Trends in Fog Frequency and Duration in the Southeast United States

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Introduction

Dense fog is a frequently occurring phenomenon across the southeast United States. The National Weather Service (NWS) designates horizontal visibility of one-quarter statute mile or less as dense fog. The objective of this research is to compile fog data to analyze the frequency and duration of dense fog events across the Southeast for each station's period of record. Seasonal and annual fog day events are examined to determine if the frequency of fog events is changing with time and if the duration of fog events is also changing. In this study, 26 stations from Alabama, Georgia, Florida, North Carolina, South Carolina, and Virginia were used to discern any trends in dense fog events across the southeast United States.

Name	State	Lat (dd)	Long (dd)	Elev (ft)	WBAN	ICAO	Begin Year	End Year	# of Missing Years
BIRMINGHAM INTL AP	AL	33.57	-86.75	615	13876	BHM	1948	2003	13
HUNTSVILLE INTL AP	AL	34.64	-86.79	631	03856	HSV	1959	2003	15
MOBILE REGIONAL AP	AL	30.69	-88.25	215	13894	MOB	1948	2003	15
MONTGOMERY DANNELLY FLD	AL	32.30	-86.41	202	13895	MGM	1948	2003	5
DAYTONA BEACH INTL AP	FL	29.18	-81.05	31	12834	DAB	1948	2003	17
JACKSONVILLE INTL AP	FL	30.50	-81.69	26	13889	JAX	1948	2003	9
MIAMI INTL AP	FL	25.79	-80.32	29	12839	MIA	1948	2003	5
TALLAHASSEE WSO AP	FL	30.39	-84.35	55	93805	TLH	1948	2003	12
TAMPA WSCMO AP	FL	27.96	-82.54	40	12842	TPA	1948	2003	6
WEST PALM BEACH INT AP	FL	26.68	-80.10	19	12844	PBI	1948	2003	16
ATLANTA HARTSFIELD INTL AP	GA	33.63	-84.44	974	13874	ATL	1948	2003	1
AUGUSTA BUSH FIELD AP	GA	33.37	-81.96	148	03820	AGS	1949	2003	12
MACON MIDDLE GA REGIONAL AP	GA	32.68	-83.65	343	03813	MCN	1949	2003	9
SAVANNAH INTL AP	GA	32.13	-81.21	52	03822	SAV	1951	2003	13
ASHEVILLE WSO AP	NC	35.44	-82.54	2161	03812	AVL	1948	2003	8
CHARLOTTE DOUGLAS AP	NC	35.22	-80.95	728	13881	CLT	1948	2003	8
GREENSBORO WSO AP	NC	36.10	-79.94	908	13723	GSO	1949	2003	5
RALEIGH DURHAM WSFO AP	NC	35.87	-78.79	415	13722	RDU	1949	2003	6
BEAUFORT MCAS	SC	32.48	-80.72	33	93831	NBC	1959	2003	9
CHARLESTON WSO AP	SC	32.90	-80.04	47	13880	CHS	1945	2003	8
COLUMBIA WSFO AP	SC	33.95	-81.12	245	13883	CAE	1948	2003	8
NORFOLK INTL AP	VA	36.90	-76.19	30	13737	ORF	1948	2003	5
RICHMOND WSO AP	VA	37.51	-77.32	178	13740	RIC	1948	2003	11
ROANOKE WSO AP	VA	37.32	-79.97	1175	13741	ROA	1948	2003	12
WASHINGTON DULLES INTL AP	VA	38.94	-77.48	309	93738	IAD	1963	2003	7
WASHINGTON REAGAN AP	VA	38.85	-77.03	75	13743	DCA	1942	2003	6

Table 1. General information about stations utilized.

Data and Methodology

Horizontal visibility was obtained from the Hourly Surface Airways (TD3280) dataset for the period of record at each station (for the majority of stations this was 1948-2003). For data to be included there must have been >=50% of the year available for yearly fog event days, >= 2 months available per season, >=12 hours available per day, and a fog event could not begin or end with a missing value for inclusion in the fog duration analysis. All data that contained missing values were pro-rated accordingly. Stations that were missing 1/3 or more of the total number of years were excluded. Since the TD3280 stations changed to 3-hourly readings for a period of 1-15 years, mostly in the 1960's and 1970's, those years were excluded to avoid underestimation of fog event days. Also excluded were years with a pattern of reporting that reflected the hours when an airport was operating.

