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A study on certain aspects of kinetic energy associated with western disturbances over northwest India

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RESUMEN

La precipitación de invierno en los Himalayas occidentales, particularmente sobre Jammu y Kashmir, en Himachal Pradesh, Uttaranchal y sus alrededores, es importante para la agricultura, la horticultura, el transporte, la logística y las cuencas de los glaciares que alimentan los ríos del norte de la India. La precipitación se debe a la interacción de gran escala entre masas de aire de latitudes medias y tropicales. El proceso de interacción lleva a la formación o intensificación de los sistemas sinópticos conocidos como perturbaciones occidentales que se mueven del oeste hacia el este. En este trabajo se analizan los términos del presupuesto energético de una perturbación occidental intensa que ocurrió sobre el noroeste de la India. Esta perturbación, que originó una precipitación ampliamente distribuida sobre la parte noroccidental del del país, se movió sobre la región del 19 al 21 de enero de 1997. La información requerida para el estudio se obtuvo de las bases de datos de reanálisis del National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). Los resultados indican que durante el paso de la perturbación occidental por el norte de la India ocurre un fuerte flujo de convergencia y la producción de energía adiabática. Se observó que el componente meridional de la energía cinética contribuye a su generación, mientras que el componente zonal de la energía cinética ocasiona la destrucción de la generación adiabática de la energía cinética a lo largo de la trayectoria de la perturbación occidental.

ABSTRACT

The winter precipitation in western Himalayas, particularly over Jammu and Kashmir, Himachal Pradesh, Uttaranchal and neighborhood is important from the point of view of agriculture, horticulture, transport, logistics and glacier basins that feed the rivers of north India. The precipitation is due to the large-scale interaction between the mid latitude and the tropical air masses. The interaction process leads to the formation or intensification of synoptic systems known as western disturbances that move from west to east.

In this paper, kinetic energy budget terms for an intense western disturbance that occurred over northwest India have been analyzed. An intense western disturbance, that gave widespread precipitation over the northwestern parts of the country, moved across the region from 19 to 21 January 1997. The data required for the study was extracted from National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis datasets. The results indicate that the strong flux convergence and adiabatic production of kinetic energy takes place during the passage of western disturbance over north India. It is found that the meridional component of kinetic energy contributes for the generation, whereas, the zonal component of kinetic energy contributes for the destruction in the adaibatic generation of kinetic energy along the track of the western disturbance.

Keywords: Western disturbances, kinetic energy, NCEP/NCAR reanalysis.

1. Introduction

Northwestern parts of India, particularly the western Himalayan region, receive significant precipitation in the form of snow in winter months (December-March) due to the movement of synoptic systems known as western disturbances. Western disturbances are eastward moving synoptic systems either at the surface or in the upper air in the regime of subtropical westerlies. Their behavior is close to middle latitude cyclones of Pacific and Atlantic, but without any marked frontal structure. Significant changes in the wind direction and speed are observed in the lower, middle and upper tropospheric levels. Rao and Srinivasan (1969), Saha and Sinha (1970) and Singh (1971, 1980) studied the tropospheric structure during winter jet stream. Their studies concluded that the core speed of jet stream increased over India and its altitude decreased on the approach of a western disturbance. This indicates that there are considerable changes in kinetic energy during the passage of western disturbances.

