MODES OF VARIABILITY OF THE COUPLED ATMOSPHERE-OCEAN SYSTEM

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Research Objectives

- Research is part of theme 1.2.2
  - Exploratory studies on joint assimilation into coupled models
  - Model background and observation errors for coupled system: ε_b and ε_o
  - Solve for B and R covariance matrices
- Identify global covariance structures of coupled system
- Locate regions of possible interest
- Explore new statistical techniques

The Data Variable Fields

- Global Atmosphere - Ocean Variables:
  - Sea Surface Temperature (SST)
  - Sea Level Pressures (SLP)
- CCCma (CGCM3) model output fields
  - atmosphere resolution: ~3.75º longitude by 3.71º latitude (96 by 48 grid points).
  - ocean variables ~ double that of the atmospheric
- NCEP reanalysis data
  - SST grid: 2º by 2º, SLP grid: 2.5º by 2.5º
  - Data range: January 1st 1948 to 2007

Principal Component Analysis

- Search for uncorrelated linear combinations of X whose variances are as large as possible

- Let $\sum$ be the covariance matrix associated with the random vector $X' = [X_1, X_2 .. X_n]$ with eigenvalue-eigenvector pairs (λ, e) .

- Then the ith principal component is given by the expression: $Y_i = e_i' X$

- Explained variance of ith component is: $\dfrac{\lambda_i}{\sum_k \lambda_k}$

Processing the Data Matrix: X

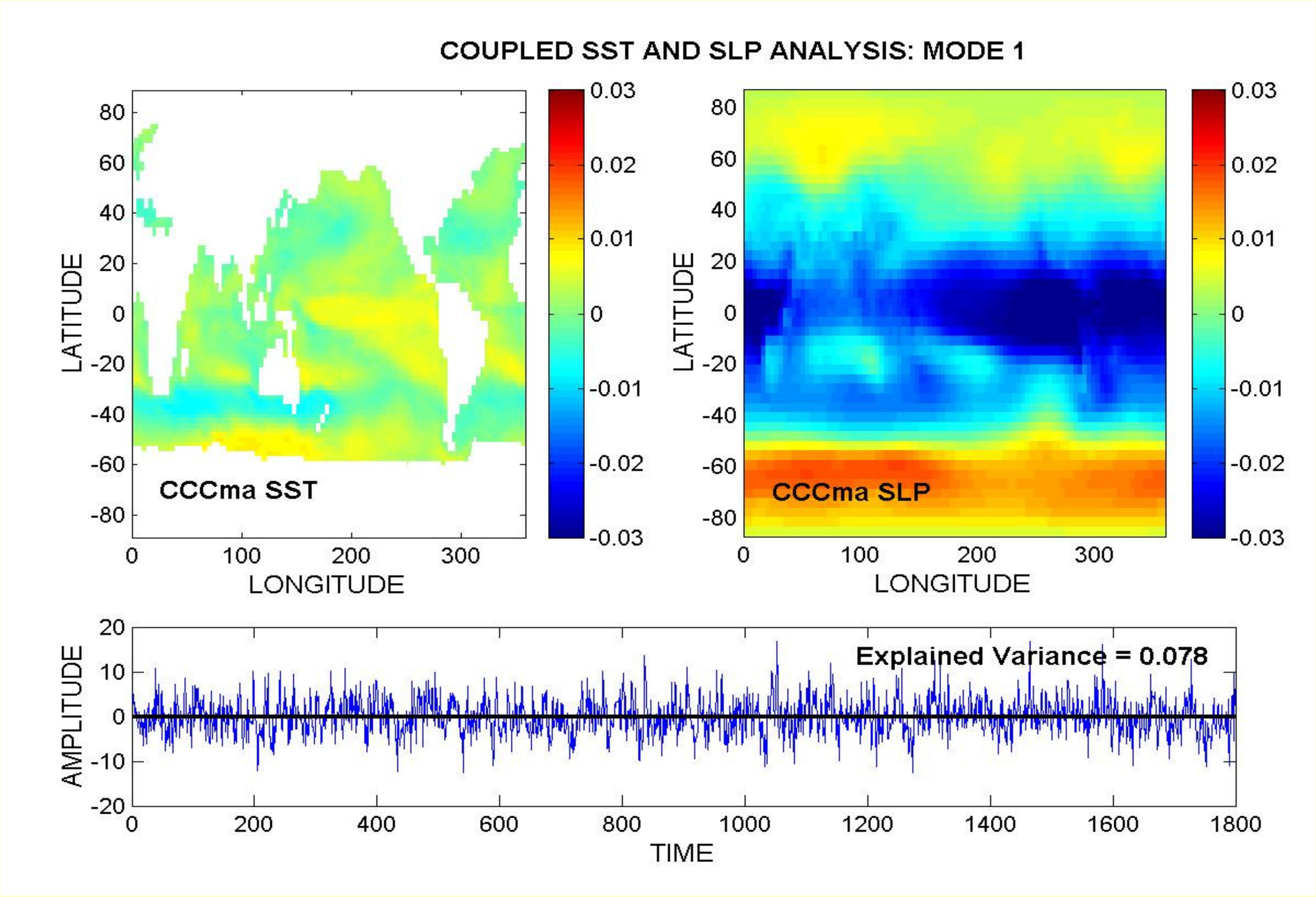
- Remove Ice cover points from data
- Detrend the data
- Remove Seasonal component from data
- Standardize data
- Area weight the data by factor $\sqrt{\cos\lambda}$
- Grid point weight data
- Combine SST and SLP fields => X matrix

$$X = \begin{pmatrix} SST_1 & SLP_1 \\ \hline SST_2 & SLP_2 \\ \hline \bullet & \bullet \\ \bullet & \bullet \\ \hline SST_p & SLP_p \end{pmatrix}$$

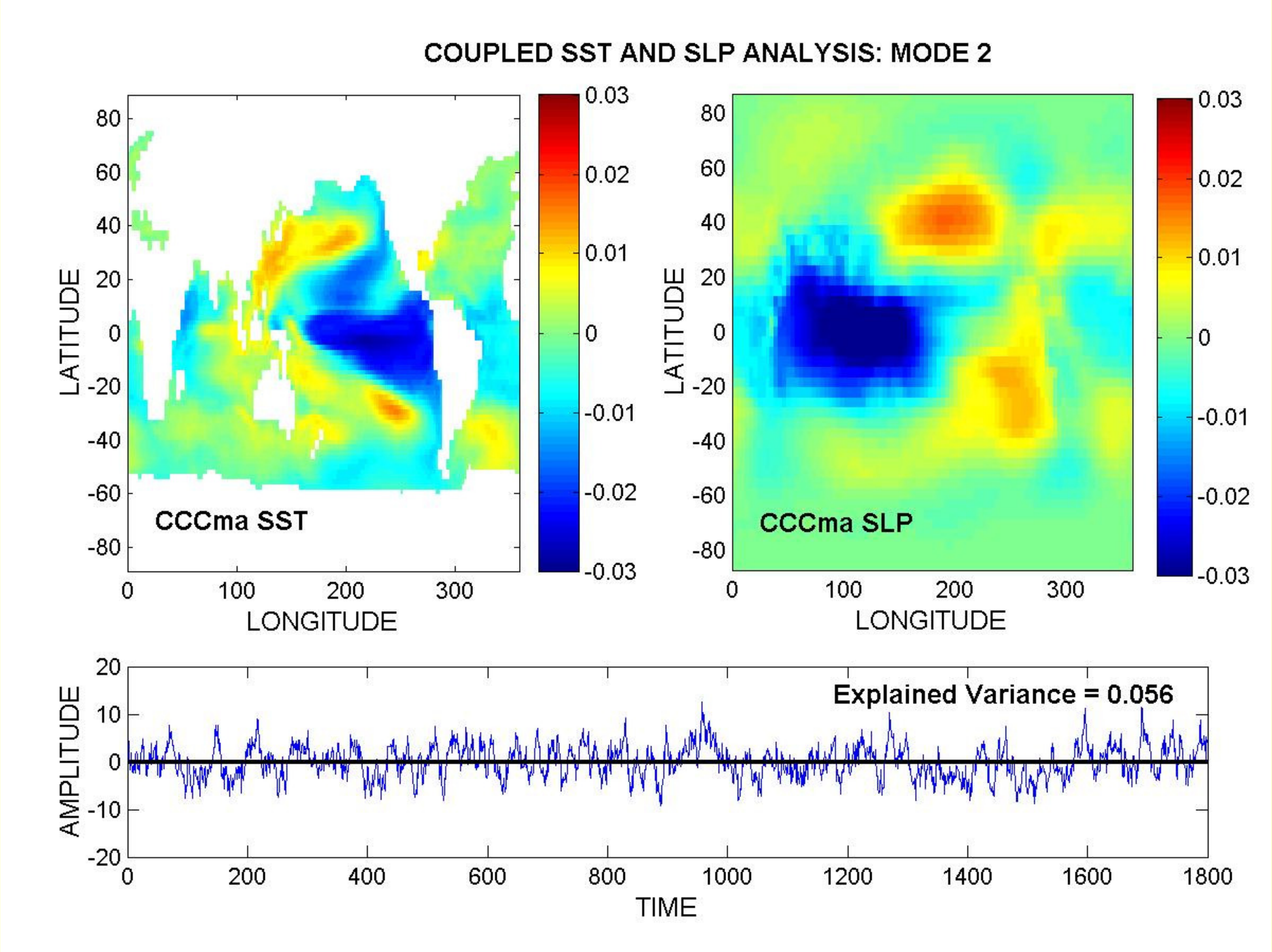
Data Matrix Dimensions

- CCCma and NCEP Data fields
  - Space dimensions: exceeding 10,000!!
  - Time dimensions: less than 2000!!
- Set up X matrix such that each row contains the "spatial" SST and SLP data at time t_i
- the Covariance matrix X*X´ is a matrix of less than 2000 x 2000 grid points
- Saves considerable computation time