Simple linear regressions were performed on annual data, seasonal data, and fog duration data. Seasons were grouped as winter (DJF), spring (MAM), summer (JJA), and autumn (SON). Fog duration frequency was divided into three categories: short duration (1-2 hours), medium duration (3-5 hours), and long duration (>= 6 hours).

The spatial distribution of the 26 stations can be seen in Figure 1. The stations, their WBAN ID, ICAO ID, elevation, begin and end year, and number of missing years are found in Table 1.

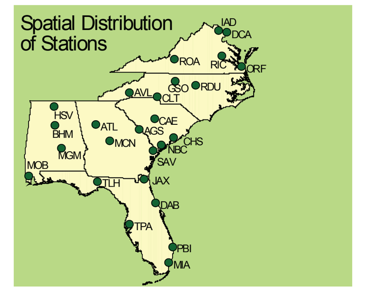

Figure 1. Spatial distribution of stations.

Annual Results

The linear regression analysis performed on the annual fog event day totals revealed 14 stations with statistically significant trends (p-values <=0.05) (Table 2). The majority (12) had decreasing trends while two stations, Augusta, GA and Jacksonville, FL, had increasing trends in fog event days. Spatially, all Virginia stations, one North Carolina station, two South Carolina stations, one Georgia station, four Florida stations, and one Alabama station indicated significant trends in fog event days (Figure 2). The R-Squared values ranged from 0.11 (NC) to 0.47 (VA). Beaufort, SC, Washington Dulles Airport, and Roanoke, VA displayed the largest decreasing trends and Augusta, GA exhibited the largest increasing trend. Figure 3 shows the scatter plots and regression lines of the stations with significant trends, along with the regression line equations and p-values.

Two stations, Columbia, SC and Asheville, NC, appeared to be special cases where for the period of record, there was no significant trend in annual fog event days; however, there was a significant trend in the data after 1973 (Figure 4). In fact, these stations had large decreasing trends with R-Squared values of 0.20 and 0.44, respectively. The reason for this phenomena will need to be further explored.

Station	State	R-Squared	Slope	p-Value
BIRMINGHAM INTL AP	AL	0.11	-0.06	0.03
HUNTSVILLE INTL AP	AL	0.04	0.09	0.31
MOBILE REGIONAL AP	AL	0.03	-0.07	0.25
MONTGOMERY DANNELLY FLD	AL	0.01	0.03	0.55
DAYTONA BEACH INTL AP	FL	0.29	-0.24	0.00
JACKSONVILLE INTL AP	FL	0.12	0.15	0.02
MIAMI INTL AP	FL	0.22	-0.09	0.00
TALLAHASSEE WSO AP	FL	0.00	0.01	0.92
TAMPA WSCMO AP	FL	0.30	-0.20	0.00
WEST PALM BEACH INTL AP	FL	0.09	-0.04	0.07
ATLANTA HARTSFIELD INTL AP	GA	0.02	-0.06	0.29
AUGUSTA BUSH FIELD AP	GA	0.26	0.30	0.00
MACON MIDDLE GA REGIONAL AP	GA	0.07	0.12	0.09
SAVANNAH INTL AP	GA	0.06	-0.10	0.13
ASHEVILLE WSO AP	NC	0.01	-0.10	0.42
CHARLOTTE DOUGLAS AP	NC	0.11	-0.14	0.02
GREENSBORO WSO AP	NC	0.02	-0.08	0.30
RALEIGH DURHAM WSFO AP	NC	0.05	-0.10	0.13
BEAUFORT MCAS	SC	0.31	-0.32	0.00
CHARLESTON WSO AP	SC	0.22	-0.19	0.00
COLUMBIA WSFO AP	SC	0.04	-0.09	0.19
NORFOLK INTL AP	VA	0.38	-0.27	0.00
RICHMOND WSO AP	VA	0.24	-0.19	0.00
ROANOKE WSO AP	VA	0.47	-0.37	0.00
WASHINGTON DULLES INTL AP	VA	0.36	-0.46	0.00
WASHINGTON REAGAN AP	VA	0.44	-0.18	0.00

Table 2. Linear regression of annual fog event days.

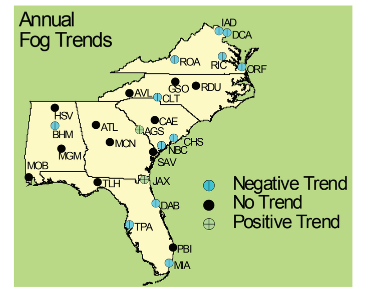

Figure 2. Spatial distribution of annual trends.

