Diagnosing two-way coupling in decadal North Atlantic SST variability using time-evolving self-organizing maps

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Goal

Understanding the internal decadal variability of the North Atlantic sea surface temperature (NASST) and the mechanisms responsible.

Model Simulation

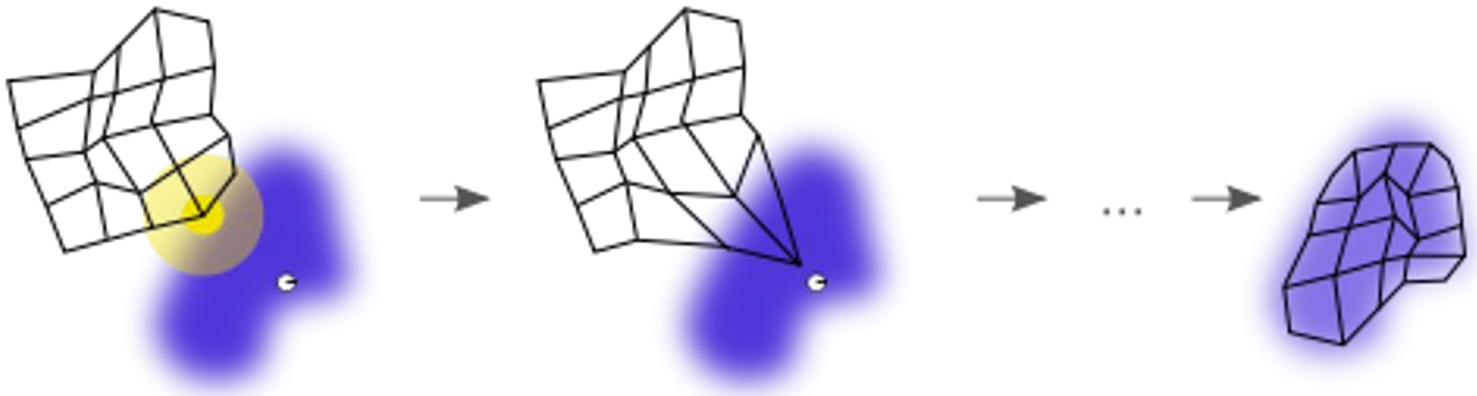
Community Earth System Model (CESM) 1

- Pre-industrial (1850) radiative forcing conditions
- Fully coupled version
- Resolution: ~1 degree
- Data length: ~1500 years

Methods – Self-organizing maps (SOM)

SOM Features

- Unsupervised machine learning method
- Clusters high dimensional datasets
- Not restricted by orthogonality or stationarity
- Identify physically relevant patterns