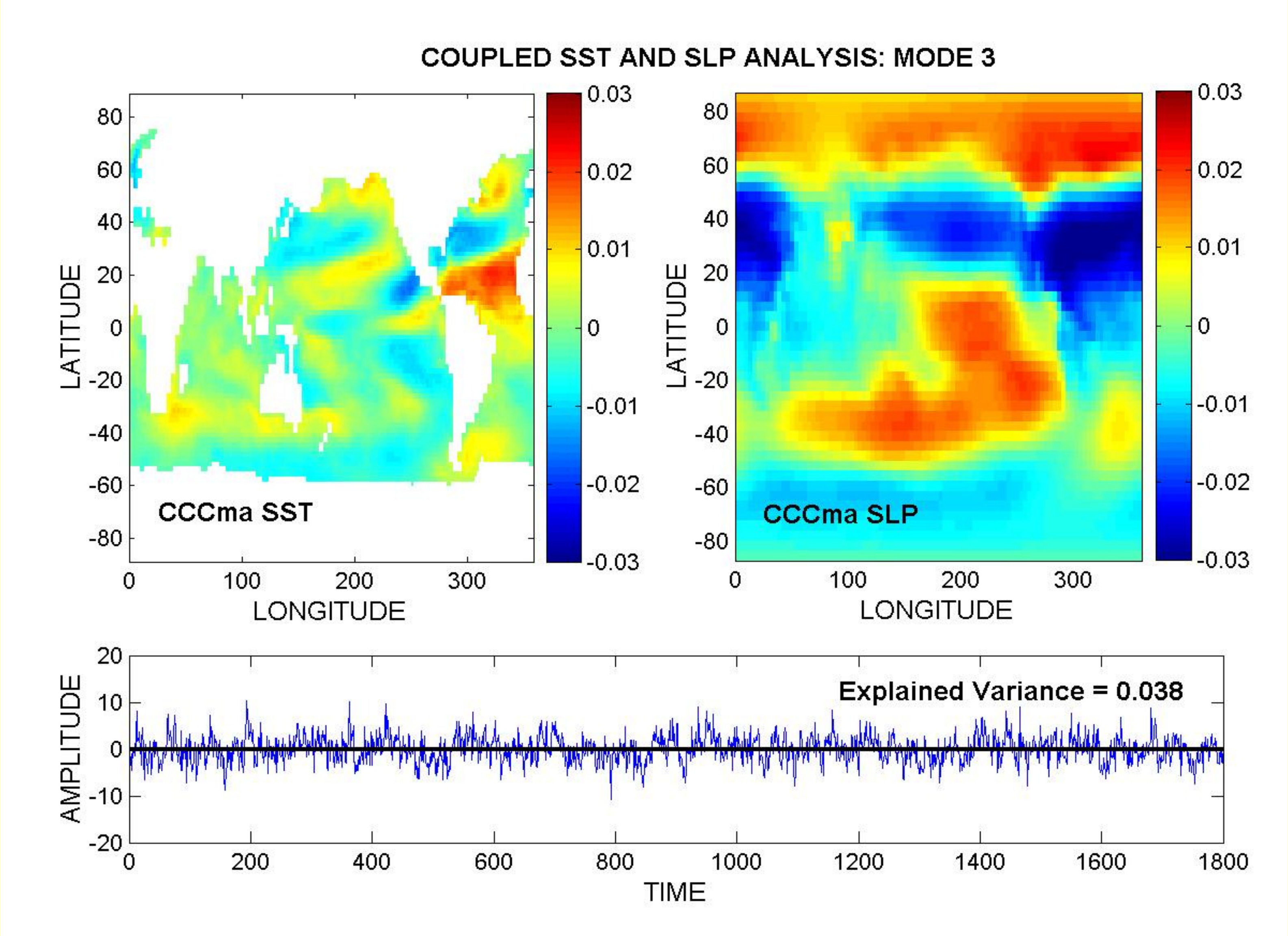
CCCma Mode 1: Southern Annular Mode (SAM)?

