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A gut-wrenching climate archive: What the stomach content of an Antarctic bird can tell us about past climate

Thale Damm-Johnsen and Ellie Honan

Picture a vast white, frozen desert reaching as far as the eye can see. It is summer and the sun is out, but the icy wind blowing towards you still makes your nose numb and your eyelashes freeze. In the far distance you see a mountain range protruding from the endless white, like spikes poking holes in a blanket.

Out of the corner of your eye you see something moving across the sky towards the mountains: a white bird, about the size of a pigeon, that almost completely blends in with its surroundings. It gives out a faint cry, as if to say hello, and gracefully disappears into the white.

You are standing on the Antarctic Ice Sheet*: a huge mass of tiny ice crystals, sustained by the cold temperatures to form one gigantic mass of ice. The bird you got a glimpse of was a snow petrel, one of the few birds that live and thrive in the Antarctic all year round (see Fig. 1 and 2). The snow petrel was heading home to its nest among the crevices of Antarctica's nunataks, the exposed rock surfaces that protrude above the ice sheet (see Fig. 2, 3, and 4). Every austral summer (December–February), the snow petrels return from the ocean to incubate and raise their chicks.

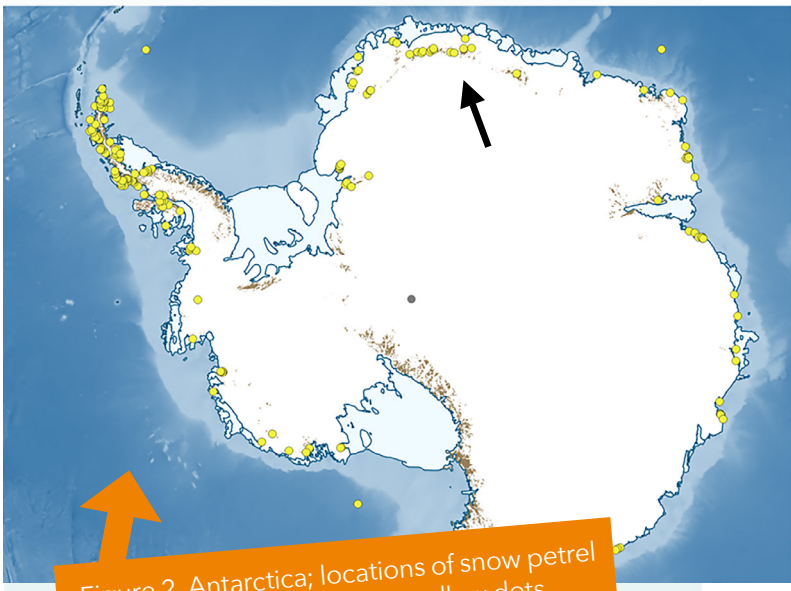

Figure 2. Antarctica; locations of snow petrel colonies are represented by yellow dots. The arrow points to where the stomach-oil deposit displayed in Figure 8 was collected.

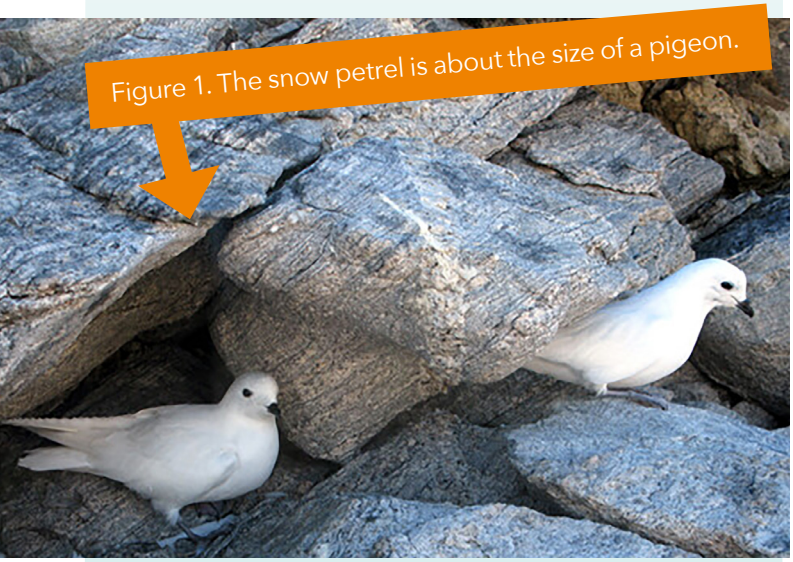

Figure 1. The snow petrel is about the size of a pigeon.

