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Canada

Updates to Version 4 of the Biogenic Emissions Landuse Database (BELD4) for Canada and Impacts on Biogenic VOC Emissions

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Presentation Outline

- Motivation for this study
- Issues with previous BELD3 database for Canada
- Overview of the first version of the Canadian BELD4 databse (based on 2001 Cdn national forest inventory)
- Updates to the Canadian BELD4 database based on the 2011 Canadian national forest inventory
- Impacts on biogenic emissions using the BELD4 database
- Conclusions

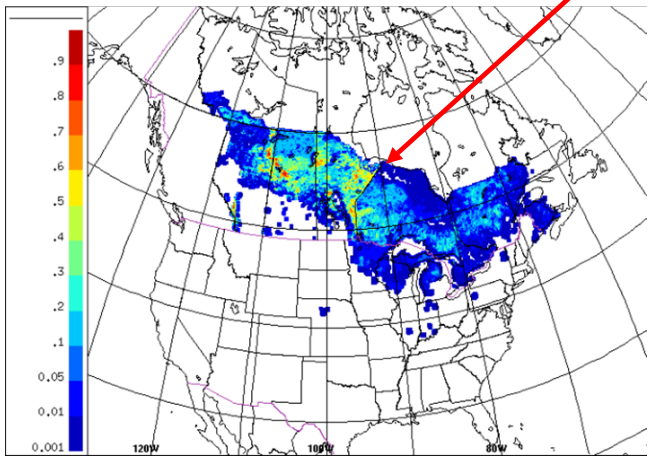
Motivation

- Terrestrial vegetation accounts for 80-90% of global VOC emissions
- The Biogenic Emissions Landuse Database, Version 3 (BELD3), which contains 230 vegetation classes at 1-km resolution, was compiled for most of North America based on early 1990's satellite imagery (Pierce et al., 2000) and has been widely used for estimating biogenic emissions
- Issues have been identified with the BELD3 database for Canada
- In 2013 the U.S. EPA updated BELD from V3 to V4 with 286 landuse categories for the contiguous United States, but only 17 broad landuse types based on MODIS satellite retrievals for Canada and Mexico
- In 2018 a U.S.-equivalent BELD4 database was extended to Canada to address the issues found in BELD3; this database has now been updated based on a newer forest inventory

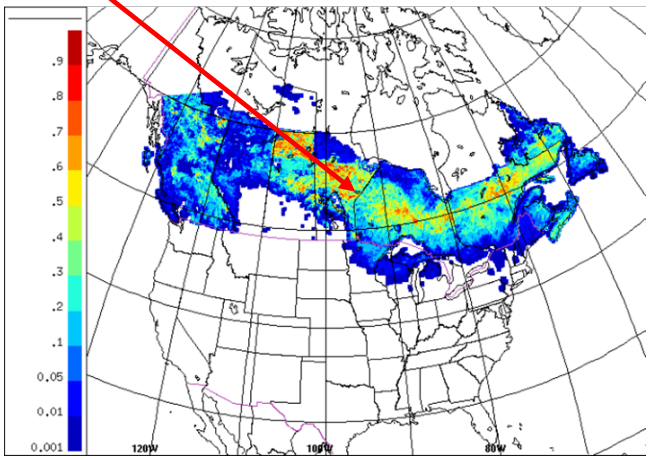
Issues with BELD3 Database for Canada (1)

- In Canada, provincial and territorial agencies are responsible for their own forest inventories. Discontinuities were often seen at the provincial/territorial borders as a result

Jack Pine



Black Spruce



- Discontinuities were also seen at the international border between Canada and the U.S. due to different input data sources
- The “unknown” species, which has zero emissions, was present as a large fraction in eastern Canada

Issues with BELD3 Database for Canada (2)

- Vegetation data were outdated for areas with rapid development, such as the Athabasca Oil Sands area in northeastern Alberta
- BELD3 was used to generate biogenic emissions for older versions of BEIS model such as BEIS3.09, which only accounts for three VOC species (isoprene, monoterpenes, and other VOCs) and NO
- BELD4 was compiled for use with newer versions of the BEIS model such as BEIS 3.60, which considers 35 different species/compounds
- To better estimate biogenic emissions using the newer versions of the BEIS model, the Canadian BELD database needs to be updated from version 3 to version 4.

First Version of Canadian BELD4 Database

- A unified Canadian National Forest Inventory (NFI) was compiled collaboratively by federal, provincial and territorial government agencies (https://nfi.nfis.org/en)
- Beaudoin et al. (2014) produced the FIRST Canada-wide forest maps (V0) based on 2001 MODIS imagery at 250 m resolution with109 specific or generic tree species
- A Canadian Annual Crop Inventory (ACI) is compiled by Agriculture and Agri-Food Canada (AAFC), which includes 71 codes/species, of which 66 are for crops (http://www.agr.gc.ca/atlas/aci)
- Annual ACI data are available from 2013 to present for all provinces of Canada at 30 m resolution.
- The 2001 NFI forest maps and 2016 ACI dataset were used to create the first version of the Canadian BELD4 database, which was presented at the 2018 CMAS Conference and published on line at https://zenodo.org/record/2231047#.XSIfe497mM8.

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Extension of Version 4 of the Biogenic Emissions Landuse Database (BELD4) to Canada

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INTRODUCTION AND MOTIVATION

- Terrestrial vegetation is an important source of VOC emissions to the atmosphere, accounting for 80-90% of total global VOC emissions.
- Landuse data with detailed vegetation types at relatively high resolution are needed to accurately estimate biogenic VOC emissions.
- The Biogenic Emissions Landuse Database, Version 3 (BELD3), which contains 230 vegetation classes at 1-km resolution, was compiled for most of North America based on early 1990's satellite imagery (Pierce et al., 2000) and has been used widely for estimating biogenic emissions.
- Issues with BELD3 have been identified for Canada, such as less detailed crop species, large region of unknown tree species with zero emissions in eastern Canada, and discontinuities at the international and provincial borders for some species (Fig. 1).
- The U.S. EPA recently updated BELD from V3 to V4 with 286 landuse categories for the contiguous United States (https://www.epa.gov/air-emissions-modeling/biogenic-emission-sources). However, this new database only contains 17 broad landuse types based on MODIS satellite retrievals for Canada and Mexico (Fig. 2),
- A U.S.-equivalent of the BELD4 dataset has now been extended to Canada.

Issues with BELD3 for Canada: Examples

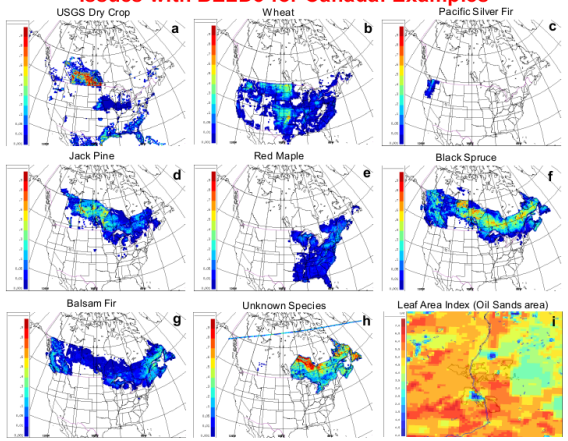

Figure 1. Examples of issues with the BELD3 data for Canada: (i) detailed crop types not available for some Canadian provinces (Panels 1a and 1b); (ii) discontinuities at international and provincial borders (Panels 1c, 1d, 1e, and 1f) and discontinuities within provinces (Panel 1f); (iii) unrealistic coverage of some tree species for some areas, such as Balsam Fir and Black Spruce for the province of British Columbia (Panels 1f and 1g); (iv) large fraction of unknown species in eastern Canada with zero emissions (Panel 1h); and (V) vegetation outdated for the Ca

Limitations of EPA BELD4 for Canada and Mexico: Examples

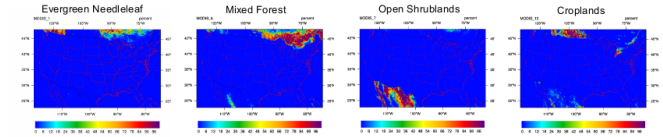

Figure 2. Examples of non-specific vegetation classes in the current EPA BELD4 database over the CMAQ CONUS 12km domain. Broad MODIS-based tree and crop classes are used for Canada and Mexico, which will result in incorrect biogenic emissions for Canadian and Mexican parts of the domain.

