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Letters to the Editor

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DIAGNOSTIC STUDIES OF AN ACTIVE WESTERN DISTURBANCE OVER WESTERN HIMALAYA

1. Western disturbances (WDs) are low pressure systems observed in the midlatitude westerlies over the sub-tropical regions of Asia. They move from west to east in all seasons, but are most prominent during winter months of December to March. In winter, over northern India, generally a high pressure at the surface level is observed and the associated weather is usually clear and dry. This situation is altered due to passage of trough in the middle and upper air westerlies, which cause cloudy conditions and light to heavy precipitation. Earlier studies (Pisharoti & Desai, 1956; Kalsi, 1980 and Kalsi & Haldar, 1992) have mentioned that interaction between the tropics and mid latitude systems are associated with extensive sheets of mid and high levels of clouds and maxima in the subtropical jet. Kalsi & Haldar (1992) suggested that mobile cloud systems are related to short waves in the sub-tropical jet and facilitate the interaction between the tropics and mid latitude systems by amplifying the long wave troughs leading to a large influence of mid latitude westerlies over the sub-tropics and lower latitudes. Therefore study of WDs, an interesting weather system of mid latitude that is modulated by tropical air mass and the Himalayas, is important.

1.1. The circulation characteristics of the atmosphere are depicted by kinetic energy budget. Kung (1996a) evaluated the boundary layer dissipation and the free atmosphere dissipation and shown that the latter is as important as former. Also, in the kinetic energy budget, the generation and dissipation are largely balanced in the atmosphere (Kung, 1996b). Lau (1979) has shown that energy generated in the source region is transported by the mean flow to the jet exit regions. Chen (1982) revealed that the large value of kinetic energy extends from the maximum core to the downstream of the tropical easterly jet. Mohanty & Ramesh (1994) observed the heat and moisture flux transfer into the summer monsoon domain. However, very few studies are carried out on kinetic budget for WD cases.

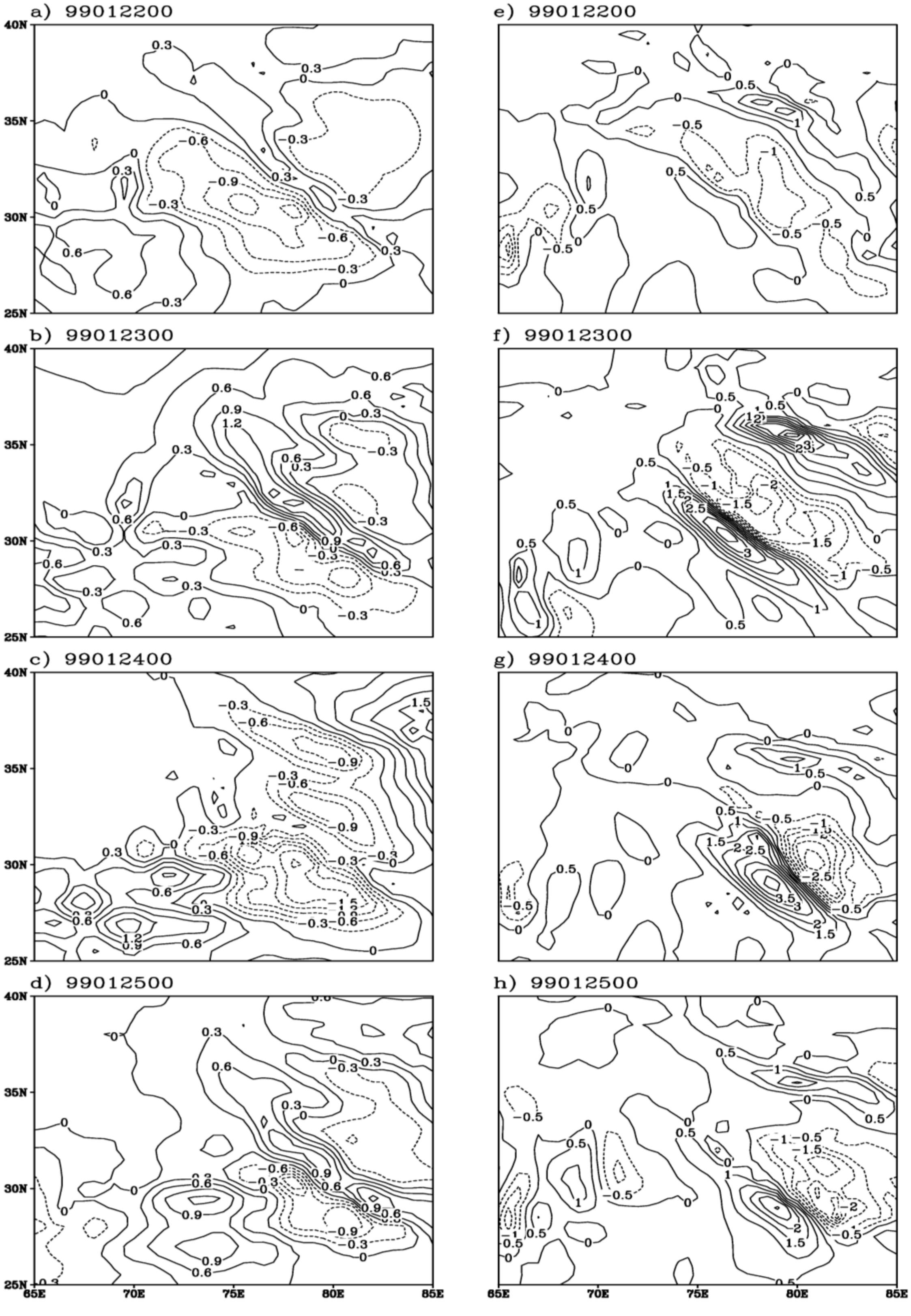
1.2. In the present study, energetics and diagnostic are presented for a weather situation associated with an active WD that occurred over Indian region in January 1999, by using a high resolution MM5 model.

