Comparison of EMSC and USGS Internet-Based Earthquake Reports from Recent Events

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Background

USGS "Did You Feel It?" (DYFI) has been crowdsourcing macroseismic intensity (MI) data from users worldwide for over 20 years. In addition to collecting and mapping felt reports, DYFI data is used by USGS ShakeMap, along with instrument data, rupture models, site condition attenuation models, and ground motion prediction models, to create maps of MI spatial distribution for earthquakes in near real time. ShakeMap has included DYFI in its shaking estimates since its inception.

Another, more recent crowdsourcing system is the European-Mediterranean Seismological Centre (EMSC) LastQuake app, which has been collecting data for almost a decade. While based in Europe, EMSC also collects data for earthquakes worldwide. In this study, we compare EMSC and DYFI felt report database to evaluate the suitability of supplementing ShakeMap with EMSC reports alongside DYFI.

ShakeMap uses a conditional multivariate normal distribution to combine various data and models, which requires quantification of the uncertainty of its inputs. In this study we calculate uncertainty formulas for EMSC data using a bootstrap method similar to that employed for DYFI. We find that uncertainty is heteroskedastic (changes with intensity), so we calculate the parameters for different intensity bins. This calculation method can be generalized, opening the possibility of including other MI collection systems in ShakeMap.

Using these uncertainty calculations, we create ShakeMap outputs using EMSC data and compare the ShakeMap estimates of MI spatial distribution from DYFI and EMSC for three recent well-reported damaging earthquakes in Europe. We also use USGS PAGER (Prompt Assessment of Global Earthquakes for Response) to compare the losses derived from these datasets. PAGER combines the output from ShakeMap output with country-specific population and loss models to create estimates of fatalities and economic losses.

DYFI CURRENT STATUS

As of August 2021, the DYFI dataset comprises more than **6.1 million** responses over 20 years of collection.

