International Workshop on "Inventory, Modeling and Climate Impacts of Greenhouse Gas emissions (GHG's) and Aerosols in the Asian Region"

Particulate Matter concentration estimation from satellite aerosol and meteorological parameters - a case study from Hanoi, Vietnam

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Outline

- Introduction
- Related work
- Methodologies
- Experiments and Results
- Conclusion

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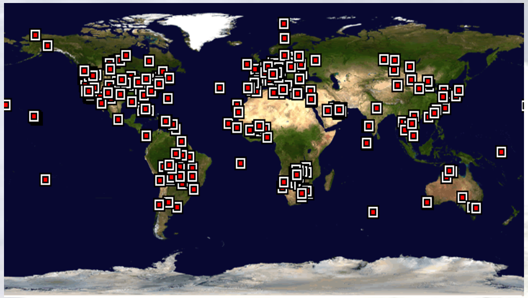
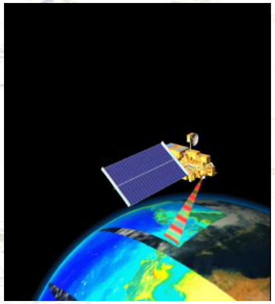
Introduction

- Aerosol Optical Thickness/Aerosol Optical Depth



AERONET sites distributed over world

C-130 aircraft in ACE-Asia Campaign 2001 (UCAR/NSF)



MODIS instrument on Terra satellite

- Particulate Matter concentration
  - PM1/2.5/10
  - Direct measurements
  - **In-direct estimation**
    - **Meteorological data**
    - **Aerosol**

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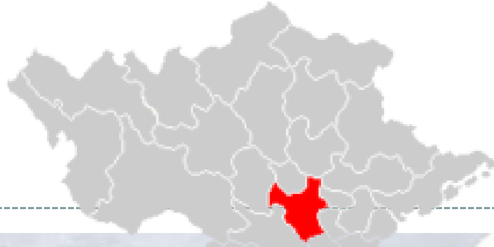
Related Work

Location	PM	AOT/AOD	Met.	Method	R^2	Ref.
Italy/LA/Beijing	PM10	AERONET[1.5]		LR	0.62	Chu et al. (2003)
US	PM2.5	MODIS[4] MODIS[3]	x	MLR	0.49 0.96	Wang et al. (2003)
US	PM2.5	MODIS[4]		LR		Engel-Cox et al. (2004)
France	PM2.5	POLDER		LR	0.3	Kacenelenbogen et al. (2006)
France	PM10	AERONET		LR	0.27/ 0.76	Pelletier et al. (2007)
Neitherland	PM2.5	AERONET[1.5] MODIS	x	LR	0.57 0.52	Schaap et al. (2009)
US/HK/SYD/SWIT /Delhi/NY	PM2.5	MODIS[3] MODIS[5]	x	LR/MLR/ NN		Gupta et al. (06, 08,09)
Nanjing, China	PM10	MODIS	x	MLR	0.21 - 0.74	Zha et al. (2010)
ER, Italy	PM10	PMMAPPER		Kriging		Campalani et al. (2011)
Peninsular Malaysia	PM10	MODIS	x	LR/MLR	0.79	Yap et al (2013)
Austria	PM10	PMMAPPER	x	SVR	0.77-0.91	Hirtl et al. (2013)

