Results from the Mt. Bachelor Observatory: Our role in INTEX-B and comparisons to MOPITT satellite retrievals of CO and GEOS-Chem model results

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Questions Guiding our Research at the Mt. Bachelor Observatory (MBO)

1. What are the inter-annual variations in CO, O_3, PAN, NO_x, NO_y, and aerosols as observed at Mt. Bachelor? How do these change in response to large-scale biomass burning, ENSO, variations in transport pathways and other factors?

2. How well do satellite observations and global models capture the inter-annual variations in CO, O_3, PAN, NO_y and aerosols? Do variations in PAN correlate with in-situ and satellite observations of tropospheric O_3?

3. How do inter-annual variations in background atmospheric composition influence surface air quality?

4. What gas and aerosol tracer ratios can be used to identify U.S. pollution, Asian industrial pollution, mineral dust, and/or biomass burning at Mt. Bachelor?

5. Can we detect changes in the mixing ratios of CO, PAN and/or O_3 associated with changing upstream (Asian) NO_x emissions? How do these changes impact the oxidative capacity of the troposphere?

Mt. Bachelor Observatory

Operating continuously since March 2004; frequently sampling free tropospheric (FT) air

INTEX-B Results from MBO

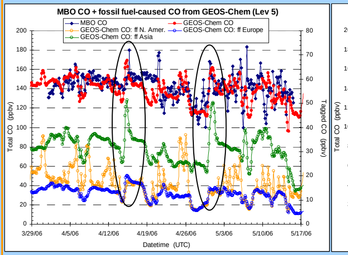
	Temp (°C)	RH (%)	Wind Speed (m/s)	Pressure (hPa)	H_2O Vapor (g/kg)	Rn (mBq/m³)	sub-µm $σ_{sp}$ (Mm⁻¹)	CO (ppbv)	O_3 (ppbv)	Hg^0 (ng/m³)	PHg (pg/m³)	RGM (pg/m³)	Total Airborne Hg (ng/m³)	Total Reactive Hg (pg/m³)	NO (pptv)	NO_2 (pptv)	NO_x (pptv)	PAN (pptv)	PPN (pptv)	NO_y (pptv)	500 nm AOD, MT	500 nm AOD, WA
ALL	-0.4 ± 5.7	73 ± 26	11.1 ± 7.5	733.9 ± 1.2	2.6 ± 1.0	372 ± 212	4.4 ± 3.9	142 ± 14	49.4 ± 9.7	1.67 ± 0.15	3.3 ± 3.0	31.3 ± 45.4	1.71 ± 0.14	34.9 ± 46.0	34 ± 77	40 ± 25	55 ± 33	339 ± 370	23 ± 25	366 ± 257	0.11 ± 0.03	0.12 ± 0.04
	(-0.9)	82	10.2	734	2.6	323	3.2	144	49.3	1.66	2.6	17.9	1.7	22.7	23	34	49	207	13	293	0.11	0.11
Apr	-3.2 ± 5.0	80 ± 23	10.8 ± 7.8	733.3 ± 1.2	2.4 ± 0.8	451 ± 257	3.0 ± 3.1	143 ± 13	49.6 ± 8.4	1.68 ± 0.14	3.5 ± 2.7	31.8 ± 26.7	1.72 ± 0.13	35.5 ± 26.8	37 ± 68	44 ± 22	54 ± 27	186 ± 173	13 ± 13	258 ± 164	0.10 ± 0.03	0.09 ± 0.04
	(-4.4)	94	9.3	733.5	2.4	304	1.9	146	49.8	1.66	3	20.3	1.7	25	22	37	50	142	10	250	0.1	0.07
May	1.9 ± 5.3	67 ± 27	11.4 ± 7.3	734.4 ± 0.9	2.9 ± 1.1	298 ± 116	6.1 ± 4.0	140 ± 15	49.2 ± 10.9	1.67 ± 0.15	3.2 ± 3.0	31.2 ± 48.3	1.70 ± 0.14	34.8 ± 49.1	32 ± 84	37 ± 27	55 ± 39	574 ± 460	38 ± 30	479 ± 287	0.12 ± 0.03	0.13 ± 0.04
	0.7	64	11	734.5	3	264	5.8	141	48.5	1.66	2.3	16.3	1.69	21.9	23	25	48	458	29	537	0.11	0.12
Wet	5.5 ± 5.1	76 ± 22	9.7 ± 6.2	734.6 ± 1.0	4.0 ± 0.4	355 ± 134	4.8 ± 3.5	138 ± 16	41.6 ± 8.5	1.65 ± 0.20	3.4 ± 2.8	14.1 ± 18.4	1.67 ± 0.19	18.3 ± 20.0	25 ± 18	40 ± 16	60 ± 43	229 ± 186	12 ± 10	146 ± 82	0.12 ± 0.03	0.09 ± 0.04
	4.9	76	9.4	734.7	3.9	341	4.7	135	42.6	1.6	3.2	11.7	1.62	16.1	21	32	47	195	10	130	0.12	0.08
Dry	-3.2 ± 4.9	46 ± 28	10.9 ± 7.7	734.1 ± 0.9	1.2 ± 0.4	387 ± 344	4.7 ± 4.0	142 ± 13	60.4 ± 9.1	1.76 ± 0.12	4.3 ± 3.1	59.3 ± 57.4	1.83 ± 0.10	63.9 ± 53.8	21 ± 22	29 ± 19	51 ± 25	536 ± 487	38 ± 33	495 ± 230	0.11 ± 0.03	0.13 ± 0.04
	(-2.8)	37	9.4	734.4	1.4	257	3.6	141	60.4	1.75	4.1	42.8	1.83	47.3	16	24	51	380	26	492	0.1	0.12
Dry - Wet Difference	-8.7, -7.7	-30, -39	1.2, 0	-0.5, -0.3	-2.8, -2.5	32, -84	-0.1, -1.1	4, 6	18.8, 17.8	0.11, 0.15	0.9, 0.9	45.2, 31.1	0.16, 0.21	45.6, 31.2	-4, -5	-11, -8	-9, 4	307, 185	26, 16	349, 362	-0.01, -0.02	0.04, 0.04
	X	[-41, -48%]	[10.8, 0%]	[< -1%]	[-108, -96%]	[9, -26%]	[-2, -34%]	[3, 4%]	[38, 36%]	[7, 9%]	[27, 35%]	[144, 174%]	[9, 12%]	[131, 137%]	[12, 22%]	[-28, -24%]	[-16, 8%]	[91, 89%]	[113, 123%]	[95, 124%]	[-9, -10%]	[33, 36%]

