CMAQ and the North American Monsoon – Arizona Air Quality

July and August, 2018

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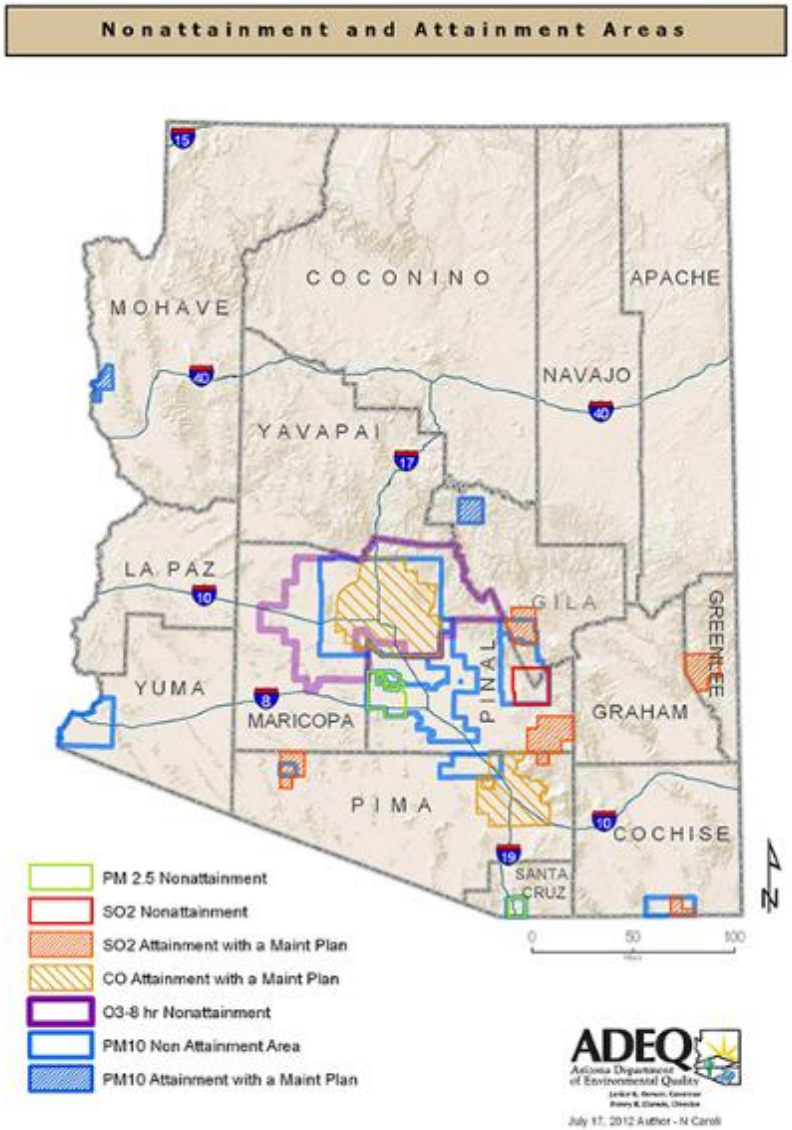
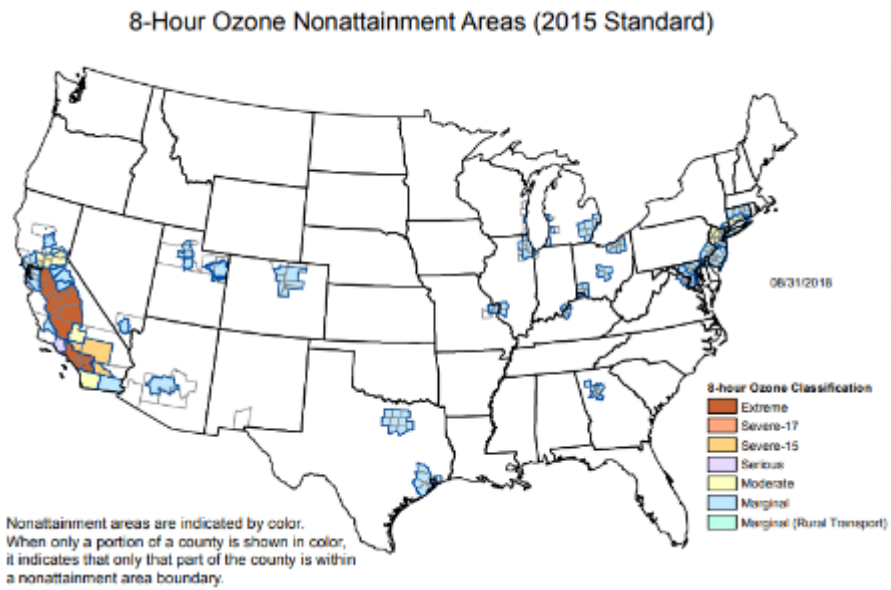
ADEQ Arizona Department of Environmental Quality

Considerations for CMAQ Evaluation

- Focus on North American Monsoon Season
  - July and August
  - High spatial and temporal weather variations likely
  - Day 1 Predictions:
    - Ozone
    - $PM_{2.5}$
- Exploring CMAQ Performance
  - Urban vs. Rural sites
  - Low vs. High Elevation sites
- CMAQ prediction range compared to reality?
- Exceedance Case Studies
  - False Positives
  - False Negatives
  - Correct Predictions

