Introduction to space-time clustering

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School on Weather Regimes and Weather Types in the Tropics and Extra-tropics:
Theory and Application to Prediction of Weather and Climate

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Universität Hamburg
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clisap

KlimaCampus

Outline

- North Atlantic Jet Latitude Index

- North Atlantic Regimes

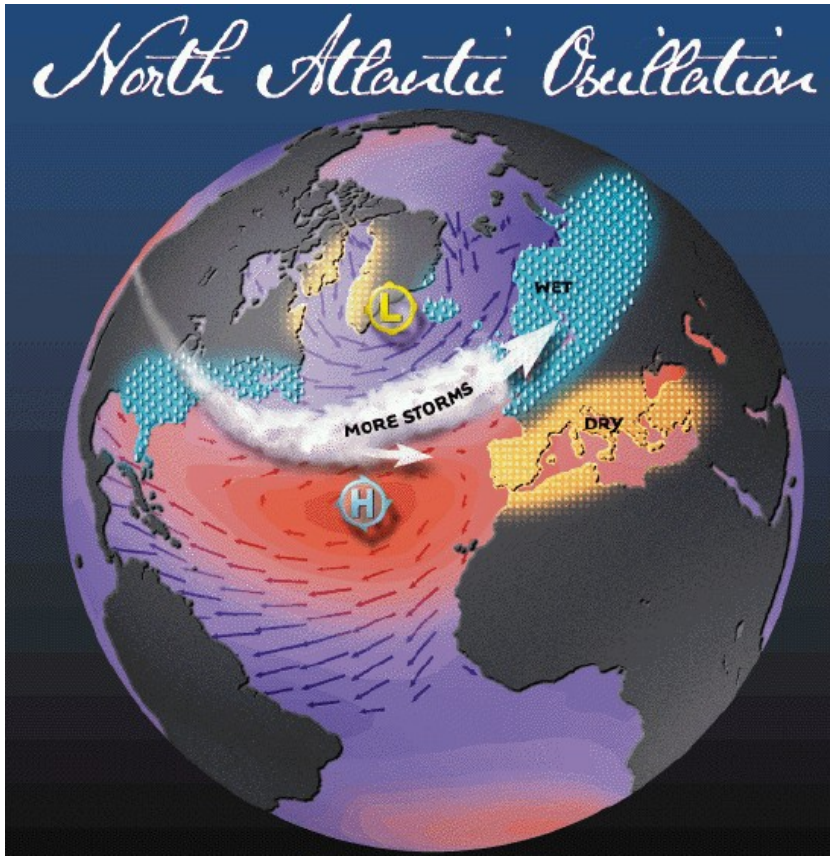
- Wave Breaking and Regimes

- Finite Element Clustering (FEM)

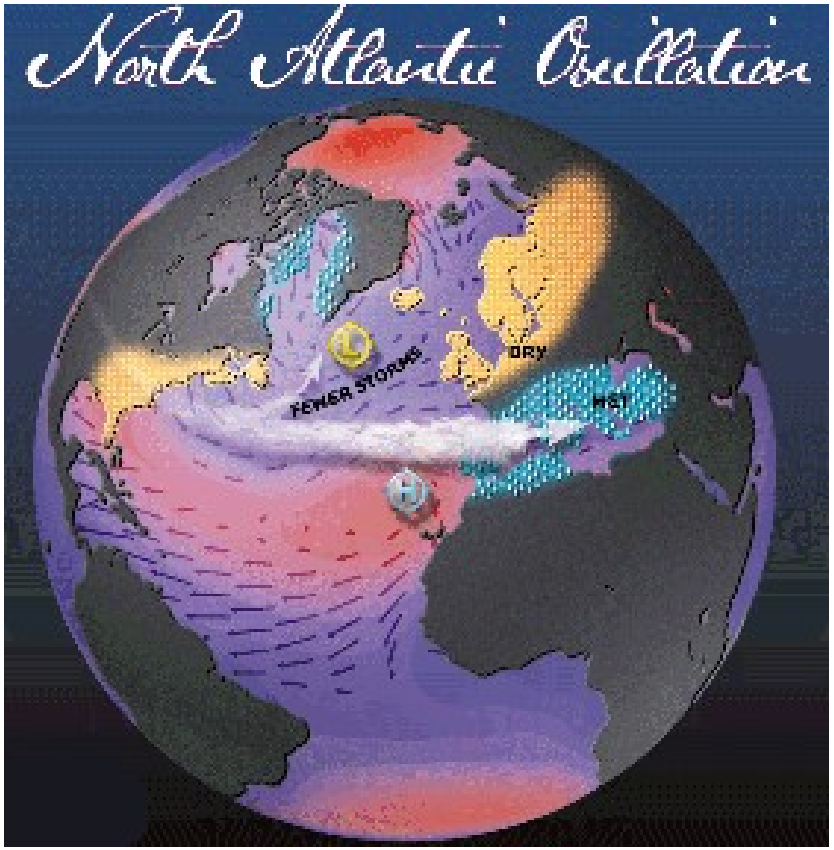
- FEM of Northern Hemisphere Circulation

