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# The pyrogeography of eastern boreal Canada from 1901 to 2012 simulated with the LPJ-LMfire model

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## Supplementary materials

**Supplement S1.** Reconstruction of the density of monthly lightning flashes ($Lm$) (n/day/km$^2$) from 1901 to 2012.

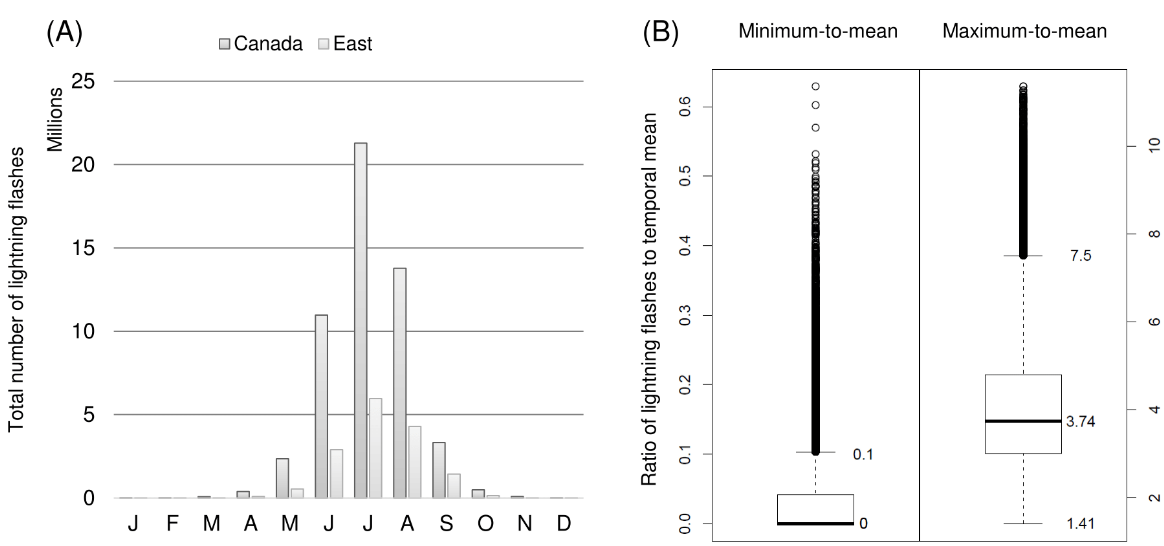
$$[1]\ coef = \max(|\max(\int_t CAPEano)|, |\min(\int_t CAPEano)|)$$

$$[2]\ CAPEano_N = {}^{CAPEano}/_{coef}$$

$$[3]\ Lm = \begin{cases} CLDNm * (1 + 7.5 * CAPEano_N), & CAPEano_N \geq 0 \\ CLDNm * (1 + 0.1 * CAPEano_N), & CAPEano_N < 0 \end{cases}$$

CAPE anomalies ($CAPEano$) correspond to monthly differences at the grid cell level at time *t* compared with the average of monthly CAPE from 1961 to 1990. For each grid cell, the time-series of $CAPEano$ was normalized to a range between -1 and 1 ($CAPEano_N$) by dividing $CAPEano$ by the maximum value between the absolute value of the largest positive and negative CAPE anomalies of the time-series (eq. [1] and [2]). Monthly flash density (/km$^2$/month) between 1901 and 2012 was calculated on the base of monthly flash climatology between 1999 and 2010 ($CLDNm$), but interannual flash variability was applied using $CAPEano_N$ and min-to-mean and max-to-mean ratios (eq. [3]). We determined min-to-mean and max-to-mean ratios (0.1 and 7.5, respectively; Fig. S1B) by compiling grid cell values of the CLDN database with more than 5 years of observations in July between 1999 and 2010 across Canada within our study area (Fig. S1A).

**Fig. S1.** (A) Total number of monthly flashes in Canada and eastern Canada (our study area) from 1999 to 2010. (B) Box plots of minimum-to-mean and maximum-to-mean ratios for flashes in July from 1999 to 2010 based on 60,747 grid cells in Canada with more than 5 years of observations.



