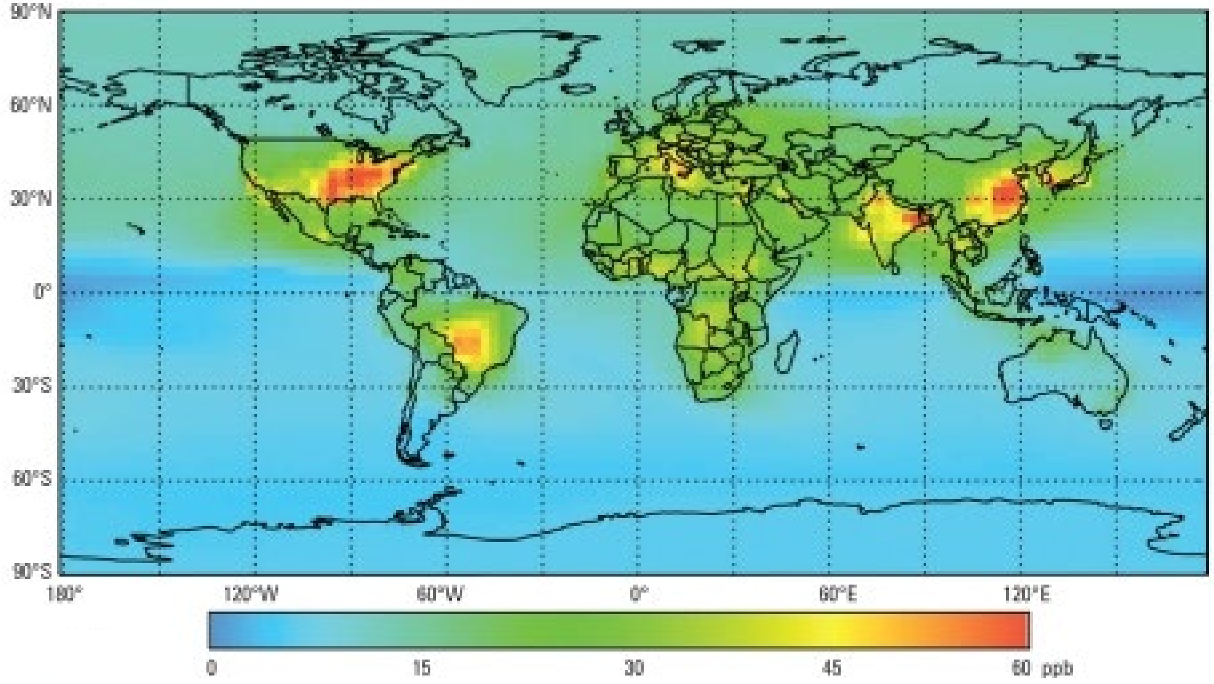
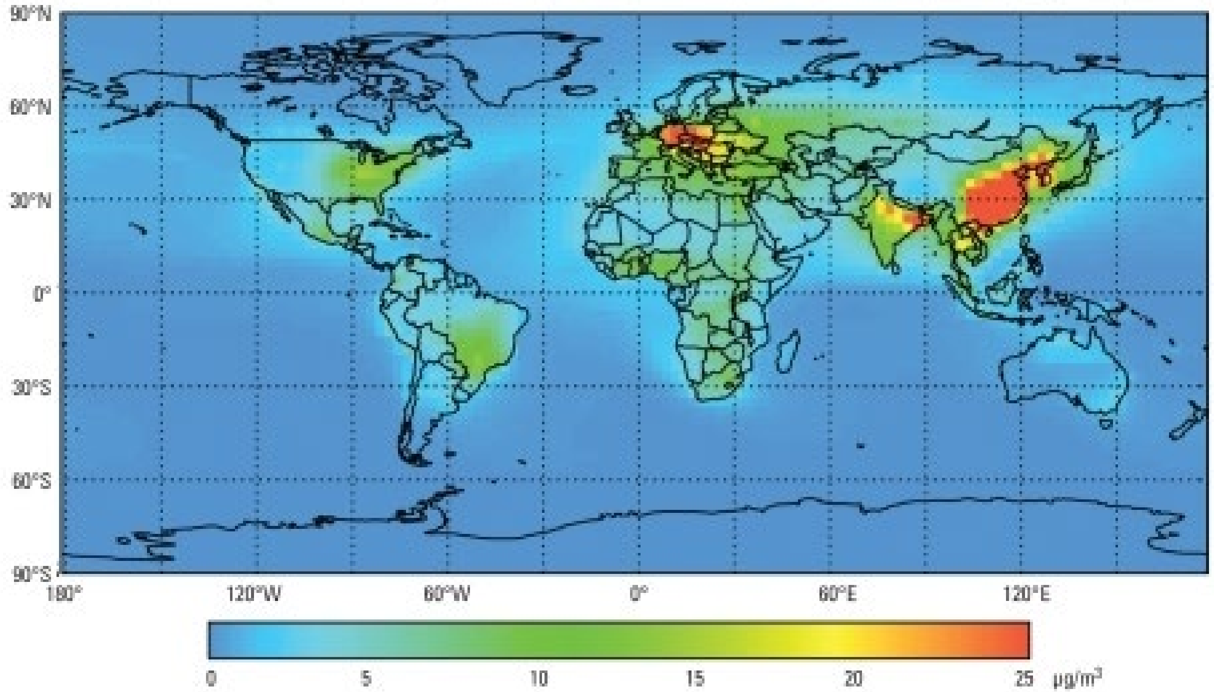
Estimating the Health Impact from Air Pollution: An Overview of Modelling Tools

O_3



$PM_{2.5}$



Horowitz et al. (2006)

Daven K. Henze
University of Colorado, Boulder

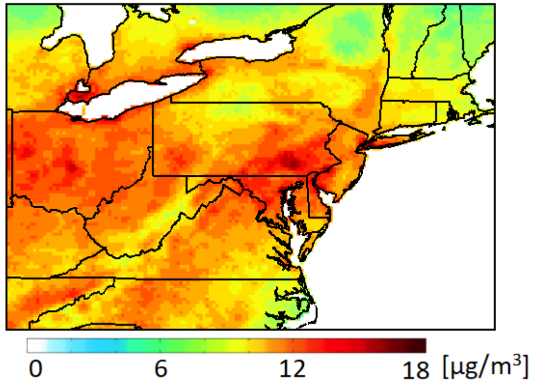
How are the health impacts (premature deaths) estimated for long-term exposure to $PM_{2.5}$ and O_3?

Three main ingredients:

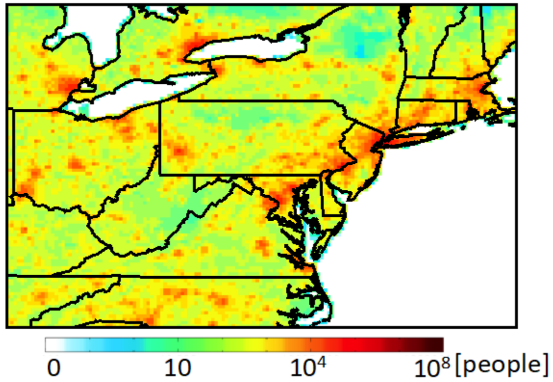
Concentrations
- Long-term averages (6 - 12 m)
- $PM_{2.5}$ and O_3
- Surface level

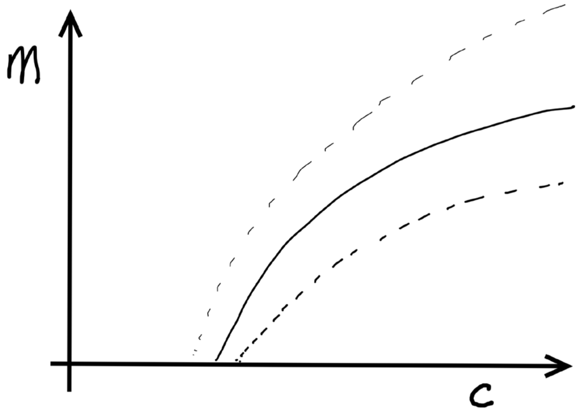
Population and health data
- Age stratified, km-scale or less
- Mortality rates

Concentration-response functions
- Quantify incidence of health outcomes from exposure
- Use statistical or functional epidemiological relationships:
    - M = f(C,pop,rate)



