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FINAL REPORT

Particulate matter source apportionment in Malaysia using source tagging modeling approach to quantify transboundary air pollution: a comparative analysis between haze and non-haze periods

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1. Summary

Transboundary air pollution is a major environmental issue in Southeast Asia, particularly during severe haze episodes caused by biomass burning. These episodes lead to dangerously high concentrations of particulate matter (PM), significantly impacting air quality, public health, and regional climate. Primary sources include peatland fires, agricultural burning, and industrial emissions and transportation emissions. While haze events are the most visible consequence, air quality degradation persists year-round. The cross-border transport of pollutants complicates management efforts, necessitating an analysis of both haze and non-haze conditions for a comprehensive understanding. This study focused on Malaysia, which is heavily affected by its proximity to major emission sources. It examined how pollutants travel into the country and assessed the contributions of local and external sources to overall air quality. The research considered various meteorological factors, including wind patterns, atmospheric stability, and climatic variations such as El Niño, along with the influence of regional topography and land-use changes. To quantify transboundary pollution and differentiate emission sources, the study employed advanced atmospheric modeling. The Weather Research and Forecasting (WRF) model simulated meteorological conditions, while the Comprehensive Air Quality Model with Extensions (CAMx) and Particulate Matter Source Apportionment Technology (PSAT) tracked pollutant movement and contributions. These models provided high-resolution insights into seasonal and meteorological variations in pollution transport. The findings underscore the need for regional collaboration, continuous monitoring, and policy-driven mitigation strategies to effectively manage transboundary air pollution.

2. Objectives

1. Quantifying Source Contributions

To apply a source tagging modelling approach in Malaysia to determine the relative contributions of local emissions and transboundary pollution to ambient particulate matter concentrations. This was achieved through:

- Implementing the WRF-CAMx/PSAT model to analyse pollution sources during haze and non-haze periods.
- Assessing the impact of meteorological factors (e.g., wind patterns, El Niño events) on pollutant dispersion.
- Differentiating between natural and anthropogenic sources of particulate matter.
- Evaluating seasonal variations in air pollution levels to understand long-term trends.

2. Policy Engagement and Knowledge Transfer

To communicate the modelled results and recommendations to governmental bodies involved in air quality and environmental policy decisions. This objective included:

- Presenting scientific findings to policymakers in a structured and accessible manner.
- Facilitating stakeholder discussions to promote evidence-based decision-making.
- Providing recommendations for air quality management strategies tailored to both haze and non-haze periods.
- Strengthening regional collaboration by sharing insights with neighbouring countries facing similar challenges.

3. Outputs, Outcomes and Impacts

Outputs	Outcomes	Impacts
Quantified share of emission sources for haze and non-haze periods (PM_{10} and $PM_{2.5}$).	Improved understanding of pollution sources for policymakers and researchers.	Better air quality management through informed policymaking.
Classification of emission sources into local and transboundary contributors.	Enhanced stakeholder engagement, allowing policymakers to interact with scientists and express their data needs.	Strengthened regional cooperation in transboundary air pollution control.
Identification of limitations and local factors unique to Malaysia that affect replication in other countries.	Formulation of targeted recommendations for haze and non-haze periods.	Reduction in air pollution-related health risks and environmental damage.
Scientific conclusions and recommendations for source-based emission control.	Recognition of the challenges in implementing air pollution reduction measures from a policy perspective.	Increased adoption of science-based regulations for air quality improvement.

4. Key facts/figures

- Transboundary air pollution is a major issue in Southeast Asia, especially during severe haze episodes.
- Air pollution is also significant during non-haze periods.
- WRF-CAMx/PSAT modelling was used to quantify pollution sources.
- PM_{10} and $PM_{2.5}$ concentrations were analysed to assess local and transboundary emissions.
- Meteorological factors like wind direction, temperature, and El Niño influence air pollution levels.
- The study provides scientific evidence for air quality management and emission control strategies.

5. Publications

No publication is currently available from this project. However, one manuscript in pre-print mode is available and ready for submission to journal; please see Appendix 2. The second manuscript is currently in progress and will be submitted as a contribution to the APN Science Bulletin by the end of April 2025.