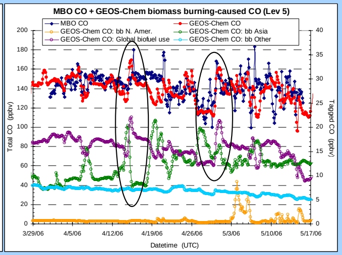
Data presented as: mean ± 1σ (median)

"Dry – Wet differences" shown as absolute [and relative] differences in means & medians

Our previous work has found that water vapor is the best indicator of FT air and that most Asian transport events at MBO occur in dry air (Jaffe et al. 2005; Weiss-Penzias et al. 2006, 2007; Swartzendruber et al. 2007).

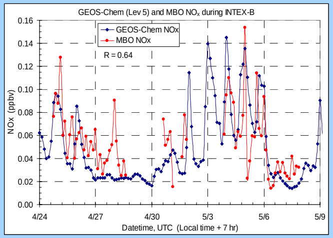
GEOS-Chem vs. MBO Comparisons during INTEX-B: Tagged CO Results

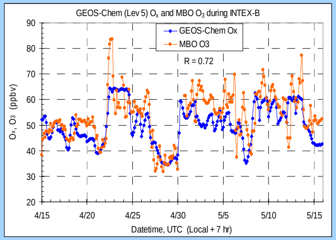




• Episodic CO enhancements due to biomass burning- and fossil-fuel-caused CO, many of which were at MBO.

