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# Relationship of convective precipitation with atmospheric heat flux — A regression approach over an Indian tropical location

Swastika Chakraborty [a], Upal Saha [b,c], Animesh Maitra [b,c,*]

[a] Department of Electronics and Communication Engineering, JIS College of Engineering, Kalyani, West Bengal, India
[b] S. K. Mitra Centre for Research in Space Environment, Institute of Radio Physics and Electronics, University of Calcutta, Kolkata, India
[c] Institute of Radio Physics and Electronics, University of Calcutta, Kolkata, India

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ABSTRACT

The response of atmospheric heat fluxes and sea surface temperatures on the convective precipitation over the tropics has been an important area of research in recent decades. A long-term observation (1979–2008) of the increase in convective precipitation in relation to the latent and sensible heat fluxes on a tropical location, Kolkata, has been investigated in the present study. Invigoration of convective precipitation has been caused by vertically integrated divergence of moisture flux, rise in sea surface temperatures, convective cloud cover and surface evaporation rate over the tropical region. A convective precipitation estimation (CPE) index is proposed, considering the Bowen ratio, surface evaporation rate, sea surface temperature and temperatures at 500 hpa pressure level during the pre-monsoon season (March–May), to estimate the amount of convective precipitation over the tropics using multiple linear regression technique is also another aim of this study. A good agreement is obtained between the results from the model and the MERRA observations during the years 2009–2013.
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## 1. Introduction

Moist convection over the continent is significantly associated with the heat fluxes of the atmosphere. In terms of the heat fluxes there exists a definite coupling between land surface and the atmosphere which leads to the convection (Alfieri et al., 2008). Sensitivity of the convective rainfall frequency to the partitioning of sensible heat flux and latent heat flux over North America has been analyzed (Berg et al., 2013) using North American Regional Reanalysis (NARR) data. Most of the general circulation model (GCM) and other models (Chakraborty and Maitra, 2012, 2013) successfully predict mean rainfall but fail to estimate precipitation intensity and frequency. The European Centre for Medium-Range Weather Forecasting (ECMWF) model is used to study the triggering algorithm of diurnal cycle of convective precipitation over tropical South America and Africa where a strong diurnal cycle is observed (Bechtold et al., 2004). The North American Mesoscale (NAM) Forecast System model is used over the Carolina Sand hills region to predict the summer convective rainfall as mesoscale and local scale effects are prominent during summer (Wootten et al., 2010), and they are enhanced by surface heat fluxes. Convective rainfall triggering mechanism is explained (Juang et al., 2007) by a semi analytical model using surface heat flux and moisture. The model performance is not satisfactory during night, but boundary layer growth and boundary layer development plays a triggering phenomenon for the convection to be happened (Gentine et al., 2013). According to the atmospheric thermodynamics, hydrological cycle is very much dependent on the interaction between land and atmosphere during warm season. Evapotranspiration (Schär et al., 1999) process successfully explains the water vapor balance of the planetary boundary layer. Intense transfer of moisture at the near surface atmosphere causes enhanced convective precipitation. Bowen ratio, i.e. the ratio of surface heat flux to latent heat flux, and potential evaporation rate have a very good impact on convective precipitation. Dryness of the soil moisture results in shallow cumuli and thereby deep convection. Explanation of continental moist convection will be incomplete without considering the partitioning of heat flux (Gentine et al., 2013).

Tropical precipitation is mostly dominated by convective phenomenon followed by stratiform precipitation (Houze, 1997). As the tropics is in close vicinity of the equator getting direct heating from the sun, clouds are of mostly cumulonimbus and cumulus types. Precipitation particles from vigorous convective region of cumulonimbus gather mass by collecting cloud water and break down into heavy shower. Over the last few years an increase of convective precipitation at pre-monsoon (warm) season is the main motivation behind this study. In the last decade, the study on convective precipitation around the world has been a topic of prior interest to the mesoscale research community (Soriano and Pablo, 2003; Guo et al., 2006; Dimitrova et al.,

* Corresponding author at: Institute of Radio Physics and Electronics, University of Calcutta, Kolkata, India.
*E-mail address:* animesh.maitra@gmail.com (A. Maitra).

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2009; Siingh et al., 2013; Ruiz-Leo et al., 2013). Entrainment of moisture in the lower troposphere following the formation of shallow cumulus is the primary necessity to form deep convection (Saha and Maitra, 2014). Deep convective large clouds bring stronger precipitation after penetrating more deeply through the troposphere, which produces stronger cold pools and yet larger buoyant clouds. Lapse rate is another important factor to initiate convection. In some cases where buoyancy is lost by air parcel because the rate of increasing buoyancy due to parcel ascent is smaller than the rate of reducing buoyancy due to entrainment. In this case though the environment is conditionally unstable deep convection will not initiate. Convective boundary layer (Parasnis, 1999) has a greater contribution in regulating updraft of energy and moisture from earth surface over land. Moisture penetrates from convective boundary layer through tropical tropopause layer to the lower stratosphere. On the contrary, deep convection does not depend on a particular time of the day or any particular time of a year, but following suitable atmospheric condition cumulus clouds grown up into cumulonimbus clouds. Cumulonimbus cloud releases energy in the form of water vapor which condenses into precipitation (Adams et al., 2013). As aerosol particle provides a good surface for the condensation of the cloud (Tao et al., 2012), the interaction between water vapor, aerosol and deep convection is important (Yang and Yum, 2007). In this paper, an effort has been made for the first time to define the land atmosphere interaction by proposing convective precipitation estimation (CPE) index to quantify convective precipitation over the tropical region in a simplistic approach.

