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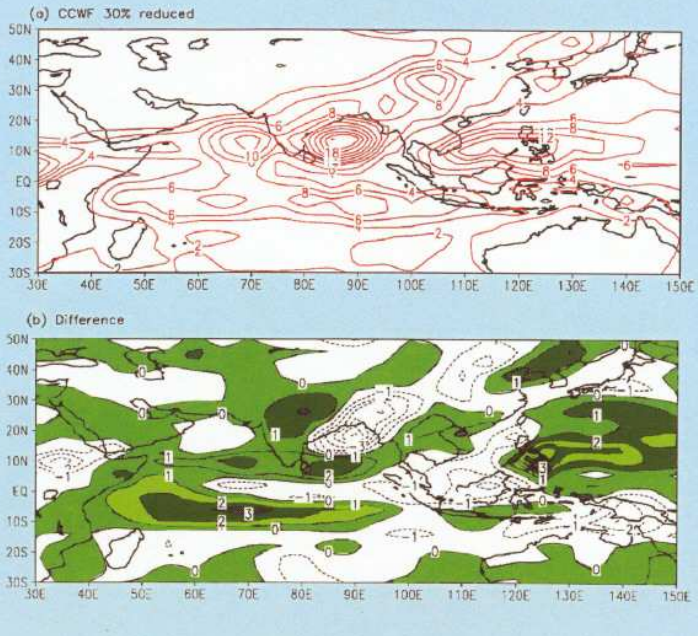

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"Sensitivity of Indian Monsoon Rainfall to Different Convective Parameters in the Relaxed Arakawa-Schubert Scheme"

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Abstract

The present study aims at investigation of the impact of different convective parameters used in the Relaxed Arakawa-Schubert (RAS) scheme of cumulus parameterization on the simulated Indian summer monsoon rainfall in a General Circulation Model (GCM). Several seasonal integrations, based on different values of Critical Cloud Work Function (CCWF) and different values of Re-Evaporation (REP) parameter of convective rainfall used in the RAS scheme have been performed. The GCM was integrated from 1st May 1988 to 30th September 1988 with different values of CCWF and REP with climatological Sea Surface Temperatures (SSTs) and observed SSTs as bottom boundary forcing. The seasonal climatology from June to September of this model integrated data shows that the convective parameters used in the RAS scheme have significant effects on the Indian summer monsoon rainfall.

Key Words : Indian Summer Monsoon Rainfall, Moist Convection, General Circulation Model, Kuo Scheme, Relaxed Arakawa-Schubert Scheme.

Introduction :

It has been found that most of the rainfall during the monsoon period over the Indian region is of convective type. There are various adjustment parameters, in different cumulus parameterization schemes, that control the amount and distribution of rainfall. For example, Betts (1986) has suggested three important adjustment parameters : (i) the saturation pressure departure (S), that determines reference humidity profile, (ii) the stability weight (W), that decides the slope of reference profile compared to the moist adiabat and (iii) the adjustment time scale (τ), that gives the time lag between the large scale forcing and the convective adjustment. Similarly the important adjustment parameters in the Relaxed Arakawa-Schubert (RAS) scheme of cumulus parameterization (Moorthi and Suarez, 1992) are values of Critical Cloud Work Function (CCWF), and amount of Re-Evaporation (REP) of convective rainfall. Several sensitivity studies have been performed using these convective parameters in various cumulus parameterization schemes by many authors. Betts and Miller (1986) carried out sensitivity test for adjustment parameters using GATE-wave data set (derived from Thomson et. al., 1979). Baik et. al., (1990a & b) incorporated the Betts-Miller scheme and showed that the scheme is able to handle different stages of the evolution of tropical cyclone. Their study also showed that simulation is sensitive to the saturation pressure departure values. Similarly, Sud et. al., (1991) investigated the role of CCWF and upper and lower bounds on entrainment by cumulus plumes in the Arakawa-Schubert scheme of cumulus parameterization. They found that increasing the threshold values of CCWF for all clouds tends to concentrate the rainfall into a narrower Inter Tropical Convergence Zone (ITCZ). It also affects the rainfall during the initial adjustment period, which suggests that it is an important parameter that can affect the spin up problem.

It is seen from the earlier studies that in the case of Indian monsoon rainfall, most of the GCMs simulate maximum rainfall over oceanic regions while the rainfall over Indian land region is underestimated (WMO, 1990 & Sperber and Palmer, 1996). As part of the Atmospheric Model Intercomparison Project (AMIP), 32 Atmospheric

General Circulation Models (AGCMs) have been run to study interannual variations of all India rainfall, Sahel and Nordeste rainfall by using common set of Sea Surface Temperature (SST) as boundary conditions for the period 1979 to 1988 (Sperber & Palmer, 1996). The results of the AMIP integrations show that, of these three regions, the interannual variability of Nordeste rainfall is relatively better simulated. In case of Indian monsoon rainfall, the link with SST is strongest under strong ENSO conditions, particularly when substantial anomalies in the tropical Pacific Ocean persist through the boreal summer, as in case of 1987 and 1988. But during other times little or no consensus among the simulations exists with regard to Indian monsoon rainfall. Pattanaik and Satyan (2000) compared two well known convection schemes namely the Kuo scheme and the Relaxed Arakawa-Schubert (RAS) scheme for the simulation of Indian summer monsoon using the Centre for Ocean-Land-Atmosphere studies GCM (COLA GCM). The rainfall climatology from June to September simulated with the RAS and the Kuo scheme and that from the observation (Xie-Arkin, 1996) for the nine years period (1986 to 1994) is shown in Fig. 1 (obtained from Pattanaik and Satyan 2000). It is seen from their study that the large-scale features and surface climatology is better simulated in the RAS scheme than the Kuo scheme. Although both schemes are unable to simulate Indian summer monsoon rainfall close to observation, the RAS scheme simulates reasonably better than the Kuo scheme in the sense that the rainfall maxima over the Bay of Bengal and west coast regions are relatively better placed and are clearly distinct with the RAS scheme, whereas with the Kuo scheme the rainfall maxima is far southwards and almost over the equator (Fig. 1). Although the RAS scheme performs relatively better than the Kuo scheme, still the problem in the RAS scheme to simulate Indian summer monsoon rainfall is that, it gives excessive rainfall over the oceanic region (mainly head Bay of Bengal region) and less rainfall over the land region of central India. The mean rainfall values obtained from Fig. 1 for observed rainfall (Fig. 1a) and that of rainfall simulated by COLA GCM with RAS scheme (Fig. 1b) and Kuo scheme (Fig. 1c) are given in Table 1.