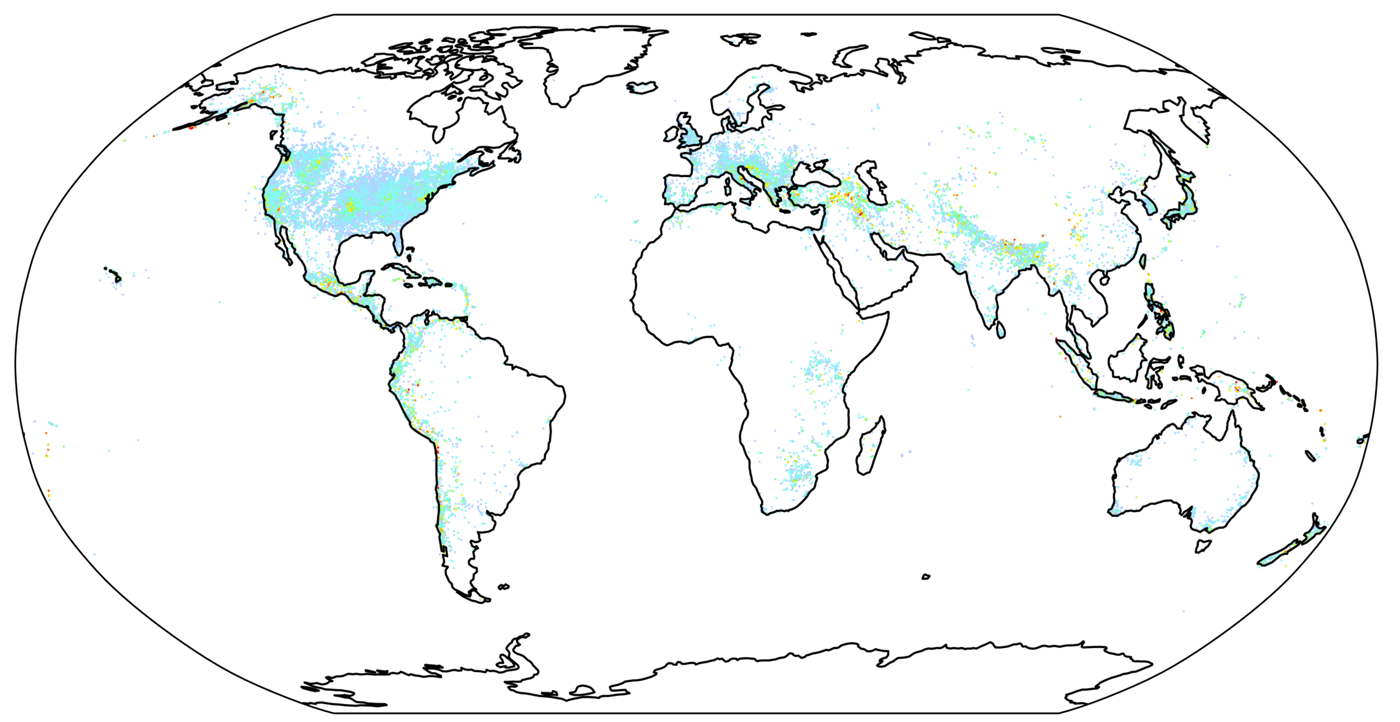


Fig. 1. DYFI cumulative responses for all events from 2000 through August 2021. In each location, the color corresponds to the maximum intensity felt at that location at any time throughout the entire collection period.

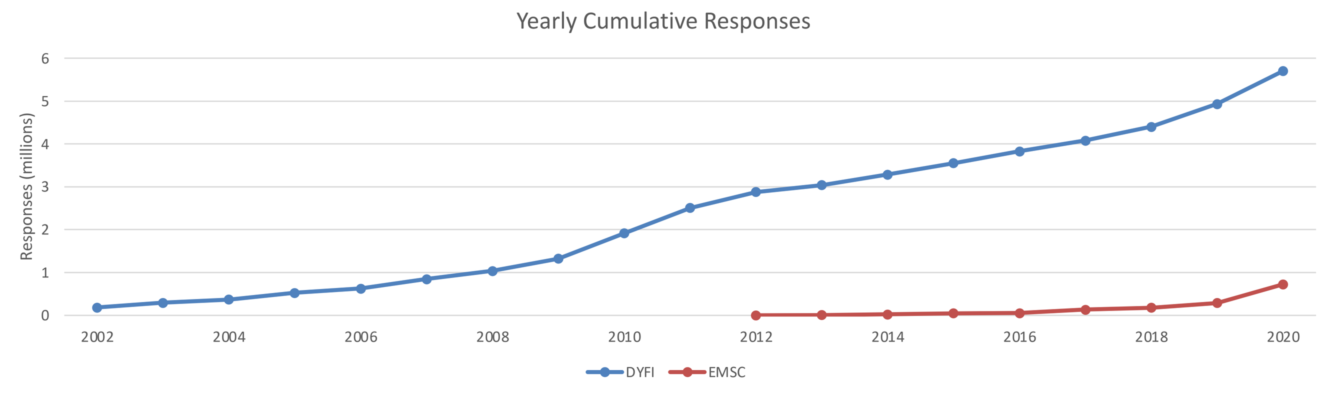


Fig. 2. Cumulative responses for DYFI and EMSC intensity surveys (questionnaires only).

DYFI Questionnaire

The DYFI questionnaire is a set of 18 questions designed to measure specific earthquake effects and observations: from simply feeling motion, to questions about reaction and behavior, to specific effects and damage types. These effects are used to calculate a Community Decimal Intensity (CDI) which is based on the MMI (Modified Mercalli Intensity) scale.

