Interpretation of CCA Loading Patterns and the Associated Time Series

Multiple Regression, Principal Component Regression, and CCA

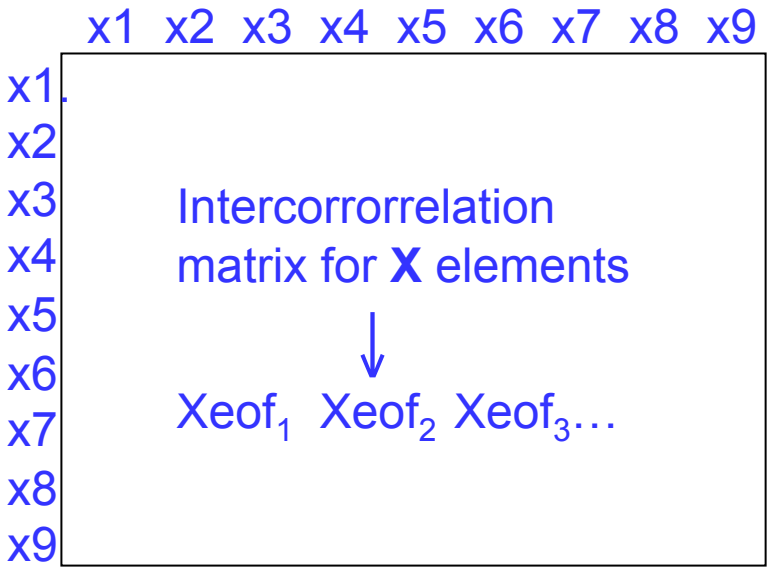
Prediction of any element **Y** individually using multiple regression

Predictors can be elements of X

$$y_1 = b_1x_1 + b_2x_2 + b_3x_3 + ...$$

$$y_2 = b_1x_1 + b_2x_2 + b_3x_3 + ...$$

$$y_3 = ...$$



OR

Predictors can be EOFs of X

(principal component regression)

$$y_1 = b_1XEOF_1 + b_2XEOF_2 + ...$$

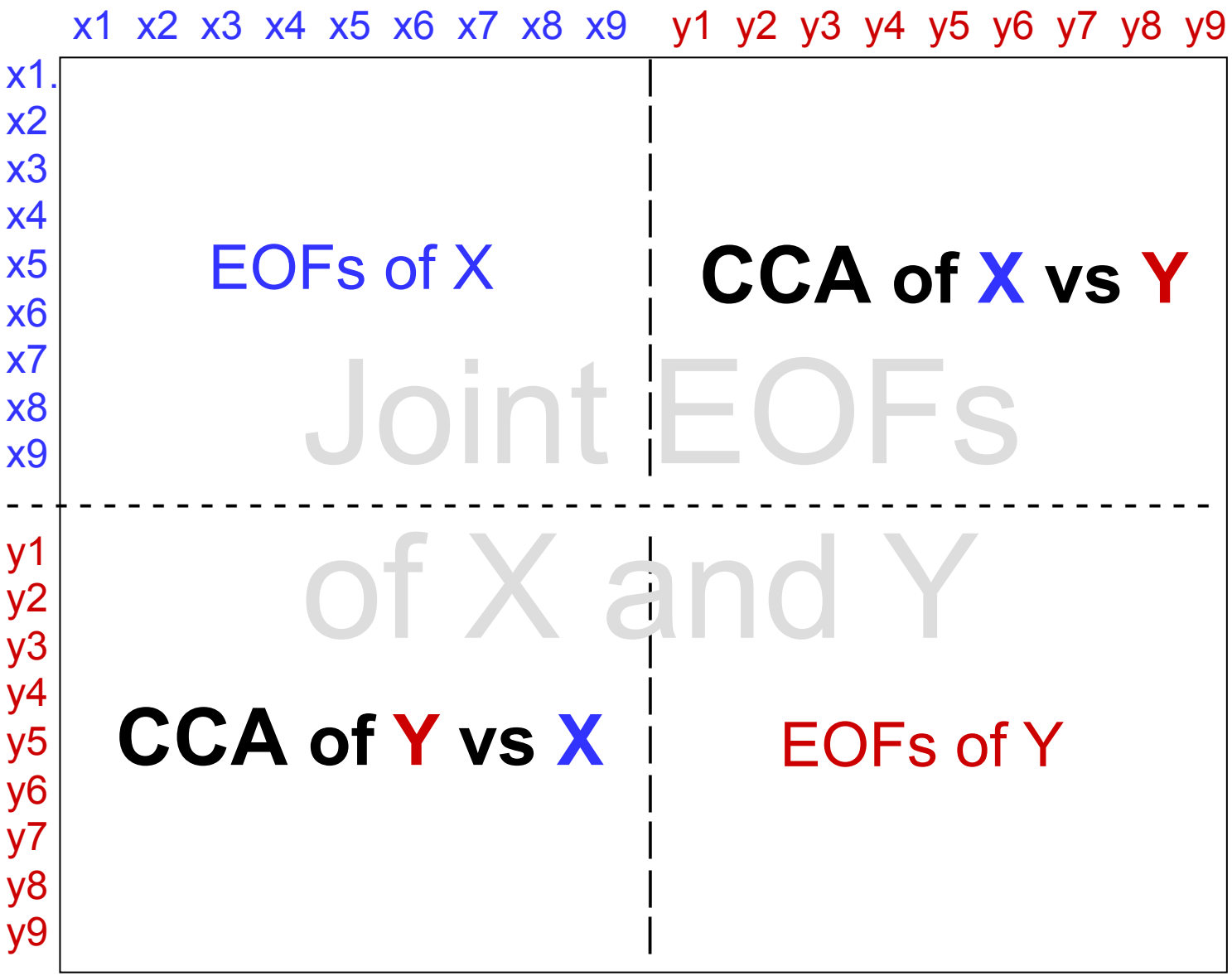
$$y_2 = b_1XEOF_1 + b_2XEOF_2 + ...$$

$$y_3 = ...$$

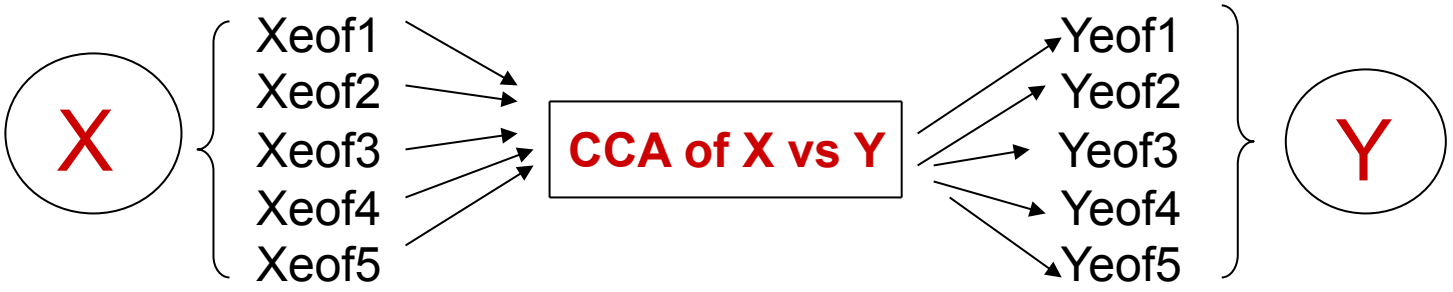
Introduction to CCA

CCA is like EOF analysis, except that there are TWO data sets (X and Y, or predictor and predictand), and the input matrix (correlation or covariance) contains cross-dataset coefficients. only (an X element with a Y element; no X-to-X or Y-to-Y). Both X and Y can be time-extended or contain multiple fields.

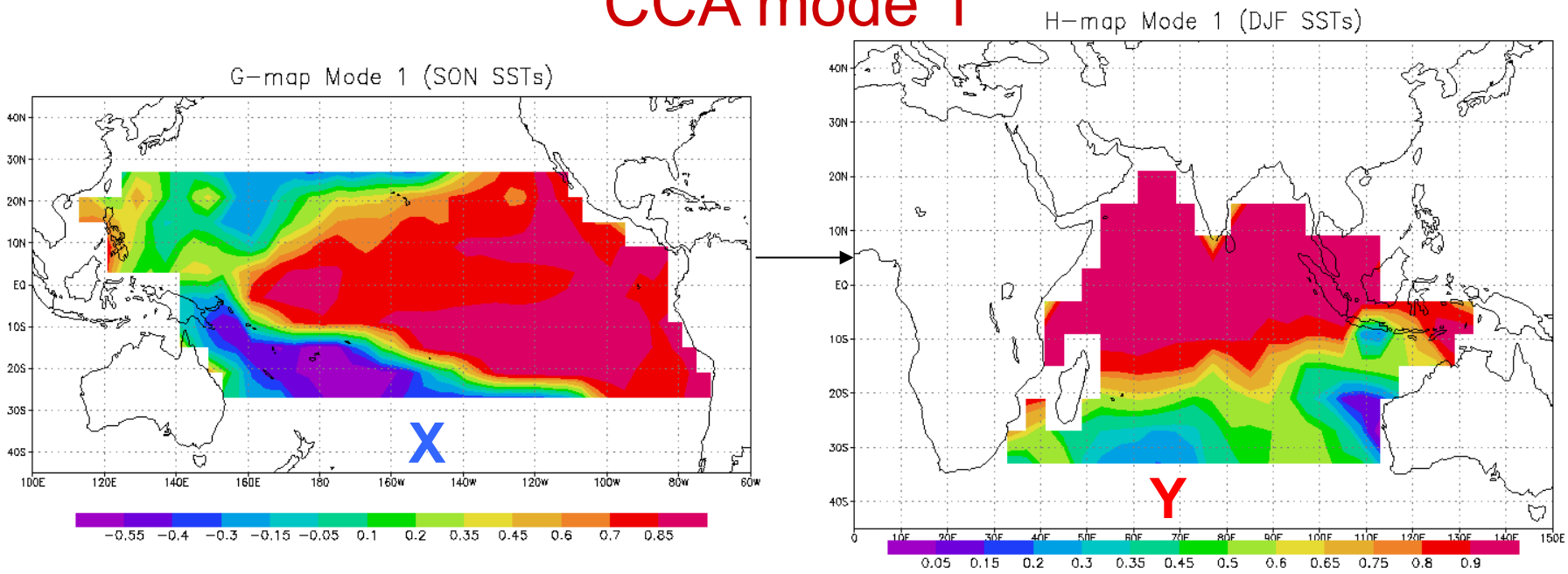
Analyses of correlation matrix of X and Y fields: 9 elements of X and Y



CCA can be done using just certain EOF time series of X and of Y:



