A diagnostic study on the energetic aspects of weak/strong spell of north east monsoon

SOMENATH DUTTA, D. M. RASE and SUNITHA DEVI

India Meteorological Department, Pune, India

(*Received 26 November 2014, Accepted 22 July 2015*)

e mail : dutta.somenath@gmail.com

सार – वर्ष 2009 और 2010 के उत्तर पूर्वी मॉनसून के लगातार कमज़ोर / प्रबल दौर के गतिकों का अध्ययन ऊर्जात्मक पहलुओं से करने का प्रयास किया गया है। विभिन्न ऊर्जात्मक टर्म के लिए उनकी उत्पत्ति और परिवर्तन का आकलन किया गया। यह आकलन 70° पू. से 85° पू., 5° उ. से 20° उ. के सीमित क्षेत्रों पर ऊपर बताए गए दोनों वर्षों में अक्तूबर से दिसम्बर के दौरान लगातार कमज़ोर और प्रबल दौर के लिए था। ये आकलन उसी अवधि के दैनिक NCEP 2.5° × 2.5° आँकड़ों के आधार पर किए गए। उत्तर पूर्वी मॉनसून के कमज़ोर दौर से प्रबल दौर का संक्रमण उपलब्ध ज़ोनल विभव ऊर्जा (*Az*) से ज़ोन गतिक ऊर्जा (*Kz*) के परिवर्तन में वृद्धि से संबद्ध है जिससे यह सिद्ध होता है कि हेडले परिसंचरण के सुदृढ़ होने से ऊपर बताए गए संक्रमण काल प्रभावित होते हैं। यह भी पता चला है कि कमज़ोर दौर से प्रबल दौर का संक्रमण बढ़ी हुई बैरोक्लीनिक ऊर्जा परिवर्तन से संबद्ध है।

ABSTRACT. An attempt has been made to study dynamics of consecutive weak/strong spell of north east monsoon for the years, 2009 and 2010 from an energetics aspect. For that different energy terms, their generation and conversion among different energy terms have been computed for consecutive weak and strong phases during Oct to Dec of the above two years over a limited region between 70 °E to 85 °E, 5 °N to 20 °N. These computations are based on daily NCEP 2.5° × 2.5° data for the same period. The transition from weak phase to strong phase of north east monsoon (NEM) observed to be associated with an enhancement in conversion of zonal available potential energy (*Az*) to zonal kinetic energy (*Kz*), implying a strengthening of Hadley circulation, favouring the above transition. It is also observed that the transition from weak phase to strong phase is associated with enhanced Baroclinic energy conversion

Key words – Energetics, North East Monsoon.

1. Introduction

The term North-East (NE) Monsoon is often used to describe rainfall during the period October to December. It is also known as "Retreating Southwest Monsoon Season". It is the main rainy season for the southeast peninsula, *viz.*, coastal Andhra Pradesh (CAP), Rayalseema (RYS) and Tamil Nadu (TN). Though the principal rainy season for south interior Karnataka (SIK), Kerala (KER) and the Arabian Sea Islands is the southwest monsoon season, still rainfall continues almost till December in these sub-divisions, in the period October to December.

A number of studies on the NE monsoon has been made in the past (Srinivasan and Rammurthy, 1973; Khole and De, 2003; Kriplani and Pankaj Kumar, 2004; Raj and Geetha, 2008 etc.).

Energetics is one of the very useful and interesting tools for diagnosing many atmospheric phenomena dynamically. There are number of studies on the energetics aspects of onset, progress, maintenance of mean monsoonal circulation during south west monsoon (SWM).

Keshavamurty and Awade (1970) found that maintenance of mean monsoon trough during southwest monsoon season against frictional dissipation is mainly due to the work done by horizontal pressure gradient. Krishnamurti (1985) has shown that available potential energy must be transferred to divergent kinetic energy *via* rising motion over warm region / sinking motion over cold region, which again is transferred to rotational kinetic energy, He has also shown that available potential energy is maintained *via* heating of warmer air & cooling of colder air.

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 conversion of zonal K. E. (K_Z), to the Eddy kinetic energy (K_E) is greater than the conversion of eddy available potential energy (A_E) to eddy Kinetic energy (K_E) *i.e.*, C($K_{z,} K_E$) > C (A_E, K_E). Rao (2006) studied K. E. budget using daily averaged (0000 UTC and 1200 UTC) reanalysis data for the period 1960-1999. His study shows that in lower troposphere K_E is balanced by adiabatic generation and frictional dissipation and in upper troposphere the same is being done by adiabatic generation and flux divergence. The adiabatic generation of K_E within boundary layer is mostly due to meridional component.

