Models and observations of North Atlantic atmospheric circulation and oscillatory climate modes induced by the Gulf Stream front

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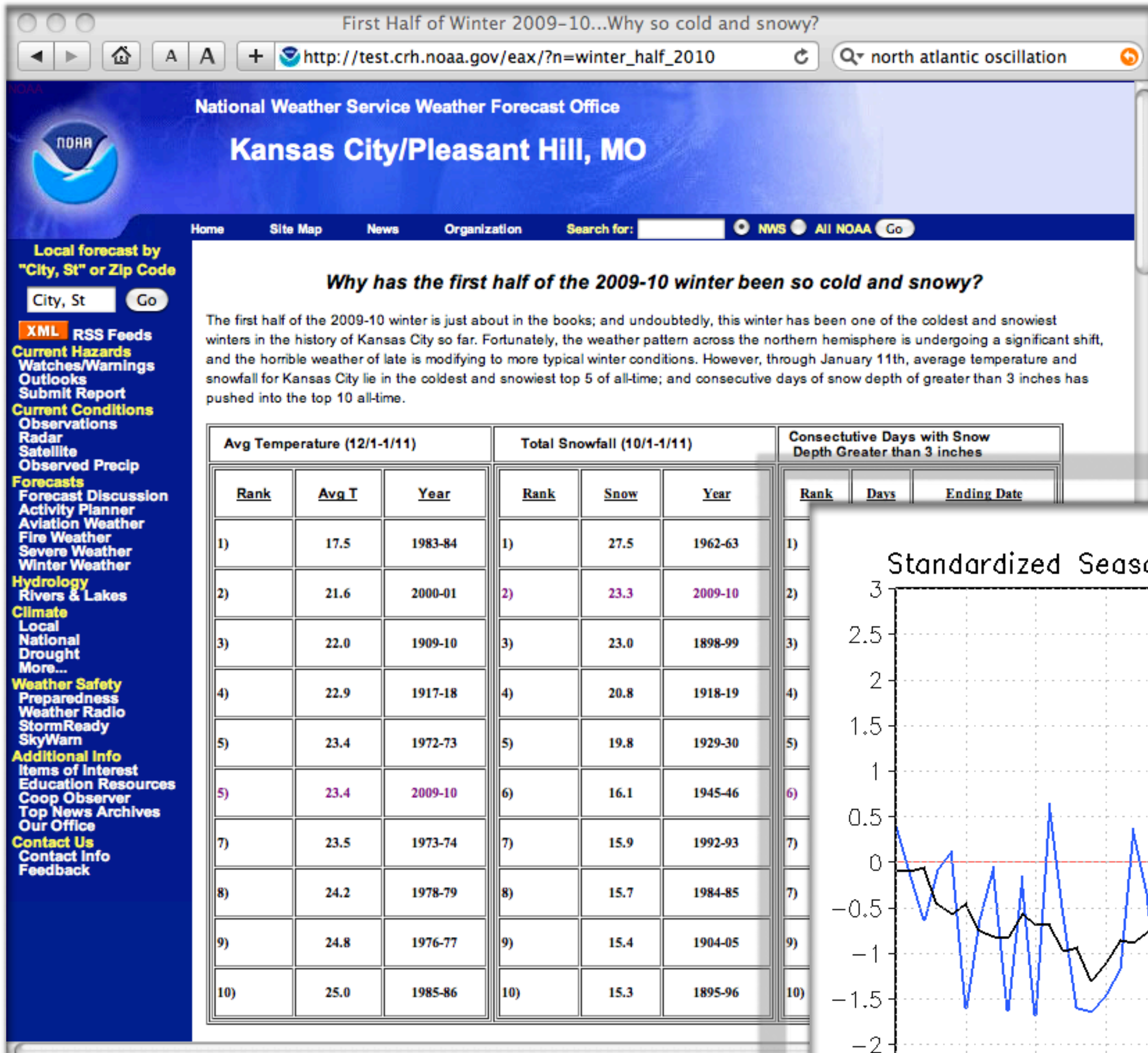
Outline

- spectral analyses of the SODA reanalysis SST field in two regions along the Gulf Stream front, 1958-2007
  - prominent and statistically significant interannual oscillations
- mechanistic model of atmospheric response to SST fronts
  - marine ABL + QG free atmosphere
- atmospheric model response to SODA monthly history
  - two extreme states of the atmospheric simulations
    - eastward extension of the westerly jet associated with the front
    - quiescent state of very weak flow
  - similar interannual periodicities to those found in SST

The North Atlantic Oscillation and our weather ...



First Half of Winter 2009-10...Why so cold and snowy?

http://test.crh.noaa.gov/eax/?n=winter_half_2010

National Weather Service Weather Forecast Office

Kansas City/Pleasant Hill, MO

Home | Site Map | News | Organization | Search for: | NWS | All NOAA | Go

Local forecast by "City, St" or Zip Code

RSS Feeds
Current Hazards
Watches/Warnings
Outlooks
Submit Report
Current Conditions
Observations
Radar
Satellite
Observed Precip
Forecasts
Forecast Discussion
Activity Planner
Aviation Weather
Fire Weather
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Winter Weather
Hydrology
Rivers & Lakes
Climate
Local
National
Drought
More...
Weather Safety
Preparedness
Weather Radio
StormReady
SkyWarn
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Education Resources
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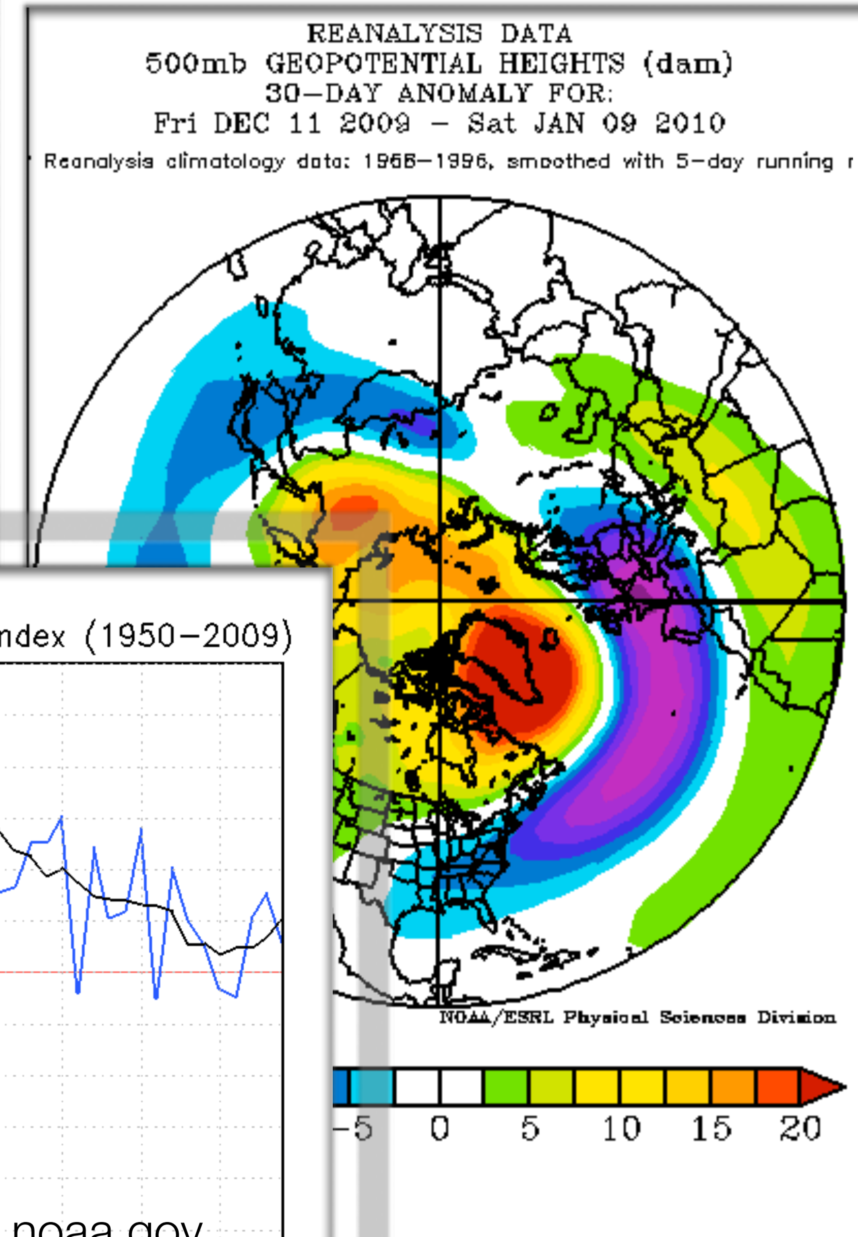
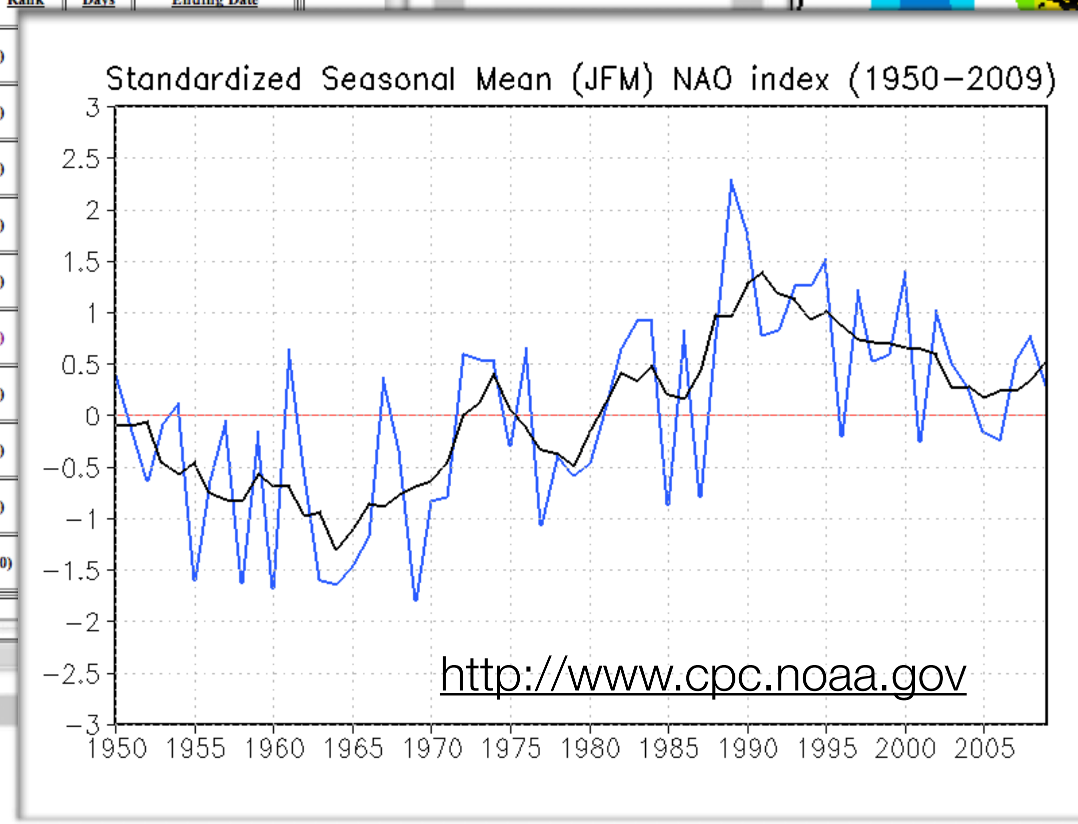
Why has the first half of the 2009-10 winter been so cold and snowy?

The first half of the 2009-10 winter is just about in the books; and undoubtedly, this winter has been one of the coldest and snowiest winters in the history of Kansas City so far. Fortunately, the weather pattern across the northern hemisphere is undergoing a significant shift, and the horrible weather of late is modifying to more typical winter conditions. However, through January 11th, average temperature and snowfall for Kansas City lie in the coldest and snowiest top 5 of all-time; and consecutive days of snow depth of greater than 3 inches has pushed into the top 10 all-time.

