D3.2 Documentation for teachers of the educational opportunities of the SchoolCO2web

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1. Introduction

The goal of the SchoolCO2web is to give pupils more insight into the carbon cycle and fluctuations of CO$_2$-concentrations in the atmosphere, to familiarize them with the ‘do’s and don’ts’ of proper measuring and to acquaint them with scientific research. This is a multidisciplinary topic, which includes mathematics, physics, chemistry and biology.

Within the SchoolCO2web, pupils learn how to measure CO$_2$-concentrations and how to interpret these. They become familiar with the requirements for good measurements and learn that obtained data should be relevant, reproducible and trustworthy and how to achieve this. The data of all participants in the SchoolCO2web are collected in a large database. Pupils learn how to extract valuable information from this by means of spreadsheet programs and statistics. This provides a tool to ultimately involve them in data analysis, which is an important skill within scientific research. In this way, pupils will get insight into professional scientific practice.

By addressing these aspects, the project creates a bridge between high school education and university science. The CO$_2$-measurements are performed at the schools themselves, thereby bringing science closer to the pupils. The obtained data are be embedded in the schools’ educational program and can be useful within scientific research at the university, as the collection of CO$_2$-datapoints reflects a broad measuring network. Finally, the international character of the project, a European network of schools contributing to the SchoolCO2web, emphasizes the international nature of the greenhouse gas science and opens up possibilities for project cooperation between pupils from different countries.

The current document is meant as an introduction for teachers and aims on stimulating them to use the SchoolCO2web and its opportunities in their lessons. The background of the SchoolCO2web is outlined in chapter 2 and 3, describing the carbon cycle, climate effects, atmospheric CO$_2$-levels and CO$_2$-measurements. In chapter 4, different classroom/pupil group activities are presented. The appendices provide concrete information and guidelines on how to work with the SchoolCO2web data, for example, the headlines of several ready-made modules and some appealing examples of SchoolCO2web data.

2. Carbon cycles, Climate effects and Carboschools

1. The carbon cycle depicts the flow of carbon around the world

Carbon is found in billions of tons all around our planet. A general overview of the system shows five major carbon reservoirs: 1) the atmosphere, 2) the terrestrial biosphere (including fresh water systems and non-living organic material), 3) the oceans (including dissolved inorganic carbon and living and non-living marine biota), 4) the sediments (including fossil fuels) and 5) the Earth’s interior (Figure 1). Continuously, carbon is exchanged between these reservoirs by means of the carbon cycle, which was initially discovered by Joseph Priestley and Antoine Lavoisier in the 18$^{th}$ century. This biogeochemical exchange occurs via a wide variety of chemical, physical, geological and biological processes and allows the recycling of carbon and its reuseage in the biosphere.

2. Transfer rates and timescales of carbon fluxes

Based on the transfer rate of carbon between the reservoirs, their size and the nature of the carbon compounds (organic or inorganic), three subcycles can be distinguished: the shortterm organic carbon cycle (high transfer rate, relatively small reservoir), the longterm organic carbon cycle and the longterm inorganic carbon cycle (both low transfer rate, large reservoir). The shortterm cycle comprises the interactions between the atmosphere and
the biosphere, such as CO$_2$-fixation by plant photosynthesis and CO$_2$-emission by animal respiration. The longterm organic carbon cycle mainly involves the formation and utilization of fossil fuels and other carbon-containing sediments, while the longterm inorganic carbon cycle focusses on the largest of all carbon reservoirs, limestone (Calcium carbonate). The three subcycles together control the atmospheric levels of CO$_2$, but do so on very different timescales which range from months (shortterm) to tens of millions of years (longterm inorganic).

3. Disturbing the carbon cycle – risk for climate change
The (im)balance in and between the three subcycles is a hot topic in the current debate on global warming. As a result of the increased energy demand of the worlds' population, an imbalance is introduced in the carbon cycle. Fossil fuels are expended at a high rate for shortterm benefits, like energy, resulting in an enormous CO$_2$-emission (approximately 29 billions of tons per year in 2007). However, only 55 – 60% of the atmospheric CO$_2$ can be absorbed again by the Earth's carbon sinks, like oceans and plants and forests. The remaining 40 – 45% of the CO$_2$ thus stays in the atmosphere and acts as a greenhouse gas. Figure 2 shows an overview of the CO$_2$-emission due to combustion of fossil fuels per country.

In 1988, the United Nations established the International Panel on Climate Change (IPCC) to report on (the risks of) climate change. Nowadays, the relation between the increase in atmospheric greenhouse gases (e.g. CO$_2$, methane, nitrous oxide) and the increase in global temperature is generally accepted. Furthermore, in 2007 the IPCC report stated that “most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations”, thus strongly focussing on the influence of human behaviour on the climate.

Not only does an increase in global temperature imply a severe risk for individual countries, threatening with floods, bad harvests or droughts, but climate change also can have more extensive effects, especially on the most vulnerable countries and regions in the world. As the Norwegian Nobel committee said in its announcement speech “Extensive climate changes may […] induce large-scale migration and lead to greater competition for the earth’s resources. […] There may be increased danger of violent conflicts and wars, within and between states”. The committee therefore decided to award the IPCC and Arnold (Al) Gore Jr. with the Nobel Peace Price 2007 for “their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundations for the measures that are needed to counteract such change”.

4. Importance of standardized measurements – risk for false interpretations and wrong conclusions
With the undeniable rise in global temperature and greenhouse gas concentrations, the worldwide interest in climate research is booming. However, climate change is hard to measure and the available data are often difficult to interpret and to translate into immediate climate effects. Large datasets are required and furthermore all measurements should be performed in a standardized way to allow comparisons between different studies. It has happened too often that wrong conclusions were drawn just because data sampling was different and thus uncomparable. A very striking example of what can go wrong is a, for a long time unexplanable, drop in seawater surface temperature (Figure 3), but not land surface temperature in August 1945. At that time, data on seawater temperatures were sampled mainly by US and UK marine ships. During the Second World War, approximately 80% of the measurements were taken by US marine ships (versus ~5% by UK ships). At the end of the war, this ratio changed to ~30% US ships and ~50% UK ships. However, the two countries used different methods: the Americans used mainly engine room intake measurements (measuring the temperature of the cooling water, generally biased for too high temperatures), while the UK ships predominantly relied on bucket measurements (measuring the temperature of captured seawater, generally biased for too low temperatures). With the share of UK ships in the measurements increasing, the average temperature obviously dropped. In a Nature publication in 2008, Thompson et al. showed that the observed drop in seawater temperature was, however, just an artefact, despite all hypotheses postulated in earlier years to explain this phenomenon.
5. How does Carboschools fit in the picture and what are the aims
Within the framework of worldwide climate change research and initiatives, the carboschools project “SchoolCO2web” aims at creating awareness of the nature of climate change, but moreover of the requirements for proper measurements as stressed above. Furthermore, the intention of the project is to involve pupils actively in scientific research by performing measurements at their schools and by working with the collected datasets themselves. For this purpose, the participating schools are provided with a CO₂-meter and a weather station (more detailed in section 3.4) to measure local CO₂-concentrations. Questions that the participating pupils should become familiar with are amongst others: 1) what actually is a measurement? 2) when can I trust my measurement? 3) is the number on the meter the exact reflection of the CO₂-concentration in the air? 4) which factors do influence CO₂-concentrations? 5) when can I say something about a trend in the measured concentrations?
By participating in the SchoolCO2web, pupils from different schools will obtain insight in the good habits of measuring greenhouse gases and, moreover, will be able to compare the collected data, thereby increasing their awareness of problems, pitfalls and possibilities of climate research. In the next section, more background information on CO₂-measurements will be described.

3. Atmospheric CO₂ cycles in a nutshell

1. The atmospheric composition
The atmosphere surrounding our planet is build up of several layers of gases (Figure 4). It protects life on Earth by absorbing ultraviolet solar radiation, by warming the surface through heat retention (greenhouse effect) and by reducing extreme temperature differences between night and daytime. Roughly 80% of the total of the atmospheric gases is located in the troposphere, which is the lowest of five principal surrounding layers. The troposphere starts at the earth’s surface and extends to approximately 7 kilometers at the poles till about 17 kilometers at the equator. Tropos in Greek means ‘turning’ or ‘mixing’, referring to turbulent mixing processes that occur in the troposphere, influencing its structure and behaviour. Most of the phenomena that are associated with our day-to-day weather take place in this layer. And most of the emitted CO₂ ends up in the troposphere, so this is the layer to investigate in CO₂-research.