Dutta *et al*., (2009), using NCEP daily composite mean data have studied the energetics aspects of hiatus in the advance of south west monsoon (SWM). They found that hiatus is associated with fall in C (A_Z, K_Z) which in turn is apparently due to anomalous cooling of northern latitude caused by frequent passage of mid-latitude westerly systems.

Dutta *et al*., (2011) have compared dynamically two drought years, *viz*., 2002 and 2009 over India from energetic aspects, using NCEP daily composite mean data. They found that although for both the years we had drought, the mean monsoon circulation itself was much weaker in 2009 as compared to 2002, in daily, monthly as well as in the seasonal scale. The weaker mean monsoon circulation, in daily scale, has been demonstrated by comparatively longer spells during June-September 2009 with negative value of conversion of zonal available potential energy to zonal kinetic energy $[C(A_Z, K_Z)]$. Large negative values of the monthly total as well as seasonal total of $[C(A_Z, K_Z)]$ indicate weaker mean monsoon circulation in monthly and in the seasonal scale. The study also shows that In both years, the Seasonal total (June-Sept) of conversion of zonal available potential energy to eddy available potential energy $[C(A_Z, K_E)]$ was positive, but in 2009 its order of magnitude was 10^{-4} J/kg/cm^2 /Sec where as in 2002 it was 10^{-6} J/kg/cm^2/Sec, indicating that the influence of mid-latitude westerly was much more in 2009, which may have attributed towards weaker mean monsoon circulation in 2009.

From the foregoing discussion, it appears that there may be many studies investigating the dynamical aspects of transition between weak and strong phases of southwest monsoon, but hardly there are similar studies for Northeast monsoon. The objective of the present study is to investigate the dynamical aspects of transition between consecutive weak and strong phases of Northeast monsoon from an energetics perspective.

Table for illustration of symbols

S. No	Symbols	Illustration
1.	A_E	Eddy available potential energy
2.	A_Z	Zonal available potential energy
3.	K_E	Eddy kinetic energy
4.	K_Z	Zonal kinetic energy
5.	$G(A_Z)$	Generation of Zonal available potential energy
6.	$G(A_E)$	Generation of eddy available potential energy
7.	$C(A_E, K_E)$	Conversion of Eddy available potential energy to Eddy kinetic energy
8.	$C(A_Z, K_Z)$	Conversion of zonal available potential energy to zonal kinetic energy
9.	$C(K_Z, K_E)$	Conversion of zonal kinetic energy to Eddy kinetic energy
10.	$C(A_Z, A_E)$	Conversion of zonal available potential energy to Eddy available potential energy
11.	$[S]$	Zonal average of 'S'
12.	$\overline{S}$	Area average
13.	S''	Departure from area average
14.	S'	Departure from zonal average
15.	S^*	Departure of zonal average from area average

2. Data

Weakly North East Monsoon Rainfall (NEMR) distributions for 2009 & 2010 have been shown in Figs. 1(a&b). From these figures it can be seen that week ending on 4th November and week ending on 11th November can be selected as consecutive weak and strong phases respectively in 2009. Similarly week ending on 22nd December and week ending on 29th December 2010 can be selected as consecutive strong and weak phases respectively in 2010.

