

Interannual Variability in the Tropical Indian Ocean Simulated by NCEP Climate Forecast System

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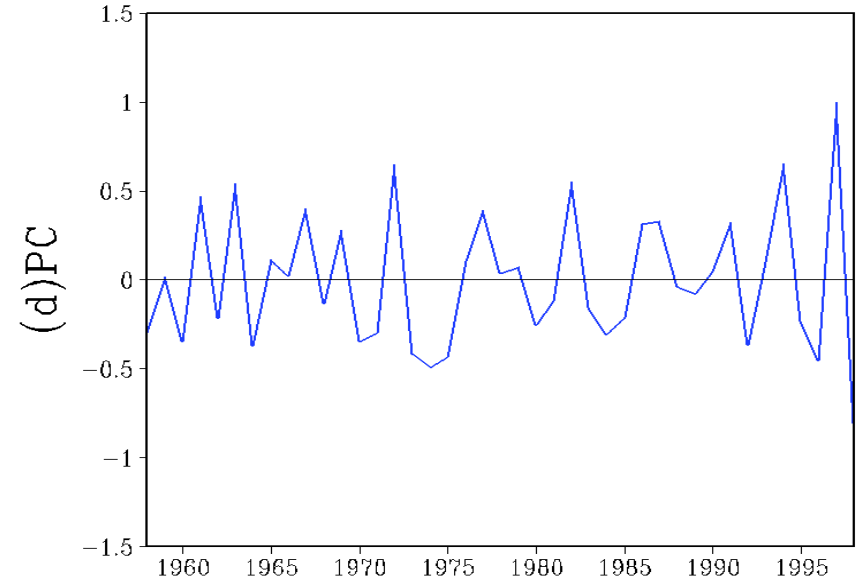
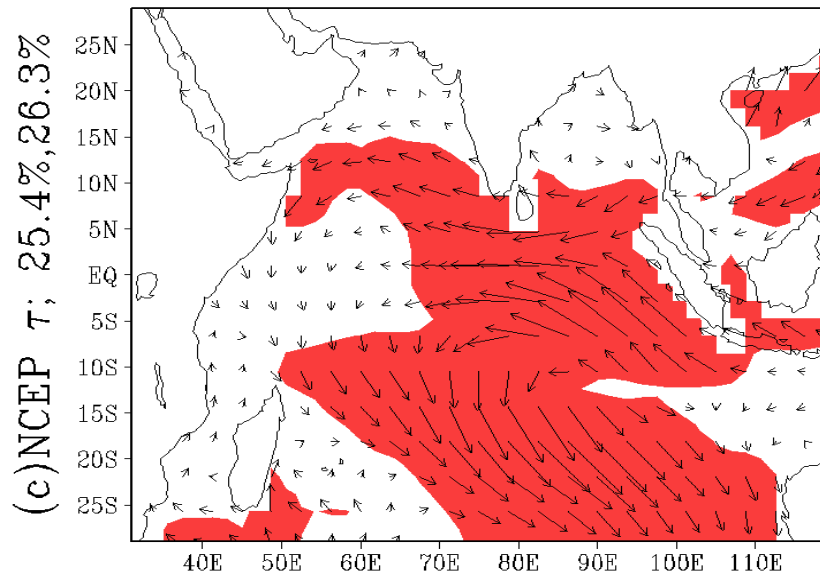
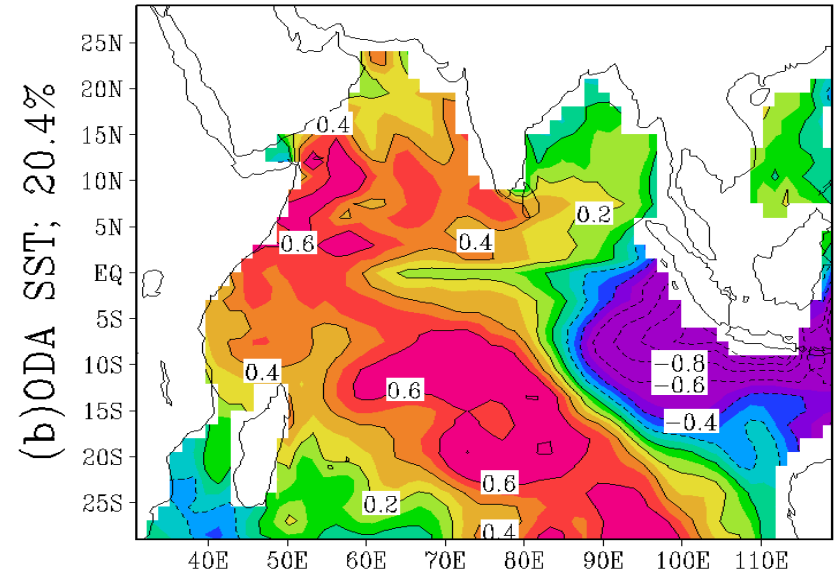
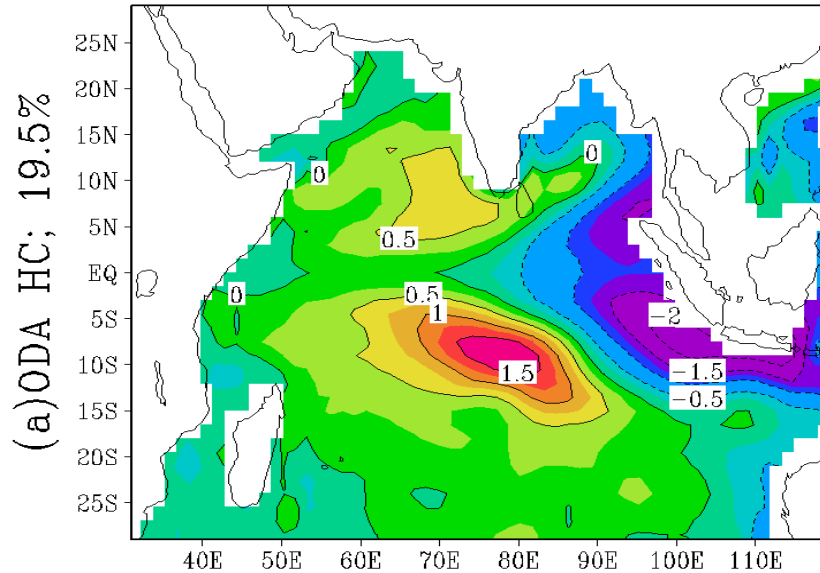
George Mason University, Virginia

Center for Ocean-Land-Atmosphere Studies, Maryland

Acknowledgments: J. Shukla, J. Kinter, Z. Wu, B. Kirtman

Indian Ocean Dipole Mode

Combined EOF, Mode 1, 22.3%, SON, 1958–1998



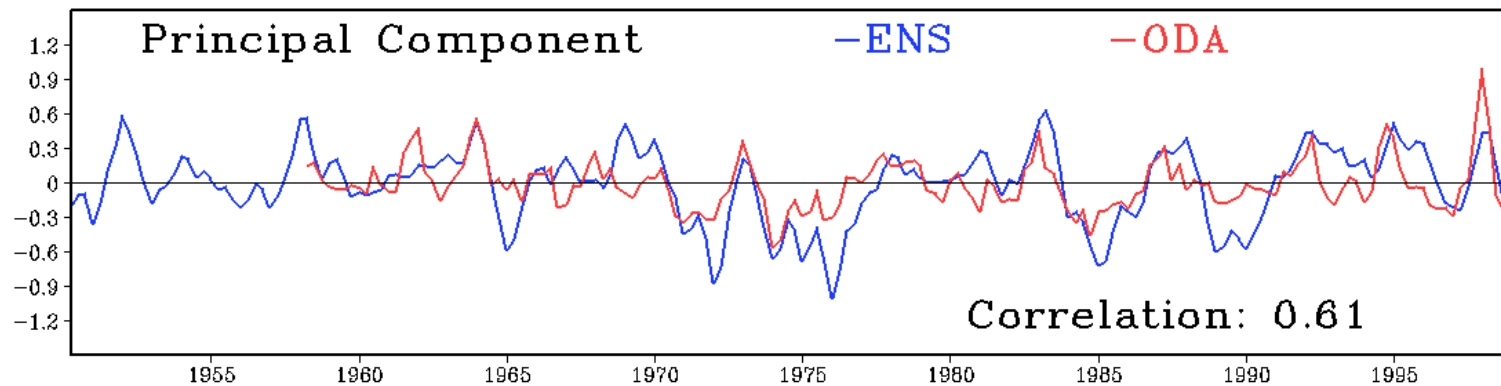
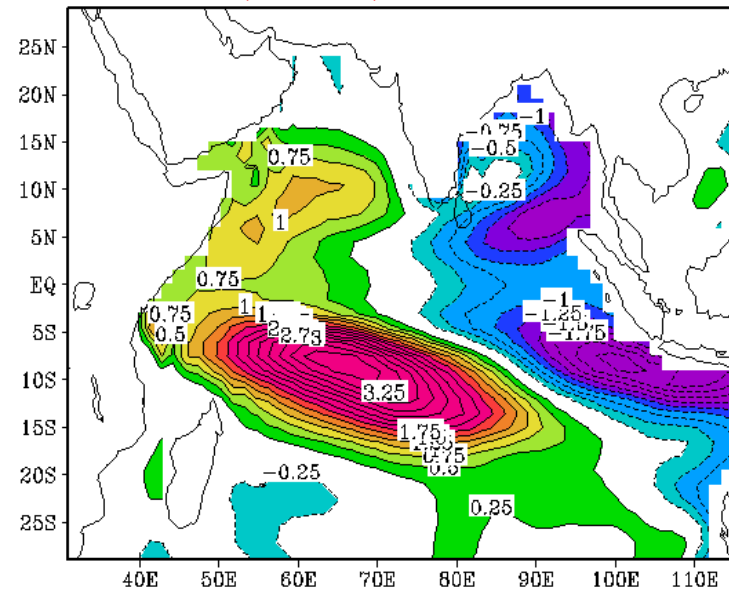
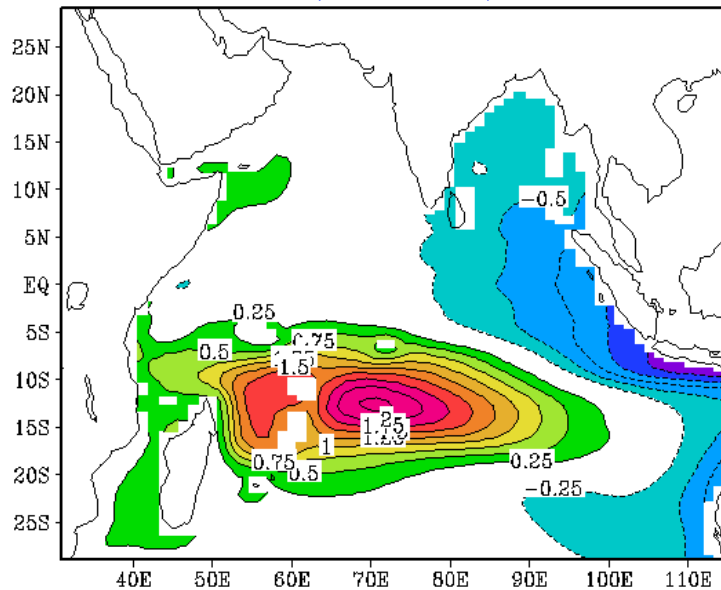
ENSO Effect: Indian Ocean

(Huang and Shukla 2007a, *J. Climate*)

9-case ensemble simulation forced with obs SST for 1950-1998
1st HCA EOF, CGCM & ODA

9-case Ens., 50.5%, 1950-1998

ODA, 18%, 1958-1998



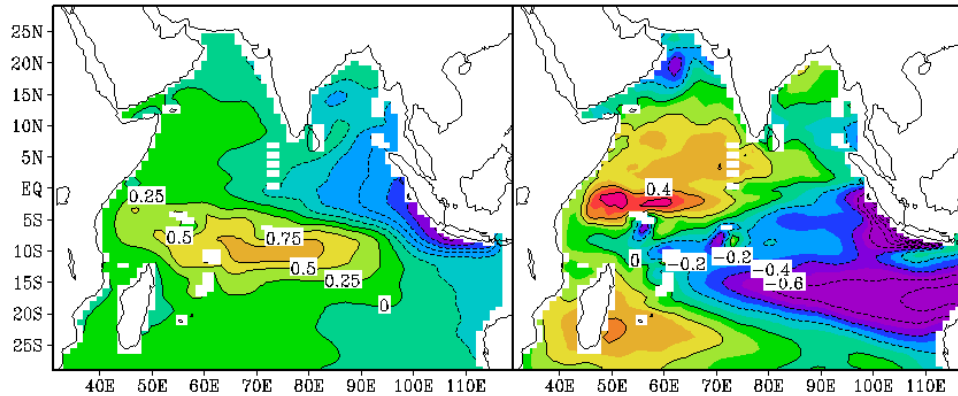
Intrinsic Modes in the Indian Ocean

(Huang and Shukla 2007b, *J. Climate*)

Combined EOF, CLIM, SON, Mode 1, 20.3%

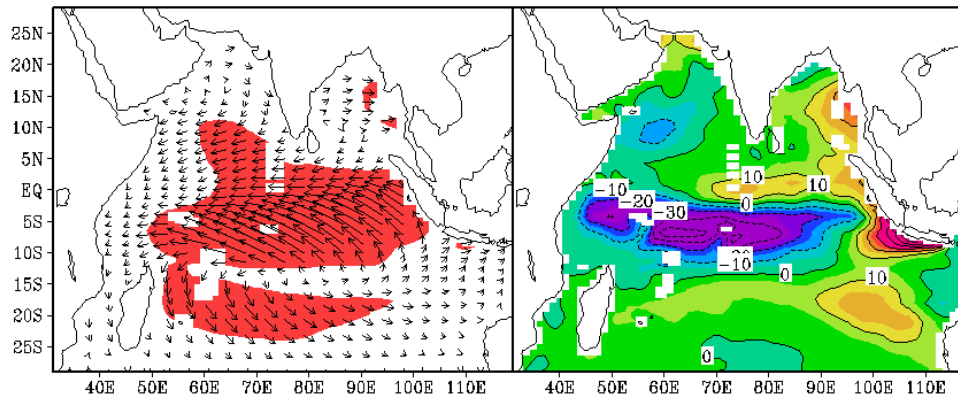
HC; 28.9%

SST; 15.8%

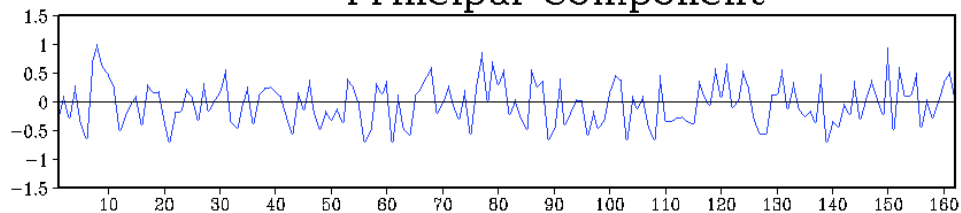


τ ; 25.8%, 15.2%

Heat Flux; 15.8%



0.05 → Principal Component



Questions

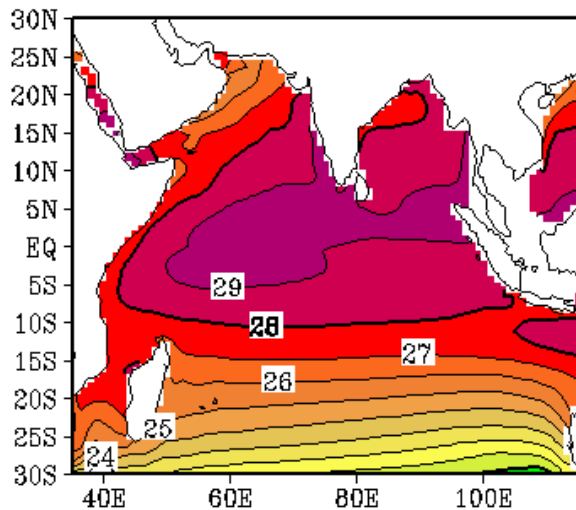
- How well do the current coupled ocean-atmosphere general circulation models (CGCM) simulate the ocean heat content (HC) variability in the Indian Ocean?
- What determines the time scales of the HC variability in the tropical Indian Ocean?