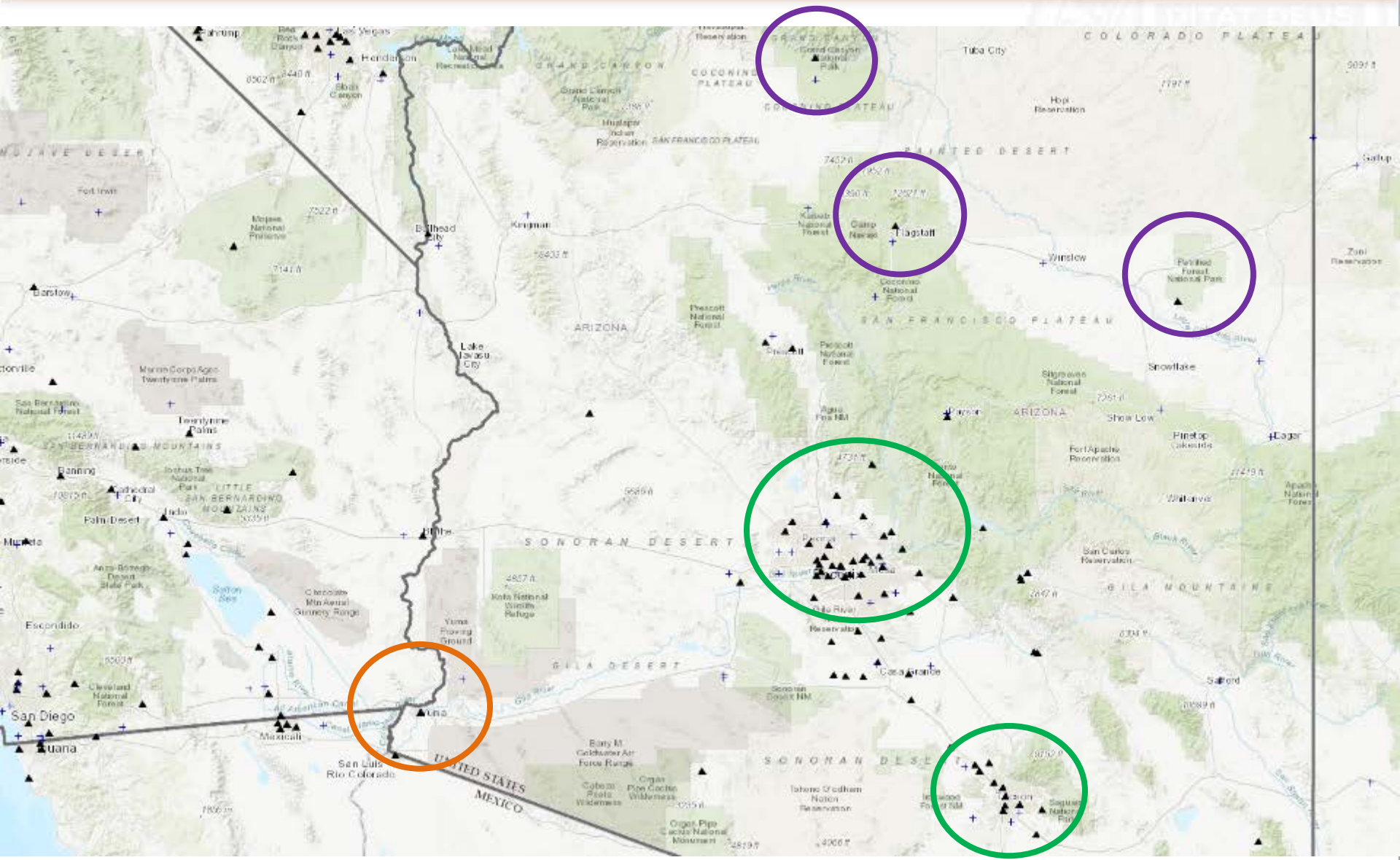
Planning Ahead



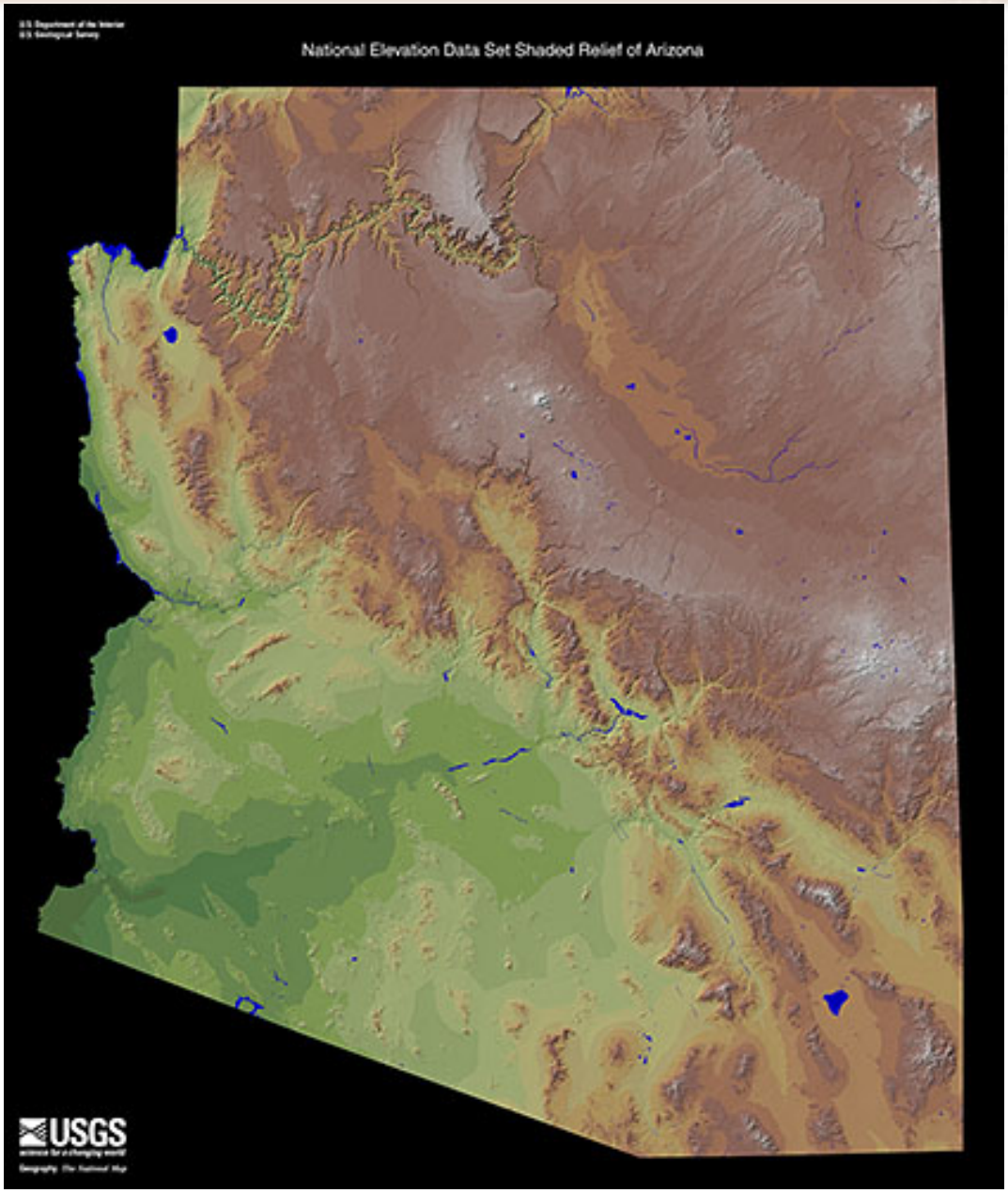


- With falling EPA standards…new nonattainment areas possible.
- How does CMAQ handle outside of Phoenix, Arizona?

