Detection of Tropical Cyclone PHET Using 19.35GHz SSM/I Data

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For detection of the cyclone PHET, brightness temperature data (BT) of Special Sensor Microwave/Imager (SSM/I) sensor at 19.35GHz over Arabian Sea (AS) was procured for the year 2010. In order to trace the cyclone PHET; study of the cyclone affected area before and after striking of the cyclone affected day is done. During analysis at 19.35GHz, the BT and rain rate data over cyclonic area was found to be exceptionally high when compared with the ordinary days. This behavior could be due to the presence of rain clouds during cyclone that emit more radiation at lower frequency (< 37GHz) than the background ocean and cloud free atmosphere. Surface roughness that is caused by high winds increases the BT. As a result at 19.35GHz the BT is found to be high at cyclonic areas as this frequency is greatly affected by rains and high winds. This result shows an insight to detect the natural hazards using passive microwave remote sensing.

[Keywords: Brightness Temperature, Microwaves, Remote Sensing, Cyclone]

Introduction

In general a tropical cyclone\(^1\) is a storm formed due to existence of low-pressure system over tropical or sub-tropical waters that leads to strong winds and heavy rain. Tropical cyclones derive their energy from the warm tropical oceans and do not form unless the sea-surface temperature is high. They are also able to produce high waves, damaging storm surge and floods, even can persist for many days and have somewhat irregular paths. They in fact cause large damage to the life and property. Inland regions are much safer than the coastal as cyclones do not get moisture and indeed looses energy while penetrating into the land.

Tropical Cyclone detection has improved a lot from last few years with the significant improvements in satellite remote sensing\(^2\). Infrared/optical imagers onboard satellite provide valuable information that help in determining the location of the Tropical Cyclone, however due presence of clouds these sensors do not lead to accurate assessment. Here is where the Microwave Remote Sensing’s unique capability of all weather penetration helps in providing the data even in presence of clouds. Microwave Sensors\(^3\) has tremendous potential and offer certain specific advantages which help in obtaining the correct information for detection, tracking and prediction of cyclone.

By regular monitoring of the microwave emissions from the ocean, one can detect the beginning of the cyclonic activity. The most important electrical parameter that affects the microwave emission over the ocean is expressly dielectric constant (DC) that is a function of surface temperature, salinity and wavelength. The emission by the ocean is also dependent on the different physical parameters including surface roughness caused by high winds, rain rate & Cloud Liquid Water (CLW)\(^4\) that change abruptly during the cyclone occurrence. The BT over the cyclonic area goes high as roughness of the sea increases, which in itself is raised due to the presence of high winds. Even the increase in CLW over the cyclone produces an increase in BT. The large amount of droplets present in the clouds also causes heavy rain as well as re-emits which add in to the satellite radiometric BT.

In this paper, a case study has been performed and is presented as an example of the application of microwave sensor data available in this millennium that can help in early detection and tracking of the cyclonic activities.

Materials and Methods

Tropical Cyclone Phet brief description

In 2010, AS witnessed many cyclones. But, PHET was one of the strongest tropical cyclone ever recorded in the AS causing a breaking record rainfall in year 2010. The cyclone formed on 30th May 2010 in the middle of AS, moved along the south-western edge of subtropical ridge and it
further twisted to the northern AS. Finally, it struck the east coast of Oman on 4th June 2010. Track of tropical cyclone PHET over the AS is shown in Figure 1.

The cyclone PHET had the rarest of the rare track over the AS with two landfall points over Oman and Pakistan and longest track as well. As a result of such unique track, the system affected three countries, viz. Oman, Pakistan and India (Gujarat and Rajasthan). While there was loss of life and property in Oman due to both heavy rain and strong wind, the loss of life and property in Pakistan was mainly due to heavy rain and there was no significant adverse impact in India, though there was heavy rain over Gujarat and Rajasthan. According to Joint Typhoon Warning Center (JTWC), PHET had maximum sustained winds of 38 meter per second with minimum sea level pressure as 970 HPa was reported.