CGCM Simulations

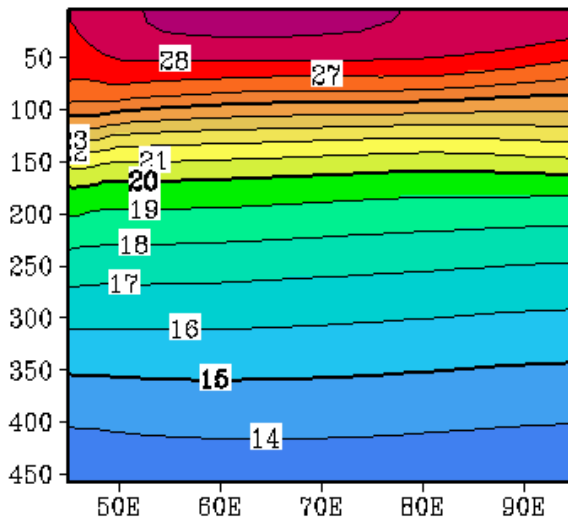
- **Climate Forecast System (CFS)**
 - **Atmosphere: GFS** (2003), T62 (~200 km), 64 sigma levels
 - **Ocean: MOM3**, 1°x1° (1/3° lat within 10°S-10°N), 40 levels, non-polar (70°S-65°N)
 - Daily coupling, 335-yr simulation
- **CCSM3.0**
 - **Atmosphere: CAM3**, T85, 26 levels
 - **Ocean: POP**, 1°x1° (~0.5°lat near equator), 40 levels
 - Daily coupling, 118-yr simulation

Ocean Temperature Climatology

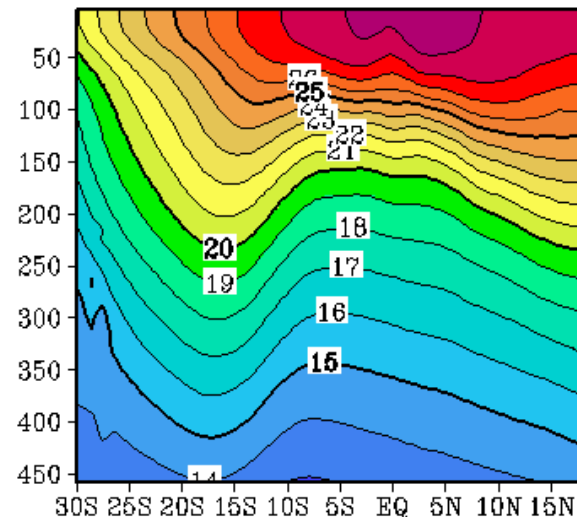
SST, CFS



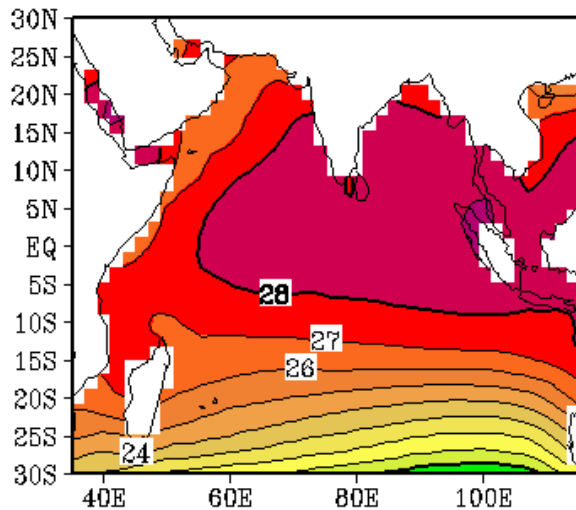
2°S–2°N, CFS



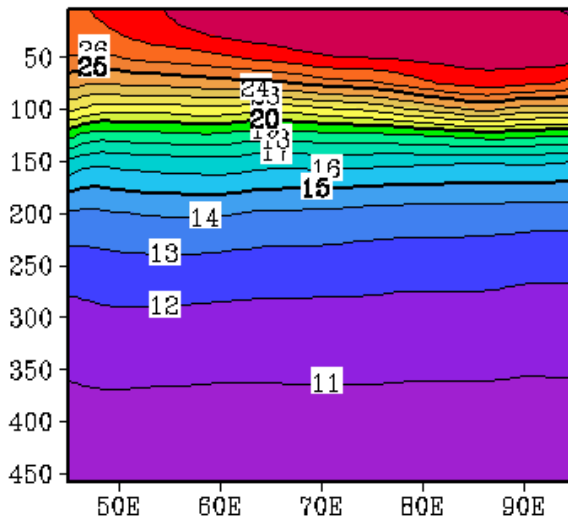
70°E, CFS



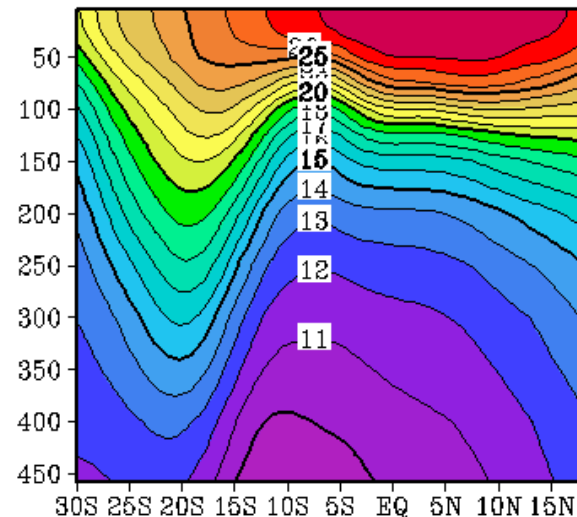
SST, CPC



2°S–2°N, WOA98

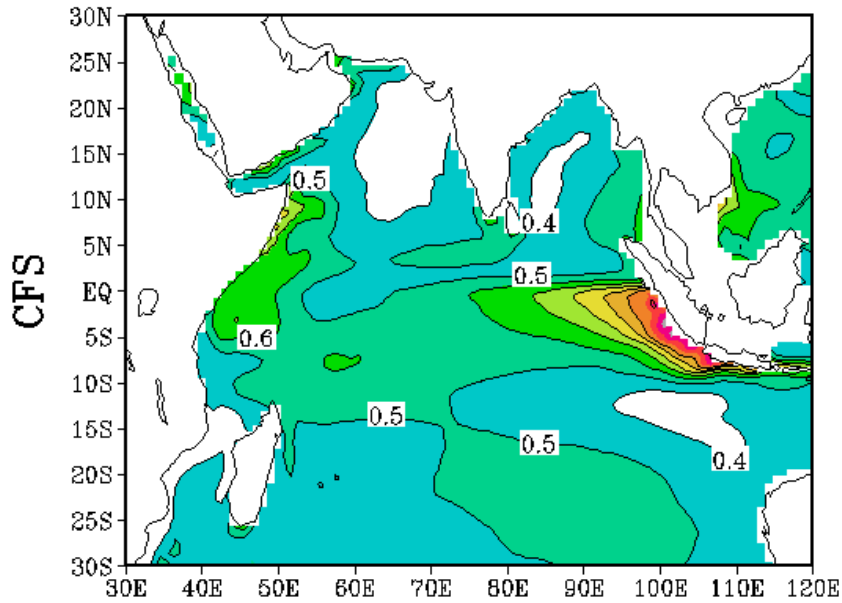


70°E, WOA98

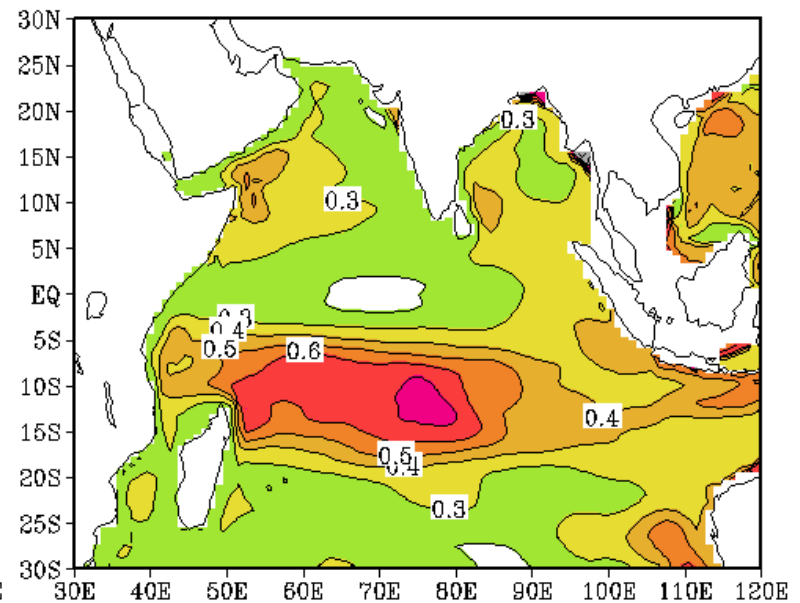
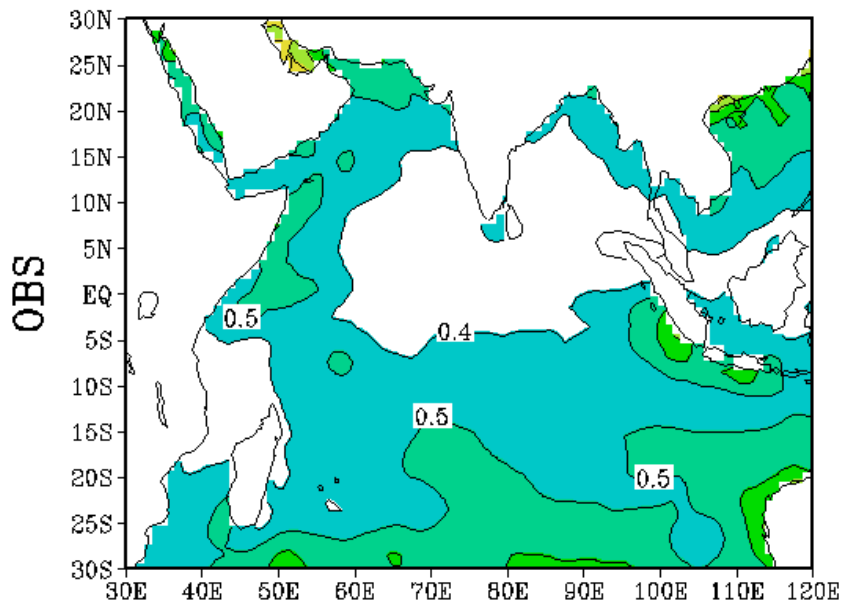
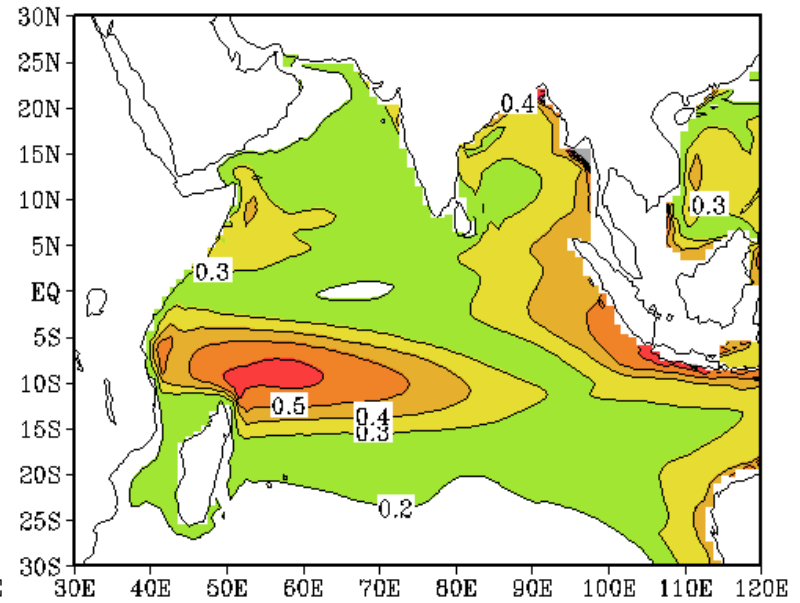


