# Environmental Effects Assessment Panel

## 38th Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer

## 2 – 6 November 2026, Kigali, Rwanda

# Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change


**EEAP Co-chairs:**
**Janet F. Bornman (Australia)**
**Paul Barnes (United States)**


THE KIGALI AMENDMENT 2016–2026

SUSTAINABLE DEVELOPMENT GOALS

# Environmental Effects Assessment Panel

## 2026 Terms of Reference

### Emerging issues

'...to pay particular attention to the most recent scientific information, including **solar radiation modification scenarios, forward-looking projections and scenarios**, and to assess the **effects of changes in the ozone layer and ultraviolet radiation and their interaction with the climate system on**:

(a) Human health;

(b) The biosphere, biodiversity, ... the ecosystem;

(c) Ecosystem services, agriculture and materials, microplastics.

...to assess the **effects and accumulation of breakdown products from controlled substances and their alternatives**, in particular any substances that are very persistent in the environment, such as **perfluoro- and polyfluoroalkyl substances [PFAS]**, including trifluoroacetic acid, in ground and surface waters and in other relevant sinks.'

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## Summary of Progress

EEAP scientific Updates & other material since 2022 that contribute to the 2026 Quadrennial Assessment







2024: Biodiversity linkages between **EEAP** & the **Convention on Biodiversity & Global Biodiversity Framework** associated with relevant SDGs




Translation of the 2022 Q&As: Chinese, Spanish



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## 2026 Schedule: EEAP Quadrennial

| 2026 | |
|---|---|
| Jan-Mar | **Draft 1 preparation continued** |
| Mar | **Quadrennial meeting 1, Santiago, Chile**<br>**Draft 1** feedback, overview of graphics in preparation for Draft 2; Q&A content, graphics; Executive Summary framework |
| Mar-Apr | **Chapters Draft 2,** Internal Panel review<br>Executive Summary Draft 1 |
| May | **Chapters Draft 3** |
| Jun | **Chapters Draft 3,** to External review; Executive Summary Draft 2 |
| Jul-Aug | **70** External Reviewers: response & Chapter revisions |
| Sep | **Quadrennial meeting 2, CPH;** 2 days with invited reviewers |
| Sep-Oct | Executive Summary Draft 3,4: **10** External Review Editors |
| Oct-Dec | Final revisions<br>Dec: Quadrennial Assessment sent to Ozone Secretariat |
| **Jan/Feb 2027** | Q&A completed and sent to Ozone Secretariat |

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| | Summary titles of Chapters – 3 emerging issues selected |
|---|---|
| 1 | **Stratospheric ozone, UV radiation**, & their interaction with the **climate** system, Germar Bernhard (Lead), Alkis Bais (Co-Lead) |
| 2 | **UV radiation, & human health**, Rachel Neale (Lead), Catherine Olsen (Co-Lead) |
| 3 | **UV radiation** & other **global changes** on tropospheric chemistry & **pollution/ health effects**, Tamara Schikowski (Lead), Sasha Madronich, (Co-Lead) |
| 4 | **PFAS – Definitions, relevance, & implications, Mads Sulbæk Andersen (Lead)** |
| 5 | **Ozone-depleting substances** & their **replacements** & **toxicology** of degradation **products**, Mads Sulbæk Andersen (Lead) |
| 6 | **Terrestrial ecosystems**, Matthew Robson (Lead), Sharon Robinson (Co-Lead) |
| 7 | **Aquatic ecosystems**, Patrick Neale (Lead), Samuel Hylander (Co-Lead) |
| 8 | **Synthetic & natural materials** in use, Liping Zhu (Lead), Krishna Pandey (Co-Lead) |
| 9 | **Solar UV radiation & climate effects on the fate of plastic** in the environment, Rosa Busquets (Lead), Anthony Andrady (Co-Lead), Marcel Jansen (Co-Lead) |
| 10 | **Potential environmental consequences of Solar Radiation Modification (SAI),** Laura Revell (Lead), Gabriel Chiodo (Co-Lead), Simone Tilmes (Co-Lead) |
| 11 | Safeguarding earth systems: Montreal Protocol & its alignment with **Planetary Boundaries & Sustainable Development Goals**, Roy Mackenzie-Calderón (Lead) |

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## EMERGING ISSUES

## PFAS as related to the Montreal Protocol

**Definitions, relevance, and implications – some clarifications**

**PFAS** (per- and polyfluoroalkyl substances)

- A term that includes millions of **p**er- and poly**f**luorinated **a**lkyl **s**ubstances; & with multiple definitions
- Ambiguity exists when the term 'PFAS' is used in reports, policy, & scientific communications
- The term not imply persistence, toxicity, bioaccumulation, or transfer across food webs (e.g., between animals & plants)
- **Montreal Protocol relevance**:

  Some of the replacements of ODS can be classified as PFAS

  & some atmospheric degradation products
- Classification differs depending on the definition

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## EMERGING ISSUES

## PFAS as related to the Montreal Protocol

**Toxicity database for TFA: progressing slowly**

**New data continue to indicate:**

- Current concentrations of TFA relevant to the Montreal Protocol do not present a risk to humans and organisms in the environment
- Similarly for concentrations predicted to 2100
- We acknowledge large concentrations from fluorochemical industrial sites (in waste water)