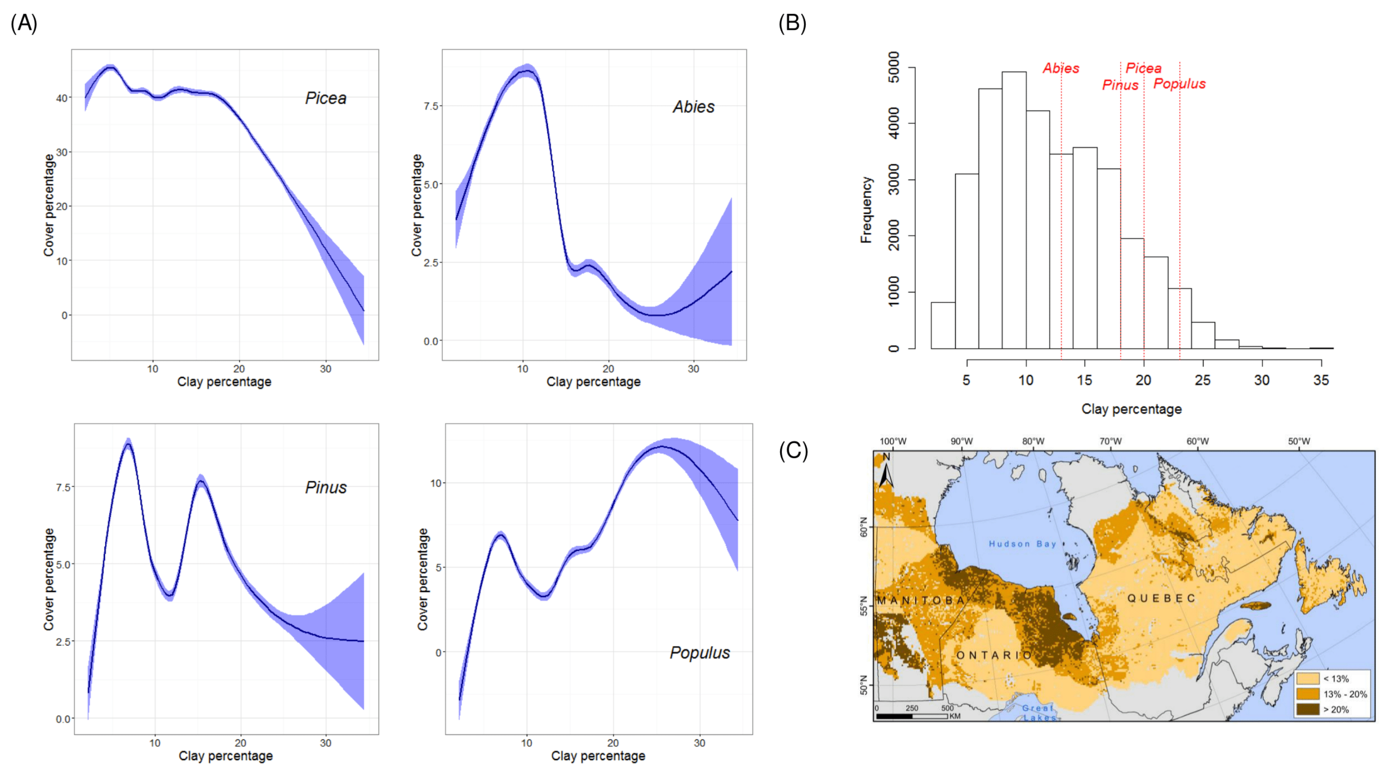
## Supplement S2

**Table S1.** LPJ-LMfire PFT parameter values used in this study (boreal needleleaf and broadleaf tree parameters values from Pfeiffer et al. (2013) were assigned for the others parameters not presented in this table).

| Parameters | | Genus-specific PFT | | | | References |
|---|---|---|---|---|---|---|
| | | *Picea* | *Abies* | *Pinus* | *Populus* | |
| **Growth form and phenology** | Fraction of roots in upper soil layer (50 cm) | 0.9 | 0.5 | 0.5 | 0.3 | Natural Resources Canada 2017 and US Forest Service |
| | Sapwood turnover period | 20 | 40 | 20 | 30 | |
| | Leaf to root ratio under non water-stressed conditions | 0.190 | 0.165 | 0.165 | 0.14 | Poorter et al. (2012) |
| | Broadleaf phenology ramp GDD5 requirement to grow to full-leaf canopy | 800 | 1400 | 766 | 180 | Girardin et al. (2011) |
| | Sapling (or grass on initialization) LAI | 3.4 | 9.3 | 4.4 | 3.2 | Calculated from Iio et al. (2014) |
| **Bioclimatic limits and climatic preferences** | Min./Max. temperature of the coldest month for establishment (ºC day) | -31.65/-6.80 | -25.25/-4.85 | -29.25/-9.15 | -29.30/3.70 | |
| | Min GDD5 for establishment (ºC day) | 300 | 400 | 550 | 345 | Thompson et al. (1999) |
| | Max. temperature of the warmest month to persist (ºC day) | 20.70 | 20.65 | 20.60 | 24.85 | |
| **Individual parameters** | Crown length | 1 | 1 | 0.4 | 0.5 | Derived from Groot and Schneider (2011) and Hély et al. (2003) |
| | Bark thickness | 0.032 | 0.031 | 0.040 | 0.027 | Andrews et al. (2005) |
| **Fire resistance** | Crown damage parameter | 1 | 3 | 2 | 0.2 | *Personal communications* |

## Supplement S3

**Fig. S2.** (A) Local polynomial regression (with 95% confidence interval (CI)) between genus-specific cover percentage from Beaudoin et al. (2014) and clay percentage from Hengl et al. (2014) in eastern boreal Canada. Only grid cells with a total cover greater than 10% for the four species studied were taken into account in these analyses. (B) Clay percentage distribution in eastern boreal Canada. Each vertical red line corresponds to the upper limit of the 90% CI of the clay percentage distribution for each PFT. (C) Map of clay percentage in eastern boreal Canada with threshold of the upper limit of the 90% CI of the distribution of clay percentage for the *Abies* and *Picea* PFTs.



