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# Carbon Monoxide Emission and Concentration Models for Chiang Mai Urban Area

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## ABSTRACT

An emission inventory containing emissions from traffic and other sources was complied. Based on the analysis, Carbon Monoxide (CO) emissions from traffic play a very important role in CO levels in Chiang Mai area. Analysis showed that CO emissions from traffic during rush hours contributed approximately 90% of total CO emissions. Regional Atmospheric Modeling System (RAMS) was applied to simulate wind fields and temperatures in the Chiang Mai area, and eight cases were selected to study annual variations in wind fields and temperatures. Model results can reflect major features of wind fields and diurnal variations in temperatures. For evaluating the model performance, model results were compared with observed wind speed, wind direction and temperature, which were monitored at a meteorological tower. Comparison showed that model results are in good agreement with observations, and the model captured many of the observed features. HYbrid Particle And Concentration Transport model (HYPACT) was used to simulate CO concentration in the Chiang Mai area. Model results generally agree well with observed CO concentrations at the air quality monitoring stations, and can explain observed CO diurnal variations.

**Key words:** carbon monoxide, emission, concentration, Chiang Mai, RAMS, HYPACT

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## 1. Introduction

Carbon Monoxide (CO) is a highly toxic gas, which is considered a dangerous asphyxiant. Combined with haemoglobin of the blood it reduces the blood's ability to carry oxygen to cell tissues; high CO mixing ratio can directly affect human health. The oxidation of CO initiates photochemical reactions, which result in Ozone ($O_3$) production on a regional scale (Novelli et al., 1998). In cities, almost all of the CO is anthropogenic due to vehicle emission and fossil fuel combustion. Natural sources, such as forest fire and biomass burning, also produce huge quantities of CO. Pochanart (2003) studied surface CO variations from measurements during 1997–2000 in rural Thailand. The CO mixing ratios in Thailand show a strong seasonal variation with a maximum in the late dry season (February–March) and a minimum in the mid-wet season (July–August). In this study CO emission and dispersion on a local scale in Chiang Mai (18°78′N, 98°98′E, 312 meters above sea level) are studied. Chiang Mai is an important city for the regional administration, business, education, medical and is well known as a tourist and cultural city. Due to economic growth, Chiang Mai is facing environmental problems, especially the air pollution problem. Because of traffic congestion most vehicles emit many types of toxic gasses. Pollutants from the internal combustion process consist of Carbon Monoxide, Sulfur Dioxide, Nitrogen Dioxide, Hydrocarbons, and Lead etc. This study concentrated on CO which was emitted from traffic, industrial processes, airport, railway station, forest fire, fuel consumption and open burning. There are only 2 ambient air pollution monitoring stations, one in an urban area and the other in a suburban area, which do not cover the whole study area.

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The CO concentration at particular locations and particular times can be known by measurement. But to understand the air pollutant behavior in the environment, it requires the air pollution model for predicting the concentration of CO, which is important for making the environmental abatement regulation.

Up to now there have been many scientists (Schaltanek, 1991; Hao et al., 2000; Angius et al., 1995; Bogo et al., 2001; Goyal and Rama Krishna, 1998) that have estimated the pollutants from vehicular traffic, such as CO and $NO_x$. Tang (2002) used the MM5 and the regional Eulerian chemical transport model to simulate the pollutant emission at urban sites and power plants in Nashville, Middle Tennessee. Boybeyi and Raman (1995) constructed a three-dimensional mesoscale meteorological model based on coupling a mesoscale meteorological model with a Monte Carlo (Lagrangian particle dispersion model) plus embedding an Eulerian dispersion model into the mesoscale meteorological model, which applied to the Tennessee Plume field experiment. Sauto et al. (2001) compared the results of a Lagrangian Particle Model (LPM), and an adaptive Puff Model (APM) coupled to the same meteorological model to study the dispersion of pollutant ($SO_2$) from coal-fired As Pontes Power Plant in Spain.

This paper consists of a CO emission inventory study from various sources relevant to the Chiang Mai city in 2002, including wind fields study by using the Regional Atmospheric Modeling System (RAMS), and time spatial distribution of CO concentration over Chiang Mai city by using HYbrid Particle And Concentration Transport model (HYPACT).