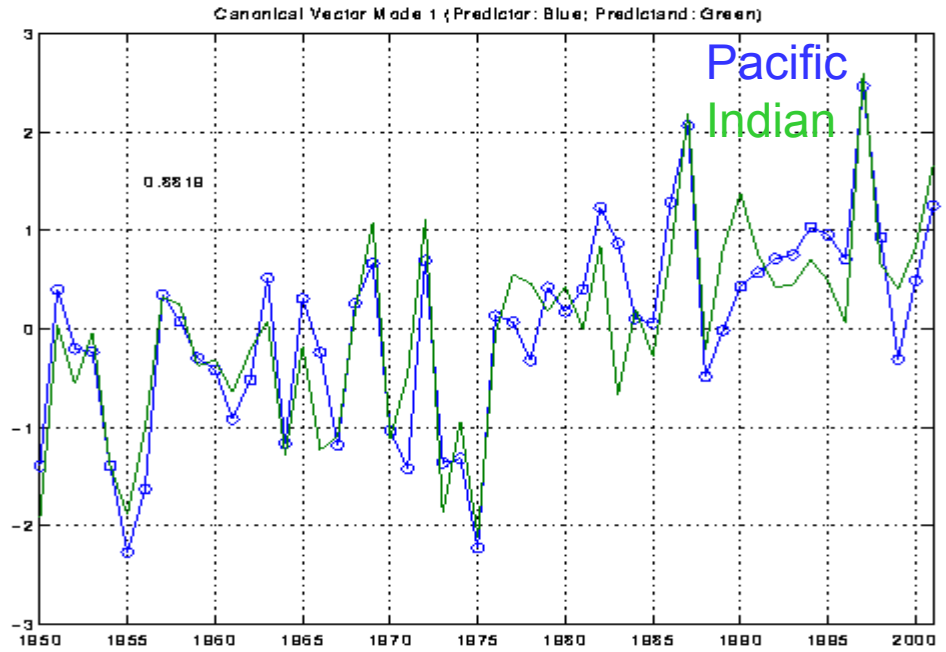
CCA mode 1



X: tropical Pacific SST, SON season

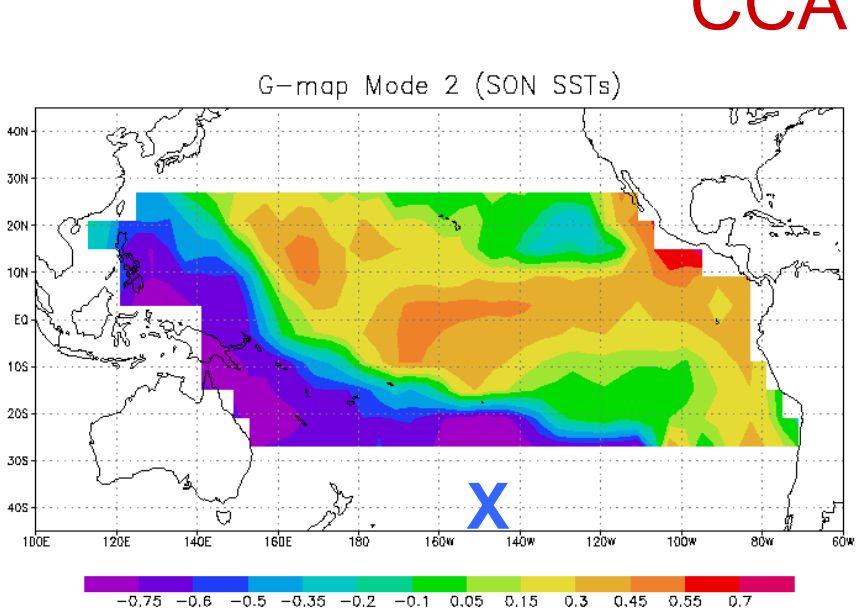
↓

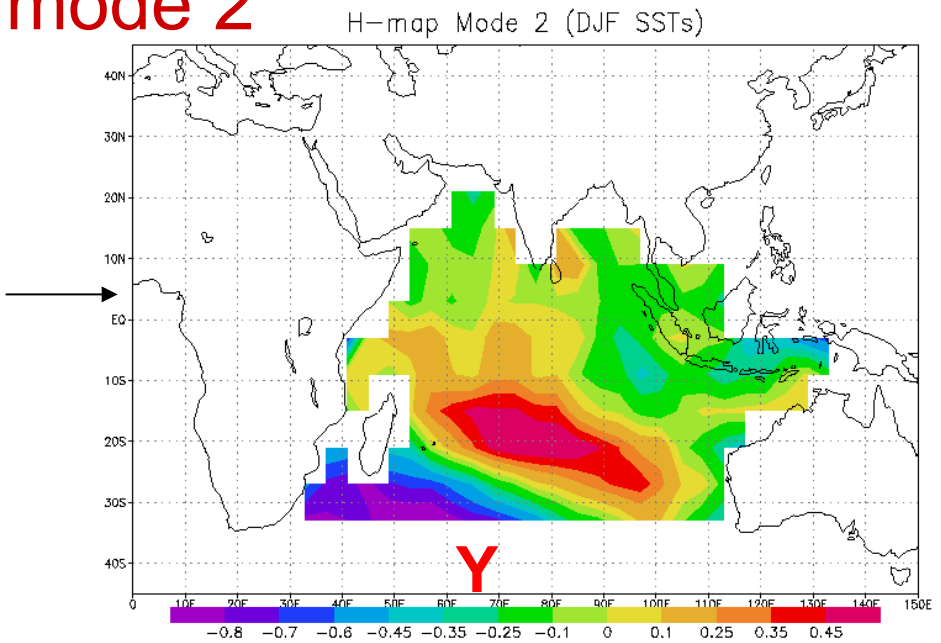
Y: Indian Ocean SST, DJF season



canon correl =.882

CCA mode 2

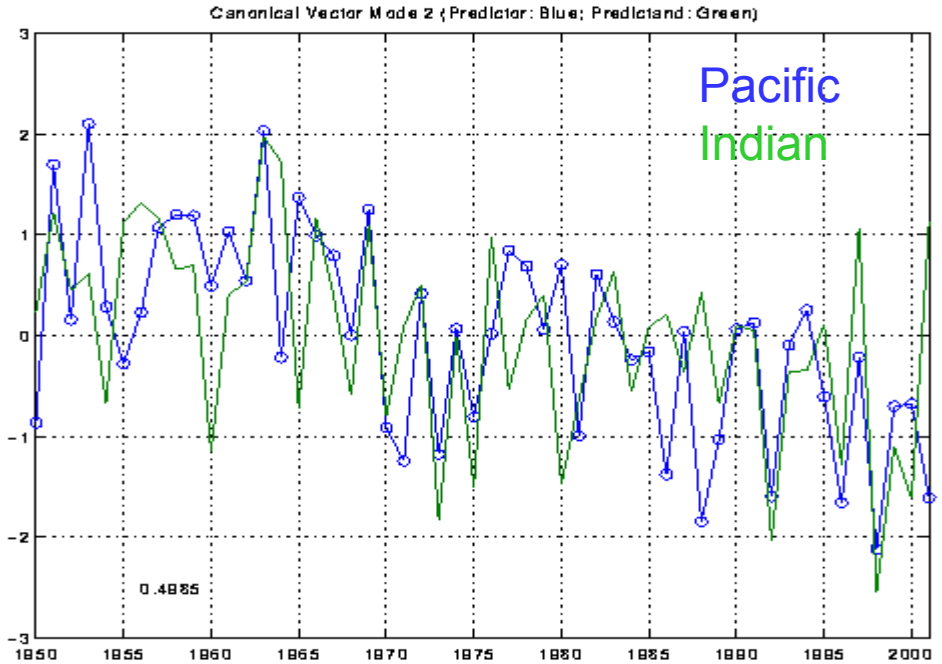




X: tropical Pacific SST, SON season

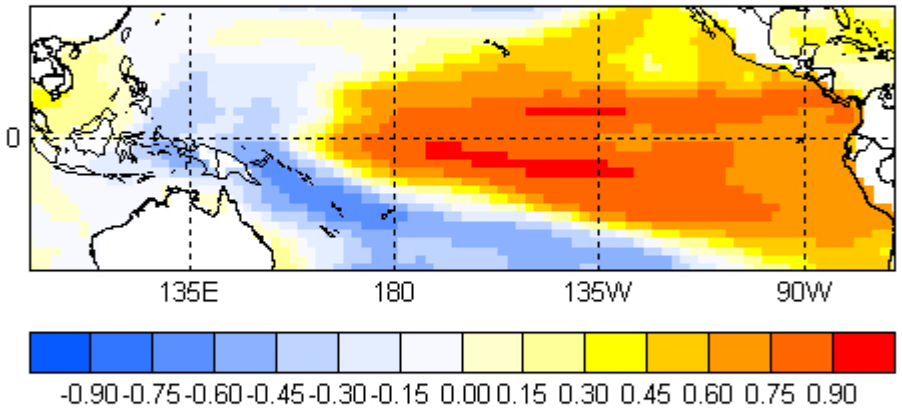
↓

Y: Indian Ocean SST, DJF season

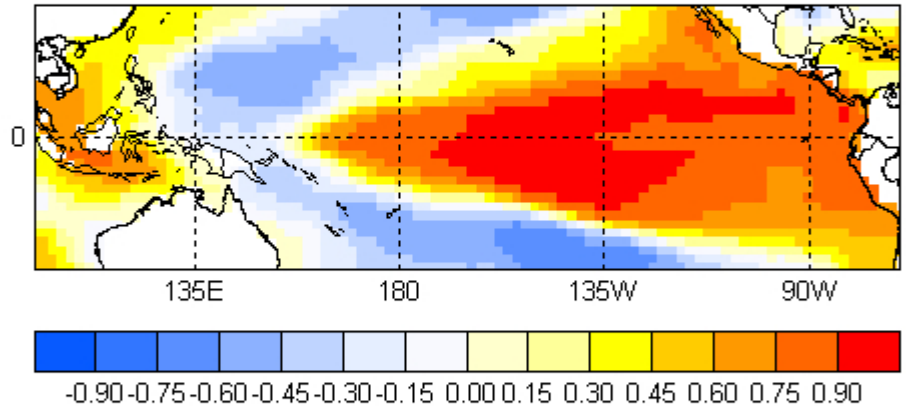


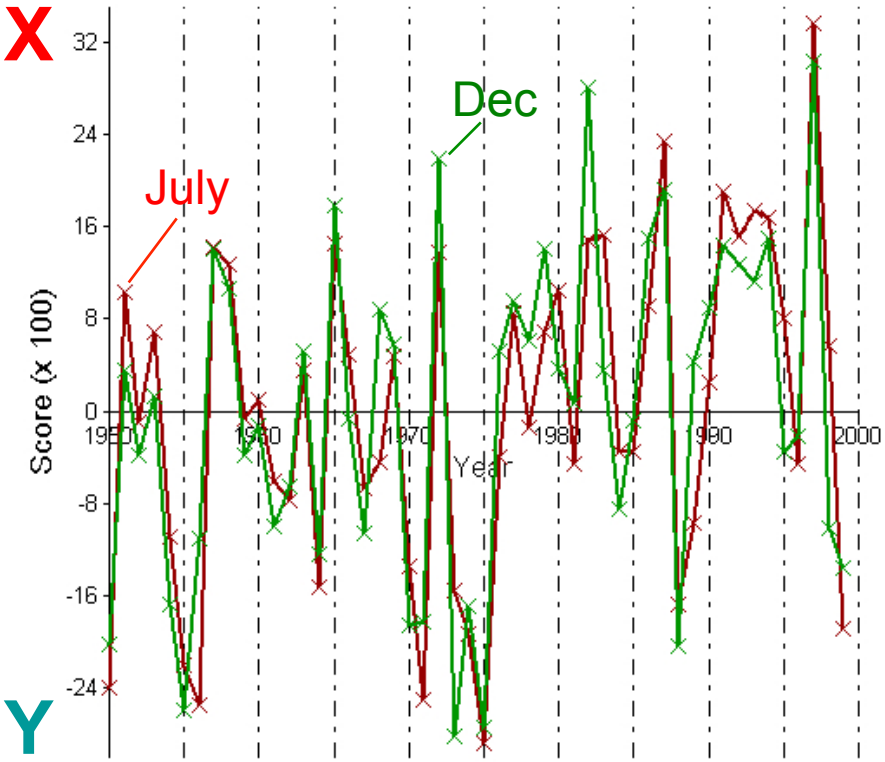
canon correl =.498

Another CCA example, using tropical Pacific SST for two separated months: July (X) and December (Y)



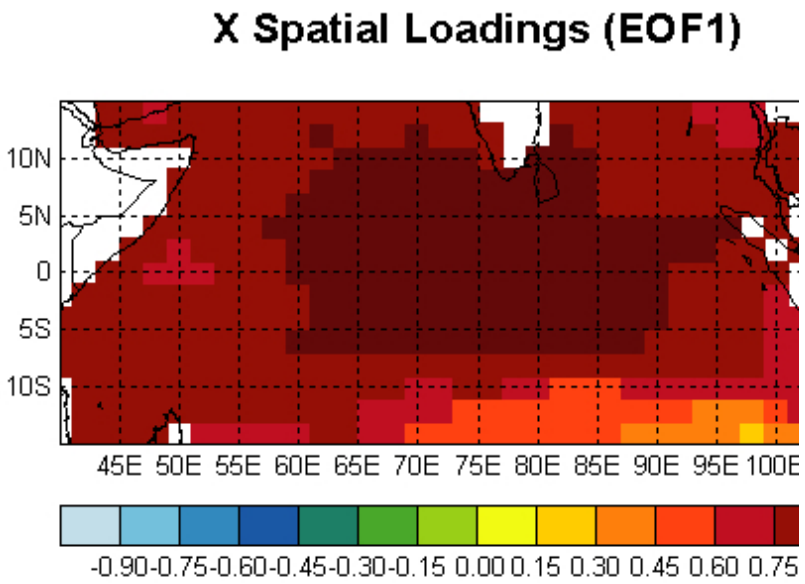
July vs. December sea-surface temperature, 1950-1999

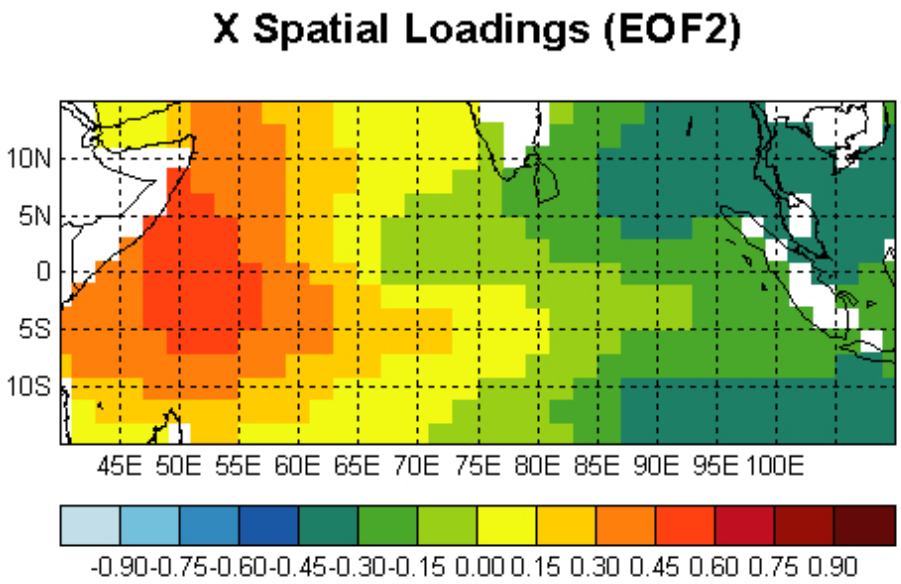




Buell patterns in EOFs:

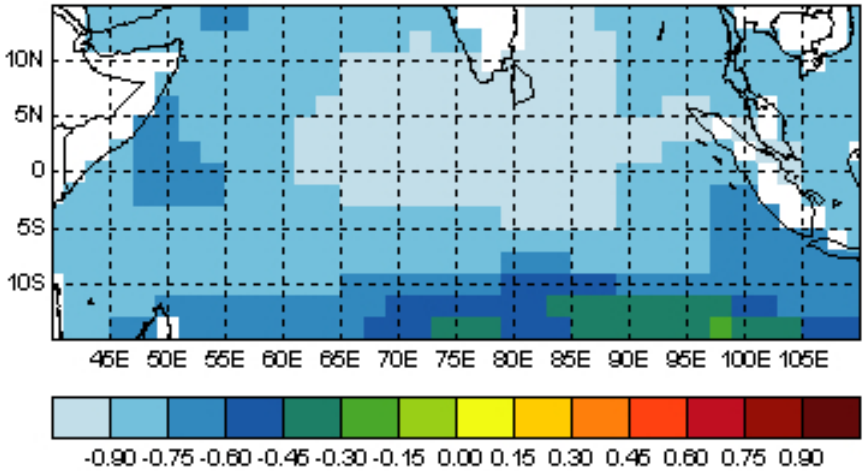
Are the following Indian Ocean EOF modes real,
or are they caused mainly by the Buell pattern phenomenon?



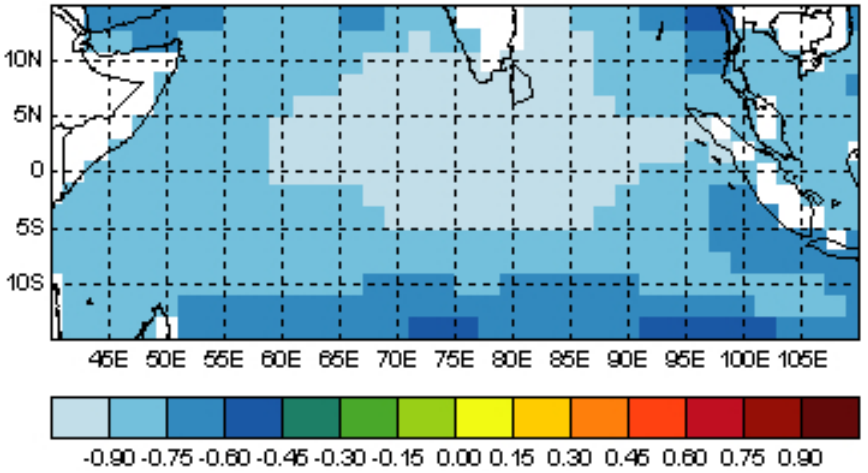


Buell patterns can sometimes also affect CCA

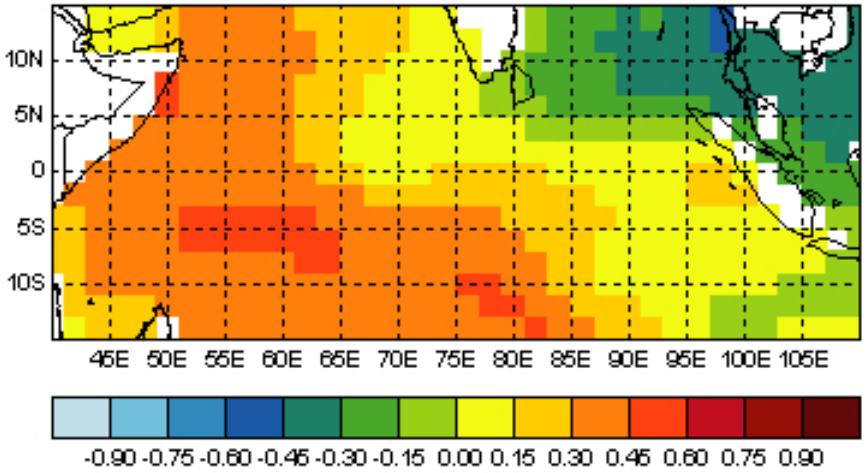
X Spatial Loadings (Mode1)



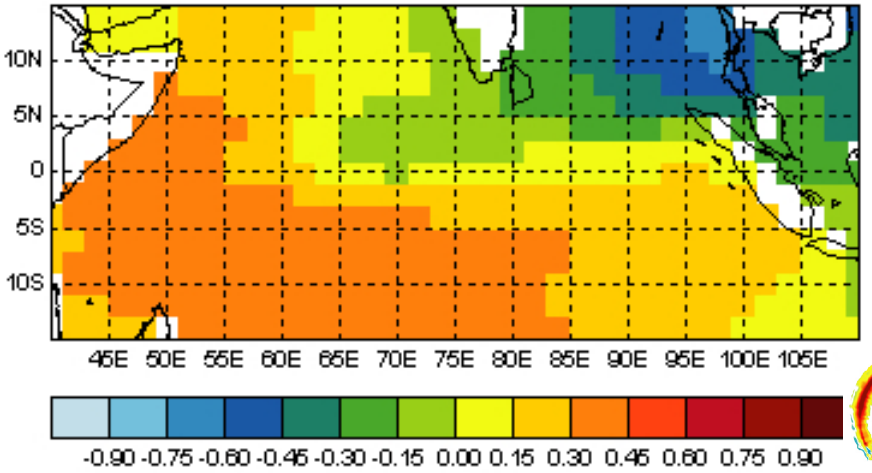
Y Spatial Loadings (Mode1)



X Spatial Loadings (Mode2)



Y Spatial Loadings (Mode2)



Two possible predictor designs in CCA

1. Observational predictor design

X is observed earlier predictors, such as the field of governing SST

2. Model MOS design

X is dynamical model prediction of rainfall pattern around a region of interest

Y is rainfall pattern prediction for a region of interest

1. is a purely statistical forecast system
2. Is a dynamical forecast corrected by a statistical adjustment