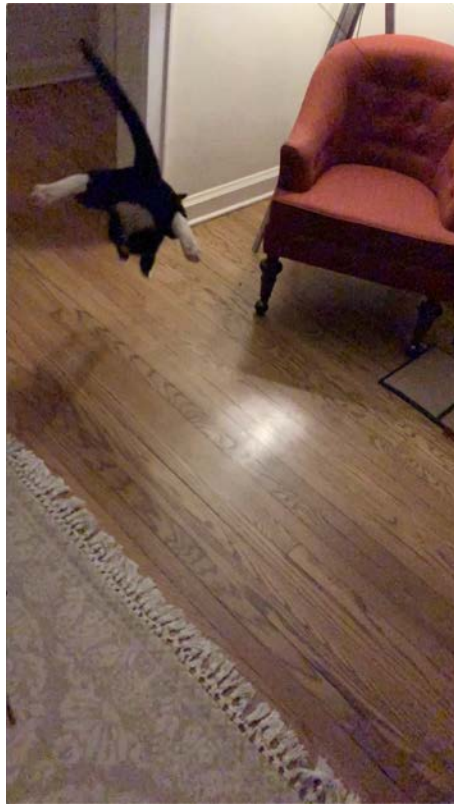


Difference between the ordinary SOM and Evolution-SOM

Ordinary SOM

Input data: A spatial pattern for a single time step

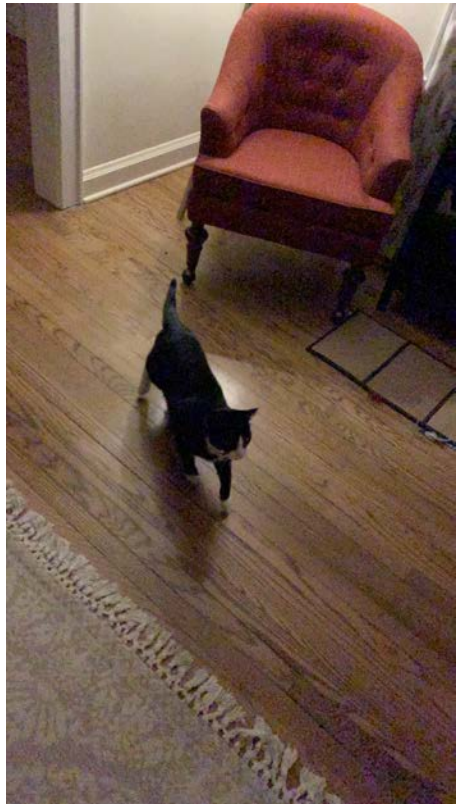
"Classifying pictures"



Evolution SOM

Input data: A number of consecutive spatial patterns

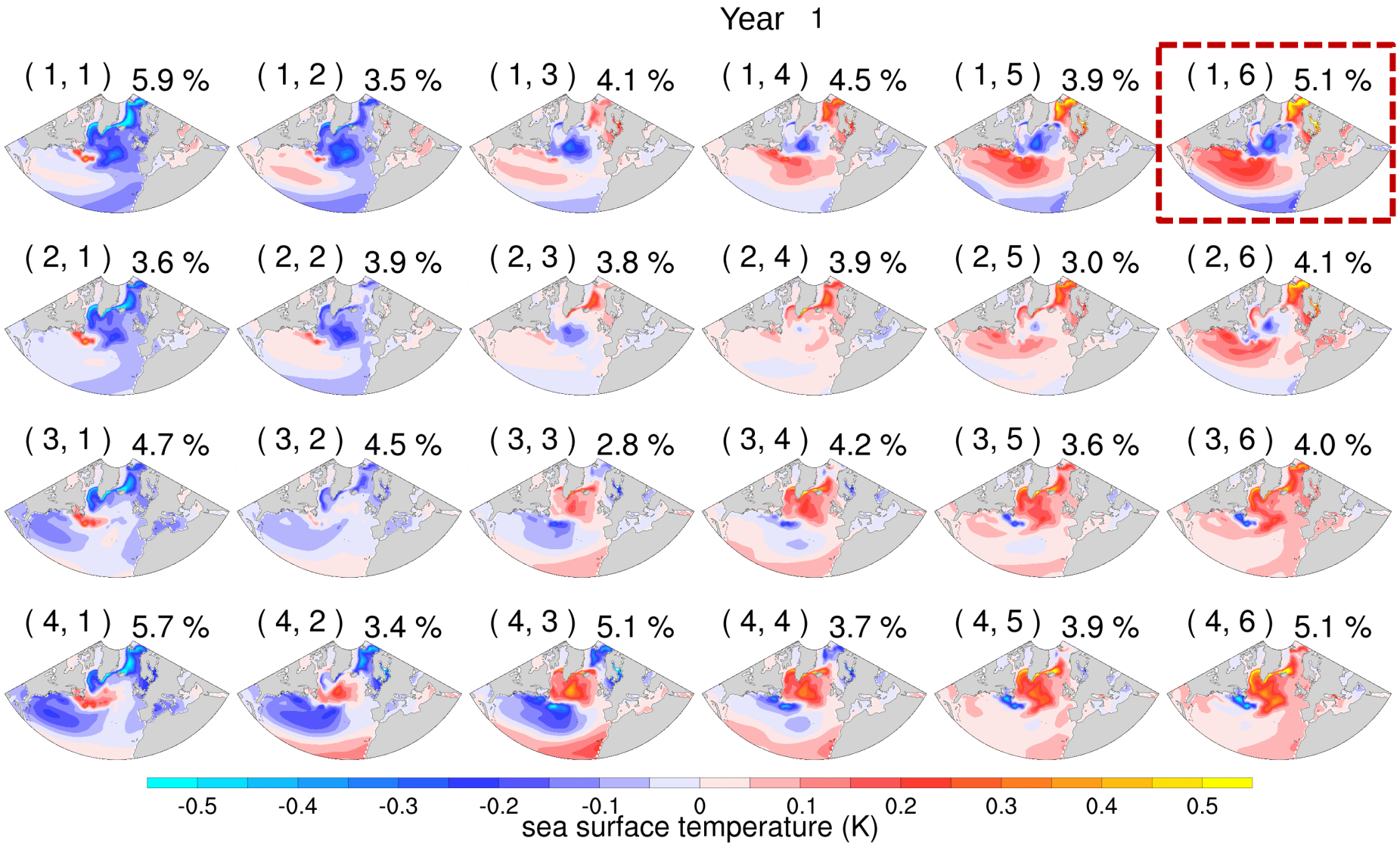
"Classifying videos"