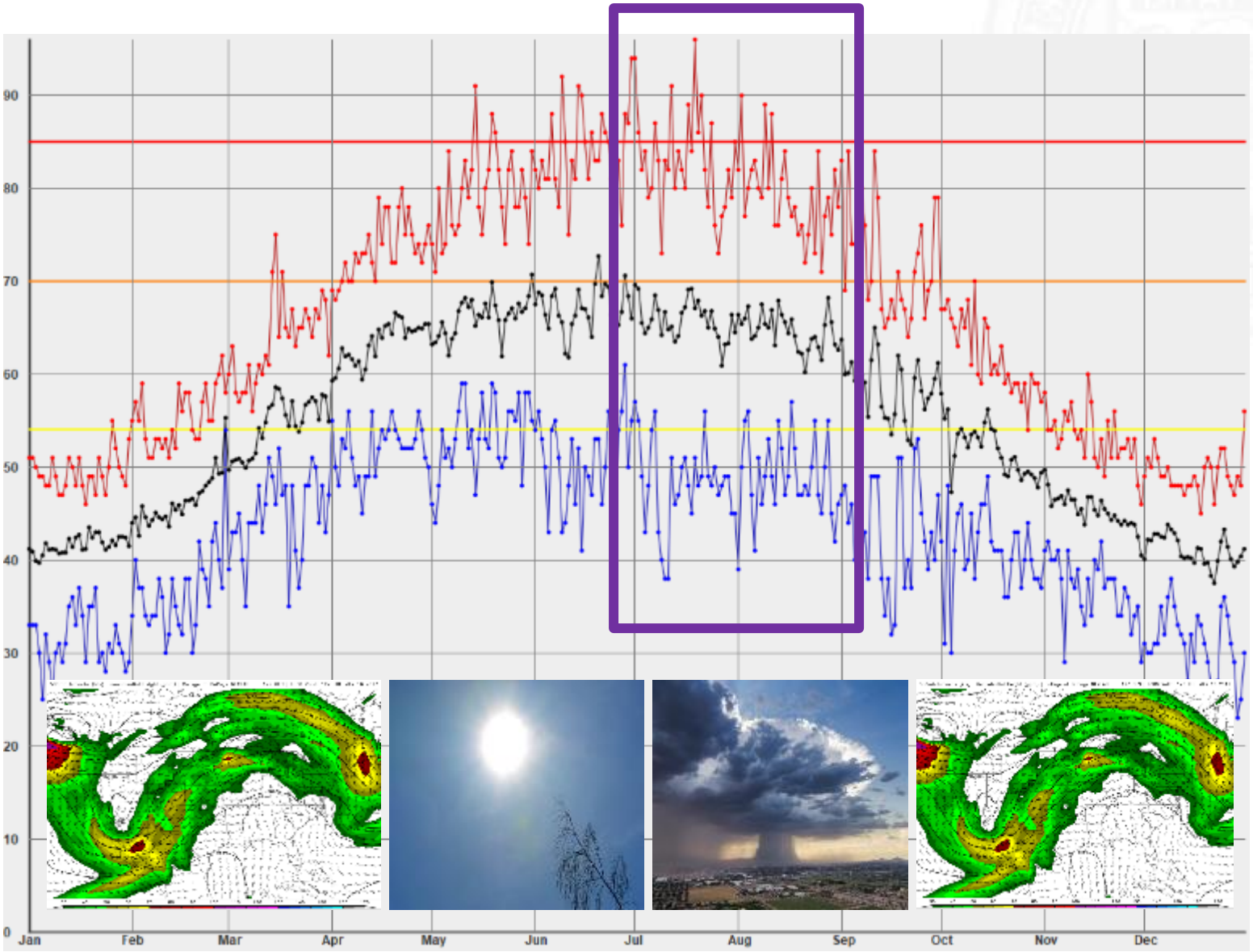
Locations of Interest for CMAQ Review



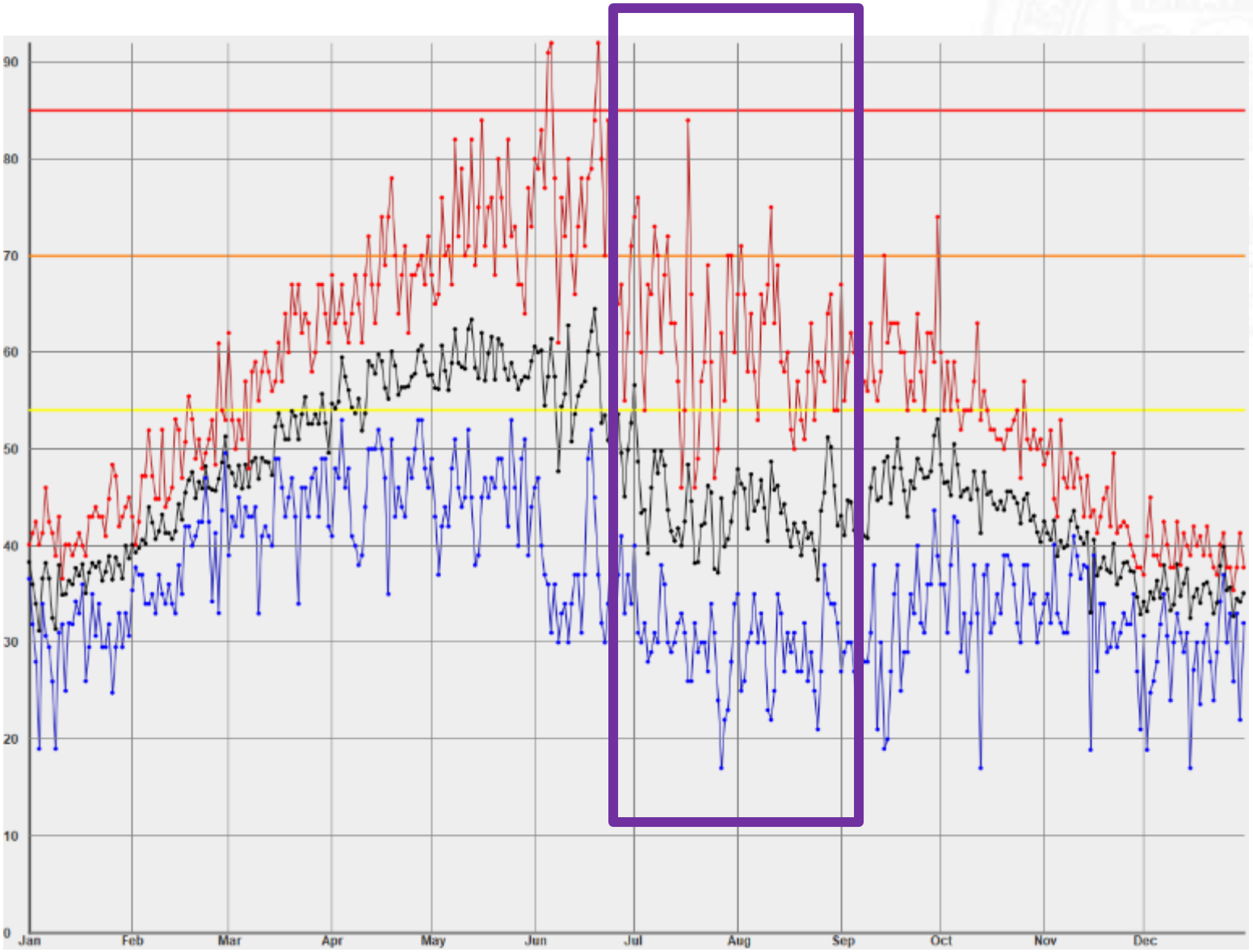
Arizona's Complex Terrain



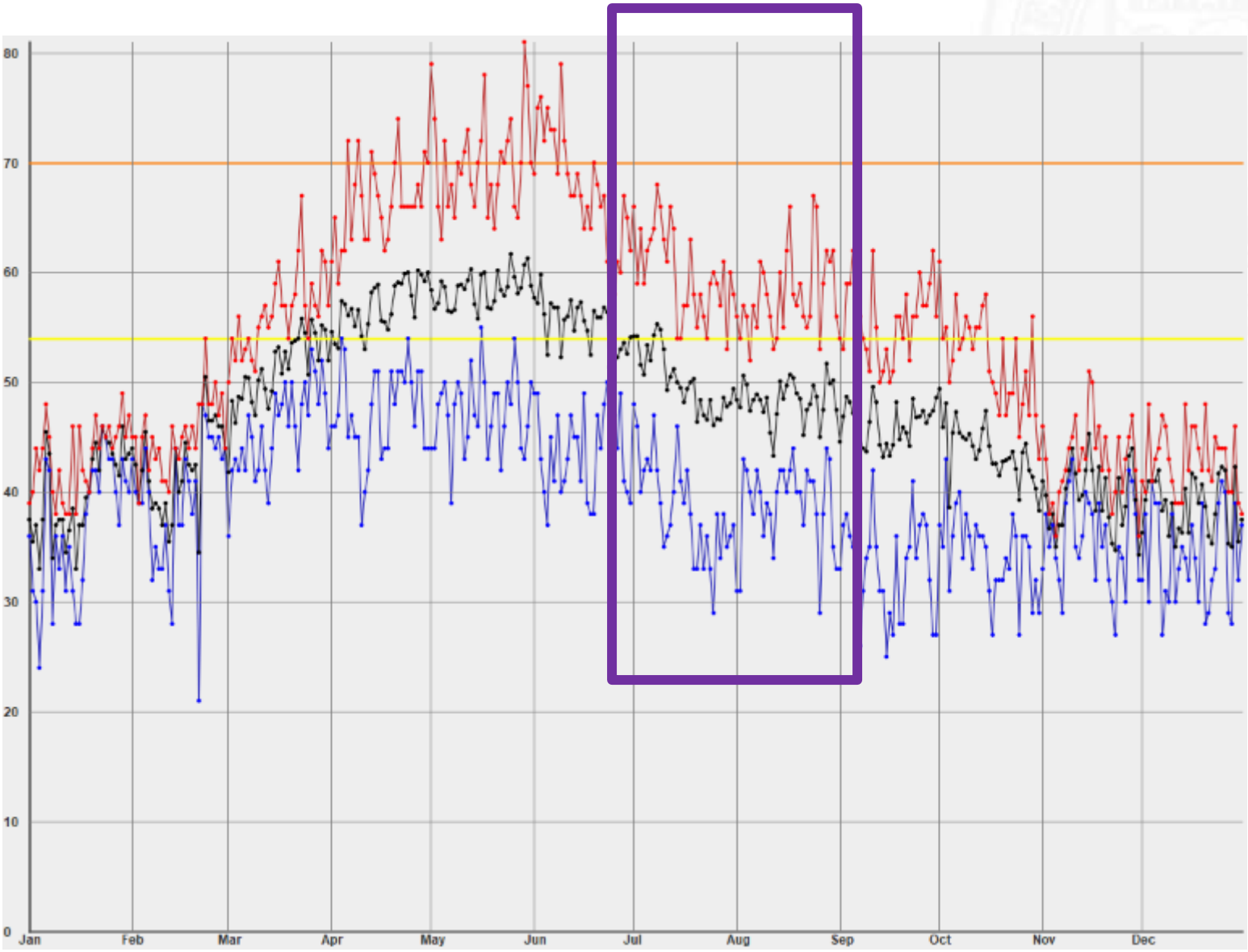
Phoenix Ozone Climatology (2005-2017)



Yuma Ozone Climatology (2005-2017)



Flagstaff Ozone Climatology (2005-2017)



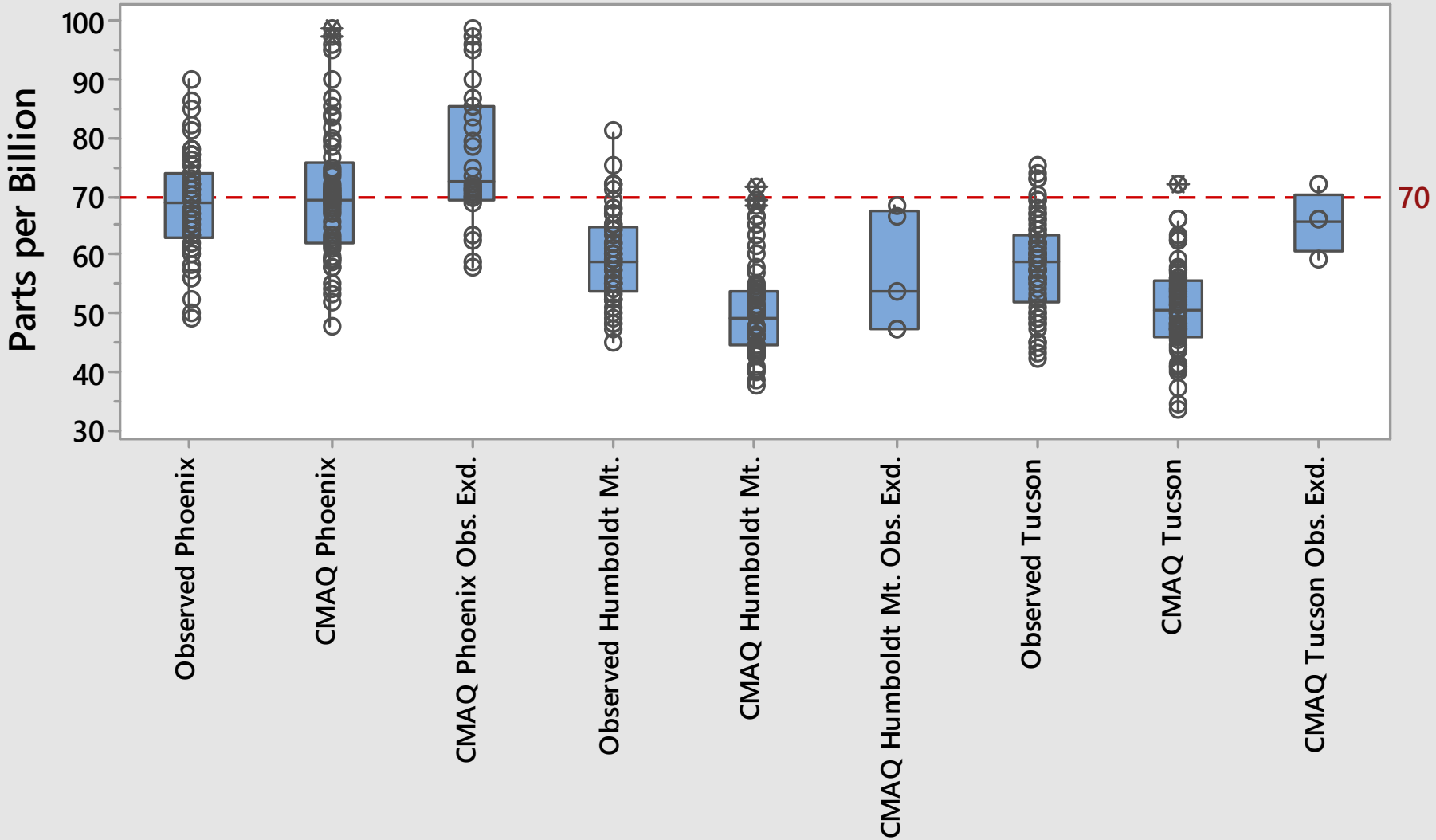
Arizona Ozone - Monsoon 2018

	Phoenix	Humboldt Mt.	Tucson	Yuma	Flagstaff	Grand Canyon N.P.	Petrified Forest N.P.
Exceedance	26	6	4	0	0	0	2
CMAQ Exd.	22 (17)	1 (0)	1 (1)	0	0	0	0
False Negative	9	0	0	0	0	0	0
Obs. Range	49 – 90	45 – 81	42 – 75	29 – 68	26 – 66	40 – 69	45 – 75
CMAQ Range	47 – 99	37 – 72	33 – 72	26 – 64	34 – 61	37 – 61	38 – 60
Mean Absolute Error	7.1	10.7	8.0	7.9	7.1	8.5	9.9
Max Daily Error (Over)	23.4	10.3	3.7	25.9	8.6	6.8	9.1
Max Daily Error (Under)	19.3	27.9	16.8	21.5	17.1	20.8	24.6