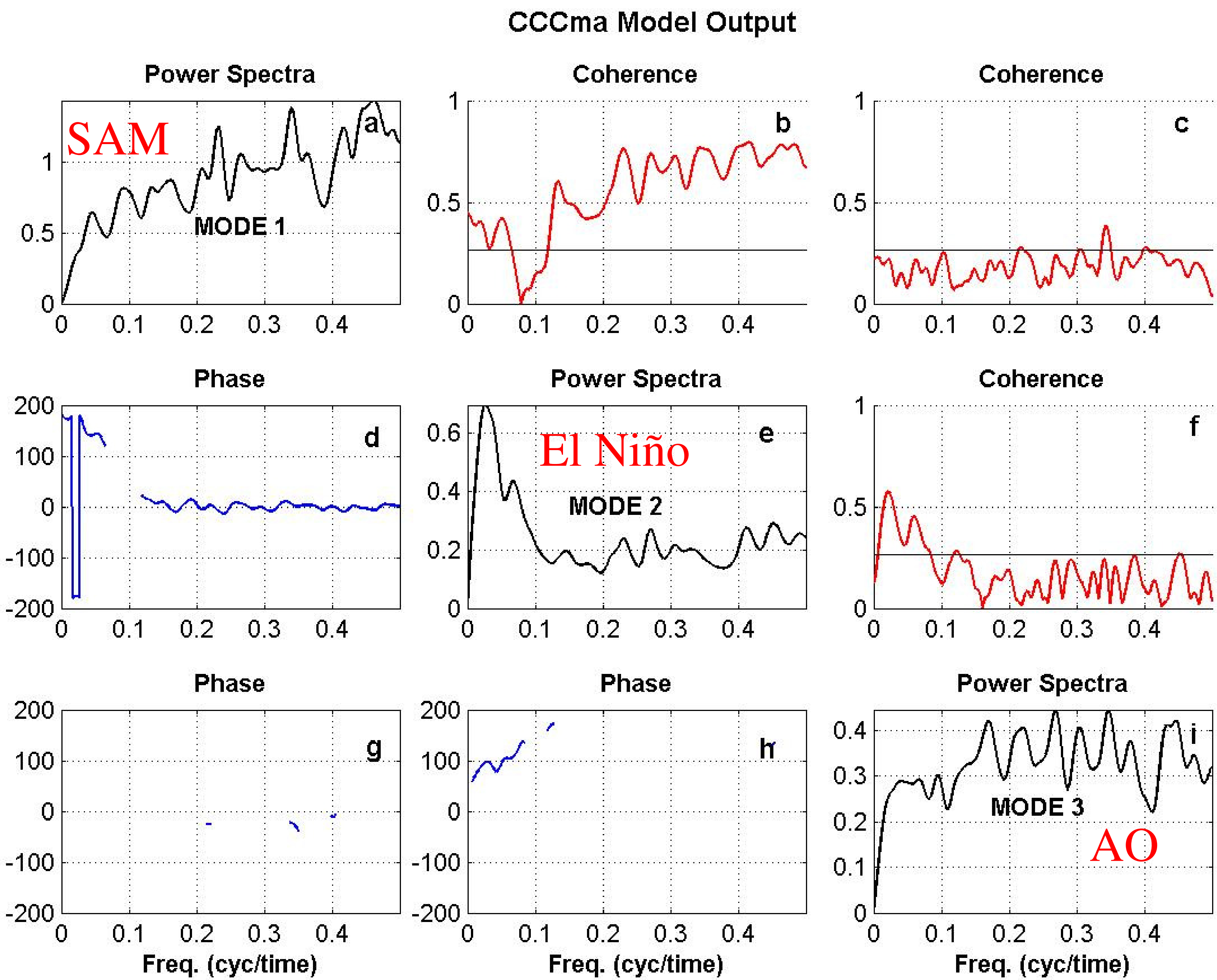


CCCma Mode 2: El Niño pattern

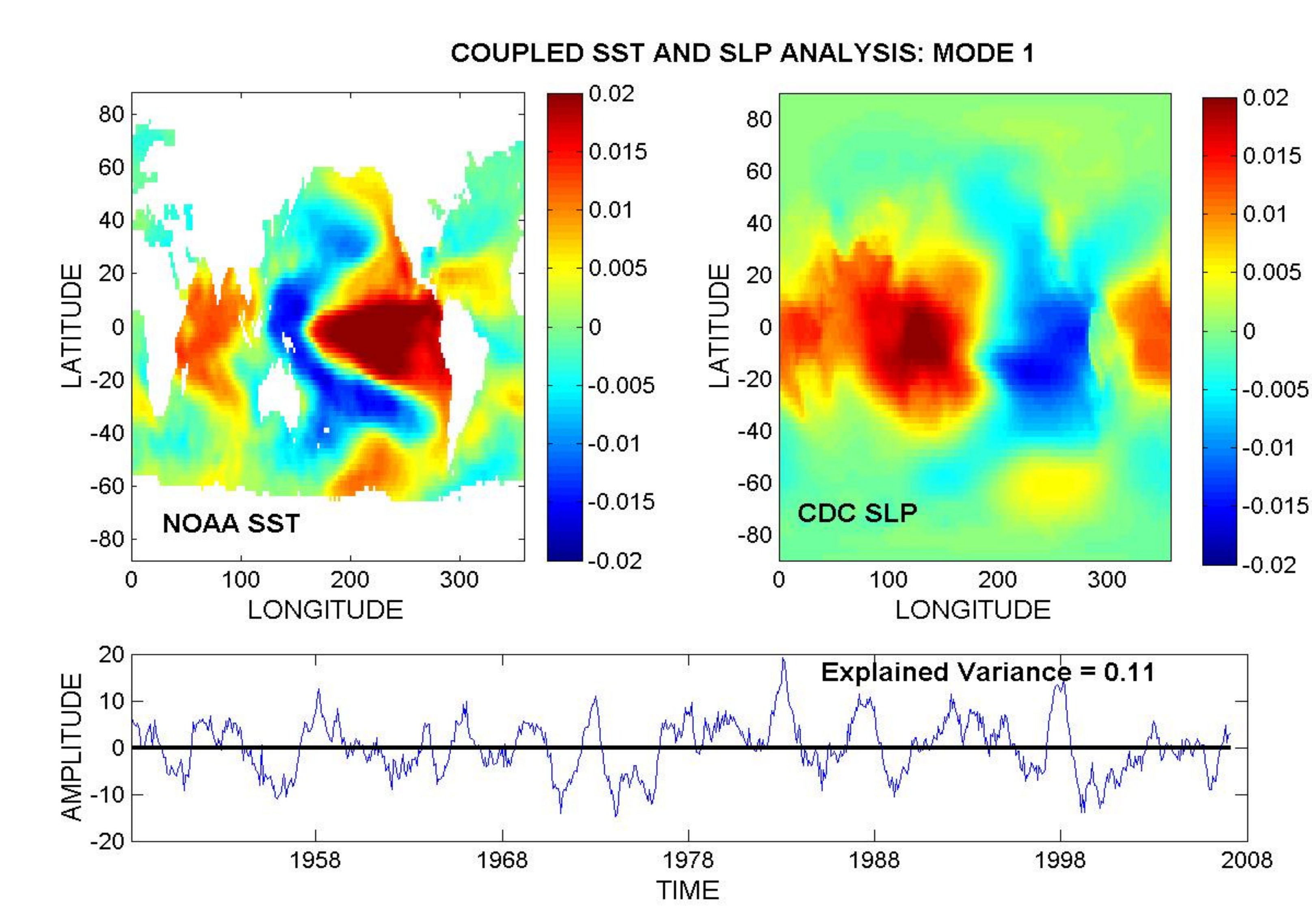


CCCma Mode 3: Arctic Oscillation (AO)?

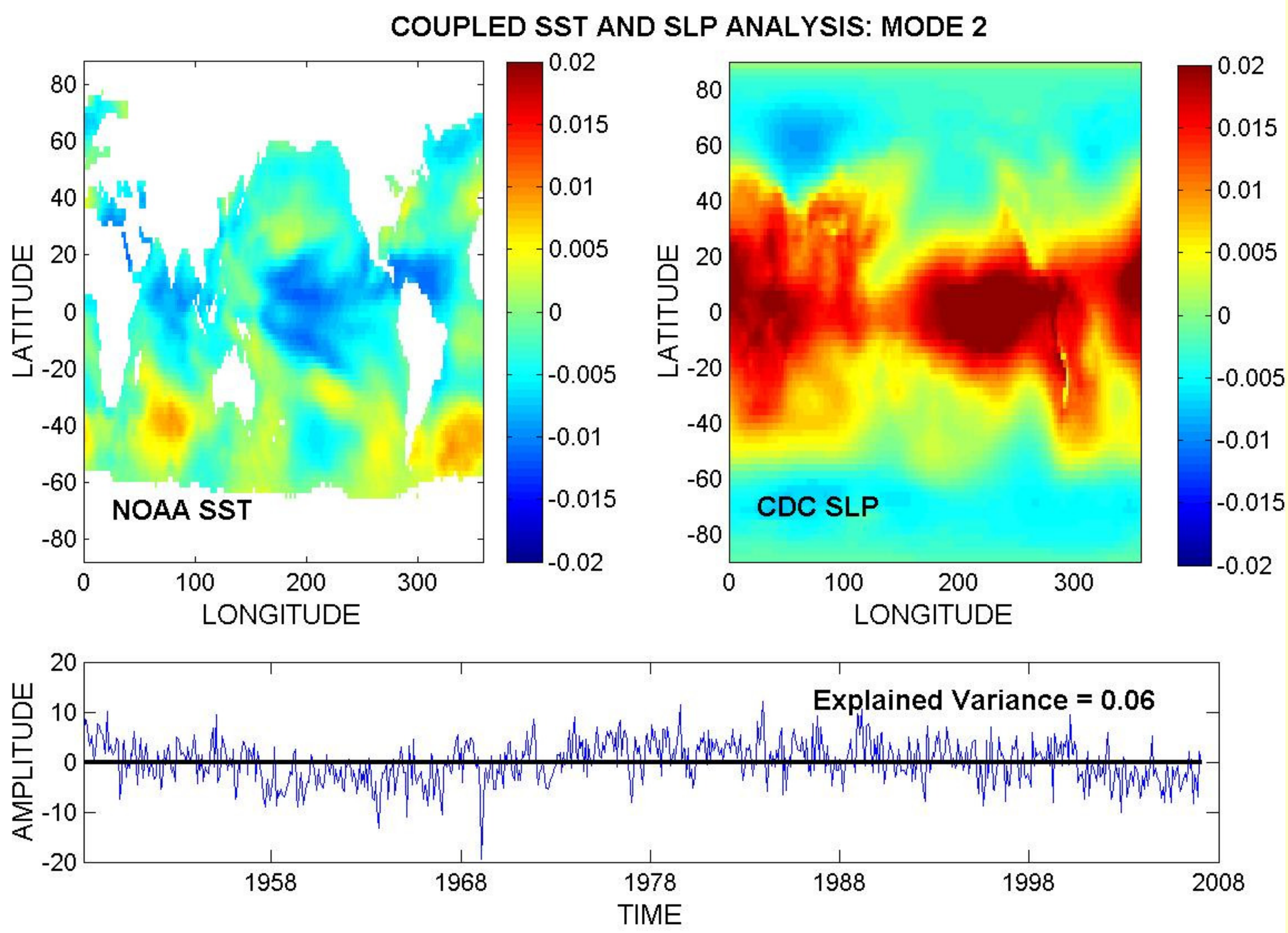



CCCma Model Output
Power Spectra
Coherence
Coherence
SAM
MODE 1
a
b
c
Phase
Power Spectra
Coherence
El Niño
MODE 2
d
e
f
Phase
Phase
Power Spectra
MODE 3
AO
g
h
i
Freq. (cyc/time)
Freq. (cyc/time)
Freq. (cyc/time)