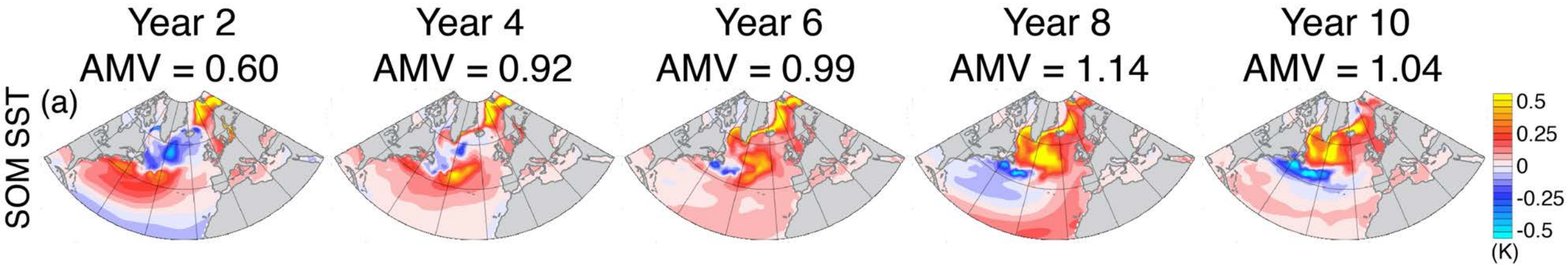
Evolution-SOM: Characterize variability in space and time simultaneously

- Classify spatio-temporal evolutions of winter NASST anomalies over the course of 10 consecutive years.
- Identify evolutions without time filtering – Capture both interannual and decadal variability
- Similar to what would be produced in a decadal prediction

Generalized 10-year spatio-temporal evolutions of North Atlantic SST anomalies



Spatio-temporal evolution of SST for node (1,6)

