Lessons learned from the 2023 Kahramanmaraş, Türkiye earthquakes: *Modeling aspects of insured portfolio losses*

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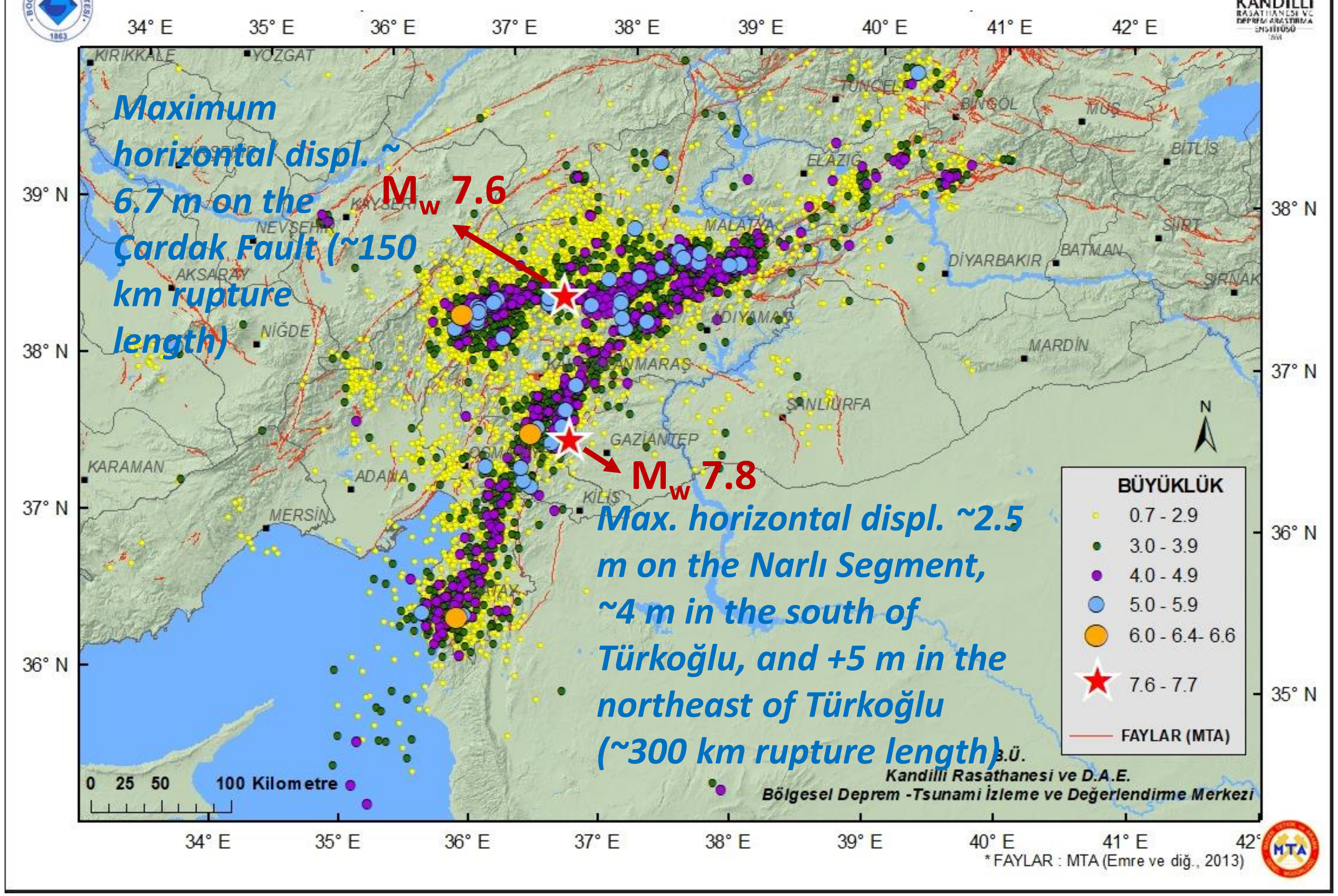
OUTLINE

01| Kahramanmaraş Earthquakes

Epicenters of February 6th M_w 7.8 and M_w 7.6 mainshocks and aftershocks (M ≥1) as of 29.05.2023



Southwestern parts of the EAFZ are reactivated during the February 6, 2023 earthquakes:
Narlı segment and EAF are activated during the M_w 7.8 event occurred at 04:17 (local time)
Çardak-Sürgü Fault is reactivated during the M_w 7.6 event occurred at 13:24 (local time)

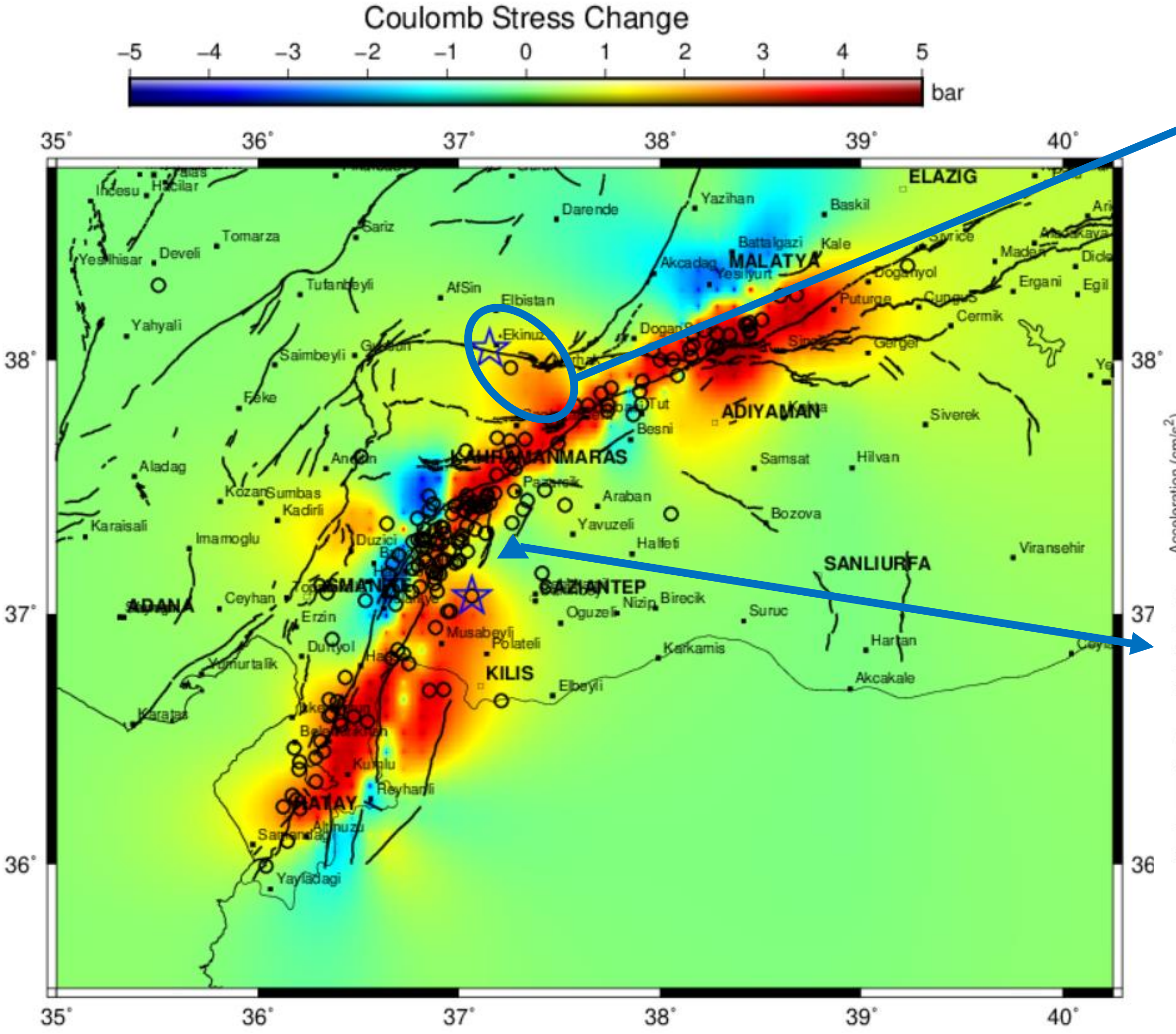
The ruptures occurred on the segments where M +7 earthquakes have not been occurred for several hundred years.

- *The 1513 (M > 7.4) and the 1114 events (M?) are the previous M+7 events on the SW part of EAFZ.*
- *The 1544 (M 6.7) event is the last largest earthquake on the Çardak-Sürgü Fault*

The instrumental data indicate infrequent M_w +4 events on the SW segments of the EAFZ where the M_w 7.8 earthquake occurred. There are no contemporary M_w +4 events reported on the Çardak-Sürgü Fault where the M_w 7.6 event occurred.

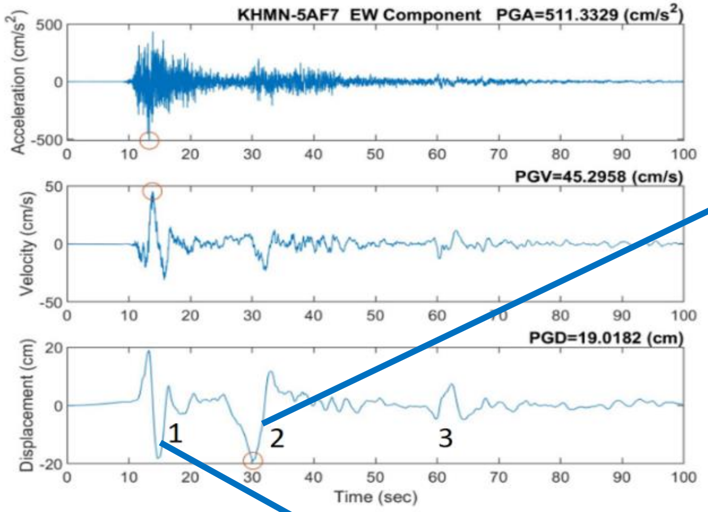
01| Kahramanmaraş Earthquakes *(M_w 7.8 event, Coulomb stress distribution, bilateral rupture)*

Coulomb stress change model of the M_w 7.8 earthquake



The Coulomb stress model of the M_w 7.8 event suggests a stress increase in the Eastern part of the Çardak-Sürgü fault resulting in a rupture on this fault segment (M_w 7.6) nine hours after the first earthquake

