Boundary wave communication of bottom pressure and overturning changes for the North Atlantic

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NATURAL ENVIRONMENT RESEARCH COUNCIL

Rapid Climate Change

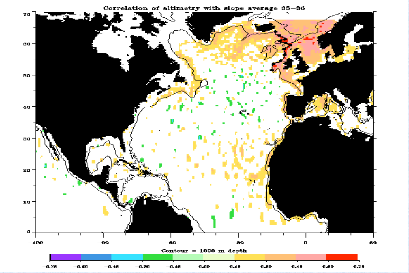
How changes in the high latitude forcing communicate over the ocean?

Downstream response at lower latitudes along the western boundary involving:

- fast boundary waves propagating against the sidewalls and along the equator (topographically trapped waves, equatorial Kelvin waves)

- an intermediate response involving changes in local circulation

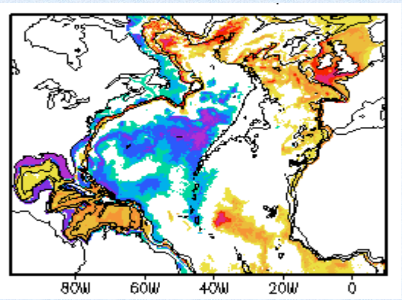
- slower advective response



Correlation of altimetry (Hughes&Meredith, 2006)

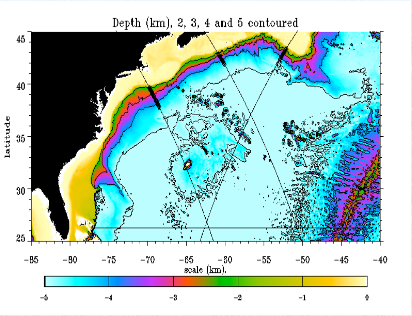
Link between bottom pressure variability and overturning changes?

Geostrophic transport estimates from the depth integral of the east-west contrasts in bottom pressure.



Link with NERC RAPID monitoring programme

which aims to detect propagating wave signals along the western Atlantic from the bottom pressure and density signals.



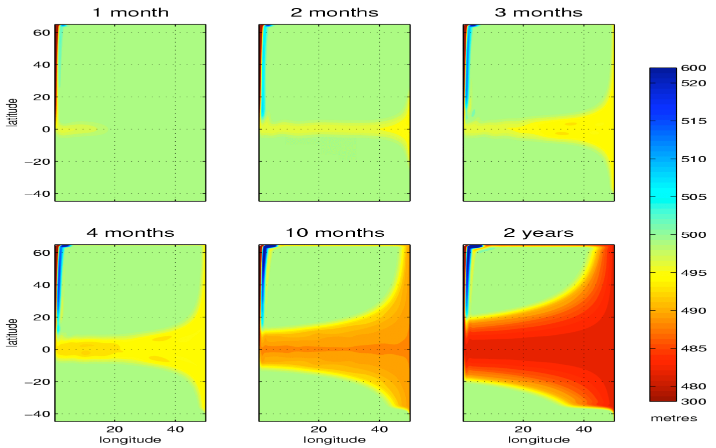
WAVE array (Western Atlantic Variability Experiment) deployment map (Hughes, Marshall, Williams, Morales Maqueda)

Background

Kelvin waves

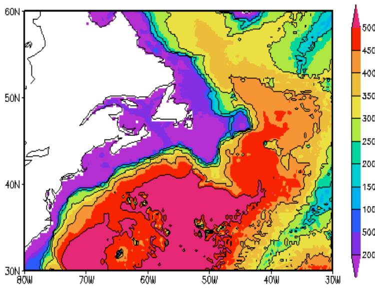
Kawase (1987) suggested, that the deep water spreading is accompanied by fast Kelvin waves, producing tropical sea surface temperature anomalies.

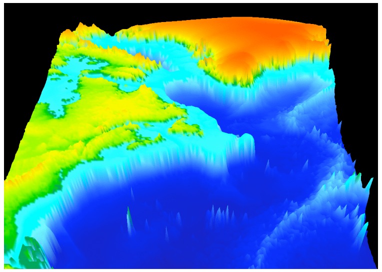
Using an idealised model, Johnson and Marshall (2002) demonstrate how overturning changes are communicated through the propagation of fast Kelvin and slower Rossby waves.



Surface layer thickness after an overturning of 10 Sv is switched on at time t = 0 on the northern boundary of the domain (Johnson and Marshall, 2002, JPO)

Is there any evidence of a similar response in more complex models or in the observations?





Boundary wave communication:
- Topographic Rossby waves
- Topographically trapped waves
  (Mysak, 1980; Huthnance, 1987)

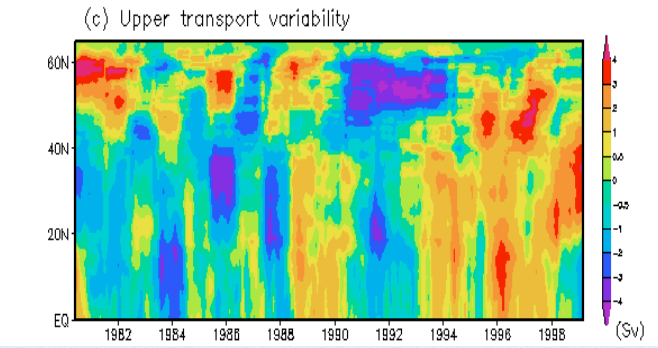
Boundary waves modified by the topography and stratification.

Model set-up

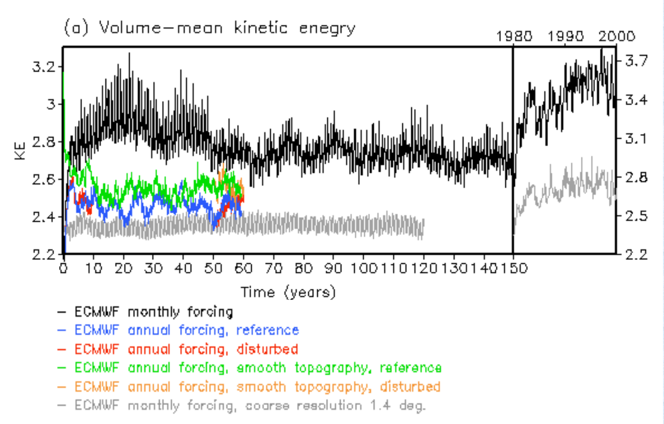
Model simulations carried out using an isopycnic model (MICOM).

Horizontal resolution is 0.23º (26 km at the equator & 13km at 60N), 16 layers in vertical (ML + 15 isopycnal layers). The model is initialised from Levitus and run for 150 years, forced by ECMWF monthly-mean winds and surface fluxes. Parallel run is performed, forced by annual mean forcing, and a twin experiment involving extra thermohaline forcing is run from year 50. The twin perturbation experiment is run for 10 years, with deep interface raised 50 m per 5 days over the northern relaxation zone.

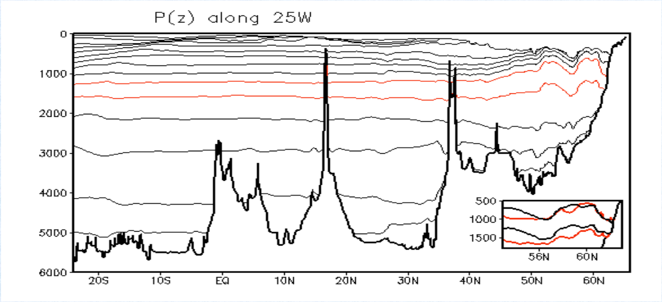
Advection is monitored by a transient model tracer, released in the Labrador Sea, when the perturbed buoyancy forcing starts.



