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Snow distribution over the Namco lake area of the Tibetan Plateau

M. Li[1], Y. Ma[1,2], Z. Hu[1], H. Ishikawa[3], and Y. Oku[3]

[1]Cold and Arid Region Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
[2]Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100085, China
[3]Disaster Prevention Research Institute, Kyoto University, Kyoto 611-0011, Japan

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Correspondence to: M. Li (mshli@lzb.ac.cn)

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Abstract

The mesoscale snow distribution over the Namco lake area of the Tibetan Plateau on October 2005 has been investigated in this paper. The control and sensitive experiments were conducted using Weather Research Model (WRF) with three nested grids that included a 1 km finest grid centered on the Namco station. Our simulation ran from 6 October through 10 October 2005, which was concurrent with long term meteorological observations. Evaluation against boundary layer meteorological tower measurements and flux observations showed that the model captured the observed 2 m temperature and 10 m winds reasonably well in the sensitive experiment. The results suggested that output snow depth maximum amounts from two simulated experiments were centered downwind shore of Namco lake. Modified surface parameters for example surface skin temperature on the lake help to increase simulated credibility.

1 Introduction

The Tibetan Plateau, known as the roof of the world, has been recognized as the heat source/sink in summer/winter for the monsoon circulation over the Tibetan Plateau. In the literature (Hahn et al., 1975; Murakami, 1987, 1965; Flohn, 1987; Ye et al., 1993; Chen et al., 2000; Zhang et al.; 2002; Waliser et al., 2003; Goswami et al., 2006; Yanai et al., 2006; Wu et al., 2007) it has been mentioned as one of the most important factors for the generation and maintenance of Asia summer monsoon circulation and rainfall. During summer, the Tibetan Plateau due to its high elevation receives a large amount of solar radiation, which effectively heats the mountain surface creating a strong heat contrast at the mid-tropospheric level. The sensible heat as well as latent heat flux released over the Tibetan Plateau drives the Asian monsoon circulation and strongly influence global circulation patterns (Murakami, 1987). Results (Flohn, 1987) also show that the latent heating plays a more important role than the sensible heating for the maintenance of the Tibetan High. There is a sharp contrast between the western and eastern plateau in terms of precipitation and moisture distribution. Studies (Murakami, 1987, 1965) show that the sensible heat flux is extremely large over arid western Tibetan Plateau during June compared to the eastern side. On the other hand, in the eastern side of the Tibetan Plateau, the latent heat flux is more, so much so that the eastern plateau is described (Luo and Yanai, 1983) as a huge chimney funneling water vapour from the lower to the upper. There are evidences to suggest that the Tibetan snow cover/depth largely affects the Asian monsoon rainy season. Results of General Circulation Model (GCM) experiments (Ose, 1996) show that the anomalous tends to produce a weak Asian monsoon cooling due to positive snow mass anomalies in early spring over Tibet. But few studies to lake effect snow phenomena have been implemented on the Tibetan Plateau. There are thousands of lakes across the Tibetan Plateau. Namco is one of the most beautiful and very important places in the Nyenchen Tanglha mountain range. It is at an elevation of 4 718 meters, covering an area of 1 940 m^2. (Wang et al., 1998) Lake-effect snow occur frequently over the Namco Lake region during the winter season as cold air outbreaks modify boundary layer air. In this study, lake effect snow was analyzed using WRF model. Firstly, the model grid configurations and numerical experiment design are introduced. Then we evaluate the modeled meteorological variables. Sensitive studies consisting of a decrease of lake surface temperatures were compared against a base simulation and some initial results are described. At last we gave the possible reason of lake effect snow on the Namco Lake area.

2 Model description and numerical experiment design

2.1 WRF model

The Weather Research and Forecasting (WRF) model (Wang et al, 2005) will be used in this study.

We simulate snowfall from 6 October to 8 October 2005. Initial value selected NCEP fnl data, WRF model. Selected physical options as follows:

- Microphysics: WSM6-class scheme;
- Longwave radiation: RRTM;
- Shortwave radiation: Goddard short wave scheme (CAM);
- Land surface scheme: Noah Land surface model;
- Cumulus parameterization: Kain-Fritsch scheme;
- Planetary boundary layer: Yonsei Universrity scheme.

