

## Inundation mapping using SENTINEL-1 data in the aftermath of super cyclone Amphan : A case study

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**सार** – नियोजन और बचाव कार्य करने के लिए सही समय में आपदा जोखिम प्रबंधकों के लिए उपयुक्तबन्धीय चक्रवात के स्थल प्रवेश के कारण होने वाले जल भराव की सीमा और गंभीरता के बारे में जानकारी होना आवश्यक है। इस संबंध में उपग्रह आधारित सुदूर संवेदन एक महत्वपूर्ण भूमिका निभाता है और यह वास्तविक समय पर प्रबंधकों को जोखिम की जानकारी प्रदान करता है। परंपरागत रूप से ऑप्टिकल डेटा का उपयोग बाढ़ / बाढ़ के मानचित्रण के लिए किया जा रहा है, लेकिन इसमें दो बाधाएँ आती हैं : मेघ आवरण के कारण और रात्रि के दौरान इसकी अनुपलब्धता। सूक्ष्मतरंगीय SAR डेटा इन दोनों बाधाओं को दूर करता है और सघन मेघ आवरण और रात्रि में भी वास्तविक जानकारी प्रदान कर सकता है। इस अध्ययन में महाचक्रवात अम्फन के स्थल प्रवेश के कारण पश्चिम बंगाल के बाढ़ प्रभावित जिलों का मानचित्रण सेंटिनेल-1 उपग्रह से प्राप्त SAR डेटा का उपयोग करके किया गया है। NOAA द्वारा इष्टतम समुद्री सतह तापमान डेटा का उपयोग महाचक्रवात अम्फन की उत्पत्ति और उसके तेजी से तीव्रीकरण के दौरान बंगाल की खाड़ी के विश्लेषण को करने के लिए भी किया जाता है। GsMAP वर्षा डेटा का उपयोग महाचक्रवात अम्फन के स्थल प्रवेश के दौरान वर्षा का आकलन करने के लिए किया गया है। सेंटिनेल-1 उपग्रह के SAR डेटा का उपयोग करके तैयार किए गए बाढ़ मानचित्रण को सेंटिनेल-2 उपग्रह से प्राप्त ऑप्टिकल छवियों के साथ मान्य किया गया। बाढ़ग्रस्त क्षेत्रों में बचाव अभियान की योजना बनाने और उसे कार्यान्वित करने के लिए SAR डेटा का उपयोग बहुत महत्वपूर्ण है।

**ABSTRACT.** Information regarding the extent and severity of inundation resulting because of the landfall of a Tropical Cyclone is required by disaster risk managers in near time to carry out planning and rescue operations. In this regards the Satellite based remote sensing plays a vital role and provides this information to risk managers in near real time. Traditionally Optical data is being used for flood/inundation mapping but it suffers from two constraints : non-availability due to cloud cover and during night time. Microwave SAR data overcomes both these constraints and can provide ground information even during heavy cloud cover and night-time. In this study, inundation mapping of the affected districts of West Bengal due to landfall of Super Cyclone Amphan is attempted by using SAR data from SENTINEL-1 satellite. NOAA Optimum Interpolation Sea Surface Temperature data is also used to carry out the analysis of Bay of Bengal during the genesis and rapid intensification of Super Cyclone Amphan. GsMAP rainfall data is used to carry out rainfall assessment during the landfall of Super Cyclone Amphan. The inundation maps generated using SENTINEL-1 SAR data were validated with the optical images from SENTINEL-2 satellite. The use of SAR data is very crucial for disaster managers in order to plan and execute rescue operations in inundated areas.

**Key words** – SENTINEL-1, Inundation mapping, Super cyclone Amphan, GsMAP.

### 1. Introduction

Cyclone is a generic term which is associated with any low-pressure system with mean surface wind greater than or equal to 34 knots. World Meteorological organization has classified cyclonic disturbances in North Indian Ocean based on the mean surface wind (WMO, 2016). Many studies have been published on the life cycle climatology and movement of cyclonic disturbances in

various ocean basins. 50% of depressions intensifying to tropical cyclones in less than 25% of tropical cyclones into a severe cyclonic storm (Mohapatra *et al.*, 2015a). Some have suggested that takes 2 to 3 days for a low-pressure area into a depression or deep depression and in next 24 hours to 48 hours for a depression or deep depression to intensify into a severe cyclonic storm or a very severe cyclonic storm (IMD, 2003). It has been shown that the tropical cyclones predominantly move in