2. CO₂-concentrations in the troposphere
As a result of the high turbulence in the troposphere, the air becomes mixed and gas-concentration differences level out. The strength of this effect increases with altitude. Near the surface, high levels of CO₂ are produced, as a result of for example animal respiration or emission by industry, while on the other hand CO₂ is taken up again by plants to use in photosynthesis. Combined with a relatively low mixing of the air, this results in strongly fluctuating CO₂-concentrations when measured close to the surface, which reflect the very local situation rather than an average for a larger area.
Professional CO₂-research stations are therefore usually positioned at a high location. The measuring station at Mauna Loa (Hawaii) is a good example. It is located at a volcano at an altitude of 3400 meters. Figure 5 depicts recent data obtained at this station, with the red line showing the monthly average CO₂-levels. As can be seen, the levels oscillate over a period of one year. These oscillations are caused by seasonal effects. During the growth season, plants exhibit an increased CO₂-fixation for photosynthesis. As a result, the atmospheric concentration drops with a few parts per million (ppm) in the period from May till September at the Northern hemisphere. The black line shows the monthly average CO₂-levels corrected for seasonal effects. During the last years, the average CO₂-level increased with almost 2 ppm per year, reflecting the combustion of fossil fuels.
3. Measuring CO$_2$-concentrations at lower altitudes

Ideally, only high altitude measuring stations would thus be used for investigating atmospheric CO$_2$-levels. However, for financial and practical reasons this is not always possible. Still, although CO$_2$-measurements at low altitudes are easily influenced by CO$_2$-drops as a result of photosynthesis by plants and CO$_2$-rises due to animal respiration, also close to the Earth’s surface good data can be obtained, as long as the experimental setup is well thought through and the collected data are filtered to leave only the relevant measurements. For the SchoolCO2web, participating schools are provided with a CO$_2$-meter and a weather station (see next section) which is located at their roofs and reports its data to the SchoolCO2web database. In addition, the network has access to CO$_2$-data measured at the professional station of the Centre for Isotopic Research of the University of Groningen in The Netherlands. This station is located at a 60-meters high pole at Lutjewad, near the Dutch Waddenzee-coast. Due to its location – the relatively high altitude, a predominantly favorable wind direction and a lack of vegetation in the area – this CO$_2$-meter gives very accurate data, which are used for scientific research by the CIO itself, but also as comparisons by the pupils of the SchoolCO2web.

4. The Vaisala CO$_2$-meter

In the SchoolCO2web project, each participating school is equipped with a Vaisala Carbocap GMP343 CO$_2$-meter, which is installed at the roof, so at a height of maximally 10 to 20 meters. This type of CO$_2$-meter is a so called non-dispersive infrared sensor. A schematic overview of the measuring unit is shown in Figure 6. The Vaisala contains a lamp which emits infrared light. Via a mirror this light is reflected to a detector for infrared light. On its way, the light encounters CO$_2$-molecules in the air, which absorb part of the light. As a result, less light will reach the detector. The difference in intensity between emitted and detected light is a measure for the number of light-absorbing CO$_2$-molecules and thus for the CO$_2$-concentration in the air.

In addition, every school got a Davis Vantage PRO weather station installed, which measures air pressure, temperature and humidity and sends the data to the Vaisala. With help of these values, the Vaisala can correct its own CO$_2$-measurements for changes in weather conditions. For example: when the air pressure increases, more particles will be present in the same space in the measuring unit of the Vaisala. As a consequence, there are also more CO$_2$-molecules and the measured level will be higher. However, researchers are not interested in the number of CO$_2$-molecules per measuring unit, but want to know the CO$_2$-levels independent of the air pressure. Using the data on the air pressure obtained by the weather station, the Vaisala calculates the CO$_2$-concentration according to a fixed value for air pressure and in this way corrects the CO$_2$-levels for the actual air pressure. The weather station also keeps track of other factors, like the amount of rain, wind speed and wind direction, which can be useful for interpretation of the CO$_2$-data as will be explained in the next section.

All data obtained by each participant are reported to the SchoolCO2web and collected in a database. One of the main aims of this Carboschools project is to make pupils aware of fluctuations in the CO$_2$-levels that are just due to the measuring conditions or their local situation instead of reflecting a general trend in atmospheric CO$_2$-concentrations. At the same time, they can perform datamining studies to actively search for relevant trends, local CO$_2$-sinks and sources, seasonal effects, etcetera. For this, comparisons between the measurements of their own school and those of another school or the CIO station can be very useful. A tutorial on how to download and the data from the SchoolCO2web can be found in Appendix 1. In the next section, an example of this kind of studies will be described. This approach can be used as a guideline for further projects as described in chapter 4 - ‘Topics in the classroom’.

5. Inversion - an example of CO$_2$-fluctuations

An illustrative example of CO$_2$-fluctuations is shown in Figure 7. For the same period of time, the 10$^{th}$ till the 14$^{th}$ of November 2008, CO$_2$-concentration data are downloaded from the SchoolCO2web and represented in graphs for both the Carl-Zeiss-Gymnasium in Jena, Germany and the Maartencollege in Haren, The Netherlands (Fig7, left). The grey and white areas in the graph represent night and day respectively. A peculiar phenomenon can be observed at the 13$^{th}$ and 14$^{th}$ of November, when there is a large increase in CO$_2$-concentration during the night and a drop during the day. This effect is called inversion, a situation in which the air next to the Earth is trapped by a layer of warmer air above it and thus, including the CO$_2$, is kept close to the Earth. Following the CO$_2$-concentration during the day, this is what happens: 1) when daylight starts, plants can perform photosynthesis and fix CO$_2$, resulting in a reduction of the atmospheric CO$_2$-level. Simultaneously, the sun heats the earth and the earth emits heat to the air, thereby evoking turbulence and mixing of the surface air layer with layers higher.
in the atmosphere. This results in an even distribution of a relatively low CO$_2$-level through the layers during daytime. 2) In the evening, the earth cools down rapidly. As a result, the air close to the surface also cools down. The higher air layers, however, are still warmer and function as a blanket to prevent mixture of the air. In addition, plants stop photosynthesizing when it becomes dark and can no longer fix CO$_2$ from the atmosphere. As a result, all the CO$_2$ exhaled by organisms accumulates in the surface layer, where also the CO$_2$-meter is located. The meter thus registers a higher CO$_2$-concentration during the night than during the day. Although a strong inversion can be seen at the 13$^{th}$ and 14$^{th}$ of November, this phenomenon is almost absent at the 11$^{th}$ and the 12$^{th}$ of November. Why is that? The answer to this question is revealed in Figure 7, right panel. In addition to the CO$_2$-concentration measured at the Carl-Zeiss-Gymnasium, also the wind speed at this location is plotted. As can be seen, the wind speed was relatively high at the 11$^{th}$ and 12$^{th}$ of November, causing the atmosphere to mix and thereby preventing inversion. During the last days there was hardly any wind, resulting in poor mixing of the atmosphere and thus inversion could be observed.

![Figure 7](Image)

**Figure 7.** Inversion patterns observed at the Carl-Zeiss-Gymnasium in Jena and the Maartenscollege in Haren. A. Atmospheric CO$_2$-levels measured at the Carl-Zeiss-Gymnasium (CZG) in Jena and the Maartenscollege (MAA) in Haren in the period from 10 – 14 November 2008. B. CO$_2$-concentrations and wind speed measured at the Carl-Zeiss-Gymnasium in the same period.

