2016 24th International Lightning Detection Conference
18 - 19 April | San Diego, California, USA
6th International Lightning Meteorology Conference
20 - 21 April | San Diego, California, USA

Lightning and Weather Associated with the Extreme 2014 Wildfire Season in Canada's Northwest Territories

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***Abstract*— The hot and dry conditions associated with a persistent high pressure system during the summer of 2014 led to the Northwest Territories experiencing the worst fire season in its history. Record numbers of cloud-to-ground (CG) flashes, lightning-initiated forest fires and area burned were observed. Prolonged periods of smoke from the wildfires led to dramatic reductions in visibility and road closures, and reduced air quality resulted in numerous health alerts. CG flash activity and polarity patterns were noticeably different in 2014 from those occurring in previous years with, for example, far more nighttime positive flashes.**

Keywords—Lightning; forest fires; smoke; northern Canada

I. Introduction

Thunderstorms play an important role in the cycling of water and energy over the boreal ecosystem of the Northwest Territories (NWT) of northern Canada during the summer months. Associated cloud-to-ground (CG) lightning also initiates forest fires. The convective storm season in this high-latitude region is influenced by the timing of the snowmelt and is characterized as short but intense with CG lightning flashes starting in late May, peaking in July and diminishing by late August.

During the summer of 2014, the NWT experienced the worst fire season in the territories' history. The fires occurred mainly in the regions surrounding Great Slave Lake and smoke from the wildfires led to dramatic air quality reductions resulting in numerous health alerts and road closures.

Several studies have investigated the characteristics of CG lightning in smoke-filled environments due to forest fires [Lyons et al., 1998; Murray et al., 2000; Kochtubajda et al., 2002; Fernandes et al., 2006; Altaratz et al., 2010; Kochtubajda et al., 2011]. The 2014 event represents an opportunity to further investigate such instances.

The particular objectives of this study are to describe the weather conditions and the impacts of the fires during this extreme 2014 season, and to compare its lightning characteristics with those from 2008-2013.

This research was supported by Environment and Climate Change Canada and the Changing Cold Regions Network funded by NSERC through its CCAR Initiative.

II. Data

This study used a variety of data sources. These include the archived lightning flash data from the Canadian Lightning Detection Network; fire data from the National Forestry Fire database; and climate data from the Environment Canada database.

The lightning data are the quality-controlled flash data sent at the end of each month by Vaisala Inc. These data describe the location, time, polarity, first-stroke peak current and multiplicity of the flash and are subject to a variety of uncertainties including measurement and calibration errors and model limitations [Cummins and Murphy, 2009]. The detection efficiency, as determined by Vaisala, is 70 – 90% or higher within the southern and central regions of NWT. A reference period from 2008-2013 was selected to develop the lightning climatology in the NWT and used to compare with the activity in 2014. Spatial patterns were derived using equal-area square grid cells of 20 km sides.

III. Weather Conditions

A. Temperature and Precipitation

Several regions of the NWT experienced a period of prolonged drought extending into the summer months of 2014. Precipitation deficits over the area surrounding Great Slave Lake (GSL) were as high as 50% below normal from autumn of 2013 to spring of 2014. Dry conditions persisted in the summer with precipitation deficits as high as 30% below normal, and temperature anomalies of 1.5 to 2.5 °C above normal during June and July (Figs. 1a, b). Overall, the summer season surface temperature departure from normal across NWT was 1.6 °C, ranking it as the 7th warmest since records began in 1948. The regionally averaged precipitation was about 10% below the 1961-90 base period average, which ranked it as the 23rd driest summer for the period of record.

