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MACROSEISMIC INTENSITY IN THE INTERNET AGE

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The Internet and the World-Wide Web are changing the collection of macroseismic data and the assigning of macroseismic intensity in the United States. Traditionally, the U.S. Geological Survey (USGS) has used macroseismic data collected with postal questionnaires (PQ's) to assign Modified Mercalli Intensity [MMI(postal)]. Beginning in 1998, the United States Geological Survey (USGS) has collected macroseismic observations from a questionnaire posted on a World-Wide Web site. We are exploring two alternative ways of calculating intensities from the web-questionnaire (WQ) data: Community Internet Intensity (CII) is calculated as a continuous function of real variables that represent the strengths of macroseismic effects, and MMI(web) is assigned from the same WQ's using a classification procedure that is intended to be equivalent to the procedure used to assign MMI(postal) from PQ's. The CII procedure is designed for speed-of-calculation, whereas the MMI(web) procedure is designed to produce an unbiased surrogate for MMI(postal). Both of the new procedures illuminate characteristics of the macroseismic intensities that are not evident from MMI(postal) alone. We illustrate with comparisons of MMI(postal), CII, and MMI(web) from the M 7.2 Hector Mine, California, earthquake of 16 October, 1999.

СЕЙСМИЧЕСКАЯ БАЛЛЬНОСТЬ В ВЕК ИНТЕРНЕТА

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Интернет и всемирная "паутина" изменяют положение дел в задаче сбора макросейсмических данных и определения балльности в США. В прошлом определение балльности по модифицированной шкале Меркалли проводилось Геологической службой США на основе макросейсмических данных, собранных с помощью почтовых опросников. Начиная с 1998 года, Геологическая служба получает макросейсмические наблюдения с помощью опросника, помещенного на сайте в интернете. Балл из интернетовских опросов населения (Community Internet Intensity) вычисляется как непрерывная функция вещественных переменных, представляющих измерения макросейсмического эффекта, и балл по Меркалли определяется с помощью процедуры классификации, которая должна быть эквивалентна процедуре, используемой для определения того же балла из почтовых опросников. Опрос с помощью интернетовского опросника имеет своей целью ускорить сбор данных, а процедура определения интернетовского балла должна дать несмещенную замену балла, определенного из почтовых данных. Оба эти новые методы подчеркивают такие характеристики балльности, которые неопределяемы в случае использования только почтовых данных. Мы сравниваем все упомянутые методы на примере землетрясения с магнитудой 7.2, произошедшего 16 октября 1999 года в Гектор Майн (Калифорния).

Introduction

A macroseismic intensity represents by a single number the level of earthquake shaking in a community, as inferred by the earthquake's effect on people, buildings, and the natural environment. As a simplified representation of complicated ground motions, the intensity is analogous to the earthquake hypocenter and magnitude, which are together a simplified representation of the earthquake source. A catalog of earthquake hypocenters and magnitudes reveals much about earthquake source processes that cannot be inferred from detailed study of a single earthquake, and may provide a basis for predicting earthquakes (e.g., [1]). Analogously, a set of macroseismic intensities reveals much about the mechanisms by which strong ground-motions attenuate or are locally amplified, and may provide a basis for estimating losses from future anticipated earthquakes.

Since 1931, the U.S. Geological Survey (USGS) and predecessor agencies have assigned intensities to U.S. earthquakes according to the Modified Mercalli Intensity (MMI) scale of 1931 ([2,3]). Traditionally, the broad outlines of an earthquake's intensity distribution are defined by means of data from postal questionnaires (PQ's); sample lines from a PQ are shown in [4]. Almost all USGS MMI in regions of little or no damage to structures (MMI VI and lower) are based on PQ's. Confirmation of intensities of VII and higher, and reliable definition of isoseismal regions within a broad region affected by intensities of VII and higher, typically require additional observations beyond those provided by the PQ's. Such observations may be obtained from field reconnaissance by USGS personnel, written reports by specialists in earthquake studies, or press reports.