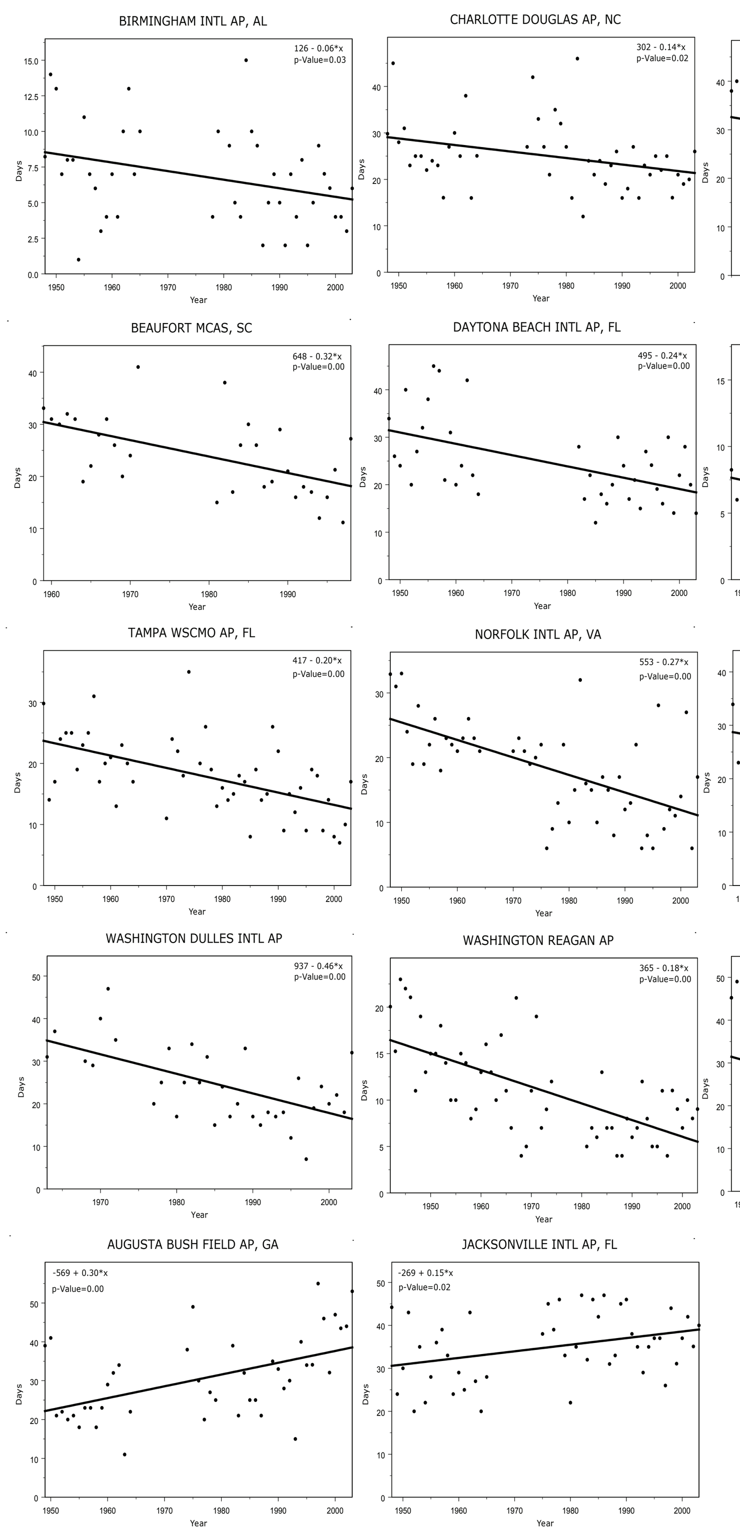

Figure 3. Regression graphs for stations with a significant trend in annual fog event days.

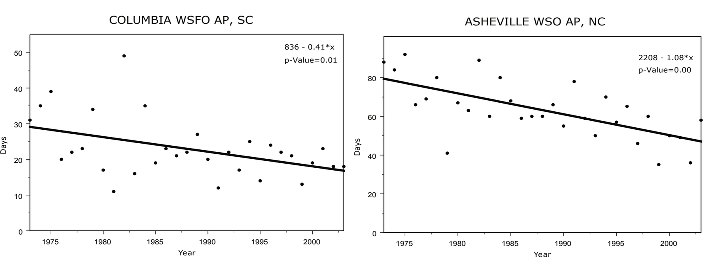

Figure 4. Regression graphs for stations exhibiting a significant trend in annual fog event days after 1973.

