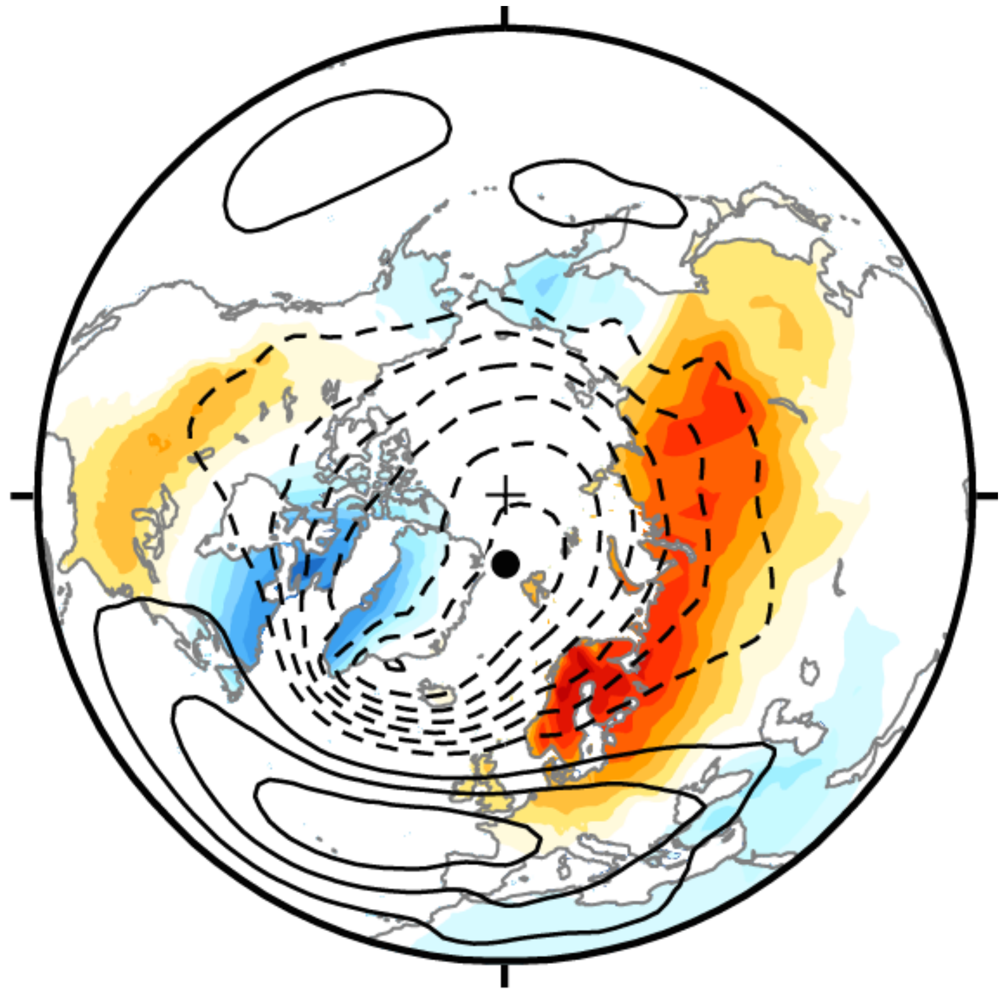
Empirical approaches to uncovering teleconnections in global climate data



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Objectives

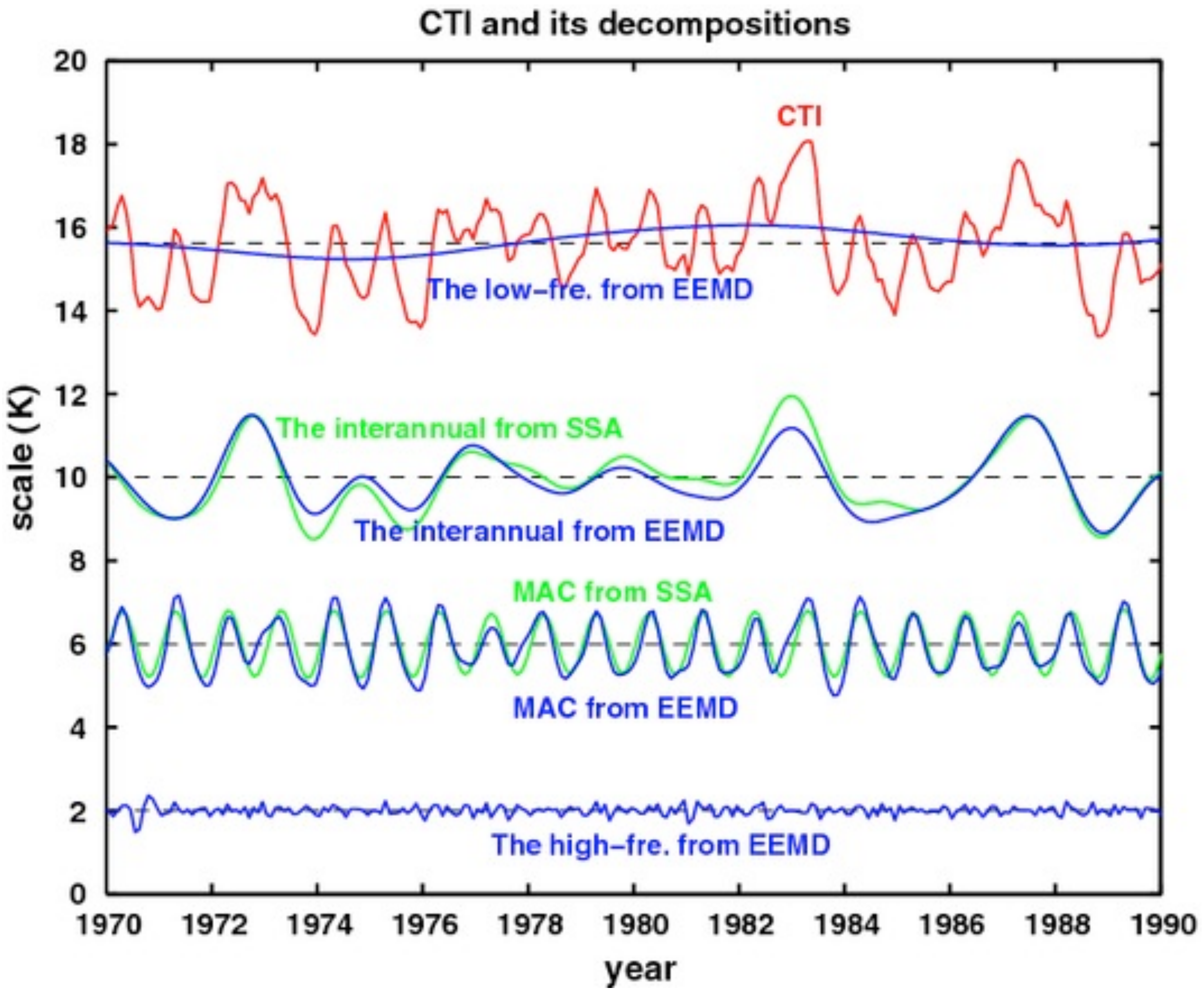
1. Introduce some **terms**, **methods**, and **conceptual models** related to atmospheric teleconnections.

