ANALYTICAL RESULTS OF THE COMPUTER-PROCESS CALCULATING THE SNOWPACK WITH REMOTE-SENSED INFORMATION IN XINJIANG

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determining the depth of snow directly and may estimate at large area for its low resolution.

1. INTRODUCTION

A simply realizable and real economic way for calculating the amount of accumulated snow about certain area is to process the plentiful information on satellite images by computers. Nowadays, we receive continuously image material about earth surface from satellites, these material have made already more advantages as large surface covered, accuracy in time and less expense. More than four years, we have made a great deal of experimental investigation on digital image processing system, and carried out a relative complete method for calculating the amount of accumulated snow in Xinjiang with remote-sense information by computer.

Before using the digital image system processing the satellite image material to calculate the amount of accumulated snow, we used to completely several steps as following:

a) Make a precise geometric correction on satellite image material. Reference [4]; b) To realize the automatic ranging and make-window the boundary of exploring region in the digital image processing system, we must make the window expand and decrease according to the size of the images. Reference [5](e). In accordance with the real situation we may divide the exploring region into some local image information blocks with their own characteristics, conveniently. Reference [5]. d) Automatically discriminate and determine the gray scale of the accumulated snow and other characteristics of earth in the image, particularly filtering process the image covering with the cloud. Reference [3](e). Determine the coefficients in calculation for the correction of errors of distortions and the basic ratio of surface.

In the experimental stage, we use the image material received by Xinjiang earth station, these material come from American 3rd generation service weather satellite TIROS-N/NOAA/AVHRR and Feng yun No.1 NOAA weather satellite with its AVHRR (advanced very high resolution radiometer) has five channels, including visible, infrared, heat-infrared three channels. We may obtain the material of image data, snow surface scanning rate, snow surface temperature, etc. It may have more good effects for the image material with higher resolution. But there is not that those of facility in Xinjiang China to receive that remote-sense information. Our material from weather satellite have limitation—mainly without microwave exploring data for water resource and seasonal temperature. The relations of the annual snowpack and natural calamity in the area, and the high mountain-snowpack seasonal temperature, the relations of the snowpack and native water resource, finally, to determine the law of snowpack distribution in the area.

KEY WORDS: Landsat, Image Processing, remote sensing application, Image Analysis, Snowpack, Xinjiang.

ABSTRACT:

The present paper have discussed the results of calculating by using digital image processing system. We have used computers to carry out a great number of experimental explorations in processing the information from the remote-sense satellite image data to calculate the snowpack in a part of Xinjiang and to explore the relation of the annual snowpack and natural calamity in the area, and the high mountain-snowpack seasonal temperature, the relations of the snowpack and native water resource, finally, to determine the law of snowpack distribution in the area.

Our analyses and process have taken the research object with the region about Urumqi Xinjiang (U.R.). Fig(1) show the satellite image of U.R. at Oct. 1987. The land satellite image shows the topography of the U.R. In the middle section of TianShan Mountain, with altitude between 500M-5450M. Its topographic, geomorphic situation have its typical representivities. It had located just on the cross of the east-to-middle section of TianShan Mt. and the south-to-north zone of Xinjiang. The two climates of the south and north side of TianShan effect this region alternatively, and the seasonal wind effect the snow seriously. Zhuixer Basin on the north side of the mountain and there are hinterland river(Urumqi River), Toutsun River(5), flowing from south to north. And Baiyang River(8) at DaBanCheng flowing toward east into Tufufan Basin. The capital of X.J.Autonomous Region has its city of Urumqi(1) on the altitude of 819M. Bogeda Mountain(9) with white cap(5445M) in the east, and in the south west there is Tianger Mountain(10) (5289M), although without long distance between each other, these two mountains have different characteristics of the distribution of snow pack. In U.R. there are several observatories for meteorology and hydrology, and the plenty data material had accumulated for many years which be convenient for real exploration. That is the reason to make the selection to calculate the accumulated snow of U.R. as an example. If the calculating method is resolved for the local area snowpack processing, than it may be extend to analyse and calculate the snowpack about the whole region of X.J.

This paper may use the computer processed image as an example, base on the collective analysis of the data from the observatories to estimate the variation of accumulated snow in the period of snowpack on the exploring region for one year. Mainly, to discuss the statistical method with its principle and results analysis, working on the information of accumulated snow which taken from the remote-sense image material. The problem of the error correction exist in the whole process, particularly, to calculating the snowpack of larger region the elimination of error is most important. The method of error elimination in
the whole process may discuss in other paper, here may touch a little at concerning paragraph.

