Characterization of the spatial and temporal variability in ozone and ozone precursors from analysis of FRAPPÉ/DISCOVER-AQ data

Project Report #1: Monitoring network assessment for the City of Fort Collins

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Date: 30 January 2017

Summary:

In the first project report we characterize the spatial and temporal variability in ozone and ozone precursors from data collected during FRAPPÉ and DISCOVER-AQ. Wind patterns dominated by typical summertime thermally driven mountain-valley flows transported polluted air from the east/south-east to the two ground sites in Fort Collins bringing ozone and VOC enriched air to the monitors. Generally, FC West, west of the city, experienced 5-10 ppbv higher ozone concentrations than FC CSU, located in the center of Fort Collins. This is likely due to higher NO emissions close to FC CSU leading to a titration of ozone forming NO_2, a temporal ozone sink. As the air is transported west to the FC West site, this temporal ozone reservoir can reform ozone by reaction of NO_2 with O_2. Additionally, there is more time available for air to chemically process while being transported from the east across Fort Collins. During nighttime, cleaner air is flowing down the slopes from the north-west bringing air lower in ozone to the plains. The lower NO_x concentrations at FC West inhibit ozone titration, whereas at FC CSU local sources lead to higher NO_x levels and a stronger ozone loss. Compared to NO_x observations in other cities in the Front Range, NO_x concentrations in the Fort Collins are on the low end of the range. VOC observations available from both aircrafts (NCAR C-130 and NASA P-3) reveal species specific spatial patterns over the Fort Collins area and their potential to form ozone was analyzed using a chemical box model. This analysis suggests that air sampled in the north-east sector of the Fort Collins area had the highest VOC concentrations and the highest potential to form ozone. Ozone concentrations in Fort Collins are therefore not only influenced by local sources, but also both by emissions to the east and subsequent transport and photochemical processing of these air masses.

1. FRAPPÉ/DISCOVER-AQ measurement campaigns

In the summer of 2014 (July 15 – August 18), a large initiative focused on studying the air quality in the Colorado Front Range. Meteorological and chemical measurements on-board four aircraft (NCAR C-130, NASA P-3B, NASA B-200 and NASA-FALCON), as part of the DISCOVER-AQ and FRAPPÉ initiatives, were combined with numerous surface-based measurements of meteorological and chemical species at several sites in the Colorado Front Range. The flight patterns of all four aircraft and the full data set including data from surface sites are publicly available at http://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html. The NASA P-3 flew a repetitive pattern on every flight conducting spirals over six core sites, one of which being Fort Collins. The NCAR C-130 followed variable patterns dictated by conditions and individual objectives.

Here we focus on characterizing the spatial and temporal variability in ozone and ozone precursors in the Fort Collins area. Figure 1 shows the Colorado Front Range, the main study region of FRAPPÉ and DISCOVER-AQ as well as a zoom into the Fort Collins area showing the NCAR C-130 and NASA P-3 aircraft tracks as well as the NASA P-3 spiral locations and the two ground sites in Fort Collins: Fort Collins West and Fort Collins CSU. In the following, the ground sites will be addressed as FC West and FC CSU, respectively. A complete list of measurements available in the Fort Collins area during the campaign period is given in Table 1.

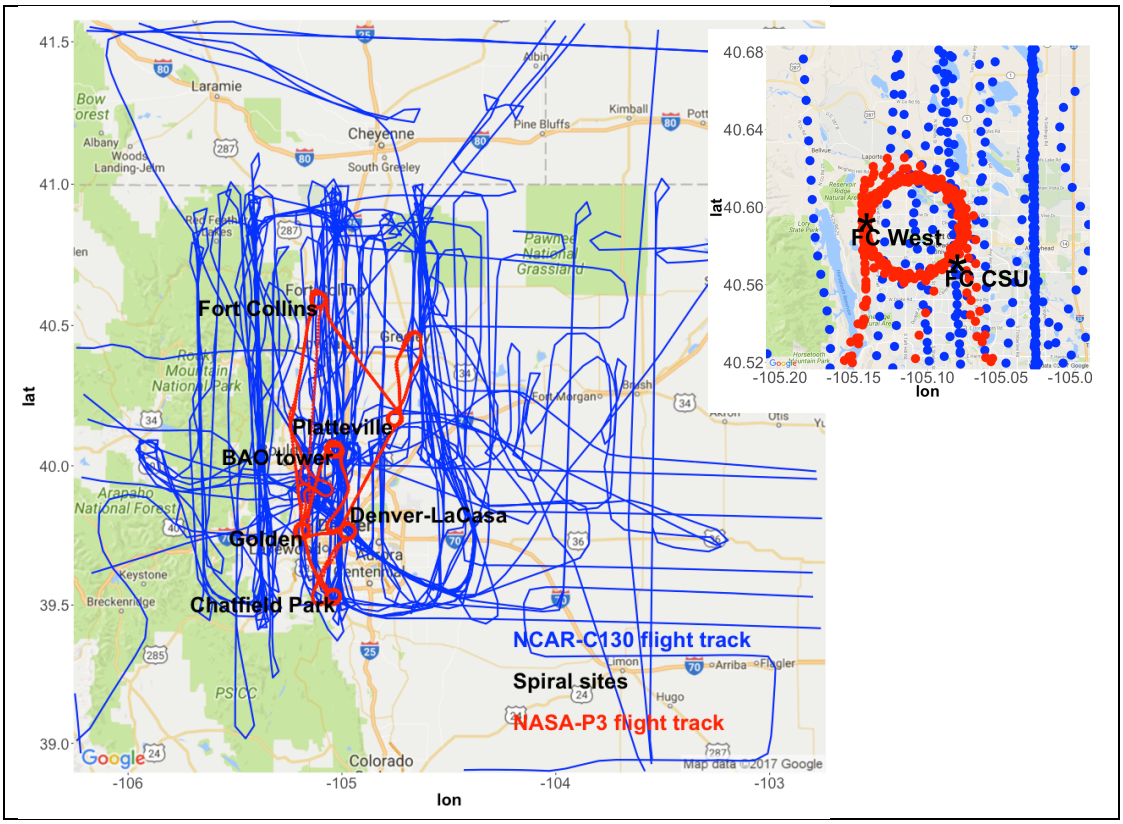

Figure 1: *Map of the Colorado Front Range showing the NCAR C-130 (blue) and NASA P-3 (red) flight tracks as well as the NASA P-3 spiral locations.*