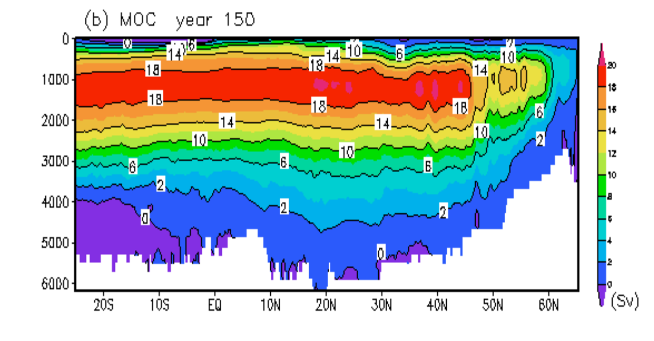
Volume mean kinetic energy



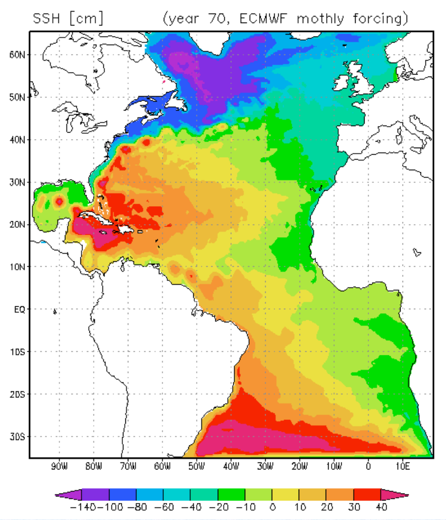
Model density interfaces along 25ºW



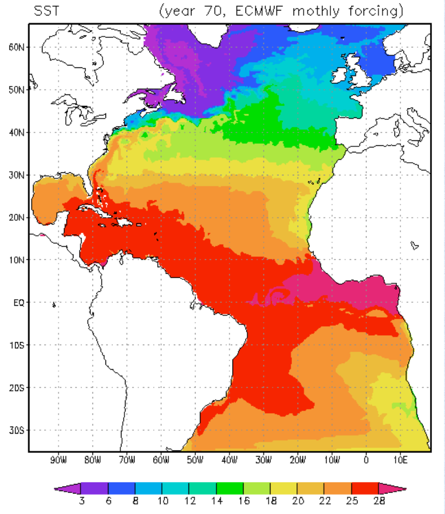
Overturning streamfunction



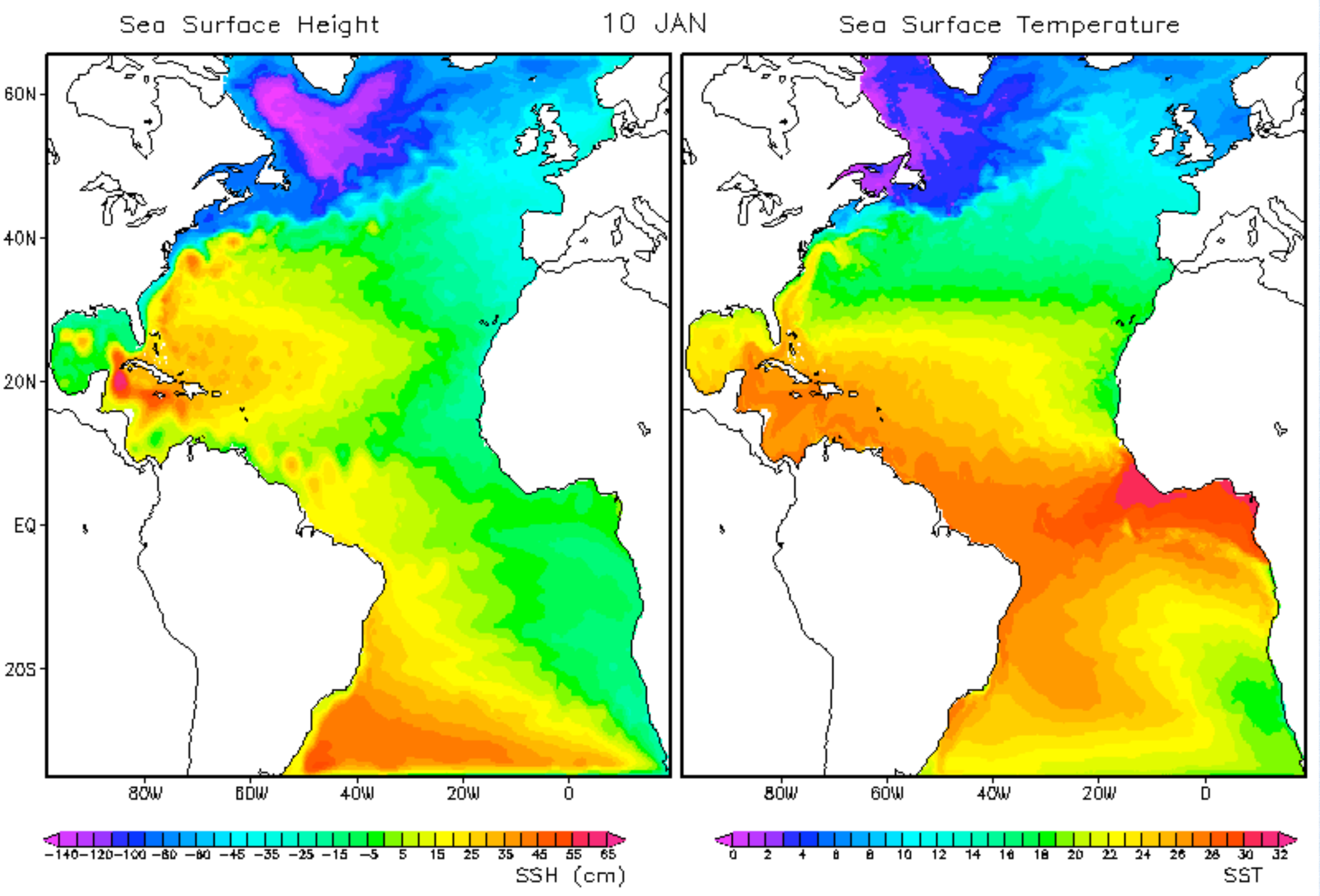
Model Sea-surface height



Model Sea-surface temperature

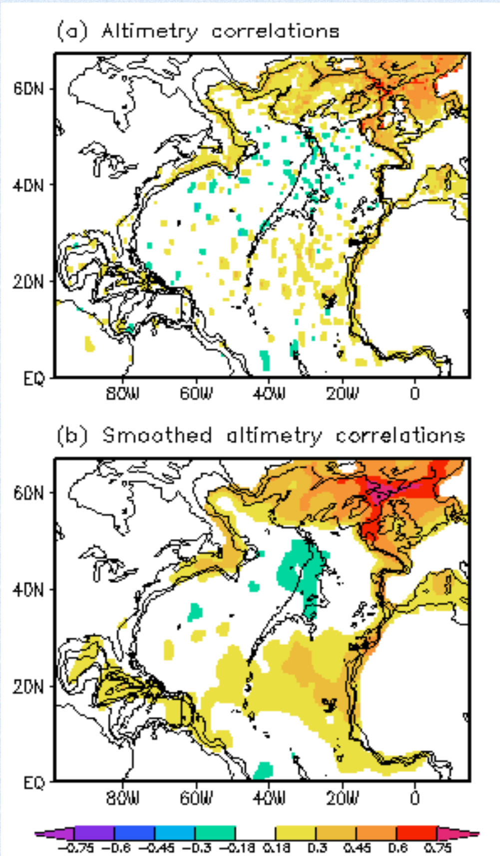


Seasonal cycle of model SSH/SST

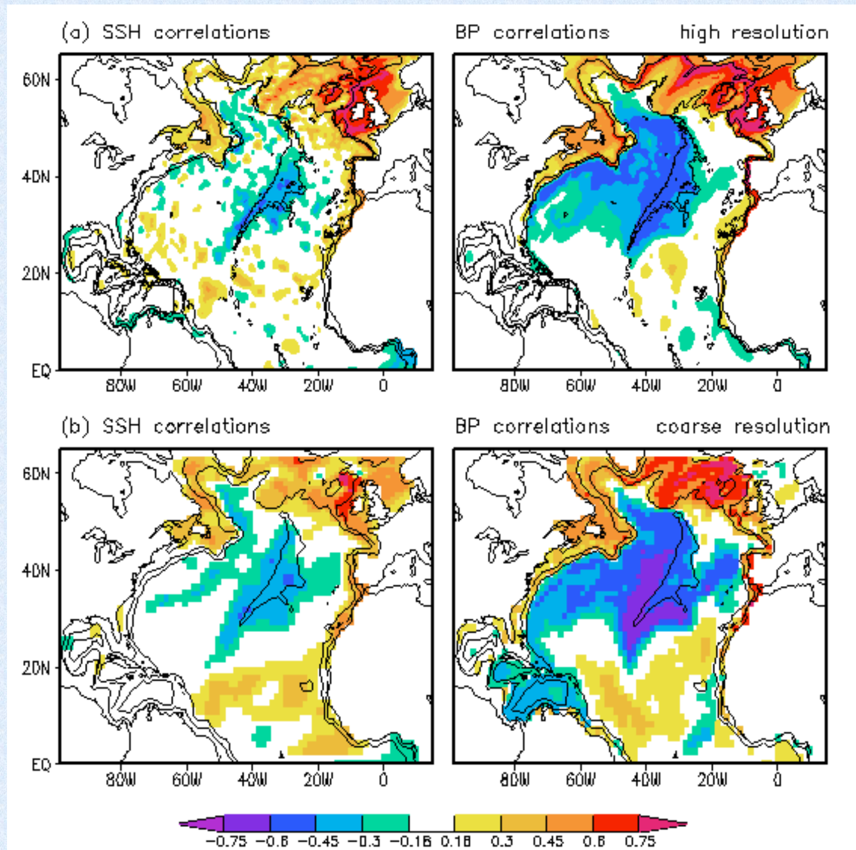


SSH and bottom pressure correlations