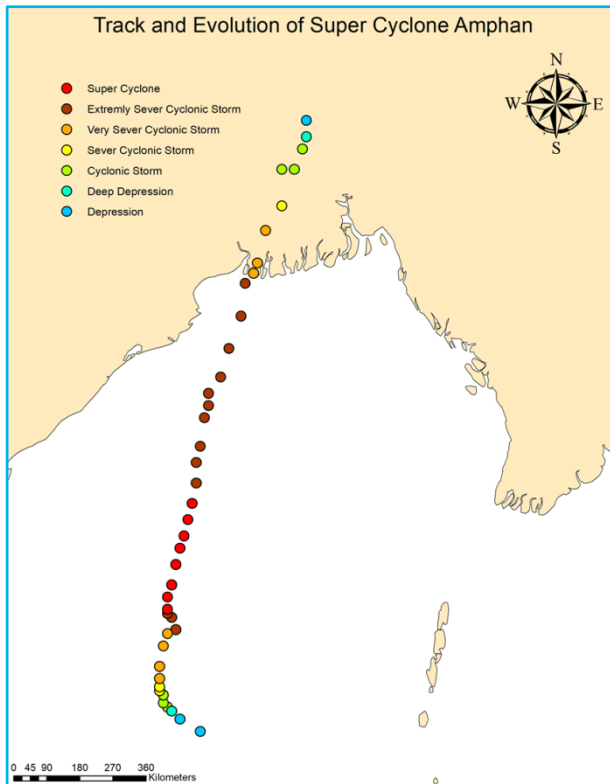


Fig. 1. Track and life cycle of super cyclone Amphan

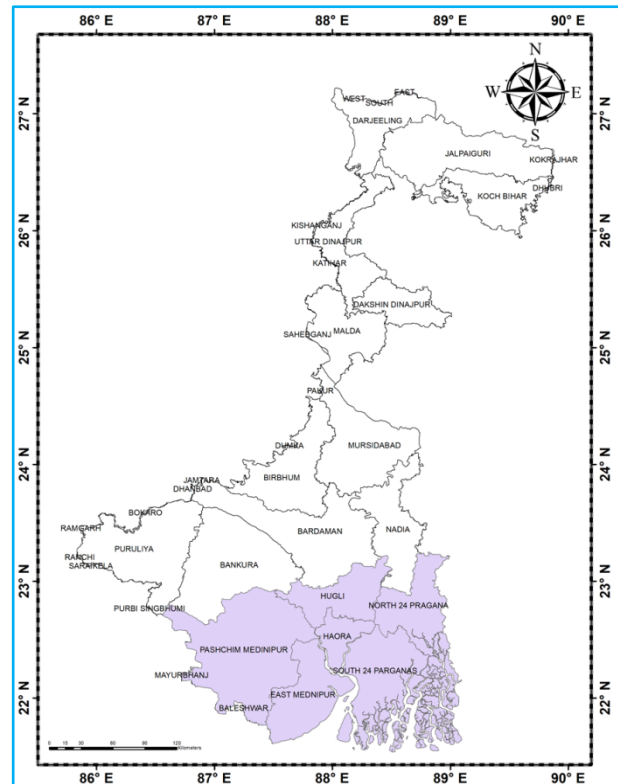


Fig. 2. Study area (Paschim Medinipur, Purba Medinipur, North 24 Parganas, South 24 Parganas, Hooghly, Howrah and Kolkata districts of West Bengal)

West North West to North West direction (Chinchole & Mohapatra, 2017). Many studies associated with the mortality rate because of cyclone have also been the different ocean basins. During last 300 years more than 75% Tropical cyclones which originated in Bay of Bengal resulted in human life loss of 5000 or more (Dube *et al.*, 2013). However, with recent advancements in both weather forecasting and disaster management the mortality rate came down (Mohanty *et al.*, 2015).

In the climatological study done by Mohapatra *et al.*, 2014b, the authors have documented that on an average 11, 9, 2 cyclonic disturbances develop into North Indian ocean, Bay of Bengal and Arabian Sea respectively. Out of these nine cyclonic disturbances over BoB about 4 Intensify into a tropical cyclone. Of these four TC two intensify into a severe tropical cyclone and 1-2 further intensify into very severe cyclonic storm. In another study Mohapatra *et al.*, 2015a, the author has documented a significant decreasing trend in intensification of cyclonic disturbances into tropical cyclones over BoB during Pre, Post and Monsoon seasons during 1961-2010.

Floods cause the most mortalities and huge economic loss among various natural disasters (Adhikari *et al.*, 2010; Schumann *et al.*, 2016; Hallegatte *et al.*,

2013). In climate change projections, it is expected that the precipitation and storms will increase in both frequency and intensity which will lead to flash floods and floods affecting people's livelihood (Pall *et al.*, 2011). The disaster managers and decision makers require near real time data at high frequency to plan and implement the rescues operations. For this purpose, remote sensing data can be used. It can provide time critical information in near real time to disaster managers in a very economic and continuous manner. Remote sensing data (both optical and microwave) have been used in recent decades to monitor water levels, inundated areas and hazard maps are prepared accordingly (Schumann *et al.*, 2009; Voigt *et al.*, 2016). Optical data is less effective in case of flood monitoring because of the presence of clouds. On the other hand, microwave data has been used extensively to flood mapping as it is not affected by adverse weather (Kuenzer *et al.*, 2013b; Mason *et al.*, 2014; O'Grady *et al.*, 2014; Schumann *et al.*, 2018).

The last super cyclone which made landfall at Indian coast was that of 1999 which made landfall near Paradeep coast with speed of 260 km per hour (Mohapatra *et al.*, 2002). Super Cyclone Amphan originated from the remnant of a low-pressure area over south Andaman Sea on 13<sup>th</sup> May, 2020. It intensified into