2. ANALYSIS AND CALCULATING METHOD

2.1 Analysis of the Presentation Snowpack

To determine the depth of the snowpack in various places is the key problem of the calculation of the accumulated snow on certain area. It may show only the depth less than 36 cm by the light reflection varying with the depth of snow, and it may be shown by the grey scale of infrared image with nice quality. Obviously, this measurement cannot realize the exploitation of snow depth in X.J. China, for the depth more than 36 cm at most region of mountain in X.J. when winter. These places are very complicated in geomorph and topograph, high mountain with steep slope, and the snow more concentrate to the gorge and canyon. The distribution of snow be different for the slope tendencies, direction of the slope surface and adjacent basin and it be effected by temperature of the local environment extra ordinarily. Most of these area cannot set an observatory. So at certain region the quantity of accumulated snow must be the result inferred by the computer with the synthesis of various measuring and processing data.

Now we discuss the inference of snowpack with the situation of U.R. The position of U.R. is in the middle section of Tianshan with the range of longitude E 8° 5'~E 9° 5' and latitude N 4° 1'~N 4° 4 1/2', the area of 11 440 km². Almost the whole region snowpack are variable in the period from the middle of November until the middle of May next year, about four to five months. There is not severe hot weather in the short summer but the seasonal temperature difference is large. The atmosphere is dry for four seasons by the gigantic snowfall. Almost all of the snowfall become seasonal snowpack, the snowfall in winter accumulated to next year when the temperature rise about 0°C be melted. The upper limit is the snowline and the lower limit of the seasonal snowpack vary with seasons and the situation on the south or north of the mountain. The permanent snowline swing about 3700 M, it varied with average temperature and atmospheric environment change for times every year. Fig (1) & (2) shown most part of U.R. are below 3700 M, its snowpack is in seasonal distribution. During the winter the atmosphere of U.R. mainly be controlled by the counter cyclone from Siberia and Americia, and in the summer air flow from Arctic Ocean and the West wind cycloning flow enlarge its effection. By the alternate effection of this two seasonal flows the distribution of the snowfall in U.R. be more on the north than the south side of Bogeda and Tianger; and the snowfall be 25~35% of the total precipitation one year (local area may reach 40% or more). The snowfall make very different amount in November for years, the snow fall down and melt repeatedly, and without regulation; this period the snowpack is unstable. The snowpack stay in a storing period about middle Nov. to middle Feb. next year this period all region is covered by snow excepting some bushy area with low reflection and Dabancheng Region with its never snowpack area in the midst of wind. In this circumstance to search the rule of snowpack variation by processing and analyzing the image may gain unsuccessful result. The middle Feb to the beginning of May every year the accumulated snow on high mountain may be melted regularly with the atmosphere and surface temperature. The snowpack stay in a storing period about middle Nov. to middle Feb. next year this period there is a effective method for search the rule of snowpack variation, that is to use the image information of snowpack calculating the covering rate in continuous time and taking about several years (at least three years) snow covering rate variation and the data material from land observatories, then using the correlation between the covering rate and the melting process of maximum snowpack decrease to permanent snowpack for solving this rule. Before process we have to certify the maximum and minimum (permanent) snowpack in this region for year and the time interval for variation from maximum to minimum snowpack. Also, the air flow, temperature, geographic environment and the wind speed of that place with in that time all be considered.

2.2 Method of Analyzing the Snowpack Material

We had analyzed and processed some parts of the continuous satellite image material of the period Jun. 1989 to Mar. 1992. We concluded the results and the analytic and processed method as following: Divide U.R. into six zones for the altitudes as: below 1000 M (zone No. 1), 1000~1500 M (No. 2), 1500~2000 M (No. 3) 2000~3000 M (No. 4), 3000~3700 M (No. 5) and above 3700 M (No. 6), and processing the image material of zones in digital image process system (Fig 2) and refer Fig 1. We may take any zone independently for analysis, it is very useful for analyzing the distribution characteristics of accumulated snow. It has denoted the high way from Urumqi to Dabancheng cutting the geographic section of U.R.; the left side is the south-west slope of Bogeda Mountain, the right side is north slope of Tianger Mountain. The parts of U.R. on the north slope of Bogeda and Tianger including Urumqi city almost are cultivated land with altitude below 1000 M, about 1000~1500 M the more low grass pasture and the less cultivated land, with in 1500~2500 M altitude are coniferous forest, and above 2500~3000 M bare rock band. The parts of U.R. on the south slope of Bogeda and Tianger with altitude 1500~1800 M are sandy land, only less portions with water there are low grass pasture, and little cultivated land, but little accumulated snow in winter: above 1800~2500 M are bare rock band.