Avg Temperature (12/1-1/11)			Total Snowfall (10/1-1/11)			Consecutive Days with Snow Depth Greater than 3 inches		
Rank	Avg T	Year	Rank	Snow	Year	Rank	Days	Ending Date
1)	17.5	1983-84	1)	27.5	1962-63	1)		
2)	21.6	2000-01	2)	23.3	2009-10	2)		
3)	22.0	1909-10	3)	23.0	1898-99	3)		
4)	22.9	1917-18	4)	20.8	1918-19	4)		
5)	23.4	1972-73	5)	19.8	1929-30	5)		
5)	23.4	2009-10	6)	16.1	1945-46	6)		
7)	23.5	1973-74	7)	15.9	1992-93	7)		
8)	24.2	1978-79	8)	15.7	1984-85	7)		
9)	24.8	1976-77	9)	15.4	1904-05	9)		
10)	25.0	1985-86	10)	15.3	1895-96	10)		

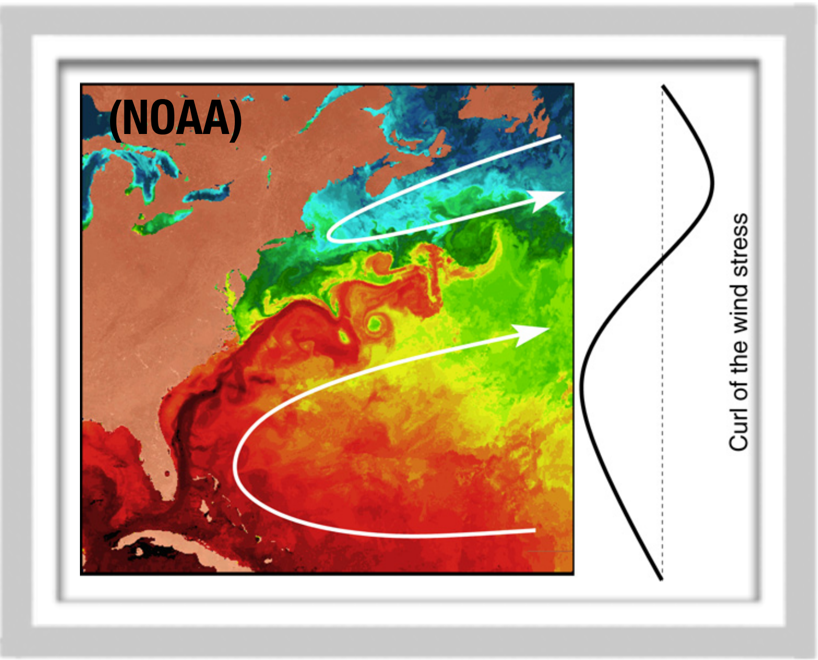




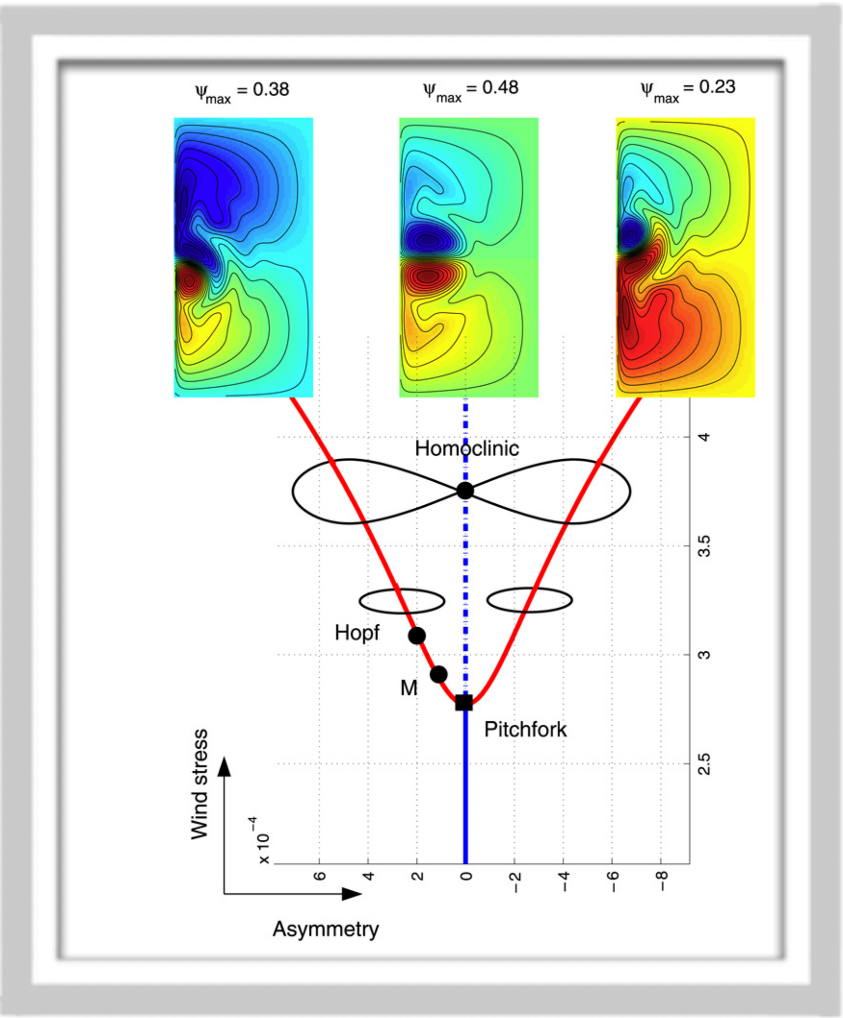
... and hopes for "near-term" decadal climate prediction?

Simple models of the ocean gyres and eddies

Satellite image of the sea surface temperature (SST)

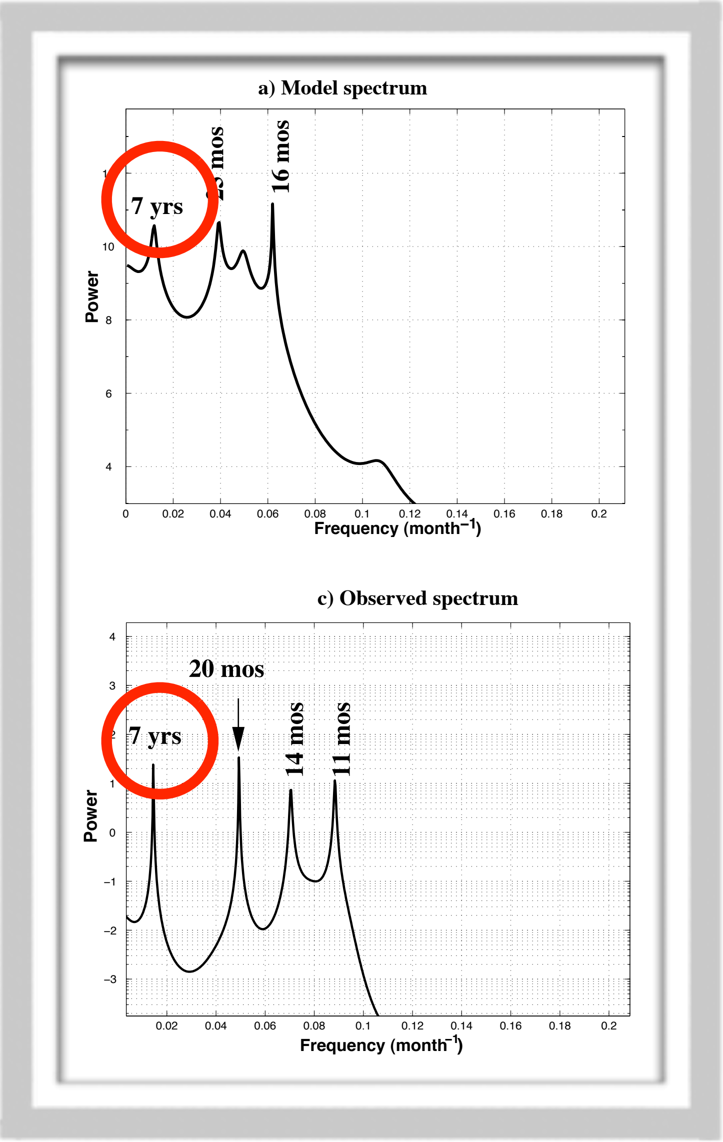


Bifurcation diagram for the barotropic QG model of the double-gyre problem



Ghil, Checkroun, Simonnet (2008)
Jiang, Jin and Ghil (1995)

Spectra of idealized double-gyre model and COADS SST



Simonnet, Ghil, Dijkstra (2005)

... could the ocean be driving the NAO through oscillations in the Gulf Stream SST front?

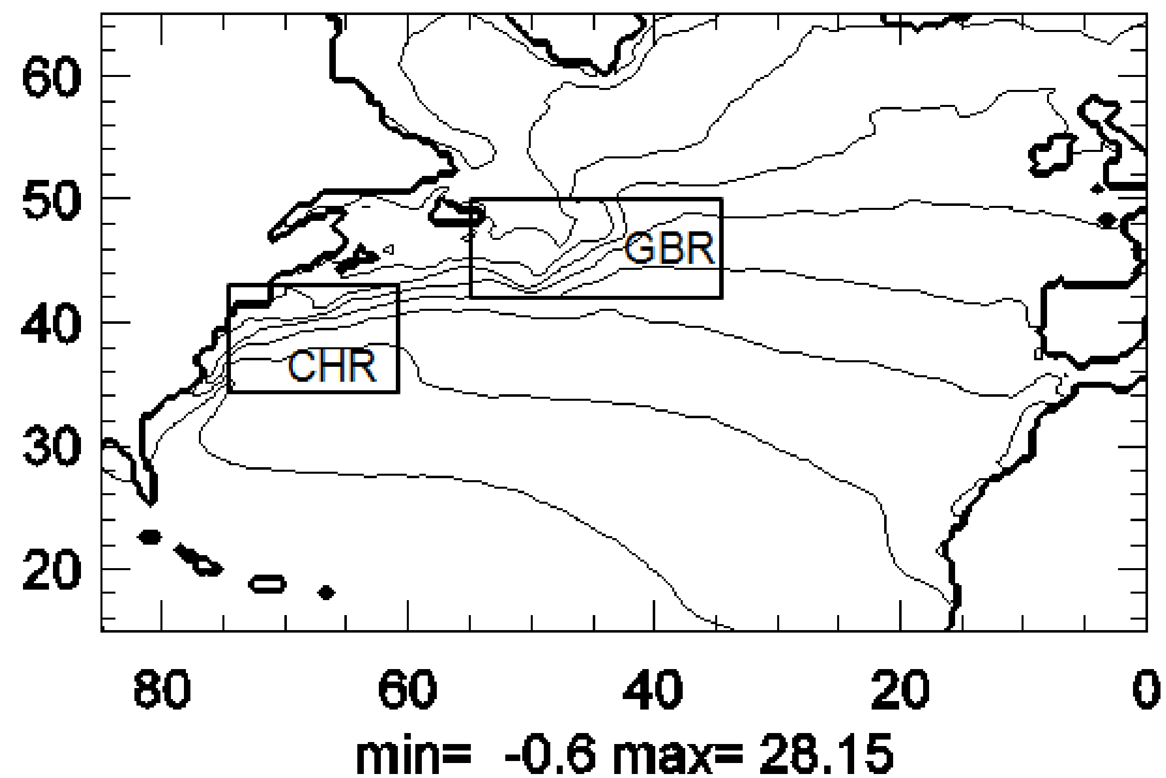
spectral analyses of the SODA

- SST (–5m), 1958-2007, monthly, 0.5° (SODA v2.0.2-4), Cape Hatteras and Great Banks regions analyzed separately

- annual cycle removed using 12-month running average

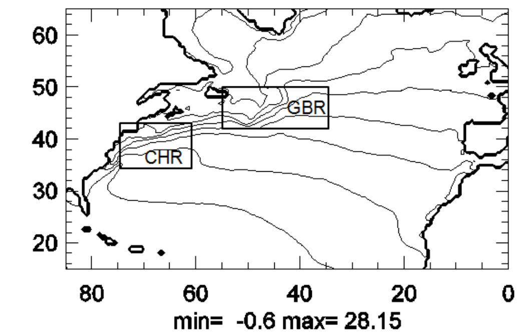
- multi-channel singular spectrum analysis (MSSA) of gridded SST