Standard Deviation

SSTA



HCA

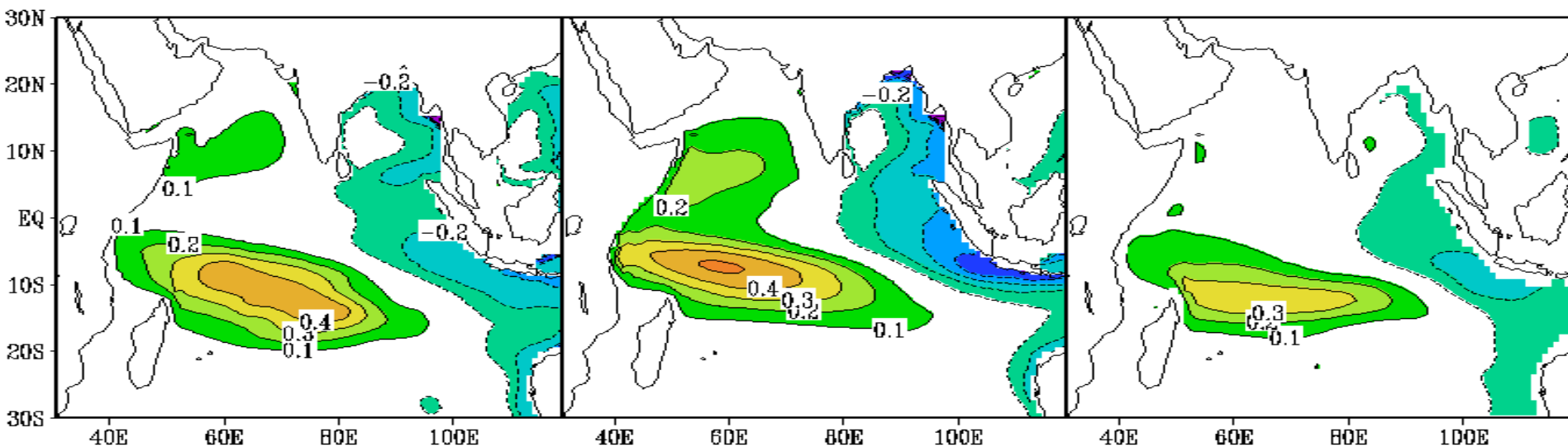


1st EOF Mode

GODAS, 17.4%

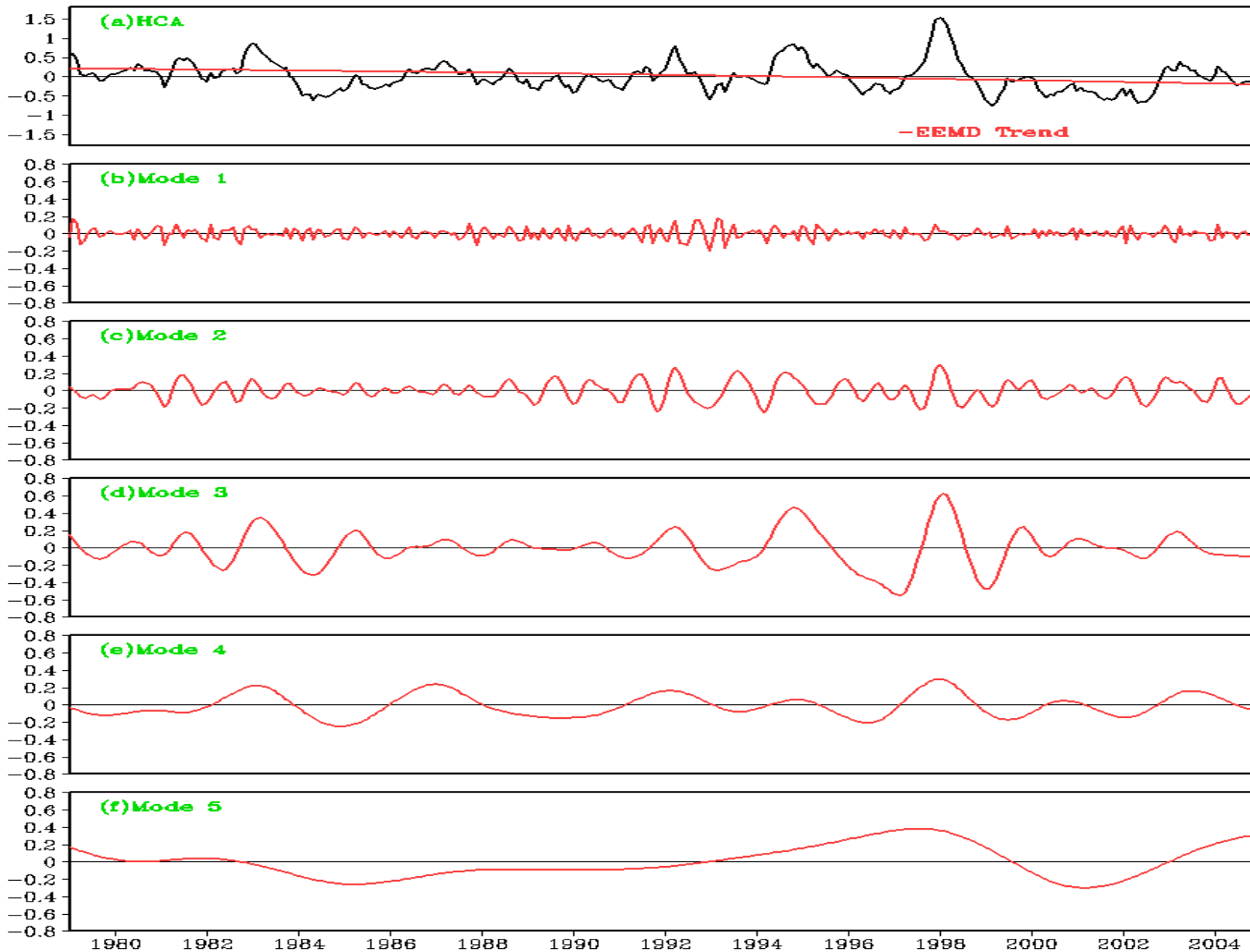
CFS, 31.3%

CSM, 17.4%



Ensemble Empirical Mode Decomposition

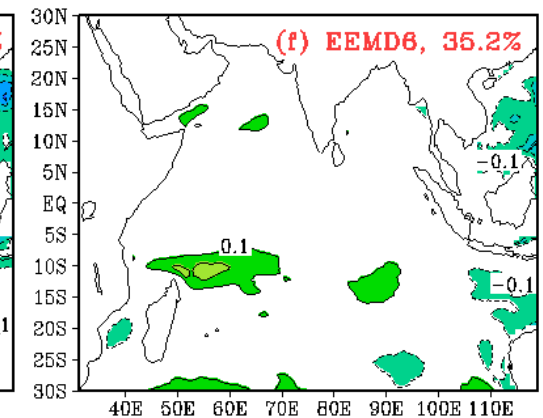
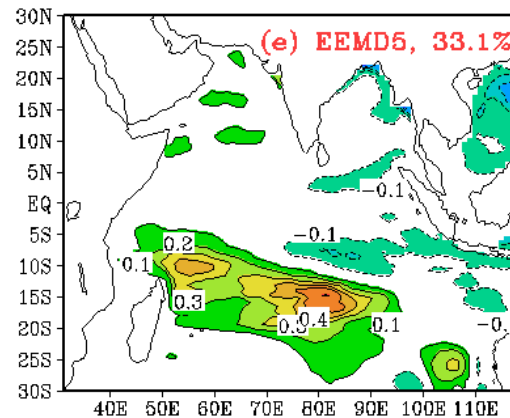
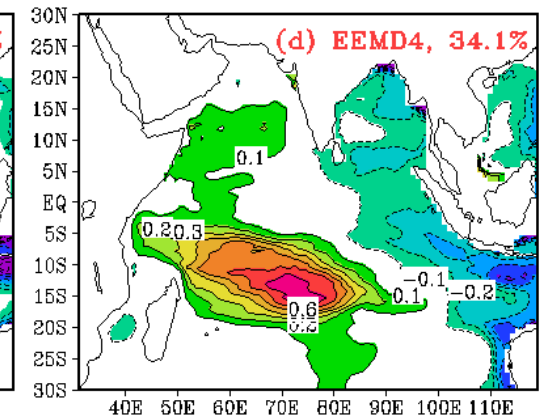
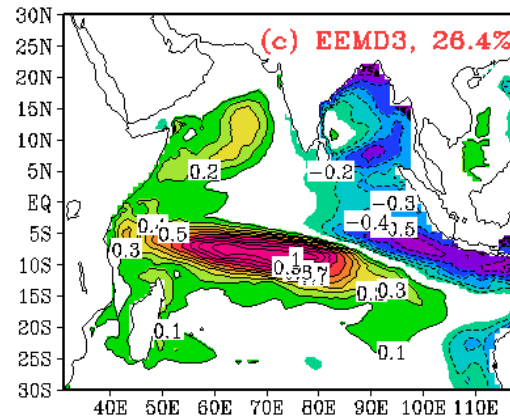
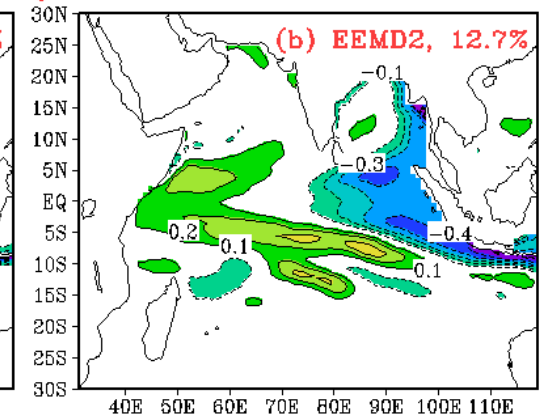
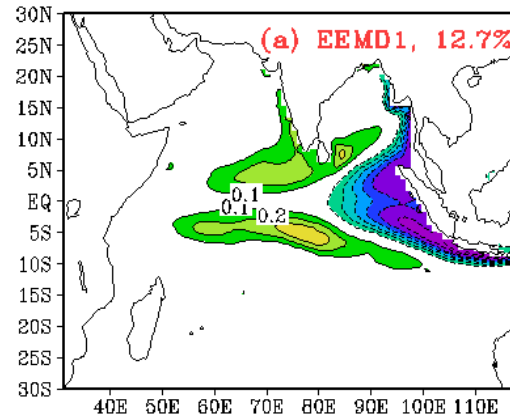
GODAS HCA (50°E–80°E, 5°S–15°S) & EEMD Modes



GODAS HCA, 1979–2004

1st EOFs of EEMD Modes

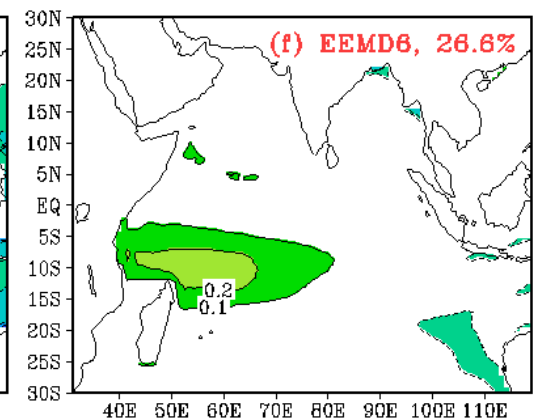
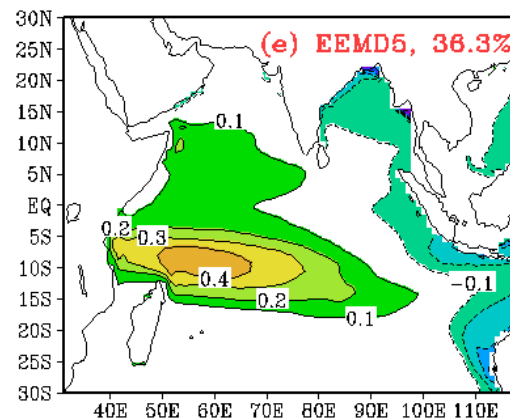
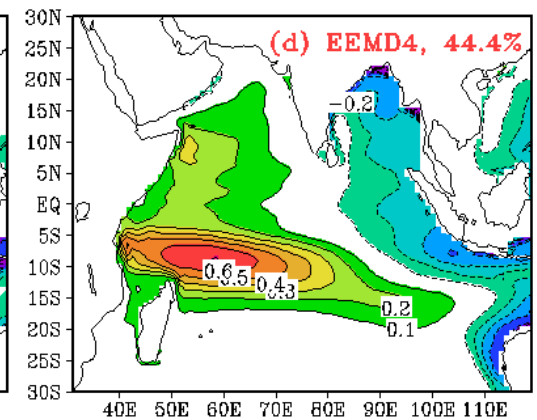
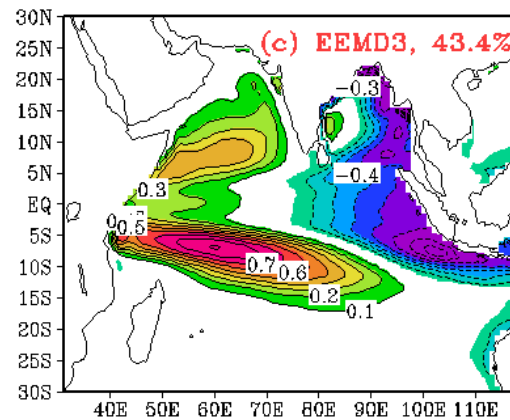
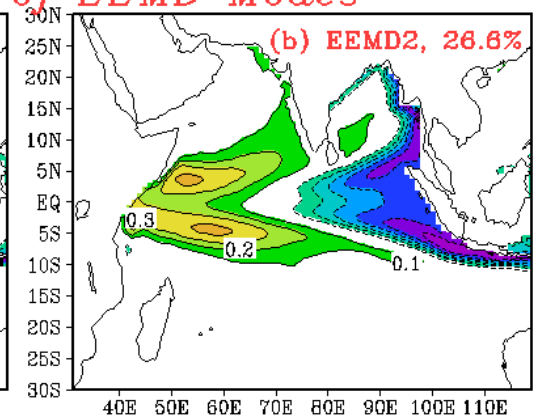
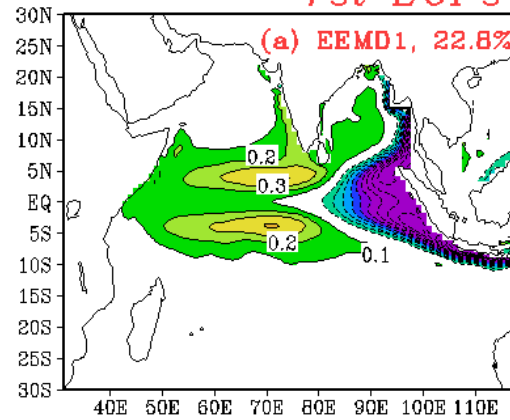
Apply
EEMD to
3-D Data