In accordance of above statement we may take image blocks with characteristics of geographic and snowpack distribution for calculating. First we calculated the area of snow and ice for each image block. Then take the real measuring depth of snow on standard base points located at every image block to calculate the average snow depth, and calculate with this by computer for the local snowpack in each image block. At last sum up for total amount of accumulated snow. Here the real measuring data on standard base points and the material of snow and ice be utilized in later statement and calculation be offered by main observatories of U.R. meteorology. Table 1 shown the geographic situation, average maximum temperature for several years, maximum depth of snowpack and the quantity of evaporates of Urumqi city, Xinjiang meteorological observatories and the hydrological observatory at YinXungqiao within U.R. for the following statement. On this table all real measuring data on land surface are taken to announcements.

2.3 Approximate Calculation of Snow Pack
2.3.1 Snowpack in zone NO.1  As shown in Fig(2), zone NO.1 of U.R.(include City)situate on the north-west slope of Bogeda, with plain outlook and slight slant from south to north. In winter the depth of snow for everywhere almost be a same quantity, and the Snow pack may be:

\[ D(t) = A_1(t) \times D_1(t) \]  

(2-1)

here \( D_1(t) \) is the average depth of snow at several real measuring points of this zone with in same time, and with the unit \( m \). \( A_1(t) \) is the area of snow and ice of this zone for same time \( t \), may be defined by following equation:

\[ A_1(t) = \sum_{i} \sum_{j} \beta_{x,y} \times 0.5 \times \left( \frac{\Delta x}{\Delta x} \right) \times \left( \frac{\Delta y}{\Delta y} \right) \times K_i \]  

(2-2)

\( \beta_{x,y} = \begin{cases} 1: & \text{when we found snow pack zone.} \\ 0: & \text{other.} \end{cases} \)

\( \beta_{x,y} = \begin{cases} 1: & \text{when we found the margin of snow pack zone.} \\ 0: & \text{other.} \end{cases} \)

The second term in eq.(2-2) right side is the sum of points which statistical snow pack or scenes margin varying at coloume position. The first term is the sum of all image elements encircle by the margin but except the second term. \( K_i \) is area coefficient , the ratio of \( R_1 \) the real geographic area of the measuring zone to \( L_1 \) the total number of the image elements in window of the measuring zone. If in zone NO.1 the number of total elements in the window is \( L_1 \) equal to 1704 , real area \( K_1 \) is the value of 936.6 Kk², then,

\[ K_1 = R_1 / L_1 = 936.6 \text{Kk}^2 / 1704 = 0.5496478 \text{Kk}^2 \]

\( \eta_i \) is the correcting coefficient of error,determined by factors as the shape of snow pack zone, geometric and other factors, etc. Altitude blow 1000m make \( \eta_i = \frac{\alpha_i}{\alpha_i} \times \frac{h_i}{d_i} \), here \( h_i \) is the altitude difference and \( d_i \) is the maximum distance in north south direction. Refer Fig(3) and reference [3].

In the condition eq.(2-3) \( f_i \) is the gray scale, \( h_i \) is the limitation for snow and other scenes in this zone.

Fig(3) Slope relation

Table(1) Data from 4 main observatories in U.R.(offered by corresponding stations and the snow depths are maximum.)

<table>
<thead>
<tr>
<th>station</th>
<th>latitude</th>
<th>snow depth</th>
<th>TC</th>
<th>evaporation</th>
<th>slope position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>cm</td>
<td>H</td>
<td>L</td>
<td>max</td>
</tr>
<tr>
<td>Yinxunqiao</td>
<td>1918</td>
<td>19</td>
<td>2.5</td>
<td>-27.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Dacugou</td>
<td>2100</td>
<td>29.0</td>
<td>4.8</td>
<td>-34.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Dabancheng</td>
<td>1225</td>
<td>2.0</td>
<td>12.9</td>
<td>-55.2</td>
<td>9.8</td>
</tr>
<tr>
<td>Xiaoquze</td>
<td>1722</td>
<td>36.0</td>
<td>9.4</td>
<td>-29.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Balkatlu</td>
<td>1920</td>
<td>46.0</td>
<td>-3.1</td>
<td>-29.5</td>
<td>-</td>
</tr>
<tr>
<td>Balantai</td>
<td>1751</td>
<td>21.0</td>
<td>-2.2</td>
<td>-23.3</td>
<td>-</td>
</tr>
</tbody>
</table>

2.3.2 Snowpack in zone NO.2 As shown in Fig(2), zone NO.2 of U.R mainly on the south slope east part of Bogeda, with mounds terrace sloped down from north to south gradually,and include the famous 30 Li wintry zone of Dabancheng;recent years little snow pack. Consider the accuracy of total quantity of snow pack may calculate with eq.(2-1) and (2-2) for it may be treated as gravel plain, and snow depth \( D_2 \) approximate unify. But the correcting coefficients of error have using \( h_i = \alpha_i \times h_i \times d_i / d_2 \), here \( h_i \) is altitude difference and \( d_2 \) is the maximum distance with in north south direction. The area coefficient \( K_2 \) be determined by following:

\[ K_2 = R_2 / L_2 = 3545.72 \text{Kk}^2 / L_2 \]

here \( L_2 \) is the total number of image elements in zone NO.2.

