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Basic ingredients of the Northern Hemisphere storm tracks

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Introduction

- NH storm tracks
- Broad structure:
  - Atlantic
  - Pacific
  - Mediterranean
- Want to understand/predict "differences" in storm track:
  - Model error
  - Climate change
    - Past
    - Future
    - Variability
- Complex feedbacks with other ES components

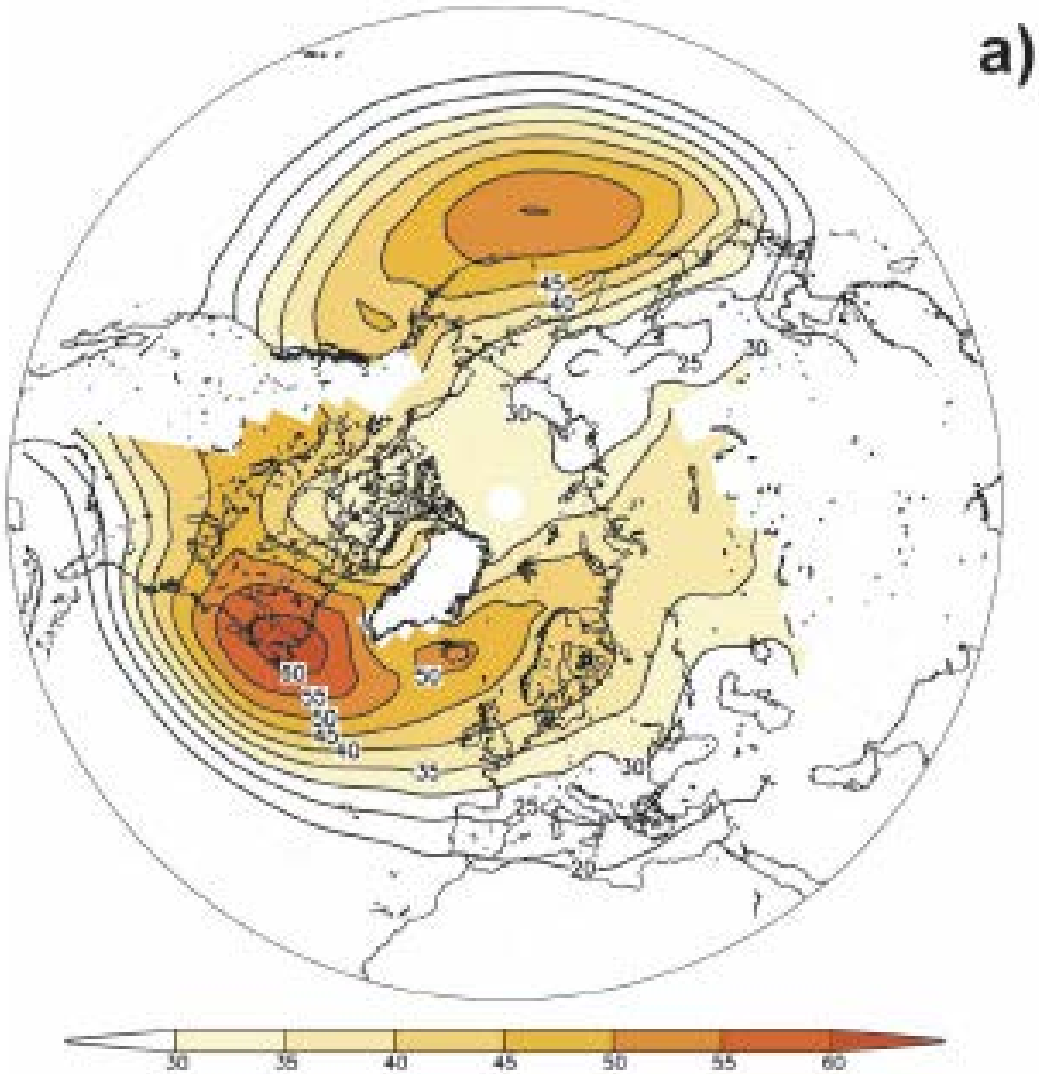

Fig: NCEP from Ulbrich et al (2008)
Winter storm track activity (2-6d BPF Geo 500)

Simplification and hierarchy

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- **Simplification:**
  - Consider the atmospheric response to imposed forcings
  - Ignore feedback of atmosphere onto other ES components
- **A practical hierarchy of "forcings":**
  - Zeroth order
    - Baroclinic instability from latitudinal differential insolation on a rotating spherical planet
  - First order
    - Features that control the gross structure of the storm tracks and atmospheric circulation, e.g., large-scale planetary topography
  - Second order
    - "Small" applied forcing that modifies the atmospheric circulation but do not cause a fundamental reorganisation.

Simplification and hierarchy

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    - "Small" applied forc … al reorganisation.

Structure of response to "higher-order" forcings is sensitive to pre-existing "lower-order" forcings

In many cases, e.g., SST anomalies or "sub-tipping-point" climate change, we are concerned with the second-order forcing

Suggests need to understand 0th and 1st order structure to interpret responses

The “semi-realistic” framework

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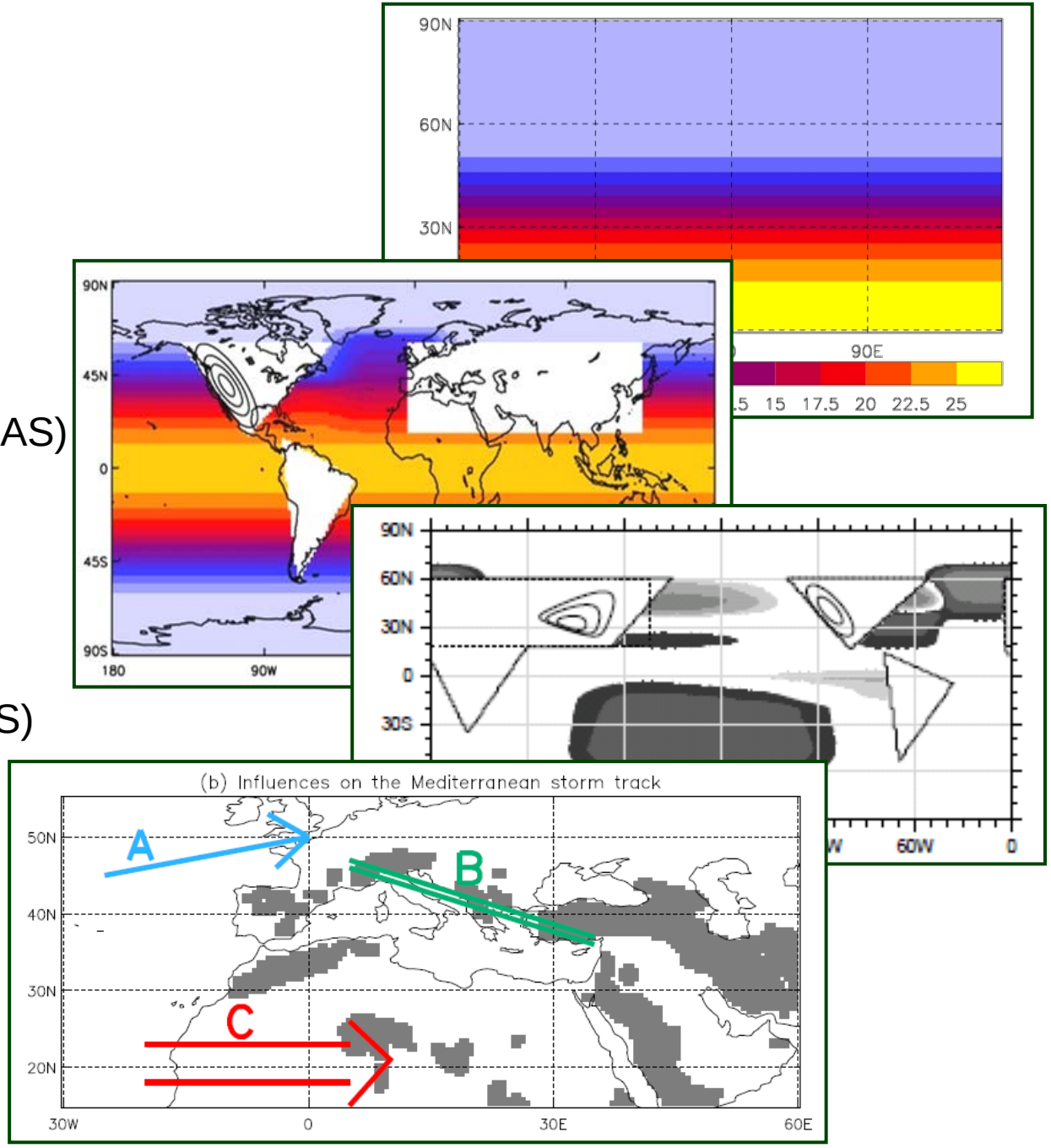
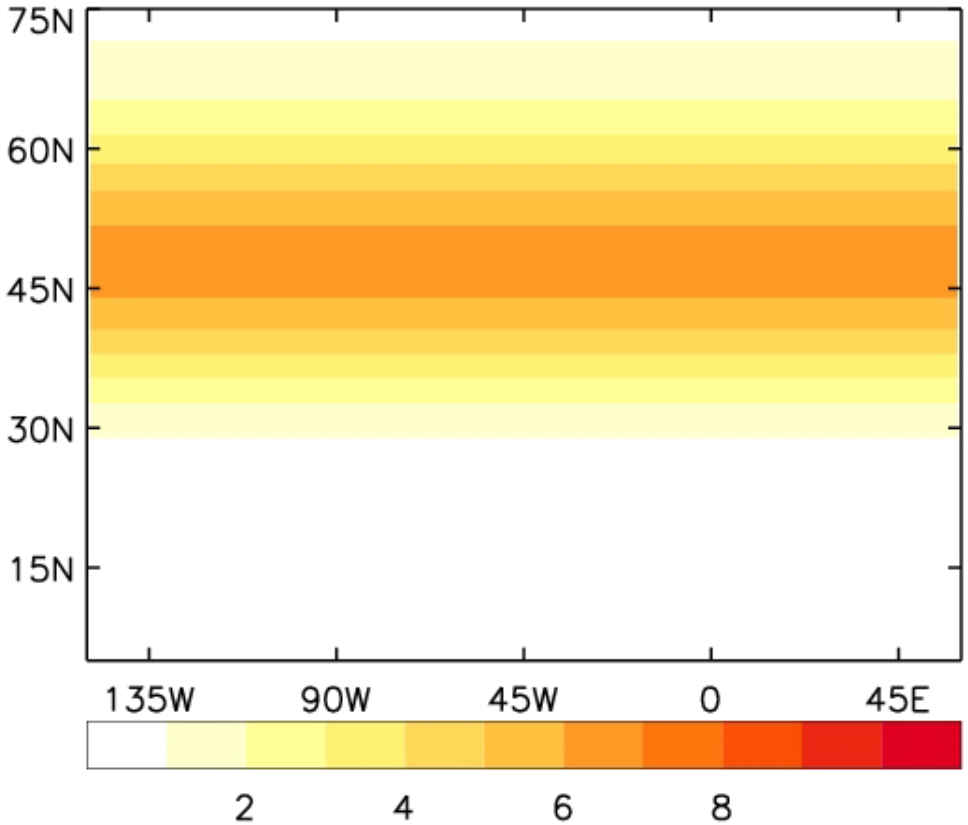
- Aquaplanet
  - Brayshaw et al (2008, JAS)
- North Atlantic
  - Brayshaw et al (2009, 2011, JAS)
- North Pacific
  - Sauliere et al (accepted to JAS)
- Mediterranean
  - Under development



Example: Gulf Stream anomaly

Scaled vertical e-vector component
(similar to v'T' @ 850 hPa)



