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Visualization and Interpretation of PM10 Monitoring Data Related to Causes of Haze Episodes in Northern Thailand

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Abstract

Monitoring of ambient air quality yields data typically presented as time series plots, tables of summarized statistical values, or other representations. This paper presents an alternative way to visualizing air quality monitoring data by presenting concentrations in the form of a calendar, offering a familiar way for reader to identify air quality trends on various time scales (daily, weekly, or monthly). One of the major air pollution problems in the northern part of Thailand is haze, which is related to the concentration of airborne particulates less than 10 microns in size (PM10). This paper presents calendars of PM10 concentrations monitored by the Pollution Control Department across northern Thailand. Hourly mean PM10 concentrations monitored at 13 stations were used to construct PM10 concentration calendars for each station. Haze episodes are clearly identifiable in the visualization; the calendar also allows easy comparison of PM10 levels between years. We also observed the absence of any haze episodes in 2011, and propose possible related factors.

Keywords: PM10; haze visualization; Northern Thailand; concentration calendar; hotspots; rainfall

Introduction

In Thailand, air quality is monitored over the entire country. In the northern region, haze has emerged as a major air quality problem, associated with increases in the concentration of particulates less than 10 microns (PM10) in size. High PM10 concentrations carry severe public health risks and cause respiratory illnesses [1].

PM10 deposition on vegetation reduces growth, yield, flowering, and reproduction [2], as well as hampering visibility [3]. PM10 has been classified as an air pollutant to be monitored and controlled in the national air quality standards of Thailand. A number of studies have focused on technical characterization and management of haze [4, 5]. Due to the importance of the issue and the wide availability of data, historical PM10 data for northern Thailand were selected for analysis in this study.

Air quality data are analyzed in various ways to monitor whether concentrations of key pollutants are above or below the set national standard values. Typically, data are presented using time series plots or summary tables. However, there are many techniques to analyze and present air quality data. Carslaw and Ropkins [6] introduced the R Package for Air Quality Data Analysis, named the OpenAir package. The calendar plot is one of the techniques available in the package, offering a reader-friendly visualization of concentrations of pollutants; this familiar form of representation is especially useful in communicating with the lay stakeholder communities or other non-expert audiences.

This paper presents the application of the calendar-style technique to visualize PM10 concentrations monitored by the Pollution Control Department in northern Thailand. Historic hourly PM10 concentrations at monitoring 13 stations were collected from the year of establishment of each station to 2014. The data were used to construct PM10 concentration calendars. The representation highlighted interesting periods of haze over the northern part of Thailand. Since other factors such as fire hotspots and climatic events are also known to influence PM10 concentrations [4], these possible factors were analyzed to explore their respective influence and correlation with periods of high and low PM10 concentrations.

Data and methodology

The PM10 monitoring data used for this work were collected by the Pollution Control Department of Thailand from 13 monitoring stations and analyzed to create calendars for each station. The period of data available varied according to station as presented in Table 1.

The conventional calendar-style layout was selected to present the data, since this is familiar to a non-technical audience. The R program with OpenAir package was used to create calendars of PM10 concentrations. Programming codes were written to read the PCD data and calculate 24-hour averages for plotting in the calendar layout. The calendar allows easy comparison of PM10 24-hour averages against the maximum limit (120 $\mu g/m^3$) set according to the National Ambient Air Quality Standard of Thailand. The sequence of hours per day was converted from the PCD's format of 01-24h to the 00-23h format before performing the analysis.

Next, the calendars were used to pinpoint interesting pollution events such as haze, and compared with data on fire hotspots, rainfall and wind at 850 hPa. The fire hotspot data used for this study were obtained from the Fire Information for Resource Management System (FIRMS), provided by the National Aeronautics and Space Administration (NASA) Earth Observing System Data and Information System [7]. Rainfall data were obtained from the Tropical Rainfall Measuring Mission (TRMM) produced by NASA and the Japan Aerospace Exploration Agency (JAXA) [8]. The version of TRMM data is 3B43 that is gridded data with resolution 0.25 × 0.25 degree. The zonal and meridional wind components of the NCEP_ Reanalysis2 data set, as provided by the NOAA/ OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at http://www.esrl.noaa. gov/psd/, were used to reveal anomalies in wind circulation cover the northern part of Thailand and neighbouring areas. The data set is gridded data with resolution of 1 × 1 degree.

Table 1 Information of the available PM10 data

Province	PCD Station ID	Data Period	Province	PCD Station ID	Data Period
Chiang Mai (CMI)	35	2006-Present (2014)	Chiang Rai (CRI)	65	2009-Present (2014)
	36	2004-Present (2014)		73	2012-Present (2014)
Lampang (LPG)	37	2006-Present (2014)	Mae Hong Son (MSN)	66	2009-Present (2014)
	38	2004-Present (2014)	Nan (NAN)	67	2010-Present (2014)
	39	2004-Present (2014)	Lamphun (LPN)	68	2010-Present (2014)
	40	2004-Present (2014)	Phrae (PRE)	69	2011-Present (2014)
			Phayao (PYO)	70	2011-Present (2014)

Analysis of wind anomaly circulation is typically used to reveal deviations in wind circulation from the normal patterns [9, 10]. The anomaly of wind component is the difference between its magnitude at the time of interest and the long-term average value. Anomalies of zonal and meridional wind components can be determined using a similar calculation concept as the following equation presents for zonal wind:

$$u_{Anom(i,j,t)} = u_{(i,j,t)} - \bar{u}_{(i,j)}$$

where $u_{Anom(i,j,t)}$ is an anomaly of zonal wind component (u) for a grid cell i, j at time t, $u_{(i,j,t)}$ is zonal wind for a grid cell i, j and time t, and $\bar{u}_{(i,j)}$ is the long-term average of zonal wind.

The 10 year long-term means for January, February, and March from 2005 to 2014 were used in this study.

Results and discussion

The PM10 data were calculated to present the 24-hour average concentration for visualization using the calendar style. Plotting the historical data indicated that for all stations, periods of high PM10 concentration (haze episodes) occur each year from January to April. Severe haze episodes were frequent in all provinces in the northern region (Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao, and Phrae), especially during March to early April as seen in a Figures 1, 2, and supplementary. It is noteworthy that since 2009, high PM10 concentrations were never seen during the month of January at Mae Hong Son station (ID. 66), whilst the data for Lam- pang (ID. 40) and other provinces revealed higher 24-hrs average PM10 concentrations during January (Figures 1 and 2). This indicates the influence of additional factors at the Mae Hong Son province compared with Lampang province and other provinces.

