IDENTIFYING AND QUANTIFYING TRANSPORTED vs. LOCAL SOURCES OF NEW YORK CITY PM2.5 FINE PARTICULATE MATTER AIR POLLUTION

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Abstract

New York City (NYC) is presently in violation of the nation's $PM_{2.5}$ annual mass standard, and will have to take actions to control the sources contributing to these violations. This work seeks to differentiate the impact of long-range transported aerosols on the air quality of downtown NYC, so that the roles of local sources can more clearly be evaluated. Past source apportionment studies have used a single site in their analyses to identify and determine local and non-local sources affecting that site. In this study, a rural site located in Sterling Forest (SF), NY, which is near to the New York City area but unaffected by local New York City sources, is instead used as a reference to separate the portion of the aerosol that is transported to our Manhattan, NYC site. Sterling Forest is confirmed as a background site via elemental comparisons with NYC during regional transport episodes of Asian and Sahara sandstorm dusts, as well as by comparisons with a second background site in Chester, NJ. Two different approaches subtracting Sterling Forest impacts from the NYC source apportionment analysis are then applied. Six source categories are identified for NYC: regional transported sulfate and trans-continental desert dust, Traffic, Residual Oil, Fe-Mn Dust and World Trade Center fires. Of these, the transported sulfates and trans-continental desert dust account for nearly half of the total $PM_{2.5}$ mass in Manhattan during 2001, with nearly two-thirds coming from transported sources during the summer months. Differing percentages of the various elements were transported vs. local, with virtually all of the Manhattan elemental carbon being of local origins, while virtually all sulfate mass being transported into the city. These results indicate meeting the ambient $PM_{2.5}$ mass standards will likely require that upwind sources outside of the State of New York will also need to be controlled if the city is to reliably comply.

Introduction

- **New York University set up two $PM_{2.5}$ monitoring sites in NYC metro area in 2001, located at**
  - Hunter College on 26th Street and 1st Ave, Manhattan, New York City (NYC)
  - Nelson Institute of Environmental Medicine, Sterling Forest in Tuxedo, NY
- **Sterling Forest (SF) is a rural site, approximately 35 miles N-NW of NYC, and is surrounded by thousands of acres of largely undeveloped woodland within New York State's Sterling Forest State Park**
- **The purpose of locating a site in SF, was to provide a background reference site for the Manhattan site that has none of the NYC local source impacts, but is similarly affected by transported pollution (that is largely carried into the NYC metro area under the west and southwest winds).**

Integrated and Semi-continuous $PM_{2.5}$ Samples Collected at 2 NYU Locations in New York City & Sterling Forest, NY (2001 onwards)

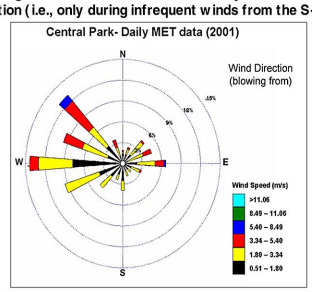
- R & P Automated Cartridge Collector Unit (ACCU) Sampler & X-Ray Fluorescence (XRF) Analysis
- R & P Tapered Elemental Oscillating Microbalances (TEOM)
- R & P Ambient Carbon Particulate Monitor (Series 5400)

New York City Concentrations Consistently Higher than Background Sterling Forest

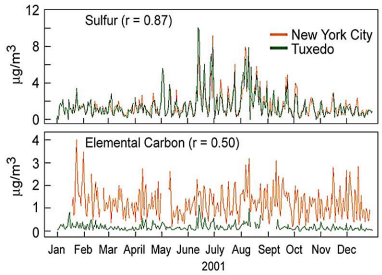
2001 Annual $PM_{2.5}$, Elemental & Carbon Concentrations (ng/m^3)

