Geospatial Methodologies in Toxicology

Linking exposure, toxicity, and disease profiles to identify U.S. regions at elevated health risks

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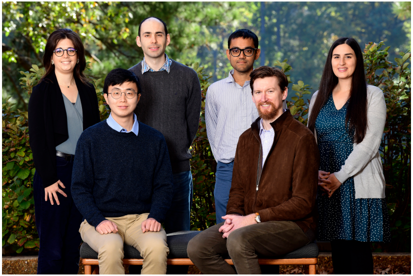
Spatiotemporal Exposures and Toxicology (SET) Group

Introduction

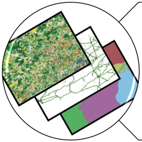
About Us

Spatiotemporal Exposures and Toxicology {SET} group

- Spatiotemporal Exposure Mapping
- Chemical and Stressor Mixtures Prediction
- Mechanistically Informed Geospatial Risk Assessment

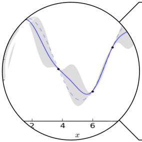


Geospatial Methods



Translational

- Maps
- Integrative



Predictive

- Interpolation
- Uncertainty

Objective

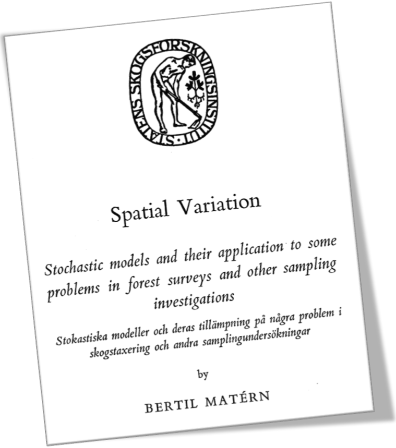
- Provide an overview of geospatial methods, data, applications, and future directions in toxicology and risk assessment

History

Mining

- Matheron and Krige developed geostatistical methods to predict ore content from core samples
- Matheron coined the term "Kriging" after Krige
- "Nugget" is a term used to random noise because predicting where gold nuggets were was so difficult

Forestry



STATENS SKOGSFORSKNINGSINSTITUT

Spatial Variation

Stochastic models and their application to some problems in forest surveys and other sampling investigations

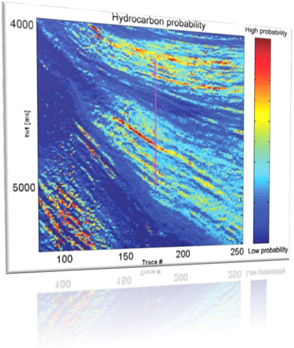
Stokastiska modeller och deras tillämpning på några problem i skogstaxering och andra samplingundersökningar

by

BERTIL MATÉRN

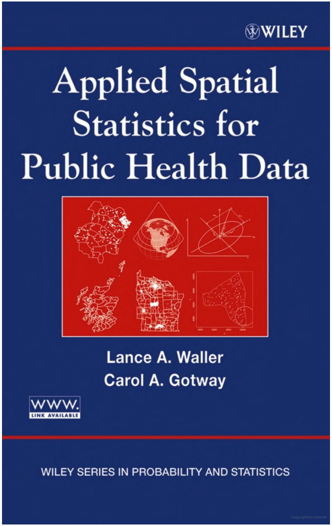
- Matérn developed correlation models for spatial variation for applications in Forestry
- To this day, we use the "Matérn" covariance function

Petroleum Engineering



- Used to evaluate the oil and gas field reservoirs
- Uses geology and seismic data

Public Health



- Cressie, 1990: Statistics for Spatial Data
- Waller and Gotway, 2004: Applied Statistics for Public Health Data
- Wide scale adoption for statisticians and engineers in ecological and human exposure and risk applications

Toxicology

- **Toxicology is a new frontier for geospatial methods**
- Aggregate Exposure Pathways
- Adverse Outcome Pathway
- GeoTox
- Source-to-Outcome

Classical Models

Uses in Public Health

- Estimate exposure to air pollutants, water contaminants, and other environmental stressors
- Geocode patient addresses to link to environmental exposures
- Estimate the spatial distribution of disease rates
- Estimate the spatial distribution of health risk factors

Land Use Regression

Linear regression for spatial data

$$Y(s) = X(s)\beta + \varepsilon$$

where $Y(s)$ is the response variable, $X(s)$ are the predictor variables, β are the regression coefficients, ε is the iid error term, and (s) denotes the spatial location.

Not a terrible idea for spatial data, but it directly violates the assumption of independence of observations.

