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A diagnostic study on the energetics aspects of hiatus in the advance of southwest monsoon

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सार – मानसून के आगमन के पश्चात् दक्षिणी पश्चिमी मानसून का आगे बढ़ना प्रायः एक सप्ताह अथवा इससे अधिक समय के लिए रूक जाता है जो किसानों और अन्य समुदायों के लिए चिंता का कारण बन जाता है क्योंकि इनके कार्यकलाप मौसम पर निर्भर होते हैं। भारत में दक्षिणी पश्चिमी मानसून मानसून के आगे बढ़ने में प्रांतराल के ऊर्जा विज्ञान के पहलू पर किए जा रहे अध्ययन का उद्देश्य इसकी गतिकीय कारणों का पता लगाना है। वर्ष 1982-2006 के दौरान दस दिनों से अधिक की अवधि के प्रांतराल के नौ मामलों को चुना गया है। प्रत्येक प्रांतराल के मामले में प्रांतराल की अवधि के दौरान विभिन्न ऊर्जा की मदों, विभिन्न संदर्भों में उनके उत्पादन और विलोमन का आकलन तथा 65° पू. से 90° पू., 5° उ. से 30° उ के मध्य सीमित क्षेत्र में प्रांतराल-पूर्व पचदिवसावधि का भी आकलन किया गया है। ये आकलन अलग - अलग प्रांतराल अवधि और परवर्ती प्रांतराल-पूर्व पचदिवसावधि के दौरान एन.सी.ई.पी. 2.5° × 2.5° पुनः विश्लेषित दैनिक संयुक्त आँकड़ों पर आधारित हैं।

इस अध्ययन से यह पता चला है कि :

(*i*) अधिकांश मामलों में प्रांतराल–पूर्व पचदिवसावधि की तुलना में प्रांतराल अवधि के दौरान क्षेत्रीय रूप से उपलब्ध संभाव्य ऊर्जा [$G(A_z)$] के उत्पादन में कमी आई है।

(*ii*) अधिकांश मामलों में प्रेक्षित प्रांतराल अवधि के दौरान क्षेत्रीय रूप से संभाव्य ऊर्जा से क्षेत्रीय गतिकीय ऊजा [$C(A_z, K_z)$] के रूपांतर में कमी आई है।

(*iii*) अधिकांश मामलों में प्रांतराल–पूर्व पचदिवसावधि की तुलना में प्रांतराल अवधि के दौरान क्षेत्रीय गतिक ऊर्जा (K_z) और भंवर गतिक ऊर्जा का (K_E) में कमी आई है।

ABSTRACT. Advance of southwest monsoon, after its onset, often gets stalled for a week or more causing concern to the farmers and other community whose activities are weather dependent. The present study on the energetics aspect of hiatus in the advance of southwest monsoon over India aims at understanding the dynamical reasons for this. Nine cases of hiatus of duration more than 10 days during 1982-2006 have been selected. For each hiatus case, different energy terms, their generation and conversion among different terms have been computed during the hiatus period and also during the pre-hiatus pentad over a limited region between 65° E to 90° E, 5° N to 30° N. These computations are based on NCEP 2.5° × 2.5° re-analysed daily composite data during different hiatus period and during corresponding pre-hiatus pentad.

From this study it is found that :

(*i*) In most of the cases there is a reduction in the generation of zonal available potential energy [$G(A_Z)$] during hiatus period compared to pre-hiatus pentad.

(*ii*) Drop in the conversion from zonal available potential energy to zonal kinetic energy [$C(A_Z, K_Z)$] during hiatus period has been observed in most of the cases.

(*iii*) In most of the cases there is a reduction in zonal kinetic energy (K_Z) and in eddy kinetic energy (K_E) during hiatus period compared to pre-hiatus pentad.

Key words – Hiatus, Energetics.

