# Examination of MODIS Leaf Area Index (LAI) Product for Air Quality Modelling

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Canada

# OUTLINE

- Motivation for this study
- Description of MODIS LAI and related products
- Features/issues identified with the MODIS LAI product
- Methodology Investigation:  Best Use of MODIS LAI
- Possible approach to creating a MODIS-based LAI dataset for air quality modelling for North America
- Summary

# MOTIVATION

- Biogenic VOC emissions have been estimated to be much larger than anthropogenic sources, accounting for 80-90% of total global VOC emissions
- Leaf Area Index (LAI) is used for calculating biogenic emissions and is also used for land surface processes in air quality models, such as dry deposition
- The Canadian GEM-MACH (Global Environmental Multi-scale - Modelling Air quality and Chemistry) model uses the Biogenic Emission Inventory System (BEIS) for estimating VOC emissions with inputs from the Biogenic Emissions Landuse Database (BELD)
- Only 4 LAI values are used for various vegetation species in Version 4 of BELD and winter fraction is used for differentiating summer and winter conditions without finer seasonal variation

| SPECIES | LAI | Winter Fraction | SPECIES | LAI | Winter Fraction |
|---|---|---|---|---|---|
| Spruce_white | 7 | 1 | Maple_sugar | 5 | 0 |
| Mixed_conifer_sp | 7 | 1 | Pine_yellow | 3 | 1 |
| Douglas_fir | 7 | 1 | Pine_whitebark | 3 | 1 |
| Larch | 5 | 0 | Wheat_Winter | 0 | 0.5 |
| Willow | 5 | 0 | Wheat_Spring | 0 | 0.5 |
| Walnut | 5 | 0 | Soybeans | 0 | 0 |
| Populus | 5 | 0 | Oats | 0 | 0 |
| Oak_white | 5 | 0 | Hay | 0 | 0.5 |

- These LAI assignments mean that all spruce and fir forests in North America will have the same amount of foliage in the model

- MODIS LAI values would allow us to account for local changes in same-species foliage and account for sub-seasonal (monthly) changes

# DESCRIPTION OF MODIS LAI AND RELATED PRODUCTS (COLLECTION 6)

HTTPS://LPDAAC.USGS.GOV/DOCUMENTS/2/MOD15_USER_GUIDE.PDF

## MODIS Products

- Fpar_500m
- LAI_500m
- FparLai_QC
  - MODLAND_QC *(Good/bad quality)*
  - Sensor *(Terra / Aqua)*
  - DeadDetector *(Detectors fine for 50% of channels/or not)*
  - CloudState *(Clear/significant cloud/mixed cloud/not defined)*
  - SCF_QC *(Main method no saturation/main method with saturation/empirical algorithm1/empirical algorithm2/no pixel retrieved)*
- Fpar_Extra_QC
  - LandSea Pass-Thru *(Land/Shore/freshwater/ocean)*
  - Snow_Ice *(no snow & ice/ snow & ice)*
  - Aerosol *(no or low aerosol / average or high aerosol detected)*
  - Cirrus *(none / detected)*
  - Internal_Cloud_Mask *(none / detected)*
  - Cloud Shadow *(none / detected)*
  - SCF_Biome_Mask *(biome outside interval 1,4 / biome inside interval (1,4))*
- FparStdDev_500m
- LaiStdDev_500m

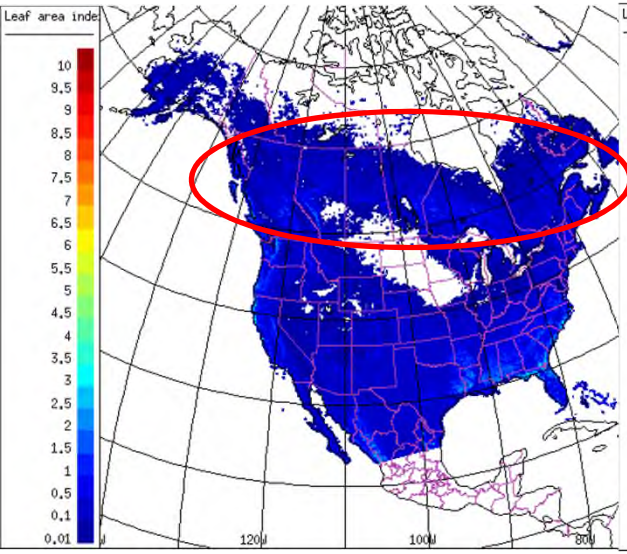
## Message from the User Guide

- MODIS C6 LAI is available globally at 500m resolution
- Two retrieval algorithms used:
  1) Look-up-Table (LUT) based main algorithm
  2) Back-up algorithm that uses empirical relationships between Normalized Difference Vegetation Index (NDVI) and canopy LAI
- Analyses of the algorithm performance indicate that best quality, high precision retrievals are obtained from the main algorithm
- LAI algorithm is executed irrespective of input quality
- User should consult the QC layers of the LAI product to select reliable retrievals
- No retrieval for urban/built-up areas

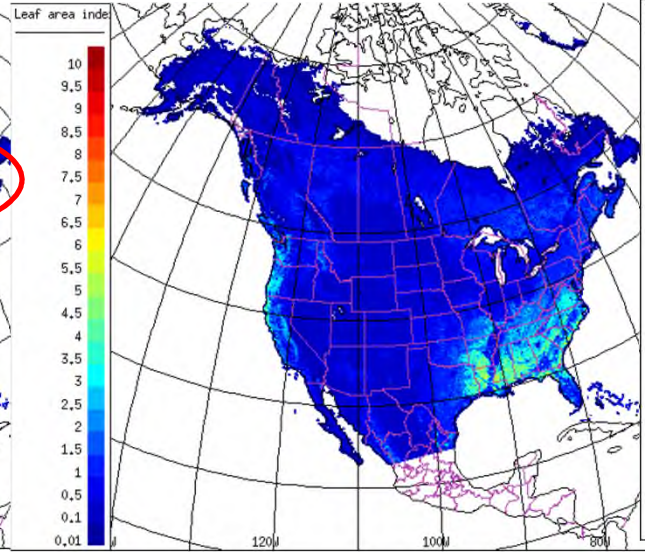
# FEATURES OR ISSUES IDENTIFIED WITH THE MODIS LAI PRODUCT (1)

