

Study on permafrost distribution in Qinghai-Tibet Plateau based on MODIS data

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Abstract—It's one of the important issues to identify the ground boundary of permafrost in the permafrost study. Mean annual ground temperature (MAGT) is the ground temperature at the depth of zero annual amplitude in permafrost layers and it is one of the main indicators for permafrost division in Qinghai-Tibet Plateau. In this paper selecting Qinghai-Tibet highway as a study area and surface temperature, elevation, equivalent latitude, soil moisture, albedo, normalized difference vegetation index (NDVI) as model factors. According to relativity analysis on MAGT and model factors mentioned above to build a ground temperature retrieval model based on MODIS data. Considering the equivalent latitude in section, the coefficient of determination increased from 0.598 to 0.617 and 0.826, the model stability and prediction is improved. Compared to permafrost map, it is found that the simulated result can effectively describe the distribution features of permafrost along the Qinghai-Tibet highway, only in the middle there are a small number of melting districts. The melting districts are mainly distributed nearby the Tuotuo river, where is a perennial river and has a large flows, appear melting district can be considered reasonable, conform to the actual distribution law of the permafrost. Although there are still some differences in individual areas, it may be improved by increasing sample points.

Key Words—MODIS, Qinghai-Tibet highway, permafrost, distribution simulation

I. INTRODUCTION

Permafrost in Qinghai-Tibet Plateau is the world's highest elevation and largest permafrost regions in the lower latitude. For its vast area and less measured data, traditional mapping methods rely on the observations of station have been largely restricted. Remote sensing can rapidly, large-area and multi-temporal get ground information related to permafrost distribution for spatial analysis, which can reduce the heavy labor of field sampling and enrich the study content of permafrost.

MODIS is one of the main remote sensing instruments in the series of EOS satellites, which was respectively equipped with Earth Observation Satellite Terra and Aqua and launched in December 1999 and May 2002. Considering the data features of free distribution, high temporal resolution and covering a wide range, MODIS data is very suitable for the

study on permafrost distribution in Qinghai-Tibet Plateau. It is mainly because the permafrost area is widely distributed in Qinghai-Tibet Plateau, and the permafrost is very sensitive to the diurnal variation of temperature. Using high-resolution remote sensing images on permafrost research will be costly, and if using too many scenes of image, time is difficult to reach agreement. Therefore high-resolution data does not have the potential to promote in a wide range. This paper is selecting Qinghai-Tibet highway as a study area, trying to introduce remote sensing techniques into the study on permafrost distribution to reflect the macro, dynamic and convenient advantage of remote sensing.

II. PREPARATION FOR MODEL DATA

It is unrealistic to consider all factors affecting the permafrost distribution in the model. Therefore we need to select several major factors affecting the permafrost distribution in the process of modeling. Comprehensively considering the main factors impact on the permafrost distribution of Qinghai-Tibet Plateau and environmental information can be provided by remote sensing for permafrost studies, selecting land-surface temperature, elevation, equivalent latitude, soil moisture, albedo, normalized difference vegetation index (NDVI) as model factors in this paper.

Permafrost is the product of atmosphere heat-exchanged through the ground and stratum, which is influenced by climatic and regional geology conditions. Under natural conditions, geology and geography, vegetation cover and hydrological conditions vary greatly in different regions, so the permafrost may be different under the same climatic conditions [1]. In order to reveal the change characteristics of permafrost under natural conditions, selected the average parameters of surface variables in the model.

A. Land Surface Temperature

The near-surface is the direct role layer of ground-air exchange, which is the important parameter to determine the existence of permafrost [2]. Compared to air temperature, land-surface temperature is more suitable to reflect the up-boundary conditions of permafrost. However the ground temperature is

not easy to be got and it can only represent the local temperature of the observation point. So in this paper selected the MODIS temperature products MOD11A2 as the land surface temperature data. The products comprehensively consider various factors that affect the inversion quality of land-surface temperature, including the impact of atmospheric, cloud and so on. And the products realize the business operation of algorithm to ensure the consistency in the quality of data [3]. The user can select the data according to the quality information supplied by the data itself. Using this data on the study of permafrost ensure the reproducibility of the work. In order to eliminate the accidental factors effect of a single year data, averaged 5-year data from 2001 to 2005 as the annual average surface temperature.