Strong-motion data recorded at ~30 km NE of the M_w 7.8 event



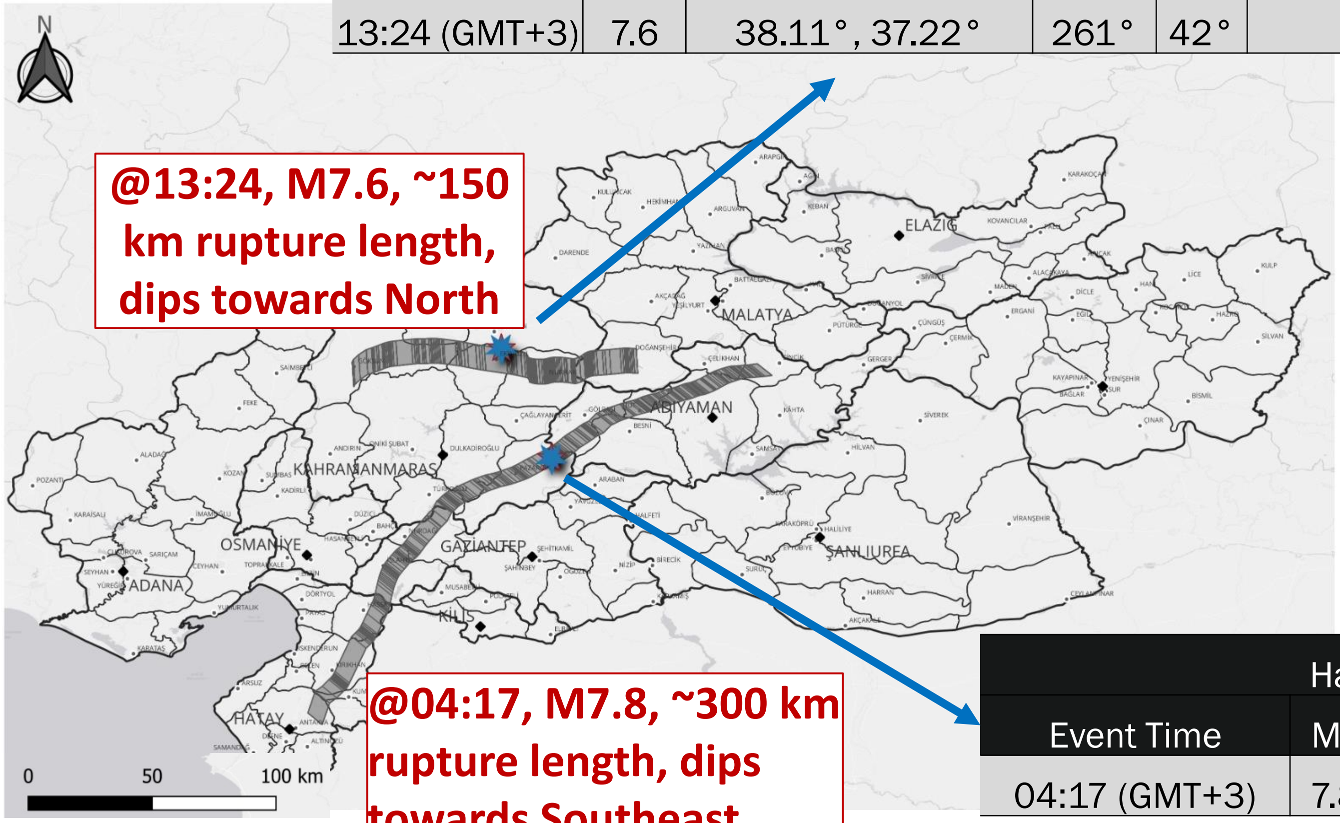
rupture propagation outwards the strong-motion station towards southwest

rupture propagation towards the strong-motion station

Bilateral rupture oriented towards NE and SW of EAFZ

01| Kahramanmaraş Earthquakes *(Ruptured segments)*

Harvard Centroid Moment Tensor Solution						
Event Time	M_w	Epicenter (Lat-Lon)	Strike	Dip	Depth (km)	L_{rup} (km)
13:24 (GMT+3)	7.6	38.11°, 37.22°	261°	42°	12	~150 km

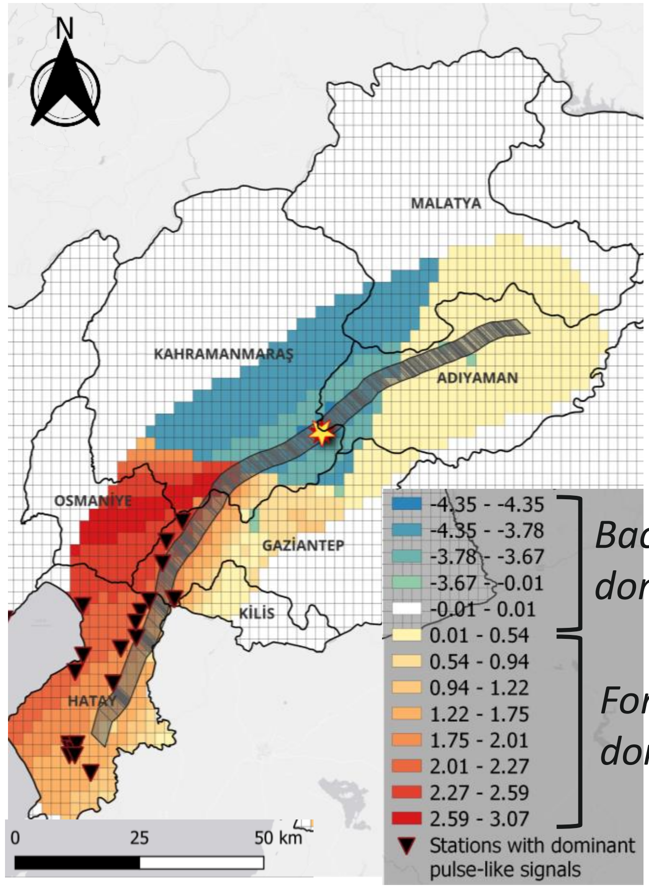


These two major events are recorded by **+379** strong-motion stations with maximum rupture distance of **~630** km. Some of the recorded ground motions feature dominant directivity effects. The most significant aftershocks of the Kahramanmaraş earthquakes are the **Nurdağı (M6.8)** and **Yayladağı (M6.3)** events

Harvard Centroid Moment Tensor Solution						
Event Time	M_w	Epicenter (Lat-Lon)	Strike	Dip	Depth (km)	L_{rup} (km)
04:17 (GMT+3)	7.8	37.56°, 37.47°	54°	70°	14.9	~292 km

01| Kahramanmaraş Earthquakes *(Directivity from Chiou and Spudich, 2013)*

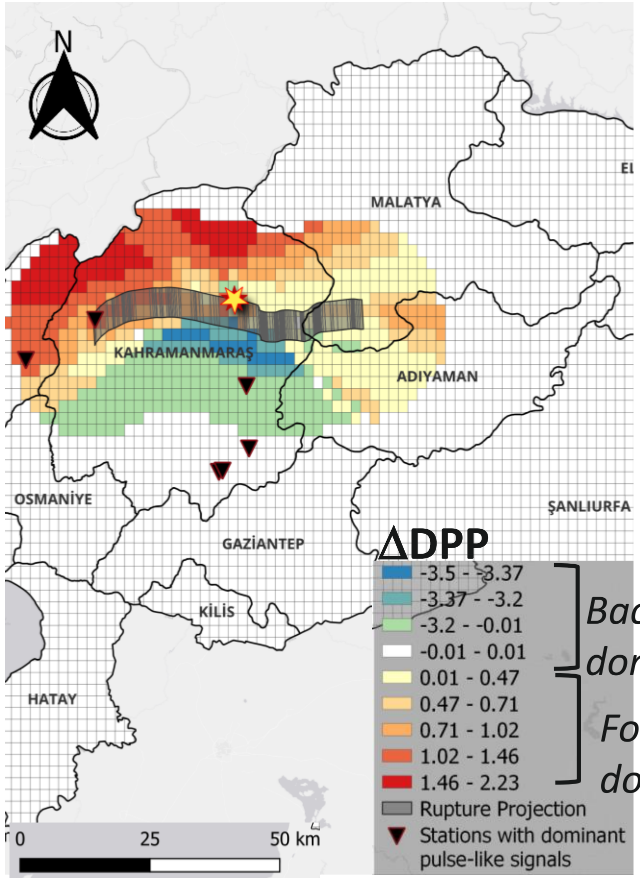
M_w 7.8 earthquake at 04:14 on Feb. 6th



Backward directivity dominant regions

Forward directivity dominant regions

M_w 7.6 earthquake at 13:24 on Feb. 6th



Backward directivity dominant regions

Forward directivity dominant regions

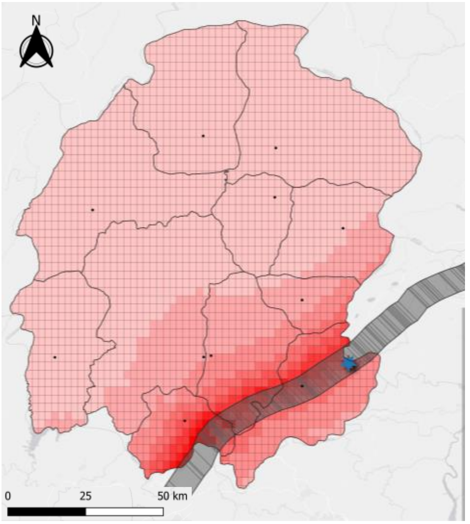
- Mostly Hatay, Gaziantep as well as Adıyaman provinces are subject to forward directivity in the first event (M_w 7.8).
- The forward directivity is prominent at Adıyaman and the North of Kahramanmaraş in the second event (M_w 7.6).