Seasonal Results

The seasonal distribution of fog event days across the Southeast revealed 37% of fog days occurred in winter, 26% in autumn, 21% in spring, and 16% in summer. Figure 5 shows the breakdown of percentage of fog day events for each station according to season.

Nine stations showed a significant trend in one season, nine stations had a significant trend in two seasons, four stations showed significant trends in three seasons, and one station, Roanoke, VA showed significant trends in all four seasons. Only two stations, Tallahassee, FL and Atlanta, GA, did not show any significant trend in any season.

Assessing trends for the winter (DFJ) season produced nine stations having winter as their largest season of fog event days, with significant negative trends, R-Squared values ranging from 0.10 to 0.36, and slowly decreasing slopes (Table 3). Virginia had the most stations with a trend (Figure 6). Spring, (MAM), when the majority of stations had much lower fog event days, produced 10 stations with significant trends, four with positive trends and six with negative trends (Figure 7). R-Squared values for these stations were from 0.10 to 0.47. Summer (JJA), usually the season with the least number of fog event days, had 13 stations with significant trends, three positive and 10 negative (Figure 8). The range of R-Squared values was 0.09 to 0.37. Half the stations exhibited significant trends in autumn (SON) with 10 stations having negative trends and three stations having positive trends (Figure 9). R-Square values ranged from 0.1 to 0.39. In fact, autumn had the highest R-Squared values of any season. Savannah, GA had a large upward trend with a slope of 1.6. Graphs of the significant seasonal regression for the 14 stations with significant annual trends are shown in Figure 10.

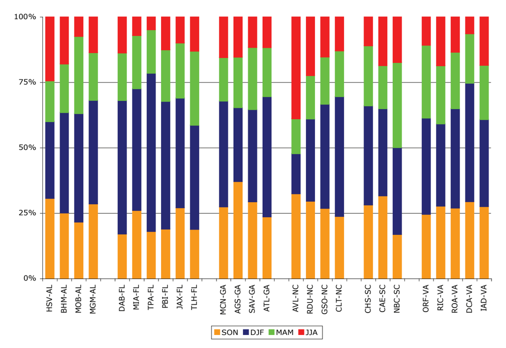

Figure 5. Seasonal contribution of total fog event days for each station's period of record.

