

# Analyzing 50 Years of Major Fog Events Across the Central Coastal Plain of Israel

DAVID N.<sup>1</sup>, RAYITSFELD A.<sup>2</sup>, GAO H.O.<sup>3,\*</sup>

<sup>1</sup> AtmosCell, Tel Aviv, Israel ([www.atmoscell.com](http://www.atmoscell.com))

<sup>2</sup> The Israeli Meteorological Service (IMS), Beit-Dagan, 5025001, Israel

<sup>3</sup> The School of Civil and Environmental Engineering, Cornell University, Ithaca, NY, 14853, United States

\*corresponding author: H. Oliver Gao

e-mail: [hg55@cornell.edu](mailto:hg55@cornell.edu)

**Abstract.** This work presents an analysis of 152 major fog events that have been occurring for five decades (1967-2017) across the central coastal plain of Israel. Analysis of the meteorological data shows that fog events in the experimental area predominantly occur under two sets of synoptic conditions – Red Sea Trough (44%) and Ridge (41%), while the incidence of fog events peaks between March and June. In particular, the results obtained indicate a decreasing trend in the number of fog events and their duration over time where the frequency of radiation fog has decreased over time when compared to the incidence of advection fog. Further investigation is required in order to determine the reasons for the decreasing fog trends observed. However, possible drivers include climate change and the urban heat island effect. The paper provides a long-term analysis of data in a region that lacks reliable time series of this length, and highlight important insights for future research.

**Keywords:** fog trends, visibility, advection, radiation

## 1. Introduction

Fog is defined as a state where water droplets suspended in the air near the Earth's surface reduce visibility below 1 km (David et al., 2013). Categorizing broadly, fog can be classified as either radiation fog or advection fog, based on the physical processes that cause it to develop (Ziv and Yair, 1994). The first is caused as the result of radiative cooling of the surface, and the optimal conditions for its creation including a clear night, allowing for efficient radiative cooling, light wind (less than 4-5 knots), stability, and humid air. Advection fog is caused by relatively warm air being cooled to saturation as a result of it being carried by a light wind over a cold surface. The optimal conditions for its creation include a 5-10 knot wind and atmospheric stability. At times, a combination of both of these processes can cause the creation of fog, for example in cases where the surface is not cold enough to cause the condensing of droplets in the air traveling over it alone, but where the addition of radiative cooling can lead to the completion of the process.

Tools for monitoring fog include a variety of ground level sensors, human observers and satellite systems. However, due to technical and practical constraints, reliable

monitoring of the phenomenon, over a wide geographic area, is still currently a challenge (David, 2015). Efforts are being made to develop techniques for monitoring fog using alternative and complimentary solutions (e.g. David et al., 2015; David and Gao, 2018).

As has been extensively reviewed by Klemm and Lin (2015), the frequency and intensity of fog events vary greatly over time. Broadly, the majority of research reports, from different locations across the world, indicate a major decrease in the frequency of fog formation, and its intensity. In most of the measuring stations where observations were carried out (e.g. Chen et al., 2006; Vautard et al., 2009; LaDochy and Witiw 2012; Williams et al., 2015). In some cases an increase was observed (e.g. Syed et al., 2012). Trends in fog frequency and intensity can be a result of changes in regional climatic conditions. The Urban Heat Island (UHI) effect, or changes in predominant circulation patterns, can lead to increasing air temperatures and a resulting decrease in Relative Humidity (RH). As long as there are no feedback mechanisms overriding the temperature effect, this may alter fog trends. Changes in the number of Cloud Condensation Nuclei (CCN) is also a potential cause for fog trends (Klemm and Lin, 2015).

In this study, we present an analysis of fog measurements taken over 5 decades (1967 – 2017) in Israel's central coastal region. Based on analysis of this data, we report a meaningful decrease in the frequency of fog creation and their duration. Additionally, we point out the key synoptic conditions that comprise the mechanism for the creation of fog in the area and analyze some of the characteristics of the phenomenon.