INPUT DATA SETS

➢ Canadian Annual Crop Inventory (ACI)

- Compiled by Agriculture and Agri-Food Canada (AAFC) (http://www.agr.gc.ca/atlas/aci); includes 71 codes/species, of which 66 are for crops
- Annual data available from 2013 to present for all provinces of Canada at 30m resolution; uses dominant species, does not cover entire country

➢ Canadian National Forest Inventory (NFI)

- Compiled collaboratively by federal, provincial and territorial government agencies (https://nfi.nfis.org/en)
- Canada-wide inventory was created using Nearest Neighbour (kNN) mapping method based on 2001 MODIS imagery at a resolution of 250m x 250m (Beaudoin et al., 2014); considers multiple species per grid cell, does not consider non-treed areas

METHODOLOGY AND RESULTS

- ➢ Original ACI data at 30m resolution were aggregated to 990m resolution and then resampled to 1km resolution to be consistent with the EPA BELD4 resolution
- ➢ Original NFI data at 250m resolution were aggregated to 1km resolution
- ➢ Sums of processed 1km resolution ACI and NFI data are larger than unity for some grid cells due to "double counting" of ACI and NFI databases (Fig. 3)
- ➢ Merged ACI and NFI data were finalized by renormalizing the grid cells with total fractional coverage larger than unity of summed ACI and NFI species (Fig. 4)
- ➢ Example plots of individual species fields are shown in Fig. 5

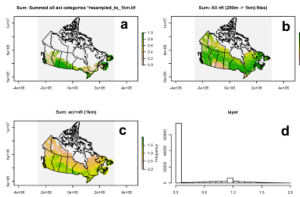

Figure 3. Sum of initial 1-km (a) ACI species, (b) NFI species, (c) total ACI and NFI species, and (d) histogram of the sum of ACI and NFI species.

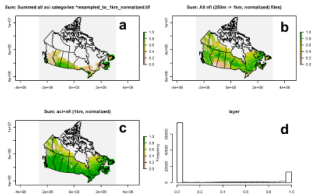

Figure 4. The same as Fig.3, but after normalization for grid cells with total fractional coverage of ACI+NFI species larger than unity.

New Canadian + EPA BELD4: Examples

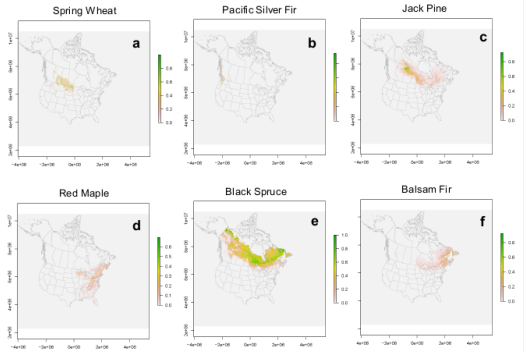

Figure 5. Examples of individual crop and tree species in the newly compiled BELD4 database with updated and improved Canadian landuse data: (i) detailed crop types match well with the EPA BELD4 data (Fig. 5a); (ii) discontinuities at international and provincial borders have largely disappeared and discontinuities within provinces are almost all entirely resolved (Figs. 5b, 5c, 5d, and 5e); (iii) significant improvement for spatial extent of Balsam Fir and Black Spruce, particularly for the province of British Columbia (Figs. 5e and 5f).

SUMMARY

- U.S.-equivalent Canadian BELD4 database has been compiled based on the most recent Canadian crop and forest inventories
- Many existing issues with the BELD3 data for Canada were solved (Fig. 1 vs. Fig. 5)
- There are still areas for further improvement. For example, the 2001-MODIS-imagery-based Canadian national forest inventory is outdated for areas undergoing rapid development, such as the Canadian Athabasca Oil Sands area (Fig. 6)

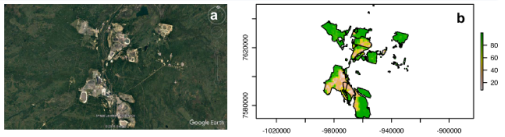

Figure 6. (a) Recent Google Earth image of the seven Athabasca Oil Sands mining facilities (light colored areas) and (b) total vegetation coverage over the same mining facilities based on the new Canadian BELD4 database which does not account for the mines opened after 2001, although it is better than BELD3 (cf. Fig. 1i).

REFERENCES

- Pierce et al., 2000, Development of a 1-km vegetation database for modeling biogenic fluxes of hydrocarbons and nitric oxide. *Sixth International Conference on Air Surface Exchange of Gases and Particles*, July 3-7, Edinburgh, https://www.epa.gov/sites/production/files/2015-08/beld3_web.ppsx
- Beaudoin, A., et al., 2014, Mapping attributes of Canada's forests at moderate resolution through kNN and MODIS imagery, *Can. J. For. Res.*, **44**, 521–532, dx.doi.org/10.1139/cjfr-2013-0401

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Dataset Open Access

U.S.-EPA-BELD4-Equivalent Landuse Database for Canada

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Volatile organic compounds (VOCs) released from terrestrial vegetation are an important source of VOC emissions to the atmosphere. Globally, natural sources of VOC emissions have been estimated to be much larger than anthropogenic sources and to account for 80-90% of total global VOC emissions. The accurate estimation of biogenic VOC emissions requires input of landuse data with a detailed description of vegetation types at high resolution. The Biogenic Emissions Landuse Database, Version 3 (BELD3), which contains 230 vegetation classes at 1-km resolution, was compiled by the U.S. Environmental Protection Agency (EPA) for most of North America (Pierce et al., 2000) and has been widely used by many regional air quality models for the last two decades to estimate biogenic emissions. However, some of the BELD3 vegetation fields were based on satellite imagery from the early 1990s and are now outdated for many parts of North America, particularly for areas undergoing rapid, large-scale development. In addition, since the release of the BELD3 database a few issues have been identified for the Canadian part of the BELD3 database, such as (1) detailed crop types not being available for some Canadian provinces, (2) discontinuities at international and provincial borders and discontinuities within Canadian provinces, (3) unrealistically large coverage of some tree species for some areas, such as balsam fir and black spruce for the province of British Columbia, and (4) a large and questionable fraction of unknown tree species in eastern Canada that will have zero emissions.

