Natural hazards and disasters around the Caspian Sea

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Forest remains on the beach near Astara (NW Iran) drowned by the 1995 highstand,

Photograph taken in 2009. Plastic shoe for scale.

Source: S.A.G. Leroy

Content

- Introduction and setting
- Types of risks and disasters
    1. Geological disasters
    2. Meteorological and climatic disasters
    3. Hydrological disasters
- Discussion
    A. Warning systems and mitigation
    B. Potential disasters
    C. Factors contributing to the making of a disaster
    D. Comparing hazards and disasters

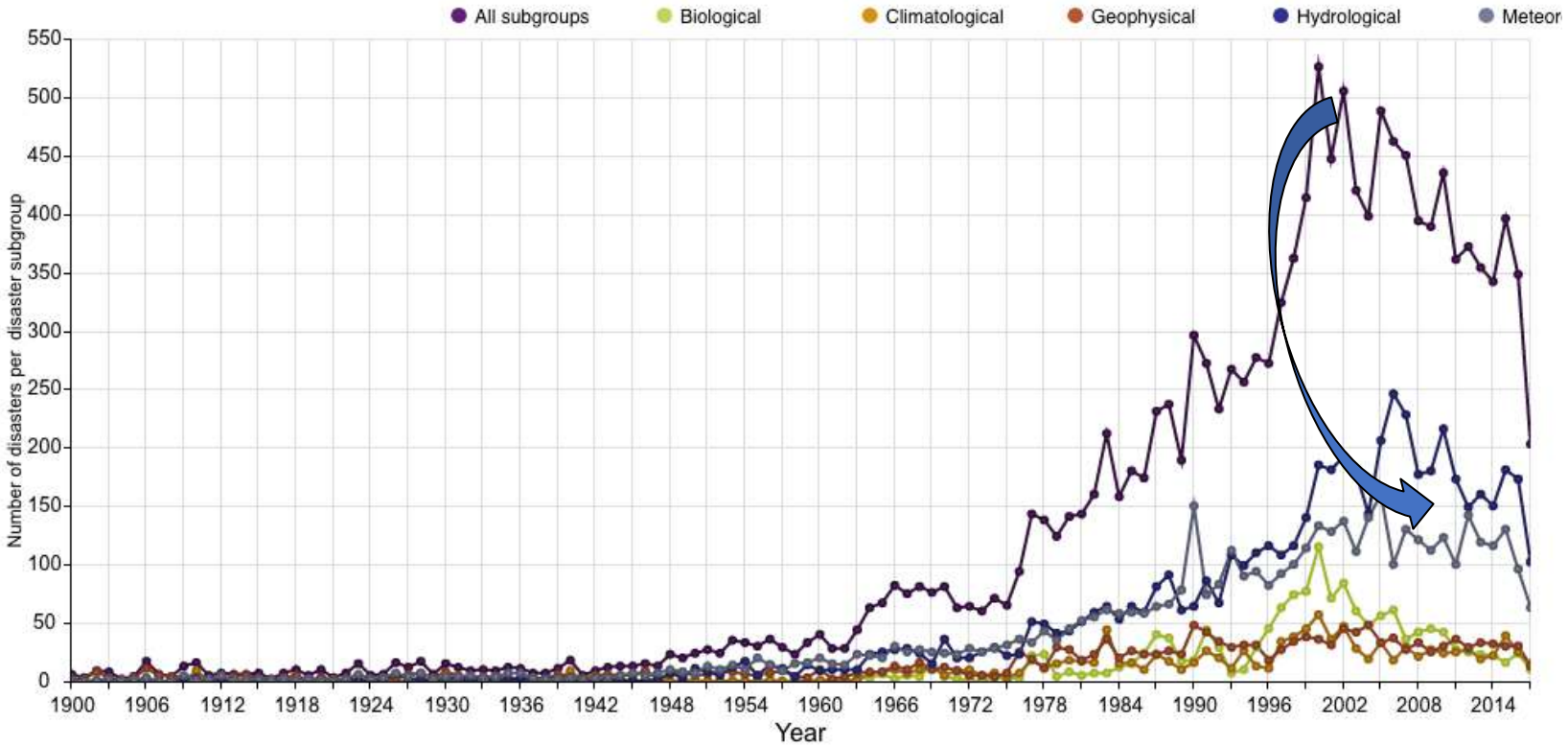
CDC

Introduction and setting

- Definitions
  - Hazard
  - Disaster
  - Catastrophe

Worldwide number of disasters rising

- ➢ Number of people is rising
- ➢ They live more in marginal areas

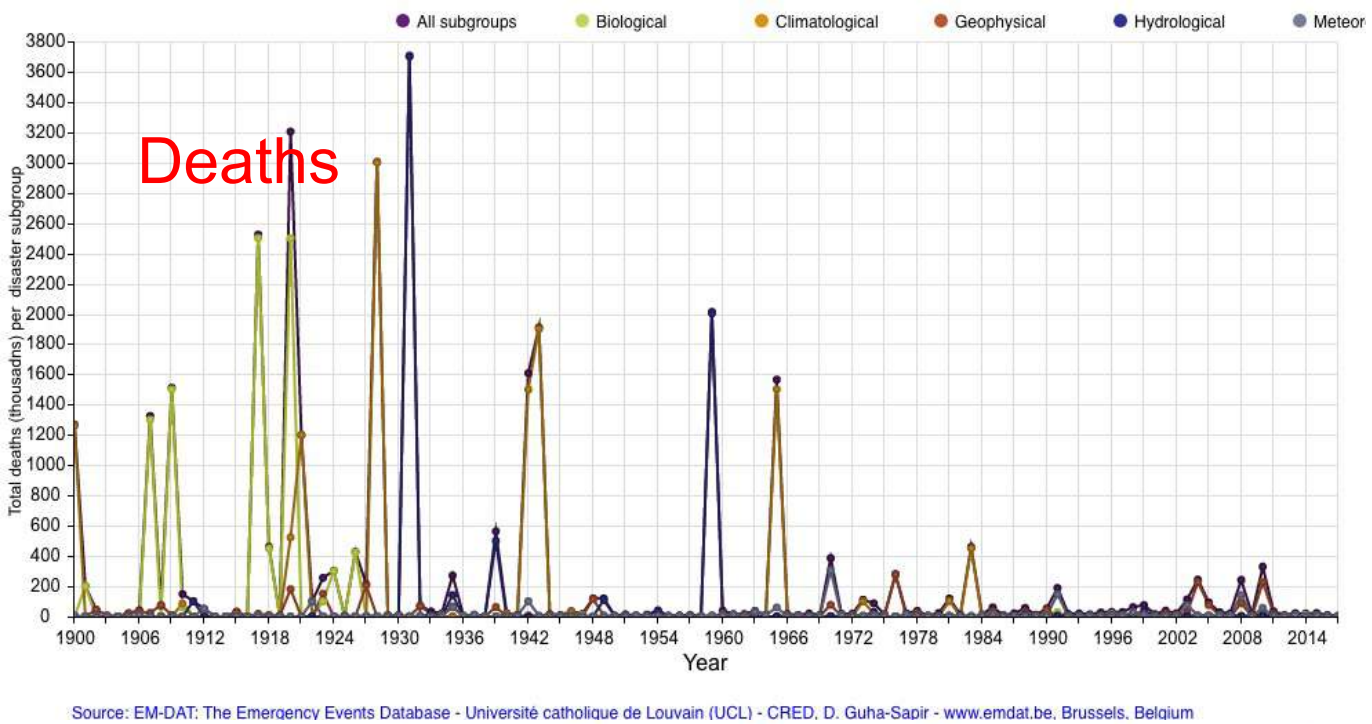


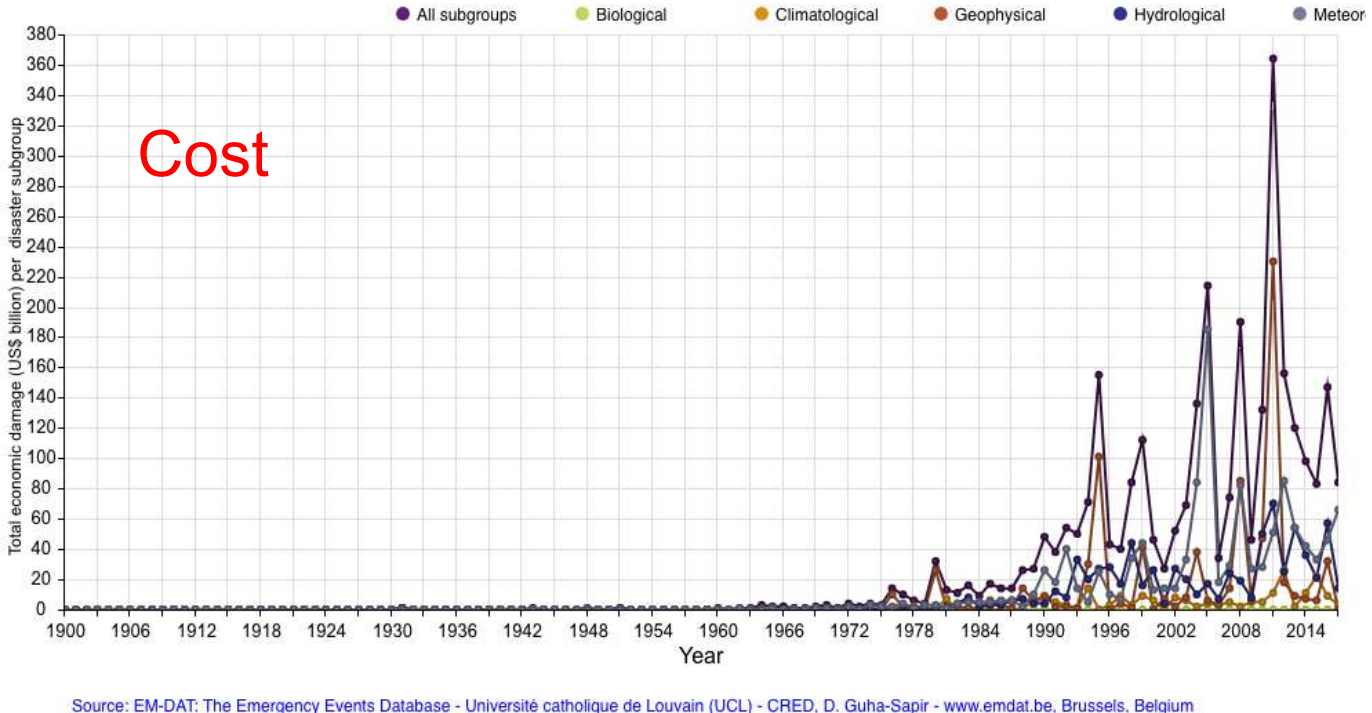
Source: EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

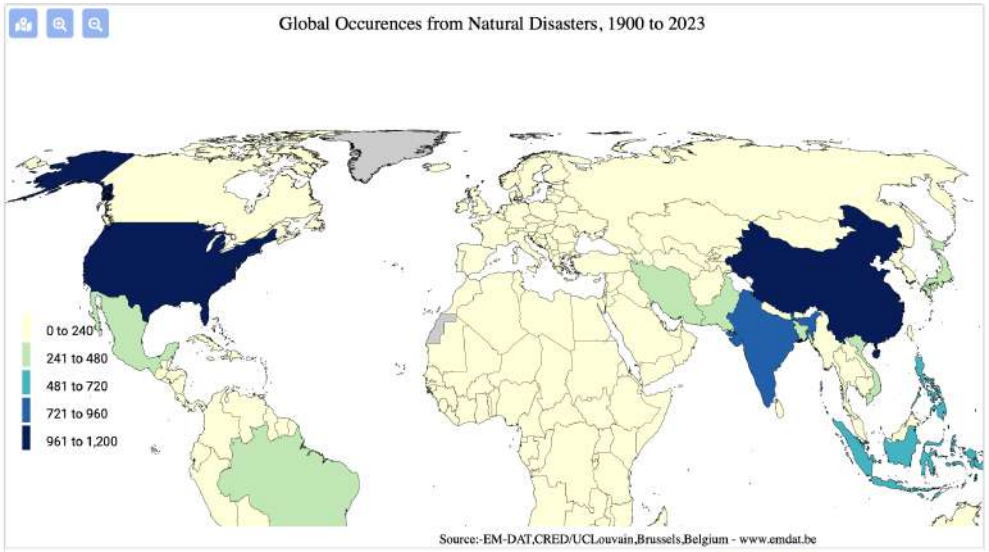
Measure

No scale to measure it

- Deaths?
- Cost?

