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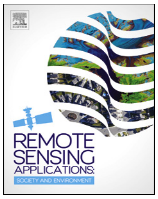

Remote sensing of convective clouds using multi-spectral observations and examining their variability over India

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ABSTRACT

Convective clouds are sources of heavy precipitation triggering flood related disasters. They are the drivers of atmospheric circulation and fundamental part of hydrological cycle. Changes in convective clouds affect atmospheric circulation and hydrological cycle. Long term reliable record of convective clouds is very useful to understand and study the hydrological cycle. Present research focuses on remote sensing of convective clouds using multispectral measurements at thermal Near Infrared channels (near 11 and 12 µm) and water vapor absorption channels (near 6.7 µm) from Meteosat First Generation (MFG) observations. Observed convective clouds are consistent with increased ice cloud water path and integrated water vapor and decreased incoming shortwave flux over Indian monsoon region. Convective clouds obtained from the present study are validated against space based radar observations from Precipitation Radar (PR) Onboard Tropical Rainfall Measuring Mission (TRMM). It is reported that present technique shows a correlation coefficient (CC) of 0.73 and Standard error of estimate of 2.96% in detecting seasonal convective clouds over India and nearby regions. 19 years record of reliable convective clouds has been generated using multispectral observations over India and nearby regions. It is reported that convective clouds show coherent variation with regional temperature over India. Impact of regional warming on convective clouds has been investigated. Present study reports that there is an increase of about 41.56% ± 11.43% in convective clouds for a unit degree increase in regional temperature over India. Results reported in this study highlight the importance of mitigation and adaptation actions against flood like disasters caused by increased convective clouds over Indian region.

1. Introduction

Convective cloud systems play a crucial role in the dynamics of atmospheric systems and hydrological cycle. These systems are key to the heat balance of the tropical atmosphere. Convective clouds bring heavy precipitation through the formation of convective storms (Mishra et al., 2010). Information about frequency, location and variability of convective clouds is essential for understanding the impact of convective clouds on atmospheric dynamics and hydrological cycle. Ground based observational network provides such information but with limited coverage. Henderson-Sellers (1992) used ground based observations and reported increase in total cloud cover over four continents, namely North America, Europe, Australia and India. An effort was made by Croke et al. (1999) to examine the cloud cover over the United States using surface based observations. They reported an increase in cloud covers during global warm periods as compared to cold periods. Very recently Jaswal et al. (2017) examined the variability of low clouds over Indian region during monsoon period using surface observations. It was found that low clouds show a decadal decreasing trend of about 1.22% over India. However, accuracy of surface based observations of cloud cover is affected due to lack of dense network. Moreover, surface based observations are not available over Oceanic region which covers about 70% of the globe. Remote sensing from Space offers an opportunity to monitor convective clouds globally. Numerous studies have been attempted to monitor convective clouds using remote sensing techniques during last few decades. Initial studies focusing on identification of convective clouds were based on threshold based techniques using observations in 11 µm channel from Earth orbiting satellites (Adler and Fenn, 1979; Reynolds, 1980; Arkin and Meisner, 1987). Arkin and Meisner (1987) used 235 K to define deep convective clouds. Deep convective clouds were identified using multispectral observations at 6.7 µm and 11 µm channels (Ackerman, 1996; Schmetz et al., 1997). Gettelman et al. (2002) detected deep convective clouds using temperature threshold of 210 K at 11 µm channel. Adler and Negri (1988) used temporal and spatial gradient approach to filter out cirrus clouds for identification of deep convective clouds. Microwave observations were also used for monitoring convective clouds over the globe. Ferraro and Marks (1995) used multiple channels from SSM/I observations to derive scattering index from the identification of convective and deep convective clouds. Microwave observations at water vapor absorption channel 183 GHz from AMSU-B were used for detection of deep convective clouds over tropical zone (Hong et al., 2005). Rajeevan and Srinivasan (2000) identified Convective clouds during South-West Monsoon season over Indian region. They had

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examined net cloud radiative forcing at the top of atmosphere using data from Earth Radiation Budget Experiment (ERBE). Berendes et al. (2008) used observations from Geostationary Operational Environmental Satellite (GOES) for the detection of convective and deep convective clouds. Convective clouds were identified and used for estimating rainfall over India from Kalpana data at 11 μm observation (Mishra et al., 2009, 2011). S.C. Liu et al. (2009) and Y. Liu et al. (2009) devised an improved technique using observations at 10.3–11.3 μm, IR2, 11.5–12.5 μm and WV 6.3–7.6 μm onboard China's first operational geostationary meteorological satellite FengYun-2C (FY-2C) to detect clouds. Structural evolution of clouds was examined by Sengupta et al. (2013) using multiangle Imaging SpectroRadiometer (MISR)-derived cloud fraction over Indian CTCZ. Multi-spectral observations at 6.7 μm and 11 μm were used from Meteosat data to examine convective clouds for estimating rainfall over Indian land and oceanic region (Mishra et al., 2010; Mishra, 2013). Aumann and Ruzmaikin (2013) used 10 years of AIRS data to monitor deep convective couds over tropics. Liang et al. (2017) used observations from Infrared and Visible Spin-Scan Radiometer (VISSR) to detect convective clouds.