Recently, the U.S. EPA updated BELD from Version 3 to Version 4 (BELD4), with 286 landuse categories at 1-km resolution (see https://www.epa.gov/air-emissions-modeling/biogenic-emission-sources). However, these updates were mostly

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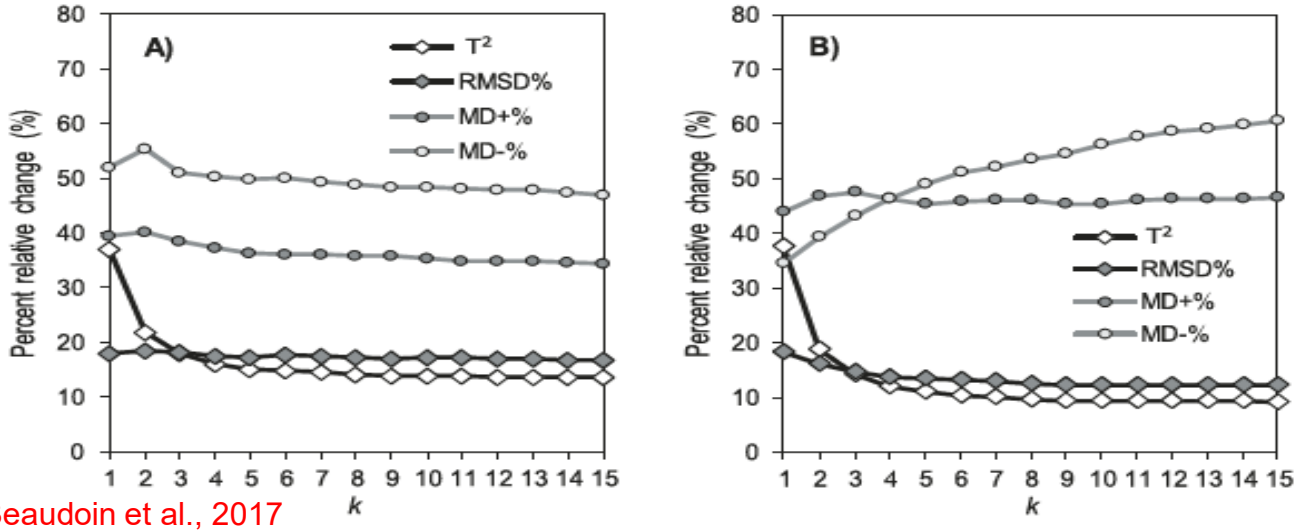
Updates to Canadian BELD4 Database (1)

- 2011-based Canadian forest maps (V1) were released in 2017 (Beaudoin et al., 2017)
- An improved mapping approach was used to reprocess the 2001 forest inventory and to create the inventory for 2011
- The new approach significantly increased the correlation coefficient and decreased the mean deviation (MD) and root mean square deviation (RMSD)

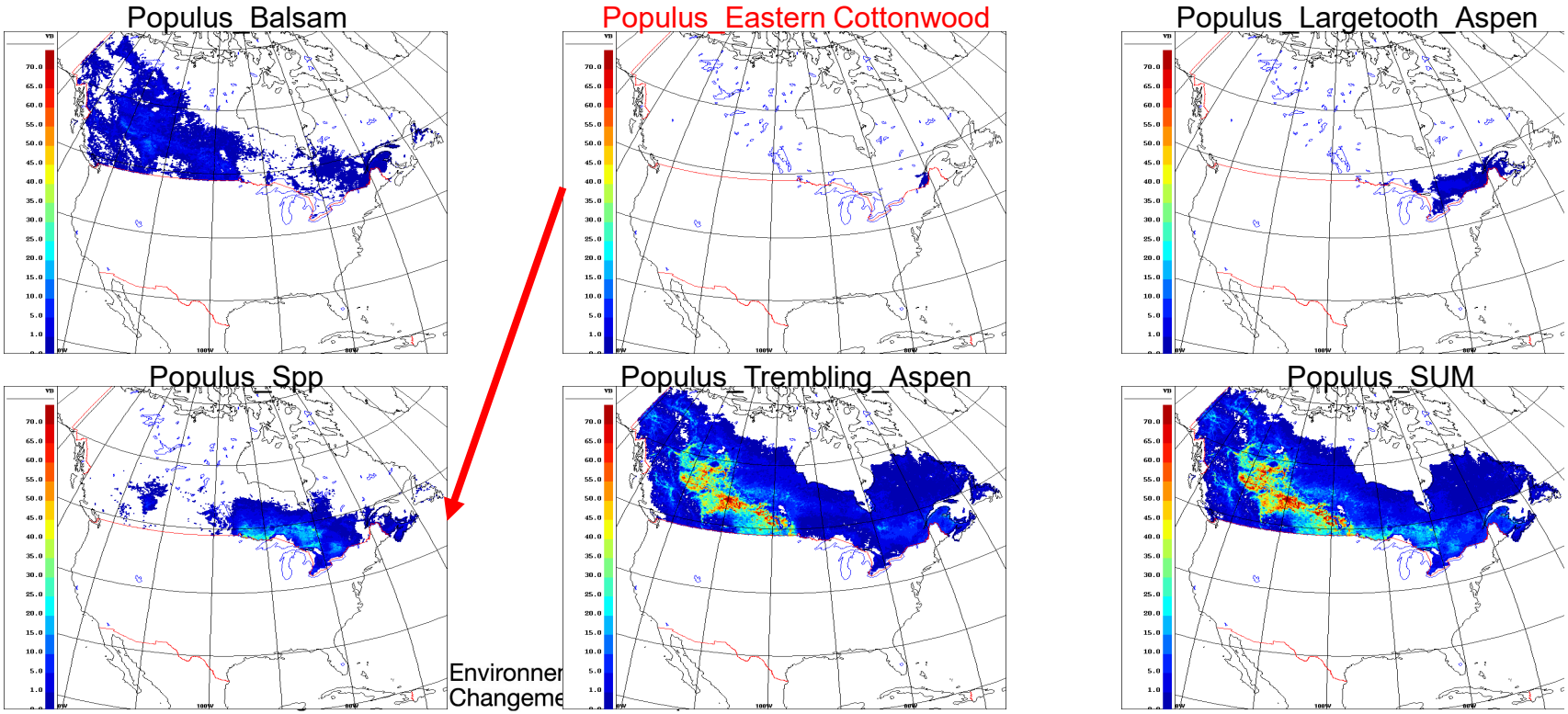
Fig. 2. Percent relative change (%) as a function of *k* for four multivariate error metrics derived from the new 2001 *k*NN process relative to the initial 2001 process from Beaudoin et al. (2014): (A) unstratified predictions and (B) stratified predictions. Values of percent relative change are positive for an increase in T^2 or a decrease in the other three measures.



From: Beaudoin et al., 2017

Updates to Canadian BELD4 Database (2)

- Number of tree species was reduced from 109 in the first version to 75 in the second version due to the least abundant species with small sample sizes being lumped with other related species; e.g., one type of Populus, eastern cottonwood, was lumped to a generic Populus species, Populus spp., in the updated version

