Free Executive Summary

Global Sources of Local Pollution: An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States

Committee on the Significance of International Transport of Air Pollutants; National Research Council

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Summary

Ten days ago factories, traffic, and cooking stoves half a world away emitted pollutants that may make the air you inhale today more hazardous to your health. Air pollutants emitted by your local electric power plant or your lawn mower today may help push air pollution levels above local air quality standards somewhere in Europe next week. Recent advances in air pollution monitoring methods and models, including satellite-borne sensors, have made it possible to show that long-range transport of air pollutants, including transpacific and transatlantic trajectories, does occur. These studies make it clear that the world has only one atmosphere and that adverse impacts of emitted pollutants often cannot be confined to one location, one region, or even one continent.

Many types of air pollutants have been observed to travel far from their sources. These include primary pollutants that are directly emitted like soot particles from diesel vehicles, windblown dust from deserts or degraded croplands, mercury from coal-fired power plants, pesticides from agricultural operations, and nitrogen oxides from motor vehicles. They also include secondary pollutants that are created in the atmosphere by chemical reaction sequences that begin with primary pollutants. Important secondary pollutants include atmospheric oxidants like ozone and hydrogen peroxide, sulfuric and nitric acids, and chemically diverse secondary smog particles. Any air pollutant with an atmospheric lifetime of at least three to four days may be transported across most of a continent, a week or two may get it across an ocean, a month or two can send it around the hemisphere, and a year or two may deliver it anywhere on Earth.

Both population and living standards are increasing in many parts of the world; often, so are the resulting pollutant emissions. At the same time, air quality standards are being tightened in response to studies that demonstrate adverse health consequences at ever lower exposures. Other studies document unwelcome impacts of air pollutants on crop yields and the viability of forests, grasslands, and other natural ecosystems. Still other studies are unveiling the interplay between air pollution levels and climate change on scales ranging from regional to global. All of these concerns have led to increasing international efforts to recognize and measure long-range transport of pollutants. They have also spurred attempts to predict how expected changes in population; in production of food, energy, and goods; and in climate will impact future pollutant transport and air quality.

REPORT GENESIS

Federal, state, and local agencies are faced with the need to understand and manage the current impact of long-range transport of pollution on health and well-being (relative to the impacts of local pollution sources), as well as the need to develop measurement methods and models to track pollution transport trends and project their future levels and impacts. Agencies with environmental regulatory responsibilities need to better understand how, when, and where long-range transport may lead to National Ambient Air Quality Standard (NAAQS) violations or pollutant levels that exceed other regulatory guidelines. Agencies with atmospheric research portfolios are interested in knowing what gaps in knowledge and capability weaken our understanding of current long-range transport of pollutants, as well as those that reduce our abilities to measure trends and predict future activity and its impacts. They would also like to envision how our atmospheric observational capabilities and diagnostic and predictive models can be improved to close these gaps.

In response to these challenges the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF) have cosponsored this National Research Council (NRC) Committee to explore these issues for four specific pollutant classes: ozone and it precursors (O_3), fine particulate matter and its precursors (PM), atomic and molecular mercury (Hg), and persistent organic pollutants (POPs).[1] Specifically, the Committee was asked to consider the impacts of long-range pollution transport on air quality, pollutant deposition, and radiative forcing[2] in the United States; the impacts of U.S. emissions on foreign air and environmental quality; and the ways these emissions and impacts may change in the future. Finally they were asked to identify how better research and information management tools might improve understanding of and the ability to quantify the impacts and implications of long-range transport of pollution. The complete Statement of Task is presented in Appendix A.

