2021

Quantification and Forecasting transport sector emissions and their carbon dynamics across Canada using MODIS Terra datasets.

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University of Waterloo

Application: Discovery Grants Program	Individual
Identification	
Applicant	
Family Name:	First Name:
Middle Name:	
Current Position:	

Administering Organization

Organization:

Department/Division:

Application

Application Title:	Quantification and forecasting transport sector emissions and their carbon dynamics across Canada using MODIS Terra datasets.	
Language of the Application:	English	French
Suggested Evaluation Group:		

Hours per month to be devoted to the research/activity or use of equipment or facility:

NSERC

PERSONAL IDENTIFICATION NO (PIN) FAMILY NAME OF APPLICANT:

Institutional Identifier		FORM 101 APPLICATION FOR A GRANT PART I	Date 2021/01/15
System-ID (for NSERC use only)			
Family name of the applicant	Given Name	Initial(s) of all given names	Personal Identification No. (PIN)

Department

Institution that will administer the grant:

Language of the application:

English French

Time (in hours per month) to be devoted to the proposed research/activity

Hours:

Type of grant applied for

Title of proposal:

Provide a maximum of 10 keywords that describe this proposal. Use commas to separate them.

Research subject code(s)		Area of application code(s)	
Primary	Secondary	Primary	Secondary

Certification Requirements

If this proposal involves any of the following, check the box(es) and submit the protocol to the university or college's certification committee

Research involving:	Humans	Humans pluripotent stem cells	Animals	Biohazards

Indicate if the proposed research takes place outdoors and if you answered YES to a), b) or c) – Appendix A (Form 101) must be completed: YES / NO

TOTAL AMOUNT REQUESTED FROM NSERC

YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5

I certify that this project will involve only industry partners with whom no prior research partnership has taken place:

SIGNATURES(Refer to instructions" What do signatures mean?")

It is agreed that the general conditions governing grants as outlined in the NSERC Program Guide for Professors apply to any grant made pursuant to this application and here by accepted by the applicant's employing institution.

Applicant

PERSONAL IDENTIFICATION NO (PIN) FAMILY NAME OF APPLICANT:

Applicant's department, Institution, tel, fax and e-mail

HEAD OF THE DEPARTMENT

DEAN OF FACULTY

PRESIDENT OF INSTITUTION
(OR REPRESENTATIVE)

SUMMARY OF PROPOSAL FOR PUBLIC RELEASE (USE PLAIN LANGUAGE)

BUSINESS TELEPHONE

EMAIL:

OTHER LANGUAGE VERSION OF SUMMARY(OPTIONAL)

PERSONAL IDENTIFICATION NO (PIN) FAMILY NAME OF APPLICANT:

PROPOSED EXPENDITURES

	CASH	IN-KIND
1. Salaries and benefits		
a. Students		
b. Postdoctoral fellows		
c. Technical/professional assistants		
d.		
e.		
2. Equipment or facility		
a. Purchase or rental		
b. Operation and maintenance costs		
c. User fees		
d.		
e.		
3. Materials and supplies		
a. Hard drive		
b. Office supplies		
c.		
d.		
4. Travel		
a. Conferences		
b. Field work		
c. Project-related travel		
d.		
e.		
5. Dissemination		
a. Publication costs		
b.		
c.		
6. Technology transfer activities		
a. Field trials		
b. Prototypes		
c.		
d.		
Total Proposed Expenditures:		
Total support from industry:		
Total support from university:		
Amount Requested from NSERC		

Supporting organizations are not required to make cash or in-kind contributions for this grant. However, if there are any contributions, please report them in the following table, and describe any in-kind contributions provided in the budget justification.

Name of the Supporting Organization

Cash contributions to direct costs of research (Transfer amounts to page three(3); except those for the Ship Time Program).

In-kind contributions to direct costs of research

1. Salaries for scientific and technical staff
2. Donation of equipment, software
3. Donation of material
4. Field work logistics
5. Provision of services
6.