B. Upper Air

A persistent and strong upper level ridge characterized the summer of 2014. This type of weather pattern creates prolonged warm spells and has been found to be suited to the

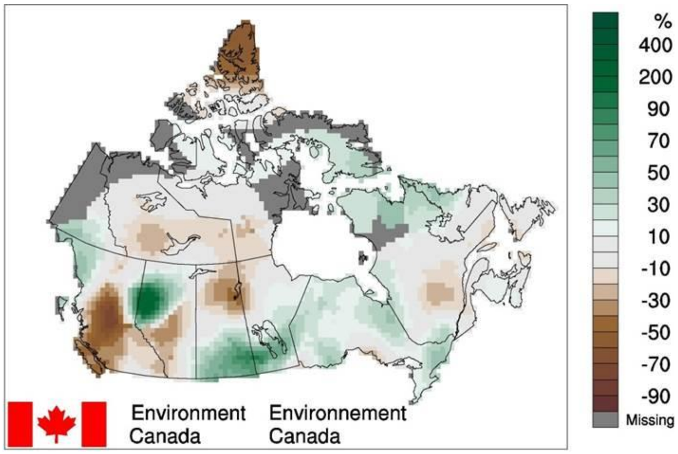

Fig 1a. Summer 2014 precipitation anomaly over Canada in comparison with the 1961-90 average.

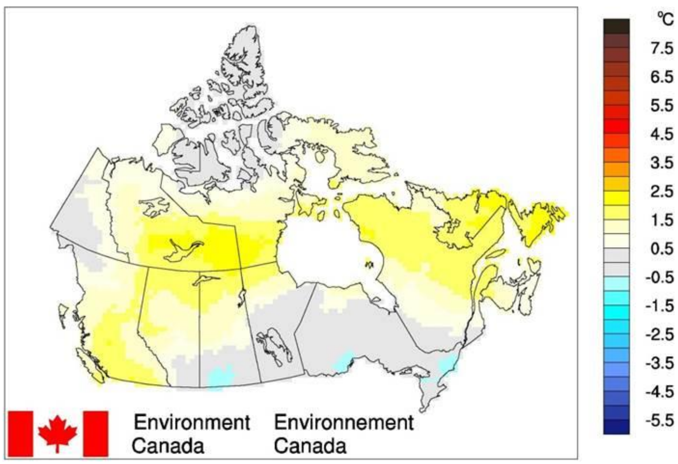

Fig 1b. Summer 2014 temperature anomaly over Canada in comparison with the 1961-90 average.

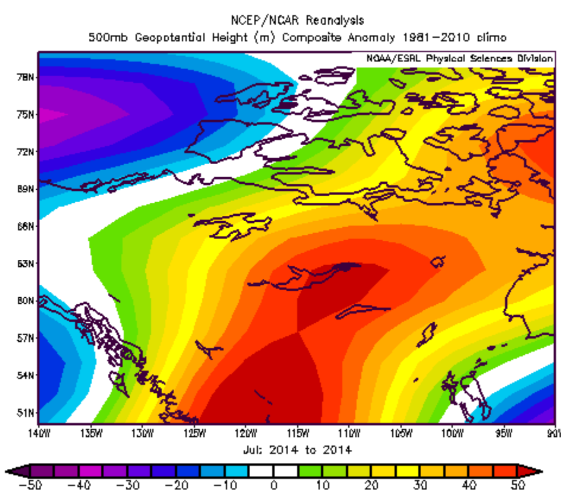

Fig 2. The July 2014 mean anomaly of 500 mb geopotential height (in meters). The anomaly was calculated using the 1981-2010 base period.

development of forest fires. Skinner et al. [1999] found that 500 hPa height anomalies were well correlated with area burned by wildland fires. The July mean 500 hPa geopotential height from the NCEP/NCAR reanalysis data shows the ridge extending northeastward into the NWT. Height anomalies over the Great Slave region were more than 50 m (Fig. 2). Upper ridge breakdowns are known to be one of mechanisms for lightning and fire starts as they allow weather systems to cross the region.

IV. Fire Conditions

The exceptional nature of the 2014 fire season is illustrated in Figure 3. The spatial distribution in 2014 (Fig. 3a) shows that the area burned was concentrated in the region surrounding Great Slave Lake. Furthermore, the patterns in grey reveal that most of the territory has been impacted by fire at some time. Over the past 26 years, about 245 forest fires have consumed about 570,000 hectares (5,700 km^2) annually. The number of fires and the area-burned are highly variable from year to year (Fig. 3b). The lowest number of fires in this period occurred in 1997 when 105 were started, whereas the highest number of fires (627) occurred in 1994 [National Forestry Database]. Typically, 45% of the fires are lightning caused. During the 2014 season, 385 wildfires burned a record 3.39 million hectares (33,900 km^2). The dominant ignition source was lightning but 17 of these fires were human-caused.

