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A THREE-DIMENSIONAL NUMERICAL STUDY ON DENSE FOG OVER MOUNTAINOUS AREAS

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Abstract: Using the non-hydrostatic meso-scale model MM5v3, dense fog that occurred from March 7 to March 8, 2001 over the Mts. Nanling area was studied. With integrated field experiments and observations, the occurrence, development and lift mechanism of fog were analyzed. The results indicate that before the coming of stratiform clouds, southerly warm and wet air ascended along mountainside and cooling condensation formed mountain fog. Then fog was formed by the stratiform on cloud-contacting mountaintop. A front inversion layer accelerated the development and extended the duration of the lower cloud and fog. The intensity, occurrence time, mass content and the variation of temperature and relative humidity of the fog agreed with those of the observation. It showed that the meso-scale model has the potential to forecast mountain fog.

Key words: fog; mountain area; numerical study; observation data

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1 INTRODUCTION

Fogs pose serious threats to expressways and airports. Their forecasts are not only important for the general public but also economically beneficial. An expressway from Beijing to Zhuhai rises past Mt. Dayaoshan, the main section of a mountain range Mts. Nanling, in northern Guangdong province. The driveway has a large variation of height above sea level (ASL), rising from more than 200 m to 800 m before dropping to more than 200 m again. Locating inside a monsoon climate zone characteristic of southern subtropical humidity, the mountainous area of Mts. Nanling experiences frequent heavy fogs from October to the following May when quasi-stationary fronts are active. The lifting by mountains worsen the damage by fogs, which seriously compromise the safety of local traffic. To set up a pre-warning and monitoring system for the notorious visibility over the section, the Ministry of Communications specially selected a project on heavy fogs hazardous to road safety during the designing and constructing periods of the expressway, the first of its kind in China[1, 2].

One after another, researchers outside China have carried out numerical study and made detailed comparison between the output and observations[3-6]. Since 1980, Chinese scientists have conducted simulation studies on fogs with 2- or 3- dimensional numerical models, mainly for radiative fogs, and obtained many significant results[7-13]. Fan et al.[14] employed the MM5, a 3-D numerical model, to run a simulation study on the radiative fog that took place in the area of Guangzhou. There has been little numerical work on heavy fogs in mountains with precipitation weather. Using a non-hydrostatic mesoscale numerical model MM5v3, this paper works on a heavy fog on March 7 - 8, 2001 in Mts. Nanling. Integrating field observations, the effect and influence of weather conditions and local orographic features are analyzed on the formation, evolution and dissipation of heavy fogs for the purpose of laying scientific foundations for

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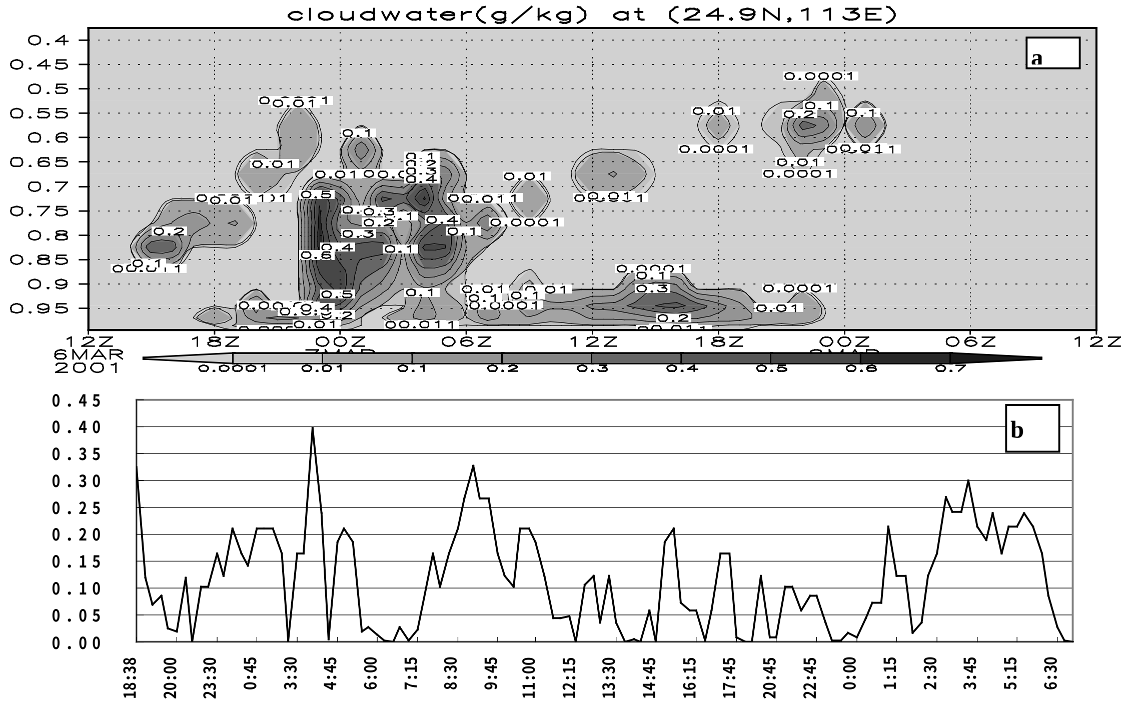

