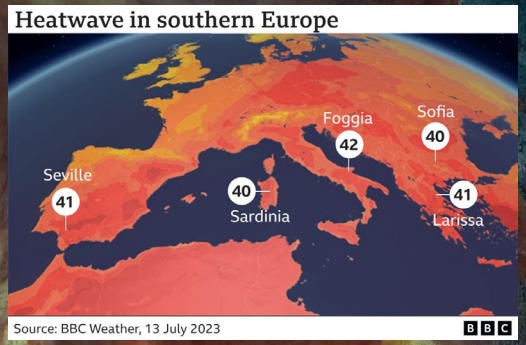
IODP WORKSHOP, WASHINGTON DC, APRIL 2024

HOLLY HOURSTON, ITA GONZÁLEZ-ÁLVAREZ, LUKE BATESON, EKBAL HUSSAIN, ALESSANDRO NOVELLINO

An automated InSAR time-series analysis tool for geological interpretations in near-real time

British Geological Survey



Europe heatwave, July 2023
(Credit: BBC Weather)

We know from case studies, fieldwork trips, etc, where many geological hazards are…

But for monitoring new or hard to predict geological hazards, or for disaster prevention and monitoring, we cannot manually interpret **2 billion data points**

Drilling rig pulled from a collapsed mineshaft, Glasgow, Scotland.
(Credit: BGS, UKRI)

Winter storms, Dorset 2013/2014 (Credit: Richard Broome, accessed phys.org)

Storm Babet, 2023, Dundee, Scotland (Credit: Sky News)

Geohazards in the UK

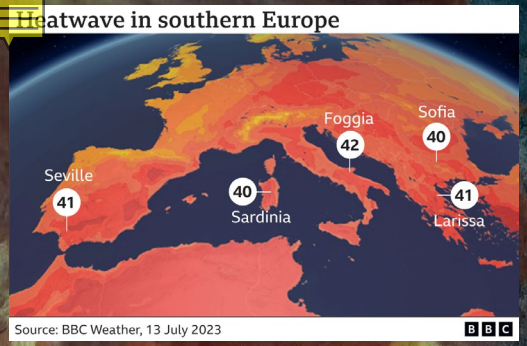
Shrink-swell subsidence/uplift

- **£64m** in post-heatwave home insurance claims from Jul-Aug 2018 [BGS]
- Insurers paid **£219 million** after the 2022 UK heatwave [ABI]
- 23,000 subsidence claims in 2022- 78% of them after the summer heatwave
- In 2022, a new subsidence claim submitted **every 15 minutes** in the second half of the year, with each costing an average sum of £9600 [City A.M.]

Image: a cracked wall in a subsiding house. Cracks can appear inside, outside, or both, causing extensive property damage.
Image credit: BGS

The costliest geohazard in the UK.

Other hazards?



European heatwave, July 2023 (Credit: BBC Weather)


Coastal erosion in Yorkshire (Credit: BBC)


Drilling rig pulled from a collapsed mineshaft, Glasgow, Scotland. (Credit: BGS, UKRI)


Winter storms, Dorset 2013/2014 (Credit: Richard Broome, accessed via phys.org)


Storm Babet, 2023, Dundee, Scotland (credit: Sky News)


Landslide on the Rest and be Thankful passage, Argyll & Bute, Scotland (Credit: Traffic Scotland)

Intro to InSAR

- Interferometric Synthetic Aperture Radar to measure ground motions
  - Satellite takes 2 radar images of the same point at different points in time
  - The difference between these two images produces an interferogram, indicating how the ground has moved.

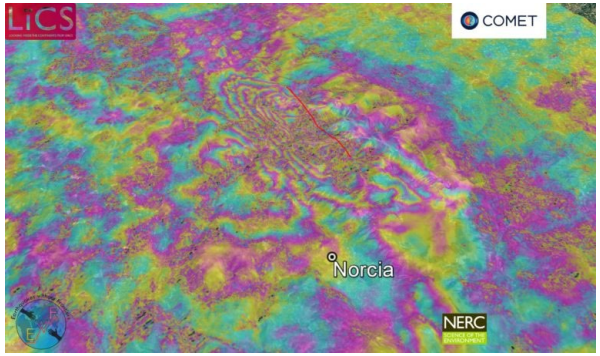
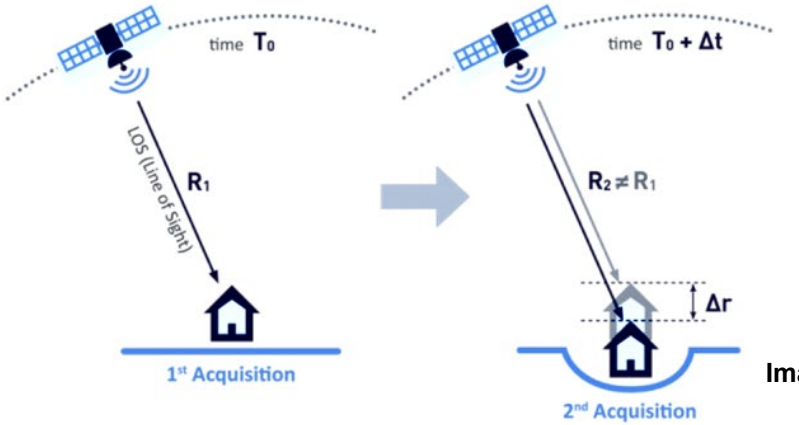


Image credit: COMET (UKRI NERC)
https://comet.nerc.ac.uk/golden-age-tectonic-remote-sensing/