The North Atlantic Oscillation

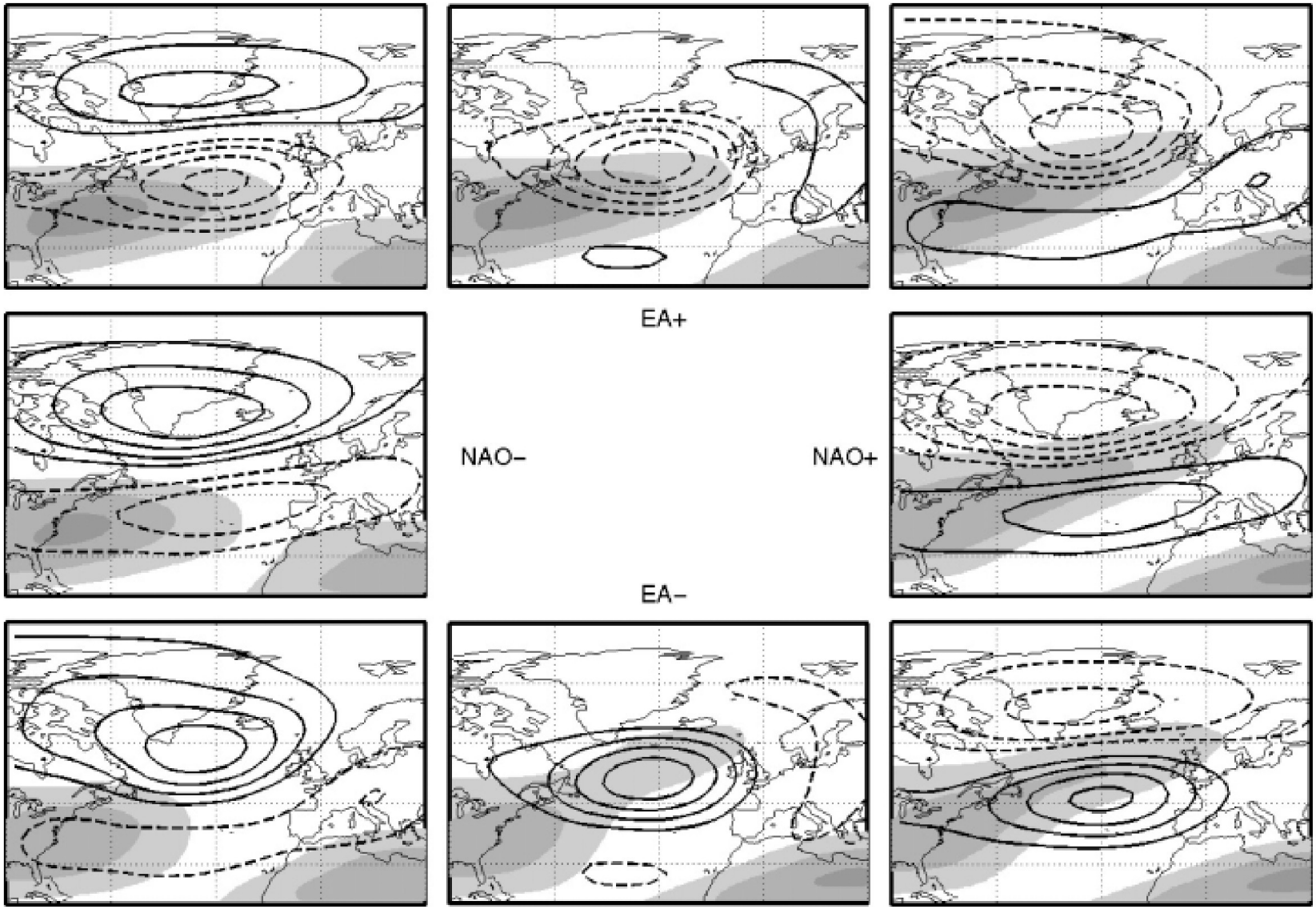
NAO+



NAO-

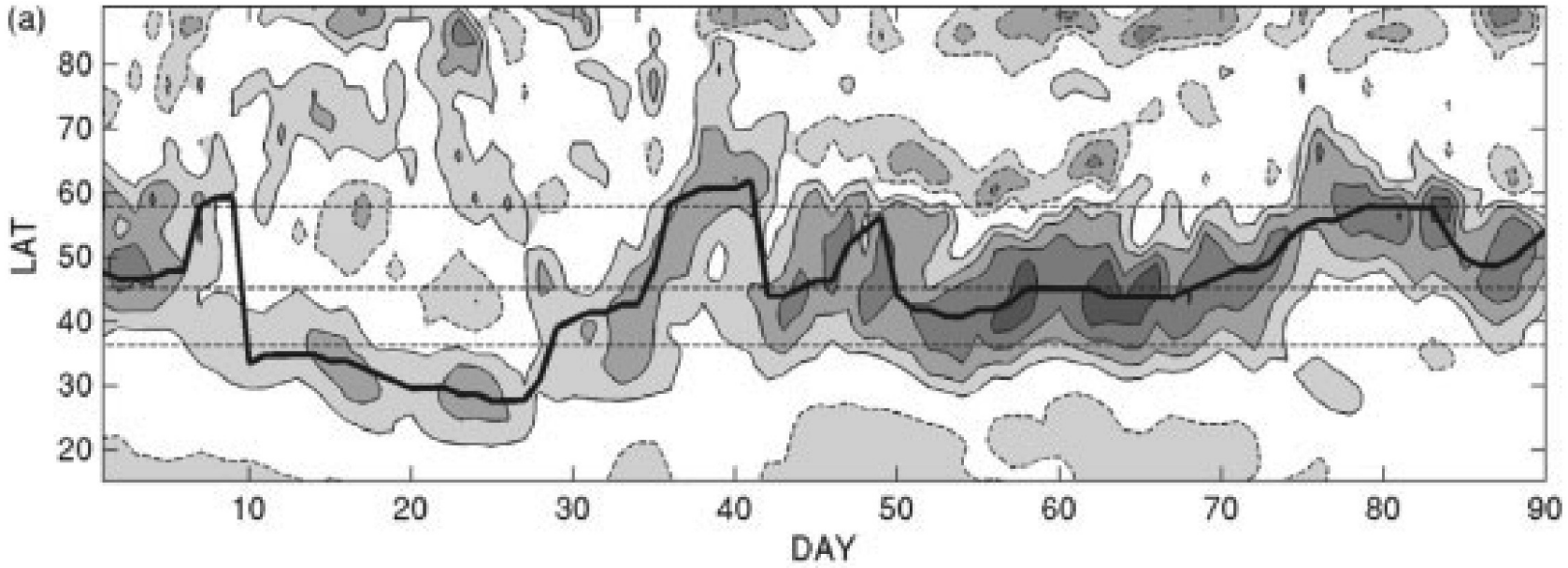


North Atlantic Climate Variability



Source: Woollings et al. 2010

Jet stream for winter season 2001/2002 (Woollings et al. 2010)



Jet Latitude Index

- Daily ERA-40 wind data (1 Dec 1957–28 Feb 2002)

1. Zonal wind is averaged over the levels 925, 850, 775 and 700 hPa.
2. The resulting field is zonally averaged over a longitudinal sector (0–60° W for the North Atlantic).
3. The field is then 10 day low-pass filtered.
4. The maximum westerly wind speed of the resulting profile is then identified and this is defined as the jet speed. The jet latitude is defined as the latitude at which this maximum is found.

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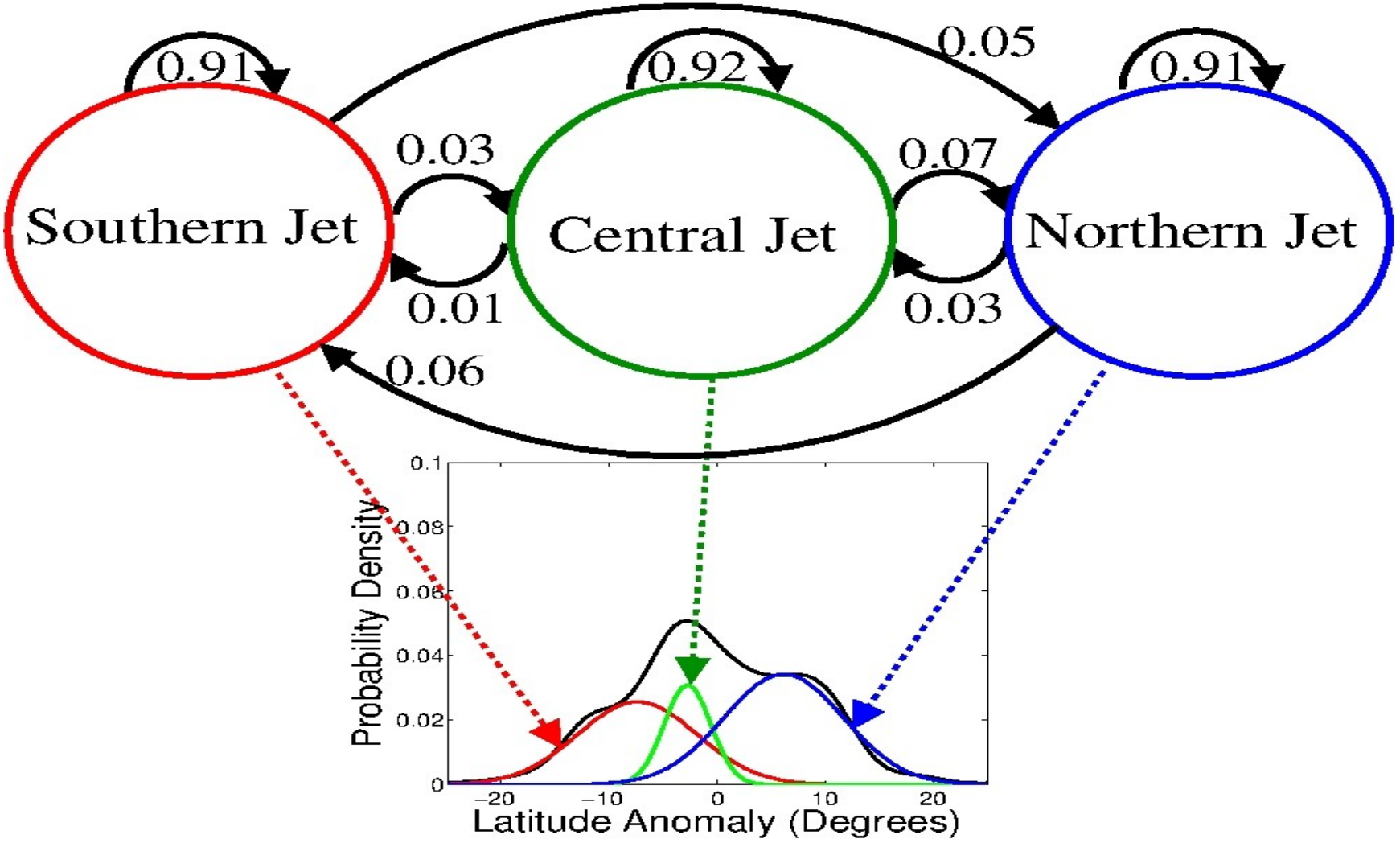
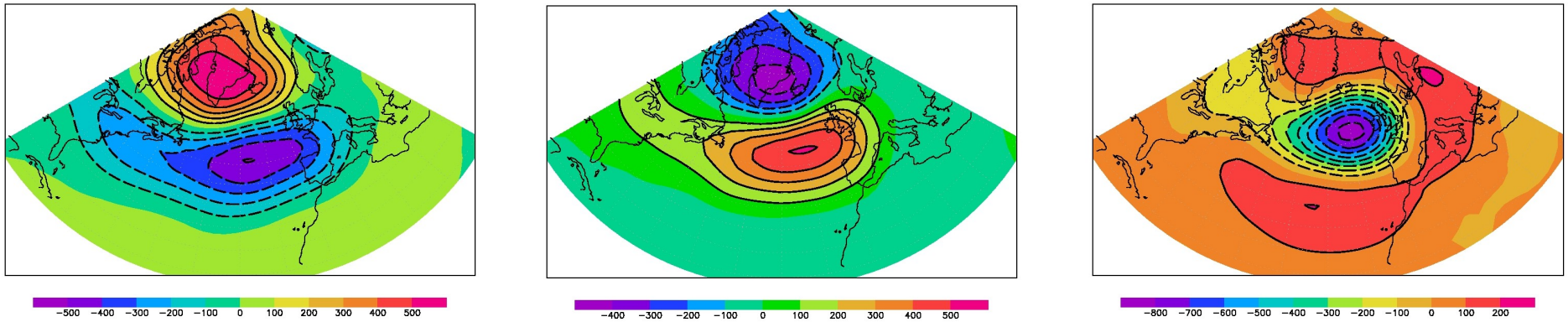
Hidden Markov Model Analysis



Franzke, Woollings and Martius, JAS 2011.