Very few studies on the energetics of western disturbances are available in the literature. Ananthakrishnan and Keshavmurty (1973) examined the generation of kinetic energy by meridional and zonal winds over India during winter. They found that kinetic energy is generated by meridional motion and consumed by zonal motion. Gupta and Mandal (1987) studied the behavior of kinetic energy generation function during a western disturbance in May 1982. Their study revealed that the increase (decrease) in the kinetic energy content of the system could not be related to the positive (negative) contribution of the kinetic energy generation function. Further, the zonal component of the kinetic energy generation function acted as a source, while the meridional component behaved as a strong sink in the upper levels throughout the life cycle of the system. Kung (1971) examined adiabatic production and destruction of kinetic energy by the meridional and zonal motion of the atmosphere at different latitudes from 20 to 70 ºN. He found that at the lower latitudes the kinetic energy is produced by the meridional motion and destroyed by the zonal motion, while in the middle and higher latitudes, functions of meridional and zonal winds are reversed. Kung and Smith (1974), Kung and Baker (1975), Kung (1977), Ward and Smith (1976), Fuelberg and Smith (1980) and Michaclides (1983) have conducted diagnostic studies, revealing the kinetic energy budgets and energy conversions of large-scale systems of the atmosphere, and stressed the importance of such systems in transfer and transformation of kinetic energy in middle latitudes. Since the circulation systems are very effective in generating and transferring kinetic energy, it would be interesting to study some aspects of the kinetic energy budget during the passage of western disturbances because these disturbances move in the border line zone between tropics and mid latitudes. Mohanty *et al.* (1998) carried out an analysis of few cases of western disturbances and their impact on precipitation over northwest India. Further, various modeling studies have been carried out in recent years to investigate the genesis and development of western disturbances and associated precipitation over northwest India (Azadi *et al.,* 2001, Hatwar *et al.,* 2005). Roy and Bhowmik (2005) analyzed the vertical structure of the atmosphere over Delhi during the passage of a western disturbance.

In the present study, intense western disturbance that gave widespread precipitation over the northwestern parts of the country, moved across the region from 19 to 21 January 1997 and has been analyzed with significant parameters of kinetic energy budget. Figure 1 depicts the observed rainfall obtained from India Meteorological Department (IMD), India during the intense western disturbance period of 19 to 21 January 1997. A heavy precipitation was noticed over Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana and neighboring states on 19, 20 and 21 January 1997. The 24 hour accumulated rainfall of more than 60 mm was recorded on 20 January 1997 over Pathankot, Jammu, Udhampur, Quazigund, Kathua, Batote, Dharamsala, Simla, Manali, Sunder Nagar, Nahan, Solan, and Mukteshwar (Fig. 1b). Since precipitation and other forms of severe weather are likely to be associated with large scale energy changes, it is felt that a case study of an intense western disturbance may bring out the changes in the kinetic energy during the passage of a western disturbance across northwest India. Though western disturbances are considered similar to middle latitude systems, they differ from them in a sense that frontal structure is rarely noticed in them. Moreover, they move across topographical features like Himalayas and may bring out energy changes which differ from the usual mid latitude depressions.

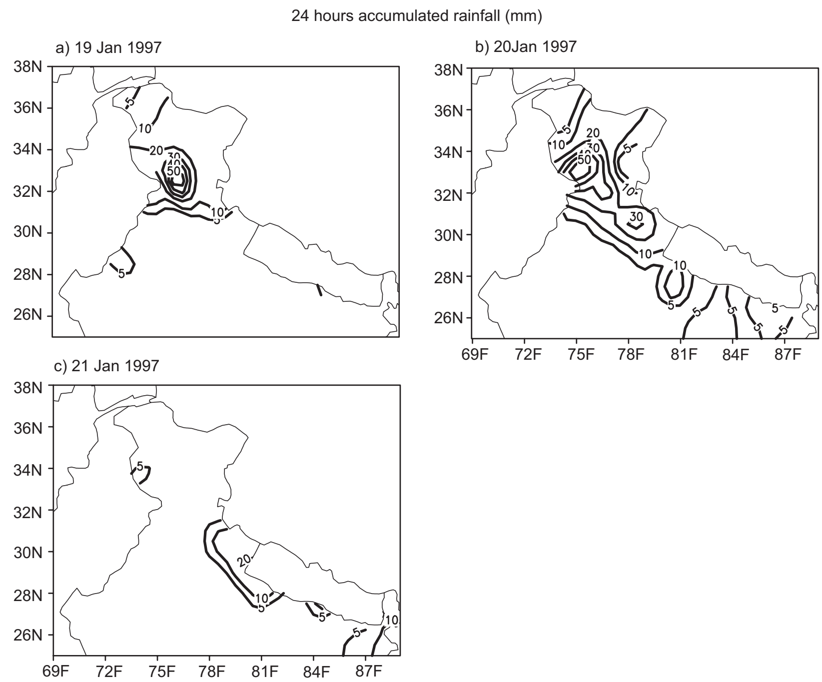

Fig. 1. Observed rainfall (mm) accumulated at 24 hours valid on a) 19 January 1997 b) 20 January 1997 and c) 21 January 1997.