- statistical significance assessed against red noise null-hypothesis

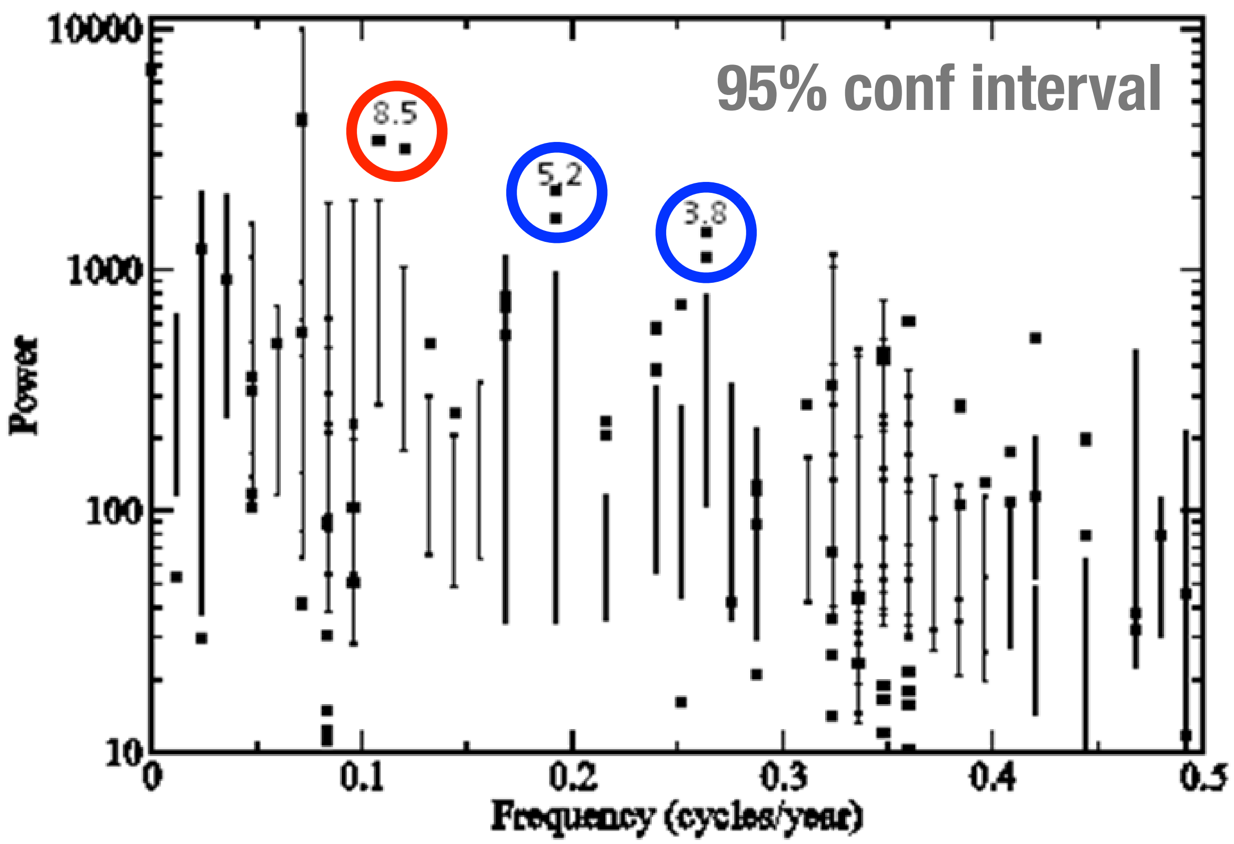


CHR: 34N–43.50N, 75W–60W
GBR: 42N–50N, 55W–35W

Cape Hatteras SST Spectrum

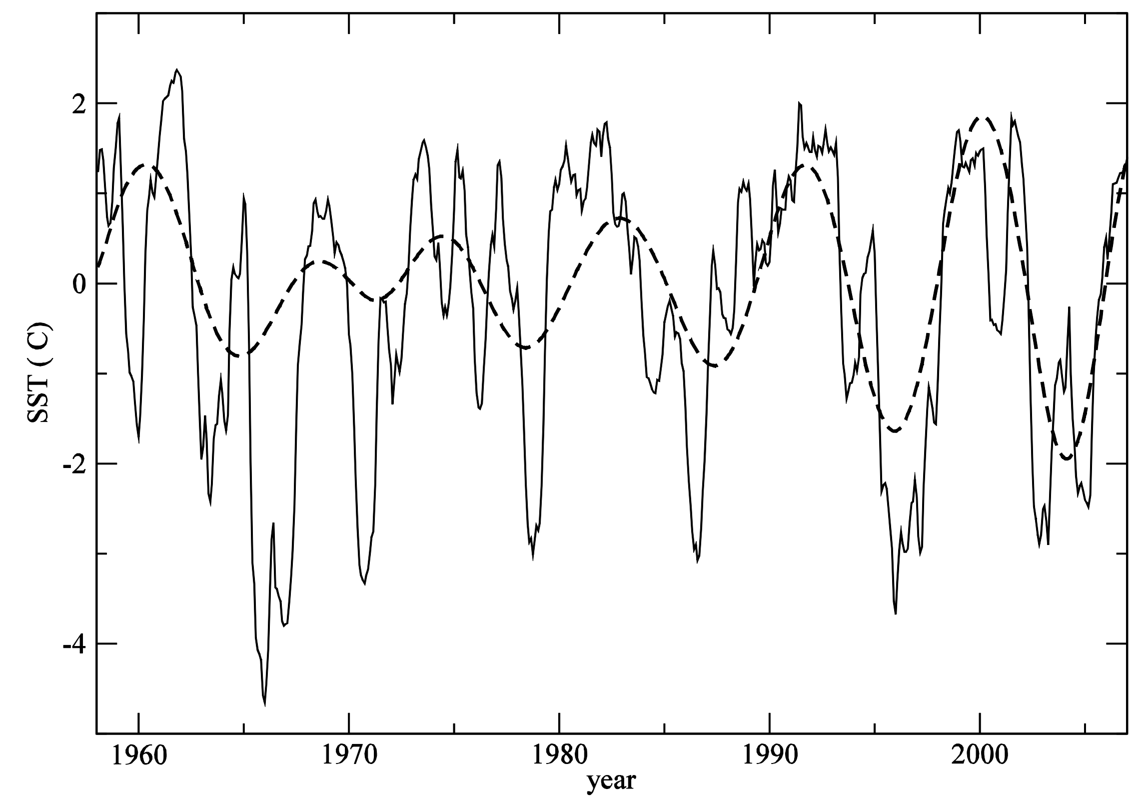


MSSA Power spectrum

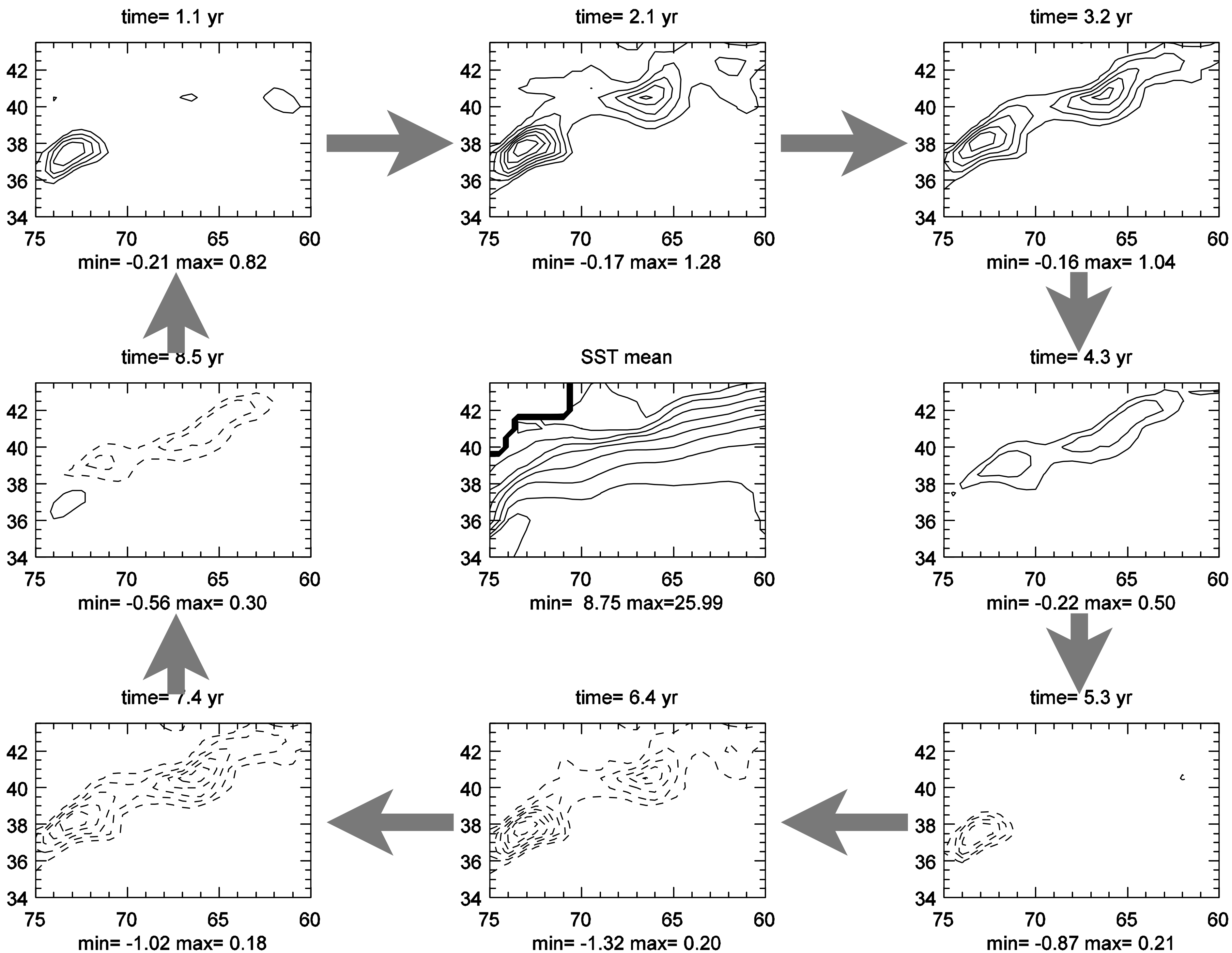


(M = 150 months)

8.5-yr compt at (74W, 37N)