## Supplement S4

**Fig. S3.** Location of stand-replacing fire history studies in eastern Canada with correspondence ID number to Table S2.

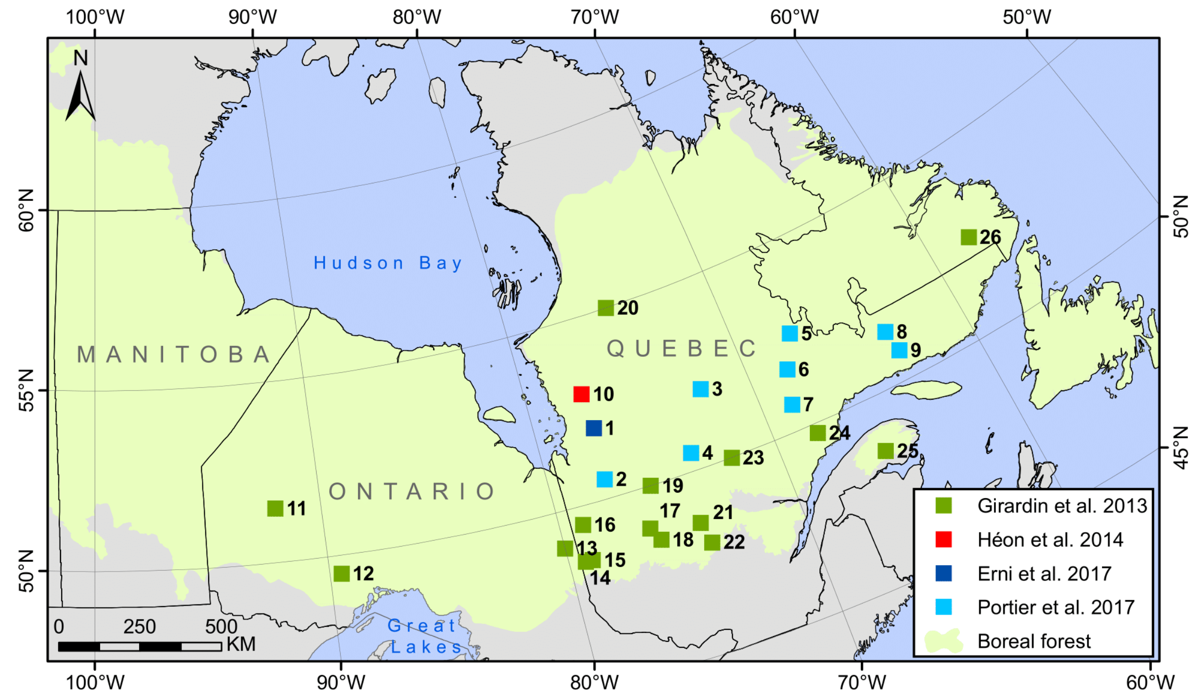
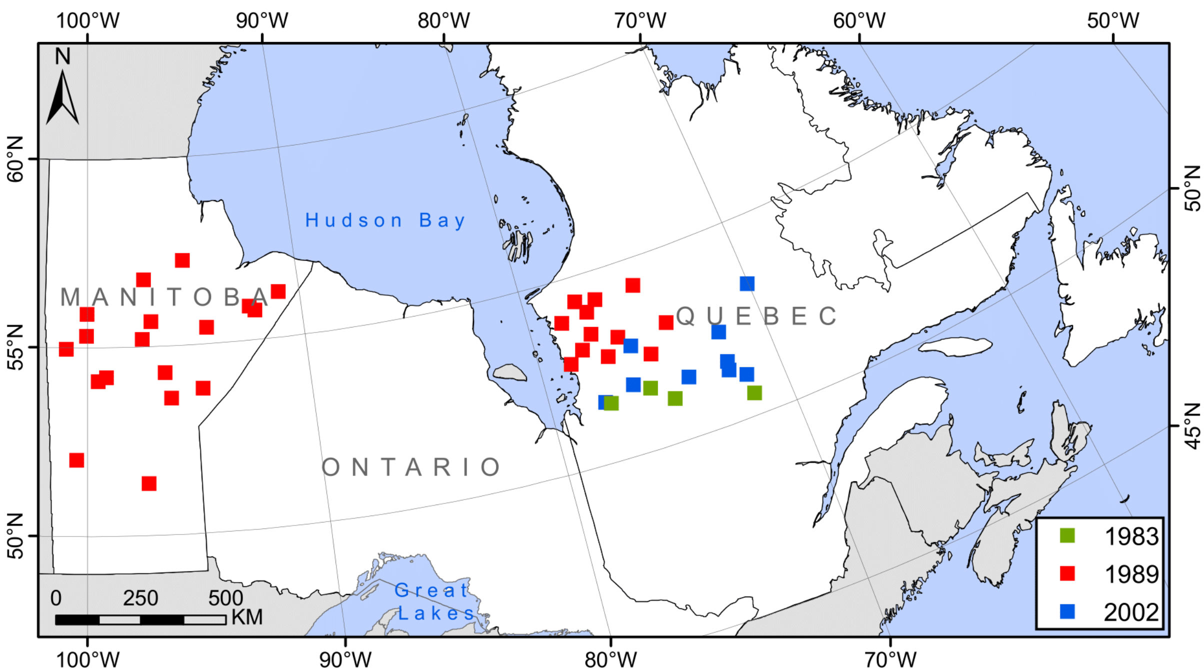