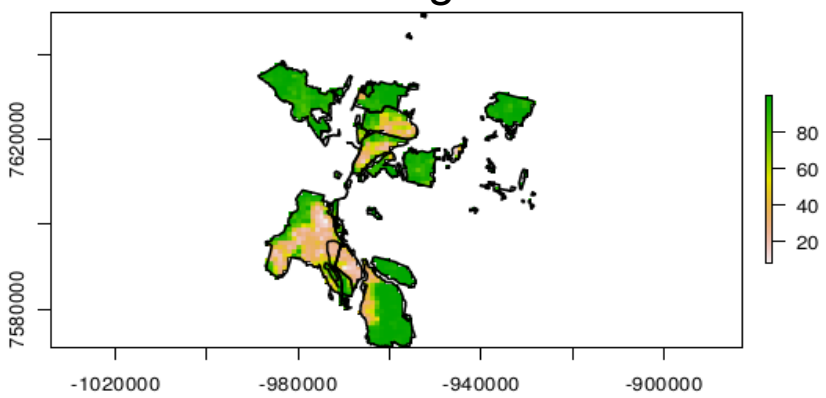


Changes to the Athabasca Oil Sand Area

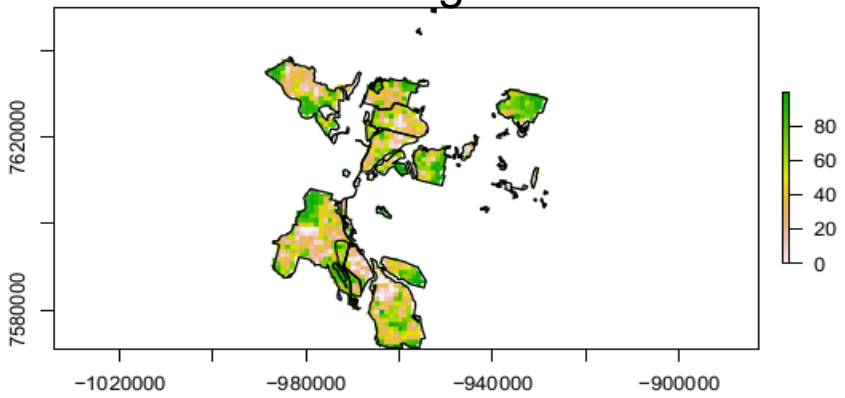
Dec. **2001** Google Earth Image

Dec. **2011** Google Earth Image

Total tree coverage: **2001** NFI

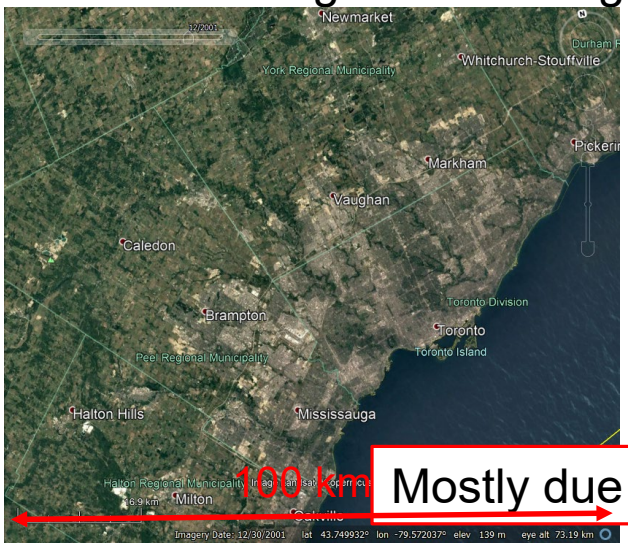


Total tree coverage: **2011** NFI



Changes to the Greater Toronto Area

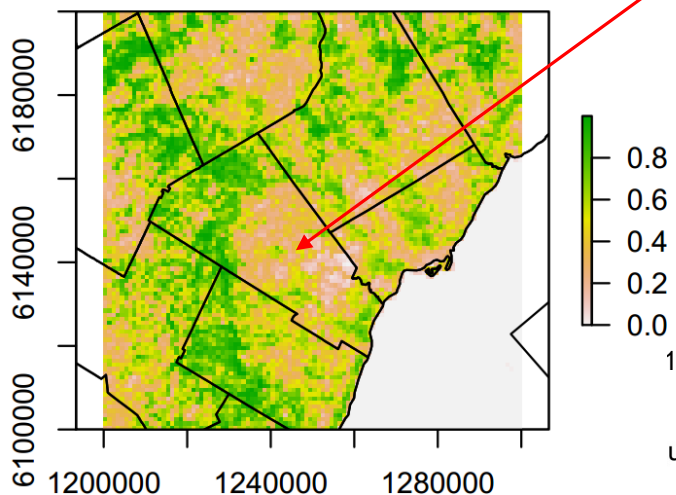
Dec. **2001** Google Earth Image



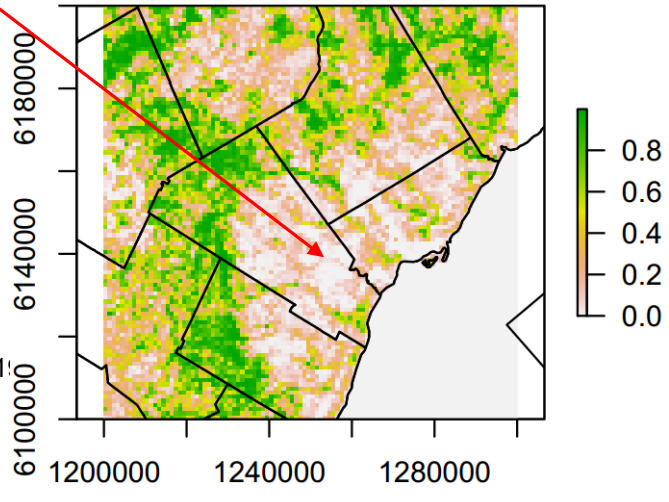
Dec. **2011** Google Earth Image

Mostly due to methodology change

Total tree coverage: **2001** NFI



Total tree coverage: **2011** NFI



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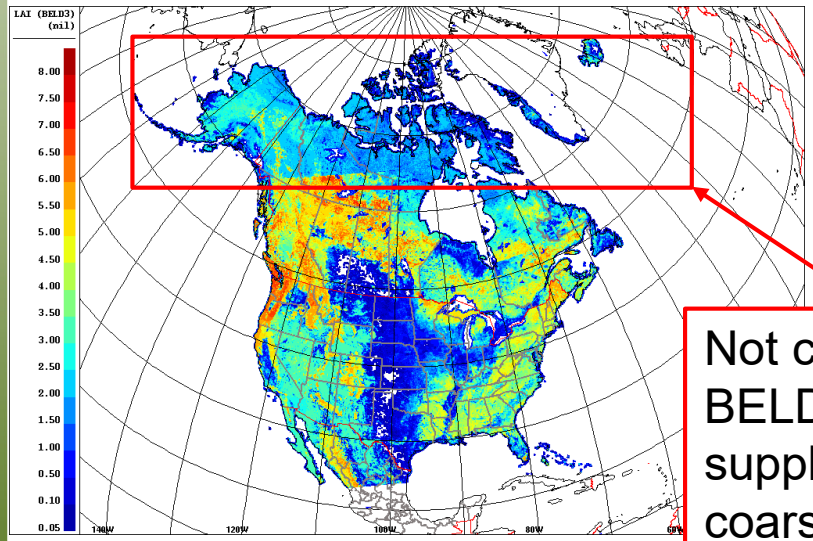
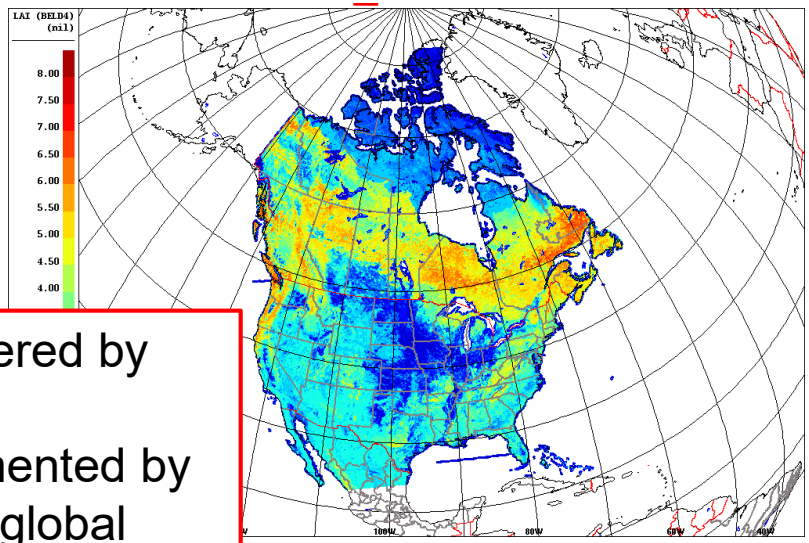
Impacts on Biogenic Emissions Using the BELD4 Database V0

- Biogenic emissions were calculated for the Canadian regional air quality forecast grid at 10 km resolution using:
  (a) the BELD3 database for BEIS 3.09 species and
  (b) the BELD4 database for BEIS 3.60 species
- BEIS 3.60 VOC species were aggregated to BEIS 3.09 VOC species for comparison