Accordingly daily composite NCEP/NCAR reanalysis data of air Temperature (*T*), zonal wind (*u*), meridional wind (*v*), vertical wind (ω) at 1000, 850, 700, 500, 300, 200 and 150 hPa levels for the above mentioned weak and strong periods over the limited region between 5° N and 20° N, 70° E and 85° E have been used.
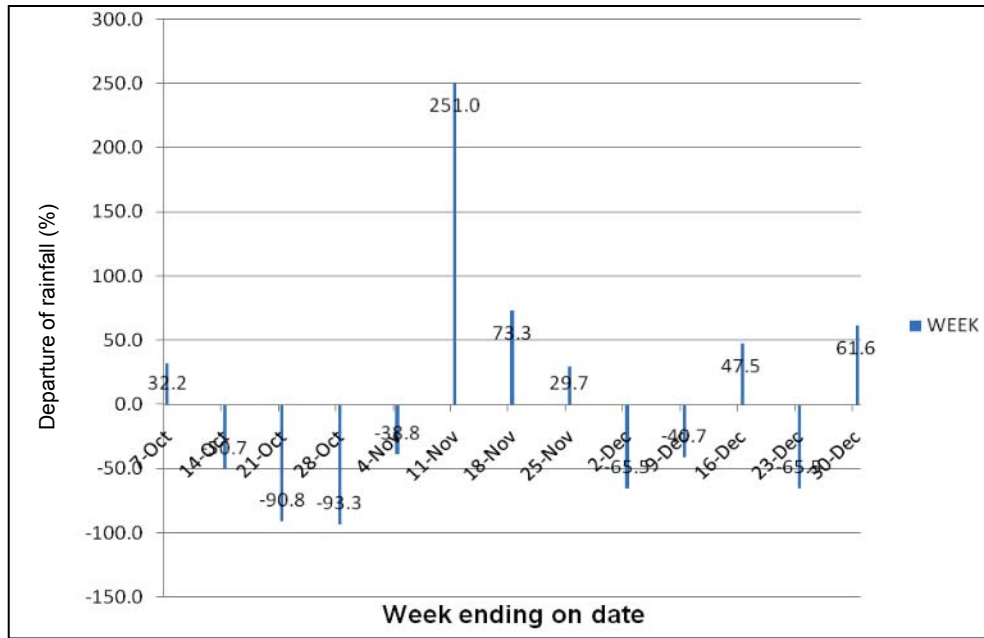
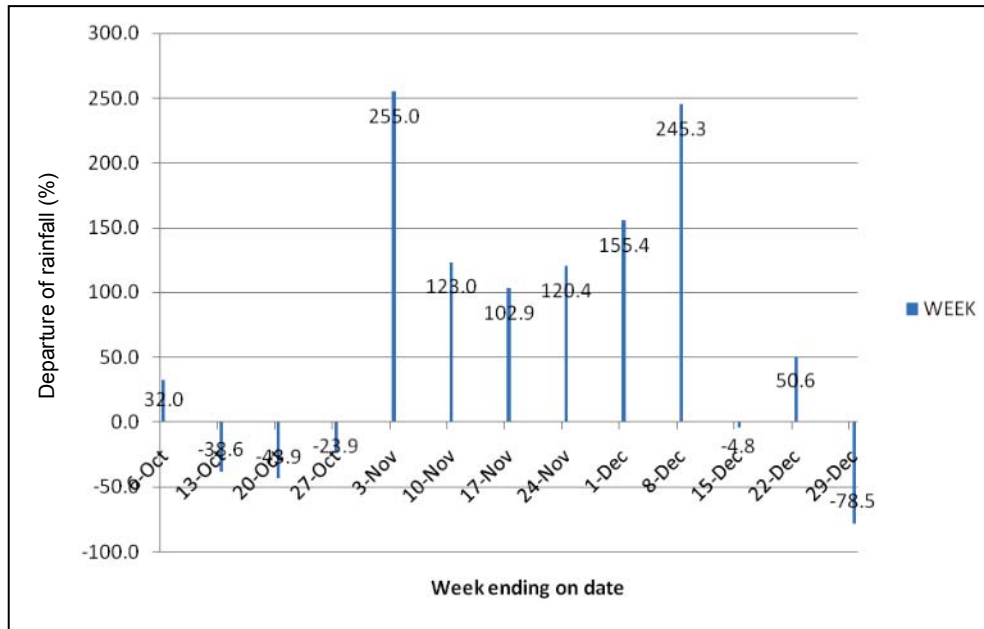**Fig. 1(a).** Weekly rainfall for NE monsoon of 2009