Kriging

Kriging and spatial models provide an explicit term for spatial correlation. A reasonable approach is a random-effect model:

$$Y(s) = \mu(s) + \varepsilon + \eta(s)$$

where $\eta \sim N_n(0, \Sigma_\theta)$

and Σ_θ is a covariance matrix with parameters, θ, that accounts for correlation between spatial and temporal locations

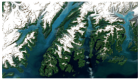
Data Sources

Common Data Sources and Types

- U.S. Census Bureau
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- National Aeronautics and Space Administration
- National Oceanic and Atmospheric Administration
- U.S. Department of Agriculture

- Land cover data
- Health statistics
- Population characteristics
- Infrastructure data
- Air quality data
- Water quality data
- Satellite imagery

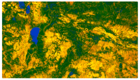
Satellite Imagery



Sentinel-2 Level-2A

The Sentinel-2 program provides global imagery in thirteen spectral bands at 10m-60m resolution and a revisit time of approximately five days. This dataset contains the global Sentinel-2 archive, from 2016 to the present, processed to L2A (bottom-of-atmosphere).

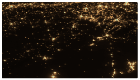
Sentinel · Copernicus · ESA · Satellite · Global · Imagery · ···



Sentinel 1 Radiometrically Terrain Corrected (RTC)

Radiometrically terrain corrected SAR imagery derived from the Sentinel 1 Level 1 GRD product.

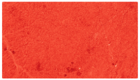
ESA · Copernicus · Sentinel · C-Band · SAR · RTC



HREA: High Resolution Electricity Access

Settlement-level measures of electricity access, reliability, and usage derived from VIIRS satellite imagery

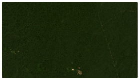
HREA · Electricity · VIIRS



Planet-NICFI Basemaps (Analytic)

Planet's high-resolution, analysis-ready mosaics of the world's tropics

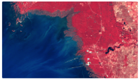
Planet · NICFI · Satellite · Tropics · Imagery



Planet-NICFI Basemaps (Visual)

Planet's high-resolution, analysis-ready mosaics of the world's tropics

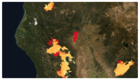
Planet · NICFI · Satellite · Tropics · Imagery



Landsat Collection 2 Level-1

Landsat Collection 2 Level-1 data from the Multispectral Scanner System (MSS) onboard Landsat 1 through Landsat 5.

