Mercury from melting permafrost – a growing threat to Arctic communities outpacing global policy.

Mercury in a Warming Arctic:
Science, Public Health Hazards and the Path Forward
Alaska: December 4, 2025

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Where does the mercury come from? Sources of a useful but neurotoxic metal.

Primary sources

- Mercury mines (China, Tajikistan, Kyrgyzstan: *Peru/Spain*)
- By-product from mining of other minerals
- Refining of certain minerals such as alumina
- By-product of the oil and gas industry (mainly gas)

Secondary sources

- Recovered from products containing mercury during recycling
- Recovered from remediation of mercury contaminated sites

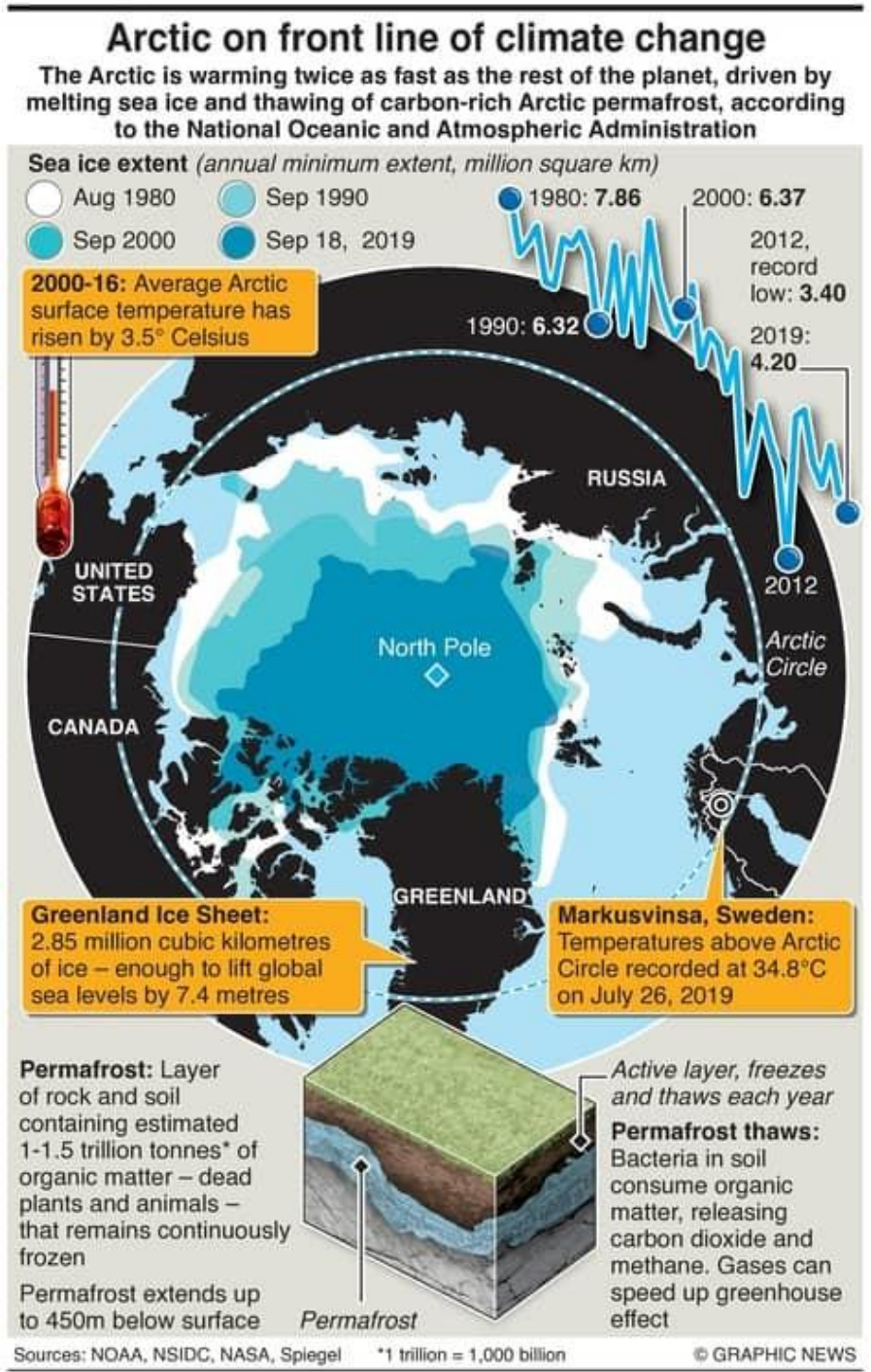
Most common sources of global mercury pollution

- Small scale gold extraction using liquid mercury (38%-45%*)
- Coal fired power plants (21%)
- Metallurgy plants (15 %)
- Cement production (10%)
- Disposal of mercury added wastes (7%)