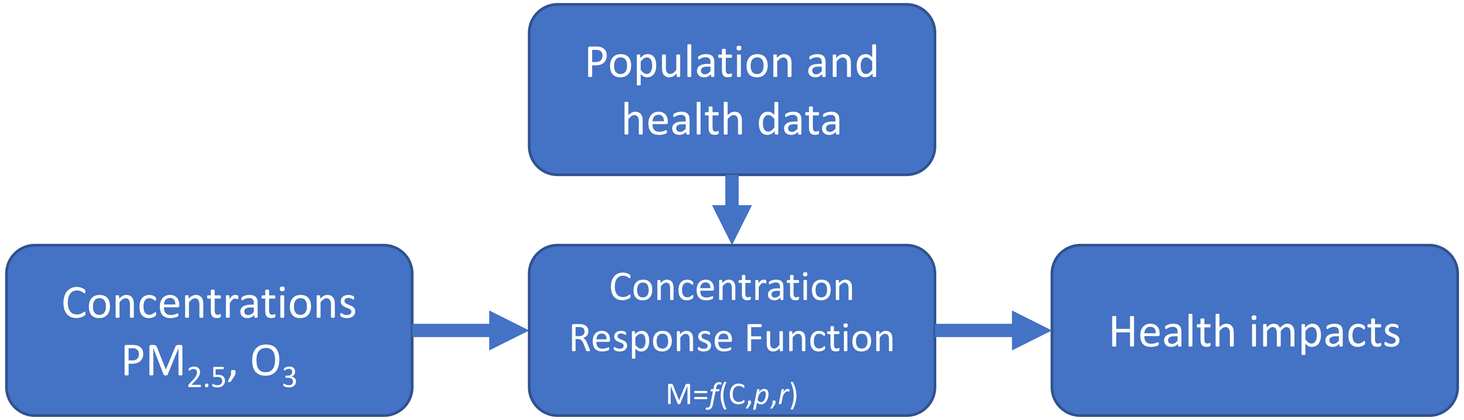
Population





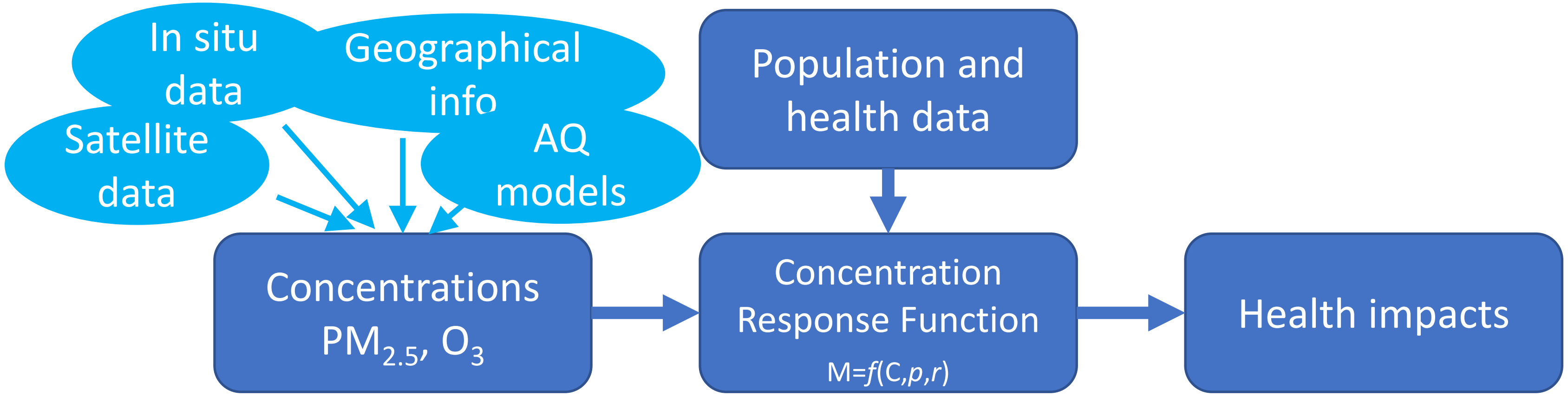
How are the health impacts (premature deaths) estimated for long-term exposure to $PM_{2.5}$ and O_3?

Computational recipe:



How are the health impacts (premature deaths) estimated for long-term exposure to $PM_{2.5}$ and O_3?

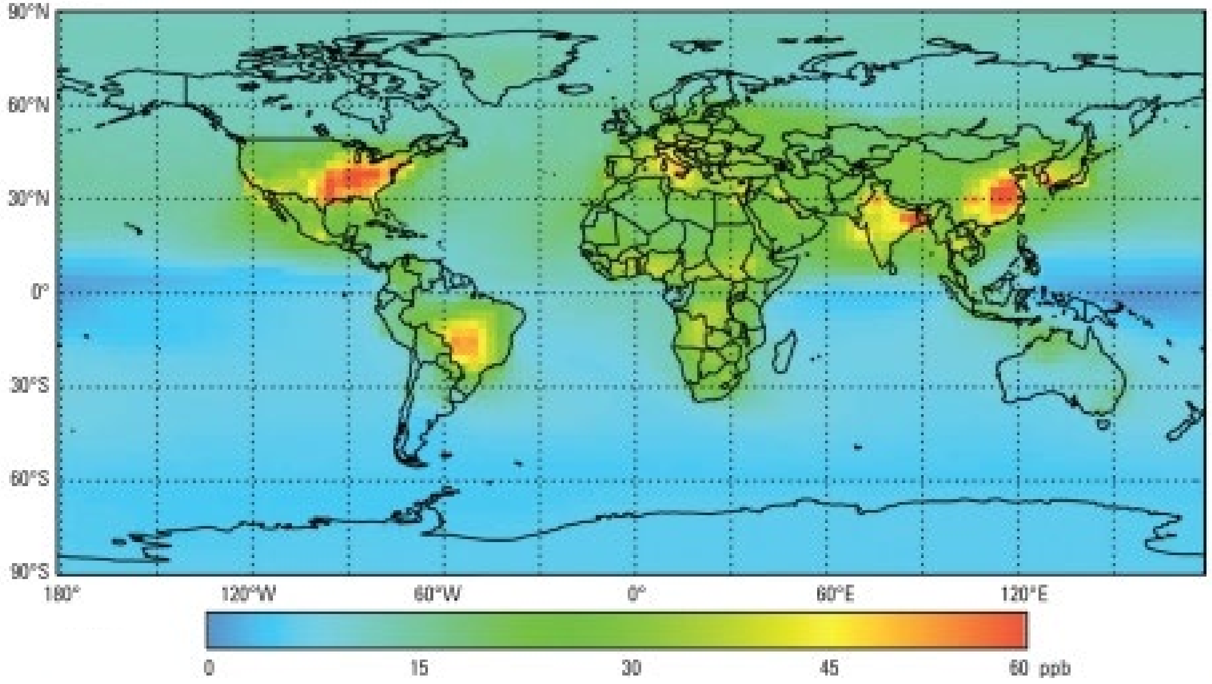
Computational recipe:



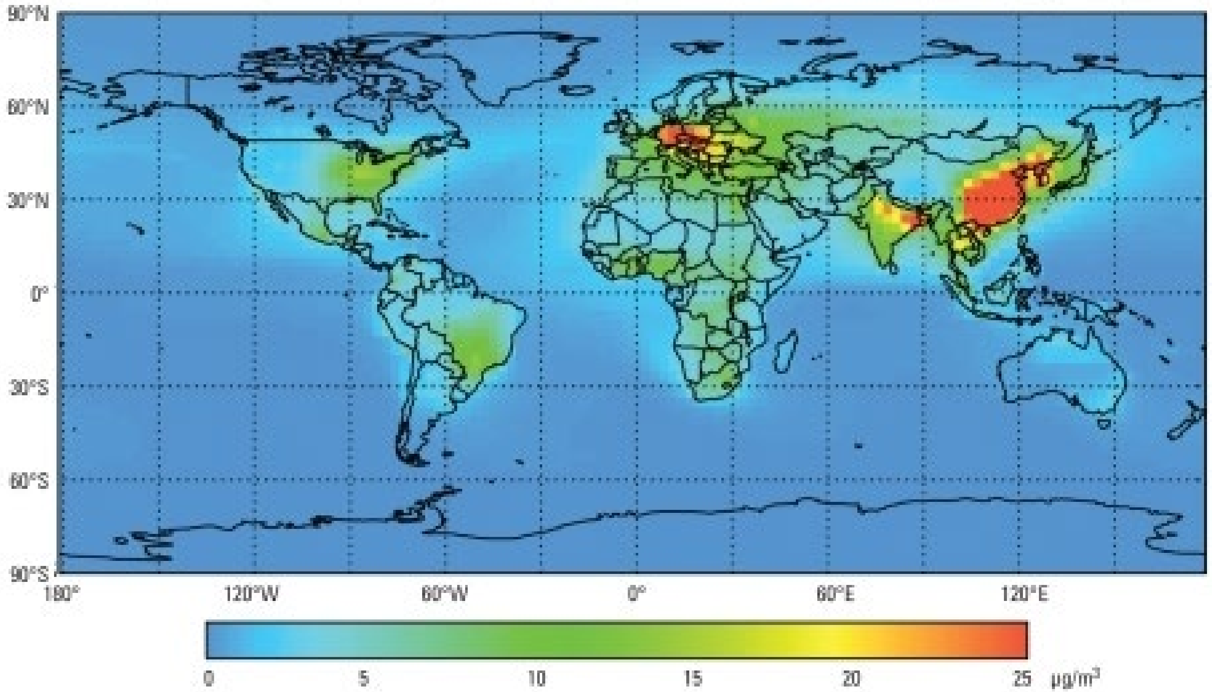
First global estimates of anthropogenic impacts on human health