The USGS is now experimenting with the use of a questionnaire posted on the World-Wide Web (WWW) to collect the type of data that have been collected by the PQ [5]. People are invited to fill out the web questionnaire (WQ) when they enter USGS earthquake websites, and some non-USGS websites, in the aftermath of an earthquake. A sample WQ may be seen in [5] or on our WWW site [http://pasadena.wr.usgs.gov/shake]. As a consequence of changing the medium with which macroseismic data are collected from most communities, the USGS must change also the procedure by which these macroseismic data are reduced to obtain an intensity value. We are exploring two different types of intensity for representing the WQ data: Community Internet Intensity (CII) and WQ-based Modified Mercalli Intensity [MMI(web)].

In what follows, "communities" may usually be considered to be equivalent to postal zones of the U.S. Postal Service, because postal-zone numbers ("Zip Codes") are the primary means of identifying locations from which PQ's and WQ's are received.

1. MMI(postal) – traditional MMI based on postal questionnaires

Following an earthquake, USGS seismologists mail postal questionnaires to the region in which the earthquake might have been felt. Each PQ asks the respondent to provide information on macroseismic effects throughout the respondent's community. Typically, one PQ is sent to each post office in the epicentral region of the earthquake. The density of canvassing decreases with increasing distance from the epicenter, but the canvassing procedure is intended to sample communities that lie beyond the region in which the earthquake is felt.

The assigning of an MMI from PQ's [MMI(postal)] is a manual classification scheme similar to that used for most macroseismic intensities [6]: the various macroseismic effects reported on a PQ are considered collectively in light of the effects that are defined as characteristic of different intensity levels, and the selected intensity is that for which the match is best in the judgement of the seismologist. USGS MMI(postal) of VI and higher are based principally on damage to buildings and effects on objects in buildings; earthquake effects on people are used only in the assigning of lower intensities [3].

2. Community Internet intensity (CII)

The Community Internet Intensity (CII) is determined by coding different responses on the WQ as numbers, calculating a weighted sum of the numbers, and converting the weighted sum to an MMI-type intensity [7,5]. The CII is calculated as a decimal number, though in some presentations the CII are rounded off to integer values. The main purpose of the CII is to rapidly produce an intensity map in the aftermath of an earthquake. Provided that telephone and electrical power systems are functioning after the earthquake, the first map of CII is commonly displayed on the WWW within ten minutes after the earthquake. The CII maps are periodically updated as new WQ's are received, and before 24 hours have elapsed a good overview of macroseismic effects is obtained. This contrasts with the period of months that is required to produce an intensity map by the traditional procedure. The rapidity with which the CII can be mapped should enable the CII to be useful in some types of disaster response.

A potential disadvantage with the CII procedure is that it differs so much from the traditional MMI procedure that one must expect systematic differences between the CII and traditional MMI for some earthquakes and communities, notwithstanding that the CII procedure is calibrated so as to agree on average with traditional MMI [5]. Calculating an intensity by assigning numerical values to macroseismic observations is much different than assigning an intensity from macroseismic observations by a qualitative process of classification. Furthermore, although the PQ and WQ address similar macroseismic effects, the questionnaires differ in detail. For example, the PQ asks the respondent to describe effects from the respondent's entire community, whereas the WQ focuses on effects directly experienced by the respondent or by the respondent's building. Finally, unlike traditional USGS MMI, CII at levels if 5.5 (VI) and above depend on human responses and subjective judgements about the severity of shaking.

3. MMI(web) – MMI from veb questionnaires (WQ's)

MMI(web) is intended to replace MMI(postal) in applications that require long-term consistency of intensity data. Unlike MMI(postal), most MMI(web) are assigned by a computerized procedure. The procedure for assigning MMI(web) is new, and may yet need to be slightly modified. At present, the USGS collects both WQ and PQ, so that we can compare MMI(web) with MMI(postal) and adjust the MMI(web) procedure to minimize any bias with respect to MMI(postal).