Station	State	Winter R-Squared	Winter Slope	Winter p-Value	Spring R-Squared	Spring Slope	Spring p-Value	Summer R-Squared	Summer Slope	Summer p-Value	Autumn R-Squared	Autumn Slope	Autumn p-Value
BIRMINGHAM INTL AP	AL	0.10	-0.02	0.04	0.03	0.01	0.28	0.05	-0.01	0.16	0.22	-0.04	0.00
HUNTSVILLE INTL AP	AL	0.02	0.04	0.43	0.31	0.06	0.00	0.07	0.04	0.17	0.02	-0.03	0.40
MOBILE REGIONAL AP	AL	0.13	-0.11	0.02	0.00	0.00	0.97	0.03	0.02	0.29	0.00	0.00	0.86
MONTGOMERY DANNELLY FLD	AL	0.03	-0.04	0.21	0.14	0.05	0.01	0.23	0.06	0.00	0.00	0.00	0.92
DAYTONA BEACH INTL AP	FL	0.09	-0.10	0.05	0.15	-0.06	0.01	0.06	-0.04	0.12	0.08	-0.03	0.08
JACKSONVILLE INTL AP	FL	0.03	0.05	0.26	0.01	0.02	0.58	0.14	0.04	0.01	0.04	0.03	0.16
MIAMI INTL AP	FL	0.13	-0.04	0.01	0.26	-0.04	0.00	0.02	0.01	0.35	0.02	-0.01	0.37
TALLAHASSEE WSO AP	FL	0.02	-0.05	0.36	0.00	0.01	0.63	0.05	0.04	0.11	0.03	0.03	0.20
TAMPA WSCMO AP	FL	0.22	-0.15	0.00	0.19	-0.06	0.00	0.04	0.01	0.15	0.03	-0.02	0.24
WEST PALM BEACH INTL AP	FL	0.02	-0.01	0.35	0.12	-0.02	0.03	0.08	0.01	0.09	0.02	-0.01	0.38
ATLANTA HARTSFIELD INTL AP	GA	0.05	-0.07	0.10	0.01	0.02	0.42	0.01	-0.02	0.40	0.00	-0.01	0.79
AUGUSTA BUSH FIELD AP	GA	0.07	0.07	0.09	0.31	0.12	0.00	0.00	0.00	0.95	0.39	0.22	0.00
MACON MIDDLE GA REGIONAL AP	GA	0.01	0.03	0.59	0.10	0.05	0.04	0.10	0.06	0.04	0.10	0.06	0.04
SAVANNAH INTL AP	GA	0.00	-0.02	0.70	0.00	-0.01	0.80	0.05	-0.02	0.16	0.21	1.60	0.00
ASHEVILLE WSO AP	NC	0.02	0.03	0.35	0.00	0.00	0.89	0.22	-0.22	0.00	0.00	0.00	0.98
CHARLOTTE DOUGLAS AP	NC	0.01	-0.03	0.44	0.01	-0.01	0.42	0.03	-0.03	0.20	0.12	-0.06	0.01
GREENSBORO WSO AP	NC	0.01	-0.04	0.40	0.40	0.00	0.93	0.12	-0.06	0.01	0.03	-0.04	0.19
RALEIGH DURHAM WSFO AP	NC	0.00	-0.01	0.75	0.01	-0.02	0.51	0.04	-0.04	0.15	0.11	-0.07	0.02
BEAUFORT MCAS	SC	0.12	-0.08	0.05	0.47	-0.20	0.00	0.37	-0.12	0.00	0.04	-0.04	0.28
CHARLESTON WSO AP	SC	0.00	-0.01	0.85	0.05	-0.03	0.13	0.20	-0.05	0.00	0.24	-0.09	0.00
COLUMBIA WSFO AP	SC	0.01	-0.02	0.55	0.01	0.02	0.41	0.09	-0.04	0.04	0.12	-0.06	0.02
NORFOLK INTL AP	VA	0.11	-0.07	0.02	0.00	0.00	0.85	0.34	-0.08	0.00	0.30	-0.11	0.00
RICHMOND WSO AP	VA	0.03	-0.03	0.22	0.01	-0.01	0.56	0.16	-0.07	0.01	0.39	-0.09	0.00
ROANOKE WSO AP	VA	0.36	-0.15	0.00	0.23	-0.07	0.00	0.25	-0.05	0.00	0.18	-0.10	0.00
WASHINGTON DULLES INTL AP	VA	0.15	-0.16	0.02	0.00	0.01	0.83	0.27	-0.12	0.00	0.21	-0.11	0.01
WASHINGTON REAGAN AP	VA	0.17	-0.07	0.00	0.01	-0.01	0.40	0.13	-0.02	0.01	0.25	-0.06	0.00

Table 3. Linear regression of seasonal fog event days.

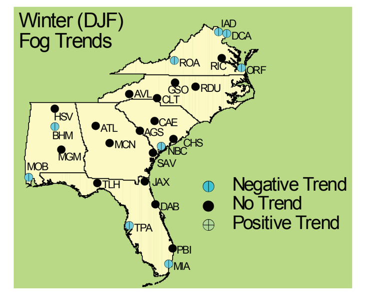

Figure 6. Spatial distribution of winter (DJF) trends.

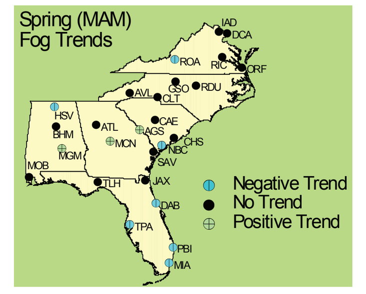

Figure 7. Spatial distribution of spring (MAM) trends.

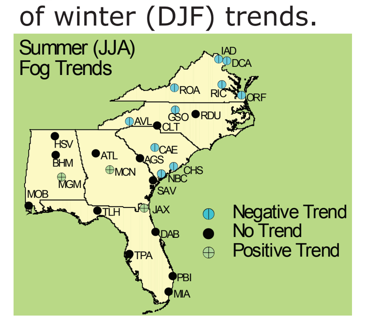

Figure 8. Spatial distribution of summer (JJA) trends.