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## EMERGING ISSUES

## PFAS as related to the Montreal Protocol

Gases relevant to the Montreal Protocol and their known persistent breakdown products **were identified as PFAS** according to classification under at least 1 of 3 broadly-used definitions, **as examples to show risk of toxicity**

<u>Commonly used definitions of PFAS</u>

Buck et al. (2011)

OECD (2018) and (2021)

US EPA (2024)

**We do not assess the merits of the different definitions but acknowledge that differences exist**

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## EMERGING ISSUES

## PFAS as related to the Montreal Protocol

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<u>Commonly used definitions of PFAS</u>

Buck et al. (2011)

OECD (2018) and (2021)

US EPA (2024)

- TFA
- perfluoropropanoic acid (PFPrA)
- perfluorobutanoic acid (PFBA)

PFPrA and PFBA considered PFAS under all 3 definitions used

And TFA under 2 of the selected definitions (not US EPA)

**We do not assess the merits of the different definitions but acknowledge that differences exist**

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## EMERGING ISSUES

## Ozone-depleting substances and their replacements

### Chemistry, fate, toxicology of persistent degradation products

**Focus** - on the gases controlled by the Montreal Protocol & their degradation products, e.g.

- hydrofluorocarbons (HFCs)
- hydrochlorofluorocarbons (HCFCs)
- hydrofluoroolefins (HFOs)

TFA: trifluoroacetic acid

PFPrA: perfluoropropanoic acid

PFBA: perfluorobutanoic acid

- **Increased since 1990's**
- **Detected in soil, water, food, beverages, & plants**
- **Sources ikely not all relevant to the Montreal Protocol**

Other sources of TFA, PFPrA, & PFBA in the environment include: Breakdown products of some pesticides, pharmaceuticals, & from industrial emissions

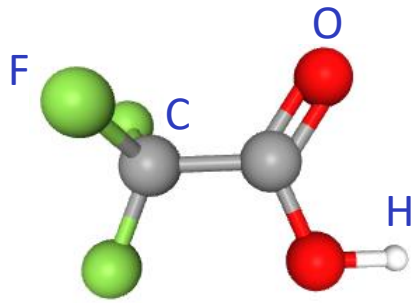
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## EMERGING ISSUES

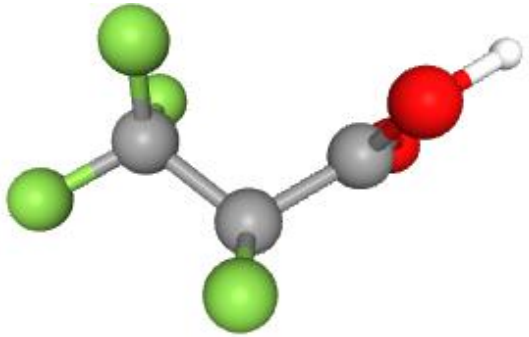
## Ozone-depleting substances and their replacements

### Chemistry, fate, toxicology of persistent degradation products

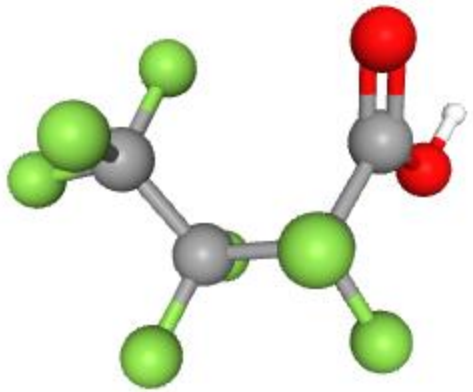
**How were the probabilistic toxicity risk assessments done for trifluoroacetic acid (TFA), perfluoropropanoic (PFPrA), and perfluorobutanoic (PFBA) acids?**




TFA, $C_2$



PFPrA, $C_3$



PFBA, $C_4$

**<u>Probabilistic risk assessments</u>: a rigorous quantitative approach to estimate the likelihood and magnitude of adverse effects using existing data from robust studies**

# EEAP approach to probabilistic risk assessments of TFA, PFPrA, & PFBA

## Methodology

**Only those studies were assessed that met the following criteria:**

1. Robust method(s) for collection of samples
2. Avoidance of field contamination during sample processing & analysis
3. Procedures to avoid sample contamination during transport, storage
   *(studies with spiked samples, i.e., boosted signal due to contamination, were not included)*
4. Full description of analytical methods & equipment
5. Purity of external standards and/or internal standards for analysis
6. Availability of raw data for concentrations of TFA, PFPrA, PFBA
7. Reporting of levels of detection & quantitation, method for detection limits stated
8. Studies with major weaknesses were not used (*e.g., sampling & analytical methods not fully described, molecular structures of TFA, PFPrA, or PFBA not specifically stated)*