Fig. 1(b). Weekly rainfall for NE monsoon of 2010

3.   Methodology

First, from the temperature data, at each grid point, heating rate $\dfrac{\dot{Q}}{C_P}$ has been computed using first law of thermodynamics $\dfrac{\dot{Q}}{C_p} = \dfrac{dT}{dt} - \dfrac{\alpha}{C_p}\omega$. Following Dutta *et al.*, (2009, 2011) in the present study also, in the computation of $\dfrac{dT}{dt}$, tendency has not been taken care of.
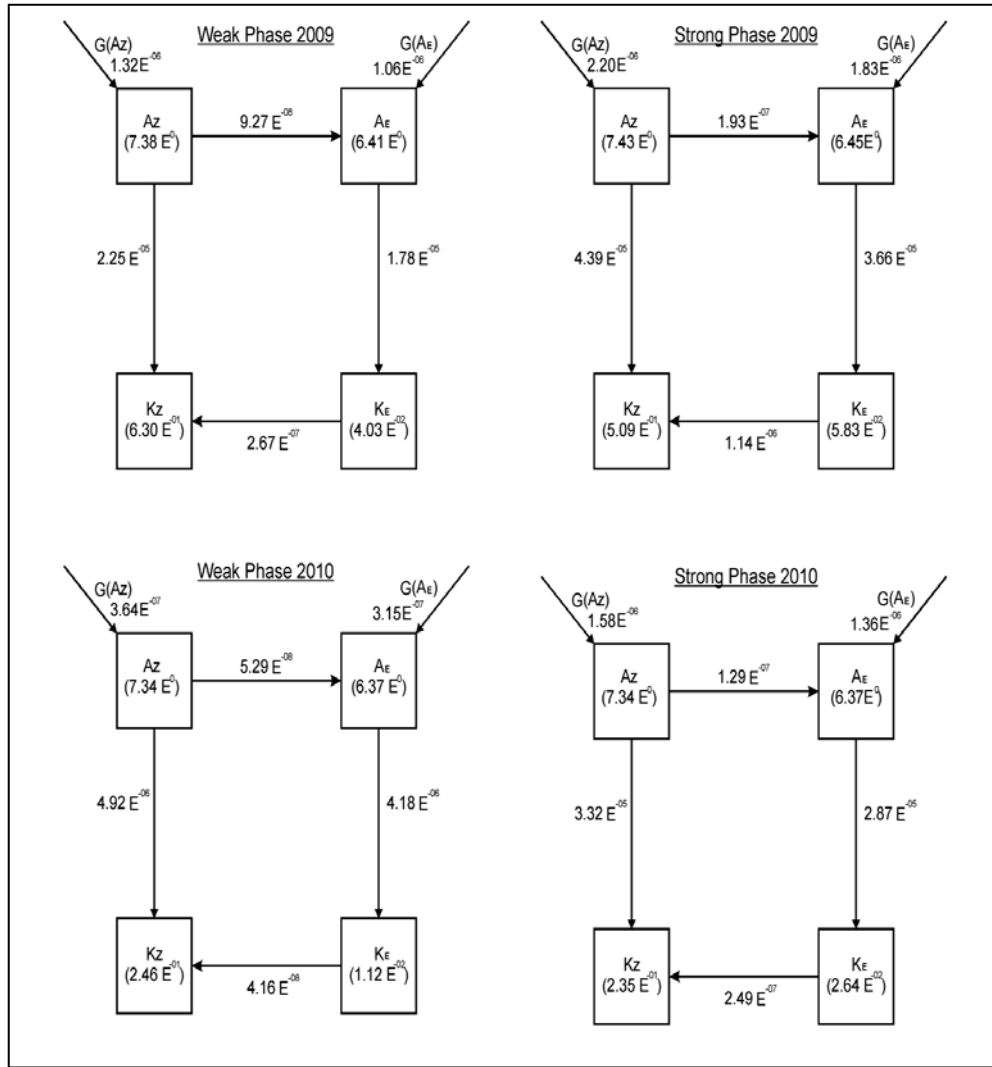
Fig. 2. Energy flow diagram

Then, following Krishnamurti 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:

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

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

$$\text{Departure from area average:- } S'' = S - \overline{S} \qquad (3)$$

$$\text{Departure from zonal average:- } S' = S - [S] \qquad (4)$$

Departure of zonal average from area average:-
$$S^* = [S] - \overline{S} \qquad (5)$$

Then using (1) to (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 Krishnamurti and Bounoua (2000), zonal available potential energy (A_z), zonal kinetic energy (K_z), eddy available potential energy (A_E), eddy kinetic

energy (A_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 following Krishnamurti and Bounoua (2000), Dutta *et al.*, (2009).

Above computations have been made daily during contrasting phases of NEM, as previously mentioned. From the daily value, pentad total of them have also been computed.