2. Argue that these methods and models can be used to assess the **robustness** of atmospheric teleconnections.

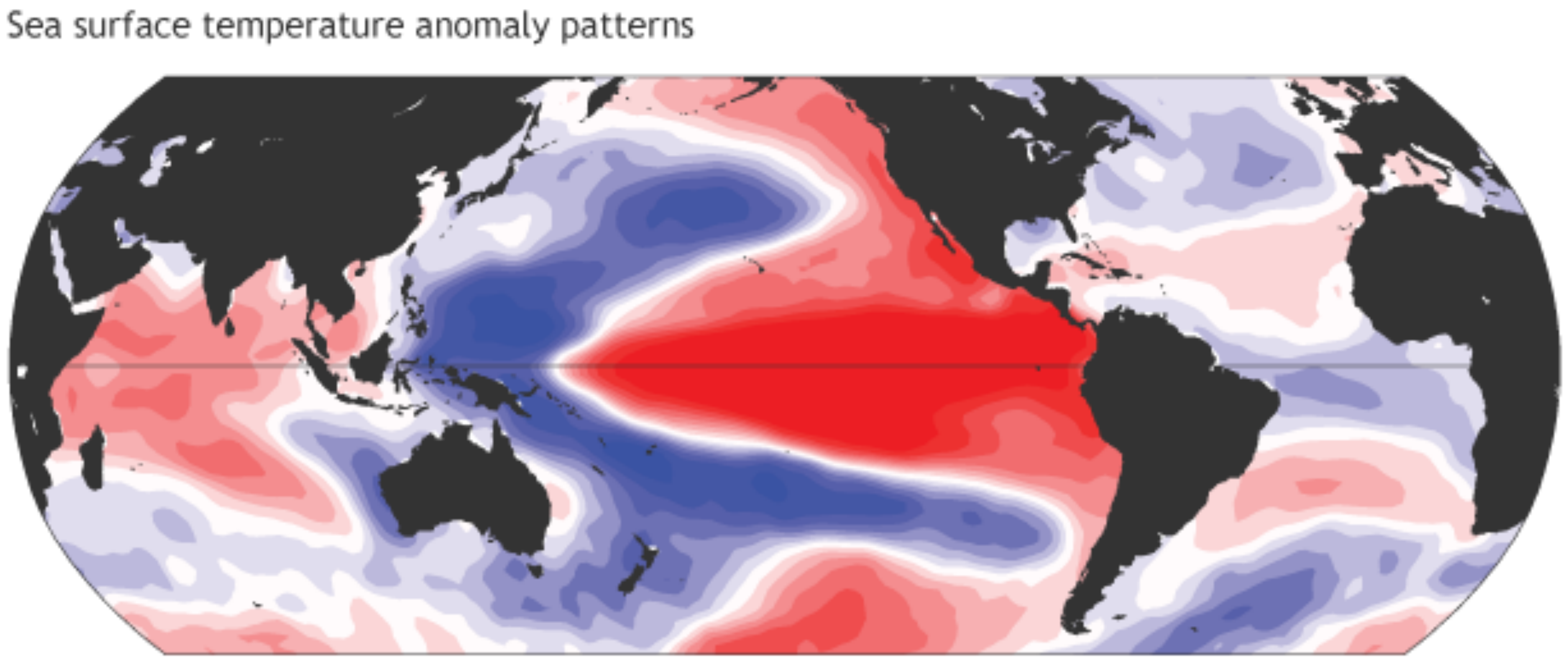
3. Discuss some **physical mechanisms** that account for the existence of atmospheric teleconnections.

Definition: Pattern of variability

A preferred structure in time or space that characterizes the variability of one or more variables



Source: Wu et al. (2008)



Source: NOAA

Method: Correlation

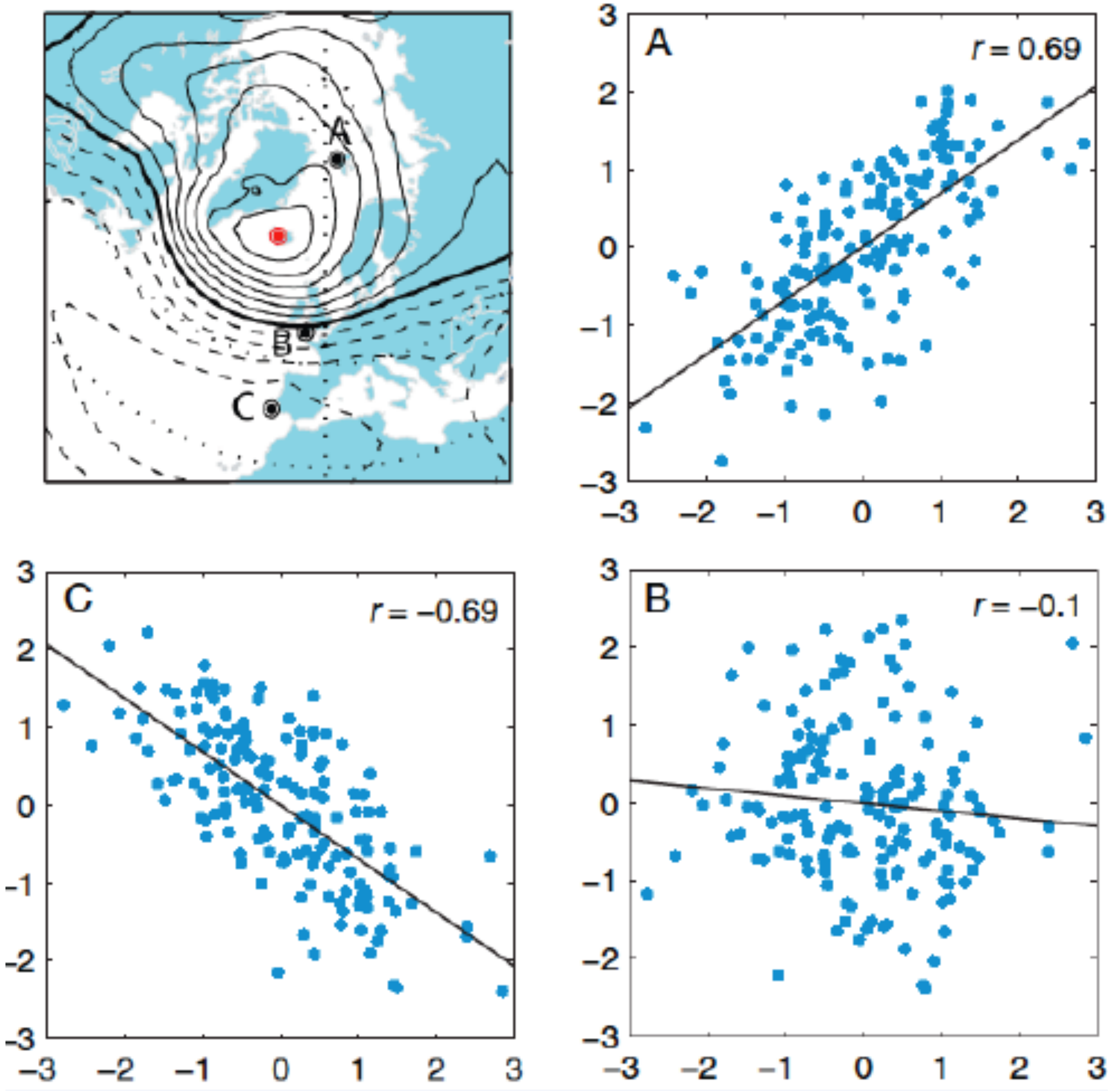
Correlation

$$r_{12} = \frac{x_1 x_2}{\sigma_{x_1} \sigma_{x_2}}$$

Correlation matrix

$$\begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix}$$

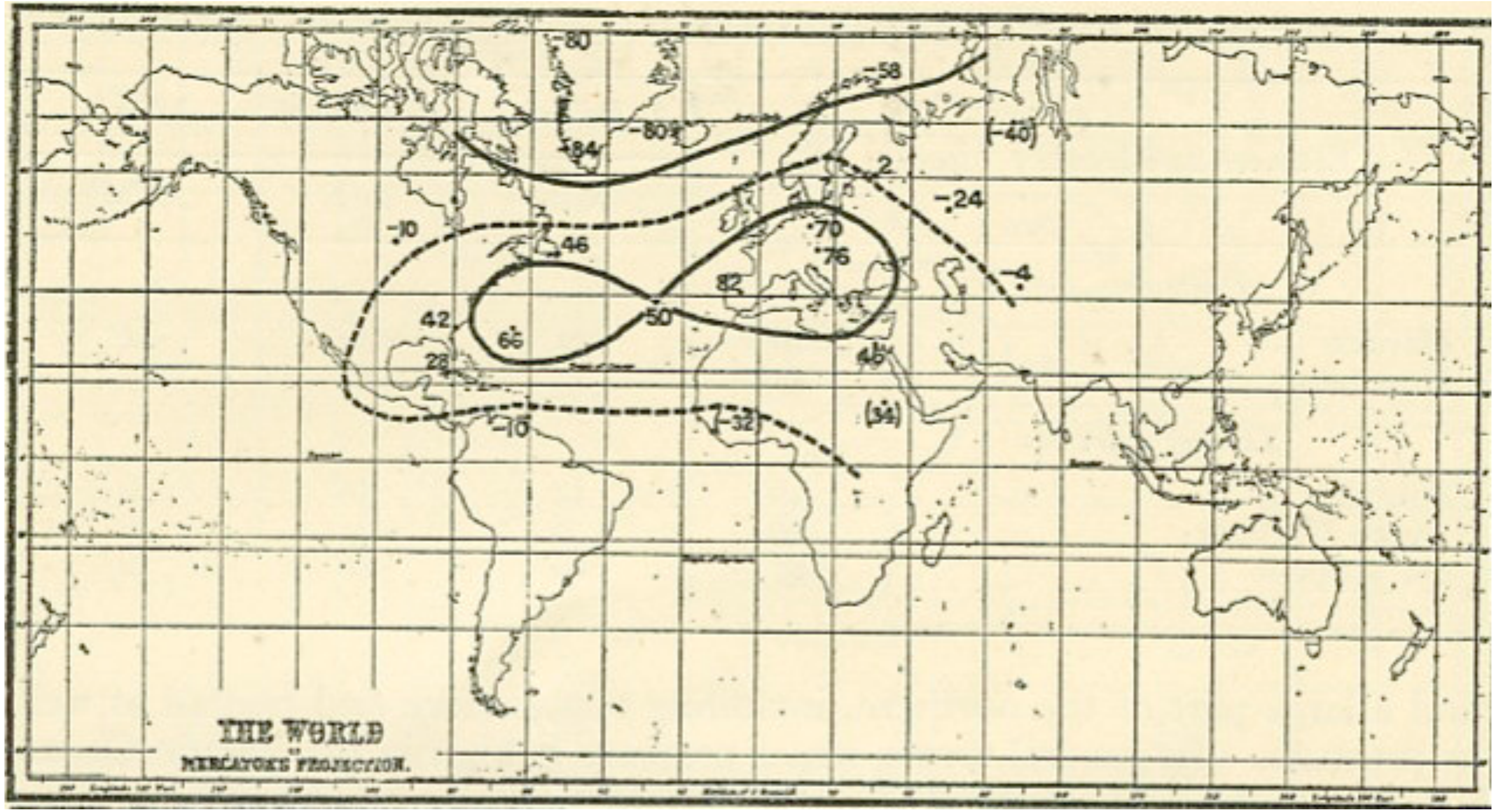
Each row or column represents a different map