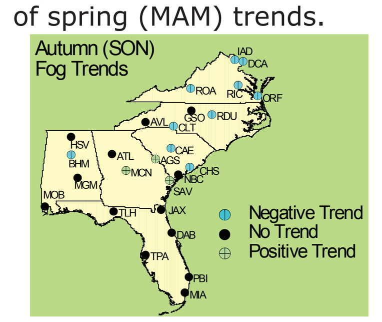

Figure 9. Spatial distribution of autumn (SON) trends.

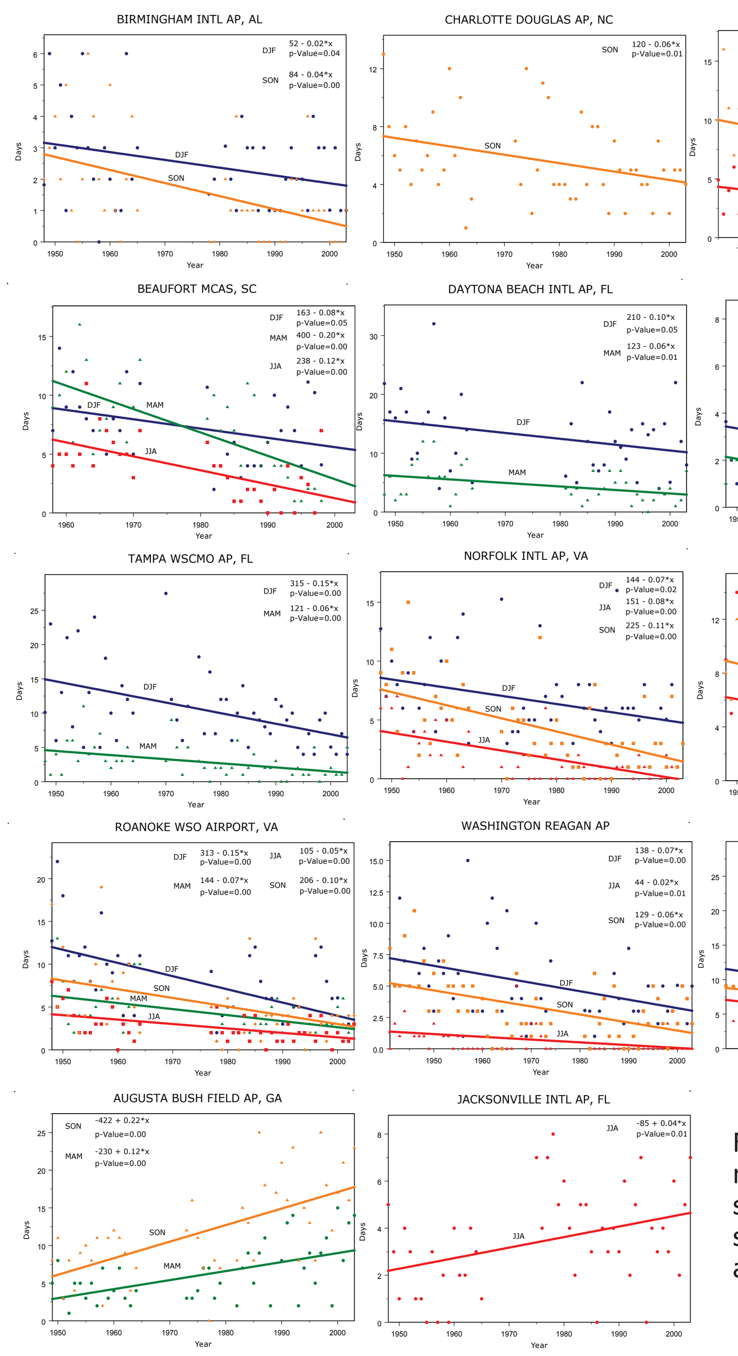

Figure 10. Seasonal regression graphs for stations with a significant trend in annual fog event days.

Duration Results

Fog of short duration (1-2 hours) was the only category that showed any positive trends (Table 4). Fifteen stations had significant trends and five of those showed an increase in the number of short-term events (Figure 11). Alabama was the only state that had no significant trends for short-term events. R-Squared values ranged from 0.08 to 0.43. Medium duration fog events (3-5 hours) all showed decreasing trends in the 11 stations that had significant trends (Figure 12). All five Virginia stations had decreasing trends with R-Squared values averaging 0.33. Negative trends were the rule for fog events of long duration (>=6 hours). The nine stations (Figure 13) that had a significant trend had R-Squared values from 0.08 to 0.46.