Exposure estimated using model simulations alone (MOZART, 2.8° x 2.8°, Horowitz et al., 2006)

O_3



$PM_{2.5}$



0.7 million from O_3 and 3.7 million from $PM_{2.5}$ (Anenberg et al., EHP, 2010)

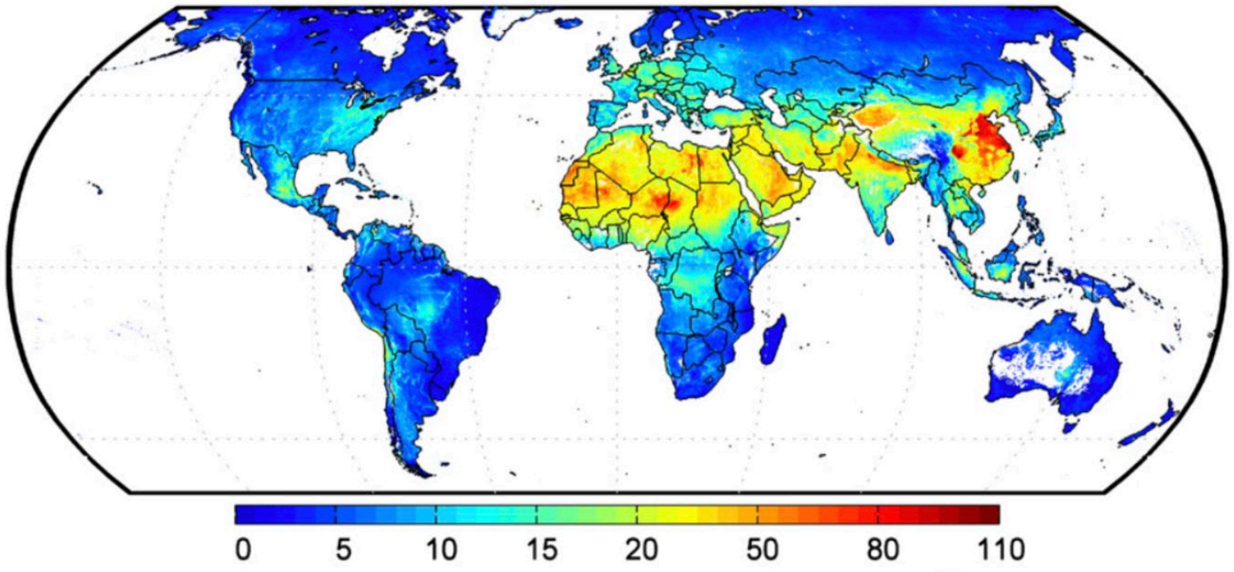
Significantly more than previous estimates of 0.8 million from Cohen et al. (2004) based on urban PM monitoring

Global estimates of $PM_{2.5}$ health impacts from satellite-derived exposure estimate

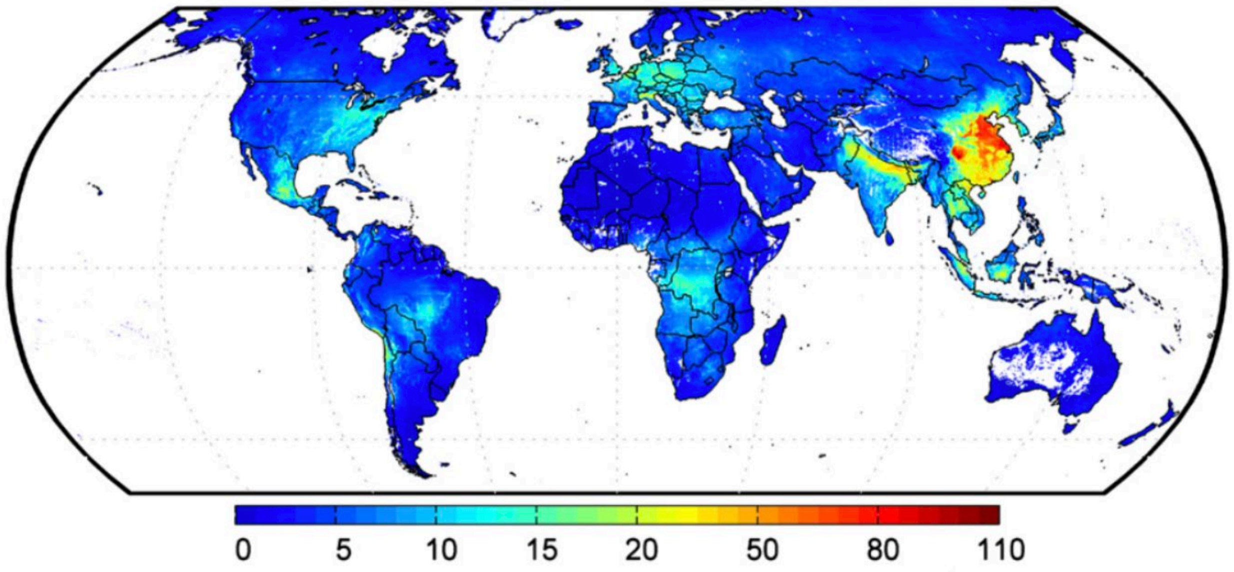
Hoff and Christopher (JAWMA, 2009) "Remote sensing of particulate pollution from space: have we reached the promised land?" – uncertainty in AOD-derived $PM_{2.5}$ reaching ~30%.

Satellite derived $PM_{2.5}$ from van Donkelaar et al. (EHP, 2010) at 0.1° x 0.1° globally:

Total $PM_{2.5}$



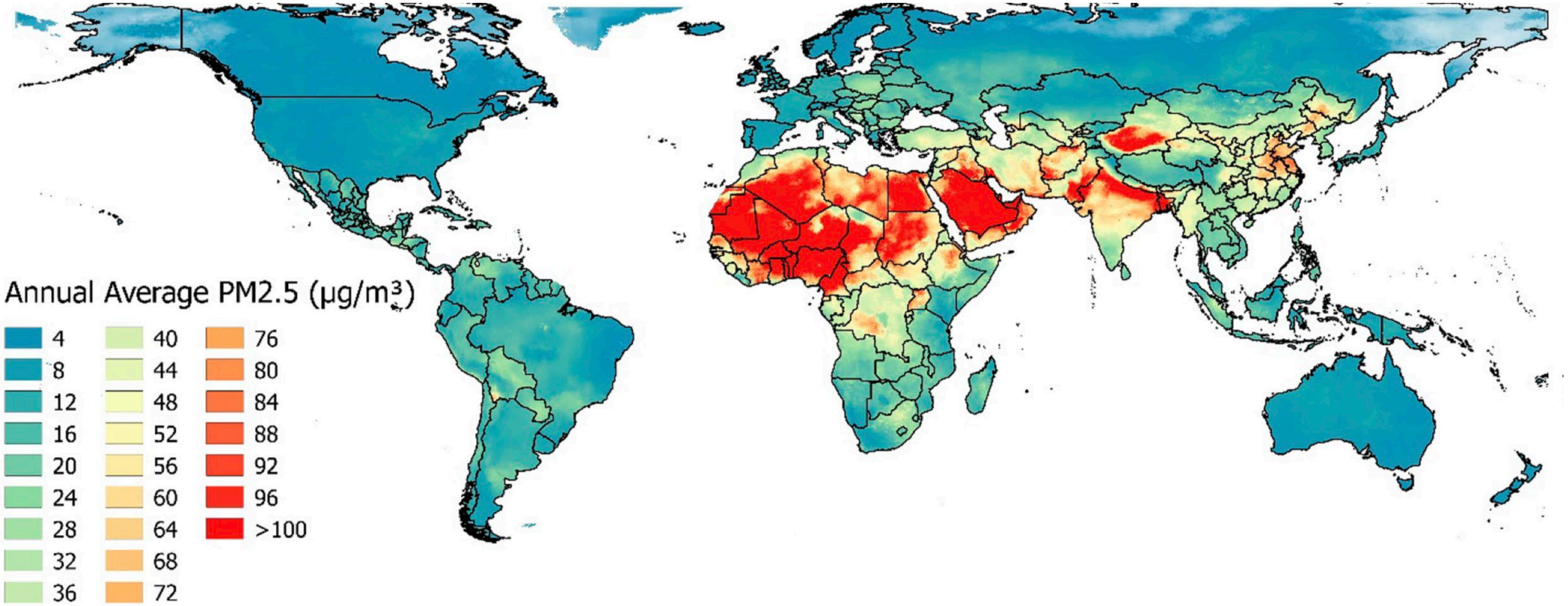
$PM_{2.5}$ with dust removed



First estimates of global $PM_{2.5}$ health impacts from satellite-derived PM2.5 (van Donkelaar et al., 2010) reported in in Evans et al. (ER, 2013): 2.4 million cause-specific premature deaths in 2004

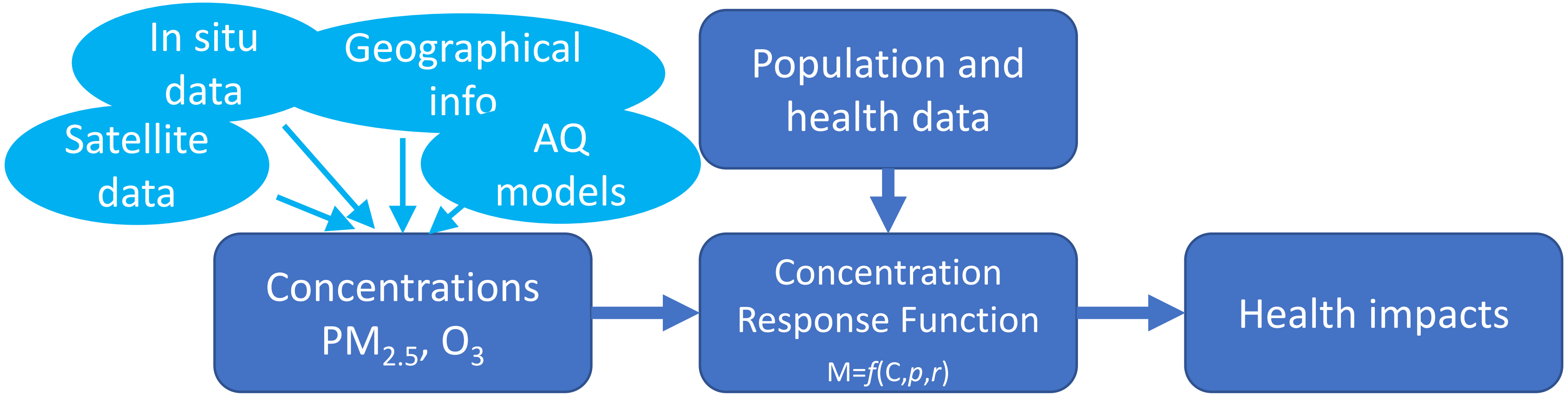
Advanced fusion of satellite and model-based $PM_{2.5}$ estimates

$PM_{2.5}$ from Shaddick et al. (2018): hierarchical Bayesian synthesis of satellite-derived products, surface observations, geostatistical information.

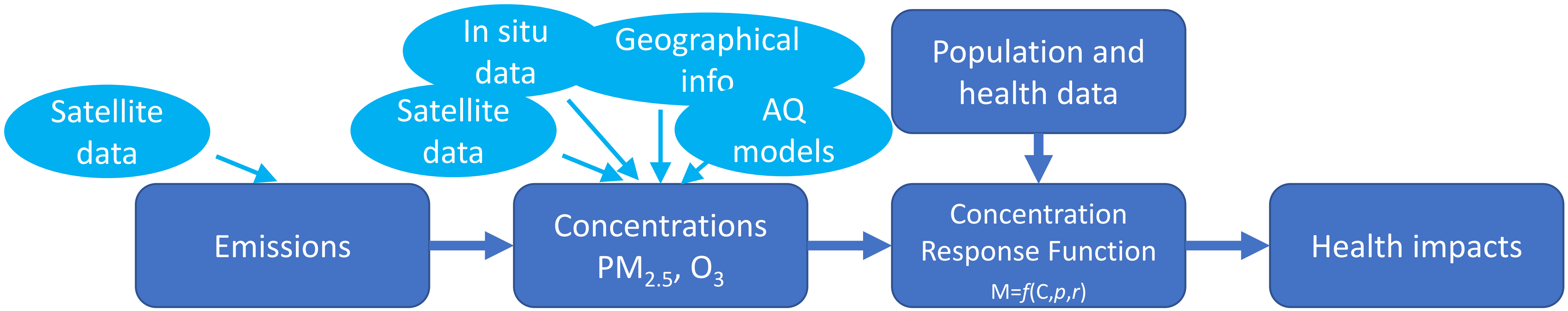


Provides exposure estimates for GBD 2015 (Cohen et al., Lancet, 2017): 4.2 (3.7 – 4.8) million premature deaths

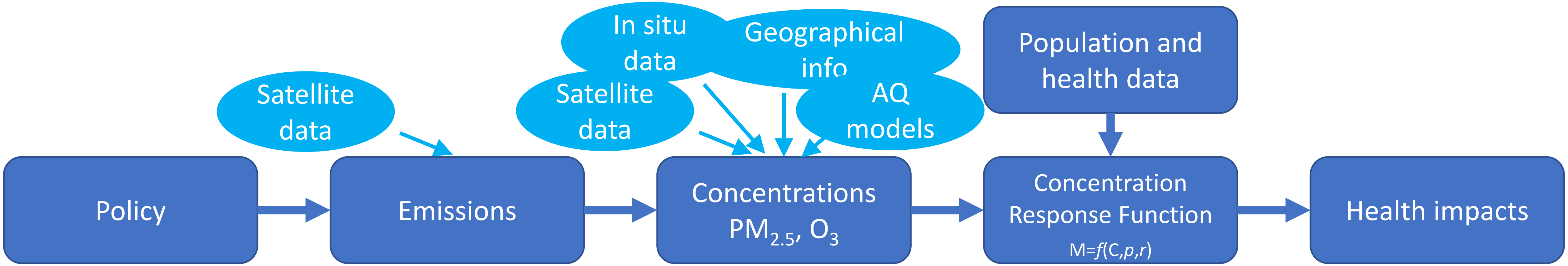
How are the health impacts (premature deaths) estimated for long-term exposure to $PM_{2.5}$ and O_3?



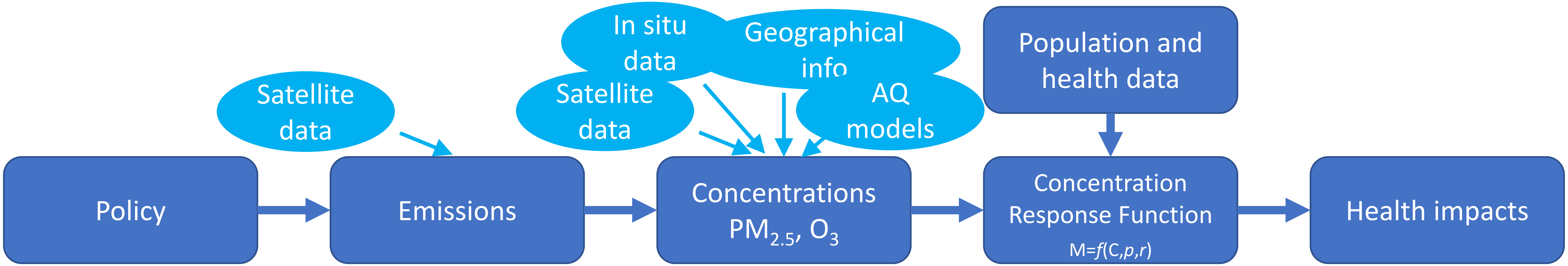
How are the health impacts (premature deaths) estimated for changes to pollutant emissions?