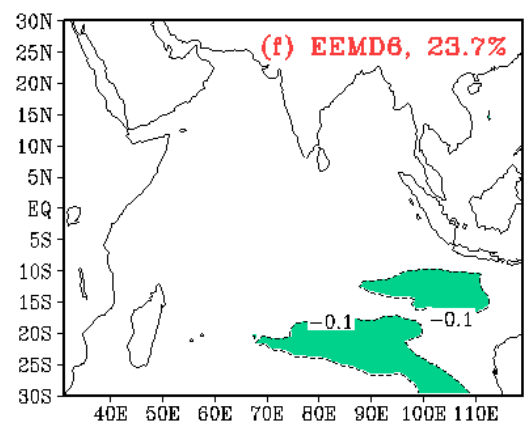
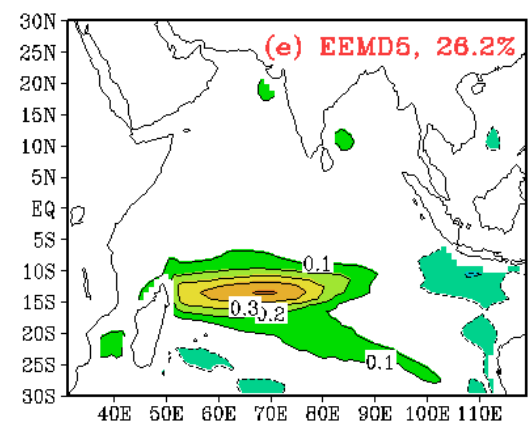
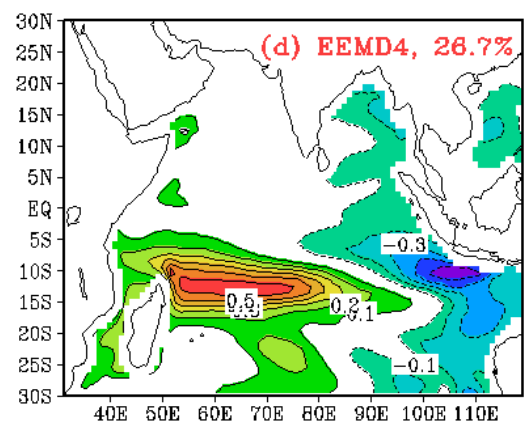
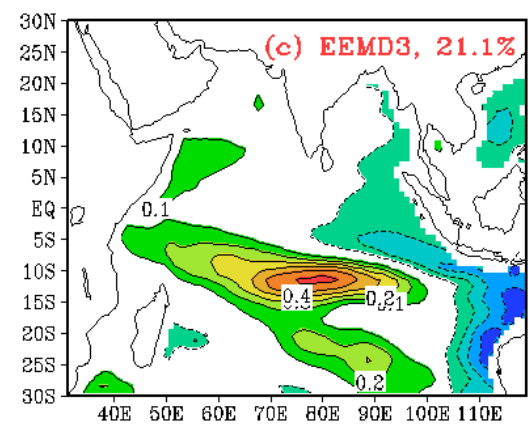
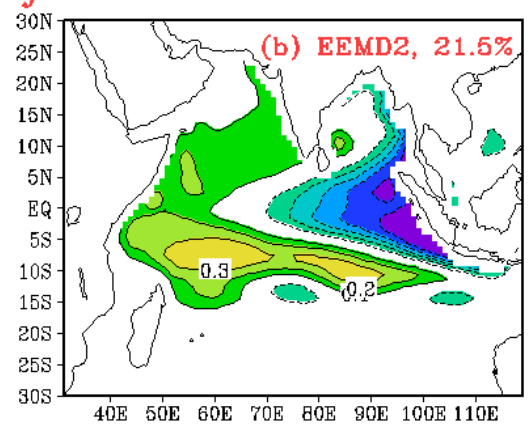
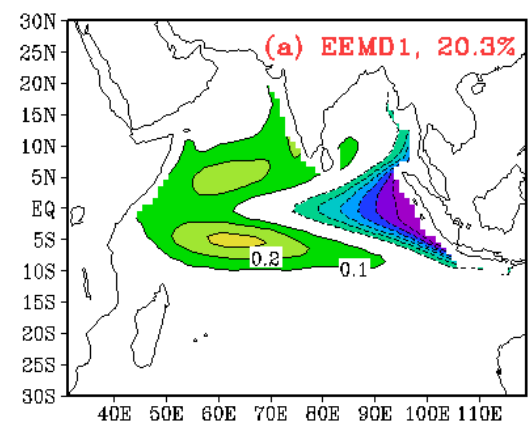
CFS HCA, 335-yrs

1st EOFs of EEMD Modes

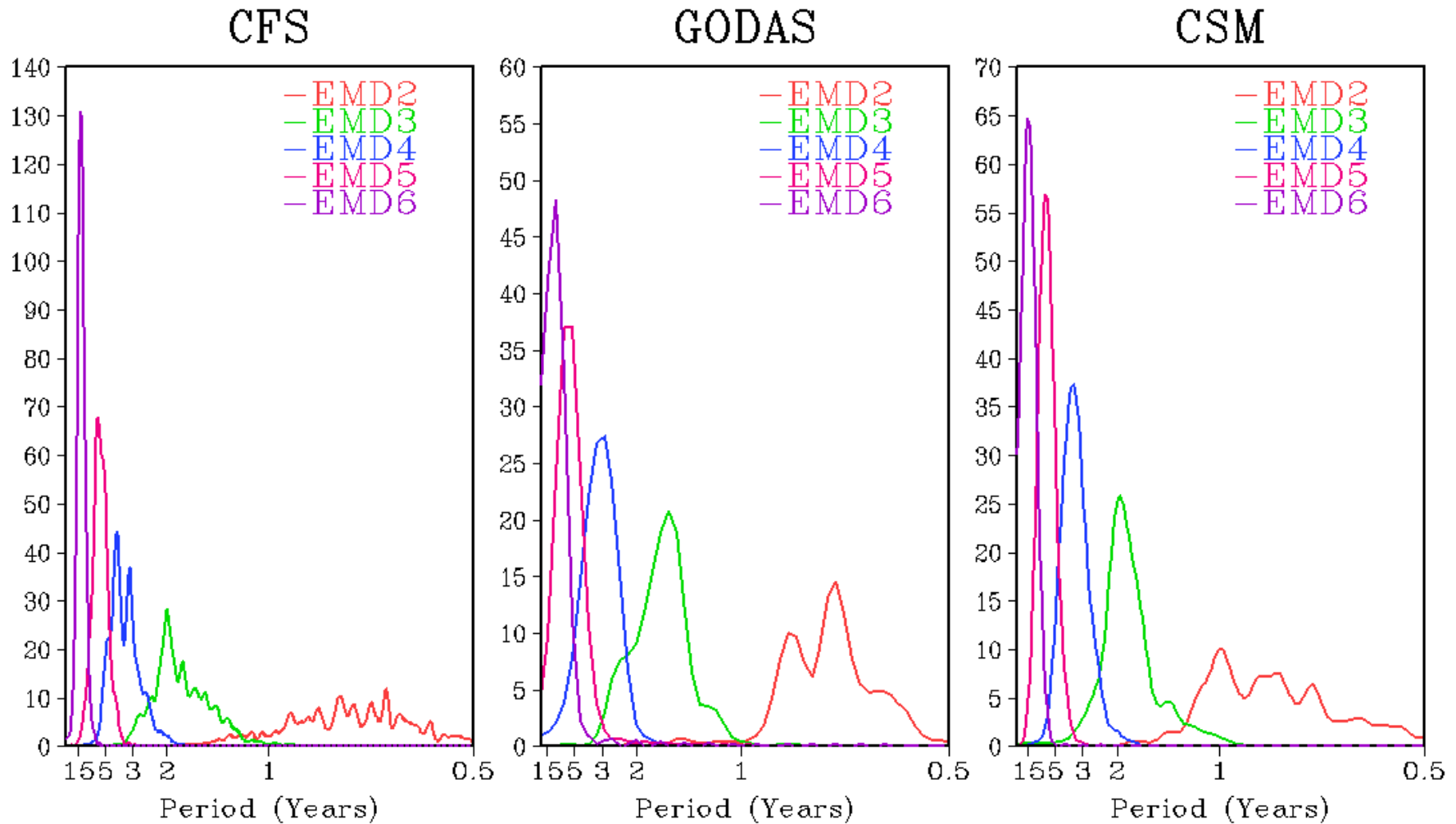
Apply
EEMD to
3-D Data



Apply
EEMD to
3-D Data



Power Spectrum of Principal Component



Sub-annual: EMD1-2
Interannual: EMD3-4

Low-frequency: EMD 5-6

Looking for Propagating Modes

- **Frequency bands:**

- Sub-annual: EEMD1-2
- Interannual: EEMD3-4
- Low-frequency: EEMD5-6

- **Method:**

- Multi-channel singular spectrum analysis
- Phase composite

Composite HCA & τ

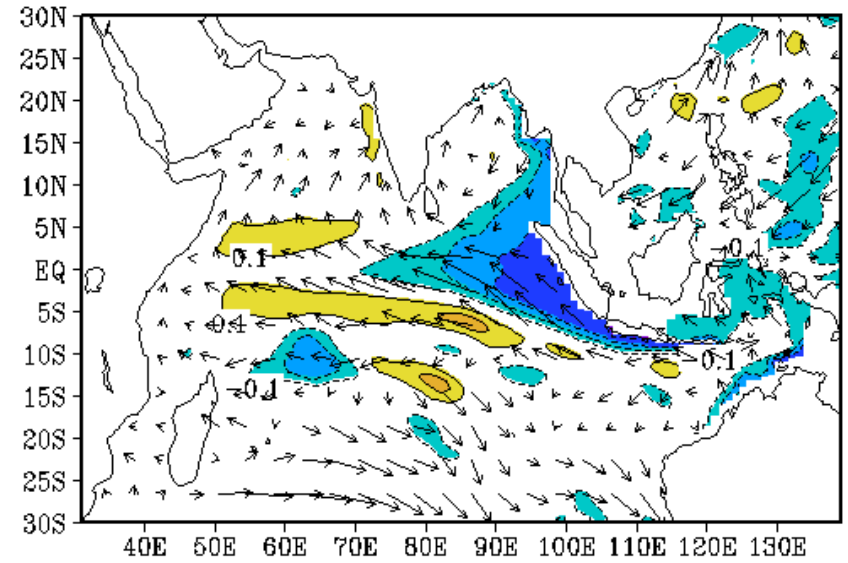
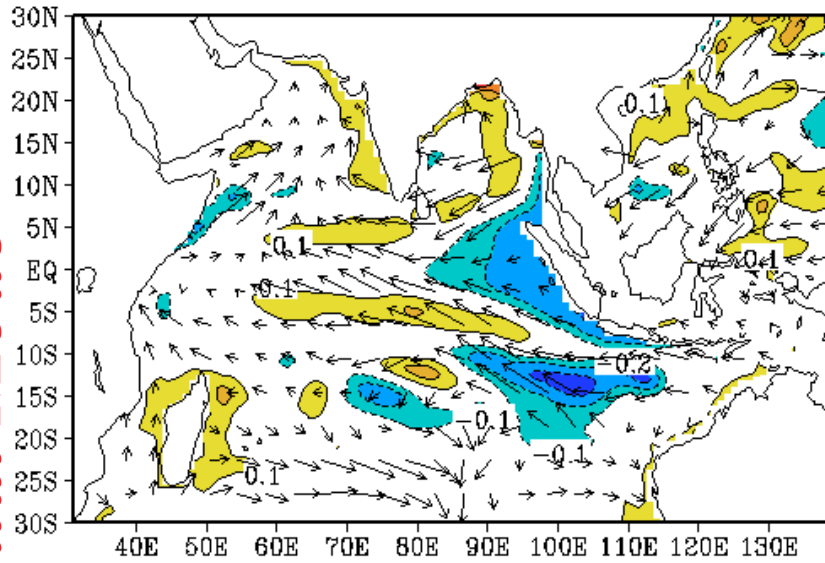
GODAS 1979-2004

Phase I

→
0.2

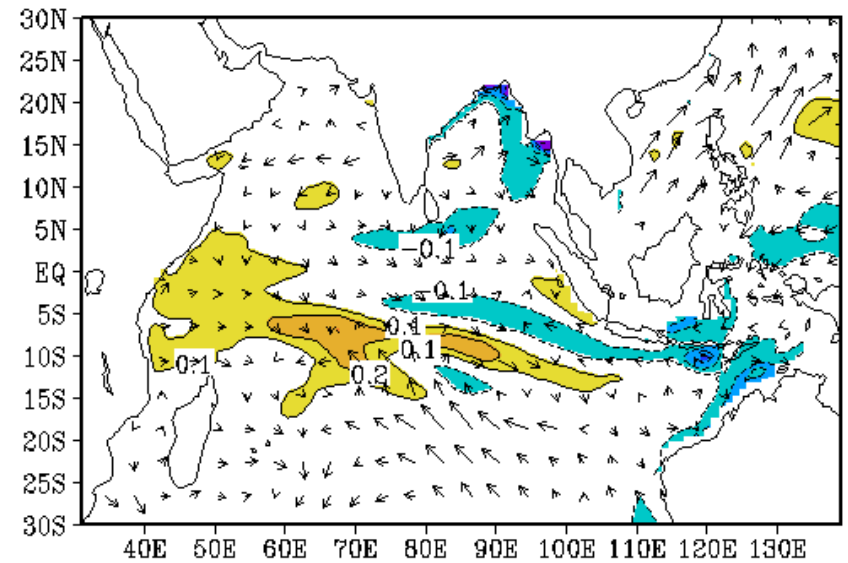
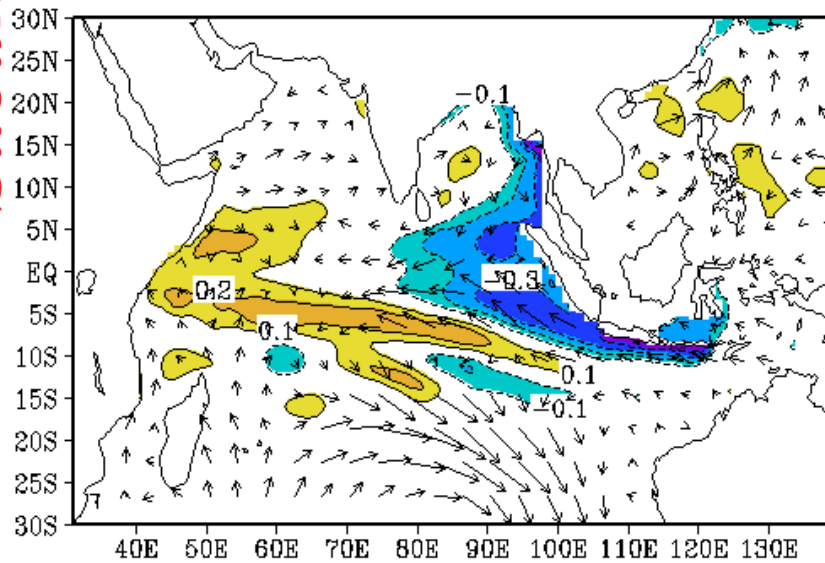
Phase II

