Third Edition
RISK MANAGEMENT
Knowledge, Forecasting, Prevention,
Protection, Planning, Preparedness
20 - 27 July 2025

GEO-HYDROLOGICAL HAZARDS & RISKS IN A WARMING CLIMATE

Fausto Guzzetti
Consiglio Nazionale delle Ricerche

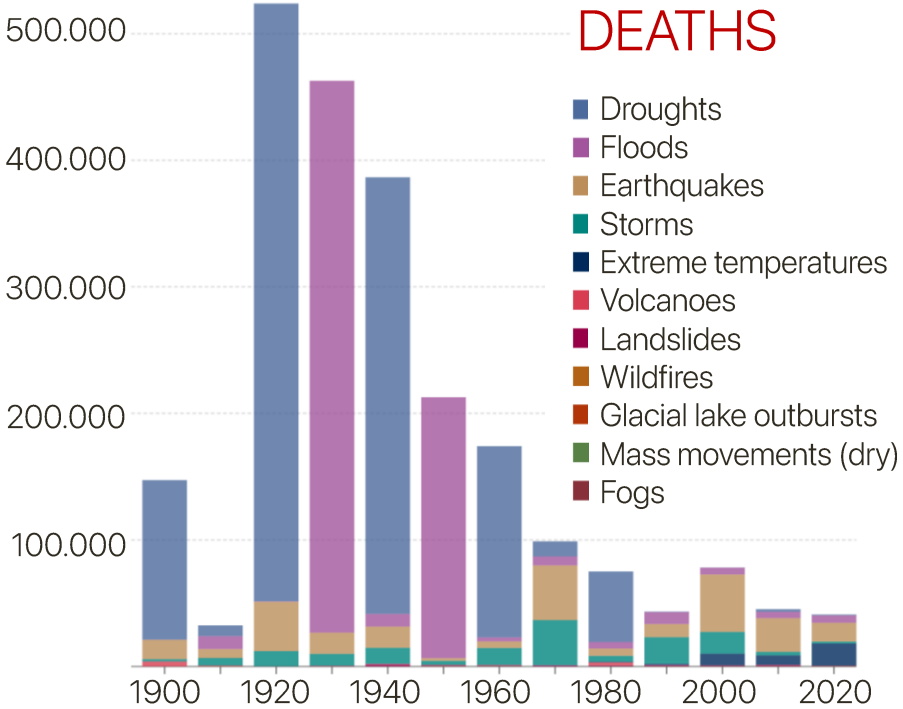
Assisi, 23 July 2025

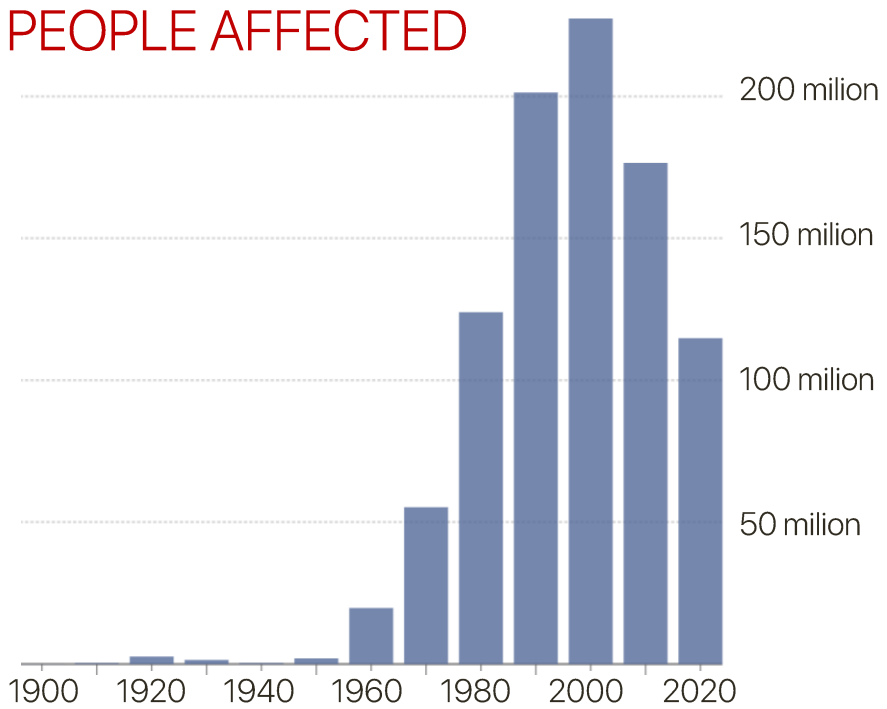
- Facts
- Floods
- Landslides
- Considerations

FACTS

Impact on population

Our World in Data





source EM-DAT, CRED / UCLouvain 2023, Brussels, www.emdat.be (D. Guha-Sapir) | CC by

Climate & geo-hydrological hazards

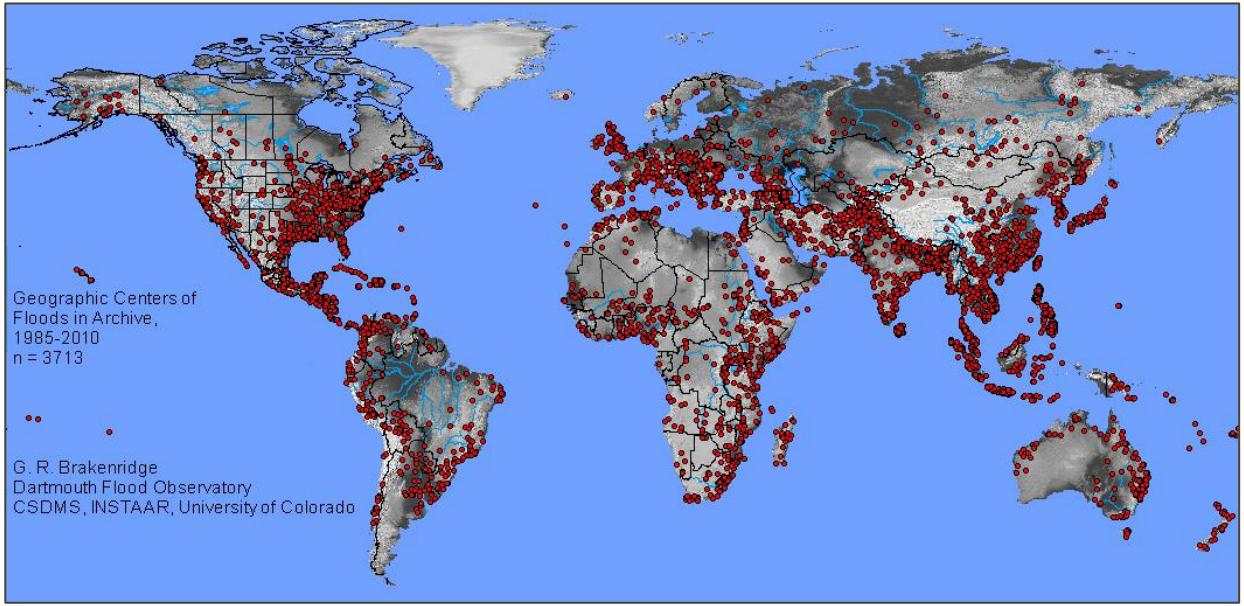
- Global warming is unequivocal.
- The effects of warming on geo-hydrological hazards are difficult to predict.

IPCC 2014

FLOODS

Large floods globally

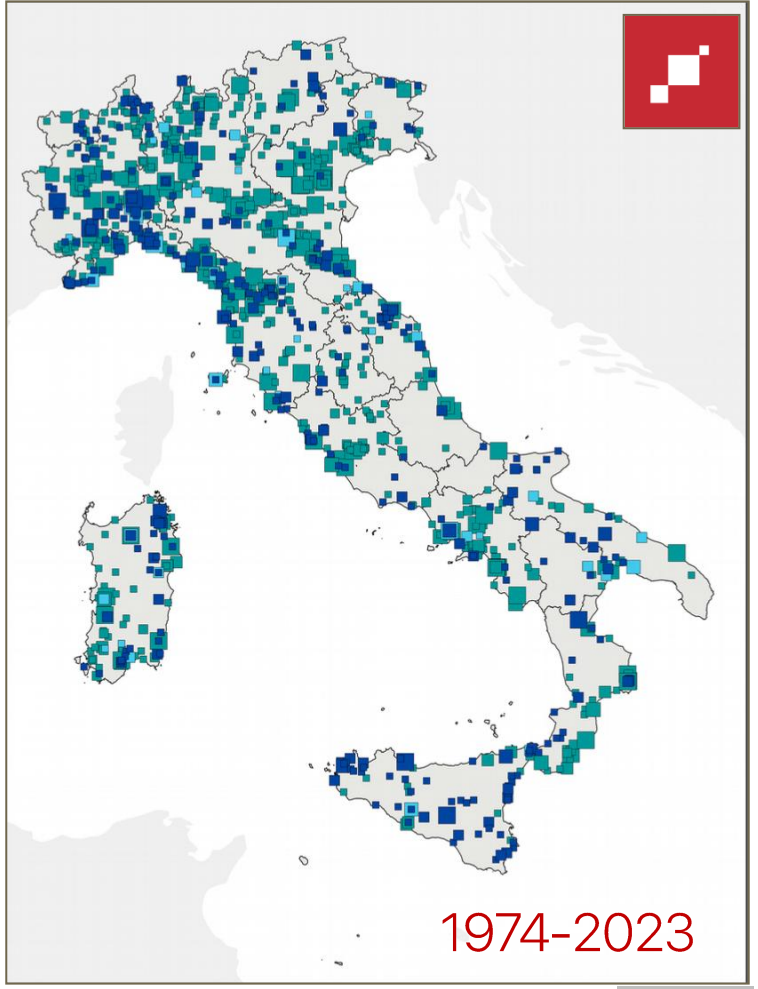
- 3713 large floods from 1985 to 2010.



