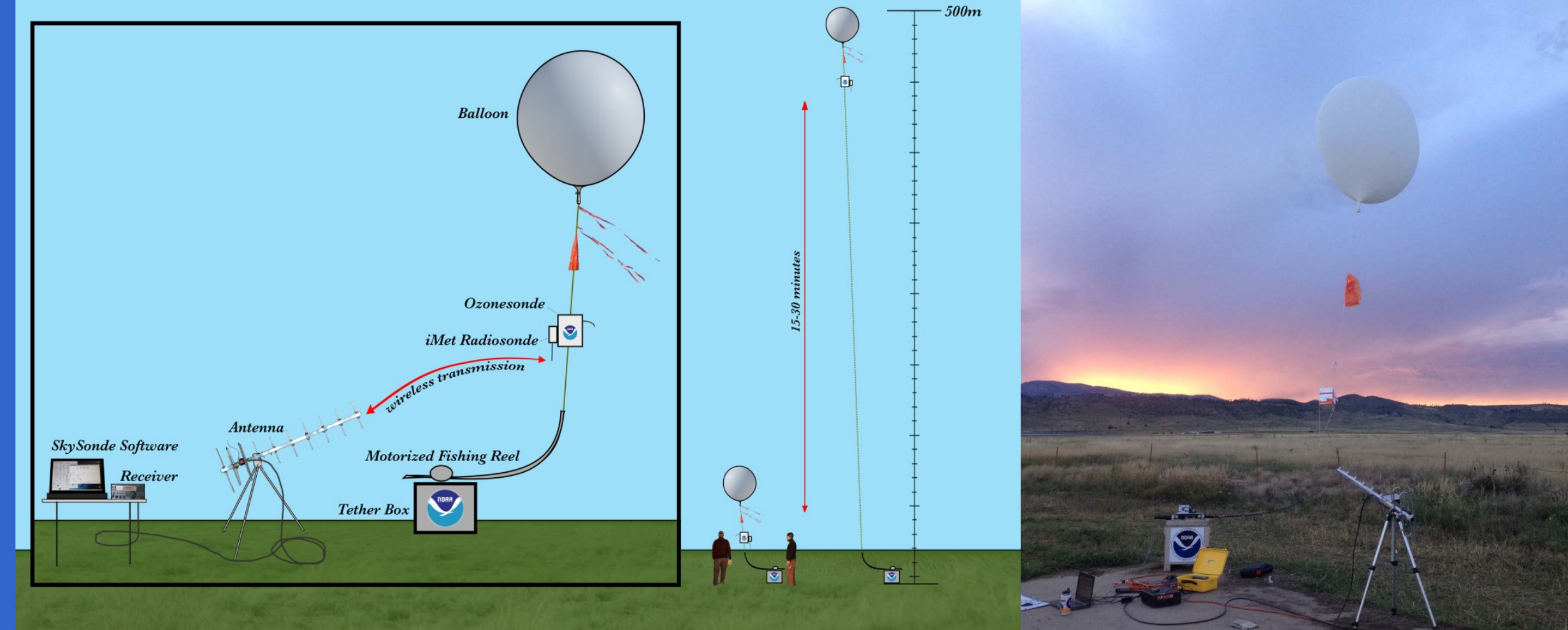


Introduction

Ozone, temperature, humidity, and wind direction profiles were measured by tethered ozonesondes at three different sites within the Colorado Front Range during July and August 2014. Over 340 profiles were obtained over the course of 10 observing days at Ft. Collins West, Denver City Park Golf Course, and Chatfield State Park as part of the Front Range Air Pollution Photochemistry Experiment (FRAPPE).

