VERIFICATION OF A GROUND METEOROLOGICAL FORCING DATASET AND ITS APPLICATION ON PERMAFROST REGION OF QINGHAI-TIBETAN PLATEAU

Hao Chen[a,b], *Zhuotong Nan*[a*]

[a]Cold and Arid Regions Environmental and Engineering Research Institute, Lanzhou, 730000, China
[b]University of Chinese Academy of Sciences, Beijing, 100049, China
* Corresponding author. E-mail: nztong@lzb.ac.cn

ABSTRACT

Available climatic observation data are very limited in Qinghai-Tibetan Plateau (QTP) because of its severe physical environment. Great efforts have been made to assimilate remote sensing data and *in situ* observation data to produce qualified datasets. This study has verified the applicability of a ground meteorological forcing dataset named CMFD in a typical site (TGL) and a typical region (XKL) in QTP by the simulation of water-heat processes with land surface model (LSM). Results show that Noah LSM simulation with CMFD-derived forcing data can accurately present the water-heat conditions of individual site as well as typical region on QTP with an NSE of 0.818 for TGL site and mean annual ground temperature discrepancy less than 1 degree compared with observation data of 8 boreholes in the total 10 boreholes in XKL. It is proved that CMFD dataset can be used as reliable data source for simulation applications on QTP.

Index Terms— Data analysis, land surface, meteorological factors, geophysics computing

1. INTRODUCTION

In recent years, more and more attentions have been paid on simulating and forecasting the climatic, hydrological and biological changes over the Qinghai-Tibetan Plateau (QTP) under climate change [1]. However, as an environmental difficult region, available data were very limited in QTP. Great efforts have been made to assimilate remote sensing data and *in situ* observation data together to improve the data quality of current datasets and they all need further test plus verification in applications such as model simulation. In this study, a ground meteorological forcing dataset named CMFD was selected to test its applicability in model simulations over QTP. Compared with the commonly used GLDAS dataset that has a rough resolution of 0.25 degree, the updated CMFD dataset has resolution of 0.1 degree and optimized data for high altitude and arid regions in China [2]. It is more suitable for the model simulation application on QTP. Compared with the empirical-statistical models applied in permafrost region of QTP, land surface models (LSMs) can comprehensively present the water and heat exchange between ground and atmosphere and has advantages in describing the coupling between water and heat in surface and subsequent soil layers in the research area. Noah LSM, owing to its simple structure, small number of parameters and less computation cost, is suitable in the verification of CMFD dataset in the simulation process. However, to fully present the unique water-heat conditions of QTP, improvement of Noah parameterization schemes are needed. In section 2, based on the understanding of the unique water-heat characteristics of Qinghai-Tibet Plateau, improvements of Noah has been introduced including: (1) a new thermal roughness calculation method; (2) soil stratification and extension of simulation depth with consideration of soil heterogeneity. In addition, a precipitation adjustment method based on snow depth is also introduced. Parameters were calibrated with considerations of soil heterogeneity. With the improved Noah model, simulations on water-heat conditions of QTP with CMFD data over a typical site in alpine-cold region named TGL and a typical region with vast permafrost distribution named XKL were carried out. In section 3, simulation results on individual site and typical regions were compared and analyzed against *in situ* observation data to figure out the applicability of CMFD data in QTP. Advantages and shortcomings of the dataset are discussed. Finally, summary of this study and future prospects of CMFD application in QTP were concluded in section 4.

2. METHOD

2.1. Improvement of Noah model and data preparation

Noah has been widely applied in global or regional land surface simulations for water-heat process. Thermal roughness refers to the turbulent roughness resulting from the inhomogeneity of temperature fields. It is an important parameter in the energy exchange between ground and atmosphere and has a significant influence on the simulations of soil temperature and soil moisture. The original thermal roughness calculation method in Noah v3.3 is proposed by Zilitinkevich in 1995 [3]. Chen et al. has found that serious bias occurred when it was applied in arid and semi-arid regions and has proposed a new thermal roughness calculation method [4]. The method was introduced in this study as shown in Equation (1).