Landsat · USGS · NASA · Satellite · Global · Imagery



MODIS Burned Area Monthly

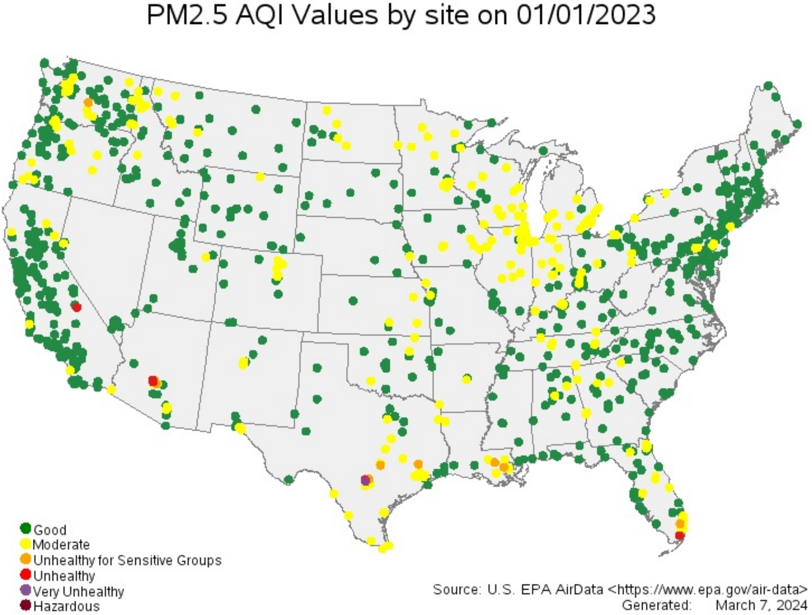
MODIS Burned Area Monthly

NASA · MODIS · Satellite · Imagery · Global · Fire · ···

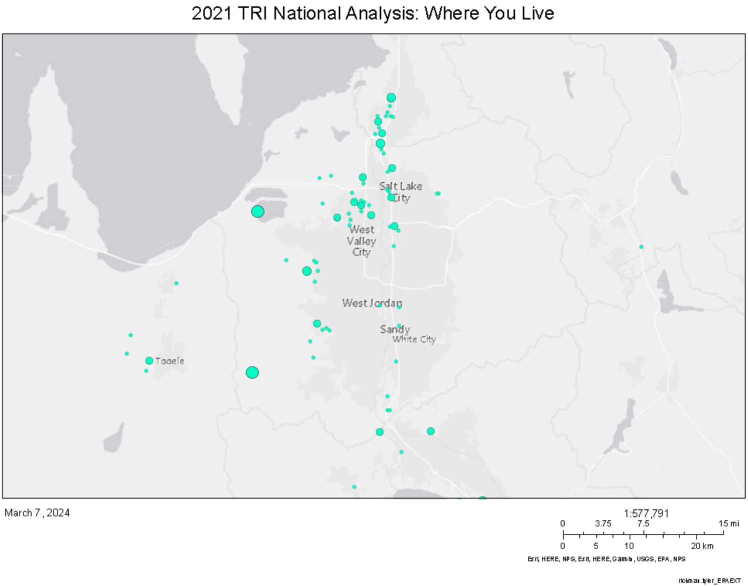
MODIS Nadir BRDF-Adjusted Reflectance (NBAR) Daily

MODIS Nadir BRDF-Adjusted Reflectance (NBAR) Daily

Air Quality Data



Toxic Release Data



Health Information

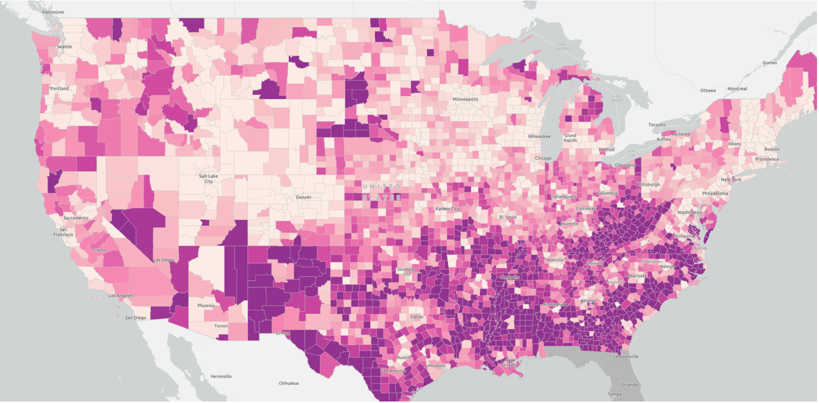
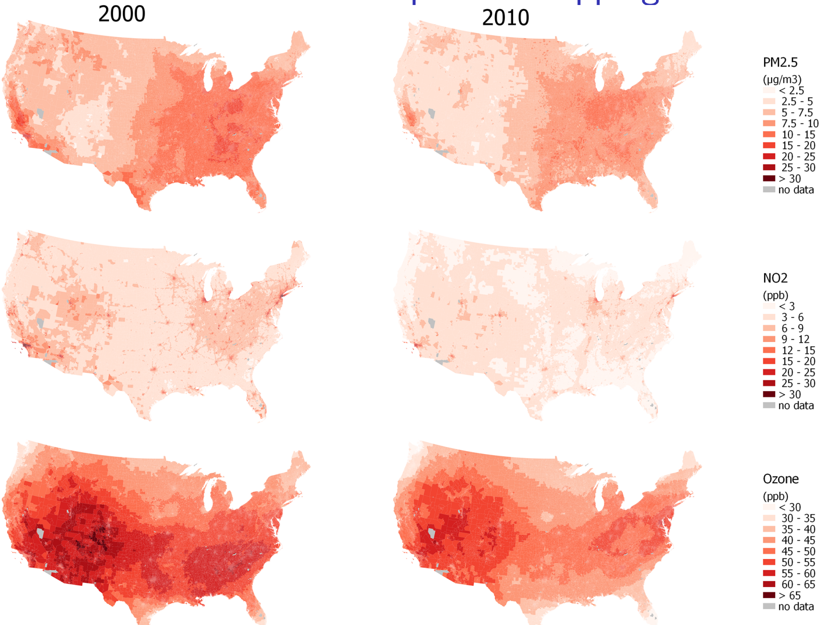