6. Media reports, videos and other digital content

The webinar was featured on the USM School of Industrial Technology YouTube channel under the title:
"Seminar on Potential Sources of Particulate Matter Using Source Tagging Modelling"
Watch here: https://www.youtube.com/watch?v=t1r_sZf4xeY

7. Pull quotes

"Application of the research results in shaping DOE's industrial standards and guidelines."
Ms. Ngis Hisao Fei, Consultant, Chemisans Konsultant Sdn Bhd, Malaysia

"Thank you for your knowledge sharing. It's very good information about the air pollution model for me.."
Dr. Ana Turyanti, Lecturer, IPB University, Indonesia

"The area of the study may be widened e.g at global or continental level."
Ms Maria Razi, Max Planck Institute for Chemistry, Mainz, Germany

"*Prospect of seminar to be widen to continent level by adding transboundary pollution aspect. That to be interesting for more wider research community and giving such efforts more visibility. Regards*"
Mr Noor Ahmad, University of Lahore, Lahore Pakistan

8. Acknowledgements

We would like to express our sincere gratitude to the Asia-Pacific Network for Global Change Research (APN-GCR) for funding this project, Project Reference Number: CRECS2020-05SY-Amil. Despite the multiple extensions required due to COVID-19 and other unforeseen challenges, APN's continued trust, patience, and support have been both reassuring and deeply appreciated.

We are also deeply thankful to our institutional collaborators — Universiti Sains Malaysia (USM), Universiti Kebangsaan Malaysia (UKM), Institut Teknologi Nasional (ITENAS), Indonesia,

Department of Environment (DOE) Malaysia, Malaysian Meteorological Department (Met Malaysia), and Badan Meteorologi, Klimatologi, dan Geofisika (BMKG), Indonesia — for their unwavering support, contributions, and engagement throughout the project. We also extend our heartfelt appreciation to the dedication and technical support of the webinar secretariat team and all part-time research assistants involved in ensuring the project's success. Finally, we sincerely thank the many researchers, government officials, and representatives from non-governmental organisations who contributed directly and indirectly.

9. Appendices

Appendix 1: Free Webinar | International Seminar on Potential Sources of Particulate Matter Using Source Tagging Modelling, August 24, 2021: 08:30 – 13:00

The Seminar on Potential Sources of Particulate Matter Using Source Tagging Modelling was held on August 24, 2021, from 8:30 AM to 1:00 PM (Kuala Lumpur UTC +8). This free seminar brought together researchers, students, and professionals in the environmental science field to discuss key issues related to air pollution, particularly particulate matter (PM). Hosted by the the PI of this project, Dr. Norhaniza Amil, the event featured distinguished speakers and trainers from Malaysia and Indonesia, including experts from the project member institution such as UKM Malaysia, MET Malaysia, the National Nuclear Energy Agency of Indonesia, and ITENAS Bandung Indonesia. Hosted in collaboration with institutions such as Universiti Sains Malaysia (USM), Universiti Kebangsaan Malaysia (UKM), and ITENAS, the seminar focused on biomass burning episodes, PM interactions with meteorological conditions, particulate matter source identification, and air quality modeling applications. Four undergraduate students acted as secretariats for the workshop: from both USM Malaysia and ITENAS Indoneisa were; Mr. Soni Pratama (ITENAS, Indonesia), Mr. Tan Jing Kai, (USM, Malaysia), Ms. Arisya Ramlan (USM, Malaysia), and Ms. Yip Kah Ying (USM, Malaysia), played a significant role in making the event a success.

In addition to expert talks, the seminar included two training modules on air quality modeling for particulate matter source apportionment and WRF-CAMx visualization, providing participants with hands-on experience. Attendees had the opportunity to join the seminar live via Webex and YouTube, ensuring accessibility to a wider audience. With 231 participants registered from 16 countries all around the globe, with various backgrounds of 52 different institution/company i.e. researchers, students, government officers, industrial engineers, and so many more, we believed that the webinar has met the target audience thus fulfilled its objective. Providing additional incentives such as CPD points, e-certificates, and e-modules, the seminar served as an important platform for knowledge sharing and capacity building in air quality research and modeling. The objectives of the webinar were to provide a platform for mid-career and early-career scientists to engage in transboundary research and to equip participants with knowledge on using WRF-CAMx/PSAT for regional research. The event began with the welcoming and opening ceremony at 8:45 a.m., officiated by Professor Ts. Dr. Norli Ismail, Dean of the School of Industrial Technology, USM Malaysia.

