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Diurnal Characteristics of Trapped Mountain Waves over the Foothills of Western Nepal Himalaya

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ABSTRACT

Late wintertime diurnal variation and spatial distribution of mountain wave excitations over the Mt. Devchuli range and its surrounding areas have been numerically simulated with the application of Weather Research and Forecasting (WRF) Modeling System. The study reveals that the region holds low-level trapped mountain waves almost all the time. The waves are confined below the stratified layer at about 3km above the mean sea level. Wave excitation over the region is highly active during the afternoon time whereas it remains at minimum level during the late morning time. These waves pose significant risk for low-level aviation and parachuting activities.

Keywords: Meteorology, mountain waves, atmospheric stratification, hydraulic jump, aviation hazards.

INTRODUCTION

Mountainous region encompasses endless varieties of hills, passes, valleys, and slopes. Himalayas represents an unparalleled topographic complexity and hence a myriad of extraordinary meteorological phenomena can be associated with this region. Unusually large wind speeds are common in mountainous terrain and the surrounding foothills. Atmospheric probes, particularly the gliders and sailplanes, developed during the late 1920s started to gather evidence of pronounced vertical undulations of the airflow in the lee of mountain (Blumen 1990). An extensive description on the characteristics of these vertical undulations may be found in Queney *et al.* (1960).

A disturbance may be created when stably stratified air is constrained to follow over the topographic barrier profile. The disturbance may develop into the internal gravity waves commonly known as mountain waves when mountains cause them. The energy associated with disturbance is usually carried away from the mountain by these waves. The excitation, maintenance, and dissipation of these waves are intimately related to complex terrain and play significant role in the energy, momentum, heat, and moisture balance in the atmosphere (Durran 1990).

Depending upon the scale of topographic complexities and the prevailing atmospheric situations, mountain waves may remain trapped within the shallow layer of lower troposphere or are allowed to propagate vertically up to thermospheric heights (Blumen 1990). Moreover, mountain waves may overturn and be associated with extremely turbulent conditions. Studies on Sierra Naveda range revealed that internal gravity waves could be highly unusual and hazardous as well. They may concentrate momentum on the lee slopes, sometimes in structures resembling a hydraulic jump, leading to violent downslope windstorms (Holmboe & Klieforth 1957). Mountain waves breaking can have significant influence on the atmosphere for a number of regions that include: clear-air turbulence (Clark *et al.* 2000); downslope windstorms (Peltier & Clark 1979); vertical mixing of water vapor, aerosols, and chemical constituents (Dörnbrack & Dürbeck 1998); potential-vorticity generation (Schär & Durran 1997) and associated upscale energy transfer (Aebischer & Schär 1998); and the aggregate effect of orographic drag on the large-scale circulation (Palmer *et al.* 1986).

Trapped lee waves, characterized by vertically oriented phase lines due to superposition of two non-hydrostatic gravity waves propagating upwards and downwards, generally have horizontal wavelengths of 5-35 km. They occur within or beneath a layer of high static stability and moderate wind speeds at low levels of the troposphere (the lowest 1-5 km) lying beneath a layer of low stability and strong winds in the middle and upper troposphere (Durran 1990). These waves assume the form of a series of waves running parallel to the ridges, and the crests of these waves often contain wave clouds, or rotor clouds in parallel bands.

Fig. 1. Mountain-wave excitation caused by the Mt. Champadevi manifested in the wavy cloud pattern over the Kathmandu valley.