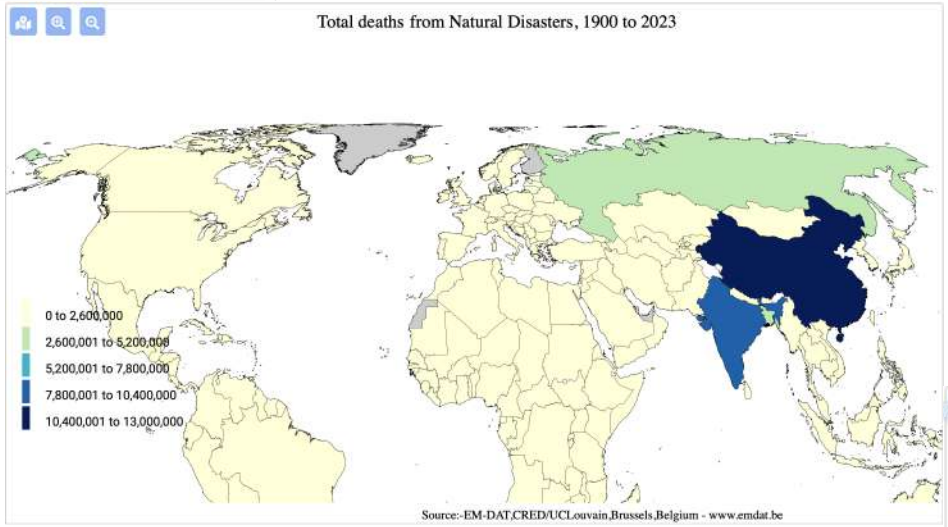




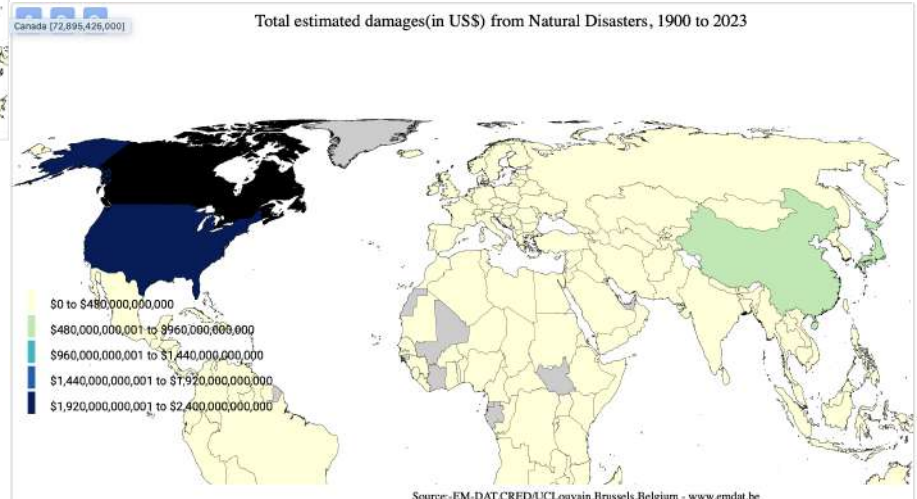


Global occurrence

From EM_DAT database



Total deaths



Total estimated damages in USD

Introduction and setting

Natural Hazards
https://doi.org/10.1007/s11069-022-05522-5

REVIEW ARTICLE

Natural hazards and disasters around the Caspian Sea

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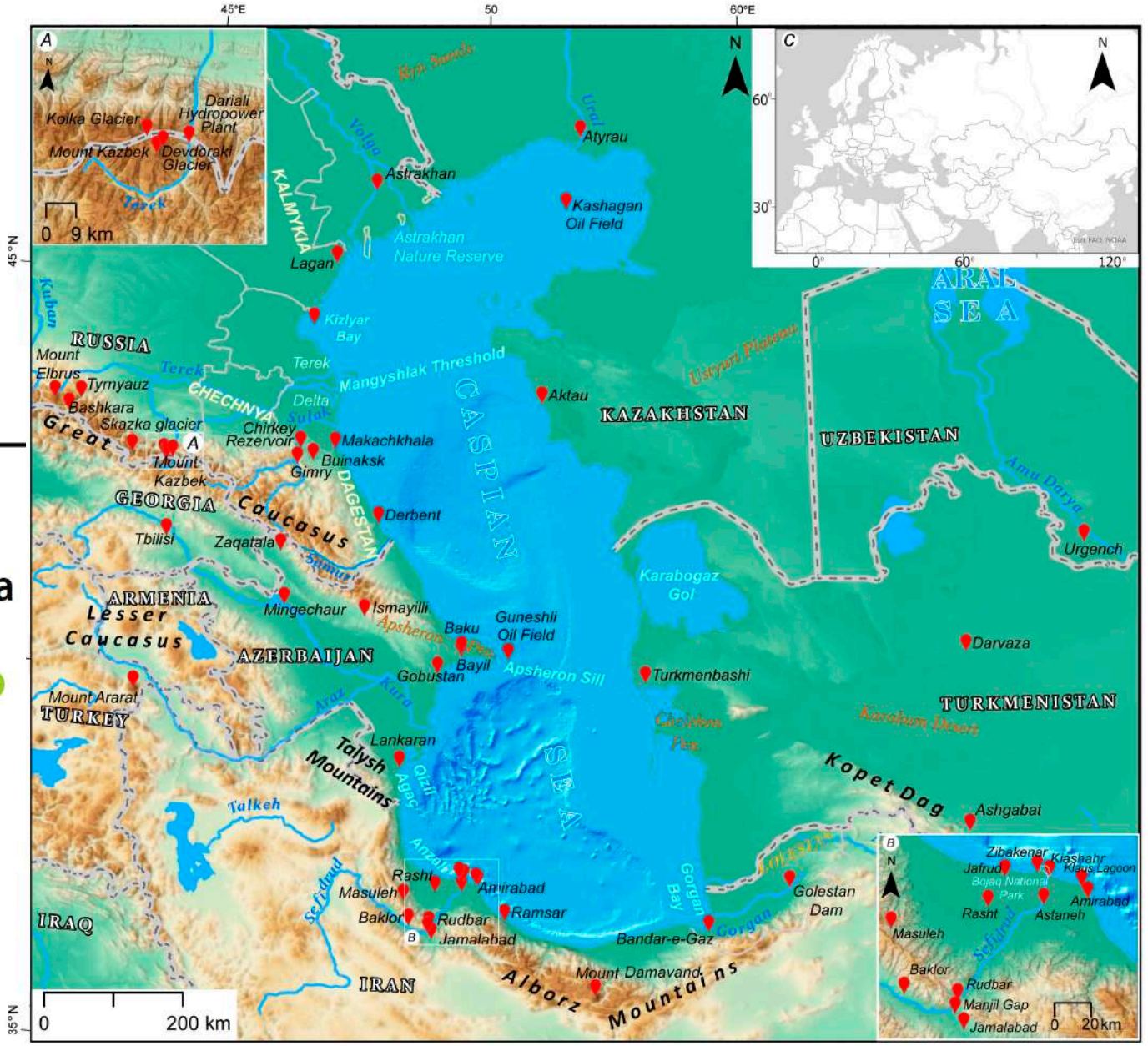
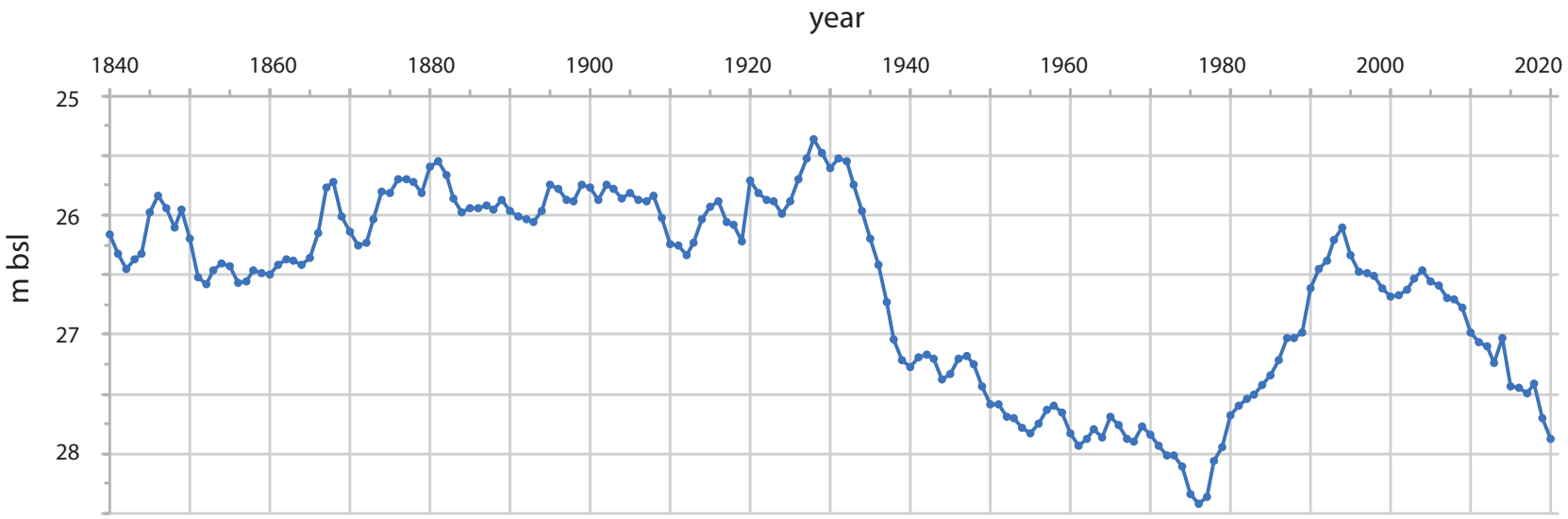
Received: 7 December 2021 / Accepted: 20 July 2022



Leroy et al., 2022

Caspian Sea level



Caspian Sea level curve from 1840 to 2020 in m below sea level, combining gauge and satellite data

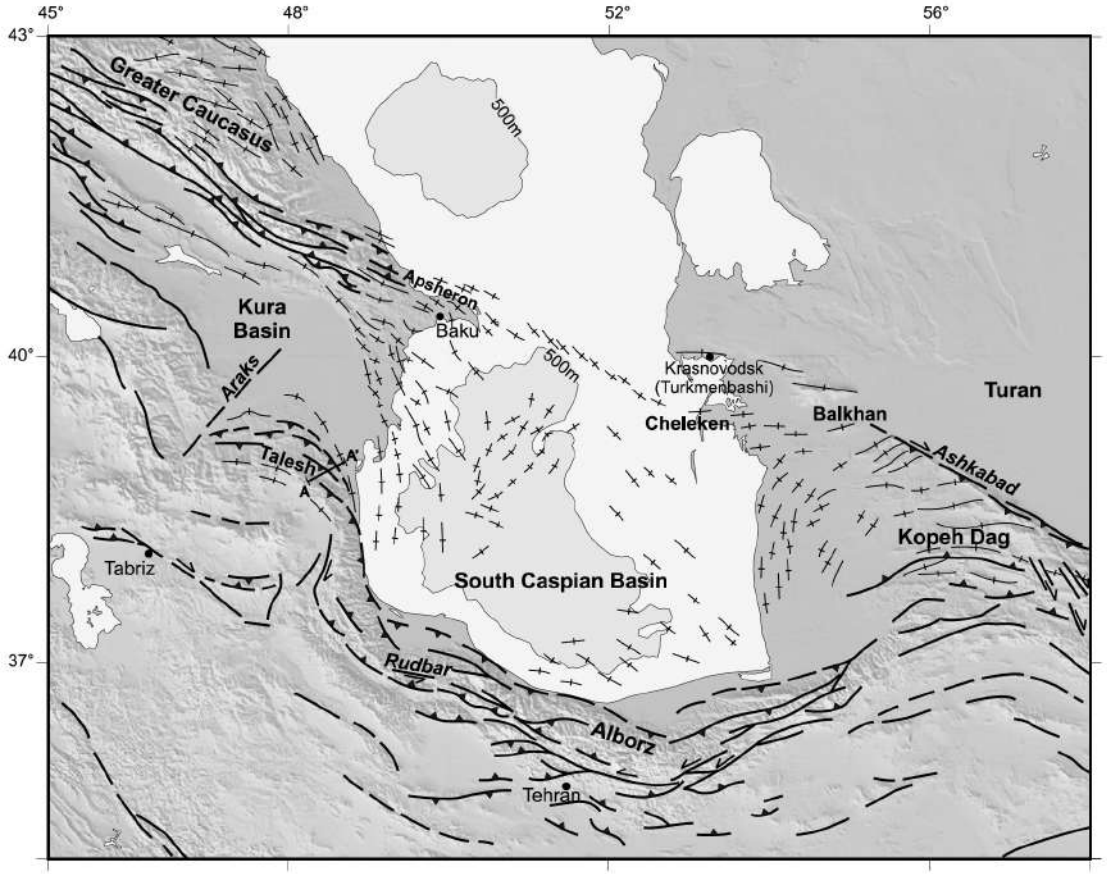
- Data from 1840 to 1992 from Golitsyn (1995)
- Data from 1993 to 2020 from Hydroweb (2021)

Leroy et al., 2022

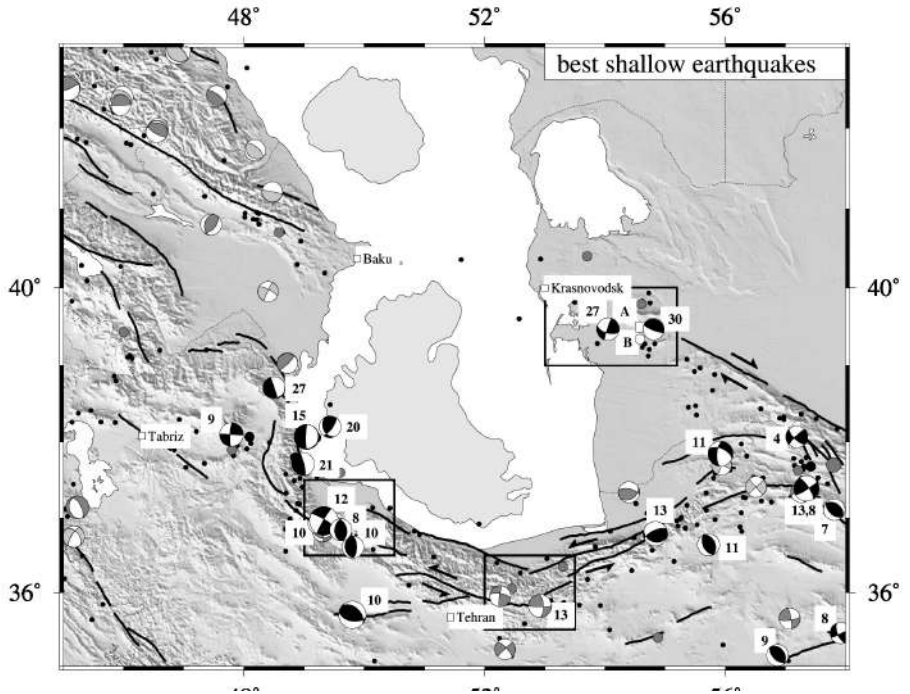
1.Geological disasters

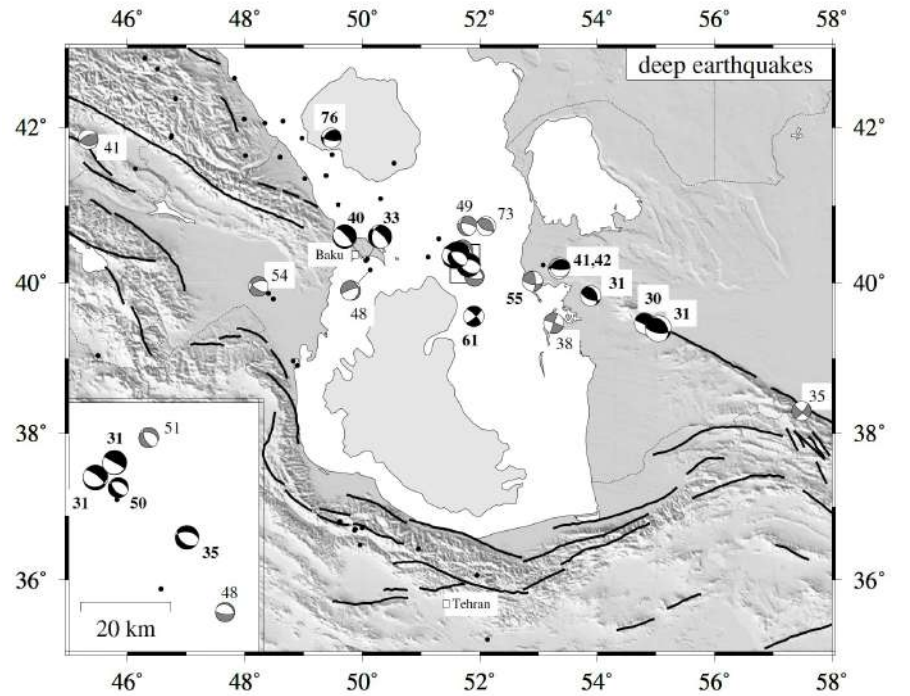
1. Earthquakes
2. Tsunamis
3. Mud volcanoes and methane seepage
4. Landslides
5. Sediment displacement
6. Major river avulsions and river profile changes
7. Shifting delta channels and lagoons

1.1 Earthquakes



Structural map





Jackson et al. 2002

1.1 Earthquakes

The 7 May 2012 Richter scale 5.6 earthquake of Zaqatala in Azerbaijan (N of Alazani) caused the destruction of 1000s houses and led to evacuations to temporary settlements

Abandoned village of Rudbar (Sefidrud Valley, Iran) after earthquake of 1990, photograph taken in 2013. Truck climbing the road for scale. (Source: S.A.G. Leroy)

1990.06.20 (Mw 7.3) earthquake, strong aftershocks, on a previously unknown fault system

~20,000 deaths
Because the earthquake happened at midnight, the administrators in charge of rescue were often amongst the casualties themselves. Rescue was difficult in the mountain, and slow

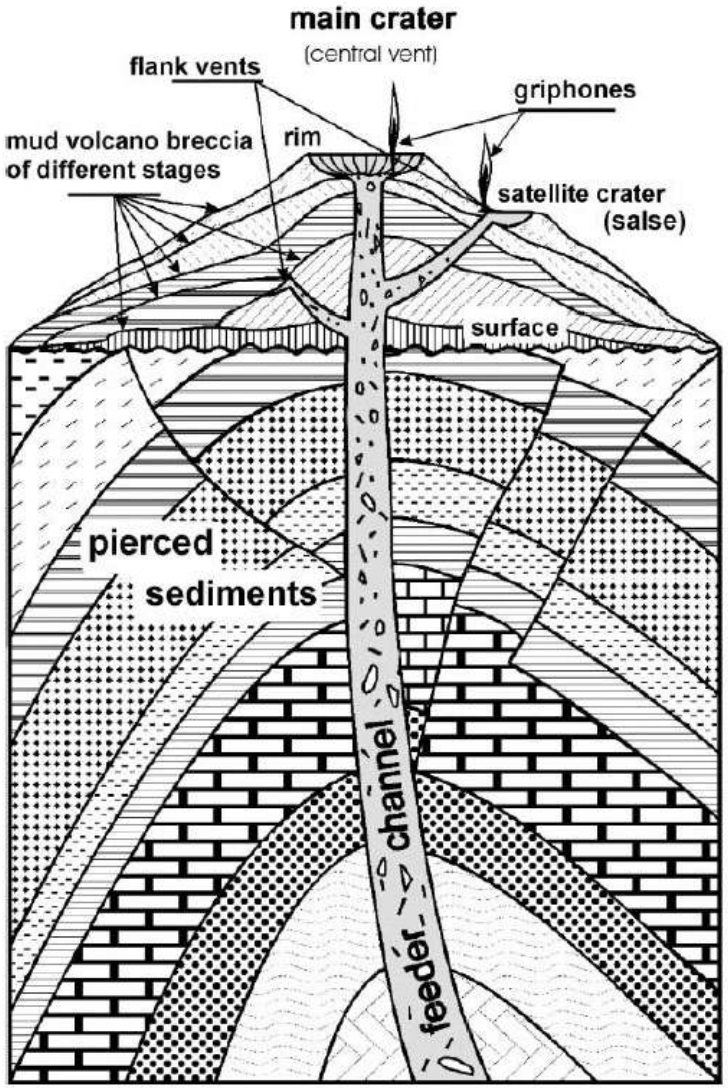
Leroy et al., 2022

1.3 Mud volcanoes and methane seepage

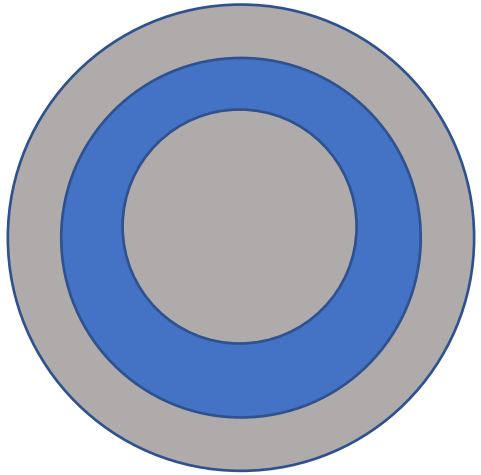
Mud volcanoes in Azerbaijan, in 2014. A small mud flow comes out to the right of the main volcano, in front of the person with the backpack. (Source: S.A.G. Leroy)

1.3 Mud volcanoes and methane seepage

- Conical hills built from clays, sometimes containing rock fragments, rich in water and gases escaping from deep-buried sediment along a more or less vertical feeder channel. Their heights vary from a few metres to as much as 500 m.
- In relation to the presence of subsurface pressurised fluids, such as methane.
- They may at times have an explosive character when the feeder is blocked. Due to high amount of gas, ignition may occur at the top.