An Example of a CCA with observational predictor design

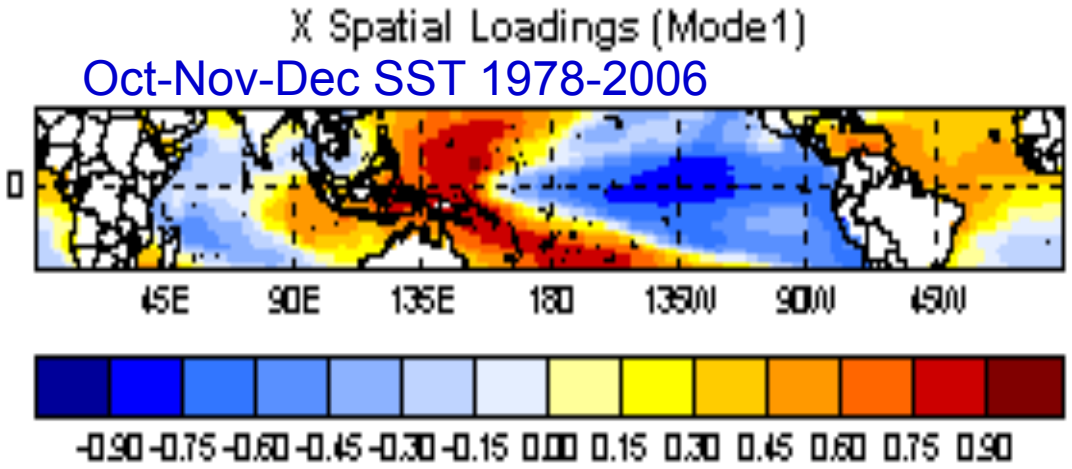
X data set: Tropical SST for Oct-Nov-Dec season

Y data set: Precipitation for 50N-50S for subsequent Jan-Feb-Mar

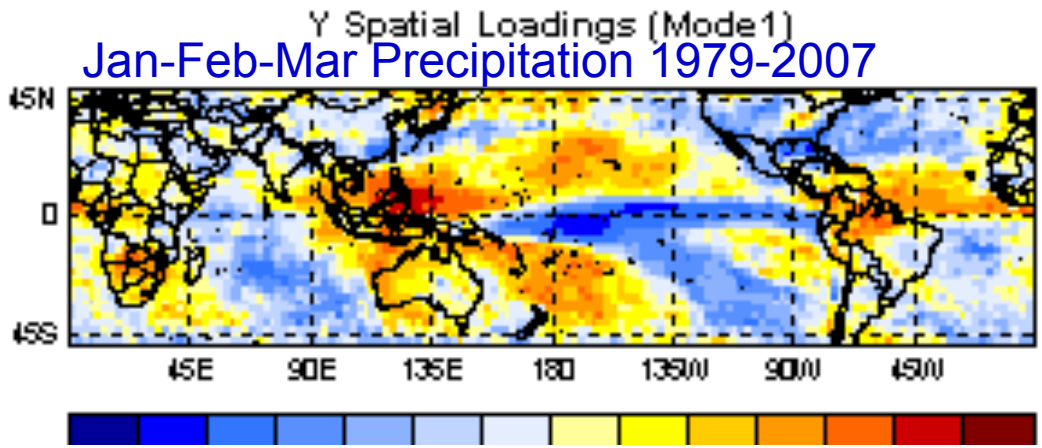
Physical basis for expecting a predictive pattern: During ENSO,
the global SST anomalies are often strongest during Oct-Nov-Dec.
The influence on global precipitation is seen most clearly during
the northern winter season.

EOFs are first taken of X and of Y, and their time series are input to CCA.

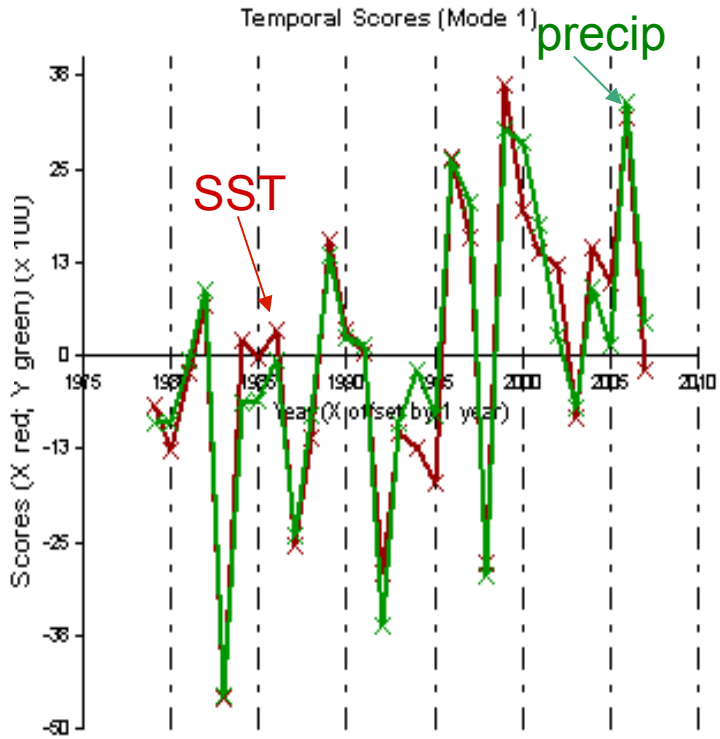
CCA Mode 1 – a “non-pure” ENSO scenario (a general trend is also slightly mixed in)



Oct-Nov-Dec SST 1978-2006

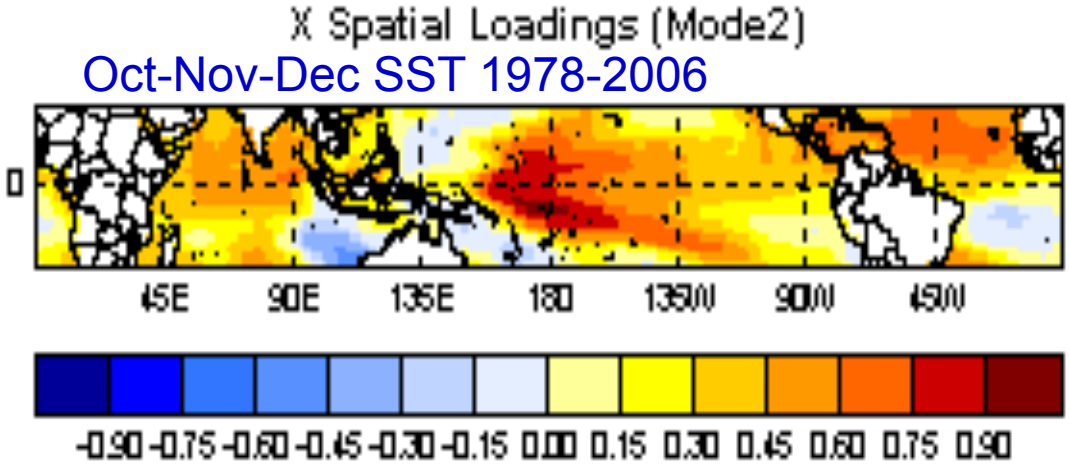


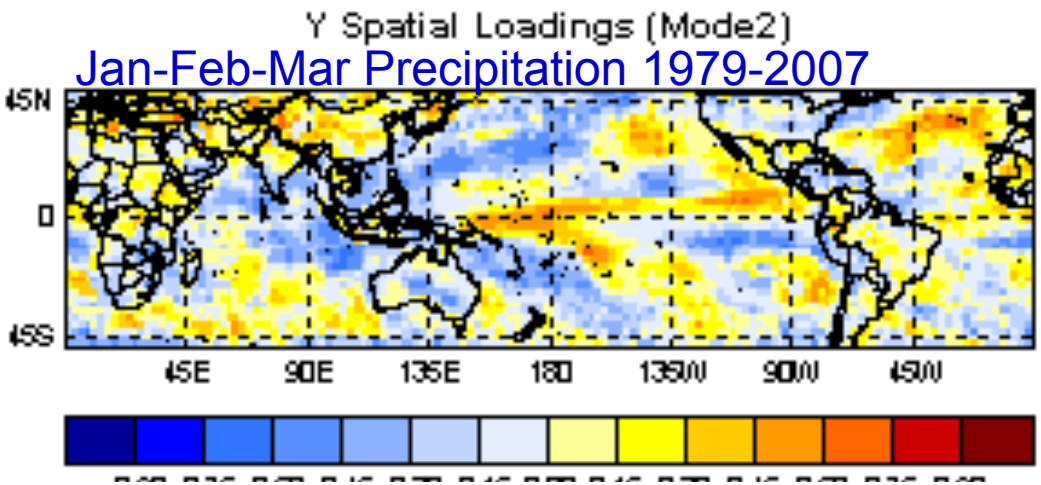
Jan-Feb-Mar Precipitation 1979-2007

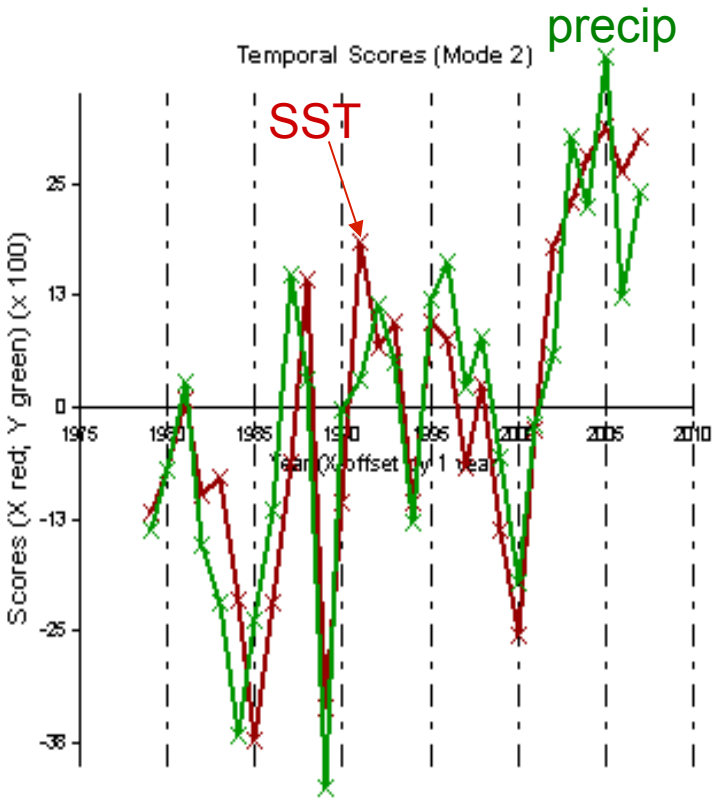


X plotted in year of Y

CCA Mode 2 – global climate change, plus a small residual of ENSO

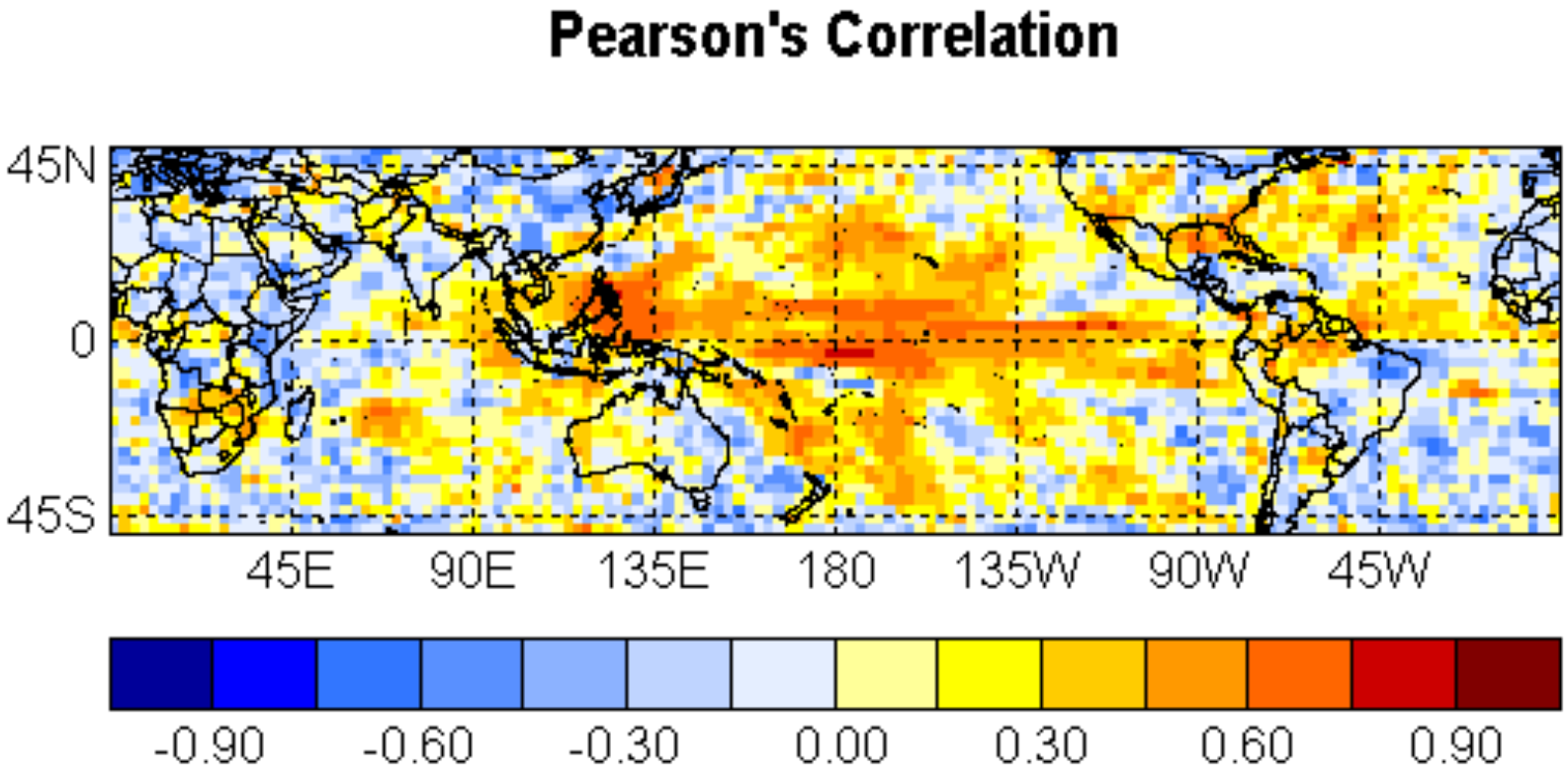






X plotted in year of Y

Skill of CCA forecast of Jan-Feb-Mar precipitation, using Oct-Nov-Dec SST anomaly as predictor, 1979-2007



Another Example of a CCA with observational predictor design

X data set: Tropical SST for Oct-Nov-Dec season

Y data set: Air Temperature for 55N-55S for subsequent Jan-Feb-Mar

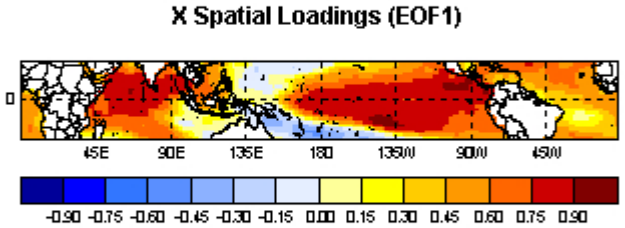
Physical basis for expecting a predictive pattern: During ENSO,
the global SST anomalies are often strongest during Oct-Nov-Dec.
The influence on global temperature is often strongest from the northern
winter season through the northern spring season (there is some phase delay).

EOFs are first taken of X and of Y, and their time series are input to CCA.

