A Numerical Simulation of the Influences of Local Circulation over Complex Terrain on Gas Dispersion on the Tibetan Plateau

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Abstract: - Due to strong radiation cooling and cold air run-off from a higher mountain region into the valley or basin by a local circulation in nighttime, there is a temperature inversion layer exited almost every day during wintertime over the complex terrain on the Tibetan Plateau. Based on some meteorological observations, the YSA’s (Yamada Science and Art) A2C atmospheric modeling system (NEW HOTMAC/RAPTAD model) is used for illustrate this local circulation and influences of this circulation on gas dispersion are simulated. Gas accumulation and dispersion processes in the volley or basin were simulated. Gas accumulation process occurred near the ground surface by cold air drainage and the accumulated higher concentration layer grown up to higher level gradually during the night and disappeared by up slope wind and turbulences gradually after sunrise. The higher gas concentration layer shifted downward while disappearing. This result provides some important insights into future CO2 flux observation and analysis over complex terrain.

Key-Words: - Gas dispersion, Complex Terrain, Temperature inversion, Local Circulation, Tibetan Plateau

1 Introduction

The Tibetan Plateau (or Qinghai-Xizang Plateau, hereafter TP) is the highest (average height >4000m) and largest plateau on Earth. The TP is characterized by very complex terrain and 1/3 of the plateau is over 4800m. TP is of immense importance both to climate and to ecosystems of the Asian continent and even the whole world [1]. Grassland occupies about 50% of the TP and may act as a carbon sink nowadays. To extend information from studies of global C dynamics and to project the influence of global warming on alpine grassland for the near future, we have measured the CO2 exchange between the atmosphere and ecosystem since August 2001 in an alpine meadow on the TP, by the eddy covariance method [2, 3, 4]. However, it seems that the local circulation over the complex terrain has some influences on the exchange observations, especially in wintertime when
absorptions of CO$_2$ were often observed during daytime even there were no photosynthesis occurred and no snow cover. It is well known that there is a circulation system related to topography as summarized by Barry [5] and there had some numerical experiments on the circulation [e.g. 6, 7, 8]. However, it is rarely demonstrated for gas diffusion or dispersion within the circulation, although there are some works on tracer dispersion over complex urban terrain [9], [10] and on air pollutions in regional sale [11], [12]. On the other hand, all the meteorological observatories on the TP are biased to the populated lower-elevation area (basins or volleys <4800m) in the eastern and southern TP. Therefore, it is very important to know the meteorological characteristics, especially the temperature distribution and variation and local circulations in the unpopulated higher-elevation area on the TP.

This paper shows an observational result of air temperature inversion obtain from observations on a mountain slope from 4300m to 5530m a.s.l. in the central part on the TP and simulation results for clarifying the local circulation effect on the temperature distribution and gas dispersion by using the YSA’s (Yamada Science and Art) A2C atmospheric modeling system (NEW HOTMAC/RAPTAD model) (refer to http://www.ysasoft.com/).

2 OBSERVATIONS

2.1 Observation sites

Figure 1 shows the main topography over the TP and the observation sites. There are no meteorological observatories in the area over 4800m a.s.l. which occupied 1/3 of TP showed as dark areas in Figure 1 (up). We set up 11 observation stations on a south slope of Mount Nyainqentanglha as shown in Figure 1 (down) at Dangxiong (30°30’ N, 91°02’ E). One of the 11 stations is a basic automatic station at about 4300m in the basin. All the meteorological elements were measured there by using measurement system of Campbell Scientific, Inc. Measurement system on the other 10 stations are Hobo weather stations (Onset Computer Corporation) settled at 4300m, 4400, 4500m, 465m, 4800m, 4950m, 5100m, 5200m 5300m 5530m on a south slope. Air temperature and humidity at 2m and soil temperature and soil water content at 5cm, 20cm and 50cm are sampled at 1 min intervals and the mean value were recorded with a data-logger at 30 min intervals. Details about the observation and some results have given by Du at al. [13]. This paper shows the air temperature inversion observed during Jan. 8 to 10, 2007.

