How Do We Address the Global Threat of Irreversibly, Accumulating Trifluoroacetic Acid (TFA)?

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Introduction

Trifluoracetic acid (TFA) is a small, hydrophilic, non-degradable molecule that has been detected in diverse environmental media, from precipitation, surface water, groundwater, ice cores, air, soils and sediments to human serum and plant-based foods and drinking water [1]. TFA is irreversibly increasing across many environmental compartments, where it may cross a threshold concentration that will cause severe harm to ecosystems or human health. Here we present the case that TFA poses a planetary boundary threat.

Emissions of TFA from multiple sources are rapidly increasing

TFA is introduced into the environment from many sources. There are a vast number of potential PFAS precursors, including those used as Fluorinated Gases (F-gases), pesticides, pharmaceuticals and industrial substances. Certain destructive treatments for PFAS can be also be a source of TFA (e.g. oxidation, incineration, electrolysis). Significant emissions hotspots include AFFF contaminated sites and landfills) and fluorochemical production facilities. A notable precursor is the F-gas HFO-1234-yf, whose increased use was supported by the UN Montreal Protocol seeking replacements to ozone depleting chlorofluorocarbons (CFCs) and F-gases with a high global warming potential. It was projected that HFO-1234-yf in the EU-28 contributed 6902 t/year of TFA in the atmosphere in 2020, but by 2050 this will be 47650 t/ year [2]. In Germany, F-gases were estimated to emit ~ 2000 t/year, followed by pesticides at ~ 457 t/year and human pharmaceuticals at ~ 29 t/year [3]. Other emission sources have largely not been quantified yet, but they could be substantial.

Exposure is irreversible and widespread due to persistence and mobility in combination with increasing emissions

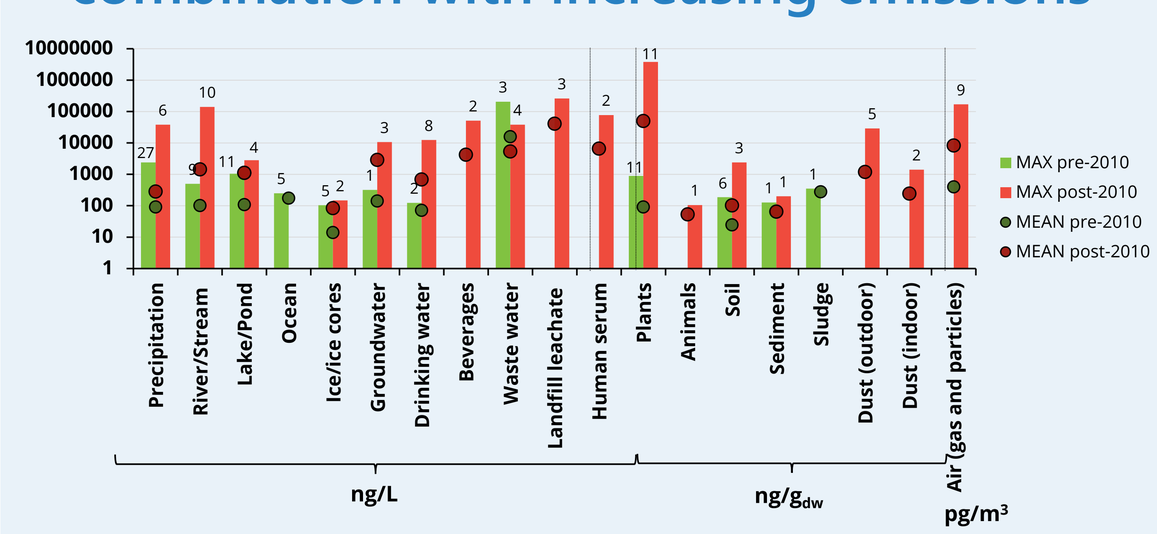


Figure 1. Pre- (green) and post-2010 (red) concentration trends in different media.
The numbers shown above bars correspond to the number of summarised individual data points.

