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Simulations of frequency, intensity and tracks of cyclonic disturbances in the Bay of Bengal and the Arabian Sea

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सार – इस शोध पत्र में भूमंडलीय जलवायु परिवर्तन के परिणामस्वरूप बंगाल की खाड़ी (बी. ओ. बी.) और अरब सागर (ए. एस.) में उत्पन्न होने वाले चक्रवातों के पैटर्न में संभावित परिवर्तनों के निर्धारण के लिए किए गए प्रतिरूपी परिक्षणों के परिणामों को प्रस्तुत किया गया है। इसके लिए कंट्रोल (सी. टी. एल.) परीक्षण के अन्तर्गत 1990 के स्तरों के अनुसार वायुमंडल में ग्रीनहाऊस गैस सांद्रण निश्चित करने और ग्रीन हाऊस गैस (जी. एच. जी.) परीक्षण में 1990 के आगे से 1 प्रतिशत की वार्षिक संयुक्त वृद्धि को बताने के लिए उक्त दो परीक्षण किए गए। वर्ष 2041 से 2060 तक की 20 वर्षों की अवधि के सी. टी. एल और जी. एच. जी. परीक्षण किए गए। इसमें प्रयुक्त निदर्श क्षेत्रीय जलवायु निदर्श है जिसमें हैडले जलवायु पूर्वानुमान और अनुसंधान केन्द्र ब्रिटेन का आर. एम. 2 है।

इन परिणामेां से उत्तरी हिंद महासागर (बी. ओ. .बी. और ए. एस.) में चक्रवात के उत्पन्न होने के पैटर्न में कुछ महत्वपूर्ण परिवर्तनों का पता चला है। सबसे अधिक महत्वपूर्ण संभावित परिवर्तन बंगाल की खाडी में मानसून ऋतु के बाद आने वाले तूफानों की बारम्बारता में वृद्धि होना है। इन प्रयोगों से वायुमंडल में बढी हुई ग्रीनहाऊस गैस सांद्रण के परिणामस्वरूप 2041 से 2060 तक मानसून ऋतु के बाद चक्रवात के उत्पन्न होने में लगभग 50 प्रतिशत की वृद्धि के होने का पता चला है। जून – अगस्त में बंगाल की खाडी में मानसून अवदाबों / तूफानों की आवृत्ति कम होने की संभावना होती है। विभिन्न ऋतुओं में आवृत्ति के घटते–बढ़ते प्रभावों के कारण बंगाल की खाड़ी में चक्रवाती विक्षोंभों की वार्षिक आवृत्ति में कम परिवर्तन हो सकता है। तथापि अरब सागर में निदर्श से आवृत्ति में महत्वपूर्ण कमी आती है जो 2041 से 2060 की अवधि में आधी हो सकती है।

इन परिणामों से मई–जून और सितम्बर – नवम्बर में तूफानों की तीव्रता का पता चलता है। जुलाई– अगस्त में मानसून के अवदाब की तीव्रता में कमी हो सकती है।

जी. एच. जी. प्रयोग में मानसून के बाद आने वाले अधिकांश तूफानों में उत्तरी आंध्र–उड़ीसा के तटों से टकराने की प्रवत्ति होती है जबकि सी. टी. एल. प्रयोग में तमिलनाडु के तट से दक्षिणी उड़ीसा के तटों से तूफानों के टकराने की प्रवत्ति है। इस प्रकार बंगाल की खाडी में मानसून ऋतु के बाद आने वाले तूफानों की तमिलनाडु – आंध्र प्रदेश के तट से उत्तर की ओर तथा उत्तरी आंध्र प्रदेश उड़ीसा के दक्षिणी तट से उत्तर की ओर बढ़ने की संभावना मुख्य रूप से रहती है। तूफान के पथों में एक अन्य महत्वपूर्ण परिवर्तन है कि 2041 – 2060 तक बंगाल की खाडी में मानसून पूर्व तूफानों की अधिक संख्या से उत्तर अथवा उत्तर पूर्व की ओर पुनः वापस आने की प्रवत्ति हो सकती है।

ABSTRACT. The paper presents the results of simulation experiments conducted for the assessment of likely changes in the cyclogenesis pattern in the Bay of Bengal (BOB) and the Arabian Sea (AS) resulting from global climate change. Two experiments were performed, namely the ‘control’ (CTL) experiment in which the greenhouse gas concentration in the atmosphere was fixed as per 1990 levels and the ‘greenhouse gas’ (GHG) experiment in which an annual compound increase of 1% from 1990 onwards was introduced. CTL and GHG experiments of 20 years length were performed for the period 2041-2060. The model used is the regional climate model Had RM2 of the Hadley Centre of Climate Prediction and Research, U.K.