LAI_BELD**3**



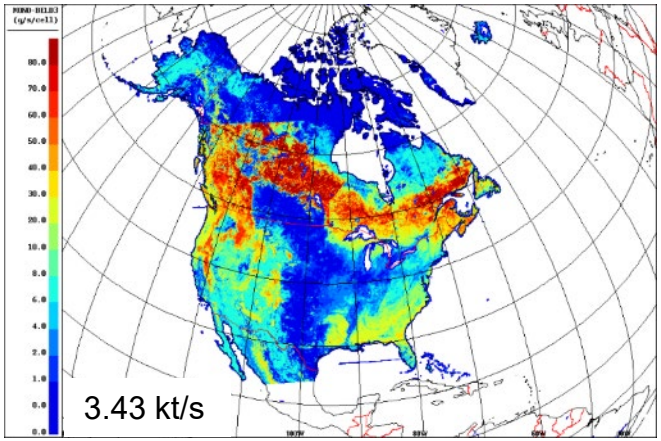
LAI_BELD**4**



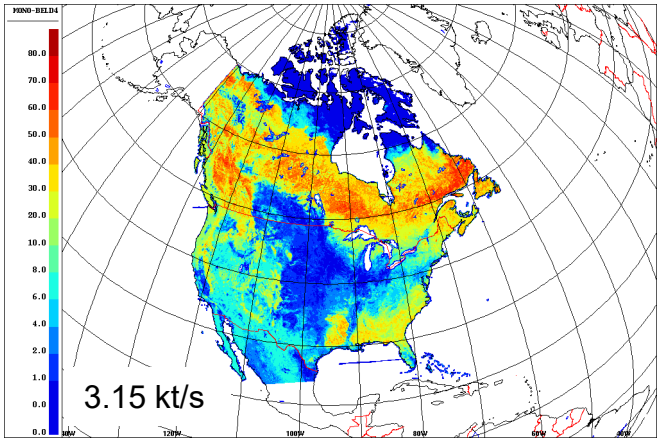
Not covered by BELD3, supplemented by coarser global land cover data

Impacts on Monoterpene Emissions

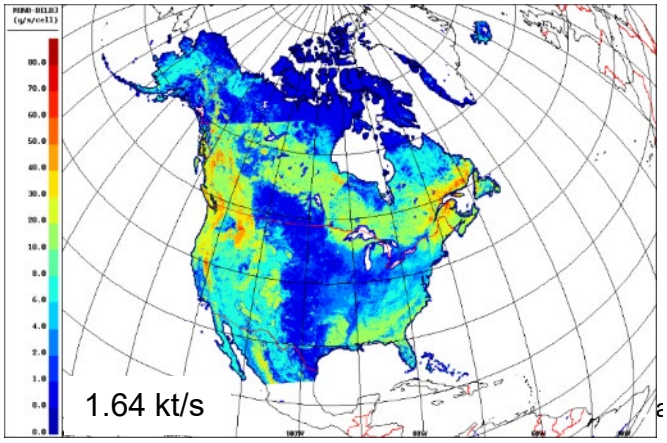
BELD**3** Monoterpenes



BELD**4**_Sum of 14 Monoterpenes



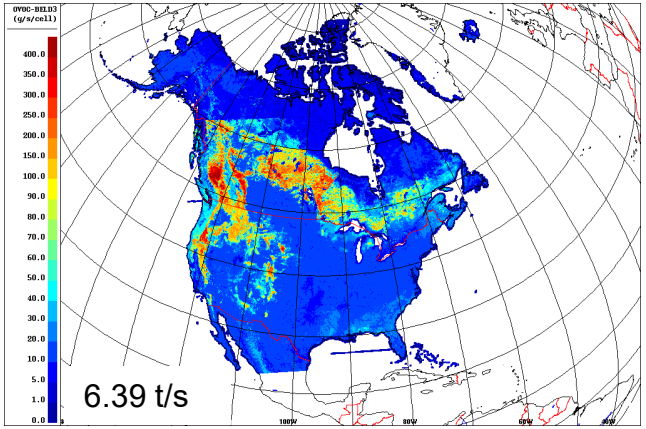
BELD**3** Monoterpenes - Adjusted



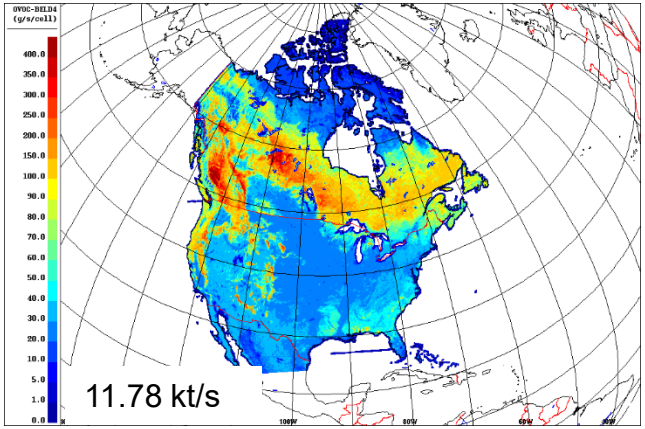
- Canada's boreal forest is a significant source of VOC emissions
- Monoterpene emissions using BELD3 seemed too high over boreal forest in Canada and were adjusted downwards
- Monoterpene emissions calculated from BELD4 are lower than those calculated from BELD3, particularly for Canadian boreal forest

