5th International Conference on Fog, Fog Collection and Dew
Münster, Germany, 25–30 July 2010
FOGDEW2010-87

The roles of circulation and aerosols in the decline of mist and dense fog in Europe over the last 30 years

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Abstract

Fog and mist are meteorological phenomena that have significant contributions to temperature variations. Understanding and predicting them is also crucial for transportation risk management. In previous work has been shown that low visibility phenomena over Europe have been declining over the past three decades (Vautard et al., 2009). The trends in mist and haze have been correlated to atmospheric aerosol trends. More recently the same analysis was extended to dense fog, together with an examination of the roles of synoptic atmospheric circulation and aerosol content on the trends of dense fog (van Oldenborgh et al., 2010). It was shown that sulphur emission trends are spatially correlated with visibility trends, with a maximum correlation when visibility is between 1 km and 10 km. Atmospheric dynamics overall contributes up to 40% of the variability of the frequency of fog occurrences. This contribution is spatially variable and highly depends on the topography and the season, with higher values in the winter. The observed long-term circulation changes do not contribute much to the trends in low visibility found in the data. This process is illustrated on three stations (De Bilt, Zürich Airport and Potsdam) for which a long-term visibility data and a thorough meteorological description are available. We concluded that to properly represent fog in future climate simulations, it is necessary to include realistic representations of aerosol emissions and chemistry, land surface properties and atmospheric dynamics.

1 Data

Horizontal-visibility data have been taken from the 6-hourly NCEP ADP land surface observations available at the National Centre for Atmospheric Research (NCAR) server `http://dss.ucar.edu/datasets/ds464.0`. We selected 329 European stations (out of 4479) within [10°W–30°E; 35°N–60°N]. Stations were selected that had data over at least 1980–2000, at least 10 years with at least two observations per day, and at least 30 observations in all half-year seasons between 1980 and 2000 (excluding 1997). The details of the selection procedure are given in Vautard et al. (2009). We also excluded 9 high-altitude stations (above 1000 m). Six stations showed very obvious breaks in a visual inspection of the time series. Due to a change in the observing system the years 2002–2006 were disregarded for all Dutch data. The other four stations were removed entirely.

About two-thirds of the stations correspond to airports or airfields, at which low visibility observations are very important and often performed with more care. When plotting the results separately for airports/airfields and other stations it is apparent that the latter subset indeed contains more noise (not shown). However, there do not appear to be other systematic differences between the two subsets. In the following we present results for the complete dataset.

We also use longer time series of daily minimum visibility observed at De Bilt 1955–2001 (available from the KNMI web site), Zürich Airport (courtesy of MeteoSwiss) and Potsdam (Deutsche Wetterdienst).

2. Observed trends

Mist and Fog occur most frequently over eastern Europe and is more rare in summer, around the Mediterranean, and along the Atlantic coasts (Fig. 1a–d). The occurrence of fog and mist have decreased sharply over the last 30 years, as was shown for 1 km visibility in Vautard et al. (2009). The number of days with minimum visibility less 2 km has declined by a factor two over his period in most areas in Europe where fog is common (Fig. 1e–f). The same holds for dense fog with visibility less than 200 meter. This decrease has a high field significance.