Table 1: *List of measurements for Fort Collins area from FRAPPÉ*

Measurement	Location	Frequency	Remarks
Ozone	Ground level, Fort Collins West*	Continuous	CDPHE monitor
Carbon Monoxide	Ground level, Fort Collins West	Continuous	CDPHE monitor
Nitrogen Oxides (NO, NO_2)	Ground level, Fort Collins West	Continuous	EPA monitor
Hydrocarbons (NMHC)	Ground level, Fort Collins West	Occasional grab samples	>50 hydrocarbon species analyzed
Ozone profiles	Ground – 15 km Fort Collins West	Semi-Continuous	LIDAR remote sensing measurements
Ozone profiles	Ground – 500 feet Fort Collins West	3 days; continuous profiling	Tethered Balloon
Aircraft profiles	Fort Collins West	2-3 Profiles/day on flight days	Numerous species incl. O_3, NO_x, CO, CH_4, oxidants, hydrocarbons, particulates.
Aircraft fly-bys	Fort Collins Area	Aircraft passes over on Flight days	Numerous species incl. O_3, NO_x, CO, CH_4, oxidants, hydrocarbons, particulates.
Aerosol Profiles, Boundary Layer Height	Ground – 15 km Fort Collins West	Semi-Continuous	Micropulse LIDAR
Ozone Sondes, RH, winds	Ground – 15 km Fort Collins West	Semi-Continuous	Balloon Sondes
NO_2 and O_3 total column	Ground – ToA^ Fort Collins West	Continuous	PANDORA instrument
Ozone	Fort Collins / CSU**	Continuous	CDPHE site
Carbon Monoxide	Fort Collins / CSU	Continuous	CDPHE site
Mobile Ground Measurements	Fort Collins area	Occasional sampling	Numerous species incl. O_3, NO_x, CO, CH_4, oxidants, hydrocarbons, particulates.

* Location of CSU site: 40.593N, 105.141W

** Location of Ft. Collins West site: 40.577N, 105.079W

^ Top of Atmosphere

2. Wind measurements at the Fort Collins West and Fort Collins CSU surface sites

Average daytime (9AM-4PM) and nighttime (8PM-7AM) wind roses for FC West and FC CSU, about 3.5 miles apart, are shown in Figure 2. At the FC CSU site, winds were measured continuously throughout the campaign with a dedicated wind sensor. At FC West, wind speed and direction was measured by the NASA GSFC TROPOZ DIAL Lidar group and was only available for a subset of the days in July/August 2014. The FC CSU data shown here is analyzed for that same set of dates to make the two sites comparable.

Nighttime winds are fairly similar between the two sites and, on average, from the NW transporting air from the Foothills to the sites. The wind direction shifts around 8-9AM to characteristic upslope flows during daytime with winds mostly from the SE and E at FC West, and from the SSE to SE for FC CSU. This implies that both sites receive fresh emissions from Fort Collins sources with FC West downwind of FC CSU. Overall, wind speeds observed at FC West are higher than at FC CSU for all times of the day, the latter site rarely ever experiencing wind speeds larger than 6mph.

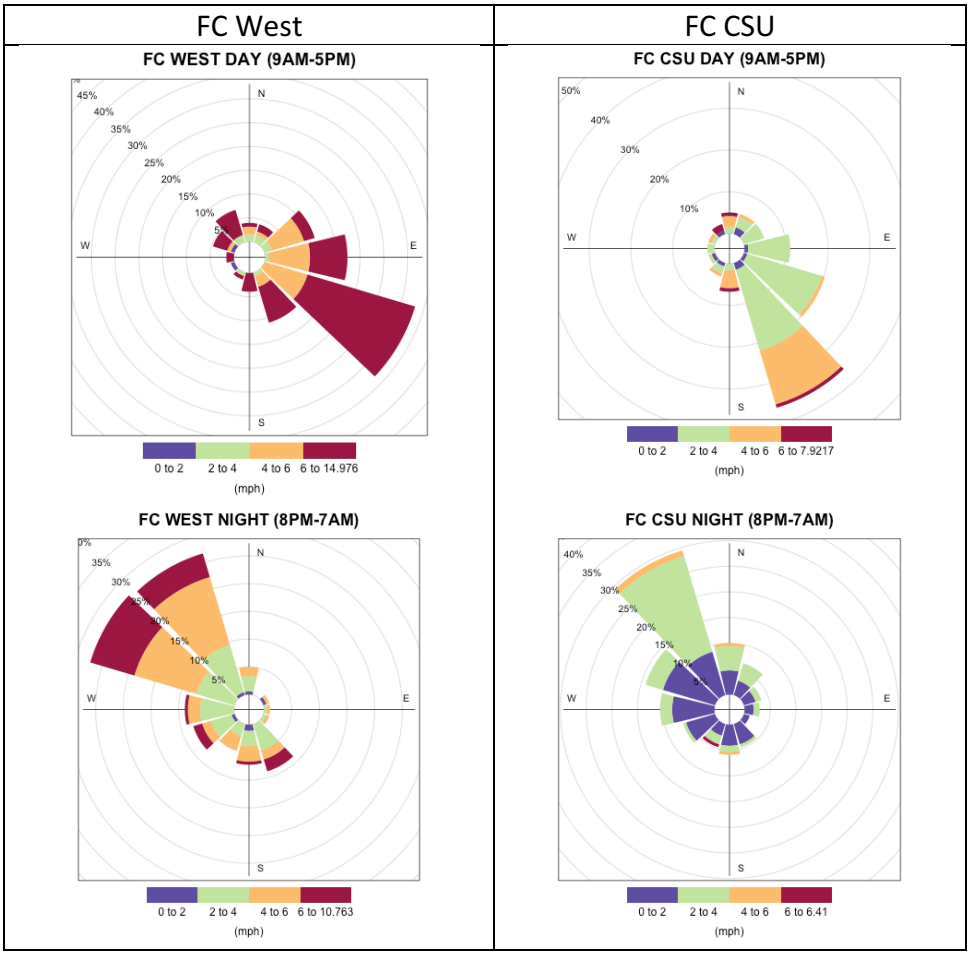

Figure 2: *Wind roses during daytime (9AM-5PM) and nighttime (8PM-7AM) measured during a subset of days (July 18-27, July 29-August 7 & August 10) at FC West and FC CSU during FRAPPÉ/DISCOVER-AQ campaign.*

3. Ozone measurements at Fort Collins West and Fort Collins CSU

At both surface sites in Fort Collins, hourly ozone concentrations were measured continuously throughout July/August 2014. Figure 3A shows the average diurnal cycles for individual days of the week, the total diurnal cycle, monthly differences and weekly statistics of ozone at both surface sites. The FC CSU site, due to its location in the city, is closer to fresh NO_x sources leading to ozone titration and the temporary conversion to NO_2. Both the reformation of ozone from the NO_2 and the longer time available for photooxidation explain the higher ozone concentrations at FC West. This is also reflected in that the peak in the diurnal cycle is both higher and broader at FC West than at FC CSU. Highest ozone concentrations are typically observed between 1PM and 4PM.