4. Results and discussions

Energy flow diagram for the contrasting phases of two cases is shown in Fig. 2. The figure shows that for most of the atmospheric energetics parameters there is an increase from weak phase to strong phase in all the cases. Barotropic energy conversion is represented by [$C(K_z, K_E)$] whereas [$C(A_z, K_z)$], & [$C(A_E, K_E)$], represent baroclinic energy conversions for zonal and for eddy flow respectively. The energy flow diagram clearly shows the presence of both conversion in all phases. It is also seen from the figure that both Barotropic and Baroclinic energy conversion are present in all phases, although conversion rates enhanced during strong phase.

From Fig. 2 it is seen that the transition from weak phase to strong phase of north east monsoon (NEM) appears to be associated with an enhancement in conversion of zonal available potential energy (A_z) to zonal kinetic energy (K_z), which in turn indicates an enhancement of mean meridional circulation (*i.e.*, Hadley circulation). Figure also shows that the transition from weak phase to strong phase of north east monsoon (NEM) appears to be associated with an enhanced influence of mid latitude Baroclinic westerly waves, which is indicated by an enhancement in $C(A_Z, A_E)$, Dutta *et al.* (2011). There is an enhancement in the generation of zonal available potential energy [($G(A_Z)$)] and the generation of eddy available potential energy [($G(A_E)$)] in both the cases from weak phase to strong phase, which may be attributed to an enhancement of diabatic heating (or cooling) of relatively warmer (or colder).

5. Conclusions

The following conclusions could be drawn from above discussions:

(*i*) In general there is an increase in most of the energetics parameters from weak phase to strong phase in all the cases.

(*ii*) The Barotropic and Baroclinic energy conversion are present in both weak and strong phases, however conversion rates enhanced during strong phase.

(*iii*) Baroclinic energy conversion dominates over Barotropic energy conversion.

(*iv*) The transition from weak phase to strong phase of north east monsoon (NEM) is observed to be associated with an enhancement in conversion of available potential energy (A_z) to zonal kinetic energy (K_z), implying a strengthening of Hadley circulation , which favours in the above transition.

(*v*) The transition from weak phase to strong phase of north east monsoon (NEM) is observed to be associated with an enhanced influence of mid latitude Baroclinic westerly waves, which is indicated by an enhancement in $C(A_Z, A_E)$.

(*vi*) There is an enhancement in the generation of zonal available potential energy [($G(A_Z)$)] and the generation of eddy available potential energy [($G(A_E)$)] from weak phase to strong phase which may be attributed to an enhancement of diabatic cooling of relatively colder air over northern latitude due to enhanced influence of mid latitude Baroclinic westerly waves

References

Dutta, Somenath, De, U. S. and Sunitha Devi., 2009, "A diagnostic study on the energetic aspects of Hiatus in the advance of Southwest monsoon", *Mausam*, 60, **4**, 427-436.

Dutta, Somenath, Narkhedkar, S. G., Sikka, D. R. and Sunitha Devi., 2011, "A dynamical comparison between two recent drought southwest monsoons 2002 and 2009 over India", *Mausam*, **62**, 2, 133-144.

George, L. and Mishra, S. K., 1993, "An observational study on the energetics of the onset monsoon vortex, 1979", *Quart. Jour. Royal. Met. Soc.*, **119**, 755-778.

Keshavamurty, R. N. and Awade, S. T., 1970, "On the maintenance of the mean monsoon trough over north India", *Mon. Wea. Rev*, **98**, 315-320.

Krishnamurti, T. N., 1985, "Summer monsoon experiment - A review", *Mon. Wea. Rev*, **113**, 1590-1626.

Krishnamurti, T. N. and Bounoua, L., 2000, An introduction to Numerical Weather Prediction Techniques", CRC press Inc., 1-286.

Khole, Medha and De, U. S., 2003, "A study on north east monsoon rainfall over India", *Mausam*, **54**, 2, 419-426.

Kripalani, R. H. and Kumar, Pankaj, 2004, "North east monsoon rainfall variability over south Peninsular India *vis-a-vis* the Indian dipole mode", *Int., J. of Climatology*, **24**, 1267-1284.

Raj, Y. E. A. and Geetha, B., 2008, "Relation between Southern Oscillation and north east monsoon as revealed in antecedent and concurrent modes", *Mausam*, **59**, 1, 15-34.

Rao, P. L. S., 2006, "The Kinetic energy budget of Asian summer monsoon", *Theor. Appli. Climatol*., **84**, 191-205.

Srinivasan, V. and Rammurthy, K., 1973, "FMU Report No. IV, 18.4".