The snow model of Noah LSM has only one layer of snow cover and simulates the snow accumulation, sublimation, melting, and heat exchange at snow–atmosphere and snow–soil interfaces. The precipitation is categorized as snow when the temperature in the lowest atmospheric layer is below 0°C. In this snow model the skin temperature is one of important parameters. Detailed scheme and physical process of the snow model is described by former literature (Chen et al., 2000).

2.2 Grid configuration and experiment design

The model domain and grid configuration are shown in Fig. 1. it comprises three levels of nested grids with the coarsest grid (grid 1) covering the whole Tibetan Plateau area at 9 km grid spacing, and the finest grid (grid 3) covering an area of 199 km×199 km, focusing on the Namco area at 1 km grid increment. The coarse grid time step is 54 s. The model central point is 30.77° N, 90.99° E same as the Namco site. The model is driven by 6-hourly lateral boundary conditions derived from NCEP fnl data.

Using the 6 October 2005 atmospheric and land surface states as an initial condition, we performed the three-nested-grid simulation with the finest grid at 1 km grid spacing. The experiment started on the 6 October 2005 and end on 10 October 2005, concurrent with Namco long term observation.

We made two experiments for contrast, one is the control experiment and another is the sensitive experiment. In the control experiment, NCEP fnl data is used to drive WRF model, the output lake skin temperature is always 300 K (see below). In the sensitive experiment, we change the input lake skin temperature to that from remote sensing retrieved.

3 Observations, site description and synoptic situation of October 2005

Namco Station for Multisphere Observation and Research, Chinese Academy of Sciences (NAMOR/CAS) (30° 46.44′ N, 90° 59.31′ E, 4730 m a.s.l.), located at the southeast shore of the Namco Lake, northern slope of the Nyainqentanglha Mts, 220 km away from Lhasa, was established for long term observation by the Institute of Tibetan Plateau Research, Chinese Academy of Sciences in 2005. Automatic Weather Stations (AWSs) and hydrologic observation sites had been set up in the south and north of Mt. Nyainqentanglha and around the Namco to collect the basic data, in order to understand the climate and hydrology in the Namco region. A 52 m boundary meteorological tower and eddy correlation and CO_2/H_2O analysis system collect meteorological data in different layers, measured fluxes of heat, moisture, and trace gases as well as pressure, temperature, humidity, wind speed, and radiation profiles at near surface layer, to study the regional land/ atmosphere processes, the moisture transport and water cycle, and to add the parameter database of effective land surface process over the Tibetan Plateau. The variations of glacier, snow cover and permafrost were observed for exploring the interactions between cryosphere and climate changes. Detailed descriptions of this station can be found on website http://www.itpcas.ac.cn/namco/introductionen.html.

The synoptic situation for our simulation time period, 6 October through 8 October 2005, can be summarized as follows: National Meteorological Center of China Meteorological Administration surface synoptic chart show that there is an area of high pressure to Siberia which extends southwards across Mongolia to the south of China

(Fig. 2). The central of high pressure removes to the southwards direction. The other feature on the chart though is the large depression in India. The block over the Tibetan Plateau has forced the area of low pressure to move south-westwards. Two main cells have formed. The isobars are tightly packed and gale force winds from the northwest are affecting many parts of the Tibetan Plateau. Snow fell over most of the domain during this simulation period.

4 Results

4.1 Model evaluation: near-surface meteorology

After inputting remote sensing retrieved lake skin temperature, we got new air temperature. Then we compare to the observations. A comparison of near-surface meteorological fields was carried out between the observations and WRF simulations for the period 6 October through 8 October 2005. Figure 3a shows the comparison of 2 m screen height air temperature between the model and observations. During the simulation period day the model agrees reasonably well with the observations, but with some cold biases, especially at midday. At night the modeled temperature value was higher than that in observations. The modeled temperature diurnal cycle is perfectly in phase with observations. The model tends to high estimate the screen height air temperature at night but does a better job predicting day temperature.