It has been reported that there is decadal increase of about 0.13 K in global temperature (Trenberth et al., 2007; Mishra and Liu, 2014). Trenberth et al. (2007) reported that water holding capacity of troposphere increases by about 7% for a unit degree increase in temperature. Increased temperature and water vapor are expected to intensify the convective cloud systems. Numerous past studies have focussed on examining the changes in cloud cover over different parts of the globe (Henderson-Sellers, 1992; Karl et al., 1993, 1995; Croke et al., 1999; Wylie et al., 2005; Kolat et al., 2013; Tang and Leng, 2013). Wylie et al. (2005) utilized NOAA High Resolution Infrared Radiometer Sounder (HIRS) polar satellite data to report an increasing trend in total and high cloud covers. However, the International Satellite Cloud Climatology Project (ISCCP) reported a decrease in total and high cloud covers. Aumann et al. (2008) related changes in convective clouds with global warming. Tang and Leng (2013) examined the changes in cloudiness and precipitation and explored their connections with summer mean daily maximum temperature variation over North America. It was reported that summer mean daily maximum temperature variance is explained by changes in cloud covers and precipitation.

Present study focuses on improved identification of long term record of convective clouds (19 years) using multispectral observations at split window channels (near 11 and 12 μm) and water vapor absorption channels (near 6.7 μm) from Meteosat 7 data over India and adjacent oceanic regions. These observations are compared with space based radar observations from PR onboard TRMM. Results are compared with ground based rain gauge observations, integrated water vapor from Atmospheric Infra Red Sounder (AIRS), ice cloud water path from Moderate Resolution Imaging Spectro-radiometer (MODIS) and downward shortwave radiation flux from GLDAS. Variability of convective clouds is examined against regional temperature over India and nearby regions. Impact of regional temperature on changes in convective clouds has been quantified using 19 years of convective cloud records derived from MFG observations.

2. Study area and data used

Area of study is illustrated in Fig. 1. Study area extends from 30° S to 40°N and 40^0 E to 110°E which includes Indian land and nearby oceanic regions.

Observations from Meteosat 7 data from Meteosat First Generation (MFG) during 1998–2016 are used in the present study. Present study utilizes multispectral observations in Thermal Infrared (TIR) 10.5 – 12.5 μm and Water vapor (WV) 5.7–7.1 from MFG, launched in 1997.

Meteosat offers measurements in multispectral Thermal Infra Red (TIR) and Water Vapor (WV) absorption band at half-hourly interval, with a spatial resolution of 5 km. Data from EUMETSAT Portal (https://www.eumetsat.int/website/home/Data/DataDelivery/EUMETSATDataCentre/index.html) was downloaded. PR observations from TRMM satellite have also been utilized for comparing the observations of convective clouds. TRMM, a joint mission of NASA and the Japan Aerospace Exploration Agency (JAXA), was launched in 1997 to study hydro meteorological parameters for weather and climate research. Reflectivity factor from level 2 Rain Characteristics Product (TRMM Product 2A25) has been used to observe convective clouds using threshold reflectivity in the study. Rain gauge based India Meteorological Department (IMD) precipitation products, available at 0.25 degree, have been used to derive convective clouds for validation of present technique. Product description is given by Pai et al. (2014). Integrated water vapor observations from AIRS have been used to compare the distribution of convective clouds derived from present study. Ice cloud water path from MODIS is also used to examine the distribution of ice in convective clouds. Convective clouds reflect incoming sunlight thereby reduce shortwave radiation flux. Incoming shortwave radiation (reaching the ground) from The Global Land Data Assimilation System (GLDAS) has been used to compare the observations from present technique. Temperature data from Global Historical Climatology Network (GHCN) has been used to quantify the impact of regional warming on changes in convective clouds. It provides monthly mean temperature data for 7280 stations from 226 countries, ongoing monthly updates of more than 2000 stations to support monitoring of current and evolving climate conditions, and homogeneity adjustments to remove non-climatic influences that may bias the observed temperature record. An annual uncertainty of about 0.1 degree C has been reported from this data. Monthly data has been available from this source at 0.5 × 0.5 degree (Lawrimore et al., 2011).

3. Methodology

Brightness temperature threshold based approach adopted by Mishra et al. (2010) was followed in present technique to identify convective clouds. It was reported by Mishra et al. (2010) that threshold based technique was not able to differentiate between cirrus and convective clouds. For this purpose, an additional filter was used to remove erroneous cirrus clouds following approach developed by Adler and Negri (1988). A slope parameter $SP(T_B)$ and a brightness temperature gradient ΔT_B were computed for each local temperature minimum. These values are given as:

$$\Delta T_B = TB_{avg} - TB_{min} \tag{1}$$

$$SP(T_B) = 0.568(T_{min} - 217) \tag{2}$$

where; TB_{min} is the local minimum (derived from TIR channel, 11 μm). TB_{avg} is the mean temperature of the 6 pixels surrounding the current pixel.

It may be noted that a large ΔT_B is associated with convective clouds and a small value shows a weak gradient and thus are representative of cirrus clouds. Convective clouds with overshooting tops were identified using difference of 11 μm and 6.7 μm channels. Occurrence of convective clouds with overshooting tops is very common feature of Indian summer monsoon. These clouds play an important role in the interaction and exchange between troposphere and stratosphere. Simultaneous observations of convective clouds with overshooting tops in the infrared window region (11 μm) and the water vapor absorption band (6.7 μm) show that the equivalent brightness temperature in the latter is larger than in the former (Kurino (1997). Convective clouds with overshooting tops were identified based on negative differences (T_{B11}-$T_{B6.7}$).

Convective clouds were identified using above discussed technique using observations from MFG. Occurrence (in %) of convective clouds were identified by dividing the convective pixels with total pixels.

Kumar (2017) identified convective clouds from space based radar observations based on 40 dBZ (reflectivity) threshold over India. This threshold was suggested by (Steiner et al., 1995). Observations from PR