**Data Procurement and Analysis**

The main objective of this paper is to detect the tropical cyclone PHET. This cyclone produced record-breaking rainfall. Detection has been done using passive microwave sensor data. For this purpose, we used the SSM/I\textsuperscript{5} BT data at 19.35 GHz. In addition, we attempted to quantify this result by comparing the cyclonic days with the ordinary days as well as by observing the behavior of two areas on same day; one affected by cyclone and the other unaffected area.

SSM/I was flown over the Defense Meteorological Satellite Program (DMSP). The SSM/I operate at four frequencies: 19.35, 22.235, 37, and 85.5 GHz. With these channels it is possible to retrieve important geophysical parameters over the ocean: near-surface wind speed (m/s), columnar water vapor (mm), columnar cloud liquid water (mm) and rain rate as well. In table 1 the detailed specification of SSM/I are shown.

**Table 1: SSM/I Satellite Specification**

<table>
<thead>
<tr>
<th>Type</th>
<th>Polar Orbiter (~ 102 min/orbit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areal Coverage</td>
<td>Twice Daily (One ascending and one Descending orbit)</td>
</tr>
<tr>
<td>Sensor</td>
<td>Passive Microwave</td>
</tr>
<tr>
<td>Measurement</td>
<td>Brightness Temperature</td>
</tr>
<tr>
<td>Frequency Band</td>
<td>19(H,V), 22(V), 37(H,V), 85(H,V) GHz where H is Horizontal Polarization and V is vertical Polarization</td>
</tr>
<tr>
<td>Swath (Km)</td>
<td>1392</td>
</tr>
<tr>
<td>Cell Footprint (Km)</td>
<td>40</td>
</tr>
<tr>
<td>Wind Height (m)</td>
<td>20</td>
</tr>
<tr>
<td>Range of Wind Speeds (m/s)</td>
<td>3-25</td>
</tr>
</tbody>
</table>

The BT along with rain rate data of SSM/I has been procured and analyzed for month of May and June 2010 when cyclone PHET formed over AS. When cyclone occurs the wind speed of that area goes high and sustained high wind speed are also the indication of cyclonic condition. Here, to validate the behavior of SSM/I BT data over cyclonic area, the rain rate data is also acquired over the same location and found to be in good co-relation with BT. Figure 2(a)(c)(e) depicts the SSMI passes of BT at 19.35 GHz with the corresponding rain rate passes shown in figure 2(b)(d)(f). Only three days passes are shown in Figure 2, since only three day satellite passes coincides with the cyclone track during cyclone PHET time period.

Present methodology is based on the concept of data mining which is an approach of analyzing data from different perspectives and summarizing it into useful information - that corresponds to different stages of tropical storm. Our methodology is based
on the monitoring of the variation of microwave BT. The variation in the BT is observed and it is found that the BT increases during cyclone disturbance as compared to the non-cyclone area. This is also validated by the rain rate data.
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Brightness Temperature Analysis

Radiometric BT\(^6\) datasets from SSM/I have been used in the present work. The data is available online. SSM/I BT data at 19.35 GHz of May and June months have been examined. Data was taken from 24th May to 8th June 2010 in AS when the cyclone genesis started and ended. During this time period BT data assessment was done using two approaches. In first approach, the BT data over cyclone affected area before and after striking of the cyclone affected day was analyzed. By the analysis one finds exceptionally high BT values over cyclonic area when compared with the normal days.

Similarly in second approach same behavior was observed when two areas of same day were compared; one affected by cyclone and the other unaffected area. This analysis has been done for three days which we have got, also shown in figure 3. The differences in BT data obtained for the cyclonic area (Block 2) and non-cyclonic area (Block 1 & 3) have been discussed with details in result and discussion section and also plotted the graphs.

Rain Rate Analysis

Increment in BT data is observed over cyclone prone area. For rain rate analysis, data of SSM/I of same date and location as that done for BT analysis are acquired. We found its behavior same as that of the BT and helps in authenticating the same. The different passes shown in figure 2 (b)(d)(f) directly indicate the high rain rate at cyclonic area in AS when compared to other open ocean areas.