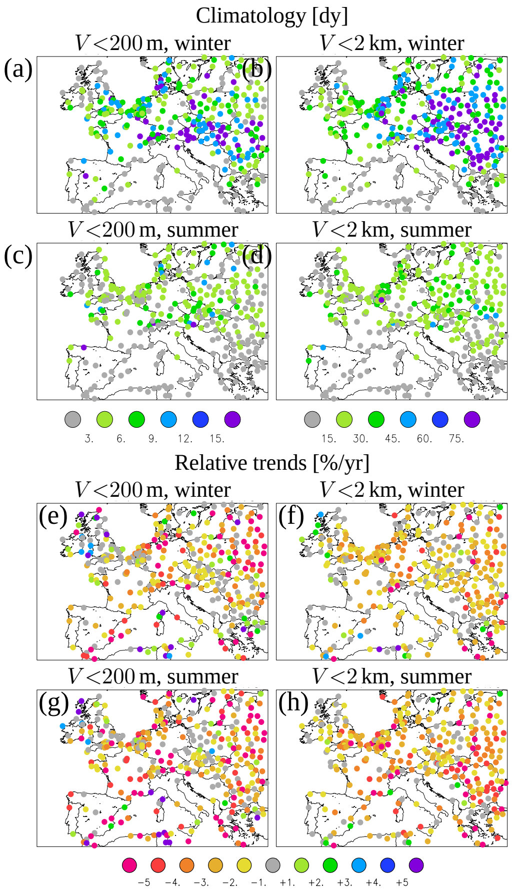

Figure 1: Mean number of days per half year with low visibility over 1976–2006 in winter **(a)** and **(b)** October–March, and summer **(c)** and **(d)** April–September. In (a) and (c) the number of days with dense fog (visibility less than 200 m) is shown, in (b) and (d) the number of days with visibility less than 2 km. **(e)**–**(f)** Relative trend in low visibility [%/yr] over 1976–2006.

3 Aerosol emissions and urbanisation

The spatial pattern of the absolute declines in numbers of fog and mist days matches the pattern of SO_2 emission trends over 1990–2007 (Streets et al., 2006) in Europe, suggesting that the improvements in air

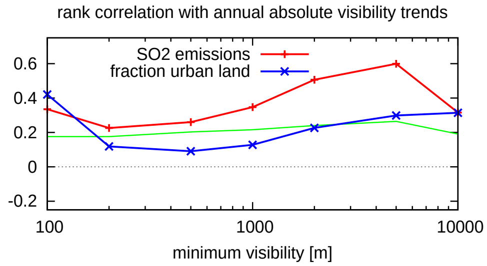

Figure 2: Spatial rank correlation of the trend in the annual number of days with minimum visibility less than a range of cut-offs with the trend in EMEP SO_2 emissions 1990–2007 (Streets et al., 2006) and with the trend in the fraction of urban land (Hurtt et al., 2006) (with sign changed) on a 2.5°×2.5° grid covering 10° W–35° E, 37°–60° N. The green line indicates the correlations that have p=0.05, using a number of degrees of freedom deduced from the spatial autocorrelation.

quality over Europe over this time contributed to the decrease. This relation is strongest for 5 km visibility, but is statistically significant for all ranges down to 100 m (Fig. 2). This is in agreement with micrometeorological modelling studies of fog Bott (1991) and von Glasow and Bott (1999), who found that urban aerosols cause higher water content and longer-lasting fog than rural aerosols.

A few stations with longer observations show an increase in fog days up to 1970 (Zřich Airport) or 1985 (De Bilt, Potsdam), and a decrease afterwards at almost all visibilities (Fig. 3). As the visibility at 5 km is directly correlated to aerosol concentrations, this reinforces the notion that aerosols also play a large role at lower visibilities.

The agreement of fog trends with urbanisation trends 1976–2005 (Hurtt et al., 2006) is much weaker: the largest absolute fog reductions have been observed in eastern Europe, whereas the largest increases in urban area have been in western Europe. Urbanisation also cannot explain the peak in fog and mist occurrences in the 1970s at Zürich Airport and the 1980s at De Bilt in Fig. 3.

4 Atmospheric circulation

Weather types obviously influence fog formation, both directly by creating circumstances favourable for fog

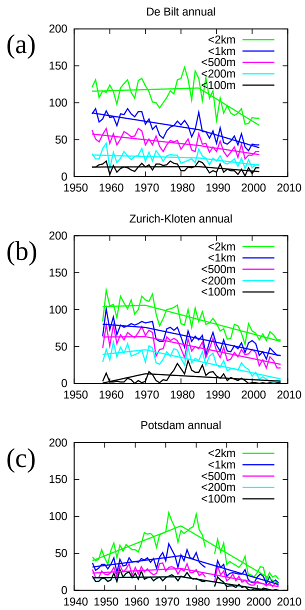

Figure 3: The annual number of days with visibility less than 100 m, 200 m, 500 m, 1 km and 2 km at **(a)** De Bilt, **(b)** Zürich Airport and **(c)** Potsdam. The straight-line fits include a break-point estimated from the 5 km visibility.

formation and indirectly by increasing aerosol concentrations near the ground. In winter the daily patterns associated with individual fog events (Fig. 4a,b) are similar to the seasonal mean weather patterns associated with seasons with many occurrences of fog or mist (Fig. 4e,f). However, in summer there is no such correspondence: the average circulation patterns of seasons with many fog days (Fig. 4g,h) are not the same as the circulation patterns on the fog days themselves (Fig. 4c,d). A study of De Bilt data shows that fog in July and August is associated with dry weather and clear skies in these months, but with rainy weather the months before. We hypothesise that the rain in late spring and early summer supplies the moisture needed for fog formation in high summer.