GEOS-Chem vs. MBO Comparisons during INTEX-B: Full Chemistry Comparison





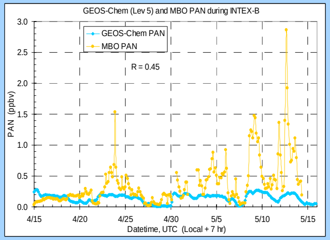
• Level 5 data (~746 hPa) correlated best with MBO results in both day- and nighttime.

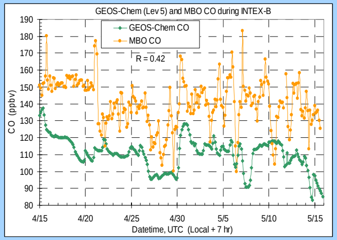
• Correlations were quite strong for O_3 and NO_x, but lower for CO and PAN.

• GEOS-Chem has systematically lower CO than what was measured at MBO (by ~30 ppbv).

• Qualitatively, the PAN correlation was fairly good, however, we measured very strong enhancements whose magnitudes were not captured in GEOS-Chem.

MBO:GEOS-Chem correlations	NO_x	O_3	PAN	CO
L3_day	0.34	0.66	0.21	0.17
L3_nite	0.14	0.69	0.37	0.07
L3 all	0.26	0.67	0.29	0.12
L4_day	0.55	0.78	0.38	0.38
L4_nite	0.3	0.63	0.4	0.31
L4 all	0.4	0.71	0.4	0.35
L5_day	0.59	0.85	0.51	0.43
L5_nite	0.59	0.54	0.43	0.37
L5 all	0.64	0.72	0.45	0.42
L6_day	0.75	0.67	0.5	0.35
L6_nite	0.49	0.47	0.35	0.23
L6 all	0.55	0.57	0.41	0.28
L7_day	0.61	0.46	0.29	0.37
L7_nite	0.56	0.34	0.2	0.17
L7 all	0.53	0.38	0.23	0.27



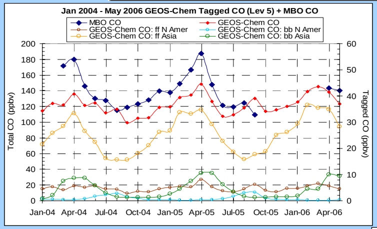


Inter-annual variability detected at MBO, with MOPITT & in GEOS-Chem?

Springtime MBO results 2004 - 2006

Mean Seasonal and Monthly Values ± 1 σ for All Data. Note, NO was measured with a different instrument in 2004 and 2005, than in 2006. NO_y measurements were not made directly in 2006 (as they were in 2004 and 2005), but are rather the sum of NO + NO_2 + PAN + PPN.