**Useful information sources:**

**Carbon cycle:**
- [http://library.thinkquest.org/11226/why.htm](http://library.thinkquest.org/11226/why.htm)

**Climate (change):**
- [http://www.ipcc.ch/](http://www.ipcc.ch/)
- [http://www.climateresearchnetherlands.nl](http://www.climateresearchnetherlands.nl)
- [http://eo.ucar.edu/kids/green/what1.htm](http://eo.ucar.edu/kids/green/what1.htm)

**Measurements:**
- [http://www.nature.com/nature/journal/v453/n7195/abs/nature06982.html](http://www.nature.com/nature/journal/v453/n7195/abs/nature06982.html) (US and UK seawater temperature)
- [http://www.esrl.noaa.gov/gmd/ccgg/trends](http://www.esrl.noaa.gov/gmd/ccgg/trends) (Mauna Loa CO$_2$ since 1958)

**Atmosphere:**
- [http://earthguide.ucsd.edu/earthguide/diagrams/atmosphere/](http://earthguide.ucsd.edu/earthguide/diagrams/atmosphere/)

**Fun links:**
- [http://www.epa.gov/climatechange/kids/games/index.html](http://www.epa.gov/climatechange/kids/games/index.html) (test your climate change knowledge)
4. Topics in the classroom

Background on the SchoolCO2web dataset and its use at schools

As the SchoolCO2web-project proceeds, the database expands. This provides the participating schools with a large collection of CO₂-measurements from a variety of European locations, which can be used for studies by pupils. At the moment, it is already possible to study daily and seasonal oscillations of the CO₂-levels and maybe before the end of the project, the first results of annual effects will become visible. In order to enable an optimal use of the large datasets, this chapter will list and explain several possible study topics. In general, two types of studies can be distinguished:

1. technical studies, relating to ‘the art of measuring’. Pupils will learn what is required to make correct use of the (calibrated!) CO₂-meters, what the right conditions are to measure, how many datapoints are required and which statistics should be implied.

2. scientific studies, making use of the obtained data. By interpreting these data, pupils can for example try to find seasonal influences, inversions or regional variations due to specific local situations.

Of course, technical and scientific studies are not two separate worlds and it is important for pupils to realise this. So although the classroom topics will be listed either under ‘technical studies’ or under ‘scientific studies’, the teacher should show the crosstalk between these types of studies. In the framework of the SchoolCO2web, pupils will be taught the lessons of good measurement in the technical studies and should become aware that these are a prerequisite to ever perform scientific studies. In addition, they will be acquainted with the fact that scientific studies are not just about obtaining new insights. Only if the included controls validate the results and the researcher can trace back known or expected phenomena in the data, he or she will be able to trust the acquired datasets.

Finally, in addition to working with the SchoolCO2web datasets themselves, classroom topics can also aim at creating general awareness among the pupils about for example CO₂-emission and climate change. An example of this is the DoMUS model, which will be explained in a separate section in this chapter.

For each described classroom topic, the following aspects will be addressed:

a. Background information
b. Learning aim for the pupils
c. Form of the activities and extent of the pupils' participation
d. Required time
e. Suggestions for reporting – present results to associated university/research institute, compare with other participating schools/pupils. For information on reporting to the SchoolCO2web, see appendix 2.

Technical studies

1. Accurate measurements

Background: In Figure 7, a structural difference of about 12 ppm could be observed between the CO₂-levels measured at the Maartenscollege in Haren and the Carl-Zeiss-Gymnasium in Jena. One could be tempted to conclude that the CO₂-concentration at the latter location is thus higher. However, pupils should be aware that a number is nothing more than just a number, unless the meter is properly calibrated. In the described situation for instance, the difference has not been caused by natural effects, but is a result of inaccuracy of one or both of the meters. As a consequence, the data cannot be compared with each other or with data from other sources. It is still possible to compare the data obtained by the same meter over a (limited) time, although this is not good scientific practice and should thus preferably not be taught to the pupils. In contrast, pupils should become familiar with the principles of calibration. When well calibrated, the meters of the SchoolCO2web can reach an accuracy of 1 ppm.

Aim: Familiarize pupils with the principles of calibration and make them aware of the famous expression “never trust a meter”. In addition to this ‘technical’ aim, pupils should also learn that small differences can be very important in scientific measurements, especially in the field of atmospheric CO₂ research, so although performing accurate measurements and calibrations is one of the more difficult and time consuming tasks, it is a prerequisite for relevant scientific research.

Activities:
The calibration itself, with a calibration gas, is normally done by a technician, preferably a few times per year. The pupils can likely not participate in the actual calibration, but they can be made aware of the effect it has. Next, some examples of activities are listed:

- To involve the students in the calibration event, they could compare several measurements: two subsequent measurements taken before calibration, two subsequent measurement taken after calibration and two subsequent measurements with the calibration in between. If the meter was already well calibrated, there should
not be too much difference, but on the schools this might actually be disappointing. In this case, the outcome will probably be that there is not much difference between two subsequent measurements, as long as they are taken at the same side of the calibration event. For comparison, they could also look at the data obtained by the professional measuring tower of the Centre of Isotope Research at Lutjewad. This meter has an accuracy of at least 0.1 ppm. To realise this accuracy, the meter automatically calibrates itself directly after each measurement, so that every measurement is taken with the highest possible accuracy. In this case, the observed difference between any two subsequently taken measurement should be very small if not almost absent.

- To see what the effect of calibration is on the long term, pupils could make graphs of measured CO$_2$-concentrations at the school of the period of for example one month before and one month after a calibration event. Do they observe a clear break in the CO$_2$-level trend, as was described in section 2.4 for the example of US and UK seawater temperature measurements? Now the pupils know that the meter has been calibrated, but let them speculate on what they would have concluded if they would not have known that.
- Depending on the equipment a school has, pupils could work in smaller groups, each equipped with a CO$_2$-meter, and per group measure CO$_2$-levels at several, specified locations in and around their school. In this case, one of the meters should be properly calibrated, while the others could be uncalibrated. The pupils could collect their data (for example the average of three measurements at each location) and compare their results with those of other group and with the results obtained by the calibrated meter. This could give them a good indication of spreading in datapoints as a results of calibration defects.

**Required time:**
This topic is more of an introduction to good measurement than a complete series of lessons, as is for example the module “measuring and interpreting” (see next section). The activities described above should be regarded as a nice starting point for pupils to get acquainted with measuring techniques and their pitfalls. The required time can therefore be limited to one lesson, embedded in the series of lessons connected to the module.

**Suggestions for reporting:**
Due to its introductory and technical nature, this topic is not very suitable for comparisons or interactions with other schools, except for merely noticing the difference in absolute CO$_2$-concentrations as mentioned above. The output expected from pupils could be graphs of their own acquired data supplemented with a short overview of the main observations.

2. Module “Measuring and Interpreting”

**Background:**
Within the Dutch NLT-platform (Nature, Life and Technology), a 40-hours module entitled “Measuring and interpreting” has been developed and certified for use at the national level in the two final years of highschool. Instead of focussing on climate change itself, the module aims at understanding the CO$_2$-measurements underlying climate change research. Even researchers themselves often feel uncertain about error-analysis and statistics of their data. In addition, climate change research is complicated by the fact that CO$_2$-concentrations vary as a result of human activities, weather conditions and CO$_2$-fixation by plants during the growth season, while margins are small and minor differences can be meaningful. The main question is therefore: How to measure properly and how to interpret the data in a correct way? For this purpose, the data of the SchoolCO2web are used. Currently, the module manual is only available in Dutch. However, in Appendix 3 an overview of the module is listed, enabling non-Dutch teachers to imply the main topics in their lessons.

**Aim:**
After finishing the module, pupils should be capable of using different types of measuring devices, be aware of inaccuracies and errors in their measurements and know how to account for these during dataprocessing and be able to interpret and, if necessary, filter their data in a correct way. Furthermore, at the end of the module, pupils will perform their own small research project, for which they should develop a proper experimental setup, using the knowledge they have acquired.

**Activities:**
The module starts with a booklet with theoretical information and questions, which the pupils should study. Halfway during the module, they will actively participate in practicals, centred around the theme of measuring inaccuracies. The last stage of the module consists of a small research project, which they will perform in couples. This part of the module is meant as a scientific study rather than a technical. The pupils should develop an experimental setup, making use of CO$_2$-data downloaded from the SchoolCO2web. They should identify, represent and interpret interesting dataseries on a chosen topic (e.g. seasonal effects, day-night rhythm, etc.).

**Required time:**
The module is established for 40 study-hours (50% classroom activities, 20% independent learning/working and 30% own research project). A short version, the minimodule “Measuring and Knowing” is also available, addressing more or less the same topics. This module is estimated on three lessons.
Suggestions for reporting:
The results obtained when working with the textbook should be documented in a portfolio. The results of their own research project should be shared with a broader public. They can write a report for their teacher, present their results in a poster presentation for their classmates and could report their project to the SchoolCO2web. Since the research project is an example of a scientific study, pupils should aim at reporting in a scientific way, so, for example, write their report in ‘article-style’ and use proper, scientifically acceptable figures, graphs, diagrams and legends.

