5th International Conference on Fog, Fog Collection and Dew
Münster, Germany, 25–30 July 2010
FOGDEW2010-115

The Continued Reduction in Dense Fog in the Southern California Region: Possible Climate Change Influences

S.Ladochy (1), M.Witiw (2)
(1) California State University, Los Angeles, California 90032 USA (sladoch@calstatela.edu/ Fax: +01-323-343-6494
(2) Embry-Riddle aeronautical University Worldwide, Everett, Washington, USA (witiw170@erau.edu / Fax: +01-425-898-1456)

Abstract

Dense fog appears to be decreasing in many parts of the world, especially in cities. An earlier study showed that dense fog (visibility < 400 m) was disappearing in the urban southern California area as well. It showed that the decrease in dense fog events could be explained mainly by declining particulate levels, Pacific SSTs, and increased urban warming. Dense fog is most prevalent along the coast and decreases rapidly inland. Using hourly data from 1948 to the present, we looked at the relationship between fog events and contributing factors in the region and trends over time. The relationship between the occurence of dense fog to the phase of two atmosphere–ocean cycles: the Pacific Decadal Oscillation (PDO) and the Southern Oscillation In addition, the influence of the urban heat island and the amount of suspended particulate matter were assessed. Results show a decrease in the occurrence of very low visibilities (<400 m) at the stations in close proximity to the Pacific Ocean. Occurrence of the frequency of low visibilities at these two locations was highly correlated with the phase of the PDO. A downward trend in particulate concentrations coupled with an upward trend in urban temperatures were associated with a decrease in dense fog occurrence at both LAX and LGB. While examining data from LAX, we saw a frequency of dense fog that reached over 300 hours in 1950, but occurrence was down to zero in 1997. Since 1997, there has been a bit of a recovery with both 2008 and 2009 recording over 30 hours of dense fog each. In the present study, we examine the relationships that control the frequency of dense fog (visibility < 400 m) in coastal southern California. To remove urban influence, we also included Vandenberg Air Force Base, located in a relatively sparsely populated area. While particulates, urban heat island and Pacific SSTs are all contributing factors, we now speculate on the direct and indirect influences of climate change on continued decreases in dense fog. Case studies of local and regional dense fog in southern California point to the importance of strong, low inversions and to a lesser contributor, Santa Ana winds. Both are associated with large-scale atmospheric circulation patterns, which have changed markedly over the period of study.

1. INTRODUCTION

The coast of California is well known as a foggy place. During the warm season, the semi-permanent Pacific high pressure remains off the California coast. The clockwise circulation around this high results in the California Current and upwelling of cold water close to the coast. Although the upwelling is strongest farther north, where summer water temperatures usually remain around 11 °C to 12 °C, temperatures remain relatively cold at latitudes well to the south including the Los Angeles area. Moist, relatively warm air moving over the cold water is chilled to its dew point, resulting in the formation of sea fog. This sea fog typically rises as it moves inland forming a low stratus deck. The density and horizontal coverage of fog and low clouds is negatively correlated with the sea surface temperature (Norris and Leovy, 1994). Usually, only the immediate coastal regions experience dense fog conditions. Even there, because of the generally large fog droplet size (resulting from the large condensation nuclei available over the ocean) very low visual ranges are rare. The main type of fog in the cool season is advection-radiation fog (Byers, 1959). Typically fog-free marine air moves inland, and frequently after the wind changes direction to an offshore component, advection-radiation fog forms. Because of the smaller fog nuclei available, this type of fog tends to produce lower visibility than advection fog (sea fog) (Leipper, 1994). October through February are characterized by a relatively high frequency of low visibility (<400 m) at both coastal Los Angeles (LAX) and Long Beach (LGB) International Airports (Baars et al., 2002). This is also the season of lower inversion heights which are necessary for dense fog formation (LaDochy and Behrens, 1991).

In the present study, we examine the relationships that control the frequency of dense fog in coastal southern California. While particulates, urban heat island and local SSTs are all contributing factors, we now speculate on the direct and indirect influences of global warming on continued decreases in dense fog. Case studies of local and regional dense fog in southern California point to the importance of strong, low inversions and to a lesser contributor, Santa Ana winds. Both features are controlled by large-scale atmospheric circulation patterns.

