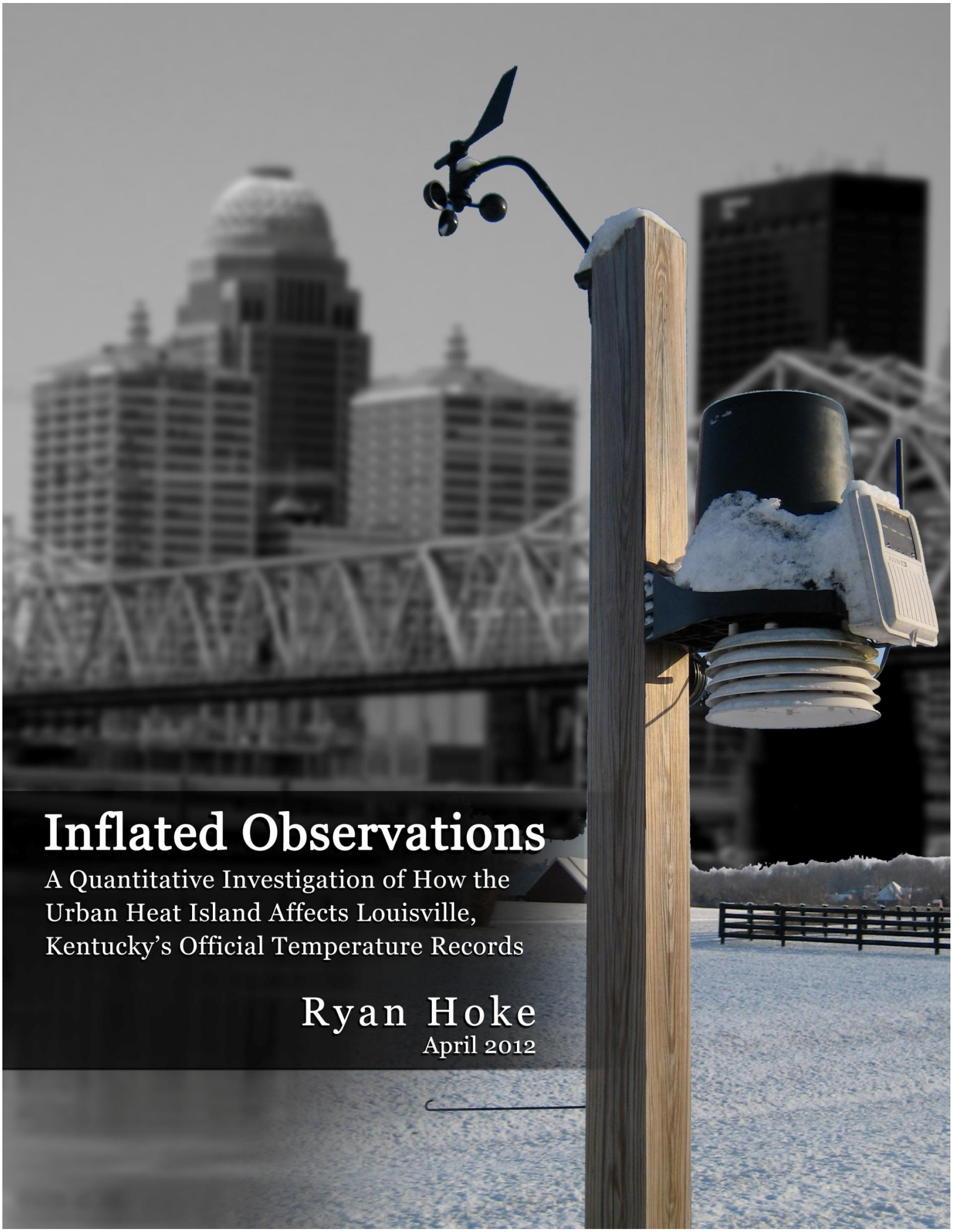

Inflated Observations

A Quantitative Investigation of How the Urban Heat Island Affects Louisville, Kentucky's Official Temperature Records

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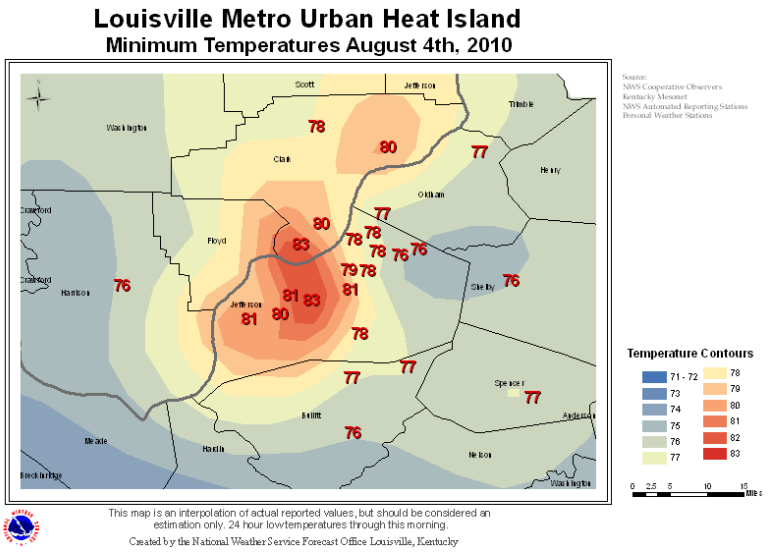
Author's Note

As a kid growing up in Louisville, Kentucky I became fascinated by the changeable weather in the region. Living through numerous winter storms, severe weather events, and even a wind storm caused by the remnants of a hurricane, I became used to having extremes right in my own backyard. In 2005 my father installed a Davis Vantage Pro2 weather station in our front yard to record and transmit observations to the Citizen Weather Observer Program. When viewing our temperature readings and comparing them to the official readings at Louisville's airport as a teenager I noticed that ours were almost always cooler. Around this time many local meteorologists at TV stations in the city began commenting on this same thing among weather stations in different parts of the city compared to the airport.