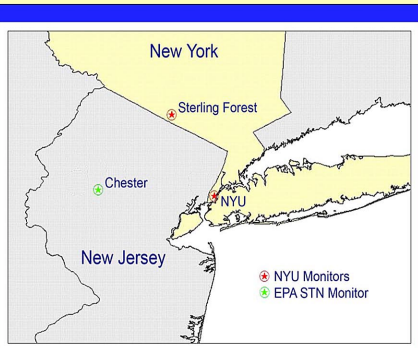
	Sterling Forest (SF)		New York City (NYC)	
	Mean	Std. Deviation	Mean	Std. Deviation
$PM_{2.5}$	11358	8301	17326	9642
Na	39	44	85	67
Mg	12	15	20	16
Al	42	57	44	50
Si	67	126	134	166
S	1512	1432	1583	1317
Cl	0	11	37	273
K	36	27	50	49
Ca	20	19	60	36
Ti	4	18	4	4
V	3	3	10	6
Mn	1	1	7	11
Fe	39	40	194	131
Ni	4	14	24	14
Cu	1	2	6	13
Zn	9	7	44	97
Se	1	1	3	2
Br	3	9	8	37
Sr	1	1	3	3
Ba	0	3	9	5
Pb	2	5	9	36
OC	1700	856	3597	1260
EC	174	139	1226	580

Sterling Forest Site is Seldom Affected by New York City Pollution (i.e., only during infrequent winds from the S-SE).

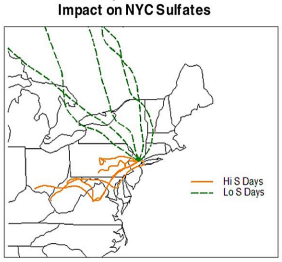


Sulfur Similar at New York City and Sterling Forest Sites, while Carbon (soot) Much Higher in NYC



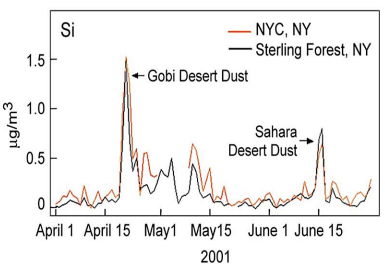


Regional Air Mass Transport from the S-SW had a Major Impact on NYC Sulfates

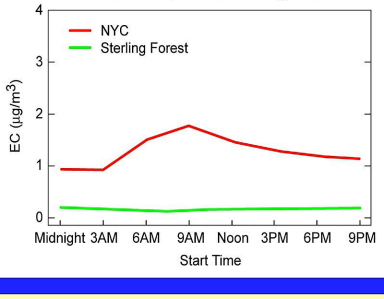


Air mass back-trajectories for the 5 highest and 5 lowest fine particle sulfur concentration days in New York City

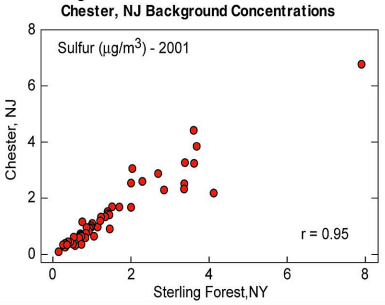
Inter-Continental Dust Storm Pollution Impacts Both Sites Similarly



Elemental Carbon Diurnal Cycle Indicates Traffic Effects in NYC, But Not Sterling Forest



Sterling Forest Sulfate Concentrations Similar to Chester, NJ Background Concentrations



Sulfate (S) Highly Correlated Across Sites while Elemental Carbon (EC) is More Local and Organic Carbon (OC) is a Mixture of Regional and Local Pollution

	n	$PM_{2.5}$	S	OC	EC
SF vs. CH	92	0.75	0.95	0.69	0.42
NYC vs. CH	87	0.80	0.96	0.74	0.56
SF vs. NYC	318	0.82	0.90	0.75	0.52

Source Apportionment Conducted Using Positive Matrix Factorization (PMF-2) Approach

The Positive Matrix Factorization (PMF) technique developed by Paatero (1997), is based on factor analysis and, assumes that x_{ij} i.e. the measured chemical species detected on a given sample is from p independent pollution sources:

$$x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij}$$

- x_{ij} is the *jth* species concentration measured in the *ith* sample;
- g_{ik} is the mass contribution from the *kth* source on the *ith* sample;
- f_{kj} is the *jth* species mass fraction from the *kth* source; and,
- e_{ij} is the error term

Analysis I. PMF Analysis: Separated Background vs. Local Sulfur Only

- In this analysis, we assume that **all** of sulfur measured at SF is transported into the region, and that the NYC site will be similarly affected by this transported pollution.

$$S_{TRANSPORTED} = S_{SF}$$

- The remainder of the sulfur in NYC could be attributed to more local sources.

$$S_{LOCAL} = S_{NYC} - S_{SF}$$

- To aid in the differentiation of transport versus local sources in the source apportionment analysis, we have included these two sulfur variable, $S_{TRANSPORTED}$ and S_{LOCAL} in the NYC PMF analysis, along with the NYC elemental data

