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Snow Cover Mapping using Microcomputer Image Processing Systems

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For many years, digital snow cover mapping using satellite data had to be carried out on large and expensive image processing systems. Recently, small computer systems (microcomputers) have been developed for image processing. Snowmelt runoff forecasting models have also been developed to run on microcomputers. Digital snow mapping procedures were surveyed, and a general snow mapping approach was developed that allows use in various snowpack regions. Tests were conducted to determine if satellite snow cover mapping could be carried out effectively on the microcomputers and which combination of software and hardware provided optimum performance. A range of computer facilities was tested and recommended capabilities for snow cover image processing were established. It was discovered that adequate microcomputer image processing systems were already on the market, and that the Snowmelt Runoff Model (SRM) could easily be run on the same microcomputer system. Further improvements will result as the 40486 microcomputers image processing systems become widely available. The microcomputer approach, as opposed to operation on larger, more expensive, and non dedicated systems, has much appeal for hydroelectric power companies and other small users who need economical, yet powerful, processing systems where both snow mapping and snowmelt runoff forecasting can be conducted.

Introduction

The areal extent and the dynamics of snow cover are of basic interest for the production of hydroelectricity. Where precipitation falls mainly as snow, *e.g.* in alpine regions, a large amount of water is stored in the snowpack. Hydropower companies must know the timing and amount of meltwater in advance for optimum reservoir manipulation. Satellite derived snow cover data can be input into models for simulation and forecasting of the snowmelt. One example of a model requiring the snow covered area, in contrast to point measurements, is the Snowmelt Runoff Model (SRM) (Martinec *et al.* 1983). In the past, initial attempts were made to digitally process the satellite data, but large and expensive image processing systems were required to overcome the problem of handling large amounts of data (Baumgartner *et al.* 1986a; Baumgartner 1990). Therefore, it was economically prohibitive for any specific user to get involved in operational snow cover mapping. In the last few years, image processing systems on microcomputers experienced remarkable development. Because SRM can be run on microcomputers in simulation and forecasting modes (Rango and Roberts 1987), it is important to know, whether the same type of microcomputer systems can be used to operationally map snow cover and what the limits of microcomputers are for snow cover mapping. If both procedures – image processing and runoff forecasting – can be carried out on similar microcomputer systems without major limitations, a future economic and industrial use may be possible.

A General Snow Cover Mapping Scheme

Digital snow cover mapping techniques have been developed in several countries. These methods depend on the specific needs for the basin under investigation and are generally not applicable to all basins. For operational snow cover mapping a faster, easier, and more widely applicable method is necessary. A general snow cover mapping scheme, combined from several existing methods, could allow the interpreter to apply the method on a variety of basins and under different snow conditions.

Existing Techniques

The U.S. National Weather Service (NWS) developed a method for operational snow cover mapping with Advanced Very High Resolution Radiometer (AVHRR) and Geostationary Operational Environmental Satellite (GOES) data based on a »change detection« approach (Allen and Mosher 1985; Holroyd *et al.* 1989; Carroll 1990). A snow-free satellite summer image is used as a reference image and is digitally compared, pixel by pixel, with a snow-covered image resulting in snow/no snow thematic maps. The brightness of the images has to be adjusted to account for the daily and seasonal solar illumination angle differences. The »change detection« approach seems to have most applicability for identifying the presence of snow in coniferous forest areas. In recent years, an alternative multispectral classification method using AVHRR data has been developed which is now used in the operational mapping (Holroyd *et al.* 1989) because it seems to be applicable to many parts of the world. The operational algorithm is still evolving, and the »change detection« approach may eventually be combined with the simple multispectral approach. In 1990, the NWS mapped 2,113 river basins using these techniques (Carroll 1990).