Total of in-kind contributions to direct costs of research

In-kind contributions to direct costs of research

1. Use of organization's facilities
2. Salaries of managerial and administrative staff
3.

Total of all in-kind contributions

Contribution to post-secondary institution overhead

Remarks:

1. Salaries and Benefits (Sub Total: $)

2. Equipment and Facilities(Sub Total: $)

3. Materials and supplies(Sub Total: $)

Quantification and forecasting transport sector emissions and their carbon dynamics across Canada using MODIS Terra datasets

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1. Background and Rationale:

Globally, urban emissions account for 70% of total Green House Gas (GHG) emissions. Systemic under-reporting of urban emissions by cities has helped to increase GHG emissions over the years, sparking calls for a system of surveillance in real-time, which supports decision makers in identifying problem areas. A rigorous and accurate evaluation of emissions would allow us to measure the real-time emission pattern for better monitoring by increased awareness campaigns. Furthermore, the evaluation of emissions from one city to the next must be coherent and permit a emission trading forum to offset carbon trajectories according to the emission targets/regulatory emission pathway. The creation of a single real-time carbon trading mechanism to measure the emissions data for each city in Canada would help to create a reliable, accurate emission trajectories backed by real-time emission data, to implement effective emission mitigation strategies. This will entail the addition of several datasets at intermediate to high resolutions with varying temporal, spatial and spectral resolutions. Local pollution and long-range transport implications in the near-urban environment are of concern to record observed concentrations of CO, CO_2, and CH_4 that attribute 70% of GHG emissions. The Moderate Resolution Imaging Spectroradiometer (MODIS) acquires data, which covers the entire earth's surface on a near-daily basis in 36 spectral bands that span the visible (0.415 µm) to infrared(14.235µm) spectra at various pixel resolutions of 1-km,500-m and 250-m with a field of view of +_55°. They have a scene width of 2230km and a temporal resolution of 1-2 days. Channels 1 to 7 are used for terrestrial ecological parametric retrieval, channels 17 to 19 are used for perceptible water estimation and finally, channels 1,3, and 7 are used for aerosol inversion, which in turn is used for atmospheric correction of channels 1 to 7. The system derives data on emissions by spectroscopically interacting radiation with the atmosphere. Using these different MODIS land materials, the surface and atmospheric energy exchange induced by the space-time dynamics of terrestrial vegetation of the Planet due to human behaviour over the season (Yienger *et al.,* 1999, Blasing *et al.,* 2005) and the diurnal fluctuations can also be measured by the understanding of anthropogenic and natural shifts.

Early studies of Yienger *et al.,* (1999) and Blasing *et al.,* (2005) present critical insights seasonal fluctuations that lead to a continuous rise in oxidation process during summer, while colder temperatures alter the overall chemical condition of the atmosphere through the cause of multiple phase interactions between gases and spray particulates during the winter. The aim of this analysis is to use the MODIS Terra soil products to calculate and predict pollutant that increase and decrease the oxidation process, directly and indirectly, which affect atmospheric variations in aerosol particles.

Table: 1 shows a range of emission compounds of interest that can be used by MODIS Terra instruments to capture near-global everyday coverage by means of Aerosol Aerosol Optical Depth (AOD) or Aerosol Optical Thickness. These aerosols scatter and absorb incoming sunlight, thereby reducing visibility and recording their existence on the spectral frame. IPCC (2013) maintains that global concentrations of aerosols and their improvements need to be characterized over time. In addition, fusing data collected by various satellite instruments ensures a uniform spatio-temporal reference framework and enhances data precision. Chang & Li, (2002) lays emphasis on the cloud drop size estimation and its variation in measurements using satellite and aircraft observation, which is one of the primary sources of uncertainty in climate modeling.

Table :1 Atmospheric emission compounds (source: https://earthdata.nasa.gov/earth-observation-data/near-real-time/hazards-and-disasters/air-quality)

Emission Compound	Description	MODIS Dataset	Spectral Resolution	Spatial Resolution
Aerosol Optical Depth (AOD)/Aerosol Optical Thickness measures the permeability of sunlight through the atmosphere.	• AOD <0.1= 'clean sky, bright sun, max visibility' • AOD between 0.5 and 1.0= 'poor visibility' • AOD >3.0 'hazardous conditions'	• MODIS Terra (L2 Aerosol, 5-min Swath, 250m) • Multi Angle Implementation of Atmospheric Correction(MAIAC) • L3 value-added aerosol optical depth MODIS		250m, 500m, 1km
Carbon Monoxide (CO)	• Measure the methane oxidation, fossil fuel consumption (factory and vehicle emissions), biomass burning. Useful for analyzing the distribution, transport, source and sinks of CO in the troposphere. • Record interaction with land and Ocean biospheres • Reduces the natural ability of atmosphere to rid itself of harmful pollutants	• Atmospheric Infrared Sounder (AIRS) measured in parts per billion by volume (ppbv) • L2 AIRS • Microwave Limb Sounder MLS Carbon Monoxide • MOPITT (L2, Daily, Day/Night, Total Column)		2km