2. Meso-scale model used in the present study, for prediction of meteorological variables associated with a WD, is a non-hydrostatic limited area model, known as MM5 modeling system, developed by Anthes & Warmer (1978) at PSU/NCAR. Dudhia (1993) used this model for validation tests and simulation of an Atlantic cyclone and cold front.

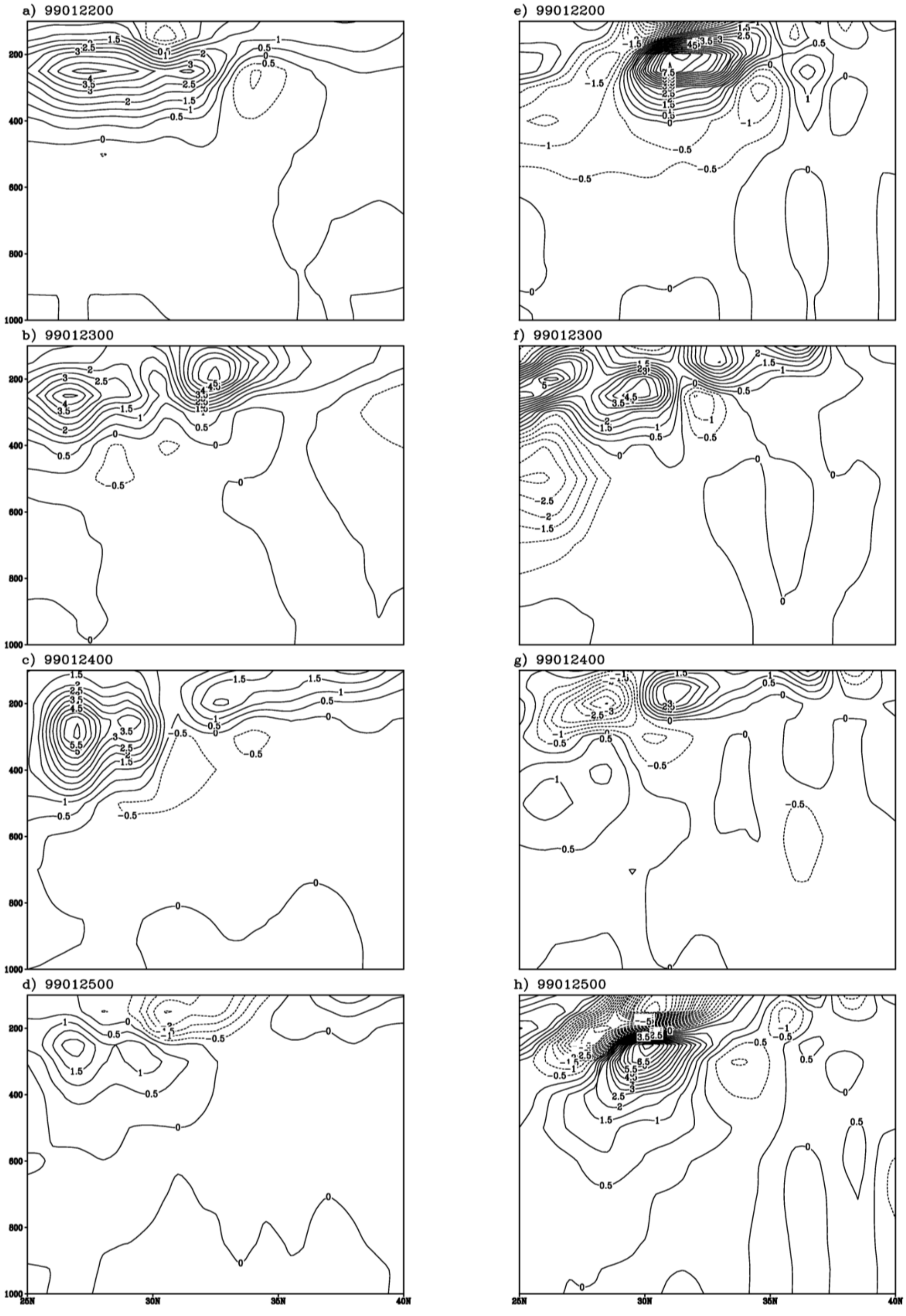
2.1. Simulation for producing four day forecasts was conducted using the initial conditions of 0000 UTC of 21 January 1999. Hong Pan Scheme (Hong & Pan, 1996) and Betts-Miller scheme (Betts & Miller 1986 and 1993) are used for parameterization of planetary boundary layer processes and convection respectively with model horizontal grid resolution of 60 km is used for the study.