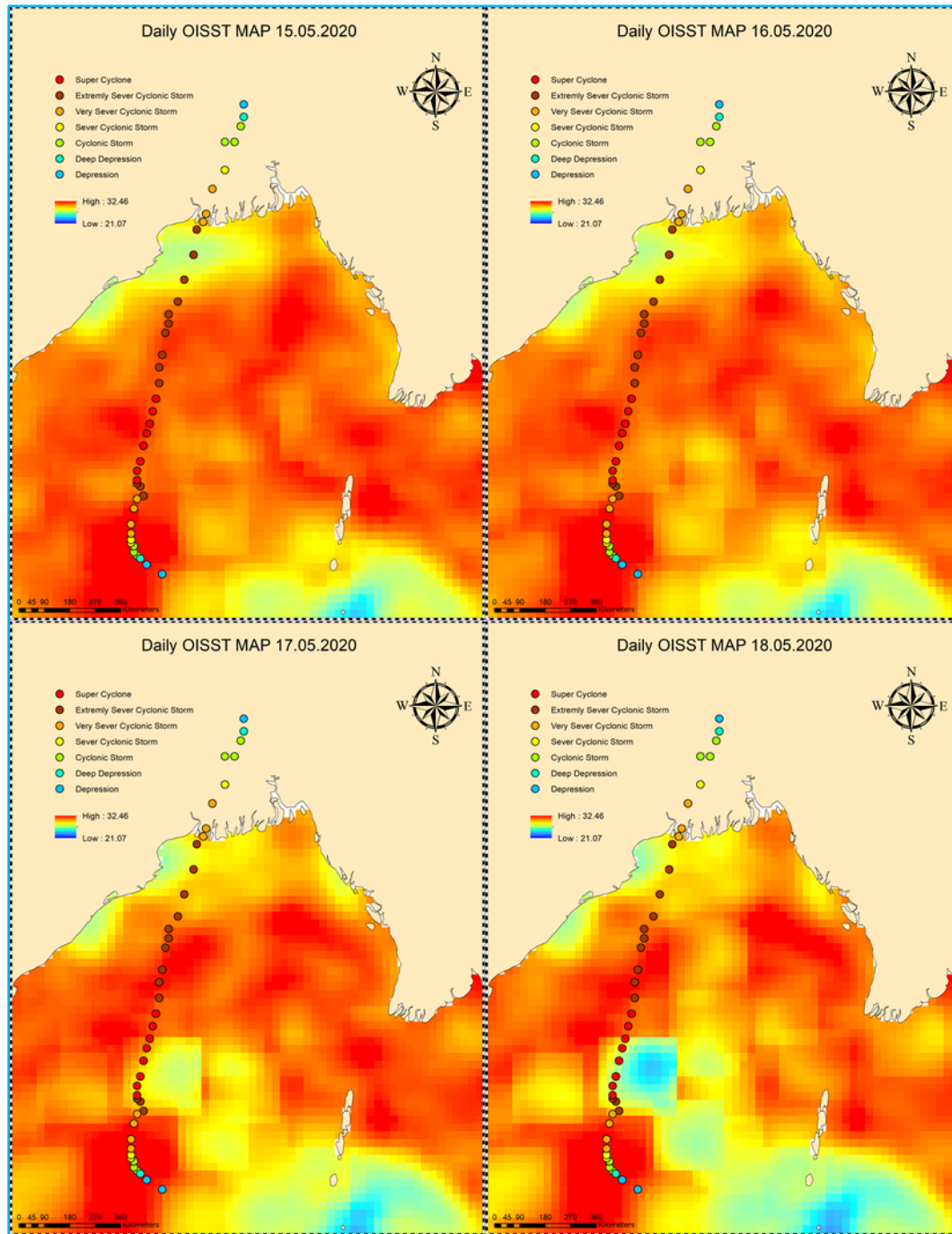


Fig. 3. Daily OISST Map for 15<sup>th</sup>, 16<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> May, 2020 for Bay of Bengal

a Depression and further into a Deep Depression on 16<sup>th</sup> May, 2020. By the evening of 16<sup>th</sup> May, 2020 Cyclonic Storm Amphan was declared. The system went under rapid intensification and by 18<sup>th</sup> May noon, it intensified into a Super Cyclonic Storm Amphan. The system intensified from a CS to SuCS in less than 36 hours. This rapid intensification as documented by Balasubramanian

& Chalamalla, 2020 is attributed to high sea surface temperature and the presence of Convectively Coupled Kelvin Wave which lead to the strong westerly burst that acted as a constant source of moisture for the system. The SuCS Amphan weakened into an ESCS around the noon of 19<sup>th</sup> May, 2020. It made landfall across Sundarbans at West Bengal and Bangladesh cost during 1530-1730 IST

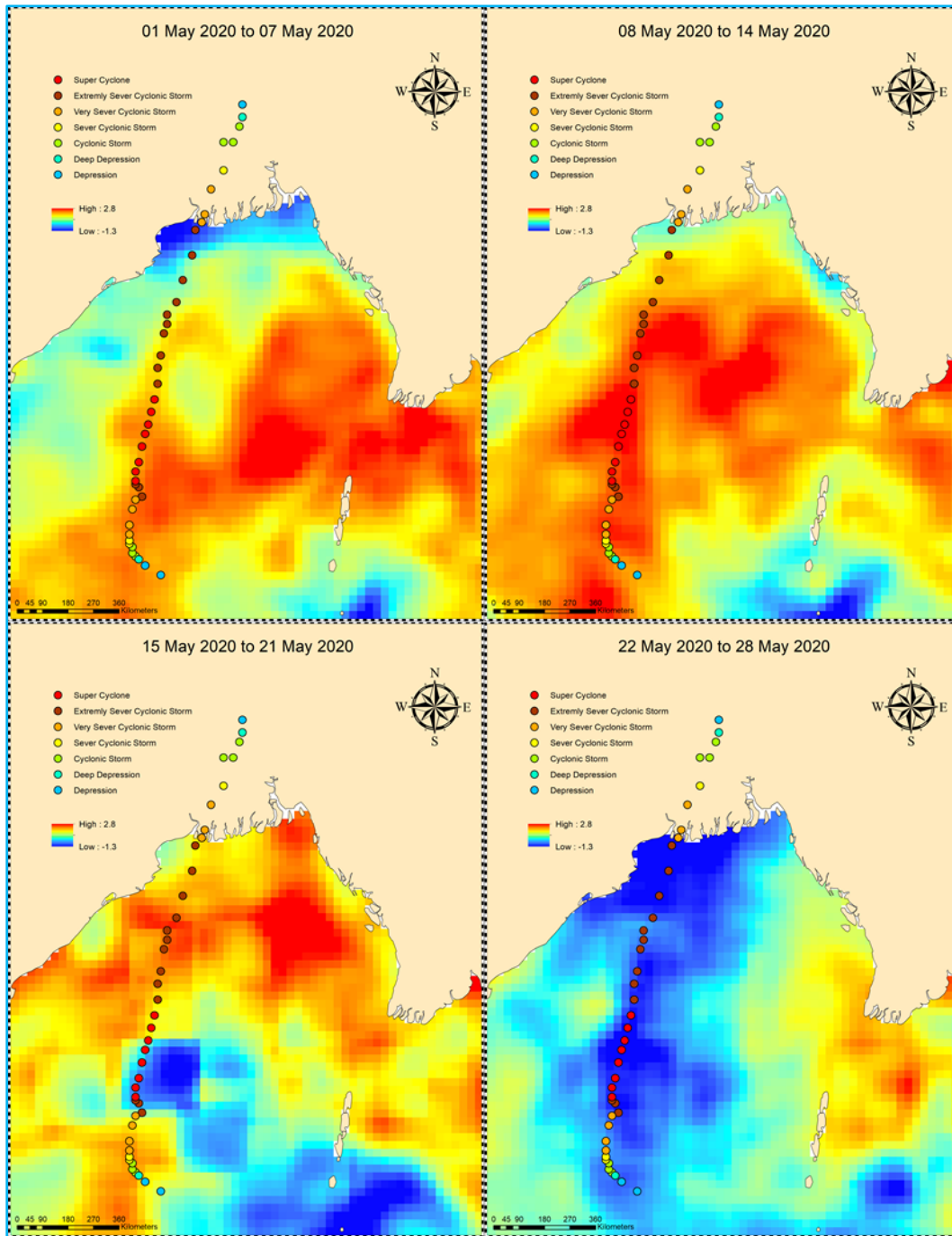


Fig. 4. Weekly OISST Anomaly Map for week1 (01<sup>st</sup> - 07<sup>th</sup> May, 2020), week2 (08<sup>th</sup> - 14<sup>th</sup> May, 2020), week3 (15<sup>th</sup> - 21<sup>st</sup> May, 2020) and week4 (22<sup>nd</sup> - 28<sup>th</sup> May, 2020) for Bay of Bengal

of 20<sup>th</sup> May, 2020 as a VSCS. The maximum sustained wind speed observed during landfall was in the range 155-165 kmph with gusting to 185 kmph. It lay over West Bengal as a VSCS giving torrential rains before moving NNE wards during late evening of 20<sup>th</sup> May, 2020. It gradually weakened into a SCS, CS, DD and D over