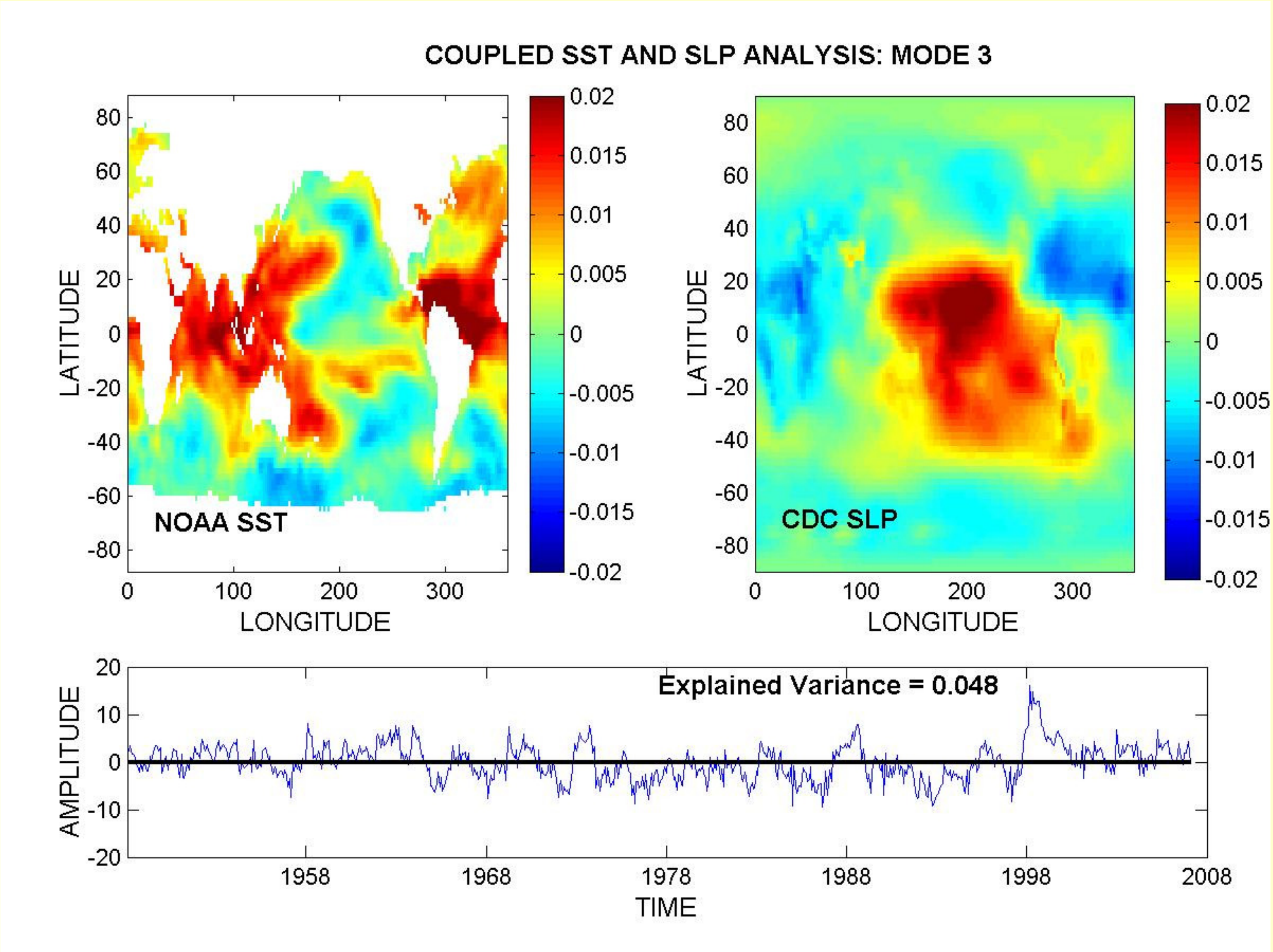
NCEP Mode 1: EL Niño pattern

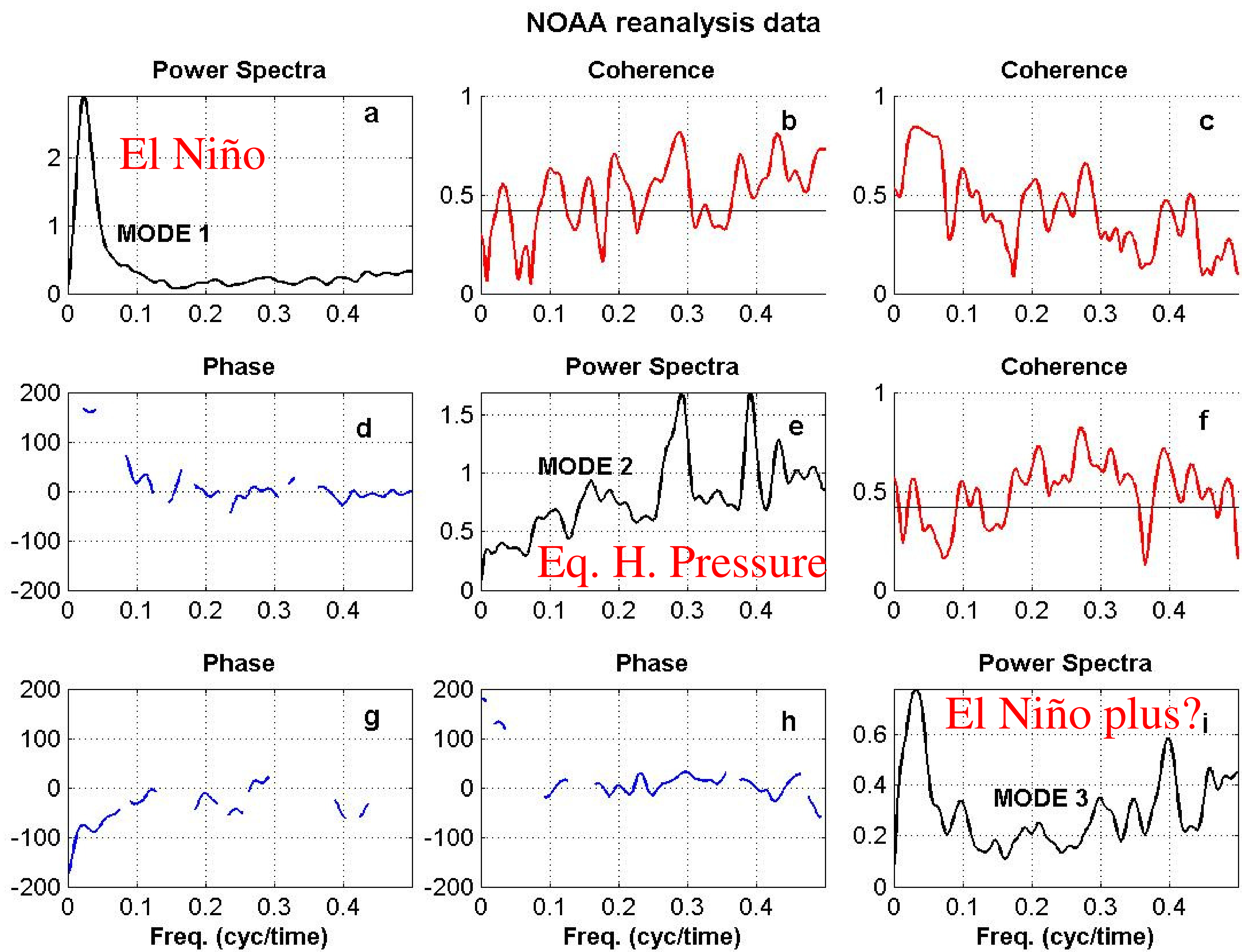


NCEP Mode 2: Equatorial High Pressure



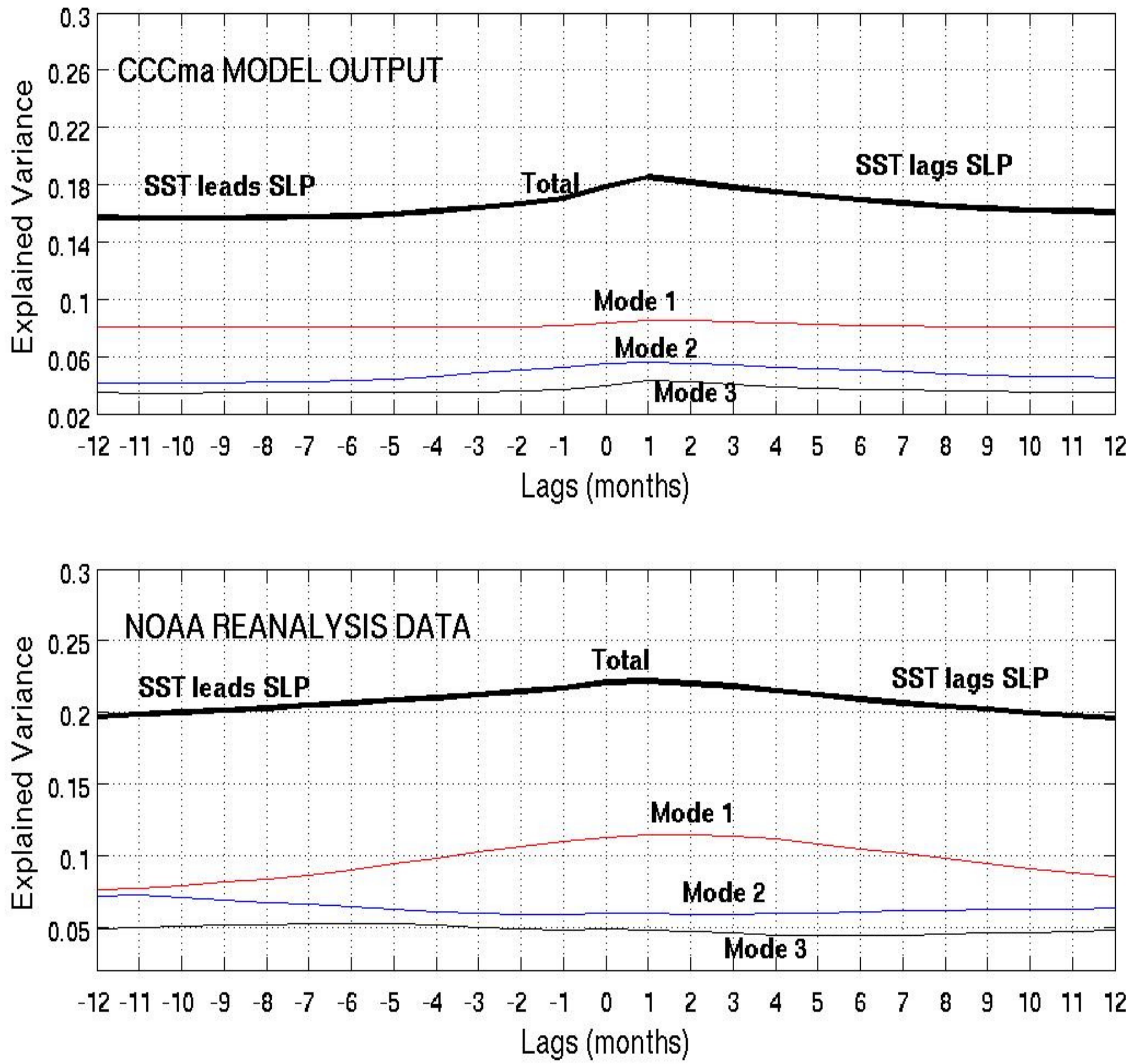
NCEP Mode 3: Propagating El Niño Signal?





NOAA reanalysis data
Power Spectra
a
El Niño
MODE 1
Coherence
b
Coherence
c
Phase
d
Power Spectra
e
MODE 2
Eq. H. Pressure
Coherence
f
Phase
g
Phase
h
Power Spectra
El Niño plus?
i
MODE 3
Freq. (cyc/time)
Freq. (cyc/time)
Freq. (cyc/time)

Time-Lagged Explained Variances



Principle Component Analysis Summary

- Similarities between CCCma and NCEP:
  - detection of El Niño signal in Pacific ocean
  - propagating feature of El Niño from Pacific to Atlantic => propagation time ~ 2 to 3 months!
  - Greatest variance explained when Global SLP leads SST by 1 month!!

Principle Component Analysis Summary

- Differences between NCEP and CCCma:
  - El Niño under-represented in CCCma (8% variability) compared to NCEP (11% variability)
  - detection of SAM and AO modes in CCCma
  - detection of high pressure anomaly in equatorial region in NCEP
  - somewhat conflicting SLP patterns associated with propagating El Niño signature

Motivation for Redundancy Analysis

- Limitation of PCA analysis
  - Identified patterns that maximized variance in SST and SLP fields … no cause or effect implied
- Address “cause - effect” relations
  - Set up a regression equation: SST = a b^T SLP
  - Find pattern in SLP that best explains the variance in SST
  - Find resultant SST pattern
- Redundancy analysis => “cause - effect”

Redundancy Analysis

- Assume a data matrix X and a separate data matrix Y related by a regression equation:

  $Y = a\, b^T X + \varepsilon$

- Reduces to two Eigenvector equations:

  $$\Sigma_{yx}\Sigma_{xx}^{-1}\Sigma_{xy} a = a\, \lambda$$

  $$\Sigma_{xx}^{-1}\Sigma_{xy}\Sigma_{yx} b = b\, \lambda$$

- b-pattern: pattern in X data that maximizes variance in Y data field
- a-pattern: resultant pattern in Y data field