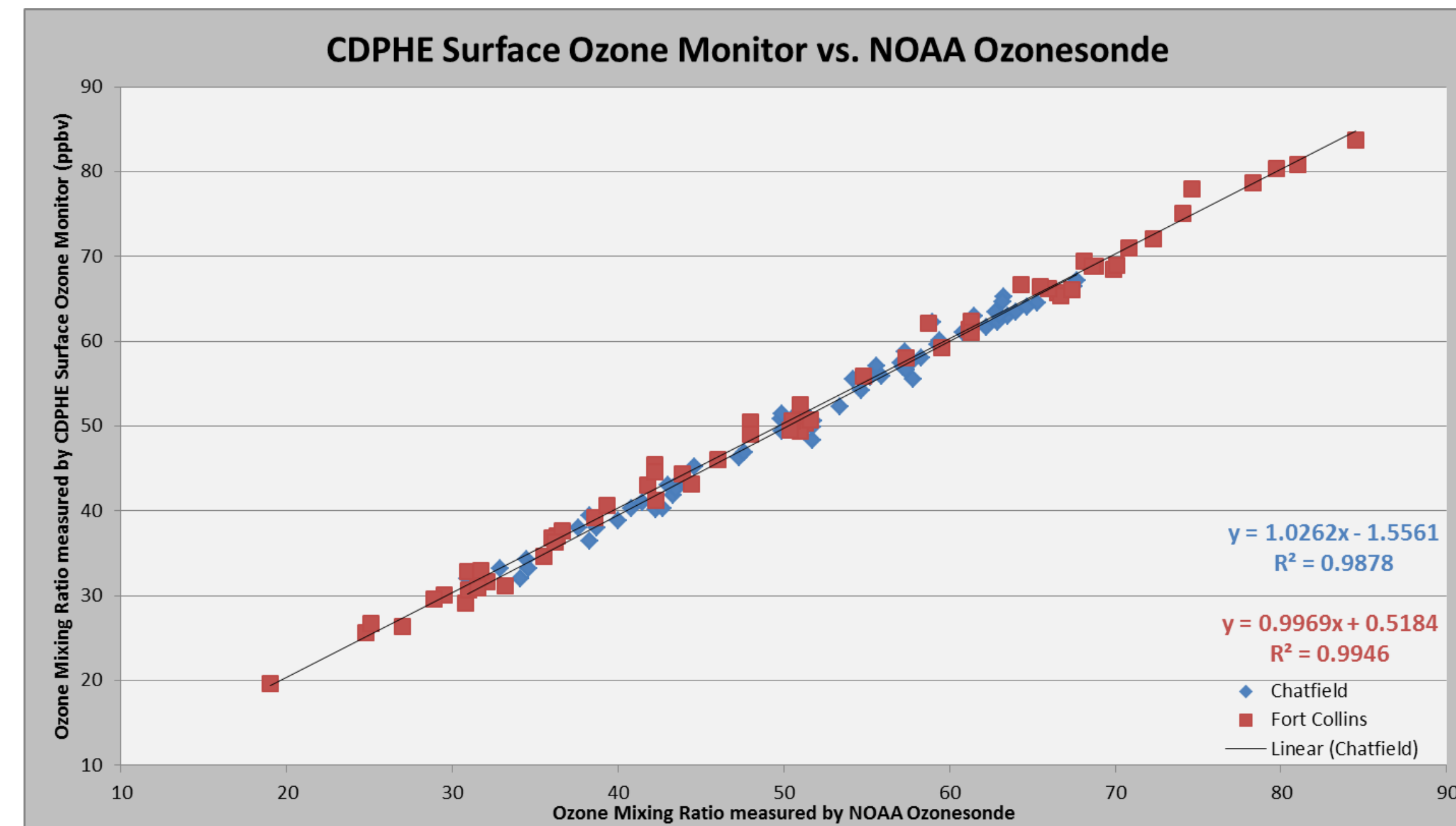


Schematic diagram of the tether system (left) and the system set up for operation (right).

FRAPPE tethered ozonesonde site locations, altitude, number of profiles and dates. A total of 344 profiles were obtained by the tethered systems.

Location	Latitude (°N)	Longitude (°W)	Elevation (m)	# of tether profiles - dates
Chatfield State Park	39.5344	105.0704	1676	130 profiles - 7/27, 8/2, 8/12
Denver City Golf	39.7533	104.9487	1621	88 profiles - 7/20, 8/7, 8/11, 8/11
Fort Collins -West	40.5928	105.1413	1572	126 profiles - 7/26, 8/3, 8/18

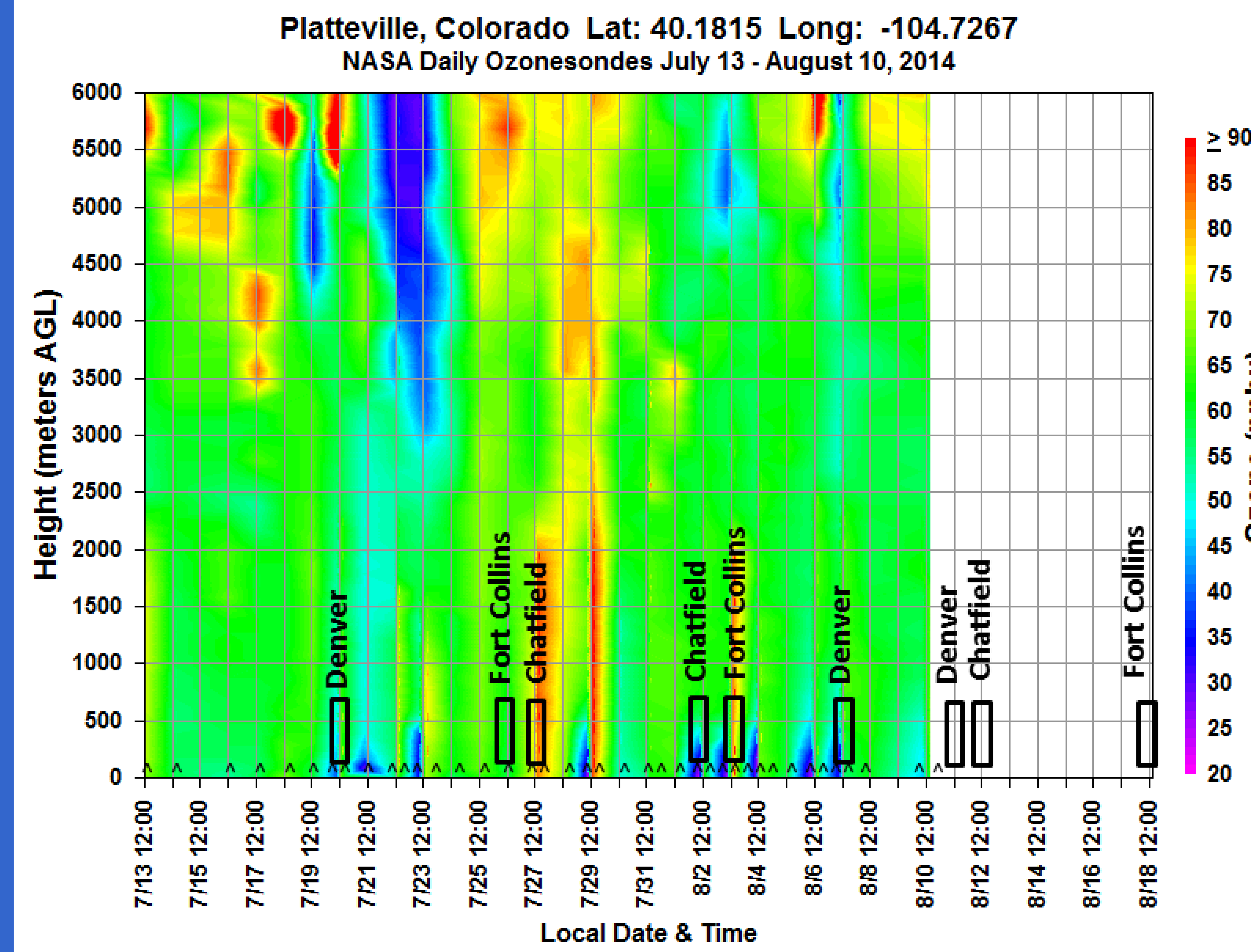
(1)



Comparison of ozone mixing ratios between CDPHE ozone monitors at Chatfield and Fort Collins, and NOAA ozone tethersondes at the same locations.