In assigning MMI(web), we imagine how effects from a community that are described in a set of WQ's would be interpreted by a single PQ from that community; we then assign the MMI (web) as though we were assigning an MMI(postal) from the imagined PQ. Many criteria of the MMI scale involve a qualitative description of the frequency of a macroseismic effect in a community (e.g., 'few', 'several', 'many'), and these qualitative descriptions are included in the PQ. For each qualitative description of frequency in the Modified Mercalli Scale, our MMI(web) procedure associates a certain frequency-of-effect from WQ data. Thus, in order to satisfy the criteria of intensity V that there were "some windows, etc. broken; a few instances of cracked plaster", the MMI(web) procedure requires that at least 10 percent of the WQ respondents reported a window broken or hairline cracks in walls. Our criteria for MMI(web) are similar to those used by Dengler and Dewey [4], Table 4 to assign MMI from phone-survey data. As is also the case with PQ's, there are communities for which the totality of WQ observations are not well described by the criteria of any single MMI value. For example, reports of hairline cracks in walls may suggest intensity V, whereas the effect of the shaking on people may suggest intensity III. The computerized procedure identifies communities for which WQ observations may be mutually inconsistent, and the MMI(web) for these communities are assigned manually, or an MMI(web) is not assigned to the community.

4. MMI(postal), MMI(web), and CII for the hector mine, California, earthquake

As of this writing, the largest WQ response at the USGS website has been associated with the Hector Mine, California, earthquake of 16 October 1999 (MW(HRV) = 7.2). The earthquake was centered in unpopulated desert northeast of Los Angeles, and damage from the earthquake was light, but the earthquake was felt throughout southern California. The USGS sent out 715 PQ's, and 60 percent of these were filled out and returned. Approximately 25,000 WQ's were returned for the Hector Mine earthquake, providing a dramatic illustration of the power of the Internet as a tool for collecting macroseismic data. The CII considered in the following paragraphs are for the 788 communities from which three or more WQ's were received; the MMI(web) are for the 734 communities from which three or more WQ's were received and for which an unambiguous MMI(web) could be assigned with the computerized procedure described in the previous paragraph.

The PQ's and WQ's are similar in their implication for the outer limits of the felt area of the Hector Mine earthquake (Fig. 1). With the PQ's, the limits of shaking are defined in part by "not felt" responses from the most distant communities (Fig. 1a). The WQ's, by contrast, are submitted only by individuals who have taken the initiative to visit the USGS web-site and submit the questionnaire. In a region in which most people did not feel an earthquake, the minority who did feel the earthquake will be greatly over-represented among those who have submitted WQ's. Consideration of the total population exposed to shaking helps account for the bias towards felt reports in the WQ data. Fig. 1b shows that plotting of population centers from which we received few or no WQ's, in addition to locations where the WQ data reliably indicate that the earthquake was felt, provides a visual basis for understanding the extent to which the earthquake was generally felt.