Analysis II. PMF Analyses Separated: Background vs. Local for ALL Elements

- In the second source apportionment analysis, we assume that SF is also a good background site for other transported or trans-continental related fine particles.
- Thus, we use this **differencing technique for all the elemental variables** to create a separate set of NYC elemental variables consisting of just the "local" contributions of each of the elements and carbon for application to PMF, separate from a PMF of the transported aerosols, based on a PMF analysis of SF.
- Factor scores from each these two PMF analyses were then applied simultaneously in a multiple linear regression of the Manhattan $PM_{2.5}$ mass on all of the identified source components, in order to convert the scores to actual mass concentration estimates for each of the transported and local source components identified by the two separate PMF analyses. For e.g.,

$$PM_{2.5} = \beta_0 + \beta_1 \cdot G_{SULFATES\ (T)} + \beta_2 \cdot G_{SOIL\ (T)} + \beta_3 \cdot G_{TRAFFIC\ (L)} + \beta_4 \cdot G_{RESID\ OIL\ (L)} + \beta_5 \cdot G_{FE\text{-}MN\ (L)} + \beta_6 \cdot G_{WTC\ (L)}$$

where G are the factor scores for Transported (T) and Local (L) components

Analysis I

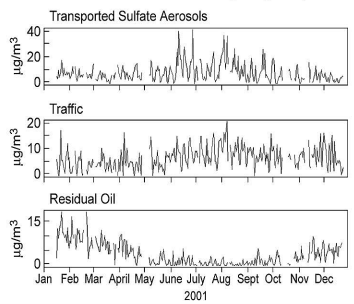
Results: Correlations between the Sources and Elemental / Carbon Concentrations

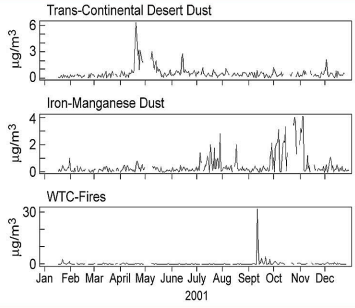
	Transp. Sulfates	Traffic	Residual Oil	Transp. Desert Dust	Fe-Mn Dust	WTC
Na	0.23	-0.08	-0.05	0.38	**0.42**	0.18
Mg	0.21	0.09	-0.13	**0.80**	0.21	0.06
Al	0.19	0.13	-0.22	**0.88**	0.15	-0.18
Si	0.21	0.07	-0.10	**0.88**	0.19	0.29
Cl	-0.06	-0.09	0.08	-0.08	-0.04	**0.92**
K	0.20	0.07	-0.07	0.35	0.17	**0.76**
Ca	0.18	**0.39**	-0.12	**0.78**	0.35	0.08
Ti	0.22	0.10	-0.20	**0.83**	0.28	0.00
V	**0.45**	0.32	**0.44**	0.14	0.18	0.06
Mn	0.06	0.15	-0.15	0.03	**0.99**	0.05
Fe	0.15	0.35	-0.13	0.38	**0.87**	0.06
Ni	-0.12	0.00	**0.86**	-0.18	-0.13	-0.08
Cu	0.05	0.10	-0.03	-0.03	0.17	**0.95**
Zn	0.01	0.05	0.05	-0.04	0.09	**0.93**
Se	**0.48**	0.10	0.42	0.17	-0.01	0.09
Br	0.01	-0.09	-0.03	-0.02	-0.02	**0.98**
Sr	0.03	-0.18	0.14	0.14	-0.08	**0.72**
Ba	0.28	0.40	-0.01	0.53	0.14	-0.02
Pb	0.00	-0.04	0.02	-0.03	0.04	**0.99**
OC	**0.65**	**0.81**	-0.28	0.19	0.32	0.10
EC	**0.38**	**0.74**	0.28	0.11	0.17	0.09
S (Transp.)	**0.93**	0.43	-0.22	0.11	0.01	-0.02
S (Local)	-0.22	0.11	0.11	-0.01	0.11	0.10
Eigen Value	2.34	2.09	1.52	4.35	2.51	5.86

Analysis I $PM_{2.5}$ Apportionment Results: Average Contributions (Annual, Winter, Summer 2001)