Kundzewicz et al 2014, Brakenridge 2016

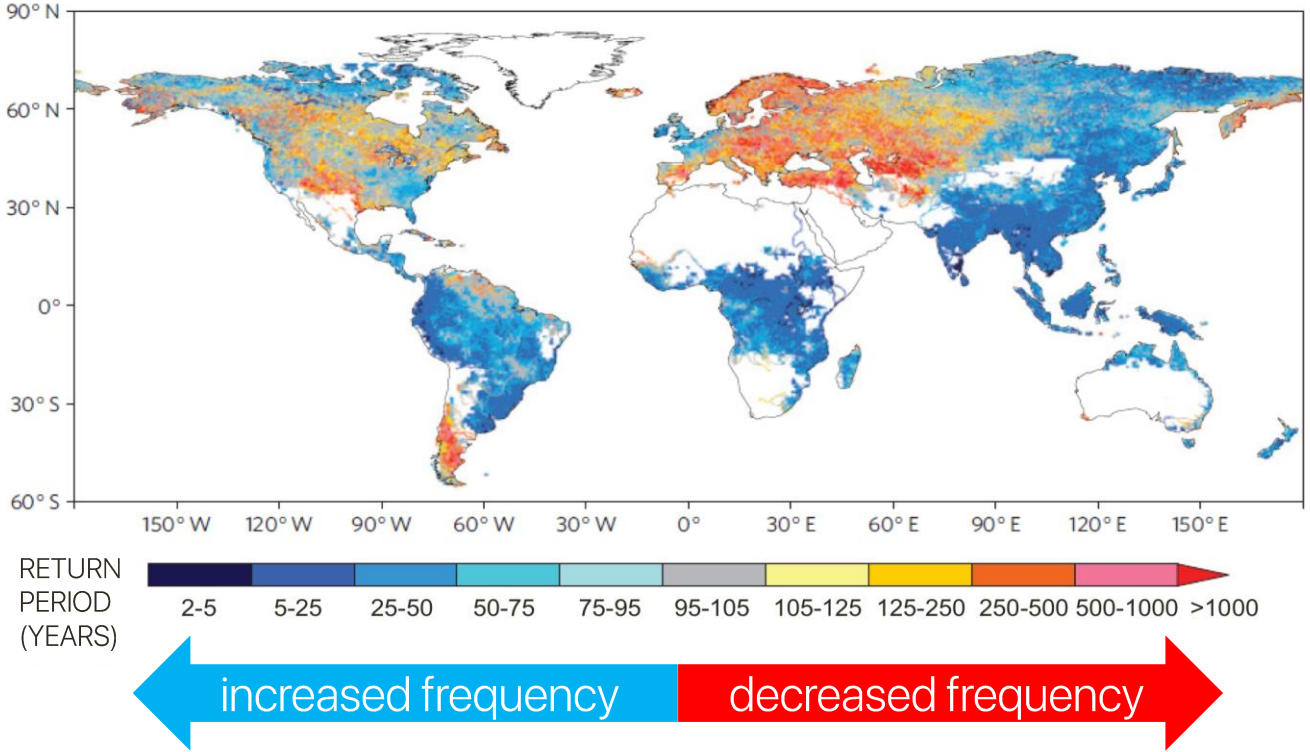
Flood consequences

- 1974-2023, 556 deaths, 30 missing, 425 injured, 195,502 evacuees & homeless
- 1380 sites in 984 Municipalities in 107 Provinces of 20 Regions



Bianchi & Salvati 2025

Climate & floods



Hirabayashi et al 2013, Jiménez Cisneros et al 2015

Climate & floods

- Simulations for the extreme flows by regional hydrological models have large biases.
- Global-scale hydrological models struggle with reproducing flood magnitude.
- Projections of future floods are hampered by difficulties and cascading uncertainties.

(with medium confidence)

IPCC 2021

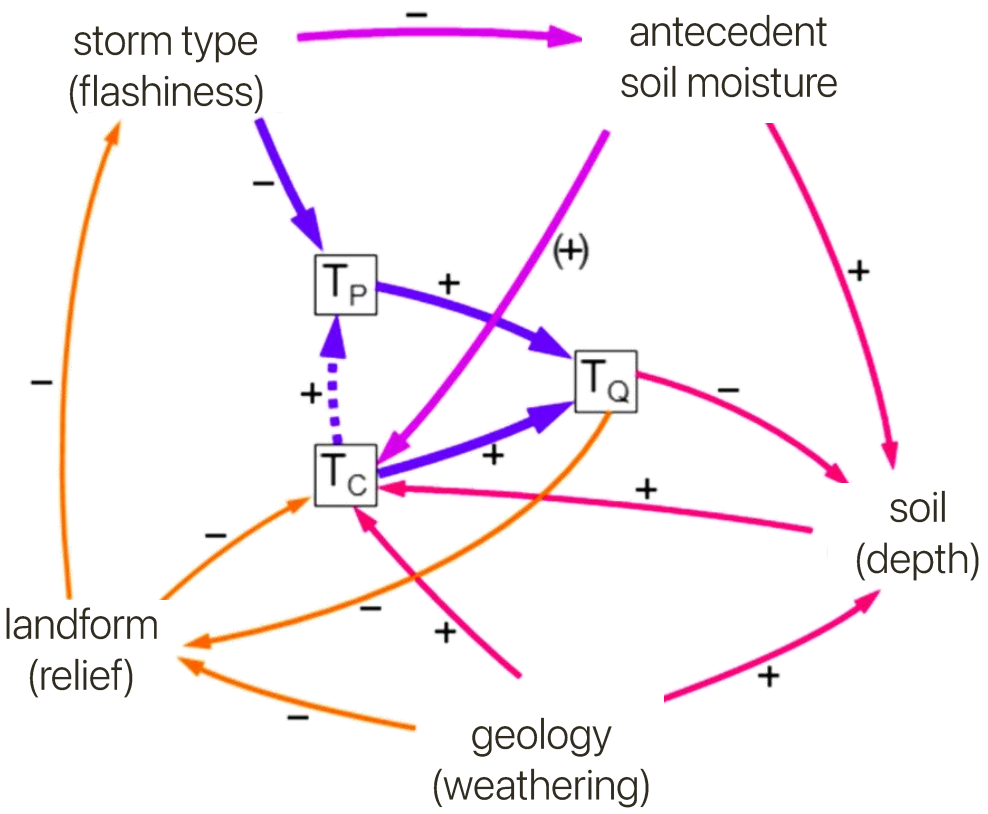
Flood timescales

T_P storm duration

T_C catchment response time

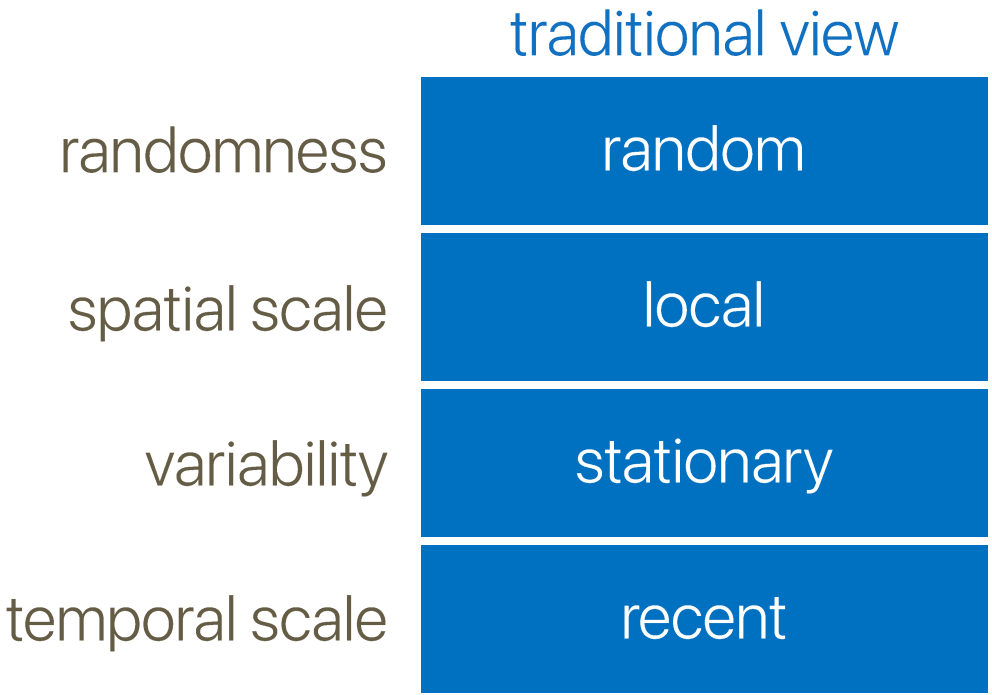
T_Q flood time scale

- event (hours)
- seasonal (months)
- soil formation (decades)
- landscape evolution (millennia)



modified from Gaál et al 2012

Climate & hydrology



Merz et al 2014

Climate & hydrology

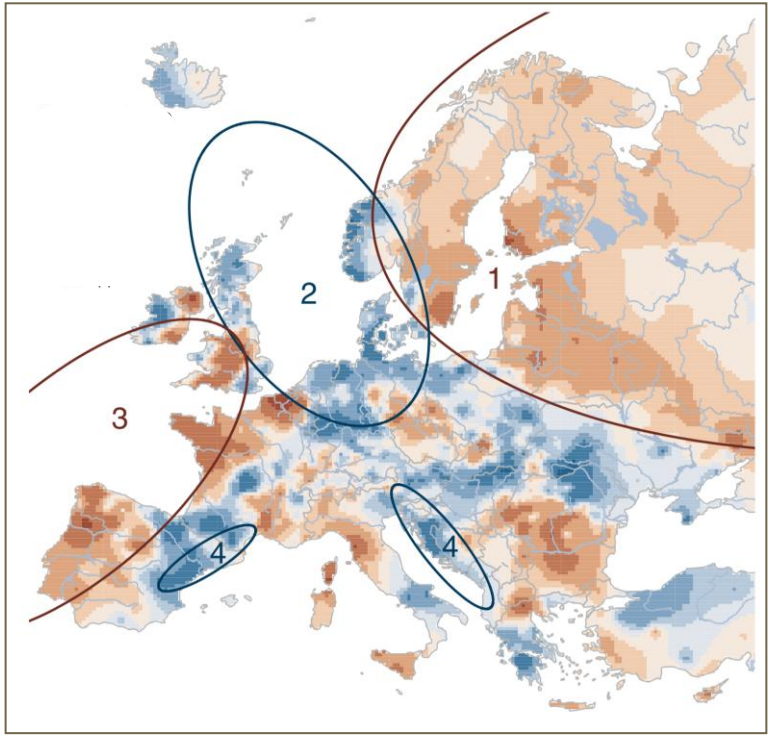
	traditional view	new perspective
randomness	random	causal processes
spatial scale	local	global
variability	stationary	time varying
temporal scale	recent	long term

Merz et al 2014

Changes in flood risk

- Will flood risk change in response to current and expected global warming?