Aquplanet experiment with zonally symmetric SSTs mimicking North Atlantic winter

Gulf Stream anomaly

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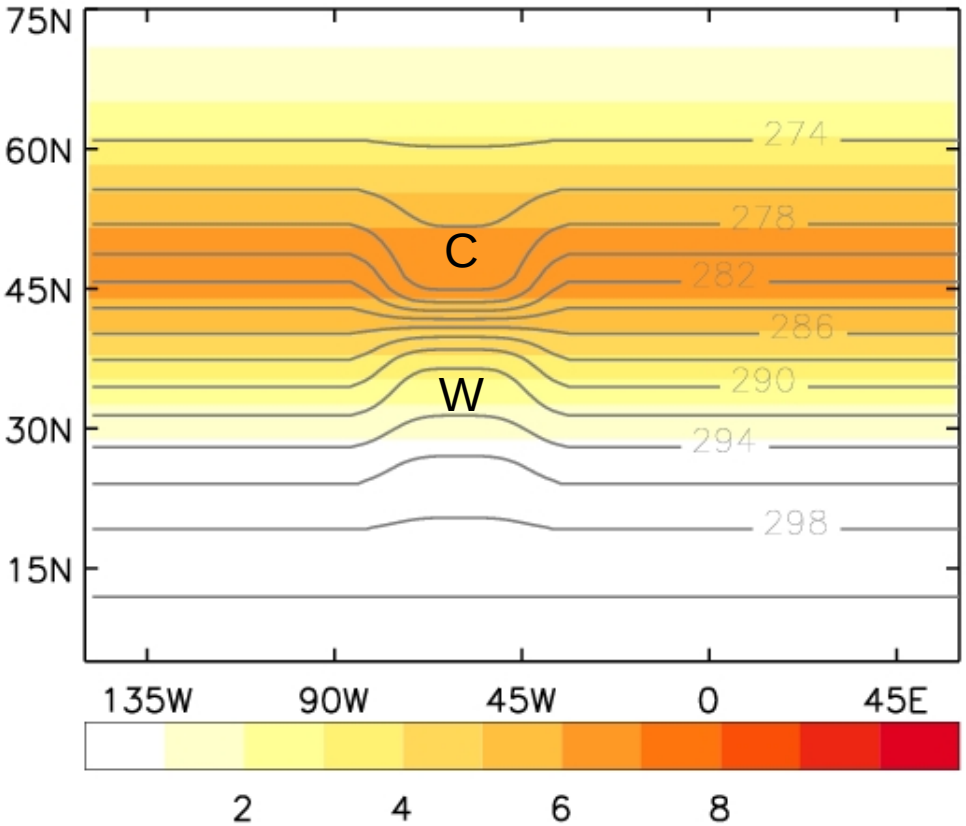
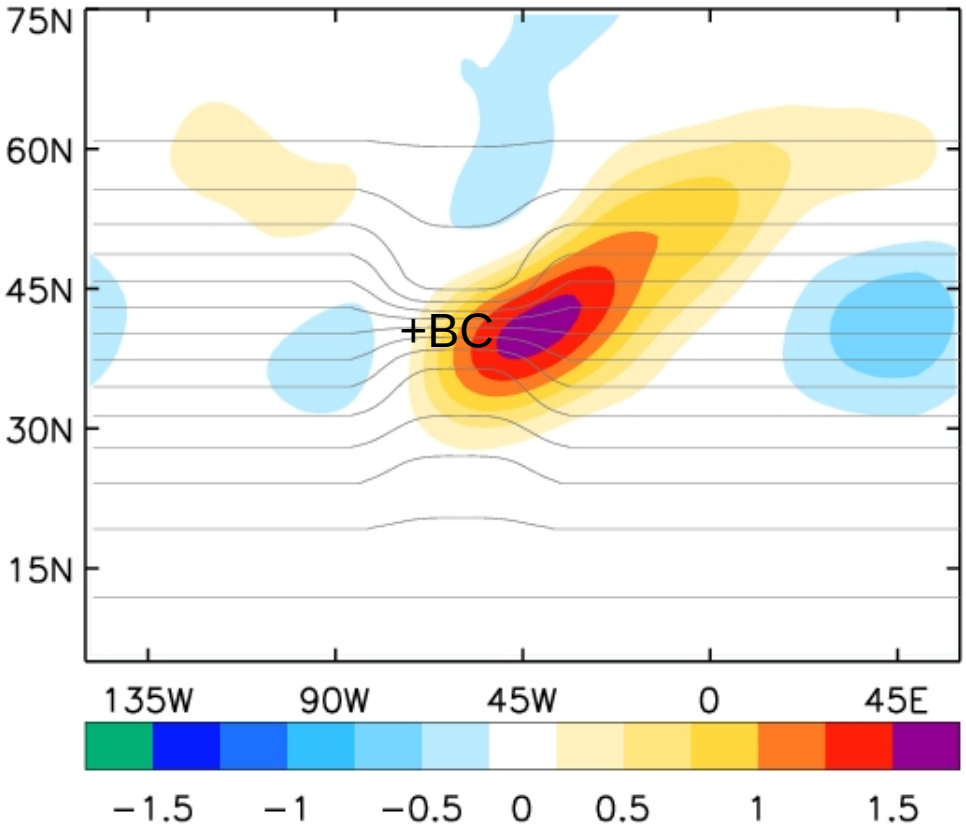


E-vector anomaly created by "adding"
the Gulf Stream



Aquplanet experiment with zonally symmetric SSTs mimicking North Atlantic winter

Add "Gulf Stream" SST dipole

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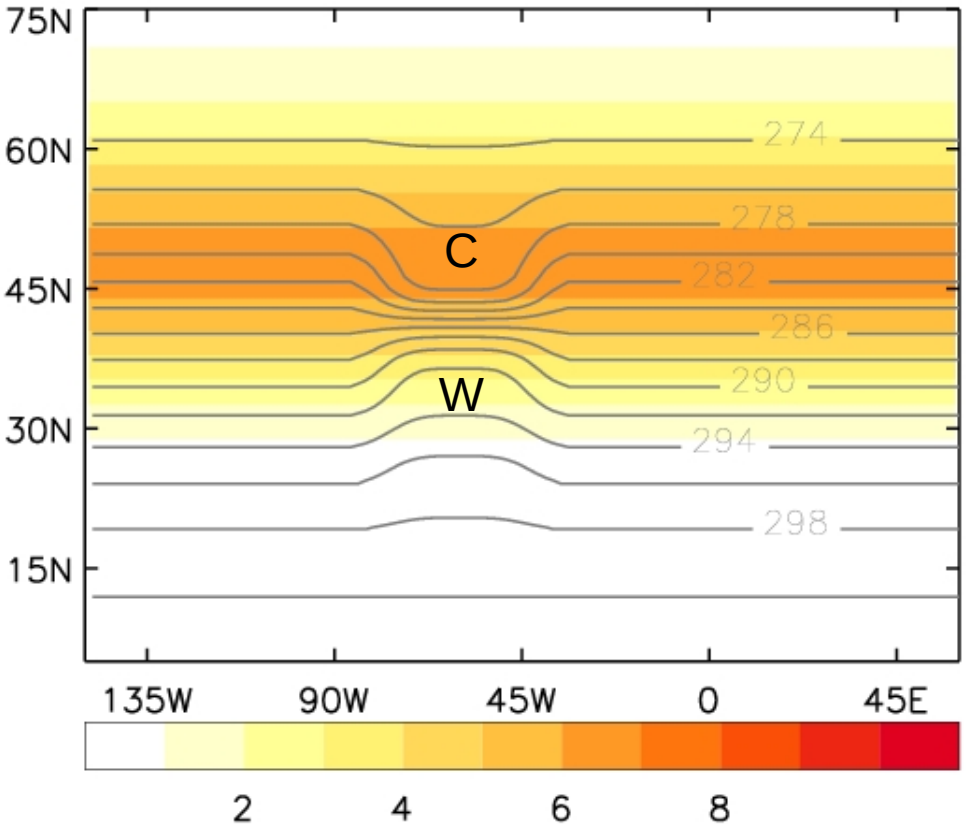

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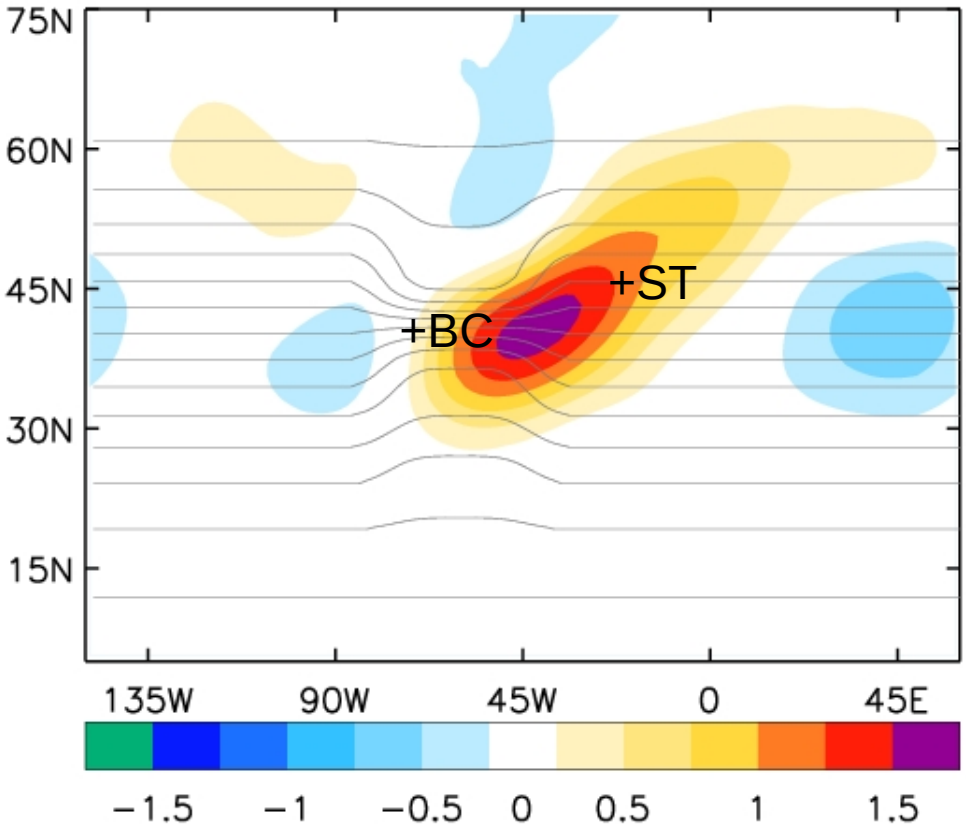

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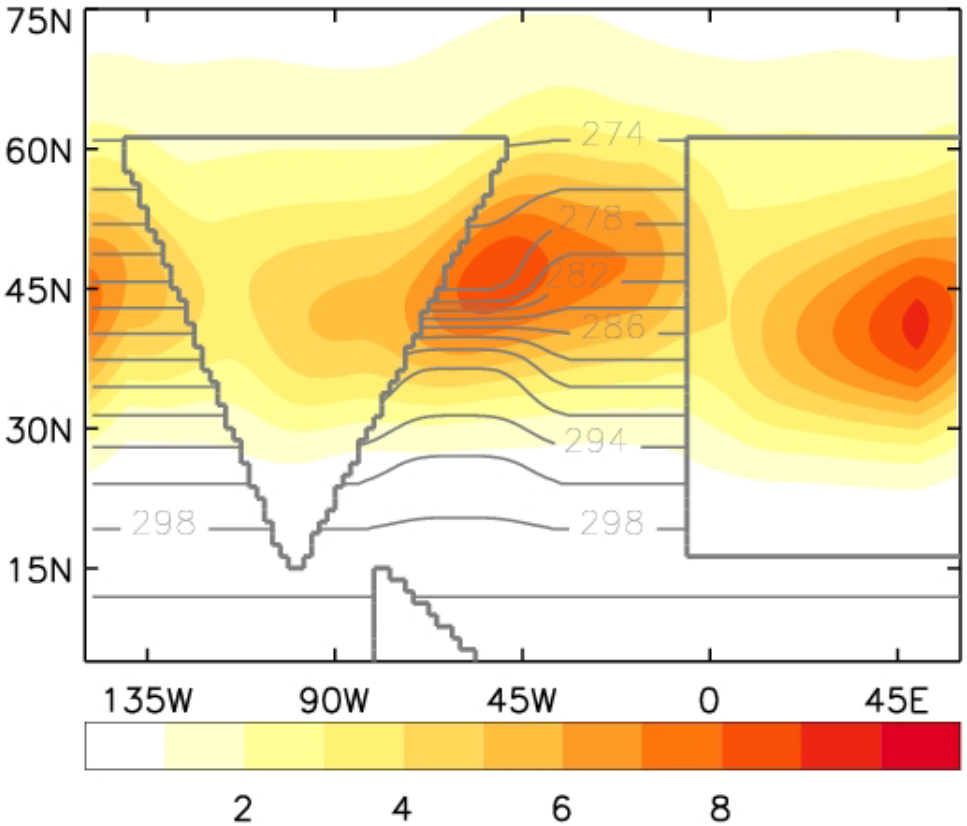

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Flat continents experiment

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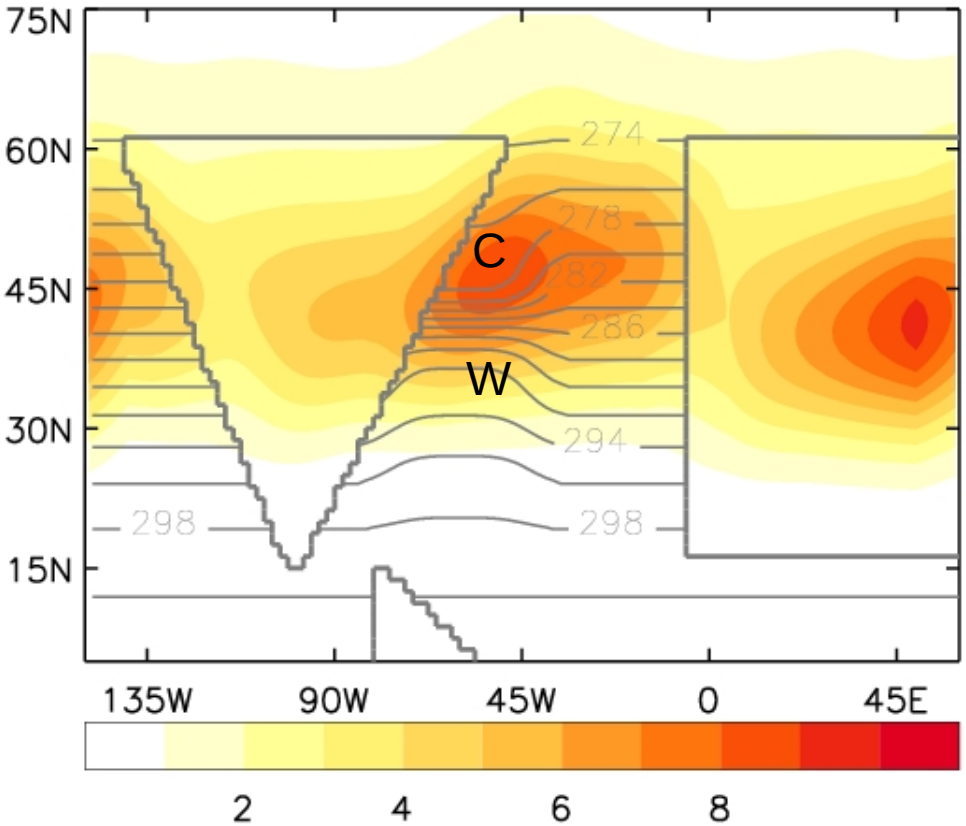