Dimitrov 2002



Very large mud volcano

Large mud volcano with a ring lake and an island in the middle, Gorgan Plain in 2014 (Iran). Quasi circular car tracks for scale. (Source: S.A.G. Leroy)

1.3 Gaz seepage

One of the most damageable impacts of mud volcanoes is their **methane** emission (+ CO_2), thus causing a significant contribution to the greenhouse effect.

Worldwide estimation of the global methane flux from onshore and shallow sublacustrine mud volcanoes at between c. 6 and 9 Mt yr^{-1}. This is the same level than ocean and hydrate sources!

Oil and gas seepages are a hazard as they may spontaneously ignite. Azerbaijan is often called the land of eternal fires.

In Turkmenistan, drilling in 1971 accidentally caused the release of methane gas at Darvaza (Derweze) in the Karakum Desert

Still-burning gas crater in Derweze.
Photograph taken during the night in 2019.
Cars in foreground and people standing on the edge of the hole for scale. (Source: S.A.G. Leroy)

1.4 Landslides

- In the Caspian drainage basin, the most important landslide area is clearly **Dagestan**
- Natural conditions favour the formation of landslides in the mountains
  - thick sedimentary rocks
  - steep slopes
  - high seismicity
  - periods of intense abrasion along the coast
- Recently, intensified landslide processes in the mountains
  - large-scale construction of wide highways
  - expansion of individual construction
  - infrastructure facilities

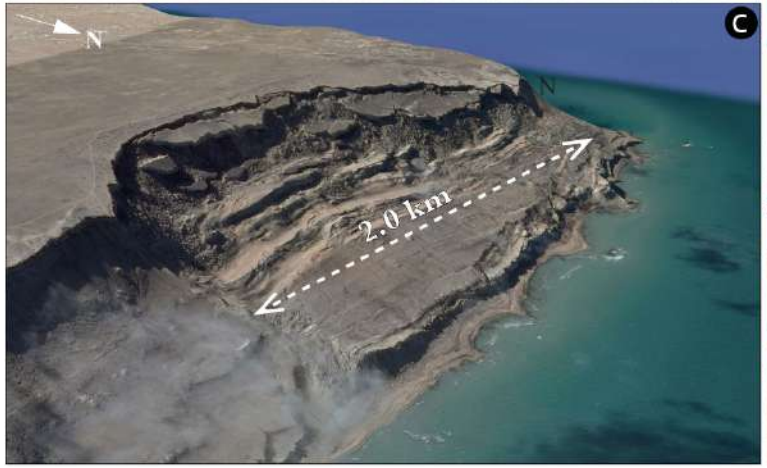
Leroy et al., 2022

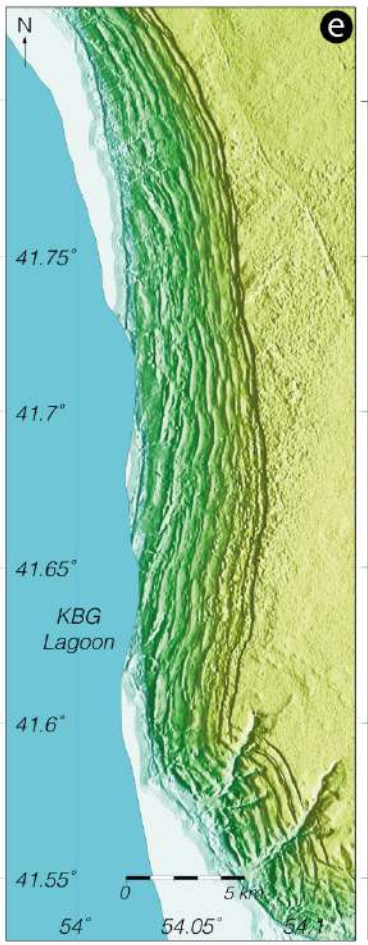
1.4 Dagestan landslides

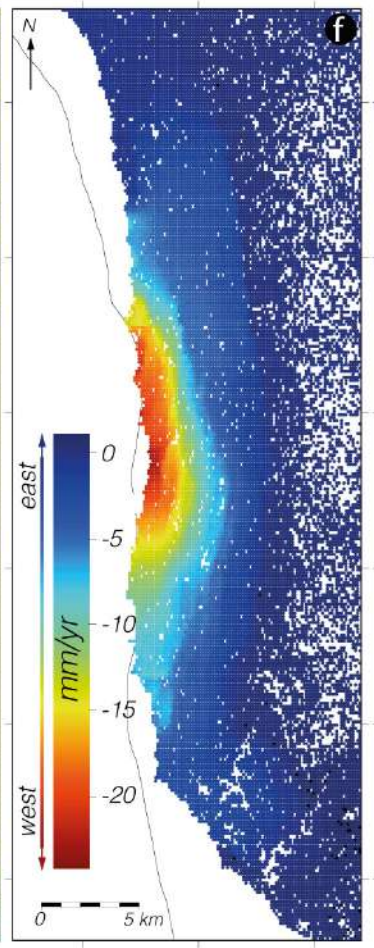
Region of Buinaksk.
Left photograph. Landslide of Buinaksk (Dagestan) in 2002.
Right Photo. A collapse along the Gimry—Buinaksk road (Dagestan) on 26 May 2021.

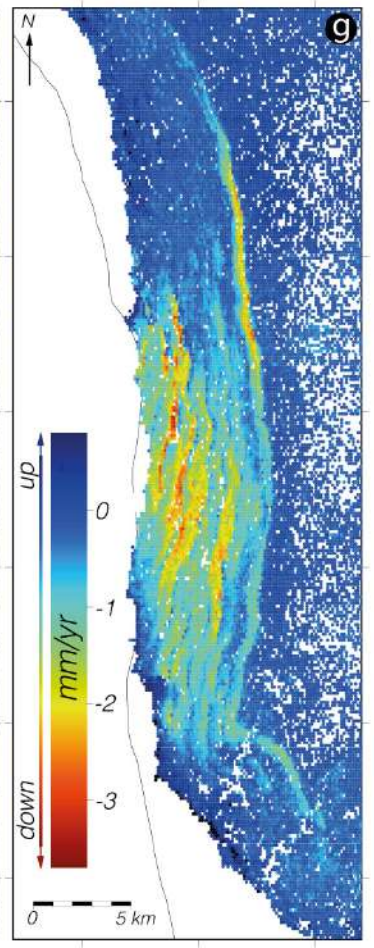
Leroy et al., 2022

1.4 Landslides along the coasts









Landslides around the Ustyurt Plateau, Kazakhstan.
b, c: landslides along the Caspian Sea.
d: landslide along the west coast of the Aral Sea.
e, f, g: Satellite views of landslides along the east coast of the Karabogaz Gol.
e) SRTM topographic map showing steps due to lateral spreading towards the lagoon,
f) horizontal component and g) vertical component, both tracked by the Sentinel satellite

Graciously provided by G. Aslan

Landslides in Azerbaijan

- On the slopes of the Greater Caucasus, active landslides cover vast areas and occur almost monthly, especially when snow melts and when it rains. From 2000 to 2013 alone, 40 landslides were described that caused destruction of settlements and infrastructure.

- On 7 March 2000, a major landslide involving an area of 15 ha occurred in the **Bayil** zone, close to the TV tower in Baku . The landslide in the Bayil slope destroyed dozens of shops, apartments and gas stations. After the incident, it was decided to remove > 300 families from this territory.
- Landslides have intensified on the Bayil slope. In late 2017 and spring 2018, >100 families were evacuated. In Badamdar (W of Sabayil), on January 2021, a landslide completely destroyed a large section of the road.
- This area has been landslide prone already since the middle of the 19th century. Further landslides in the same area are likely.
- The causes are both the location close to seismic faults and illegal building at the slope top, with vibrations of heavy traffic and further construction work (Yetirmishli et al. 2015).

Leroy et al., 2022

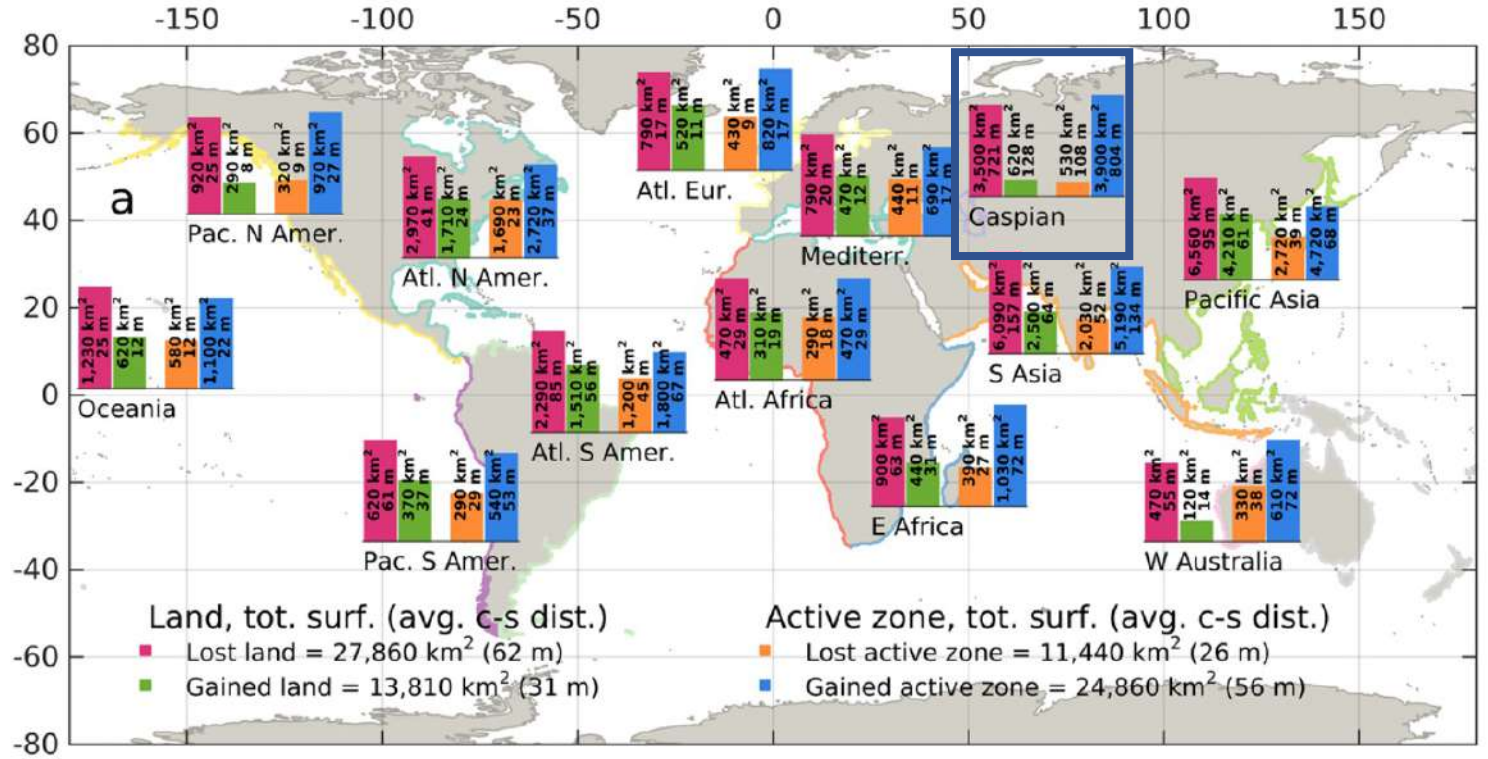
1.5 Sediment displacement

- A global evaluation of coastal morphological changes has been compiled over 32 years, i.e. from 1984 to 2015. Over a background of worldwide land loss, the Caspian coast stands out with the highest rate of land loss.
- **Coastal active zone** = The buffer area between permanent land and water occasionally submerged, due to the action of tides, waves and rivers in the estuarine zones.
- It is a highly dynamic area that provides protection from coastal natural hazards

Mentaschi et al. 2018

Sediment displacement & CS

- Between 1984 and 2015
- Worldwide: the active zone expands mainly by encroaching into previously permanent land.
- The region with the highest change per unit coast is the CS
  - ~ 600 m of average net cross-shore land loss
  - ~700 m of active zone gain



Mentaschi et al. 2018

c-s = cross-shore

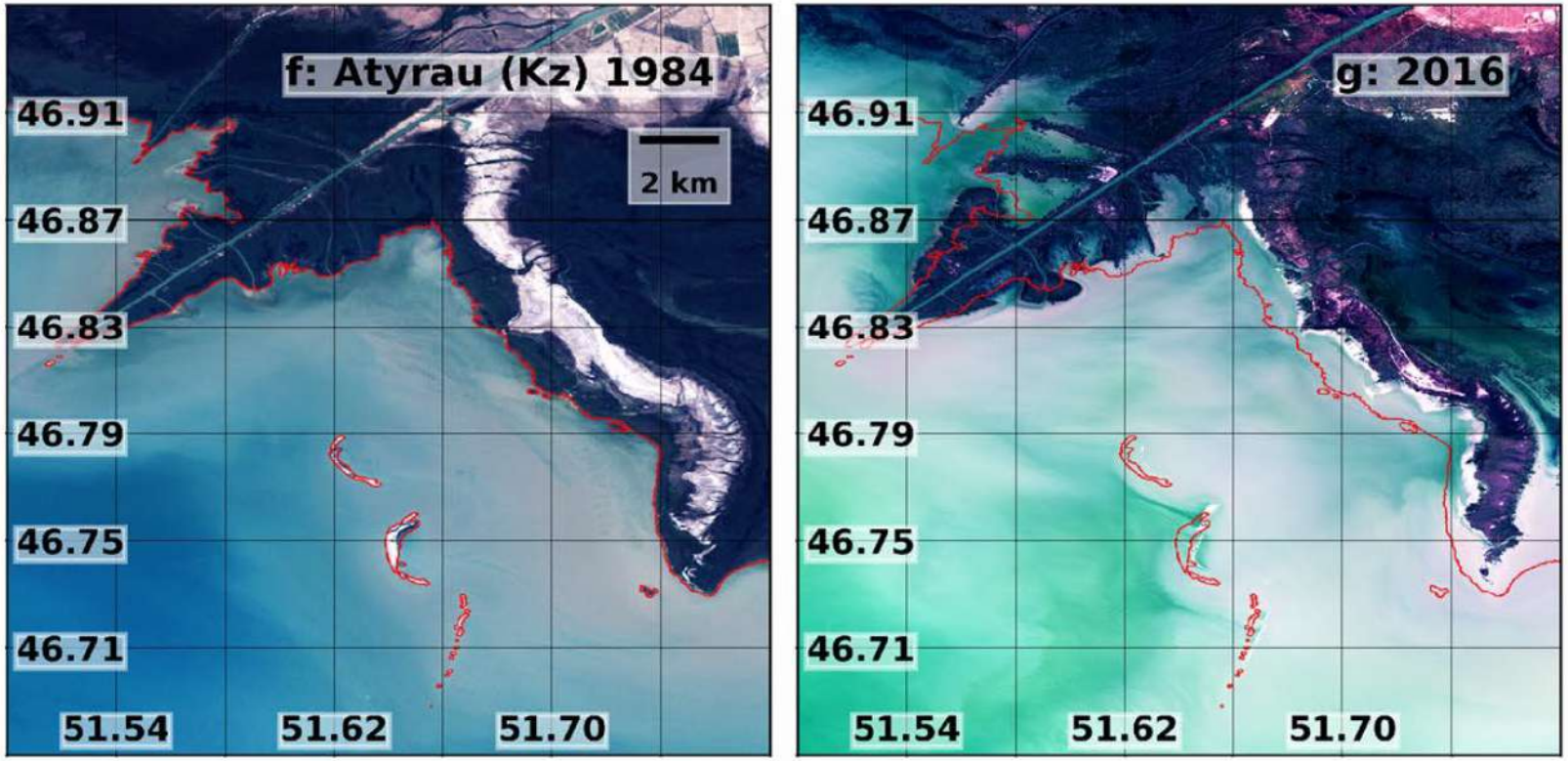
1.5 Sediment displacement in the CS

Combination of

natural factors such as water level rise (specifically along the Russian and Kazakhstan coasts) and

human ones such as extraction of sand and river damming upstream (e.g. on the Volga River)