OND SST

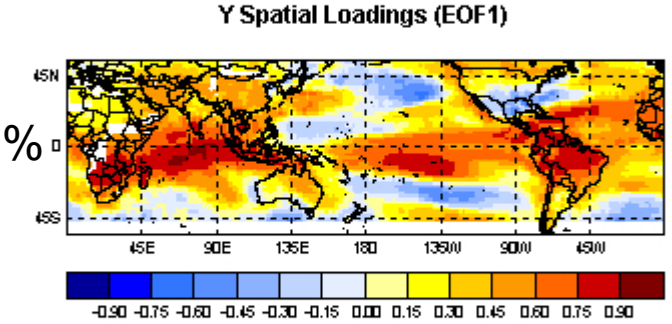
EOFs: Mode 1

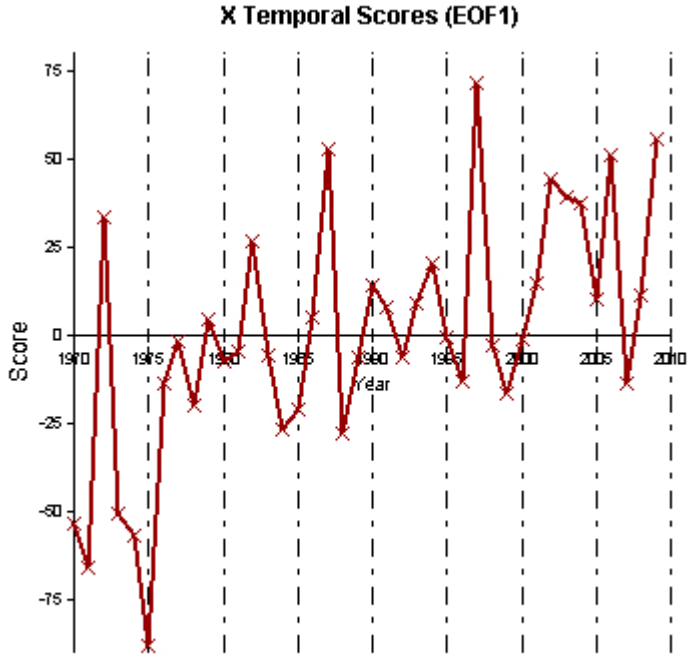
JFM Air Temperature

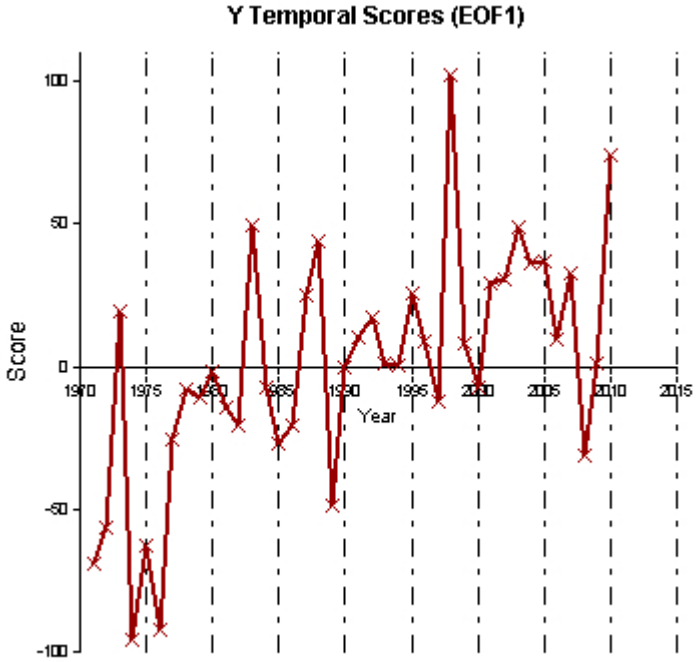


35%

22%



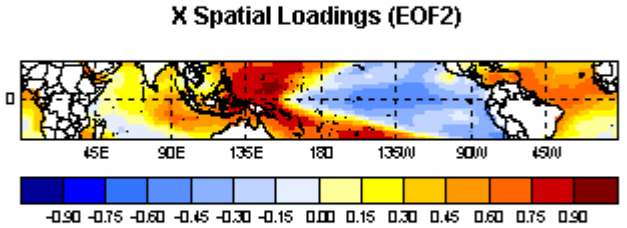




OND SST

EOFs: Mode 2

JFM Air Temperature



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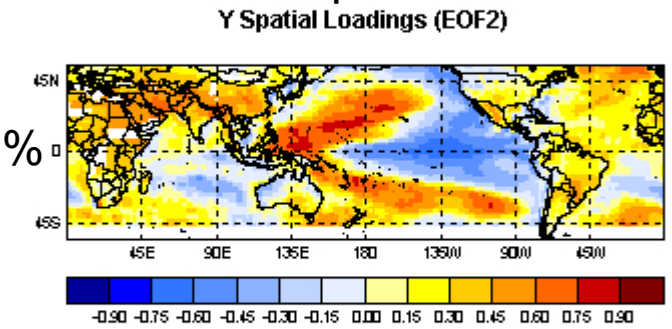
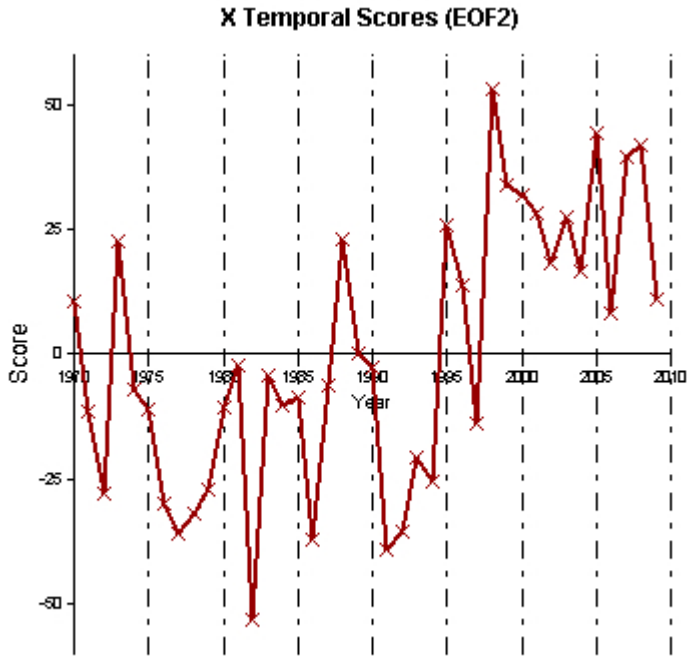
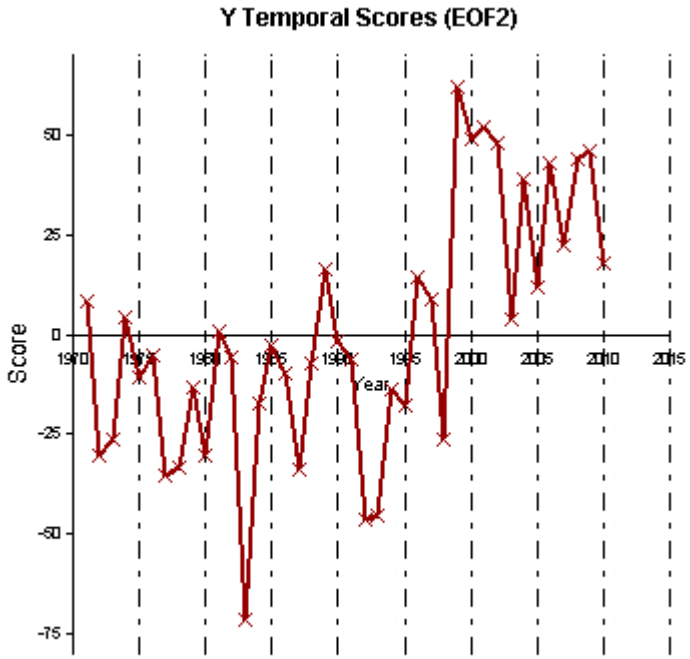
12%

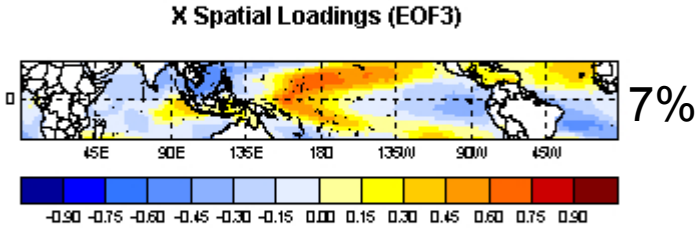






OND EOFs: Mode 3 JFM

SST Air Temperature



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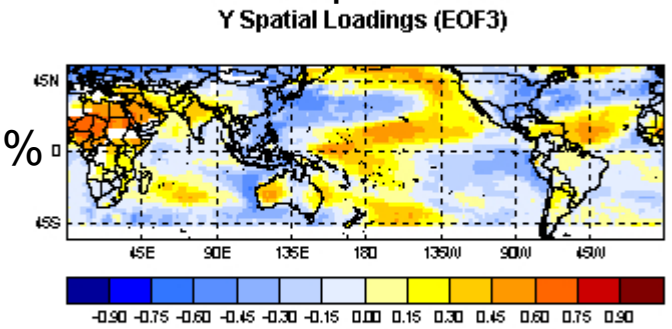
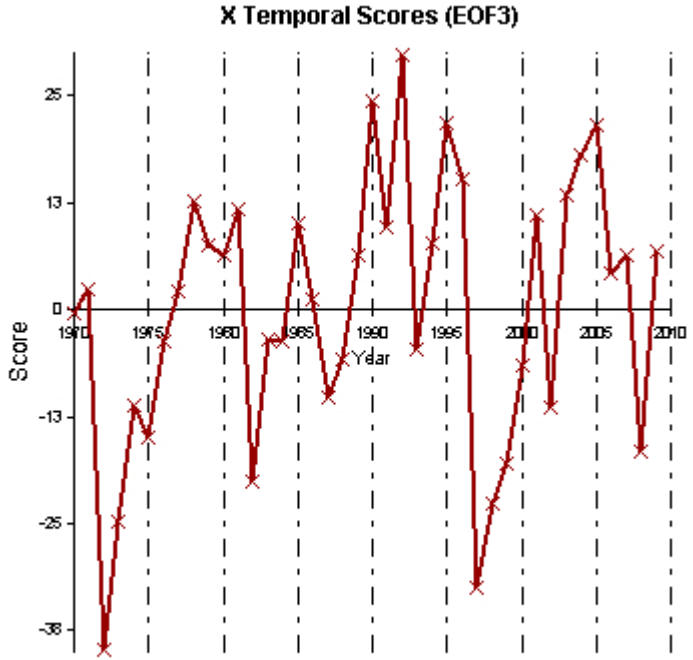
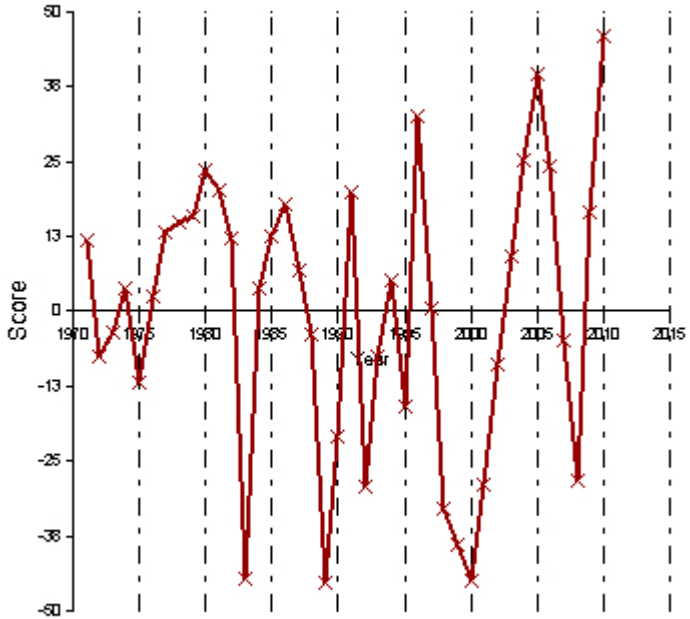
7%



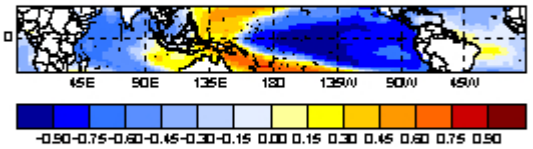




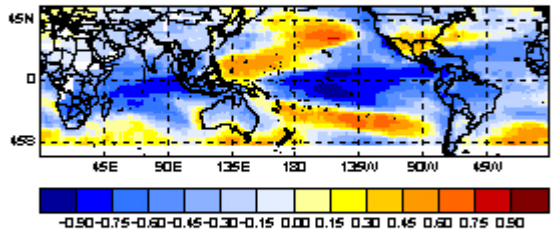
Leading CCA modes for OND SST versus JFM Air Temperature

X Spatial Loadings (Mode1)

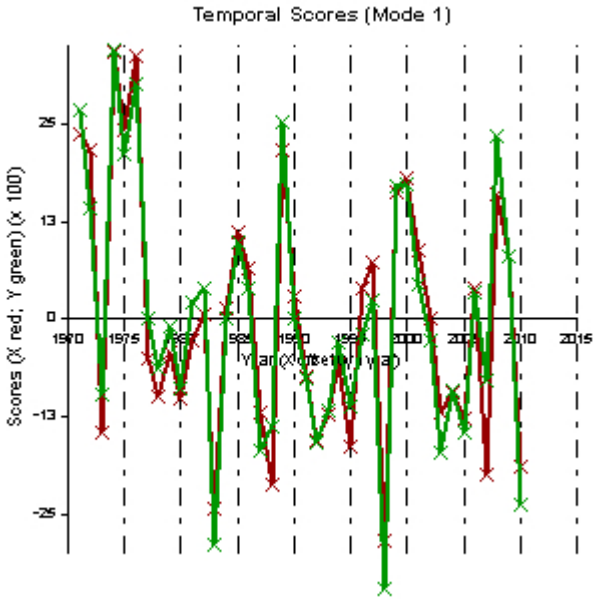
X



Y



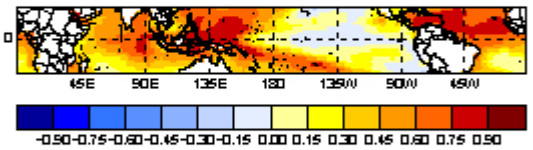
CCA Mode 1



can cor 0.96

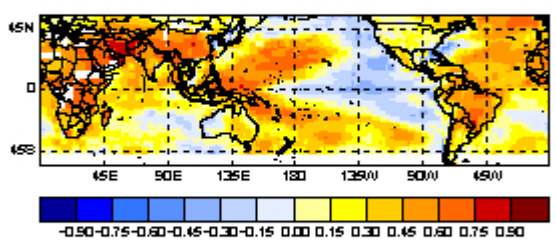
X Spatial Loadings (Mode2)

X

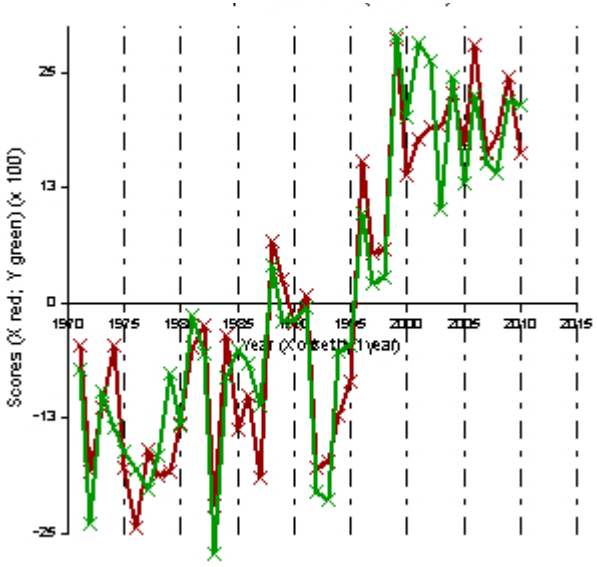


Y Spatial Loadings (Mode2)

Y



CCA Mode 2

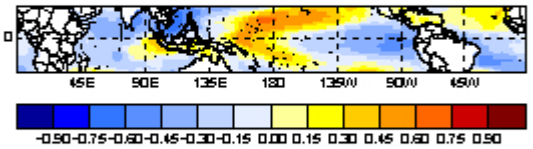


can cor 0.95

Leading CCA modes for OND SST versus JFM Air Temperature

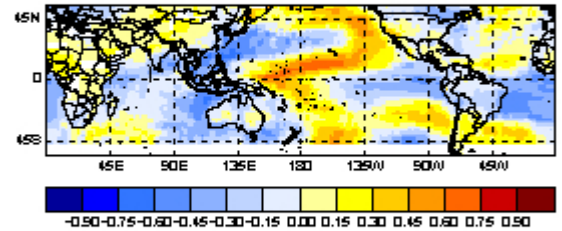
X Spatial Loadings (Mode3)