- *ASGM is surging

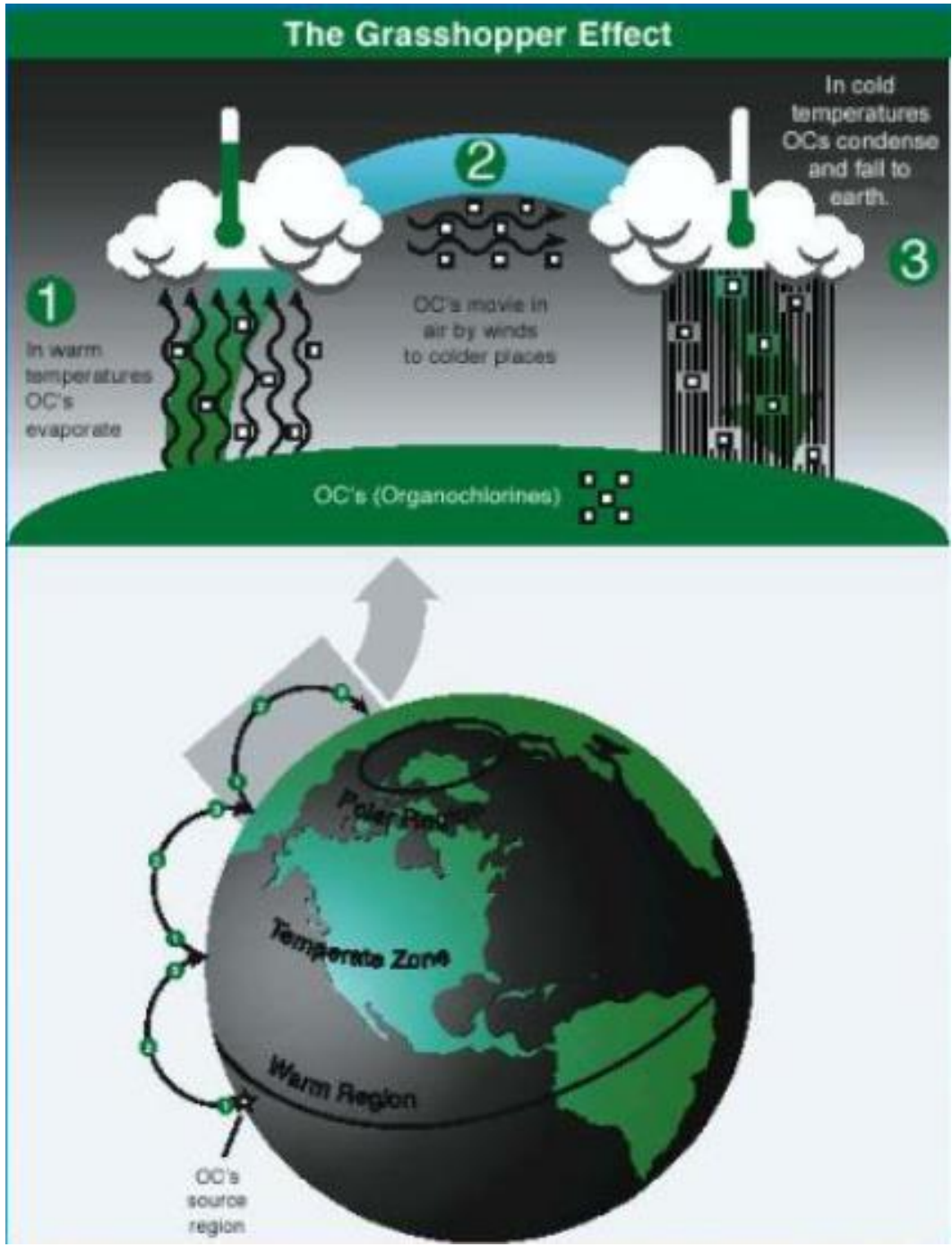
Arctic impacted first by climate change

- Average surface temperature rising by 3.5^{O}C
- Sea ice shrinking
- Permafrost thawing



Second impact on Arctic by atmospheric mercury pollution from global distillation effect.

- Mercury pollution in the Arctic is primarily caused by global distillation processes, where mercury emitted from lower latitudes is transported and accumulates in Arctic ecosystems, posing significant health risks to wildlife an Indigenous communities.



Third impact – mercury contamination from ocean currents carrying large inventories of legacy mercury

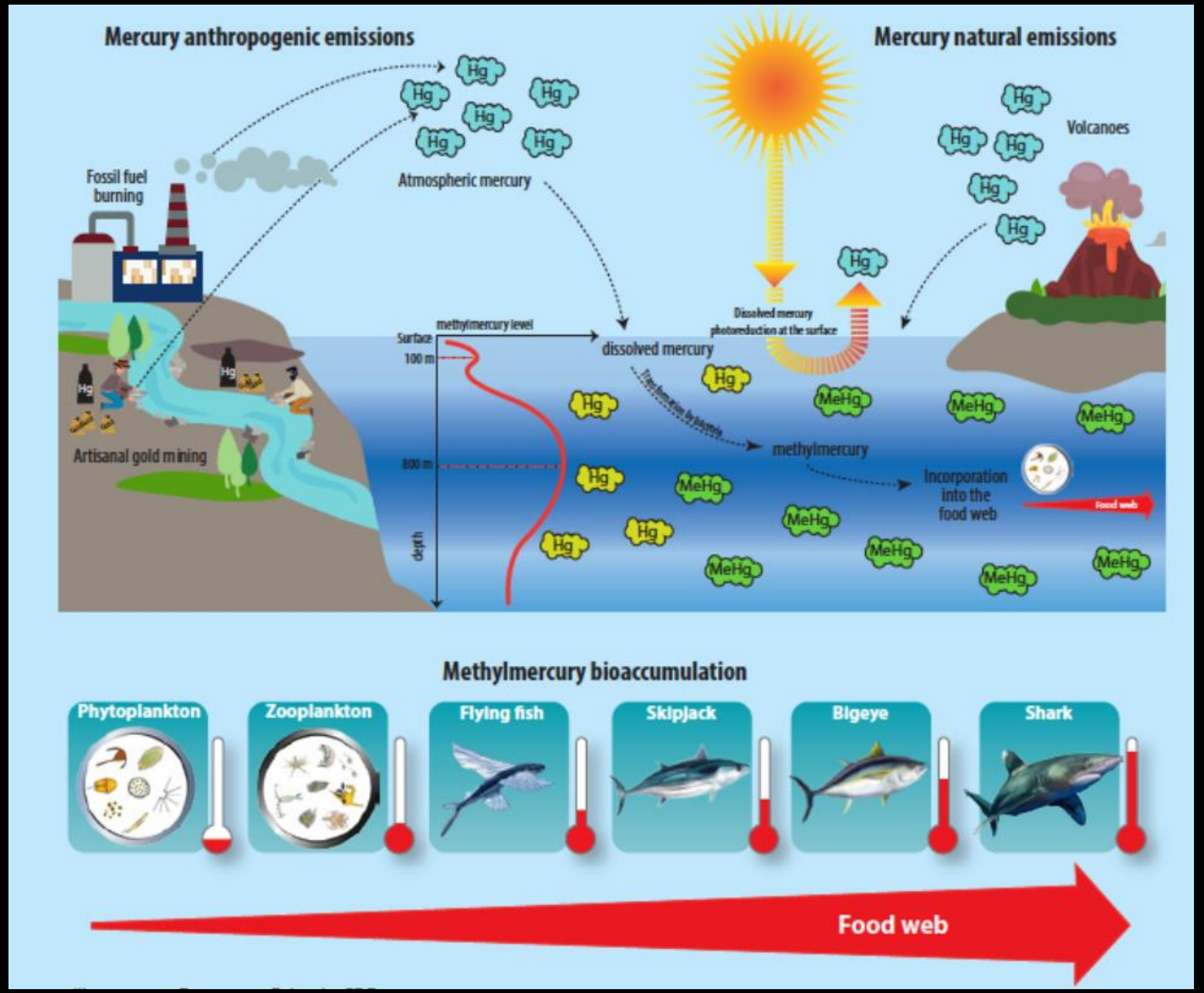
Since the dawn of industrialization, small-scale gold mining and the burning of fossil fuels, resulting in a ~ 5-fold increase of Hg in the atmosphere and a ~3-fold increase in surface ocean waters.

