portance, as being related to ENSO, sunspot and tidal phenomena. The modelling and forecasting skill of the proposed method has been demonstrated to be statistically significant. Apart from the statistics reported in Table 5, results of Figure 6 *a–c* are interesting. It is observed that the nature of departure from long-term average (normal) rainfall has been foreshadowed correctly in eleven out of fourteen years. Even in years where the forecast appears to be poor, the value is within a known error band. Persistence of drought-like conditions in SIKNT and NIKNT during 1999–2003 has also been captured by the present model in a forecast mode. In comparison with regional-scale rainfall, the present data show lower levels of modelling and forecasting efficiency measured in terms of PP_m and PP_f. This is attributable to the higher coefficient of variation and lack of stationarity property with the present data series. The efficiency of the present method for modelling other subdivisions which have still higher levels of (σ/m) value is yet to be investigated.

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Quick look isoseismal map of 8 October 2005 Kashmir earthquake

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The isoseismal map for the devastating *M* 7.6 Kashmir earthquake of 8 October 2005 is constructed based on the immediate damage scenario provided by the teachers trained under the Himalayan School Earthquake Laboratory Programme as well as that reported in electronic and print media. The nature of the damage pattern imprinted on different vulnerable classes of buildings at some 80 sites enabled to map out intensity distribution in earthquake-affected region to a value above IV on the European Macroseismic Scale (EMS-98). The isoseismal map provides a fair picture of the distribution of ground-shaking effects to distant places. This would serve as a useful guide in future earthquake hazard assessment in the region. The Kashmir valley was widely affected and the meizoseismal zone encompassing the township of Balakot and Muzzafrabad experienced a maximum intensity of XI on the EMS-98 scale. The use of this maximum intensity and the dimension of the area covered by isoseismal VI in the well-established intensity–focal depth and intensity–moment relations respectively, allowed for estimating the focal depth and the magnitude. Since in the present approach, the map is prepared based on the damage scenario immediately after the main shock, it will be free from biases due the subsequent damages caused by aftershocks that advertently tend to contaminate the maps prepared by conventional field surveys.

Keywords: Focal depth, Kashmir earthquake, intensity distribution, isoseismal map, magnitude.

THE *Mw* 7.6 worst ever earthquake shook the Kashmir valley on 8 October 2005 at 03:52 UT (09:22 IST). The shallow focus earthquake (depth 10 km) with its epicentre (34.432°N, 73.537°E, USGS), ~124 km to the west of Srinagar, caused widespread destruction and casualties (>50,000) in the region. In the west, the event was widely felt in Pakistan and Afghanistan and in the east shaking of the earth was felt as far as Himachal, Punjab, Haryana, Uttaranchal, Delhi, Rajasthan, Gujarat and western Uttar Pradesh. Earlier also this region experienced a number of moderate and major earthquakes. Among those the most recent ones are the Northwest Kashmir earthquake of 2002 (*M* 6.4) and Pattan earthquake of 1974 (*Mw* = 7.4)[1]. Previous destructive earthquakes in the Kashmir valley that occurred in 1555 (magnitude not known), 1885 (*Mw* 7.5), 1842 (*Mw* 7.5 Kinnuar) and the Kangra earthquake of 1905 (*Mw* 7.8) are reported at http://asc-india.org/events/051008_pak.htm.

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Table 1. European Macroseismic Scale-98

Intensity value	Expected damage according to scale	Observed/examined damage
XI	Most buildings of vulnerability classes 'A' and 'B' sustain damage of grade 5 and class 'C' suffer wide cracks, i.e. grade 4.	Devastating scene. Almost all the buildings of 'A' type seen collapsed, i.e. grade 5. In Balakot, one well-constructed building does not show any features of collapse; however grade 3 damage from inside has been reported.
X	Most buildings of class 'A' sustain damage of grade 5, class 'C' will suffer grade 4 damage.	All 'A' class buildings collapsed, i.e. Grade 5 damage in Tithwal and adjoining areas. Well-constructed Aman Setu bridge suffered grade 5 damage to one of the pillar.
IX	General panic; many buildings of class 'A' sustain damage of grade 5, class 'B' sustain damage of grade 4 and class 'C' may suffer damage grade 3.	General panic among the community; many buildings of vulnerability class 'A' suffered grade 5 damage, e.g. Uri and Tangdhar co-seismic features like huge landslides and land fissures. Pillars seen overturned at Uri.
VIII	Many buildings of class 'A' suffer damage of grade 4 but few may suffer grade 5 damage, and class 'C' suffers grade 3 damage; furniture overturns.	Moti Mahal (class 'C') palace in Poonch suffered grade 4 damage. In Baramulla, grade 4 damage has been reported from class 'C' buildings. However grade 2 and 3 damage has been reported in most of the houses and adobe houses suffered grade 4 damage.
VII	Most people are frightened, furniture is shifted and buildings of class 'A' suffer damage of grade 3.	Slight damage to old fort and small cracks in adobe buildings, Damage to Charare Sharief and Hazaratbal Darah (grade 2 damage); land fissures in Slamabad.
VI	Slightly damaging, grade 1 damage is sustained in many buildings of classes 'A' and 'B'.	Slight damage reported from Jammu, Tissa and Chamba. Panic in Udhamnagar and grade 1 and 2 damage in class 'A' buildings.
V	Earthquake was felt indoors by most, hanging objects swing; doors and windows swing and minor hair-line cracks may appear in building classes 'A' and 'B'.	Further east the event was felt by all, swing of poles have been reported from Mandi, Sarkaghat, Kangra area. In Amritsar, an earthquake was reported.