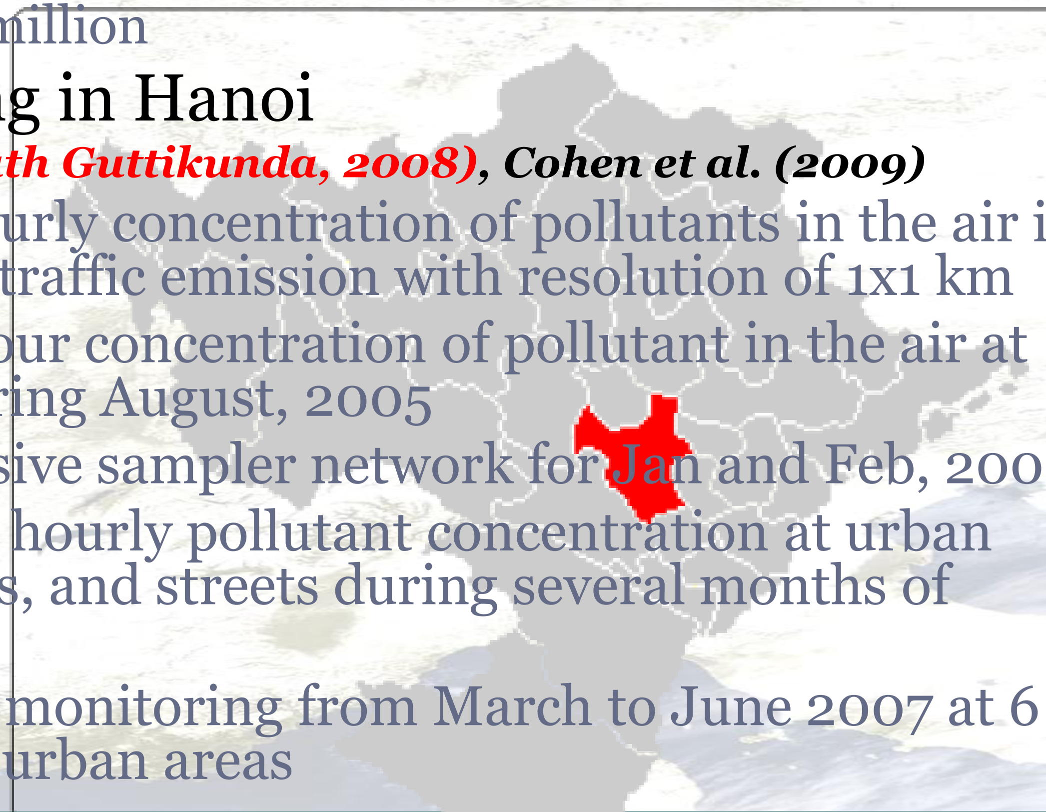
Related Work



- City of Hanoi, Vietnam
  - Coordinates: 21°2' N, 105°51'E
  - Area: 3,344.7 km^2
  - Population (2009): 6.5 million
- Air Quality monitoring in Hanoi

(Hien et al, 2002, 2004), (Sarath Guttikunda, 2008), Cohen et al. (2009)

  - **MONRE**: Collected hourly concentration of pollutants in the air in 2003 and estimated of traffic emission with resolution of 1x1 km
  - **JICA**: Monitored 24 hour concentration of pollutant in the air at traffic intersections during August, 2005
  - **SVCAP**: Operated passive sampler network for Jan and Feb, 2007
  - **DONREH**: Monitored hourly pollutant concentration at urban centers, industrial areas, and streets during several months of 2006-2007
  - **CENMAL**: Conducted monitoring from March to June 2007 at 6 industrial areas and 13 urban areas



Objectives

- Will the usage of satellite aerosol improve PM estimation accuracy?
- Which approach will be appropriate for PM estimation from satellite aerosol and meteorological data **in site domain**?
- Which approach will be appropriate for PM estimation from satellite aerosol and meteorological data **in map domain**?
- How to validate PM maps?