How are the health impacts (premature deaths) estimated for air quality policy?



How are the health impacts (premature deaths) estimated for air quality policy?



Integrated assessment tool
+ emissions allocation & processing

Chemical transport model
(CTM)

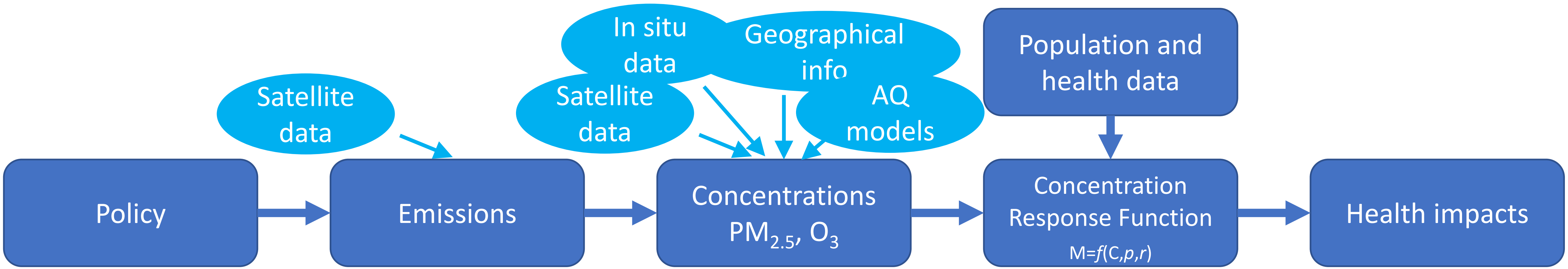
Algebraic computations

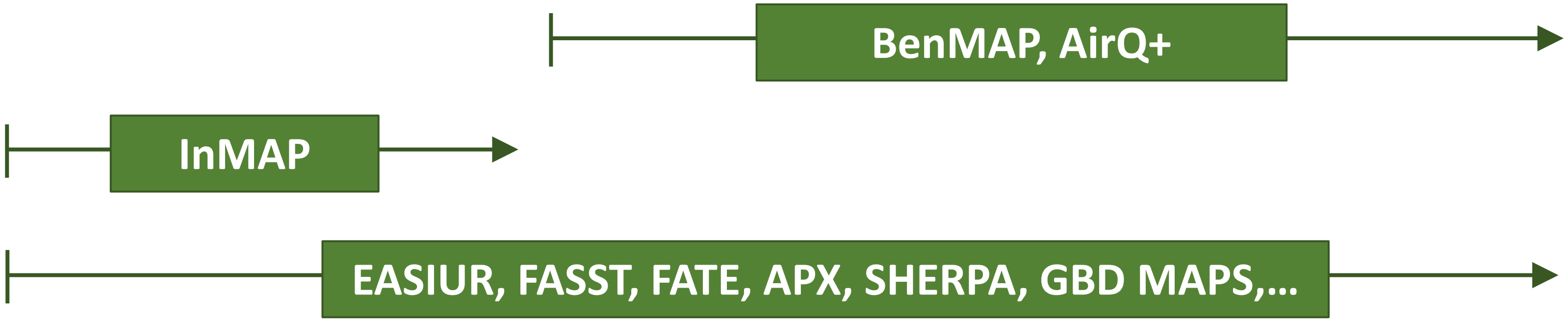
E.g. **GAINS + ECLIPSE** → **GEOS-Chem** → **+/-/÷/x/∑** →

"Rigorous calculations"

- requires wide range of expertise
- CTM requires workstation or supercomputer
- not amenable to exploration of myriad scenarios

How are the health impacts (premature deaths) estimated for air quality policy?





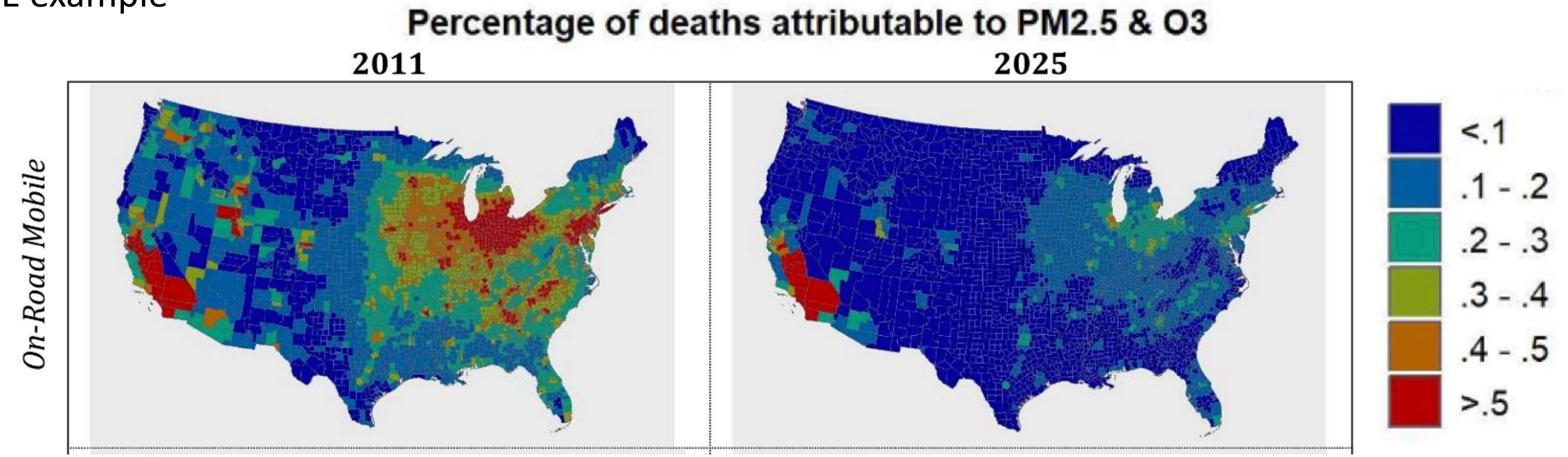
Many parts packaged into a variety of policy, decision support, and research tools.

Note: illustrative but not comprehensive set shown here. For more exhaustive review of tools: Anenberg et al. (2016)

Given concentrations, what are the health impacts?

BenMAP and AirQ+: input concentrations (gridded or tabulated, modeled or measured), estimate health burden

BenMAP-CE example



From Davidson et al., ERL, 2020: deaths due to $PM_{2.5}$ and ozone from the on-road sectors in 2011 and 2025. Concentrations from CAMx (AQ model)

These types of tools often consider additional health impacts (mortality, morbidity, DALY,…) and options (alternative CRF's) for how they are estimated.

Comparisons: BenMAP-CE and AirQ+

Similarities

Table 3. Comparison of Estimated Benefits of Meeting the World Health Organization (WHO) Air Quality Guideline (AQG) Annual $PM_{2.5}$ value of 10 μg/m^3 Using BenMAP—CE and AirQ+.

Results	BenMAP—CE		Air Q+	
	Subregion 1	Subregion 2	Subregion 1	Subregion 2
Estimated Attributable Proportion (%)[1]	8.9 (6.0–11.7)	11.1 (7.5–14.5)	8.9 (5.9–11.6)	11.1 (7.4–14.4)
Estimated Number of Attributable Cases	965 (652–1271)	1278 (867–1677)	966 (640–1262)	1280 (852–1665)
Estimated Number of Attributable Cases per 100,000 Population at Risk[2]	83.5 (56.4–109.9)	91.9 (62.3–120.5)	83.6 (55.4–109.1)	92.0 (61.2–119.7)

Note: Results represent the central estimate and 95% confidence intervals. [1] Estimated Attributable Proportion (%) = (Estimated Number of Attributable Cases/[(Population per 100,000) × (Mortality Rate per 100,000)]) [2] Estimated Number of Attributable Cases per 100,000 Population at Risk = (Estimated Number of Attributable Cases/Population) × 100,000.