Bangladesh by 21<sup>st</sup> May evening (RSMC New Delhi Bulletins). The entire life cycle and tract of Super Cyclone Amphan is depicted in Fig. 1.

The purpose of this study is to bring out an approach for using SENTINEL-1 data for mapping inundated areas

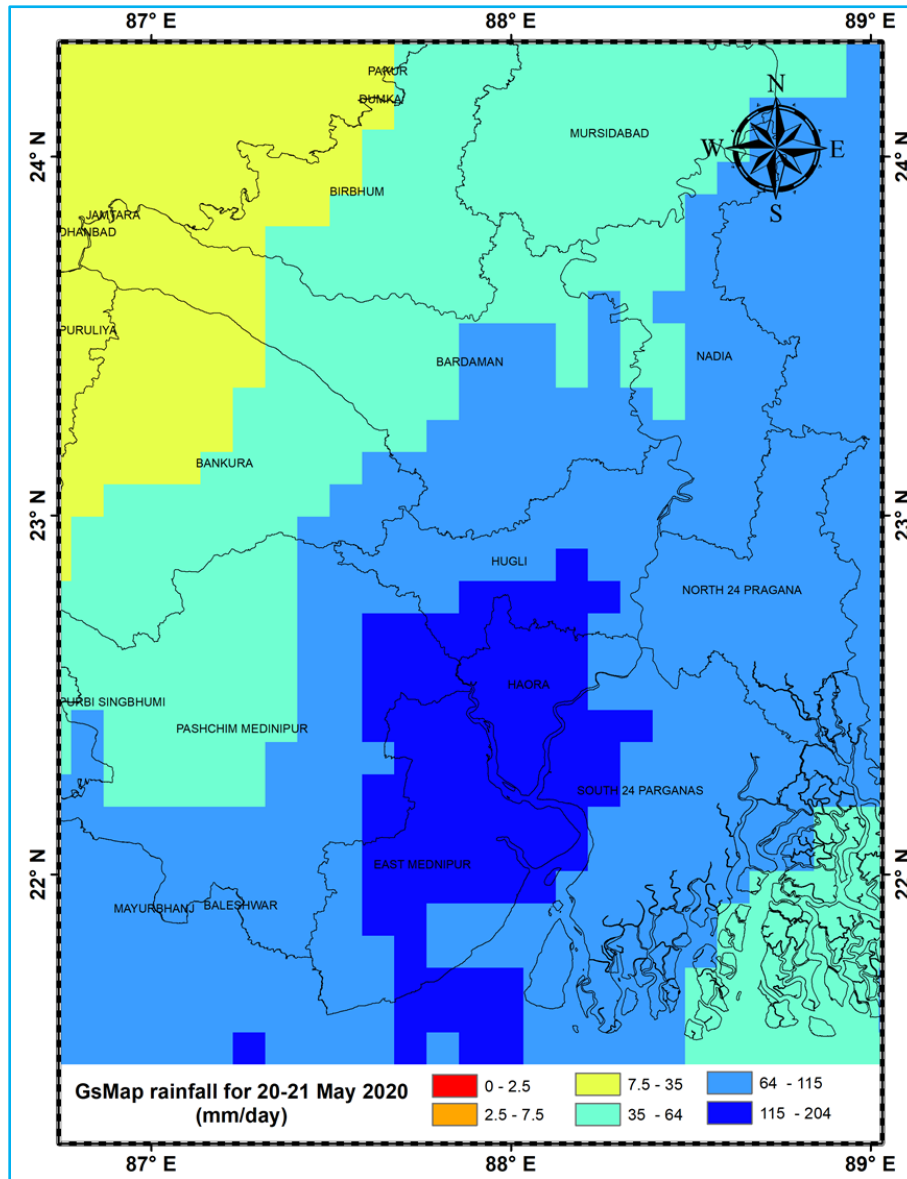


Fig. 5. GsMAP Rainfall for 20-21 May, 2020 (mm/day) during landfall of super cyclone Amphan

because of the torrential rains and storm surge associated with Super cyclonic Storm Amphan, after its landfall in the Indian states of West Bengal and during its passage near the Coastal Orissa districts. This data can be used by disaster managers to focus their efforts in worst affected areas.