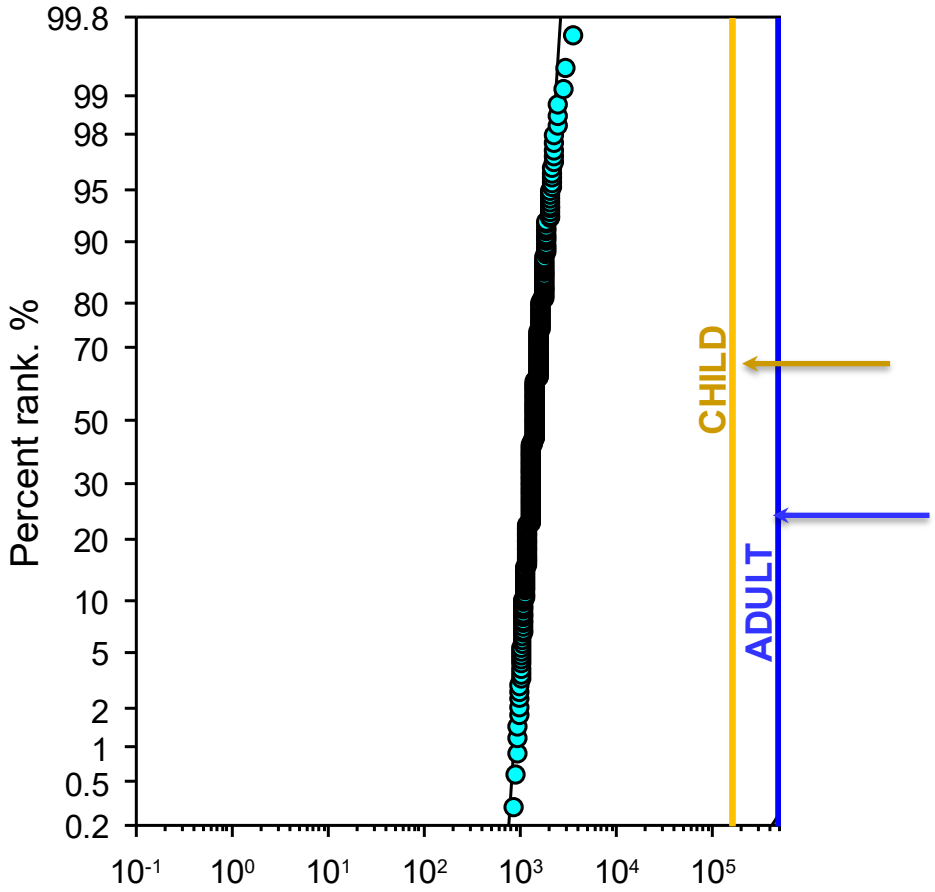
# Risk assessment of effects in relation to exposures of TFA concentrations — Some explanations of the data

Horizontal axis:
TFA concentrations

Vertical axis:
data ranked from smallest to largest exposures as a percentage

**Toxicity benchmark**:
a known concentration used as a reference point that serves as a standard against which we can measure or predict an outcome

A threshold conc. at which risk is judged to be minimal by various organisations



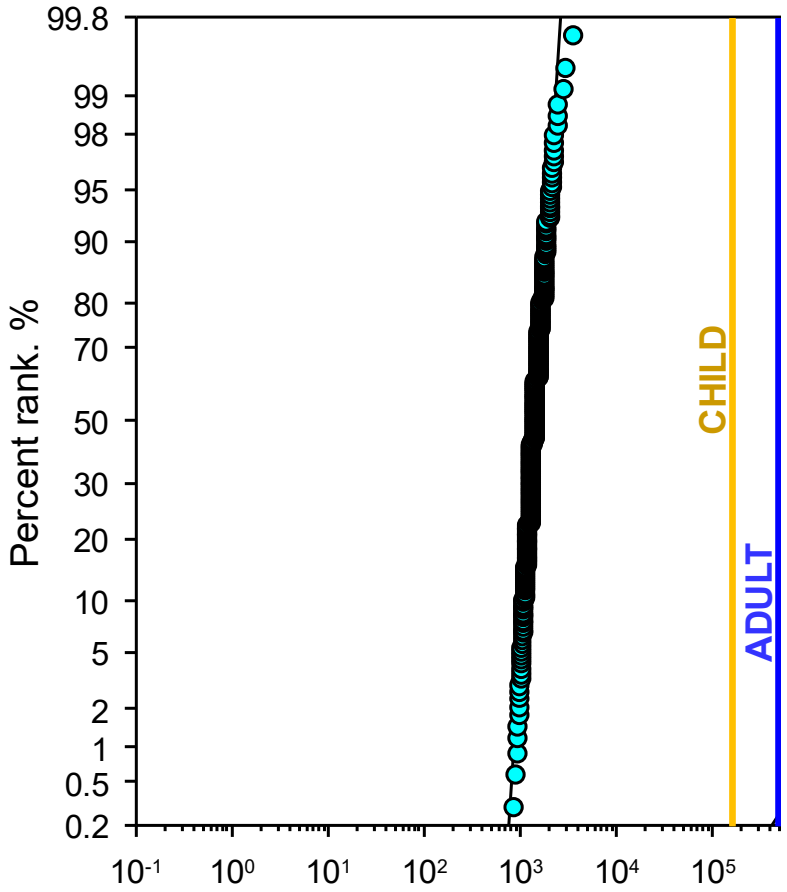
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**Toxicity benchmark**: a known concentration used as a reference point that serves as a standard against which we can measure or predict an outcome

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**Concentration of Na-TFA in surface water**