X

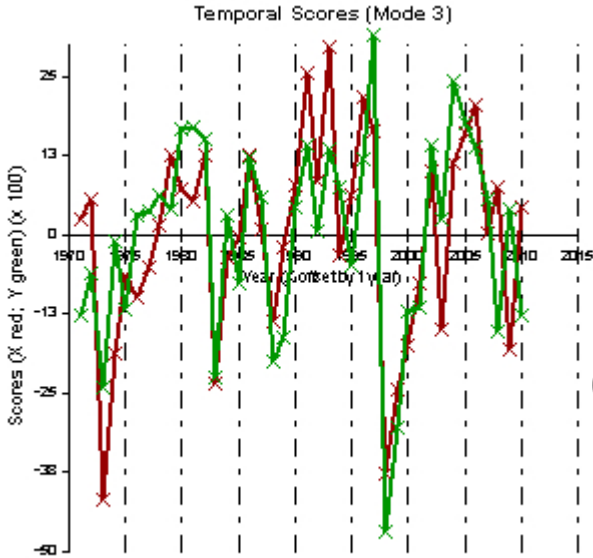


Y Spatial Loadings (Mode3)

Y



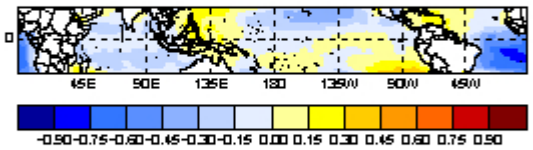
CCA Mode 3



can cor 0.75

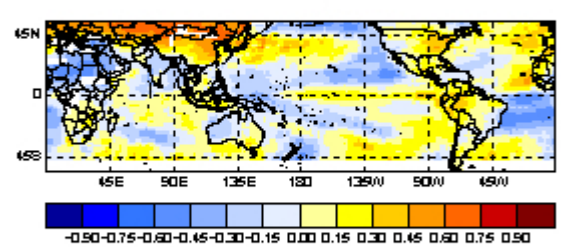
X Spatial Loadings (Mode4)

X

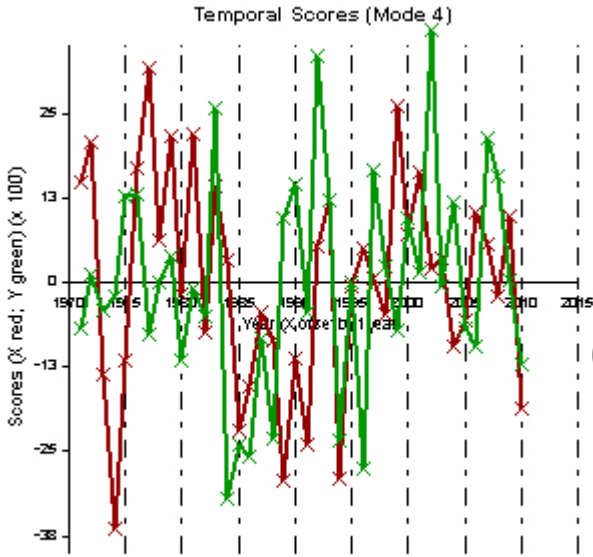


Y Spatial Loadings (Mode4)

Y

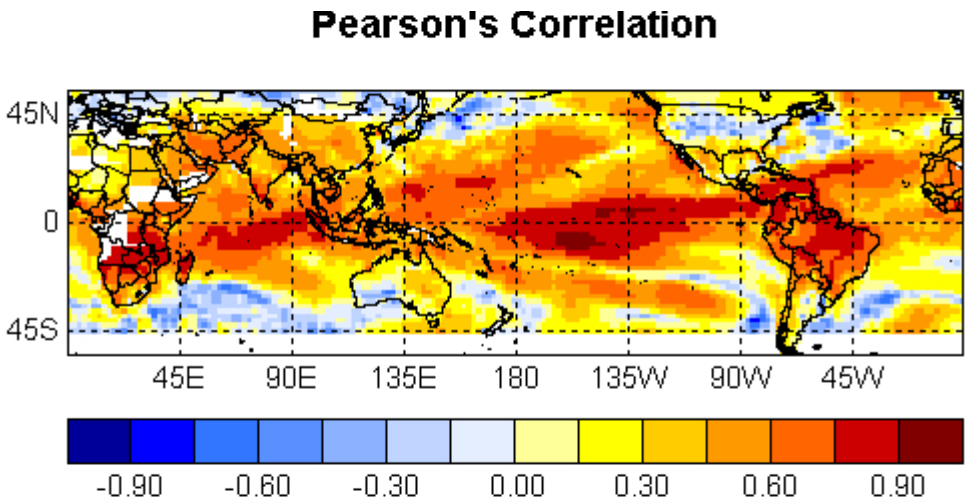


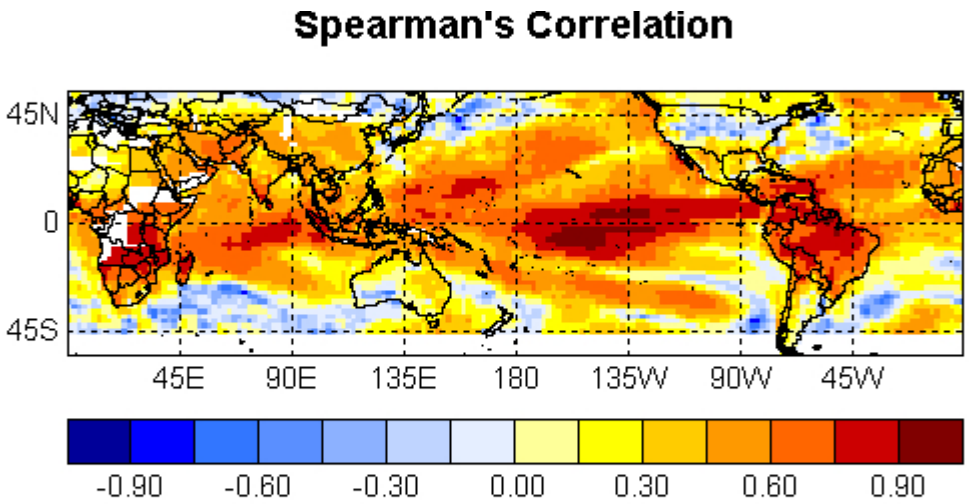
CCA Mode 4



can cor 0.21

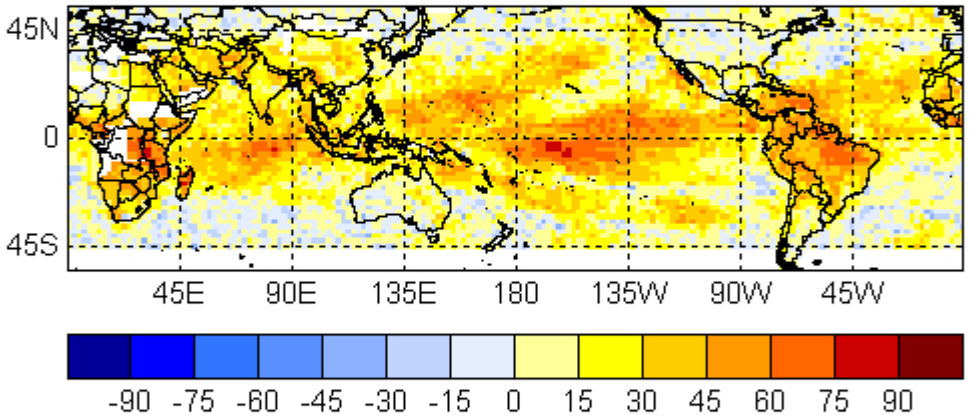
Skill of OND SST versus JFM Air Temperature



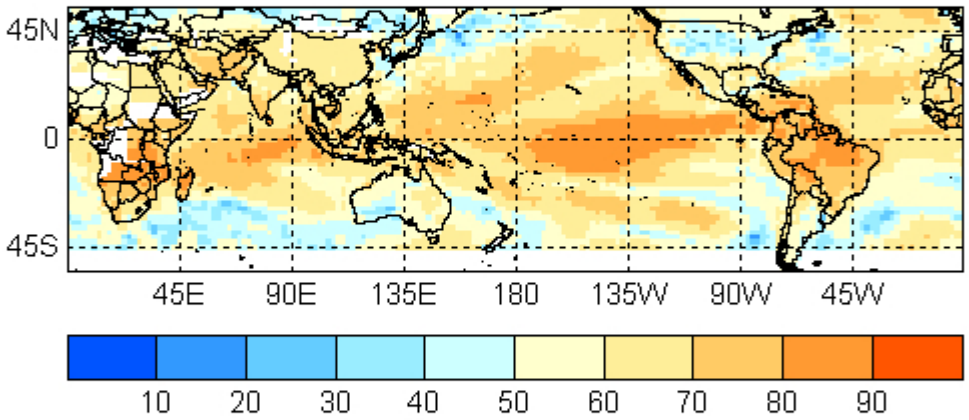


Skill of OND SST versus JFM Air Temperature
Heidke Skill Score

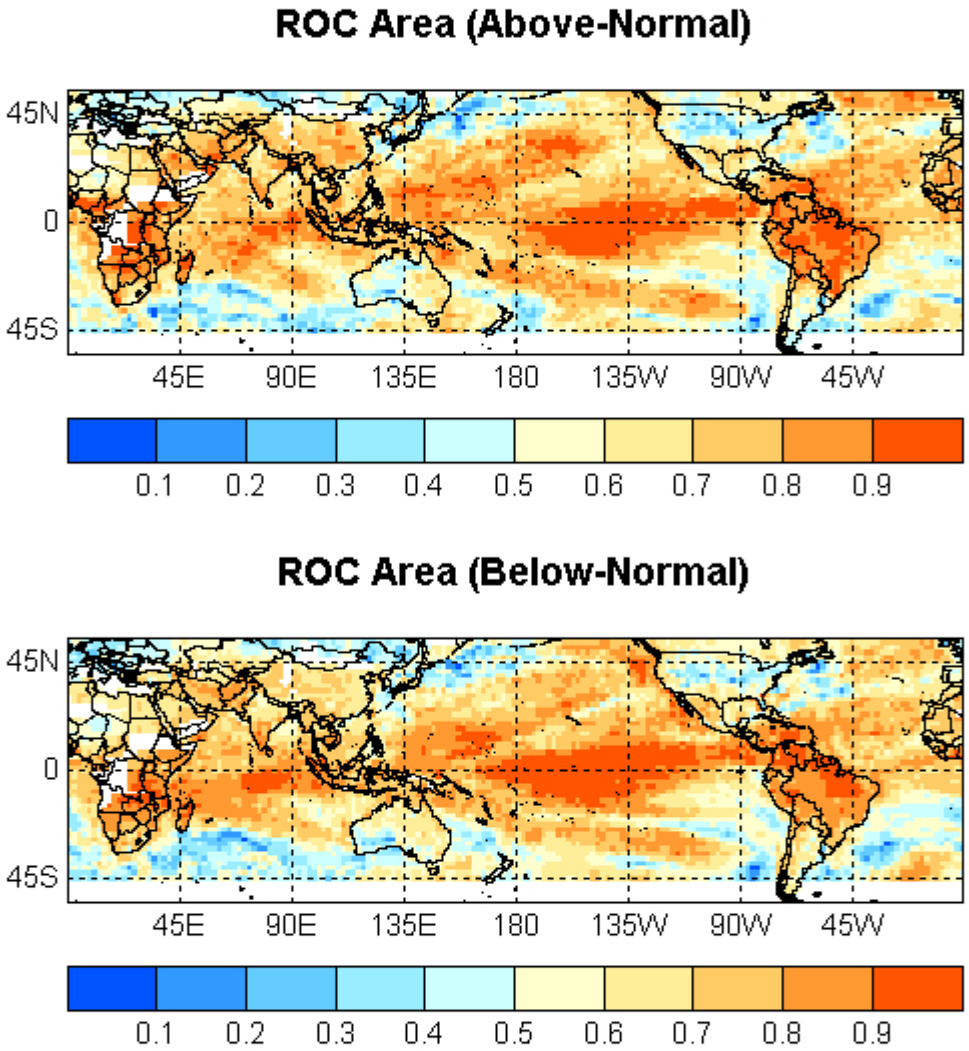
Hit Skill Score



2AFC Score

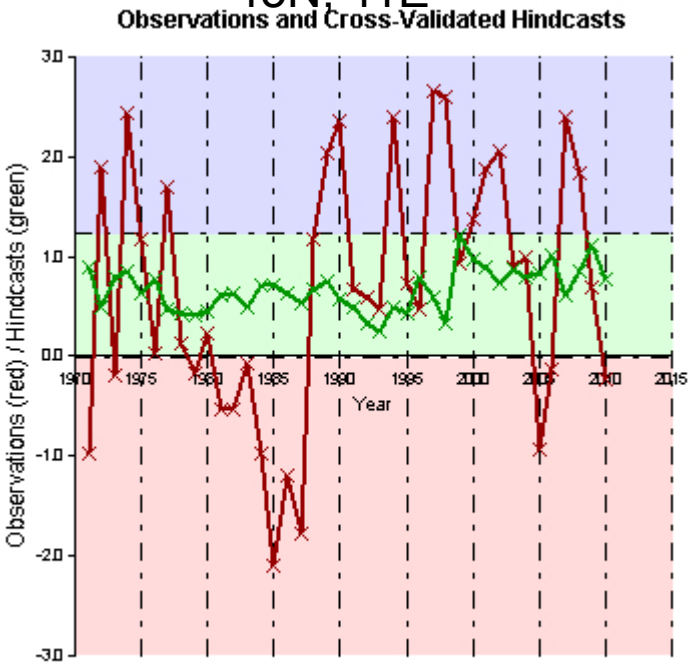


Skill of OND SST versus JFM Air Temperature



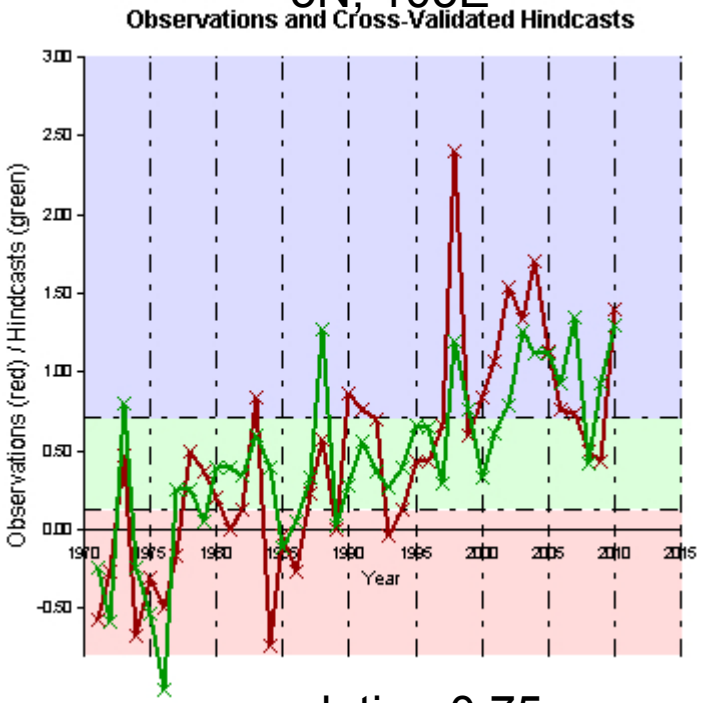
Hindcasts for a well-predicted and a poorly-predicted location

northern Italy
45N, 11E



correlation -0.05
variance ratio 0.03

western Malaysia
5N, 103E



correlation 0.75
variance ratio 0.65

Ethiopian Seasonal Rainfall Prediction Using CCA

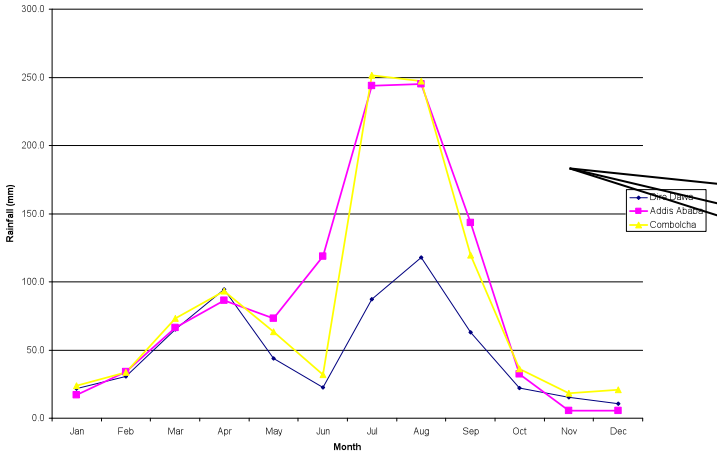
A. Empirical predictor design, using SST