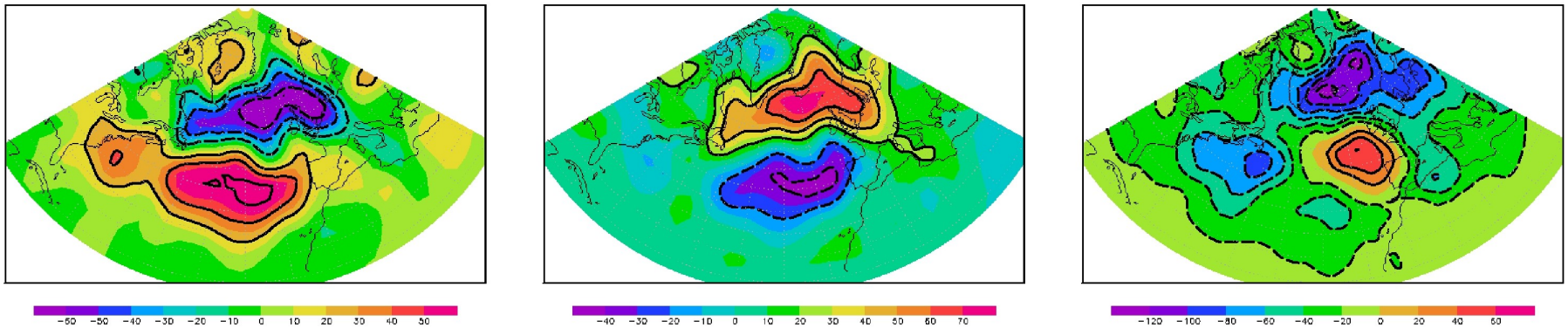
Regime States

Southern Jet | Northern Jet | Central Jet



Anomalous 500 hPa Geopotential Height (Annual cycle subtracted)

Mixture of NAO and EA teleconnection Patterns (Woollings et al. 2010)

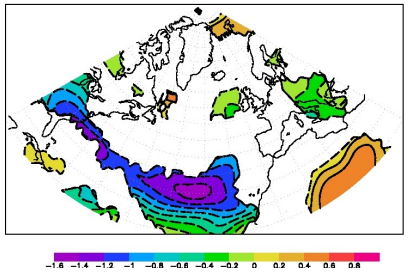


Standard deviation of 500 hPa Geopotential Height (Annual cycle subtracted)

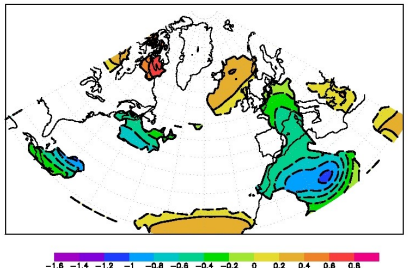
Extreme Events

Skewness

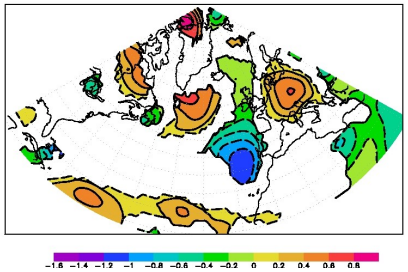
a) Southern Jet



b) Northern Jet

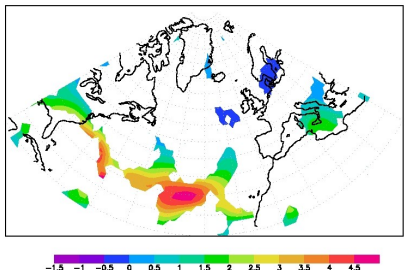


c) Central Jet

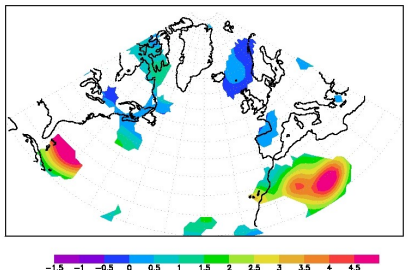


Kurtosis

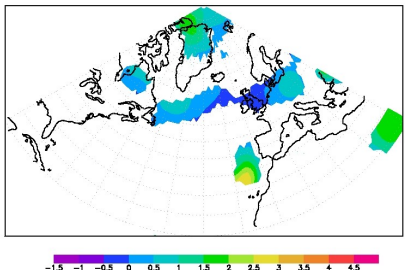
a) Southern Jet



b) Northern Jet

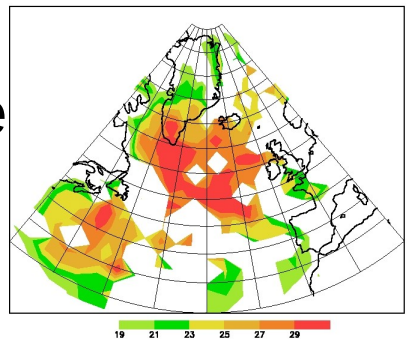


c) Central Jet

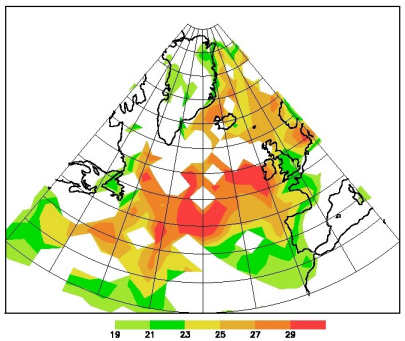


Extreme Surface Wind Speeds

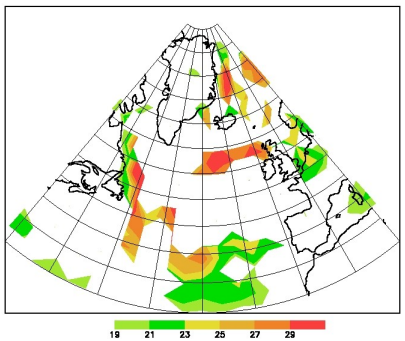
a) Southern Jet



b) Northern Jet

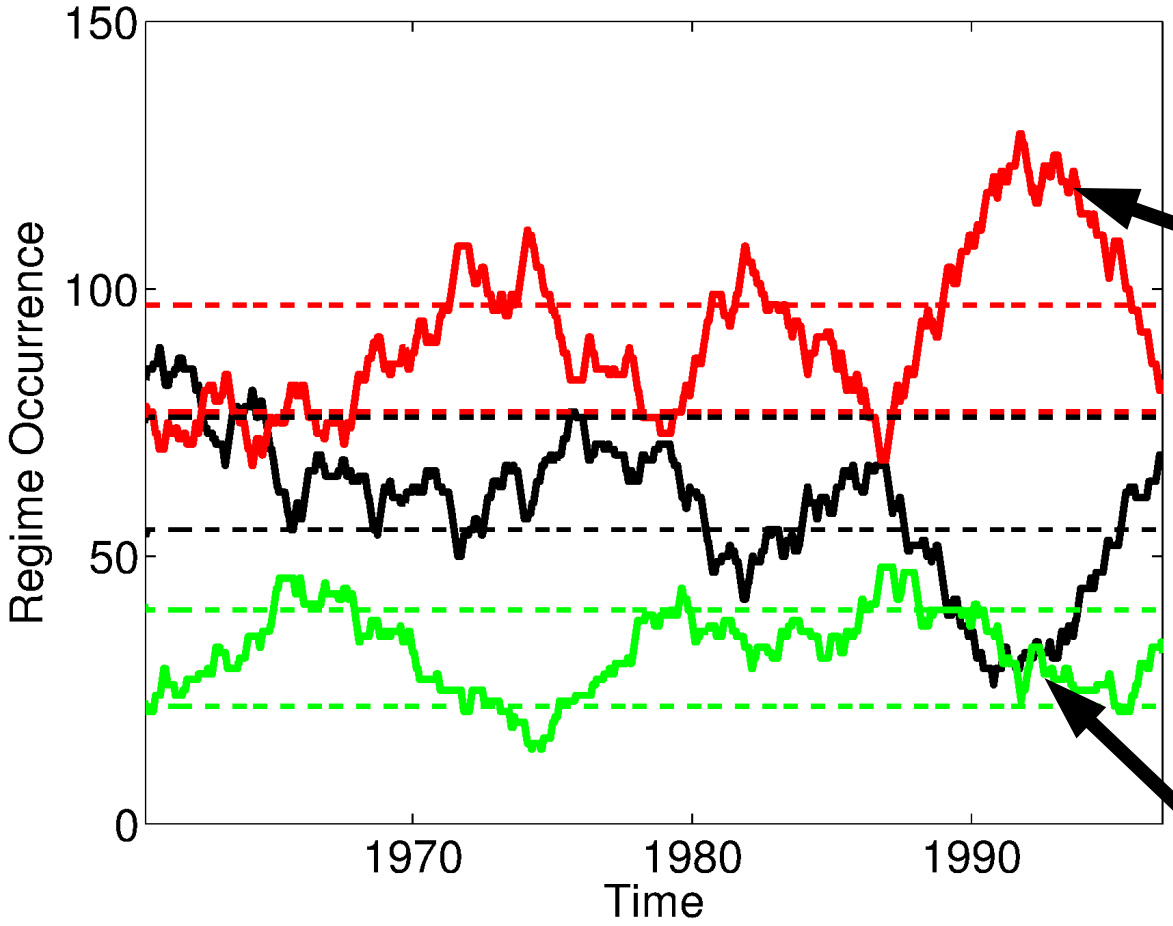


c) Central Jet



Franzke, 2013: Phil. Trans.

Interannual-Decadal Regime Variability



External factors?

Impact on Extreme Events

Red: Southern Jet Regime
Black: Northern Jet Regime
Green: Central Jet Regime

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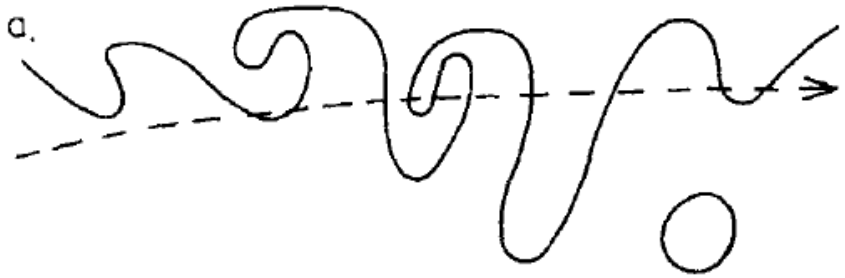
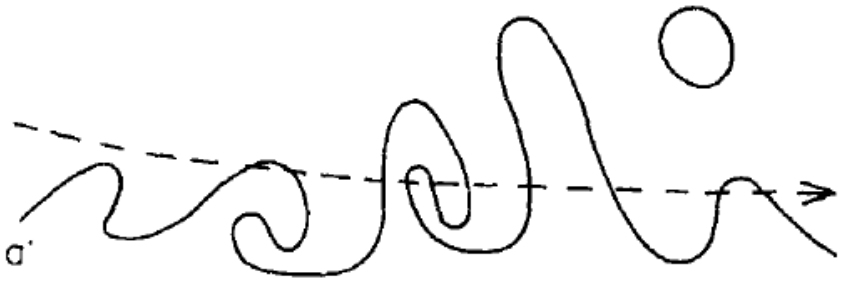
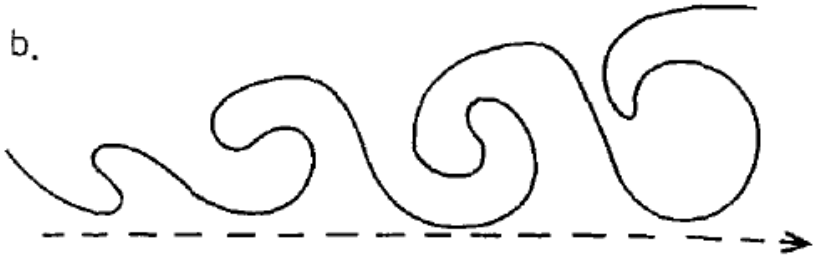
LC1 (Anticyclonic)