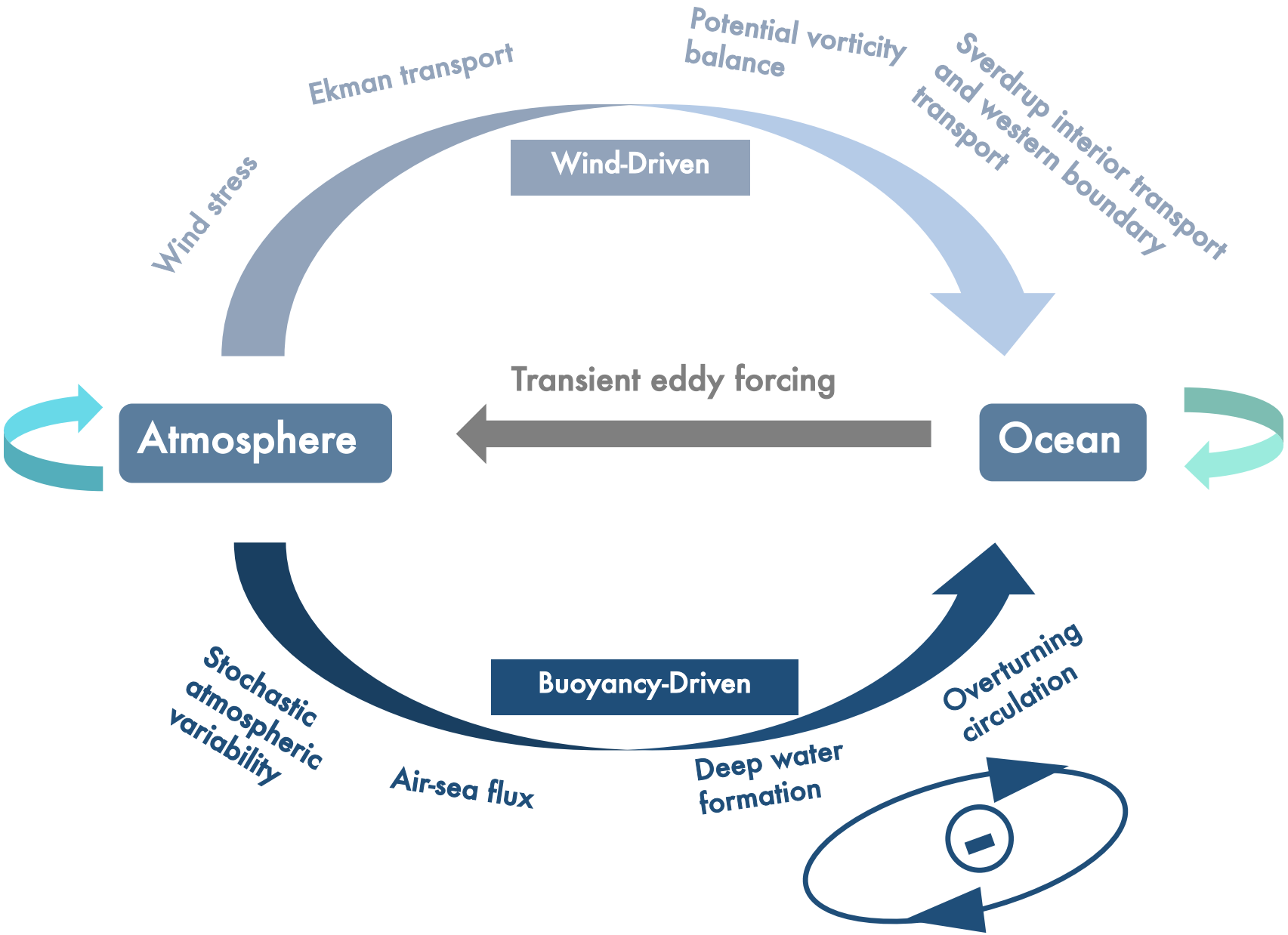


~NAO+ SST pattern → ~AMV+ SST pattern → Weak ~NAO– SST pattern

- Identify spatial patterns that cannot be well captured by the AMV index.
- Capture ~NAO+ to ~AMV+ without time filtering.
- Evolution from ~NAO+ to ~AMV+ occurs within 6 years.

NAO: North Atlantic Oscillation; AMV: Atlantic Multidecadal Variability

Three dominant mechanisms



Coupled relationships between SST patterns, transient-eddy activities, and jet streams

E-vector:

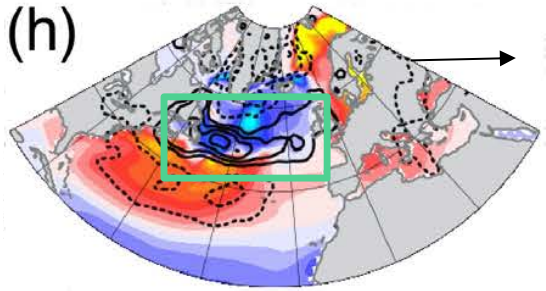
- A diagnostic method proposed by Hoskin et al. (1983)
- Describe vertical eddy activity propagation and its feedback onto the mean flow

- Vertical component of E-vector
  - $\overline{v'T'}$ at 850hPa
  - Lower troposphere eddy heat transport
  - A measure of the vertical eddy activity propagation
- Horizontal component of E-vector
  - $\mathbf{E}_h = (\overline{v'^2} - \overline{u'^2}, -\overline{u'v'})$ at 200hPa
  - An estimate of the eddy momentum forcing of the zonal time-mean flow
- Methods
  - A 8-day high pass Butterworth filter is applied to u (zonal wind), v (meridional wind), and T (temperature) to isolate baroclinic eddy activity.