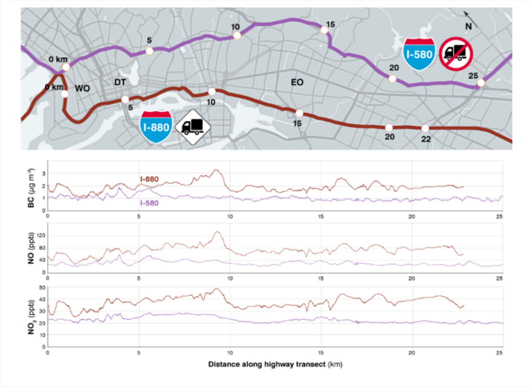
Figure 1: CDC Places Health Outcome Data: Diabetes Prevalence

Case Studies

Air Pollution Exposure Mapping



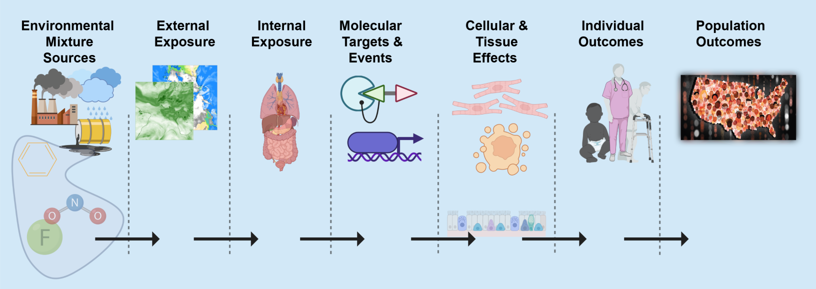
Tale of Two Freeways



- All measured pollutants were consistently higher on I-880 compared to I-580
- I-580 has a heavy duty truck ban
- Heavy duty trucks are forced onto I-880 to get to the Port of Oakland

Source-to-Outcome

Source-to-Outcome Modeling



Source-to-Outcome Modeling

- Source-to-Outcome is a framework for linking environmental sources to human health outcomes
- The framework is based on the Aggregate Exposure Pathway (AEP) and Adverse Outcome Pathway (AOP) concepts

Source-to-Outcome Modeling

- Next generation risk of cumulative and total exposomic effects on human health
- A balance between mechanistic and translational research
- A framework for integrating multiple data sources and models
- Incorporate biological and geospatial information on communities and individuals

Getting Two Frameworks to Work Together

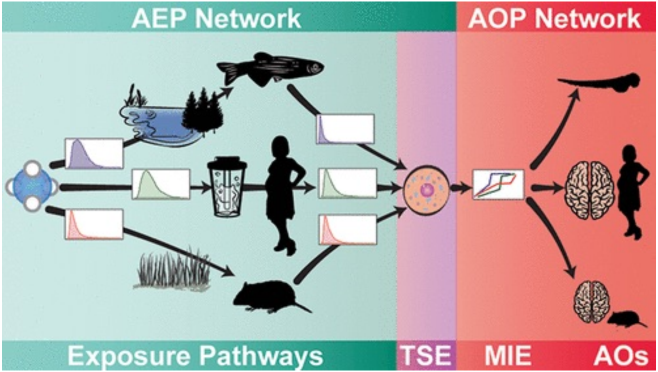
Aggregate Exposure Pathways

- AEP is a comprehensive external analysis of source, media, and transformations

Adverse Outcome Pathway

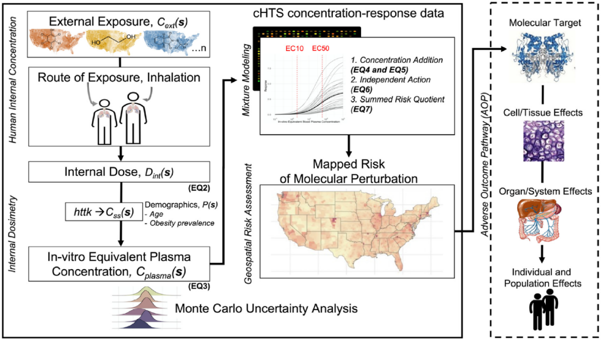
- AOPs provide a linkage specific biological target, pathway or process by a stressor and an adverse outcome(s) considered relevant to risk assessment

AEP-AOP



Hines, D. E., Conolly, R. B., & Jarabek, A. M. (2019)