Background

The reason for the sudden uptick in comment about these warmer-than-usual observations was because Louisville's official weather observation location had been moved from the National Weather Service office in suburban South Louisville to Louisville International Airport (KSDF) in January 2006 (National Weather Service Louisville, KY 2010). The switch to the Louisville ASOS at the airport put the official observations back where they were before a move to the forecast office in 1995. Since the airport is closer to the city center and in an area of denser urban development and concrete, it is affected by what is referred to as the urban heat island effect. According to The American Meteorological Society's Glossary of Meteorology (1994), the difference in temperature between urban and rural locations in large cities can be 1 to 2 degrees Celsius (about 2 to 4 degrees Fahrenheit) during the daytime and 12 degrees Celsius (about 22 degrees Fahrenheit) at night. While Louisville, only a medium-size city of 741,096 (Business First 2011), may not exhibit as much variation, this observable phenomenon explains why the temperatures recorded at KSDF are warmer than quite a bit of the rest of the city of Louisville inside Jefferson County, KY (Pine 2010).



(Pine 2010 – Image generated by NWS Louisville)

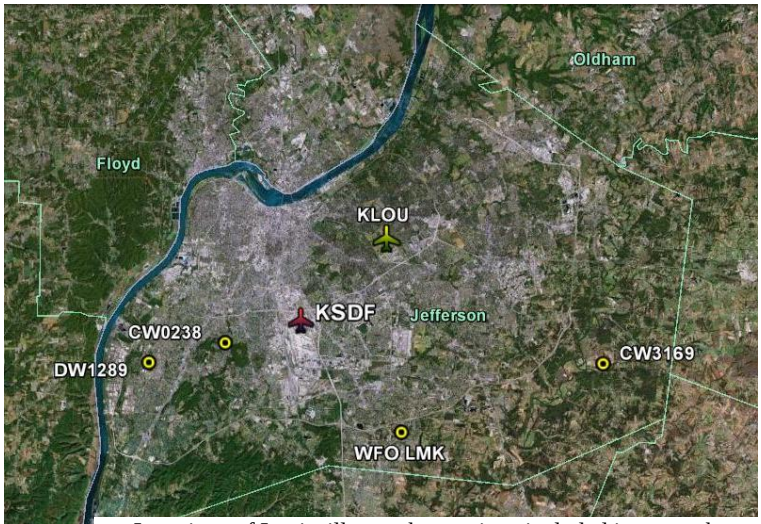
Knowing that the urban heat island effect "distorts" temperature readings at the airport, does this mean that these temperatures are inaccurate? No, but observing temperatures in an area that has an enhanced area of concrete, asphalt, and other man-made low albedo surfaces brings into question the appropriateness of having these observations represent the entire city. Louisville encompasses the entirety of Jefferson County, Kentucky and the area inside the city that experiences the most inflated heat island temperatures, which includes KSDF, is fairly small. It is understandable that the observations taken at the airport may represent Downtown Louisville and other dense urban areas well, but these inflated temperatures do not fairly represent the city as a whole.

Research Methodology

Previous research in multiple cities by Gallo and Owen (1999) shows that weather observation stations in urban areas do indeed show higher minimum, maximum, and average temperatures than rural ones due to the urban heat island. Urban

stations also have a lower daily temperature range than ones in rural areas according to previous research cited by Gallo and Owen.

This research seeks to quantify the amount by which the official temperature observations at the Louisville International Airport (KSDF) ASOS site are warmer than the rest of the city. Since there are a limited number of alternate observation sites within the city limits, this will obviously be a rough estimate that will make somewhat tangible the degree by which the airport's observations are skewed. The observation sites that are used to compare KSDF's temperature to include three Citizen Weather Observation Program stations, Louisville's Bowman Field airport ASOS site, and observations taken at the National Weather Service Weather Forecast Office in Louisville.



Locations of Louisville weather stations included in research

Even though there a quite a few more personal and residential weather observation stations in the city of Louisville that have their data online than what is represented here, the criteria for which stations could be included in this research is strict. These criteria are 1) the stations must be registered with the Citizen Weather Observation Program for MADIS (Meteorological Assimilation Data Ingest System) data quality checking, 2) the stations must also report to the Weather Underground website so that reliable observation records can be obtained in a .CSV format and 3) the stations must have been in service between January 2009 and October 2010.

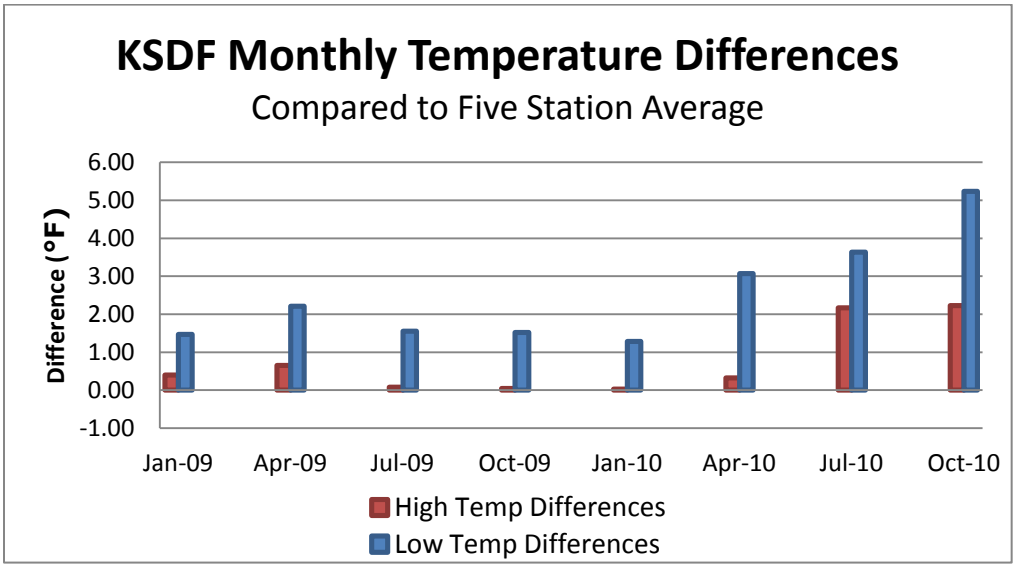
The daily high and low temperature data from these sites was then collected for January, April, July, and October of 2009 and 2010. These months were chosen because they are evenly spaced and represent data in all four seasons. More recent data for 2011 was not used because the data from KSDF and WFO Louisville is not yet available for the entirety of that year yet as of this writing. Even though the above criteria were met for the three Citizen Weather Observation Program stations that are used in this research, there are still some holes in their data. This is particularly true with CW0238 in West Louisville, which has data missing for the entire month of October 2010 and partial data for July 2010, January 2010, and January 2009. These holes, possibly caused by computer issues, power outages, or other barriers to reporting to the internet, are tolerable because the quality of the data that is present is very good according to MADIS and cursory comparison. Taking all of CW0238's data out of this research does not alter the results much either, so it was allowed to remain in an attempt to have as many areas in the city represented as possible.

