



# Ozone Vertical Profile Measurements in the Northern Front Range of Colorado in July-August 2014 during FRAPPE /DISCOVER-AQ

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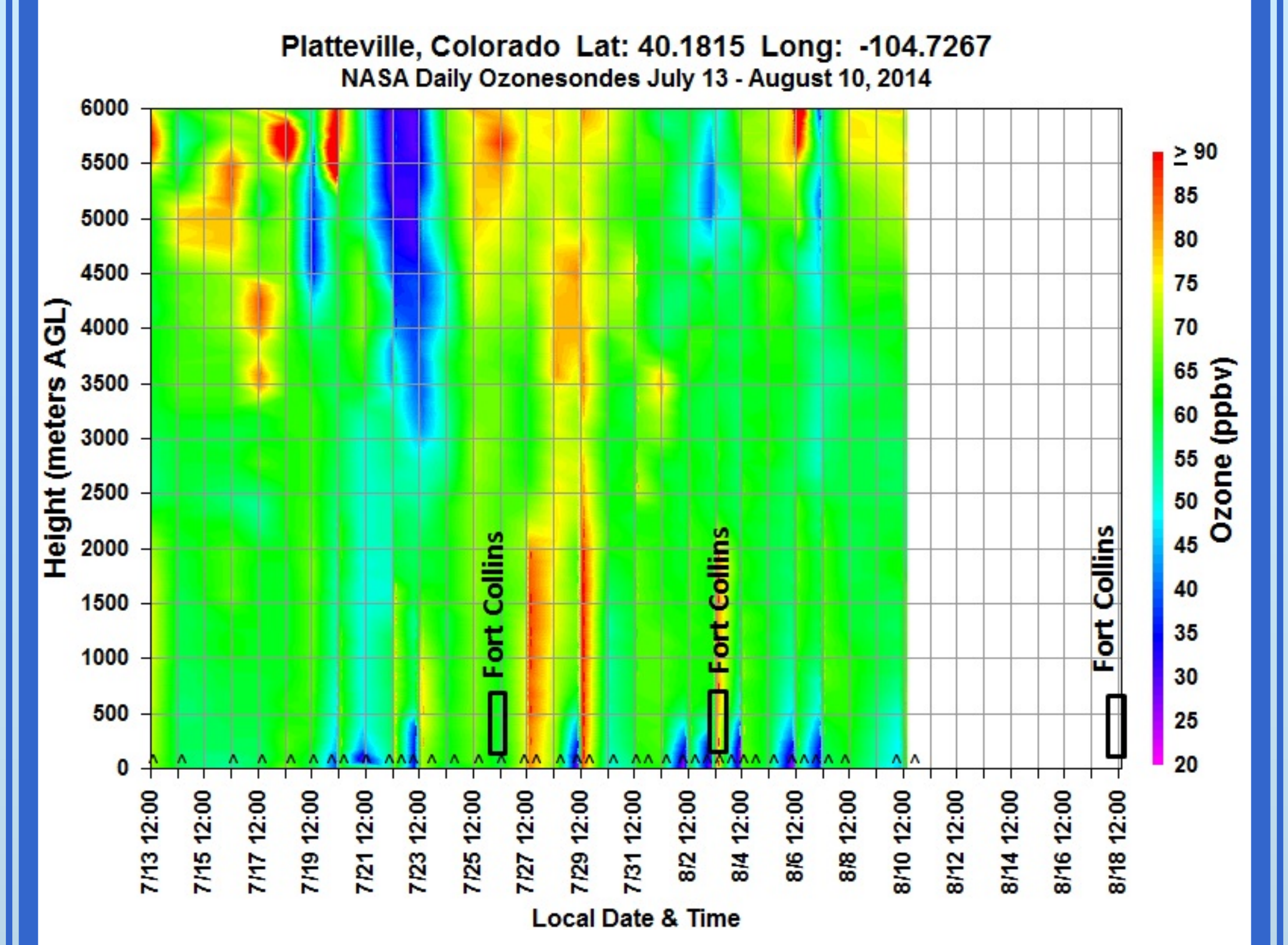
## Introduction

Ozone and temperature profiles were measured from tethered ozonesondes, from release ozonesondes, and continuously from a 300 m tower instrumented at two levels during the FRAPPE/DISCOVER-AQ campaigns in summer 2014. Tethersonde measurements were made on 3 days at a site west of Ft. Collins typically, between 8:30 AM and 4:30 PM, averaging 40 profiles a day. Forty release ozonesondes were flown from Platteville with multiple profiles on a number of days. Continuous O<sub>3</sub> profiles from a tall tower (6 and 300 m) east of Boulder tracked O<sub>3</sub> variability through the experiment. The release ozonesondes demonstrated the important role of morning mixing from the upper boundary layer or lower free troposphere into the lower boundary layer. This mixing established the mid-morning boundary layer O<sub>3</sub> mixing ratio from which the daily photochemical production progressed. The generally constant mixing ratio with height and highest mixing ratios above the surface seen in the near continuous tethersonde profiles indicate that photochemical O<sub>3</sub> production was taking place throughout the profile. This suggests that O<sub>3</sub> precursors are mixed through the boundary layer enabling widespread O<sub>3</sub> production.

