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Impacts of intercontinental transport of anthropogenic fine particulate matter on human mortality

Abstract

Fine particulate matter with diameter of 2.5 µm or less ($PM_{2.5}$) is associated with premature mortality and can travel long distances, impacting air quality and health on intercontinental scales. We estimate the mortality impacts of 20 % anthropogenic primary $PM_{2.5}$ and $PM_{2.5}$ precursor emission reductions in each of four major industrial regions (North America, Europe, East Asia, and South Asia) using an ensemble of global chemical transport model simulations coordinated by the Task Force on Hemispheric Transport of Air Pollution and epidemiologically-derived concentration-response functions. We estimate that while 93–97 % of avoided deaths from reducing emissions in all four regions occur within the source region, 3–7 % (11,500; 95 % confidence interval, 8,800–14,200) occur outside the source region from concentrations transported between continents. Approximately 17 and 13 % of global deaths avoided by reducing North America and Europe emissions occur extraregionally, owing to large downwind populations, compared with 4 and 2 % for South and East Asia. The coarse resolution global models used here may underestimate intraregional health benefits occurring on local scales, affecting these relative contributions of extraregional versus intraregional health benefits. Compared with a previous study of 20 % ozone precursor emission reductions, we find that despite greater transport efficiency for ozone, absolute mortality impacts of intercontinental $PM_{2.5}$ transport are comparable or greater for neighboring source-receptor pairs, due to the stronger effect of $PM_{2.5}$ on mortality. However, uncertainties in modeling and concentration-response relationships are large for both estimates.

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Impacts of intercontinental transport of anthropogenic fine particulate matter on human mortality

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Abstract Fine particulate matter with diameter of 2.5 μm or less ($PM_{2.5}$) is associated with premature mortality and can travel long distances, impacting air quality and health on intercontinental scales. We estimate the mortality impacts of 20 % anthropogenic primary $PM_{2.5}$ and $PM_{2.5}$ precursor emission reductions in each of four major industrial regions (North America, Europe, East Asia, and South Asia) using an ensemble of global chemical transport model simulati coordinated by the Task Force on Hemispheric Transpor Air Pollution and epidemiologically-derived concentrat response functions. We estimate that while 93–97 % avoided deaths from reducing emissions in all four reg occur within the source region, 3–7 % (11,500; 95 % co dence interval, 8,800–14,200) occur outside the source reg

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from concentrations transported between continents. Approximately 17 and 13 % of global deaths avoided by reducing North America and Europe emissions occur extraregionally, owing to large downwind populations, compared with 4 and 2 % for South and East Asia. The coarse resolution global models used here may underestimate intraregional health benefits occurring on local scales, affecting these relative contributions of extraregional versus intraregional health benefits. Compared with a previous study of 20 % ozone precursor emission reductions, we find that despite greater transport efficiency for ozone, absolute mortality impacts of intercontinental $PM_{2.5}$ transport are comparable or greater for neighboring source-receptor pairs, due to the stronger effect of $PM_{2.5}$ on mortality. However, uncertainties in modeling and concentration-response relationships are large for both estimates.

Keywords Health impact assessment · Particulate matter · Long-range transport · Chemical transport modeling

Introduction

Fine particulate matter, particles with diameter of 2.5 μm or less ($PM_{2.5}$), is associated with deleterious health effects, including premature mortality due to cardiopulmonary disease and lung cancer (Krewski et al. 2009). Despite its relatively short atmosphere lifetime (days to weeks), both $PM_{2.5}$ and its precursors can travel long distances, affecting air quality and health far from the emission source (e.g., Langner et al. 1992; Park et al. 2003; Park et al. 2004; Heald et al. 2006; Chin et al. 2007; Hadley et al. 2007; Liu et al. 2009a; Liu et al. 2009b; TF HTAP 2010; Yu et al. 2008; Ewing et al. 2013). Although $PM_{2.5}$ is transported most efficiently at altitude in the free troposphere, $PM_{2.5}$ originating from distant sources can influence surface $PM_{2.5}$ concentrations where people are exposed (Park et al. 2004; Chin et al. 2007; Liu et al. 2009a). In addition to dust, which is the dominant contributor to aerosol transport globally (Chin et al. 2007; Liu et al. 2009a; Yu et al. 2012), anthropogenic emission sources can affect $PM_{2.5}$ air quality on intercontinental scales through emissions of primary $PM_{2.5}$ (black carbon (BC) and primary organic aerosol); precursors of secondary $PM_{2.5}$ components including sulfate (SO_4), nitrate (NO_3), and secondary organic aerosol; and changes to oxidants that influence the formation of secondary $PM_{2.5}$ (Pham et al. 1995; Leibensperger et al. 2011; Fry et al. 2012). Because secondary components may be formed downwind, they typically affect air quality on larger spatial scales than primary emissions (Heald et al. 2006; Liu et al. 2009a; Leibensperger et al. 2011).