Figure 3 shows the distribution of fire hotspots across the northern part of Thailand and neighbouring provinces. The data indicates a relatively small number of hotspots, implying that fire hotspots contribute less to elevated PM10 levels during January, as compared to February and March. Tables 2 and 3 show the numbers of registered vehicles and factories in the provinces of Thailand’s northern region, as collected by the Department of Land Transport and the Department of Industrial Works, respectively. The data show fewer registered vehicles in Mae Hong Son province compared with Chiang Rai, Chiang Mai, Lampang, Lamphun, Nan, Phayao, and Phrae by factors of approximately 12, 23, 8, 5, 4, 5, and 5x, respectively. Mae Mae Hong Son province also has fewer factories than Chiang Rai, Chiang Mai, Lampang, Lamphun, Nan, Phayao, and Phrae- by factors of around 18, 22, 14, 8, 4, 4, and 16x, respectively. These data indicate fewer emissions of PM10 from mobile and industrial sources in Mae Hong Son than other provinces. This may help explain the relatively lower PM10 levels observed during January in Mae Hong Son, compared with all other provinces in the region.

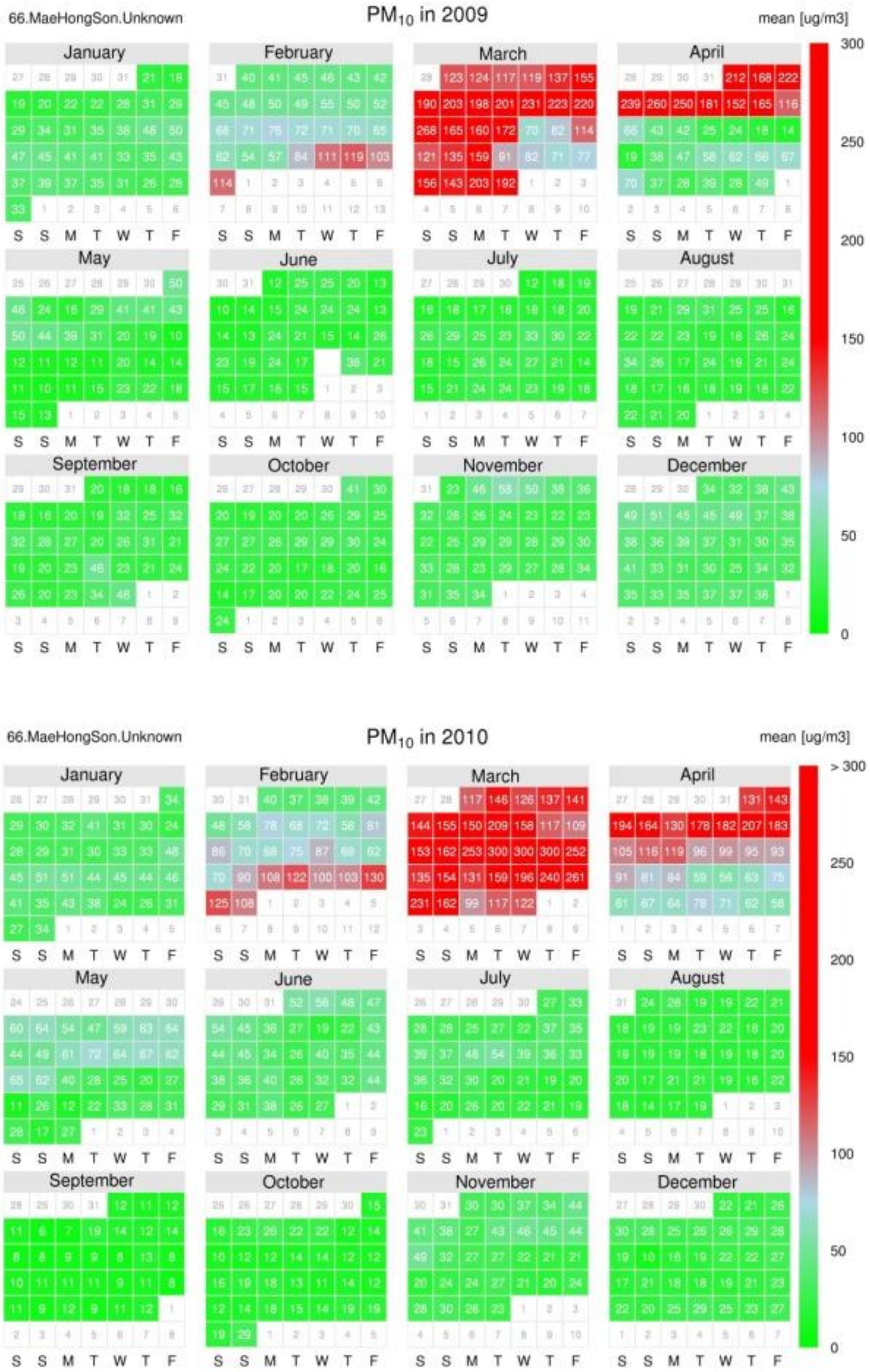
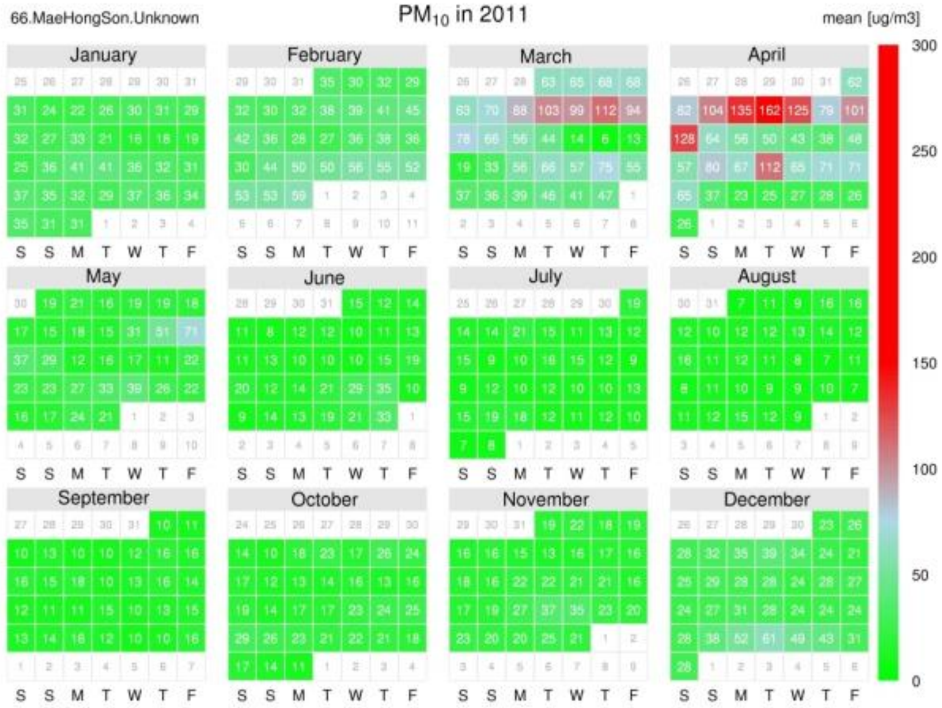


