P1.1 FOG CLIMATOLOGY NEAR THE ATLANTIC COAST OF NOVA SCOTIA

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1. INTRODUCTION

Investigations conducted early in the twentieth century found that offshore waters of Atlantic Canada, particularly the Grand Banks, were among the foggiest regions on earth with fog being most prevalent from May to September, inclusive (Lewis et al, 2004). Such a propensity for fog in this area is explained by its location. Atlantic Canada (see figure 1) lies in the mid-latitudes at the eastern extremity of North America where the warm waters of the Gulf Stream merge with the cold Labrador Current. During the summer season, southerly winds frequently bring warm and moist air to the area. Atlantic waters easily cool this warm moist air to its dew point producing fog that spreads over the land at night. Daytime heating over the land often enables the fog to recede to the coast by late morning. Fog then lurks along the coast or near shore during daytime hours and gradually spreads over the land in the evening. Fog persists offshore until winds shift to westerly bringing drier air to the area.

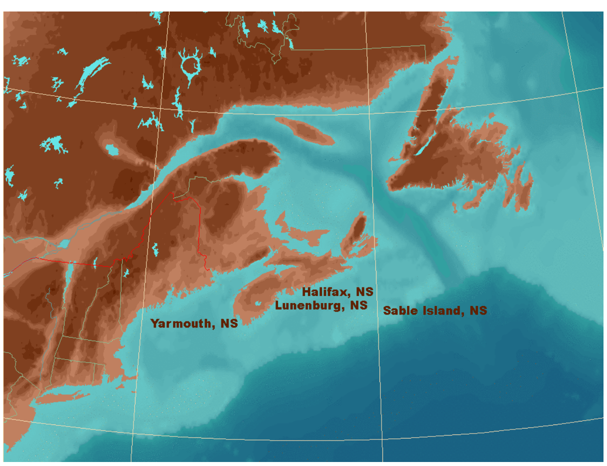

Figure 1: Map of Atlantic Canada (excluding Labrador). Source: Environment Canada

Coastal and marine data collected during past decades at sites along or near the Atlantic Coast of Nova Scotia are analyzed to determine fog occurrences revealing both annual and monthly trends. Parameters including air temperature, dew point temperature, precipitation, wind speed and sea surface temperature are examined to determine correlations with trends in visibility data.

Upper air data, available in the area for approximately the past fifty years, provide a means for detecting temperature inversions and very high relative humidity exposing the vertical extent of fog. More recently, wind profiler data have become available at Lunenburg, Nova Scotia providing data in the boundary layer with enhanced temporal and spatial resolution at a point. These data are used to display greater vertical detail during recent fog events.

2. DATA ANALYSES

Most recent normals, calculated using 1971-2000 data, continue to show high frequencies of fog during the summer months at coastal stations in Atlantic Canada. For example, data from this period collected at the Yarmouth Airport, located at the southwestern tip of Nova Scotia, are plotted in figure 2 to show the monthly distribution of hours with fog where fog is defined as visibility reduced to less than one kilometre.

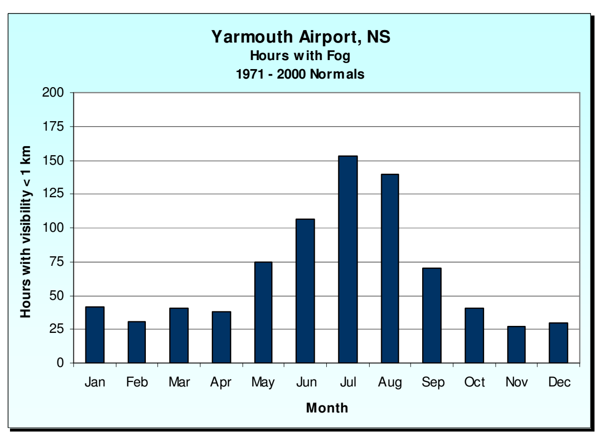

Figure 2: Hours with fog, visibility less than 1 km, 1971-2000 Normals, Yarmouth Airport, NS. Data source: Environment Canada

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Visibility

Visibility data for the period of record, approximately fifty years, for each station are used to determine fog occurrences for each year and month to reveal both annual and monthly trends. Increasing variability obscures a slight decrease that occurs in linear trends of annual days with fog over the past five decades at coastal sites in Nova Scotia. Despite substantial variability, linear trend lines are remarkably flat for each month from May to September inclusive at Yarmouth Airport. Similarly, linear trends are flat or show a slight decrease at CFB Shearwater and Sable Island during these months. A slightly decreasing trend in days with fog at CFB Shearwater in July is overshadowed by the variability in the data.

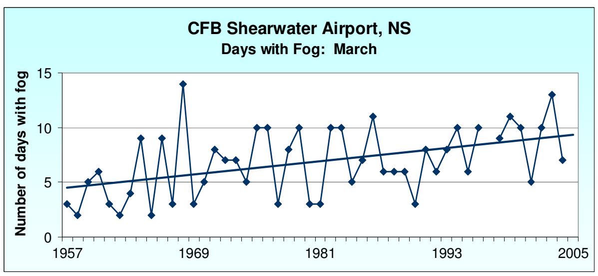

Figure 3: Days with fog, visibility less than 1 km, March 1957 - 2005 at CFB Shearwater, NS. Data source: Environment Canada.

