Report on definition of the Anthropocene.

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REPORT

The definition of the Anthropocene and its temporal arc is still under debate (Barbante *et al.*, 2017). The Anthropocene can be defined as the epoch where human activities are the dominant cause of most global environmental changes. Crutzen and Stoermer (2000) proposed that this epoch began with the Industrial Revolution and James Watt's 1784 refinement of the steam engine. The most common criticism of this point in time is the lack of a **"**golden spike**"** stratigraphic marker that is globally detectable in geological and environmental records and that can be used to mark the start of the epoch. Recently two scientific papers have tried to clarify this point by fixing exact starting dates. The first (Lewis and Maslin, 2015) proposed two start dates: 1610 which is consistent with changes in several environmental parameters, such as species movements and atmospheric CO_2 increase along with other auxiliary stratotypes, or 1964, which coincides with the ^{14}C peak from atmospheric nuclear tests that is detectable in several environmental archives. The second paper published by Ruddiman and co-workers (Ruddiman *et al.*, 2015) fixed the beginning of the Anthropocene on the 16th of July 1945, the date of the first atomic bomb test that took place at Alamogordo, New Mexico, USA. This data point was chosen because the isotopic fingerprint of the first nuclear detonation is detectable in several environmental archives in Mexico.

Many organic compounds are naturally produced, but mankind has developed and introduced an enormous array of new compounds into the environment, all of which can reach the Polar Regions. As mentioned above, it has been suggested that human activity really began to change the environment at the beginning of the 19th century (Crutzen and Stoermer, 2000) with the introduction and use of the steam engine. But the major part of man's influence on the global environment occurred during the **'**Great Acceleration**'** after 1950 (Lewis and Maslin, 2015). The **'**Great Acceleration**'** is identified as **"**a major expansion in human population, large changes in natural processes, and the development of novel materials from minerals to plastics and the presence of Persistent Organic Pollutants (POPs)**"**. The presence of POPs such as Polycyclic Aromatic Hydrocarbons (PAHs; Gabrieli *et al.*, 2010), Brominated Flame Retardants (BFRs; Hermanson *et al.*, 2010), and Organophosphate Pesticides (OPPs; Isaksson *et al.*, 2003) in Arctic ice cores, are clear markers of human activity, and shows just how widely these compounds can be dispersed in the environment.

Analyses of POPs from ice cores collected in Polar Regions are rare. The large amount of sample required limited measurements of these compounds to surface snow or dedicated shallow ice cores. However, high-resolution (at least annual resolution) analyses of these compounds in the snowpack can improve our understanding of anthropogenic contamination processes in Polar Regions. Since most POPs exist in nature at very low concentration, their presence in the Polar Regions is closely linked to anthropogenic contamination. Very few studies on their presence in ice cores from the Arctic exist. A study by Isaksson *et al.* (2003) reports the determination of Naphthalene in the Lomonosovfonna ice core (Svalbard Islands, Norway) where they detected a steady increase from the 1940s to the 1970s with a sharp doubling in concentrations from 10 ng kg^{-1} to 20 ng kg^{-1} in only 10 years up to the 1980s, where concentrations peaked at 50 ng kg^{-1}. Although the temporal resolution was low, these results showed that even Naphthalene and other PAHs can reach the Svalbard archipelago and other Polar Regions and have done increasingly so from the 1940s onwards.

Analyses of POPs in Antarctica are also rare. A study conducted by Giannarelli *et al.* (2017) on a dedicated ice core collected at the coastal site of GV7 (Victoria Land, Antarctica), showed the presence of POPs in the Antarctic atmosphere over the last century. These results confirmed the diffusion of these chemicals to a continent considered one of the most uncontaminated in the world. Relevant concentrations of Polychlorinated biphenyls (PCBs) were detected in the ice core in sections connected with the years of their industrial production (1930 - 1990), showing the effectiveness of long distance transport processes of these compounds that enable them to even reach the most remote areas. Although the temporal resolution of the study was approximately 5 years/sample, they clearly showed an increase in pollutants after 1970. The results presented by Giannarelli *et al.* (2017) agreed with those from a previous study conducted at the coastal site of Talos Dome (Victoria Land), by Fuoco *et al.* (2012), showing a similar PAH profile. Both studies were done on samples from high accumulation coastal Antarctic sites (Talos Dome, at 300 km from the coastline and GV7 at approximately 150 km from the coastline).

Within the Antarctic continent, Dome C is one of the most remote drilling sites, it is located approximately at 1000 km from the coastline and at 3300 m a.s.l. Thus, the Dome C site can be considered a unique and pristine site since the distance from any anthropogenic source (except for the research station built after 1996), means it is representative of the average atmospheric background composition.

The main aim of our study within iCUPE was to evaluate the presence of PAHs and OCPs (Organochlorine Pesticides) in this unique remote site. Although the temporal resolution obtained from the shallow core analysed is lower than those presented by Giannarelli *et al.* (2017) and Fuoco *et al.* (2012), since the snow accumulation in Dome C is one order of magnitude lower that of GV7 and 30% of Talos Dome, our results clearly show an increase of PAHs (in particular for the Benzo[k]fluoranthene - BKF) since the 1950s, while the increase in OCPs is less evident, and will not be further discussed in this report.

The increase in BKF in the Dome C ice core suggests that the introduction of this compound by human activities has had a wider distribution than expected, with its presence determined in one of the most remote places on the Earth. The definition and identification of a precise "golden spike" based on PAHs would require a denser dataset than currently available, that would include other sites in Polar Regions as well as from glaciers in the mid-latitudes. For this reason, it is not our aim to propose a new golden spike based on PAH data, but to contribute with our results in support of a date that has already been proposed.

Indeed, the Dome C PAH dataset supports the idea proposed by Ruddiman *et al.* (2015), where the beginning of the Anthropocene was set on the 16th of July 1945, the date of the first atomic bomb test that took place at Alamogordo. Although our approach is different to that of Ruddiman and co-workers, and we are using different markers (anthropogenic organic contaminants instead of radionuclides), our results point in the same direction. In other words, there is a clearly detectable human signal widely dispersed on a global scale that begins in the 1950s.

The results present in the literature, as well as those produced within iCUPE, show some limitations to the use of the PAHs as a definitive marker for "setting the beginning of the Anthropocene". Giannarelli *et al.* (2017) suggested an increase in the 1970s, Isaksson *et al.* (2003) determined a sharp increase in the 1980s, while our results show a significant increase after 1950. We should consider that the PAH concentrations in polar ice depend on the location of the sampling site, and whether or not it is affected by air mass transport from industrial areas, or specific industrialised countries. The Dome C PAH record on the other hand minimises variability connected to regional scale transport due to its remoteness and gives us a better view of global contamination.

The data discussed in this report and produced within iCUPE suggest that PAHs can be considered in the future as another marker that can better constrain the definition of the beginning of the Anthropocene. However, two main points should be keep in mind during future studies using this approach: 1) dedicated ice cores with increased temporal resolution in the data are needed to define the periods of rising concentration; 2) local or regional differences in PAH concentrations, and in particular the timing of their concentration rise due to human activities, should be considered limiting factors in their possible use as precise marker for the beginning of the Anthropocene epoch.

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