Once Hg enters the Arctic, it biomagnifies in the long Arctic food webs, creating high Hg loads in long-lived top predators such as toothed whales, polar bears (*Ursus maritimus*) and humans, thereby constituting a threat to biodiversity and health due to adverse neuroendocrine disruption.

In recent decades, atmospheric Hg deposition has generally decreased across the Arctic due to global reduction of anthropogenic Hg emissions, whereas predominantly increasing Hg trends occur for many biological matrices in the Arctic, including marine and freshwater fish and marine mammals. This mismatch leaves important knowledge gaps regarding Hg sources and pathways to and within the Arctic.

Søndergaard, J., Elberling, B., Sonne, C. *et al.* Stable isotopes unveil ocean transport of legacy mercury into Arctic food webs. *Nat Commun* **16**, 5135 (2025). https://doi.org/10.1038/s41467-025-60356-6

- Despite atmospheric anthropogenic mercury pollution levels declining – mercury levels in key Arctic species are rising.
- Isotope ‘fingerprinting’ of mercury pollution in ocean currents is showing the missing factor is high levels of legacy mercury are being transported to the Arctic.
- Much of this mercury will be from historical coal based power and current/historical ASGM activity.



Fourth impact – mercury from permafrost melt.

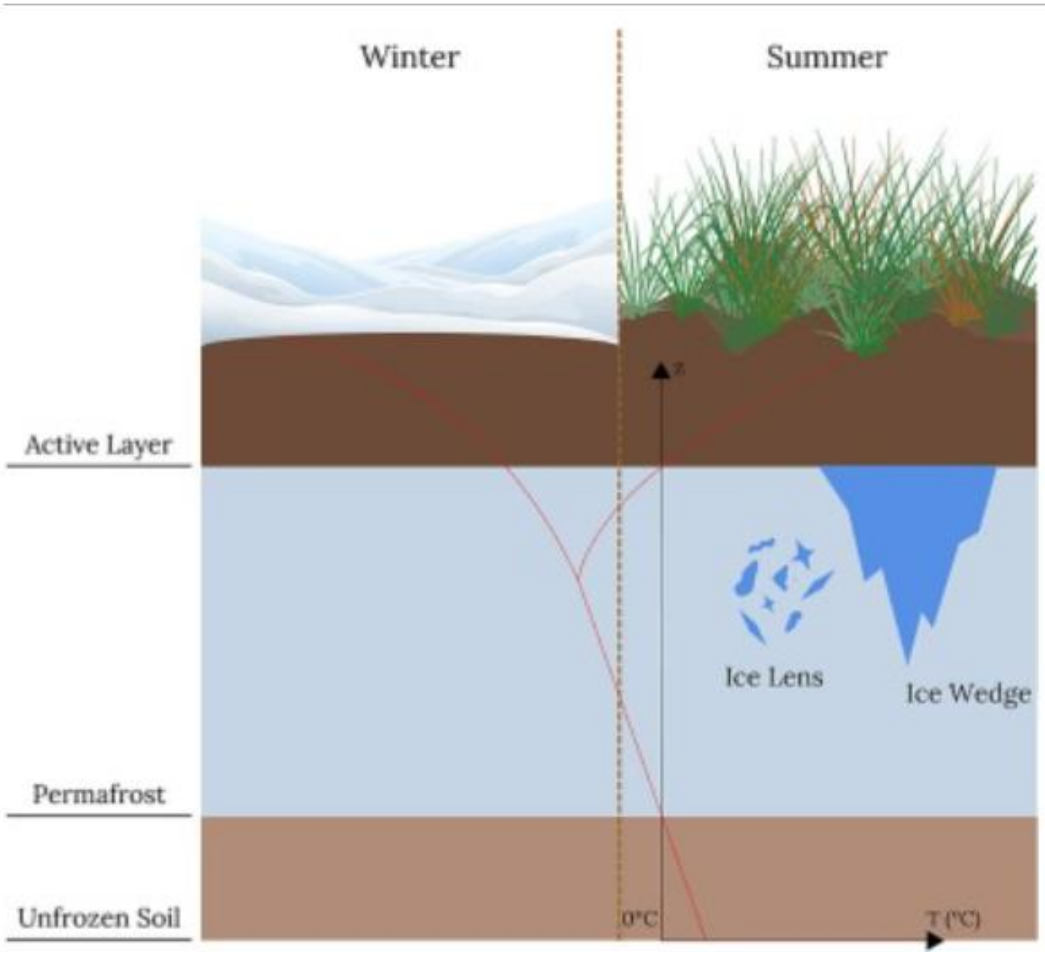
- Sediments in permafrost are estimated to store more mercury than Earth's oceans, atmosphere, and soil combined. And, as climate change causes permafrost to thaw, the mercury stored in permafrost becomes available for release into the surrounding environment.
- Retrogressive thaw slumps (RTSs) can mobilize vast quantities of sediments and solutes downstream