Ozonesondes were compared to a NIST traceable ozone standard before deployment. At Chatfield and Fort Collins the Colorado Department of Public Health and Environment (CDPHE) has a certified surface ozone monitor. Before each tethered profile, a comparison of the ozone mixing ratio was conducted between the tethered sonde and the in situ ozone monitor to validate the ozonesonde reading. This was done by operating the ozonesonde at a fixed height (~2 meters above ground level) for 1 minute. This demonstrates that even small (~1 ppb) changes with time and altitude are valid in the sonde profiles.

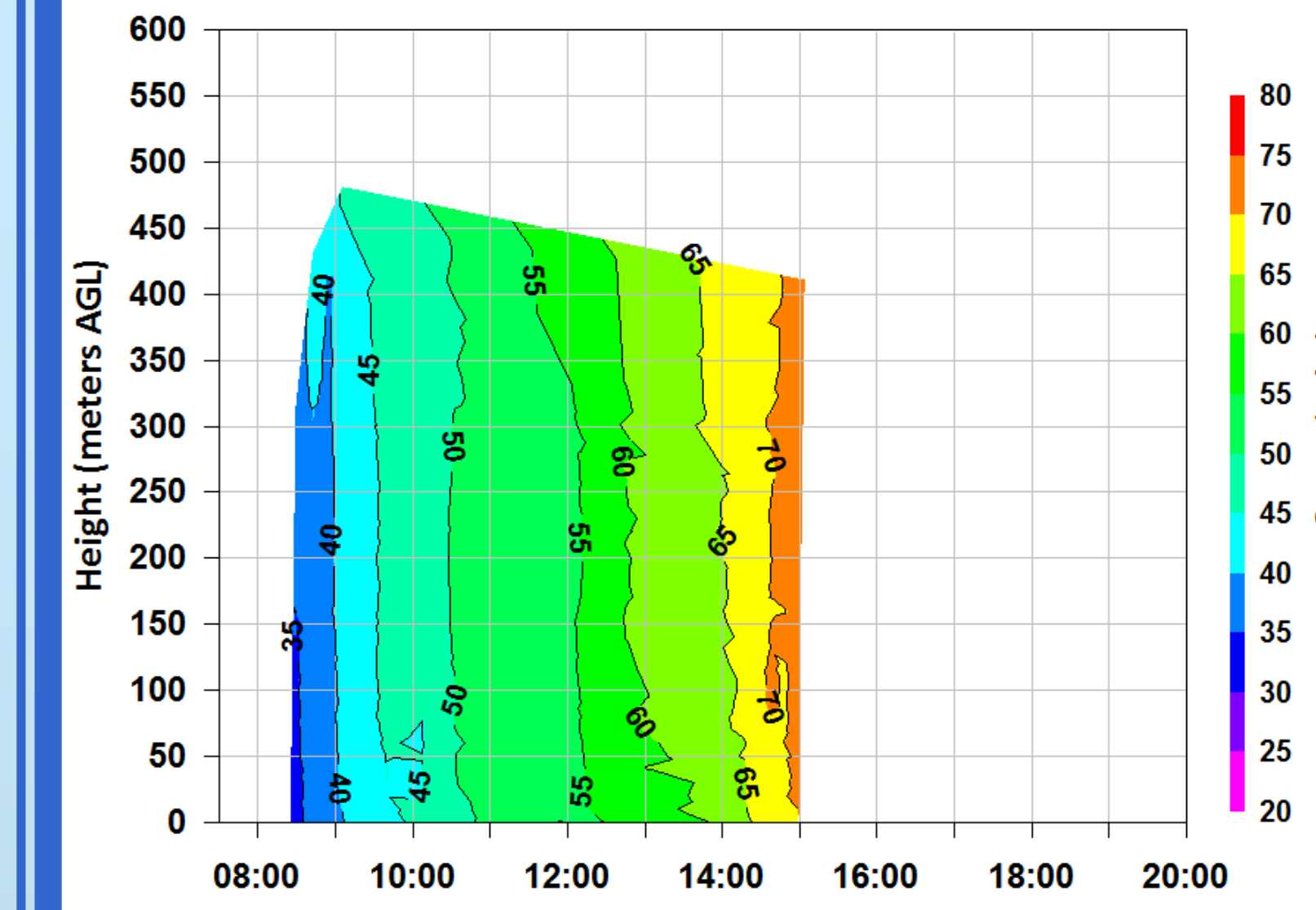
(2)



Contour plot of ozone mixing ratio (ppbv) from the Penn State/NASA free flying ozonesondes launched daily and twice daily on flight days during DISCOVER AQ at Platteville, Colorado. The 42 pointers along the x-axis show the time of launch for the free flying ozonesondes. The site - name blocks along the x-axis show the days when NOAA tether ozonesonde measurements were made during FRAPPE in 2014 and at which locations.