## 2. CO emission inventory

Most CO in urban areas is generally emitted from the traffic activities in the transportation network. Therefore, this study focused on the emitted CO from the traffic source.

### 2.1 CO *from traffic*

The magnitude of vehicle emission rate is estimated by using emission factors, which vary by vehicle class, traffic volume and traffic speed in specific areas. This study adopted the Mobile-THAI model, which is based on the US EPA Mobile4 for predicting the vehicular emission factor. The traffic flow can be measured in various ways. The most accurate way is to count the number and detect the speed of vehicles passing a specific location mechanically or manually but is labor intensive and costly. Nevertheless, it is not realistic to count traffic volume on all roadways; therefore, TRANsport PLANning model, TRANPLAN, was adopted for estimating the traffic flow in this study. For a road link, the total CO emission rate can be computed by multiplying the emission rate with the traffic volume. The traffic emission rate can be estimated by using the formula:

$$Q = EV \ , \tag{1}$$

where $Q$ is traffic emission rate, $E$ is emission factor, $V$ is traffic volume.

### 2.2 CO *from other sources*

The other sources emission rates were determined by the US EPA emission factors.

## 3. Model used

In this study the Regional Atmospheric Modeling System (RAMS) was used to calculate the meteorological data set, which includes temperature, and wind fields covering the domain 18.3°N to 19.7°N and 98.4°E to 99.5°E, with the resolution 2000 m×2000 m in the horizontal and 50 layers in the vertical up to 1000 m. For calculation of the CO concentration and dispersion the Hybrid Particle And Concentration Transport model (HYPACT) was used.

## 4. Model test

The meteorological data set for input into RAMS are taken from the European Center for Medium range Weathers Forecasts (ECMWF), which 8 cases, i.e., May 2002–August 2002 were selected as the case study to represent the local wet season and February 2002–April 2002 and December 2002, were selected as the case study to represent the local dry season. The HYPACT calculated CO concentration and distribution by using meteorological data set from RAMS and CO emission rates from emission inventory results.

## 5. Results

### 5.1 *Emission inventory*

#### 5.1.1 CO *emission rate from traffic*

The output from TRANPLAN showed that in the urban area, especially the areas that generate and attract trips, the traffic volumes were higher than the other areas. But the traffic speeds were lower than the other areas. The forecasted traffic volumes and traffic speeds from the TRANPLAN model were combined with the emission factors from the Mobile-THAI; the results of this methodology are the CO emission rates from traffic. In order to conveniently incorporate data into the HYPACT, the CO emission rates from traffic were transformed into spatial grids. The Chiang Mai urban area was divided to 100 grids of 1 km×1 km in each grid. Consequently, the CO emission rates in each

