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# INTERCOMPARISON OF ASIAN SUMMER MONSOON 1997 SIMULATED BY ATMOSPHERIC GENERAL CIRCULATION MODELS

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# Intercomparison Of Asian Summer Monsoon 1997 Simulated By Atmospheric General Circulation Models

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## ABSTRACT

To study the impact of El Niño on Asian summer monsoon of 1997, an international project titled 'CLIVAR Asian/Australian monsoon Atmospheric General Circulation Model intercomparison" was carried out. Under the project, a set of 10 ensemble Integrations for 2-years from September 1996 to August 1998, with observed boundary forcing of SST by 11 Atmospheric General Circulation Models (AGCMs) had been carried out. On invitation, IITM participated in the project and carried out AGCM simulations using the Hadley Centre climate model (HadAM2b).

The aim of the present study is the intercomparison of Asian summer monsoon of 1997 simulated by AGCMs. Ensemble mean anomalies of Mean Sea Level Pressure (MSLP), circulations at lower and upper levels, precipitation and moist static stability have been compared with corresponding observed anomalies. Comparison of Southern Oscillation Index (SOI) with observation indicates that the sign of SOI simulated by AGCMs is correct, although magnitude differs. MSLP anomalies are simulated reasonably well over India and neighboring oceans by majority of AGCMs. Large scale Asian monsoon circulation in 1997 was weak, which all AGCMs except IAP model, simulated well, as seen from Webster-Yang index. Models differ from observation in simulating Goswami and Lau index. All AGCMs correctly simulate precipitation over Asian-Australian region. AGCMs have difficulty in simulating precipitation averaged over smaller regions such as East Asia and India.. Large negative moist static stability anomalies over Pacific ocean are simulated by AGCMs, with magnitude of anomalies overestimated except IITM AGCM. AGCMs failed to simulate the negative moist static stability anomalies in the Indian ocean.

Results of intercomparison in the present study are not sufficient to draw definite conclusion regarding which ACM's simulation of monsoon 1997, is closest to observation, as AGCMs differ in their simulation of various parameters.

## 1.1 INTRODUCTION

Asian summer monsoon is a major component of the atmospheric general circulation and plays a key role affecting the livelihood of the vast population of the Asian region. The agriculture, industrial and economic productivity is heavily dependent on the variability of the monsoon in this region. Recently, considerable research has been carried out in understanding and prediction of monsoon (For a review on monsoon refer Webster et.al. (1998)). Numerous observational and General Circulation Modeling (GCM) studies in the past have established a relationship between Asian summer monsoon and El Niño/Southern Oscillation (ENSO) (Rasmusson and Carpenter (1982), Shukla and Paolino (1983), Palmer (1992), Ju and Slingo (1995), Soman and Slingo (1997)). Palmer and Anderson (1994) have shown that the rainfall simulation by GCM over India and Sahel are sensitive to initial conditions. Their results illustrate the need for ensemble integration for seasonal prediction of monsoon.

Relationship between monsoon and ENSO has been extensively studied revealing that many El Niño situations are associated with below normal rainfall over India and negative SOI leading to drought conditions. In contrast, La Nina events are seen to be associated with positive SOI and generally above normal monsoon over India (Pant and Parthsarathy (1981), Ropelewski and Halpert (1989)). However, some recent studies (Kripalani et.al (1997), Krishnakumar et.al. (1999)) have shown that the relationship between monsoon and ENSO has weakened in recent decades. Some of the examples are monsoons of 1994 and 1997. The El Niño of 1997 was one of the strongest El Niño of the last century. During 1997, large-scale Asian monsoon circulation was suppressed, convection was suppressed over equatorial eastern Indian Ocean, west Pacific and Indonesia, but the monsoon rainfall over India was 102% of the Long Period Average. (IMD, 1997).

A number of intercomparison studies of monsoon simulated by GCMs for recent past El Niño/La Nina episodes of 1982/83 and 1987/88 were conducted internationally under the Working Group on Numerical Experimentation (WGNE) and Monsoon Numerical Experiment Group (MONEG) (WMO (1986), WMO (1992)). Sperber and Palmer (1996) evaluated the interannual variability in 32 AGCMs as part of Atmospheric Model Intercomparison Project (AMIP). They showed that the rainfall variations over India and Sahel are less well simulated compared to Nordeste regions of Brazil. Gadgil and Sajani (1998) carried out intercomparison of monsoon precipitation and their seasonal migration in AMIP runs. However, the most recent 1997 El Niño episode is not covered in the AMIP period, so there has not been any attempt of intercomparison so far. 'CLIVAR Asian/Australian monsoon AGCM intercomparison Project' has provided a unique opportunity for evaluation of performance of AGCMs in simulating monsoon of 1997 when forced with observed Sea Surface Temperature (SST).

The intercomparison between various AGCMs has several advantages in improvement over the individual processes modifying a single model. So, the AGCM intercomparison was proposed by World Climate Research Program (WCRP)-CLIVAR to promote the performance of AGCMs and the monsoon predictability. The WCRP/CLIVAR

Asian/Australian monsoon panel initiated the AGCM intercomparison project. The main objectives of the program are intercomparison of intraseasonal oscillation, monsoon dynamics and hydrology, atmosphere-ocean interaction and global heat budget at the top of the atmosphere and at the surface, as simulated by AGCMs. Eleven AGCM groups from 6 different countries participated in the project with their models, viz. COLA (USA), DNM (Russia), GFDL (USA), GLA (USA), IAP (China), IITM (India), MRI (Japan), NCAR (USA), SNU (Korea), NCEP (USA), GEOS (USA). (Group name followed by country name in brackets). Indian Institute of Tropical Meteorology (IITM) participated in this project, for which Hadley Centre climate model version HadAM2b has been used. The details of the project and the results of intercomparison are available on the web site **http://climate.snu.ac.kr/clivar**

We report here, study of intercomparison of Asian monsoon 1997 simulation by the AGCMs. Experimental design is described in section 1.2 followed by brief description of all models participated in intercomparison in section 1.3. Objective of the study is discussed in section 1.4. Observed features of monsoon 1997 are discussed in 2.1. Results of the intercomparison are presented in section 2.2 and summary in section 2.3.

## 1.2 EXPERIMENTAL DESIGN

To study the impact of 1997/98 El Niño on monsoon, a set of 10 ensemble experiments for the period 1st September 1996 to 31st August 1998 with the same SST boundary forcing but with different initial conditions have been carried by 11 AGCMs. The SST boundary forcing used for the experiments is the observed weekly Optimum Interpolated (OI) SST from National Centre for Environmental Prediction (NCEP). Sea-ice is prescribed by the climatological monthly mean data. Initial conditions used for 10 ensembles are taken from the long-term integration of the respective model corresponding to 1st September 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994 and 1995. In addition to a set of ensemble simulations for the 1996-1998 period, each AGCM group performed the long integration for the period January 1979-August 1998 with the observed SST to produce model's climatology. This long integration is the extension of AMIPII where AMIPII period corresponds to January 1979- February 1996. The observed SST and sea ice used for this long integration for the period 1979-1998 are AMIPII monthly mean SST and sea ice for the AMIPII period and OISST (NCEP) afterward.