Snow petrel chicks hatch as small balls of grey fluff, reliant on their parents for food and occasional warmth during the first months of their life (see Fig. 5). The warmth is truly only occasional, as the parents regularly leave the chicks for several days at a time to find food at sea. However, despite their winsome appearance, the chicks are anything but defenseless.

Figure 3. Nunataks sticking up out of the inland ice. Photo taken by Ellie Honan in the Sør Rondane mountains.

Figure 4. A snow petrel in its nest, covered by dripping stomach oil deposit.

But let's back up a second. What makes a bird like the snow petrel want to live in the hostile cold of Antarctica in the first place? The answer doesn't lie in the ice sheet itself, but in the waters just offshore (see Fig. 6). The annual cycle of freezing ocean water in winter (when the temperature drops to –2 degrees Celsius or 28 degrees Fahrenheit) and melting of the sea ice in summer forms the foundation of one of the most fertile waters on the planet. In winter, tiny holes in the sea ice serve as the home and breeding ground of small organisms called sea-ice* algae. During spring, the ice melts and the algae are released into the water where they become a vital meal for krill, a small crustacean about the size of your little finger. The krill form the base of the food chain for the larger organisms in the Southern Ocean, from the tiniest fish, to birds like the snow petrel, and true giants like the blue whale.

Figure 5. A snow petrel chick: i.e. a grey ball of fluff.

Figure 6. Snow petrels commute from their nests on land out to the sea ice to hunt for food. This photo shows snow petrels at the edge of the big ice sheet covering Antarctica, where the sea ice begins.

The snow petrel feeds at the edge of the sea ice and in rare openings within the sea-ice pack; they live primarily off of fish and krill that are found in the upper meters of the water column. These nutrient-rich foods serve as the snow petrels' main energy source needed for them to be able to grow and survive in the extreme cold throughout the year. During the summer, they convert the fat-rich fish and krill to an oil that they store in a small organ located just above their stomach. The organ is linked to the stomach, but storing the oil in this organ instead of the stomach allows them to hold onto all the energy and fat from their prey. They are thereby able to save the bright orange oil, allowing the snow petrel parents to provide their chick with the nutrients they need to grow. When the snow petrels return to the nest, they can regurgitate this oil easily into the chick's beak.

However, don't be fooled by the innocent expression of the snow petrel! If a predatory bird (like a skua) or an unfortunate researcher gets too close, the snow petrels will defend themselves in a particularly smelly way: they spit with impressive force at the intruder. But unlike us (and llamas), they

Figure 7. Both young and old snow petrels can protect themselves from big skuas by regurgitating stomach oil.

don't use saliva: instead, they spit their stomach oils (see Fig. 7). Beside smelling strongly of half-digested seafood, the stomach oil clings to the feathers of the attacker. A coating of oil makes the predator's feathers less waterproof, affecting its ability to keep itself warm and weighing the bird down as it becomes waterlogged. In Antarctica, a lack of insulation and the inability to fly can mean death for oily birds.

Figure 8. Stomach oil deposit back in the lab ready for analysis. The stomach oil deposit is sliced in three sections to reveal the inner stratigraphy.

Luckily for science, some of this stomach oil never makes it onto the intruder but lands in the vicinity of the bird's nest, settling among the rocks of the crevices where they nest. As snow petrels return to the same nest site year after year, the stomach contents slowly but steadily solidify and accumulate into grey-brown layers that we call stomach-oil deposits (see Fig. 8). The largest one found so far by humans is 90 cm thick—just imagine the generations of snow petrels needed to make this deposit!

The freezing, desert-like climate of Antarctica helps to preserve these stomach-oil deposits, which record the signal of the snow petrels' diet through time. The bottom layer of the deposits is the oldest and gets younger upwards, either gradually or in leaps, depending on how often the snow petrels returned to this exact nesting spot. Antarctic climate scientistic have dated some of these deposits to be almost 60,000 years old! We know that climate has changed quite a lot over the past 60,000 years, so we bring these deposits all the way back from Antarctica and into the lab to perform a chemical analysis on the deposit. This allows us to study how the snow petrel diet might have changed in response to changing climate through the time the deposit was accumulating.

