CLIMATIC VARIATIONS IN HURRICANES AND THEIR POTENTIAL EFFECTS ON WAVES AND SURGES IN THE GULF OF MEXICO

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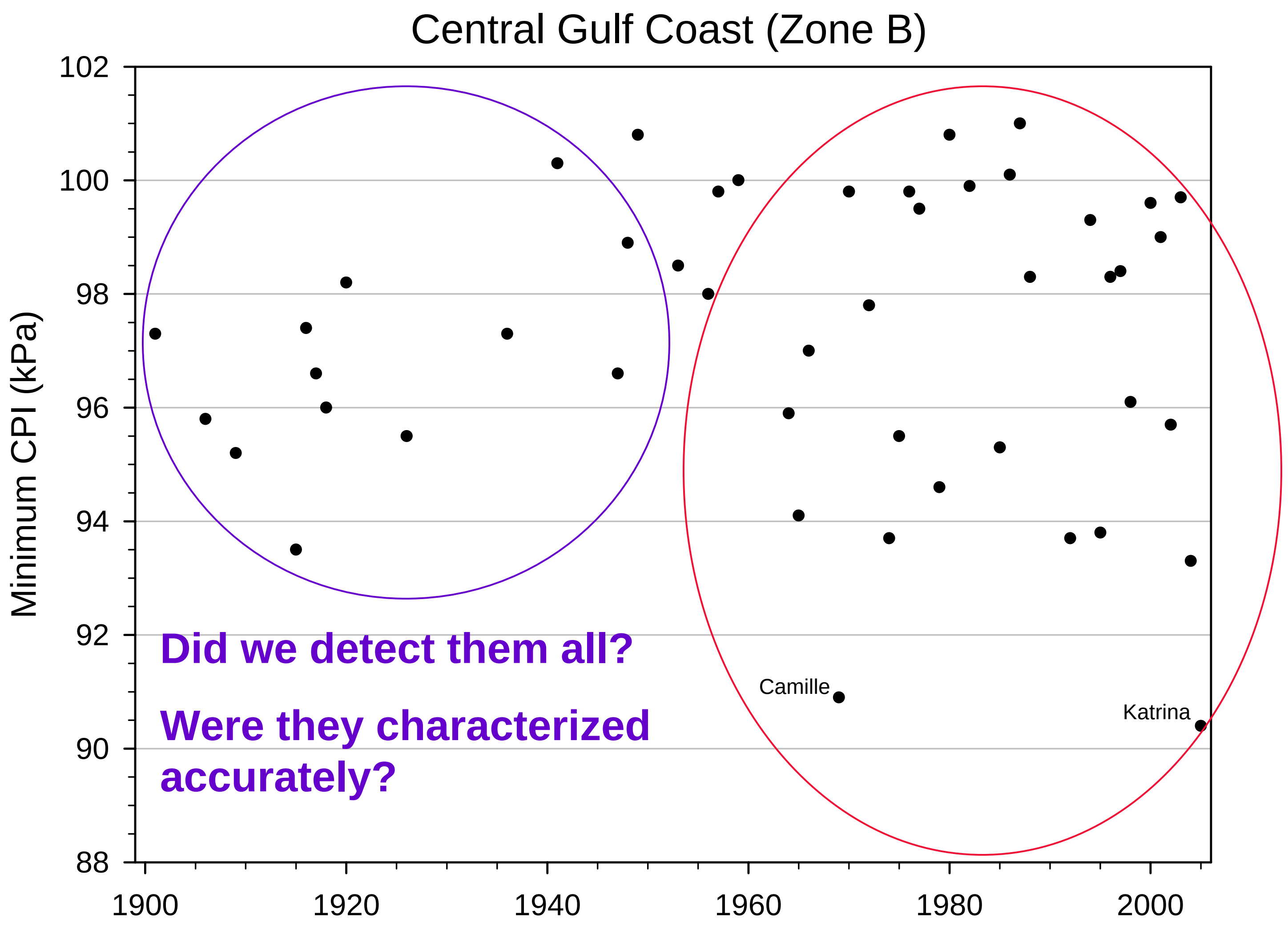
Sometimes we push things just a bit too far!

And learn the hard way.


August 29th – St. Bernard Parish:
There’s a levee under this water.

What is the Hurricane Threat?

- **Are we adjusting to new information and understanding of the hurricane threat?**



Higher storm frequency since 1960?

More intense storms?

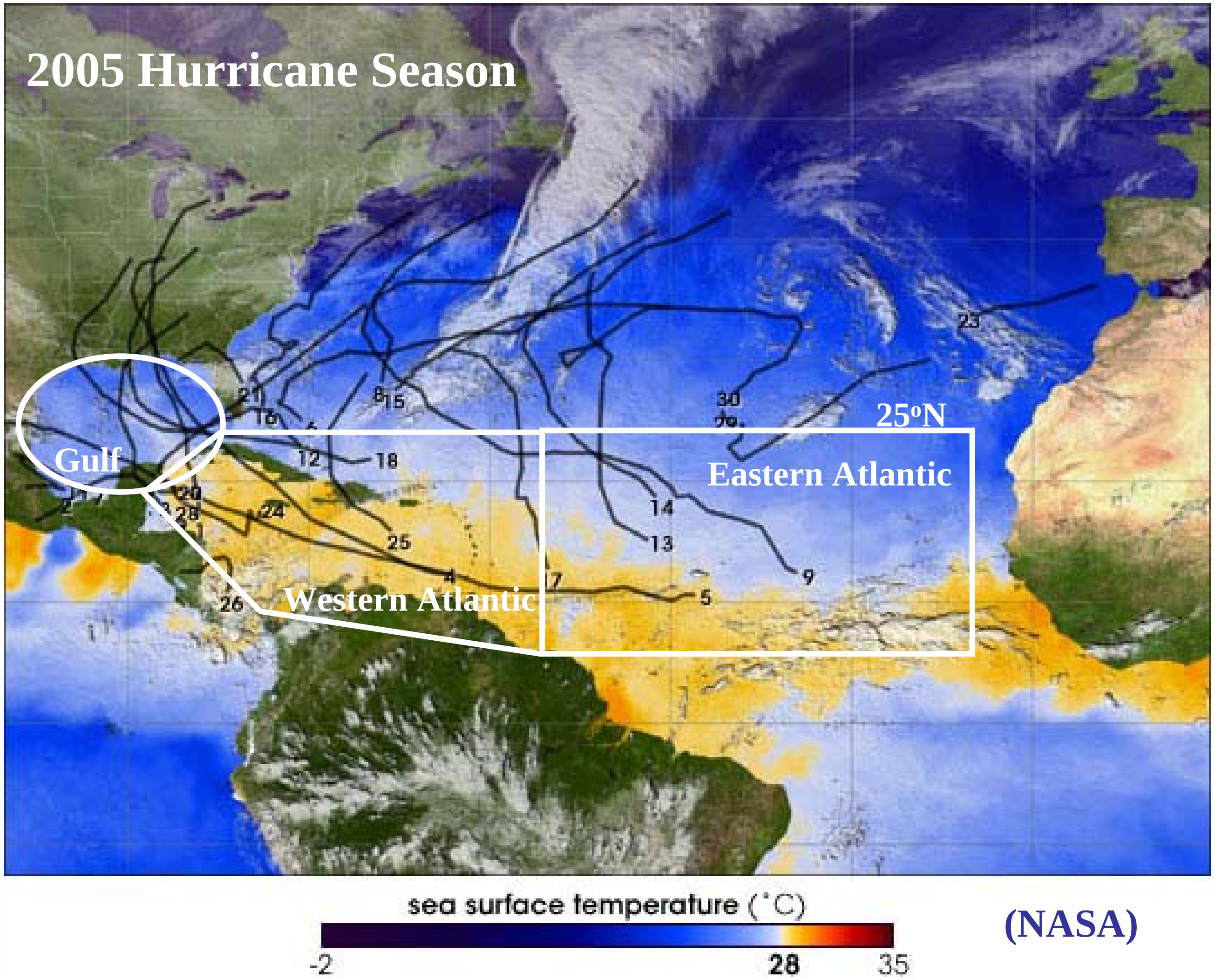
Huge implications on level of protection provided by our projects and risk

Many recent publications have examined the apparent increase in hurricane frequency over the last decade or so in the Atlantic basin.

The objective of this paper is to

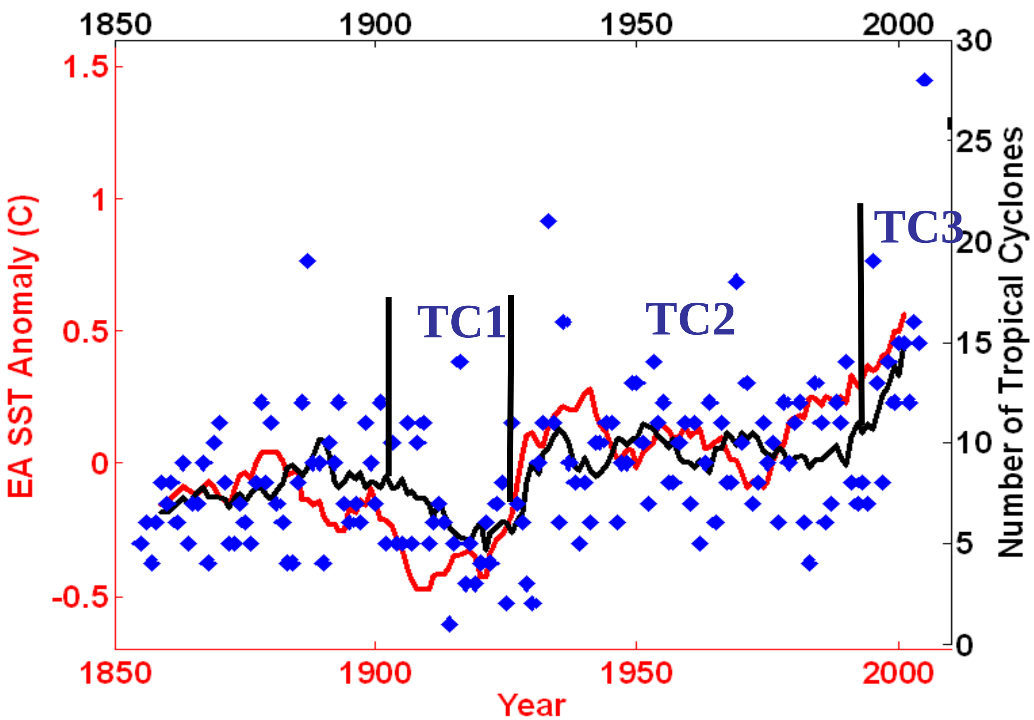
1. **examine variations in hurricane frequency and intensity in the Gulf of Mexico;**
2. **examine large-scale patterns of atmospheric circulation and sea surface temperature to see in any of these are correlated with hurricane activity;**
3. **estimate the impact of large-scale variability on hurricane activity; and**
4. **estimate the impact of potential variations in hurricane activity on extreme surges and waves within the Gulf of Mexico.**

Regions



(NASA)

TC Number-SST Relationship



From: Holland and Webster, 2006.

Changes between TC climate regimes are accompanied by similar changes in eastern Atlantic SSTs;

SST leads cyclone changes and explains >60% of the variance in TC numbers (due entirely to regime changes).

Have we entered a new climatic regime for hurricanes?? If so, what are the consequences on waves and surges in the Gulf of Mexico?

Three Sets of Data used here:

1. Sea Level Pressure (SLP) Fields – 1950-2005
   NOAA-tropic data set 0-110 W, 0-40N

2. Sea Surface Temperature (SST) Fields – 1950-2005
   ERSST data set

3. Hurricane Data 1950-2005
   Oceanweather parameter files
   NCDC parameter files
   (Central pressure, Rmax/Rp, track, forward speed, + …)

ANALYSES

Pressure Fields

Remove seasonal effects <u>P</u>'=<u>P</u>-<u>M</u>(5-day)
73 5-day "anomaly" pressure fields per year
EOF analysis for entire year
Define weightings on EOF's

$$W_{ij} = \sum_{k=1}^{N} \varepsilon_{ik} \hat{p}_{jk}$$

Sea Surface Temperature Fields

Averaged over the entire Gulf of Mexico (Jul-Oct)

Hurricanes

Define measure of combined frequency and intensity:

$$KE_{total} = \sum E_k \qquad \text{for entire season}$$

$$E_k \sim \iint V^2(x,y)\,dx\,dy = \iint V^2(r,\theta)\,r\,d\theta\,dr$$

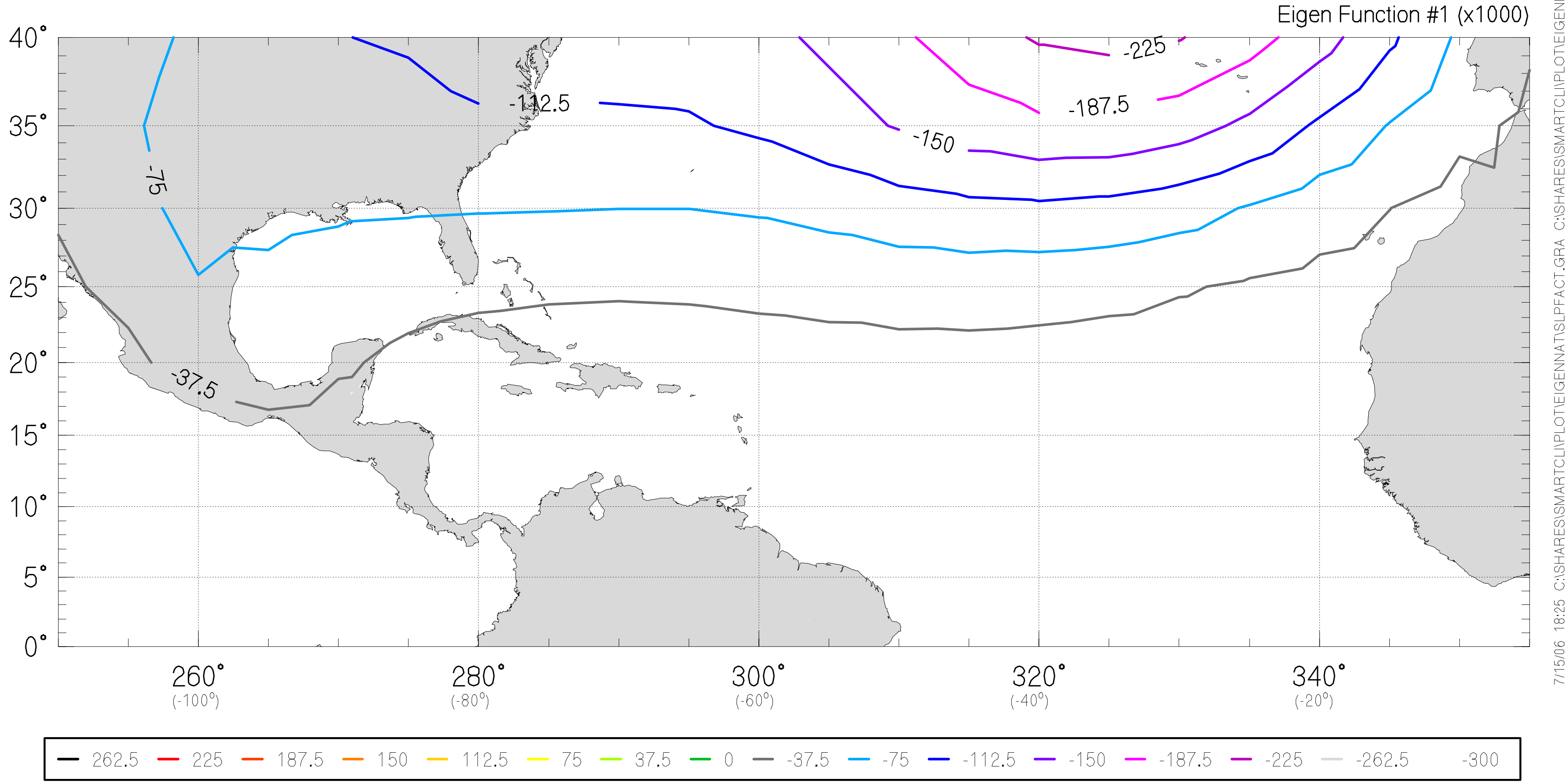
$$\text{given that } V(r,\theta) = V_{\max}\phi_1\left(\frac{r}{R_{\max}}\right)\phi_2(\theta-\theta_0) \text{ then}$$

