Land Use/Cover Changes, Environment and Emissions in South/Southeast Asia
– An International Regional Science Meeting, 22-27th July 2019, Johor Bahru, Malaysia

Overview of Atmospheric Aerosol Studies in Malaysia: Known and unknown

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Presentation Outline

- Significance of aerosols studies in Malaysia
- Sources of aerosol data
- Aerosol studies using remote sensing
- Research gaps and challenges in studying atmospheric aerosol in Malaysia

Significance of aerosols studies in Malaysia

- Air pollution -serious environmental problem in the developing Southeast Asian countries
- Major sources of air pollution – urbanisation & associated industrial and transportation activities, land clearing, open burning & forest fire.
- Trans-boundary aerosols transport –southwest monsoon
- Malaysia is ranked as the 83rd worst country among 180 nations worldwide in terms of air quality (EPI., 2018)

Can Effect:

➢ **Human health** (***respiratory problems*** ,***cardiovascular issues*** , ***birth defects and premature death, allergic*** (Morgenstern et al., 2008), ***symptoms of aging*** (Vierkotter et al., 2010), ***skin cancer*** (Puntoni et al., 2004)

➢ **Climate** (by altering radiation budgets, cloud properties)

➢ **Poor visibility**

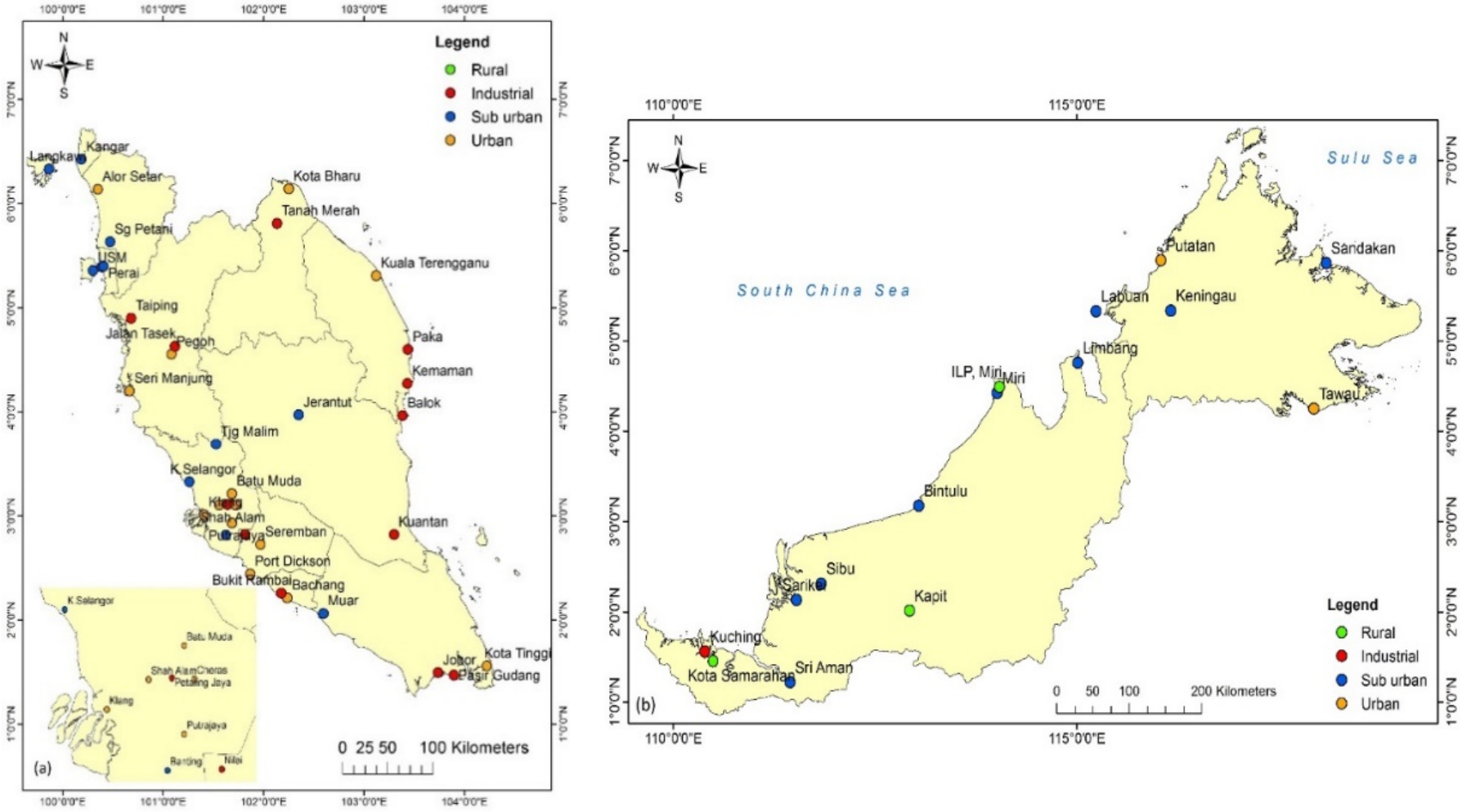
Aerosol Monitoring in Malaysia

- Ground based monitoring
- WMO Global Atmospheric Watch (GAW) Network
- AERONET
- Space borne remote sensing

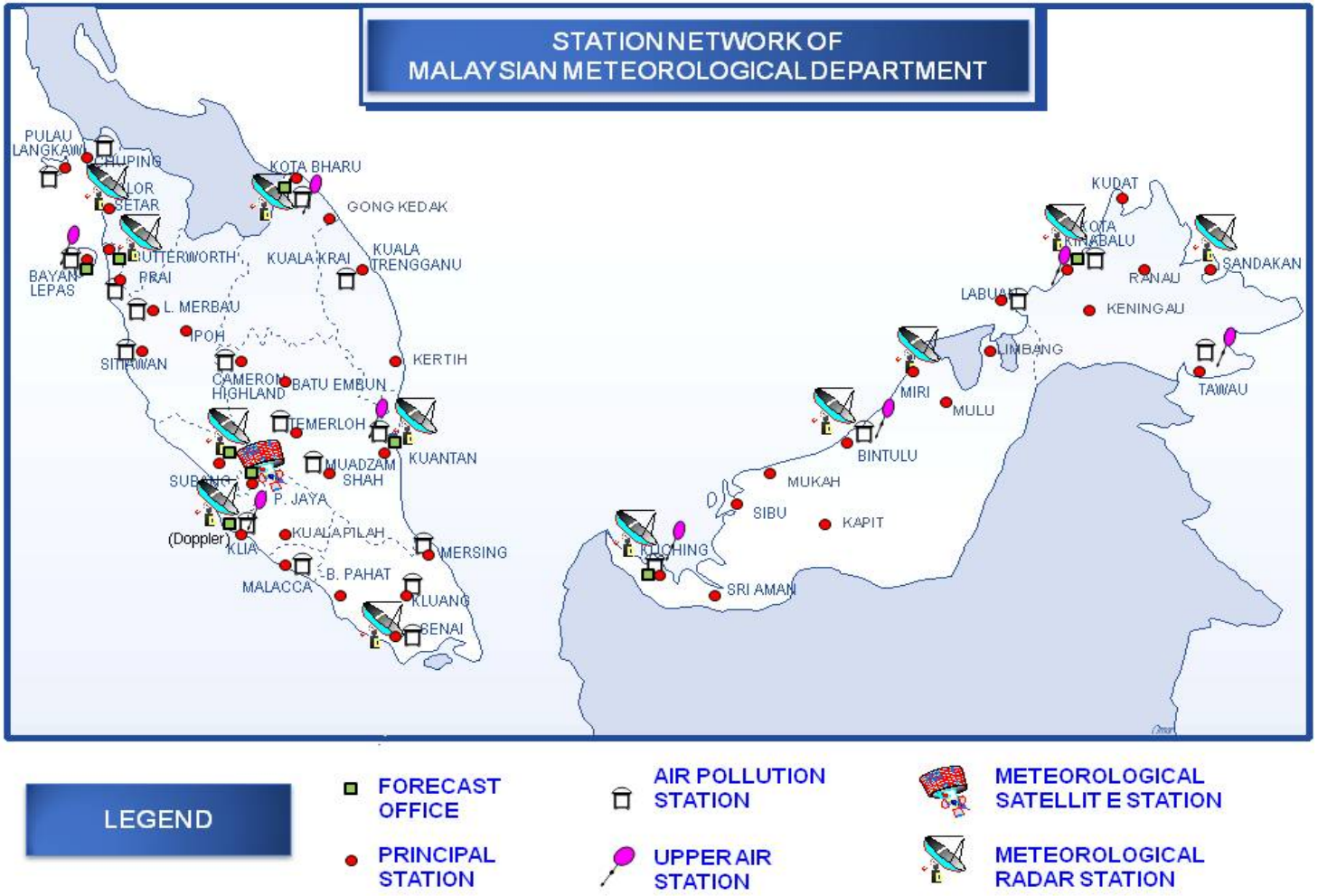
Ground Based Air Quality Monitoring

Department of Environment (DOE)	Malaysian Meteorological Department (METMalaysia)
▪ 65 Continuous Automatic Air Quality Monitoring (CAQM) stations	• 14 stations measure TSP (PM <100 μm) & 9 stations measure PM10
▪ Measurements from industrial, residential, traffic and rural areas	• Only ambient conditions are monitored
• CAQM measures PM2.5, PM_{10} and other gases such as SO2, NOx , CO, O3 , CH4, Non-Methane Hydrocarbon • starting mid-August 2018, DOE improved the calculation of API by using $PM_{2.5}$ • Meteorological parameters i.e. Wind Speed, Wind Direction, Temperature and Ultra Violet radiation	• TSP, atmospheric O3 and reactive gases (i.e. surface O3, CO, volatile organic compounds (VOCs), oxidised nitrogen compounds (NOx, NOy), and SO2 • Co-located with climatological stations
▪ Collected, processed, analysed and distributed by a private company known as Pakar Scieno TW Sdn Bhd (PSTW) ▪ Teledyne API, UV radiometer, High Volume PM10 Sampler	• High Volume PM10 Sampler