Floods in Europe (1960 - 2010)

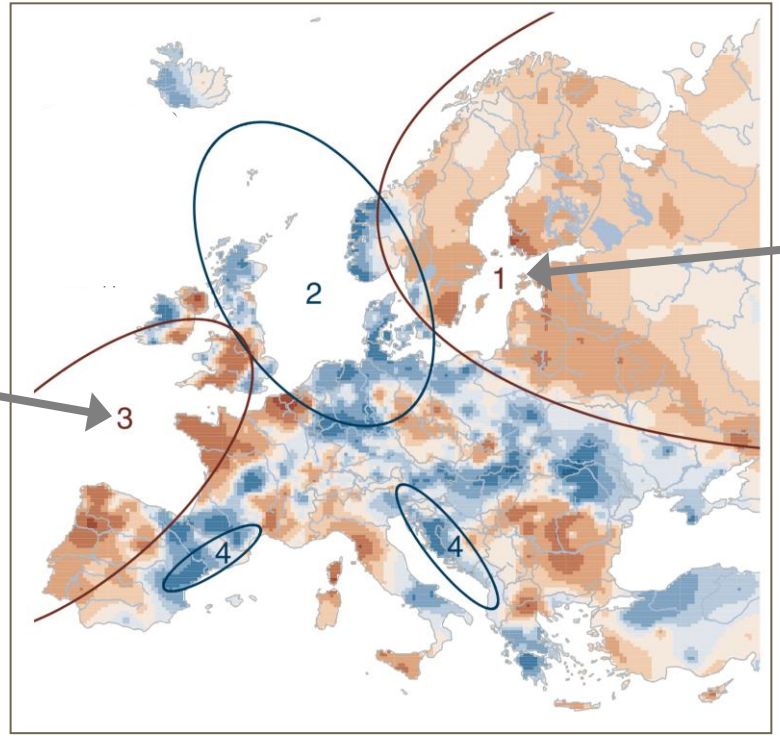


4262 hydrological stations from 1960 to 2010

Blöschl et al 2017

Floods in Europe (1960 - 2010)

earlier floods
earlier soil
moisture maximum



earlier floods
earlier snowmelt

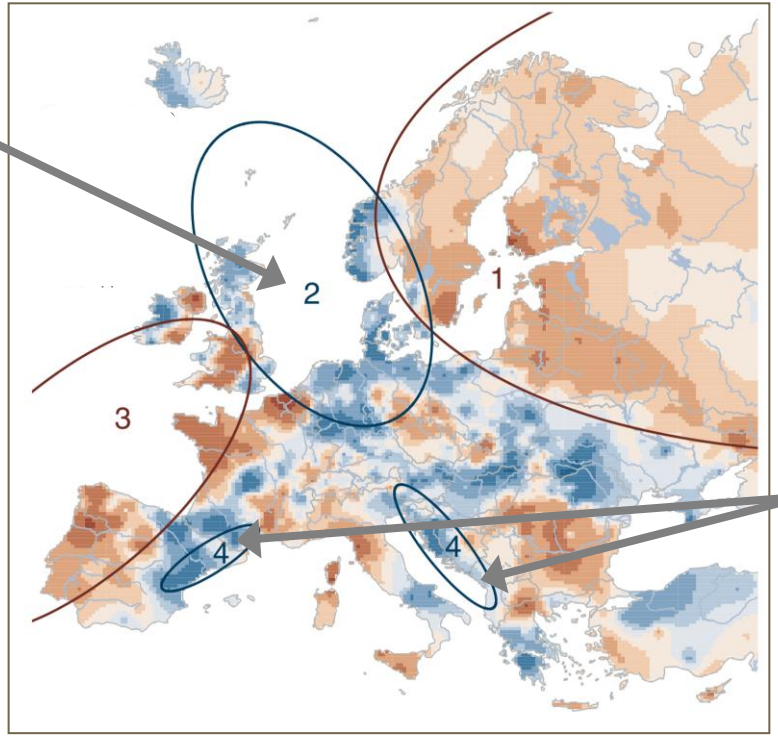
Blöschl et al 2017

4262 hydrological stations from 1960 to 2010

earlier later

Floods in Europe (1960 - 2010)

later floods
later winter storms



later floods
stronger Atlantic influence in Winter

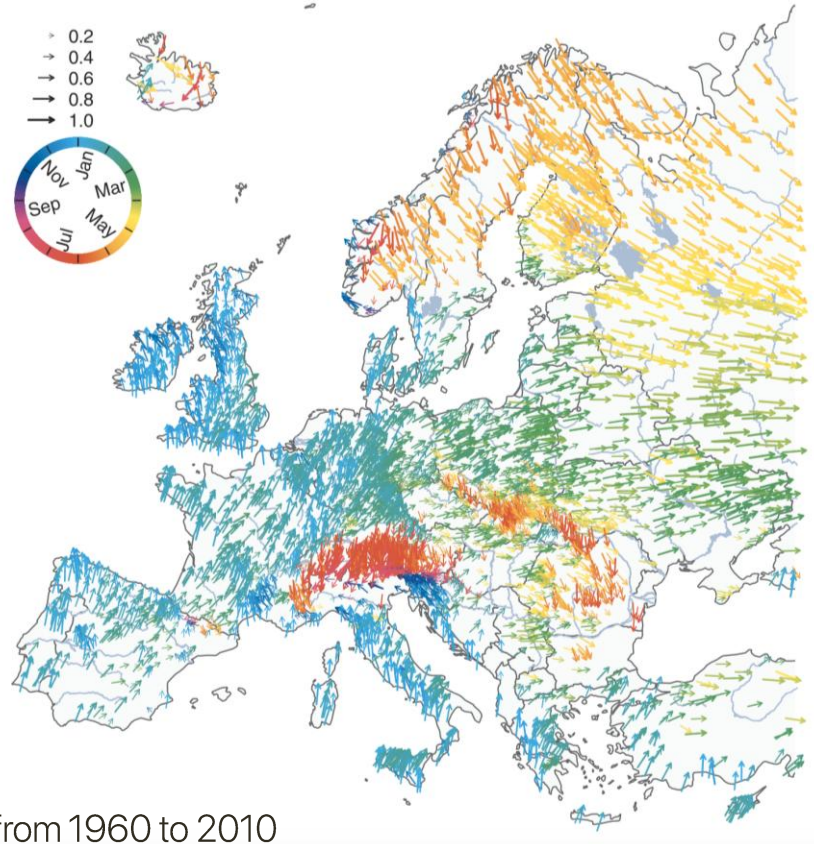
Blöschl et al 2017

4262 hydrological stations from 1960 to 2010

earlier later

Floods in Europe (1960 - 2010)

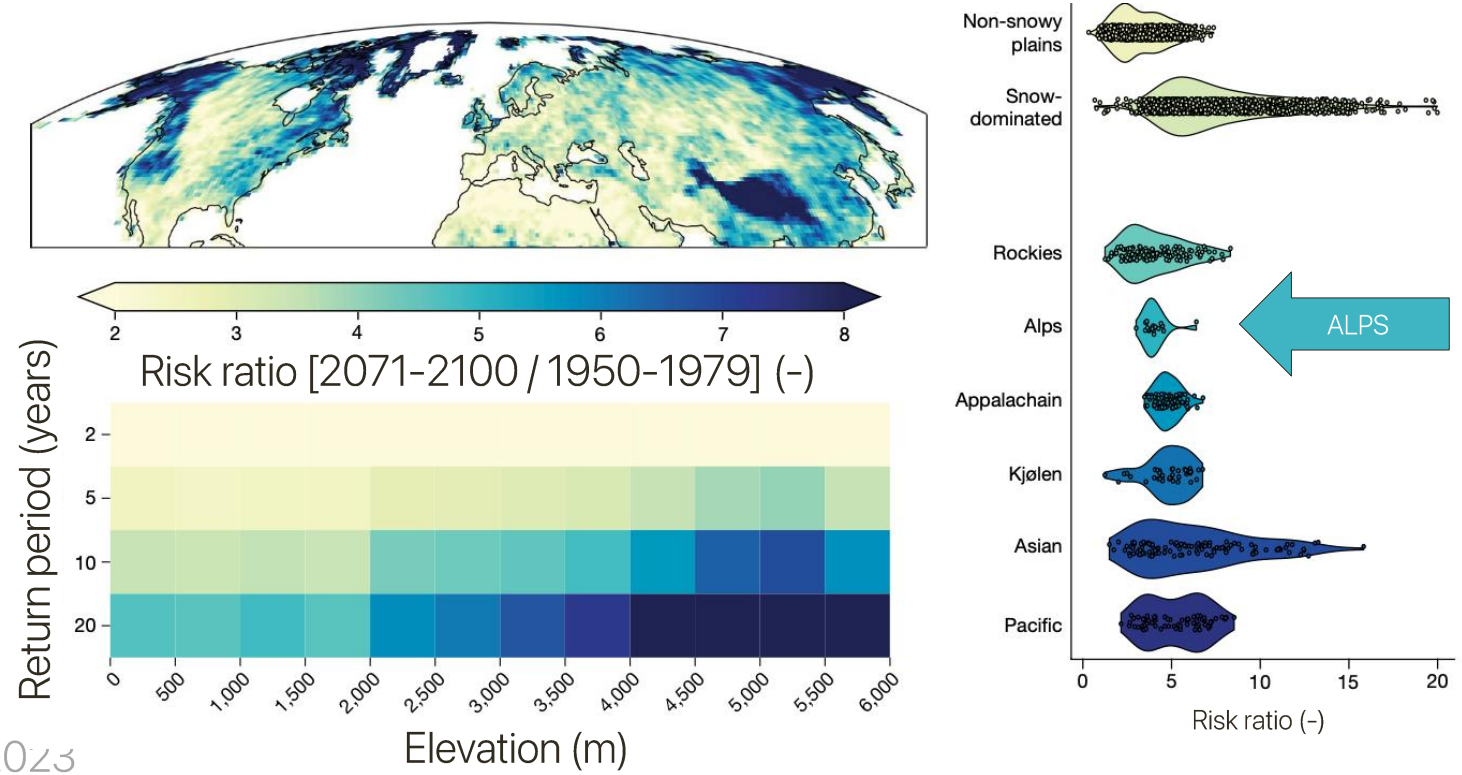
"The average flood period varies from west to east ... and from south to north ..."



Blöschl et al 2017

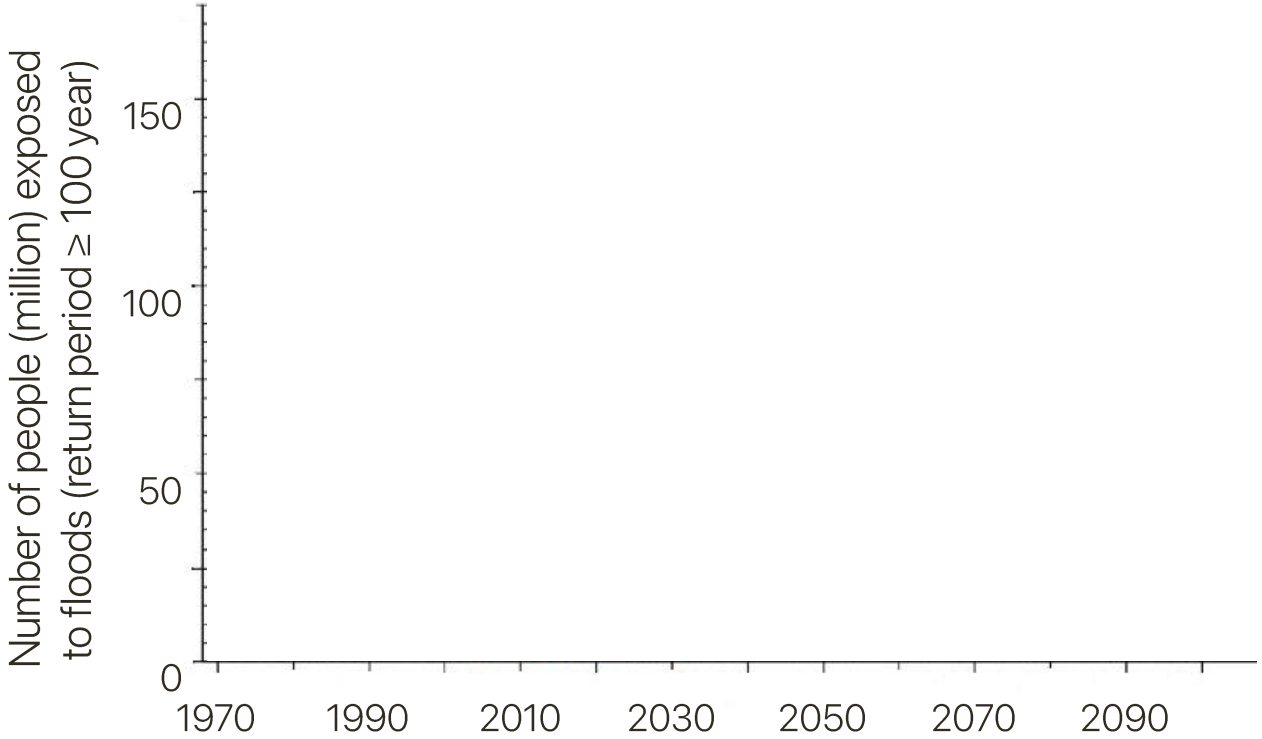
4262 hydrological stations from 1960 to 2010

Snow or rain?