The observed 10 m wind speed and direction comparisons are more divergent than that demonstrated with temperature (Fig. 3b and c). The observed and modeled wind speed average 3.16 m/s and 4.14 m/s, the observed and modeled wind direction average 172° and 195° respectively for the entire simulation period. Both observed and modeled winds demonstrate diurnal cycles. During the day, a strong northwesterly wind persists (except it was southerly wind on 7 October, the nights are calm with more sporadic changes in wind direction. The general trends in observed wind speeds and directions are captured in the simulation, but the model overestimates the wind speeds, and has more changes in wind direction compared to the observations.

4.2 Comparison of skin temperature between two experiments

The output surface temperature from model domain 3 is over 300 K in lake area an example of simulated result at simulated 41 h (Fig. 4). Mountain area is lower than land area. Lake surface temperature (Fig. 4a) is unreasonable compare to remote sensing retrieved surface temperature (Fig. 4c). After input the remote sensing retrieved lake skin temperature, output lake surface temperature is consistent with the satellite data (Fig. 4b).

4.3 Comparison of mixing rate of snow at 550–300 mb and surface heat fluxes

Surface heating difference in two experiments produce different mixing rate of snow. The control experiment (Fig. 5a) was larger along longitude than the sensitive experiment (Fig. 5b). On the lake surface, cool air displaces lighter warm air by sliding under the warm air during early winter. More heating over the lake, more vapour water transfer upward. Surface heating field including sensible heat flux and latent heat flux was stronger in control experiment (Fig. 5c and e) than that in sensitive experiment (Fig. 5d and f).

4.4 Comparison of snow depth between control experiment and sensitive experiment

The maximum amounts of snowfall were over northeastern of the Namco shore in both experiments. In the control experiment (Fig. 6a), the snow cover is larger than that in the sensitive experiment (Fig. 6b), and near the northeastern of Namco Lake there are no snow while the sensitive experiment has shallow snow accumulation. We suggest that input high lake surface skin temperature result to melting snow near the bank of lake in control experiment. From 450 mb wind field, there was prevailing northwesterly wind on the lake area. So the maximum amounts of snowfall were over northeastern of the Namco shore in both experiments.

5 Summary and discussion

Lake effect snow on the Namco Lake area during early winter 2005 was investigated using WRF including two numerical simulation experiments. Model evaluation against boundary layer tower measurements and flux observations showed that modified lake surface skin temperature can increase modeled ability.

The mechanisms that lead to snow maximum amounts centered on the downwind shore of Namco Lake were explored. Namco Lake-effect snow is produced in the early winter when cold, northwesterly winds move across warmer lake water, providing energy and picking up water vapor which freezes and is deposited on the lee shores.

Our numerical study suggests that detailed, high-resolution, mesoscale studies need to be undertaken for long term monitoring Namco station as well. Mesoscale numerical experiments can be a powerful tool to help determine the unique meteorological conditions associated with each tower, and to study the water and energy distribution on the Tibetan Plateau.

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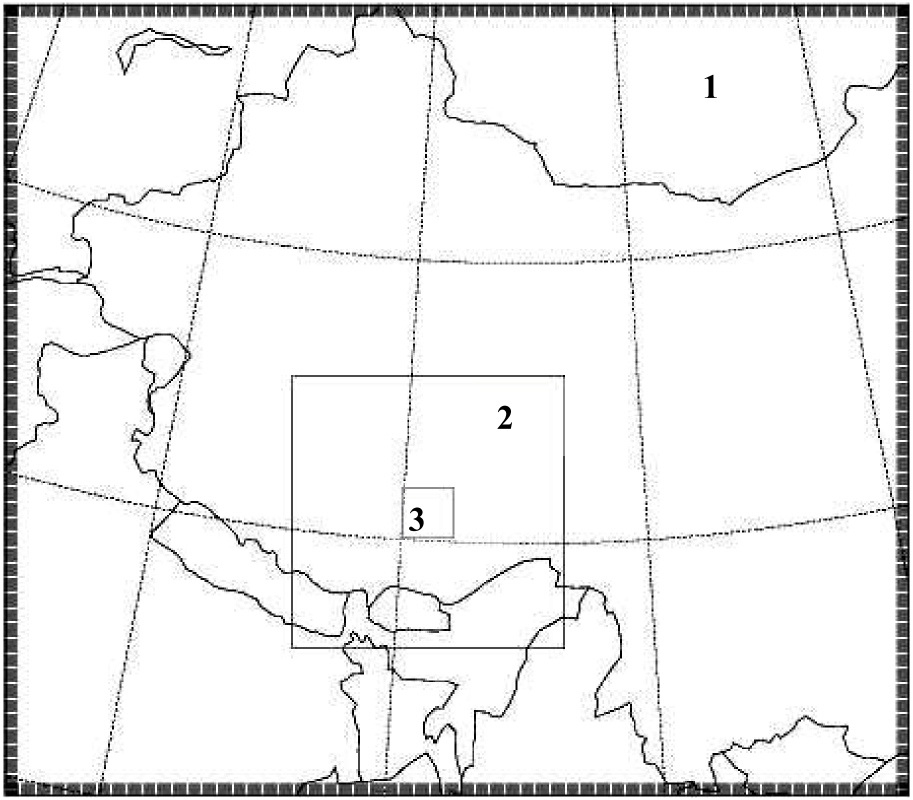

