Large Area Soil Moisture Variations in Response to Cyclone Phailin in Eastern India


Abstract—In October 2013, a very severe cyclonic storm Phailin that originated from a remnant cyclonic circulation from the South China Sea progressed westward toward the Indian subcontinent and made its landfall in Gopalpur town of an eastern Indian state of Orissa. The landfall (on October 12, 2013) was followed by very heavy rainfall in the Indian states of Orissa, Andhra Pradesh, Chhattisgarh, Jharkhand, Bihar, and West Bengal, threatening floods in some of these states. In this letter, an attempt has been made to build up a correlation between in situ rainfall and soil moisture, which is retrieved using brightness temperature data from Advanced Microwave Scanning Radiometer 2 (AMSR2), for the cyclone period (October 10–16, 2013). Using brightness temperature as the forcing parameter, the land parameter retrieval model has been employed to retrieve soil moisture at 12 hourly intervals for the period October 10–16, 2013. The study reveals a good agreement between the variations of rainfall (cause) and soil moisture (response) with correlation coefficient greater than 0.6 and the sensitivity of AMSR2 brightness temperature to soil moisture variations.

Index Terms—Dielectric constant, passive microwave remote sensing, soil moisture, tropical cyclones.

I. INTRODUCTION

CYCLONE Phailin was formed on October 4, 2013, in the Gulf of Thailand as a tropical depression and dissipated on October 14, 2013, over West Bengal, India. In between, it moved westward, passing over the Malay Peninsula and into the Andaman Sea by October 7, 2013. On October 9, 2013, it developed into a cyclonic storm and passed over the Andaman and Nicobar Islands into the Bay of Bengal. Subsequently, cyclone Phailin intensified into a very severe cyclonic storm category 1 hurricane on the Saffir–Simpson hurricane wind scale (SSHWS) on October 10, 2013, and developed into an equivalent category 5 hurricane on the SSHWS by October 12, 2013, before weakening and its landfall near Gopalpur town, Orissa, around 2230 IST on the same day [1]. Fig. 1(a) shows the observed and predicted cyclone Phailin track as reported by the Indian Meteorological Department (IMD) [1], and Fig. 1(b) shows the satellite (Kalpana-1) image of cyclone Phailin at its near peak intensity on October 11, 2013.

Satellite microwave radiometers, although constrained by coarse spatial resolution (≥25-km footprint), provide a convenient means of estimating surface soil moisture under all weather conditions during day/night as the measured radiation is independent of the Sun’s illumination and presence of clouds. Temporal monitoring of soil moisture is a good indicator to assess the conditions that may lead to drought or flooded conditions, as the case may be. Oza et al. [2] used SSM/I surface wetness index to study soil moisture variations with the rainfall and concluded that it works for areas with vegetation cover up to 40%. Chakraborty et al. [3] successfully used AMSR Soil Moisture Index to monitor soil moisture conditions for the major crop sowing period between June and August to identify the favorable areas for crop sowing. The satellite-derived soil moisture, which, in the present study, is demonstrated as one of the responses of heavy rainfall which occurred after the cyclone Phailin, will have its further utility in identifying potential flood-affected regions [4].

II. STUDY AREA

The geographical area, covering the Indian states that were on the path of cyclone Phailin, was identified to study the cyclone impact on soil moisture conditions, and it is shown in Fig. 1(c).

III. DATA USED

Daily rainfall data for the study period of October 10–16, 2013, from IMD have been used to monitor the rainfall in the Indian states affected by cyclone Phailin after the landfall on October 12, 2013.

Additionally, Advanced Microwave Scanning Radiometer 2 (AMSR2) multichannel microwave brightness temperature data from both ascending (time of acquisition 1330 IST) and descending (time of acquisition 0130 IST) for each of the days of the study period have been processed and used in the estimation of surface soil moisture. It may be noted that the soil moisture sensing depth of the microwave-emitted radiation sensed by AMSR2 is highly sensitive to soil moisture content and decreases exponentially with increasing soil moisture content.

IV. METHODOLOGY

Surface soil moisture for the study duration of October 10–16, 2013, was retrieved using land parameter retrieval model (LPRM) and level-3 brightness temperature data
Fig. 1. (a) Observed track of Phailin on October 8–14, 2013. (b) Satellite image of Phailin on October 11, 2013, near its peak intensity. (c) Study area (in gray shade).

Fig. 2. Schematic diagram of soil moisture retrieval from AMSR2 brightness temperature based on LPRM.

Fig. 3. Average rainfall over the cyclone-Phailin-affected states.