Figure 1 Calendars of PM10 concentrations (24-hour average values) from 2009 to 2014 of the Mae Hong Son station (ID.66)



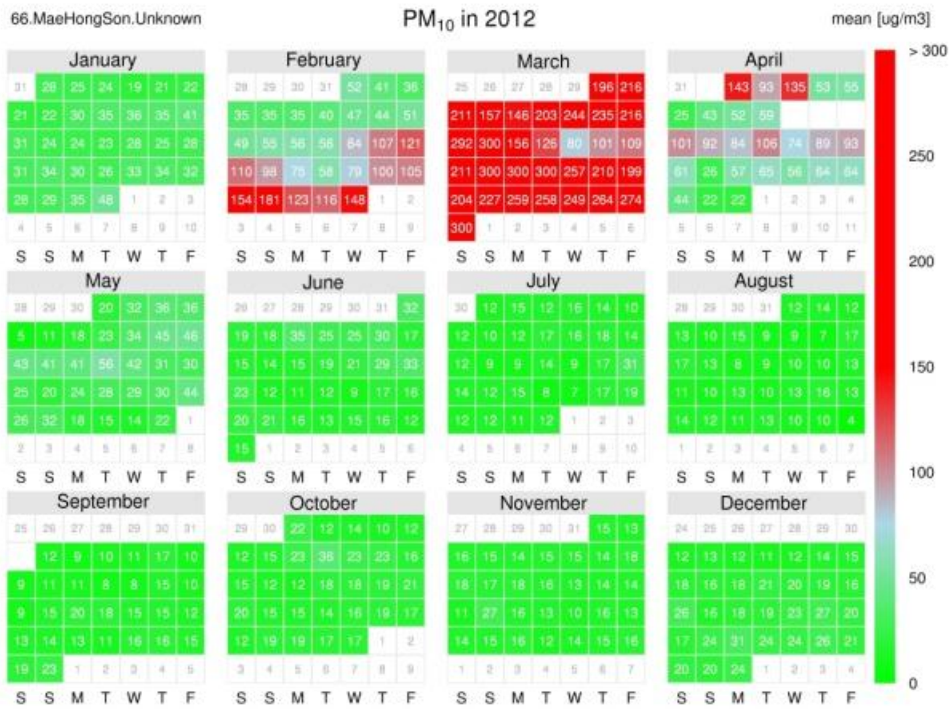
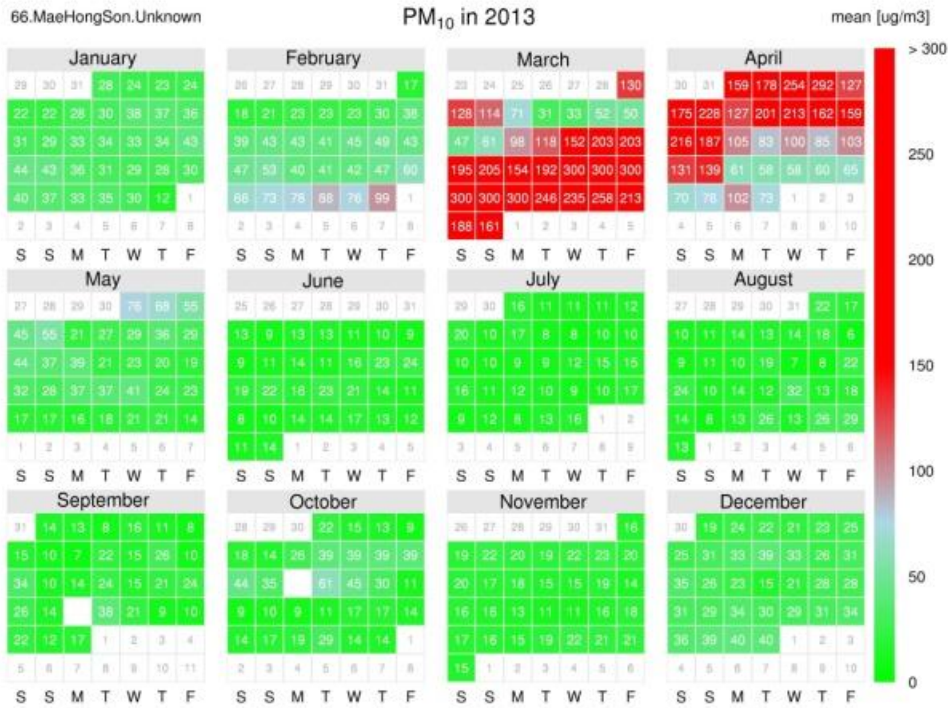


Figure 1 Calendars of PM10 concentrations (24-hour average values) from 2009 to 2014 of the Mae Hong Son station (ID.66) (*continued*)