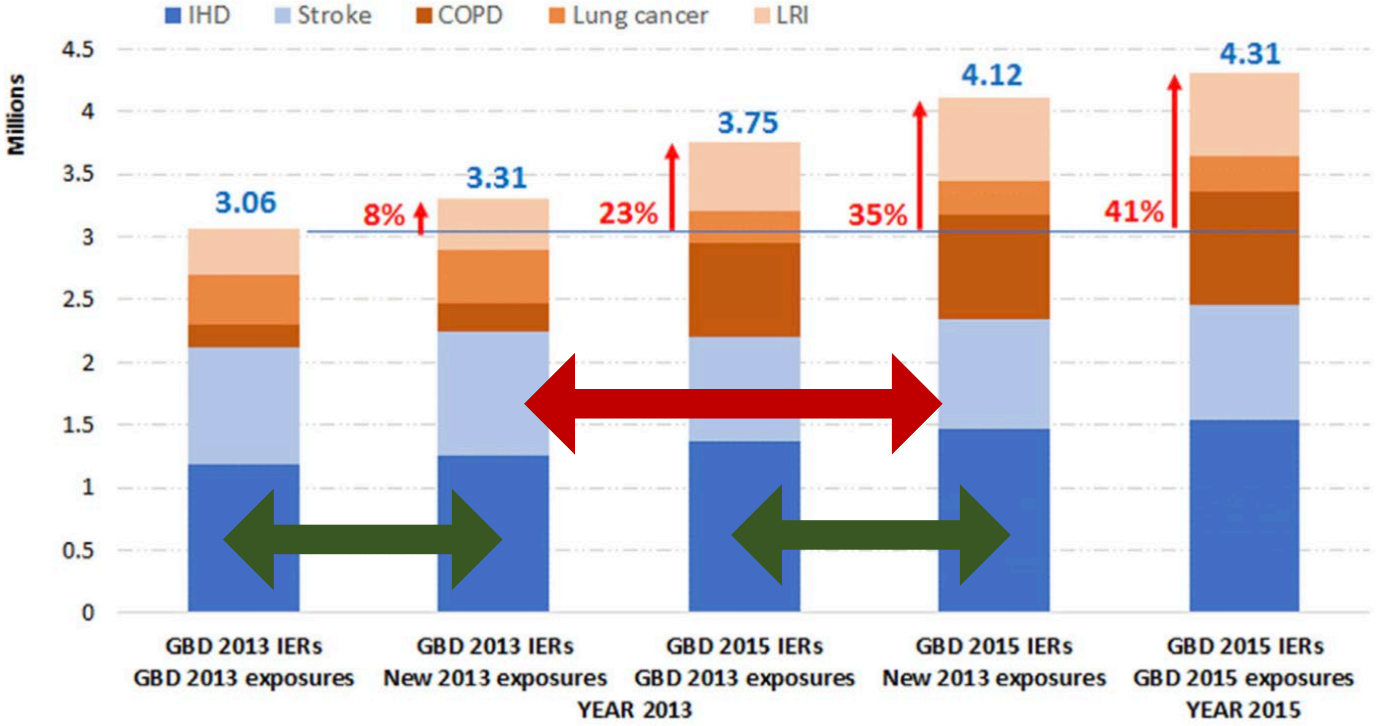
Differences

- BenMAPS health impacts functions are specific to US policy applications, whereas AirQ+ is a decision support tool for public health specialists

From Sacks et al., Quantifying the Public Health Benefits of Reducing Air Pollution: Critically Assessing the Features and Capabilities of WHO's AirQ+ and U.S. EPA's Environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP—CE), *Atmosphere* **2020**, *11*(5), 516.

Sources of uncertainties: concentrations vs CRFs

Comparison of GBD ambient AQ health impacts across the years (Ostro et al., 2018)

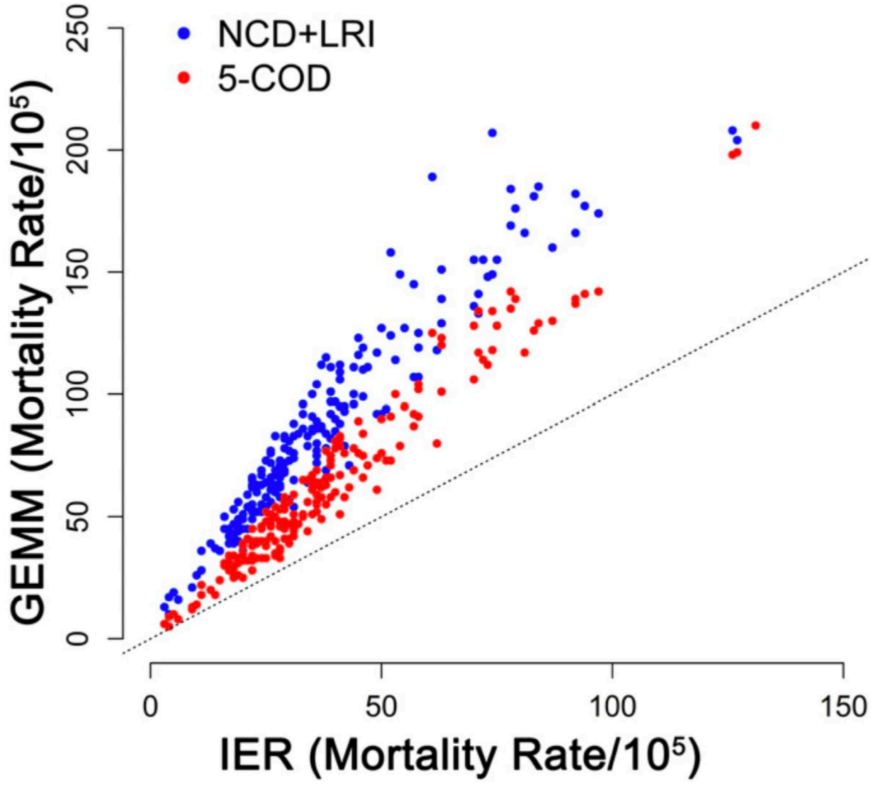


Δ updating concentration: 8% and 12%

Δ updating CRF (IER): 27%

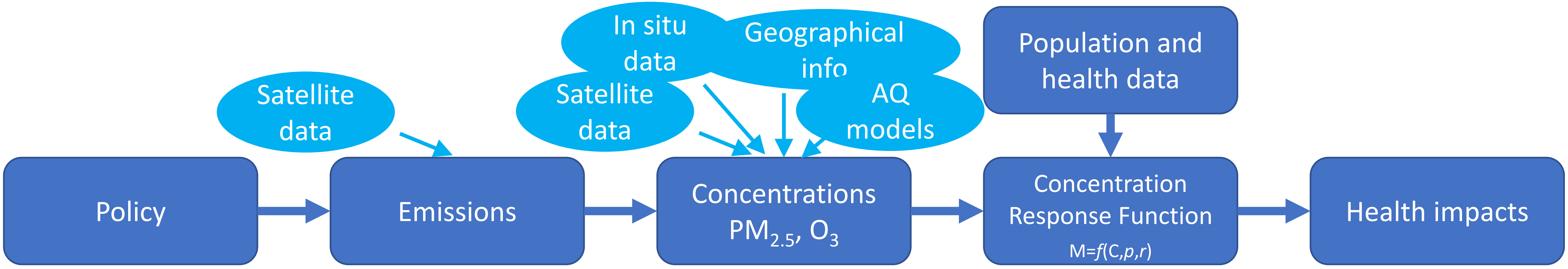
Also, ranges around central estimate for any single CRF often ~30%

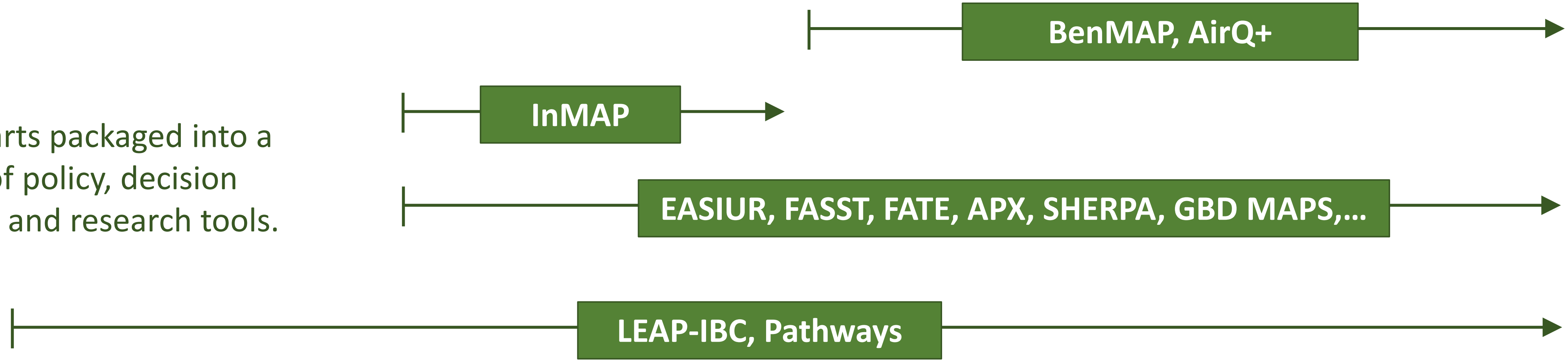
GEMM >> IER (Burnett et al., 2018)



Δ concentration-response function (GEMM based on studies of exposure to high ambient concentrations): x2

How are the health impacts (premature deaths) estimated for air quality policy?