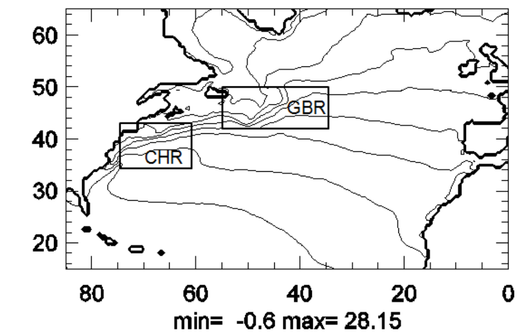


Phase composites of 8.5-yr mode
Cape Hatteras SST

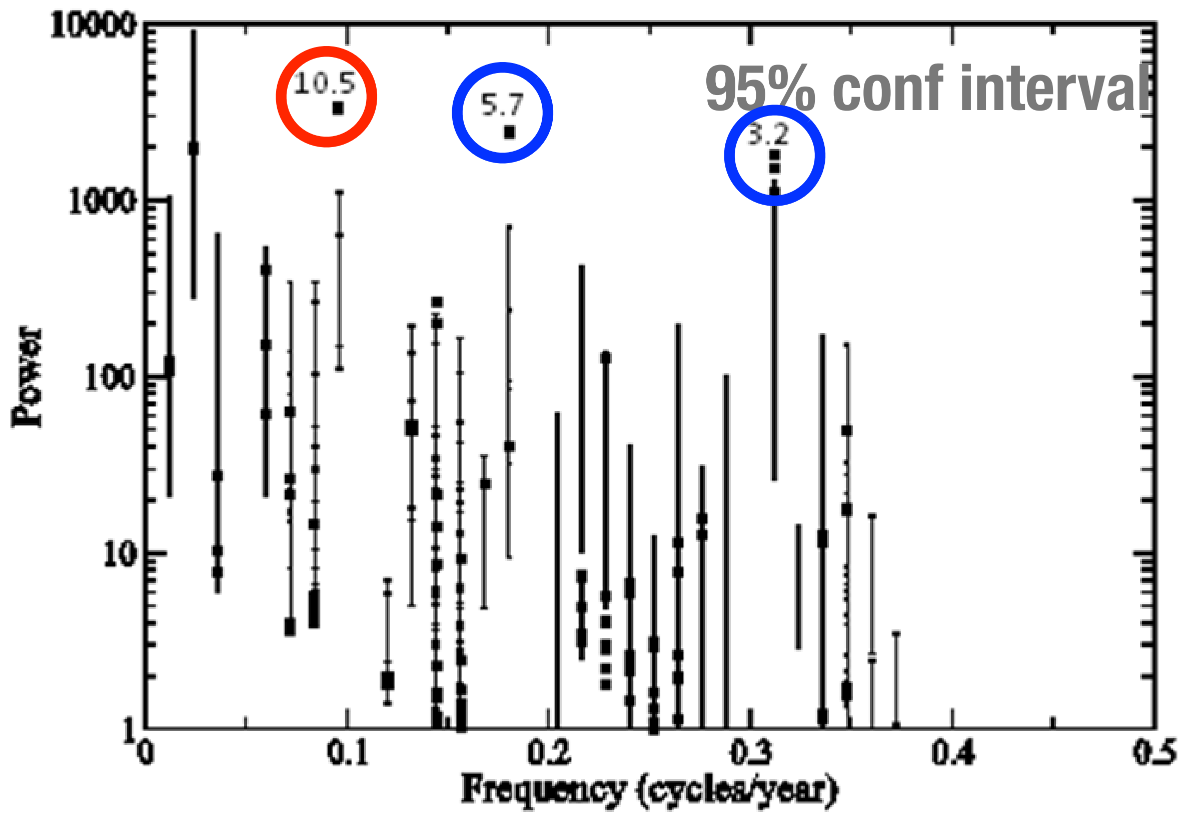


- large scale meander of front
- 5.2 and 3.8-yr modes exhibit similar structure

Grand Banks Region SST spectrum

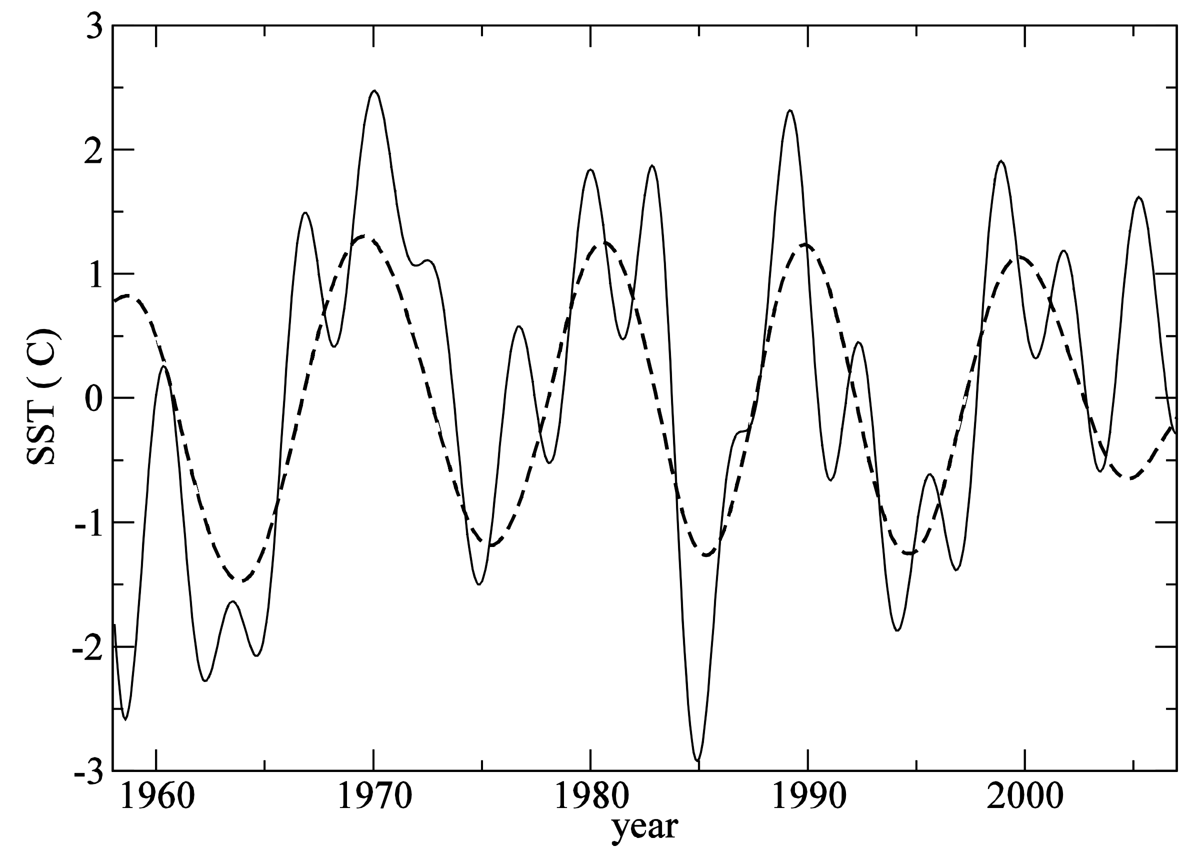


MSSA Power spectrum



(M = 150 months, detrended)

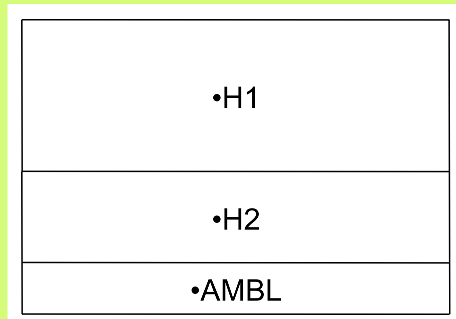
10.5-yr compt at (47W, 44N)



- extension/contraction of the current
- 5.7 and 3.2-yr modes exhibit similar structure

Atmospheric model

A quasi-geostrophic (QG) atmospheric model in a periodic β-channel, first barotropic (Feliks et al., 2004; FGS'04), then baroclinic (FGS'07). Marine atmospheric boundary layer (ABL), analytical solution.



$\Delta x = \Delta y = 50$km

QG Potential Vorticity eqn:

$$\frac{\partial q}{\partial t} + \beta \frac{\partial \psi}{\partial x} + J(\psi, q) = r_H \nabla^4 \psi,$$

$$q \equiv \nabla^2 \psi + \frac{\partial}{\partial z}\left(\frac{1}{S}\frac{\partial \psi}{\partial z}\right)$$

Lower boundary condition:

$$\frac{H}{H_a}\frac{d}{dt}\left[\frac{\partial}{\partial z}\left(\frac{1}{S}\frac{\partial \psi}{\partial z}\right)\right] = \frac{H}{H_a} w_a(x, y, z = 0, t)$$

$$= \gamma \nabla^2 \psi - \alpha \nabla^2 T,$$

Atmospheric boundary layer model:

constant-depth, well-mixed moist boundary layer in equilibrium with the underlying SST field

$$\frac{1}{\rho_0}\frac{\partial p}{\partial y} = \frac{1}{\rho_0}\frac{\partial}{\partial y} p(H_E) - \frac{g}{\theta_0}(H_E - z)\frac{\partial \theta}{\partial y}.$$

$$k_0 \frac{\partial^2 v}{\partial z^2} - fu - \frac{1}{\rho_0}\frac{\partial p}{\partial y} = 0.$$

Response to an idealized SST front

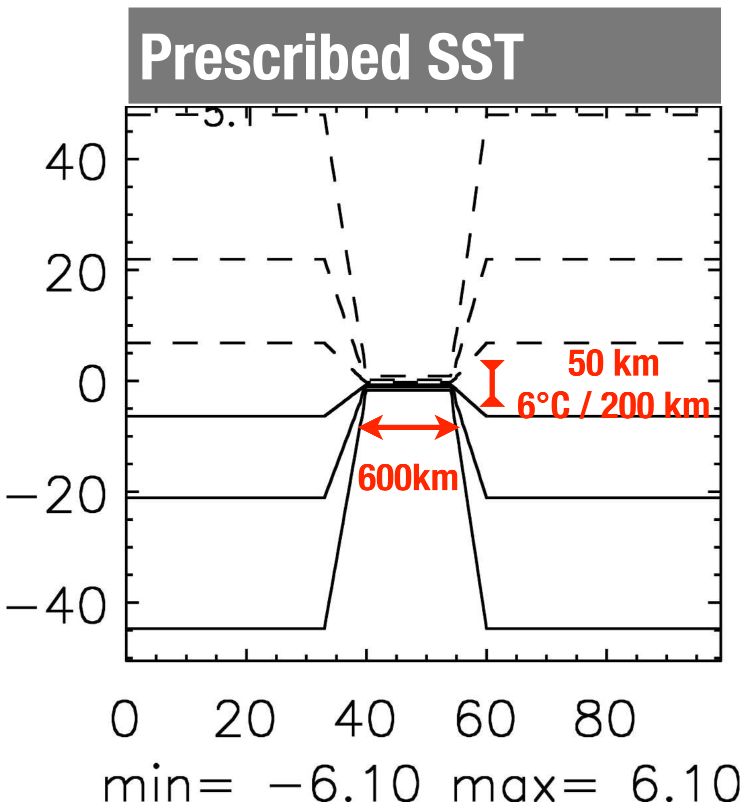


FIG. 1. Prescribed SST pattern for an oceanic front of length 600 km with strength $T^* = 6.1°C$ and frontal-width parameter $d = 50$ km; see Eq. (15). Contour interval (CI) is 2°C, starting at ±6°C; positive contours are solid; negative and zero contours dashed. Axes in nondimensional units of Δx counts, where $\Delta x = \Delta y = 50$ km/L, L being the length scale; see Eq. (1).

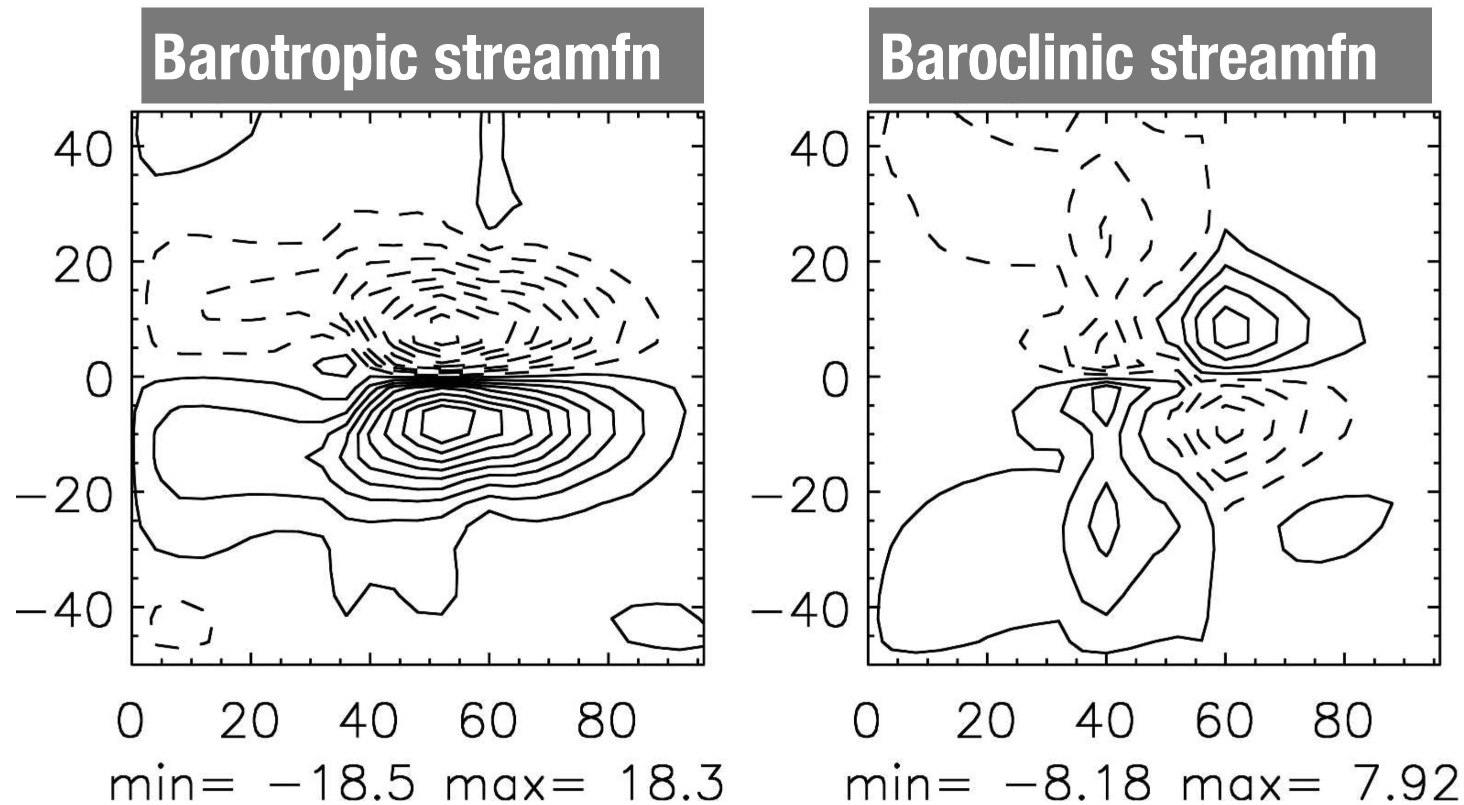
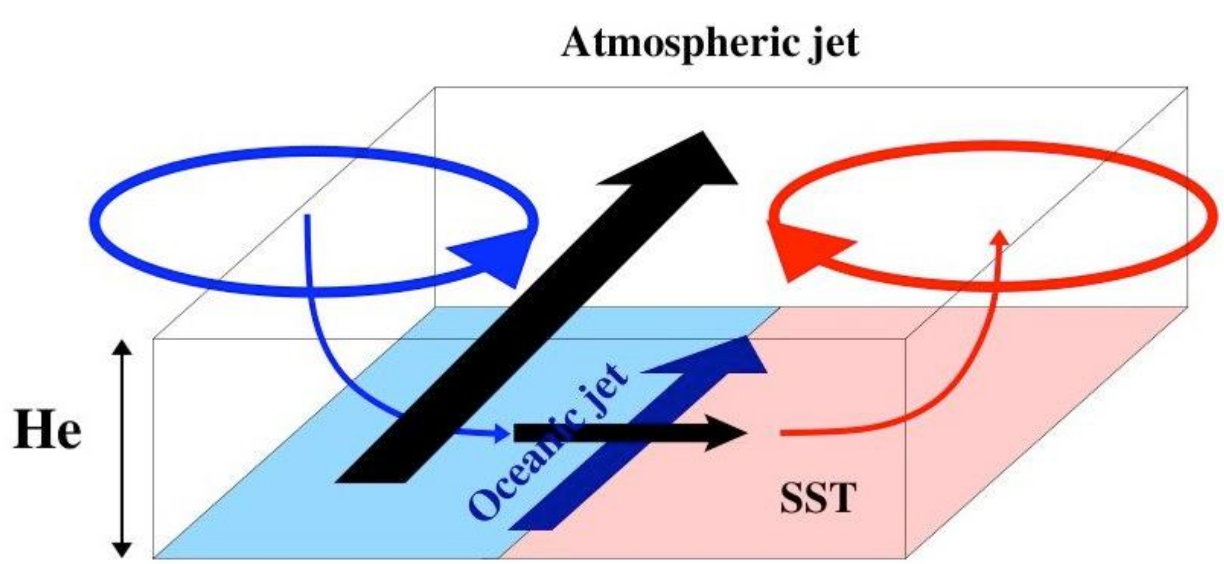