01| Kahramanmaraş Earthquakes *(Estimated ground-motion fields at Kahramanmaraş –Directivity included-)*

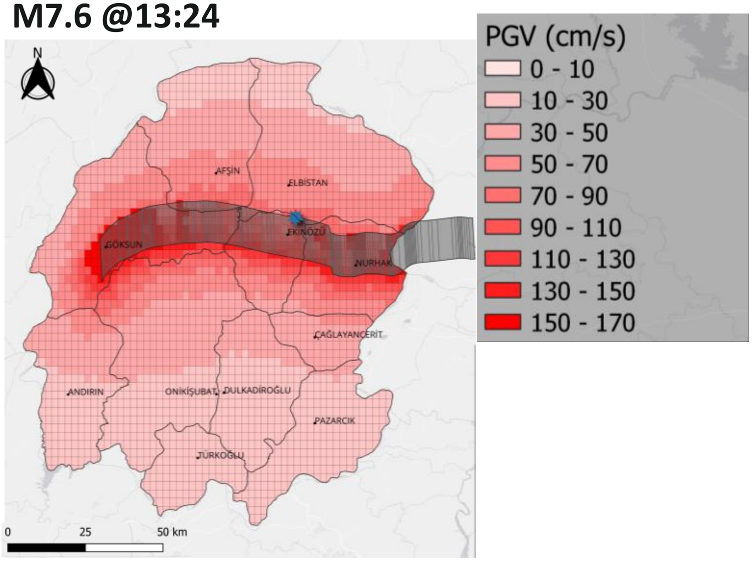
Forward directivity Included

PGV Distribution (84 percentile)

M7.8 @4:14



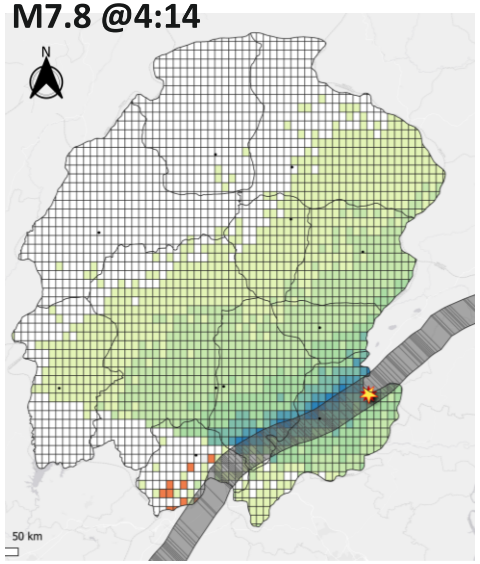
M7.6 @13:24



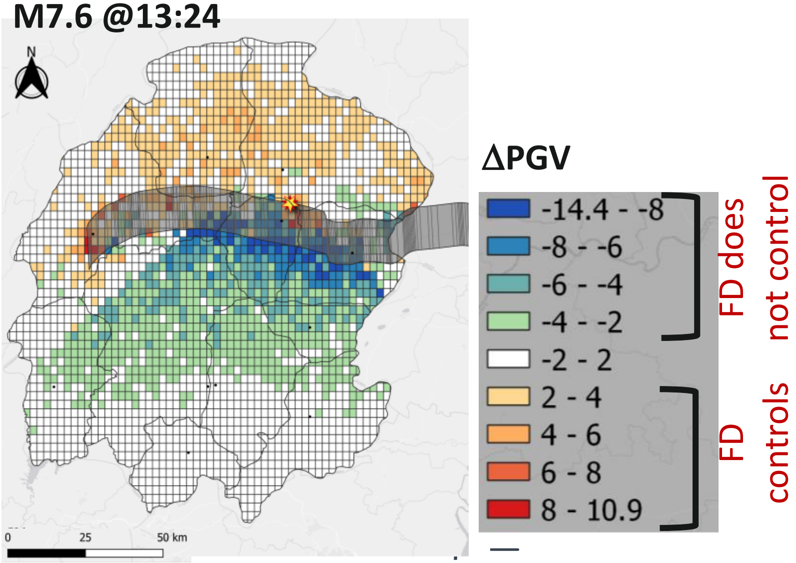
For the first event, Kahramanmaraş province is mainly in the backward directivity region-it does not necessarily mean that PGVs are small-

$\Delta PGV = PGV_{directivity\ model} - PGV_{no\text{-}directivity model}$ (84 percentile)

M7.8 @4:14



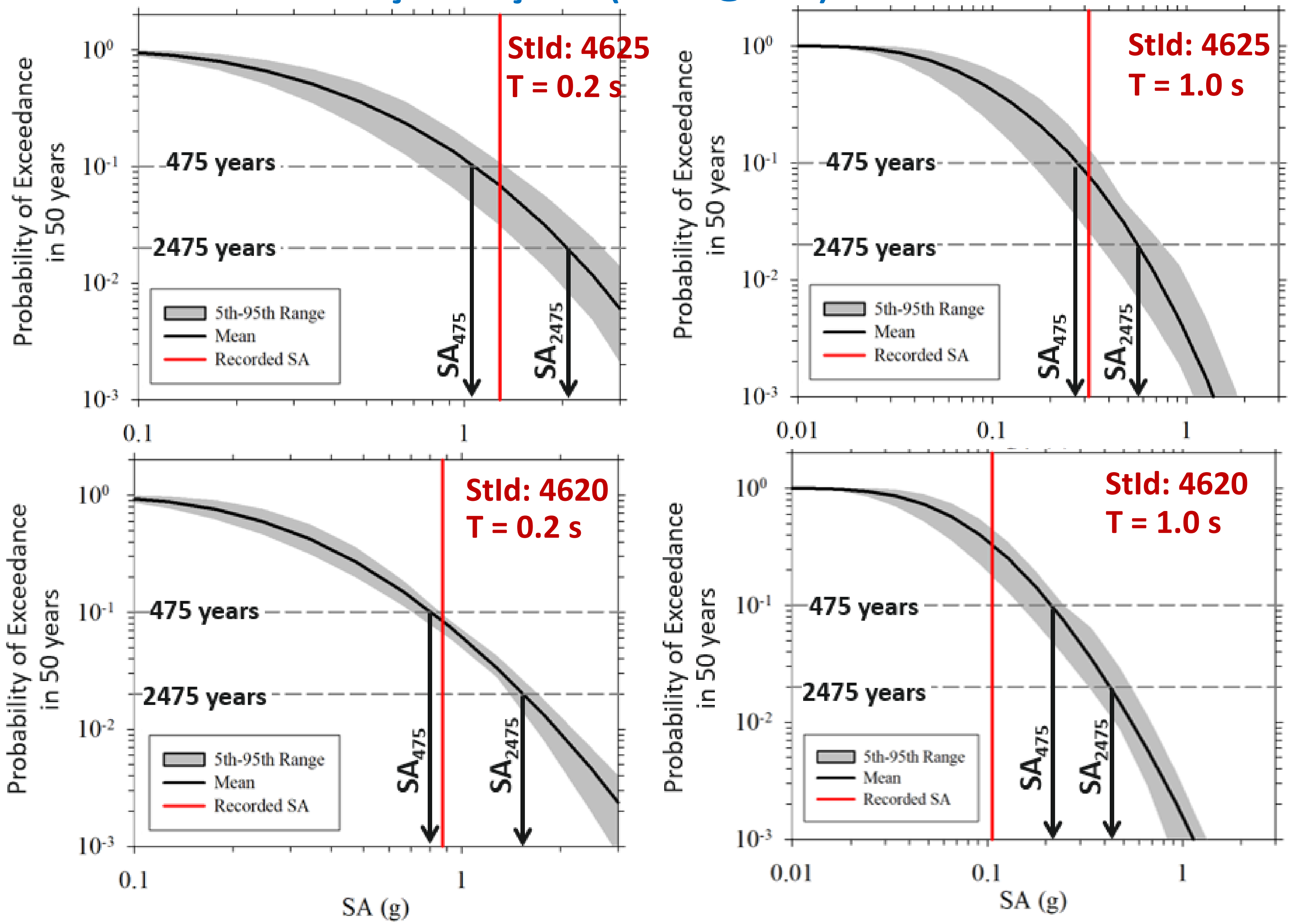
M7.6 @13:24



North of Kahramanmaraş province is controlled by forward directivity in the second event

01 | Kahramanmaraş Earthquakes *(Comparisons with current national hazard map)*

Kahramanmaraş- Onikişubat (M7.8 @4:14)



Observed ground-motion SA at T = 0.2 s and T = 1.0 s are mostly in between reference rock 475-year and 2475-year mean hazard spectral ordinates of national seismic code

Disclaimer

- *This observation is limited to two recording sites at the Onikişubat sub-province of Kahramanmaraş.*
- *Observed ground motion is rescaled for reference rock conditions (V_{S30} = 760 m/s)*

02| Loss model components investigated

Given a specific event with magnitude $M_W = m_w$ and a single risk at a site $R_{RUP} = r_{rup}$ km from the ruptured fault segment, the probability of loss exceeding a specific threshold *l* ($P(L \geq l)$) is

$$P(L \geq l) = \sum_{i=1}^{n} \underbrace{P(L \geq l | IM = im_i, V_{S30} = v_{s30})}_{\text{Loss conditioned on ground motion (vulnerability)}} \cdot \underbrace{P(IM = im_i | V_{S30} = v_{s30})}_{\text{Ground motion conditioned on } V_{S30}} \cdot \underbrace{P(V_{S30} = v_{s30})}_{\text{Soil condition } (V_{S30})}$$

The above expression indicates that the uncertainty in

a. Vulnerability model and
b. soil conditions at the site of interest (provided that the ground-motion model as well as the ground-motion intensity metric used in the loss analyses can unbiasedly represent the hazard and can rationally correlate with damage)

If the loss estimations are for a building portfolio, the uncertainty in the spatial distribution of portfolio as well as its granularity (in terms of structural types) will also be the other points of concern in loss modeling

Notwithstanding, the Kahramanmaraş earthquakes challenge the loss modeling by the two sequential major earthquakes, occurring with nine hours of difference, that amplify the damage of the insured assets in the portfolio

02| Loss model components investigated

Under the explanations given in the previous slides, this presentation focuses on the uncertainties in

V_{S30} (parameter describing the soil conditions at portfolio sites)

- *Median V_{S30} vs. V_{S30} distribution at each portfolio site*

Spatial distribution of portfolio

- *Portfolios lumped at the district centers*
- *Portfolios distributed at 0.1, 0.05 and 0.025 degree cells within the provinces*