Table 1. The rainfall climatology averaged over the Indian land only region during June to September obtained from COLA GCM simulation with RAS scheme, Kuo scheme and from the corresponding observed rainfall climatology (Xie-Arkin).

Rainfall over the land only region	COLA GCM with RAS scheme	COLA GCM with Kuo scheme	Observed rainfall (Xie-Arkin)
(5^0N-30^0N, 70^0E-90^0E)	5.33 mm/day	4.29 mm/day	5.78 mm/day

Thus it is seen from Table 1 that with the RAS scheme the rainfall simulated over India region is closer to observation although it is slightly underestimated with respect to observation. It is also seen from Fig. 1 that simulated rainfall over Bay of Bengal region is more with the RAS scheme compared to its corresponding observed climatology value. In the present study we have carried out sensitivity study of different convective parameters in the RAS scheme on the rainfall simulation over the Indian monsoon region using the same version of COLA GCM used by Pattanaik and Satyan (2000) for the mean monsoon study. The same version of COLA GCM is also used recently by Krishnan et. al., (2003) for the study of monsoon of 2000.

First, the basis of using the particular CCWF data sets (Lord et. al., 1982) in the RAS scheme is discussed. Secondly, the full role of REP used in the RAS scheme is analysed. The role of these two convective parameters used in the RAS scheme are discussed in Section. 2. The GCM details and experimental design is discussed in Section 3. The results of the sensitivity studies are discussed in Section 4. Finally conclusions are presented in Section 5.

2 Role of Different Convective Parameters used in the RAS scheme

2.1 Critical Cloud Work Function (CCWF)

As discussed by Arakawa-Schubert (1974), the primary source of kinetic energy generation for convection is the buoyancy force. Therefore the Cloud Work Function (CWF) is defined as the sub-ensemble kinetic energy generation per unit cloud-base mass flux due to work done by the buoyancy force, i.e.

$$A(\lambda) = \int_{z_B}^{\hat{z}(\lambda)} \frac{g}{\overline{T}(z)} \eta(z,\lambda) \left[T_{vc}(z,\lambda) - \overline{T}_v(z) \right] dz$$

Where λ is entrainment parameter and its value is fixed for particular sub-ensemble. Where $T_{vc}(z,\lambda)$ and $\overline{T}_v(z)$ are the sub-ensemble and environmental virtual temperatures, $\hat{z}(\lambda)$ is the sub-ensemble cloud-top height, and $\eta(z,\lambda)$ is normalized vertical mass flux. For a given λ, $A(\lambda)$ depends solely on the large scale thermodynamical vertical structure. The closure scheme, which is necessary to complete the parameterization is interpreted as a balance between the cumulus cloud ensemble and the grid scale variables. In case of Arakawa-Schubert scheme (Arakawa and Schubert 1974), the closure assumption is derived from a kinetic energy quasi-equilibrium for the cumulus ensemble which expresses a near balance between the generation of kinetic energy by large scale processes and dissipation by various cumulus processes. Lord and Arakawa (1980) concluded that the dissipation should depend primarily on cloud type and, consequently, CWF calculated under different synoptic conditions should be quasi-constant for each cloud type. In case of the RAS scheme the cumulus convection occurs for those cloud types for which the CWF exceeds an empirically determined critical value. This is known as Critical Cloud Work Function (CCWF) and is denoted by $A_0(\lambda)$. This CCWF is a function of entrainment parameter λ. When a discrete version of the RAS scheme of cumulus parameterization is used in a prognostic model, it is convenient to decompose the cloud ensemble into sub-ensembles according to the cloud top level (rather than the fractional entrainment rate λ).

From the definition of large scale forcing for the 'ith' sub-ensemble is the change in CWF due to large-scale processes and can be written as

$$F(i) = \left[\frac{d\,A(i)}{dt}\right]_{LS}$$

Where the subscript LS refers to the large-scale processes and A(i) is CWF of i^{th} sub-ensemble. The effects of the large-scale processes (e.g. large scale vertical and horizontal advection of temperature and moisture, radiative heating and boundary layer processes) are applied over a time step Δt to modify the large scale thermodynamical variables ψ (temperature, water vapour, mixing ratio etc.), such that ψ_0 denotes the variable at particular time t_0 and ψ' after a time interval of Δt. If CWF for i^{th} sub-ensemble calculated from ψ' be denoted by $A'(i)$ and that from ψ_0 as $A_O(i)$.

Then the large scale forcing will be

$$F(i) = A'(i) - A_o(i)$$

Hence in case of computation of large scale forcing F(i), there should be predetermined value of $A(i)$ that is $A_o(i)$. In case of observational data, as done by Lord (1982), $A_o(i)$ can be calculated from data at a given observation time. But in case of prognostic model, like GCMs, $A_o(i)$ can be replaced by a characteristic value for the i^{th} sub-ensemble.

The CCWF used in the GCM is written as

$$A_o(i) = A_N(i)\left[P_B - \hat{P}(i)\right]$$

Where $A_N(i)$ are CCWF data (Table 2 of Lord et. al., (1982)) derived from the observed temperature and humidity profiles over the Marshall Islands(Reed and Recker 1971) and a few other tropical observations (Lord 1978) and are listed in Table 2 here. The data shown in Table 2 represents the time averaged CWF for observations. P_B and $\hat{P}(i)$ are cloud base pressure and cloud top pressure of i^{th} sub-ensemble. The CCWF is an important limiting parameter that controls the onset of different cloud types.

If we go by the fact that CWF computed over tropics and subtropics fall into a well defined narrow range for each sub-ensemble, in that case it is reasonable to use the Table 2 values in GCM. But there is problem in using $A_N(i)$ values from Table 2 in the RAS scheme and it is due to the difference in entrainment relation in original Arakawa-Schubert (AS) and RAS schemes.

Table 2

The average observed CWF and $A_N(i)$ for each cloud type

$\hat{P}(i)(hP_a)$	$A_N(i)$
150	1.6851
200	1.1686
250	0.7663
300	0.5255
350	0.4100
400	0.3677
450	0.3151
500	0.2216
550	0.1521
600	0.1082
650	0.0750
700	0.0664
750	0.0553
800	0.0445
850	0.0633

The modification of entrainment relation produces a smaller CWF in the RAS scheme than in the standard AS scheme (Moorthi and Suarez 1992). It is because of larger value of entrainment parameter (λ) in modified entrainment relation in the RAS scheme. In other words the linear increase with height of the mass entrainment in the RAS scheme implies that, for a given (λ) there is less dilution of clouds air at upper levels and thus results in deeper clouds than when the AS formula is used. This means clouds that detrain at a given level will have a smaller CWF, which imply a larger large-scale forcing in standard implementation of the AS scheme than the RAS scheme (Moorthi & Suarez 1992). The original value of $A_N(i)$ as given above is used in the COLA GCM.

