Accurate estimation of CO_2 background level from near ground measurements at non-mixed environments

Short Summary, full version on : http://www.klima2009.net/en/papers/4

© Climate 2009, Dr. Francis Massen, Ernst-Georg Beck
email: francis.massen@education.lu

Abstract

Atmospheric CO_2 background levels are sampled and processed according to the standards of the NOAA (National Oceanic and Atmospheric Administration) Earth System Research Laboratory mostly at marine environments to minimize the local influence of vegetation, ground or anthropogenic sources. Continental measurements usually show large diurnal and seasonal variations, which makes it difficult to estimate well mixed CO_2 levels.

Historical CO_2 measurements are usually derived from proxies, with ice cores being the favorite. Those done by chemical methods prior to 1960 are often rejected as being inadequate due too poor siting, timing or method. The CO_2 versus wind speed plot represents a simple but valuable tool for validating modern and historic continental data. It is shown that either a visual or a mathematical fit can give data that are close to the regional CO_2 background, even if the average local mixing ratio is much different.

Daily pattern of CO_2 mixing ratios

The daily pattern of the CO_2 mixing ratio depends essentially on the presence and/or the strength of the near ground inversion layer. This layer (which exists mostly at night, during the morning hours or at late afternoon) prevents a thorough mixing up of the atmosphere and coincides usually with large CO_2 peaks (Massen, 2007). During the midday hours, solar heating is normally at a maximum and creates the strongest convective air movements. As a consequence, the atmospheric boundary layer is well mixed up, and CO_2 mixing ratios fall to their daily minimum. This minimum is seen as the most representative measure of the regional CO_2 background level.

The inversion periods are much shorter and less intense at the border of open sea or at smaller islands, where a quasi continuous breeze mixes up the boundary layer at most periods of the day. As a consequence, the daily CO_2 variation is much lower at these locations; that are considered as the most suitable for background CO_2 measurements.

Meanwhile vertical profiles of the atmospheric CO_2 concentration are available at many environments; they usually show different mixing ratios, with location having a much greater influence than altitude.

The problem of continental near-ground CO_2 measurements

CO_2 data sampled at continental environments near ground usually show large diurnal and seasonal variations which make it difficult to estimate the proper well mixed levels. Historical measurements prior to the high quality continuous recordings available since 1958 have been shown as being often very precise, done with great care by outstanding scientists. Many have been done in rural, semi-urban and marine environments (Beck, 2007). These measurements were usually spot measurements, made at different times of the day, and as such are difficult to evaluate: depending on the measurement routine, they may have a positive bias (for instance for measurements done during the morning hours) or show large variations. Nevertheless, there exist historical continuous sampling series done under fixed conditions over one or more seasons.

When meteorological parameters have been registered together with the CO_2 mixing ratios, there is a good chance to validate historical as well as modern continental data by using a CO_2 versus wind-speed plot.

The typical CO_2 versus wind-speed profiles

It is well known, that CO_2 pattern vary with latitude and time: mixing ratios and seasonal amplitude are lowest at the South Pole and highest at northern locations. Semi-rural, inland located stations like Diekirch (L) have a very different CO_2/windspeed pattern: the absence of a strong seasonal swing gives a typical boomerang-shaped graph.

This boomerang pattern is typical for inland stations, and shows up for instance at the Neuglobsow and Schauinsland stations, located in the North and in the Black Forest of Germany. The pattern of the graph shows the magnitude of the regional background level; a primitive mathematical model allows calculation of the asymptotic mixing ratio that would be present if wind speed was infinite.

