Agricultural and Forest Meteorology 186 (2014) 43–47

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Coherent structures contribution to fluxes of momentum and heat during stable conditions for pre monsoon thunderstorm season

Bhishma Tyagi[a,*], A.N.V. Satyanarayana[b]

[a] Department of Meteorology (MISU), Stockholm University, Stockholm 106 91, Sweden
[b] Centre for Oceans, Rivers, Atmosphere and Land Sciences (CORAL), Indian Institute of Technology, Kharagpur, Kharagpur 721302, West Bengal, India

ARTICLE INFO

Article history:
Received 21 June 2013
Received in revised form 30 October 2013
Accepted 25 November 2013

Keywords:
Coherent structures
Momentum and heat flux
Zero crossing

ABSTRACT

The contributions of Coherent Structures (CS) to fluxes of momentum and heat have been analyzed for night time stable conditions during pre-monsoon thunderstorm periods over two tropical stations: Kharagpur and Ranchi. Fast response data recorded using sonic anemometers have been used for 2007, 2009 and 2010 for Kharagpur and 2008–2010 for Ranchi. The signals were decomposed in several time scales and then used for zero-crossing method using discrete wavelet transform. Significant contributions by CS have been found for both momentum and heat flux at both the sites and these contributions during night time stable conditions differs for days with a thunderstorm activity from a clear day with no activity, even though at both sites thunderstorm events are occurring during daytime unstable conditions.

1. Introduction

Organized structures often termed as coherent structures (CS) are important in atmospheric boundary layer turbulent flows as they transport fluxes of momentum and heat from surface to upper atmosphere and have been widely reported in the literature (e.g. Kline et al., 1976; Antonia et al., 1979; Gao et al., 1989; Mahrt, 1999; Barthlott et al., 2007; Zhang et al., 2011; Steiner et al., 2011). Duration of CS may spans several seconds up to a few minutes, and forms of CS may change depending on the boundary layer stratification (Fesquet et al., 2009). Various techniques have been used for CS detection in atmosphere and the most recent techniques are making use of wavelet transform (Brasseur and Wang, 1992; Farge, 1992; Hunt et al., 1993; Brunet and Irvine, 2000; Chen and Hu, 2003; Thomas, 2005; Zeri and Sa, 2011; Zhang et al., 2011).

CS contributions over a pine forest using quadrant analysis has been studied by Bergström and Högström (1989) and they found that CS are contributing 92.7% in fluxes of momentum and 87.5% in fluxes of heat. Collineau and Brunet (1993) found this percentage is 26% for momentum and 40% for heat using the Mexican-Hat wavelet. Lu and Fitzjarrald (1994) found 40% contribution to both fluxes by use of Haar wavelet. Barthlott et al. (2007) have used Mexican-Hat wavelet (zero-crossing) over a smooth surface and found that CS are contributing 44% in momentum and 48% in heat flux. These percentage contributions varies for different studies over different sites by use of different wavelets, e.g. 16% in momentum and 26% in heat over a heterogeneous terrain (Thomas and Foken, 2007a), 40% in heat over Penatal Wetland area (Zeri and Sa, 2011), 11% in momentum and 19% in heat over a flat cotton field (Zhang et al., 2011).

In the present study, zero crossing wavelet technique has been employed to identify CS and their contribution to the fluxes of momentum and heat at two tropical sites, Kharagpur (22°30′N, 87°20′E) and Ranchi (23°25′N, 85°26′E) during the stable stratification periods during thunderstorm days (TD) and non thunderstorm days (NTD) of pre-monsoon months of April and May. Both the sites are experiencing same type of thunderstorms, i.e. Type ‘A’ thunderstorms, which are multi cellular in nature passes through Ranchi and moves further towards Kharagpur (India Meteorological Department (IMD), 1944). But different soil and land surface characteristics are believed to play different roles in occurrence of these thunderstorms.

The contribution to fluxes of momentum and heat are found to be different for TD and NTD during unstable stratification at both the sites (Tyagi and Satyanarayana, 2013). But no such investigation has been made for night time stable hours, which are free from thunderstorm activity at both the sites but may have a profound influence in developing the day time convective activity. Generally at these two tropical sites during pre-monsoon months, enormous heating is occurring in daytime. Further these thunderstorms are mainly occurring at both the sites during convective day time hours and hence it is difficult to find any stable period during daytime. However, such stable periods exists in night time. The stable hours used in the present study are from night time of those days where thunderstorm occurs in day or clear weather days. Hence, in the

* Corresponding author.: Tel.: +46720215476.
E-mail addresses: bhishmatyagi@gmail.com (B. Tyagi), banvsatya@coral.iitkgp.ernet.in (A.N.V. Satyanarayana).

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http://dx.doi.org/10.1016/j.agrformet.2013.11.011

present study we made an attempt to analyze the CS contributions to fluxes of momentum and heat during stable/night time hours of TD and NTD over Ranchi and Kharagpur.

2. Site description

The present study is based on data collected at two different sites: Kharagpur (22°30′ N, 87°20′ E), and Ranchi (23°25′ N, 85°26′ E). The study site at Kharagpur is located in an agriculture farm at Indian Institute of Technology Kharagpur, Kharagpur region of west Midnapore, Gangetic West Bengal, India. A 50-m micrometeorological tower with six level of instrumentation (2, 4, 8, 16, 32 and 50 m, respectively) has been erected at this site. The tower intended to measure all basic meteorological parameters to study Nor'westers during the pre-monsoon season. Kharagpur site consists of sandy loam soil, which is a mixture of sand (64.1%), silt (20.1%), and clay (15.8%) (Panigrahi and Panda, 2003; Roy, 2006). Topographically the site is flat and grassy with a roughness length of ∼0.0027 m. Details of employed sensors can be obtained from Tyagi and Satyanarayana (2010).