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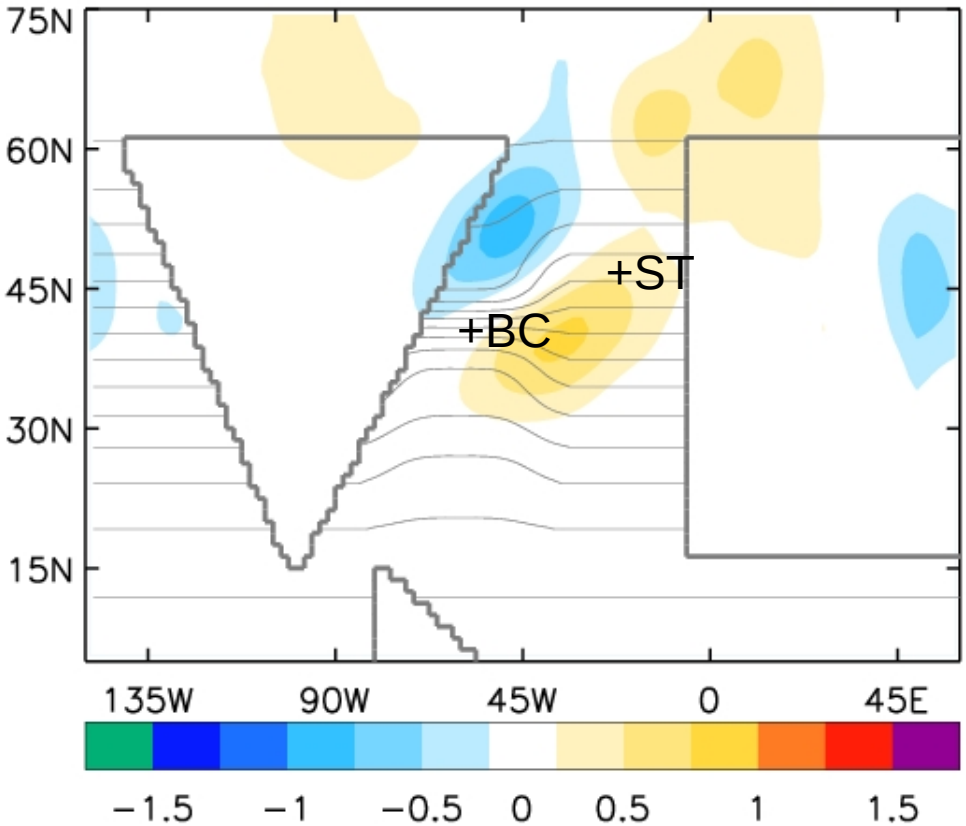

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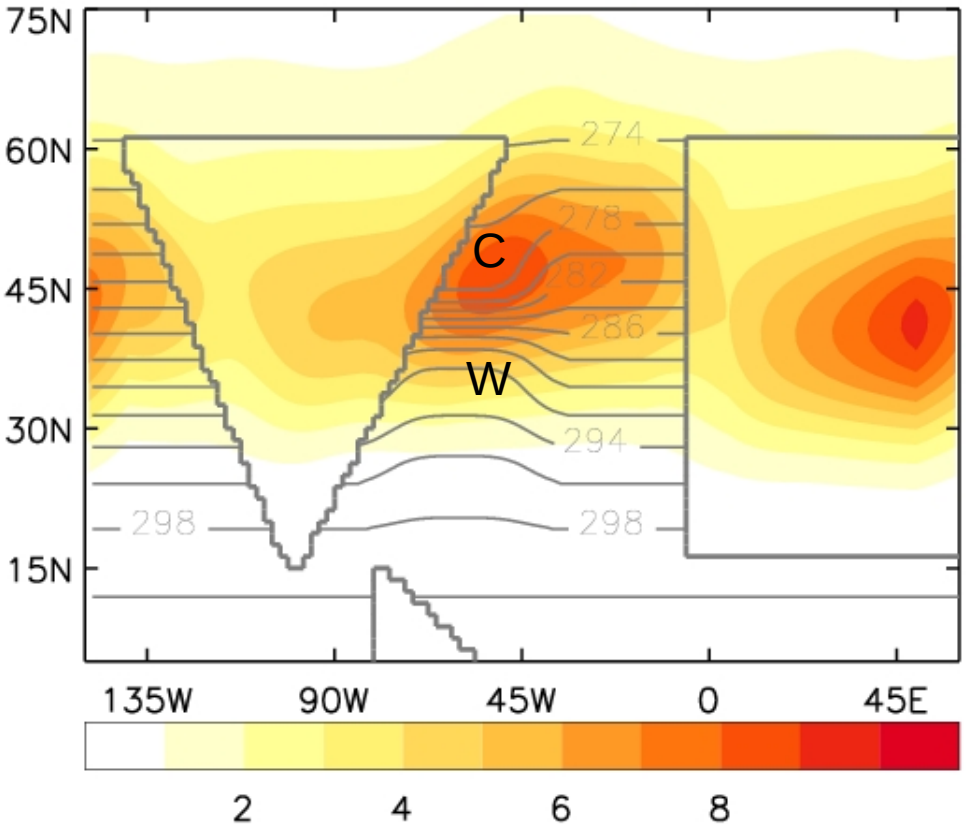

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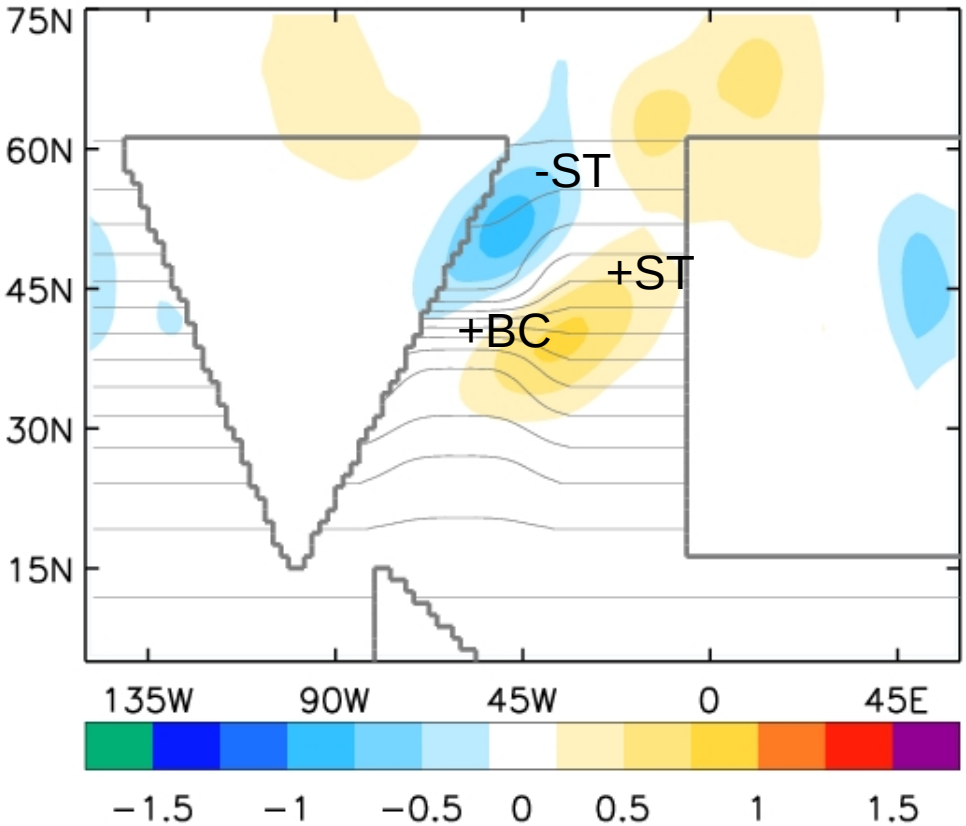

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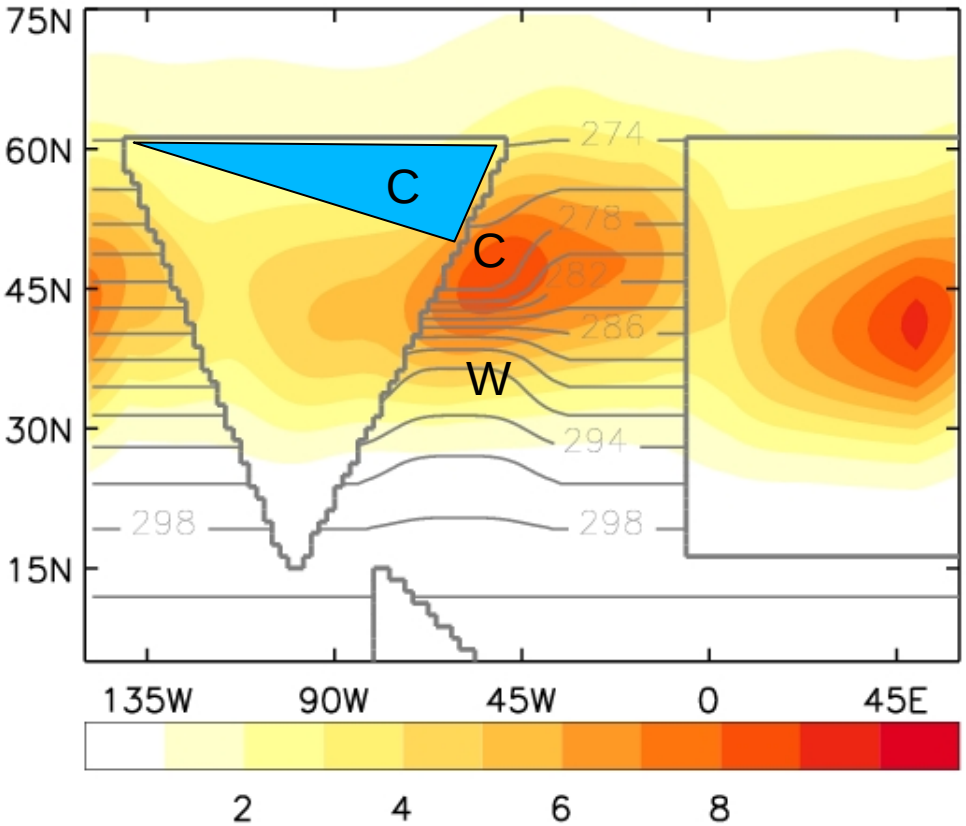

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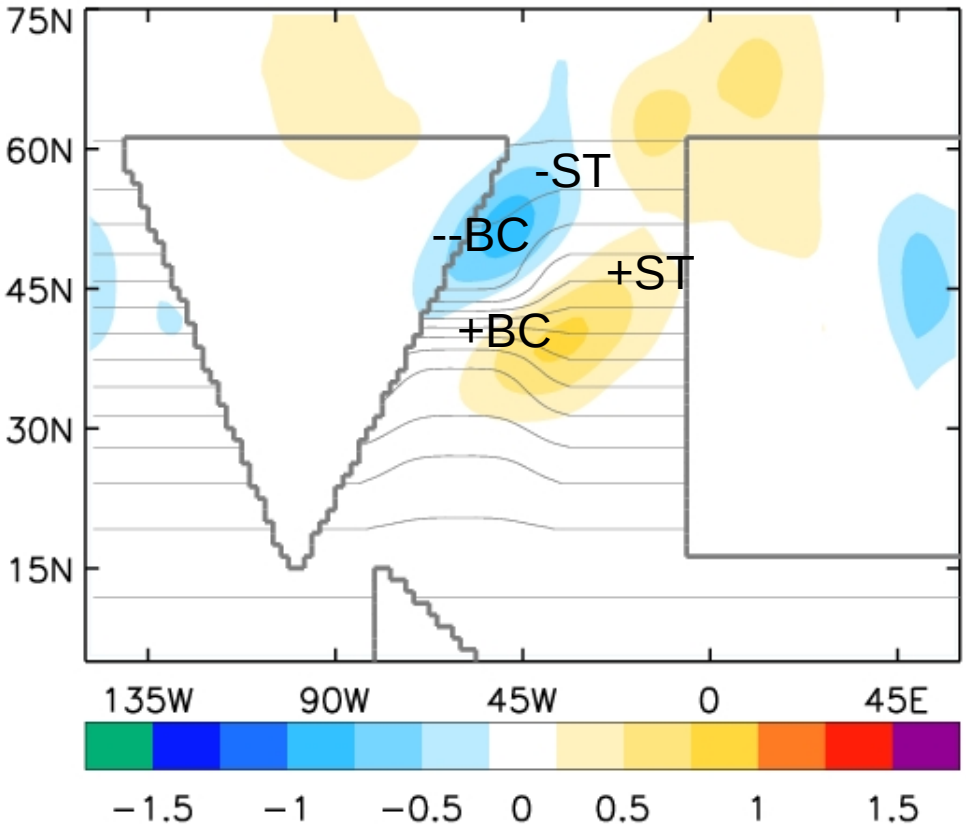