$$Z_{0h}=(70v/u_*)\times\exp(-7.2u_*^{0.5}|T_*|^{0.25}) \quad (1)$$

where Z_{0h} is thermal roughness. u_* is friction velocity and v is liquid viscosity. T_* stands for potential temperature. At the same time, soil stratification and extension of simulation depth with consideration of soil heterogeneity were also implemented by modifying model codes. Model parameters were calibrated with considerations of soil heterogeneity. Zhang et al. has found out that insufficient capture of precipitation in routine meteorological observation is common in cold seasons on QTP [5]. We tried to use the snow depth observed by the meteorological station to compensate the corresponding equivalent amount of precipitation. When the temperature is below 0°C and the snow depth increases by more than 2cm in the observation interval, it is considered that there is snowfall at that time and a precipitation adjustment method based on snow depth, propose by Pomeroy et al. and shown as Equation (2) are introduced [6]:

$$\rho_{snowfall}=67.9+51.3e^{T/2.6} \quad (2)$$

where $\rho_{snowfall}$ is fresh snow density, T is air temperature at that time(ºC). The density of new snow will be estimated and the water equivalent of snow at that moment will be calculated by combining the increase in snow depth at the observation interval. Thus the precipitation can be deduced from the water equivalent of snow.

2.2. TGL site and data

The TGL site (91º56′E, 33º04′N) is located on the Qinghai-Tibet Plateau with an elevation of 5100m. Permafrost is underlain in the research area and the surface is covered with typical cold alpine meadow. The annual mean air temperature at 2m height is −4.9 degree Celsius [7]. The TGL integrated observation system includes an automatic weather station (AWS), an observation system of the active layer and boreholes. All the regular meteorological observations come from the AWS. Verification data including soil temperature and moisture in the active layer come from the active layer system from ground surface to 3m depth since 2005. A borehole was drilled vertically to a depth of 34.5m to monitor ground temperature since 2006. The observation data of TGL is not assimilated in CMFD and forcing data prepared from TGL observation data is independent from forcing data derived from CMFD dataset. Thus simulation results achieved from forcing data of the two data source can be compared for evaluation.

2.3. XKL region and data

XKL region (78.8°~81.5°E; 34.5°~36.1°N) is located in the northwest QTP with an area of 43.7 thousand square kilometer and elevation around 4300~6000m. The annual mean air temperature at 2m is -6.3 degree Celsius. The topography and geologic structure of this region is rather complicate with mountain, basin, glacier, lake, lacustrine deposit area, alluvial plains and hilly areas. We divided the entire XKL into 432 grids in the resolution of 0.1 degree and adopted the corresponding forcing data extracted from CMFD dataset for simulations. In 2009, China's Ministry of Science and Technology launched a research project named "Investigation of permafrost and its environment over the Qinghai-Tibetan Plateau" and set up a series of active layer observation systems and boreholes in XKL [8]. With the data support from this project, soil temperature records of 10 boreholes were used as verification data of simulation performance of CMFD in XKL. General situations of the boreholes can be found in Table 1.

Table 1 Representative boreholes in XKL

ID	Code	Latitude (°)	Longitude (°)	Borehole altitude (m)
1	YH	35.77	79.40	4850
2	K512	35.86	79.39	4766
3	QTDB	35.68	79.49	5175
4	K529	35.72	79.46	4952
5	TSH	35.36	79.55	4834
6	LMCN	34.56	80.39	5050
7	LMCB	34.64	80.39	5016
8	JSDB	34.54	80.42	5177
9	LMCD	34.61	80.64	5156
10	LZL	34.80	81.33	5009

2.4. CMFD dataset

CMFD is a ground meteorological forcing dataset produced by Data Assimilation and Modeling Center for Tibetan Multispheres of Qinghai-Tibet Plateau Research Institute. Generally speaking, it has merged a variety of data sources including China Meteorological Administration station data for the period of 1979-2010, TRMM satellite precipitation analysis data (3B42) for the period of 1998-2008, GLDAS precipitation for the period of 1979-2010, GEWEX-SRB downward shortwave radiation for the period of 1983.07-2007.12, Princeton forcing data for the period of 1979-2008 and GLDAS data for the period of 2009-2010. Its spatial resolution is 0.1 degree and its temporal resolution is 3 hour. Yang et al. has found that downward solar shortwave radiation is significantly higher on QTP than that of its surrounding areas, while atmospheric longwave radiation is much lower [2]. Therefore, satellite remote sensing data and ground observation data were assimilated to revise the long-wave and shortwave radiation so that the part of the Qinghai-Tibet Plateau of the dataset could be more accurate.