2. Data and methodology

Due to very difficult and complex terrain, there is general lack of observational data. With the availability of remotely sensed observations, the data coverage over the Himalayas and neighborhood has improved. Further, the global circulation models use the data from various sources and is properly assimilated and reanalyzed at regular grid points. One of the reliable and homogeneous global circulation data set available is the National Center for Environmental Prediction /National Center for Atmospheric Research (NCEP/NCAR, hereafter NCEP) reanalysis. The data set is a result of the cooperative effort of NCEP and the NCAR to produce a 50 years (1948-1997) record of global analysis of the atmospheric fields to support the needs of the research and climate monitoring community. The effort involves the recovery of land surface, ship, rawinsonde, aircraft, satellite data and delayed mode GTS data, and quality control and assimilation with four dimensional data assimilation system that is kept unchanged over the entire period (Kalnay *et al.* 1996). Based on this data set, a study of some aspects of kinetic energy associated with an intense western disturbance is investigated. The region covered is 15, 45 ºN, 45, 90 ºE and the calculations have been carried out at 0000 UTC on the specified dates. The levels examined include 700, 300 hPa and vertically integrated values between 1000 to 100 hPa. The kinetic energy is entirely determined by the horizontal flow of the atmosphere.

The kinetic energy budget equation may be written as

$$\frac{\partial K}{dt} + \vec{\nabla} \times (K\vec{V}) + \frac{\partial\,(K\omega)}{\partial p} = -\vec{V} \times \vec{\nabla}\varphi + \vec{V} \times \vec{F} \tag{1}$$

Where K is kinetic energy, V is two dimensional wind vector, ω is vertical velocity, ϕ is geopotential and F is the frictional force. The first term on the left hand side in eq. (1) denotes the local rate of change of the kinetic energy. The second term describes the horizontal flux divergence of the kinetic energy and the third term indicates the vertical flux divergence of the kinetic energy. Similarly the first term on the right hand side of the equation denotes the conversion of potential energy into kinetic energy through the action of pressure forces (adiabatic generation of kinetic energy). The last term signifies the dissipation of kinetic energy by turbulent frictional processes and is usually calculated as a residue. In fact it is a sink or disappearance of kinetic energy from the observed scales of motion, which could be interpreted as the net loss of kinetic energy, which has been input into various scales of motion. Computations by Kung and Baker (1975) have shown that in the total atmospheric column from 1000 to 100 hPa, the horizontal transport or horizontal flux divergence, the adiabatic generation and frictional losses are the biggest terms in the equation. Since frictional losses are calculated as a residue, it will be advantageous if one studies the behavior of two terms viz. horizontal flux divergence and the adiabatic generation of kinetic energy.

3. Discussion of results

The comprehensive analysis has been carried out for intense western disturbance during 19-21 January 1997 over northwest India based on significant terms in the kinetic energy budget such as horizontal flux, adiabatic generation and zonal and meridional generation of kinetic energy.

