Atmospheric Research 151 (2015) 200–211

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

A climatological study of fog in Japan based on event data

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ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form 2 April 2014
Accepted 3 April 2014
Available online 13 April 2014

Keywords:
Fog climatology
Atmospheric visibility
Fog type
Climate change
Japan

ABSTRACT

A climatological study is carried out to understand the characteristics of fog in Japan. This study uniquely focuses on fog density and fog type using atmospheric visibility data from surface observations. The main results are summarized below, within the following three contexts: 1) the characteristics of fog and dense fog, 2) fog type, and 3) long-term change in the number of foggy days.

1) Most of the foggy and densely foggy regions in Japan are inland mountainous areas, basin areas, and the Pacific coast of eastern and northern Japan. Fog density varies seasonally. Although the warmer seasons have the highest frequency of fog occurrence in Japan, the density of fog tends to be higher in the colder seasons. Land cover also affects the density of fog. In the urban area, fog rarely forms, with dense mist sometimes forming.
2) The most common type of fog in Japan is radiation fog, which accounts for half of all fog events. The dominant fog types of the inland areas, the Pacific coast, and the western part of Japan are radiation fog, advection fog and rain fog, respectively.
3) The numbers of foggy days decrease at many of the observation sites during a 40-year period from 1966 to 2005. Inland and basin sites showed the largest decrease. Urban areas were once affected by fogs, but now experience mist instead. In contrast, most coastal sites showed no clear trend of decrease and some sites even showed an increase in the numbers of foggy days.

1. Introduction

An improved scientific understanding of the formation and effects of fog is important due to the close connection of fog with human life and industry. Fog often increases the risk of traffic accidents by limiting atmospheric visibility, and its effect on meteorological conditions has significant impacts on industries such as agriculture, fisheries and forestry. Many studies have been carried out into fog worldwide (e.g. Lewis et al., 2004; Gultepe et al., 2007; Niu et al., 2010).

One of the main approaches to fog studies is climatological research in a specific region to better understand and forecast fog in that region. The most common methodology is to analyze the mean annual or monthly number of foggy days over a country or a region (e.g. Peace, 1969; Hardwick, 1973; Yoshino, 1975; Ladochy, 2005). Recently, fog events have been identified from changes in the observed atmospheric visibility and have been used in a new climatological index of fog frequency (e.g. Meyer and Lala, 1990; Tardif and Rasmussen, 2007; Haeffelin et al., 2010). Tardif and Rasmussen (2007) identified fog events from atmospheric visibility data in the City of New York and categorized each event using a simple classification algorithm based on the trigger mechanisms for fog formation. Haeffelin et al. (2010) also classified fog events in Paris using the algorithm suggested by Tardif and Rasmussen (2007).

Specifically focusing on fog phenomena in Japan, the north Pacific region, including Japan, has been reported to have one of the world's highest frequencies of sea fog, due to the meeting of cold and warm currents in this area (U.S.

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http://dx.doi.org/10.1016/j.atmosres.2014.04.003
0169-8095/

Department of Agriculture, 1938). As a result of this, fog also often appears on the Pacific coast in the northern part of Japan. Several observations and numerical modeling studies of the sea fog in this region have been carried out (e.g. Uyeda and Yagi, 1984; Kodama et al., 2009). Studies on the physics of sea fog in Japan were initiated by Hori (1953). More recently, the vertical and horizontal structures of sea fogs have been revealed by observations made by millimeter-wavelength radar (e.g. Hamazu et al., 2003; Uematsu et al., 2005a,b).

In Japan, fog also often occurs in the basin regions, as well as on the Pacific coast. There are numerous basins in Japan, and basin fog often forms in these areas between the fall and early winter. Some studies on basin fog have been carried out, and they have captured the life cycle of fog events in each individual basin (Miyata, 1994; Teshiba et al., 2004; Ohashi et al., 2004; Ohashi et al., 2012).

In other regions, the Japan Meteorological Agency (JMA) has performed some local investigations into fog. The local fog information provided by them has helped forecasters to better understand and forecast fog at each observation site. However, these studies have focused on only small regions and little comparative analysis has been carried out to investigate whether the characteristics reported by these studies are common nationwide or are regionally specific.