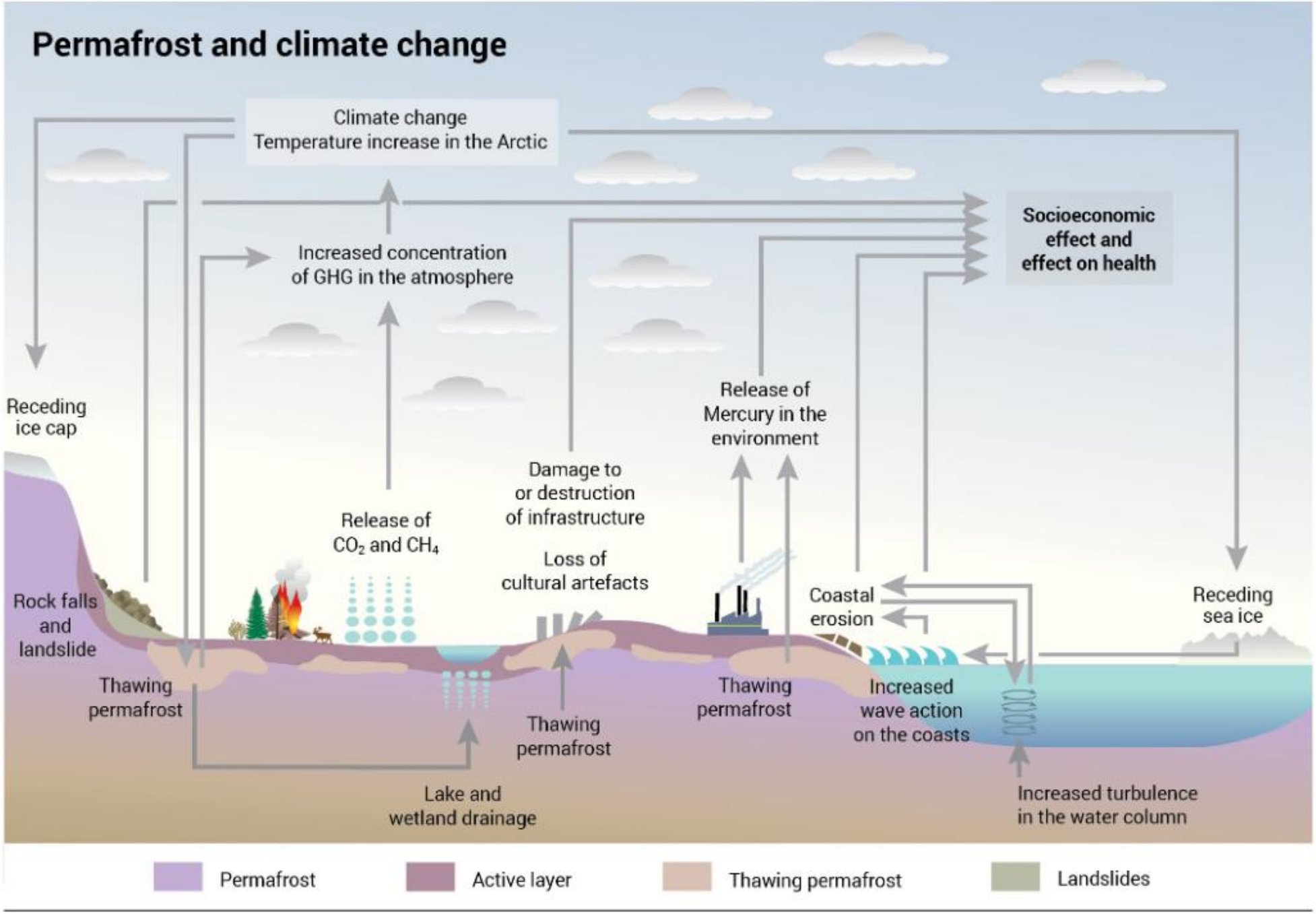
- "Concentrations of mercury were elevated for at least 2.8 kilometres downstream of thaw slumps."
- However, because the mercury is locked within sediments, the scientists are unsure as to whether this mercury could be consumed by organisms in the area and whether this mercury poses any threat to the security of northern food webs.
- It is estimated that ~5% of the Hg stored for centuries or millennia in northern permafrost soils (88 Gg) is susceptible to release into modern-day Hg biogeochemical cycling from further climate changes and thermokarst formation.