Source: Wallace and Hobbs (2006) 2nd Ed.

Method: Teleconnection

The relationship of climate anomalies at distance

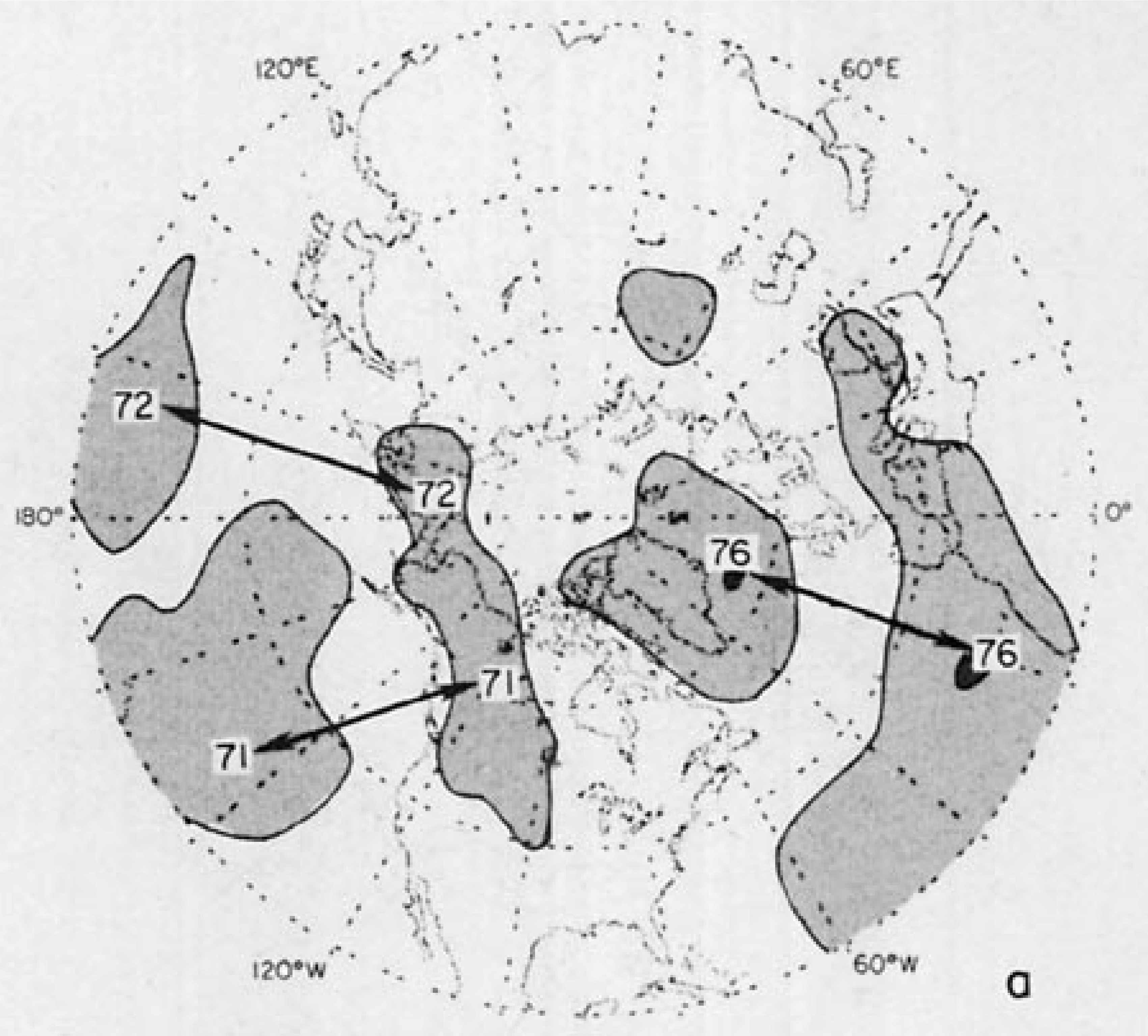


Source: Walker and Bliss (1932)

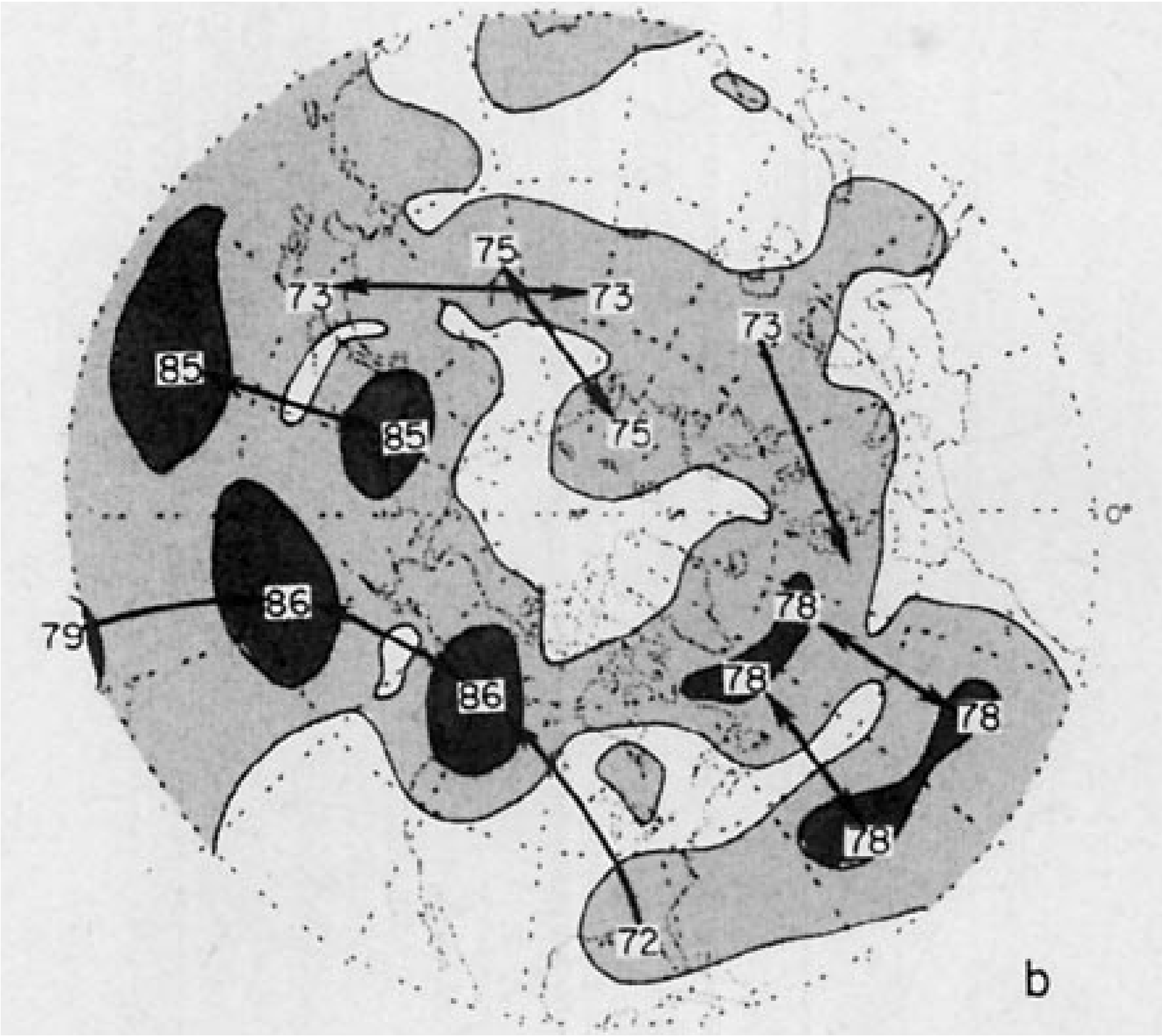
Method: "Teleconnectivity"

$$T_i = |min(r_{ij}) \text{ for all } j|$$

Sea-level pressure



500mb geopotential height



Source: Wallace and Gutzler (1981)

