
Gloria Jacobson (1), Ken Davis (2), Scott Richardson (2), Natasha Miles (2), Thomas Lauvaux (2,3), Aljun Deng(2), Gian-Paul Calonder (4), Marc Ruesch (5), Michael Lehning (5), Andre Bals (1), Phil DeCola (6), and Chris Rella (1)

(1) Picarro, University of California at Santa Barbara, CA
(2) The Pennsylvania State University, Department of Meteorology, University Park, PA 16802
(3) Gloveau Engineering, 19401 Oexy Cedex, France
(4) CRM, Institute fur Schwanefeld, Switzerland
(5) IRIS, für Schweiz- und Limmatwetter, CH 2401 Flawil, Switzerland
(6) Sigma Space Corporation, 4800 Fortessa Blvd., lanham, MD 20706

Abstract
Efforts to reduce anthropogenic greenhouse gas emissions require validation. Atmospheric measurements capture all emissions, and provide a unique and powerful means of continuous validation and feedback. To demonstrate the utility of real-time greenhouse gas measurements, in-situ GHG mixing ratio instruments were deployed in Davos, Switzerland to measure emissions from the city before, during and after the World Economic Forum (WEF). Three instruments were deployed at two separate locations over 3 months (late December 2011 to February 2012). One site was located in the middle of the Davos urban area and a second site was located out of the valley in the surrounding mountains. Carbon Dioxide (CO2), Methane (CH4), Carbon Monoxide (CO) and water vapor (H2O) were measured continuously by Picarro G2401 instruments at both sites. Additionally, a Picarro flux analyzer was deployed to the city to evaluate the inverse fluxes. The mesoscale atmospheric model, WRF, nudged to meteorological observations (WRF-FDDA), was used to simulate the transport of GHG over the valley of Davos at 1.33 km resolution. A Mini Micro Pulse LiDAR (MinMPL) from Sigma Space was deployed to evaluate the simulated planetary boundary layer depth from the WRF-FDDA model. The initial flux estimates for CO2 were constructed based on inventories reported for 2005. CO2 mixing ratio measurements prior to WEF suggest the difference between modeled (real-time) and inventory (annual) emissions to be on the order of ±4%. The enhancement is likely due to the increased use of heating fuel in the winter. We present here the temporal variability in the inverse fluxes, which are correlated with a cold wave severely affecting Western Europe during the past winter, as well as changes in anthropogenic activities during the week of the WEF meeting. Also presented are new analyses of composite diurnal cycles of hourly CO/CO2 ratios, which provide additional information on the contributions of traffic relative to heating fuel. The absence of traffic peaks during the WEF meeting indicate a change in road emissions potentially responsible for the observed decrease in the city emissions during the meeting.

Why Measure Urban Emissions?
• Cities house more than half the world’s population
• Cities produce more than 70% of the world’s anthropogenic CO2 emissions
• Cities hold the greatest potential for greenhouse gas emission reduction

Atmospheric Transport Modeling

The WRF model grid configuration used for this demonstration is comprised of four grids: 36-km, 12-km, 4-km and 1.33-km, all of which are co-centered at Davos, Switzerland. The 36-km grid, with a mesh of 110×110 grid points, contains the entire continental Europe, and parts of the Atlantic Ocean. The 12-km grid, with a mesh of 151×151 grid points, contains France, Italy, Switzerland and Germany. The 4-km grid, with a mesh of 157×157 grid points, contains Western Europe, southern Germany, northern Italy, western Austria and all of Switzerland. The 1.33-km grid, with a mesh of 202×202, covers portions of northern Italy, southern Germany, western Austria and eastern Switzerland, with the grid centered at Davos. 50 vertical terrain-following layers are used, with the center point of the lowest model layer located 12 m above ground level (AGL). The thickness of the layers increases gradually with height, with 27 layers below 650 mPA (1550 m AGL).

CO2 Emissions from Davos

Two concentration measurement sites were deployed in Mid December, 2011 approximately 3.7 km apart (using Picarro, Inc. model G2401, Santa Clara, CA), one on the valley floor in the urban area and one to the west in the surrounding mountains, and are shown in the figure above. The mountain site provides background influent atmospheric concentrations while the downwind site measures the urban environment. Each site measures CO2, CO, CH4, H2O, and H2, the latter is used to correct for the dilution effect (Reiff et al., 2012). The mountain site was installed with help from the Institute of Snow and Avalanche Research (SLF) at the Weissfluhjoch test site at an altitude of 2,924 m, just 150 m before the Weissfluhjoch. Model height was approximately 5 m at both sites and measurements of all species were made every 10 s and 1.33-km at both sites. The carbon isotopes were measured at the beginning of the data collection period (mid-January 2012) and at the conclusion of data collection (mid-March 2012).

Acknowledgments: Calibration tanks were provided by C. Seawater, NOAA ESRL.

Modeling the Atmosphere

Carbon Monoxide – a tracer for anthropogenic combustion

Diurnal emissions for carbon dioxide (left panel) and carbon monoxide (right panel), averaged for the duration of the field campaign. For carbon dioxide, the signal at the mountain site is flat, indicating that there are no local emissions sources. The difference between the urban and mountain sites represents the increased emissions from the urban area, as well as the effect of atmospheric storage variations over the 24 hour period. The carbon monoxide shows a similar, although not identical, urban signature. The small CO peak at around noon at the mountain top site is not yet understood. This peak was removed before subtracting the two signals.

Using the CO2/CO2 ratio to understand emissions sources

The month before WEF, daily average emissions from Davos were found to be 25% above inventory numbers. During WEF, emissions dropped unexpectedly by 40%. After WEF, since the meeting’s conclusion, daily emissions climbed to 45% above pre-meeting levels.

Ambient temperature is clearly a significant contributor to emissions, however, the influence of other drivers is also seen.

Using modern measurement and modeling technology, urban emissions measurements are possible with a modest investment.

Pist of the diurnal cycle of the CO2/CO2 emission ratio before, during, and after the WEF. Fixed combustion sources (such as heating) tend to emit small amounts of CO with CO2/CO2 ratios typically 1 – 3 ppb (ppm). Conversely, mobile combustion sources (i.e., cars and trucks) tend to have a much higher CO2/CO2 emission ratio (20 – 100 ppb). The diurnal cycle clearly shows the effect of nighttime heating (low ratio) and daytime transit (high ratio).