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A Case Study of the June 2013 Biomass-Burning Haze Event Using WRF-Chem

Yaasiin Oozeer, Andy Chan, Maggie Chel Gee Ooi, Kenobi Isima Morris
Faculty of Engineering, The University of Nottingham (Malaysia Campus)

Jun Wang
Earth and Atmospheric Sciences, University of Nebraska-Lincoln

Santo Salinas
Centre for Remote Imaging, Sensing and Processing (CRISP), National University of Singapore

Introduction

- Biomass burning haze (BBH) – an environmental concern which has attracted much attention during the past decade.
- BBH due to agricultural burning and intentional forest fires to convert forests to agricultural land.
- Alarming detrimental health effects (Dawud 1998; Aditama 2000; Kunii et al. 2002).
- Fire season in Southeast Asia – dry summer monsoon season.

Introduction

- Intense biomass burning occurred over Sumatra in June 2013.
- Satellite imageries from NASA's Terra and Aqua satellites show that large scale forest fires from Sumatra were mainly responsible for the occurrence of haze in the region (NASA 2013).
- Air Pollution Index (API) readings exceeded the hazardous level of 300 on several occasions in Peninsular Malaysia.
- State of emergency declared in Malaysia in June 2013.

Introduction

- Previous studies of the June 2013 event mostly include statistical studies of the impacts of haze on air quality (Betha et al. 2014; Ho et al. 2014; Velasco and Rastan 2015).
- Oozeer et al. (2016) have numerically studied the convective mechanisms that uplifted the haze emissions from Sumatra over to Peninsular Malaysia during the 2013 event.
- Investigate the uniqueness and occurrence of the June 2013 haze event.

Study Area

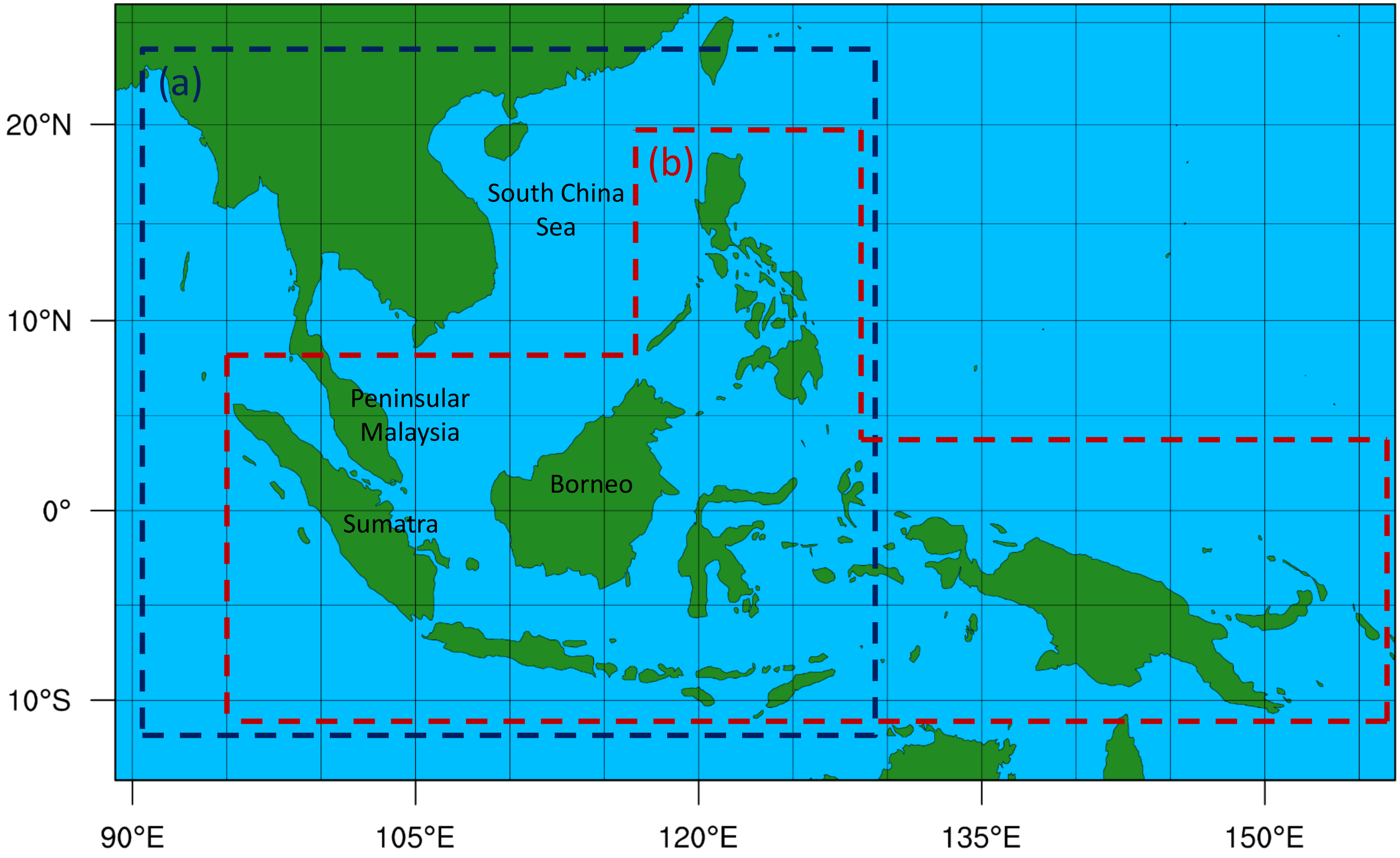

Figure 1. (a) Domain setup (blue) and (b) Maritime Continent (red).