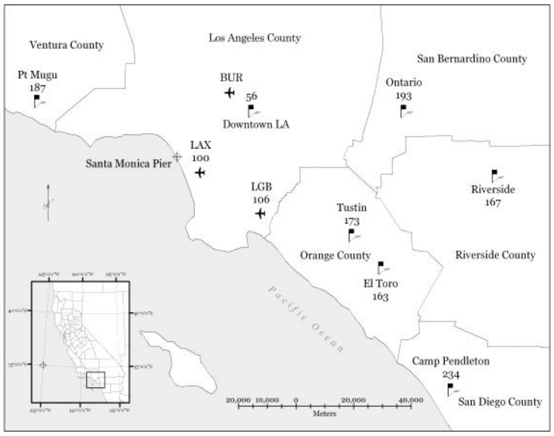

Fig. 1. Study area-Los Angeles Basin with average annual days with fog (visibility < 1km).

2. DATA AND METHODOLOGY

Visibility and significant weather is recorded hourly at the three airport stations in the coastal plains of the Los Angeles Basin, LAX, LGB and BUR (Burbank International Airport). Dense fog is recorded when visibility is less than ¼ mile (<400 m). Hourly visibility were recorded for both LAX and LGB from 1948-2009 from the National Climate Data Center, NCDC. From the mid-1960s through June 1999, downtown Los Angeles had automatic weather observations without visibility observations, resulting in visibility data being available only for the complete years 1961-1964 and 2000-2004. Burbank Airport had hourly data from 1982 through 2004, with missing data for the first half of 1998. Monthly mean, max and min temperatures for LAX and downtown Los Angeles were also obtained from NCDC for the period of the study. Monthly and annual particulate air pollution data was recorded as total suspended particulates (TSP) from 1966 to 2008 from the South Coast Air Quality Management District (SCAQMD). Monthly Pacific climatic indices, Pacific Decadal Oscillation (PDO) and Southern Oscillation Index (SOI) were downloaded from Mantua (2010) website and NOAA (2010) website, respectively, for the 1948-2009 period.

Simple linear regressions and Pearson correlations were calculated between annual totals of hourly and daily dense fog occurrences at LAX and LGB and contributing variables- annual PDO and SOI values, downtown Los Angeles annual TSP amounts, mean monthly and annual temperatures at LAX and downtown Los Angeles, and annual sea surface temperatures (SST) at Santa Monica Pier. Fog frequencies at LAX and LGB were also examined for trends. For comparisons, fog frequencies were also examined for BUR and downtown Los Angeles. As expected, dense fog frequencies were higher at locations near the ocean (Fig. 1).

3. RESULTS

Table 1 shows the average annual number of hours visibility was less than 400 m at various Los Angeles Basin locations over the study period, 1948-2008. Data for downtown Los Angeles (CBD) were only available for the two periods noted, although the station has been moved since 1999. Data for Burbank were not available for the first part of 1998 and therefore 1998 were omitted.

Table 1. Average annual hours visibility < 400m (excludes 1998 for BUR)

LAX 1948-2008	74
LGB 1948-2008	109
LAX 1982-2008	27
LGB 1982-2008	39
BUR 1982-2008	7
CBD 1961-1964	10
CBD 2000-2004	3

There has been a significant decrease in dense fog hours at all locations studied in the Los Angeles Basin. Most notable are the two coastal airports, LAX and LGB (Figs. 2 and 3). Dense fog disappeared completely in 1997 at both stations, but rebounded somewhat in more recent years.