Air Quality Monitoring Stations by Dept. Environment



Air Quality Monitoring Stations by METMalaysia



Source:METMalaysia., 2018

WMO Global Atmospheric Watch (GAW) Network of Stations

- One global (Danum Valley, Sabah) and two regional (Tanah Rata in Cameron Highlands and Petaling Jaya) stations
- Regional stations:
  - PJ stations measures TSP & PM_{10}
  - To study urban air quality and meteorology and providing urban air pollution forecasts
  - Tanah Rata station includes Rainwater chemical composition, reactive gases, aerosol load and chemical composition, surface ozone and meteorology.
- Danum valley station monitors background concentrations of atmospheric parameters to study long-range transport of pollutants and ability of forests to act as sinks for atmospheric pollutants

WMO Global Atmospheric Watch (GAW) Network of Stations

World Meteorological Organization
Weather · Climate · Water

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

Global	■	Reporting	●
Regional	●	Partly Reporting	●
Contributing networks	▲	Non-reporting	●
Local	★	Closed	●
Other networks	+	Planned	●
		Pre-operational	●

AERONET Stations

- Information of columnar aerosol properties
- Available in Malaysia since 2011
- Three AERONET stations:

AERONET Stations	Kuching	USM, Penang	Tahir
Started operation	2nd Aug 2011	8th Nov 2011	21st Jun 2012
Location	Kuching International Airport	Universiti Sains Malaysia	Universiti Sains Malaysia
Others	Operating	Operating	Ceased (operated for 5 months)

Remote Sensing for Aerosols

Satellite sensor	Operational period	Aerosol products	Resolutions	Wavelength used	Accuracy	Remarks	Reference
AVHRR	Since 1979	Aerosol Optical Depth (AOD), Angstrom exponent	Daily, weekly, monthly, 1 degree	Visible Shortwave infrared	AOD (10%) for single channel AOD (3.6%) for two channel	Providing aerosol products over worlds oceanic surfaces only since 1988	Stowe *et al.* (1997); Mishchenko *et al.* (1999) Ignatov *et al.* (2004)
TOMS	1979-1993 and 1996-2005	Ultra Violet (UV)-absorbing aerosol index, UV Aerosol Optical Depth (AOD)	Daily, Monthly, 1 degree	Ultraviolet channels (331 and 360 nm)	AOD (20 ~ 30%)	Could differentiate biomass-burning smoke and dust	Torres *et al.* (2002)
OMI	Since 2004	UV Aerosol Index, Aerosol Absorption Optical Depth, Aerosol Extinction Optical Depth (AOD) and Single Scattering Albedo	Daily, monthly, 13 × 12 km^2, 13 × 24 km^2, 13 × 48 km^2	Includes 330 to 380 nm channels	AOD (30%)	Can detect minerals and carbonaceous aerosols	Torres *et al.* (2007)

Remote Sensing for Aerosols (cont.)

SeaWIFS	1997 – 2010	aerosol optical thickness and fine mode fractional volume, Angstrom Exponent	Daily and monthly 13.5x13.5 km at the center of the swath	510 nm, 670 nm, and 865 nm	AOD (~5 -10%)	Uses Deep Blue algorithm to retrieve AOD and size parameters over ocean, land and dessert	Sayer *et al.* (2012) Hsu *et al.* (2013)
MODIS	Since 2000 (Terra) Since 2002 (Aqua)	AOD, Angstrom exponent, Fine mode fraction	Daily, 8days and monthly 10 km, 1 degree	550 nm	AOD (~5 -15%)	Widely used to study air pollution, climate and health impacts of aerosols	Remer *et al.* (2005)
MISR	Since 2000	AOD, Angstrom exponent, single scattering albedo, non-spherical fraction	1.1km (non-red band) 275m (red band)	555 nm	AOD (10 ~20%)	Wide range of along track view angles (one at nadir and eight symmetrical views at 26.1, 45.6, 60.6 and 70.5 degrees forward and aft of the nadir). Enables aerosol retrieval over ocean, land, bright desert and sun-glint regions Yields information on particle size and shapes which can be used to identify aerosol types	Kahn *et al.* (2005)

Remote Sensing for Aerosols (cont.)

POLDER	1996 -1997 2002- 2003 2004 – present	AOD, Angstrom exponent, non-spherical fraction, scattering phase function	Daily, 18.5 km	0.443, 0.490, 0.565, 0.665, 0.765, 0.865 and 0.910µm	AOD (20 ~30%) Angstrom exponent correlated well with AERONET, but with underestimation of 30%	Provides multi-directional and polarization measurements and can separate atmospheric contribution from surface contribution	Herman *et al.* (1997)
SCIAMACHY, GOME 1, GOME 2	2002-2012 1995-2003 2010-present	UV-absorbing Aerosol Index (AI)	Daily, monthly 60 x 30 km 320 x 40 km 80 x 40 km	340 and 380 nm	AI (~40%)	Able to detect and discriminate desert dust and biomass burning aerosols	Graaf and Stammes (2005)
MERIS	2002-2012	AOD, Angström exponent	Daily, 1.2km	15 channels between 0.39-1.04 µm	AOD (~20%) AOD retrieved at both blue and red bands show an overestimaton of AOD compared to AERONET AOD	Not suitable for high reflectance area or retrieval of non-spherical particles likes desert dust aerosols (Kokhanovsky et al., 2007)	Vidot *et al.* (2008)

Remote Sensing for Aerosols(cont.)

MERIS/AATSR	2002-2012	Synergistic Aerosol Optical Depth (AOD)	Daily, 7km (default based on BEAM software toolbox)	21 TOA radiance (8 from AATSR and 13 from MERIS)	Good correlation with AERONET (R^2 between 0.60 and 0.90) mainly depending on land cover types	Combining the spectral and angular information from the AATSR and MERIS instruments shows potential for improved characterization of aerosol properties and surface reflectance compared with single-instrument retrievals	North *et al.* (2009) Benas *et al.* (2013b)
SUOMI NPP	Available since 2013	Visible Infrared Imaging Radiometer Suite (VIIRS) provides AOD, Angstrom exponent, suspended matter, Dust single scattering albedo	AOT and Angstrom exponent at 6 km and 10 km at nadir and edge respectively Suspended matter at 0.75 km and 1.2 km at nadir and edge respectively.	22 channels covering from 0.412 to 12.05μm	VIIRS AOD is biased high compared to MODIS on Aqua (by 50% or more over land, and 10% over ocean). Comparing against	New generation of operational satellite sensors that are able to provide aerosol products with a similar quality to MODIS	Xiao *et al.* (2016)

Remote Sensing for Aerosols

- Spatial and temporal patterns of AOD
- Aerosol size and types
- Identifying source regions of aerosols
- Impact of Aerosols on Solar radiation
- Particulate Matters Mapping/Modeling

