NUMERICAL STUDY OF THE ROLE OF ENSO ON THE TRANSPORT OF BIOMASS BURNING EMISSION FROM INDOCHINA TO ELEVATED GROUND IN TAIWAN

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1. INTRODUCTION

The farmland clearings and wildfires have recurred over the years during the dry season in the northern Indochina (Lin et al. 2013). The biomass burning (BB) plumes was found to be transported to southern China, Taiwan and even across the Pacific Ocean. The fire hot spots are detected as soon as December and last until May, however, the transboundary BB plume is not commonly apparent until the month of March and April at the elevated ground in Taiwan, LABS (Lulin Atmospheric Background Station; 2862m AMSL; 23°28'07'' N, 120°52'25'' E).

The India-Burma trough has subsided and brought in dry air to fuel the fire (Huang et al. 2016), while the higher terrain and its leeside vortex over the northcentral Indochina have lifted the BB plume into the subtropical Pacific high (700 to 800 hPa) (Lin et al. 2009, 2013). The plume is then transported eastward to LABS. It is also discovered that the coincidence of Asian dust storm and Indochina biomass burning is able to carry large amount of particulate matters to the lower surfaces of Taiwan with high population (Dong et al. 2018).

The El-Niño Southern Oscillation (ENSO) system is the positive anomaly of sea surface temperature and wind over tropical eastern Pacific Ocean which occur on a frequency of 3 to 5 years. The presence of ENSO can induce a hot and dry weather condition over the Southeast Asia region. Therefore, it can reduce moisture and creates a conducive environment for burning (Li and Wen 2016; Huang et al. 2016). From which the north-shifting ITCZ (Wang et al. 2001) can lift the burning plumes further up into the subtropical jet stream. Several studies have also confirmed that the ENSO can enhance the formation of high-pressure anti-cyclone in the South China Sea (SCS) (Yen et al. 2013; Chuang et al. 2015) and strengthen the high pressure outflow from the continental Asia (Chen et al., 2004). Either the sole or the coupled influence of the ENSO are likely to affect the burning and emission as well as maneuver the transport direction of flow.

The work has attempted to study the role of ENSO on the transport of the plume with the WRF-CMAQ model by incorporating the in-line plume rise module for the biomass burning emissions. It also improves the prediction of pollution transport episode from Indochina to Taiwan.

2. BACKGROUND STUDY

The study has used the Multivariate ENSO Index (MEI) from ESRL as ENSO indicator. It accounts for several parameters to ensure the credibility of the indicators. This includes the sea-level pressure, U- and V- of the surface wind, sea and surface air temperature, and total cloudiness fraction of the sky.

When MEI is larger than 0.5, it indicates strong ENSO, while MAI smaller than -0.5 indicates strong La-Niña. From Figure 1, it is discovered that the higher pollutant levels (CO > 300 ppb, PM10 > 35 ug m^{-3}, PM2.5 > 30 ug m^{-3}) are recorded at LABS when the previous year experienced stronger ENSO winter (Dec to Feb), as seen in 2007, 2010 and 2012. Knowing that the potential influence of the ENSO system to the high pollutant period in LABS, the paper has further extended to look at the respective role of ENSO on the burning activities and emission production on site, as well as its contribution on the transport of plumes to LABS. The former is studied with existing satellite and reanalysis data while the latter utilizes the WRF-CMAQ chemical transport model.