Many parts packaged into a variety of policy, decision support, and research tools.

Note: illustrative but not comprehensive set shown here. For more exhaustive review of tools: Anenberg et al. (2016)

Given emissions, what are the health impacts?

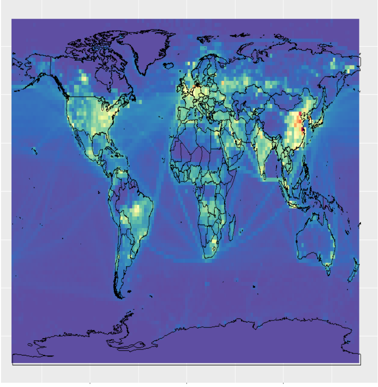
What do you know about the emissions?

- individual sources (EASIUR)

- county, stack height (APX)

- gridded emissions inventories (InMAP, FATE, FASST)

vs

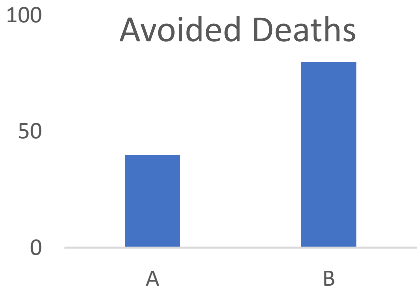


Emissions: point sources to global scenarios

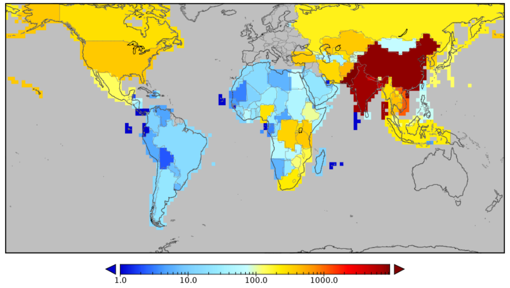
Where do you evaluate health impacts?

- spatially disaggregated impacts
  - grid scale, global (InMAP, GBD Maps)
  - US (EASIUR w/APSCA)

- aggregated impacts
  - city (SHERPA)
  - county (APX)
  - national (FATE, FASST, EASIUR)



vs



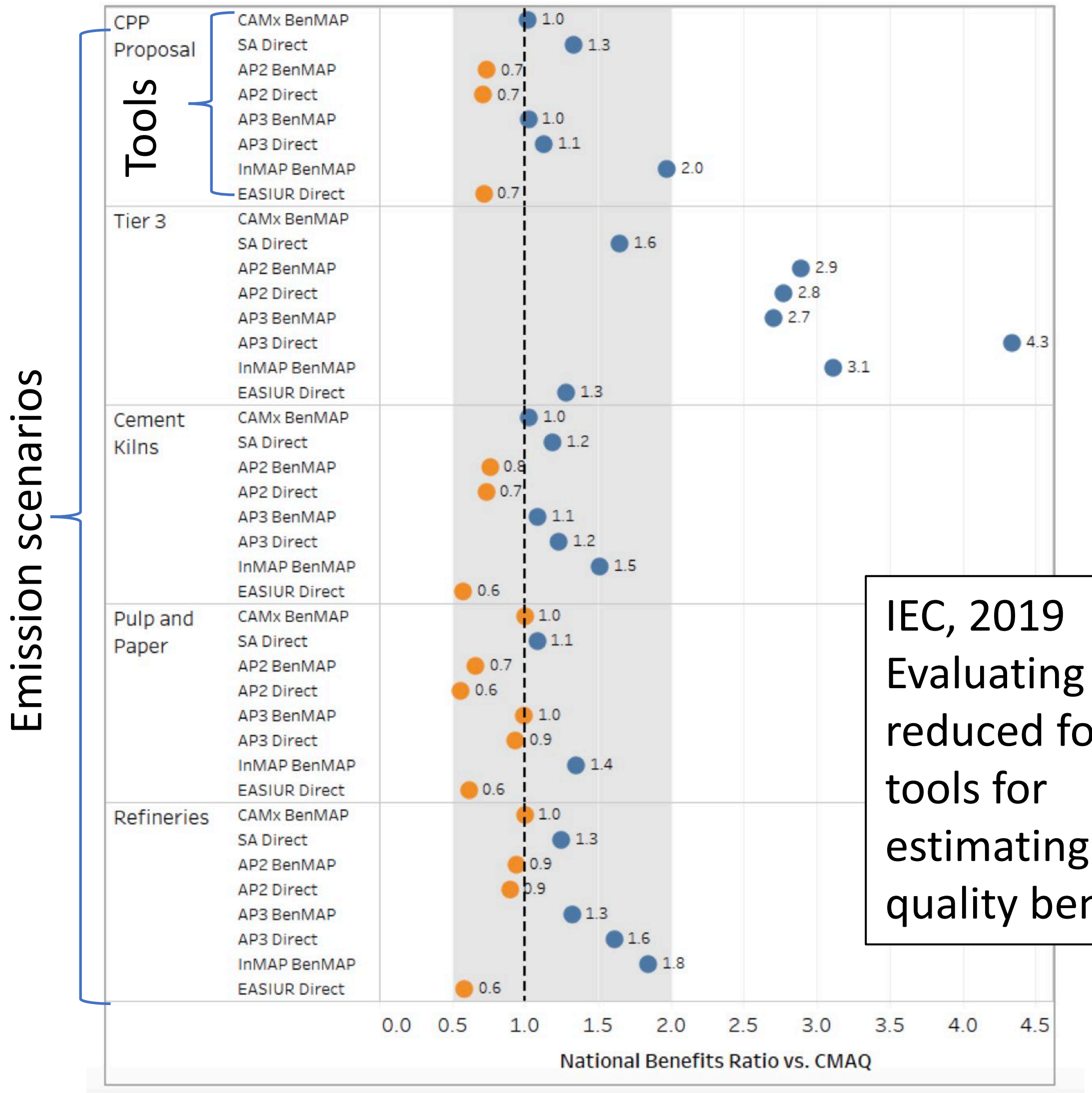
Impacts: $\Delta PM_{2.5}$, ΔO_3, premature deaths, \$/ton…

Comparisons: emissions → impacts

Emissions to concentration is most expensive step in an explicit health impact calculation