Coupled relationships between SST patterns, transient-eddy activities, and jet streams

Year 2 of node (1,6)

Shading: Composites of SST anomalies;
Unfilled Contours: Composites of $\overline{v'T'_{850}}$ anomalies
Positive $\overline{v'T'_{850}}$: Enhanced and upward propagated eddy activity

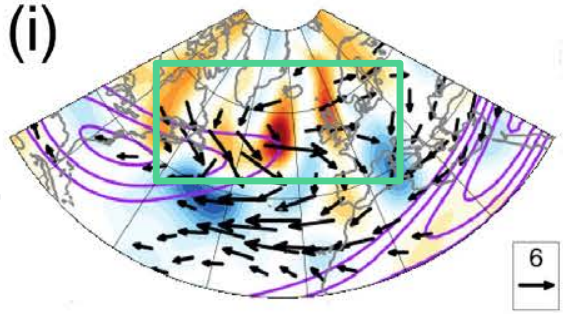


~NAO+ signal

Increased surface baroclinicity associated with the large SST gradient

Enhanced and upward propagated eddy activity

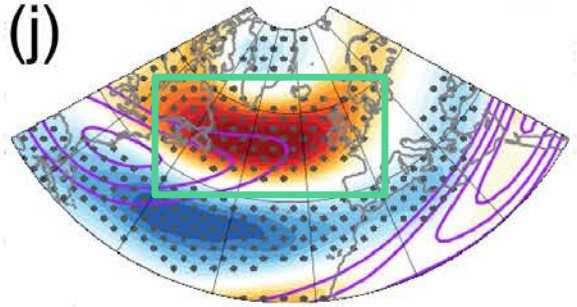
Vectors: Composites of horizontal E-vector anomalies at 200hPa
Shading: Composites of spatially smoothed horizontal E-vector divergence (warm colors) / convergence (cold colors) anomalies at 200hPa
Purple contours: Winter jet climatology (wind speed at 200hPa > 30 m/s)



Divergence of horizontal E-vector aloft associated with the enhanced low-level activity

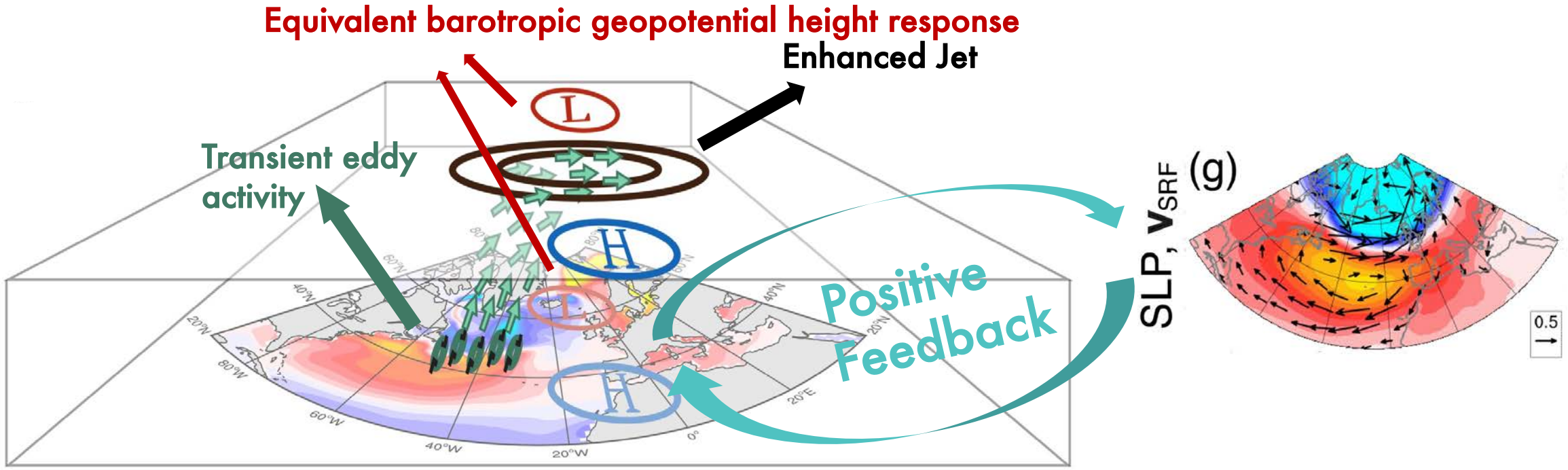
Enhanced eddy activity provides energy to the mean flow aloft