2.2. Initial conditions for the model are extracted from NCEP reanalysis data of 2.5° × 2.5° of resolution which was interpolated to the model domain.

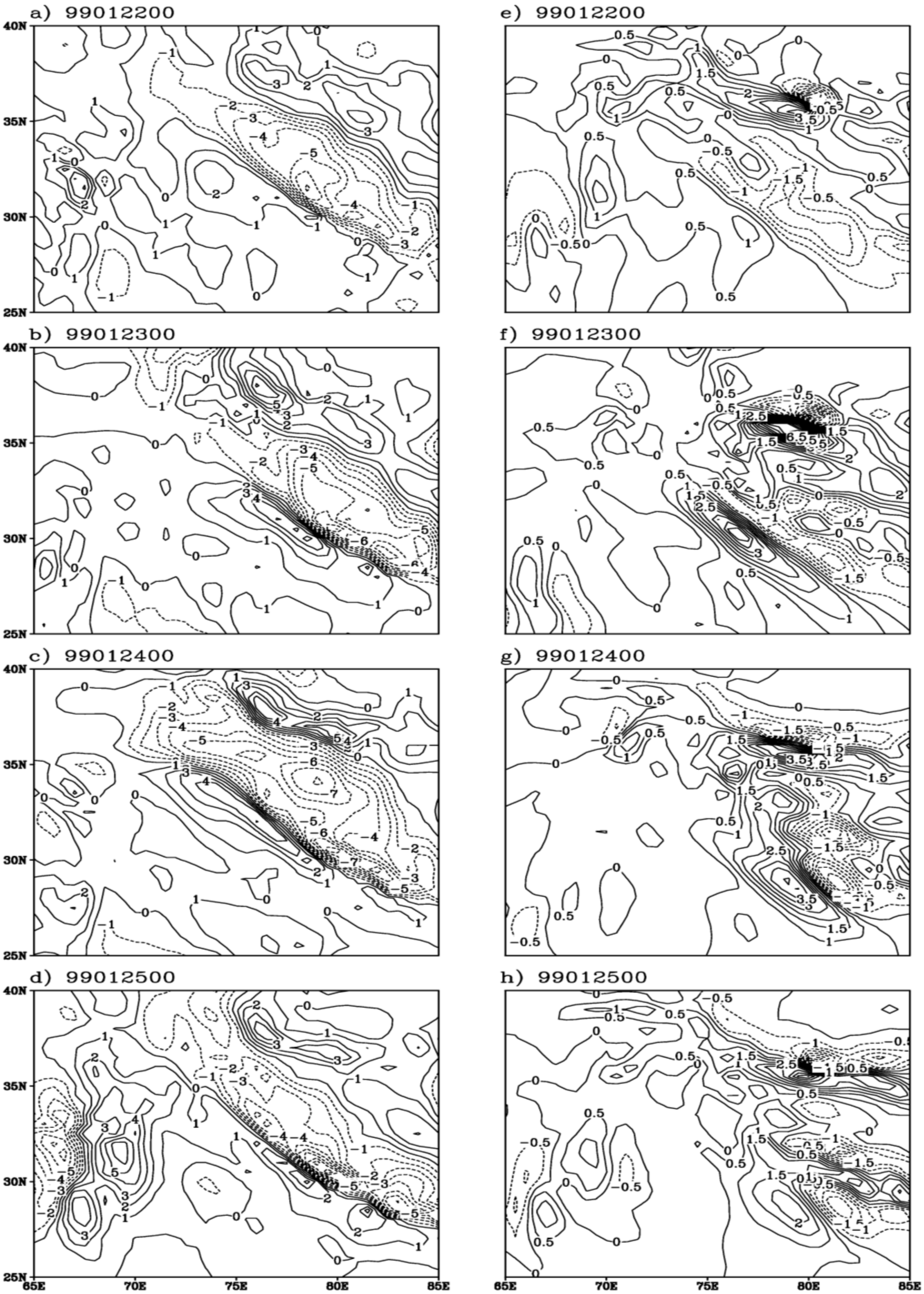
3. On 21 January 1999 a trough at 500 hPa was observed extending from Afghanistan to northwest India that was associated with a low pressure at surface. On 22 January 1999 the low on the sea level persisted. The associated upper air circulation could be seen upto 700 hPa and trough aloft extended upto 300 hPa. The trough tilted westward with height. Precipitation amounts varying between 2 & 6 cms were recorded at number of places in northwest India. On 23 January 1999, at 0000 UTC the pressure trough persisted at the same location with considerably strong pressure gradient over the region. The associated upper air cyclonic circulation also strengthened and could be seen extending upto 500 hPa and trough aloft upto 200 hPa. The upper air cyclonic circulation and the associated trough tilted westward with height. On this day, precipitation amounts varying between 2 & 6 cms were recorded at a number of places in northwest India. On 24 January 1999 low pressure area could be marked over Rajasthan and the steep pressure gradient to the north of it could still be observed over northwest Indian states. The associated cyclonic circulation extended upto 500 hPa and trough aloft upto 200 hPa. The trough was located close to 70° E. On this particular day the rainfall amount varying between 2 & 9 cms were recorded at many places over northwest India. On 25 January 1999 the low pressure area over Rajasthan weakened considerably and moved east northeastwards. The associated upper air trough was noticed between 700 hPa and 200 hPa. The precipitation amounts varying between 2 & 4 cms were recorded at a



