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Behaviour of kinetic energy generation function during a western disturbance in May 1982

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सार — गतिज ऊर्जा के क्रास समदाबी उत्पादन से, जिसे कि —**V.** $\nabla\phi$ नाम से परिभाषित किया गया है, गतिज ऊर्जा उत्पादन फलन कहते हैं। इस फलन के क्षेत्रीय और रेखांशिक एककों का पश्चिमी विक्षोभ के संबंध में परिकलन किया गया है, इसके कारण उत्तर भारत पर दूर-दूर तक गर्जन की व्यापक गतिविधियां रहती हैं। प्रत्येक घटक के आचरण का, इस प्रणाली के निश्चित आयतन पर क्षैतिज और ऊर्ध्वाधर दिशा में अध्ययन किया गया है। इन परिणामों से पता चलता है कि प्रणाली के गतिज ऊर्जा तत्व में वृद्धि (ह्रास), गतिज ऊर्जा उत्पादन फलन के धनात्मक (ऋणात्मक) योगदान से संबंधित नहीं हो सकती।

ABSTRACT. The cross isobaric generation of kinetic energy which is defined by the term $-\mathbf{V}.\nabla\phi$ is known as kinetic energy generation function. The zonal and meridional components of this function were computed for the case of a western disturbance that caused widespread thunder activity over north India. The behaviour of each component is studied in the horizontal and vertical direction over a fixed volume of the system. The results show that the increase (decrease) in the kinetic energy content of the system cannot be related to the positive (negative) contribution of the kinetic energy generation function.

1. Introduction

The cyclonic vortices in the lower troposphere over sub-tropical north Indian region are known as "western disturbances" in meteorological literature. Though these systems form and move eastward throughout the year, but their main impact is felt during winter and in early summer when often they cause widespread rainfall and thunderstorm activity over northwest India. The initial formation of these systems is noticed as a secondary disturbance over Indo-Pakistan region. Their further development, movement and decay are governed by the presence of an upper tropospheric westerly trough over the mid-latitudes.

Diagnostic studies, revealing the kinetic energy budgets and energy conversions of large scale systems of the atmosphere, have been made by a number of investigators (Kung *et al.* 1974, 1975), Kung (1975), Ward *et al.* (1976), Fuelberg (1980) and Michaclides (1983). These studies have stressed the importance of such systems in transfer and transformation of kinetic energy in middle latitudes. In the present study, we discuss the behaviour of kinetic energy generation function during the life cycle of a western disturbance in May 1982.

2. Kinetic energy generation function

The generation of kinetic energy in large scale motion can be expressed as $-\mathbf{V}.\nabla\phi$ where $\mathbf{V}$ is the horizontal wind vector and ϕ is the geopotential. This term includes the re-distribution of potential energy within the volume and conversion of available potential energy into kinetic energy. This conversion process can be related to vertical motions of cold and warm air within the volume. Since this generation is adiabatic and thermodynamically reversible, it implies (*i*) a positive $-\mathbf{V}\cdot\nabla\phi$ means the generation of kinetic energy at the expense of available potential energy and (*ii*) a negative $-\mathbf{V}.\nabla\phi$ indicates the destruction of kinetic energy or transformation into available potential energy of the atmosphere.

In x, y, p coordinate system, the kinetic energy generation function ($-\mathbf{V}.\nabla\phi$) can be resolved into its zonal and meridional components as $[-u(\partial\phi/\partial x]$ and $[-v(\partial\phi/\partial y)$ respectively. When we integrate these terms over a fixed mass M of the atmosphere, the two components become :

