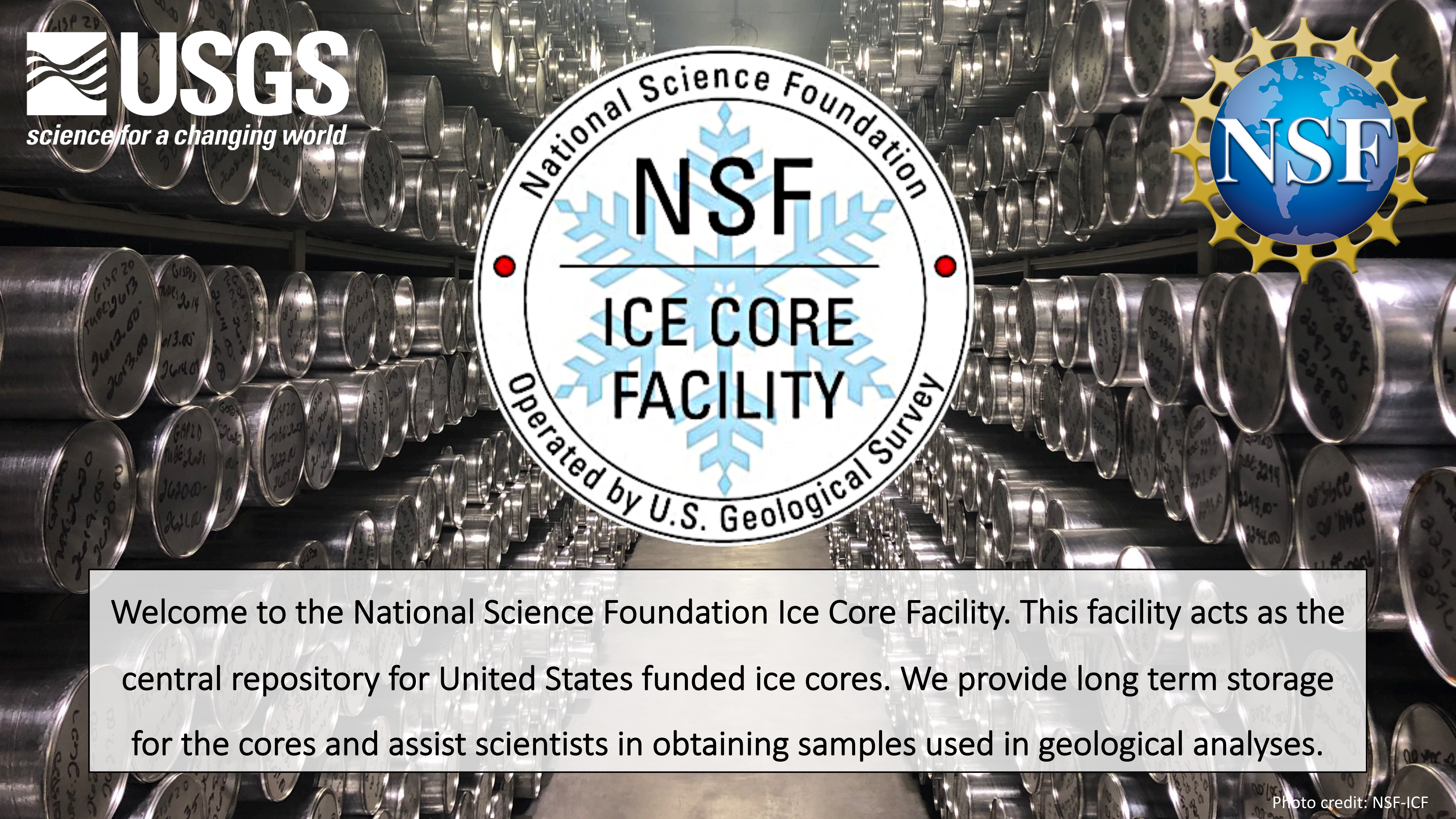
USGS
science for a changing world

National Science Foundation

NSF ICE CORE FACILITY

Operated by U.S. Geological Survey

NSF



Welcome to the National Science Foundation Ice Core Facility. This facility acts as the central repository for United States funded ice cores. We provide long term storage for the cores and assist scientists in obtaining samples used in geological analyses.

Photo credit: NSF-ICF

FUN FACTS!

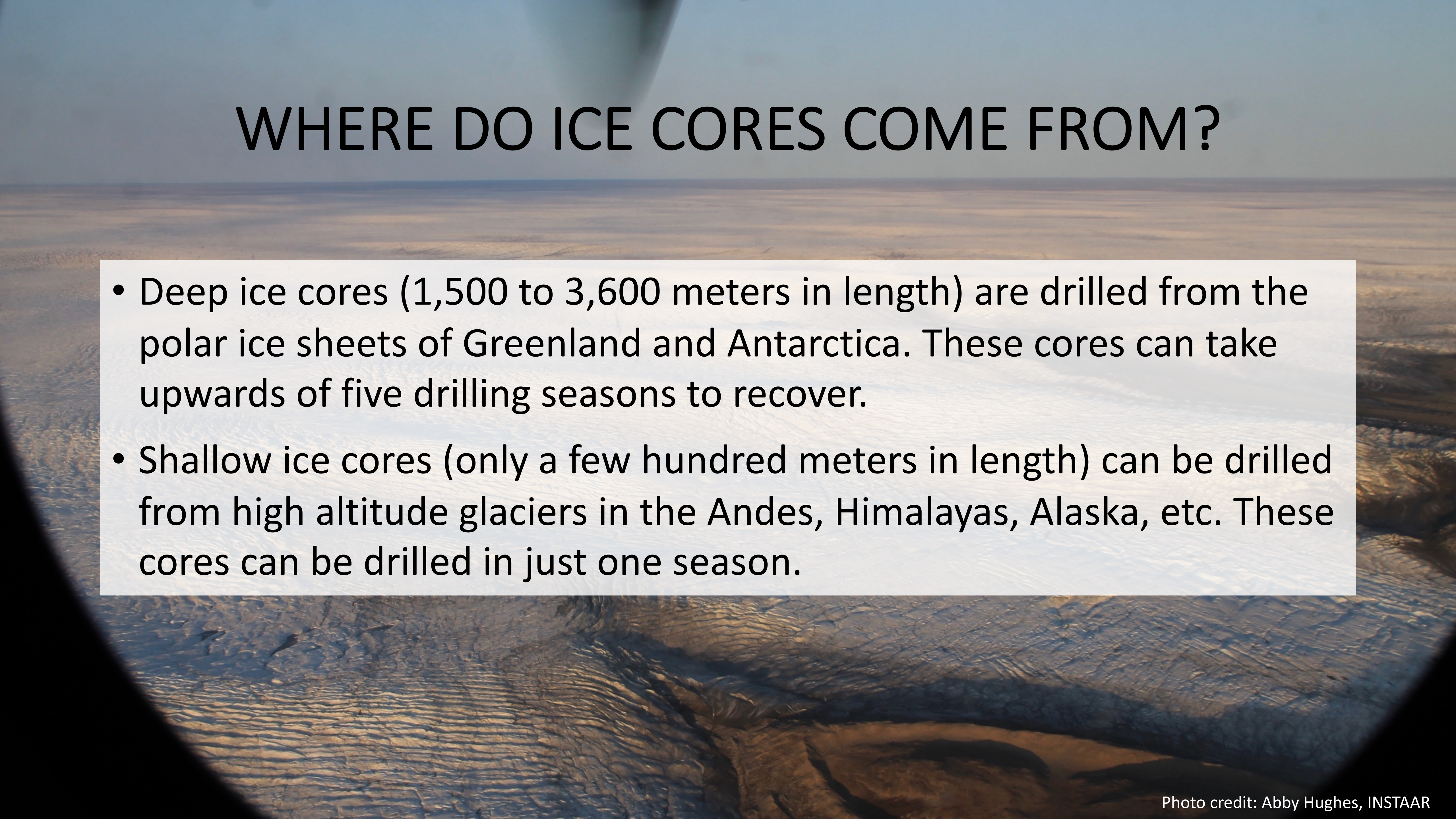
1. This facility stores over 22,000 meters of ice core collected from various location in Antarctica, Greenland and North America

2. The ice cores are stored at -36°C (-32.8° F)

3. The oldest ice we have stored at this facility is approximately 2 million years old!

Photo credit: Chloe Brashear, NSF-ICF

WHERE DO ICE CORES COME FROM?



- Deep ice cores (1,500 to 3,600 meters in length) are drilled from the polar ice sheets of Greenland and Antarctica. These cores can take upwards of five drilling seasons to recover.
- Shallow ice cores (only a few hundred meters in length) can be drilled from high altitude glaciers in the Andes, Himalayas, Alaska, etc. These cores can be drilled in just one season.

Photo credit: Abby Hughes, INSTAAR

Photo credit: NASA

Greenland Drill Sites:

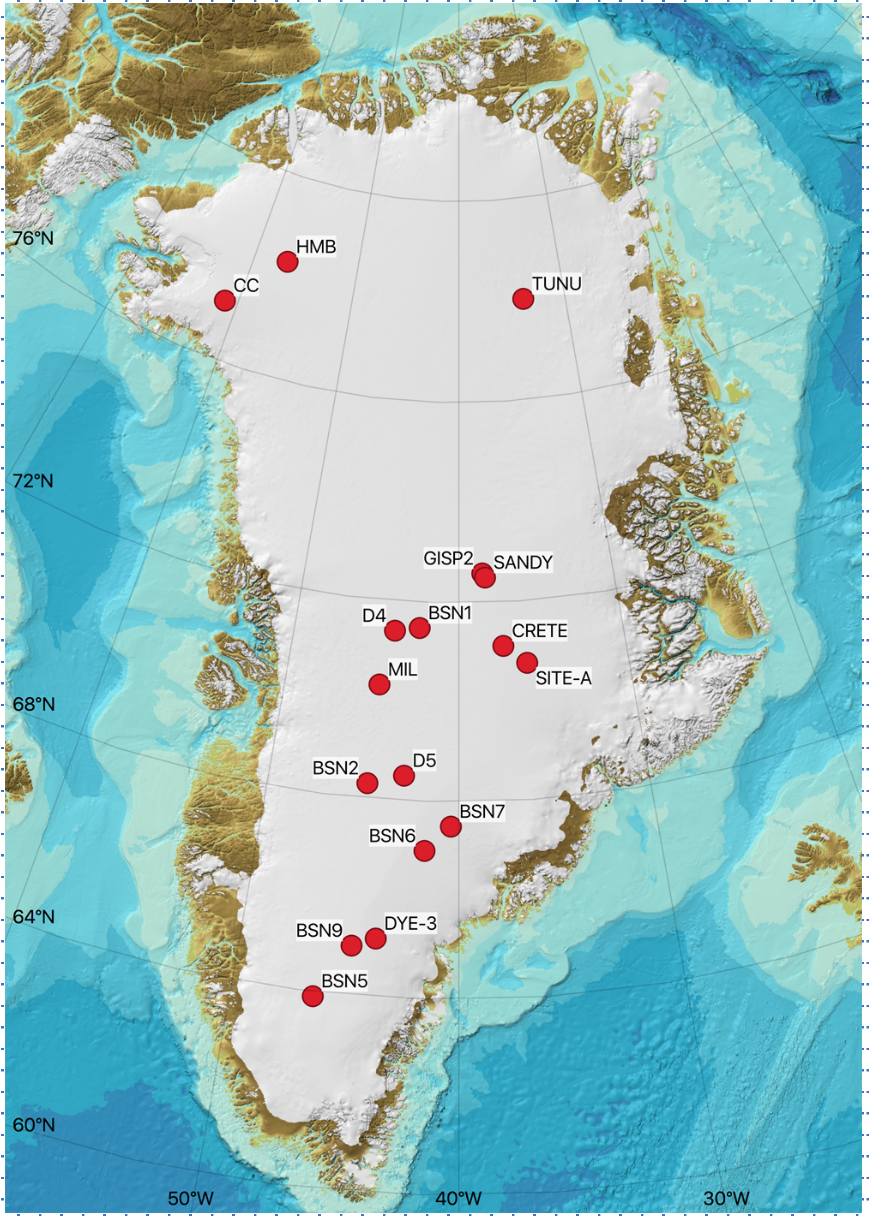


Photo credit: NSF-ICF

This map shows locations of Greenlandic ice cores that are stored at the NSF-ICF. A few important cores to point out are:

- **Camp Century** (1959-1967): This was the first ever American deep ice core to be drilled and is well known for its unique history. It was promoted as a scientific research operation to better understand past climate, but it was also being used as a cover up for the military operation Project Iceworm. This project aimed to build a secret network of mobile nuclear missile launch sites beneath the Greenland ice sheet during the Cold War.
- **GISP 2** (1993): This ice core was drilled at the summit of Greenland and reached a final length of 3053 meters. At the time, this was the longest ice core in history.