The results have brought out some significant changes in the cyclogenesis pattern in the North Indian Ocean (BOB and AS). The most significant likely change is the increase in the frequency of post-monsoon storms in the Bay of Bengal. The experiments show an increase of about 50% in the post-monsoonal cyclogenesis by 2041-2060 as a result of increased greenhouse gas concentrations in the atmosphere. The frequency of monsoon depressions / storms in the BOB is likely to decrease considerably during June-August. Due to varying impacts in different seasons, the annual frequency of cyclonic disturbances may change marginally in the BOB. In the Arabian Sea, however the model has simulated a significant reduction in the frequency which may be halved by the period 2041-2060.

The results show intensification of storms during May-June and September-November. The monsoon depressions during July-August are likely to become less intense.

In GHG experiment most of the post-monsoon storms have a tendency to strike north Andhra-Orissa coasts whereas in CTL experiment the storms strike coast from Tamilnadu to south Orissa. Thus, the focus of post-monsoon storms in the BOB is likely to shift northwards from Tamilnadu-Andhra Pradesh coast to north Andhra Pradesh-south Orissa coast. Another important simulated change in storm tracks is that more number of pre-monsoon storms in the BOB may have a tendency to recurve north or northeastwards by 2041-2060.

Key-words – Simulation, Climate model, Cyclonic disturbance, Storm track, Cyclogenesis, Greenhouse gas.

1. Introduction

Proper assessment of regional impacts of global climate change resulting from anthropogenic emissions is necessary for preparedness programmes. According to recent estimates by 2040-2069 the increase in greenhouse gas concentrations in the atmosphere could result in an increase of about 1.5° C - 3.0° C in surface air temperature in south Asia during cyclone seasons (IPCC, 2007).

In recent decades, there have been some perceptible changes in the cyclogenesis pattern in the north Indian Ocean (Bay of Bengal and Arabian Sea). For instance, there has been a downtrend in the frequency of monsoon depressions and storms (Singh and Khan, 1999, Singh, 2001; Patwardhan and Bhalme, 2001). On the other hand the frequency of severe cyclonic storms has shown an uptrend during the intense cyclonic period of the year, namely, May, October and November (Singh *et al*., 2001). Thus the impacts of atmospheric and oceanic warming on the cyclogenesis in the North Indian Ocean seem to vary from season to season (even from month to month).

The main objective of present work is to simulate the characteristic features of north Indian Ocean cyclogenesis, *i.e*., the frequency, intensity and tracks of storms using the regional climate model, Had RM2. Earlier, the model has been used to simulate the characteristic features of Asian summer monsoon (Singh *et al*., 2006) and the rainfall and temperature scenarios over the Indian subcontinent (Bhaskaran *et al*., 1996; Bhaskaran and Mitchell, 1998; Rupakumar and Ashrit, 2001).

2. Model and experiments

Had RM2 is a second generation regional climate model of the Hadley Centre for Climate Prediction and Research, U.K. It is a high resolution climate model which covers a limited area of 5000 km × 5000 km. The horizontal resolution of the model is 0.44° × 0.44° *i.e*., about. 50 km × 50 km at the Equator with 19 hybrid vertical levels. The initial conditions to start the model are taken from the second generation coupled ocean-atmosphere model Had CM2. The atmospheric component of Had RM2 is a hydrostatic primitive equation model with 19 hybrid vertical coordinate levels, lowest at about 50 m and highest at 0.5 hPa (Cullen, 1993). The model equations are solved in spherical coordinates. The model needs a time step of 5 minutes to maintain the numerical stability (Jones *et al*., 1995). The radiation scheme includes seasonal and diurnal cycles of insolation, computing short-wave and long-wave fluxes that depend upon temperature, water vapour, O_3, CO_2 and clouds (Jones *et al*., 1995).