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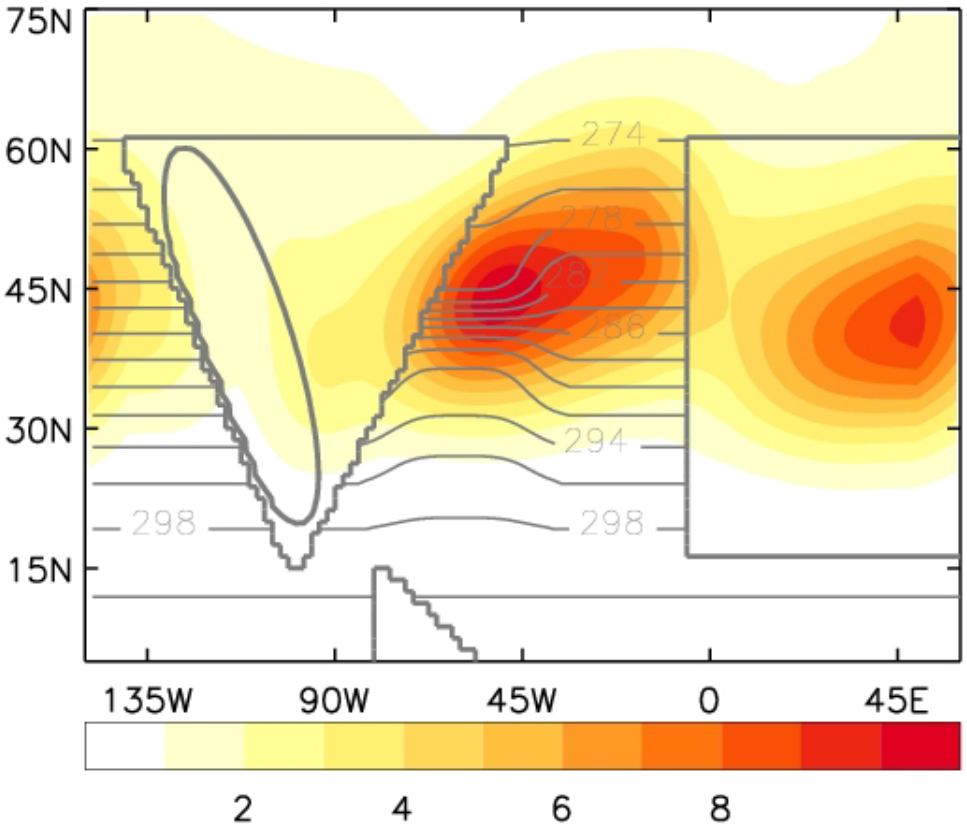

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Rocky Mountain experiment

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Gulf Stream anomaly

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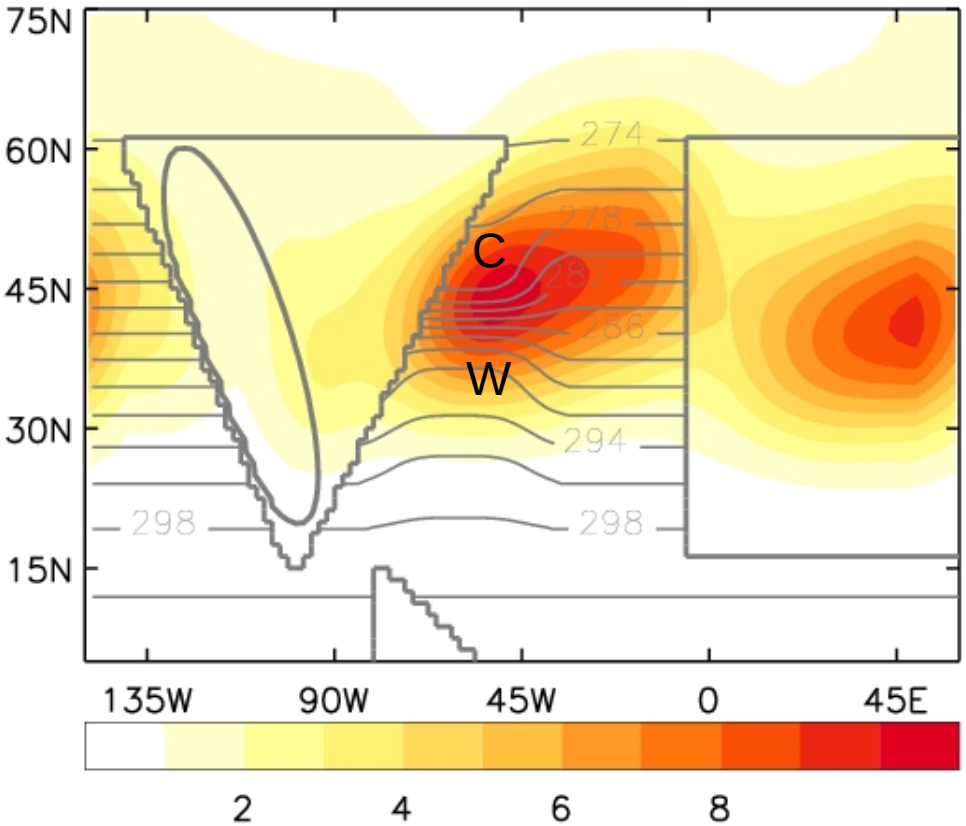

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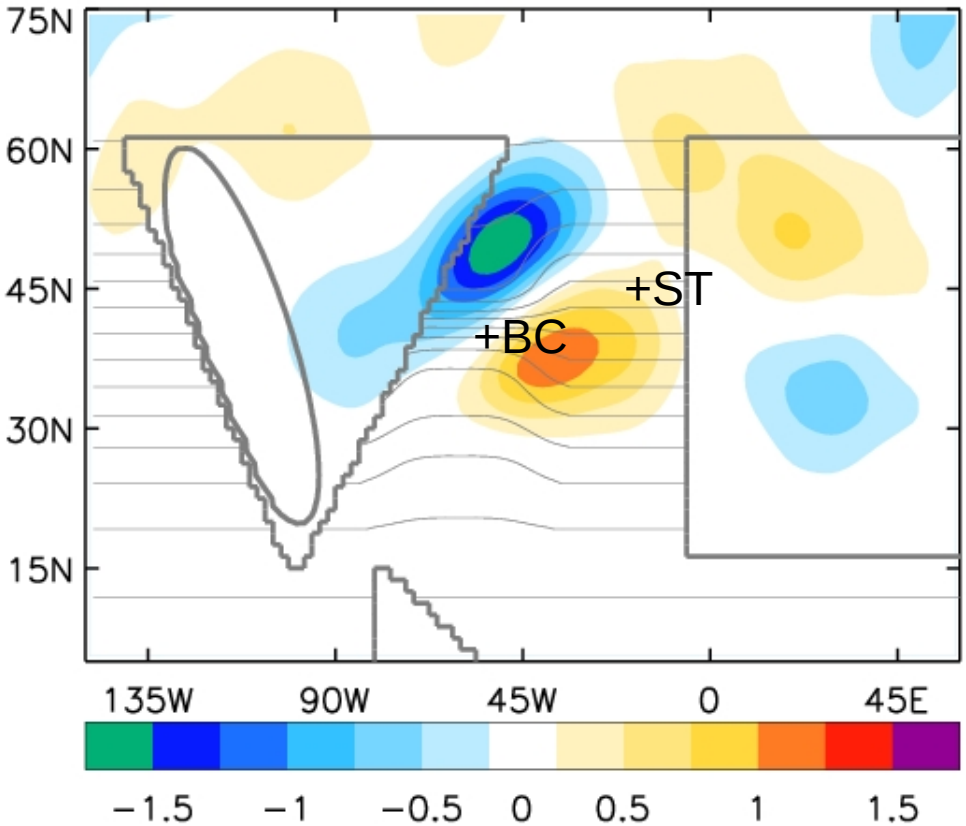

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Gulf Stream anomaly

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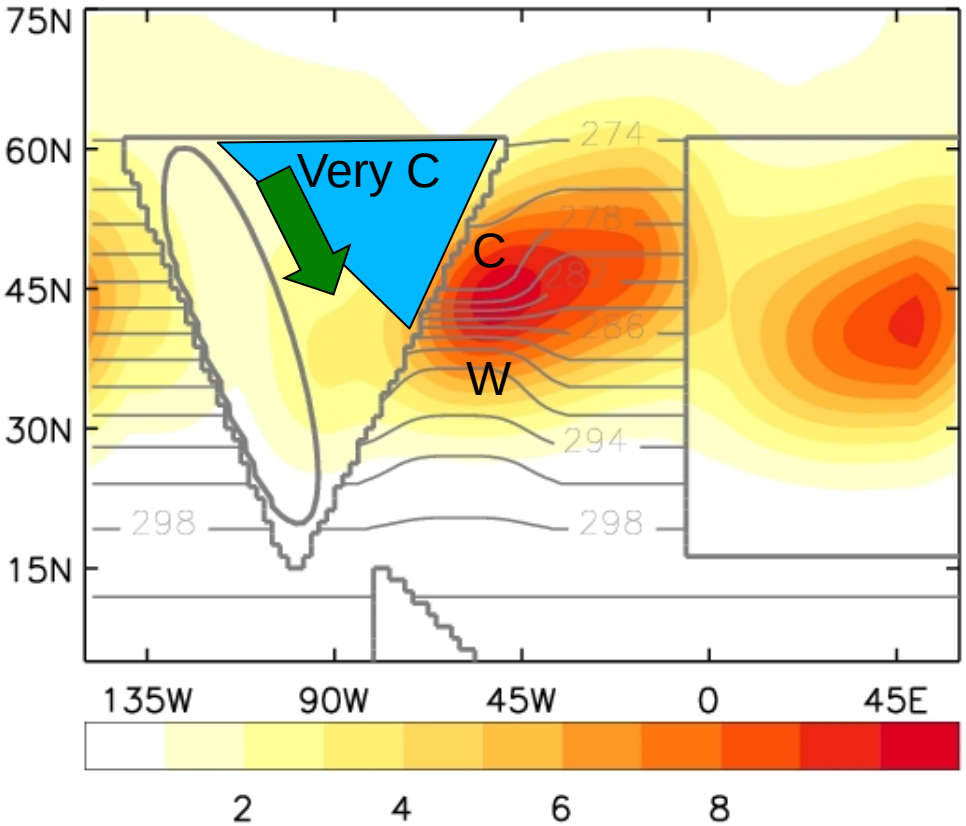

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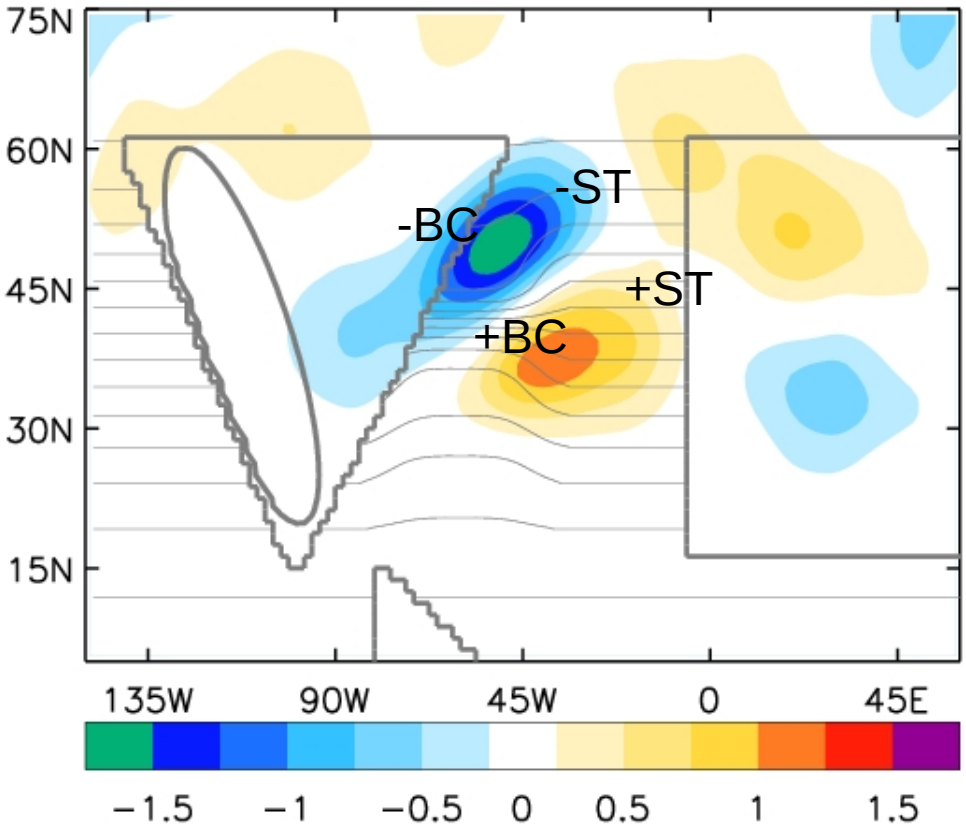