Fig. 1. Model simulation domain of three nested grids. The coarse grid to the finest grid intervals are 9, 3 and 1 km, respectively.

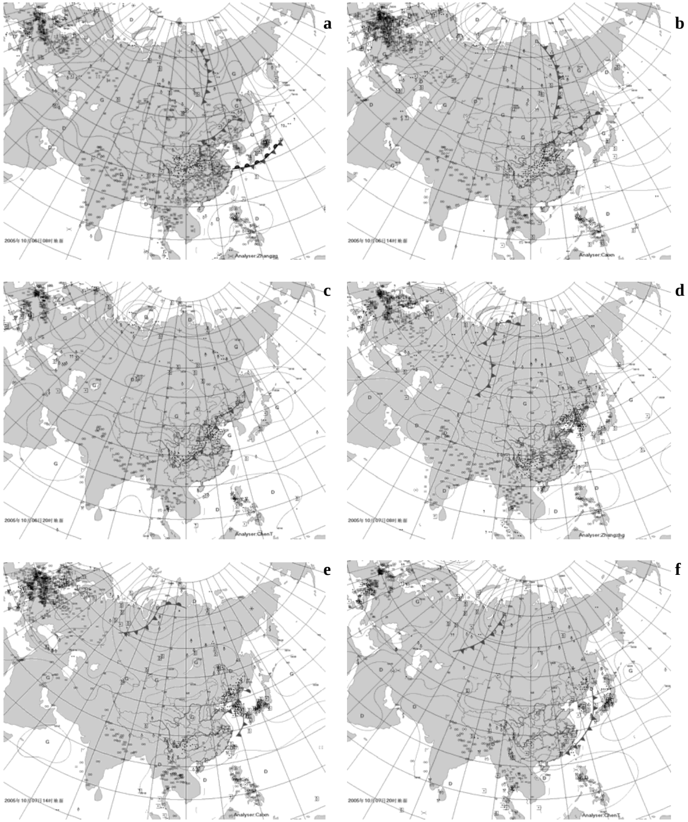

Fig. 2. National Meteorological Center of China Meteorological Administration surface synoptic chart at 08:00, 14:00, 20:00 BST on 6 October 2005 (**a**, **b**, **c**) and 7 October 2005.