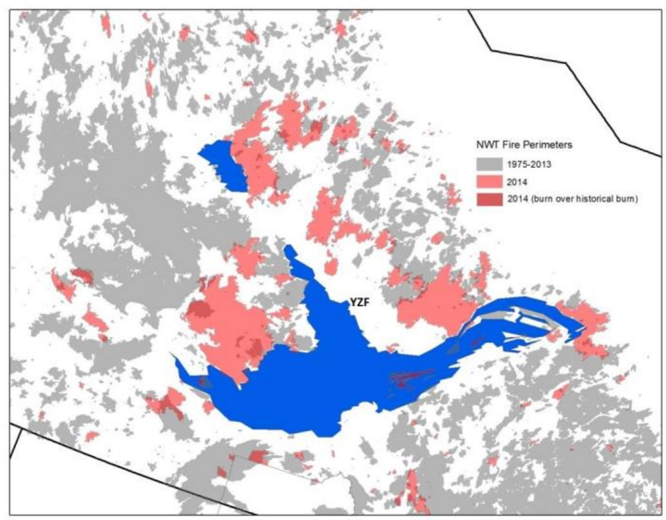

Fig 3a. The area burned by 2014 wildfires (red) in relation to past wildfires from 1975-2013 (grey) over the NWT. The large lake is Great Slave Lake, and Yellowknife (YZF) is situated on the northern shore.

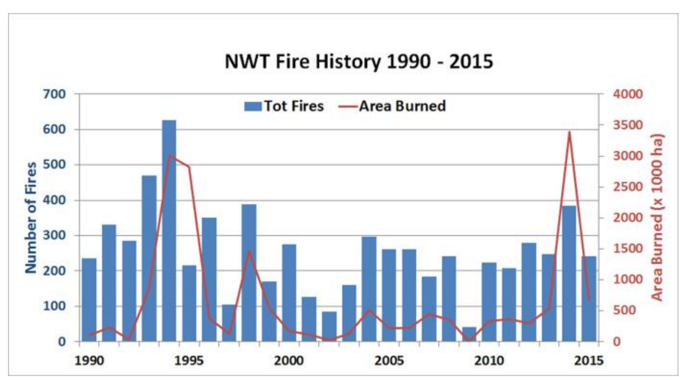

Fig 3b. Annual variation of the number of fires (bars) and area burned (line) from 1990 to 2015 in the NWT.

V. Smoke And Visibility

Smoke from the wildfires led to prolonged periods of reduced visibility, air quality and elevated particulate matter smaller than 2.5 µm (PM2.5) in several regions of the NWT. Hourly ambient concentrations of PM2.5 in the NWT typically range from 0 to 10 µg m^{-3}. The maximum hourly PM2.5 during the season at Yellowknife reached 873 µgm^{-3} in early August (Fig. 4) and exceedances of ambient air quality standards PM2.5 were frequent. During the period from July 19 to August 6 visibilities as low as 0.4 km were reported at the Yellowknife weather station.

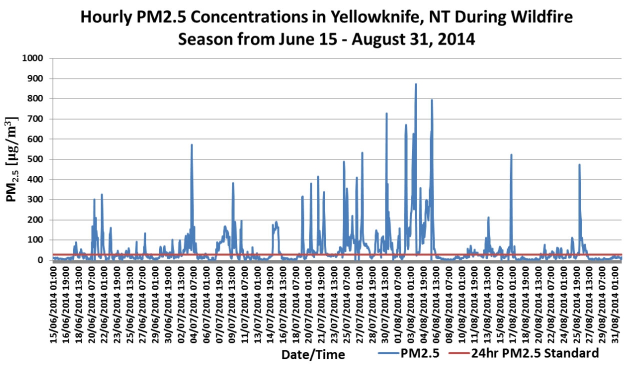

Fig 4. Hourly ambient concentrations of PM2.5 in Yellowknife, NWT from June 15 to August 31, 2014. The red line represents the 28 µgm^{-3} 24hr mean air quality standard for PM2.5.