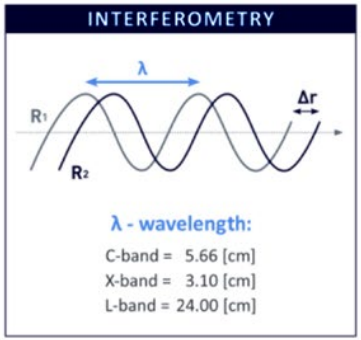


Image credit: TRE-ALTAMIRA

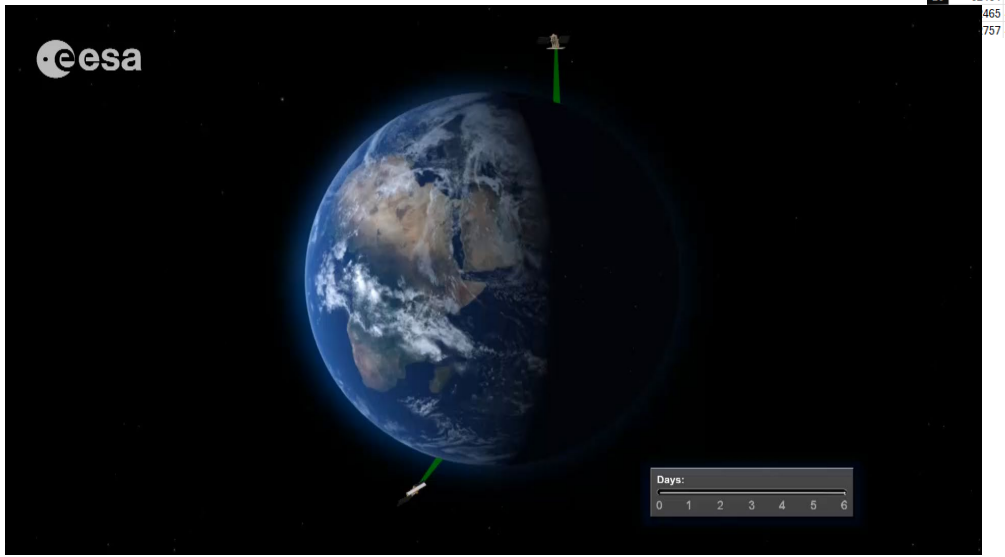
- Accurately measures deformations on planetary bodies (mm-scale)
  - *Planetary science mission: NASA VERITAS future mission (2031, Venus)*
  - *Earth science mission: NASA-ISRO NISAR (2024)*

Intro to InSAR

Downloaded InSAR data can look like this:

- *Which isn't very helpful, or easy on the eye!*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		pid	easting	northing	height	rmse	mean_vel(	mean_vel(	accelerati	accelerati	seasonali	seasonali	20160105	20160111	20160117	20160123	20160129
2	62440	40d1glmW	3617050	3200050	4.1	0.8	-1.6	0	-0.14	0.03	0.2	0	0.2	0.8	1.1	0.3	0.1
3	62441	40d1lSRIR	3617050	3200150	4.7	0.8	-2.2	0	0	0.03	0.1	0	1.6	0.4	-0.2	-0.1	-0.2
4	62442	40d1q970	3617050	3200250	5	0.7	-2.3	0	0.15	0.03	0.2	0	-0.1	-0.6	-1.3	-0.7	-0.5
5	62443	40d1upmf	3617050	3200350	4.9	0.6	-1.8	0	0.03	0.03	0.4	0	0.7	0.6	0.4	0.7	1.1
6	62444	40d1zWRv	3617050	3200450	8.1	0.6	-1.7	0	0.02	0.03	0.3	0	-0.4	0.7	1.1	0.9	0.7
7	62445	40d24D6k	3617050	3200550	4.9	0.7	-1.5	0	0.09	0.03	0.6	0	0.2	0.1	0.2	0.3	0.2
8	62446	40d28tlzQ	3617050	3200650	4.2	0.7	-1.6	0	0.19	0.03	0	0	0.8	1.5	1.2	0.6	0.3
9	62447	40d2DaRE	3617050	3200750	14.4	0.9	-1.7	0	0.15	0.03	0.1	0	-2.2	-2	-1.4	-0.5	0.6
10	62448	40d2IH6Tc	3617050	3200850	16.8	0.9	-1.3	0	0.17	0.04	0.3	0	-1	-1.4	-1.3	-0.2	0.5
11	62449	40d2Mxlj0	3617050	3200950	7.3	0.9	-1.4	0	-0.08	0.03	0.3	0	0.8	1.1	1.3	0.1	-1
12	62450	40d2ReQy	3617050	3201050	6	0.8	-1.3	0	0.14	0.03	0.6	0	-1.1	-0.7	-0.5	-0.6	-0.4
13	62451	40d2WL6D	3617050	3201150	6.2	0.6	-1.3	0	0.16	0.02	0	0	-0.4	-0.7	-0.4	0	-0.2
14	62452	40d2b1lSa	3617050	3201250	8.5	0.4	-1.3	0	0.04	0.02	0	0	0.4	-0.5	-0.8	-0.4	-0.1
15	62453	40d2fiQhn	3617050	3201350	11.8	0.6	-1.3	0	0.09	0.02	0.8	0	-0.1	0.1	0.6	1.2	1.2
16	62454	40d2p5lCA	3617050	3201550	4.3	1.6	-1.6	0	0	0.06	1.1	0.1	-0.7	1.2	0.7	-1	-2.5
17	62455	40d2tmQF	3617050	3201650	8.8	0.6	-1.5	0	0.04	0.02	0.1	0	0	0.2	0.6	0.3	0.2
18	62456	40d2yT5g2	3617050	3201750	9.8	0.8	-2	0	-0.13	0.03	0.2	0	-0.4	-0.3	-0.6	-0.4	0.5
19	62457	40d339kvl	3617050	3201850	10	0.7	-2	0	-0.13	0.03	0.3	0	0.3	-0.5	-1.1	-1.5	-1.3
20	62458	40d37qQA	3617050	3201950	11.4	0.6	-1.6	0	0.21	0.02	0.5	0	-0.7	-0.5	-1	-1.4	-0.7
21	62459	40d3CX5Q	3617050	3202050	8.3	0.9	-1.1	0	0.11	0.04	0.9	0	-0.3	0.5	0.2	-1.5	-2.3
22	62460	40d3HDkfl	3617050	3202150	7.2	0.7	-1.5	0	0.04	0.03	0.4	0	-1.5	-0.7	-0.1	-0.1	-0.1
23	62461	40d3LuPu	3617050	3202250	6.6	0.9	-1.5	0	0.01	0.03	0.7	0	1.4	0.7	0.2	-0.2	-0.4
24	62462	40d3Qb59	3617050	3202350	9.2	0.7	-1	0	0.03	0.03	0.4	0	0.7	0.8	0.6	0	-0.4
25	62463	40d3VHkC	3617050	3202450	13.8	0.5	-1	0	0.07	0.02	0.1	0	0.7	0.5	0	-0.4	-0.8
26	62464	40d3ZyPe7	3617050	3202550	12.6	0.6	-0.9	0	0.12	0.02	0.1	0	0.1	-0.1	-0.5	-0.6	-0.6
	465	40d3ef4tUa	3617050	3202650	8.6	0.8	-0.7	0	0.04	0.03	0.4	0	0.8	0	-0.6	-0.6	-0.1
	757	40d1glmW	3617150	3200050	5.9	0.7	-1.8	0	0.06	0.03	0.1	0	-0.3	0.2	1.1	0.8	0.3