3.1 Horizontal flux of kinetic energy

The horizontal flux of kinetic energy at 0000 UTC from 19 to 21 January 1997 for the intense western disturbance case at 700, 300 hPa and vertically integrated horizontal flux of kinetic energy between 1000 to 100 hPa are given in Figure 2. The top, middle and bottom panels show, 700, 300 hPa and vertically integrated fluxes, respectively. It is observed from figures at 700, 300 hPa that small magnitudes of convergence of horizontal fluxes of kinetic energy are located in the immediate neighborhood of the surface position of the western disturbance. The convergent magnitudes are higher on 19 January 1997 (Figs. 2a and b), in the vicinity of the low-pressure center but decrease later. The lowest and steepest horizontal flux of kinetic energy and the gradient is observed on 20 January 1997 (Figs. 2d and e). It may be possible that increasing convergence flux of kinetic energy follows the fall of pressure and associated pressure gradient. From 20 January 1997, the convergent magnitude of horizontal flux of kinetic energy at 300 hPa decreases considerably, which is reflected in the subsequent pressure rise and decreasing pressure gradient (figure not shown). But at 300 hPa there is a sharp increase in the convergence flux of kinetic energy and it may vary between 400 to 800 units (10^{-4} W kg^{-1}). The vertically integrated flux of kinetic energy also shows very high values of convergence flux of kinetic energy. The integrated magnitude is about three orders higher than that of 300 hPa. Thus, it may be inferred that large changes in the flux of kinetic energy take place in upper troposphere where probably subtropical jet stream and the large variation in the speed and

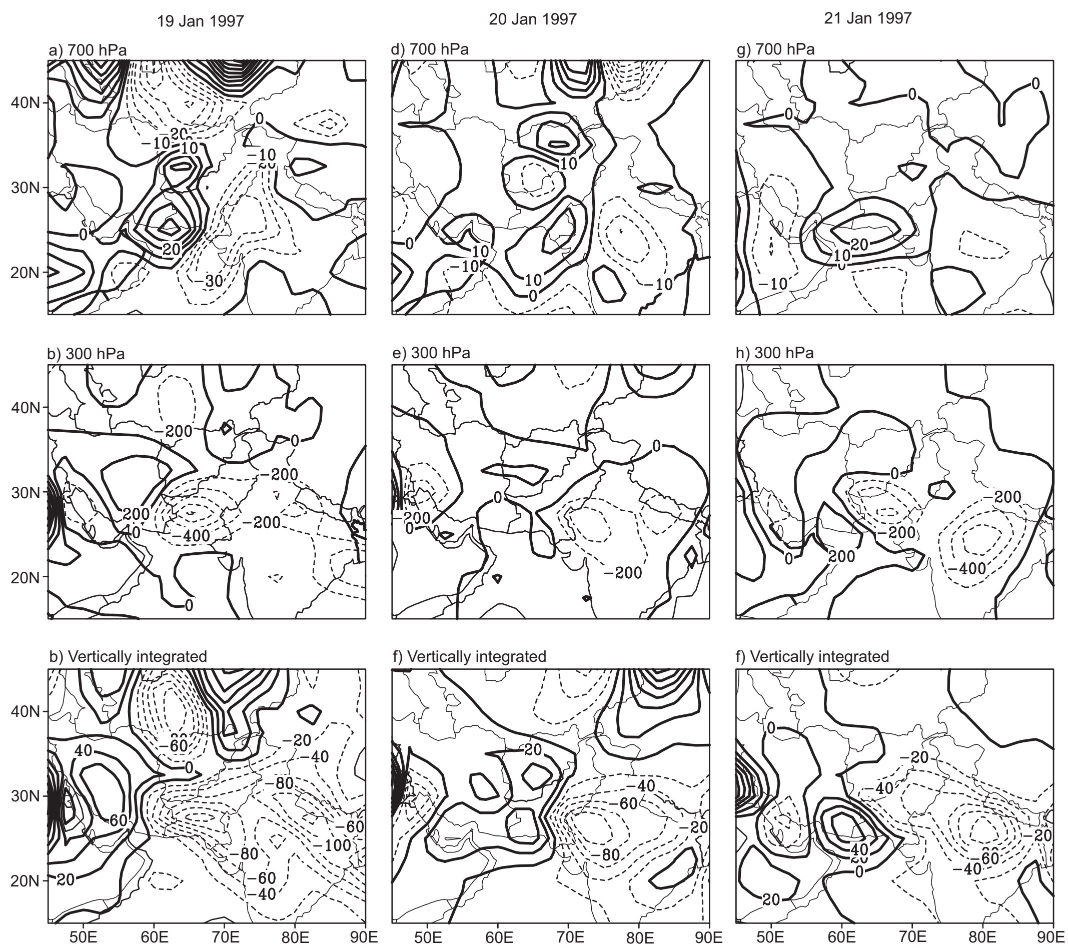

Fig. 2. Horizontal flux of kinetic energy (W kg^{-1}) for 700 hPa (top panel), 300 hPa (middle panel) and vertically integrated (bottom panel) kinetic energy (W m^{-2}).

