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Rare Super Cyclone Phailin in the Indian Ocean: Analysis of VIIRS High-Resolution IR Images and 40 kHz Sferics Data

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Abstract VIIRS high-resolution infrared (IR) images of the rare super cyclone Phailin of the Northern Indian Ocean as well as 40 kHz sferics data as recorded over Kalyani have been analyzed in this paper with a view to investigate the characteristics of the super cyclone. The maximum IR brightness temperature in the eye of the cyclone was pretty warm and it was illuminated by airglow. The Phailin was one of the strongest cyclones with a peak estimated intensity of 140 kts. Our round-the-clock sferics data also reveals remarkable changes in the sferics record on October 10, 2013, when the super cyclone was active.

Keywords Super cyclone · Sferics · Infra red images · Tropical storm

1 Introduction

The rare super cyclone of the Northern Indian Ocean appeared on October 9, 2013 and grew into powerful form named as Phailin which finally made landfall in eastern India. NASA's Aqua and NASA/NOAA's Suomi-NPP satellites captured imagery of the storm

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on its approach to land[1,2,3] (Chen et al. 1993). With a view to investigate the characteristics of the rare super cyclone Phailin in the Indian Ocean, we have considered both VIIRS high-resolution IR images as well as 40 kHz sferics data as recorded over Kalyani (22.98°N, 88.46°E), West Bengal. The Indian Ocean experienced similar type of Super Cyclone since 2007 (Mühr et al. 2013).

2 Particulars of the Cyclonic Storm Phailin

Tropical depression identified as 02B was produced on October 9, 2013 from low pressure system 90 W about 537 nautical miles south of Chittagong of Bangladesh which is situated near 13.4°N and 92.8°E. The depression 02B soon strengthened into a tropical storm Phailin and moved to the west-northwest at 7 kts after its formation. The tropical cyclone so produced had maximum sustained winds near 40 kts (74.0 kph) shortly after its birth. On October 10 at 0720 UTC, the MODIS instrument aboard NASA's Aqua satellite captured a visible image of Phailin in the Bay of Bengal when it headed for landfall in west-central India (see footnote 1) (Hanley et al. 2001; Zaitseva 2006; Hart 2003). On October 11, it attained the peak speed with maximum sustained winds close to 140 kts (259 km h^{-1}) and, in fact, on the same date NASA/NOAA's Suomi NPP satellite passed almost directly over the cyclone. At that time, the VIIRS instrument aboard captured a high-resolution infrared image of the storm, indicating the storm's eye very prominently. As the said Suomi-NPP is a polar-orbiting satellite, VIIRS could only observe the cyclone twice a day. However, VIIRS produced infrared imagery at 375 m resolution. During the morning of October 12, 2013 the Phailin acquired the strength of a Category 4 hurricane, according to the Saffir–Simpson hurricane scale. On that day the Phailin's center was approaching the coast of the state of Odisha. An experience of strong storm surge was gathered which brought seawater into farms and fields causing coastal flooding and structural damage. Date, time, location and dominant features of the cyclone are presented in Table 1.

3 VIIRS High-Resolution IR Images

VIIRS being on a polar-orbiting satellite, it was impossible to get an image of the cyclone every 30 min and in fact, the VIIRS only views a cyclone like Phailin twice per day. But, it has some added advantage due to its higher resolution as it can produce infrared (IR) imagery at 375 m resolution.

Figure 1 exhibits images as obtained from high resolution IR band. Figure 1a is an IR image of Phailin taken at 20:04 UTC on October 10, 2013. VIIRS is a scanning radiometer that scans a swath that is ~3,040 km wide and this is, in fact, wide enough to prevent data gaps near the equator. The coldest cloud tops are found in the rain band to the west of the eye wall appearing as purple color and are temperature of −94 °C. Also it is observed that

[1] "All India Weather Summary October 8, 2013". India Meteorological Department. October 8, 2013. Archived from the original on October 13, 2013.