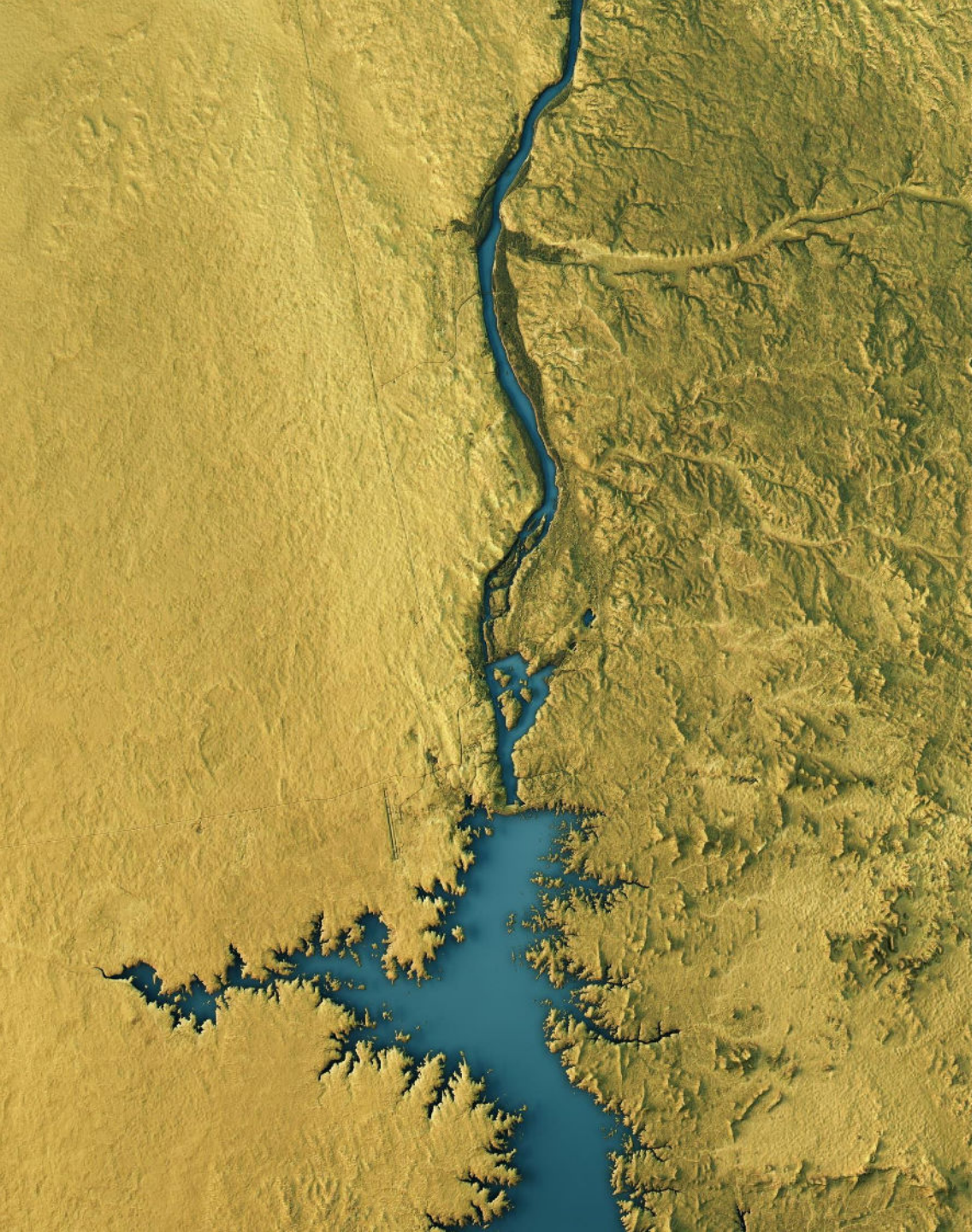
- Permafrost thaw may also be a part of climate change feedback loops.

Permafrost thaw slump - Peel Plateau in the Northwest Territories, Canada. 2025
https://pubmed.ncbi.nlm.nih.gov/30474969/

Global distribution of permafrost: 14 million km^2




Permafrost and climate change
Climate change
Temperature increase in the Arctic
Increased concentration of GHG in the atmosphere
Socioeconomic effect and effect on health
Receding ice cap
Release of Mercury in the environment
Damage to or destruction of infrastructure
Release of CO_2 and CH_4
Loss of cultural artefacts
Rock falls and landslide
Coastal erosion
Receding sea ice
Thawing permafrost
Thawing permafrost
Thawing permafrost
Increased wave action on the coasts
Lake and wetland drainage
Increased turbulence in the water column
Permafrost
Active layer
Thawing permafrost
Landslides



Damage from the thaw

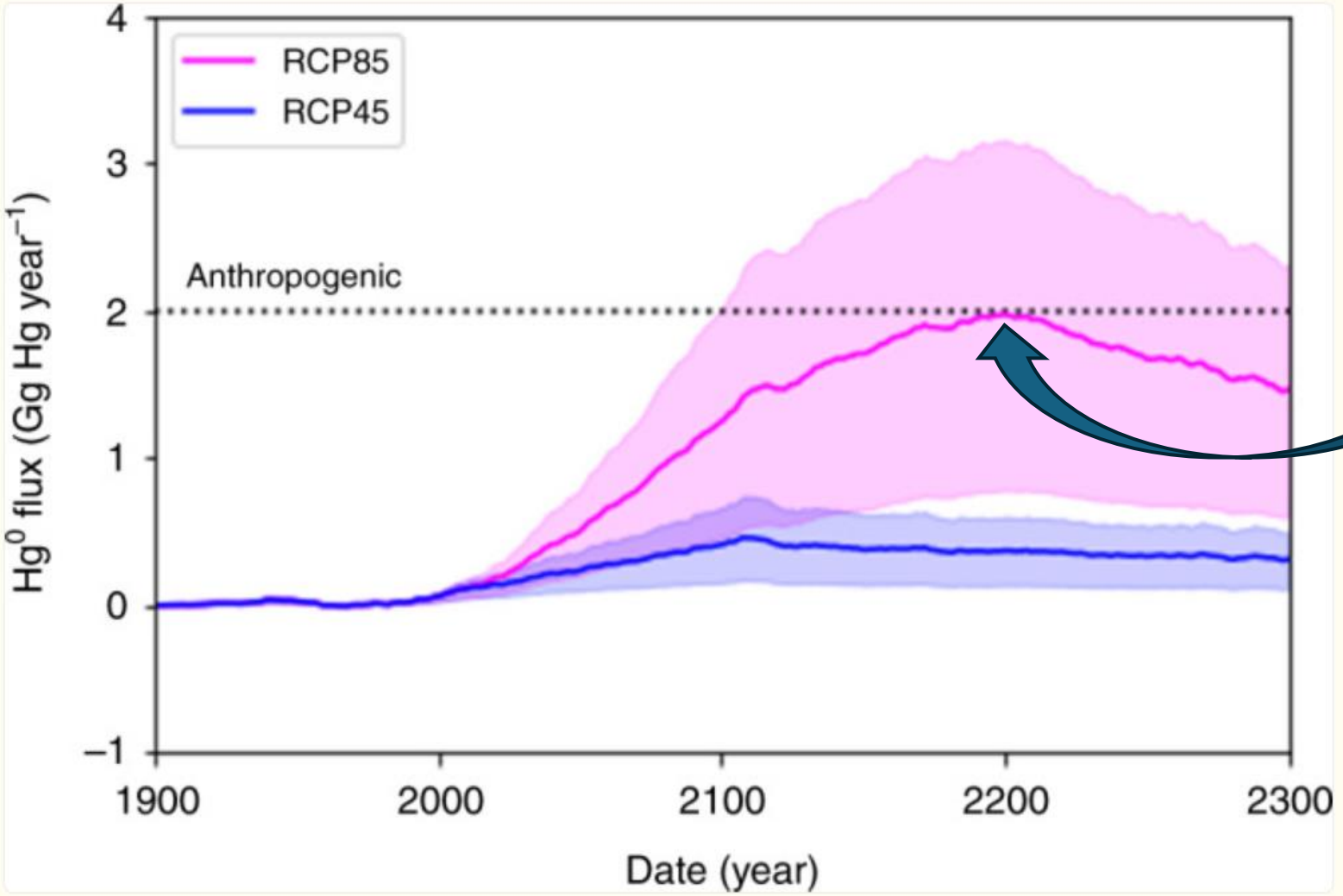
- In ice-rich areas it can lead to the formation of thermokarst lakes, and erosion of lake shorelines, valleys and coastal areas resulting in thaw slumps that may contribute to significant volumes of material transport downstream, including mercury.
- Loss of cultural artefacts and impacts on burial grounds
- Damage to infrastructure: e.g. ice roads, structures, airstrips etc
- Release of further GHG creating a spiral effect.

