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[1] **BRITISH GEOLOGICAL SURVEY**

Understanding multi-hazard cascades from the Türkiye 2023 Earthquakes

British Geological Survey

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Background & Context

Disaster details:

- 6th February 2023, 1st earthquake 04:17am, 2nd earthquake 13:24pm
- Affected Southern Türkiye, northern Syria
- >57,000 deaths, ~ 130,000 injured
- >$150 bn USD [*The Guardian*], including $34bn purely in damage costs
- 760,000 internally displaced people [*UNFPA*]
- 9.1 million affected [*UNFPA Situation Report, 5 February 2024*]

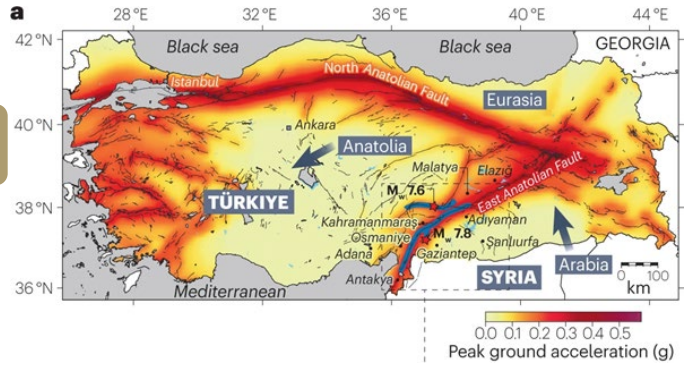
How did this hazard turn into such a disaster?

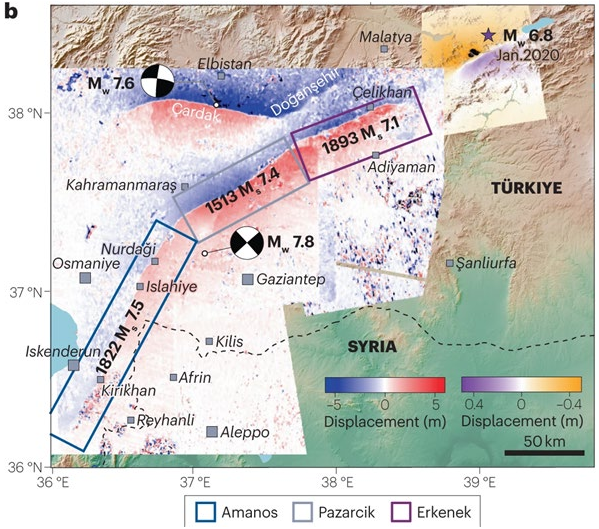
- Cascading and compounding hazards & impacts in a highly exposed area
- High social vulnerability of population to physical geohazards (poverty, building corruption)

What difficulties obstruct our ability to untangle the hazards and their impacts?

- Factors dominating post-seismic landslides and their compounded hazard with floods over such a large area are difficult to map together
- Such a large affected area cannot be ground surveyed quickly

The BGS along with several partner organisations are addressing these challenges through the ESA-funded project ***"Advancing knowledge of multi-hazard events and their impacts"***