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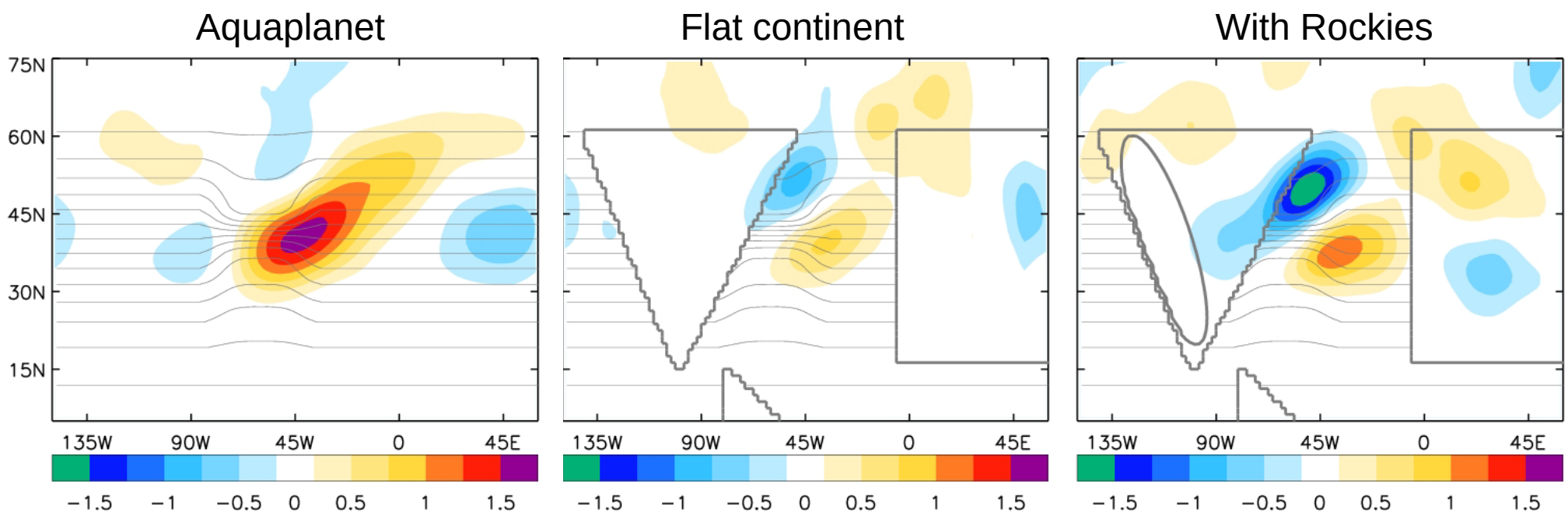
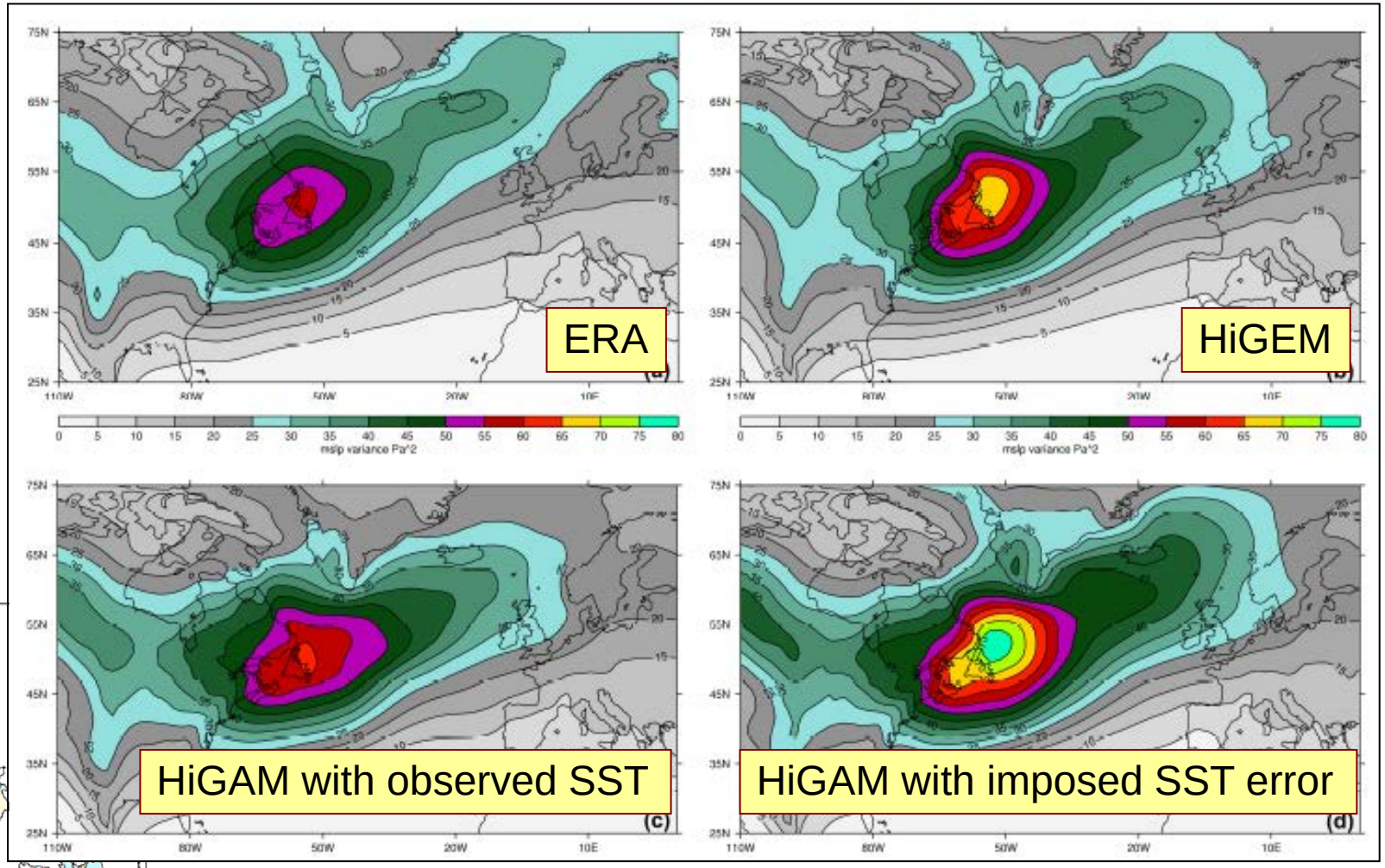
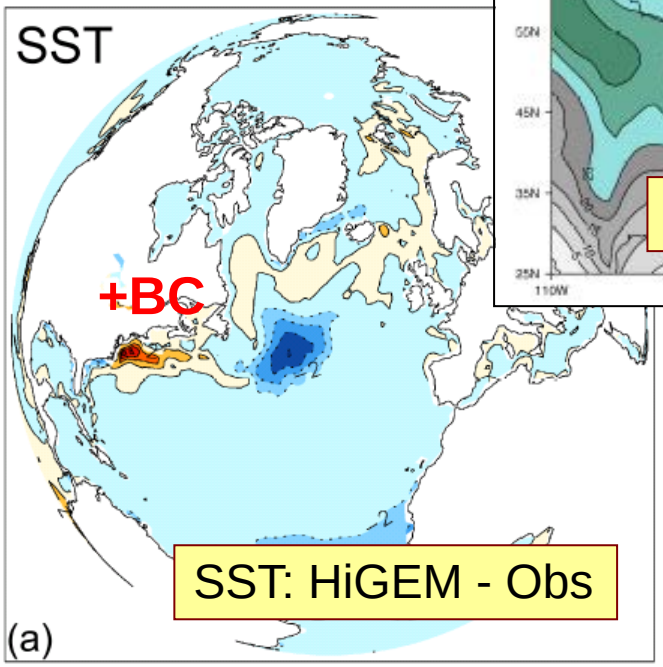


Response to “Gulf Stream” SST perturbation is sensitive to background structure

Gulf Stream anomaly



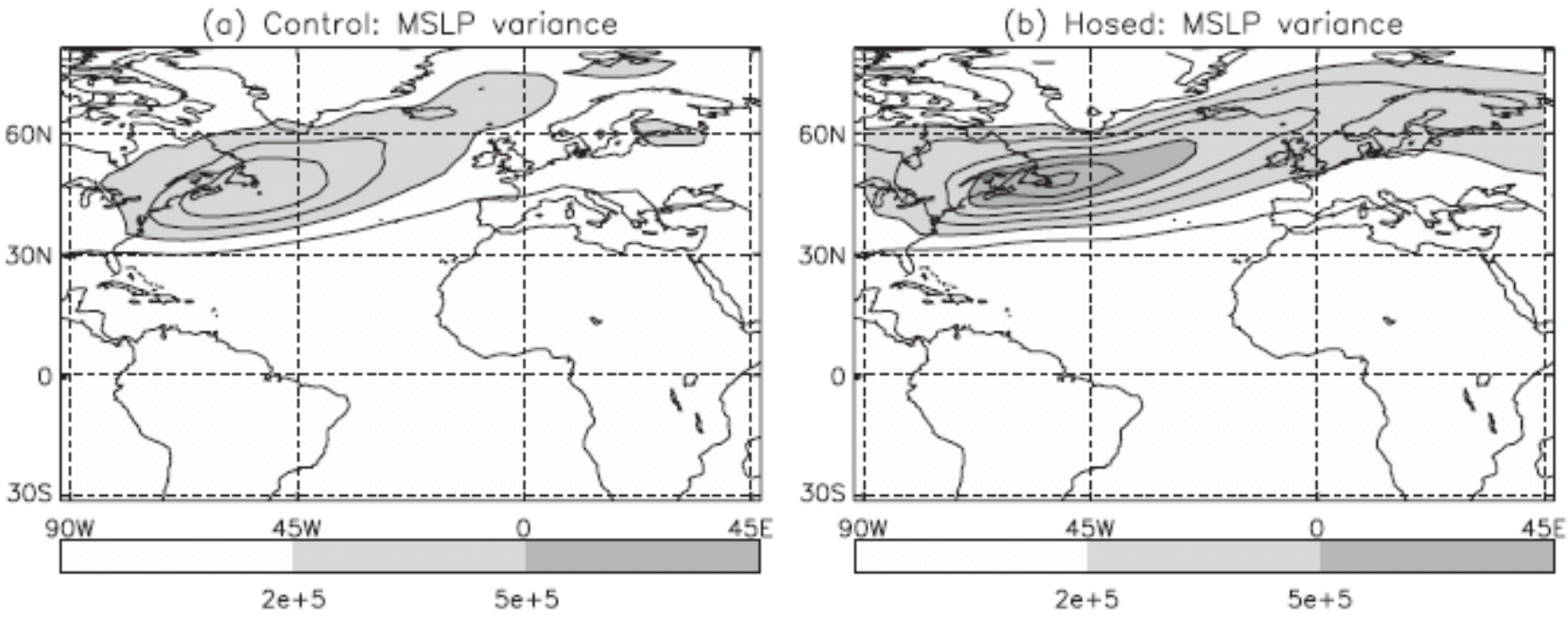


Coupled HiGEM storm track error at least partly associated with North Atlantic SST error

Particularly increased baroclinicity at coastline

Keeley et al (submitted QJRMetS)

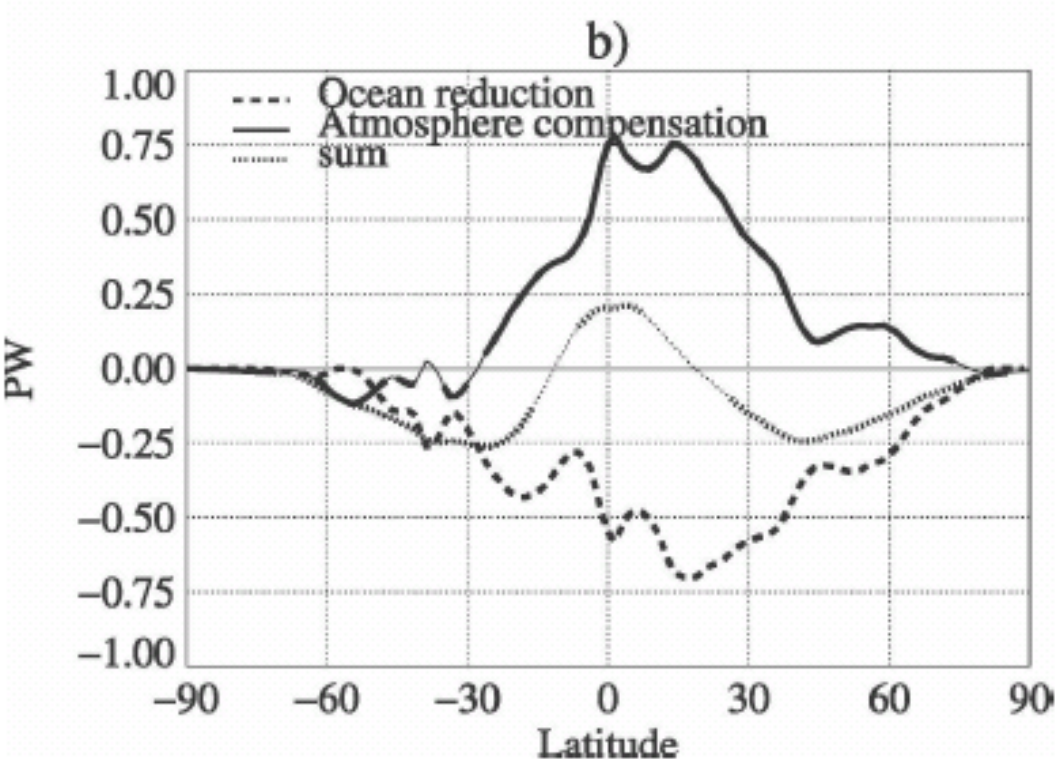
SST fronts and energy transport



- MOC shutdown experiment (reduced ocean Poleward Heat transport, PHT)
- Storm track analysis (Brayshaw et al 2009; data from Velinga and Wu 2008)
  - Stronger NH storm tracks
  - PHT by NH storm track stronger
  - Associated with local increases in tropospheric baroclinicity due to ocean circulation change