## Monthly LAI Created from the Original 8-day MODIS LAI Data without QC

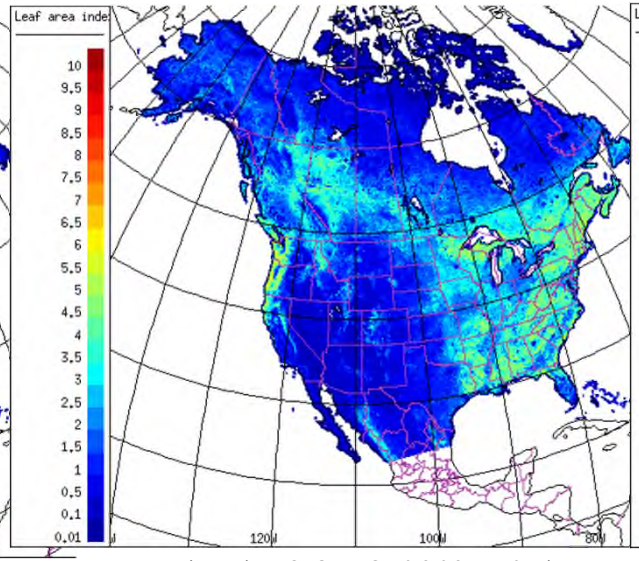
January



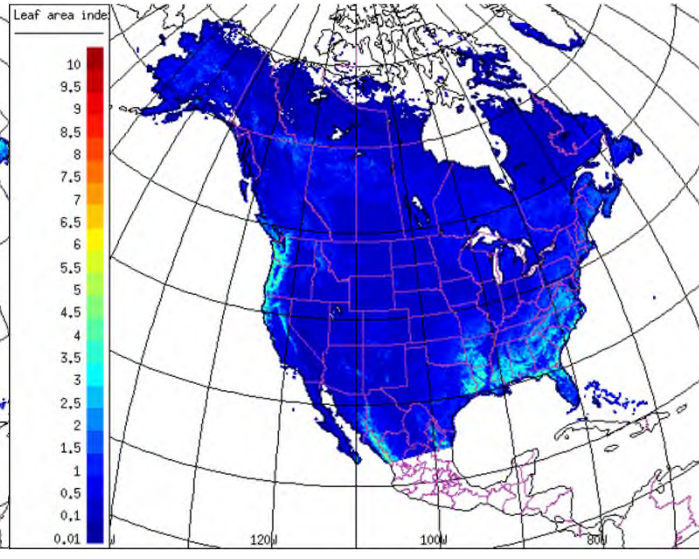

April




July




October

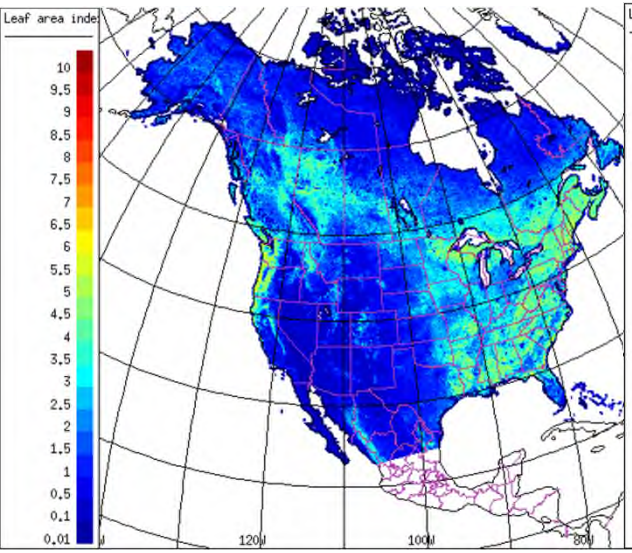



- Overall seasonal variation looks reasonable
- Canadian boreal forest is largely evergreen: decrease in winter is not correct
  - Indicates issue with satellite retrieval when the ground is covered by snow

# FEATURES OR ISSUES IDENTIFIED WITH THE MODIS LAI PRODUCT (2)

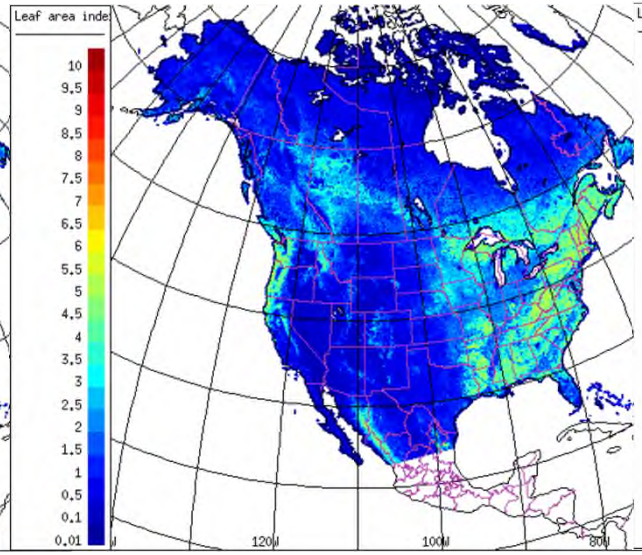
## Monthly LAI Created from the Original 8-day MODIS LAI Data without QC