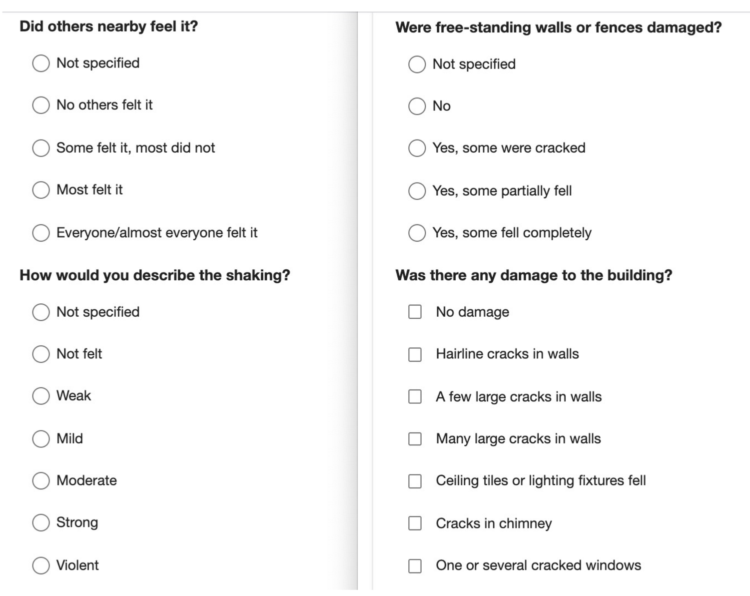


Fig 3. Two sections of the DYFI questionnaire with questions related to personal reaction (left) and observed damage (right).

EMSC Questionnaire

The EMSC questionnaire uses a set of 12 cartoon images and asks the user to select the one most like their experience. Each