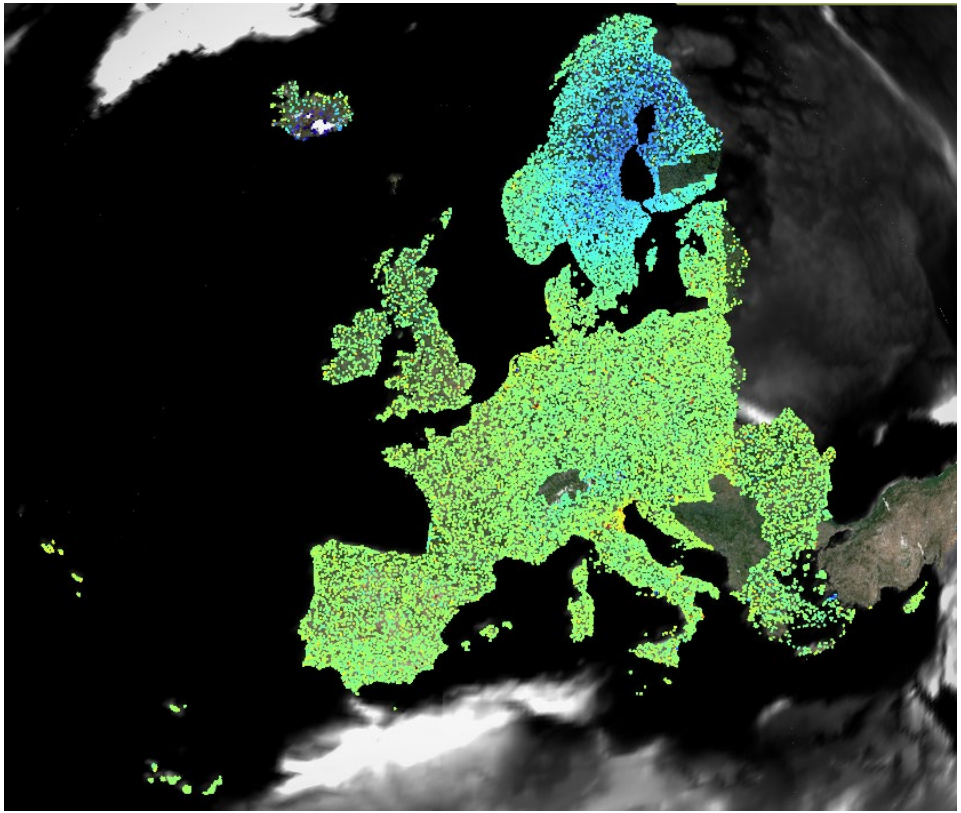


Credit: ESA/ATG medialab

We typically use data from the ESA Copernicus Sentinel-1AB satellite pair

Sentinel-1 satellites revisit each measurement point every 6 days

EGMS Interface



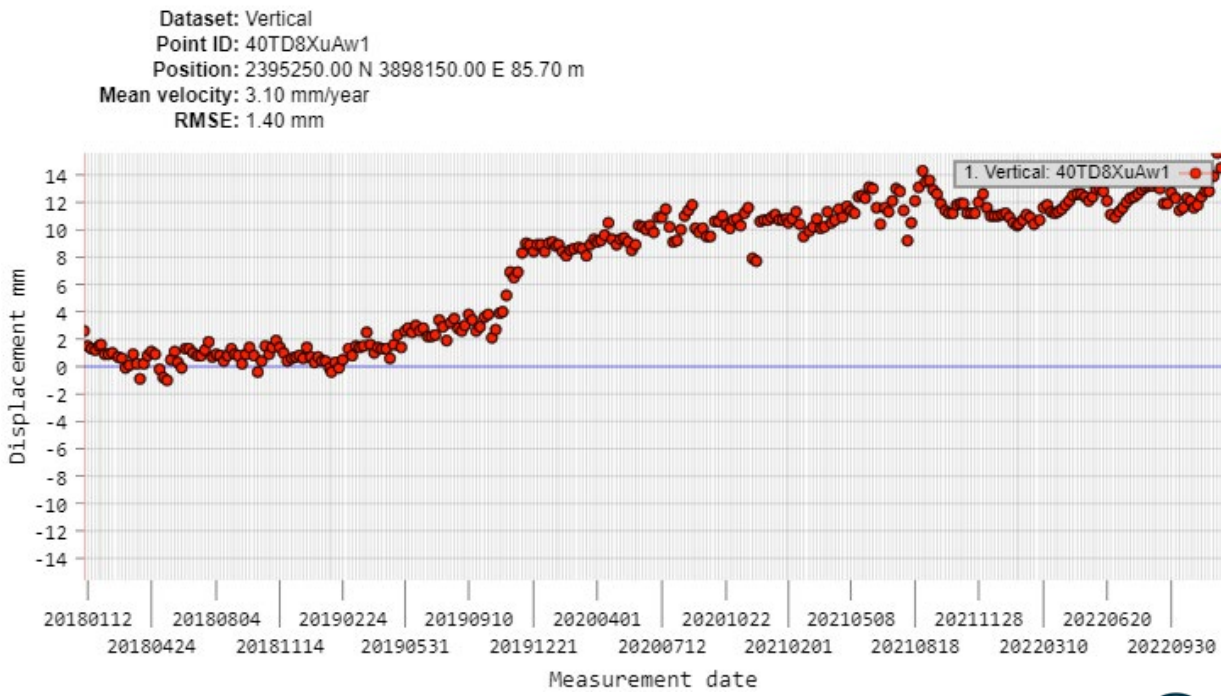
The UK alone has **2.5 billion** data points for a 5-year period (standard EGMS data download size)

→ A **lot** of data for Europe!