direction of winds are responsible for such a behavior pattern. The convergence center at 300 hPa or in the integrated values is usually located to the west or west-northwest of the surface location of western disturbance. Strong flux convergence noticed over Iran and Afghanistan which may be due to presence of another low-pressure system. The largest amount of precipitation observed over Jammu and Kashmir, Himachal Pradesh and Punjab/Haryana on 20 January 1997 (Fig. 1b), when the pressure at the center of the system was lowest and the pressure gradient steepest (figure not shown). However, convergence of horizontal flux of kinetic energy, particularly at 300 hPa and the vertically integrated magnitude, was highest on 19 January 1997, i.e. a day earlier.

3.2 Adiabatic generation of kinetic energy

Adiabatic generation of kinetic energy at 0000UTC from 19 January to 21 January for the western disturbance case at 700, 300 hPa and vertically integrated magnitude between surface and 100 hPa are given in Figure 3. Positive magnitudes indicate the generation of kinetic energy from the available

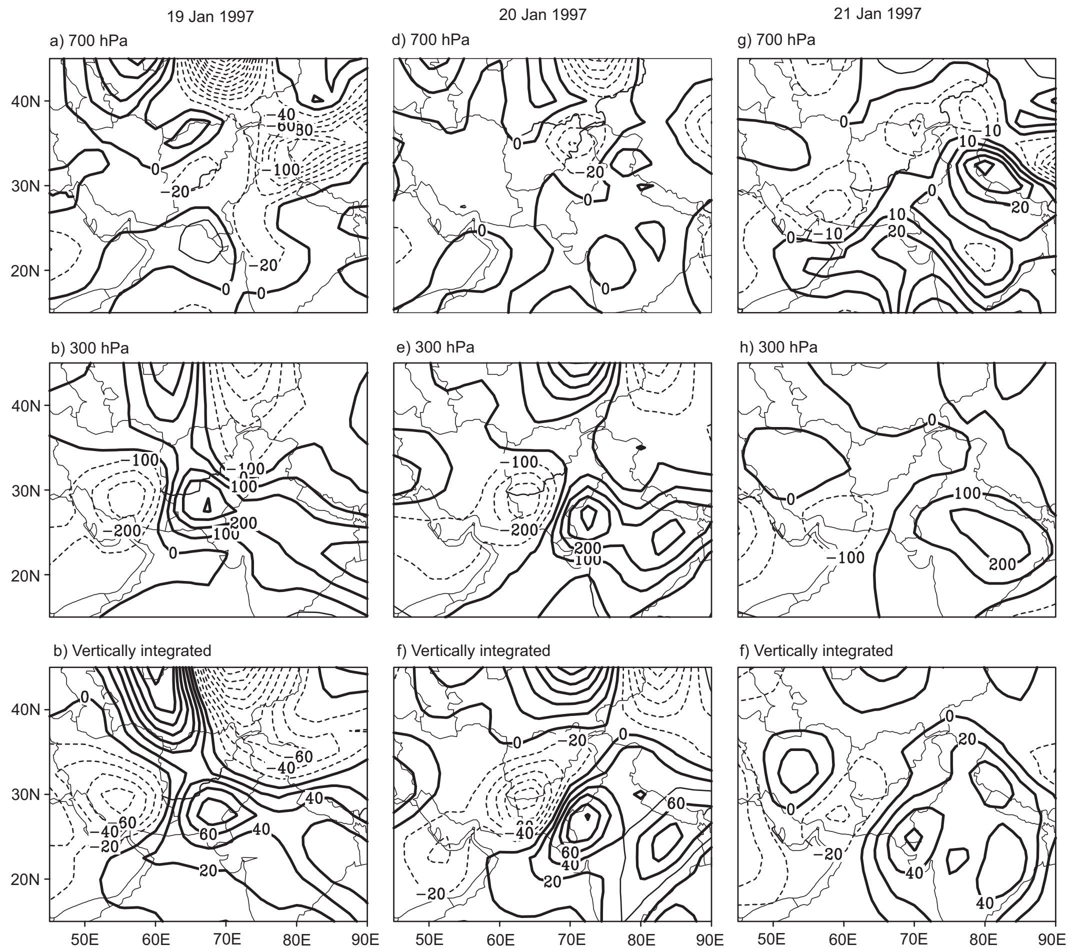

Fig. 3: Adiabatic generation of kinetic energy (W kg^{-1}) for 700 hPa (top panel), 300 hPa (middle panel) and vertically integrated (bottom panel) kinetic enrgy (W m^{-2}).

potential energy, and negative magnitudes signify the conversion of kinetic energy back to available potential energy. It is observed that at 700 hPa (Fig. 3), weak magnitudes of dissipation of kinetic energy takes place in the immediate neighborhood of surface position of western disturbances. In the upper level at 300 hPa there is a sharp increase in the dissipation of kinetic energy and it may vary between 300 and 400 units (10^{-4} W kg^{-1}). There is dissipation of kinetic energy in the vicinity of the surface center of low pressure. This magnitude is smaller than the flux of kinetic energy at the same level. Thus, the flux of kinetic energy may be more important source than adiabatic generation of kinetic energy. The vertically integrated generation of kinetic energy shows dissipation in the immediate proximity of the center of low-pressure area and generation to the west of it. The dissipation and generation attain maximum magnitudes on 19 and 20 January 1997, when the associated precipitation is maximum, while on 21 January 1997, the dissipation or generation of kinetic energy decreases appreciably and so does the precipitation. The generation of kinetic energy during western disturbances depends fundamentally upon a phase difference between the pressure trough and the thermal trough, and these effects are significant when thermal trough lags the pressure trough by 90º. If the troughs and ridges of the isotherms and