Air Quality studies

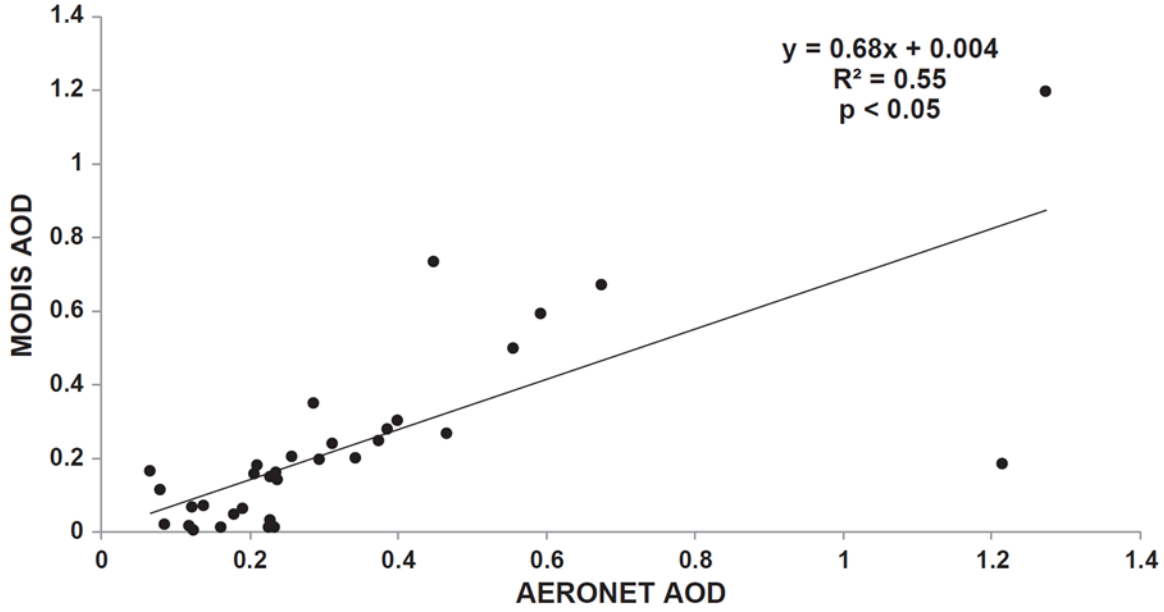
- PM10
  - Severe pollution in highly urbanized areas (KL, JB, George Town)
  - Main cause- motor vehicles during rush hours and late evening due to low mixing height and decreased wind speed
  - Study based on DOE data- PM10 exhibits remarkable seasonal variation (dry versus wet)- Juneng et al., 2009
- PM2.5
  - Studies in the east and west coasts of Pen. Malaysia (Tahir et al., 2013a,b;Ee-Ling et al., 2015;Khan et al., 2016)
  - Concentrations exceeded the limit of air quality standards (WHO-25 µgm-3)

Air Quality studies

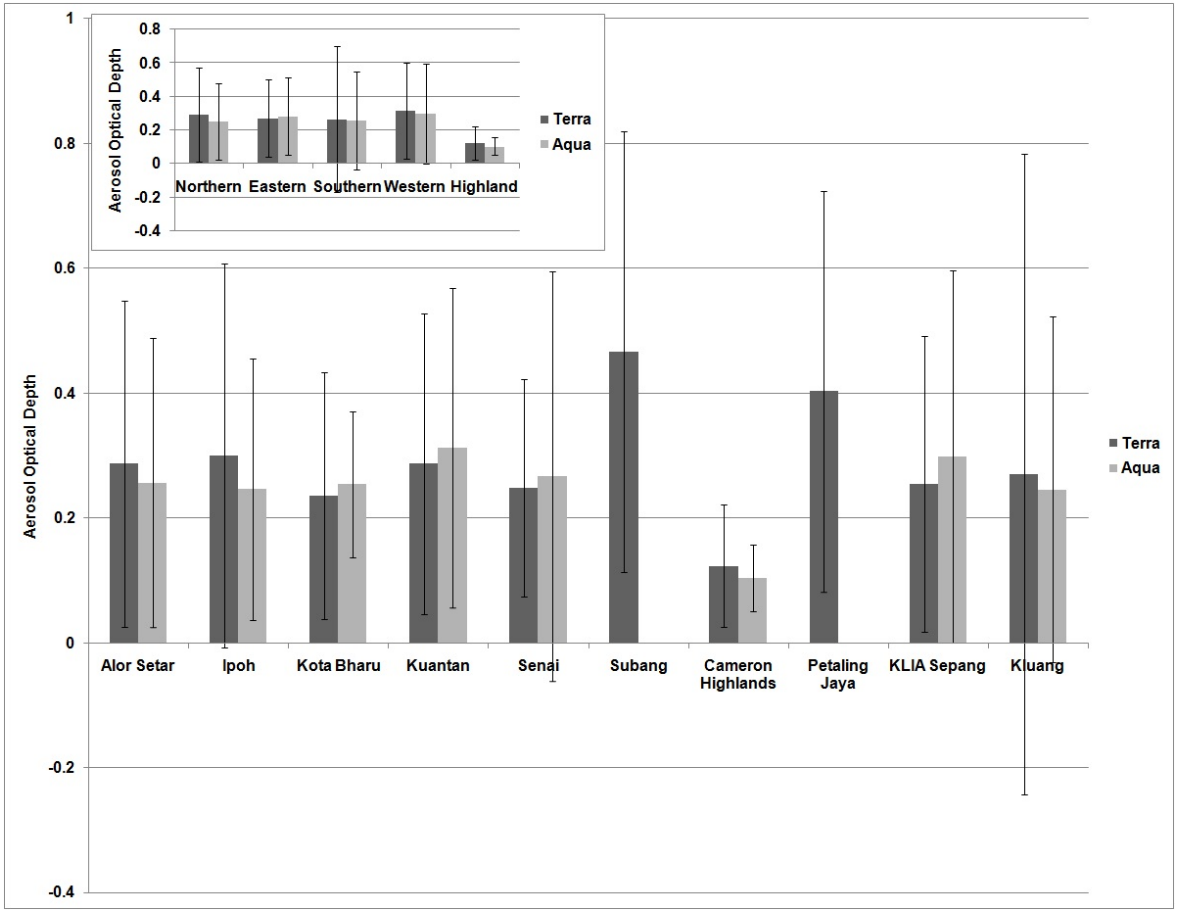
- Ozone
  - Data from DOE
  - Highest concentration in sub-urban areas (60±20ppbv)-influenced by photochemical processes and effects of oxidization of Nitrogen Oxides, long and mid range transport from South China Sea.
  - Other ozone studies using GAW data (Toh et al., 2013)- high levels in the dry season-biomass burning emissions from Indonesia and pollution transported from Indochina and enhanced photochemical production of O3

Aerosol Optical Depth

- Aeronet data- Salinas et al., 2013, Tan et al., 2015, Hee et al., 2014, Kanniah et al., 2014- seasonality, aerosol types
- Validation of MODIS AOD (Singapore (2011), Songkhla (2007), Kuching (2011), Penang (2011))



Aerosol Optical Depth



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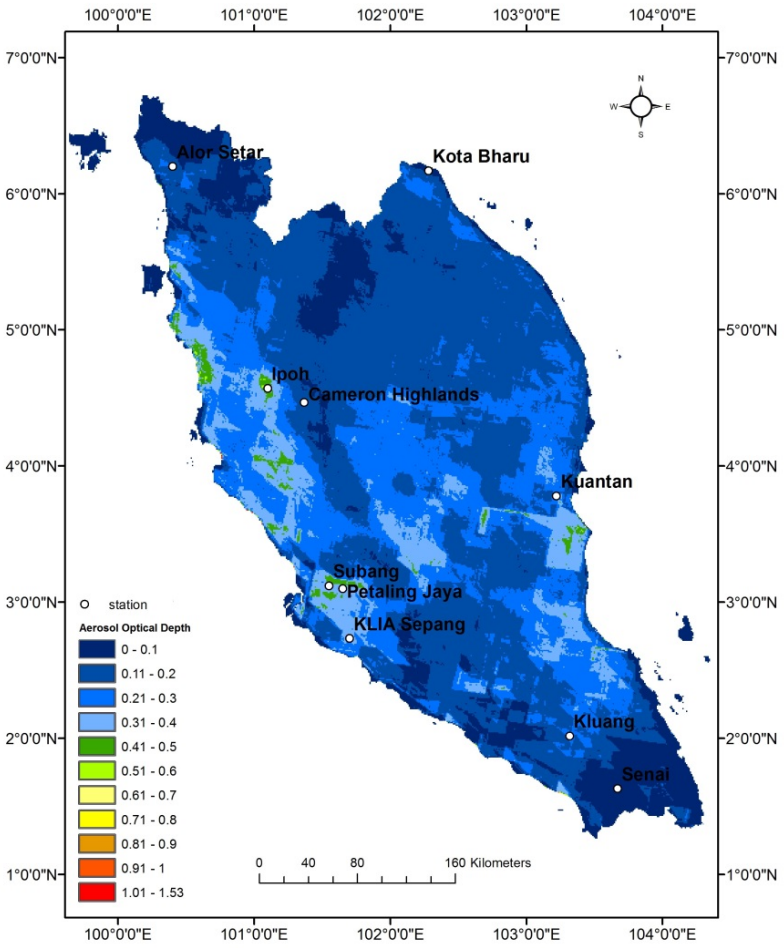
Investigating aerosol properties in Peninsular Malaysia via the synergy of satellite remote sensing and ground-based measurements