**Table S2**. Observed versus LPJ-LMfire-simulated annual burn rates (with 2.5 and 97.5 percentiles) from stand-replacing fire history studies from 1911 to 2012. Significant differences are underlined.

| ID | Time | Localization | | Observed | Simulated | References |
|---|---|---|---|---|---|---|
| 1 | 1911 - 2012 | A | North | 4.875 (3.119 – 10.642) | 0.384 (0.175 – 0.773) | Portier et al. (2016) (originated from Erni et al. (2017)) |
| 2 | | | South | 0.637 (0.410 – 1.030) | 0.427 (0.211 – 0.768) | Portier et al. (2016) |
| 3 | | B | North | 3.190 (1.462 – 11.151) | 0.345 (0.069 – 0.752) | |
| 4 | | | South | 0.477 (0.323 – 0.762) | 0.484 (0.231 – 0.879) | |
| 5 | | C | North | 2.859 (2.110 – 4.827) | 0.186 (0.043 – 0.373) | |
| 6 | | | Center | 0.354 (0.177 – 0.791) | 0.199 (0.042 – 0.458) | |
| 7 | | | South | 0.146 (0.070 – 0.326) | 0.262 (0.054 – 0.597) | |
| 8 | | D | North | 1.761 (0.923 – 3.800) | 0.163 (0.026 – 0.373) | |
| 9 | | | South | 0.129 (0.052 – 0.386) | 0.151 (0.025 – 0.362) | |
| 10 | 1910-2013 | James Bay | | 2.400 | 0.415 (0.164 – 0.835) | Héon et al. (2014) |
| 11 | ~1870-1974 | Northern Ontario | | 1.920 | 0.648 (0.335 – 1.164) | Girardin et al. (2013) |
| 12 | unknown -2000 | Lake Nipigon | | 0.711 | 0.689 (0.379 – 1.116) | |
| 13 | 1740-1998 | LAMF | | 0.580 | 0.466 (0.000 – 0.855) | |
| 14 | ~1750-1988 | Western Quebec | | 0.720 | 0.414 (0.000 – 0.726) | |
| 15 | 1580-2000 | Western Abitibi South | | 0.334 | 0.415 (0.000 – 0.753) | |
| 16 | 1530-1996 | Western Abitibi North | | 0.604 | 0.531 (0.297 – 0.892) | |
| 17 | 1770-1995 | Eastern Abitibi | | 0.708 | 0.435 (0.226 – 0.746) | |
| 18 | 1760-1998 | Abitibi East | | 0.900 | 0.441 (0.241 - 0.747) | |
| 19 | 1720-2000 | Waswanipi | | 0.812 | 0.439 (0.238 – 0.788) | |
| 20 | 1920-1984 | Northern boreal | | 1.000 | 0.196 (0.074 – 0.378) | |
| 21 | 1720-1998 | Central Quebec 2 | | 0.665 | 0.513 (0.224 – 1.067) | |
| 22 | 1720-1998 | Central Quebec | | 0.790 | 0.505 (0.192 – 0.930) | |
| 23 | unknown-2000 | Lac-Saint-Jean | | 0.286 | 0.411 (0.093 – 0.791) | |
| 24 | 1640-2000 | North Shore | | 0.367 | 0.272 (0.048 – 0.555) | |
| 25 | 1680-2000 | Gaspésie | | 0.643 | 0.150 (0.000 – 0.419) | |
| 26 | 1870-1975 | Southeastern Labrador | | 0.200 | 0.124 (0.000 – 0.272) | |