EGMS Time Series: what can we see?

Earthquake in November 2019, Le Tiel, southern France

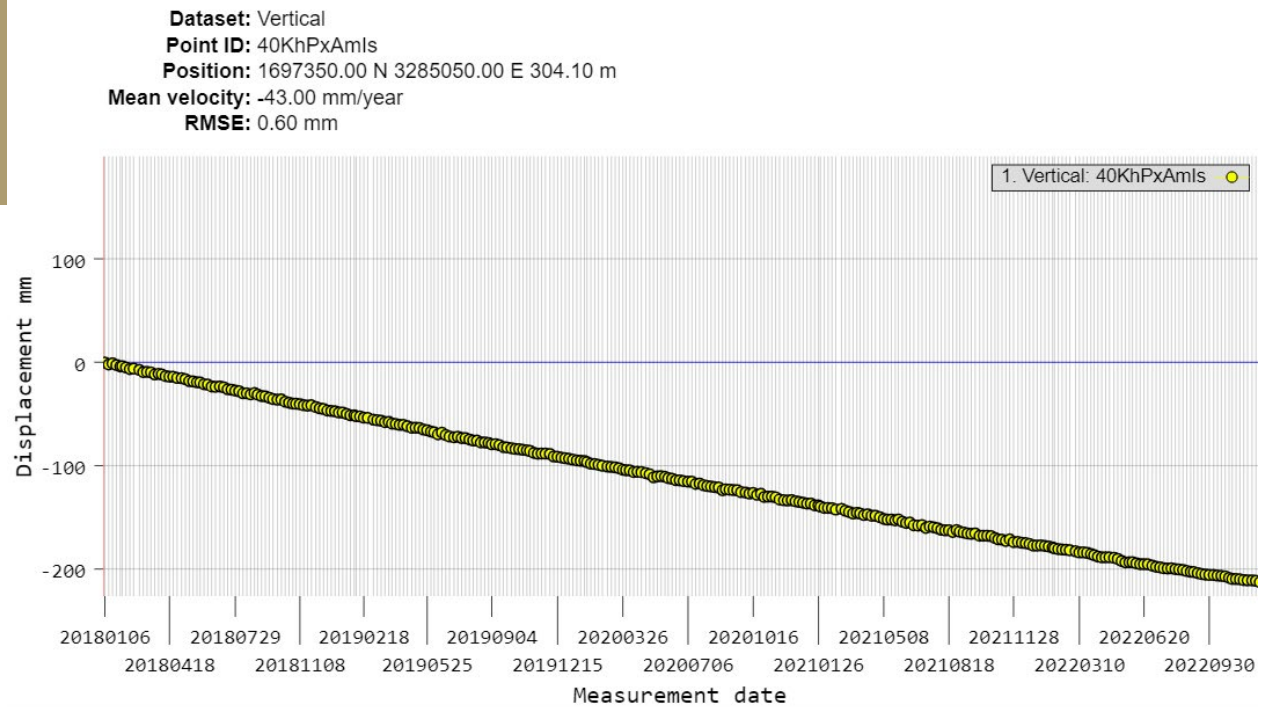
Credit: google maps



EGMS Time Series: what can we see?

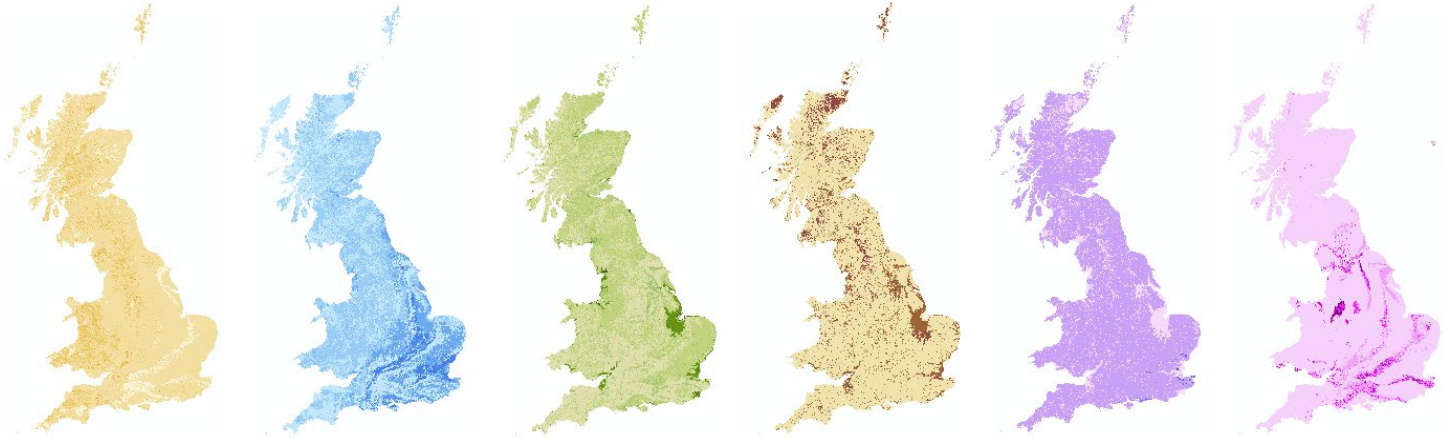
Groundwater extraction, Lorca, southern Spain

Credit: google maps



BGS Datasets & InSAR

- BGS is the authoritative body on geohazards in the UK
- Founded in 1835→ nearly 200 years of geological data!
  - GeoSure: hazard susceptibility maps for 6 UK geohazards
- We utilise EGMS data, from Sentinel-1 satellites, for InSAR



THE POINT IS…

We cannot manually interpret every data point!
We need to know not only **where** is vulnerable-
but **what is happening and why it's happening.**