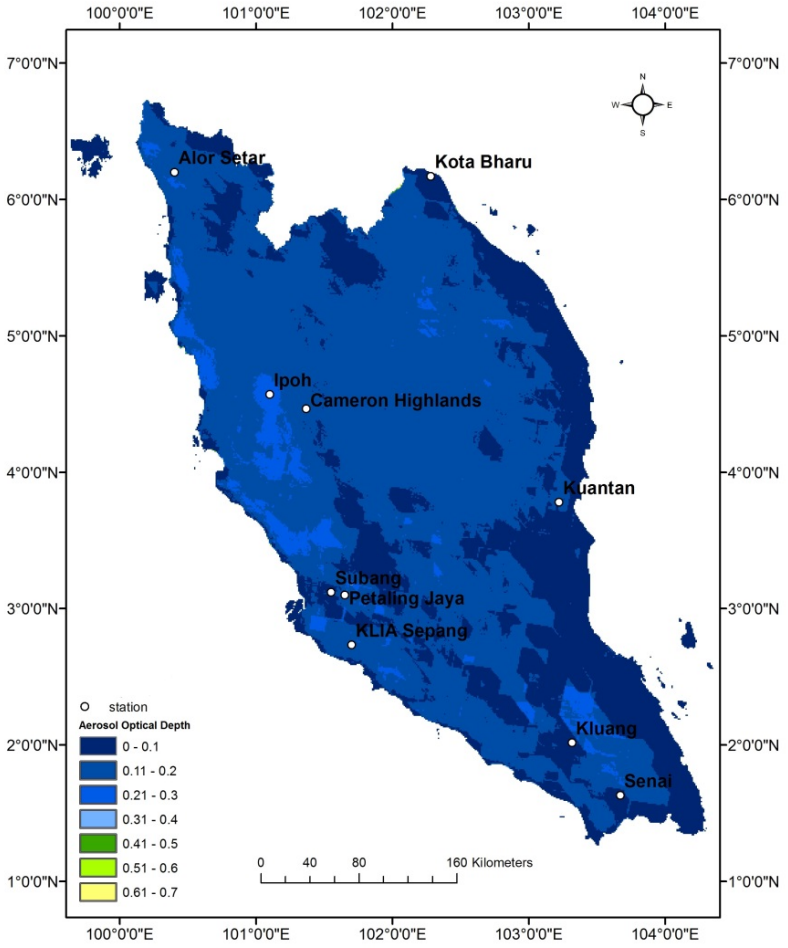
Kasturi Devi Kanniah [a,*], Hui Qi Lim [a], Dimitris G. Kaskaoutis [b], Arthur P. Cracknell [c]

Terra 2000-2006 and Aqua 2002-2008

Spatial Pattern AOD (MODIS)

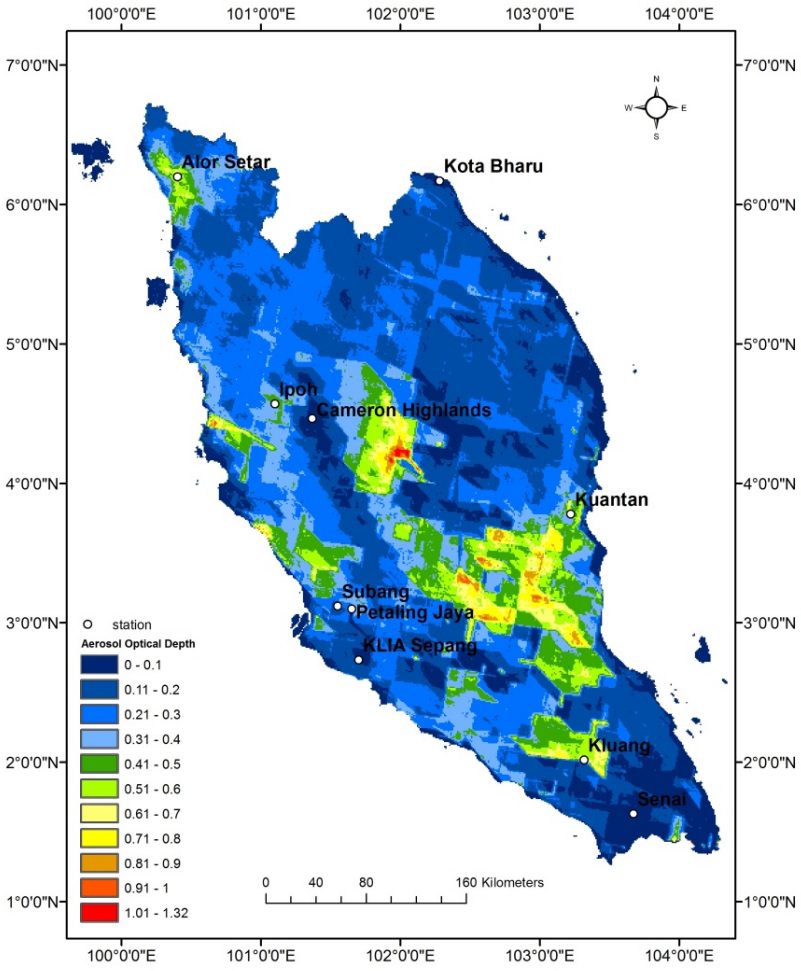


Dry Season (June-Sept)

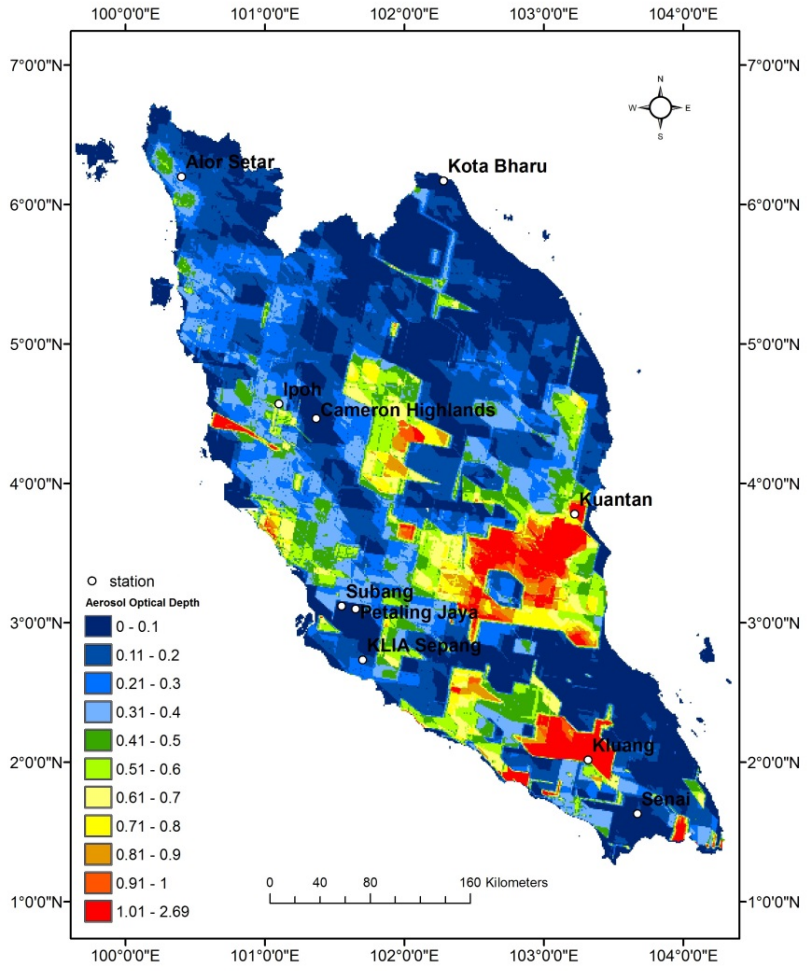


Wet Season (Dec-Mar)