July



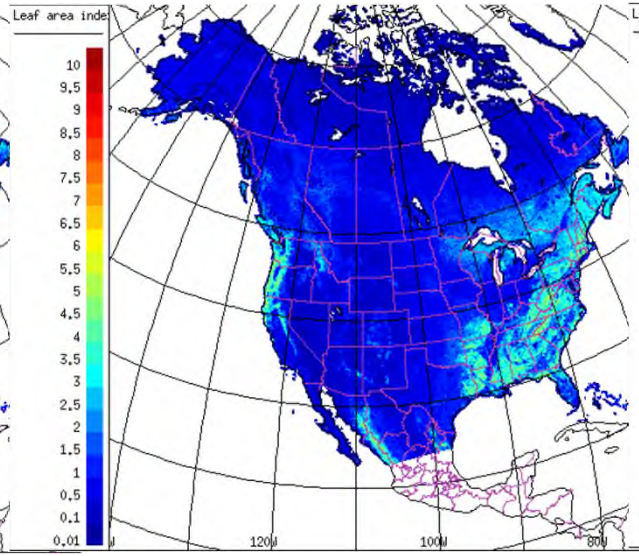

North_America_MODIS_LAI_GM10_249-255_to_0_Jul

August



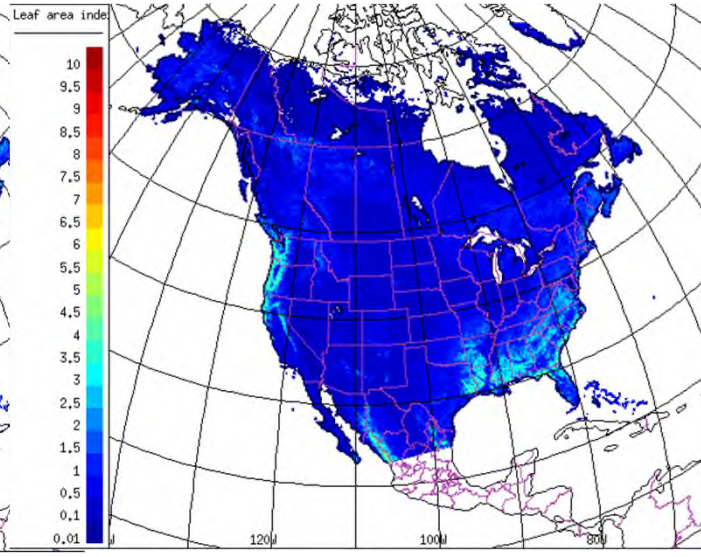

North_America_MODIS_LAI_GM10_249-255_to_0_Aug

September




North_America_MODIS_LAI_GM10_249-255_to_0_Sep

October

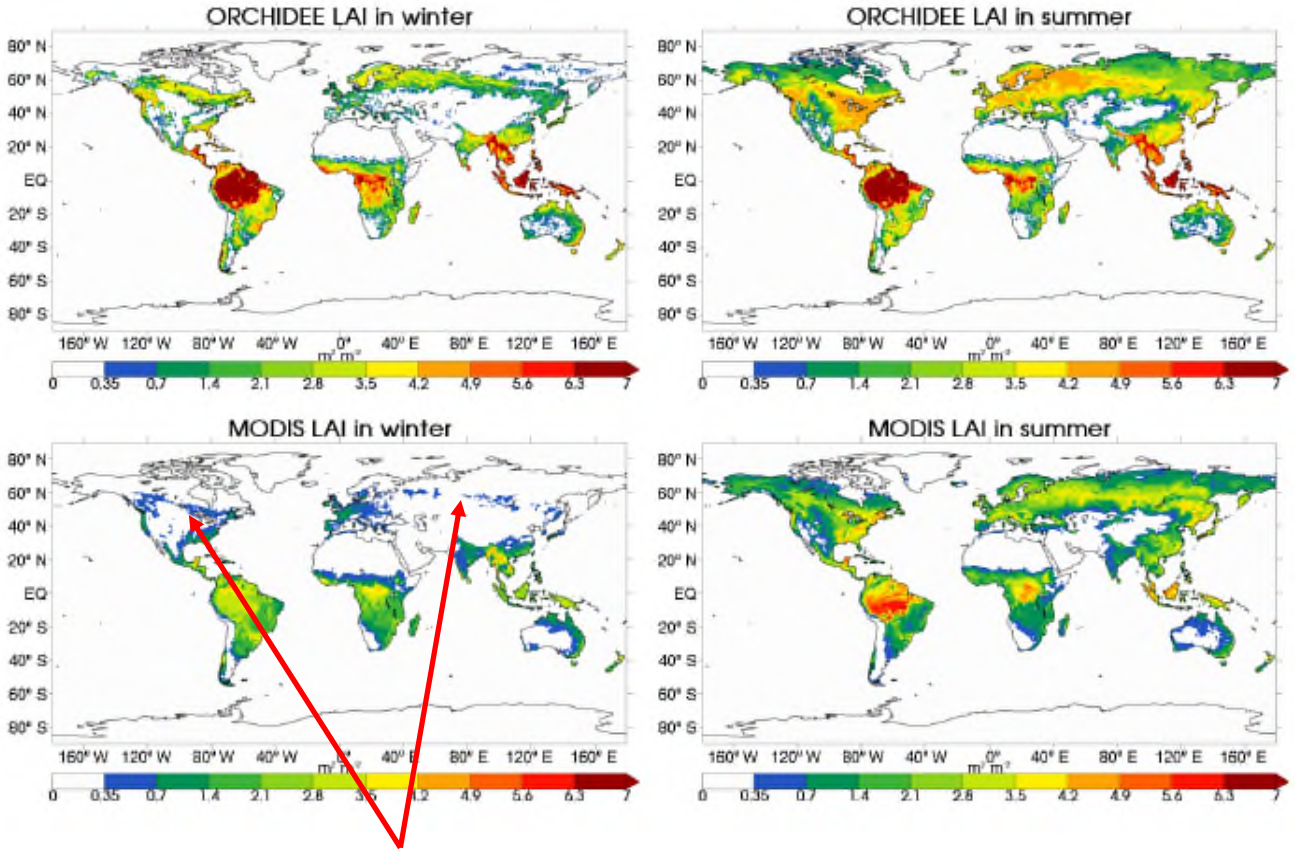


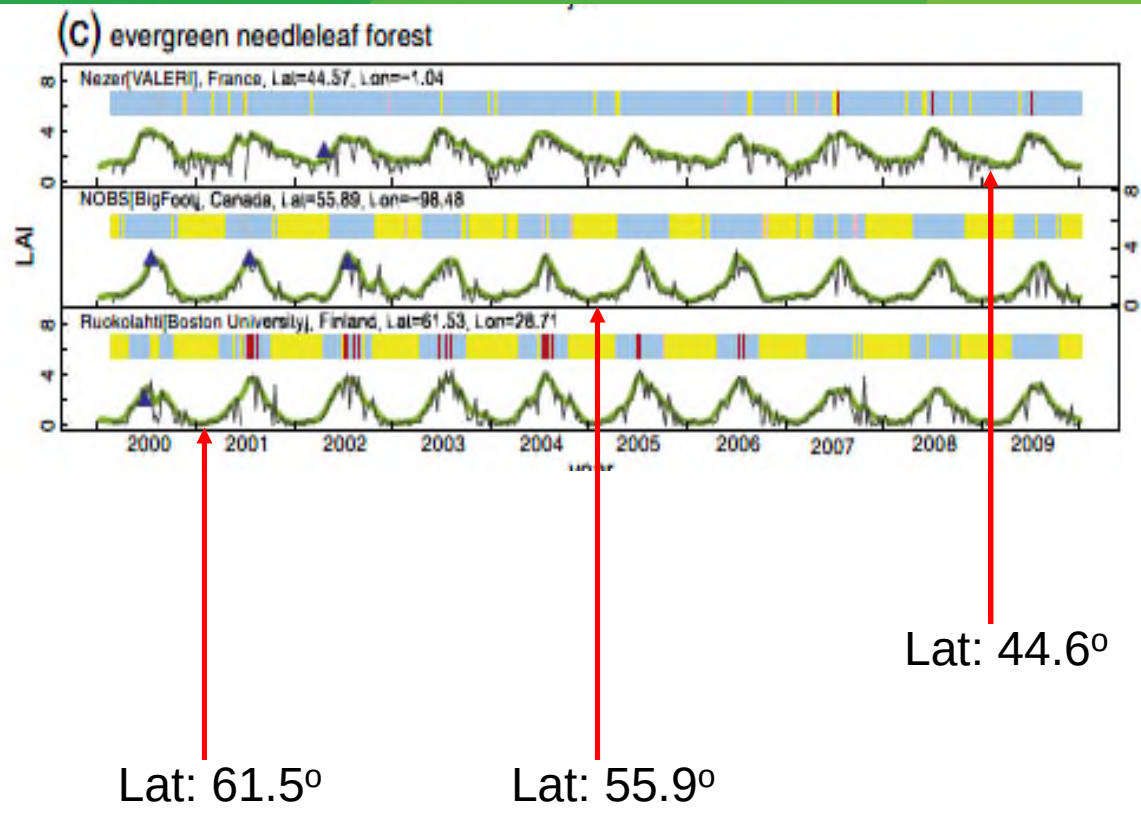

North_America_MODIS_LAI_GM10_249-255_to_0_Oct

- Snow cover may not be the only issue for the boreal forest because LAI is already relatively low for September when snow is unlikely on the ground
- Low sun angle may also affect the quality of satellite retrieval
- Cloud amount is highly seasonal, reduce number of valid retrievals when cloud amount is high