KEY CONCLUSIONS

Both observational and modeling studies confirm that significant quantities of the pollutants considered in this study are transported over long distances, both to and from North America. Meteorological conditions off the east coasts of both Asia and North America are conducive to lofting pollutants into the midlatitude free troposphere, where strong winds aloft can rapidly transport polluted Asian air masses to North America and polluted North American air masses to Europe. Satellite observations and high-altitude in situ measurements observe polluted air masses in the free troposphere crossing both the Pacific and Atlantic ceans. The mixing of these pollutants down to ground level is not well characterized, and thus the question of how much and where long-range transport of pollution from distant emissions can impact local air quality is much harder to determine. Other mechanisms that transport pollutants over long ranges at lower altitudes and lower latitudes are also incompletely characterized. Nonetheless, atmospheric chemical transport models do predict the occurrence of ground-level pollution due to long-range transport, and low-altitude and ground-level measurements do at times clearly detect such events. The Committee thus concludes that long-range transport of pollutants from foreign sources can under some conditions have a significant impact on U.S ambient concentrations and deposition rates for each of the four pollutant classes considered and that U.S. environmental goals are affected to varying degrees by nondomestic sources of these pollutants. Similarly, long-range transport of pollutants originating in the United States can significantly affect air quality and other

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[1] Long-lived greenhouse gases, such as CO_2 (recently ruled to be a "pollutant" by the U.S. Supreme Court), have long been known to undergo global-scale transport, but the Committee's charge did not include consideration of such gases.
[2] Radiative forcing (RF) of climate is a quantitative measure (usually in watts per square meter) of the instantaneous imbalance in the climate system caused by the addition of greenhouse gases or aerosols to the atmosphere.

environmental concerns elsewhere (e.g., northern and central Europe, the Arctic). The relative importance of long-range pollutant contributions from foreign sources is likely to increase as nations institute stricter air quality standards that result in tougher emissions controls on domestic sources.

Our current ability to fully characterize long-range transport and its impacts is limited, due to a number of factors: uncertainties in foreign emission source strengths, incomplete understanding of pollutant chemical and phase transformations during transport, poorly characterized mechanisms and rates of pollutant transfer between the boundary layer and free troposphere, and the fact that very few air quality research and monitoring sites are equipped to discern long-range pollutant contributions amid the normally much larger pollutant inputs from local and regional sources. Conclusions about the overall magnitude of pollution inflow and outflow must be drawn from modeling estimates, which are constrained by many uncertainties, including those listed above.

The Committee concludes that the most effective way to improve our capability to characterize current long-range pollutant impacts and to predict future trends is the development and implementation of an integrated pollutant-source attribution observation and modeling system. Key components must include

- timely, more highly resolved and more accurate multipollutant **emission scenarios** for all significant activity sectors (including sources associated with the natural environment) in key source regions;
- frequent **satellite observations** (and associated analyses) of a range of important primary and secondary pollutants with adequate horizontal and vertical resolution in order to identify long-range transport events and to verify regional emissions estimates with inverse modeling;
- more capable **in situ monitoring** of multipollutant ground-level and vertical profile concentration measurements at judiciously chosen receptor sites with measurement capabilities designed to fingerprint pollutants from foreign sources and provide key pollutant ratios and other data necessary to establish trends and allow source attribution calculations;
- periodic intensive **field measurement campaigns** designed to track long-range transport events, better characterize chemical and physical transformations of key pollutants, and identify and quantify mechanisms that transport pollutants from the surface into the free troposphere and back; and
- improved **chemical transport models** capable of using inversion techniques (wherein pollutant emissions are derived from measured atmospheric concentrations), to better verify emission estimates, provide better estimates of source/receptor relationships, and predict trends based on informed scenarios for future emissions and changing climate conditions.

Pollutant-Specific Findings

The assessment of long-range transport of pollution involves many issues that are common to all pollutant species (e.g., the need to quantify sources, characterize atmospheric transport pathways, define baseline concentrations, integrate observational and modeling analyses), but each type of pollutant has its own unique characteristics and environmental significance. The Committee thus developed a range of findings and recommendations for each of the four main pollutant classes considered. Detailed recommendations for future research needs are presented at the end of Chapters 2-5. Below is a brief overview of key findings regarding what is known and not known about long-range transport, and resulting impacts for each of these pollutants. The list highlights but does not fully duplicate the key findings from the individual pollutant chapters.