## 2. Data and methodology

NCEP reanalysis project provides data for analysis towards forecasting a climate system (Kalnay et al., 1996). Physical science division gives a subset of the above data. Latent heat flux and ground heat flux have been obtained from NCEP/NCAR reanalysis data, directly obtained from the website http://www.esrl.noaa.gov/psd. The sensible heat flux is thus calculated from ground heat and latent heat flux. The Modern-Era Retrospective analysis for Research and Applications (MERRA) is a climate-quality analysis that places NASA's EOS observations into a climate context. The Global Modeling and Assimilation Office (GMAO) has used its GEOS-5 atmospheric data assimilation system (ADAS) to synthesize the various observations collected over the satellite era (from 1979 to the present) into an analysis that is as consistent as possible over time because it uses a fixed assimilation system. MERRA observations are directly obtained from the website http://gdata1.sci.gsfc.nasa.gov. Convective precipitation rate, latent heat flux, sensible heat flux and surface evaporation rate are also obtained from MERRA whereas sea surface temperature data is obtained from NOAA Optimum Interpolation (OI) SST V2. Convective cloud cover data has been obtained from ISCCP D2 Monthly climatology from 1997 onwards.

Bowen ratio is calculated as the ratio of sensible heat flux to latent heat flux in the following three ways:

i) According to Monin–Obukhov (Emanuel et al., 1994) theory, sensible heat flux is

$$F_{sh} = \rho c_p c_h u_a (T_s - T_a) \tag{1a}$$

and latent heat flux is

$$F_{LE} = \rho l_v c_l u_a (q_s - q_a) \tag{1b}$$

where $u_a$, $T_a$, $q_a$ are the wind velocity, air temperature and specific humidity at reference level, $T_s$ and $q_s$ are surface temperature and specific humidity at surface; $C_h$ and $C_l$ are aerodynamic bulk coefficients; $\rho$ is the density of air, $C_p$ is the specific heat of air at constant pressure and $l_v$ is the latent heat of vaporization. Thus Bowen ratio ($B_o$) is calculated as,

$$B_o = \frac{F_{sh}}{F_{LE}}. \tag{2}$$

ii) The data for sensible heat flux, latent heat flux are directly available from MERRA website [http://gdata1.sci.gsfc.nasa.gov].

iii) The data for ground heat flux, latent heat flux are directly available from NCEP website [http://www.esrl.noaa.gov/psd], thereby sensible heat flux is calculated from there as follows:

$$\mathrm{H_S} = \mathrm{R_N} - (\mathrm{H_L} + \mathrm{H_G}) \tag{3}$$

where,
$\mathrm{H_S}$ (often just called H) is the upward surface sensible heat flux,
$\mathrm{H_L}$ (=LE) is the upward surface latent heat flux due to evaporation at rate E,
$\mathrm{H_G}$ is the downward ground heat flux into the subsurface medium,
$\mathrm{R_N}$ is the net downward radiative flux (longwave + shortwave),
L ($= 2.5 \times 10^6$ J kg$^{-1}$) is the latent heat of vaporization.

The data for sensible heat flux, latent heat flux and potential evaporation rate are taken from MERRA for the year 1979 to 2013. Convective precipitation estimation (CPE) index is formed by dividing surface evaporation rate by Bowen ratio, the significance of which is explained in the subsequent sections. Convective precipitation amount is plotted against convective precipitation index. Hence, the purpose of the present study is to investigate the long-term pattern of convective precipitation rate with the changes in atmospheric heat flux (latent heat and sensible heat) over the tropical location, Kolkata (Fig. 1) from 1979–2008. Multiple linear regression analysis is done on the above dataset. From the regression equation, the estimated convective precipitation amount can be validated taking the data for the year 2009 to 2013. Fig. 2(a) shows the yearly variation of Bowen ratio as calculated from the above mentioned three sources. There is a decreasing trend of Bowen ratio over the years, which signifies the increase in the atmospheric heat fluxes in context to the precipitation involved with convective phenomena. Fig. 2(b) shows the variation of Bowen ratio (as calculated from the three sources) with convective precipitation rate from 1979–2013 over the same location. The figure indicates a decrease in convective precipitation rate with the increase in Bowen ratio. Alternatively, it may be mentioned that with lower values of the Bowen ratio there is an increased rate of convective precipitation. As we have calculated Bowen ratio from three different sources or techniques, the figure may also be an indicative of the fact that the Bowen ratio as calculated from MERRA observations is the best one over this tropical region. Therefore, Bowen ratio calculated in the further study from latent and sensible heat fluxes is taken from MERRA data source.

## 3. Results and discussion

The cycling of combined atmospheric heat flux and moisture content is an important aspect of Earth's climate system, which plays an important role in determining the atmospheric energy budget. The role of convective precipitation over the tropics can have a significant association with the scavenging of aerosols and also acts to remove and transport aerosols and soluble gases both within and below clouds, and thus strongly affects the chemical composition and aerosol distribution. The purpose of the study is to determine the long-term relationship of convective precipitation with atmospheric heat flux and to quantify it in a tropical urban metropolis like Kolkata via multiple linear regression approach.

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