# FEATURES OR ISSUES IDENTIFIED WITH THE MODIS LAI PRODUCT (3)

## Examples of MODIS LAI from Literature



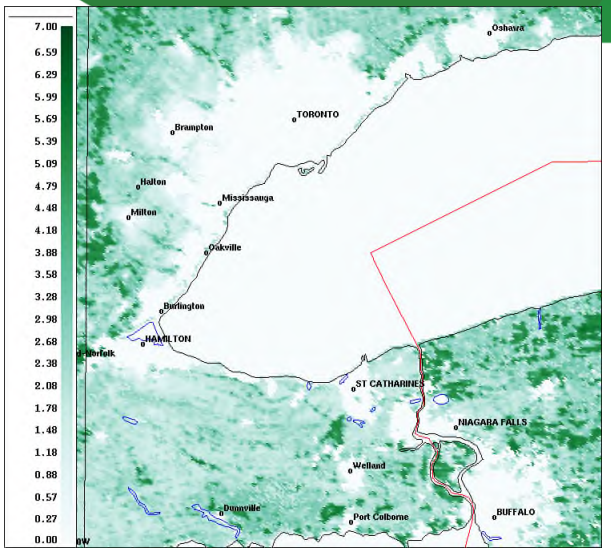

- MODIS LAI used by MEGAN (Model of Emissions of Gases and Aerosols from Nature) for calculating biogenic emissions is very low for the winter time over the boreal forest in the Northern Hemisphere (e.g. Fig. 4 of Messina et al., 2016)

- MODIS LAI is still too low in winter for the evergreen needle leaf forest even after considerable efforts have been made to improve the MODIS LAI product (e.g., Fig. 9c of Yuan et al., 2011) - the further north, the lower MODIS LAI in winter for the evergreen needleleaf forest

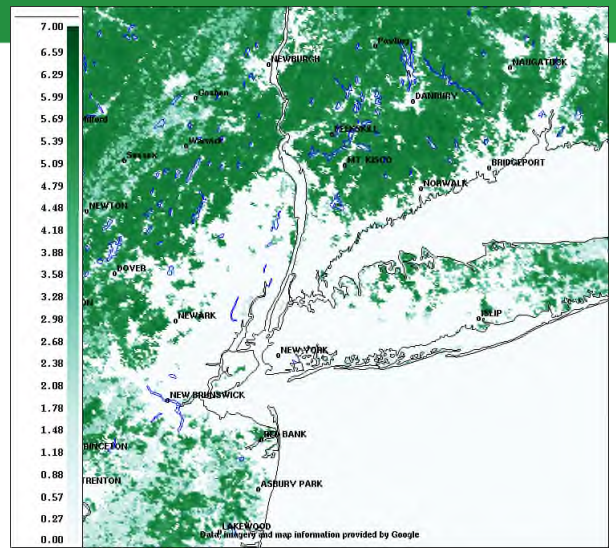
# FEATURES OR ISSUES IDENTIFIED WITH THE MODIS LAI PRODUCT (4)

## Examples of MODIS LAI over Urban Areas

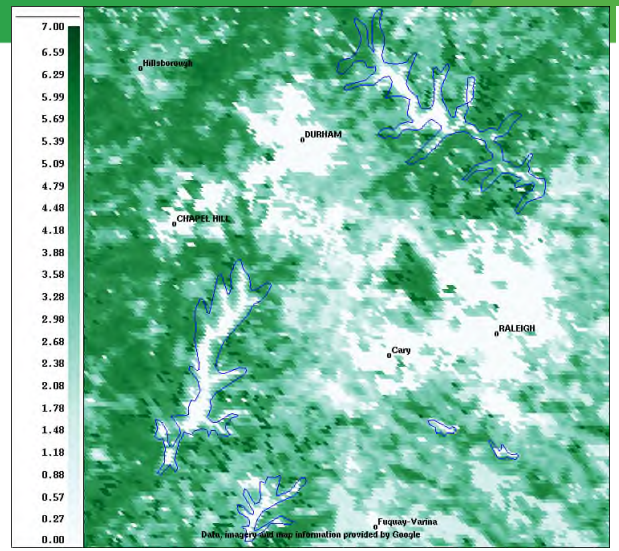
**MODIS LAI - Toronto**



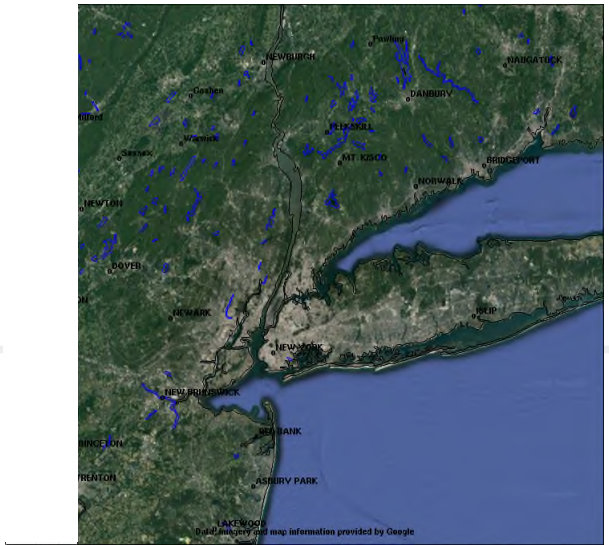

**MODIS LAI – NY City**

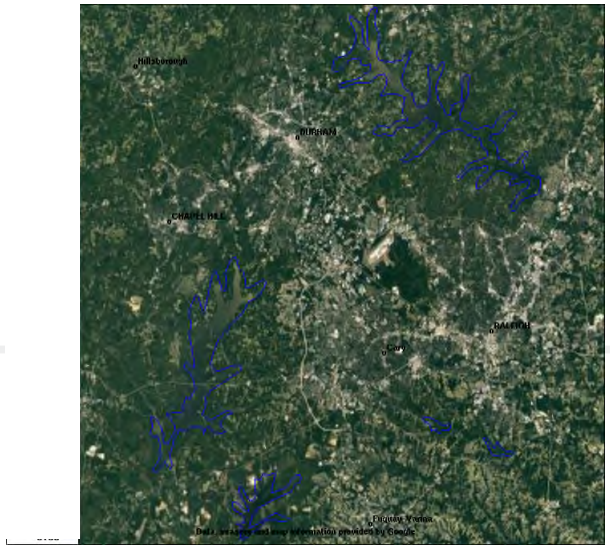



**MODIS LAI – Research Triangle**




**Google Satellite Images**


- MODIS retrieval automatically excludes urban regions, returning no LAI there
- Can result in dramatic underestimates if MODIS LAI is used for calculating biogenic VOC emissions over urban areas
- Areas outside Toronto have much lower LAI than other two areas which can be explained by differences in land cover type (i.e. crops vs. trees)

# METHODOLOGY INVESTIGATION: BEST USE OF MODIS LAI (1)

## Application of QC

- **Applied the following QCs for MODIS LAI to obtain the best possible LAI data**

**QC_Good** = 0 Good Quality (main algorithm with or without saturation)
**QC_CloudState** = 0 Significant clouds NOT present (clear)
**QC_Scf** = 0 Main (RT) algorithm used, best result possible (no saturation)
**QC_Snow** = 0 No snow/ice detected
**QC_Aero** = 0 No or low atmospheric aerosol levels detected
**QC_Cirrus** = 0 No cirrus detected
**QC_Cloud** = 0 No clouds
**QC_Shadow** = 0 No cloud shadow detected