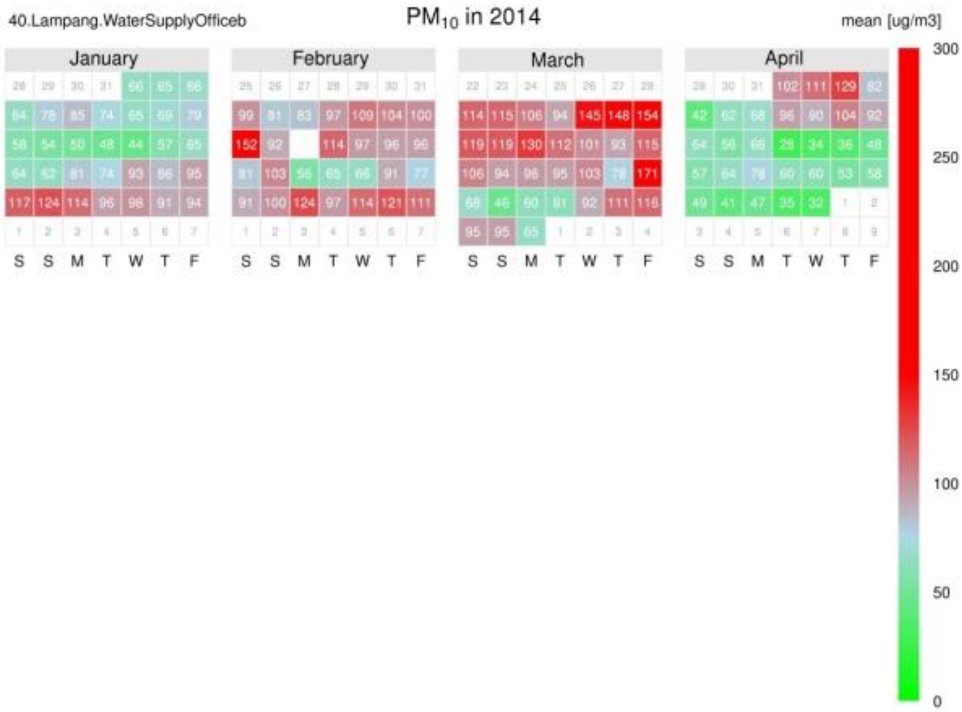


Figure 1 Calendars of PM10 concentrations (24-hour average values) from 2009 to 2014 of the Mae Hong Son station (ID.66) (*continued*)

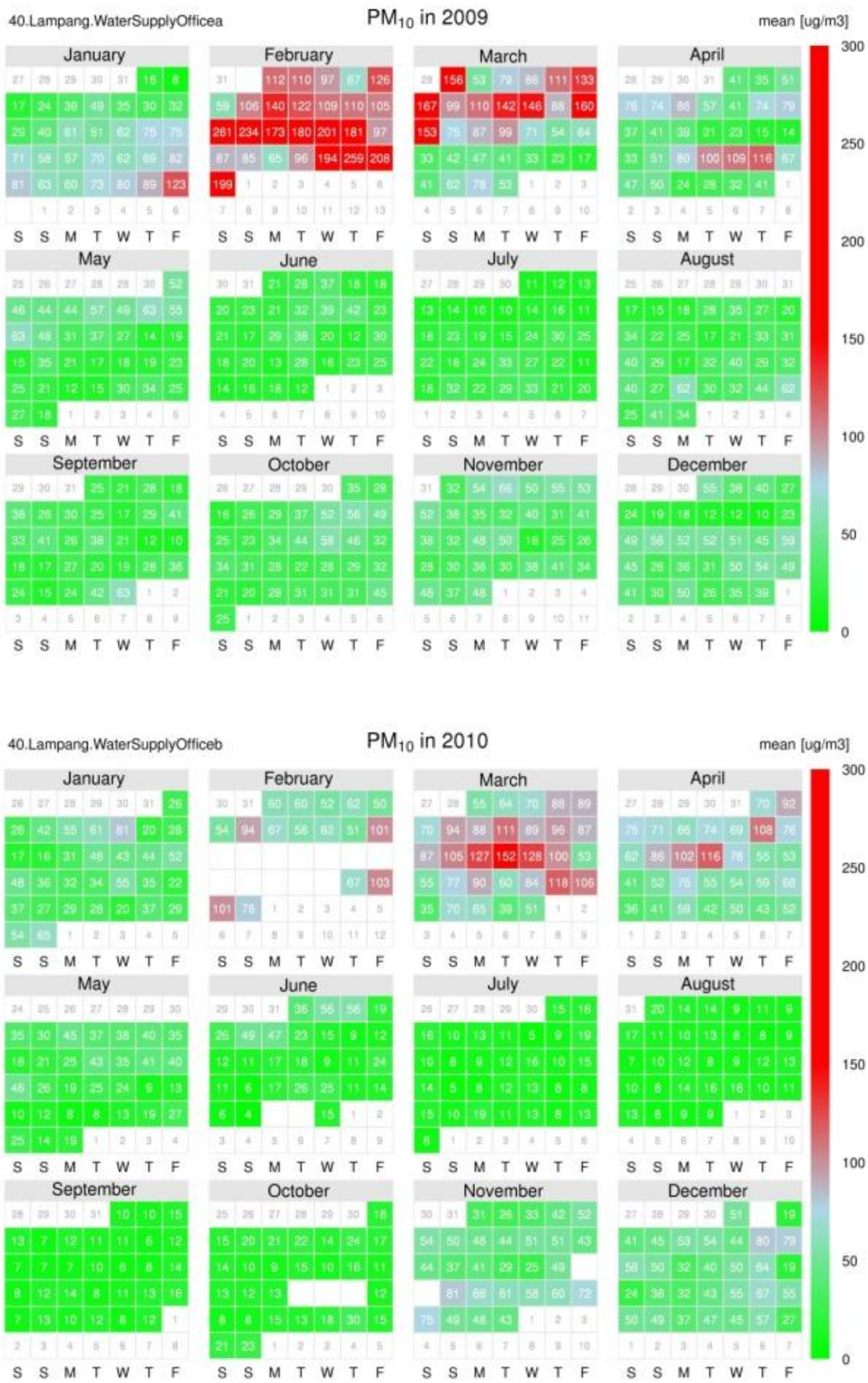


Figure 2 Calendars of PM10 concentrations (24-hour average values) from 2009 to 2014 of the Lampang station (ID.40)