Subannual Mode



Phase III

Phase IV



Composite HCA & τ

CFS, 335-years

Phase I

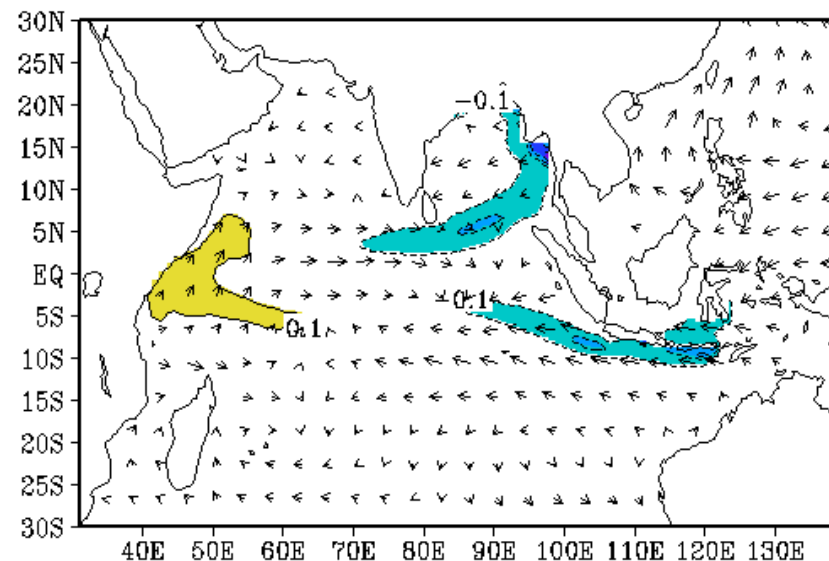
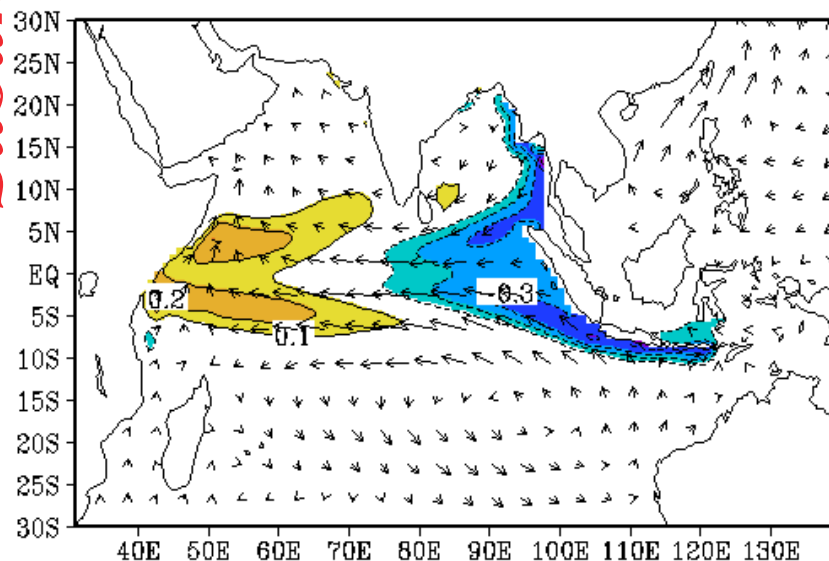
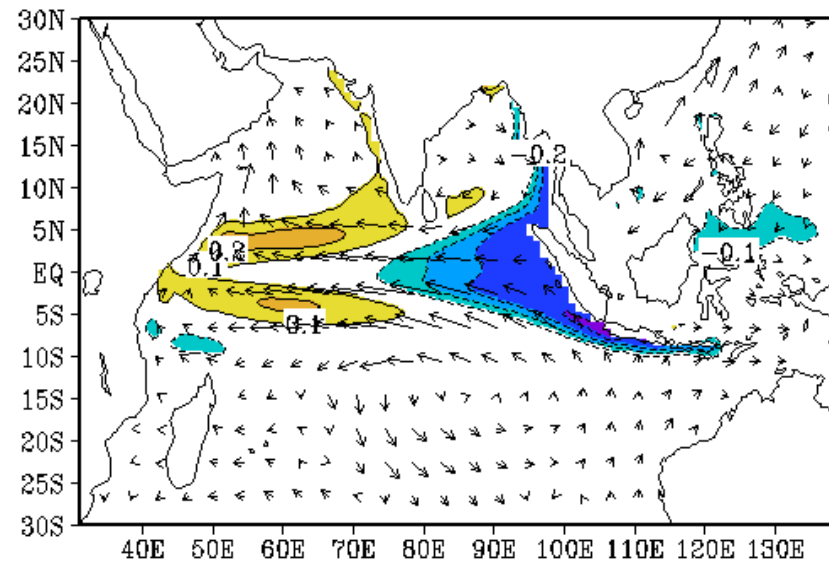
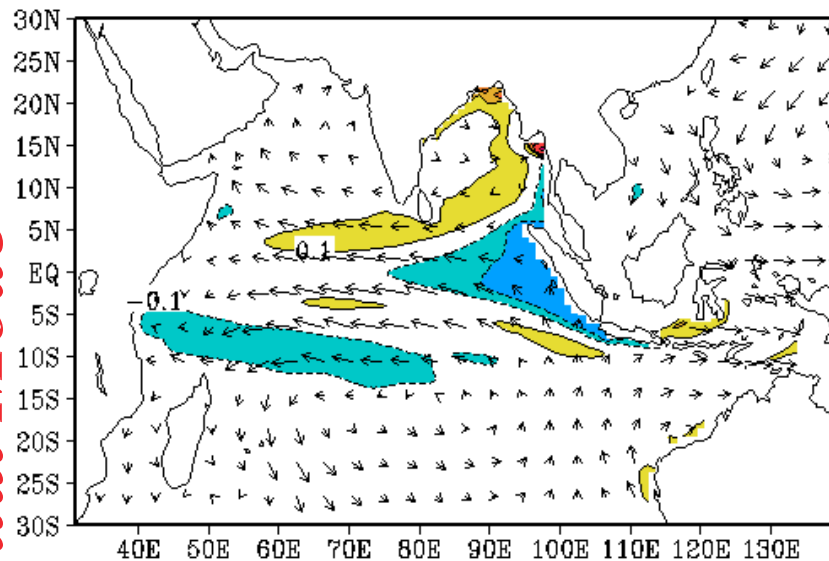
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Phase II

Phase III

Phase IV

Subannual Mode

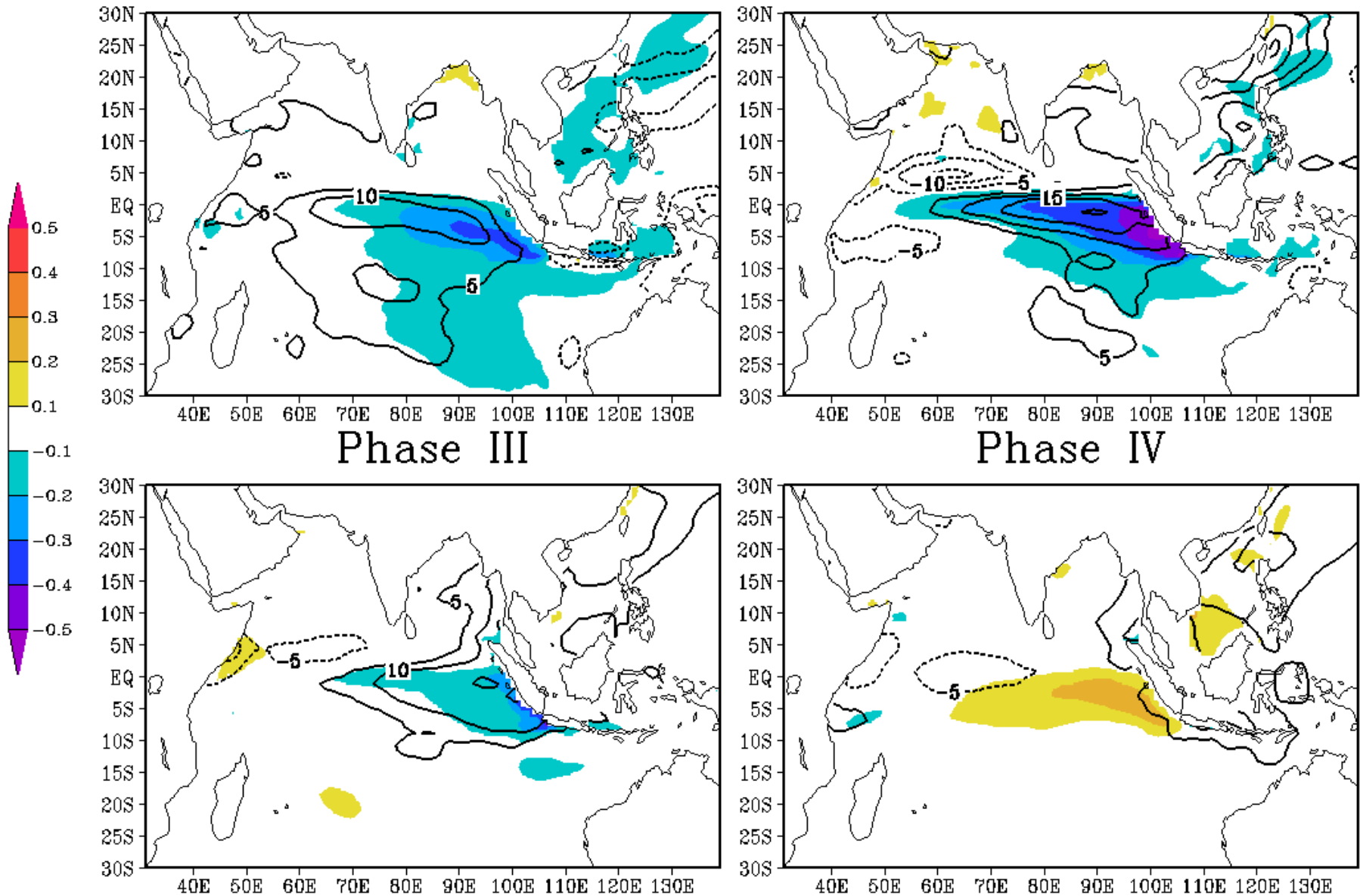


SHF (contour) & SST (shading)

CFS, 335-years

Phase I

Phase II



Composite HCA & τ

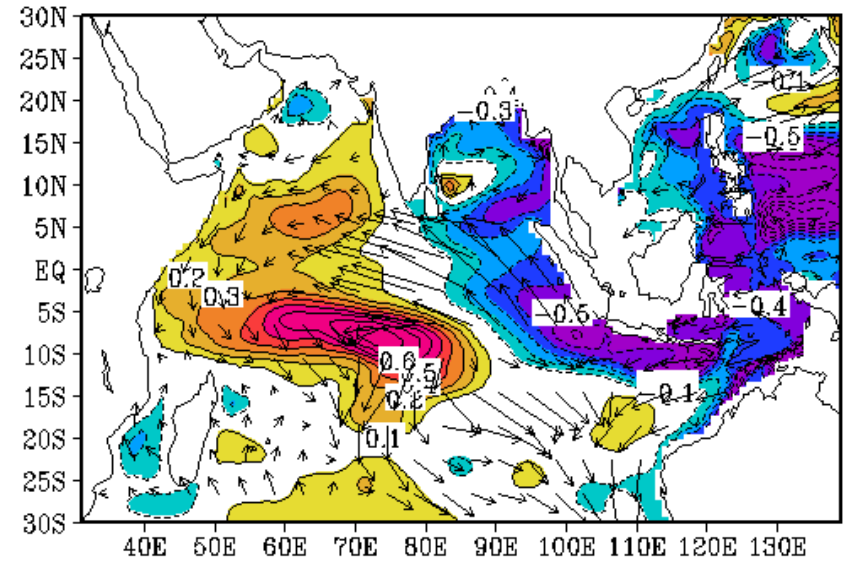
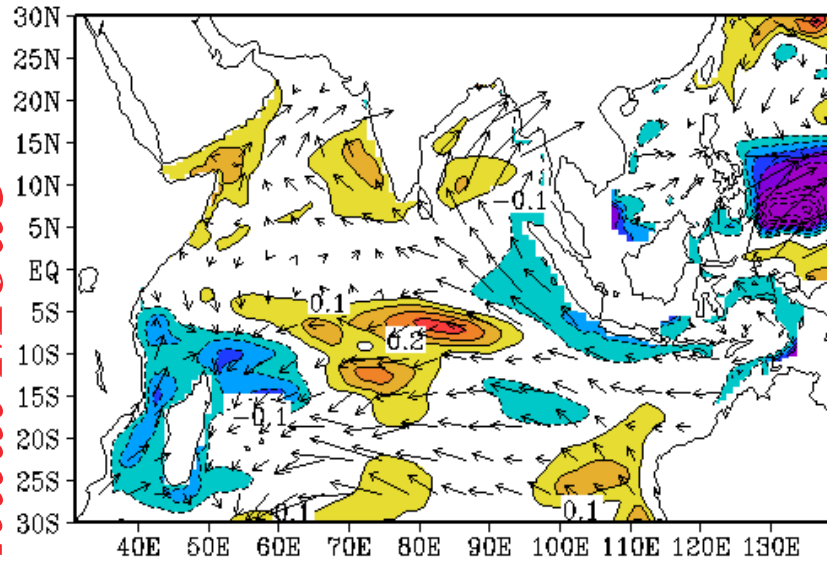
GODAS 1979-2004

Phase I

→
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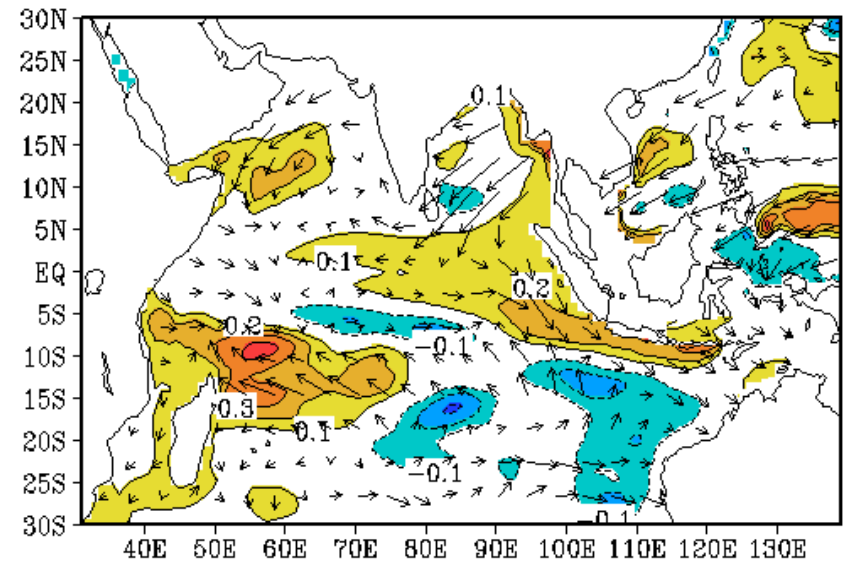
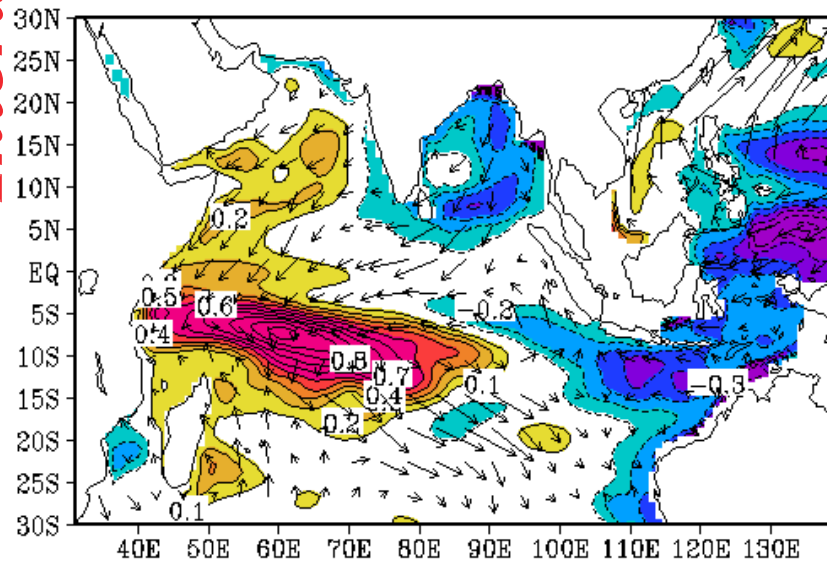
Phase II