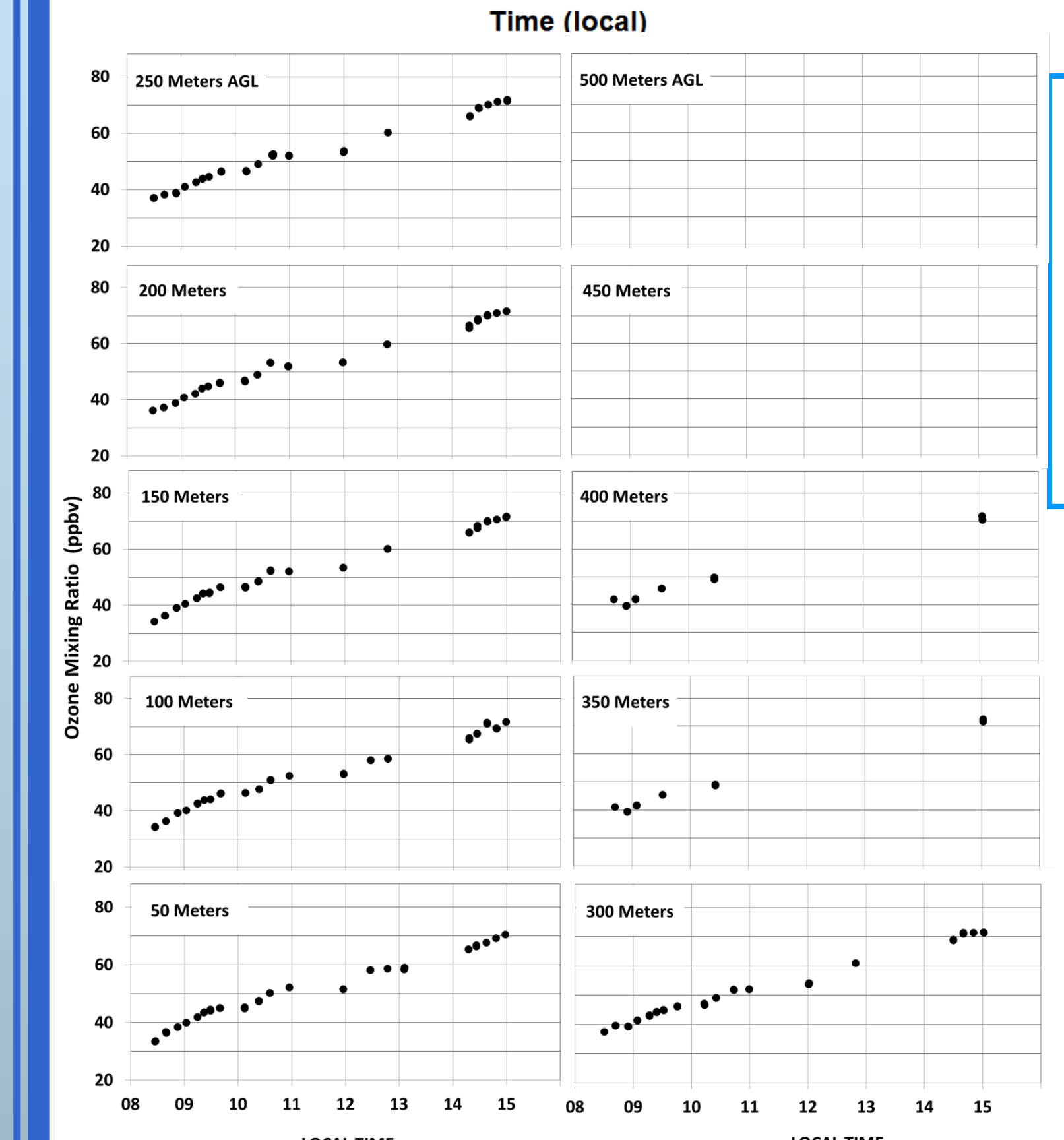
There were a limited number of days with larger ozone production events during the period encompassed by the ozonesondes at Platteville. Two of these events (July 27 and August 3) were also captured by the tethersondes. The Ft. Collins tether site was closest to Platteville.

(3)



Results from profiles on July 27, 2014 from Chatfield (moderate ozone production day - perhaps stronger at Platteville)

Contour plot (cross-section) of ozone mixing ratios.