Complex processes at work: permafrost and rivers.

- Permafrost predominates in polar and high mountain regions, encompassing nearly 15 % of the exposed land in the Northern Hemisphere. It denotes soil or rock that remains at or below 0 °C for the duration of at least two consecutive years. These frozen soils serve as a barrier to contaminants that are stored and accumulated in permafrost over extended periods of time.
- While retrogressive thaw slumps (RTSs) beginning in the 1980's are a clear problem, river systems also play a growing role.
- Researchers have found complex erosion and reburial processes at play as rivers change course gradually over time, varying sediment types are eroded or deposited along its banks.
- This influences the mercury content in these materials. Finer sediments were found to hold more mercury than coarser materials, indicating specific soil types may represent greater risks.
- The Yukon River in Alaska is anticipated to release more mercury as climate change increases and the river erodes at melting permafrost, shifts mercury bearing sediment and encourages methylation processes from bacteria making the mercury more bioavailable and toxic.
- A study by Schaeffer et al. 2020 considered the role of the Yukon river in mercury releases from thawing permafrost.

Permafrost thaw mercury flux to atmosphere under low GHG scenario of 2% (blue) and high emission scenario (pink)

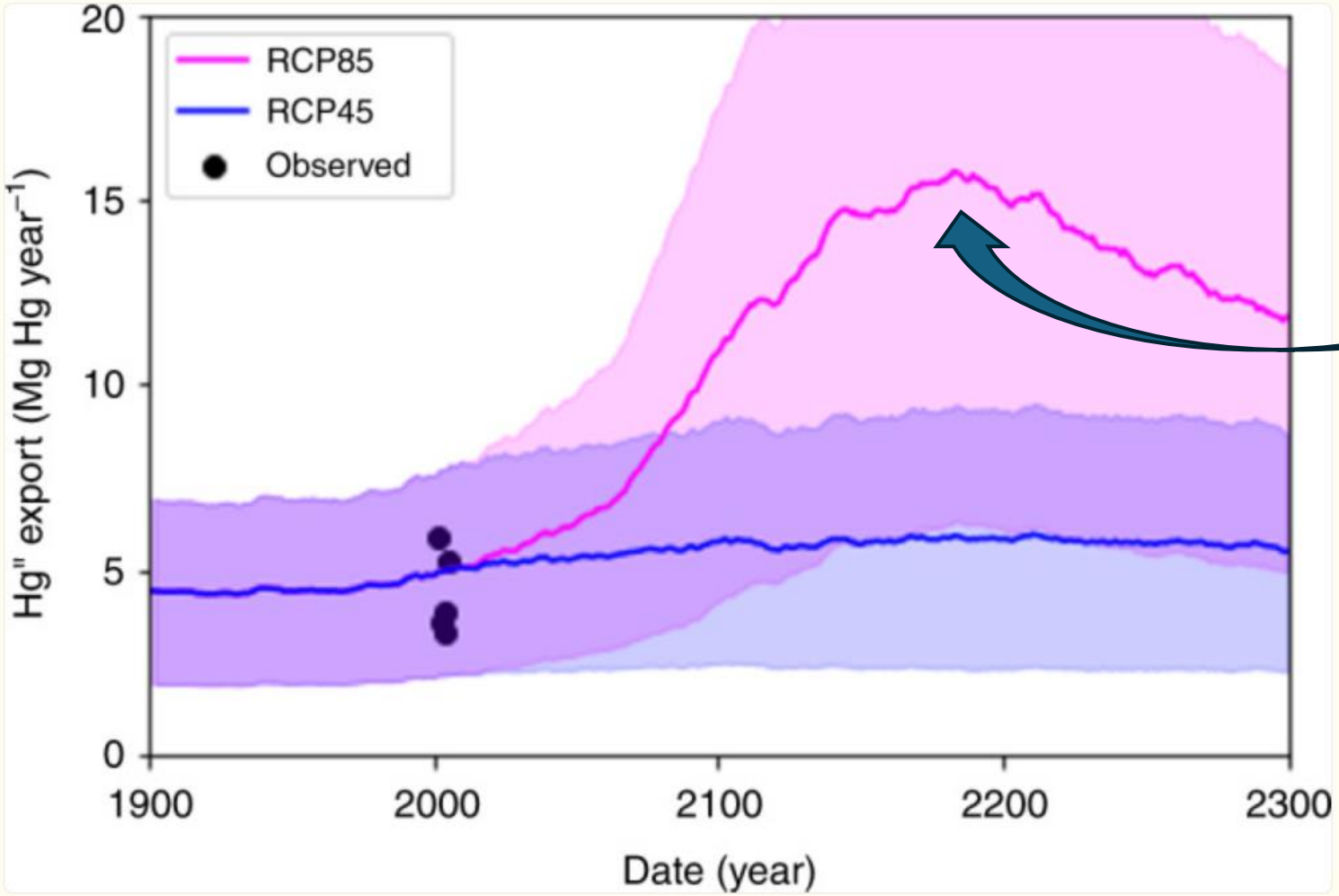
Fig. 2. Annual net elemental mercury (Hg^0) flux into the atmosphere.



