Atmospheric Environment 96 (2014) 380–392

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

A new dust transport approach to quantify anthropogenic sources of atmospheric PM_{10} deposition on lakes

Lee Weiss [a], Jesse Thé [c], Bahram Gharabaghi [a,*], Eleanor A. Stainsby [b], Jennifer G. Winter [b]

[a] University of Guelph, 50 Stone Road East, Guelph, Ontario, N1G 2W1, Canada
[b] Ministry of the Environment, Etobicoke, Ontario, M9P 3V6, Canada
[c] Lakes Environmental, 60 Bathurst Drive, Unit 6, Waterloo, Ontario, N2V 2A9, Canada

HIGHLIGHTS

- We developed an integrated dust model and tested it on Lake Simcoe.
- We used Dust Response Units to characterize PM_{10} emissions.
- The dust model was validated using observed deposition data.
- A comparison with background deposition data shows opportunity to reduce loading.
- Model results show bulk of the deposition originates from areas close to the lake's shoreline.

ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form
30 July 2014
Accepted 31 July 2014
Available online 1 August 2014

Keywords:
Dust emissions
Lake Simcoe
Phosphorus
Deposition
Dust model

ABSTRACT

Windblown dust simulations are one of the most uncertain types of atmospheric transport models. This study presents an integrated PM_{10} emission, transport and deposition model which has been validated using monitored data. This model characterizes the atmospheric phosphorus load focusing on the major local sources within the Lake Simcoe airshed including paved and unpaved roads, agricultural sources, construction sites and aggregate mining sources. This new approach substantially reduces uncertainty by providing improved estimates of the friction velocities than those developed previously. Modeling improvements were also made by generating and validating an hourly windfield using detailed meteorology, topography and land use data for the study area. The model was used to estimate dust emissions generated in the airshed and to simulate the long-range transport and deposition of PM_{10} to Lake Simcoe. The deposition results from the model were verified against observed bulk collector phosphorus concentration data for both wet and dry deposition. Bulk collector data from stations situated outside the airshed in a remote, undeveloped area were also compared to determine the background contribution from distant sources.

1. Introduction

The current application of dust models to compute windblown emissions, atmospheric transport, and deposition to water bodies contains a great deal of uncertainty (Lu and Shao, 1999), limiting its usefulness in regional environmental management. Dust can contain nutrients, which add to eutrophication processes when dust is deposited on the surfaces of lakes and ponds (Weiss et al., 2013). A study by Watson and Chow (2000) outlined the typical presence of chemicals and nutrients at various particle sizes and showed that PM_{10} or fugitive dust encompasses most particle sizes found in the atmosphere Table 1.

Agricultural lands and practices associated with agricultural production are a major source of dust, particularly during high wind events or during 'disturbance activities', such as tilling (Kjelgaard et al., 2004). Modeling results have shown that windblown or atmospheric dust, defined as particles of size 10 μm or less (PM_{10}), generated by agricultural processes constitute the majority of dust loading globally (Tegen and Fung, 1995; Sokolik and Toon, 1996; Ginoux et al., 2001; Saxton et al., 2000; Korcz et

* Corresponding author. Room 2417, Thornbrough Building, School of Engineering, University of Guelph, 50 Stone Road East, Guelph, Ontario, N1G 2W1, Canada.
E-mail address: bgharaba@uoguelph.ca (B. Gharabaghi).
URL: http://www.uoguelph.ca/~bgharaba/

http://dx.doi.org/10.1016/j.atmosenv.2014.07.060
1352-2310/

Table 1
BMP participation by township for the Lake Simcoe airshed (Statistics Canada, 2006).

Township/municipality	Crop residue	No-till	Cover crop	Windbreak
Bradford West Gwillimbury	84%	18%	14%	31%
Innisfil	88%	35%	12%	30%
New Tecumseth	81%	29%	20%	33%
Adjala-Tosorontio	67%	20%	17%	33%
Clearview	83%	14%	21%	31%
ESSA	88%	29%	20%	38%
Oro-Medonte	66%	18%	8%	38%
Ramara	65%	24%	4%	25%
Severn	51%	13%	6%	23%
Springwater	90%	27%	16%	28%
Tay	66%	10%	7%	35%
Tiny	61%	14%	11%	26%
Average BMP participation	**74%**	**21%**	**13%**	**31%**

al., 2009; Amodio et al., 2014). Dust generated by these processes has been directly related to nutrient/chemical loading (Leys, 1999; Leys and McTainsh, 1999; Sharratt et al., 2007; Salvador et al., 2014). The United States Department of Agriculture (USDA) has developed windblown emissions models, such the Wind Erosion Equation (WEQ) and later the Wind Erosion Prediction System (WEPS; Fryrear et al., 2001; Hagen, 2004; Feng and Sharratt, 2007, 2009) to estimate the impact of dust emissions from agricultural land use. However, both models have been shown to be somewhat inaccurate due to the broad estimation of shear velocity across local and regional scales. Marticorena and Bergametti (1995) developed models to represent the mechanics of soil entrainment which use relationships between soil parameters with vertical and horizontal dust fluxes to estimate dust emissions. Although the parameters for these models were independently verified, limitations related to characterizing dust emissions over more local scales still exist. As a result, various researchers employ field dust emissions measurements (Gillette et al., 2004; Nickling and Gillies, 1993; Rooney and White, 2006; King et al., 2011). One of the critical sources of uncertainty associated with estimating these emissions is the friction velocity, which acts as a surrogate to represent the shear stress causing the suspension of particulates (Lu and Shao, 1999).

