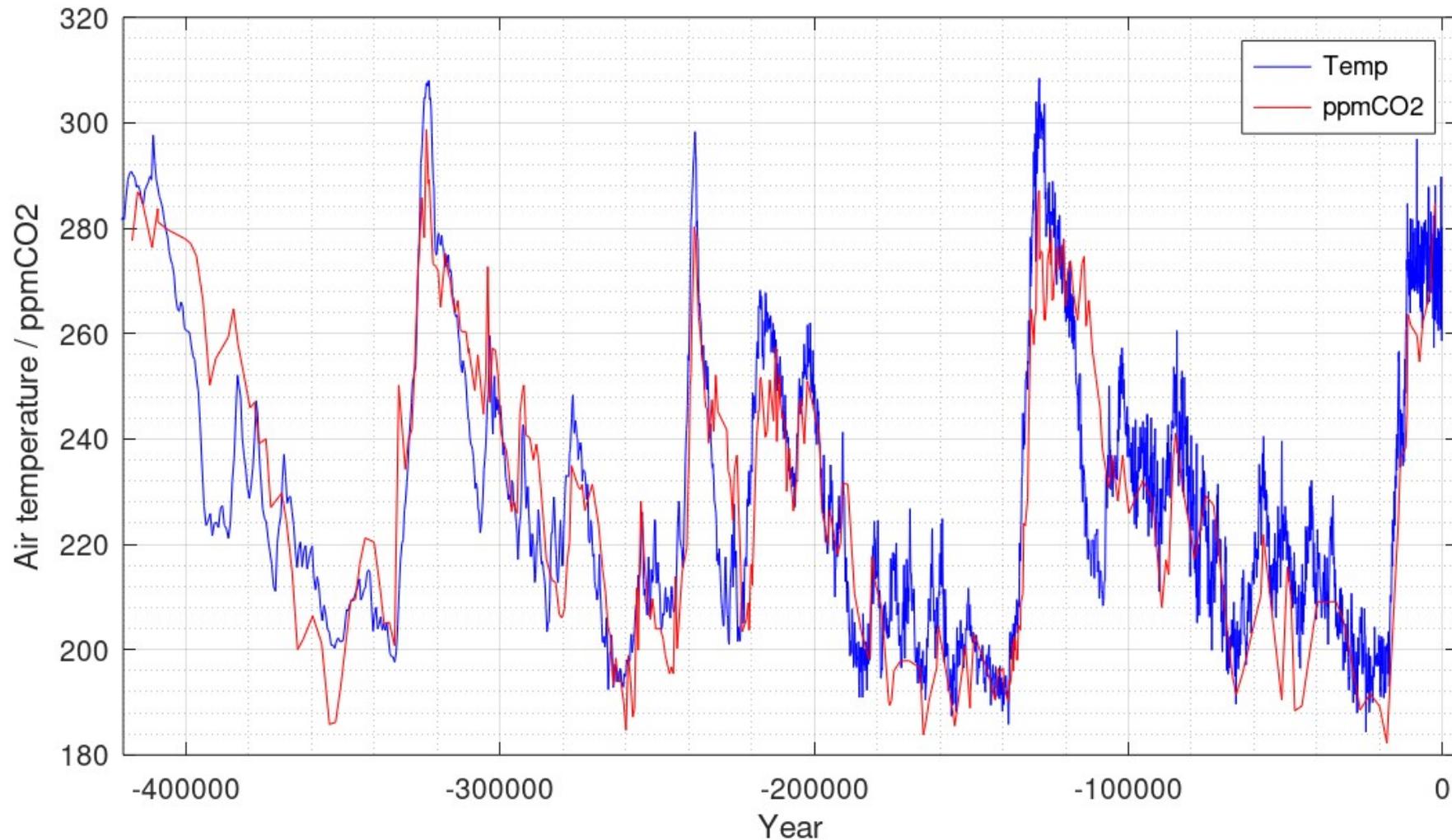
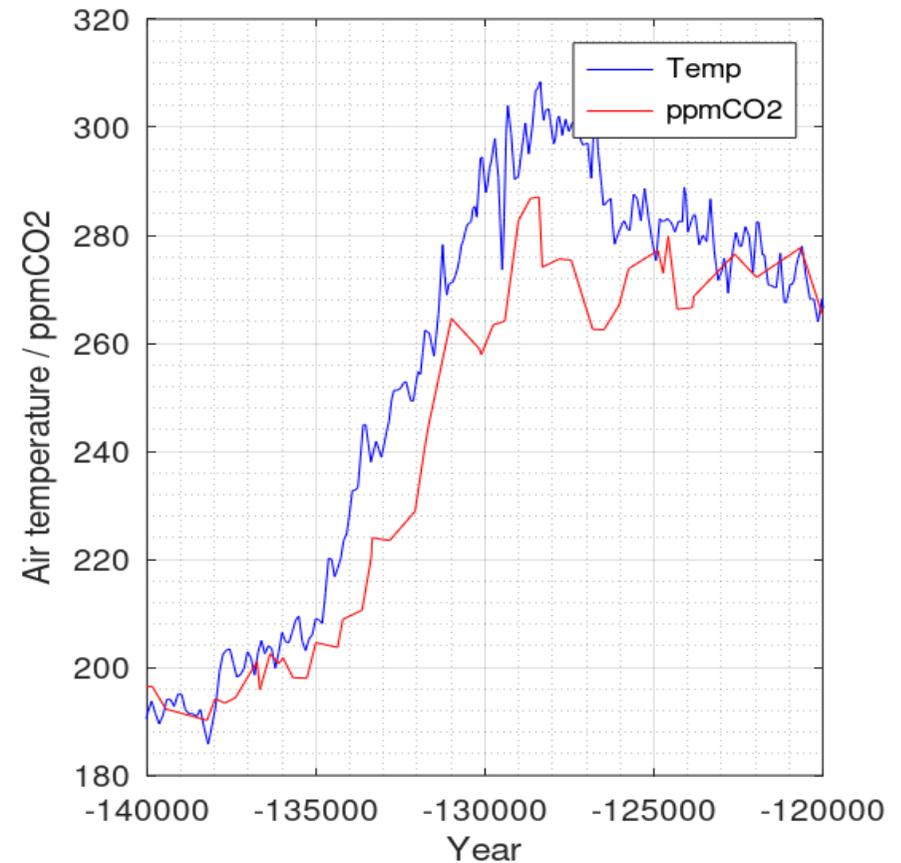