B. Elevation

Elevation is the most important factors to control the distribution of permafrost in Qinghai-Tibet Plateau, which is an essential effect factor in the model. Digitized contour of 1:250000 topographic map and interpolated to build the DEM.

C. Equivalent Latitude

Equivalent latitude is a long-term potential factor of solar direct radiation on the surface, which is calculated by aspect, slope and latitude. Thus it considers the aspect and slope comprehensively [4].

D. Soil Moisture

Download daily soil moisture products (AMSR_E_L3_DailyLand) from the National Snow and Ice Data Center (NSDIC). AMSR-E sensor equipped with the Earth Observation Satellite Aqua launched on May 4, 2002 [5]. So it can only download the product since June 19, 2002. In this paper, we collected 3 years AMSR_E daily soil moisture products from 2003 to 2005. Affected by the shape of the earth, there are gaps in the daily data between each scan track in the low and middle latitude. In order to cover the study area completely, soil moisture products used in the paper are three days synthesized. Repeated region used the next day's value, and averaged every three days data of a year as the average soil moisture data. In order to eliminate the unusual factors impact of individual years, averaged three years data as the annual average soil moisture data.

E. Soil Moisture

Download the MODIS albedo products (MCD43B3) from the NASA website. The time of the data is from 2001 to 2005. The data spatial resolution is 1km, and used the same process flow with the temperature products to obtain the annual average albedo.

F. Vegetation Index

Download the monthly composite vegetation index products MOD13A3 from the NASA website, the time is from 2001 to 2005. The data spatial resolution is 1km, and used the same process flow with the temperature products to obtain the annual average NDVI.

G. Ground Temperature Data of Permafrost

Mean annual ground temperature (MAGT) is the ground temperature at the depth of zero annual amplitude in permafrost layers, which can well reflect the combined effect of zone and region on permafrost [2]. Currently MAGT is one of the main indicators for Qinghai-Tibet plateau permafrost division. The MAGT data used in the model is mainly from Chinese glaciology and frozen soil map of 1:4000000 (2006), partly from the published monographs and papers, a total of 51 ground temperature data.

III. MODEL BUILDING

In this paper used the MODIS data as the main data source, based on the GIS technology to extract the surface variables related with permafrost distribution. Established the relationship of surface variable and MAGT to obtain the MAGT indirectly, and achieved the purpose of identifying permafrost.

A. Correlation Analysis

Most of the data used in the model are MODIS products and their spatial resolution is 1 km. In order to ensure the consistency of data accuracy, resample the DEM and soil moisture data into the same resolution with MODIS data.

Using MAGT data and surface variables to have a spearman rank correlation analysis. Despite the sample points used for statistical analysis is limited, the significance of relationship between the MAGT and surface variables is still clearly. Where the correlation of elevation and MAGT reached -0.601, it is consistent with the conclusion "elevation is the most important factors affecting the permafrost distribution in Qinghai-Tibet Plateau". The formation and preservation of permafrost undoubtedly has a great relationship with the average annual temperature condition, and the vegetation is also the main factors that affect the permafrost thermal condition. When the significance level is 0.01, soil moisture is significantly related with MAGT, but compared to elevation and mean annual surface temperature, the significance is relative weak. It is mainly because that the spatial resolution of soil moisture data is 25km, although resample it to 1km, it still represents an average state of soil moisture content in 625km². Compared to other data the accuracy is relative low.