Spatial Pattern AOD

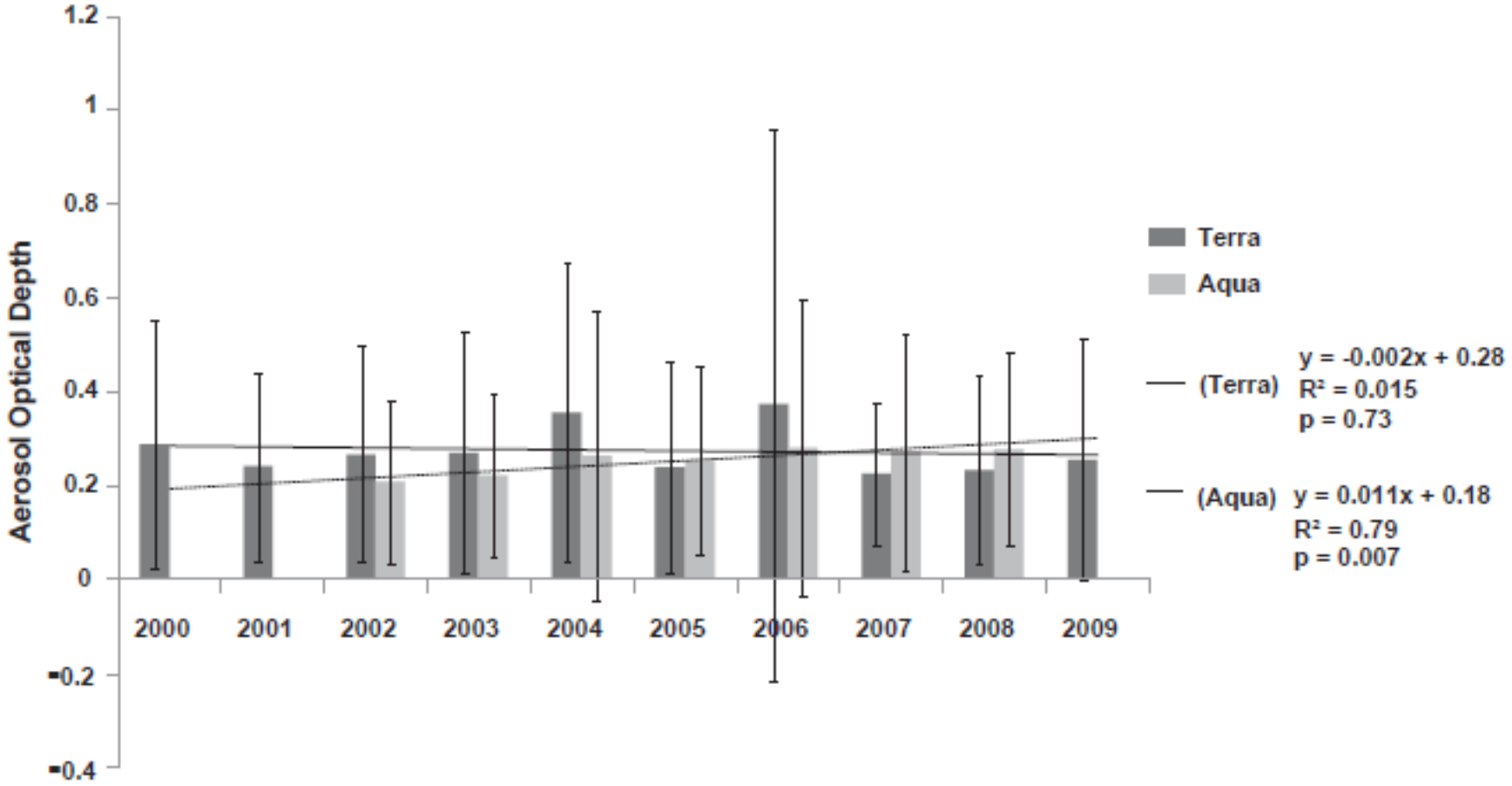


Inter-monsoon (Apr-May)

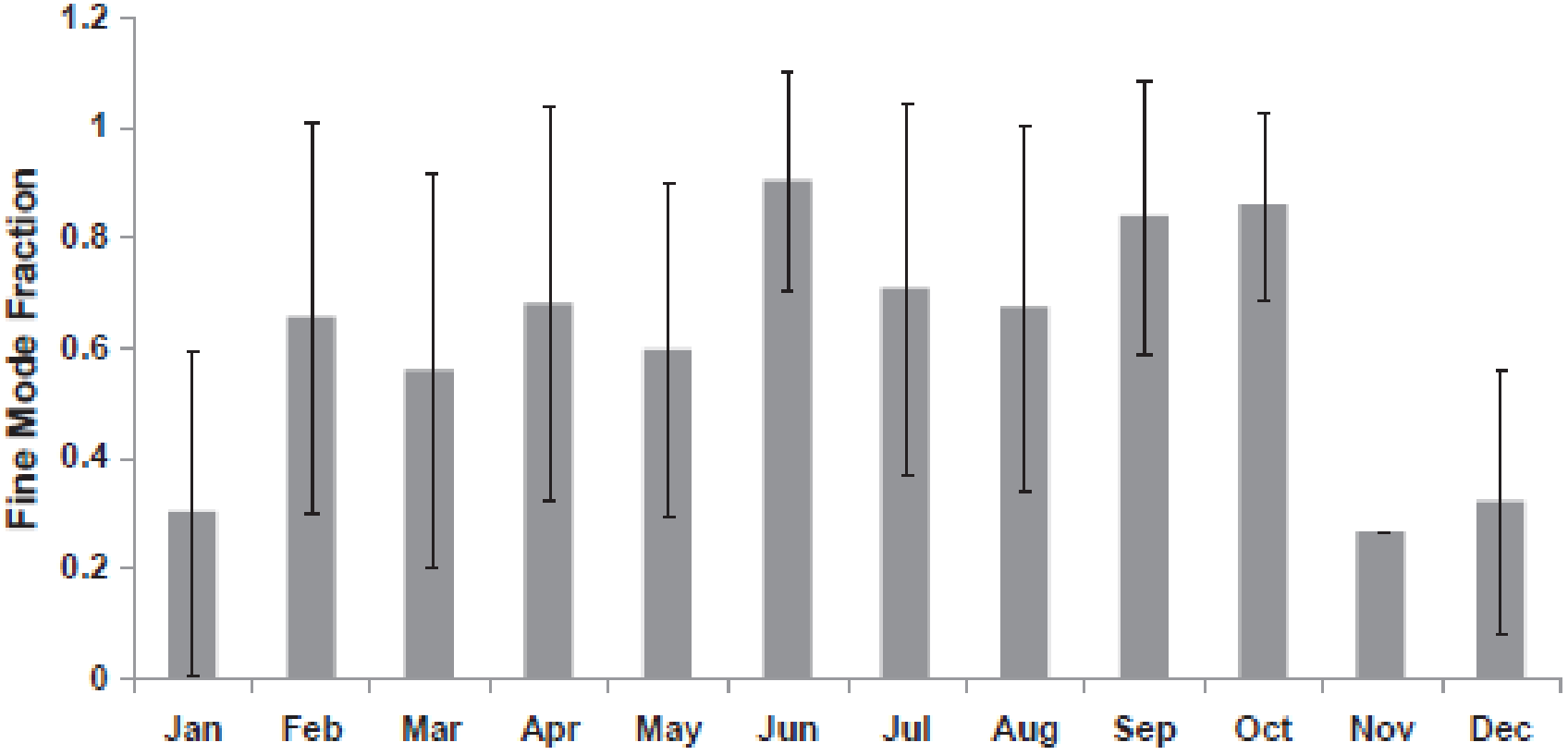


Inter-monsoon (Oct)

