# Drought is Nonstationary

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"If we want everything to stay as it is, then everything must change".

Giuseppe Tomasi di Lampedusa, *The Leonard*

Google Scholar search drought “nonstationarity”: 6480 refs!

drought “nonstationary”: 14,300 refs  This literature is nonstationary

# Key Points

**Climate** exhibits Power Laws in space and time, with
higher variance at longer timescales, larger spatial areas.
It is naturally, intrinsically, **Nonstationary.**

The *subject* is drought, severe and sustained.

What is the *goal*?

- To detect change?
- To predict future change?
- To contextualize recent events?
- To guide investments in mitigation?
- To predict conditional transition to/from drought?

Tell us the goal, then we can play the game.

Only probabilistic answers are possible.

# Key Points

Can we detect the effect of anthropogenic forcing (changing parameters)?

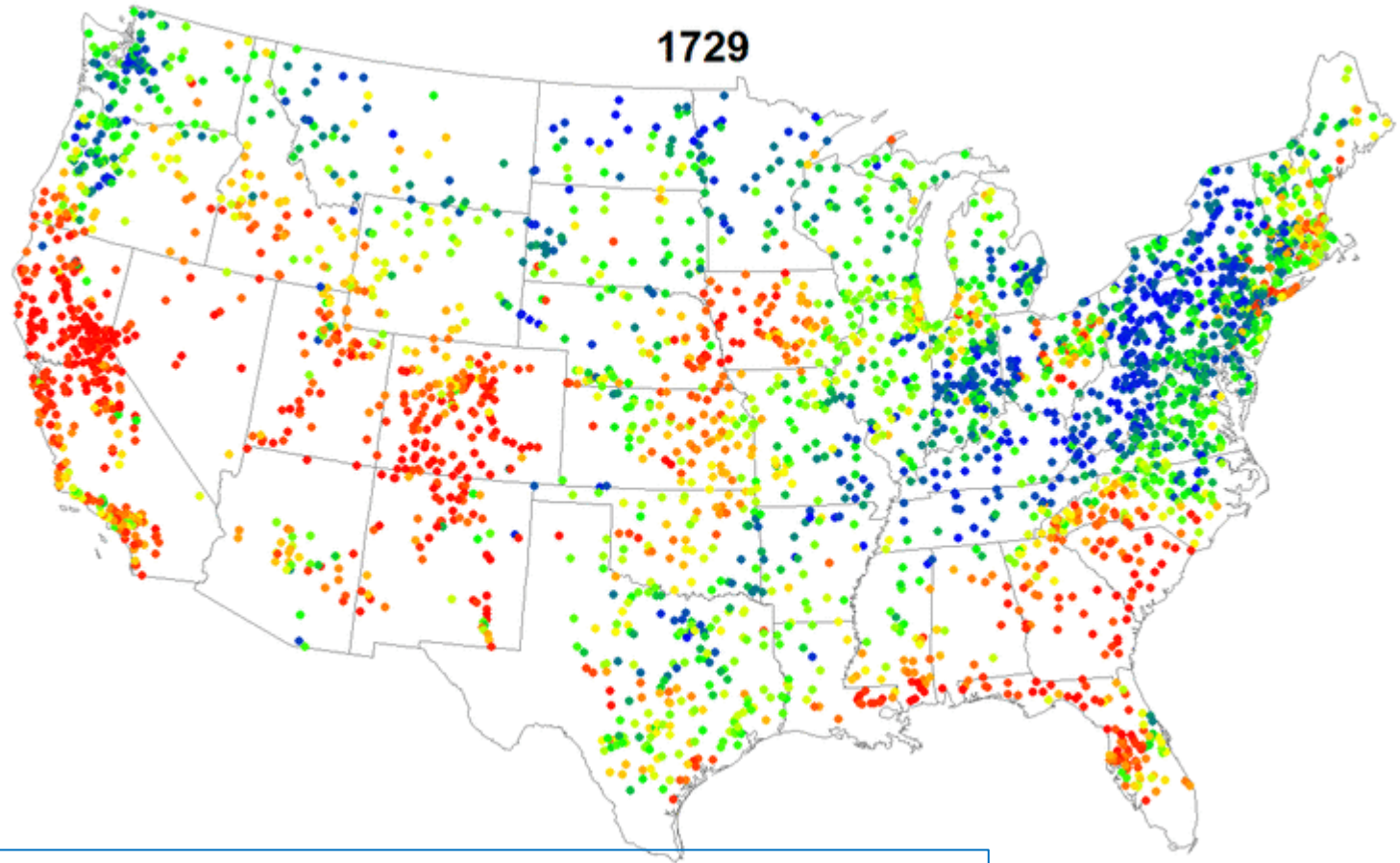
- Physics based model simulations based hypothesis testing
  - But the parameters of these models are tuned, and may not reflect changed dynamics
- Paleoclimate based hypothesis testing
  - Uncertainties, biases (e.g. variance reduction in reconstructions)
  - Spatial Transferability of sequences?
- 20$^{th}$ century plus observations with anthropogenic forcing as a covariate