- **Calculated monthly average LAI for the following 17 land cover classes**

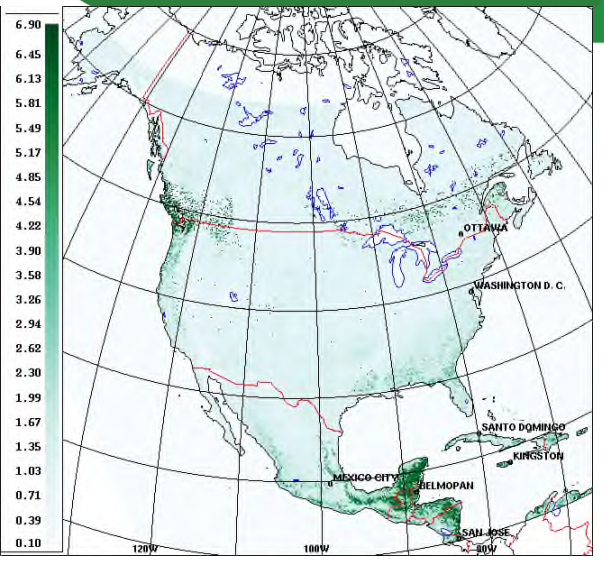
Table 3: MCD12Q1 International Geosphere-Biosphere Programme (IGBP) legend and class descriptions

| Name | Value | Description |
|---|---|---|
| Evergreen Needleleaf Forests | 1 | Dominated by evergreen conifer trees (canopy >2m). Tree cover >60%. |
| Evergreen Broadleaf Forests | 2 | Dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%. |
| Deciduous Needleleaf Forests | 3 | Dominated by deciduous needleleaf (larch) trees (canopy >2m). Tree cover >60%. |
| Deciduous Broadleaf Forests | 4 | Dominated by deciduous broadleaf trees (canopy >2m). Tree cover >60%. |
| Mixed Forests | 5 | Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2m). Tree cover >60%. |
| Closed Shrublands | 6 | Dominated by woody perennials (1-2m height) >60% cover. |
| Open Shrublands | 7 | Dominated by woody perennials (1-2m height) 10-60% cover. |
| Woody Savannas | 8 | Tree cover 30-60% (canopy >2m). |
| Savannas | 9 | Tree cover 10-30% (canopy >2m). |
| Grasslands | 10 | Dominated by herbaceous annuals (<2m). |
| Permanent Wetlands | 11 | Permanently inundated lands with 30-60% water cover and >10% vegetated cover. |
| Croplands | 12 | At least 60% of area is cultivated cropland. |
| Urban and Built-up Lands | 13 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Cropland/Natural Vegetation Mosaics | 14 | Mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation. |
| Permanent Snow and Ice | 15 | At least 60% of area is covered by snow and ice for at least 10 months of the year. |
| Barren | 16 | At least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation. |
| Water Bodies | 17 | At least 60% of area is covered by permanent water bodies. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

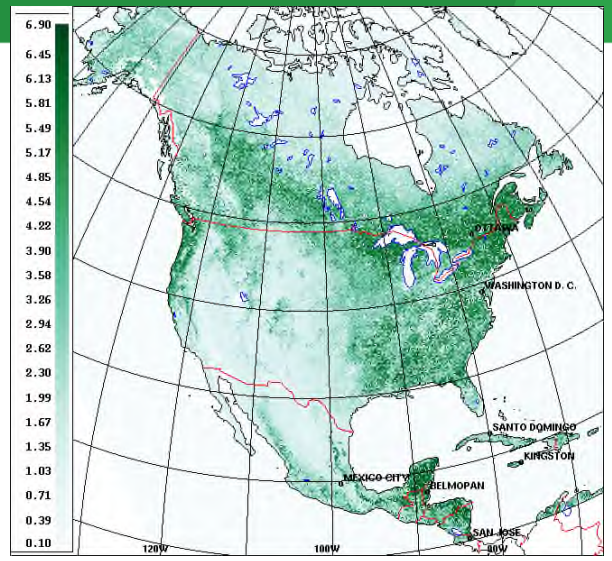
# METHODOLOGY INVESTIGATION: BEST USE OF MODIS LAI (2)