Correlations of altimetry



Correlations of model SSH and bottom pressure



- coherent SSH signals along continental slope;

- positive correlation on the continental slope, negative in the deep interior;

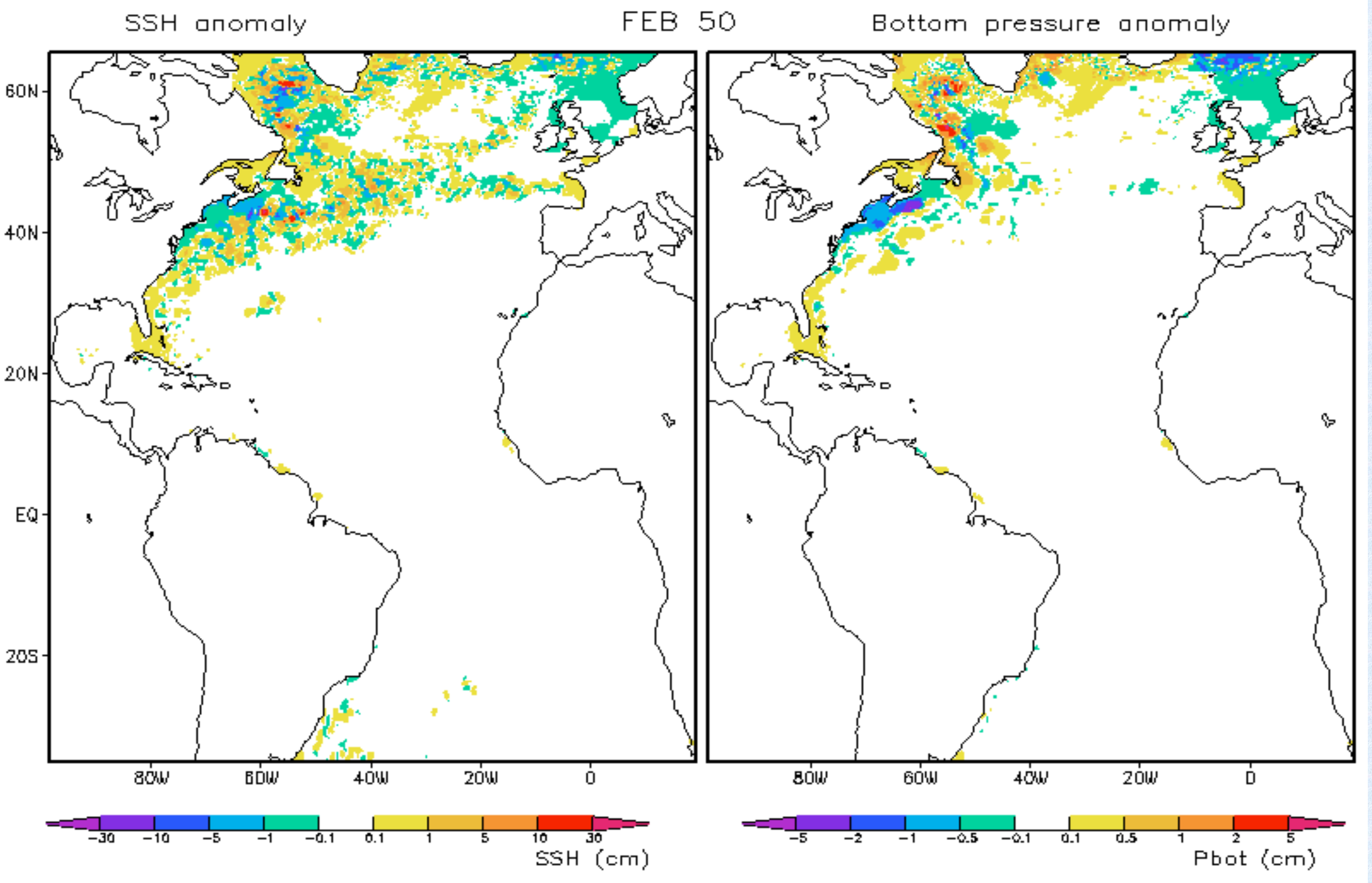
- extended BP signals and tighter gradients;

- similarity of SSH/BP signals over the shelf or in regions with weak stratification

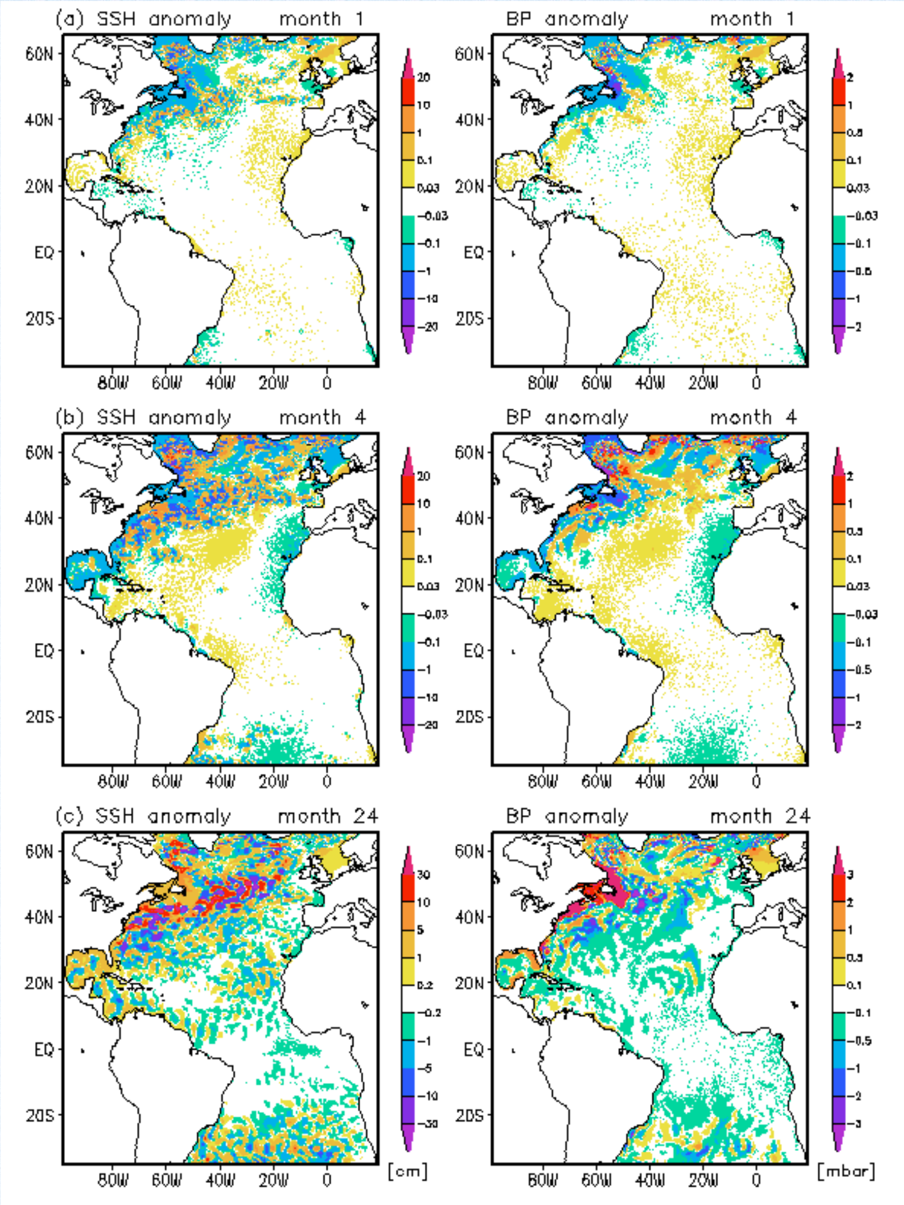
- higher correlations in case of smoothed altimetry/smooth topography