Talk 1

The presentation by Prof. Dr. Talib begins with an introduction, setting the stage for the discussion on haze episodes. It then explores the causes of haze episodes, identifying key contributing factors such as biomass burning, industrial emissions, and meteorological influences. A section on the history of haze episodes in Malaysia provides an overview of significant past events, their impacts, and responses. The presentation then delves into the role of the El Niño-Southern Oscillation (ENSO) in exacerbating haze conditions, explaining its climatic influence on regional air quality. Following this, the focus shifts to data from continuous monitoring and field sampling, highlighting measurement techniques and key findings. The analysis extends to the composition of fine and nanoparticles, discussing their sources, chemical characteristics, and health implications. Prof. Dr. Talib concluded by emphasizing that this knowledge is essential for developing effective mitigation strategies and promoting better air quality management.

Talk 2

Dr. Hanashriah Hassan's presentation explores the interaction between PM_{10} concentration and meteorological conditions at different temporal scales. It begins with an overview of atmospheric monitoring by MET Malaysia, detailing monitoring stations, measurement instruments, and the sampling site. The analysis of annual PM_{10} variations from 1996 to 2016 highlights major haze episodes, particularly those linked to strong El Niño events. Using wavelet analysis, the study identifies periodic variations in PM_{10} concentrations across different time scales, including annual, seasonal, and intra-seasonal cycles. The presentation further examines local-scale interactions between PM10 levels and meteorological parameters such as temperature, precipitation, wind speed, and relative humidity through correlation analysis and polar plots. Overall, the presentation highlighted the complex interactions between PM_{10} concentrations and meteorological conditions across different temporal scales. These findings emphasize the need for continuous monitoring and climate-aware air quality management strategies.

Talk 3

Prof. Muhayatun's presentation explores air pollution, focusing on particulate matter (PM) and its sources using advanced analytical techniques. It begins with an introduction to air quality issues, highlighting the significance of studying PM due to its impact on health and the environment. The presentation explains the characteristics of PM, including its different types (PM_{10}, $PM_{2.5}$) and chemical composition. Various source apportionment techniques, such as Positive Matrix Factorization (PMF) and Chemical Mass Balance (CMB), are discussed to identify pollution sources. Case studies illustrate how these methods have been applied in different regions to determine the origins of PM pollution. Furthermore, the presentation outlined various sampling techniques and analytical methods used in Indonesia, demonstrating their implementation in real-world scenarios.

Overall, Prof. Dr. Muhayatun Santoso's presentation provided valuable insights into the analysis of particulate matter for source identification, emphasizing its significance in air pollution studies. The discussion highlighted the adverse effects of air pollution and the importance of understanding particulate matter composition to assess its impact on health and the environment. The talk also explained the role of fine particulate matter analysis in identifying pollution sources and guiding air quality management strategies.

Training Module 1

Dr. Didin Agustian's presentation provides an in-depth look at air pollution, its sources, and its impact on the environment and human health. It begins with an introduction to air quality issues, highlighting key pollutants and their effects. The discussion then explores various sources of air pollution, including industrial emissions, transportation, and natural contributors. The presentation also covers monitoring and measurement techniques, explaining the use of both ground-based sensors and satellite observations for air quality assessment. Additionally, the talk introduced the PSAT (Particulate Source Apportionment Technology) probing tools, highlighting their role in identifying pollution sources and assessing their contributions. Case studies are presented to illustrate practical applications of air quality monitoring in environmental management, demonstrating how scientific data can support policy and mitigation efforts. In conclusion, the presentation provided a comprehensive understanding of air quality modeling, focusing on the modeling chain and its key components. It explained the methodology used in air quality modeling studies, detailing how different factors influence pollutant dispersion and concentration.

Training Module 2

The presentation "Visualizing WRF and WRF-CAMx Output" by Assoc. Prof. Dr. Yusri Yusup introduces VERDI, a Java-based visualization tool sponsored by the US EPA, designed for analyzing meteorological and air quality modeling data. It begins with an overview of various visualization software, comparing CLI-based tools (such as NCL, R, Python, and MATLAB) with GUI-based options like Panoply and VERDI. The presentation then provides a step-by-step guide on installing VERDI on Windows and macOS, including account creation on the CMAS Center website and configuring security settings.