Fig.1 Time-altitude cross sections of simulated cloud water content (a, with a σ-ordinate) and its observed evolution with time (b) at 24.9°N, 113°E.

the above-mentioned system.

2 BRIEF ACCOUNT OF DATA AND MODEL DESIGN

A large-scale comprehensive field observation was performed in February - March, 2001 in the section of the expressway where heavy fogs usually appear in Mts. Nanling. With the observation site at 815 m ASL at 113°6′E, 25°5′N, items like dual-parameter low-level sounding, tethersonde, aerosol spectra, chemical composition of fog water and rainwater, spectra of droplets and liquid water content in fog and visibility as measured with instrument and the bare eye are observed, in addition to such conventional surface meteorological elements as wind, temperature, pressure and humidity. A complete dataset has been acquired for the formation, evolution and dissipation of heavy fogs.

The MM5v3 from PSU and NCAR was used here due to its adaptability for a range of weather processes. The Grell scheme for convective parameterization, the Blackadar high-resolution boundary-layer scheme with emphasis on describing boundary layers near the bottom, the Dudhia scheme for explicit cloud physics with a simple ice phase and a cloud radiation scheme were used. The center of the simulation was set at the main observing site (25°N, 113°E), with three two-way nesting in the horizontal direction and grid intervals at 27 km, 9 km and 3 km, 23 vertical layers and model top pressure set at 100 hPa. For the mesh of 27 km and 9 km, orographic data for 10 min and 5 min are used respectively. Data for the third mesh are obtained by interpolation from those of the second mesh. Thirteen types of surface characteristic data are used for the underlying surface. Beginning from 20:00 March 6, 2001, the model is started using NCEP's 1°×1° reanalysis data available every 6 h for a total run of 48 hours. Local time is used for all but Section 4.

3 SUMMARY OF RELEVANT WEATHER

Until the arrival of cold air on March 6, migratory short-wave troughs and ridges maintained in the middle and higher latitudes while an upper-level trough was deepening over the area north of Lake Baikal to Xinjiang, China, to channel cold air through to the area south of theYangtze River. At the time, the southwestern China had a large negative pressure change at 850 hPa, the southerly airflow intensified obviously, which was mostly larger than 5 m/s at the surface on March 5 and 6 with the extreme values at 9 m/s and 7 m/s, respectively. At the same time, the southern westerlies trough moved to the east as it strengthened. In the early morning of March 7, the cold air began moving to affect Mts. Nanling while a pattern of two migratory troughs combining with one migratory ridge maintained at 500 hPa in the middle and higher latitudes, making the south of China in the SW-SWW airflow in front of the southern westerlies trough over the Bay of Bengal. A shear south of the