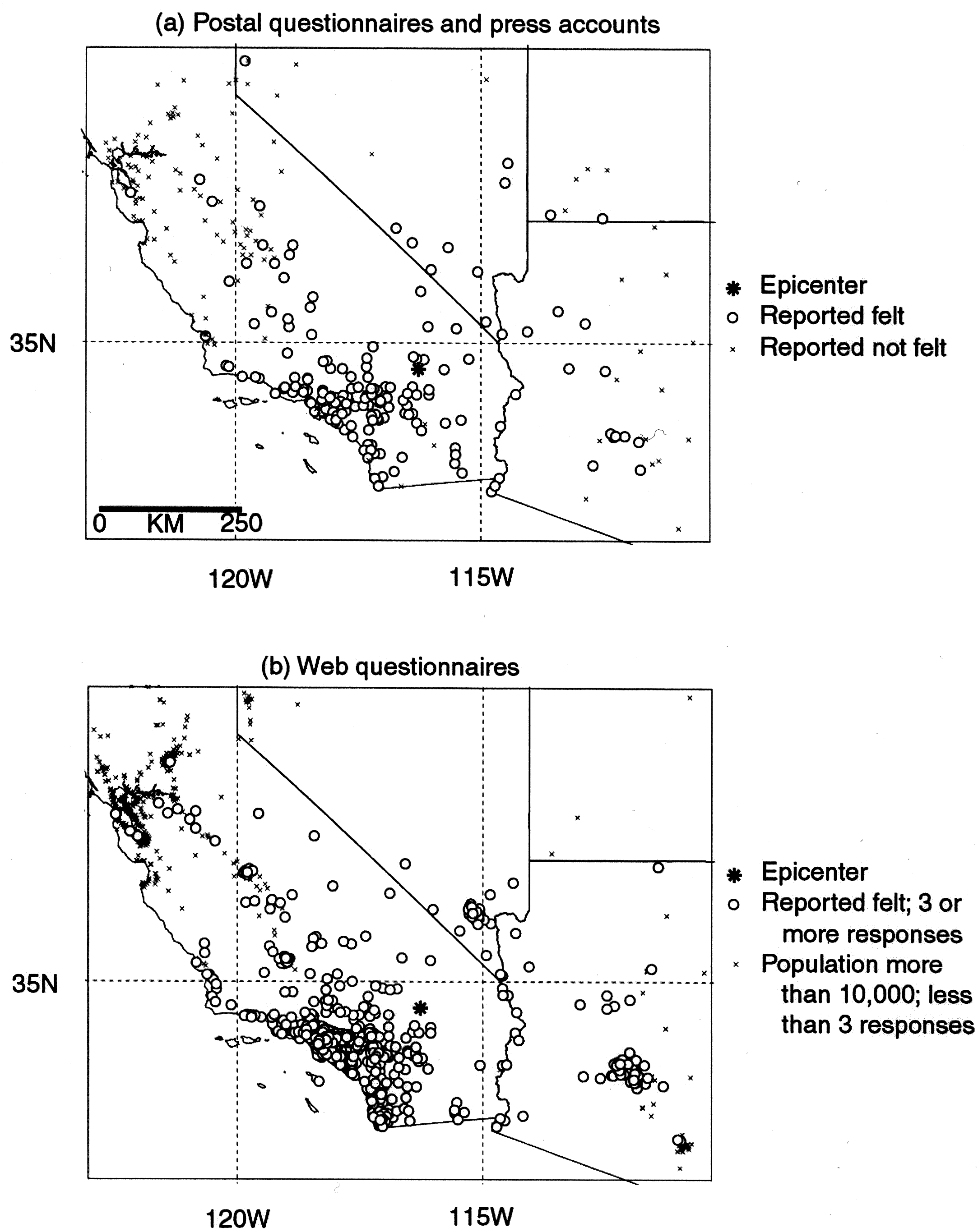

Fig. 1. The felt area of the Hector Mine, California, earthquake as revealed by (a), postal questionnaires and press accounts, and (b), web questionnaires and postal zones from which web-questionnaires might have been expected if the earthquake had been felt in those centers

For evaluating the effectiveness of CII and MMI(web) near the source of the Hector Mine earthquake, our standard of comparison is a set of traditional USGS MMI that includes both MMI(postal) and MMI that are based on engineers' reports and press accounts. In the near-source region, the CII procedure does a better job than the MMI(web) procedure in replicating the map of traditional USGS MMI, because the CII identifies the region of intensity VII near the causative fault (Fig. 2). Fig. 2 suggests that the CII is preferable to MMI(web) for the hours and days immediately after the earthquake, when emergency response procedures would depend on officials knowing the region of strongest shaking. An intensity map prepared months after the earthquake, in which most intensities were MMI(web) but in which the highest intensities were based on press accounts and engineers' reports in addition to WQ's, would also have shown some MMI VII values near the earthquake source.

