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Original Article

Climate change impacts on air quality-related meteorological conditions in upper northern Thailand

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Abstract

In this study, the outputs from Weather Research and Forecasting (WRF) regional climate model that has been dynamically downscaled the ECHAM5 Global Climate Model was used to investigate the regional climate change impact on air quality–related meteorological conditions in upper northern Thailand. The analyses were compared between the future (2045–2064) and present (1990–2009) of the downscaled climate results. The meteorological variables that can potentially affect the regional air quality include temperature, planetary boundary layer height (PBLH), wind speed and ventilation index were analyzed during the majority air pollution season (haze season, January-April) in the study area. It was found that increase in T_{max} can cause the increase of pollution sources while the increase in T_{min}, causing the reduction of the vertical dispersion potential of pollutants, and yielding a favorable meteorological condition for pollutant accumulation. The surfaces wind and PBLH were predicted decreasing during air pollution season in the future, leading weaker ventilation rate in this region.

Keywords: climate change, climate impacts, air quality, meteorology, Thailand

1. Introduction

Upper northern Thailand is an area of vulnerability to weather changes, due to its geographic location consisting of complex mountains and basins. In addition to such complex meteorological conditions, the area often suffers from air pollution problems, especially air pollution from the biomass burning haze. Concentrations of particulate matters with an aerodynamic diameter smaller than 10 mm (PM10) consistently exceed the national air quality standard levels, and this area is ranked as one of the regions with the highest PM10 concentration nationwide in the haze season. The number of days where the PM10 levels exceeded the national standards was varied 30-40% of the monitoring days (120 days) during the haze season each year (The Pollution Control Department [PCD], 2015). During the haze problem, there was an increase in the number of respiratory patients, such as asthma, admitted to the hospital, which significantly increased their association with the amount of particulate matter (Wiwatanadate, Wiwatanadate, Liwsrisakul, Yipmantasiri, & Inpunkaew, 2007). The PMs, especially PM2.5 can penetrate deeply into the lung and be retained in lung tissue, resulting in lung cancer (Vinitketkumnuen, Chewonarin, Taneyhill, & Chunrum, 2007). Several previous studies worldwide had discovered the correlations between mortality and fine-particle air pollutants (Gonçalves *et al.*, 2005; Lee, Jo, & Chun, 2015; Peng, Dominici, Pastor-Barriuso, Zeger, & Samet, 2005; Pope *et al.*, 2002; Tagaris *et al.*, 2009). Analysis of factors that affect the air quality in the specific area is considered very important. Emission source is one important factor affecting air quality in the area which if they lack control it will result in poor air quality. The geographical terrain is another factor that plays an important role for regional air quality, especially in the mountainous areas are complex and characterized by valleys,

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which are more likely to experience air pollution than flat areas (Clements, Whiteman, & Horel, 2003; De Wekker & Whiteman, 2006; Dorninger *et al.*, 2011; Silcox, Kelly, Crosman, Whiteman, & Allen, 2012; Whiteman *et al.*, 2001; 2004; Zhong & Whiteman, 2008; Zhong, Whiteman, Bian, Shaw, & Hubbe, 2001). This geographic factor could not be avoided for the local people except they migrate to another area. Another important factor is the meteorological conditions of the area such as temperature, wind speed and direction, mixing height and atmospheric stability, respectively. These meteorological conditions are varying from season to season, and climate change due to global warming has also affected these meteorological changes (Dawson, Bloomer, Winner, & Weaver, 2014; Jacob & Winner, 2009; Pasch, MacDonald, Gilliam, Knoderer, & Roberts, 2011). There are some of the previous studies have investigated the potential impact of climate change on regional air quality. For instance, the Los Angeles regional climate change could increase ozone and PMs concentration through feedbacks to meteorological fields such as temperatures, atmospheric stability, winds, precipitation, etc. (Jacob & Winner, 2009). While the regional air quality is predicted to get worse in quality over the continental United States caused by the future changes in meteorological fields, such as surface temperature, solar radiation, and ventilation, especially during fall (Leung, 2005). The Ventilation Index is a numerical value used in air pollution meteorology, related to the potential of the atmosphere to disperse air pollutants which based on the wind speed in the height of mixed layer (Lin, Holloway, Carmichael, & Fiore, 2010; Mukhopadhyay *et al.*, 2014; Zhao *et al.*, 2011). It plays an important role in the turbulent transport of air pollutants (Miao *et al.*, 2015; Pal, Lee, Phelps, & De Wekker, 2014) Therefore, changing the ventilation index in the future can change the potential for air pollution problem.