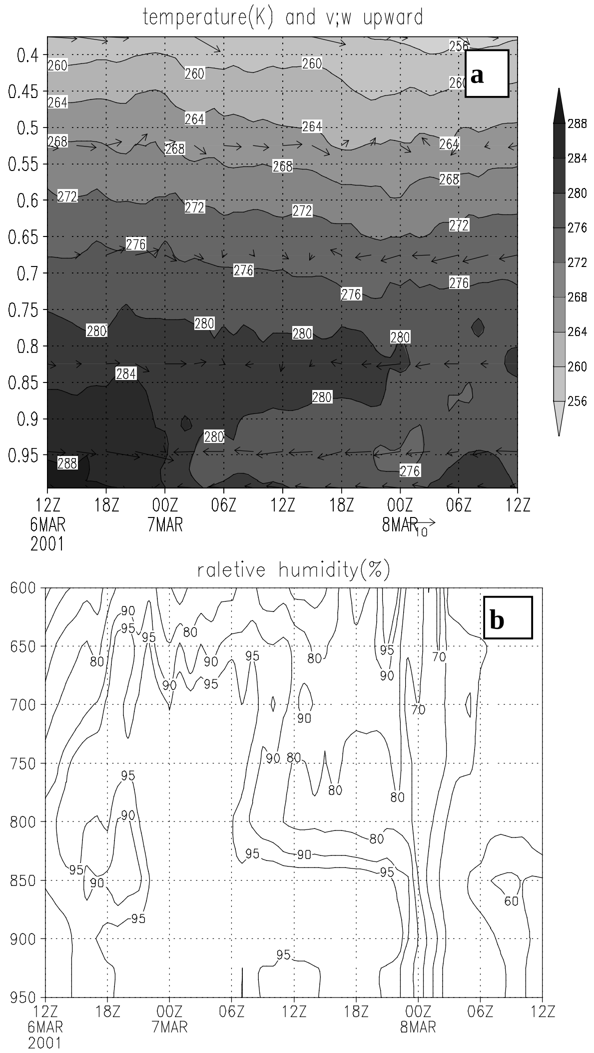

Fig.2 The simulated temporal evolution of temperature stratification and wind vectors (a) and that of relative humidity (b) at the observation site.

Yangtze River rapidly moved south and weakened. At 08:00 March 8, an 850-hPa cold front progressed as far south as the coast. With its passage, low levels were soon under the control of dry and cold northeasterlies to decrease the moisture content rapidly. Mild to moderate rains were recorded over most of Guangdong and the weather of overcast and rain maintained for 2 days.

4 COMPARISON AND ANALYSIS OF HEAVY FOGS AT OBSERVATION SITE

Fig.1a gives the time-altitude cross section of cloud liquid water as simulated with the third set of mesh at mountain top (24.9°N, 113°E), in which the values on the abscissa indicate the universal time, same below). Fig.1b gives the evolution of observed liquid water content in fog. The two figures show that the intensity and time of occurrence of the simulated fog are close to those of the observed one, i.e. a general picture is reproduced to show how a heavy fog evolves in Mts. Nanling.

Fig.2 is the simulated temporal evolution of temperature stratification and wind vectors and that of relative humidity at the observation site (24.9°N, 113°E). Fig.3 is the vertical profiles of simulated and observed temperature and dew point at the site of observation for 17:00 March 7. Fig.4a gives the temporal evolution of surface temperature and relative humidity and Fig.4b that of the observed surface temperature and relative humidity. For analyses of other aspects, refer to the Chinese edition of the journal.