Greenland is an autonomous territory within the Kingdom of Denmark. Because of this, the US must collaborate with Denmark when attempting to drill on this ice sheet.

Antarctic Drill Sites:

This map shows locations of Antarctic ice cores that are stored at the NSF-ICF. A few important cores to point out are:

- **WAIS Divide (WD)** (2011): this core was drilled to a depth of 3,400 meters and dates back about 68,000 years.
- **South Pole (SP)** (2016): this core was drilled to a depth of 1,750 meters and dates back about 54,000 years.
- **Vostok (V)** (1998): this core was drilled in 1998 to a depth of 3,600 meters and dates back about 420,000 years.

The large difference in depth and age of these ice cores is because accumulation varies from West Antarctica to East Antarctica. In the West, high accumulation causes seasonal layers to be very thick so while these cores don't go back in time very far, they are very high resolution. In the East, low accumulation causes seasonal layers to be very thin so ice cores here will extend far back into time but lack resolution.

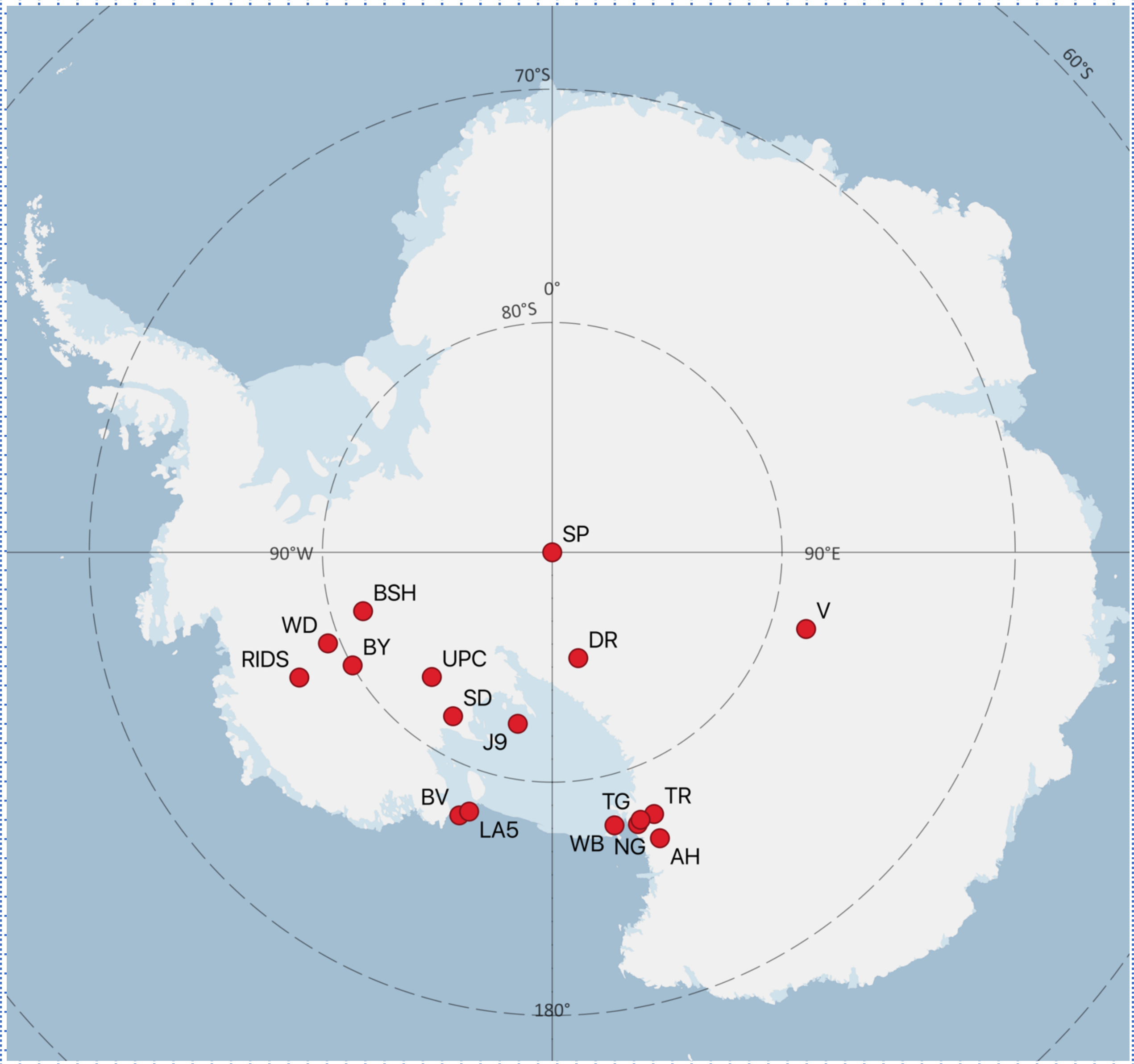


Photo credit: NSF-ICF

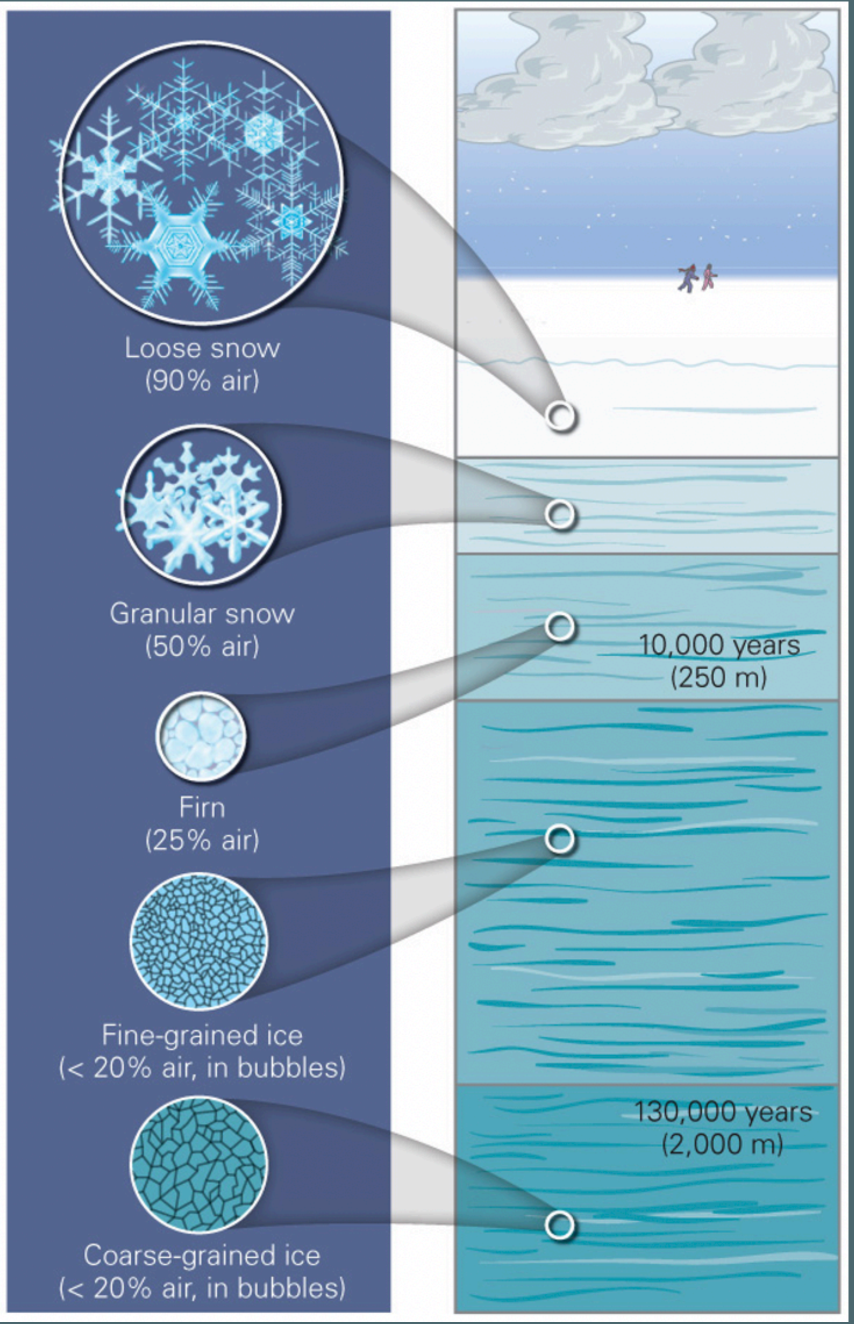


Photo credit: The City University of New York

HOW DOES GLACIAL ICE FORM?

The top ~50 to 150 meters of an ice sheet are composed of loose snow and firn (compacted snow that resembles Styrofoam). Within these layers, modern atmospheric air is able to move through tunnels created by the snow crystals.

Once enough pressure is exerted onto the firn, it compresses into glacial ice. At this layer, the tunnels are sealed off and air is trapped within the ice sheet. This allows scientists to understand what the atmosphere was comprised of thousands of years ago.