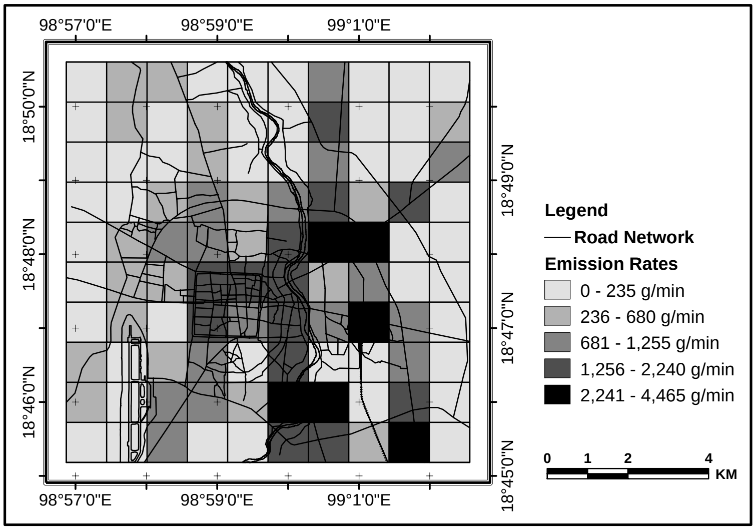

**Fig. 1.** CO emission rates from traffic in Chiang Mai urban area.

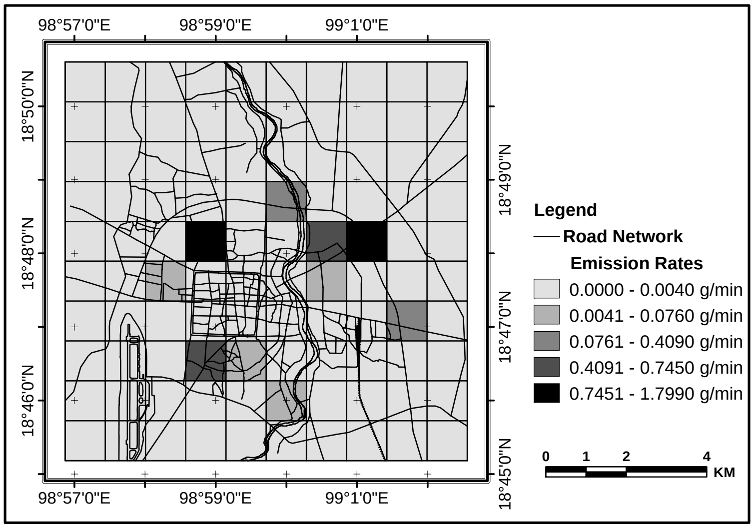

**Fig. 2.** CO emission rates from medical waste incinerator and crematorium in Chiang Mai urban area.

grid were produced. The high CO emission rates from traffic area sources corresponded to the locations where the traffic activities occurred, such as arterial road, major collector road, and major intersection as shown in Fig. 1.

#### 5.1.2 CO *emission rate from the other sources*

The CO emission rates from medical waste incinerator and crematorium correspond to the locations where they are located, as shown in Fig. 2.

The high CO emission rates from biomass burning correspond to the locations where the forest fire often occurs, such as the hill slope of Suthep-Pui mountain range and open burning from agricultural residue area, as shown in Fig. 3.

#### 5.1.3 *Combined* CO *emission rates*

When all sources were combined, the CO emission rates from traffic showed the dominant source when compared with the other sources. It contributed to about 90% of the CO emission rates during the traffic rush hour. The combined sources in Chiang Mai urban area are illustrated in Fig. 4.

### 5.2 *Model results*

#### 5.2.1 *Diurnal variation of simulated and observed wind fields*

In this study, May 2002–August 2002 were selected as the case study to represent the local wet season and