Shading: Composites of wind speed anomalies at 200 hPa
Purple contours: Winter jet climatology (wind speed at 200hPa > 30 m/s)



Poleward shifted and eastward extended jet

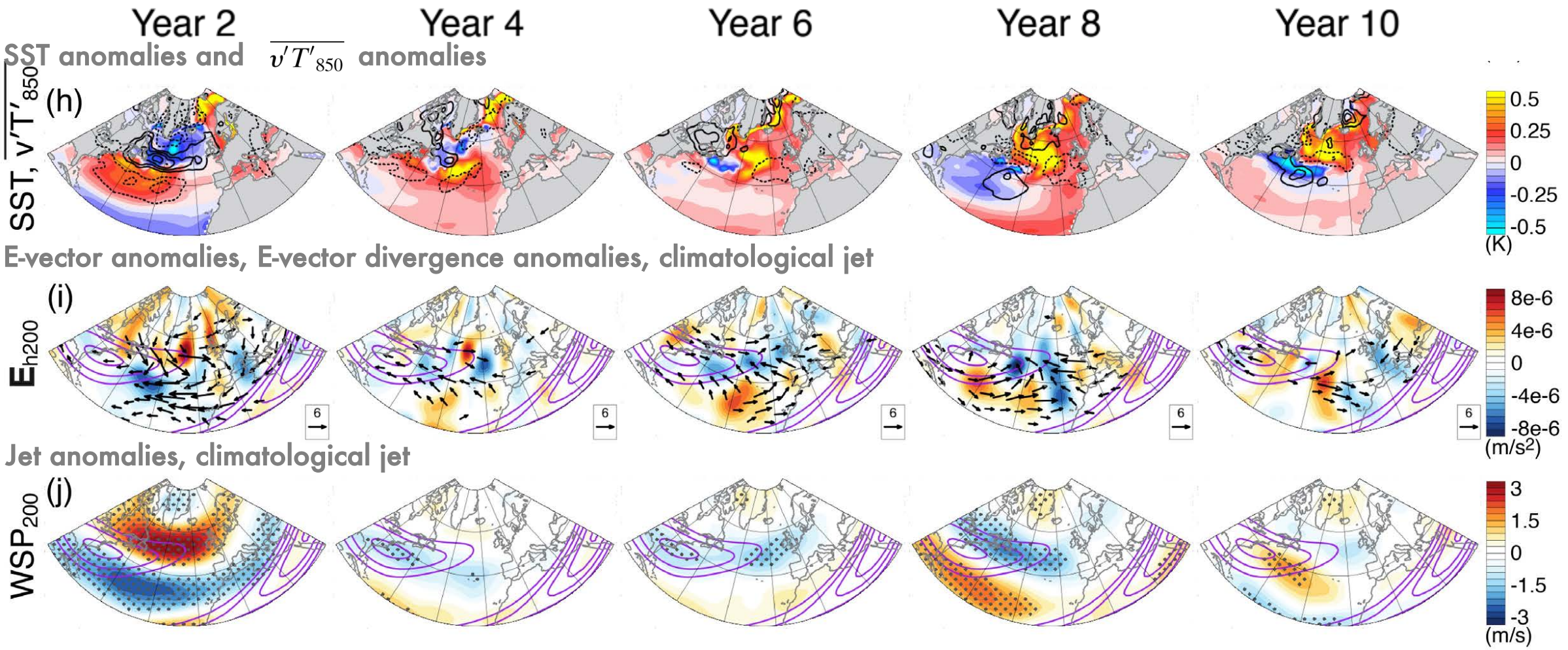
Ocean-atmosphere transient-eddy feedback



Positive NAO-related enhanced westerlies and associated wind-driven circulation → Strengthened SST gradient → Transient eddy response → Enhanced jet → Equivalent barotropic geopotential height response → Enhanced NAO