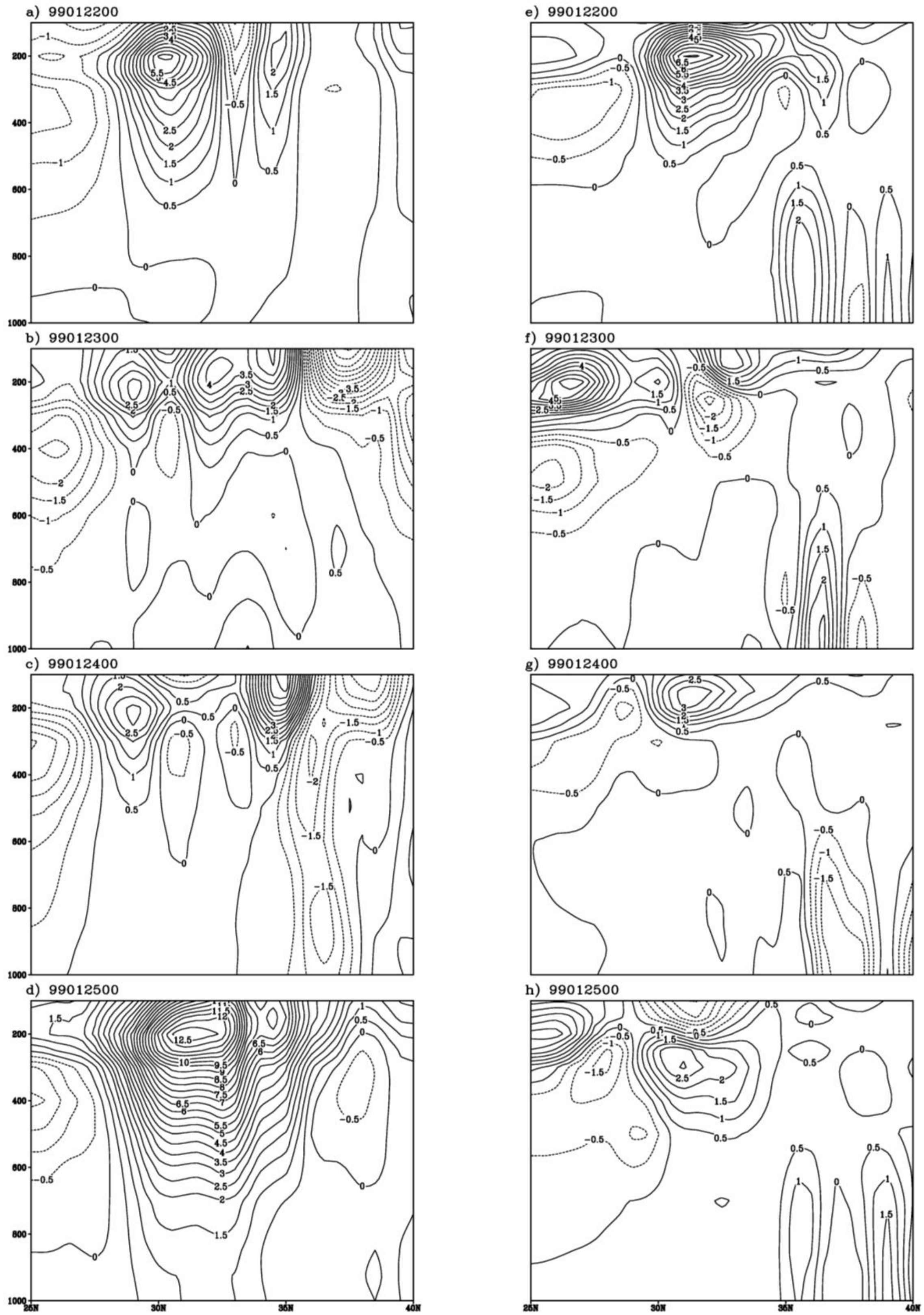
Figs. 1(a-h). Vertically integrated horizontal flux of kinetic energy (10^2 W kg^{-1}) : (a-d) Analysis, (e-h) Simulated