3. Measuring CO2 by hand

Background:
For the SchoolCO2web, measurements of the atmospheric CO2-concentrations are taken by the Vaisala CO2-meter that is positioned at the roof of the school. The advantage of this location is that it is likely the most optimal for each school and measurements are fully automated, guaranteeing a constant supply of data to the database. The disadvantage of this location is that the pupils are not actively involved in taking measurements. It would therefore be nice to equip them with a CO2-meter and enable them to perform measurements themselves. For this purpose, there are two options. The first option is to remove the Vaisala meter, which actually is quite small, from the roof and let the pupils use this to measure CO2-concentrations at different test locations. The second option is to use additional, special small hand CO2-meters. Which option is preferred, depends on the objective of the measurements. The small hand meters are far less accurate than the Vaisala-meter (25-50 ppm versus 1 ppm accuracy), but are usually good enough for measuring large differences as, for example, in the classroom and, also important, do not lead to an interruption in the data collected for the SchoolCO2web. However, when higher accuracy is required, for example when pupils would like to perform measurements on photosynthesis, the Vaisala should be used.

Aim:
Involve pupils actively in taking CO2-measurements and let them argue on the choice of the correct measuring device, given the aim of the measurements they are going to take.

Activities:
Pupils can measure CO2-concentrations either indoors or outdoors. The activities can either be class-activities or individual activities. In class activities, groups of pupils can measure the CO2-concentration at specified locations, according to a protocol provided by their teacher and generally with a focus on technical aspects of the measurements. Afterwards, they can compare their data with those of their classmates. The individual activities could be incorporated in a research project, making it a more scientific study. In this case, pupils should also design their own experiments. Some examples of activities are listed below:

- Pupils can measure the effect of respiration by humans on the indoor CO2-concentration. In classrooms with many students and often only little ventilation, CO2-levels can rise quickly. The rate of CO2-generation depends on the number of people in the room, their size and their physical activity. By ventilation, CO2-concentrations can be decreased. The average adult's breath contains about 35,000 to 50,000 ppm of CO2 (100x higher than outdoor air). Pupils can make estimations of the expected CO2-concentration in their classroom based on the conditions (amount of people, size of the room, degree of ventilation) and can perform CO2-measurements. They can compare their actual results with their estimations and can try to explain any observed differences or similarities.

- Pupils can measure the CO2-levels in their classroom as an indication for the indoor air quality. Research has shown that CO2-levels are most of the time too high. The CO2 itself is not a health concern, but conditions with high CO2-concentrations lead however to lower learning performances and absence through illness. Pupils can measure the indoor CO2-concentration under different circumstances, for example time (first hour of the day compared to final hour), physical activity (pupils listening to the teacher compared to pupils working on a test), length of the pupils (first grade compared to final grade), classroom type (chemistry room, gym class, computer room), etcetera. An option to extend this research is to also measure other parameters and study if there is a correlation between for example CO2-concentration, temperature and humidity.

- Pupils can measure outdoor CO2-concentrations directly in the open air. For this purpose, they can study their environment by Google Earth and identify possible sinks and sources of CO2 (discussed in more detail in the section ‘scientific studies’). In addition they should consider possible effects of wind speed and direction. With this information, the pupils can make a list of interesting measuring locations, times and weather conditions and describe their expectations for each situation. After performing the measurements, they can interpret the data and compare them with their expectations.

- A nice example of CO2-measurements has been performed by the SchoolCO2web partners in Barcelona, Spain. Pupils have measured CO2-concentrations at different altitudes. Of course, these type of measurements can only be done if the local terrain permits.
Pupils can measure CO$_2$-concentrations in a CO$_2$-box to mimic the natural situation on the ground. As illustrated in Figure 8, test conditions can be created in agreement with the research question. For example CO$_2$-uptake by photosynthetic effects can be studied when a plant is being grown in the box, while CO$_2$-emission by respiration can be studied in the presence of animals. Also, both animals and plants can be present in the box, thus showing a scenario of co-existence and its effects. A manual is available explaining these and other test situations.

**Required time:**
Depending on the chosen activity, the required time can be just one lesson, but also a few hours to a (short) project which the pupils perform partially as homework. If the activities are done in the framework of technical studies, maximally a few hours is enough to focus on technical aspects of the measurements. If the pupils are more actively involved in setting up the experimental procedure, it will most likely become a more scientific study, which is very suitable for a short research or examination project.

**Suggestions for reporting:**
Again, this depends on the nature of the chosen activity. When a class is divided into groups, which measure at different test locations or under different test conditions, a way to report would be via short presentations to the rest of class. The presentation session could be concluded by a classroom discussion on what is underlying the observed differences in the obtained data. Pupils could be stimulated to come up with suggestions for improvement of the measurements and suggestions for further research.

When the activities are performed in a (short) research project by individual pupils or couples of pupils, they could write a (article-style) report and/or give a powerpoint presentation on their results. Pupils could also give a demonstration of a short CO$_2$-box experiment as an outreach activity, for example on an information and orientation day for prospective pupils at their school.

**Scientific studies**

1. **Atmospheric CO$_2$ cycles**

**Background:**
As mentioned in chapter 3, atmospheric CO$_2$-concentrations vary due to different reasons. The first impulse of someone not familiar with CO$_2$-research might be to immediately draw conclusions from these fluctuations. However, first one should know the underlying causes for the observed variations in CO$_2$-levels. For example, normal seasonal variations occur through an increased CO$_2$-fixation in the growth season, leading to a drop in the CO$_2$-concentration. There are, however, also more accidental fluctuations, like inversions caused by the absence of wind and therefore an incomplete mixing of the measured air. These fluctuations have nothing to do with rising or dropping CO$_2$-levels, but rather just reflect the local situation at that particular day, time and condition. Important questions to deal with are therefore: How is it possible to discriminate between the different types of fluctuations? Which fluctuations reflect a relevant underlying reason? Which fluctuations are nothing more than just a disturbance in the CO$_2$-levels? When can trends in CO$_2$-concentrations be discerned? By involving pupils in scientific studies on atmospheric CO$_2$-concentrations, they learn how the CO$_2$-data should be studied, what can be concluded (and what not) and what could be tested in further research. With the data of the SchoolCO2web pupils could study a wide variety of research questions.

**Aim:**
Active participation of pupils in scientific studies. Pupils should get acquainted with climate research and CO$_2$-concentration measurements. They should learn that, although CO$_2$-levels fluctuate, relevant trends and oscillations can be found. Based on this knowledge they can formulate a research question, design a research plan and use existing dataseries on the SchoolCO2web for a (small) research project.

**Activities:**
Pupils should set up an experimental design to discover relevant trends and oscillations in existing dataseries. For this purpose, they could use dataseries of their own school, but also of other SchoolCO2web-partners. In their research plan, they should identify the right time and conditions to uncover the trend or oscillation that is the subject of their project. By doing so, they can try to answer any of the below listed questions. Appendix 4 discusses a number of concrete examples on these topics:

- **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.
- **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?
• Is there a correlation between temperature and CO\textsubscript{2}-concentrations? If so, is this a positive or a negative correlation and can the correlation be used to predict future developments?
• 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 dataseries. 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 dataseries under these conditions? And can they demonstrate a correlation between these factors and CO\textsubscript{2}-concentrations?
• 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?
• Is it already possible to see any annual effects? For this it is important to do correct filtering, so this project might be a little more complicated to do in the classroom. It is however possible to approach a scientist for help. In that case, pupils could work on this in an examination project under supervision of a CO\textsubscript{2}-researcher at the supporting University or Research Institute.

Required time:
All listed activities are very suitable to use as topics for (small) research projects, typically examination projects.

Suggestions for reporting:
If indeed the topics are used in examination projects, pupils could report in a written report, article-style and perhaps also in a presentation. It would also be nice if they upload their report to the SchoolCO\textsubscript{2}web, so that other pupils could benefit from their achievements. Especially when the pupils work on an international topic, like the length of the growing season in different regions in Europe, they could contact pupils from a school in one of these regions and exchange their findings and comments and work on the project together. For this it would be nice if they could set up some kind of interface, like a networkgroup on internet, which could be used for communication and data transfer.