Result and Discussion

Tropical cyclone PHET was the second strongest tropical cyclone recorded in the AS in year 2010. For the detection of cyclone many researches have been carried out. Here, in this paper a different type of analysis and approach to detect cyclone has been discussed which is carried out using microwave radiometric system SSM/I. The different day’s data of SSMI have been procured and by analysis one can see that the cyclonic activity taking place (found exceptionally high values of BT and rain rate over cyclonic area) from 30th May 2010 to 1st June 2010 in AS. As seen by these passes the BT values over cyclonic area goes high as compared to those area where cyclonic activity is observed. This is observed in all three passes of SSM/I. This increment in BT could be due to the presence of rain clouds in the atmosphere and roughness of sea surface due to high winds. Rain cloud or even rain in fact absorbs and re-emit microwaves radiation which leads to BT increment. Hence one can validate the presence of cyclonic activity with the help of rain rate as one of the parameter. We found the soaring rain rate of more than 10 mm per hour (figure 2(b)(d)(f)) over the cyclone and approximately nil rain rate in nearby open ocean. Hence one can use these parameters obtained from passive microwave sensor onboard satellite for detecting the cyclone genesis.

For the detection of cyclone using first approach, in this data of before and after days of cyclone were compared and found an extraordinarily high BT values over the cyclonic area nearly an increase of 45K to 70K in horizontal polarization and 30K to 55K in vertical polarization when compared with the previous days. In this analysis, on 30th May 2010 when a low pressure area at 925 km toward the southwest of Mumbai, has been formed, one can see the values of BT are so high when compared with the previous days. Similar behavior is seen for the 31st May 2010 and 1st June 2010 when the cyclone moved along the south western periphery of the midlevel subtropical ridge and it further turned
toward the northern AS. Graphs of variation in BT with respect to number of days for all three passes of SSMI are shown in the figure 4, 5 and 6.

During analysis using second approach, the BT values over cyclonic area were found too high as compared to those areas where no cyclonic activity was taking place during the same pass. The differences have been observed around 60-70 K for horizontal polarization. This difference between $B_T$ in vertical polarization leads to a difference of 45-55 K which is still large enough. So, these large differences in $B_T$ may be due to cyclonic activity in AS. This type of analysis has been done for three days of cyclonic period during 30th May 2010 to 7th June 2010 and observed almost same difference on each day at different locations which are shown in graphs (figure 7, 8 and 9) for $B_T$ observed in horizontal as well as in vertical polarization. Similar analysis is done for rain rate data and found same behavior as that of BT. The figure 7, 8 and 9 depicts the behavior of BT as well as rain rate with respect to Latitude and longitude. One can see from the graphs that the rain rate reaches a high value of 12 mm/hr in cyclone affected area and found to be approximately ~ 0 in the areas that are not cyclone affected. Looking at the graphs one can clearly identify the cyclonic activity taking place in AS.
Fig. 7(a)(b)- SSM/I satellite brightness temperature (19.35GHz frequency channel) and rain rate variation with blocks (1 2 & 3) over cyclone and non cyclonic area of date 30 May 2010 horizontal and vertical polarization.

Fig. 8(a)(b)- SSM/I satellite brightness temperature (19.35GHz frequency channel) and rain rate variation with blocks (1 2 & 3) over cyclone and non cyclonic area of date 31 May 2010 horizontal and vertical polarization.
Fig. 9(a)(b)- SSM/I satellite brightness temperature (19.35GHz frequency channel) and rain rate variation with blocks (1 2 & 3) over cyclone and non cyclonic area of date 01 June 2010 horizontal and vertical polarization

Conclusion
One can say by the analysis that the passive microwave sensor measurements have the potential to detect the cyclones. In this paper we utilized this potential to develop a detection technique for cyclones. Increment in the BT value was found over the cyclonic area, by which one can detect the presence of cyclone. For better prediction one can verify the possibilities using the wind speed and significant wave heights data. Multifrequency analysis can also be used for this purpose. This paper opens new horizons for researchers who are involved in investigating the prediction and detection of tropical cyclones using microwave remote sensing.

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