	N, hrs	$σ_{sp}$, Mm⁻¹	CO, ppbv	O_3, ppbv	Rn, mBq/m³	WV, g/kg	Wind Speed, m/s	Temp., °C	Press., hPa	RH, %	NO, ppbv: '04+'05 pptv: '06	NO_2, pptv	PAN, pptv	PPN, pptv	NO_y, ppbv: '04+'05 pptv: '06	Hg^0, ng/m³	RGM, pg/m³	PHg, pg/m³	TGM, ng/m³	Reactive Hg, pg/m³
All Data																				
4/1 - 5/31 2004	1471	6.6 ± 7.1	161 ± 24	43.5 ± 8.1	N/A	2.9 ± 1.0	9.6 ± 6.3	-1.3 ± 4.8	728.9 ± 5.0	63 ± 24	0.208 ± 0.730	N/A	N/A	N/A	0.250 ± 0.570	N/A	N/A	N/A	1.77 ± 0.12	N/A
4/1 - 5/31 2005	1471	2.5 ± 3.0	166 ± 24	47.7 ± 6.6	644 ± 470	3.2 ± 0.8	11.3 ± 6.9	-2.0 ± 5.1	733.8 ± 1.0	91 ± 16	0.066 ± 0.282	N/A	N/A	N/A	0.201 ± 0.312	1.65 ± 0.16	21.0 ± 47.4	5.1 ± 3.9	1.67 ± 0.16	27.3 ± 51.3
4/1 - 5/31 2006	1471	4.4 ± 3.9	142 ± 14	49.4 ± 9.7	372 ± 212	2.6 ± 1.0	11.1 ± 7.5	-0.4 ± 5.7	733.9 ± 1.2	73 ± 26	34 ± 77	40 ± 25	339 ± 370	23 ± 25	366 ± 257	1.67 ± 0.15	31.3 ± 45.4	3.3 ± 3.0	1.71 ± 0.14	34.9 ± 46.0
Apr '04	727	8.4 ± 8.6	180 ± 19	46.1 ± 7.4	N/A	2.5 ± 1.0	9.4 ± 6.6	-1.8 ± 5.7	729.2 ± 5.9	53 ± 24	N/A	N/A	N/A	N/A	0.203 ± 0.324	N/A	N/A	N/A	1.81 ± 0.12	N/A
Apr '05	727	2.3 ± 2.6	187 ± 16	48.6 ± 5.6	862 ± 570	2.9 ± 0.7	12.5 ± 7.2	-4.5 ± 4.0	733.6 ± 0.9	94 ± 10	0.080 ± 0.381	N/A	N/A	N/A	0.231 ± 0.382	1.56 ± 0.07	67.4 ± 69.7	4.5 ± 0.9	1.63 ± 0.02	69.3 ± 72.3
Apr '06	727	3.0 ± 3.1	143 ± 13	49.6 ± 8.4	451 ± 257	2.4 ± 0.8	10.8 ± 7.8	-3.2 ± 5.0	733.3 ± 1.2	80 ± 23	37 ± 68	44 ± 22	186 ± 173	13 ± 13	258 ± 164	1.68 ± 0.14	31.8 ± 26.7	3.5 ± 2.7	1.72 ± 0.13	35.5 ± 26.8
May '04	744	4.9 ± 4.8	145 ± 14	41.1 ± 8.0	N/A	3.4 ± 0.7	9.8 ± 6.0	-0.8 ± 3.8	728.6 ± 3.9	73 ± 19	0.208 ± 0.730	N/A	N/A	N/A	0.289 ± 0.712	N/A	N/A	N/A	1.70 ± 0.08	N/A
May '05	744	2.7 ± 3.3	147 ± 9	46.7 ± 7.4	421 ± 129	3.6 ± 0.7	10.2 ± 6.5	-0.4 ± 4.8	734.0 ± 1.0	88 ± 19	0.052 ± 0.110	N/A	N/A	N/A	0.167 ± 0.202	1.65 ± 0.16	19.0 ± 45.2	5.1 ± 4.0	1.67 ± 0.17	25.4 ± 49.6
May '06	744	6.1 ± 4.0	140 ± 15	49.2 ± 10.9	298 ± 116	2.9 ± 1.1	11.4 ± 7.3	1.9 ± 5.3	734.3 ± 0.9	67 ± 27	32 ± 84	37 ± 27	574 ± 460	38 ± 30	479 ± 287	1.67 ± 0.15	31.2 ± 48.3	3.2 ± 3.0	1.70 ± 0.14	34.8 ± 49.1
Dry Data																				
2004	177	8.6 ± 13.1	180 ± 30	54.8 ± 7.8	N/A	1.5 ± 0.5	10.4 ± 7.1	-1.6 ± 5.5	732.2 ± 3.3	41 ± 25	N/A	N/A	N/A	N/A	0.135 ± 0.067	N/A	N/A	N/A	1.87 ± 0.17	N/A
2005	294	2.1 ± 2.6	186 ± 21	51.5 ± 6.3	998 ± 742	2.1 ± 0.2	12.8 ± 7.3	-7.1 ± 4.7	733.4 ± 1.0	88 ± 18	0.032 ± 0.074	N/A	N/A	N/A	0.141 ± 0.120	1.45 ± 0.27	115.4 ± 129.5	8.6 ± 5.9	1.48 ± 0.42	135.8 ± 135.9
2006	271	4.7 ± 4.0	142 ± 13	60.4 ± 9.1	387 ± 344	1.2 ± 0.4	10.9 ± 7.7	-3.2 ± 4.9	734.1 ± 0.9	46 ± 28	21 ± 22	29 ± 19	536 ± 487	38 ± 33	495 ± 2307	1.76 ± 0.12	59.3 ± 57.4	4.3 ± 3.1	1.83 ± 0.10	63.9 ± 53.8
Wet Data																				
2004	171	7.8 ± 4.5	154 ± 21	41.1 ± 5.5	N/A	4.1 ± 0.2	8.3 ± 5.4	2.3 ± 2.4	730.6 ± 3.0	79 ± 13	0.119 ± 0.372	N/A	N/A	N/A	0.252 ± 0.521	N/A	N/A	N/A	1.68 ± 0.08	N/A
2005	294	3.3 ± 3.9	149 ± 11	44.8 ± 6.1	501 ± 134	4.3 ± 0.3	9.2 ± 6.2	2.0 ± 3.7	734.0 ± 0.9	91 ± 13	0.069 ± 0.148	N/A	N/A	N/A	0.258 ± 0.348	1.71 ± 0.15	7.4 ± 13.7	3.4 ± 3.1	1.72 ± 0.14	10.6 ± 14.5
2006	271	4.8 ± 3.5	138 ± 16	41.6 ± 8.5	355 ± 134	4.0 ± 0.4	9.7 ± 6.2	5.5 ± 5.1	734.6 ± 1.0	76 ± 22	25 ± 18	40 ± 16	229 ± 186	12 ± 10	146 ± 82	1.65 ± 0.20	14.1 ± 18.4	3.4 ± 2.8	1.67 ± 0.19	18.3 ± 20.1