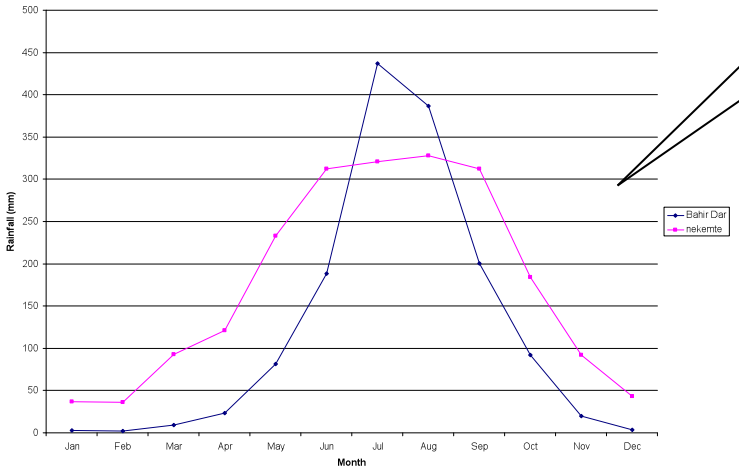
B. Dynamical model correction design:

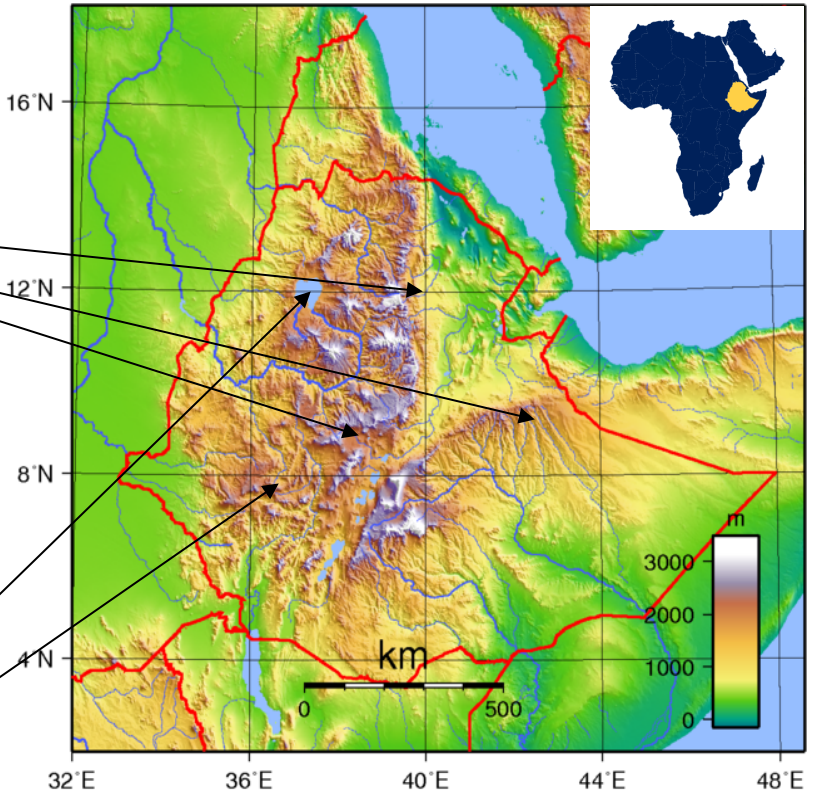
(1)Model rainfall → rainfall

(2) Model v-wind → rainfall

Seasonal cycle of rainfall at various locations in Ethiopia

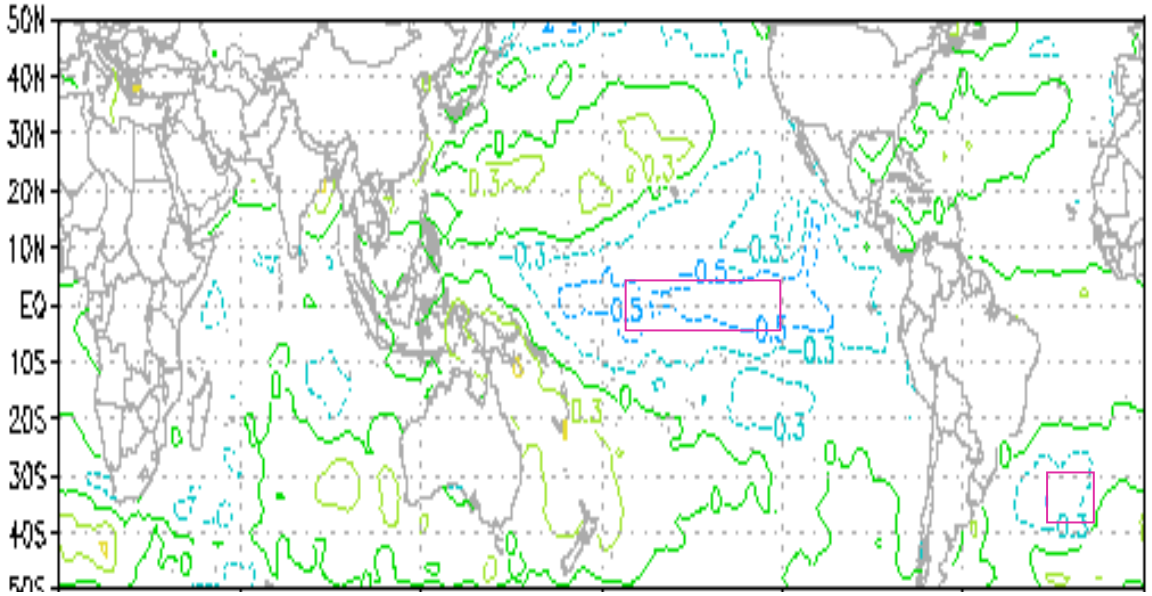




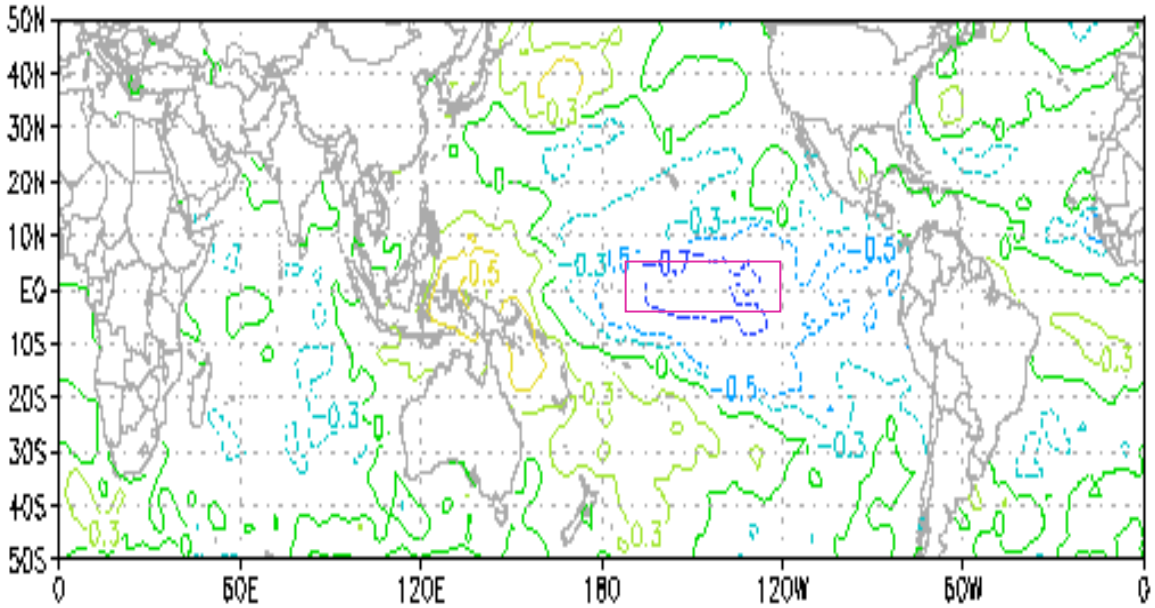


Except for southern and eastern Ethiopia, main rainy season is from June to September

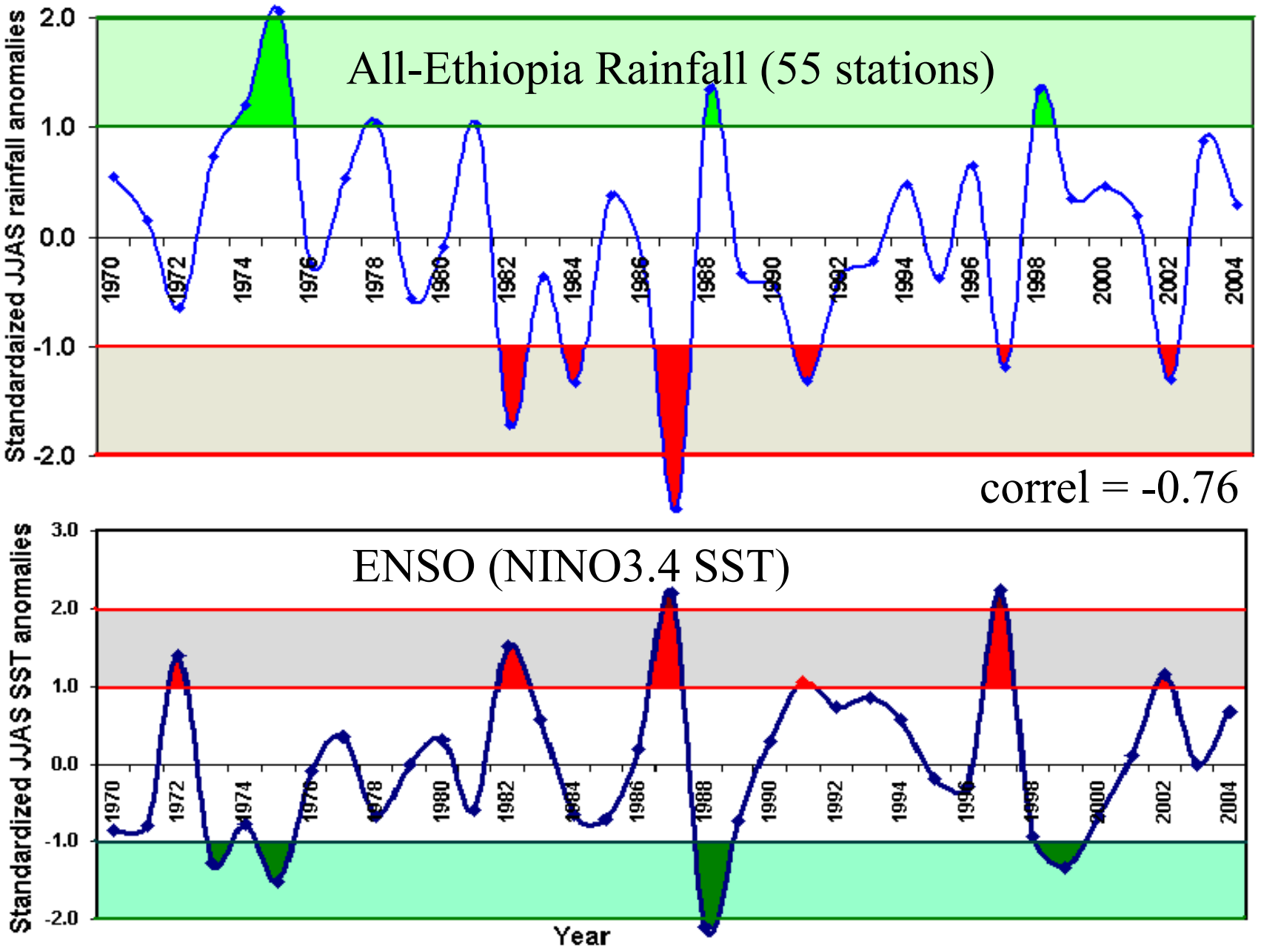
1970-2004 correlation: JJAS All-Ethiopia rainfall vs….



Correl: May SST vs. all-Ethiop rainfall



Correl: Aug SST vs. all-Ethiop rainfall


All-Ethiopia Rainfall (55 stations)
Standardaized JJAS rainfall anomalies
2.0
1.0
0.0
-1.0
-2.0
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
correl = -0.76
ENSO (NINO3.4 SST)
Standardized JJAS SST anomalies
3.0
2.0
1.0
0.0
-1.0
-2.0
Year

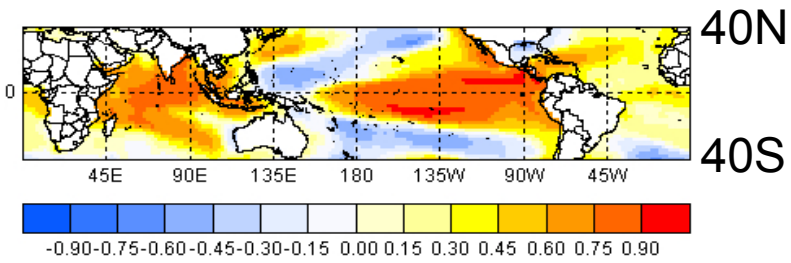
Data:

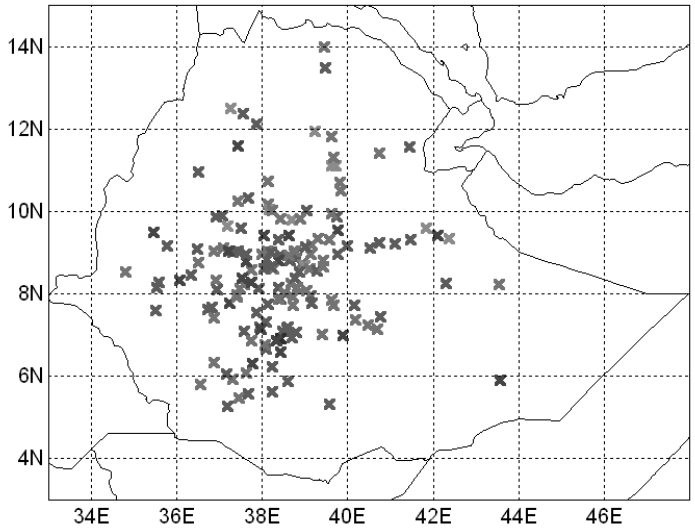
• 162 gauge data from National Meteorological Agency (NMA) of Ethiopia

• WCRP GPCC precipitation gridded data set

• ECHAM4.5 Precipitation and U & V wind components

• SST seasonal average for 40°N – 40°S: 2° x 2° resolution, from (NOAA/NCDC) version 2—i.e., the ERSSTv2 data set