GeoTox

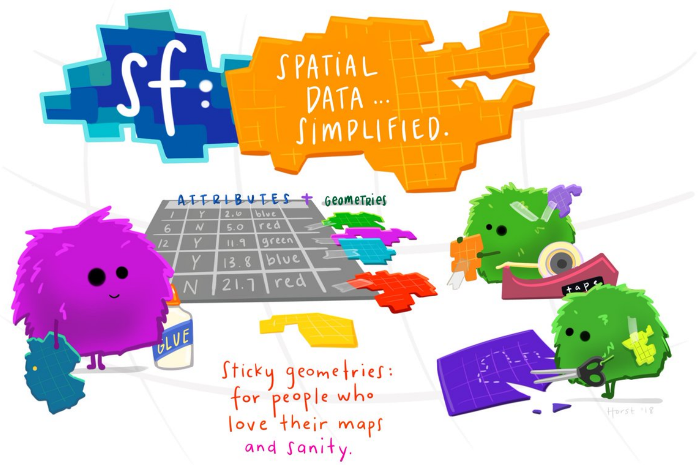


Dr. Kristin Eccles, Former Visiting Fellow in DTT and SET, Now at Health Canada

GeoTox

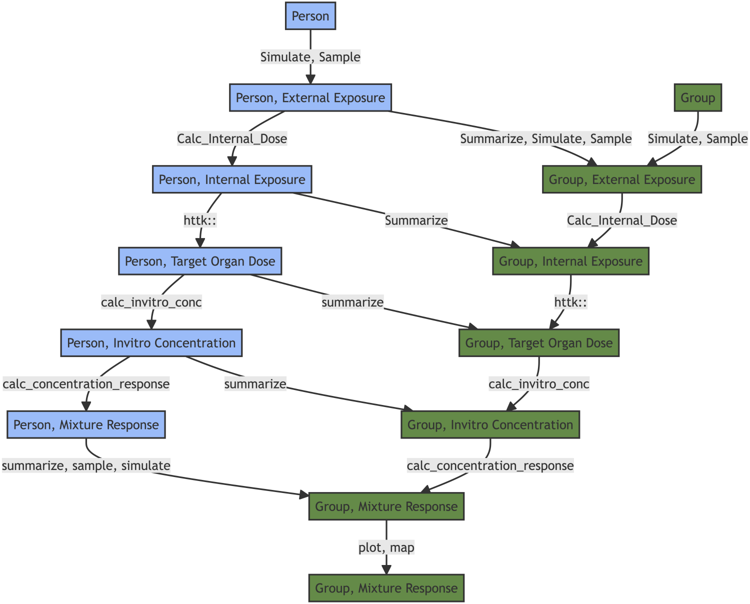
- Goal is to develop extensible, open-source software for facilitate source-to-outcome modeling (FAIR+)
- Working with Drs. David Reif and Skylar Marvel (NIEHS/DTT)
- Submitting to CRAN
- Static website hosted via {SET}group website
- Maintained, Documented, and Supported

GeoTox



sf package for spatial data in R (Edzer Pebesma and others)
(Illustration (c) 2018 by Allison Horst)

GeoTox

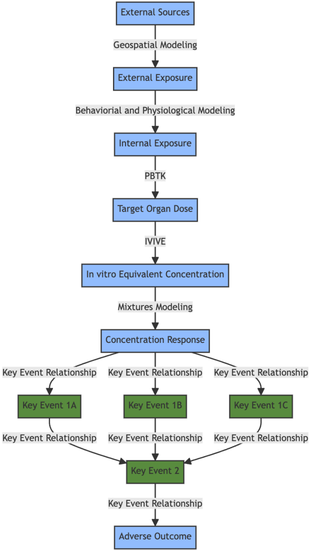

Person
Simulate, Sample
Person, External Exposure
Group
Calc_Internal_Dose
Summarize, Simulate, Sample
Simulate, Sample
Person, Internal Exposure
Group, External Exposure
httk::
Summarize
Calc_Internal_Dose
Person, Target Organ Dose
Group, Internal Exposure
calc_invitro_conc
summarize
httk::
Person, Invitro Concentration
Group, Target Organ Dose
calc_concentration_response
summarize
calc_invitro_conc
Person, Mixture Response
Group, Invitro Concentration
summarize, sample, simulate
calc_concentration_response
Group, Mixture Response
plot, map
Group, Mixture Response

Conclusions

Looking Forward

- The tools for each step of the source-to-outcome modeling framework are available, but the integration is still a work in progress
- The integration of these tools will allow for the development of a comprehensive source-to-outcome modeling framework that can be used to assess the risk of cumulative and total exposomic effects on human health

Multiple Assays Informing an AOP



Looking Forward

- Incorporate more refined information on individual and population-level susceptibility to environmental exposures
- It is going to be a massive code and software development challenge

Looking Forward

- Geospatial **exposures** are the foundation of a spatial, total exposome risk approach

Acknowledgements

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