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Rainfall estimation from liquid water content and precipitable water content data over land, ocean and plateau

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ABSTRACT

A simplistic approach has been proposed to estimate annual rainfall amount from cloud liquid water content and precipitable water content utilizing the data pertaining to the period of 1997–2006. The study involves seven land locations over India, seven stations over plateau and seven locations over the Indian Ocean. The wavelet analyses exhibit prominent annual peaks in the global spectra of rainfall, cloud liquid water content and precipitable water content. Power–law relationships are found to exist between the global wavelet peaks of precipitation and those of both the parameters, namely, cloud liquid water content and precipitable water content. Again, a linear relationship exists between global wavelet peaks of rainfall amount and total rainfall amount. The rainfall estimations utilizing cloud liquid water content data exhibit better matching with the measured values than those utilizing precipitable water content data.

1. Introduction

Estimation of rainfall amount from the observations of various atmospheric parameters can serve useful purpose where rainfall measurements are not readily available. The prediction of rainfall occurrence and its intensity in the troposphere still remains a challenging issue for the meteorologists. Such studies are sparse over tropical land surfaces (Jamandre and Narisma, 2013). The Indian Summer Monsoon (ISM), during June to September contributes in a major way to the total rainfall amount at most Indian locations. Also, a significant amount of rainfall occurs during the pre-monsoon (March–May) and the winter (December–February) seasons in different Indian regions. As the tropical region experiences moderate to high rain at different times of the year, the study of variation of liquid water content over different seasons of the year is important for proper modelling of precipitation in terms of atmospheric parameters (Kumar and Sarkar, 2007; Gerlitz et al., 2015). The present study is an attempt to find relations between precipitation and cloud liquid water content (LWC) as well as precipitation and precipitable water content (PWC) to estimate the total annual rainfall at tropical locations in India as well as any location over the Indian Ocean and plateau region in and around India from the knowledge of LWC or PWC data.

The oceans have a thermal contrast to land surface that plays different roles in the interplay between LWC/PWC and rainfall compared to that over land surface. Precipitation over different parts of the Indian ocean (Kumar and Sreejith, 2005) have been studied thoroughly using different datasets obtained from different programs, namely, Climate Prediction Center Merged Analysis Precipitation (CMAP), Microwave Sounding Unit (MSU), National Centre for Atmospheric Research Reanalysis (NRA) and Global Precipitation Climatology Programme (GPCP). It has been found that different parts of the ocean experience different annual rainfall with a substantial inter-annual variability. A number of studies quantifying precipitation from relative humidity measurements over the Tropical Ocean are available in the literature (Neelin and Zeng, 2000; Holloway and Neelin, 2010; Muller et al., 2009; Sherwood, 1999; Sahany et al., 2012; Zeng, 1999; Allan et al., 2010; Chakraborty et al., 2015). Precipitation over the ocean has already been estimated using the relationship between precipitation and IWV (Bretherton et al., 2004). A study on precipitation, water vapour path and cloud liquid water path over northern high-latitude open seas revealed that precipitation changes are mostly due to the changes in cloud liquid water path rather than local evaporation (Zuidema and Joyce, 2008). Thus, it is quite pertinent to quantify the annual rainfall amount at places over oceanic region by using LWC and PWC data.

Again, in the plateau region, orographic lifting of moisture plays a major role in causing rainfall. Also, the Tibetan Plateau is an elevated heat source during summer causing significant effect in atmospheric circulation and, thereby, precipitation (Yao and Zhang, 2013). Orographically induced precipitation over different plateau regions, namely, the Tibetan plateau and Colorado plateau have been the subjects of interest in the literature (Liu and Yin, 2001; Liu et al., 2009; Maussion et al., 2011, 2013; Li et al., 2010; Hereford et al., 2002). Another study over the western plateau of the United States demonstrated the influence of Pacific sea surface temperatures on the seasonal variability of rainfall (Sheaffer and Reiter, 1985). Therefore, the interplay between

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precipitation and cloud liquid water content have also been considered separately over the plateau regions in this study.