## 1.3 MODEL DESCRIPTION

Brief descriptions of Eleven AGCMs (that participated in the project) such as resolution, vertical levels and important parameterization schemes like radiation, convection, land-surface processes and cloud, with their references are described in Table-1.

| Model | NUMERICS | RADIATION | CONVECTION | LAND SURFACE PROCESS | CLOUD FORMATION | GRAVITY WAVE DRAG | CHEMICAL |
|---|---|---|---|---|---|---|---|
| COLA/COLA1.1 | R40L18 2.8×2.8 | Harshvardhan et al. (87) | Relaxed Arakawa-Schubert (RAS) | Deardorff(78) force-restore, diffusion | Slingo (87) | ○ | Ozone by GFDL climatologies |
| DNM/A5421 | 4×5,L21 | Slingo(89) for SW, Chou et al(91a,91b,,93) for LW | Kuo/Sela deep convection, Tiedke shallow convection | Volodin and Lykossov(97) | Slingo (87) | ○ | Ozone(Wang et al,95) |
| NASA/GEOS (GEOS-2) | 2×2.5,L43 | Chou and Suarez(94) | RAS, (Sud and Molod,88) | Schemm et al.(92) off-line based on simple bulk model | Slingo and Ritter(85) | ○ | |
| GFDL/DERF GFDLSM197 | T42L18 | Lacis & Hansen (1974) for SW, Rodgers & Walshaw (66), Stone & Manabe (68) for LW | MCA/Tiedke | no heat storage, bucket | Wetherald & Manabe (88) | ○ | Ozone (Hering & Borden, 65) |
| IAP/LASG GOALS | R15L9 | (ESFT),Shi(81) | (Manabe et al,65)(MCA), No shallow convection | Xue et al.(91) SSib model | | × | |
| IITM/KadAM2b V4.0,UKMO | 2.5×3.75, L19 | Ingram (93)for SW, Slingo & Wilderspin (86) for LW | Mass flux(Gregory and Rowntree) based on bulk cloud model(Yanai), | heat diffusion, single moisture reservoir with variable hydraulic capacity/conductivity | Smith (90a) | × | Ozone(Keating et al. (87), McPeters et al. (84) |
| MRI/GCM2 | 4×5, L15 | Lacis and Hansen(74)for SW, Shibata and Aoki(89) for LW | Arakawa-Schubert/Tokioka et al. | Katayama(78),Kitoh et al(88) | 5 types | ○ | Ozone(McPeters et al.,84) |
| NCAR/CCM3 | T42 | Briegleb(92) for SW, Ramanathan and Dickinson(79), Kiehl and Brieleb(91) for LW | Mass flux scheme(Zhang and McFarlane,95) | heat conduction, Bhumralkar(75), backward implicit Crank-Nicholson numerical scheme | Slingo(87),Kiehl94) | ○ | |
| SNU | T31L20 | 2-stream k-distribution radiation scheme (Nakajima and Tanaka,86) | RAS, Simplified Arakawa-Schubert, Diffusion-type Shallow Convection | Bonan's Land Surface Model(Bonan,96).,Non-local PBL/Vertical diffusion (Holtslag and Boville 93) | LeTreut and Li(1991) | ○ | |
| SUNY/GLA GCM-01.0 | 4x5, L17 | Harshvardhan et al. (87) | Modified Arakawa-Schubert | Deardorff (1978) force-restore, diffusion of moisture | Zeng et al. (89) | × | Ozone(Rosenfield et al,87). No aerosol |

**Table 1. Description of the GCMs participating in the CLIVAR/Asian-Australian Monsoon GCM intercomparison project**

IITM group participated in the project and carried out integrations of the Hadley Centre climate model on Silicon Graphics Power Challenge XL machine. The CPU time required for 1 day integration on this machine is ~ 15min. Description of HadAM2b AGCM in addition to that given in table-1 is as follows:

The atmospheric prediction scheme is based on the hydrostatic primitive equations. The model uses a grid-point scheme on a regular latitude-longitude grid in horizontal and hybrid vertical grid, which is terrain following (sigma) near the surface but evolving to constant pressure surfaces higher up. A split-explicit scheme is used to solve the equations. Time step is 30 minutes. The physical processes represented include:

- Atmospheric radiation
- Land surface processes
- A treatment of the form drag due to the sub-grid scale variations in orography
- Vertical turbulent transport within boundary layer
- Large scale precipitation
- Convection
- Gravity wave drag

## 1.4 OBJECTIVE

The objective of the present work is the intercomparison of Asian summer monsoon of 1997 simulated by AGCMs. The purpose is to assess the ability of AGCMs to simulate Asian summer monsoon of 1997, forced with observed SST. The year 1997 witnessed one of the most severe El Niño events of the last century. The impact of the El Niño was global and has been studied by several researchers (Bell and Halpert (1998), Annamalai and Slingo (1998), Moron and Ward (1998), Monteverdi and Null (1998), Shen and Kimoto (1999), Lau and Wu (1999)).

## 2.1 Observed features of Asian summer monsoon of 1997

El Niño of 1997 began in early 1997 and developed rapidly. The mature pattern of SST anomalies was present in the summer, with warm SST anomalies along the Peruvian coast and characteristic 'horseshoe' pattern of cold anomalies in the west and subtropical Pacific ocean. Through the remainder of 1997, El Niño continued to intensify, with the warmest anomalies gradually extending westwards into the central Pacific. Both growth rate and the intensity of 1997/98 El Niño were the highest compared to six major El Niño events since 1950 (Slingo (1998)). Strong SST anomalies were also observed in the Indian ocean in 1997/98. The extent and magnitude of the warming of the Indian ocean was unprecedented (Webster et.al. (1998)). The global climate was affected by this extreme El Niño event and is studied by several authors and is briefly described next.

The assessment of Bell and Halpert (1998) over Asian region shows (1) near record-to-record rainfall in southeastern Asia during June-August (2) In Indonesia, below normal rainfall from June through December resulted in extreme drought and contributed to uncontrolled wildfires. (3) Near-normal rainfall across India during Indian monsoon season (June to September).

Annamalai and Slingo (1998) examined the summer monsoon of 1997. Some of the notable features are substantial delay in onset, reduced Somali jet and above normal activity of tropical cyclones over west Pacific and the monsoon depressions over India during August 1997. Shen and Kimoto (1999) discussed in detail the influence of 1997 El Niño on Indian Summer Monsoon (ISM). They showed that the large-scale Asian monsoon circulation was suppressed but the monsoon rainfall over India was near normal due to intraseasonal variability. Lau and Wu (1999) assessed the impacts of 1997/8 El Niño on Asian-Australian monsoon. Their results suggest that the observed 1997-1998 Asian-Australian monsoon anomalies are very complex with approximately 34% of the anomalies of Asian summer monsoon attributable to basin-scale SST influence associated with El Niño.