Vulnerability models

- *Mean vulnerability vs. vulnerability distribution*

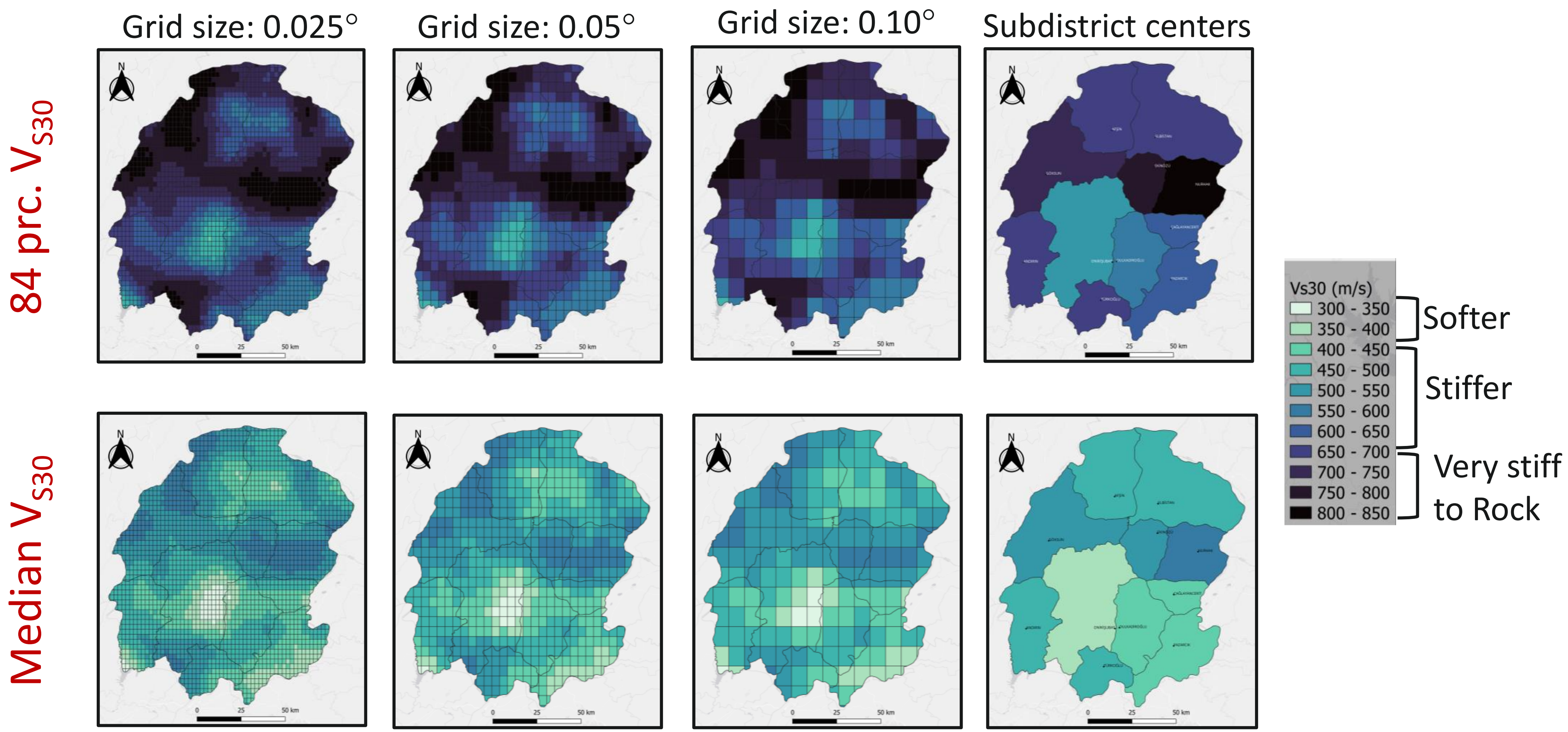
Granularity of portfolio

- *Policies as is (distributed over geological coordinates)*
- *All policies in the portfolio are mid-rise (4 to 9 story buildings) and are lumped at the district centers*
- *All policies in the portfolio are low-code (built before 1975) and are lumped at the district centers*
- *All policies in the portfolio are mid-rise (4 to 9 story buildings) and low-code (built before 1975). They are lumped at the district centers*

Modeling of two sequential events

- *Two events separately*
- *Aggregate the damaging effects of two sequential events with alternative damage models*

02| Loss model components investigated *(Uncertainty in V_{S30} and consequences on spatial distribution)*



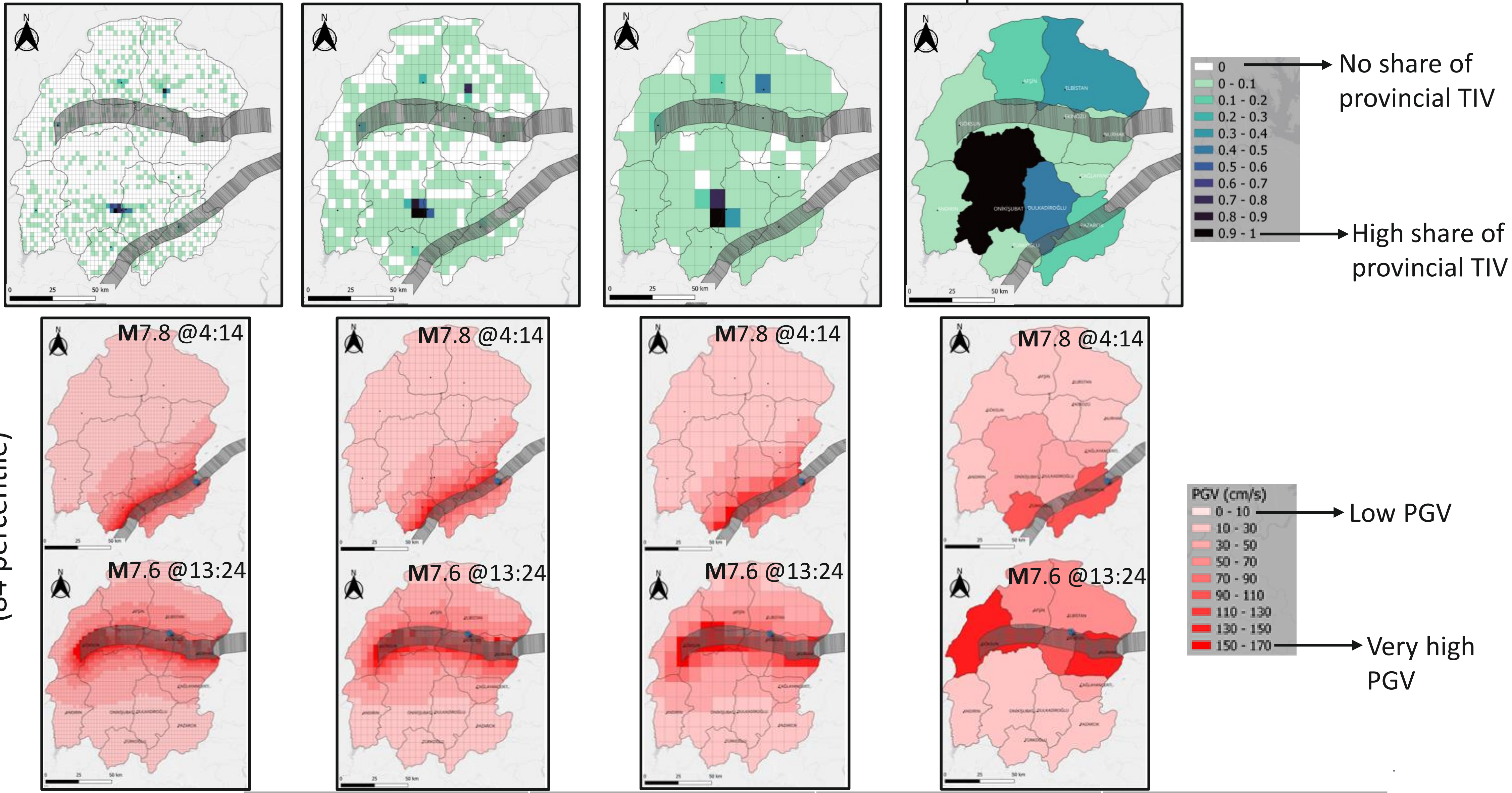
From fine-to-gross grid structure the variation in soil conditions is captured at different levels (the coarsest grid structure is defining everything at the subdistrict centers

02| Loss model components investigated *(Portfolio distribution and consequences on grid size - emphasis on ground-motion distribution-)*

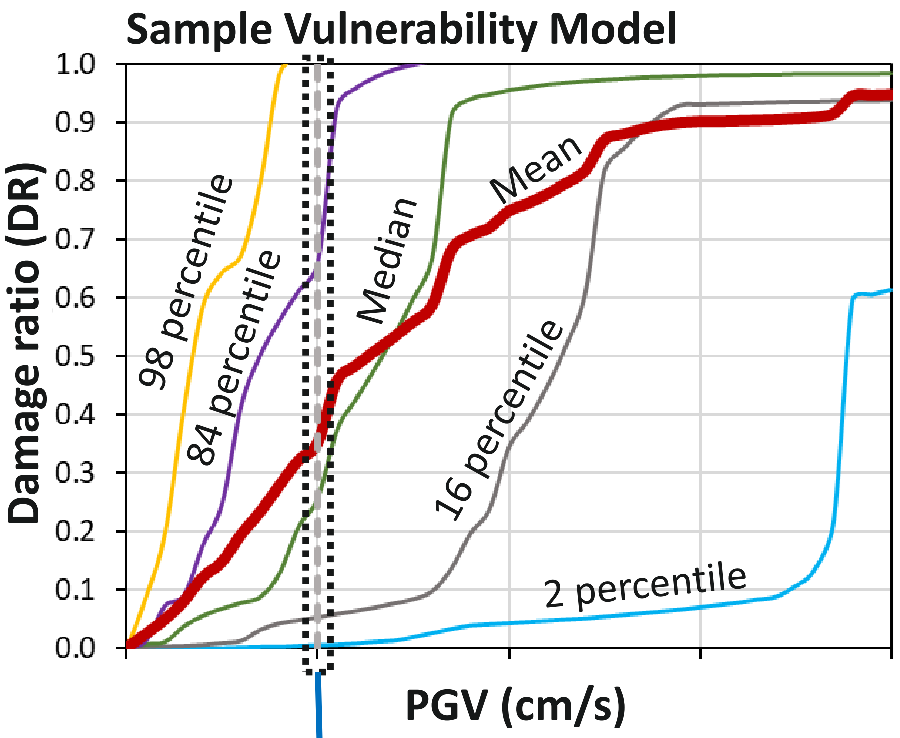
Grid size: 0.025° | Grid size: 0.05° | Grid size: 0.10° | Sub-province centers