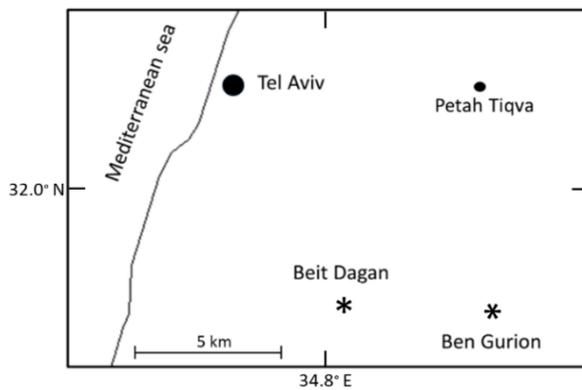
## 2. Classification for advection and radiation fog

In order to distinguish between the two types of fog we examined the vertical structure of the temperature and the dew point in the lower tropospheric levels up to 850 mb. The classification process was performed on the basis of the radiosonde measurements, launched from Beit Dagan station every night between 23:00 to 00:00 UTC (Figure 1). Depending on the two different profile types, two types of fog were observed.

*Radiation fog* was typically characterized by a deep temperature inversion which extended from the surface level up to a pressure level of about 950 mb (~500m above sea level). Simultaneously, the dew point was increasing with the increasing temperature, conditions that created a stable moist layer. This, while winds on the lower two levels were measured to be less than 4 knots (i.e. at ground level and at a height of 1000 millibars). The fog was classified as *advection fog* when measured wind speed was higher than 4 knots (an up to 10 knots) during a low marine inversion and / or a weak ground inversion.

### 3. Results

We studied 152 fog major events which took place between March 1967 to March 2017 across the test site located in the central coastal plain of Israel. Figure 1 shows the experiment site where meteorological measurements and visibility estimates, acquired by professional human observers, were taken from Beit Dagan surface station. Additional visibility estimates were taken by observers located at Ben Gurion airport.



**Figure 1.** The experiment site situated in the central coastal plain of Israel. The asterisks mark the locations of the surface stations, in the vicinity of the city of Tel Aviv.

Fog events were determined according to the Israeli Meteorological Service (IMS) database - based on visibility data, relative humidity, wind velocity, radiosonde records and synoptic conditions. The measurements that were available for the entire period were stored in SYNOP code, and accordingly, are available at a sampling frequency of once every three hours. The set of radiosonde measurements analyzed was gathered from nightly releases from the Beit Dagan station. We also note that events documented in the database at only one specific hour were considered as events of 1 hour duration in the calculations. The analysis of the results focused on fog events that we defined as 'significant', that is, events that were observed by both stations in the same time frame. Thus, an event was defined as a fog event when visibility was estimated by the professional observers at Beit Dagan and Ben Gurion Airport to be less than 1 km simultaneously, or, at times where visibility was estimated to be less than 1 km at one station, under the condition that fog was also detected at the other station within a 6 hour time interval from when it was detected at the first station.

Figure 2 presents general details regarding the fog events that took place across the experiment site between 1967 and 2017, and particularly, the frequency of fog creation given a certain synoptic condition (Fig. 2a), the total

number of fog events occurring per month (Fig. 2b) and the distribution of average visibility estimates at each station (Fig. 2c). It can be seen, then, that most of the fog events in the experiment area occur under conditions of Red Sea Trough (44%) and Ridge (41%), where the incidence of events in the area peaking between March and June. In the major percentage of fog events (observed by both stations, as defined here) a average visibility is lower than 600 meters.

Figure 3 shows the total number of radiation fog events (Fig. 3a), advection fog (Fig. 3b) and the distribution of the total number of events combined divided into three equal periods (Fig. 3c). From analysis of the data we found that 64% of the fog events analyzed had radiation fog characteristics, while 36% had characteristics of advection fog. We note, in the overall view, that while the incidence of radiation fog has decreased over time, the incidence of advection fog has increased when compared to the first third of the experiment period. In particular, the total number of fog events decreased measurably over time.

We focus, then, on this aspect. Figure 4 shows the trend of fog creation frequency and duration. The linear fit approximations of the fog event records are listed at the top right of each panel. It can be seen that the total number of events per year has generally decreased over time (Fig. 4a) and that the total number of hours where fog existed per year has decreased as well (Fig. 4b). Figure 4c, which was constructed from Figure 4b and 4a shows the average duration of a single fog event. The linear fit calculated, indicates a more or less constant (an overall very small decreasing trend) in the average duration of each single event.

### 4. Summary and conclusions

In this paper 5 decades of fog data from Israel's central coastal plain was analyzed. The measurements indicate a decrease in the incidence of fog creation and a decrease in the frequency of radiation fog when compared to advection fog events. The decreasing fog trends detected here are in line with fog trends that have been widely observed across different parts of the world (e.g. Chen et al., (2006); Vautard et al., (2009)). An in-depth investigation of the possible reasons for the decreasing fog trends in the experimental area is beyond the scope of this work, and is left for future research. However, we shall indicate possible mechanisms that may have a role in creating the trends we report here.

