Fusing surface and satellite-derived PM observations to determine the impact of international transport on coastal $PM_{2.5}$ concentrations in the western U.S.

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Outline

Health Impacts

Figure: Donora, PA at noon on October 29, 1948

- 20 people died, thousands were sickened by smog from a steel mill.
- $PM_{2.5}$ one of the most harmful pollutants, can get lodged in lungs and cause respiratory problems

PM and AOD

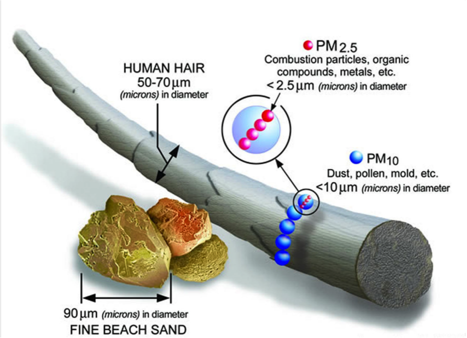


Figure: Size of $PM_{2.5}$ compared to other particulate matter

- $PM_{2.5}$ is a particulate matter that is less than 2.5 micrometers in diameter.
- Aerosol Optical Depth (AOD) measures the amount of light from the sun blocked by dust and pollutants.

Pollution in Western U.S.

- The Clean Air Act imposes a national standard of permissible amount of $PM_{2.5}$.
- Sites in California, such as in the Los Angeles area consistently violate this standard.
- Want to investigate the possibility of external impact by international air travel of $PM_{2.5}$.

Outline

1. Introduction
2. Data Sources and methods
3. Experiments
   - $PM_{2.5}$ time series
   - AOD and $PM_{2.5}$ fitting
4. Conclusions

$PM_{2.5}$

- Ground sites of $PM_{2.5}$ measurements, as collected by EPA
- Data collected either daily, every three days or every six days.

AOD

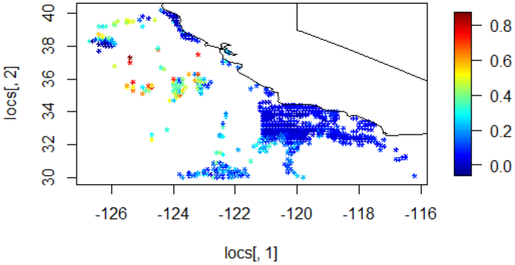


Figure: AOD readings on Jun 6, 2009

- AOD data collected over Pacific Ocean, near coast of California.
- Satellites travel around the Earth once every 16 days.
- AOD data is collected at each location least twice a month.

Data Cleaning

Figure: (left) CA $PM_{2.5}$ sites we compared with AOD data, (right) Hawaii $PM_{2.5}$ sites we compared with AOD data

- Picked PM sites closest to coast (13 in California, 9 in Hawaii)
- Found closest locations of AOD measurements to these sites
- Matched data by date of AOD/PM readings

Using additional data

Challenges

- AOD and $PM_{2.5}$ datasets are quite sparse in space-time.
- Need additional information to improve fits and predictions.

Covariates used in this analysis

- wind speed and direction
- humidity
- planetary boundary layer height
- air temperature
- added values of these measures at each location at each date

Overall big picture

Fuse AOD and $PM_{2.5}$ datasets to

- Understand their quantitative relationships,
- Predict PM measurements from years 1991 – 2000.

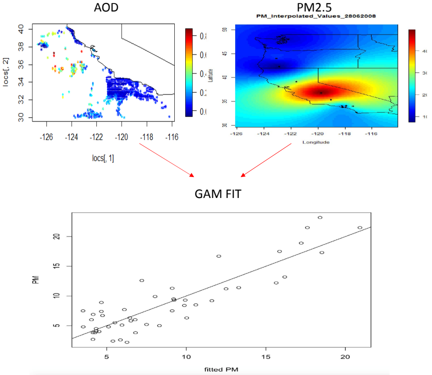
Overall Goal

Methods:

1. Time Series

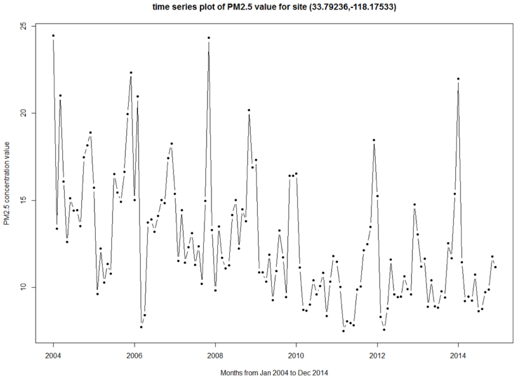
2. Spatial Interpolation

3. Multivariate Regression



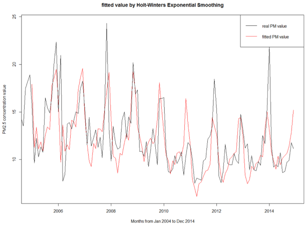
Outline

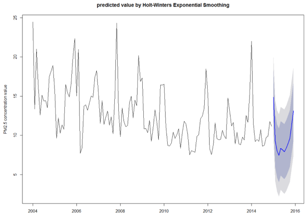
$PM_{2.5}$ Time Series



- Goal is to make predictions about $PM_{2.5}$ in 2015.
- Overall pollution appears to be decreasing.
- Seasonal variations are observed.
- Two methods used – Holt-Winter Exponential smoothing and ARIMA model

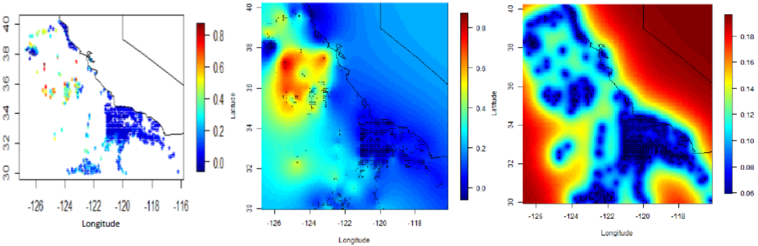
Holt-Winters Exponential Smoothing





- Mean square error is 5.5 but the mean of $PM_{2.5}$ values is 12.6
- Similar result observed using different method - ARIMA.
- $PM_{2.5}$ dataset itself not sufficient to make predictions
- This motivates using covariates and AOD data.

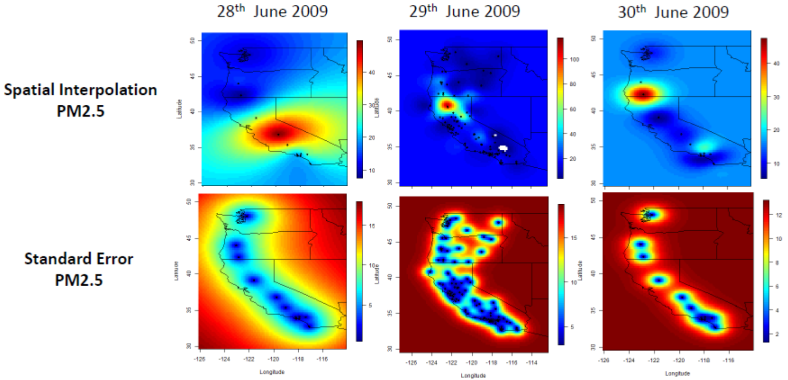
Spatial interpolation of AOD data



AOD values from AVHRR | Interpolated AOD values | Standard Error

- Interpolation using Ordinary Kriging.
- The quality of interpolation depends on availability of data.
- Understand the transport of pollutants to inform regression models.

Spatial interpolation of $PM_{2.5}$ data



Need further validation with satellite date to confirm plume tracking.

$PM_{2.5}$ vs AOD

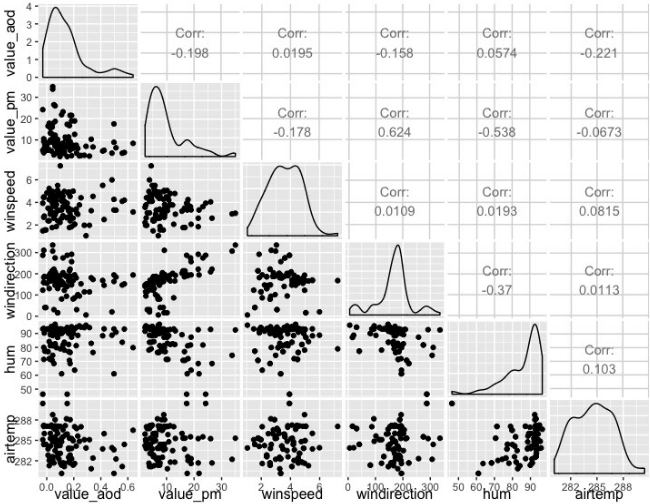
- Goal - relationship between $PM_{2.5}$ and AOD in presence of other meteorological variables.
- Response variable - $PM_{2.5}$ - "What we want to predict"
- Covariates - "What we use to predict"
  - continuous variables: wind direction, wind velocity, relative humidity, air temperature
  - factors: season – a discrete variable that models seasonality.
- Model the relationship at a particular $PM_{2.5}$ site or combine data from two nearby $PM_{2.5}$ sites along the west coast of United States.