1. Introduction

Southwest monsoon progresses over India, generally, in a direction from south to north in the peninsular and central India and from east to west over northern parts of the country. The normal onset date of southwest monsoon over Kerala is 1st June and the date of covering the entire country is 15th July. But there are wide variations to this travel time of monsoon in different years. Whereas the onset of Indian summer monsoon over Kerala is of importance, the advance of monsoon over other parts of the country is also equally important. The advance of monsoon is not a continuous process rather it is pulsatory in nature. There are several years when a hiatus occurs and the northward or westward propagation of monsoon is arrested. Most of the years there are only short lulls of 7-10 days, but there are years when this stalling of the hiatus of monsoon continues for over two weeks period. Such hiatus causes concerns to the farmers and other weather dependent activities.

Kesavamurty & Awade (1970) found that maintenance of mean monsoon trough against frictional dissipation is mainly due to work done by horizontal pressure gradient. Their study also indicates a loss in standing eddy kinetic energy by rising of relatively colder air and sinking motion of relatively warmer air.

Rao & Rajamani (1972) studied the heat source & sinks and generation of available potential energy of the atmosphere over the Indian region during southwest monsoon season. Their computation showed a net generation of APE over the region of study.

Krishnamurty & Ramanathan (1982) have shown that a sharp rise in the rotational kinetic energy is an interesting aspect of onset of Indian Summer Monsoon (ISM). Awade and Bawiskar (1982) have shown that bad monsoon activity is associated with large divergence of heat at sub-tropics and large convergence of heat at extra tropics. According to Pasch (1983) the onset of planetary scale monsoon is preceded by an organization of cumulus convection on the planetary scale. Awade *et al*., (1985) have shown that in good monsoon years there is large divergence of momentum in sub-tropics, while there is large convergence of momentum in mid latitude. They argued that this situation leads to a stronger westerly in mid-latitude and stronger easterly at tropics. Krishnamurty (1985) has shown that divergent kinetic energy, must be transferred to rotational kinetic energy, available potential energy must be transferred to divergent kinetic energy *via* rising motion over warm region/ sinking motion over cold region. He has also shown that available potential energy is maintained *via* heating of warmer air & cooling of colder air. Rajamani (1985a) computed the diabatic heating and generation of APE over south Asia for typical monsoon month July 1963. The study has inferred positive generation of both zonal and standing eddy APE. Rajamani (1985b) made a study on available potential energy (APE) and its transformation into kinetic energy. This study shows that differential heating between Asian landmass and Indian ocean causes the generation of zonal APE (A_z), a part of which is converted into zonal kinetic energy (K_z). The study also indicates that diabatic heating generates standing eddy APE (A_E), which is again converted into standing eddy kinetic energy. Ramasastry *et al*., (1986) brought out some features of the process of hiatus. Krishnamurti & Surgi (1987) have shown that around the period of the onset of monsoon rains over India, there is a sharp rise in the conversion of zonal available potential energy (A_z) to zonal Kinetic energy (K_z).

Yanai *et al*., (1992) have shown that reversal of north-south temperature gradient in the layer between 700 and 200 hPa triggers the onset of South Asian monsoon. George and Mishra (1993) had examined the temporal variations of the zonal and eddy kinetic and available potential energy in association with the formation, growth and maintenance of vortex during southwest monsoon. Their study indicated that barotropic eddy energy transfer dominates over baroclinic eddy energy transfer. They have also showed that $C(K_z, K_E) > C(A_E, K_E)$. Biswas *et al*., (1998) have studied the role of the mechanical barrier of the Himalayan massif – Tibetan plateau and the mid tropospheric sub-tropical ridge in the hiatus in the advance of southwest monsoon.

Krishnamurti *et al*., (1998) studied the energetics of south Asian monsoon. Using FSU Global spectral model at T 170 resolution, they examined the maintenance of the monsoon. This study indicates that differential heating leads to the growth of APE, which is next passed on to the divergent motions and then finally divergent K.E. is converted to rotational K.E, which of course critically depends on the orientation of the isopleths of ψ and χ. Results of the study by Wu and Zhang (1998) are in conformity with that of Yanai *et al*., (1992). These studies indicate that during the onset of South Asian monsoon there is a sudden increase in the zonal available potential energy.