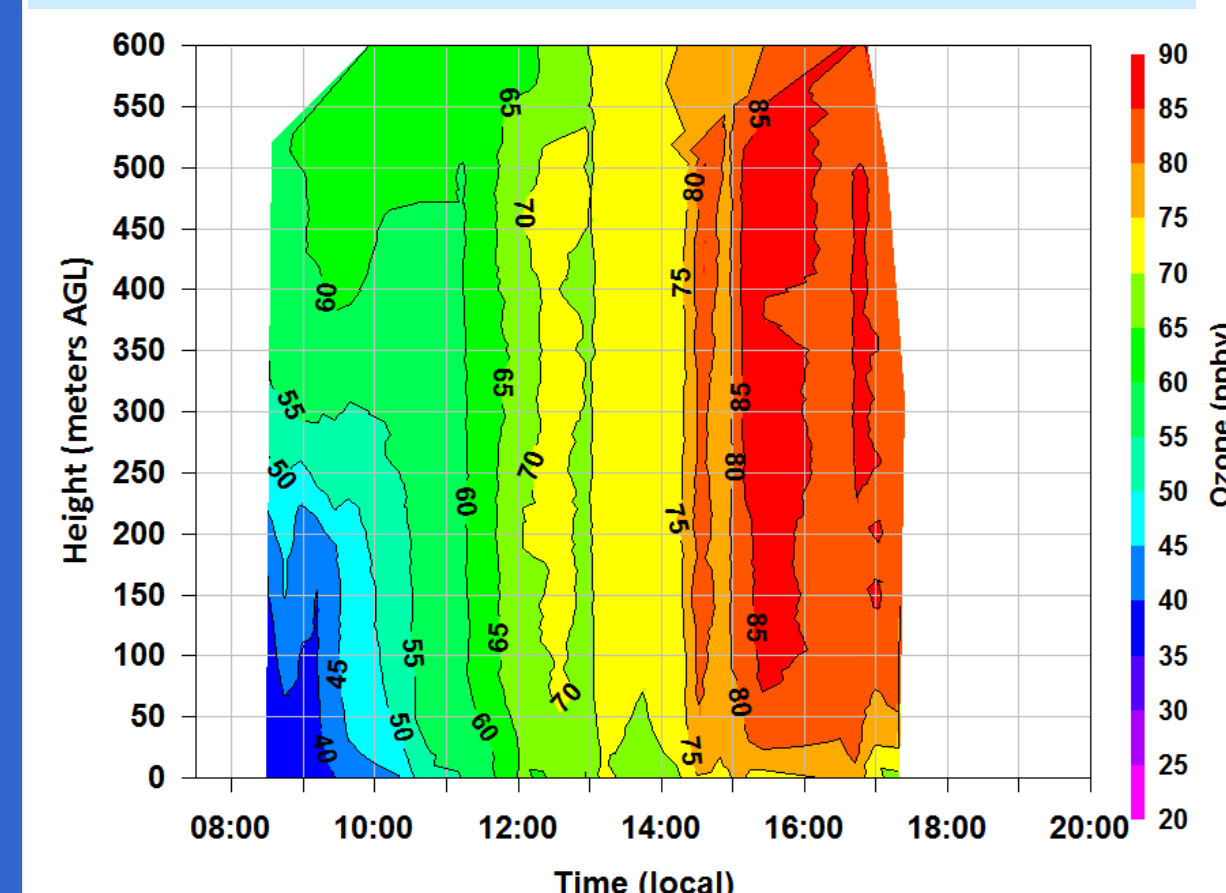


Ozone mixing ratio (parts per billion) versus local time at the Chatfield site beginning at 0830 and ending at 1500 MDT on July 27.

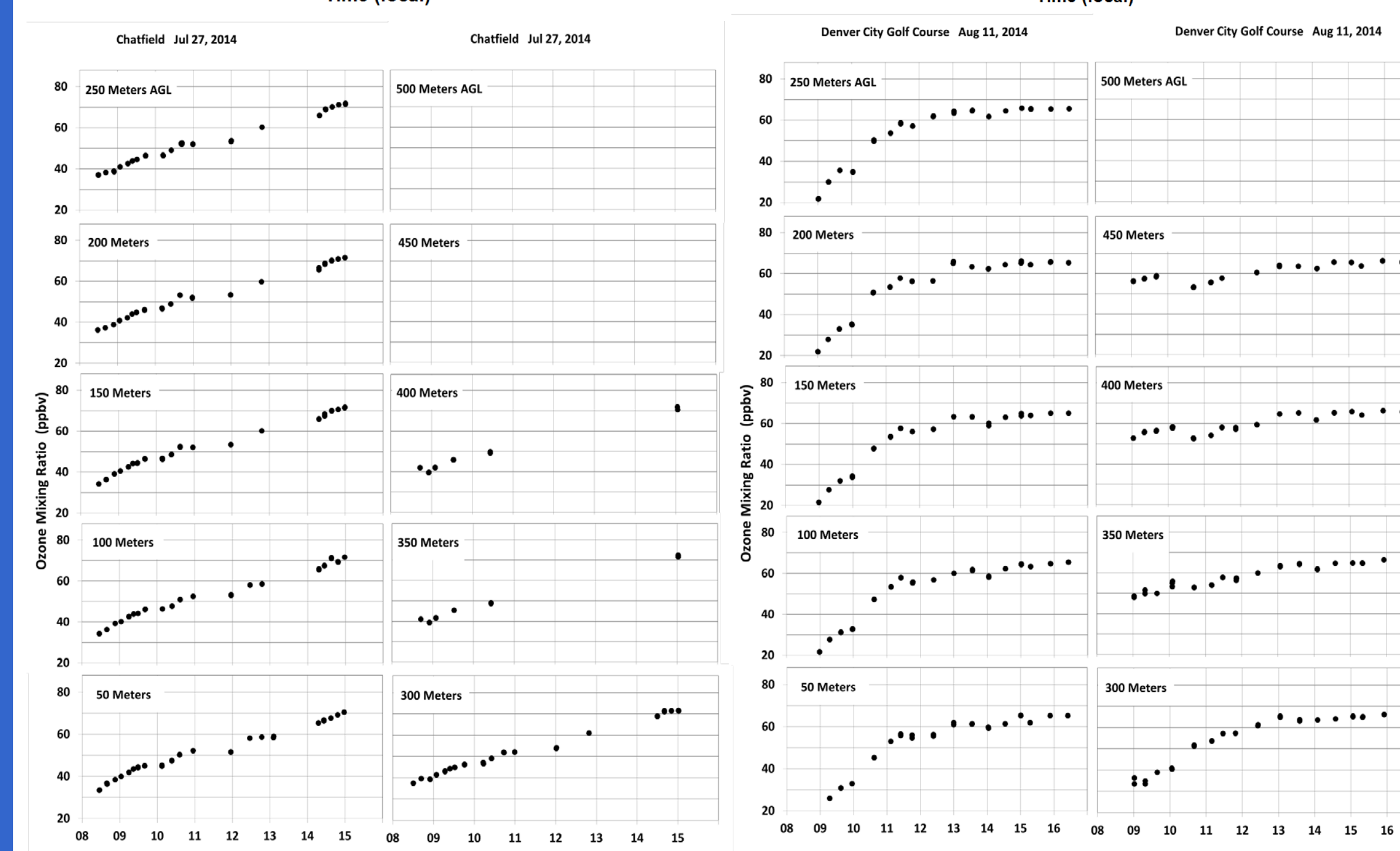
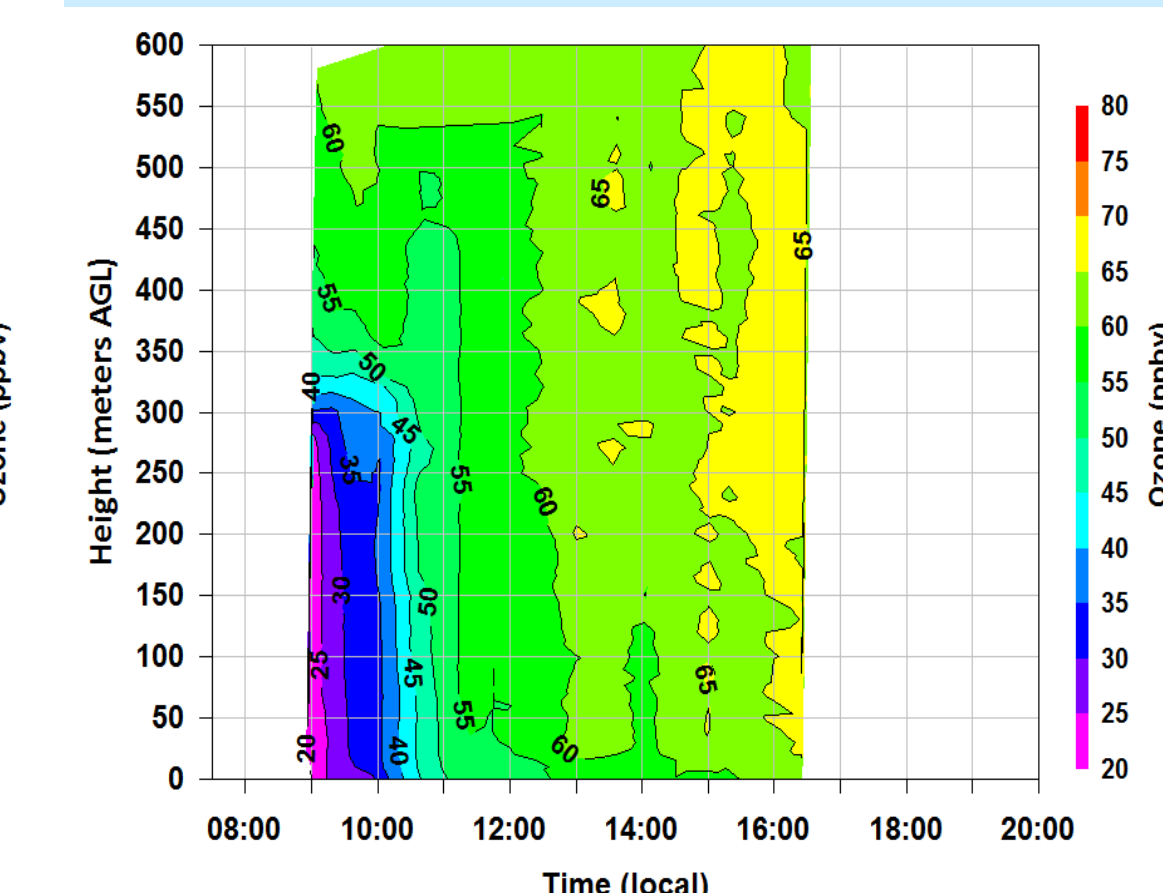
Ozone starts increasing early and the increase is occurring nearly simultaneously throughout the column suggesting precursors are also available through the column.