In this study, the outputs of WRF model (Chota monsak, 2011; Chotamonsak, Salathé, Kreasuwan, Chantara, & Siriwitayakorn, 2011) that have been applied as regional climate model to dynamically downscale the ECHAM5 global climate data (named WRF-ECAHM5) were used to investigate the impact of climate change on upper northern Thailand air quality. Dynamical downscaling of GCMs adds more realistic spatial and temporal details to regional climate projections, especially obvious over regions with strong mesoscale forcing, associated with complex topography. Therefore, the advantage of WRF-ECHAM5 dynamical downscaling could add more realistic mesoscale features in upper northern Thailand where the topography is terrain complexity. Analyzes have focused on the potential impacts of air quality-related meteorological variables change on regional air quality in upper northern Thailand. The study results could give us an idea of the severity of air quality problem, which is very useful in planning, preventing and controlling air pollution in the future.

2. Experiments

In this study, the outputs from WRF-ECHAM5 regional climate model were used to investigate the regional climate change impact on air quality–related meteorological conditions in upper northern Thailand. This regional climate simulation has applied WRF as a regional climate model (Salathe, Zhang, Leung, & Qian, 2009; Zhang, Duliere, Mote, & Salathe, 2009) and dynamically downscaled ECHAM5 global climate model data (Jungclaus *et al.*, 2006; Roeckner *et al.*, 2003) to 60-km mother and 20-km nested domain gridded resolution. The selected parameterization schemes consist of the WRF Single-Moment 6-Class Microphysics (WSM6) scheme (Hong, Dudhia, & Chen, 2004), Betts-Miller-Janjic convective parameterization scheme (Janjic, 1994), Dudhia shortwave radiation (Dudhia, 1989), Rapid Radiative Transfer Model (RRTM) longwave radiation, the Yonsei University planetary boundary layer (PBL) scheme (Hong & Pan, 1996), the Noah Land Surface Model (LSM) four-layer soil temperature and moisture model with canopy moisture and snow-cover prediction (Chen & Dudhia, 2001), soil-state parameters from the NCEP/NCAR Reanalysis (NNRP) to initialize the lower boundary (National Center for Atmospheric Research, 2008). The WRF-ECHAM5 has been run under the IPCC AR4 SRES A1B emission scenario. The 20-year (1990-2009) is represented as the current climate and the 20-year (2045-2064) is represented as the future climate, respectively. The regional climate model reproduced well the observed spatial distribution of temperature with a slightly cold bias for maximum temperatures and warm bias for minimum temperatures (Chotamonsak, Salathé, Kreasuwan, Chantara, & Siriwitayakorn, 2011). The model output used in this study is 20-km grid spacing, was taken from the nested domain simulations. The meteorological variables that can potentially impact on the regional air quality include temperature, planetary boundary layer height (PBLH), wind speed and ventilation index were analyzed during the majority air pollution season (haze season, January-April) in the study area. Comparisons were made between the future (2045–2064) and present (1990–2009) downscaled climate results. To investigate the impact of climate change on regional air quality in upper northern Thailand, the air quality-related meteorological variables were selected based on the analyzed results of previous studies (Chotamonsak & Lapyai, 2018; He, Yu, Liu, & Zhao, 2013; Wang, Wu, & Liang, 2009; Zhao, Chen, Kleeman, Tyree, & Cayan, 2011). The selected air quality-related metrological variables consist of the maximum (T_{max}) and minimum temperature (T_{min}), near-surface wind speed (wspd10), plenary boundary layer height (PBLH) and ventilation index. The PBLH is a diagnostic variable in the WRF model that is calculated based on the instability and wind shear of the atmosphere. The ventilation index was calculated by multiply of the 10m wind speed and PBLH as shown in equation 1 (IVL Swedish Environmental Research, 2002).

$$\text{Ventilation Index} = \text{Wind Speed x PBLH} \qquad (1)$$

Figure 1 is the analysis area covering the nine provinces of upper northern Thailand including Chiang Mai (CMI), Chiang Rai (CRI), Phayao (PYO), Prae (PRE), Nan (NAN), Lamphun (LPN), Lampang (LPG), Mae Hong Son (MHS) and Tak (TAK).

