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Observing low-altitude features in ozone concentrations in a shoreline environment via uncrewed aerial systems

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S1: CHEESEHEAD19 Tower and UAS Comparison

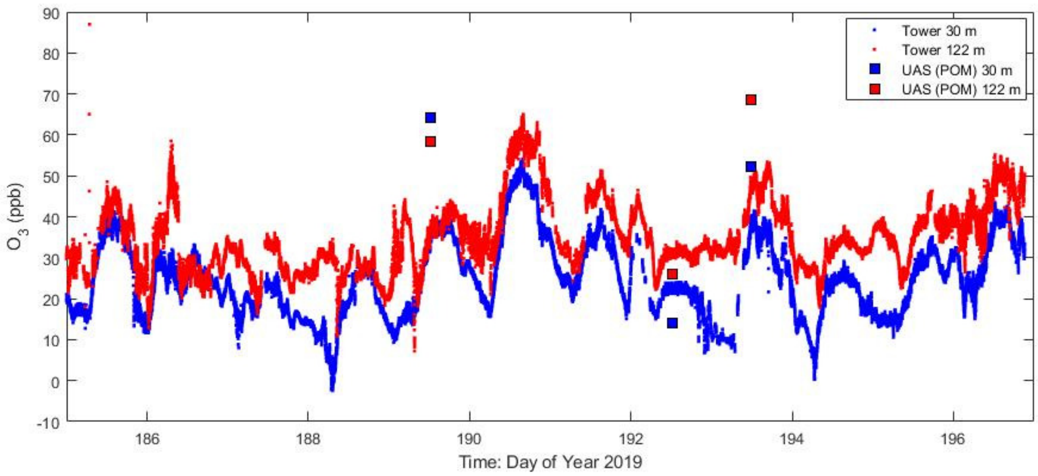

Figure S1: Tower ozone observations from Park Falls WLEF tower at 30 m (blue) and 120 m (red) using TOF and 49i photometric analyzer and UAS platform POM observations (squares) at same altitudes.

Table S1. Data from CHEESEHEAD19 UAS and Tower observations.

Date	POM (± σ,n) 122 m	POM (± σ,n) 30 m	Tower (± σ,n) 122 m	Tower (± σ,n) 30 m
	O_3 (ppb)			
Jul-8	**58.2(±6.2,n=12)**	**64.1(±7.4,n=16)**	**36.23(±0.99,n=8)**	**35.18(±0.42,n=8)**
Jul-11	**25.9(±17.7,n=60)**	**14.0(±12.5,n=57)**	**31.05(±0.0.47,n=60)**	**22.34(±0.60,n=60)**
Jul-12	**68.5(±15.3, n=41)**	**52.4(±8.9, n=48)**	**47.38(±0.85,n=50)**	**38.29(±0.95, n=50)**

S2. Evidence of Lake Breeze

Satellite imagery, near-surface meteorology and Doppler lidar observations can be used to identify the presence of marine-influenced air during these field operations. Satellite imagery which shows a distinct lack of cumulous clouds over Lake Michigan with a clear delineation of a cumulous cloud front over land is evidence for a lake breeze, as seen in Figures S2 and S3. Note that the wind direction at the ground station changed from SW to SE most mornings the week of June 15-20 (Figure 3), temperatures were rising before the wind shift and then plateaued or rose slower throughout the day after the wind direction change with the onset of the lake breeze.(Cleary et al., 2022),(Wagner et al., 2022) Surface meteorological observations show sustained wind shifts to E, SE or SSE at 10:40 UTC (5:40 CDT) on June 15, 11:20 UTC (6:20 CDT) on June 16, 10:40 UTC (5:40 CDT) on June 17, 13:20 UTC (8:20 CDT) on June 18 and 11:15 UTC (6:15 CDT) on June 19, 2020. The corresponding lidar observations show easterly winds (negative *u* (zonal) winds) after the ground observation of a wind shift. The time of lake breeze onset discerned from the Doppler lidar data appears later than ground observations, after 14:00 UTC, 9:00 CDT on June 18 and 19, likely because recovery only starts at altitudes above 100 m AGL. Afternoon easterly winds extend to altitudes up to 1500-1000 m AGL on June 18 and to 700 m AGL on June 19. The mid-afternoon marine layer, which we assign as altitudes with negative *u* (zonal) winds, showed multiple bands of higher backscatter on both June 18 at 150 and 250 m AGL and June 19 at 500, 250 and 125 m AGL. High backscatter is attributed on these days to high particle concentrations in the atmosphere (where no fog was present).

