Air pollution monitoring project in Vietnam

THANH T.N. NGUYEN, HUNG Q. BUI, HUNG V. LUU, HA V. PHAM, BANG H. PHAM

UNIVERSITY OF ENGINEERING AND TECHNOLOGY, VIETNAM NATIONAL UNIVERSITY HANOI
Outline

- Introduction
- Objective and Approach
- Daily PM2.5 estimation
- PM2.5/PM10 estimation using Landsat 8 images
- Conclusion
Outline

• Introduction

• Objective and Approach

• Daily PM2.5 estimation

• PM2.5/PM10 estimation using Landsat 8 images

• Conclusion
Introduction

- Aerosol Optical Thickness/Aerosol Optical Depth

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

- Air Quality Index
Air pollution in Vietnam

PM\textsubscript{10} in Hanoi, DaNang, Hochiminh Cities from 2005 to 2009
(Source: TTKTTV Quốc Gia, 2010; Chi cục BVMT Tp. Hồ Chí Minh, 2010)

TSP in Vietnam in urban areas from 2005 to 2009
(Source: Các trạm QT&PTMT vùng (Dất liền 1,2,3); Mạng lưới QTMT quốc gia, 2010)
Air pollution in Vietnam

- **Projects**
  - **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

- **Automatic stations for air pollution monitoring (24)**
  - Hanoi (6), Haiphong (1), Hochiminh (9), The National Hydro – Meteorological service (8)

- **Automatic PM stations in Vietnam (CEM)**
  - Quang Ninh, Phu Tho, Ha Noi, Hue, Da Nang, Khanh Hoa

**: Tổng quan hệ thống quan trắc và phân tích môi trường, CEM, 2013
Outline

- Introduction
- **Objective and Approach**
  - *Daily PM2.5 estimation*
  - *PM2.5/PM10 estimation using Landsat 8 images*
- Conclusion
Project’s Overview

- **Objective:** Developing an Air pollution monitoring and warning system in Vietnam using satellite images
- **Leader:** Thanh T.N. Nguyen
- **Starting Time:** Jan 2014
- **Sponsor:** VNU UET
- **Partners:**
  - CEM, Vietnam Environment Administration
  - CEMA, Hanoi Natural resources and Environmental Department
  - MEEO s.r.l, FE, Italy
  - VUB, Brussel, Belgium
Research Objective and Approach

**Objectives**
- Monitor PM2.5/PM10 based on satellite images
- Provide products at different spatial and temporal scales

**Approach**
- Estimate PM2.5
  - Daily basis, 10 km and 6 km (MODIS/NPP AOT), Over Vietnam
- Estimate PM2.5/PM10 using Landsat 8 images
  - When required, 90 – 150 m for urban areas, at city scale
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**Approach**

- **Study area:** Vietnam
- **Data:**
  - Satellite-based aerosol: MOD04/MYD04 aerosol products (daily, 10km)
  - Satellite-based meteorological products: MOD07/MYD07
  - Ground - measurements PM$_{2.5}$ from 5 CEM automatic stations
  - Ground –measurements AOT from 7 AERONET stations
- **Methodology:**
  - Develop PM$_{2.5}$ regression model based on aerosol and meteorological data
  - Develop interpolation model on PM$_{2.5}$ to obtain continuing maps
MODIS AOT vs. AERONET AOT

Data

<table>
<thead>
<tr>
<th>Station</th>
<th>Bac Giang</th>
<th>Bach Long Vy</th>
<th>Bac Lieu</th>
<th>Nghia Do</th>
<th>Nha Trang</th>
<th>Red River Delta</th>
<th>Son La</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Samples</td>
<td>169</td>
<td>13</td>
<td>89</td>
<td>48</td>
<td>87</td>
<td>2</td>
<td>21</td>
</tr>
</tbody>
</table>

- Number of samples: 429
- \( R = 25 \text{km}, T = 30\text{min} \)