Ozone and Precursors

- There is clear evidence that baseline levels of tropospheric O_3 have risen above pre-industrial levels in the Northern Hemisphere by 40-100 percent, and much of this increase can be directly attributed to human-caused emissions of O_3 precursor species. Baseline tropospheric O_3 abundances at many remote locations in the Northern Hemisphere have increased over the last few decades; the rates vary by location and the causes of these recent changes are not clear.

- Plumes containing high levels of O_3 and its precursors can be transported between continents and are observed downwind of major industrial regions (and large wildfires) in North America, Europe, and Asia. These plumes are observed in the free troposphere over affected regions, but less frequently at the surface due to dilution in the boundary layer.

- Multimodel studies calculate that a 20 percent reduction in ozone precursor emissions from any three of the four major industrial regions of the Northern Hemisphere will reduce surface O_3 in the fourth region by about one part per billion (ppb) on average but with large spatial and seasonal variations.

- U.S. NAAQS ozone violations are caused primarily by domestic emissions but are augmented by a changing baseline, as well as episodic nonlocal events, such as emissions from wildfires, lightning NO_x, stratospheric intrusions, and occasional plumes from distant anthropogenic sources. Most violations are only a few ppb above the standard, and thus increasing baseline O_3 can contribute to these violations.

- It is clear that distant pollution does contribute to increased concentrations of O_3 over populated regions and that such increases may have detrimental impacts on human health, agriculture, and natural ecosystems. One study estimates that the number of premature cardiopulmonary deaths that could be avoided per year in North America due to a 20 percent emission reduction in other major Northern Hemisphere industrial regions is in the hundreds. The uncertainty in this estimate is large (at least ± 50 percent), reflecting uncertainties in modeling both O_3 change and health effects.

Particulate Matter and Precursors

- Observations demonstrate that PM can undergo long-range transport, primarily through episodic events associated with biomass burning plumes, dust storms, and fast transport of industrial pollution. Such episodes are most easily identifiable in remote area observations with low ambient PM concentrations. More persistent long-range transport also occurs but at relatively low concentrations that are difficult to distinguish from local and regional PM sources. There is not enough observational evidence to demonstrate clear trends in average baseline levels of surface PM on a global or hemispheric scale.

- Chemical transport models are increasingly being used to estimate long-range transport contributions to atmospheric PM concentrations. Uncertainties in model estimates result from factors such as lack of observational constraints, particularly in the free troposphere, where much of the transport occurs; poorly constrained or unknown emissions of some primary particles and the emissions and conversion of PM precursors (especially secondary organic PM); and poorly constrained wet and dry PM removal processes as reflected in the large differences in PM lifetimes among models.

- There are growing capabilities for observing total column amounts of PM, but the linkages between column amounts and surface concentrations are not well understood, which limits the ability to quantify the effect of persistent transport on surface concentrations based on column observations.

- With the exception of occasional extreme episodes, long-range transport of PM is estimated to represent a negligible contribution to PM NAAQS exceedances in most regions of the United States. However, increases in surface PM from episodic or persistent transport can be significant in places with low ambient pollution levels, particularly in developing strategies to achieve compliance with the U.S. EPA's Regional Haze Rules, which are aimed at returning visibility in protected regions to natural levels.

- Some studies have begun to estimate the premature mortalities attributable to long-range transport of PM, but they are limited by large uncertainties in estimates of imported and exported PM and by lack of a mechanistic understanding of how the individual components of PM are linked to health. Domestic sources of PM are thought to be by far the larger risk to human health, but (because there is thought to be no threshold for PM health impacts) the import of PM from distant sources could add to the health burden. Other impacts, such as perturbations to the regional radiative balance and harmful ecological and agricultural impacts of long-range PM transport, could be significant but have not been rigorously evaluated.