B. Model Building

Using the data mentioned above to have a multiple regression analysis in the software of SPSS, established the ground temperature retrieval model based on RS and GIS. MAGT as the dependent variable, the surface variable data extracted from remote sensing data as independent variables, the regression equation is:

$$T_{cp} = -0.003 \times H + 8.976 \times NDVI + 13.570. \quad (1)$$

Where T_{cp} is the MAGT, and the last significant variables selected into the equation are elevation and normalized difference vegetation index, the determination coefficient is 0.598.

Using $T_{cp}=0.5$ as the divide line of permafrost and seasonal frozen soil, obtained the simulation result of permafrost along Qinghai-Tibet highway. Compared it to the permafrost map (Fig.1), the simulation result is not a good reflection of the permafrost distribution along Qinghai-Tibet highway. Therefore the model needs further improvement.

Solar radiation is strong in Qinghai-Tibet Plateau, and the hillside orientation has an important effect on the permafrost distribution. Solar radiation effect on different aspect and slope varies greatly, and the MAGT on south and north slope in some areas of Qinghai-Tibet Plateau can have a difference of 2°C [6], which results a significantly difference of permafrost distribution in different slope and aspect. However equivalent latitude is not selected into the equation (1) in the stepwise regression analysis. As mentioned above, attempted to consider the equivalent latitude in section and used 0°C as the dividing line to have multiple stepwise regression analysis, the regression equations are:

$$T_{cp} = -0.003 \times H + 7.465 \times \text{NDVI} - 0.031 \times \text{Equat} + 13.656 \quad (2)$$

$$T_{cp} = -0.003 \times H + 10.435 \times \text{NDVI} + 0.209 \times T_s + 8.156 \quad (3)$$

The determination coefficient increased from 0.598 to 0.617 and 0.826, the model stability and prediction is improved. But in the segment consideration, factors selected into the regression equation are different. Affected by the aspect the mountain permafrost often characterized asymmetric [7], so the surface factors affected the distribution of MAGT are also different in the south and north aspect. When we used equation (1) to simulate the MAGT distribution, it will certainly have great error.

C. Simulation Result

Using equation (2) and (3) to obtain the simulation result of permafrost distribution along the Qinghai-Tibet highway (Fig.2), the accuracy of simulation result is improved. Compared it to permafrost map, it is found that the simulated result can effectively describe the distribution features of permafrost along the Qinghai-Tibet highway, only in the middle of the road there are a small number of melting districts. The melting districts are mainly distributed nearby the Tuotuo river compared to the permafrost map, where is a perennial river and has a large flows, appear melting district can be considered reasonable, conform to the actual distribution law of the permafrost.

D. Compared to Simulation Result of ASTER Data

High spatial resolution remote sensing images have great potential in the simulation of permafrost distribution. Due to the unique high-latitude, surface characteristics and climatic environment, cloud cover is very much in Qinghai-Tibet Plateau. Therefore the image covered the specified area is less able to meet little cloud cover and close time. This paper selected 6 scene ASTER images in April 13, 2002 which

covered parts of Qinghai-Tibet highway. Selecting five parameters of land surface temperature, elevation, equivalent latitude, vegetation index and land surface humidity index to build multivariate analysis model, and simulating the permafrost distribution in Qinghai-Tibet highway. Compared the results with the simulation results based on MODIS data; it shows that the results based on ASTER data intended better with permafrost distribution map. Melting district exist in Simulation results, which is the same with the results of MODIS data, meeting the permafrost actual distribution law. No matter which data simulation results appear melting district, although the distribution area is different, the position appears broadly similar, which show the effect is ubiquitous in the permafrost distribution, it need to be given proper attention in the follow-up studies.