Figures from E. Hussain et al, 2023

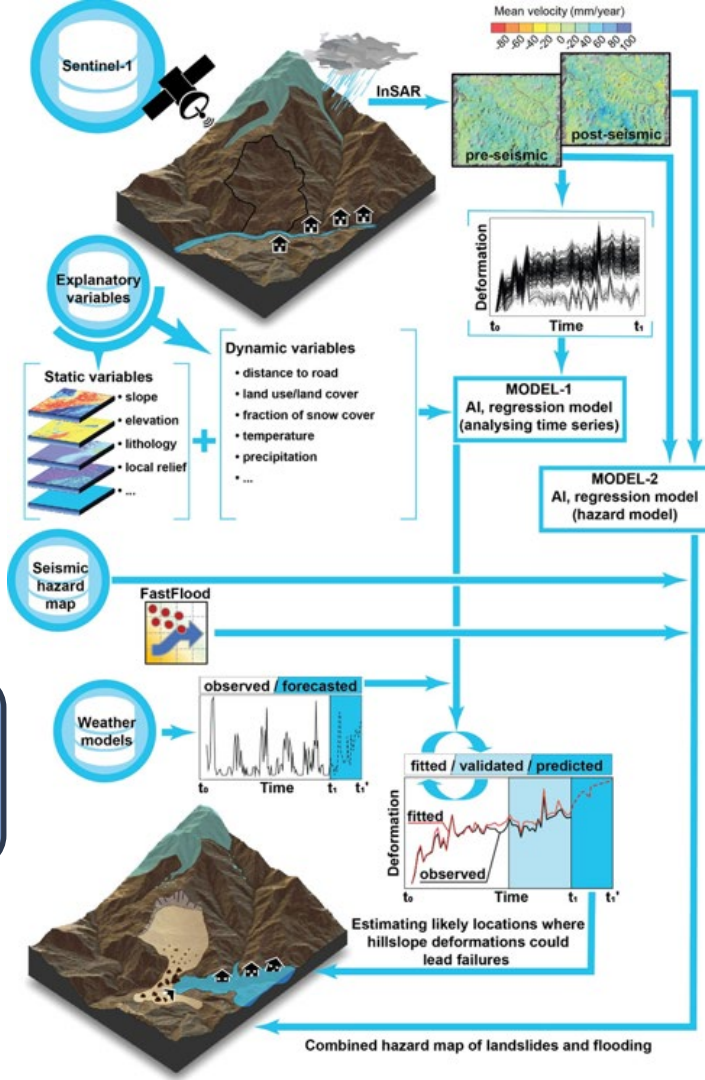
Background & Context

Want to determine not only landslides which were immediately caused by the earthquakes, but which ones were destabilised and failed in the far future, and any whose motion has been accelerated, to predict future failures

This presentation will cover **preliminary results** of a grey literature database of multi-hazard events, and the interactions of these hazards in seismic zones in a geospatial context

Focus on **cascading** and **compounding** hazards in small regions of the wider affected area of southern Türkiye

We will also present **EO-backed evidence** from InSAR analyses of landslides & surface ruptures reported in the database



Multi-hazard database

- Firstly, the earthquake events allowed us to construct a **post-event multi-hazard database** of significant **geological** and **hydrometeorological** events in the days and months immediately following the earthquakes
- Gathered data via literature search, social media posts, news reports, EO press releases…

Date of event, time (TRT)	Time (TRT)	Hazard	Is it in area of concern?	Size	Duration
before February 6th		Heavy rainfall	Y		
06/02/2023	04:17:00	Earthquake 1	Y	Mw 7.8	
06/02/2023	04:28:00	aftershock after earthquake 1	Y	Mw 6.8	
06/02/2023	~04:39	aftershock	Y	Mw 6.7	Lasted an hour and a half
06/02/2023		Landslides	Y	500m landslide	
06/02/2023	13:24:00	Earthquake 2	Y	Mw 7.7	
Arrived 25 mins after 1st earthqua	04:42:00-04:50	Small tsumani	Y	max. wave height of 14 cm at 4:50am	
warning: 15 min (after the earthquake)		Tsunami	Y	(12.3cm) at Erdemli, and (17cm) at Gazimagusa	
06/02/2023		Surface rupture	Y	Longest of the pair caused by first earthquake(Mw 7.8)measured	320km, while the 2nd measured 150km(Mw7.6)
06/02/2023		Landslides	Y	chasms roughly 500m long by 300m wide by 30m deep	Locals reported heavy rainfall for a few days leading
06/02/2023		Rockfall	Y	Countless rock falls observed	
06/02/2023		secondary effect- homelessness	Y		over half still remain homeless (01/08/2023)
06/02/2023		destroyed infrastructure and building	Y		ongoing reconstruction and aid - 01/08/2023
06/02/2023		homelessness	Y		ongoing reconstruction and aid - 01/08/2023
06/02/2023		Liquefaction	Y		
06/02/2023	onwards, "regular"	Flooding	Y		Regular flooding post-feb 6th
06/02/2023		Fires	Y	More than 1,000 containers caught on fire	Extinguished on 10th of February
06/02/2023		Ground motion	FEVIPASA	Ground acceleration of 1.62 g	
06/02/2023		Earthquake	N	***other countries***	Buildings shook for 40 seconds
06/02/2023-09/02/2023		Extreme cold	Y	-2 degrees celsius in Kilis and Osmaniye	
6/2/2023-9/2/2023		Snow	Y	Residents reported several inches of snow	
6/2/2023-21/2/2023		Liquefaction and Lateral spreading	Y	ed 760 sites with liquefaction and lateral spreading features	
6/2/2023-27/2/2023		Other Aftershocks	Y	Range	Remaining aftershocks ended 3 weeks after main
02/07/2023		Water system contamination	Y		
07/02/2023		Subsidence	Y	200 meters of water pools were formed from the coast towards the interior.	
07/02/2023		Water pollution	Y	Spread across 10 provinces	Still present in regions like Hatay in August 2023
09/02/2023		Flooding	Y		
09/02/2023		Earthquake	Y	Mw 6.4	
09/02/2023		Earthquake	Y	Mw 5.8	
10/02/2023		landslides	Y	able to identify more than 100 landslides in cloud and snow-free regions	
10/02/2023		extreme cold		temperatures of -4 to -8 celsius over Saturday 11th to Friday 17th	
14/02/2023		landslide	Y		
14/02/2023		landslide	Y		
21/02/2023	20:04:00	Earthquake	Y	Mw 6.4	
27/02/2023	12:04:00	Earthquake/aftershock	Y	5.6 Mw	