Temporal Pattern AOD

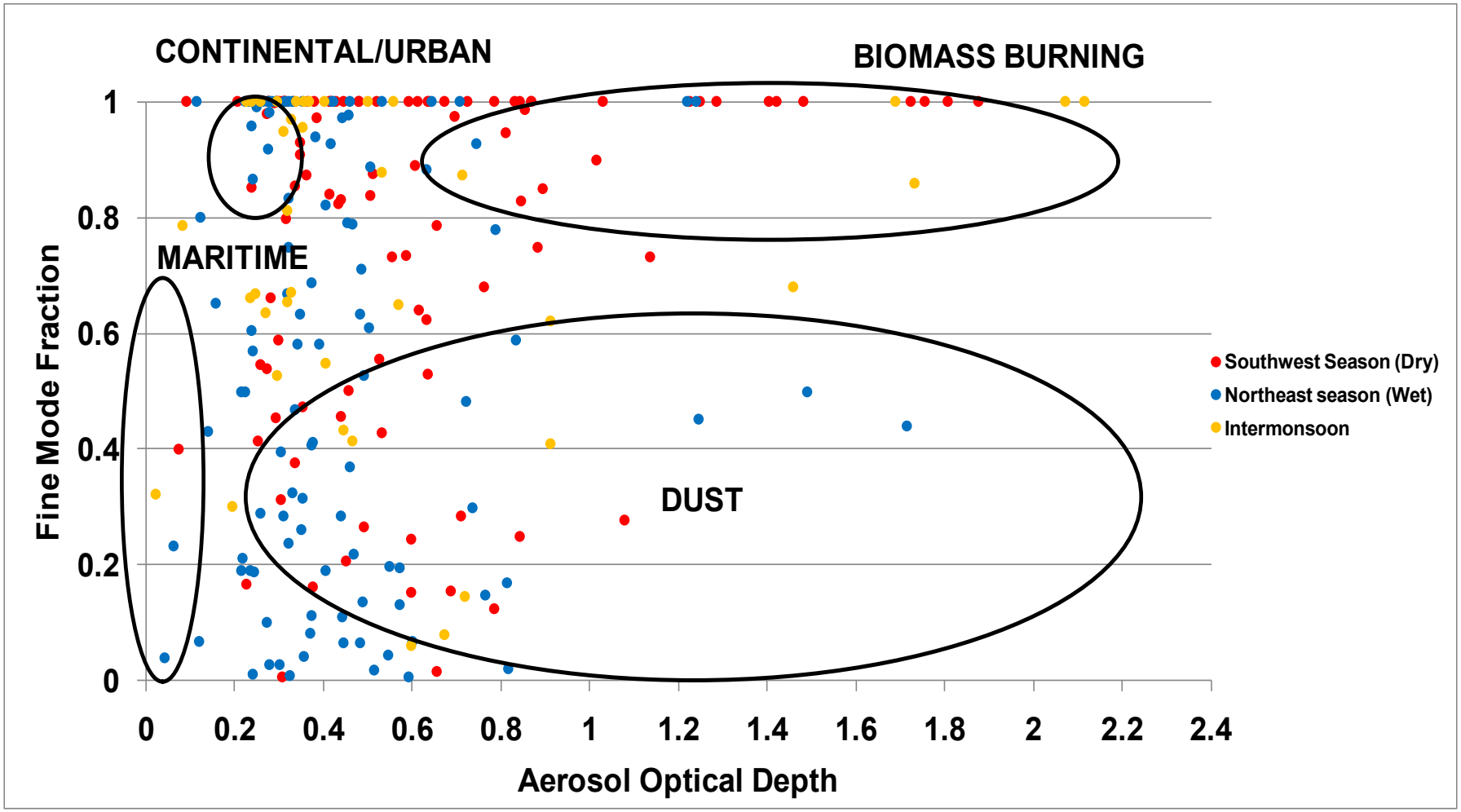


Aerosol Size

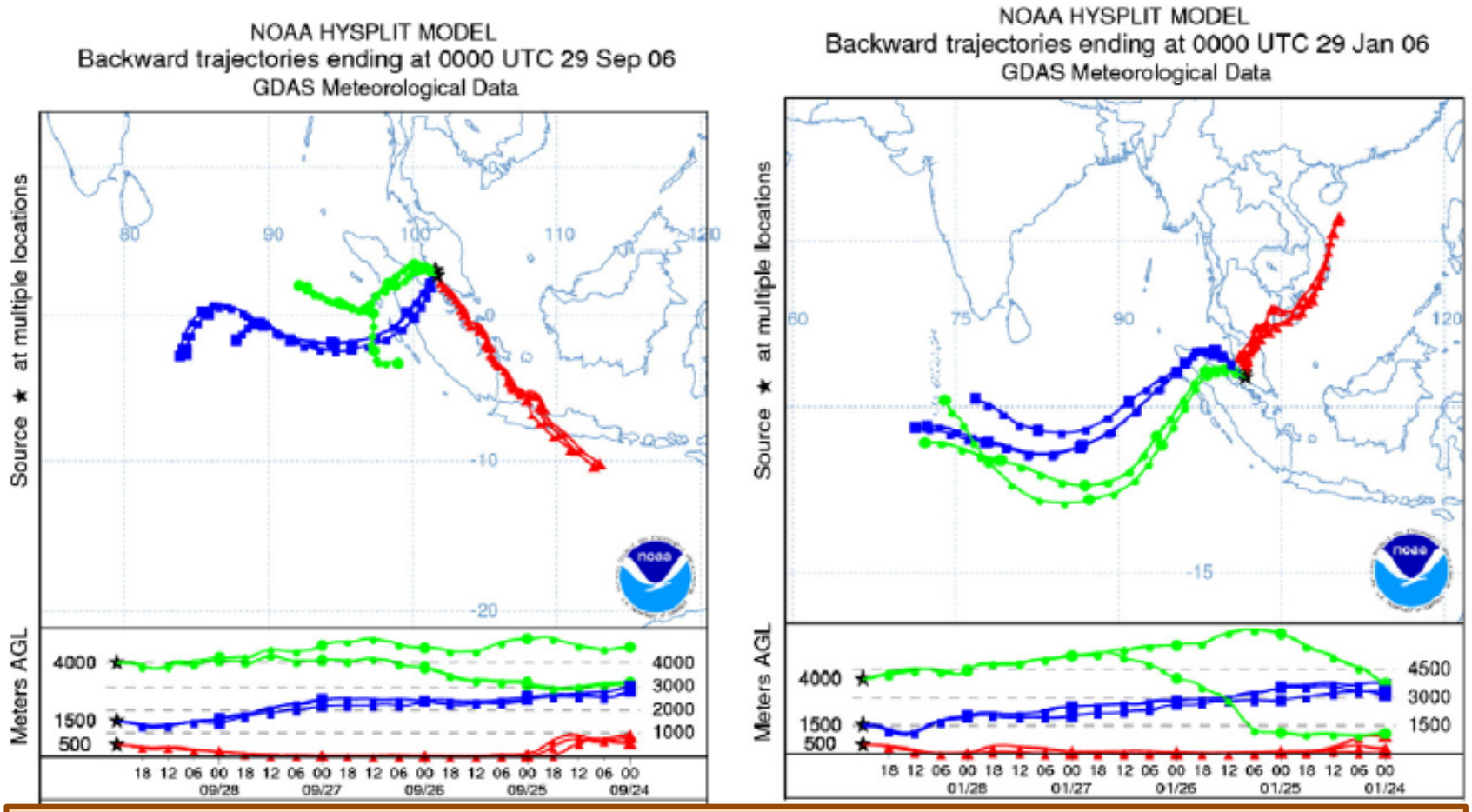


Monthly-mean (±1 standard deviation) variation of the Terra MODIS FMF values averaged over 10 selected sites in Peninsular Malaysia

Aerosol Types

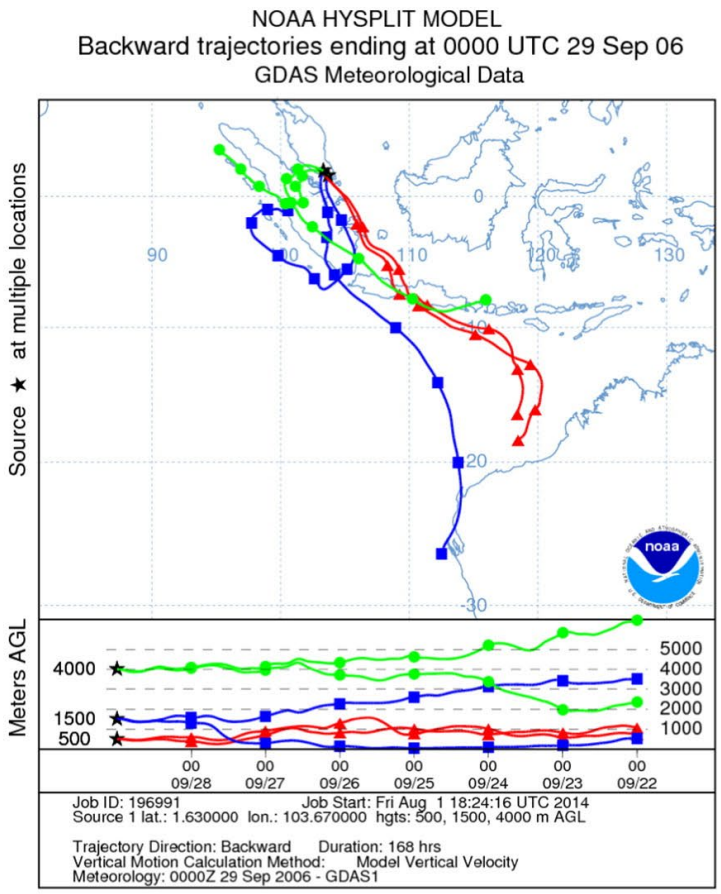


Source Regions of Aerosols

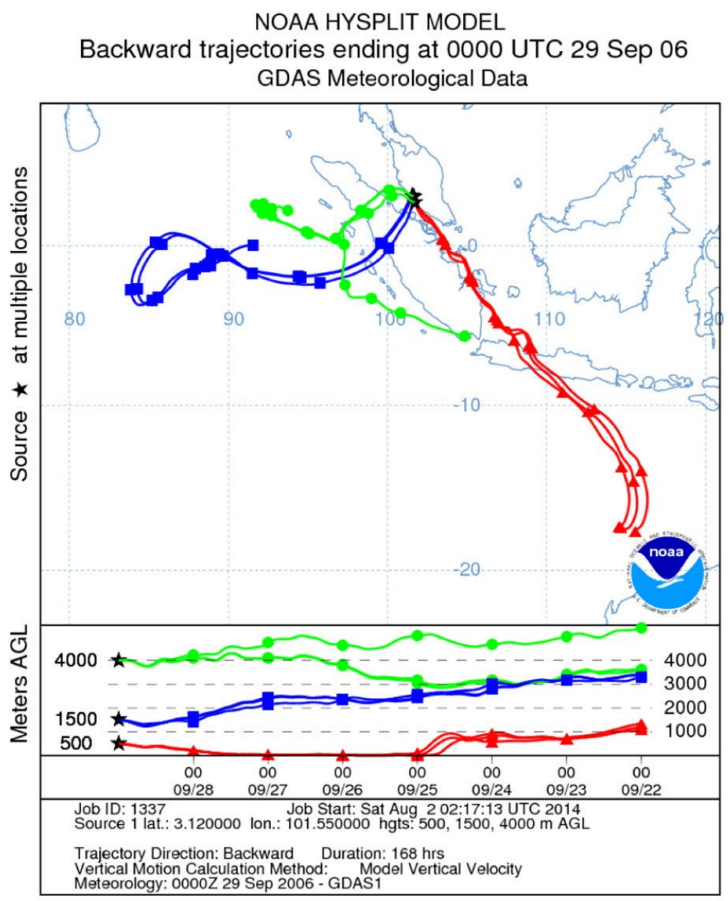


5-day backward trajectories ending at the western Malaysian sites for the dry (left) and wet (right) seasons