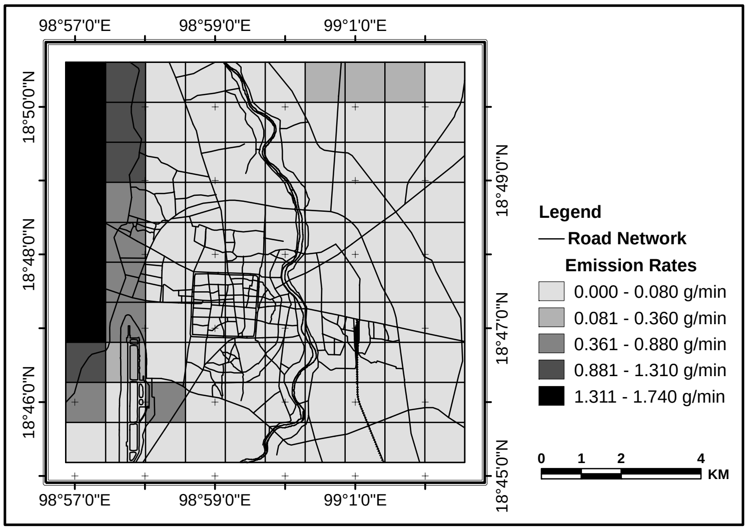

**Fig. 3.** CO emission rates from biomass burning in Chiang Mai urban area.

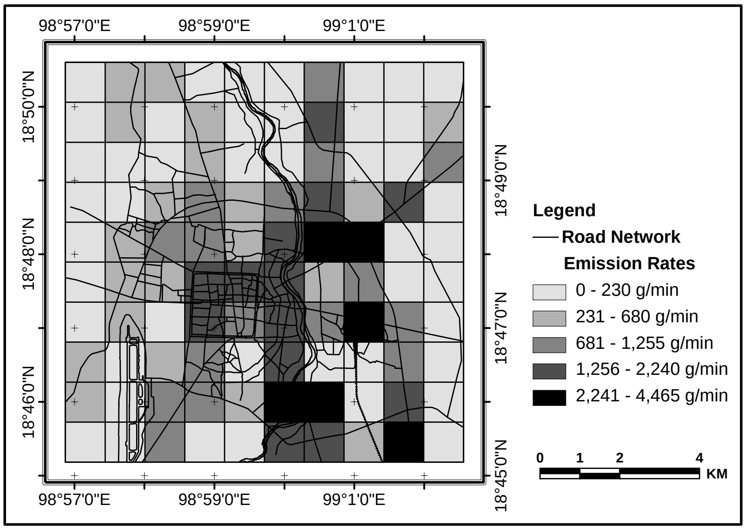

**Fig. 4.** CO emission rates from combined sources in Chiang Mai urban area.

February 2002–April 2002, December 2002 were selected as the case study to represent the local dry season. The two days (48 h) in each month were selected to represent for these months. The simulated wind fields from RAMS at 50 meters above ground surface were compared with the observed wind fields from the meteorological monitoring station.

The example time series (LST) of wind vectors in each season are shown in Figs. 5–6. During the selected period, the wind generally blows from a southern direction (South wind) in the wet season and blows from northern and southern directions (North and south winds) in the dry season. Even though RAMS's grid size is 2 km×2 km and the observed wind fields are 1 hour average, RAMS can generally simulate the diurnal variation in good agreement with the observed data.

The model evaluation of RAMS by adopting the Factor of Two is shown in Table 1.

The model evaluation of RAMS in wind fields shows a good performance (most model performances exceed 70 percent) during the wet season. During the dry season the model shows a quite good performance (most model performances exceed 50 percent).

### 5.2.2 *Diurnal variation of simulated and observed temperatures*

The simulated temperatures from RAMS at 50 meters above ground surface were compared with the observed temperatures from the meteorological monitor-

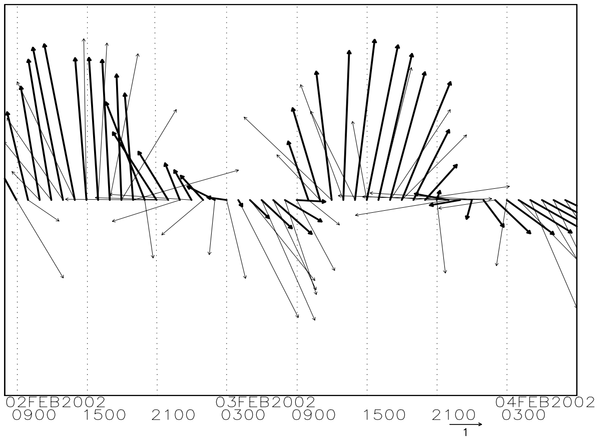

**Fig. 5.** Simulated (thick) and observed (thin) wind fields at 50 m, above ground surface at the meteorological monitoring station during 2–4 February 2002 (Dry season).

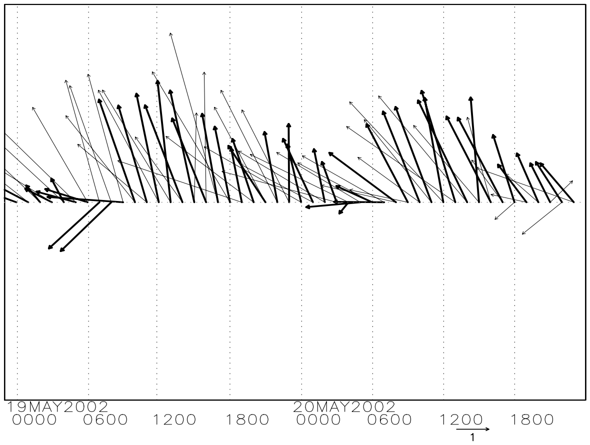

**Fig. 6.** Simulated (thick) and observed (thin) wind fields at 50 m, above ground surface at the meteorological monitoring station during 19–20 May 2002 (Wet season).