Performing this analysis on samples from the deposits is an intricate process, with many steps necessary before scientists can read the signal from the stomach oils. However, the reward is high, as we can detect tiny chemical fossils known as biomarkers that give us a direct indication of what the birds ate. The biomarkers are invisible to the naked eye, and specific to different organisms. You and I, the apple you had for lunch, and the fish that swim in the sea all have different biomarkers. Which biomarkers are found in an organism is partly dependent on the environment the organism lives in. For example, the temperature, the amount of rain, and whether it lives in water or on land all affect the type of biomarkers that we find. But the biomarker content is also dependent on what an organism consumes. Therefore, you can expect your own

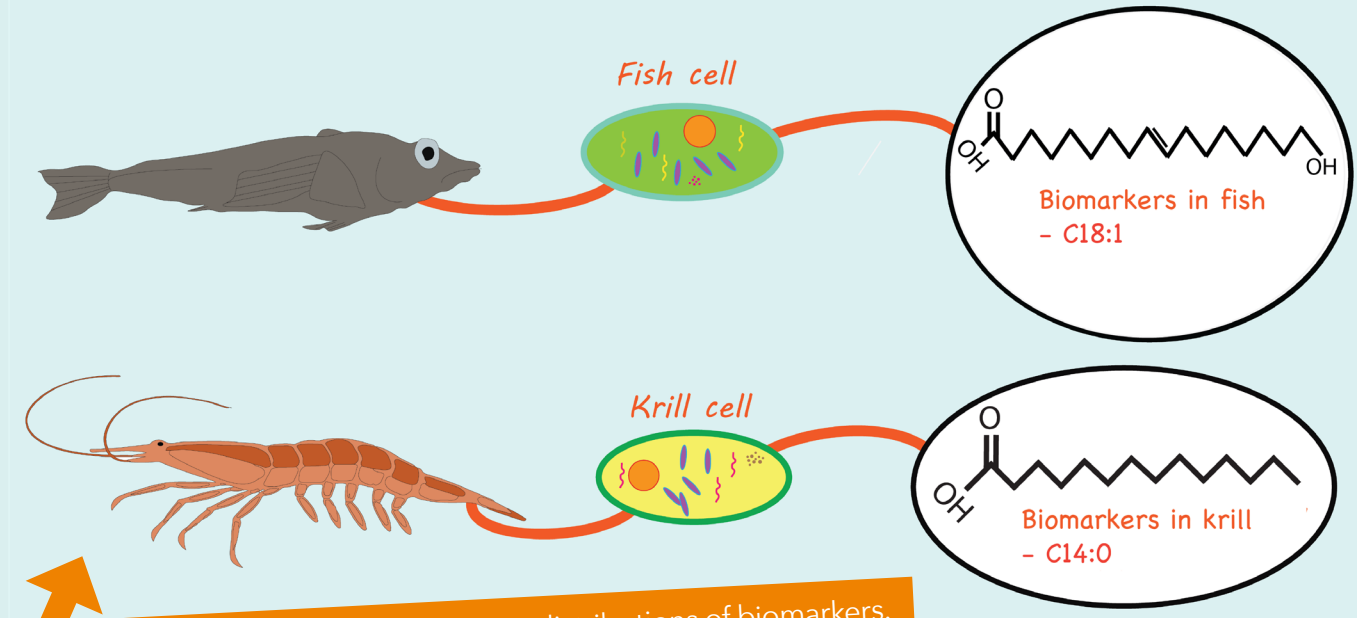

Figure 9. Fish and krill contain different distributions of biomarkers.

biomarker content to be affected by the apple you ate, and that your biomarker content would change if you ate a piece of bread instead. The same principle applies to the snow petrel. Based on modern observations, the birds have a dominant diet of either krill or fish, depending on how close to the shores of Antarctica they collect their food (see Fig. 9).

Close to Antarctica, the ocean gets shallower, and the sea surface temperatures are colder. Even in summer the surface of the ocean is below zero degrees Celsius (32°F), and the ocean is shielded from the atmosphere by a layer of sea ice. As snow petrels cannot penetrate the sea ice to feed, they must travel offshore to where there is less dense sea ice and the ocean surface is exposed (see Fig. 10). This means that how far out the summer sea ice stretches from the Antarctic coast affects where food is available for the snow petrel. However, as the petrels are restricted to breeding on land, if the sea-ice edge is too long a commute during the period where adult snow petrels are taking care of their chicks, it is thought that they may take advantage of openings within the sea ice, called polynyas.

