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Assessment of hailstorm damage in wheat crop using remote sensing

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Heavy rainfall and hailstorm events occurred in major wheat-growing areas of India during February and March 2015 causing large-scale damages to the crop. An attempt was made to assess the impact of hailstorms in the states of Punjab, Haryana, Uttar Pradesh (UP), Rajasthan and Madhya Pradesh (MP) using remote sensing data. Multi-year remote sensing data from Resourcesat 2 AWiFS was used for the purpose. Wheat crop map, generated by the operational FASAL project, was used in the study. Normalized difference vegetation index (NDVI) deviation images were generated from the NDVI images of a similar period in 2014 and 2015. This was combined with the gridded data of cumulative rainfall during the period. The logical modelling approach was used for damage classification into normal, mild, moderate and severe. It was found that the northern and southern districts in Haryana were severely affected due to rainfall/hailstorm. Eastern Rajasthan and western MP were also highly affected. Western UP was mildly affected. Crop cutting experiments (CCE) were carried out in two districts of MP. The CCE data showed that the affected fields had 7% lower yield than the unaffected fields. Empirical yield model was developed between wheat yield and NDVI using CCE data. This model was used to compute the loss in state-level wheat production. This showed that there was a reduction of 8.4% in national wheat production. The production loss estimated through this method matched with the Government estimates.

Keywords: Crop cutting experiments, hailstorm, rainfall, remote sensing, wheat.

HAIL is a solid, frozen form of precipitation that causes extensive damage to properties and growing crops[1]. Hence an accurate method for monitoring and quantifying hailstorm/heavy rainfall damage to crops can be of assistance in the decision-making processes for agriculture insurance agencies and policy planners. However, current practices of hailstorm damage detection and its assessment have limitations, especially on a large spatial scale. The traditional method for damage assessment needs labour-intensive field surveys which are time-consuming with high cost. The use of remote sensing can provide alternative techniques for the assessment of damaged crop area. With the advantages of a wide swath, short repetition cycle, multiple sources and multiple resolutions[2], remote sensing imageries have widely been used in assessing hail damage.

An early example of hail damage detection from satellite remote sensing was the use of visible band of the GOES-8 to identify surface damage along a 120 km path of 'almost complete vegetative defoliation and destruction' in western South Dakota, USA that was caused by large hail (>5 cm) and severe winds (>50 m s^{-1}), including complete devastation of range grasses, planted crops and extensive defoliation of trees[3]. Later, remote sensing-based normalized difference vegetation index (NDVI) was used in hailstorm and wind damage assessment[4–6]. In a study by Bentley *et al.*[5], a hailstorm-damaged vegetation had significantly lower NDVI values as the crop was completely destroyed, whereas wind damaged vegetation had relatively minor differences in NDVI values due to only temporary disruptions in photosynthesis. Potential of infrared (IR) colour and standard colour aerial photographs was evaluated to measure the crop–hail losses[7]. Landsat TM data were used to map the hailstorm-damaged

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*For correspondence. (e-mail: shibendu.ncfc@nic.in) areas for an operational salvage harvest in just over two weeks[8]. MODIS NDVI time-series images were used to assess the hailstorm impact on crops[9].

During the last few years, Indian agriculture has faced many natural calamities like cyclone, drought[10], pest/disease attack[11], unseasonal heavy rainfall and hail damage, which have caused severe loss to the economy. As a meteorological disaster, hailstorms caused by abnormal weather change have led to severe loss of crops and infrastructure. In March 2014, Madhya Pradesh (MP) and Maharashtra were severely affected due to hailstorms and farmers faced significant economic losses[1]. In February–March 2015, northern and central India were the most affected regions due to hailstorms. Major wheat-growing areas like Punjab, Haryana, MP, Rajasthan and Uttar Pradesh (UP) experienced severe losses to wheat and other crops[12].

The objective of this study was to assess the utility of satellite imagery for hailstorm/heavy rainfall damage assessment in crops and to develop techniques to differentiate between damaged and unaffected crops.

The study was carried out for hailstorm/heavy rainfall affected areas during February–March 2015. Analysis was carried out for the major wheat-growing states like Haryana, MP, Rajasthan and UP. Punjab could not be included in the study due to unavailability of cloud-free data.