At three test locations the dependence of fog and mist occurrence on the atmospheric circulation can be parametrised well by local sea-level pressure gradients: the geostrophic wind components and vorticity (see also Clark and Hopwood, 2001;

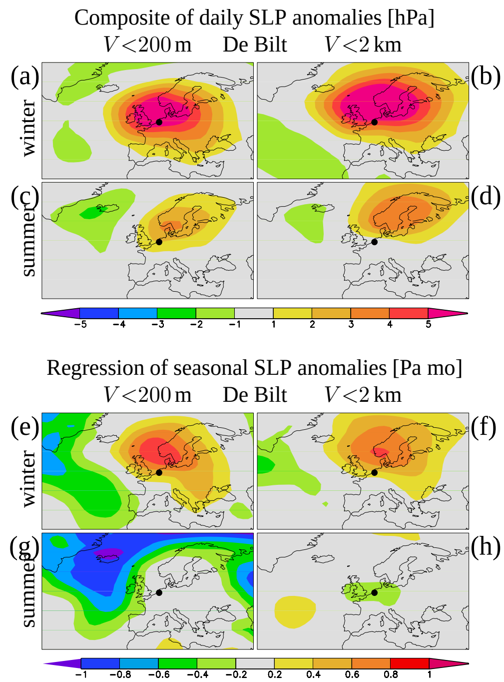

Figure 4: Composite of daily mean sea-level pressure anomalies [hPa] at days with low visibility in De Bilt, the Netherlands (dot) in winter **(a)** and **(b)** October–March, and summer **(c)** and **(d)** April–September. In (a) and (c) SLP anomalies at days with dense fog (visibility less than 200 m) is shown, in (b) and (d) at days with visibility less than 2 km. **(e)–(f)** Regression of the seasonal mean sea-level pressure on the number of days with low visibility in De Bilt [Pa month], the Netherlands (dot).

van Ulden and van Oldenborgh, 2006). There is no way to distinguish the direct effect of the circulation (low wind speeds for low geostrophic wind, clear nights associated with negative vorticity) with the air quality effects (advection of polluted air, stably stratified atmosphere, no precipitation).

In Central Europe, north of the Alps, westerly flows in winter with clean air, strong winds and cloudy skies are associated with fewer fog and mist days. Just north of the Alps and in eastern Europe, southerly flows also increase the number of fog days. High pressure (negative vorticity) increases fog and mist everywhere except the eastern edge of the study area (see

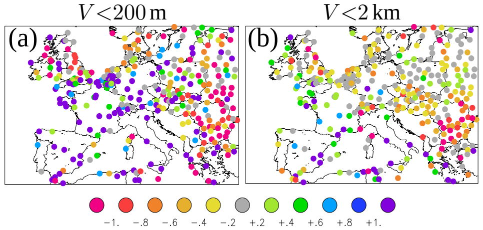

Figure 5: Relative trend in visibility [%/yr] due to circulation changes in January–March. **(a)** dense fog (200 m), **(b)** mist (2 km).

van Oldenborgh et al., 2010, for the figures).

The study period 1976–2006 has seen an increase in westerly flow over much of Europe in January–March (see e.g. van Oldenborgh and van Ulden, 2003; Osborn, 2004; van Oldenborgh et al., 2009). However, the effect of this increase on the decrease of fog days is much smaller than the other factors influencing fog trends (compare Fig. 5 with Fig. 1e–f, note the factor 5 difference in the colour scale) and only occurs in second half of winter.

5. Summary and Conclusions

This study only addressed the associations of fog and mist with aerosols, urbanisation and atmospheric circulation. Other factors, such as the availability of moisture due to water table management, the stability of the atmosphere and possible decreased night-time cooling due to greenhouse warming have not yet been addressed. However, as these trends are unlikely to change sign over the next decades, projected further increases in air quality, increases in westerly circulation in winter and maybe drought in summer will likely further decrease the occurrence of fog and mist.

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