Raju *et al*., (2005) studied the onset characteristics of the southwest monsoon over India. Their study reveals that the low level kinetic energy, vertically integrated generation of kinetic energy and net tropospheric moisture can be used as potential predictors to predict the onset of southwest monsoon. Rao and Mohanty (2007) have shown that the onset of the Indian southwest monsoon over the Bay of Bengal is discernible by a gradual increase in the adiabatic generation of kinetic energy, while over the Arabian Sea it is first noticeable by a steep and abrupt increase of generation.

From the foregoing discussion it appears that hardly there is any study on the energetic aspects of hiatus, although there are ample studies on energetics during onset and energetics on monsoon disturbances.

The present study aims at analyzing the energetic aspects of hiatus of southwest monsoon.

2. Data

The different cases of hiatus period in the advance of SW monsoon have been obtained from the isochrones of monsoon advance prepared by the India Meteorological Department. For the present study we have used data for *u*, *v*, ω, *T*, rh obtained from NCEP/NCAR. We have used daily composite data of the above fields for the hiatus period and for pre-hiatus pentad of individual cases over the limited region between 5° N and 30° N, 65° E and 90° E.

3. Methodology

First, from the temperature data, at each grid point, heating rate $\frac{\dot{Q}}{C_p}$ has been computed using first law of thermodynamics $\frac{\dot{Q}}{C_p} = \frac{dT}{dt} - \frac{\alpha}{C_p}\omega$. In the computation of $\frac{dT}{dt}$, tendency has not been taken care of. Then, following Krishnamurty and Bounoua, (2000), zonal average, area average, deviation from the area average, deviation from zonal average and finally the departure of the zonal average from area average of an arbitrary field 'S' have been computed as below:

Zonal average $$[S] = \frac{1}{\lambda_e - \lambda_w}\int_{\lambda_w}^{\lambda_e} S\,d\lambda \qquad (1)$$

Area average

$$\overline{S} = \frac{1}{\sin\varphi_n - \sin\varphi_s}\int_{\varphi_s}^{\varphi_n}[S]\cos\varphi\,d\varphi \qquad (2)$$

Departure from area average

$$S'' = S - \overline{S} \qquad (3)$$

Departure from zonal average

$$S' = S - [S] \qquad (4)$$

Departure of zonal average from area average

$$S^* = [S] - \overline{S} \qquad (5)$$

Then using Eqns. (1-5), zonal averages, area averages, departure from zonal and area average and finally zonal eddy components of the above fields, including heating rate, have been computed. Using these averages and zonal eddies, following Krishnamurty & Bounoua (2000), zonal available potential energy (A_z), zonal kinetic energy (K_z), eddy available potential energy (A_E), eddy kinetic energy (K_E), generation of zonal available potential energy [G(A_z)], generation of eddy available potential energy [G(A_E)], conversion of A_z to A_E[C(A_z, A_E)], conversion of A_z to K_z [C(A_z, K_z)], conversion of A_E to K_E [C(A_E, K_E)] and conversion of K_z to K_E [C(K_z, K_E)] have been computed as below:

$$(A_z) = \int_{100}^{P_s}\frac{\overline{T^{*2}}}{2\sigma}\,dp \qquad (6)$$

$$(A_E) = \int_{100}^{P_s}\frac{\overline{T'^2}}{2\sigma}\,dp \qquad (7)$$

where, σ is the static stability parameter of the atmosphere.

$$K_z = \frac{1}{2g}\int_{100}^{P_s}\overline{\left([u]^2 + [v]^2\right)}\,dp \qquad (8)$$