In addition to the regional research mentioned above, a few nationwide climatological studies have been performed (Kondo, 2006; Nomoto, 2003). Kondo (2006) conducted a comparative investigation of the long-term trends in annual mean number of foggy days in cities and rural areas from 1931 to 2005. He notes the following conclusions on his web site: 1) the number of foggy days in cities has decreased through the period studied; 2) in rural sites with an ambient environment that experienced less change, the number of foggy days showed little or no change, and some of observation sites located on the Pacific coast showed a trend of increasing numbers of foggy days. Nomoto (2003) investigated the trend of annual mean foggy days over 45 years from 1951 to 1995 and concluded that the number of foggy days has declined in cities and in rural basins in recent years. Additionally, he pointed out that the number of foggy days in some rural basins showed a remarkable decline in the warm season, whereas the number of foggy days in cities declined throughout the year. He speculates that the decrease in foggy days in rural basins may be driven by a reduction in the number of paddy fields over all of Japan since 1969, following changes to the Japanese government's food policy.

As yet, no nationwide climatological analysis has been carried out that focuses on the characteristics of fog, such as density, timing of its appearance and fog type. Kondo (2006) and Nomoto (2003) used only the number of foggy days, and did not focus on the characteristics of the fog at each observation site. This is mainly due to the fact that digital information only contained the number of foggy days. It is therefore necessary to create a database of the density and appearance time of fog from the original observation records, requiring a large amount of time and energy. Therefore, it is only viable to compile such information for climatological surveys of fog in limited areas, and not for nationwide fog investigations. However, recently, some JMA surface observation sites, whose data collection has been automated for similar amounts of time, have introduced atmospheric visibility meters that can provide digital data of atmospheric visibility; there were 78 sites with such technology in June 2009. Through this, information on the density and the timing of the appearance of fog became accessible, and could be used for nationwide climatological surveys.

This study aims to provide a climatological study of fog across the entirety of Japan. A unique point of this study is its focus on fog density and fog types, using hourly atmospheric visibility data. Furthermore, we focus on the relationship between the fog density and the surrounding environment, including topography and land use.

In the following Section 2, data sets and analysis methods in this study are described. Section 3.1 presents results from the analysis of active fog and dense fog regions and their seasonalities, using the number of foggy days as an index. The results of the analysis of fog type and fog duration are described in Section 3.2. Based on these analyses, the relationship between the density of fog and the surrounding environment are discussed in Section 4, as well as the long-term changes in fog occurrence. Section 5 summarizes the study.

2. Data and methodology

2.1. Analysis using density of fog each day as an index

We classify surface observation sites into four groups: mountain, basin, plain and urban areas, in order to reveal potential relationships between fog density and the surrounding environment of the observation stations, including topography and land use. The varying geography across Japan is shown in Fig. 1a.

The original observation reports from the JMA are used to identify foggy days at 60 different locations across Japan (Fig. 1b). Data were collected over a five-year period from 2004 to 2008. The observation reports provide information about when atmospheric visibility hindrances occur due to the presence of fog or mist[1]. In these reports, atmospheric visibility hindrances are classified into four groups by the minimum atmospheric visibility recorded each day: dense mist, fog, quasi-dense fog, and dense fog, which each have a minimum atmospheric visibility of less than 2000 m, 1000 m, 500 m, and 100 m, respectively.

2.2. Analysis using fog events as an index

Surface hourly data, including atmospheric visibility, temperature, wind speed, and precipitation, from the JMA are used to identify and characterize fog events in Japan. Data from 40 observation sites are used here, as shown in Fig. 1. At each of these sites a forward scatter atmospheric visibility meter had been introduced prior to the analysis period.

The fog events at individual stations are defined using the concept first introduced by Tardif and Rasmussen (2007). Fog events are defined as those in which atmospheric visibility of less than 2000 m is recorded for at least 3 h within five consecutive hours, with an atmospheric visibility of less than 1000 m being recorded at least once in this time. Thus, events lasting less than 2 h are not included as fog events in this study. In contrast, even if atmospheric visibility is

[1] The term mist is used in this paper to refer to cases when the visibility is 1000 m or more. Additionally, we classify dense mists as having visibility of 1000 m or greater, but less than 2000 m.