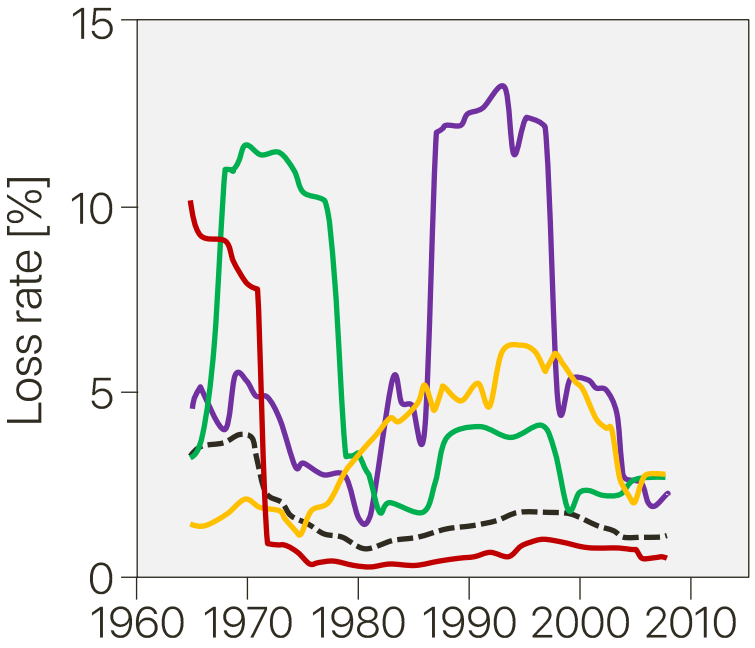
Ombadi et al 2023

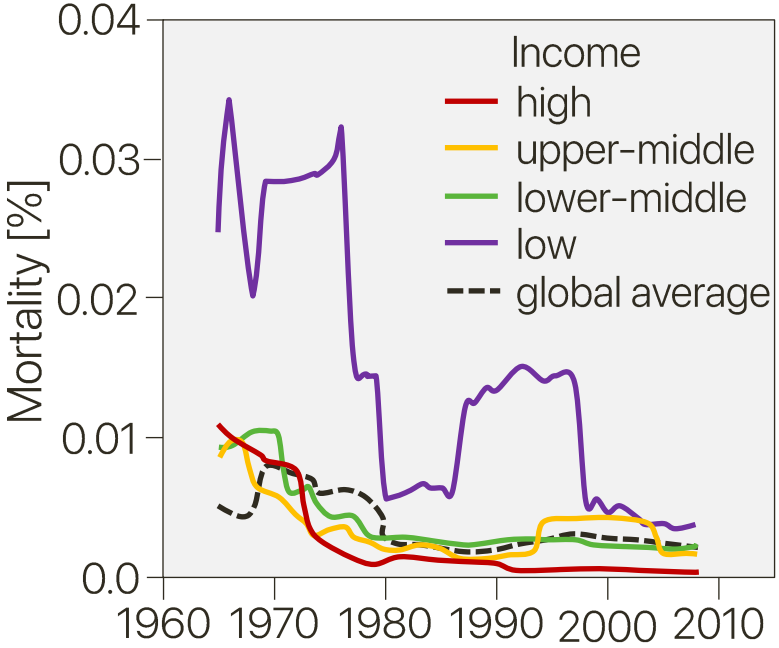
Climate & flood risk



Hirabayashi et al 2013, Jiménez Cisneros et al 2015

Global flood vulnerability





modified from Tanoue et al 2016

What can we expect?

- More flash floods
  - caused by short but intense rainfall

- More pluvial floods
  - caused by short but intense rainfall

- Less large river floods
  - caused by prolonged rainfall

What can we expect?

- More flash floods

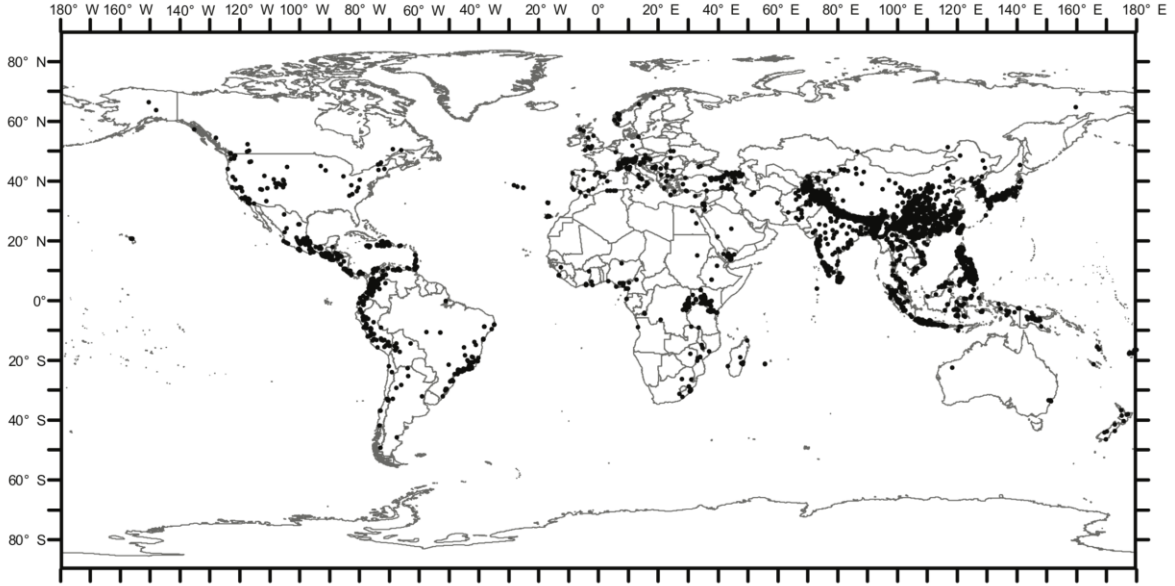
conclusion: flood risk to the population is expected to increase

- Less large river floods
  - caused by prolonged rainfall

LANDSLIDES

Global landslide fatalities

- 55,997 fatalities caused by 4862 landslides in the 13-year period 2004 - 2016.



non seismically triggered landslides

Froude & Petley 2018

Landslide consequences

- 1974-2023, 1060 deaths, 10 missing persons, 1443 injured, 138,743 evacuees & homeless
- 2681 sites in 1380 Municipalities in 99 Provinces of 20 Regions

Deaths, missing

- >5
- 4-5
- 2-3
- 1

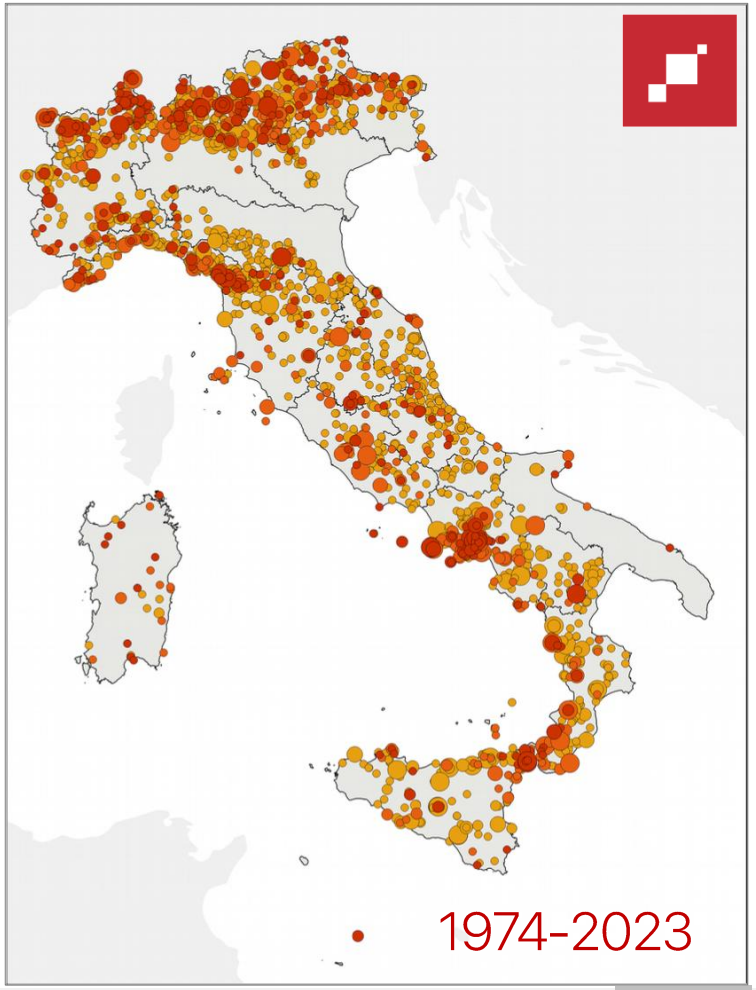
Injured

- >5
- 4-5
- 2-3
- 1

Homeless

- >250
- 151-250
- 101-150
- 51-100
- 1-50

Bianchi & Salvati 2025



Changes in landslide risk

- Will landslide risk change in response to current and expected climate warming?