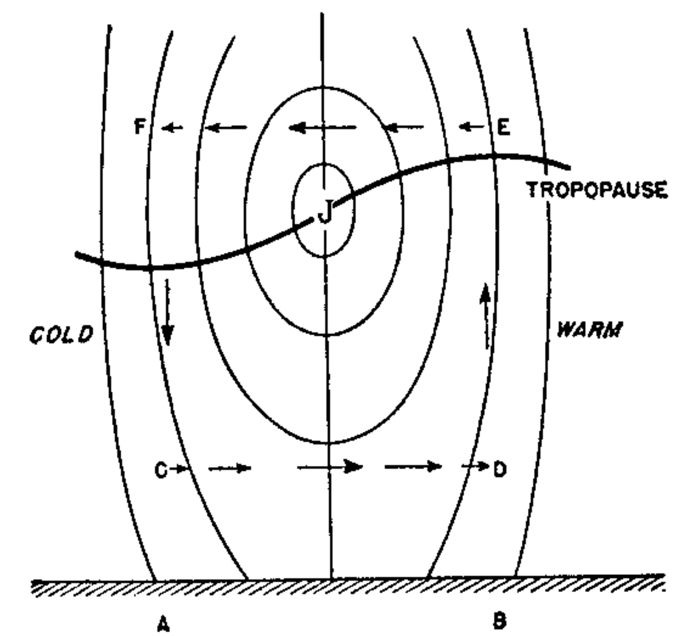
FIG. 3. Mean streamfunction field for $T^* = 6.1°C$ (CI = 2): (a) barotropic and (b) baroclinic.

Total circulation: stronger and longer jet in the upper layer than in the lower

Feliks et al (2007)

Interpretation of atmospheric response





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CONFLUENCE THEORY OF THE HIGH TROPOSPHERIC JET STREAM

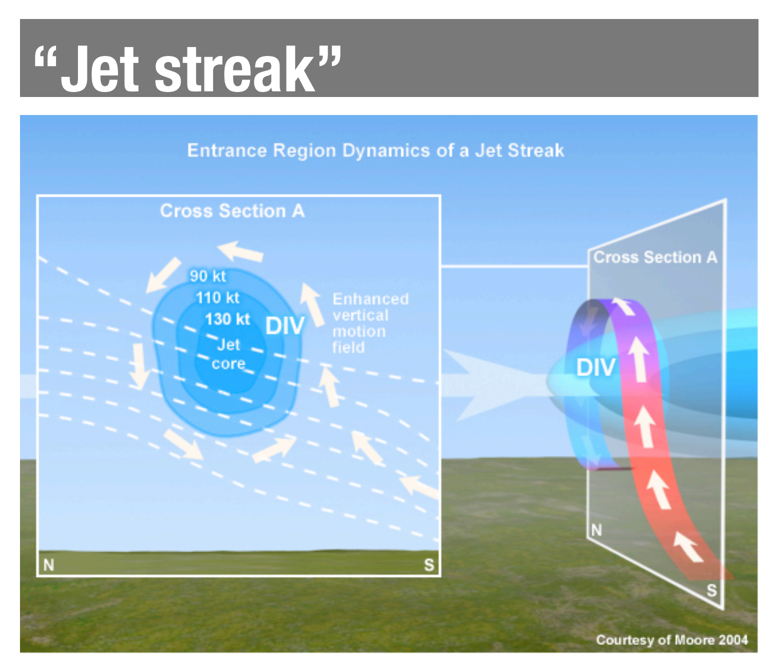
By Jerome Namias and Philip F. Clapp

U. S. Weather Bureau, Washington, D. C.

(Manuscript received 31 January 1949)

$$\frac{H}{H_a}\frac{d}{dt}\left[\frac{\partial}{\partial z}\left(\frac{1}{S}\frac{\partial \psi}{\partial z}\right)\right] = \frac{H}{H_a} w_a(x, y, z = 0, t)$$

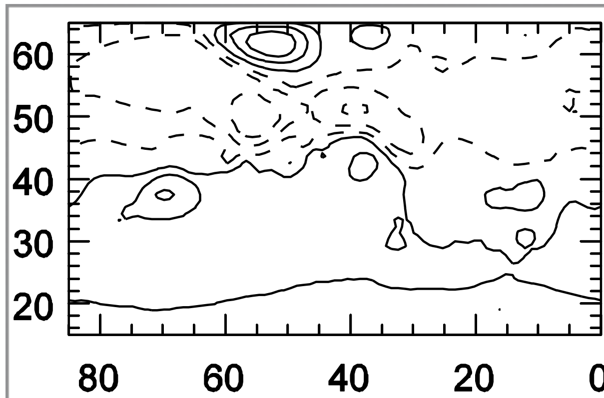
$$= \gamma \nabla^2 \psi - \alpha \nabla^2 T,$$



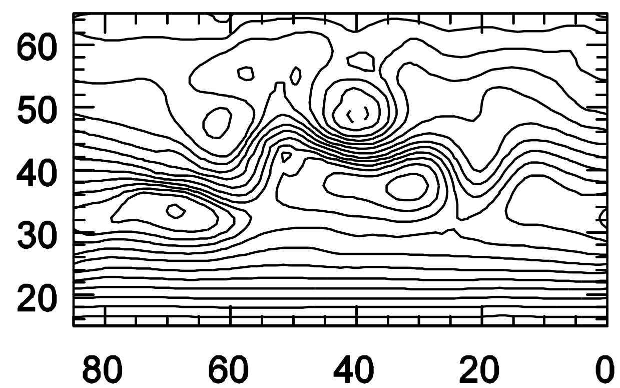
SST-front driven pumping drives
thermally direct circulation
“PV injection”