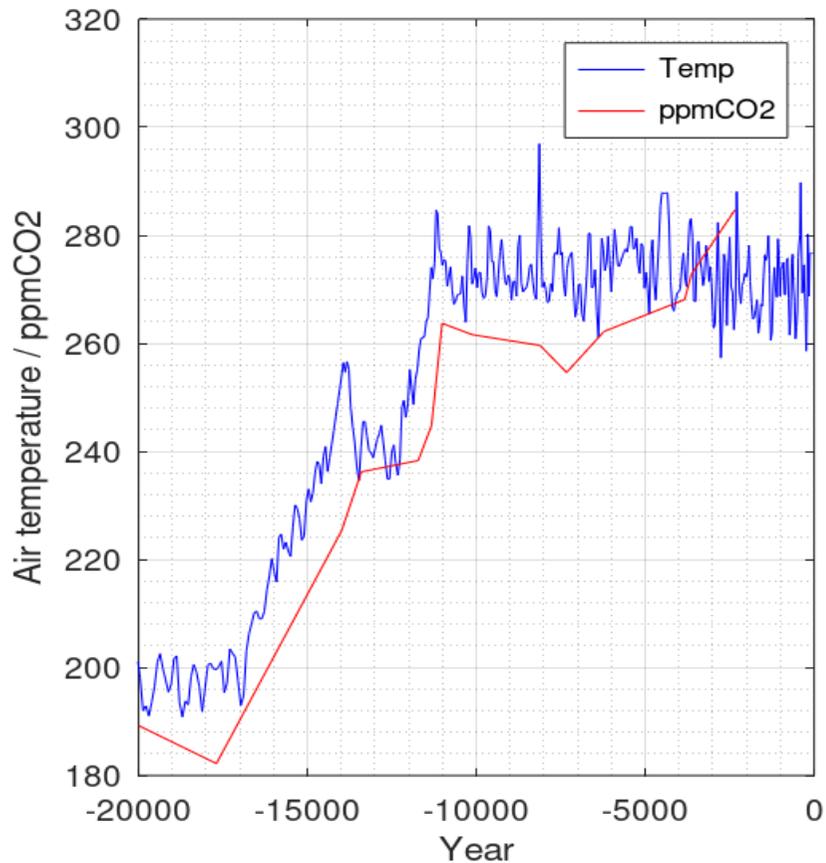