Ozone: Parts per Billion

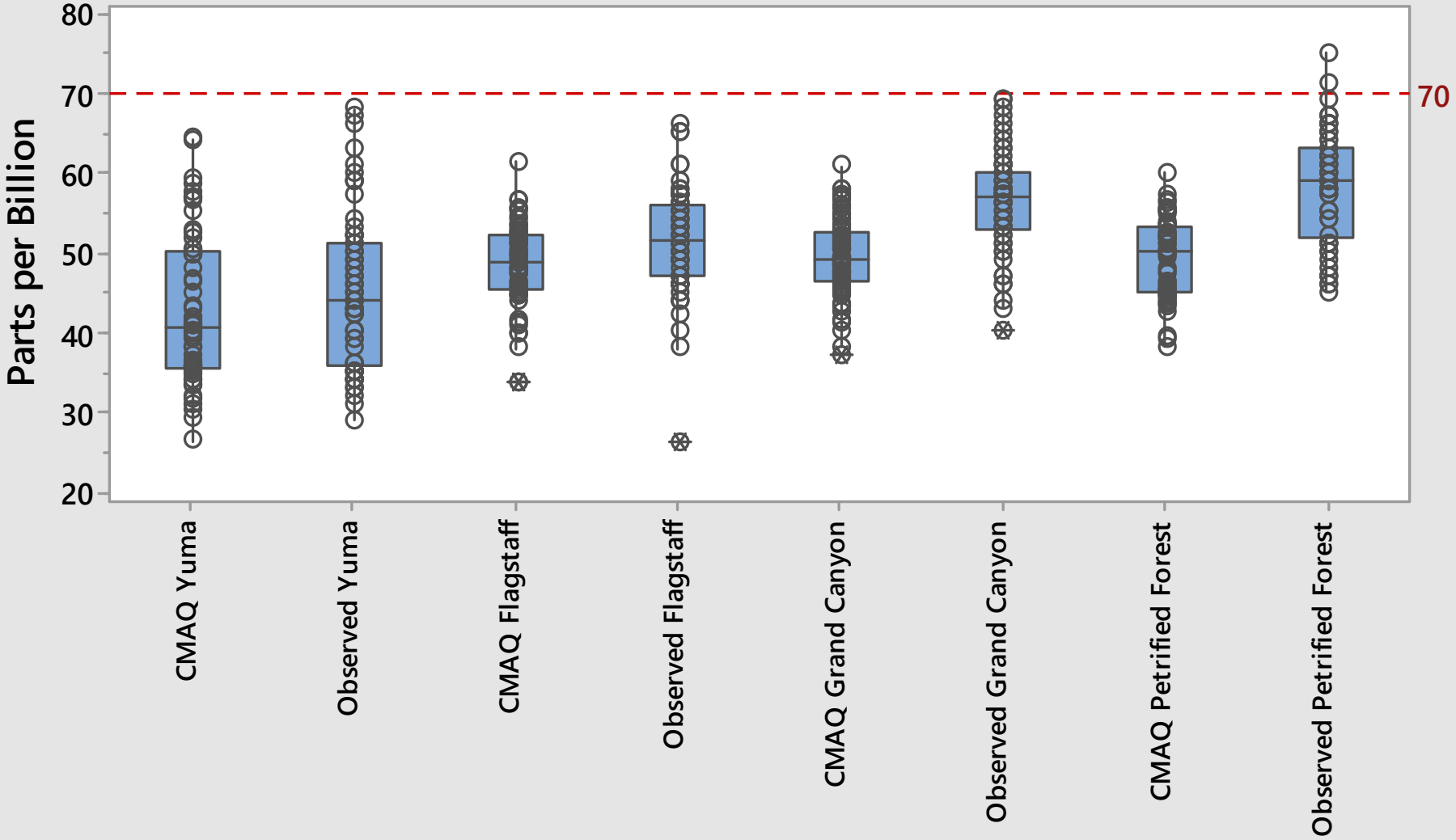
Metropolitan Ozone

North American Monsoon Season



Rural Ozone

North American Monsoon Season



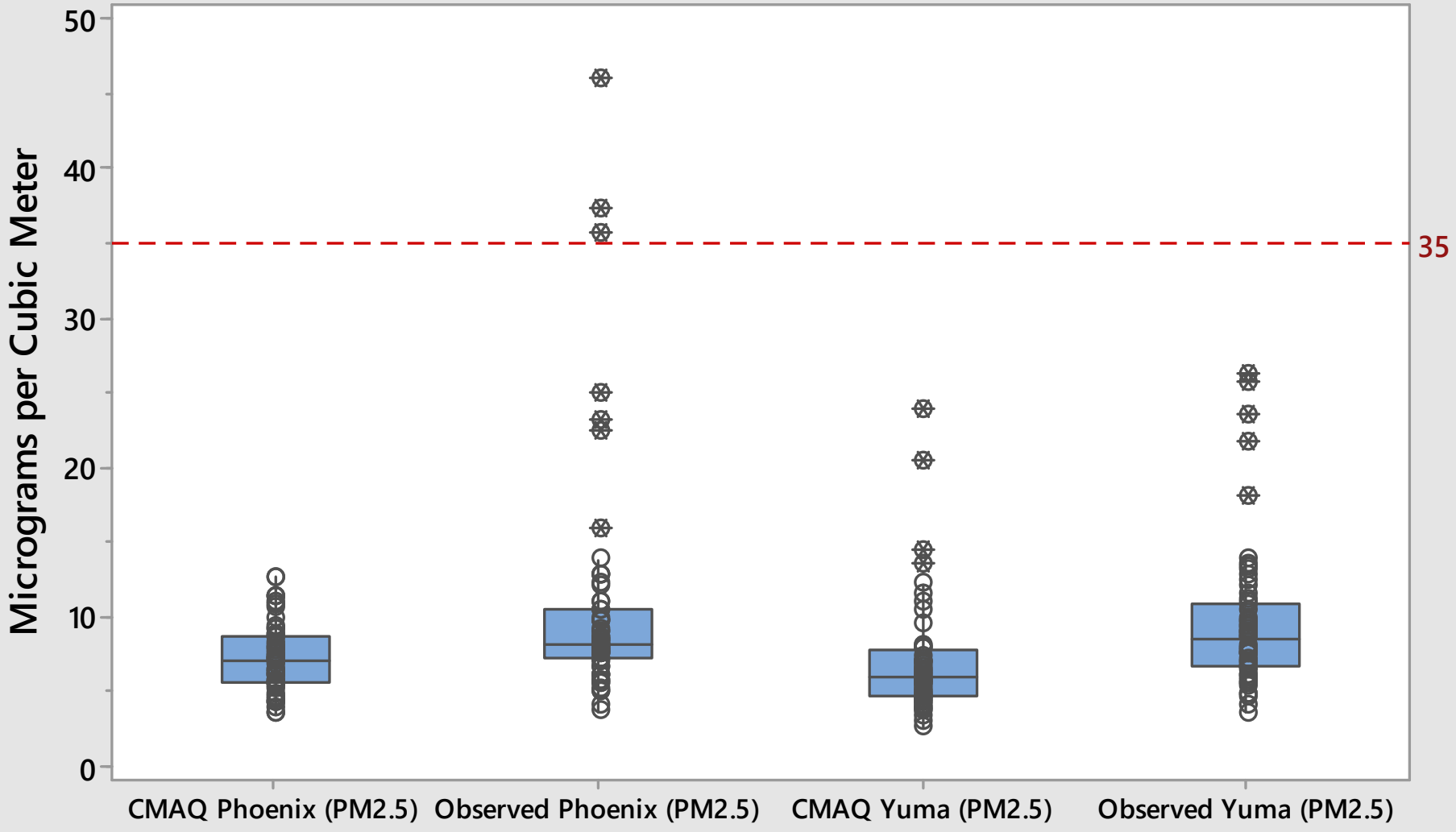
Arizona $PM_{2.5}$ - Monsoon 2018 - µg/m3

	Phoenix (PM2.5)	Phoenix (PM10)	Yuma (PM2.5)	Yuma (PM10)
Exceedance	3	9	0	4
CMAQ Exd.	0	-	0	-
False Negative	0	-	0	-
Observed Range	3.6 – 46.0	20 – 503	3.5 – 26.1	12 – 292
CMAQ Range	3.4 – 12.6	-	2.5 – 23.9	-
Mean Absolute Error	4.7	-	4.1	-
Max Daily Error (Over)	5.3	-	15.4	-
Max Daily Error (Under)	40	-	20.6	-