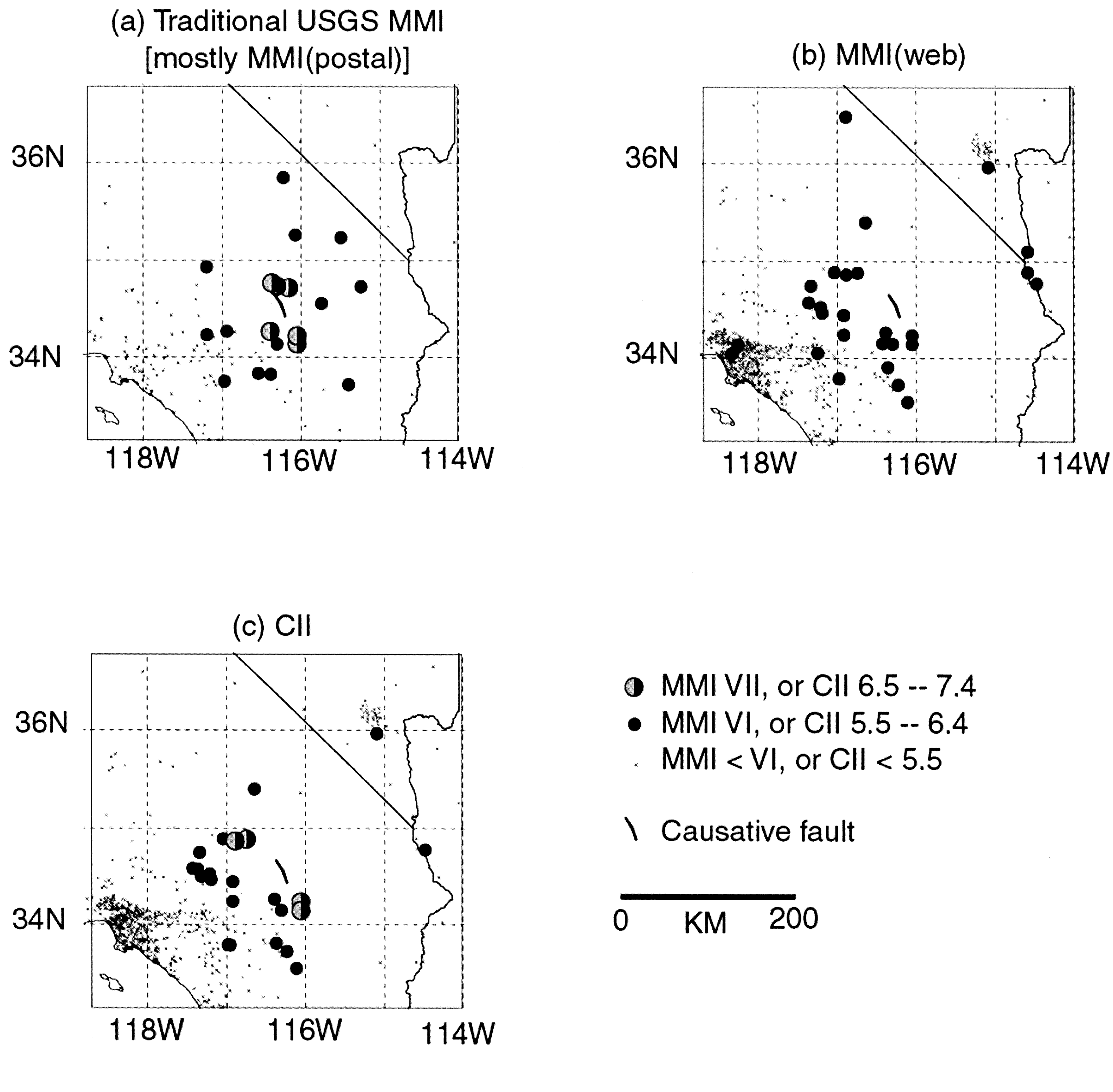

Fig. 2. Comparison of regions of strongest shaking in the Hector Mine, California, earthquake, as implied by (a) traditional USGS MMI, (b) MMI(web), and (c), CII. Most of the traditional intensities are MMI(postal), but the values of VII near the causative fault are due to, or influenced by, press reports and engineers' field observations. MMI(web) and CII are only shown for postal zones from which three or more web questionnaires were submitted

We evaluate the internal consistency of the MMI(postal), MMI(web), and CII by plotting these intensities as functions of distance from the causative fault of the Hector Mine earthquake (e.g., Fig. 3). We consider that the more self-consistent data will tend to show less dispersion as a function of distance. To minimize apparent dispersion that would result from attenuation of intensities being less rapid northeast of the epicenter than southwest of the epicenter, we plot only observations from azimuths 135° through 315° with respect to the epicenter. MMI(web) based on three or more observations (Fig. 3) per community appear to be as self-consistent as MMI(postal) at intensities lower than VI. The CII show less dispersion than MMI(web) at all intensities, but are systematically lower than both MMI(web) and traditional MMI at lowest intensities.