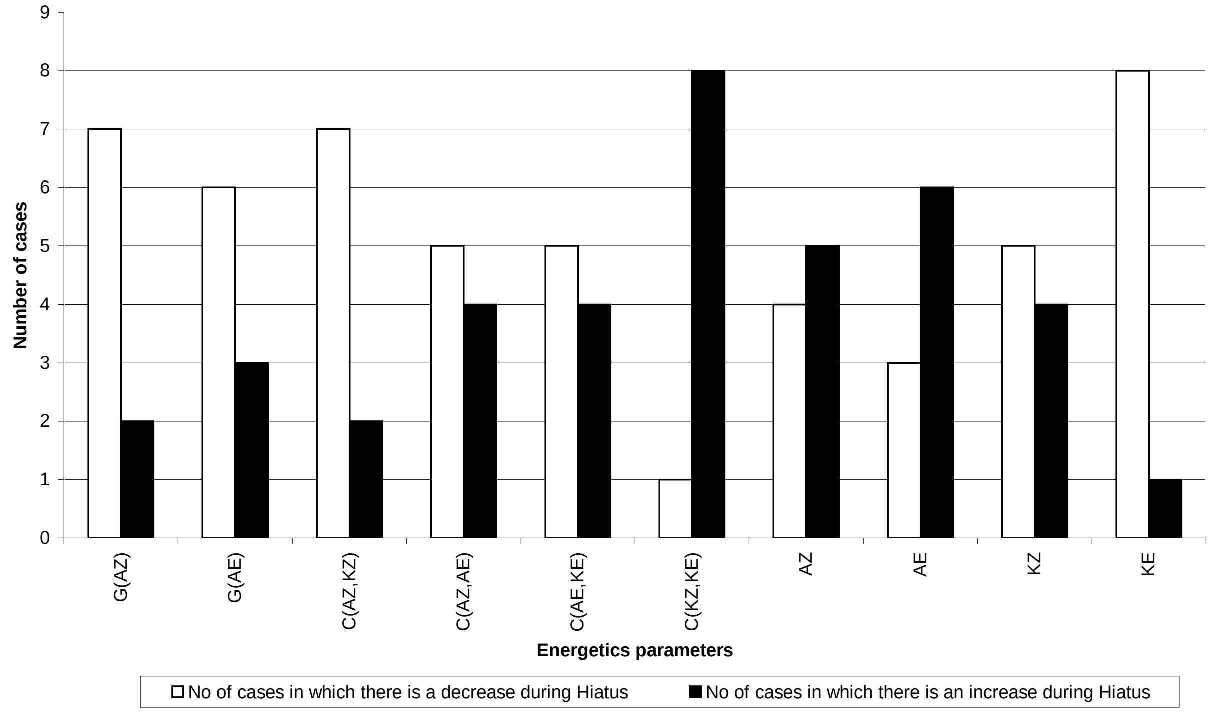

Fig. 1. Frequency distribution for the number of cases when parameters are less during Hiatus/Pre-Hiatus pentad

TABLE 1

Cases under study

Case No	Hiatus period	Number of Hiatus days
1	17th June - 12th July 1982	26
2	30th June - 24th July 1986	25
3	11th June - 11th July 1991	31
4	22nd June - 10th July 1995	19
5	10th June - 22nd June 2000	13
6	5th July - 18th July 2000	14
7	20th July - 14th August	26
8	19th June - 03rd July 2004	15
9	7th - 22nd June 2006	16

$$\mathrm{K_e} = \frac{1}{2\mathrm{g}} \int_{100}^{P_s} \overline{\left(u'^2 + v'^2\right)} \mathrm{d}p \tag{9}$$

$$\left[\mathrm{C}(\mathrm{A_z}, \mathrm{A_E})\right] = -\int_{100}^{P_s} \left[\overline{\frac{1}{\sigma} v' T' \frac{\partial T^*}{a \partial \varphi}} + \overline{\frac{1}{\sigma} \omega' T' \frac{\partial T^*}{\partial p}} \right] \mathrm{d}p \tag{10}$$