2.5. Simulation with improved Noah

The improved Noah v3.3 and the precipitation adjustment method are used in simulation. The extracted forcing data includes wind speed/direction, air temperature, relative humidity, surface pressure, incoming solar radiation, downward long wave radiation and precipitation. At TGL site, forcing data are prepared from observatory data of the integrated observation system and CMFD respectively. Parameters including soil, vegetation and deep soil temperature together with initial values including soil moisture, soil liquid and soil temperature were all extracted from observation data. The simulation started from 16:00 on April 1, 2007 (UTC) to 15:00 on Jan 1, 2010 (UTC). The time steps of simulation and output were 30 minutes. In XKL region, forcing data are prepared from CMFD data from 2001 to 2010. The influence of initial values on model simulation was removed by spinning up forcing data. The whole soil columns were divided into 23 layers and the simulation depth was 18m for both TGL site and XKL region.

3. RESULTS AND DISCUSSIONS

3.1. TGL Simulation Results

In TGL site, simulated soil temperatures of 23 soil layers by both forcing data, namely the CMFD data and *in situ* observation data, were plotted against the corresponding observed soil temperature.

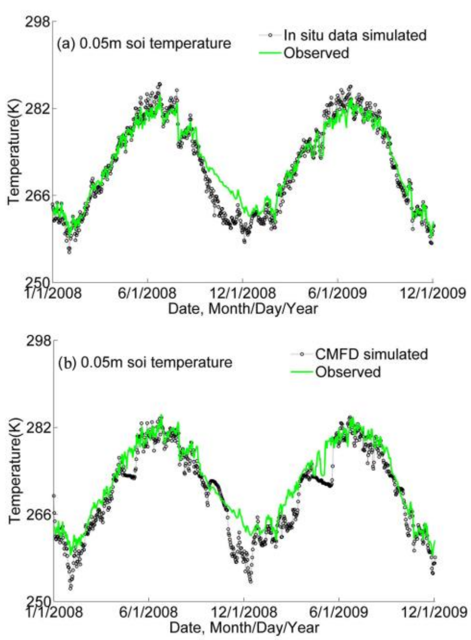

Figure 1 Soil temperatures at 0.05m simulated by forcing data from (a) *in situ* observation and (b) CMFD dataset in the TGL site

Table 2 NSE and SEE of soil temperature at 0.05m by observation and CMFD dataset in the TGL site

Metric	With *in situ* observation	With CMFD
NSE	0.911	0.818
SEE	2.116	3.018

Results of surface layer were taken as example to evaluate the simulation performance. Figure 1 shows the variation trend of simulated 0.05m soil temperature by both *in situ* observation and CMFD dataset in contrast to the observed 0.05m soil temperature and Table 2 shows the corresponding simulation performance. It can be seen from Table 2 that the Nash-Sutcliffe coefficient (NSE) for simulation driven by CMFD forcing data is 0.818, and that by *in situ* observation forcing data is 0.911, indicating that the accuracy of the two forcing data are rather good, while the observation forcing data is more accurate. The standard error of the estimate (SEE) shows that the simulation bias of CMFD forcing data is larger than that of observation forcing data. Given the 3hr time series of CMFD data were not as accurate as the 1hr of *in situ* observation forcing data and the CMFD data were actually the production of data interpolated and assimilated of various sources of remote sensing data and *in situ* observation data, the higher simulation bias of CMFD data is reasonable. However, it is fairly close to the observed value and the accuracy proves suitable for model simulation studies on QTP.