## 2.2 RESULTS

Intercomparison of Asian summer monsoon of 1997 simulated by AGCMs in 10-member ensemble integration with observed SST forcing (which participated in CLIVAR Asian/Australian AGCM intercomparison project) is carried out. Ensemble mean anomalies of Mean Sea Level Pressure (MSLP), circulation, precipitation and moist static stability simulated by 10 AGCMs for June to September (JJAS) 1997 have been compared with observations. Though 11 models participated in the intercomparison project, simulations of 10 AGCMs are discussed in the present study, as one of the AGCMs - GEOS climatology is not available with us. Precipitation is compared with Climate Prediction Center Merged Analysis of Precipitation (CMAP). MSLP, circulation and moist static stability simulations are compared with NCEP/NCAR reanalysis data. For details of CMAP data refer to Xie and Arkin (1998) and for NCEP/NCAR data, refer to Kalnay et. al. (1996). Ensemble mean anomalies of JJAS 1997 are calculated by subtracting ensemble mean from long term climatology of the respective model. The descriptions of MSLP, circulation, precipitation and moist static stability simulations by 10 AGCMs are discussed in subsections a, b, c and d respectively.

### 2.2a Mean Sea Level Pressure

Figure 1 shows SOI for JJAS 1997 simulated by 10 AGCMs and corresponding observation from Climate Diagnostic Bulletin of October 1998 (No. 98/10). El Niño and Southern Oscillation (SO) are two aspects of ENSO system, which is a coupled atmospheric oceanic phenomenon. El Niño refers to the oceanic component and the southern oscillation to the atmospheric component. Southern Oscillation is an atmospheric pressure oscillation on a global scale spanning Pacific and Indian oceans. The linkage between El Niño and SO is so intimate that they are studied under the common name ENSO. El Niño of 1997 being one of the strongest, SOI is strong negative (~-2) in summer 1997. All AGCMs simulated the sign of SOI realistically compared to observations, except SNU GCM. The magnitude of SOI varies from model to model, GFDL and GLA overestimating it and DNM, IAP, NCAR underestimating it. Realistic simulation of SOI indicates that almost all AGCMs correctly simulate response of atmosphere to SST of 1997.

Figure 2(a-j) shows spatial distribution of MSLP anomaly for JJAS 1997 simulated by 10 AGCMs. Corresponding observed MSLP anomaly from NCEP/NCAR reanalysis is shown in figure 2k. Small positive anomalies are present over India and neighboring oceans in observations (Figure-2k). All AGCMs simulated weak positive anomalies over India except IAP and IITM. Weak positive anomalies over Indian Ocean are also simulated by most of the AGCMs except IITM, IAP and NCAR. Negative anomalies are noticed over small region between $40^0$E-$60^0$E and $25^0$N-$40^0$N. Only SNU AGCM simulated these negative anomalies realistically.

## 2.2b Circulation

The regional monsoon circulation indices that characterize the variability of Asian summer monsoon and its subcomponents have been calculated for ensemble mean simulations of 10 AGCMs and compared with corresponding observations. Reliable rainfall estimates over oceanic region are available after 1979 (when satellite data became available). Researchers have defined dynamically consistent circulation indices, which give the same information contained in precipitation indices.

To quantify monsoon variability, various monsoon circulation indices have been used to measure different components of the Asian summer monsoon by many authors such as Webster and Yang (1992), Goswami et.al. (1999) and Lau (2000). Circulation indices defined below have been compared with corresponding indices computed from NCEP reanalysis data.

(i)Webster-Yang index = $[u^*_{850}(40^0\text{E-}110\text{E}, 0\text{-}20^0\text{N}) - u^*_{200}(40^0\text{E-}110^0\text{E}, 0\text{-}20^0\text{N})]$
(ii)Goswami index = $[v^*_{850}(70^0\text{E-}110^0\text{E}, 10^0\text{N-}30^0\text{N}) - v^*_{200}(70^0\text{E-}110^0\text{E}, 10^0\text{N-}30^0\text{N})]$
(iii)Lau's index = $[u^*_{200}(110^0\text{E-}150^0\text{E}, 40^0\text{N-}50^0\text{N}) - u^*_{200}(110^0\text{E-}150^0\text{E}, 25^0\text{N-}35^0\text{N})]$

Where u and v are zonal and meridional components of horizontal wind respectively. Inner bracket shows the area over which these components are averaged. * Refers to anomalies of the respective quantities from the climatologies.

Figure 3 shows ensemble mean WYI, Goswami index and Lau index simulated by 10 AGCMs for JJAS 1997 and corresponding indices computed from observations of NCEP reanalysis. It is seen from the figure that observed WYI is negative while Goswami and Lau indices are near normal in monsoon season 1997. Strong negative WYI indicates weak circulation. All 10 AGCMs simulated weak circulation as observed from negative WYI, except IAP GCM. GLA and GFDL GCMs simulated very weak circulation compared to observed. Though the sign of WYI is correctly simulated by the AGCMs, its magnitude differs across AGCMs. Lau et.al. (2000) have shown that WYI is not an appropriate regional index for Indian monsoon and Bay of Bengal rainfall variability. WYI has higher correlation with Southeast Asian rainfall, indicating that WYI is an appropriate regional index for Southeast Asian rainfall. As will be seen from precipitation observation (section 2.2c), precipitation over Southeast Asia was on the negative side of normal in 1997 monsoon. Goswami index is highly correlated with rainfall over south Asia and Lau index with rainfall over Southeast Asia. It is clear from the figure 3 that the Goswami and Lau indices simulated by AGCMs differ largely from their observational counterparts.

Figure 4(a-k) shows spatial distribution of ensemble mean wind anomaly at 850hPa over region $30^0$E-$120^0$E, $20^0$S-$40^0$N for JJAS 1997 simulated by 10 AGCMs and observation from NCEP reanalysis. Contours of magnitude of the wind anomaly greater than 2m/sec is also shown in the same figure superposed on vector wind. Figure 4k shows very weak observed anomaly over India which most of the AGCMs simulated except IITM model, which shows westerly anomalies greater than 2m/sec over western peninsula and anomalies greater than 3m/sec over a small part of Arabian sea. Easterly anomalies over equatorial Indian ocean are strong with maximum anomaly of 4m/sec over $80^0$E-$90^0$E. NCEP, SNU, COLA and IITM models simulate these, though the magnitude and location of the anomalies are not realistic. NCAR and GLA models failed to simulate easterly anomalies in Equatorial Indian ocean and a few AGCMs namely DNM, IAP and MRI simulated very weak wind anomalies all over the region.

