SOAR: Southern Ocean Atmospheric Radiocarbon – the world's longest direct atmospheric trace gas record

Our Wellington record of radiocarbon in carbon dioxide ($\Delta^{14}CO_2$) is a collaboration between GNS Science and NIWA and we have been making measurements since 1954. This makes it the longest direct atmospheric trace gas record worldwide, predating CO_2 concentration measurements by several years. In 1957, Athol Rafter gave a speech describing the consequences of expected global warming, and how the Wellington $\Delta^{14}CO_2$ measurements could help to understand climate change – all this before the more well-known Keeling Curve CO_2 concentration measurements had even started in the Northern Hemisphere. Those early $\Delta^{14}CO_2$ measurements were also some of the first evidence for the consequences of atmospheric nuclear weapons testing, which culminated in a near-doubling of atmospheric $\Delta^{14}CO_2$ in the early 1960s.

Those early measurements began at the Nuclear Sciences facility in Lower Hutt under DSIR, and have continued in the CRI era, supported by both GNS and NIWA SSIF funding, the former through the Global Change Through Time (GCT) programme.

In the 1960s and 1970s, the Wellington dataset was complemented by measurements at Scott Base, Antarctica; Campbell Island in the subantarctic; and several Pacific locations, most of which were discontinued as the threat of nuclear weapons testing abated. Since 2016, we have restarted measurements at Scott Base, taken over measurements at Macquarie Island in the subantarctic, and established new measurements from ships of opportunity traversing the Southern Ocean. These new measurements have been funded by GNS SSIF (GCT), the Marsden Fund, the Deep South National Science Challenge, and the Antarctic Science Platform, along with support from CSIRO Australia, the Royal New Zealand Navy, Sanford fishing company and Heritage Expeditions.

Rafter's early speech was prescient, and the Wellington $\Delta^{14}CO_2$ record has been critical in an astonishing array of research fields, cited directly and indirectly in the scientific literature more than 1,000 times. It is critical to the radiocarbon dating of recent "post-bomb" (since the 1960s) materials, which can be determined to within a single year by comparing with atmospheric records from the appropriate part of the world. The Wellington record is the primary Southern Hemisphere record. Such measurements are used to determine the age of fishes, the age of maturity of paua, catch illegal ivory trade banned under the CITES agreement, establish the age and growth rate of trees, determine the timing and frequency of earthquake and landslide events, ascertain whether toilet paper is made from old growth trees or short-lived plants, and find the age or time of death of individual humans and animals. Yet these applications are only the tip of the iceberg, and these measurements are most vitally used in understanding how carbon moves within the Earth System, from fossil fuel CO_2 emissions into the atmosphere, and cycling through the oceans and land biosphere.

Comparing the bomb peak at Wellington and Northern Hemisphere sites shows that it takes a little over a year for air to mix between the hemispheres. The decline from the bomb peak documents the rate of uptake of CO_2 into the oceans and land biosphere, and by comparing with the $\Delta^{14}C$ content of soil carbon, is used to examine the stability of carbon locked (or not) into soils as our climate changes, and test for the amplification of climate change through destabilisation of soil carbon. Our expanded Southern Ocean measurements are being used to track the rate of uptake of carbon into the Southern Ocean, which is the world's most important carbon "sink", but whose capacity to take up carbon may reduce as climate changes over the Southern Ocean. Perhaps most famously, $\Delta^{14}CO_2$ measurements are used in Aotearoa and around the world to pinpoint how much CO_2 is being emitted by fossil fuel combustion, taking advantage of the extreme age of fossil fuels that means they contain zero

radiocarbon. The Wellington record is the backbone with which we must compare every other Aotearoa measurement to establish the local emission rate.

This special dataset is highlighted in the most recent IPCC report, used by researchers in Aotearoa and worldwide, and underpins a range of scientific advice to government and industry. The measurements have survived the many changes of staff, organisational changes, and countless technical improvements over the last 70 years. It is a shining example of the vital role for public good science services.