[2] Joint Typhoon Warning Center (October 5, 2013). "Significant Tropical Weather Outlook for the Western and South Pacific Ocean October 5, 2013 13z". United States Navy, United States Air Force. Archived from the original on October 6, 2013.

[3] Joint Typhoon Warning Center (October 12, 2013). "Tropical Cyclone 02B (Phailin) Warning 15 October 12, 2013 15z". United States Navy, United States Air Force. Archived from the original on October 12, 2013.

Table 1 Date, time, location and dominant features of the cyclone (http://www.cedim.de/download/CEDIM-Phailin_Report1.pdf)

Date and time	Location and dominant features
10.10.2013: 08:30 IST	Cyclonic storm, Phailin over east central Bay of Bengal moved westwards and intensified into a severe cyclonic storm which laid centered at about lat. 14.5°N and long. 91.0°E
11.10.2013: 08:30 IST	It moved west-northwestwards, laid cantered over east central Bay of Bengal at about lat. 16.0°N and long. 88.5°E
12.10.2013: 08:30 IST	It moved west-northwestwards and further intensified into a very severe cyclonic storm which then laid centered over west central and adjoining northwest Bay of Bengal at about lat. 17.8°N and long. 86.0°E
12.10.2013: 20:30 to 21:30 IST	It moved north-northwestwards and crossed the coast near Gopalpur of the state of Odisha
13.10.2013: 08:30 IST	It further moved north-northwestwards and laid centered over Odisha at about lat. 21.0°N and long. 84.0°E which is approximately 50 km south of Sambalpur
13.10.2013: 14:30 IST	It further moved north-northwestwards and then weakened into a cyclonic storm, centered over Odisha at about lat. 21.8°N and long. 83.8°E, close to southwest of Jharsuguda
14.10.2013: 08:30 IST	The deep depression then moved north-northeastwards, weakened into a depression and laid centered near southwest of Daltonganj of Jharkhand
14.10.2013: 14:30 IST	It weakened further and laid over southwest Bihar and neighborhood as low pressure area
15.10.2013: 05:30 IST	It weakened further into low pressure area over southwest Bihar

the brightness temperature gradient on the west side of the eye is much sharper than on the east side of the eye mainly due to the location of the satellite which is west of eye looking down on the storm at an angle and thus showing primarily about the side of the eye wall on the east side. In Fig. 1b we have shown how the super cyclone Phailin was appeared in the high-resolution IR channel on the next night at 19:45 UTC when it attained its maximum intensity. In this situation, the cyclone was much closer to nadir as the nadir line passes through the center of the image. In the image we are nearly looking straight down into the eye on this orbit. The corresponding day/night band image taken at 19:45 UTC is presented in Fig. 1c. From the analysis it was noted that the day/night band also captured the power outages caused by Phailin. In Fig. 1d we have made a side-by-side comparison of day/night band images along the coast of the state of Odisha, which took a direct hit from the cyclone—a zoomed in and labeled version of the October 10 image i.e. 2 days before landfall (shown at left side) against a similar image from October 14, 2013 i.e. 2 days after landfall (shown at right side).

In Fig. 2a we have shown another visible image of tropical cyclone Phailin. This photograph was taken by NASA's Aqua satellite at 07:20 UTC on October 10, 2013 when the storm was in the Bay of Bengal while Fig. 2b exhibits another very high-resolution infrared image of Phailin, taken on October 11 at 19:43 UTC. The VIIRS instrument from NASA/NOAA's Suomi NPP satellite was able to capture this image. VIIRS is, in fact, identifying wave features in the eye wall which is impossible to detect by other current IR sensors.