Figure 5(a-k) shows spatial distribution of ensemble mean wind anomaly at 200hPa over $30^0$E-$120^0$E, $20^0$S-$40^0$N for JJAS 1997 simulated by 10 AGCMs and corresponding observation. Figure 5k shows that the westerly anomalies of the order of 3-4m/sec are observed over central and peninsular India and very strong (about 7m/sec) westerly anomalies over southwest Indian Ocean. Westerly anomalies over south peninsula indicate weak Tropical Easterly Jet (TEJ). GLA GCM realistically simulates the spatial distribution of wind anomalies at 200hPa while rest of the AGCMs simulated very weak anomaly compared to observation.

## 2.2c. Precipitation

Ensemble mean precipitation anomalies for JJAS 1997 simulated by 10 AGCMs and observation, averaged over four regions viz. – (I) Asian-Australian (AA) region ($30^0$E-$180^0$E, $40^0$S-$60^0$N) (ii) South Asia ($70^0$E-$100^0$E, $10^0$N-$30^0$N) (iii) South-east Asia ($100^0$E-$130^0$E, $5^0$N-$25^0$N) (iv) India ($65^0$E –$95^0$E, $5^0$N-$30^0$N) are shown in figure 6(a-d) respectively. It is seen from the figure 6a that all AGCMs simulate precipitation over AA region realistically compared to observations. Magnitude and sign of precipitation deficit simulated by all AGCMs over AA region are comparable to observation except SNU GCM, which simulated very large negative anomalies. When precipitation is averaged over smaller regions, it is seen from anomaly in figures 6(b-d) that AGCM simulations differ from observation. Observed anomaly shows that the precipitation during JJAS 1997 over Southeast Asia was below normal, near normal over south Asia and slightly positive over India. South Asian region differs from Indian region in that it includes Bay of Bengal in addition to India. Other notable features are: IITM and GLA GCMs show large anomalies over Southeast Asian and Indian regions, which differ from observation largely in magnitude. IITM GCM overestimates precipitation and GLA underestimates it.

Figure 7(a-k) shows spatial distribution of ensemble mean precipitation anomaly for JJAS 1997 simulated by 10 AGCMs and observed anomaly over $30^0$E-$120^0$E, $20^0$S-$40^0$N region. Prominent features of observed anomaly (Fig.7k) are positive precipitation anomalies over Indian land area except over southeast peninsula, large negative anomaly of the order of 6mm/day over southeast equatorial Indian ocean and positive anomaly over southwest equatorial Indian ocean. Comparison of the simulations by AGCMs with observation indicates that IITM, MRI, NCAR, COLA and IAP AGCMs simulate positive precipitation anomaly over India correctly. All AGCMs except IAP and GLA simulated negative precipitation anomaly over southeast equatorial Indian Ocean.

## 2.2d Moist static stability

Shen and Kimoto (1999) examined moist static stability anomalies for JJA 1997 over equatorial oceans and showed that large negative i.e., unstable anomalies exist over central and east Pacific as well as most of the tropical Indian ocean especially over the western Indian ocean. To examine whether AGCMs simulated such negative (unstable) anomaly over Indian Ocean, moist static stability anomaly along the equator is calculated as difference of moist static energy between 1000hPa and 700hPa. Figure 8(a-e) shows moist static stability anomaly along equator for JJAS 1997 simulated by 5 AGCMs. For the rest of AGCMs, parameters required for calculation of moist static stability are not available with us. Moist static stability anomaly from NCEP/NCAR reanalysis observation is shown in figure 8f. Large negative anomalies indicating instability are observed over Pacific ocean and comparatively small negative anomalies over Indian Ocean. All AGCMs simulated negative anomaly over Pacific ocean larger in magnitude than observed except IITM model which simulated anomaly comparable to observed. However, AGCMs failed to simulate negative anomaly over Indian ocean.

## 2.3 SUMMARY AND CONCLUSION

Intercomparison of Asian summer monsoon of 1997 simulated by 10 AGCMs that participated in 'CLIVAR Asian/Australian monsoon AGCM intercomparison project', have been carried out. Ensemble mean MSLP, circulation, precipitation and moist static stability anomalies for monsoon 1997, have been compared with corresponding observations.

Comparison of SOI simulated by AGCMs with observation indicates that all AGCMs simulated sign of SOI correctly except SNU GCM. Observed MSLP anomalies are weak positive over India and Indian ocean which are simulated by all AGCMs except IAP and IITM. Negative anomalies are simulated over Indian ocean by IITM and IAP AGCMs.

Monsoon indices such as WYI, Goswami and Lau's indices simulated by AGCMs have been compared with observations. Large scale Asian monsoon circulation was weak in 1997 as seen from observed negative WYI, which is simulated by all AGCMs except IAP. AGCMs differ from observation in simulation of Goswami and Lau index. Observed lower level wind anomaly is very weak over India which most of the AGCMs simulated correctly. Position and magnitude of observed strong easterly anomalies over equatorial Indian ocean are not simulated realistically by any AGCM. Comparison of AGCM simulated 200hPa wind anomalies with observation shows that GLA GCM performed reasonably well whereas rests of the AGCMs differ from observation.

Area averaged precipitation simulation over four different regions by AGCMs, shows that all AGCMs simulated precipitation over AA region correctly. AGCMs differ from observation in simulation of precipitation over smaller regions such as East Asia and India. Examination of spatial distribution of precipitation simulation reveals that excepting a few AGCMs, positive precipitation anomaly over India is simulated reasonably well by AGCMs. Negative precipitation anomaly over southeast equatorial Indian ocean is simulated by all AGCMs except IAP and GLA.

All AGCMs simulated negative moist static stability anomalies over Pacific ocean although the magnitudes of anomalies are larger than observed except IITM model. Moist static stability anomalies over Indian ocean simulated by AGCMs are of opposite sign to that of observed anomalies.

Results of the present intercomparison study again emphasis the previous result that AGCMs have difficulty in simulating Indian summer monsoon rainfall. In spite of having state of the art AGCMs and each one integrated for 10 ensembles, monsoon simulation differs from observation when all 5 parameters are considered. To elaborate this point, consider SNU AGCM, which simulates sign of SOI opposite to that of observation whereas all other AGCMs simulate correct sign of SOI. However, SNU model is comparable to observation for MSLP and circulation. GLA AGCM overestimates SOI, MSLP, various monsoon circulation indices and circulation at lower level but underestimate rainfall over Indian region. So detail study of more parameters is required to select AGCM that is best compared with observation.