Accurate prediction models

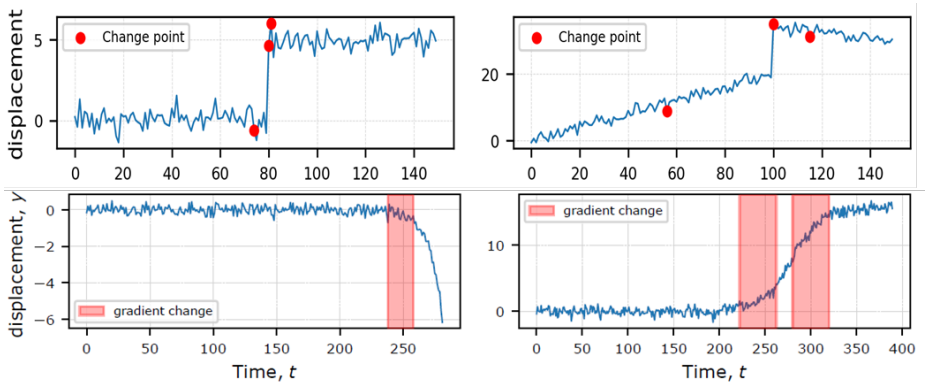
Quicker disaster responses

Functioning warning & forecast systems

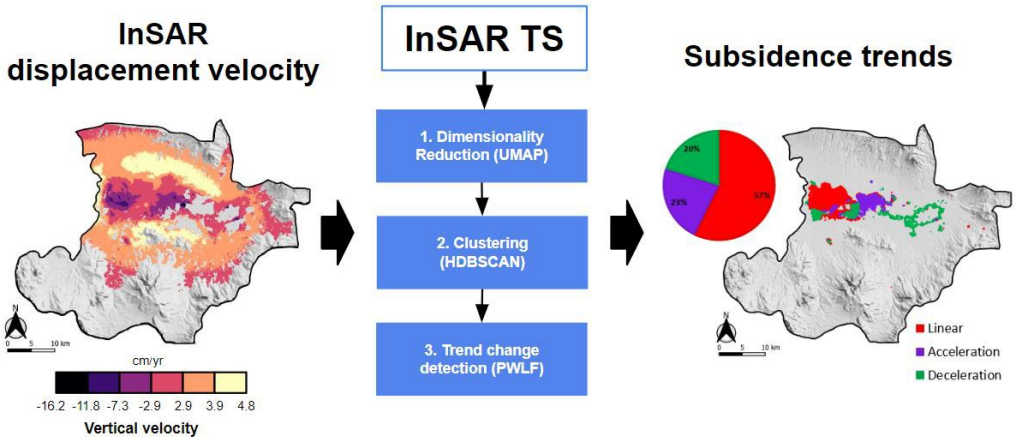
Current Research at BGS

Automatic extraction of information from InSAR time series:

- Methods to **cluster data** into areas of statistically similar motions (unsupervised machine learning)
- Methods to **identify changes** within a time series – detectors.



Hussain et al., 2020

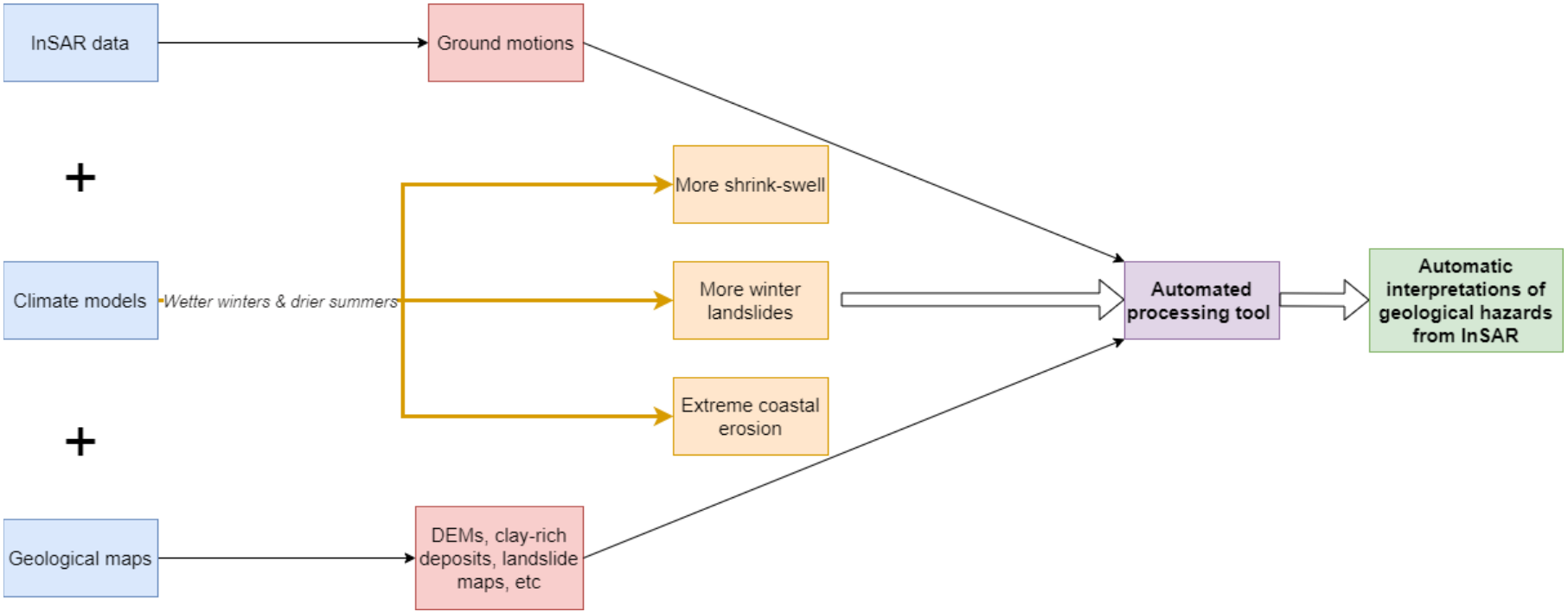


Rygus et al., 2023

InSAR change detector allows significant changes in time series to be identified for millions of measurement points in **near-real time**