3. Results and Discussion

The climate-induced changes to meteorological variables that affect air quality were explored by comparing the future (2045-2064) and present (1990-2009) 20-years averages during the haze season (January-April). The 20-year averages for this season were calculated for each grid cell

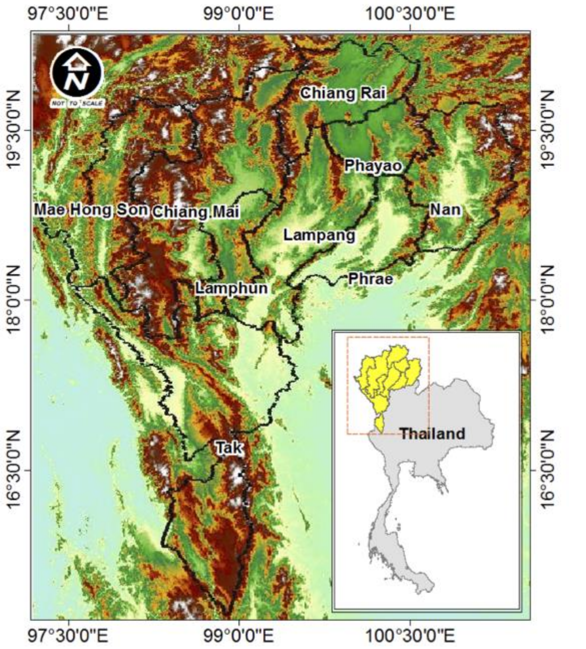

Figure 1. Topography of upper northern Thailand and analysis domain.

using the hourly averaged values in the analysis domain (the 20-km resolution domain). The spatial distributions of the differences between the 20-year future and 20-year present averages emphasize how different climate change could affect upper northern Thailand air quality.

3.1 Near surface temperature changes

The predicted future T_{max} changes (future–present) from WRF-ECHAM5 were positive (0.5-1.5 °C) for the whole domain during the haze season (Figure 2), and the largest temperature increase of 1.5 °C. The highest increase is seen in January while the lowest is predicted in February. The maximum daytime temperature was found to play an important role in upper northern Thailand air quality. The recent study found that the higher T_{max} could intensify the air pollution problem in term of intensifier the biomass burning which is the source of the major pollutants in the region (Chotamonsak & Lapyai, 2018). Therefore, the projected increase in T_{max} during the haze season in upper northern Thailand can cause the increasing of pollution sources in the future climate. The projected increase in daytime temperature in the future causing not only can increased fires emission sources but also increased in O_3 concentrations (Nolte, Spero, Bowden, Mallard, & Dolwick, 2018).