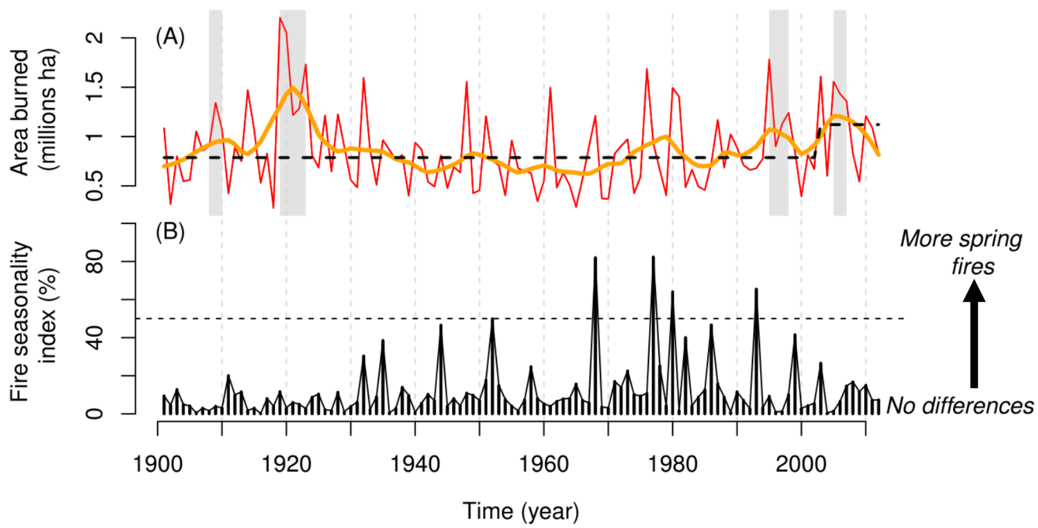
## Supplement S5

**Fig. S4.** Location of fires exceeding 50,000 ha in eastern Canada for three years of extreme fire activity.



**Supplement S6**

**Fig. S5.** (A) Time-series of total annual area burned from 1901 to 2012. Gray blocks correspond to periods with at least three years of annual area burned above the mean annual burn rates for the 1901-2012 period. Orange line corresponds to smoothing values using a LOESS function (span = 0.15). Black dashed line corresponds to the weighed means of the regimes obtained by the sequential application of Student's t-test. (B) Percentage of differences between spring and summer total area burned (called fire seasonality index; FSI) from 1901 to 2012. Black dashed line corresponds to FSI equal to 50%.



## Supplement S7

**Fig. S6.** LPJ-LMfire NPP (T/ha/yr) simulated across eastern boreal Canada with (A) ‘Climate + $CO_2$’ and (B) ‘Climate-only’ experiments through five periods from 1911 to 2012. (C) Percentage of increase in NPP due to the $CO_2$ effect.