**Our toxicity benchmarks** were based on the European Food Safety Authority (**EFSA**) and its acceptable daily intake;

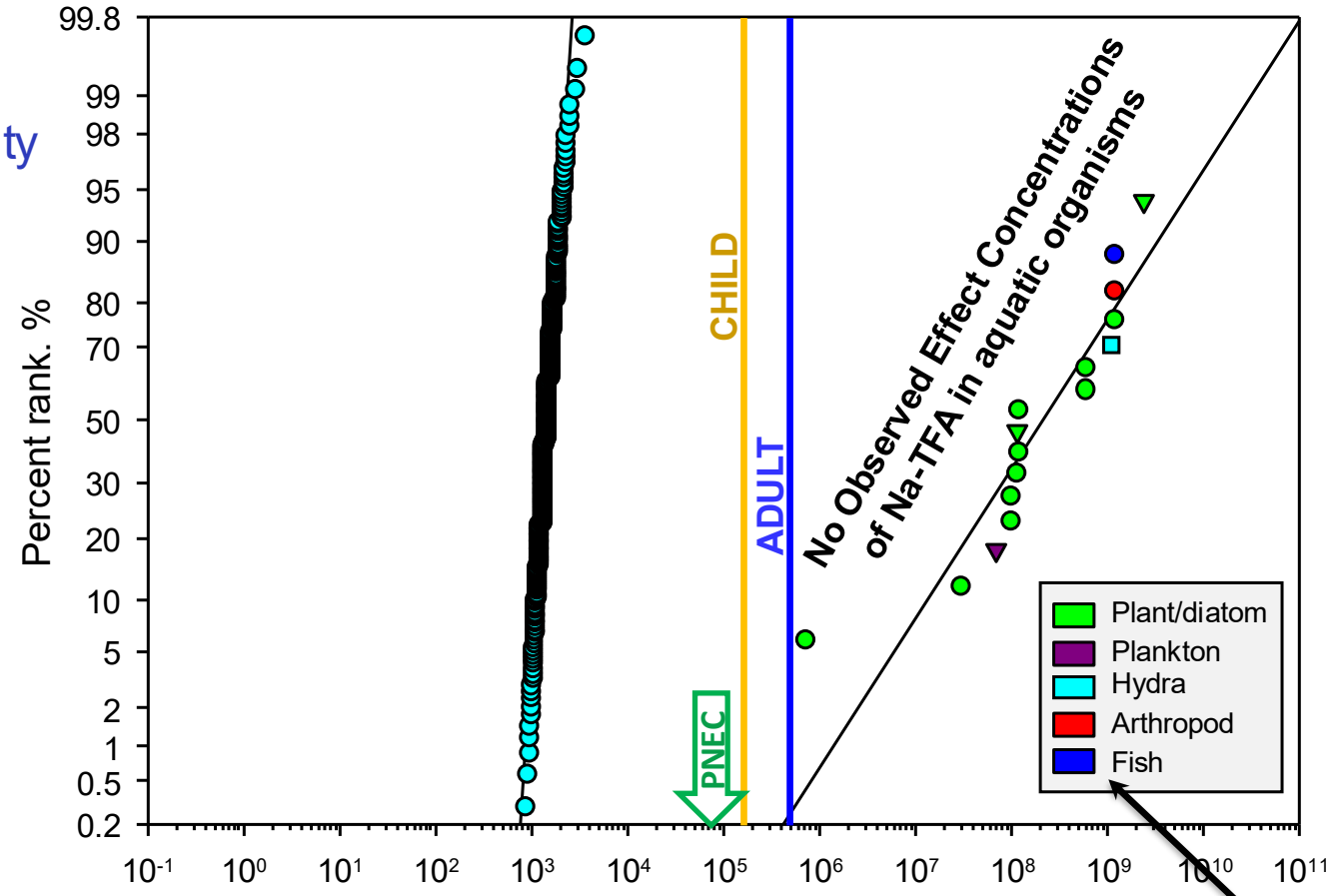
and the **US EPA reference dose**: max acceptable dose likely without appreciable risk of deleterious effects

# Risk assessment of effects in relation to exposures of TFA concentrations — Some explanations of the data

The slope of the line is a visual measure of variability

**Benchmark**

**PNEC (arrow)**: **predicted** no effect concentration, used in the EU. Concentrations less than this are *de minimis* risk