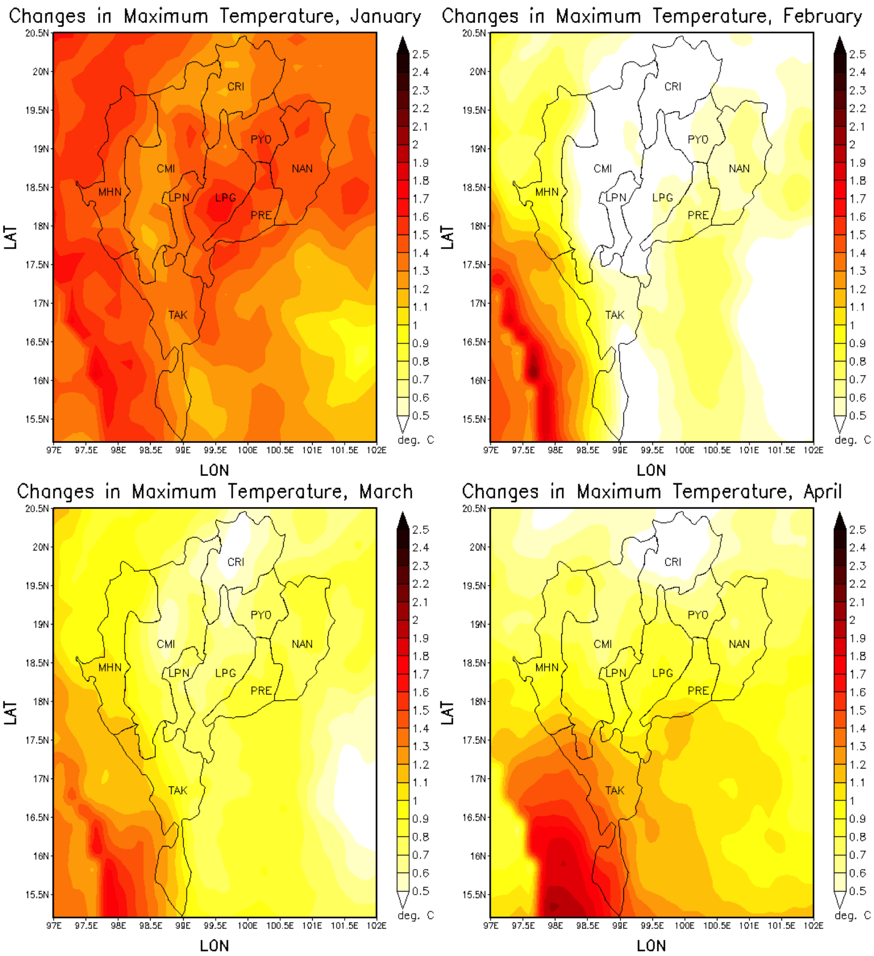

Figure 2. Predicted change in 20-year averaged T_{max} in haze season (January –April).

For T_{min} (Figure 3), the increase is expected much higher than that increase for T_{max}. The highest increase is seen in January while the lowest is also appealed in February. The nighttime temperature (T_{min}) shows a greater increase than daytime temperature (T_{max}) lead to a decrease of the diurnal temperature (DTR) (data not shown). This increase in DTR could affect to air quality problem in many ways. For instance, it causes to reduce the potential of vertical dispersion of pollutants, yielding a favorable meteorological condition for pollutant accumulation near the ground surface during haze season.

3.2 Near surface wind speed changes

Figures 4 show the spatial distribution of the changes in near-surface wind speed during the haze season. Overall, the wind speed decreased over almost regions of upper northern Thailand during the haze season, except in January. The regional-averaged change was approximately 0.5 m/s^2 in the future. These changes indicated a slightly weaker ventilation rate. The decreasing wind speed in February and March can affect the potential for the dispersion of air pollution, resulting in the pollutants accumulation over the study area, where the topography contained several small basins. Near-surface wind speed also plays major roles in the transport and dispersion of air pollutants in other areas (Goyal & Rama Krishna, 2002; Xue, Li, & Liu, 2015) because wind strength determines the extent to which pollutants are diluted at their source, weak winds can result in high pollutant concentrations.

3.3 PBLH changes

Figures 5 show the spatial distribution of the regionally averaged PBLH (mixing height) difference (future-present) during the haze season. The results revealed the decreasing of PBLH during haze seasonal over almost part of upper northern Thailand. In January and February, the PBLH is slightly decreased. However, some areas such as the western part of the study area (Mae Hong Son and western part of Tak Province) are likely to increase during the period. In March, the month for severe air pollution problem in upper northern Thailand, PBLH was predicted to decrease, especially in Chiang Mai-Lamphun basin. The highest decrease in PBLH is obviously appealed in April, with decrease ranges 60 to 100 meters compared to the 20-year baseline average. Previous studies have shown that aerosols are mainly concentrated within PBLH, and the low PBLH will lead to high

