HYPER-TEMPORAL ACTIVE FOREST FIRE DETECTION USING INSAT-3D/3DR OVER INDIA

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ABSTRACT:
Forest fire spatial scale may range from small fires with very little impact to very large fires having serious large-scale impact on our environment. It is necessary to locate the active fire areas for managing the forest fire. Satellite remote sensing is very effective for detecting active forest fire events if we have a set of suitable channels with suitable spatial and temporal resolution. The polar orbiting satellites with active fire detection capability and high spatial resolution suffer from frequent revisit, however, with INSAT-3D/3DR in geostationary orbit with modest spatial resolution is capable of providing hyper-temporal data at every 15 minute. With the availability of MIR channel (3.9µm) in INSAT-3D/3DR, first time we have gained the capability for monitoring active forest fire in the country. The SAC developed fire detection algorithm employs multi-channel contextual technique, which includes multi-channel thresholds and comparison with the background pixels. This paper discusses about the algorithm and inter-satellite product validation of recent fire case studies. We compared MODIS and INSAT-3D/3DR based forest fire products over major forest fire outbreaks in Uttarakhand during April –May 2016, Mount Abu during April 2017 and Katra, Jammu during May 2017. The index of agreement obtained from inter-product comparison (INSAT-3D/3DR vs MODIS) shows that the science product of active forest fire is useful for monitoring progression of sufficiently large forest fire events.

1. INTRODUCTION

Forest fires are mostly caused by anthropogenic activities and it happens regularly during summer seasons in India. It is necessary to locate the active fire areas not only for managing the forest fire but also for a number of other studies related to environmental impacts. It is useful for planning, management and prevention of future fire hazards and helps in prediction of fires or making a fire risk analysis. Off late, the problem has become more serious as compared to past decades. Satellite remote sensing with its synoptic and temporal coverage with availability of suitable channels can augment the ground operations in terms of fire detection, monitoring, damage assessment and planning the mitigation in a time and cost efficient manner. Active fires can be monitored even at a very low spatial resolution due to substantial increase in MIR brightness of a fire pixel over its background (Robinson, 1991). Several international programs have been established towards the goal of gaining complete information on fire activity around the world using satellite sensors. These include the International Geosphere Biosphere Program Data and Information System (IGBP-DIS), Global fire Product initiative, the world fire web, the ATSR World Fire Atlas, the MODIS (Justice et al., 2006) and S-NPP/VIIRS fire products (Schroeder, 2015).

India's own INSAT-3D satellite launched on 26 July 2013 and INSAT-3DR launched on 8 September 2016, having six channel imager is also capable of detecting large forest fires due to presence of MIR channel (3.9µm) and TIR channel (10.8 µm) with hyper-temporal capability because of its position in geostationary orbit. Put together these two satellites are capable of giving us data every 15-minute interval. Therefore, this hyper-temporal resolution is expected to give us a handle on fire progression monitoring very effectively. The algorithm developed for identifying active forest fire (thermal anomaly) using INSAT-3D/3DR imager data has potential of forming India's own system of real time forest fire monitoring. The multi-channel contextual algorithm has been used for active forest fire detection. The improvement in parameter values through a sensitivity analysis has brought down the false fire alarms drastically. The recent forest fire events of 2016-2017 have been monitored successfully using INSAT-3D/3DR based active fire products.