Multi-date IRS-P6 AWiFS (56 m resolution, 740 km swath, five-day revisit and four bands) data were used in the study. The data of similar period in two years (2014 and 2015) were used for comparison of crop conditions. The dates of data used were 16, 17 and 22 March of 2014, and 17 March and 21 March of 2015.

Radiance was computed from digital numbers of the AWiFS images using the scale factors available in the metafile. NDVI was computed from radiance values according to the equation

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}, \qquad (1)$$

where NIR is the radiance in near infrared band and RED is the radiance in red band.

A percentage difference index (PDI), which accounts for the change in remote sensing index, was computed using data of similar period in 2014 and 2015. The year 2014 was a normal one for crop condition. Hence, a positive change (higher NDVI in 2015 than in 2014) indicates better crops, while high negative change may be caused by some stress, either abiotic or biotic.

$$\mathrm{PDI} = \frac{\mathrm{NDVI}_j - \mathrm{NDVI}_i}{\mathrm{NDVI}_i}, \qquad (2)$$

where NDVI_i is the NDVI value of a particular date in 2014 and NDVI_j is the NDVI value of a similar date in 2015.

Wheat cropped area map prepared under the FASAL (forecasting agricultural outputs using space, agrometeorology and land-based observations) project[13] was used in the study and a mask of wheat pixels was generated for the study area. For the wheat pixels, PDI of NDVI was generated between the corresponding NDVI images of 2014 and 2015. The PDI image of NDVI was categorized into two classes; PDI value below –10% was considered as a probable affected area and above –10% as an unaffected area. These thresholds were decided based on ground truth information of the affected area.

The affected pixels under each district were computed and the districts were classified into four categories: ≤5% affected pixels; 5–20% affected pixels; 20–40% affected pixels and >40% affected pixels.

Additionally, gridded rainfall data were downloaded for the period 25 February 2015–20 March 2015 from the website of India Meteorological Department (IMD). Cumulative rainfall map was prepared and rainfall was categorized into four categories: ≤ 30 mm; 30–50 mm; 50–100 mm, and >100 mm.

Based on the district-level NDVI-based affected area and cumulative rainfall, a logical modelling approach was used for categorizing the damage, i.e. normal, mild, moderate and severe (Figure 1). District-wise percentage damage area map was also prepared.

In order to verify the analysis, the ground truth was carried out in five states, i.e. Punjab, Haryana, Rajasthan, UP and MP. Field photographs were collected during the survey which showed the damaged wheat crops (Figure 2). For the quantitative estimation of final yield and the hailstorm effect, crop cutting experiments (CCEs) were carried out at sample locations, in collaboration with State Agriculture Departments. Empirical yield model was developed between wheat yield and NDVI using

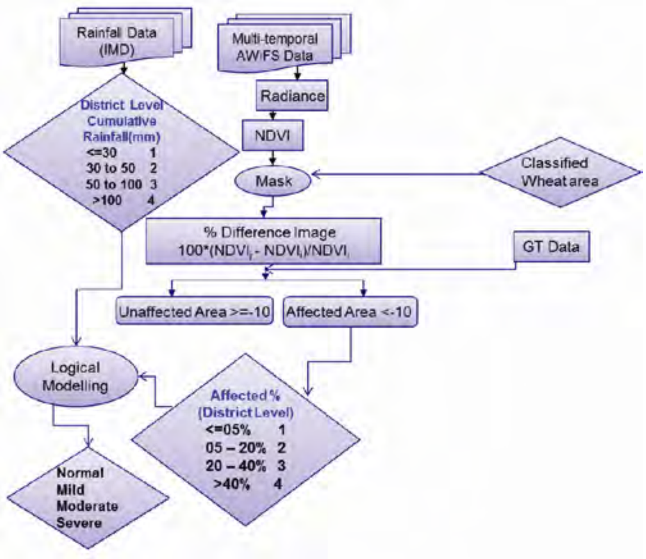

Figure 1. Flow chart of methodology.

CCE data. The yield model was used to compute loss in state-level wheat production.