image directly corresponds to an EMS-98 intensity value. The intensity for a location is the average of the answers in that location. EMSC applies a linear correction in order to be more consistent with the EMS-98 macroseismic scale.

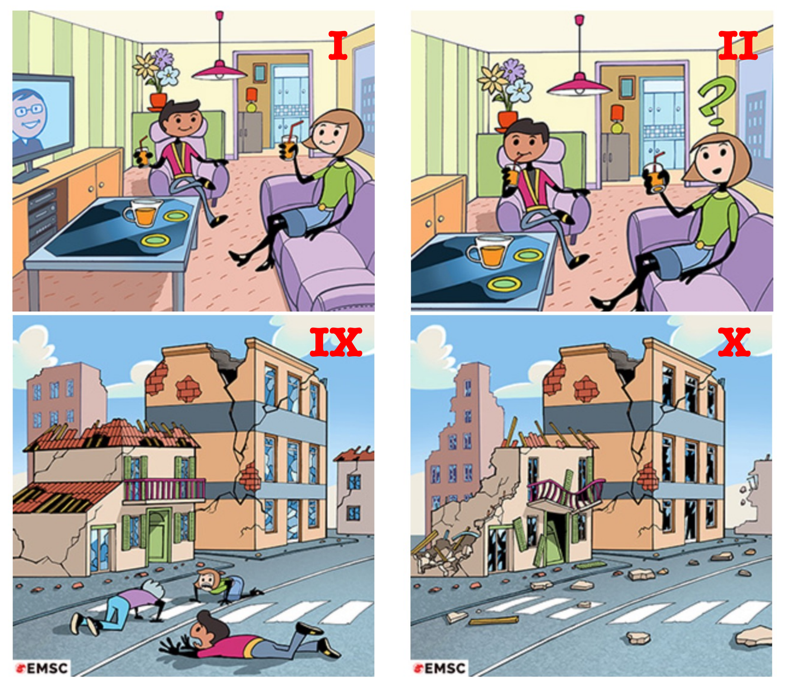
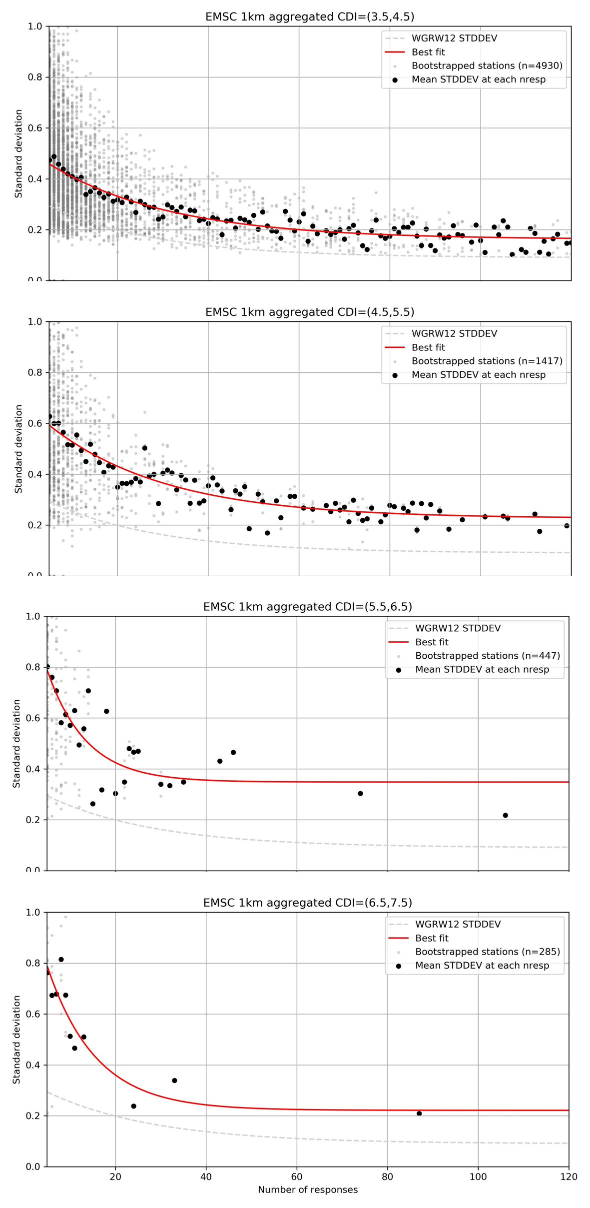


