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Interannual variability of sea fog frequency in the Northwestern Pacific in July

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ABSTRACT

The interannual variability in the sea fog frequency (SFF) in July in the midlatitude Northwestern Pacific (40°N–50°N, 140°E–170°W) from 1979 to 2009 is investigated with observations and reanalysis datasets. Composite analysis shows that in high-SSF years the center of the Northwestern Pacific subtropical high (SH) shifts eastward and a strengthened ridge exists in the midlatitude Northwestern Pacific. Under such conditions, large amount of moisture from the subtropics are transported northwardly by the southerlies over the west flank of the SH. The ridge is helpful for stable stratification and conductive to fog formation. In contrast, in low-SFF years the center of the SH expands westward and drifts further south; thus moisture can hardly reach the midlatitudes. Meanwhile an anomalous trough in the midlatitudes and the associated anomalous northerlies both weaken the southerlies and reduce the stability, unfavorable for fog occurrence. The case studies confirmed that the air parcels moving from the subtropical zone to the midlatitudes controlled by the SH, kept the higher temperature and humidity when flowing across the Kuroshio Extension, and then cooled down over the cold oceanic surface in fog case. The SFF in the Northwestern Pacific would decline under the conditions of global warming.

1. Introduction

Sea fogs occur over oceans and coastal regions when tiny water droplets sustain in the atmospheric boundary layer and cause the atmospheric horizontal visibility less than 1 km (Wang, 1985). As the low visibilities may cause traffic accidents and influence shipping activities, sea fogs have long been widely concerned in the coastal nations. In addition, marine stratus (sea fogs can be defined as the marine stratus approaching to the sea surface, Koračin et al., 2001) plays an important role in the energy balance of the earth atmosphere system (Sherwood et al., 2014). Therefore, it is necessary to investigate the sea fog climatology, especially changes in the temporal and spatial distributions of the frequency of sea fog occurrence, and to understand the controlling factors.

Sea fogs in the Northern Pacific occur frequently over the following areas, by and large: the Kuril islands, the ocean near Hokkaido, the midlatitude Northwestern Pacific, the California coast, and the Yellow and East China seas (U.S. Department of Agriculture, 1938; Uyeda and Yagi, 1982; Wang, 1985; Warren et al., 1988; Lewis et al., 2003, 2004; Cho et al., 2000; Gultepe et al., 2007; Zhang and Bao, 2008). Changes in the sea fog frequency (SFF) were analyzed in previous literature. Lewis et al. (2004) and Warren et al. (2013) indicated that sea fogs were frequently observed over the cold current area in summer, especially over the Oyashio zone and the Labrador Current area. The cold sea surface contributed to fog frequency maximum in July around the Korean peninsula (Cho et al.,

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2000). Zhang et al. (2008, 2009, 2011) suggested that the changes in sea surface prevailing winds were responsible for the starting and ending of the climatological sea fog season in the Yellow and East China Seas.

In addition to the seasonal variations of the SFF, the interannual variability and the corresponding controlling factors of the SFF are investigated in recent years. Bai et al. (2010) proposed that the anomalies in the water vapor transport, which was associated with the sea surface temperature (SST) and wind directions, in the key area (122°E–130°E, 28°N–32°N) was essential for the interannual variations of the SFF in the Yellow Sea near Qingdao, Shandong. Ding et al. (2011) found that there were remarkable interannual variations in the starting date of the Yellow Sea fog season which is from April to July (Wang, 1985; Zhang et al., 2009), and that the date was associated with a synoptic high over the sea surface. The effect of the synoptic circulation associated with the Okhotsk high and the Northern Pacific high was related to the interannual variations and long-term trends of the SFF over Hokkaido Island (Sugimoto et al., 2013). The concentration of aerosol particles was suggested to be responsible for the reducing SFF in California coastal, and the PDO (Pacific Decadal Oscillation) warm phase could enhance the SFF reducing trend (Witiw and LaDochy, 2008).

Based on the above analysis, the interannual variations of the SFF are mainly associated with the atmospheric circulations, local meteorological hydrological conditions and particulates concentrations. Note that the previous studies mainly focused on the sea fogs in the coastal areas, islands and marginal seas. When it comes to the open oceans, e.g. the midlatitudes of the Northwestern Pacific, our knowledge falls short possibly due to the lack of observations. In this study, our efforts are especially paid to the interannual variations of the SFF in the broad midlatitude Northwestern Pacific in July when the SFF peaks, as well as to the affecting factors. We also projected possible changes of the SFF under conditions of global warming.