The worst is the Kazakh coast



Rising after 1977

Falling after maximum of 1995

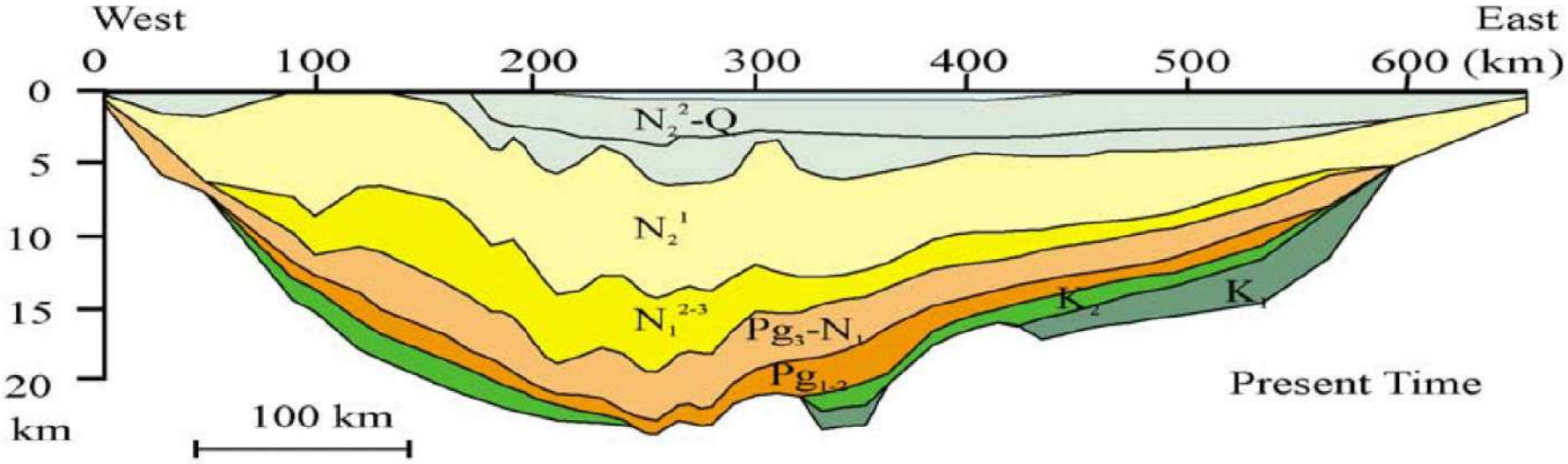
Mentaschi et al. 2018

1.5 Sediment displacement

on the long-term: natural

- Strong orogenesis and subsidence
- From the top of the mountains to the bottom of the Caspian basin, sediment is eroded and deposited in unusually large amounts: it is possible to evaluate the sedimentation rate at the scale of the Pliocene–Quaternary: > ~ 0.5 mm yr^{-1}.
- These high values contribute explaining why the south Caspian basin has produced oil and gas in such large amounts.

Accumulation of 20 km



Leroy et al., 2022 from Brunet et al. 2003

1.5 Sediment displacement

In the short-term: human-made

Sefidrud plume in the CS

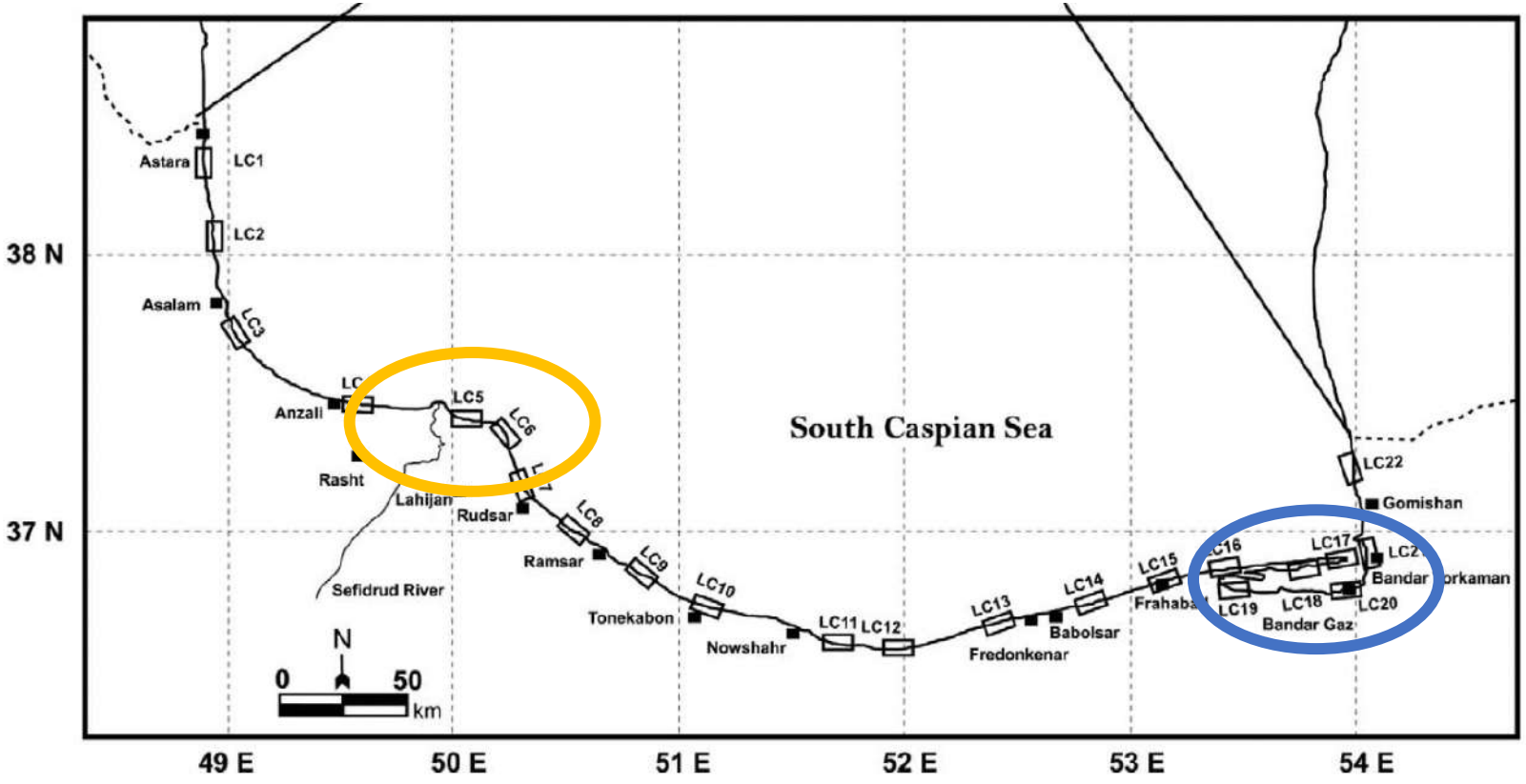
- >75% of the solid discharges are delivered in the North and Middle Caspian,

- although the Sefidrud (south basin) is bringing the largest volume of sediment to the CS.

- Erosion in a mountainous catchment
- Flushing activities from the dam
- Sand extraction for building

Manjil dam, Kavian et al. 2016

1.6 and 1.7 Shoreline changes



Seaward shift
LC5

Landward shift
LC19

By LANDSAT satellite imagery over the period 1975 to 2001,
i.e. a period of predominantly rapid water level rise

Both offshore (accumulation) and landward (erosion) shifts were found.

A maximum of 1.7 km per year landward shift has been found in low-angle coastlines with a lagoon.

In deltas, minor changes, both landward and offshore, were observed

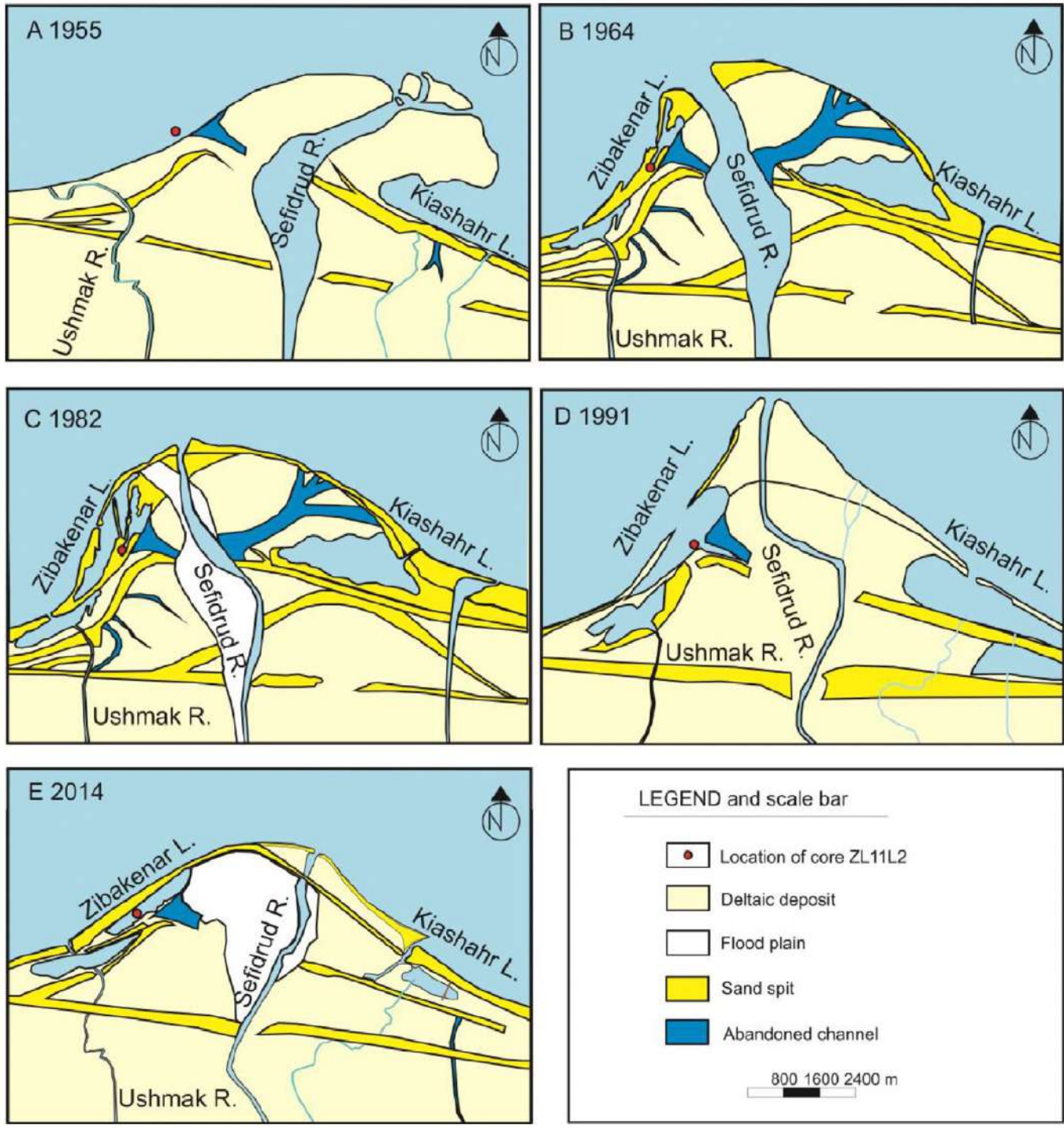
Kakroodi et al. 2014

1.7 Zibakenar Lagoon appearing

Evolution of the new Sefidrud Delta since 1955, based on historical aerial photographs (A, B and C) and satellite images (D and E).

River avulsion
Role of dam for rapid filling
Nature parks adapting?

Haghani et al. 2016



2. Meteorological and climatic disasters

1. Desertification and soil salinisation
2. Droughts
3. Dust storms
4. Storm and storm surge

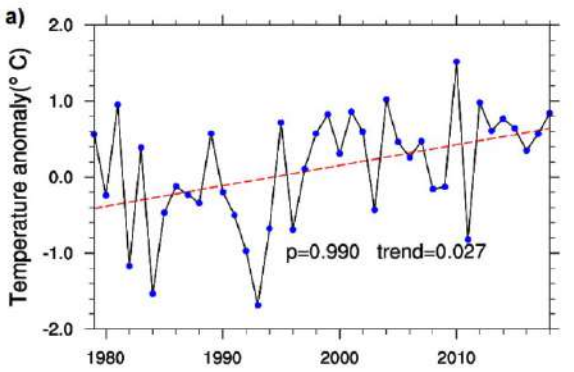
Unusual heavy snow event in Feb. 2014 along the Iranian shore.
This extreme event caused the collapse of a filling station roof amongst other disasters. (Source: S.A.G. Leroy)

Increasing SST, increasing hazard

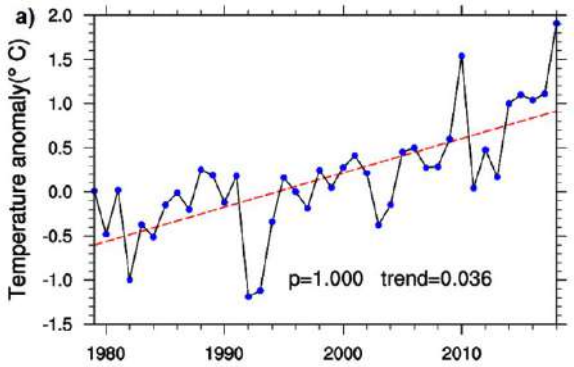
- With Global Climate Change, extreme weather events are forecasted to become **more frequent** and extreme (IPCC 2021). The countries in the Caspian basin similarly suffer from severe weather events.

- Such events will become more likely with the observed sea surface temperature **increase**. Indeed relatively warm waters are needed to enhance evaporation of the CS and to increase the humidity content of the air, and to contribute to a **strong vertical instability** of the atmosphere.

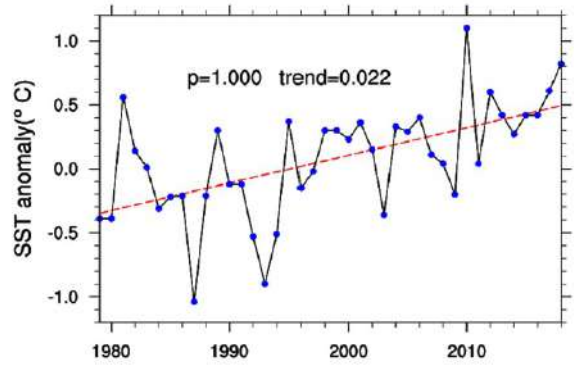
- With Global Climatic Change, it has been shown that **compound** extreme events are more likely such as storm surge combined with extreme rainfall, or heatwave with drought.