\( R^2 = 0.79 \)
## Satellite- vs. Ground-based measurements

<table>
<thead>
<tr>
<th></th>
<th>R² (502 samples)</th>
<th>PM1</th>
<th>PM2.5</th>
<th>PM10</th>
<th>MOD07 Pressure</th>
<th>MOD07 Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CEM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CEM Pres.</td>
<td>0.0400</td>
<td>0.0300</td>
<td>0.0069</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CEM Temp.</td>
<td>0.5300</td>
<td>0.5100</td>
<td>0.2770</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td><strong>MOD07</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MOD07 Pres.</td>
<td>0.01470</td>
<td>0.0090</td>
<td>0.0009</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MOD07 Temp.</td>
<td>0.4200</td>
<td>0.4100</td>
<td>0.2360</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MOD04</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MOD AOD</td>
<td>0.2370</td>
<td>0.2200</td>
<td>0.1100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>HN</th>
<th>HUE</th>
<th>PT</th>
<th>DN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Samples</strong></td>
<td>34</td>
<td>84</td>
<td>75</td>
<td>163</td>
</tr>
<tr>
<td><strong>PM2.5-AOD</strong></td>
<td>0.123</td>
<td>0.084</td>
<td>0.143</td>
<td>0.257</td>
</tr>
<tr>
<td><strong>PM2.5-Temp</strong></td>
<td>0.286</td>
<td>0.513</td>
<td>0.647</td>
<td>0.194</td>
</tr>
</tbody>
</table>
Number of Samples by Year

PM2.5 Regression

Number of samples over PM stations

January February March April May June July August September October November December

2012 2013 2014
# PM2.5 Regression (MLR)

## Year Model

<table>
<thead>
<tr>
<th>Year</th>
<th># Training</th>
<th># Testing</th>
<th>R²</th>
<th>RMSE</th>
<th>RE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>323</td>
<td>35</td>
<td>0.314</td>
<td>13.995</td>
<td>222.493</td>
</tr>
<tr>
<td>2013</td>
<td>273</td>
<td>85</td>
<td>0.523</td>
<td>12.214</td>
<td>43.279</td>
</tr>
<tr>
<td>2014</td>
<td>283</td>
<td>75</td>
<td>0.612</td>
<td>31.749</td>
<td>39.992</td>
</tr>
</tbody>
</table>

## Station

<table>
<thead>
<tr>
<th>Station</th>
<th># Training</th>
<th># Testing</th>
<th>R²</th>
<th>RMSE</th>
<th>RE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HN</td>
<td>323</td>
<td>35</td>
<td>0.314</td>
<td>13.995</td>
<td>222.493</td>
</tr>
<tr>
<td>HUE</td>
<td>273</td>
<td>85</td>
<td>0.523</td>
<td>12.214</td>
<td>43.279</td>
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<td>283</td>
<td>75</td>
<td>0.612</td>
<td>31.749</td>
<td>39.992</td>
</tr>
<tr>
<td>DN</td>
<td>195</td>
<td>163</td>
<td>0.261</td>
<td>16.169</td>
<td>101.297</td>
</tr>
</tbody>
</table>

## Over All

<table>
<thead>
<tr>
<th>Year</th>
<th># Training</th>
<th># Testing</th>
<th>R²</th>
<th>RMSE</th>
<th>RE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>323</td>
<td>35</td>
<td>0.314</td>
<td>13.995</td>
<td>222.493</td>
</tr>
<tr>
<td>2013</td>
<td>273</td>
<td>85</td>
<td>0.523</td>
<td>12.214</td>
<td>43.279</td>
</tr>
<tr>
<td>2014</td>
<td>283</td>
<td>75</td>
<td>0.612</td>
<td>31.749</td>
<td>39.992</td>
</tr>
<tr>
<td>2012-2014</td>
<td>357</td>
<td>357</td>
<td>0.536</td>
<td>15.548</td>
<td>74.138</td>
</tr>
</tbody>
</table>
## PM2.5 Interpolation