Multi-hazard database

- Columns include hazard type, size/magnitude/volumetric information, impact (on people, buildings or infrastructure), satellite imagery if available, name of provinces affected and specific villages/towns/cities/ coordinates.
- Then, we constructed temporal multi-hazard networks for the whole region and by province from these different sources to build a fuller story behind the disaster.

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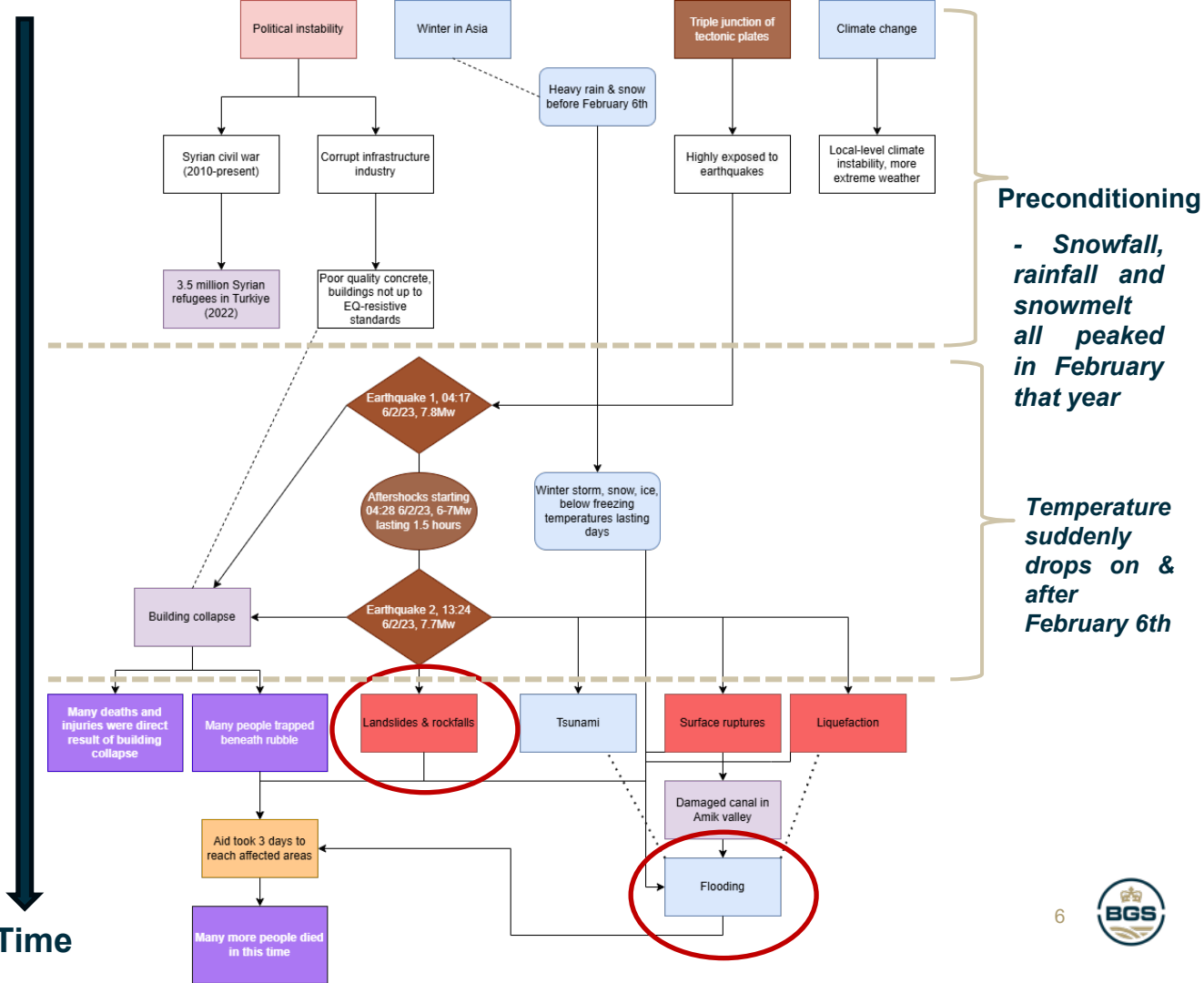
Multi-hazard flowchart example across all affected provinces