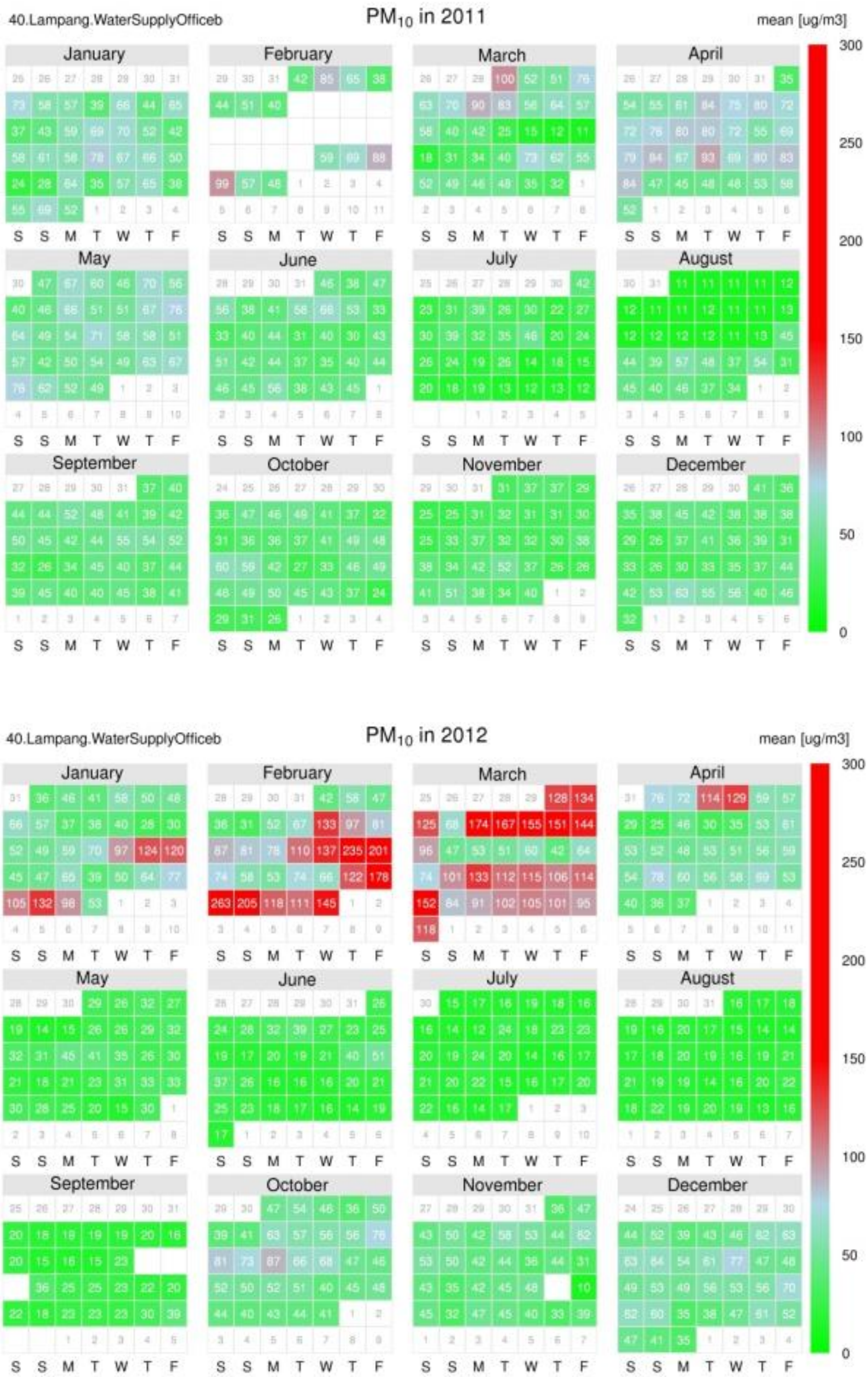


Figure 2 Calendars of PM10 concentrations (24-hour average values) from 2009 to 2014 of the Lampang station (ID.40) (*continued*)

Figure 2 Calendars of PM10 concentrations (24-hour average values) from 2009 to 2014 of the Lampang station (ID.40) (*continued*)