The experiments, namely CTL and GHG of 20 years length each have been conducted for the period 2041-2060. In CTL the greenhouse gas concentration is kept constant (at 1990 level) whereas in GHG an annual compound increase of 1% per annum has been introduced. The storms in the Bay of Bengal and the Arabian Sea have been identified in both the experiments separately. The criteria used for the identification of storms, in addition to the local minimum was:

(*i*) Sea level pressure departure (SLP) < -5hPa,

(*ii*) Maximum wind speed > 15m/s and

(*iii*) Duration of storm at least 2 days.

All cyclonic disturbances (storms) in the Bay of Bengal and the Arabian Sea during the 20 years period from 2041-2060 were identified in CTL and GHG experiments to assess the impacts of enhanced greenhouse gas emissions (and consequent warming) on the frequency, intensity and tracks of storms in the Bay of Bengal and the Arabian Sea.

3. Results and discussion

3.1. *Simulated frequencies of cyclonic disturbances*

Monthly and seasonal frequencies of cyclonic disturbances as simulated by HadRM2 are presented in Tables 1 and 2. Before comparing the results for CTL and GHG experiments, it is necessary to assess the closeness of CTL frequencies with observed average frequencies as CTL represents the existing climatic conditions. The

TABLE 1

Simulated monthly frequency of cyclonic disturbances in the north Indian Ocean (Bay of Bengal and Arabian Sea) for 2041-2060

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
CTL	0	0	0	1	17	19	31	28	24	26	18	10	176
GHG	0	0	0	1	16	14	18	21	33	29	15	3	151

TABLE 2

Simulated seasonal frequency of cyclonic disturbances in the Bay of Bengal and Arabian Sea for 2041-2060

Experiment	Pre-monsoon		Monsoon		Post-monsoon		Annual	
	Bay of Bengal	Arabian Sea	Bay of Bengal	Arabian Sea	Bay of Bengal	Arabian Sea	Bay of Bengal	Arabian Sea
CTL	11	7	74	28	21	23	113	63
GHG	15	2	72	14	31	14	121	30

model simulated highest number of cyclonic disturbances *i.e*., 5 per season during the monsoon which is very close to the long-term average frequency (4-5) of the monsoon depressions. However, in recent decades the frequency of monsoon depressions has gone down and therefore, the model-simulated frequencies, though close to the normal, do not reveal the observed downtrends. The frequency of cyclonic disturbances in the north Indian Ocean during post-monsoon is about 2 per season in CTL experiment which is also close to the observations but the model seems to simulate higher/lower frequency in the Arabian Sea/ Bay of Bengal (Table 2). The simulated frequency during pre-monsoon is about 1 per season which is again close to the normal frequency.

Thus the simulated seasonal and annual frequencies of cyclonic disturbances in the north Indian Ocean are close to the observed frequencies. However, the model seems to simulate higher than normal frequencies in the Arabian Sea. Significant differences in the simulated storm frequencies were observed in the Arabian Sea in GHG and CTL experiments. In GHG experiment, the annual frequency in the Arabian Sea decreased by 50% as compared to CTL *i.e*., from 3 storms every year (CTL) to 3 storms every 2 years (GHG), which shows that the annual frequency of storms in the Arabian Sea is likely to decrease in coming decades. The simulated monthly frequencies show that the number of monsoonal cyclonic disturbances decreased considerably during June-Aug in GHG experiment. During September, however, the frequency increased. The frequency of pre and post-monsoon storms increased in the Bay of Bengal in GHG experiment by about 25% and 50% respectively, showing an uptrend in the frequency of intense storms in the Bay of Bengal.

