Atmospheric Environment 107 (2015) 70–84

Contents lists available at ScienceDirect

Atmospheric Environment

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

Long-term NO_x trends over large cities in the United States during the great recession: Comparison of satellite retrievals, ground observations, and emission inventories

Daniel Q. Tong [a, b, c, *], Lok Lamsal [d, e], Li Pan [a, b], Charles Ding [a, f], Hyuncheol Kim [a, b], Pius Lee [a], Tianfeng Chai [a, b], Kenneth E. Pickering [e], Ivanka Stajner [g]

[a] NOAA Air Resources Laboratory (ARL), NOAA Center for Weather and Climate Prediction, 5830 University Research Court, College Park, MD 20740, USA
[b] Cooperative Institute for Climate and Satellites, University of Maryland, College Park, MD 20740, USA
[c] Center for Spatial Information Science and Systems (CSISS), George Mason University, Fairfax, VA 22030, USA
[d] Goddard Earth Sciences Technology and Research, Universities Space Research Association, Columbia, MD, USA
[e] NASA Goddard Space Flight Center, Greenbelt, MD, USA
[f] University of California at Berkeley, Berkeley, CA, USA
[g] NOAA National Weather Service, Silver Spring, MD 20910, USA

HIGHLIGHTS

- Derived multi-year urban NOx trend from satellite (OMI) and ground observations (AQS).
- Revealed NOx responses to the 2008 Economic Recession by OMI and AQS.
- The trend not well captured by emissions used for national air quality forecasting.
- Demonstrated how to use space and ground observations to evaluate emission updates.

ARTICLE INFO

Article history:
Received 11 April 2014
Received in revised form
2 January 2015
Accepted 14 January 2015
Available online 15 January 2015

Keywords:
NO_x
Emission
Trend
Air quality forecast
Recession
OMI NO2
Ozone
AQS
NAQFC

ABSTRACT

National emission inventories (NEIs) take years to assemble, but they can become outdated quickly, especially for time-sensitive applications such as air quality forecasting. This study compares multi-year NO_x trends derived from satellite and ground observations and uses these data to evaluate the updates of NO_x emission data by the US National Air Quality Forecast Capability (NAQFC) for next-day ozone prediction during the 2008 Global Economic Recession. Over the eight large US cities examined here, both the Ozone Monitoring Instrument (OMI) and the Air Quality System (AQS) detect substantial downward trends from 2005 to 2012, with a seven-year total of −35% according to OMI and −38% according to AQS. The NO_x emission projection adopted by NAQFC tends to be in the right direction, but at a slower reduction rate (−25% from 2005 to 2012), due likely to the unaccounted effects of the 2008 economic recession. Both OMI and AQS datasets display distinct emission reduction rates before, during, and after the 2008 global recession in some cities, but the detailed changing rates are not consistent across the OMI and AQS data. Our findings demonstrate the feasibility of using space and ground observations to evaluate major updates of emission inventories objectively. The combination of satellite, ground observations, and in-situ measurements (such as emission monitoring in power plants) is likely to provide more reliable estimates of NO_x emission and its trend, which is an issue of increasing importance as many urban areas in the US are transitioning to NO_x-sensitive chemical regimes by continuous emission reductions.

1. Introduction

Nitrogen oxides (NO_x = NO + NO_2) are key precursors to tropospheric ambient ozone (O_3) and fine particulate matter ($PM_{2.5}$) (Crutzen and Gidel, 1983; Spicer, 1983), which has been

* Corresponding author. NOAA Air Resources Laboratory (ARL), NOAA Center for Weather and Climate Prediction, 5830 University Research Court, College Park, MD 20740, USA.
E-mail address: Daniel.Tong@noaa.gov (D.Q. Tong).

http://dx.doi.org/10.1016/j.atmosenv.2015.01.035

associated with adverse health effects, including respiratory diseases and cardiovascular mortality (Pope et al., 2002; Jerrett et al., 2009). As of December 2013, the United States Environmental Protection Agency (US EPA) estimates that more than one-third of the US population lives in areas that exceed the national ambient air quality standards (NAAQS) for either O_3 or $PM_{2.5}$ (US EPA, 2014a, 2014b). To assist state and local agencies in mitigating the effects of unhealthy levels of air pollution, the National Air Quality Forecasting Capability (NAQFC) system (Otte et al., 2005), currently operated by the National Weather Service, was designed to provide air quality forecasting guidance over the contiguous United States, Hawaii, and Alaska for next day forecasts (Stajner et al., 2012). NO_x are emitted from both anthropogenic sources (transportation, power plants, and fertilizers) and natural sources (biomass burning, lightning, and soils) (Warneck, 2000). Once emitted, NO_x reacts with volatile organic compounds under sunlight to form tropospheric ozone (Liu et al., 1987) and particulate nitrate, an important component of $PM_{2.5}$. Hence, quantifying the amount of NO_x emitted into the atmosphere is essential for reliable prediction of surface ozone and $PM_{2.5}$.