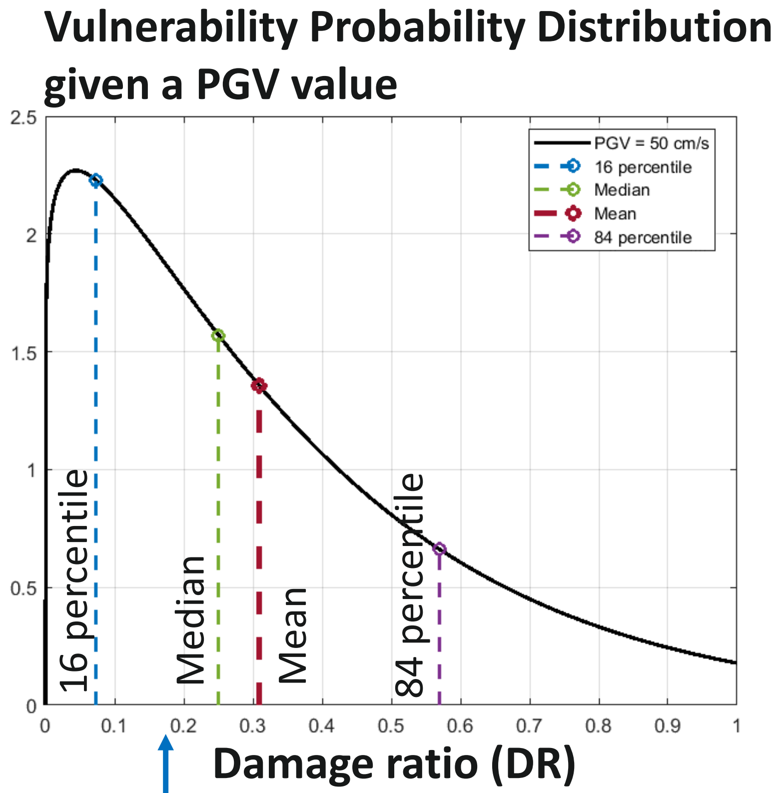
Portfolio Distributed (as normalized TIV)

PGV Distribution (84 percentile)



02| Loss model components investigated *(Vulnerability models: mean vs. distribution)*

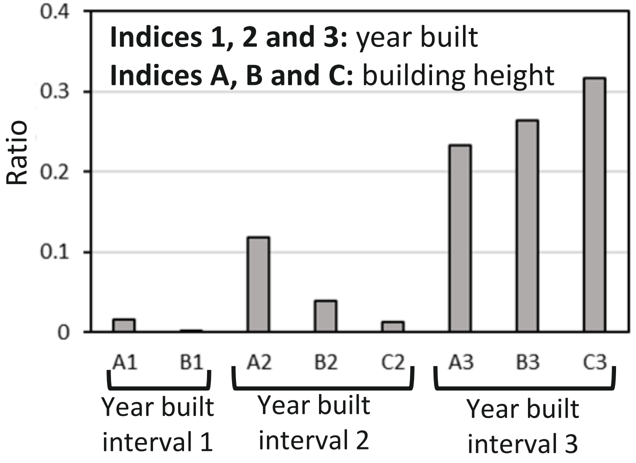




02| Loss model components investigated *(Portfolio granularity and consequences on damage modeling of portfolio)*

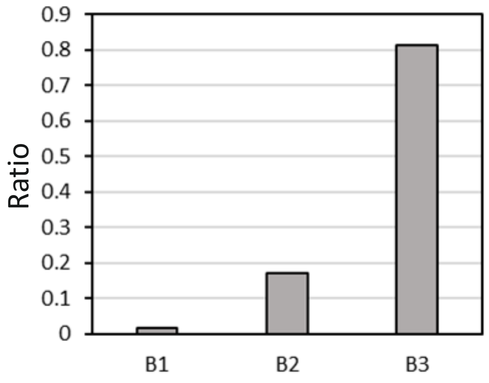
Original portfolio

Portfolio as is

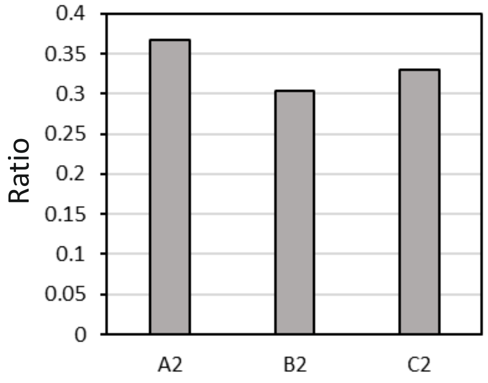


Portfolios derived from original portfolio at different levels of granularity

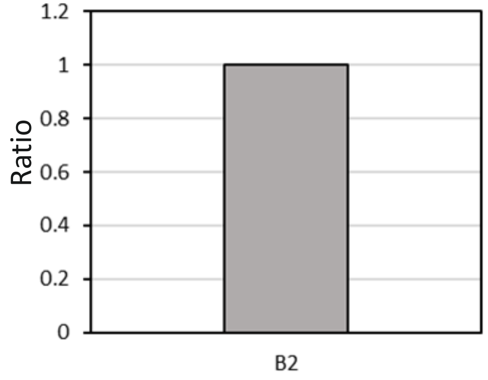
Building variation is disregarded



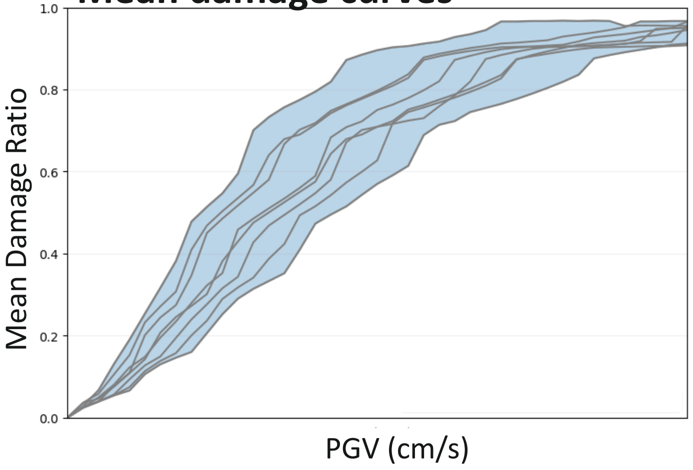
Year built is disregarded



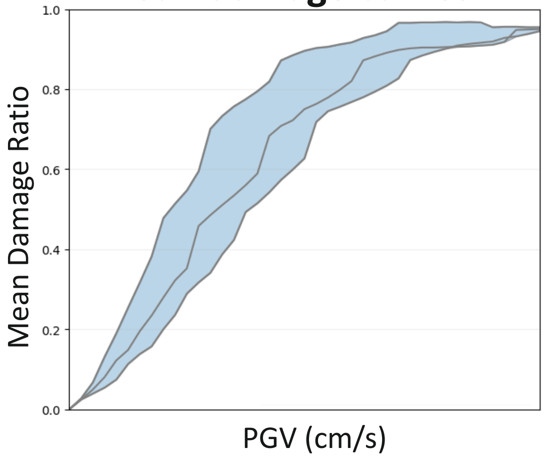
Building height and year built are disregarded