**FRAPPE tethered ozonesonde site, ozonesonde, and BAO Tower locations, altitude, number of profiles and dates.**

Location	Latitude (°N)	Longitude (°W)	Elevation (m)	# of tether profiles - dates
Fort Collins - West	40.5928	105.1413	1572	126 profiles - 7/26, 8/3, 8/18
Platteville	40.1800	104.7300	1523	Twice Daily 7/13 - 8/10
Erie BAO Tower	40.0500	105.0040	1572	Hourly 7/13 - 8/18

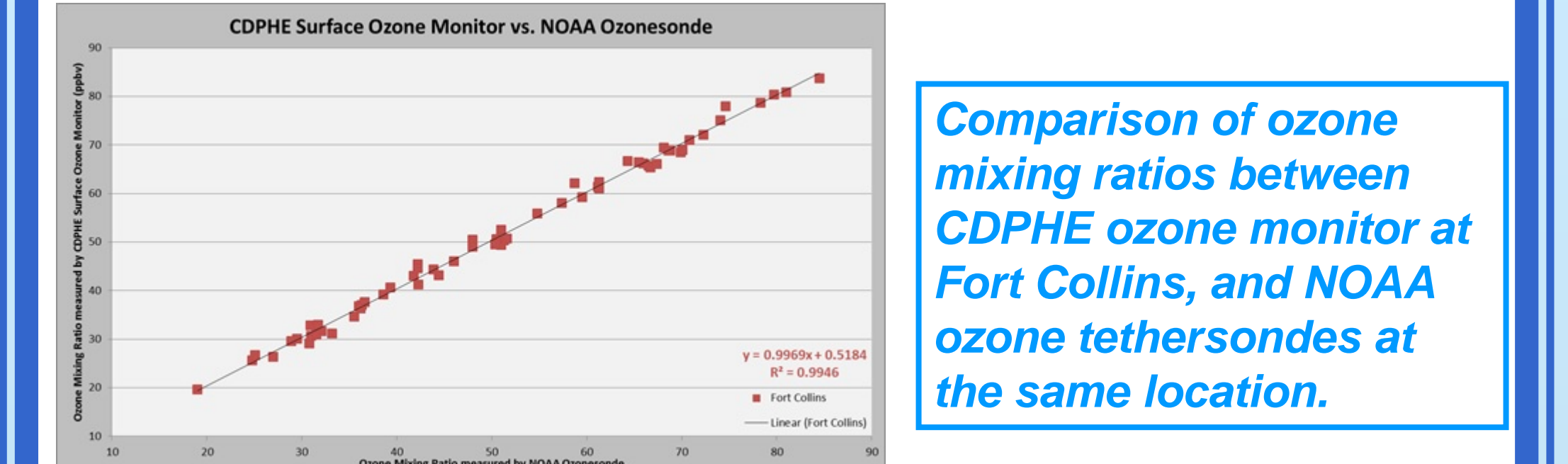
(1)