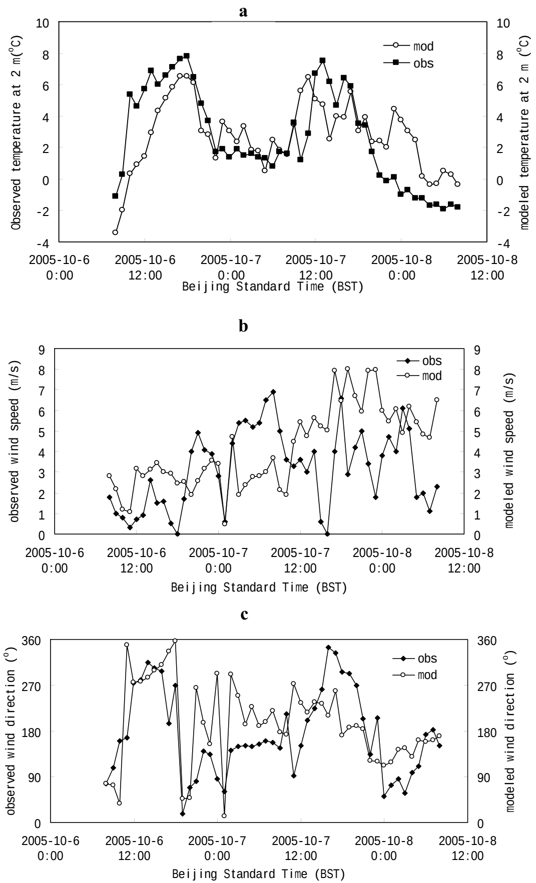

Fig. 3. Modeled versus observed screen 2 m air temperature **(a)**, 10 m wind speed **(b)** and wind direction **(c)**.

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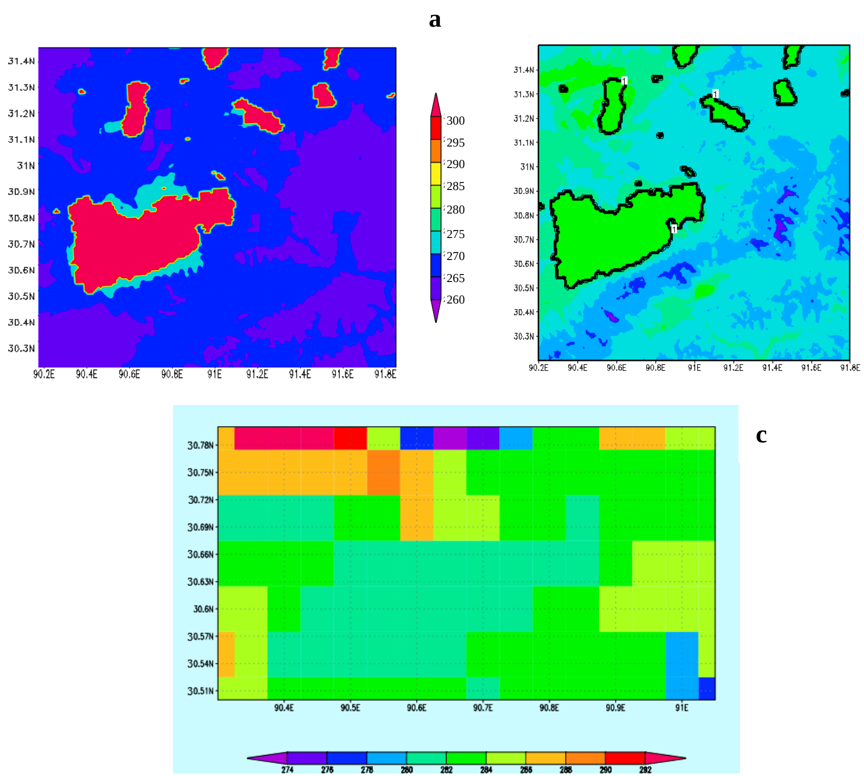

Fig. 4. The output surface temperature (unit: K) from model domain 3 in control experiment **(a)** and sensitive experiment **(b)** at simulated 41 h, remote sensing retrieved surface temperature **(c)**.