Response to SODA: Steamfunction snapshots

time = 1980.8 | **time = 1992.3**

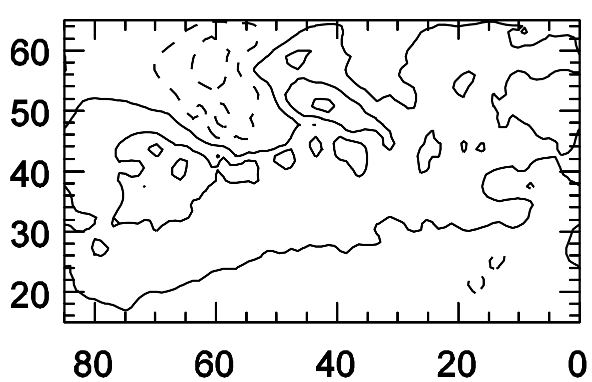


min= -26.4 max= 29.24

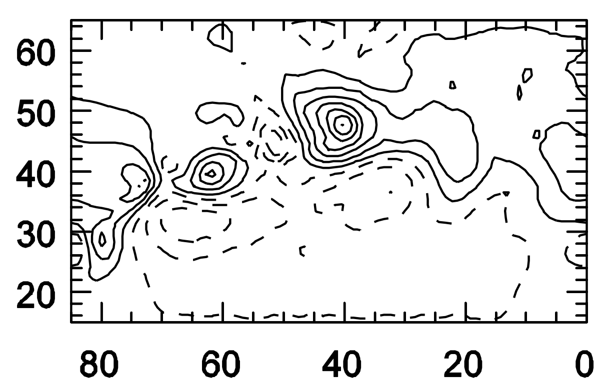


min= -15.5 max= 97.71

Barotropic

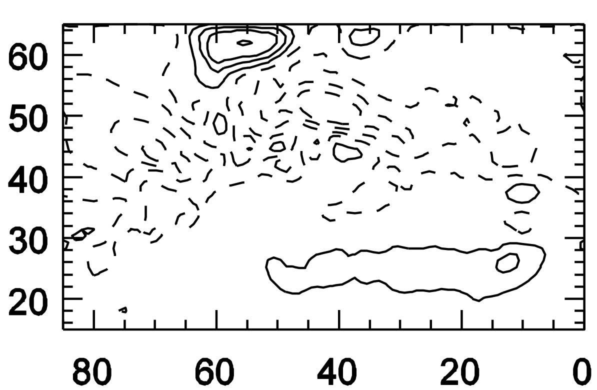


min= -15.4 max= 17.73

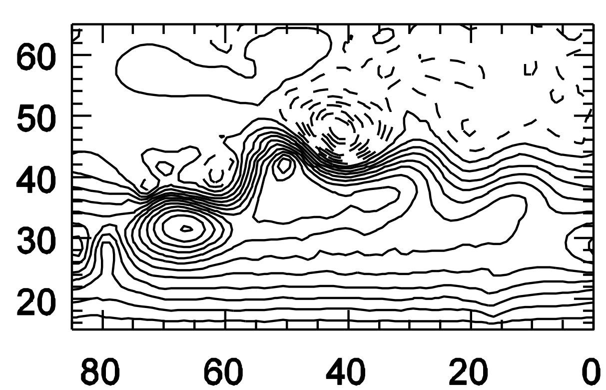


min= -18.6 max= 41.54

Baroclinic



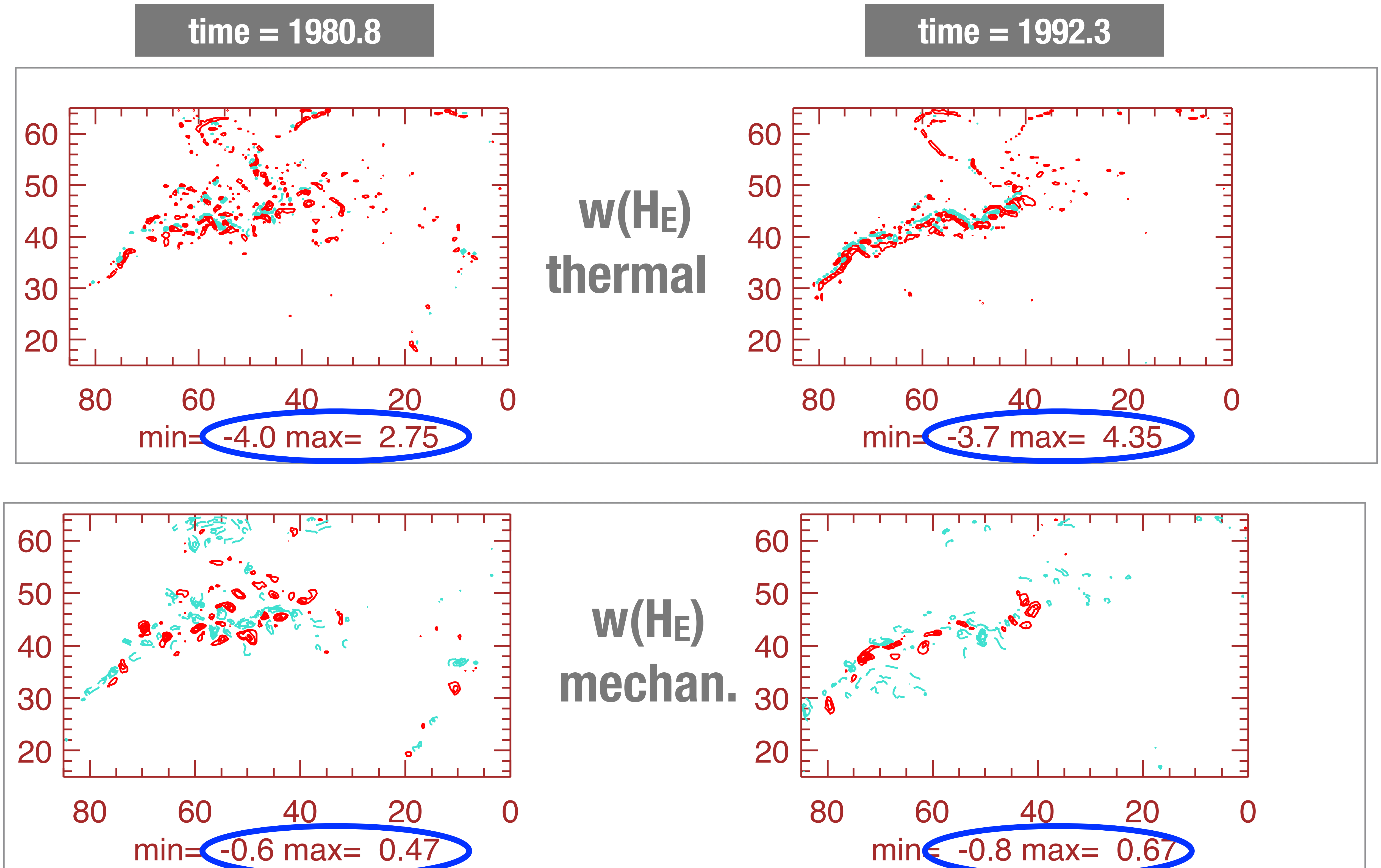
min= -41.8 max= 39.60



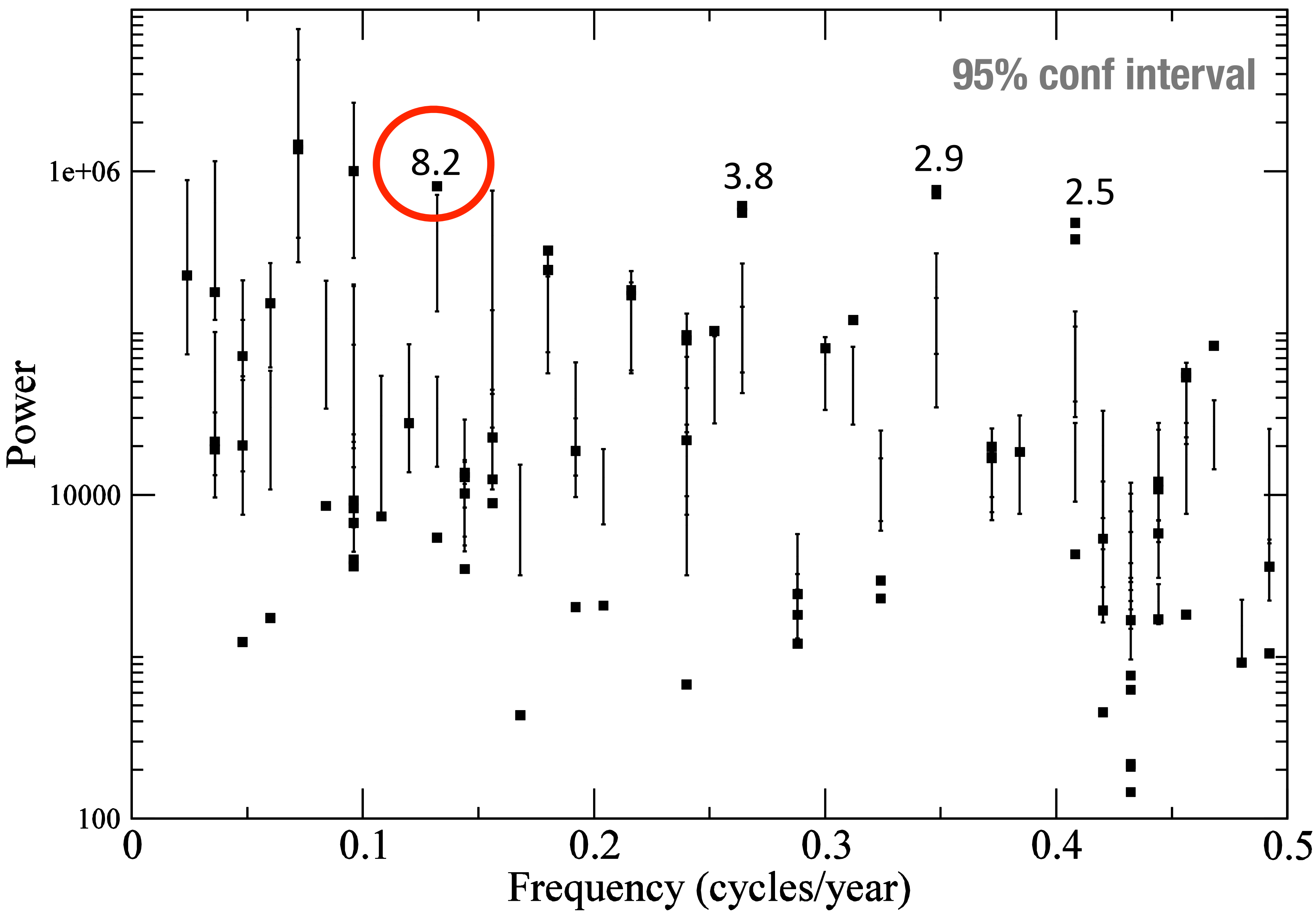
min= -81.6 max=119.38

Surface
(BT-2*BC)

SST front and $w(H_E)$



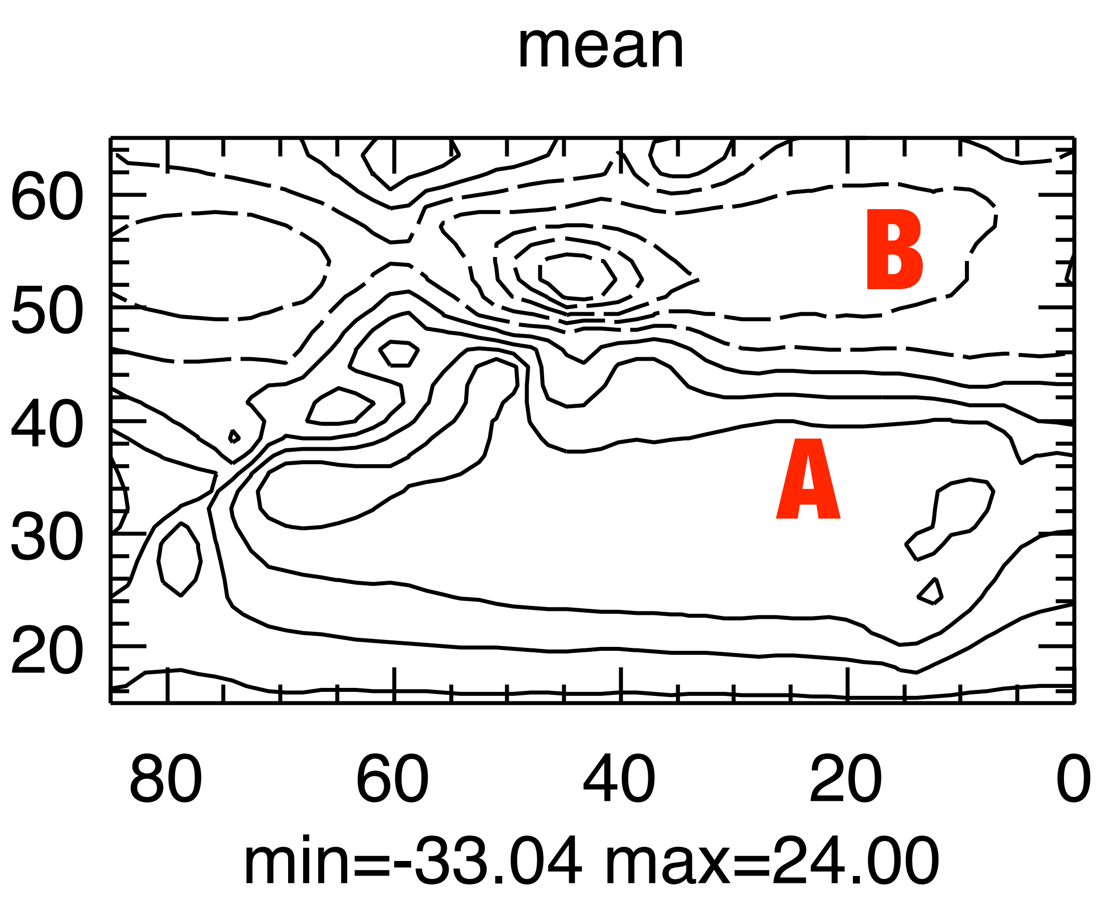
Spectrum of atmospheric response

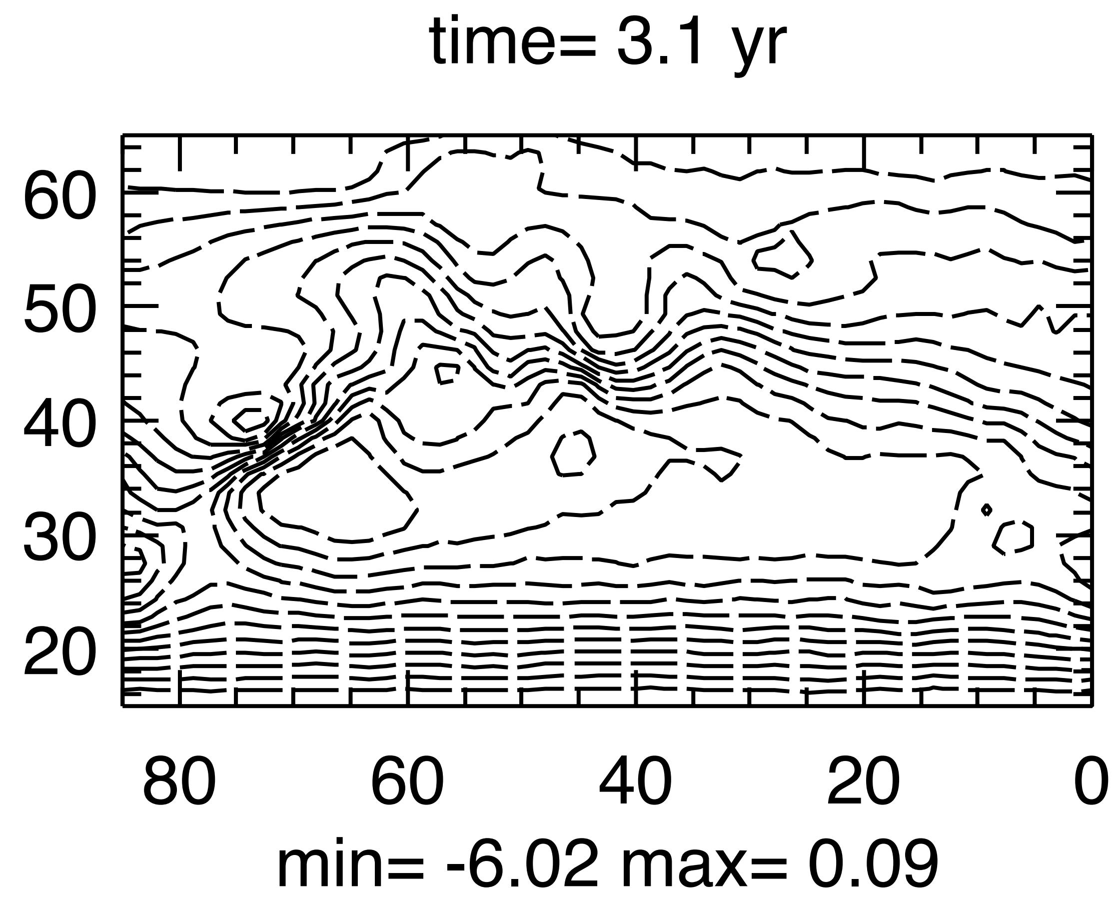


(M = 150 mon)