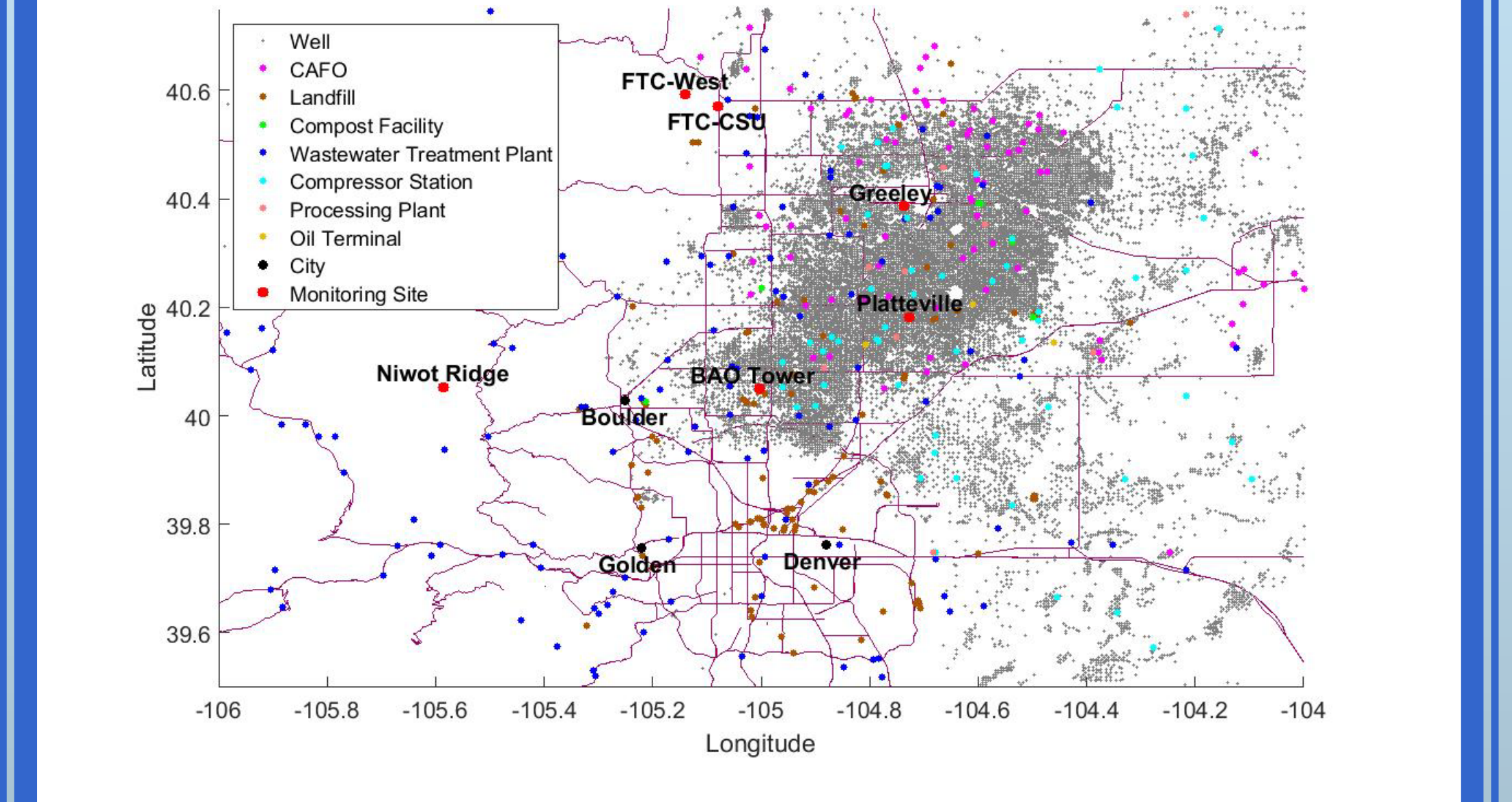
Contour plot of ozone mixing ratio (ppbv) from the Penn State/NASA free flying ozonesondes launched daily and twice daily on flight days during DISCOVER AQ at Platteville, Colorado. The 42 pointers along the x-axis show the time of launch for the free flying ozonesondes. The site - name blocks along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

There were a limited number of days with larger ozone production events during the period encompassed by the ozonesondes at Platteville. One of these events on August 3 was also captured by the tethersondes. The high O<sub>3</sub> day on July 27 was not seen at the BAO tower while July 28 & 29 were high days at the tower (see panel 7).

(2)



