Scientific Service Group

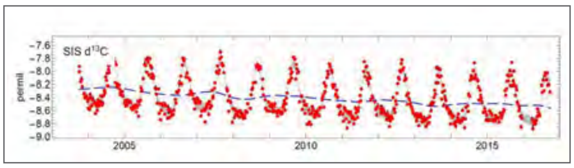
Stable Isotope Laboratory

The Stable Isotope Laboratory (BGC IsoLab) is a highly specialised laboratory analysing stable isotope ratio variations in air, soil, water, and plant material. Traditionally, stable isotope ratios are analysed using isotope ratio mass spectrometry. Samples need to be converted into pure gases, such as CO_2, N_2, H_2 or O_2, requiring a careful chemical conversion and separation. These sample gases are first ionised, and subsequently the different isotopic species (isotopologues, e.g. $^{12}CO_2$ and $^{13}CO_2$) are collected in specific detectors where the ratio of the different ion currents is recorded. The same procedure is applied to a reference gas and a standard, both with known isotopic composition. On this basis, a very precise comparision is made allowing for accurate isotopic characterisation of a sample.

Application of stable isotope systems

Isotopes are atoms of the same element with the same number of electrons and protons but different numbers of neutrons. For example, carbon has two stable isotopes, ^{12}C and ^{13}C, with natural abundances of 98.9 % and 1.1 %, respectively. A third isotope ^{14}C is radioactive (half-life: ~ 5730 years), has an abundance of $\sim 10^{-12}$, and is used for radiocarbon dating. The extra neutron in the heavy isotope leads to a very small weight difference between the lighter (^{12}C) and heavier (^{13}C) isotope. The incorporation of different isotopes into molecules, e.g. $^{12}CO_2$ and $^{13}CO_2$, causes molecules to have slightly different weights, which in turn affects their reactivity in biogeochemical and physical processes.

Photosynthesis is a good example. Using sunlight, photosynthesising organisms convert CO_2 and water into organic matter. During this process, the catalysing enzymes preferentially use the isotopically light $^{12}CO_2$, rather than the heavier $^{13}CO_2$. Therefore the produced organic matter has less ^{13}C than the air CO_2, which is enriched in the heavier isotope. While the resulting variations are extremely small, they are highly significant and robust over time. All fossil fuels have been generated by photosynthesis in the distant past. Therefore, the combustion of oil, coal and natural gas leads to an addition of isotopically light (^{12}C containing) CO_2 to the atmosphere. We can analyse this long-term addition of isotopically light CO_2 to the atmosphere and relate it to anthropogenic activity. We also observe annual variability which is correlated to the growth of plants during spring/summer (uptake of $^{12}CO_2$) and the biodegradation of organic matter during autumn/winter (release of $^{12}CO_2$).



Long-term (2003 – 2017) $\delta^{13}C$ measurements of CO_2 in air (red dots) on the Shetland Islands. Annual variability (grey line) is explained by seasonally variable photosynthesis. The long term trend (blue line) is explained by anthropogenic fossil fuel burning. (Prof M. Heimann, unpublished data)

Two MAT 252 (Thermo Finnigan) isotope ratio mass spectrometers (IRMS) coupled to homemade BGC-Air Traps, that separate CO_2 from the other air components. These two systems are used for $\delta^{13}C$ and $\delta^{18}O$ analyses of CO_2 in air, and the production of JRAS-06 CO_2-in-air reference standards. Photo: H. Moossen

Climate of the past

Isotopic signatures of organic molecules found in Earth's geological archives (sediments, soils, oil, ice cores) can also be used to reconstruct past climate change. The water that plants use for photosynthesis is ultimately derived from atmospheric moisture and the resultant rain. The hydrogen isotopic composition of the water depends on a number of factors including, but not limited to temperature, altitude, and amount of rain. Changes in the hydrological cycle affect the isotopic signature of the water that plants use to produce organic matter, and the plant organic matter subsequently records these changes.

The hydrogen isotopic signature of higher plant-derived organic matter (e.g. *n*-alkanes), that is found in





marine/lacustrine sediments, can therefore be used to study palaeohydrological changes.

Isotopes in the hydrological cycle

The BGC IsoLab is specialised in analysing the $^{13}C/^{18}O$ and the $^{13}C/^{2}H$ isotopic signatures of CO_2 and CH_4 in atmospheric samples. It has developed a standard based on carboantes for the analyses of isotopes of CO_2 in air. This “Jena Reference Air Set” is used by international laboratories to standardise their CO_2 measurements. The BGC-IsoLab acts as central calibration laboratory for the Global Atmospheric Watch community since 2010 and has been measuring isotopic ratios of CO_2 and CH_4 since 2002 and 2012, respectively, from samples coming from all over the world. Such long term records of gases relevant to climate change enable scientists to better study anthropogenic and natural climate change with its impact on humans and the natural environment.

Dual inlet sector field mass spectrometer (MAT 253) for high-precision analyses of pure CO_2 gas. Photo: S. Héjja

Atmospheric O_2 concentration change.

In addition to these direct stable isotope observations, we use the same technology to measure present day O_2 concentrations with very high precision. The well known, human driven increase in CO_2 is accompanied by a (less well publicised) decline of O_2 in the atmosphere in a complementary fashion. For every fossil fuel carbon combusted to CO_2, one molecule of O_2 is removed from the atmosphere. Hence, there is a stoichiometric relationship. However, the change of the atmospheric O_2 concentration happens against a much larger background (O_2 has a concentration of ~21 % in air, CO_2 only ~0.04%). Therefore, making these measurements at the required levels of precision and accuracy is a challenge, which we have mastered successfully by developing our own equipment and designing our own sample handling and calibration protocols. By studying the record of both, CO_2 and O_2, we get a deeper insight into the carbon cycle which we would not be able to get by studying CO_2 alone.

Flask autosampler on the BGC-Air trap. Here athmospheric samples from sampling stations situated all over the world are analysed. Photo: A. Schroll

Portrait of the Group Leader

Heiko Moossen has managed the BGC IsoLab since April 2016. He studied chemistry at the Carl von Ossietzky University in Oldenburg (Germany). Subsequently he moved to the University of Glasgow (UK), to investigate Holocene North Atlantic climate change as part of his PhD. He then worked at the University of Birmingham (UK) where he was integral to the setup of the organic geochemical laboratory and its analytical equipment. His main interest is centered on the application and development of stable isotopes for palaeoclimate reconstructions.

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