ML methods applied to InSAR reveals subsidence trends in Indonesia

The Big Idea:


InSAR data
Ground motions
+
Climate models
Wetter winters & drier summers
More shrink-swell
More winter landslides
Extreme coastal erosion
+
Geological maps
DEMs, clay-rich deposits, landslide maps, etc
Automated processing tool
Automatic interpretations of geological hazards from InSAR

Automatic piecewise linear regression (PLR) of time series trends:

Time series

STL decomposition

Trend analysis

Automatic piecewise linear regression

Test for break points:
2 break points → linear
>2 → non-linear

Trend behaviour

Linear - stable

Linear - uplift

Linear - subsiding

Non-linear

Number of segments

Temporal analysis

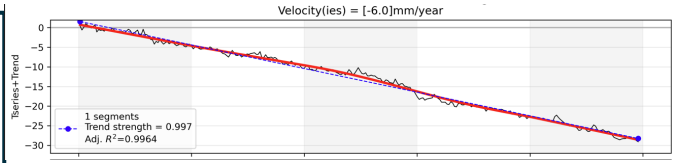
Seasonality analysis

Seasonality strength

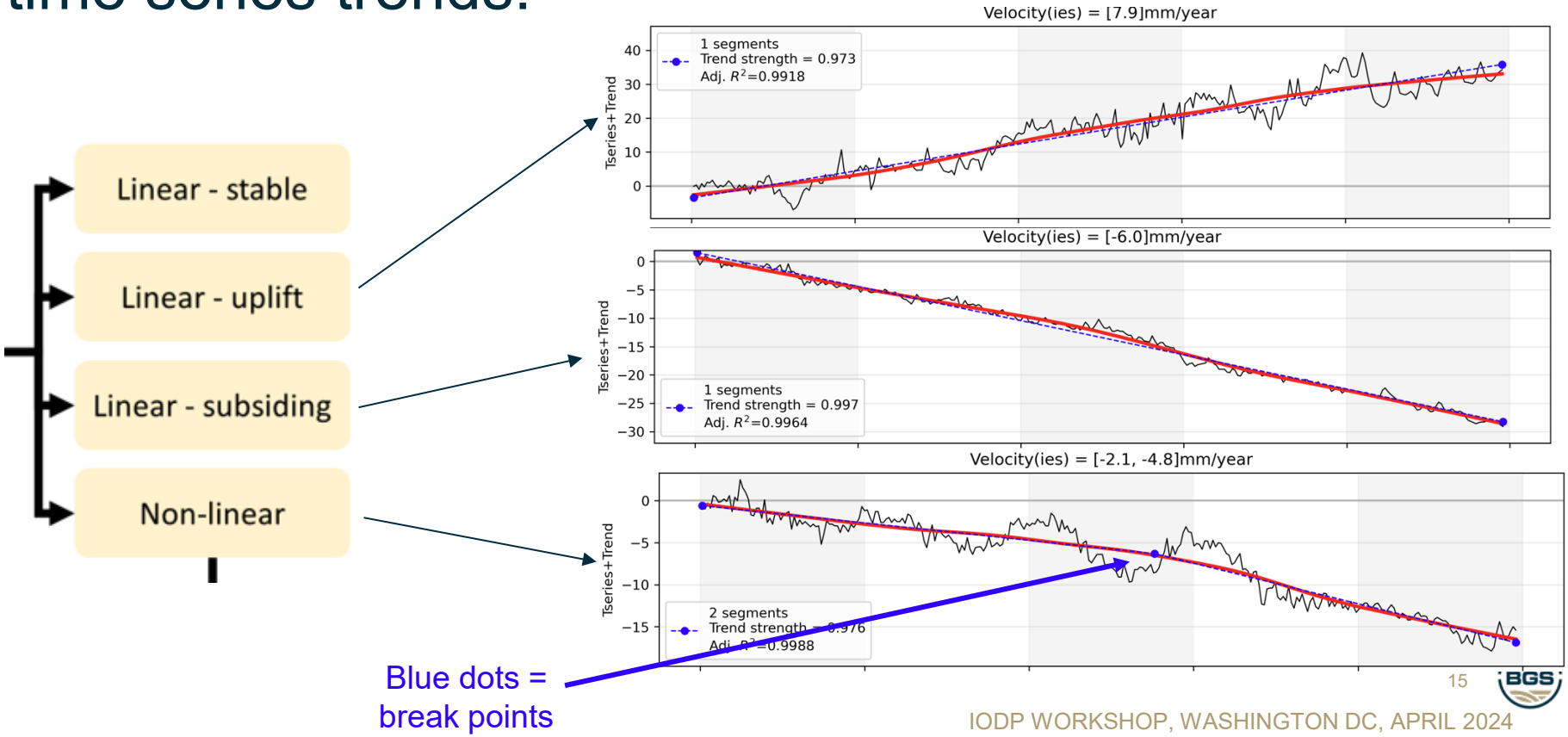
Residuals analysis

Ground velocity

STL = Seasonal Trend Decomposition using LOESS
[*Skipper S. & Perktold J., 2010*]