Compared with aerosols, intercontinental transport of ozone has generally received more attention in both science and policy arenas, since ozone has a longer atmospheric lifetime (about a month) and is transported in the atmospl more efficiently (TF HTAP 2010). However, $PM_{2.5}$ ha stronger effect on mortality (e.g., Bell et al. 2004; Je et al. 2009; Krewski et al. 2009) and is the dominant cont utor to premature mortality from outdoor air pollu (Anenberg et al. 2010; Lim et al. 2013). Previous studies that ozone precursor emissions affect health globally, witl to >50 % of regional ozone-related deaths caused extraregional emissions (Anenberg et al. 2009; West e 2009). North American and European emissions are estim to have greater health impacts outside the source region t within, mainly due to large exposed populations in East South Asia (Duncan et al. 2008; Anenberg et al. 2009; V et al. 2009). One previous study addressed the health imp of intercontinental $PM_{2.5}$ transport, using a tagging appro to estimate that intercontinental transport of nondust aero is associated with nearly 90,000 annual premature de globally, approximately 60 % of which occur in the den populated East Asia, India, and Southeast Asia (Liu e 2009b).

Here, we calculate the impacts of intercontinental trans of anthropogenic $PM_{2.5}$ on surface air quality and hu mortality using an ensemble of global chemical trans models coordinated by the Task Force on Hemisph Transport of Air Pollution (TF HTAP 2010). We multimodel simulations of 20 % anthropogenic prin $PM_{2.5}$ and $PM_{2.5}$ precursor emission reductions in eacl four major industrial regions to calculate their impact premature mortality within the region and elsewhere in world. Compared with estimates made using a single at spheric model, using a multimodel ensemble allows a n robust estimate and characterization of uncertainty du intermodel differences (e.g., Fiore et al. 2009). As amb air quality standards continue to tighten and controlling l emissions becomes increasingly expensive in some count improved understanding of foreign emission contribution $PM_{2.5}$ concentrations and mortality may help inform fu mitigation strategies (Keating et al. 2004).

Methods

We use TF HTAP multimodel ensemble estimates of impact of 20 % regional emission reductions on $PM_{2.5}$ c centrations around the world. The TF HTAP was establis in 2004 by the Convention on Long-Range Transbounc Air Pollution (CLRTAP) to improve understanding of intercontinental transport of air pollutants across Northern Hemisphere for consideration by the CLRT Over the last decade, the TF HTAP has organized a serie multimodel experiments to advance the state of the scie related to the transport of pollutants, including ozone $PM_{2.5}$, among others. The first set of multimodel experim

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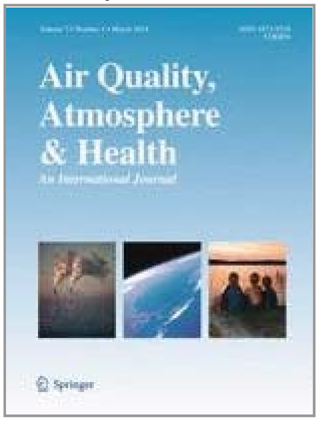

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Supplementary Material (1)

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- 6. Lawrence Livermore National Laboratory, Livermore, CA, USA
- 7. Swiss Federal Institute of Technology, Zurich, Switzerland
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- 13. Seoul National University, Seoul, Korea
- 14. NASA Goddard Institute for Space Studies, New York, NY, USA
- 15. Columbia Earth Institute, New York, NY, USA
- 16. Research Institute for Applied Mechanics, Kyushu University, Fukuoka, Japan
- 17. European Commission, Joint Research Center, Institute for Environment and Sustainability, Ispra, Italy