Appendix 4: Examples of using the SchoolCO2web

In this appendix, some examples will be shown illustrating some of the questions listed in Chapter 4, section ‘Scientific studies – atmospheric cycles’.

**Question:** Is there a difference in day-night cycle between a summer and a winter day? Would any potential effect be caused by different day lengths, increased or decreased photosynthesis, higher or lower temperature, etcetera, or a combination of different factors.

**Approach:** A typical winter day would be a day in January and a typical summer day in July. To get an overview, take a week in January and a week in July and show graphs with the CO$_2$-concentration on the left y-axis and the temperature on the right y-axis. In this case, the following series were taken:

Maartenscollege Haren, The Netherlands 01.01.2010 – 07.01.2010:

![Graph 1](image1)

Maartenscollege Haren, The Netherlands 01.07.2010 – 07.07.2010:

![Graph 2](image2)

**Observation of differences:**
1. The nights are (obviously) much shorter in summer
2. The pattern is more regular in summer: clear inversions
3. The temperature differences between day and night are much smaller in winter
4. In summer the inversion effect is much stronger. This can be explained by temperature and photosynthesis. The CO$_2$-level drops a lot during the day (growth season of plants – CO$_2$-fixation. Long daylight time, so long time to perform photosynthesis) and increases again during the night. This increase is likely caused by a drop in temperature, so less turbulence in the air. Probably, also the wind speed decreased during the summer nights and therefore the air is no longer properly mixed, resulting in accumulating of CO$_2$ in the lower air layers, where the CO$_2$-meter is located. This should be confirmed by checking the wind speed for these days.
5. The difference in minimum and maximum CO$_2$-levels on a day is smaller in winter. In winter, there is no or little plant growth and thus no or little CO$_2$-fixation by photosynthesis and CO$_2$ removal from the air.
**Question:** Are there differences in patterns between a relatively warm and a very cold day in winter? If so, how do these differences relate to differences between a typical summer day and a typical winter day?

**Approach:** First search for a relatively warm and a very cold day in winter. To do so, check the temperatures for a month and pick the best suitable days. For this example, check December 2008 at the Stellingwerfcollege in Oosterwolde, The Netherlands. A period with first some relatively warm days followed by some cold days is 23.12.2008 – 30.12.2008. Make a graph with CO\textsubscript{2}-concentration on the left y-axis and temperature on the right.

![Graph showing CO\textsubscript{2} concentration and temperature changes over time.](image)

Observation: the CO\textsubscript{2}-concentration is lower from 23-26.12.2008 and increases from 26-30.12.2008. The temperature on the other hand is higher in the first days and decreases from the 26\textsuperscript{th}. The graph suggests that the CO\textsubscript{2}-concentration increases when the temperature decreases. A possible explanation would be that a lower temperature results in less turbulence of the air and thus an accumulation of CO\textsubscript{2} in the lower air layers, where also the CO\textsubscript{2}-meter is located. Another reason, however, could be that there is just a difference in wind speed: more wind in the first days and less wind in the last days of this week. To check this, make another graph. In this case with the CO\textsubscript{2}-concentration on the left y-axis and wind speed on the right y-axis.

![Graph showing CO\textsubscript{2} concentration and wind speed changes over time.](image)

As can be seen from the graph, the wind speed is generally low in this week, with the exception of the 24\textsuperscript{th} of December. It can be observed that on this day, the CO\textsubscript{2}-concentration drops even further. However, the low CO\textsubscript{2}-concentration in the first days of the week is not caused by a generally higher wind speed in this period compared to low wind in the last days. It is therefore likely that the temperature difference between a relatively warm winter day, e.g. the 23\textsuperscript{th} or the 25\textsuperscript{th} of December, and a cold winter day, e.g. the 30\textsuperscript{th}, is reflected in the CO\textsubscript{2}-concentration. It is, however, not possible to conclude from just this graph that there is a real negative correlation between temperature and CO\textsubscript{2}-concentration. This requires a proper correlation analysis.

Another observation is that the difference between a ‘warm’ and a ‘cold’ winter day is different from the difference between a typical winter day and a typical summer day. The winter pattern in general is more irregular than the summer pattern. An explanation can be found in the absence of photosynthetic effects in the winter. There is thus no drop in the CO\textsubscript{2}-levels during the day because of CO\textsubscript{2}-fixation by plants. The only drop that is observed is caused by increased turbulence during the day compared to the night. However, with the low day temperatures in winter, this effect is also not very strong.
**Question:** Under which conditions does inversion occur? Correlations with wind speed have been established, but pupils can try to find more examples of inversion through low wind speed in the existing datasets. In addition, they could debate the effect other weather conditions/local situations might have on inversion. Which factors would promote inversion? Which factors would inhibit inversion? When would these factors be optimal for inversion to occur? Can they then indeed find inversion patterns in the datasets under these conditions? And can they demonstrate a correlation between these factors and CO$_2$-concentrations?