2. Module “World wide climate change”

Background:
An 8-lessons module about climate change has been developed in the framework of CarboEurope to enable teachers to include the SchoolCO\textsubscript{2}web data in the curriculum. The central theme in this project is the fluctuating atmospheric CO\textsubscript{2}-concentration as mentioned above. The difference with the activities described in the previous section, is that this approach is more guided. The complete class of pupils will work on this theme, out of a preset module. The lessons will focus on the question on how these CO\textsubscript{2}-fluctuations can be explained. To answer this question, pupils will first be taught background knowledge on climate change, analyse the data of the SchoolCO\textsubscript{2}web and perform a practical study on the role of plant activity on CO\textsubscript{2}-levels. One of the important things that the pupils will learn from this project is the scientific eye-opener that one, well-formulated hypothesis does not necessarily have to be fully accepted or fully rejected by the results of the experiment. Often, researchers will discover that it did not work as they initially thought and they have to think of alternative causes, formulate a new hypothesis and additional research questions. The manual to the module is available only in Dutch, but the main terms, aims and activities are outlined in Appendix 3.

Aim:
Pupils will learn to not only prove or reject a hypothesis, but also to adjust it. For this purpose, they use climate research as a framework. They should be aware of the fact that many more causes are possible for explaining the observed climate phenomena and not just the hypothesis that they have formulated. They will therefore also learn the importance of formulating well-defined and testable hypotheses, which is a delicate task in a field as complex as climate research. It is of no use stating something if it is not possible to test exactly the influence on, for example, the CO\textsubscript{2}-concentration of the factor that is valued so high in the hypothesis.

Activities:
The project consists of different activities. In the first part, the pupils work with a textbook and assignments about climate change. The second part involves working with the data of the SchoolCO\textsubscript{2}web. The pupils are provided with different dataseries that they have to investigate with help of Microsoft Excel. A major learning aim in this phase of the project is also to improve their skills in working with Excel by performing practical tasks. The third part of the module consists of a practical about the influence of light on plants. They have to perform standard experiments and later on analyse and explain their data.

Required time:
The total time for the module is 8 lessons. It is also possible to do parts of the module.
not easy to detect local sources by measuring CO

time-dependent. One can think of the contribution of fossil fuels in traffic, industry and heating in winter. It is often

in the data measured by the nearest CO

Suggestions for reporting:

Make pupils aware of the effect local conditions can have on the CO

D3.2: Documentation for teachers of the educational opportunities of the SchoolCO2web

3. Sinks and sources

Background:

Normally, the atmospheric CO2-concentrations in different regions do not differ too much. However, sometimes

local differences are observed. Before ever continuing with the scientific interpretation of these differences, one

should first of all be absolutely sure that the measurements have been carried out accurately and that the

observed differences are statistically significant. When this is the case, the next point of action is to identify the cause(s) of these differences. In the past, the main aim of CO2-research has been to determine the average global CO2-levels and their trend. Recently, however, differences between regions are also taken into account.

The current challenge of carbon research is to model the carbon cycle as accurately as possible. For this purpose, it is important to know what the effect of each region is on the atmospheric CO2-level. Regions can function either as a source of CO2 or as a sink for CO2. A typical CO2-sink, so a region that takes up more CO2 than it emits, is a region with a lot of vegetation or water, for example large forests or oceans. CO2-sources are characterized by a nett CO2-emission over CO2-uptake and, of this, two types can be distinguished: 1) natural sources, by respiration of animals and plants, release of CO2 by oceans (depending on the conditions, water can act as sink or source), forest fires and volcanic eruptions and 2) anthropogenic sources, caused by humans, which include burning of fossil fuels and deforestation. These sources can be very local, strong and often also time-dependent. One can think of the contribution of fossil fuels in traffic, industry and heating in winter. It is often not easy to detect local sources by measuring CO2-concentrations, due to the mixing of the air. Usually, only nearby sources will be detected and even then, this depends on the wind direction.

Aim:

Make pupils aware of the effect local conditions can have on the CO2-levels that are measured by the station. They learn what the characteristics of sinks and sources are and can try to identify them using for example Google Earth. Furthermore, pupils can learn about different dispersion models which predict the distribution of CO2 in the environment.

Activities:

Pupils can use software like Google Earth to look for sinks and sources close to a measuring station, either that of their own school or of any of the other Carboschools. When looking for sources near their own school, they can use the handmeters or the dismantled Vaisala from the roof to perform measurements on local sinks and sources as described earlier in “Measuring CO2 by hand” in the section on technical studies.

Alternatively, they can estimate the possibility that a local CO2-source affects the CO2-concentrations measured at a CO2-station of one of the Carboschools partners. For this purpose, dispersion models can be used, which predict the distribution of CO2 emitted from a certain source as dispersed by the wind. One of these models is the Gaussian Plume model. How to use this model is described in Appendix 5 - Tools. An excellent example of a CO2-source is the one near the Maartenscollege in Haren, The Netherlands. This source has been identified by pupils from the Carl-Zeiss-Gymnasium in Jena, Germany by using the SchoolCO2web. More information on this example can be found in Appendix 4 – Examples of using the SchoolCO2web.

Required time:

Identifying a source or sink by help of Google Earth and using a Gaussian Plume model to trace back its effects in the data measured by the nearest CO2-station is a topic that is suited very well for an examination project. It would be useful to approach a scientist of the local supporting university/research institute for assistance.

Suggestions for reporting:

Pupils could present their results in a written report and in a presentation for their classmates or for the research group of the supervising scientist. Especially when pupils examine a source or sink that is not near to their own school, but is located near to one of the other participants, they could contact pupils from the other school and start a collaboration, in which they work on the project together and report to and discuss with one another. This would clearly demonstrate the international nature of CO2-research and would provide an international podium.

Pupils could also upload their results to the SchoolCO2web, where it could function as demonstration material for pupils in other participating schools.
Creating awareness

1. DoMUS model and game and ecological footprints

Background:
Climate researchers keep telling us that the world is awaiting enormous disasters if we continue using our natural resources like we do. A drastic reduction in CO₂-emission is required to prevent the global temperature from increasing to a level at which irreversible effects are inevitable. An important role is played by politicians and climate advisors. At global conferences, like the climate conferences in Kyoto and, more recently, Copenhagen, agreements were to be made, obliging countries to maximally engage themselves to reduce CO₂-emissions. However, it turns out to be hard to achieve unconditional engagements of all partners. The interests of industries, governments, climate researchers, etcetera often point in different directions, complicating negotiations. But among the general publicum awareness increases that we cannot continue like this and many interest groups fight for the reduction of fossil fuels combustion, the increased usage of alternative energy sources like wind energy, solar energy and electric cars, the improvements of living conditions in developing countries or the protection of landscapes like glaciers and polar ice. In addition to these organized interest groups, individuals can also play a role in reducing CO₂-emission. The DoMUS model and DoMUS game have been developed to give people insight in the amount of energy they use and the amount of CO₂-emission this results in. By using their own household as scale, the consequences of personal conducts are directly reflected in terms of energy usage and CO₂-emission.

Aim:
Create awareness among pupils of the consequences of their daily behaviour on energy consumption and CO₂-emission and hopefully stimulate them to change their behaviour in order to reduce their energy requirements and, thus, CO₂-emission.