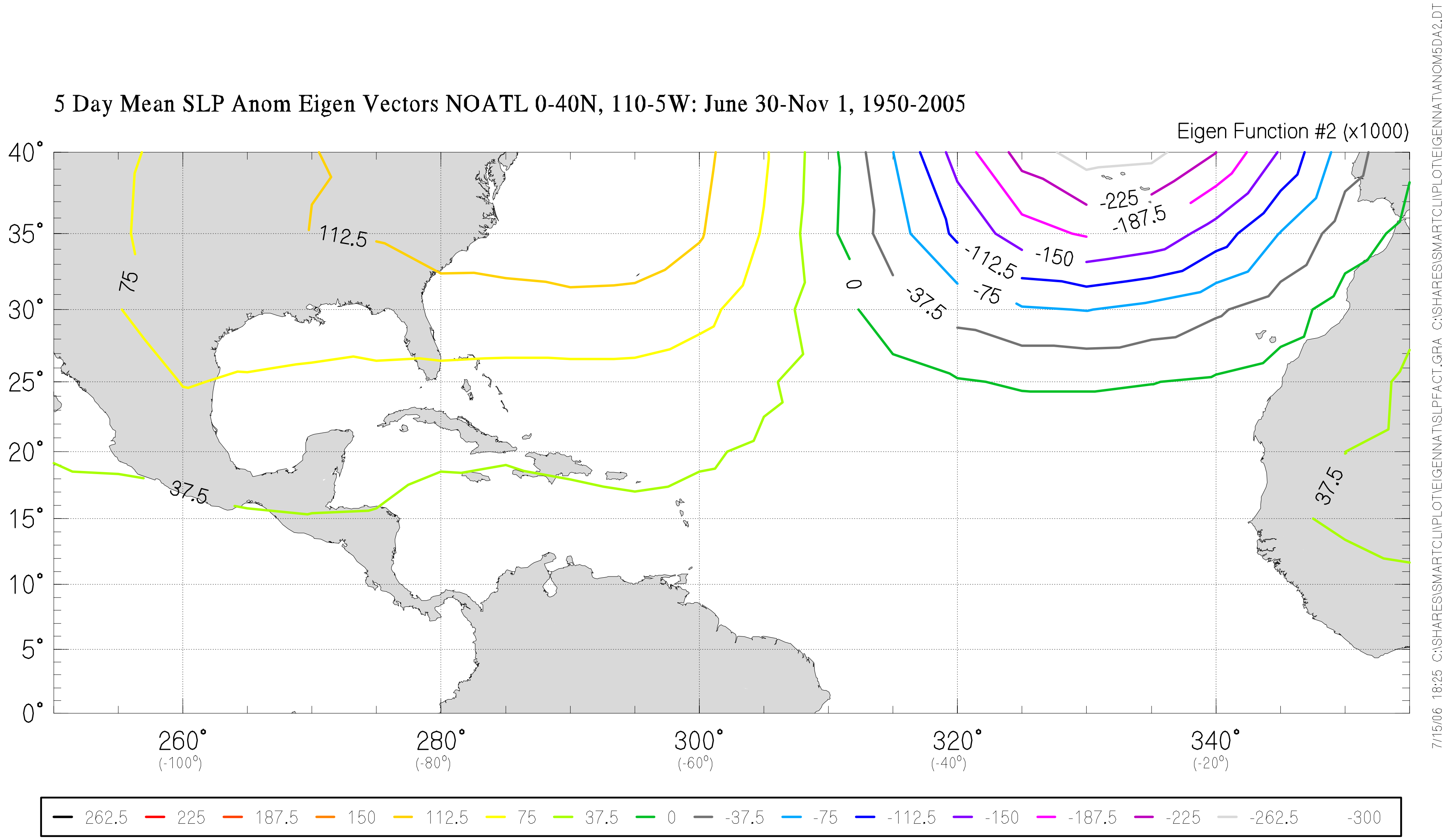
$$E_k \sim V_{\max}^2 R_{\max}^2$$

Percentage of Total Variance Associated with each Eigenfunction

Eigenfunction #	Percentage Variance	Cumulative Variance
1	37.52	37.52
2	14.62	52.13
3	10.21	62.34
4	8.74	71.08
5	6.62	77.70
6	4.66	82.36
7	2.93	85.29
8	2.39	87.68
9	1.90	89.58
10	1.60	91.18
11	1.17	92.35
12	1.04	93.39
13	0.92	94.31
14	0.65	04.96
15	0.53	95.49

5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005




5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005
Eigen Function #2 (x1000)
40°
35°
30°
25°
20°
15°
10°
5°
0°
260°
(-100°)
280°
(-80°)
300°
(-60°)
320°
(-40°)
340°
(-20°)
75
112.5
37.5
0
-37.5
-75
-112.5
-150
-187.5
-225
262.5
225
187.5
150
112.5
75
37.5
0
-37.5
-75
-112.5
-150
-187.5
-225
-262.5
-300
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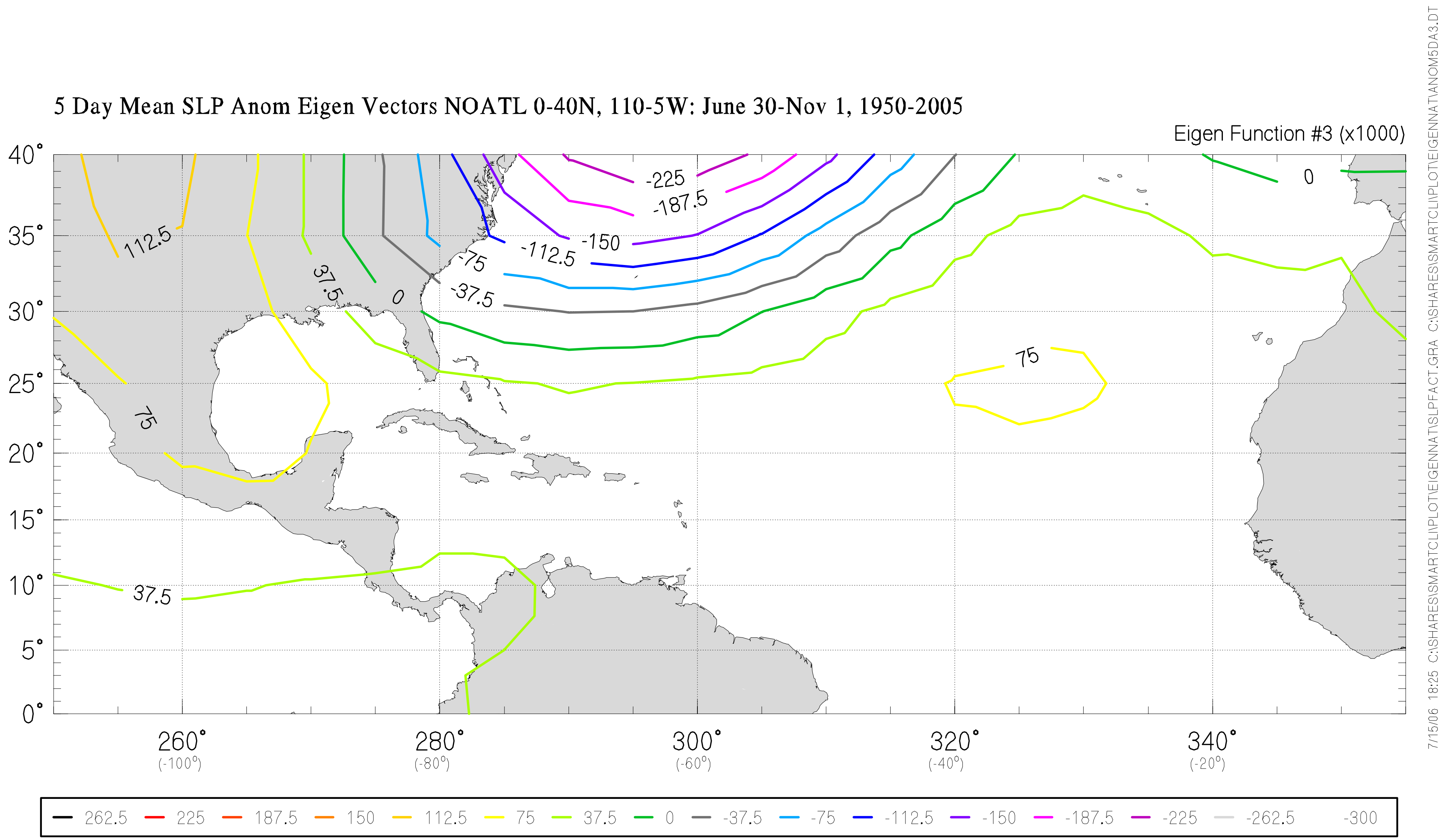