The observed trends in the frequencies of monsoonal cyclonic disturbances and intense storms of pre and post-monsoon seasons in recent decades also show similar pattern (Singh, 2001 and Singh *et al*., 2001). The model has simulated a total of 151 disturbances in the north Indian Ocean in GHG experiment as compared to 176 in CTL experiment during the 20 years period from 2041-2060 which shows a slight reduction in the annual frequency. The observed trends in the annual frequency of cyclonic disturbances in the north Indian Ocean (Bay of Bengal & Arabian Sea) in recent decades also show a downtrend, though not significant (Singh & Khan, 1999). Thus the model-simulated seasonal and annual trends in the storm frequencies in GHG experiment are in good agreement with the observed trends in recent decades, though the magnitudes vary. For instance, the observed downtrend in the frequency of monsoon depressions is much more than the downtrend projected by Had RM2. Similarly, the uptrend in the frequency of post-monsoon storms of Bay of Bengal simulated by the model is steeper than the observed trends.

3.2. *Changes in the intensity of cyclonic disturbances*

In addition to the frequency, the intensity of storms is another important feature of cyclogenesis. Any change in the average intensity of storms is linked to the

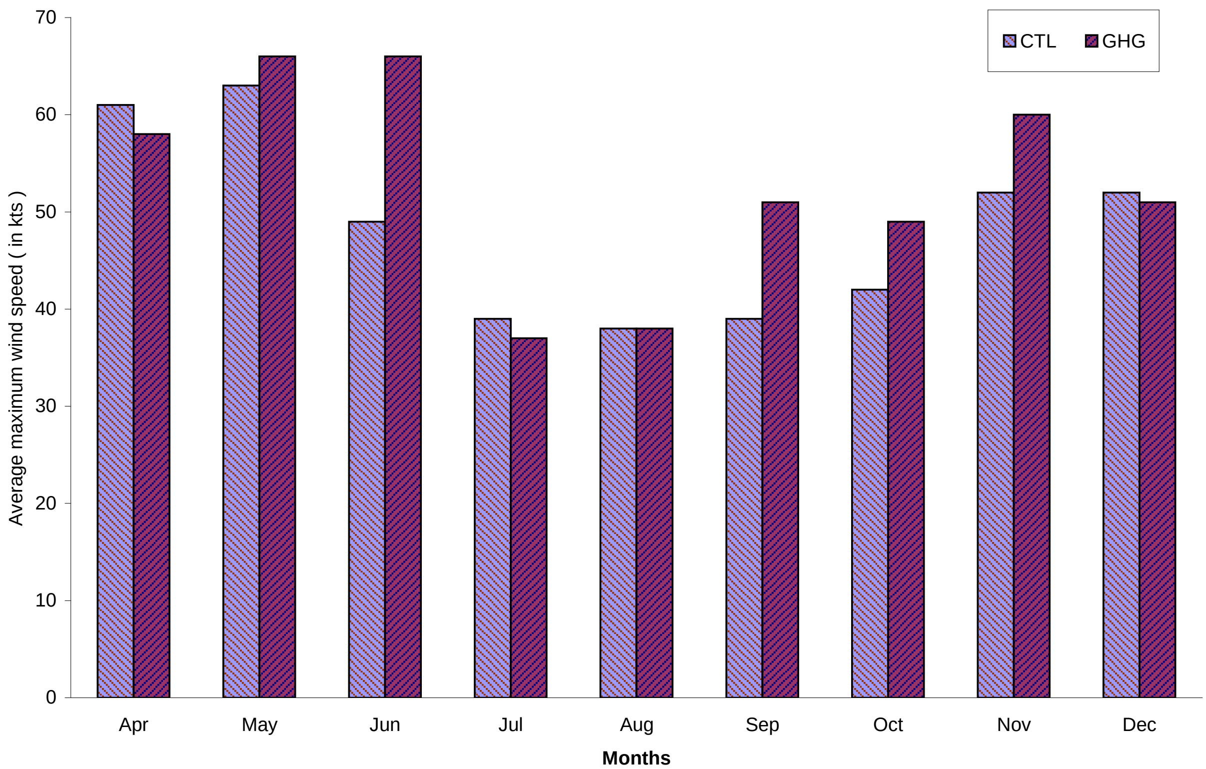
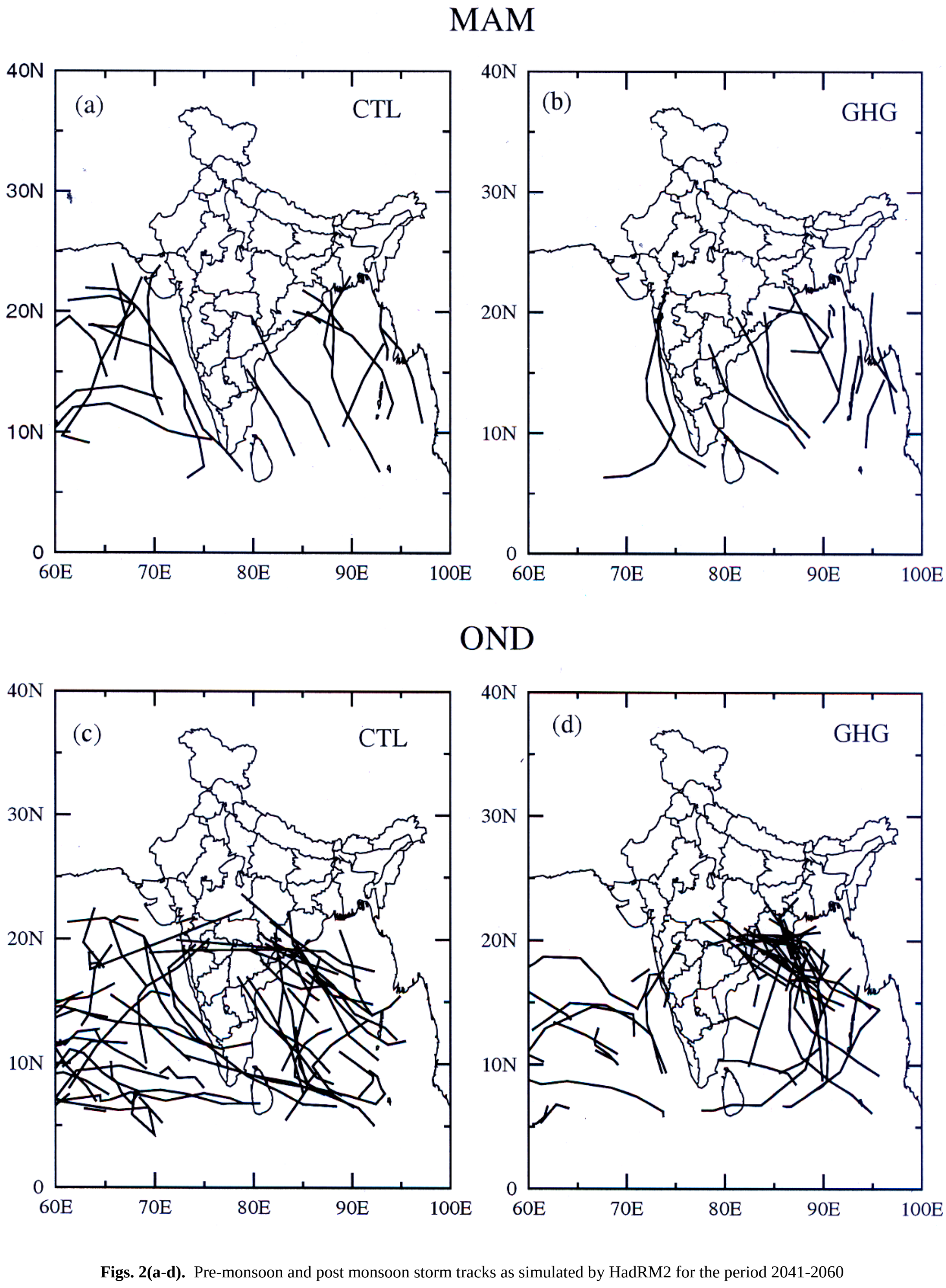


Fig. 1. Average maximum wind speed of cyclonic disturbances in CTL and GHG experiments