P1

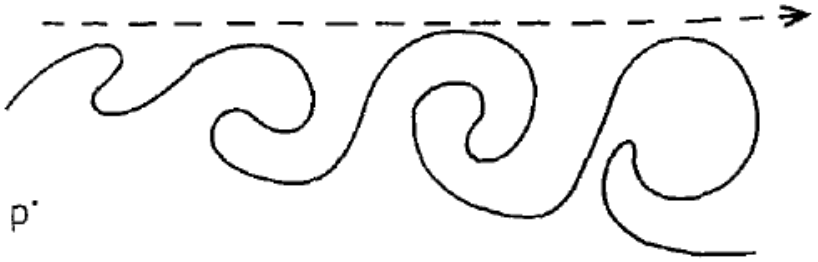


LC2 (Cyclonic)



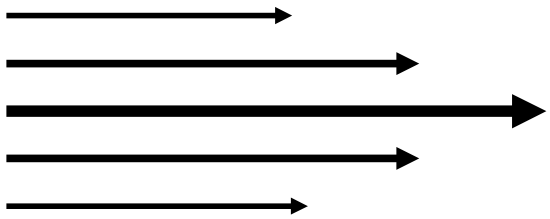
Thorncroft et al. 1993

P2



Peters and Waugh 96

Side of jet determines shear, and so also the direction of wave-breaking

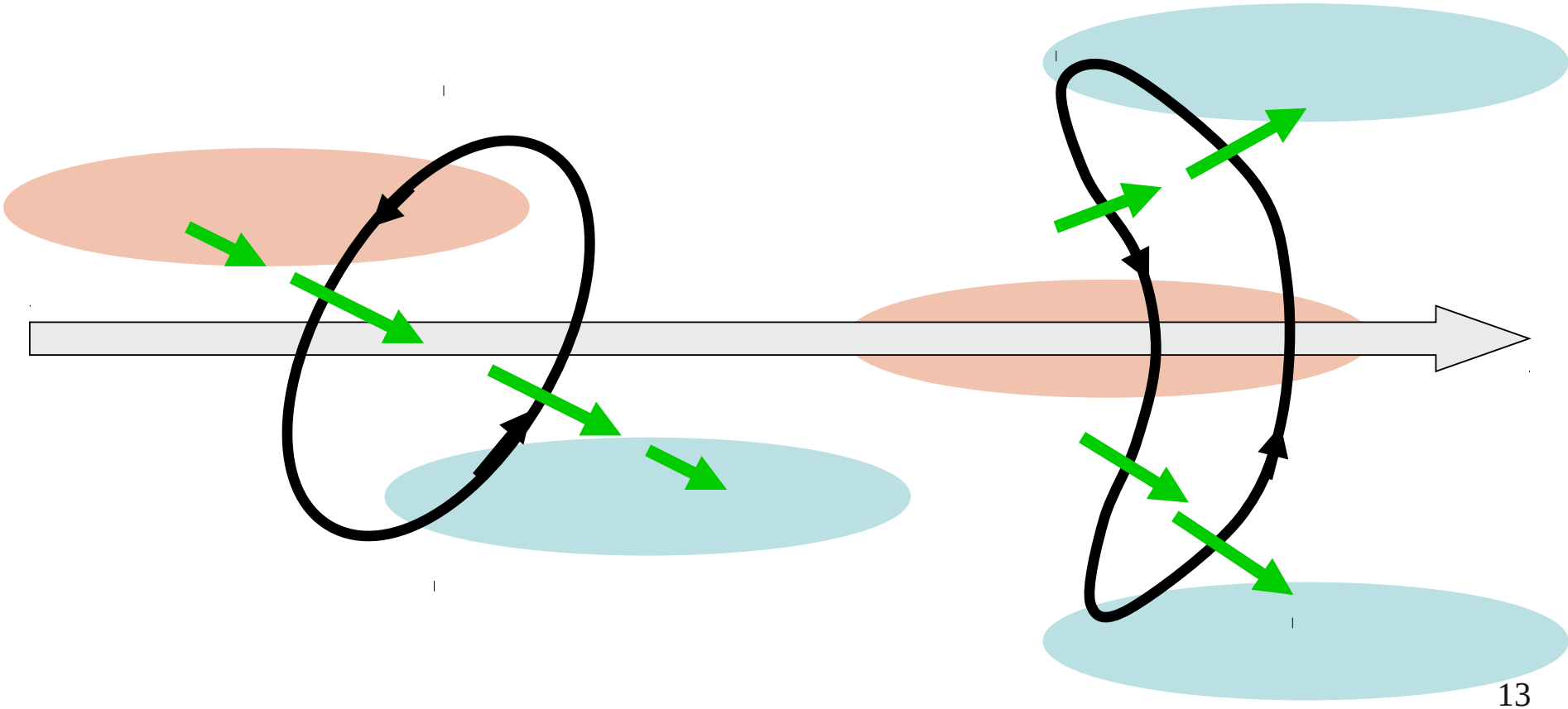


E Vectors ~ wave activity flux

$$E=\left(\overline{v'^2-u'^2} \quad \overline{-u'v'}\right)$$

Divergence : Accelerates westerlies

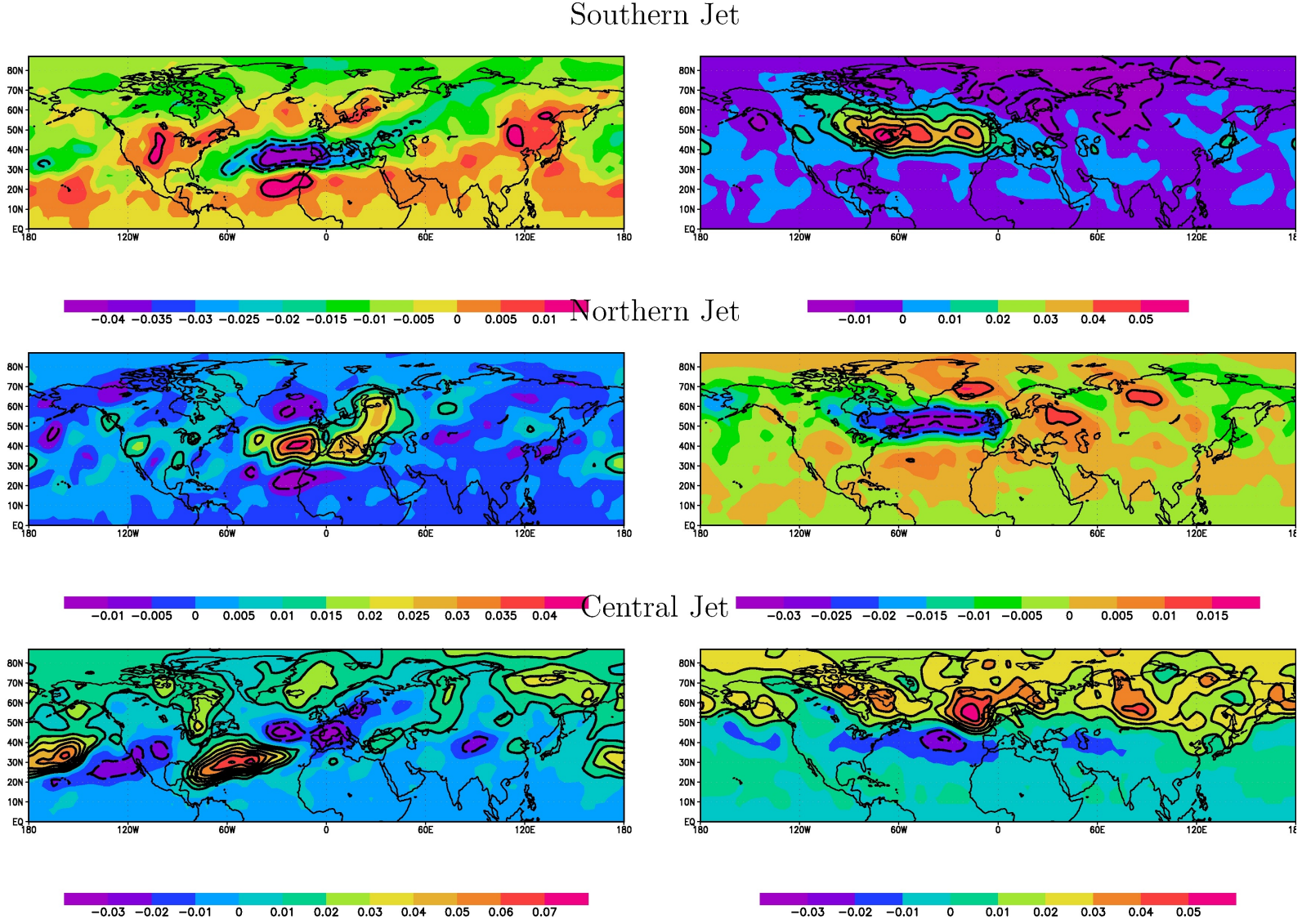
Convergence : Decelerates westerlies



Hoskins et al 83

Regime States

a) LC1 (Anticyclonic Wave Breaking) b) LC2 (Cyclonic Wave breaking)



