A Massive Global Economic and Environmental Transformation is Underway ... Driven by Changes in the Carbon, Water and Nitrogen Cycles.

So How Do We Measure these Changes?

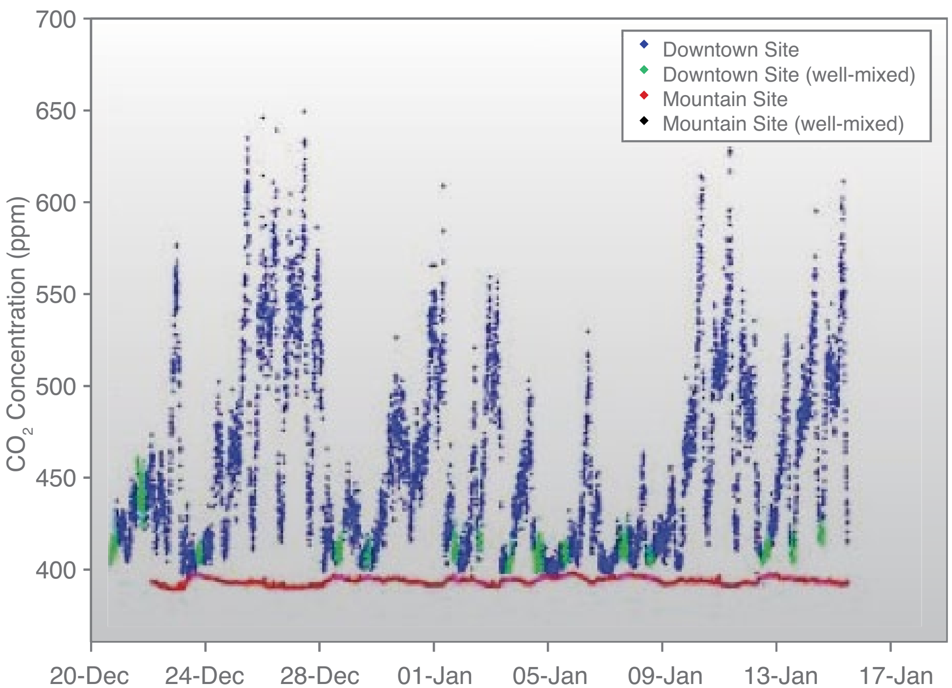
CITYCARBON
The New Model

Here's How:

1. Start by collecting greenhouse gas concentration* data from high-precision instruments deployed in strategic locations

**One ppm of CO_2 means that if you counted all the molecules in a sample of air, you would find 1 out of every 1 million molecules was CO_2. Measuring a ppb is like measuring a pinch of salt in a 10-ton bag of potato chips*

Here is the CO_2 concentration data from the two measurement stations in Davos over a week



Mountain measurements (red) are flat because air from the city does not usually travel up to the station, so this measurement gives a baseline of how much CO_2 is present in the air coming into Davos

City measurements (blue) show a lot of variation, which reflects both human sources (transportation, heating) and changing atmospheric conditions (wind, temperature , and pressure).

The peaks in the city (blue) data do not necessarily correspond to the periods of high emissions. Instead they correspond to very stable atmospheric conditions – times when the winds are light and the emissions stay very close to the earth's surface.

The data marked in green are periods when winds have stirred up the air around the city. These (periods marked in green) are the primary data that we use to estimate emissions from the city.

Why do you choose to use data from the periods when the air is well mixed (green points)?

- Selecting only the CO_2 data from times when the air is well mixed (think of stirring sugar into coffee) simplifies the job of simulating the impacts of weather on the concentration.