Overall, the presentation provided a comprehensive guide to using VERDI for visualizing WRF and WRF-CAMx output, highlighting its capabilities in processing meteorological and air quality modeling data. It covered the installation process, key functionalities, and different visualization options available within VERDI. Participants were guided through practical steps to generate various plot types, configure visualization settings, and save projects for future use. The session ended with a discussion, addressing questions and clarifying aspects of using VERDI effectively.

By the end of the seminar, attendees developed a deeper understanding of air pollution and its impact, learned to analyze particulate matter composition, and acquired skills in modeling and data visualization. The discussions and Q&A sessions further enhanced knowledge sharing, equipping participants with the tools and methodologies needed for air quality research and policy development.

The feedback from some of the participants of the APN Webinar and Training Seminar, highlighting their experiences and suggestions. Participants from various countries, including Malaysia, Indonesia, the Philippines, Thailand, and Germany, shared their thoughts on the quality of presentations, the relevance of the topics covered, and areas for improvement. Many appreciated the informative sessions, the knowledge shared by speakers, and the discussions on air quality and modeling. However, some of the participants still hope for hands-on training for the WRF-CAMx/PSAT; 84% of the respondent. Please refer to the table below for some of the feedback from the participants. Overall, feedback from participants was great. 100% of respondent would recommend the seminar to others, 70% rate the seminar 5 full rating while the rest rate 4 out of 5, more than 70% find the content was very helpful and the seminar was extremely useful. Overall, the feedback reflects a generally positive reception of the seminar, with useful insights for future improvements.

Written feedback from participants of the webinar.

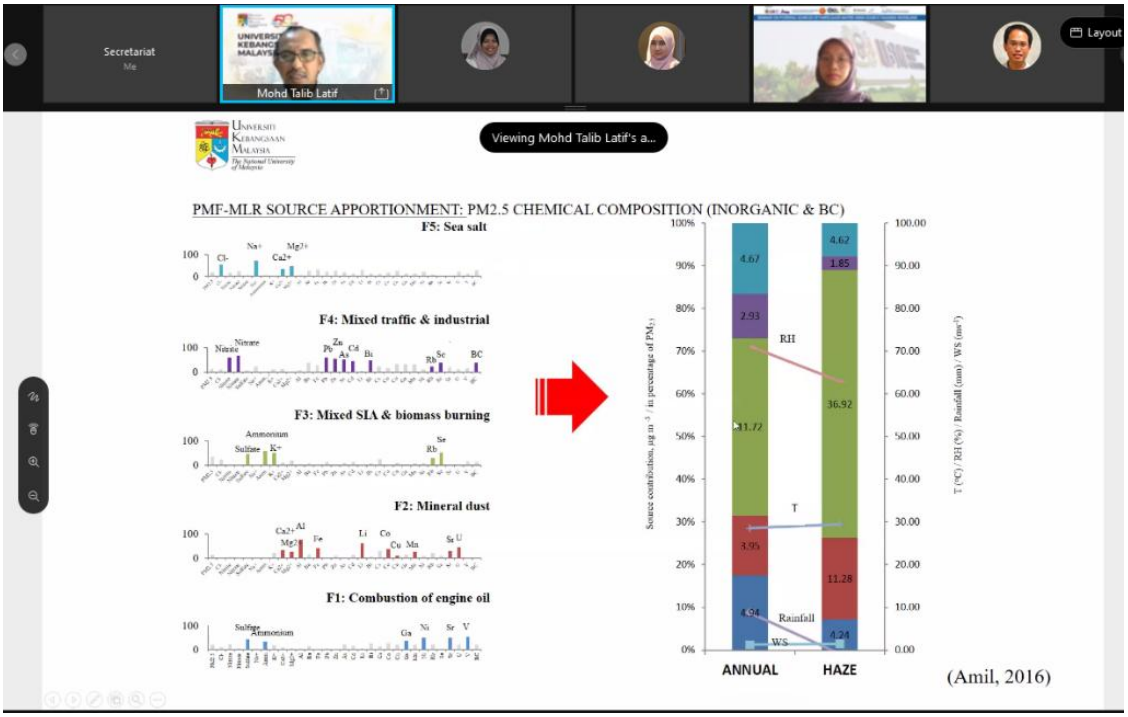
Full Name	Country	Position & Institution / Company	Comment
Dr. Ahmad Mirza bin Mokhtar	Malaysia	Postgraduate student, University of Nottingham Malaysia (UNM)	The WebEx beep alert for participants joining and leaving was very annoying and should be left off. Other than that, thank you so much to the hosts and facilitators for an amazing seminar.
Mr. Mark Angelo N. Sanchez	Philippines	Graduate Student, De La Salle University	None, all is good.
Mrs. Sheila Dewi Ayu Kusumaningtyas	Indonesia	Researcher (> 5 years experience), Met Indonesia	It would be very helpful and powerful to have hands-on training on the use of VEBDI in a separate workshop.
Mrs. Anis Syuhada Binti Omar Madman	Malaysia	Postgraduate student, Universiti Sains Malaysia (USM)	Very informative and thank you! I got new knowledge.
Ms. Nurul Ummi Binti Mohd Nizam	Malaysia	Postgraduate student, Universiti Kebangsaan Malaysia (UKM)	Great job, keep up with the fine seminar that postgraduates can attend too.