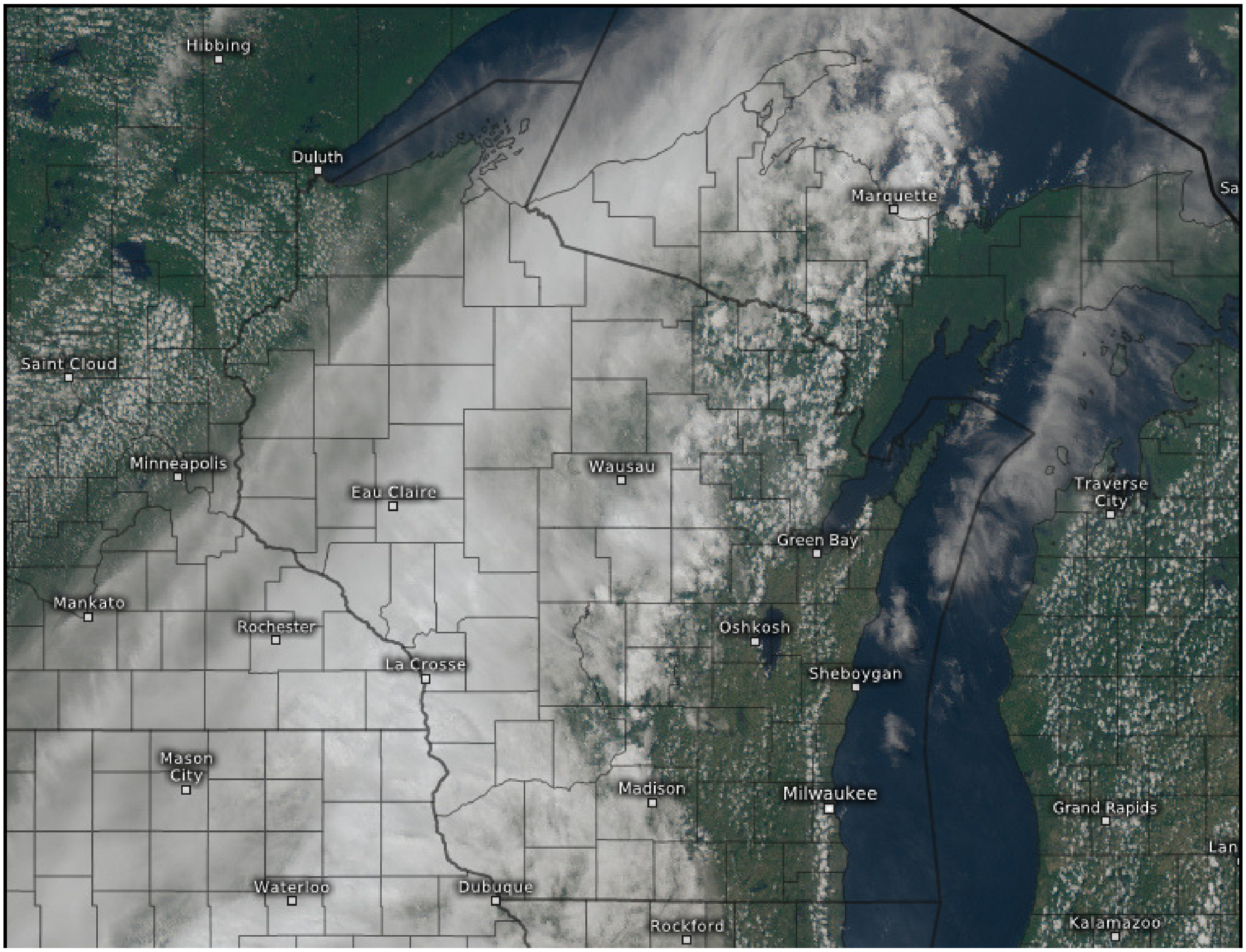

Figure S2: June 19, 2020 high definition color GOES-East satellite image of clouds over Wisconsin at 1400 CDT with a resolution of 1.0 km.

Figure S3: WISCODisco20 field work image at Chiwaukee Prairie State Natural Area. The right side of this image shows cloud suppression over Lake Michigan during this field campaign on Friday, June 19, 2023.

Table S2. Flight Details for WiscoDISCO20 flights. The POM operated at 0.1 Hz, thus n=30 for each hovering altitude.

Date	Start	End	Flight	Hovering Altitudes (m AGL)
	hh:mm CDT	hh:mm CDT		
6/15/2020	**15:31**	**16:55**	**PM**	
	15:31	15:52	1	9.1, 15.2, 30.5, 45.7
	16:15	16:31	2	45.7, 61.0, 76.2, 91.4
	16:39	16:55	3	91.4, 106.7, 121.9
6/16/2020	**7:57**	**9:11**	**AM**	
	7:57	8:18	1	9.1, 15.2, 30.5, 45.7