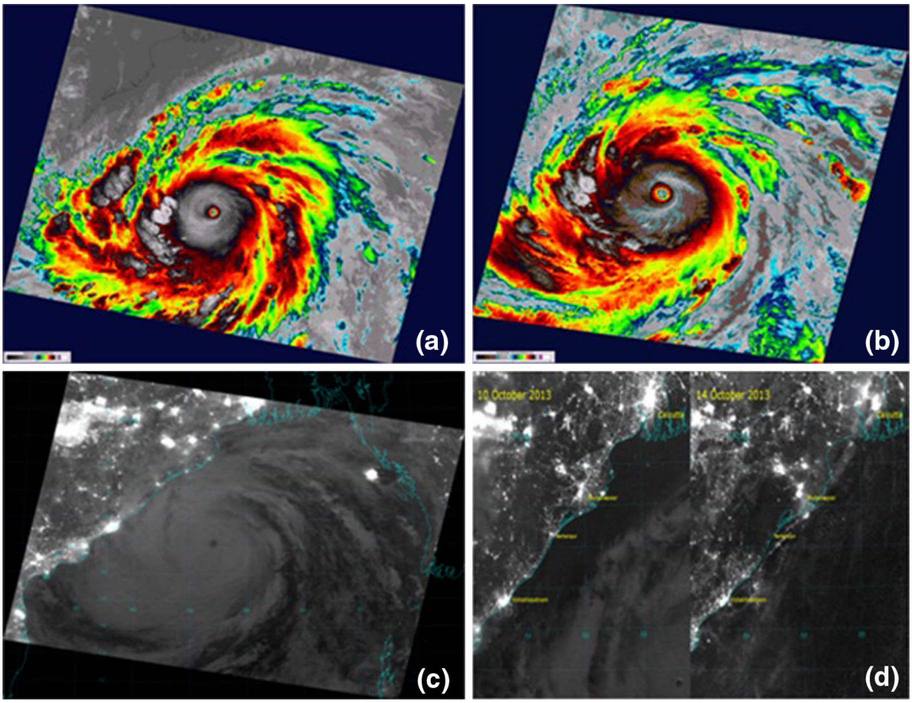

Fig. 1 **a** VIIRS high-resolution IR image of Phailin, as obtained on October 10, 2013, **b** VIIRS high-resolution IR image of Phailin, as obtained on October 11, 2013, **c** VIIRS day/night band image of super cyclone Phailin, taken on October 11, 2013, **d** VIIRS day/night band images before and after landfall of Phailin along the east coast of India (http://rammb.cira.colostate.edu/)

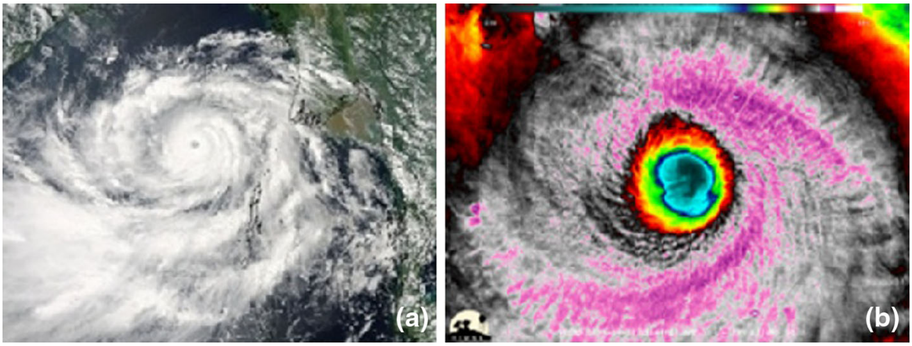

Fig. 2 **a** A visible image of Phailin taken by NASA's Aqua satellite on October 10 when the storm was in the Bay of Bengal (Image Credit: NASA MODIS Rapid Response Team), **b** Another high-resolution infrared image of Phailin (Image Credit: UWM/William Straka III/NASA/NOAA)

