Retrospective Dynamic Model Evaluation for Regional Haze

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Regional Haze Planning Work Group 2017 Teach-In series

Oct 19, 2017

Introduction/Motivation

- Photochemical model simulations can be used to simulate visibility conditions for a recent year and to project visibility improvements in future years.
- Models can have bias and error in the simulation of individual species that contribute to visibility impairment, and this suggest several questions:
  - Do models accurately simulate the observed trends in speciated PM concentrations at IMPROVE monitors.
  - How have the modeled contributions from source categories such as international transport, natural sources, and anthropogenic sources changed over time.
  - Do photochemical models accurately simulate the benefits of anthropogenic emissions for reducing visibility impairment.
  - Are there additional model evaluation approaches that can provide better scientific foundation for the use of models in regional haze planning.

Four Model Evaluation Techniques

- Operational Evaluation – statistical metrics (bias & error) and graphical analyses to determine the modeled simulated variables are comparable to measurements.
- Diagnostic Evaluation - process-oriented analyses that determine whether the individual processes and components of the model system are working correctly, both independently and in combination.
- Retrospective Dynamic Evaluation: assess the ability of the air quality model to predict changes in air quality given changes in source emissions or meteorology.
- Probabilistic Evaluation: assess the level of confidence in the model predictions through techniques such as ensemble model simulations.

Description of model evaluation approaches is from the EPA Draft Modeling Guidance, available at:
https://www3.epa.gov/scram001/guidance/guide/Draft_O3-PM-RH_Modeling_Guidance-2014.pdf

Retrospective Dynamic Model Evaluation

- Retrospective dynamic evaluation compares model predicted historical trends with observed trends:
  - o Goal is to examine the ability of the model to respond to emissions changes by comparing trends in observed ozone or PM2.5 concentrations to the model predicted trend over the same time period.
- Retrospective analysis evaluates model performance in a way that is closely related to how models are used in SIPs/TIPs.
- Can potentially diagnose why a strategy did or did not work as expected.
- Retrospective dynamic evaluation is always recommended, but the measurements and resources needed for a dynamic evaluation may not be readily available to many air agencies performing SIP/TIP modeling. Consequently, retrospective dynamic evaluations may be beyond the scope of many SIP/TIP modeling demonstrations.

Steps in a Dynamic Model Evaluation

- Identify appropriate case studies in which responses to emissions changes are large enough to be distinguished in ambient data.
- Developing emissions inventory data for multiple historical years.
- Disentangle the confounding influences of year to year changes in meteorology and emissions.
    - Because differences in meteorology between years can confound the apparent change in pollutants, a complete retrospective analysis could include multiple sensitivity runs using both year-specific meteorology and constant meteorology.
    - The year-specific meteorology would allow the modeler to compare modeled and observed trends most accurately.
    - The constant meteorology would help inform the analysis on what portion of the change in pollutant concentrations were due to emissions versus meteorological differences

Dynamic Model Evaluation for Ozone

- Several retrospective dynamic model studies have been performed for ozone, both in the eastern and western U.S.

- In some cases, models have underestimated the rate of progress that was observed in reducing ozone.
  - Models can underestimate the rate of progress if they underestimate the contribution of anthropogenic emissions and overestimate the contribution of background ozone.
  - Errors in emissions of VOC and NOx or in modeled sensitivity of ozone to NOx can cause models to underestimate the rate of progress achieved from NOx reductions.

Dynamic Model Evaluation for PM/AOD

- Turnock et al., 2015, Modelled and observed changes in aerosols and surface solar radiation over Europe between 1960 and 2009.
  - Hadley Centre Global Environment Model: biased low for sulfate but accurately simulates trends in aerosols, including simulated 78% reduction in sulfate compared to observed 68% reduction in Europe.
- Pozzer et al., 2015, AOD trends during 2001–2010 from observations and model simulations.
  - European Centre EMAC model reproduces MODIS observed AOD trends. Decreasing AOD trends over the eastern U.S. and Europe are due to the decreases in emissions.
- Boys et al., 2014, Fifteen-Year Global Time Series of Satellite-Derived Fine Particulate Matter.
  - GEOS-Chem simulations agree well with observed PM2.5 trends in the eastern U.S.
- Chin et al., 2014, Multi-decadal aerosol variations from 1980 to 2009: a perspective from observations and a global model.
  - NASA GO-CART model found that aerosol optical depth (AOD) and PM concentration over polluted land regions generally vary with anthropogenic emissions, but the magnitude of this association can be dampened by the presence of natural aerosols, especially dust.

Dynamic Evaluation with variable Met Data

- The year-specific meteorology, year-specific biogenic and wild fire emissions, and year-specific boundary conditions would allow for more accurate comparisons of modeled and observed trends:
  - To fully implement approach would require year-specific model input data and performance evaluations for each year from 2000 to 2016, and this is not feasible given limited time and resources.
  - There may be some benefits from simulating year-specific model input data for a few selected years to better understand interannual variability, but this is also subject to resource constraints and may have limited benefits.