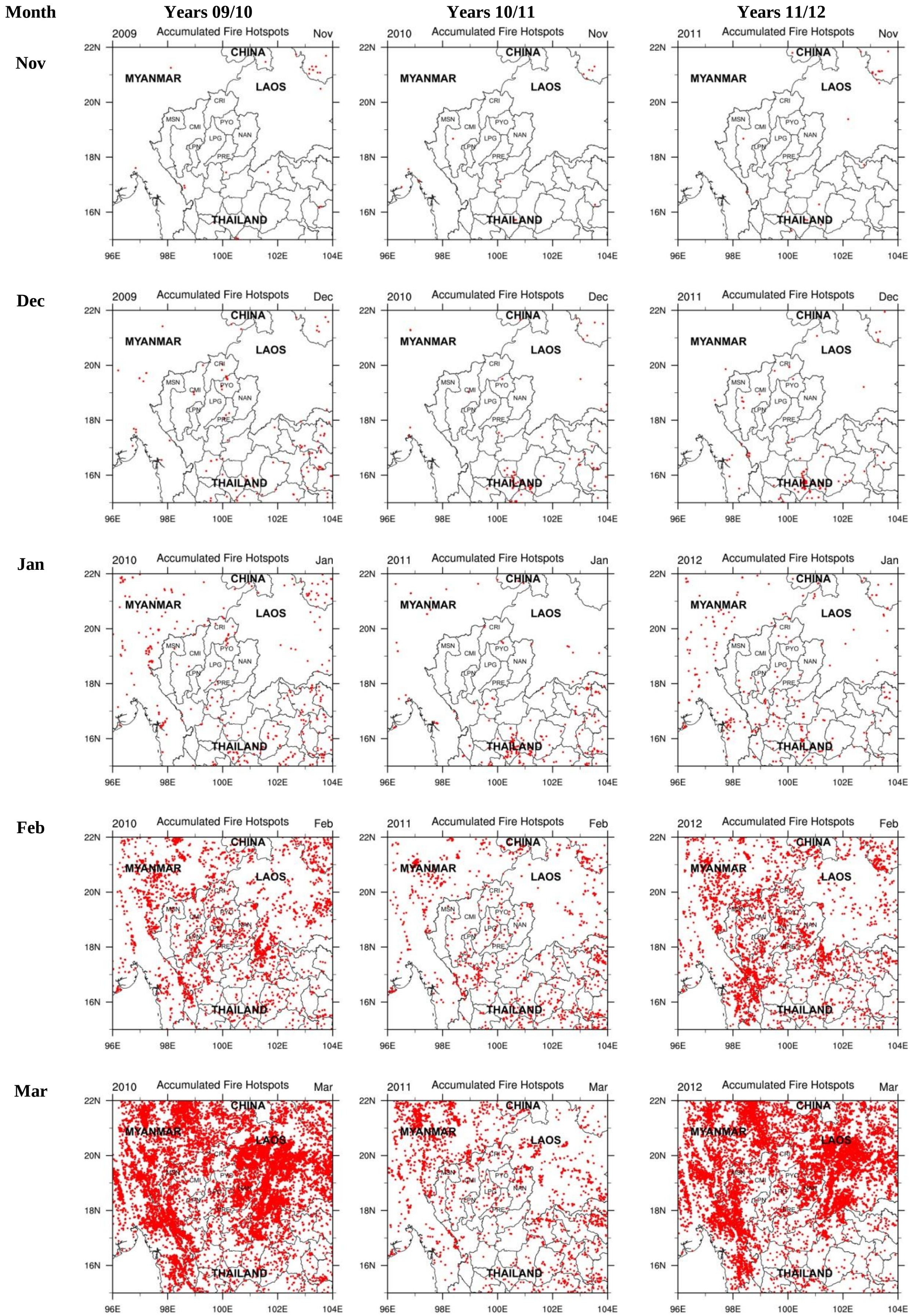


Figure 3 Monthly accumulated fire hotspots from the FIRMS

Table 2 Number of registered vehicles (×10^3 vehicles)

Year	Province							
	CRI	CMI	LPG	LPN	MSN	NAN	PYO	PRE
2009	495.6	915.3	351.2	223.3	39.2	166.3	199.3	204.1
2010	525.1	970.1	364.7	229.4	41.8	174.5	209.9	210.4
2011	556.8	1033.4	378.6	235.1	44.8	184.0	220.5	217.8
2012	597.5	1114.4	396.8	245.2	47.9	195.3	234.3	228.2
2013	637.1	1196.1	415.9	255.9	51.2	204.9	246.4	236.8
2014	660.8	1250.9	425.9	260.6	53.5	210.3	252.3	242.6

Table 3 Number of registered factories (all factory types)

Year	Province							
	CRI	CMI	LPG	LPN	MSN	NAN	PYO	PRE
2012	2,002	2,449	1,586	960	113	417	460	1,808
2013	2,066	2,506	1,667	961	112	415	474	1,923
2014	2,091	2,573	1,711	969	113	410	466	2,028

The calendars of PM10 concentrations of all stations located across northern Thailand also clearly highlights very low PM10 levels at all stations in 2011, compared with other years (Figures 1, 2, and supplementary) - there were no haze episodes identified by high PM10 concentrations over northern Thailand during 2011.

Analysis of related data was undertaken to gain some insight into possible explanations for the low observed PM10 levels concentrations in 2011. One potential factor is fire hotspots, where PM10 are emitted by the burning of crop residues or open vegetation, and from forest burning. A second reason could be rain- high rainfall may remove particulates matter from the atmosphere. A third reason could be flooding- this would reduce the amount of fuel available for open burning. The fourth factor could be wind, related to transportation of airborne pollutants.

The fire hotspot data of FIRMS were used for investigation. The monthly accumulated fire hotspot data from November 2010 to March 2011 was analyzed for the absence of haze episodes, and compared to the previous and the following years to reveal the difference. Figure 3 shows fewer fire hotspots in 2011 compared to the previous and the following years, suggesting that the number of fire hotspots may be associated with reduced PM10 concentrations and fewer haze episodes.

Because of the possibility of climate change impacts on rainfall patterns [11, 12] precipitation data from TRMM was analysed to investigate the influence of rainfall on a number of fire hotspots. The data were used to present precipitation patterns over the area covering northern Thailand as well as neighbouring provinces across the border in Myanmar and Lao PDR. Figure 4 illustrates the different sequence of rainfall in 2010/2011 compared with other years. There was less precipitation during November 2010 compared to the previous and the following years, while December showed higher precipitation than the others. This may affect vegetation growth or the availability of crop residues for burning. Nevertheless, it is clear that the increased precipitation over northern Thailand, and some parts Myanmar and Lao PDR compared with adjacent years would significantly reduce the fire risk. More study is needed to quantify the linkage.