$$\left[\mathrm{C}(\mathrm{K_z}, \mathrm{K_E})\right] = \frac{1}{\mathrm{g}} \left\{ \begin{array}{l} \displaystyle\int_{100}^{P_s} \left[\cos\varphi \, u'v' \frac{\partial}{a\partial\varphi} \left[\frac{[u]}{\cos\varphi} \right] \right] \mathrm{d}p \\ \displaystyle + \int_{100}^{P_s} \overline{\left[v'^2 \frac{\partial [v]}{a \partial \varphi} \right]} \mathrm{d}p + \int_{100}^{P_s} \overline{\frac{\tan\varphi}{a} u'^2 [v]} \mathrm{d}p \\ \displaystyle + \int_{100}^{P_s} \overline{\left[\omega' u' \frac{\partial [u]}{\partial p} \right]} \mathrm{d}p + \int_{100}^{P_s} \overline{\left[\omega' v' \frac{\partial [v]}{\partial p} \right]} \mathrm{d}p \end{array} \right\} \tag{11}$$

$$\left[\mathrm{C}(\mathrm{A_E}, \mathrm{K_E})\right] = -\frac{1}{\mathrm{g}} \int_{100}^{P_s} \frac{R}{p} \overline{\omega' T'} \mathrm{d}p \tag{12}$$

TABLE 2(a)

Comparison of G (A_Z) between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad G(Az) J/kg.cm^2.sec	Hiatus period G(Az) J/kg.cm^2.sec
12 – 16 June 1982	17 June – 12 July 1982	3.680E-07	6.360E-08
25 – 29 June 1986	30 June – 24 July 1986	4.560E-07	8.530E-08
06 – 10 June 1991	11 June – 11 July 1991	1.530E-07	8.690E-08
17 – 21 June 1995	22 June – 10 July 1995	9.710E-08	4.890E-08
05 – 09 June 2000	10 – 22 June 2000	-4.730E-09	9.040E-08
15 – 19 July 2002	20 July – 14 Aug 2002	6.870E-09	6.840E-08
30 June – 04 July 2002	05 – 18 July 2002	2.190E-07	1.990E-07
14 – 18 June 2004	19 June – 03 July 2004	9.670E-08	6.240E-08
02 – 06 June 2006	07 – 22 June 2006	1.030E-07	7.450E-08

TABLE 2(b)

Comparison of G (A_E) between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad G(A_E) J/kg.cm^2.sec	Hiatus period G(A_E) J/kg.cm^2.sec
12 – 16 June 1982	17 June – 12 July 1982	1.450E-07	-2.850E-08
25 – 29 June 1986	30 June – 24 July 1986	1.740E-07	1.440E-08
06 – 10 June1991	11 June – 11July 1991	3.490E-08	-1.380E-09
17 – 21 June 1995	22 June – 10 July 1995	1.020E-08	-2.720E-08
05 – 09 June 2000	10 – 22 June 2000	-5.740E-08	-5.740E-10
15 – 19 July 2002	20 July – 14 Aug 2002	3.380E-10	1.710E-08
30 June – 04 July 2002	05 – 18 July 2002	9.850E-08	9.020E-08
14 – 18 June 2004	19 June – 03 July 2004	-1.180E-08	1.290E-09
02 – 06 June2006	07 – 22 June 2006	3.670E-08	-2.790E-09

TABLE 2(c)