The first objective of the analysis was to determine whether the hail damage effect in the wheat crop or agricultural area could be detected and mapped using remote sensing. Visual observation of the satellite data clearly shows hailstorm/heavy rainfall damaged crop (Figure 3 *b*), compared to normal crop of the previous year (Figure 3 *a*). Through the visual interpretation of satellite data, it is evident that there are spectral differences between crops that are hail-damaged and those are unaffected by hailstorm/heavy rainfall. The changes that occur after hailing can be explained by the amount of plant foliage that was destroyed. The greater the amount of foliage damage, the closer the spectral response curve migrates toward that of bare soil[14].

Figure 4 shows the radiance value of different sites, including affected and unaffected crops. Radiance value of healthy and affected crops showed large difference in the green spectral band. There was also a significant difference in crop in the red band. This difference in the red band could be due to loss/damage of chlorophyll pigment as the plant dies in case of heavy hailstorm damage and dry plant stubble remains in the field. The differences we found in the red band were similar to those of an earlier study[14].

There was slight difference in radiance value in green and red spectral bands of healthy wheat crops of 2014 and 2015. Thus, it showed that the crops which were unaffected had very low spectral difference between the two years, whereas the affected crops had high differences between the years. The radiance values in NIR and SWIR region showed low differences between affected and healthy crops. Affected crops showed lower NIR values compared to healthy crops, which may be attributed to damage of leaf structure and loss in foliage density. Affected crops had slightly higher radiance value in SWIR band compared to healthy crops. This may be due to drying of crops due to hailstorm effect.

Cumulative rainfall analysis showed that the Northern part of India, especially Himachal Pradesh, and Jammu & Kashmir received the highest rainfall during 25 February 2015–20 March 2015 (Figure 5). Northern and western Haryana received 25–100 mm rainfall. Eastern Rajasthan and northern MP received 100–150 mm rainfall, i.e. very

Mewat district, Haryana

Barabanki district, Uttar Pradesh

Figure 2. Field photographs of damaged crops.

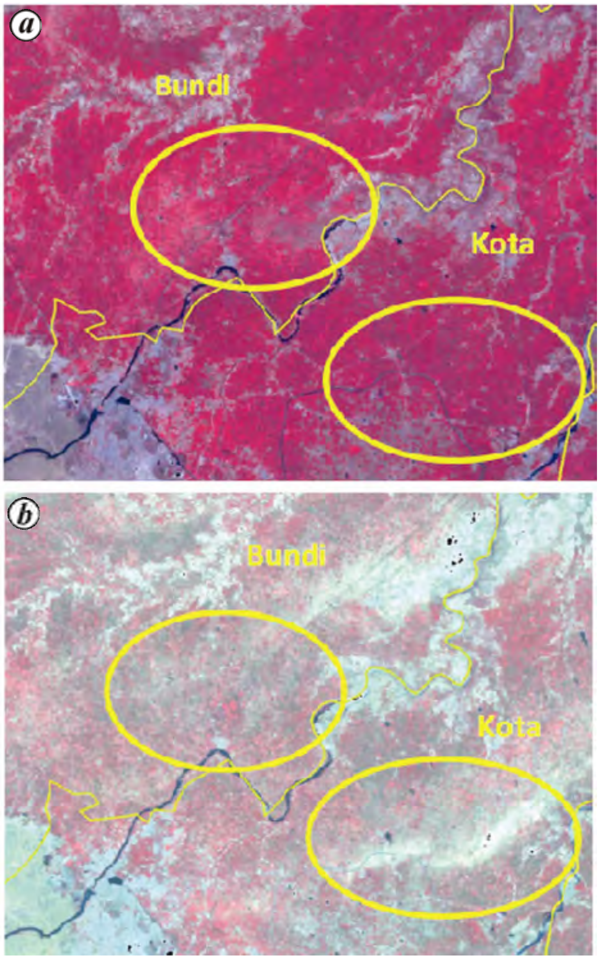

Figure 3. ***a***, Crop condition (healthy) in Kota district, Rajasthan and surrounding areas (16 March 2014). ***b***, Crop condition (affected) in Kota and surrounding areas (21 March 2015).

heavy rainfall during 25 February–20 March. Eastern UP received 5–50 mm, low rainfall compared to MP, except in a few patches which received heavy rainfall.