Full Name	Country	Position & Institution / Company	Comment
Dr. Muhammad Ikram A. Wahab	Malaysia	Lecturer, Universiti Kebangsaan Malaysia (UKM)	Very good information sharing experience from the speaker. In the future, it would be great to have a workshop like this for beginners. Amazing, good job!
Dr. Tay Joo Hui	Malaysia	Lecturer, Universiti Malaysia Pahang	Very informative seminar, please continue these seminars/workshops. Great job!
Mr. Wisasawa Malakan	Thailand	Postgraduate student, Mahidol University	Adding IRAP in a new course in the seminar.
Ms. Willin Julian Sari	Indonesia	Researcher (> 5 years experience), Indonesia National Institute of Aeronautics and Space	All good so far.
Dr. Nur Lil Hamizah Binti Mustafa	Malaysia	Researcher (> 5 years experience), Universiti Kebangsaan Malaysia (UKM)	Very insightful seminar, I really enjoy it. Thanks for organizing.
Prof. Sarawut Thepanondh	Thailand	Lecturer, Mahidol University	Hands-on training will be much more useful after this seminar. However, it may be separated for each topic to prevent the spending of time for 3 days.
Mr. Floro Junior Roque	Philippines	De La Salle University	Increase the time of breaks between sessions, but generally, the entire seminar was excellent.
Mr. Eka Febriansah	Indonesia	BMKG Pangkajene	Good.
Ms. Sharifah Farhah binti Syed Mahbar	Malaysia	Meteorological Officer, Met Malaysia	It is preferable if the hands-on training is conducted face-to-face. However, it is understood that we have to avoid physical contact due to the pandemic.