Comparison of C(A_Z,K_Z) between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad C(A_Z,K_Z) J/kg.cm^2.sec	Hiatus period C(A_Z,K_Z) J/kg.cm^2.sec
12 – 16 June 1982	17 June – 12 July 1982	7.280E-06	7.560E-09
25 – 29 June 1986	30 June – 24 July 1986	9.570E-06	8.740E-07
06 – 10 June 1991	11 June – 11 July 1991	4.440E-06	1.700E-06
17 – 21 June 1995	22 June – 10 July 1995	7.490E-07	-6.040E-07
05 – 09 June 2000	10 – 22 June 2000	-2.520E-07	1.830E-06
15 – 19 July 2002	20 July – 14 Aug 2002	-3.400E-06	3.140E-07
30 June – 04 July 2002	05 – 18 July 2002	3.620E-06	1.950E-06
14 – 18 June 2004	19 June – 03 July 2004	1.570E-06	-5.430E-07
02 – 06 June 2006	07 – 22 June 2006	1.750E-06	8.290E-07

TABLE 2(d)

Comparison of $C(A_Z,A_E)$ between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad $C(A_Z,A_E)$ $J/kg.cm^2.sec$	Hiatus period $C(A_Z,A_E)$ $J/kg.cm^2.sec$
12 – 16 June1982	17 June – 12 July 1982	4.060E-08	4.270E-08
25 – 29 June 1986	30 June – 24 July 1986	6.770E-08	1.910E-08
06 – 10 June1991	11 June – 11 July 1991	4.060E-08	4.180E-08
17 – 21 June 1995	22 June – 10 July 1995	1.370E-07	1.280E-08
05 – 09 June 2000	10 – 22 June 2000	1.960E-08	5.440E-08
15 – 19 July 2002	20 July – 14 Aug 2002	1.280E-07	9.770E-08
30 June - 04 July 2002	05 – 18 July 2002	4.490E-08	2.190E-08
14 – 18 June 2004	19 June – 03 July 2004	1.170E-07	7.040E-08
02 – 06 June 2006	07 – 22 June 2006	8.030E-08	4.160E-08

TABLE 2(e)

Comparison of $C(A_E,K_E)$ between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad $C(A_E,K_E)$ $J/kg.cm^2.sec$	Hiatus period $C(A_E,K_E)$ $J/kg.cm^2.sec$
12 – 16 June 1982	17 June – 12 July 1982	4.320E-06	-2.070E-06
25 – 29June 1986	30 June – 24 July 1986	5.600E-06	-7.180E-07
06 – 10 June 1991	11 June – 11 July 1991	5.310E-07	-1.190E-06
17 – 21 June 1995	22 June – 10 July 1995	-4.050E-06	-1.710E-06
05 – 09 June 2000	10 – 22 June 2000	-2.450E-06	-1.540E-06
15 – 19 July 2002	20 July – 14 Aug 2002	-4.820E-06	-2.150E-06
30 June – 04 July 2002	05 – 18 July 2002	2.390E-06	1.380E-06
14 – 18 June 2004	19 June – 03 July 2004	-3.290E-06	-2.820E-06
02 – 06 June 2006	07 – 22 June 2006	-1.210E-06	-1.500E-06

TABLE 2(f)

Comparison of A_Z between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad A_Z $J/kg.cm^2$	Hiatus period A_Z $J/kg.cm^2$
12 – 16 June 1982	17 June – 12 July 1982	1.310E+00	1.340E+00
25 – 29 June 1986	30 June – 24 July 1986	1.330E+00	1.320E+00
06 – 10 June1991	11 June – 11 July 1991	1.360E+00	1.330E+00
17 – 21 June 1995	22 June – 10 July 1995	1.340E+00	1.330E+00
05 – 09 June 2000	10 – 22 June 2000	1.320E+00	1.330E+00
15 – 19 July 2002	20 July – 14 Aug 2002	1.330E+00	1.34E+00
30 June – 04 July 2002	05 – 18 July 2002	1.330E+00	1.320E+00
14 – 18 June 2004	19 June – 03 July 2004	1.330E+00	1.330E+00
02 – 06 June 2006	07 – 22 June 2006	1.320E+00	1.320E+00

TABLE 2(g)