2.3.3 snowpack in zone NO.3 As know in Fig(2), in regard the variation per year of the snow pack in zone NO.3, for the calculation we must know the snow depth distribution on the high mountain with altitude above 1500m. Here we make analysis on the rule of variation of snow depth in this zone NO.3 in the storing snowfall period. Fig(4) shows the snow depth distribution with altitudes for a month on north slopes of Bogeda and Tianer. In the accumulating period snow depth increase with altitude, linear slop increase with time. A respective analysis on south slopes is made also. The results shown for every month the snow depth is an increasing function of altitude, the winter snowpack of mountain slopes with its depth distribution may be presented by an increasing function of altitude,average.

After accumulating period the snow depth of melting period is shown as Fig(5).This time interval the distribution of snow depth also has a linear relation with altitude as same in accumulating period. Zone NO.1 has its accumulating period till middle March, and followed by melting period. From middle March to the beginning of May, lowerpart of slope the snow be melted with the temperature rise, and accumulated on higher parts, the linear slop increasing rapidly. At the altitude about 3700M, the snow depth distribution have a approximate linear slope for all the time in snow fall and melting period, that is the melted quantity independent with altitude. This seem contrary with the higher place the lower temperature and less melted quantity. Consider the surface heat equilibrium, the input and output heat depend on temperature include the latent term and the appear term. According to results of observation the appear term be positive, the latent term be negative, and the sum of these two less than the equilibrated value of radiation. So in the melting period for melted quantity the sun radiation is essential as comparing with temperature. The surface of snowpack receive radiation quantity independent with altitude, the melted quantity in melting period are also independent to altitude and may be a constant. These results are obtained from collecting and arranging real observed data from representative observatories in U.R.[Reference[1]]

By this analysis , we may obtain the characteristics of the snow pack distribution of mountain slopes of other. 
U.R. On the time interval from beginning accumulate snow time $t_1$ until the evading time $t_2$, a place with altitude $h_1$ has accumulated snow depth $\Sigma D(h_1)$ having a proportional relation with $\Sigma D(h_0)$ the accumulated snow depth at altitude $h_0$ and may be shown as following:

$$\Sigma D(h_1) = a(h_1) \Sigma D(h_0) \quad (2-4)$$

Let $t_1 < t < t_2$, $t_1 < t < t_2$.

Thus the time starting calculating, $t_1$ is the evading time, at shows a place with altitude $h_1$ and a basic point with altitude $h_0$ both accumulated snow depth use in proportional relation with same time starting is calculate. Also eq(2-4) may show the slope $a(h)$ increases with the altitude rise, and Fig(6) shows $a(h_1)$ and $h_1$ appearing a linear function relation, that is

$$a(h) = a(h_0) + a_1(h_0 - h_1) + 1 \quad (2-5)$$

Here $a(h)$ is called snow pack proportional coefficient. We let $h_0 = h_1$ the basic point has proportional coefficient $a(h_0) = 0$, and $a(h)$ may be calculated by following methods.

For the reason of easily to observe and to take data, then may calculate the snow depth of any altitude point. If in eq (2-4) certain altitude points calculating, examine it by real measured data, if basic point located at Heijing (918m) depth of any altitude for checking up the accuracy and $a(h)$ may be determined by following eq:

$$K_3 = R_{a}/L_4 = 2542.2126Km^2/L_3$$

In the eq. $l_3$ is the total number of image elements in zone No.3

2.3.4 Snowpack in zone No.4 and No.5

For the may as in zone No.3 we may get the eq.s of zone No.4 and No.5 respectively:

$$S_3 = A_3 W_3 (D(h_1)) [a(h_1) (h_1 - h_0) + 2] / 2$$

$$S_4 = A_4 W_4 (D(h_1)) [a(h_1) (h_1 - h_0) + 2] / 2$$

In previous eq. $D(h_0)$ is snow depth on basic point, unit in h, $h_0$ is the area of snow pack of the zone No. 3 with in that period may be calculated by eq.(2-2) but the correcting coefficient of error $\eta = (h_1 - h_0) / \sin\psi = d_2 / \cos\psi$, as shown in Fig(3). $S_3$ may be obtained on image by mouse or in real calculation. The area coefficient $K_4$ may be determined by following eq:

$$K_4 = R_4/L_4 = 2614.13Km^2/L_4$$

In this eq. $l_4$ is the total number of image elements in zone No.4.