Dust	A parameter of the AIRS Level 1B infrared quality assurance subset. The AIRS Dust Score (Ocean, Day/Night) indicates the level of atmospheric aerosols in the earth's atmosphere over the ocean.			2km
Nitric Acid (HNO_3)	Formed by the conversion of nitrogen monoxide into nitrogen dioxide. It reacts with gaseous ammonia to form aerosol nitrate. Limits formation of ozone	MLS(Aura)- measured in parts per billion by volume (ppbv)		
Nitrous Oxide	A byproduct of natural decay process of land and ocean.	MLS(Aura)- measured in parts per billion by volume (ppbv)		
Ozone	Maintains atmospheric chemistry and radiative balance throughout the atmosphere.	MLS(Aura)- measured in parts per billion by volume (ppbv)		2km
Sulfur Dioxide (SO)	A colorless gas with pungent, suffocating odor which is water soluble to produce H_2SO_3 Produced by combustion of coal, fuel oil and gasoline.	AIRS(Aqua), MLS(Aura),OMI(Aura), OMPS(Suomi NPP) PM2.5		
Ocean carbon				

This research needs to define significant factors influencing climate change in order to measure emissions in real-time. Schmeisser *et al.,* (2017) argues that aerosol types can be identified through optical properties such as aerosol optical depth, Angstrom exponent(AE), single scattering albedo (SSA), fine mode fraction (FMF) and aerosol relative optical depth (AROD). In addition, crucial insights into annual and seasonal characteristics of aerosol forms, by means of ground-based measuring, can be helpful in producing classification maps based on their inherent properties. The variation in temperature affects the solubility of CO_2, in water, so higher temperatures can cause permanent harm to the environment on the downwind streams. Early research studies presented by Bornstein (1968), Bornstein and Johnson (1977),

[1]https://www.transportation.gov/sustainability/climate/transportation-ghg-emissions-and-trends

Bornstein (1995), Bornstein *et al.,* (2000) "*state that urban areas create their own climates and modify the local meteorological fields including temperature, wind, moisture, convective cloudiness, precipitation and the composition of ozone*". Oke and Hannell (1970), Oke(1973) and Oke(1978) contributed to more experimental observations of urban heat island (UHI) that could intensify the impact of regional and global climate locally. The size of the urban heat islands is determined by the population density, urban development, proximity to ports and traffic density in and around these areas for instance US, China and India have large urban heat islands as compared to Europe, Middle East and Africa. This leads to the development of computation and physical models to quantify the space-time heterogeneity of urban heat islands across different geographies of scales (local, regional and national).

We can create effective computational and physical models by using fixed point sampling techniques to track emissions in real-time along transport networks. In addition, the horizontal and vertical propagation profile of each pollutant through the built landscape is useful in addition to measuring pollutants along such transport networks. This dataset collection fused with MODIS Terra will help us determine the origin and spatial diffusion of low level and vertical ground level pollutant concentration induced by atmospheric conditions (temperature, wind and moisture). Briggs *et al.,* (2000) and Grunfeld (2005) presents numerous mathematical methods used to model pollution of traffic through dispersion rules. The geographic spread of these traffic emissions is a factor of the wind velocity and wind directional vectors that defines the catchment area. In addition, the merging of traffic emissions data with ecological models, digital terrain models and metrological models will provide new insights. Telmer and Veiga (2009) argue that '*the fate and transport of emitted mercury is difficult to define because of the regionally different injection heights which lead to unique plume trajectories and associated chemistries and deposition*'. The climatic conditions play a predominant role on wet and dry depositions across downstream vector that has significant impact on soil surface as well as water streams. Air quality dispersion modelling systems such as AERMOD Modelling system[1], CAL3QHC[2], CTDMPLUS[3], OCD[4] can help us accurately model and estimate source/sink geographic areas along the transport networks. The dispersion models depend on numerous factors such as

- Emission parameters along transport network, for example: source, altitude and location, exit velocity from source and exit atmospheric temperature
- Atmospheric conditions such as wind velocity and wind vector, ambient air temperature, solar radiation, cloud cover
- Geographic terrain elevation at the source and receptor locations, urban or rural landscape
- Location, height and width of any obstruction in the path of emitted gaseous plume as well as the terrain surface roughness.