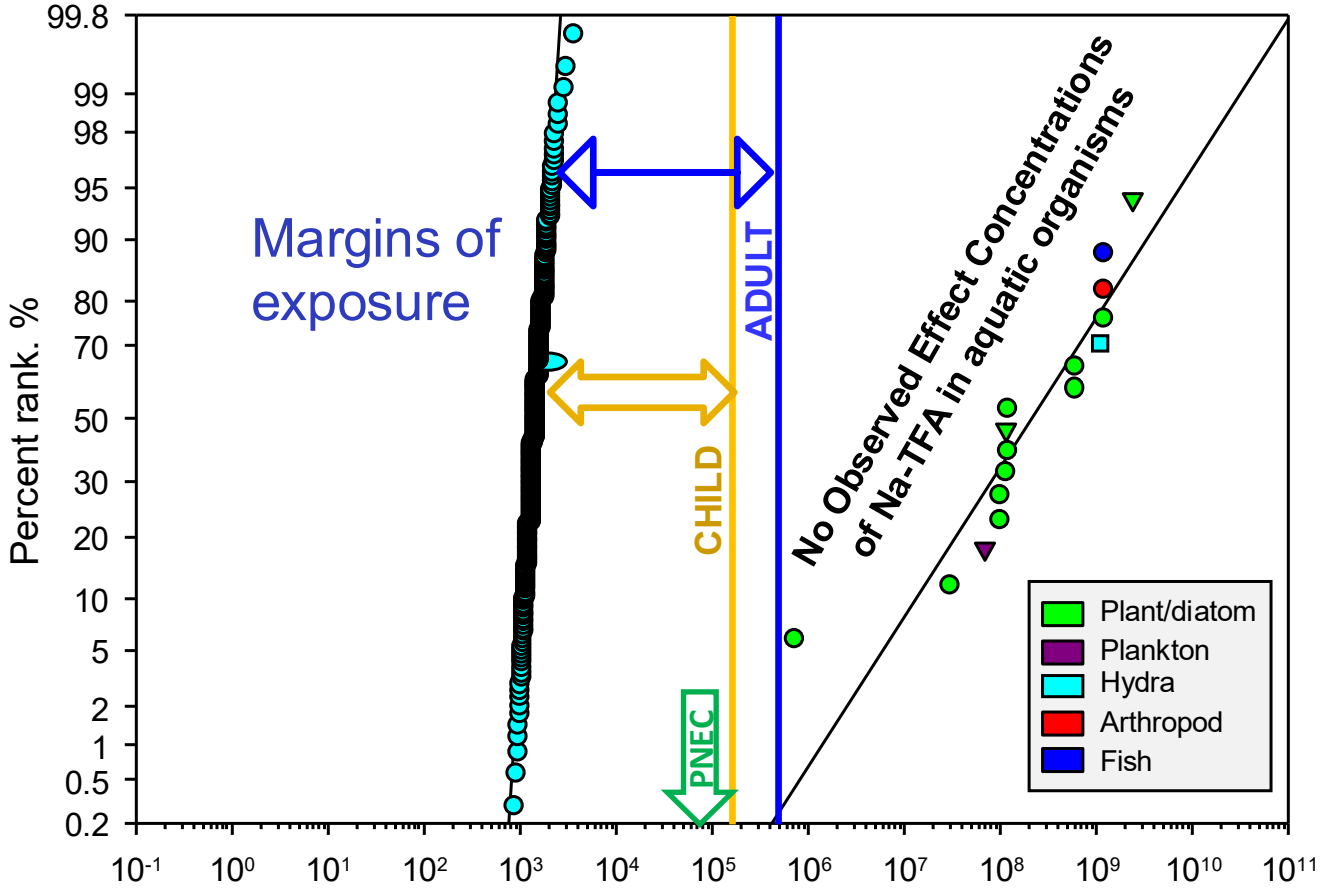



**Concentration of Na-TFA** in **surface water,** and **No Observed Effect Concentration (NOEC)** for **aquatic organisms**

