

GEOL 553 Lab 2: Vostok Ice Core

Name _____ Date: _____

Summary

In this lab, students learn how to use data from the Vostok ice core to measure and compare temperature between different temporal periods. Ice core samples contain several climate indicators: the amount of dust in each layer from volcanic debris, airborne continental dust and biological material, and cosmic particles; all the aforementioned mix with snow and act as a barrier between different ice layers. The composition of bubbles of air trapped in the ice is a measure of the makeup of the atmosphere in ancient times. The isotopic composition of water, and in particular, the heavy isotope of oxygen, as well as deuterium, is indicative of the temperatures in the environment. Understanding the historic and contemporary content of ice core samples enables scientists to make accurate predictions regarding the Earth's climate future.

Goals

Students will learn the following:

- To become familiar with ice core data
- To explore the implications of ice core data on the Earth's past, present, and future climate
- To form predictions regarding the Earth's climate

Evidence from paleoclimate research suggests an anthropogenic influence on global warming trends. Ice core samples offer uninterrupted information on significant properties of paleoclimate, including local temperature and precipitation rate, humidity, wind speed; additionally, ice core samples reveal changes in atmospheric composition.

Description

The Vostok core was drilled in East Antarctica, at the Soviet station Vostok from an altitude of 3488 m, and has a total length of 2,083 m. Ice samples have been analyzed with respect to isotopic content in ^2H , dust, and methane and carbon dioxide trapped in air bubbles. The profiles of ^2H , methane, and carbon dioxide concentrations behave in a similar way with respect to depth in the core, showing a short interglacial stage, the Holocene, at the top, a long glacial stage below, and the last interglacial stage near the bottom of the core. The record goes back in time about 160,000 years. (In January 1998, the collaborative ice-drilling project at the Russian Vostok station reached a depth of 3,623 m. Preliminary data indicate the Vostok ice-core record extends through four climate cycles, with ice slightly older than 400 ka (Petit et al. 1997, 1999). but for this lab, we will analyze the 160ky data as an exercise.)

Part I. Gas Age versus Ice Age

Age is calculated in two different ways within an ice core. The ice age is calculated from an analysis of annual layers in the top part of the core, and using an ice flow model for the bottom part. The gas age data accounts for the fact that gas is only trapped in the ice at a depth well below the surface where the pores close up.

GEOL 553 Lab 2: Vostok Ice Core

Task 1: Open the Vostok ice core Excel file. Plot both the ice age and the gas age as a function of depth on the same graph. Describe the graph and answer the following questions:

What are the units of both age scales?

What are the depths of the shallowest and deepest data points?

For the rest of the lab, assume that the most shallow ice core measurements represent the environmental conditions in the 18th century before the Industrial Revolution.

Does age increase or decrease down the core?

Why do the two age curves differ?

How much younger is a bubble of gas than the ice that surrounds it, at a depth of 250 m?

Is the thickness of an annual layer of ice smallest at the top or bottom of the core?

Why?

Part II. Delta-Deuterium (δD) As a Proxy for Temperature

Task 2: Next you will calculate the temperature based on the isotopic composition of the ice. Insert a blank column into the table to the right of the delta-deuterium column (δD). Isotopic ratios are used to model temperature. Calculate the temperature at Vostok based on the following formula describing the empirical relationship between temperature and deuterium concentration:

$$\text{Temperature (}^{\circ}\text{C)} = -55.5 + (\delta D + 440) / 6$$

*Be sure to save your temperatures for plotting

Now plot your calculated temperature vs. ice age (Plot 1).

How long ago did the maximum temperature occur (last interglacial)?

How long ago did the minimum temperature occur (last glacial maximum)?

Visit the following website: <http://www.worldclimate.com/>

Determine the current average Vostok temperature:

How do these temperatures compare to the current average Vostok temperature? (Note: you will need to compute an average of the temperatures given on this site (24h average temperature).)

GEOL 553 Lab 2: Vostok Ice Core

Part III. CO₂, CH₄, and Dust

Task 4: Copy and paste Plot 1 to make Plot 2. In Plot #2, also plot CO₂ as a function of gas age, so Temp and CO₂ are both on the same plot. Use a secondary vertical axis for CO₂. How closely does the plot of CO₂ resemble that of temperature?

Now plot CO₂ (x axis) against temperature (y axis). Add a trend line and record the R² value.

R²-Value:

What is the regression equation?

Do you think this correlation is significant?