Satellite observations

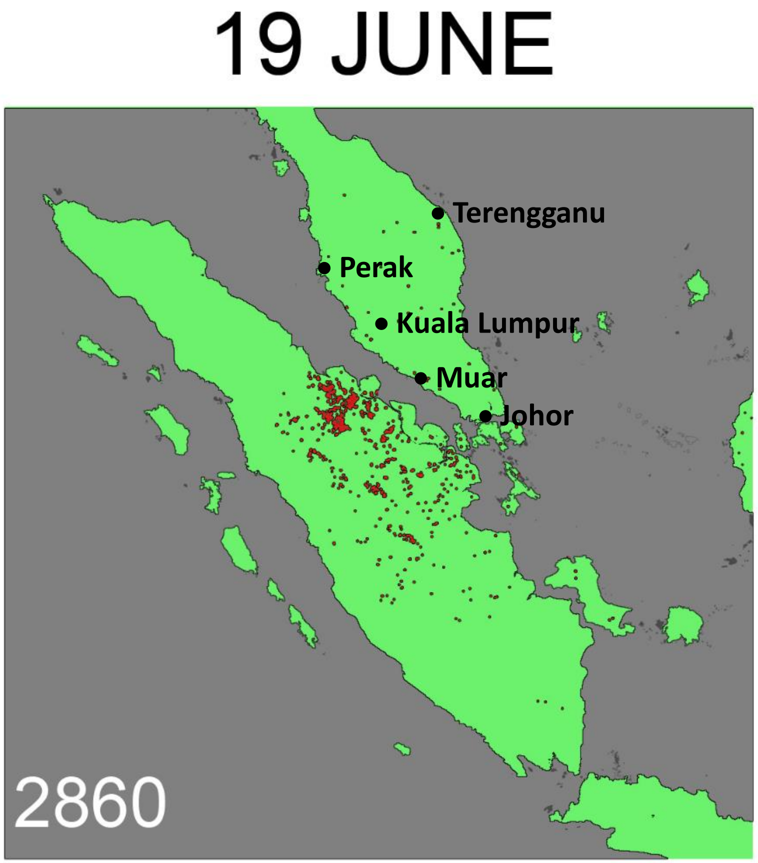

Figure 2. Fire hotspots detected by MODIS on 19th June 2013.

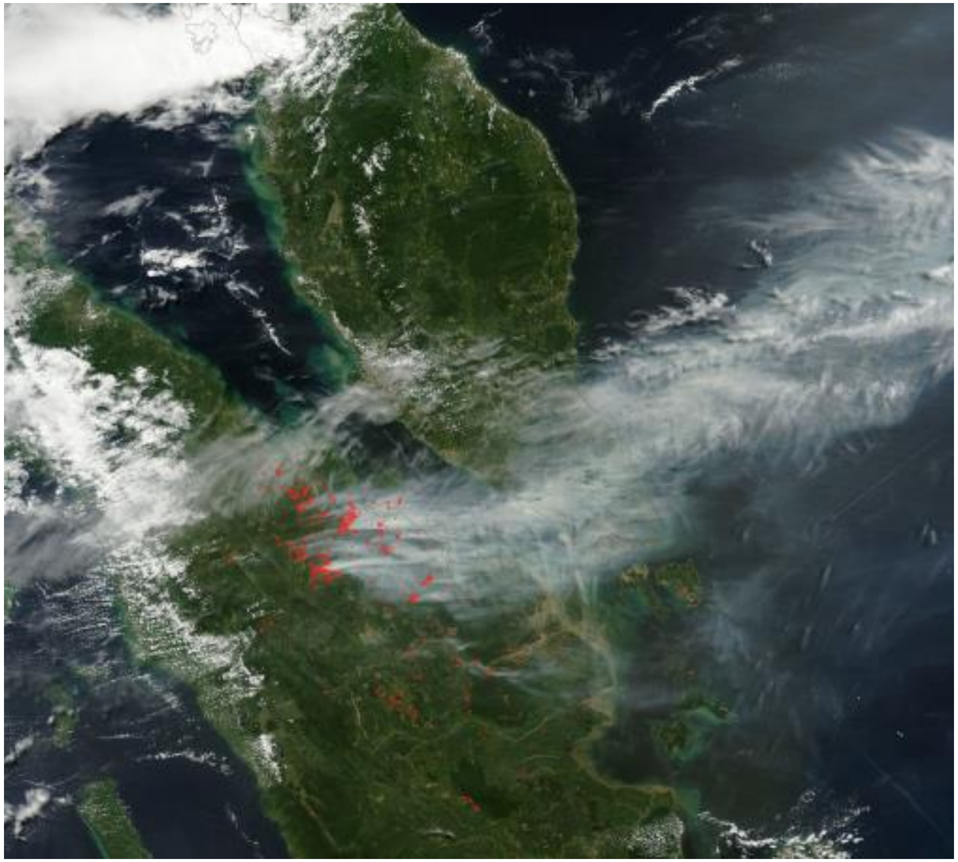

Figure 3. Satellite imagery (NASA Terra) of haze over Sumatra and Peninsular Malaysia on 19th June 2013.

Uniqueness of the June 2013 Haze Event

- Intense haze events during ENSO years.
- El-Nino – dominant factor in total fire activity between 2003 and 2009 (Reid et al. 2012).
- Multivariate ENSO Index (MEI, Wolter and Timlin 1998)
  - Positive MEI – El-Niño conditions
  - Negative MEI – La-Niña conditions