During nighttime, ozone concentrations at FC West are ~10 ppbv higher than at FC CSU, likely due to higher NO_x at FC CSU and lower NO_x at FC West This leads to a stronger titration effect at FC CSU than FC West. In summary, ozone at FC West shows characteristics of a site that is more strongly impacted by transported pollution, whereas FC CSU shows the characteristics of a site that is impacted by nearby sources. The average values for the month as well as day to day differences for the entire day (Figure 3A) and daytime 10AM-4PM only (Figure 3B) show that ozone at both sites was higher in July and that lowest ozone concentrations were, on average, seen on Fridays. However, it has to be kept in mind that we have only a limited data set (i.e. 4 weeks) available for deriving these statistics. This is why further analysis will compare the statistics derived for the FRAPPÉ and DISCOVER-AQ time period to multi-year analysis of ozone measurements at the two monitoring sites to (1) put July/August 2014 into perspective to other years and (2) assess more robust statistics on weekday/weekend differences.

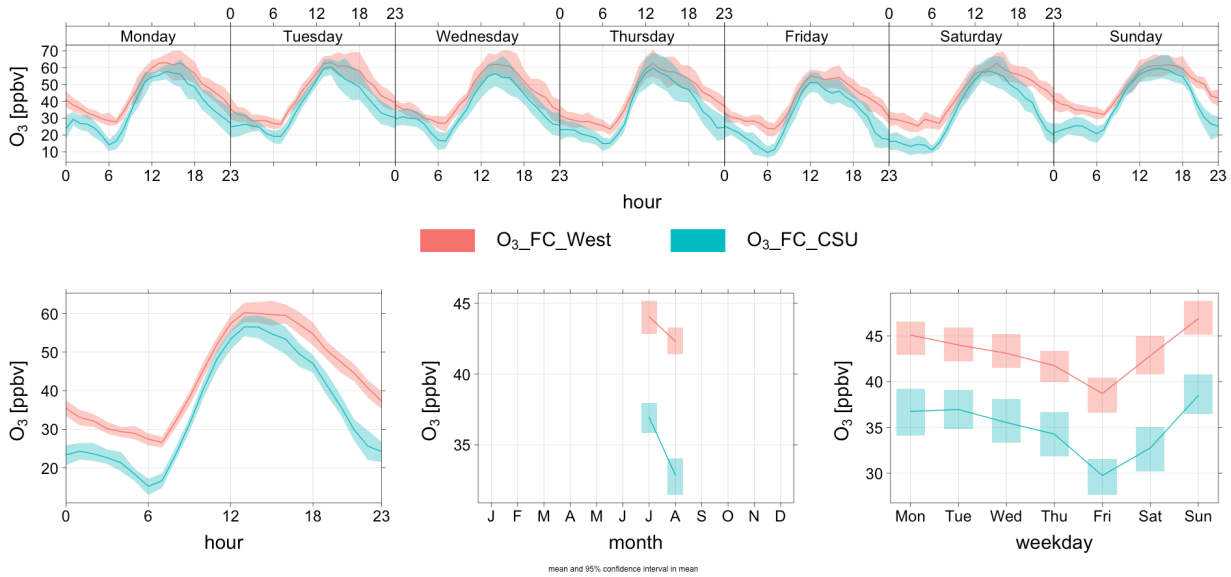

Figure 3A: *During FRAPPE/DISCOVER-AQ ozone was measured at Fort Collins for 63 days starting from July 1, 2014 – September 1, 2014. This leads to 9 measurements for each weekday. This figure shows the statistical analysis of all ozone data collected at the FC surface sites during FRAPPE/DISCOVER-AQ.*

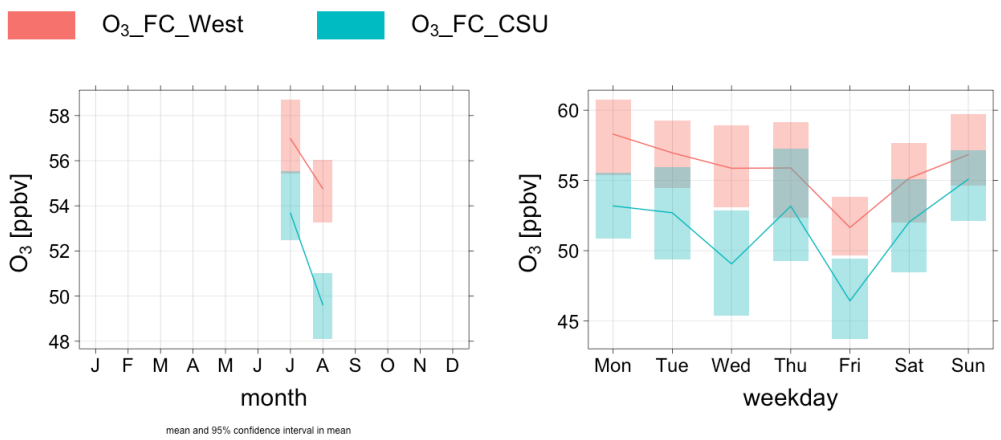

Figure 3B: *Monthly and weekday analysis of daytime (10AM-4PM) only.*

4. Polar plots of ozone and other trace gases at FC West and FC CSU

Combining wind measurements and trace gas measurements at the surface sites allows to map which wind direction and wind speeds are associated with higher and lower pollution events, respectively. These graphs are shown in Figure 4A for the morning hours (10AM-12PM) and in Figure 4B for the afternoon hours (12PM-5PM). Similar to Section 2 and Figure 2, the data is subset to the days in July/August 2014, when both sites had available wind data to make the two sites more comparable.

In the morning (Figure 4A), the highest ozone pollution at FC West coincides with higher wind speeds from the SE, which is also the dominant wind direction; the highest NO_x levels coincide with the same SE wind direction, but are associated with somewhat lower wind speeds. At FC CSU, the highest ozone levels in the morning coincide with winds from the SSE, again the dominant wind direction. FC CSU had no NO_x measurements, but available carbon monoxide measurements indicate anthropogenic influenced air arriving to the site from the SE sector at fairly low wind speed indicating a close by source. Air arriving occasionally from the NW is cleanest at both sites and for all analyzed pollutants.

In the afternoon (Figure 4B), winds are more variable and high ozone concentrations at FC West originate from the entire east sector. High NO_x concentrations at FC West at this time of the day are associated with high wind speeds from the SE. At FC CSU, highest ozone concentrations are seen with all wind directions from the east with significant variability. High CO concentrations at FC CSU originate from low wind speeds from the west sector in line with our statement above of a potential nearby sources. We will investigate this further in future reports by looking at the weekday/weekend changes as well integrating the analysis of emission inventories in our work.