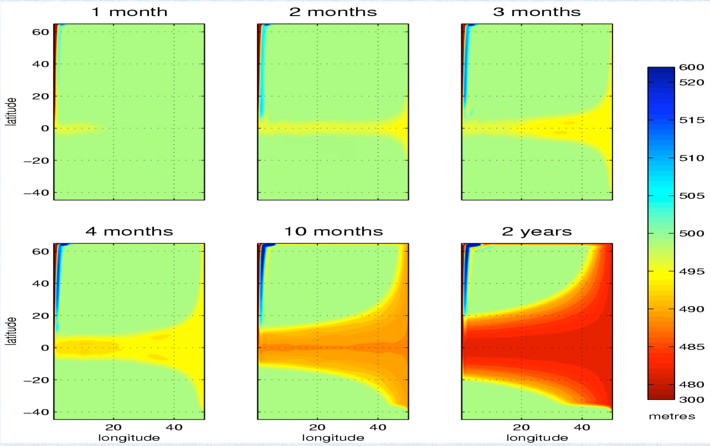
TOPEX/Poseidon and ERS-1/2;
high-pass filter, T < 360 days
(Hughes&Meredith, 2006)

Model SSH and bottom pressure anomaly propagation



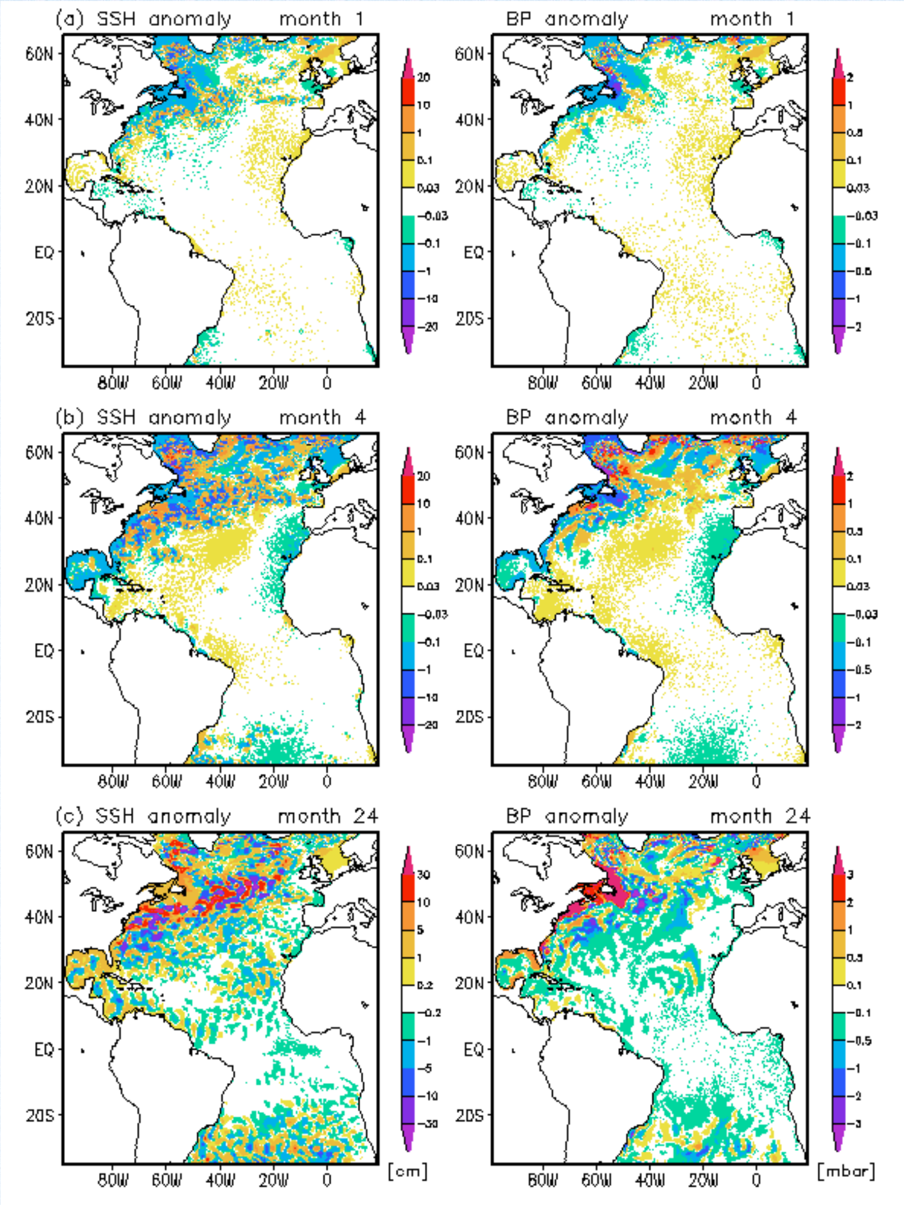
SSH and bottom pressure adjustment





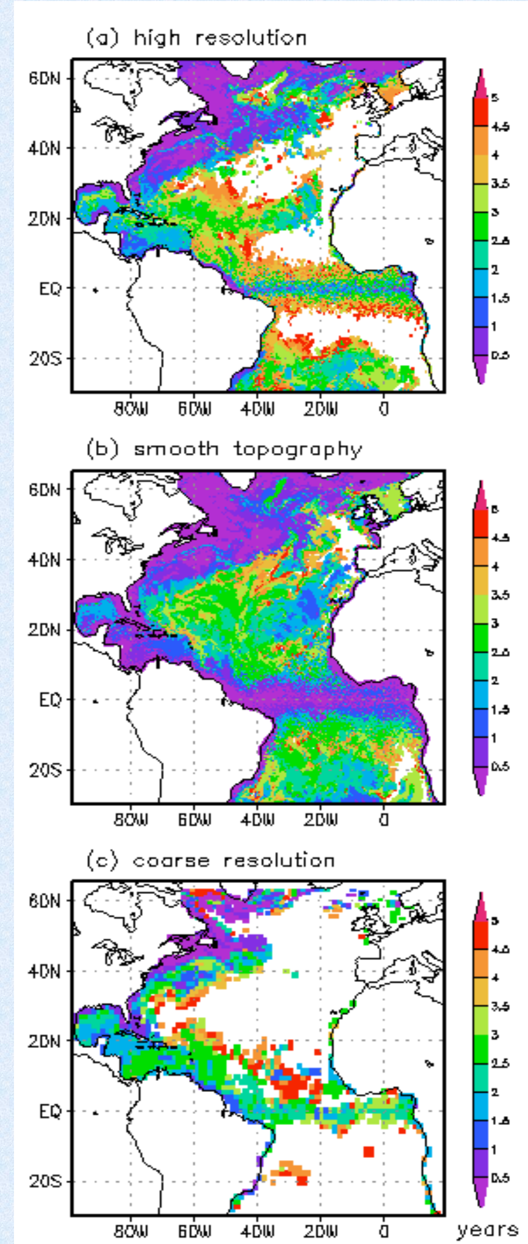
- rapid spreading along the western boundary
- slower spreading along the eastern boundary
- Rossby waves generated on the eastern boundary and propagate into ocean interior
- SSH and BP anomalies appear related, but with SSH signals on a slightly broader scale
- eddy-scale variability over the Gulf Stream extension