Fig 4. Examples of the EMSC questionnaire thumbnails. The corresponding EMS-98 intensity is added in red.

EMSC Uncertainty

For DYFI, Worden et al. (2012) estimates the standard deviation of intensity as a function of the number of responses in an area. We apply the same method to the entire EMSC thumbnail questionnaire database through 2020 (n=724,963).

We find that the EMSC data are heteroskedastic (uncertainty increases with increasing intensity). We calculate different coefficients for uncertainty for each intensity bin. Each bin is one intensity unit wide and centered on intensity values from 2 to 7. Intensities above 7.5 do not follow this formula, we suspect due to lack of sufficient data, so we impose a sigma value of 0.8 for all intensity values above 7.5.



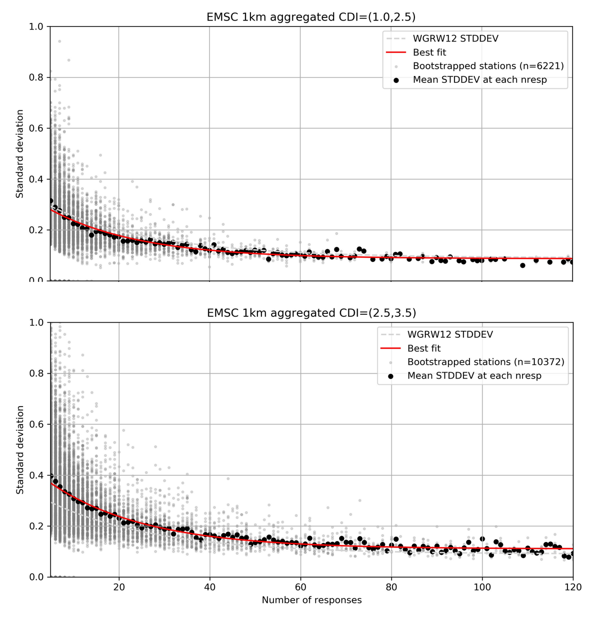


Fig. 5. Best fit standard deviation (red lines) for EMSC data aggregated into 1 km cells (grey dots) at different intensity ranges, compared to the uncertainty used for DYFI (dotted line). Black dots are the mean standard deviation for all cells with the specified number of responses. Plots for 1 km cells aggregation shown; results for 10 km aggregation are similar.