The authors found that a simple dilution formula like

$$CO_2 = a + b * e^{-c*windspeed} \quad \text{[eq.1]}$$

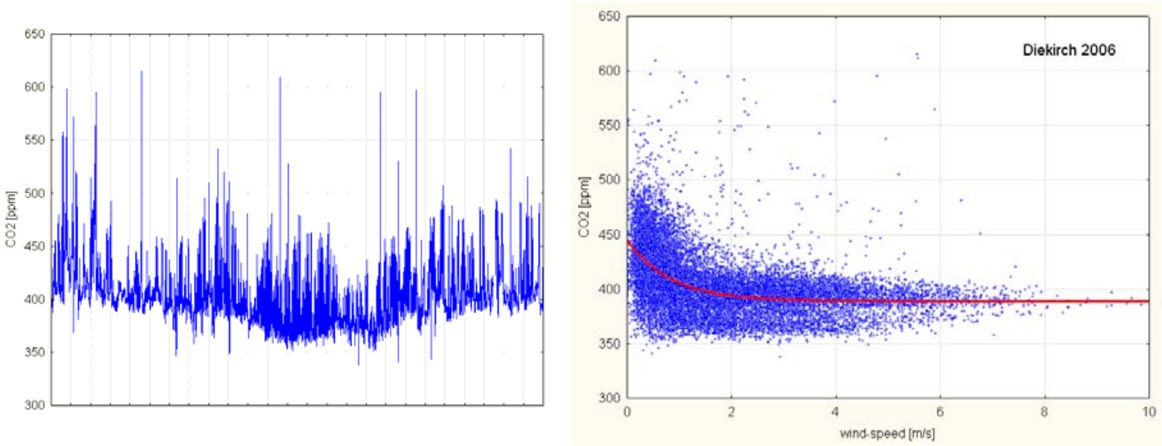

Fig.7* Year 2006 CO_2 levels and CO2 versus wind-speed pattern at Diekirch, Luxembourg.

often is adequate. For the Diekirch data shown in fig.7 this model suggest

$$CO_2 = 389 + 56.1 * e^{-1.2*windspeed} \qquad \text{[eq. 2]}$$

with an asymptotic value of 389 ppm (red curve in right plot of fig.7). R = 0.51 and the fit parameters are all significant at the 5% level (calculations done using the Statistica 7 package, Levenberg-Marquardt algorithm applied). The yearly average was 404.1 ppm, considerably higher than this asymptotic value.

The year 2006 Mauna Loa average was 381.7 ppm. If we assume a latitudinal gradient of 0.06 ppm/degree (as suggested by a prior unpublished study of one of the authors) this would correspond to 381.7 + 0.06*(50 -20) = 383.5 ppm for a sea-side station at the latitude of Diekirch. The NOAA CO_2 average for the whole globe is 382.5 ppm for 2006.The example shown above represented the single year 2006 situation. It is quite interesting to note that applying the wind-speed method to multi-year data also can give a very close estimate of the mean global background CO_2 mixing ratio for this extended period. We will use the 17 year series from the Harvard Forest Station (Ameriflux project) to document this:

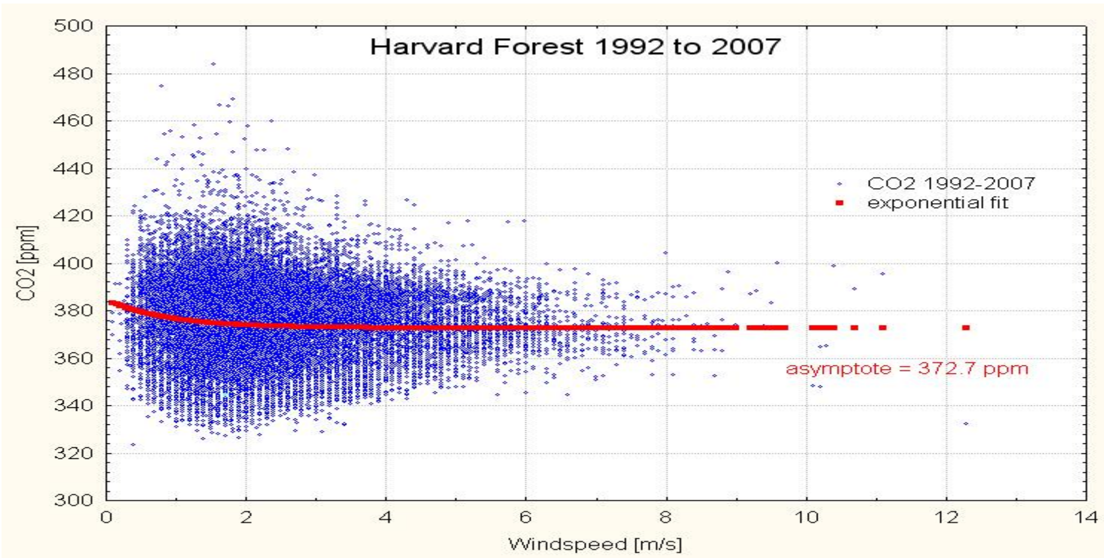

Fig.8* 1992 - 2007 yearly averaged data from Harvard Forest, Ameriflux (data source: Bill Munger, Steven Wofsy): the asymptotic value of 372.7 ppm deduced by an exponential fit differs only by 1.2% from the mean global value at sea level (and only by 0.6% from the latitude adjusted mean Mauna Loa levels over the same 16 years period)

Validation of historical data

The accuracy of historic measurements is estimated at being least at 3% (Beck, 2007); this means that the insecurity interval of a result of for example 355 ppm is [344...366 ppm]. We will apply the preceding validation checks to 3 historical CO_2 measurement series made at Giessen (D), Liège (B) and Vienna (AU) during the 19th and 20th centuries. Only the Giessen data are presented in this summary.