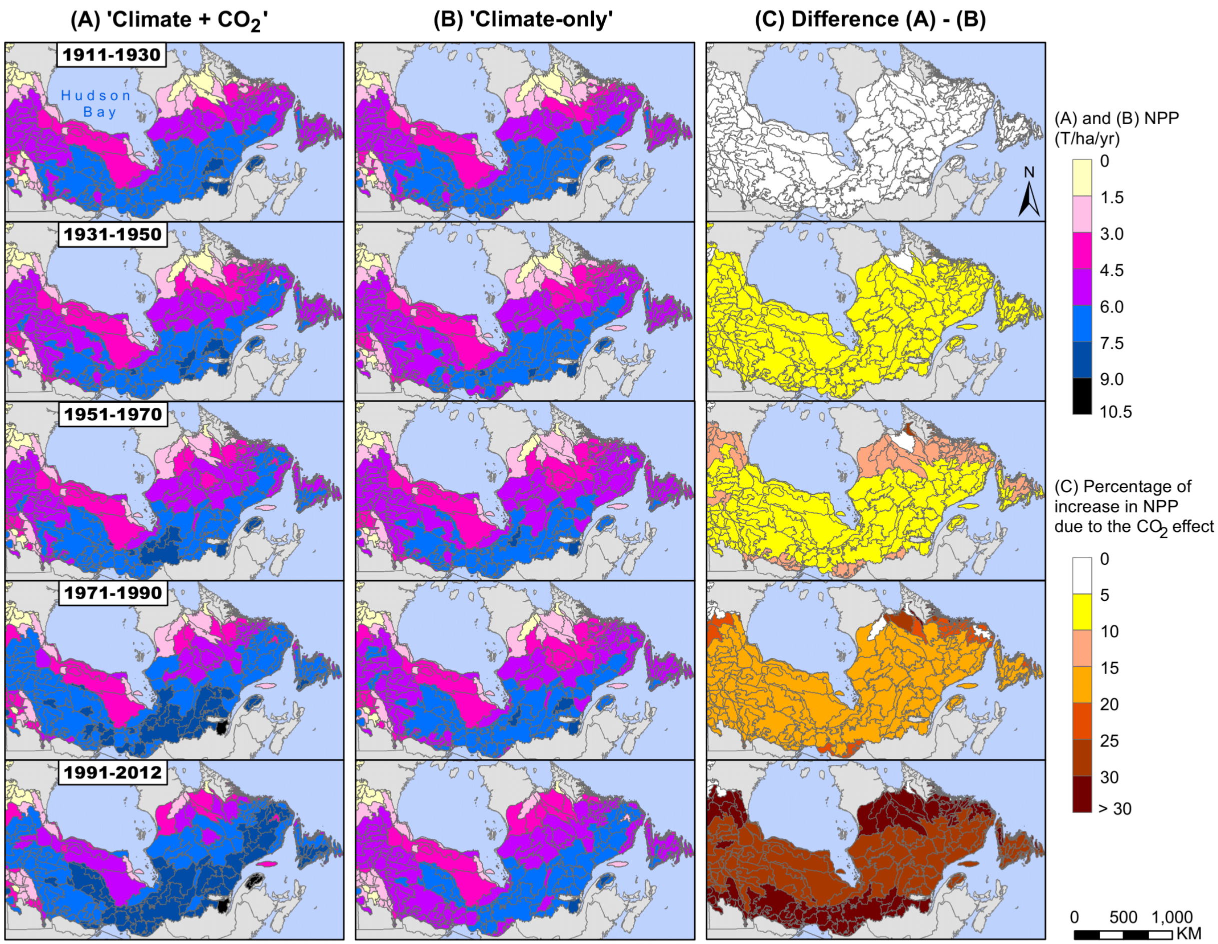
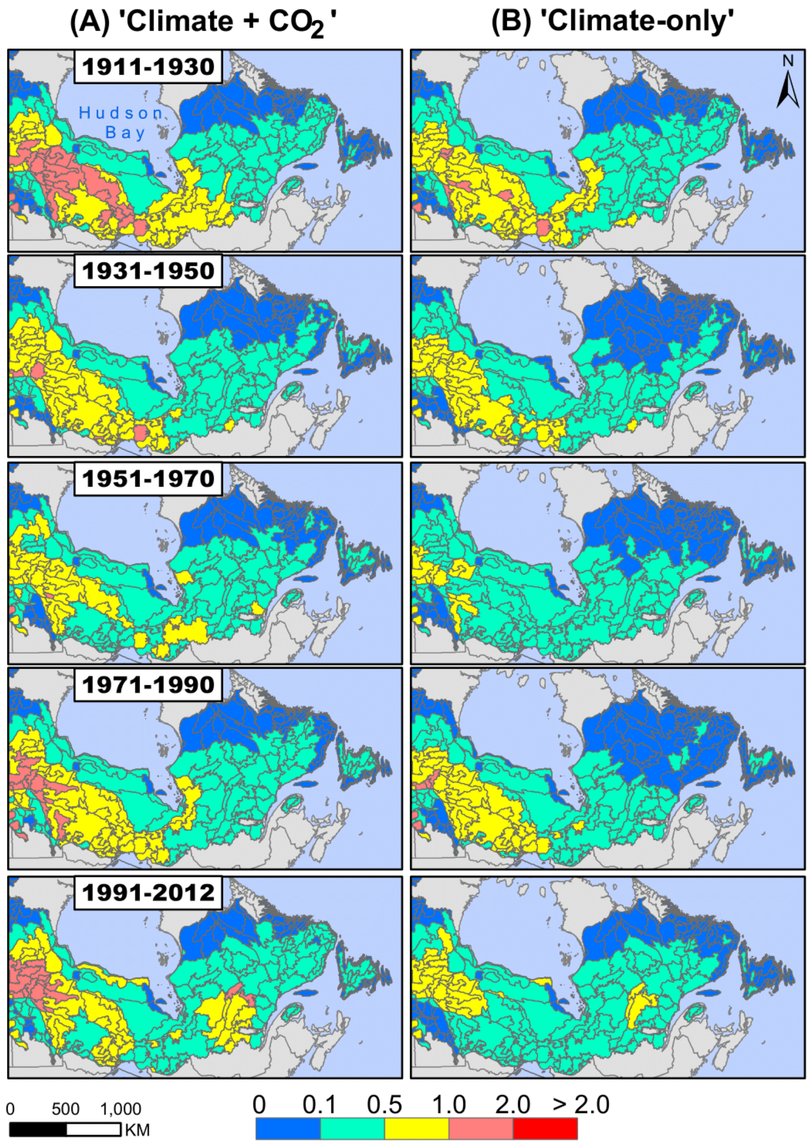