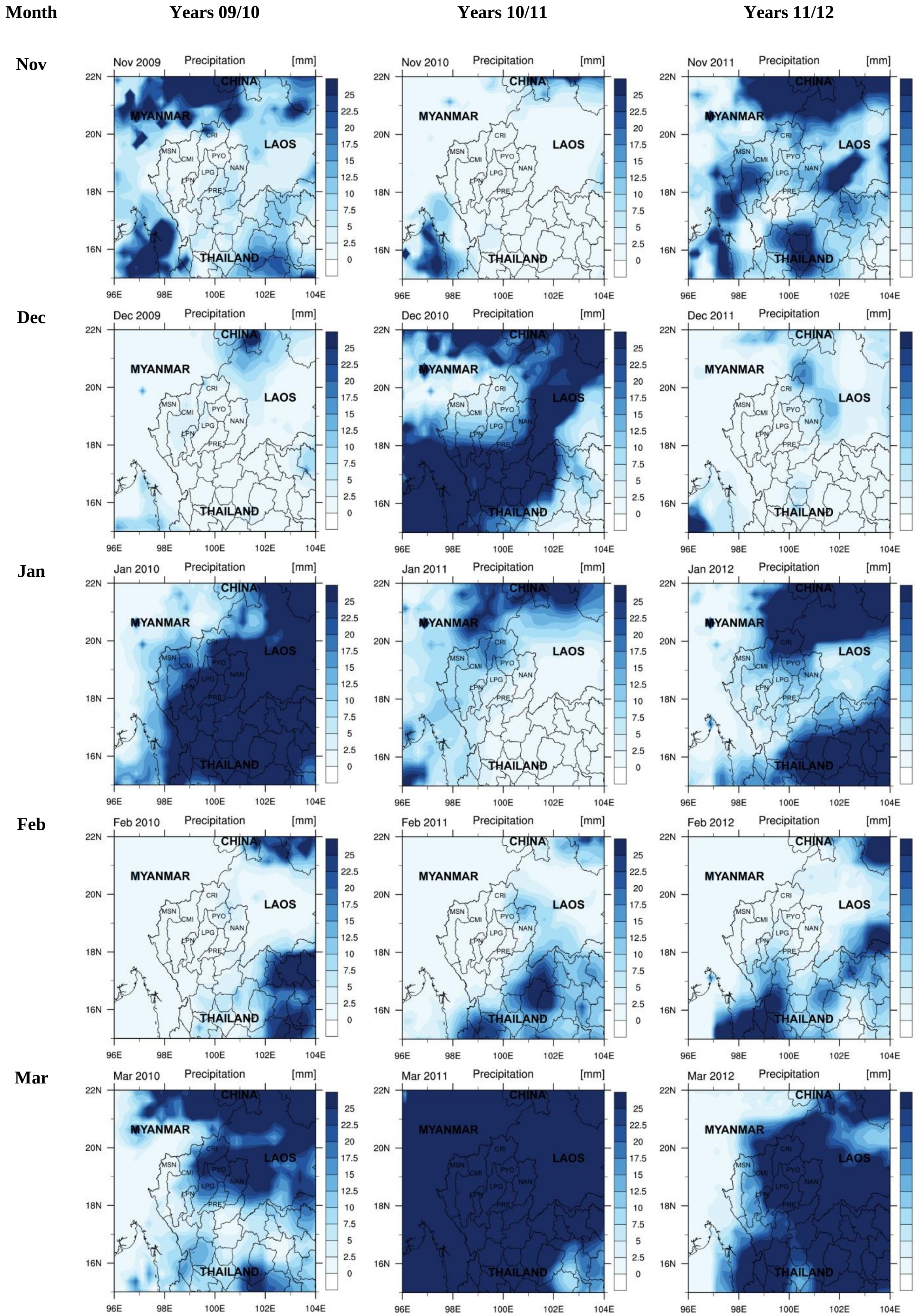


Figure 4 Monthly accumulated precipitation (TRMM data)

Flooding may also have contributed to the reduction in fire hotspots in 2011. Figure 5 shows satellite data on flooding from the Geo-Informatics and Space Technology Development Agency (Public Organization), Thailand (GISTDA). Floods occurred in northern Thailand in the month of November in both 2010 and 2011, but not during January to March in either year. Hence, flooding could not have been a factor in preventing haze in 2011.

From the above discussion we may conclude that rainfall is likely to be one of the explanatory factors in the absence of haze in 2011, but flooding does not seem to be related. Considering the possible influence of climatic factors such as the El Niño Southern Oscillation (ENSO), a study of climate issue in 2011 [11] analyzed national rainfall data in the context of the 2011 flooding in Thailand. The study found that La Niña had only a minor influence on rainfall in the area. Similarly, the ENSO, represented by the Niño-3.4 index, on rainy season precipitation over the entire Indochina peninsula was also found to have minimal influence on the rainfall amount [12]. Therefore, ENSO is not obviously linked as an explanator to the observed reduction in fire hotspots that in turn resulted in a haze-free 2011.

To assess the significance of wind as a factor in transport of air pollutants, analysis of wind anomalies revealed differences in wind circulation patterns. Low level winds at 850 hPa were used for the analysis because they can represent the prevailing wind (e.g. monsoons) over the region [9, 10]. Wind anomalies were determined using the long-term mean from 2005 to 2014 as a basis for calculation for each month (January, February, and March). The wind anomalies indicate differences of wind circulation and strength at any particular time to the mean stage of circulation.

Figure 6 shows that was a strengthening of wind in the West to East direction over northern Thailand during January to March in 2010 and 2012, whereas strengthening of southerly northerly and northeasterly winds was observed for the same period in 2011. These winds may well be responsible for the observed changes in PM10 concentrations as there were fewer fire hotspots in the upwind areas (Figure 3). Moreover, in March 2011, the northeasterly wind was strong over Thailand, resulting in a high ventilation coefficient [13]. Higher values indicate the atmosphere's increased ability to disperse pollutants and signifies higher air quality [13, 14]. Therefore, strong northeasterly winds appears to be at least one of the causes of reduced PM10 concentration level during March 2011.

Finally, all analyses found that the absence of haze episodes during January to April 2011 was related to the number of fire hotspots, the amount of precipitation, and the wind circulation and its strength, whereas there was no evidence of links with flooding and ENSO as causal factors. However, it will be interesting to study these linkages in greater depth in order to understand the underlying mechanism, particularly the linkages between the PM10 level and the variability of monsoon strength, which is related to variations in wind and precipitation. Variability in the planetary boundary layer (PBL) may also be of importance since it is related to changes in atmospheric volume that can allow accumulation of pollutants.