Comparison of $C(K_Z,K_E)$ between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad $C(K_Z,K_E)$ $J/kg.cm^2.sec$	Hiatus period $C(K_Z,K_E)$ $J/kg.cm^2.sec$
12 – 16 June 1982	17 June – 12 July 1982	-1.370E-07	9.810E-09
25 – 29 June 1986	30 June – 24 July 1986	1.230E-07	1.730E-07
06 – 10 June 1991	11 June – 11 July 1991	-2.300E-07	-1.770E-08
17 – 21 June 1995	22 June – 10 July 1995	-3.410E-08	-2.120E-07
05 – 09 June 2000	10 – 22 June 2000	2.450E-08	-2.900E-07
15 – 19 July 2002	20 July – 14 Aug 2002	-2.830E-07	4.050E-08
30 June – 04 July 2002	05 – 18 July 2002	-1.740E-08	6.470E-08
14 – 18 June 2004	19 June – 03 July 2004	-4.640E-07	-1.990E-07
02 – 06 June 2006	07 – 22 June 2006	-4.980E-07	6.230E-09

TABLE 2(h)

Comparison of K_E between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad K_E $J/kg.cm^2$	Hiatus period K_E $J/kg.cm^2$
12 – 16 June 1982	17 June – 12 July 1982	5.610E-02	1.920E-02
25 – 29 June 1986	30 June – 24 July 1986	6.900E-02	4.530E-02
06 – 10 June 1991	11 June – 11 July 1991	6.060E-02	1.950E-02
17 – 21 June 1995	22 June – 10 July 1995	5.890E-02	1.840E-02
05 – 09 June 2000	10 – 22 June 2000	7.600E-02	4.980E-02
15 – 19 July 2002	20 July – 14 Aug 2002	7.350E-02	2.630E-02
30 June – 04 July 2002	05 – 18 July 2002	4.120E-02	4.680E-02
14 – 18 June 2004	19 June – 03 July 2004	7.140E-02	4.690E-02
02 – 06 June 2006	07 – 22 June 2006	1.110E-01	1.830E-02

TABLE 2(i)

Comparison of K_Z between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad K_Z $J/kg.cm^2$	Hiatus period K_Z $J/kg.cm^2$
12 – 16 June 1982	17 June – 12 July 1982	4.050E-01	9.420E-01
25 – 29 June 1986	30 June – 24 July 1986	7.200E-01	1.400E+00
06 – 10 June 1991	11 June – 11 July 1991	1.510E+00	1.360E+00
17 – 21 June 1995	22 June – 10 July 1995	1.770E+00	1.020E+00
05 – 09 June 2000	10 – 22 June 2000	1.630E+00	1.130E+00
15 – 19 July 2002	20 July – 14 Aug 2002	1.220E+00	9.520E-01
30 June – 04 July 2002	05 – 18 July 2002	5.900E-01	5.230E-01
14 – 18 June 2004	19 June – 03 July 2004	1.420E+00	1.020E+00
02 – 06 June 2006	07 – 22 June 2006	6.860E-01	9.730E-01

TABLE 2(j)

Comparison of A_E between the pre-hiatus pentad and hiatus period

Pre-hiatus pentad	Hiatus period	Pre-Hiatus pentad A_E J/kg.cm^2	Hiatus period A_E J/kg.cm^2
12 – 16 June 1982	17 June – 12 July 1982	1.230E+00	1.240E+00
25 – 29 June 1986	30 June – 24 July 1986	1.240E+00	1.220E+00
06 – 10 June1991	11 June – 11 July 1991	1.250E+00	1.230E+00
17 – 21 June 1995	22 June – 10 July 1995	1.230E+00	1.240E+00
05 – 09 June 2000	10 – 22 June 2000	1.230E+00	1.230E+00
15 – 19 July 2002	20 July – 14 Aug 2002	1.230E+00	1.240E+00
30 June – 04 July 2002	05 – 18 July 2002	1.240E+00	1.240E+00
14 – 18 June 2004	19 June – 03 July 2004	1.230E+00	1.230E+00
02 – 06 June 2006	07 – 22 June 2006	1.230E+00	1.230E+00