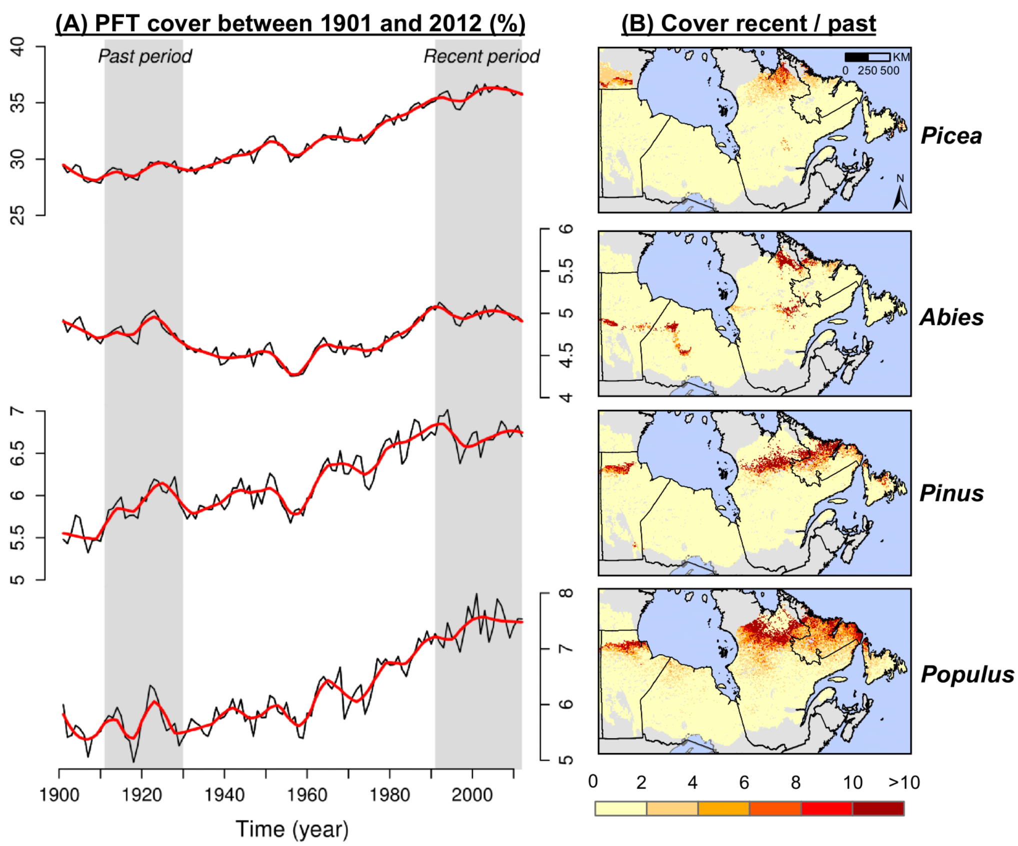