Mercury

- Hg is truly a global pollutant, as it has the potential, once emitted from any source, to be transformed to different chemical forms, transported through the atmosphere, and deposited long distances from the point of origin. Reservoirs that accumulate Hg include the atmosphere, the oceans, freshwater systems, soils, biota, and the cryosphere. Hence intercontinental transport is an important process that clearly affects U.S. exposures. Continued emissions will increase the amount of Hg in the global pool available for long-range transport and recycling among these reservoirs in the environment.

- As a result of increasing emissions, Hg deposition to the contiguous United States has increased since the beginning of the industrial revolution. Recent modeling studies suggest that a range of 10 to 80 percent of Hg deposited to the United States is from domestic anthropogenic sources, with an average of about 30 percent for the country as a whole. The rest is derived from natural sources and the global pool. It is clear that a component of Hg in fish (the primary route of human exposure to Hg) is derived through atmospheric deposition coming from the global atmospheric Hg pool.

- Our ability to quantify the magnitude and rates of exchange among these Hg reservoirs is limited by incomplete knowledge about atmospheric chemical processing, dry deposition, and the resuspension of deposited Hg back to the atmosphere, and by insufficient observational data needed to evaluate models.

Persistent Organic Pollutants

- There is substantial observational evidence that POPs can be transported over long distances. Transpacific atmospheric transport of POPs to the continental United States is relatively well characterized, but other potentially important transport pathways are not.

- There is evidence that atmospheric concentrations of historically used pesticide-related POPs are declining due to global regulations, while concentrations of combustion-related POPs, as well as some chemicals currently in use that have the potential to be considered POPs, are increasing due to growing emissions.

- U.S. efforts to reduce exposures to POPs are clearly impacted by long-range transport, and there is potential for the U.S. population (as well as some remote high-elevation and high-latitude U.S. ecosystems) to be exposed to increasing concentrations of certain POPs. This includes the re-release of legacy POPs by melting glaciers, forest fires, and vaporization from soils and oceans.

- At present it is difficult to quantify intercontinental transport fluxes or characterize the significance of this influence because of limited observations and modeling tools, incomplete scientific understanding of the photochemical processes that affect POPs during transport, and lack of standard national goals for POPs deposition.

All four pollutant classes had similar findings regarding expected future changes in long-range transport trends and impacts. Future climate change is likely to affect the patterns of emission, transport, transformation, and deposition for all pollution species. Predicting the net impacts resulting from all the various potential changes, however (e.g., changes in meteorology, atmospheric chemistry and dynamics, source and sink strengths), is extremely difficult with present knowledge.

Likewise, for all of the pollutants in question, future anthropogenic emissions are expected to increase in East Asia and much of the rest of the developing world, based on population and economic growth projections. In the long run these increases could be mitigated by increasingly stringent pollution control efforts and future international cooperation in developing and deploying pollution control technology and information exchange programs.

CROSSCUTTING RECOMMENDATIONS

The Committee identified a number of crosscutting opportunities to create multipollutant tools and methods that will allow better characterization (and eventually control) of long-range pollutant transport problems.

Pollutant fingerprinting. To better identify source-specific characteristics for individual pollutants and complex particles, the Committee recommends continued investment in advancing cutting-edge fingerprinting techniques (e.g., source-specific ratios of pollutant gases and particles, isotopic analyses, single-particle analysis systems) and the widespread deployment of such techniques in both ground- and air-based studies aimed at refining our assessment of pollution sources, transport, and chemical transformation. Particular emphasis should be placed on using these techniques to advance understanding of the complex heterogeneous reactions of organic species and the complexities of the mercury biogeochemical cycle.

Emission inventories and projections. To enhance our ability to understand, forecast, and manage changing emission sources, and thus adequately model long-range pollutant transport events, the Committee recommends designing field experiments that not only confirm emission totals but also link them to the fundamental sources and processes that generate them; improving the accuracy, timeliness, spatial and temporal resolution, multipollutant coverage, and inter-comparability of Northern Hemisphere regional and national emission inventories; enhancing understanding of legacy emissions of Hg and POPs; and stimulating the collection, evaluation, and use of airborne and satellite multipollutant concentration data using inverse chemical transport modeling techniques to independently evaluate available emission inventories.