SST fronts and energy transport

- Atmosphere/ocean PHT compensation not complete
  - Vellinga and Wu, 2008

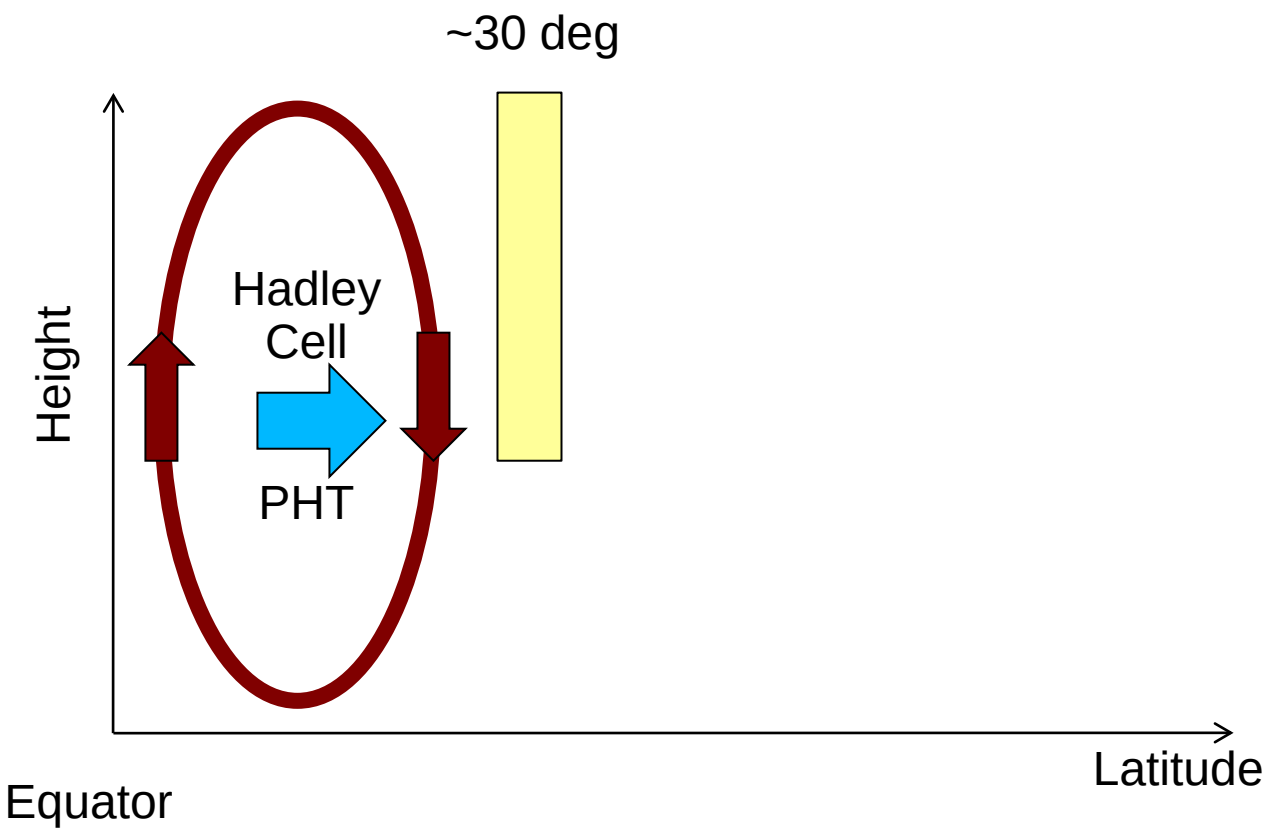


- Perhaps surprising?
  - Bjerknes compensation
  - Stone (1978) constraints

SST fronts and energy transport

Two “sources” of baroclinicity (c.f., Nakamura 2004, 2008; Brayshaw et al 2008):

- Tropical circulation (subtropical jet)



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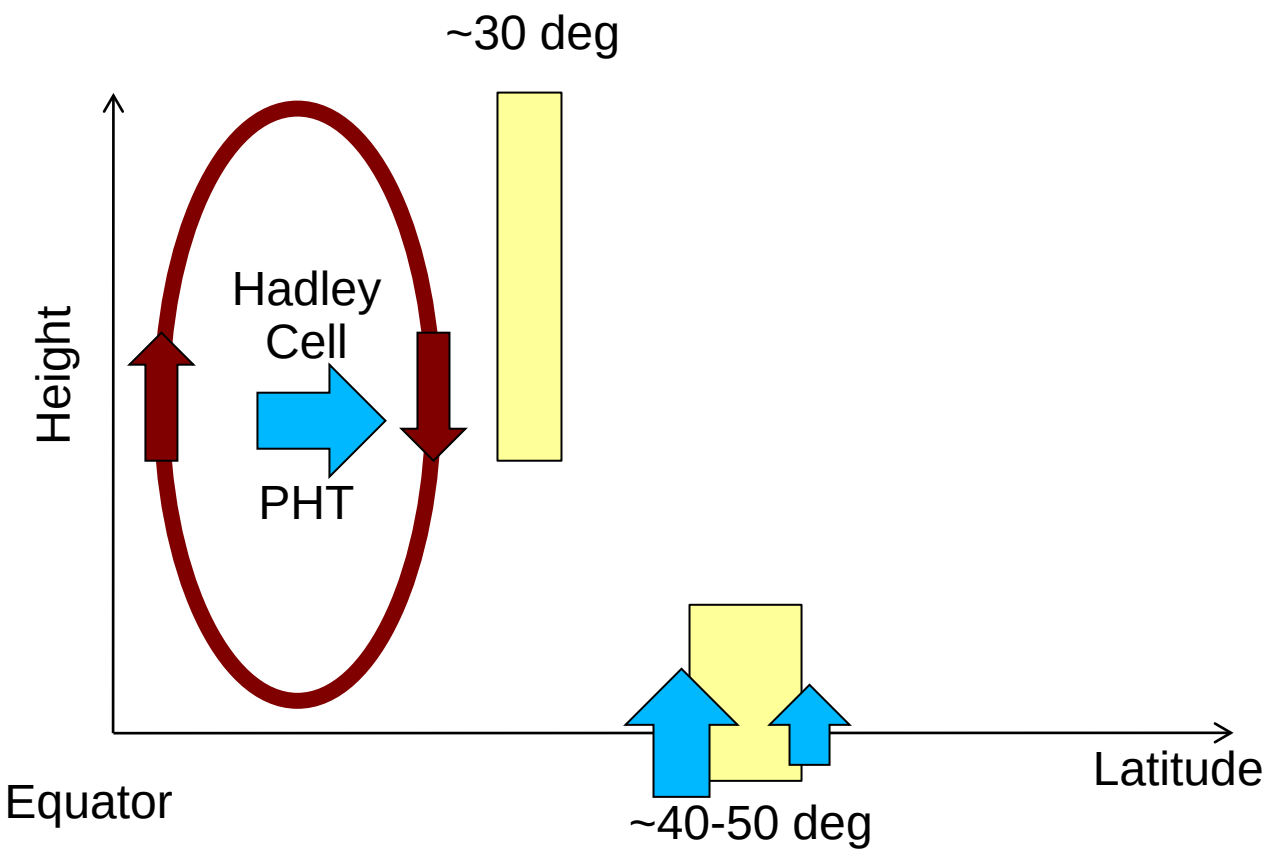

Differential surface heat fluxes
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SST fronts and energy transport

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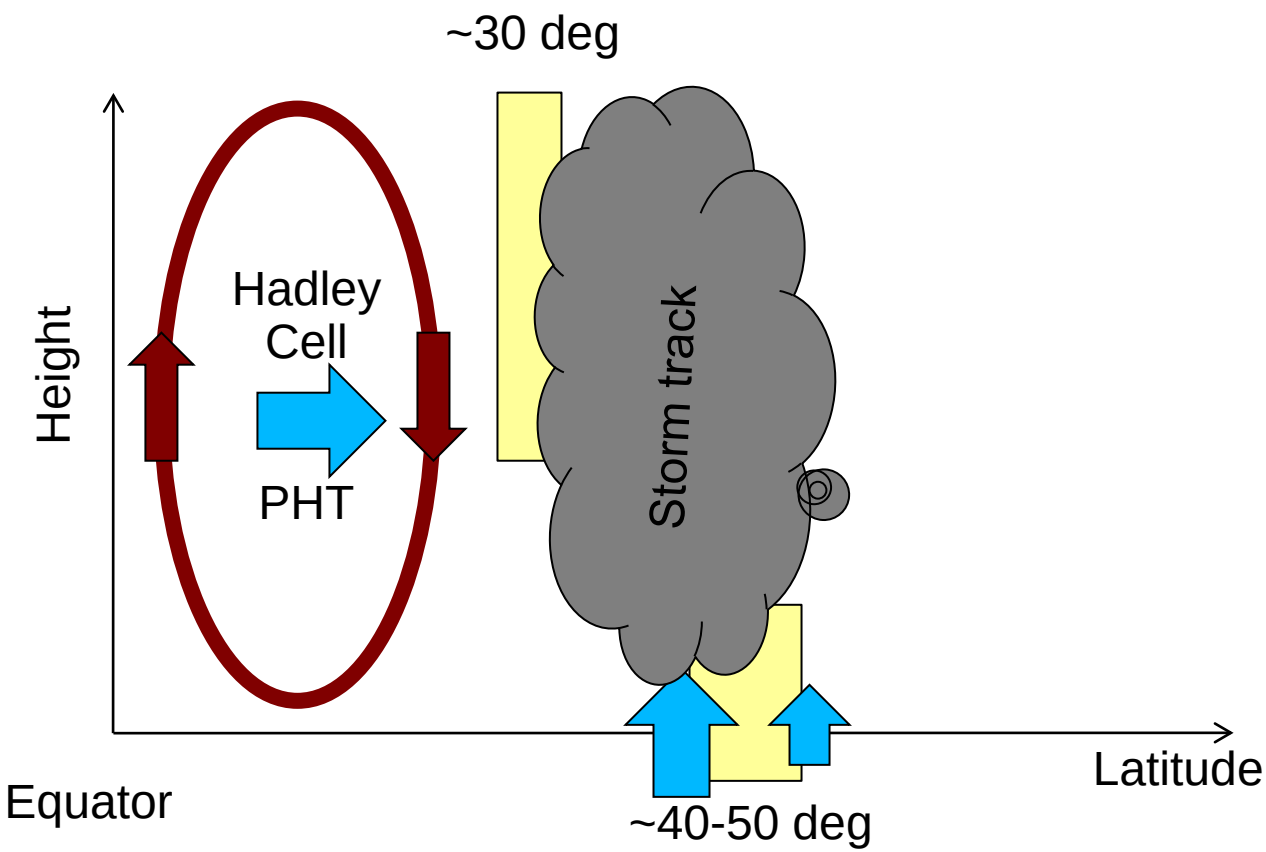

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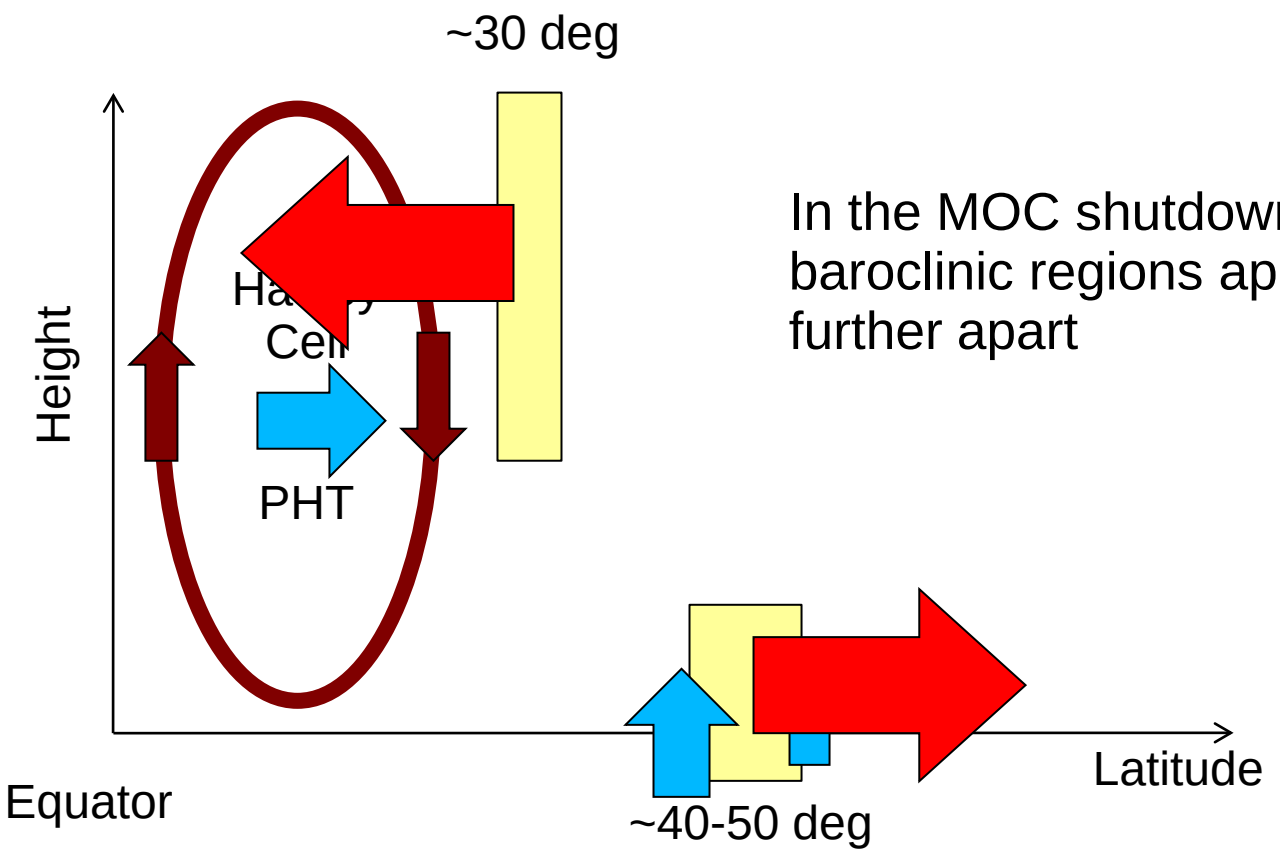