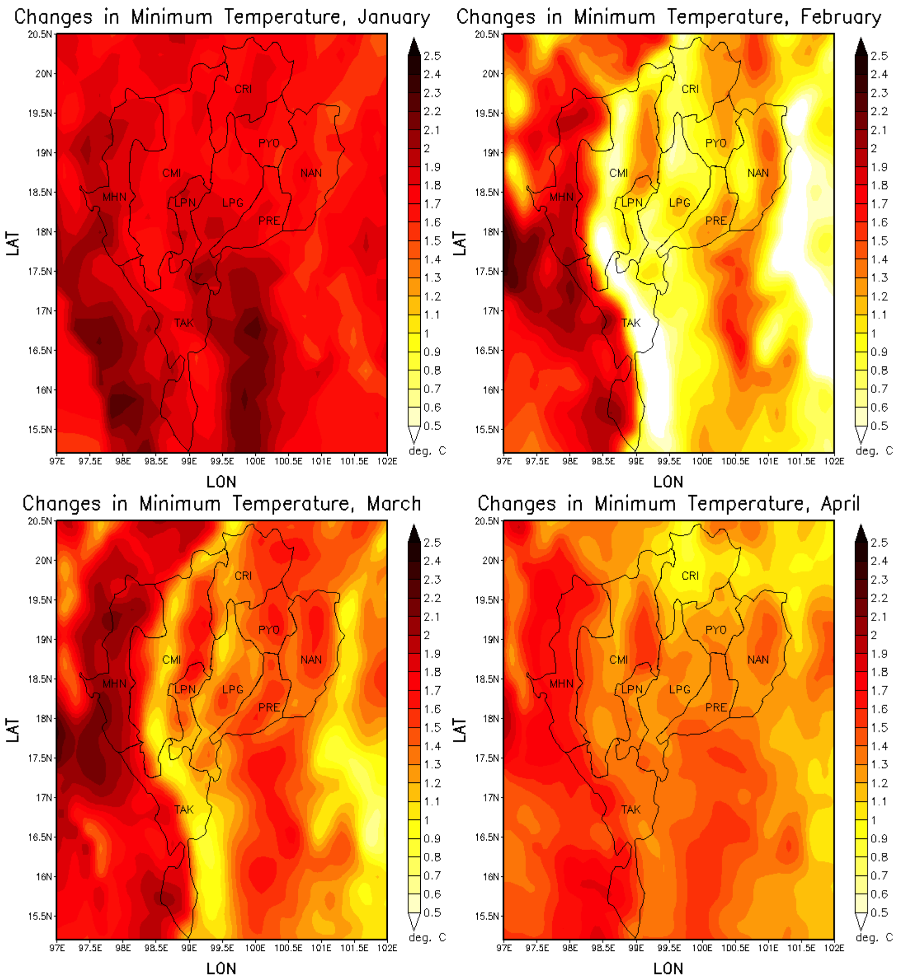

Figure 3. Predicted change in 20-year averaged T_{min} in haze season (January –April).