Interannual Mode



Phase III

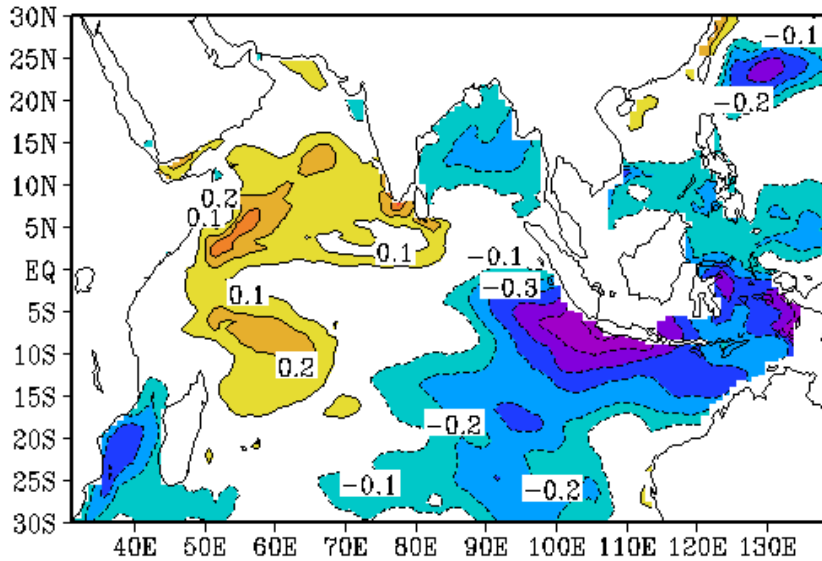
Phase IV



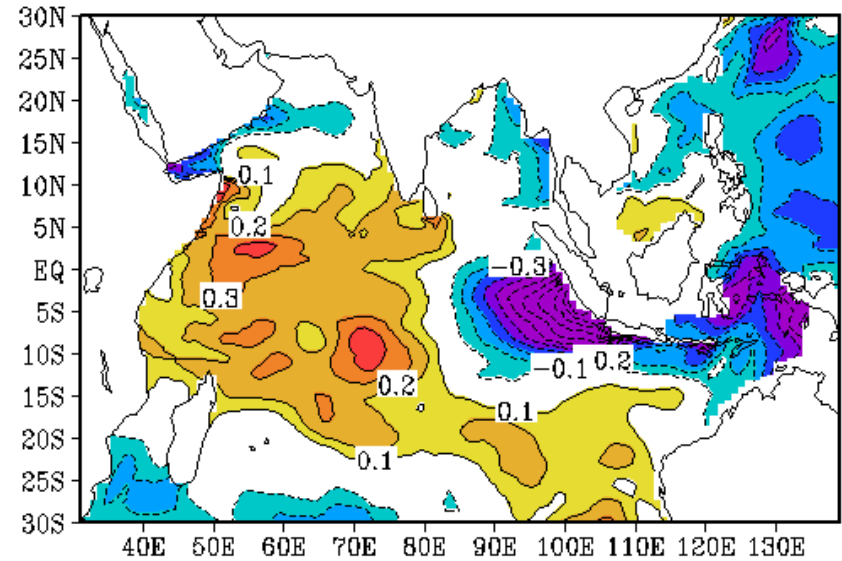
SSTA Composite

GODAS 1979-2004

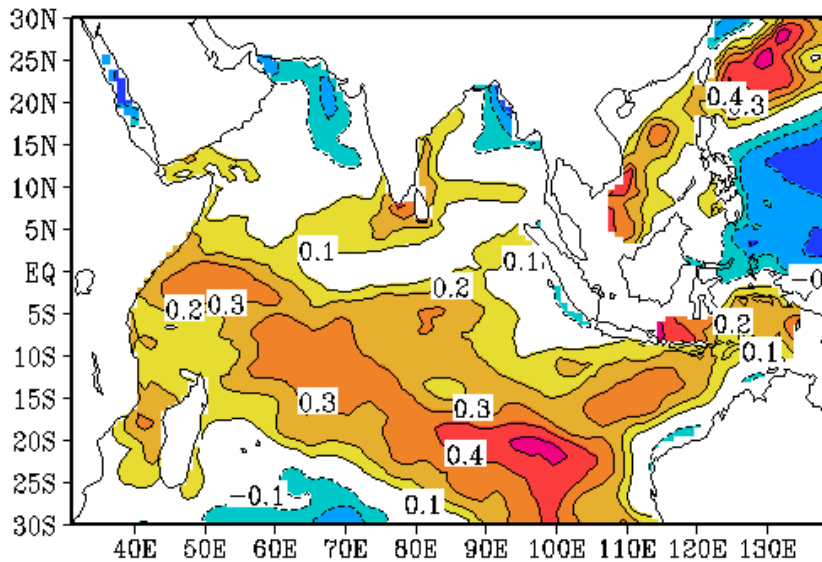
Phase I



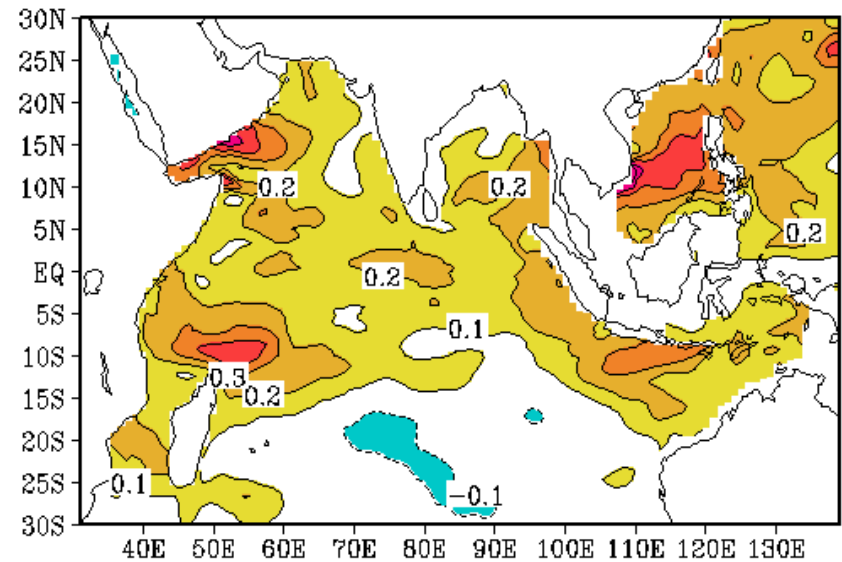
Phase II



Phase III



Phase IV



Composite HCA & τ

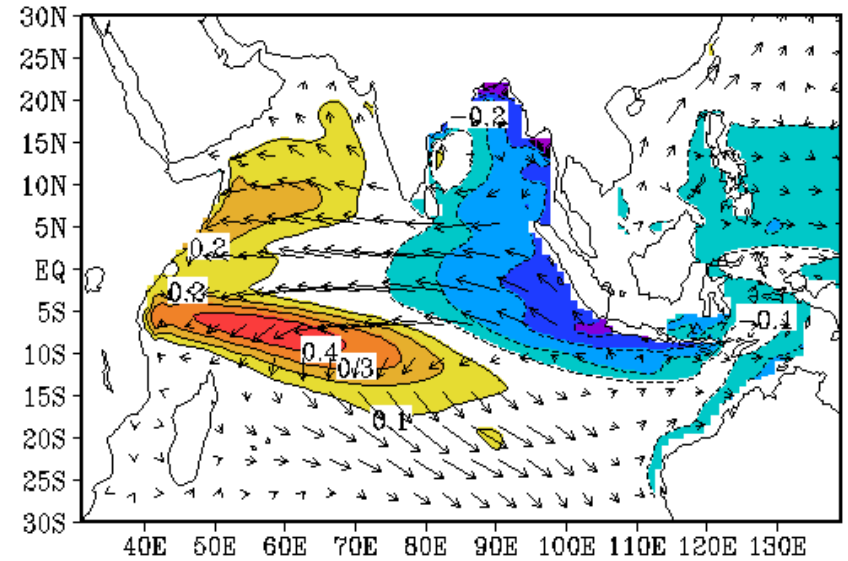
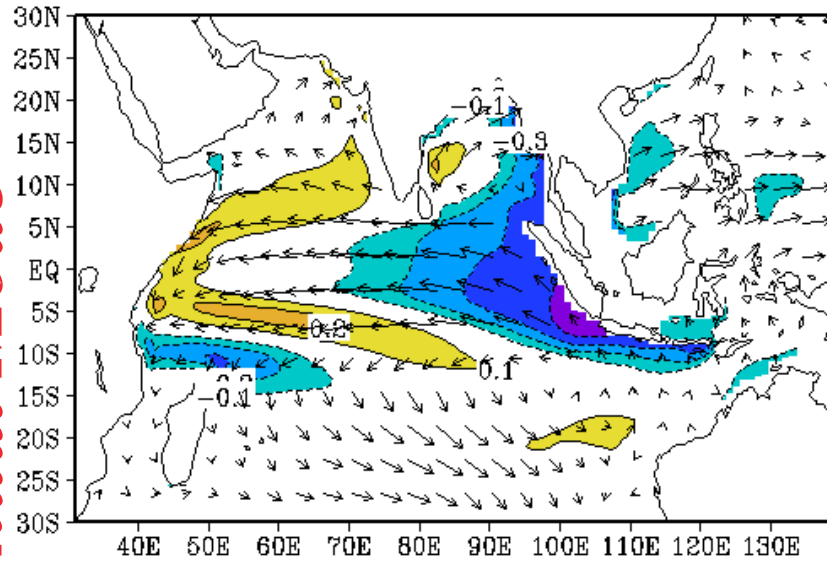
CFS, 335-years

Phase I

→
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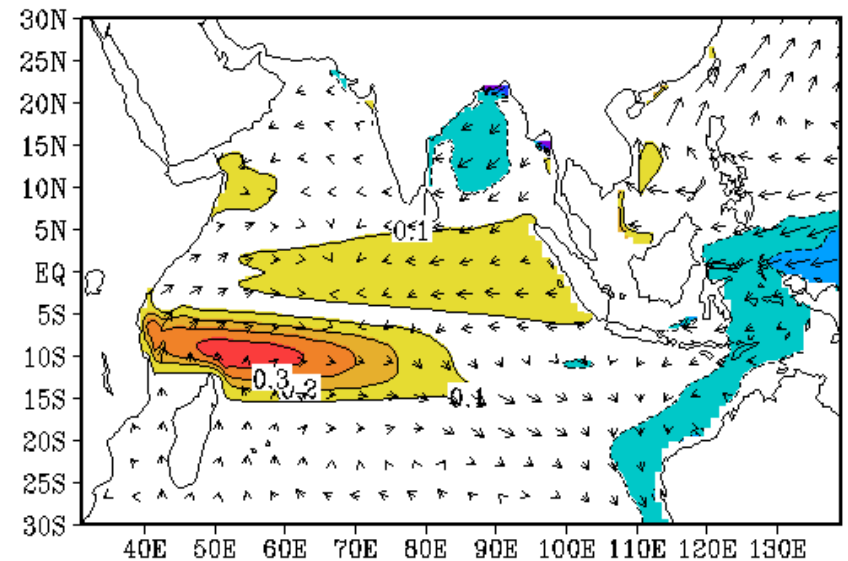
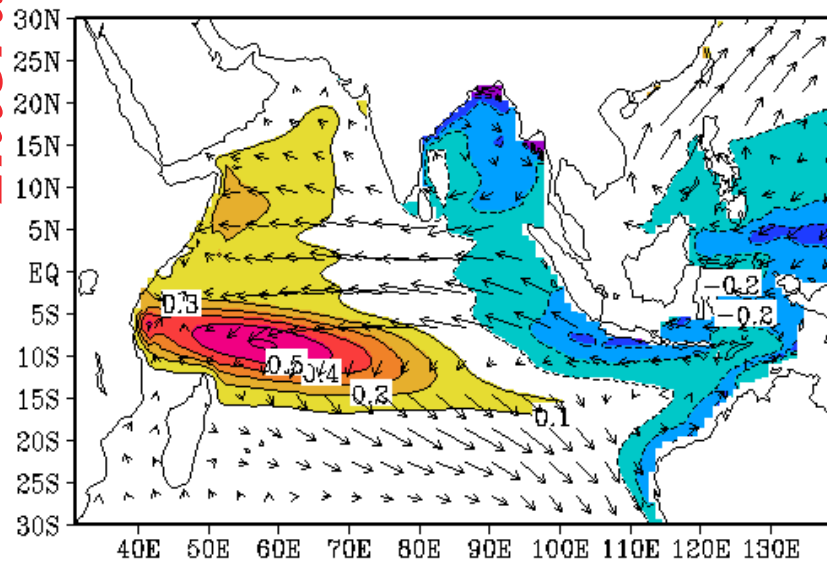
Phase II