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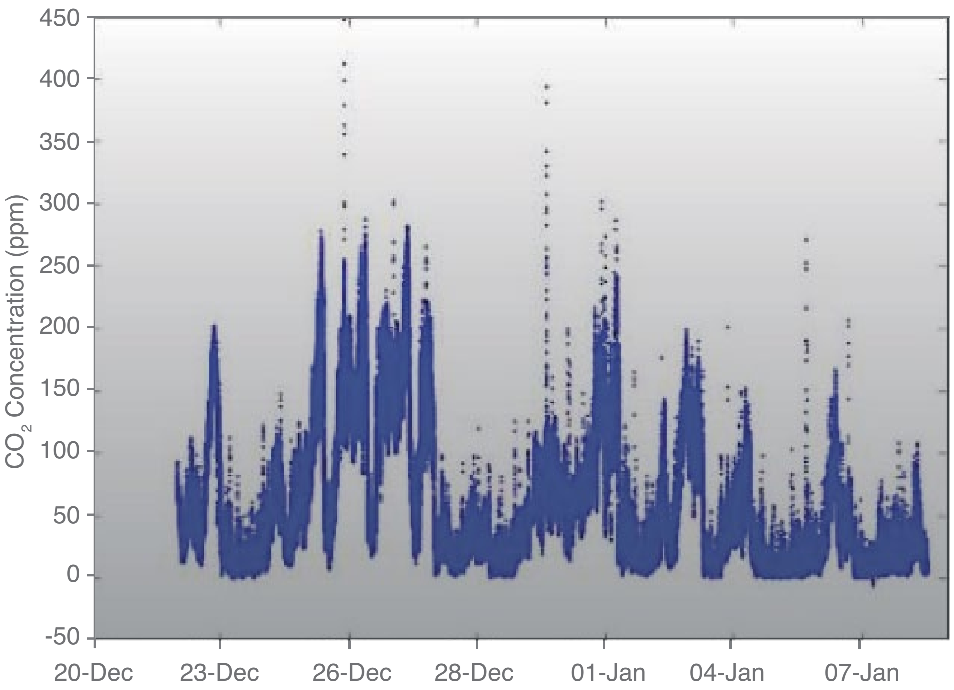
2. Calculate the CO_2 enhancement in the atmosphere due to the city of Davos

Here is the CO_2 enhancement from Davos



Calculating the enhancement is done by subtracting off CO_2 that did not come from Davos

The mountain site measurement of CO_2 is very close to the northern hemisphere “background” levels of CO_2 in the winter.

In order to see just the emissions coming from Davos, the mountain measurements (background) are subtracted from the city measurements.

The difference (shown in the graph to the left in blue) shows the CO_2 over Davos that has been emitted only by sources within the valley where the city is located.

How does this compare to global measurements of CO_2?

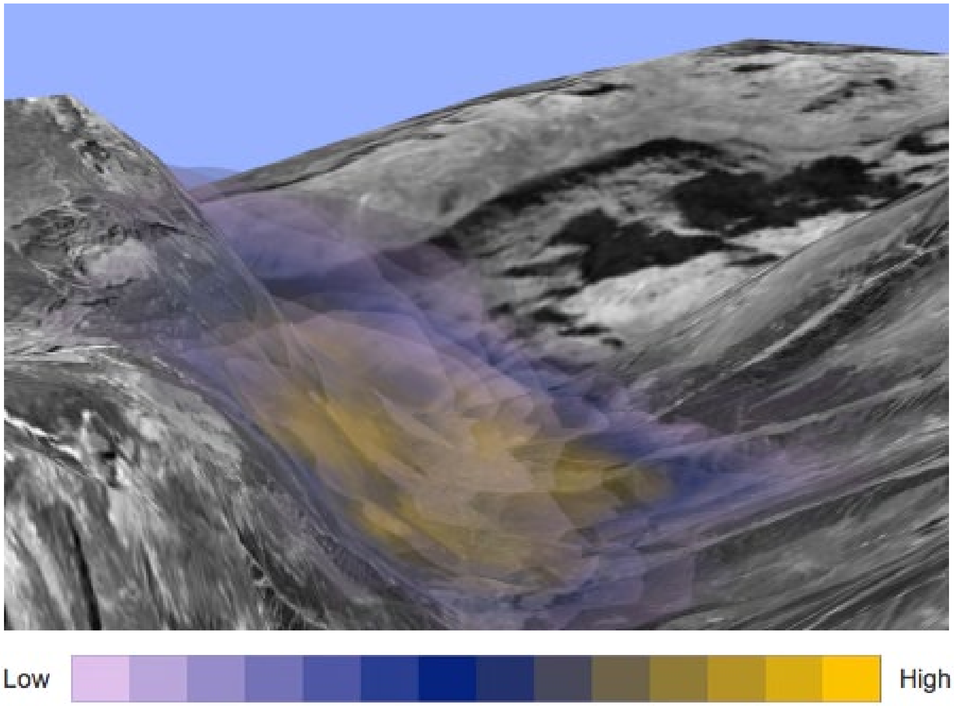
- The average global atmospheric concentration of CO_2 is 390 ppm and is rising at a rate of ~2 ppm per year.
- Prior to the industrial revolution, the atmospheric CO_2 concentration was around 280 ppm.