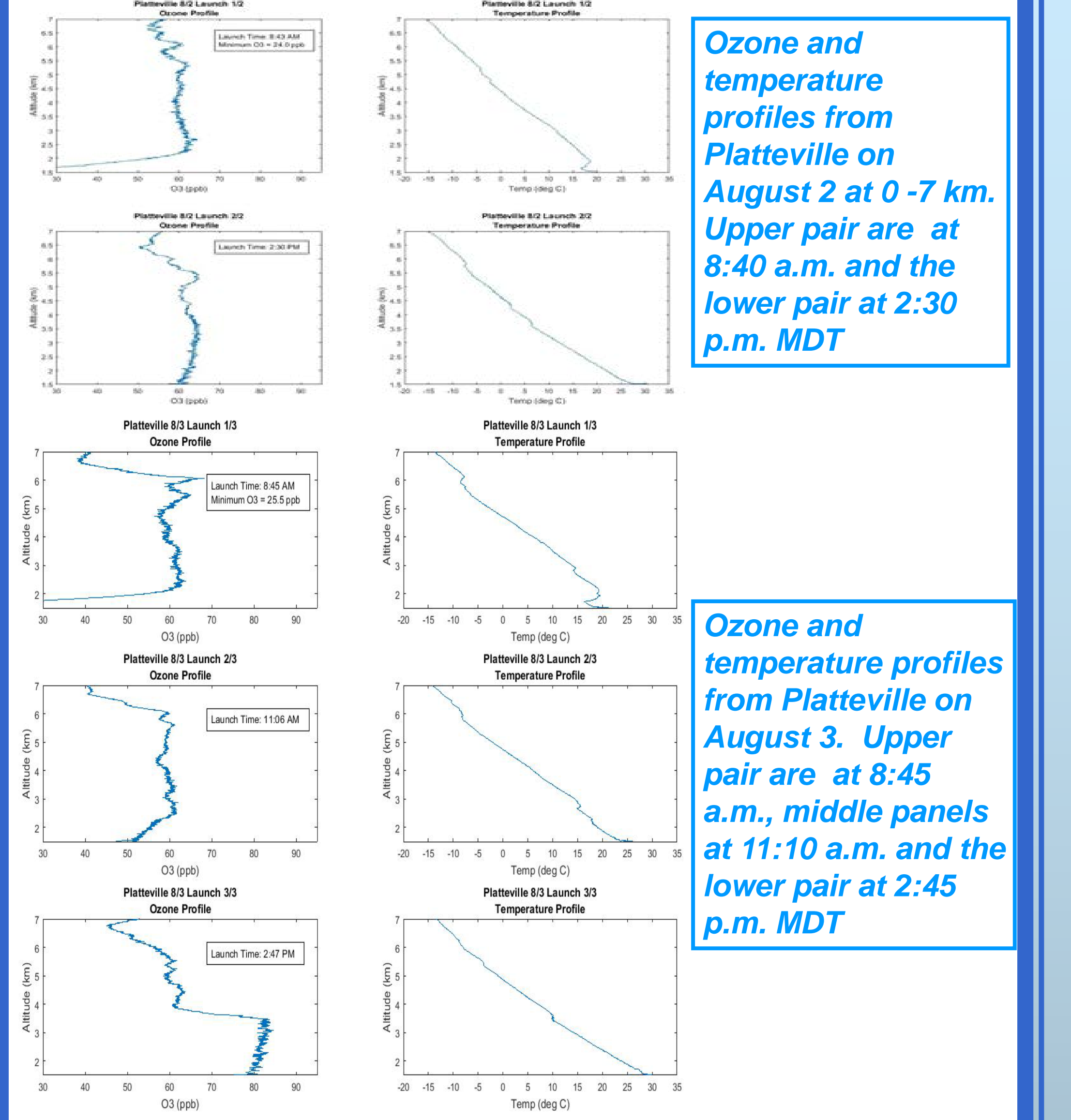
Ozonesondes were compared to a NIST traceable ozone standard before deployment. At Fort Collins the Colorado Department of Public Health and Environment (CDPHE) has a certified surface ozone monitor. Before each tethersonde profile, a comparison of the ozone mixing ratio was conducted between the tethersonde and the in situ ozone monitor. Even small (~1 ppb) changes with time and altitude are valid in the sonde profiles.



Map of the Colorado Northern Front Range (NFR) with the observing locations, oil and gas wells, as well as cities and other facilities emitting potential ozone precursors.

(3)