Among the many ecological parameters used to estimate carbon sinks which absorb these urban emissions, EVI and NDVI are the most widely used vegetation index. In addition to this, leaf area index (LAI) is another key indicator to measure various energy cycles, CO_2 cycles and material cycles in canopies. They are directly correlated to evapotranspiration, soil water balance, photon interception in canopies, NPP (*a parameter used to quantify net carbon absorption rate by living plants*), GPP (*gross primary productivity*). Using MODIS Terra imaging datasets presents an opportunity to bridge the gaps by correlating ecological parameters with transport emissions to devise a comprehensive and consistent assessment on a regional and national scale. Nevertheless, it is important to remember that reducing pollution from transportation systems would be a daunting task which is resultant of stringent policies, high cost of (transport) clean technologies (Santos, 2017) and change of behaviours in the choices adopted by citizens with reference to the use of transportation modes. A strategic approach to bring about awareness among the citizens is to mark highways with monthly carbon footprints and by levying additional tax on individual vehicle operators who do not car pool to work or use clean energy vehicles.

2. Research Objectives and Methodology

The objective of this project is to investigate and develop new

Research Objectives:

The research objects are organized by themes.

A. Short-term goals

The short-term objective of this research is to build a real-time

B. Long-term objectives

The long-term objective of this research is to build a global real-time

i. Research questions

- What role does wind velocity and wind vectors play in the geographical spread of traffic emissions downstream?
- To build an integrated methodology on soil carbon stock and flux measurements at different scales using MODIS data.
- To discuss the relevance of soil carbon stock measurements within the terrestrial carbon cycle and climate system.
- To measure disproportionalities in the source of pollution along transportation networks using MODIS data?
- To measure the efficacy of local policies and activism across administrative regions of Canada using MODIS data?
- What biogeochemical models for mercury in forested areas will provide an understanding of the source/sink balance for a geographic region and thus accumulation or depletion in an ecosystem?
- What algorithmic techniques help us estimate mercury emission using MODIS data for local, regional and national resolutions?
- To estimate burn area measurements and their geographic spread due to wind velocity and wind vectors using MODIS data?