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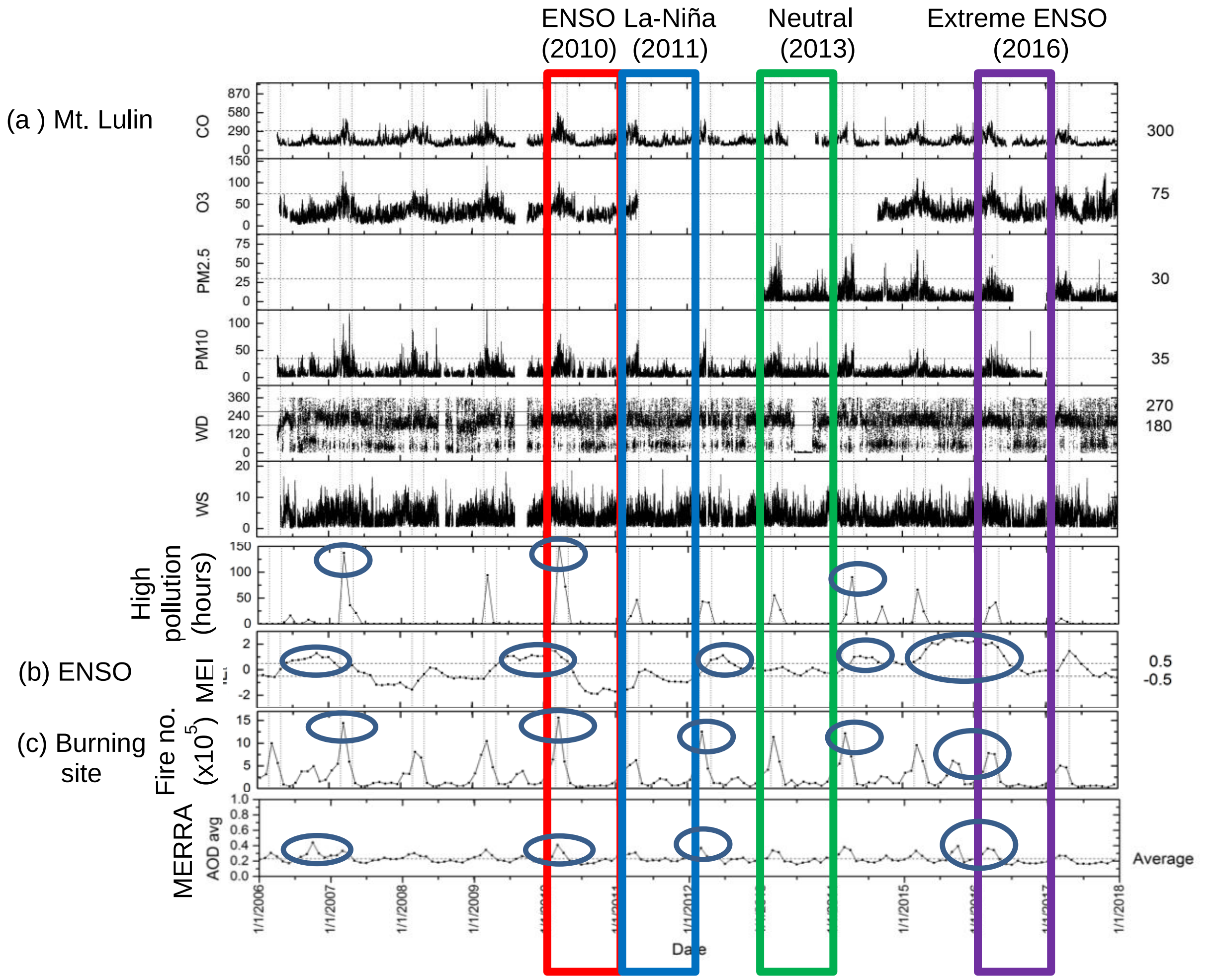


Figure 1: (a) Hourly variation of CO, O_3, $PM_{2.5}$, PM_{10}, wind direction, wind speed and monthly high pollutant hours at LABS; (b) Monthly ENSO MEI value (Strong ENSO if MEI>0.5; strong La-Nina if MEI < -0.5); (c) Monthly total MODIS fire count and averaged MERRA AOD within transport route. Blue circle indicates strong ENSO period, while colored boxes indicates years chosen for different weather anomaly conditions.

3. METHODOLOGY

The WRF v3.9.1 is used to generate the 40-layers vertical weather field and CMAQ v.5.2.1 as the chemical transport model. The model settings are given in Table 1. The current model settings incorporate the in-line plume rise model which acquires weather data, location of burning, injection height, emission rate and buoyancy flux. The module facilitates the inclusion of biomass burning emission on daily basis to determine the plume rise directly according to the atmospheric inversion layers. From here onwards, we have used different years to indicate different ENSO condition: 2010 (ENSO), 2011 (Neutral), 2013 (La-Niña), 2016 (extreme ENSO).