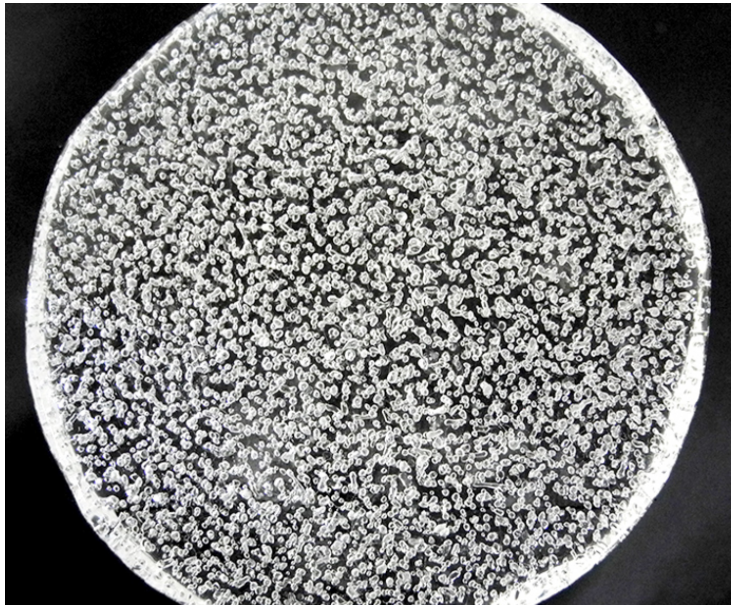
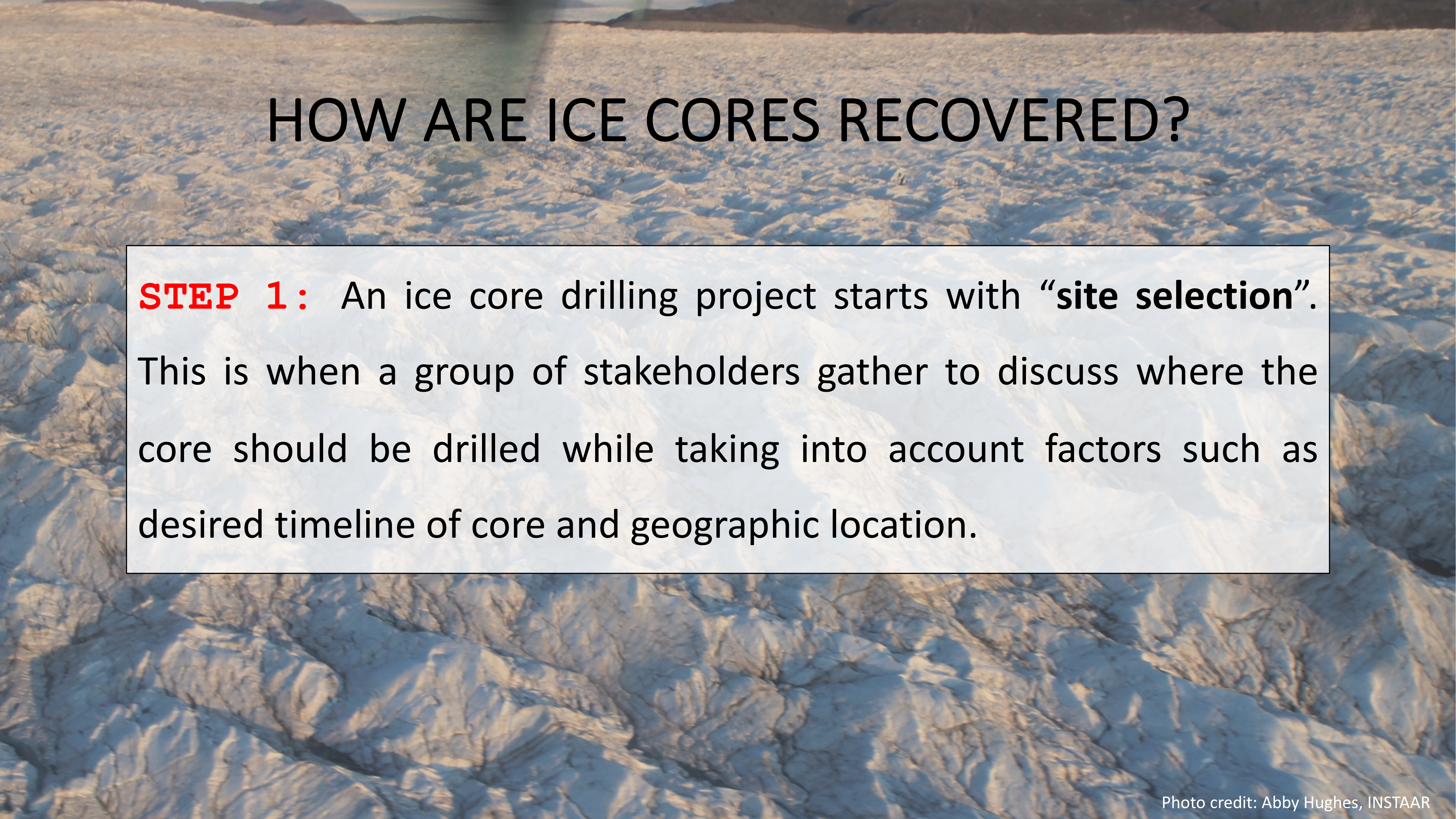


Photo credit: Tas van Ommen, Australian Antarctic Division

HOW ARE ICE CORES RECOVERED?

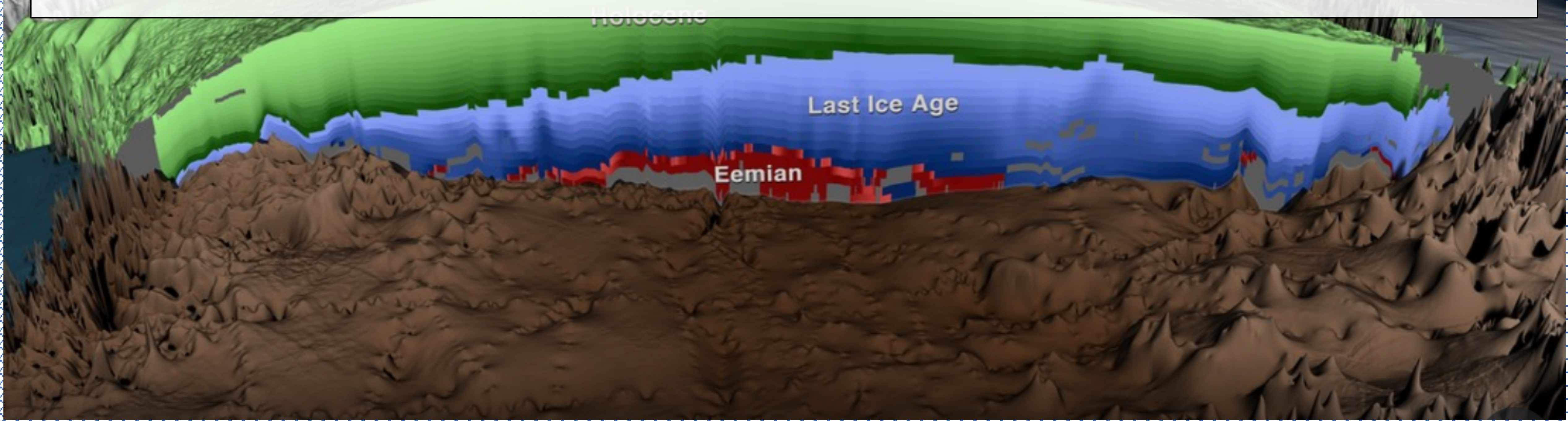


STEP 1: An ice core drilling project starts with "**site selection**". This is when a group of stakeholders gather to discuss where the core should be drilled while taking into account factors such as desired timeline of core and geographic location.

Photo credit: Abby Hughes, INSTAAR

The link below is to a video that shows a typical method used in site selection. Ice penetrating radar allows scientists to "see" below the ice sheet to optimize the temporal extent of the ice core while also decreasing stratigraphic deformation.

See video at https://svs.gsfc.nasa.gov/4249



HOW ARE ICE CORES RECOVERED?

STEP 2: The next step in an ice core drilling project is **field work**. This work is completed from May through August in Greenland and between November and January in Antarctica. The sun shines 24 hours a day during these months so scientists and support staff are supplied with plenty of light. The temperatures are also less severe (usually around -12°C/10°F in Greenland and - 35°C/-30°F in Antarctica).

Photo credit: Abby Hughes, INSTAAR

The following slides show scenes from the field season at WAIS Divide, an ice core drilling camp in West Antarctica. Other deep ice core camps will look and operate very similarly to this one.

Field work begins with travel. For trips to Antarctica, scientists and support staff must travel from Los Angeles, CA to Auckland, NZ to Christchurch, NZ to McMurdo Station and then out to the final field site.

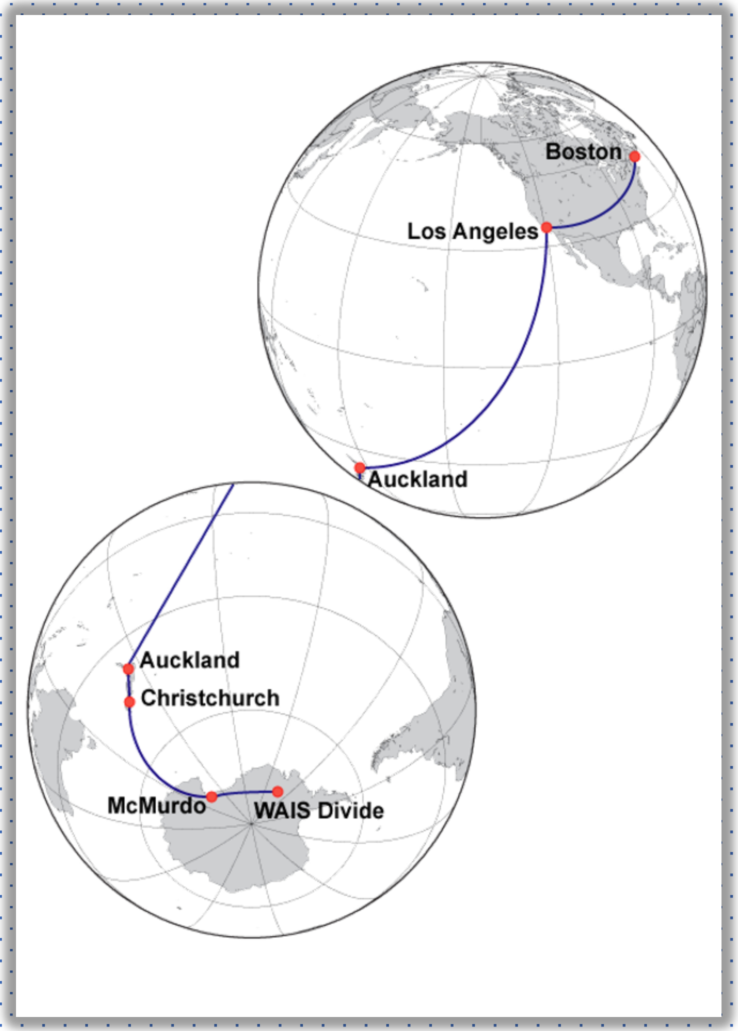


Photo credit: NSF-ICF

Scientists and staff must wait here until the weather is good enough to fly to the remote ice core drilling site.

McMurdo Station is a US funded research station and is the largest community in Antarctica. It can support up to 1,200 residents.

Photo credit: NSF-ICF

"Tent City" = where everyone sleeps!

LC-130 aircrafts = outfitted with oversized skis so that they can safely land on ungroomed snow

The drilling arch = where the ice core is drilled and processed

Photo credit: NSF-ICF

The link below is to a NSF-produced video that discusses the WAIS Divide ice core deep drilling project.

See video at https://www.youtube.com/watch?v=ZnZH2nB5esA

HOW ARE ICE CORES RECOVERED?

STEP 3: The final step is **shipping the ice cores** back to our facility in Lakewood, Colorado. The cores must stay below a certain temperature (-20°C/-4°F) throughout the entire trip. A freezer technician accompanies the cores throughout this journey (5-6 weeks) in case there's an emergency.

Photo credit: Abby Hughes, INSTAAR

The ice cores are first packed into insulated boxes with fresh snow or ice packs.

These boxes are then loaded onto pallets and flown to McMurdo Station.

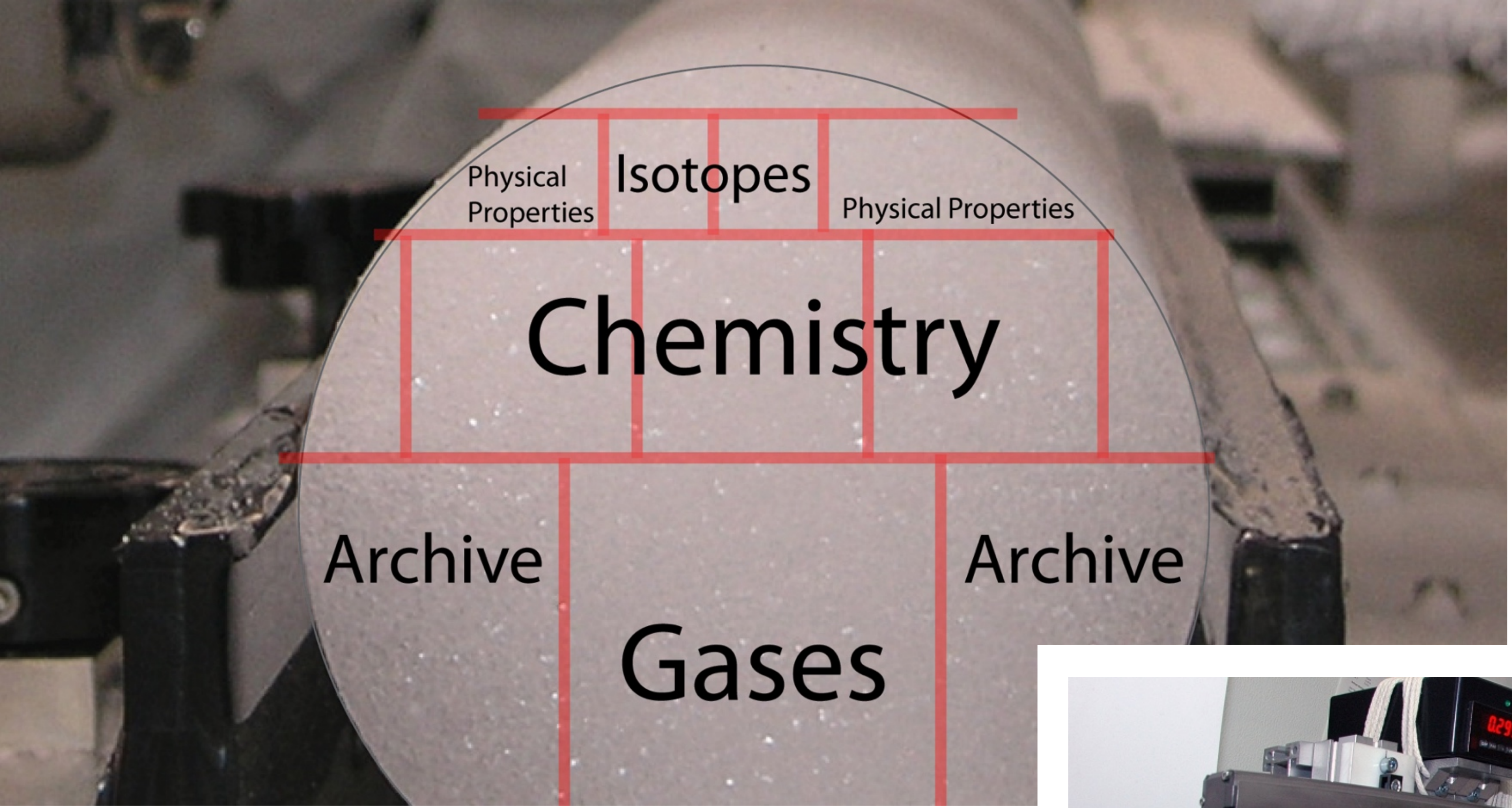
Photo credit: NSF-ICF

Next, the pallets are loaded into mobile freezer units which are then placed onto a container vessel. This ship sets off for Port Hueneme in California before winter hits Antarctica.