- Methods: (often require dimension reduction, another source of error)
  - Wavelets (Time, Space-Time) to inform changes in scaling laws?
  - Bayesian Framing for Hierarchical inference – but at the regional or global scale?
    - Latent Variable Models/Embedding
  - Predictive ability, especially for a combination of models and data sources?
    - A common feature is the need to project the data into a lower-dimensional embedding space and then examine the question.

# Reconstructing 500 years of streamflow

availability

## Annual Flows




Ho, M., et al. (2017), WRR, doi:10.1002/2016WR019632

**Large areas have similar wet/dry conditions persist for many years**

**How to characterize drought as a spatio-temporal process AND an event process?**

# Formalism – Spatio-Temporal Process

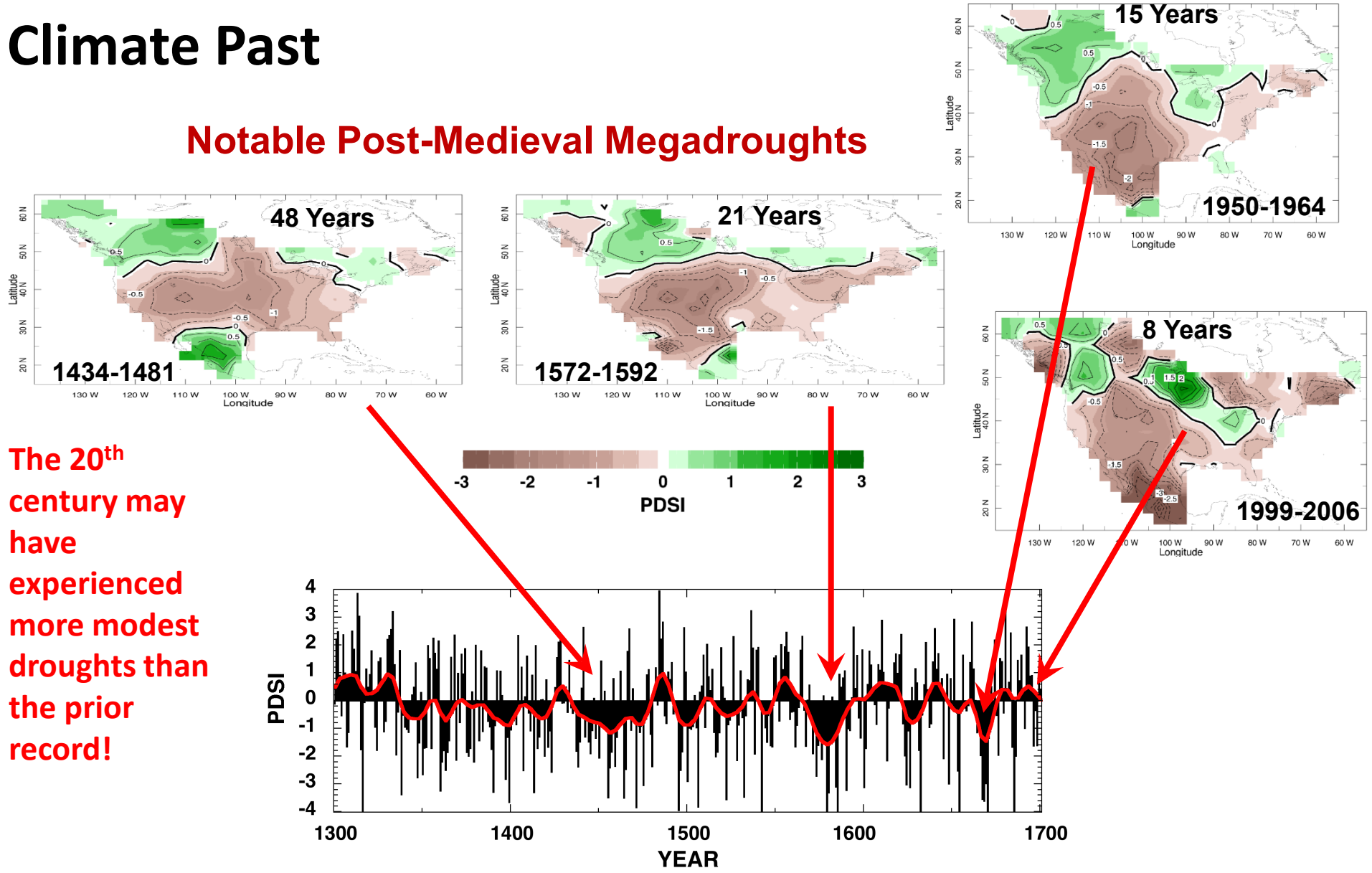
Model the primary climate variables as spatio-temporal processes