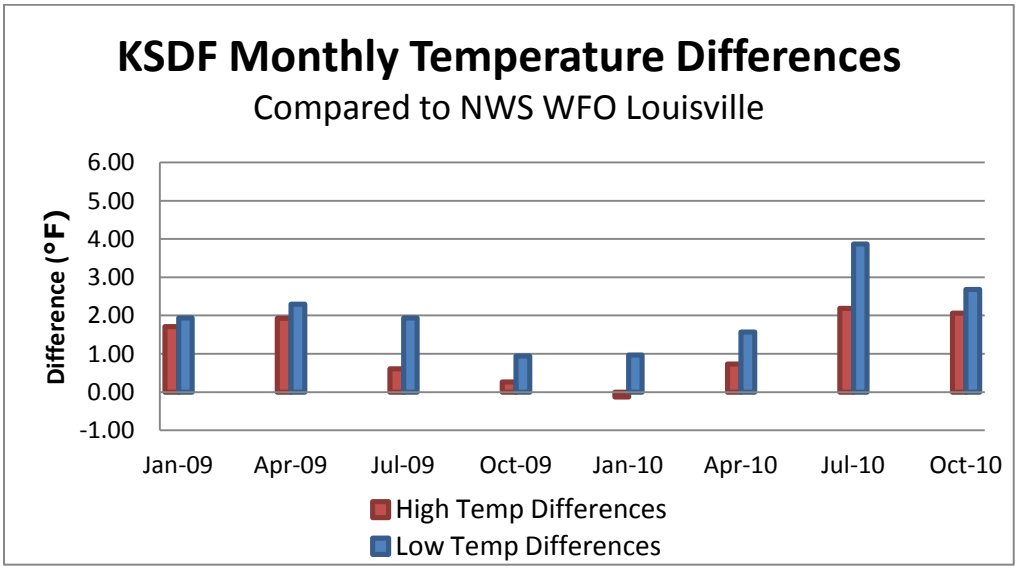
In regard to representing the entire city, it is worth noting that the five locations chosen in this study do leave rather large areal gaps in representation in the northeastern and northwestern sections of Louisville. This is because there are no stations in these areas that meet the quality criteria set for this research. It's also worth noting that a hypothetical station in the northwestern section of the city could exhibit the same heat island issue that KSDF does because of the very high density of urban development there. The satellite map with the stations chosen for this research on the left shows very clearly where the highest urban development is and hence where the highest urban heat island issues are by the finding the concentrated gray-colored area that stretches from south of KSDF to northwestern sections of Louisville on the Ohio River. Most of the city inside Jefferson County is a

greener hue with patches of grey urban development mixed in.

Results

When comparing high and low temperatures at KSDF for the aforementioned months with an average of these same numbers from the chosen weather reporting stations in the city, KSDF shows an average 0.74 °F higher high temperature and an average 2.50 °F higher low temperature. When only comparing KSDF to the old official reporting site at the National Weather Service in Louisville, KSDF has an average 1.17 °F higher high temperature and a 2.03 °F higher low temperature. Graphical monthly comparisons of this data are available below. The raw data from this study is available in the next few pages of this report. All temperatures and differences in the proceeding data are in degrees Fahrenheit.





	KSDF		WFO LOU		KLOU		CW3169		CW0238		DW1289					
Jan '09	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Avg High	Avg Low	Diff High	Diff Low
1	43	18	42	16	43	19	44	12			43	17	43.00	16.00	0.00	2.00
2	49	33	48	30	48	29	48	25			49	29	48.25	28.25	0.75	4.75
3	55	32	53	30	56	28	56	24			54	28	54.75	27.50	0.25	4.50
4	61	35	59	34	61	36	61	36			60	34	60.25	35.00	0.75	0.00
5	36	27	34	25	36	27	36	27			34	27	35.00	26.50	1.00	0.50
6	41	33	40	31	41	33	42	32			40	32	40.75	32.00	0.25	1.00
7	41	31	39	30	41	31	41	31			40	31	40.25	30.75	0.75	0.25
8	34	22	32	19	33	22	33	18			33	20	32.75	19.75	1.25	2.25
9	47	20	46	18	47	20	46	15			48	18	46.75	17.75	0.25	2.25
10	51	32	49	30	50	32	50	28			50	31	49.75	30.25	1.25	1.75
11	33	30	32	28	34	30	32	29	37	31	33	29	33.60	29.40	-0.60	0.60
12	40	28	38	27	40	29	40	24	43	28	40	26	40.20	26.80	-0.20	1.20
13	42	15	39	15	41	16	40	23	41	16	41	15	40.40	17.00	1.60	-2.00
14	40	15	39	13	40	16	20	18	41	15	40	14	36.00	15.20	4.00	-0.20
15	15	4	15	3	17	4	18	4	21	4	15	4	17.20	3.80	-2.20	0.20
16	18	-1	17	-3	18	-1	18	-4	25	-1	18	-2	19.20	-2.20	-1.20	1.20
17	39	9	37	7	38	10	38	2	42	8	39	7	38.80	6.80	0.20	2.20
18	38	29	35	27	38	29	37	29	38	30	38	29	37.20	28.80	0.80	0.20
19	29	18	28	17	30	18	28	19	34	19	30	19	30.00	18.40	-1.00	-0.40
20	28	13	25	12	27	15	25	8	34	13	28	13	27.80	12.20	0.20	0.80
21	35	13	34	10	35	13	34	4	40	12	34	12	35.40	10.20	-0.40	2.80
22	53	26	52	25	53	25	53	15	58	28	53	27	53.80	24.00	-0.80	2.00
23	61	33	59	31	60	32	60	26	64	34	60	32	60.60	31.00	0.40	2.00
24	34	22	32	20	33	21	33	14	42	22	34	21	34.80	19.60	-0.80	2.40
25	24	15	24	13	24	15	25	10	26	17	24	16	24.60	14.20	-0.60	0.80
26	28	20	27	19	28	20	28	21	30	21	27	19	28.00	20.00	0.00	0.00
27	32	24	30	22	34	24	32	24	32	24	31	24	31.80	23.60	0.20	0.40
28	33	22	31	19	33	21	32	21	32	22	32	21	32.00	20.80	1.00	1.20
29	29	22	27	19	29	21	28	21	29	22	28	21	28.20	20.80	0.80	1.20
30	30	19	28	16	29	15	29	7	33	17	29	15	29.60	14.00	0.40	5.00
31	42	11	37	7	41	8	36	0	38	9	37	8	37.80	6.40	4.20	4.60
Avg KSDF	38.10	21.61	Avg WFO	36.39	19.68								**Average Difference**		**0.40**	**1.47**
			Avg Diff	1.71	1.94											