Source Regions of Aerosols



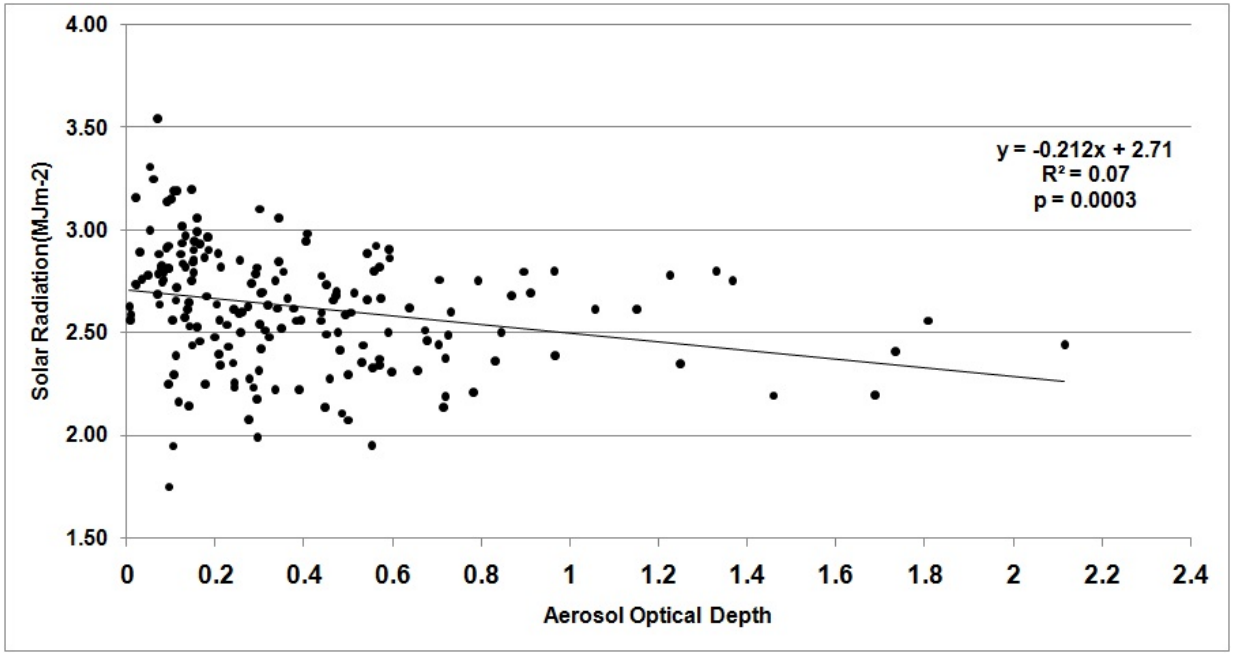
(a)



(b)

7 days trajectory- at lower altitudes- Java sea and northwest Australia

AOD Versus Solar Radiation



- Enhanced aerosol loading attenuates (scatters and absorbs) solar radiation decreasing the amount reaching the Earth surface
- The decrease in global solar radiation (~0.21 or 0.8% for a 0.1 increase in AOD
- Biomass burning and local emissions of fossil-fuel black carbon

Particulate Matter Mapping

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Estimating Particulate Matter using satellite based aerosol optical depth and meteorological variables in Malaysia

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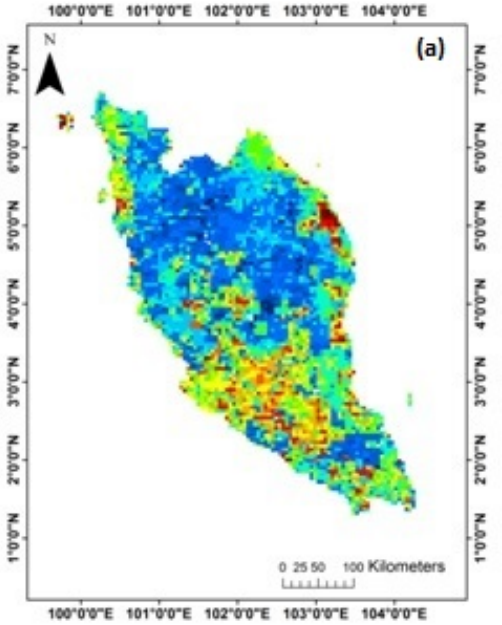
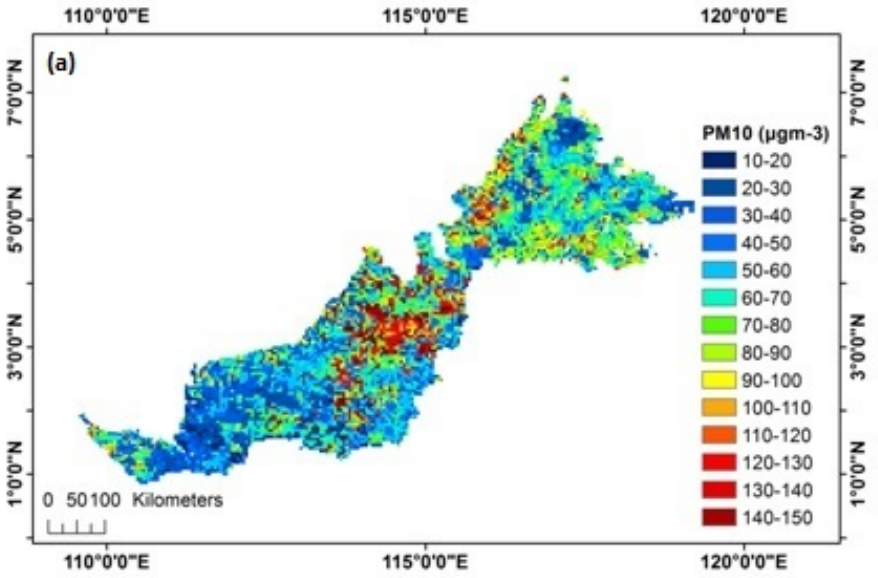
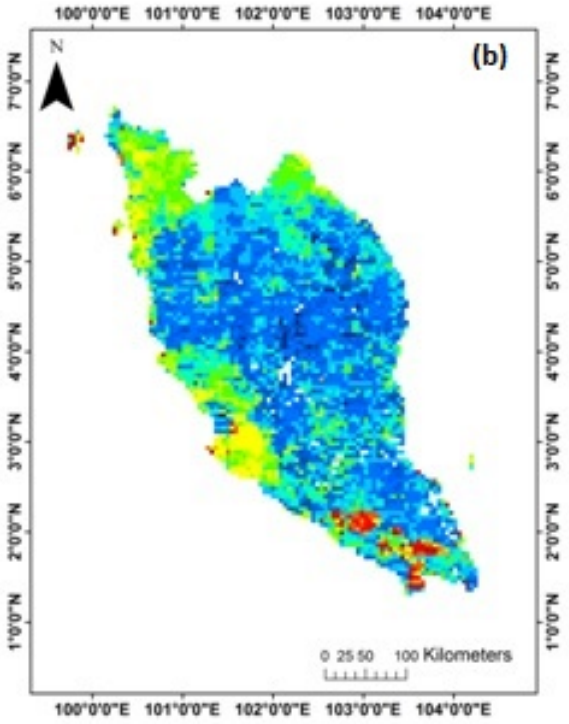
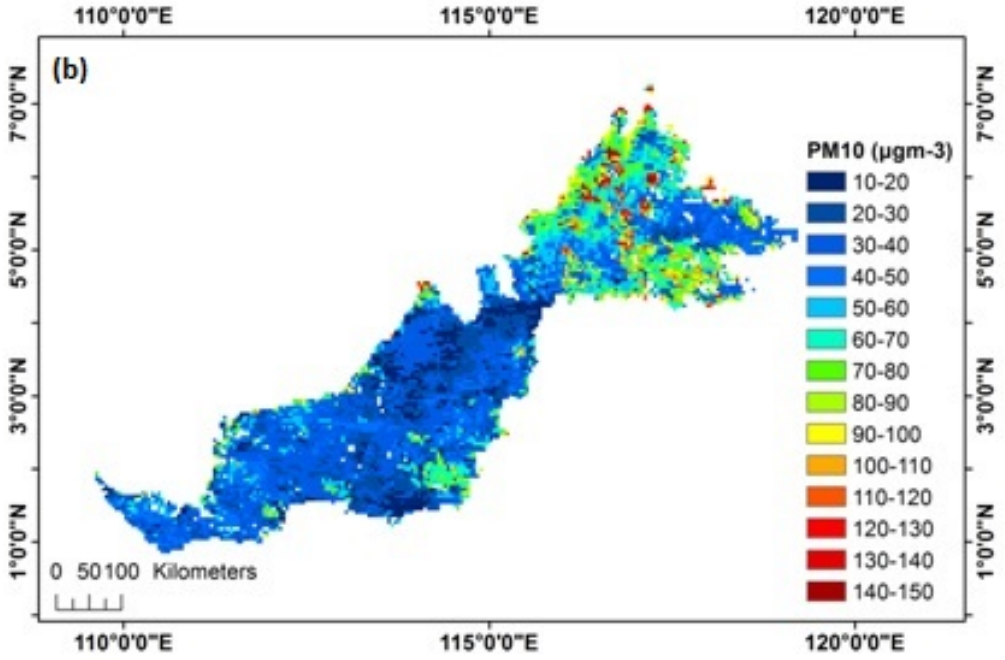