barotropic and baroclinic streamfunctions stacked together

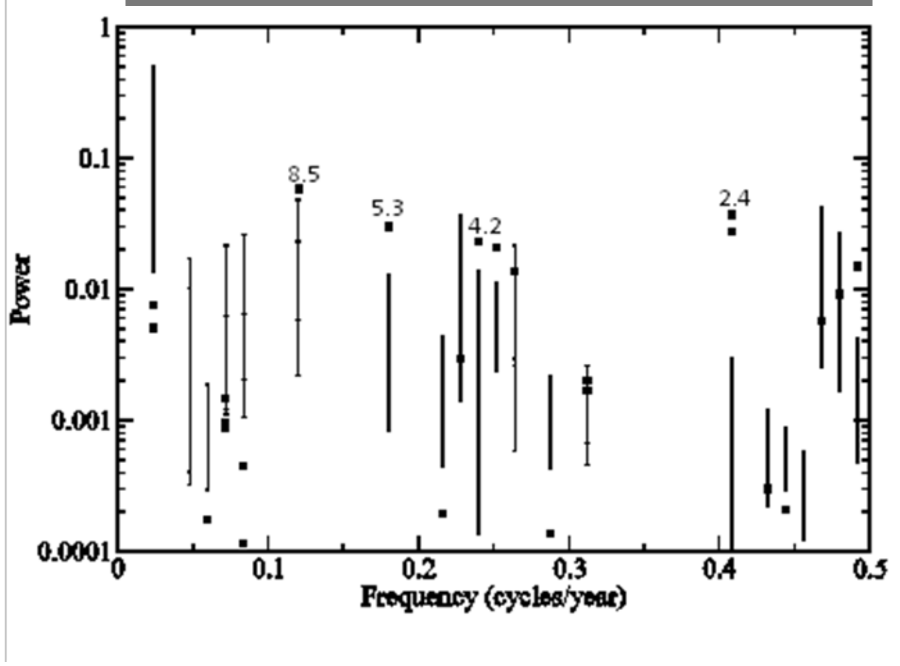
Structure of 8.2-yr mode at the surface



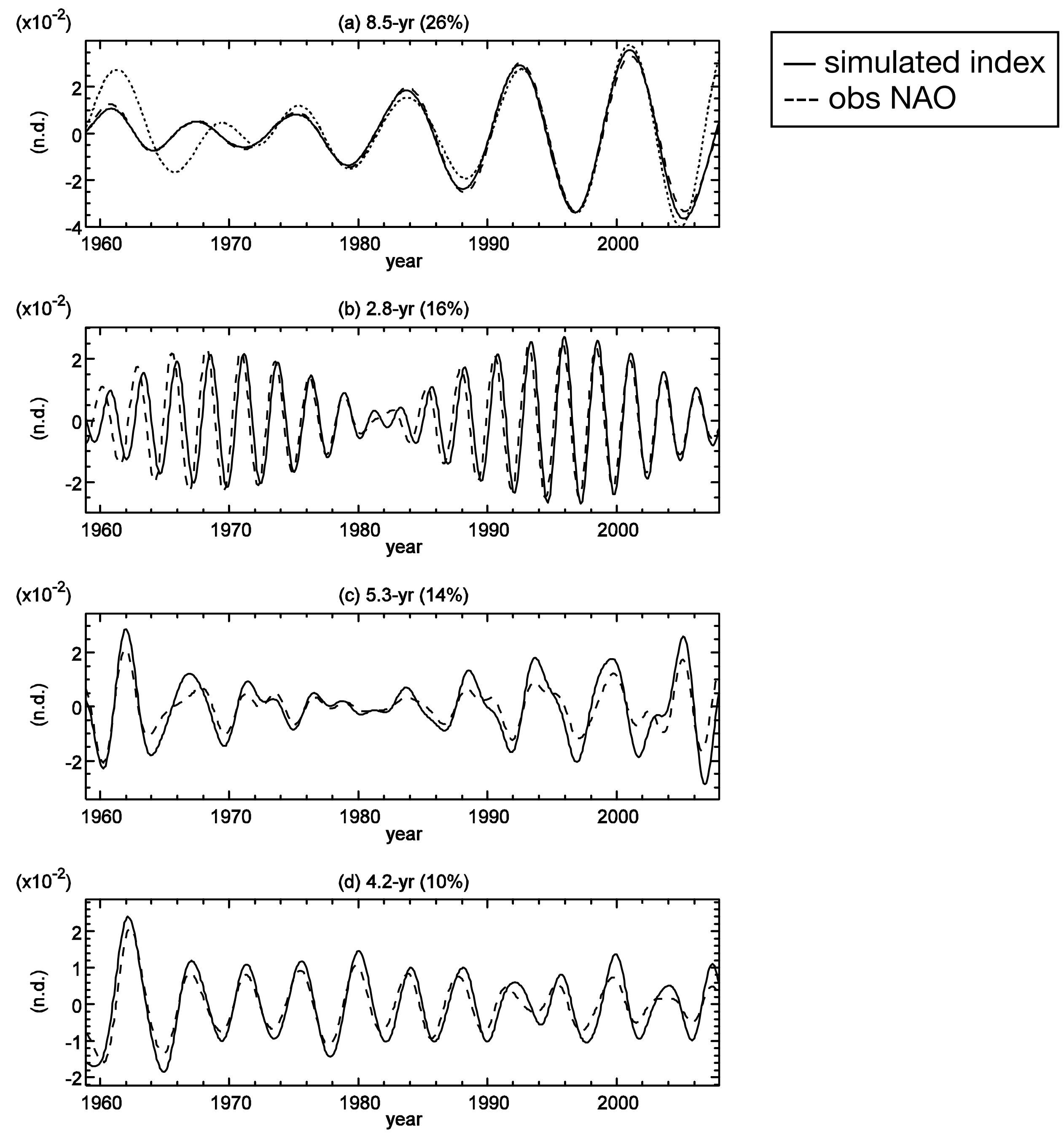


Bi-spectra of observed and simulated NAO index

MSSA Power spectrum

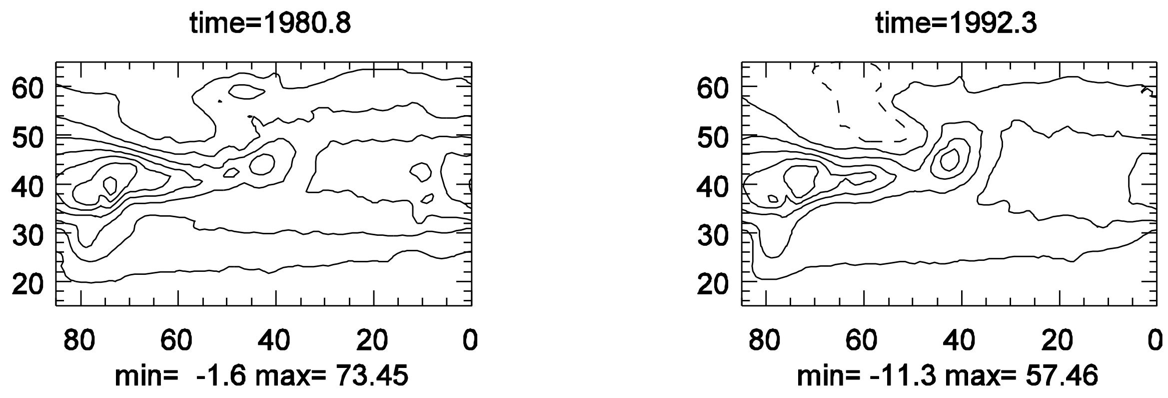


Reconstructed components

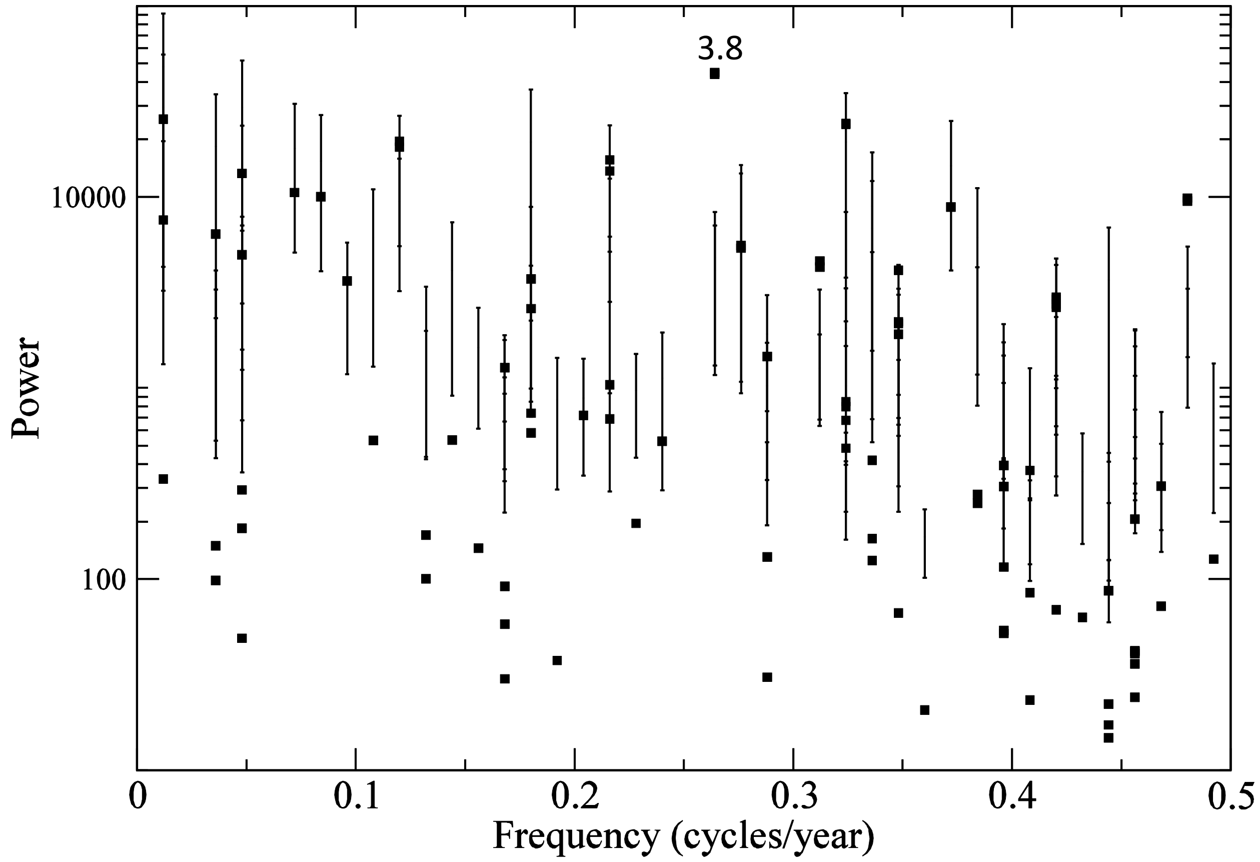


Atmospheric response when driven by spatially-smoothed SODA SST

Surface streamfunction snapshots

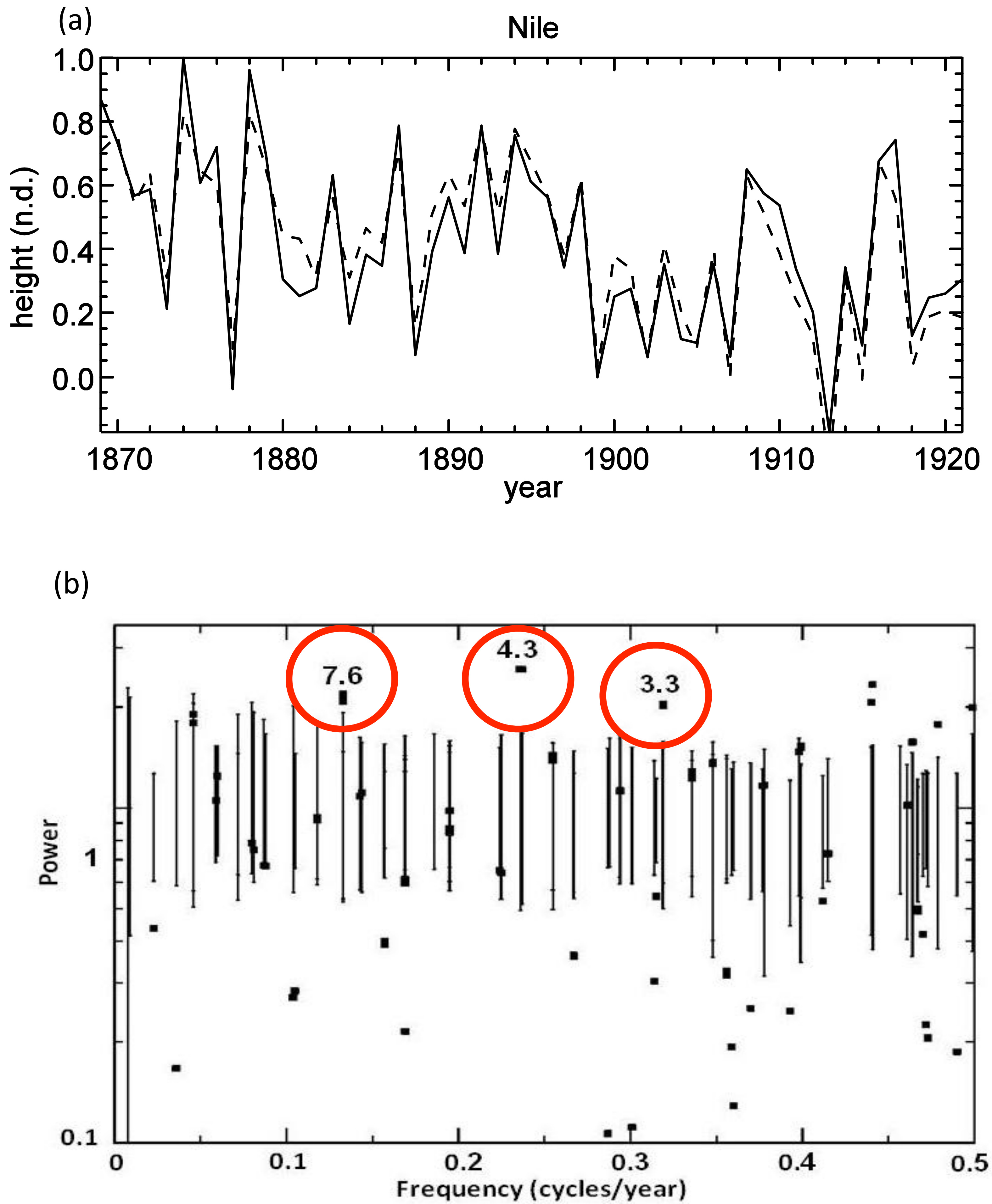


MSSA Spectra



Overall energy is much weaker

Postscript: spectrum of Nile River flow



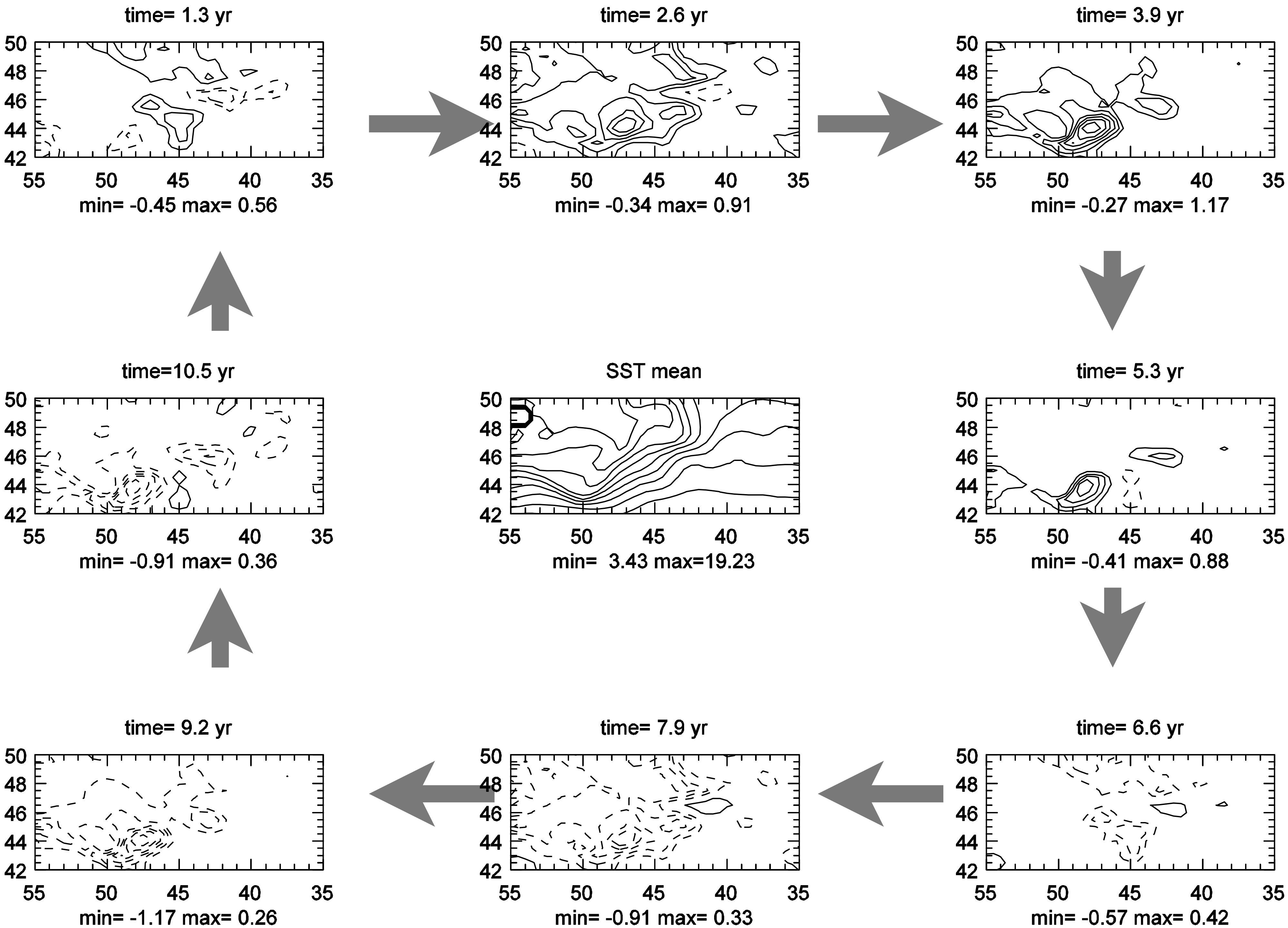
Feliks et al. (2010, sub judice)

Summary

- spectral analyses of the SODA reanalysis SST field in two regions along the Gulf Stream front, 1958-2007
  - prominent and statistically significant interannual oscillations
- mechanistic model of atmospheric response to SST fronts
  - marine ABL + QG free atmosphere