Uniqueness of the June 2013 Haze Event

- MEI values 1980 - 2016

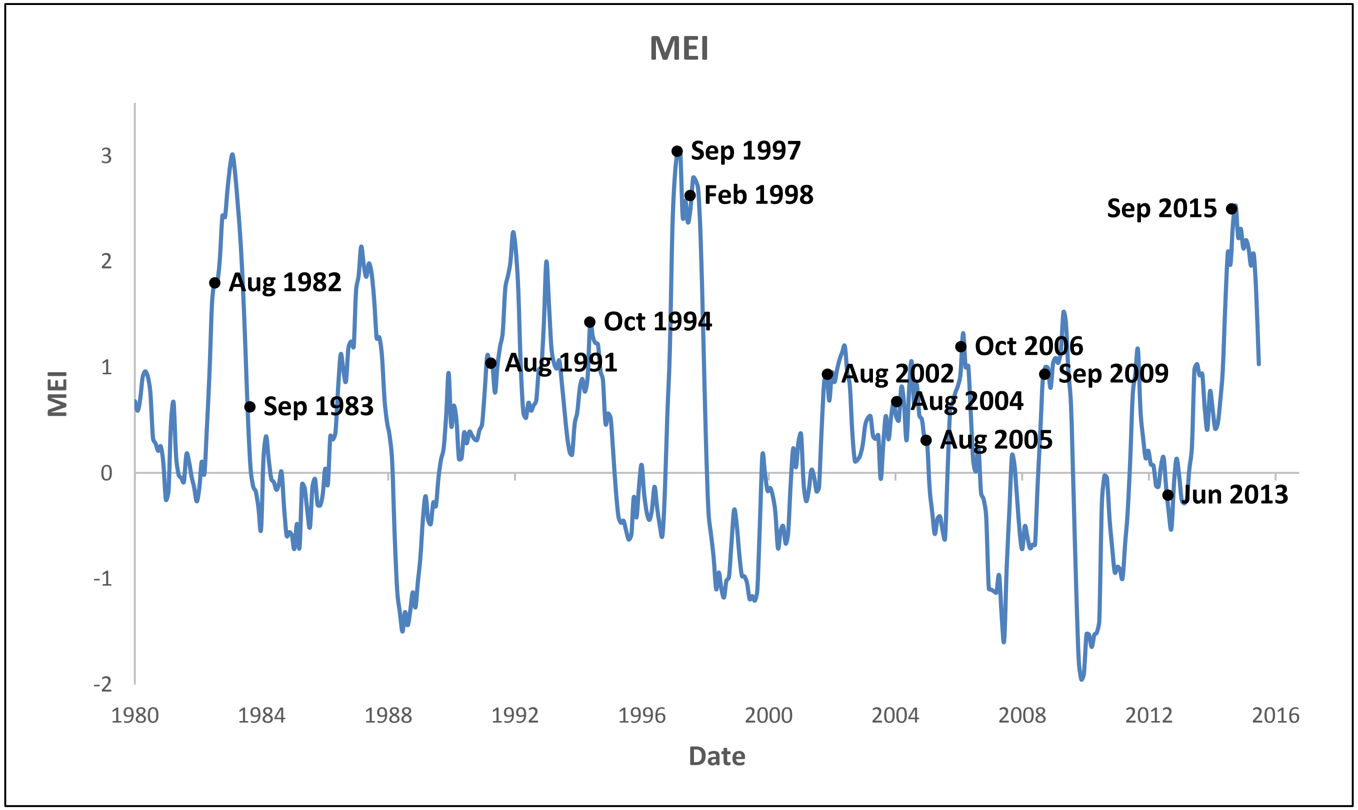

Figure 4. MEI values for the years 1980 to 2015.

Uniqueness of the June 2013 Haze Event

- MODIS fire count in the Maritime Continent (MC).

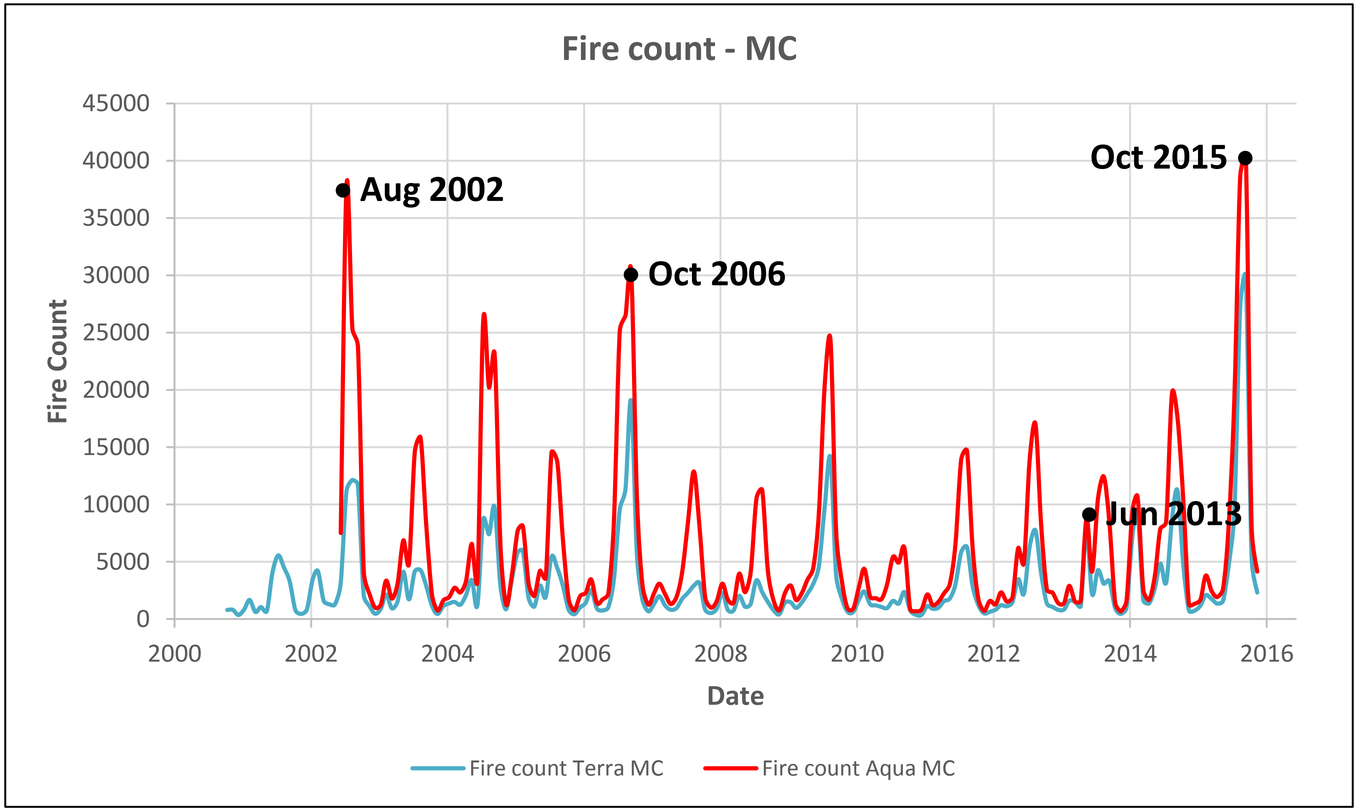

Figure 5. MODIS fire count from Terra (blue) and Aqua (red) satellite data over the Maritime Continent (MC) for the years 2000 to 2015.

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Uniqueness of the June 2013 Haze Event

- MODIS fire count in Sumatra and Peninsular Malaysia (SPM).