Total collapse of building is grade 5, partial collapse of some walls is grade 4 and opening of wide cracks in walls is grade 3 damage. Grade 2 damage refers to development of visible cracks in walls and grade 1 hair-line cracks in walls. The information has been updated with the field observations[15].

The isoseismal maps prepared based on an immediate study of the damage pattern in the earthquake-affected region have been an effective tool in evaluating the ground motion characteristic of the region as well as the earthquake magnitude and its focal depth[2–4]. A quick appraisal of the damage pattern also proves useful in planning immediate disaster rehabilitation strategies. With the introduction of a dense network of accelerometers, the precision and quantification of ground motions and site amplification studies has greatly improved. However, in the sparsely instrumented regions, the isoseismal maps continue to be a potential tool in the characterization of ground shaking caused by the main event. The isoseismal maps for the recent devastating earthquakes of the Indian subcontinent, e.g. 1993–Latur[5], 1991–Uttarkashi[6], 1999–Chamoli[7] and 2001–Bhuj[8] clearly illustrate the effectiveness of these maps in earthquake hazard assessment. Secondly, but more importantly, if the nature of ground motion so obtained can be revalidated by modern equipment, the classical approaches can be extended to historical earthquakes, where only information on damage may be preserved in ancestral scriptures. Tracing damage records of historical natural catastrophes from old scriptures is an emerging area of research[9,10]. Recognizing this potential of isoseismal maps in future assessment of seismic hazard, an attempt is made to prepare an isoseismal map for the recent 8 October earthquake in the Kashmir valley that still remains sparsely instrumented. The present attempt has introduced two innovations; one that it incorporates information on damage pattern from teachers trained under the earthquake awareness programme and secondly, it implements information on the damage scenario from the press and media reports.

The Department of Science and Technology, Govt of India, under its mission-mode project on seismology has introduced an innovative scheme entitled 'Himalayan School Earthquake Laboratory Programme (HIMSELP)'. Through close networking between research institutions and schools, the programme aims to create scientific awareness about earthquakes amongst young students by teaching basic principles and encouraging their direct participation in seismological measurements. As a part of this project, Wadia Institute of Himalayan Geology, Dehradun is establishing 50 seismometers in NW Himalaya and recently conducted a training session for the teachers from 29 September to 4 October 2005 at Dehradun. These teachers trained in earthquake physics and field practice became an important source of information in providing immediate