It is often challenging to provide accurate estimates of NO_x emissions for time-sensitive applications such as NAQFC, given the rapid progression of emission control and other socioeconomic events that affect emission loading (e.g., Harley et al., 2005; van der A et al., 2008; Stavrakou et al., 2008; Konovalov et al., 2010; Pinder et al., 2011; Castellanos and Boersma, 2012; Duncan et al., 2013). NAQFC relies on national emission inventories (NEIs) to account for thousands of anthropogenic emission sources and other emission models for natural sources. The substantial cost and effort entailed in collecting data relevant for compiling NEIs are prohibitive for frequent and timely updates of NO_x NEIs using conventional emission modeling approaches. As a result, the emission data used in NAQFC are several years behind the forecasting year, imposing uncertainties on air quality forecasting (Tong et al., 2012).

Can satellite-based emission data provide reliable information in order to rapidly update NO_x emission inventories and thereby support NAQFC-type air quality applications? NO_2 retrievals from polar orbiting satellite sensors such as SCIAMACHY and GOME have been used to update anthropogenic NO_x emission inventories (Martin et al., 2003; Lamsal et al., 2011; Mijling and van der A, 2012). This satellite-based approach, while showing great potential to reduce the emission time lag, has yet to be verified with independent data sources. To evaluate the robustness of this approach, this study thus compares the long-term NO_2 trends derived from the Ozone Monitoring Instrument (OMI) (Boersma et al., 2007) with the operational emission data used in NAQFC predictions, with emphasis on both the emission changes between major updates and the year-to-year progression over eight metropolitan areas from 2005 to 2012. A third data source, the EPA's AQS ground observations, serves as an independent reference to help verify urban NO_x trends. Estimation of future year emissions for air quality and climate modeling often relies on emission projections (Bond et al., 2004; Granier et al., 2011). NAQFC emissions are updated annually based on the available emission inventories, emission measurements, and projections. Rigorous evaluations of these annual updates, however, have not been performed regularly, largely because of the lack of observational data to directly verify emission projections. Meanwhile, AQS data have been used as a proxy for urban emissions since morning rush-hour concentrations are predominantly influenced by emissions from heavy commuter traffic (Godowitch et al., 2010). The AQS measurements have been coupled with other data to identify source strength and the origin of reactive nitrogen oxides over the Southeastern United States (Tong et al., 2005). Therefore, all three data sources provide independent quantification of NO_x emissions that can be compared over a fixed time period.

The intercomparisons of changes in NO_x from NAQFC, OMI, and AQS are expected to serve dual purposes: 1) to compare the NO_x trends derived from space and ground observations; and 2) to evaluate NAQFC emission updates against satellite and ground observations. We focus here on the NO_x trends over eight major metropolitan areas (Fig. 1) where NO_x emission density is high and AQS monitors are abundant. We further concentrate on the NO_x trends during summertime when the NO_x photochemical lifetime is shorter (4 h at noon), the carryover from the previous day is limited and regional transport is at minimal, yielding a column that is especially representative of local surface emissions (Russell et al., 2010). Further, the number of available satellite measurements is maximized during summer months, when cloud cover is lowest. Finally, these studied areas are among the most populous cities in

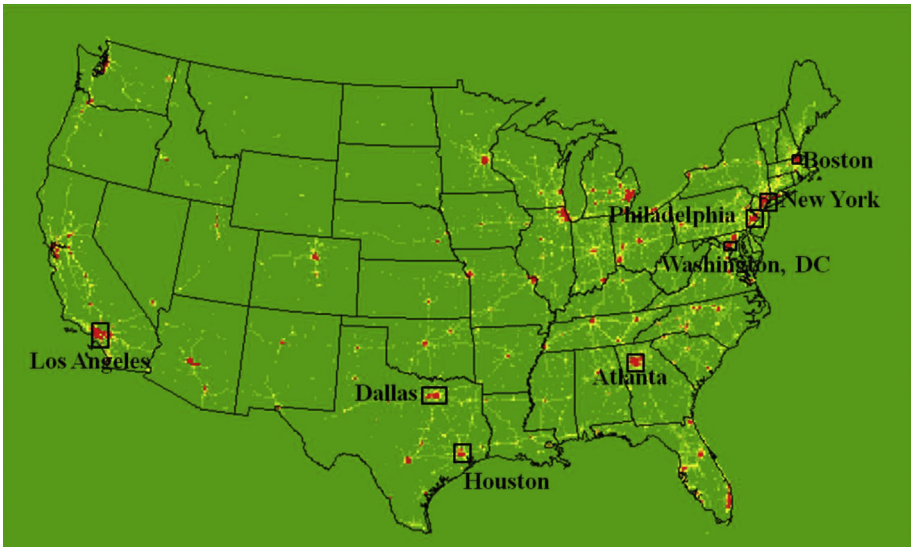

Fig. 1. Locations of the eight selected metropolitan statistical areas, which are among the most densely populated cities in the United States. The background color represents NO_x emission density based on the NAQFC emission data, with red indicating high NO_x emission density. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)