(4)

Ozone Cross Section, August 3, 2014, Ft. Collins



Ozone Cross Section, August 11, 2014, Denver

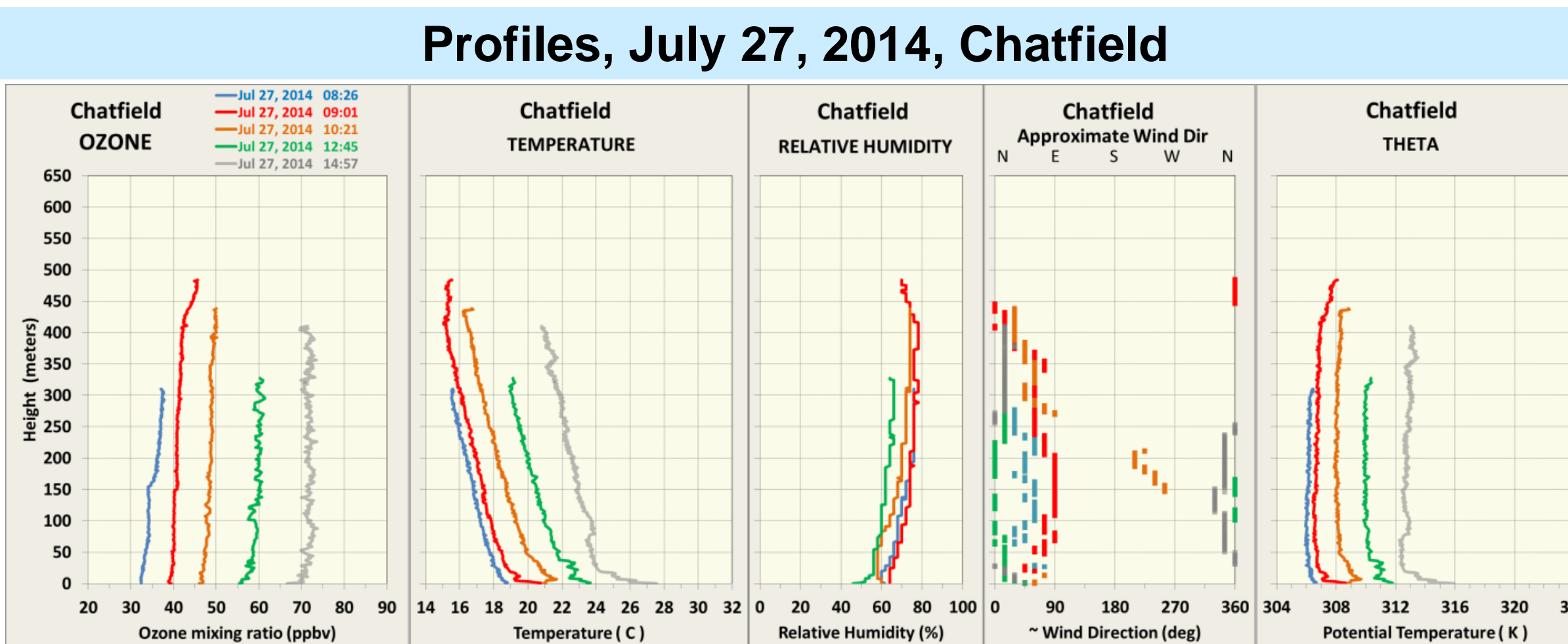


Lower ozone in morning, strong ozone production beginning in mid-morning, continued production through the day.