## Application of QC – Single Year LAI

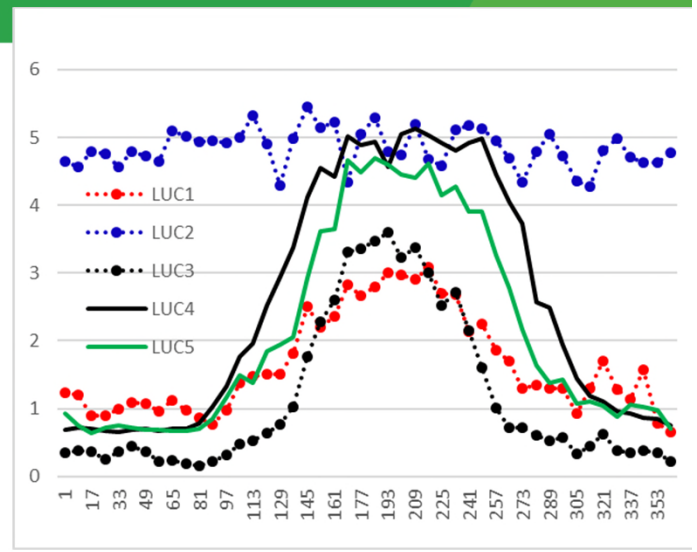
### Jan LAI without QC



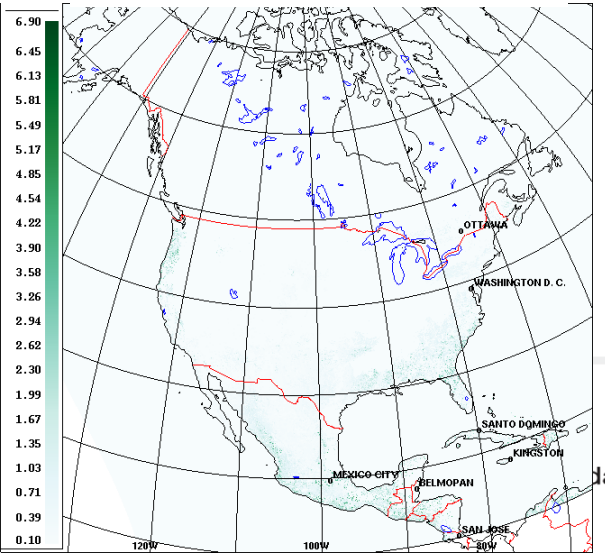

### July LAI without QC



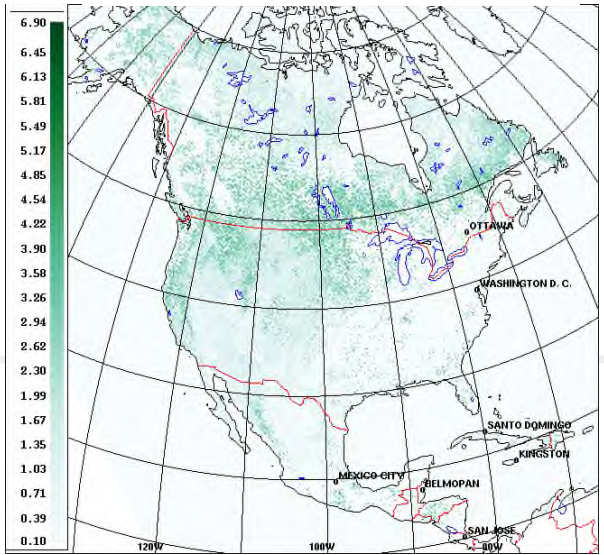

### Domain Average LAI without QC



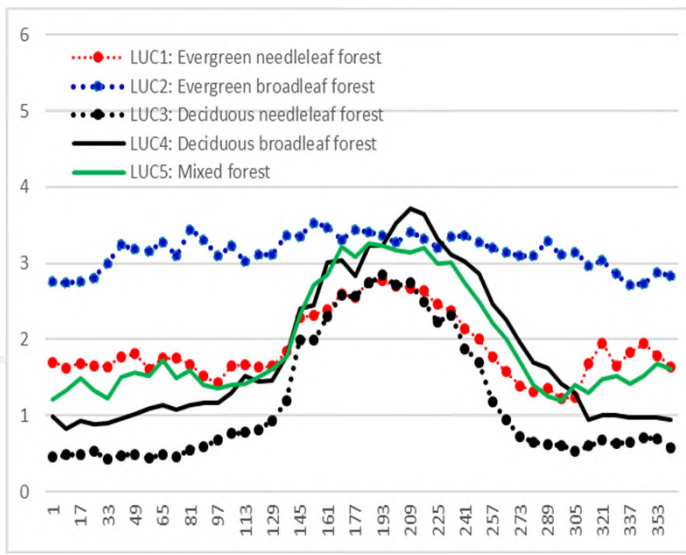

### Jan LAI with QC




### July LAI with QC




### Domain Average LAI with QC

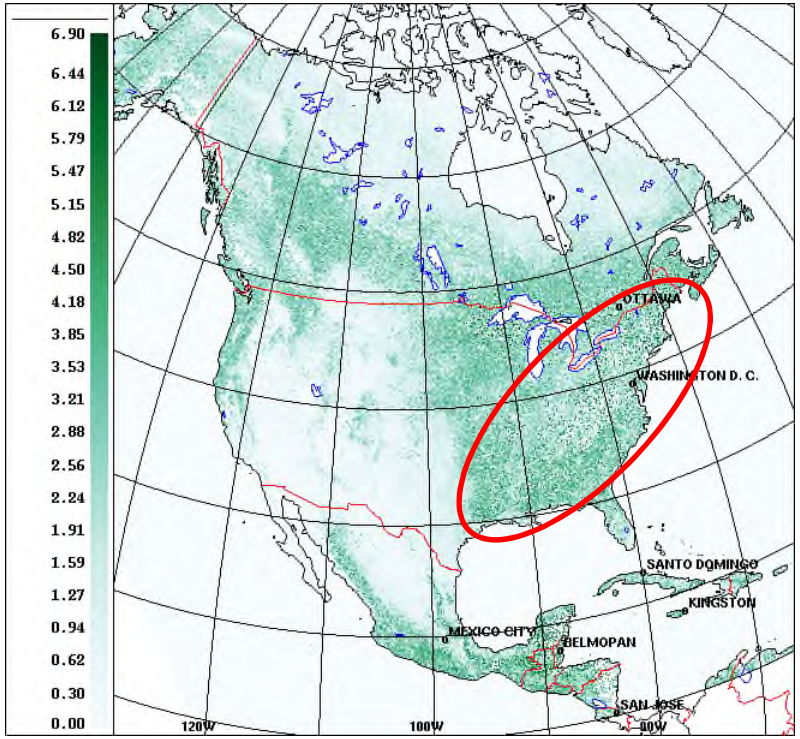



- LAI is much lower with QC applied
- With QC, no valid LAI in winter for northern part of North America due to snow coverage, and in summer for eastern North America probably due to clouds and/or aerosols
- Seasonal variation is smaller for evergreen needle leaf forest with QC due to removal of very low LAI in areas with winter snow coverage
- Compared with LAI used by BELD4, average LAI after QC seems too small

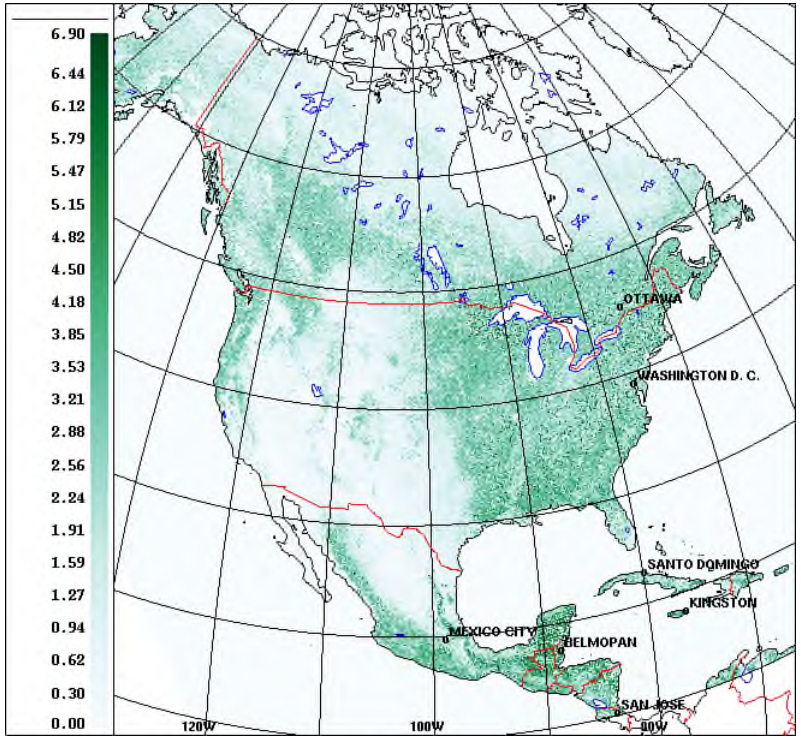
# METHODOLOGY INVESTIGATION: BEST USE OF MODIS LAI (3)