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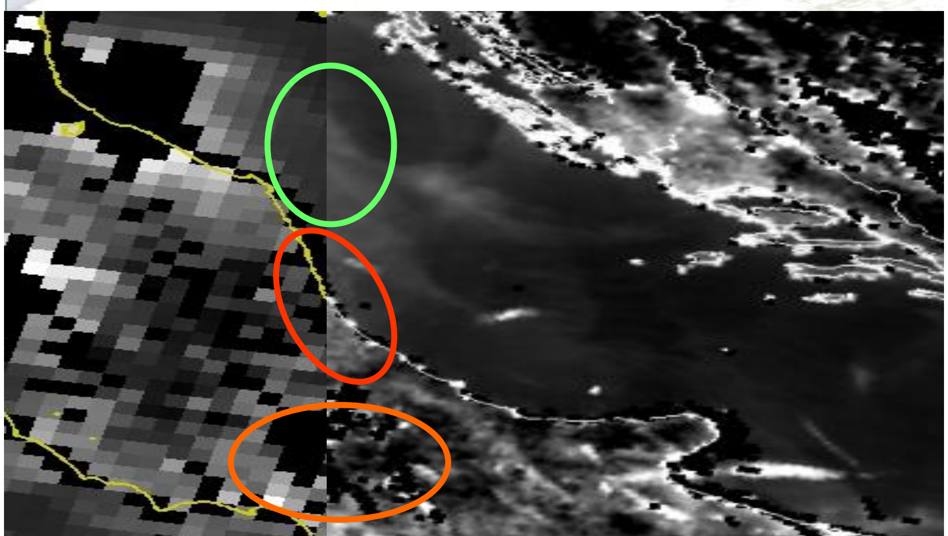
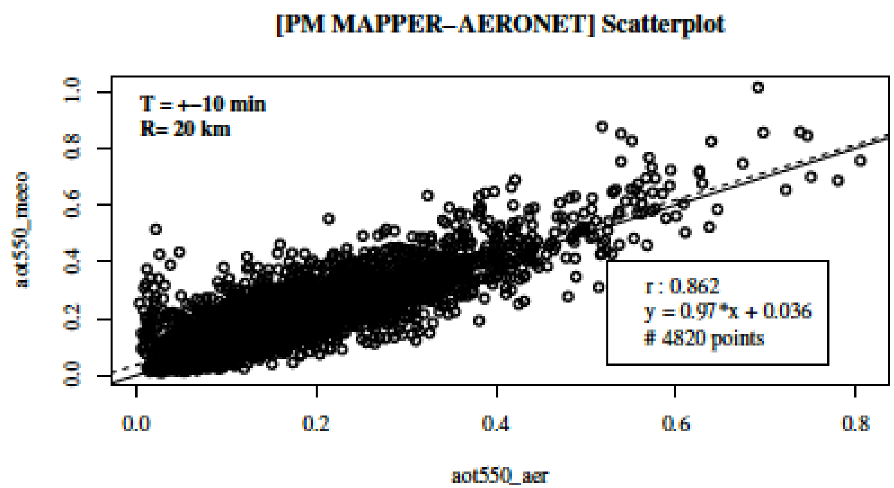
Data Collection

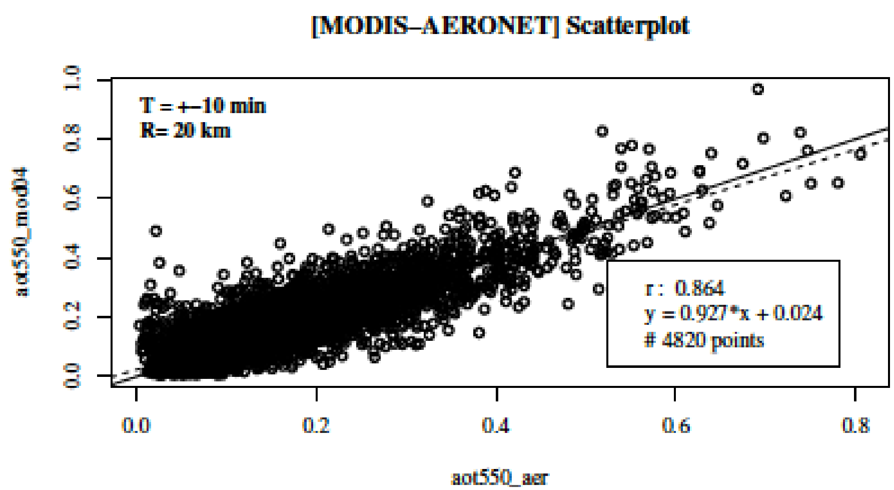
- Satellite-based aerosol
  - MODIS AOT: MOD04 L2
  - PMMAPPER aerosol product *(Nguyen et al., 2010; Campalani et al., 2011)*
    - 1x1 km of spatial resolution
    - Validated over Europe areas (2007-2009, 5500 granules, ~170 AERONET sites)