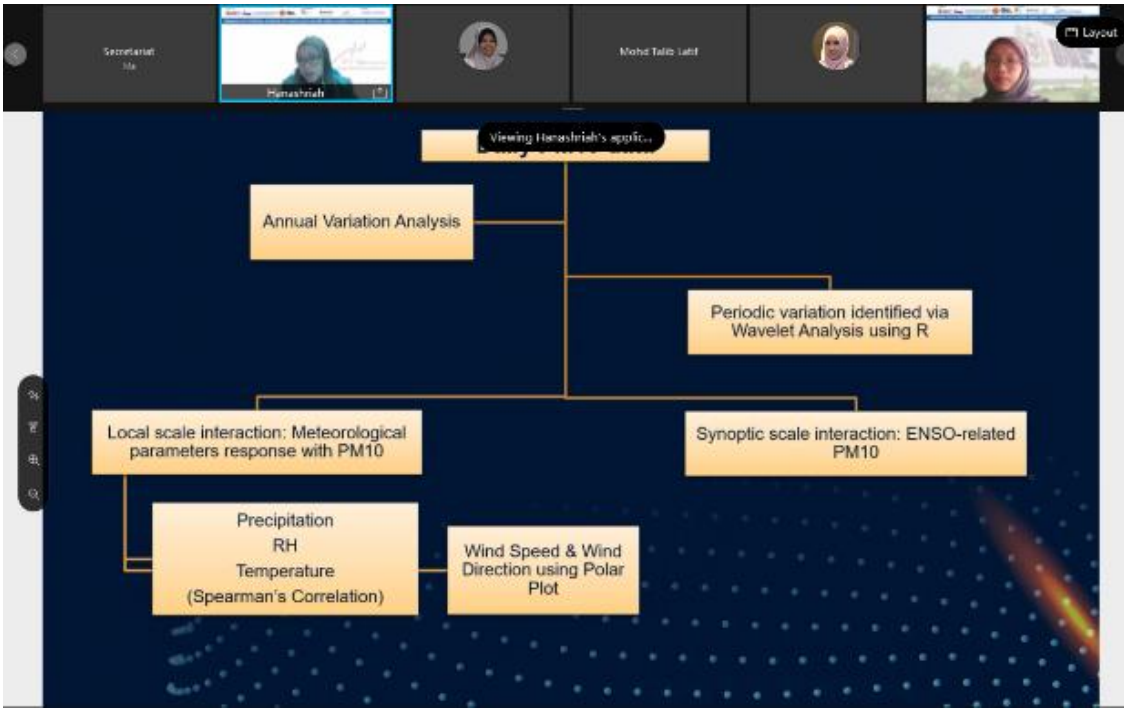
Glimpses from the webinar

Poster prepared for webinar promotion purposes

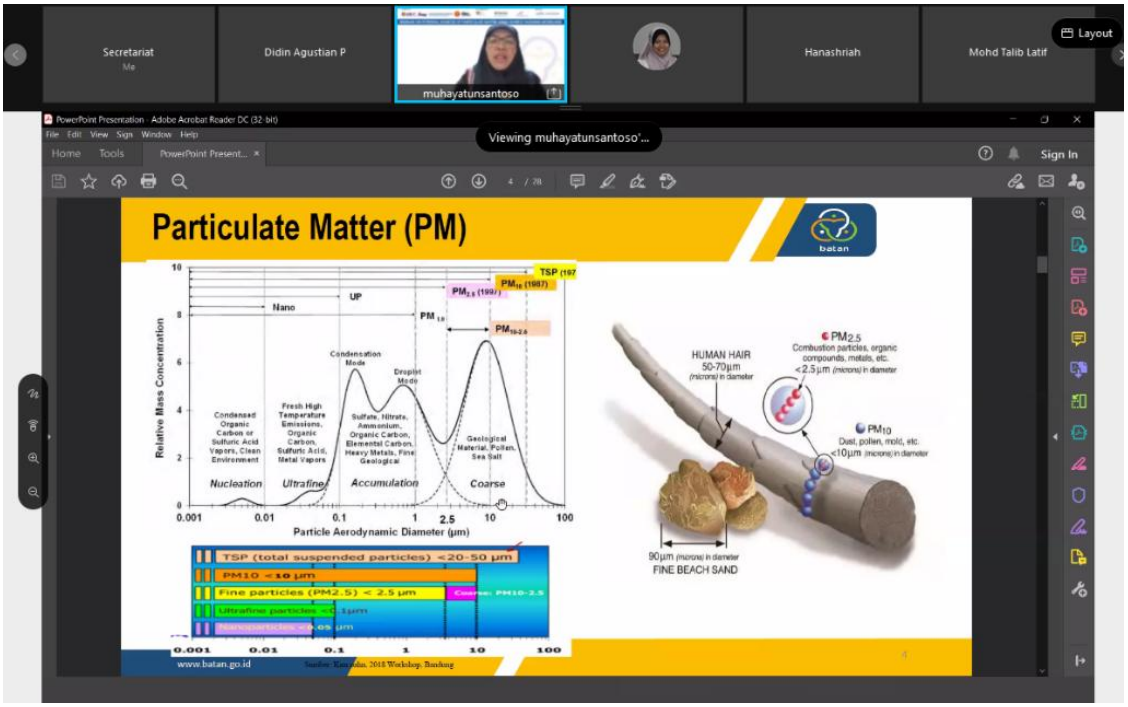
All participants in the webinar: Posing for photo