Climate & landslides

Climate variable

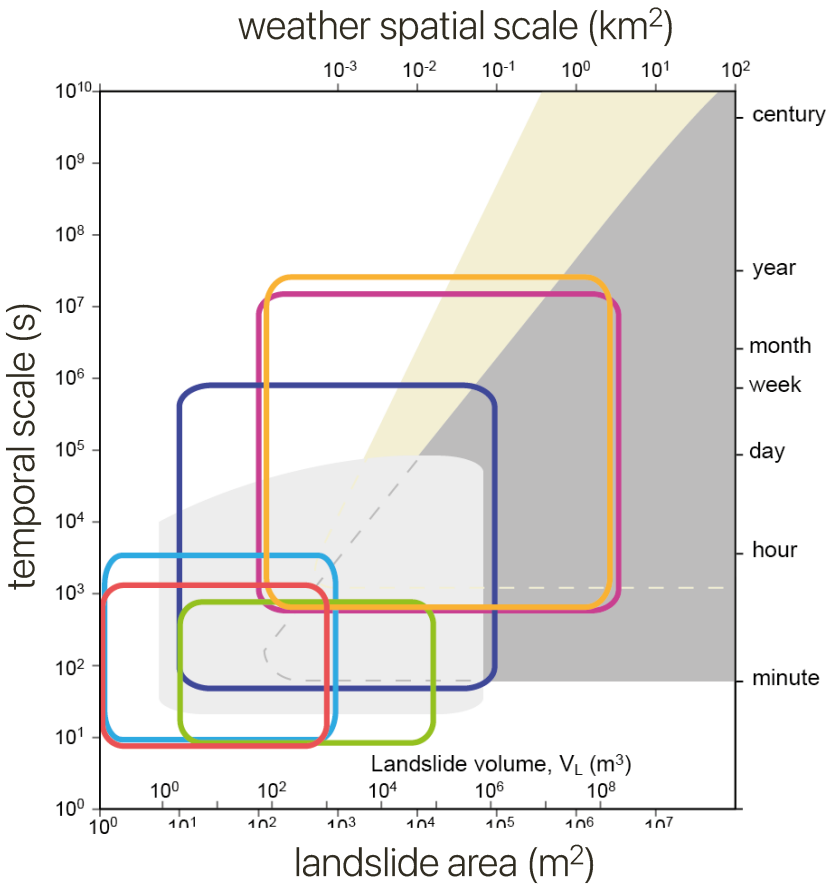
Air temperature

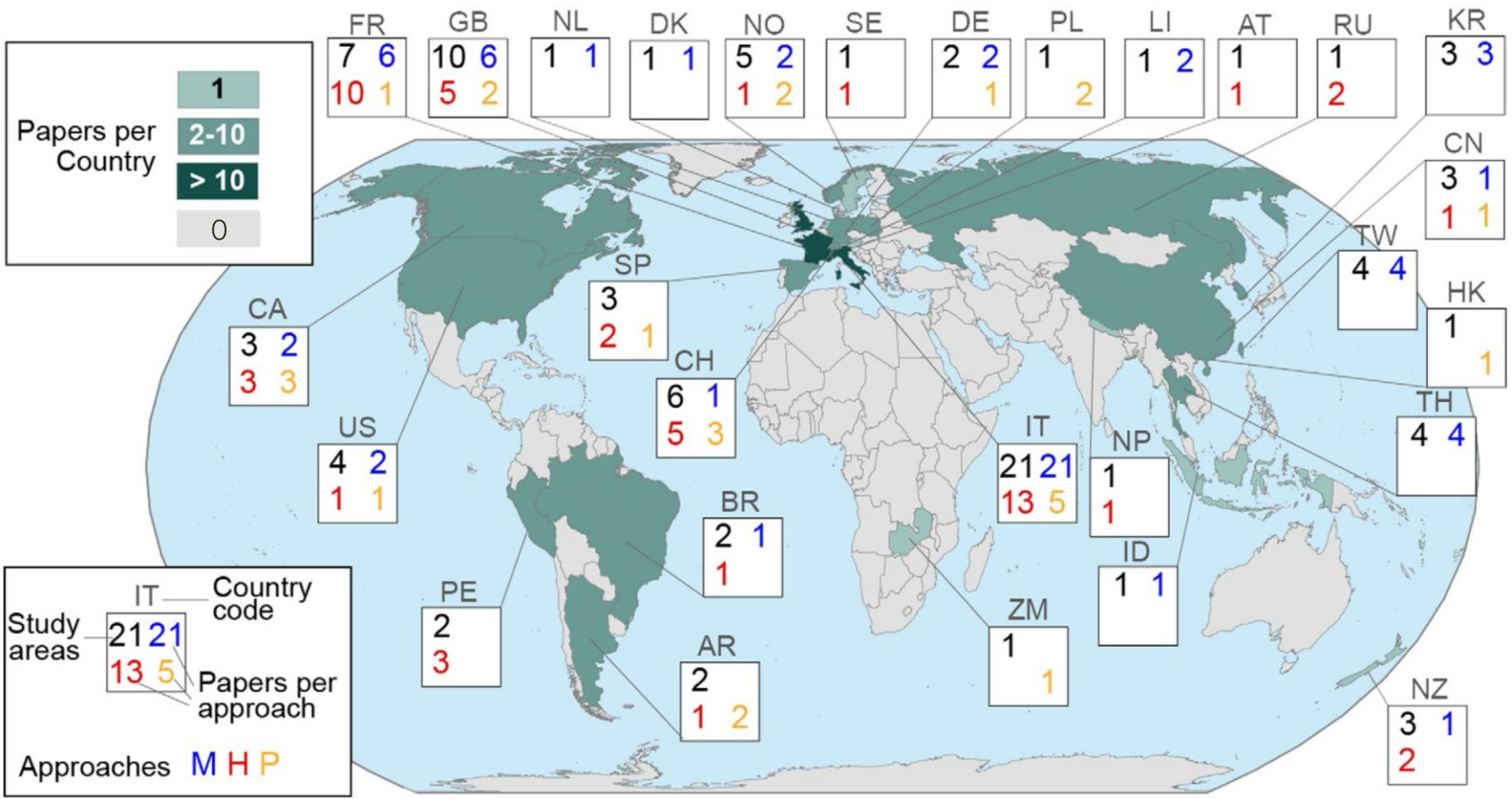
Cumulated rainfall

Rainfall intensity

Rock fall
Ice fall
Debris flow
Mud flow
Earth flow
Rock slide

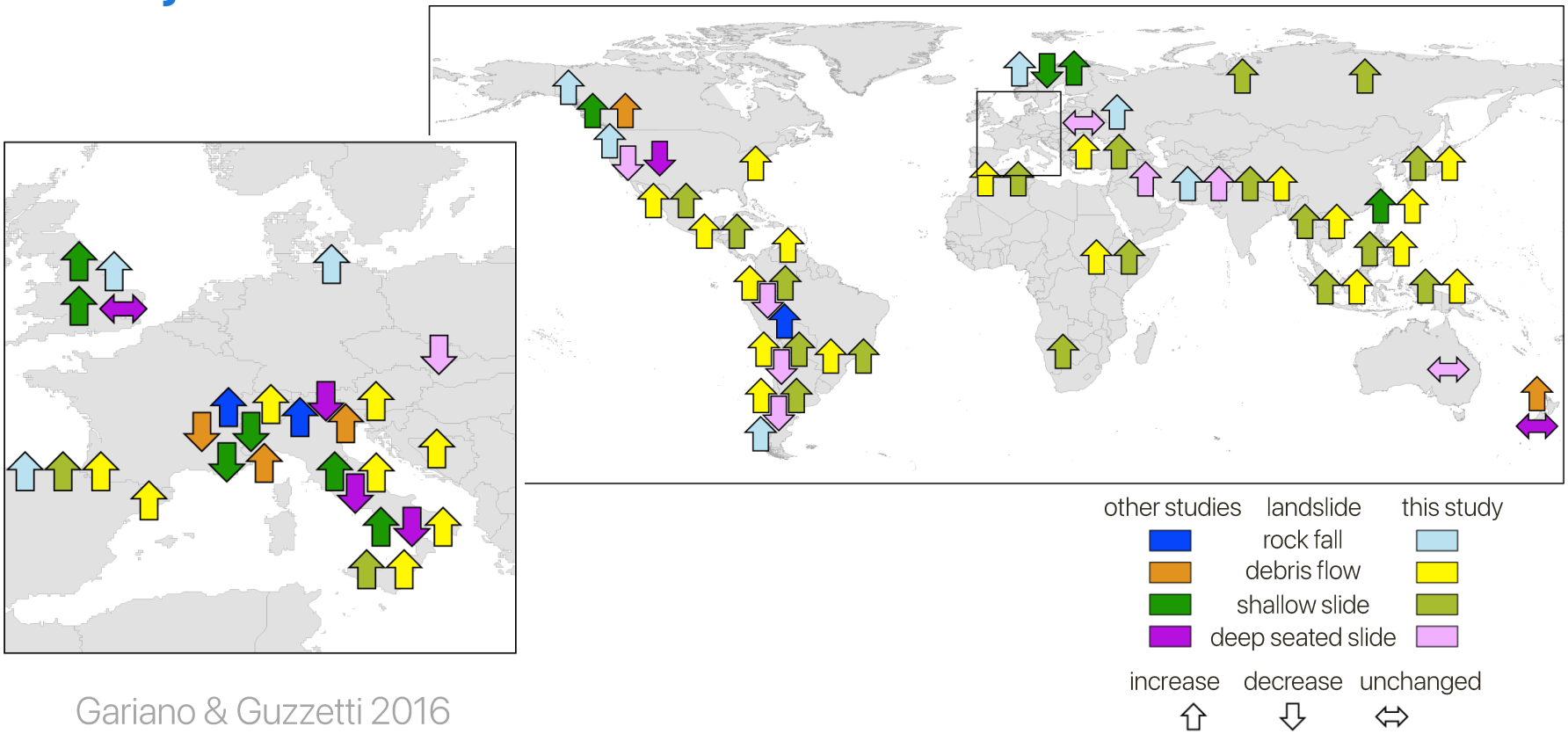
Gariano & Guzzetti 2016





Gariano & Guzzetti 2021

Projections

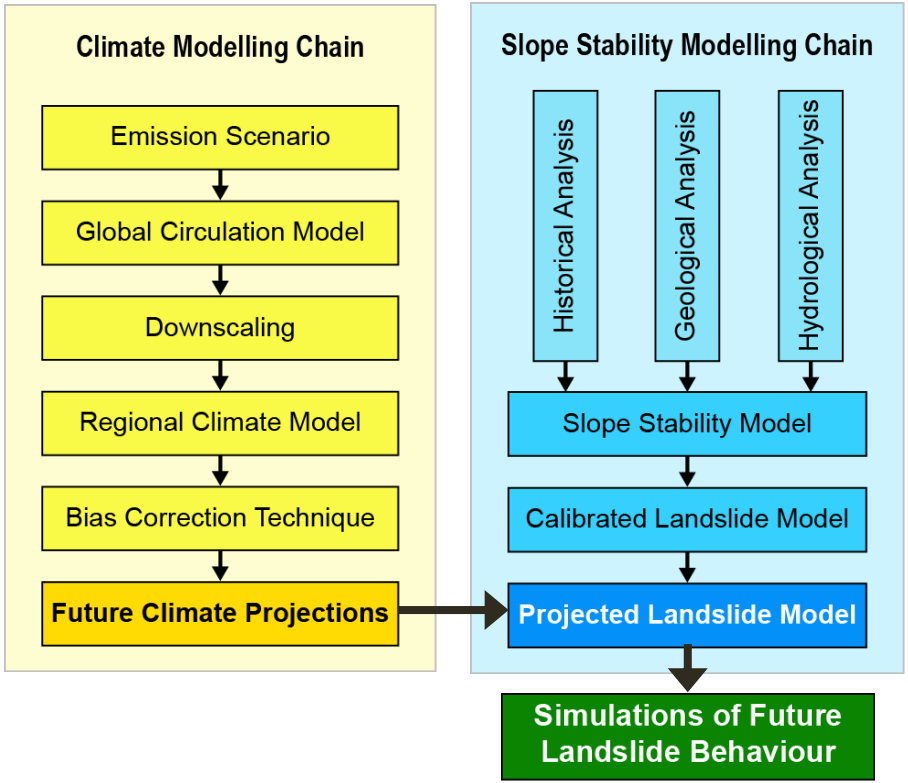


Gariano & Guzzetti 2016

Modelling approach

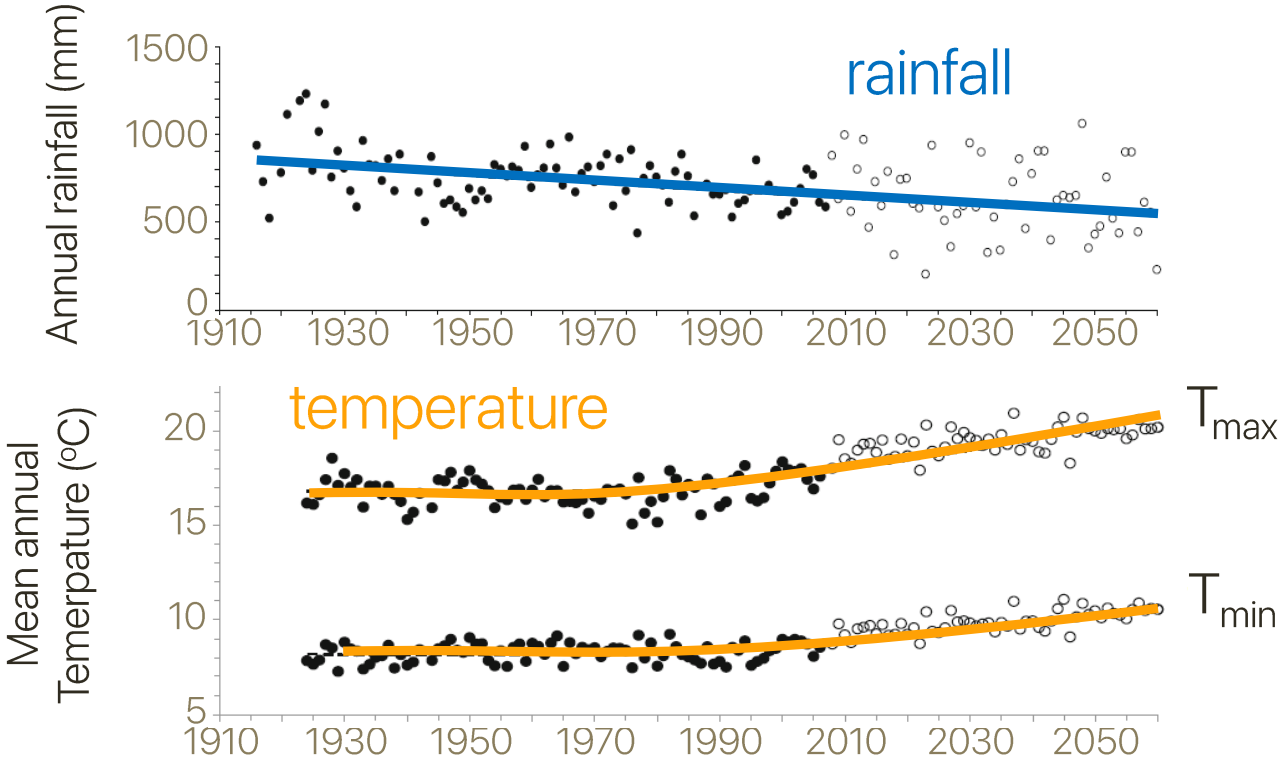
single landslide

entire landscape