Combining the rainfall data and NDVI deviation data, the districts of the affected states were classified into mild, moderate, severely affected areas (Figure 6). Seventeen districts in Rajasthan (Ajmer, Alwar, Banswara, Baran, Bharatpur, Bhilwara, Bundi, Chittaurgarh, Jaipur, Jhalawar, Jhunjhunun, Kota, Sikar, Tonk, Dausa, Karauli and Sawai Madhopur), 11 districts in Haryana (Faridabad, Gurgaon, Jhajjar, Karnal, Mewat, Palwal, Panipat, Rewari, Rohtak, Sonipat and Yamunanagar), 12 districts in MP (Ashoknagar, Dhar, Guna, Indore, Jhabua, Mandsaur, Neemuch, Ratlam, Sheopur, Shivpuri, Ujjain and Gwalior) and 2 districts in UP (Banda and Baghpat) were found to be severely affected by the hailstorm/heavy rainfall. Thus majority of the severely affected districts were found in Haryana, Rajasthan and MP.

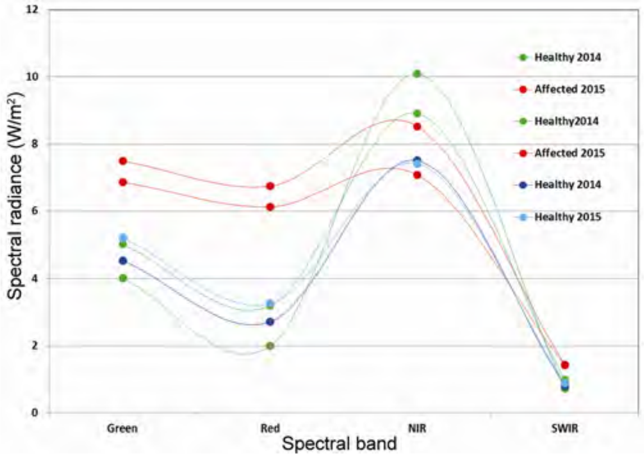

Figure 4. Spectral profile of healthy and affected wheat crops.

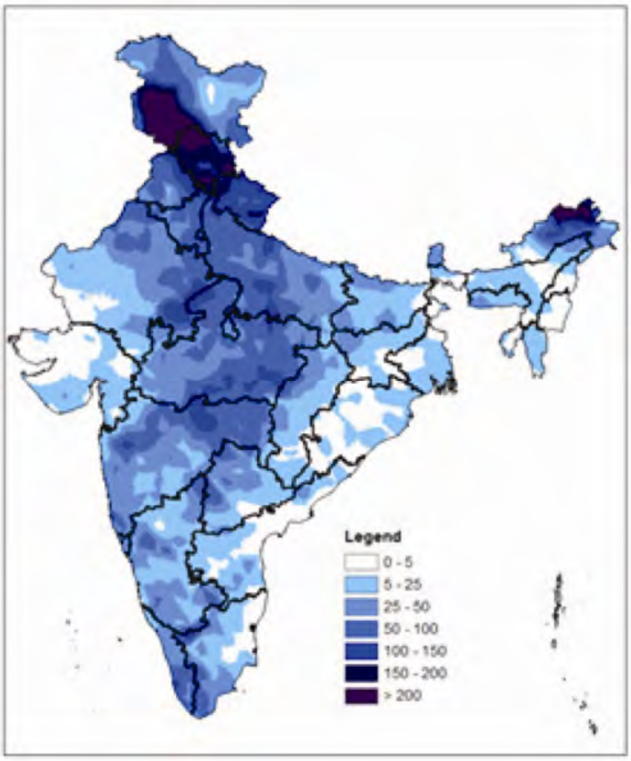

Figure 5. Cumulative rainfall during 25 February 2015 to 20 March 2015.

CCEs for wheat crop were carried out at 49 sites in 2 districts of MP, i.e. Betul and Hoshangabad. These sites were selected based on stratified random sampling where stratification was done using NDVI images of the pre-event period. Out of the 49 sites, 16 were found to be affected (at least to some extent) by hailstorm and heavy rainfall. The average yield of affected sites was found to be at least 7% lower than unaffected sites (Table 1).