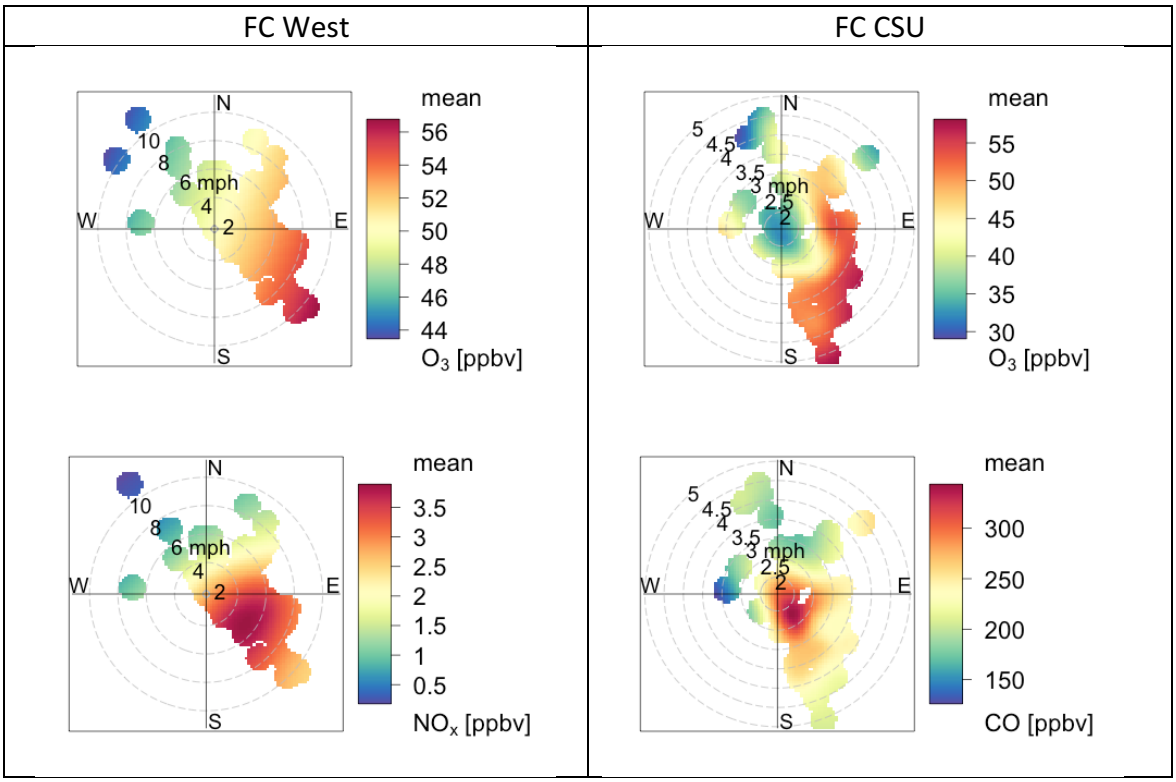

Figure 4A: *Polar plots of ozone and other trace gases as measured during morning (9AM-12PM) at the two surface sites: FC West (left), FC CSU (right)*

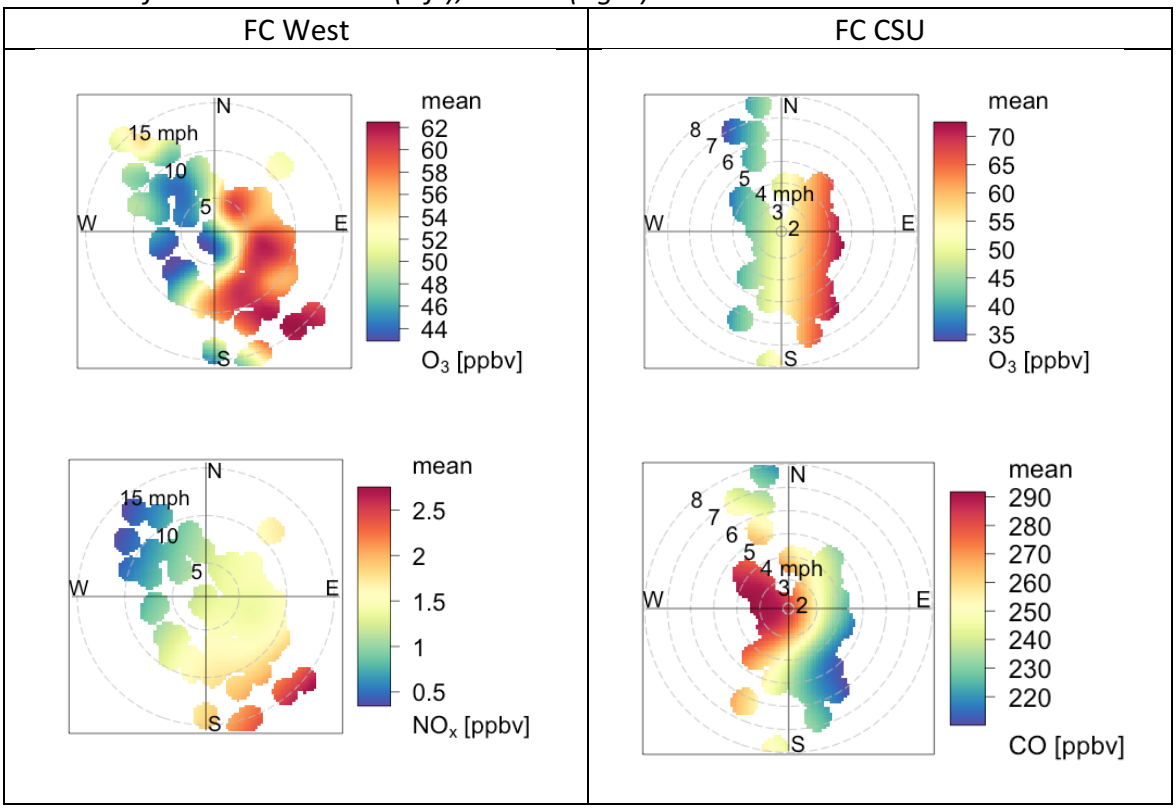

Figure 4B: *Polar plots of ozone and other trace gases as measured during afternoon (12PM-5PM) at the two surface sites: FC West (left), FC CSU (right)*

5. NASA P-3 spiral data over the city of Fort Collins

The NASA P-3 aircraft spiraled over 6 different locations in the Colorado Front Range collecting vertically resolved concentrations of a number of trace gases. One of these six locations was Fort Collins. In total, 38 vertical profiles (spirals) were conducted over Fort Collins, 22 of these were done during midday between 9:30AM and 4:00PM, the reminder before 9:00AM (not shown). In Figure 5 all available data for the 9:30-4:00PM time window is shown in the upper left plot; the stars indicate the surface site locations FC West and FC CSU. Each spiral was analyzed individually to locate the highest concentration over Fort Collins and the remainder of the plots in Figure 5 show the location and the corresponding highest concentration in each spiral. During the spirals, the wind measurements of the P-3 are not useable and thus we cannot apply any additional filtering in wind direction.