pressure contours become more or less in phase, little kinetic energy is produced, because rising and descending motions ahead of and behind the pressure trough occur at nearly the same temperature. Extending the logic further, if the thermal trough leads the pressure trough, there would be dissipation of kinetic energy. Thus, it is quite probable that from 19 to 21 January, the thermal trough was lagging the pressure trough, particularly at 300 hPa or aloft, giving rise to dissipation of kinetic energy immediately aloft the surface position of western disturbances and generation to further west of it. In the case of weak dissipating disturbance, the thermal trough could lead to the pressure trough, creating the reverse pattern of generation of kinetic energy.

3.3 Zonal and meridional generation of kinetic energy

In order to examine the generation of kinetic energy, the winds at various levels were split into zonal and meridional components and generation of kinetic energy was calculated separately with each component at various levels. Examination of Figures 4 and 5 bring out that the zonal and meridional generation of kinetic energy act in opposition to each other though the magnitudes may not be the same. An examination of the zonal and meridional winds at 300 hPa and aloft brings out that northerlies are associated with dissipation of kinetic energy while southerlies are regions of generation of kinetic energy. The zonal generation or dissipation is not clearly understood but it could be transferred from southern latitudes i.e. tropics. Palmén and Newton (1969) has stated that generation of kinetic energy in extra tropical storm occurs largely through the vertical solenoid circulations in the planes oriented more or less zonal. The energy generated is largely in the form of meridional kinetic energy and there is significant transfer of zonal kinetic energy from the tropics. Moreover, the local change of total kinetic energy always depends very much on the flux terms that no simple rules can be given concerning the actual change of kinetic energy in open systems.

The zonal generation of kinetic energy at 300 hPa and vertically integrated values take place to the west or northwest of the surface position of the low, and zonal dissipation of kinetic energy is occurring to the east or northeast of the surface position of the low. The generation in the intense western disturbances has reached its highest value on 20 January 1997, the day when maximum precipitation was recorded. Figure 5 brings out that meridional generation of kinetic energy is in opposite phase to the zonal generation. Further, as stated earlier, the northerlies (southerlies) are associated with the meridional dissipation (generation) of kinetic energy.