SSH and bottom pressure adjustment



Periods of BP adjustment

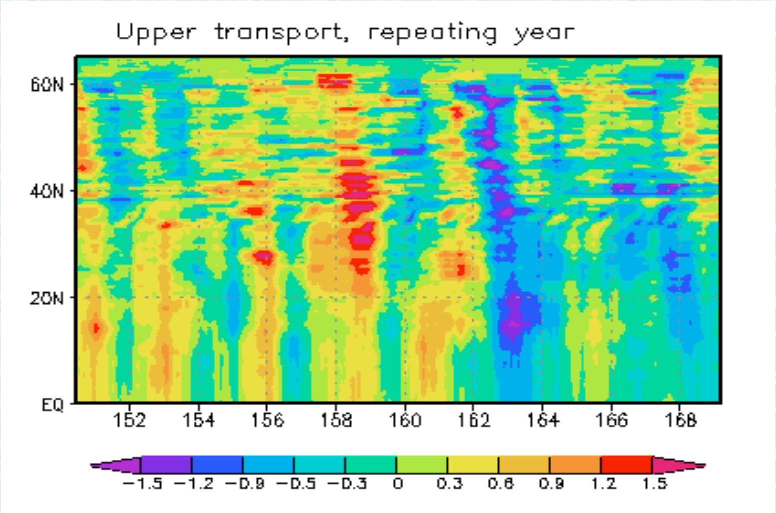
- **periods < 6 months along the western boundary**
- **Equatorial signal reaches eastern boundary in < 1 year**
- **slower interior adjustment**
- **faster adjustment in case of smooth topography**



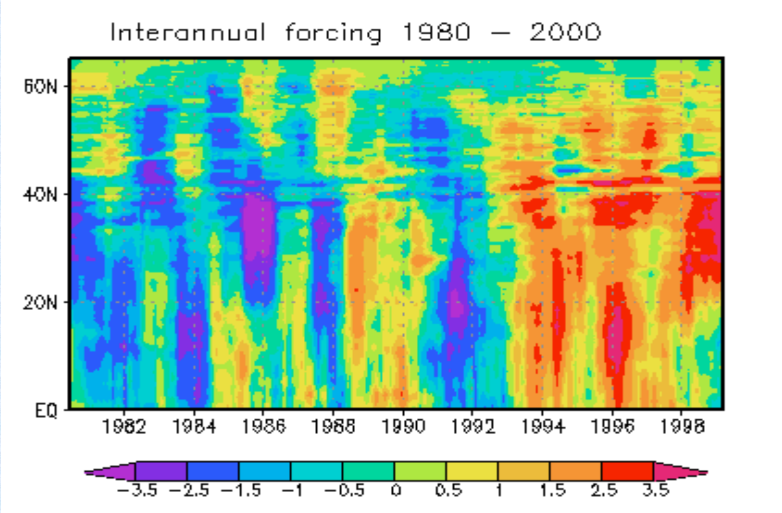
Time for |ΔBP| to adjust to: (0.1 + 1.0 |*sin* φ|) mB