Rossby Wave Breaking; ECMWF reanalysis

Summary of HMM clustering

- 3 Persistent Regime States in North Atlantic Region

- Large Interannual and Decadal Regime Variability

- Wave Breaking Causes Persistent Regimes (Eddy-Mean Flow Feedback)

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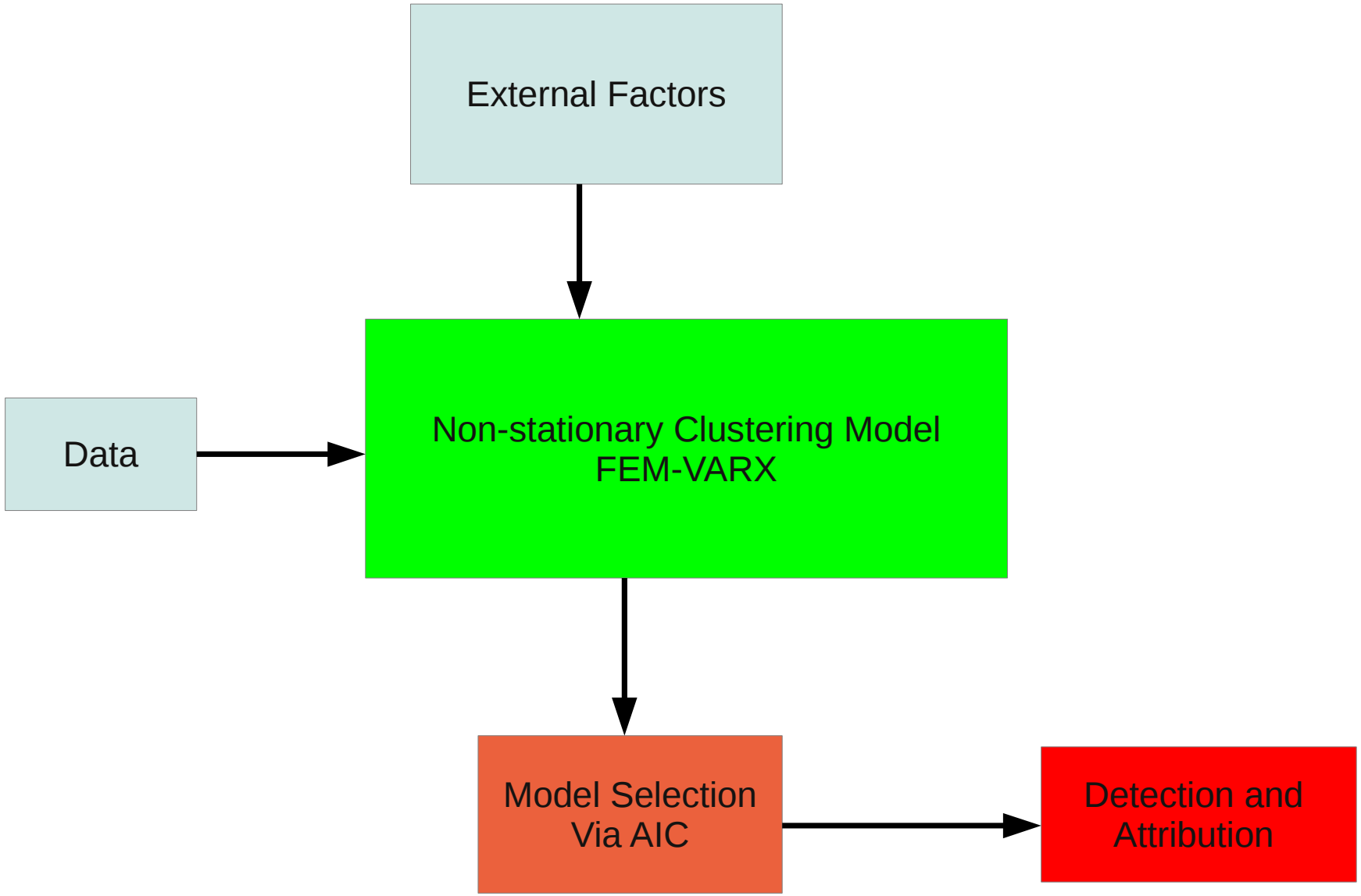
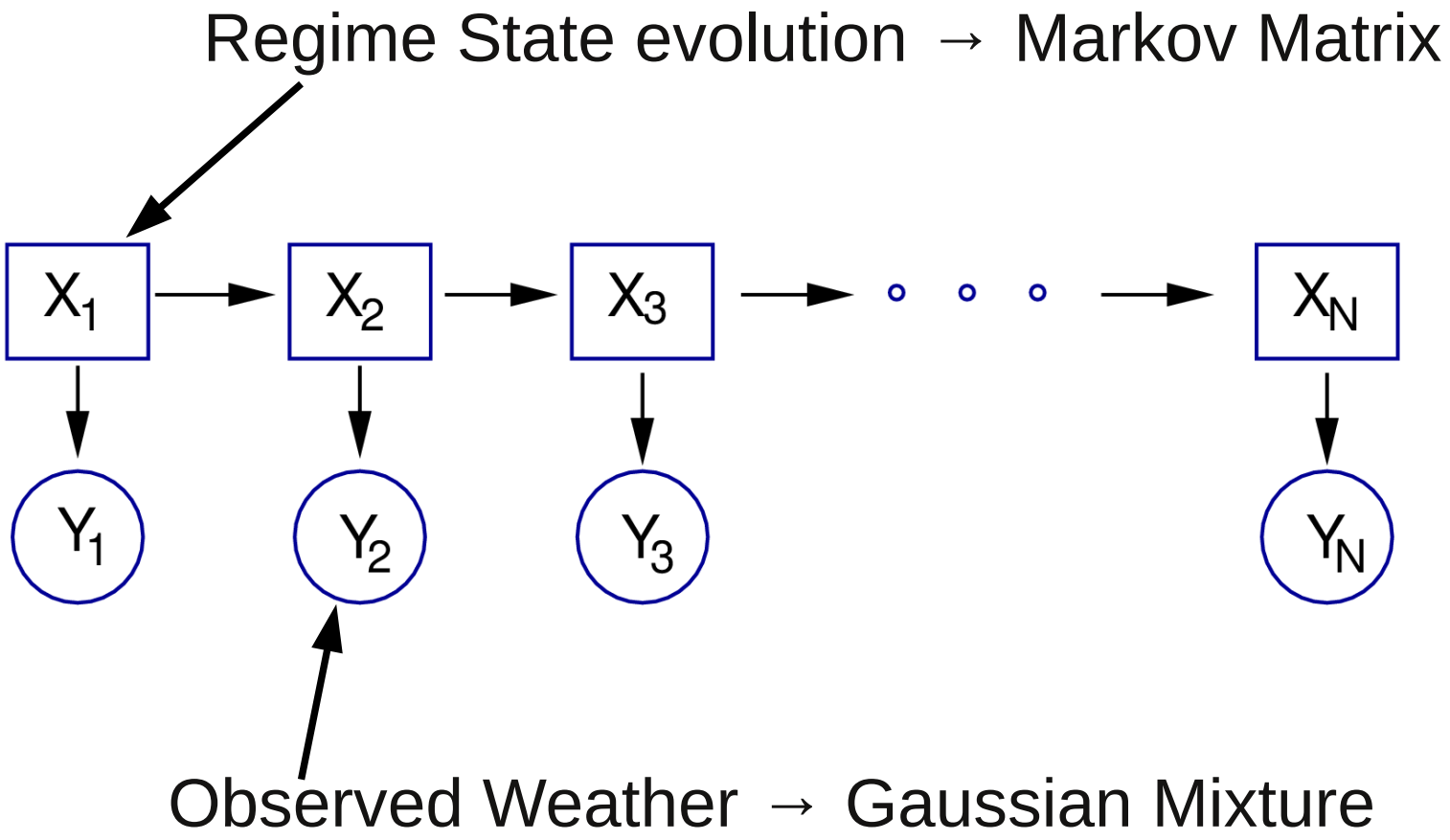
Non-Stationary Clustering