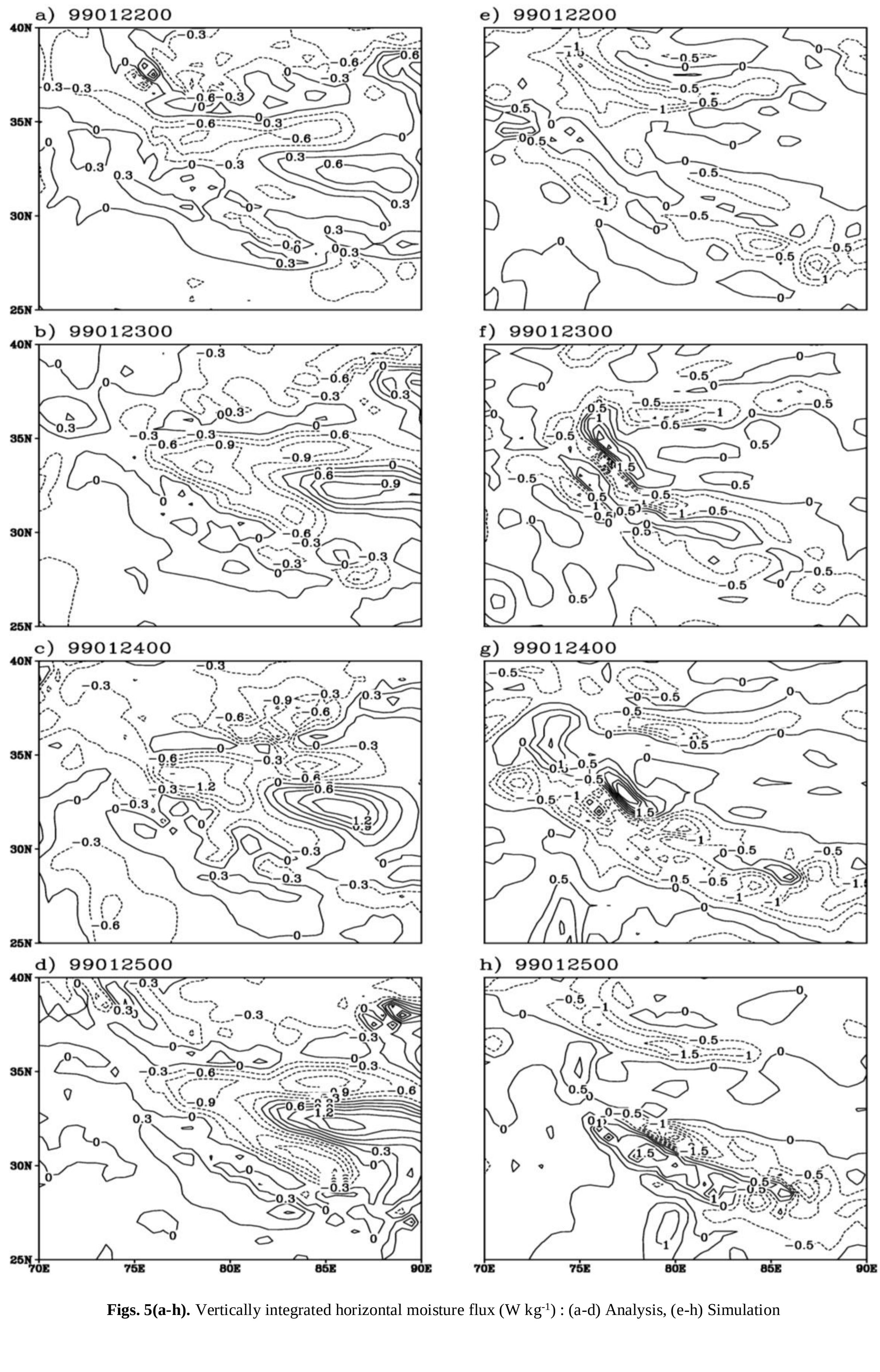
Figs. 2(a-h). Vertical profile of horizontal flux of kinetic energy (10^{-2} W kg^{-1}) at 75° E : (a-d) Analysis, (e-h) Simulated