	KSDF		WFO LOU		KLOU		CW3169		CW0238		DW1289					
Apr '09	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Avg High	Avg Low	Diff High	Diff Low
1	65	41	64	38	64	40	65	34	67	38	65	38	65.00	37.60	0.00	3.40
2	76	44	75	43	76	42	75	34	76	40	75	39	75.40	39.60	0.60	4.40
3	60	45	57	40	60	43	59	36	59	45	59	45	58.80	41.80	1.20	3.20
4	64	37	63	33	64	36	64	29	65	36	65	34	64.20	33.60	-0.20	3.40
5	76	49	75	47	76	50	76	37	76	47	76	44	75.80	45.00	0.20	4.00
6	52	36	51	35	53	35	54	36	56	37	53	36	53.40	35.80	-1.40	0.20
7	48	35	46	33	48	35	46	34	48	35	46	35	46.80	34.40	1.20	0.60
8	61	35	60	32	60	33	59	27	62	34	61	34	60.40	32.00	0.60	3.00
9	67	36	66	36	67	36	66	28	68	35	68	35	67.00	34.00	0.00	2.00
10	63	50	62	48	63	50	62	50	63	50	63	49	62.60	49.40	0.40	0.60
11	60	44	58	42	60	44	59	40	62	44	60	44	59.80	42.80	0.20	1.20
12	61	39	59	37	61	40	59	33	62	40	60	40	60.20	38.00	0.80	1.00
13	71	47	69	45	71	47	69	46	72	47	72	47	70.60	46.40	0.40	0.60
14	56	45	53	43	55	45	55	45	57	46	56	45	55.20	44.80	0.80	0.20
15	50	43	48	42	50	44	49	43	50	43	50	43	49.40	43.00	0.60	0.00
16	64	47	62	45	64	46	62	42	65	50	64	47	63.40	46.00	0.60	1.00
17	75	41	73	41	74	42	74	32	77	39	75	38	74.60	38.40	0.40	2.60
18	78	48	76	44	77	47	77	38	79	45	78	44	77.40	43.60	0.60	4.40
19	65	55	61	53	64	55	61	54	64	55	64	55	62.80	54.40	2.20	0.60
20	63	49	61	47	62	50	62	43	63	49	62	50	62.00	47.80	1.00	1.20
21	53	43	51	41	53	43	52	42	53	42	52	43	52.20	42.20	0.80	0.80
22	68	40	66	35	68	36	66	32	69	36	68	36	67.40	35.00	0.60	5.00
23	72	45	71	44	72	43	71	36	73	42	73	41	72.00	41.20	0.00	3.80
24	87	62	85	61	87	63	86	53	87	61	87	61	86.40	59.80	0.60	2.20
25	87	70	85	66	86	70	86	58	87	68	87	68	86.20	66.00	0.80	4.00
26	88	62	85	63	86	60	86	51	88	59	87	62	86.40	59.00	1.60	3.00
27	86	69	83	63	84	68	84	56	85	66	85	66	84.20	63.80	1.80	5.20
28	76	63	71	59	75	63	72	60	75	63	75	63	73.60	61.60	2.40	1.40
29	78	64	77	61	78	64	78	61	79	63	79	62	78.20	62.20	-0.20	1.80
30	78	64	77	62	77	64	76	60	77	64	78	63	77.00	62.60	1.00	1.40
													Average Difference		**0.65**	**2.21**
Avg KSDF	68.27	48.27	Avg WFO	66.33	45.97											
			Avg Diff	1.93	2.30											