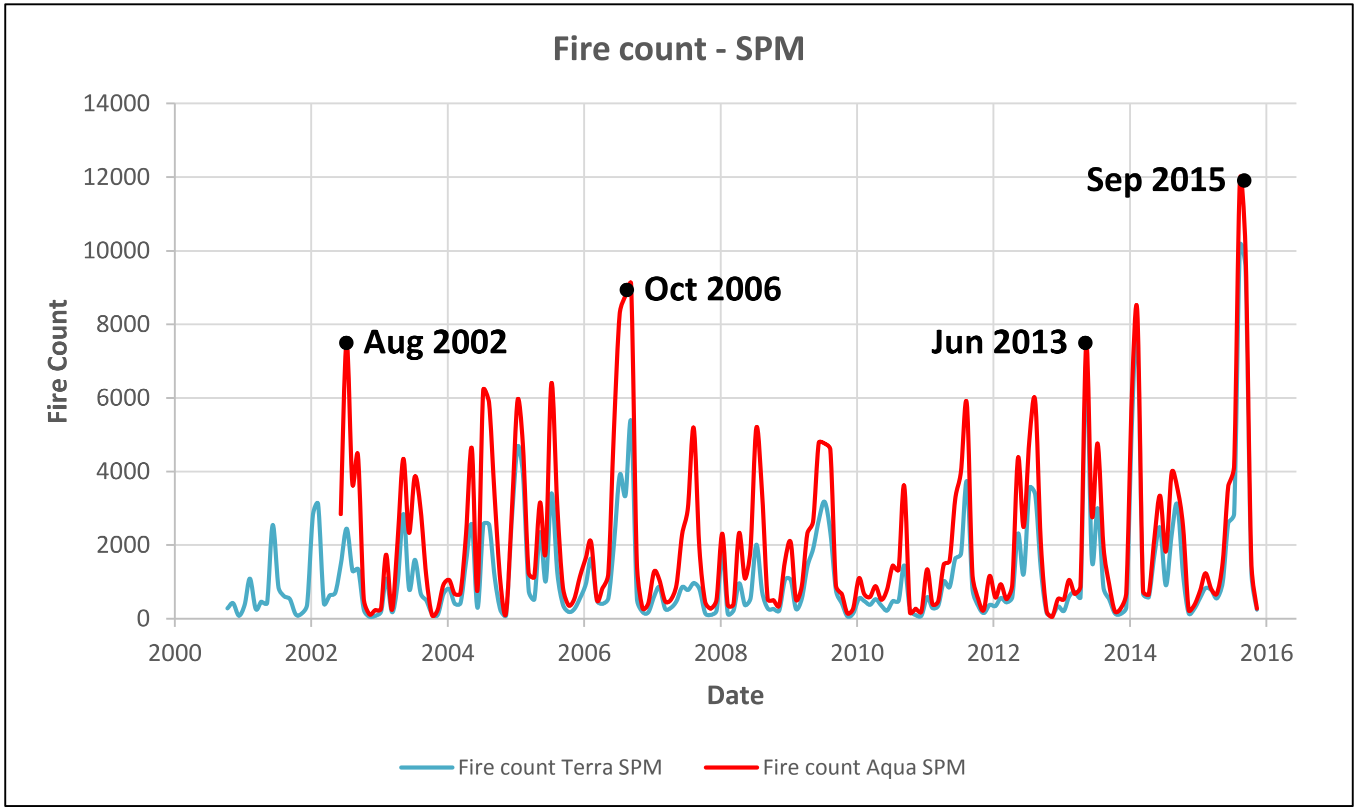


Figure 6. MODIS fire count from Terra (blue) and Aqua (red) satellite data over Sumatra and Peninsular Malaysia (SPM) for the years 2000 to 2015.

Uniqueness of the June 2013 Haze Event

- MODIS fire count ratio SPM/MC.

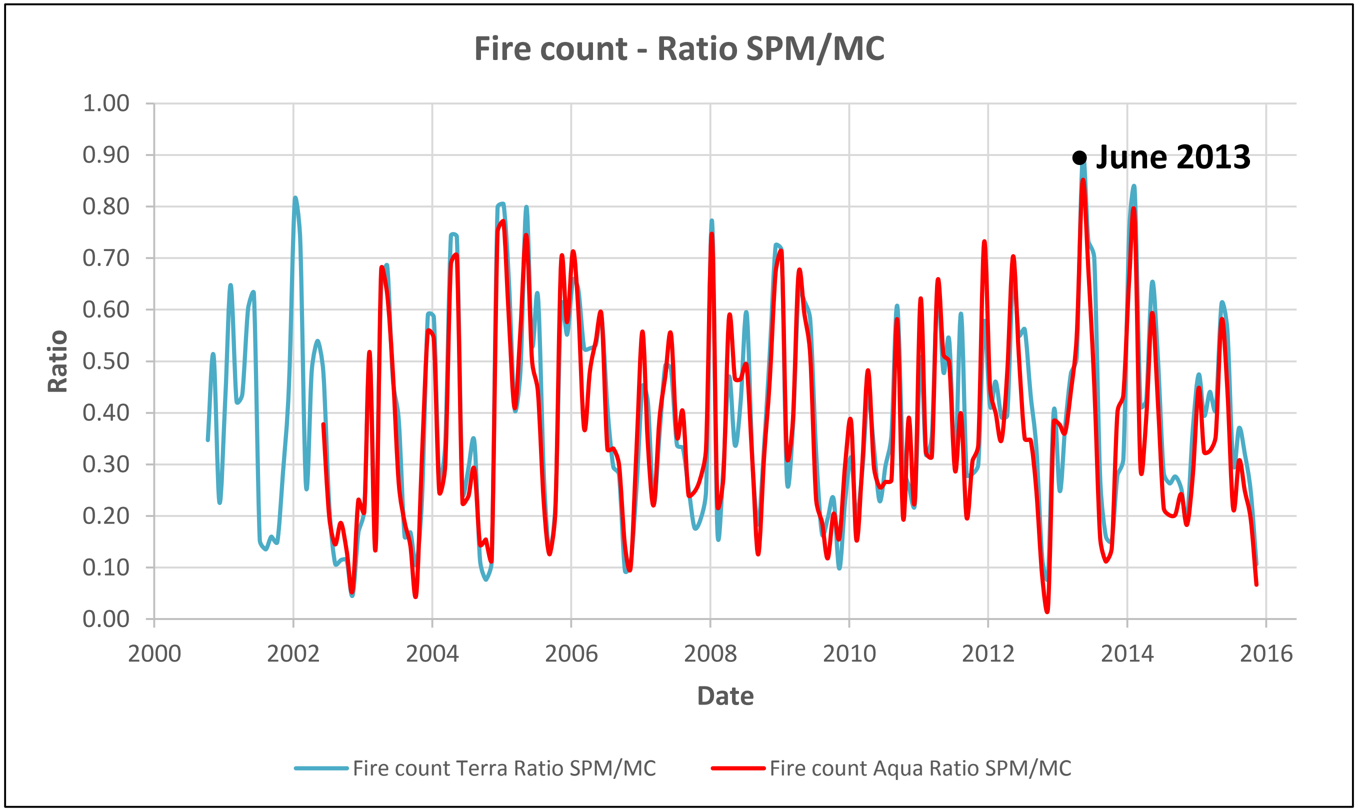


Figure 7. Ratio of MODIS fire count SPM/MC from Terra (blue) and Aqua (red) satellite data for the years 2000 to 2015.

Uniqueness of the June 2013 Haze Event

- Major fire events usually occur between August and October in the Maritime Continent (MC).
- June 2013 episode
  - La Nina conditions (MEI = -0.144)
  - Early
  - Highest SPM/MC fire count ratio (0.89)
- The intense fire event in June 2013 is rather uncharacteristic of the seasonality of extreme fire events in the MC.
- WRF-Chem simulations to investigate the occurrence and intensification of the June 2013 episode.