It has been shown that a temperature increase (and a decrease of the aerosol concentrations) can lead to increased visual range, i.e. a decrease of fog (Klemm and Lin, 2015). More specifically to the experimental area discussed here, recent research conducted on extreme temperature (and precipitation) indices in Israel between 1950 and 2017 – a period that covers the entire period of research of this work – found that temperatures (specifically, the daily minimum / maximum temperatures) are trending upwards (Yosef et al., 2019). Due to the relationship between the increase in temperature and the increase in visibility range, it is reasonable to assume that the decrease in fog is driven by climate change (Klemm and Lin, 2015). That being said, we note that this is a

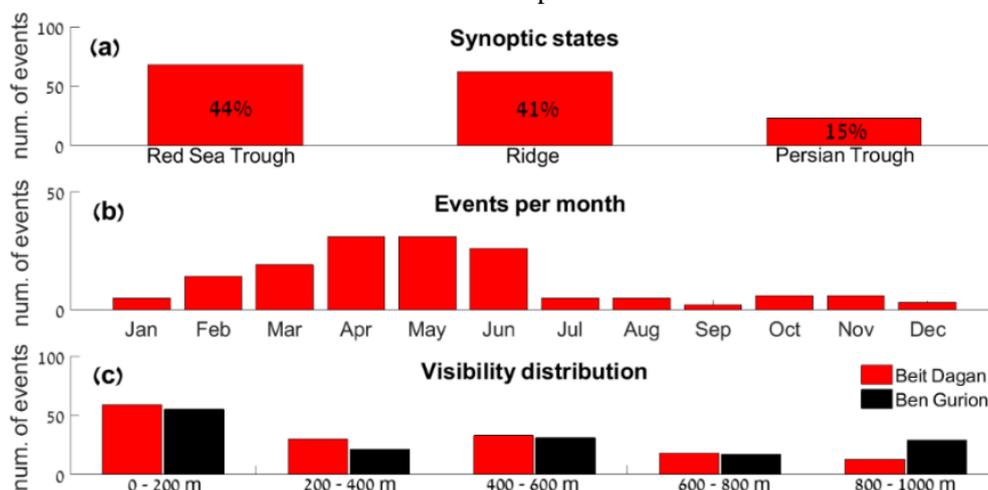
general statement, and downscaling it to the specific case reviewed here is non-trivial, and requires future research.

We also note that over the years since the experiments beginning and until the writing of this paper, major changes have occurred in the area studied, as shown in Figure 5. The specific location where the measuring station is situated (a sand lot) has not changed meaningfully over the years, however the changes in land surfaces in the area are clearly apparent. In particular, vegetation gave way to concrete and asphalt roads, buildings, and other structures – all surfaces that absorb, rather than reflect, solar energy. As a result, surface temperatures, as well as overall ambient temperatures have risen. Thus, the urbanization process in the area, i.e. the UHI effect is also a probable cause for the temperature increase (Rotem-Mindali et al., 2015), and the meaningful reduction in the creation of fog, as a result. Notably, if urbanization, as was observed in the experimental area (Fig. 5), is associated with increased air pollution, then fog formation can be enhanced (Klemm and Lin, 2015). As comprehensive air pollution measurements for the entire experiment period were not available to us, and since this aspect was beyond the scope of this study, it was not investigated. A recent research has shown, though, that when urbanization and aerosol-pollution act together, the inhibiting effect of urbanization on fog dominates the much weaker aerosol-promoting effect (Yan et al., 2020).