Derive the Area-Duration-Severity-Location- Event Conditional Probabilities

- Drought measures
  - P(x,t) – Primary variable used to define drought: Precip, PDSI, Supply-demand cumulative deficit.
  - Drought index D(x,t)= f(P*(x),P(x(t)), where P*(x) is a location specific threshold
    - D(x,t) = max(0,P(x*)-P(x,t)) or D(x,t) = max(0, $\Sigma_t$(O (x,t)-I(x,t))
  - Drought event measures:
    - Contiguous Area and time over which D(x,t)>0 = Areal extent $CA_i$ and duration $Dd_i$
    - Drought event centroid $EC_i = (\bar{x}, \bar{t})_i$
    - Drought severity $S_i = \int \max(D(x,t)_i, 0)dx\,dt$ or $S_i(x) = \int \max(D(x,t)_i, 0)dt$
  - Stochastic Process of Interest at the event scale:
    - Joint/conditional probability distribution of $CA_i$, $Dd_i$, $Ec_i$, $S_i$ =f(**De**$_i$)
    - Conditional on t, $CO_2$, ENSO…..
  - Model P(x,t) and derive f(**De**$_i$)

# Climate Past

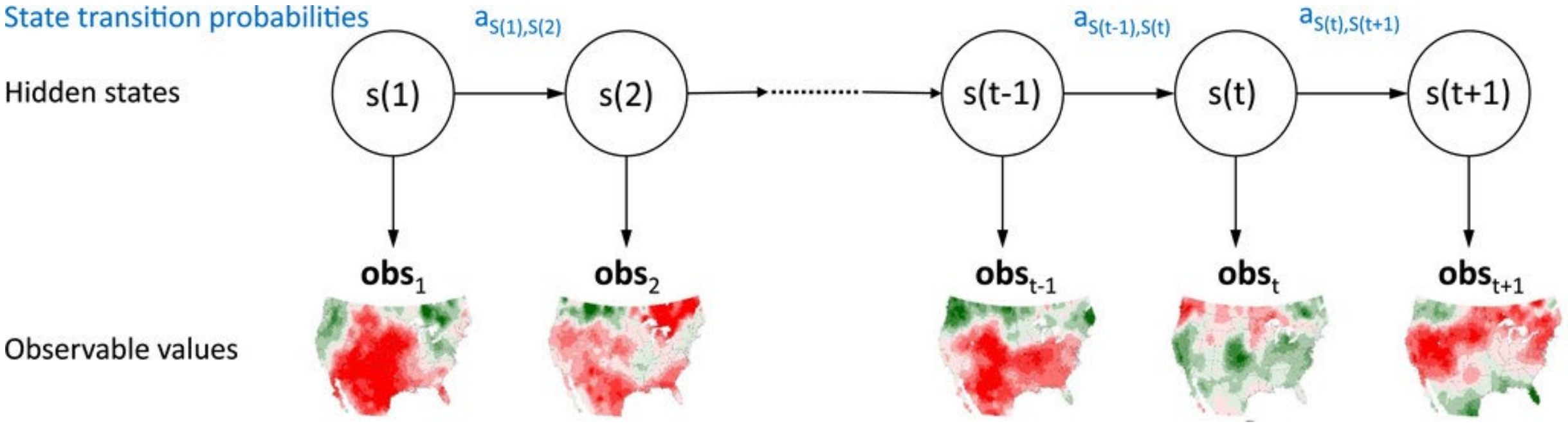
## Notable Post-Medieval Megadroughts




**The 20th century may have experienced more modest droughts than the prior record!**

**Ed Cook**
Lamont-Doherty Earth Observatory, Palisades, NY

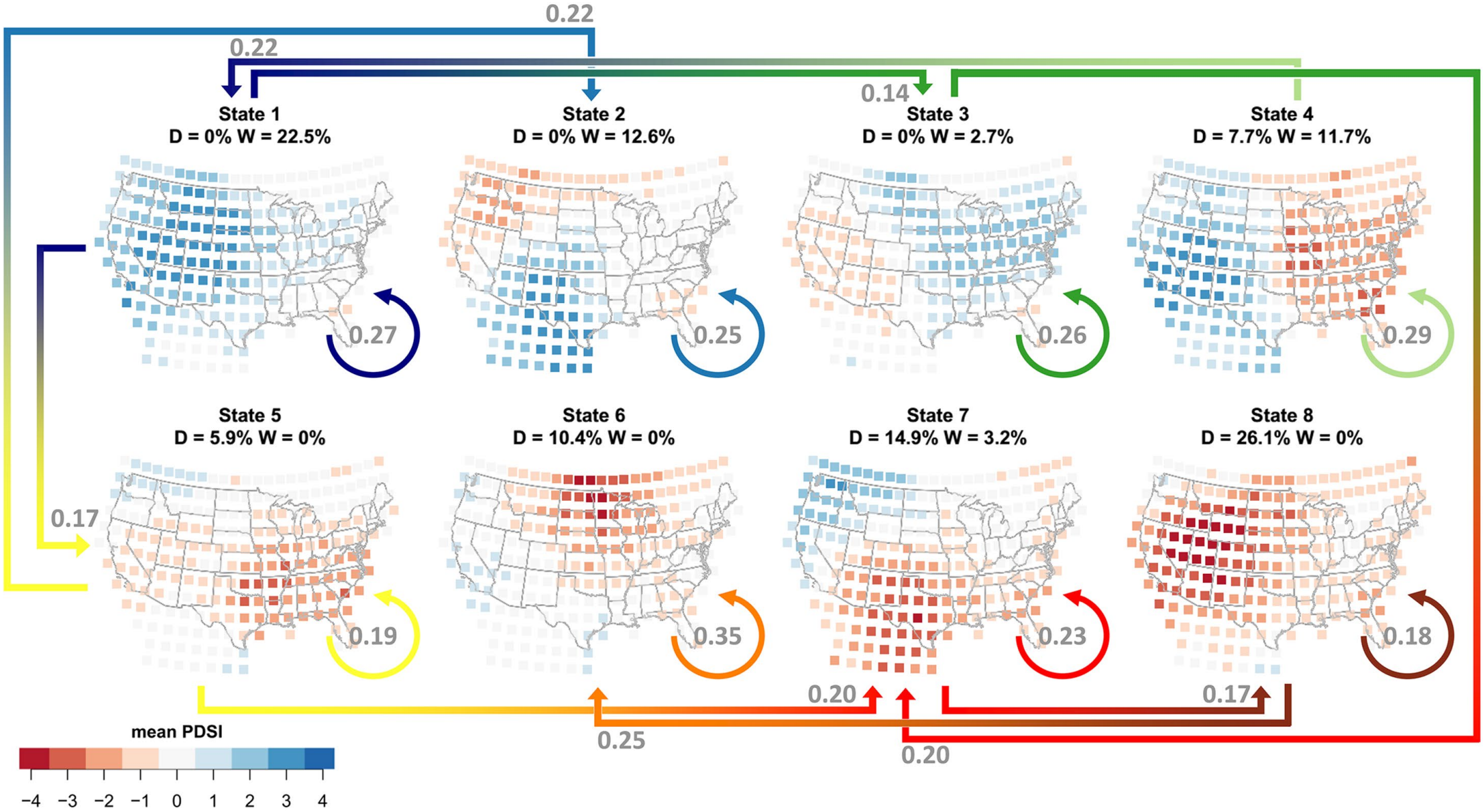
- **Hidden Markov Model** – Spatio-temporal process




Ho, M., U. Lall, and E. R. Cook, 2018: How Wet and Dry Spells Evolve across the Conterminous United States Based on 555 Years of Paleoclimate Data. *J. Climate*, **31**, 6633–6647, https://doi.org/10.1175/JCLI-D-18-0182.1.