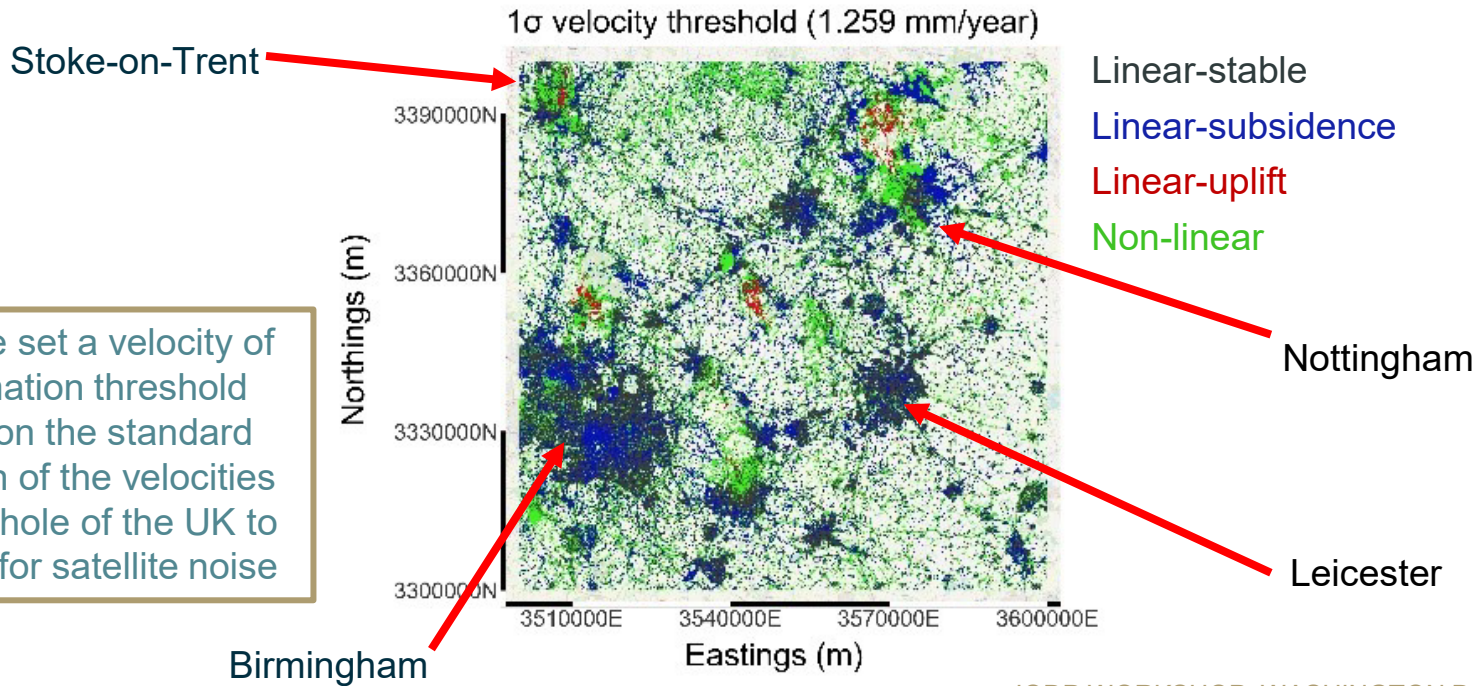


Automatic piecewise linear regression (PLR) of time series trends:



Results: Test 1

- By plotting the different groups of trend behaviours, we observe spatial trends
  - *The algorithm takes in no spatial data, yet returns spatial information*



We have set a velocity of deformation threshold based on the standard deviation of the velocities for the whole of the UK to account for satellite noise

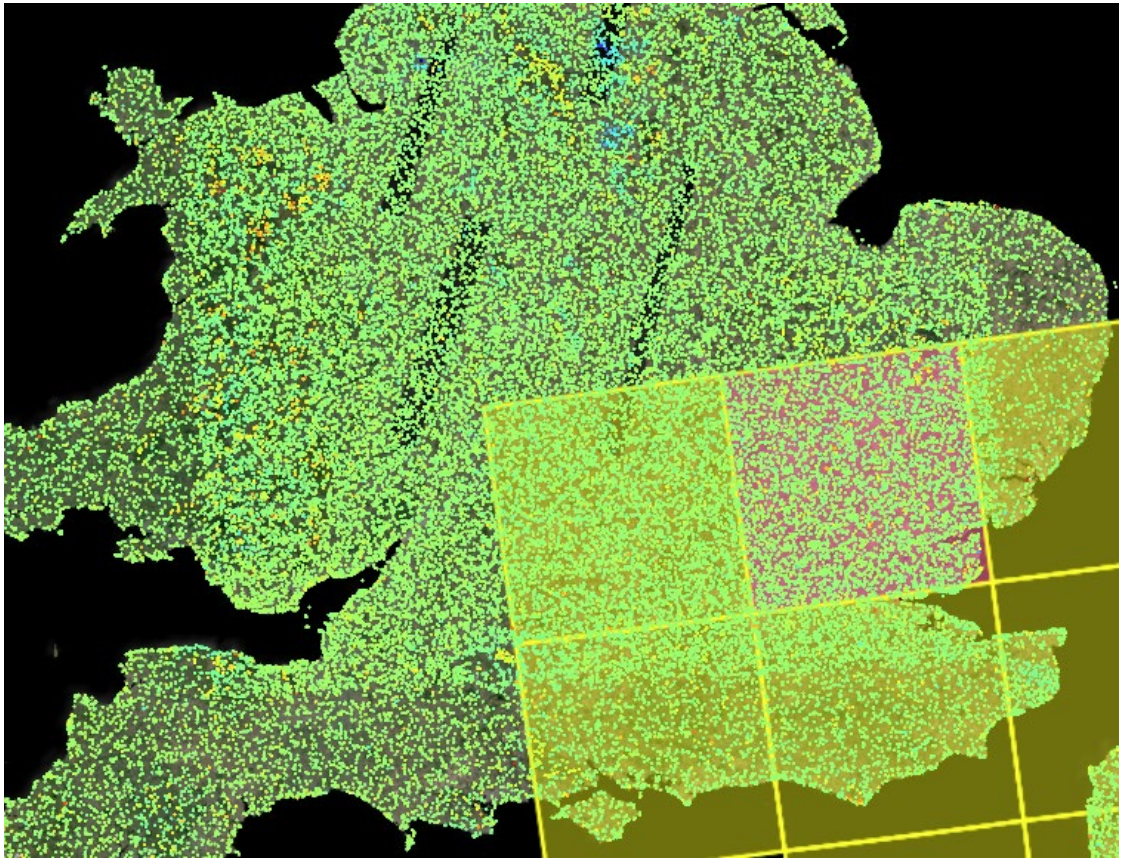
Results

Location: SE England (selected quadrant in EGMS in pink)