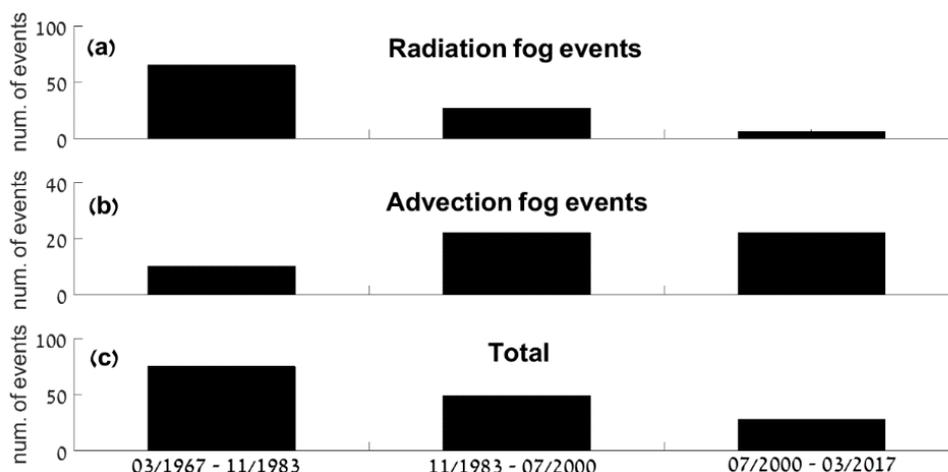
We note that the literature data as reviewed (e.g. Klemm and Lin, 2015) indicates that, overall, as urbanization increases, decreases in fog occur more frequently than increases, as was also the case here.

Naturally, there are uncertainty factors in carrying out the observations. Thus, for example, for the database we used, the measurements were stored at 3-hour intervals. It is possible, then, that relatively shorter fog events might have occurred in between these sample times, and therefore were not tallied in this research. Additionally, the instruments measuring the different parameters were updated over time. It is possible that the location of the instruments was changed slightly. Also, different human observers carried out the visibility observations, which may have affected the objectivity of the estimates, etc.

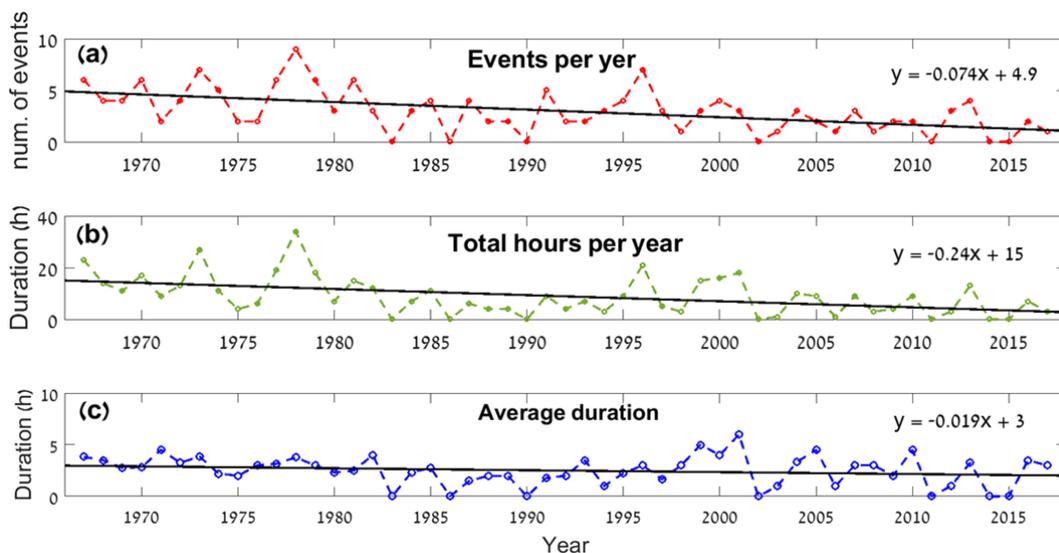
We note that between 2017 and the time of writing this paper, a number of significant fog events occurred in the experimental area. Future studies will need to examine whether the fog trends reported here continue to exist. The results of this work can form the basis for further research that could be conducted on fog life cycles in the area, further studying its evolution over time and more. Achieving better insight into the different mechanisms of fog formation, maintenance, and dissipation may lead to better forecasting capabilities, and, as a result, better capacity to contend with the dangers associated with this phenomenon.



**Figure 2.** Analysis of fog events between 1967 and 2017. (a) Frequency during different synoptic conditions. (b) Total major fog events per month. (c) Distribution of average visibility estimates.



**Figure 3.** Radiation and Advection fog. Number of radiation fog events (a), number of advection fog events (b), and total number of fog events (c), divided into 3 equal periods.



**Figure 4.** Incidence and duration of fog per year for the experimental area. Number of meaningful fog events per year (a), total number of fog event hours in every year (b), average duration of fog event per year (c).



**Figure 5.** The experiment area, early 60's (a) vs 2017 (b) (Credit: IMS).

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