Max. air T anomaly in Rasht



Min. air T anomaly in Rasht

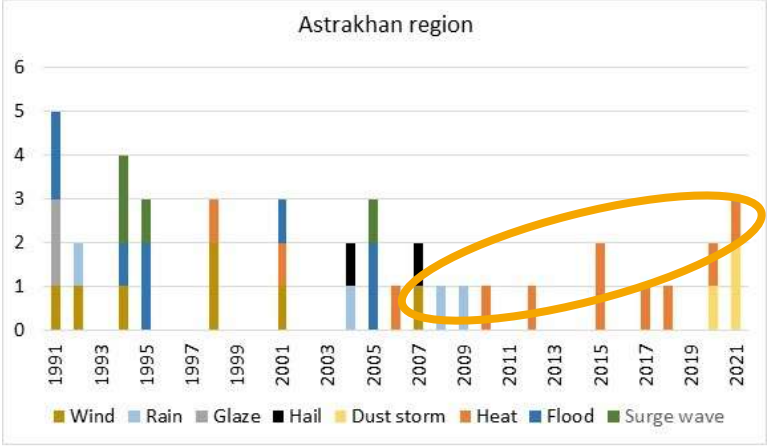


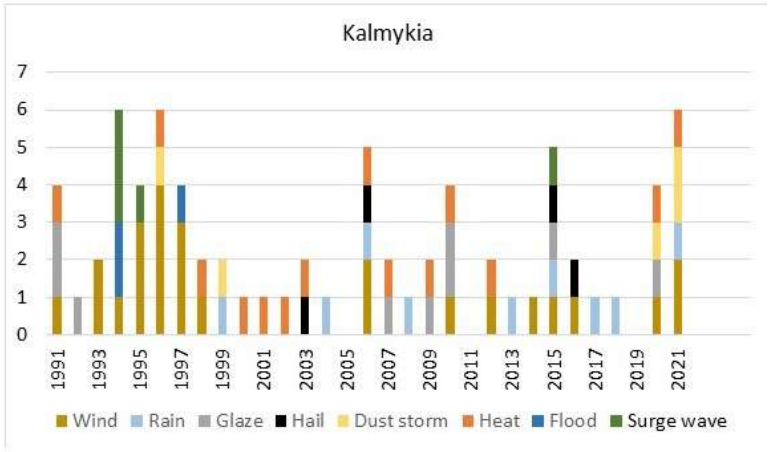
Average of SST anomaly

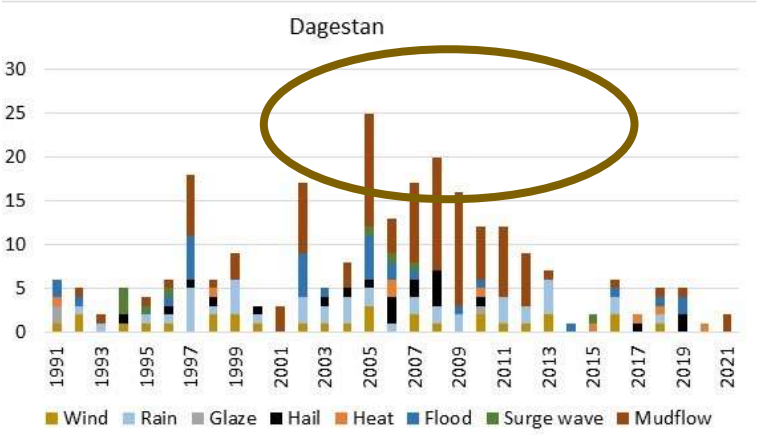
Ghafarian and Tajbakhsh 2019

The number of individual weather and weather-induced events

Events that cause material and social damage in the adjacent areas of the north-western Caspian, by years, 1991–2021 =➔

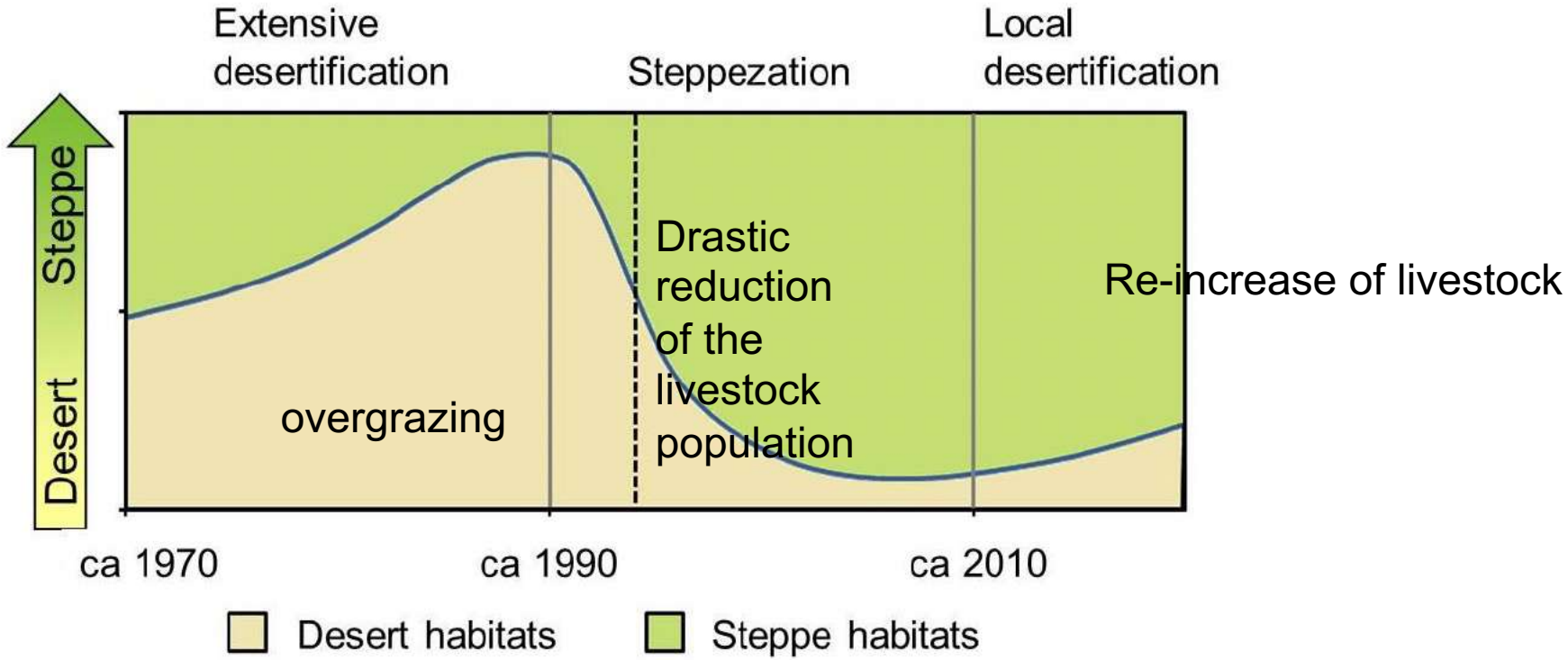






Leroy et al., 2022

2.1 Desertification and soil salinisation: example of Kalmykia



Scheme of landscape change over time in the rangelands of Kalmykia.
~ 1970-1990 – extensive expansion of desert habitats; anthropogenic desert
~ 1990-2010 – state of emergency; reduction of livestock; less erosion
~ 2010 – the beginning of new desertification, local expansion of desert habitats; extension of private livestock.

Tchabovsky et al. 2018

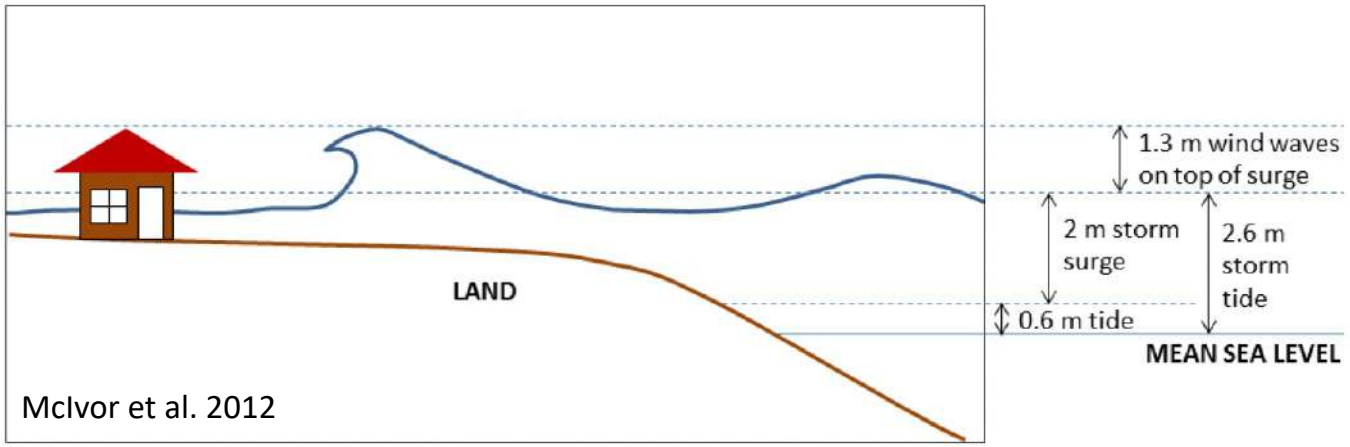
Soil salinisation in Lankaran

- No salinity observed in this area during early soil surveys for planting tea.
- In the 1980s, young tea bushes began to die almost simultaneously in the Lankaran lowland. During soil studies in 1987, it was found that the soils were saline from a depth of 40–60 cm. When the root system of the tea bushes reached these depths, the bushes died.
- This was an obvious consequence of the Caspian level rise

observations by one of the authors of this article

2.3 Dust storm Astrakhan

Dust storm near Astrakhan (Russia) on 19 May 2021.
Houses for scale.
(Source: courtesy of D. Kravchenko)



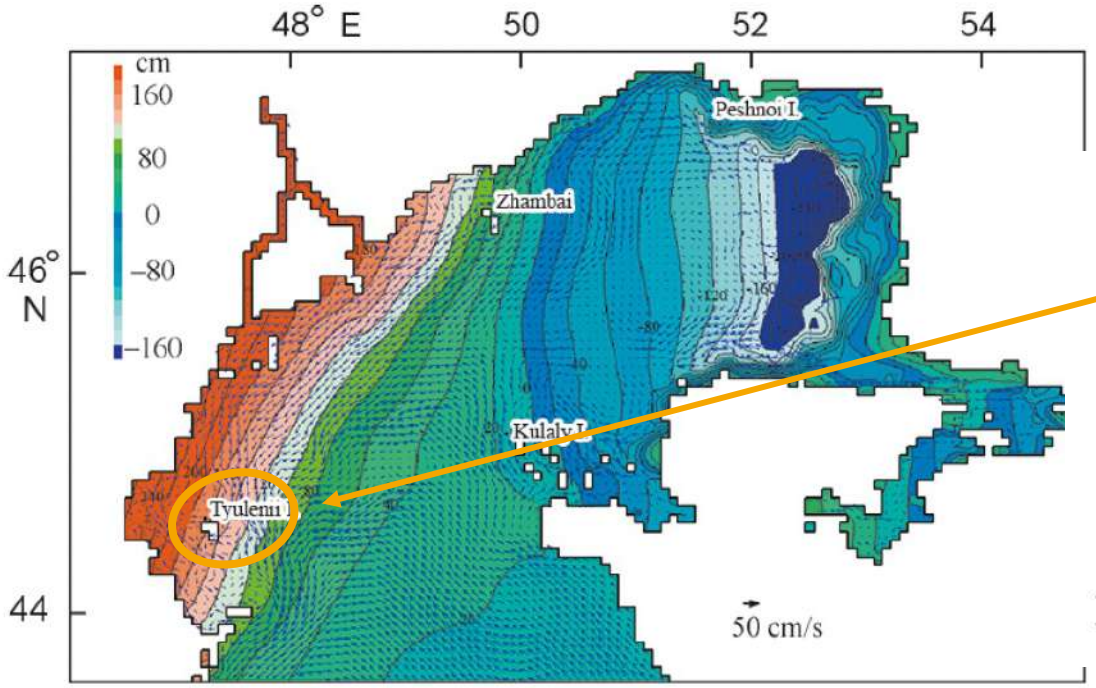
McIvor et al. 2012

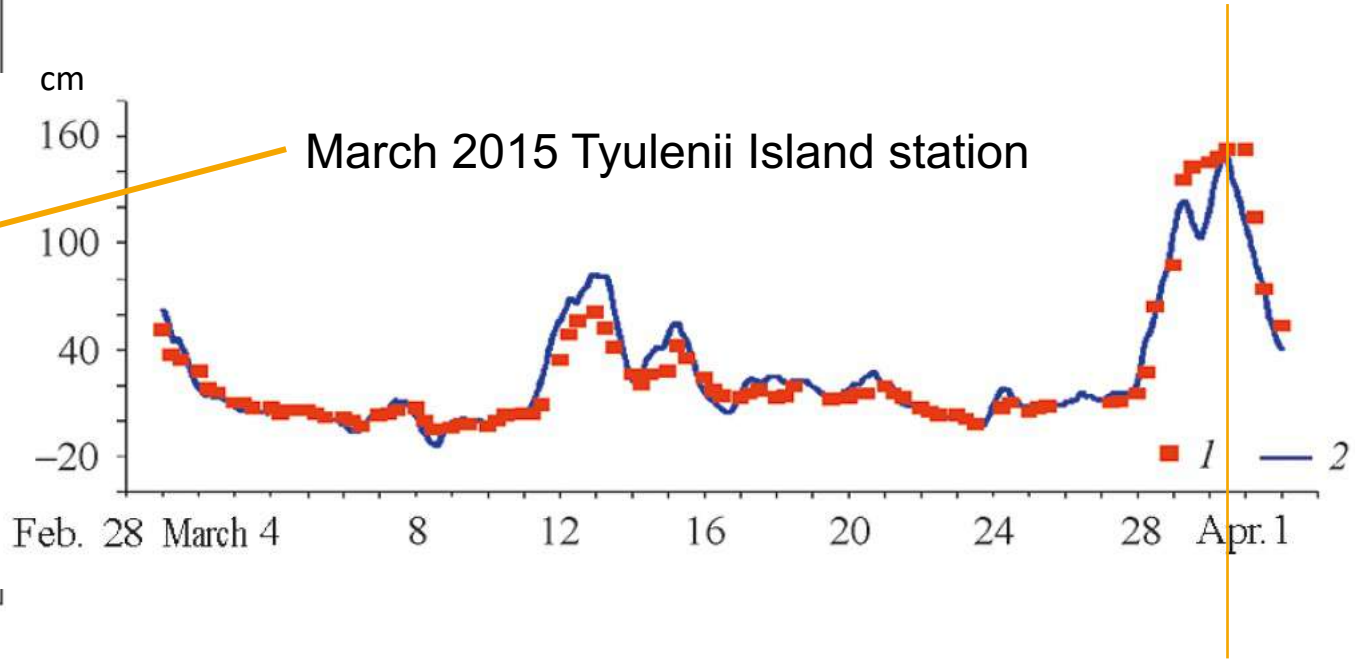
2.4 Surges: up and down

- During the period of instrumental observations in the northern part of the sea **surges** reached the maximum value of **4.5 m (1952**) and **ebbs** culminated **1.7 m (1995**),
- both led to the shoreline displacement by tens of km. In 1952: flooding area: 3 x Moscow
- Duration of storm winds may range from several hours to 5-6 days.
- The coastline is extremely unstable and constantly migrates

Kurbatova and Gorbachev 2011

Storms and storm surges
e.g. in 2015



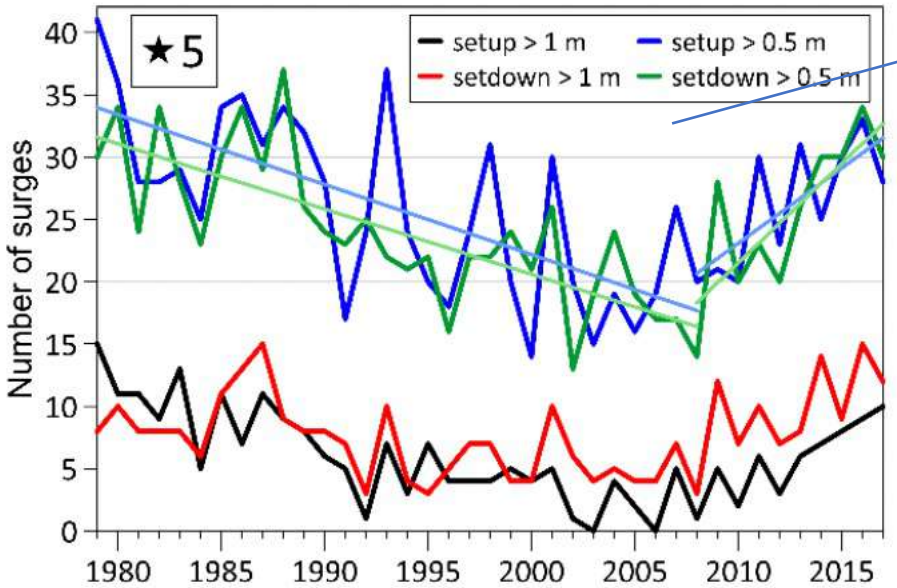


March 2015 Tyulenii Island station

The calculation of sea level (isolines, the coloured scale) and velocities of currents (arrows) in the North Caspian at the surge peak moment at 12:00 on March 30, 2015.