## 2. Study area

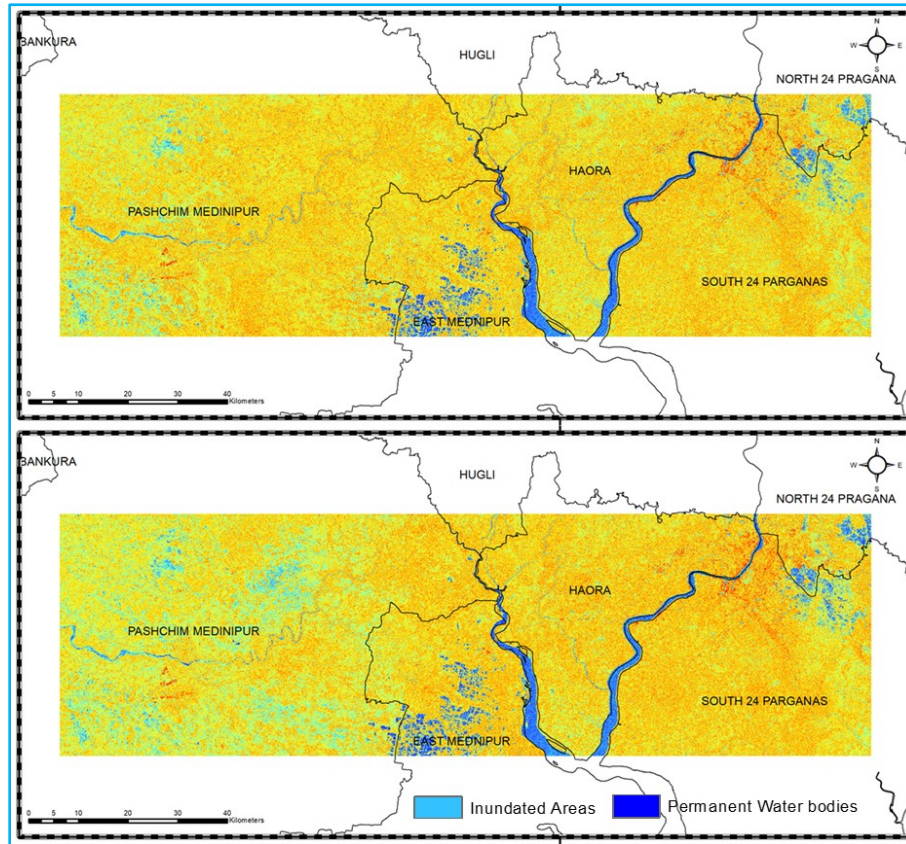
The study area is located in the Indian state of West Bengal as shown in Fig. 2. The Super Cyclonic storm before making landfall in Sundarbans areas of West Bengal on 20<sup>th</sup> May, 2020 and laid over West Bengal as

VSCS till late evening of 20<sup>th</sup> May, giving torrential rains in coastal and adjoining districts of West Bengal.

## 3. Data and methodology

### 3.1. SENTINEL-1 SAR data

The SENTINEL-1 mission is operated by European Space Agency (ESA) in the framework of European Union's Copernicus Programme. It consists of two systematically acquiring satellite sensors SENTINEL-1A and SENTINEL-1B with a repeat cycle of six days for the final constellation. Both are equipped with a C-band SAR



**Fig. 6.** Pre-landfall and post-landfall scans from SENTINEL-1 showing increase in area under water category (blue colour)

payload (at 405 GHz). Over landmasses the interferometric wide swath (IW) mode is used by default acquiring dual polarized SAR data with VV/VH polarization. (Torres *et al.*, 2012). The SENTINEL-1 data is downloaded from Copernicus Open Access Hub. The Ground Range Detected (GRD) dataset of the SAR is used in this study. GRD dataset is a multi-looked SAR dataset which is projected to ground range using earth ellipsoid model. GRD dataset is available in square pixels with reduced speckle and it represents only detected amplitude values (the phase information is discarded). The whole process is repeated to generate two time series over the study area one for pre-Super Cyclone Amphan period and another for post-Super Cyclone Amphan period. Both the scenes were compared on pixel level and threshold was worked out for classifying the inundated area and non-inundated areas.

### 3.2. Optimum Interpolation Sea Surface Temperature (OISST)

The NOAA Optimum Interpolation Sea Surface Temperature (Huang *et al.*, 2020) is an analysis constructed by combining observations from different

platforms (satellites, ships, buoys and Argo floats) on a regular global grid. A spatially complete SST map is produced by interpolating to fill in gaps. The methodology includes bias adjustment of satellite and ship observations (referenced to buoys) to compensate for platform differences and sensor biases. Version 5.2 Sea Surface Temperature dataset (PFV52) is a collection of global, twice-daily 4 km sea surface temperature data. SST data is used to analyse the rapid intensification of Super Cyclone Amphan. Daily anomaly of SST with 40-year average SST in Bay of Bengal for 15<sup>th</sup>, 16<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> May, 2020 was calculated as shown in Fig. 3. Weekly anomaly was also calculated as shown in Fig. 4.

### 3.3. GsMap rainfall

Global Satellite Mapping of Precipitation (GSMaP) provides a global hourly rain rate with a  $0.1^\circ \times 0.1^\circ$  resolution. GSMaP is a product of the Global Precipitation Measurement (GPM) mission, which offers global precipitation observations at three-hour intervals. Values are estimated using multi-band passive microwave and infrared radiometers from the GPM Core Observatory