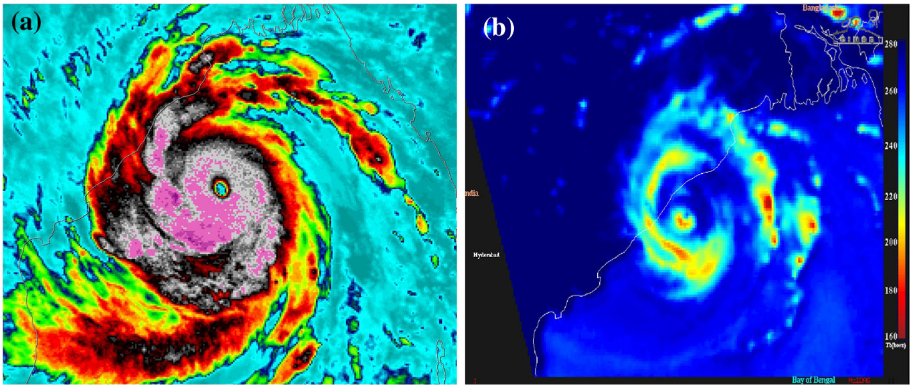

Fig. 3 **a** Images of EUMETSAT Meteosat-7 11.5 μm IR channel data showing very cold cloud tops exhibited by Phailin, **b** DMSP SSMI/S 85 GHz microwave data indicating that the Phailin was undergoing an eye wall replacement cycle prior to landfall (https://cimss.ssec.wisc.edu/goes/blog/archives/14100)

With a view to make a better comparison, geostationary satellite observations have been taken into account during the dates of peak activity of the Phailin. Figure 3a revels images of EUMETSAT Meteosat-7 11.5 μm IR channel data, showing the expansive area of very cold cloud tops exhibited by Phailin, with IR brightness temperatures in the range of −80 to −90°C (violet to darker purple color enhancement). Figure 3b, on the other hand, shows DMSP SSMI/S 85 GHz microwave data suggesting that Phailin was undergoing an eye wall replacement cycle prior to landfall, indicating a likely accounts for its drop in intensity to a Category 4 storm. It was available at 15 UTC on October 12, 2013 (https://cimss.ssec.wisc.edu/goes/blog/archives/14100).

4 Super Cyclonic Storm VIS-À-VIS 40 kHz Sferics

In our laboratory at Kalyani (22.98°N, 88.46°E), West Bengal, we are operating round-the-clock sferics instrument at 40 kHz imported from RAS (Radio Astronomical Supplies,

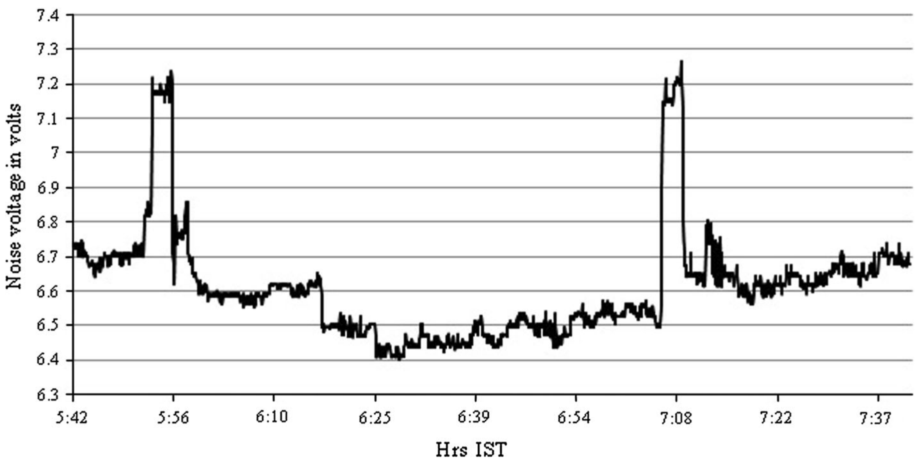

Fig. 4 Variation of 40 kHz sferics recorded on October 9, 2013 when the tropical depression developed into a cyclonic storm

USA). The records of the instrument noted very interesting variations in the level during the whole journey of the Phailin. Figure 4 reveals the variation of 40 kHz sferics recorded on October 9, 2013 when the tropical depression developed into a cyclonic storm. When the variation of sferics level is examined, it appears that there is a random fluctuation of the noise voltage in between 6.4 and 7.3 V with occasional sudden enhancement and rapid fall. This nature of constant fluctuation in the signal level seems to be associated with the random changes of the electrical properties of the associated cyclone. In the record we have demonstrated the pattern formed in the sferics level for a period of 2 h only.