NOEC, highest tested conc. where no effects were seen

## Overlap of the exposure lines with benchmarks or NOEC: risk

## No overlap: *de minimis* risk

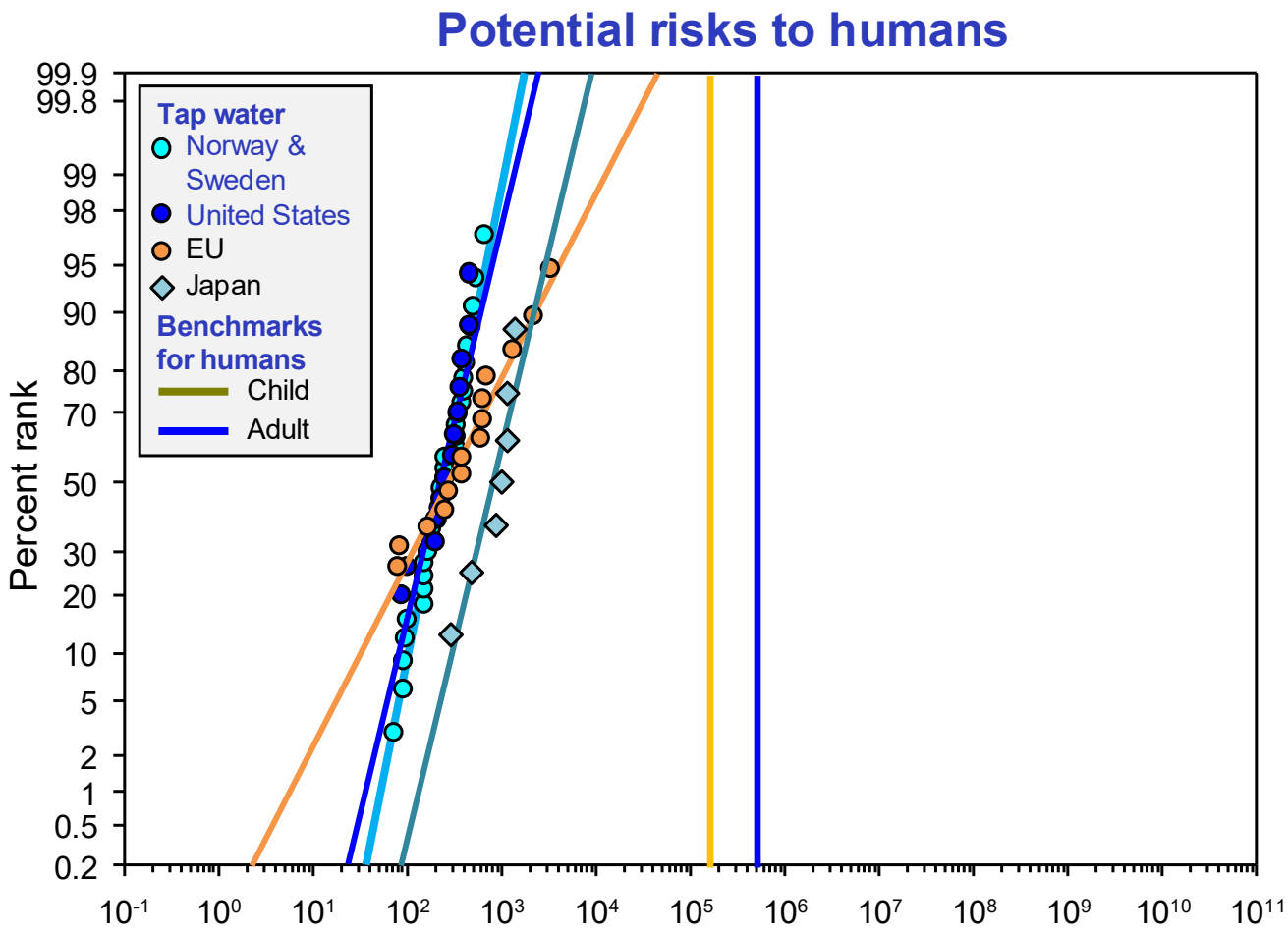



**Concentration of Na-TFA** in **surface water,** and **No Observed Effect Concentration (NOEC)** for **aquatic organisms**