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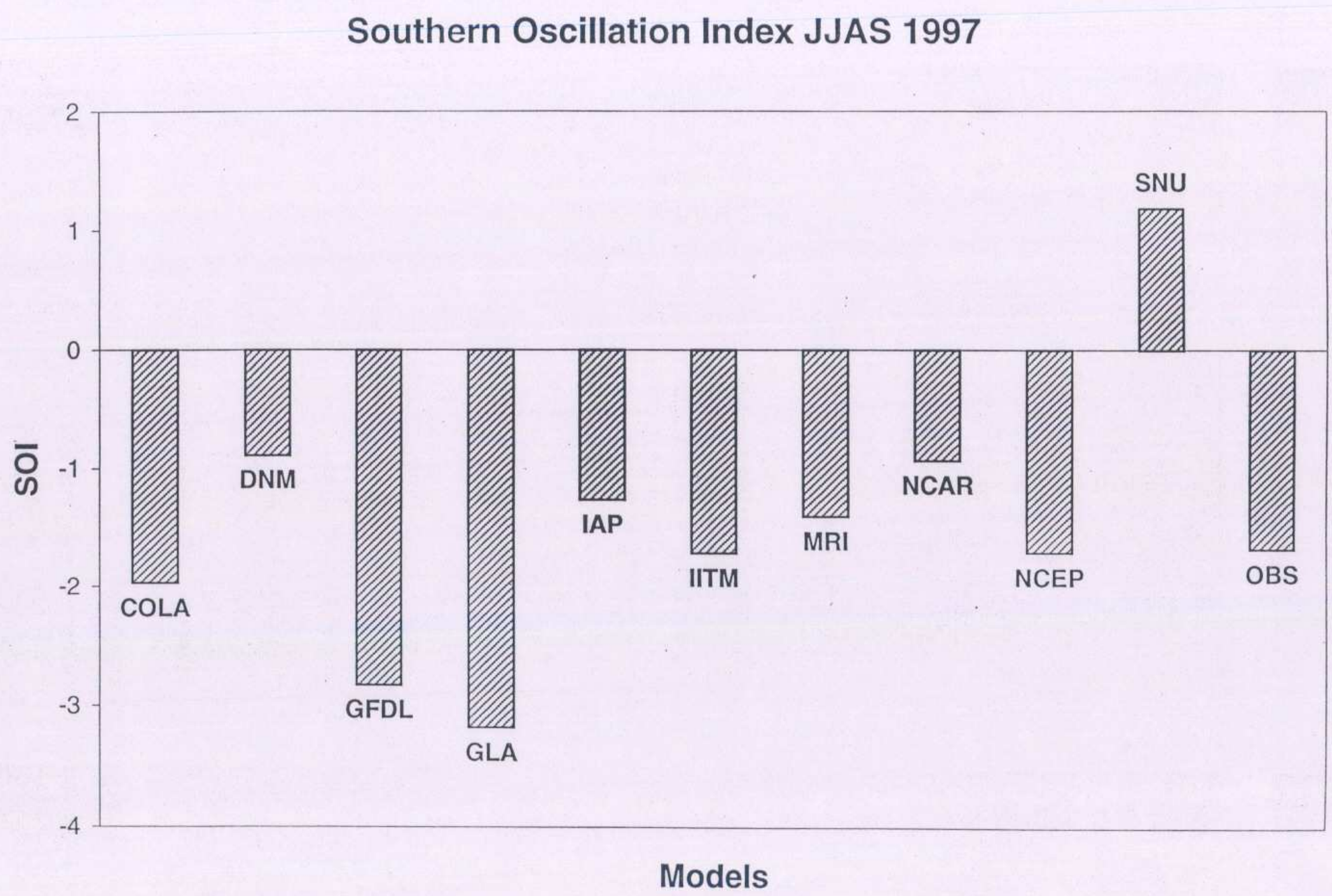

Southern Oscillation Index JJAS 1997
SOI
2
1
0
-1
-2
-3
-4
COLA
DNM
GFDL
GLA
IAP
IITM
MRI
NCAR
NCEP
SNU
OBS
Models