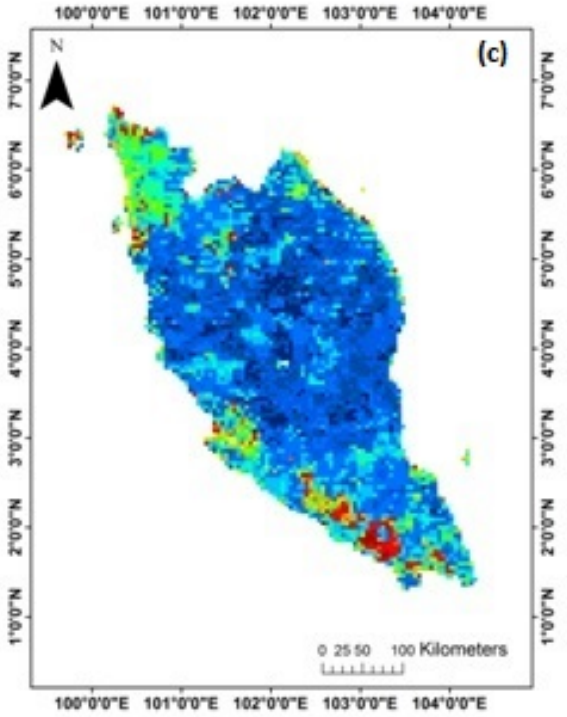
PM 10 (μgm^{-3}) Dry Season (June-Sept 2007-2011)

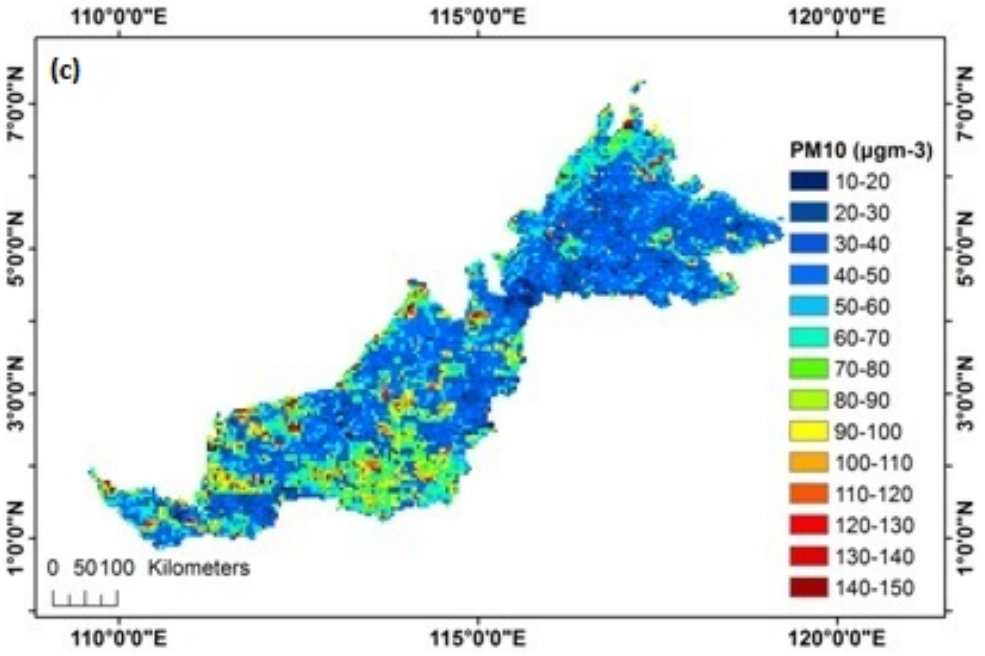
PM 10 (μgm^{-3})Wet Season (Dec-May)



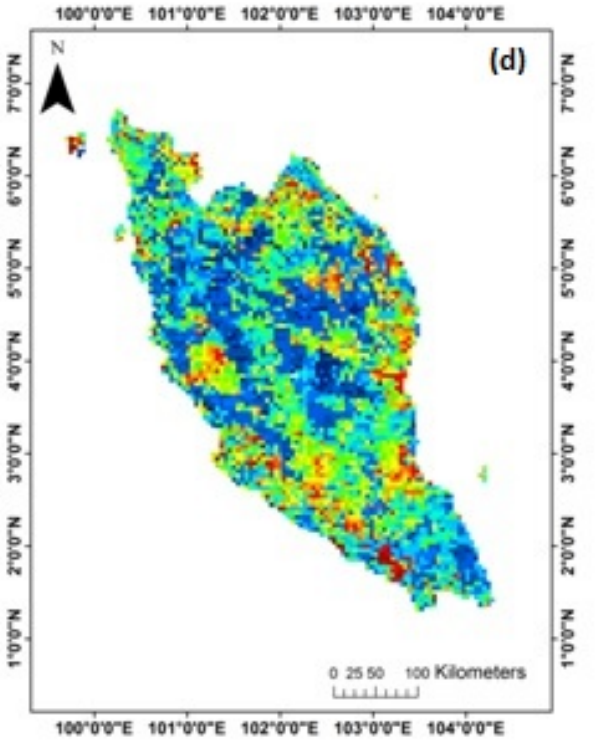


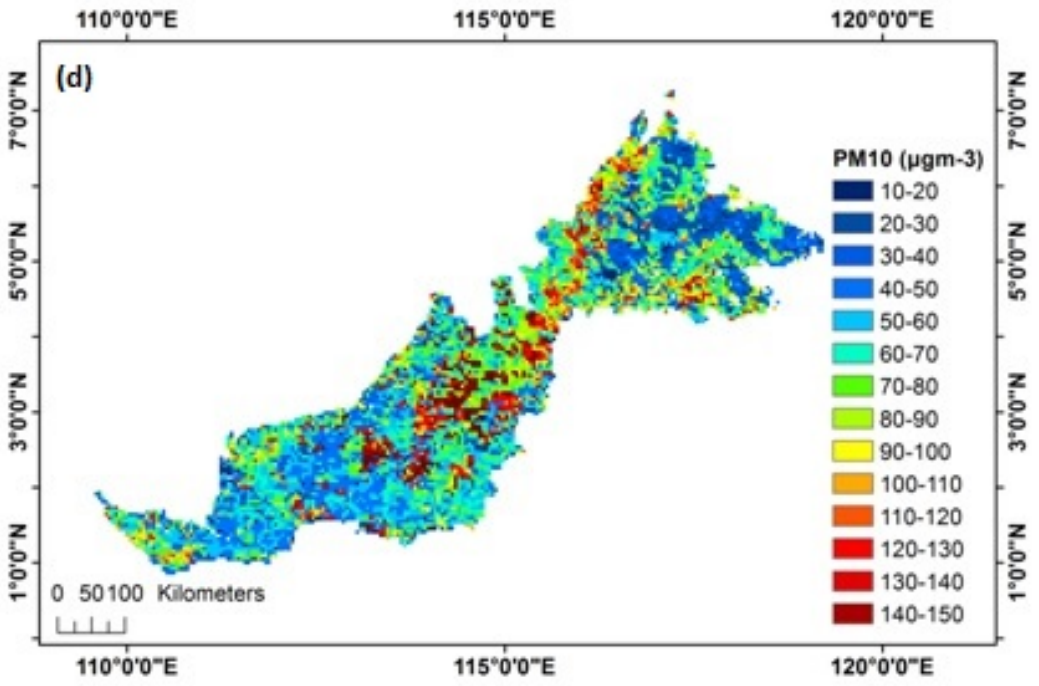
PM10 (μgm^{-3}) Inter-monsoon (Apr-May)





PM 10 (μgm^{-3}) Inter-monsoon (Oct)





Knowledge Gaps (the Unknown)

- Spatial patterns of aerosols
  - Aerosols loading and composition over East Malaysia and urban areas are not so well documented
  - Coarse spatial resolution aerosol data for urban areas- MERIS, MODIS (3 km-high bias at AOD >0.1)
- Aerosol Size
  - Previous study showed most data points were identified as mixed type
  - Up to 40% of aerosols are dust (MODIS-FMF)- FMF <0.6 and AOD >0.3- may have marine influence during NE monsoon
  - They may mix with continental/urban/biomass burning aerosols-form turbid atmosphere after coagulation and humidification.
  - Need to examine the influence of dust in air pollution

Knowledge Gaps (the Unknown)

- Aerosol climate implication
  - Aerosol radiative forcing due to biomass burning aerosols
  - Need more data on dominant aerosol types and their composition in different seasons and locations
  - More AERONET stations may provide data
- PM monitoring
  - Limited observations on fine mode PM
  - PM2.5 and PM 1.0 in Penang island-large contribution of fine PM during turbid days
  - Limited fine PM data prevents from studying health impact of PM

Challenges

CHALLENGES

- PM2.5 and PM10 monitoring stations – DOE (65 stations) and METMalaysia (23 stations)
- AERONET- 2 stations (Kuching, Penang, Tahir)
- Satellite observation having limitations as cloud cover and orbital gaps of satellite track
- Limited data on fine particle concentrations such as $PM_{2.5}$ limits studies on the impact of fine particles to human health and physical environment particularly during haze episodes.

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Invited review article

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UTM
UNIVERSITI TEKNOLOGI MALAYSIA

THANK YOU