Analysis I	Transp Sulfates	Transp. Desert Dust	Traffic	Residual Oil	Fe-Mn Dust	WTC
Annual Contributions (ug/m3)	8.3	0.5	6.8	3.6	0.4	0.4
Winter Contributions (Jan-Mar '01)	6.6	0.2	4.4	8.6	0.2	0.3
Summer Contributions (Jun-Aug '01)	12.9	0.5	9.1	0.9	0.4	0.1

2001 Time-series Plots of Contributions from the 6 Identified Sources (Analysis I)





Analysis II

Results: Correlations between the Sources and Elemental / Carbon Concentrations

	Transported Aerosols (SF concentrations)		Local NYC Aerosols (NYC minus SF concentrations)			
	Transp. Aerosols	Transp. Desert Dust	Traffic	Residual Oil	Fe-Mn Dust	WTC
Na	0.06	0.43	0.11	-0.23	0.35	0.17
Mg	0.06	**0.76**	0.33	-0.19	0.17	0.05
Al	0.07	**0.84**	0.30	-0.17	0.13	-0.19
Si	0.07	**0.86**	0.34	-0.13	0.15	0.28
S	**0.92**	0.23	0.42	-0.05	0.02	0.01
Cl	-0.06	-0.05	-0.05	-0.02	-0.05	**0.93**
K	0.12	0.37	0.18	-0.10	0.16	**0.75**
Ca	0.11	**0.68**	**0.57**	-0.04	0.36	0.07
Ti	0.08	**0.81**	0.27	-0.20	0.26	-0.01
V	0.33	0.20	0.48	**0.40**	0.14	0.05
Mn	0.03	0.15	-0.02	-0.15	**0.96**	0.03
Fe	0.08	0.44	0.31	-0.11	**0.85**	0.04
Cu	0.03	0.02	0.06	-0.06	0.18	**0.93**
Zn	0.01	0.02	0.05	0.02	0.09	**0.93**
Se	0.36	0.23	0.45	0.27	-0.08	0.07
Br	0.00	0.00	-0.05	-0.07	-0.02	**0.99**
Sr	-0.02	0.14	0.09	-0.08	-0.13	**0.72**
Ba	0.22	0.51	0.62	-0.01	0.10	-0.02
Pb	-0.01	0.00	-0.01	-0.04	0.04	**0.99**
OC	**0.65**	0.29	**0.63**	-0.08	0.31	0.09
EC	0.39	0.18	**0.77**	0.33	0.14	0.09

Analysis II $PM_{2.5}$ Apportionment Results: Average Contributions (Annual, Winter, Summer 2001)

Analysis II.	Transported Aerosols (SF concentrations)		Local NYC Aerosols (NYC minus SF concentrations)			
	Transp. Aerosols	Transp. Desert Dust	Traffic	Residual Oil	Fe-Mn Dust	WTC
Annual Contributions (ug/m3)	6.9	1.0	4.7	3.8	0.8	0.4
Winter Contributions (Jan - Mar '01)	5.0	0.6	4.3	5.8	0.3	0.3
Summer Contributions (Jun - Aug '01)	12.4	1.1	5.4	2.5	0.8	0.2

The Fraction of Transported Pollution in $PM_{2.5}$, Sulfur, Organic Carbon and Elemental Carbon Varied Across Components and Season

	Analysis I. PMF Analysis Incorporating 2 Sulfur Variables: S_{SF} & $S_{(NYC\text{-}SF)}$			Analysis II. Two Separate PMF Analyses of SF and "Local" (NYC-SF) Datasets		
	Annual (2001)	Winter (Jan-Mar '01)	Summer (Jun-Aug '01)	Annual (2001)	Winter (Jan-Mar '01)	Summer (Jun-Aug '01)
$PM_{2.5}$	0.44	0.33	0.56	0.45	0.34	0.61
S	0.80	0.79	0.85	0.90	0.86	0.94
OC	0.31	0.26	0.67	0.40	0.32	0.53
EC	0.12	0.08	0.15	0.05	0.04	0.09

Fraction of NYC total $PM_{2.5}$ mass and Elemental / Carbon Concentrations Due to Transported Aerosols

Conclusions

- On an annual basis approximately half of NYC $PM_{2.5}$ is contributed by transported aerosols; during the summer months this estimate is as high as 60%
- 90% of the sulfur observed in NYC, is due to transport from outside the NY metro area
- Almost all (~90-95%) of the EC can be attributed to local NYC combustion sources
- Local and non-local sources are both responsible for the OC levels in NYC

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