MODIS vs. PM MAPPER



Overlay of MODIS AOT map @ 10x10 km² (left) and PM MAPPER AOT map @ 3x3 km² (right)



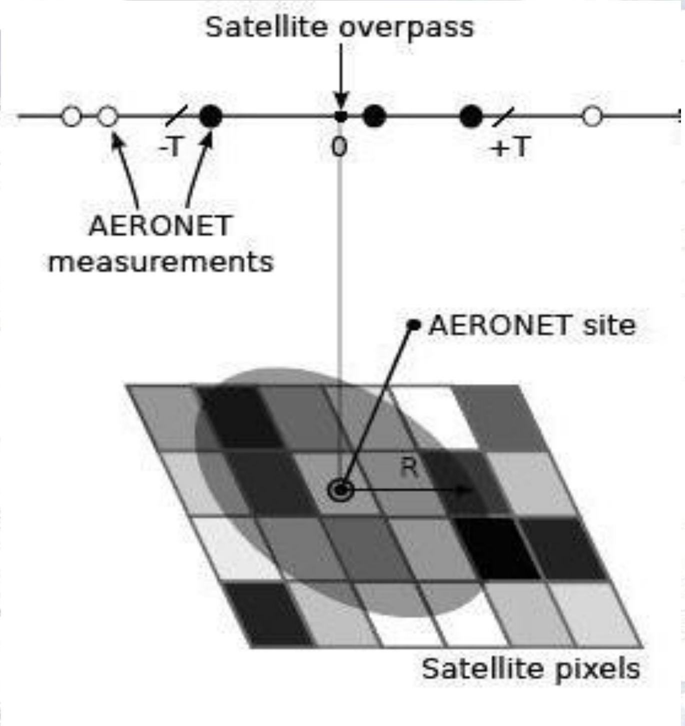


Data Collection

- Ground-based aerosol
  - AERONET
  - Nghiado station, Hanoi
  - AOT in various wavelengths: 0.340, 0.380, 0.440, 0.500, 0.675, 0.870, 1.020, and 1.640 µm in interval of *15 minutes* in average.
- Ground PM concentration and meteorological data
  - PM1, PM2.5, PM10 *(24 hour average)*
  - Wind speed (Wsp), Temperature (Temp), Relative Humidity (Rel_H), pressure (Bar) and Radiation (Rad) *(hourly average)*
  - Provided by Center for Environmental Monitoring (CEM), Vietnam Environment Administration

Data Integration

- Constraints (Ichoku, 2002)
  - Collocate in space (R)
  - Synchronize in time (T)
- Optimal thresholds (R, T) are selected by experiments
- Integrated datasets
  - PMMAPPER AOT and AERONET AOT
    - Validate PMMAPPER AOT product
  - PMMAPER AOT and PM1/2.5/10, meteorological parameters
    - Modeling and testing process of PM estimation



Spatial-temporal window fro extracting satellite/ground-based measurements

Modeling Techniques

- Problem statement

  Given a training dataset including l samples:

  $$\{(x_1, y_1), \ldots, (x_l, y_l)\} \in X \times Y \quad where \quad X \in R^n, Y \in R$$

  The modeling process will find an appropriate function f that minimize error ϵ. The general form of a model would be:

  $$Y = f(X) + \epsilon$$

- Linear Regression (LR)/Multiple Linear Regression (MLR)

  $$Y = b_0 + b_1 X_1 + \ldots + b_n X_n + \epsilon$$

  The problem is to estimate b_i as that which minimizes the sum of the square error, $\epsilon^T \epsilon$

Modeling Techniques

- Support Vector Regression (SVR)
  - Proposed by Vapnik, 1995
  - Based on structural risk minimization principle from computational learning theory ~ finding maximize regression margin hyperplanes in feature space
  - Compared with ANN (Artificial Neural Network), SVR has main advantages as follows:
    - The SVR solution may be a global optimum than a local optimum as ANN's
    - The SVR may minimize the risk of over-fitting.