## 17 year (2003-2019) Summer LAI (mid-June to mid-August)

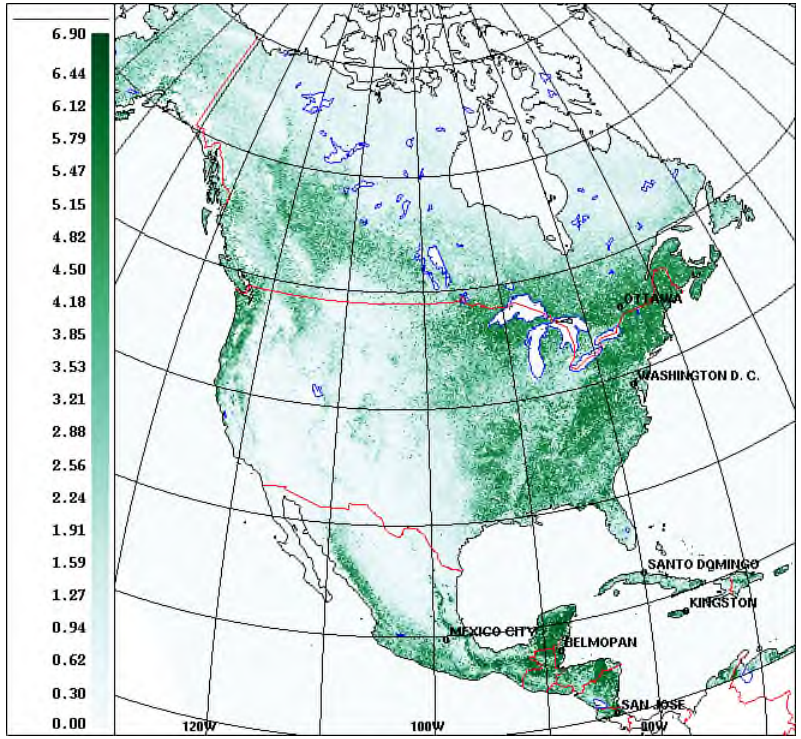
**LAI with QC – best possible**




**LAI with QC – aerosol QC off**



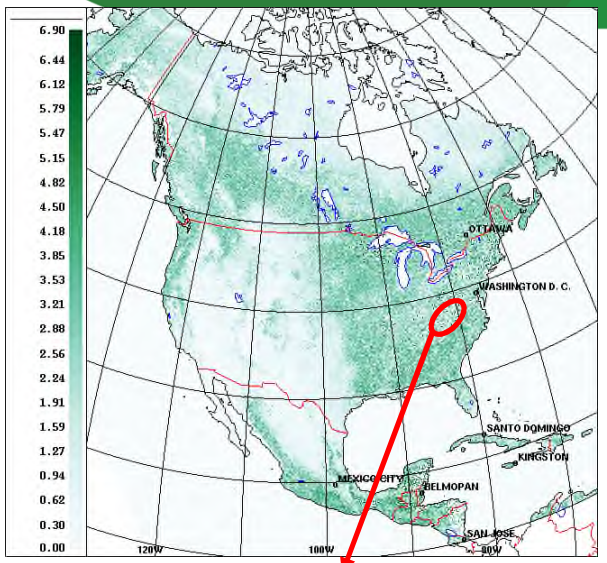

**LAI with QC – main + backup algorithm**




- To eliminate the impact of clouds and aerosols on retrieval, 17 years of MODIS LAI were used to build a climatological LAI product
- Even with 17 years of data, valid LAI is still missing in some areas (e.g. area within the red oval)
- Coverage improved for eastern North America after turning off aerosol QC
- Coverage also improved after using both the main and backup algorithm even with aerosol QC applied
  - LAI retrieved by the backup algorithm is higher than that by the main algorithm

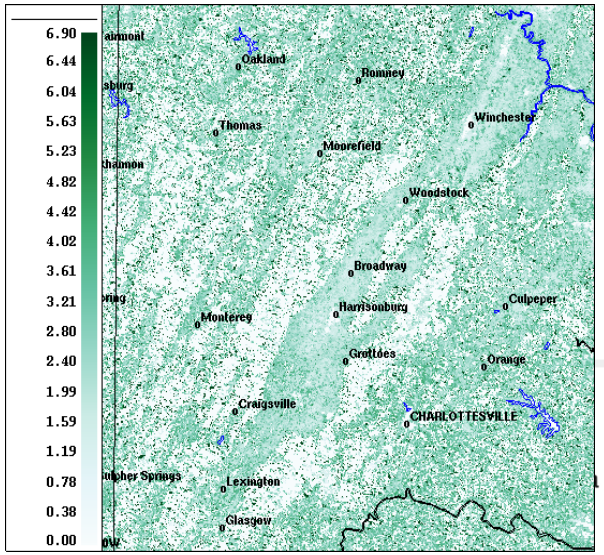
# METHODOLOGY INVESTIGATION: BEST USE OF MODIS LAI (4)

## 17 year (2003-2019) Summer LAI (mid-June to mid-August): Details Over a Small Area

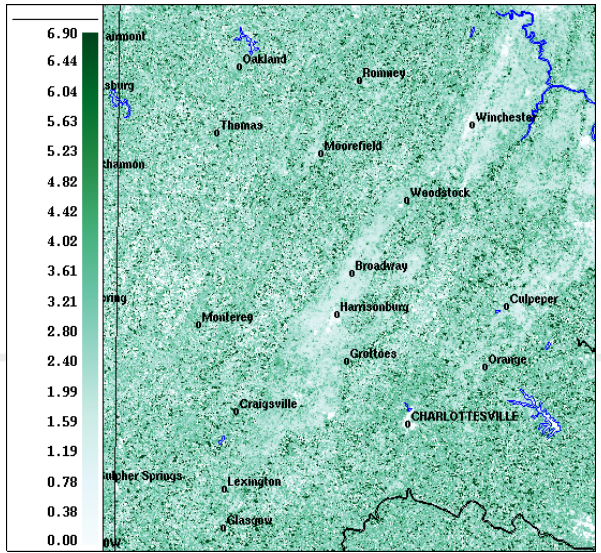



- Valid LAI is missing for forest area in eastern North America under best possible QC, even with 17 years data
  - One reason is due to persistent aerosol over this area in summer
  - Another reason is due to unfavorable conditions for applying the main retrieval algorithm
- Again, LAI retrieved from the back-up algorithm is higher than that from the main algorithm and seems to agree better with the typical LAI used by BELD4
- Spatial distribution of MODIS LAI agrees very well with satellite image