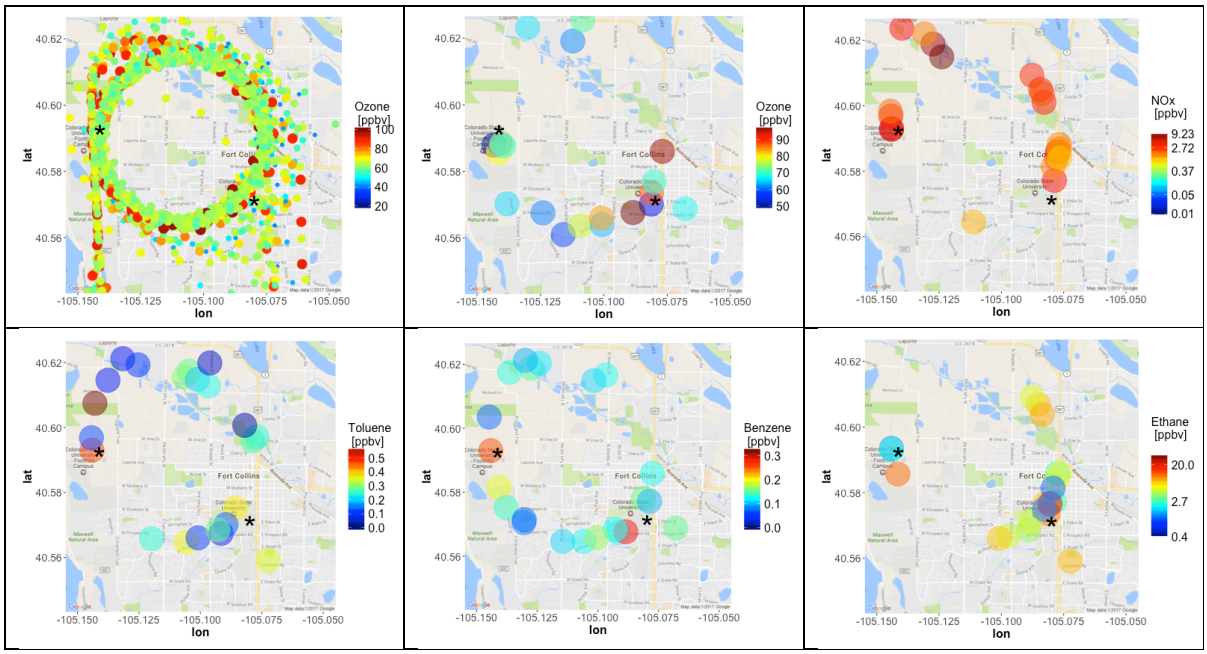

Figure 5: *Data from all spirals collected on the NASA P-3 over Fort Collins between 9:30 AM and 4 PM are shown in the top left plot. In the other 5 plots the location and corresponding concentration of observed maxima in each spiral is shown for ozone, NO_x, Toluene, Benzene and Ethane.*

Some trace gases show a clear signature on where in the spiral typically the highest concentrations occur, while other compounds are more uniformly distributed. The latter is a result of primary versus secondary species, species lifetime and local versus distant sources. Ozone is mostly higher in the south half of the spiral. NO_x, a tracer for transportation and urban sources, is higher in the northern part of the spirals, whereas ethane, a tracer for oil and natural gas sources, is highest on the east part with an additional hot spot over the FC West site. Benzene and toluene show no clear signature in location and this might be because they originate from both urban and oil/gas sources. One limitation of this analysis is that the NASA P-3 is flying in a circle while at the same time increasing in altitude. Figure 5 shows a combined picture between

vertical and horizontal heterogeneity even though only data in the first 1km above ground is used. This decreases but does not eliminate the effect of vertical heterogeneity assuming a well-mixed boundary layer. Diurnal variations in chemistry and transport are also impacting the analysis, but a more stringent filtering would decrease the sample size and the robustness of the results.

6. NO_2 column measured by GeoTaso

The NASA B-200 aircraft was equipped with the GeoTaso testbed instrument for the future geostationary TEMPO mission retrieving NO_2 and O_3 column measurements. Here we only focus on the preliminary NO_2 column retrievals and show results from one flight over the whole Front Range study area (Figure 6) as an example for NO_2 distribution in the Front Range relative to the Fort Collins area. It is legitimate to assume that most of the NO_2 in the columns is near the ground. Generally, NO_2 columns measured by GeoTaso are much smaller in Fort Collins compared to the campaign hotspot measured in the Denver and Boulder area. High NO_2 concentrations are found in areas with power plants such as Denver and Boulder. In contrast, Fort Collins which does not have a power plant near the city has lower NO_2 concentrations. On July 31 (Figure 6), NO_2 columns over Boulder and Denver are on the order of $2*10^{16}$ molecules cm^{-2} with some hot spots in Denver reaching up to $6*10^{16}$ molecules cm^{-2}. In comparison, in Fort Collins highest measured values are on the order of $1*10^{16}$ molecules cm^{-2}. As of now we only applied a first filtering to the retrievals and we are working with the GeoTaso Team on the optimal data quality control so as to enhance the signals over the Fort Collins area. Future work will then compare GeoTaso patterns to emission inventories for their representativeness. Table 2 shows measured NO_2 at different surface sites in the Front Range, confirming Fort Collins as a relatively low NO_2 region. We will also compare these measurements with the predictions from the newly released NEI2014 emissions inventory.