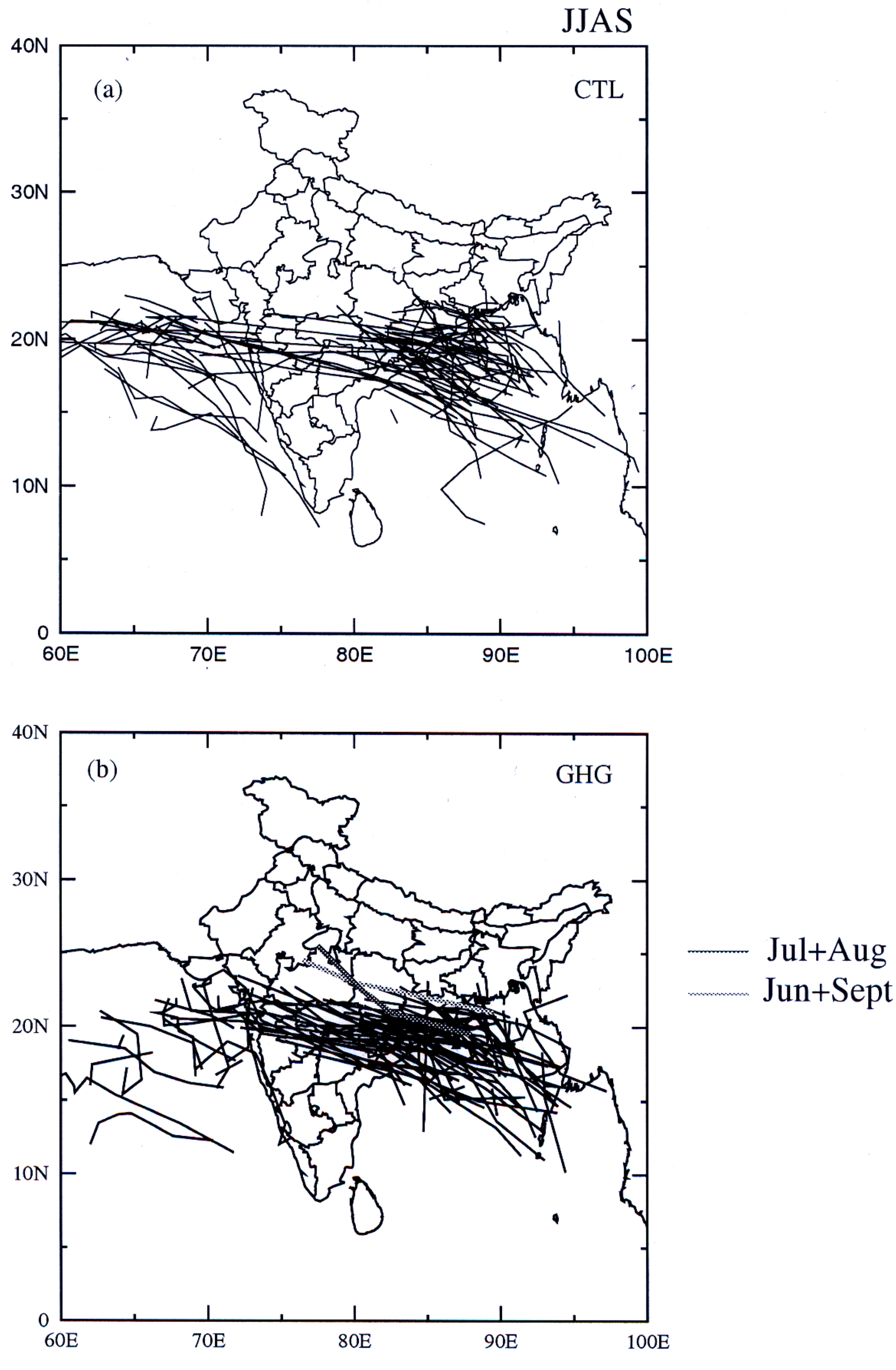
intensification or weakening of the storms in coming decades. Keeping this in view, the average maximum wind speed associated with the cyclonic disturbances forming in each month was computed for CTL and GHG experiments and the results are presented in Fig. 1. It is interesting to note that June storms are likely to intensity significantly. Average maximum wind speed of June disturbances increased to 66 kts in GHG as compared to 50 kts in CTL. Therefore, the number of intense storms is likely to increase during June, though the total number of disturbances may be reduced. This may be an indication of the extension of pre-monsoonal features in June. Similarly, the increase of average maximum wind speed of disturbances in GHG experiment during September-November is indicative of early onset of post-monsoonal features implying the truncation of southwest monsoon season in coming decades (Bhaskaran and Mitchell, 1998). As revealed by Fig. 1 the average intensity of monsoon depressions during July decreased in GHG as compared to CTL. The model simulated a reduction in the average intensity of cyclonic disturbances during December and April also. Thus the main features of intensity simulations is that the storms of intense cyclonic period May-June and September-November may intensity whereas the monsoon depressions of July-Aug may weaken in coming decades.