5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005
Eigen Function #3 (x1000)
40°
35°
30°
25°
20°
15°
10°
5°
0°
260°
(-100°)
280°
(-80°)
300°
(-60°)
320°
(-40°)
340°
(-20°)
112.5
75
37.5
0
-37.5
-75
-112.5
-150
-187.5
-225
262.5
225
187.5
150
112.5
75
37.5
0
-37.5
-75
-112.5
-150
-187.5
-225
-262.5
-300
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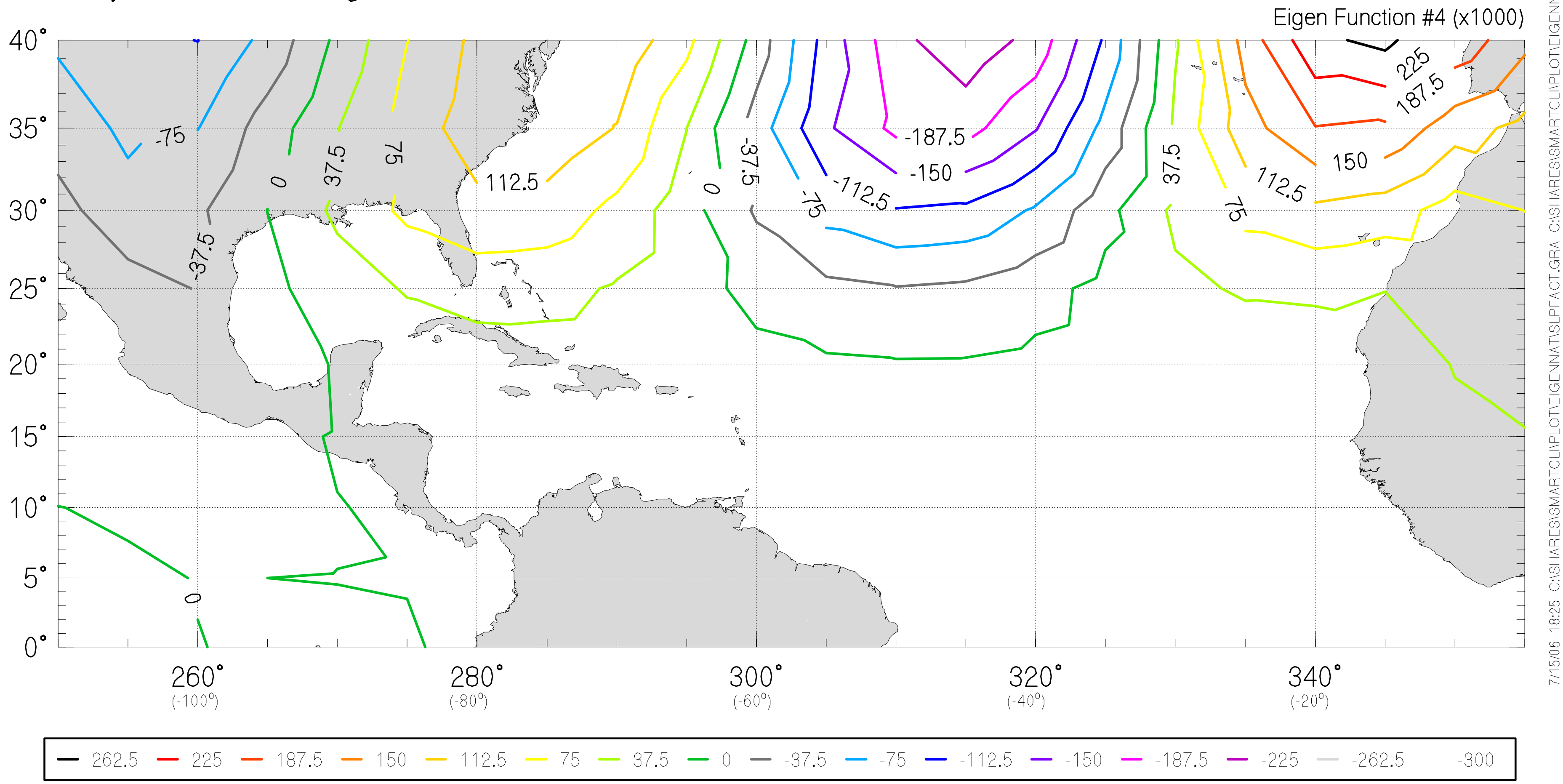
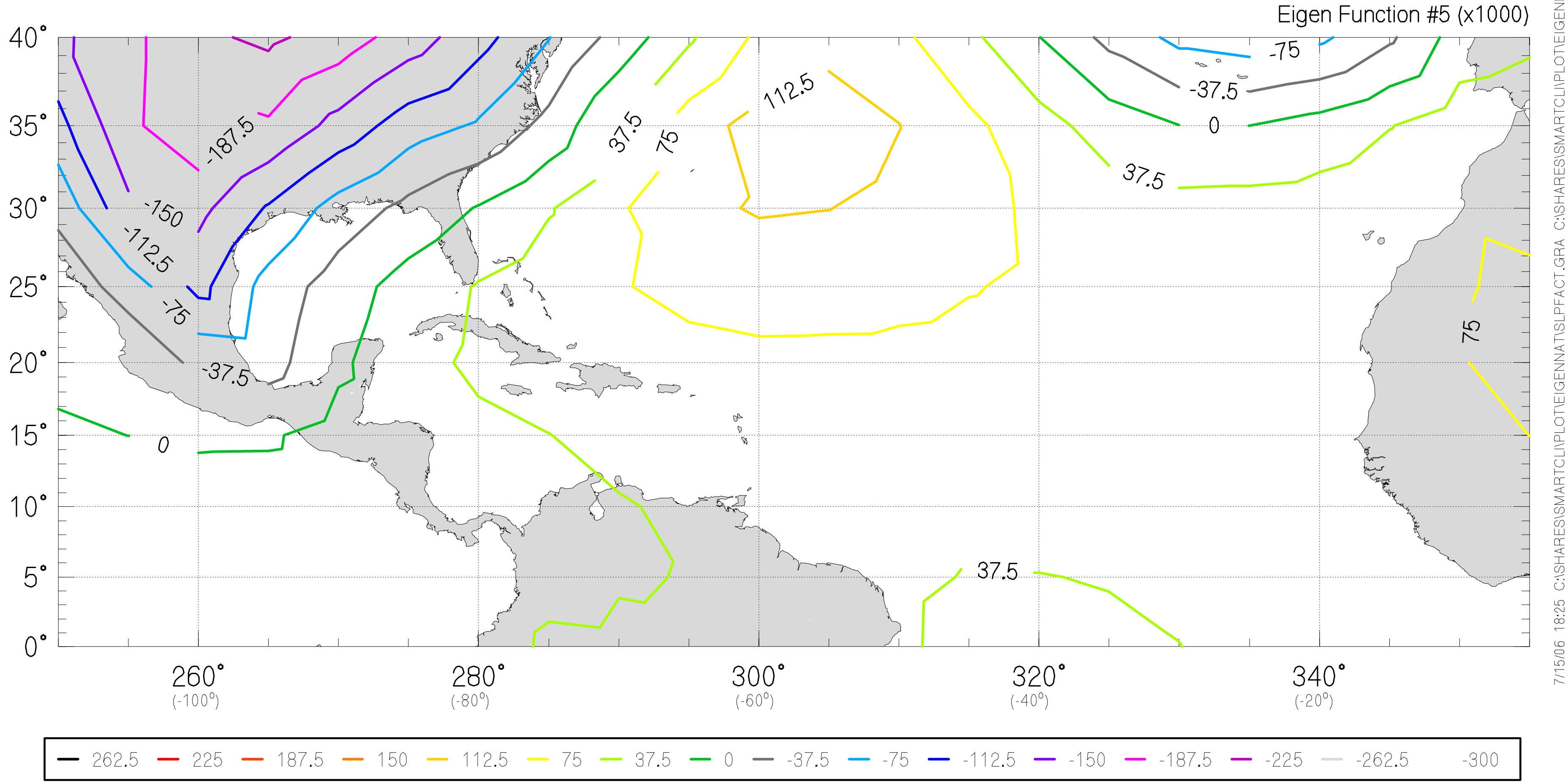
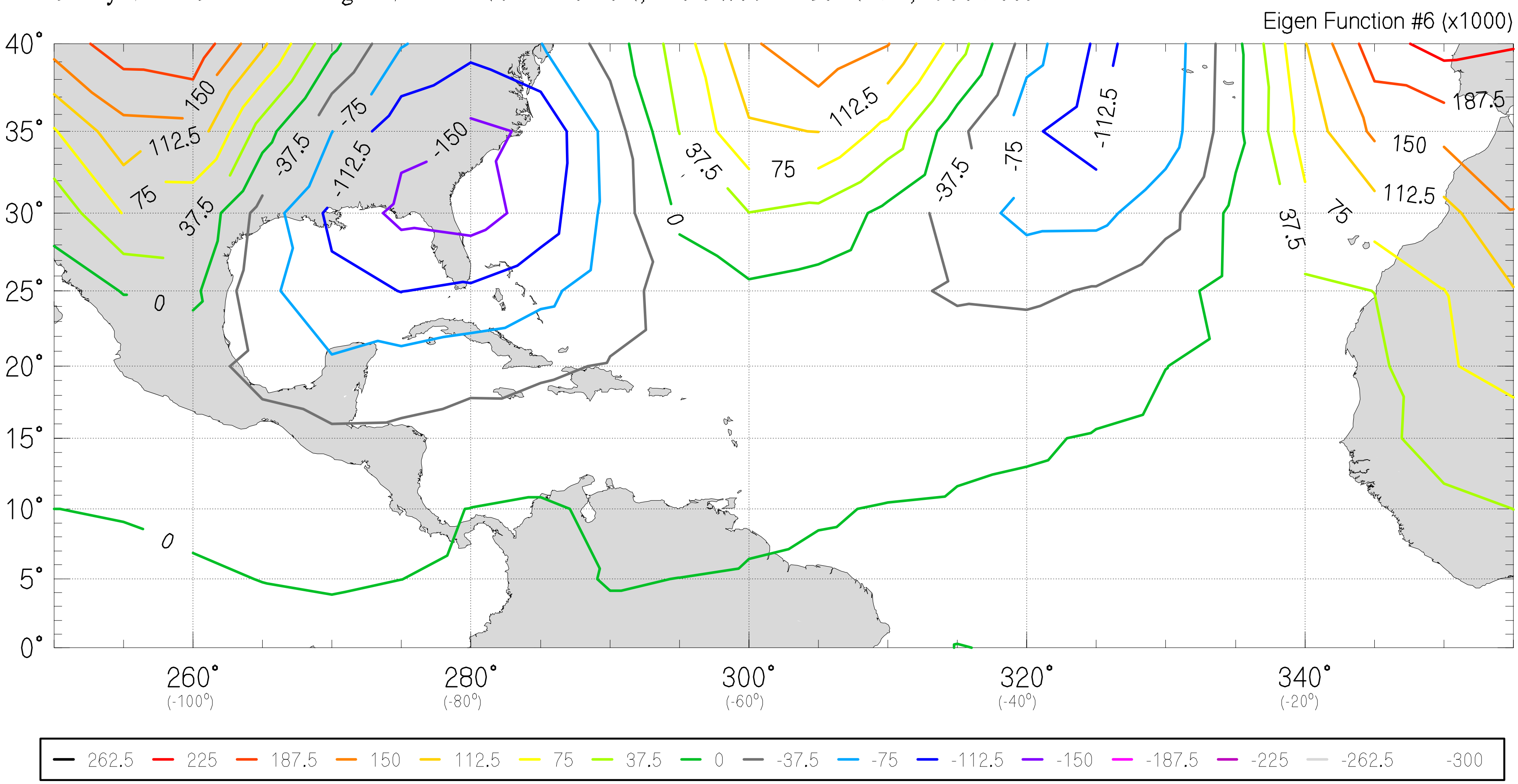
5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005



5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005



5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005



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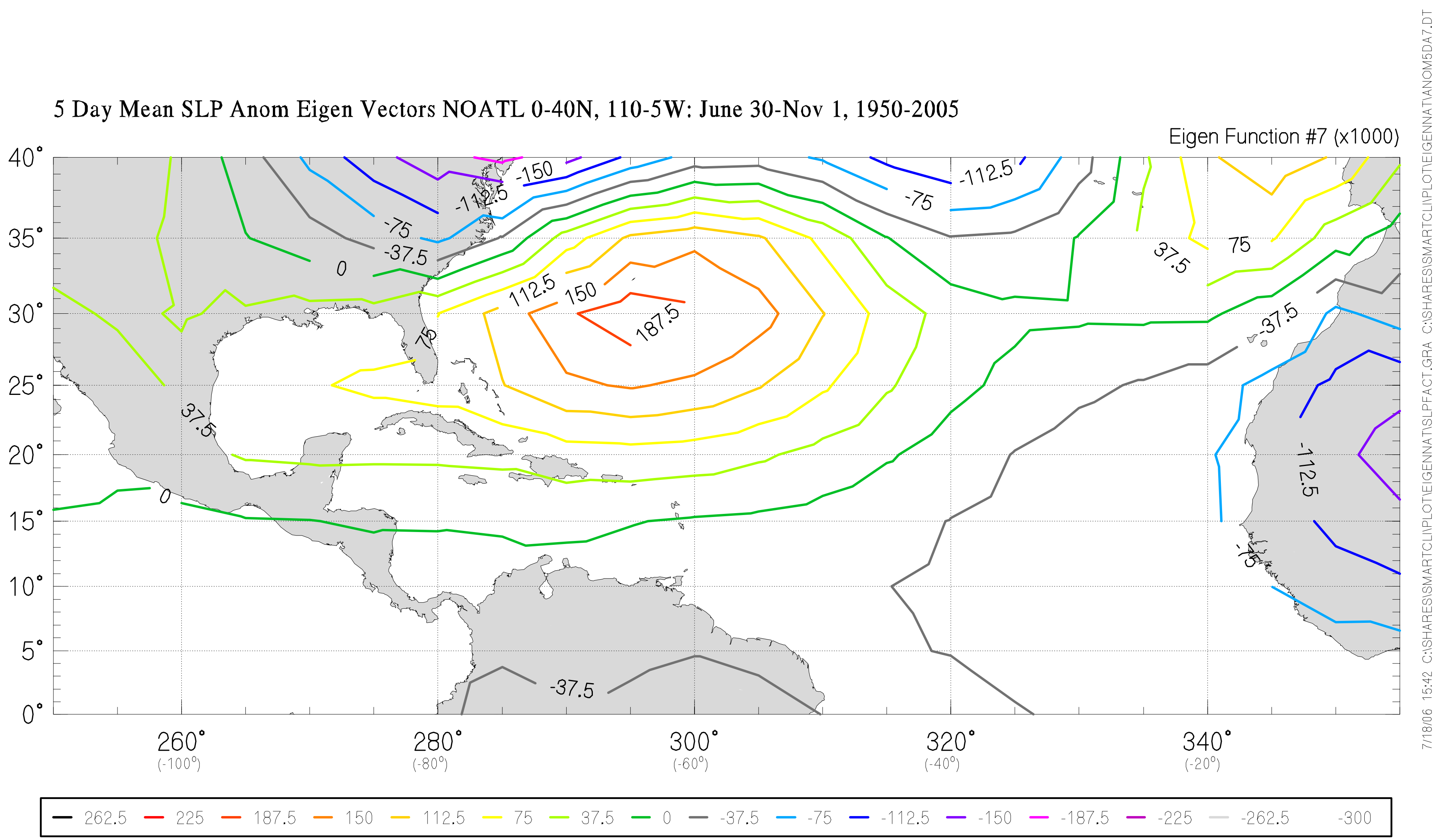