Method: Empirical Orthogonal Functions

$$[C]\mathbf{e} = \lambda\mathbf{e} \qquad \text{or, equivalently} \qquad ([C] - \lambda[I])\mathbf{e} = \mathbf{0}$$

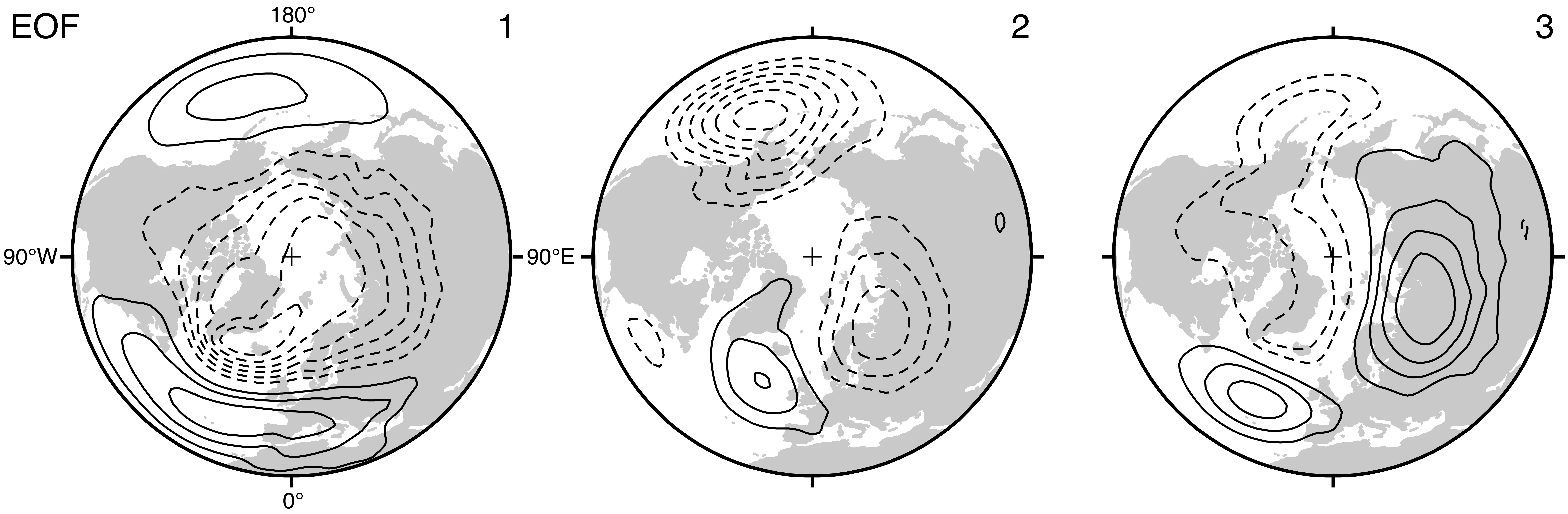
Applies the classic eigenvalue problem to 2D data via a covariance matrix. Yields:

Empirical orthogonal functions (EOFs), spatial structures	$\mathbf{e}$
Principal components (PCs), describe variation in sampling dimension	$\mathbf{u} = \mathbf{e}^{\mathrm{T}}\mathbf{x}'$
Eigenvalues, represent the amount of variance explained by each EOF	λ

By construction, EOFs and their corresponding PCs are mutually orthogonal.

Eigenvectors ranked in terms of their explained variance.

Method: Empirical Orthogonal Functions



Source: Smoliak and Wallace (2015)

SLP regression; contour interval 1 millibar per standard deviation of reference time series; positive solid, negative dashed.

Method: Empirical Orthogonal Teleconnections

Alternative to EOF analysis that relaxes orthogonality constraint in space *or* time. Yields:

Empirical orthogonal teleconnections (EOTs), spatial structures

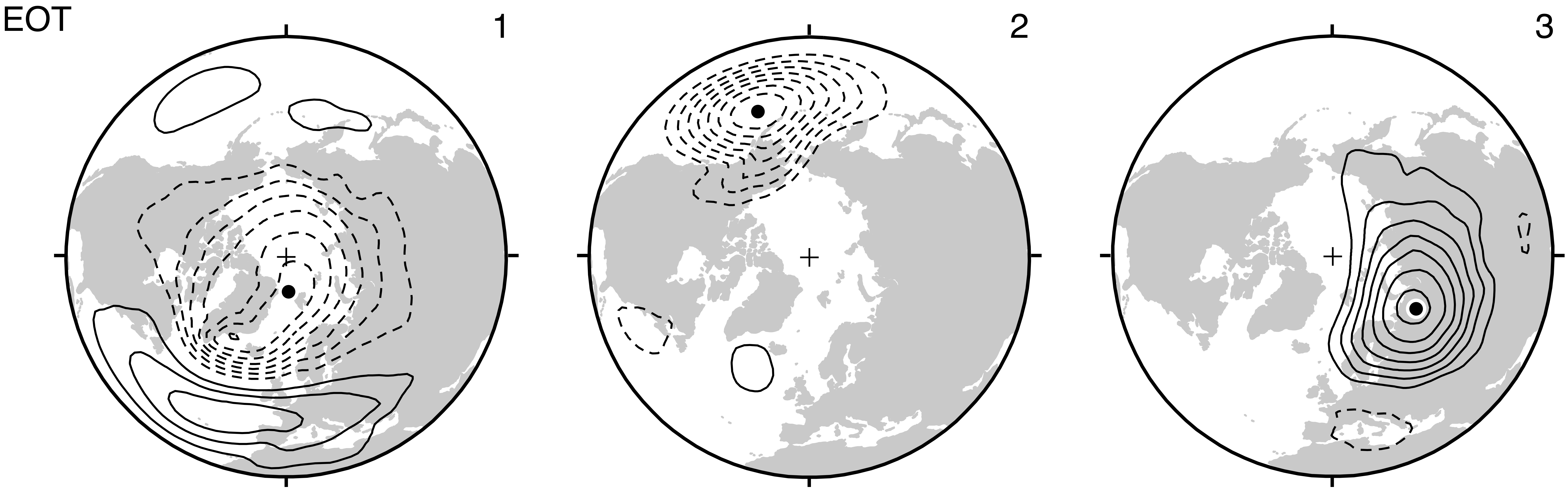
Expansion coefficients (time series), describe variation in sampling dimension

By construction, either the EOTs *or* their expansion coefficient time series are mutually orthogonal. Unlike EOFs, EOTs are only orthogonal in one dimension:

In the normal setup, the methodology seeks the point in space that explains the most variance at all other points. Takes the regression map associated with that point as the EOT pattern, and the time series at that point as the expansion coefficient time series. Subsequent EOTs are found using residual data after successive EOT time series are regressed out of the raw data.

Source: van den Dool et al. (2000)

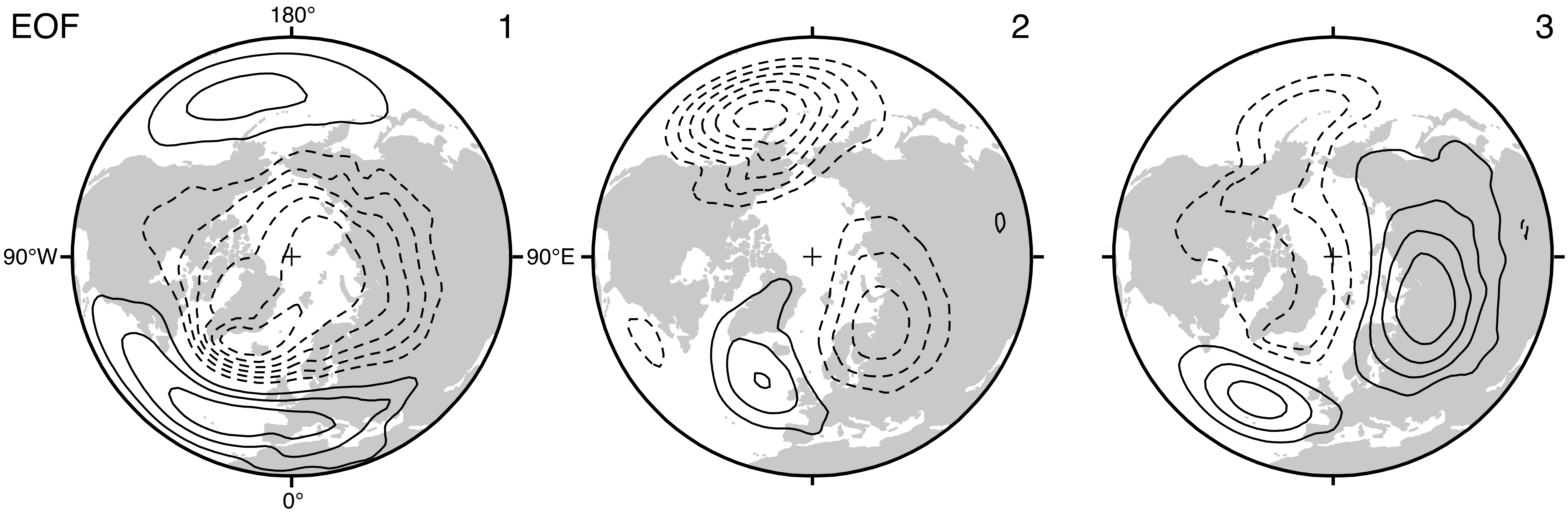
Method: Empirical Orthogonal Teleconnections