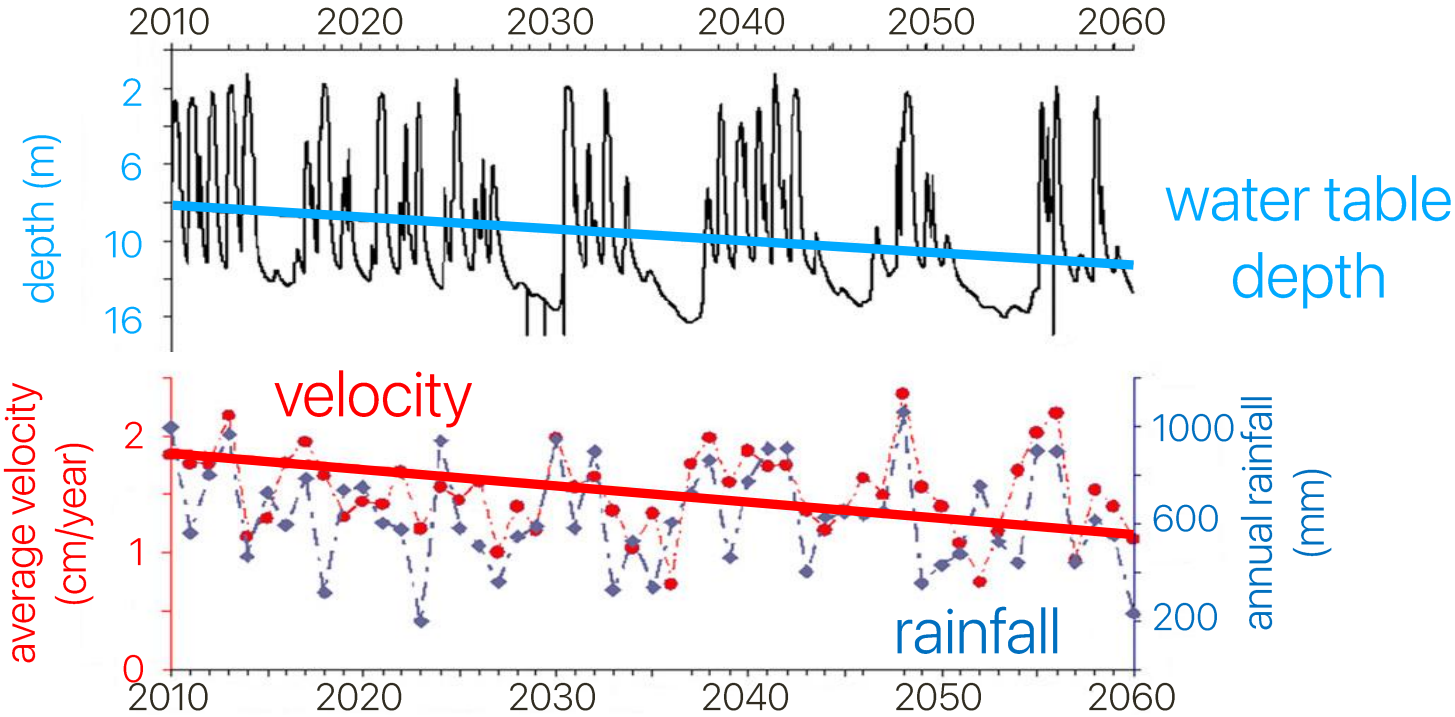
Gariano & Guzzetti 2016

Single landslide



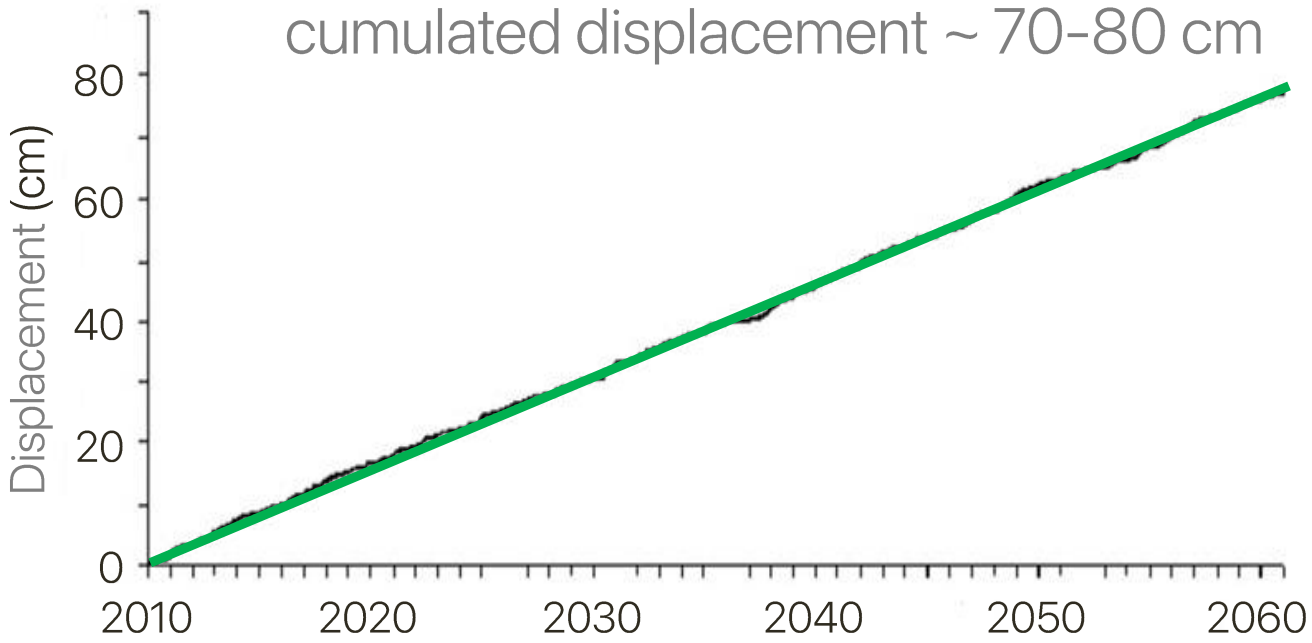
Comegna et al 2013

Single landslide



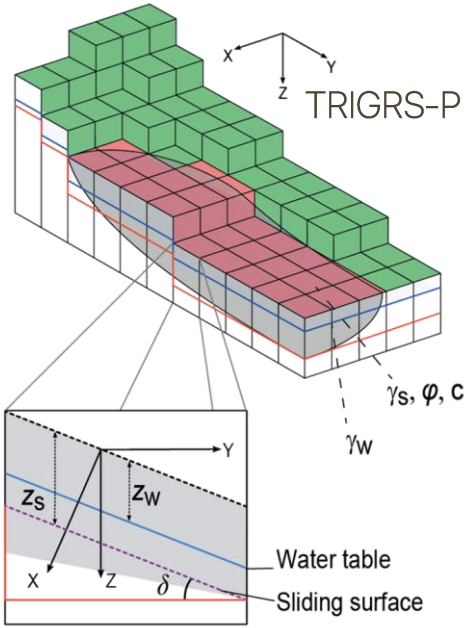
Comegna et al 2013

Single landslide



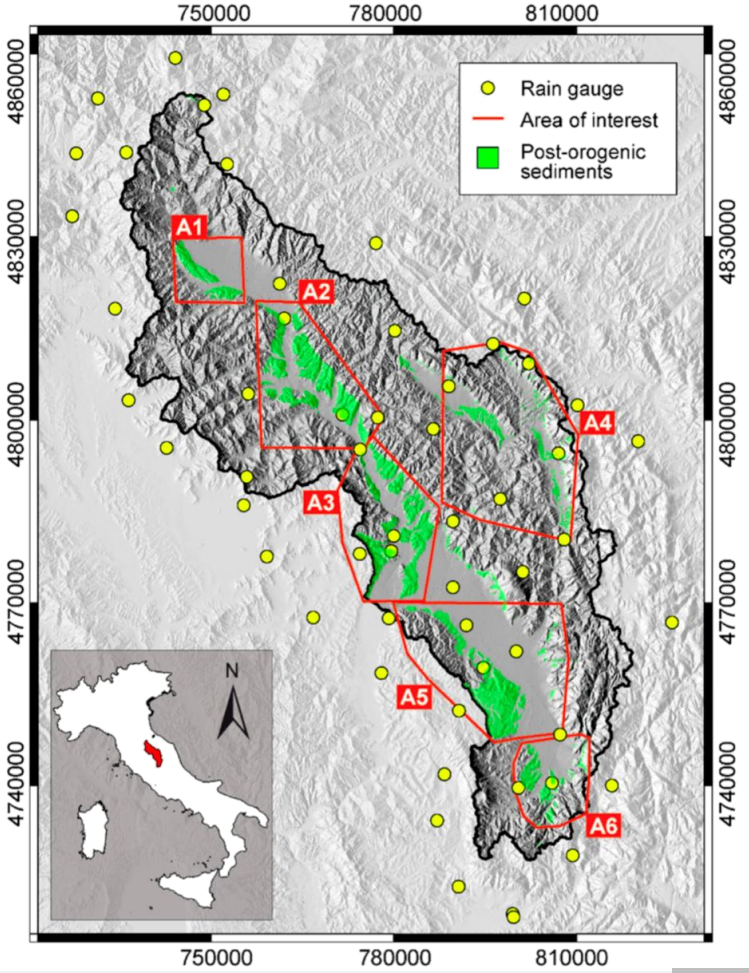
Comegna et al 2013

Landscape response

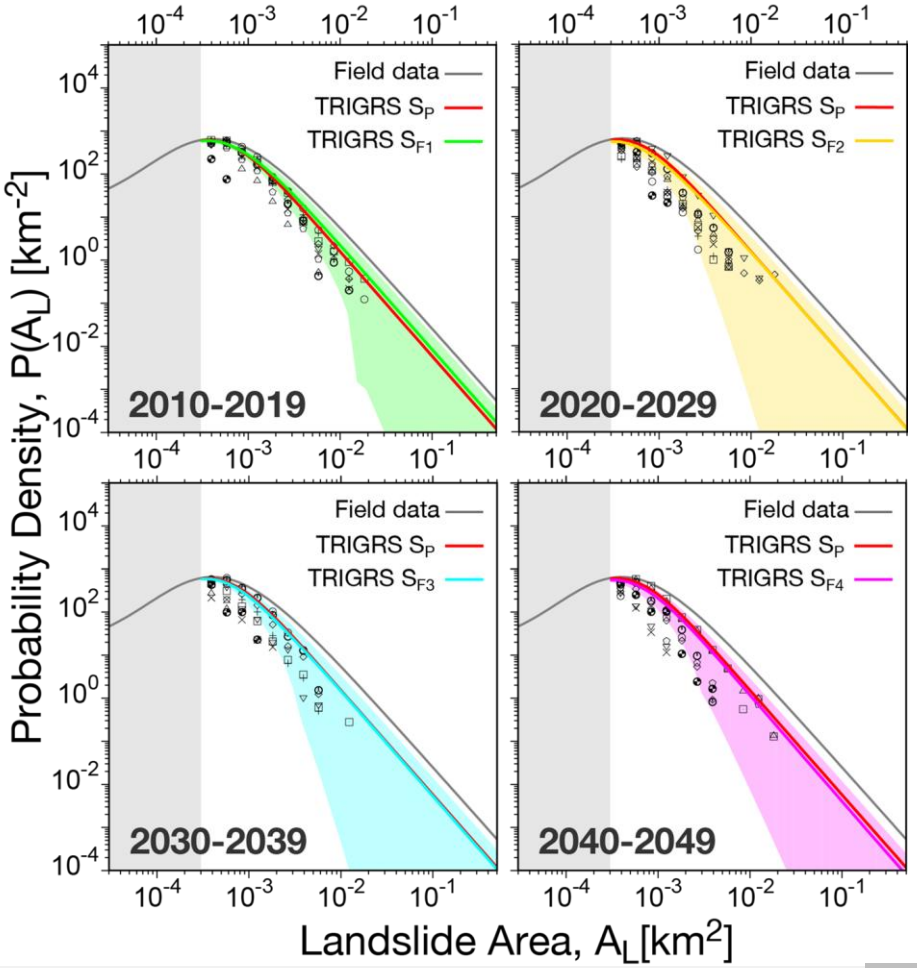


$$FS = \frac{R}{D} = \frac{tan(\varphi)}{tan(\delta)} + \frac{c - \psi \cdot \gamma_w \cdot tan(\varphi)}{\gamma_s \cdot z_s \cdot sin(\delta) \cdot cos(\delta)}$$