Activities:
• In the DoMUS game pupils follow one or more setup characters during a week of his/her life. Every day, they have to make choices for this person, regarding dinner, sports, evening activities, destination for a daytrip, etcetera. All the choices affect the budget, the environment and the happiness of the person. At the end of the game, pupils will be informed on whether or not they reached the criteria. An outcome can be that their character was very happy, but has put a too large burden on the environment. By giving feedback, pupils realise what the consequences of different types of behaviour are and how they can live happily, without weighing down to much on the Earth. The game can also be played sequentially with different characters or scenarios, for example first playing with a high income character, then with a middle-income character and finally with a low-budget character. Pupils will then become aware of the fact that it is easier to cut down on CO₂-emission when one can afford more energy efficient appliances. However, the richer characters will most likely spend more money and energy on vacations and daytrips, thereby increasing their CO₂-emission.
• The DoMUS model is more complicated than the DoMUS game and is more difficult for pupils, since it requires knowledge about different aspects of their household that they probably do not have, like, for example, how much gas is used per year, what kind of insulation the house has and which type of heating. However, testing the model in a class of one of the SchoolCO2web-partners showed that pupils do like to enter their own household situation and look for improvements.
• As an alternative, numerous websites are available on which pupils can quickly determine how big their own (households’) demand is. This so called ecological footprint is represented as the percentage of the Earth’s surface is required to sustain their own or their own households’ energy request. For every person in the world, 2.1 acres are available. The average footprint of a Dutch person is 4.1 acres. By filling in the details of their own household, pupils can assess how much Earth they require. The nice thing of these websites is that the entered number can be adapted to the personal situation, but that also averages are provided so the questionnaire can be filled in even if one does not know exactly how the households’ situation is. Example of sites on which the personal ecological footprint can be determined are:
  o www.epa.vic.gov.au/ecologicalfootprint (Australian, option for personal, school, etc footprint)
  o www.ecologicalfootprint.com (UK)
  o www.duurzaamheidinactie.nl (Dutch)
• Currently, there is a global initiative triggering people to reduce their own CO₂-emission with 10% per year, starting in 2010 (the 10:10 competition). Using DoMUS, pupils can get insight in the energy demand and CO₂-emission of their own household even, by scaling up, of their school. This could form a nice starting point for setting up a plan to reduce their CO₂-emission in the framework of the 10:10 competition. More information on 10:10: www.1010global.org

Required time:
The DoMUS game can be used as an introduction for the DoMUS model, but can also be used independently. The game itself does probably take some 10 – 15 minutes per character/scenario. As a further introduction to the
DoMUS model, the websites on ecological footprints can be used. Usually, filling in the questionnaire takes about 10 minutes. The real DoMUS model requires more preparation time, in order to find all information about the status of the household concerning for example energy usage and insulation. As homework, pupils could collect the necessary data for their own household or in a project could try to find the data for their school.

Suggestions for reporting:
If pupils make a DoMUS model or an ecological footprint for their own situation, they could be stimulated to come up with suggestions for CO₂-emission reduction, which they could present in small notes that they report to an ‘action board’ in their classroom. The action board could either be a sheet of paper on the wall to which they stick memo’s or an electronic interface to which they post their suggestions. This topic is very suitable for competitions. Pupils could be asked to come up with suggestions to reduce the schools’ CO₂-emission. The best idea or the highest reduction could be awarded with a prize and of course, the school should commit itself to actually follow up the suggestions, as long as these are feasible (things like switching off lights or computers rather than installing a complete new insulation system). In addition, pupils could take part in a 10:10-like competition, either individually or with their class or they could challenge pupils from other Carboschools to come up with a plan for CO₂-reduction.

Some additional aspects that might be addressed in the classroom

Working with meteorological data
Based on meteorological data, pupils can study phenological issues. They can investigate the relationship (if any) between factors such as temperature, rain fall and day length and for instance the return of migratory birds or the start of the blooming of plants. Pupils can look for information in books and on internet, but can also actively document data themselves and try to find a relationship. They can note observations on changes in nature in their own environment and can look up historical data on the internet. Many countries have phenological observation networks, which can provide a lot of information.

Pupils can also study weather patterns, both at their own school and in collaboration with other Carboschools. Data on temperature, air pressure, wind speed and direction are all available in the SchoolCO2web database. In addition pupils could note observation on the weather appearance, like number of sun hours, degree of coverage of the sky, etcetera. Combining these data, they could for example investigate whether there is a relation between the weather conditions and the coverage of the sky.
Appendix 1. How to work with the CO₂ data from the SchoolCO2web

1. How to download the CO₂ data
Within the SchoolCO2web a tool has been developed to download or graphically display the CO₂-concentrations and weather conditions from the SchoolCO2web. This tool can be found on the website of Carboschools, in the SchoolCO2web section: www.carboschools.org. The tool is also available in Dutch on www.schoolCO2web.nl/

Operation of the download interface is quite simple. A graph can be created by performing the following steps:

1. Select the parameter that should be displayed on the left Y-axis. In this case “CO₂-concentration (ppm)”.
2. Optional: select the parameter that should be displayed on the right Y-axis.
3. Select the stations from which the measurements should be included in the graph. If more than one station should be selected, use CTRL (Windows) or CMD (Mac) during selection.
4. Select the period from which the data should be displayed by entering the start and end date.
5. Click “Show graph”. It may take a while to display the graph, especially if the selected period is long.
6. The measurements can also be downloaded as data files (*.csv). These files can be loaded into spreadsheet programs like Excel. The data will be downloaded for the specified period at the selected measuring stations. In the data file, all parameters will be stored, so not just the ones selected for the y-axes. Save the datafile using an informative name. In case the file does not automatically get a .csv extension, add this to the name. It is easiest to select just one school at a time and merge data of different schools later.

2. How to import the *.csv file into excel:
- import data in excel:
  - start with empty worksheet
  - go to ‘data’ and choose ‘import external data’ and next ‘import data’. Choose your *.csv file
  - in the dialog box, choose next
  - in step 2 of 3, tick ‘semi-colon’. Choose finish and in the next dialog box, choose OK
  - the data are now shown in the worksheet and can be used in the tutorial
  - NB. Do make sure that your excel version treats the measurements as number and not as text. This depends on whether comma’s or dots are used to separate decimals in your local excel version.
    - The file is ready to use if all measurements are aligned to the right side of each cell in the worksheet.
    - If the measurements are aligned to the left side of the cells, go to ‘edit’, ‘replace’. At ‘find what’, fill in a dot. At ‘replace with’, fill in a comma. Click replace all.

3. Tutorials on how to work with the data of the SchoolCO2web in excel
At the website, three tutorials are available that illustrate how to work with the SchoolCO2web data. These tutorials can be used in different ways:

1. as a specific introduction to a topic, like a correlation between windspeed and CO₂-concentrations as described in tutorial 2
2. as a general introduction to working with the CO₂-data, like for example calculating average CO₂-levels as illustrated in tutorial 4. Teachers and/or pupils can then later on adapt the data handling so that it fits the aim and approach of their own research projects.

Location of the tutorials: http://www.carboeurope.org/education/schoolsweb.php
Scroll down on the page to find the tutorials.
Below, the tutorials are included as written instruction which can be used side by side with the videotutorials.
Tutorial 2: Correlation between CO₂ concentration and average wind speed

Background: As an example the same data as for the inversion illustration were downloaded (Figure 7). These data were obtained at the Carl-Zeiss-Gymnasium in Jena, Germany, from the 10th until the 14th of November 2008. As mentioned before, the CO₂-levels rise during the night as a result of inversion, unless there is enough wind to mix the atmosphere. An intuitive conclusion would therefore be that the CO₂-levels decrease when the wind speed increases. In order words: a negative correlation between wind speed and CO₂-concentrations is expected. Tutorial 2 “Correlation between CO₂-concentration and wind speed” shows how a graph can be made to visualize this correlation.

How to do this in excel:
1. Go to chart (select ‘chart wizard’- symbol or via ‘insert’ – ‘chart’)
2. Choose ‘XY (Scatter)’. Click next
3. Go to sheet ‘series’. By clicking ‘remove’, remove all series till the box is empty. Click ‘add’. Data for name, x- and y-values will appear.
4. Click on the symbol right to x-values (indicated by the red dot). Now select all data in the column with windspeed (in the picture, column K). This selects all data in the column, as indicated by the dotted line around it. Click again on the symbol in the small dialog box (indicated by the blue dot).
5. For y-values, do the same, but now select the column named ‘CO2-conc’. (in the tutorial, column D). Click next
6. In step 3 of 4: enter names for the axes. At ‘values (x) axis’ write ‘average wind speed (m/s)’. At ‘value (Y) axis’ write ‘CO2 concentration (ppm)’. Click finish. The graph will now appear in the worksheet and can be positioned at an empty spot.
7. Remove the legend by selecting it and pushing ‘delete’ on your keyboard.
8. Rightclick on the points forming the dataseries. A window will pop up. Click ‘add trendline’. Choose ‘linear’. Click OK.
Tutorial 3: Filtering CO\textsubscript{2} levels in a well-mixed atmosphere

**Background:** For many investigations, it will be necessary to use only those measurements taken when the atmosphere is well mixed. This will for example be the case when one wants to determine the average CO\textsubscript{2}-level (see tutorial 4). The two main requirements for well-mixing are: 1) the time of the day (the atmosphere is well mixed during the day because of turbulence) and 2) the speed of the wind (the atmosphere is well mixed when the wind speed is high). The best datapoints are therefore the measurements taken between 13 – 17 h and at an average wind speed above 2.5 m/s. Only those datapoints should be used to determine the average CO\textsubscript{2}-concentration. This can be achieved by filtering of the data. Tutorial 3 “Filtering CO\textsubscript{2} levels in well mixed atmosphere” explains how to do this. For this tutorial the following data were downloaded with the SchoolCO\textsubscript{2}web tool: “NL CIO” from the 3\textsuperscript{rd} of June until the 5\textsuperscript{th} of September.