	KSDF		WFO LOU		KLOU		CW3169		CW0238		DW1289					
July '09	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Avg High	Avg Low	Diff High	Diff Low
1	73	62	72	61	74	63	72	60	73	63	74	62	73.00	61.80	0.00	0.20
2	71	65	70	62	72	65	67	63	72	63	72	63	70.60	63.20	0.40	1.80
3	80	62	80	58	81	60	80	64	82	60	80	59	80.60	60.20	-0.60	1.80
4	73	66	71	63	73	65	73	59	73	65	73	65	72.60	63.40	0.40	2.60
5	74	65	71	64	74	65	73	65	74	66	74	65	73.20	65.00	0.80	0.00
6	84	62	83	61	85	59	84	58	86	61	84	60	84.40	59.80	-0.40	2.20
7	86	64	86	61	87	62	85	57	88	62	87	62	86.60	60.80	-0.60	3.20
8	86	66	83	64	85	66	84	60	88	66	87	66	85.40	64.40	0.60	1.60
9	87	70	86	64	88	70	86	65	89	67	88	67	87.40	66.60	-0.40	3.40
10	89	70	87	68	89	71	88	66	90	69	90	68	88.80	68.40	0.20	1.60
11	84	75	83	71	85	74	83	75	84	73	85	74	84.00	73.40	0.00	1.60
12	86	71	85	68	86	72	86	66	88	71	86	71	86.20	69.60	-0.20	1.40
13	85	67	84	62	85	65	83	60	87	63	86	63	85.00	62.60	0.00	4.40
14	85	64	84	63	86	65	85	58	86	64	86	63	85.40	62.60	-0.40	1.40
15	82	70	80	68	82	70	79	64	81	68	82	67	80.80	67.40	1.20	2.60
16	85	74	85	71	86	74	85	68	86	74	86	74	85.60	72.20	-0.60	1.80
17	78	65	79	65	80	66	77	60	79	65	78	66	78.60	64.40	-0.60	0.60
18	70	60	70	58	71	60	69	55	70	59	70	59	70.00	58.20	0.00	1.80
19	73	56	74	55	73	56	72	50	74	55	74	56	73.40	54.40	-0.40	1.60
20	80	58	80	57	79	58	79	52	80	57	80	56	79.60	56.00	0.40	2.00
21	81	60	82	58	82	58	68	67	82	59	82	58	79.20	60.00	1.80	0.00
22	73	65	70	63	73	66	70	63	72	65	72	65	71.40	64.40	1.60	0.60
23	81	67	82	66	82	67	80	63	81	67	82	67	81.40	66.00	-0.40	1.00
24	83	64	85	64	84	64	81	58	84	63	85	63	83.80	62.40	-0.80	1.60
25	84	66	84	65	85	66	83	65	83	66	84	66	83.80	65.60	0.20	0.40
26	84	68	84	66	85	65	84	62	85	66	85	66	84.60	65.00	-0.60	3.00
27	85	65	86	64	85	64	85	58	86	64	86	65	85.60	63.00	-0.60	2.00
28	82	68	79	66	82	68	80	61	81	66	82	66	80.80	65.40	1.20	2.60
29	82	68	82	68	82	68	81	68	82	69	81	68	81.60	68.20	0.40	-0.20
30	84	68	83	68	84	68	83	68	84	70	85	70	83.80	68.80	0.20	-0.80
31	83	68	84	67	83	68	82	67	84	68	84	68	83.40	67.60	-0.40	0.40
Avg KSDF	81.06	65.77	Avg WFO	80.45	63.84								Average Difference		0.08	1.55
			Avg Diff	0.61	1.94											

	KSDF		WFO LOU		KLOU		CW3169		CW0238		DW1289					
Oct '09	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Avg High	Avg Low	Diff High	Diff Low
1	68	49	68	47	66	45	67	39	68	59	68	45	67.40	47.00	0.60	2.00
2	69	58	69	54	68	57	68	46	70	52	69	52	68.80	52.20	0.20	5.80
3	66	53	66	51	65	52	65	45	67	54	65	54	65.60	51.20	0.40	1.80
4	64	48	63	45	63	48	63	43	64	47	64	47	63.40	46.00	0.60	2.00
5	71	47	71	44	70	44	70	38	73	45	71	43	71.00	42.80	0.00	4.20
6	66	53	66	53	66	54	66	46	66	52	66	50	66.00	51.00	0.00	2.00
7	65	48	66	48	65	49	65	43	67	48	65	48	65.60	47.20	-0.60	0.80
8	62	49	61	47	62	48	62	42	61	47	61	47	61.40	46.20	0.60	2.80
9	67	55	65	54	67	55	66	55	66	55	66	55	66.00	54.80	1.00	0.20
10	61	47	60	45	59	45	58	42	62	46	60	46	59.80	44.80	1.20	2.20
11	62	42	62	40	61	41	61	38	64	43	61	40	61.80	40.40	0.20	1.60
12	67	46	68	47	66	47	67	42	68	47	68	44	67.40	45.40	-0.40	0.60
13	62	53	60	51	61	52	59	51	60	53	60	53	60.00	52.00	2.00	1.00
14	53	44	51	42	53	44	52	43	54	44	53	44	52.60	43.40	0.40	0.60
15	51	46	50	45	51	46	50	46	51	47	51	46	50.60	46.00	0.40	0.00
16	47	43	46	43	47	44	46	43	47	44	46	43	46.40	43.40	0.60	-0.40
17	52	40	52	38	52	39	51	33	53	41	51	40	51.80	38.20	0.20	1.80
18	56	33	55	32	56	32	55	26	58	32	56	30	56.00	30.40	0.00	2.60
19	63	36	63	35	62	36	63	28	65	34	63	34	63.20	33.40	-0.20	2.60
20	70	43	71	42	69	43	70	34	71	42	70	42	70.20	40.60	-0.20	2.40
21	68	44	69	44	67	43	68	36	71	42	69	39	68.80	40.80	-0.80	3.20
22	69	50	69	49	69	48	70	42	70	48	70	46	69.60	46.60	-0.60	3.40
23	73	58	72	57	73	59	71	58	73	58	73	58	72.40	58.00	0.60	0.00
24	59	43	59	43	59	42	59	37	60	42	59	42	59.20	41.20	-0.20	1.80
25	64	38	63	38	63	38	64	31	65	37	66	35	64.20	35.80	-0.20	2.20
26	69	40	70	42	68	38	70	33	72	38	70	36	70.00	37.40	-1.00	2.60
27	55	47	54	46	56	46	55	40	55	46	55	45	55.00	44.60	0.00	2.40
28	60	54	59	53	59	54	59	53	60	54	60	54	59.40	53.60	0.60	0.40
29	68	47	68	48	69	47	69	41	70	49	69	44	69.00	45.80	-1.00	1.20
30	81	54	80	58	81	55	81	64	81	60	81	60	80.80	59.40	0.20	-5.40
31	54	42	58	40	55	41	53	43	60	47	60	46	57.20	43.40	-3.20	-1.40
Avg KSDF	63.29	46.77	Avg WFO	63.03	45.84								Average Difference		0.05	1.52
			Avg Diff	0.26	0.94											