Under the FASAL project, state and national production estimates were carried out using remote sensing data[13,15]. The yield estimates were derived by combining the estimates from (i) semi-physical remote sensing-based model[16]; (ii) correlation weighted agro-met model[17], and (iii) crop simulation model[18]. Additionally, analysis based on remote sensing and rainfall data was carried out to identify the extent of damage in various districts due to heavy rainfall and hailstorm. The yield was reduced in the affected districts based on a factor derived from remote sensing-based regression yield model between NDVI and CCE yield. The all-India wheat production estimate using remote sensing data, after incorporating the impact of heavy rainfall and hailstorm, showed a reduction of 8.4% (Table 2). The Government of India (GoI), in its final wheat estimate, had also shown a loss of 9.6% compared to its first estimate, when the impact of hailstorm had not been considered.

Hailstorms cause large-scale damage to properties, human life and also to agricultural crops. The combined effect of heavy rainfall and hailstorm during February and March of 2015 caused extensive damage to wheat crops of north and northwest India. This study explored

Table 1. Comparison of yield values of hailstorm-affected and with unaffected wheat crops

Crop type	No. of sites	Average yield (kg/ha)	Range (kg/ha)
Affected	16	2381	272–4614
Unaffected	33	2568	1054–4420

Table 2. All-India wheat production estimates for 2014–15

Estimate	Government	Remote sensing-based
Early estimate (without considering hailstorm effect; million tonnes (mt))	95.76	92.80
Final estimate (after incorporating impact of hailstorm; mt)	86.63	85.05
Reduction (%)	9.6	8.4