**Fig. S7.** LPJ-LMfire annual burn rates (%) simulated across eastern boreal Canada with 'Climate + $CO_2$' and 'Climate-only' experiments through five periods from 1911 to 2012.



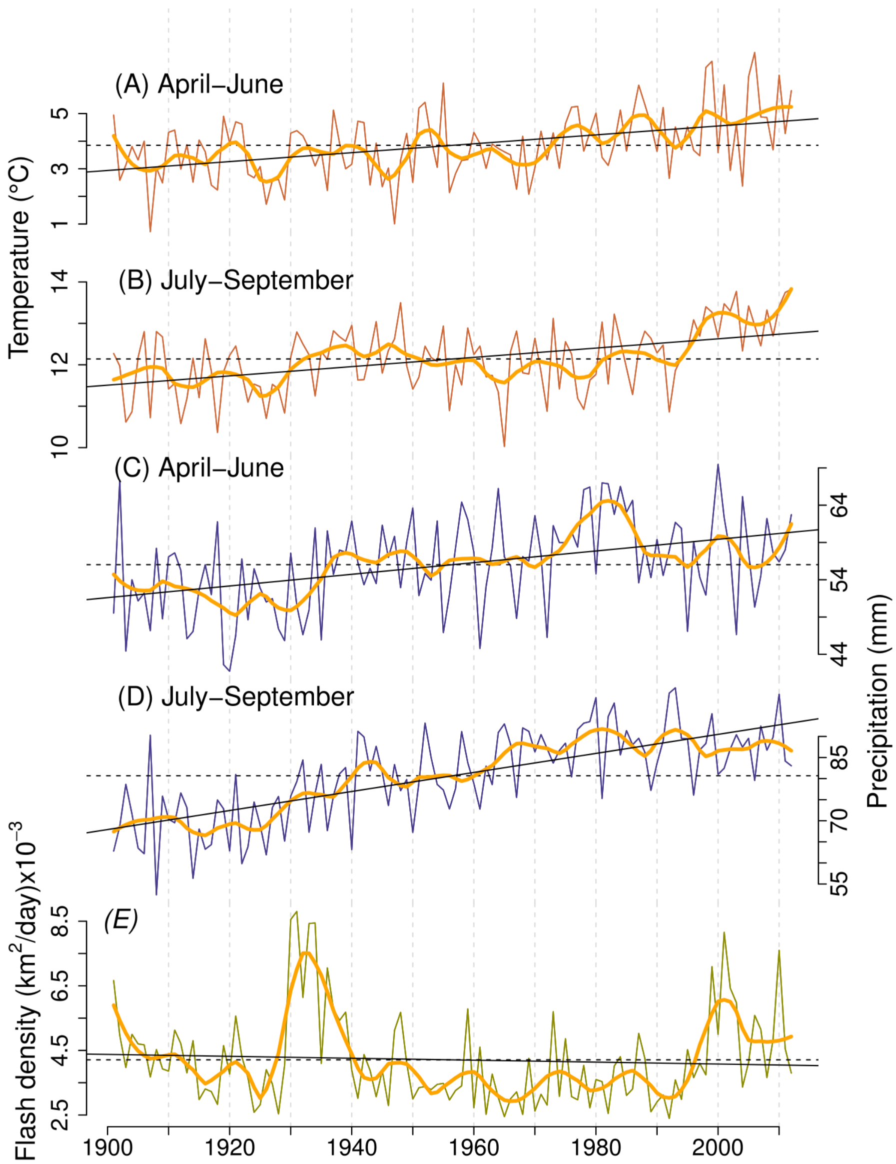
## Supplement S8

**Fig. S8.** (A) Average of cover percentage for each PFT in eastern boreal Canada from 1901 to 2012. Red line corresponds to smoothing values using a LOESS function (span = 0.15). (B) Ratio of cover percentage between a recent period (1911-1930) and a past period (1991-2012). The two periods correspond to the grey background on (A).



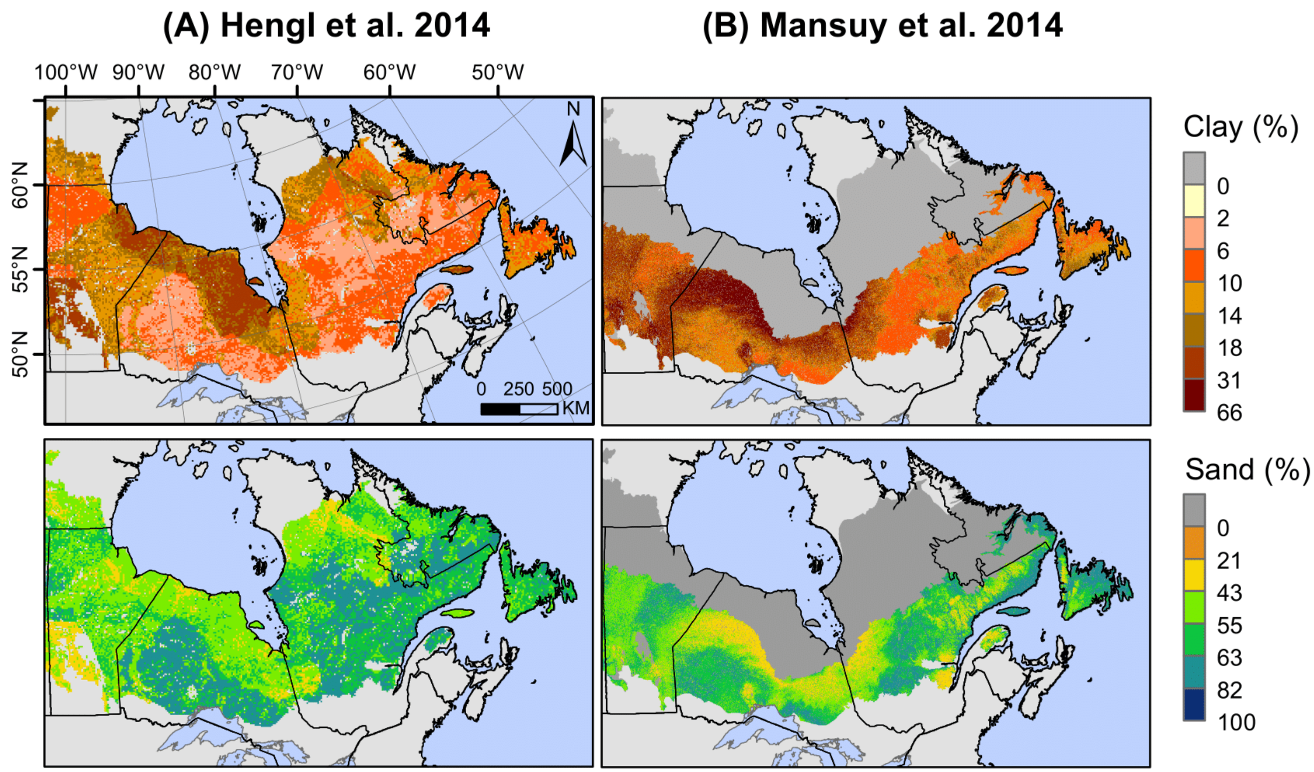
**Supplement S9**

**Fig. S9.** Temporal series of (A) spring and (B) summer mean temperatures, (C) spring and (D) summer mean precipitation, and (E) mean flash density. Black dashed lines, black full lines and orange lines correspond to the mean, regression lines, and smoothing values using a LOESS function (span = 0.15), respectively, for each time-series.



**Supplement S10**

**Fig. S10.** Percentage of clay and sand in the mineral horizons across eastern boreal Canada at a 10-km resolution from (A) Hengl et al. (2014) (0-30 cm depth) and (B) Mansuy et al. (2014) (0-15 cm depth).



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