<table>
<thead>
<tr>
<th>Year</th>
<th>Available Data Rate (%)</th>
<th>Number of Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>2011</td>
<td>N/A</td>
<td>No data</td>
</tr>
<tr>
<td>2012</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>2013</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>2014</td>
<td>40</td>
<td>17</td>
</tr>
</tbody>
</table>

**Simple Kriging**

**Spherical model**

(Nugget: 55.23774
Sill: 174.24463
Range: 4.780275)
## PM2.5 Interpolation

### Average Cross-validation (3 folds) results on each image

<table>
<thead>
<tr>
<th>Year</th>
<th># Images</th>
<th>AVG of Images</th>
<th>AVG of R</th>
<th>AVG of RMSE</th>
<th>AVG of RE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>11</td>
<td>2966</td>
<td>0.878677</td>
<td>6.499963</td>
<td>121.244</td>
</tr>
<tr>
<td>2012</td>
<td>16</td>
<td>2465</td>
<td>0.871235</td>
<td>5.922812</td>
<td>109.886</td>
</tr>
<tr>
<td>2013</td>
<td>11</td>
<td>3151</td>
<td>0.913579</td>
<td>5.387152</td>
<td>72.3679</td>
</tr>
<tr>
<td>2014</td>
<td>17</td>
<td>3562</td>
<td>0.899345</td>
<td>6.001101</td>
<td>81.5715</td>
</tr>
</tbody>
</table>

### Validation results using PM station values (4 CEM stations in total)

<table>
<thead>
<tr>
<th>Year</th>
<th># Images</th>
<th>AVG of PM Values</th>
<th>AVG of RE(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>11</td>
<td>No Data</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>16</td>
<td>1.4</td>
<td>88.0205</td>
</tr>
<tr>
<td>2013</td>
<td>11</td>
<td>2.09</td>
<td>53.3951</td>
</tr>
<tr>
<td>2014</td>
<td>17</td>
<td>3</td>
<td>53.1727</td>
</tr>
<tr>
<td>Image</td>
<td>% Data</td>
<td>R</td>
<td>RE (%)</td>
</tr>
<tr>
<td>--------------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>2012.308.0350</strong></td>
<td>30%</td>
<td>0.918381</td>
<td>53.4267</td>
</tr>
<tr>
<td><strong>2014.024.0310</strong></td>
<td>60%</td>
<td>0.917052</td>
<td>12.3272</td>
</tr>
</tbody>
</table>
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Approach

- Develop PM2.5/PM10 estimation using Landsat 8 images
  - Study area: Hanoi
  - Data: LandSat 8, directly measured PM10
  - Methodology:
    - Estimating relative aerosol from LandSat 8 *
    - Applying regression and interpolation to estimate PM10 map using relative aerosol from Landsat 8 and measured PM10

*Sifakis N., Mapping of Air Pollution Using SPOT Satellite Data, 1992*
Relative Aerosol Estimation

- **Study area:** Hanoi, Vietnam
- **Images**
  - Destination: 2014-019
  - Reference: 2013-160
- **AERONET station**
  - Nghia Do, Hanoi (Long=105.800, Lat=21.048)
- **Validation**

<table>
<thead>
<tr>
<th>AERONET</th>
<th>Target</th>
<th>AVG of 9 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.64313</td>
<td>0.725444</td>
<td>1.067241</td>
</tr>
</tbody>
</table>
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Conclusion

- Overview of Air pollution monitoring project in Vietnam
- PM2.5 estimation using MODIS aerosol and meteorological Data
  - Daily product at 10 km spatial resolution
  - Moderate quality
  - Ancillary data (DEM, LC) should be included
- Relative aerosol estimation in Hanoi from Landsat 8 image
  - Get some qualitative results
  - Need more investigation
Q & A

THANK YOU FOR YOUR ATTENTION