Figs. 3(a-h). Vertically integrated generation of kinetic energy (10^2 W kg^{-1}) : (a-d) Analysis, (e-h) Simulation



Figs. 4(a-h). Vertical profile of generation of kinetic energy at 75° E (10^2 W kg^{-1}) : (a-d) Analysis, (e-h) Simulation



Figs. 5(a-h). Vertically integrated horizontal moisture flux (W kg^{-1}) : (a-d) Analysis, (e-h) Simulation few places in northwest India. On 26 January 1999 the trough became very feeble (Figures not presented).

4. The maintenance and intensity of general circulation of the atmosphere depends on the balance between generation and dissipation of kinetic energy. The kinetic energy of the atmosphere is generated through the conversion of Available Potential Energy (APE) and eventually dissipated through frictional forces. The kinetic energy is basically produced by ageostrophic component of flow. Positive magnitude denotes the generation of kinetic energy through the conversion of APE and negative magnitude denotes the destruction of kinetic energy, *i.e*., transformation of kinetic energy back to APE. The production region of kinetic energy is characterized by strong horizontal flux divergence.

4.1. Three significant terms, *viz*., the horizontal flux, the generation and dissipation of kinetic energy govern the local balance of kinetic energy. The mean horizontal flux of kinetic energy is further divided into its two constituents namely the component due to mean part of the flow and the component due to eddy part of flow. In the present study sectorial mean of kinetic budget is considered at 75° E.

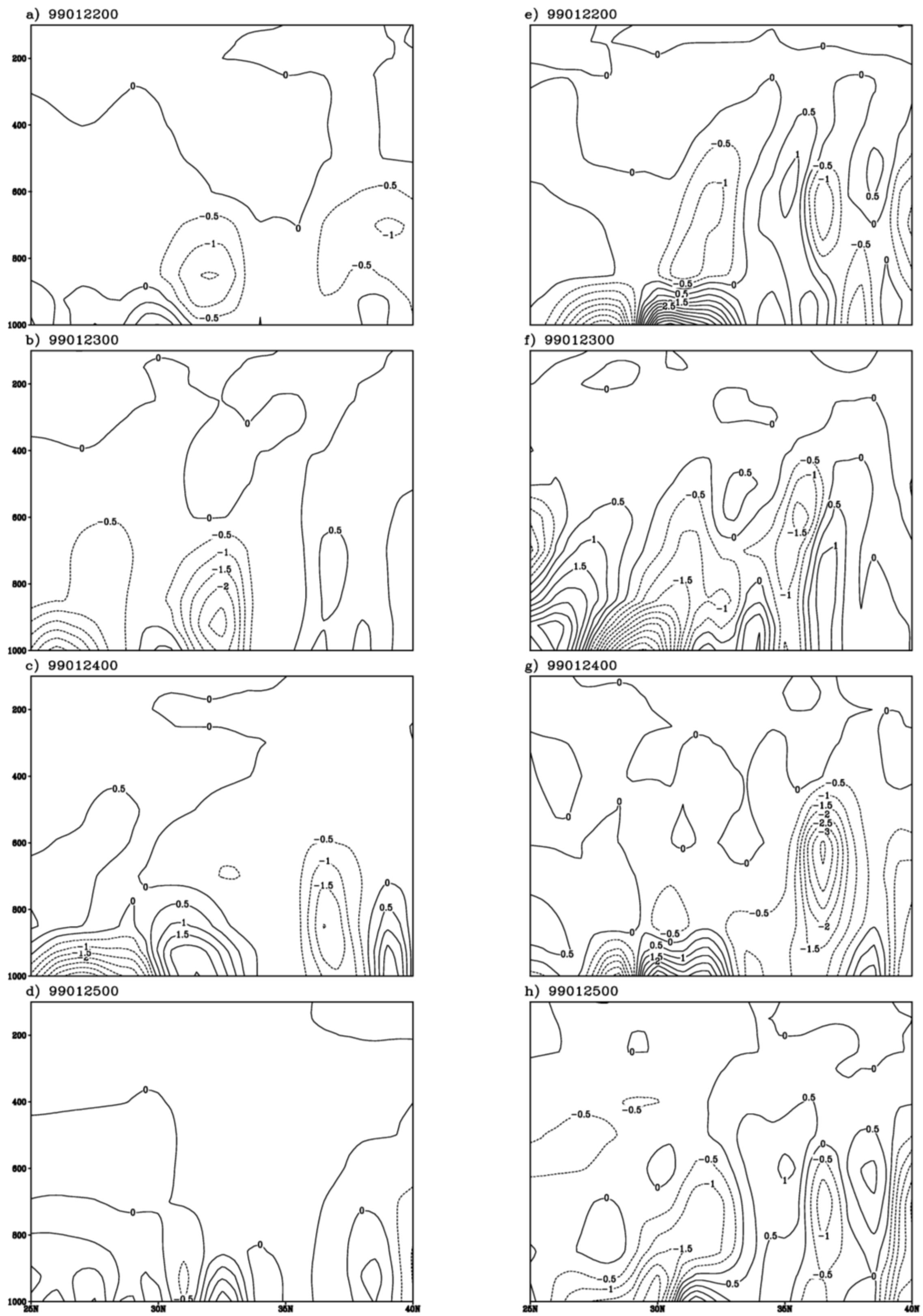
4.1.1. The vertically integrated (1000-100 hPa) distribution of significant kinetic energy budget terms are studied for simulated and analysis fields. The vertically integrated horizontal flux of kinetic energy is depicted in Fig. 1. There are two zones of convergence are observed, which are more predominant in simulation. One zone of maxima is seen lying along the Himalaya and other one over Tibetan plateau. One zone of divergence is seen between these two maxima of convergence. The zone of kinetic energy flux transport maxima/minima are situated at respective location of entrance/exit of WD flow. In order to establish the intensification and dissipation of WD, it has seen that with intensification of WD convergence flux of KE has increased and strong zones of convergence are noticed on 23 January 1999 and 24 January 1999 in both analysis and simulation. By 25 January 1999 these fluxes get dissipated.