Alvioli et al 2018



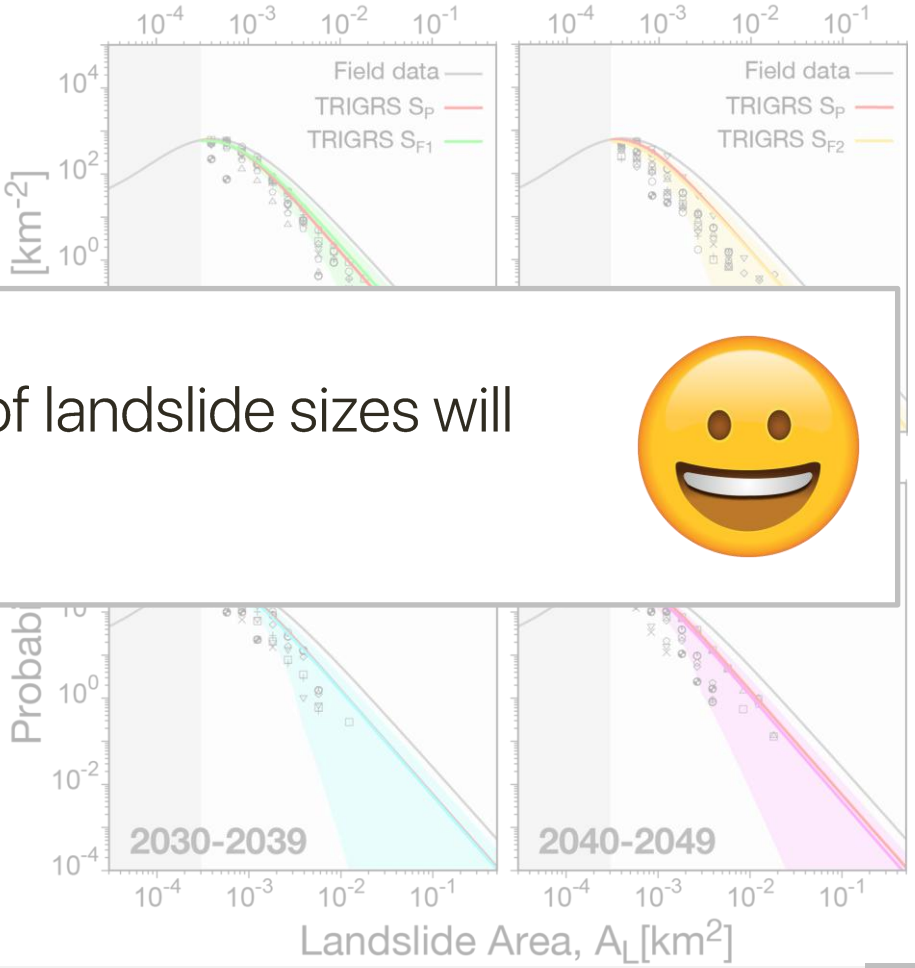
Landslide area



RCP4.5, strong mitigation

Alvioli et al 2018

Landslide area

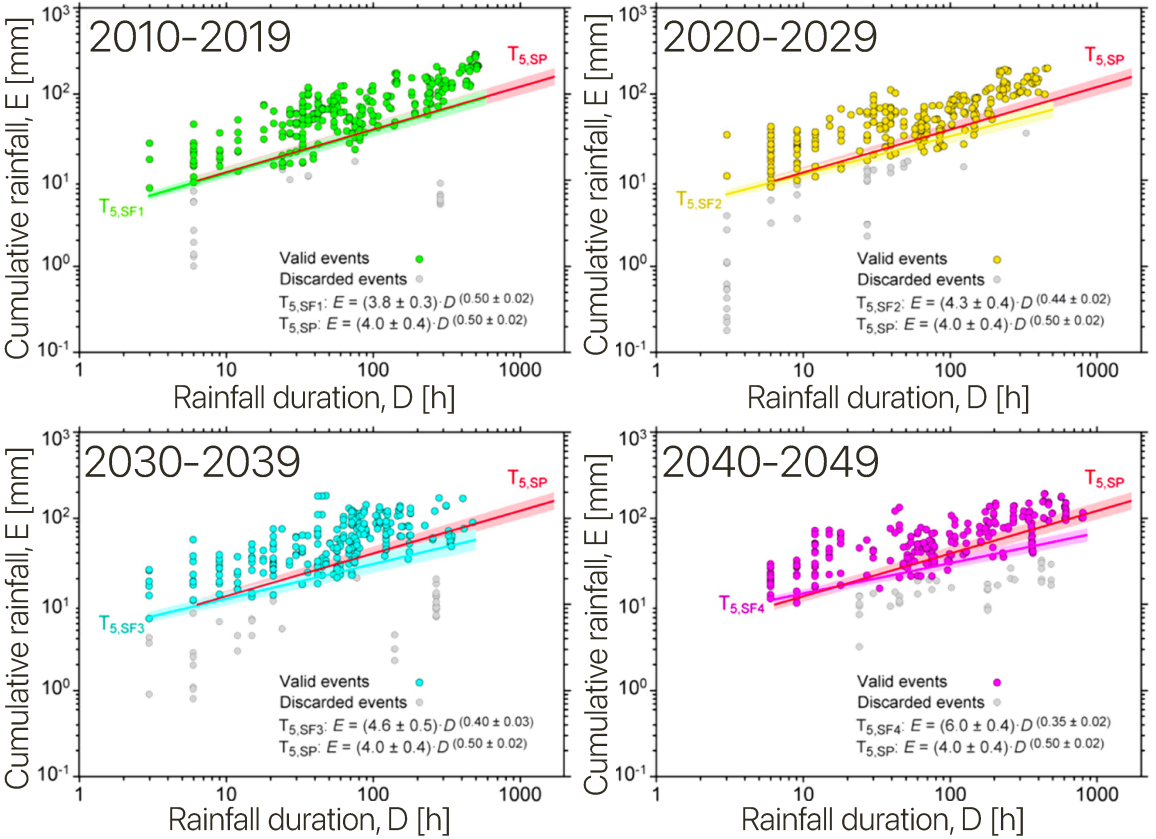


conclusion: the distribution of landslide sizes will not change

RCP4.5, forte mitigazione

Alvioli et al 2018

Rainfall thresholds

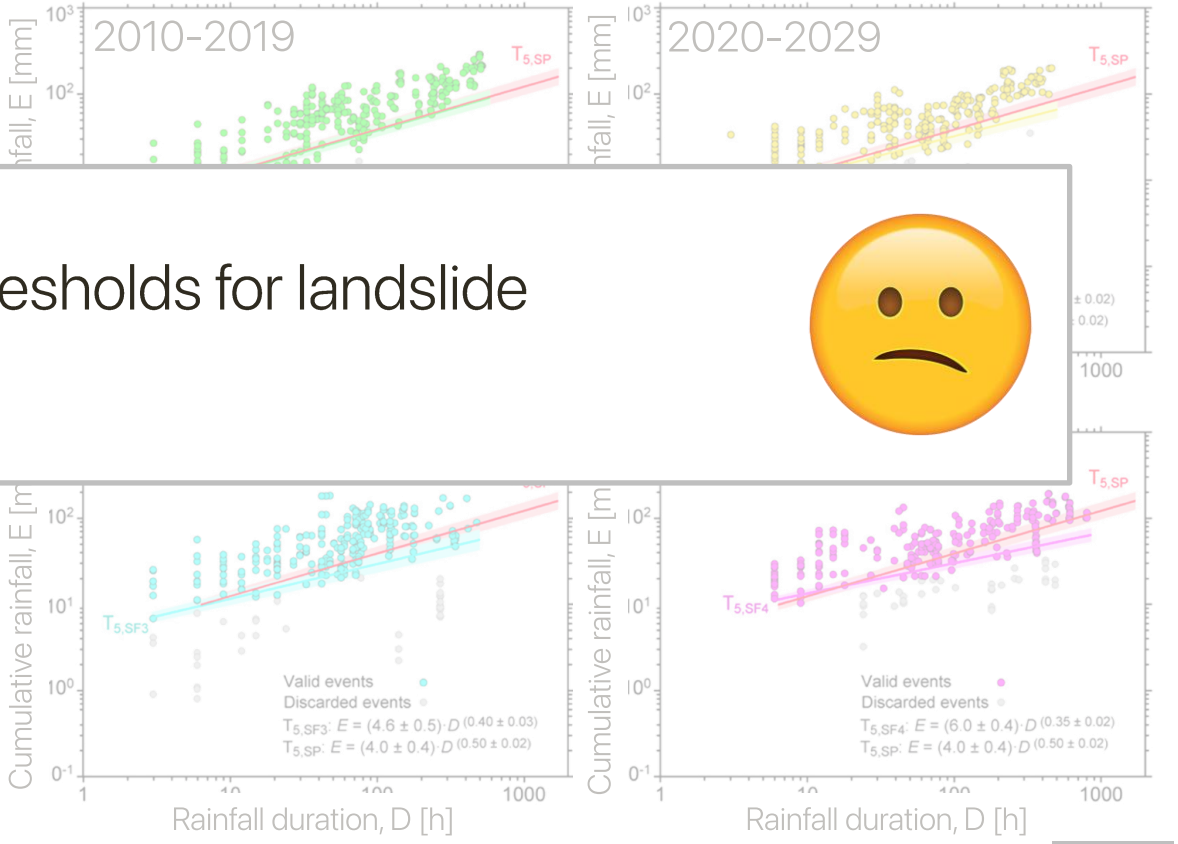


RCP4.5, strong mitigation

Alvioli et al 2018

Rainfall thresholds

conclusion: rainfall thresholds for landslide triggering will change



RCP4.5, strong mitigation

Alvioli et al 2018

What can we expect?

- More shallow and fast landslides
  - caused by short, heavy rainfall

- Fewer deep and slow landslides
  - caused by prolonged rainfall

- More shallow and deep landslides
  - caused by rapid snow melting a permafrost melting

What can we expect?

- More shallow and fast landslides

conclusion: landslide risk to the population is expected to increase

- More shallow and deep landslides
  - caused by rapid snow melting a permafrost melting

CONSIDERATIONS

Fragile landscapes

Assets

- 5.9×10^7 people in 3.0×10^5 km^2
- 1.4×10^7 buildings & 3.1×10^7 homes
- 1.8×10^5 km of roads & railways
- 5.0×10^6 enterprises
- 1.8×10^7 employees
- € 2.1×10^{12} PIL (2024)

Istat

https://commons.wikimedia.org/wiki/File:Satellite_image_of_Italy_in_March_2003.jpg | Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC, Public domain, via Wikimedia Commons

Population at risk

- 2.2×10^7 seismic risk
- 2.5×10^6 volcanic risk
- 7.0×10^6 flood risk
- 2.0×10^6 landslide risk
- 1.5×10^7 water scarcity risk

https://commons.wikimedia.org/wiki/File:Satellite_image_of_Italy_in_March_2003.jpg | Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC, Public domain, via Wikimedia Commons

A safe place?

- We will not be able to make the natural and built environment a safe place … any time soon.
- Too difficult, expensive, uncertain, socially unacceptable.

What to do?

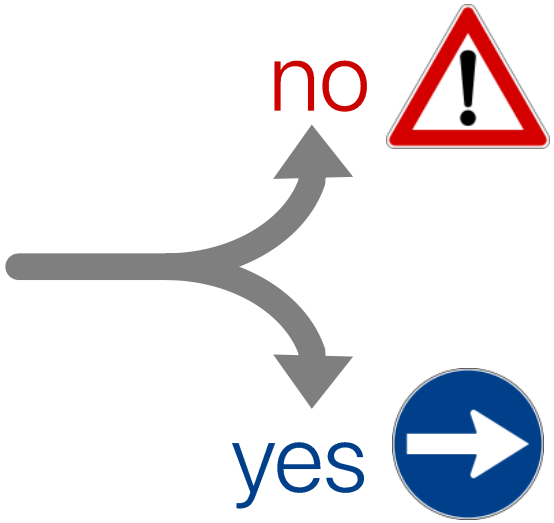
- Invest in early warning systems, at all time and geographical scales.
- Improve forecasting.

Predictions

- One would like exact predictions.
- But all prediction systems are subject to uncertainties and errors.