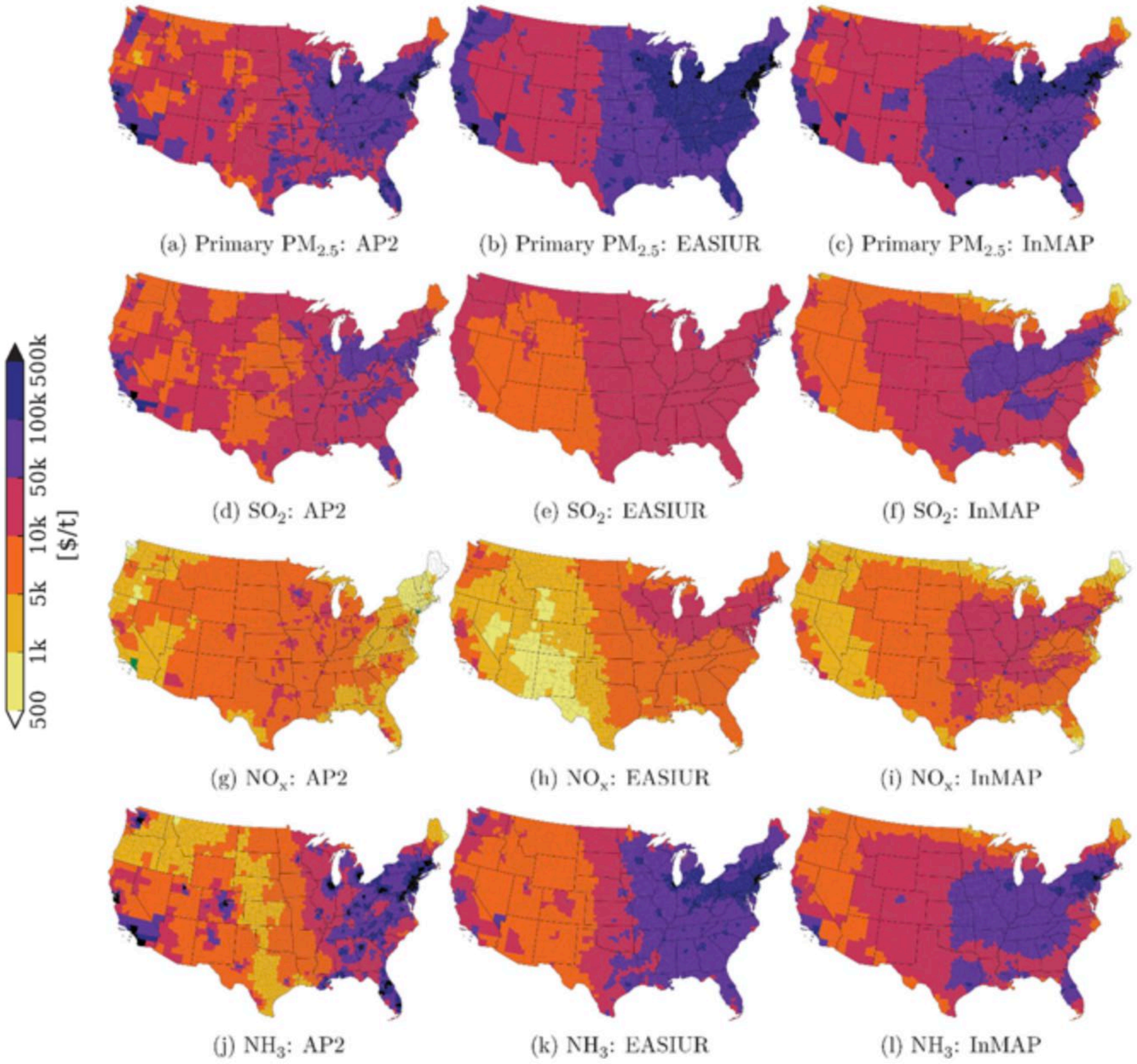
- Different tools use different approaches to approximate this step
- Most approximations are linear (1st order) estimates
- When applied to the same emissions changes (right), tools show widest diversity for a vehicle emission scenario
- In contrast, range was much smaller when considering the response of only primary EC

Ratio of tool estimates' to explicit calculation with CMAQ



IEC, 2019 Evaluating reduced form tools for estimating air quality benefits

Comparisons: emissions → impacts



Gilmore et al. (ERL, 2019) Marginal social costs for ground-level emissions for each US county by pollutant and by air quality model (in USD per tonne).

See also: Baker et al., A database for evaluating the InMAP, APEEP, and EASIUR reduced complexity air-quality modeling tools, Data in Brief, 28, https://doi.org/10.1016/j.dib.2019.104886, 2020.

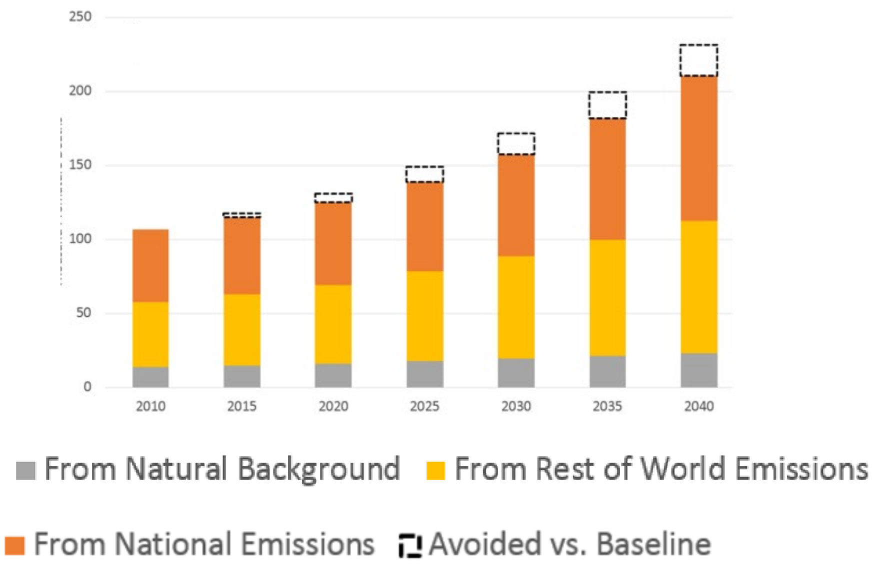
vs

Given policy, what are the health impacts?

National and international scale policies

LEAP-IBC:
- detailed energy planning tool (LEAP: policy → emissions) with Integrated Benefits Calculator (IBC: emissions → impacts)

Example: short-lived climate pollutant mitigation co-benefits



Kuylenstierna et al., 2020

- ~10,000 avoided deaths, 60% of which from SLCP mitigation
- ~20,000 in concert with global initiatives
- Total burden rises from pop growth

City policies

Pathways:
- estimates of benefits from urban scale initiatives in ~100 cities world-wide
- urban energy planning coupled with InMAP (emissions → concentrations)

These tools require detailed datasets describing current emissions controls, energy sources, transportation, etc., specific to the areas in question.

What is under the hood?

The emission → concentration from substantial (100's to 1000's of hrs of workstation or supercomputer simulations):

- APX: National-scale Gaussian dispersion model (CRDM; Latimer 1996), tuned to AQS
- EASIUR: Regression based on ensemble of CMAQ runs
- InMAP: Flexible grid re-calculation of annual averages from WRF-Chem (US) and GEOS-Chem (global) simulations
- TM5-FASST: Ensemble of emission perturbation simulations with TM5
- GBD-MAPS: Ensemble of emission perturbation simulations with GEOS-Chem
- LEAP-IBC, FATE: Ensemble of GEOS-Chem adjoint simulations

Tools may include:

- bias correction using in situ or remote sensing data
- downscaling of source locations or exposure using proxy data or remote sensing

Availability and complexity

- EASIUR: web-based or data-file download
- TMF-FASST: web-based, data-file download, or script
- Pathways: Spreadsheet (TBD)
- APX: MATLAB scripts
- FATE: Python scripts (TBD)
- BenMAP-CE, AirQ+: Desktop software, open access
- LEAP-IBC: Desktop software
- InMAP: Workstation software, open access

References and links

- EASIUR: https://www.caces.us/easiur, Heo et la., Environ. Sci. Technol. 50 6061–70, 2016; Heo et al., Atmos. Environ. 137 80–9, 2016.

- TMF-FASST: https://tm5-fasst.jrc.ec.europa.eu, van Dingenen et al., ACP, https://doi.org/10.5194/acp-18-16173-2018, 2018.

- APX (APEEP, AP2): https://public.tepper.cmu.edu/nmuller/APModel.aspx, Muller and Mendelsohn, J. Environ. Econ. Manage. 54 1–14, 2007; Muller, et al., Am. Econ. Rev. 101 1649–75, 2011

- BenMAP-CE: https://www.epa.gov/benmap

- AirQ+: https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution

- LEAP-IBC: https://www.sei.org/publications/leap-ibc/, https://leap.sei.org, Kuylenstierna et al., *Environ. Int.*, 145, 106155, https://doi.org/10.1016/j.envint.2020.106155, 2020.

- InMAP: https://github.com/spatialmodel/inmap/, Tessum et al., PLoS ONE 12(4), e0176131, 2017; Thakrar et al., https://doi.org/10.26434/chemrxiv.14330375.v1.

Summary

- Wide range of decision support tools and models exist to help relate policy to health impacts
- Key differences: inputs (policy, emissions, or concentrations), resolution (points, aggregates, gridded maps), and coverage (city to global)
- Air quality models used for estimation of exposure and processing of remote sensing data, as well as for decision support tools.
- Large diversity owing to emissions → concentration approximations, and large uncertainty from the concentration response function and health data
- Remote sensing, in situ data, and other proxy information used to calibrate and downscale
- Tools range from spreadsheets to heavier sets of scripts and executables, and all much faster than running grid-based AQ models

Thanks!