4.1.2. In order to analyze the vertical distributions, the sectorial mean of horizontal flux of kinetic energy for analysis and simulation is depicted in Fig. 2. The region is characterized by flux convergence at lower level and divergence at upper level, which are more intense in simulation. Usually, kinetic flux is divided into its components due to mean and eddy flows. Normally the mean component depicts convergence and the eddy components divergence in the upper level. The flux transport of kinetic energy is found to be balancing mean flow flux transport over the extra tropics with strong flux transport of kinetic energy. In upper levels, the transient eddies are found to supplement the mean flow transport leading to net flux transport of KE from the region.

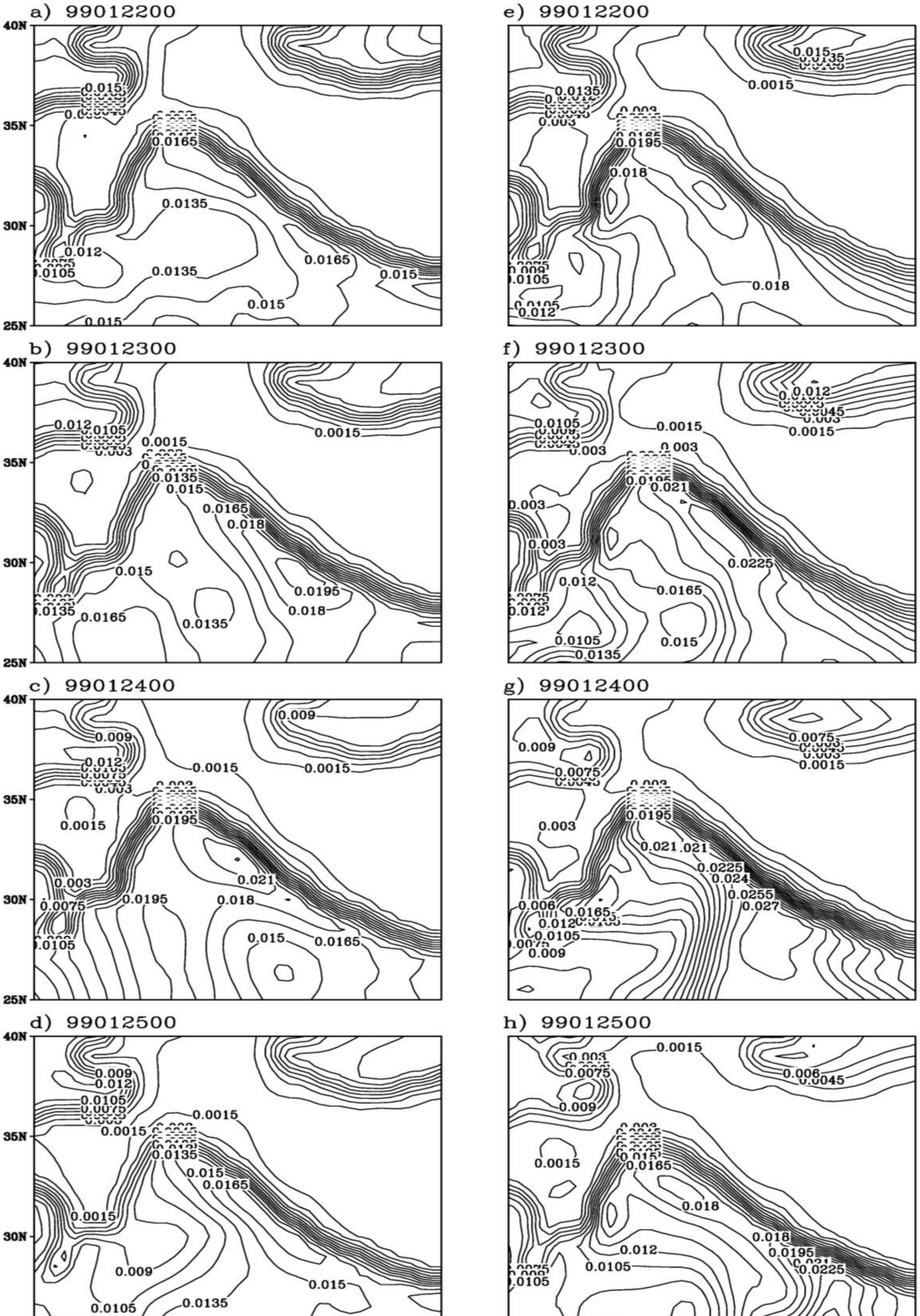
4.1.3. Similarly, while analyzing vertically integrated (1000-100 hPa) generation of kinetic energy, Fig. 3, a zone of flux convergence extending all over the Himalaya is observed. This zone delineates two maxima, the first situated over Leh and its surroundings and other over Tibetan plateau. The flux of divergence zone is observed between these two zones of convergence. Further, the significant features depicted by the zonal component include the general production of kinetic energy over the Leh and surrounding area, which is seen to be a peculiar feature for WD. It contributes for destruction of kinetic energy over Tibetan plateau. The meridional component contributes for the destruction of kinetic energy over Leh and surrounding areas and production over Tibetan plateau. The existence of two kinetic energy maxima over the above mentioned locations is vital for the maintenance of the flux divergence maxima situated over the same location.