Impacts on Other VOC and NO Emissions

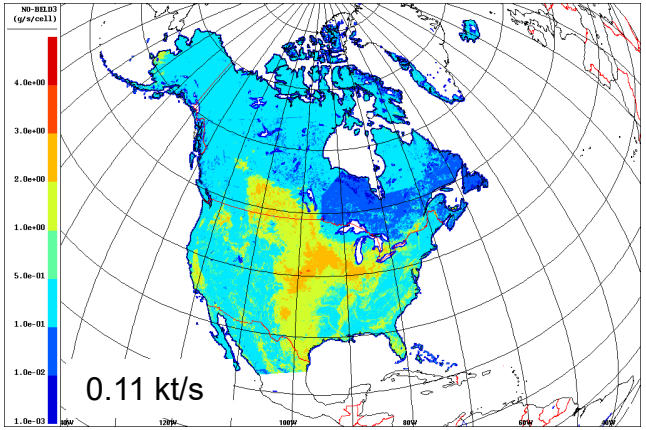
BELD3 Other VOC



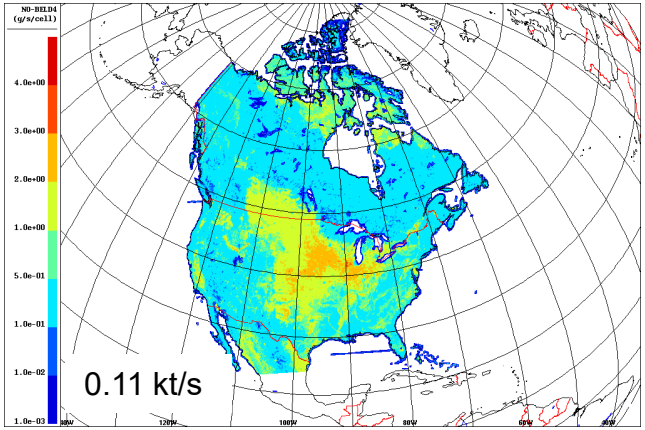
BELD4 Other VOC



BELD3 NO

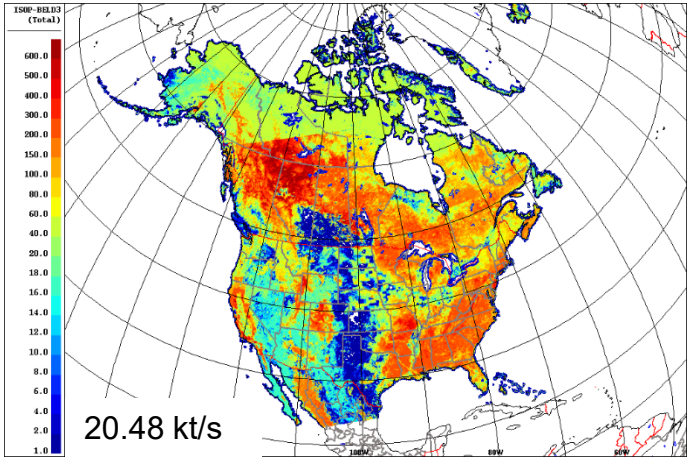


BELD4 NO

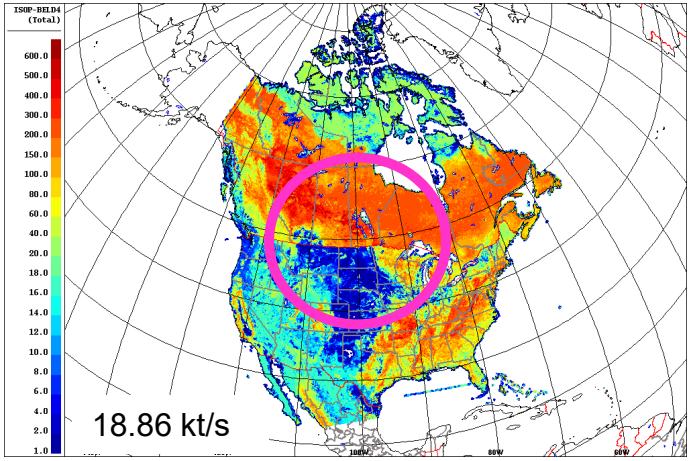


Impacts on Isoprene Emissions

BELD**3** Isoprene

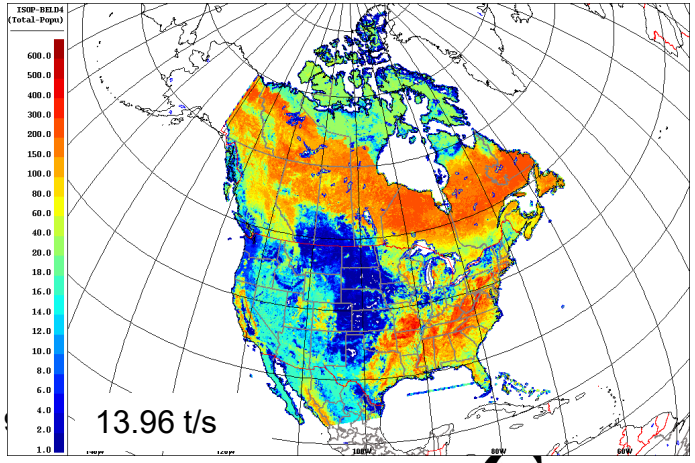


BELD**4** Isoprene



- Isoprene emissions calculated from BELD4 are higher for eastern Canada but lower for the U.S. than those calculated from BELD3
- Discontinuity for BELD4 seen at the international border is mainly due to emissions from Populus

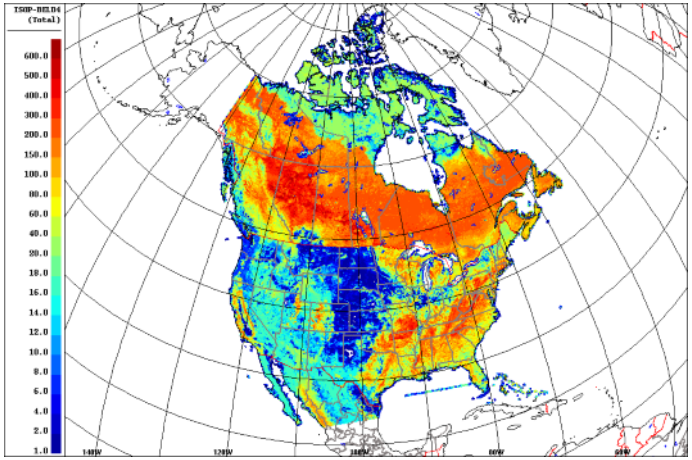
BELD**4** Isoprene without Populus



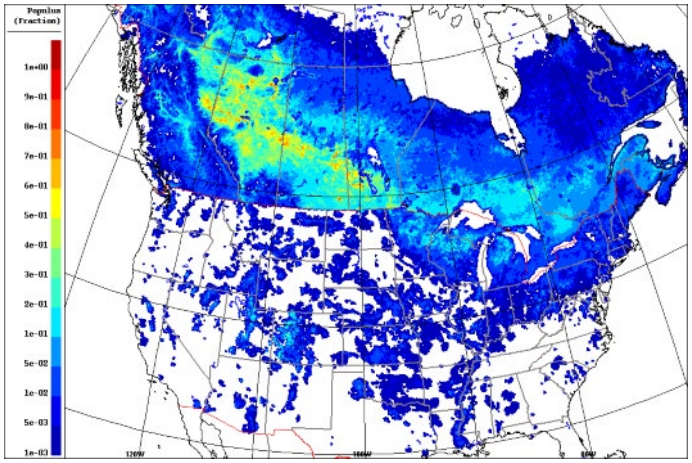
Canada

Discontinuity in BELD4 Isoprene Emissions at the International Border (1)

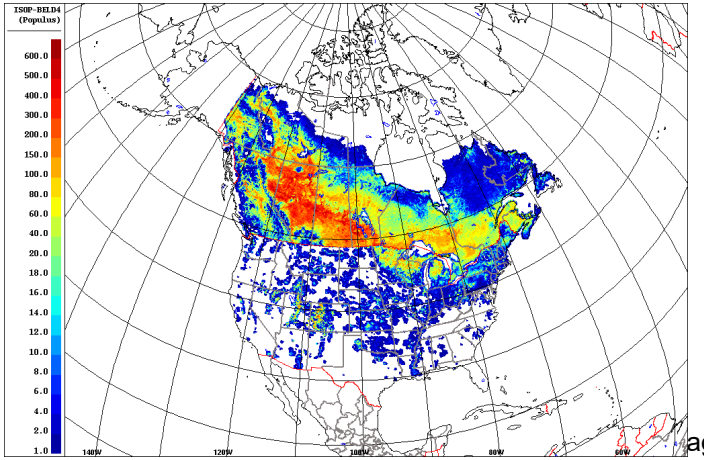
BELD4 Isoprene



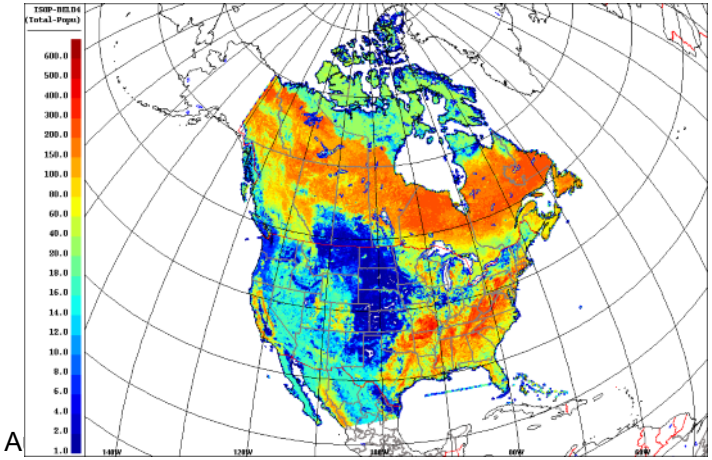
BELD4 Populus Coverage



Populus Isoprene Emissions



BELD4 Isoprene without Populus



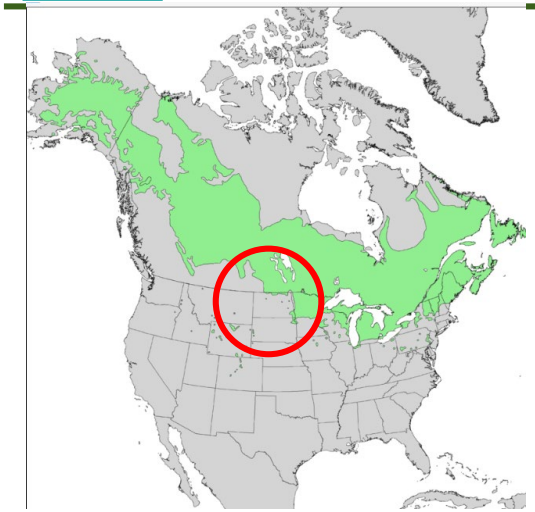
Discontinuity in BELD4 Isoprene Emissions at the International Border (2)