Figure 1

# MSLP Anomaly JJAS 1997

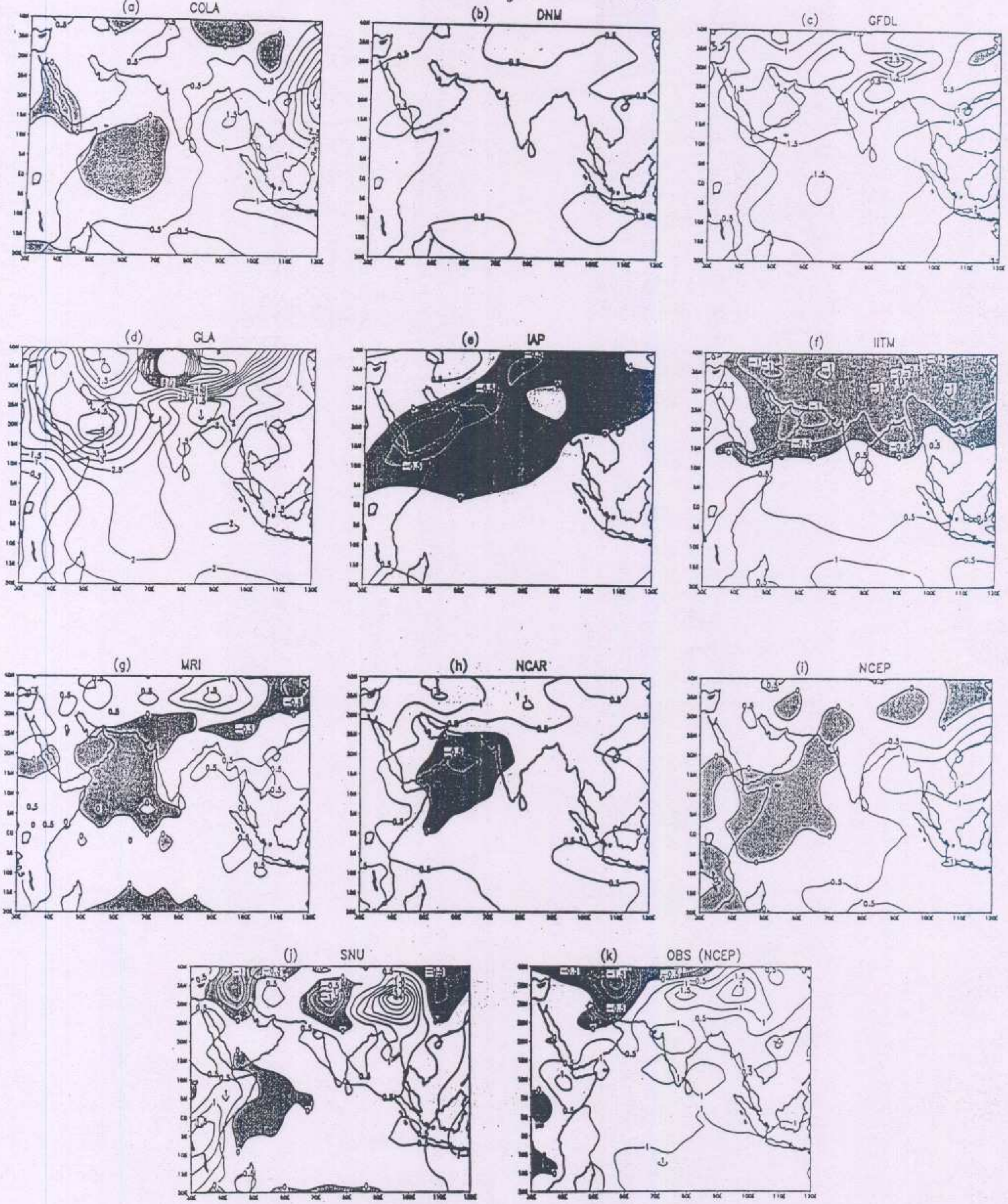
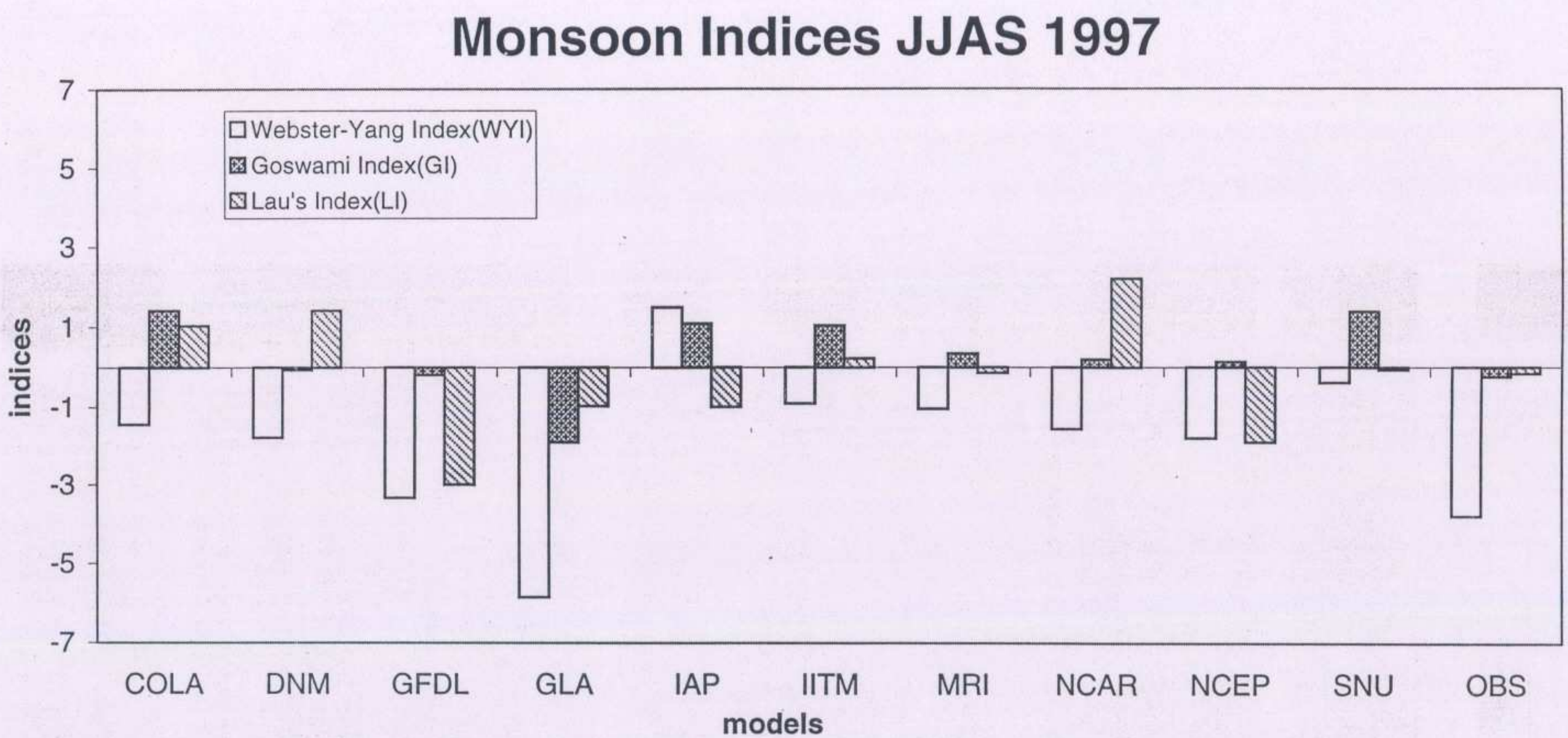



**Figure 2**




WYI=U*850 (40E – 110E and 0N-20N) – U*200 (40E – 110E and 0N-20N)

GI=V*850 (70E – 110E and 10N-30N) – V*200 (70E – 110E and 10N-30N)

LI=U*200 (110E – 150E and 40N-50N) – U*200 (110E – 150E and 25N-35N)