Legend
Brown: tectonics
Red: secondary geohazards
Pale red: stress factors
Purple: anthropogenic influences/effects
Blue: hydrometeorological or hydrogeological



Multi-hazard database main findings

Three main hazards can be said to have been instrumental in creating and compounding this violent and long-lasting event:

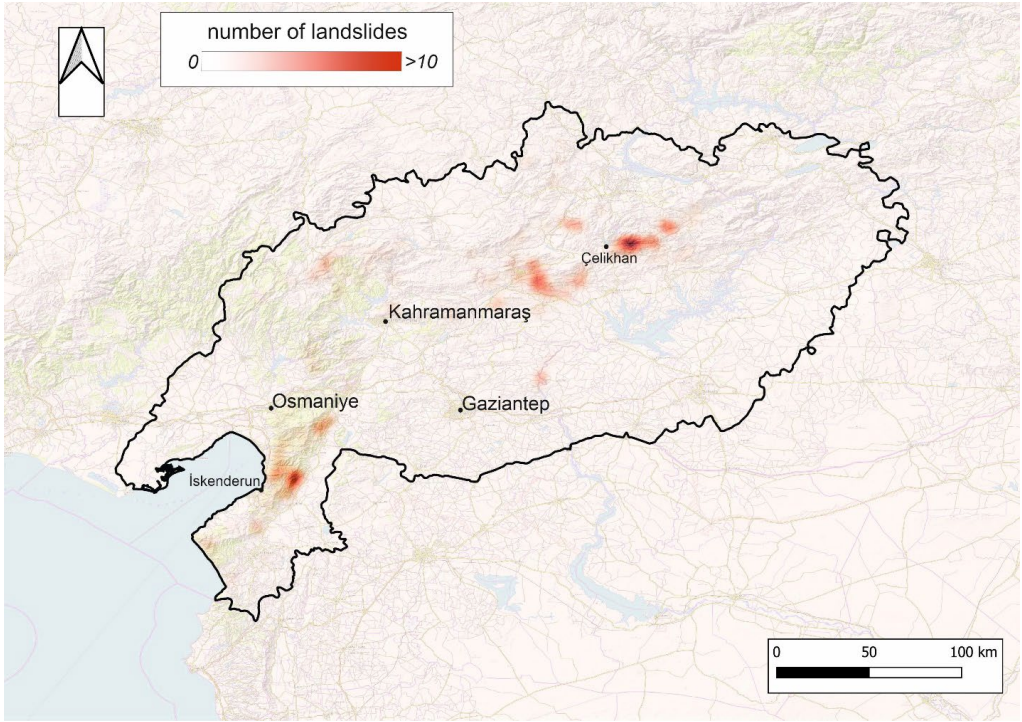
1. country-wide heavy rainfall before February 6th
2. pair of very powerful earthquakes on February 6th early in the morning, and thousands of aftershocks which not only contributed to further building collapse but also negatively affecting survivors' PTSD and mental health
3. Snowstorm & sub-zero temperatures, hindered rescue efforts, and attributing to far greater loss of life

Next steps – integrating qualitative data with EO

Pre- and co-seismic landslide database

- Sentinel-2 data was used in a Machine Learning model called “U-Net” to map landslide events at large scale (80,000km^2)
- U-Net is a supervised ML technique which we trained on ~3000 real-world mapped landslides