Model setup

- WRF-Chem model (Grell et al. 2005).
- 27km grid resolution domain (160x150).
- 50 sigma levels, most tightly packed in the boundary layer and near the tropopause.
- Initial and boundary meteorological conditions:
  - ERA-interim (ECMWF; http://apps.ecmwf.int/datasets/data/interim-full-daily/).
  - Spatial resolution: 80 km (T255 spectral) on 60 vertical levels from the surface up to 0.1 hPa.
  - 6-hourly atmospheric fields on model levels.
- FLAMBE emissions (Reid et al., 2009)

Model setup

- Four-dimensional data assimilation (FDDA) applied using ERA-interim datasets. (Four nudged fields: u and v horizontal wind components, temperature and specific humidity).
- Simulation period: 14th to 27th June 2013.
- First 3 days of simulation considered as spin up.
- FLAMBE emissions (increased by a factor of 2) updated for everyday of simulation.

Model setup

Table 1. Model physics and chemistry

Model Physics		Model Chemistry	
Microphysics	Morrison double-moment microphysics scheme (Morrison et al. 2009)	**Gas-phase chemistry mechanism**	Regional Acid Deposition Model, 2nd generation (RADM2) (Stockwell et al. 1990)
Radiation	Short-wave and long-wave radiation schemes (RRTMG)	**Aerosol model**	Modal Aerosol Dynamics Model for Europe (MADE) and Secondary Organic Aerosol Model (SORGAM) aerosol model (Ackermann et al., 1998; Schell et al., 2001)
Convective parameterisation	Grell 3D cumulus scheme		
Land_surface model	Noah (Chen & Dudhia 2001)		
Planetary boundary layer	Mellor-Yamada-Janjić (MYJ) scheme (Janjić, 1996, 2002)		

Model evaluation

- Spatial matching between the model and observations:
  - The grid index (i,j) corresponding to the geographical location of the observation site is determined.
  - The model value at the estimated grid index (i,j) is calculated from the surrounding four model grid points by bi-linear interpolation.
- Statistical metrics:
  - Root mean square error (RMSE)
  - Correlation coefficient (r)

Model evaluation

- Surface data:
  - Data source: Malaysian DOE
  - Stations: Johor (1.495˚N, 103.736˚E), Terengganu (5.308˚ N, 103.120˚ E), Perak (4.201˚N, 100.664˚E), Muar (2.062˚ N, 102.593˚ E) and Kuala Lumpur (3.212˚ N, 101.682˚ E).
  - Variable evaluated: 2m Temperature, PM2.5/PM10
- MODIS satellite data:
  - AOD retrievals at 550nm for both Ocean (best) and Land (corrected) with all quality data.

Model evaluation

- 2m Temperature

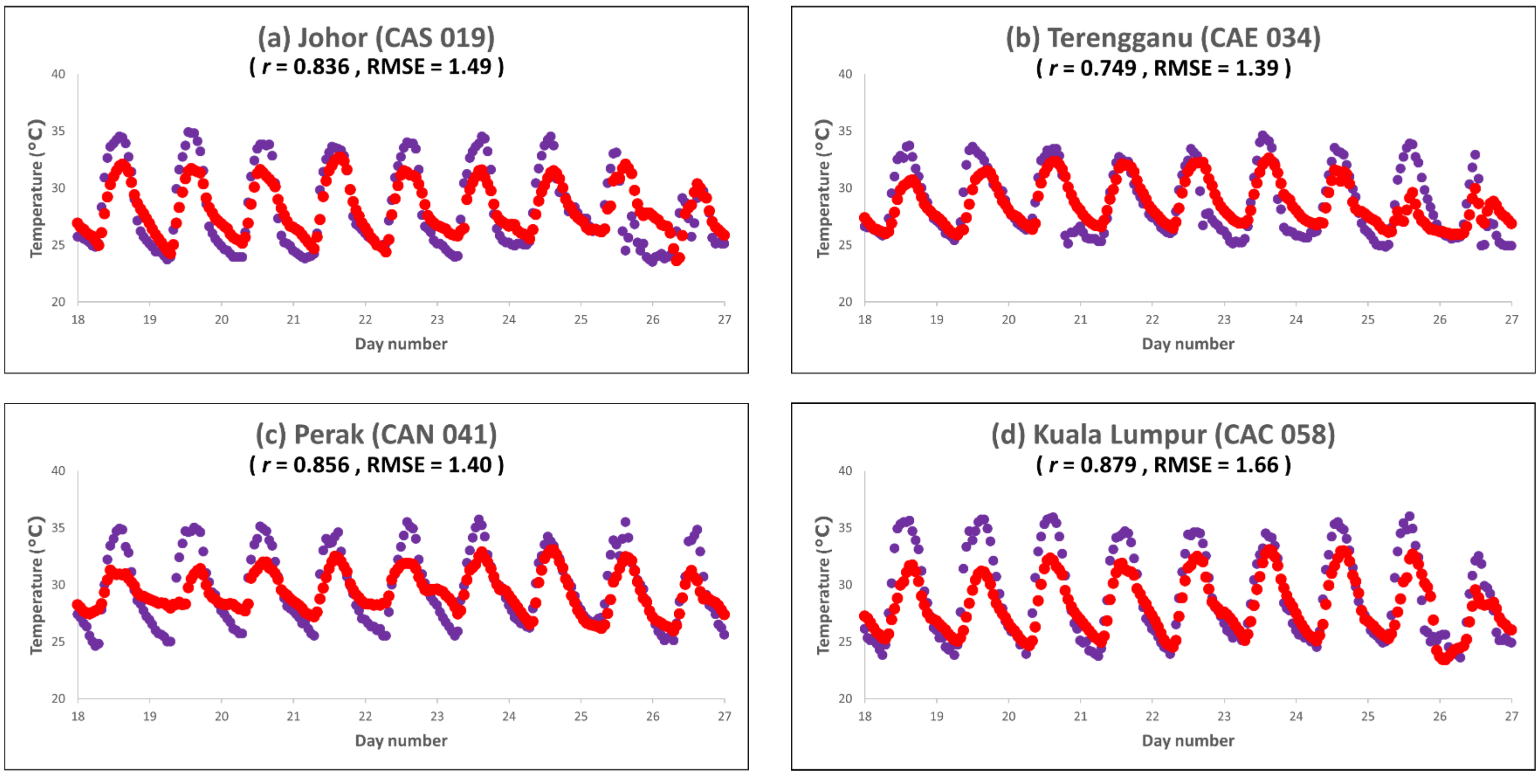


Figure 8. Comparison of observed and model simulated 2m Temperature (˚ C) for the period 18th to 27th June 2013 at (a) Johor, (b) Terengganu, (c) Perak and (d) Kuala Lumpur.

Model evaluation

- PM2.5/PM10

Table 2. Correlation (r) and root mean square error (RMSE) between WRF-Chem hourly simulated PM2.5 concentrations and measured PM10 concentrations at ground stations over Malaysia from 21st to 25th June 2013.