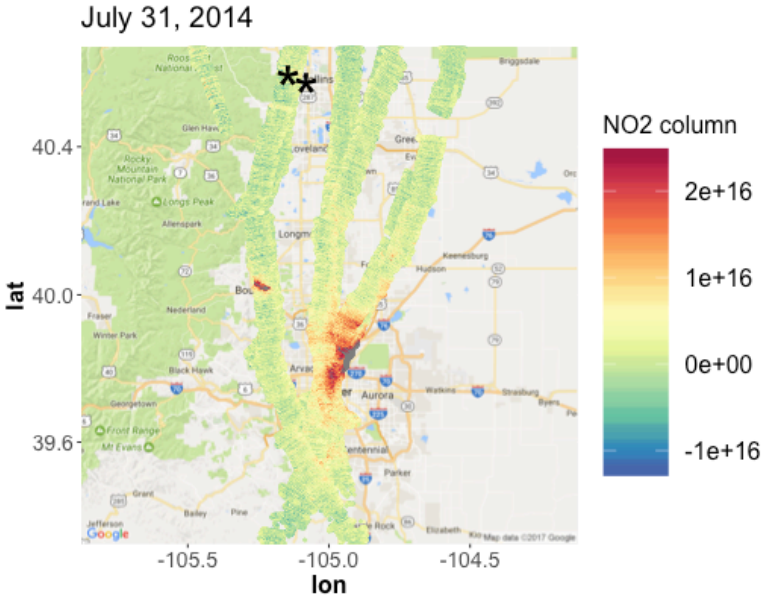

Figure 6: *NO_2 column measured by GeoTaso on July 31, 2014 in the Colorado Front Range area.*

Table 2: *U.S. EPA NO_2 measurements with a Teledyne T500U CAPS analyzer at four sites in the Front Range for 15 July – 11 August 2014, at Platteville with the NASA NATIVE mobile lab from 14 July – 12 August 2014 and at the BAO Tower in Erie from 9 July-19 August 2014.*

Monitoring Site	***Mean (ppb)***	***10th Percentile (ppb)***	***90th Percentile (ppb)***
FC West	2.3	0.7	4.7
Denver I-25	24.3	9.5	38.8
Chatfield	2.7	0.6	6.1
NREL Golden	4.5	1.3	9.3
Platteville	8.4	1.9	17.6
BAO Tower Erie	3.43	0.5	7.5

7. Different VOC mix and OH reactivity and ozone formation potential

As shown in Figure 1 and discussed earlier, the NCAR C-130 covered a larger area than the NASA P-3. The NCAR C-130 also carried a more comprehensive chemical payload providing measurements of all relevant VOCs suited for detailed ozone production analysis. To examine the spatial differences in ozone precursors and related changes in chemistry, all data collected during 10AM to 4PM over the Fort Collins area from the NCAR C-130 was divided into six sectors: north-west (NW), north-center (NC), north-east (NE), south-west (SW), south-center (SC) and south-east (SE). Figure 7 shows these six areas over a map centered over Fort Collins. The data sampled on the NCAR C-130 is shown in color. For comparison with Figure 5, the NASA P-3 spirals are indicated in grey demonstrating the small scale variability picked up by the spirals.

From the larger spatial coverage that is given by the NCAR C-130, we find the highest NO_x concentrations on the eastern legs, which likely reflects influence from I-25. NO_x concentrations over the P-3 spiraling area are lower compared to the values shown in the P-3 analysis, but this is because for the P-3 data set we selected the maximum trace gas amount in each spiral from a total of 22 spirals, whereas for the C-130 data we have only limited coverage available and we use all data available over the Fort Collins area. Many measured VOCs such as e.g. formaldehyde (CH_2O) show a gradient from east to west with higher concentrations in the east. Some VOCs such as ethane show a hotspot in the NE with low concentrations in all other areas, which is in agreement with the P-3 analysis that the highest ethane comes from the East. The two center sectors in Figure 7 show both high and low values. The low values coincide with wind directions from the north, whereas all other shown values are collected when winds were from the south, southeast and east.

In the following we did not separate the two wind directions, but concentrations, OH reactivity and ozone production potential as analyzed in the following increase slightly in the two center sectors (NC and SC) if data from air arriving from the north is filtered out. The average concentrations from each sector for a set of measured compounds are given in Table 3. The number of data points for each area is dependent on the number of overpasses of the NCAR C-130 over each area as well as the sampling frequency of the individual instruments. Data coverage for each sector ranged from 15-75 individual 10-second measurements for fast sampling instruments to 1-7 measurements per sector for slow VOC measurement techniques (TOGA and WAS). The exact number of measurements available for each sector and compound

is listed in brackets in Table 3. To assess the corresponding reactivity of the mix of trace gases and therefore the potential to form ozone, the OH reactivity for each sector was calculated and is discussed below.