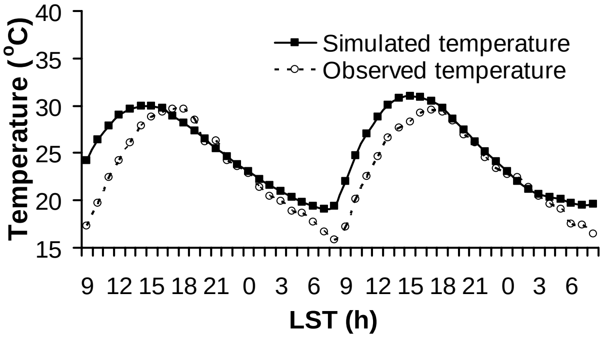

**Fig. 7.** Simulated and observed temperatures at 50 m, above ground surface at the meteorological monitoring station during 2–4 February 2002 (Dry season).

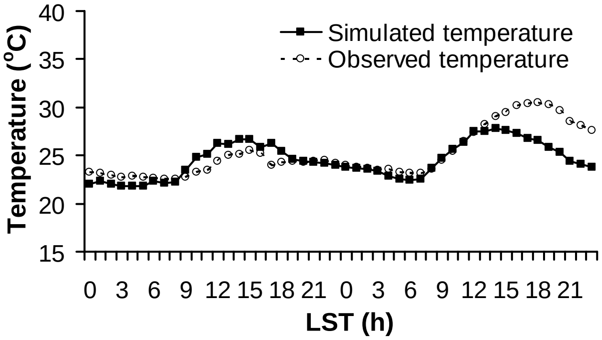

**Fig. 8.** Simulated and observed temperatures at 50 m, above ground surface at the meteorological monitoring station during 19–20 May 2002 (Wet season).

ing station. The example time series of temperatures in each season are shown in Figs. 7–8. During the selected period, the temperature diurnal variation in the dry season generally showed a higher variance than the wet season because of the effect of solar radiation. This study found that RAMS's simulated temperatures are in very good agreement with the observed temperatures.

### 5.2.3 *HYPACT output*

In order to evaluate the model output, the observed CO concentrations from the sub-urban air quality monitoring station, 18.84°N and 98.97°E, and urban air quality monitoring station, 18.79°N and 98.99°E were compared with the simulated CO concentration results from HYPACT, as shown in Figs. 9–10. The model evaluations show a good relation between the simulated and the observed CO concentrations. The high simulated CO concentrations were corresponded to the morning traffic peak hour when the traffic activities were higher than in the other periods. The variations of CO concentrations at the urban air quality monitoring station are higher than the sub-urban

**Table 1.** Model performances in wind fields.

| Month | Date | Model performance (%) | |
|---|---|---|---|
| | | Wind speed | Wind direction |
| Dry season | | | |
| February | 2–4 | 69 | 58 |
| March | 7–8 | 58 | 77 |
| April | 19–20 | 54 | 63 |
| Wet season | | | |
| May | 19–20 | 77 | 75 |
| June | 16–18 | 75 | 56 |
| July | 14–15 | 71 | 77 |
| August | 5–6 | 60 | 71 |
| Dry season | | | |
| December | 5–7 | 46 | 48 |

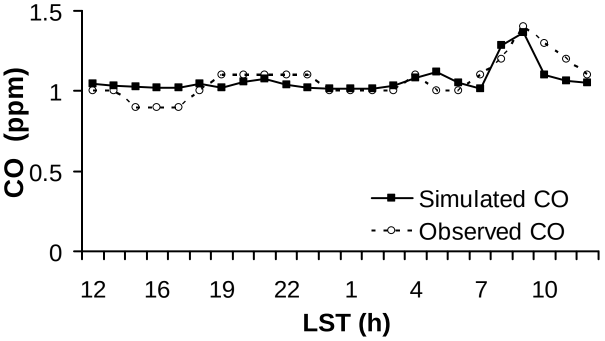

**Fig. 9.** The diurnal variation of simulated and observed CO concentration at sub- urban air quality monitoring station during 7–8 March 2002.