5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005
Eigen Function #7 (x1000)
40°
35°
30°
25°
20°
15°
10°
5°
0°
260°
(-100°)
280°
(-80°)
300°
(-60°)
320°
(-40°)
340°
(-20°)
262.5
225
187.5
150
112.5
75
37.5
0
-37.5
-75
-112.5
-150
-187.5
-225
-262.5
-300
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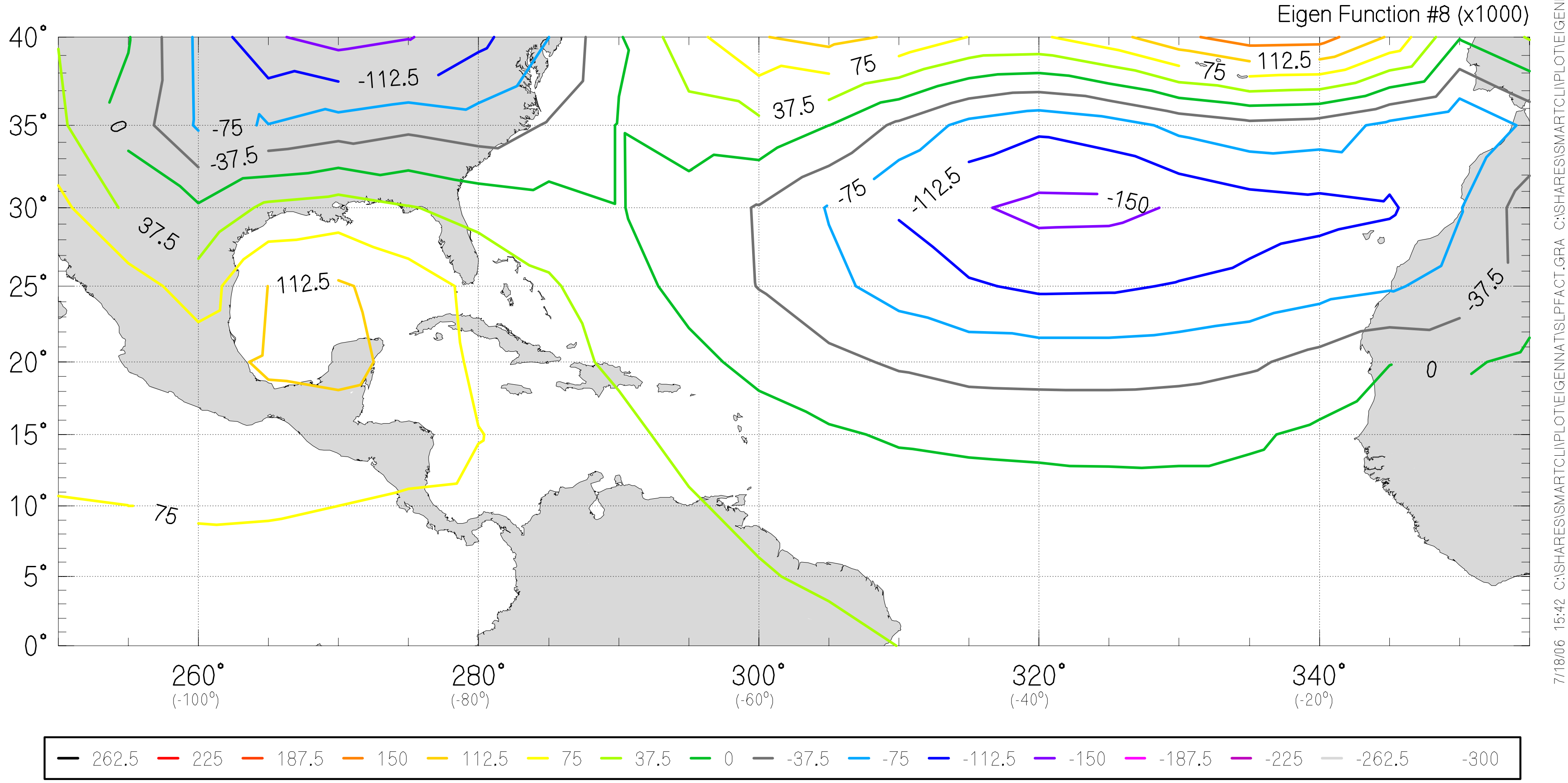
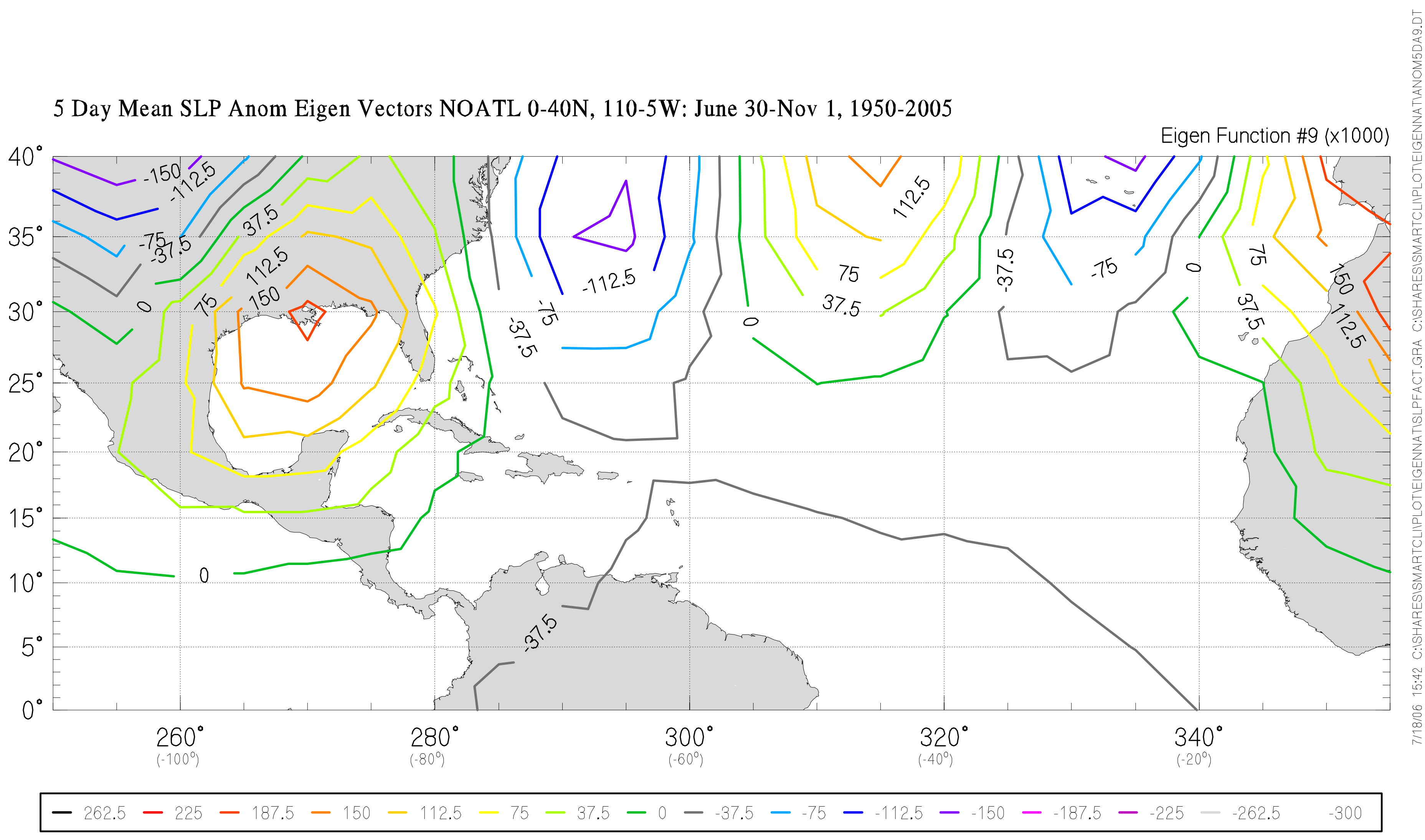
5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005




5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005
Eigen Function #9 (x1000)
40° 35° 30° 25° 20° 15° 10° 5° 0°
260° (-100°) 280° (-80°) 300° (-60°) 320° (-40°) 340° (-20°)
262.5 225 187.5 150 112.5 75 37.5 0 -37.5 -75 -112.5 -150 -187.5 -225 -262.5 -300
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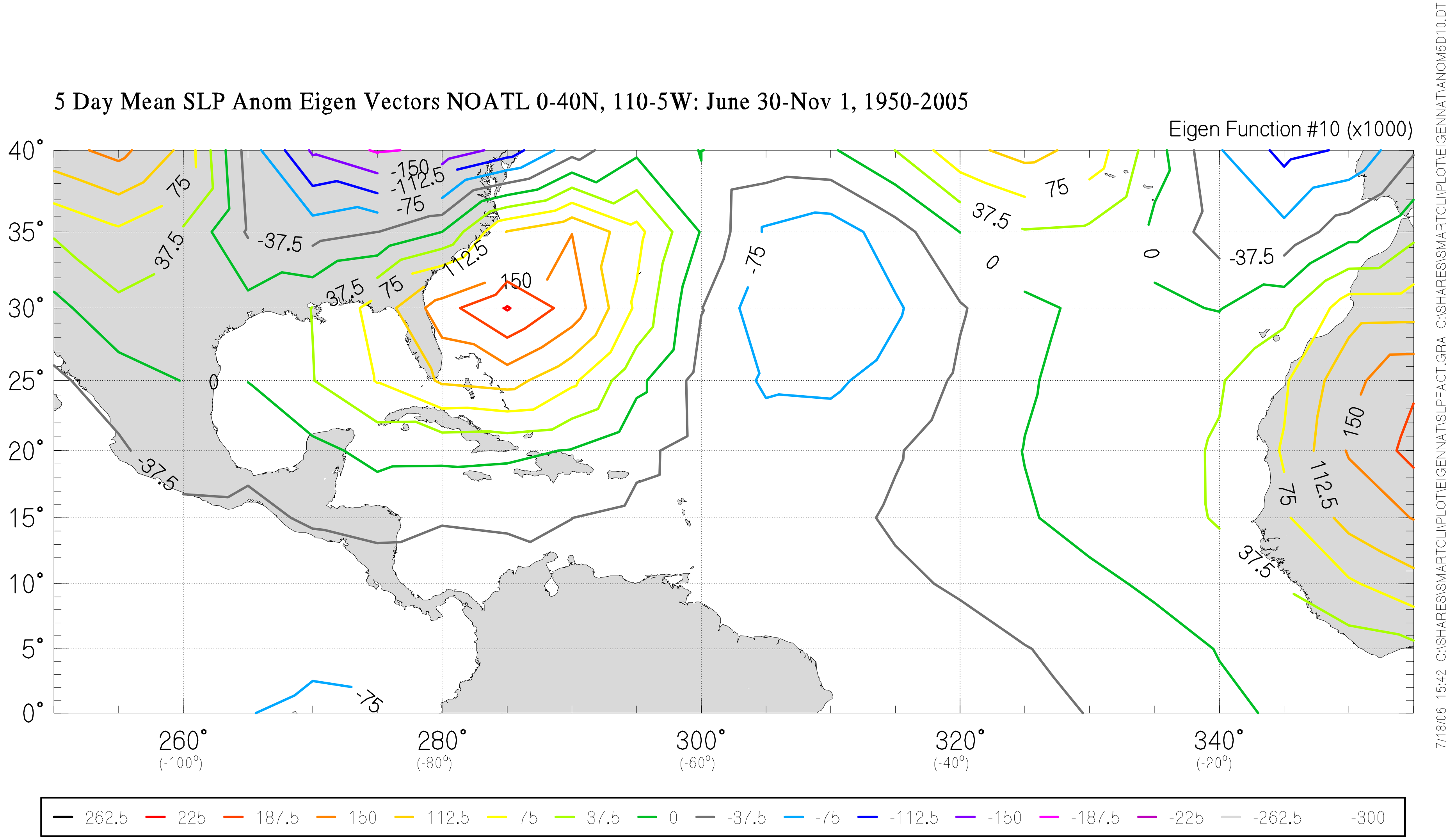
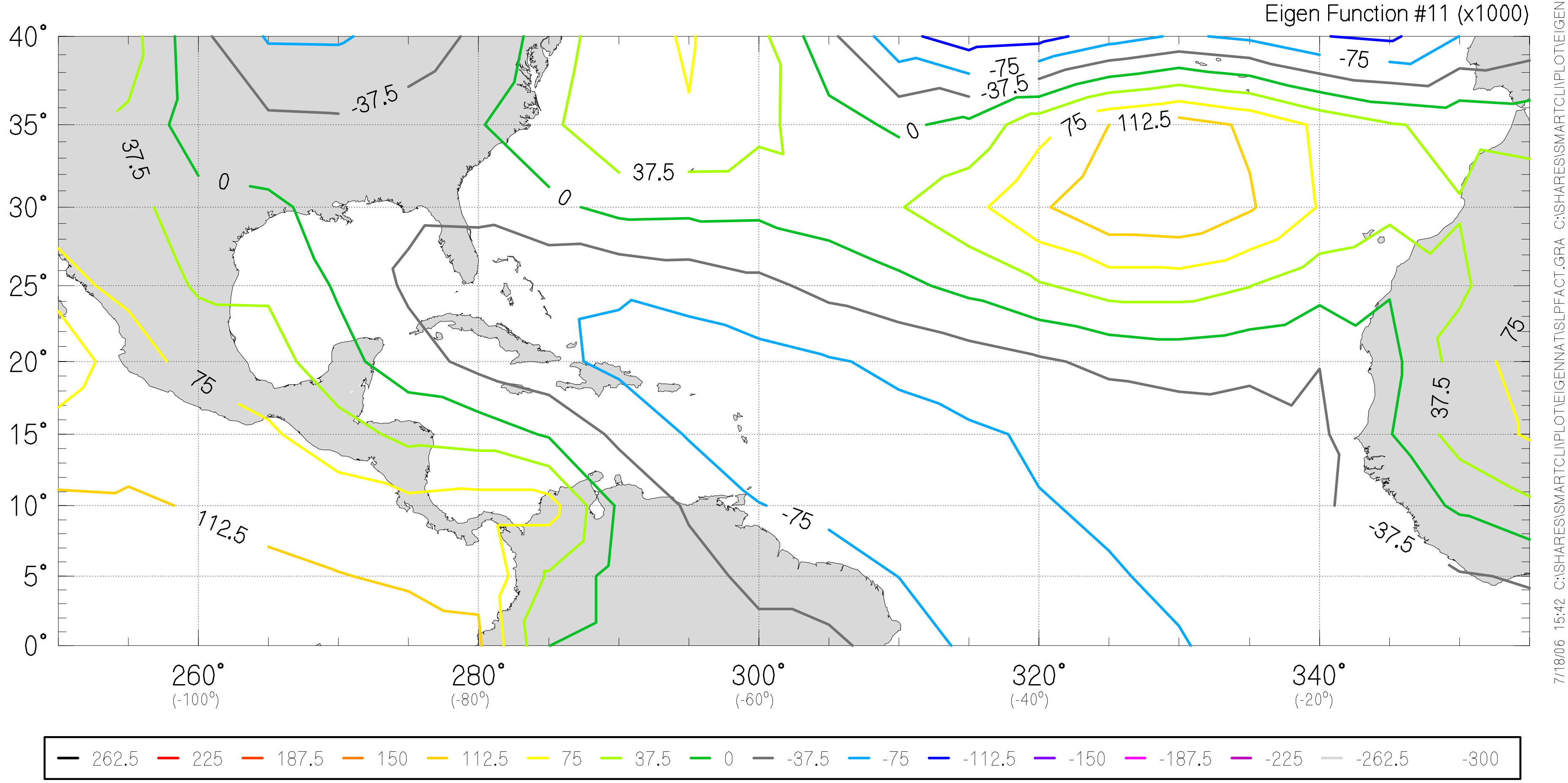
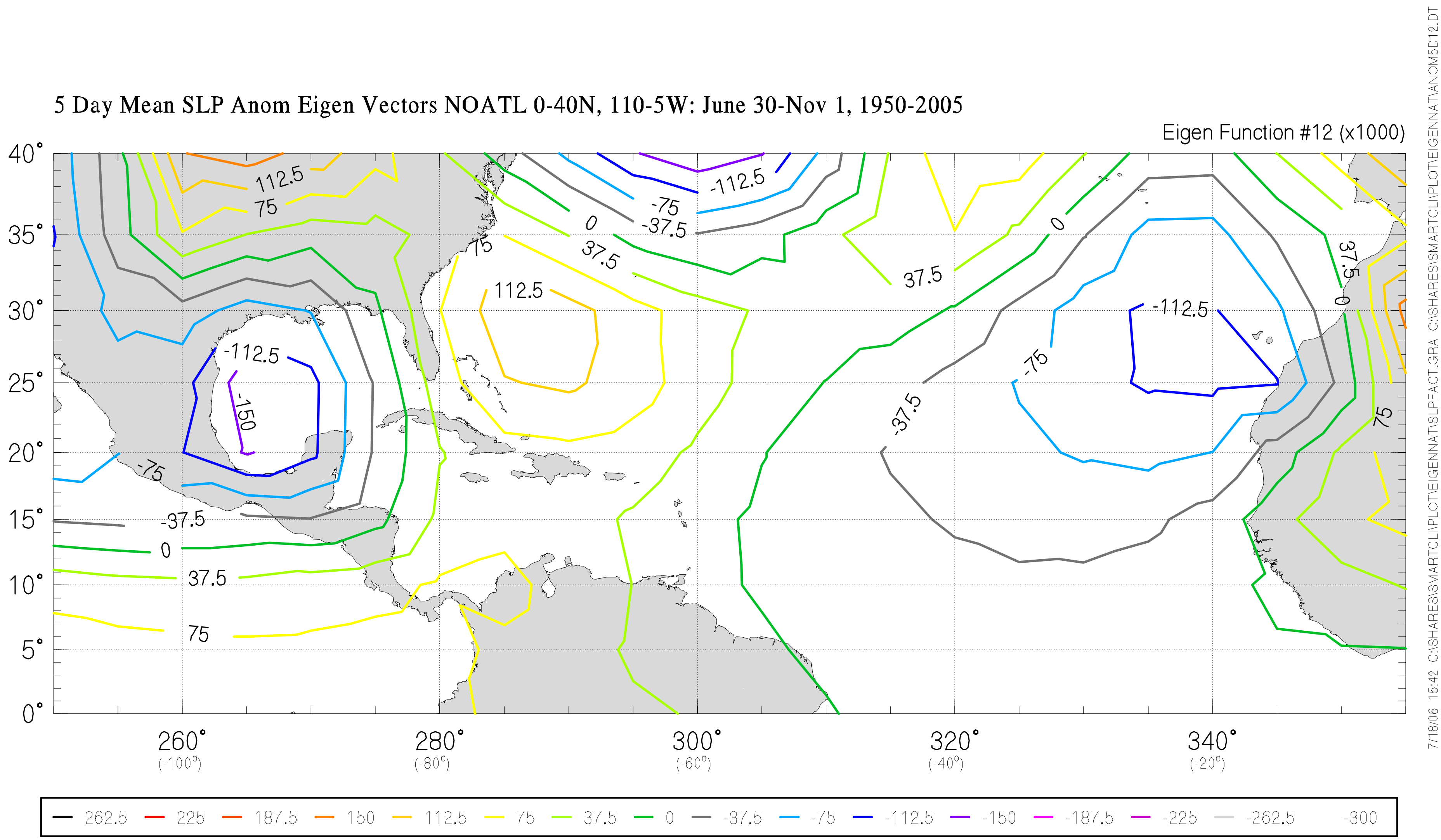
5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005