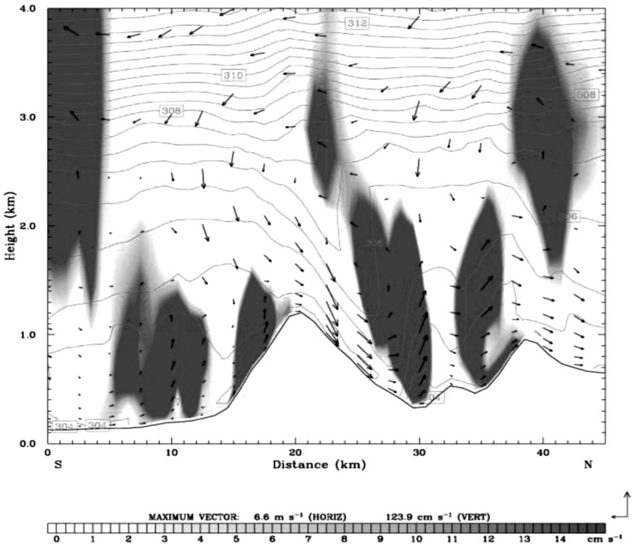


Fig. 2. South-North vertical cross-sectional plot of potential temperature, wind vectors and updrafts passing through the Hurhure Danda of Mt. Devchuli range on 02 February 2010 (Regmi 2012).

Because wave energy is trapped within the stable layer, these waves may dissipate only very slowly downwind, and they can continue downstream for many wavelengths spanning many tens of kilometers (Fig. 1). Flow beneath the wave crests is often turbulent, thus presenting a significant hazard to low-level aviation.

In this paper we will describe the diurnal characteristics of trapped mountain wave excitations in clear weather situation during the late wintertime over the Mt. Devchuli range of Western Nepal Himalaya located in the Nawalparashi District of Nepal. The motivation for this study comes from the earlier study (Regmi 2012) on diurnal variation of meteorological flows over the region in the context of wind power potential assessment where an extreme subsidence associated with overturning of mountain waves over the Hurhure Danda of the Mt. Devchuli range. As much as 1500 meters jump of isentropes were predicted over the region (Fig. 2). Furthermore, this is one of the regions from where a busy air route passes and parachuting trainings of Nepal Army are performed.

MATERIALS AND METHODS

The mountain wave excitation over the Mt. Devchuli range has been numerically simulated with the application of the Weather Research and Forecasting (WRF) Modeling System (Skamarock *et al.* 2008). The domain system consisted a triply nested two-way interacting mesh. The coarse and the fine domain include 51 x 51 x 34 grid points, and horizontal grid size are 9 and 3 km, respectively, whereas the finest domain include 70 x 70 x 34 grid points with horizontal grid size 1 km. The centers of all the three domains were placed at the top of Hurhure Danda (27°46’ N, 84°07’ E). The area covered by the finest domain and important locations are shown in Fig. 3.

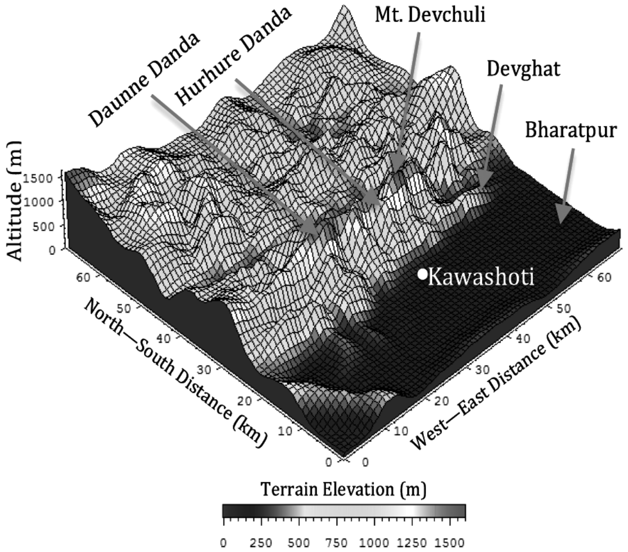


Fig. 3. Bird-eye view of Mt. Devchuli range and its surrounding areas enclosed by the finest domain of calculation.

The model was initialized with meteorological data from the operational analysis performed every 6 hours at the National Centers for Environmental Prediction (NCEP 1°x1° Final Analysis) and the 24 categories land-use and 30 second terrain elevation data by United States Geological Survey (USGS). The simulation was carried out for the period of 28 February 0000 UTC (0545 LST) to 3 March 0000 UTC (0545 LST), 2010.