Under a high GHG emissions scenario permafrost released mercury will be equivalent to all current anthropogenic mercury pollution by 2200

Predicted mercury export from Yukon River, Alaska

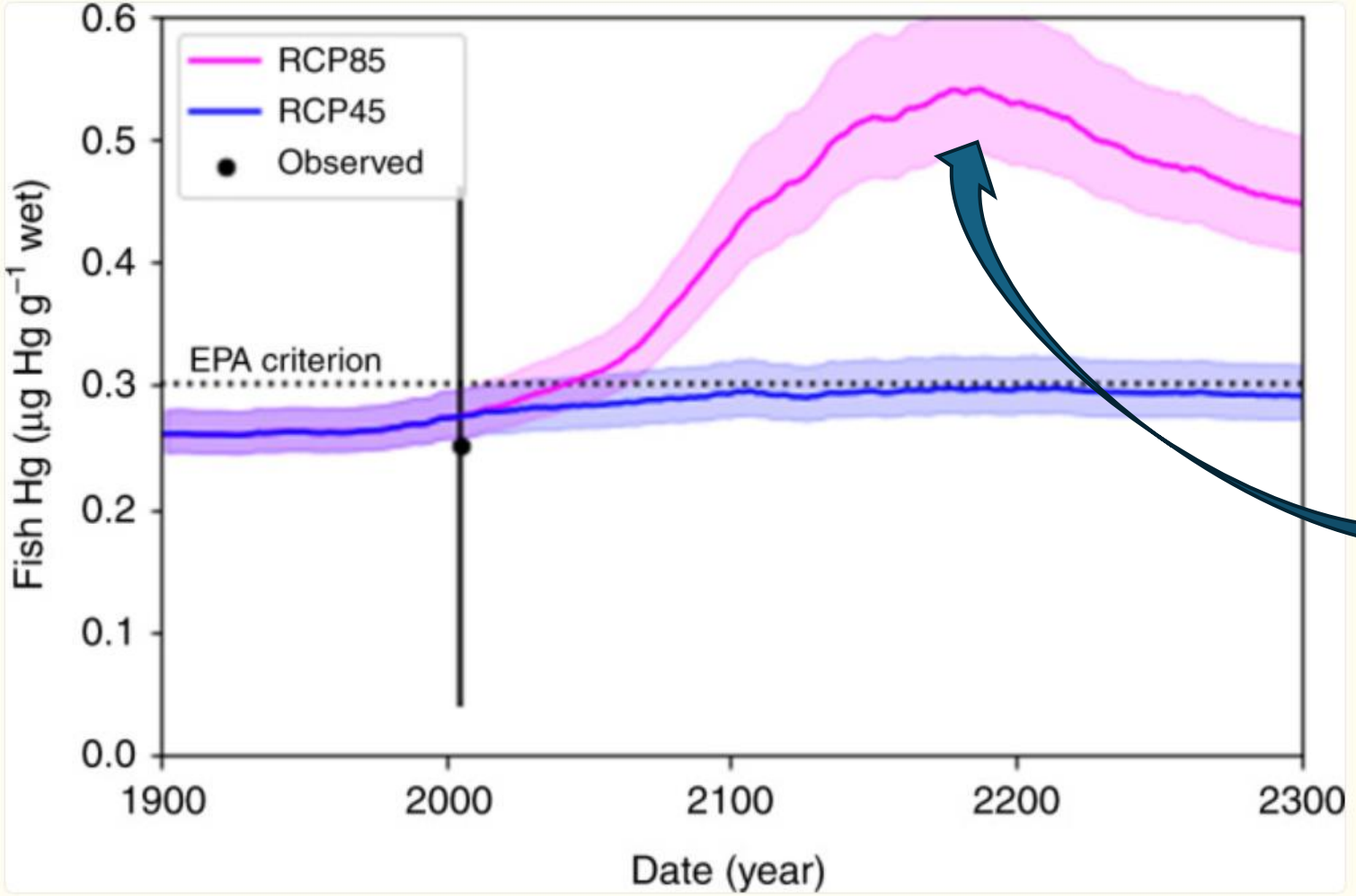
Fig. 4. Mercury cation (Hg^{II}) export for the Yukon River Basin (YRB).



Modelling shows a high GHG scenario (RCP85 pink) assumes permafrost thaw throughout the basin resulting in doubling of Hg export by 2100 and a tripling by 2200.

Predicted mercury levels in fish Yukon River

Fig. 6. Mercury (Hg) concentration in fish in the Yukon River.



A high GHG scenario will see Yukon river fish mercury concentrations increases by 175% by 2100 and 222% by 2300

Mercury methylation and bioavailability

- In its metallic form mercury is not easy for humans to absorb (bioavailable) but can be inhaled as fumes which are neurotoxic.
- When mercury from permafrost thawing enters biologically active areas such as wetlands, swamps, rivers, lakes and oceans, bacteria can convert the mercury to methylmercury which is highly bioavailable to humans and toxic. This is why fish often accumulate methylmercury.
- Studies have also identified that fully thawed permafrost areas linked to an elevated pool of biologically mobile Hg (Fahnestock et al., 2019) are often hotspots for Hg methylation.

Many factors affect the total volume and toxicity of mercury release from permafrost

- Ambient temperature
- Composition and amount of organic matter in permafrost
- Soil type: sandy or rich with organic matter.
- Rainfall rates
- Soil and water microbial levels and types: abundant in fully thawed ecosystems, while frozen and semi-frozen systems exhibited lower abundance.
- Microbial bacteria can heavily influence the toxicity of mercury released from permafrost depending on its methylation potential.