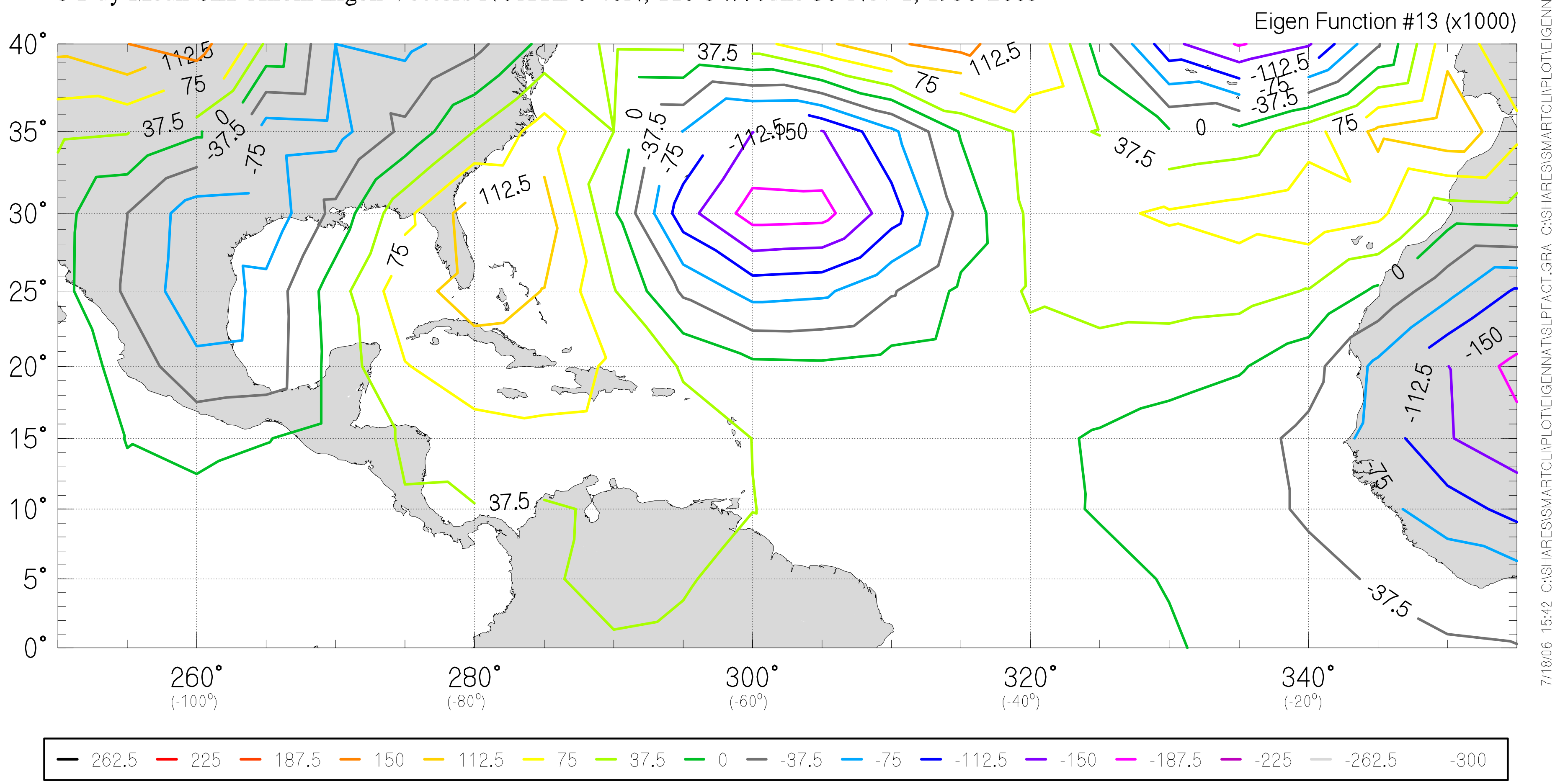
5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005



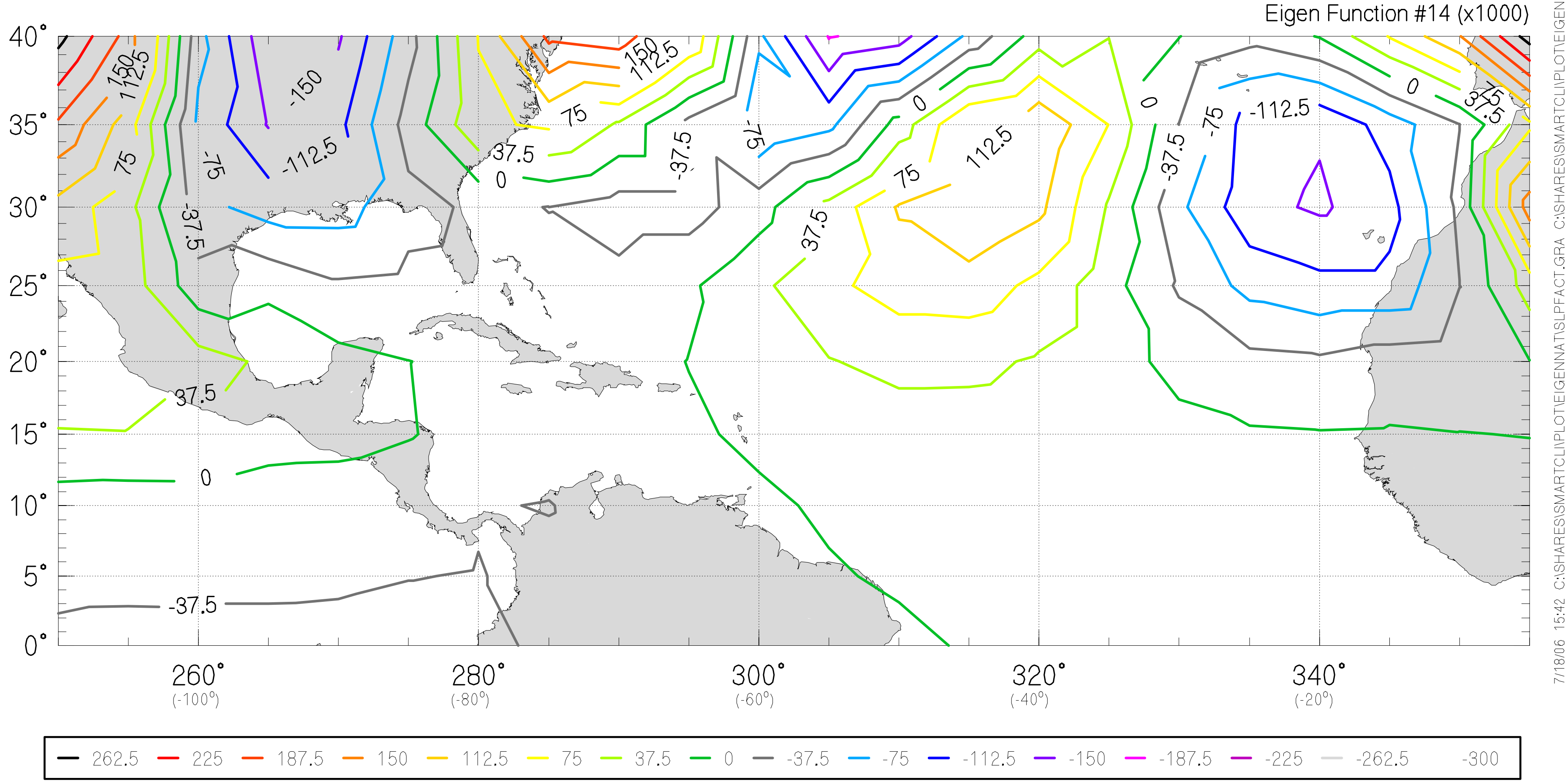
5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005



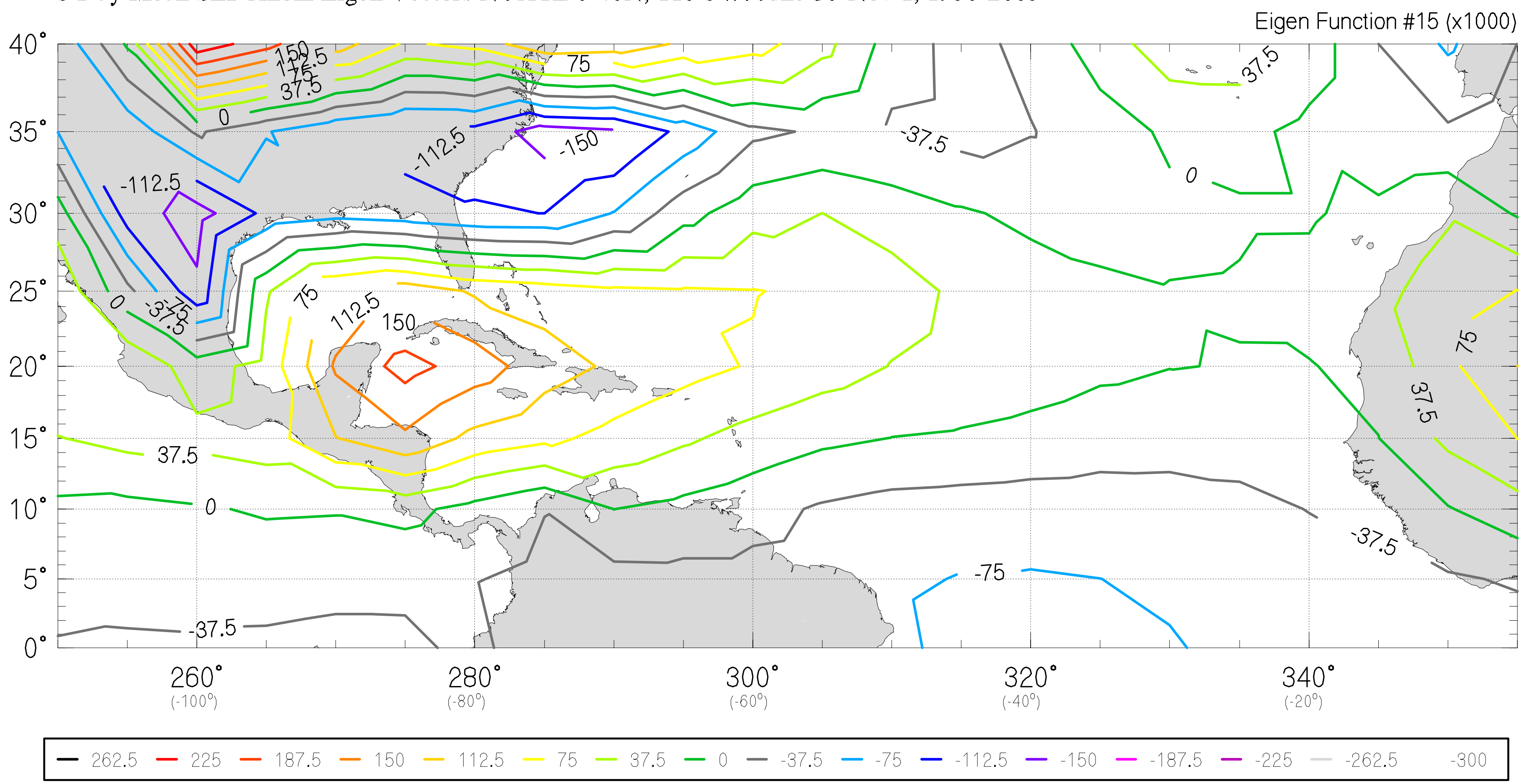
5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005