4.1.4. The sectorial mean of generation of kinetic energy for analysis and simulation is depicted in Fig. 4. The kinetic energy generation is more over the strong flux divergence regions and weak production is over the flux convergence region. While analyzing, zonal and meridional generation of kinetic energy, it is found that zonal term contributes for the destruction of kinetic energy in the lower level and production in upper level. However, meridional generation term contributes for the production in the lower and upper levels of the WD region. Comparisons show that with the advent of WD generation of kinetic energy is quite significant and dissipates with WD.

4.2. Moisture is another important element of the atmosphere, which controls the weather. The inhomogeneous moisture distribution over the region hampers its analysis, especially over the data sparse region. Since WD circulations to a large extent sustained and maintained by the moisture convergence, it is imperative to study the moisture distribution over the area considered for study. Sectorial mean of moisture budget is considered at 75° E. Moisture flux convergence plays an important role in controlling the moisture distribution over the region. The moisture flux transported into the region is



Figs. 6(a-h). Vertical profile of horizontal moisture flux (10^{-4} W kg^{-1}) at 75° E : (a-d) Analysis, (e-h) Simulation



Figs. 7(a-h). Vertically integrated moisture (mm): (a-d) Analysis, (e-h) Simulated transferred to upper levels due to orographic lifting and turbulent exchange mechanism. In the upper levels the moisture undergoes phase transformation and releases latent heat. Thus the formation of heat source takes place.

4.2.1. Vertically integrated horizontal moisture flux (1000-100 hPa) is depicted in Fig. 5. Comparison shows that simulations are overestimating the moisture flux, though following the similar flux transport with intensification/movement of WD. Two zones of maxima are observed, one along the Himalayan range and other, although not pronounced, over Tibetan plateau. Most of the moisture is found to be accumulated towards windward side of mountain range and hence signifies the orographic effect.

4.2.2. The vertical distribution (1000-100 hPa) of horizontal moisture flux is depicted in Fig. 6. Strong flux convergence of heat in the lower levels and strong flux divergence of heat in the upper levels seem to be characteristic features of the WD. The lower level flux convergence depicts maxima around 30° N and divergence field at around 35° N. The upper level maximum is due to release of latent heat through condensation mechanism. The vertical profile of moisture distribution shows a zone of strong flux convergence in this region. Further vertically integrated horizontal moisture flux shows affect of the Himalaya, as most of the convergence zones are lying along the Himalayan range.

4.2.3. Thermodynamic characteristics of WD are analyzed by studying vertically integrated moisture over the region. Vertically integrated moisture is depicted in Fig. 7. It shows effective role played by the Himalaya. Most and maximum precipitation is observed all along the Himalayan range. Apart from this there are smaller zone of maxima too are observed all along the field.

5. Author acknowledges anonymous referee.

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