Source: Smoliak and Wallace (2015)

SLP regression; contour interval 1 millibar per standard deviation of reference time series; positive solid, negative dashed.

Method: Empirical Orthogonal Functions



Source: Smoliak and Wallace (2015)

SLP regression; contour interval 1 millibar per standard deviation of reference time series; positive solid, negative dashed.

Definition: Mode of variability

Better interpreted in the frame of dynamical systems

e.g., normal modes of linearized equations:

Pacific North American (PNA) pattern, East Atlantic (EA) pattern…*Simmons et al. (1983)*

El Niño / Southern Oscillation (ENSO)…*Thompson and Battisti (2001)*

Northern Annular Mode (NAM)…*Zhao and Takahashi (2006)*

Two Conceptual Models: Teleconnections

Statistical patterns

Normal modes

→

Climate noise

Intrinsic modes

Method: Assessing Robustness

Different methodologies yield similar pattern

Consistent pattern emerges in analyses of different variables

Choice of domain

Choice of season

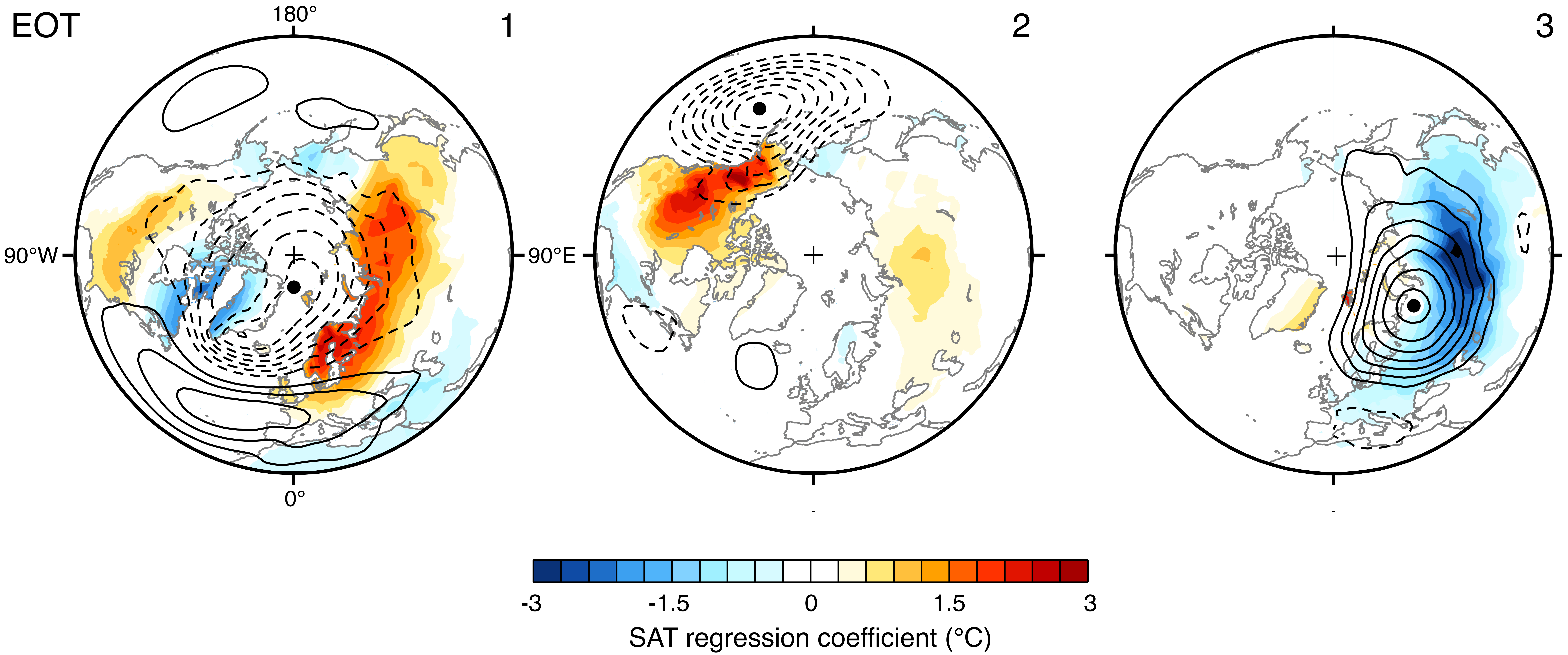
Arbitrary subsets of data (e.g., even/odd years)

Non-arbitrary subsets of data (e.g., first and second halves)