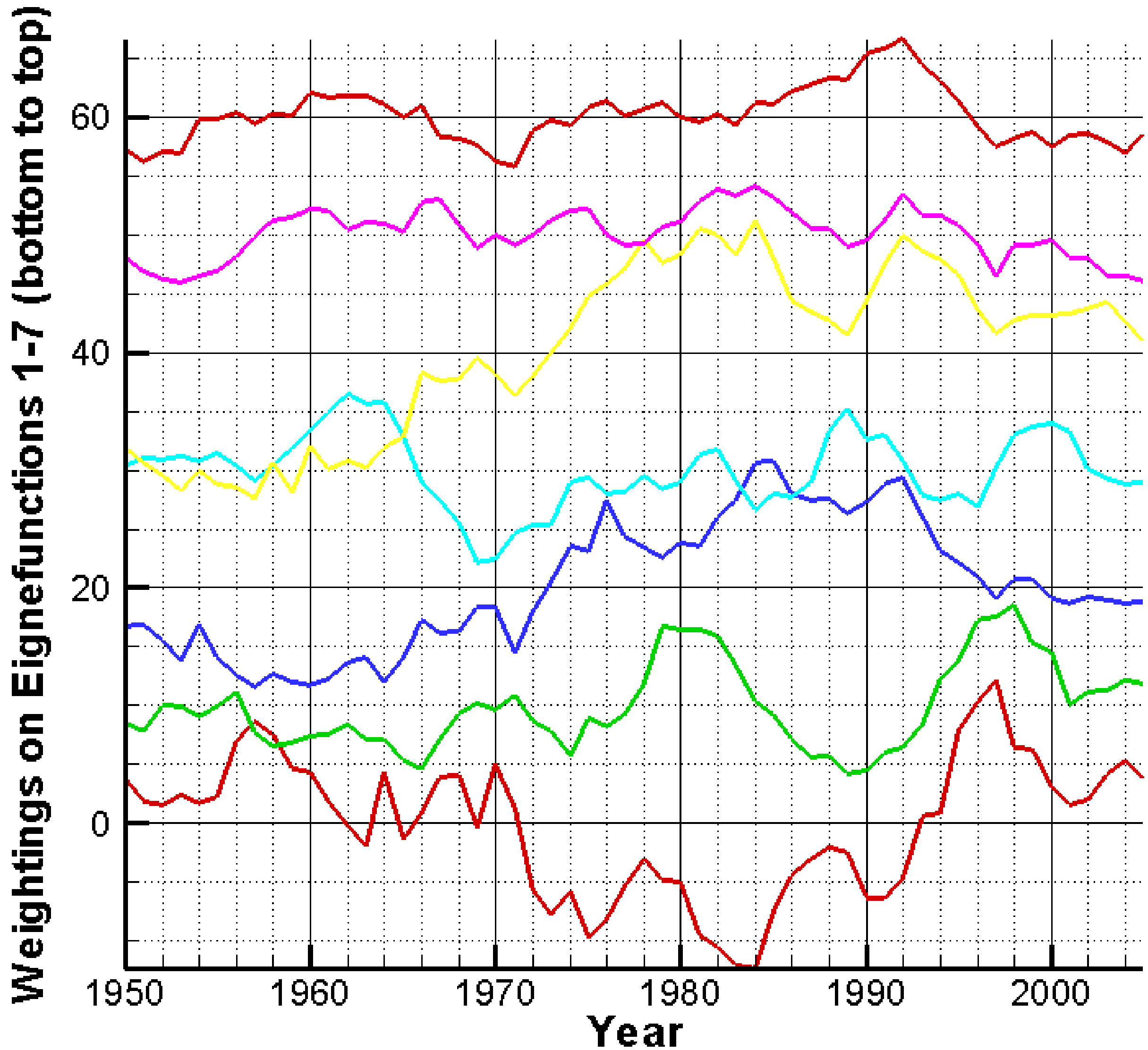


5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005

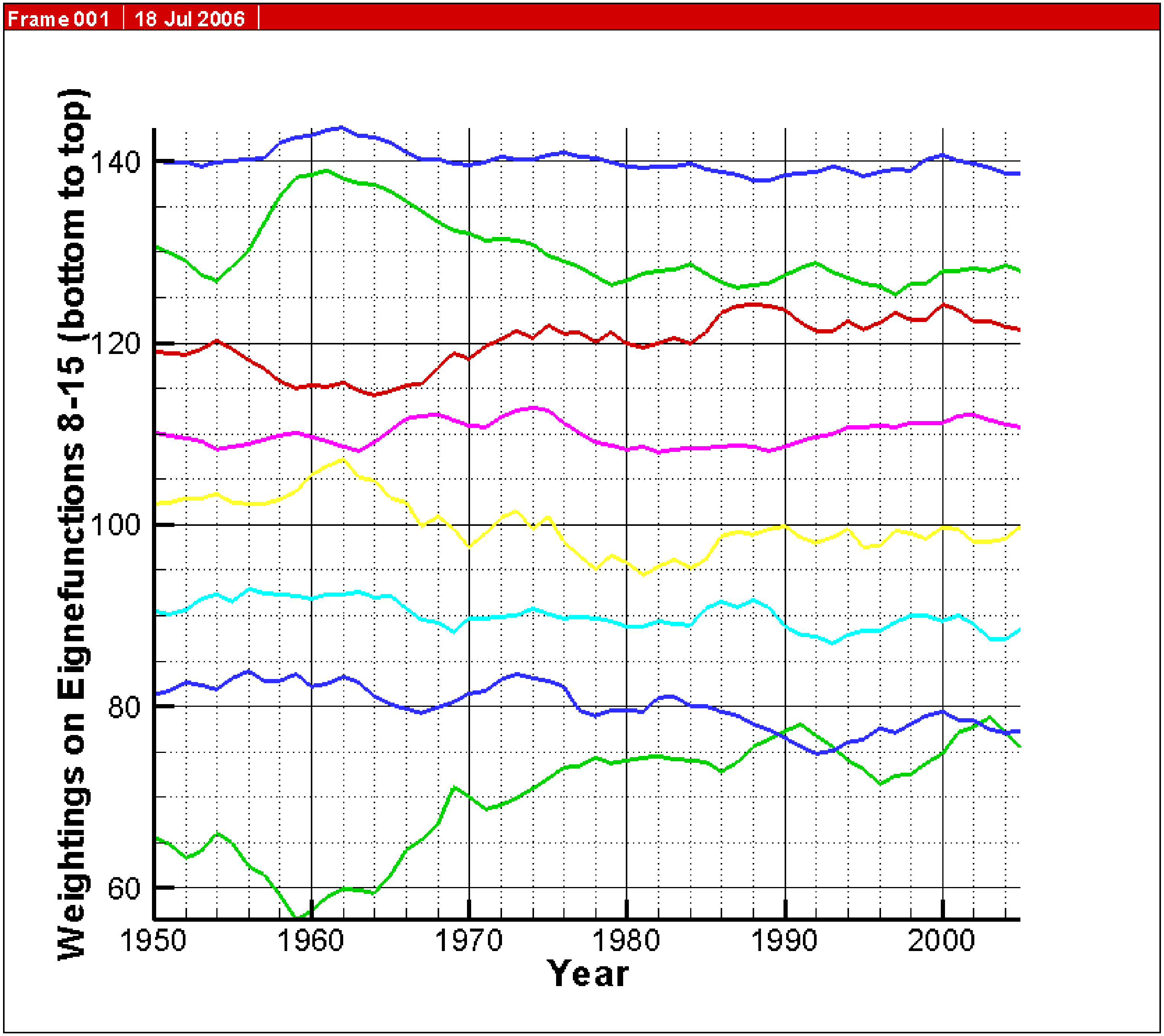


5 Day Mean SLP Anom Eigen Vectors NOATL 0-40N, 110-5W: June 30-Nov 1, 1950-2005

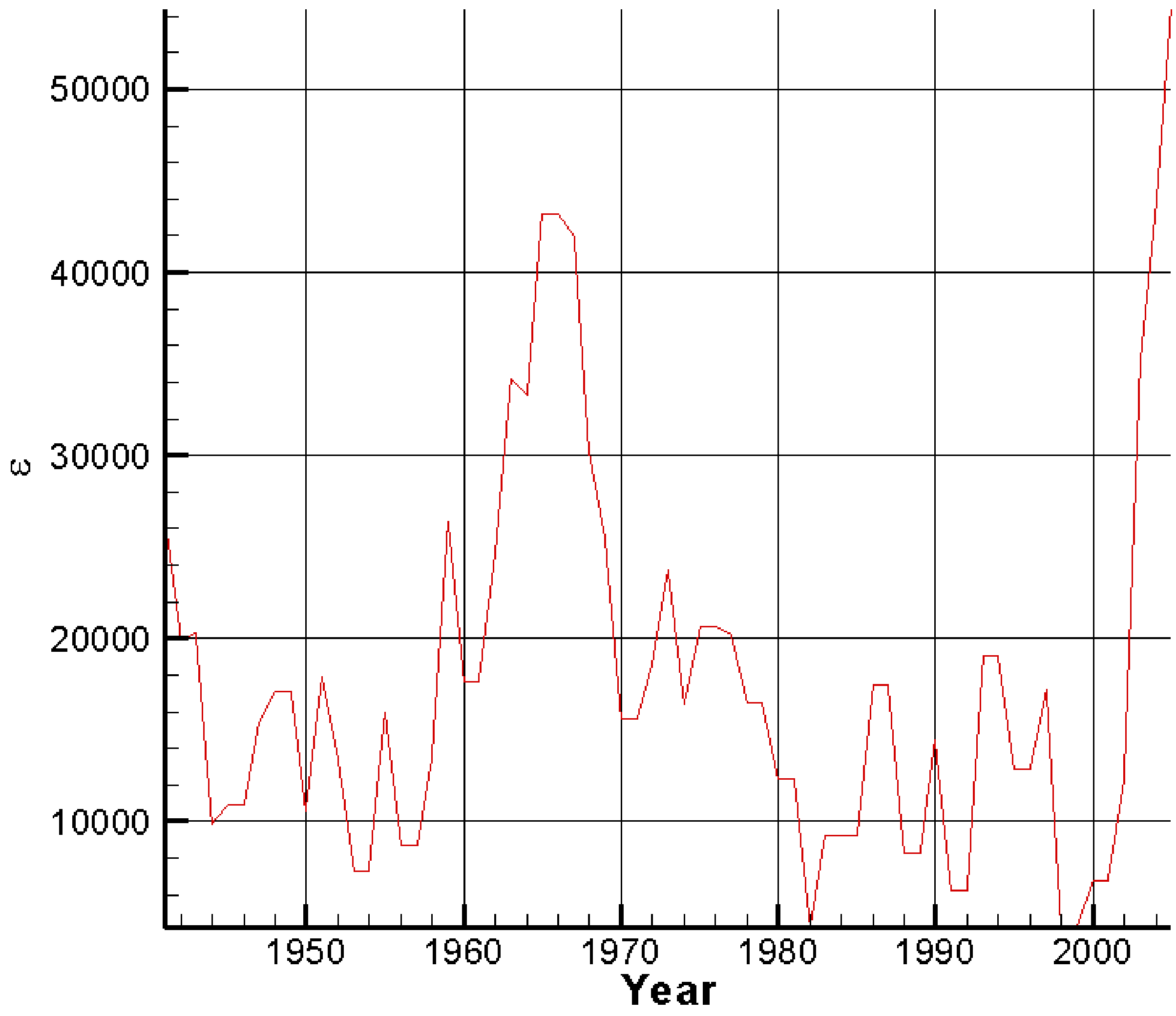




Very large decadal and longer scales of variation – not just a single cycle!!!!



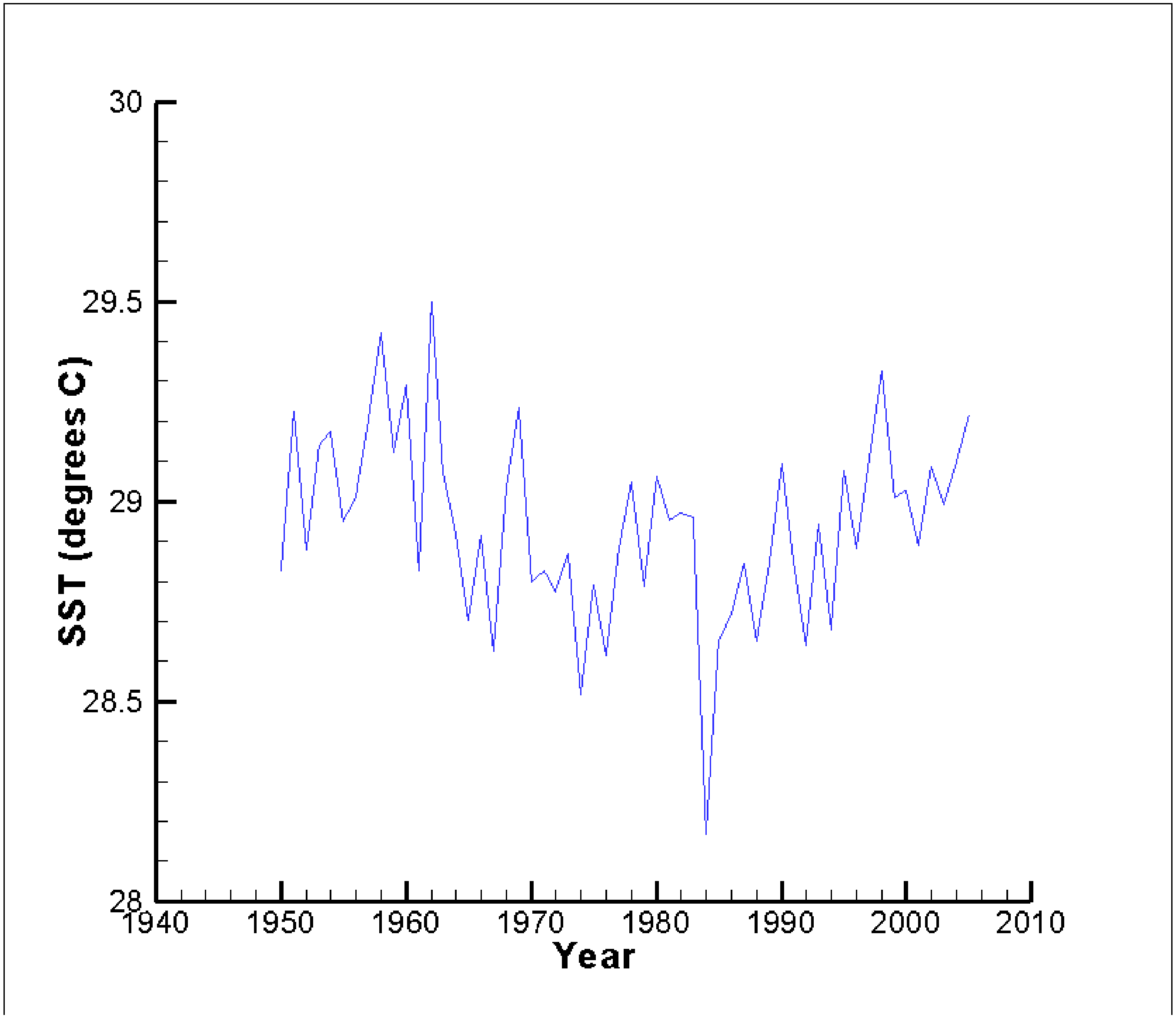
Frame 001
18 Jul 2006
Weightings on Eignefunctions 8-15 (bottom to top)
140
120
100
80
60
1950
1960
1970
1980
1990
2000
Year