Table 2. Kashmir earthquake intensity at main locations

Location	MMI	Latitude	Longitude	Report	Source
Muzzafrabad	XI	34.34	73.47	Total devastation, region shook for more than 1 min; total devastation	*The Hindu* *Amar Ujala*
Balakot	XI+			Grade 5 damage, total devastation	Many sources
Dragar	XI	34.38	73.79	Devastating, completely flattened	*The Hindu*
Chitrakot	XI	34.36	73.80	Completely flattened	*The Hindu*
Satpura	XI	34.34	73.82	Maximum destruction	*Amar Ujala*
Gabra	XI	34.36	73.85	Maximum destruction	*Amar Ujala*
Chamkot	XI	34.37	73.81	Maximum destruction	*Amar Ujala*
Bhadarkot		34.36	73.79	Maximum destruction	*Amar Ujala*
Dildar	XI	34.25	71.65	Maximum destruction	*Amar Ujala*
Jinna	XI			Maximum destruction	*Amar Ujala*
Bagh	X	34.26	73.85	Total destruction, 7000 dead	*Amar Ujala*
Kupwara	X			Maximum destruction, 350 dead	*Amar Ujala*
Tangdhar	X	34.40	73.87	Maximum destruction, 300 dead	*Amar Ujala*
Titwal, Tangdhar	X	34.40	73.87	Completely flattened	*The Hindu*
Baramulla	VIII	34.21	74.35	About 50% buildings of 'A' class suffered grade 4 damage and 60 to 70% of them have developed grade 2 and grade 3 damage. Some well-constructed structures (class 'C') suffered grade 4 damage, 900 reported dead	*The Hindu* *Amar Ujala*
Punch	VIII	33.77	74.08	Famous Moti Mahal building completely destroyed, landslips, 850 dead	*The Hindu* *Amar Ujala*
Salmabad	VII+	34.08	74.80	Land fissure development	*India Today*
Srinagar	VII	34.06	74.48	Charare Sharief and Hazaratbal Darah developed of grade 2 damage	Electronic media and *Times of India*
Anantnag	VI	34.08	74.04	Damage to adobe buildings	*Indian Express* and *Times of India*
Raisi	VI	33.05	74.50	Slight damage to old fort and small cracks in adobe buildings	Personal contact *Indian Express*
Chamba	V	32.33	76.10	Development of minor cracks and waves was severe and lasted for few seconds.	Reported by teacher
Tisa	V	32.82	76.14	Cracks have been reported from buildings of adobe type	Reported by teacher
Gurdaspur	V	32.04	75.28	One child killed except any damage, shaking was very severe and people were frightened	Reported by teacher
Amritsar	V	31.35	74.56	No crack has been reported	*Panjab Keshri*
Sulyali (Nurpur)	V	32.30	75.96	Severe shaking observed by most people. Felt unbalanced	Reported by teachers
Dharamshala	V	32.14	76.24	Severe shaking was felt for few seconds, no casualty	Reported by teacher
Palampur	V	32.04	76.29	Building cracks	*The Hindu* and reported by teacher
Baijnath (Bir)	V	32.02	76.80	Severe shaking and swinging of trees has been observed, reported unbalanced condition during an earthquake	Reported by teachers
Mandi	V	31.43	76.55	Swinging of electric poles has been noticed, unbalancing during an earthquake	Reported by teacher
Kullu	V	31.96	77.06	Swinging of poles and trees observed, most of the people felt imbalance	Reported by teacher
Sarkaghat	V	31.69	76.75	Imbalance, swinging of fans and waves in standing water has been reported	Reported by teacher
Bilaspur	V	31.18	76.48	Shaking was severe, most people ran outdoors. No cracks in buildings have been reported	Reported by teacher
Nahan	IV	30.55	77.30	Severe shaking, felt twice	Reported by teacher
Dehradun	IV	30.19	78.03	Felt for about 20 s, no causality	*Amar Ujala*
Mussoori	IV	30.65	78.08	Felt by many peoples	Reported by teacher
Delhi	III	28.39	77.13	People fled outside, city shook over 30 s	*The Hindu*
Gurgoan	III	28.25	77.17	People fled outside	*Amar Ujala*
Almora	III	29.77	79.77	Felt for a few seconds	*Amar Ujala*
Haldwani	III	29.13	79.31	People fled outside	*Amar Ujala*
Pantnagar	III	29.05	79.52	Felt slightly	*Amar Ujala*
Jaspur	III	29.28	78.82	Felt slightly	*Amar Ujala*
Rudrpur	III	30.45	77.85	Felt many times	*Amar Ujala*
Kashipur	III	29.22	78.95	Felt slightly	*Amar Ujala*
Khatima	III	28.92	79.97	Felt slightly	*Amar Ujala*
Champavat	III	29.20	80.06	Felt by a few	*Amar Ujala*
Pithorgarh	III	29.58	80.22	Felt by a few	*Amar Ujala*
Bageshar	III	29.85	79.77	Felt by a few	*Amar Ujala*
Nanital	III	29.20	79.42	Felt slightly by a few	*Amar Ujala*

response on the nature and extent of damage pattern inducted by the devastating earthquake of 8 October 2005, a basic input to prepare quick isoseismal maps. The teachers situated at widely spaced places in Uttaranchal, Himachal and Kashmir Himalaya, took comprehensive stock of the damage pattern to different types of structures in their village/town on the same day and responded to specific questions to enable intensity assignment for the reporting site on the European Macroseismic Scale-(EMS-98)[11]. This critical information was independently supplemented by the wide-ranging information on the destruction pattern scenario reported by electronic media through government and private TV channels as well as reports in daily newspapers. In recent years, the use of information compiled through media and personal judgments is becoming successful in preparing isoseismal maps of different earthquakes[12–14].