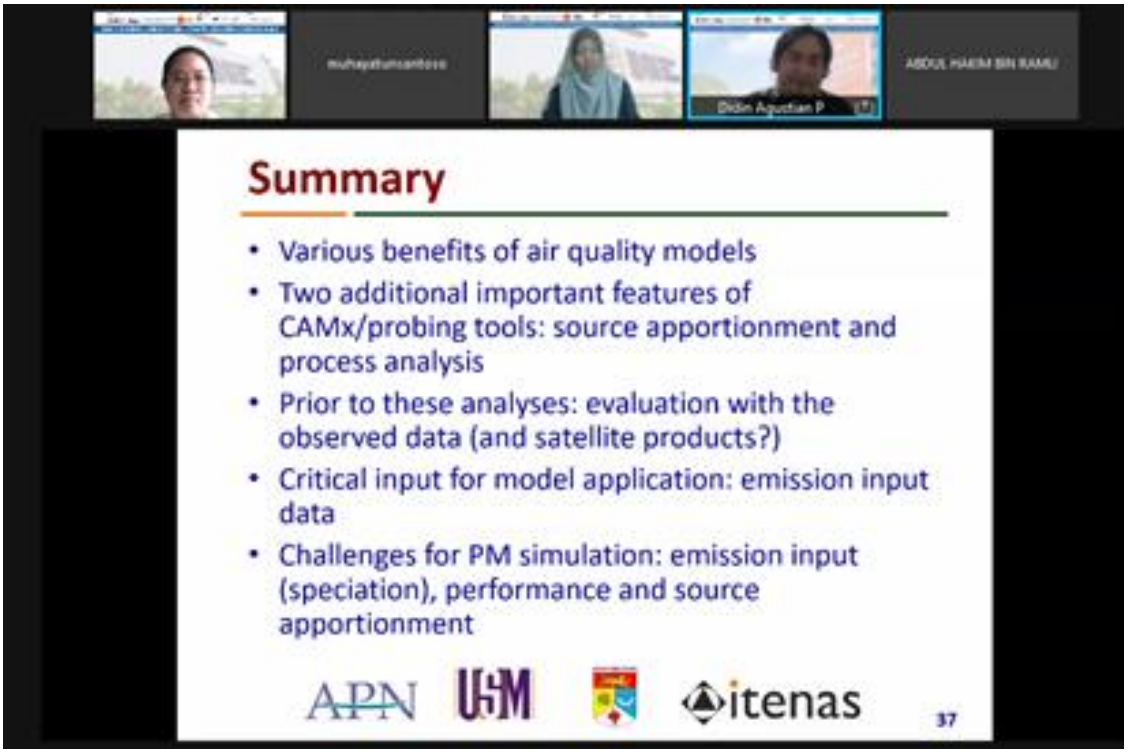
Prof. Dr. Mohd Talib Latif presenting on the air quality during biomass burning episode in Malaysia



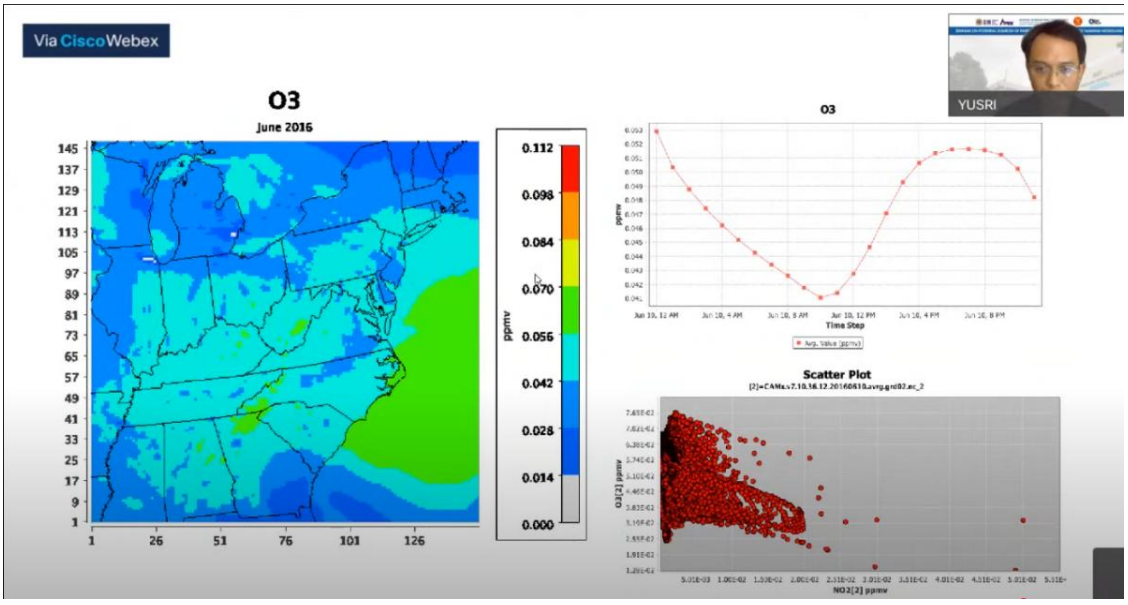
Dr. Hanashriah Hassan presenting on the interaction of PM_{10} concentration with local and synoptic meteorological conditions at different temporal scales