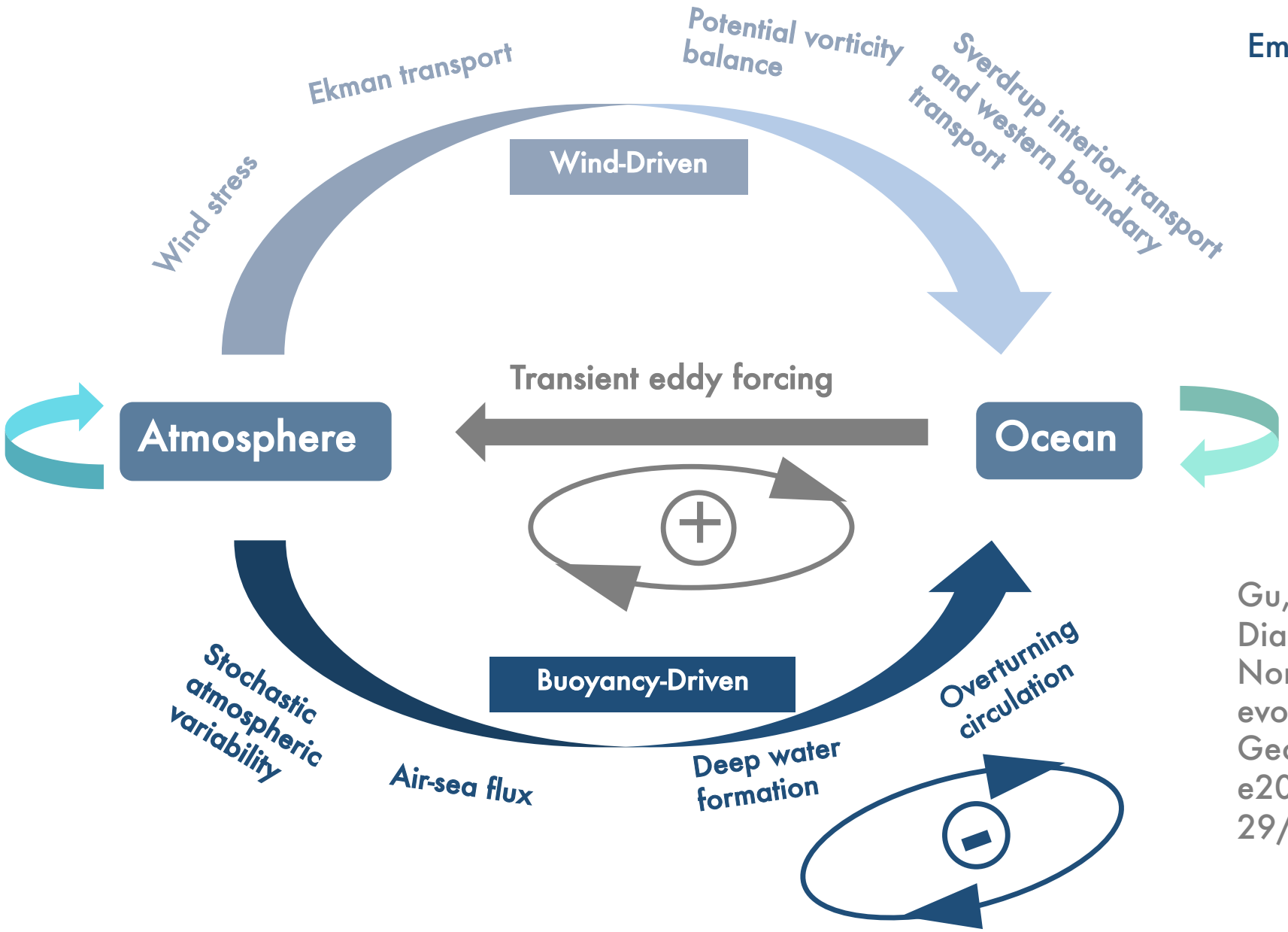
Ocean-atmosphere transient-eddy feedback

Composites of variables for node (1,6)



Coupled relationships between SST, transient-eddy activities and jet streams exist over 10 years, and transient eddy feedbacks as well as the response of atmospheric circulation depend on details of SST anomalies.

Summary



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