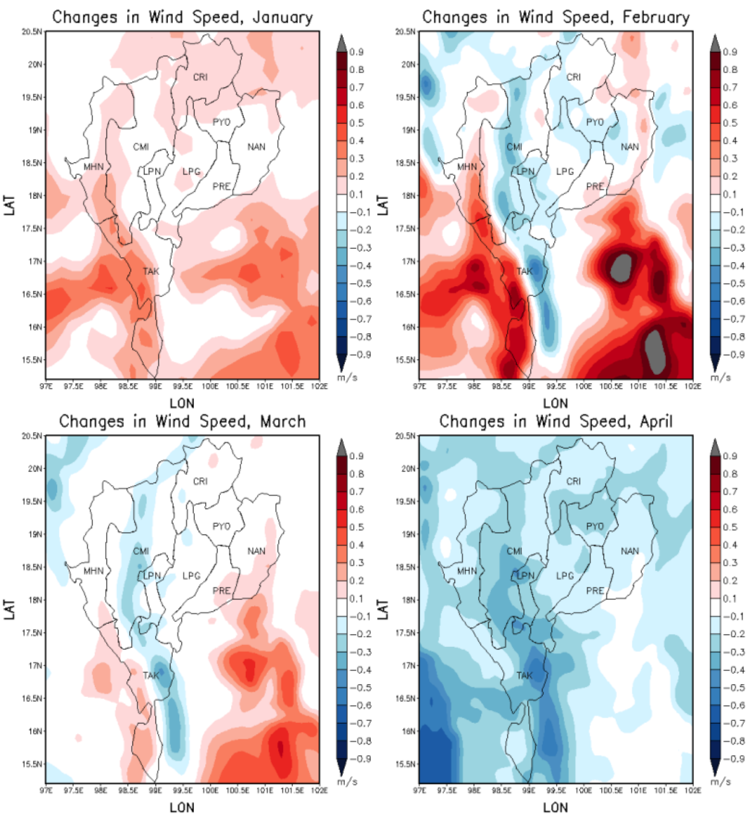

Figure 4. Predicted change in 20-year averaged wind speed in haze season (January –April).

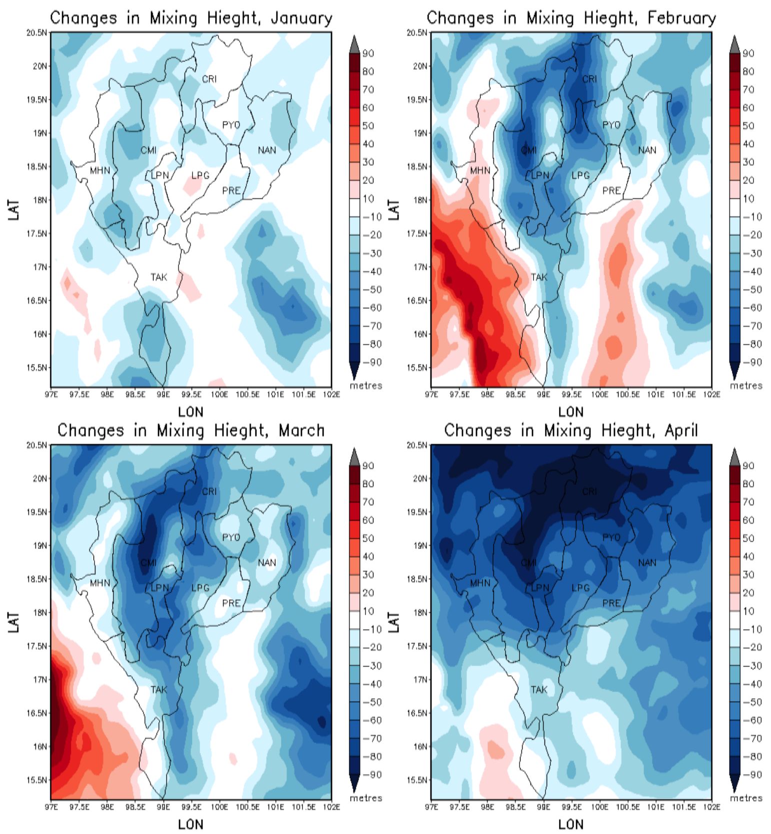

Figure 5. Predicted change in 20-year averaged Mixing Height (PBLH) in haze season (January- April).

particulates matter (PM) concentration (Qu, Han, Wu, Gao, & Wang, 2017). Therefore, the projected decrease in PBLH in the future indicates the decrease in the potential air updraft which is conducive to the accumulation of near-surface pollutants in upper northern Thailand.

3.4 Ventilation index changes

The change in PBLH and wind speed is correlated with the trend of change in the ventilation index. If the ventilation index indicates low, then the air pollutants can tend to build up, causing air pollution. The results show that the ventilation index (Figure 6) was unchanged in January over almost upper northern Thailand, but some areas the ventilation rate is predicted to increase. In February, March, and April, the ventilation rate was predicted to decrease almost the region, especially in April when a decreasing ventilation rate at maximum was predicted. Therefore, the trend of change in ventilation rate and its impact on regional air quality can be discussed. When the air pollution conditions and sources in each month in the future are the same that in the present, the change in ventilation rate will cause February, March, and April to have an intensify the air pollution problem. This due to the reduced of air pollution dispersion potential, resulting from reduced ventilation, causing air pollution will be limited in dispersion both vertical and horizontal air pollution and accumulated near the surface, make this area are likely to experience more air pollution problem in compared to the baseline years.

