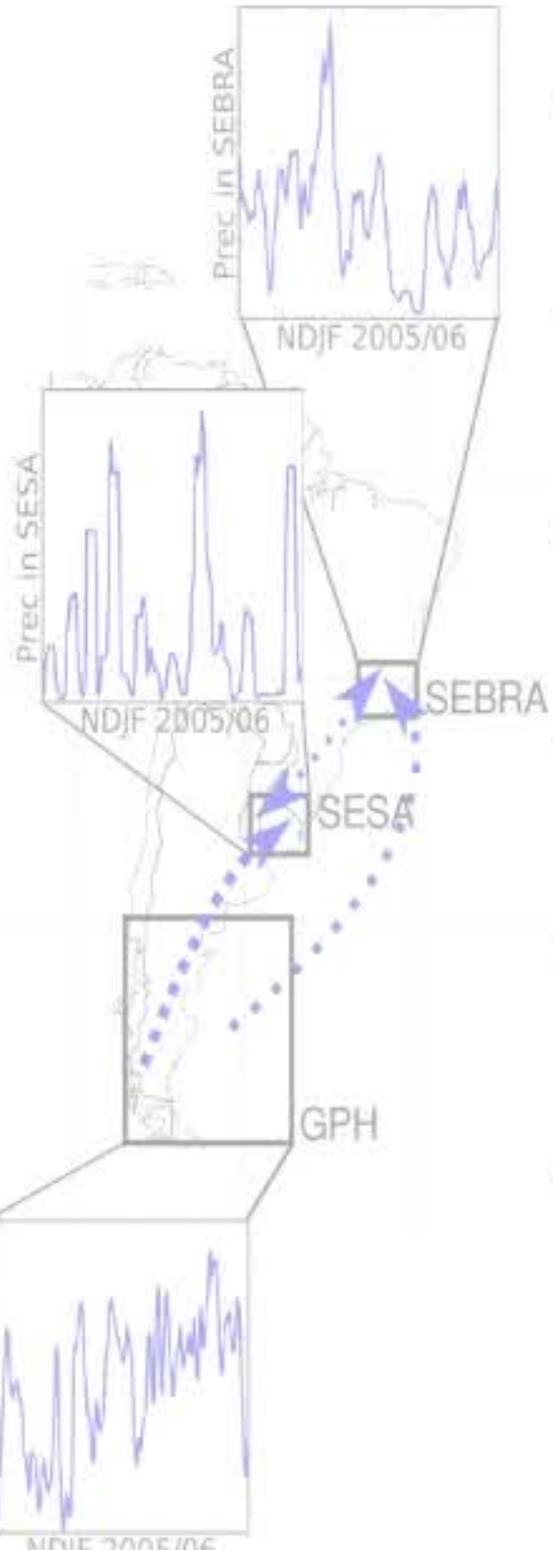
- Show how PCA/EOF pattern of precipitation data can result from a travelling wave
- **Ansatz:** free travelling wave
  + add gaussian damping along and perpendicular to propagation direction

$$\Box\left(h(x,t)\right) = 0$$

$$p(x,t) = \frac{\partial}{\partial x} h(x,t)$$

- **LSE fit** to data EOFs

Summary



- Data-driven analysis shows phase coherence: subsystems synchronize and are therefore coupled
- EOF pattern explainable by simple conceptual model based on a travelling wave
- "Backward" propagating extreme events explainable
- Alternating High/Low pressure systems determines outlet of the moisture pathway
- Dipole driven by Rossby Wave and not just by a direct interaction between SESA and SEBRA
- **Outlook**
  - study temporal evolution → relation to extreme events
  - investigate amplitude / monsoon onset
  - simple forecast model

Outlook: MCBB

- New project
- Numerical Method / Tool to analyze multistability and bifurcations in mid/high – dimensional complex systems
- Based on random sampling, suitable statistics and clustering methods
- Monte Carlo Basin Bifurcation Analysis (MCBB)
- To be released as a package for Julia programming language very soon
- Talk to me after the session for more information about it