Determine the present monthly atmospheric CO₂ concentration (ppm) according to Scripps' CO₂ data: http://scrippsco2.ucsd.edu/data/atmospheric_co2 Enter the latest monthly "seasonally adjusted filled" 2015 data here: [CO₂]:

Insert today's CO₂ concentration into the linear regression equation from above and determine what the past relationship between CO₂ and temperature predicts that today's temperature should be at Vostok.

Predicted Temperature:

How does your calculation compare with the known value?

Task 5: Make the same plots for CH₄. (CH₄ vs gas age, CH₄ (x axis) vs temperature (y axis), Add a trend line and record the R² value).

R²-Value:

What is the regression equation?

Is CO₂ or CH₄ more closely correlated with temperature?

Why do you think that is?

Now make a plot of dust as a function of ice age. Compare this to the temperature vs ice age plot.

Next plot the dust against temperature and plot a regression line.

R²-Value:

What is the regression equation?

GEOL 553 Lab 2: Vostok Ice Core

How well do the changes in dust concentration correlate with the temperature changes?

Task 6: Determine the latest atmospheric CH₄ concentration (ppb) directly measured at Mauna Loa, Hawaii at the following website:

<http://www.epa.gov/climatechange/science/indicators/ghg/ghg-concentrations.html>

2014 [CH₄]:

Determine the average CO₂ (ppm) and CH₄ (ppb) concentrations for the 18th century using the EPA link above.

18th century [CO₂]:

18th century [CH₄]:

Calculate the changes in CO₂ and CH₄ concentrations between the last glacial maximum (~20 ka ago) and the 18th century, and between the 18th century and today.

20 ka [CO₂]:

20 ka [CH₄]:

18th century – 20 ka [CO₂] =

18th century – 20 ka [CH₄] =

2015 – 18th century [CO₂] =

2015 – 18th century [CH₄] =

Is the change in the most recent 200 years larger or smaller than the change in last 20 ka before 18th century?

Task 7: Insert today's CH₄ concentration into the linear regression equation from Task #5 to determine what the past relationship between CO₂ and temperature predicts that today's temperature should be at Vostok.

Predicted Temperature:

How does your calculation compare with the known value?

GEOL 553 Lab 2: Vostok Ice Core

Part IV. Trends

One can calculate the rate of change of temperature (degrees/ka) by subtracting one temperature from the next oldest and dividing by the ice-age difference.

That is: (younger temp - older temp) / (younger ice age - older ice age) = rate of change

- positive for warming, negative for cooling
- younger is shallower

Task 8: Calculate the warming rate for the entire time series and plot warming rate vs. ice age. What is the most rapid warming that occurred during the deglaciation that began around 15,000-20,000 years ago?

What is the rate based upon the most recent 25 years? Here is a link:

https://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-ts-6.html

25 year rate (°C/yr):

How do the rates of warming that you've calculated compare with the current warming characterized in the 2007 assessment report from the IPCC in °C/year?

Task 9: Now calculate the rate of change in greenhouse gas concentrations (CO₂ and CH₄) versus gas age for this time period, using the 2013 IPCC report. CO₂ is plotted in figure 2.1 and CH₄ is plotted in figure 2.2. Here is a link for your source data:

https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter02_FINAL.pdf

25 year rate (CO₂ppm/yr) =

25 year rate (C H₄ ppb/yr) =

Now calculate the rate of change in greenhouse gas concentrations (CO₂ and CH₄) for the past century, using the following links. Click on the pdf link and enter your email address, you will be emailed a link to a plot. Use these plots for the following rate calculations.

CO₂ <http://www.eea.europa.eu/data-and-maps/figures/atmospheric-concentration-of-co2-ppm-1>

CH₄ <http://www.eea.europa.eu/data-and-maps/figures/atmospheric-concentration-of-ch4-ppb-1>

100 year rate (CO₂ppm/yr) =

100 year rate (C H₄ ppb/yr) =

GEOL 553 Lab 2: Vostok Ice Core

How do these rates of change compare with the changes in carbon dioxide and methane concentrations that have occurred over the past 100 years?

Task 10: Note that there were two major warming events representing two deglaciations in the Vostok calculated temperature data. Plot (since last 30 ka) and look at how CO₂ and CH₄ change during last deglaciation period. From the data provided in this lab, can you tell which changes first, temperature or greenhouse gas (CO₂, CH₄) concentrations?

Discussion Questions

1. Why do ice age and gas age change with depth in the core? Why does the thickness of annual layers change?
2. Why were CO₂, CH₄, and dust concentrations different during the glacial time as compared to the 18th century?
3. How did conditions during the last glacial maximum (around 20,000 years ago) differ from today's conditions?
4. How do the glacial/interglacial changes in temperature, carbon dioxide, and methane compare to the changes since the 18th century?