The US National Oceanic and Atmospheric Administration (NOAA) coordinated the development of a continental scale dust model, embedded in the Weather Research and Forecasting (WRF) model and integrated with chemical modules (WRF/CHEM; Grell et al., 2005). The windblown emissions model, GOCART, generates emissions in the WRF model. The grid cells are large in size and all emissions modeled are instantly mixed within the grid cell. This makes identifying the main contributors of dust events virtually impossible for small parcels of land.

The goal of this study was to quantify long range versus local source contributions of the atmospheric phosphorus load to a large lake. Specific emission sources by land use were also quantified through the development of a customized and integrated model. Long-range transport and deposition contributions were then mapped within the airshed, to enable resource managers to design a cost-effective and targeted dust control Best Management Practice (BMP) implementation plan as part of an overall phosphorus reduction strategy.

This study presents a new approach to more accurately estimate dust loading. The algorithm used a precise windfield model to generate the hourly spatial distribution of winds. This distribution was used as input to a windblown emissions estimation process to create individual dust sources within the airshed. An air dispersion model was then employed to advect, diffuse, and deposit dust over the water bodies. Extensive dust deposition monitoring data were used to validate the new model.

The model was developed for Lake Simcoe, the largest inland lake in Southern Ontario, Canada. Its watershed supports an estimated population of 350,000 residents with an additional 50,000 cottagers (LSRCA, 2009). A decline in water quality attributed to excessive inputs of phosphorus has been observed over the past few decades (LSRCA, 2009; Palmer et al., 2011). Various studies have estimated 25–50% of the total phosphorus entering the lake is from atmospheric deposition (Winter et al., 2007). Lack of vegetative cover, along with soil disturbance related primarily to agricultural activities, results in higher susceptibility to wind erosion and dust emission of soil particles loaded with phosphorus from fertilizers. Other sources include paved and unpaved roads, pits and quarries and construction sites. Recently, phosphorus loading to Lake Simcoe from atmospheric sources accounted for an estimated 19 tonnes per year on average, based on Lake Simcoe Region Conservation Authority and Ministry of the Environment datasets on phosphorus loading for 2002–2007 (LSRCA, 2009).

Earlier work by Ramkellawan et al. (2009) and Brown et al. (2011) provided various TP deposition estimates for Lake Simcoe. Ramkellawan et al. (2009) used weather data to estimate the bulk deposition to the lake and Brown et al. (2011) analyzed the bulk collector data in conjunction with a high level analysis of the meteorological landscape within the airshed.

Weiss et al. (2013) continues this work and goes further to characterize one of the major atmospheric sources to the lake. Weiss et al. (2013) outlines the agricultural emission summary within the airshed, which includes a modified form of the Gillette and Passi (1988) dust emission model (MGP88), updated to reflect local climate and crop behavior. In urban environments vehicular traffic on paved and unpaved roads is the primary mechanism for dust emissions (Watson and Chow, 2000). An extension of the Weiss et al. (2013) study is the addition of paved and unpaved roads, pits and quarries and construction within the airshed.

1.1. Objectives

The main objective of this study is to develop more accurate methods and estimates of both wet and dry atmospheric deposition of nutrients to Lake Simcoe. To accomplish this, an integrated modeling approach was developed to incorporate widely accepted dust emission models with models based on real-time geophysical data. The specific objectives are to calculate the atmospheric loading of nutrients on Lake Simcoe due to: (1) wet deposition based on detailed analysis of spatial distribution of rainfall intensity data and rain water quality data; and (2) dry deposition based on detailed analysis of wind velocity and direction data and air quality data. Special attention was given to identify the location and magnitude of local sources of air pollution near the lake's shoreline.

Agricultural emissions were modeled using a modified form of the GP88 dust emission model (Gillette and Passi, 1988; Weiss et al., 2013) and unpaved road emissions were calculated using the AP-42 emission equation developed by the USEPA (USEPA AP-42, 1995). An accurate windfield of the Lake Simcoe airshed was developed with simultaneous input from the Mesoscale Meteorological Model (MM5; Grell et al., 1994) model and meteorological stations. The MM5 weather model produces gridded prognostic meteorological output fields used as inputs to CALMET. CALMET is the meteorological pre-processor for CALPUFF and is a diagnostic meteorological model that produces the final higher resolution three-dimensional wind and temperature fields and two-dimensional fields of other meteorological parameters (Scire et al., 2000). The purpose of the CALMET wind modeling exercise was to precisely