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Editorial

Understanding the Earth system in the Anthropocene

1. The Anthropocene

The rising environmental challenges in contemporary society are alarming. From water scarcity, terrific groundwater loss, disappearance of large surface water bodies, and deforestation, to rise in global mean sea level, frequent devastating floods, droughts and wildfire events, the Earth system is experiencing series of transformations (e.g., Hugonnet et al., 2021; Tellman et al., 2021; Bierkens and Wada, 2019). The complexities and impacts associated with these chain of transformations will continue to grow, affecting human well-being and constraining the health of natural ecosystems. These transformations mark the end of the stable Holocene era, and a transition to the Anthropocene, a new geologic era characterized by increasingly large human footprints and impacts of climate change (e.g., Ndehedehe et al., 2023; Di Baldassarre et al., 2017). The frequency and magnitude of extreme climate events (e.g., droughts and floods) have intensified in the last century due to climate change (e.g., Cook et al., 2022), further triggering several deleterious impacts of climate change on modern-day human society. But we now live in a new dispensation, the Anthropocene where the plenitude of human activities (e.g., dam constructions, groundwater extraction, water transfer and harvesting, etc.) are predominantly important drivers of environmental change. These Anthropogenic footprints have increased over the last few decades, coalescing with climate change to further amplify the disturbance and instability of the earth system in the Anthropocene (e.g., Rounce et al., 2023; Chiang et al., 2020; Steffen et al., 2018). For instance, much of the groundwater depletion caused by over extraction will end up in the ocean, through runoff, and evaporation thus contributing to considerable rise in global sea level, which in turn leads to severe devastations (e.g., Bierkens and Wada, 2019).

2. How real is climate change?

The Antarctic ice sheet lost 2720 ± 1390 billion tonnes of ice, which correspond to a mean sea level rise of 7.6 ± 3.9 mm between 1992 and 2017 (IMBIE, 2018). In the last 20 years, global glaciers showed a mass loss that is 47% larger than that of the Greenland and Antarctic Ice Sheet (Hugonnet et al., 2021). By 2100, projected glacier mass loss will range from 26 ± 6% (+1.5 °C) to 41 ± 11% (+4 °C) due to increasing temperatures (Rounce et al., 2023). Apart from the loss of glaciers, rising temperatures caused by changes in the global climate system are increasing the duration, frequency, and severity of extreme events across several regions of the world (e.g., Ndehedehe et al., 2023; Cook et al., 2022; Hugonnet et al., 2021; Brito et al., 2018). Climate is indeed changing! This has being challenged nonetheless, and some have taken a different perspective on climate science, arguing that the concept of global warming is *underpinned by scientific fraud* (Plimer, 2017). But the continued ugliness and peril of climate change across several regions, which we have witnessed in our life time attest to its reality. For instance, the permanent lost of surface water in one of Africa's largest freshwater bodies, the Lake Chad due to prolonged drought in the early 1980s and other sundry impacts of unprecedented extreme drought events on large hydrological systems (e.g., Ndehedehe, 2022; Peterson et al., 2021) underscore the reality of climate change. Apart from drought, the awareness of society to the impacts of climate induced flood events is evident in the number of flood related social media tweets across the globe (de Bruijn et al., 2019). These tweets and other related social media posts facilitate our understanding of where these events are occurring on a near and/or real-time basis but much more, they remind us of the rapid changes in the Earth system in the Anthropocene. Every year, droughts continue to affect approximately 55 million people globally and between 2000 and 2015, about 290 million people across several regions of the world were direct recipients of devastating flood events (Schumacher et al., 2022; Tellman et al., 2021).

3. The human side of things

Human population is expected to reach over 10 billion by 2059, doubling population count from the 5 billion people reported in 1987 (UN, 2022). The rise in human population and urban centers will impact on biodiversity, forest ecosystems, land cover changes, coastal resources, and the environment generally (Laurance and Engert, 2022). Ecologically, these impacts include, loss of habitats for 30,393 species of terrestrial vertebrates moving into the future (2015–2050) (Simkin et al., 2022). The rise in human population will also translate to some challenges in agriculture, water use and rising energy demand. Increasing food production under a changing climate will require more freshwater (e.g. surface water and groundwater). Currently, more than 50% of the world's largest aquifers are under stress due to rapid declines in groundwater storage (e.g., Bierkens and Wada, 2019; Solander et al., 2017). These losses in groundwater are jeopardizing global food and water security and the sustainability of ecosystems, constraining human adaptation to climate change (e.g., Ndehedehe et al., 2023; Jasechko and Perrone, 2021). Satellite measurements of 227,386 water bodies between late 2018 and mid 2020 revealed that about 57% seasonal surface water storage variability occurred in human-managed reservoirs (Cooley et al., 2021). The near desiccation and disappearance of large freshwater bodies like the Lake Mead, Aral Sea, and Lake Chad are some evidence of climate change underpinned by human water management and the absence of contemporary best practice in guiding water management (Donchyts et al., 2016).

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4. Maintaining balance and pursuing justice and stability

The alterations of the Earth system are increasingly being driven by a plethora of anthropogenic activities. Together with climate change, they coalesce to regulate net contributions to sea level rise (Hugonnet et al., 2021; WCRP Group, 2018). The collective effort to change the trajectory of the Earth system in the Anthropocene from potentially damaging conditions to a more stable habitable state has been advocated (Steffen et al., 2018). The resilience of the Earth system is being challenged in the Anthropocene and changing this trajectory is thus crucial. This is because of the interconnection between the biosphere and the broader Earth system, which also includes the atmosphere and the climate system and the implications of such connectivity on human wellbeing and prosperity (Folke et al., 2021). Maintaining balance and pursuing a safe and just planet within the United Nation's Sustainable Development Goals-SDGs (https://sdgs.un.org/goals) is thus critical. As a sign of progress, the newly launched SDGSAT-1 satellite mission will accurately collect data on various human activities and provide data for various SDG indicators to support applications in climate related hazards and natural disasters, among several others (Guo et al., 2022). In terms of fixing the biodiversity decline problem, Obura et al. (2022) detailed six actions to achieving Earth system justice, including recommendations to *"reduce and reverse direct and indirect drivers causing decline"*. The assessment of Earth system planetary boundaries to ensure a safe and just planet is now receiving attention and from a perspective that acknowledges human well-being as a function of Earth system stability and resilience. The Earth Commission (https://earthcommission.org/) is pioneering this assessment underpinned by several working groups and partnerships with advocacy groups-science, business and philanthropy, among others (Rockström et al., 2021). In line with key strategic objectives that complement ongoing assessments by the Intergovernmental Panel on Climate Change, other reports (e.g., McKay et al., 2022; de Graaf et al., 2019; IMBIE, 2018), including those of Earth Commission have documented evidence suggesting that some of the thresholds for a healthy stable planet and people, e.g., for climate, water, aerosol, biosphere among others have already been crossed (https://earthcommission.org/publications/). For instance, thresholds for groundwater have been transgressed in intensively irrigated areas of the world. In these regions, groundwater pumping is unsustainable, exceeding recharge from rivers and rainfall, and environmental flow limits are expected to be reached for up to 79% watersheds by 2050 (de Graaf et al., 2019). Achieving resilience and stability of the Earth system where humans are substantially less vulnerable to risk is critical and will require that these thresholds and climate tipping points (McKay et al., 2022) are not exceeded further.

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