In this eq. $l_5$ is the total number of image elements in zone No.5.

In general, with in the altitude 1500~3700m, may divide the experiment region with different altitudes into n blocks, $x=1,2,\ldots,n$ and south and north slope denote by 1,2. Then the total quantity of snowpack within this region is equal to the snow of individual quantities. And may be calculated by following eq:

$$S_{ex} = E \Sigma A W D(h_0) \sin\psi / h_0$$

$$S_{ex} = \Sigma A W D(h_0) (h_0 / h_0)^{2} / 2 \quad (2-10)$$

Obviously, the more blocks divided, the sufficiently line dividing margins of blocks, This sum may have delicate valve. But cause the calculating complicated and large, The calculating interval and procedure of process also be enlarged. Particularly, the measurements of basic point may be difficult, generally the real measuring on snow depth of basic point have take average value of points at a same contour line.

2.3.5 Snowpack in zone No.8 As shown in Fig(2), above 3700m, near the top of montain the snow depth inversely decrease by height for both south and north slopes of U.R. and previous distributing rule of snow depth is impracticable, referenc[1]. There are several reasons cause this condition. This area take a little proportion of the total montain area. The snow pack on this zone almost be the permanent snow pack.
may be melted in the interval from June to the beginning of September, so make little effect with the spring flood every year, but more effect with the flow of four seasons rivers. The snow and ice quantity in this zone may be estimated according to average wind speed for year, quantity of snow and ice last year, average temperature per year, and general snow depth of U.R. The estimate eq. is:

\[ S = A_0 + D_0 + S_f \]  

(2-11)

Here the area \( A_0 \) calculated by eq. (2-2) and \( n_0 = 1 + 2 \times 10^{-7} \) determined by the average slope of this zone, area coefficient \( k_a \) may be determine by following eq:

\[ K_a = R_a / L_a = 1084.8 \text{Km}^2 / L_a \]

In this eq. \( L_a \) is the total number of image elements in zone No. 6. \( D_0 \) is determined by the accumulated snow and depth from beginning snowfall to the measuring time. \( S_f \) is the quantity of permanent snow and ice last year. This calculation all are based on total quantity as 61.9x10^6 announced by the gouverment in 1987, and estimate year by year. Finally, in whole region the snow ice quantity of U.R. may be calculated:

\[ S = S_f + S_0 + S_1 + S_2 + S_3 + S_4 + S_5 + S_6 \]  

(2-12)

With processing the remote-sense images of Aug. 1990, we have the minimum snowpack this year as 3154.46m.雪山

the maximum snowpack is 50.32x10^6m³ for March 1991. Because of the average temperatize for 1989 is 6.5°C, it is higher than that of recent years, it is a rare dry year. And coincide with the condition of the retreated glacier, this tendency start at 1970 and retreated year by year for all glaciers in U.R.

3. CONCLUSION

Generally, about previous statement, all processes are compild for real programe with PASCAL language, and realized on WT-2 digital image process system, may analyses and estimate rapidly for snowpack information from any remote-sense image material with continuous or discontinuous in time. It is very suitable to use for measuring, analyzing and statistics on satellite image region the snow the maximum speed must larger than that of recent years, and estimate year by year. Refer to Table (2), the snow pack decreased, the snow be flown down into valleys and heaped to gorges and canyons, thus the snow pack estimation of snow pack and error elimination be more complicated.

For without the satellite image material of before middle of 1989, here we processed parts of satellite images of the interval Jan. 1989 to March 1992. So some result can not be concluded, particularly in the band above 2500m and the midst of wind at 1000-1500 m. Although have calculated approximately the storing quantity, but can not collate by previous data with continuous material, so only concluded later for more investigation.

REFERENCE


Table (2) Average wind speed in winter for several years unit: m.sec⁻¹

<table>
<thead>
<tr>
<th>Year</th>
<th>Urumqi city (916m)</th>
<th>Dabancheng (1225)</th>
<th>Tian Shan station (3500)</th>
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<tr>
<td>Nov</td>
<td>1.5</td>
<td>4.1</td>
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<tr>
<td>Dec</td>
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</tr>
<tr>
<td>Jan</td>
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</tr>
<tr>
<td>Feb</td>
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<tr>
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<tr>
<td>Apr</td>
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