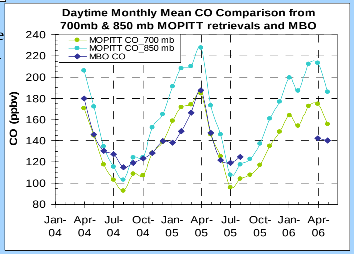
• Near constant inter-annual CO levels in the model

• A significant decrease in the MBO CO from the springtime maximum in 2005 (~180 ppbv) to that in 2006 (~140 ppbv).

• Slightly increasing CO due to fossil-fuel burning in Asia has not been seen at MBO yet

• A decrease in springtime maximum is seen from both platforms, although it is significantly lower in the MBO data; these lower values (~140 ppbv) are more in line with our FT aircraft observations in 1999, 2001 & 2002 and imply a decline from the higher levels seen in 2003 – 2005.

• Summertime minima are lower in the 700 mb MOPITT retrieval than at MBO probably due to stronger upslope flow, bringing local pollution to the summit of MBO. This will be tested by comparing the summer FT (i.e., dry) data with MOPITT data, and is already supported to some degree by noting that the 850 mb MOPITT CO agrees better with MBO in summertime.



Conclusions

♦ MBO is a valuable site frequently sampling FT air and is capable of detecting inter-annual variability in trace gases, particularly in springtime

♦ Strong correlation exists between GEOS-Chem results and measurements at MBO for the most part

♦ Inter-annual variability can be seen among a a variety of platforms (remote sensing, chemical transport models and in situ measurements)

Future Work

♦ Examine inter-annual variability at other North American West Coast sites (e.g., Whistler, Cheeka Peak, Trinidad Head, etc.)

♦ Utilize other remote sensing platforms to see if variability in other trace gases seen at MBO is corroborated (OMI, GOME, SCIAMCHY, etc.)

References

1) Weiss-Penzias et al.: Atmospheric mercury fluxes based on rations with CO in pollution plumes from biomass burning and East Asian pollution sources, *Atmos. Environ.*, 2007

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