Atmósfera 28(4), 231-241 (2015)
doi: 10.20937/ATM.2015.28.04.02

Atmospheric energy conversion characteristics of heavy rainfall in Sindh during the 2011 monsoon

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Received: December 11, 2012; accepted: June 19, 2015

RESUMEN

El monzón del sudeste asiático se presenta todos los años de junio a septiembre en la mayor parte del subcontinente indio, lo cual incluye a Paquistán, la India y Bangladesh. Estos vientos ricos en humedad son forzados a elevarse por la cordillera del Himalaya, lo que ocasiona precipitación extrema en varias partes del subcontinente, especialmente en Paquistán. El objetivo de este estudio es analizar las características y distribución de la conversión de energía atmosférica durante la intensa precipitación registrada en Sindh, Paquistán, durante el periodo agosto-septiembre de 2011. Los resultados muestran que la atmósfera cambia de estable a inestable cuando el valor de la energía es igual o mayor a siete. Bajo la influencia de las circulaciones atmosféricas y las condiciones del terreno, la energía cinética es bloqueada por las montañas y convertida de manera continua en energía potencial dentro del sistema de precipitación. Cuando la fase de energía máxima persiste por un tiempo considerable, puede ocasionar precipitaciones intensas cuya humedad procede principalmente del Mar Arábico y la bahía de Bengala.

ABSTRACT

South Asian monsoon occurs in most parts of the Indian subcontinent including Pakistan, India and Bangladesh during the period June to September of every year. These winds rich in moisture are forced to lift by the

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Himalayas causing extreme precipitation in different parts of the subcontinent, especially in Pakistan. The aim of this study is to explore the characteristics of atmospheric energy conversion and distribution during the heavy rainfall in Sindh, Pakistan for the period August-September 2011. The results show that when the energy value is greater than or equal to seven, the atmosphere jumps from stable to unstable. Under the influence of atmospheric circulations and terrain conditions, the kinetic energy is blocked by the mountains and is continuously converted into potential energy inside rainfall system. The peak phase of energy persisting for a considerable amount of time can lead to heavy rainfall. Moisture of this heavy rainfall mainly comes from the Arabian Sea and the Bay of Bengal.

Keywords: Heavy rainfall, atmospheric energy, monsoon.

1. Introduction

The South Asian monsoon is characterized by seasonal changes in atmospheric circulation and precipitation associated with asymmetric heating of land and sea. Northern and central parts of the Indian subcontinent heat up considerably during the hot summers, causing the moisture-laden winds from the Indian Ocean to move over the surface (Bedi and Bindra, 1980; Rasmusson and Carpenter, 1983; Zhi, 2001; Singh, 2006; Syed *et al.*, 2010; Zhang *et al.*, 2015). The occurrence of severe rainfall is highly dependent upon the strength of moisture content and tracks of monsoon winds. The summer monsoon over the Indian subcontinent is divided into two parts, the Arabian Sea branch and the Bay of Bengal branch. Monsoon precipitation not only brings a welcome relief to the scorching heat of summer, but it is also the major driving factor of economy. In particular, it is directly related to the agricultural production of the region (Parthasarathy and Pant, 1985; Parthasarathy *et al.*, 1988; Gadgil *et al.*, 1999). Pakistan is influenced by the monsoon regime during the months of July to September. Mostly northern, northeastern and southeastern parts of the country are affected by the monsoon weather system. In 2011, Sindh was hit by the worst heavy rainfall ever. More than two million people suffered from flood-related diseases following torrential rain. It is estimated that about 5.3 million people were affected directly by the flood, 434 civilians were killed, and 1.5 million houses destroyed. This flood also affected Sindh's agriculture, since at least 1.7 million acres of croplands were inundated.

Heavy rainfall during the monsoon is one of the most serious hazards occurring in India and Pakistan (Rahmatullah, 1952; Awade *et al.*, 1982; Izumo *et al.*, 2008; Rasul *et al.*, 2004, 2008; Krishnan *et al.*, 2009; Ge *et al*., 2014). This kind of weather phenomena is closely monitored by meteorological departments with a high cost in manpower and material resources. However, these countries are still struggling to have an efficient forecast method to predict extreme weather events.

According to atmospheric energetics, a heavy rainfall system is the process of energy accumulation and release. The characteristics of atmospheric energy in heavy rainfall events have been summarized in many previous studies (Yeh, 1949; Zeng, 1983). Some interesting results have been found, such as the fact that baroclinic waves in mid-latitude storm tracks tend to be organized in localized wave packets that clearly exhibit downstream development (Chang, 1993; Lee and Held, 1993). Chang and Yu (1999) extend the analyses of the Southern Hemisphere and the summer seasons to examine the seasonal and hemispheric dependence on wave packet characteristics. Recently, Ge *et al.* (2008) showed that the characteristics of wave-packet propagation in a severe cold surge occurred in South China. Guo *et al.* (2010) summarized the propagation and accumulation of wave-packet in a Tibetan heavy snowstorm. The previous studies primarily focused on the influence of kinetic energy or potential energy in the weather and climate system. In this work, we derive the whole energy parameter E from atmospheric energetics theory and discuss the characteristics of atmospheric energy conversion during a heavy rainfall in Sindh, Pakistan. The rest of the work is organized as follows: section 2 describes the data and methods of the analysis used in this paper. The rainfall distributions and characteristics of atmospheric energy conversion are separately illustrated in sections 3 and 4. The characteristics of vapor transportation and energy propagation are shown in section 5. The conclusion follows in section 6.

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