DYFI and EMSC comparisons

DYFI only | EMSC only | Survey

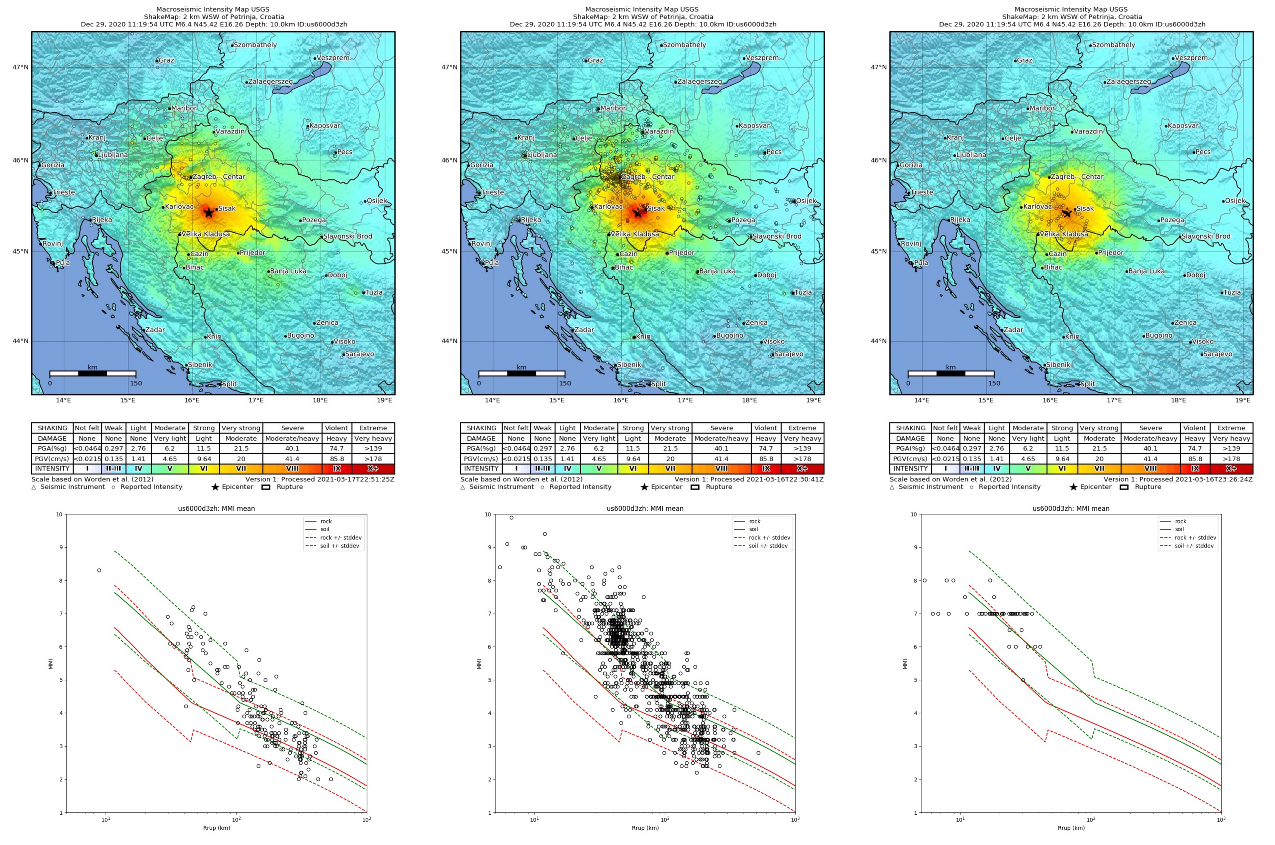


Fig 6. ShakeMaps for the **M6.4 Croatia (29 December 2020)** event. Comparison of shaking maps (first row) and plots of intensity observations vs. epicentral distance (second row) using the DYFI dataset (left), EMSC (center), and intensity estimates from a field survey (right; Univ. Zagreb) show subtle but important differences. The EMSC map has many more observations but overestimates the extent and magnitude of high intensities near the epicenter (in red) compared to the DYFI and survey reports. Lines are intensity estimates by ShakeMap for rock (red) and soil (green) based on earthquake magnitude and the region-specific ground motion model.

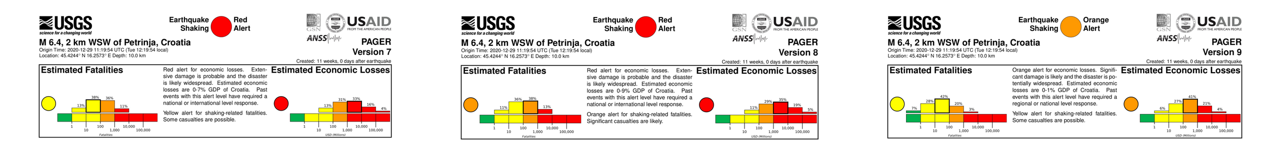


Fig. 7. PAGER alerts derived from ShakeMap for each dataset. The alert levels show the most likely range of estimates for fatalities (left side) and economic losses (right side). DYFI (left) shows a slightly higher estimate for fatalities (Yellow alert), and EMSC (center) somewhat higher (Orange alert), compared to the field survey-derived estimate (Yellow alert). Both DYFI and EMSC estimate similar economic losses (Red alerts) compared to the survey (Orange alert). There were 9 reported fatalities and $6.7B in losses for this event, which would correspond to a Yellow alert for fatalities and Red for losses.