Fig. 4. Spatial distribution of rainfall (in millimeters) for the period of October 10–15, 2013.
temperature based on radiative transfer formulation of Owe et al. [6]. The adopted approach takes into account the effects of soil texture and sparse vegetation cover and includes modeling of soil dielectric constant [7] as a function of soil moisture variations. Fig. 2 shows the scheme of the adopted procedure to model brightness temperature and estimate soil moisture using AMSR2 data. Subsequent to arriving at the modeled brightness temperature, soil moisture is retrieved by iteratively minimizing the difference of modeled and AMSR2-observed brightness temperatures following the Brent method [8]. The procedure, in its current version, assumes known constant values for surface roughness parameters [9] and single scattering albedo [6]. The vegetation optical depth is derived from the microwave polarization difference index, the single scattering albedo, and the dielectric constant of the soil using a numerical solution developed by Meesters et al. [10]. The surface temperature is derived using 36.5-GHz V-polarized brightness temperature [11].

The use of 36.5-GHz V-polarized brightness temperature for retrieving surface temperature is limited by snow, frost, and frozen soil, as these conditions prevent the parameterization of emissivity [11]. Also, the active precipitation scatters the surface emissions if droplet size is close to the size of the wavelength (∼8 mm for 36.5 GHz) [12]. Therefore, IMD hourly rainfall data have been used to identify and screen out the regions with active rainfall at the time of data acquisition (i.e., 0130 and 1330 IST) to avoid erroneous computation of surface temperature. The retrieval model performs poor when the vegetation is too dense because the signal from the soil surface is absorbed by the vegetation layer. Therefore, in this study, the regions with permanent snow cover, frozen surfaces, evergreen forests, steep terrains, and large water bodies have been masked using land use and land cover information from the National LULC mapping project (ISRO) for 2011–2012.

V. RESULTS

Following the aforementioned procedure, surface soil moisture has been estimated over the Indian region on a daily basis for the period October 10–16, 2013. Fig. 3 shows the daily average rainfall (computed using hourly rainfall data from IMD) over the cyclone-Phailin-affected Indian states. It may be noted that, although rainfall is more around the cyclone Phailin track over land, the area averaged rainfall for the respective states during the study period is probably much lower than that in areas directly along the path of cyclone Phailin. Fig. 4 shows the spatial distribution of rainfall that has accumulated in the last 24 h over the study area on October 10–15, 2013. It can be concluded from Figs. 3 and 4 that Orissa and its neighboring states have received significant rainfall after the landfall. Fig. 4 shows very less rainfall over Orissa on October 10, 2013, followed by gradually increasing rain after the landfall. While Jharkhand and Bihar show heavy rainfall on October 13, 2013, no rain was observed over these states by October 15, 2013, which indicates negligible/subsided effect of cyclone Phailin landfall.

Fig. 5 shows the soil moisture conditions retrieved using LPRM over the cyclone-Phailin-affected states with increased soil moisture conditions along and around the track of cyclone Phailin after the landfall. As expected, a comparative evaluation of rainfall variations and estimated soil moisture for corresponding areas shows a good agreement, indicating
Fig. 6. Response of retrieved surface soil moisture to rainfall during cyclone Phailin (October 10–16, 2013).

the “cause” and the “response.” The impact of cyclone-Phailin-induced rainfall is evident in the form of increased soil moisture conditions over the study region. For example, low soil moisture conditions (∼0.1 m³/m³) are observed over Orissa on October 11, 2013, at 1330 IST (before the landfall), and significantly increased soil moisture conditions (>0.4 m³/m³) are observed after the landfall between October 12, 2013 (0130 IST), and October 14, 2013 (1330 IST). These observations are in good agreement with the surface soil moisture estimates available from the satellite Soil Moisture and Ocean Salinity for the same duration [13].

Fig. 6 shows the estimated surface soil moisture using AMSR2 brightness temperature data against rainfall for three locations that were along the track of the cyclone Phailin, viz., Bhubaneswar (20.27° N, 85.84° E) in Orissa, Ranchi (23.35° N, 85.33° E) in Jharkhand, and Darbhanga (26.17° N, 85.90° E) in Bihar for the period of October 10–16, 2013. These sites were selected because of the continuous availability of rainfall data for this period. The plots show the interpolated soil moisture values wherever satellite data were not available due to missing acquisition or active rainfall at the time of data acquisition. For all of the three stations, soil moisture conditions show a very good agreement in terms of response to incident rainfall as a function of time. Linear regression equations for estimated soil moisture and rainfall have been developed for all of the three locations separately, and the corresponding regression parameters have been presented in Table I.

VI. CONCLUSION

This study has indicated the potential of high temporal resolution (∼12 h) sensors like AMSR2, which have their unique utility during event-specific studies despite of lower spatial resolution (∼25 km). Also, during an event like cyclone, when other waveband (like IR and visible bands) sensors limit their utility, brightness temperature from microwave sensor has been potentially employed to estimate soil moisture. The soil moisture estimated using microwave brightness temperature is found to be well correlated with the rainfall, and the correlation coefficients for the three sites, i.e., Bhubaneswar, Ranchi, and Darbhanga, are 0.8238, 0.7179, and 0.6313, respectively.

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REFERENCES