The freezer units are finally loaded onto flatbed trucks which drive directly to our facility in Lakewood, Colorado.

Photo credit: NSF-ICF

CORE PROCESSING



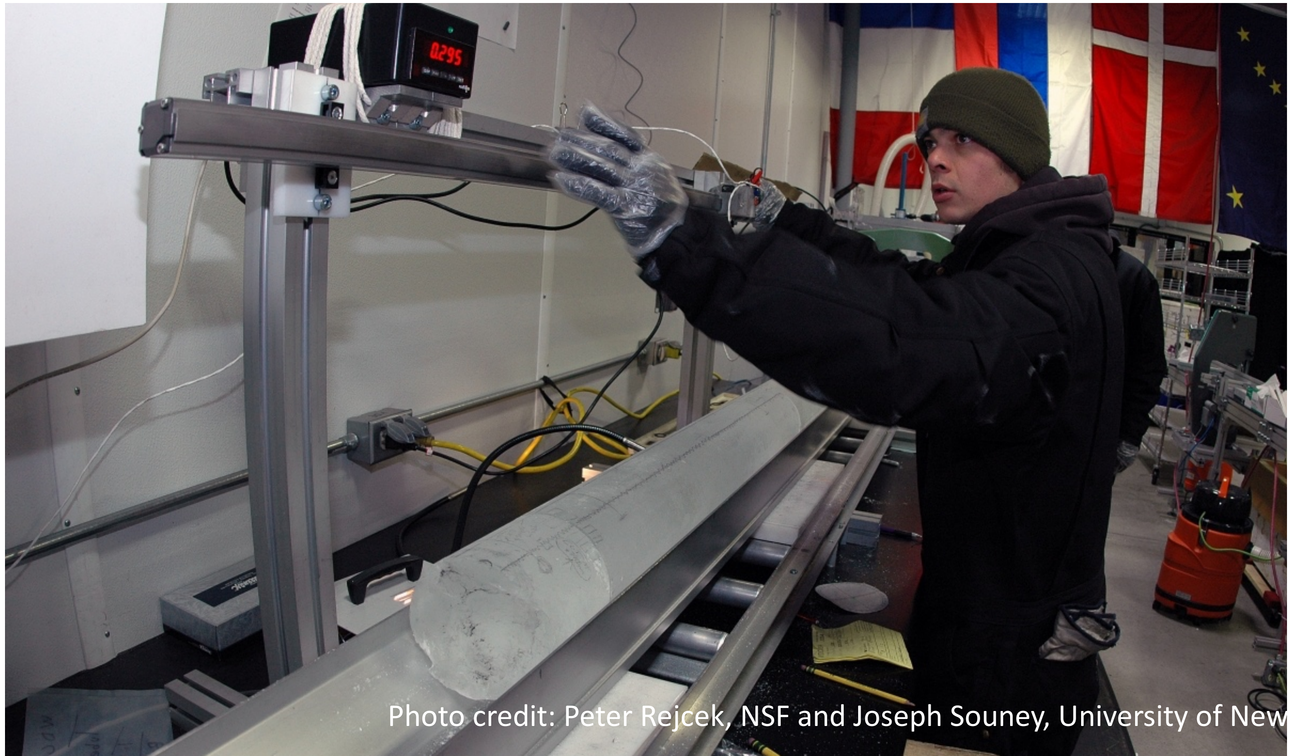
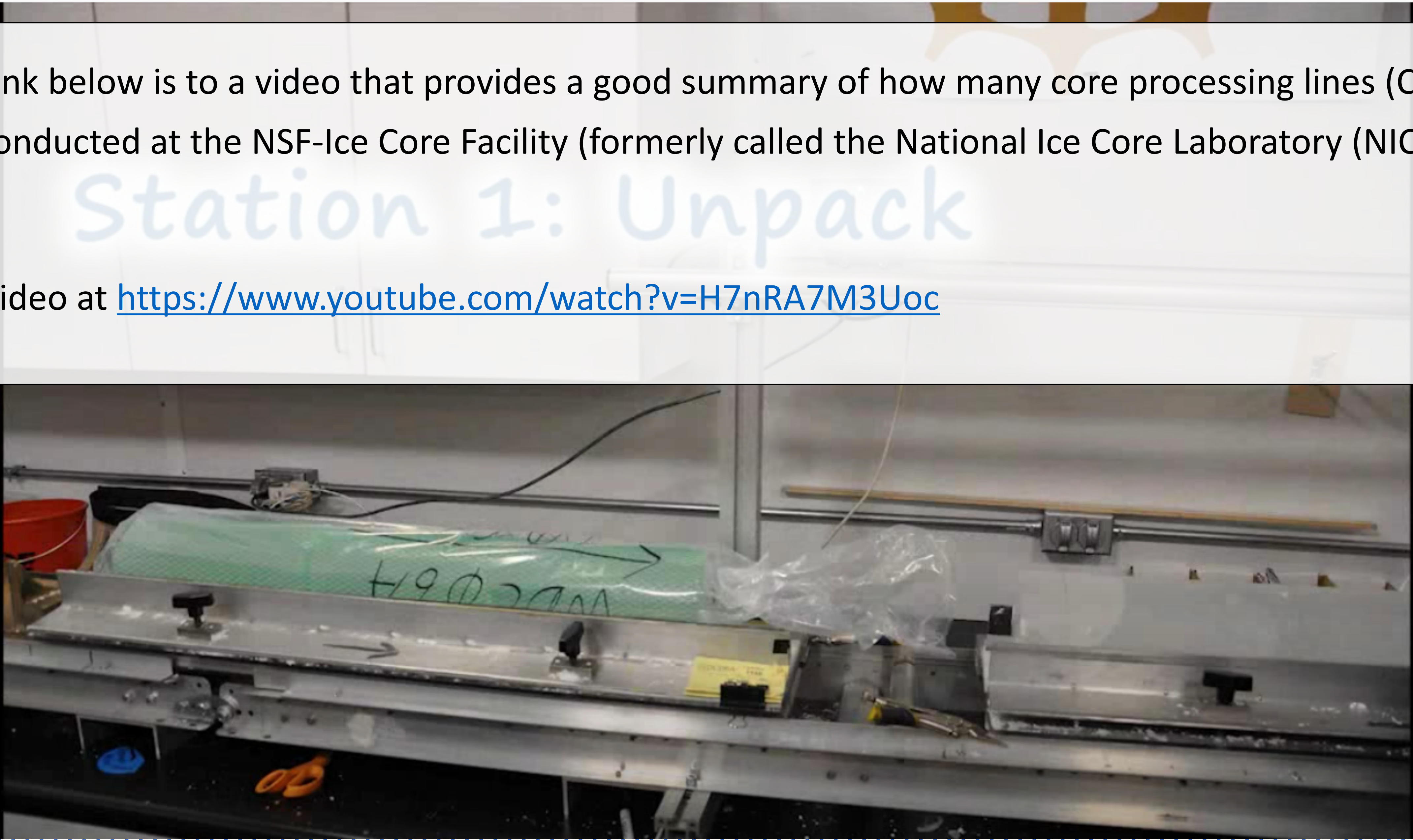


Photo credit: Peter Rejcek, NSF and Joseph Souney, University of New Hampshire

The link below is to a video that provides a good summary of how many core processing lines (CPLs) are conducted at the NSF-Ice Core Facility (formerly called the National Ice Core Laboratory (NICL)).

See video at https://www.youtube.com/watch?v=H7nRA7M3Uoc



WHAT DO ICE CORES TELL US ABOUT CLIMATE?

1. **Atmospheric Composition** (from gases trapped in the ice)
2. **Temperature** (from water isotopes)
3. **Climatic Timelines** (from visual inspection, ECM, volcanic layers)

… and much, much more …

Photo credit: Chloe Brashear, NSF-ICF

Atmospheric Composition

As mentioned before, the formation of glacial ice traps and stratifies gases from our atmosphere within ice sheets. Scientists can extract these ancient gases (carbon dioxide, methane, etc.) and reconstruct what the atmosphere was composed of many thousands of years ago.

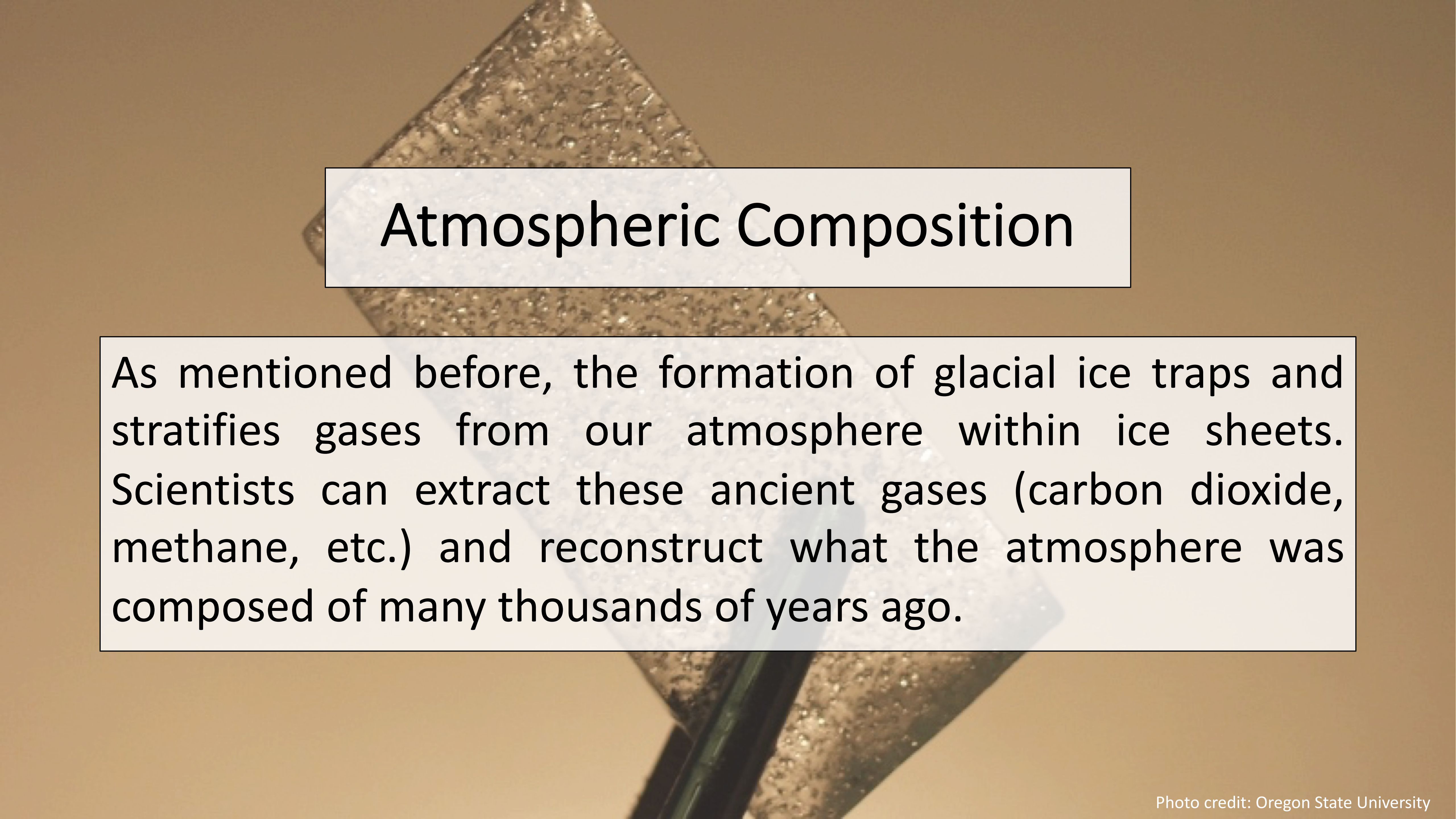
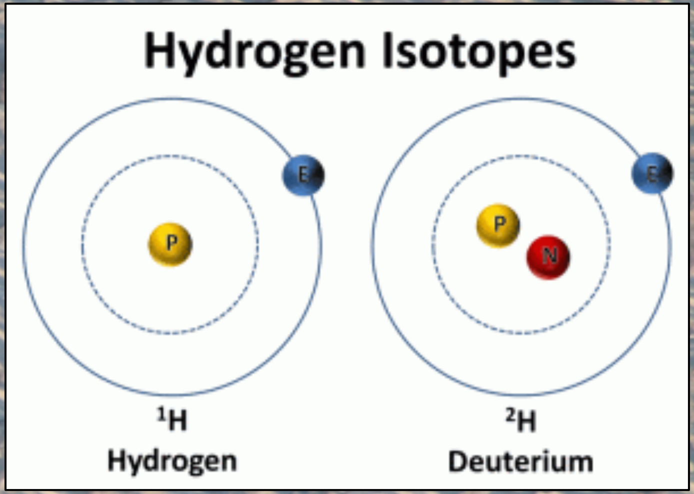