Fig. 1 The main topography over the Tibetan Plateau (up) and observation sites and simulations domains (down). The Tibetan Plateau is shown as the shaded region where elevation is higher than 3000 m a.s.l.. Black contour lines show topography with an interval of 1000 m (up) and 300m (down). The bold line indicates observation transection and ● indicates the AWS with wind observation. ○ indicates the areas of gas imission in the numerical simulation.

2.2 Formation of air temperature inversion

Fig. 2 Variation of air temperature profiles along the south slope from 16:00 BST Jan. 8, 2007 to 10:00 BST Jan. 9, 2007.
Air temperature inversion existed almost every day during winter in our observation area [13]. Figure 2 shows an example of the formation and variation of the air temperature inversion during Jan. 8 to 9, 2007. A temperature inversion was formed around sunset (before 20:00 BST, local time is about 2 hours earlier) and developed gradually until next morning. Inversion layer reached to 5100m at about 8:00 BST and disappeared rapidly after sunrise. Figure 3 gives the diurnal variation of solar radiation, net radiation, relative humidity, wind speed and direction for the same period in the basin. It can be concluded that this was a typical nocturnal inversion by radiation cooling in a valley or basin. After sunset (solar radiation changes to zero), net radiation changed form plus (heating effect) to minus (cooling effect) and wind speed decreased rapidly. After several hours cooling, inversion layer became thinker and thinker and wind direction changed from SSW, valley wind to NNE, wind from the mountain slope. Therefore, this was a nocturnal inversion in valley or basin mainly deduce by nocturnal radiation cooling. Usually, this kind of temperature inversion occurs on clear calm night. It is well known that calm day is not prevailing on the TP, especially in wintertime. As shown in Fig. 3, the wind speed at our basin station was more than 1m/s in the night. It seems that certain wind can accelerate heat exchange within a valley or basin and let the inversion layer developed to a higher place.

3 SIMULATIONS

3.1 Models
We used YSA’s (Yamada Science and Art) A2C atmospheric modeling system (NEW HOTMAC/RAPTAD model) to simulate the local circulation and gas dispersion with the local circulation. A2C offers a high degree of accuracy in simulating, forecasting, and visualizing airflow and gas dispersion in an urban environment—around buildings or over complex terrain. Superior quality 2-D and 3-D graphics along with a user-friendly interface make A2C an indispensable tool.

HORMAT is a three-dimensional numerical model for weather forecasting. The basic equations of HOTMAC were described in detail by Yamada and Bunker [14]. RAPTAD is a Lagrangian model in which a number of puffs are released at the source and in which the change with time of puff characteristics, such as the location of the center and the size and age of the puff, is computed at every time step by using the air flow results deduced by MOTMAC. The basic equations of RAPTAD were described in detail by Yamada and Bunker [14] and some new features were discussed by Yamada [15].

3.2 Initial and boundary conditions
3.2.1 Airflows and temperature
We deployed nested grids 3 of domains to include both large topography (50*100km, a part of Mount Nyainqentanglha) and small topography (18*13km, only the valley and the slope where the observation obtained) as shown in Fig. 1. Simulations initiated at 14:00 Jan. 8 and stopped at 14:00 Jan. 10. Initial wind directions were westerly (250°) and wind speeds in the upper levels were 2 m/s. Only air temperature at sea level was introduced as initial temperature. Potential temperature gradients in the vertical direction were 0.001 K/m for the first 1000 m above the ground and 0.003 K/m in the levels greater than 1000 m above the ground. The top of computational domain was 10000m above the highest ground elevation, which was 5530 m for the present study.

3.2.2 Gas dispersion
In order to know the influence of the local circulation on CO₂ flux observation. The CO₂ releases were
considered and two round release areas were set as shown in Fig. 1. One was on a hilltop and another was in the basin. The gas release areas had radius of 2km and gas emission height is at ground surface. Gas release rate was continually and constantly during the simulation period.