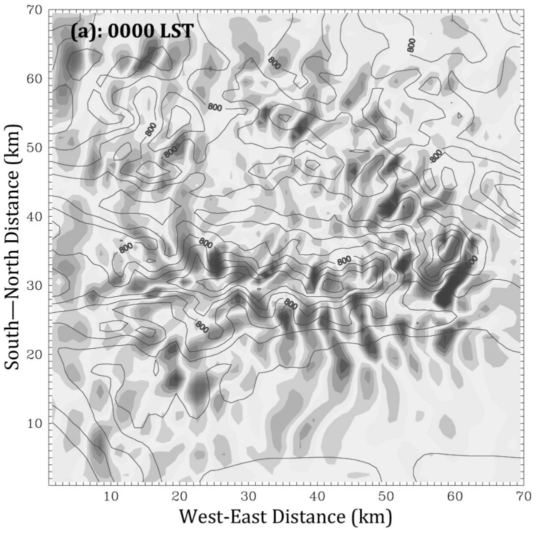
In this calculation we have adopted the following schemes and models: Thompson graupel for microphysics, RRTM for longwave radiation, Dudhia for shortwave radiation, YSU for planetary boundary layer and the Noah land-surface model. The WRF output history interval was set at 15 minutes.

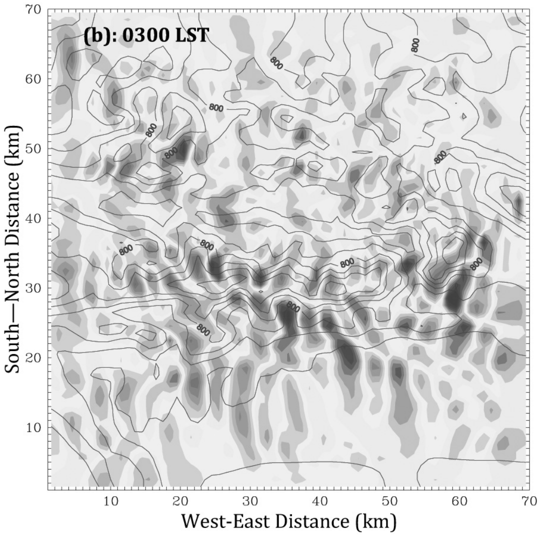
RESULTS AND DISCUSSION

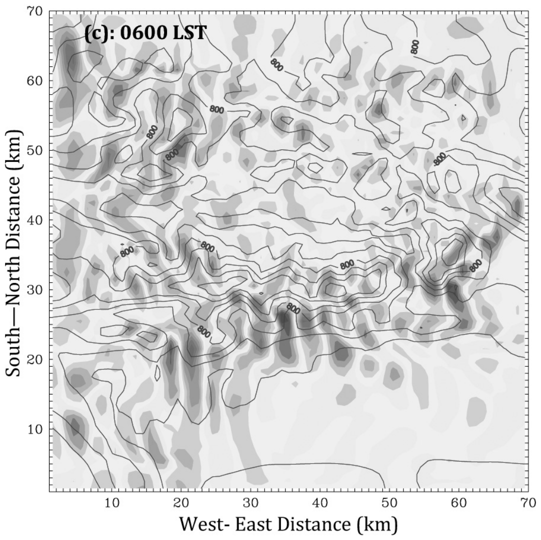
The temporal and spatial distribution of near surface wind as well as vertical thermal and wind structure over the area have been described in Regmi (2012). Thus, in this paper, we confine our discussion on the diurnal characteristics of the mountain waves over the Mt. Devchuli range and its surroundings taking the case of 02 March 2010.