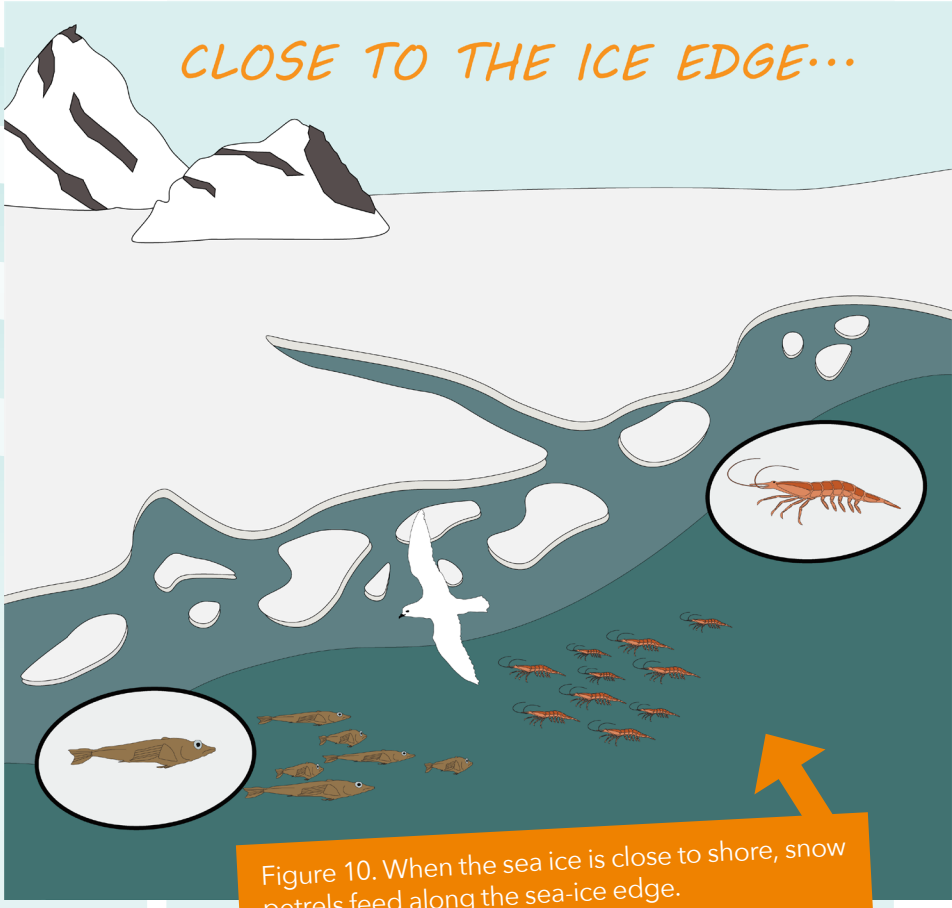

Figure 10. When the sea ice is close to shore, snow petrels feed along the sea-ice edge.

Polynyas situated close to the coast are usually formed by winds blowing over the land toward the ocean that push the newly formed

Figure 11. When the sea ice edge is far from land, it is hypothesized that they feed in openings within the sea ice that form during winter when winds are stronger.

sea ice further away from the coast, leaving the surface ocean and the fish and krill living there exposed for the snow petrels to feed on (Fig. 11). This affects both their diet and the environment where the snow petrels feed, thus affecting the biomarkers of the snow petrels' stomach oils. Therefore, the stomach-oil deposits give us indirect insight into how the sea-ice extent has evolved parallel to a changing climate, and how sea ice and climate affected the diet of the snow petrels.

Sea ice is a difficult environment to measure and model, so we still have lots to learn about how it reacts to climate change. Records of the past, like the stomach-oil deposit, will provide a new perspective on an aspect of the climate system that we know very little about. This knowledge can further be used to improve our best guess for how climate may change in the future, which we sorely need if we want to decipher how our climate will react to enhanced CO_2 emissions. However, as no one has looked into these deposits in a systematic way before, we are not yet completely sure what we are going to find—but that's the thrill about being a climate scientist, entering the unknown!

Back on the white ice you stare into the endless white horizon. You can't see it, but in the far distance is the ocean, partly covered by a shifting blanket of ice. The wind howls around you, but inside your hood and thick snow suit it's warm and cozy.

Another faint cry floats through the wind, and you look up to see the white silhouette of a snow petrel soaring over the sky above you. Perhaps it has delivered its fat-rich stomach contents to its chicks, assuring the survival of the next generation, and is on its way out for new rations.

The nature of these tenacious birds, who fly hundreds of kilometers across the ice in order to access their food and raise their chicks, is extraordinary on its own, and can perhaps help us climate scientists solve the still mysterious climate puzzle of how the southern polar regions will react to climate change.

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