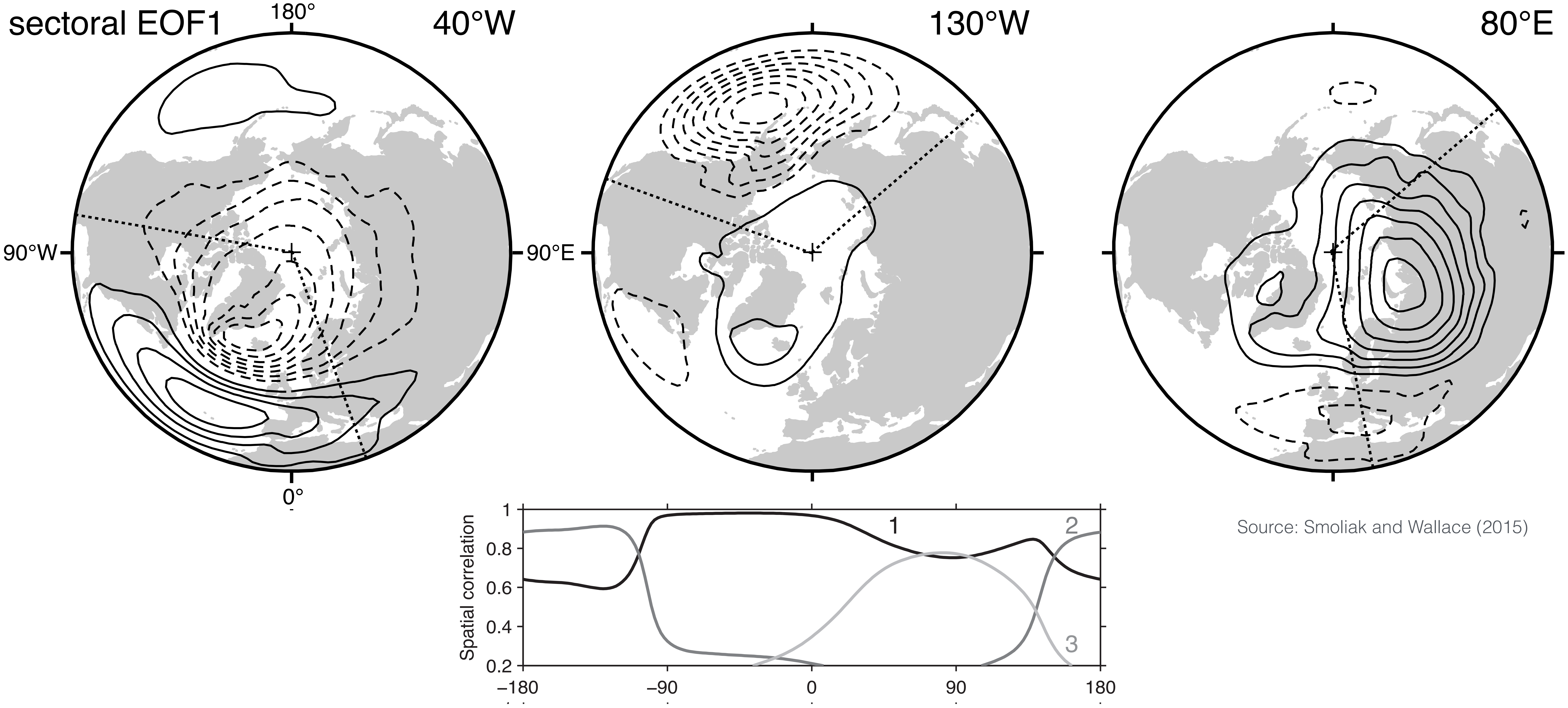
Choice of frequency band

Cross-validation using independent data

Robustness: Consistency between variables

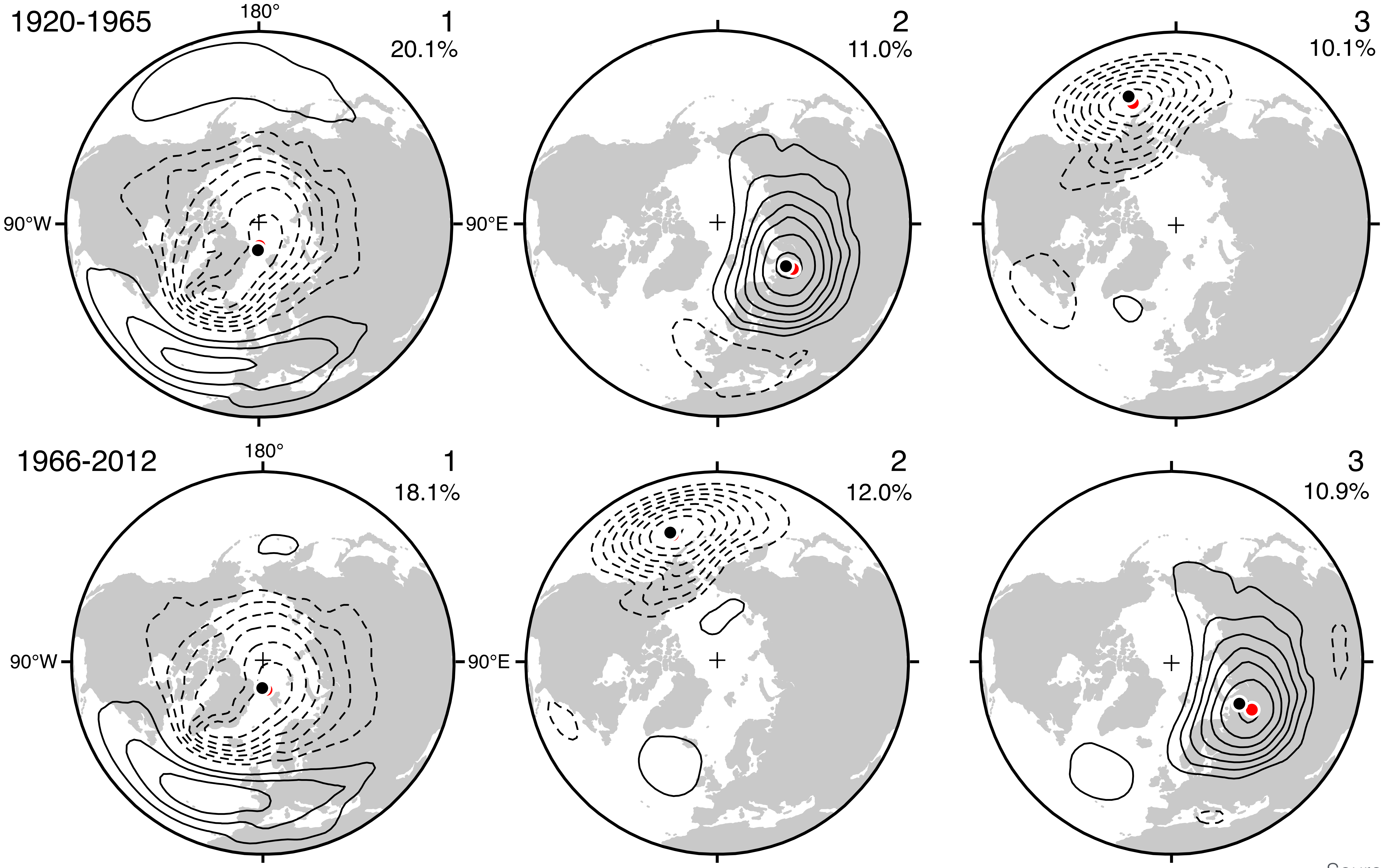


Robustness: Insensitive to domain choices



Source: Smoliak and Wallace (2015)

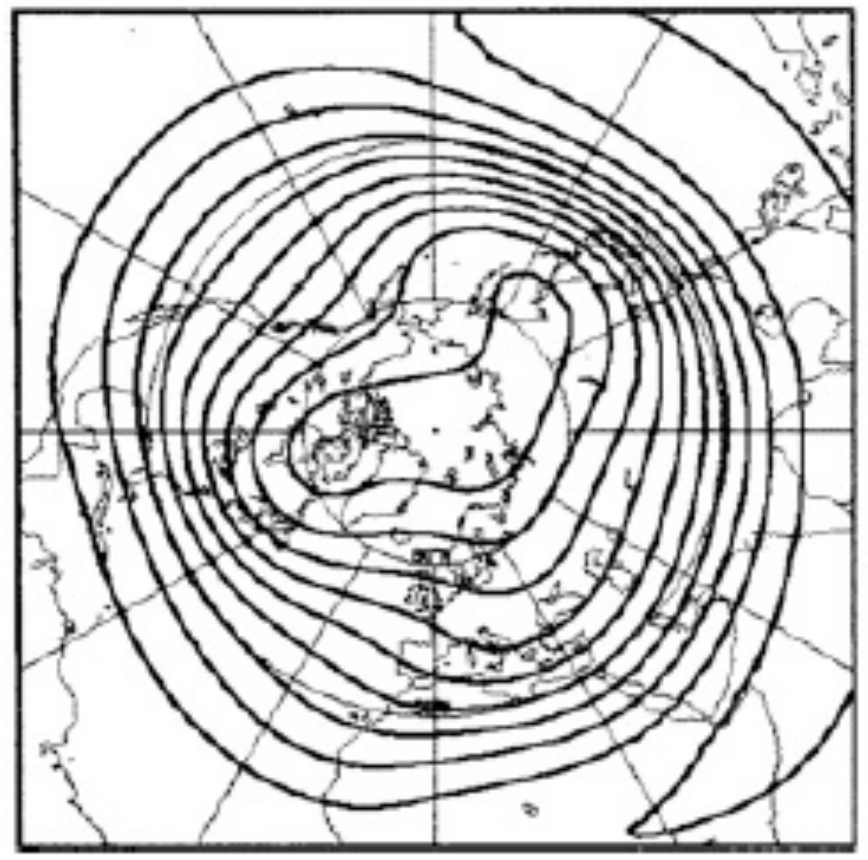
Robustness: EOTs of data subsets

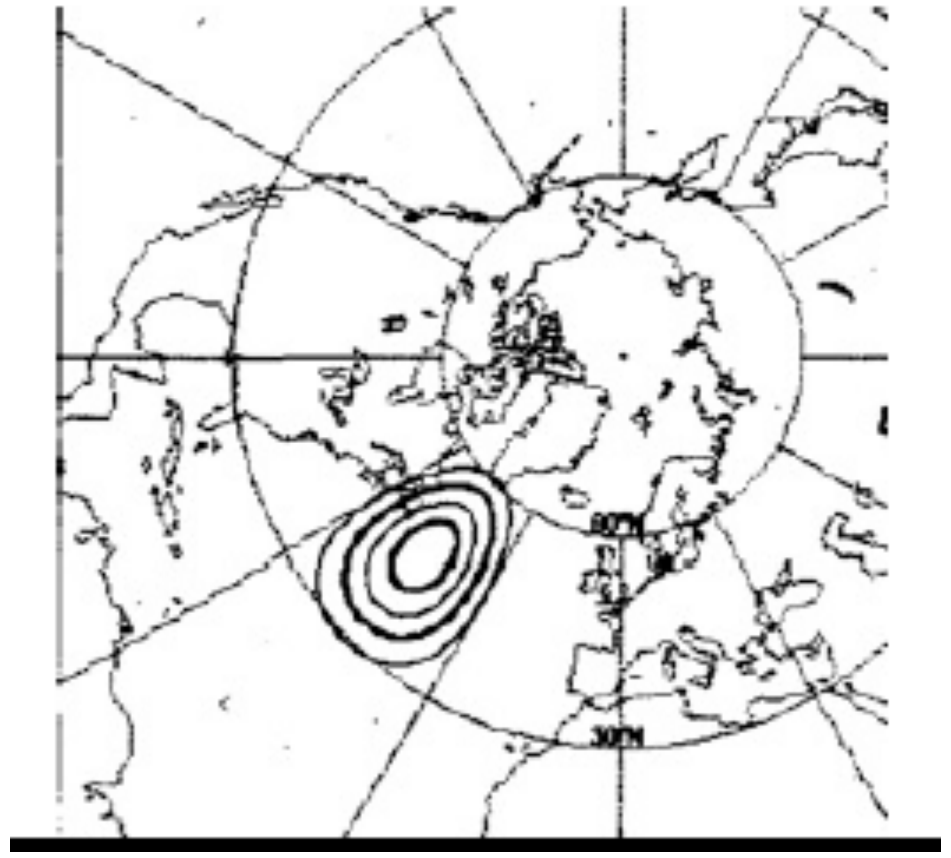


Source: Smoliak and Wallace (2015)