Photo credit: Oregon State University

Water Isotopes

Water contains hydrogen and oxygen, and each of these elements contains multiple isotopes, or varieties of the same element with differing mass. ^{2}H (hydrogen with 1 neutron and mass of 2) and ^{18}O (oxygen with 10 neutrons and mass of 18) are considered “heavy” isotopes. These isotopes behave uniquely within the water cycle and can be used to track global hydrologic patterns.



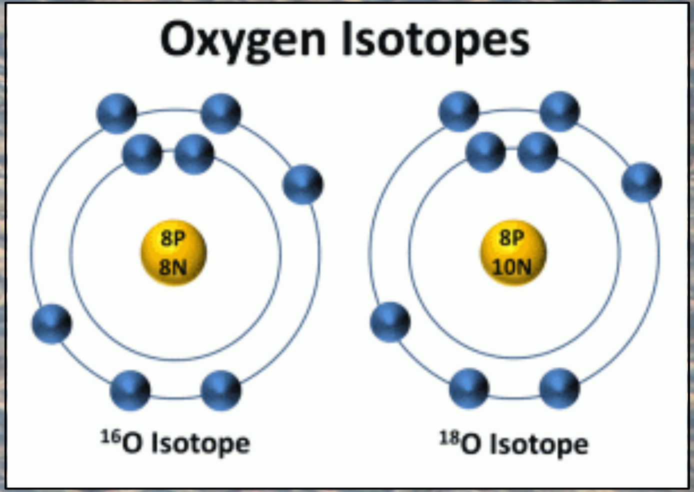


Photo credit: Abby Hughes, INSTAAR and NASA CSI

Water Isotopes

Due to a process called isotopic fractionation, heavy isotopes (^{2}H and ^{18}O) are preferentially, but not exclusively, precipitated out of clouds first. This causes precipitation at the poles to be isotopically lighter than precipitation at the equator. Similarly, during glacial periods, clouds will precipitate more often on their way poleward and so precipitation at the poles will be even isotopically lighter at this location than during inter-glacial periods. This chemical behavior allows scientists to reconstruct past temperature from ice cores.

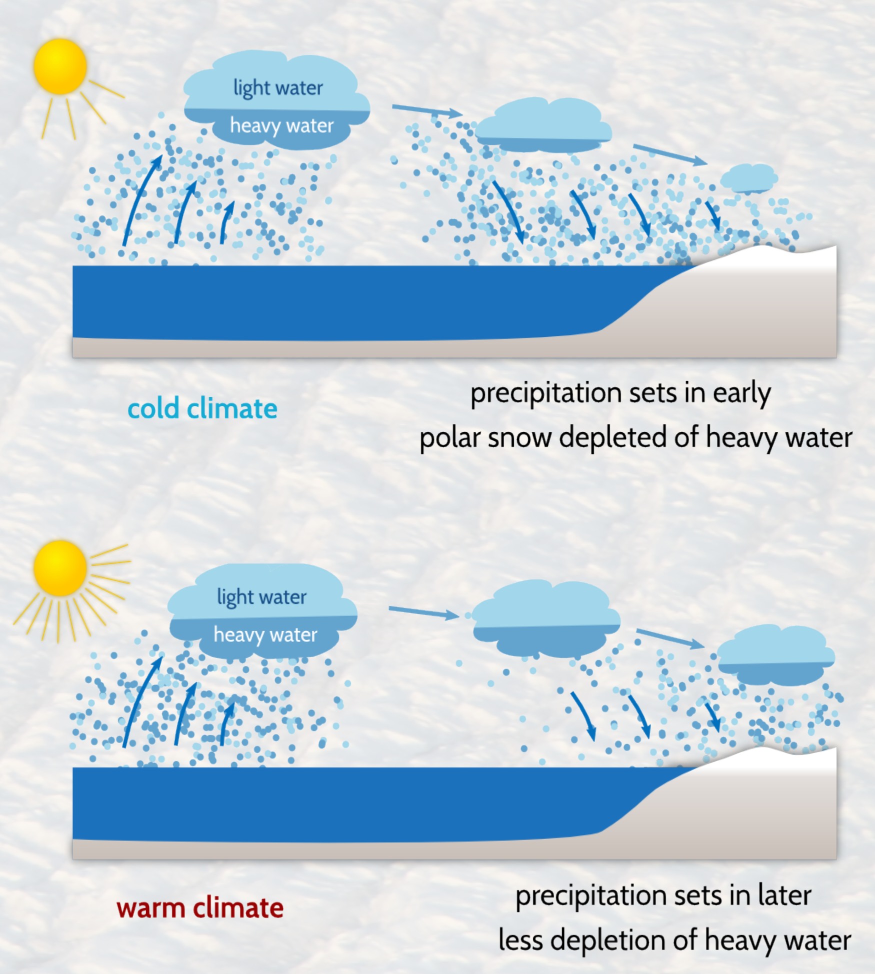


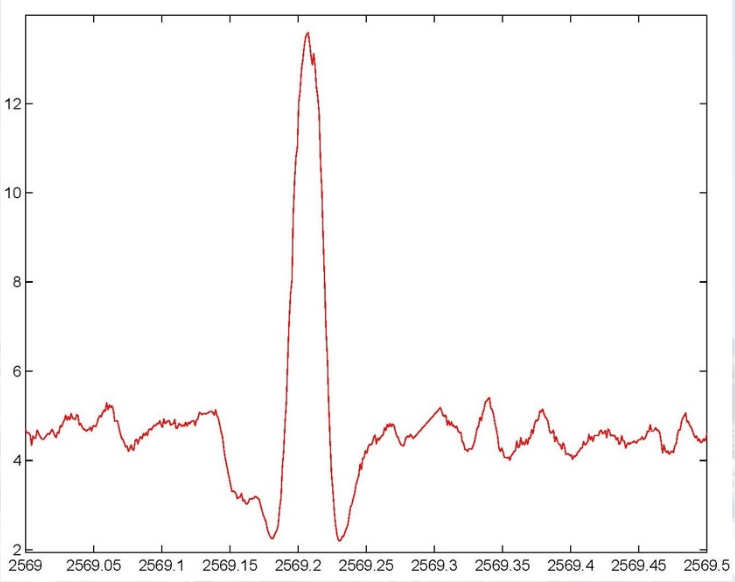
Photo credit: Abby Hughes, INSTAAR and SAHRA, University of Arizona

Climatic Timelines

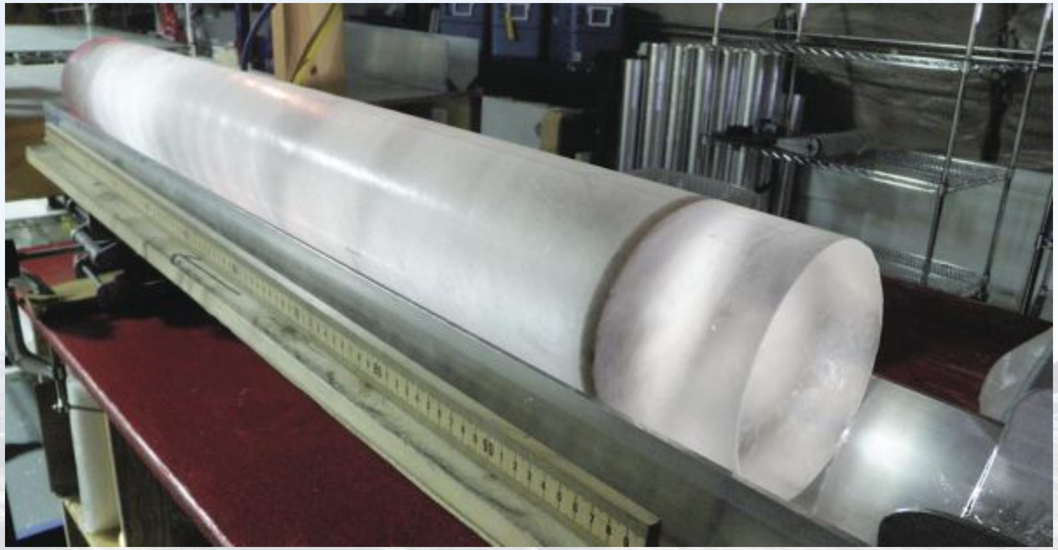
There are multiple techniques used to date an ice core. Seasonal patterns in snow and dust/ash accumulation are highly informative because they are stratigraphically locked into the ice sheet. Scientists analyze these seasonal layers to determine age-depth scales for various ice cores.

These age-depth scales allow scientists to contextualize other findings, such as temperature or atmospheric composition, and draw climatic conclusions.

Photo credit: Chloe Brashear, NSF-ICF



An electrical conductivity meter (ECM) is used to identify invisible seasonal peaks and troughs in atmospheric dust and ash.



Volcanic layers help create temporal tie-points once the annual signal has been thinned beyond recognition.

Scientists are usually able to count annual layers by visually inspecting the uppermost sections of an ice core.