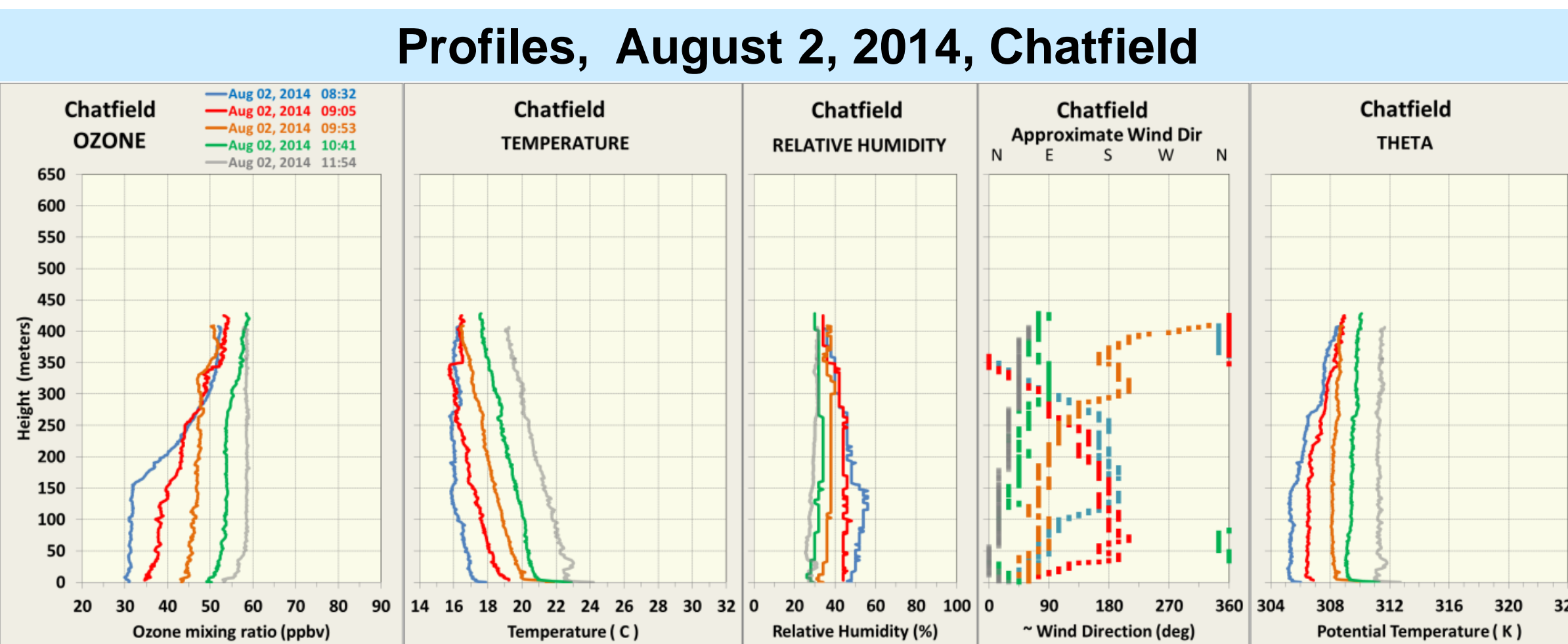
(5)

Rapid early morning increase from mixing. Limited production during day.

Relationship of O₃ profiles with Temp., Humidity, Wind Dir. (five selected profiles throughout the day)



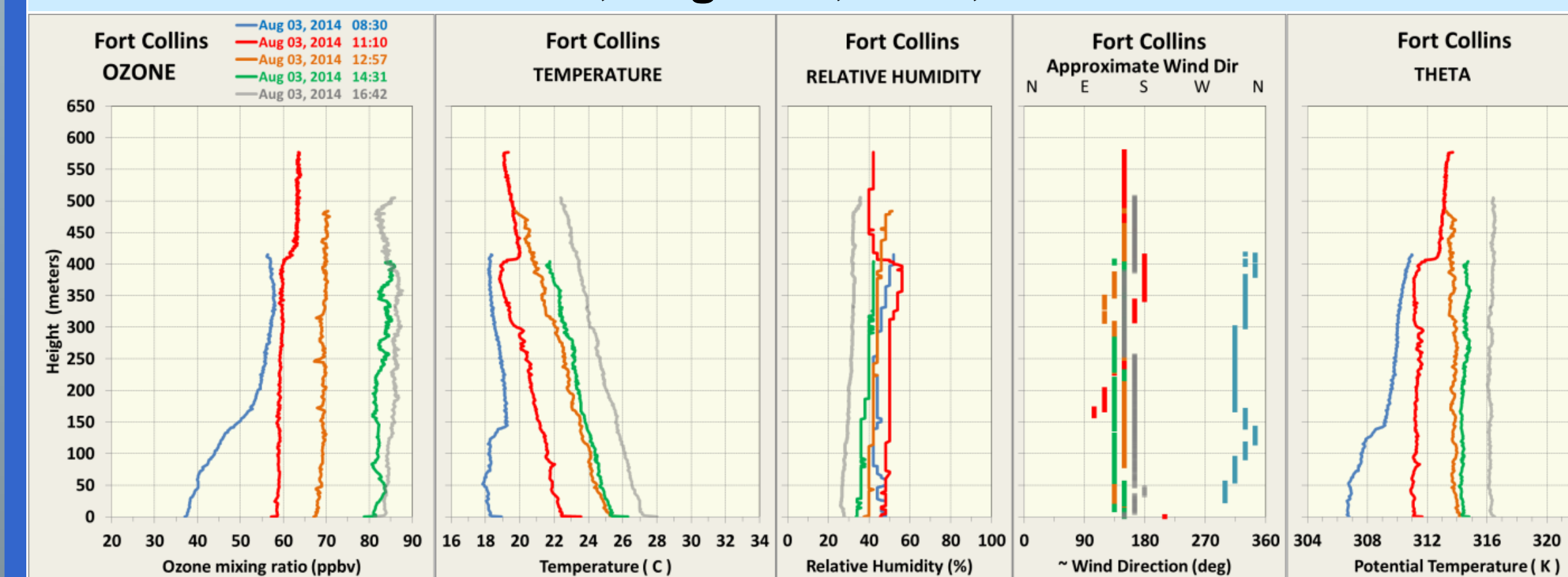
Well mixed profiles throughout the day. Winds from N to NE suggestive of air coming from the city of Denver.