3.3 Results

3.3.1 Airflows and temperature

![Fig. 4 The modelled wind and temperature distributions at 2 m above the ground (up: 16:00; down: 07:00). Arrows indicate wind directions and wind speeds are proportional to the lengths of arrows.](image)

Figure 4 shows the modelled horizontal wind and temperature distributions in domain 1 at 2 m above the ground at 16:00 and 07:00 local time. During the daytime westerly wind was proving in the whole domain area and air temperature was higher in the lower valley. As the ground began cooling before sunset at about 17:40, westerly breezes changed to hill breezes and upslope flows changed to down slope flows over the hills. In the basin, westerly wind changed to easterly wind due to down slope flows from both mountain sides (north wind and south wind) at about midnight just like the observation as shown in Fig. 3 and air temperature was lower than that on the lower part of the mountain slope. The local circulation between mountain and valley was very thin, especially during the nigh time as shown in Fig. 5. However, this circulation accelerated the cooling process in the valley (bring cold air from higher place to lower places).

![Fig. 5 The modelled wind and temperature distributions in the vertical cross section along the observation slope. (up: 16:00; down: 07:00). Arrows indicate wind directions and wind speeds are proportional to the lengths of arrows.](image)

3.3.2 Gas dispersions

![Fig. 6 Visual distribution of gas puff within the domain area at different times (18:00, 24:00, 06:00](image)
and 12:00). The color of the puff indicates age of the puff.

As shown in Fig. 6, the local circulation controlled gas dispersion processes. Gas released on the hilltop could be dispersed smoothly to other places and could not be stayed there for as long as 3 hours. However, most of the gases both released at the bottom of the basin and on the hilltop accumulated at the bottom of the basin after sunset and stayed there for even more than 12 hours. Accumulated gases dispersed to leeward higher places from sunrise until later in the afternoon.

![Fig. 7 The modelled wind and gas concentration distributions in the vertical cross section along the center of the two gas release areas during the nighttime.](image1)

This process can be found more clearly from the gas concentration distributions in the vertical cross section along the two gas release areas as shown in Fig. 7 and Fig. 8. Due to the thin layer of cold air drainage on the slope as shown in Fig. 5, gas released at hilltop transported to the bottom of the basin and accumulated there with the gas released in the basin where wind speed was lower and the atmosphere was stable. The accumulated higher gas concentration layer grown up to higher level gradually during the night showing that all the gases seem to be released from the bottom of the basin.

To the contrary, the accumulated gases dispersed mainly by up slope wind along the leeward slope and some gases dispersed by turbulences after sunrise. The higher gas concentration layer shifted downward and disappeared gradually until later in the afternoon as if all the gases were gone into the bottom of the basin. Therefore, a downward gas flux maybe observed at the bottom of the basin.

![Fig. 8 The modelled wind and gas concentration distributions in the vertical cross section along the center of the two gas release areas during daytime.](image2)

Fig. 8 The modelled wind and gas concentration distributions in the vertical cross section along the center of the two gas release areas during daytime.

### 4 Conclusions

In order to clarify the vertical pattern of air temperature in high mountain regions where no meteorological observatories, we set ten simple observation stations along a south slope from 4300m to 5530m in central part of the TP since August 2005. Observations show that there is a temperature inversion layer exited during wintertime over the complex terrain on the Tibetan Plateau due to strong radiation cooling and cold air run-off from a higher mountain region into valley or basin by a local circulation in nighttime. Based on the meteorological observations, the YSA’s (Yamada Science and Art) A2C atmospheric modeling system (NEW HOMAC/RAPTAD model) is used for illustrate this local circulation and influences of this circulation on gas dispersion are simulated. The AC2 atmospheric modelling system can be used to simulate the local circulation and temperature profile in high mountain region. Simulation of gas dispersion shows that gas accumulation process occurred near the ground.
surface by cold air drainage and the accumulated higher gas concentration layer grown up to higher level gradually during the night and disappears by up slope wind and turbulences gradually after sunrise. The higher gas concentration layer shift downward while disappearing showing a downward gas flux. This process could explain why absorptions of CO$_2$ were often observed during daytime even there was no photosynthesis occurred and no snow covers in winter. This result provides some important insights into future CO$_2$ flux observation and analysis over complex terrain.

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References: