Journal of Atmospheric and Solar-Terrestrial Physics 146 (2016) 58–68

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Thermodynamic and dynamic structure of atmosphere over the east coast of Peninsular Malaysia during the passage of a cold surge

Azizan Abu Samah [a,d], C.A. Babu [a,b], Hamza Varikoden [c], P.R. Jayakrishnan [d,*], Ooi See Hai [a]

[a] National Antarctic Research Centre, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Atmospheric Sciences, Cochin University of Science and Technology, Cochin 682016, India
[c] Indian Institute of Tropical Meteorology, NCL, P. O., Pune 411008, India
[d] Institute of Ocean and Earth Sciences, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 22 December 2015
Received in revised form
11 May 2016
Accepted 22 May 2016
Available online 24 May 2016

Keywords:
Cold surge
Malaysian winter monsoon
Thermodynamic structure
Divergence and vorticity pattern

ABSTRACT

An intense field observation was carried out for a better understanding of cold surge features over Peninsular Malaysia during the winter monsoon season. The study utilizes vertical profiles of temperature, humidity and wind at high vertical and temporal resolution over Kota Bharu, situated in the east coast of Peninsular Malaysia. LCL were elevated during the passage of the cold surge as the relative humidity values decreased during the passage of cold surge. Level of Free Convection were below 800 hPa and equilibrium levels were close to the LFC in most of the cases. Convective available potential energy and convection inhibition energy values were small during most of the observations. Absence of local heating and instability mechanism are responsible for the peculiar thermodynamic structure during the passage of the cold surge. The wind in the lower atmosphere became northeasterly and was strong during the entire cold surge period. A slight increase in temperature near the surface and a drop in temperature just above the surface were marked by the passage of the cold surge. A remarkable increase in specific humidity was observed between 970 and 900 hPa during the cold surge period. Further, synoptic scale features were analyzed to identify the mechanism responsible for heavy rainfall. Low level convergence, upper level divergence and cyclonic vorticity prevailed over the region during the heavy rainfall event. Dynamic structure of the atmosphere as part of the organized convection associated with the winter monsoon was responsible for the vertical lifting and subsequent rainfall.

1. Introduction

The Asian winter monsoon plays a vital role in all activities in the Maritime Continent. The winter monsoon over the Maritime Continent has a peculiar behavior associated with the formation of intermittent cold surges. Usually cold surges are formed during November to February with maximum intensity in January (Cheang, 1980). Chang et al. (2006) brought out an elaborate review on the role played by the cold surges on the East Asia winter monsoon. They described the formation of cold surges as a result of strengthening and southeastward movement of the Siberian–Mongolian High (SMH), which leads to an increase of northeasterly wind and a decrease of surface temperature to the east and south of the SMH. Outbreaks occur with an extension of the SMH to the southeast or a split of the high pressure area that moves to the southeast coast of China (Lim and Chang, 1981; Chan and Li, 2004; Chan, 2005). In early September, the Siberian–Mongolian High (SMH) builds up and becomes intense by November. Cold air emanating from the SMH affects the South China and Indo-China in early October and the central South China Sea by late October. When the event progresses rapidly southward and affects the tropics, particularly in the vicinity of the South China Sea, the weather system is referred as a cold surge.

The development of a cold surge starts with the building up and subsequent southeastward extension or split of the SMH pressure area. The center of the SMH either moves southeastward (Ding and Krishnamurti, 1987; Zhang et al., 1997) or remains nearly stationary but with packets of cold air propagates eastward in conjunction with small high pressure or anticyclonic centers (Wu and Chan, 1995; Chan and Li, 2004). Jeong et al. (2006) found a precursory signal in the stratospheric circulation prior to the formation of the cold surge in East Asia. They found strong stratospheric negative potential vorticity anomalies and rising of geopotential height over northern Eurasia about one week before the cold surge occurrence. Changes in upper tropospheric circulations over Siberia are favorable for the formation of cold surges. When northwesterly forms in the vicinity of Lake Baikal that is associated with an upper level wave, the situation causes the formation of a surge over southern coast of China by 1 to 2 days

* Corresponding author.
E-mail address: babumet@gmail.com (C.A. Babu).

http://dx.doi.org/10.1016/j.jastp.2016.05.011
1364-6826/

(Ramage, 1971; Lum, 1976; Chu, 1978; Boyle and Chen, 1987). Compo et al. (1999) showed that upper tropospheric northeasterly anomaly associated with a developing ridge over northern Siberia serves as a precursor of a cold surge several days ahead.

The magnitude of the surface temperature drop diminishes over the equatorial South China Sea due to the modification by the warm sea surface (Chang et al., 1979; Johnson and Zimmerman, 1986). Approach of a cold surge over the South China Sea is indicated by strengthening of northerly wind, decrease in surface temperature and increase in surface pressure (Boyle and Chen, 1987; Compo et al., 1999; Thompson, 1951; Lau and Li, 1984; Chu, 1978; Chang et al., 1983; Tick and Samah, 2004). It is evident that the frequency and intensity of cold surges associated with the winter monsoon play vital role in the rainfall pattern over the Maritime Continent (Juneng et al., 2007).