Andersen and Odegaard (1980) developed another method for snow cover mapping in Norway using NOAA-AVHRR data as input to operational forecasts of the inflow into reservoirs for hydroelectric power production. Because the snow is not evenly distributed due to wind transport, the snow cover observations show numerous snow patches throughout the melt period. As a result, a contiguous snow line does not exist. With the coarse spatial resolution of the AVHRR sensor (1,100 m × 1,100 m), it was not sufficient to classify these large pixels as either snow covered or snow free. Therefore, the Andersen and Odegaard (1980) approach was developed to determine the percent snow coverage within each pixel. Training areas are selected for use as typical snow free and snow covered areas, and the mean brightness value for both types are determined. Between the average dark (snow free) pixel value and the average bright (snow covered) pixels, a linear relationship is assumed, *i.e.* the brightness increases linearly with increasing snow coverage. In this approach it was assumed that topographic variability was small and the ground was uniformly covered by dark soils, grass and small bushes.

Thomsen (1985) in Denmark developed an approach for calculating the fractional snow coverage from AVHRR data using microcomputers. This method is a further development of the Andersen and Odegaard (1980) approach and also incorporates the »change detection« approach. A snow-free scene is used as a reference image. Due to different solar illumination angles (between reference and snow image) and topographic effects (bidirectional function of the radiance difference between two images), data have to be normalized and converted into albedo values before calculating the snow coverage.

Lillesand *et al.* (1982) modified a method reported by Tarpley *et al.* (1979) which compensates for variability due to site characteristics. The technique is based on the »change detection« approach but uses training samples for each cover type occurring in a scene. In a non-snow image, for each category a reference dark level is found and a delta factor, representing the difference between the site mean and the reference dark level for each category, is determined. For the snow covered image, again the darkest value is found and added to the delta factor. The results are taken as estimates for the non-snow brightness level for each site. If the brightness of a category in the snow image exceeds the brightness of the reference image – dependent on the non-snow brightness level – it is classified as snow covered (otherwise as snow free). This procedure compensates for variations within cover types, for between date variations within cover types, and for differing site characteristics.

In multispectral analysis of digital satellite data, the following procedures are mainly used (Duda and Hart 1973; Haralick 1976; Fu and Rosenfeld 1976):

a) Preprocessing: radiometric and geometric corrections; mosaicking of image frames; reformatting; and restoration of defective image parts.
b) Feature selection: transformation of the feature space for increased class separability; and reduction of redundance – multispectral data often have redundant information because neighboring spectral bands show a high correlation.
c) Classification by supervised learning, carried out in two steps: learning: selection of samples and determination of a decision rule based on the statistics of the samples; and assigning (classifying): based on the conditions above, all pixels are assigned to their corresponding category.

These multispectral analysis procedures are often used in snow cover mapping and show precise classification results (Haefner 1980; NASA 1990; Keller 1987; Baumgartner 1987) but are expensive and cannot be carried out fully automatically, *i.e.* without an interpreter's *a priori* knowledge. Using a different approach based on spectral band combinations, Holroyd *et al.* (1989) and Carroll (1990) show how multispectral data can be used in an automatic procedure for snow cover mapping. A prerequisite for this method is the normalization and calibration of the raw data.

In any of the methods mentioned, cloud cover always presents a problem for mapping snow cover, and the 1.55-1.75 μm band on Landsat-TM (Thematic Mapper) allows automatic discrimination between snow and clouds. Where clouds are present over a basin, a method has been developed to estimate the snow cover under the cloud cover by extrapolation from the cloud free portion of the basin (Lichtenegger *et al.* 1981; Baumgartner *et al.* 1986b).

Developing a General Snow Cover Mapping Scheme

By analyzing the above procedures, it becomes obvious that none of the approaches accounts for all factors necessary for an overall operational snow cover mapping scheme. A combination of several approaches, integrated into a general scheme, could allow the user to select procedures according to any special needs. Such a scheme must allow flexible adaptation to features such as geographical characteristics of a basin, sensor used, and objectives of the mapping. Fig. 1 shows the proposed »general snow cover mapping scheme« and its relationship to the Snowmelt Runoff Model (SRM).