In our round-the-clock record a similar pattern of rapid fluctuation with very occasional sudden enhancement was noticed almost throughout. Sferics recorded at 40 kHz on October 10, 2013 when the cyclone converted to Phailin as a severe cyclonic storm in a more intensified form is shown in Fig. 5a partly. In Fig. 5b, on the other hand, we have reproduced a typical pattern of 40 kHz sferics record obtained on a locally undisturbed day, as reported by India meteorological Department and also visually observed from the observatory, for better understanding and comparison to the characteristic variation as found during the Phailin. It has been reported earlier that during severe pre monsoon thunderstorms the sferics activity exhibits gradual rise, sudden enhancement and steady fall in the level which are assumed to be associated with the developing, mature and dissipating stages of the accompanying thunderstorms (Sarkar et al. 1980). The intense swash exhibited between 9.07 and 9.36 h (IST) in Fig. 5a is definitely striking feature suggesting that the vigorous but irregular charge activities at such times are associated for sferics formation at those higher levels. Analyzing our round-the-clock sferics data we have noted significant differences in the sferics record on October 10, 2013, when the super cyclone was active, showing higher noise voltage level varying from around 7–9 V in comparison to that on October 1, 2013, during a locally clear day, when the voltage level at local daytime comes down even below 7 V. However, it will be highly interesting to make a thorough study of this phenomenon during the course of future similar disturbances.