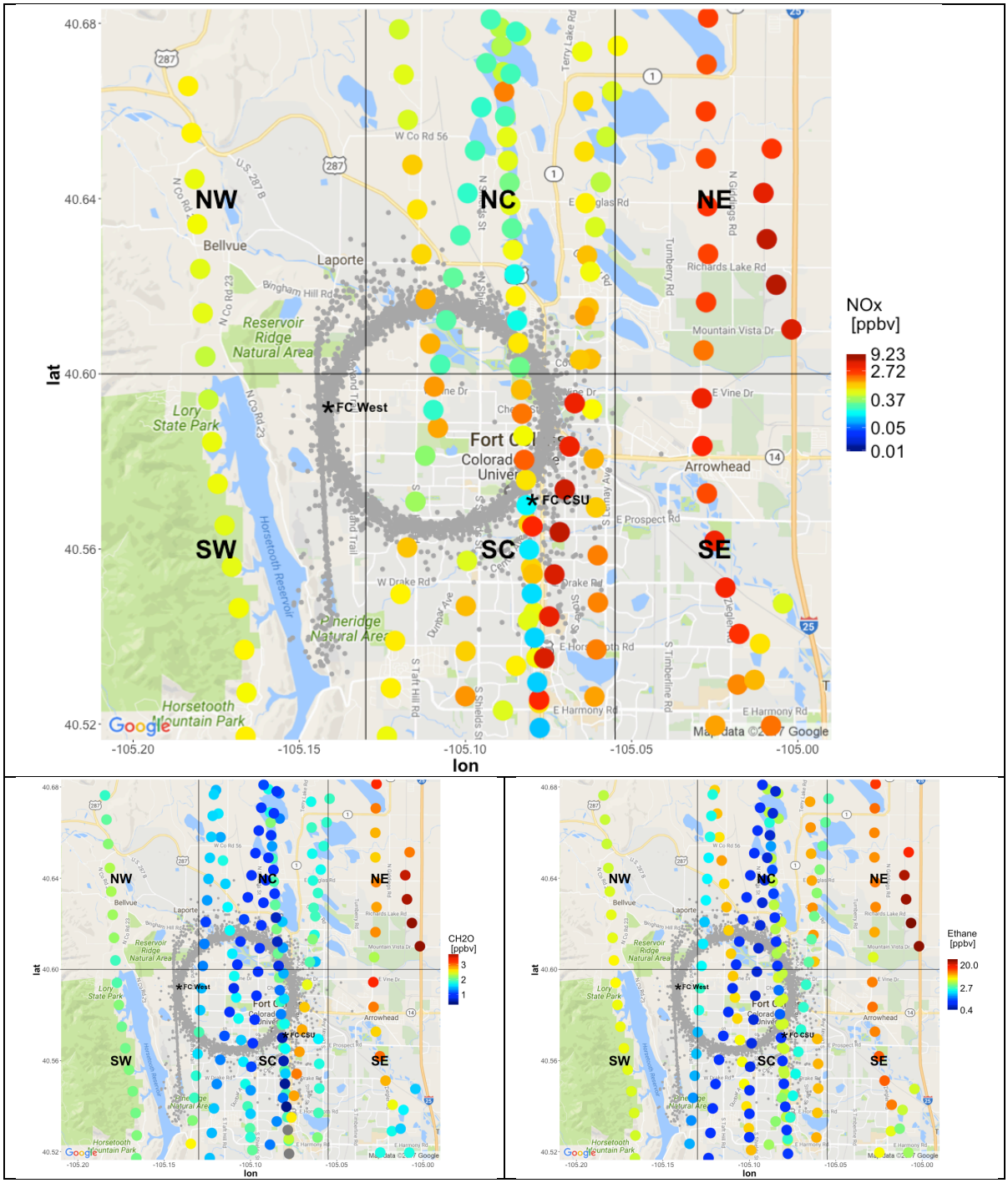

Figure 7: Maps with trace gases measured on the NCAR C-130 in color, the Fort Collins surface sites are marked with black stars, grey markers indicate NASA P-3 spirals and the black lines divide the map centered in Fort Collins into six sectors: north-west (NW), north-center (NC), north-east (NE), south-west (SW), south-center (SC) and south-east (SE).

OH is the main oxidant in the daytime troposphere and leads to a cleansing of the atmosphere from the trace gases in the air. As an unwanted byproduct in this cleansing process, ozone is produced. OH reactivity, the reciprocal of OH lifetime, is a measure how much of the reactive compounds is available in the mix. OH reactivity is calculated as the product between the VOC concentration and its corresponding reaction rate with OH. The total OH reactivity is the sum over all individual OH reactivities. Table 4 lists the OH reactivity of key trace gases for the different sectors. Overall, the highest total OH reactivity is observed in the NE with a value of 3.9 s^{-1} and the lowest in the NW with a value of 1.7 s^{-1}. The values for all other sectors range from 2 – 2.6 s^{-1}. This indicates that the trace gas mix is most reactive in the NE sector. Looking at overall NMHC concentrations, the NE is also much higher with a total of 70 ppbv when summing up all measured VOC species. In comparison, total measured VOC concentrations range from 29 to 37 ppbv for the other sectors. NMHC that add especially to the increased OH reactivity and concentration in the NE result from a combination of VOCs from urban and OG sources: propane, butane, pentane, formaldehyde, acetaldehyde, propanal, methanol and ethanol. Concentrations and OH reactivities of these NMHCs and other trace gases are given in Table 3 and 4. The OG tracers are significantly enhanced in the NE sector compared to all other sectors and at the same time we also find a high OH reactivity from NO_2 for the NE sector.
The C-130 flights over the Fort Collins area are limited in spatial and temporal coverage and we cannot exclude that unique conditions and incomplete sampling might distort the results. Future work will extend the analysis to include simulations with an air quality model and will help to evaluate the representativeness of the observational data. For now, our analysis is limited to the observational data set.

8. Ozone formation potential

The ozone formation potential in the six sectors over Fort Collins was further analyzed by using the VOC concentrations as an input to the chemical boxmodel BOXMOX (chemical mechanism: MOZART T1). For more information on BOXMOX please see: http://boxmodeling.meteo.physik.uni-muenchen.de.
Selected key input concentrations such as NO, NO_2, O_3, and some VOC's are listed in Table 3. The first 8 hours of oxidation of the different trace gas mixtures is shown in Figure 8A. The left plot shows a model run were all measured trace gas concentrations (including O_3 and NO_x) were used as starting conditions. Both the trace gas mix in the SE and NE sector lead to the highest ozone concentrations after 8 hours of oxidation, but the SE sector run starts approximately 7 ppbv higher in ozone at time zero. To normalize the samples in regard to ozone initial conditions, the center plot of Figure 8A shows results from a model run where the starting ozone concentration in all six sectors was fixed to 60 ppbv (NO_x is still constrained by individual measurements). For this run, the trace gas mix in the NE sector has the largest ozone formation potential followed by the SE, SC and SW sectors. To investigate the ozone formation potential purely dependent on VOCs, we fixed the ozone initial concentrations at 60 ppbv and, in addition, constrained NO to 100 pptv and NO_2 to 1200 pptv (Figure 8A – right).
This reveals the influence of the VOC mix on ozone formation potential and shows that the NE sector has the largest ozone formation potential in good agreement with this sector also showing the highest OH reactivity and the highest total VOC concentration in the region. In summary,

independent of the scenario assumed, the NE sector appears as the area in Fort Collins with the most reactive mix of tracers followed by the SE sector. Given the average wind direction from the SE during the day and assuming spatial heterogeneity, we expect that the NE sector will have minor influence on FC West and FC CSU but that the monitoring sites will experience influence from the SE sector.

As noted in section 7, we included all available data for the input to BOXMOX and did not sort for wind directions. A separate model run (Figure 8B) excluding wind from the N resulted in higher VOC concentrations and a slight increase in OH reactivity and ozone production potential in the center sectors (NC & SC).

Table 3: *Average concentrations from key compounds are listed for the six different sectors. The numbers in the brackets show the available number of measurements in each sector and for each compound.*

Compound/Sector	NW	NC	NE	SW	SC	SE
NO (pptv)	125 *(9)*	113 *(59)*	593 *(20)*	159 *(15)*	286 *(58)*	563 *(15)*
NO_2 (pptv)	486 *(9)*	435 *(59)*	1962 *(20)*	602 *(15)*	1253 *(58)*	1790 *(15)*
O_3 (ppbv)	67 *(12)*	63 *(70)*	61 *(20)*	62 *(15)*	60 *(65)*	67 *(15)*
propane (pptv)	2185 *(1)*	2936 *(3)*	15120 *(2)*	3817 *(1)*	2234 *(3)*	3052 *(2)*
ethane (pptv)	3983 *(22)*	3843 *(66)*	12315 *(20)*	3097 *(24)*	3087 *(72)*	8140 *(15)*
butane (pptv)	1052 *(3)*	1029 *(7)*	4031 *(1)*	1118 *(2)*	1462 *(6)*	2119 *(2)*
pentane (pptv)	307 *(3)*	310 *(7)*	1281 *(1)*	337 *(2)*	447 *(6)*	710 *(2)*
ethanol (pptv)	480 *(3)*	460 *(7)*	1049 *(1)*	567 *(2)*	606 *(6)*	631 *(2)*
methanol (pptv)	6021 *(3)*	5058 *(7)*	8463 *(1)*	6891 *(2)*	5791 *(6)*	5387 *(2)*
formaldehyde (pptv)	2011 *(22)*	1746 *(65)*	3606 *(20)*	2487 *(24)*	2152 *(72)*	2435 *(15)*
acetaldehyde (pptv)	631 *(3)*	572 *(7)*	1383 *(1)*	726 *(2)*	725 *(6)*	817 *(2)*
propanal (pptv)	55 *(3)*	58 *(7)*	190 *(1)*	33 *(2)*	77 *(6)*	90 *(2)*