Station	r	RMSE
Johor (CAS 019)	0.605	99.4
Perak (CAN 041)	0.322	188.0
Muar (CAS 044)	0.505	192.1
Kuala Lumpur (CAC 058)	0.361	162.6

Model evaluation

- AOD retrievals at 550nm

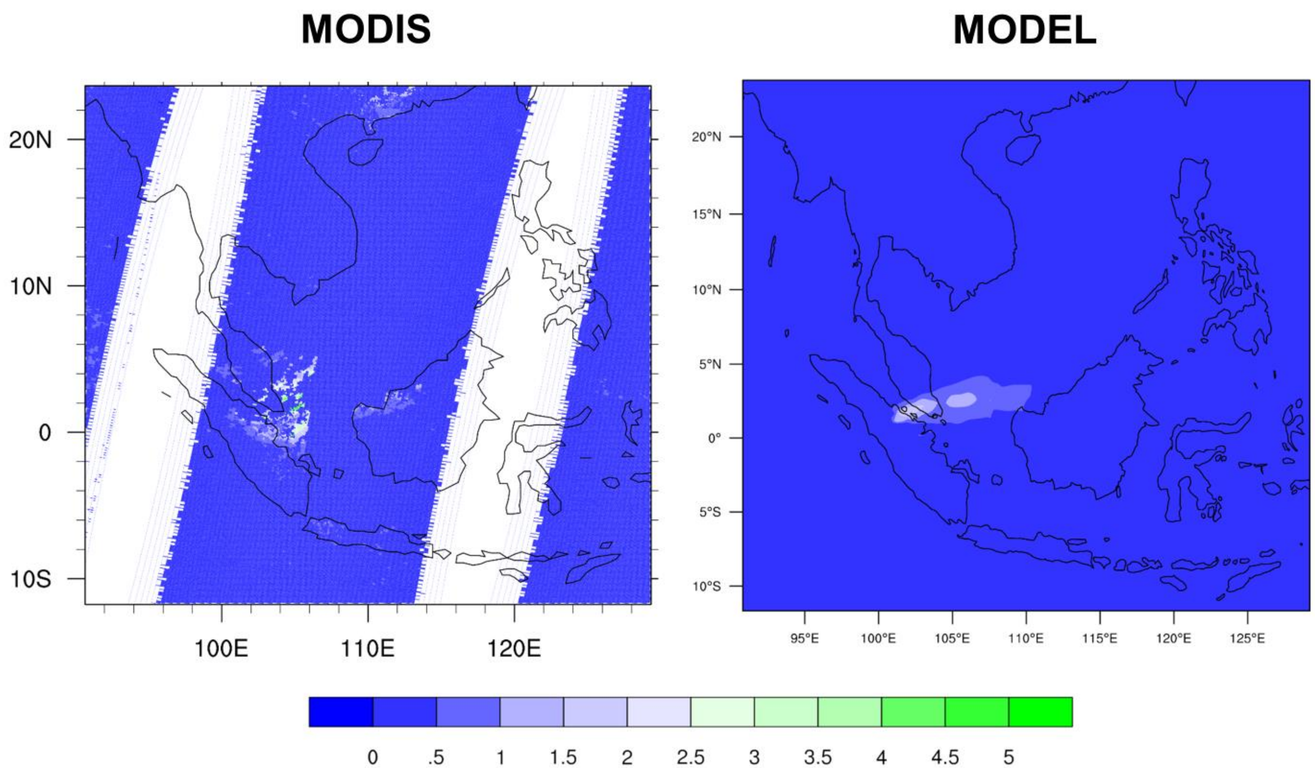


Figure 9. AOD at 550nm on 21st June 2013 over the MC from the retrievals of MODIS on Terra and the corresponding WRF-Chem simulations. The MODIS retrievals for both Ocean (best) and Land (corrected) with all quality data.

Effect of tropical cyclone Bebinca

- Summer monsoon – ITCZ migrates northwards.
- Western North Pacific (WNP) most active basin of tropical cyclogenesis in the world (Neumann 1993).
- 2013 tropical cyclone (TC) season in the WNP marked by an above average genesis of TCs and was characterised by an early active TC season in June (Al et al. 2014).
- In fact, 4 TCs were generated in June 2013 – much higher than the climatological average of 1.8 TCs.
- TCs were associated with regions of active organised deep convection.

Effect of tropical cyclone Bebinca

- Tropical cyclone Bebinca generated from a low pressure system on 20th June.
- Large scale subsidence and induced dryness over the MC, especially Sumatra.
- Stronger southwesterlies.
- Increase in fire hotspots and haze propagation while Bebinca prevailed.