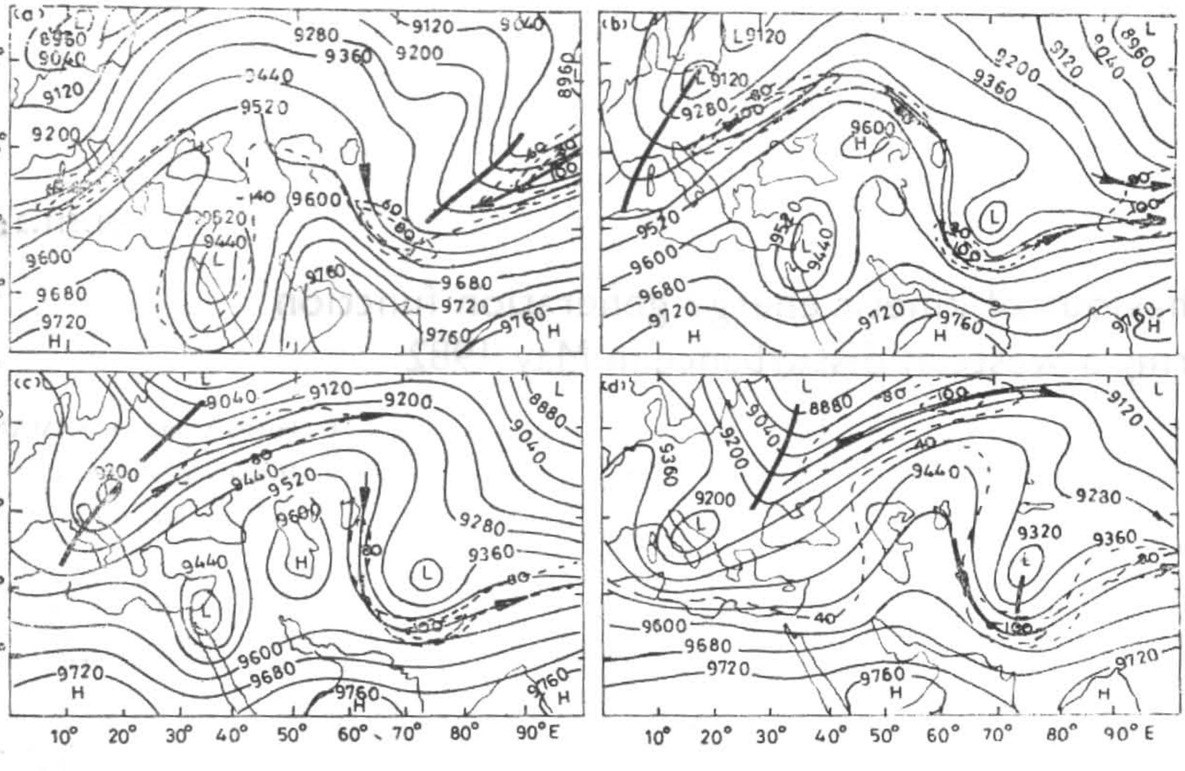
Zonal Kinetic Energy Generation Function

$$\text{(ZKEGF)} = -\int_M u\left(\frac{\partial\phi}{\partial x}\right)\delta M \qquad (1)$$

Meridional Kinetic Energy Generation Function

$$\text{(MKEGF)} = -\int_M v\left(\frac{\partial\phi}{\partial y}\right)\delta M \qquad (2)$$

where, M is element of mass $(=g^{-1}\,\delta x\ \delta y\ \delta p)$, g acceleration due to gravity and u, v the zonal and meridional components of the wind respectively.



Figs. 1 (a-d). 300 mb, 12 GMT flow patterns for (a) 11 May, (b) 12 May, (c) 13 May & (d) 14 May