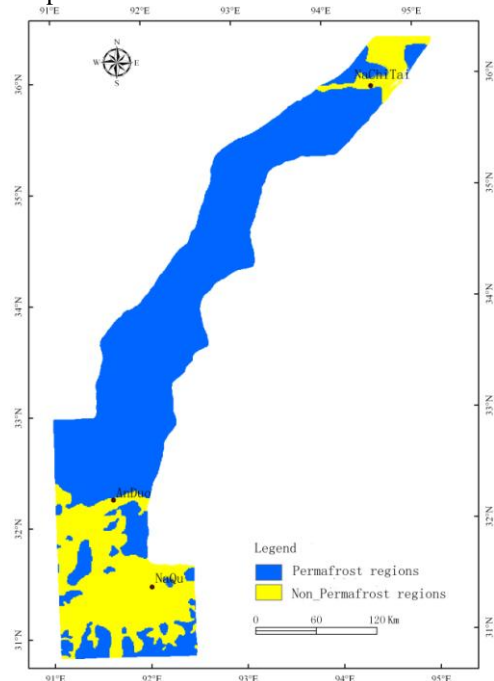


Fig.1. Permafrost Map

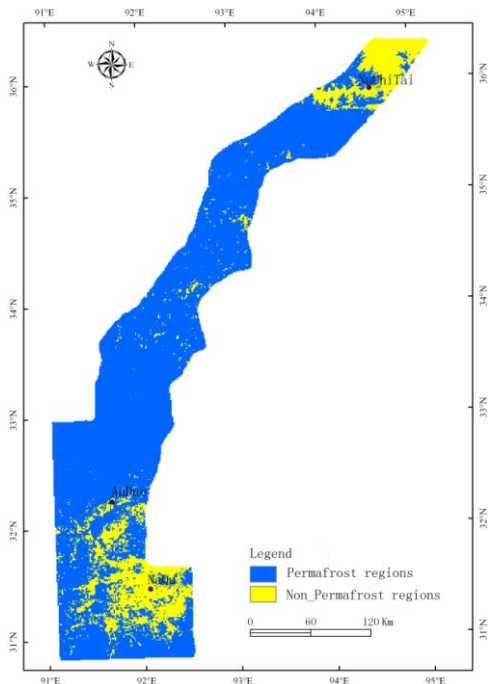


Fig.2. Simulation Result of Permafrost Based on MODIS Data

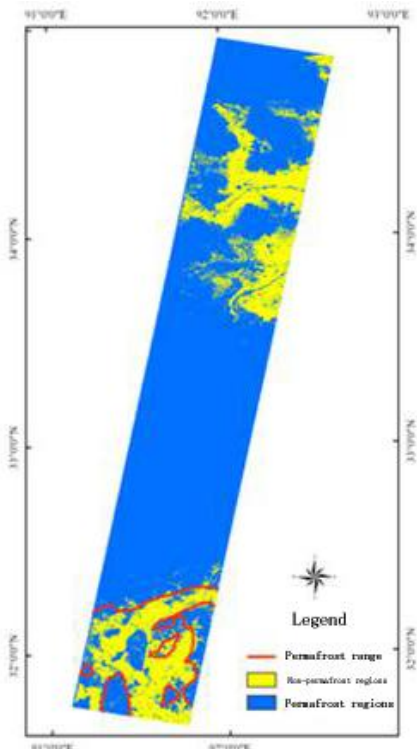


Fig.3. Simulation Result of Permafrost Based on ASTER Data

IV. CONCLUSION

In the paper, successfully applied MODIS temperature data in the research of permafrost in Qinghai-Tibet Plateau, which is a meaningful attempt to solve the issue of permafrost distribution in Qinghai-Tibet Plateau. Although there are still some differences in individual areas, it may be improved by increasing sample points.

Compared with the simulation results of ASTER data, the results of ASTER data fit better with the permafrost map. It is due to the high spatial resolution of ASTER data, which can reflect the local terrain and surface variables distribution more detailed. The simulation results existed melting districts, the melting districts mainly distributed in the range from Tongtian river to Tuotuo river, banded distribution along the river. Regardless of the data and simulation methods, simulation results existed melting districts. Although the distribution area is different, the position is similar, which reflected the impact is widespread in the simulation of permafrost, it should be given proper attention in the follow-up studies.

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