## Daily development of O<sub>3</sub> profiles – role of mixing and photochemical production



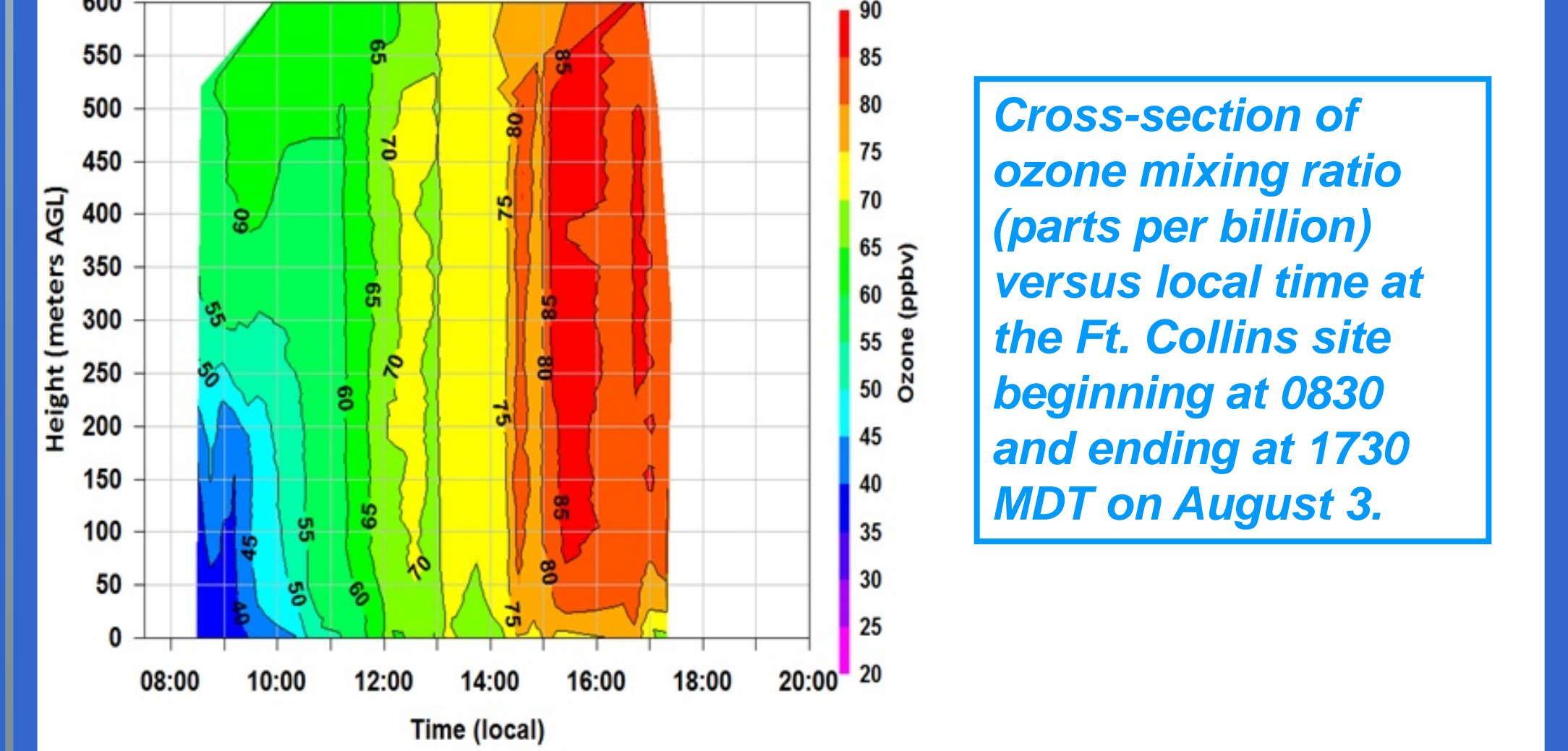
Ozone and temperature profiles from Platteville on August 2 at 0-7 km. Upper pair are at 8:40 a.m. and the lower pair at 2:30 p.m. MDT

Ozone and temperature profiles from Platteville on August 3. Upper pair are at 8:45 a.m., middle panels at 11:10 a.m. and the lower pair at 2:45 p.m. MDT

Morning profiles show shallow nocturnal temperature inversion with low O<sub>3</sub> that is mixed away by the mid morning when the surface layer approximates the mixed boundary layer. On Aug. 2 there is minimal O<sub>3</sub> production. On Aug. 3 there is a 2 km lower boundary layer with high O<sub>3</sub> (~80 ppb)