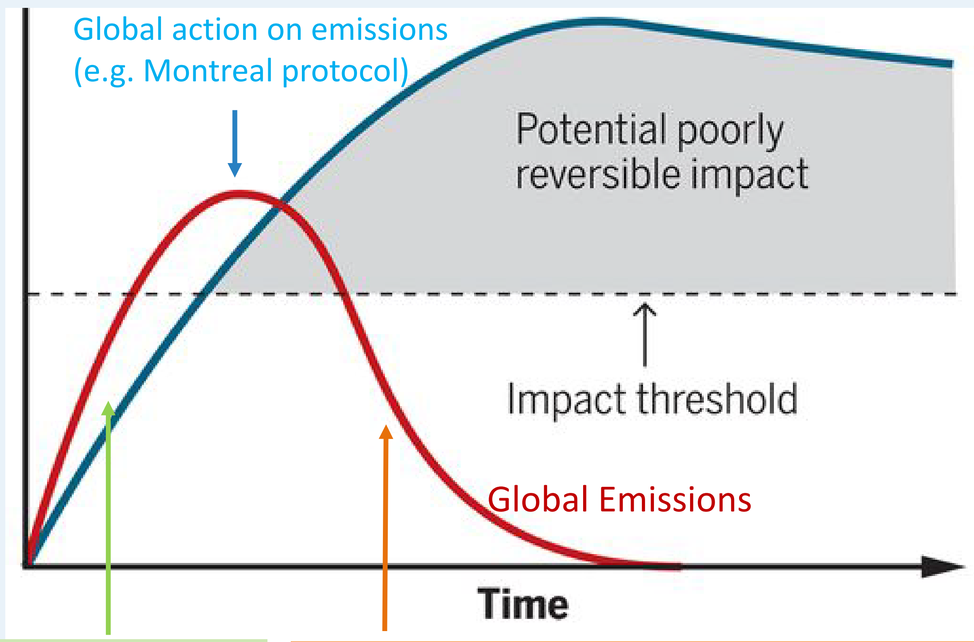
Pre- and post-2010 concentration trends in different media have increased by orders of magnitude in both maximum and mean concentrations (e.g. in precipitation, rivers and streams, groundwater and drinking water, soil and plants). While aquatic media was the main focus of monitoring studies dated pre-2010 (especially precipitation), more data from other media became available after this cut-off year – with new emerging media related to human exposure (e.g. beverages, crops, indoor and outdoor dust, human serum) and ecosystem exposures (e.g. animals such as locusts, autochthonous tree species) that were not available pre-2010 or were rarely measured (e.g. drinking water). There are still large monitoring gaps to trace this increased, irreversible exposure in different media.

Disruptive Effects on Earth System Processes

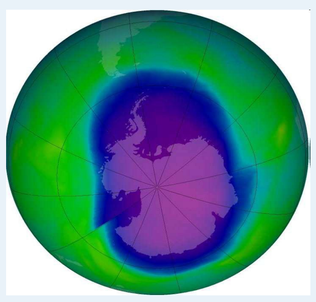
Known and unknown disruptive thresholds. TFA is accumulating in many ecosystems for which effect thresholds are unknown. Predicted No-Effect Concentrations (PNECs) that were derived for different local and regional environments span from 0.12 µg/L to 5.6 mg/L. Such effects data was based on 36 – 90 day chronic exposure studies, which are not representative for life-time exposure of TFA. Germany has submitted a dossier indicative of TFA's reproductive toxicity in humans [4]. Some studies have connected TFA presence in the atmosphere with its influence on aerosols and cloud formation, boosting the formation of atmospheric clusters [5]. As per Persson *et al*. [6], TFA meets the three criteria of a planetary boundary threat as it i) poses an (unknown) disruptive effect on vital Earth system process or global health of which we are ignorant, ii) the discovery of the effects would occur when the entity is distributed at a planetary scale, and iii) its impacts would be poorly reversible because the levels in the environment cannot be reduced (Figure 2).

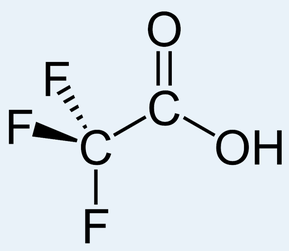
Figure 2. Example of CFC emissions and their poorly reversible impacts – a parallel with TFA
Figure adapted from MacLeod et al. [7]

Late lessons from early warnings: Emissions of persistent entities lead like CFC and TFA lead to increasing concentrations that are poorly reversible. When a planetary threshold is reached, that impact also becomes intergenerational. TFA should be considered a planetary boundary threat. Action should be taken to avoid TFA precursors now to avoid irreversible impacts in future, especially in underexplored ecosystems and processes



Global Concentration /Impact above a threshold (e.g. CFC, TFA)





CFCs pose "no conceivable hazard"
Lovelock J (1988). The Ages of Gaia: A Biography of Our Living Earth

"Environmental levels of TFA … do not pose a threat to the environment" (1999) [8]

CFCs pose "no conceivable toxic hazard"
Lovelock J (2000). Homage to Gaia: The Life of an Independent Scientist

Similar to CFC, once a global impact has been realized for TFA, reducing emissions at this point will not be able to reduce the impact.

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