# Hidden Markov Model for LBDA Dynamics: States and transition probabilities

a)

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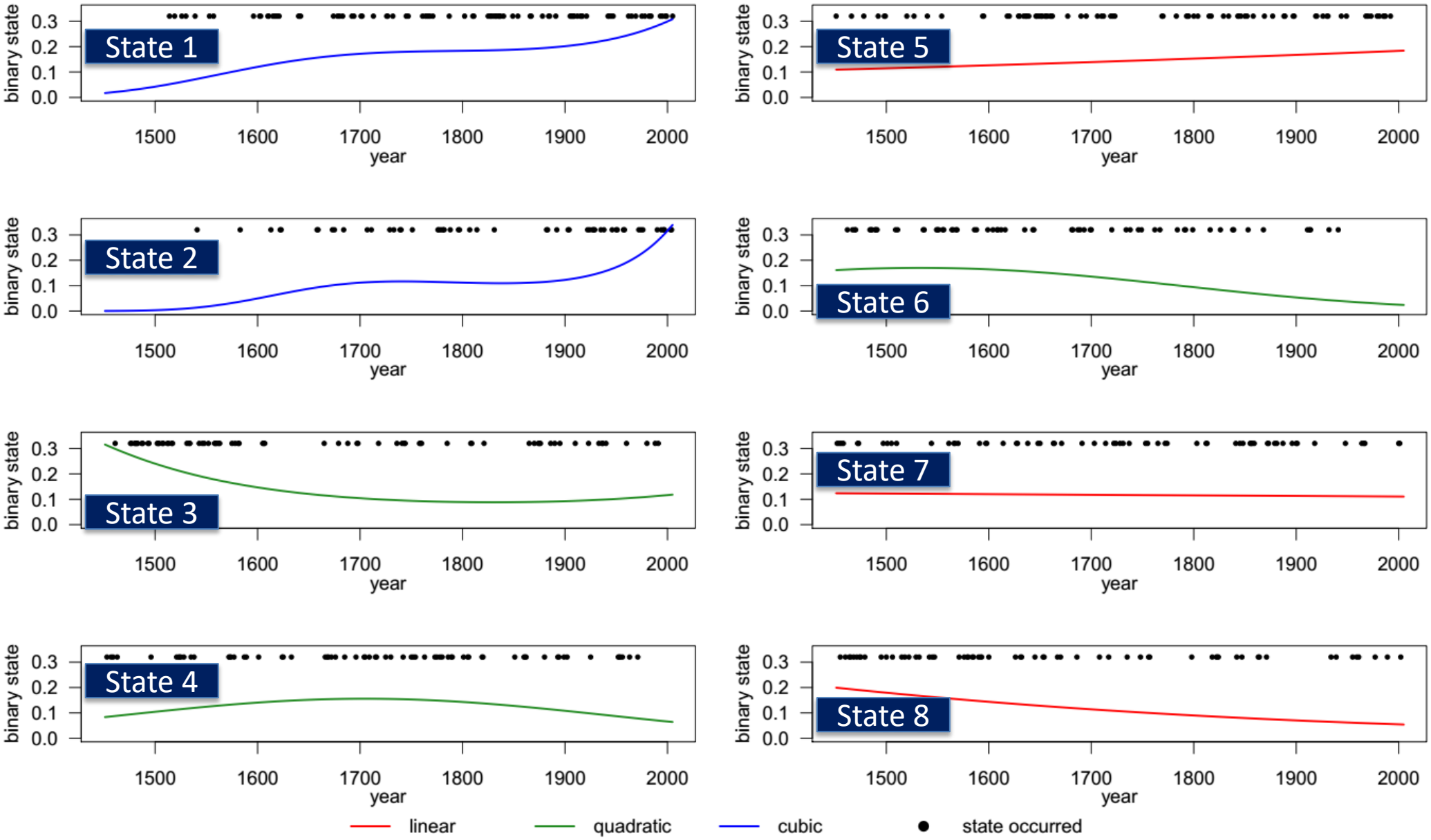
# Trends in the probability of each state

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