Prof. Dr. Muhayatun Santoso presenting on the analysis of particulate matter samples for source identification



Dr. Didin Agustian Permadi providing training on air quality modelling application for particulate matter source apportionment



Assoc. Prof. Dr. Yusri Yusup providing training on visualizing WRF-CAMx Output

Appendix 2: Journal Article

1. **Extension of the Study: Impact of Meteorological Conditions on $PM_{2.5}$ Concentrations in Malaysia (Submitted to Elsevier, SSRN, Pre-print)**

Abstract

This study examines the impact of meteorological conditions on $PM_{2.5}$ concentrations in Malaysia by utilizing the Weather Research and Forecasting (WRF) model. Given the global concern over particulate matter pollution and the need to understand the relationship between meteorological factors and $PM_{2.5}$ concentrations, particularly in Southeast Asia, it is crucial to investigate these dynamics to mitigate public health risks and improve air quality. The WRF 4.3.3 model was employed and configured with a domain covering the Klang Valley in Peninsular Malaysia from August 2011 to July 2012. The model was validated using error metrics such as MSE, RMSE, MAE, and MAPE, and data from the Department of Environment (DOE) Malaysia, including temperature, humidity, wind speed, and air pollutants. The results indicate that meteorological parameters, such as wind speed, wind direction, precipitation, temperature, and relative humidity, significantly impact $PM_{2.5}$ concentrations, which consist of various individual compounds. For instance, wind speed and direction substantially influence pollutants such as CO, NO_2, and SO_2. Precipitation demonstrates a high positive correlation with NO and NO_2. On the other hand, temperature has a strong negative correlation with NO_x, NO, and NO_2, suggesting its role in reducing the concentrations of these pollutants. Additionally, relative humidity significantly correlates with NO and moderately correlates with NO_2, indicating its relevance in influencing these pollutants. The analysis and testing results indicated that the peak concentrations of pollutants are most likely to occur during the northwest monsoon, which typically takes place from December 2011 to March 2012. The concentrations of pollutants during this period are significantly higher than during the other monsoon periods, suggesting that the atmospheric conditions during the northwest monsoon are more favourable for accumulating these pollutants.

Keywords

$PM_{2.5}$, Chemical composition, Haze events, Meteorological influence

Suggested Citation

Adomako, A. B., Amil, N., Yusup, Y., Latif, M. T., & Permadi, D. A. (2025). Assessing the Influence of Meteorological Conditions on Pm2.5 Concentrations in Malaysia Using the Wrf Model. Available at SSRN: https://ssrn.com/abstract=5109289 or http://dx.doi.org/10.2139/ssrn.5109289

Appendix 3: List of young researchers

Name of Young Scientist	Institute	Country	Contact detail
Mr. Soni Pratama	ITENAS	Indonesia	
Mr. Yugi Agus Rianto	ITENAS	Indonesia	
Mr. Tan Jing Kai	USM	Malaysia	jingkaitan98@gmail.com
Ms. Abigail Birago Adomako	USM	Malaysia	cleo1066613@gmail.com