	KSDF		WFO LOU		KLOU		CW3169		CW0238		DW1289					
Jan '10	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Avg High	Avg Low	Diff High	Diff Low
1	31	16	31	16	32	17	34	16			31	16	32.00	16.25	-1.00	-0.25
2	24	12	24	12	24	13	23	13			24	12	23.75	12.50	0.25	-0.50
3	25	7	25	7	25	8	24	7			24	6	24.50	7.00	0.50	0.00
4	26	16	26	16	26	18	26	18			26	15	26.00	16.75	0.00	-0.75
5	25	12	25	11	26	12	25	13			26	11	25.50	11.75	-0.50	0.25
6	24	16	24	16	24	18	18	12			24	16	22.50	15.50	1.50	0.50
7	29	11	28	11	28	11	28	10			28	11	28.00	10.75	1.00	0.25
8	19	11	17	10	19	11	18	10			18	10	18.00	10.25	1.00	0.75
9	24	16	23	15	24	17	24	17			24	16	23.75	16.25	0.25	-0.25
10	26	17	27	15	25	17	26	7			26	16	26.00	13.75	0.00	3.25
11	29	18	29	14	29	16	29	5			29	16	29.00	12.75	0.00	5.25
12	33	20	31	20	32	20	31	12			32	19	31.50	17.75	1.50	2.25
13	39	17	40	16	39	18	40	6			39	14	39.50	13.50	-0.50	3.50
14	51	23	50	22	51	22	50	12			51	20	50.50	19.00	0.50	4.00
15	51	41	53	39	51	41	52	34			52	40	52.00	38.50	-1.00	2.50
16	57	37	56	35	56	36	55	31			54	36	55.25	34.50	1.75	2.50
17	46	36	47	35	47	35	46	29			47	35	46.75	33.50	-0.75	2.50
18	37	30	39	29	38	30	39	28			36	30	38.00	29.25	-1.00	0.75
19	49	30	51	30	48	28	51	27			47	30	49.25	28.75	-0.25	1.25
20	40	37	41	36	41	37	40	37			40	37	40.50	36.75	-0.50	0.25
21	47	37	47	36	48	37	48	37			45	37	47.00	36.75	0.00	0.25
22	46	43	45	41	46	43	45	35			45	42	45.25	40.25	0.75	2.75
23	55	43	55	42	55	44	55	42			56	42	55.25	42.50	-0.25	0.50
24	54	45	53	46	54	46	53	46			55	44	53.75	45.50	0.25	-0.50
25	44	33	46	33	46	33	46	33			44	33	45.50	33.00	-1.50	0.00
26	35	23	35	23	35	23	35	22	36	24	35	23	35.20	23.00	-0.20	0.00
27	40	21	41	19	40	20	40	15	41	20	40	19	40.40	18.60	-0.40	2.40
28	41	20	41	19	40	20	40	20	40	21	40	20	40.20	20.00	0.80	0.00
29	23	17	22	16	23	17	22	17	24	18	22	17	22.60	17.00	0.40	0.00
30	31	17	30	15	32	17	30	4	32	16	32	15	31.20	13.40	-0.20	3.60
31	33	8	36	5	33	10	35	-4	36	8	33	7	34.60	5.20	-1.60	2.80
Avg KSDF	36.58	23.55	Avg WFO	36.71	22.58								**Average Difference**		**0.03**	**1.28**
			Avg Diff	-0.13	0.97											

	KSDF		WFO LOU		KLOU		CW3169		CW0238		DW1289					
Apr '10	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	Avg High	Avg Low	Diff High	Diff Low
1	84	55	83	56	83	59	82	41	84	57	83	55	83.00	53.60	1.00	1.40
2	85	59	84	55	84	54	83	42	85	54	85	56	84.20	52.20	0.80	6.80
3	71	53	71	50	70	52	70	44	72	53	71	50	70.80	49.80	0.20	3.20
4	79	46	79	44	78	44	78	36	80	42	79	40	78.80	41.20	0.20	4.80
5	85	63	85	64	84	61	83	51	85	62	85	62	84.40	60.00	0.60	3.00
6	87	68	85	66	86	68	85	68	86	68	86	66	85.60	67.20	1.40	0.80
7	78	61	75	60	77	61	77	66	77	62	76	60	76.40	61.80	1.60	-0.80
8	61	46	60	42	61	46	62	38	60	44	60	43	60.60	42.60	0.40	3.40
9	61	42	61	40	61	40	60	36	63	39	61	39	61.20	38.80	-0.20	3.20
10	71	39	70	38	70	37	70	30	74	37	72	35	71.20	35.40	-0.20	3.60
11	77	44	77	43	77	42	76	35	79	41	78	39	77.40	40.00	-0.40	4.00
12	79	50	78	48	78	47	77	40	80	48	79	46	78.40	45.80	0.60	4.20
13	83	52	82	50	82	49	81	42	85	49	84	47	82.80	47.40	0.20	4.60
14	84	55	83	52	83	52	83	45	86	52	85	50	84.00	50.20	0.00	4.80
15	86	59	85	57	85	55	84	47	86	54	85	52	85.00	53.00	1.00	6.00
16	83	59	82	58	83	56	80	47	84	58	82	57	82.20	55.20	0.80	3.80
17	65	47	64	44	65	45	62	44	67	48	65	47	64.60	45.60	0.40	1.40
18	63	39	63	37	64	37	62	33	66	37	63	35	63.60	35.80	-0.60	3.20
19	67	42	65	41	67	39	65	34	69	40	66	38	66.40	38.40	0.60	3.60
20	67	50	66	48	69	49	66	43	69	51	68	46	67.60	47.40	-0.60	2.60
21	72	45	72	45	72	44	71	36	73	43	72	40	72.00	41.60	0.00	3.40
22	74	49	74	48	74	47	73	39	75	47	75	48	74.20	45.80	-0.20	3.20
23	73	58	71	57	71	58	70	52	73	59	72	59	71.40	57.00	1.60	1.00
24	72	59	72	58	73	59	74	59	72	60	72	59	72.60	59.00	-0.60	0.00
25	70	56	68	55	70	56	69	55	69	56	68	53	68.80	55.00	1.20	1.00
26	56	53	55	52	56	51	56	50	57	52	57	52	56.20	51.40	-0.20	1.60
27	62	46	62	43	62	40	60	38	62	44	62	42	61.60	41.40	0.40	4.60
28	66	39	66	37	66	36	65	31	67	38	66	37	66.00	35.80	0.00	3.20
29	75	45	76	44	75	43	75	37	76	42	76	40	75.60	41.20	-0.60	3.80
30	83	60	83	60	83	61	82	54	83	56	83	56	82.80	57.40	0.20	2.60
Avg KSDF	73.97	51.30	Avg WFO	73.23	49.73								**Average Difference**		**0.32**	**3.07**
			Avg Diff	0.73	1.57											