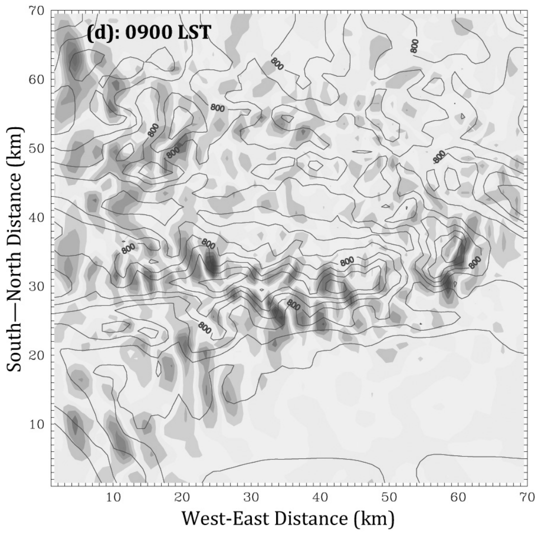
Examining the series of vertical profile of potential temperature and the undulations produced over the Mt. Devchuli range (Fig. 2), it can be said that the atmosphere above 3km from mean sea level is highly stratified and the undulations produced over the area are confined below this stratified layer rather than propagating vertically upwards to great height. Thus, the mountain waves excitations over the area are basically low-level trapped mountain waves.

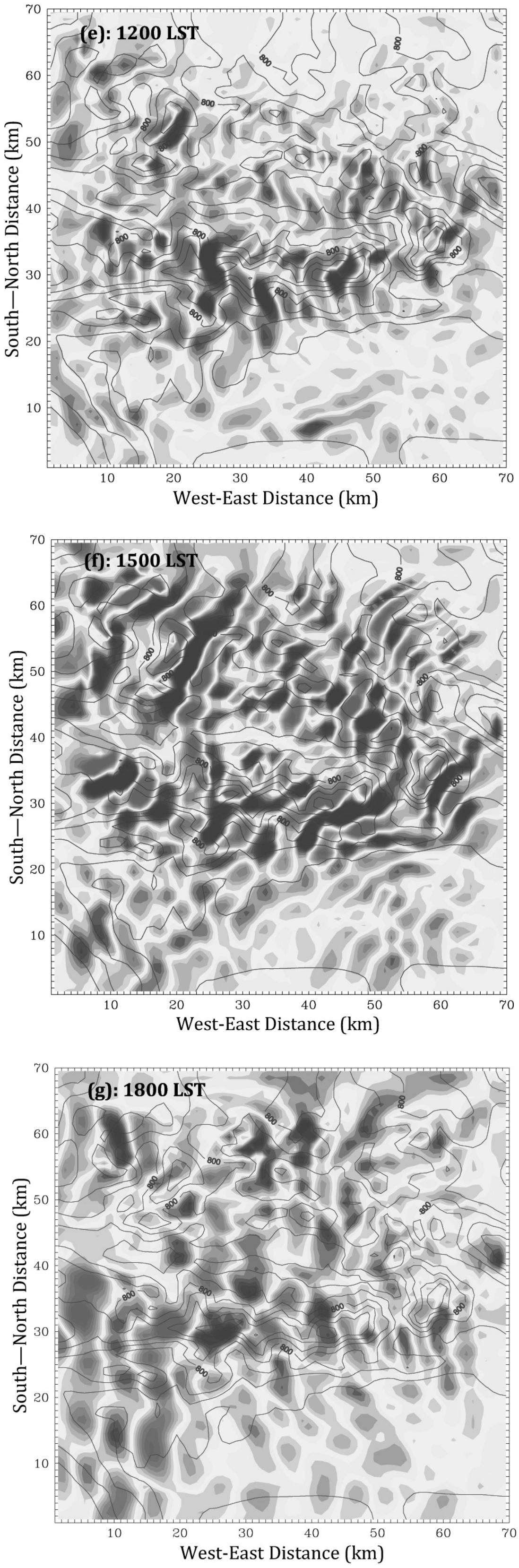
Fig. 4 show the horizontal plot of vertical wind speed at height of about 2 km above the sea level, which reflects the wave pattern over the Mt. Devchuli range and its surrounding areas for every 3 hours interval. The three days long simulation during 28 February to 03 March 2010 reproduced almost the similar temporal and spatial distribution pattern of waves. This may indicate that during the clear days of late wintertime, trapped mountain wave excitation occurs regularly over the area. Thus, the diurnal wave pattern predicted for 02 March 2010 over the area may be taken as the representative characteristics for the season as well.