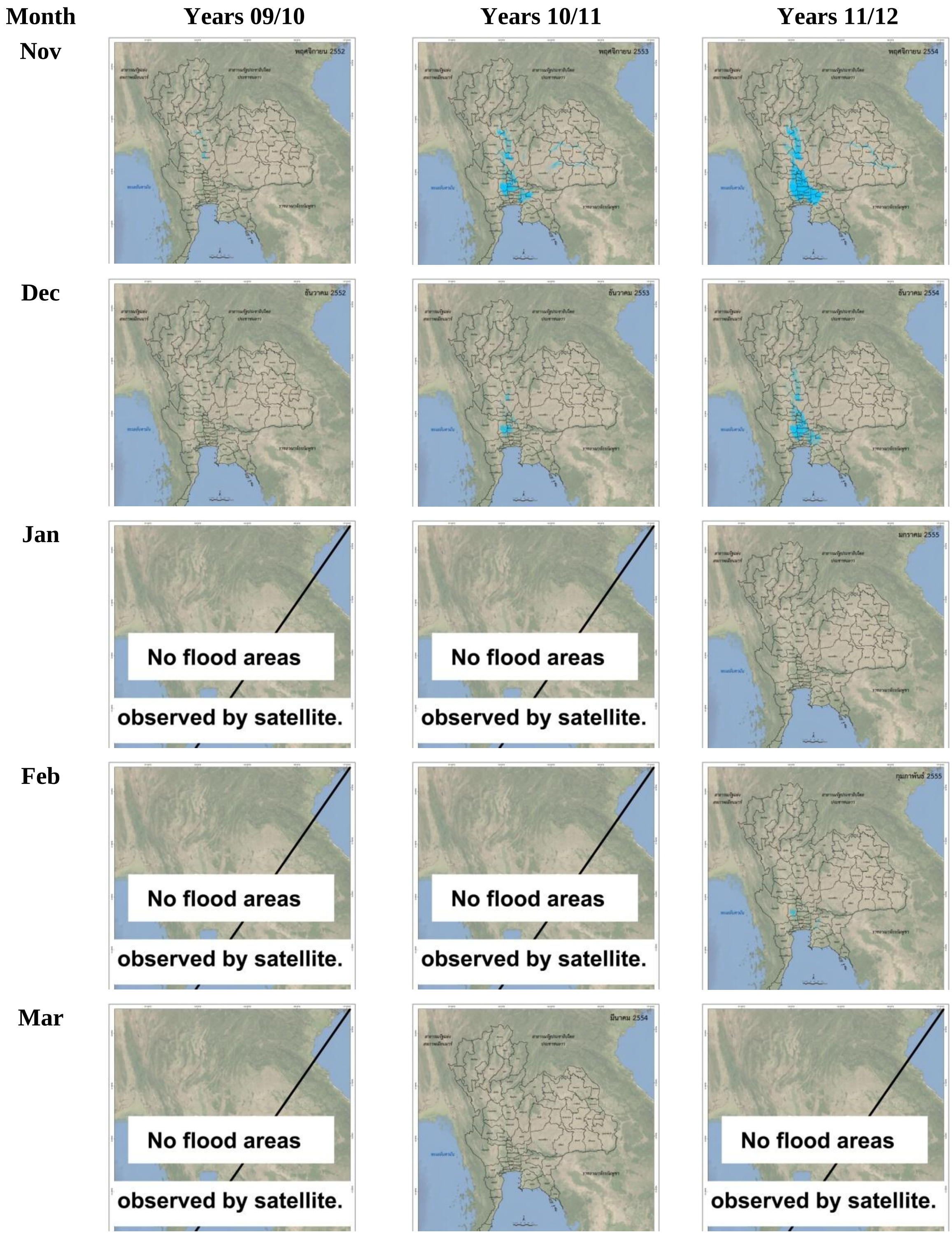


Figure 5 The flooded area (blue color) provided by GISTDA

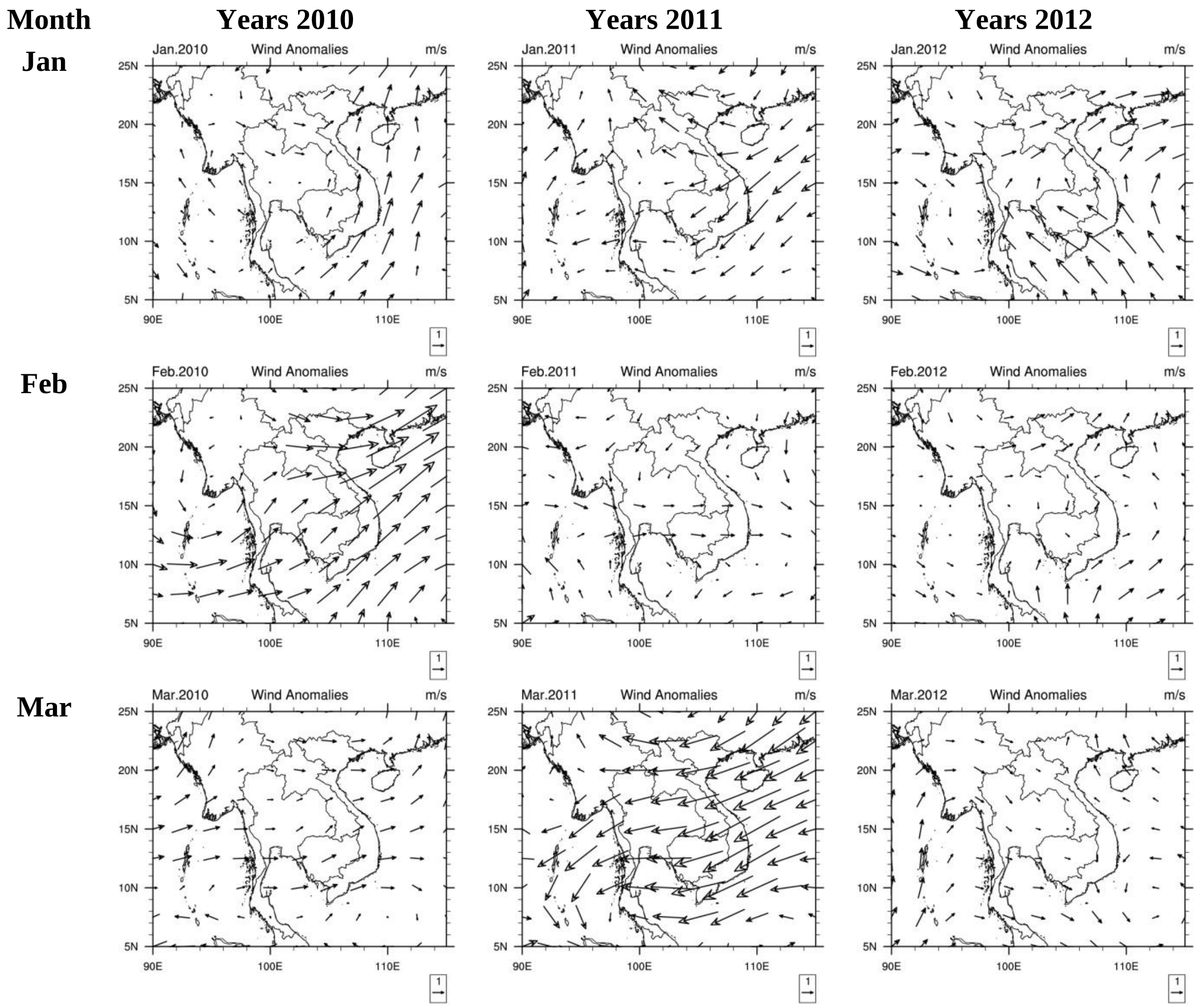


Figure 6 Wind anomalies at 850 hPa on January, February, and March in 2010, 2011, and 2012

Conclusion

Visualization of PM10 using a conventional calendar style proved easy to understand, and the annual haze episodes in northern Thailand were easily distinguished from periods of high PM10 concentration from January to April. In this region, severe haze episodes occur most frequently from March to early April. However, the data also highlighted the absence of haze episodes in 2011. Analyses of related data point to some possible explanations: reduction in number of fire hotspots, changing rainfall amount, and changing wind circulation all appear to have played a role in reducing PM10 concentrations in 2011. However, flooding and the ENSO were ruled out as influencing factors. Further study should focus on the relationship between PM10 level and wind variability, and on the role of the PBLs. A greater understanding of these linkages may contribute to effective management of the haze problem.

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