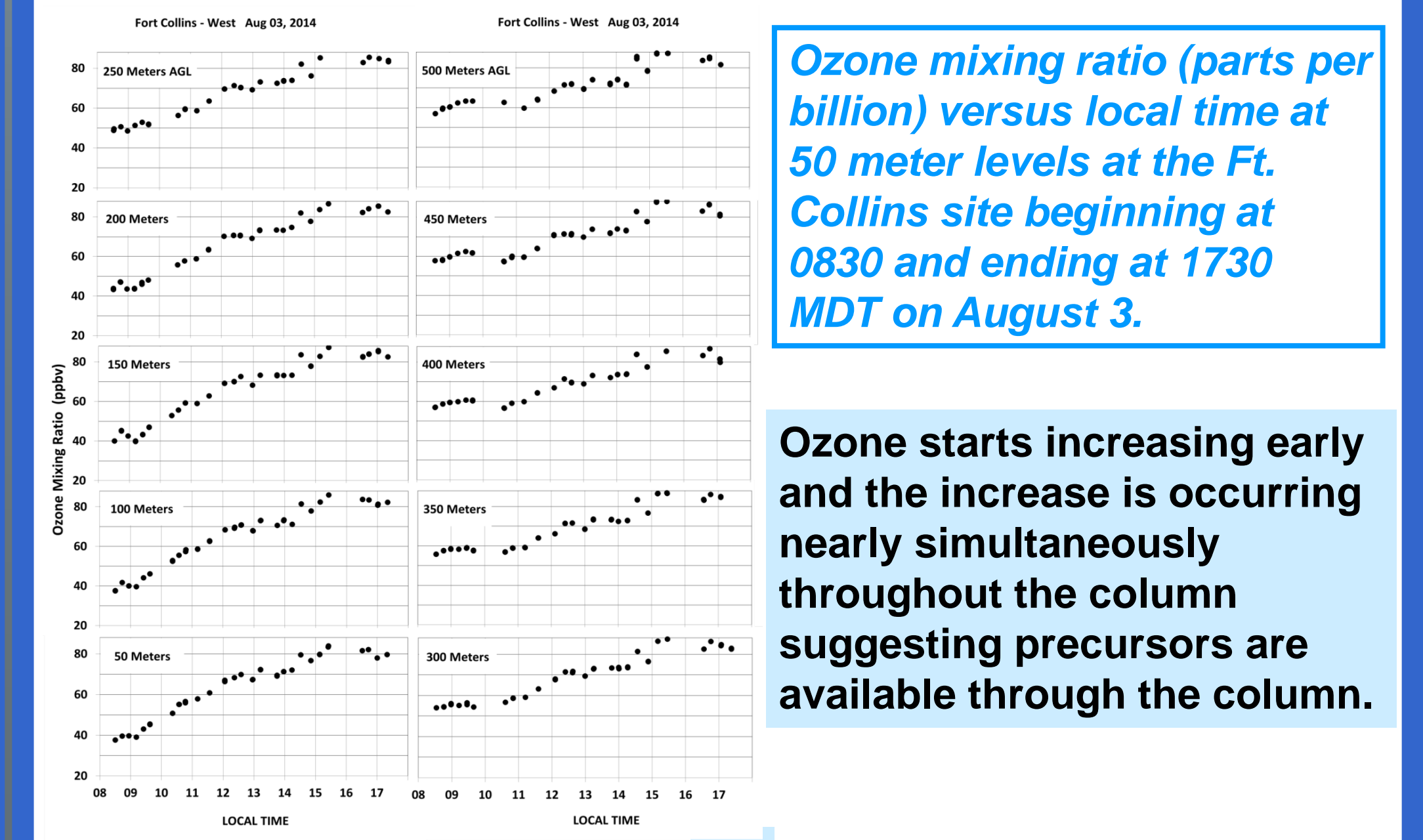
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## Ozone Cross Section - August 3, 2014, Ft. Collins



Cross-section of ozone mixing ratio (parts per billion) versus local time at the Ft. Collins site beginning at 0830 and ending at 1730 MDT on August 3.

Low ozone in the morning. Mixing in mid morning establishes ~55 ppb lower boundary layer O<sub>3</sub> value. Strong ozone production beginning in mid-morning with continued production through mid afternoon with peak values >85 ppb. This is very similar to the Platteville ozonesonde profiles (panel 4).

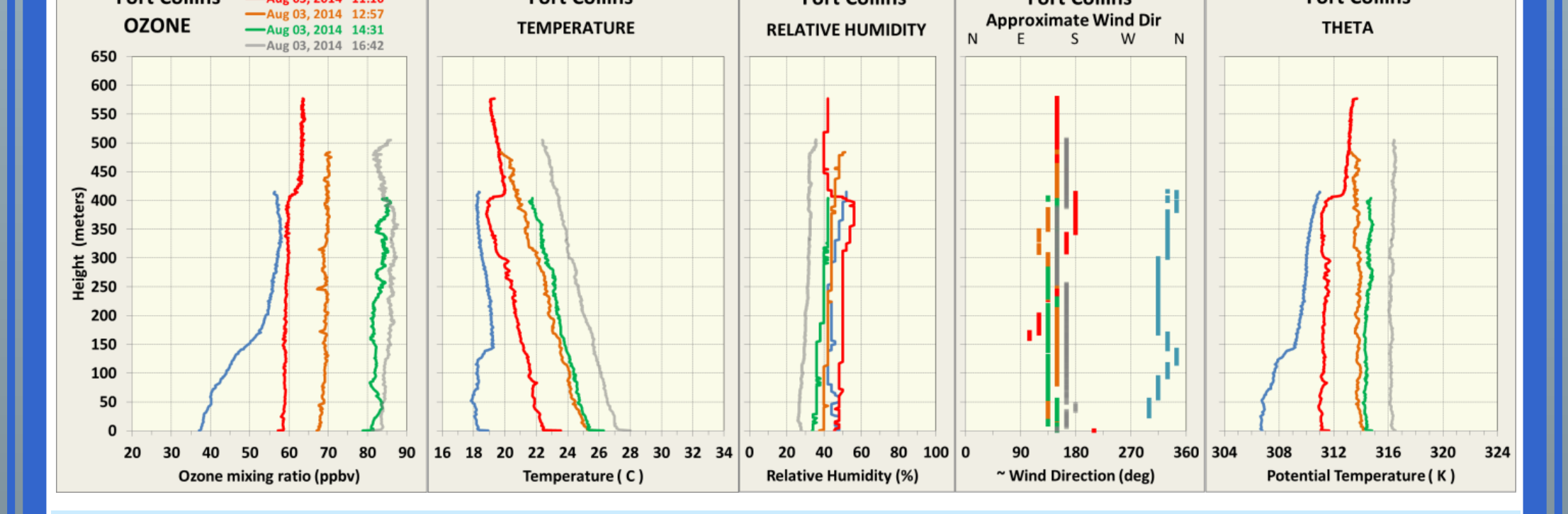


Ozone mixing ratio (parts per billion) versus local time at 50 meter levels at the Ft. Collins site beginning at 0830 and ending at 1730 MDT on August 3.