**How to do this in Excel:**

1. Select all data on the worksheet by pressing “CTRL + A”
2. Go to ‘data’ – ‘filter’ – ‘autofilter’
3. Click the pull down button next to the column ‘time’ and click on ‘custom’
4. To include only those measurements taken from 13 till 17 hours, select the appropriate time interval. To do so: click on the first pull down button under time and select ‘is greater than or equal to’. For the time, fill in 13:00.
5. In the same way, select the second limit for the time by choosing ‘is less than or equal to’ at the other pull down button. Choose as time 17:00. Click OK.

6. The next step is to only include those measurements that are taken at a wind speed of at least 2.5 m/s. To do so, go to the column ‘wind speed’ and click on the pull down button. Go to ‘custom’ and fill in that the wind speed should be greater than or equal to 2.5. Click OK
7. Next copy the data another worksheet. Make sure all data are selected (if not, ‘CTRL + A’). Copy by ‘edit’ – ‘copy’ or by ‘CTRL + C’
8. Open worksheet 2 and paste the data (‘edit’ – ‘paste’ or ‘CTRL + V’)
9. Additional to tutorial: to return worksheet 1 into its original state (undo autofiltering), select all and then go again to ‘data’ – ‘filter’ – ‘autofilter’.
10. A helpful suggestion:
   - Use an additional worksheet (e.g. worksheet 3) to document what has been done, as a sort of journal. Especially when you are not following a ready-made tutorial, it is very important to know and document how the data handling has been done. In this worksheet, write down all information about filtering settings, copying of the data to continue with other steps, remarkable observations, etcetera.
Tutorial 4: Calculation of average CO$_2$-levels

Background: To calculate the average CO$_2$-level, usually filtered data are used, taking only those measurements that were taken under proper conditions (time and wind speed). In this tutorial, the difference is shown between the average CO$_2$-level for all the data and that for only the filtered data. The hypothesis is that the CO$_2$-levels for the filtered data are lower, because the measurements are taken in a well mixed atmosphere. Tutorial 4 “Calculation of the average CO$_2$ levels” shows how to calculate the average CO$_2$-levels. Although not statistically proven, it can be seen that the average CO$_2$-level for a mixed atmosphere is indeed lower (370 ppm) than for all the measurements (377 ppm).

How to do this in Excel:
1. The video tutorial starts with a dataset similar to the one created in tutorial 3, so with worksheet 1 and 2 containing data. In the example in tutorial 3, both worksheet contained filtered data. If we now want to have unfiltered data in worksheet 1 and filtered data in worksheet 2, the autofiltering in worksheet 1 should be switched off. That is done by first selecting all data on this sheet, then go to ‘data’ – ‘filter’ – ‘autofilter’. As a result, worksheet 1 now contains all data again, while worksheet 2 contains only the selected, filtered data.
2. Start with the unfiltered data (worksheet 1). To calculate the average CO$_2$-level, go to an empty cell on the sheet. Write ‘average CO$_2$-level’ (for example from C10)
3. Select the cell right from ‘average CO$_2$-level’ and go to the formula-sign in the textfield.
4. Select ‘average’ and click OK. In the next step, select all data in the column with CO$_2$-concentrations. Click OK. The value appears in the cell.
5. Do the same on the worksheet with filtered data.
6. Compare the two averages to see which one is higher.
Appendix 2: Reporting to the SchoolCO2web

The SchoolCO2web is accessible via the Carboschools website (http://www.carboeurope.org/education). In addition to the already mentioned database and the tutorials on how to work with the SchoolCO2web data, the site also contains a link to a support website, which is hosted by the University of Groningen: http://fwn-school-co2-net.hosting.rug.nl/

On this website, a subpage ‘teaching materials’ is available. It would be very useful to list the different pupil projects that have been performed within the SchoolCO2web framework on this page. Teachers can send a short summary of their pupils’ project(s) to the SchoolCO2web. This contribution should contain the following aspects:
- an informative title of the project
- a short description of the project
  - What have the pupils investigated/worked with? If applicable: what was their (research) question?
  - In case pupils worked with data downloaded from the SchoolCO2web, please indicate from which school and from which period the data have been used
  - What was the main conclusion of the project?
- the school level and grade the topic is suitable for
- an indication of the required time
- how many pupils did participate in this project?
- the contact email address of the teacher

Teachers can in this way share information with each other. By contacting the responsible teacher for an interesting project, other teachers can learn from their experiences and imply the topic at their own school.
### Appendix 3: An overview of the content of the different modules

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<thead>
<tr>
<th>Title</th>
<th>Measuring and Interpreting</th>
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<tbody>
<tr>
<td>School</td>
<td>Pre-university school</td>
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<tr>
<td>Level</td>
<td>Upper level</td>
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</tbody>
</table>
| Description | The first part of the module deals with the theory about measuring. It addresses the terms measuring levels, measurings inaccuracies and continuing calculations with these inaccuracies. Several practicals demonstrate the practice of these concepts.  

The second part of the module deals with interpreting measurements. At first, pupils are taught a critical attitude towards interpretation of data. Afterwards, the basics about correlation and regression is discussed: when is a coherence between two measured variables proven? Can the results be interpolated and extrapolated? Filtering of data can be a valuable tool for interpretation. Incorrect filtering, however, can be misleading. The final theoretical part of the module teaches pupils how to deal with these difficulties.  

Finally, pupils should put the theory into practice by performing their own research project. This intents at using a CO$_2$-datseries from the SchoolCO2web, interpreting the data and correlating the data to other variables such as temperature and wind speed. |
| Concepts | - Measuring scales  
- Measuring inaccuracies  
- Statistical correctness  
- Correlation and regression  
- Filtering of datasets  
- CO$_2$-measurements  
- CO$_2$ in the atmosphere |
| Skills | After finishing the module, a pupil can:  
- take inaccuracies into account when performing a measurement  
- use different types of measuring devices and choose the optimal one for different conditions  
- indicate that measurements contain measuring inaccuracies  
- continue calculations considering measuring inaccuracies  
- describe correlations in the data  
- perform a regression analysis using the data  
- critically judge (interpretations of) data  
- apply a considered filtering to a dataset |
| Pupil activities / practicals | Pupils learn the theory largely by studying a textbook and answering accompanying questions.  
The practicals are centred around the theme of measuring inaccuracies. All pupils of the class determine for example the content of a block, using different methods (measuring dimension, immersing in water).  
In their own research project they investigate data from the schoolCO2web, for example as indicated in appendix 4. |
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>School</td>
<td>Pre-university school</td>
</tr>
<tr>
<td>Level</td>
<td>Upper and lower level, depending on the type of experiment</td>
</tr>
<tr>
<td>Description</td>
<td>The CO₂-box is a tool, which can be used for demonstration purposes or by pupils to perform their own experiments. In a tight box, conditions and arrangements can be set as desired for the experimental question (e.g. a photosynthesizing plants, respirating animals, a fire, etc). The CO₂-level in the box can continuously be measured and the effects of additions or removals of components in the box can be seen.</td>
</tr>
</tbody>
</table>
| Concepts | - Controlling conditions (e.g. temperature for plant/animal survival)  
- Changing experimental setup in order to answer research questions  
- CO₂-measurements  
- Influences on CO₂ in the atmosphere |
| Examples of experiments – duration – required foreknowledge | 1. plant – appr. 1.5 hours – photosynthesis  
2. algae – appr. 1.5 hours – photosynthesis  
3. day/night rhythm – appr. 8 hours – photosynthesis  
4. Fire – 15 minutes – combustion  
5. Plant + animal – appr. 1–1.5 hours – photosynthesis + respiration  
6. Turf – appr. 1–1.5 hours – photosynthesis + respiration  
7. Cactus – appr. 8 hours – photosynthesis CAM plants  
8. Temperature optimum – 1 uur – transform graphs |
| Skills | After working with the CO₂-box, a pupil can:  
- understand a pre-set experimental setup  
- critically discuss experimental setups  
- design their own experimental setup (depending on the level: classroom usage of the CO₂-box or incorporating the CO₂-box in their own research project)  
- analyse data collected over the course of an experiment  
- interpret the collected data |
<table>
<thead>
<tr>
<th>Title</th>
<th>World Wide Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>Pre-university school</td>
</tr>
<tr>
<td>Level</td>
<td>Upper level</td>
</tr>
</tbody>
</table>