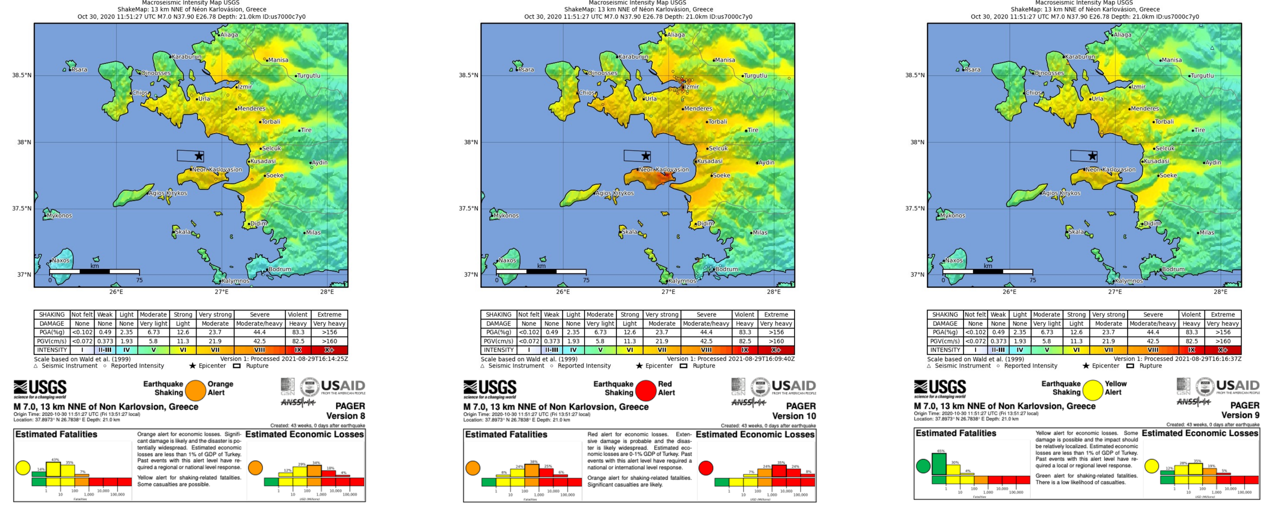


Fig 8. ShakeMaps and PAGER results for the **M7.0 Greece (30 October 2020)** event. Comparison of shaking maps (first row) and PAGER estimates (second row) using the DYFI dataset (left), EMSC (center), and estimates from only instrumental data (right). Ground motion data from stations, are converted to intensity estimates via a GMICE (Ground Motion to Intensity Conversion Equation; Worden et al., 2012). The EMSC map shows higher (VIII+) intensity values in eastern Samos and in Izmir. These correspond to higher fatalities and losses (Red Alerts) compared to either the DYFI or instrumental estimates. For this event there were 119 reported casualties and more than $400 million in damages, corresponding to an Orange Alert for both casualties and losses. The value of the abundant reported intensities is clear.

DYFI and EMSC comparisons (cont'd.)

DYFI only | EMSC only | No observations

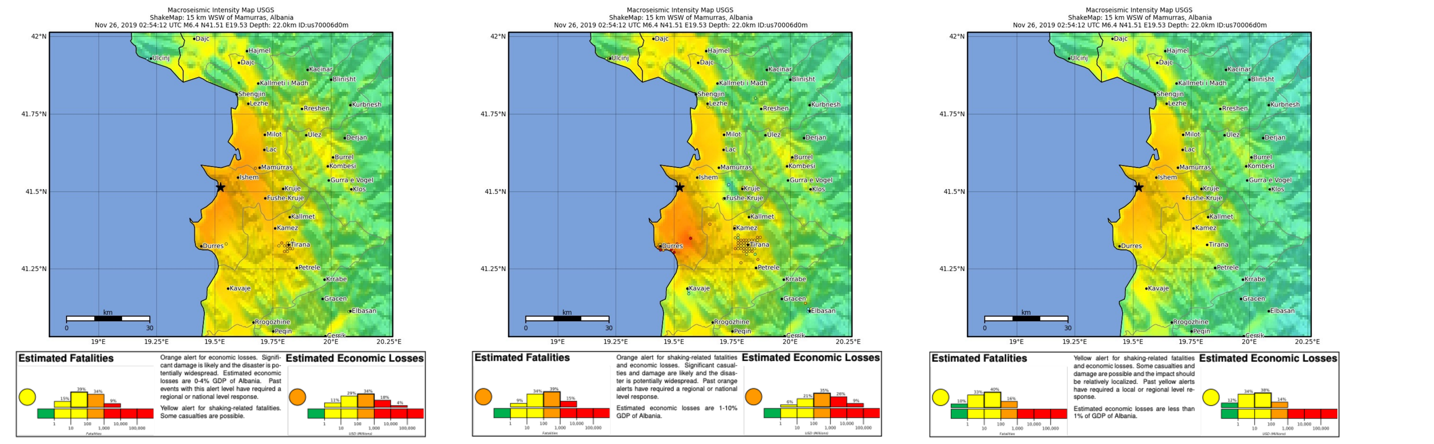


Fig 9. ShakeMaps and PAGER estimates for the **M6.4 Albania (25 November 2019)** event. Comparison of shaking maps (first row) and PAGER estimates (second row) using DYFI (left), EMSC (center), and estimates from instrumental data alone (right). The EMSC data includes areas of high intensity (VIII+) south of the epicenter, contributing to an estimated Orange Alert for both fatalities and economic losses. For this event there were at least 51 reported fatalities and more than $1B in damage, corresponding to Yellow (fatalities) and Red (losses). Again, the value of the abundant reported intensities is obvious.