Particulates: µg/m^3

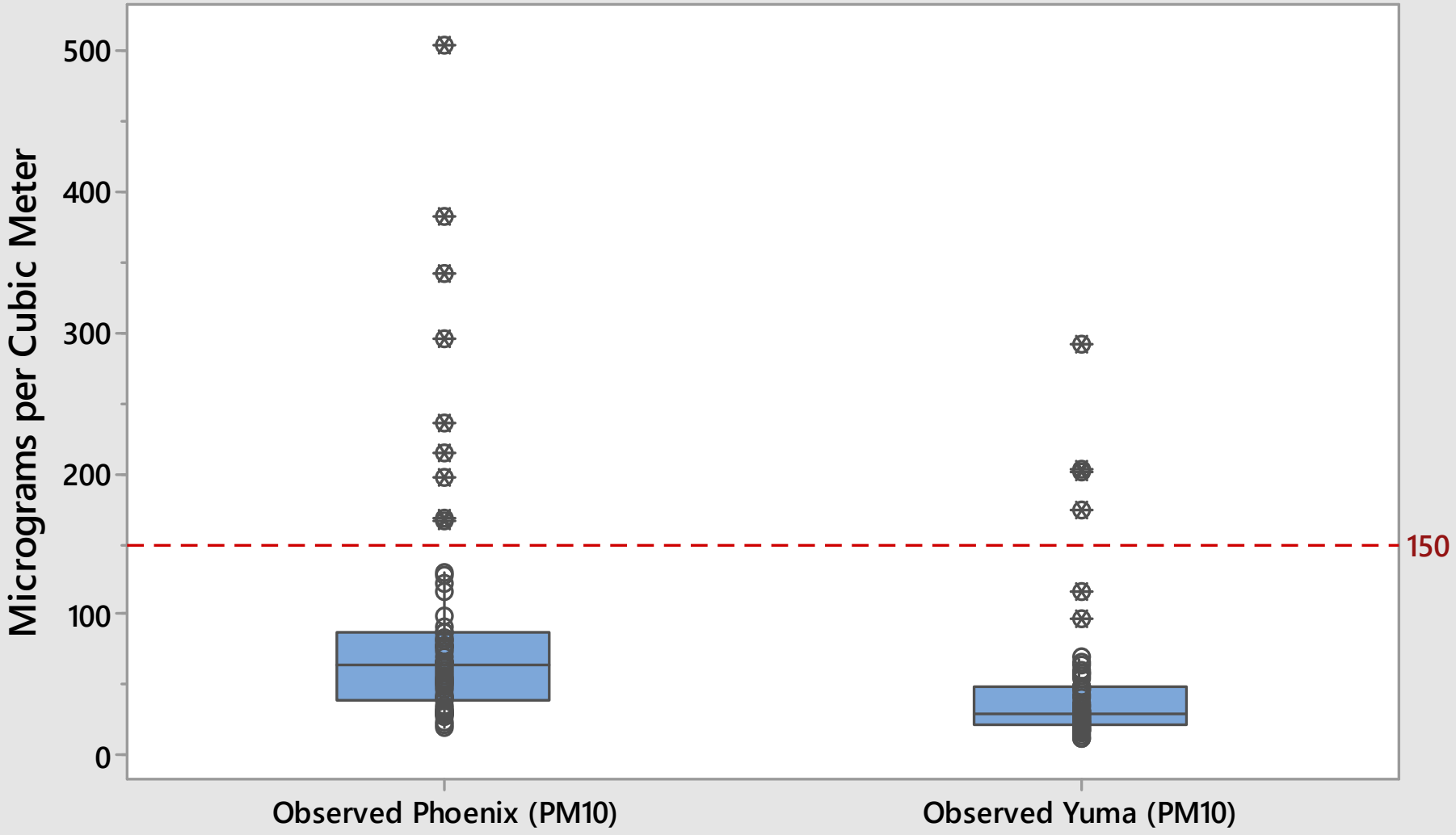
Fine Particulates

North American Monsoon Season



Coarse Particulates

North American Monsoon Season



Phoenix Daily Ozone Concentrations

ADEQ Arizona Department of Environmental Quality

Daily Maximum Ozone Concentration (ppb)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	51	55	53	58	54	71	63	82	47			
2	45	57	55	60	62	76	67	90	48			
3	45	55	56	69	66	73	49	77	52			
4	48	59	55	63	64	76	52	66	58			
5	45	53	57	67	70	59	70	64	59			
6	44	51	50	65	66	69	60	74	62			
7	47	49	53	51	76	70	63	74	72			
8	44	49	52	56	72	68	73	77	64			
9	39	49	55	64	76	62	72	75	59			
10	41	52	48	69	59	64	72	76	58			
11	42	53	44	68	59	66	71	81	53			
12	45	39	53	61	62	67	72	71	53			
13	51	42	56	56	60	63	66	75	58			
14	48	35	53	61	60	59	57	66	64			
15	47	38	53	63	66	41	67	72	61			
16	43	39	53	60	65	50	78	64	63			
17	41	41	53	71	64	54	86	70				
18	44	44	52	78	71	62	69	58				
19	49	47	55	63	73	69	65	61				
20	42	50	60	62	65	81	71	63				
21	42	50	60	69	64	74	66	63				
22	44	52	47	69	60	71	68	63				
23	43	49	54	74	66	68	78	62				
24	47	50	51	78	61	58	78	56				
25	46	50	56	75	61	73	71	62				
26	49	55	57	73	61	66	72	56				
27	47	52	56	70	64	71	77	50				
28	43	49	56	65	67	73	77	67				
29	48	NA	52	62	76	64	69	60				
30	48		58	60	67	62	65	61				
31	53		59		63		85	71				

- High ozone exceedance potential during Monsoon.
- Phoenix ozone exceedances tend to be episodic.

Phoenix Daily $PM_{2.5}$ Concentrations

ADEQ Arizona Department of Environmental Quality

Daily Maximum PM2.5 Concentration (µg/m3)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	199.3	23.7	11.6	8.4	9	7.7	3.6	10.3	7.9			
2	25.5	24.2	18.5	5.2	7.4	9.4	6	35.6	8.1			
3	NA	23.3	12.9	9.5	8.4	7.4	7.6	9.6	5.4			
4	18.1	19.9	4.3	13.4	9.2	8	23.1	7.9	5.4			
5	19.9	17.5	13.3	12.6	10.9	8.8	9.9	7.6	7.2			
6	28	13.8	10.8	7.9	7.7	8.8	8.2	8.9	9.9			
7	28.5	11.7	12.7	7.5	10.4	8.8	12.8	22.4	6			
8	18.1	21.2	12.6	7.7	9.3	8	46	15.8	6.1			
9	13.2	16	10.7	11.2	8.6	8.4	37.2	12.8	6.2			
10	6.5	14.8	7.2	14.1	8.3	6.5	10.4	11	7.1			
11	20	9.5	5.9	10.7	10.1	8.3	8.4	7.4	6.3			
12	25.8	11	9.4	13.8	8.6	8.6	8.4	9.7	5.9			
13	25.1	6.3	17.8	3.5	7.4	7.7	7.2	8.6	8			
14	25.7	14	11.9	5.2	5.1	9.7	7.2	12.2	8			
15	19.1	8.6	5.5	9.2	7	9.4	7.6	11	7.3			
16	16.4	17.4	6.5	12.9	8.4	7.4	7.6	5.6	7.5			
17	11	26	6.1	8.6	6.6	5.5	6.5	5.5				
18	15	21.1	3.6	7.7	10.6	8	8.9	5.4				
19	13.5	6.2	8.7	14.4	7.6	6.1	5.1	5.7				
20	14.3	8.8	9.5	10.3	6	8.2	6	13.8				
21	9.3	10.5	11.3	6.9	5.9	5.8	24.9	8				
22	11.2	7.4	7.6	10	5.8	6.7	4.1	7.5				
23	13.1	8.1	3.8	9	6.3	9.5	6.6	6.1				
24	10.1	10	5.8	11.8	5.6	8.2	9.1	7.5				
25	10.1	22.4	7.6	9.9	5.1	6.2	8	5				
26	14.9	16.2	8.1	10.2	10.4	11.7	8.1	5				
27	18.6	9.9	6.2	10.2	12	8.3	7.8	6.9				
28	19.2	5.7	7.1	9.7	7.2	6.7	8.5	7.4				
29	9.9	0	6.9	7.5	7.3	9.9	7.8	8.3				
30	15.3		10.6	17.5	6.8	6	12.7	12				
31	16		11.9		5.6		9.6	8.2				

- Fine particulates driven by dust.
- Severe dust storms force $PM_{2.5}$ exceedances.

Phoenix Daily PM_{10} Concentrations

ADEQ Arizona Department of Environmental Quality

Daily Maximum PM10 Concentration (µg/m3)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	237	110	33	31	98	50	31	87	63			
2	104	123	56	62	40	52	78	503	76			
3	109	87	36	42	51	48	65	78	33			
4	114	54	20	67	56	85	53	39	34			
5	101	95	50	71	61	66	115	31	71			
6	84	116	64	61	46	49	55	61	84			
7	77	97	73	61	72	54	90	295	127			
8	104	122	74	46	77	69	382	235	50			
9	228	86	81	70	73	57	342	122	40			
10	19	53	43	71	86	48	60	81	60			
11	46	77	11	102	216	58	41	20	63			
12	49	80	40	386	56	79	28	168	81			
13	48	32	61	44	27	54	42	47	78			
14	43	63	77	27	48	78	54	98	82			
15	67	13	71	38	49	86	28	130	56			
16	71	47	47	76	68	18	77	40	45			
17	53	38	29	85	69	19	65	64				
18	83	31	20	63	63	36	76	26				
19	70	95	47	161	69	49	24	31				
20	107	55	61	71	39	72	29	166				
21	17	56	65	41	127	79	215	50				
22	56	40	66	42	49	66	22	77				
23	72	62	43	65	46	76	34	81				
24	68	23	41	61	48	41	57	86				
25	49	38	38	60	46	61	48	33				
26	74	62	60	78	77	80	74	29				
27	59	60	41	72	71	69	83	50				
28	42	12	52	70	41	71	70	66				
29	87	NA	52	48	69	54	52	65				
30	100		65	100	43	43	197	128				
31	88		45		60		40	52				

- Frequent blowing dust events.
- Morning stagnation and lingering dust a factor.

CS1 – CMAQ: 63.0 ppb; Obs. 78.0 ppb – 7/24/2018

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Site/Site AQS/Param/POC	Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg	Max
Pinnacle Peak C/040132005/O3/1	07/24/18	46	39	36	38	50	50	48	49	53	60	62	70	78	84	82	88	89	73	67	58	46	38	39	44	57.79	89

Time ↑	Temperature	Dew Point	Humidity	Wind	Wind Speed	Wind Gust	Pressure	Precip.	Precip Accum	Condition
12:51 AM	99 ° F	54 ° F	22 %	E	6 mph	0 mph	28.6 in	0.0 in	0.0 in	Fair
1:51 AM	96 ° F	56 ° F	26 %	CALM	0 mph	0 mph	28.6 in	0.0 in	0.0 in	Fair
2:51 AM	94 ° F	58 ° F	30 %	CALM	0 mph	0 mph	28.6 in	0.0 in	0.0 in	Partly Cloudy
3:51 AM	93 ° F	57 ° F	30 %	E	5 mph	0 mph	28.6 in	0.0 in	0.0 in	Fair
4:51 AM	92 ° F	57 ° F	31 %	CALM	0 mph	0 mph	28.6 in	0.0 in	0.0 in	Partly Cloudy
5:51 AM	93 ° F	54 ° F	27 %	E	5 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
6:51 AM	94 ° F	56 ° F	28 %	E	8 mph	0 mph	28.7 in	0.0 in	0.0 in	Partly Cloudy
7:51 AM	98 ° F	54 ° F	23 %	E	3 mph	0 mph	28.7 in	0.0 in	0.0 in	Partly Cloudy
8:21 AM	99 ° F	53 ° F	21 %	E	10 mph	0 mph	28.7 in	0.0 in	0.0 in	Thunder in the Vicinity
8:51 AM	97 ° F	59 ° F	28 %	N	5 mph	0 mph	28.7 in	0.0 in	0.0 in	Thunder in the Vicinity
9:14 AM	96 ° F	66 ° F	37 %	VAR	3 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
9:51 AM	99 ° F	58 ° F	25 %	S	3 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
10:51 AM	106 ° F	53 ° F	17 %	VAR	3 mph	0 mph	28.7 in	0.0 in	0.0 in	Partly Cloudy
11:51 AM	109 ° F	52 ° F	15 %	SE	5 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
12:51 PM	111 ° F	51 ° F	14 %	ESE	7 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
1:51 PM	113 ° F	49 ° F	12 %	VAR	5 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
2:51 PM	116 ° F	50 ° F	11 %	WSW	9 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
3:51 PM	115 ° F	48 ° F	11 %		0 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
4:51 PM	115 ° F	48 ° F	11 %	W	15 mph	20 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
5:51 PM	115 ° F	48 ° F	11 %	WNW	16 mph	23 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
6:51 PM	114 ° F	48 ° F	11 %	W	17 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
7:51 PM	111 ° F	48 ° F	12 %	WNW	12 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
8:51 PM	108 ° F	50 ° F	15 %	W	7 mph	0 mph	28.6 in	0.0 in	0.0 in	Partly Cloudy
9:51 PM	106 ° F	52 ° F	17 %	WSW	7 mph	0 mph	28.6 in	0.0 in	0.0 in	Partly Cloudy
10:51 PM	103 ° F	53 ° F	19 %	WSW	7 mph	0 mph	28.6 in	0.0 in	0.0 in	Partly Cloudy
11:51 PM	103 ° F	52 ° F	18 %	W	9 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy

CS2 – CMAQ: 73.7 ppb; Obs. 62.0 ppb – 8/23/2018

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Site/Site AQS/Param/POC	Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg	Max
Fountain Hills/040139704/O3/1	08/23/18	44	41	39	38	37	36	35	35	93	41	46	51	53	60	61	67	64	60	62	53	50	49	49	46	48.57	67