3.1 Air-sea interactions and their influence on fog Frequencies

Previous studies found that coastal sea surface temperatures and Pacific climatic indices, such as The El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) influence southern California weather and climate, including dense fog frequencies. While ENSO, as quantified by the Southern Oscillation Index (SOI), was only weakly correlated to dense fog, annual PDO values explained over 34% of the variance seen in the amount of dense fog (p<.001) at LAX and 18% of the variance at LGB (p<.05) (Witiw and LaDochy, 2008). The fact that the study period overlaps with mostly 1 cycle of the PDO from 1948 to 1997 is not trivial, although more cycles would make the analyses more rigorous. As noted by Mantua (2010), the PDO shifted from a cool phase to a warm phase at about 1977. During cool phases of PDO there are more numerous La Niña episodes and less El Niños, while the opposite occurs during the warm phase. Dense fog frequencies decrease during El Niño events (LaDochy 2005) and disappeared during the 1997-98 major El Niño event. In the same study, annual sea surface temperatures recorded along the coastline at Santa Monica Pier were found to be highly significant at explaining LAX dense fog frequencies (p<.001) and at LGB (p<.001) for the years 1950-2001.

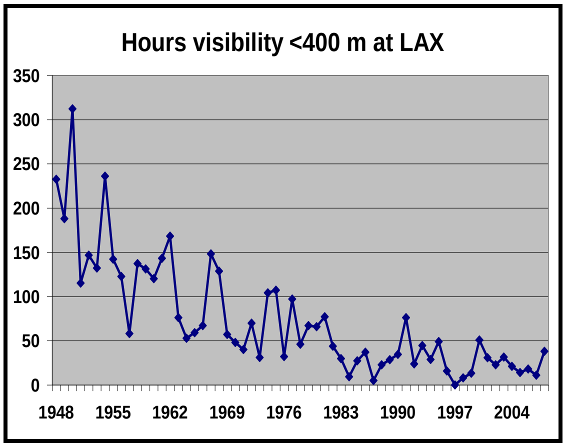

Fig. 2. Dense fog trend at Los Angeles Int. Airport, 1948-2008.

3.2 Particulate air pollution influence

Annual TSP data for downtown Los Angeles was available from 1966 to 2008 (SCAQMD 2009). The trend indicates a significant decrease throughout the period (p<.001), dropping to less than half the values of the 1960s by the end of the century. The last decade, 1999-2008, was the cleanest of the record. Witiw and LaDochy (2008) found TSP to be highly significant in explaining hours of dense fog variability with R2 =.343 for LAX and .319 for LGB. As TSP levels continue to fall, there are less condensation nuclei available for fog droplet formation. Using multiple regression analyses, the authors showed that the combined effect of TSP and PDO index increased the variance in fog hours explained to 36% at LAX and 33% at LGB for the years 1966-2004.

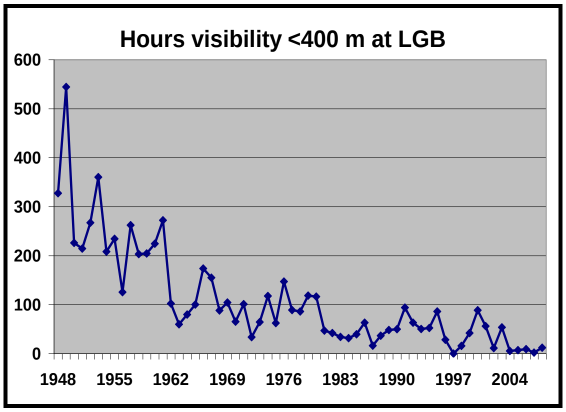

Fig. 3. Dense fog trends at Long Beach International Airport, 1948-2008.

3.3 Urban heat island influence

The temperature trend for downtown Los Angeles shows marked warming over the study period, moreso for Tmin than Tmax. Comparing downtown temperatures with annual days of dense fog, LaDochy (2005) found correlations between annual average temperatures and dense fog highly significant. As temperatures increased, dense fog frequencies decreased. PDO values and coastal SSTs also correlated highly with Los Angeles temperatures, while all three variables correlated inversely with TSP.