An increasing trend is generally noted during the spring in both March (see figure 3) and April while a decrease is depicted in most cases during the autumn months of October and November. Although a linear trend line is depicted in figure 3, statistical significance cannot be claimed based on its low r-squared value of 0.2.

Air Temperature

Mean annual temperature along the coast of Nova Scotia during the past sixty years has been fairly steady according to linear trends. With the exception of Yarmouth Airport, preliminary results from other coastal sites suggest a warming trend during the most recent decade. Investigation of mean monthly temperatures for the past six decades implies warming during the summer months, particularly August. Remaining months of the year indicate little temperature change with the exception of cooling in January.

Examination of maximum and minimum temperatures at coastal stations reveals some warming during the summer months. Apart from a small increase in maximum temperatures in August and a decrease in minimum temperatures in January, temperature trends at Yarmouth are remarkably flat over the past sixty-five years. Preliminary results for Shearwater Airport suggest slightly more warming during August than June and July while subtle increases are noted in May and September. Cooling is most prominent in January data with greater cooling occurring in minimum temperatures.

Dew Point Temperature

Dew point temperatures are calculated from archived hourly dry bulb temperatures and hourly relative humidity values using an approximation based on the Clausius-Clapeyron equation (Iribarne and Godson, 1981). Daily maximum, minimum and mean dew point values are calculated from these hourly values and then used to determine monthly means and extreme values.

Although considerable variability is found in annual mean dew points for the past five decades, the linear trend is flat. Similar to findings for dry bulb temperatures, mean annual dew points show an increase during the summer months, particularly in August, and a decrease in January.

A slight increase is apparent in minimum dew points at Yarmouth Airport during the summer months of July and August while maximum dew points show flat linear trends. March and April show the most noticeable trends with increases in maximum dew points and decreases in minimum dew points. However, these two months also exhibit the greatest variability.

Precipitation

In this location, the number of days with precipitation is at its lowest during the summer and early autumn months; increases during the spring and is highest during the winter months. It would appear from the annual count that the number of days with precipitation has increased somewhat over the past sixty years, particularly during the 1980's and early 1990's. A slight decline is noticeable in most recent years.

Investigation of the number of days with precipitation on a monthly basis shows generally flat trends during the summer months and hints of increases during spring and fall months. Both December and January show an increase in days with precipitation and also display considerable variability. Unlike the annual trend, January shows the increase persisting to the present.

Wind Speed

In contrast to the increasing tendency for precipitation days, the annual number of days with strong wind speeds appears to be on the decline. Although the number of days with wind speeds equaling or exceeding 28 knots for the period from 1957 to 2005 at Yarmouth Airport could be described as somewhat erratic, there is a possibility that a decadal cycle could be identified.

Summer months contribute very little to wind speeds in this range. Slight decreases are apparent during winter months. March data resembles the annual count of days with strong winds and also shows a similar decline in the number of days in this category.

Sea Surface Temperature

International Comprehensive Ocean Atmosphere Data Set (ICOADS) monthly summary statistics for areas defined by latitude and longitude at resolutions of one and two degrees are used to analyze sea surface temperature. These data are provided by the Data Support Section of the Scientific Computing Division at the National Center for Atmospheric Research (NCAR) which is supported by grants from the National Science Foundation. More information on these data can be found online at icoads.noaa.gov.

Since sea surface temperature data from 1800 to 1997 at a two degree resolution is the only variable available using the adaptive quality control statistical methodology, these data are selected for use here. In addition, sea surface temperature data from 1960 to 2005 at a one degree resolution using the enhanced quality control statistical methodology are also analyzed.

Six two by two degree boxes with southwest corners at latitudes 42 and 44 degrees north and longitudes extending from 60 to 68 degrees west are selected. Annual mean sea surface temperatures suggest some warming in the vicinity of the southwest tip of Nova Scotia (see figure 4), no change in offshore waters south of Nova Scotia, cooling in offshore waters southeast of Nova Scotia and little change or a very slight hint of warming in near shore waters southeast of Nova Scotia.

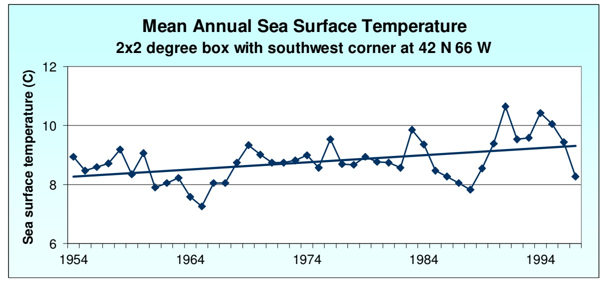

Figure 4: Mean annual sea surface temperature within a 2x2 degree box with southwest corner at 42N 66W. Data source: icoads.noaa.gov.

Due to the enormous variability in the number of observations (see figure 5), data prior to 1954 were excluded from these graphs.