The site at Ranchi is situated at main campus of Birla Institute of Technology, Ranchi. A 32 m height tower with six level of instrumentation (1, 2, 4, 8, 16 and 32 m, respectively) has been erected at this site. The soil is of ultisol type, having sandy loam texture. This site also consists of sandy loam soil, which is a mixture of sand (60%), silt (8.7%), and clay (31.3%) (Gupta and Gajbhiye, 2002). The site is having scanty dry patchy grass near the instrumentation area, and having clear fetch towards North West to South directions. The roughness length for the site is ∼0.0016 m. Details of employed sensors at the site is given in Tyagi et al. (2012).

3. Data and quality check

The fast response data (10 Hz) of wind and temperature has been collected using sonic anemometer installed at 10 m height at both sites. Data sets collected during pre-monsoon months (April–May) of 2007, 2009, and 2010 at Kharagpur under STORM (Severe Thunderstorms: Observations and regional modeling) programme (Storm Science Plan, 2005), and 2008–2010 at Ranchi are used in the present study. The fast response data sets of 30 min time series has been used for the analysis at both sites. In general, the classification of a TD is based on occurrence of thunderstorm event at any time of that particular day (Rodriguez et al., 2010). The log-book information during the experiment, tower observations and Doppler Weather Radar (DWR) imageries collected from Cyclone detection centre, India Meteorological department, Kolkata are used in finalizing the time of occurrence and duration of the thunderstorm event at the field site. Based on the occurrence of thunderstorms during the study period 18 TD cases are selected for Kharagpur and 19 TD cases have been selected for Ranchi. When during the whole day no weather activity is noticed, the day henceforth referred as non-thunderstorm days (NTD). The chosen TD and NTD cases for both sites can be seen in Tables 1 and 2. It is to be noted that all TD events chosen at both sites are day time thunderstorm and none of them occurred during stable conditions. Information about timings of thunderstorm events can be obtained from Tyagi and Satyanarayana (2013). The data sets used for these TD and NTD are during stable conditions for that day in the present study to see the CS contributions differences in fluxes of momentum and heat for two different days meteorological conditions.

Extensive quality checks of data have been done before using it in the analysis. At first, physical check of data has been done to check and remove any missing values or Not a Number values recorded by instruments in events of no data values. Data sets for the rainfall hours has been discarded before the analysis, because of possible effects of water droplets on transducer heads of sonic anemometers significantly influencing the shape of the time series (Thomas and Foken, 2007b). The data sets further processed with windowing technique for ±3 standard deviation from the mean (Viswanadham et al., 1997a,b), double rotation (DR) scheme and tilt angle corrections incorporation after the physical check of data (Kaimal and Finnigan, 1994; Wilczak et al., 2001; Foken, 2008).

Noise reduction (fluctuations emerging from stochastic turbulence) by the use of biorthogonal wavelet filter, BIOR 5.5 has been employed (Thomas and Foken, 2005). BIOR 5.5 uses the definition of a threshold value for the critical filter frequency ($Dc \leq 6.2$), separating the high-frequency stochastic turbulence from the low-frequent coherent structures, which is in agreement with previous studies of CS (Brunet and Collineau, 1994; Chen and Hu, 2003; Thomas and Foken, 2007a,b; Zhang et al., 2011). Spectral analysis with 1/3 power law has been done for all the data sets. The data sets following the power law are passed for further analysis. The data sets which passed all the aforesaid quality checks have been considered for the analysis.

4. Methodology

The contribution for fluxes has been checked for the night time stable conditions ($z/L > 0.09$, where z is the measurement height, and L is the Obukhov length). CS contribution using the wavelet technique has been computed by the use of Discrete Wavelet transform (DWT) (e.g. Thomas and Foken, 2007a; Barthlott et al., 2007; Zeri and Sa, 2011; Zhang et al., 2011) by zero-crossing method for

Table 1
Daily average CS contributions to fluxes of momentum and heat during stable conditions by zero crossing method for Kharagpur.

	Day (Kharagpur site)	CS contribution in momentum flux (%)	CS contribution in heat flux (%)
TD	26 April 2007	22	29
	27 April 2007	13	27
	7 May 2007	12	31
	8 May 2007	11	26
	18 May 2007	20	39
	19 May 2007	23	26
	21 May 2007	18	31
	28 May2007	13	31
	6 May 2009	21	26
	11 May 2009	19	30
	12 May 2009	20	62
	14 May 2009	19	30
	5 May 2010	23	39
	7 May 2010	34	40
	9 May 2010	31	31
	21 May 2010	21	25
	22 May 2010	16	42
	29 May 2010	17	34
	Average	20	33
NTD	14 April 2007	24	30
	22 April 2007	25	27
	23 April 2007	30	31
	28 April 2007	25	24
	29 April 2007	27	25
	30 April 2007	24	35
	4 May 2007	17	26
	24 May 2007	21	35
	13 April 2009	25	22
	15 April 2009	38	43
	18 April 2009	29	32
	10 May 2009	34	45
	4 May 2010	20	25
	8 May 2010	24	28
	11 May 2010	26	27
	12 May 2010	22	26
	15 May 2010	20	26
	16 May 2010	22	27
	Average	25	29