Nesterov et al. 2018

Number of surges



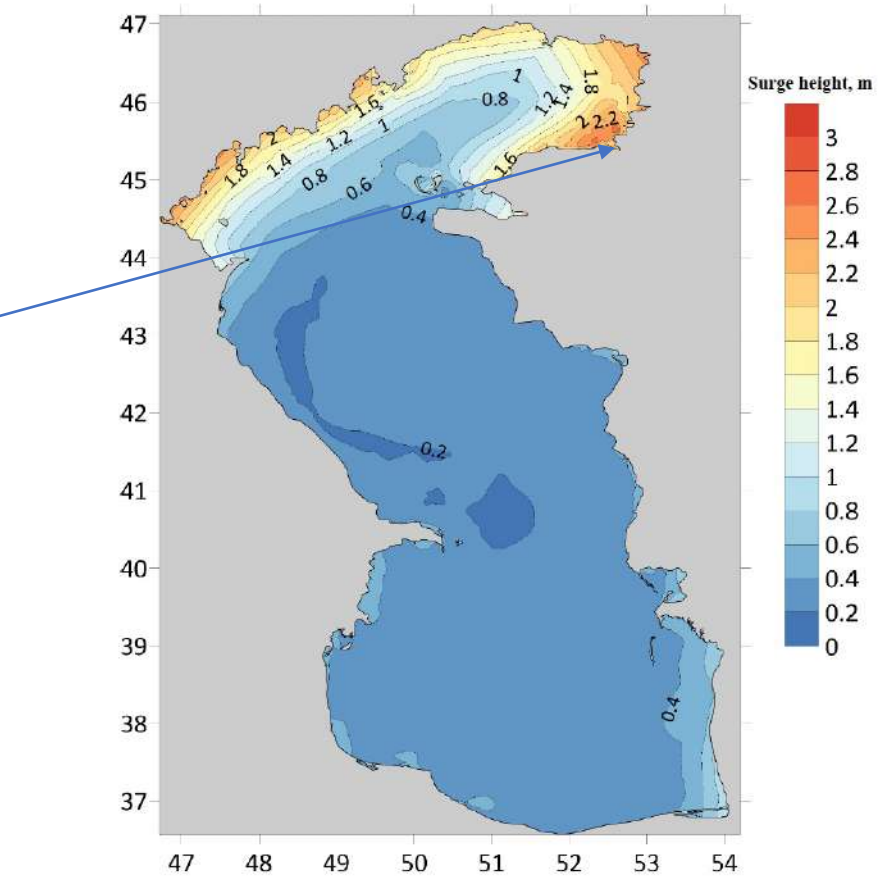


Figure 5. Distribution of the maximum surge heights for period 1979 – 2017.

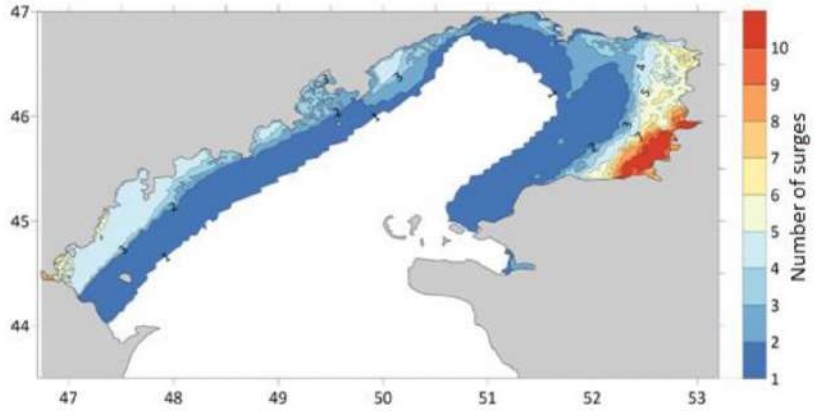


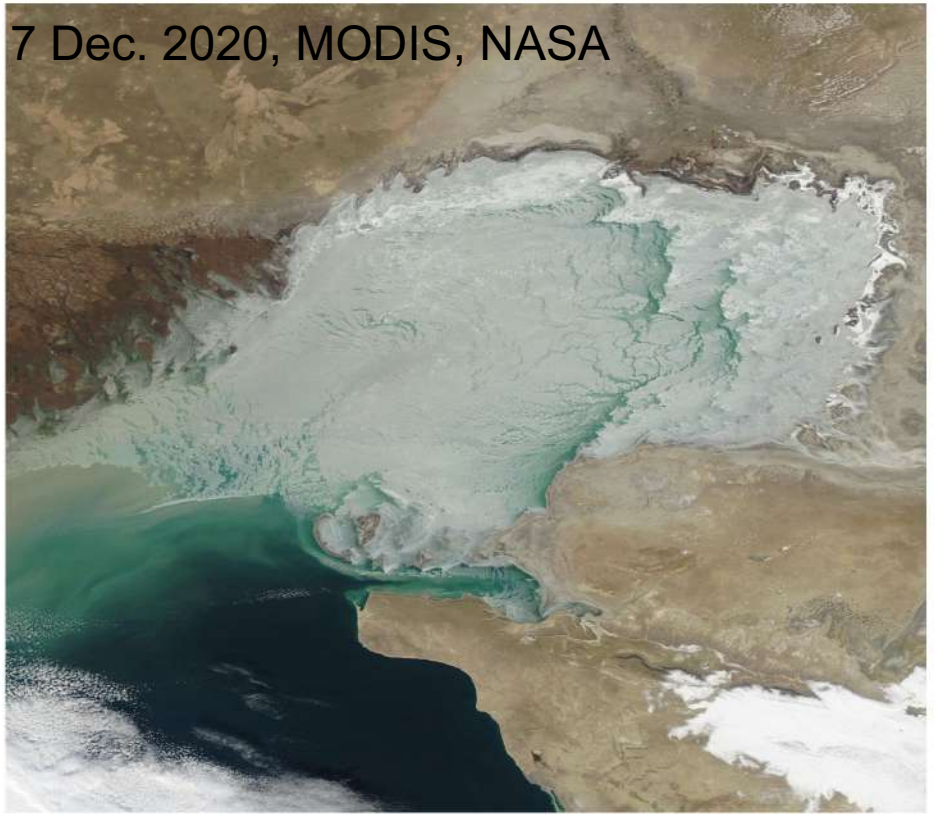
Figure 6. Number of surges more than 1 meter in 1981.

Point 5 is in NE of CS,
where max heights and and max numbers of surges > 1m

Pavlova et al. 2021

3. Hydrological disasters

1. River floods
2. Glaciers and related phenomena
3. Extreme seasonal icing over the Caspian Sea
4. Rip currents



The already-endangered Caspian seal raises its young on the sea ice and is particularly at risk *(Sue Wilson)*

The Caspian seal needs ice to raise her pup

3.1 Flooding

in Golestan 2019
Following
2001 (largest), 2002, 2005

20 March 2019 flood disaster in Golestan Province

Tourani et al. 2022

3.1 River flooding: Terek River

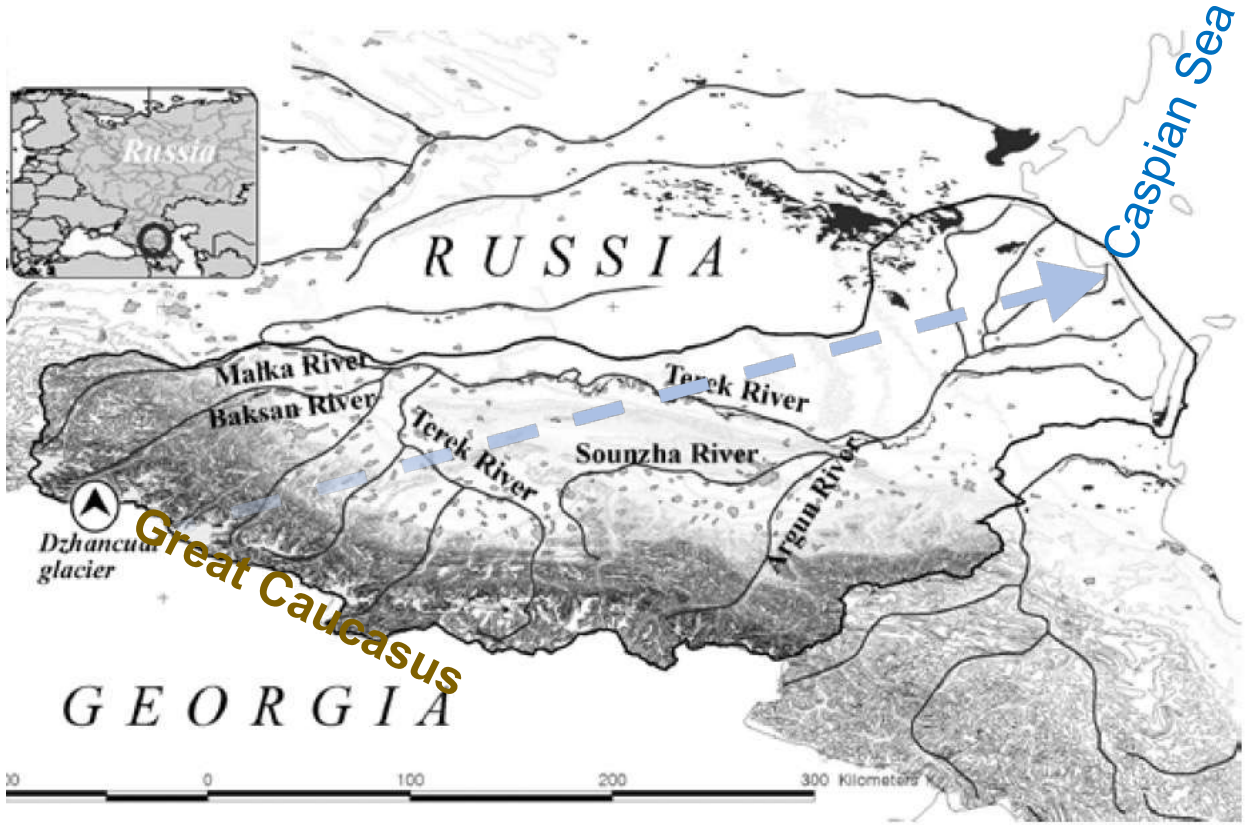


Fig. 1 Terek River basin.

In general a problematic river. Its main source of water is glacial melting and groundwater.
Sediment is transported in especially large magnitude from the Great Caucasus to the middle Caspian Sea.
This dynamic situation is source of multiple disasters.

A catastrophic flood occurred in summer **2002**; this was part of a more general flooding of N Caucasus rivers.
This flood was unique in terms of volume and duration as well as amount of sediment remobilised.

It has left deep modification in the delta morphology.

Debris flow and other glacier–related hazards in the Caucasus.

Leroy et al., 2022

3.2 Glacier melting

The Skazka glacier melts and constantly pours rocky material into the Terek tributary, east of Mount Kazbek, Greater Caucasus.

The glacier descends from the pass from 3907 m down to 2400 m elevation.

This photograph more specifically shows the Tsey gorge. A person is visible on the green moraine ridge, bottom left, for scale. (Source: R. Gracheva)

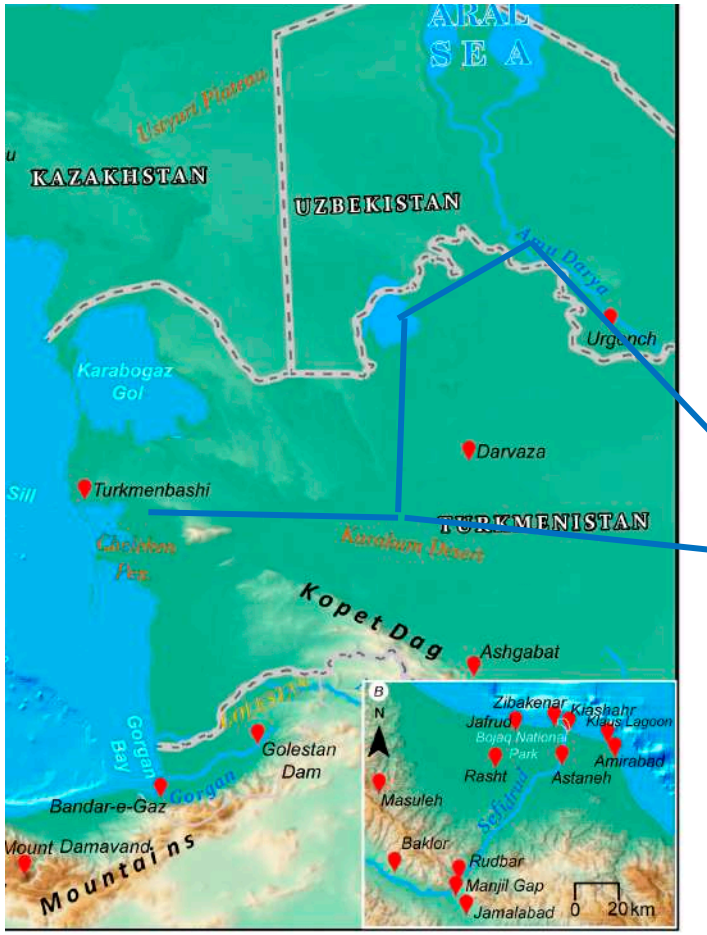
Discussion

A. Potential disasters
B. Warning and mitigation
C. Factors contributing to the making of a disaster
    - Speed of onset and duration of the hazard
    - Size of the area or proportion of the settlement affected by the hazard
    - Level of adaptability or freedom of the society
    - Recurrence or diversity of successive hazards
D. Comparing hazards and disasters

A. **Potential disasters**: hydrographic changes and volcanic eruptions

An **avulsion of the Amu Darya** from the Aral Sea to the CS may occur due natural or human-made factors.

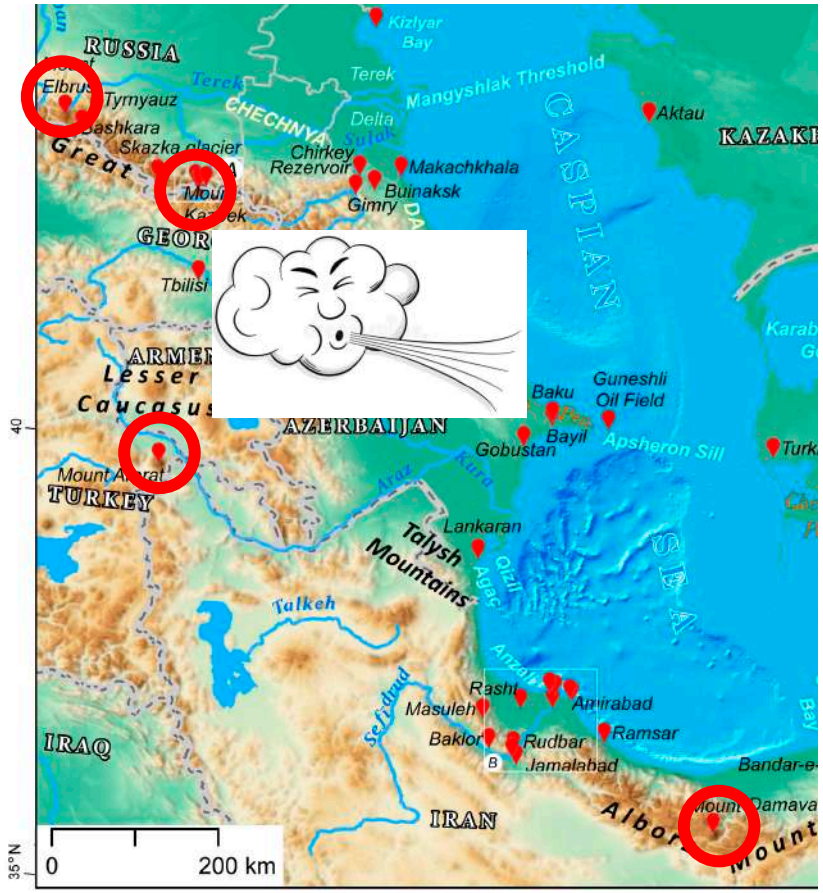
- The Amu Darya lower reaches are in a relatively flat area and a small fault displacement or heavy flooding can easily cause the river to return across the Karakum Desert towards the CS via its old bed, the Uzboy, a now dry river bed.
- During historical wars, a major dam built in the 10th century in Urgench was repeatedly destroyed.
- In the 13th century, Genghis Khan troupes destroyed this dam in an act of revenge. The river waters ran into the Uzboy, reached the CS and caused a well-documented temporary increase in the water level by ~ 7 to 9 m.
- The tsars in the years 1870–1890 had projects to return the Amu Darya to the CS at a relatively low engineering cost with the aim of completing a waterway between India and the Baltic Sea.
- Subsequent Soviet plans in 1920s renewed the idea but at a smaller scale.



Leroy et al., 2022

A. Volcanic activity

- The proximity of the Caspian Sea to many volcanoes cannot be overlooked. Volcanoes in the Alborz (Mount **Damavand**), Lesser Caucasus (Mount **Ararat**) and Great Caucasus Mountains (e.g. Mounts **Elbrus** and **Kazbek**) are known to have been active in the last millennia.
- Beyond **local destruction**, westerly winds would carry **ashes** to the east causing for example a standstill of air transport and health problems over the densely populated centres of the SW and S Caspian coasts.