2. PHYSICAL BASIS

In Space Applications Centre (SAC), the feasibility of detecting active forest fire events using satellite data has been explored and an algorithm has been developed for accurately detecting large active forest fire events using half hourly INSAT-3D and INSAT-3DR satellite data. The mid-infrared part of the spectrum produces a very strong signal in response to high temperatures and this makes it most suitable region for fire detection. This can be explained with the help of Wien's displacement law according to which the hotter a surface is, the peak of its Planck curve shifts to the shorter wavelengths and vice-versa (fig.1). With the help of the Wien's displacement formula (λmax = 2897/T; μm) it is possible to know the wavelength at which the radiation peaks, if the temperature of the blackbody is known. For example, when the temperature is 750K (fire condition) then on applying Wien's displacement law the maximum temperature would be along band 3.8 – 4.0μm. But, if the temperature is 300K (normal condition) the maximum temperature would be at a wavelength of 9.66μm. Most of the fire detection studies have used bands centred around 3.9μm and 10.8μm for detection of fire as these bands are selected in the regions of atmospheric window. The band centered at 3.9μm during the day receives reflected energy from the sun and the Earth's radiant energy; however, during the night it receives only the Earth's radiant energy. Therefore, this band responds differently to hotspots at day and night. As the band centered around 10.8μm receives only the earth's radiant energy during the day and night, it differs in hotspot response as compared to 3.9μm band (EUMETSAT & CGMS, 1999). Figure 2 depicts the response of sub-pixel fires in 3.9μm and 10.8μm bands. The temperature of band 3.9μm is 350K when the fire occupies 4 per cent of the pixel and remains substantially higher as the area of the hotspot in the pixel increases. Temperature of band 10.8μm is 35K lower than that at band 3.9μm for the same fraction of pixel covered by fire (EUMETSAT & CGMS, 1999). On the other hand, the band at 3.9μm has a strong thermal response even if only a small portion of the pixel is covered by fire and this characteristic is vital for fire detection. INSAT MIR Channel (3.8 to 4.0μm) is located near the spectral maximum for radiative emission for objects at temperature around 400-1200K. This is close to the temperature of forest fire. INSAT TIR-1 Channel (10.3μm – 11.3μm) is located near the spectral maxima for normal environment temperature i.e. around 300K (fig.1, table.1). Therefore, both these channels are employed for active fire identification.

Table 1: INSAT-3D Imager Specification.

Channel No	Wavelength (μm)	Resolution (Km)
1	0.55 - 0.75	1
2	1.55 - 1.70	1
3 (ch3, MIR)	3.8 - 4.0	4
4	6.5 - 7.1	8
5 (ch5, TIR-1)	10.3 - 11.3	4
6	11.5 - 12.5	4

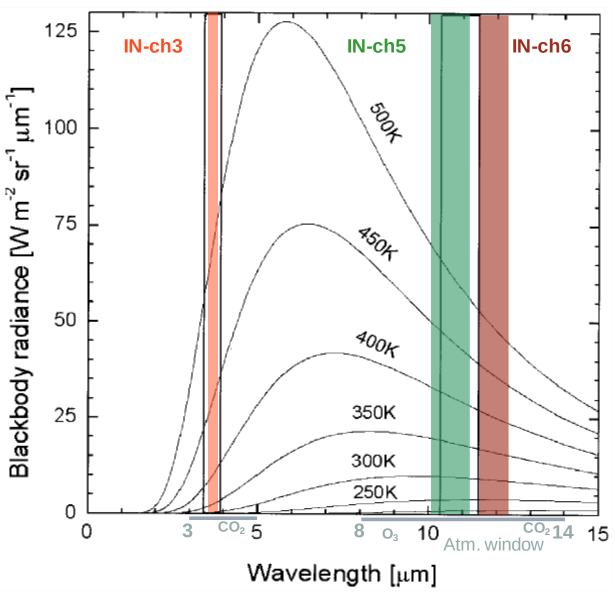

Figure 1: Spectral exitance distribution curve and location of INSAT-3D Channel 3, 5 and 6.

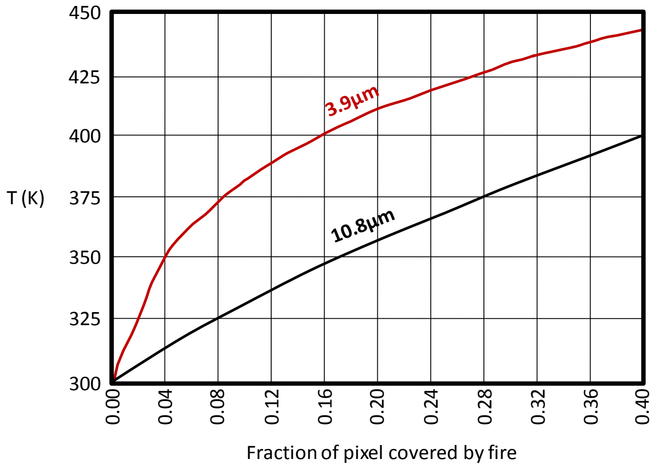

Figure 2: Response of 3.9 &10.8µm bands to fraction of pixel covered by fire.