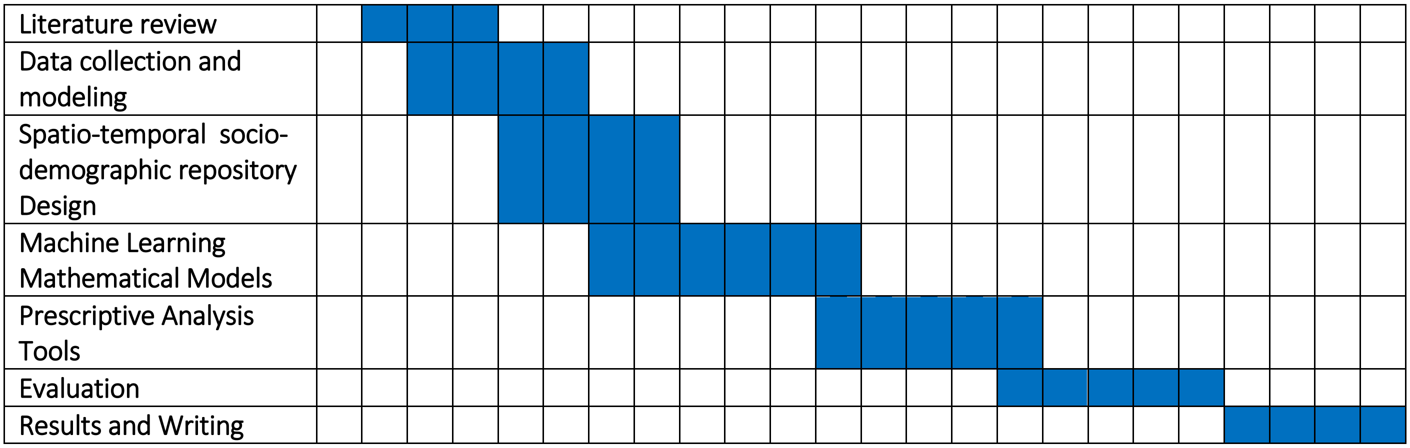
- How does fire dynamics data available from satellite measurements (MODIS Terra) help us identify geographic spread due to wind velocity and wind vectors?
- What models and algorithmic technique help us estimate emission of mercury from fires using MODIS data?
- To identify the average monthly spatial distribution of carbon emissions across various administrative division of Canada using MODIS data?
- What ecological retrieval parameters from optical remotely sensed data can help us describe carbon cycle models with MODIS data for local, regional and national resolutions?
- What algorithmic techniques help us estimate uncertainty induced due to cloud distortions with MODIS data?
- To estimate the seasonal variations from combustion along transport networks and agricultural sources?
- What machine learning models can help us accurately classify MODIS Terra data to extract emission parameters along various transport networks across Canada?
- How does the difference in temperature, wind direction, oxidants, biogenic emissions and boundary layer dynamics between winter and summer impact secondary aerosol formation?
- What models reflect seasonal and diurnal spatiotemporal emission trajectories on local and regional scales?
- Estimating the large uncertainties in emission inventories on regional and national scales using MODIS data?
- What strategies would help us track pollution plumes along transportation highways and their seasonal impact on aerosol due to downwind stream lofting?
- What metrological phenomena loft pollutants over the downwind stream across Canada and the United States?
- To build spatio-temporal simulation models to identify downwind catchment areas of emission sources using MODIS data
- To build spatio-temporal simulation models to device policy estimates to lower total GHG emissions along an administrative division
- To quantify and forecast emissions from combustion and agricultural sources between winter and summer on regional and national scale? How do these differences affect distribution and processing of pollutants downwind catchment areas?
- What models better reflect carbon dioxide flux due to biophysical and biochemical activities by forest vegetation?
- How can we estimate nitrogen levels in permafrost soils using MODIS Terra datasets?

2.1. Innovations and Milestones

The objective of this project is to create a

Table 1: Project activities and milestones

Milestones	Month1-2				Month3-4				Month5-6				Month7-8				Month9-10				Month11-12			
Project kickoff meeting																								



2.2 Research competence

The research team consists of the applicant, 2 Ph.D.,

2.3 Creation of New Collaborative Relationship

2.4 Industrial Relevance

This project would serve as real-time analytical platform for devising data-driven policy making and assessing its impact on a national and global scale. In phase one, it's focus is on designing a resilient framework for North America which can further be expanded to the European and Asian continents.

3. Study Areas and Data Set

One of the key challenges is to secure highly accurate data for each category, that could serve to provide multi-dimensional perspectives and design new mathematical models that not only take into socio-demography, but also Spatio-temporal aspects in real-time. This project aims to create real-time data collation framework from numerous open data platforms, public, private agencies and online questionnaire to record the exposure assessment of occupational and environmental epidemiological studies.

4. Anticipated Impact and Significance

5. Technology Transfer

The University of Waterloo team will be working closely with national and international partners on developing Spatio-temporal epidemiological models and tools for data-driven policy making. Devising frameworks to assess the efficacy of these data-driven policies in real-time. The tool will be licensed to the governing bodies through a annual subscription platform.

6. Knowledge Dissemination

This work will significantly benefit to Canadian governing agencies and its economy by revolutionizing the way we capture, collate, synthesize and simulate potential scenarios for Spatio-temporal socio-demographic epidemiological modeling.

- Conferences
- Publications
- Stakeholder meeting with Public Health Agency of Canada or Public Health Authorities

7. Training plan

This section outlines the rationale for the training program to equip, doctorate, graduate and bachelor students with skills and tools to successfully build a real-time Spatio-temporal analytical platform. It also identifies various workshops that would serve to build competence in the field of Spatial endemics, Spatio-temporal analytics, Geostatistics and Remote Sensing using hyper spectral imaging.

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