TABLE 1

Vertical distribution of K, ZKEGF, MKEGF and KEGF from 11 to 14 May 1982

Layer (mb)	KE (10^5 J/m^2) Date				ZKEGF (W/m^2) Date				MKEGF (W/m^2) Date				KEGF (W/m^2) Date			
	11	12	13	14	11	12	13	14	11	12	13	14	11	12	13	14
Sfc-900	0.11	0.09	0.09	0.05	0.08	0.05	0.03	0.05	0.17	0.37	—0.12	—0.02	0.25	0.42	—0.09	0.03
900-800	0.13	0.11	0.16	0.07	0.43	0.31	0.03	0.06	0.53	0.62	—0.10	—0.04	0.96	0.93	—0.07	0.02
800-700	0.31	0.28	0.30	0.11	0.37	0.68	—0.29	0.19	1.33	—0.03	0.43	—0.09	1.70	0.66	0.14	0.10
700-600	0.46	0.47	0.45	0.34	0.57	0.75	—0.41	0.45	1.25	—0.81	0.23	—0.66	1.82	—0.06	—0.18	—0.21
600-500	0.55	0.67	0.72	1.01	2.18	0.21	—0.23	1.11	—0.31	—1.23	—1.59	—2.09	1.87	—1.02	—1.82	—0.98
500-400	1.33	1.23	1.51	2.05	5.26	—0.26	—0.17	3.15	—6.28	—2.97	—2.46	—4.30	—1.02	—3.23	—2.63	—1.15
400-300	3.36	2.36	3.30	3.56	10.07	—0.51	1.48	7.29	—20.13	—6.86	—1.08	—5.98	—10.06	—7.37	0.40	1.31
300-200	4.54	2.98	3.99	4.94	10.05	1.89	1.31	7.19	—20.44	—6.73	—4.17	—8.14	—10.39	—4.84	—2.86	—0.95
200-100	3.23	2.18	2.68	3.42	5.72	0.39	2.59	—0.02	—10.14	—0.28	—1.88	0.13	—4.42	0.11	0.71	0.11
Total	14.02	10.37	11.48	15.54	34.73	3.51	4.34	19.47	—54.02	—17.92	—10.74	—21.19	—19.49	—14.41	—6.40	—1.72

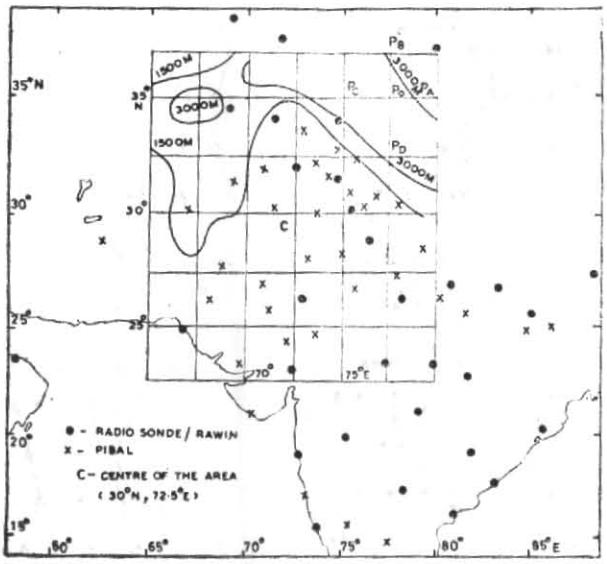


Fig. 2. Boundaries of the area under study marked by dark continuous line. Positions of the stations used in this study, ● Radiosonde/Rawin, X-PIBAL, A grid network at P_0 used for five point filter & thick lines indicate the contours of topography

Thus the Kinetic Energy Generation Function (KEGF) $-\int_M \mathbf{V} \cdot \nabla \phi \, \delta M$ becomes :

$$\text{KEGF} = \text{ZKEGF} + \text{MKEGF}$$

The kinetic energy of mass M of the atmosphere can be represented as :

$$K = \int_M (\tfrac{1}{2}) (u^2 + v^2) \, \delta M.$$

3. Data and computation

The data used in this study are the 1200 GMT pilot, rawin, radiosonde winds and geopotential heights for surface, 850, 700, 500, 300, 200 and 100 mb of 11 to 14 May 1982. We have chosen a fixed area of 15°(N-S) and 15°(E-W) bounded by 22.5°N to 37.5°N and 65°E to 80°E shown in the Fig. 2 as the area of the study for computational purpose. The domain covers about half the wavelength of the associated wave disturbance in the upper levels. A careful analysis of charts was made by utilising the maximum number of observations which are shown in Fig. 2. The wind direction, speed and contour heights were manually picked up from these charts at a grid interval of 2.5-degree. These values were further interpolated in the vertical direction at the interval of 100 mb. The final values were obtained after applying a five points filter at each level to reduce the spurious gradients. The type of the five points filter used in this study is based on the work by Shuman (1956) and can be denoted as :

$$P_N = P_0 + \triangle \times 0.25 \times (P_A + P_B + P_C + P_D - 4P_0)$$

where P_A, P_B, P_C, P_D and P_0 denote the values of parameter at the grid network shown in Fig. 2. P_N is new value of the parameter at P_0. In order to have the mild effect of the filter, '$\triangle$' smoothing factor was taken as .07.