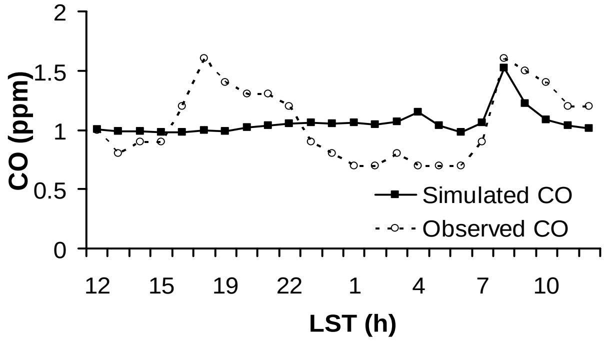

**Fig. 10.** The diurnal variation of simulated and observed CO concentration at urban air quality monitoring station during 7–8 March 2002.

air quality monitoring station caused by the high variation of the traffic volume adjacent to the station. Sometime the relations between simulated and observed CO concentrations at the urban air quality monitoring station are not good, because not only the CO concentration depends on the emission rate but also the effect by the wind field. It may be affected by the error of emission rate due to this site adjacent to the heavy traffic in the major intersections. Furthermore, the urban air quality monitoring station is surrounded by the buildings which the friction forces of the Earth surface may affect the observed wind speed and observed wind direction.

Figure 11 shows the vertical wind fields and CO distribution at the topography cross section where air passes the location of the sub-urban air quality monitoring station during 0800–1000 LST and 1800–2000 LST 19 May 2002. The $x$-axis shows the Longitude (degrees) and $y$-axis shows the number of vertical levels. The solid line (positive number) and dash line (negative number) illustrate the contour line of upward and downward wind respectively; the unit of wind speed is meters per second. The grey scale illustrates the CO concentration in ppm and the numbers below these figures show the scale of CO concentration.

During morning traffic rush hour (0700–0800 LST) the high CO emission rate was emitted. In addition, the mixed layer (ML) occurred due to solar heating of the ground and began to grow in depth. The CO was emitted and rose from the earth's surface by the effect of ML. The high CO concentrations occurred during the traffic rush hour and decreased with time.

During afternoon traffic rush hour (1700–1800 LST) the high CO emission rate was emitted. But the high CO concentration occurred at 2000 LST, due to the effect of the boundary layer.

## 6. Conclusions

In this study the CO emission rate and concentration in Chiang Mai city were studied. The CO emission rate from traffic source was estimated by using: (1) TRANsportation PLANning model (TRANPLAN), which predicted the traffic volume and traffic speed in the Chiang Mai road network; and (2) Mobile-THAI, which was based on the US EPA Mobile 4, determined the emission factors of Chiang Mai's vehicle fleet. The CO emission rates from other sources were estimated by adopting the US EPA emission factor. This study found that the CO emission rate from traffic played an important role in the study area. Analysis reveals that CO emission rate from traffic during rush hours contributed approximately 90% of total CO emission rates.

The Regional Atmospheric Modeling System (RAMS) was used to simulate the wind fields and temperatures of the wet and dry seasons, in which 4 months in each season were considered. To assess the model performance, the simulated wind fields and temperatures were compared with the observed data set from the Pollution Control Department (PCD)'s meteorological monitoring station. The model evaluation in wind fields show that during the wet season the simulated and observed wind fields are in good agreement. Sometimes, the simulated and the observed wind fields show a difference due to the local turbulence. The performances of the model exceed 70 percent. During the dry season the wind vector time series show a quite good performance between the simulated and the observed wind fields. The performances of the model exceed 50 percent. The time series of the simulated and the observed temperature show a very good agreement and the model evaluation shows a very good performance (most of them exceed 80 percent).

The CO concentration in the study area was simulated by the HYbrid Particle And Concentration Transport model (HYPACT). The HYPACT was driven by the RAMS output and CO emission rates from the CO emission inventory processes. The simulated CO concentrations were compared with the observed data set from the PCD's air quality monitoring