$$\left[\mathrm{C}(\mathrm{A_z},\mathrm{K_z})\right] = -\frac{1}{\mathrm{g}}\int_{100}^{P_s}\frac{R}{p}\overline{\omega^{*}T^{*}}\,\mathrm{d}p \qquad (13)$$

$$\mathrm{G}(\mathrm{A_z}) = \frac{\mathrm{R_d}}{\mathrm{C_p}}\oint\frac{[\theta]^{*}[\dot{\mathrm{Q}}]^{*}}{p\left(-\frac{\partial\bar{\theta}}{\partial p}\right)}\mathrm{d}m \qquad (14)$$

$$\mathrm{G}(\mathrm{A_E}) = \frac{\mathrm{R_d}}{\mathrm{C_p}}\oint\frac{\theta'\dot{\mathrm{Q}}'}{p\left(-\frac{\partial\bar{\theta}}{\partial p}\right)}\mathrm{d}m \qquad (15)$$

The above computations have been made for the hiatus period and also for corresponding pre-hiatus pentad for different hiatus cases being studied.

4. Selection of cases

The cases which are discussed in the present study have been given in Table 1. From the table it can be seen that only those cases for which the further advance of SW monsoon had been stalled by more than twelve days only have been considered in the present study.

5. Result and discussions

Tables 2(a-j) show the comparison of values of different energetic parameters during pre-hiatus pentad and during hiatus. Total nine cases have been studied. The histograms in Fig. 1 shows frequency distribution of number of cases in which energetic parameters have been reduced (or increased) during hiatus period as compared to during pre-hiatus pentad. From this it is apparent that out of nine cases, in seven cases there are fall in $G(A_z)$, $C(A_z, K_z)$, in eight cases there are fall in K_E, in six cases there are fall in $G(A_E)$ and in five cases there are fall in K_z, $C(A_E, K_E)$ and $C(A_z, A_E)$.

From the expression of $C(A_z, K_z)$ it appears that it is positive if there is rising motion of relatively warmer air and sinking motion of relatively colder air. During the advance of southwest monsoon (SWM), northern latitude is having warm anomaly and southern latitude is having cold anomaly. This sets up a solenoidal circulation with a rising limb over warmer north and sinking limb over colder south. This causes surface southerly and the advance in SWM, this also cause $C(A_z, K_z)$ positive. Now, when north is relatively colder and south is relatively warmer, then this solenoidal circulation is either reversed or weakened, resulting in arrest of monsoon advance. Hence in the above-mentioned seven cases, due to reversal or weakening of $C(A_z, K_z)$, monsoon advance is stalled. It may be due to weakening or reversal of the north-south temperature gradient pattern.

The above result is in conformity with the findings of Biswas *et al.*, (1998), where it was argued that massif Himalaya acts as a barrier to the passage of westerly trough, causing northerly cold advection to the west of it, which may lead to a weakening of above mentioned north-south temperature gradient.

In these cases, $G(A_z)$ have also been observed to be reduced during hiatus, which is due to reduction in the net heating. Reduction in the net heating appears to be mainly due to rising motion of unstable relatively warmer air over southern latitude and sinking motion of unstable relatively colder air over northern latitude during hiatus. As in the zonal kinetic energy budget $C(A_z, K_z)$ is a source term, hence reversal or weakening of $C(A_z, K_z)$ also results in a reduction in K_z also, which further results into deceleration in monsoon advance.

6. Conclusions

(*i*) In most of the cases under study, a fall in $G(A_z)$ during hiatus period has been observed.

(*ii*) A fall in $C(A_z, K_z)$ during hiatus period as compared to during pre-hiatus pentad has been observed in most of the cases.

(*iii*) There are observed reduction in K_z and K_E during hiatus as compared to during pre-hiatus pentad.

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