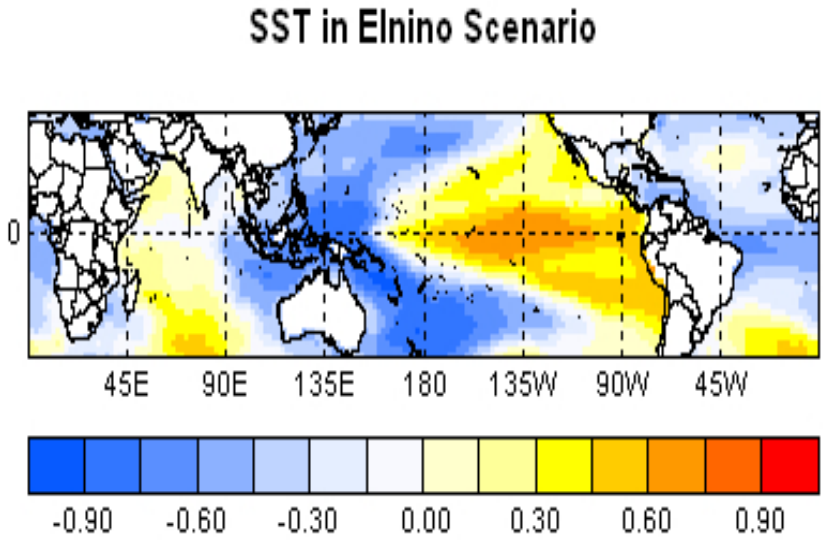


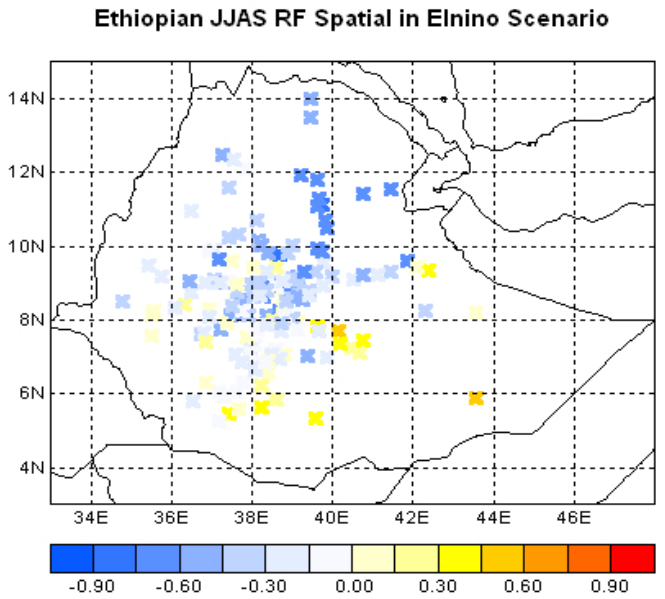
Gauge stations network used

Empirical Prediction Design:

Mode 1 for JJAS *station rainfall*, using May SST as predictor:

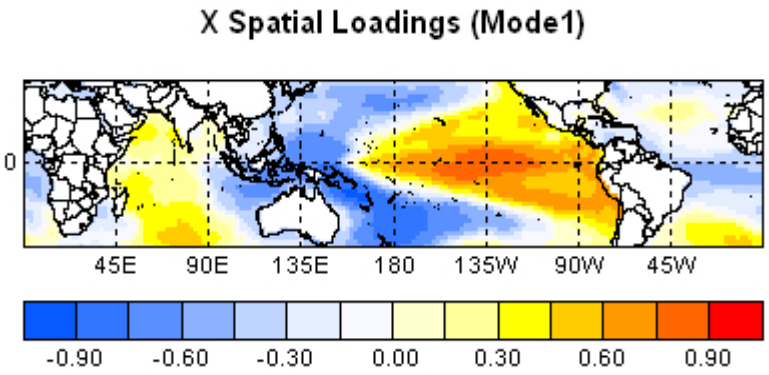
Warm ENSO phase is associated with deficient rainfall in much of central and northern Ethiopia

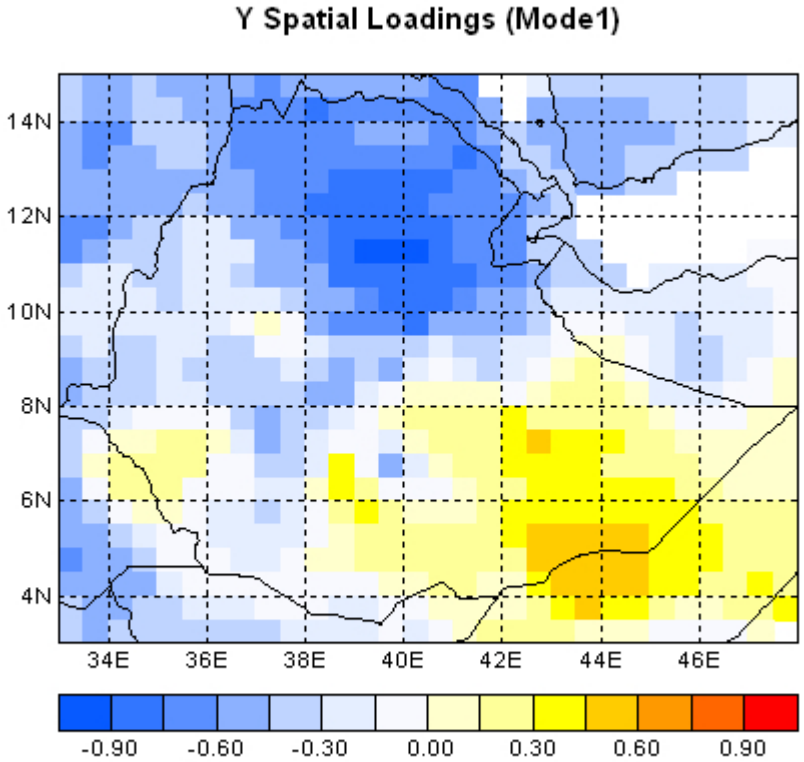




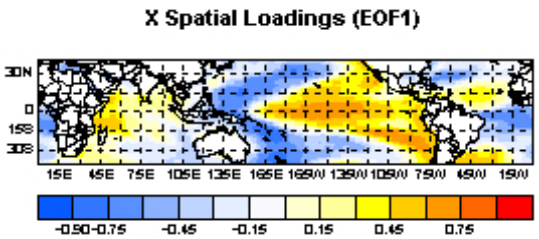
Empirical Prediction Design:

Mode 1 for JJAS WCRP (GPCC) *gridded rainfall*, using May SST as predictor: Again, warm ENSO phase is associated with deficient rainfall in much of central and northern Ethiopia. Station and gridded rainfall data results agree.

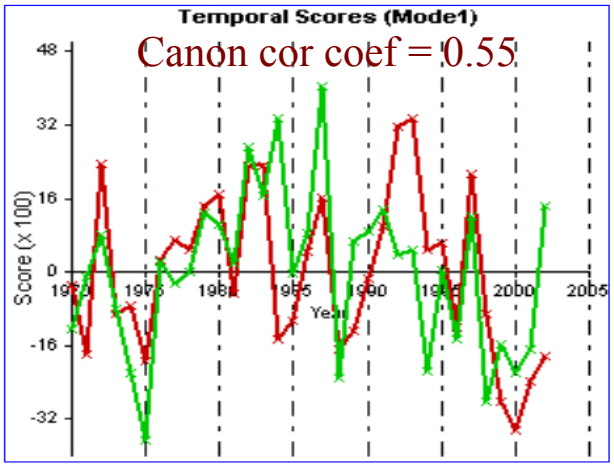




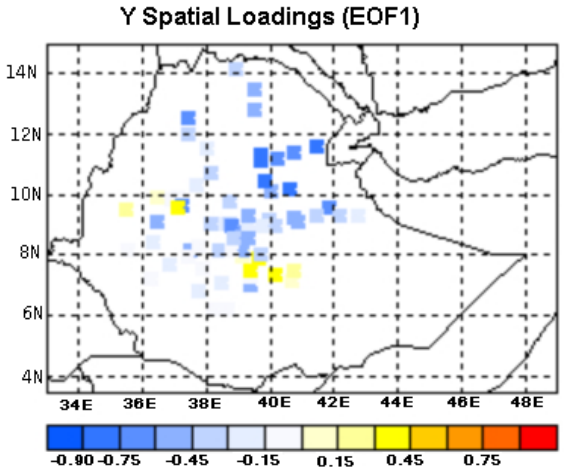
CCA using Climate Predictability Tool: 1 CCA mode only, using just 78 best stations



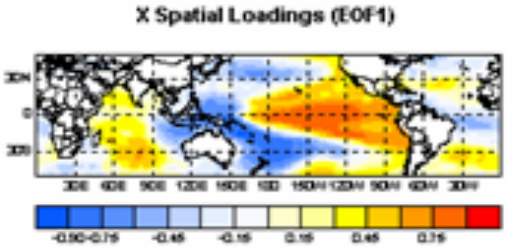
SST loadings,
May



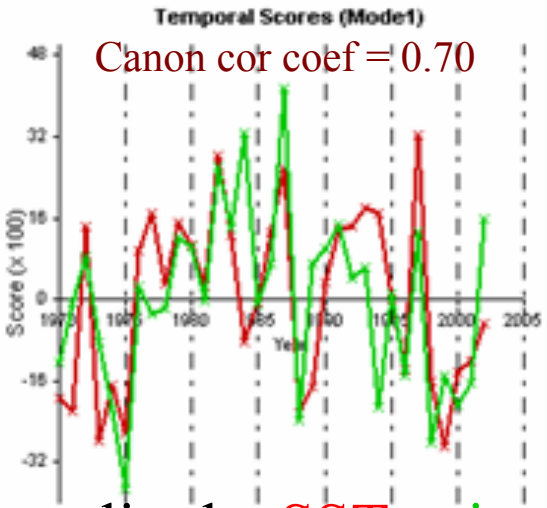
amplitude: SST, rain



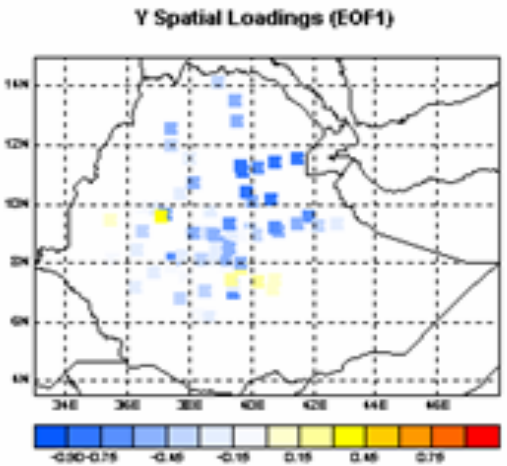
JJAS rainfall loadings



SST loadings,
JAS



amplitude: SST, rain



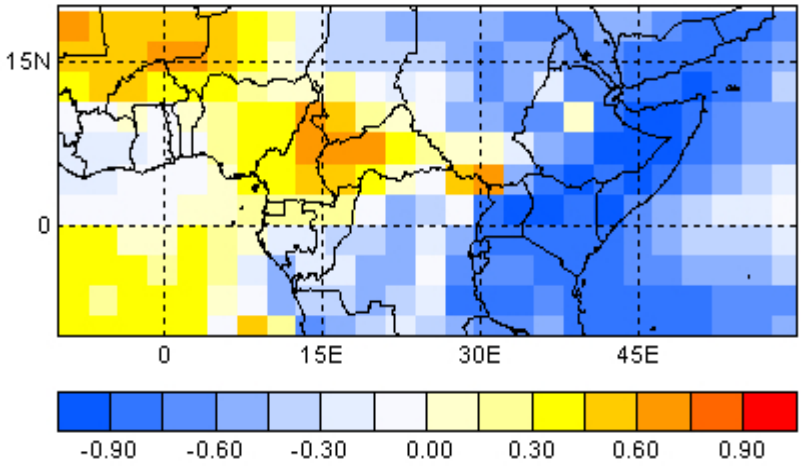
JJAS rainfall loadings

Dynamical model correction design:

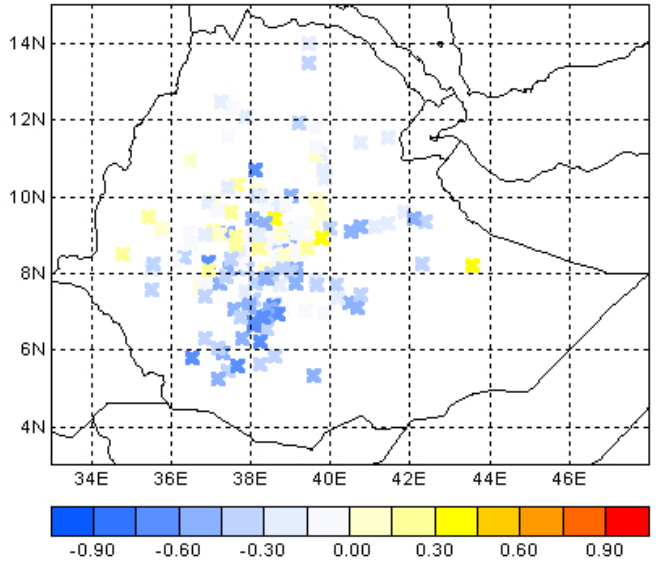
Mode 1 for JJAS station rainfall, using ECHAM4.5 AGCM rainfall forecast as predictor:

Pattern correction is slight, but local calibrations are noted.

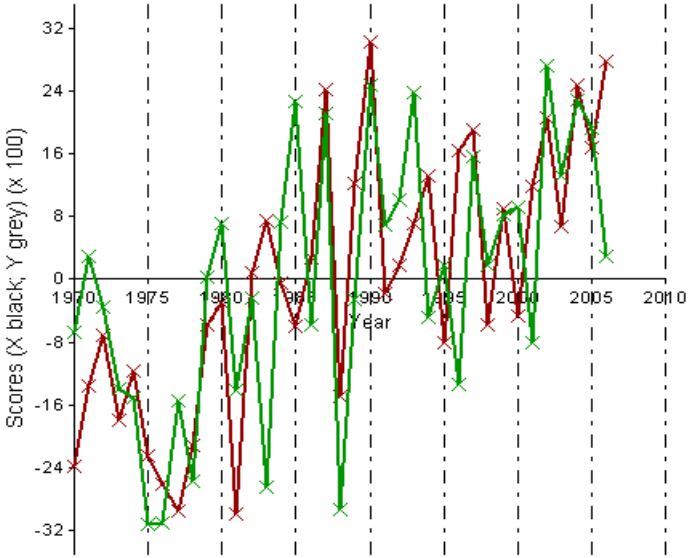
X Spatial Loadings (Mode1)



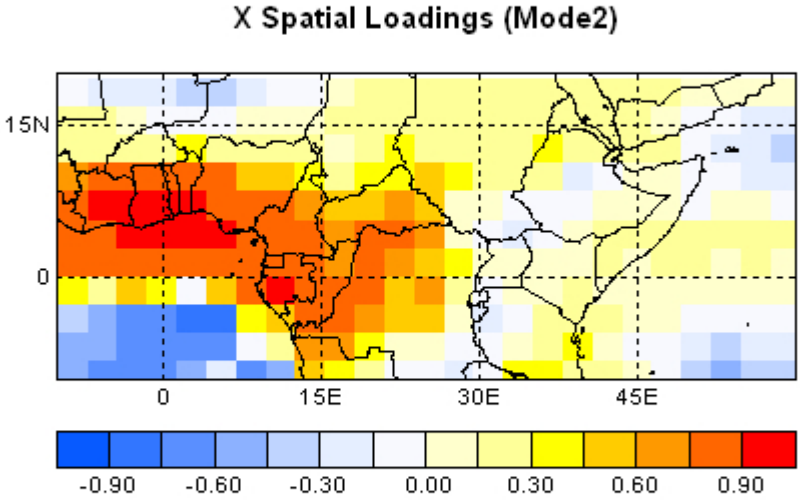
Y Spatial Loadings (Mode1)

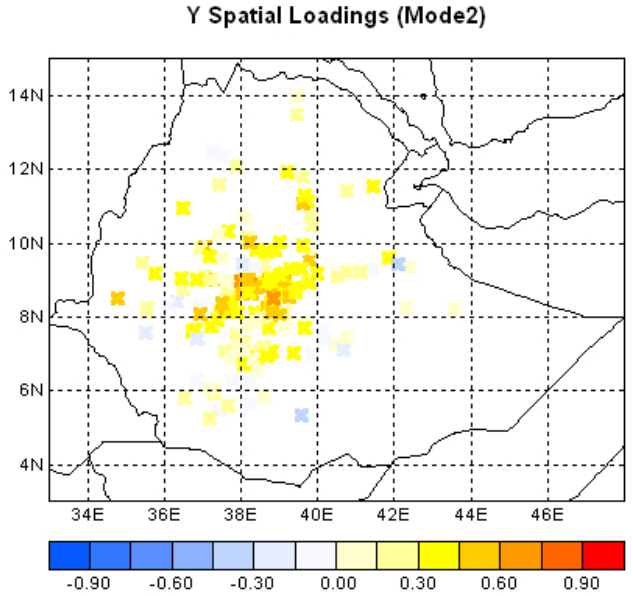


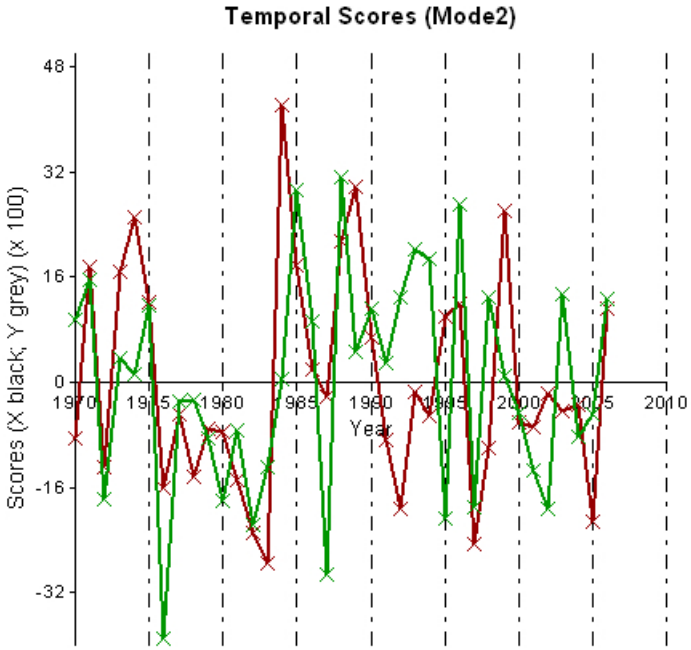
Temporal Scores (Mode1)