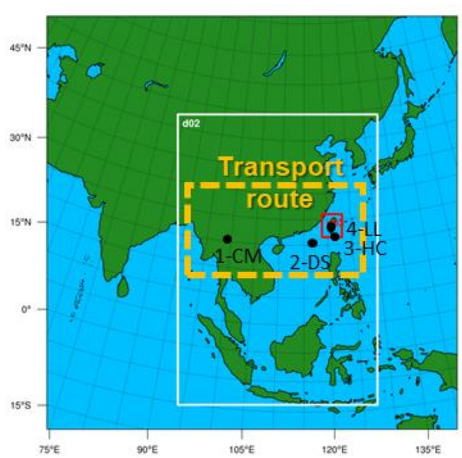


Figure 2: Domain settings of model. Black dots are location of stations verified in Figure 3a.

Table 1: Model settings

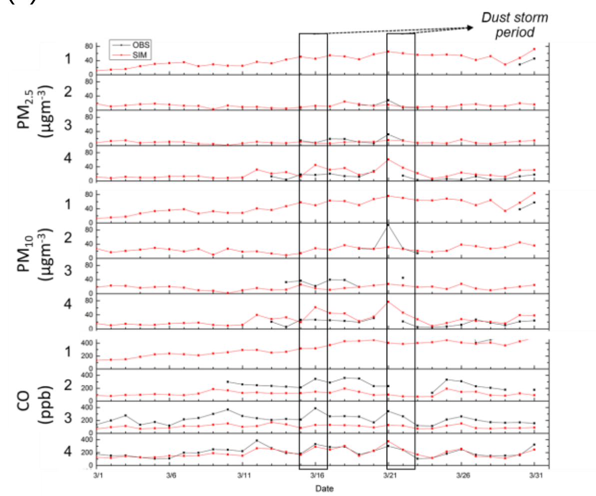
Domain	Settings
1st domain	Include LRT of Taiwan emission to entire SEA
2nd domain	Cover transport route
3rd domain	Taiwan (Receptor)
Weather model	WRF version 3.9.1; NCEP FNL lateral boundary condition; with nudging
Period	1st– 31th Mar • Control Run: 2010 • Run with 2010 emission inventories: 2011, 2013, 2016
Gas-phase chemistry and aerosol mechanism	CB05e51 + AE6 (with aqueous chemistry)
Emission inventory	d01, d02: MICS-ASIA 2010 include biogenic emission produced from MEGAN 2.10 d03: Taiwan local emission inventory (TEDS v8.0)
Biomass burning emission	FINN v1.5 + CMAQ in-line plume rise algorithm

4. CASE STUDY OF 2010

In the strong ENSO year of 2010, a total of 94 hours is recorded as high pollution episodes in LABS. The HYSPLIT backward trajectory suggests that the emission is originated from the northern Indochina region where the burning occurred. This agrees well with the large numbers of hot spots (approx. 156,000 detected by MODIS satellite) and high AOD value (MERRA-2 reanalysis data) within the transport route. According to the MERRA-2 AOD and 700 hPa wind profile data (Figure 4), the longer influence period of biomass plumes in LABS is mainly caused by frequent extension of cold surge and SCS anticyclone activities over Taiwan. The CMAQ model has, therefore, attempted to reproduce the biomass burning transport case of 2010.

The model output is compared with the available observation data on the daily CO, $PM_{2.5}$, PM_{10} in Figure 3a. With the limited amount of data, the model result agrees well with the observation data at the burning site (Station 1) on the last 2 days, while the receptor site (Station 4) shown good correlation of the CO variation.