http://www.esrl.noaa.gov/gmd/obop/mlo/

3. Create a simulation of the atmosphere by feeding initial estimates of emissions* and atmospheric measurements from LIDAR into a sophisticated simulation of regional winds and local atmospheric turbulence.

** Initial estimates can come from Inventories, which are self-reported emissions estimates calculated from records of human activity (fuel sales, road travel) and demographics (house and business sizes and density, heating and lighting systems). Inventories can be accurate, but assembling them is difficult and time consuming, so these assessments are not done frequently (if at all)..*

Here is a snap shot in time of the atmospheric simulation of CO_2 in the Davos valley



This sophisticated simulation of atmospheric CO_2 concentration has high spatial and temporal resolution, is based on the laws of conservation of momentum, energy and matter, and is itself nested inside a simulation that spans a large portion of Europe.

Note that in truth, CO_2 is a colorless gas. Colored contours have been added here to enable the areas of high concentration to be visualized.

Learn more about how this is created at citycarbon.picarro.com/know

How do atmospheric measurements like LIDAR help us to estimate city emissions?

- LIDAR (Light Detection And Ranging) is a technology that can measure the depth of the "atmospheric boundary layer" using a laser beam.
- The Planetary Boundary Layer (PBL) is the layer of air closest to the earth, which collects the CO_2 emissions from the city of Davos.
- The distance between the ground and the PBL (the PBL depth) changes depending on many factors including: pressure, temperature, terrain and moisture levels.
- The depth of the boundary layer is also simulated by our weather model, which is compared to LIDAR measurements to make corrections.
- Direct, local measurements using LIDAR ensure that we don't have errors in the simulation that might skew the emissions estimates.
- If the simulated boundary layer is too deep, this would lead to underestimated emission while simulations which are too shallow lead to overestimated emissions.

4. Calculate the offset between the simulated CO_2 (which uses the inventories to describe city emissions) and the measured CO_2 enhancement (city measurements – mountain measurements from step 2).

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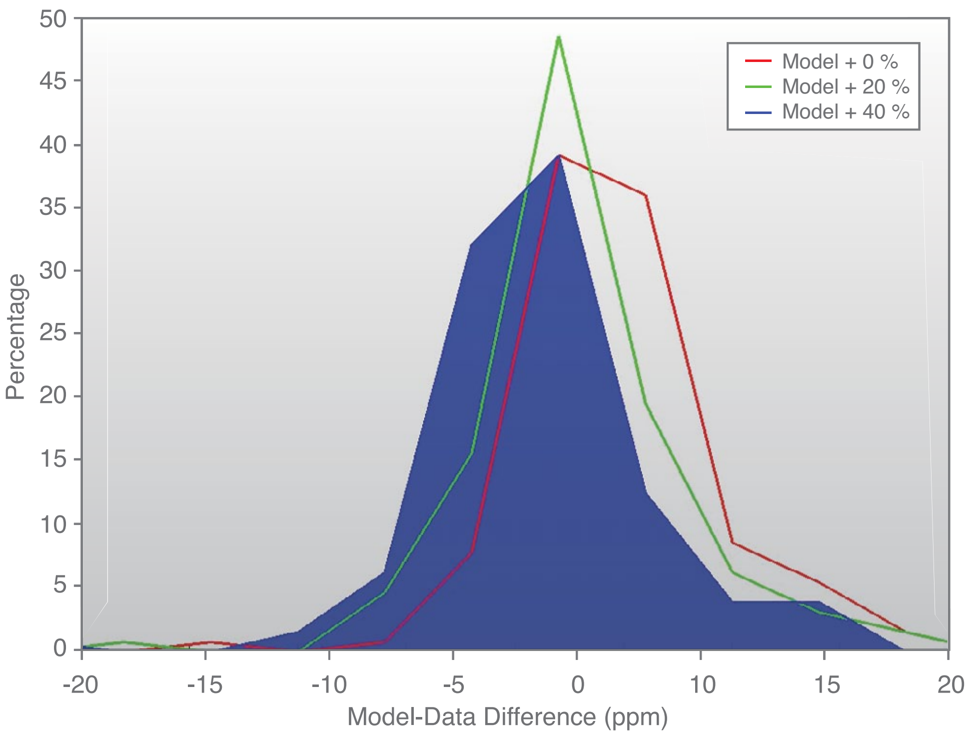
Here is the comparison of the simulation and the measurement data for Davos