Physics: Barotropic Instability

300mb stream function climatology



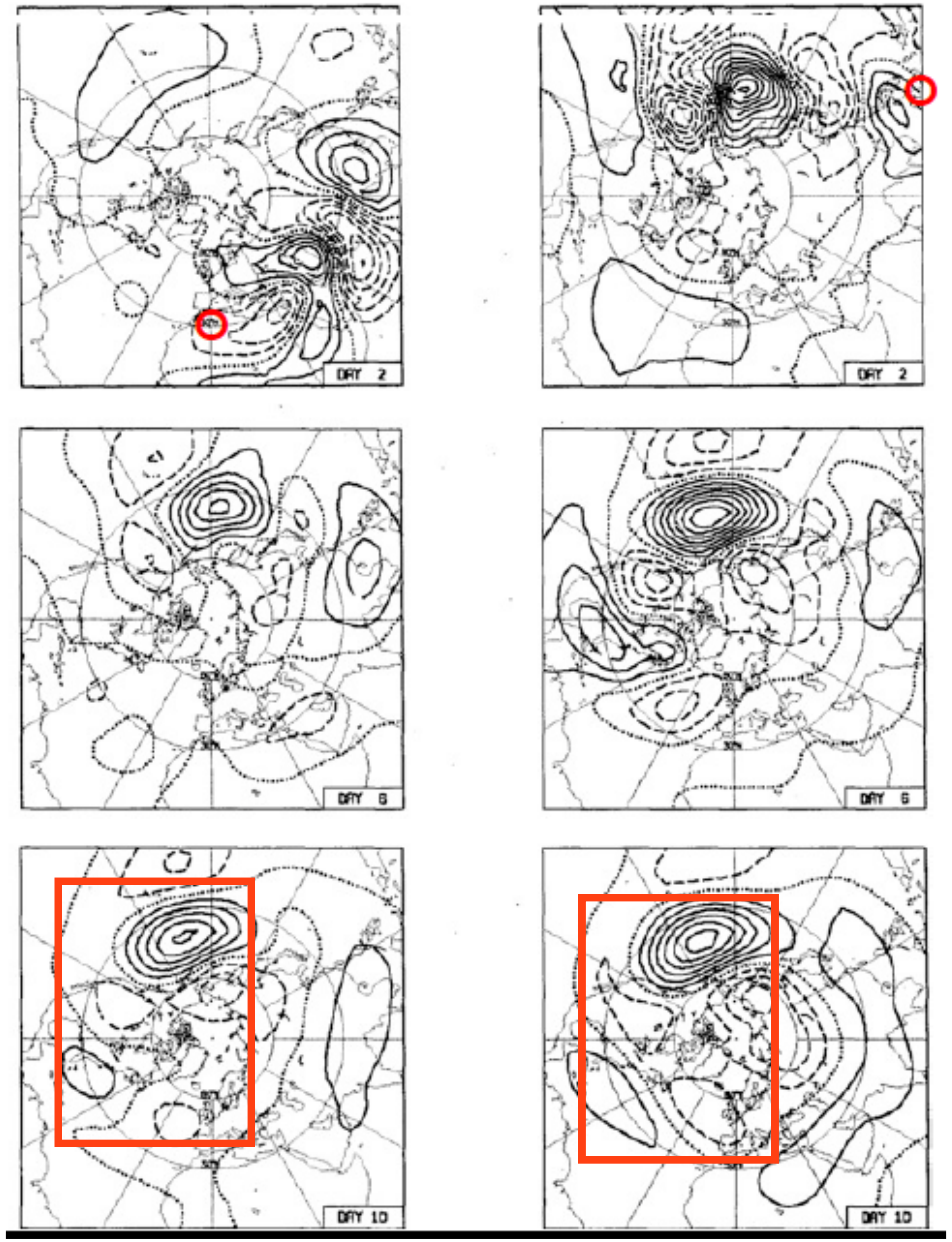


Example forcing distribution

Perturb flow at ○

Allow flow to respond

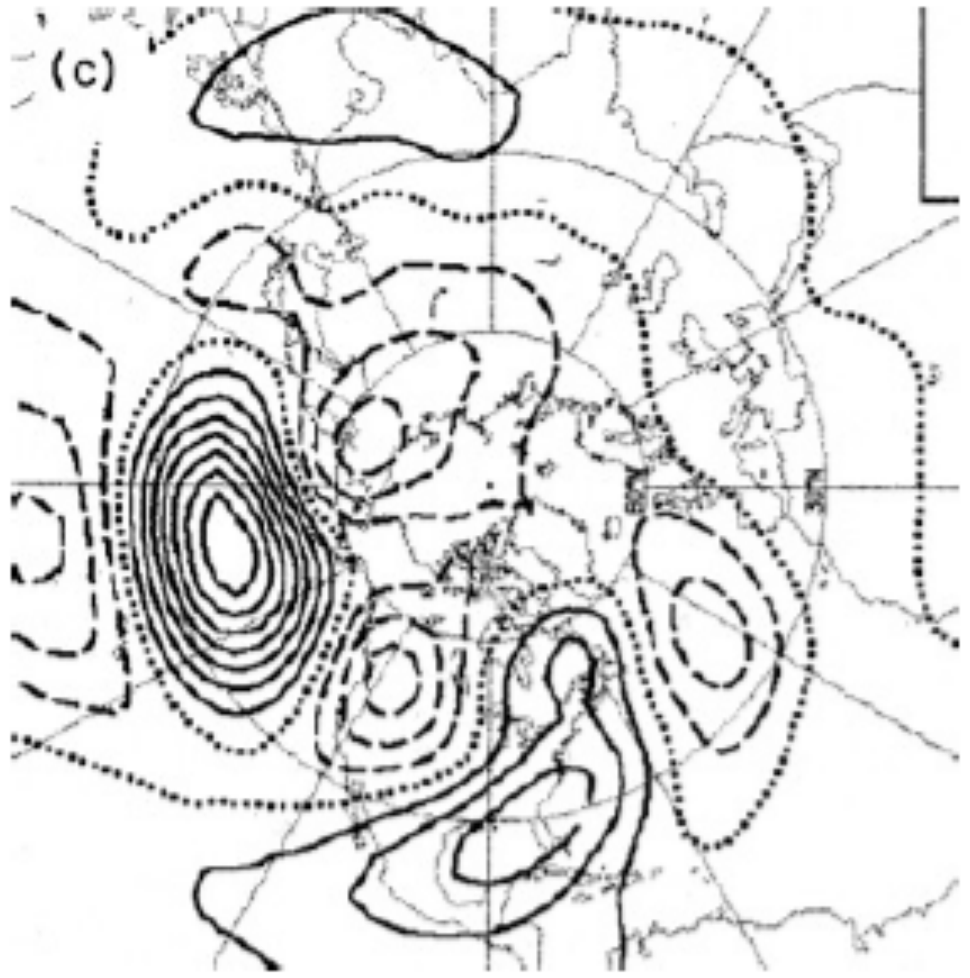
Analyze subsequent patterns



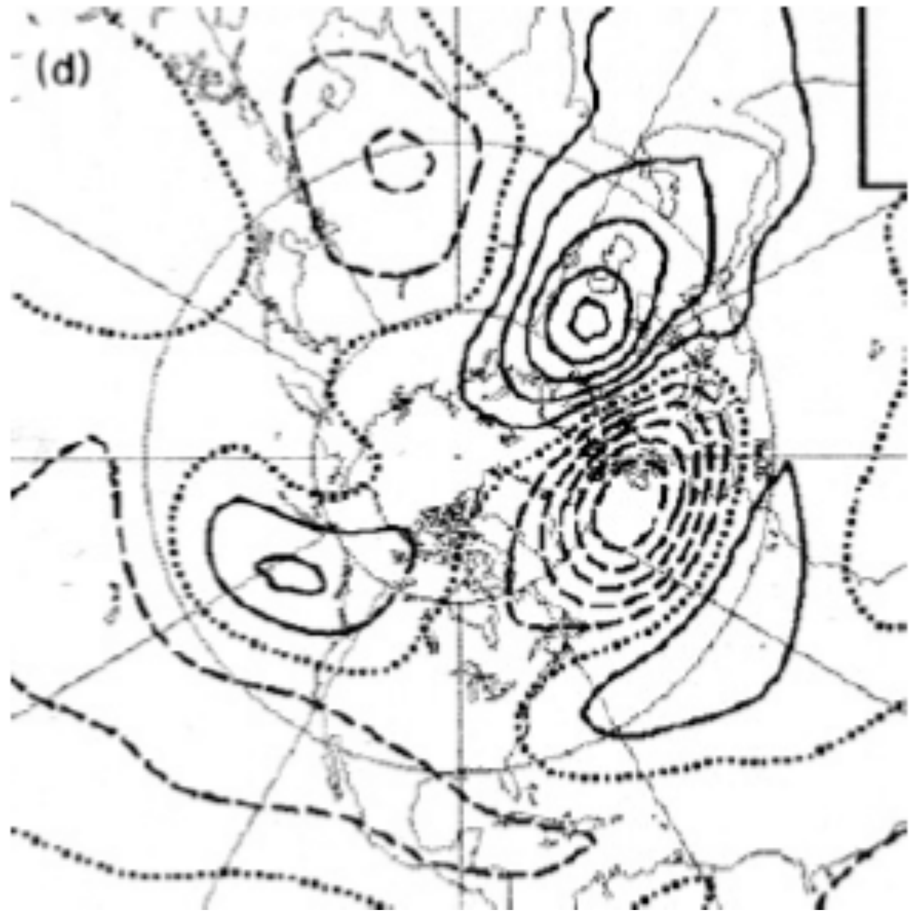
Source: Simmons et al. (1983)

Physics: Model–observation comparison

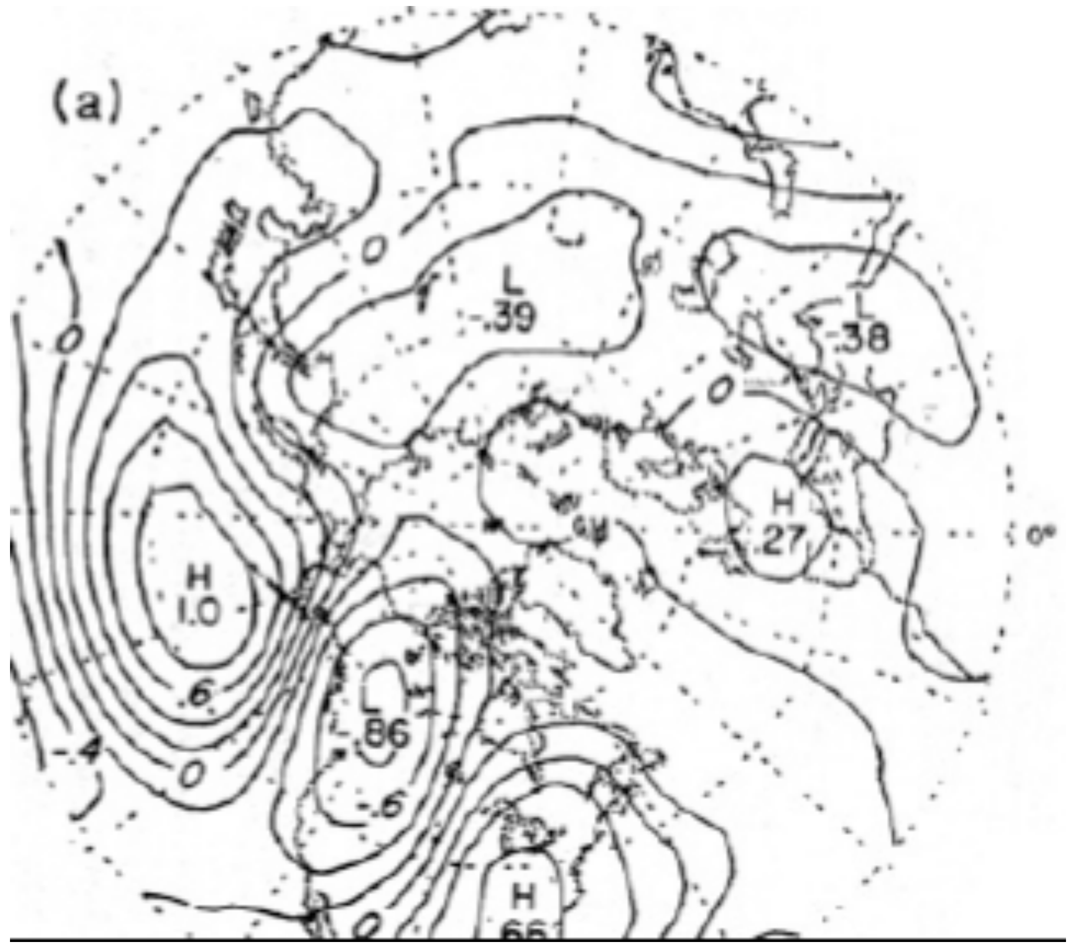
Pacific–
North American
Pattern