2. Data and methodology

In order to find the relationship between rainfall amount and LWC and between rainfall amount and PWC over land surface, seven different Indian stations were considered representing the seven different climatic zones of the Indian subcontinent, namely, Eastern Peninsular India (Port Blair; L_A; 11.7°N, 92.7°E), Southern Peninsular India (Chennai; L_B; 13°N, 80.3°E), Western Peninsular India (Ahmedabad; L_C; 23°N, 72.6°E), Northern Central India (Bhopal; L_D; 23.25°N, 77.4°E), North Western India (Jodhpur; L_E, 26.3°N, 73°E), North Eastern India (Dibrugarh; L_F, 27.5°N, 95°E) and Northern Mountainous India (Patiala; L_G; 30.3°N, 76.4°E). The validation of the proposed model for land surface was done with data from four different Indian locations, namely, Hyderabad (L_1; 18°N, 78.8°E), Bombay (L_2; 19°N, 72.8°E), Kolkata (L_3; 22.6°N, 88.4°E) and Delhi (L_4; 28.6°N, 77.2°E).

To find similar relations between rainfall and LWC as well as rainfall and PWC over the Indian Ocean, seven locations were selected which are given by their surface coordinates as O_A (4°N, 76°E), O_B (4°N, 78°E), O_C (8°N, 76°E), O_D (8°N, 84°E), O_E (14°N, 84°E), O_F (14°N, 88°E) and O_G (14°N, 92°E). Four other locations over the Indian Ocean (O_1: 12°N, 90°E; O_2: 14°N, 96°E; O_3: 16°N, 88°E; O_4: 18°N, 90°E) were identified for the validation of the proposed model.

For the plateau region, seven locations, namely, P_A (14°N, 76°E), P_B (24°N, 78°E), P_C (26°N, 92°E), P_D (30°N, 66°E), P_E (31°N, 70°E), P_F (33°N, 88°E) and P_G (34°N, 79°E) were selected in and around India, to obtain the models for rainfall estimation. Data from four other locations (P_1: 14°N, 78°E; P_2: 26°N, 88°E; P_3: 26°N, 91°E; P_4: 33°N, 86°E) were taken for validation of the proposed model. Fig. 1 illustrates all the thirty-three locations over land surface, ocean and plateau in and around India. Table 1 summarizes the necessary explanations of the abbreviations used in the map of Fig. 1 to locate the different stations.

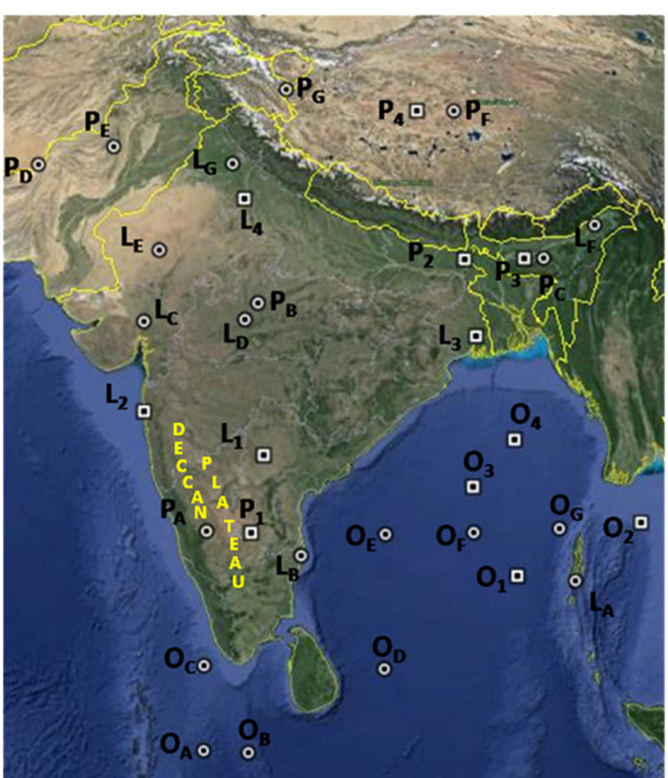

Fig. 1. Location of different stations over land (indicated by L_*), ocean (indicated by O_*) and plateau (indicated by P_*).