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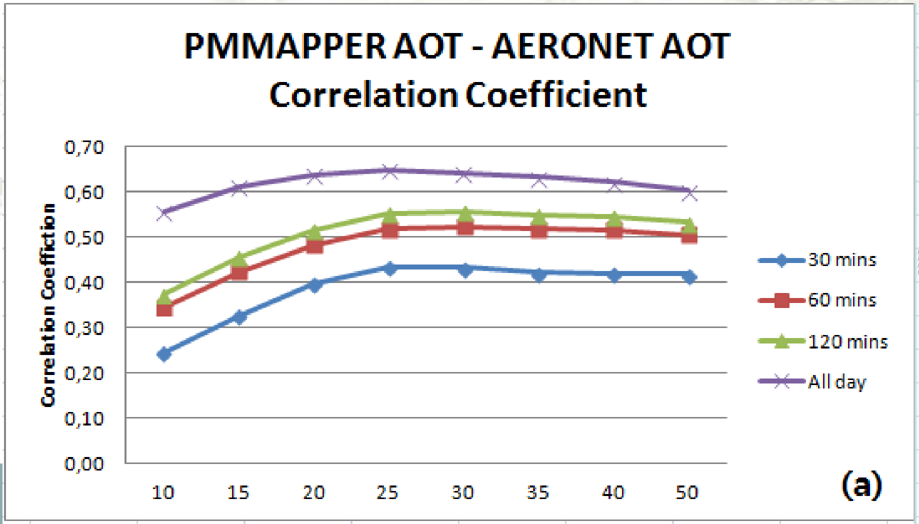
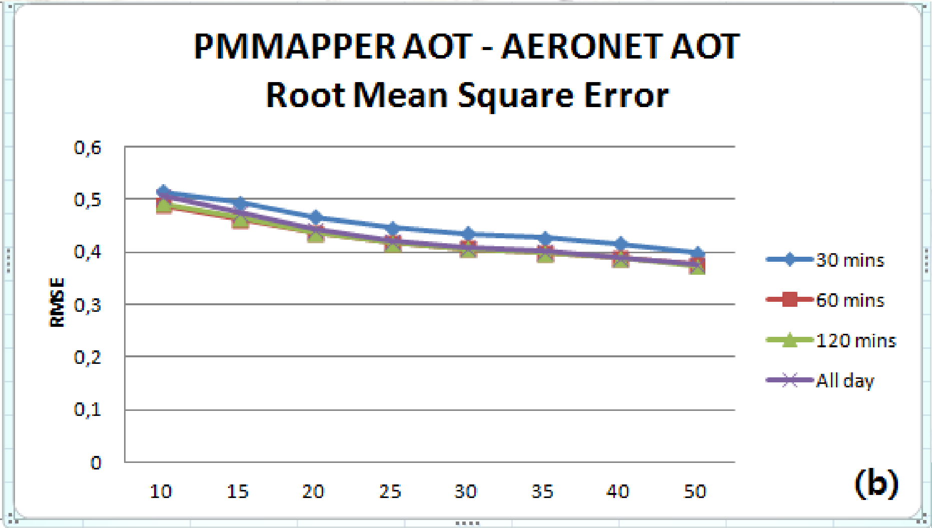
Satellite aerosol validation

- Data:
  - From Dec. 2010 to Nov. 2011
  - PMMAPPER AOT maps cover Hanoi, Vietnam
  - AERONET AOT collected at Nghiado station in Hanoi
- Integration
  - Temporal windows T=30, 60, 120 minutes or 24 hours
  - Spatial windows R=10, 15, 20, 25, 30, 35, 30, 50 km
- Results
  - The best match would be happened with T=24 hours and R=25 km
  - R = 0.648 and RMSE=0.421 (RMSE% = 37.4)