In order to test whether factors besides urban heating and particulates are influencing decreasing fog, we are also looking at dense fog frequencies at Vandenberg Air Force Base, approximately 130 miles (210 km) northwest of downtown Los Angeles near the central California coast. While Vandenberg is far from urban influences, it has a different fog regime, with most fog coming in the summer months, while the Los Angeles area shows a winter maximum. Preliminary data show some slight decreasing tendencies. This may, however, be an artifact of how visibilities are calculated using automated sensors versus humans and should be examined more thoroughly. Data were incomplete from the mid-1970s to the mid 1990s when automated observing began.

4. DISCUSSION

In this study we continue to explore the relationships between atmospheric and oceanic variables and the trend in decreasing Los Angeles area's dense fog frequencies. While urban warming and decreasing pollution are definite contributors, there are also influences coming from the Pacific. PDO values, which may be shifting back into the cool (negative) phase, may nudge fog frequencies higher in the coming years. However, other large-scale influences, particularly global warming, may lead to the opposite, a continuation of decreases.

Dense fog is associated with strong, low inversions over coastal California (Leipper, 1994). Recent trends show that inversion strength has decreased over the last few decades (1960-2007) and that inversion frequencies vary partly in association with SSTs along the California coast (Iacobellis et al., 2009). This would explain one of the mechanisms linking rising SSTs with decreasing dense fog.

Hughes et al., (2009) found that Santa Ana events declined over 30% over the period 1959-2001. They believe that differential warming, that is more rapid warming inland than over the ocean, would make conditions less favorable for these offshore wind events. Santa Ana events are often followed by dense fog, such as on Feb. 7, 2007, when several stations in southern California recorded visibility at 0.0 miles. This followed a strong Santa Ana event.

Several trends in climatic variables, many driven by climate change, point to decreasing dense fog frequencies in the Los Angeles region. If the same trend is occurring along the entire west coast, this may become another important positive feedback in enhancing global warming.

5. REFERENCES

[1] Baars, J.A., Witiw, M.R., Al-Habash, A., Ramaprasad, J.: Determining fog type in the Los Angeles basin using historic surface observation data. Proceedings of the 16th Conf. on Probability and Statistics in the Atmospheric Sciences, Orlando, FL, American Meteorological Society, Boston, pp. J104-107, 2002.

[2]Byers, H.R., General Meteorology, 3rd ed. McGraw-Hill, New York, 1959.

[3]Hughes, M., Hall, A., Kim, J.: Anthropogenic Reduction of Santa Ana Winds. CEC Publication # CEC-500-2009-015f. Available at: http://www.energy.ca.gov/2009publications/CEC-500-2009-015-F.PDF, 2009.

[4]Iacobellis, S.F., Norris, J.R., Kanamitsu, M., Tyree, M., Cayan, D.C.: Climate Variability and California Low Level Temperature Inversions. CEC Publication # CEC-500-2009-020-F. Available at: http://www.energy.ca.gov/2009publications/CEC-500-2009-020-f.pdf, 2009.

[5]LaDochy, S.: The disappearance of dense fog in Los Angeles: Another urban impact? *Physical Geography* 26, 177-191, 2005.

[6]LaDochy, S., Behrens, D.: Particulate air pollution patterns over metropolitan Los Angles. In Majumdar, S.K., Miller, E.W., Cahir, J.C. (Eds.), Air Pollution: Environmental issues and health effects. Pennsylvania Academy of Sciences, pp. 444-459, 1991.

[7]Leipper, D.F.: Fog on the U.S. west coast: a review. Bull. Amer. Meteorol. Soc. 75, 1794-1796, 1994.

[8]Mantua, N.J.: PDO homepage. Available at: http://www.atmos.washington.edu/mantua/pdo.html, 2010

[9]NOAA:. ENSO homepage. Available at: http://www.enso.noaa.gov, 2010.

[10]Norris, J.R., Leovey, C.B., 1994. Interannual variability in stratiform cloudiness and sea surface temperatures. *J. Climate* 7, 1915-1925, 1994.

[11]SCAQMD: Air Quality Annual Summary, 1979-2008. Southern California Air Quality Management District, Diamond Bar, California, 1980-2007.

[12]Witiw, M.R., LaDochy, S., 2008. Trends in fog frequencies in the Los Angeles Basin. Atmospheric Research 87, 293-300, 2008.