(a)



(b)

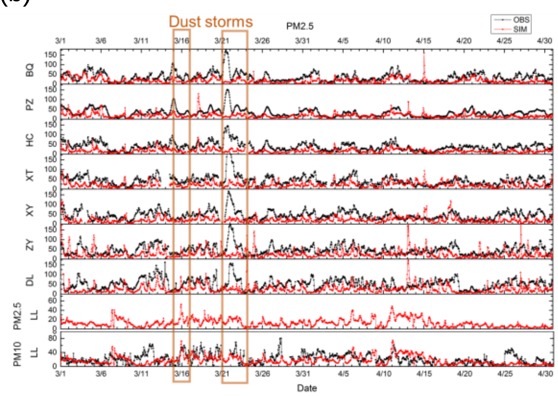


Figure 3: (a) Verification of daily CO, $PM_{2.5}$, PM_{10} with observation data for (1) ground level burning site, (2,3) ground station stations along transport route in d01, (4) high ground LABS receptor site, The sites are marked in Figure 2; (b) The comparison of hourly $PM_{2.5}$ and PM_{10} with the observation data at ground measurement sites in Taiwan at d03

The model has underpredicted the $PM_{2.5}$ and PM_{10} for the two ground stations along the transport route. Similarly, the hourly variation of modelled $PM_{2.5}$ (PM_{10} at LABS) for stations in Taiwan (Figure 3b) showed the underestimation of the pollutant level mainly occurred during the event of dust storm from Gobi Desert (https://taqm.epa.gov.tw/dust/tw/default. aspx). Such negative bias is expected since the windblown dust scheme in CMAQ is still under testing and therefore is not activated in this context. The model showed satisfactory MFB and MFE during biomass burning period, after dust storm period is removed (not shown). Aside from the dust storm, several mixed events of exceedance due to biomass burning from

Indochina and dust storm from the Gobi Desert has also occurred. The mixed occurrence is likely to further hike up the pollution levels due to subsidence of the cold surge (Dong et al. 2018).

5. ROLE OF ENSO

5.1 Burning activities and biomass burning emissions

At the burning site, MODIS fire count and MERRA monthly average AOD within the transport route (10°N to 30°N, 90°E to 120°E; yellow dashed box marked in Figure 2) are used to represent the burning activities and emission formed respectively. As shown in Table 2, the ENSO year showed the greatest number of burning hotspot detected, AOD values recorded as well as high pollutant hours in LABS. This implies that the burning plumes has in fact being transported to LABS. This is different from the case of extreme ENSO which high AOD is measured within the usual transport route, but number of polluted hours are lesser than the Neutral year.

Table 2: Total fire hotspot, averaged AOD value within transport route and total polluted hours in LABS during 4 different weather anomaly condition in March

Mar	Fire Hotspot ($x10^5$)	Avg AOD	LABS polluted hours
2010	**15.6**	**0.41**	**94**
2011	5.2	0.30	15
2013	11.3	0.34	55
2016	7.8	0.36	31

5.2 The biomass burning haze transport

The hourly simulation output of $PM_{2.5}$, PM_{10} and CO are show in Figure 4. The number of high pollution hours at LABS in the sequence of less to most is given as La-Niña, ENSO, Neutral, Extreme ENSO.

During the La-Nina, there is less cold surge and/or SCS cyclone, but the intrusion of cold surge tends to arrive at the north SCS region (Zhang et al, 2011). It is then able to carry the plume southwards, which the pollutants are dispersed over large area and becomes lower in concentration as shown in Figure 5. For the