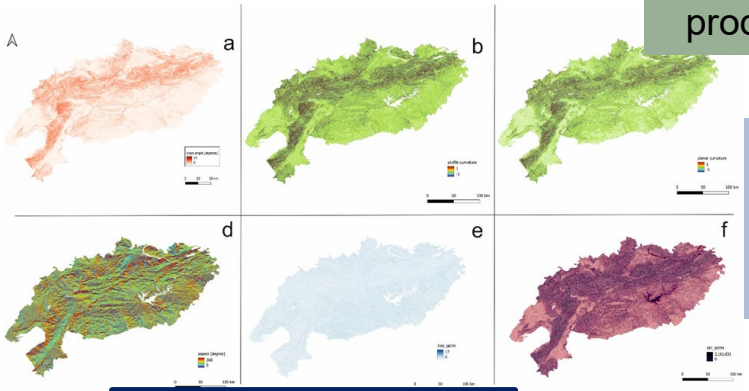
- From this approach, we mapped a total of 4,399 events over our 80,000 km^2 area of interest as polygons. Cumulatively, they cover an area of ~ 30km^2
  - 3,854 co-seismic
  - 545 pre-seismic.



Creating the co-seismic landslide multi-hazard susceptibility map

Landslide inventory will be used for training and validation of a ML model (RF, MaxEnt or GAM) to produce a landslides hazard map

Focusses on compounding hazards **only** at this stage! Cascades may be introduced in future



Sentinel-1 imagery analysed over 2014 until February 2023

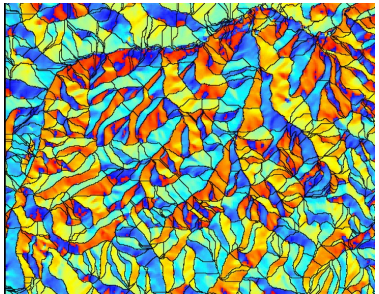
+ static co-variates (lithology, slope angle, geomorphometric parameters, etc)

Spatial overlay

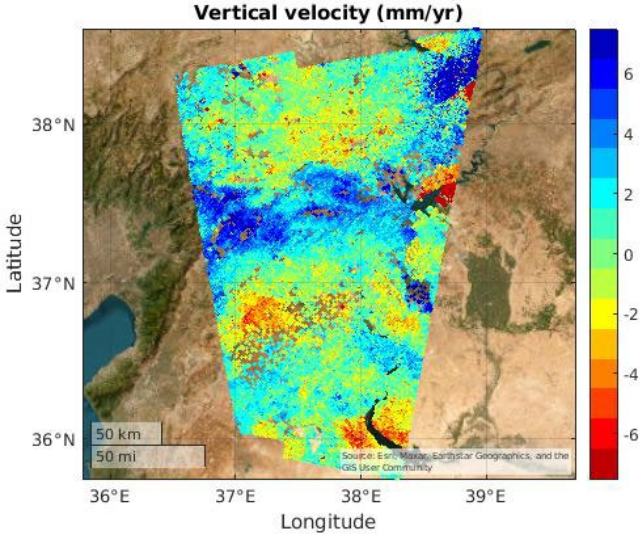
+ dynamic data from InSAR

Integrate all variables by slope unit (539,697 units)

constructed from 5m DTM (SRTM, generated in 2000)



Environmental co-variates



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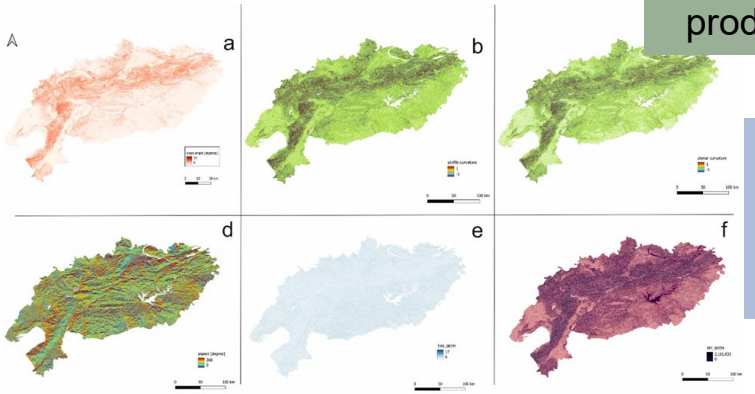
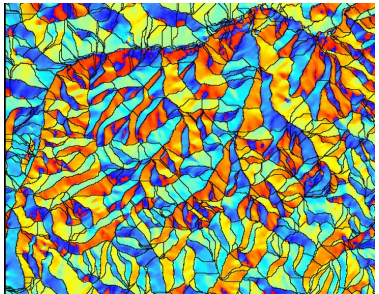