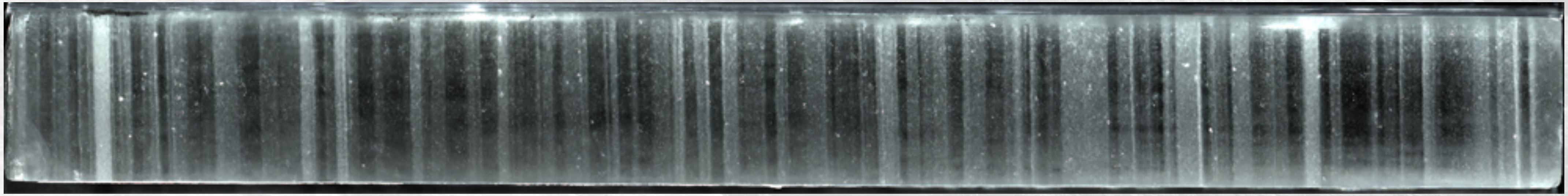
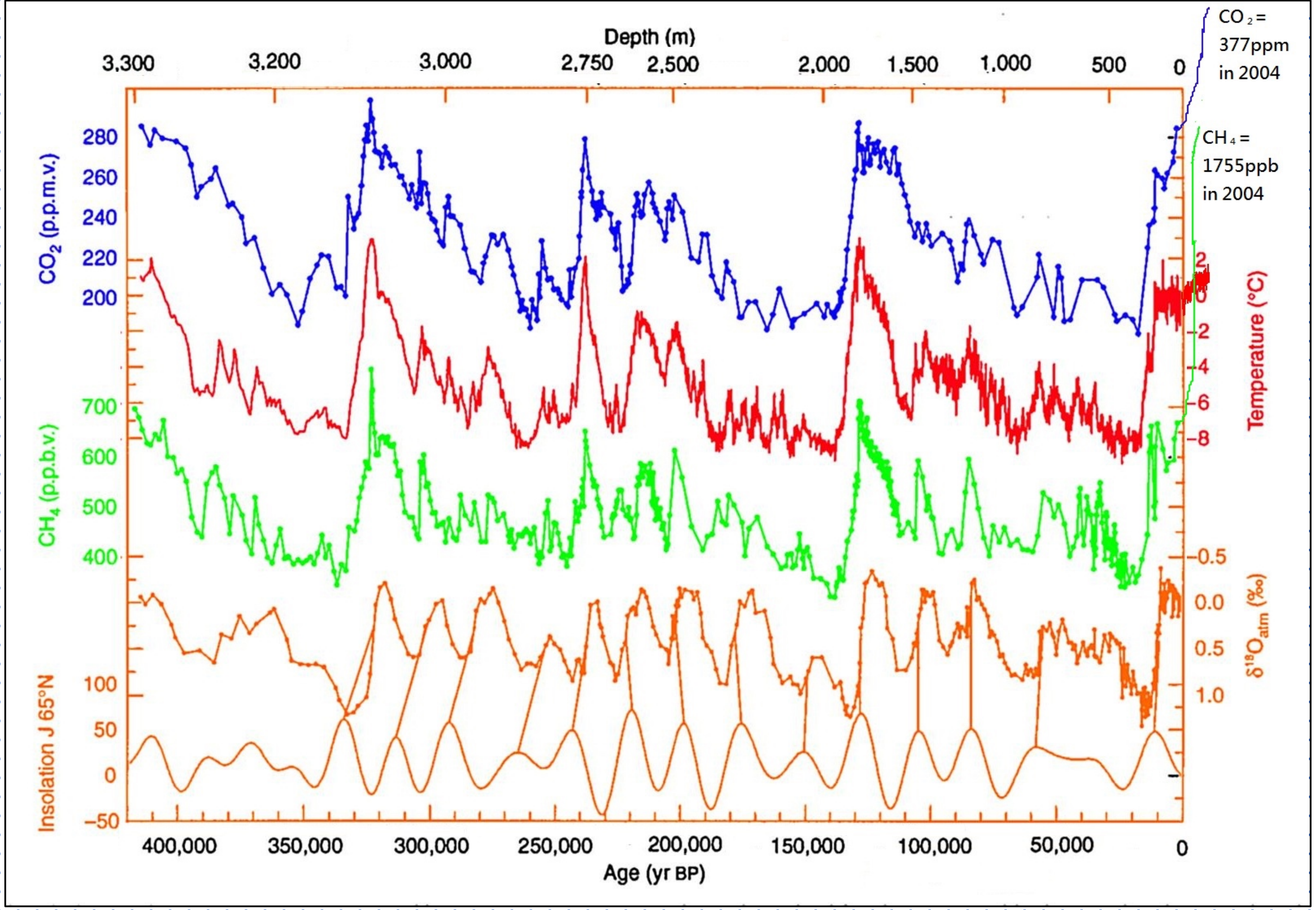


Photo credit: Chloe Brashear, NSF-ICF

Combing these scientific analyses leads to… CLIMATE RECONSTRUCTIONS



The ultimate goal in ice core science is to better understand past climate. Reconstructions show how the Earth has experienced very stable 100,000 year climate cycles throughout the past 800,000 years. Unfortunately, human activity has caused changes to this pattern. For example, atmospheric gases like CO2 and CH4, continuously break historic highs and temperature is rapidly increasing.

Photo credit: antarcticglaciers.org

Why did climate oscillate in the past?

Long term climate is largely driven by changes in Earth's position relative to the Sun. Specifically, three types of Earth's orbital movements (eccentricity, precession and axial tilt) affect levels of incoming solar radiation and are responsible for triggering the start and end of glacial periods. Each of these movements operate on unique cycles, but eccentricity (which has a period of 100,000 years) has largely driven climate cycles for the past 800,000 years.

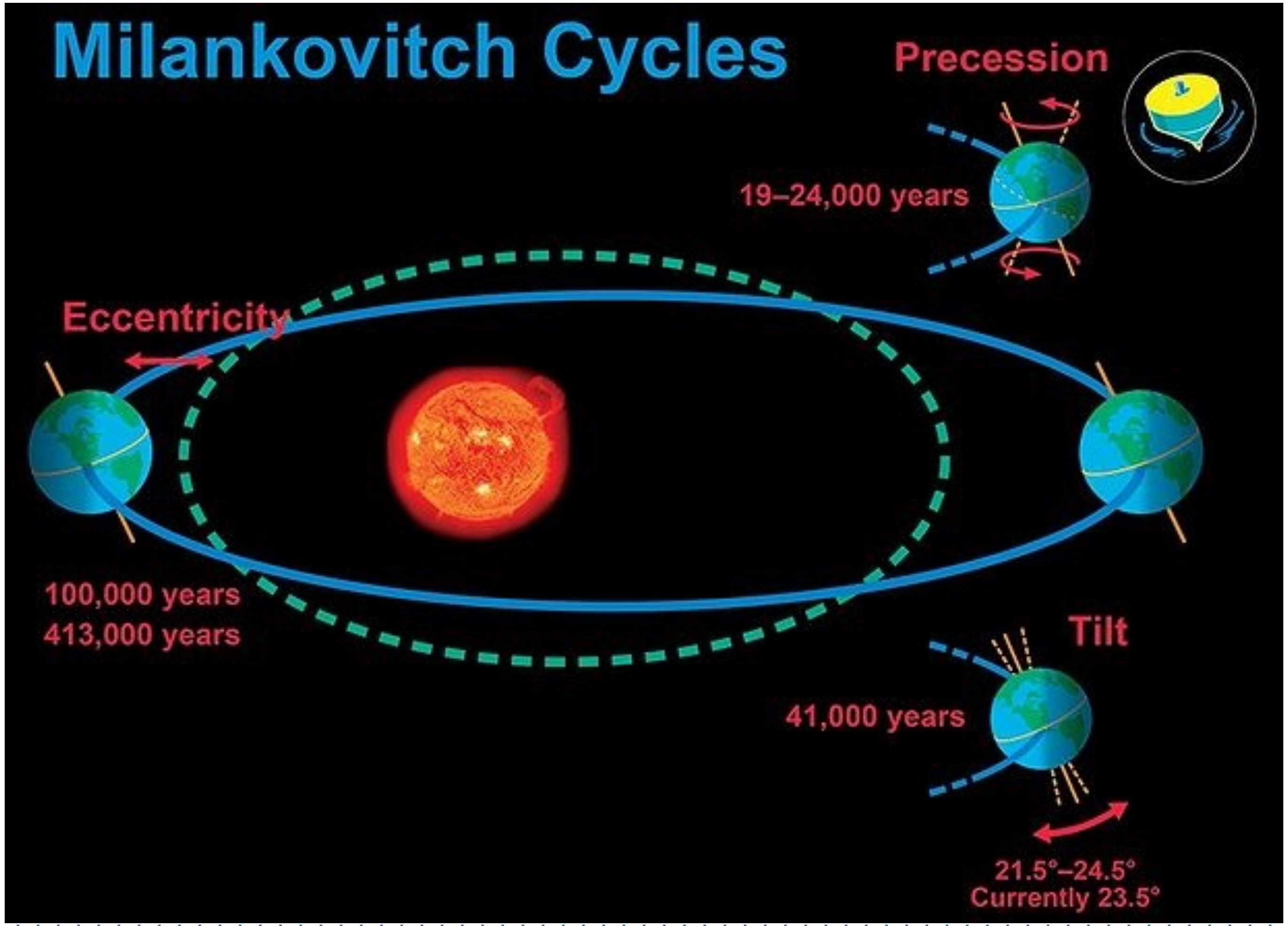
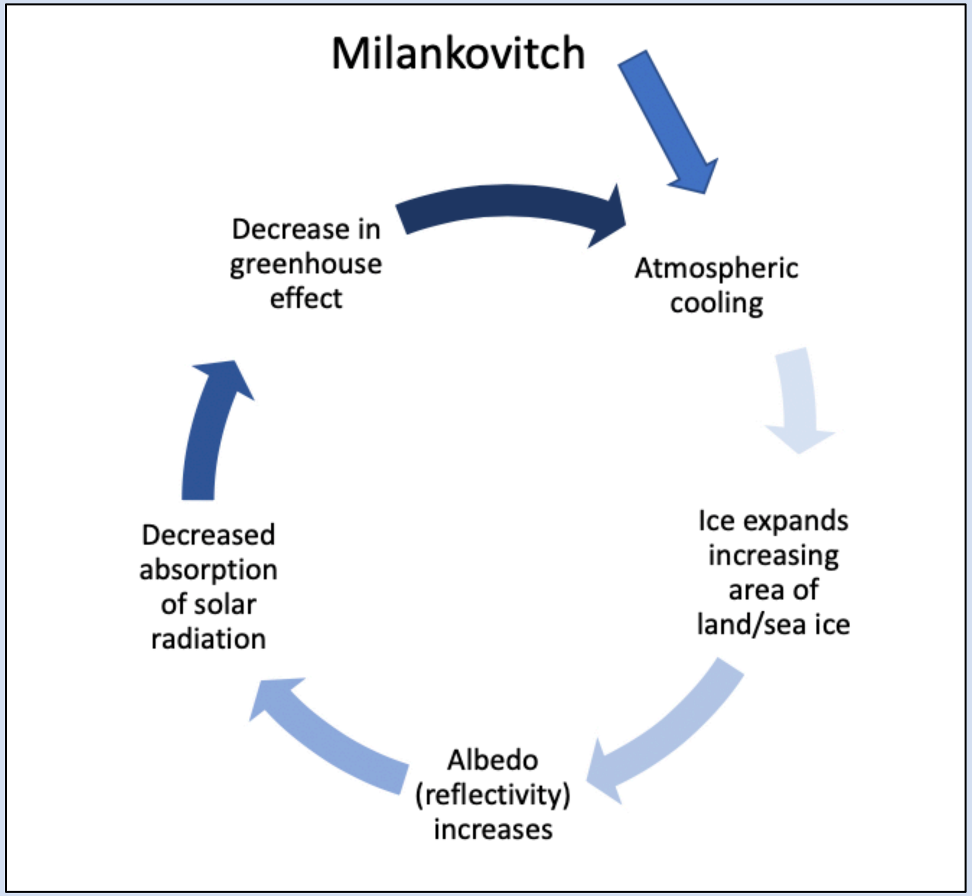