Figure 3

Wind Anomaly at 850 hPa JJAS 1997

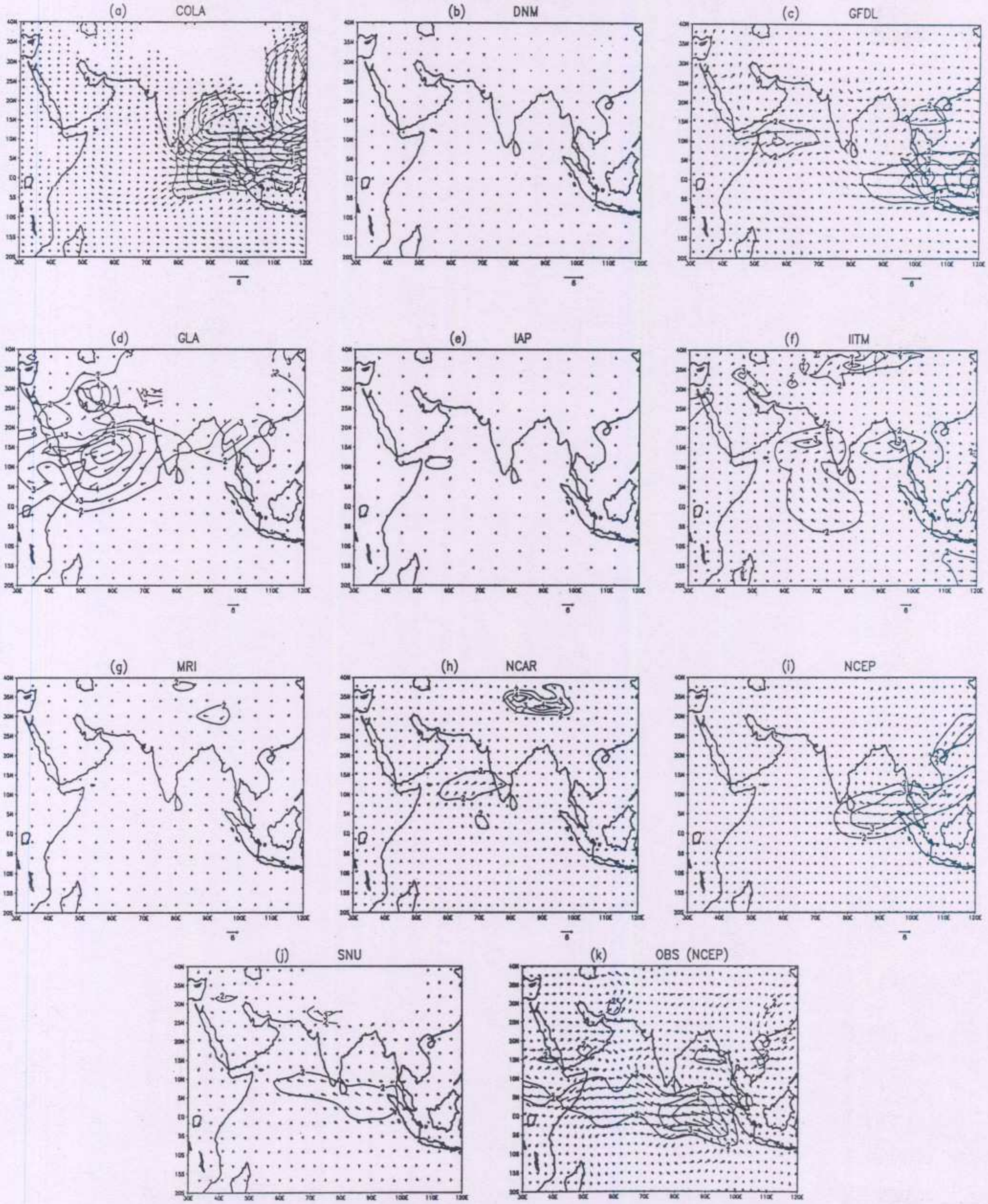
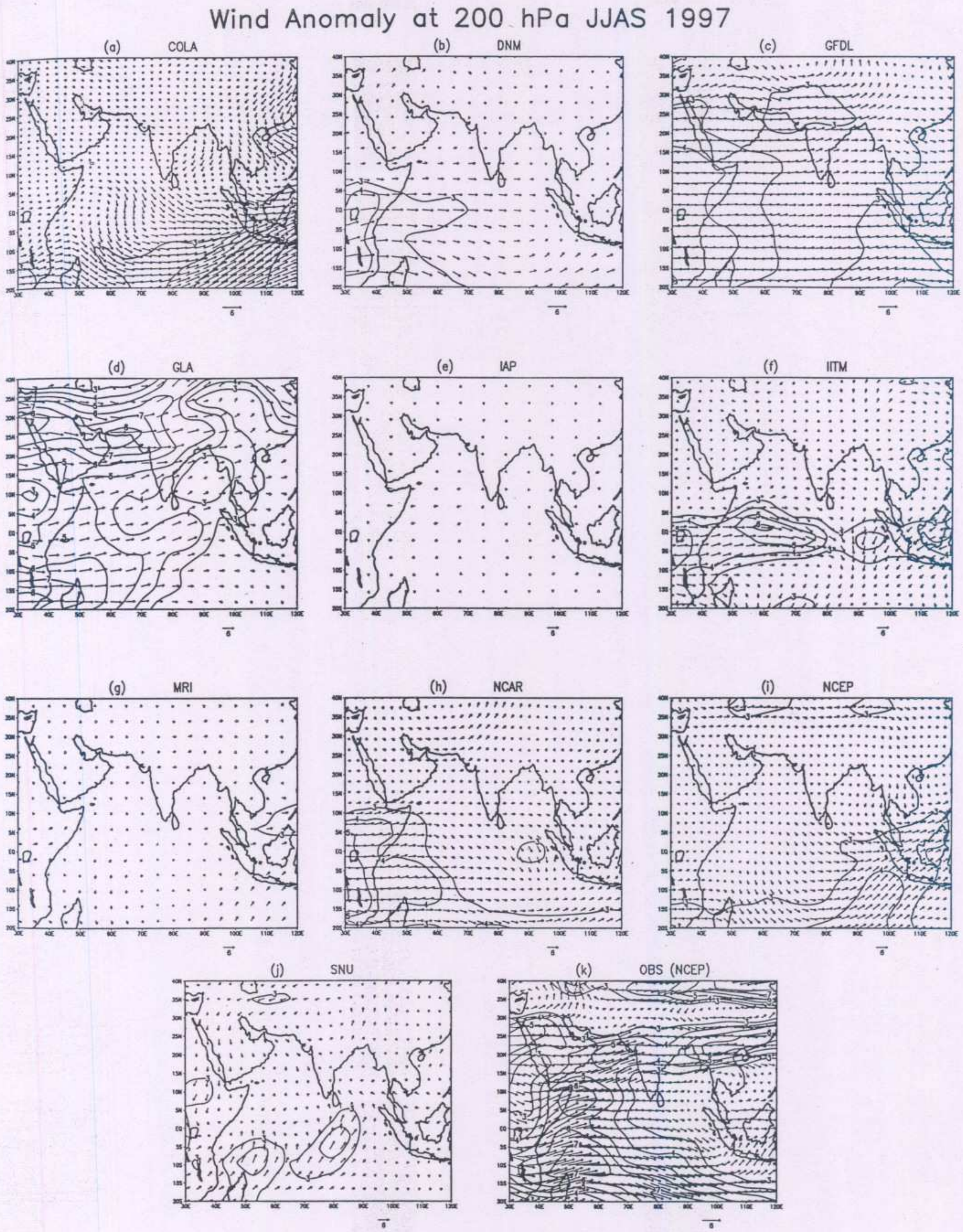