In the MOC shutdown experiment, the baroclinic regions appeared to shift further apart

Differential surface heat fluxes from surface

SST fronts and energy transport

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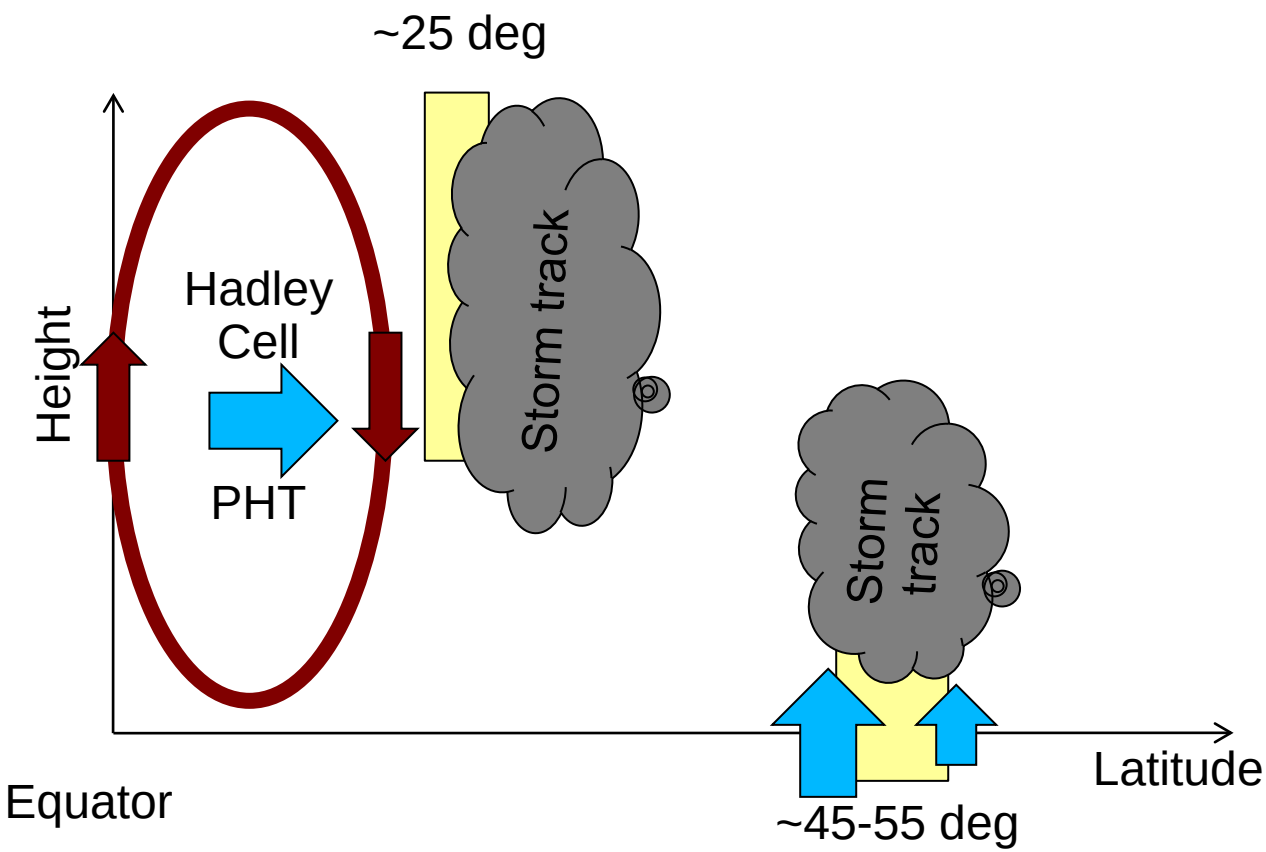

Differential surface heat fluxes
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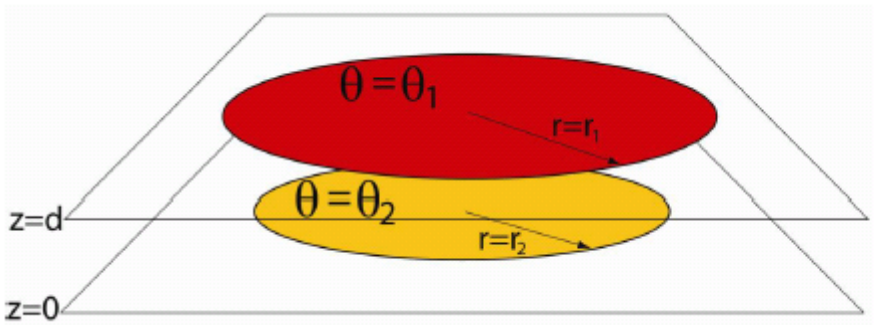
SST fronts and energy transport

- Ben Harvey (PhD Thesis)
- Surface QG model



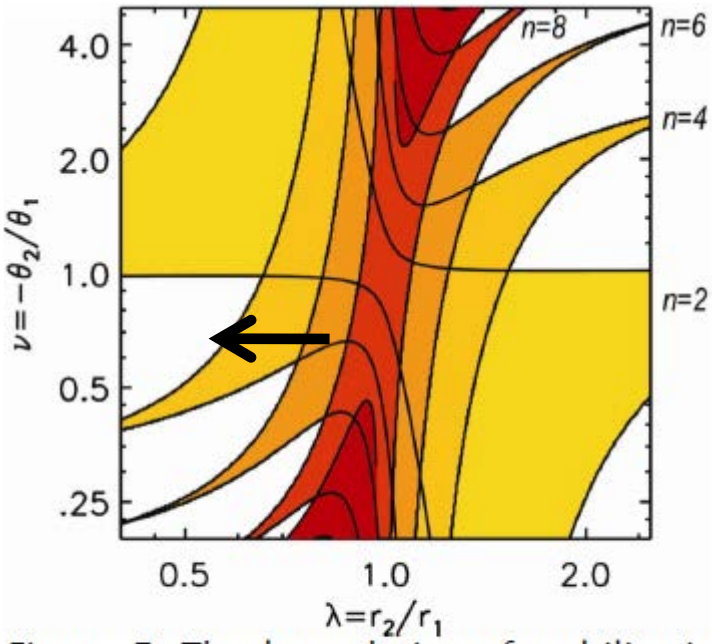
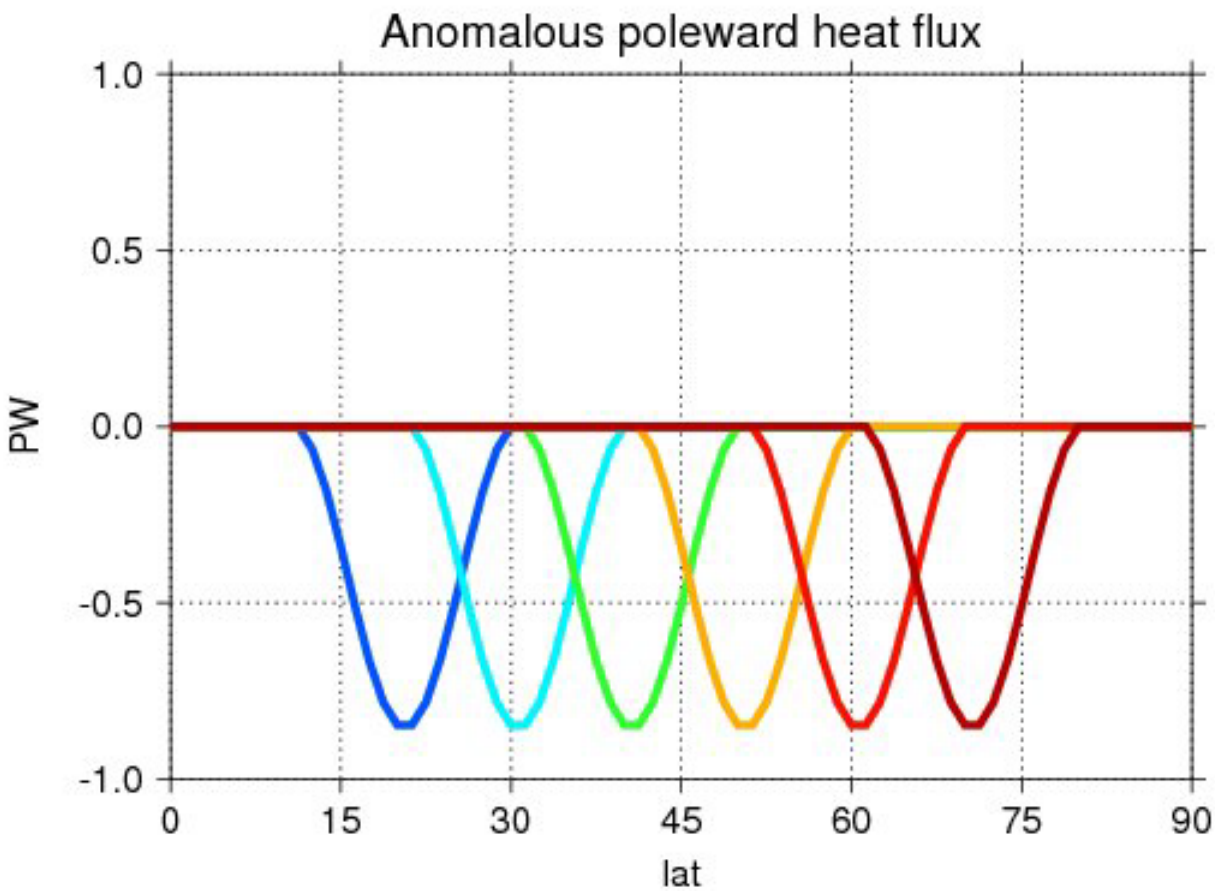


Figure 5: The boundaries of stability in parameter space. The two example cases are indicated by the letters.

As the upper and lower “fronts” move further apart in latitude, baroclinic instability decreases

SST fronts and energy transport

- HadGAM + slab ocean experiments, zonally symmetric
- Zero total ocean heat flux convergence
- Perturb ocean PHT to induce surface “fronts”
- 6 experiments: fronts at 20, 30, 40, 50, 60, 70 degrees latitude



Imposed ocean PHT anomaly

SST fronts and energy transport

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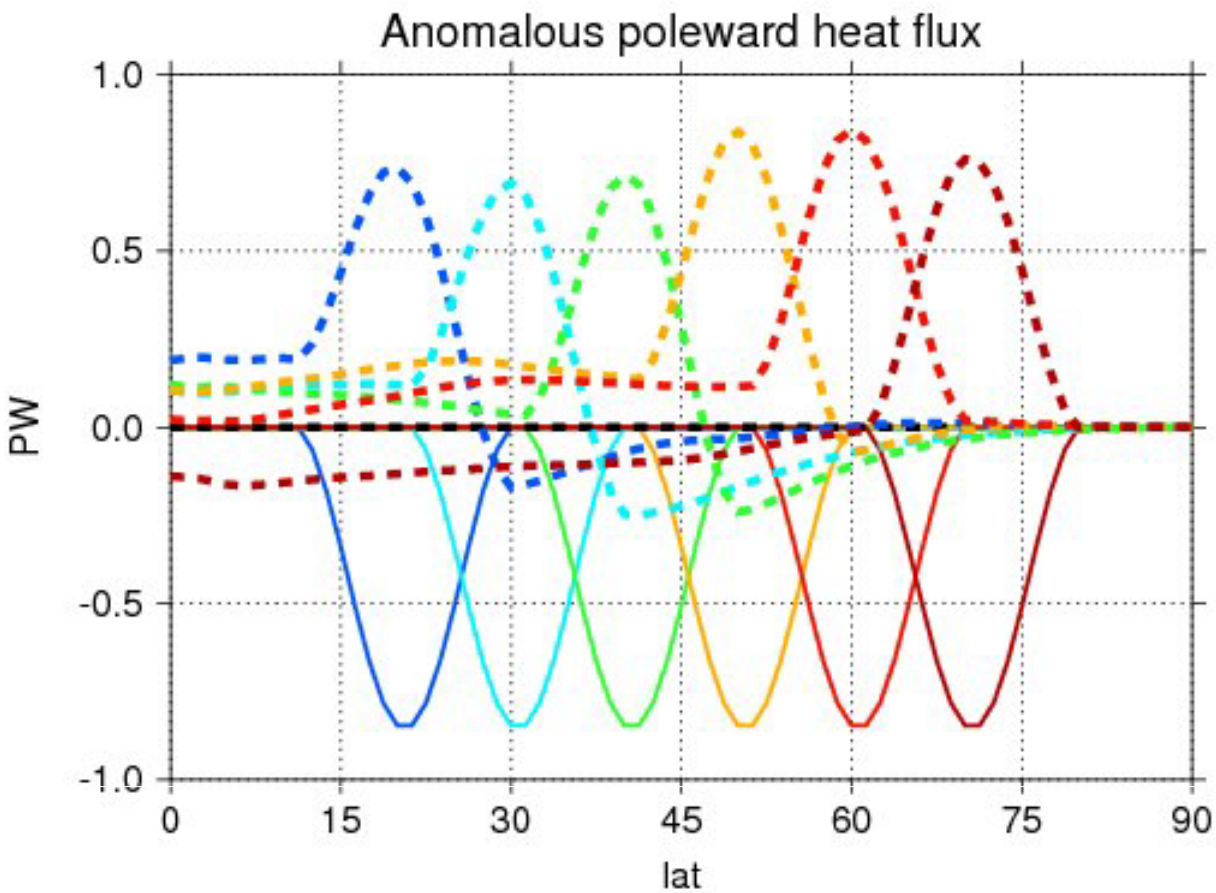