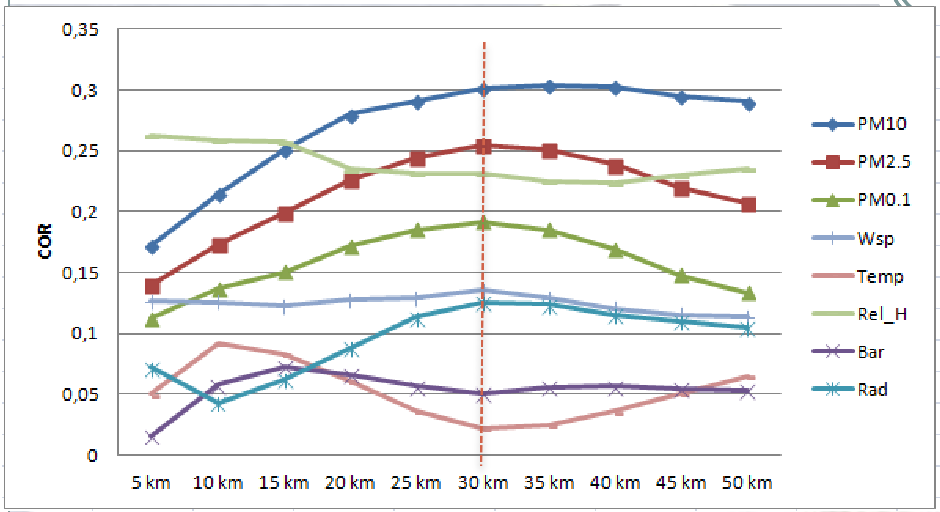
PM Estimation

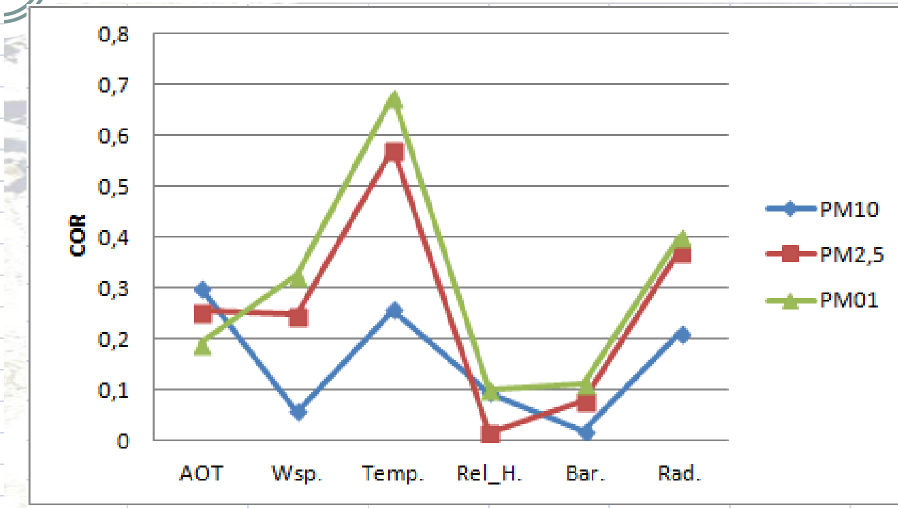
- Threshold selection
  - Identify spatial and temporal thresholds for integration data in order to obtain samples for the PM1/2.5/10 modeling step.
- Investigate important factors to PM1, PM2.5, PM10 estimation
- PM estimation using MLP and SVR
  - Estimators of different types of particle mass concentration (PM1, PM2.5 and PM10)
  - Role of satellite AOT
  - Performance of two regression methodologies