Interannual Mode



Phase III

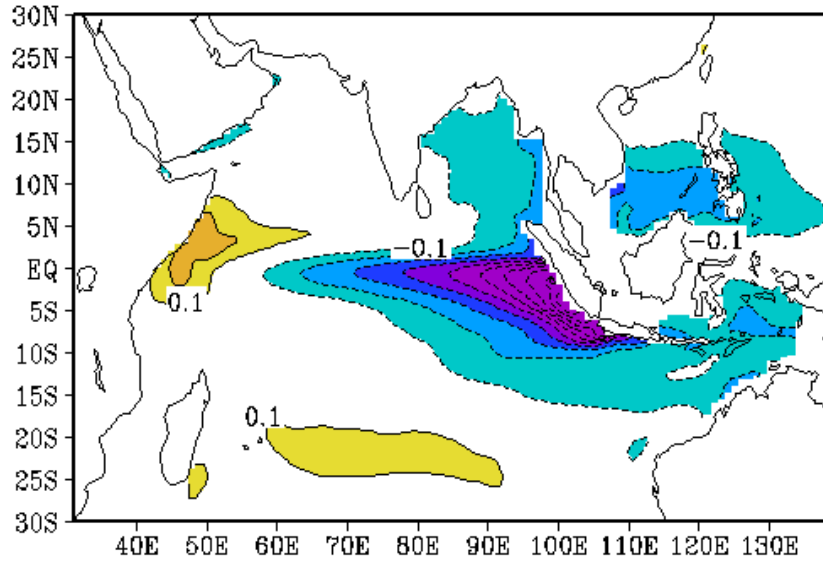
Phase IV



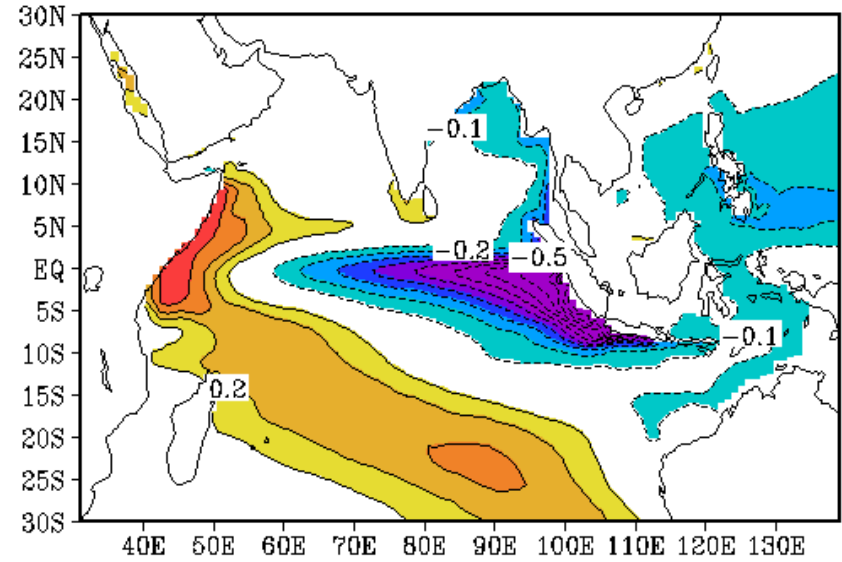
SSTA Composite

CFS, 335-years

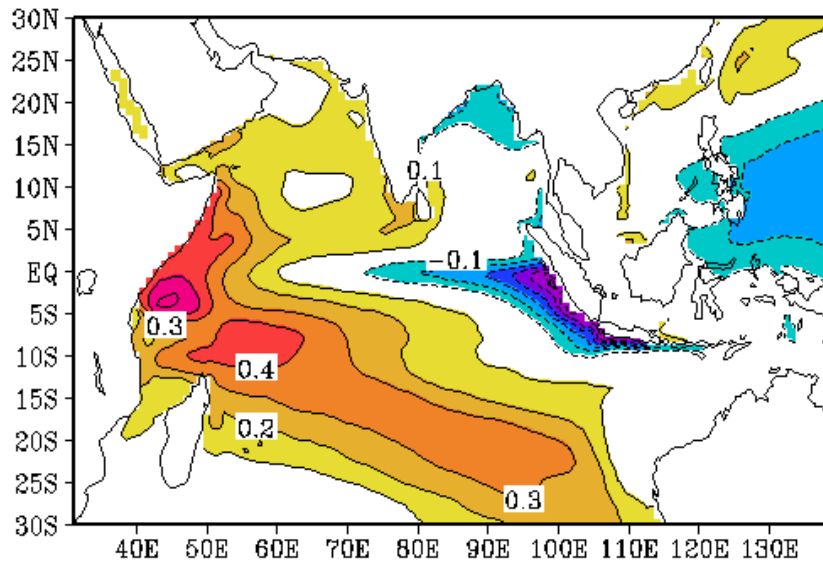
Phase I



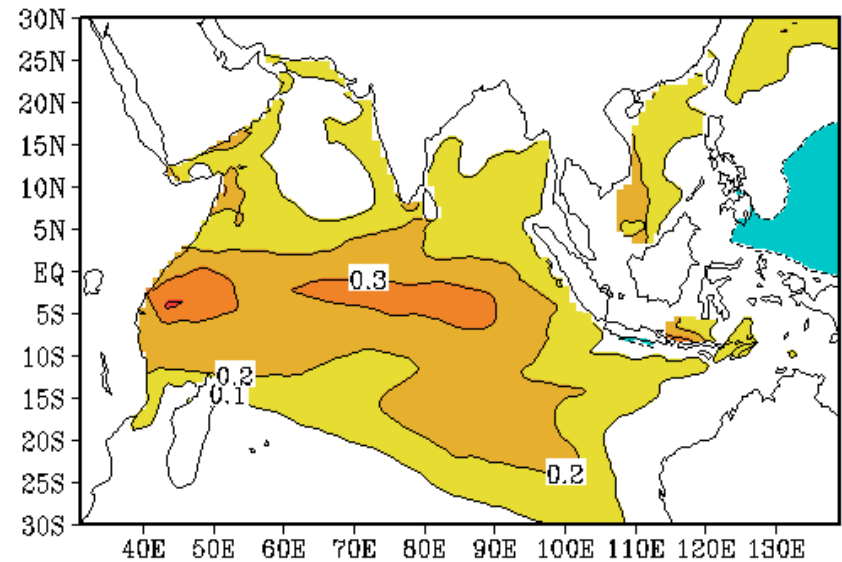
Phase II



Phase III

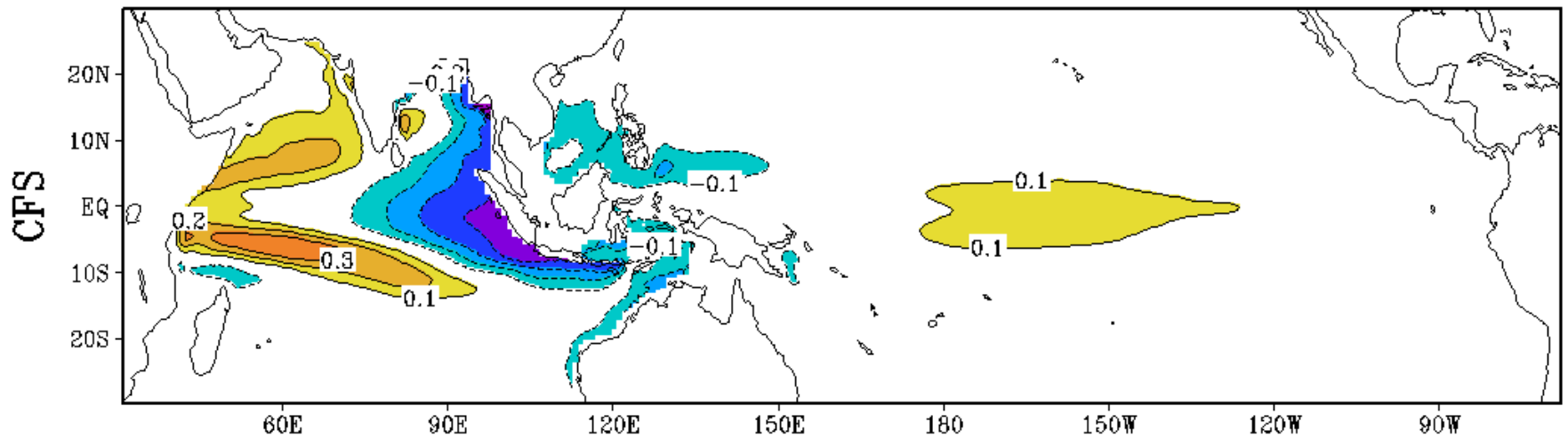
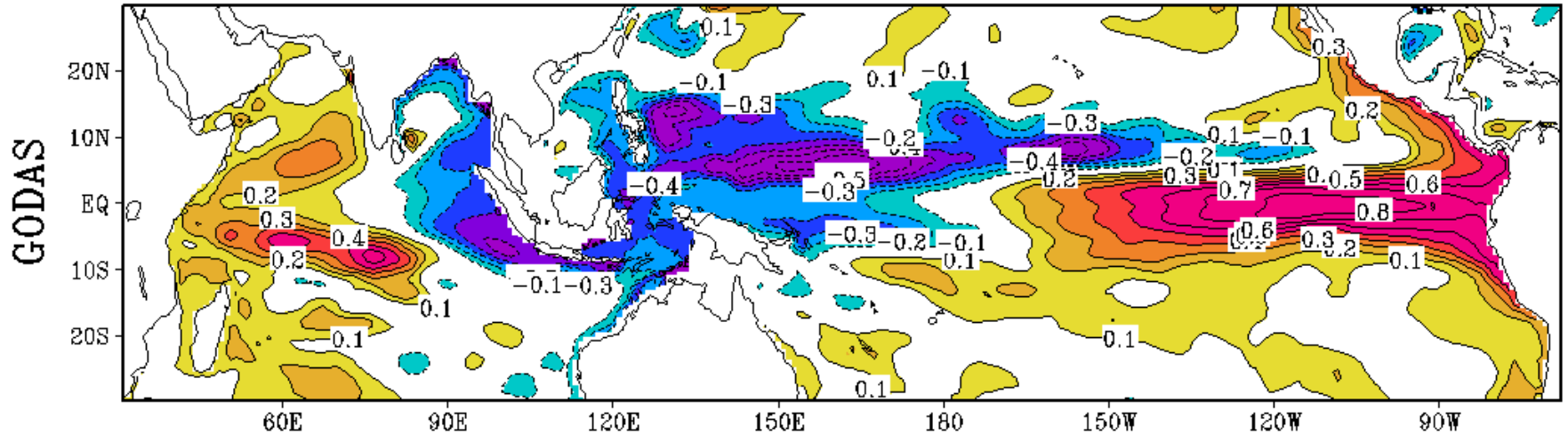


Phase IV



Quasi-biennial Component

Peak Phase of HCA Composite



Composite HCA & τ

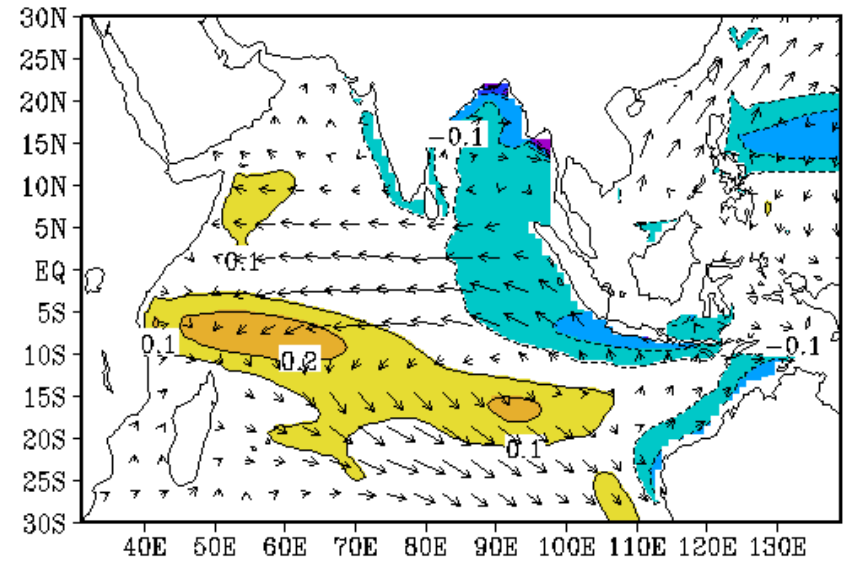
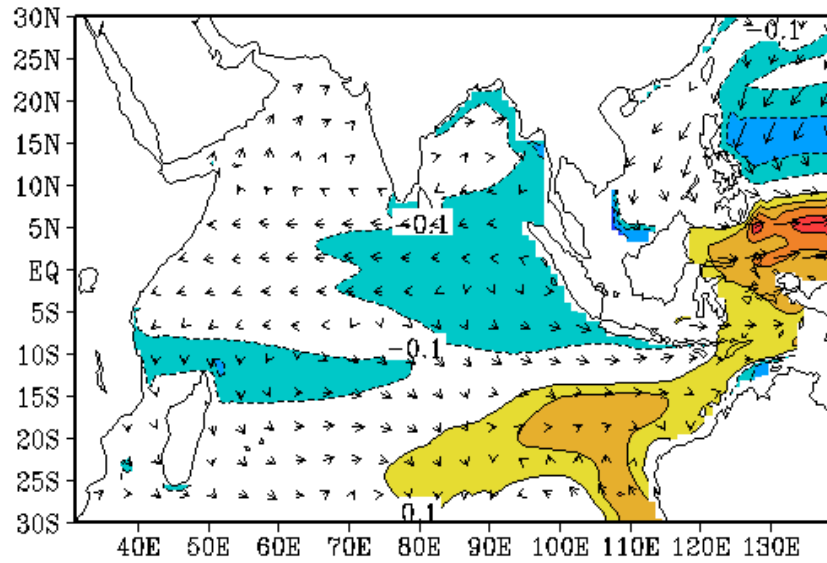
CFS, 335-years