The multi-thresholding contextual algorithm was first proposed by Giglio et. al., 2003, which works on channel specific thresholds. INSAT-3D/3DR imager based active fire detection works on multi-channel contextual algorithm with fine-tuned dynamic thresholds and improvised techniques developed at SAC. Apart from the threshold values there are kernel size (for background details) and σ 'sigma' (SD) value which needs to be adjusted in order to do fire detection. To arrive at the optimal parameter values, a sensitivity analysis was carried out and it was found that 9x9 kernel size with 2 sigma value is optimal setting which subside most of the false fire detects without compromising on the probable actual fires (Singh & Gujrati, 2015).

3. ALGORITHM SPECIFICATIONS

The fire detection algorithm employs multi-channel contextual technique, which includes multi-channel thresholds, and compares with the background pixels (a kernel used). An initial threshold test reduces the number of candidate pixels. The improved current version of the algorithm uses dynamic threshold for every acquisition using solar zenith angle. The second test computes the mean and standard deviation of the threshold variables from non-potential fire pixels surrounding a potential fire pixel. After obtaining these statistics, contextual test is performed to confirm a fire. At first, all static masks (land/sea, non-forest, cloud, sun-glint) are applied. However, cloud mask is a dynamic mask which is used from another data product generated for each acquisition. The sun-glint masking is another dynamic mask which is implemented as part of the fire algorithm through computation of principal point of sun-glint, PPS (Prakash *et al.*, 1994) as:

$$a_{sat} - a_{sun} = 0 \qquad (1)$$

$$| A_{sat} - A_{sun} | = \pi \qquad (2)$$

where, a_{sat} , a_{sun} = Elevation of satellite, sun
A_{sat} , A_{sun} = Azimuth of satellite, sun
A sun-glint mask is drawn for a circle of diameter 700km (Prakash *et al.*, 1994) from the PPS. After this, the pixel is flagged as potential fire if channel $T_3 > 300 + 15 * cos$ (sun zenith) and $T_5 > 290 + 5 * cos$ (sun zenith). Where, T_3 is Brightness Temperature (BT) of Channel 3 and T_5 is BT of Channel 5. Then, the pixels with difference of the BT of T_3 and T_5 is taken out if its greater than a predefined threshold value (7 K) for further test. Now, if the BT of T_3 and difference of T_3 and T_5 departs substantially for the remaining candidate pixels from the non-fire background pixels (contextual test) as given below:

$$if \quad T_3 > \mu_3 + 2 * \sigma_3; \qquad (3)$$

$$T_{3\text{-}5} > \mu_{3\text{-}5} + 2 * \sigma_{3\text{-}5} \qquad (4)$$

Where, μ = Mean, σ = SD of the kernel (9 x 9 - pixel window), then the output is generated as binary active fire map with Fire flag: 1 - Fire pixels, 0 - Non-fire pixels. The product is generated as KML file for each acquisition.

4. RESULTS AND DISCUSSIONS

The INSAT-3D fire product was tested for a large fire which broke out in hills of Uttarakhand. MODIS (Terra/Aqua) detected 2123 fire events which was about 3 times higher than the fire events detected (752) by INSAT-3D imager (fig.3 & 4). This is mainly because MODIS has higher spatial resolution (1x1km) as compared to 4x4km of INSAT-3D and a dedicated narrow channel (3.929 – 3.989µm) centred around 3.96 µm for fire detection with better NEdT (0.2K for MODIS and 0.5K for INSAT-3D @typical scene temperature). Moreover, the sensitivity of MODIS is 0.01 ha (*i.e.* 100 m^2) at 800 – 1000K of fire temperature (with 50% probability). In comparison to this, INSAT-3D can only detect large fires of 0.2 ha (i.e. 2000 m^2) at similar fire temperature. Despite having only four overpasses (Aqua/Terra) MODIS could detect more number of forest fire pixels. However, INSAT-3D due to its better temporal resolution (30 min) could detect certain forest fire events which MODIS could not detect.