Effect of tropical cyclone Bebinca

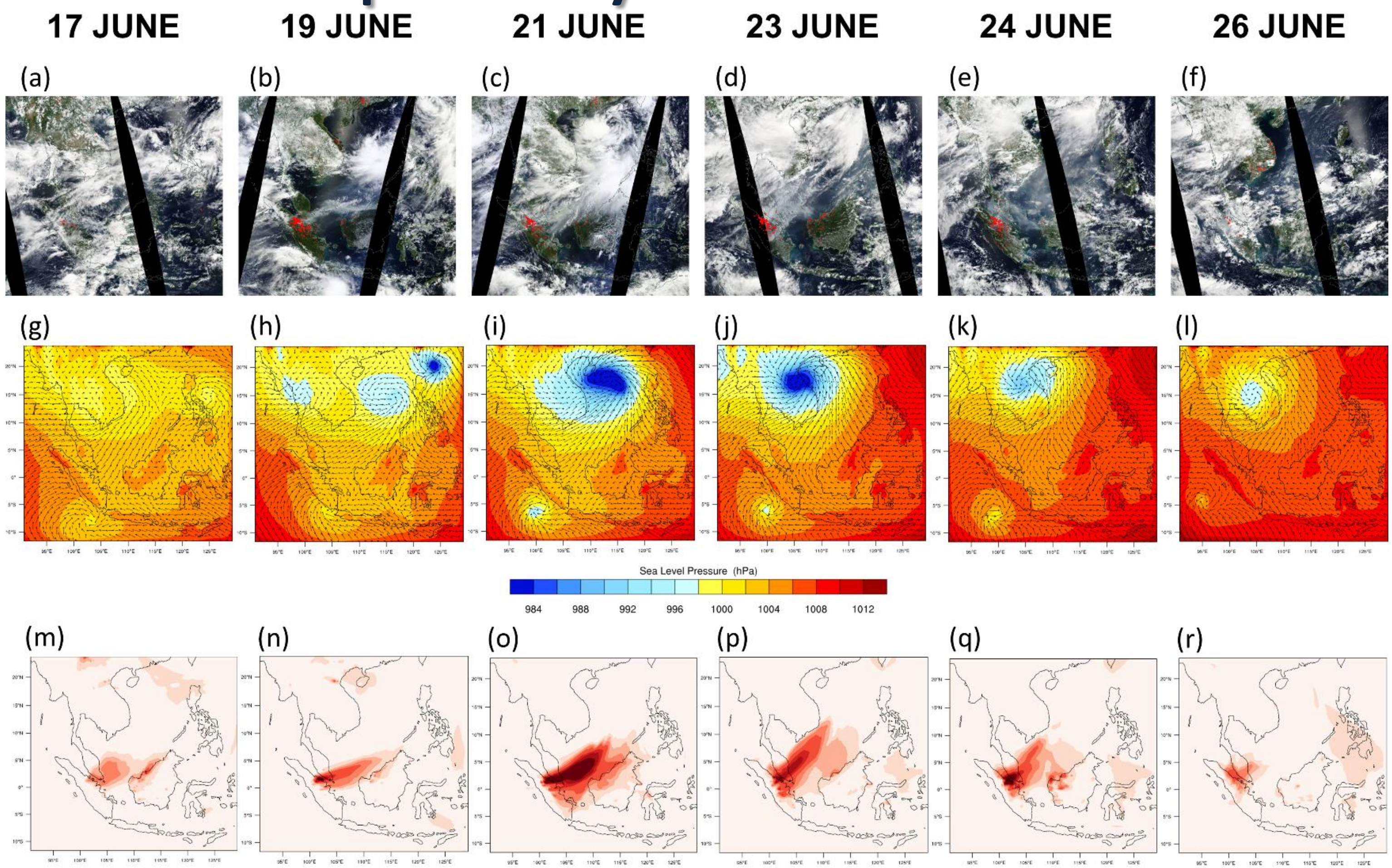


Figure 10. MODIS images from the Terra and Aqua satellites for days between 17th and 26th June 2013 (a-f). The red spots correspond to regions of fire hotspots. (g-l) The corresponding WRF-Chem simulated daily averaged SLP (hPa) and near-surface wind fields (m/s). (m-r) The daily averaged and vertically integrated PM2.5 emissions (Darker red plumes indicate higher concentrations of $PM_{2.5}$).

Effect of tropical cyclone Bebinca

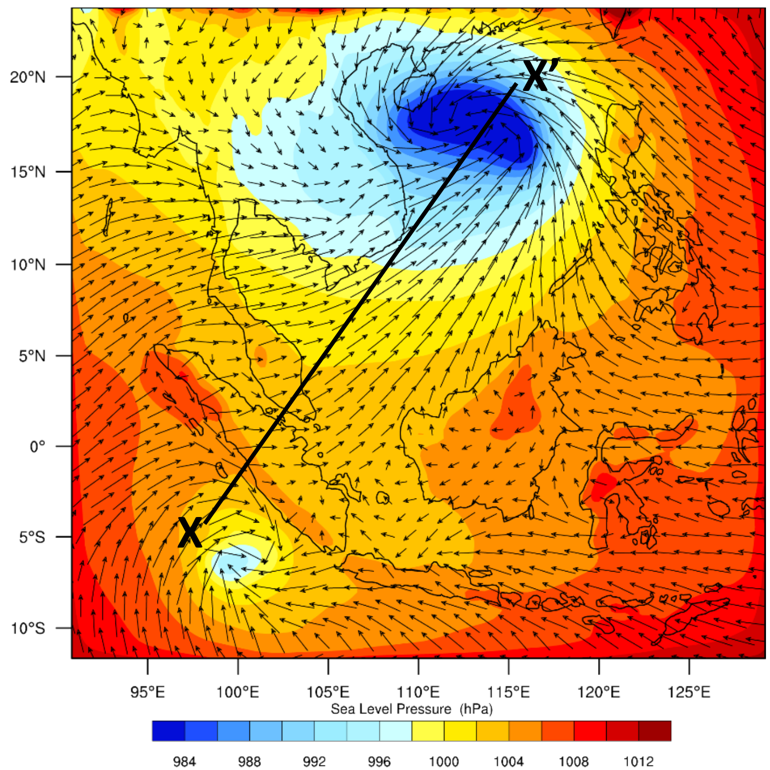


Figure 9. (top) WRF-Chem simulated daily averaged SLP (hPa) and near-surface wind fields (m/s) on 21st June with cross-section XX'