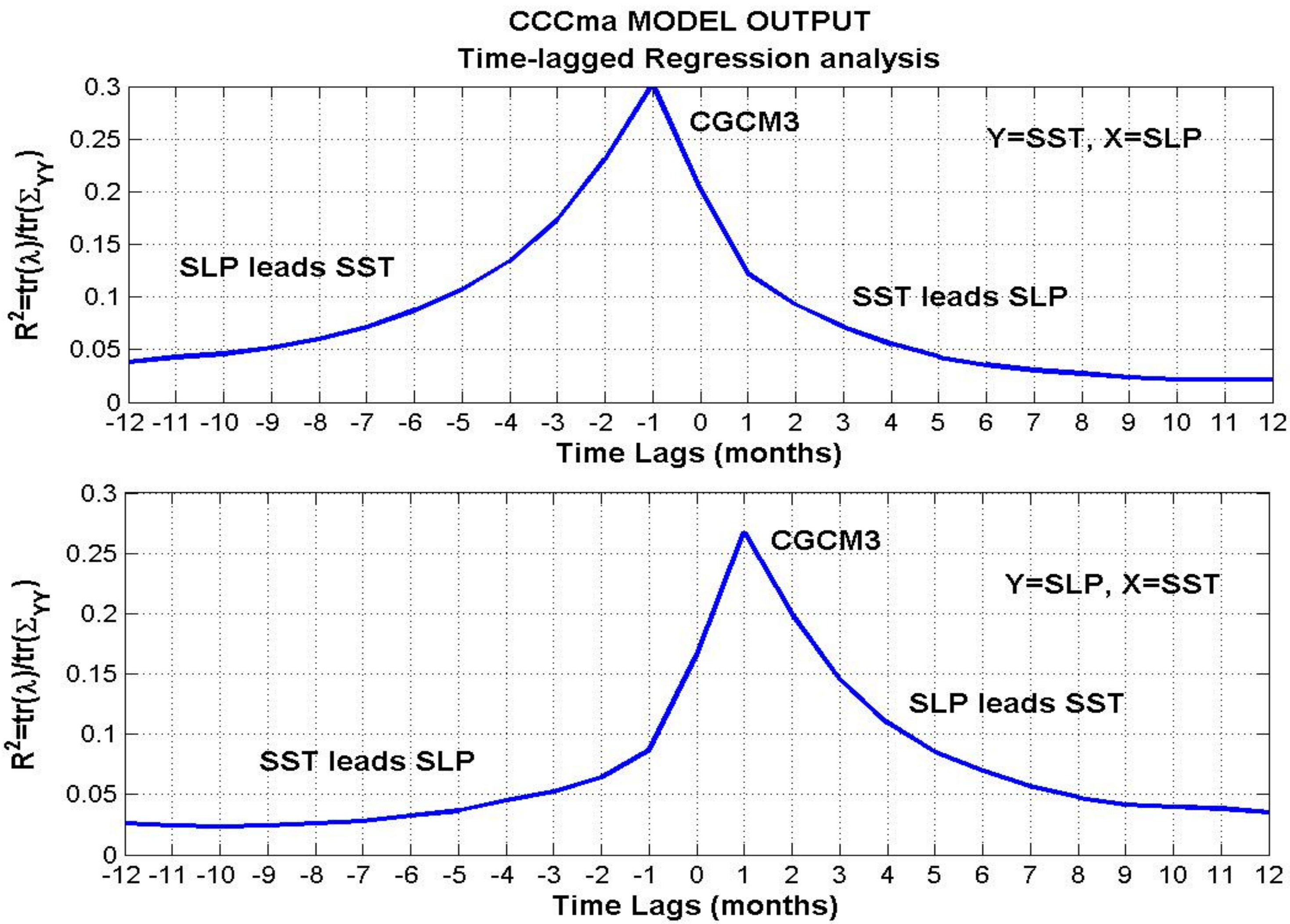
Redundancy Index

- A measure of how much variance in Y data field is expressed by the modeled $\hat{Y} = a\, b^T X$ field (or basically how redundant information in Y is provided information in X):

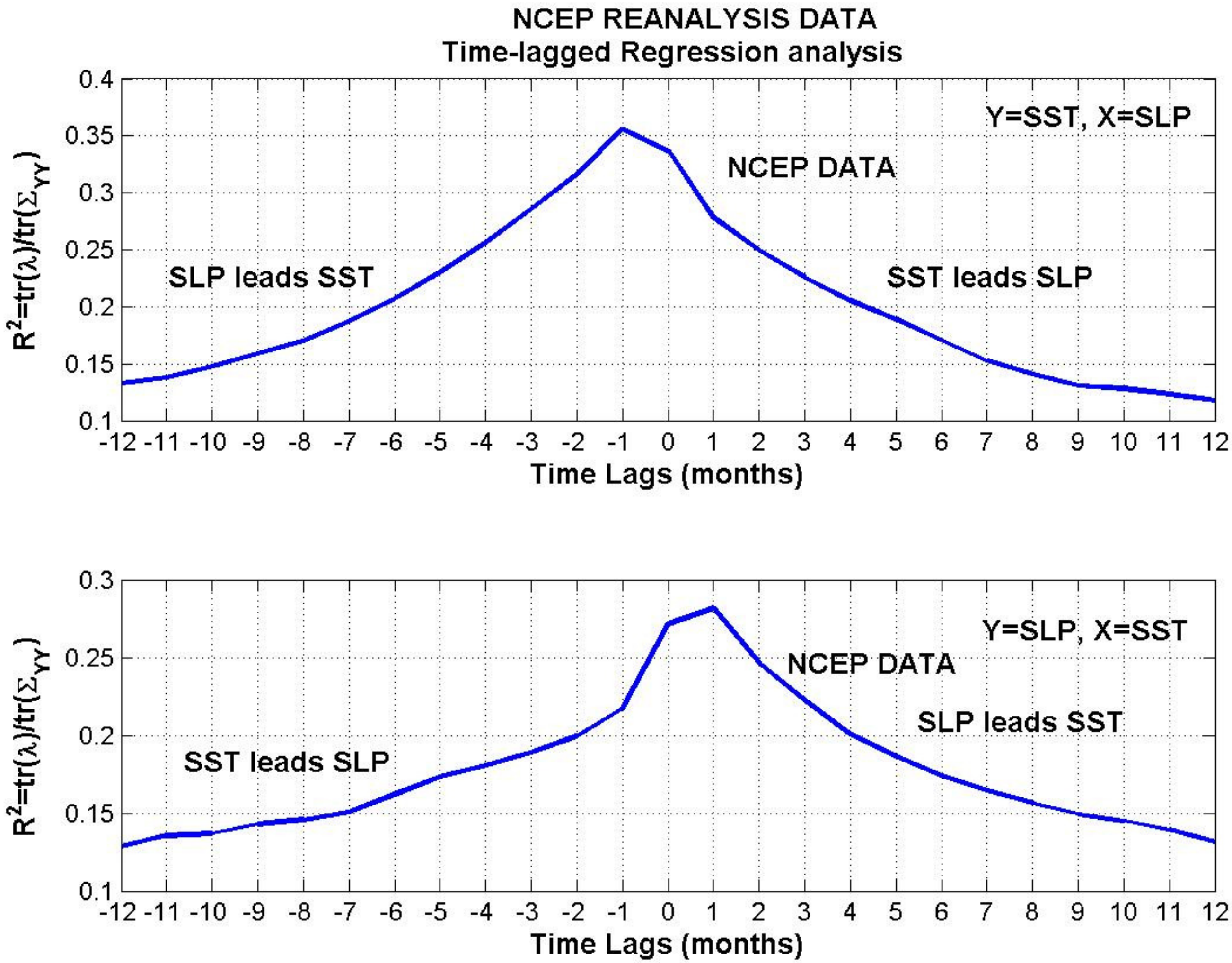
$$R^2(Y:\hat{Y}) = \frac{\sum_{j=1}^{k} \lambda_j}{tr(\Sigma_{YY})}$$

- Time-Lagged Redundancy Index as an indicator of cause-effect relation

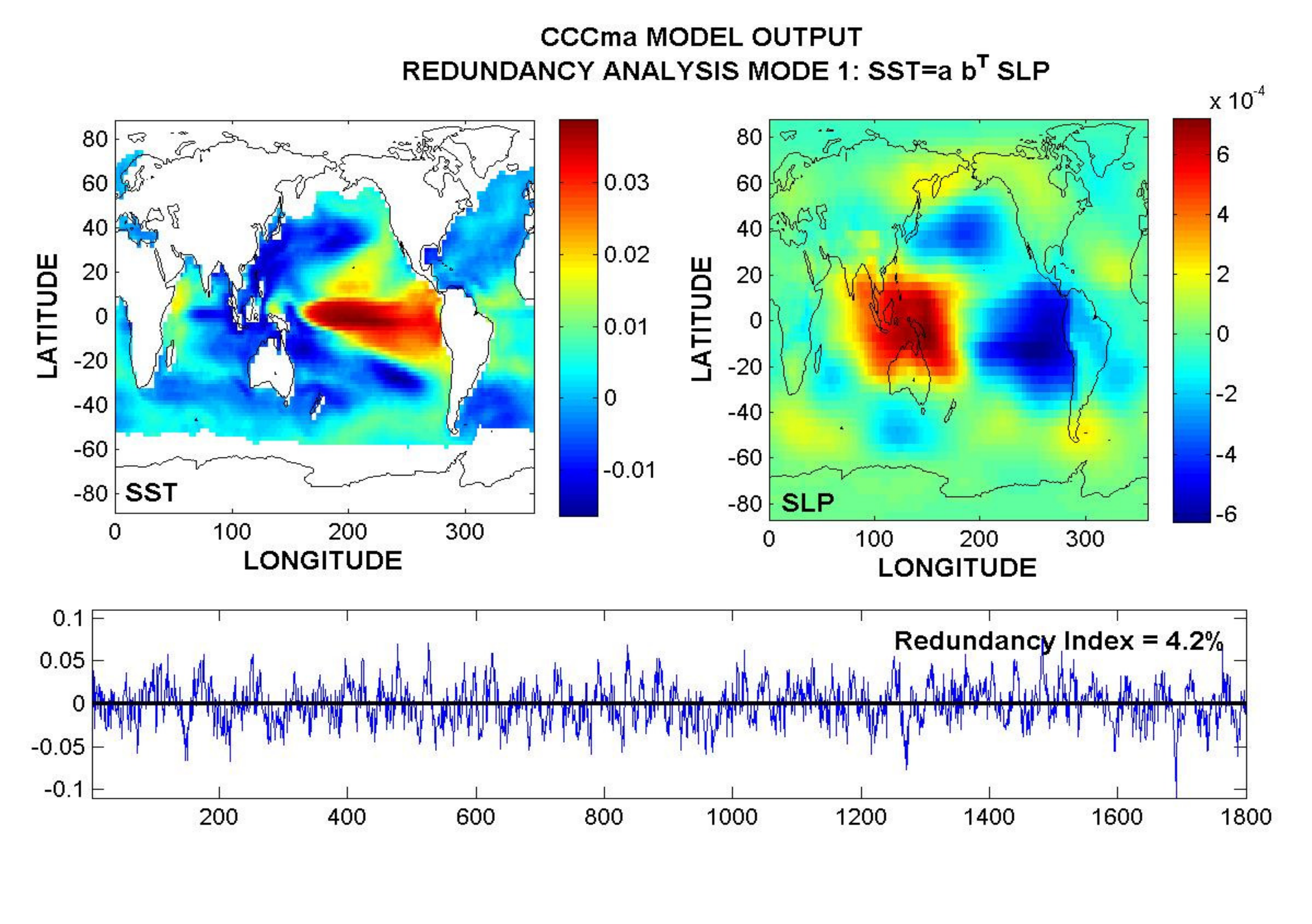
CCCma Global Redundancy Index: SLP leads SST