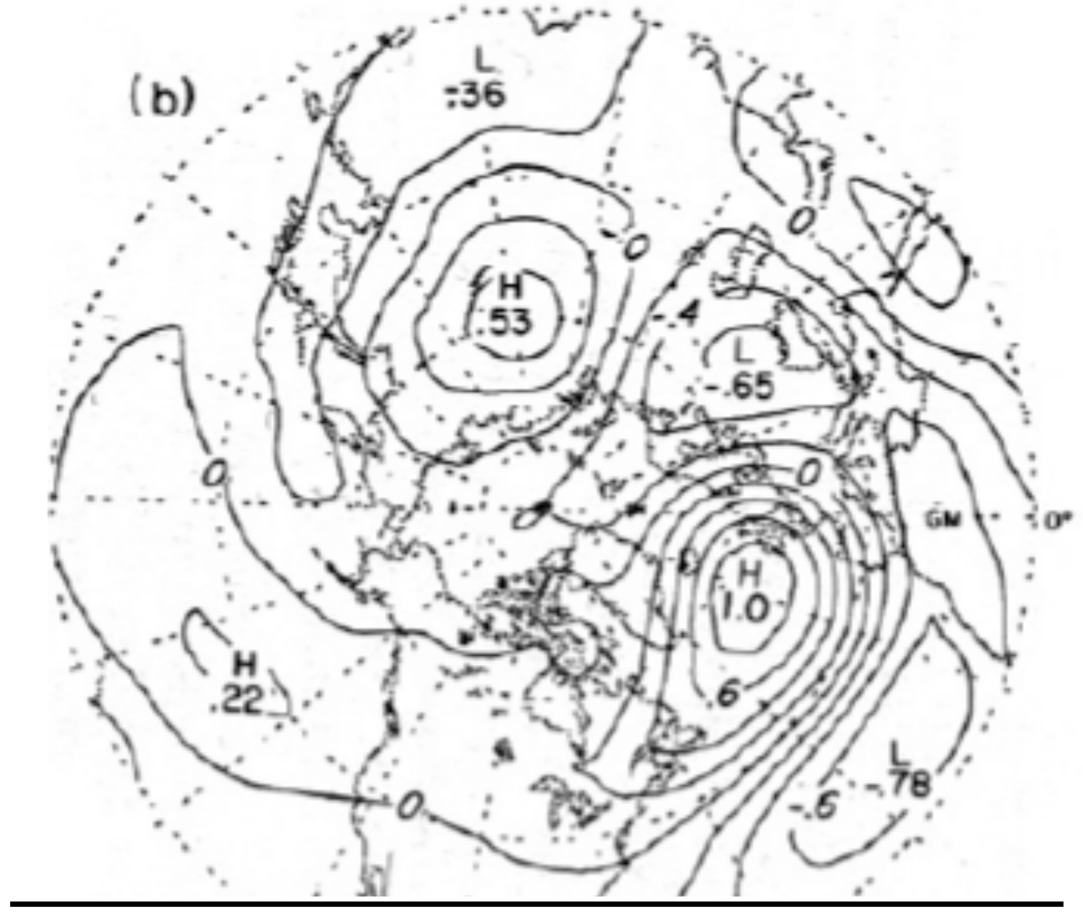
Model
(snapshots from
nonlinear runs)



East
Atlantic
Pattern



Observations



Source: Simmons et al. (1983)

Source: Minnesota Alumni Association

Thank you for your attention.

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Reference:

Smoliak, B. V., and J. M. Wallace, "On the Leading Patterns of Northern Hemisphere Sea-Level Pressure Variability," *J. Atmos. Sci.*, *Early Online Release*, doi: 10.1175/JAS-D-14-0371.1