CO₂ and temperatures in the past ages (Vostok station , Antarctica)

In January 1998, the collaborative ice-drilling project between Russia, the United States, and France at the Russian Vostok station in East Antarctica yielded the deepest ice core ever recovered, reaching a depth of 3,623 m . Ice cores are unique with their entrapped air inclusions enabling direct records of past changes in atmospheric trace-gas composition. The resulting data indicate the Vostok ice-core record extends through four climate cycles, with ice slightly older than 400000 year, thus encompassing the last four ice ages ([Petit et al. 1997, 1999](#)).

Vostok air temperature /ppmCO₂





2.2 The Vostok ice core records

Ice drilling in this [russian station](#) in Antarctica extends for more than 3000 m depth. Indeed in January 1998, the collaborative ice-drilling project between Russia, United States and France yielded the deepest ice core ever recovered, reaching a depth of 3,623 m.

This allows to go back in the history of climate and CO₂ concentration to around 420 kY kiloyears before present (kY BP). Microscopic air bubbles trapped in ice, analyzed by mass spectrometry, give the air composition, and by the same way isotopic ratio between O-16 and O-18 in ice water informs us about the temperature at the time of snow deposition.

According to Barnola et al. (1991) and Petit et al. (1999) these measurements indicate that, at the beginning of the deglaciations, the CO₂ increase either was in phase or lagged by less than ~1000 years with respect to the Antarctic temperature, whereas it clearly lagged behind the temperature at the onset of the glaciations.

This utmost interesting data set can be elaborated and presented in different ways, employing the Octave functions. However the first step is to download the data and transform them in two local files, named 'vostok_temp.txt' and 'vostok_CO2.txt'.

```
f = urlwrite('https://cdiac.ess-dive.lbl.gov/ftp/trends/temp/vostok/vostok.1999.temp.dat','vostok_temp.txt')
f = urlwrite('https://cdiac.ess-dive.lbl.gov/ftp/trends/co2/vostok.icecore.co2','vostok_CO2.txt')
```

Once downloaded, one recognizes that the two data sets are not equally spaced, and moreover that temperature is not listed as an absolute value, but as an anomaly from the actual temperature (setting to 0 its average value in the recent 120 years). Before comparing the two data sets, one (temperature) has to be properly scaled to the other. This is done by [Octave script below](#). After usual cut-off of the comments and fill up of the matrix 'X', the mean of ppmCO2 and temperature anomaly are calculated by the `mean()` function and assigned to two scalar mCO2 and mTemp. Thereafter the corresponding standard deviation are given by `std()` function and assigned to stdCO2 and stdTemp scalars. The ratio a2 of the latter values gives the enlargement factor while (mCO2 - mTemp) gives the shift in order to push up the temperature data thus allowing for comparison.

By examining the plots in fig.2 and enlarged in fig.3 it is clearly confirmed that in the deglaciations periods temperature precedes CO2, in a cause to effect sequence.

Fig 2.2 Vostok ice core data compared (blue= temperature, red= ppmCO2). Temperature is scaled (see text).