Meteorological processes. To improve our knowledge of how pollutants move between the atmospheric boundary layer (where most pollutants are emitted and eventually redeposited) and the free troposphere (where long-range transport is most efficient), the Committee recommends developing a better understanding of the basic dynamic processes involved in the entrainment, long-range transport, and deposition of pollutants through focused field studies, advances in satellite technology, improved data assimilation methods, and enhanced meteorological and transport modeling capabilities. Meteorologists and atmospheric chemists, including both modelers and measurement specialists, should collaborate on efforts to develop better measurement techniques and improved numerical models that will enable us to adequately quantify the role of distant sources on local air quality.

Ship and air transport emissions. It is necessary to better understand how emissions from ocean shipping and transport aircraft affect atmospheric composition, and can complicate the detection and characterization of long-range atmospheric pollutant transport from traditional land-based sources. The Committee thus recommends coordinating studies of long-range atmospheric pollution transport with studies of ship and aircraft emissions, with the goal of determining methods to distinguish among these pollutant sources in source attribution studies.

Integrated source attribution system. Determining the impacts of distant emissions on U.S. receptor sites is a daunting task because local and regional sources usually dominate long-range transport from foreign sources. Approaching this problem one pollutant at a time is sub-optimal since most sources emit a suite of pollutants that are transported together. Further, no one type of observation or atmospheric model is likely to solve complicated source attribution problems. The Committee strongly recommends that an integrated source attribution program be established to assess the contribution of distant sources to U.S. air quality and to evaluate the effectiveness of national control strategies to meet environmental targets. The program should focus on improving capabilities within the following key areas: emissions measurements and estimates, atmospheric chemical and meteorological modeling, long-term ground-based observations, satellite remote sensing, and process-focused field experiments. These different components need to be integrated as effectively as possible to focus on source attribution applications. An expert group should be established to help design this source-attribution network (e.g., suggesting parameters to be measured, identifying appropriate monitoring sites, developing an embedded research program). These efforts should consider the need for international cooperation with opportunities to collaborate existing international efforts, such as the World Meteorological Organization's International Global Atmospheric Chemistry Observation program.

CONCLUDING THOUGHTS

The pollutants discussed in this study do not represent all species of concern, but they do illustrate the variability of pollutant composition and behavior and provide focused examples for analyzing the phenomenon of long-range pollutant transport. Present global socioeconomic scenarios predict that adverse air quality impacts from distant sources of pollution are likely to grow and cause increasing concern in the United States and other nations that are determined to provide clean air for their citizens and their ecosystems. Enhancing atmospheric observations, chemical transport models, trend analyses, the understanding of pollutant chemical and physical transformations, and emission inventories and projections will all be critically important to better quantify such effects.

The Committee wishes to emphasize that our atmosphere connects all regions of the globe, and pollution emissions within any country can affect populations, ecosystems, and climate properties well beyond national borders. Likewise, measures taken to decrease emissions in any region can have benefits that are distributed across the Northern Hemisphere. The United States, as both a source and receptor of long-range pollution, has an interest in remaining actively engaged in this issue, including support of more extensive international cooperation in research, assessment, and ultimately, emissions control efforts.

It is clear that local pollution can be affected by global sources, although in most cases air quality violations are driven by local emissions. Regardless of where the pollution originates, protecting human and ecological systems from dangerous levels of pollution should be the policymakers' primary objective. Meeting this objective will require strengthening domestic pollution control efforts to whatever levels are required to ensure that a population's total pollution exposure (from local, regional, and distant sources) does not exceed safe levels. Reducing the impacts of distant emissions on local air quality cannot be achieved by domestic efforts alone. Cooperative international action needs to be pursued vigorously to advance our understanding of long-range transport of pollution and its impacts, and to use that understanding to effectively control emissions from both domestic and foreign sources.

Global Sources of Local Pollution

An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States

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Committee on the Significance of International Transport of Air Pollutants

Board on Atmospheric Sciences and Climate

Division on Earth and Life Studies

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