Snapshot of the dataset

date	value_aod	value_pm	winspeed	windirection	hum	airtemp	season
2006-12-28	0.01794	17.8	4.25	193.17	71.9	283	4
2007-01-12	0.10983	21.8	3.33	194.59	61.1	281	4
2007-01-21	0.04382	17.7	3.83	190.70	81.1	283	4
2007-03-28	0.17270	7.2	4.53	173.31	76.3	283	1
2007-04-18	0.13014	3.6	4.97	122.07	78.0	282	1
2007-05-18	0.01794	5.2	2.38	130.32	93.2	283	1
2007-06-05	0.24137	2.5	3.78	95.29	95.4	285	2
2007-06-11	0.10983	5.1	4.74	163.40	92.0	285	2
2007-08-10	-0.02195	4.0	4.44	158.96	93.4	287	2
2007-09-21	0.06187	8.2	2.91	188.68	92.6	288	3

- $PM_{2.5}$ sites' coordinates near Eureka, CA - (40.8, -124) and (40.9, -123)
- This site was chosen since it provides best fits.

Preliminary Analysis I



- Shows nonlinear relationships between covariates and responses.
- skewed data, outliers.

Multiple Linear Regression Model

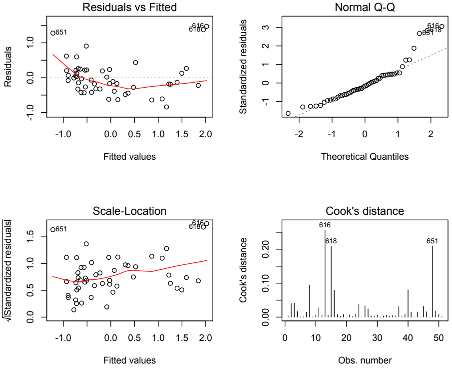
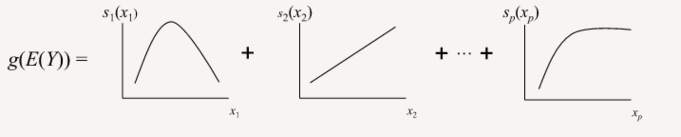


Figure: Some model diagnostics

Multiple linear regression does not provide good fits.

Generalized Additive Model



- Regression splines:

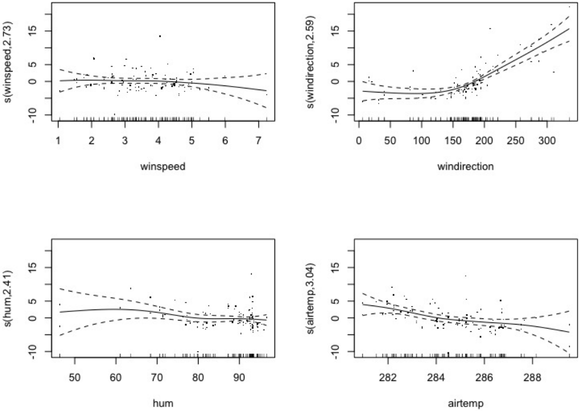
$$s_j(x) = \sum_{j,k} \beta_{jk}\phi_{jk}(x) = \boldsymbol{\beta}'\phi_j$$

- Estimate β by minimizing the penalized least squares objective function.

Results I

- Formula: $\mathrm{PM}_{2.5} \sim$ AOD + s(windspeed) $+$ s(winddirection) $+$ s(hum) $+$ s(airtemp) $+$ season
- Coefficient = 4.085, β_{AOD} = -2.283 (t = 3.84, p-value = 0.0023).
- R^2 = 0.782, Deviance = 81.4%
- We compared various models using a subset of covariates and chose the model with the smallest AIC (Akaike's Information Criterion).

Results II



- Equivalent degrees of freedom = (2.69, 2.54, 2.37, 3.00)

Outline

Conclusions and future work

Conclusions

- AOD has a linear relationship with the $PM_{2.5}$ measurements.
- Meteorological information is also important in predicting $PM_{2.5}$ (particularly wind speed).
- GAM model better than multivariate linear regression model better than mixed effects model.

Future work

- Perform analysis on Hawaii sites.
- Use data from more years to train our model.
- Performing spatio-temporal analysis.

Acknowledgments

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