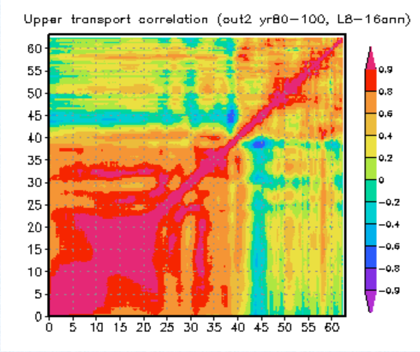
Overturning variability

Monthly forcing



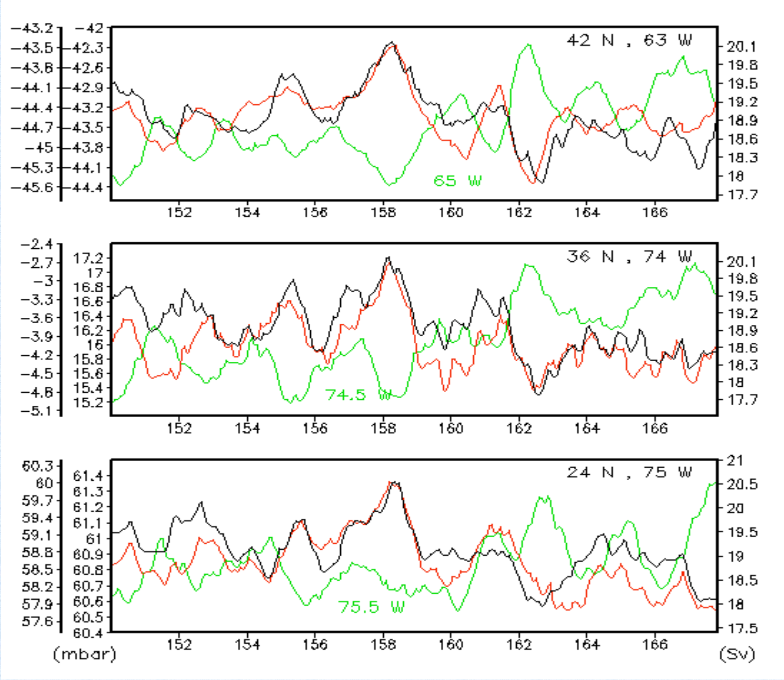
Realistic forcing 1980 – 2000



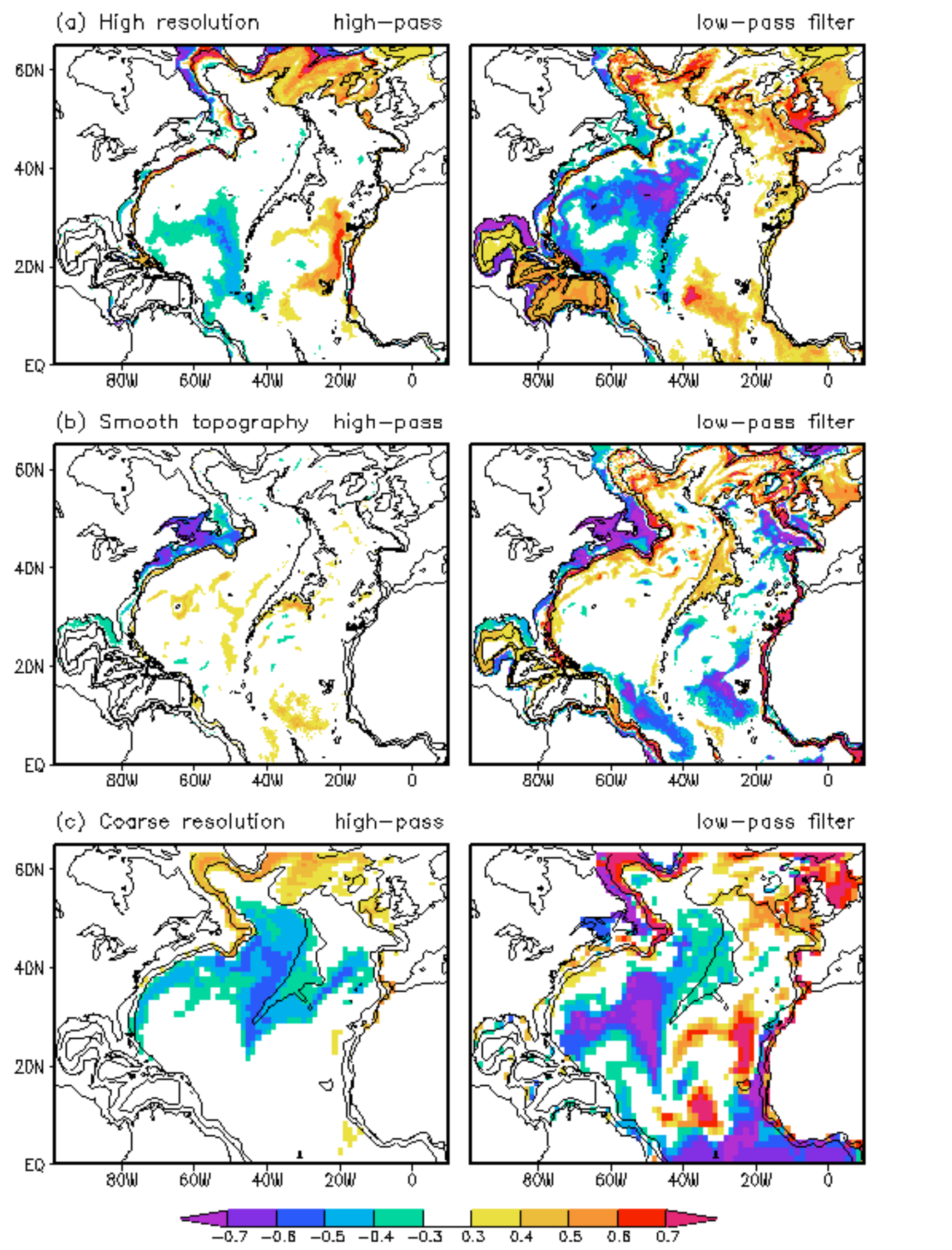


Meridional coherence of the N. Atlantic MOC, Bingham et al., GRL 2007

Bottom pressure along western boundary



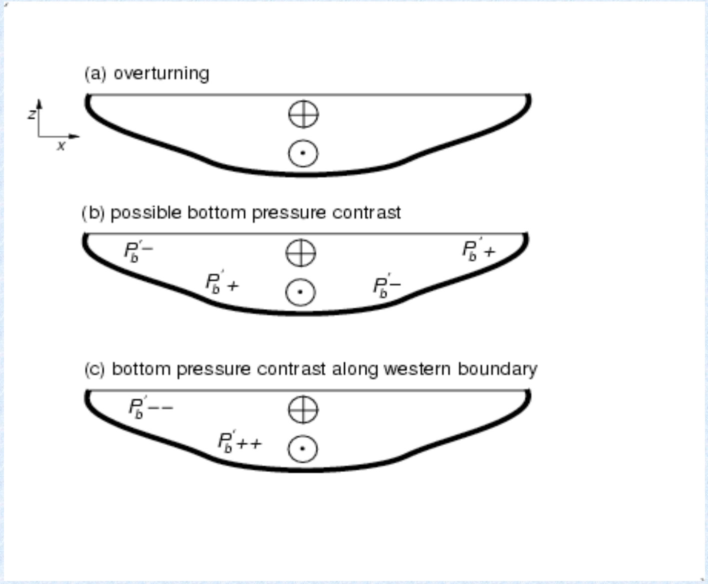
BP shelf *BP continental slope* *Upper transport*

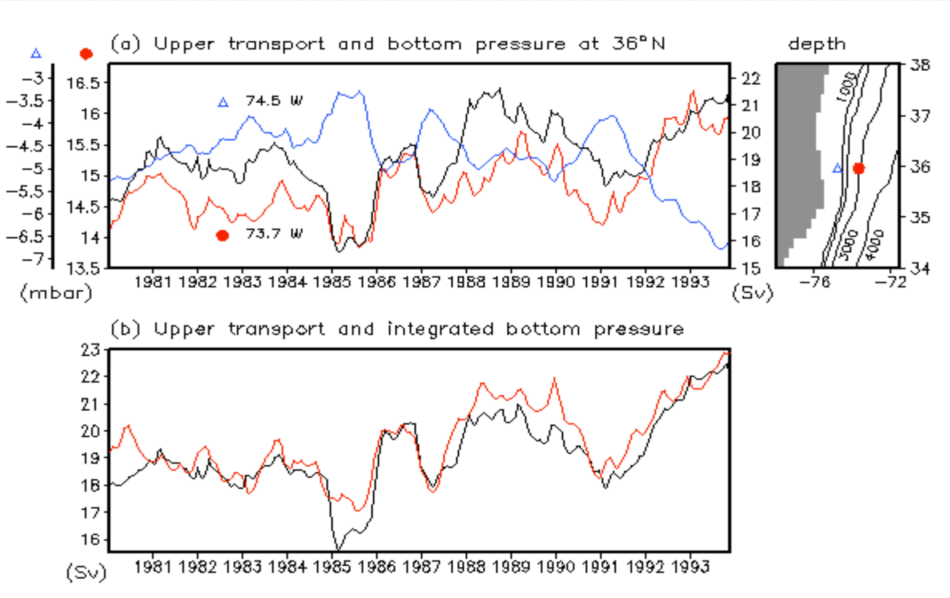


Bottom pressure and overturning correlations

- narrow, positively correlated coherent signals along the continental slope
- negative correlation over the shallow shelf
- higher correlations and contrasts in case of smooth topography
- similar response in coarse resolution model, but less clear signals

Link between bottom pressure and overturning variability



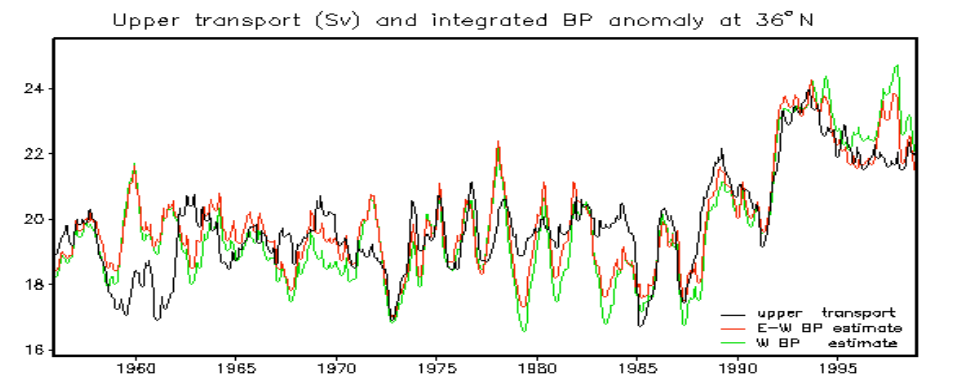


$$\rho_o f v_g = \frac{\partial P}{\partial x}$$

$$\rho_o f \int_{x_w}^{x_e} v_g dx = P_e - P_w$$

$$\rho_o f \int_z^{\eta} \int_{x_w}^{x_e} v_g dx dz = \int_z^{\eta} (P_e - P_w) dz$$

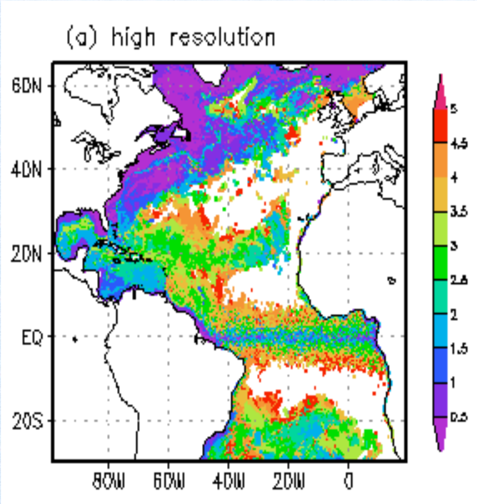
$$\psi(y, z) = \frac{1}{\rho_o f} \int_z^{\eta} (P_e - P_w) dz$$



- **Close agreement of the model transport variations and BP derived estimates on longer timescale**
- **Changes in overturning can be efficiently inferred from the western boundary BP variations**

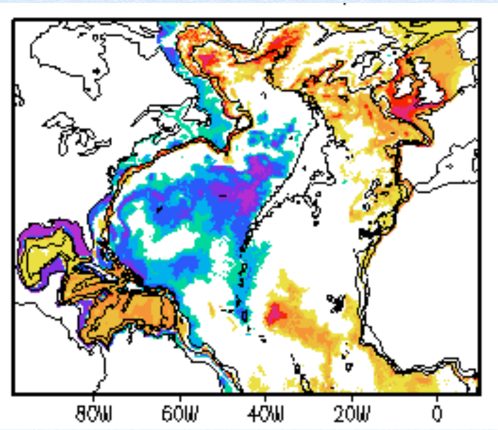
Conclusions

How changes in the high latitude forcing communicate over the ocean?