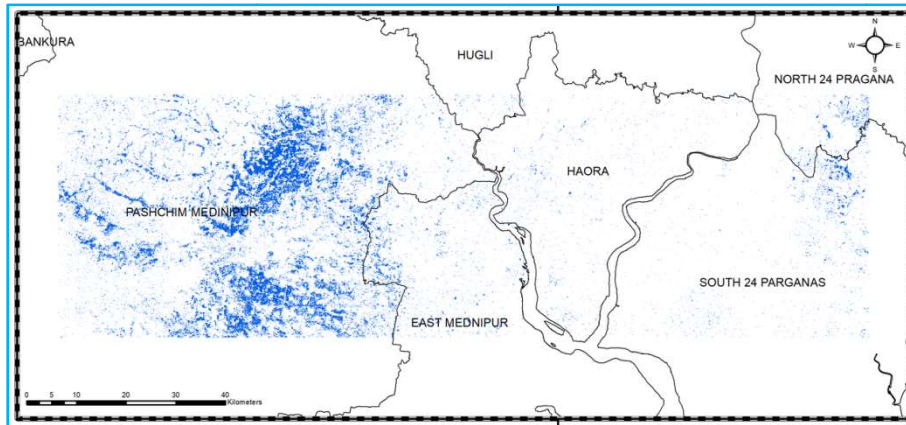


Fig. 7. SENTINEL-1 Inundation area as captured from SENTINEL-1

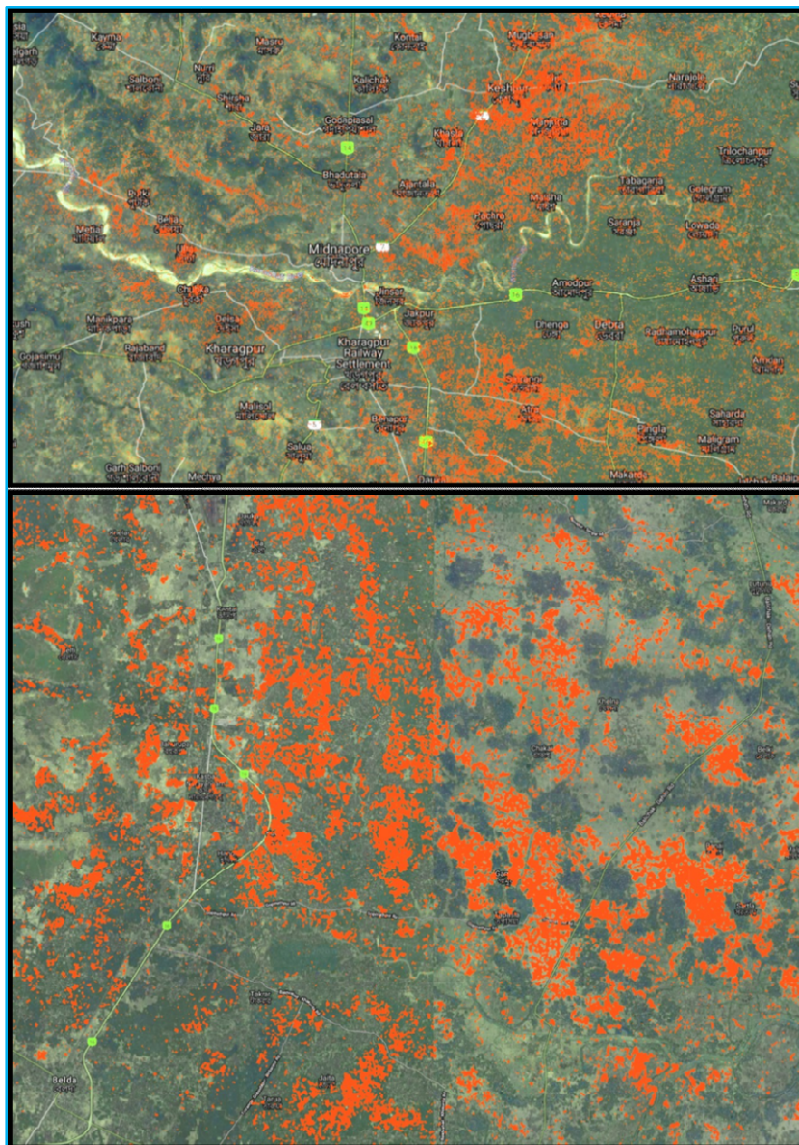


Fig. 8. SENTINEL-1 Inundation Map (RED colour) of Paschim Medinipur district superimposed on Google Earth Engine

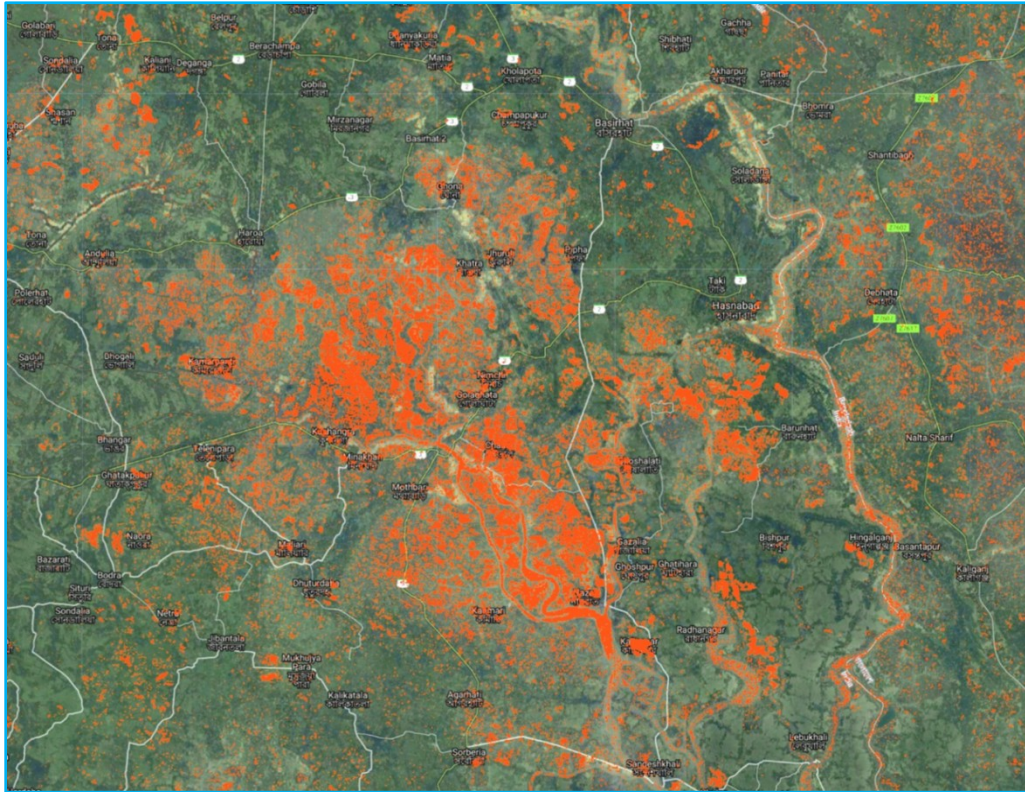


Fig. 9. SENTINEL-1 Inundation Map (RED colour) of South 24 Parganas district superimposed on Google Earth Engine