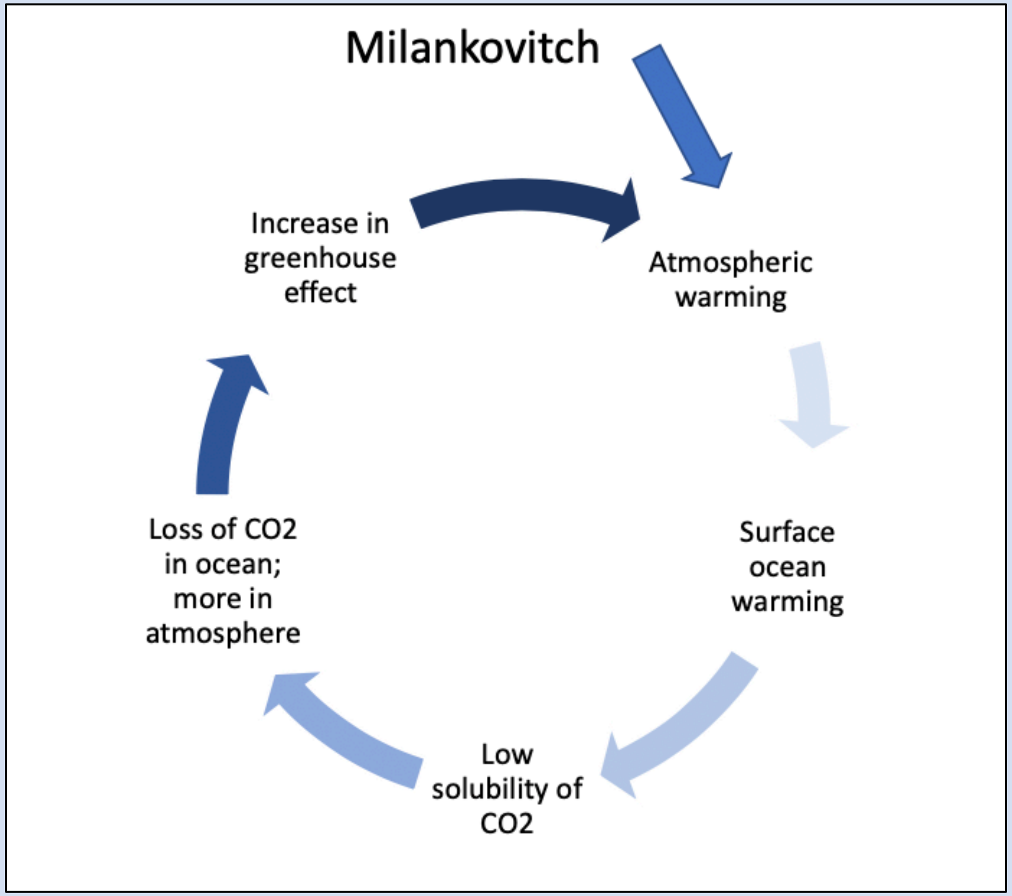
Photo credit: universetoday.com

How do Milankovitch cycles trigger and end glacial periods? Positive feedback loops!

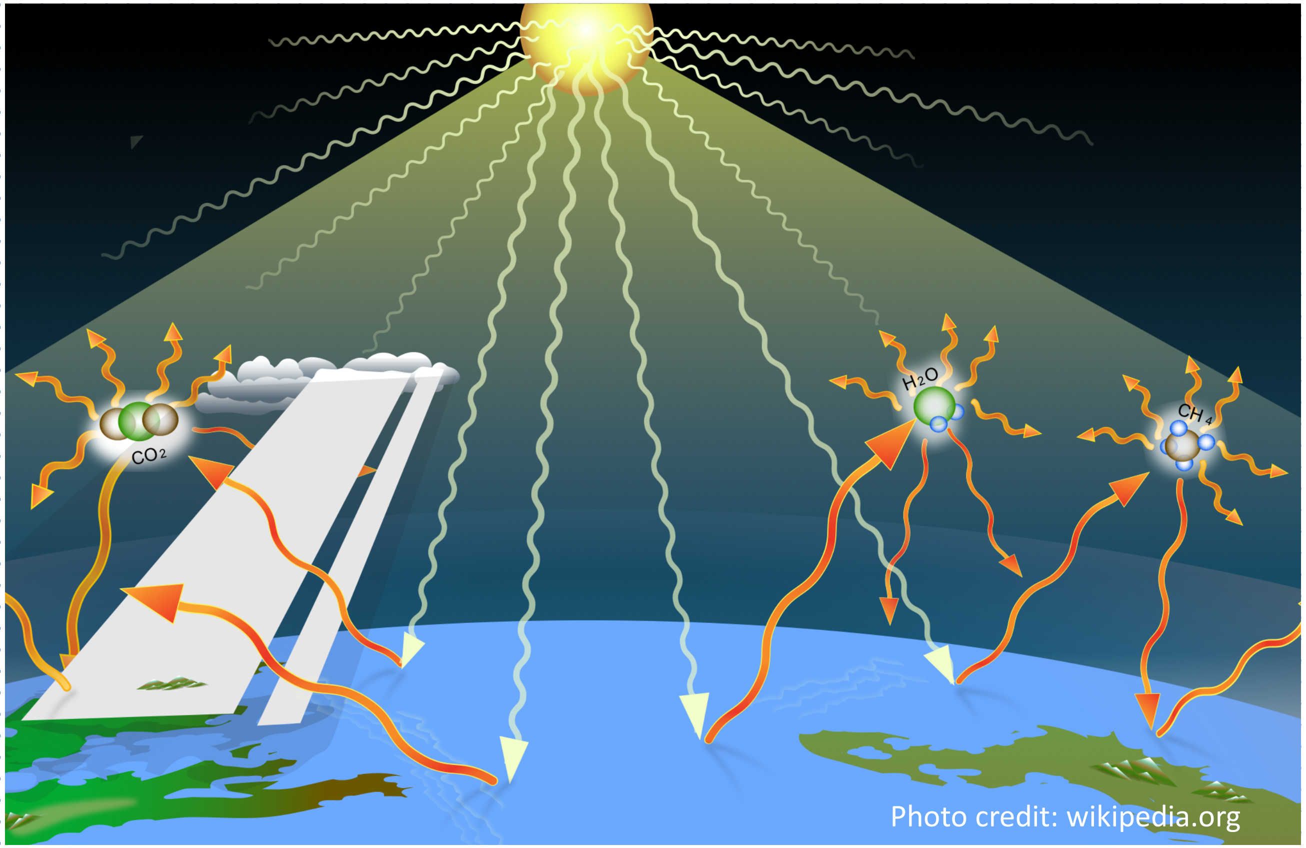
Start of glacial period example:



End of glacial period example:



Why is climate changing?



Greenhouse gases present in Earth's atmosphere: CO_2 (carbon dioxide), CH_4 (methane), H_2O (water vapor), N_2O (nitrous oxide) and various fluorinated gases

The greenhouse effect describes the process by which gases in a planet's atmosphere trap heat and significantly warm the surface of that planet. Short wave radiation (UV, visible and near-infrared) travels from the Sun to Earth and is either reflected back to space by clouds, absorbed by gases in the atmosphere or absorbed by the surface. The Earth then releases long wave radiation (infrared) back to space. Some of this energy escapes the atmosphere, but most is trapped and reflected back to the surface by greenhouse gases. This causes a warming effect and makes life possible on Earth.

Why is climate changing?