The y-axis shows the percentage of time the offset is the value on the x-axis.

The goal is to get the average difference as close to zero as possible.

This is done by Increasing the emissions in the simulation until the offset between the simulated and observed CO_2 enhancement is zero on average.

The graph to the left shows how adding 40% to the reported emissions has an average offset between the simulation and the observations which is the closest to zero (the goal). This means that the offset between the measured emissions and the inventory-reported emissions is about 40%.

Why are the measured CO_2 emissions 40% greater than the inventory?

- Remember the emissions estimations are an annual average and contain no information about seasonal or daily variations.
- In the real world, it is likely the increased use of heating fuel in the winter leads to higher emissions, which is reflected in the actual measurement, but not in the estimate. It also could be that the inventories are wrong (maybe missing a source), or out of date (emissions may have changed since the inventory was conducted about 5 years ago).
- If CO_2 measurements in Davos continued for a year, the total measured CO_2 could be compared to the bottom-up reported number and used to uncover potential errors or monitor changes in emissions over time.

What could be improved in this process?

One obvious limitation of this demonstration is that we only use a subset of the measurements (shown in green on the first graph) to derive emissions estimates. There are two reasons for this. First, a single point measurement does not represent a large volume of air if the atmosphere is not well mixed. Second, it is difficult to simulate atmospheric transport under very stable (light wind) conditions. Davos, sheltered in a valley and covered with snow (which prevents sunlight from generating convection during the day by reflecting the sun's energy back into space), is an extreme case. Most cities will have more "well mixed" conditions. And even with the extreme conditions in Davos, we find good results. But more is possible. More measurements of CO_2 (imagine a tall tower instrumented at many levels above ground, for example), more measurements of the turbulence and mixing in stable atmospheric conditions, and improved weather simulations for stable atmospheric conditions would all improve our ability to estimate fluxes around the clock.

Where did the initial emissions estimates for Davos come from and how were they used?

The inventory, or initial estimate of CO_2 emissions in Davos consists of one single number for the year 2005 published by Walz et al. in 2008. The inventory is broken down by energy source (Heating, Mobility, Machines,...), but does not contain spatial or seasonal references, and therefore poses three main challenges for using it effectively in a real-time analysis.

The first challenge is the age of the inventory and the absence of information of the evolution of city emissions since 2005. The second issue is related to the seasonality. The annual emission estimate from the inventories does not indicate the changes of energy use during the course of the year. Our experiment takes place in the middle of winter, with a large increase of energy consumption for heating and machines primarily. Finally, our last missing piece of information is the distribution in space of these emissions. The inventories account for emissions at the county scale of Davos, which is about 250 km^2, but only 6 km^2 of this is actually urban.

To solve our first two problems, we use measurement data to appropriately scale the initial inventory estimates for seasonality and evolution of the city emissions over the last 6 years. With a period of observations of about one month, we can provide a corrected estimate for the month of January 2012.

In order to get some sense of the spatial distribution of emissions, we used land cover maps, which describe the land cover types of the area (urban, forest, prairies, ...). We distributed the county level emissions over the urban areas based on the population density. And thanks to the integrator effect of the atmosphere, i.e. the fact that the air moves quickly and mixes the signals homogeneously in the valley, one single observation station in the city is sufficient to capture the emissions from the city of Davos.