Table 1
Symbols used to locate different stations.

Symbol Used	Used For	Type	Latitude, Longitude
L_A	Modelling	Land	11.7°N, 92.7°E
L_B	Modelling	Land	13°N, 80.3°E
L_C	Modelling	Land	23°N, 72.6°E
L_D	Modelling	Land	23.25°N, 77.4°E
L_E	Modelling	Land	26.3°N, 73°E
L_F	Modelling	Land	27.5°N, 95°E
L_G	Modelling	Land	30.3°N, 76.4°E
L_1	Validation	Land	18°N, 78.8°E
L_2	Validation	Land	19°N, 72.8°E
L_3	Validation	Land	22.6°N, 88.4°E
L_4	Validation	Land	28.6°N, 77.2°E
O_A	Modelling	Ocean	4°N, 76°E
O_B	Modelling	Ocean	4°N, 78°E
O_C	Modelling	Ocean	8°N, 76°E
O_D	Modelling	Ocean	8°N, 84°E
O_E	Modelling	Ocean	14°N, 84°E
O_F	Modelling	Ocean	14°N, 88°E
O_G	Modelling	Ocean	14°N, 92°E
O_1	Validation	Ocean	12°N, 90°E
O_2	Validation	Ocean	14°N, 96°E
O_3	Validation	Ocean	16°N, 88°E
O_4	Validation	Ocean	18°N, 90°E
P_A	Modelling	Plateau	14°N, 76°E
P_B	Modelling	Plateau	24°N, 78°E
P_C	Modelling	Plateau	26°N, 92°E
P_D	Modelling	Plateau	30°N, 66°E
P_E	Modelling	Plateau	31°N, 70°E
P_F	Modelling	Plateau	33°N, 88°E
P_G	Modelling	Plateau	34°N, 79°E
P_1	Validation	Plateau	14°N, 78°E
P_2	Validation	Plateau	26°N, 88°E
P_3	Validation	Plateau	26°N, 91°E
P_4	Validation	Plateau	33°N, 86°E

2.1. Precipitation data

In this study, ten years (1997–2006) of precipitation data were collected from the archives of the Indian Institute of Tropical Meteorology (IITM) for all the land locations and precipitation data over the previously mentioned ocean and plateau locations were collected from the NCEP/NCAR dataset.

The NCEP (National Centers for Environmental Prediction)/NCAR (National Center for Atmospheric Research) project aims to generate long-term global data of the atmospheric parameters using a model similar to a weather forecast model. The measured data from different sources like weather stations, ships, aircraft, radiosonde and satellites are used for the model initialization. The Physical Science Division (PSD) of the Earth System Research Laboratory (ESRL) conducts climate research to improve climate prediction on a global-to-local scale. The dataset used in this paper is taken from the website www.esrl.noaa.gov, the details of which have been provided in the paper by Kalnay et al. (1996).

The present data set consists of monthly averaged precipitation rate values (mm/day) which have been converted to monthly precipitation amounts. Ten years (1997–2006) of precipitation data are collected from this data set for different locations over the Indian Ocean and plateau regions in and around India for the formulation as well as validation of the models over oceans and plateaus, respectively.

2.2. Radiosonde data

Radiosonde measurements during the period 1997–2006 were taken from the official website of the British Atmospheric Data Center (BADC). The data of pressure, temperature and dew point temperature at different heights are available up to a height of 15 km. Clapeyron's equation is used to find the saturation vapour pressure of water at any