2.2 Re-Evaporation Parameter (REP)

It is not good enough to predict the total precipitation. Another problem of cumulus parameterization is prediction of warming and drying of the atmosphere, which means the prediction of temperatures and humidity profiles. The RAS scheme, as well as the Arakawa-Schubert scheme accomplish this through the cloud model and the closure assumption of quasi equilibrium of the CWF. It is seen that (Moorthi and Suarez 1992), the vertical profiles of the time averaged cumulus warming and drying produced by the RAS scheme is not closer to the corresponding observed estimates of the warming and drying from the GATE data. The predicted warming seems to under estimate the observed and the predicted drying overestimates the observed at lower levels. This problem also exists in the standard implementation of AS scheme (Lord 1982, Fig. 12).

The excessive low level drying can be reduced by two means (i) by inclusion of cumulus-induced down drafts (Cheng and Arakawa, 1990) and (ii) by inclusion of re-evaporation of falling rain (Sud and Molod 1988). Evaporation of falling precipitation is dependent on a parameterized drop-size distribution and upon relative humidity. There is also a modified effect so that at levels where relative humidity is high the re-evaporation rate is reduced which is in some ways similar to the idea controlling the 'b' (moistening parameter) in the Kuo convection scheme as modified by Anthes (1977). In the present version of COLA GCM the re-evaporation parameter is set to 15%, which is based on experimental results to try to achieve two goals.

(i) Moisten the lower troposphere since this can become quite dry if some rain re-evaporation is not included.

(ii) Avoid grid point storms if the rain re-evaporation parameter is set to too high, a value at which convection can act to moisten the column too much and thus lead to grid point storm type phenomena.

This re-evaporation reduces the net precipitation reaching the surface of the earth. The amount of re-evaporation depends on the temperature, pressure and relative humidity of the air traversed by the falling raindrops (If RH is 100% re-evaporation is zero).

3 Model Description and Experimental Design :

3.1 The COLA GCM

The COLA GCM used in this study is based on a modified version of the NMC (National Meteorological Center, now NCEP) global spectral model used for medium range weather forecasting (see Sela, 1980 for original formulation; see Kinter et. al., 1988 for modified version). The GCM horizontal resolution is triangular truncation at a total wave number of 30, corresponding to $3.75^0 \times 3.75^0$ grid. The vertical structure of the model is represented by 18 unevenly spaced levels using sigma as the vertical co-ordinate. For the varying height of the surface, the U.S. Navy ten minute resolution model terrain height data set was used for each COLA GCM Gaussian grid box.

The land surface parameterization was changed to Simple Biosphere (SiB), a biophysical formulation [Sellers et. al., (1986), Sato et. al., (1989) and Xue et. al., (1991)]. The sub-grid scale vertical transfer of momentum, heat and moisture in the atmosphere is treated using the level 2.0 closure scheme of Mellor and Yamada (1982). The GCM employs an efficient radiation scheme which resolves the diurnal cycle and includes terrestrial radiative heating (Harshvardhan et. al., 1987) and solar radiative heating (Lacis and Hansen, 1974; modified by Davies, 1982). Short and longwave radiative fluxes are computed every three and six hours respectively in the present version of the GCM. The original version of the model employs a modified version of the Kuo convection scheme (Anthes, 1977; after Kuo, 1965) to represent deep precipitating convection. In one of the integrations, the Kuo convection scheme is replaced by the RAS scheme of Moorthi and Suarez (1992). In conjunction with the deep convection, shallow non-precipitating convection is modelled following Tiedtke (1983). In addition to deep convection and shallow convection, the COLA GCM also includes the process of large scale condensation (relative humidity criteria as in Sela, 1980). The large scale condensation is computed after the convection adjusts the atmosphere.

The model employs diagnosed clouds for cloud-radiation computation, as implemented by Hou (1990) which is based on the work of Slingo (1987). In radiation transfer model, convective type and stratiform type of clouds are considered separately. Convective type is diagnosed according to the three hour mean convective precipitation rate, whereas stratiform clouds are computed from relative humidity (RH). These RH-dependent clouds are divided into 3-layers, high, middle, and low clouds. The RH clouds will form when RH exceeds a certain critical value. For more details see Kinter et. al., (1997).

3.2 Experimental Design :

Considering the importance of the convective parameters used in the RAS scheme, here we try to see the effect of these two parameters (CCWF and REP) in the RAS scheme to the rainfall distribution over the Indian region. For carrying out several experiments for the sensitivity study of these convective parameters we consider the good monsoon year in the recent time 1988. We performed several seasonal (June to September) integrations with the different values of CCWF and different values of REP with climatological Sea Surface Temperature (SST). By choosing the suitable values of CCWF and REP from the set of experiments two more seasonal integrations are performed for the same year 1988 with observed SST. The original value of CCWF used in the COLA GCM is as given in Table No.2 and the original value of REP is 15%.

We change the REP value from its original value of 15% to different values to see its effect on rainfall intensity and distribution. Regarding the CCWF, the value $A_N(i)$ for different cloud types as discussed in subsection 2.1 is taken from Table 2. As discussed in subsection 2.1, the systematic tendency of the RAS scheme to produce a smaller CWF can be easily remedied by using a correspondingly lower CCWF than that obtained by Lord (1978) as listed in Table 2. Although there is considerable uncertainty in the appropriate critical values (Sud et. al., 1991), here we used lower critical values to compensate the decrease in large scale forcing in the RAS scheme.

Keeping these considerations we performed several experiments whose details are given in Table 3.