Cheang (1980) made an extensive study on the features of the Malaysian winter monsoon in association with cold surges. When the cold surges are in phase with the westward moving equatorial disturbance over the South China Sea, the disturbance can develop into a well defined vortex in the near equatorial trough followed by widespread torrential rainfall. Chang and Lau (1982) reported that about one day after the arrival of the surge at the northern South China Sea, enhanced deep tropical convection occurs downstream from the surge and accelerates both Hadley and Walker circulations through increased upper level divergence. Cheang (1987) brought out the coincidence of winter monsoon onset with (1) penetration of cold surge, (2) southward movement of monsoon trough into equatorial Southeast Asia and (3) reversal of wind from easterlies to westerlies at 200 hPa level over the southern China.

When a short wave propagates into the quasi-stationary East Asian long wave trough near Japan, the intensification of the trough strengthens the northerly wind and almost simultaneously the cold surge reaches in the northern region of the South China Sea. A jet streak that is often associated with the short wave plays a vital role in forcing the SMH through subsidence in the jet entrance region (Wu and Chan, 1995; Chan and Li, 2004). Even though it originates from the middle latitude upper levels, the surge over the South China Sea is mostly confined in a shallow layer between the surface and 850 hPa (Ramage, 1971). The strong cold air advection associated with the upper level northerly wind component around Lake Baikal that precedes the cold surge must exceed the subsidence warming, so that air parcels descend the isentropic surface and reach the northern South China Sea as a cold surge (Chang et al., 2005). Lu et al. (2007) made a numerical case study of a cold surge during the passage at Taiwan. They found that the leading edge of the cold surge was maintained primarily by meridional thermal advection in comparison with that in the zonal and vertical.

Thermodynamic and dynamic structure of the atmosphere was not properly understood during the passage of a cold surge over the east coast of Peninsular Malaysia. Hence an attempt was made to study the thermodynamic and dynamic characteristics during the passage of a cold surge over the coastal station, Kota Bharu (situated in the east coast of the Peninsular Malaysia) by arranging an intense field observation. This study brings out variation in thermodynamic and dynamic structure of the atmosphere (and rainfall characteristics) during the passage of a cold surge over Kota Bharu utilizing 3 to 6 hourly radiosonde temperature, humidity and wind profile data in addition to surface meteorological observations from Malaysian Meteorological Department, satellite derived products and reanalysis data sets. This is a step forward towards better understanding of cold surge related thermodynamics and dynamic processes in the tropical atmosphere. Thus the objectives are (1) to bring out variation of air temperature, wind and humidity at the surface and above during the passage of a cold surge, (2) to understand the depth of the atmosphere in which the cold surge influences on these parameters, (3) to study the thermodynamic structure of the atmosphere in association with the cold surge and (4) to study the dynamic structure associated with the synoptic circulation as part of the winter monsoon to identify the mechanism responsible for heavy rainfall during the period.

2. Data and methods

The study was carried out during the winter monsoon season in 2008 utilizing Vaisalasonde observations of temperature, humidity and wind during the passage of a cold surge at Kota Bharu station (latitude: 6°10′ N, longitude: 102°18′ E and height above msl: 5 m) situated in the east coast of Peninsular Malaysia (Fig. 1). This station was selected for the study because it is located in the east coast facing the South China Sea in the gate way of cold surge and hence to meet the requirements for capturing signature of cold surge properly. The vertical profiles of temperature, humidity and wind were made available at a vertical resolution of about 6 hPa (by taking measurements at every 4 s after releasing the balloon). The sensor specification is given in Table 1. The intense observation period was chosen from 26th November to 1st December, 2008 with two days before and after the passage of a cold surge over Kota Bharu. 44 observations were taken during the period at an interval of 1–6 h. The time of observation is given along with thermodynamic parameters in Table 2. Since the raw data from the Vaisalasonde are not in regular intervals of pressure, we employed logarithmic interpolation scheme to obtain the data at 10 hPa interval in the vertical for all the profiles. We consider that this interpolation preserves the thermodynamic and dynamic characteristics of the individual soundings.

In addition, data from National Centre for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) reanalysis, Tropical Rain Measuring Mission (TRMM) rain rate, Infra Red (IR) satellite imageries and other surface meteorological observations were also utilized for a better understanding of the thermodynamic and dynamic structure of the atmosphere during the passage of the cold surge.

In order to study the features of rainfall associated with passage of a cold surge, it is better to have rainfall data at high temporal resolution. We utilized TRMM rain rate available at a temporal resolution of 3 h and a spatial resolution of 0.25° × 0.25° latitude–longitude grid (Kummerow et al., 1998) to bring out the rainfall features during the intense observation period.

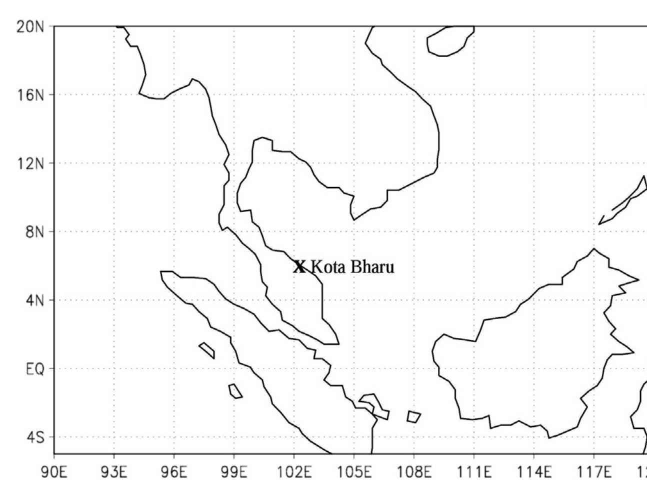

Fig. 1. Location of Kota Bharu station in the east coast of Peninsular Malaysia.