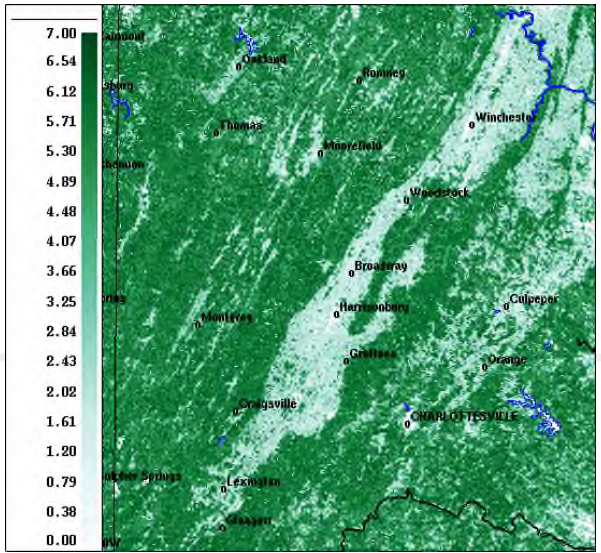
**LAI with QC**



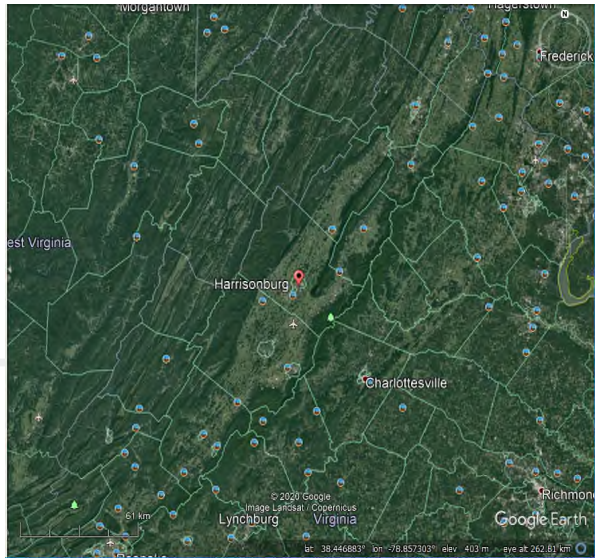

**LAI with QC – aerosol QC off**




**LAI with QC – main + backup**



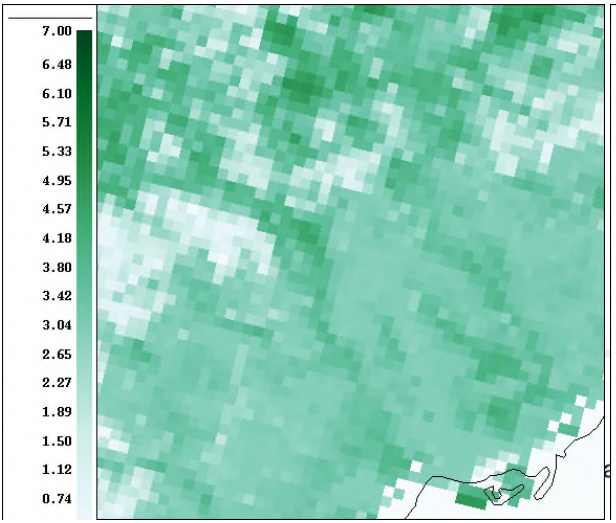

**Google Satellite**



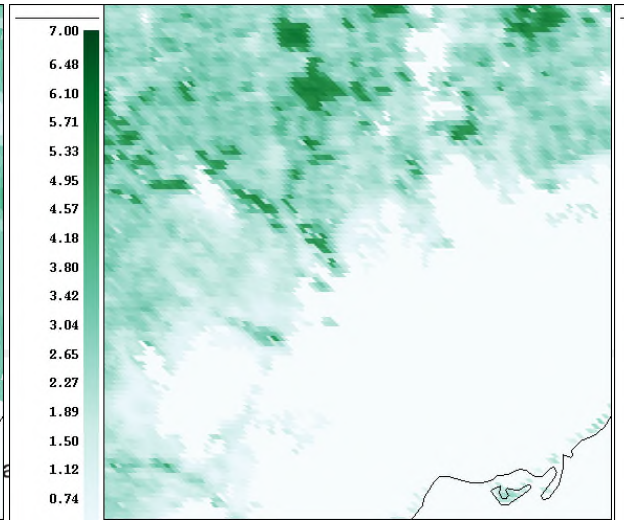
# POSSIBLE APPROACH FOR CREATING MODIS-BASED LAI DATASET FOR AIR QUALITY MODELLING FOR NORTH AMERICA

1. Use 17 years of summer MODIS LAI retrieved by both the main and backup algorithms to create summer-time peak LAI
2. Fill urban areas using LAI calculated from BELD4
3. Determine the monthly LAI: MODIS summer-time peak LAI * BELD4 evergreen/deciduous land use fraction * monthly fraction of the peak LAI
   - Create monthly profiles for two broad types of vegetation species (i.e. evergreen and deciduous) based on domain total MODIS LAI with QC
   - Calculate fractions of evergreen and deciduous vegetation species for each MODIS pixel based on the detailed vegetation species data in the BELD4 dataset
   - Calculate monthly LAI for each pixel based on the summer peak LAI, monthly profiles, and fractions of evergreen and deciduous vegetation species

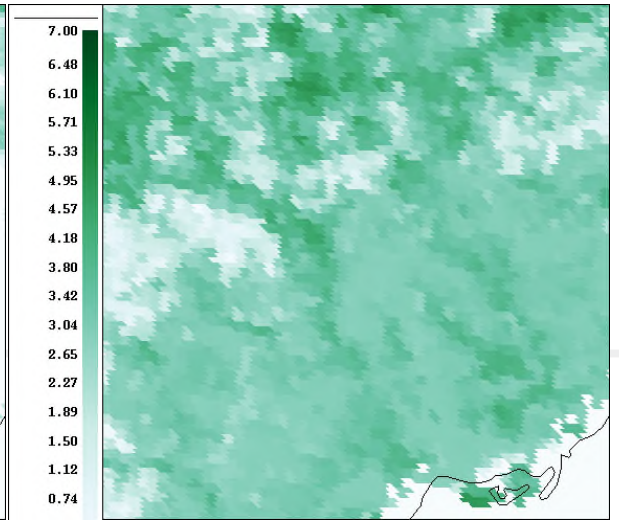
BELD4 Summer LAI (1km) - Toronto



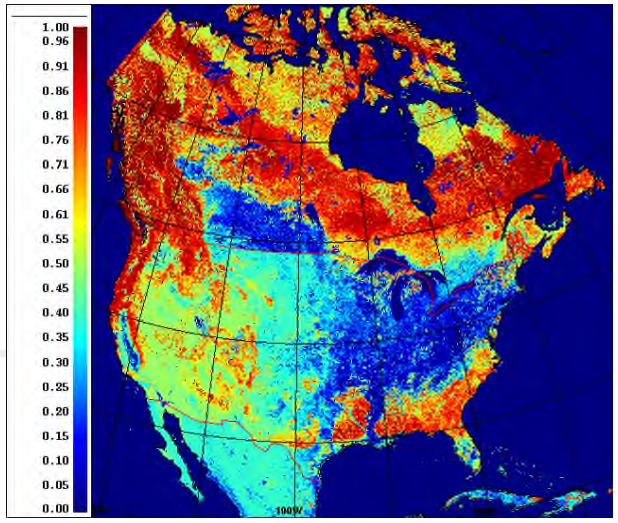

MODIS Summer LAI (500m) - Toronto




Resampled BELD4 Summer LAI (500m)




BELD4 Evergreen Fraction



# SUMMARY

- LAI is important for air quality modelling for calculating biogenic emissions and for land surface processes
- Limitations exist for two widely used datasets (BELD4 and MODIS LAI) used to calculate LAI for North America
- It is possible to create a climatological LAI product based on 17 years of MODIS LAI contingent on solving two main issues:

  1) Filling gaps for urban/built-up areas

  2) Correcting winter evergreen LAI for areas with snow coverage or low sun angle
- Combining MODIS LAI with BELD4 Land Use Classifications to determine evergreen LAI is a possible option to build a reasonable monthly LAI product for regional air quality modelling for North America