VI. Lightning

The diurnal cycle of lightning during the summer of 2014 shows both similarities to and differences from climatology (Fig. 5a and 5b). The peak of lightning in the mid-afternoon in 2014 is similar to the climatological cycle. The fraction of positive CGs through the day in the climatological cycle was fairly constant, varying between 13% and 21%. In 2014, that fraction varied between 30% and 32%. There are long hours of daylight in the north and dissipation of thunderstorms can be gradual and storms can linger into the night. Nocturnal activity from 00 to 08 MDT in 2014 was quite different from climatology. The fraction of positive CGs was significantly higher varying from 35% to 53%. Heat from nearby wildfires may have acted to maintain convective activity.

The spatial patterns of lightning day occurrence, lightning density and positive CG activity were noticeably different in 2014 from the average patterns from 2008-2013. Fig. 5c and 5d show the average number of days per year of CG lightning occurrence during the period from 2008 to 2013 and in 2014, respectively. Typically, the southern regions of the NWT experience between 12 and 18 days of lightning per year, generally decreasing to less than 3 days to the north and northeast of GSL. In 2014, these regions experienced an additional 3 to 10 more lightning days.

The flash density pattern during the reference period in Fig. 5e shows that the area between Fort Liard extending eastward and northward to Hay River experiences an average flash density between 0.5 and 0.8 flash km^{-2} y^{-1}. The area northeast of Great Slave Lake typically experiences an average flash density < 0.15 flash km^{-2} y^{-1}. In 2014, the flash density pattern was significantly expanded (Figure 5f); extending eastward to Fort Smith and northward past Wrigley. High flash densities between 1.0 and 1.2 flash km^{-2} y^{-1} occurred near several locations, including Fort Resolution located on the southern edge of GSL, near Buffalo Lake and northwest of Fort Simpson.

Typically, 17% of the CG activity transfers positive charge to the ground in the NWT [Kochtubajda et al, 2010]. The pattern of positive polarity flashes in Fig. 5g shows that the greatest fractions occur in the region southwest of GSL from Hay River to Fort Liard and decrease to the north and northeast. In 2014, the spatial pattern north of GSL was very different (Fig. 5h). The highest fractions (>48%) occurred in the region north to northeast of GSL where smoke from the fires was prevalent.

VII. Conclusions

The extreme fire season experienced in the NWT in 2014 was linked to several factors. The very dry surface conditions in the fall of 2013 continued through the winter and spring and, combined with a persistent high pressure system during the summer, led to record numbers of cloud-to-ground (CG) flashes, lightning-initiated forest fires and area burned. The lightning was linked to synoptic conditions favouring severe storm development, especially those tied to the diurnal cycle. As suggested in previous studies [Lyons et al., 1998; Murray et al., 2000; Kochtubajda et al., 2002; Fernandes et al., 2006; Altaratz et al., 2010; Kochtubajda et al., 2011], there may be a connection between the dense smoke and the ensuing enhancement of positive flashes during the 2014 season.

Acknowledgment

Vaisala Inc. of Tucson, Arizona, USA processes the CLDN data and provides telecommunications services to Environment Canada. The data are the property of Environment Canada. Climate data were obtained from the National Climate Data and Information Archive which is maintained by Environment Canada (http://www.climate.weatheroffice.ec.gc.ca). Fire statistics were obtained from the National Forestry database (http://nfdp.ccfm.org/fires/national_e.php). We thank Lucie Vincent from the Climate Research Branch of Environment Canada for providing the temperature and precipitation anomaly maps.