Uncertainties

- Managing uncertainties and probabilities is difficult because decisions are binary.



Decisions

"Give me a one-handed economist. All my economists say 'on the one hand ...', then 'but on the other ...' "

https://en.wikipedia.org/wiki/Harry_S._Truman

Harry S. Truman, 33rd & 34th President of the USA

Uncertainty & decisions

"Uncertainties abound. That much is clear. But it is equally clear that the greatest obstacle [...] is political rather than the underlying science."

Wagner 2021

Knowledge & decisions

"While knowledge will always be incomplete, the associated risks are of a magnitude that do not justify postponing policy decisions."

https://en.wikipedia.org/wiki/Thomas_Stocker

Stocker 2021

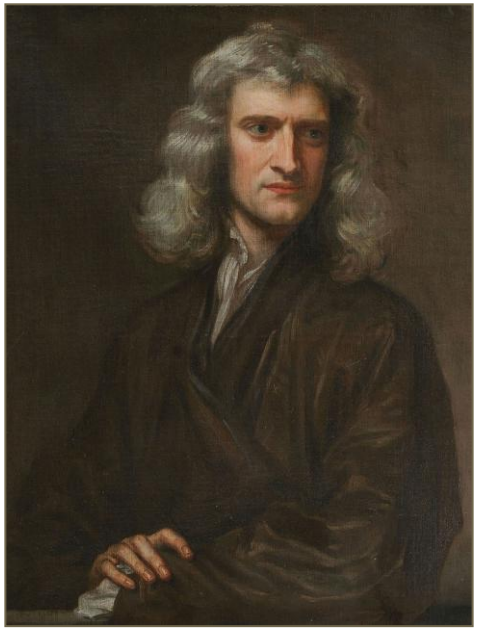
Inform & communicate

- Inform about risks and their consequences.
- Communicate uncertainties.

Science & politics

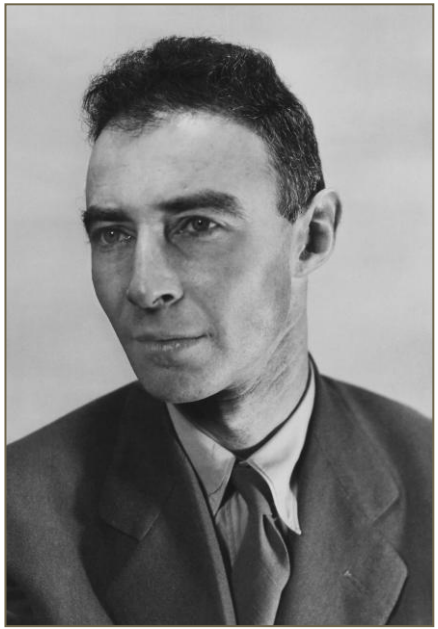
https://it.wikipedia.org/wiki/Leonardo_da_Vinci#/media/File:Leonardo_self.jpg

Leonardo da Vinci



https://upload.wikimedia.org/wikipedia/commons/f/f7/Portrait_of_Sir_Isaac_Newton%2C_1689_%28brightened%29.jpg

Isaac Newton

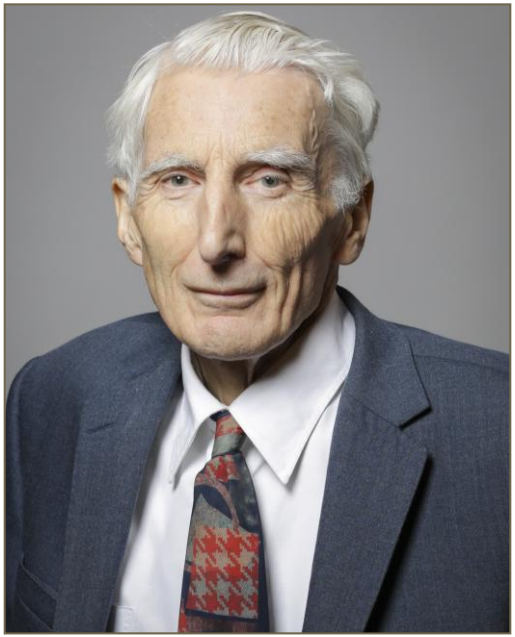


https://upload.wikimedia.org/wikipedia/commons/f/f7/Portrait_of_Sir_Isaac_Newton%2C_1689_%28brightened%29.jpg

J. Robert Oppenheimer

Scientists & politics

"... scientists should be on tap, but not on top"



https://en.wikipedia.org/wiki/Martin_Rees

Rees 2022 p 105

Science & legislation

- Science is general, legislation is local.
- Legislation and ethics define operational, legal, social responsibilities.

Ethics

- A medical doctor does not study medicine (only) to understand how the human body works, but to cure people.
- A geo-scientist does not study natural phenomena (only) to understand how the planet works, but to help communities cope with hazards.

Skin in the game

"Avoid taking advice from someone who gives advice for a living, unless there is a penalty for their advice."

https://www.youtube.com/watch?v=IsHNb-4IxDY

Taleb 2018

THANK YOU

Fausto Guzzetti
Consiglio Nazionale delle Ricerche

Assisi, 23 July 2025

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