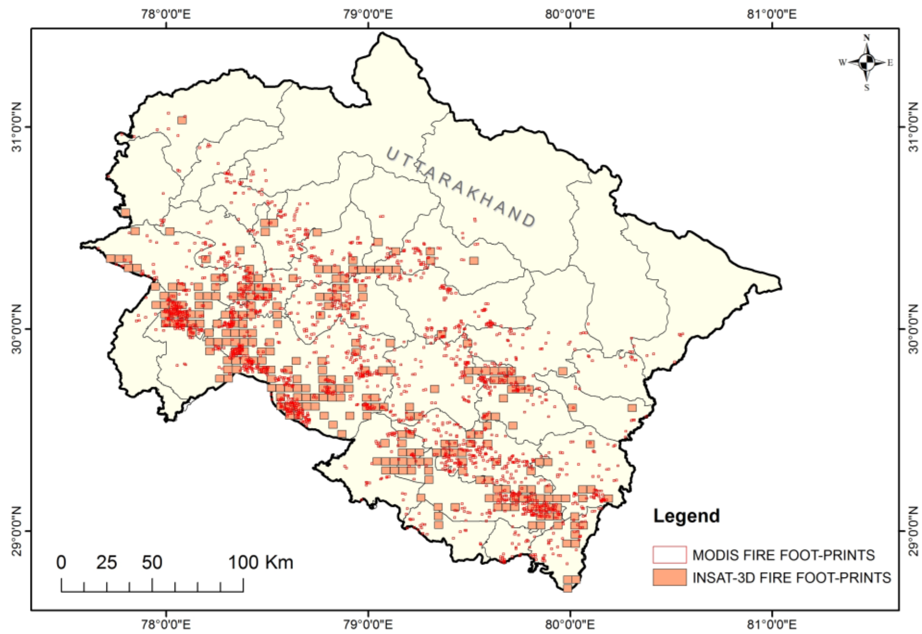

Figure 3: Map of fire foot-prints co-location: INSAT-3D Vs MODIS (21 April to 5 May, 2016).

Nonetheless, a very good matching of the fire frequency trend and spatial location was observed between MODIS and INSAT-3D (87%) with the criterion of adjacency. This criterion addressed the spatial anomaly of pixel centre given as fire in both the products as well as the error in pixel co-location. Moreover, 43% fire events of MODIS were falling exactly within the foot-prints of INSAT-3D fire. The remaining extra points in INSAT-3D are mainly because of its hyper-temporal resolution. Another temporal analysis revealed that only 20% fire events (149 out of 752) were detected once and rest 80% fire events were detected by INSAT-3D in subsequent passes too (detection ranging from 2 to 27 times). However, similar analysis of MODIS based fire revealed that only 3 fire events were detected twice.

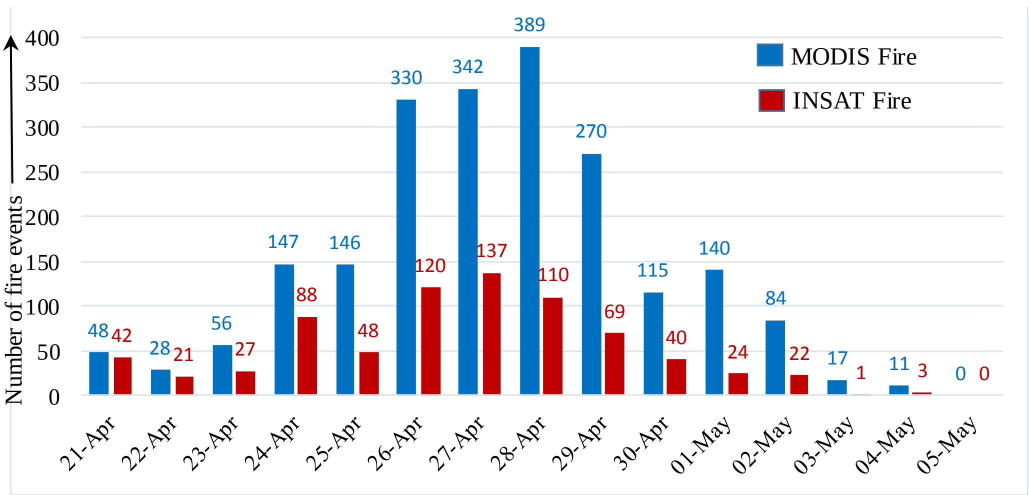

Figure 4: Bar graph showing MODIS Vs INSAT-3D daily forest fire counts.

Post launch INSAT-3DR was tested over a forest fire event which took place in Mount Abu on 14th April, 2017 (fig.5). However, fire of small sizes scattered over the hill were reported by media which were undetected due to coarse resolution (4x4km). Interestingly, MODIS could not detect any fire but Visible Infrared Imaging Radiometer Suite (VIIRS) could detect more fires around fire points detected by INSAT-3D and 3DR.