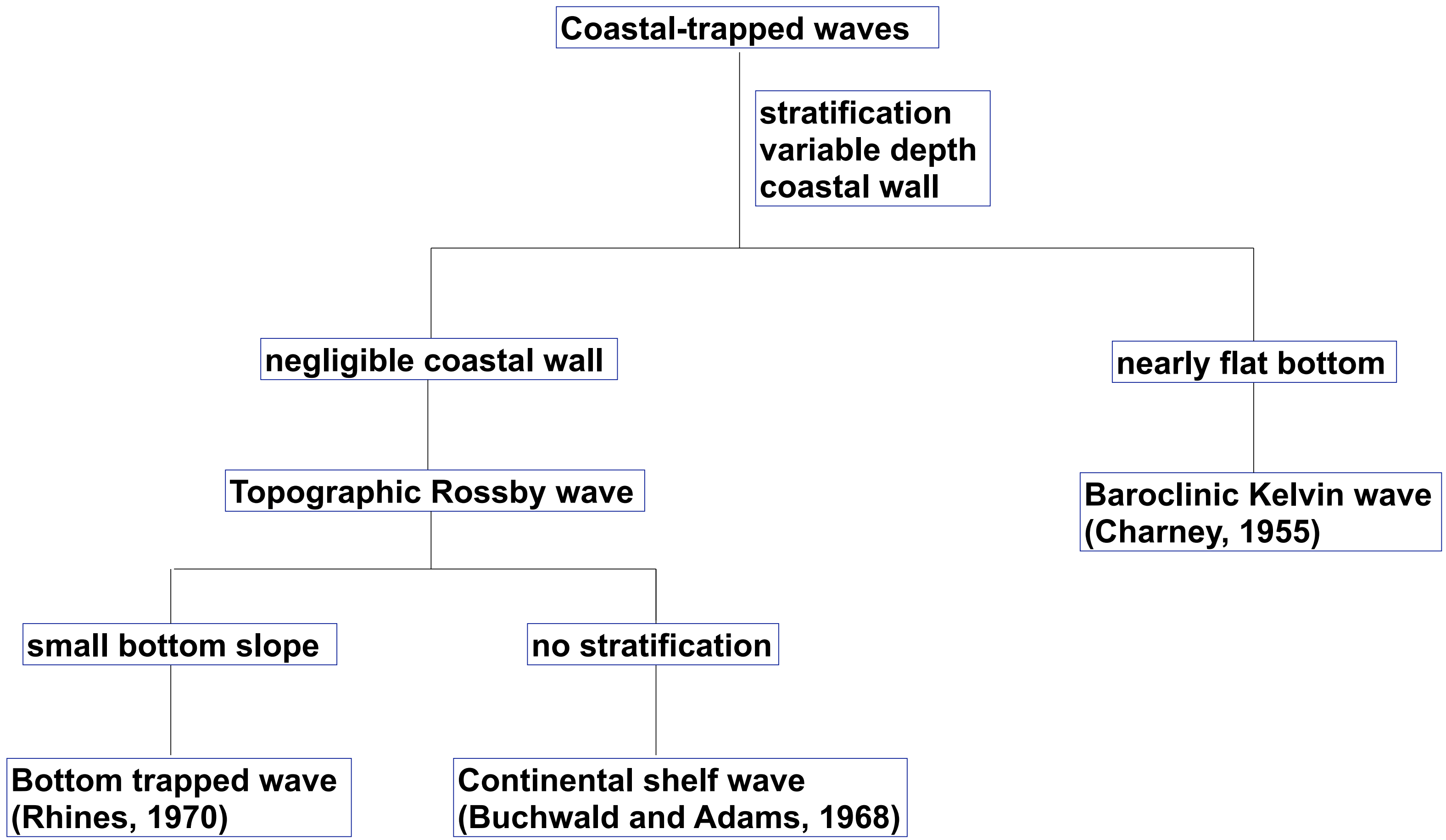
- **Boundary wave propagation on time scale of months to years**
- **Connected to interior via equatorial Kelvin waves and basin-wide Rossby waves**
- **Waves modified by the topography and stratification**
- **Higher frequency boundary waves scattered by the rough topography**
- **Wave signals associated with changes in basin-wide overturning of typically 1 – 4 Sv, occurring prior any deep advective signal**

Link between bottom pressure variability and overturning changes?



- **Boundary waves communicate bottom pressure changes rapidly around the basin, which alters the overturning**
- **Overturning variability is strongly correlated with bottom pressure changes along the continental slope**
- **Changes in overturning can be efficiently inferred from the western boundary bottom pressure variations**

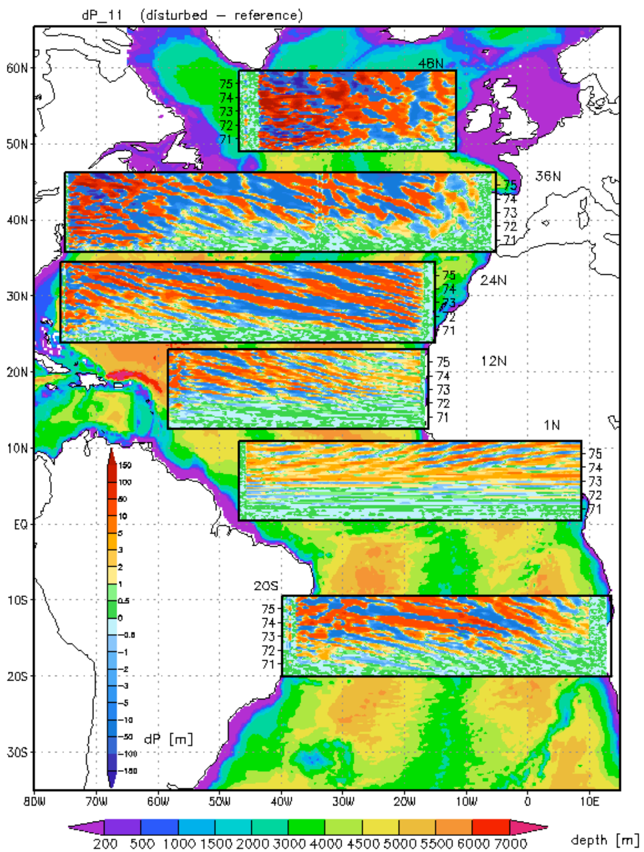
Background



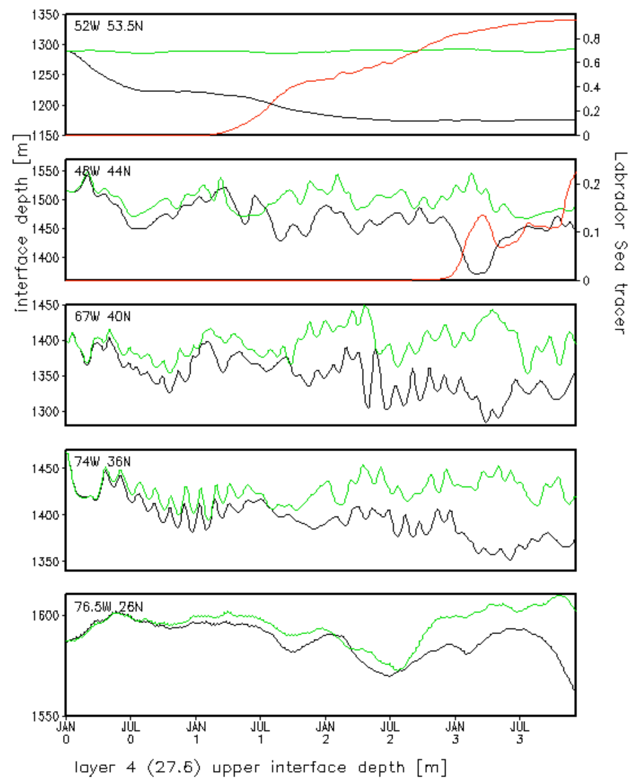
Reproduced from:
Wang and Mooers, JPO, 1976