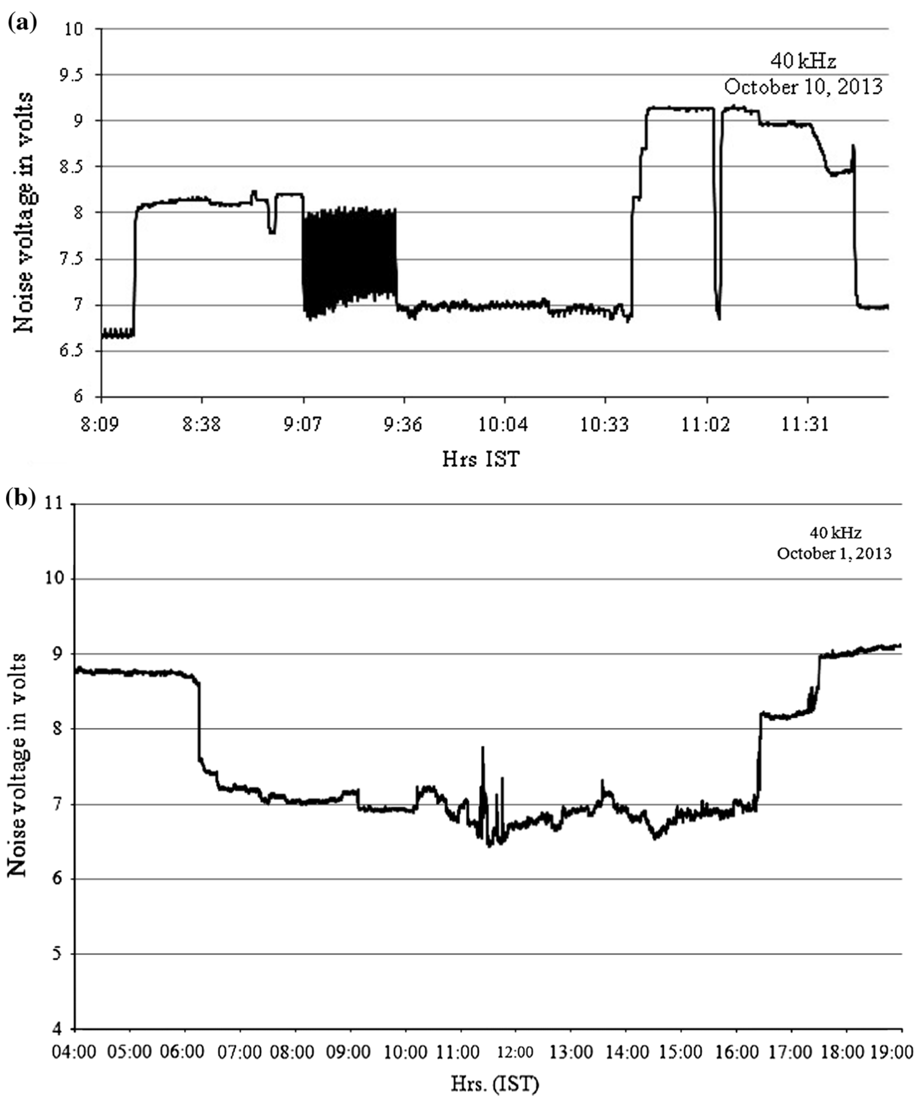

Fig. 5 **a** A part of sferics record at 40 kHz as recorded on October 10, 2013. **b** Typical record of sferics recorded at 40 kHz during a locally undisturbed day

5 Discussion

It was noted that the maximum IR brightness temperature in the eye of the cyclone in the 20:04 UTC on October 10, 2013 image was 24.4 °C, which is pretty warm for a hurricane/cyclone/typhoon eye (see footnote 2) (Hanley et al. 2001; Mayr et al. 1985). In fact, it is rare for the observed IR brightness temperature inside the eye to exceed 25–26 °C. Of course, the upper limit becomes the sea surface temperature, which is hardly above 31–33 °C. The satellite's spatial resolution affects the observed brightness temperature, along with certain other factors (see footnote 3) (Chen et al. 1993; Yassine 2010). It has been seen that a warm eye is related to a lack of clouds in or covering up the eye. A warm eye is related to a lack of clouds covering up, the satellite having high enough spatial resolution for identifying pixels that does not contain cloud and the underlying sea surface temperature. Powerful, slow moving storms may churn the waters sufficiently for mixing cooler water from the thermocline up into the surface layer and thus reducing the sea surface temperature. The sea surface temperature may also be lowered by heavy rains and cloud cover from the storm. In general, the Phailin was over 28–29 °C water and was apparently moving fast enough i.e. the warm water was deep enough to not mix too much cool water from below by a well known process called upwelling (Sen et al. 1982; Bhattacharya et al. 1998). The high resolution IR imagery VIIRS may able to break some records on warmest brightness temperature ever observed in a tropical cyclone eye. It may further be pointed out that there was lack of lights in and around the small city of Berhampur, an area where Phailin made landfall.

The cyclone was illuminated by airglow and some of the outer rain bands were also being lit up by city lights, which were visible through the clouds. With a peak intensity estimate at 140 kts (259 km h^{-1}) the Phailin was one of the strongest cyclones ever in the Indian Ocean.

6 Conclusions

In the paper the VIIRS High-Resolution IR Images and Meteosat records have been elaborately analyzed in course of the movement of the strong super cyclone besides the sferics record at 40 kHz. Under undisturbed condition of the atmosphere, sferics record exhibits a regular variation in the level showing higher values during nighttime and the level comes down during daytime. In our records the intense swash between 9.07 and 9.36 h (IST) and the associated variations in the sferics level, as obtained in Fig. 5a, is highly striking which appears to be linked with the concerned super cyclone Phailin. In fact, in our years together round-the-clock recorded data of sferics this is our first experience of recording such characteristic changes in the level. We believe that if similar observations can be done in course of future super cyclone and supplemented by other observational techniques valuable information may come out.

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