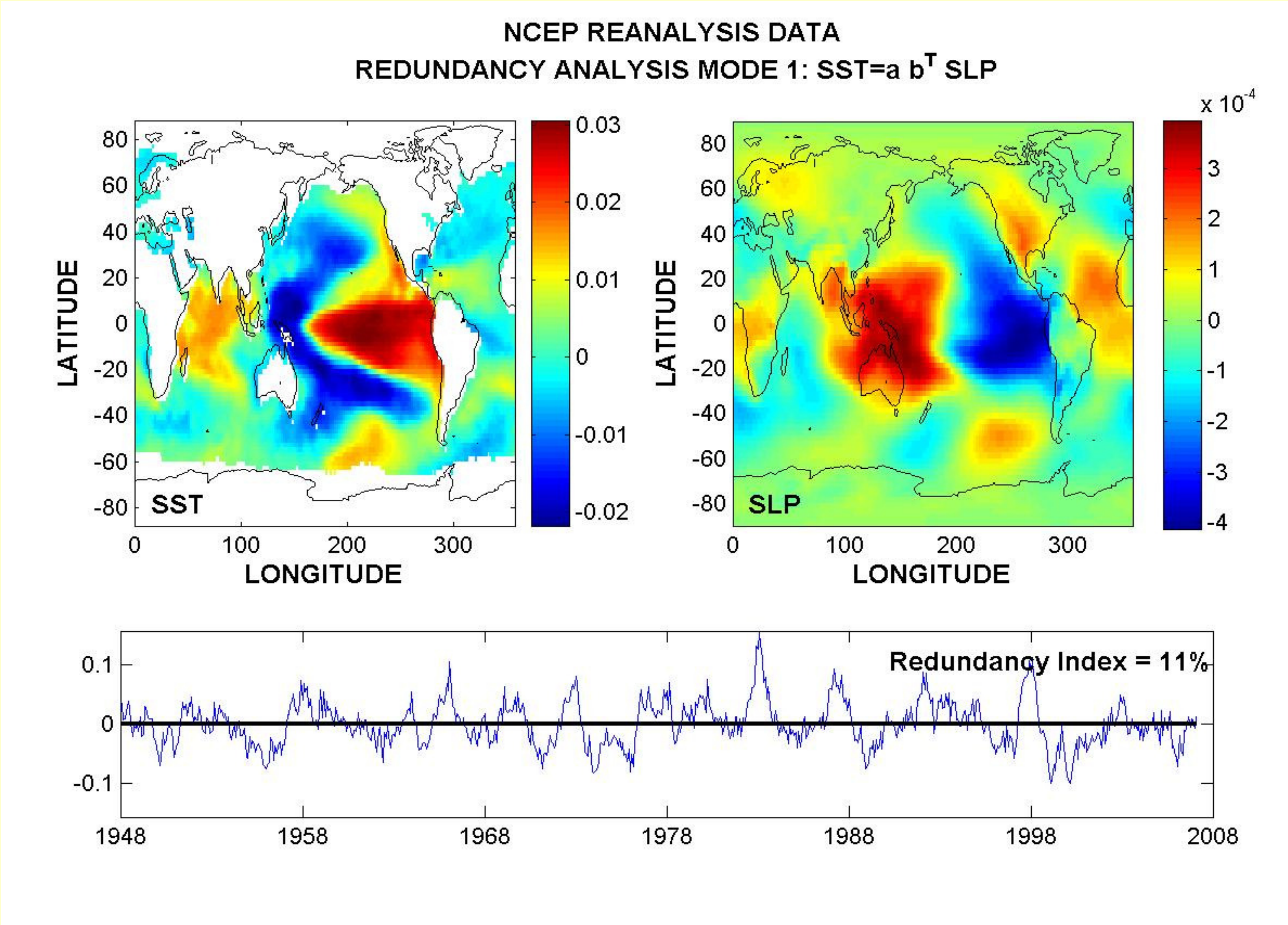
NCEP Redundancy Index: SLP leads SST



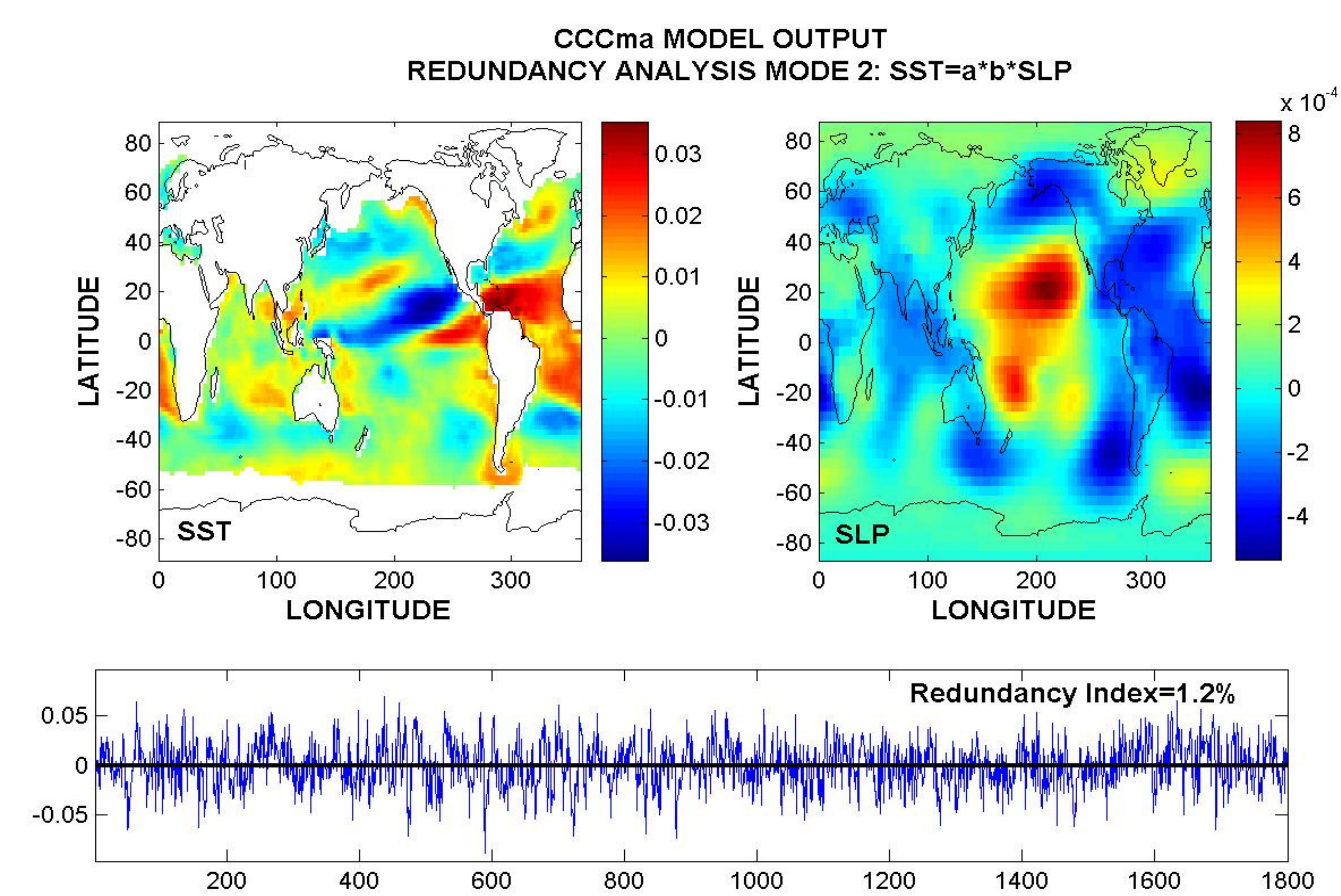
CCCma Redundancy Analysis: Mode 1



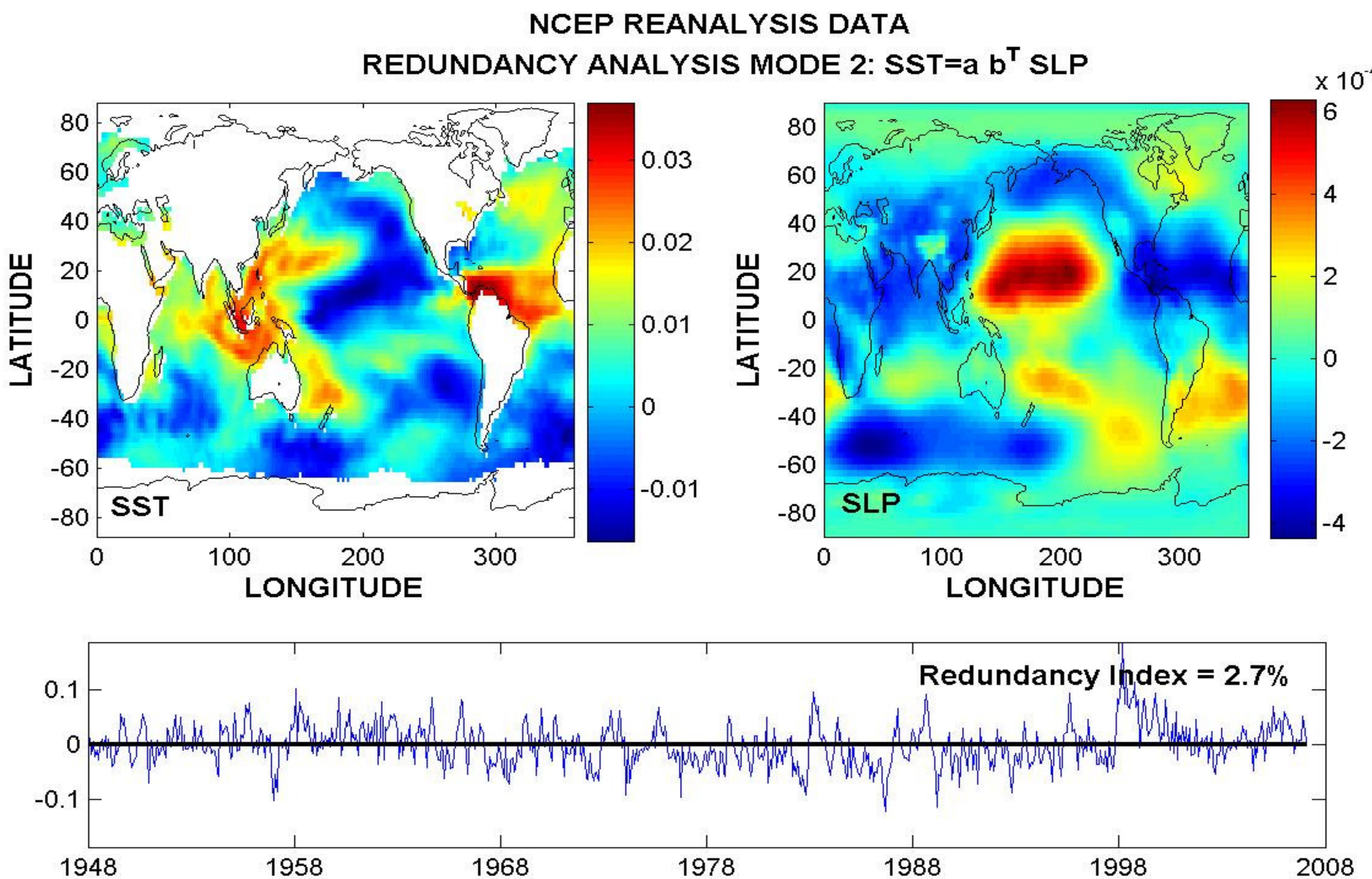
NCEP Redundancy Analysis: Mode 1



CCCma Redundancy Analysis: Mode 2



NCEP Redundancy Analysis: Mode 2



Redundancy Analysis Summary

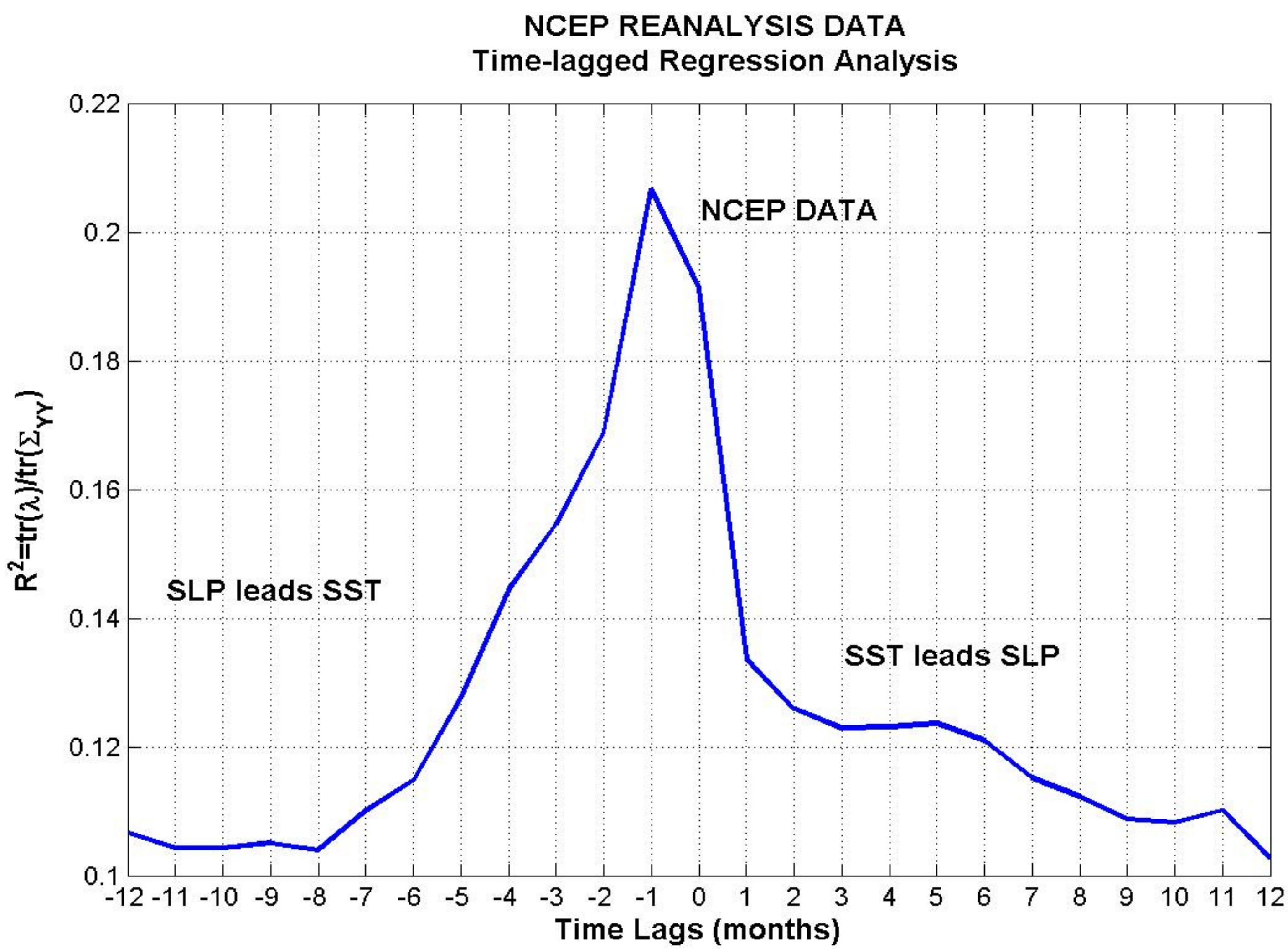
- R^2 is maximum when global SLP leads global SST by 1 month