Trends in International Transport

- Variability in international transport contributions to visibility impairment can make it difficult to identify U.S. versus international contributions to impairment in the IMPROVE data.
- Anthropogenic emissions of NOx and SO2 increased in Asia from 2000 to about 2011 and are thought to have decreased since 2011. Trends in anthropogenic emissions in Canada and Mexico are uncertain.
    - Increasing Asian emissions might have masked the progress at IMPROVE sites from U.S. emissions reduction from 2000 to 2011, and IMPROVE monitors might show more rapid progress after 2011.
- Retrospective dynamic modeling can be used to estimate trends in international transport contributions to light extinction at IMPROVE monitors and assess how this affects modeled progress in reducing impairment.

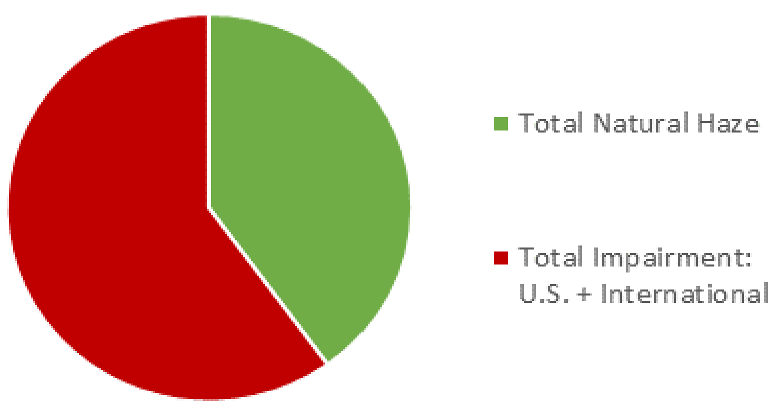
Dynamic Evaluation of International Transport

- Can global and regional scale photochemical models be used to estimate international contributions to impairment in the baseline period and for key milestones: 2016, 2028.
- Can we quantify interannual variability in international transport from natural sources of haze: volcanoes, wild fires, dust.
- Dynamic modeling of international emissions can be performed for:
  - Constant U.S. emissions and a constant meteorological data year using year-specific global model simulations to provide boundary condition data for 2002, 2016, 2028.
  - Also need global model simulations for each year with zero international anthropogenic emissions to develop source attribution information in the BC.
  - Evaluation of trends can be performed in the western U.S. using stand alone global scale model simulations (no regional scale simulations).

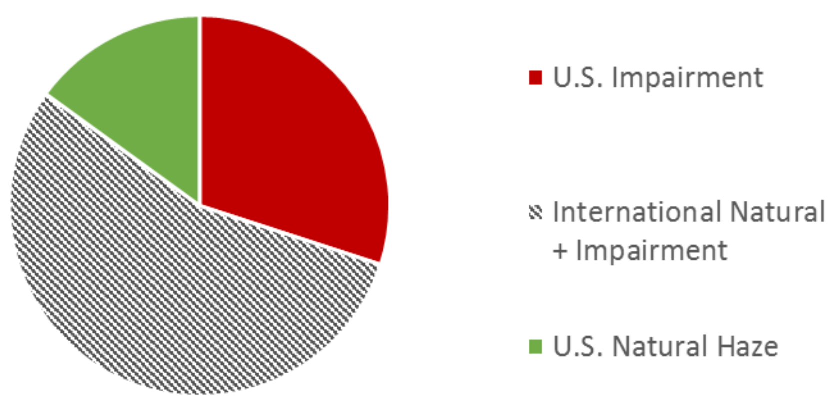
Evaluating Impairment from International Transport

- Using currently available regional scale photochemical models, we cannot compare estimates of natural haze and impairment in the IMPROVE data and in the photochemical model because the boundary condition (BC) data derived from global scale models do not distinguish between natural and anthropogenic PM2.5.

IMPROVE data statistical analysis



Photochemical Model Source Attribution current BC approach

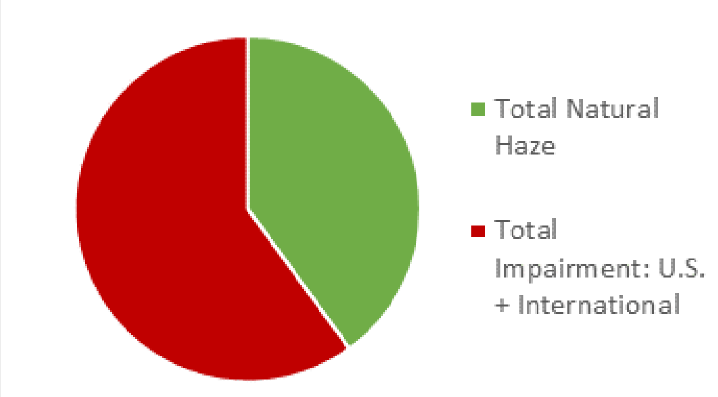


Note: hypothetical values are used in the pie chart to illustrate the method.