Time ↑	Temperature	Dew Point	Humidity	Wind	Wind Speed	Wind Gust	Pressure	Precip.	Precip Accum	Condition
12:51 AM	88 ° F	66 ° F	48 %	SSE	12 mph	0 mph	28.7 in	0.0 in	0.0 in	Cloudy
1:51 AM	87 ° F	67 ° F	51 %	NNE	3 mph	0 mph	28.7 in	0.0 in	0.0 in	Cloudy
2:51 AM	86 ° F	66 ° F	51 %	S	6 mph	0 mph	28.7 in	0.0 in	0.0 in	Cloudy
3:51 AM	85 ° F	66 ° F	53 %	E	9 mph	0 mph	28.7 in	0.0 in	0.0 in	Cloudy
4:51 AM	84 ° F	67 ° F	56 %	ESE	9 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
5:51 AM	83 ° F	68 ° F	60 %	SE	9 mph	0 mph	28.8 in	0.0 in	0.0 in	Cloudy
6:51 AM	84 ° F	68 ° F	58 %	SSE	5 mph	0 mph	28.8 in	0.0 in	0.0 in	Mostly Cloudy
7:51 AM	85 ° F	69 ° F	59 %	CALM	0 mph	0 mph	28.8 in	0.0 in	0.0 in	Mostly Cloudy
8:51 AM	88 ° F	67 ° F	49 %	ENE	5 mph	0 mph	28.8 in	0.0 in	0.0 in	Mostly Cloudy
9:51 AM	92 ° F	68 ° F	45 %	SE	6 mph	0 mph	28.8 in	0.0 in	0.0 in	Mostly Cloudy
10:51 AM	92 ° F	68 ° F	45 %	CALM	0 mph	0 mph	28.8 in	0.0 in	0.0 in	Mostly Cloudy
11:51 AM	95 ° F	66 ° F	38 %	SSW	6 mph	0 mph	28.8 in	0.0 in	0.0 in	Mostly Cloudy
12:51 PM	96 ° F	65 ° F	36 %	CALM	0 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
1:51 PM	99 ° F	66 ° F	34 %	SE	6 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
2:51 PM	100 ° F	64 ° F	31 %	W	9 mph	0 mph	28.7 in	0.0 in	0.0 in	Mostly Cloudy
3:51 PM	102 ° F	63 ° F	28 %	S	7 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
4:51 PM	100 ° F	63 ° F	29 %	VAR	7 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
5:51 PM	99 ° F	63 ° F	30 %	S	12 mph	0 mph	28.6 in	0.0 in	0.0 in	Mostly Cloudy
6:00 PM	99 ° F	63 ° F	30 %	S	8 mph	0 mph	28.6 in	0.0 in	0.0 in	Thunder in the Vicinity
6:14 PM	96 ° F	64 ° F	35 %		0 mph	0 mph	28.6 in	0.0 in	0.0 in	Thunder
6:51 PM	83 ° F	71 ° F	67 %	WNW	26 mph	33 mph	28.7 in	0.0 in	0.0 in	T-Storm / Windy
6:53 PM	82 ° F	69 ° F	65 %	WNW	18 mph	33 mph	28.7 in	0.0 in	0.0 in	Heavy T-Storm
7:01 PM	80 ° F	68 ° F	67 %	NNW	8 mph	0 mph	28.7 in	0.2 in	0.0 in	T-Storm
7:11 PM	81 ° F	72 ° F	74 %	ESE	9 mph	0 mph	28.7 in	0.2 in	0.0 in	Heavy T-Storm
7:31 PM	83 ° F	70 ° F	65 %	ESE	20 mph	0 mph	28.7 in	0.3 in	0.0 in	T-Storm
7:51 PM	83 ° F	73 ° F	72 %	S	8 mph	0 mph	28.7 in	0.3 in	0.0 in	Thunder in the Vicinity

CS3 – CMAQ: 47.1 ppb; Obs. 75.0 ppb – 8/11/2018

ADEQ Arizona Department of Environmental Quality

Site/Site AQS/Param/POC	Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg	Max
Humboldt Mounta/040139508/O3/1	08/11/18	62	60	60	60	55	57	58	57	58	61	63	63	64	63	66	69	73	78	79	76	75	75	75	74	65.88	79

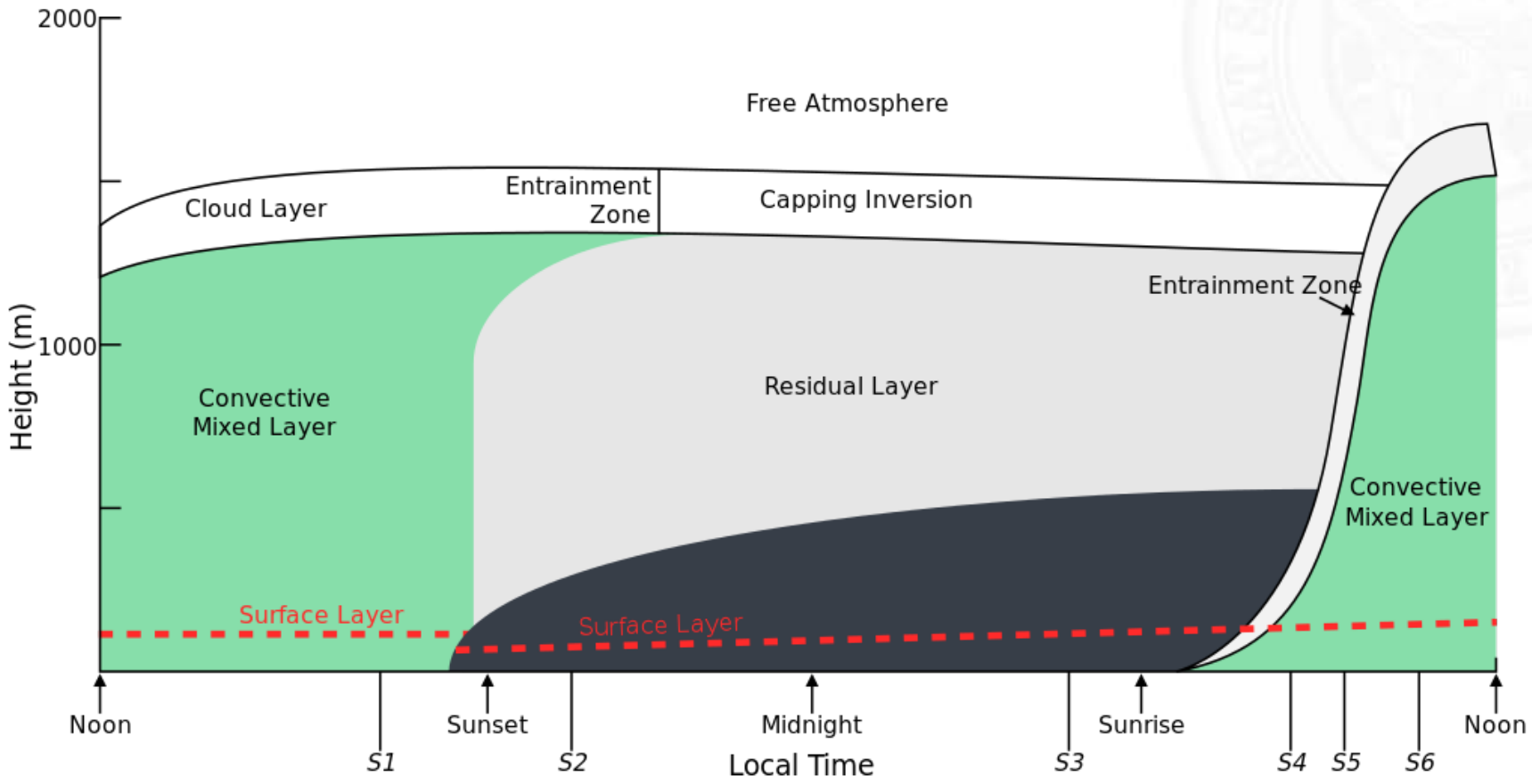
Time ↑	Temperature
12:00 AM	76 ° F
12:16 AM	76 ° F
12:27 AM	76 ° F
5:51 AM	80 ° F
6:51 AM	78 ° F
7:51 AM	84 ° F
8:51 AM	84 ° F
9:51 AM	87 ° F
10:51 AM	90 ° F
11:51 AM	93 ° F
12:51 PM	95 ° F
1:51 PM	96 ° F
2:51 PM	98 ° F
3:51 PM	100 ° F
4:51 PM	100 ° F
5:51 PM	99 ° F
6:51 PM	98 ° F
7:51 PM	97 ° F
8:51 PM	97 ° F
9:51 PM	92 ° F
10:51 PM	94 ° F
11:51 PM	92 ° F

Daily Maximum Ozone Concentration (ppb)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	51	55	53	58	54	71	63	82	47			
2	45	57	55	60	62	76	67	90	48			
3	45	55	56	69	66	73	49	77	52			
4	48	59	55	63	64	76	52	66	58			
5	45	53	57	67	70	59	70	64	59			
6	44	51	50	65	66	69	60	74	62			
7	47	49	53	51	76	70	63	74	72			
8	44	49	52	56	72	68	73	77	64			
9	39	49	55	64	76	62	72	75	59			
10	41	52	48	69	59	64	72	76	58			
11	42	53	44	68	59	66	71	81	53			
12	45	39	53	61	62	67	72	71	53			
13	51	42	56	56	60	63	66	75	58			
14	48	35	53	61	60	59	57	66	64			
15	47	38	53	63	66	41	67	72	61			
16	43	39	53	60	65	50	78	64	63			
17	41	41	53	71	64	54	86	70				
18	44	44	52	78	71	62	69	58				
19	49	47	55	63	73	69	65	61				
20	42	50	60	62	65	81	71	63				
21	42	50	60	69	64	74	66	63				
22	44	52	47	69	60	71	68	63				
23	43	49	54	74	66	68	78	62				
24	47	50	51	78	61	58	78	56				
25	46	50	56	75	61	73	71	62				
26	49	55	57	73	61	66	72	56				
27	47	52	56	70	64	71	77	50				
28	43	49	56	65	67	73	77	67				
29	48	NA	52	62	76	64	69	60				
30	48		58	60	67	62	65	61				
31	53		59		63		85	71				