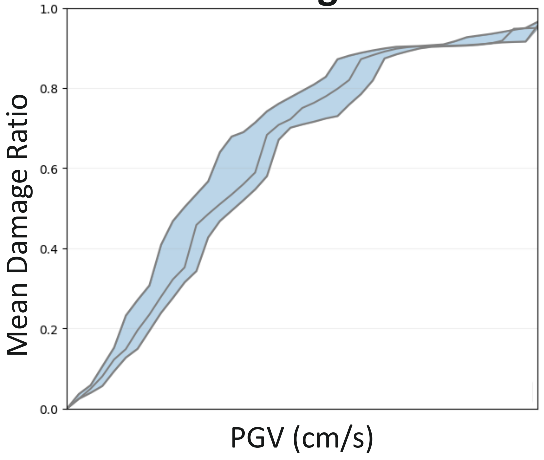
Mean damage curves



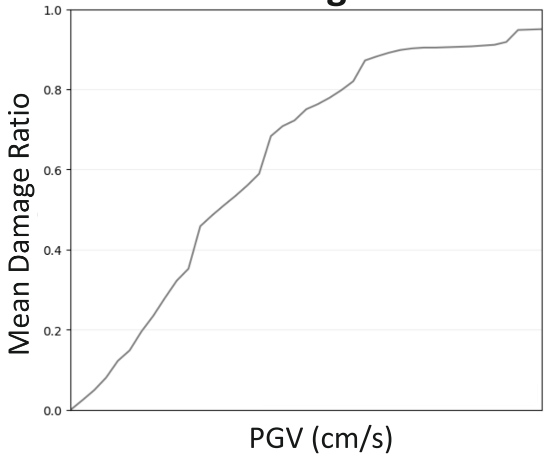
Mean damage curves



Mean damage curves

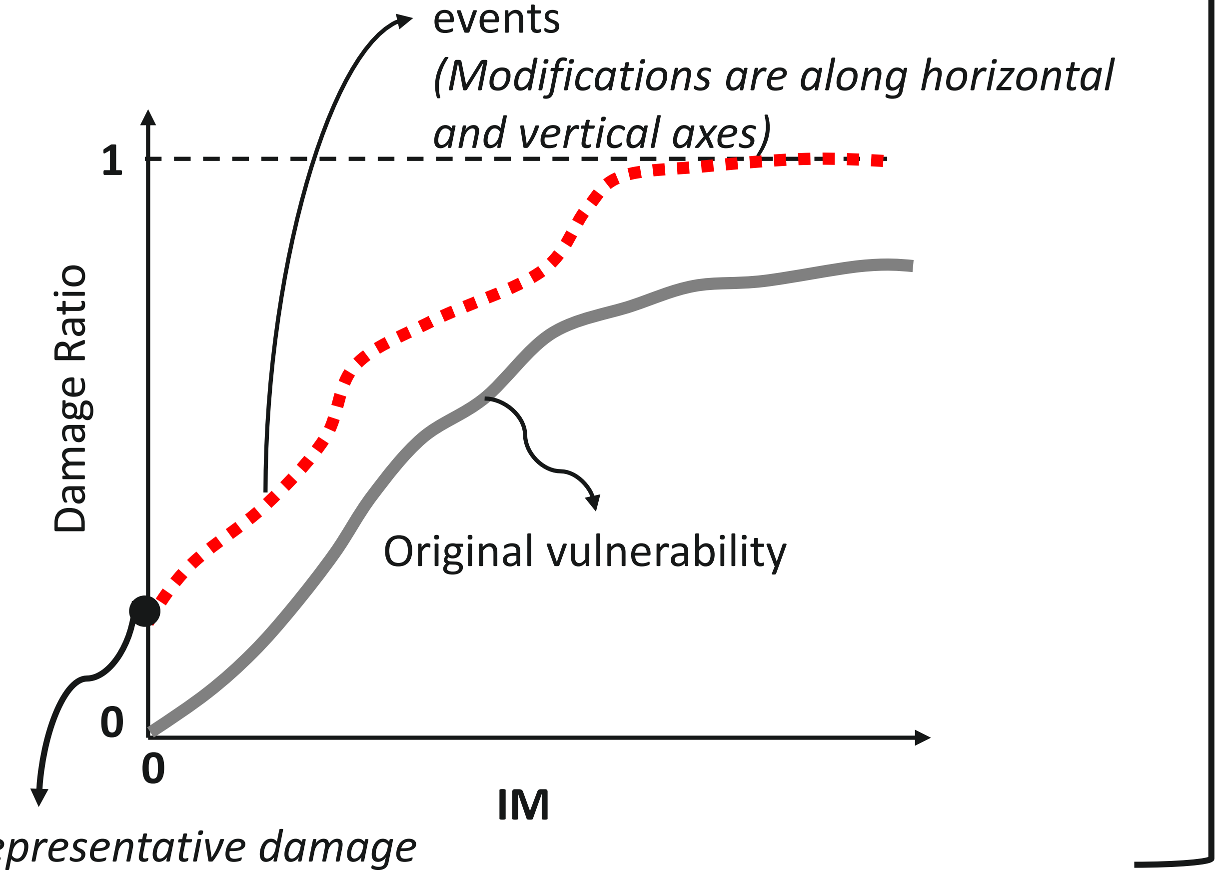


Mean damage curve



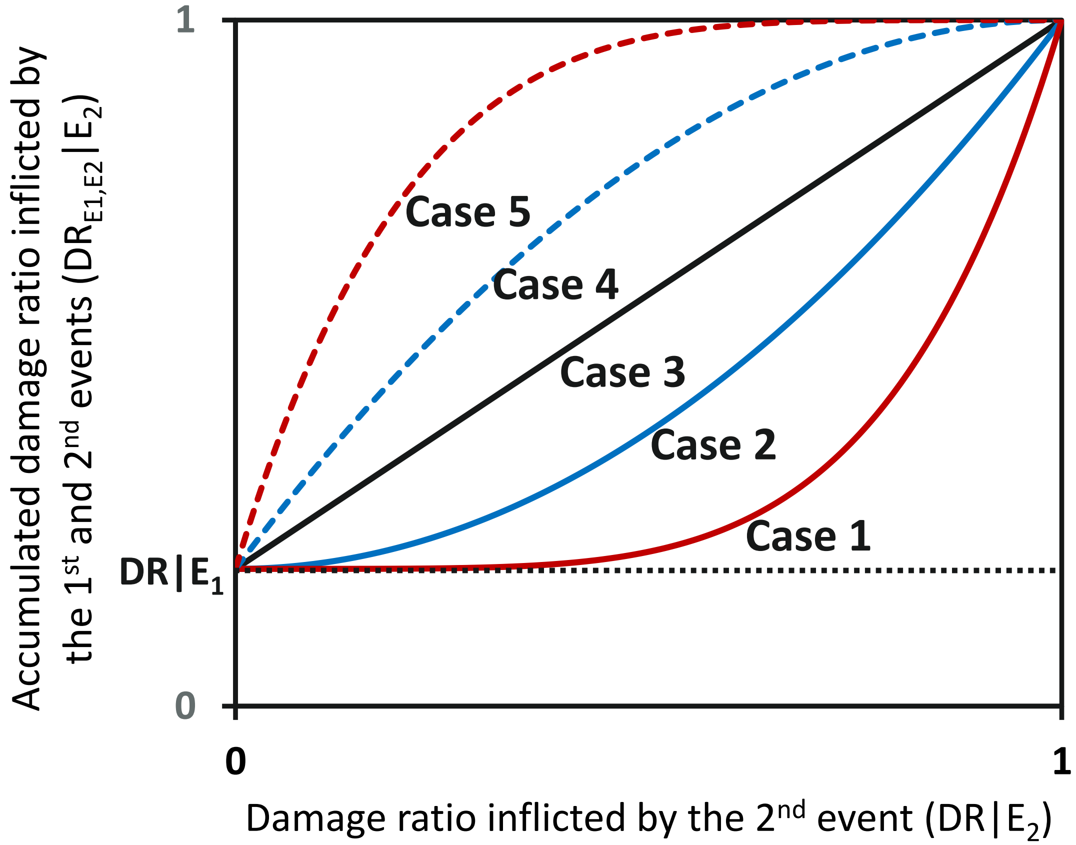
02| Loss model components investigated *(Consideration of sequential earthquakes on loss)*

Modified vulnerability due to damage incurred in the 1st and 2nd events
(Modifications are along horizontal and vertical axes)



Representative damage ratio incurred in the 1st event ($DR|E_1$)

Sample cases of modifying models used to account for damage incurred in the 1st and 2nd events together

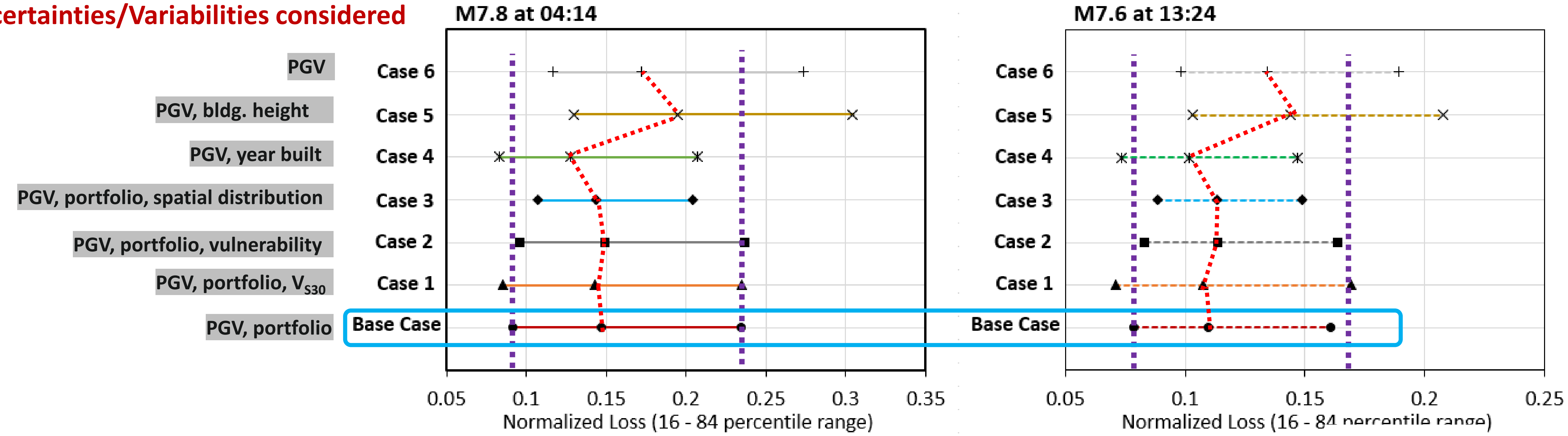


There can be different models to describe different damage modalities

03| Observations *(Influence of V_{S30}, vulnerability modeling, spatial distribution of portfolio and portfolio granularity on estimated loss)*

Case	Portfolio granularity	Portfolio spatial distribution	Vulnerability	V_{S30}
Base Case	**As is**	**Lumped at each sub-province center**	**Mean vulnerability curves**	**Mean V_{S30}**
Case 1	As is	Lumped at each sub-province center	Mean vulnerability curves	Distributed V_{S30}
Case 2	As is	Lumped at each sub-province center	Distributed vulnerability models	Mean V_{S30}
Case 3	As is	Distributed over 0.025 degree grids	Mean vulnerability curves	Mean V_{S30}
Case 4	Disregard building height variation	Lumped at each sub-province center	Mean vulnerability curves	Mean V_{S30}
Case 5	Disregard year built	Lumped at each sub-province center	Mean vulnerability curves	Mean V_{S30}
Case 6	Disregard both building height and year built	Lumped at each sub-province center	Mean vulnerability curves	Mean V_{S30}