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

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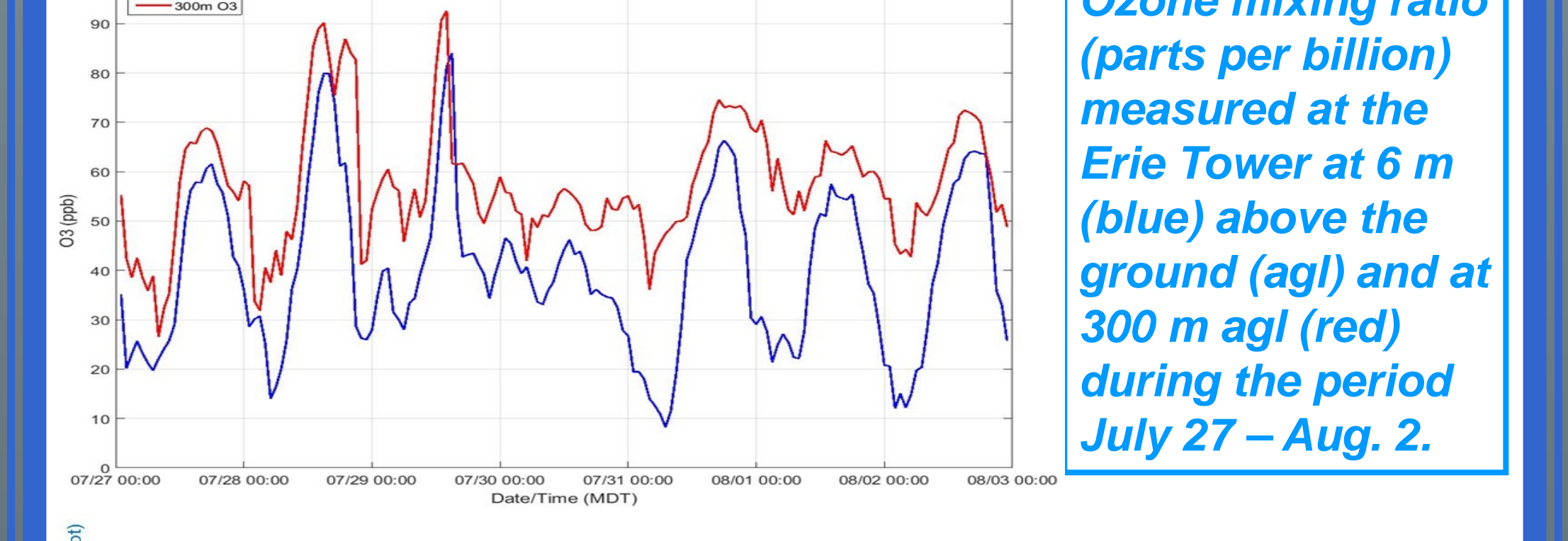
## Relationship of O<sub>3</sub> profiles with Temp., Humidity, Wind Dir. (five selected profiles throughout the day)



Profiles become mixed after mid-morning. Winds strongly confined to SSE direction, a preferred direction for oil and gas emission sources..