Condition
Light Rain with Thunder
T-Storm
Light Rain
Cloudy
Mostly Cloudy
Mostly Cloudy
Mostly Cloudy
Mostly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Partly Cloudy
Mostly Cloudy
Partly Cloudy
Mostly Cloudy
Mostly Cloudy

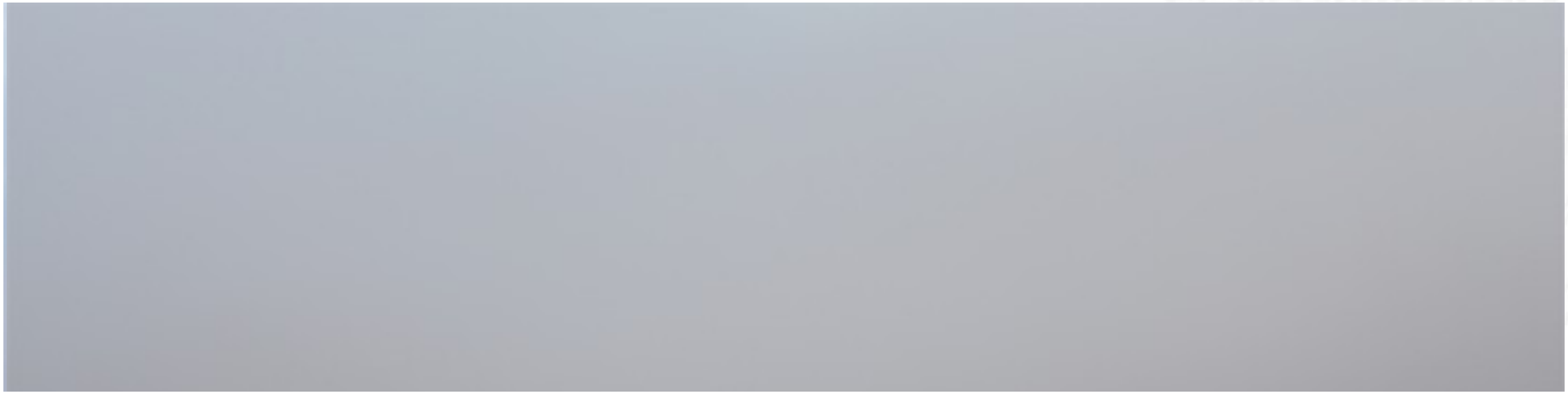
CS3 – CMAQ: 47.1 ppb; Obs. 75.0 ppb – 8/11/2018



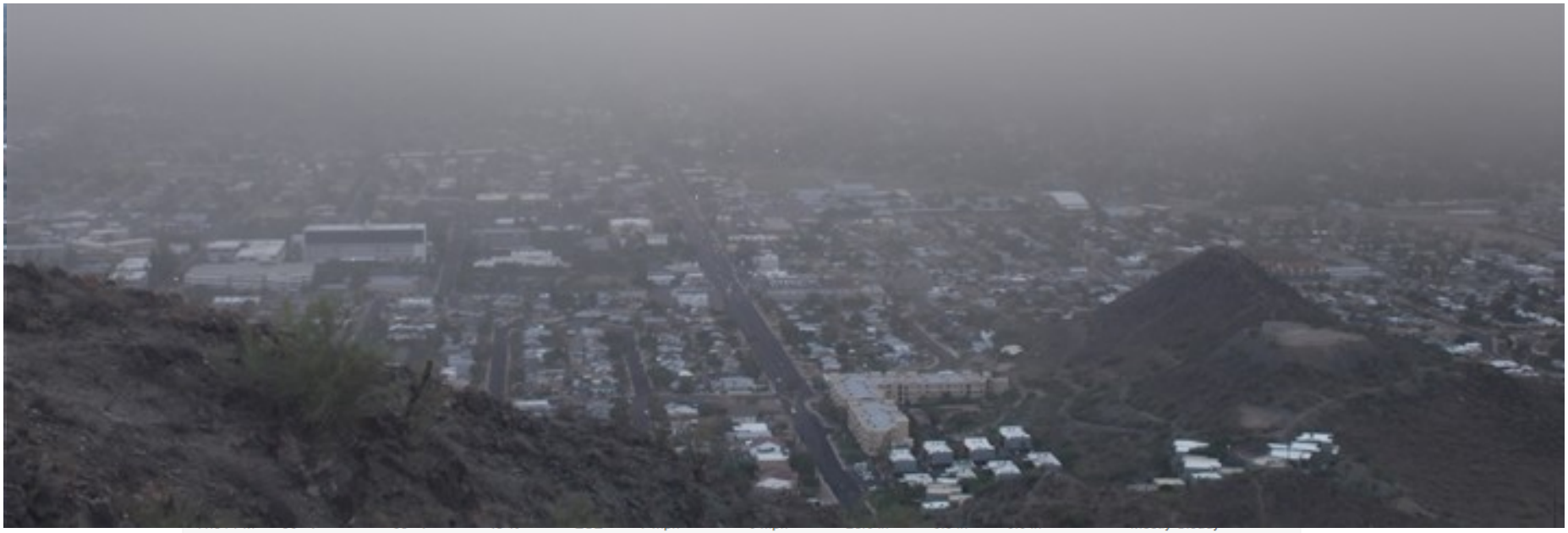
- Aged ozone in residual layer underestimated?
- Fumigation considerations.

CS4 – CMAQ: 84 ppb; Obs. 90 ppb – 8/2/2018
CMAQ: 11.3 ug/m3; Obs. 35.6 µg/m^3; Obs. 503 (PM_{10})

ADEQ Arizona Department of Environmental Quality

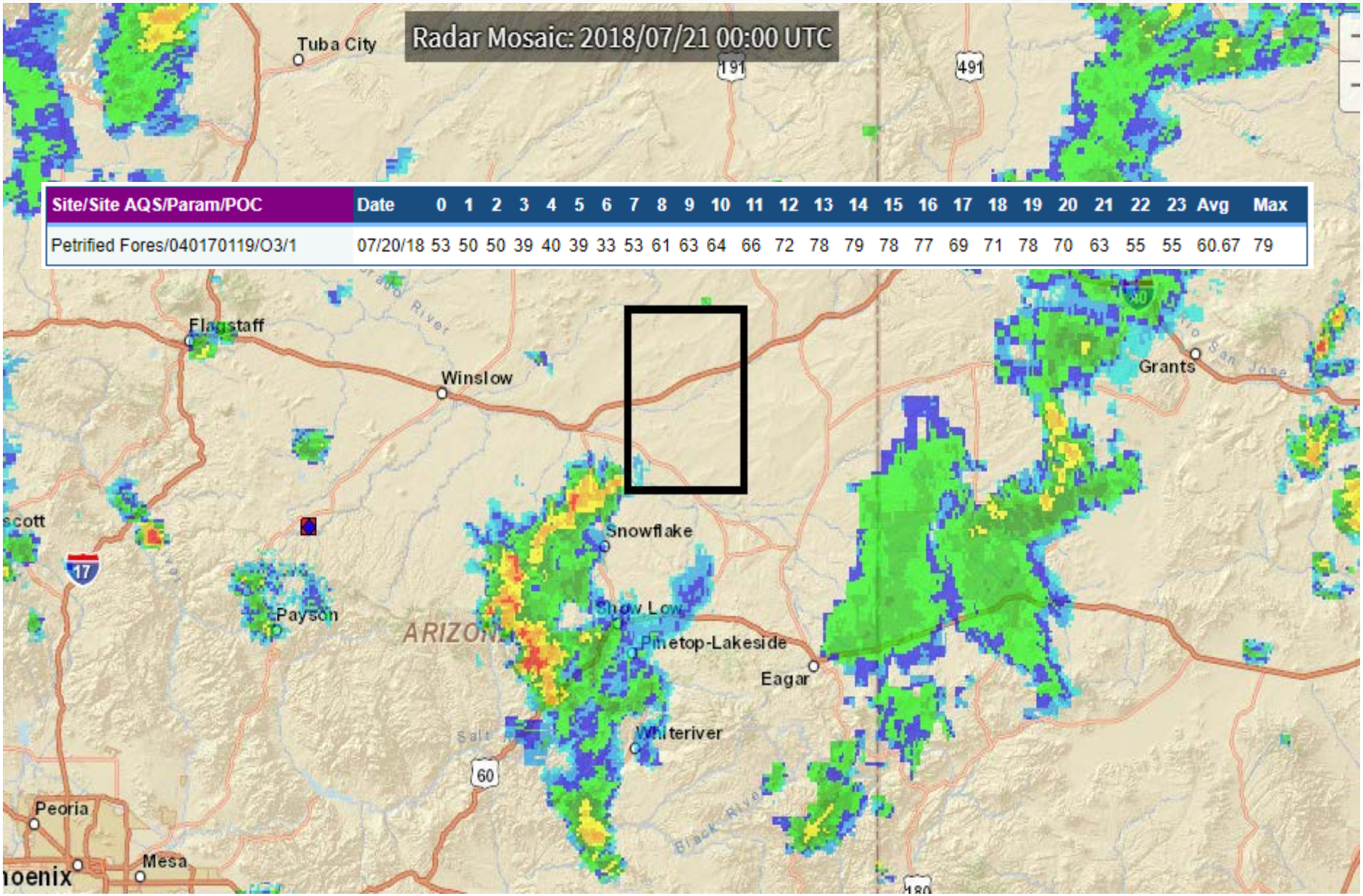


Site/Site AQS/Param/POC	Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg	Max
Mesa - Brooks R/040131003/PM2.5-88101/3	08/02/18	6.5	7.8	9.8	8.6	6.7	5.9	6.8	9.2	8.8	10.1	8.9	7.7	8.8	9.3	6.9	7.6	7.3	8.9	50	553.5	62.1	17.2	12.1	14.5	35.63	553.5



CS5 – CMAQ: 50.4 ppb; Obs. 75.0 ppb – 7/20/2018

ADEQ Arizona Department of Environmental Quality



Site/Site AQS/Param/POC	Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg	Max
Petrified Fores/040170119/O3/1	07/20/18	53	50	50	39	40	39	33	53	61	63	64	66	72	78	79	78	77	69	71	78	70	63	55	55	60.67	79