Figure 1. Ground observations. ***a***, Total collapse grade 5 damage in Balakot, the place of maximum destruction. ***b***, Stone and mud-constructed building collapsed (grade 3) at Uri (Courtesy: *India Today* and *Outlook*).

The realistic assessment of intensity from the damage scenario implanted by ground shaking requires classification of existing building types into different vulnerability classes, defined as classes A to F on the diminishing scale of vulnerability in the EMS-98 scheme[11]. For this purpose, the adobe-type (made up of irregular stone with mud as cementing material) buildings are taken under 'A' class vulnerability, the dressed stone masonry structures fall under class 'B', whereas concrete masonry with bricks are included in class 'C'. Since buildings with earthquake-resistant features were non-existent in the earthquake-affected region, no structure was included in classes D to F. The first look damage pattern imprinted on different categories of buildings was used to assess the intensity distribution pattern. Our dataset included the intensity values from nearly 80 sites, largely confined to a narrow conical sector centred near the epicentre and extending to epicentral distances over 600 km in the SE direction. The nature of the damage scenario was found adequate to constrain the intensity value above IV in the earthquake-affected region. Table 1 shows the type of expected and observed effects from each intensity zone of EMS-98 code. In this scale (EMS-98), the Balakot and Muzzafrabad area fall under mezizoseismal zone (Intensity XI), where a total devastating scenario (Figure 1 *a*) prevailed. Further east, the region around Uri and Tangdhar that suffered heavy destruction (Figure 1 *b*) was assigned intensity IX. In Baramulla and Punch many buildings of vulnerability class 'A' have suffered grade 4 damages. However, more than 60% buildings suffered damage of grade 2 and 3. About 15% buildings like Dayal Furniture House, Baramulla and Moti Mahal palace, Punch having vulnerability class 'C' suffered grade 4 damage; thus intensity VIII has been assigned to them. The data have been consistent with field observations[15]. In Srinagar, in localities like Batamaloo less than 15% houses suffered grade 4 damage, whereas grade 2 and 3 damage prevailed in more than 60% houses, thus assigning an intensity VII. In this area more than 70% buildings are adobe-type and major devastation has been caused due poor construction. As we proceed further SE, the damage pattern diminishes from total destruction to different types of cracks in the buildings. These intensity values have been interpreted as point values and the resulting isoseismal maps for the M 7.6 Kashmir earthquake of 8 October 2005 are shown in Figures 2 and 3. Both manual (subjective) as well as computer-generated (objective) contour plots are shown in Figure 2. Their close agreement suggests that density of observation points in the limited observational domain is adequate to produce bias-free maps by automatic computer-based numerical routines. In Figure 3, the resulting isoseismal contours are shown against the background of the major tectonic features as well as the relief map of the region. Inset in Figure 3 gives the tentative isoseismal map only up to intensity VIII, prepared by Geological Survey of India based on ground observations. The close agreement of isoseismal contours between GSI and present study reposes confidence in the new approach adopted here that allowed to map larger area extending the isoseismal to intensity IV. Also included in Figure 3 are the epicentres of the main and aftershocks of the 8 October 2005 earthquake. Slip movements as calculated by Chen[16] are superimposed on Figure 2, wherein red colour shows the highest rupture velocity and blue the lowest. Using the slip history, Chen[16], based on a finite fault inversion formulation, also calculated the focal mechanism of the earthquake. He suggested that the main nodal plane having strike 333 degree and dip 37 degree defined the causative fault. Within the syntaxial bend, the elongated axis of the isoseismals has dominant NNW orientation, closely following the focal plane of the earthquake as well as the axis defined by the main shock and aftershocks. However, moving away from the epicentre zone, the isoseismals elongate to align with the regional tectonic features (MBT and MFT), suggesting control of tectonics in the propagation of shaking effects and inflicted damage pattern to distant places.

In addition to the characterization of ground motion, the meizoseismal maps thus developed have also proved effective in providing the focal depth estimate. Application of the empirical relations established independently by various authors[3,4] to the intensity distribution map shown in Figure 2, yielded focal depths in the range of 9.6 to 10 km. The inferred depths are in fair agreement with the instrumentally derived value of 10.2 km, reported by USGS[17] and IMD[18]. We also calculated the seismic moment and its moment magnitude using the intensity–moment relation[2]. The estimated value of 3.72×10^{20} Nm and 7.7 respectively, for the seismic moment and moment magnitude are slightly higher from the instrument estimated values by USGS. The intensity–moment relation[2] used the attenuation factor obtained from instrumentally recorded earthquakes in the California region. Using the intensity–moment relation[2], Mahajan and Kumar[19] observed similar differences in moment magnitude for the great Kangra earthquake than that estimated by other authors[9]. The incremental differences in the two estimates may be due the adopted attenuation factor that is sensitive to the design code and material used in building construction in a given region. This only highlights the need to establish a regional-sensitive relation between observed intensity and earthquake size by synthesizing isoseismal maps for many big earthquakes of the Himalayan region.