**19 probalistic assessments were done, 2 are shown in the next slides**

# Probabilistic risk assessment - 1

**Benchmark**



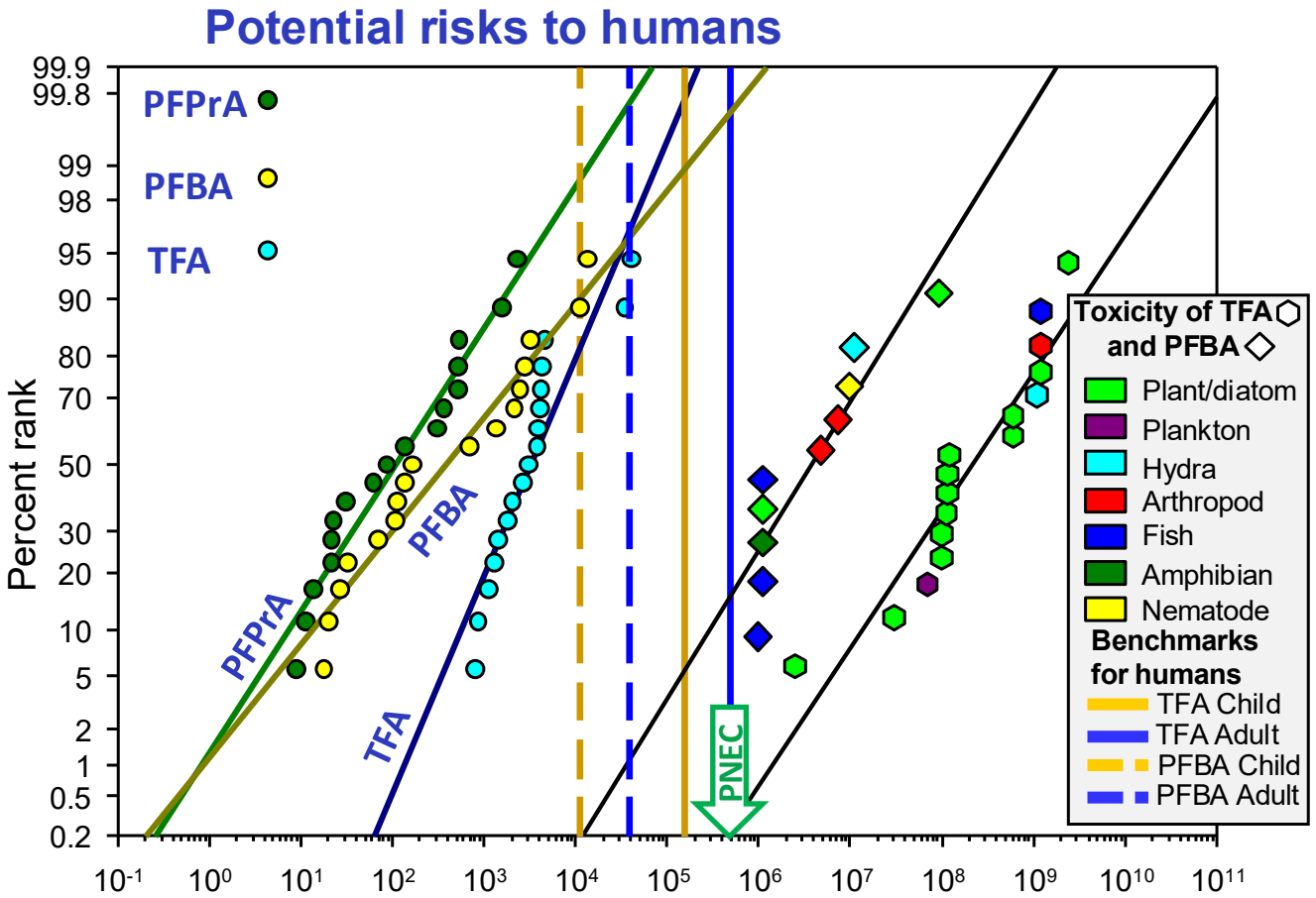

**Concentration of Na-TFA in tap water** from **Norway and Sweden, United States, EU, and Japan** (ng $L^{-1}$). N = 32, 15, 18, and 7, respectively

# Probabilistic risk assessment - 2

**Benchmarks**

PFBA, — — child
PFBA, — — adult

TFA, —— child
TFA, —— adult




**Concentration of Na-TFA, PFPrA, & PFBA in surface water** at a **fluorine chemical manufacturing site**, Fuxin, **China** (ng $L^{-1}$). N=17

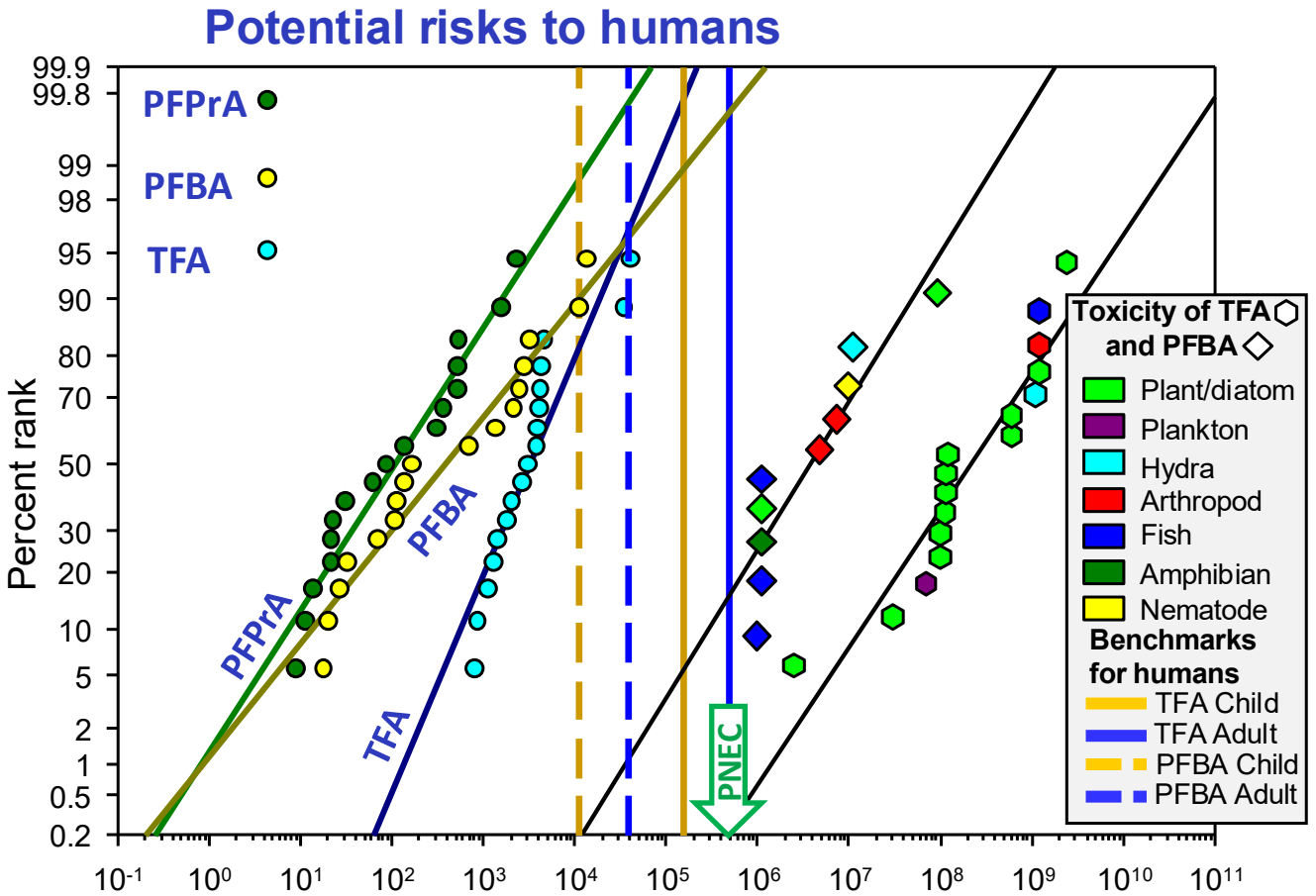
**Some of the concentrations were close to the human benchmarks**

# Probabilistic risk assessment - 2

**Benchmarks**

PFBA, — — child
PFBA, — — adult

TFA, ——— child
TFA, ——— adult




**Concentration of Na-TFA, PFPrA, & PFBA in surface water** at a **fluorine chemical manufacturing site**, Fuxin, **China** (ng $L^{-1}$). N=17