- Populus is one of the tree species that have the highest Isoprene emission rate: 26,250 gC/km^2-hr
- There is only one Populus species in the EPA BELD4 database, but there are four individual Populus species, in addition to the generic Populus spp., in the Canadian NFI. All five have been matched to the EPA BELD4 Populus species for the updated Canadian BELD4 database

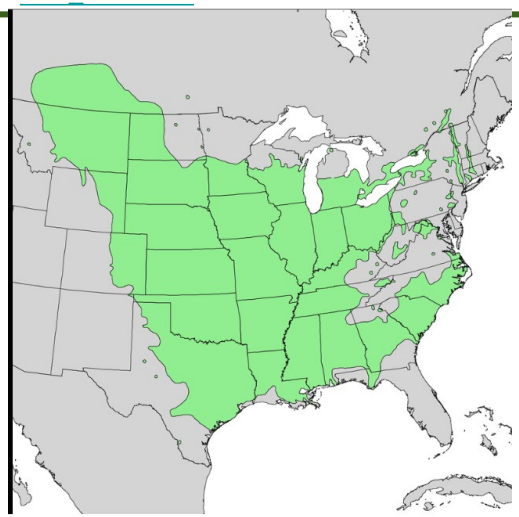
Canadian Populus Species	US-BELD4	BELD4 Description
Balsam poplar (tacamahac)	Populus	Cottonwood, poplars, and aspens
Populus spp.	Populus	Cottonwood, poplars, and aspens
Largetooth aspen	Populus	Cottonwood, poplars, and aspens
Trembling aspen	Populus	Cottonwood, poplars, and aspens
Black cottonwood (western balsam poplar)	Populus	Cottonwood, poplars, and aspens

Spatial Range of Various Populus Species in North America

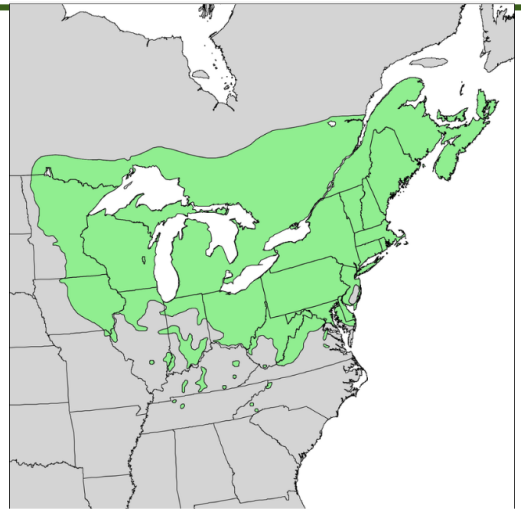
Balsam poplar:
https://en.wikipedia.org/wiki/Populus_balsamifera



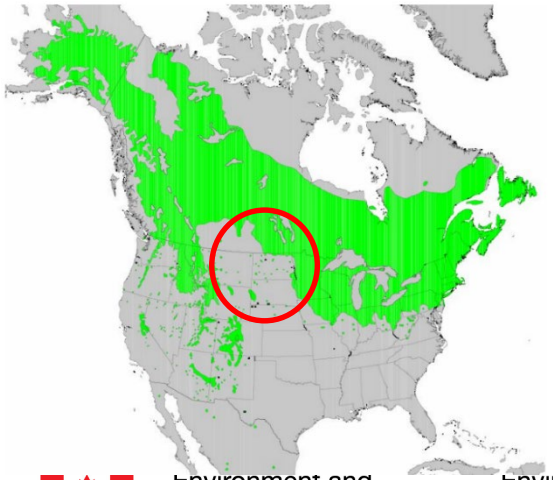
Eastern cottonwood:
https://en.wikipedia.org/wiki/Populus_deltoides



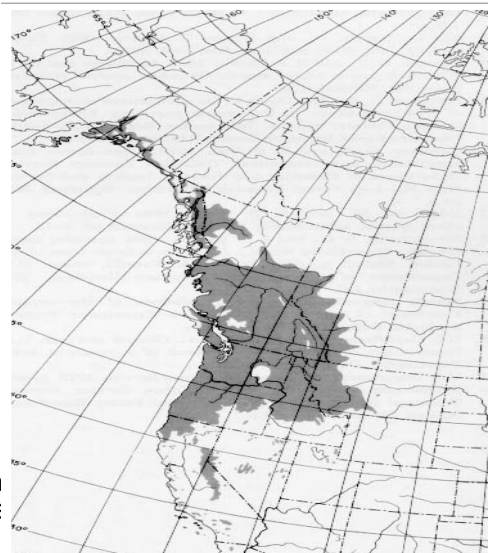
Largetooth aspen:
https://en.wikipedia.org/wiki/Populus_grandidentata



Trembling aspen:
http://nativeplantspnw.com/quaking-aspen-populus-tremuloides/



Black cottonwood:
https://en.wikipedia.org/wiki/Populus_trichocarpa

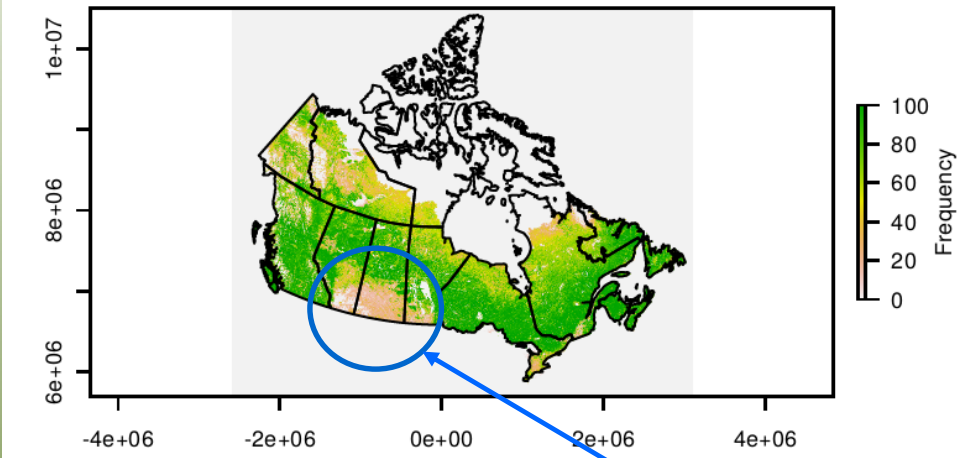


- We do see a discontinuity at the international border.
- Is the discontinuity of emissions real?
- Is the Canadian coverage of Populus too high or the US coverage too low?

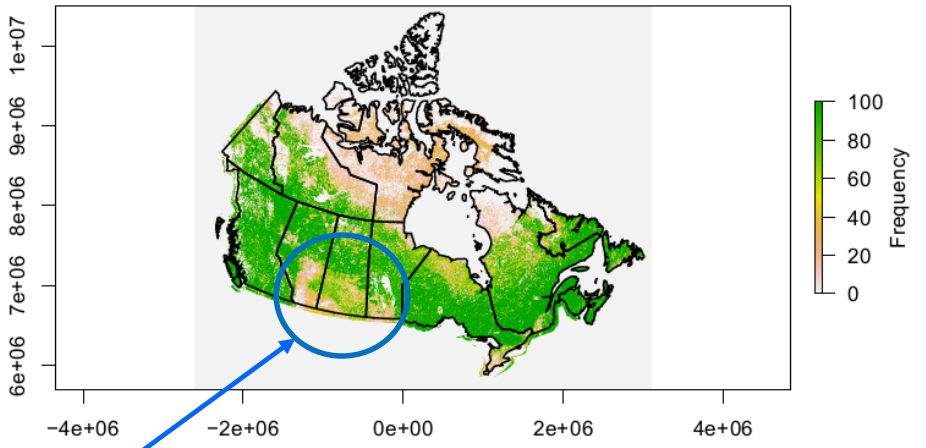
Discontinuity in BELD4 Isoprene Emissions at the International Border (3)

- 2011-based Canadian BELD4 database won't help!