3.3. *Simulation of storm tracks*

The information on the track of movement of a storm is necessary to determine the landfall point on the coast and therefore, it is very important in disaster management. Any change in the normal tracks of north Indian Ocean storms in different seasons due to climate change may have far reaching consequences in the region, especially in the countries bordering the Bay of Bengal, namely India, Bangladesh, Myanmar and Sri Lanka. As Bay cyclones inflict heavy loss of life and property in the region, it is necessary to simulate the likely changes in their storm tracks resulting from the climate change due to anthropogenic activity. On an average about 5-6 storms form in the Bay of Bengal every year, of which about 2 may reach to severe stage. Post-monsoon storms are most disastrous which have a tendency to strike Andhra Pradesh/Tamil Nadu coasts of India. Some of these storms may strike Sri Lanka coast. A few of them may recurve and hit Bangladesh and Myanmar coasts also. Pre-monsoon storms of the Bay of Bengal have a tendency to



Figs. 2(a-d). Pre-monsoon and post monsoon storm tracks as simulated by HadRM2 for the period 2041-2060



Figs. 3(a&b). Monsoon storm tracks as simulated by HadRM2 for the period 2041-2060 recurve north/northeastward and generally strike Orissa/West Bengal coasts. These observed features are well simulated by Had RM2 in CTL tracks Figs. 2(a-d).

A few significant changes were found in the storm tracks for 2041-2060 simulated by the model in GHG experiment. Most important change is the northward shift of the affected zone during post-monsoon (OND). Most of the Bay storms strike Orissa/north Andhra Pradesh coasts in GHG and only few of them strike Tamil Nadu/south Andhra Pradesh coasts. During pre-monsoon (MAM) there is a tendency for more storms to recurve north/northeastward in GHG experiment as compared to CTL experiment. The significant reduction in the storm frequency in the Arabian Sea is clearly brought out by Figs. 2(a-d). An important change in the Arabian Sea storm tracks seems to be that more storms are likely to hit Maharashtra coast near Mumbai during pre-monsoon in GHG experiment which is not the case with CTL experiment.

Figs. 3(a&b) depicts the simulated tracks during southwest monsoon (JJAS). The tracks of monsoon depressions generally remain along the monsoon trough zone in both the experiments. The significant difference, however seems to be in the length of tracks. In CTL more depressions seem to traverse central India and emerge into the Arabian Sea whereas in GHG most of the depression tracks get truncated in Maharashtra.

4. Conclusions

The simulation experiments have brought out the following results

(*i*) The model has simulated an increase in the frequency of post-monsoon cyclonic disturbances in the Bay of Bengal by 50% by the period 2041-2060 as a result of increased greenhouse gas emissions in the atmosphere.

(*ii*) In the Arabian Sea, the model has simulated a significant reduction in the annual frequency of cyclonic disturbances in coming decades.

(*iii*) The simulation experiments have shown a reduction in the frequency of monsoon depressions in the Bay of Bengal during July-Aug.

(*iv*) Due to varying impacts of increased anthropogenic emissions on the cyclogenesis in different seasons, the annual frequency of storms in the north Indian Ocean (Bay of Bengal and Arabian Sea) is not likely to change much. The model has simulated slight reduction in the annual frequency which is in agreement with the observed trends in recent decades.

(*v*) The model has simulated the intensification of storms formed during May-June and September-November and weakening of monsoon depressions during July-Aug.

(*vi*) Most of the Bay of Bengal storms of post-monsoon season strike Orissa/north Andhra Pradesh coasts in the greenhouse gas experiment instead of Tamil Nadu/Andhra Pradesh coasts as observed in the control experiment.

Acknowledgement

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