Geology: clay-rich soils → high risk area for shrink-swell hazard

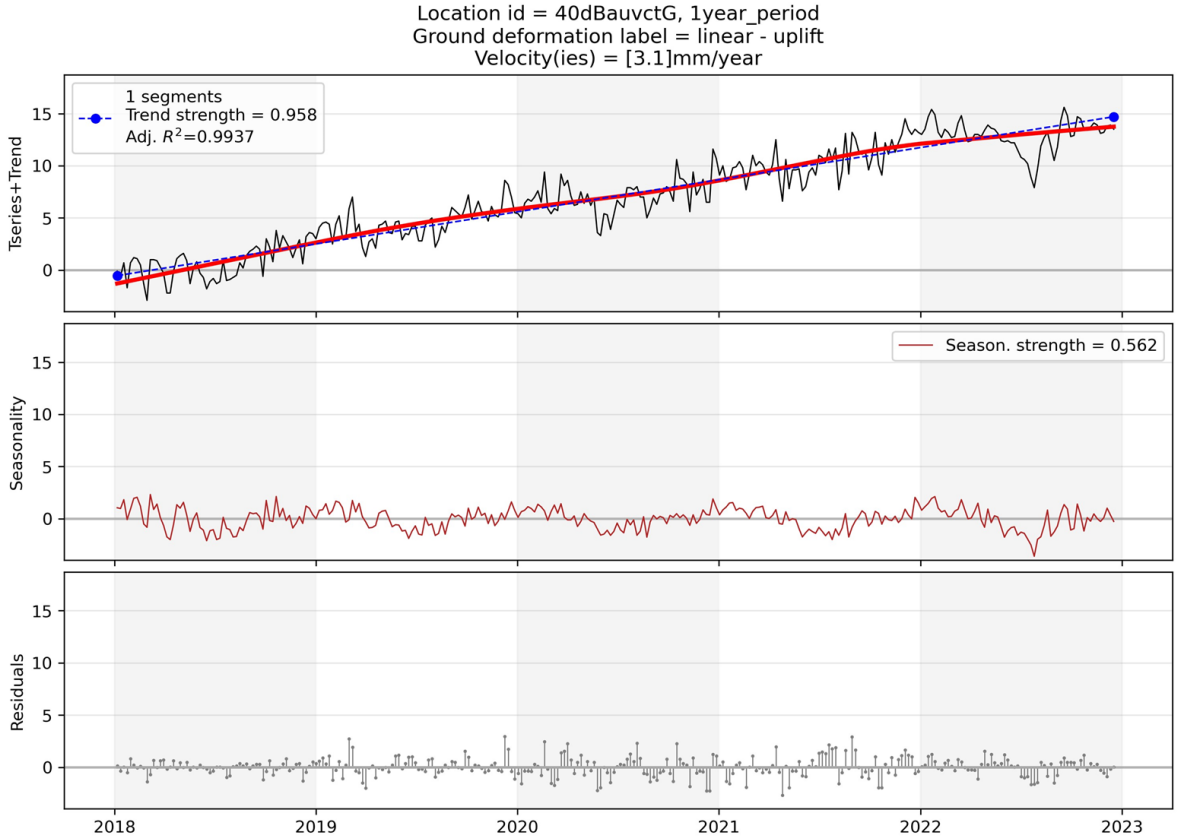
Velocity threshold: 1.5σ (σ = deviation in the mean rates of ground motions in Great Britain as a whole)

1.5σ = 1.889 mm/year



Results

- Example processed measurement point: uplifting
- Only uses 1 segment to map the general trend (blue dashes)
- Looking only at the modulus of seasonality, notice a **large increase in seasonality strength in Summer 2022**
  - UK Heatwave, SE England reached 42 ° C (107° F)



Next steps?

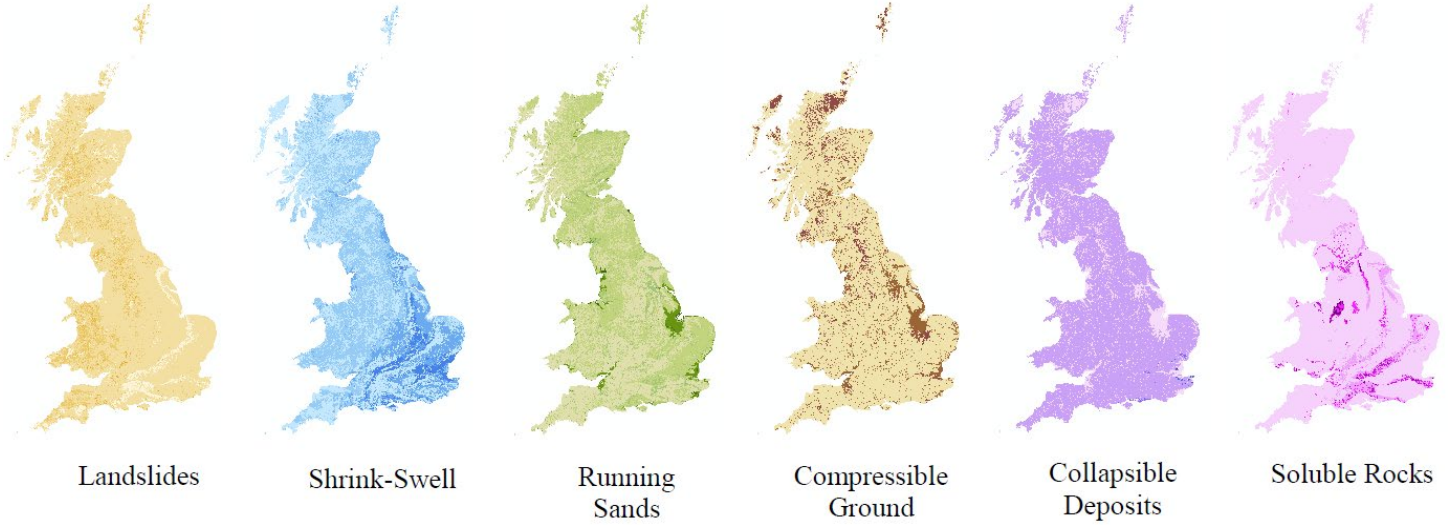
Add in geological hazard susceptibility data

- Superficial deposit maps
- Mining areas
- Slope angles

Decision tree ?

Thank you! Any questions?

Feel free to email: hhourston@bgs.ac.uk



Add synthetic InSAR data from expected trends → **future climate impacts**

-reference with rological time data → identify mation change triggers