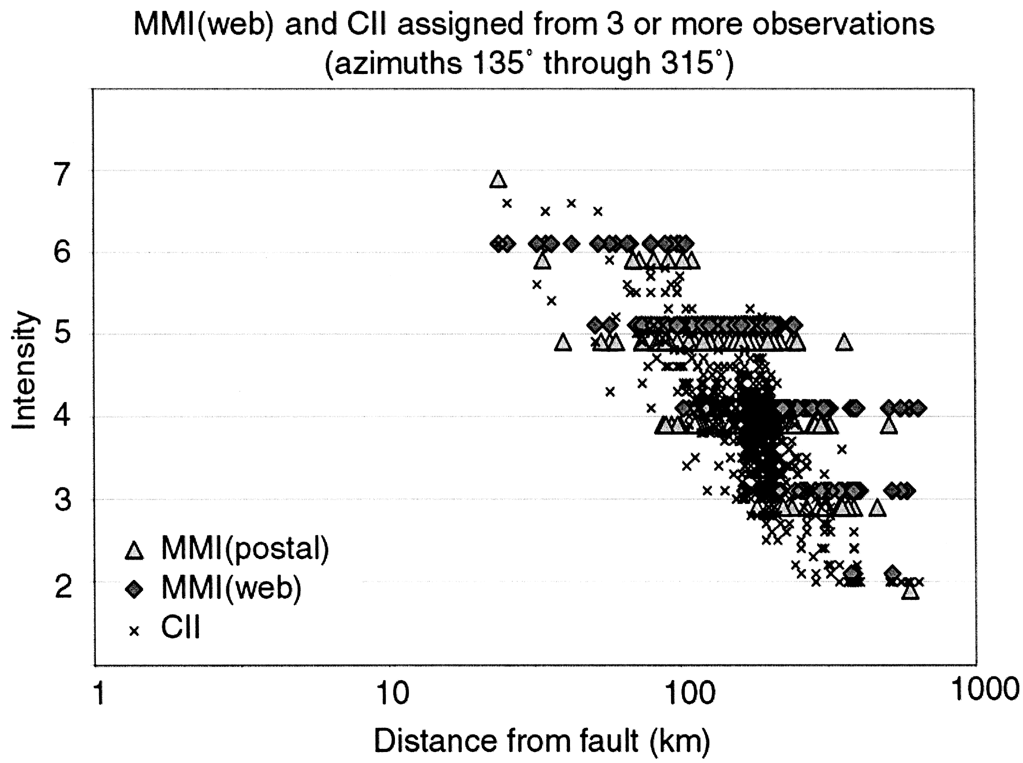

Fig. 3. Attenuation of MMI(postal), MMI(web), and CII as a function of distance from the causative fault, for communities situated southwest of the epicenter

Discussion

As illustrated here with data from the Hector Mine earthquake, and as is also the case with other earthquakes we have studied, MMI(web) and CII are broadly similar to MMI(postal) and to traditional USGS MMI inferred from non-PQ data. We have seen some systematic differences between MMI(web), CII, and traditional MMI/MMI(postal): the differences are not serious in light of the way that MMI(web) and CII are used, but the differences provide information on aspects of macroseismic intensities that are not obvious from traditional MMI alone. For example, a tendency for CII in regions of light shaking to be low with respect to MMI(postal) will not pose a major problem in the public's interpretation of the rapidly produced CII maps that are posted on the Web. For some purposes, such as the resolution of significant variations of shaking within regions that are assigned uniform Modified Mercalli Intensities, any problem associated with bias in the CII data may be less important than the advantages that arise from the lower dispersion of the CII data [4]. To cite another example, consider the tendency for MMI(web) to be less than traditional MMI in the communities where traditional MMI of VII were assigned. The fact that none of the MMI(web) were as high as

VII is due specifically to the fact that fewer than ten percent of WQ respondents in communities nearest the epicenter actually observed intensity VII damage in their own buildings. The discrepancy may reflect a general tendency for traditional MMI VII to be based on effects that are typical of only a small percentage of buildings in the community.

The authors congratulate Professor V.I. Keilis-Borok on the occasion of his 80th birthday.

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