→ Landslide susceptibility per slope unit

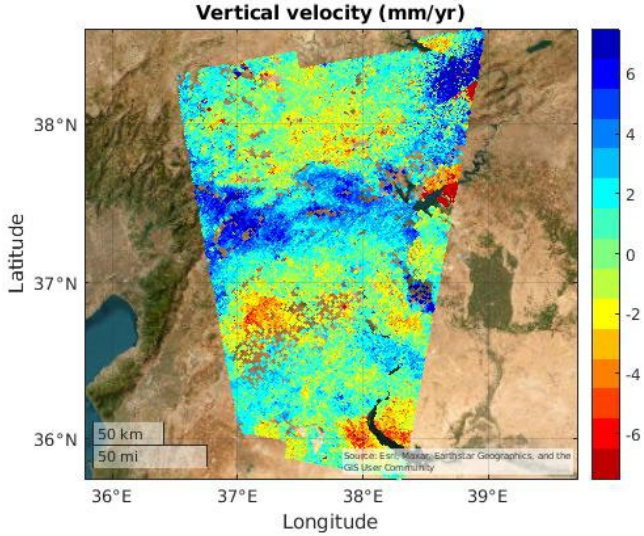
(lithology, slope angle,

Overlaying with floods mapped from optical and SAR imagery

from InSAR

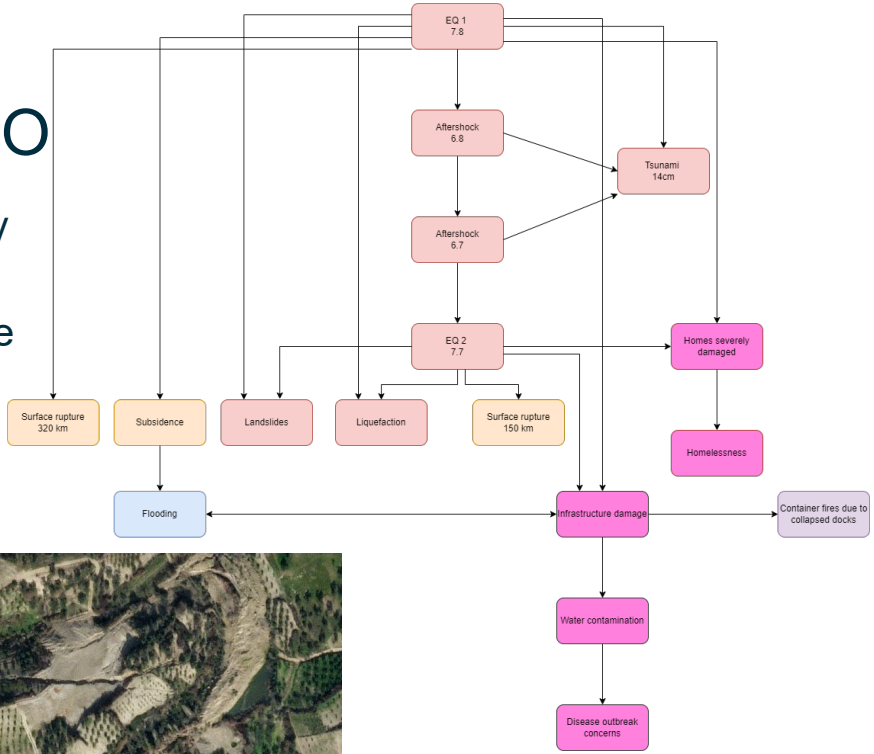


Co-seismic landslide and flood susceptibility map



Integrating qualitative data with EO

- We know from the multi-hazard database that Hatay reported several landslides
- As part of disaster response, launching the landslide tracker algorithm can map these automatically