- Redundancy index is asymmetric:

  $$R^2(x:y) \neq R^2(y:x)$$
- Both Modes 1 and 2 of NCEP and CCCma patterns agree to first order
- El Niño pattern "driven" by low-high SLP centers over Equatorial Pacific ocean
- Propagating El Niño feature "driven" by high SLP center over mid-pacific ocean

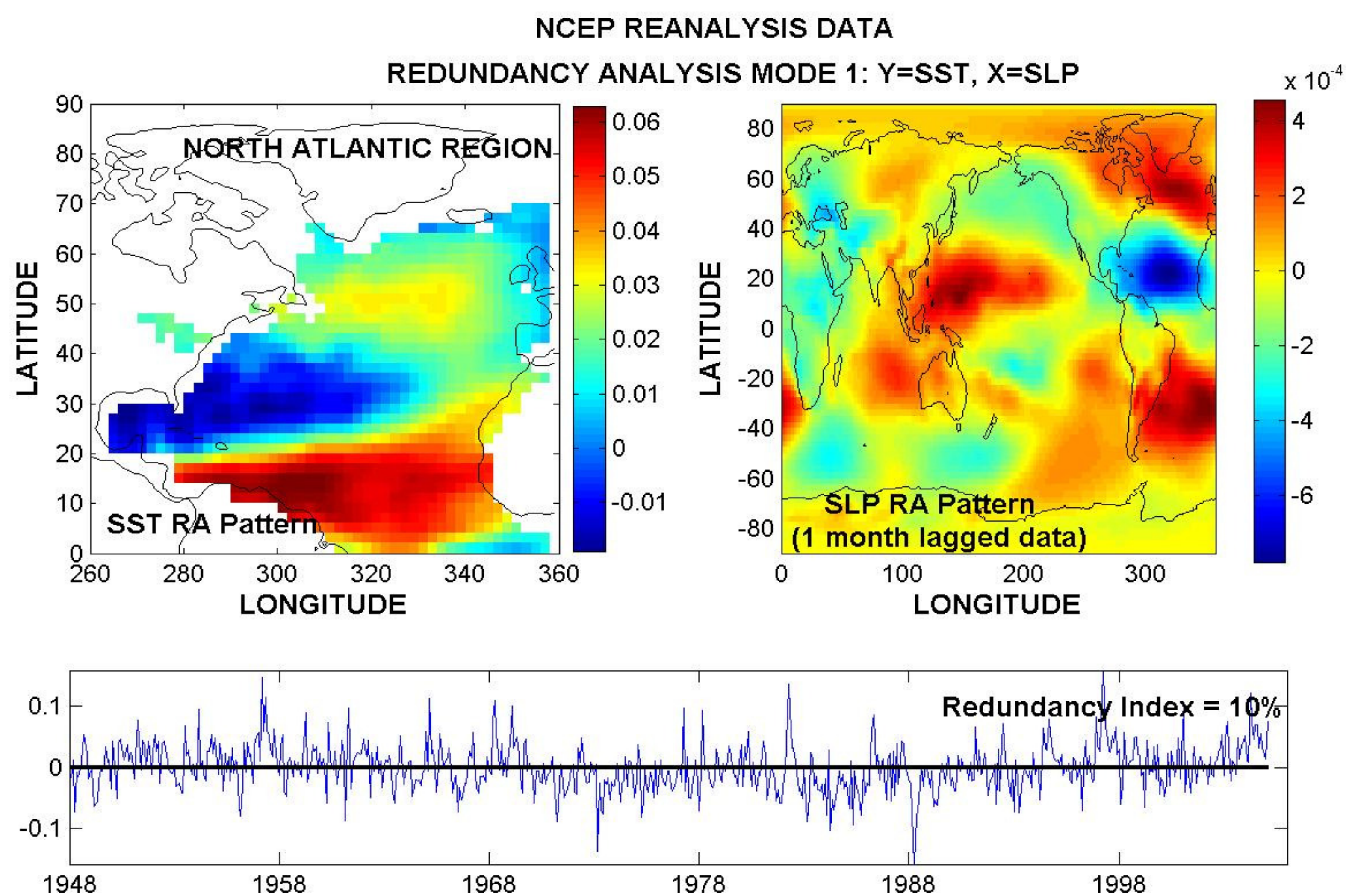
A Geographic Focus: North Atlantic Region