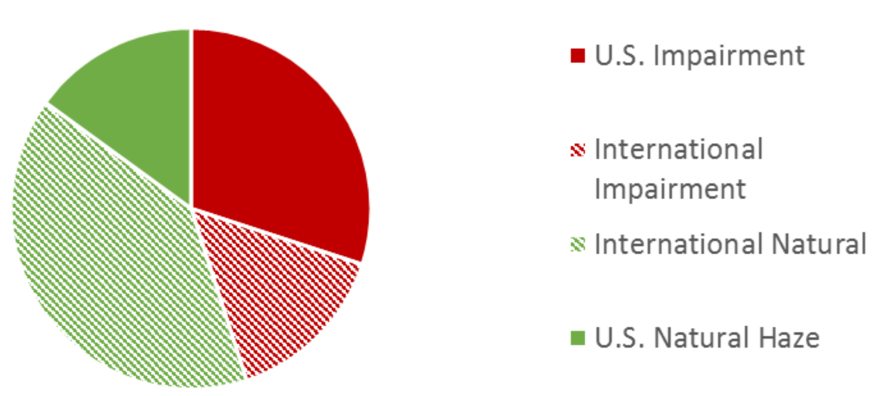
Boundary Conditions from Global Models

- Global model source attribution is needed so that regional models can distinguish transported natural haze and impairment in the boundary conditions.
  - Global model simulation with zero anthropogenic emissions can be used quantify modeled natural haze and this can then be compared to the natural haze estimates used in the statistical analysis of IMPROVE data.

IMPROVE data statistical analysis



Photochemical Model with Global Model BC Source Attribution



URP from IMPROVE data

- Statistical model is used to apportion observed anthropogenic and natural extinction and to estimate anthropogenic impairment for each day of IMPROVE data:

  impairment (deciviews) = $10 \ln(bext_{total}/bext_{natural})$

- URP is the straight line from estimated total deciviews in the baseline 2000 to 2004 period extended to estimated natural conditions in 2064.
- The URP can be adjusted to account for impairment from international transport and certain fires, although the method to implement this is not specified in the revised Regional Haze Rule.
- Uncertainties in the statistical model:
  - Draft recommended approach seeks to quantify episodic natural contributions from wildfire and dust storms, but the method does not perfectly label all wildfire impacts as natural.
  - Trijonis natural haze estimates have large uncertainty.
  - Draft recommended approach assumes natural contribution each day is proportional to observed concentration each day.

URP from a Photochemical Model

- Under the EPA rule, the URP must be calculated using monitoring data and appropriate data analysis techniques. The rule and the draft EPA guidance do not allow or disallow air quality modeling from being considered an appropriate data analysis technique. If photochemical modeling is used as a data analysis technique, model source apportionment can be used to estimate relative contributions of anthropogenic and natural extinction and to estimate anthropogenic impairment for each day of IMPROVE data:

$$\text{impairment (deciviews)} = 10 \ln(bext_{total}/bext_{natural})$$

- URP is the straight line from estimated total deciviews in the baseline 2000 to 2004 period extended to estimated natural conditions in 2064.
- Model simulations can be used to estimate U.S. contributions to impairment and to adjust the URP to account for impairment from international transport and certain fires.
- Uncertainties in the photochemical model:
  - Model can have error and bias in simulating speciated PM.
  - There is uncertainty in the emissions inventories used in modeling.
  - Model uncertainty is generally largest for natural sources of PM and smaller for U.S. anthropogenic emissions.

Improving estimates of the URP

- There is uncertainty in the both the statistical model and the photochemical model data analysis techniques for estimating the URP.
    - The slope of the URP can be different using these two approaches.
    - The URP cannot be compared on a consistent basis using currently available photochemical models because the boundary condition data in the regional scale models did not distinguish between natural and anthropogenic transport.
- International anthropogenic emissions have changed over time, increasing from 2000 to 2011 and decreasing from 2011 to the present.
    - Difficult to account for trends in international emissions in the statistical model.
    - Photochemical models can be used to estimate international transport contribution to impairment in 2000-2004, in 2016 and in the future (although with uncertainty in the emissions).

Uses of Retrospective Dynamic Modeling for Regional Haze

- Modeling of the baseline period can be used to directly compare model estimates of impairment for each species to the estimates based on the statistical analysis of the IMPROVE data in the baseline period.
- Trends in modeled extinction for each species can be compared to the IMPROVE data to determine if the model accurately simulated the observed trends in light extinction for each species.
- Model simulations for the baseline period and future years can be compared to evaluate cumulative modeled benefits of emissions reductions for reducing U.S. contributions to impairment.
- Model simulations can be used to estimate trends in international contributions to impairment and predict how those contributions will change in the future.