Leroy et al., 2022

B. Warning systems and mitigation

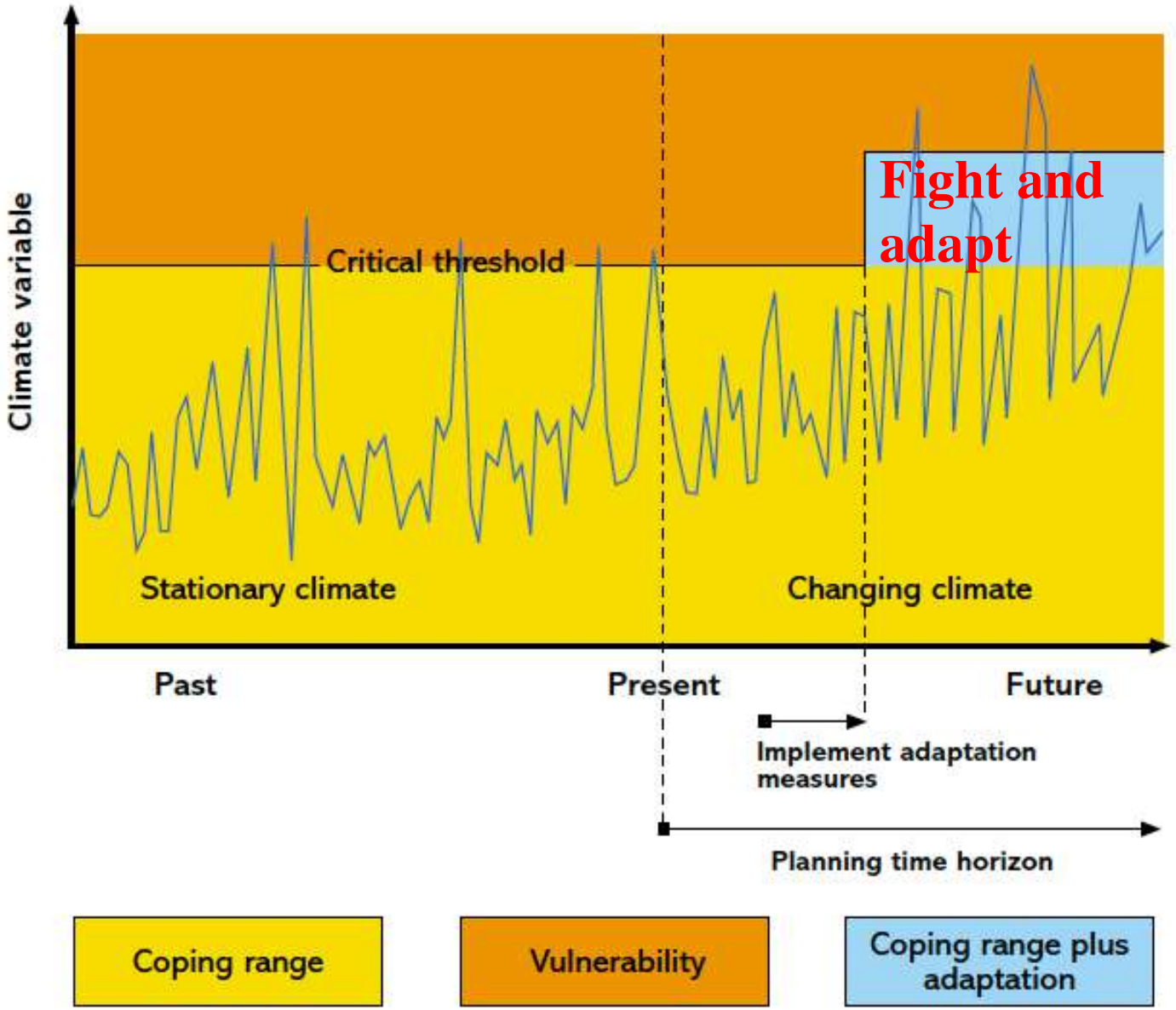
- Laws and transboundary conventions
  - In 2018, the signature of the “Convention of the Legal Status of the Caspian Sea” provides renewed hope.
  - Need of something similar at scale of the drainage basin
- Early warning systems
  - Some countries have developed some aspects of early warning systems, e.g. Georgia and Iran for floods and drought risks, with use of mobile phones in remote mountain areas.
  - Need of transboundary systems.
- Mitigation
  - Education
  - A network of emergency centres in vulnerable zones
  - Barriers and protective measures vs adaptation and managed retreat

Leroy et al., 2022

B. Wind protection in Turkmenistan

Desertification protection (soil stabilisation against wind erosion) in Turkmenistan in 2019.
Plastic bottles in the foreground for scale. (Source: S.A.G. Leroy)

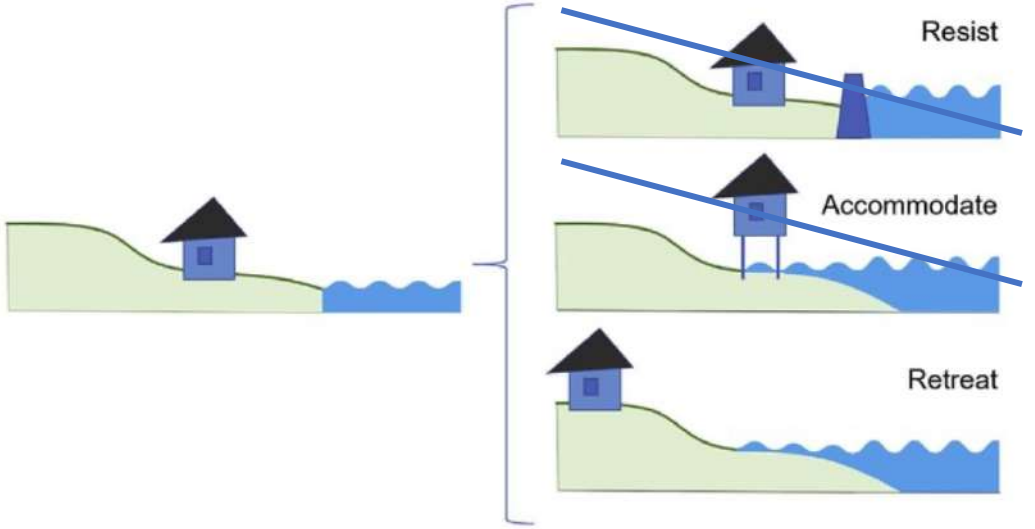
B. Adaptation



Adaptation has a cost
Who wants Baku to move in order to avoid loosing half of its coastal area?

UKCIP, 2003

Managed retreat



= the purposeful, coordinated movement of people and assets out of harm's way

Provides long-term risk reduction and potential for transformation.

Smaller economical cost in the long-run and protection of natural habitats.

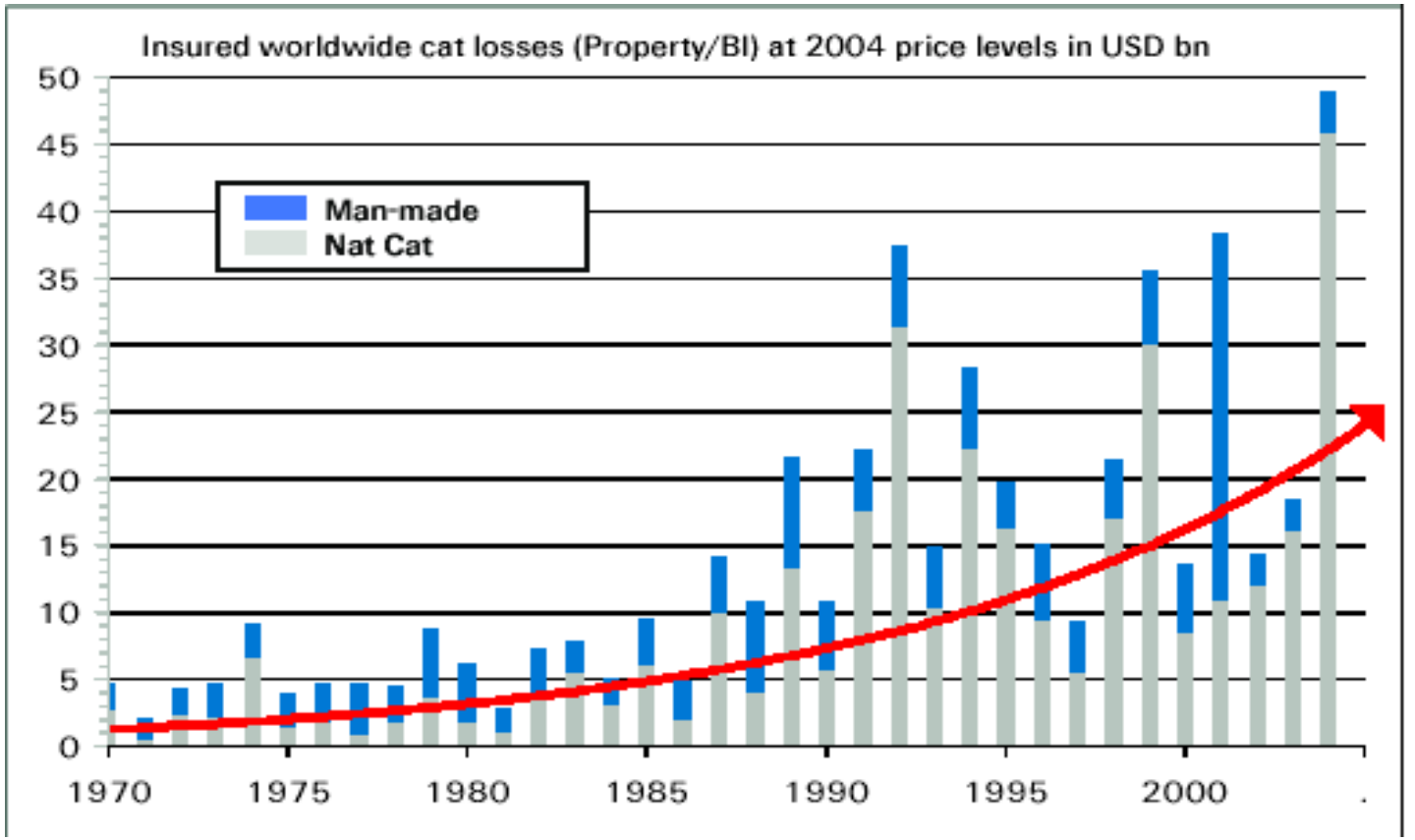
Siders 2019

B. New forces => economical

- Nowadays, governments cannot any more force people to move. Thus only voluntary displacements :
  - Displaced people go where where are jobs
  - The insurance compagnies = messenger of the impacts via conditions and costs

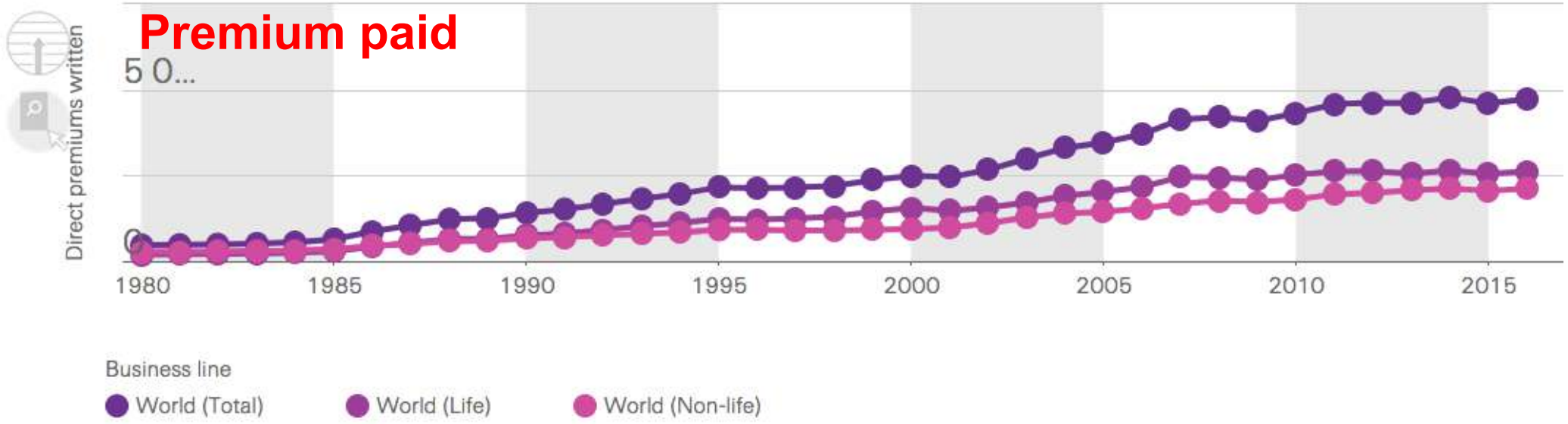
Leroy et al., 2022

B. New forces to displace people



www.itc.nl/unu/dgim/unedra/refresher/_docs/ guest_lectures/20_09_2005_Swiss_Re_hazard_modelling.pdf -