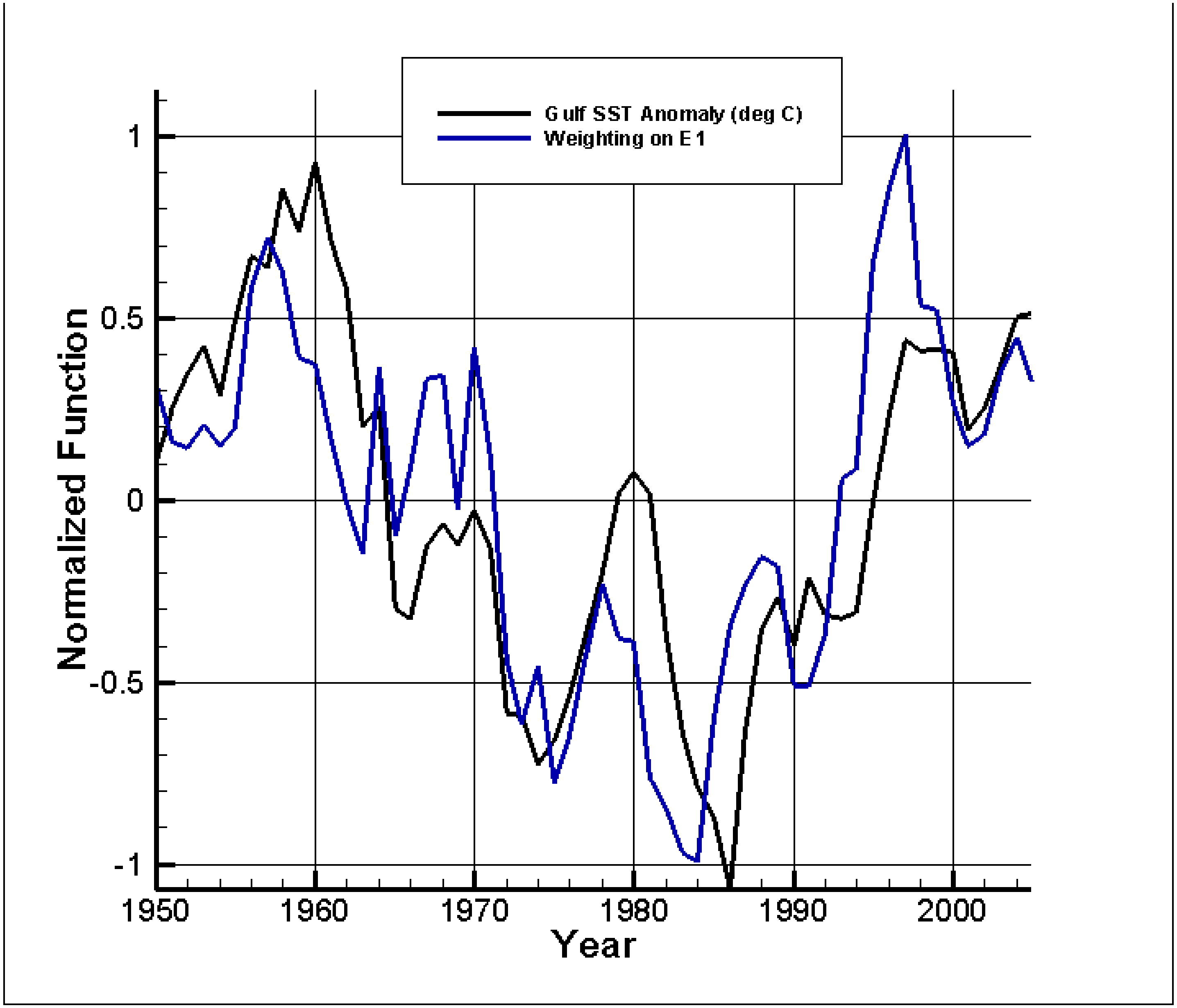
Variation in seasonal total kinetic energy in Gulf of Mexico

Correlation between Smoothed Annual KE and Eigenfunctions 1-15
Underline denotes significance at .01 level of confidence

Eigenfunction	***Correlation***	***Student's T***
1	0.1493216	1.109727
2	-0.2459255	1.864435
3	-0.3340233	<u>2.604129</u>
4	-0.1314833	0.9746628
5	-0.1915766	1.434362
6	-7.9412408E-02	0.5854084
7	-0.1434847	1.065417
8	-0.2273055	1.715246
9	1.8339736E-03	1.3476920E-02
10	-5.3688638E-02	0.3950992
11	0.2781583	2.128020
12	0.3209944	2.490618
13	-0.4129986	<u>3.332384</u>
14	0.4549139	<u>3.753832</u>
15	0.2868412	2.200305



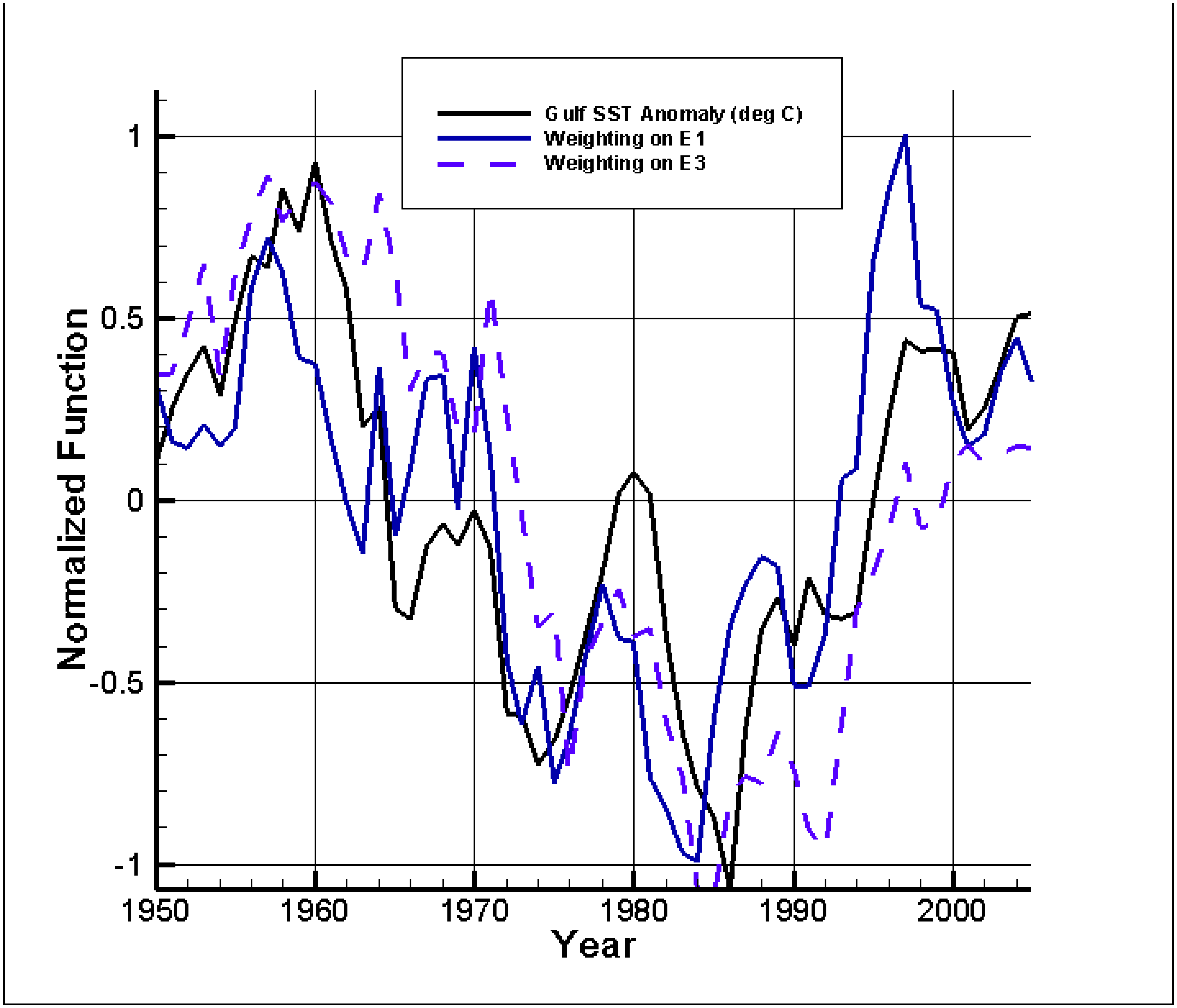
Variation of hurricane season Gulf of Mexico SST’s 1950-2005



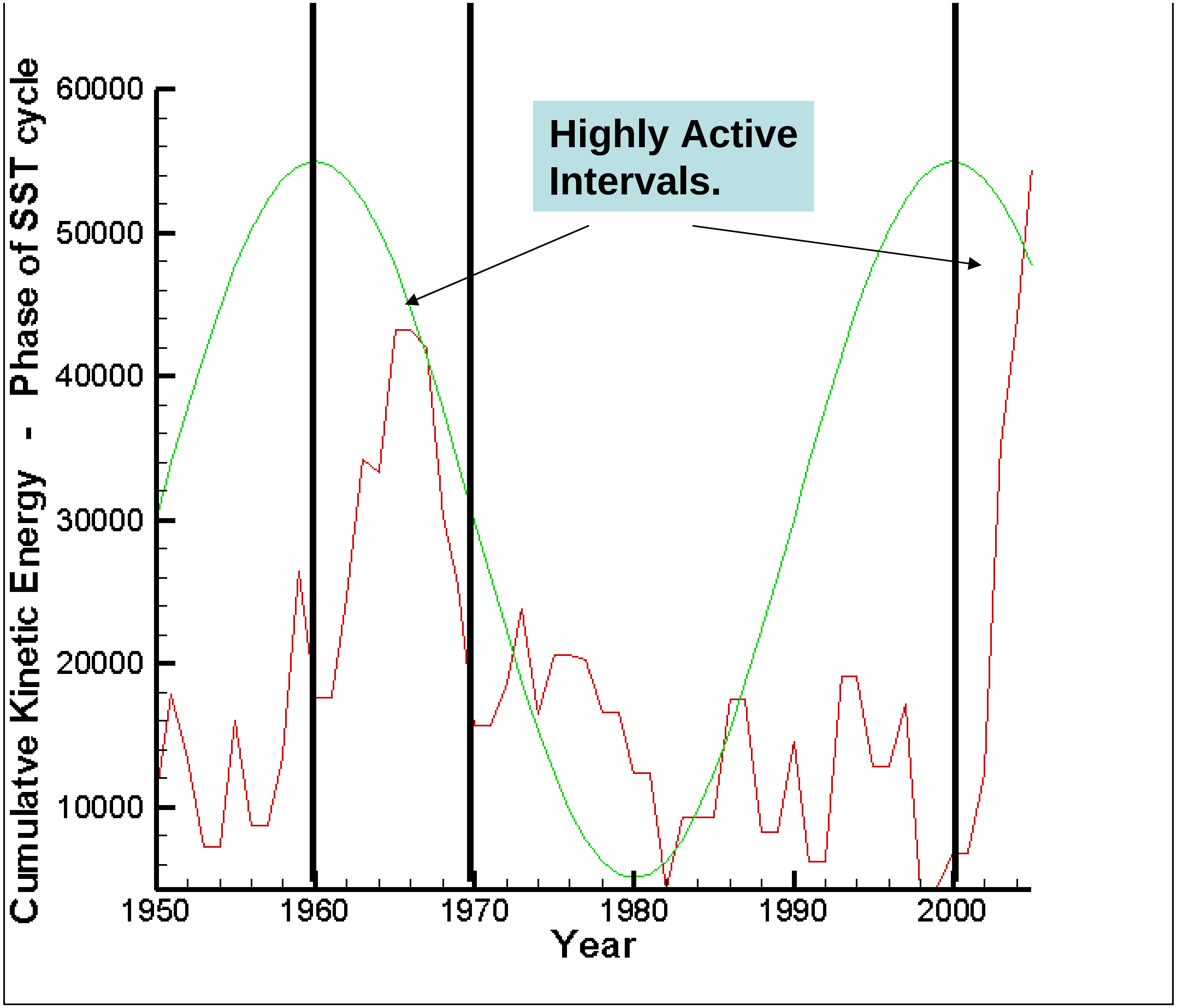
Weightings on Eigenfunction 1 and SST with normalized ranges.

Correlation coefficient between weightings on E1 and SST's through time for different lag/lead values.

LAG (years)	Correlation Coefficient	Student's T
-3	0.72	7.426
-2	0.79	9.251
-1	0.79	9.243
0	0.75	8.342
1	0.61	5.571
2	0.48	3.908
3	0.39	3.032



Weightings on Eigenfunctions 1 & 3 and SST with normalized ranges.



Total KE per season with 40-year cycle superimposed.

Table 3. Landfalling central pressures for Group 1 and Group 2

Group 1 (39 years)			Group 2 (17 years)		
Year	Name	Central pressure (at landfall)	Year	Name	Central pressure (at landfall)
1957	Audrey	963.6	1961	Carla	936.4
1974	Carmen	942.8	1964	Hilda	960.0
1979	Frederic	949.7	1965	Betsy	945.2
1980	Allen	945.0	1967	Beulah	950.0
1992	Andrew	949.0	1969	Camille	905.8
1996	Opal	940.2	1970	Celia	944.0
1999	Earl	953.0	2002	Lili	966.3
			2004	Charley	950.2
			2004	Ivan	955.1
			2005	Dennis	951.9
			2005	Katrina	919.4
			2005	Rita	945.8
			2005	Wilma	951.1

If the distribution of x is influence by a "large-scale" variation then We can used a conditional probability integral to estimate p(x).

$$P(x) = \int P(x \mid \vec{S})\, p(\vec{S})\, d\vec{S} \qquad \approx \sum P(x \mid \vec{S}_k)\, p(\vec{S}_k)$$

For a discretized set of "populations" we can use the following form To estimate the return period T(x)

$$T(x) = \frac{1}{1 - \sum \lambda_n \beta_n F_n(x)}$$

where

λ_n is the frequency of storms in Group n

$\mathrm{F_n}(x)$ is the cumulative distribution function (CDF) for storms in Group n

and β_n is the proportion of years in Group n

For the case where populations are identically distributed, we have

$$T(x) = \frac{1}{1 - F(x) \sum \lambda_n \beta_n}$$

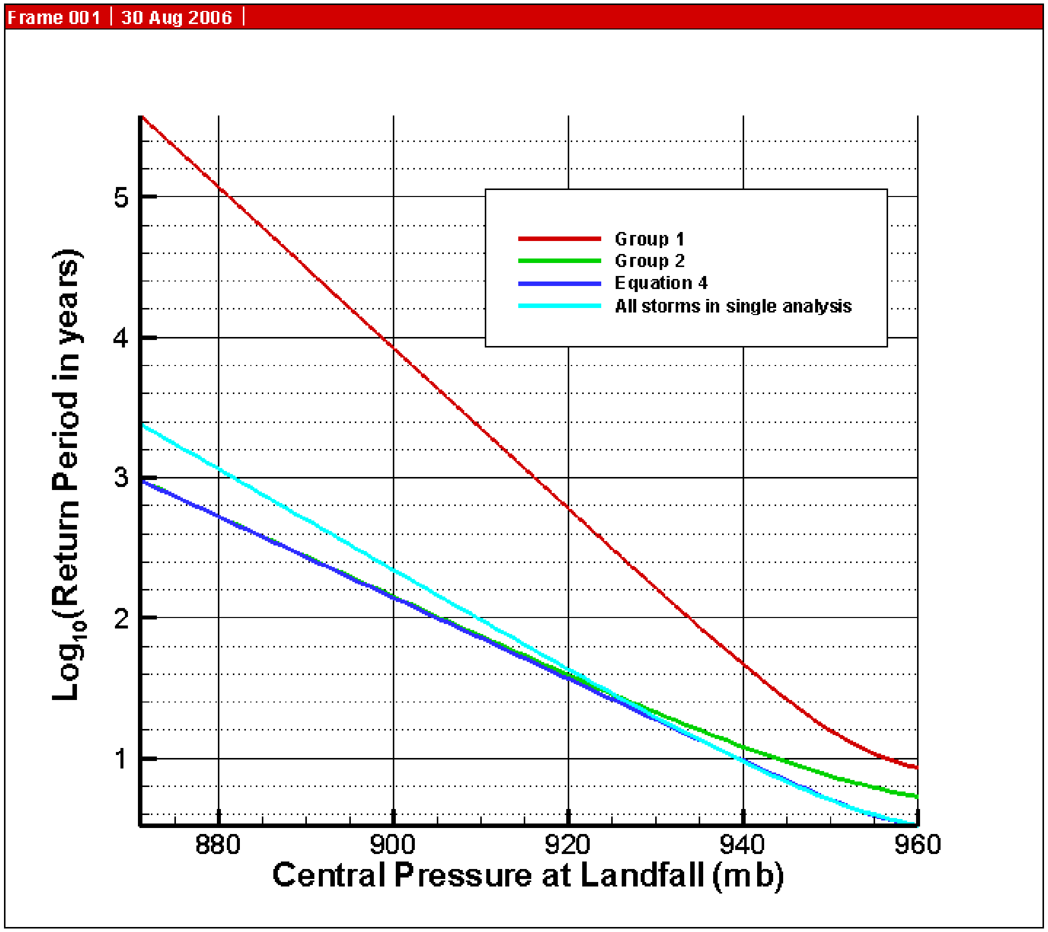
where F(x) is the general CDF for all Groups.