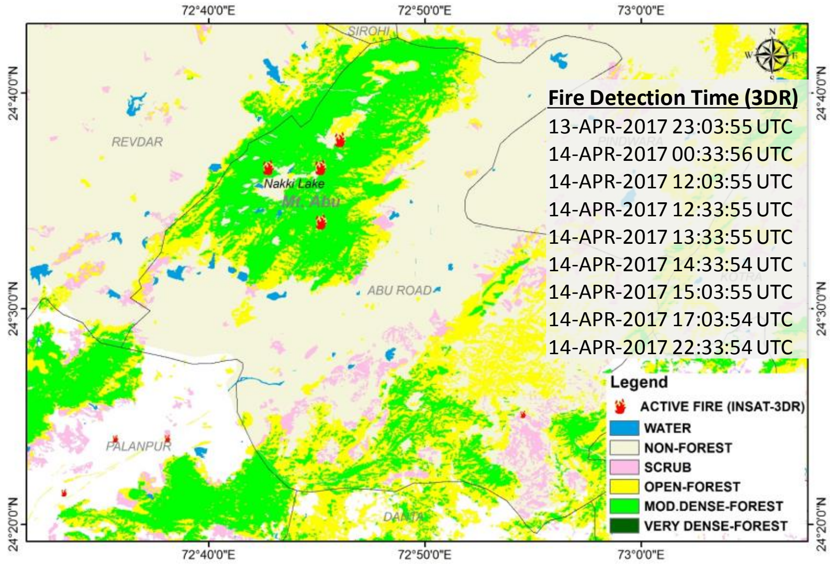

Figure 5: Map showing active fire detected by INSAT-3DR in Mount Abu, Rajasthan.

Subsequently, another forest fire broke in the Trikuta Hills (J&K), Near Vaishno Devi, Katra which was captured by fire product from INSAT-3D & 3DR (fig.6) and it also has very good match with MODIS and VIIRS products.

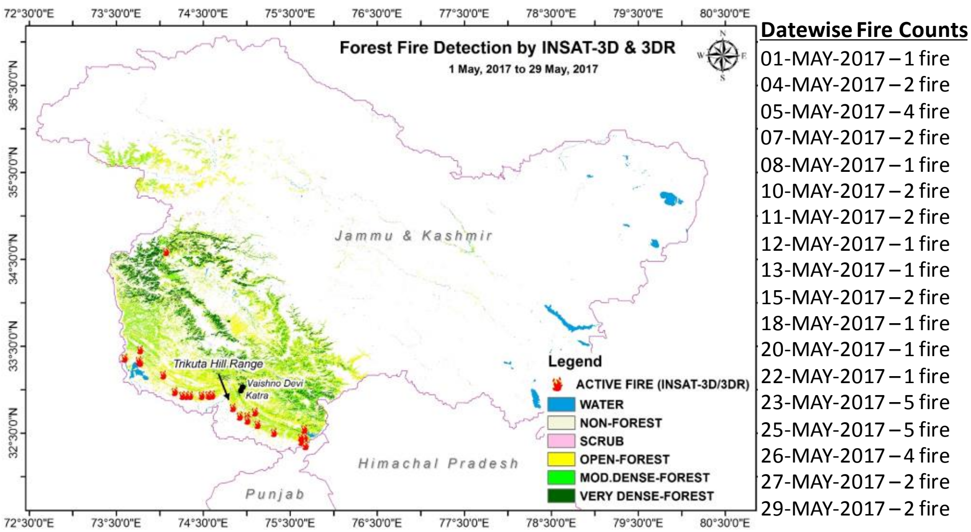

Figure 6: Map showing active fire detected by INSAT-3D and 3DR in Jammu.

5. CONCLUSION

The results are encouraging as the number of false fire pixels have been controlled with the new algorithm implementation. Some of the small fires as picked up by MODIS are not being detected by INSAT-3D due to its coarser spatial resolution. However, INSAT-3D/3DR is found suitable for monitoring large forest fire events due to its better temporal resolution. Therefore, INSAT-3D/3DR is very much suitable for monitoring the progression of sufficiently large forest fires.

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