Integration is performed at a set of grid points 7×7 and in the vertical from surface to 100 mb. Derivatives were obtained by using centred finite difference methods.

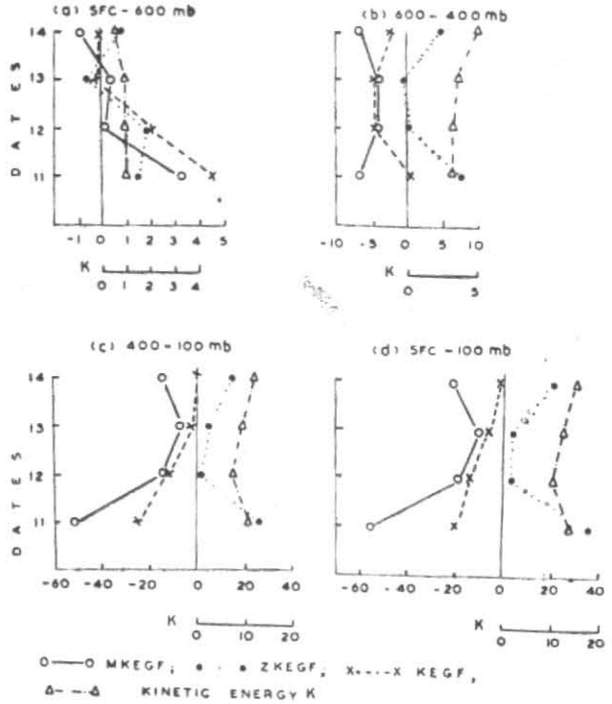
Diurnal variations of KEGF were excluded by using data of 12 GMT observations only.

As the computation of kinetic energy and its generation/dissipation requires a very high degree of accuracy in wind components and contour gradients. The quality of these inputs was enhanced by utilising the maximum number of observations and by keeping the time and space continuity. However, due to the presence of high terrain in the northern parts of the domain (contours of 1500 m and 3000 m height are shown in Fig. 2), some error in the inputs at the lower levels may influence the computed values. Even then, the values and their changes are significant and may be considered relevant for the interpretation.

4. Synoptic situation

On 11 May, a low level circulation was located over southwest Pakistan and adjoining areas. This circulation rapidly intensified into a well marked system between 11 and 12 May 1982 under the influence of a developing westerly trough in the middle and upper troposphere. The system moved slowly northeastward and lay over central parts of Rajasthan on 13 May where it reached its maximum intensity. On 14 May, it weakened over Punjab and adjoining areas. Under its influence, widespread thunderstorm and heavy rain occurred over many places in north India.

The major feature and behaviour of 300 mb flow for the period 11-14 May 1982 are shown in Figs. 1(a)-1(d). The significant feature was the presence of a strong jet at 300 mb and above on the upstream side which gradually migrated eastward as the system intensified and moved northeastward. The three phases of the life cycle of the system growth, mature and decay corresponds to the periods 11-12 May, 12-13 May and 13-14 May respectively.



Figs. 3 (a-d). Daily variation in K, ZKEGF, MKEGF and KEGF for the layers : (a) Surface-600 mb, (b) 600-400 mb, (c) 400-100 mb and (d) Surface-100 mb

Units for $K = 10^5$ J/m² and for other Watt/m². Scale for K is shown below the scale meant for others

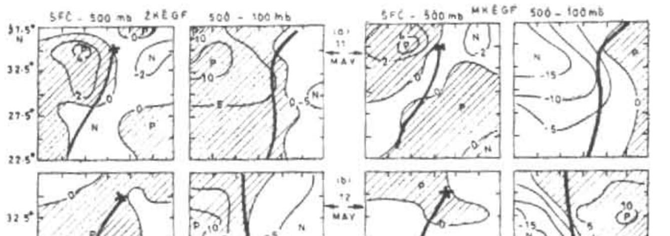


Fig. 4. Horizontal distribution of ZKEGF and MKEGF for (a) 11 May, (b) 12 May, (c) 13 May and (d) 14 May

Units : Deca Watt/m²; P—Positive, N—Negative, cross and thick lines indicate the positions of centre and trough line respectively