The basis for the scheme is derived from the above mentioned snow cover mapping procedures. The relatively simple Thomsen (1985) approach which used a snow-free reference scene can be used for basins with low topographic influence and homogeneous vegetation coverage. This method corrects for solar illumination and topographic effects. Because of its simplicity, the method should only be

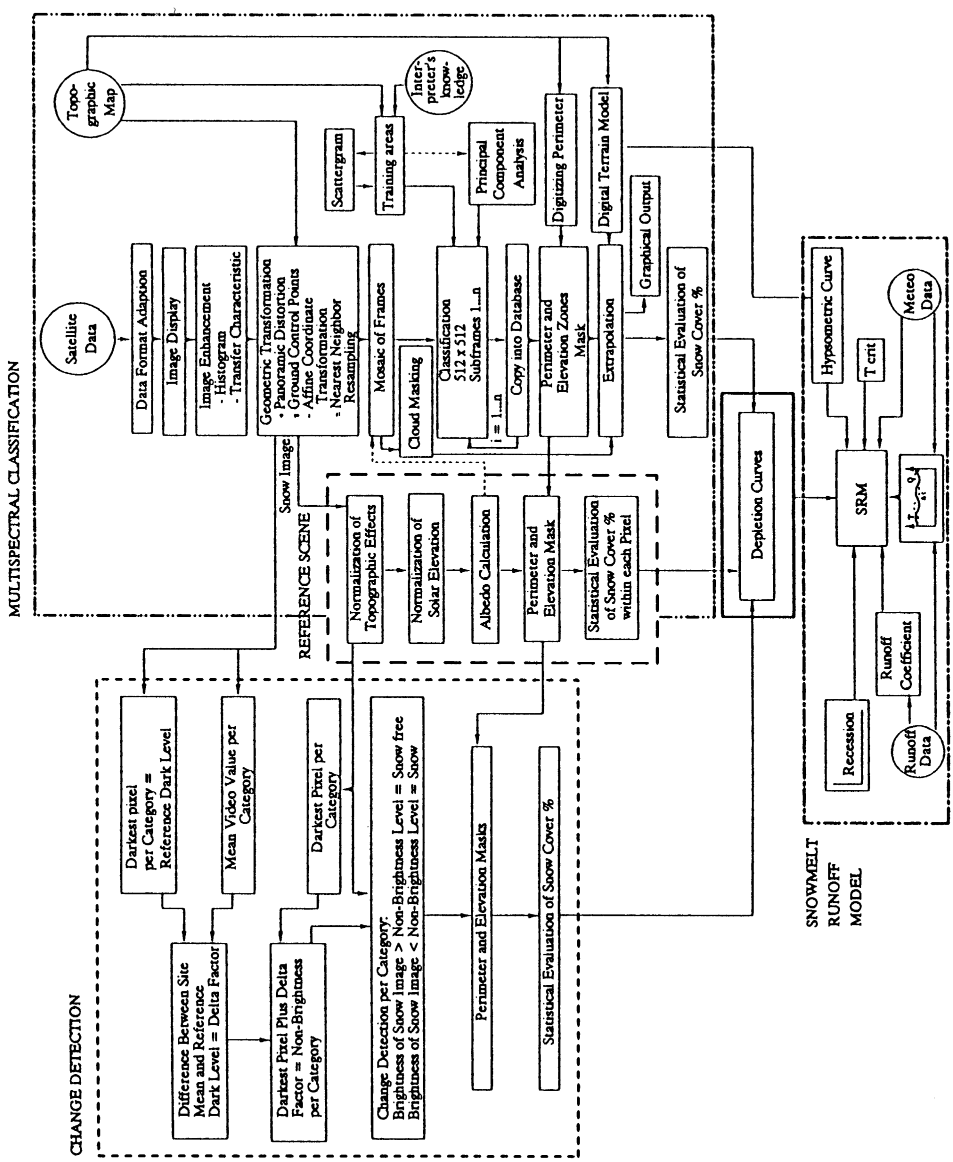

Fig. 1. General snow cover mapping scheme for use on microcomputers.

applied for large area investigations based on coarse resolution sensor systems such as GOES and AVHRR.

The Lillesand *et al.* (1982) approach, which is based on change detection, corrects for topography, sun angle, cover type, and variations within a cover type. Because more complex variations within a basin can be taken into account, this procedure can be used in small to large scale investigations based mainly on AVHRR data. It does not allow the same level of detailed analyses as a »multispectral image processing« approach.