Uncertainties/Variabilities considered

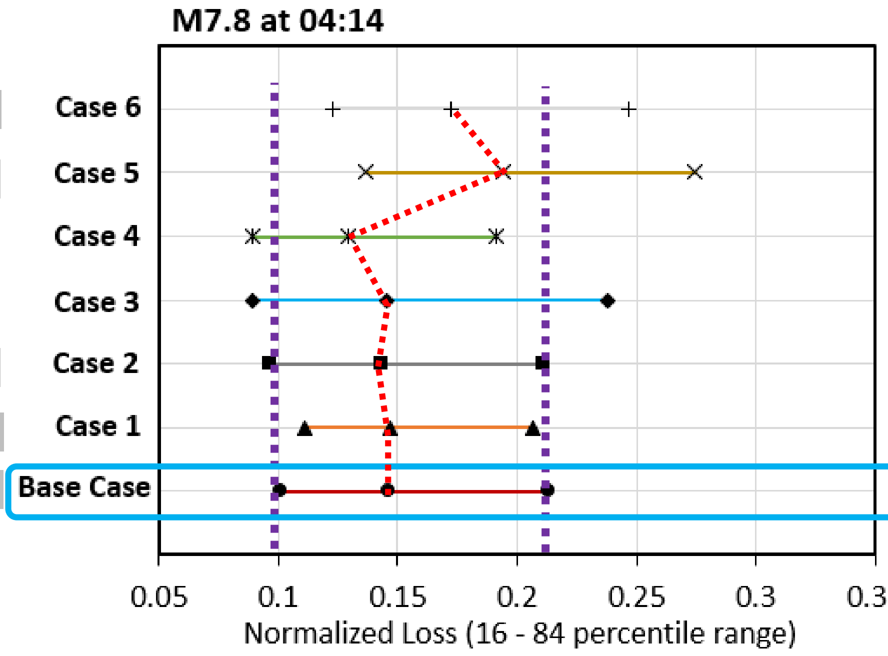


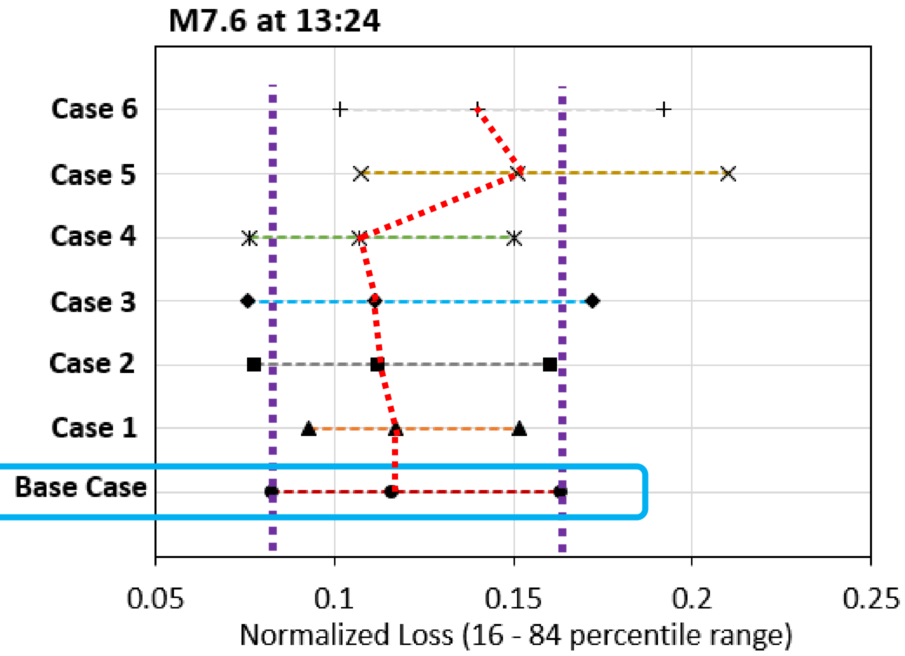
03| Observations *(Influence of V_{S30}, vulnerability modeling, spatial distribution of portfolio and portfolio granularity on estimated loss)*

Case	Portfolio granularity	Portfolio spatial distribution	Vulnerability	V_{S30}
Base Case	**As is**	**Distributed over 0.025 degrees**	**Distributed vulnerability models**	**Distributed V_{S30}**
Case 1	As is	Distributed over 0.025 degrees	Distributed vulnerability models	Mean V_{S30}
Case 2	As is	Distributed over 0.025 degrees	Mean vulnerability curves	Distributed V_{S30}
Case 3	As is	Lumped at each sub-province center	Distributed vulnerability models	Distributed V_{S30}
Case 4	Disregard building height variation	Distributed over 0.025 degrees	Distributed vulnerability models	Distributed V_{S30}
Case 5	Disregard year built	Distributed over 0.025 degrees	Distributed vulnerability models	Distributed V_{S30}
Case 6	Disregard both building height and year built	Distributed over 0.025 degrees	Distributed vulnerability models	Distributed V_{S30}

Uncertainties/variabilities considered

- PGV, vulnerability, V_{S30} (Case 6)
- PGV, bldg. height , vulnerability, V_{S30} (Case 5)
- PGV, year built , vulnerability, V_{S30} (Case 4)
- PGV, portfolio, vulnerability, V_{S30} (Case 3)
- PGV, portfolio, spatial distribution, V_{S30} (Case 2)
- PGV, portfolio, spatial distribution, vulnerability (Case 1)
- PGV, portfolio, spatial distribution, vulnerability, V_{S30} (Base Case)





03| Observations *(Overall remarks from previous two slides)*

1) A well-defined portfolio granularity → Leads to → Insignificant variations in median losses due to uncertainties in V_{S30}/vulnerability, as well as the spatial distribution of portfolio

2) Dispersion about median losses are sensitive to the uncertainties in V_{S30}/vulnerability as well as the spatial distribution of portfolio → But → if portfolio granularity is well-defined, betterment in portfolio's spatial distribution results in a decrease in dispersion about median loss

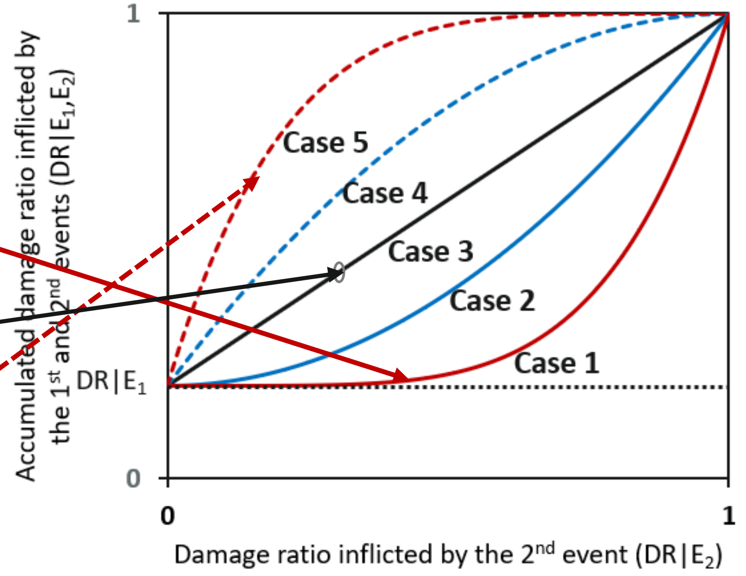
3) Intricate interaction between loss and V_{S30}/vulnerability uncertainty → This is because → V_{S30} uncertainty affects the ground-motion distributions, which eventually affects the loss distribution due to inflated/deflated vulnerability uncertainty

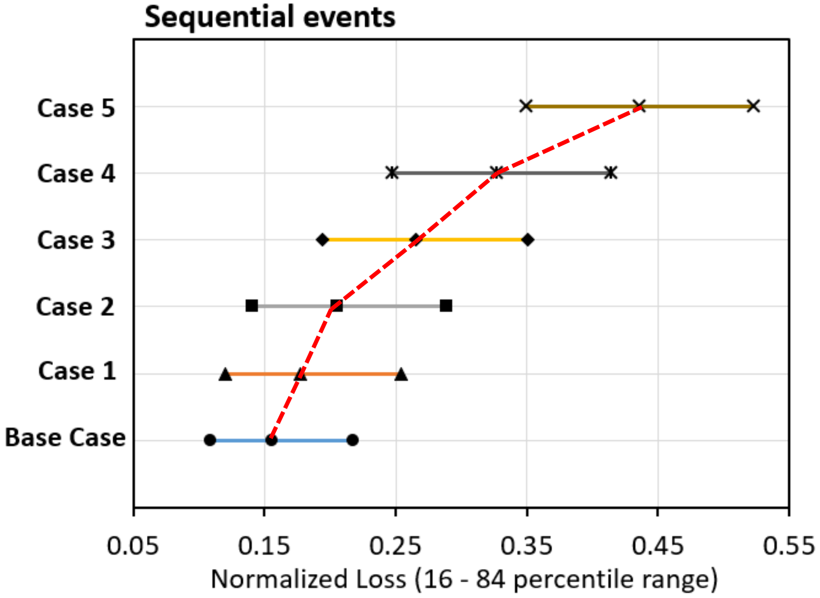
4) Underreported portfolio granularity (height variation/year built) shifts the loss distribution → This is because → The damage modalities of the portfolio are biasedly affected due to deficient physical properties of assets in the portfolio

03| Observations *(Modeling of sequential earthquakes)*

- ***Portfolio is lumped at the sub-province centers/V_{S30} as distribution/Vulnerability as distribution***

Case	Assumption
Base Case	**Maximum loss of 1st and 2nd earthquakes**
Case 1	Portfolio exhibits very slow deterioration after 1st earthquake
Case 2	Portfolio exhibits slow deterioration after 1st earthquake
Case 3	Portfolio exhibits moderate deterioration after 1st earthquake
Case 4	Portfolio quickly deteriorates after 1st earthquake
Case 5	Portfolio severely deteriorates after 1st earthquake





Variations in modifying models change the loss distributions as each time the portfolio damage modality changes

03| Observations *(Modeling of sequential earthquakes)*

Step #1 Collect damage states of building portfolio from public-open databases and computing a “reference damage index” to select a “fairly suitable” modifying model among the alternatives that are tailored to estimate portfolio loss subjected to sequential earthquakes.

Step #2 Perform loss analyses with the alternative modifying models. The resolution of the damage data would be the guidance on the level of complexity in loss calculations. For example, loss estimations are at sub-province level, if compiled damage data is very crude.

Step #3 Compare loss estimations of alternative modifying models with reference damage indices by, for example, error analysis.