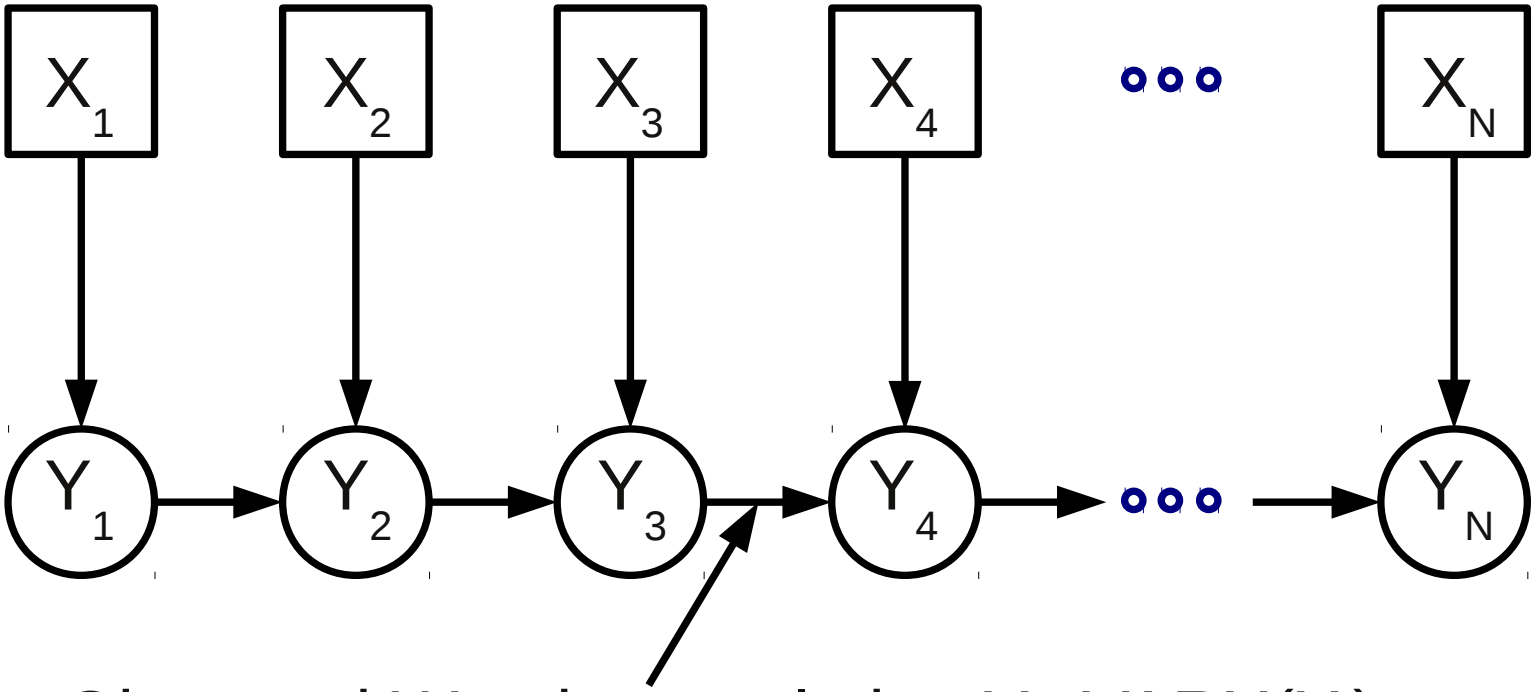
Hidden Markov Model



Non-Stationary Clustering

FEM-VARX (Horenko 2010)

Geometric description of regime evolution X_t

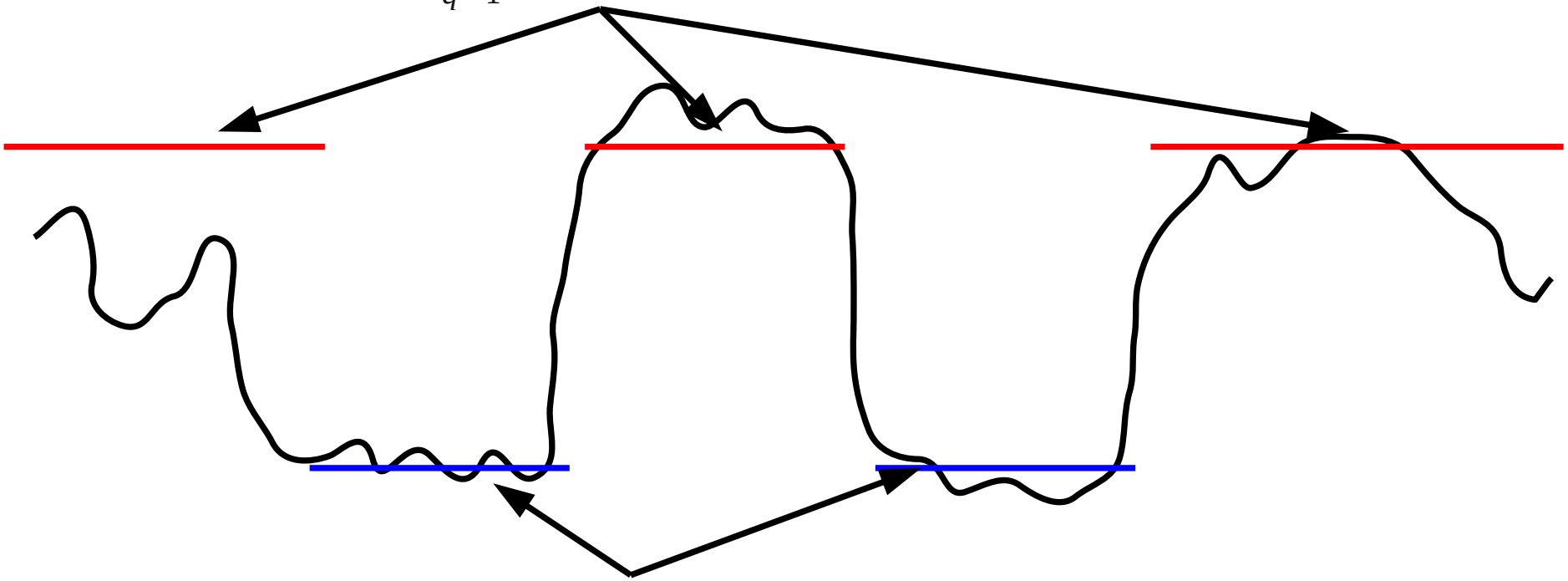


Observed Weather evolution Y_t: VARX(X_t)

$$Y(t) = \mu_X + \sum_{q=1}^{m} A_{q,X} Y(t - m\tau) + B_X u(t) + C_X \varepsilon_t$$

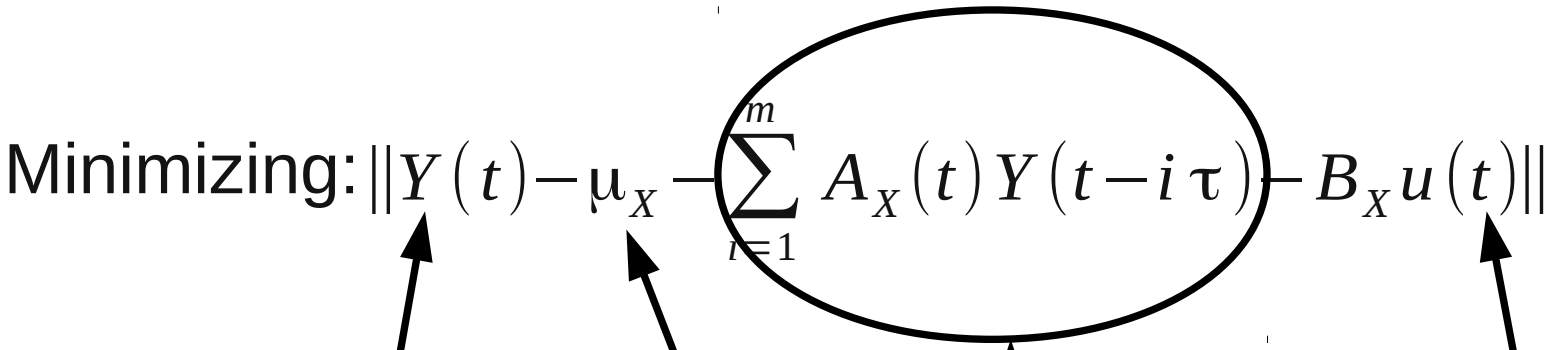
FEM-VARX Clustering

Regime 1: $Y(t)=\mu_1+\sum_{q=1}^{m} A_{q,1}Y(t-m\tau)+B_1u(t)+C_1\varepsilon_t$



Regime 2: $Y(t)=\mu_2+\sum_{q=1}^{m} A_{q,2}Y(t-m\tau)+B_2u(t)+C_2\varepsilon_t$

FEM-VARX Clustering



Observed Data
N Dimensional

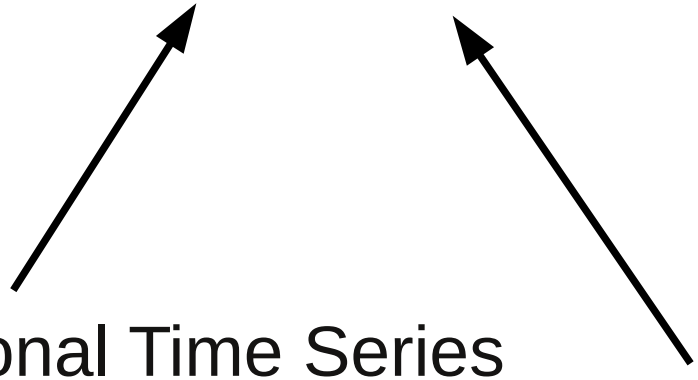
Vector AR(p) Process

Mean (dependent on regime state)

External Forcings:
(CO2, Aerosols, etc)

FEM-VARX Clustering

Model distance functional: $g\left(Y\left(t\right),\theta\left(t\right)\right)$



N Dimensional Time Series

Model Parameters

Model Affiliation: $\gamma_i\left(t\right)$

Minimizing average cluster functional: $\sum_{i=1}^{K}\sum_{t=1}^{T}\gamma_i\left(t\right)g\left(Y\left(t\right),\theta_i\right)$

FEM-VARX Clustering

1) Minimization is solved by adaptive Finite Element technique (Horenko 2010)