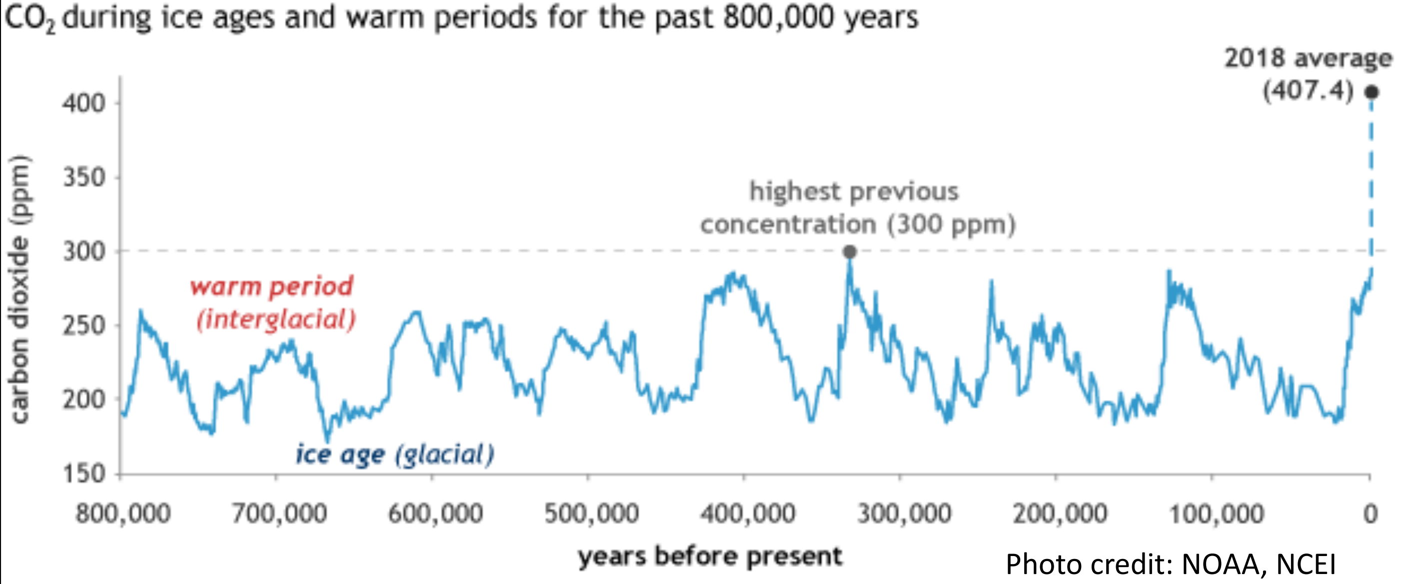


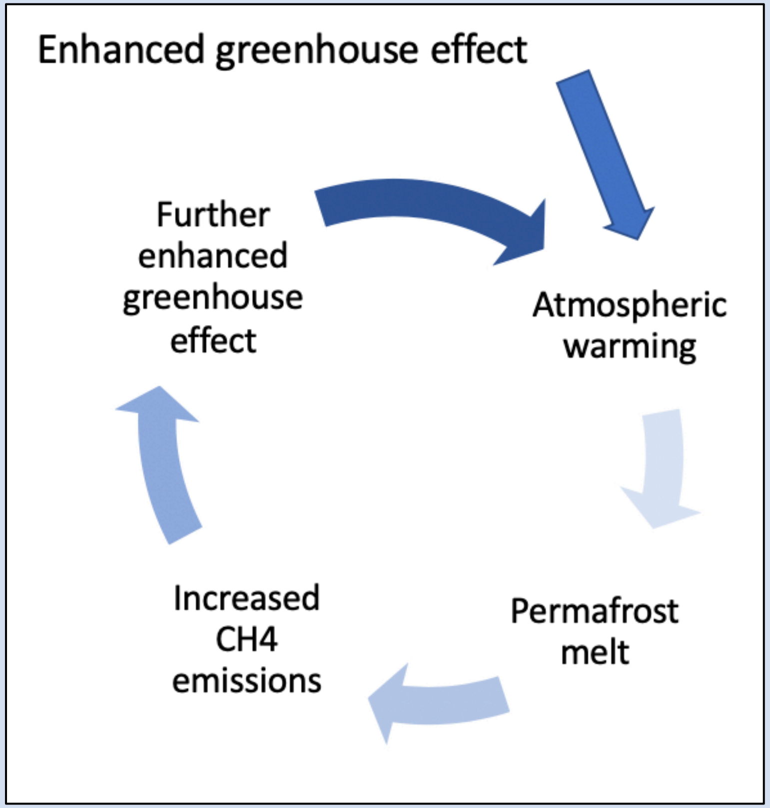
Photo credit: NOAA, NCEI

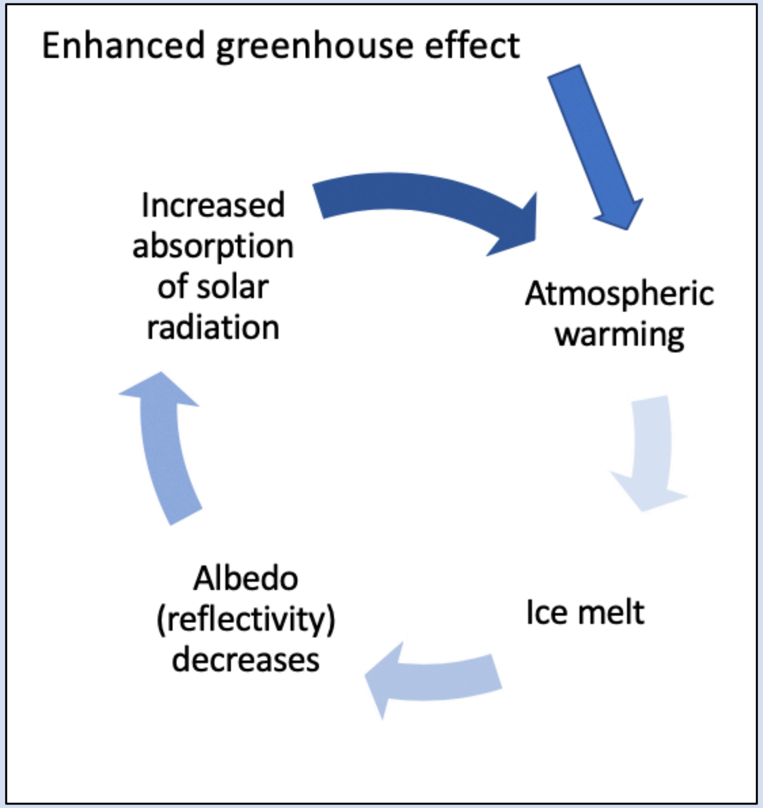
Photo credit: Wikipedia

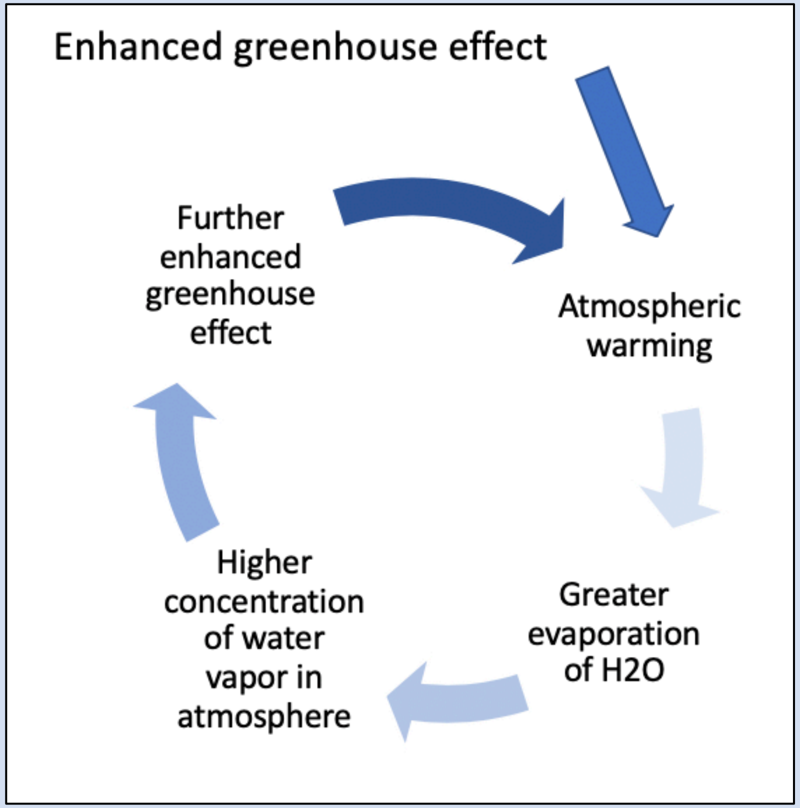
BUT...

Increases in human population have led to increases in global energy demands. To solve this problem, we started burning fossil fuels to power our homes and cars and began deforesting large swaths of land for raw materials and agricultural use. Activities like these release more greenhouse gases, like CO_2 and CH_4, into the atmosphere and cause an ***enhanced*** greenhouse effect. This leads to an increase in global temperatures and disrupts Earth's natural equilibrium.

An **enhanced** greenhouse effect reinforces other positive feedback loops! Examples:







How do we know humans are responsible?

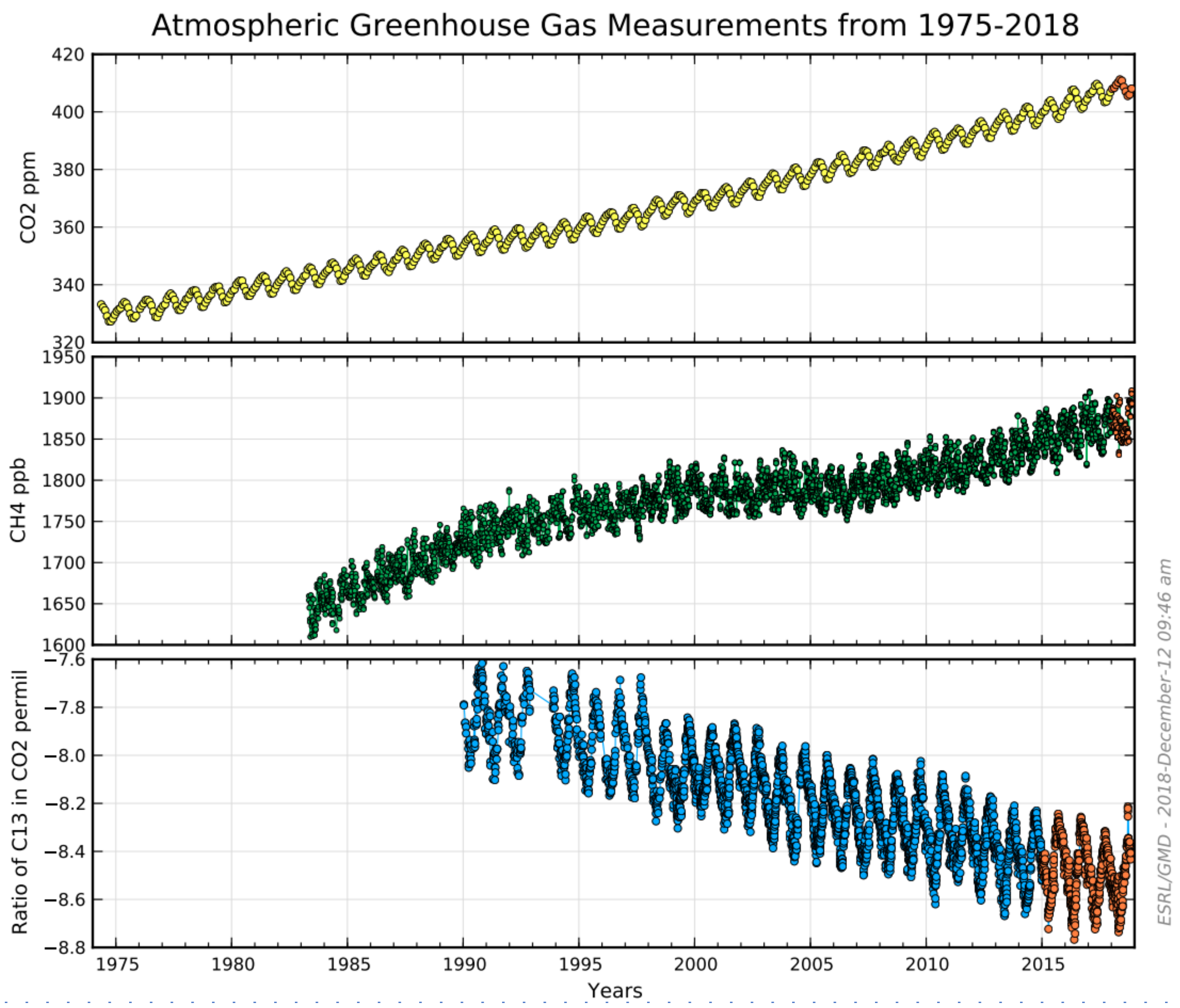


Photo credit: ESRL GMD

High resolution measurements show that atmospheric concentrations of CO_2 and CH_4 have increased dramatically over the past several decades. Scientists use isotopic analysis to demonstrate how the fossil fuel industry caused this change.

The bottom plot shows the ratio of ^{13}C to ^{12}C in modern atmospheric CO_2 over time. Plants preferentially take up ^{12}C during photosynthesis and therefore, fossil fuels are enriched in this specific isotope. The burning of fossil fuels pumps ^{12}C rich CO_2 into the atmosphere and causes the ratio of ^{13}C to ^{12}C to decrease over time, as shown.

As a result, global temperatures are rising and will continue to rise.

Factors affected by global warming:

- Agriculture and food security
- Water security
- Sea level
- Climate variability
- Habitable land
- Wildfires
- and more..

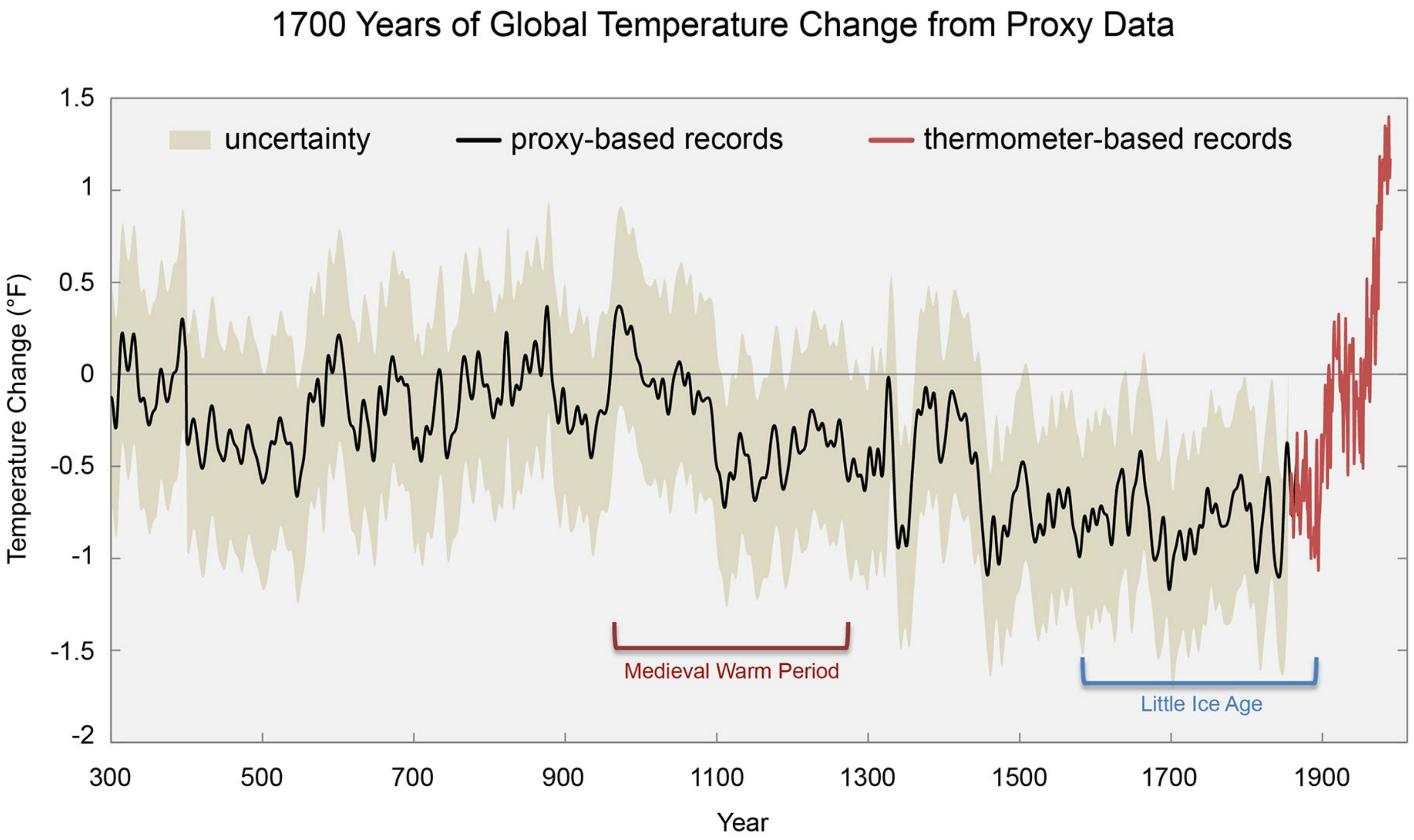


Photo credit: globalchange.gov, adapted from Mann et al. 2008

Conclusion

- Ice cores have been monumental in understanding Earth's most recent geologic period, the Quaternary. They have shown us how climate behaved before modern humans and how we fundamentally changed the climate system. More importantly, ice cores may provide scientists the necessary tools to accurately predict what additional change lies ahead.

Photo credit: NASA

Thank you for your time!

Photo credit: Vlad Silver