CO_2 and weather data were measured by Wilhelm Kreutz in Giessen, Germany (latitude 50.5°) from the 31th August 1939 to the 31st May 1941 by a volumetric chemical method (a variant of the Pettenkofer method), using an automatically working system (Kreutz, 1941; Beck, 2007). The instrument used was a commercially available Riedel RICO C gas analyzer with an accuracy of ~1.5% .

Kreutz in 1939-1941 had calculated an average of 417 ppm showing western influence of the city of Giessen and lowest CO_2 levels of ~377 ppm in the northern and eastern winds from the open rural regions in the afternoon.

The CO_2 versus wind speed plot using data sampled at 2 m above ground until May 1940 has neither clear finger nor a boomerang shape, but the high wind speed data suggest a possible CO_2 range between 466 and 326 ppm, a range too large to be of much use. The mathematical fit by an exponential function (eq. 1) points to a regional background level of 387 ppm (R = 0.15, the asymptote and damping parameter being statistically significant). The IPCC (Intergovernmental Panel on Climate Change) consensus is that global CO_2 levels were about 310 ppm during that period. If we agree to the fact that the Giessen measurements were done with uttermost care and great precision, that higher wind speeds cause a more thorough mixing up and that as a consequence the asymptotic level detected will not be an artifact due to poor sampling time and sub-optimal siting, the 310 ppm global CO_2 level seems much lower than the regional background level at Giessen during 1939/1940.

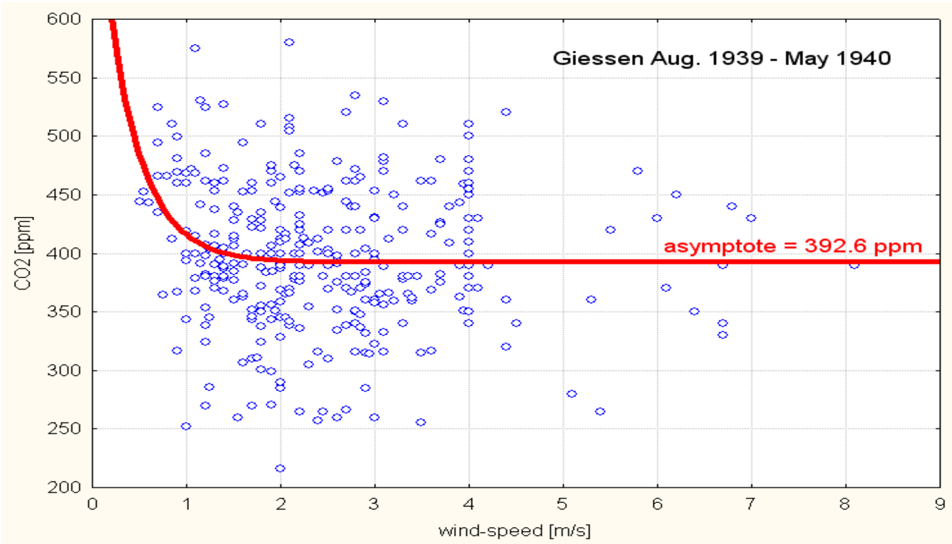

Fig.10* The CO_2 versus wind speed plot of the Giessen measurements by W. Kreutz (average = 398, stdev = 62) * Figures in correct listing as in the full paper

Conclusion

It has been shown that the CO_2 versus wind-speed plot can represent a valuable tool to estimate continental local background CO_2 levels despite of distorted mixing ratios or local influences. Applying the procedure to recent well known data gives results that are relatively close to the yearly average of the observational data at Mauna Loa and suggest a maximum difference of about 10 ppm with the global CO_2 background as given by NOAA (National Oceanic and Atmospheric Administration).

A validation check has been made for 3 historical CO_2 series. The overall impression is one of continental European historic regional CO_2 background levels significantly higher than the commonly assumed global ice-core proxy levels.

The CO_2 versus wind-speed plot seems to be a good first level validation tool for historical data. With the required caveats it could deliver a reasonable approximation of past regional and possibly past global CO_2 background levels.

References (extract)

1) Ameriflux Network, Harvard Forest Station
http://cdiac.esd.ornl.gov/programs/ameriflux/data_system/aaHarvard_Forest_g2.html
2) Beck, E. G.: 180 years of atmospheric CO2 gas analysis by chemical methods. Energy & Environment, vol 18 no.2, 2007.Massen, F.: Pattern of CO_2 and other atmospheric gases during a cold weather inversion, 2009. http://meteo.lcd.lu/papers/
3) Kreutz, W. Kohlensäure Gehalt der unteren Luftschichten in Abhaengigkeit von Witterungsfaktoren," *Angewandte Botanik,* vol. 2, 1941, pp. 89-117,

* Figures in correct listing as in the full paper