2. Data and methods

2.1. Data

The observed visibility and weather phenomena (e.g. rainfall and snow) data from the International Comprehensive Ocean–Atmosphere Dataset (ICOADS) in IMMA (The International Maritime Meteorological Archive) format (Woodruff, 2010) are used to get the SFF in the area (35°N–50°N, 140°E–160°E) where relatively more observational data are available (Fig. 1a). We use the cloud liquid water (CLW) data from the climate forecast system reanalysis (CFSR) with a spatial resolution of and a temporal resolution of four times a day (Saha et al., 2010) to get the fog-proxy over a broader region (40°N–50°N, 140°E–170°W, Fig. 1b), and additionally other variables (e.g. relative humidity, air temperature, geopotential height and wind) to analyze the meteorological conditions. The data from Global Data Assimilation System (GDAS), National Centers for Environmental Prediction (NCEP), is used for backward trajectory analysis in the case study applying HYSPLIT-4 (Hybrid Single Particle Lagrangian Integrated Trajectory) model (Draxler and Hess, 1997). The spatial resolution of the GDAS data is 50 km with a temporal interval of 3 h. We use the Coupled Model Intercomparison Project Phase 5 (CMIP5) data (Taylor et al., 2012), the projections of climate changes being applied to IPCC's (Intergovernmental Panel on Climate Change) fifth assessment report (AR5), to assess the trend of the SFF under global warming conditions. Monthly mean HadISST (the Hadley Center sea ice and sea surface temperature) data in grid is used in the composite analysis. Sea level pressure (SLP) from ECMWF (European Centre for Medium-Range Weather Forecasts) with grid and 4 times daily temporal resolution is applied in the case study. The period used in the interannual analysis ranges from 1979 to 2009 including only July, because fogs appear most frequently in this month (figure not shown).

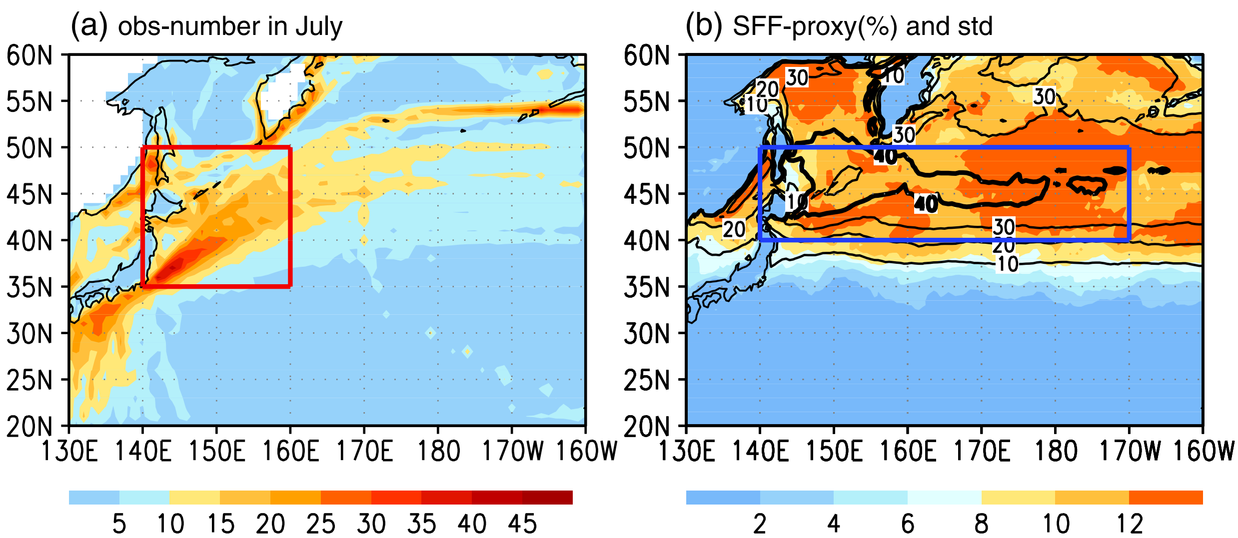

Fig. 1. a) Long-term monthly mean observation times in July from 1979 to 2009 in ICOADS. Red rectangle represents the region where observation times are mainly more than 15 times. b) The spatial distribution of standard deviation for SFF-proxy (shaded) and long-term monthly mean SFF-proxy (contour, unit: %) in July from 1979 to 2009; the blue rectangle represents high-SFF area.