**Approach:** As can already be seen from the examples above, inversion is a widespread phenomenon. Generally, inversion effects are stronger in spring/summer than in autumn/winter. In spring/summer the difference between the maximum and the minimum CO$_2$-concentration on a day is bigger, for two reasons:

1. a longer time of daylight and massive activity of plant growth and thus photosynthesis. High amount of CO$_2$ are thus fixed and removed from the atmosphere
2. a bigger difference in temperature between day and night times. During the day, the high(er) temperature results in increased turbulence, a good mixing of the air and thus lower measured CO$_2$-concentrations. During the night, turbulence as a result of heating decreases. The only turbulence left could be caused by wind speed. Often, in summer the wind speed decreases in the evening/night, thereby provoking inversion conditions

To look for inversion which is increased by either the temperature or the photosynthesis component, it would be good to compare random weeks from winter, spring, summer and autumn. For this purpose, look into the data of the Carl-Zeiss Gymnasium in Jena, Germany.

Carl-Zeiss-Gymnasium, 01.02.10-07.02.10, CO$_2$-concentration and wind speed

This picture shows a very clear example of inversion in the winter period. In the first days, there was more wind and thus less inversion. From the 4th of February on, the wind speed decreased and clear inversion can be observed.

Carl-Zeiss-Gymnasium, 16.05.10-23.05.10, CO$_2$-concentration and wind speed

This picture shows an inversion pattern in spring. The wind speed was often low during the night and thus inversion could occur. Judging from the shape, the peaks are sharper than the ones in the winter week. Also, the CO$_2$-concentration drops more during the day, indicating CO$_2$-fixation by plants. Since this is the same school and the same CO$_2$-meter, it is possible to compare the absolute levels in ppm between the winter and spring week. In general, the inversion effect seems stronger in spring than in winter.
Carl-Zeiss-Gymnasium, 01.08.10–07.08.10, CO₂-concentration and wind speed

This picture shows an inversion pattern in a summer week. Compared to the spring pattern, the peaks are even sharper and the differences between the lowest and the highest CO₂-concentration are even bigger. This is the result of CO₂-fixation during the, long, daylight and very well mixing of the air due to the high temperatures (~24°C during the day).

Carl-Zeiss-Gymnasium, 01.10.09 – 07.10.09, CO₂-concentration and wind speed

This picture shows an example of an inversion pattern in autumn. Inversion is visible and also the wind effect is clearly shown (04.10.09, high wind, low CO₂ at night). The peaks have decreased compared to summer and are in height comparable with spring. However, the picture is a kind of contrary to the spring inversion pattern. The drop in CO₂-concentration during daytime is less, indicating the end of the growth season. In autumn, the increase during the night is the most apparent feature, while in spring the decrease during the day is the eye-catching pattern, corresponding in the latter case with an increase in photosynthesis early in the growth season.
**Question:** Is there a difference in length or start of the growing season between different schools’ environments? How do you observe the start of the growing season in the dataseries? When does the growing season start in for example the German schools’ environment? And in The Netherlands? Or Italy? What can be seen when comparing the growing season out of the dataseries of two Dutch schools?

**Approach:** The start of the growing season is characterized by drops in CO$_2$-concentrations during the day as a result of CO$_2$-fixation by photosynthesizing plants. To find the start of the growing season in the data, one should first make an assumption. When is the start expected? Likely, the growing season starts sometime between the first of March and the end of April. As a start, therefore make a graph of the CO$_2$-concentrations measured in March and April at the Carl-Zeiss-Gymnasium in Jena, Germany.

In this picture, a more regular pattern start to appear in the beginning of April. At that moment, the CO$_2$-concentrations drop during the day. However, one can never be entirely sure whether they drop because of photosynthesis or because of the better mixing of the air due to increased temperature. It is likely a combined contribution of both temperature and CO$_2$-fixation. On the other hand, an increased temperature is also important for plants to start growing, so a close relationship between these two factors is only normal.

For clarity, zoom in on the period around the start of the growing season, so from 25.03.2010 till 10.04.2010. For confirmation that indeed the temperature also has an added effect to the drop in temperature during the day, include the temperature in the graph on the right y-axis.

In the picture, it can indeed be seen that the temperature increases and that the CO$_2$-concentrations drop much more during the daytime from the 1st of April. The start of the growing season can therefore be estimated at this date.

To determine the end of the growing season, do the same, but now look for diminishing drops in CO$_2$-levels during the day. The end of the growing season would be expected in September – October. By focussing on October, the following graph can be made.

Used data: Carl-Zeiss-Gymnasium, 06.10.09 – 30.10.09, CO$_2$-concentration and temperature.
First of all, it should be noted that this is not the best series in the measured data at the Carl-Zeiss-Gymnasium. However, in the first days, the temperature is still quite high and there are clear drops in CO$_2$-concentrations during the day. In the period from 11.10.09-20.10.09, the peaks are only small. In this time, there was somewhat more wind, which could explain the reduced CO$_2$-accumulation at night. From the 20$^{th}$ of October on, the peaks increase again, but the trend seems to be reversed: less drop during the day and more increase during the night. The end of the growth season can thus be estimated at approximately 10 – 20 October.

The growth season in Jena thus ranged from the first of April till the 10$^{th}$ or 20$^{th}$ of October 2009, so over a period over approximately 7.5 months. In the same way, the growth season can be determined for other SchoolCO2web participants and the lengths can be compared. However, not all participants have data available over a long enough time, so it might be hard to see differences between the various regions in Europe.