- Let us consider the patterns that emerge when global fields are mixed with localized fields
  - Do global SLP control local SST? Or do local SST dominate global SLP?
  - What variable should one choose as the predictand or predictor?
  - What patterns emerge in the fields when considering global and local fields?

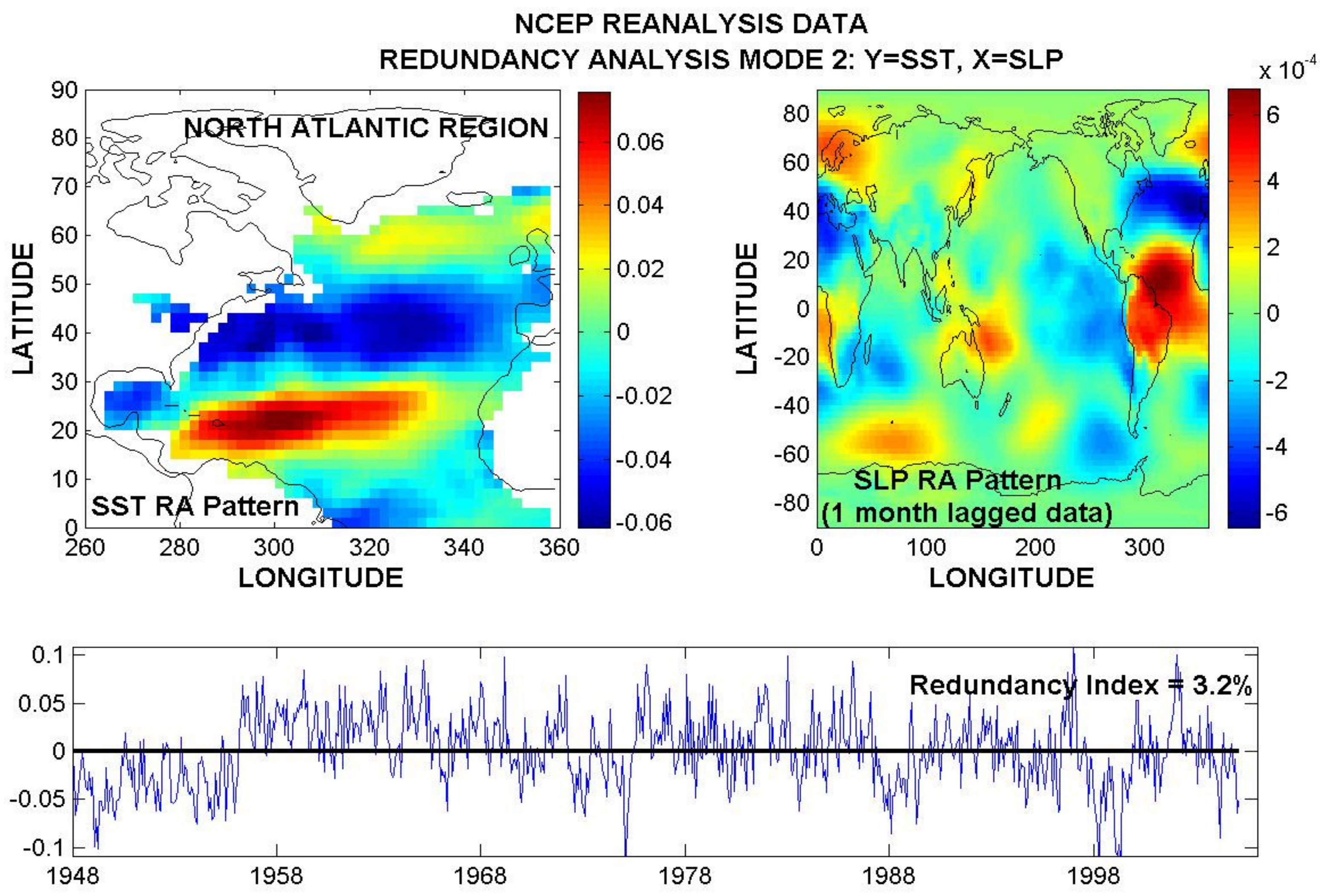
$R^2\,(Y_{\text{Global SLP}}: X_{\text{N. Atlantic SST}})$



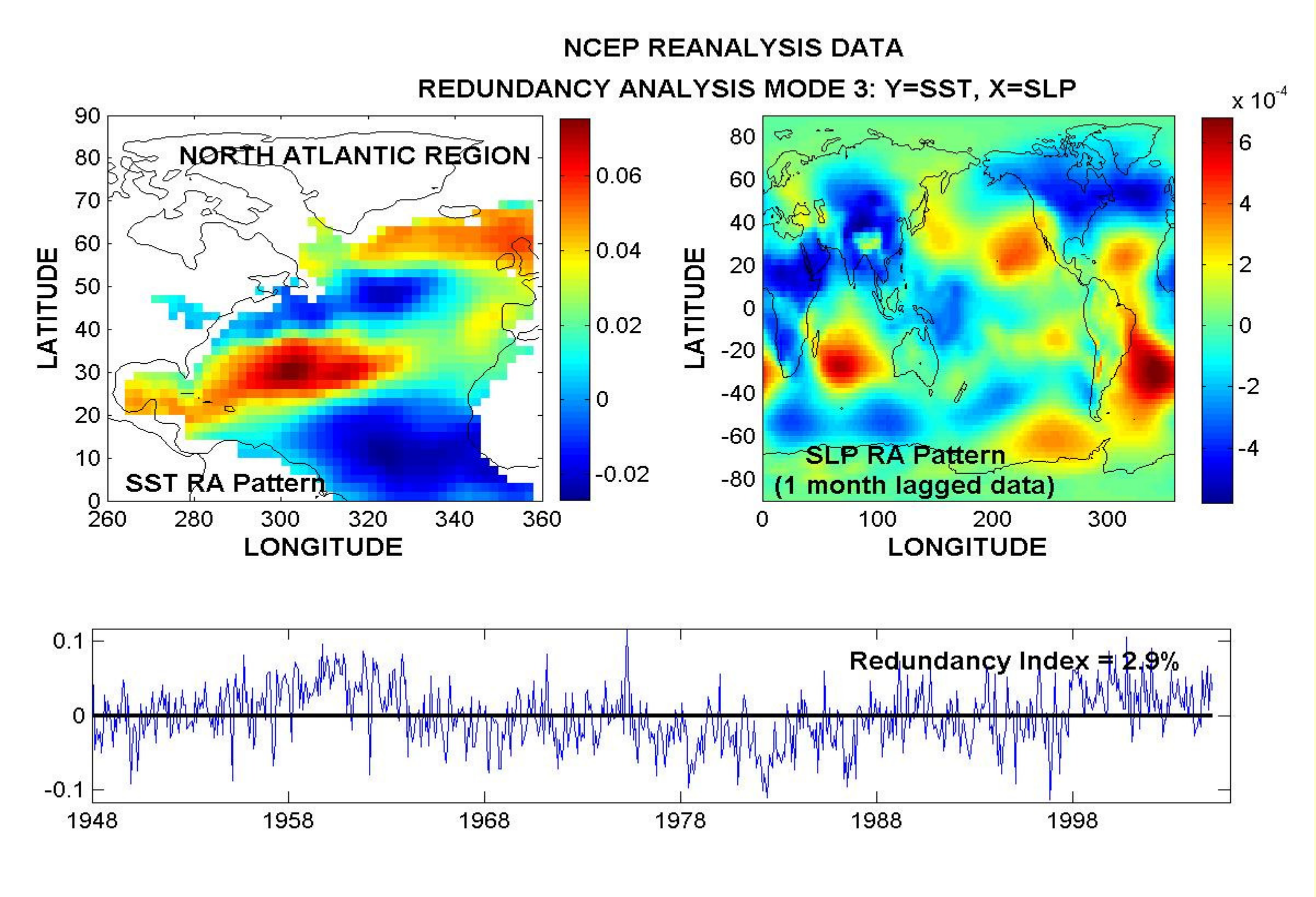
Mode 1: North Atlantic Region



Mode 2: North Atlantic Region



Mode 3: North Atlantic Region



North Atlantic Region Summary

- Variations in Azores High and Icelandic Low Pressure drives Tripole SST anomaly in mid-North Atlantic Latitudes

- Variations in Azores and Icelandic Pressure systems linked to South Atlantic Pressure system (negative correlation)

References

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