Four stations experienced decreases in duration for all three categories and one station had an increasing trend for short duration and decreasing for the other two categories (Figure 14). For all categories, Augusta, GA had the largest positive trend (occurring in the short duration category) and Washington Dulles Airport had the largest negative trend (also in the short duration category) (Figure 15).

Station	State	Short Duration R-Squared	Short Slope	Short p-Value	Medium Duration R-Squared	Medium Slope	Medium p-Value	Long Duration R-Squared	Long Slope	Long p-Value
BIRMINGHAM INTL AP	AL	0.07	-0.04	0.09	0.05	-0.02	0.16	0.11	-0.01	0.03
HUNTSVILLE INTL AP	AL	0.08	0.12	0.12	0.00	0.01	0.77	0.05	-0.02	0.23
MOBILE REGIONAL AP	AL	0.00	-0.02	0.68	0.03	-0.04	0.31	0.11	-0.05	0.03
MONTGOMERY DANNELLY FLD	AL	0.00	-0.01	0.85	0.02	0.02	0.32	0.01	0.01	0.51
DAYTONA BEACH INTL AP	FL	0.25	-0.19	0.00	0.18	-0.08	0.01	0.01	-0.01	0.61
JACKSONVILLE INTL AP	FL	0.09	0.10	0.04	0.01	0.03	0.43	0.08	0.05	0.05
MIAMI INTL AP	FL	0.21	-0.08	0.00	0.06	-0.02	0.09	0.00	0.00	0.64
TALLAHASSEE WSO AP	FL	0.13	0.20	0.02	0.00	0.01	0.89	0.21	-0.11	0.00
TAMPA WSCMO AP	FL	0.16	-0.14	0.00	0.24	-0.08	0.00	0.05	-0.02	0.11
WEST PALM BEACH INTL AP	FL	0.08	-0.04	0.08	0.09	-0.02	0.06	0.04	-0.01	0.25
ATLANTA HARTSFIELD INTL AP	GA	0.08	-0.11	0.04	0.01	-0.02	0.00	0.00	0.01	0.79
AUGUSTA BUSH FIELD AP	GA	0.43	0.45	0.00	0.00	-0.01	0.87	0.00	0.01	0.76
MACON MIDDLE GA REGIONAL AP	GA	0.22	0.24	0.00	0.04	0.04	0.21	0.08	-0.04	0.07
SAVANNAH INTL AP	GA	0.02	-0.05	0.39	0.00	0.00	0.99	0.17	-0.06	0.01
ASHEVILLE WSO AP	NC	0.12	0.22	0.02	0.11	-0.13	0.02	0.16	-0.10	0.57
CHARLOTTE DOUGLAS AP	NC	0.05	-0.07	0.11	0.13	-0.07	0.01	0.00	-0.01	0.71
GREENSBORO WSO AP	NC	0.07	-0.11	0.06	0.01	-0.03	0.44	0.00	0.00	0.99
RALEIGH DURHAM WSFO AP	NC	0.06	-0.09	0.09	0.04	-0.05	0.17	0.07	0.04	0.06
BEAUFORT MCAS	SC	0.22	-0.23	0.01	0.07	-0.06	0.14	0.18	-0.07	0.02
CHARLESTON WSO AP	SC	0.21	-0.16	0.00	0.09	-0.07	0.03	0.00	-0.01	0.66
COLUMBIA WSFO AP	SC	0.02	-0.04	0.37	0.02	-0.03	0.37	0.01	-0.01	0.51
NORFOLK INTL AP	VA	0.26	-0.19	0.00	0.32	-0.11	0.00	0.08	-0.03	0.04
RICHMOND WSO AP	VA	0.06	-0.07	0.10	0.32	-0.11	0.00	0.05	-0.03	0.12
ROANOKE WSO AP	VA	0.37	-0.23	0.00	0.40	-0.14	0.00	0.46	-0.07	0.00
WASHINGTON DULLES INTL AP	VA	0.19	-0.28	0.01	0.31	-0.19	0.00	0.21	-0.08	0.01
WASHINGTON REAGAN AP	VA	0.16	-0.11	0.00	0.31	-0.06	0.00	0.20	-0.03	0.00

Table 4. Linear regression of fog duration.