Propagation of signals along the western boundary

Depth anomaly of perturbed isopycnal



Twin experiment time series

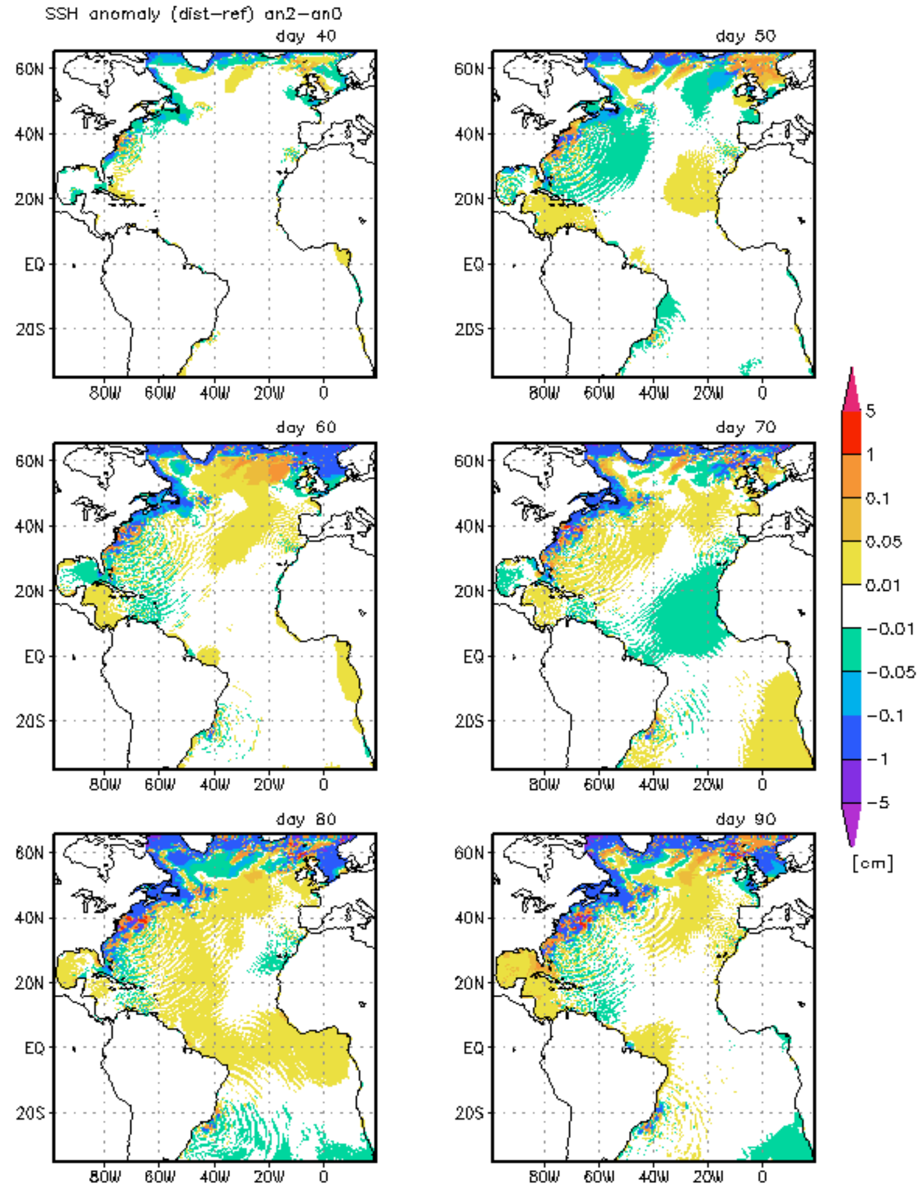


--- default; --- perturbed model run; --- Labrador Sea tracer

- **boundary wave propagation on time scale of months to years**
- **connected to interior via equatorial Kelvin waves and basin-wide Rossby waves**

- **fast wave response; range of frequencies; wave interactions**
- **waves modified by the topography and stratification**
- **an intermediate response involving changes in local circulation**
- **slower deep advection**

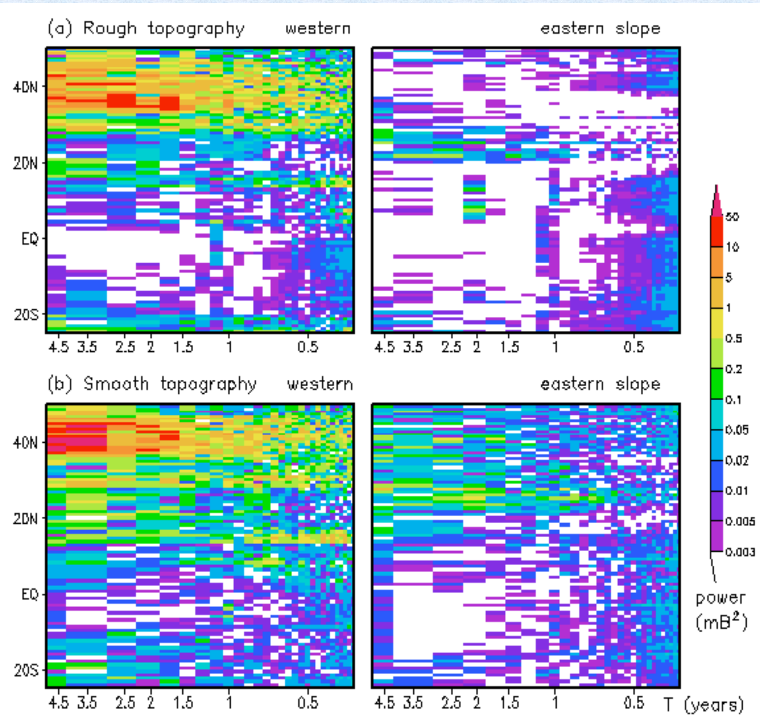
Initial adjustment of model SSH



- Rapid spreading along the western boundary
- Fast barotropic adjustment on basin scales
- Western boundary anomalies generated by the incoming Rossby waves

Propagation of signals along the western boundary

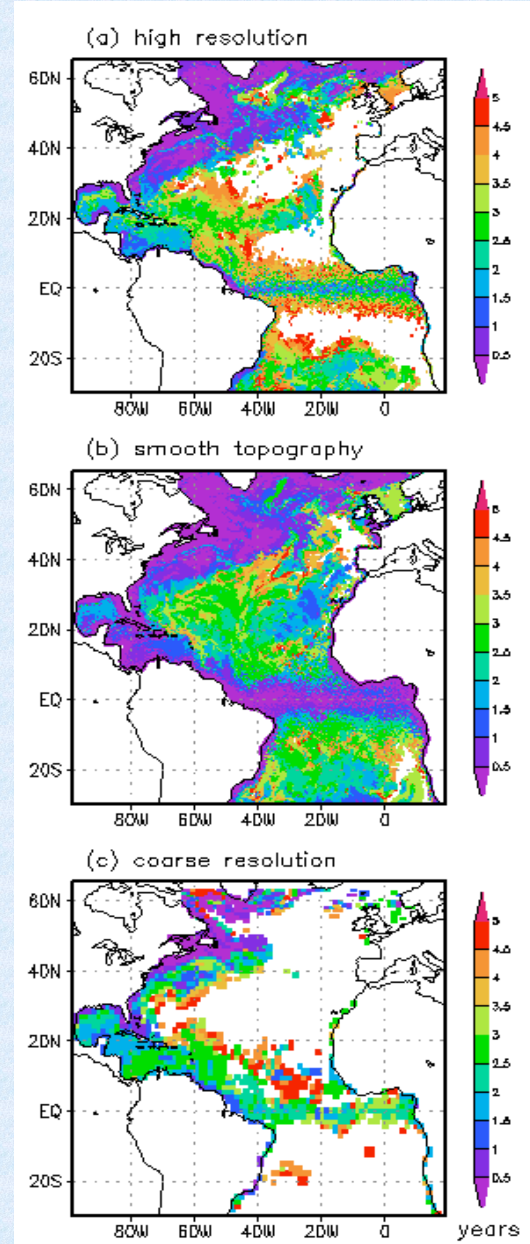
Power spectrum of bottom pressure anomalies along 1000 m isobath



- waves modified by the topography and stratification.
- larger BP signals along the western boundary
- lower frequency variability along the eastern boundary and at low latitudes
- scattering of the boundary waves by the topography

Periods of BP adjustment

- periods < 6 months along the western boundary
- Equatorial signal reaches eastern boundary in < 1 year
- slower interior adjustment
- faster adjustment in case of smooth topography



Time for |ΔBP| to adjust to: (0.1 + 1.0 |*sin* φ|) mB