Ozone Formation

Ozone formation occurs through the following sequence of reactions:

$$VOC + OH \xrightarrow{[O_2]} RO_2 + H_2O \quad \text{R1}$$

$$CO + OH \xrightarrow{[O_2]} HO_2 + CO_2 \quad \text{R2}$$

$$RO_2 + NO \xrightarrow{[O_2]} \text{secondary VOC} + HO_2 + NO_2 \quad \text{R3}$$

$$HO_2 + NO \rightarrow OH + NO_2 \quad \text{R4}$$

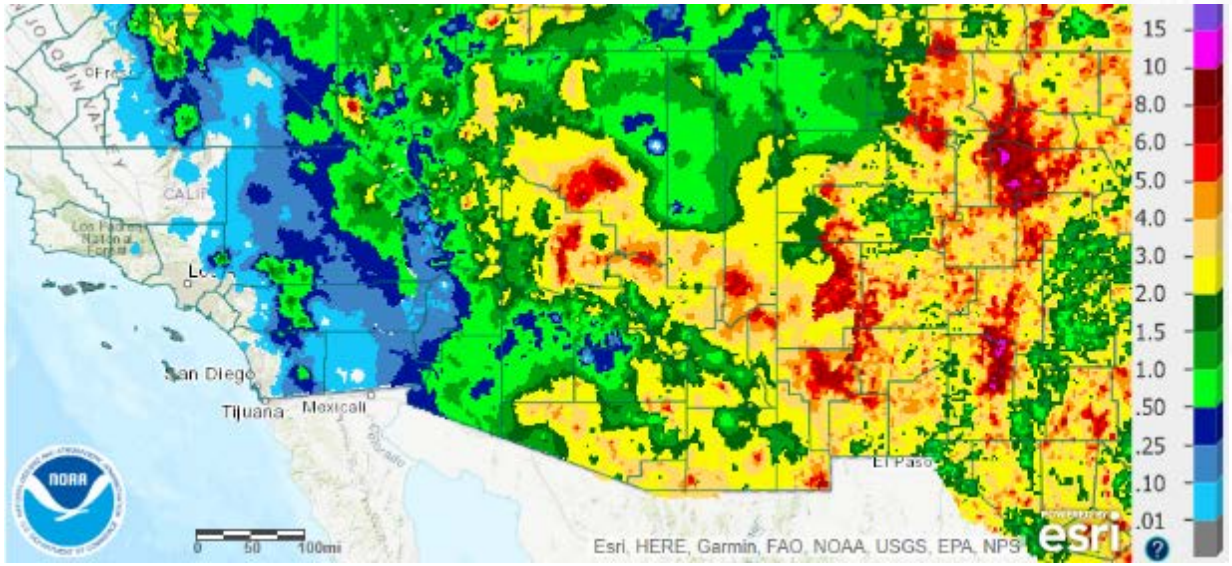
$$NO_2 + h\nu \rightarrow NO + O \quad \text{R5}$$

$$O + O_2 + M \rightarrow O_3 + M \quad \text{R6}$$

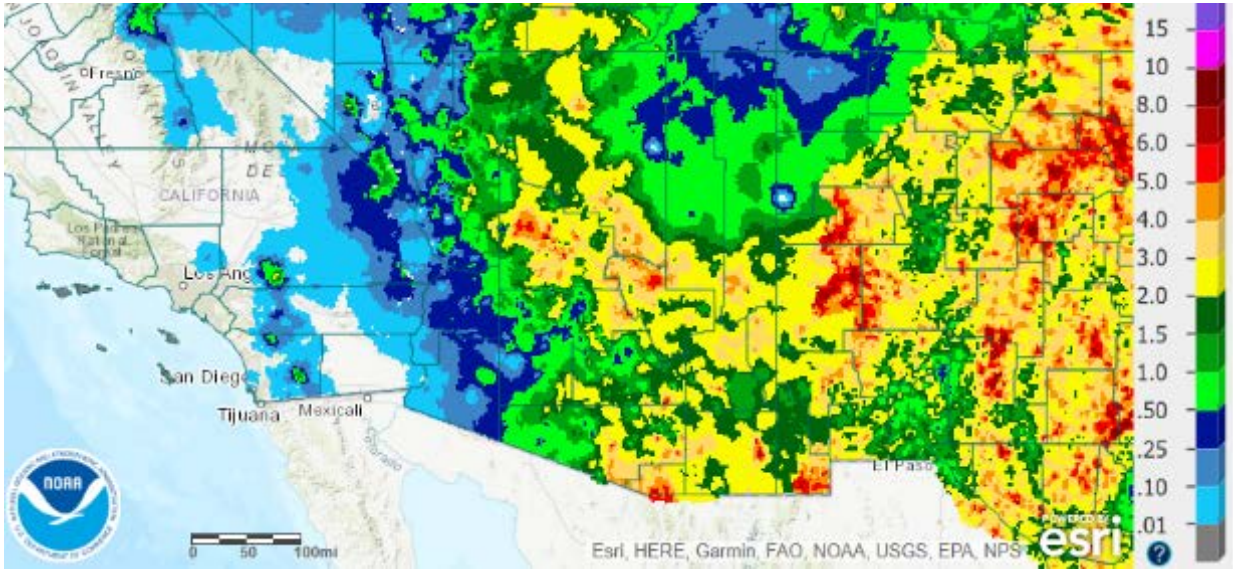
The sequence is almost always initiated by the reaction of various VOC or CO with the OH radical [**R1, R2**]. This is followed by the conversion of NO to NO_2 (through reaction with HO2 or RO2 radicals), which also regenerates OH [**R3, R4**]. NO_2 is photolyzed (broken down with light) to generate atomic oxygen, which combines with O2 to create O_3 [**R5, R6**].

Observed Precipitation - July (A) – August (B)

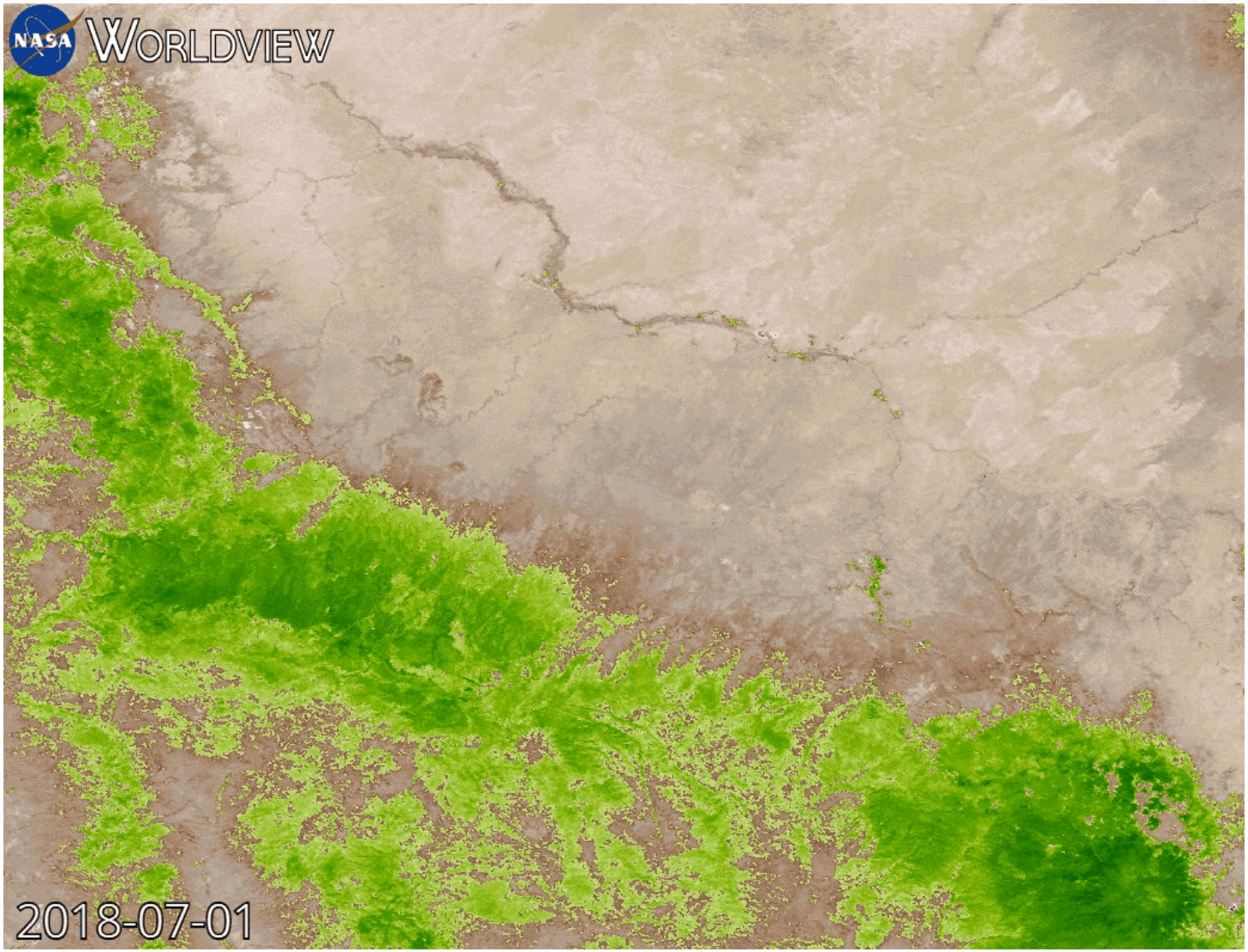
A



B



Monsoon Plant Blooms



Normalized Difference Vegetation Index (NDVI) – Rolling 8-day Average

Key Takeaways

- CMAQ remains a viable guidance tool for preparing air quality forecasts in Arizona
- Caution with use during dynamic atmospheres.
  - Outflows Boundaries (ozone and particulates)
  - Cloud Cover
- CMAQ has unrealistically high predictions in Phoenix at times.
  - Emissions inventory issue?
- General underprediction for rural high elevation sites.
  - Unaccounted for emissions inventory?
- Humboldt Mountain low bias.
  - Underestimate of ozone in nocturnal residual layer?
- How are possible biogenic VOCs ("green blooms") in model handled?
  - May help explain lower CMAQ baseline for Petrified Forest N.P. site
- More weight needed on blowing dust for $PM_{2.5}$
- Soil Moisture Considerations?
  - Suppression of PM_{10} leads to lower $PM_{2.5}$
  - Catalog of specific dust sources likely necessary (e.g., Pinal County)
- Can CMAQ include cultural events (e.g., July 4^{th} Fireworks)?
  - CMAQ: 5.33 $\mu g/m^3$; Obs. 23.1 $\mu g/m^3$