Fig 2.3 Selected areas of fig 2.2 (blue= temperature, red= ppmCO2)

2.3 Why temperature preceds and CO2 lags behind

Carbon dioxide is a reactive gas, which actively participates in the carbonatic equilibria in seawater. Generally speaking, chemical equilibria in seawater arise among reactive species (like H₂CO₃, HCO₃⁻, CO₃⁻, H₃O⁺, OH⁻ and others). These equilibria can only be tackled by accounting for the high ionic strength of the reaction medium, being hopeless to extrapolate the equilibrium constants values for pure water. Indeed the presence of high amounts of ionic charges (spectator ions, like Na⁺, Ca⁺⁺, Mg⁺⁺, and others) strongly affects the equilibrium parameters (like equilibrium constants). For those curious, all the empirical expressions for the chemical equilibria in seawater and an outline of a computational strategy are published in a book entitled 'algorithms in ocean chemistry', some of them are also to be found here

Breathe in, breathe out..like a giant lung, oceans absorb a vast amount of CO₂ from the atmosphere, and release it once again as cold water currents reach warmer areas of the globe. The solubility of CO₂ varies with temperature, so over cold surfaces, there is CO₂ uptake, and release of this over warmer. The El-Nino-3.4 region is an area of warm temperatures and therefore CO₂ outgassing; its amount can be readily calculated [here](#). To this aim I suppose, quite reasonably, a DIC (Dissolved Inorganic Carbon, the sum of the concentrations of dissolved C species) of 2.07, a ppmCO₂ value of 410 and a temperature coming from the sum of an average value of 26°C plus the thermal anomaly for this region. The resulting temperature (26° + anomaly) can be used to calculate the amount of CO₂ disequilibrium by [SeaWaterCalc programs](#), however, the timing of CO₂ release needs a kinetic model, to explain the time response of the system (i.e. the time needed to reach this equilibrium from an unbalanced situation). To the latter purpose, we use a reasonable model described in Williams 2011. The kinetic model is simply :

$$[\Delta C_t] = [\Delta C_0] \cdot \exp(-t/\tau) \quad \tau = 3 \cdot 10^7 \text{ seconds}$$

ΔC_0 is the disequilibrium contribution which decays exponentially as ΔC_t at the time t in seconds.

```
clear;clc;format short;format compact;
% ----- ppm CO2 -----
S = fileread('vostok_CO2.txt');      % vostok_temp.txt is the file 'as downloaded' from web site
a1 = 1403;                            % start of the useful data structure
M = S(a1:end);                        % M is a 'reduced' string only containing data
X = str2num(M);                       % the row vector is converted into a proper matrix
xYearCO2 = -X(':',3);                 % years before present (air age !!)
yCO2 = X(':',4);                     % ppmv CO2
mCO2 = mean(yCO2)
stdCO2 = std(yCO2)
% ----- temperature -----
S = fileread('vostok_temp.txt');      % vostok_temp.txt is the file 'as downloaded' from web site
a1 = 4571;                            % start of the useful data structure
M = S(a1:end);                        % M is a 'reduced' string only containing data
X = str2num(M);                       % the row vector is converted into a proper matrix
xYearTemp = -X(':',2);               % years before present
yTemp = X(':',4);                   % temperature difference from last 100 years Before Present (BP)
mTemp = mean(yTemp);
yTemp = yTemp + mCO2 - mTemp;
mTemp = mean(yTemp);
stdTemp = std(yTemp);
a2 = stdCO2/stdTemp;
yTemp = a2*(yTemp - mTemp) + mTemp;
plot(xYearTemp,yTemp,'b',xYearCO2,yCO2,'r');grid on;grid minor on;
axis([-420000,5000,180,320]);xlabel('Year');ylabel('Air temperature / ppmCO2');
title(' Vostok air temperature /air ppmCO2');
figure
subplot(1,2,1)
plot(xYearTemp,yTemp,'b',xYearCO2,yCO2,'r');grid on;grid minor on;
axis([-20000,0,180,320]);xlabel('Year');ylabel('Air temperature / ppmCO2');
subplot(1,2,2)
plot(xYearTemp,yTemp,'b',xYearCO2,yCO2,'r');grid on;grid minor on;
axis([-140000,-120000,180,320]);xlabel('Year');ylabel('Air temperature / ppmCO2');
```

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