3.2. XKL Simulation Results

In application of CMFD data in water-heat simulation of XKL, 432 grids were simulated with grid resolution at 0.1 degree. The depth of zero annual soil temperature amplitude (DZAA) in XKL can be deduces from simulation results. Temperature at DZAA is known as the mean annual ground temperature (MAGT). Figure 2 shows the simulated general MAGT distribution map of XKL region. Table 3 shows the simulation performance of the 10 boreholes in XKL.

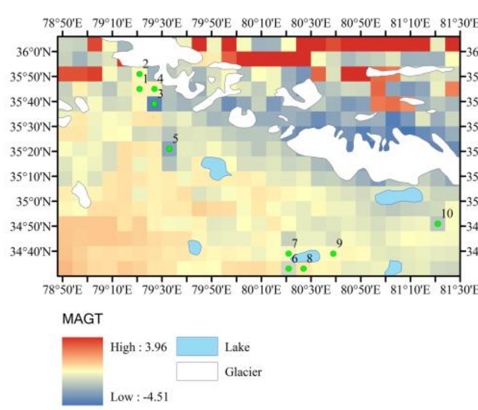

Figure 2 Simulated MAGT distribution over the XKL area

Table 3 Simulated and observed MAGTs in 10 boreholes and corresponding bias

Code	ID	Simulated MAGT(ºC)	Observed MAGT(ºC)	Bias (ºC)
YH	1	-1.87	-0.71	-1.16
K512	2	-1.93	-1.10	-0.83
QTDB	3	-4.24	-2.75	-1.49
K529	4	-1.87	-1.67	-0.20
TSH	5	-3.55	-3.00	-0.55
LMCN	6	-2.67	-1.94	-0.73
LMCB	7	-2.13	-1.80	-0.33
JSDB	8	-1.70	-1.32	-0.38
LMCD	9	-1.80	-1.25	-0.55
LZL	10	-2.94	-2.27	-0.67

It can be seen from Table 3 that MAGT simulation discrepancies are within 1.00 degree for 8 boreholes of the total 10 ones. The other two has discrepancy within 1.50 degree, indicating that the CMFD data shows comparatively good accuracy in simulating water-heat conditions of typical areas in QTP. Field investigations show that borehole No.1 YH is about 600m away from several salt lakes and the discrepancy of simulated MAGT can be ascribed to the positive influence on borehole temperature by salt lakes. Borehole No.3 QTDB is located in the alpine pass, its slope is 200 degrees with sunny southwest aspect. Although the CMFD data has taken the influence of elevation on solar radiation into account, it use the average radiation within grid to represent the whole grid. Compared with the high radiation on boreholes in individual sunny slope, the corresponding CMFD radiation can be quite lower, resulting in lower simulated temperature in QTDB. As soil temperature is hard to be simulated accurately when the underground soil features are not clear, the simulation discrepancies are mainly attributed to the inaccuracy of soil parameter data but not the inaccuracy of CMFD data.

From above results, it can be seen that uncertain sub-grid factors may have impact on the observation results in grids and make verification of simulation results unreliable, the resolution in areal simulation is absolutely necessary to be improved. As the simulation resolution is determined by the resolution of forcing data, that means although the resolution of CMFD is proved to be comparatively good on QTP, it still needs to be down scaled in future studies.

4. SUMMARY

With improved Noah model and a precipitation adjustment method based on snow depth, we have successfully carried out simulation on permafrost region of QTP using CMFD-derived forcing data. By analyzing simulation results, the applicability of CMFD data in model simulations on QTP is well proved with comparatively good simulation accuracy in both a typical individual site and a typical region. Large simulation discrepancies are mainly caused by local factors. On the other hand, to ensure better simulation of key permafrost properties in QTP, the improvement on resolution and further involvement of sub-grid factors still needs to be considered in the next version of CMFD. In the future, we also planned to extend model simulation based on CMFD to the whole QTP and further verify the applicability of the dataset.

5. ACKNOWLEGEMENT

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6. REFERENCES

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