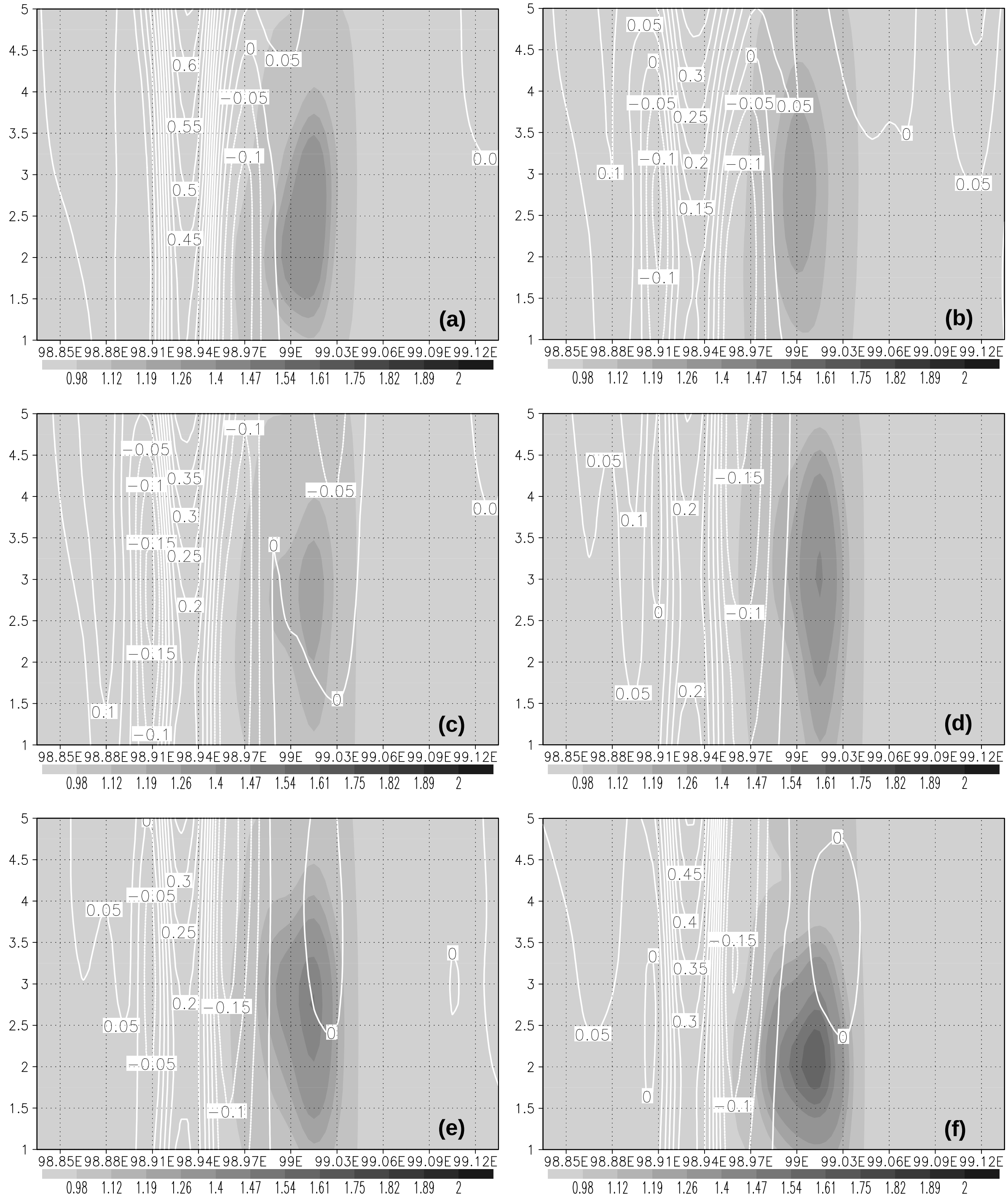

**Fig. 11.** Simulated vertical wind fields and CO distribution at (a) 0800 (b) 0900 (c) 1000 (d) 1800 (e) 1900 (f) 2000 TST on 19 May 2002.

stations. The model evaluations reveal a good relationship between the simulated and the observed CO, which corresponded to the traffic peak hours. The diurnal variation of CO showed that during the morning, the high CO concentration occurred and corresponded with the high emission rate period (morning traffic rush hour), but during the afternoon it didn't relate to the afternoon traffic rush hour. Since these phenomena were affected by the Planetary Boundary Layer (PBL) which during day time the CO can be well mixed in the Mixed Layer (ML), but during night time the Mixing Height was decreased, the emitted CO in Stable Boundary Layer (SBL) dispersed relatively little in the vertical and dispersed more rapidly in the horizontal. In addition, the mountainous topography in the study area produces the local winds (mountain wind during night time and valley wind during day time), these phenomena also illustrate that the airflow tends to form a closed circulation, so that if CO was continuously emitted in the study area, they would be accumulated in the study area.

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