Table No. 3 : Experiment Details

Name of The Expt.	Initial condition	Sea Surface Temperature	CCWF $A_N(i)$	REP Parameter
C1	1st May 1988	Climatological	As from Table 2	15%
E1	1st May 1988	Climatological	20% Less	15%
E2	1st May 1988	Climatological	30% Less	15%
E3	1st May 1988	Climatological	As from Table 2	0% (no evaporation.)
E4	1st May 1988	Climatological	As from Table 2	10%
C2	1st May 1988	Observed	As from Table 2	15%
E5	1st May 1988	Observed	30% Less	10%

4. Results and Discussion :

Here the results of different experiments as mentioned in Table 3 are discussed. The two experiments C1 and C2 are control experiments with climatological and observed SSTs by using the actual value of $A_N(i)$ and original value of REP as 15%. Figure 2 shows June to September (JJAS) mean precipitation for experiment C1 and experiment E1 along with the difference of precipitation between E1 and C1. The seasonal mean rainfall distribution from June to September (JJAS) with experiment E1 is shown in Figure 2b. It is clear from the Figure 2c that by reducing the CCWF value by 20% although there is changes in distribution of rainfall, there is no improvement of precipitation over the land region of India. More precisely, there is no increase of precipitation over most of the land region of India except in very small parts. However, there is decrease of excessive precipitation over the Bay of Bengal region. If we consider the experiment E2 (when CCWF is reduced by 30%), there is considerable improvement in the seasonal rainfall distribution as shown in Figures 3a and 3b. Figure 3b shows the difference of precipitation between E2 and C1. It is seen that there is decrease in excessive precipitation over Bay of Bengal region and increase over the land region of India in experiment E2. Thus our experiment shows that the 30% decrease in $A_N(i)$ yields slightly better for the rainfall distribution over the Indian region. To quantify the improvement of rainfall over the land region of India we have compared the simulated rainfall averaged over the central India region between the experiment E2 and C1 during the monsoon season from June to September. The rainfall averaged over the central India (15^0 N-30^0 N, 72.5^0E-85.5^0E) in case of experiments E2 and C1 is 5.32 mm/day and 3.98 mm/day respectively. Thus there is an increase of rainfall over central India in experiment E2 (with 30% reduction in CCWF) by 1.34 mm/day, which is 33.6% more than that from the value obtained from control experiment C1).

The results of experiments E3 and E4 with different values of REP are shown in Figure 4 and 5 respectively. When there is no re-evaporation (Figure 4a), the rainfall pattern over India does not improve, which is indicated from the difference E3-C1 as shown in Figure 4b. It is also seen that there is considerable reduction of rainfall over Indian land region with no re-evaporation. The rainfall averaged over central India (15^0 N-30^0 N, 72.5^0E-85.5^0E) for the experiments E3 and C1 is 3.0 mm/day and 3.9 mm/day respectively. However, when the REP parameter is 10% (Expt. E4), there is considerable improvement in rainfall as shown in Figure 5a with increase in rainfall over most part of Indian land region. The difference of rainfall E4-C1 is shown in Figure 5b, which shows the increase in rainfall over land region of India with rainfall over central India over the same region in experiment E4 is 5.1 mm/day, which is higher by 1.2 mm/day (30.7 %) from the control experiment C1. Thus it is seen that there is about 30% increase of rainfall over central India with 30% reduction in CCWF (Expt. E2) and by keeping the REP value at 10% (Expt. E4). Guided by these findings, we have carried out two more seasonal integrations combining the values from experiment E2 and E4. These are named as C2 and E5 as mentioned in Table 3. The second control experiment with observed SSTs is named as C2. The experiment E5 represents the combination of 30% reduction in CCWF and the REP as 10%. The results of comparison of C2 and E5 are shown in Figs. 6a, 6b and 6c. The improvement in rainfall over Indian region is clear from the difference of rainfall between the experiments E5 and C2 as shown in Figures 6c, with increase in rainfall over the land region of India and decrease in rainfall over the oceanic region (mainly Bay of Bengal region) in experiment E5. The rainfall averaged over central India and the Bay of Bengal regions with observed SST for experiments E5 and C2 are given in Table 4. It is seen from Table 4 that by using observed SSTs with modified values of CCWF and REP (Expt. E5), the rainfall over central India is also increased by 1.7 mm/day. At the same time over the Bay of Bengal region the excess precipitation observed in control experiment 'C2' is also decreased in experiment E5 by about 3.8 mm/day from its corresponding value from control experiment C2.

Table 4. The rainfall averaged over central India and Bay of Bengal region obtained from experiments E5 (CCWF reduced by 30% + EVP=10%) and C2 (control) with observed SST during June to September.

Rainfall over different regions	**Experiment 'E5'**	**Experiment 'C2'**	**Difference 'E5-C2'**
Bay of Bengal (5^0 N-20^0 N, 80^0 E-95^0 E)	9.9 mm/day	13.7 mm/day	-3.8 mm/day
Central India (15^0 N-30^0 N, 72.5^0 E-82.5^0 E)	5.1 mm/day	3.4 mm/day	1.7 mm/day

As the Outgoing Long wave Radiation (OLR) is a proxy for convection, the OLR simulated with experiment E5 and control experiment C2 along with the difference between these two are shown in Figure 7. The OLR anomalies are negative over central India in experiment E5 and positive over the Bay of Bengal (Fig. 7c). Thus the convective activity is decreased over Bay of Bengal and increased over central India in experiment E5 with modified values of CCWF and REP. As large part of tropical rainfall comes from deep cumulus clouds, this study shows that the rainfall distribution over Indian monsoon region is very sensitive to these convective parameters.

It may be mentioned here that the results of these sensitivity studies are based on single initial condition of 1st May. However, the results may change with different initial conditions considering the sensitivity of summer monsoon simulation to different initial conditions (Sperber and Palmer, 1996). But the main objective of this paper is to highlight that the changes in different convective parameters used in the RAS scheme may give slightly better simulation of Indian monsoon rainfall. An attempt will be made in future to carry out long term model integrations with different initial conditions with these modified values of CCWF and REP used in the RAS scheme to prepare the new model climatology of COLA GCM.

5 Conclusions :

The sensitivity of Indian summer monsoon rainfall to changes in different convective parameters used in the Relaxed Arakawa-Schubert (RAS) scheme of cumulus parameterization is investigated using the COLA GCM. Several seasonal integrations, based on different values of Critical Cloud Work Function (CCWF) and different values of Re-Evaporation (REP) parameter of convective rainfall used in the RAS scheme have been performed. starting from 1st May 1988 to 30th September 1988 with climatological Sea Surface Temperature (SST) and observed SSTs as boundary forcings.

The seasonal climatology from June to September of this model integration shows that the convective parameters used in the RAS scheme have significant effects on the distribution of Indian summer monsoon rainfall. The decrease in large-scale forcing calculated using the RAS scheme compared to that of original Arakawa-Schubert scheme is compensated by using a relatively lower value ,of Critical Cloud Work Function (CCWF) in the RAS scheme. Our present study shows that the rainfall distribution over the Indian monsoon region is reasonably better simulated with these modified values of CCWF and REP in the sense the excessive precipitation over the Bay of Bengal is reduced and there in also increase of precipitation over central India. The rainfall over central India is increased by about 30% in experiment E2 (CCWF value decreased by 30%) and in experiment E4 (by keeping the REP value at 10%). The results of these sensitivity studies are based on single initial condition. However, the results may change with different initial conditions considering the sensitivity of summer monsoon simulation to different initial conditions.

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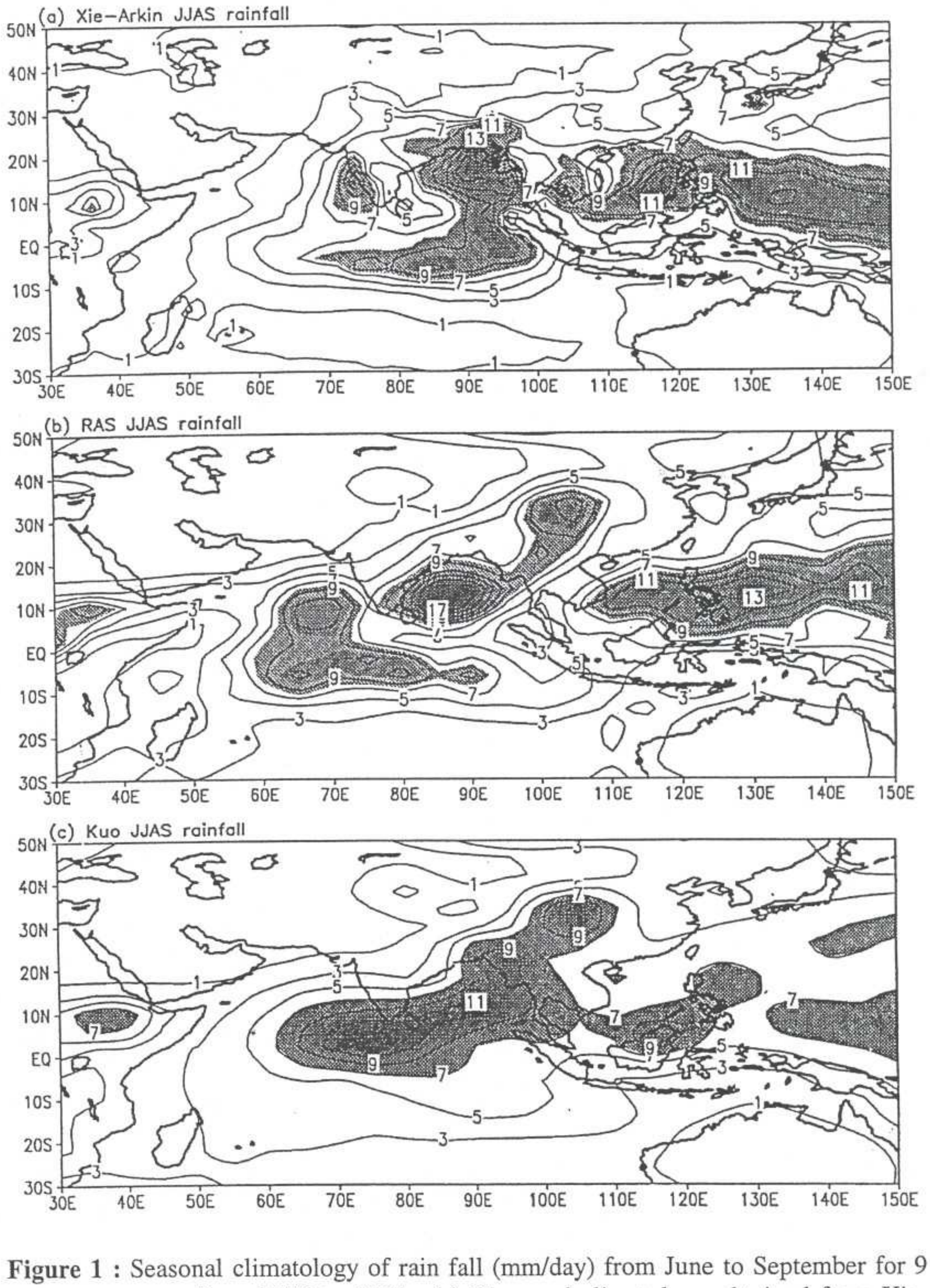

Figure 1 : Seasonal climatology of rain fall (mm/day) from June to September for 9 years from 1986 to 1994. (a) Observed climatology obtained from Xie-Arkin rainfall. (b) Simulated rainfall with the RAS scheme for the same period (c) Simulated rainfall with the Kuo scheme for the same period. (This figure obtained from Pattanaik and Satyan 2000)

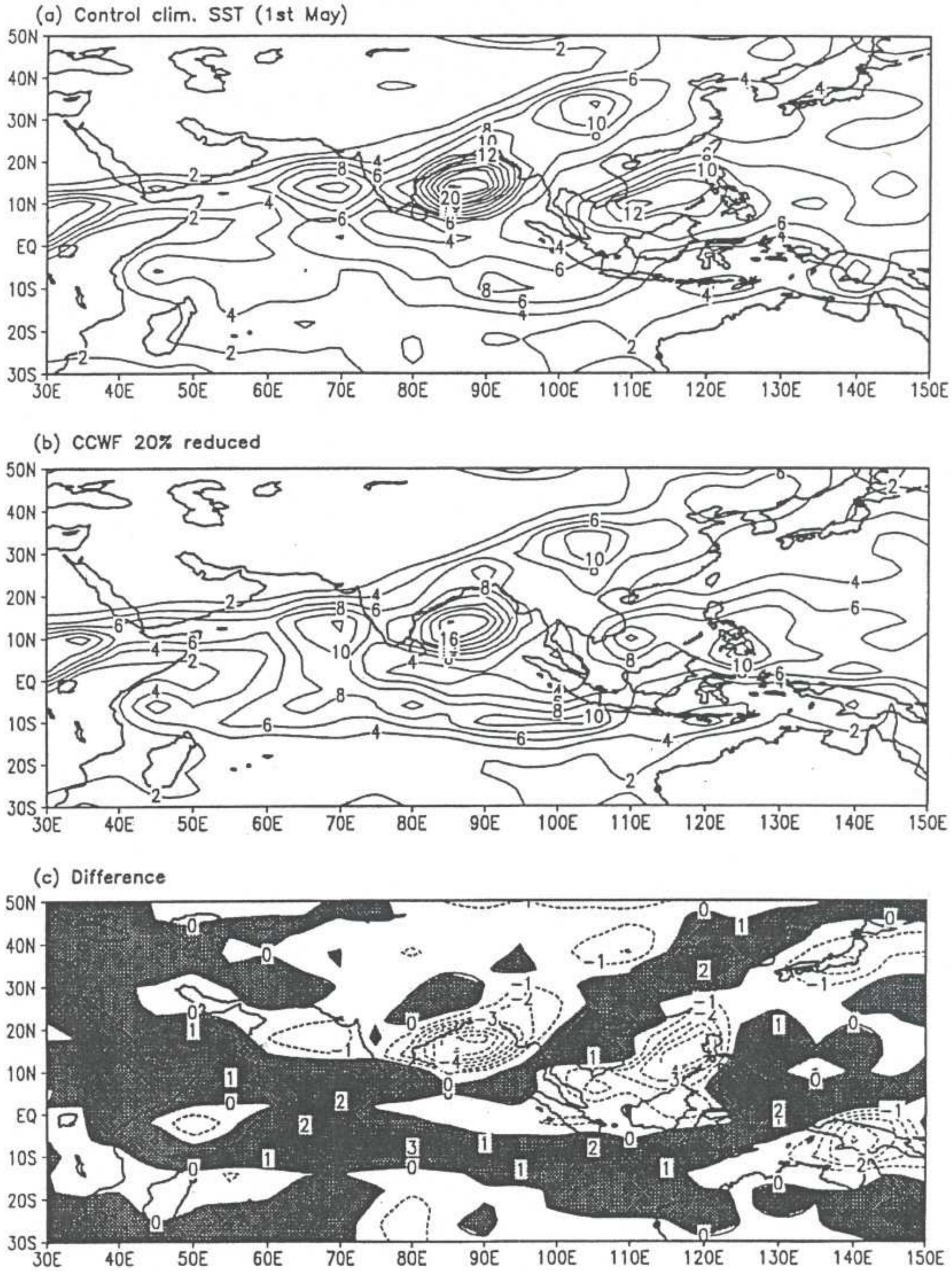

Figure 2 : Simulated rainfall from June to September (JJAS) in mm/day with climatological sea surface temperature (a) From the control experiment C1. (b) From the experiment E1 with 20% reduction in CCWF. (c) Difference E1-C1.

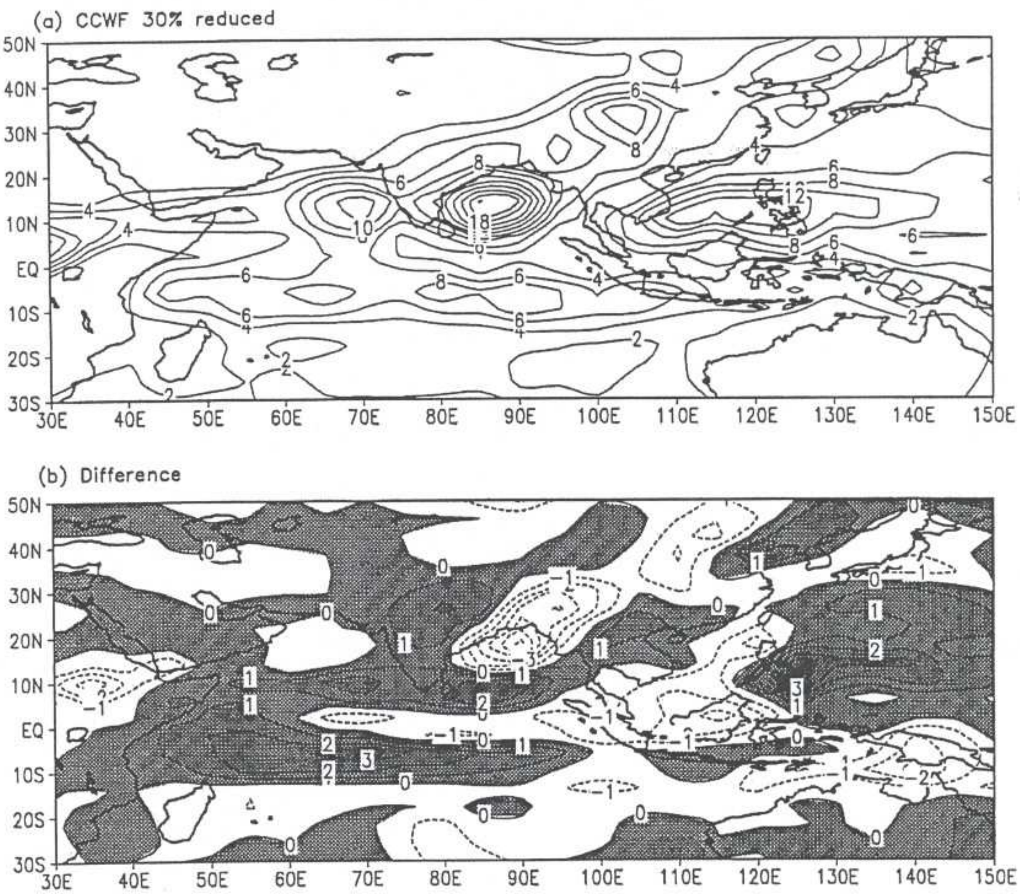

Figure 3 : Simulated rainfall from June to September (JJAS) in mm/day with climatological sea surface temperature (a) From the experiment E2 with 30% reduction in CCWF. (b) Difference E2-C1.

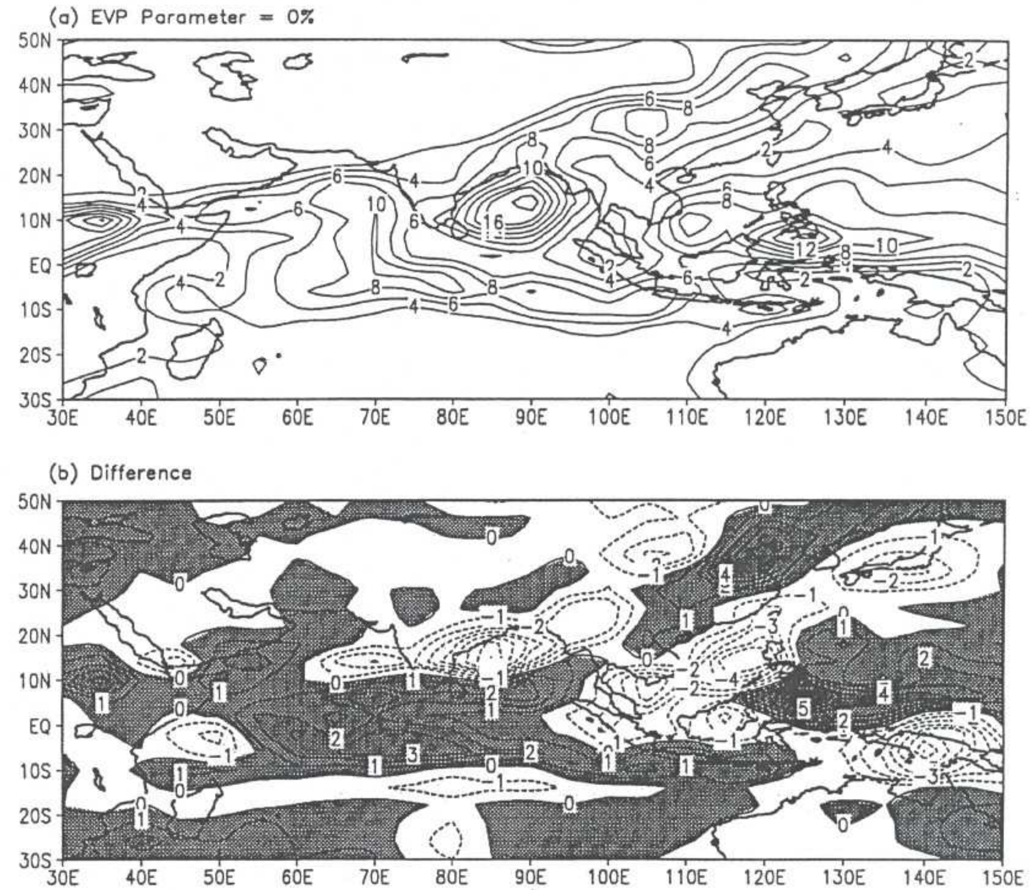

Figure 4 : Simulated rainfall from June to September (JJAS) in mm/day with climatological sea surface temperature (a) From the experiment E3 with no Re-evaporation (REP=0). (b) Difference E3-C1.

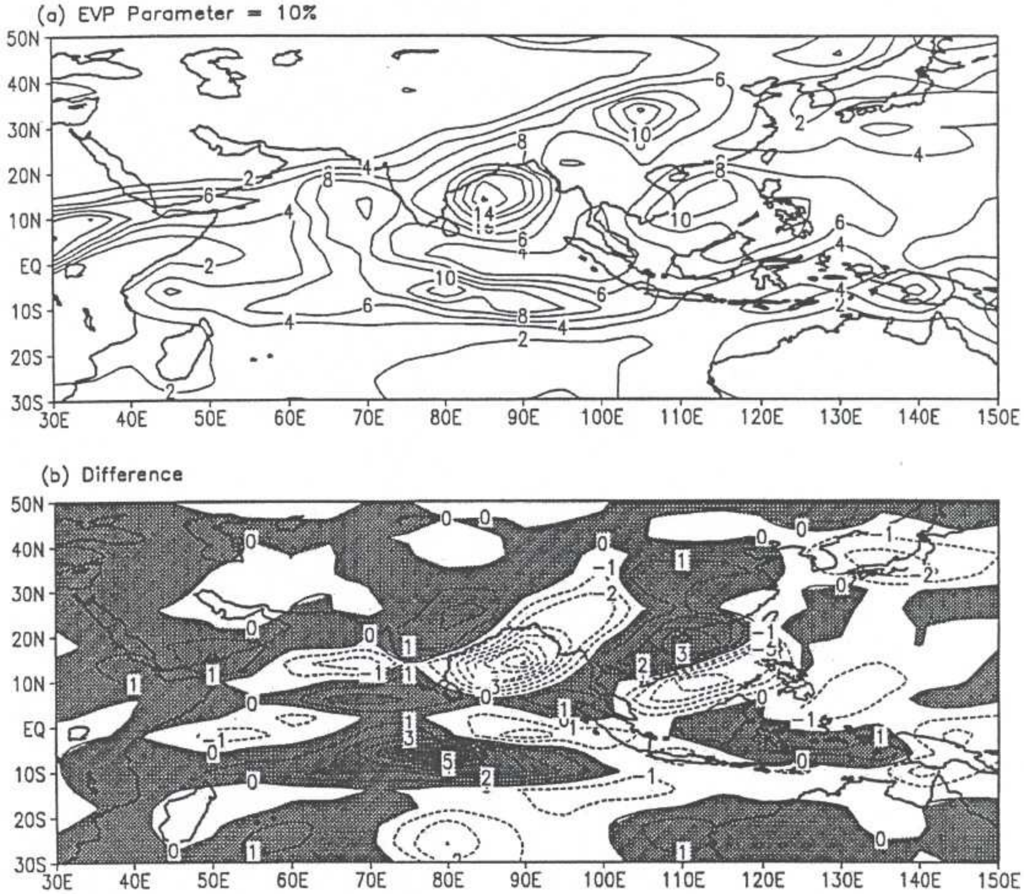

Figure 5 : Simulated rainfall from June to September (JJAS) in mm/day with climatological sea surface temperature (a) From the experiment E4 with no Re-evaporation (REP=0). (b) Difference E4-C1.

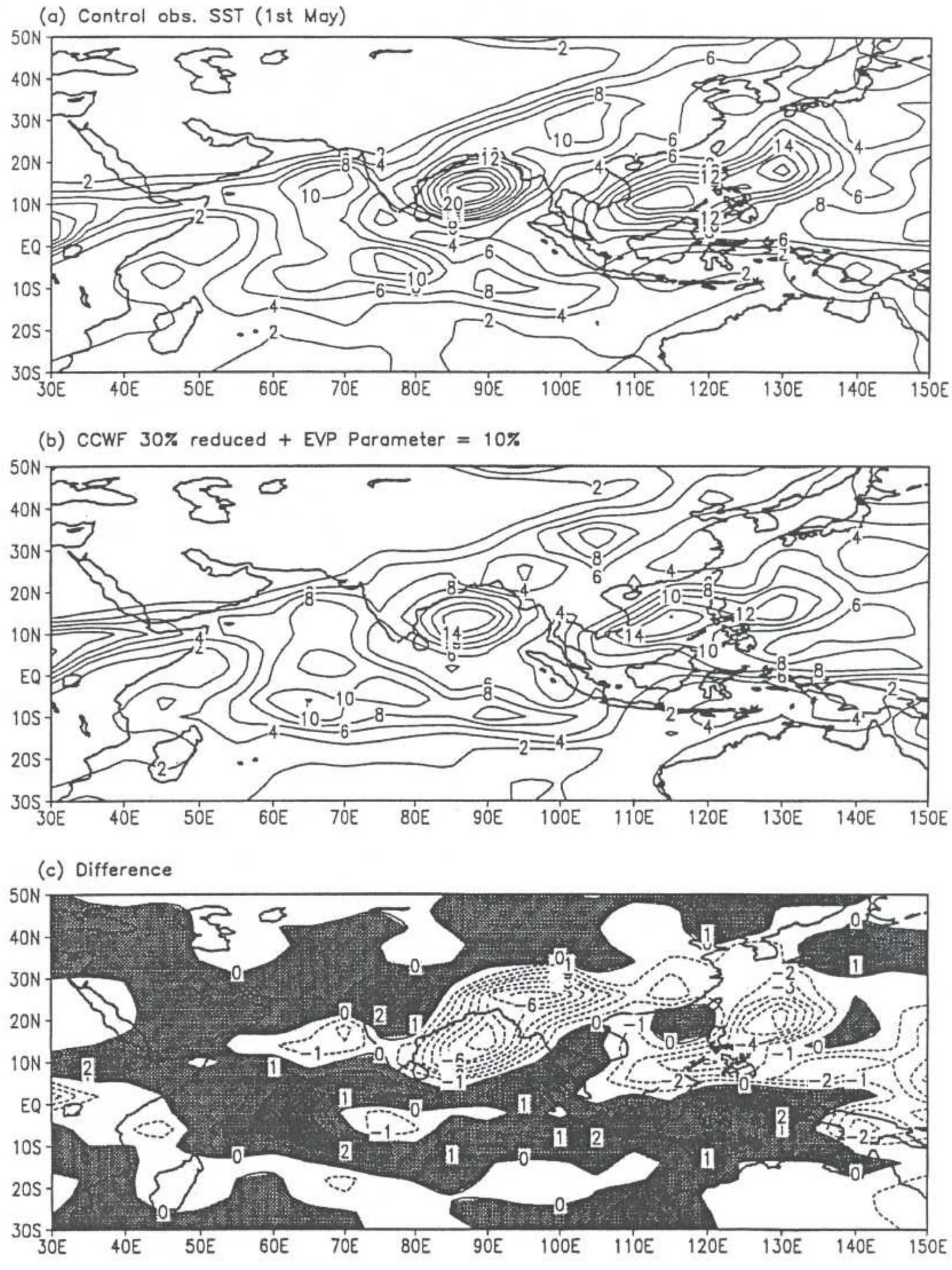

Figure 6 : Simulated rainfall from June to September (JJAS) in mm/day with observed sea surface temperature (a) From the control experiment C2. (b) From the experiment E5 with 30% reduction in CCWF and REP=10%. (c) Difference E5-C2.

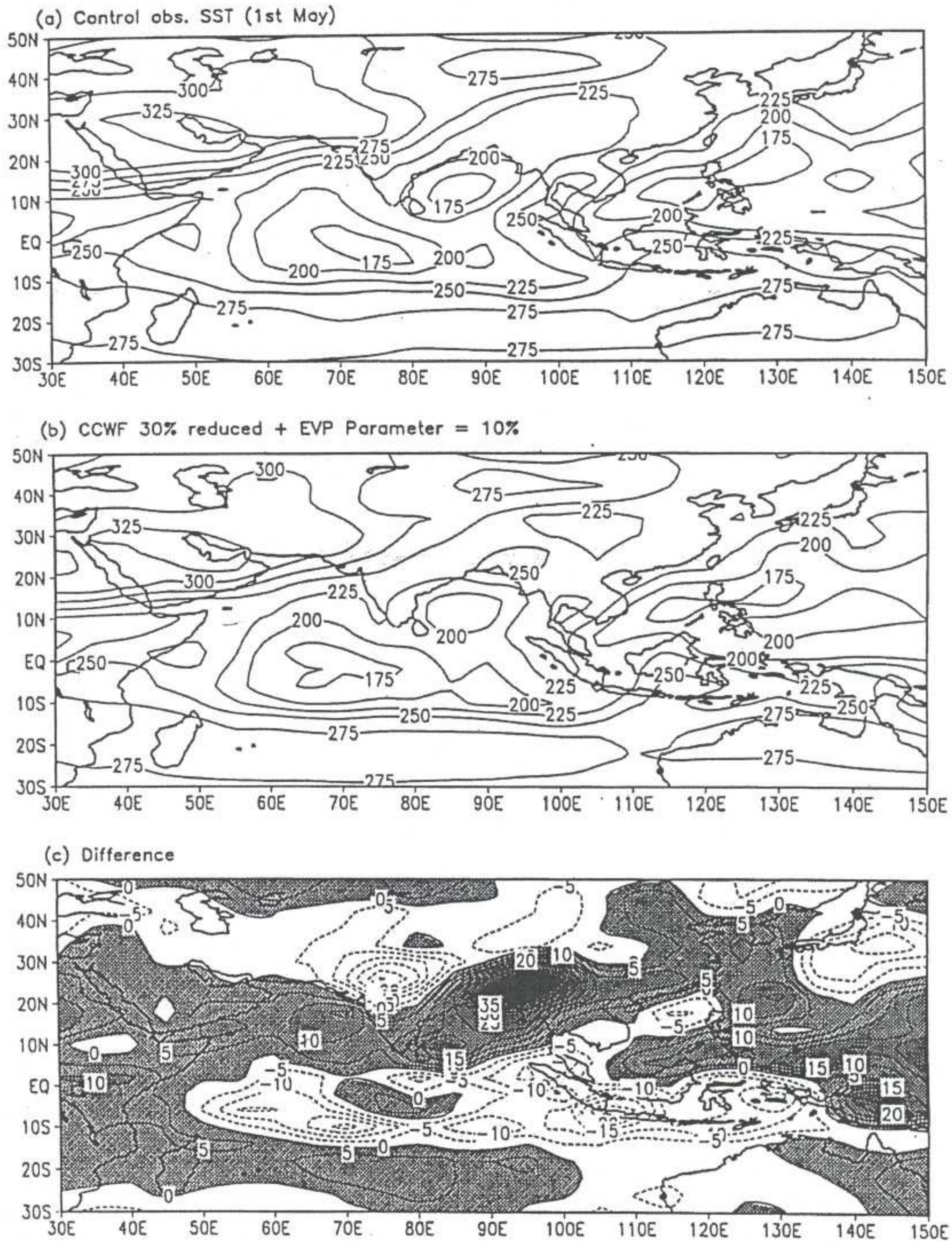

Figure 7 : Simulated Outgoing longwave radiation from June to September in watts/m^2 with observed sea surface temperature (a) From the control experiment C2. (b) From the experiment E5 with 30% reduction in CCWF and REP=10%. (c) Difference E5-C2.

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