**Overlap of the exposure lines with benchmarks or NOEC: risk (likelihood)**

**No overlap: *de minimis* risk**

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## Stratospheric Aerosol Injection, SAI

**Potential environmental consequences**

Injecting aerosols into the stratosphere to reflect & scatter solar radiation to reduce global temperatures

EEAP evaluated selected SAI scenarios used in model studies to assess ecosystem impacts

**3 categories of scenarios**:

1) Peakshaving *vs* strong SAI scenarios

2) Geoengineering Modeling Intercomparisons SAI scenarios
   - based on moderate to large GHG forcing scenarios

3) Abrupt termination

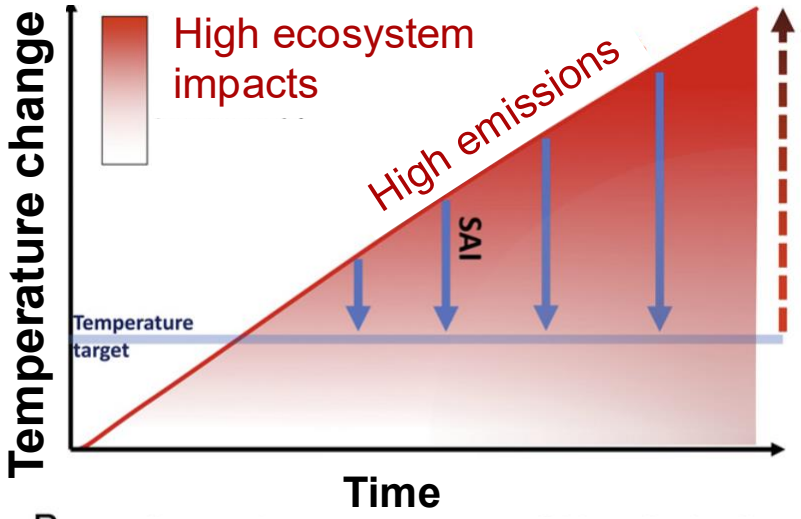
SAI may be a temporary approach to limit warming. However, it does not reverse trends in GHGs or $CO_2$-related ocean acidification)

Recent projections under existing government policy point to a median warming of 2.8°C above preindustrial levels by 2100 (*UNEP 2025 Emissions gap report 2025: Off target*)

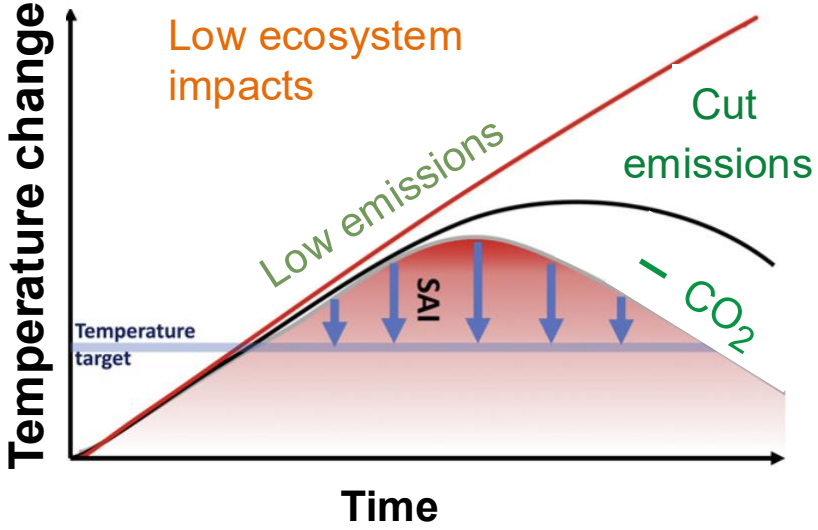
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## Stratospheric Aerosol Injection, SAI

A **No climate change mitigation + SAI**




B **Mitigation + SAI peakshaving**




**Potential temperature change under 2 SAI scenarios & environmental effects**

**A.** GLENS scenarios: **high GHG emissions** requiring large-scale SAI to reach a required temperature target

***Higher potential*** for ecosystem impacts (red shading), & for termination shocks

**B.** Peakshaving scenario: smaller SAI, slow phase-in, then phased out as $CO_2$ decreases

***Potential risk to ecosystems from SAI is lower*** (red shading)

*Figure adapted from Zarnetske et al. (2021). https://doi.org/10.1073/pnas.1921854118*

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## Stratospheric Aerosol Injection, SAI

### Challenges for assessing environmental effects under SAI

- A general lack of relevant ecological models to simulate SAI effects
- To date, projected **increased uptake in global carbon** over land & oceans compared to GHG warming & no SAI – studies show **increases in global productivity**, but also projected declines in some regions due to reduced precipitation under SAI
- Cooling at **low latitudes**: expect reduced thermal stress, enhanced photosynthesis
- Cooling at **high** latitudes: reduced photosynthesis
- **Sudden termination** *vs* controlled phase-down: rapid global warming would result in **>** 90% of terrestrial mammals not migrating fast enough to survive; **> > >** impact than climate change

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## 38th Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer

**Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change**




nasa.gov/climate-change/