July '10	KSDF High	KSDF Low	WFO LOU High	WFO LOU Low	KLOU High	KLOU Low	CW3169 High	CW3169 Low	CW0238 High	CW0238 Low	DW1289 High	DW1289 Low	Avg High	Avg Low	Diff High	Diff Low
1	83	63	79	60	81	60	76	56	82	64	81	64	79.80	60.80	3.20	2.20
2	86	64	82	59	84	61	81	50	84	59	84	57	83.00	57.20	3.00	6.80
3	92	66	92	59	91	60	91	56	90	59	92	58	91.20	58.40	0.80	7.60
4	93	76	92	71	92	74	90	65	91	73	92	74	91.40	71.40	1.60	4.60
5	94	74	93	71	92	73	91	66	92	70	93	71	92.20	70.20	1.80	3.80
6	96	72	95	73	94	69	93	62	93	67	95	67	94.00	67.60	2.00	4.40
7	97	75	95	69	96	69	94	64	96	70	96	69	95.40	68.20	1.60	6.80
8	96	77	95	73	94	75	92	68	94	73	95	73	94.00	72.40	2.00	4.60
9	87	75	84	73	85	75	82	72			85	74	84.00	73.50	3.00	1.50
10	90	73	87	70	88	72	87	66			89	70	87.75	69.50	2.25	3.50
11	93	72	91	69	90	70	89	66			91	69	90.25	68.50	2.75	3.50
12	88	74	86	72	87	74	85	69			86	72	86.00	71.75	2.00	2.25
13	88	70	85	67	86	69	83	69			86	68	85.00	68.25	3.00	1.75
14	94	73	93	69	92	71	91	66			92	70	92.00	69.00	2.00	4.00
15	96	76	93	72	94	72	92	68			95	72	93.50	71.00	2.50	5.00
16	95	77	92	73	93	77	92	73			94	73	92.75	74.00	2.25	3.00
17	93	74	91	68	91	73	89	69			91	72	90.50	70.50	2.50	3.50
18	91	76	89	72	89	75	88	73			88	75	88.50	73.75	2.50	2.25
19	93	73	92	70	92	72	91	70			92	72	91.75	71.00	1.25	2.00
20	91	72	89	69	90	71	89	69			90	70	89.50	69.75	1.50	2.25
21	90	75	88	72	89	74	87	73			88	76	88.00	73.75	2.00	1.25
22	94	76	91	73	92	75	91	72			92	74	91.50	73.50	2.50	2.50
23	96	81	93	76	95	78	93	74			95	78	94.00	76.50	2.00	4.50
24	96	80	96	73	95	79	94	71			96	77	95.25	75.00	0.75	5.00
25	94	82	93	75	94	80	92	74			93	80	93.00	77.25	1.00	4.75
26	90	78	87	73	88	76	86	71			89	75	87.50	73.75	2.50	4.25
27	92	78	91	74	89	77	91	71			92	75	90.75	74.25	1.25	3.75
28	93	78	91	73	92	75	87	71			92	75	90.50	73.50	2.50	4.50
29	93	76	91	73	91	75	90	72			92	76	91.00	74.00	2.00	2.00
30	87	67	83	65	84	66	82	60			85	65	83.50	64.00	3.50	3.00
31	89	66	83	63	87	65	82	64			89	65	85.25	64.25	3.75	1.75
Avg KSDF	91.94	73.84	Avg WFO	89.74	69.97								**Average Difference**		**2.17**	**3.63**
			Avg Diff	2.19	3.87											

Oct '10	KSDF High	KSDF Low	WFO LOU High	WFO LOU Low	KLOU High	KLOU Low	CW3169 High	CW3169 Low	CW0238 High	CW0238 Low	DW1289 High	DW1289 Low	Avg High	Avg Low	Diff High	Diff Low
1	76	54	74	50	75	50	74	44			75	52	74.50	49.00	1.50	5.00
2	77	47	72	44	74	44	73	35			73	43	73.00	41.50	4.00	5.50
3	63	48	60	42	61	49	50	47			61	44	58.00	45.50	5.00	2.50
4	65	46	61	41	61	45	57	40			62	39	60.25	41.25	4.75	4.75
5	70	44	68	42	68	39	67	32			69	40	68.00	38.25	2.00	5.75
6	78	46	76	41	76	40	75	30			76	41	75.75	38.00	2.25	8.00
7	84	58	81	52	82	52	80	41			83	56	81.50	50.25	2.50	7.75
8	87	51	84	48	84	44	83	36			86	44	84.25	43.00	2.75	8.00
9	89	50	87	47	87	45	87	36			88	44	87.25	43.00	1.75	7.00
10	91	52	89	50	88	49	88	40			89	47	88.50	46.50	2.50	5.50
11	90	55	87	55	88	53	84	43			88	50	86.75	50.25	3.25	4.75
12	83	62	79	58	81	58	80	50			82	60	80.50	56.50	2.50	5.50
13	79	59	76	54	77	54	76	49			77	55	76.50	53.00	2.50	6.00
14	70	49	68	46	68	46	67	40			68	46	67.75	44.50	2.25	4.50
15	71	53	70	48	70	47	68	39			69	48	69.25	45.50	1.75	7.50
16	74	44	73	40	72	39	72	32			73	39	72.50	37.50	1.50	6.50
17	85	48	84	48	83	46	83	36			83	47	83.25	44.25	1.75	3.75
18	83	55	82	52	81	52	81	44			82	50	81.50	49.50	1.50	5.50
19	69	53	68	50	67	49	67	41			67	48	67.25	47.00	1.75	6.00
20	73	45	71	41	71	42	71	33			71	39	71.00	38.75	2.00	6.25
21	71	50	70	44	69	44	67	36			69	43	68.75	41.75	2.25	8.25
22	71	40	70	36	70	38	70	26			70	34	70.00	33.50	1.00	6.50
23	81	50	82	64	78	46	79	38			79	44	79.50	48.00	1.50	2.00
24	82	64	81	62	81	60	81	50			81	54	81.00	56.50	1.00	7.50
25	77	63	75	61	74	62	74	60			75	61	74.50	61.00	2.50	2.00
26	80	51	77	49	79	51	79	51			78	51	78.25	50.50	1.75	0.50
27	78	50	77	48	76	46	76	37			77	50	76.50	45.25	1.50	4.75
28	68	47	65	45	67	47	67	46			69	46	67.00	46.00	1.00	1.00
29	59	36	56	35	56	37	56	29			57	35	56.25	34.00	2.75	2.00
30	70	35	69	33	68	33	68	24			68	29	68.25	29.75	1.75	5.25
31	67	45	65	41	65	40	64	32			65	41	64.75	38.50	2.25	6.50
Avg KSDF	76.16	50.00	Avg WFO	74.10	47.32								**Average Difference**		**2.23**	**5.23**
			Avg Diff	2.06	2.68											