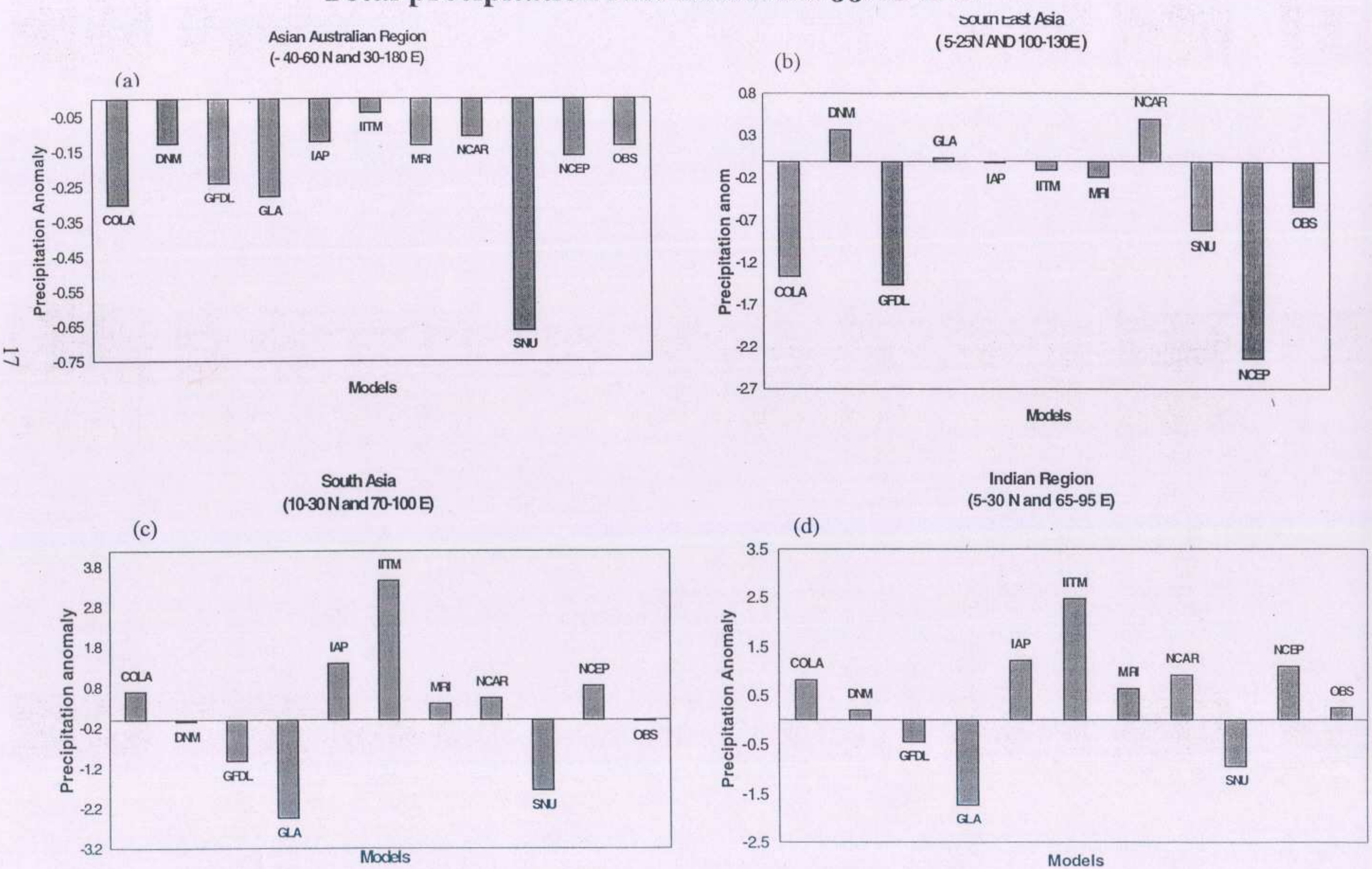

Figure 4



Wind Anomaly at 200 hPa JJAS 1997
(a) COLA
(b) DNM
(c) GFDL
(d) GLA
(e) IAP
(f) IITM
(g) MRI
(h) NCAR
(i) NCEP
(j) SNU
(k) OBS (NCEP)


Figure 5

# Total precipitation rate anomalies JJAS 1997



Total precipitation rate anomaly JJAS 1997


Figure 7

MOIST STATIC STABILITY ANOMALY JJAS 1997

(between 1000 and 700 hPa along equator (5S – 5N)

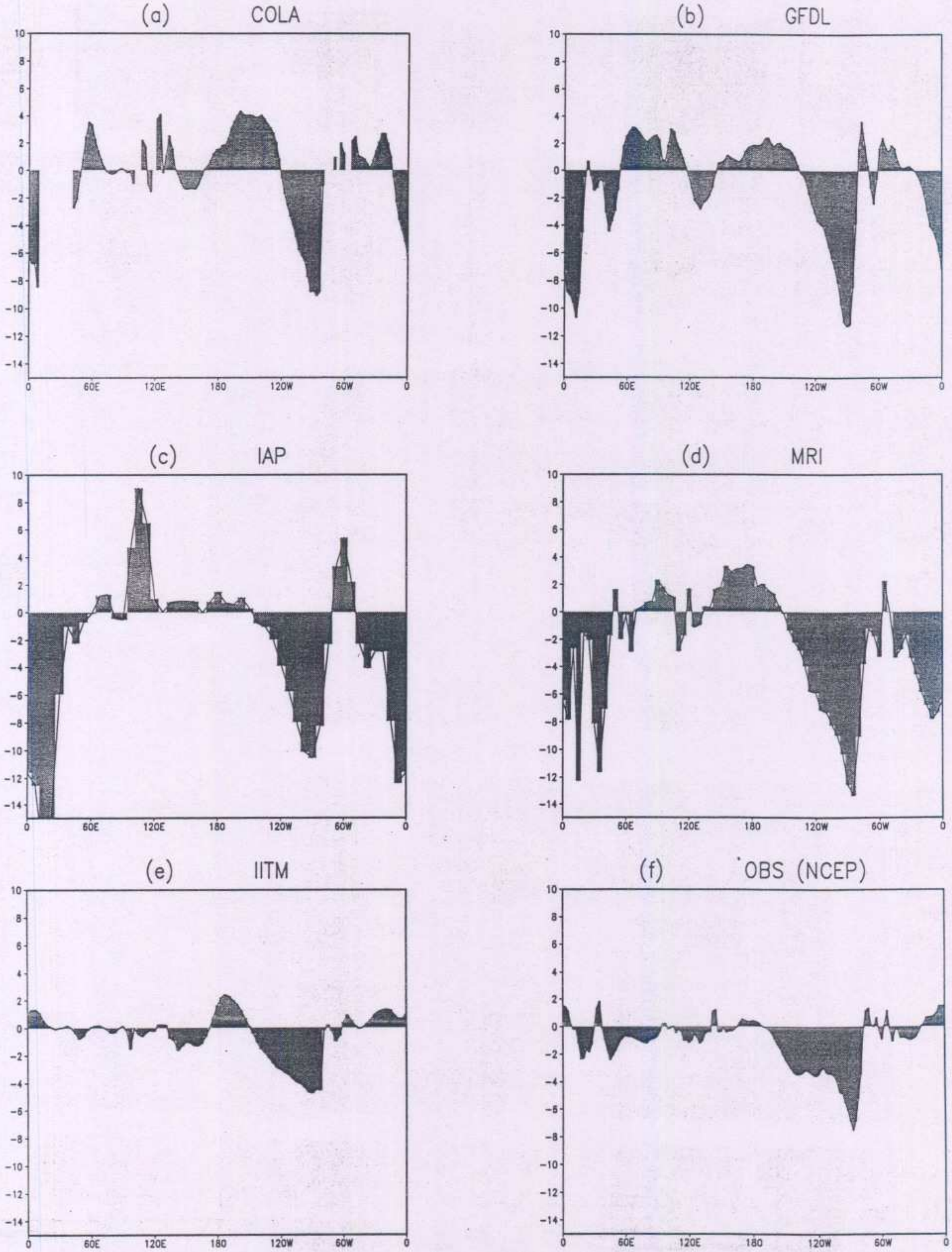



Figure 8

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