Total Tree Coverage - **2001**



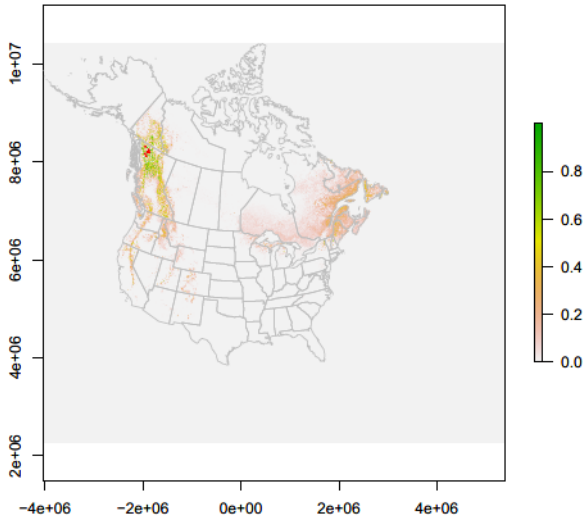
Total Tree Coverage - **2011**



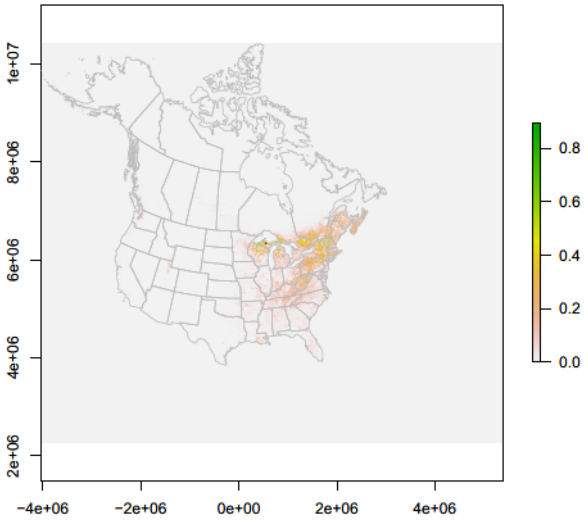
2011 database has higher tree coverage for the area in question

Spatial Distribution of Generic Species, Examples

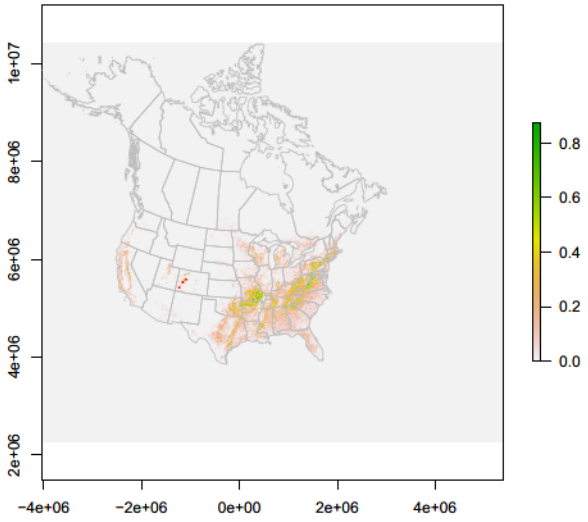
Fir Group (12 species)



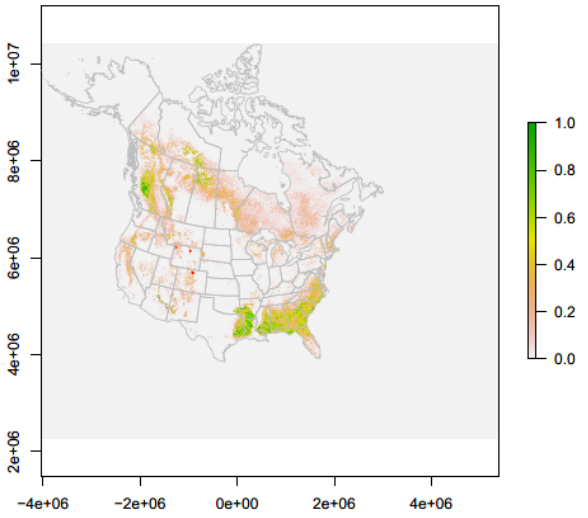
Maple Group (13 species)



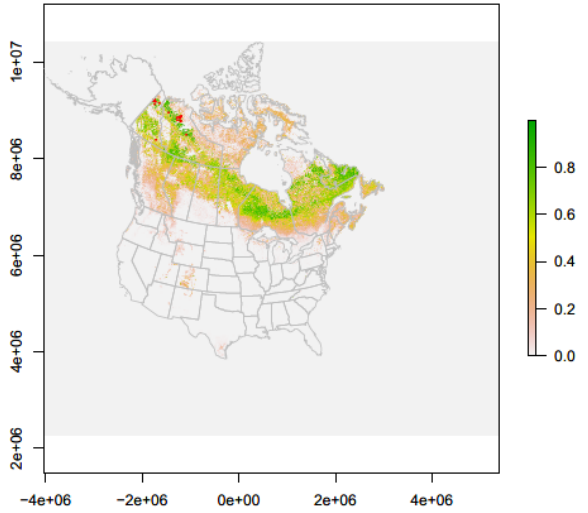
Oak Group (44 species)



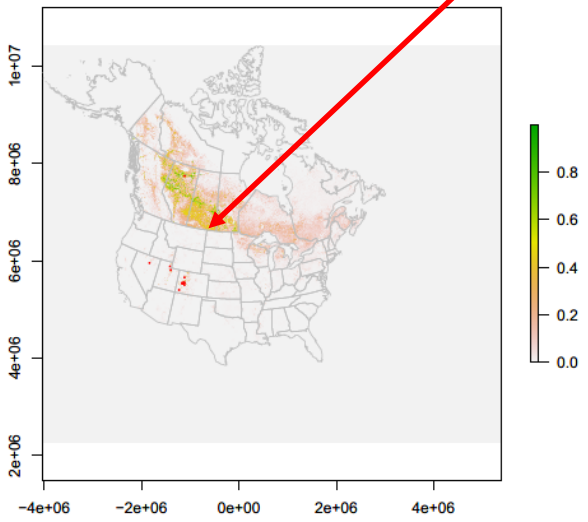
Pine Group (39 species)



Spruce Group (9 species)



Populus Group (1 species)



Conclusions

- The first version of the U.S.-equivalent Canadian BELD4 database built with the 2016 Canadian annual crop inventory and 2001 national forest inventory was released in 2018
- Although many existing issues with the BELD3 database for Canada were addressed by the first BELD4 version, there are still areas for further improvement, such as the Athabasca Oil Sands (AOS) area
- Improved methodology has been developed by the Canadian Forest Service to update the 2001 forest maps and create new ones for 2011
- The Canadian BELD4 database has been updated using the 2011 national forest inventory and will be released publicly shortly
- Improvements were seen for total coverage, for areas undergoing rapid development such as the AOS area, and for urban areas
- Impacts of the Canadian BELD4 database on biogenic emissions vs. BELD3 are significant
- Some issues requiring further investigation remain, such as the discontinuity in isoprene emissions at the international border