Table 4: *Average OH reactivities from key compounds and the total OH reactivity are listed for the six different sectors.*

Compound/Sector	NW	NC	NE	SW	SC	SE
NO_2 (1/s)	0.10	0.09	0.39	0.12	0.25	0.36
propane (1/s)	0.02	0.06	0.30	0.08	0.04	0.00
ethane (1/s)	0.02	0.02	0.06	0.01	0.02	0.04
butane (1/s)	0.05	0.04	0.17	0.05	0.06	0.09
pentane (1/s)	0.02	0.02	0.09	0.02	0.03	0.05
ethanol (1/s)	0.03	0.03	0.06	0.03	0.03	0.04
methanol (1/s)	0.10	0.08	0.14	0.11	0.09	0.09
formaldehyde (1/s)	0.30	0.26	0.55	0.38	0.33	0.37
acetaldehyde (1/s)	0.19	0.17	0.41	0.22	0.22	0.24
propanal (1/s)	0.02	0.02	0.07	0.01	0.03	0.03
total OH reactivity (1/s)	**1.67**	**1.97**	**3.92**	**2.29**	**2.41**	**2.62**

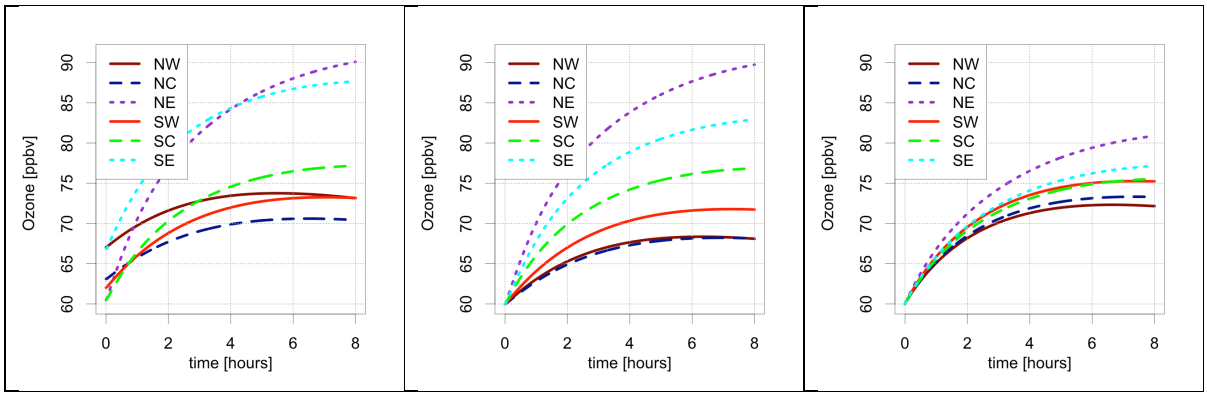

Figure 8A: *Ozone formation potential of the trace gas mix measured by the NCAR C-130 for the six different sectors above Fort Collins. The left plot includes differences in all trace gases, the center plot fixes all ozone starting concentrations to 60 ppbv and the right plot fixes ozone to 60 ppbv as well as NO to 100 pptv and NO_2 to 1200 pptv.*

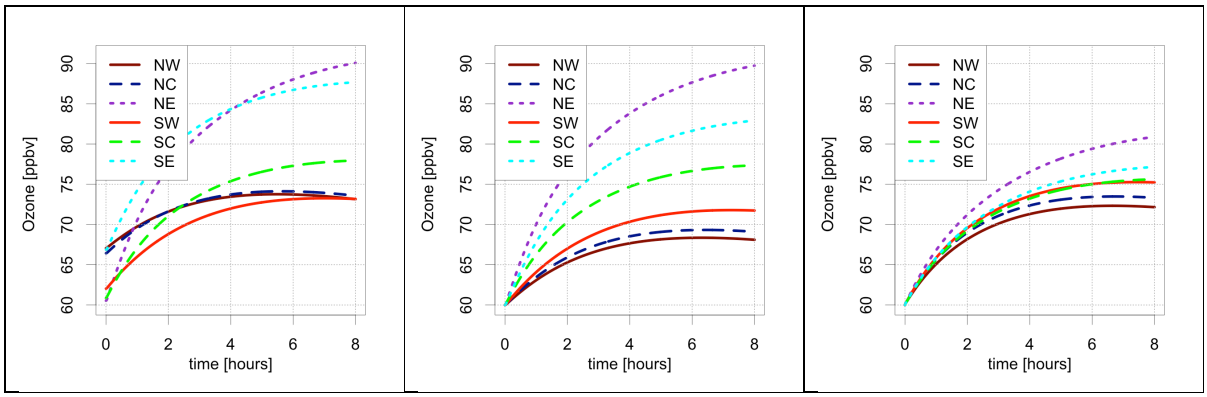

Figure 8B: *as Figure 8A but excluding samples with a wind direction from the north.*

Future work

Our analysis to date has focused on the analysis of measurements over Fort Collins conducted during the FRAPPÉ and DISCOVER-AQ campaign. This data set provides highly valuable information on the distribution and reactivity of trace gases and their potential to form ozone, but the robustness of the conclusions is impacted by the spatial and temporal limitations in the data set. For this reason, we will extend our follow-up analysis to include multi-year analysis of surface ozone measurements at FC West and FC CSU, air quality modeling results for the FRAPPÉ and DISCOVER-AQ period and different sector-based emission inventories. This will allow to test the robustness of the derived results and also put July/August 2014 into a multi-year perspective.

Acronyms:

NO Nitrogen Oxide
NO2 Nitrogen Dioxide
NOx Nitrogen Oxides (NO + NO2)
OH Hydroxy Radical
ppbv parts per billion volume
pptv parts per trillion volume
TOGA NCAR Trace Organic Gas Analyzer
VOC Volatile Organic Compounds
WAS Whole Atmosphere Sampler