Combining intensity datasets

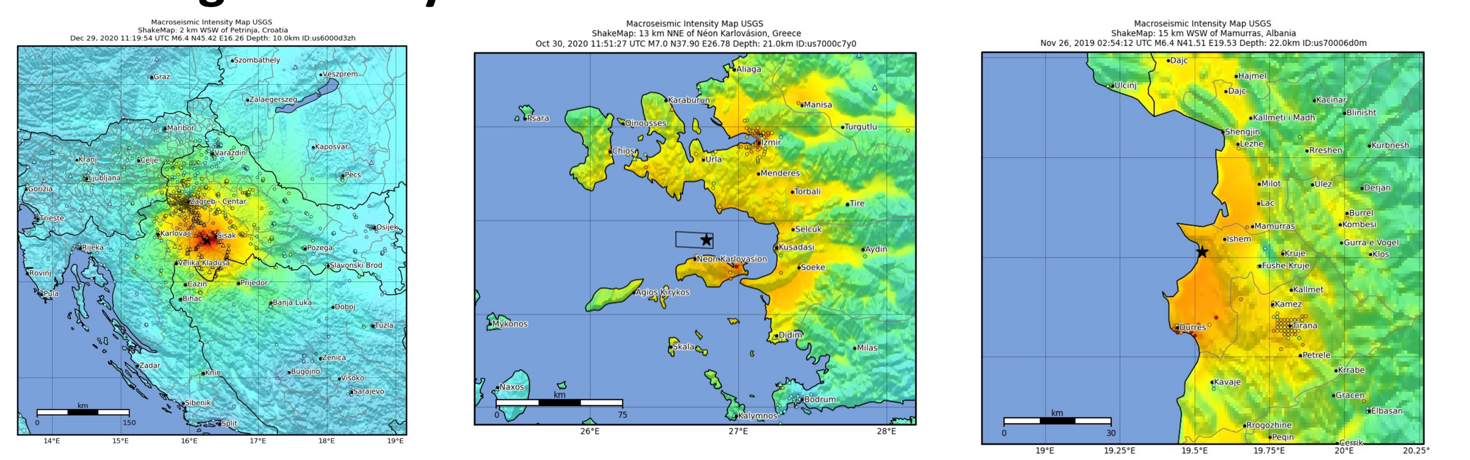


Fig. 10. Combined intensity ShakeMaps for M6.4 2020 Croatia (left), M7.0 2020 Greece (center), and M6.4 2019 Albania (right). All intensity sources (DYFI, EMSC, and observers) are shown as circles, while seismic stations (from EU ShakeMap) are triangles.

Conclusions

We present a method of uncertainty computation for EMSC felt reports that can be generalized to allow the inclusion of other MI sources into ShakeMap products. We find that higher intensities for EMSC correspond to higher uncertainties, consistent with the known difficulty of assigning high intensities by nonexpert observers (i.e., higher MI assignments require damage and structural information that only expert observers are able to ascertain). In all three earthquake examples, the combined ShakeMaps show elevated near-epicenter intensities compared to the estimates derived from ShakeMaps without MI inputs (using only instrumental data, rupture models, and ground motion models as inputs). Additional ground observations and further comparisons may lead to revisions of the ground motion model or the GMICE for this region, reevaluation of the relative uncertainty assignments among macroseismic and EMSC Felt Reports, or recalibration of the EMSC adjustment (bias) calculation, if warranted. Nonetheless, we have established the framework for including EMSC Felt Reports, and similar data sets, into ShakeMap with a full accounting for their uncertainties. For the three events analyzed, the resulting loss estimates, as given by PAGER, are closer to those reported when the abundant and rapidly-available MI reports are employed, whether from DYFI or EMSC.

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