2) Model Order selection via Akaike Information Criterion (AIC): Number of states and memory depth

$$AIC = -2 \log L_{max} + 2M$$

L_{max}: Maximum likelihood

M: Number of model parameters

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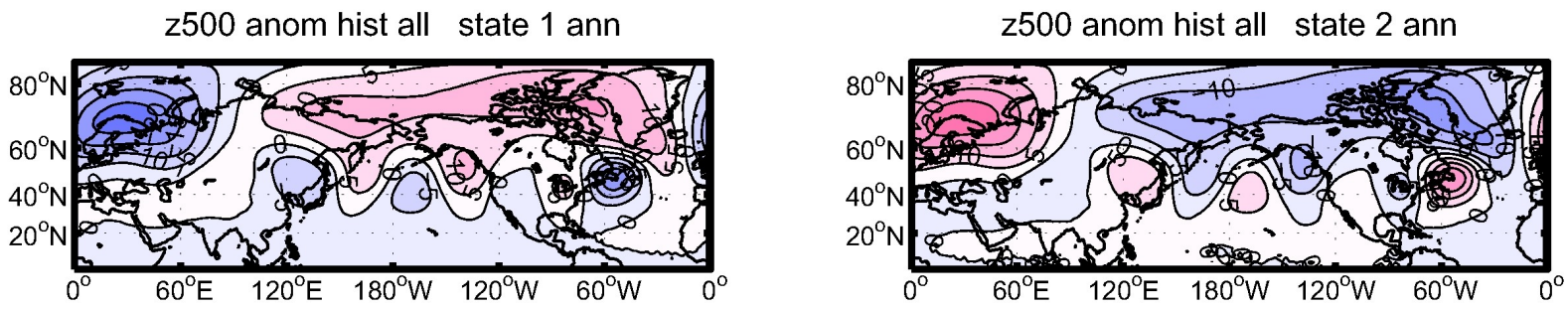
FEM-VARX Clustering of NH Circulation

Data: - Daily 500 hPa geopotential height

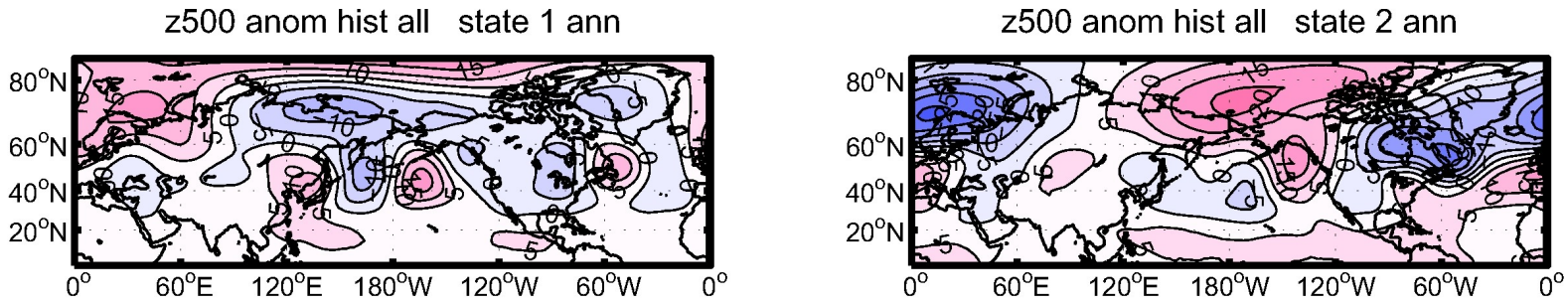
- 20^{th} Century Reanalysis: 1871-2009
- NCEP-NCAR Reanalysis: 1948-2009

- Prior to clustering: EOF decomposition and using leading 20 EOFs

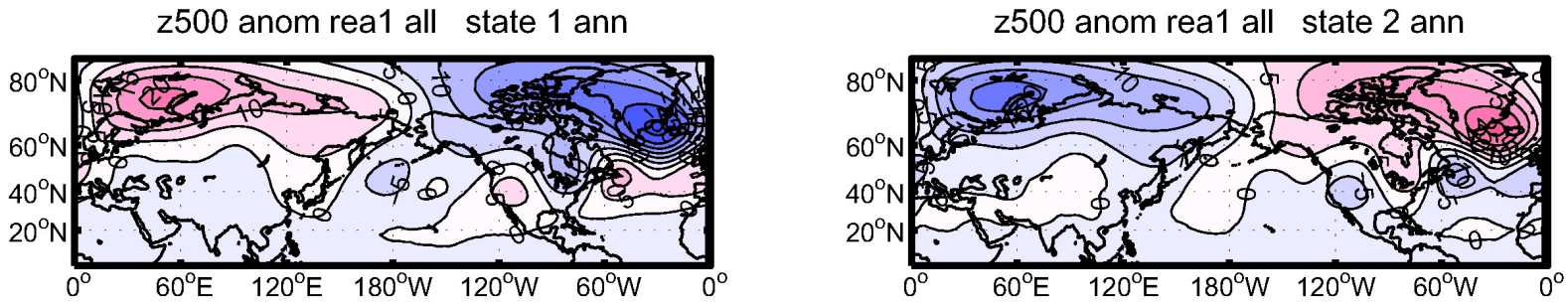
FEM-VARX Clustering of NH



(a) 20CR 1871–2009



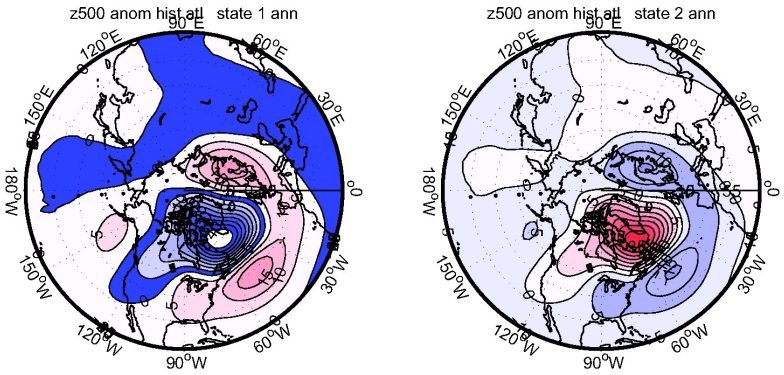
(b) 20CR 1948–2009



(c) NNR1 1948–2009

Circumpolar Wave Guide (Branstator 2002) and Arctic Oscillation

FEM-VARX Clustering of Atlantic Region



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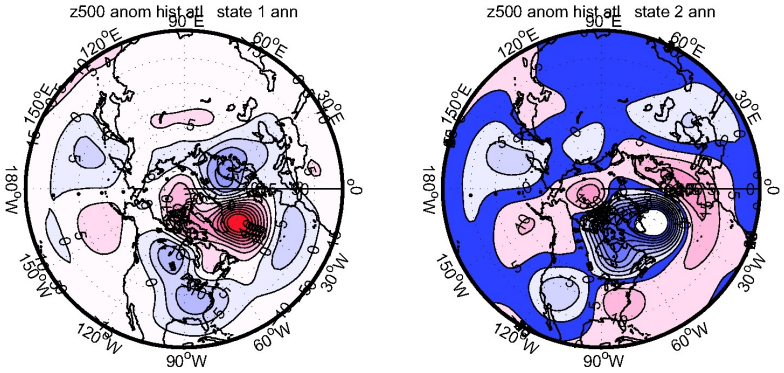

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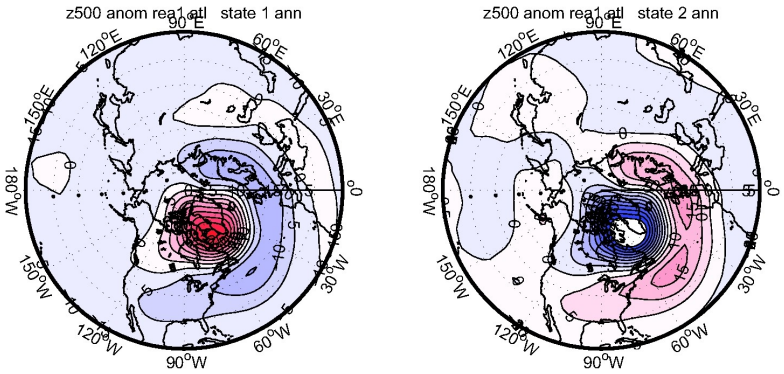
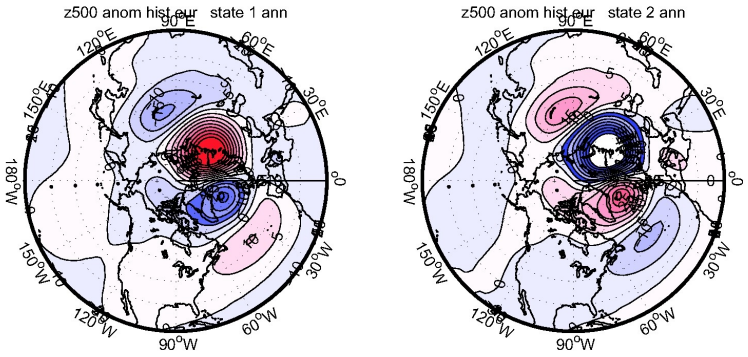


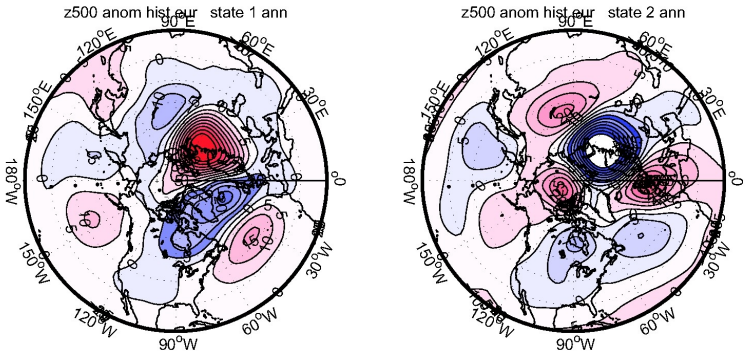
(c) NNR1 1948–2009

North Atlantic Oscillation (NAO)

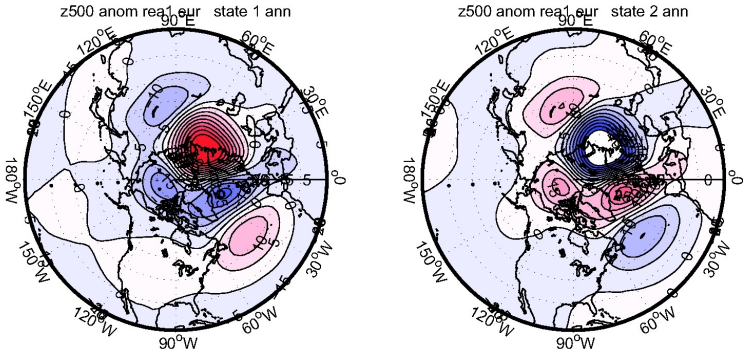
FEM-VARX Clustering of European Region



(a) 20CR 1871–2009



(b) 20CR 1948–2009



(c) NNR1 1948–2009

Scandinavian Blocking

Summary

- Non-stationary FEM-VARX clustering with external factors

- FEM-VARX clustering models non-Markovian effects

- FEM-VARX clustering finds many well known NH teleconnection patterns

- FEM-VARX clustering allows attribution of regime changes (My talk next Tuesday)

References

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- O'Kane et al. 2013: Changes in the metastability of the midlatitude Southern Hemispheric circulation and the utility of nonstationary cluster analysis and split-flow blocking indices as diagnostic tools. J. Atmos. Sci., 70, 824-842.