**Description**
The central question in this module is “How can the fluctuations in the CO₂-concentrations be explained?”. To answer this question, pupils will first study climate change, making use of the information booklets of CarboEurope. Next, pupils will analyse the measurements taken by the CO₂-meters of the SchoolCO2web. This will be done using preset Excel examples. Optionally, practicals can be held in which the role of plant activity on the CO₂-level can be studied. An important aspect in this module is the use and formulation of hypotheses. It is not as black and white as accepting or rejecting a hypothesis. Most often, hypotheses should be adapted and challenged again. Pupils should then learn that a proper hypothesis is one that is well-defined and testable.

**Concepts**
- Energy (sources, types, transport, conversion and sustainable energy)
- Nature and Life (balance, sustainability)
- Relations between humans, animals and plants (influence of the sun, photosynthesis, green plants, food chain, degradation products)
- Interactions of humans, plants and animals with their environment (ecosystem, cycles, agriculture and food production, environmental pollution)
- Influence of technological and scientific applications on durable quality of life (biotechnology, recycling, production processes, information technology, scientific research, alternative energy sources, sustainable materials)
- Processes related to environment (environmental pollution and climate change)
- Combustion and heating (temperature, heat transport, fossil fuels, greenhouse gases)

**Skills**
After finishing the module, pupils should be able to:
- indicate the three main findings on world wide climate change
- indicate two anthropogenic causes for increased atmospheric CO₂-concentrations
- explain what the greenhouse effect is and what greenhouse gases are
- explain that it is plausible that humans are the cause of global warming
- explain that the current knowledge is insufficient for making accurate predictions
- explain why it is so hard to predict climate change
- explain what socioeconomic scenario’s are and relate these to climate change predictions
- explain that Carboschools projects are not on their own, but are parts of a global scientific project
Appendix 4: Examples of using the SchoolCO2web

In this appendix, some examples will be shown illustrating some of the questions a 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:

Maartenscollege Haren, The Netherlands 01.07.2010 – 07.07.2010:

**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\(_2\)-concentration on the left y-axis and temperature on the right.

Observation: the CO\(_2\)-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\(^{th}\). The graph suggests that the CO\(_2\)-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\(_2\) in the lower air layers, where also the CO\(_2\)-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\(_2\)-concentration on the left y-axis and wind speed on the right y-axis.

As can be seen from the graph, the wind speed is generally low in this week, with the exception of the 24\(^{th}\) of December. It can be observed that on this day, the CO\(_2\)-concentration drops even further. However, the low CO\(_2\)-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\(^{th}\) or the 25\(^{th}\) of December, and a cold winter day, e.g. the 30\(^{th}\), is reflected in the CO\(_2\)-concentration. It is, however, not possible to conclude from just this graph that there is a real negative correlation between temperature and CO\(_2\)-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\(_2\)-levels during the day because of CO\(_2\)-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 dataserries. 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 dataserries 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 long(er) 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 4\(^{th}\) 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.
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 CO$_2$-concentration are even bigger. This is the result of CO$_2$-fixation during the long, daylight and very well mixing of the air due to the high temperatures (~24°C during the day).

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 CO$_2$ 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 CO$_2$-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 starts 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 1$^{st}$ 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 focusing 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 CO₂-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 CO₂-accumulation at night. From the 20th 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 10th or 20th 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.
Appendix 5: Tools

**Tools**

1. The Gaussian Plume model

**Background:**

The Gaussian Plume model is a (relatively) simple mathematical model that is used to estimate concentrations of air pollutants originating from an indicated emitter, in our case CO$_2$-emission by a CO$_2$-source. The main assumption of the model is that, over short periods of time, steady state conditions exist with respect to air pollutant emissions and meteorological changes. The air pollution is represented by an idealized plume, which comes from a smokestack and has a given height and a given diameter (Figure A2). Depending on the conditions, the plume will disperse in a certain direction and over a certain surface. The first calculation of the Gaussian Plume model regards the vertical movement of the plume. Assume the investigated source is a coal-burning electricity-producing plant. In this plant, the gases are heated, resulting in a vertical movement. The hot plume will thus move upwards to some distance above the top of the stack (= the effective stack height). This can be calculated based on the speed with which the gas exits the stack (= the exit velocity), the temperature of the gas and the temperature of the surrounding air. The next calculation of the model regards the dispersion of the plume in three dimensions: the downwind direction, the crosswind direction and the vertical (downwards) direction. The progression in these dimensions depends on the mean wind speed and the relative stability of the surrounding air. The influences of these factors will determine the final dispersion of the emitted CO$_2$ and the local concentrations of the gas in different areas of the Plume. More information about the Gaussian Plume model can be found here: [http://san.hufs.ac.kr/~gwlee/session9/gaussian.html](http://san.hufs.ac.kr/~gwlee/session9/gaussian.html)

Although the model might be relatively simple for mathematicians, it is not that simple for highschool pupils. However, by entering the right data as described under “How to use the Gaussian Plume model”, pupils can make dispersion diagrams that can help them to estimate the possibility to measure increased CO$_2$-concentrations at the station near the identified CO$_2$-source.

**How to use the Gaussian Plume model:**

- Go to [http://ready.arl.noaa.gov/READY_gaussian.php](http://ready.arl.noaa.gov/READY_gaussian.php)
- Select: Gaussian model using user-entered data
- Fill in the coordinates of the source that is to be studied: degrees latitude and longitude. Continue
- The next page shows a long list of parameters. Some data are used automatically, for example the ‘cloud ceiling’ which is set at 2000 foot if unknown. In most cases, pupils will not know the exact value, so do leave it at the set number. Do however change the following parameters, depending on the local situation:
  - Wind direction: it is indicated in degrees (with 0 = Northern Wind, 90 is Eastern Wind, etc.)
  - Wind speed: the default settings are ‘knots’, but the option ‘m/s’ can be ticked
  - A nice option: tick the box ‘Google Earth’ in the field ‘Create GIS output of contours?’
- Click ‘request dispersion run’. A picture like the one in Figure A3 appears.
- The dispersion diagram shows the dispersion of the plume and the local concentrations
- Below the dispersion diagram, links to other output files are shown.
- Open ‘Google Earth Results’ for displaying the dispersion diagram on the local map

Based on the obtained dispersion diagram, pupils could estimate how likely it is that they can measure a rise in the CO$_2$-concentrations originating from emission by the local source.
2. Identifying the origin of air packages

Background:
The atmosphere is constantly moving. The air is circulating and an air package is at one moment located here and next it has traveled to somewhere else. By movement of the air packages, the CO₂-content travels with the air. It can therefore be important to know where air packages travel to and where they originate from. At the site of the National Oceanic and Atmospheric Administration (NOAA) in the US, an application from the Air Resource Laboratory enables calculations on where the wind and the air packages come from.

How to determine the origin of air packages:

- Go to [http://ready.arl.noaa.gov/HYSPLIT_traj.php](http://ready.arl.noaa.gov/HYSPLIT_traj.php)
- Select Compute archive trajectories. Click Next
- Select ‘1’ for Number of Trajectory Starting Locations and ‘Normal’ for Type for Trajectory. Click Next
- Select GDAS (global, 2006-present) for meteorological data
- Fill in the coordinates of the location: degrees latitude and longitude. Continue
- Select a specific week for GDAS1 Meteorological File, Default is the current 7 days. Click Next
- In this fill in screen only change under Trajectory direction: Forward into Backward
- Click Request trajectory. The model will now calculate and produce a plot which might take a minute
- The plot will show where the air package is coming from at the default height of 500 m. The model can be rerun after changing the scenario, e.g. changing the height