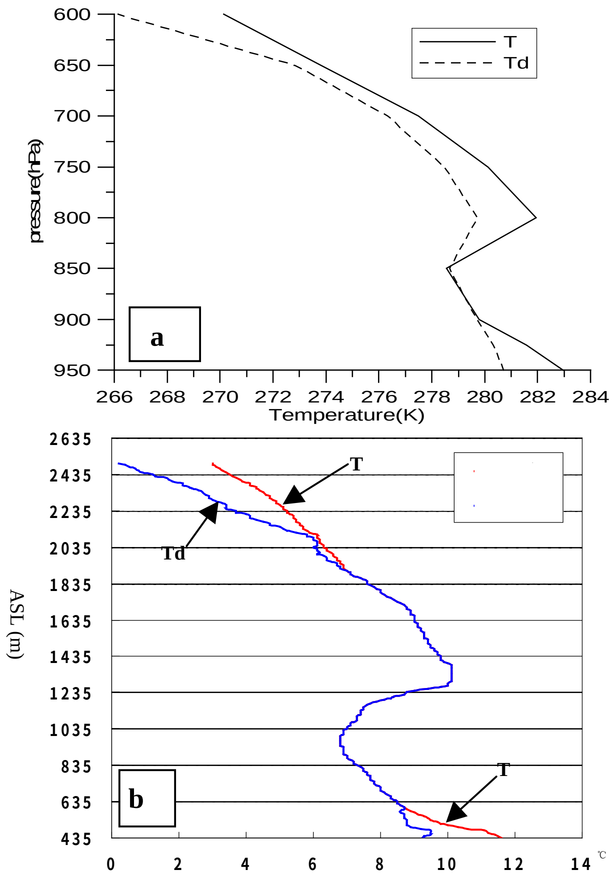

Fig.3 The vertical profiles of temperature and dew point at the site of observation for 17:00 March 7. (a) is for the simulation and (b) for the observation.

5 CONCLUSIONS AND DISCUSSIONS

(1) The simulated weather patterns are quite consistent with the observation. Before the arrival of large-scale principal body of stratiform clouds, low-level warm and humid southerlies is lifted up along the slope to cool down and condense to form uphill fog so

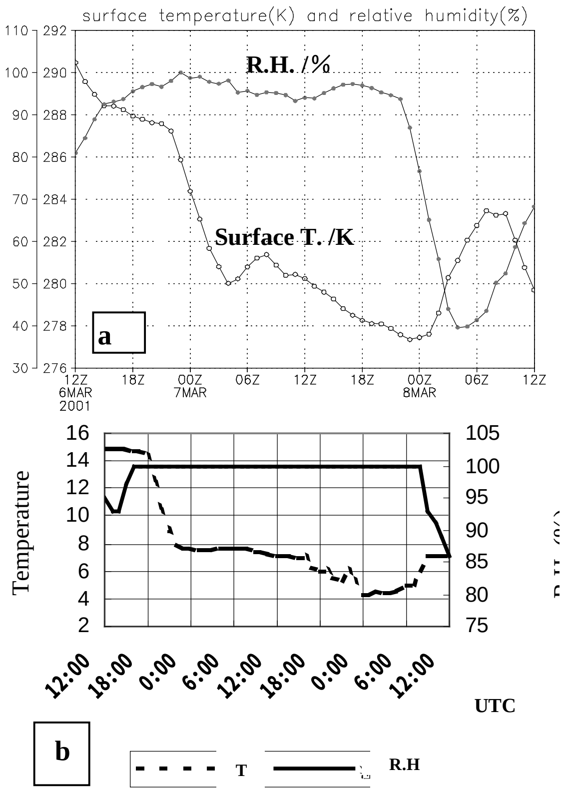

Fig.4 The temporal evolution of surface temperature and relative humidity at the site of observation. (a) for the simulation; (b) for the observation.

that the surface fog occurred early. Then, heavy fogs are formed by large scale stratiform clouds making contact with the hilltops. With the passage of the clouds, low-lying clouds beneath an inversion layer formed heavy fogs.

(2) As shown in a numerical experiment, when the altitude of the topographic features is lower to 600 m or below, airflows decrease the ascent up the slope to restrain the formation of uphill fogs on the one hand, the main body of clouds do not touch ground as often to decrease the amount of clouds that touch the ground and lessen the liquid water content in clouds on the other. It shows that the hilltops are a necessity for heavy fogs to form.

(3) For the temporal evolution of temperature and humidity as well as the intensity, occurring time, liquid water content in the fog, the simulation generally agrees with the observation. The intrusion of very cold air lowered the surface temperature and low-level northerly flows acted with upper-level warm and humid southerly flows to form a severe layer of inversion on the front. The long presence of the inversion and sufficient supply of water vapor helped the heavy fog to grow and sustain. With further southward movement of the cold air, however, the inversion disappeared and the body of fog dissipated.

(4) Non-hydrostatic mesoscale models can be used to simulate and forecast the formation, evolution and dissipation of mountain fogs so that scientific foundations are laid for the setting-up of a pre-warning and monitoring system for expressways going through elevated mountains.

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