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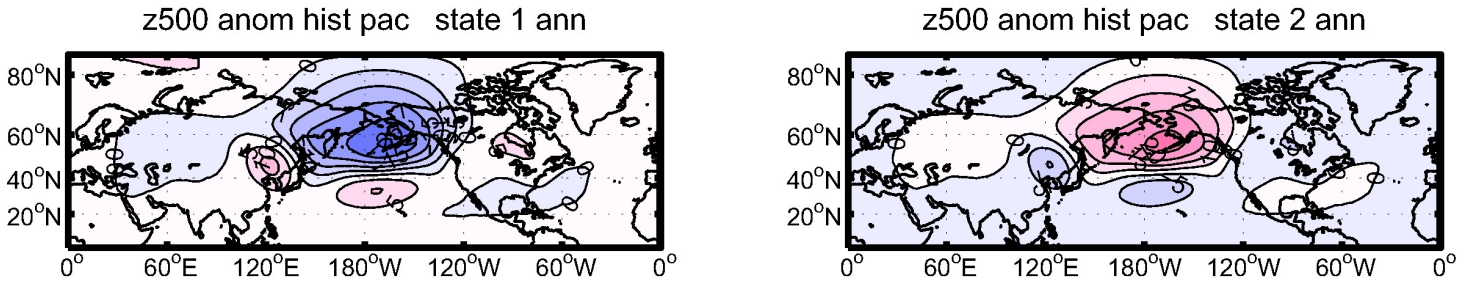
FEM-VARX Clustering of Pacific Region



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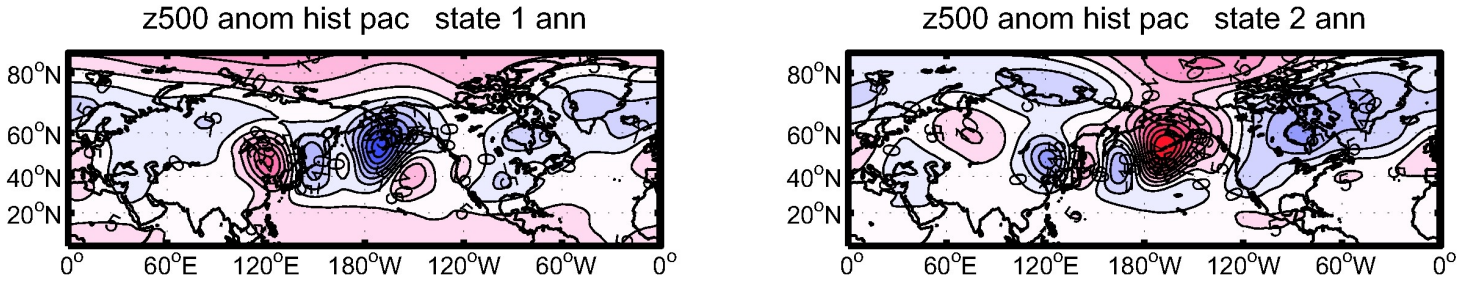

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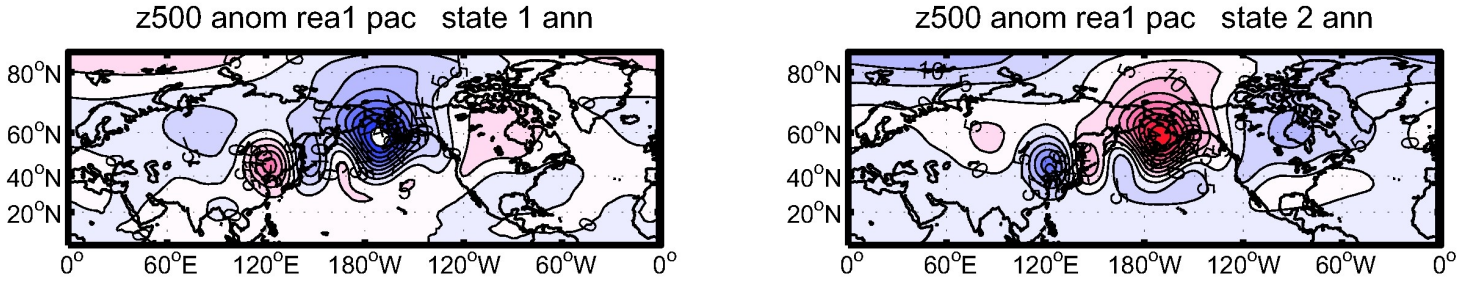
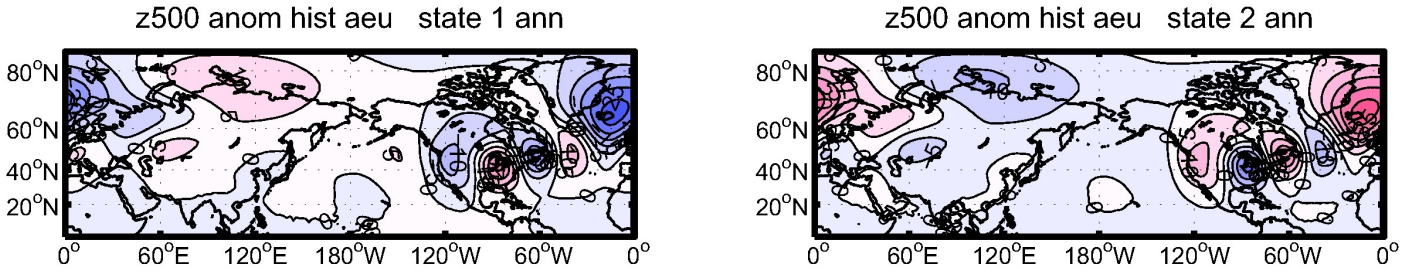


(c) NNR1 1948–2009

Pacific-North American (PNA) Pattern

FEM-VARX Clustering of Atlantic-Euro Region



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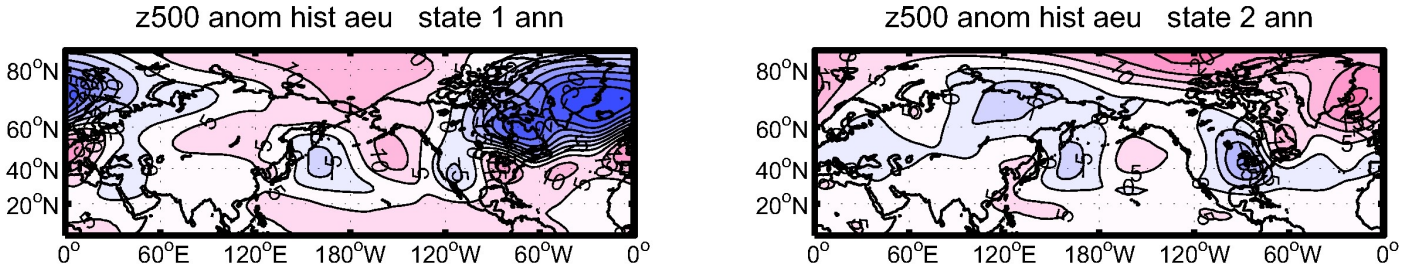
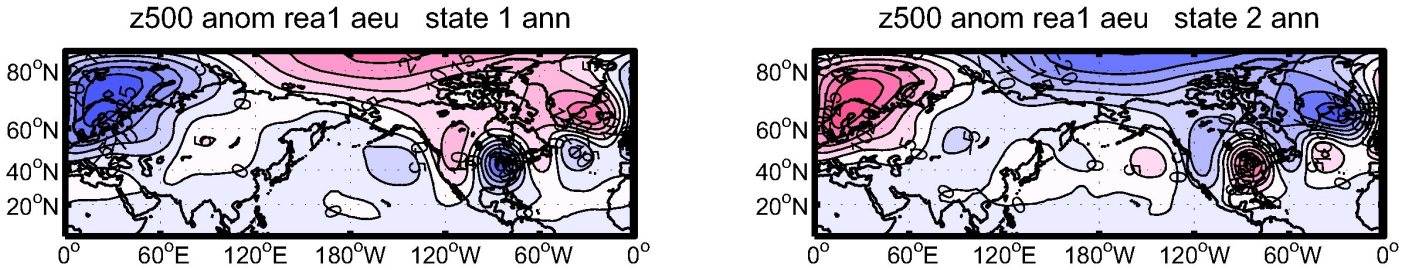


(b) 20CR 1948–2009



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Circumpolar Wave Guide