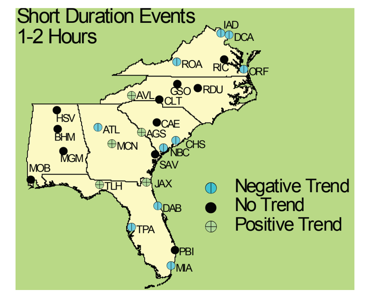

Figure 11. Spatial distribution of short duration trends.

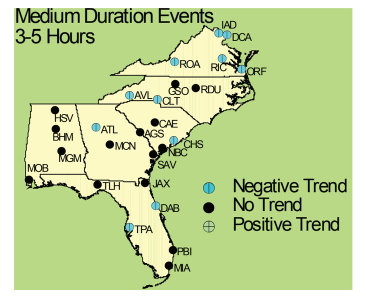

Figure 12. Spatial distribution of medium duration trends.

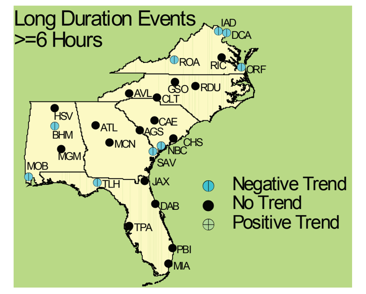

Figure 13. Spatial distribution of long duration trends.

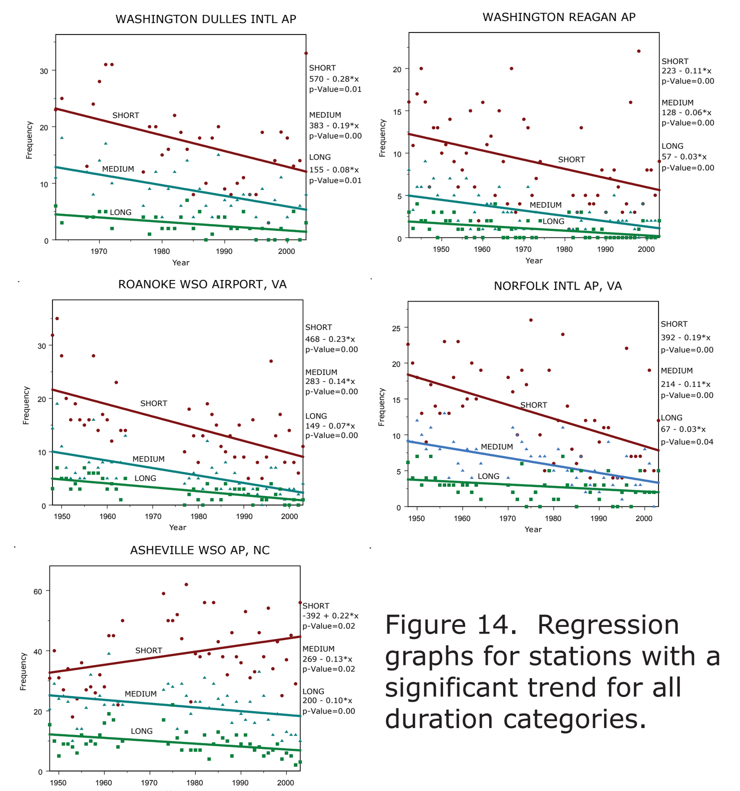

Figure 14. Regression graphs for stations with a significant trend for all duration categories.

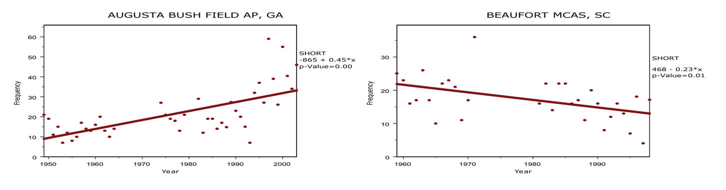

Figure 15. Regression graphs for stations with large trends for duration.

Conclusions and Future Work

Twenty-six stations across the Southeast were evaluated for trends in the number of fog event days, annually and seasonally, and the fog duration for period of record at each station. Studies in Germany (Sachweh and Koepke 1995), London (Brazell 1964), and Shanghai (Djen 1992) have shown a decrease in dense fog events in urban areas. With the exception of Augusta, GA and Jacksonville, FL, the results of this study concur with the results of those studies. The reason(s) for these decreases (or increases) is unclear at this time and future work will include determining if a particular season, or seasons, is the driving force behind annual trends, what factors might be causing seasonal changes, and if there are any relationships between ENSO and fog event days.

References:

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