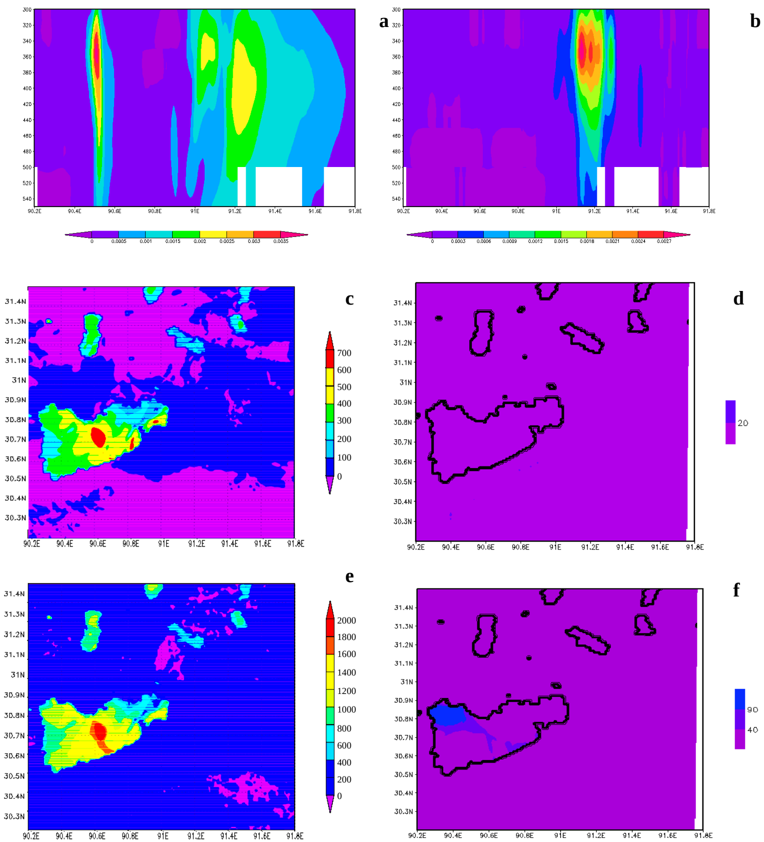

Fig. 5. Mixing rate of snow (unit: kg/kg), sensible hest flux (unit: $W\,m^{-2}$) and latent heat flux (unit: $W\,m^{-2}$) in the control experiment (**a**, **c** and **e**) and the sensitive experiment (**b**, **d**, **f**), respectively.

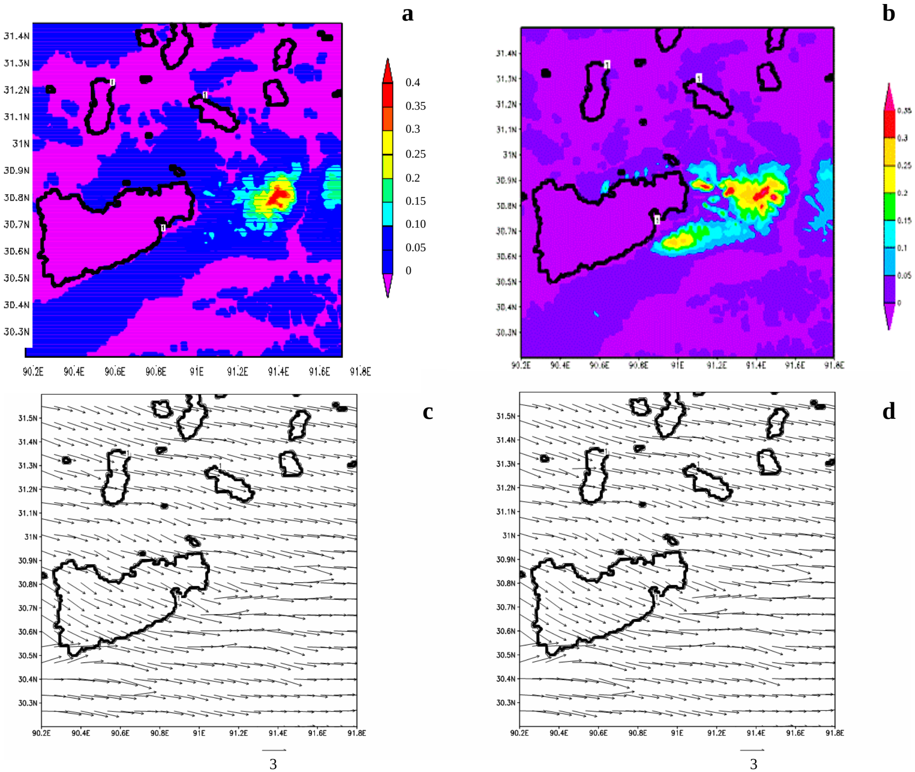

Fig. 6. Simulated snow depth (unit: mm) and 450 mb wind field (unit: $m\,s^{-1}$) in the control experiment (**a**, **c**) and the sensitive experiment (**b**, **d**).

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