4. Conclusions

In this paper, the present and future air quality-related meteorological variables were analyzed from the outputs of the WRF-ECHAM5 regional climate data under the IPCC AR4 SRES A1B scenario. The spatial resolution of analyzed data is 20-km grid spacing over the 20-year (1990-2009) in the present and (2045-2064) in the future. The changes in the predicted future air quality-related meteorological factors during the haze season (January-April) were investigated to assess the future air quality situation in upper northern Thailand. Compared to the current climate, the upper northern Thailand air quality problem was predicted to increase during the haze season in the future through changes in meteorological factors. The projected increase in T_{max} during the haze season in upper northern Thailand can cause the increase of pollution sources in the future climate. The increase in night-time temperature (T_{min}) leads to the decrease of diurnal temperature (DTR), causing the reduction of the vertical dispersion potential of pollutants, yielding a favorable meteorological condition for pollutant accumulation near the ground surface during haze season. The decrease in near-surface wind

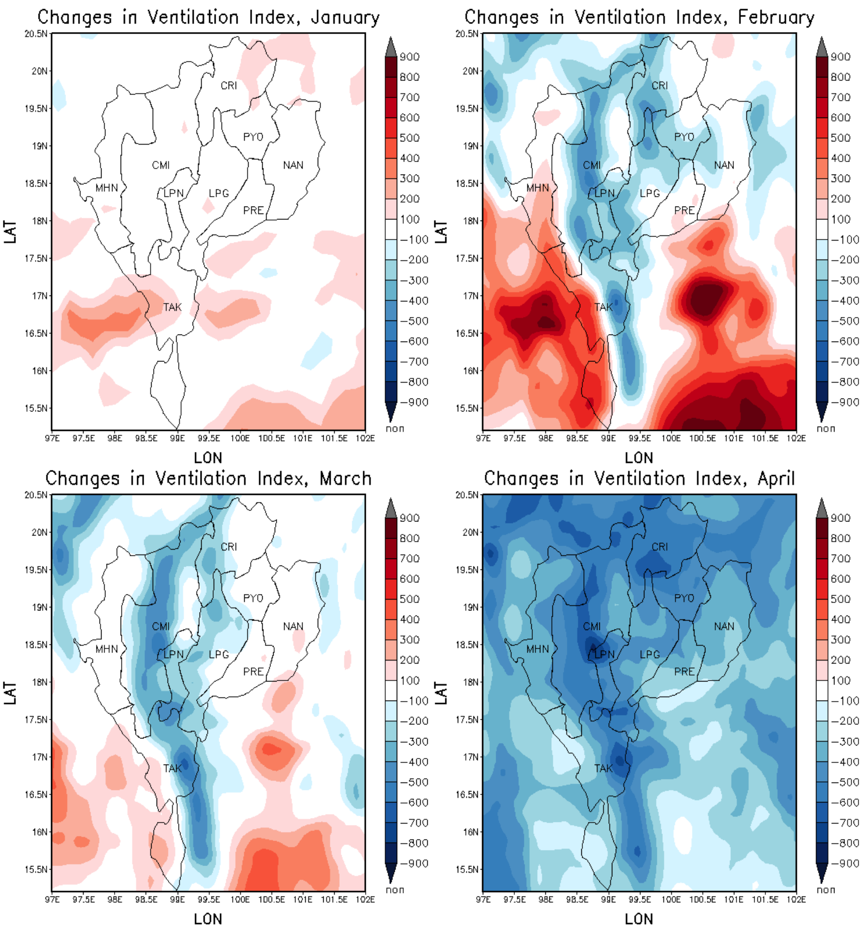

Figure 6. Predicted change in 20-year-averaged Ventilation Index in haze season (January –April).

speed during extreme pollution events can potential trap the pollutants close to its emission sources. The wind speed and PBLH were predicted to decrease. These factors would provide less ventilation rate which the suitable meteorological conditions for pollutants accumulation during the haze season. Therefore, upper northern Thailand is predicted to face with the intensifier air pollution problem under global warming and climate change.

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