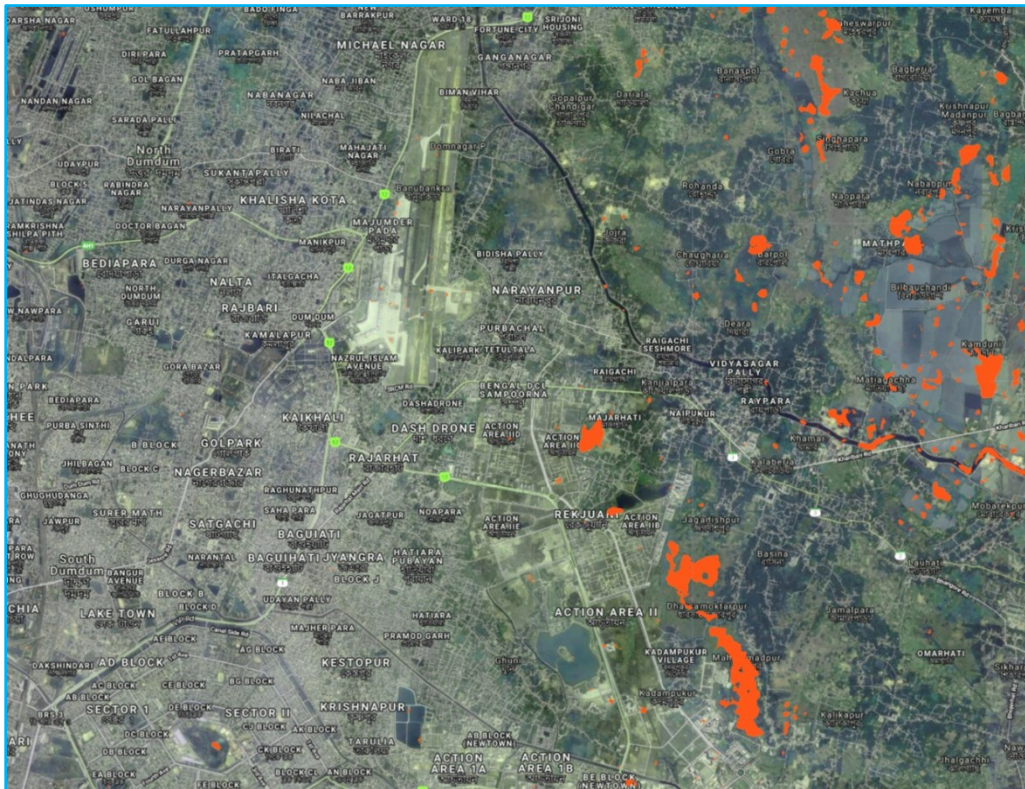
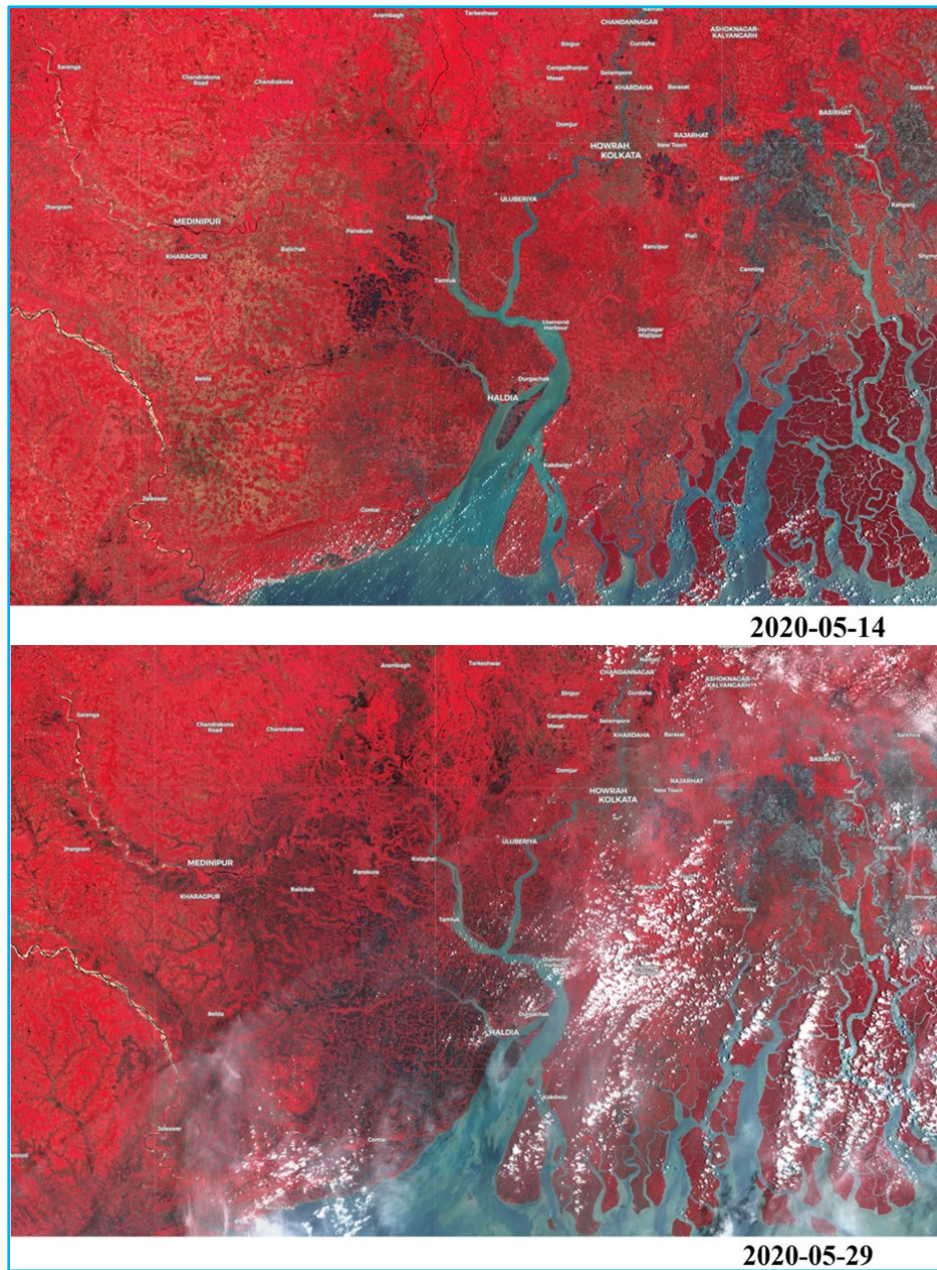


Fig. 10. SENTINEL-1 Inundation Map (RED colour) of Kolkata district superimposed on Google Earth Engine





**Fig. 11.** Inundation Map (Dark Grey) as observed by Optical Sensor of SENTINEL-2 superimposed on Google Earth Engine

satellite and with the assistance of a constellation of other satellites. GPM's precipitation rate retrieval algorithm is based on a radiative transfer model. The gauge-adjusted rate is calculated based on the optimization of the 24 h accumulation of GSMaP hourly rain rate to daily precipitation by NOAA/CPC gauge measurement (Okamoto *et al.*, 2005; Kubota *et al.*, 2007; Aonashi *et al.*, 2009; Ushio *et al.*, 2013). This dataset is processed by GSMaP algorithm version 6 (product version 3). GsMap Rainfall is used in this study to do rainfall analysis on the

day of landfall for the areas which experienced torrential rains as shown in Fig. 5. Those areas were selected for carrying out the inundation studies.