5. Discussion of results

5.1. *Vertical distribution*

Table 1 shows the daily area averaged values of K, ZKEGF, MKEGF and KEGF for each 100 mb layer from surface to 100 mb. From this table, the distribution of these four parameters was integrated vertically in three layers which are surface to 600 mb (lower troposphere), 600-400 mb (middle troposphere) and 400 - 100 mb (upper troposphere). Daily variations of K, ZKEGF, MKEGF and KEGF for these three layers and for the whole atmosphere are shown in Figs. 3(a) to (d) respectively. The salient features are :

(*a*) *Surface to* 600 *mb* — Due to the presence of high terrain in this layer, the changes in the values of each parameter are considered significant. The kinetic energy content (K) remained unchanged during growth and mature stage but decreased markedly in the decaying stage. The contributions of ZKEGF and MKEGF towards KEGF were small and positive in the initial stage but became negative during dissipating stage.

(*b*) 600 - 400 *mb* — The value of K increased significantly (from 1.9 units to 3.06 units) during the life cycle of the system. The contribution of ZKEGF was positive and had a decreasing tendency from 11 to 14 May. The opposite of this was the behaviour of MKEGF. The combined effect of ZKEGF and MKEGF resulted into negative values of KEGF. Thus, there was mild destruction of kinetic energy in the region.

(*c*) 400-100 *mb* — During growth stage, there was a decrease of K (from 11.13 units to 7.52 units) which may be due to the weakening of upper winds. But during growth stage, a significant decrease in the value of ZKEGF (from 25.8 units to 1.8 units) and the marked increase in the value of MKEGF (from —50.7 units to —13.9 units) resulted into the reduced destruction of kinetic energy in the region, which is reflected in the value of KEGF. In later stages the trends in K, ZKEGF, MKEGF and KEGF were similar in nature.

(*d*) *Surface*-100 *mb* — As the behaviour of MKEGF was to act as a strong sink of kinetic energy in the upper levels, the net effect on KEGF was the destruction of kinetic energy in the region. Thus there was a decreasing destruction of kinetic energy from one stage to the next stage of the system.

5.2. *Horizontal distribution*

As the contribution of each component was found to be dominant in the upper levels, it was considered sufficient to present the main features in two layers, namely lower troposphere (Surface to 500 mb) and upper troposphere (500 - 100 mb). The results are presented in Figs. 4 (a, b, c, d) respectively. In order to examine the distribution of ZKEGF and MKEGF with respect to the disturbance, the *positions* of the system at 700 mb and 300 mb were chosen as the representative for lower and upper troposphere respectively. Therefore, the corresponding positions of centre/trough are marked in the same figures.

Salient features of the distribution are given below :

(*a*) *ZKEGF*

Lower troposphere — During the life cycle of the system the significant positive values (source of kinetic energy) is located behind the trough and negative values (sink of kinetic energy) are generally found in the forward portion of the trough.

Upper troposphere — The pattern was same as found in the lower troposphere. The division between the positive and negative areas was done by the associated trough of the system. The magnitude of the positive values was almost twice of the negative values.

(*b*) *MKEGF*

Lower troposphere — Throughout the period the pattern has shown that the positive areas were confined to northwest and southeast sectors of the system and negative areas were lying over the other two sectors. The trough line lies in the region of negative contribution and separates the areas of generation of kinetic energy.

Upper troposphere — The pattern is just opposite to the distribution of ZKEGF in the upper levels. The positive area is found in the forward sector of the trough and the negative area is located on the backward side of the trough. The zone of maximum gradient lies between 28°N & 32°N.

6. Conclusion

The study has revealed that the zonal component of kinetic energy generation function acted as a source whereas meridional component (MKEGF) behaved as a strong sink in the upper levels throughout the life cycle of the system. Due to this behaviour of MKEGF there was continuously decreasing destruction of kinetic energy from one stage to the next stage of the system. This destruction does not correspond to the increase in the kinetic energy content of the system during mature and dissipating periods. Therefore, the behaviour of KEGF cannot be related to the increase or decrease of the kinetic energy content of a system because the latter depends also on the other terms in the kinetic energy tendency equation. The other terms includes the effect of boundary fluxes and sub-grid scale processes which were not taken into consideration in this study.

The above results are subject to its limitations such as the presence of orography in the lower levels, part of the wave in the domain and a fixed volume of the system.

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