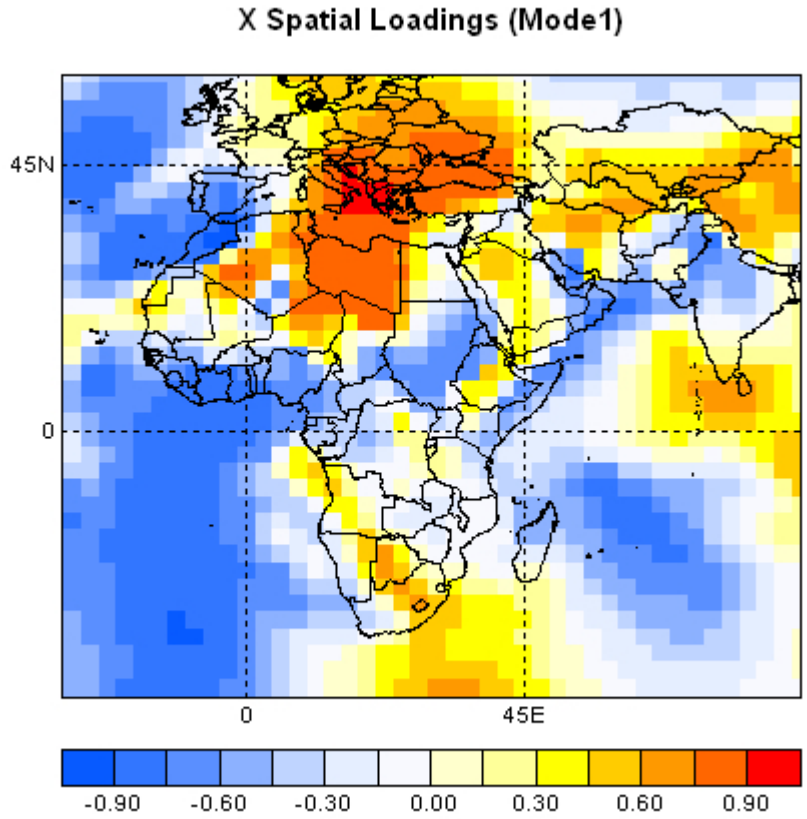


Dynamical model correction design:
Mode 2 for JJAS station rainfall, using ECHAM4.5 AGCM rainfall forecast as predictor:
Pattern correction is substantial, and local calibrations are also noted.

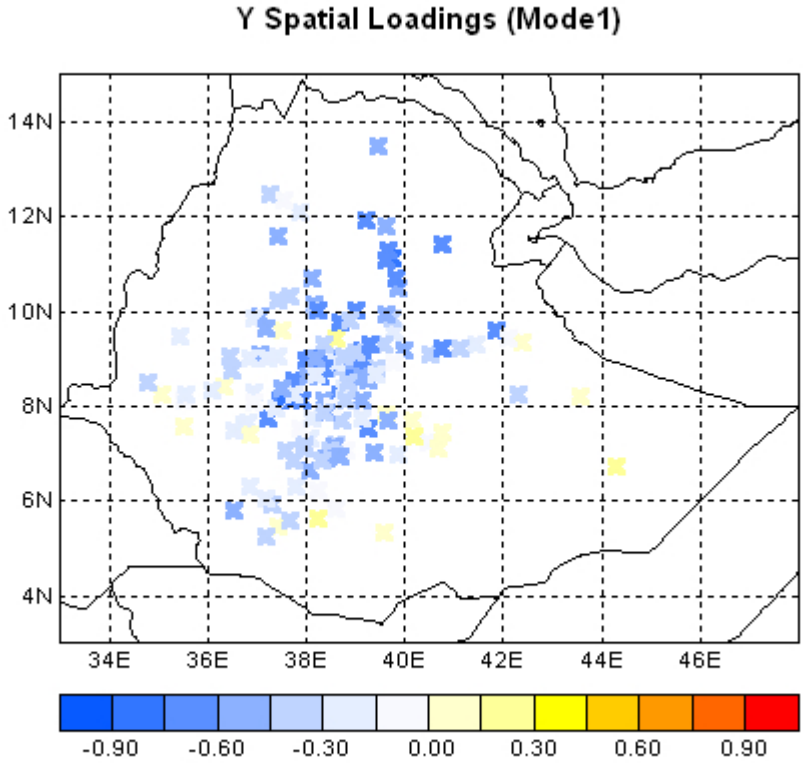


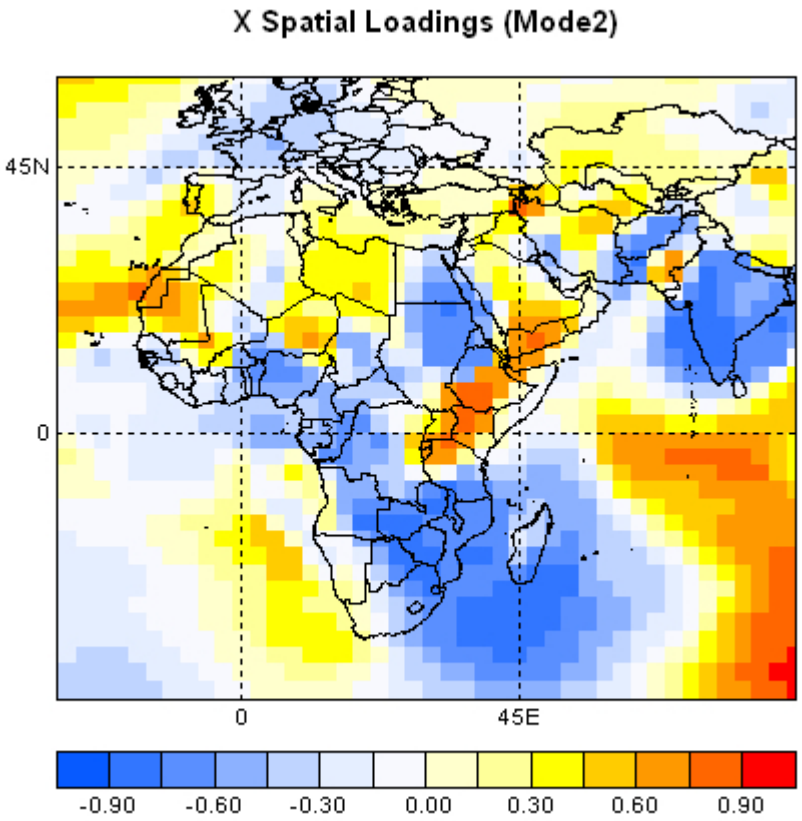




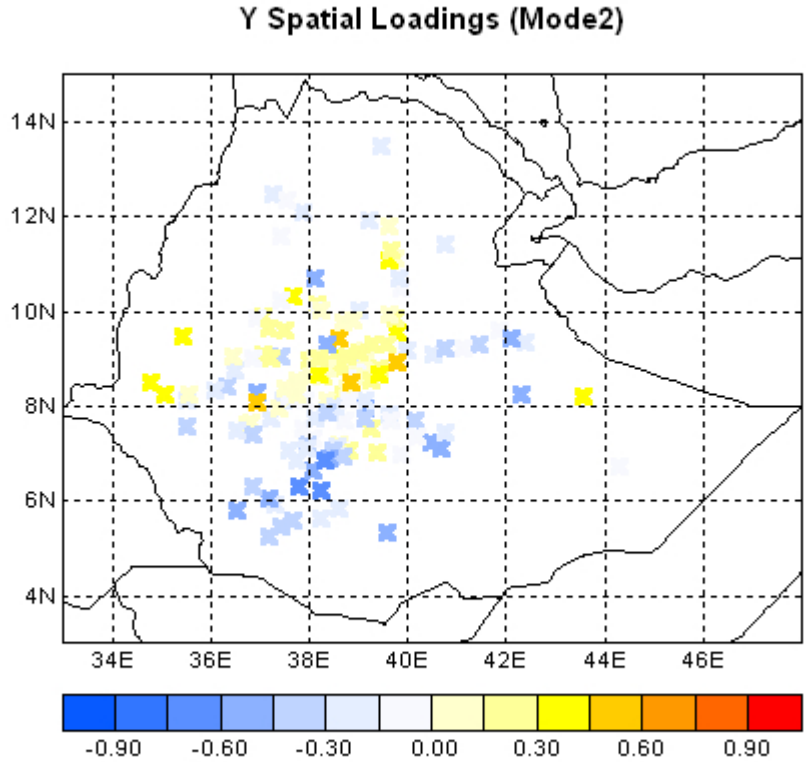


Dynamical model correction design:
Mode 1 for JJAS v-wind component, using ECHAM4.5 AGCM v-wind forecast as predictor:
Pattern correction is substantial, and local calibrations are also noted.



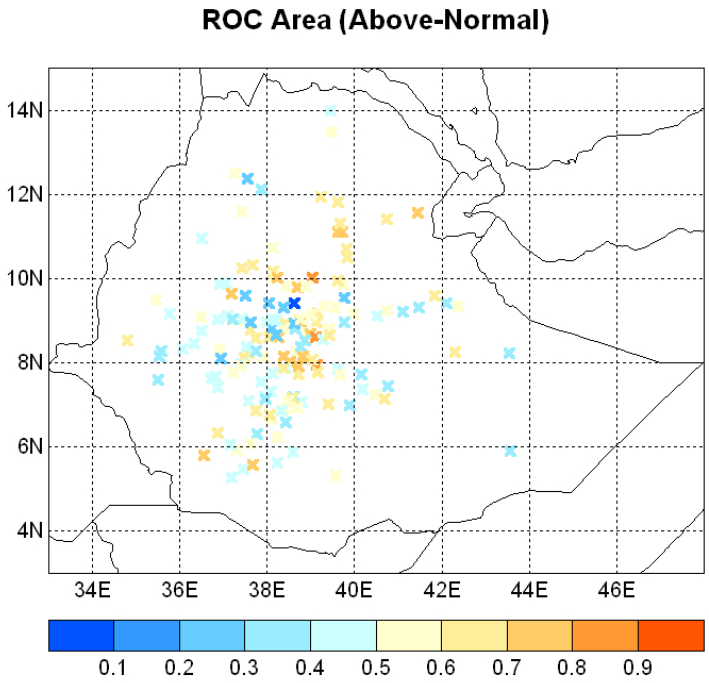


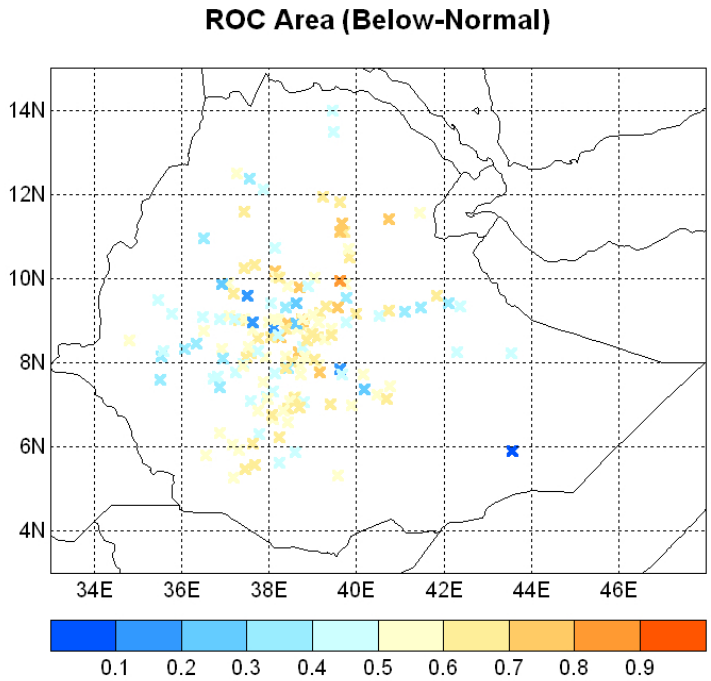
Dynamical model correction design:
Mode 2 for JJAS v-wind component, using ECHAM4.5 AGCM v-wind forecast as predictor:
Pattern correction is substantial, and local calibrations are also noted.

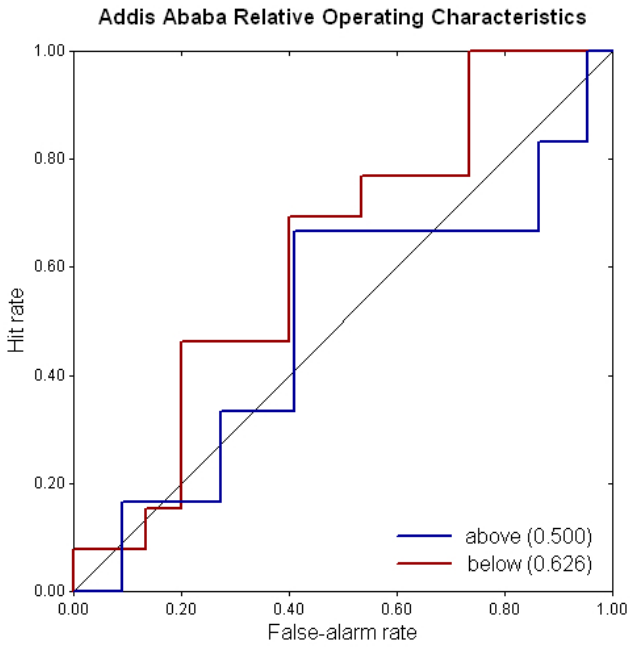


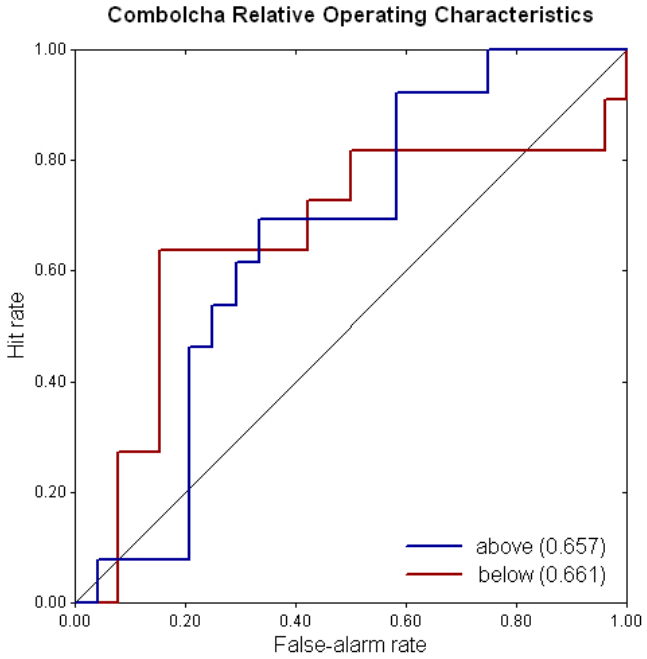
Skill map for JJAS rainfall using empirical (SST) design:

Area under Relative Operating Characteristics curve









ROC curves and ROC areas for four Ethiopia stations. Skill is modest but useful at some stations for certain tercile categories