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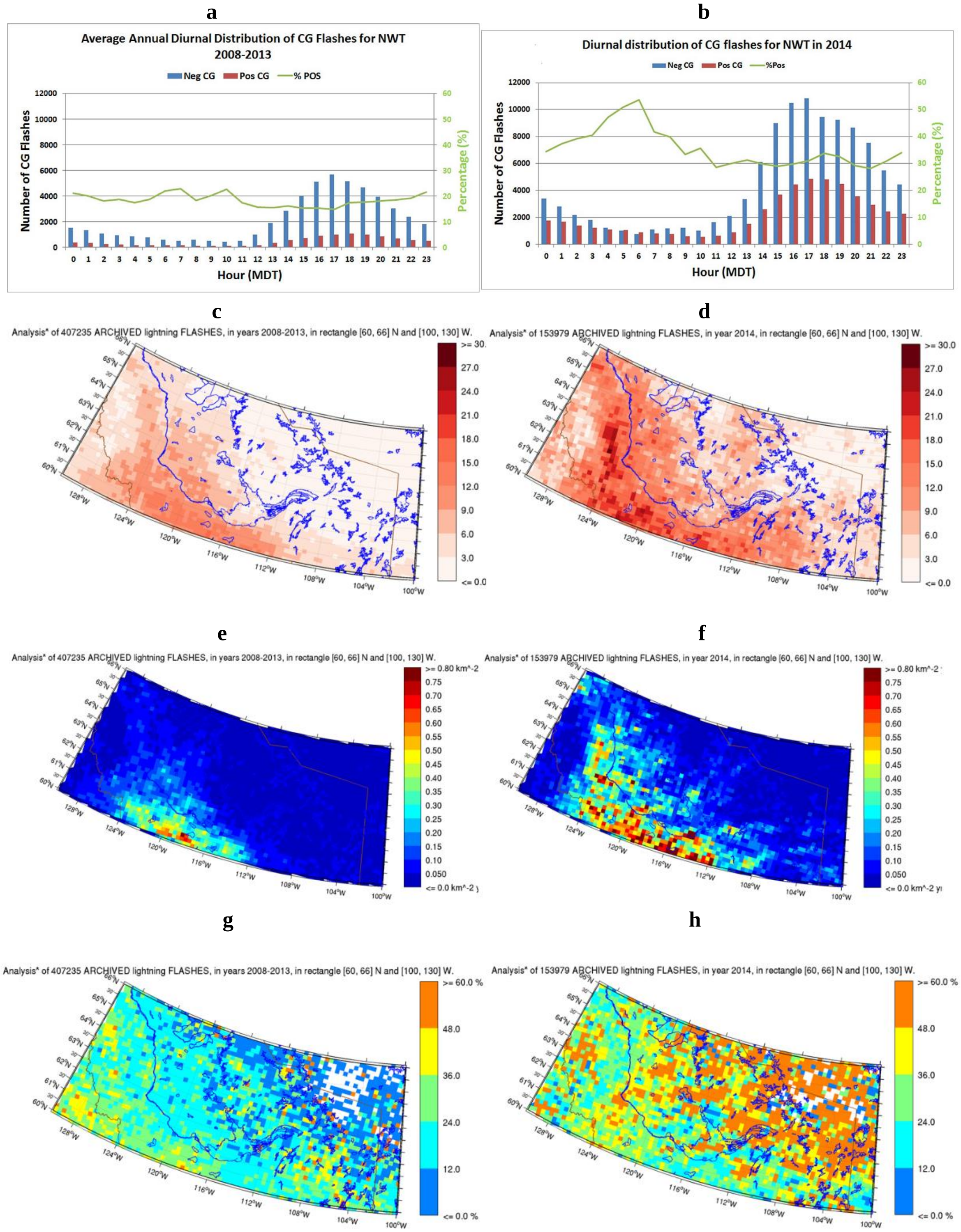

Fig. 5. A comparison of lightning characteristics from climatology and during the 2014 extreme season in the Northwest Territories. The diurnal activity of positive and negative CG flashes and the spatial patterns of the annual average number of lightning days, flash density (flash km^{-2} y^{-1}) and fraction of positive CGs (%) for the period 2008-2013 (a, c, e, g, respectively) and for 2014 (b, d, f ,h, respectively). The resolution of each grid cell is 20 km by 20 km.