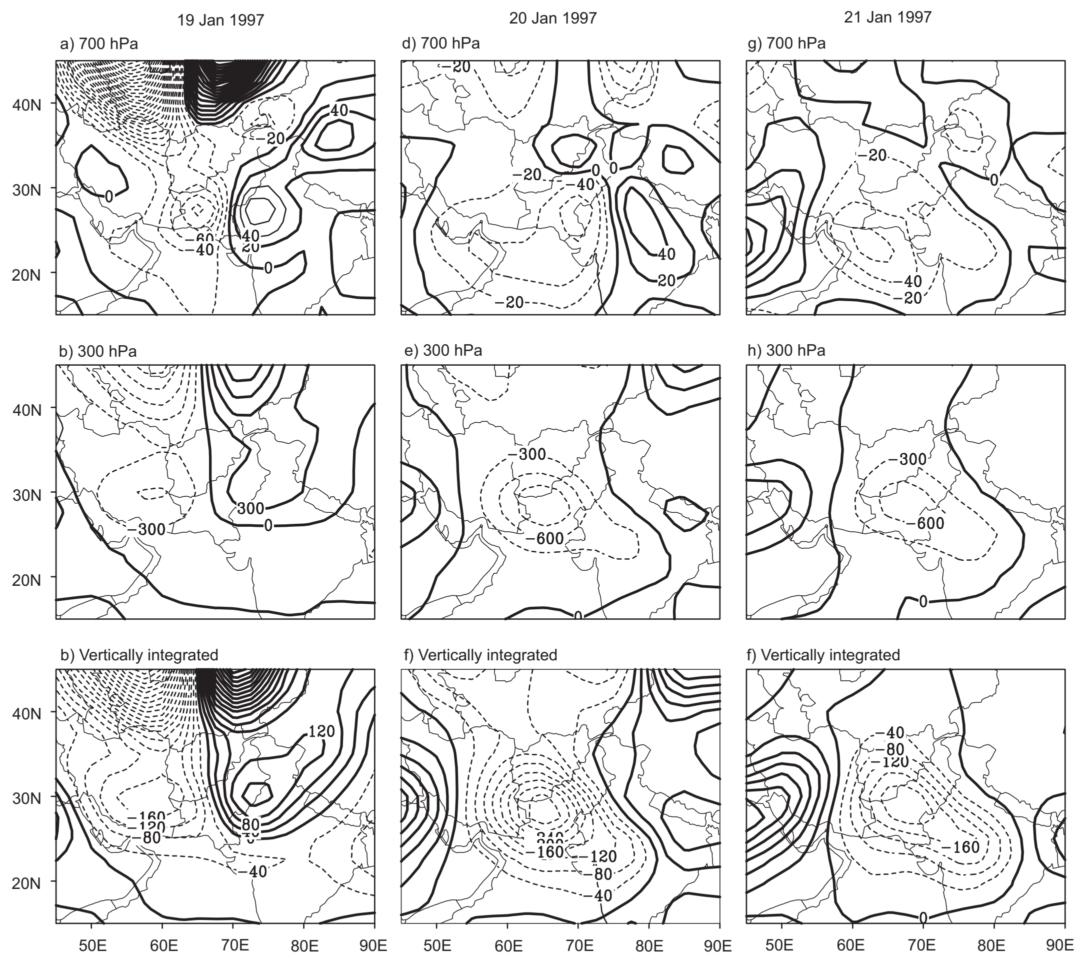

Fig. 4. Zonal generation of kinetic energy (W kg^{-1}) for 700 hPa (top panel), 300 hPa (middle panel) and vertically integrated (bottom panel) kinetic energy (W m^{-2}).

4. Conclusions

In the present paper, the detailed analyses of various kinetic energy budget parameters for western disturbances over northwest India reveal the following broad conclusions.