Threshold selection

- Data were collected from August 2010 to July 2012:
  - Daily AOT maps at 1 km^2,
  - Daily particulate matter concentration (PM_1, $PM_{2.5}$, PM_{10})
  - Hourly meteorological parameters (wind speed, temperature, relative humidity, pressure and sun radiation)
- Temporal and spatial windows
  - The nearest time - T1, average of two nearest times - T2 and average of four nearest times - T3
  - R=5, 10, 15, 20, 25, 30, 35, 40, 45 and 50km

Threshold selection & factor assessment





Correlation Coefficients in distance between satellite AOT and other factors

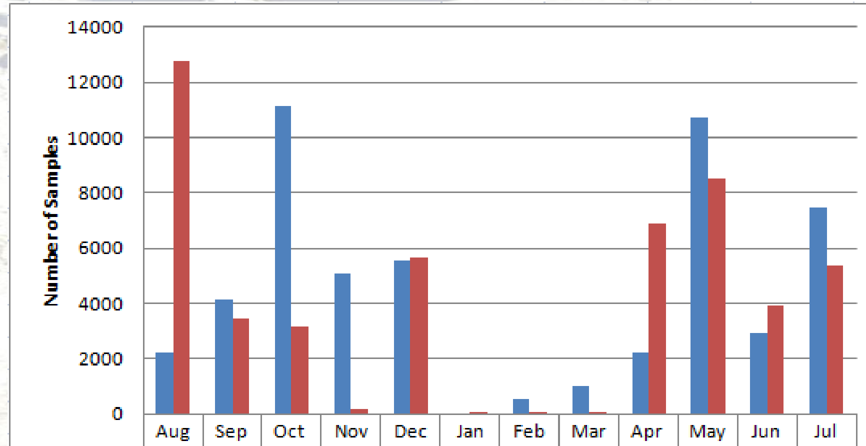
Correlation coefficients between PM1/2.5/10 and other factors in the selected dataset.

- Temporal and spatial thresholds for integration of satellite and ground measurements are
  - The nearest time T1
  - R=30km

- PM and AOT correlation increase in the order of their aerodynamic diameters (i.e. 1, 2.5 and then 10 µm)
- Whereas, PM and Wsp, Temp, Bar, Rad correlation decrease in the order of PM mass sizes

PM Estimation Using MLP and SVR

- Datasets
  - PM1/2.5/10 estimators
    - Year 1
      - With AOT
      - Without AOT
    - Year 2
      - With AOT
      - Without AOT
- Modeling
  - One year data for modeling and another year for validating
  - Using MLP and SVR



	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Year 1	2213	4171	11164	5092	5554	0	546	1035	2231	10736	2901	7488
Year 2	12792	3436	3154	179	5645	31	3	26	6863	8496	3930	5353

Statistics on total datasets

PM Estimation Using MLP and SVR

PM10	MLR w/o AOT	MLR w AOT	SVR w AOT
COR	0.038	0.174	0.239
RMSE	109.225	96.656	74.935
PM2.5			
COR	0.429	0.598	0.593
RMSE	40.836	31.071	31.674

PM1			
COR	0.608	0.659	0.694
RMSE	24.591	22.939	22.349

- PM1 and PM2.5 can be estimated well by both methods while PM10 estimation is worst much.
- The use of satellite AOT in PM1/2.5/10 prediction is able to improve regression correlation and accuracy significantly
- SVR is better than MRL for PM10 and PM1 estimation. Meanwhile, MRL and SVR perform in nearly same way for PM2.5 estimation

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Conclusion

- Case study in Hanoi, Vietnam for PM1/2.5/10 estimation from satellite AOT and meteorological parameters using MLR and SVR techniques
- The thresholds for combination of satellite and ground-based measurements should be selected by experiments.
- Estimation quality decreases by PM10, PM2.5 and PM1 as results of loose relationship of PM10 on meteorology parameters in comparison with PM2.5 and PM1
- The use of satellite AOT in modeling is able to improve all PM estimators' accuracy significantly.
- SVR outperforms MLP. It should be a good method for PM estimation

Q & A

THANK YOU FOR YOUR ATTENTION