  - transverse thermally direct circulation spins up QG jet over front
  - anticyclonic vorticity to the south and cyclonic to the north of the jet axis gives rise to Ekman damping and spin down
- atmospheric model response to SODA monthly history
  - two extreme states of the atmospheric simulations
    - eastward extension of the westerly jet associated with the front
    - quiescent state of very weak flow
  - similar interannual periodicities to those found in SST

additional slides

Phase composites of Grand Banks SST: 10.5-yr mode



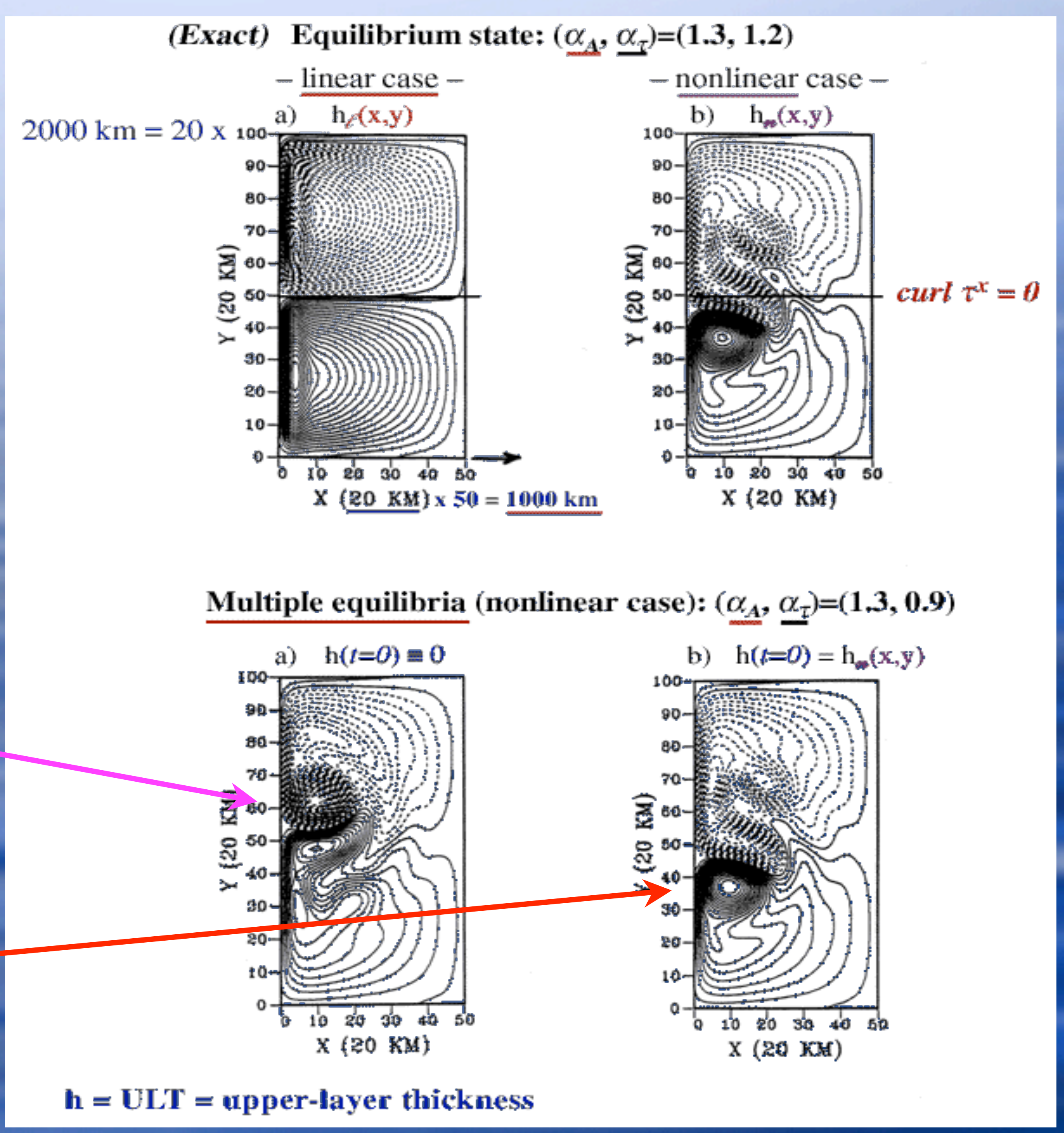
- extension/ contraction of the current
- 5.7 and 3.2-yr modes exhibit similar structure

The JJG model's equilibria

Nonlinear (advection) effects break the (near) symmetry: (perturbed) pitchfork bifurcation?

Subpolar gyre dominates

Subtropical gyre dominates



Jiang, Jin and Ghil, JPO, 1995

Observed and simulated NAO indices