Socio-political impacts of climate/mercury pollution

- Most mercury pollution impacting the arctic arises from gold mining and coal combustion elsewhere on the planet with no real financial or ecological benefit to Arctic communities – quite the opposite.
- Mercury from these activities benefit others while the arctic environment and inhabitants bear the risk and negative impacts.
- This scenario is a clear example of environmental injustice where distributive risk is unequally apportioned to those least able to protect themselves while those generating the risk benefit from it.
- The are not marginal risks but very substantial risks to food security, personal health, future generations, community cohesion and cultural practices.

Global policy controls on mercury pollution

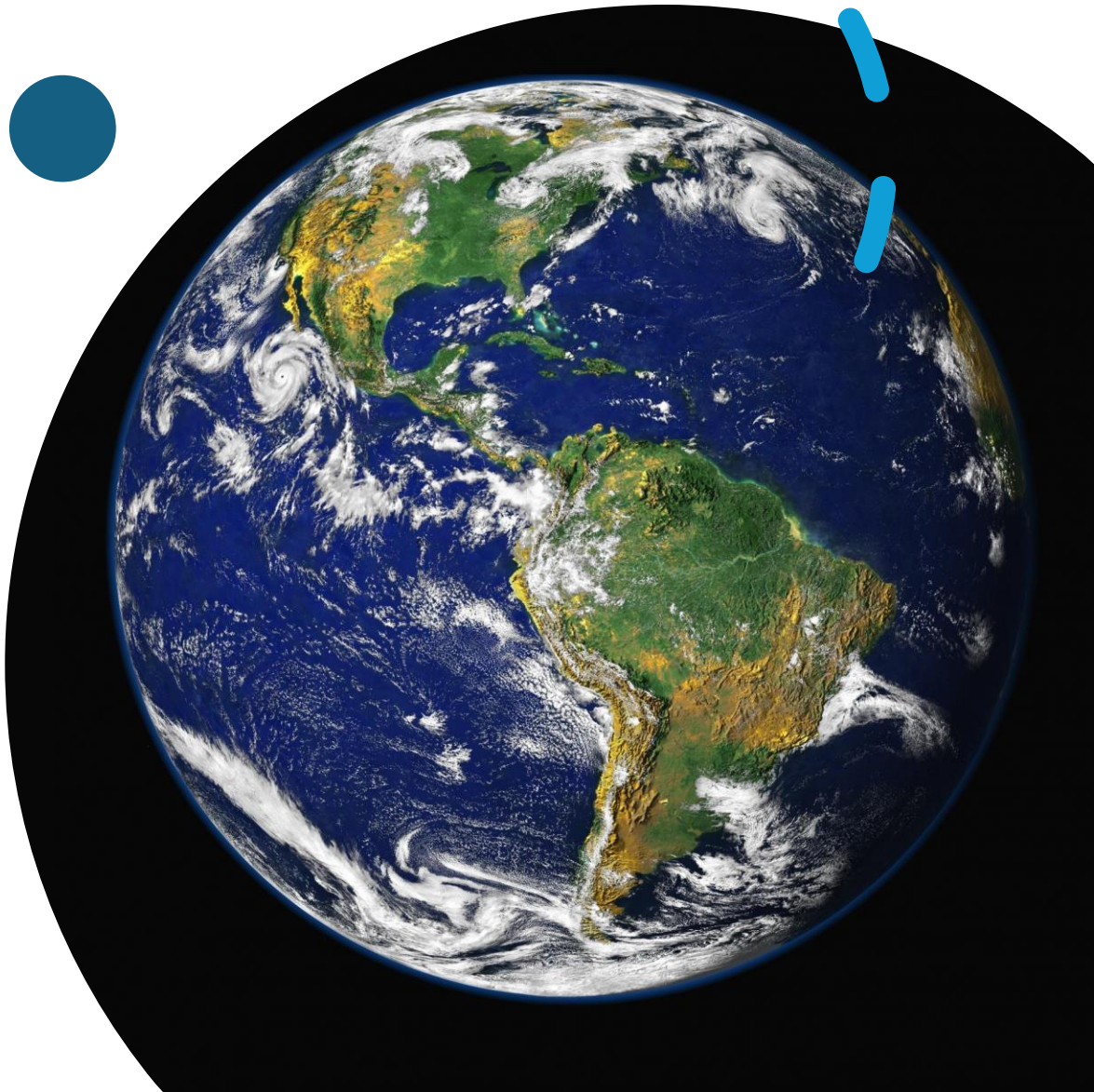
Minamata Convention on Mercury

- Only addresses anthropogenic mercury pollution, not naturally occurring mercury releases. (what are the implications for permafrost?)
- Has some restrictions on trading mercury mainly related to end use or source. (e.g. mercury from primary mercury mining cannot be sold to be used in ASGM – but is often mislabelled).
- Requires BAT BEP controls for new emission sources (e.g. coal fired power plants) but not for existing plants and there are no limits on the number of new plants.
- Has phased out most mercury containing products (e.g. fluorescent lights, thermometers) and industrial processes using mercury (e.g. chlor-alkali plants
- The biggest mercury pollution source – small scale gold mining is subject to phase down plans at national level but has no end date for phase out. ASGM is not being effectively controlled by the convention and is highly polluting. Releases of 1500 -2000 tonnes of mercury per annum have been estimated.
- Mercury releases from soil erosion and permafrost melt are not addressed by the convention.

Can global mercury policy help?

Potentially!

- The Minamata Convention on Mercury has the most powerful measures to limit mercury pollution but the treaty has important loopholes.
- The main loophole being the allowed ongoing trade in mercury and its use in gold mining. This releases around 2000 tonnes of mercury per annum to the environment – every year! This will remain a challenge for decades even if the convention loopholes are closed.
- The phenomenon of legacy ocean mercury pollution continuing to impact Arctic species means that if we were to ed all mercury use tomorrow we would still see rising mercury pollution in Arctic species for decades before it plateaus.
- The key is to stop all mercury use and trade as soon as possible.
- Climate Change agreements may also be able to reduce global warming and slow permafrost melt but the current geopolitical realities suggest that will be some time away. The rapid uptake of renewable energy may achieve major inroads into GHG production, but the petrochemical sector will remain a challenge looking ahead due to their lack of commitment to stop exploring and extraction.



Thanks for your attention!