$$F(\hat{x}) = e^{-e^{-\hat{x}}}$$

GEV analysis of central pressures

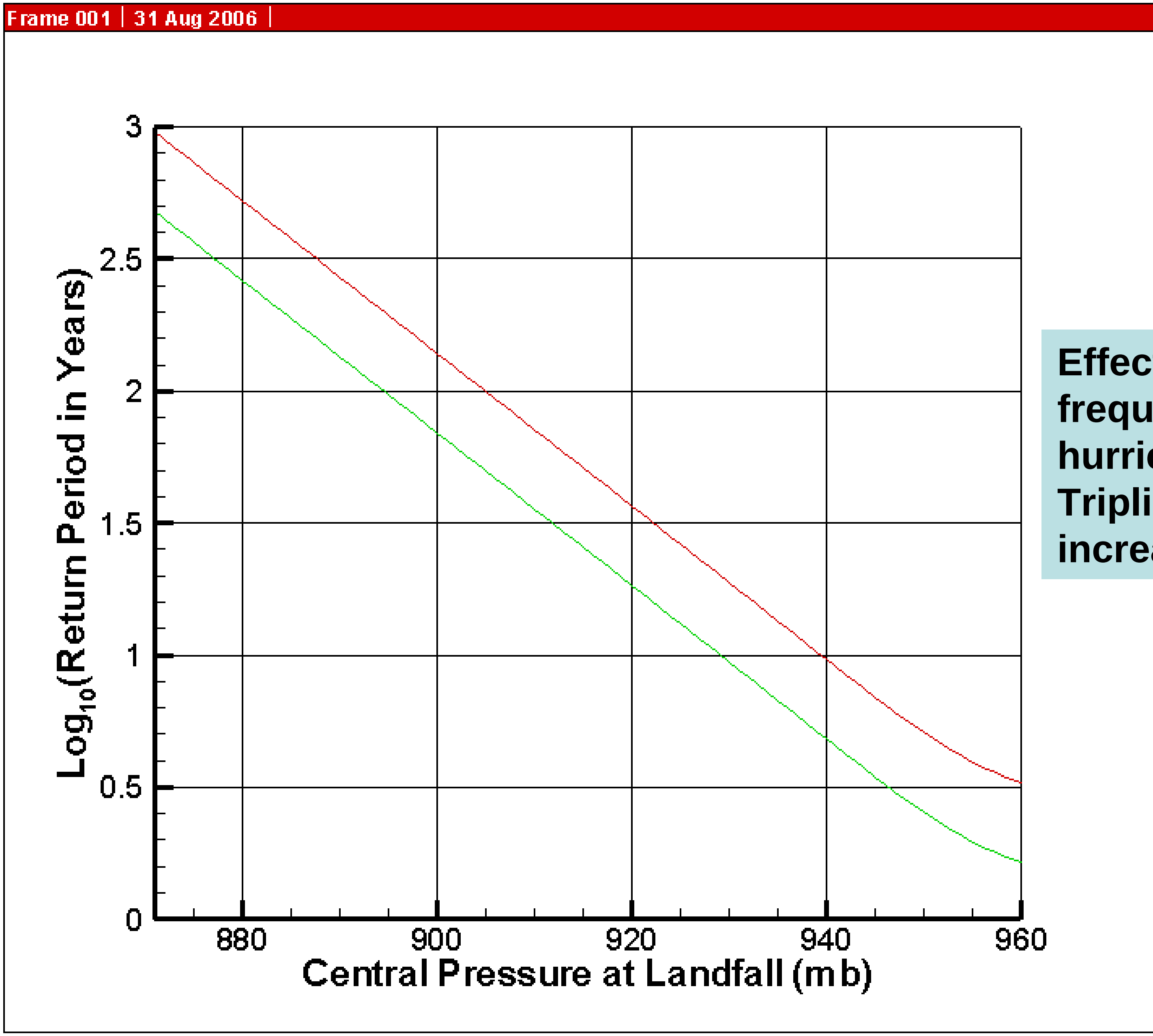
where

$$\hat{x} = A + B\left(\frac{1-e^{-Cx}}{C}\right) \qquad \hat{x} = \frac{x-a}{b}$$

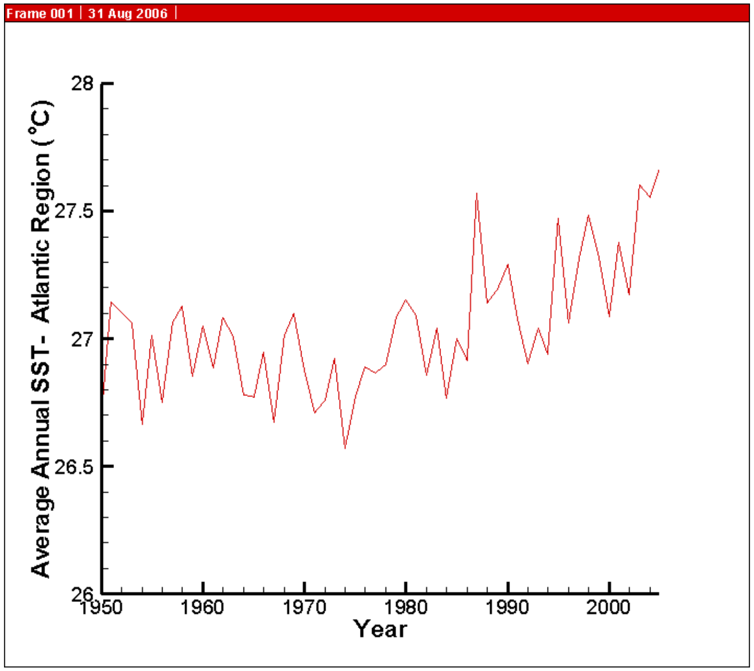


Extremes are dominated by "active-season" hurricanes.

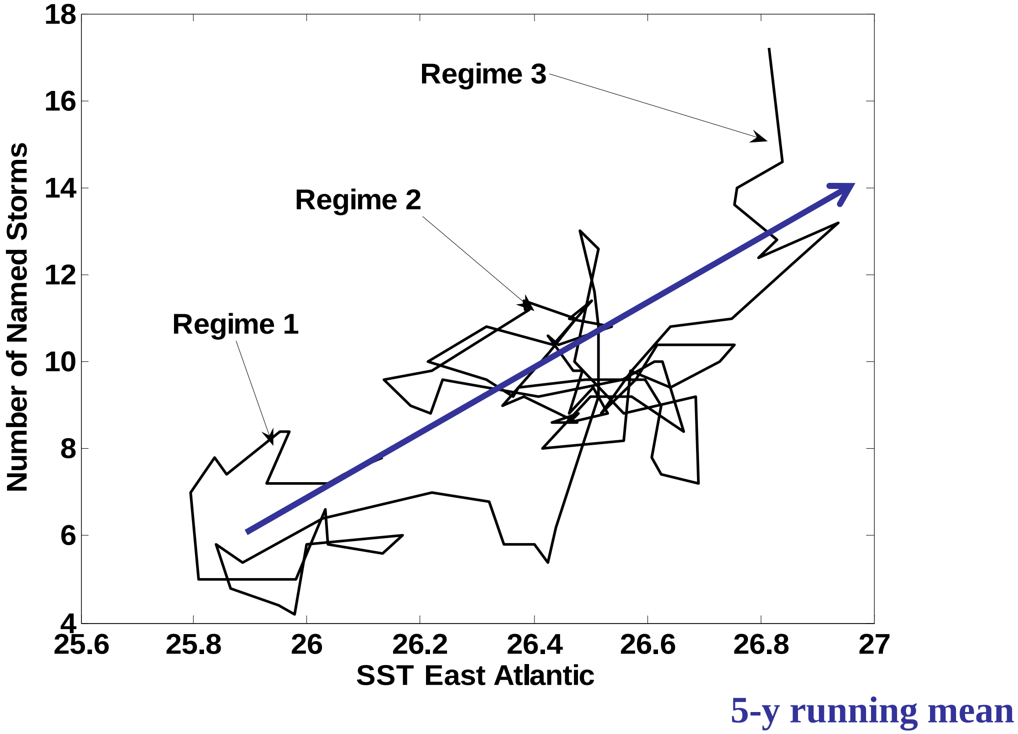
Both the slope and the frequency of intense storms varies from one population to the other.



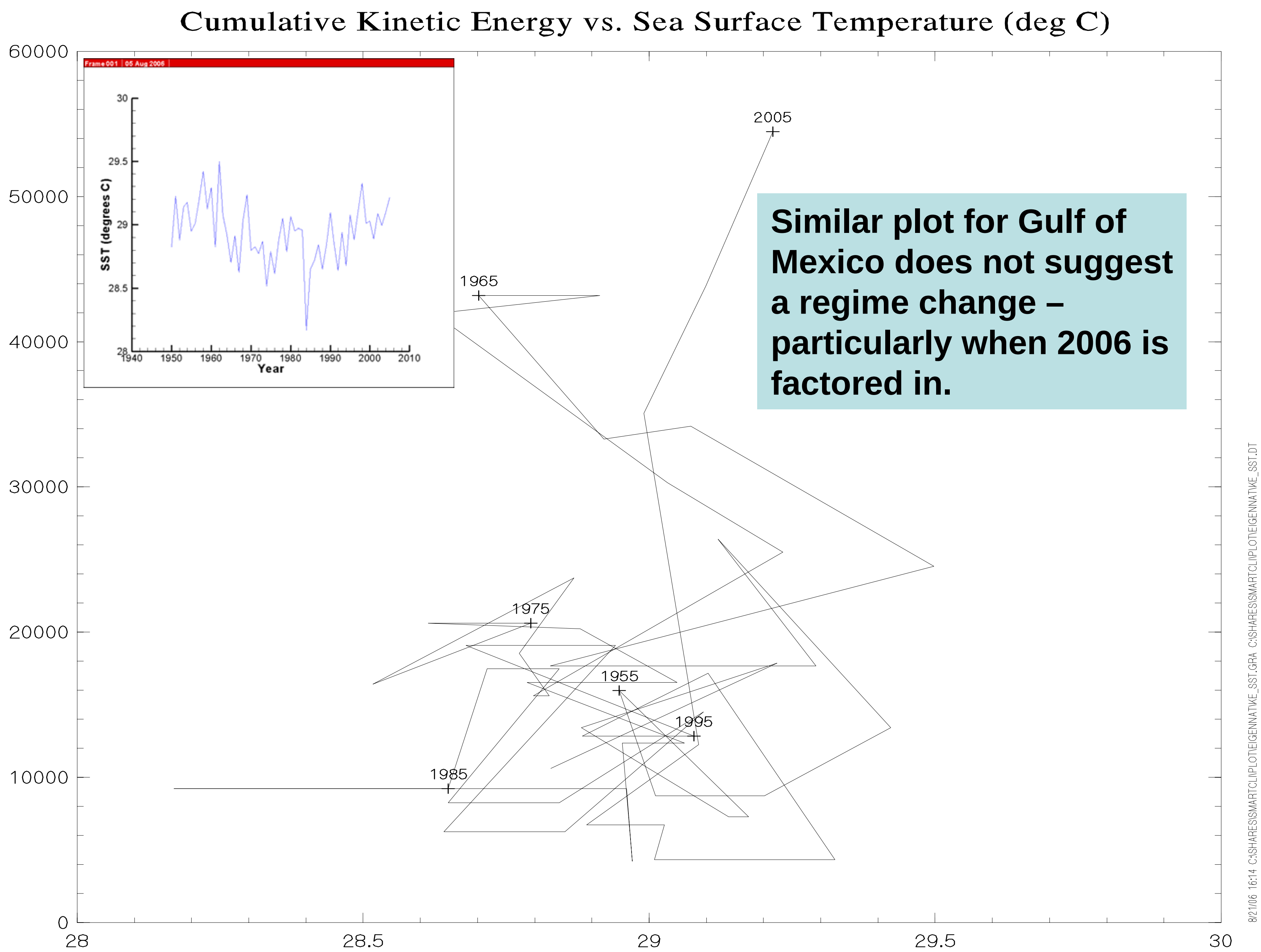
Effect of doubling the frequency of active hurricane seasons. Tripling is the maximum increase possible.



From Holland and Webster (2006)



The post-1980 SST warming provides a clear trend to the type of plot Used by Holland and Webster for showing potential transitions to alternative Regimes in tropical activity in the Atlantic Basin.



Similar plot for Gulf of Mexico does not suggest a regime change – particularly when 2006 is factored in.

Wave Scaling

$$H_{\max} \sim \frac{u_{\max}^{9/7}}{g^{2/7}} \left(< V_f - c_g > \right)^{5/7}$$

Surge Scaling

$$\eta_{\max} \sim \frac{u_{\max}^2}{g} \Psi(\hat{R}_{\max})$$

where $R_{\max}$ is a nondimensional storm size parameter, given by

$$R_{\max} = \frac{gR_{\max}}{u_{\max}^2}$$

Table 5. Estimated changes in extreme waves heights and surges for selected return periods, given a doubling of years with high hurricane activity.

Return Period (years)	Change in Wave Height (percent)	Change in surge (percent)
25	+15	+18
50	+13	+16
100	+12	+15
250	+11	+12
500	+10	+ 9


QUESTIONS?