Phase I

→
0.2

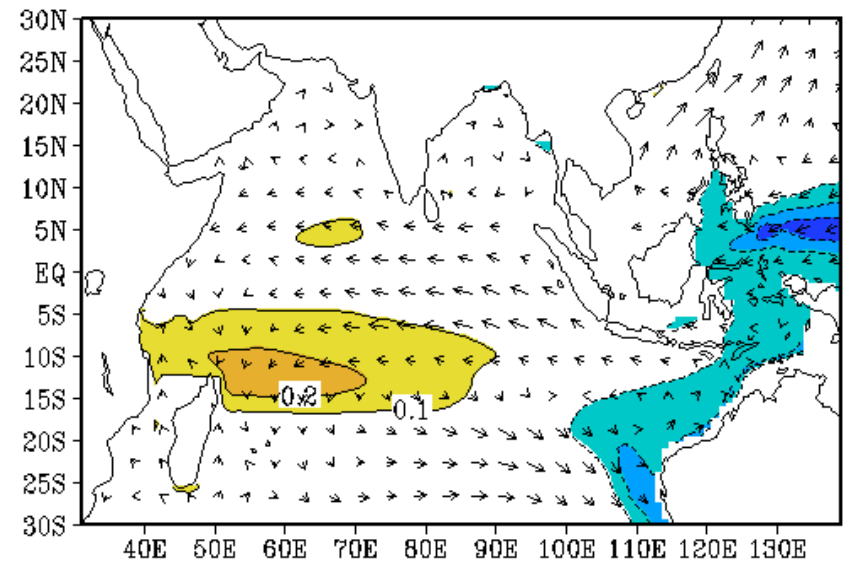
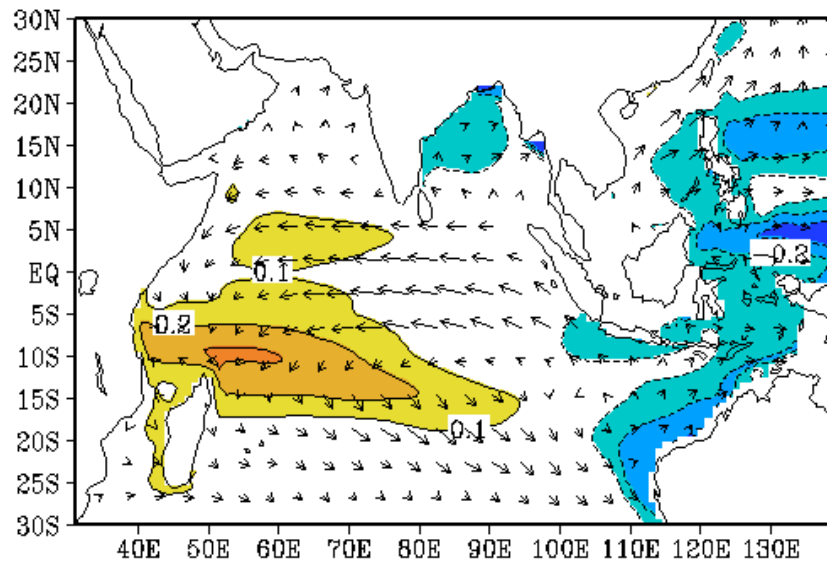
Phase II

Low-frequency

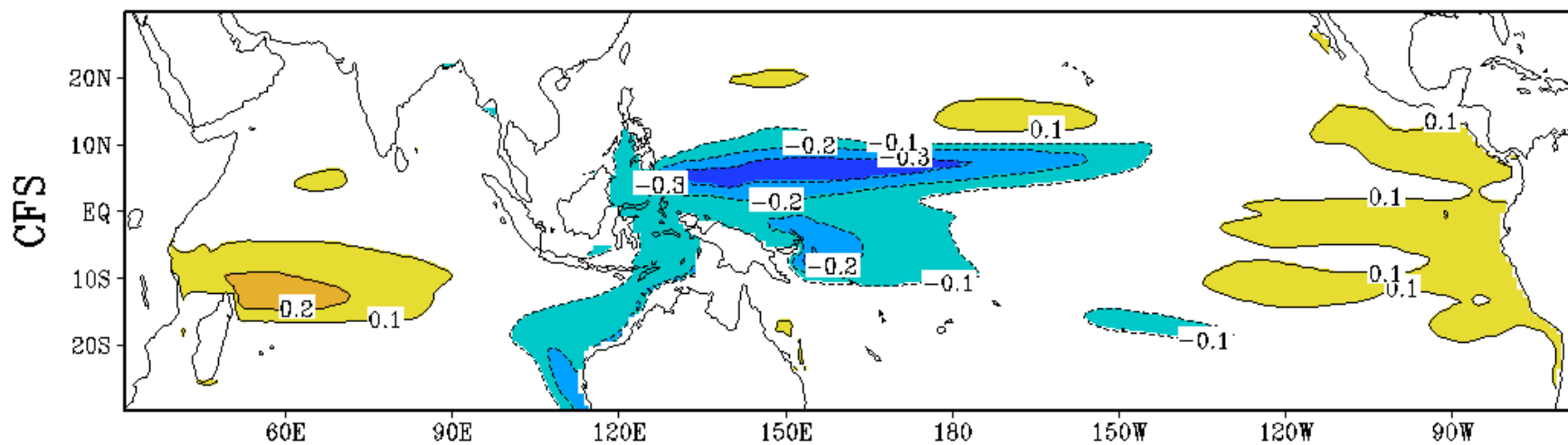
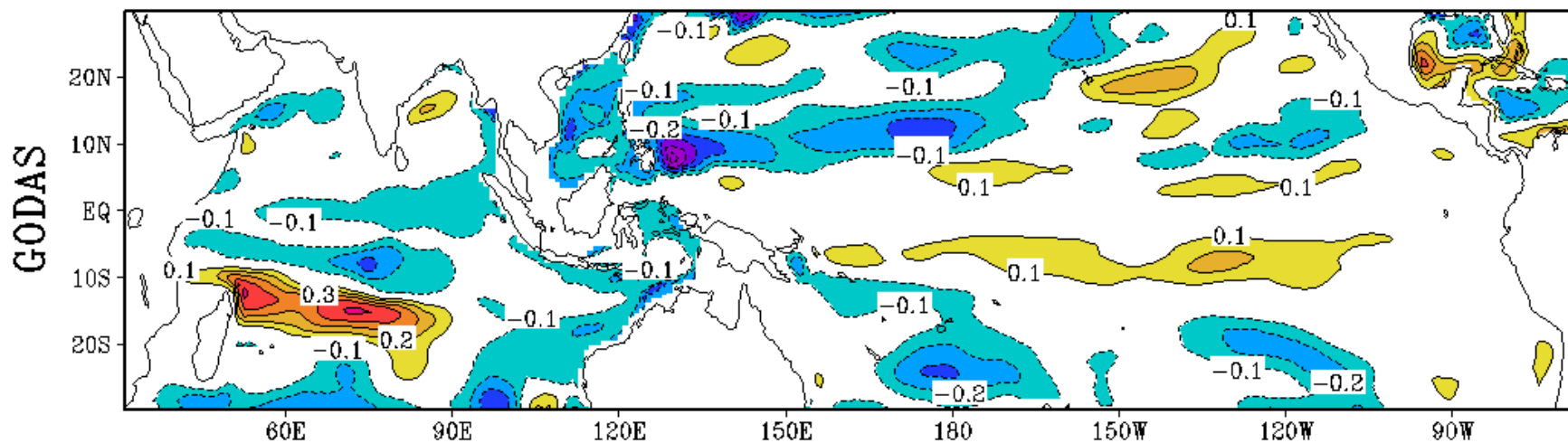


Phase III

Phase IV



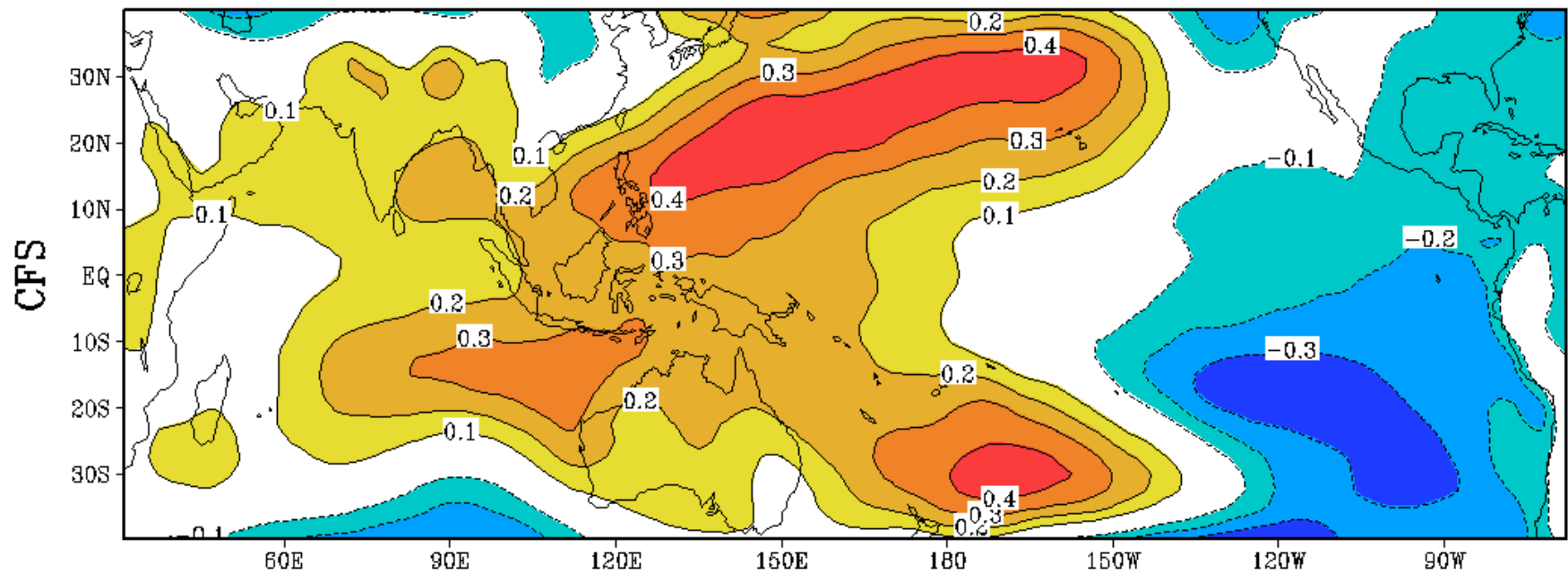
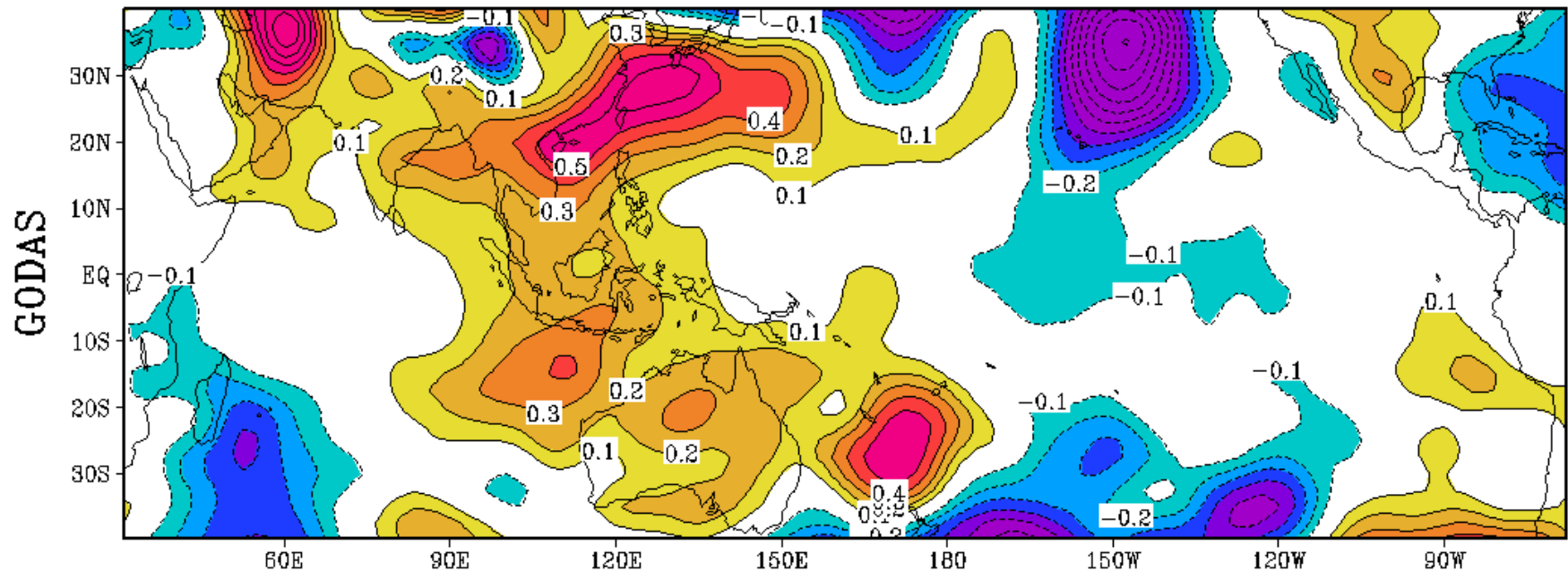
Peak Phase of HCA Composite



Summary

- HCA in the tropical Indian Ocean fluctuates on distinct time scales
- The sub-annual mode is associated with equatorial waves within the Indian Ocean
- The interannual mode is closely linked to the ENSO cycle
- The low-frequency mode is driven by Rossby waves in South Indian Ocean
- CFS (and CSM) simulate the major HCA modes realistically
- The HC influence is exaggerated in CFS by overly strong upwelling near the Sumatra coast

Peak Phase of SLPA Composite



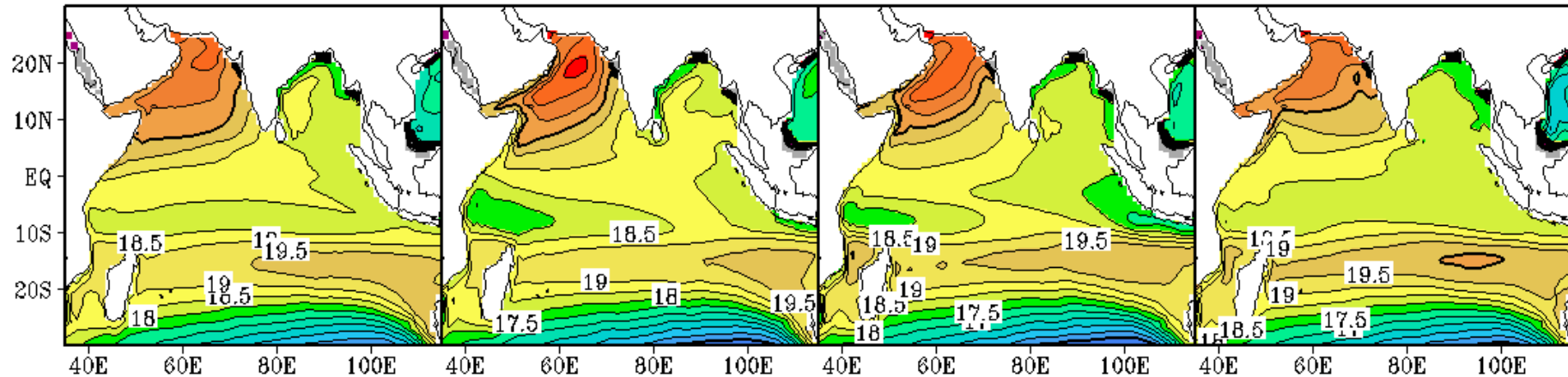
Ocean Heat Content (0–450m)

MAM, CFS

JJA, CFS

SON, CFS

DJF, CFS



MAM, GODAS

JJA, GODAS

SON, GODAS

DJF, GODAS