We have generated an isoseismal map of the devastating *M* 7.6 Kashmir earthquake of 8 October 2005 based largely on the damage pattern reports provided by teachers especially trained in the earthquake awareness programme as well as compiled from the various media reports. The sa-

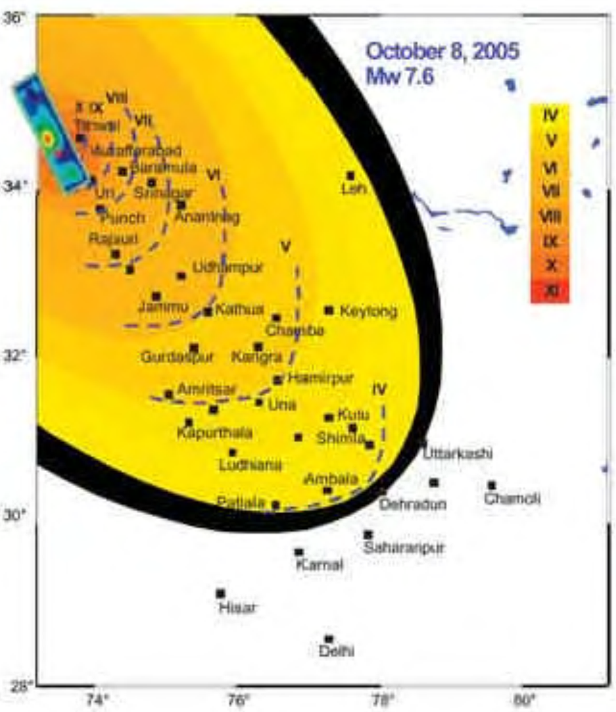

Figure 2. Isoseismal contour map for the 8 October 2005 Kashmir earthquake along with the projection of slip distribution[16]. Intensities are well constrained for more than a value of IV using data of approximately 80 stations. Isoseismals in the epicentre zone are elongated to align with the strike direction of slip motion.

Figure 3. Macroseismic distribution for the 8 October 2005 Kashmir earthquake in the backdrop of topography and tectonic elements of the region. KBT, Kashmir Boundary Thrust; MBT, Main Boundary Thrust; MFT, Main Frontal Thrust. (Inset shows the contours of high intensity isoseismals obtained by present approach (blue color) with those prepared by GSI (Source: http://www.gsi.gov.in/pokeq/pokeq.htm).

lient features of the map show that this was a devastating shallow-focus earthquake generated merely at a depth of 10 km from the surface and the maximum intensity was adjudged XI on EMS-98 scale (Figures 2 and 3). The damage pattern in the area clearly indicates that majority of the buildings have been constructed using irregular big stones which caused maximum devastation (Figure 1 *b*) and intensity was assigned based on the vulnerability class and damage grade according to the EMS-98 scale. The broad agreement of the deduced earthquake parameters (depth and magnitude) with instrumentally obtained values reinforces confidence in the approach adopted to prepare isoseismal maps of devastating earthquakes. The isoseismal map also enabled us to trace out the general distribution of shaking effects to distant places in Kashmir, NW Himalaya and Central Himalaya and thus has important implications for future earthquake-hazard assessment. Cross-verification of estimated ground motion even at distant places like the National Capital Region, where state-of-the-art accelerometer was in operation at the time of the present earthquake, will be critical in further validating the proposed approach or point to any possible bias in media or personal reporting. On the similar count, a comparison with the conventional ground survey-based intensity map will allow us to constrain the extent of the biases, if present. Generally, a full compilation of isoseismal maps, based on conventional ground surveys, over the extended region may take a few days to a week and, hence, estimate of the picture of the damage pattern may be biased by the subsequent damage caused by aftershocks. In this respect, the present approach has a advantage because compilation is based on the immediate information received within hours or on the first day following the main shock. Therefore, it is likely that web- and media-based assessment will become increasingly common for future destructive earthquakes worldwide. Clearly, the potential of the suggested approach will be in the interpretation of historical earthquakes for which the only available information may come from old printed media records. Preparation of isoseismal maps using human resources illustrates the need for undertaking such training courses on a regular basis to increase earthquake awareness among the masses and also to develop expertise in earthquake field practices, particularly in earthquake-prone areas. It would be particularly important to organize training programmes for media persons, so that prompt and accurate reporting could be directly used to prepare quantitative isoseismal maps.

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