Atmos PHT response

Imposed ocean PHT anomaly

SST fronts and energy transport

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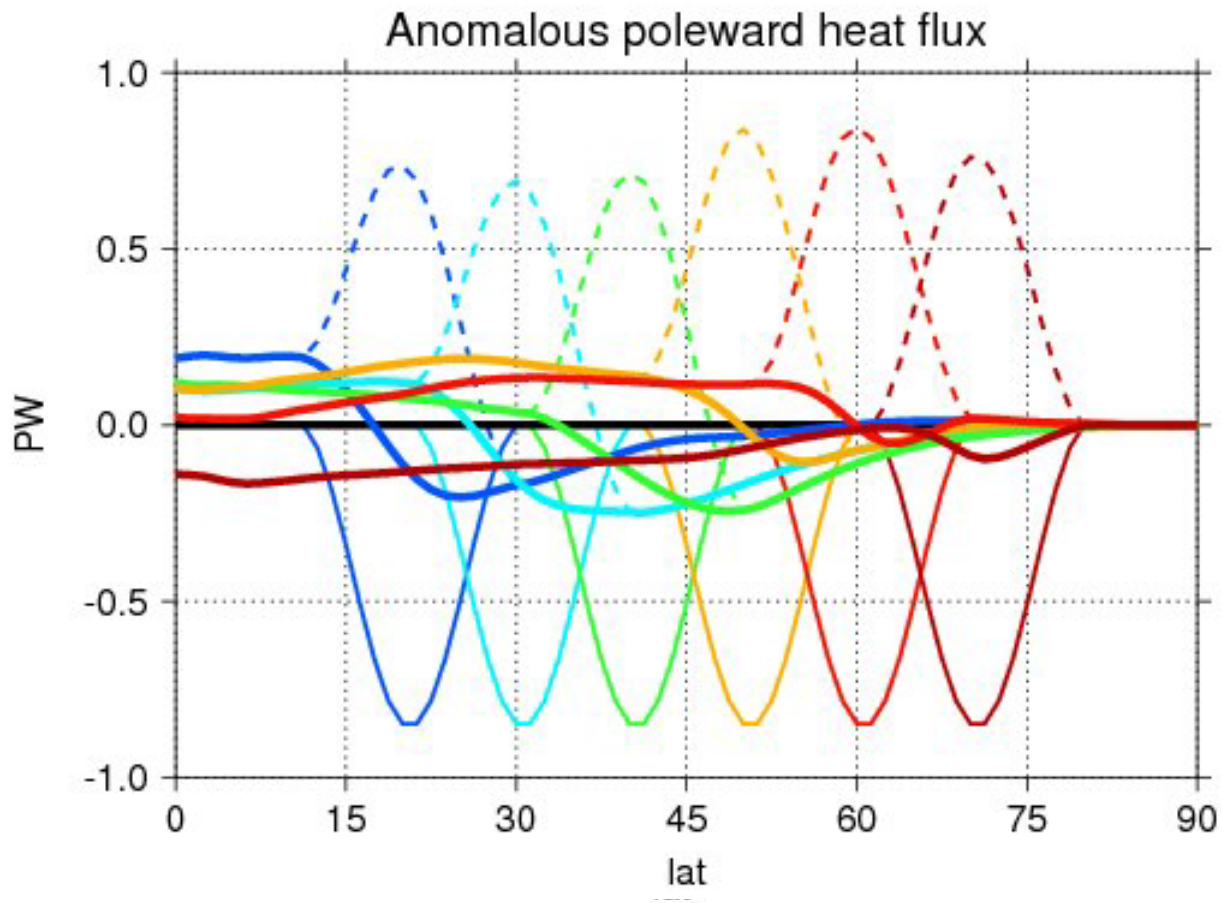

Atmos PHT response

Total PHT response

Imposed ocean PHT anomaly

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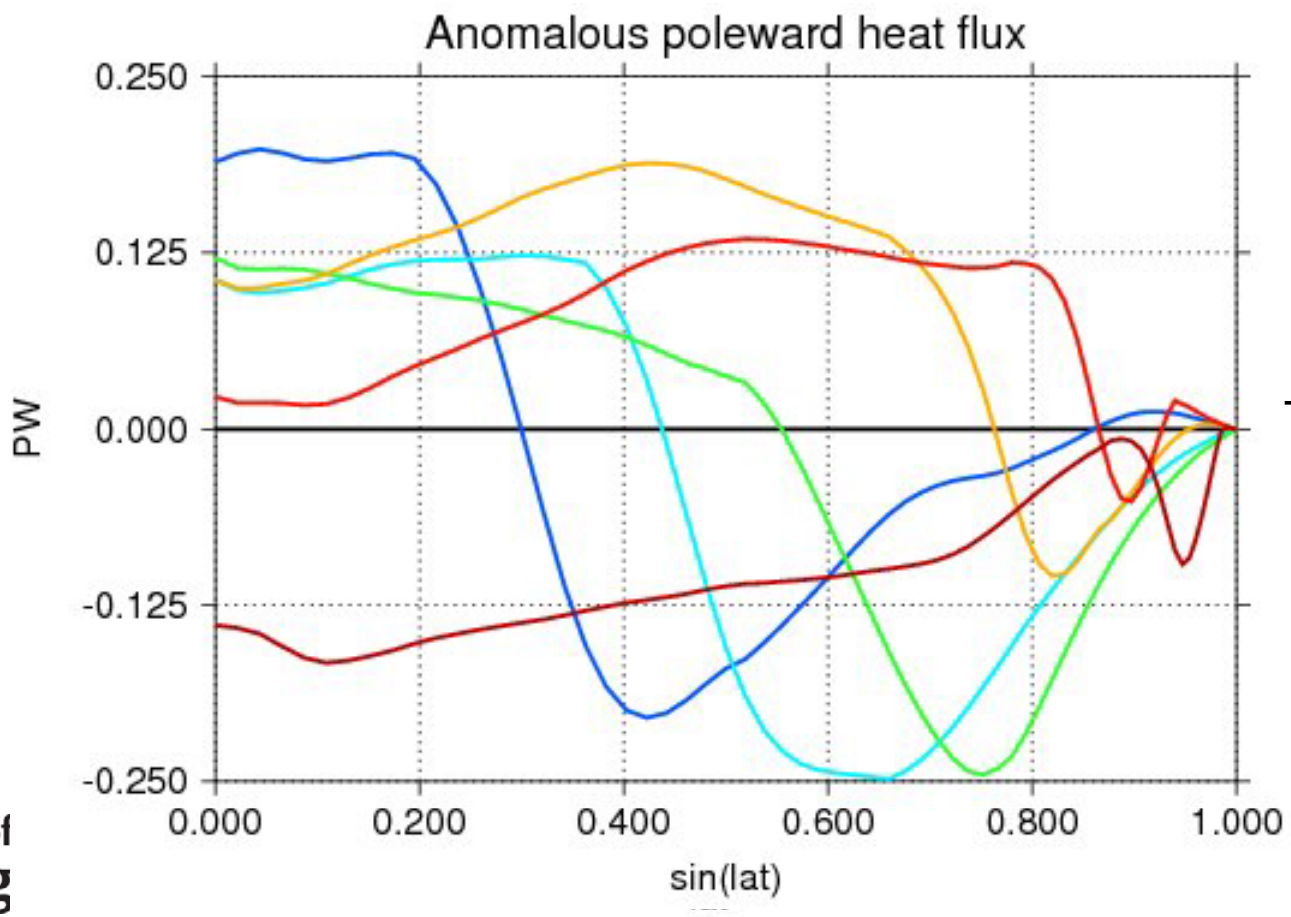
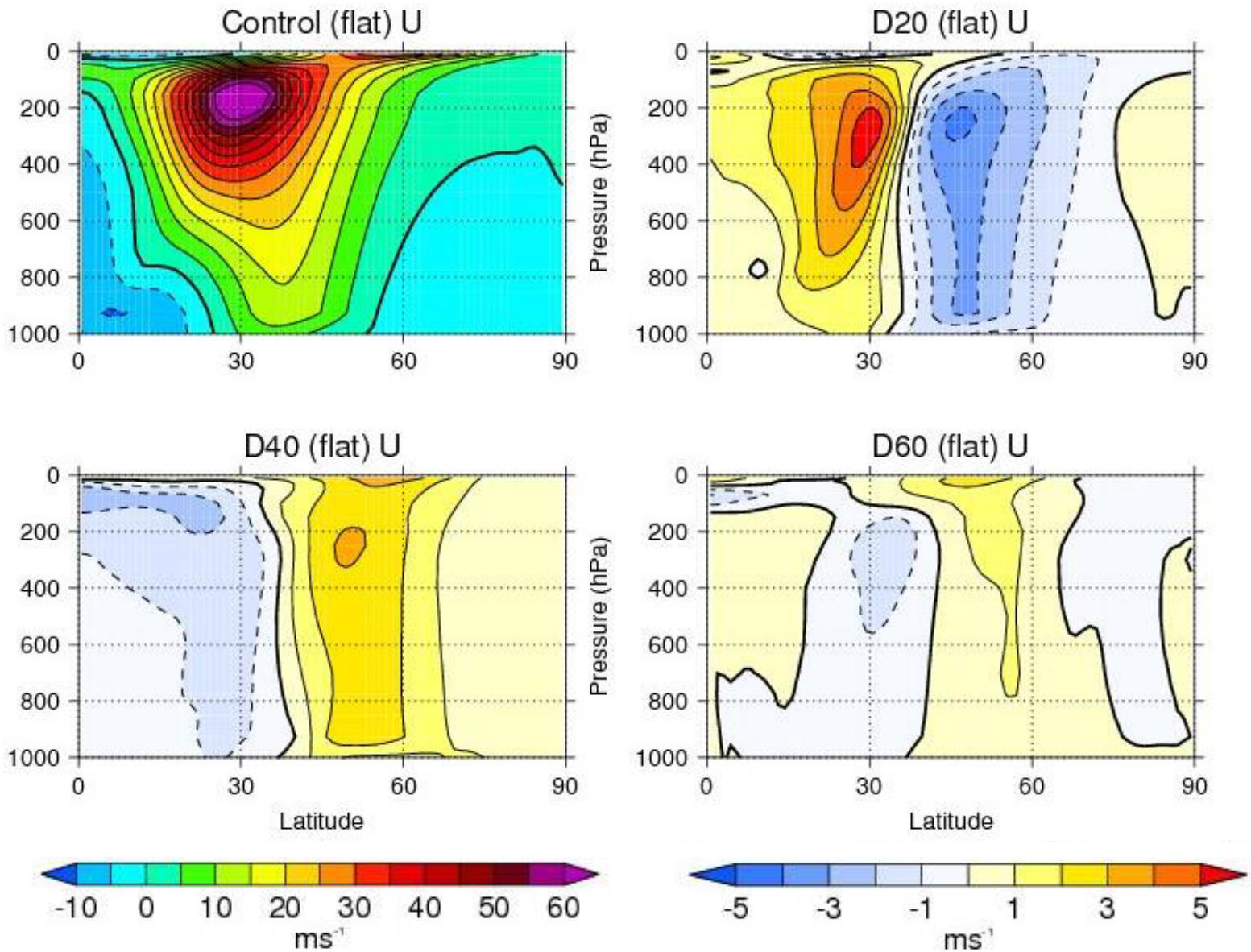


Total PHT response

SST fronts and energy transport



Summary

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- Non-compensation of poleward heat flux ~25% of imposed oceanic change
  - Need to confirm significance and understand mechanism
  - Is this a “real feature” or model artefact?
  - Thought experiment: constraints on circulation

- “Basic ingredients” of storm track structure
  - North Atlantic and North Pacific
  - Mediterranean (to follow, 2012-2013)

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Simplification and hierarchy

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  - Consider the atmospheric response to imposed forcings
  - Ignore feedback of atmosphere onto other ES components
- **A practical hierarchy of "forcings":**
  - Zeroth order (*existence of storm tracks*)
    - Baroclinic instability due to latitudinal differential insolation on a rotating spherical planet generates a zonally-symmetric storm track
  - First order (*gross structure of storm tracks*)
    - Features that control the gross structure of the storm tracks and atmospheric circulation, e.g., large-scale planetary topography
  - Perturbative (*local adjustment of storm tracks*)
    - "Small" applied forcing that modifies the atmospheric circulation but do not cause a fundamental reorganisation.
      - Structure of storm track response sensitive to existing "first order" structure, e.g.,
        - Extratropical SST anomaly
        - Insolation change

Understanding lower-order structure

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- Traditional approaches:
  1. (Non-)linear stationary wave modelling
     - e.g., Held et al 2002 for a review
  2. “Remove feature X” GCM experiments
     - e.g., Wilson et al 2010, Manabe & Broccolli 1990
  3. Very simplified GCM experiments
     - e.g., Inatsu et al 2003, Cash et al 2005

- Problems
  1. Prescribed heating and links to real boundary conditions
  2. Attribution of local response to a particular feature
  3. Interpretation of response in terms of real BCs