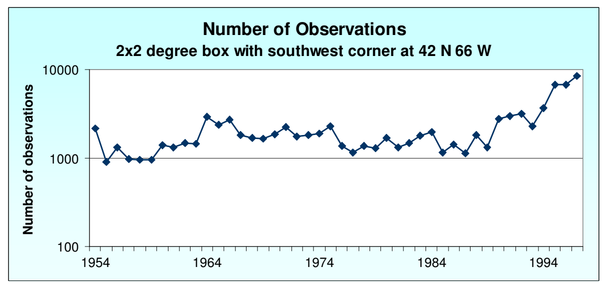

Figure 5: Number of observations each year within a 2x2 degree box with southwest corner at 42N 66W. Data source: icoads.noaa.gov.

The linear trend line on the graph shown in figure 4 can be interpreted, with caution, to suggest that warming appears to be occurring in this area. Both warmest and coolest points generally appear to be getting warmer with time. A marked increase in the number of observations during the 1990's can be seen in figure 5.

Monthly analyses often exhibit similar tendencies as annual means with greater variability. Number of observations shows similar patterns as the annual analyses for each area. In waters southwest of Nova Scotia, summers show some cooling while winters show some warming. The month of March indicates more warming than other months in the box depicted in figure 4. Waters due south of Nova Scotia show little change while waters southeast of Nova Scotia indicate some warming during the summer months with August being most noticeable in near shore waters in this area. Similar to previous analyses, r-squared values are too low to support statistical significance in these graphs. Analyses of data at the finer resolution of one degree for the same area show warming in each area. However, this trend is frequently due to data beginning during the cool 1960's. Warming is indicated in some areas during most recent years.

Sea surface temperature data are also available from offshore buoys in the area from the late 1980's and continue to the present although missing periods do occur in these records.

Upper Air

Upper air data, available in the area for approximately the past fifty years, provide a means for detecting temperature inversions and very high relative humidity exposing the vertical extent of fog. Heights of temperature inversions and depths of layers from the surface with relative humidity near 100 percent show considerable variation. Rather than exhibiting an increasing or decreasing trend in these heights over this time period, considerable variability persists.

Wind Profiler

More recently, wind profiler data have become available at Lunenburg, Nova Scotia. These data are used to display greater vertical detail during recent fog events.

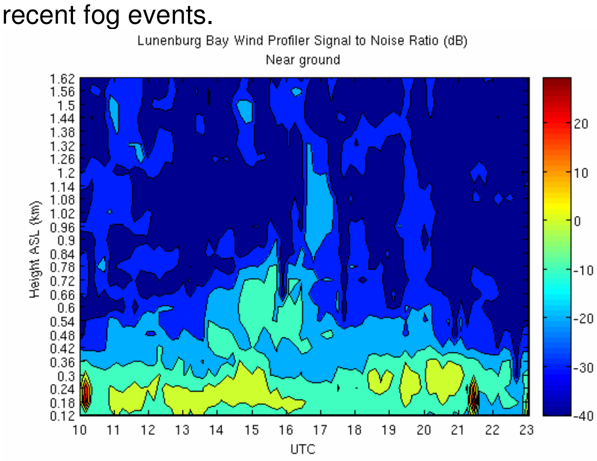

Figure 6: Wind profiler range corrected signal to noise ratio; June 18, 2004, 1000 - 2300 UTC. Data source: Environment Canada.

In addition to providing wind velocities in the vertical and daytime temperatures, range corrected signal to noise ratio plots are produced as stronger signals are received in saturated rather than in dry air as shown in figure 6 during a fog episode on June 18, 2004.

Discussion and Summary

Visibility reduced to below one kilometre in fog continues to be observed along the Atlantic Coast of Nova Scotia, particularly during the summer months, as recorded for well over a century. Increased variability in days with fog appears to overshadow a slightly decreasing annual trend. While little change is apparent during the summer months, a noticeable increase is depicted during March and April that is offset by a decrease during October and November.

Slightly increasing temperature trends during the summer months, particularly August, appear to be matched by increasing dew points and warmer near shore sea surface temperatures reflecting no changes in days with fog.

As January tends to have few fog days, cooling temperatures and dew points during this month have little or no direct impact on fog days.

Changes during March and April include increased maximum and decreased minimum dew points along with greater variability, hints of increasing days with precipitation, a decline in days with strong winds and warmer sea surface temperatures in waters near the southwestern tip of Nova Scotia. This combination favours an increase in fog formation. Changes in days with fog during spring and autumn could be altered by changes in frequency and duration of mid-latitude storms which is beyond the scope of this study.

Upper air data analyses have yet to offer any results that would suggest changes in fog occurrences. Additional data is gleaned from a wind profiler while it is engulfed in fog.

References

Iribarne, and Godson, 1981: Atmospheric Thermodynamics. D. Reidel Publishing Company, Dordrecht, Holland, 259 pp.

Lewis, J. M., D. Koracin, and K.T. Redmond, 2004: Sea Fog Research in the United Kingdom and United States, Bull. Amer. Meteor. Soc., **85**, 395 – 408.