B. Re-Insurances, worldwide

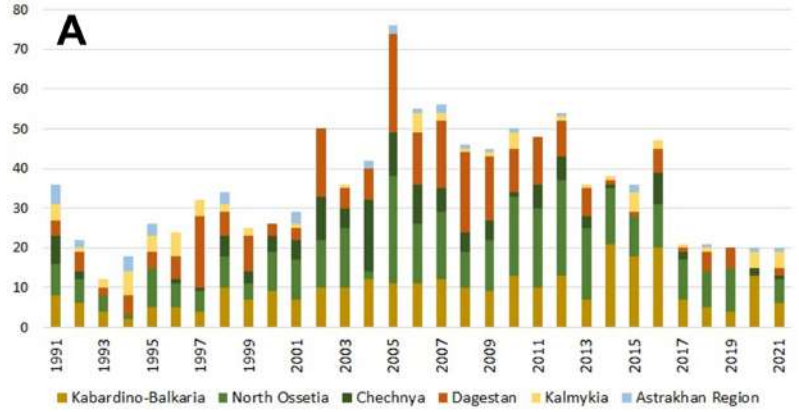


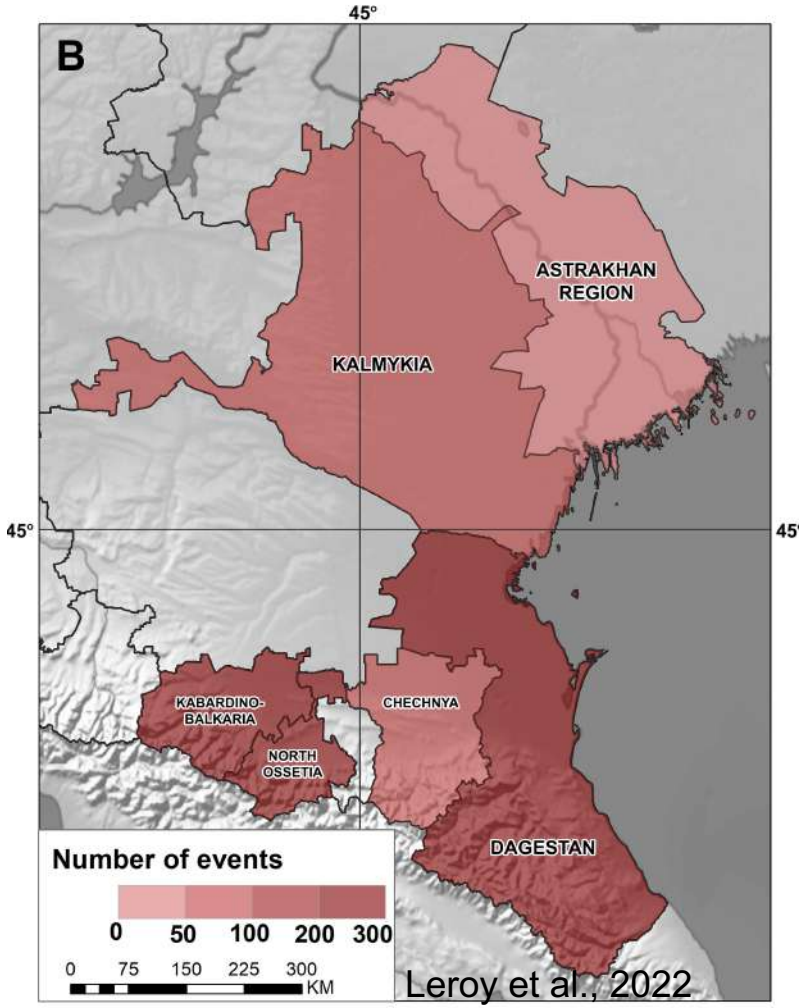
http://www.sigma-explorer.com/

C. Factors contributing to the making of a disaster: **combination of events**

The weather and weather-induced events over time

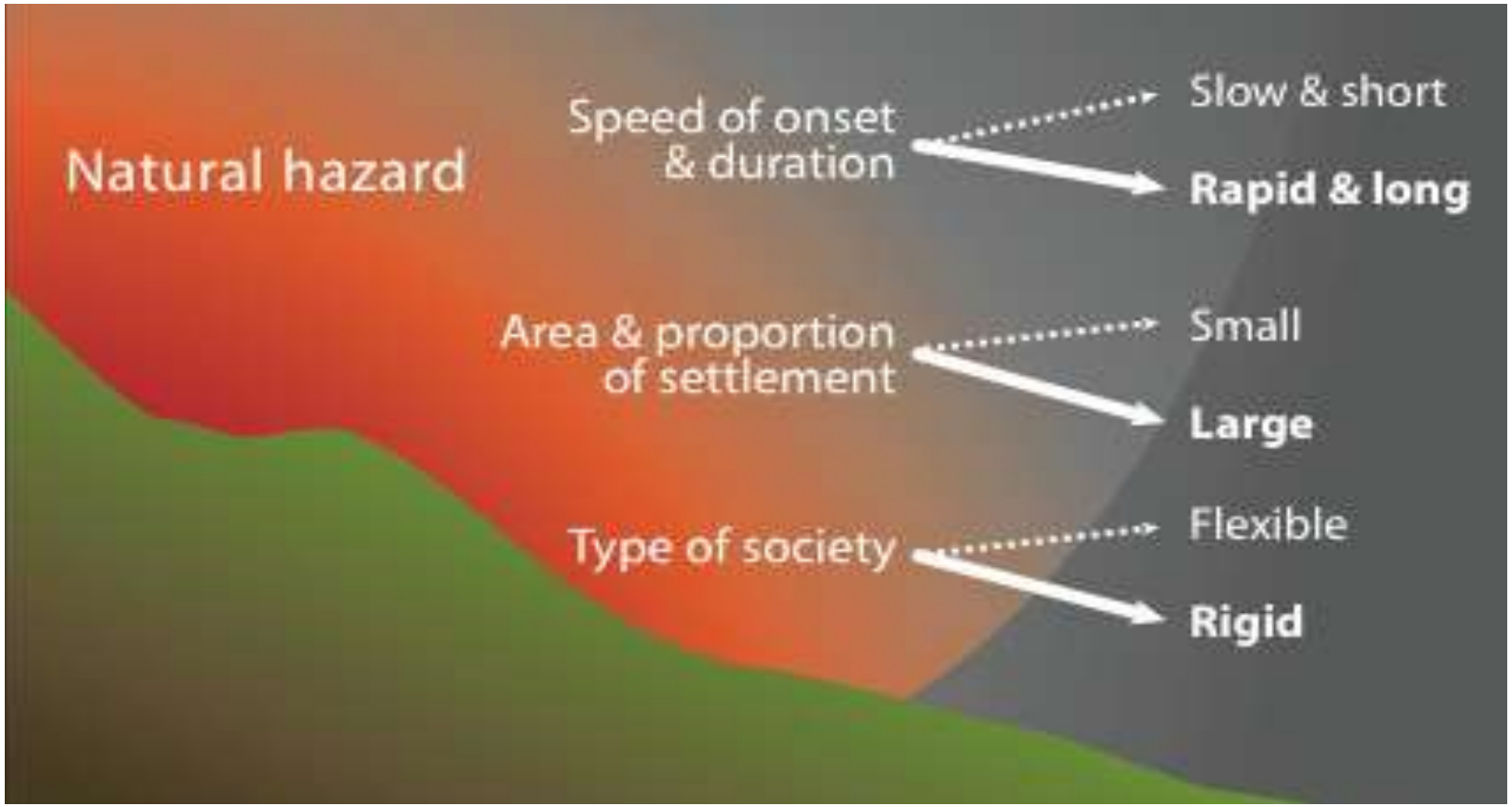
- Very few data bases. Nothing at the scale of the whole Caspian drainage.
- The number of weather and weather-induced events that caused material and social damage in some regions of the north-western Caspian, 1991–2021
- No trend in the plains
- **Peak in 2002-2015, in mountainous regions**





Leroy et al., 2022

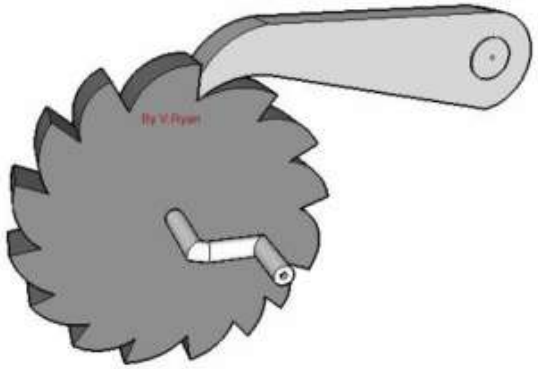
C. Factors contributing to the making of a disaster
Three factors for the amplitude of change



longer than the food storage capacity

nowhere to escape

lack of freedom to innovate



Accumulation of disasters
The ratchet effect

Leroy 2006

C. The ratchet effect

- Two or more disasters may occur in quick succession (before total societal recovery) or even at the same time.
- Following an accumulation of disasters, it becomes more difficult or impossible to return to previous conditions: this is known as the ratchet effect (Ford et al. 2006).
- Each time there is a new disaster the capacity for the society to recover decreases and it may reach a point when there is a societal collapse.

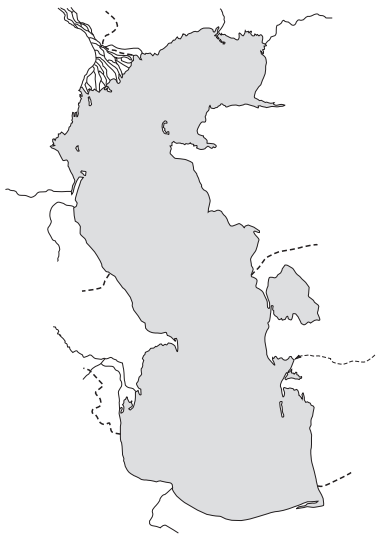
D. Comparison with 5 questions

1. **Which records does the CS drainage basin break?**
   - the world highest density of mud volcanoes (Baku region)
   - the largest landslides (Ustyurt Plateau)
   - the highest rate of land loss due to coastal erosion
   - one of the world highest rates of mountain erosion, esp. close to its glaciers
2. **What is the most frequent disaster?**
   - Fluctuations in CS level are pervasive. However as they are slow, they may escape attention with no long-term memory (young population) or absence of communication of monitoring data
3. **What is the scale of the area affected?**
   - 7500 km of coastline; horizontal movement of the shoreline is especially large in shallow areas such as the N basin coast, making it inhospitable
   - Along the Ustyurt Plateau, the largest landslides in the world, in area and speed of movement
4. **What is causing the most expensive disaster?**
   - CSL change affects the areas with the highest population density
5. **What is causing the highest number of victims?**
   - Ashgabat earthquake in 1948 with > 110,000 deaths, the Armenian earthquake of 1988 and the Rudbar earthquake in 1990

Leroy et al., 2022

D. Comparison of disasters

Earthquakes Landslides Snowstorms & blizzards ….	→	Very brief and very intense High numbers of casualties
Windstorms & surges Dust storms Floods Glacier-related flows ….	→	Brief and intense Low numbers of casualties
Drought/Desertification Caspian Sea levels	→	Pervasive Low numbers of casualties



Desertification	→	Low population density, large area	→ Low economical cost
Caspian Sea levels (especially rise)	→	**High population density, 7500 km of coastline**	→ **High economical cost**

Leroy et al., 2022

Is our society more or less resilient?

- Resilience = the capacity to recover quickly from difficulties
- We rely more on technique: However we do not know how to catch a rabbit, skin it and cook it on a wood fire
- Are we more fragile?
  - Eg volcanic eruption and disruption to air traffic
  - Eg frost and electric lines broken

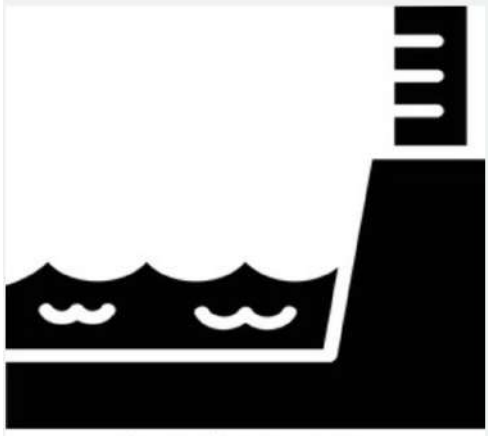
Leroy 2013

Resilience? We are interconnected! Is it always for the best?

- Of the 5 largest power failures in the world in terms of number of people affected,
- 4 have resulted from the cascading effects of localized outages due to poor weather in a rather small area
- eg Southern Brazil in 1999 (75 million people affected) due to a lightning strike

Leroy 2013

Conclusions



Summary of disasters

- the Terek River is troublesome from spring to delta
- landslides occur not only on the slopes of steep mountains but also along edge of Ustyurt Plateau
- floods are more frequent in Golestan and the Caucasus at large
- the largest European desert is in the peri-Caspian plain (Black Lands and Ryn Sands)
- sediment displacement is remarkably dynamic in a large portion of the Caspian drainage basin
- substantial volumes of glaciers and debris have moved suddenly

We have seen that of all disasters affecting the Caspian region, water level change is not the deadliest (seismic hazard is), but certainly is affecting the largest surface/ worst economic impact, and therefore is the most pervasive of all disasters.

How reasonable is it to build close to the coast of the Caspian Sea?

Leroy et al., 2022

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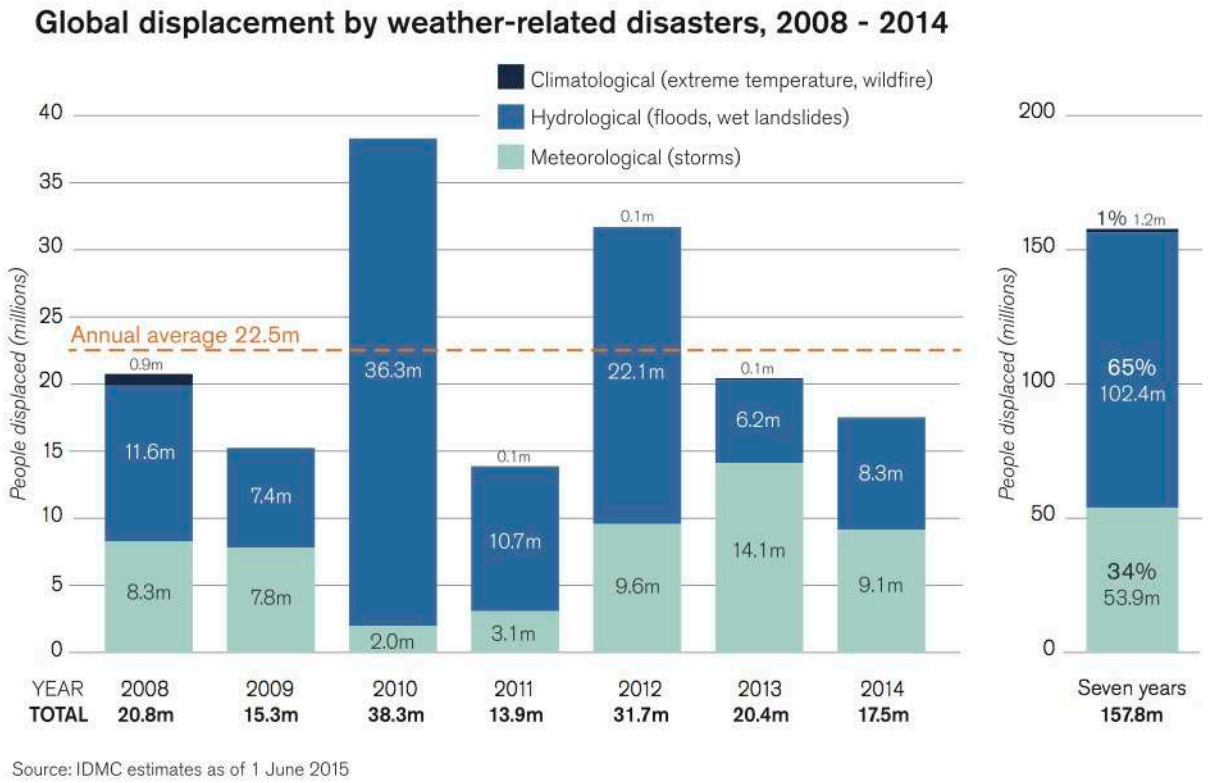
Managed realignment

Coastal (intertidal) habitats are highly effective at attenuating wave energy. This helps to reduce offshore sediment transport and therefore erosion. These habitats also form dense root mats which increase the stability of sediments, helping to reduce erosion rates

Zhou et al. 2010

B. Population displacement

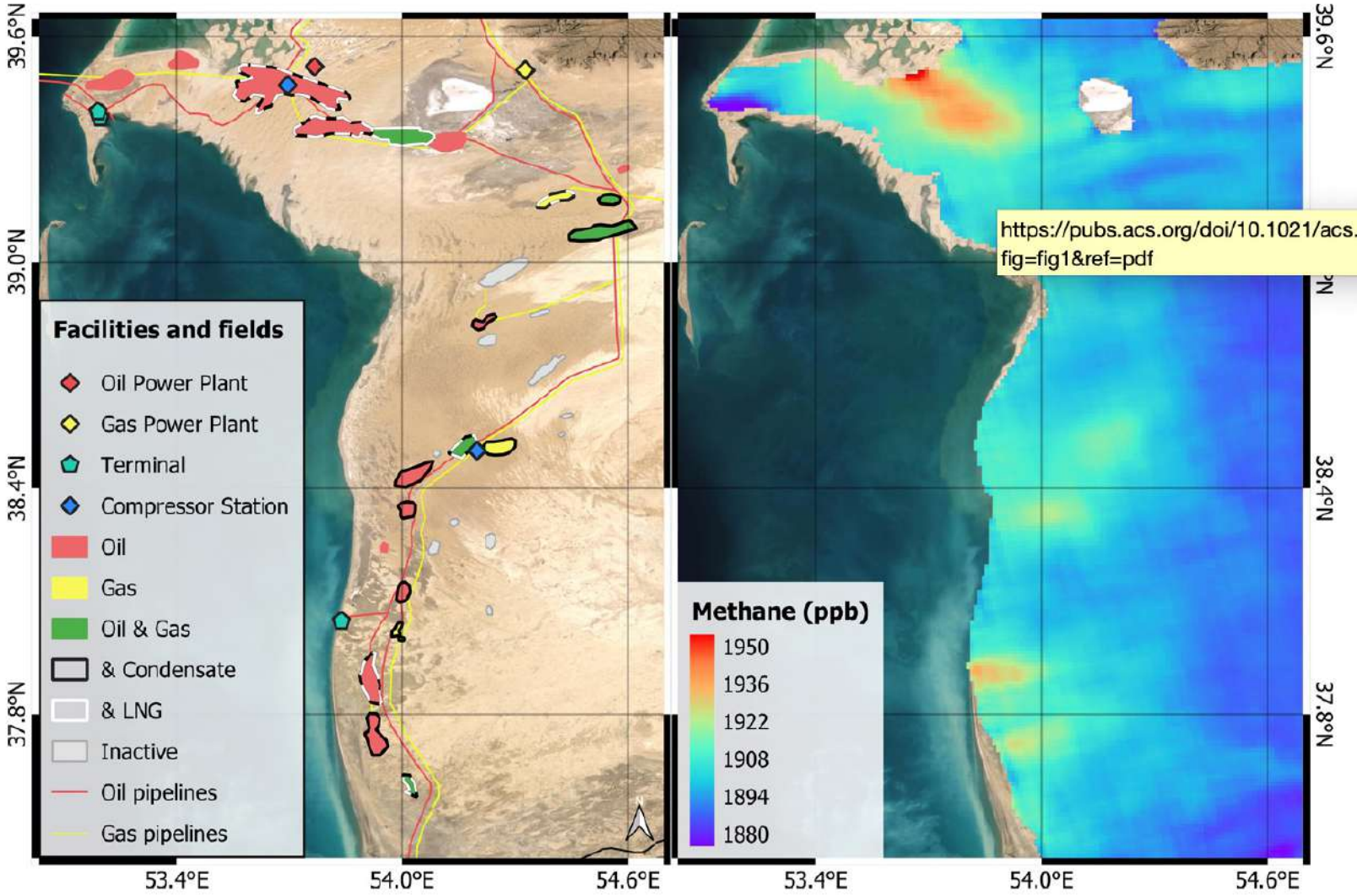


- 90% in developing countries
- Mostly in East Asia and the Pacific

https://public.wmo.int/en/resources/bulletin/disaster-related-displacement-changing-climate

Methane emissions from human–controlled facilities

- A change from flaring (visible) to venting (invisible)
- Venting now detected by satellite imagery
- From extraction fields mainly dedicated to crude oil production
- Turkmenistan one of the first emitters worldwide
- Methane = the second most important greenhouse gas, with a stronger warming potential than CO_2



Irakulis-Loitxate et al. 2022

https://www.theguardian.com/world/2023/may/09/mind-boggling-methane-emissions-from-turkmenistan-revealed?fbclid=IwAR2rz84ElTtTc7U__O7Z6TXd_ndI2HDYx0C5ZXUb9e27W63Mzx7htSpWdhM