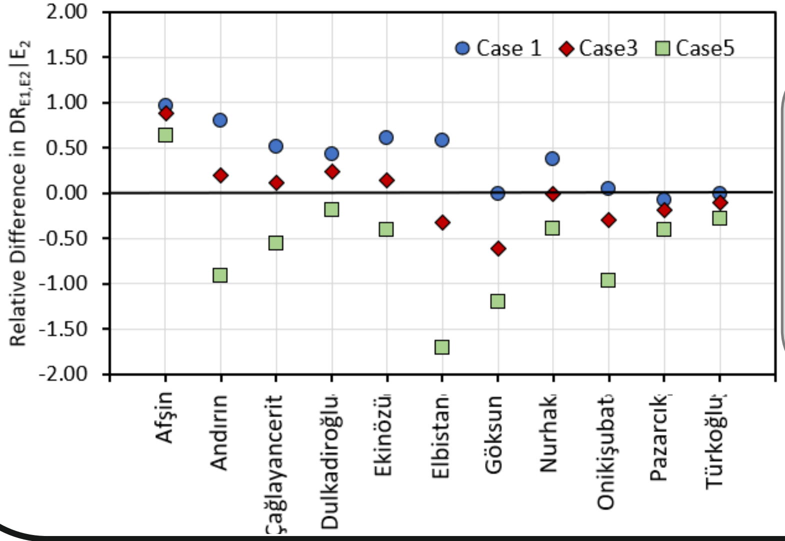
03| Observations *(Modeling of sequential earthquakes)*

Step #1 *Public open data (Ministry of EUC as of 27/02/2023)*

Compound loss determined from local fragility studies

Sub-province	No Damage	Light	Moderate	Severe	Collapse	Reference Index
Afşin	49.0%	28.2%	1.2%	17.5%	4.0%	0.25
Andırın	68.0%	22.7%	2.1%	6.2%	1.0%	0.10
Çağlayancerit	42.4%	32.6%	4.3%	16.8%	3.8%	0.25
Dulkadiroğlu	45.0%	30.1%	2.1%	16.4%	6.3%	0.26
Ekinözü	27.9%	22.3%	6.9%	37.0%	6.0%	0.47
Elbistan	61.9%	23.3%	0.7%	7.9%	6.3%	0.17
Göksun	33.4%	29.2%	3.3%	26.4%	7.7%	0.38
Nurhak	15.3%	29.4%	3.5%	37.5%	14.3%	0.56
Onikişubat	46.4%	37.2%	3.1%	10.7%	2.6%	0.18
Pazarcık	33.8%	31.9%	1.7%	22.6%	10.0%	0.36
Türkoğlu	37.5%	31.5%	2.1%	17.7%	11.2%	0.33

Step #3 *Relative differences of each model wrt Reference Index*



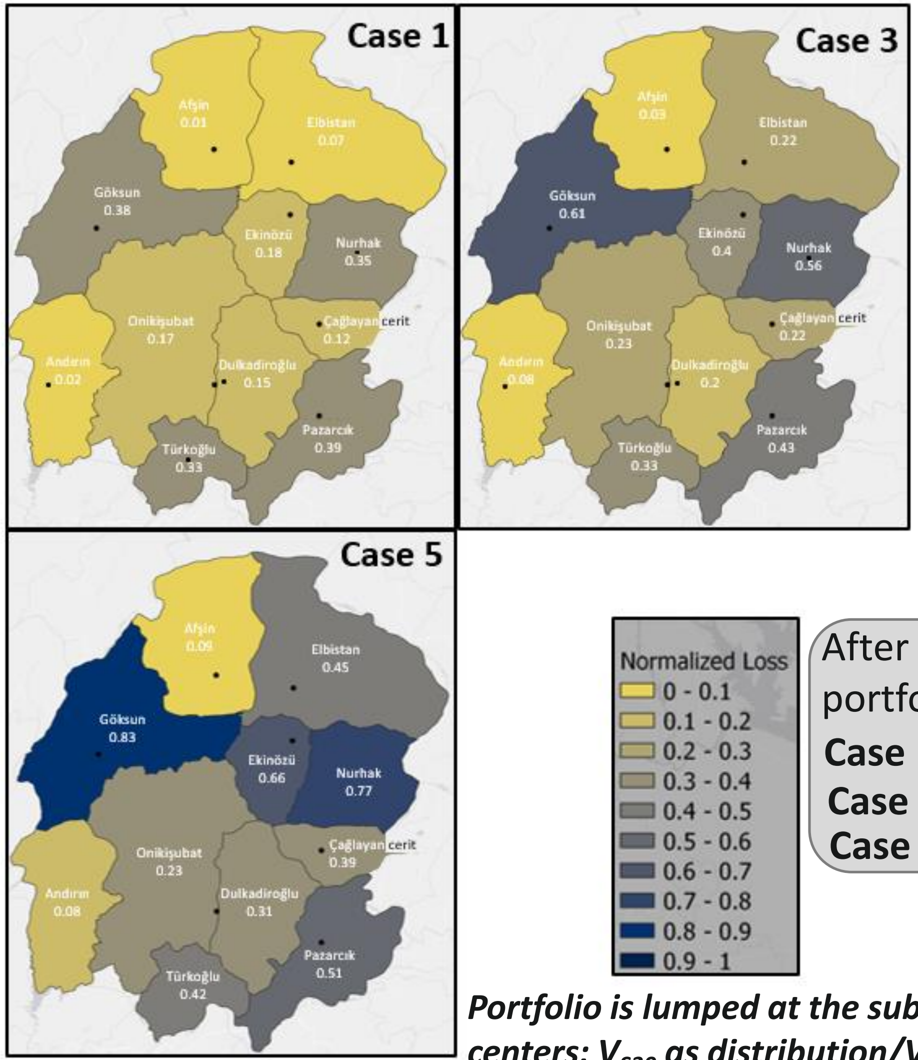
Averages of relative differences for each model:

Case 1: 0.38

Case 3: 0.01

Case 5: -0.58

Step #2 *Normalized median losses of each sub-province by the corresponding TIV with alternative modifying models*



After 1st event, portfolio deteriorates

Case 1: very slowly

Case 3: moderately

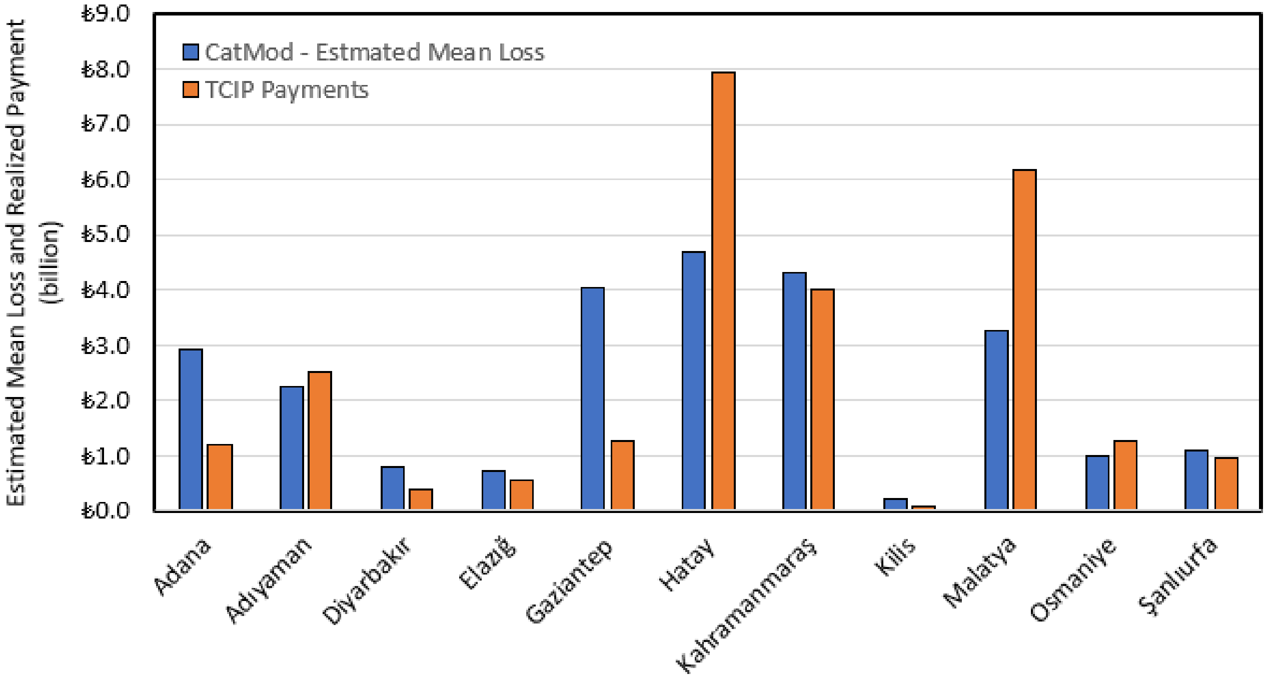
Case 5: severely

Portfolio is lumped at the sub-province centers; V_{S30} as distribution/Vulnerability as distribution

03| Observations *(Modeling of sequential earthquakes – Estimated mean losses and comparisons with TCIP payouts)*

Using Model 3 to account for sequential earthquakes of M7.8 and M7.6 – Portfolio as is; lumped at sub-province centers; uncertainty in site conditions and vulnerabilities

	Estimations by CatMod		
Province	**Mean Loss (billion)**	**Standart Deviation**	**TCIP Payout (07/06/2023)**
Adana	₺2.935	₺1.141	₺1.212
Adıyaman	₺2.242	₺0.842	₺2.504
Diyarbakır	₺0.780	₺0.348	₺0.371
Elazığ	₺0.735	₺0.591	₺0.558
Gaziantep	₺4.057	₺1.863	₺1.274
Hatay	₺4.698	₺1.379	₺7.932
Kahramanmaraş	₺4.310	₺1.374	₺4.001
Kilis	₺0.214	₺0.175	₺0.086
Malatya	₺3.256	₺1.447	₺6.165
Osmaniye	₺0.984	₺0.476	₺1.260
Şanlıurfa	₺1.094	₺0.413	₺0.958



Mean estimated loss: ₺25.31 billion

Current TCIP payments: ₺26.32 billion (estimated to reach ~ ₺30 billion)

The theme of this year's GEM Conference is "*Are we making a difference?*"

And in my opinion, "YES WE DO." But as in all fields, the progress in catastrophe risk modeling is still facing a lot of challenges as different players in catastrophe risk have their own perspectives per "challenges" they are faced.

In order to overcome these challenges, interaction between different players in catastrophe risk is a "MUST"

As a person with academic origin, I can only comment about the "*research-based interaction*" component of this interaction.

The earthquake risk modeling of Kahramanmaraş Earthquakes **taught me** and also **reminded me** how important to "interact" with risk modelers of different perspectives.

Through online and f2f meetings, I exchanged a lot of information with local and worldwide scientists/modeling professionals working in different components of earthquake risk modeling.

I went over the previous work done by GEM, traced the old local studies in Turkiye, used my learnings from past studies (SHARE, NERA, EMME, STREST, SERA, DASK, TSB, …), talked with the scientists who work on the recordings of Kahramanmaraş Earthquakes, and etc.

I learned from them and they learned from me. And **I found** my own way to handle the challenges I faced to solve the problem (damage data, trustable ground motions, rupture features, vulnerabilities etc).

There are a lot of unknowns in earthquake risk modeling and there are many approaches to solve them because this topic has "NO TRUTH" but only RATIONALE and DEFENDABLE approaches. And, to achieve them, we need to TALK more.

T-RUPT