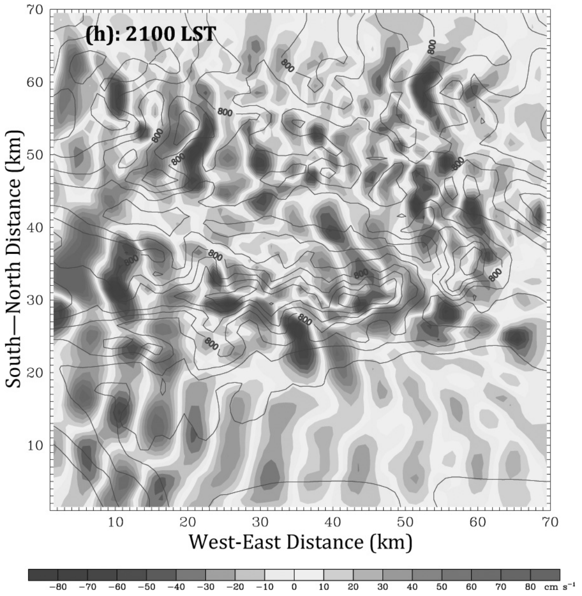


Fig. 4. Temporal and spatial distributions of vertical wind speed over the Mt. Devchuli range and its surrounding areas. The alternate updraft (+ve values) and downdraft (-ve values) of vertical wind speed represent the mountain waves.

During the midnight time, the Mt. Devchuli range and associated areas appear to be under the mountain waves of wavelength of about 8 km throughout the calculation domain. However, the wave strength appears to be more pronounced along the east-west oriented Mt. Devchuli range as well as along the southeast-northwest line in the northern mountainous areas of the calculation domain (Fig. 4a) towards Pokhara valley.

As the morning progresses, the same wave pattern appear to continue over the Mt. Devchuli range ridgeline but it gradually vanishes over the northeastern mountainous areas (Fig. 4c). The mountain wave activities appear to be at minimum level during the late morning times (Fig. 4d). However, wave amplitude gradually increases beyond the late morning and it becomes very pronounced in the noontime (Fig. 4e).

In the afternoon (Fig. 4f), the mountain waves excitation activities becomes most effective but again assumes southeast-northwest orientation as in the midnight times. Over the Mt. Devchuli range ridgeline and the whole northern part beyond the Mt. Devchuli range are under the influence of very intense waves whereas they are rather less active over the southern plain areas. The wave activities apparent during the afternoon time may continue until the late afternoon (not shown) and it gradually dies beyond the late afternoon. However, the wave excitation still remains highly active over the Mt. Daunne Danda (Fig. 2) and associated areas (Fig. 4g).

During the evening and late nighttime (Fig. 4h), wave excitation over the whole southern plain becomes very pronounced whereas over the areas north to the Mt. Devchuli range appears rather unorganized. After late night, the mountain wave excitation pattern over the region gradually returns to the pattern apparent during the midnight time described earlier.

CONCLUSIONS

Present study on mountain wave excitation over the Mt. Devchuli range reveals that low-level trapped mountain waves may remain active almost all the time during the late winter season. These low-level trapped mountain waves can have significant negative implications for the low-level aviation and parachuting or gliding activities. However, it should be noted that the results presented in this paper are not validated with the observations and hence should be understood with this limitation. To the best of our knowledge, low-level trapped mountain wave excitations over the foothills of Nepal have not been studied in the past. Hence, the present findings are expected to be an excellent point for further in-depth studies.

As one of the busy air route passes through this area, a detail long-term numerical investigation usefully complemented with field observation are recommended which can greatly reduce impending aviation risks over the area.

ACKNOWLEDGEMENTS

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