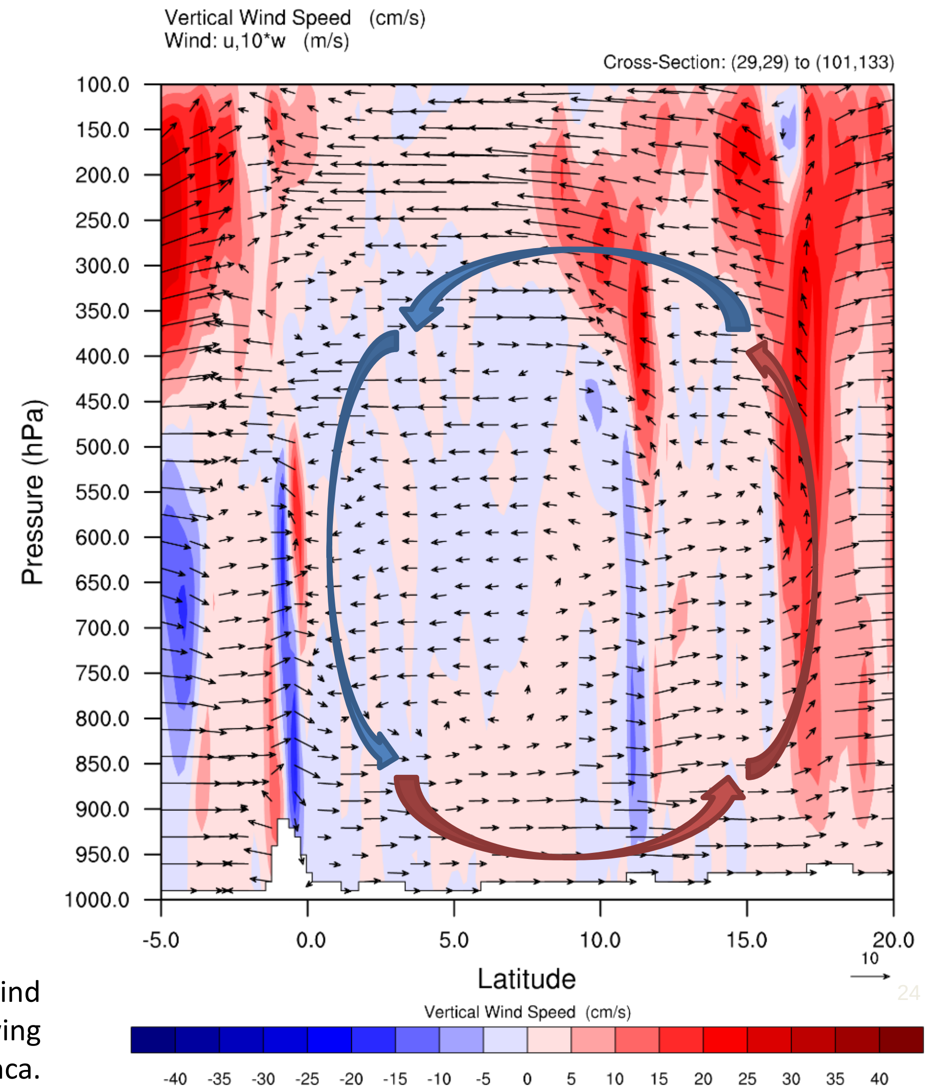
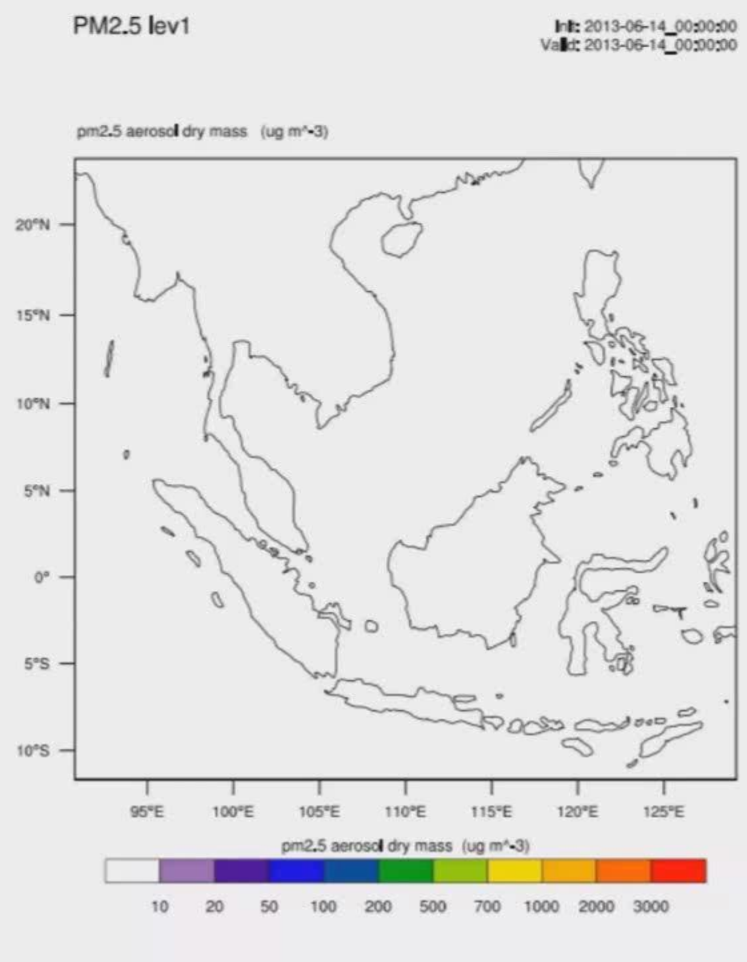
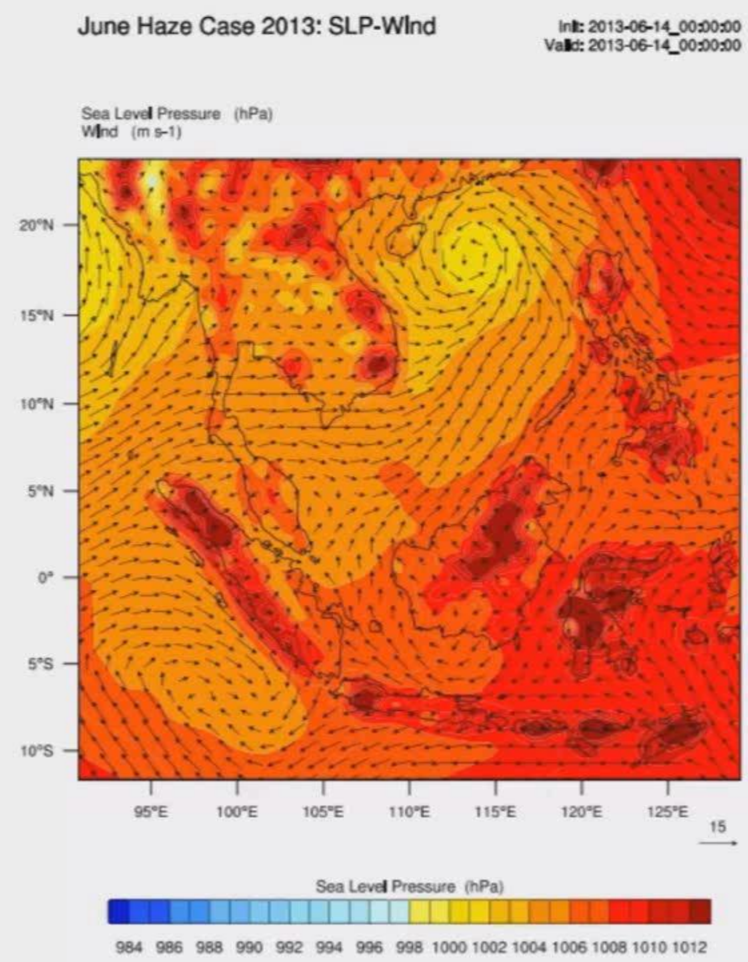


Figure 10. (right) Wind fields (m/s) (arrows) and Vertical Wind Speed (cm/s) (shaded colors) on 21st June along XX' showing subsidence due to the cyclone Bebinca.

Effect of tropical cyclone Bebinca





Effect of tropical cyclone Bebinca

- Weakening and dissipation of cyclone Bebinca marked the end of the haze episode over Peninsular Malaysia and Sumatra thus indicating the high correlation between the intensification and propagation of forest fires and the transport of BBH over the MC due to TC activity over the SCS.
- Climate change due to greenhouse warming will increase the global average intensity of tropical cyclones (Knutson et al., 2010).
- Uncharacteristically early and intense haze episodes like that of June 2013 could occur more regularly in the coming years as the regional climate intensifies.

Summary

- WRF-Chem used to simulate biomass burning haze from Sumatra.
- Good agreement between measured and observed data and model data, showing strong performance of the model.
- Uniqueness of the June 2013 episode.
- June 2013 BBH event highly correlated to cyclone Bebinca.
- Intense and early TC seasons over the WNP can be an indication of the occurrence of early and extreme haze events over the MC.