	8:24	8:45	2	45.7, 61.0, 76.2, 91.4
	8:55	9:11	3	91.4, 106.7, 121.9
6/16/2020	**14:39**	**15:55**	**PM**	
	14:39	15:00	1	9.1, 15.2, 30.5, 45.7
	15:07	15:29	2	45.7, 61.0, 76.2, 91.4
	15:39	15:55	3	91.4, 106.7, 121.9
6/17/2020	**8:06**	**9:23**	**AM**	
	8:06	8:28	1	9.1, 15.2, 30.5, 45.7
	8:36	8:58	2	45.7, 61.0, 76.2, 91.4
	9:05	9:23	3	91.4, 106.7, 121.9
6/17/2020	**15:04**	**16:26**	**PM**	
	15:04	15:10	1	9.1, 15.2, 30.5, 45.7
	15:36	15:58	2	45.7, 61.0, 76.2, 91.4
	16:10	16:26	3	91.4, 106.7, 121.9
6/18/2020	**7:51**	**9:21**	**AM**	
	7:51	8:18	1	9.1, 15.2, 30.5, 45.7, 61.0
	8:27	8:48	2	61.0, 76.2, 91.4, 106.7
	8:58	9:21	3	91.4, 106.7, 121.9, 15.2
6/18/2020	**14:58**	**16:11**	**PM**	
	14:58	15:19	1	9.1, 15.2, 30.5, 45.7
	15:25	15:47	2	45.7, 61.0, 76.2, 91.4
	15:55	16:11	3	91.4, 106.7, 121.9
6/19/2020	**13:47**	**15:02**	**PM**	
	13:47	14:13	1	9.1, 15.2, 30.5, 45.7, 61.0
	14:20	14:37	2	61.0, 76.2, 91.4
	14:46	15:02	3	91.4, 106.7, 121.9

S2. Realtime Air Quality Modeling System, RAQMS

The Realtime Air Quality Modeling System (RAQMS) was utilized in Chiwaukee Prairie during the WISCODisco20 field campaign. RAQMS (Pierce et al., 2003) is a stratospheric and tropospheric chemistry modeling system that was developed by the NASA Langley Research Center and the University of Wisconsin-Madison. RAQMS on-line global chemical predictions account for photochemical and advective processes and the exchange of trace gases through convection and boundary layer turbulence (Pierce et al., 2003). Specifically, for the WISCODisco20 campaign, the RAQMS model with a 1° x 1° latitude-longitude resolution was used for forecasting synoptic scale conditions for deployment during this ozone season.

A comparison with hourly ground observations and 6-hour ozone analyses from the 1° x 1° RAQMS model are given in Figure 4. The resolution of this model is not adequate to capture lake breeze dynamics, particularly if it is shallow. However, the figure illustrates that the RAQMS model generally captures the diurnal and synoptic variation in observed ozone during this period (daytime bias of 11.5 ppbv, nighttime bias of 0.5ppbv, correlation of 0.66 with hourly surface observations), except for June 19, when the RAQMS analysis significantly underestimated ozone concentrations. The disagreement between observations and the model simulation is typical during lake-breeze influenced ozone exceedances, which require much higher (on the order of 1-3km) resolution meteorological and chemical forecasts to predict steep gradients at a shoreline location. Higher resolution modeling efforts would be useful to understand the impact of the marine layer vertical dimensions on the ozone production chemistry.

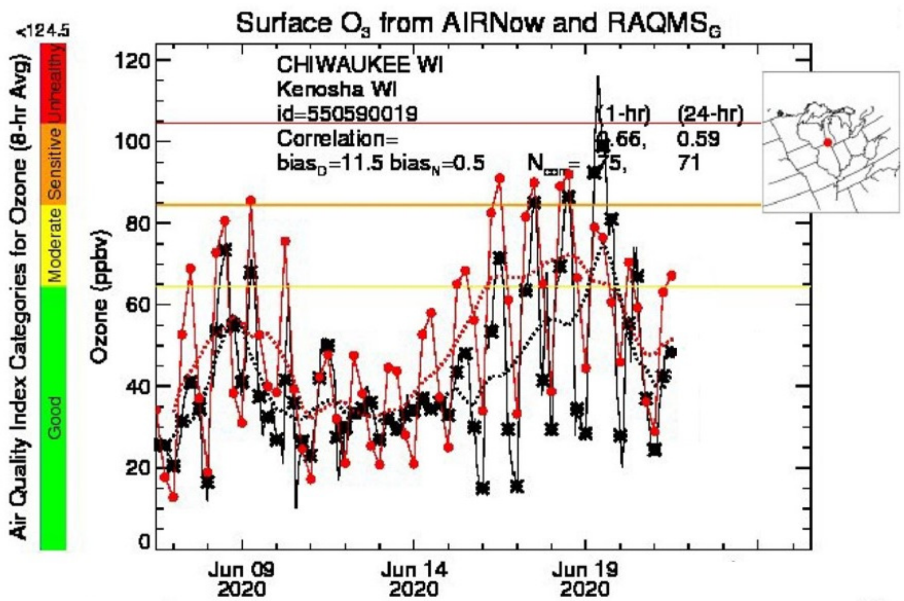

Figure S4: RAQMS instantaneous 8-hour ozone model output at Chiwaukee Prairie (red) and hourly ground station observations (black) from June 7-21, 2020. Dotted lines are smoothed 24-hour averages of RAQMS model (red) and observations (black).

References

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