Analysis

As stated before, this research does not seek to prove that KSDF's observations are skewed by the urban heat island since that is already well-documented, but rather seeks to quantify the degree by which this happens. With that said, the fact that KSDF's low temperatures are warmer than surrounding stations to a much higher degree than high temperatures verifies that the data collected represents the situation well. Since the concrete, asphalt, and other low albedo surfaces near the airport collect solar radiation during the day and release this as longwave terrestrial radiation at night, it makes sense that overnight lows would be more affected. Areas in other parts of the city with higher amounts of grass, trees, and other high albedo surfaces would therefore experience cooler overnight lows due to less longwave radiation being emitted from these surfaces. This is not to say that longwave radiation stops during the daytime, but its effects are amplified because incoming solar radiation is not warming up the ground as the longwave radiation is being released.

The fact KSDF is warmer than the old official observation site at the National Weather Service office in Louisville by nearly the same degree as the five stations average also drives another interesting point. If temperatures within the city outside of the maximum Urban Heat Island area had great variance, not only would the individual data points not compare with one another, but the five-station average compared to NWS Louisville by itself would also have quite a bit of variance. KSDF's high and low temperatures being warmer than both NWS Louisville and the five-station average within one half of a degree further proves that KSDF is simply too far off from the rest of the city to accurately represent the official measurements for Louisville.

It is unclear why April, July, and October of 2010 each have a much higher temperature difference between the airport and the five-station average compared to the other months contained in this research. Missing data from CW0238 may have played a part in this, but it seems unlikely given that a lack of data from this station in January 2010 and January 2009 did not cause a similar spike in temperature difference. It's possible the localized weather phenomena at CW3169 (mentioned below) or equipment calibration issues may have caused this, but it's not very easy to pick either of these out given the coarseness of the data used in this research.

Phenomena that may have affected these measurements, and thus the results of this study include frontal passages, topography, and summertime convection. Cold fronts moving through the city could have affected high and low temperature records for all stations because the timing at which these fronts move through can cause one side of the city to be cooler than the other for a period of time, which may include times of peak heating or cooling. Topography also plays a huge role in data quality because Louisville ranges from being nearly flat along the Ohio River to having some fairly high hills on the southeast side.

One station in particular CW3169 seems to be affected by these hills on the southeast side of town because overnight lows are markedly cooler than the rest of the city while high temperatures seem to be more in line. This is likely because of cold air settling during the overnight hours into the valley where this station is located according to CWOP analysis of this station's data: "It appears that your station is sited in a location where cool air collects at night. This is often near the bottom of a valley. The cool nighttime readings are probably correct, and the analysis values are not taking into account the local topography." (Gladstone 2012) This station likely caused a bit of the half degree difference between NWS Louisville and the five-station average's low temperature comparison with KSDF.

Finally, spotty summertime convection can cause rapid cooling at a location while missing other locations within the city completely. This

means that some stations may have dramatically cooler high temperatures than the other stations in the city if a summertime thunderstorm moves over the station during the peak heating of the day. While these altering factors are very real and may well have affected the outcome of this research, averaging these stations together takes the edge off of these effects. While it may be possible to calculate some sort of small degree range that these effects may have on the final numbers, the coarseness of the data in this research and its overall goal of obtaining a rough estimate precludes doing this.

Conclusion

Given the data obtained in this study it seems that the official high and low temperature measurements for the city of Louisville, Kentucky at KSDF are warmer than the rest of the city by somewhere close to two and a half degrees for lows and near three fourths of a degree for highs. These numbers show a significant difference, one that most recognize just by comparing the official measurements at the airport (KSDF) to what they have in their own backyard. The urban heat island skews KSDF's temperatures to the point where they are "out of touch" with the rest of the city.

Many may argue that the city's official measurements should be taken in an area of town closer to the city center where the urban heat island is greater simply because this is where the traditional "city" is. This is a feasible argument, but the problem here is that the definition of "Louisville" extends to the borders of Jefferson County. Since most of the land area inside of the city limits does not experience the level of warmer temperatures from the urban heat island that the airport and downtown does, it is therefore unfair to say that this small portion of land area represents the city as a whole. A solution to this may be to have two official observation sites for the city of Louisville, one within this Urban Heat Island area and one outside. This could be as simple as having NWS Louisville come back online as an official observation station for the city since they still take observations that are readily available. It may be very difficult to somehow split climate records between two stations in the same city since one record has always been kept, but for the most objective records this may need to happen.

Future studies that may seek to find a more precise estimate of how warm KSDF is compared to the rest of the city will definitely want to use higher spatial and temporal resolution data than what this study used. As more personal weather stations come online and continue to archive their data, higher-resolution data will be easier to obtain. As stated before, some stations within the city had to be excluded in this research because they were simply too new and didn't have archived data that fell within the limits required for analysis. Future studies may also want to further examine how topography and terrain affect these observed numbers and possibly adjust for those effects.

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