## BAO Tower Observations

### BAO Ozone and Flask Obs. (July 27- August 2, 2014)

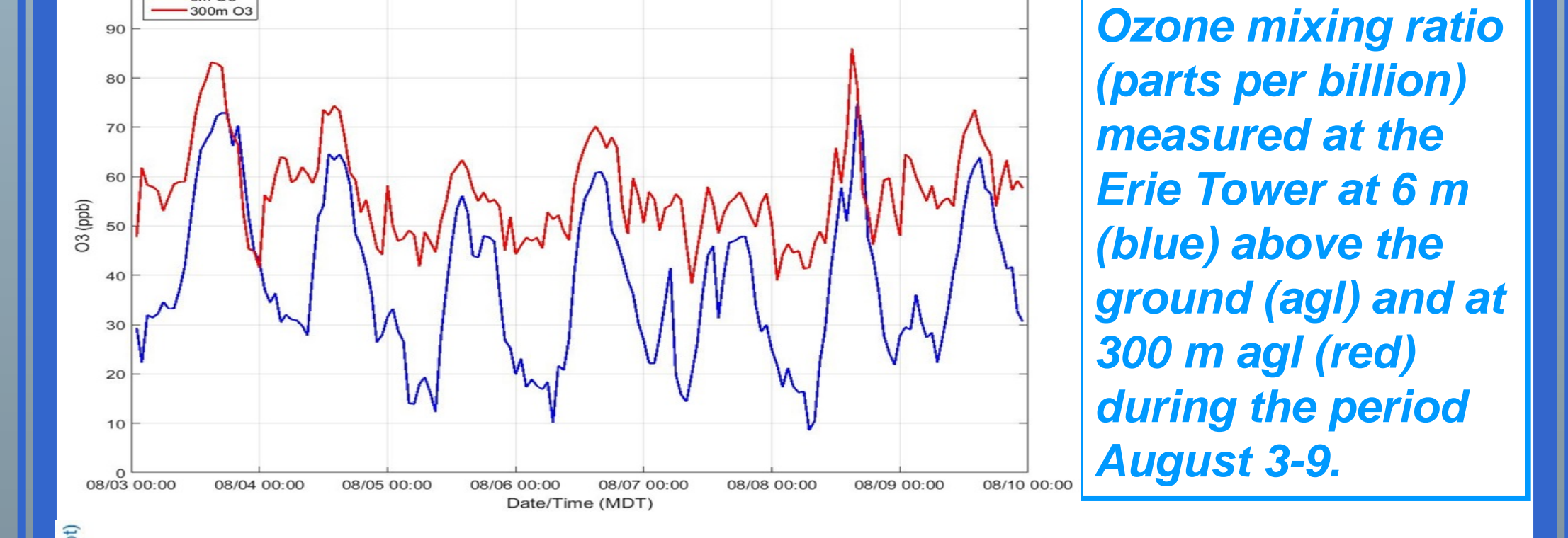


Ozone mixing ratio (parts per billion) measured at the Erie Tower at 6 m (blue) above the ground (agl) and at 300 m agl (red) during the period July 27 - Aug. 2.

Flask samples from 300 m agl at BAO during the period July 27 - Aug. 2.

(6)

## BAO Ozone and Flask Obs. (August 3-9, 2014)



Ozone mixing ratio (parts per billion) measured at the Erie Tower at 6 m (blue) above the ground (agl) and at 300 m agl (red) during the period August 3-9.

Flask samples from 300 m agl at BAO during the period Aug. 3-9.

The BAO observations provide a near continuous picture of O<sub>3</sub> changes in the lower boundary layer. Daily flask samples analyzed for a number of constituents give a snap shoot of possible sources of the O<sub>3</sub> precursor emissions that may impact O<sub>3</sub> formation. On Jul. 28 and Aug. 8 higher O<sub>3</sub> amounts (>70 ppb) are associated with constituents identified with oil and gas emissions (methane, propane, benzene). All days during the campaign in July and August with elevated oil and gas related emissions had higher O<sub>3</sub> (>70 ppb). Other days with higher O<sub>3</sub> (e.g. Aug.3) had only modestly elevated oil and gas emissions suggesting additional sources of O<sub>3</sub> precursors such as urban emissions, however, CO was not elevated on Aug. 3. On days with higher oil and gas emissions acetylene is also often higher suggestive of possible automobile emissions. When oil and gas emission amounts are higher the winds are from the east during the day. It is likely that this wind pattern would also carry auto emissions from nearby highway I-25 to BAO.

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## Calculated Ozone Growth Rate (ppb/hour)

Height meters	Fort Collins West, 8/3/14, 10:00 a.m. - 3:00 p.m.									BAO			
	0	50	100	150	200	250	300	350	400	450	500	6	300
Growth ppb/hr	5.9	5.2	5.4	5.2	5.3	4.6	4.6	5.1	5.1	4.8	4.5	5.6	4.8

At Ft. Collins on 8/3 daytime O<sub>3</sub> growth associated with photochemical production (~5 ppb/hr at all altitudes). Growth rates at the BAO tower are similar on this day. The bit larger growth near the surface at each site reflects the mixing of the nocturnal boundary layer near the surface. From the O<sub>3</sub>sonde at Platteville the mixed layer is ~2 km thick with O<sub>3</sub> production through the entire layer.

## Summary

- Daily Ozonesondes, tethered balloon soundings, and tall tower continuous measurements captured development of ozone and meteorological variables at 3 sites during FRAPPE/DISCOVER-AQ in July-August 2014.
- On days with the strong ozone production 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 (<200 m thick) stable layer.
- On the days with significant ozone production at Ft. Collins and Platteville winds were consistently from directions with potential oil and gas precursor sources. At BAO there were both potential oil and gas sources as well as other sources.
- On some days strong O<sub>3</sub> production was evident at all sites while on other days only at a single location.

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