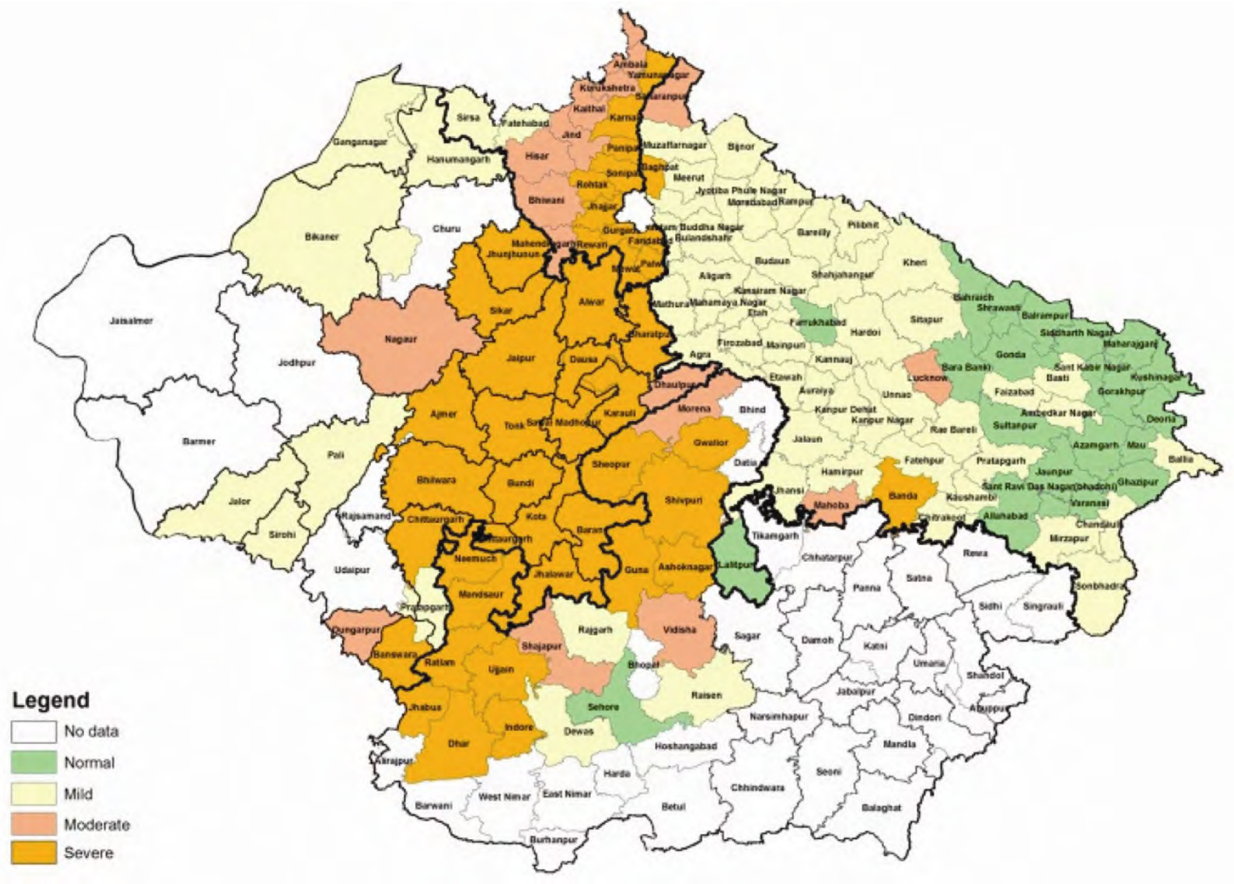

Figure 6. District-wise agricultural condition based on rainfall and percentage crop damage area.

the use of remote sensing data for crop damage assessment due to hailstorms. Additionally, we tried to derive an estimate of total production loss, based on an empirical model developed using remote sensing-based index.

The results indicate that remote sensing data could be used for analysing hail damage at least for moderate to severe cases. Low crop damage is difficult to assess due to non-significant changes in spectral response. The spectral radiance values in red band were found to be better in distinguishing the levels of damage for identification of moderate to severe hail damage. However, both red and NIR spectral regions did not provide a graded consistency between the extremes, making the identification of minor damages difficult[19,20]. Resoucesat-2 AWIFS data, which are 56 m resolution, have been used in the analysis. With these data field-level assessment could not be feasible.

The production loss at national level estimated using remote sensing-based index, matched well with the official estimate of GoI. However, quantification of crop loss at farm level is still difficult to achieve.

Under the newly launched crop insurance programme (Pradhan Mantri Fasal Bima Yojana), there is a need to assess the impact of hailstorm (a localized risk) at farm level. In order to suitably use remote-sensing data for damage assessment for insurance purpose, there is need to have high spatial resolution data with high temporal frequency[21]. It is also needed to develop remote-sensing index-based models for quantification of crop loss using remote-sensing data.

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Vulnerability of Indian Central Himalayan forests to fire in a warming climate and a participatory preparedness approach based on modern tools

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Wildfires have been considered as part of the natural cycle, but the globe is witnessing them more often outside the natural cycle. In recent years, incidences of wild fire/forest fire are increasing globally, and also in India. The Himalayan region is not an exception, where wide inter-annual fluctuations occur in fire events, and a few of them lead to disasters resulting in immediate and cascading social and economic impacts and thus to vulnerability and exposure of Himalayan forests to current climate variability. Mountainous topography and insufficient state resources are a bottleneck to respond to fire disasters. This study analyses the role of climate as a precursor to large-scale forest fires, and the perception of village forest councils on the impact of forest fire and climate change. A framework has been proposed for integration of ground-based observation network and prevailing modern technologies as a mechanism to develop a fire potential index to reduce disturbances and for resource optimization in case of disastrous fires.

Keywords: Climate change, community forest, fire potential index, forest fire, Himalaya.

FOR the countries of the world, impacts of climate change are consistent with a significant lack of preparedness for current climate variability[1]. A changing climate leads to changes in the attributes of extreme events (frequency, intensity, spatial extent, duration and timing); hence unprecedented extreme weather and climate events are becoming frequent[2,3]. Impacts from recent climate-related extremes (heat waves, droughts, floods, cyclones, wildfires, etc.) reveal significant vulnerability to current climate variability (very high confidence)[2] and exposure to ecosystems[4], including many human systems. Global records from 1880 indicate a steady increase in warm years and increasing frequency[5], particularly after 1980 (Figure 1 *a*). This is also evident by the occurrence of ten warm years during the past decade (2001–10) and the warmest year (among all the previous years) till date[6], i.e. 2015. The same holds true for the Asian continent, where deficit in annual precipitation during the southwest monsoon season in India was also observed for the same year

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