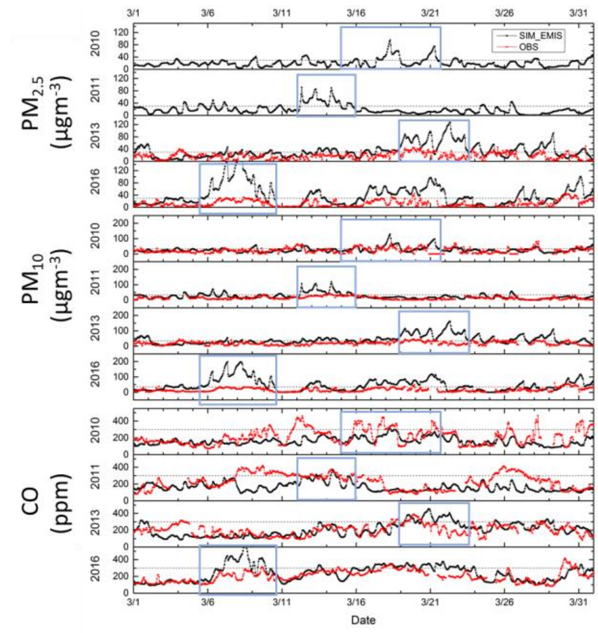


Figure 4: Hourly variation of $PM_{2.5}$, PM_{10}, CO from model output for each simulation of different year: 2010, 2011, 2013, 2016 but with the same emission inventory, including biomass burning. The blue boxes are period extracted for discussion in Figure 5.

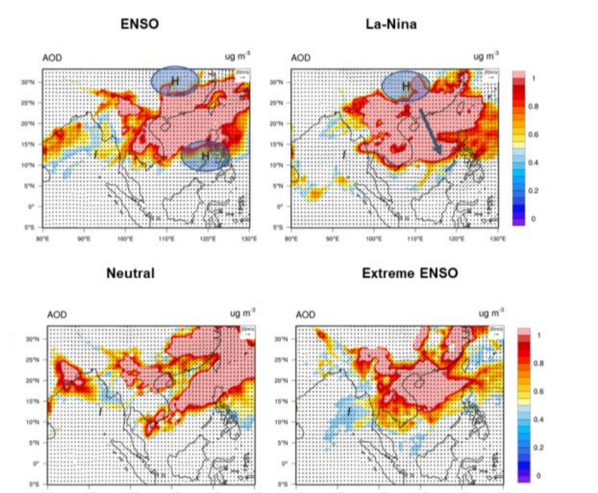


Figure 5: Modelled AOD column distribution and surface wind profile under the 4 types of weather anomaly condition in March.

Neutral year, the frequent hours of high pollution have occurred due to the concurrent events of weather condition conducive for transport with high burning emission on site (not shown), e.g. 2013. During the ENSO, the strong cold surge (Chen et al, 2004; Wu and Leung, 2009) and SCS anticyclone (Zhang et al, 2011; Yen et al. 2013) that induced a push-and-pull effect when either one is prevailed. The latter, usually the cold surge, can give few days clear of pollutant to LABS. The SCS anticyclone inhibits plume to carry southwards and causes the higher concentration being transported eastwards. The mechanism of extreme ENSO condition is similar with ENSO condition, but the cold surge occurs more frequently (Geng et al, 2017) hence brings in more emissions into Taiwan.

6. CONCLUSION

The burnings (hotspot counts and burning area AOD) in northern Indochina are greatly influenced by ENSO condition, but not for the extreme ENSO episode. Transport of biomass burning plume is governed by the interaction of cold surge from East Asian monsoon and SCS anticyclone – ENSO might not be as conducive as other condition, but most conducive during the extreme ENSO period. Hence, burning and emission control are important during both ENSO and extreme ENSO years; ENSO is prone to create dry environment for burning to sustain, extreme ENSO years can transport more emission to LABS. This has also intrigued another question to understand the role of upwind weather anomaly on the burning and vertical lifting on the burning site

In this paper, in-line plume rise model is applied in CMAQ model. The model showed fairly well performing AOD and pollutant result during biomass burning period, however, the further effort will need to look into the distribution of PM species and vertical lifting and distribution of the plumes. Follow-up work will also be done to improve the model performance by calibrating the fire and regional emission inventories, as well as focusing on cases when there is only influence of biomass burning emissions.

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Data List

ENSO MEI: ESRL: Physical Sciences Division (2018), https://www.esrl.noaa.gov/psd/enso/mei/table.html

MERRA-2 Analyzed wind vectors: GMAO (2015), M2I6NPANA, GES DISC, 10.5067/A7S6XP56VZWS

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