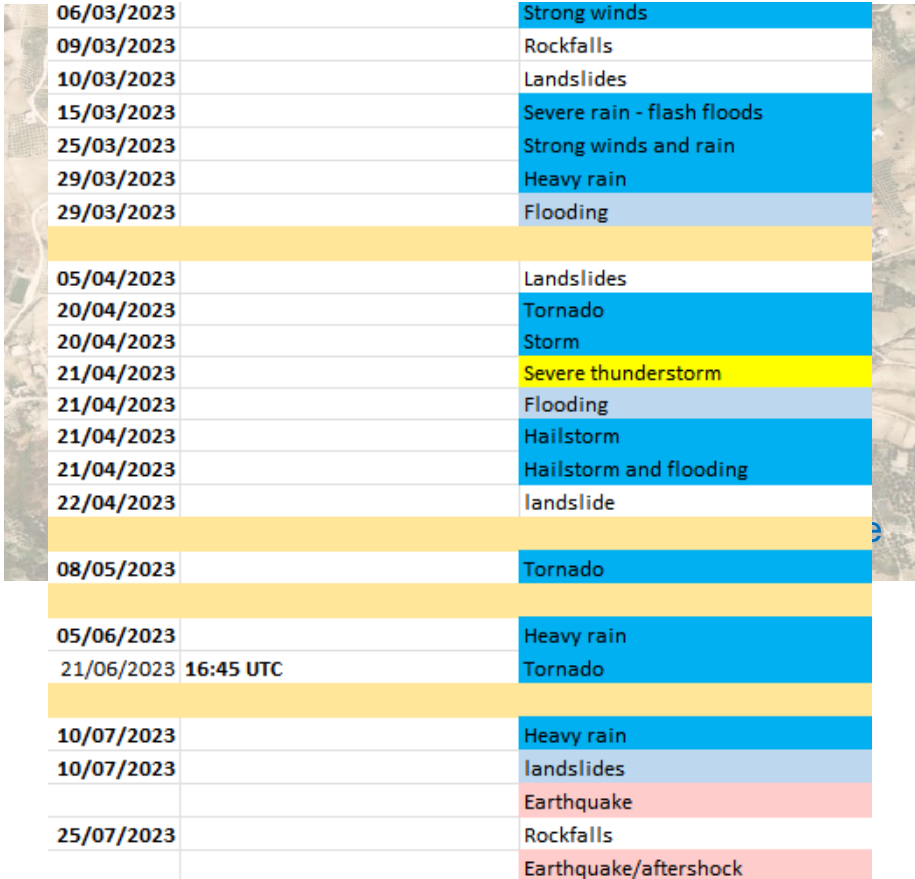
Landslide in Tepehan, Hatay [*Görüm et al 2023*]

Tepehan landslide in satellite imagery
[*Image credit: Planet, SkySat*]

Integrating qualitative data with EO

- The automatic landslide detector successfully identifies the Tepehan olive grove landslide from post-event Sentinel-2 imagery
- To the north, there was reported lateral spreading and liquefaction ejecta along canals near Hatay airport, which led to floods and damaged runways [Taftsoglou et al 2023] → unusable airport, no flown-in aid?
- We also know that in the summer following the earthquakes, Hatay experienced a heatwave and water commodification

→ Cascading and compounding hazards all affecting the same vulnerable population



06/03/2023		Strong winds
09/03/2023		Rockfalls
10/03/2023		Landslides
15/03/2023		Severe rain - flash floods
25/03/2023		Strong winds and rain
29/03/2023		Heavy rain
29/03/2023		Flooding
05/04/2023		Landslides
20/04/2023		Tornado
20/04/2023		Storm
21/04/2023		Severe thunderstorm
21/04/2023		Flooding
21/04/2023		Hailstorm
21/04/2023		Hailstorm and flooding
22/04/2023		landslide
08/05/2023		Tornado
05/06/2023		Heavy rain
21/06/2023	16:45 UTC	Tornado
10/07/2023		Heavy rain
10/07/2023		landslides
		Earthquake
25/07/2023		Rockfalls
		Earthquake/aftershock

Database conclusions

- 3 main hazards identified
- 2 hydrometeorological hazards compounded the earthquakes
- All three hazards had their own hazard cascades, which then compounded each other's cascaded hazards

EO data conclusions

- We have successfully gathered pre- and co- seismic landslides using a Machine Learning-powered model and Sentinel-2 data
- Flood maps can be included in future phases to construct a hazard susceptibility map for the area
- Further future steps could be using more refined multi-hazard models to integrate not only compounding hazards, but cascades into the final hazard maps