The vertical integrated divergence flux of kinetic energy (1000-100 hPa) is observed to be convergent in an intense western disturbance. It is found that there is sharp increase in the convergence flux of kinetic energy and weak adiabatic generation of kinetic energy over the troposphere. The vertically integrated generation of kinetic energy shows destruction in the proximity of the center of low pressure area and generation take place west of it in the intense western disturbance.

The zonal and meridional generations of kinetic energy indicate that they act in opposition to each other. The northerlies are linked with dissipation of meridional generation of kinetic energy, while southerlies are associated with generation.

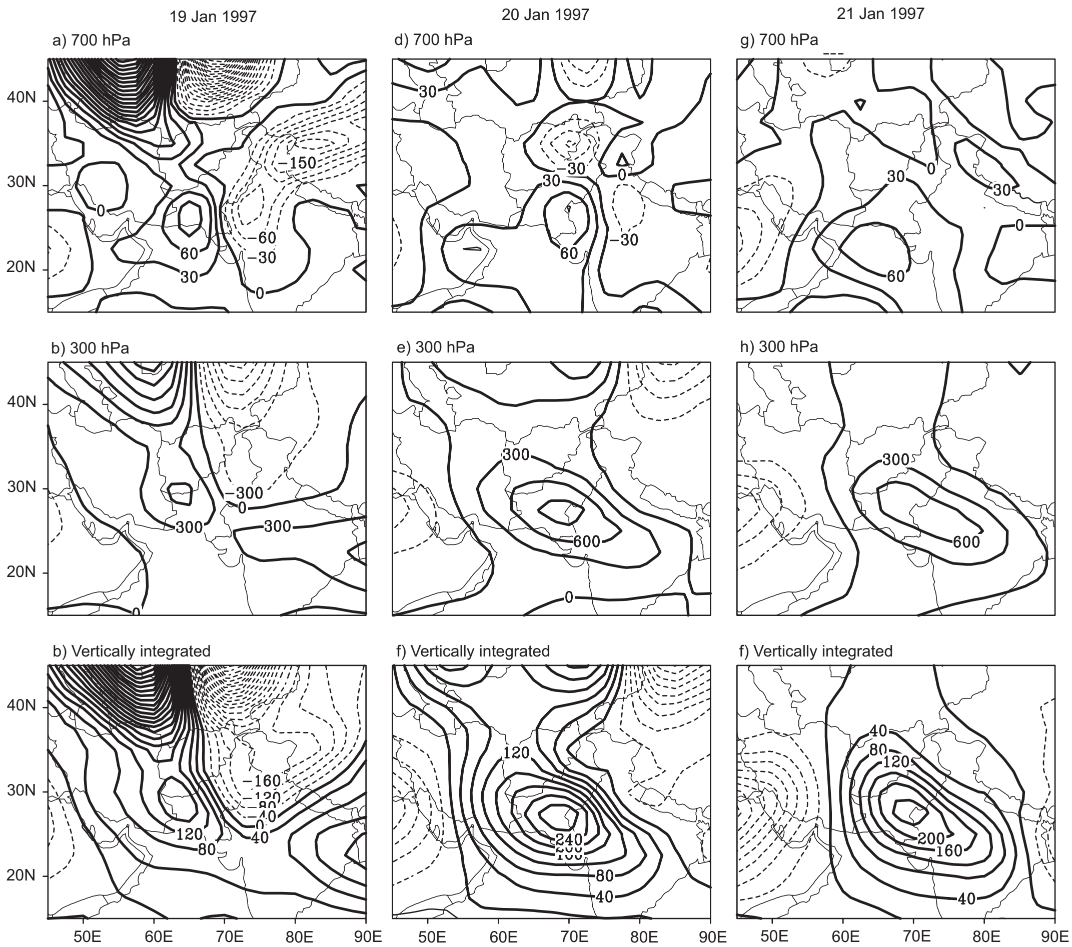

Fig. 5. Meridional generation of kinetic energy (W kg^{-1}) for 700 hPa (top panel), 300 hPa (middle panel) and vertically integrated (bottom panel) kinetic energy (W m^{-2}).

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