### 3.4. *Sentinel-2 Optical data*

The SENTINEL-2 mission is operated by European Space Agency (ESA) in the framework of European Union's Copernicus Programme. It consists of two polar-orbiting satellites placed in the same sun-synchronous

orbit, phased at 180° to each other with a repeat cycle of five days for the final constellation. The Multi Spectral Instrument (MSI) payload provides three possible spatula resolution of 10 m, 20 m and 60 m based on band number. The swath width of SENTINEL-2 is 290 km. This data is used for validating the inundation maps generated using SENTINEL-1 SAR data.

## 4. Results and discussion

### 4.1. Rapid Intensification of super cyclone Amphan

Fig. 3 depicts the SST anomaly values in BoB for 15<sup>th</sup>, 16<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> May, 2020 and Fig. 4 depicts the weekly anomaly for week1 (01-07<sup>th</sup> May, 2020), week2 (08<sup>th</sup>- 14<sup>th</sup> May, 2020), week3 (15<sup>th</sup>-21<sup>st</sup> May, 2020) and week4 (22<sup>nd</sup>-28<sup>th</sup> May, 2020). For the Week1 it can be seen that in the region of cyclogenesis the SST values were very high resulting in positive anomaly making it favourable for cyclone genesis. The intense heating of sea surface persisted during week2 also. It can be seen from Fig. 3 that higher sea surface temperature values in the range of 32 degree Celsius over South East and South West Bay of Bengal and extended upto West Central and East Central Bay of Bengal on 15<sup>th</sup> May, 2020. The higher values were seen on 16<sup>th</sup> May also resulting in the formation of depression on that day. With the availability of hot waters, the system underwent rapid intensification. Therefore, it can be seen that the higher values of SST played a role in cyclogenesis and rapid intensification of Super Cyclone Amphan.

### 4.2. Torrential rainfall during landfall

Fig. 5 shows the rainfall associated with the Super Cyclone Amphan over the costal districts of West Bengal as captured by GsMap. It can be seen that very heavy (115-204 mm per day) to heavy rainfall (64-115 mm per day) occurred over Paschim Medinipur, Purba Medinipur, North 24 Parganas, South 24 Parganas, Hooghly, Howrah and Kolkata districts on 20<sup>th</sup> and 21<sup>st</sup> May, 2020. As a result of torrential rains and storm surge many parts of these districts got inundated.

### 4.3. Inundation mapping

The processed SAR data from SENTINEL-1 showing pre landfall and post landfall scans over the study area is shown in Fig. 6. It can be seen from the Fig. 6 that a large portion of these districts were inundated because of storm surge and torrential rains. The inundated areas are shown in blue colour. The pixel by pixel analysis of the inundated area is shown in Fig. 7. A large portion of Paschim Medinipur district can be seen as inundated area.

In order to do the analysis of inundation areas in detail, the SENTINEL-1 SAR data was converted into KML form to superimpose it over Google Earth Engine. In Fig. 8 area around Kharagpur and Takra, Paschim Medinipur district is shown on Google Earth Engine. The flooded / inundated areas are shown in RED colour. Similarly, Figs. 9&10 show the inundation mapping of the area in South 24 Parganas and Kolkata districts respectively.

### 4.4. Validation of inundation map

The inundation maps generated using SENTINEL-1 satellite were validated with the SENTINEL-2's Multi Spectral Instrument (MSI) payloads Optical data. The pre landfall and post landfall MSI False colour composite image superimposed on Google Earth Engine is shown in Fig. 11. It can be seen that after the landfall of Super Cyclone Amphan the area under water category has increased in Paschim Medinipur, Purba Medinipur, North 24 Parganas, South 24 Parganas, Hooghly, Howrah and Kolkata districts.

## 5. Summary and conclusions

Super Cyclone Amphan originated from the remnant of a low-pressure area over south Andaman sea on 13<sup>th</sup> May, 2020. It intensified into a Depression and further into a Deep Depression on 16<sup>th</sup> May, 2020. The system went under rapid intensification and by 18<sup>th</sup> May noon, it intensified into a Super Cyclonic Storm Amphan. It made landfall across Sundarbans at West Bengal and Bangladesh coast during 1530-1730 IST of 20<sup>th</sup> May, 2020 as a VSCS. Higher values of SST played a role in cyclogenesis and rapid intensification of Super Cyclone Amphan as seen from Optimum Interpolation Sea Surface Temperature data. During the landfall of Super Cyclone Amphan very heavy (115-204 mm per day) to heavy rainfall (64-115 mm per day) occurred over Paschim Medinipur, Purba Medinipur, North 24 Parganas, South 24 Parganas, Hooghly, Howrah and Kolkata districts on 20<sup>th</sup> and 21<sup>st</sup> May, 2020. As a result of torrential rains and storm surge many parts of these districts got inundated.

In this study an attempt is made to showcase the use of SENTINEL-1 data for mapping inundated areas because of the torrential rains and storm surge associated with Super cyclonic Storm Amphan. The inundation maps were converted to KML format for its use on Google Earth Engine. The inundation maps generated using SENTINEL-1 satellite were validated with the SENTINEL-2's Multi Spectral Instrument (MSI) payloads Optical data. The optical data is not available during the event because of the presence of high amount of cloud

cover. Hence in this study we have shown that the microwave data can be used for near real time information dissemination and decision making to disaster risk managers. With a repeat time of 6 days SENTINEL-1 data can be used for flood monitoring. Attempts will be made to make this algorithm operational so that it can be implemented in real time basis and qualitative information may be provided to disaster risk managers in near real time.

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