Variable direction with altitude from N to South less likely to bring air from urban precursor sources to Chatfield.

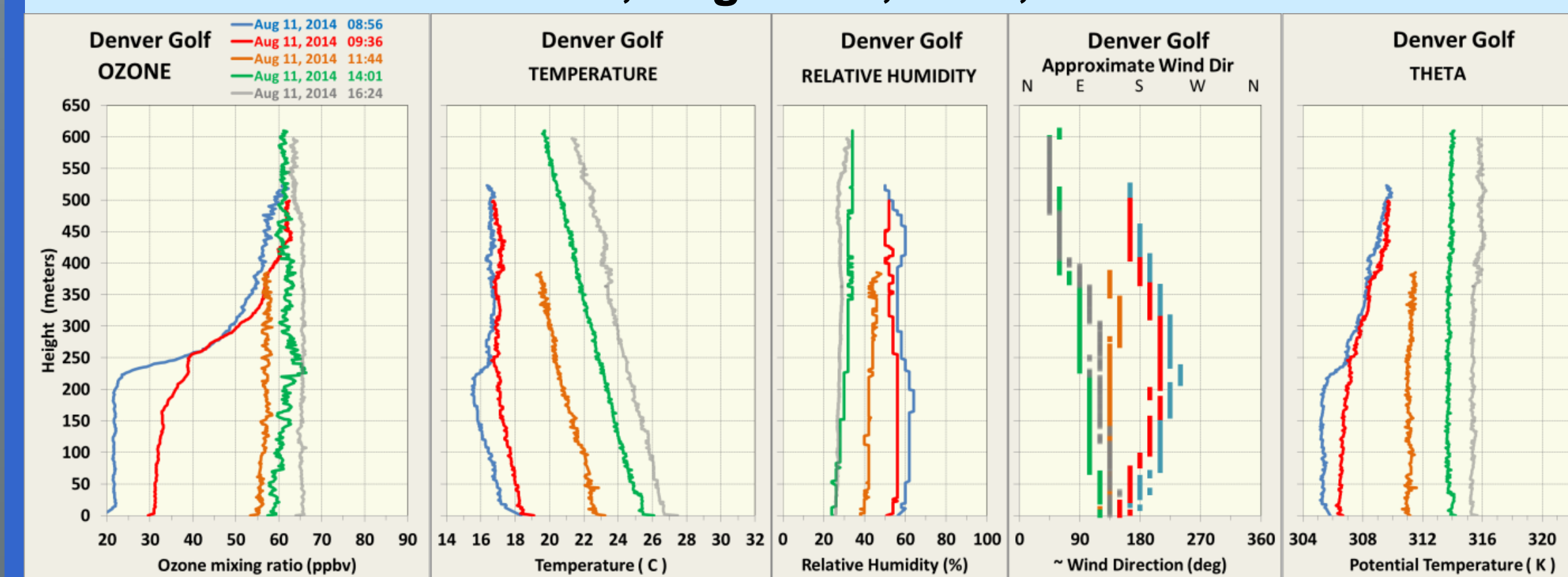
(6)

Profiles, August 3, 2014, Ft. Collins



Profiles become mixed after mid-morning. Winds strongly confined to ESE to S direction suggestive of air coming from the Platte River valley or eastern plains.

Profiles, August 11, 2014, Denver



Variable wind direction with altitude over the course of the day limits production. Large morning increase likely associated with mixing from layer above 200 mgl with the breakdown of the lower level stable layer (see θ plot). Apparent NO titration and surface deposition in early morning profiles.

(7)

Calculated Ozone Growth at Three Sites (ppb/hour)

Site, Day, Rate Calc. Time	Tether Height Above Ground Level (m)										
	0	50	100	150	200	250	300	350	400	450	500
Chatfield State Park, 7/27/14, 10:00-3:00	4.6	4.7	4.9	4.8	4.8	4.6	5.1	5.0	4.7	N/A	N/A
Fort Collins West, 8/3/14, 10:00-3:00	5.9	5.2	5.4	5.2	5.3	4.6	4.6	5.1	5.1	4.8	4.5
Denver City Golf Course, 8/11/14, Start-11:30	14.4	14.8	15.2	15.1	14.9	14.6	10.0	2.8	0.4	-0.9	N/A

At Chatfield on 7/27 and Ft. Collins on 8/3 daytime O₃ growth associated with photochemical production (~5 ppb/hr at all altitudes). At Denver on 8/11 large, rapid early morning growth below 300 m due to mixing.

Summary

- Over 340 tethered balloon soundings captured daily development of ozone and meteorological variables at 3 sites during FRAPPE in July-August 2014.
- On days with the strongest ozone production (7/27 and 8/3) ozone increased nearly uniformly with altitude from mid morning to mid afternoon indicating the mixing of precursors through the column.
- Rapid early morning ozone increases at the 3 sites were associated with mixing of air from above associated with the breakdown of a relatively shallow (~250 m thick) stable layer.
- On the days with significant ozone production winds were consistently from directions with potential precursor sources. At Chatfield on 7/27 winds were from the N to NE bringing air from the city of Denver. On 8/3 at Ft. Collins winds were from the ESE suggestive of air coming from the Platte River valley or eastern plains.

Acknowledgements: Funding and site logistics support were provided by the Colorado Department of Public Health and Environment.

(8)