This last approach (multispectral image processing) should mainly be used for detailed snow cover evaluations under difficult topographic conditions in small basins using data of Landsat-MSS (Multispectral Scanner) and -TM, SPOT (System Pour l'Observation de la Terre), and MOS (Marine Observation Satellite). Because of the large amount of data involved with these sensors, this approach is more realistically used on small basins. In certain situations it can be used with NOAA-AVHRR data if mapping on larger basins is desired.

The »general snow cover mapping scheme« is put together in a way that one is not limited to the above defined approaches. It allows the user to combine the different procedures as needed depending on the specific objectives. It must be mentioned that this scheme does not represent a final solution to digital snow mapping, but should be seen as a basis for further discussions. Important aspects such as microwave remote sensing and new methods in image processing (*e.g.* texture analysis or pattern recognition) must be kept in mind for future extensions of this scheme.

Definition of Software and Hardware Requirements and System Evaluation

The heart of any remote sensing image processing system is the software. Primarily, software should be chosen that best suits the specific needs of the user, allowing that decision to dictate the hardware requirements.

The software should include the classic multispectral image processing steps and data handling procedures. The user should not be forced to develop these basic software modules but should concentrate work on software development concerning the specific needs of the study. Consequently, an appropriate tool kit for merging purchased and user-developed software must be available.

Basic Software Functions

The basic demand of a software package is its user-friendliness. It has to be highly interactive, clearly structured, and easily understandable even for users not experienced in remote sensing. With batch-mode based systems, the ability to easily experiment with the data is lost. Many image enhancement steps are best made by trial and error in order to achieve the best results. If forced to generate these enhancements using predefined parameters, much of the interpretative capabilities of the system are lost. For advanced interpreters in operational work, the menu-handling must be exceptionally fast. In such a case, the often preferred command-line input can be neglected. A necessary feature is the command file allowing procedures which have to be repeated many times with unchanged parameters to be run in batch mode. For using the system in an operational environment, an extended list of programs must be available as shown in Appendix I. Some of the important features are discussed in detail here.

It is necessary to have some means of loading the image data from computer compatible tapes (CCT) onto the system. This is not as easy a task as might be imagined, as tapes from different satellite sensors come in widely varying formats. Even within one data type, there are several different formats. One has to be certain that the tape reading utilities to be purchased will handle all data types to be used (including all international formats).

Another important function is displaying data on a screen. This sound trivial but must be considered carefully. To take full advantage of the satellite data, the image monitor must be able to display at least 8 bits for each color band (red (R), green (G), blue (B)). The software must be able to display and manipulate all the colors simultaneously. Without the capability to manipulate and display a full 8 bits of color per band, one will not be able to distinguish subtle changes in the satellite data (Muller 1988). Additionally, it must be possible to display and process various amounts of image data.

It must be possible to interactively change the display parameters allowing one to choose which spectral band is assigned to what color gun, to stretch the data in various ways (*i.e.,* perform basic contrast enhancement techniques), and to zoom and pan through the image. Advanced software functions must be available in two different ways. First, to be applied on the image processing board and, secondly, to be applied on hard disk for large scene processing capabilities.

The geometric distortions in satellite images play a fundamental role in a further data processing. When time series data have to be evaluated, a precise geocoding is demanded. It is not sufficient, to deal only with an affine or polynomial coordinate transformation. For large field of view (FOV) systems (*e.g.* NOAA-AVHRR) a panoramic correction is necessary. Additionally, in mountainous regions, the topography must be included into the geocoding process. If this it not done, significant deviations (such as the radial deformation in aerial photographs) will occur.

The problem of calibrating thermal data, normalizing sun angle and topography, and correcting atmospheric effects are vital. Although most of these procedures are of basic need for most of the remote sensing applications, no software is available on commercial systems. Therefore, users have to write their own programs.

Another important module represents the classification procedure. A classification module must contain software for classification by supervised and unsupervised learning. For sophisticated, problem-oriented classifications, all the algorithms contained in Appendix I must be available. A necessary feature during the classification process is the scatterplot of training data. It allows the interpreter to visualize, how data are distributed or clustered in the feature space – a basic requirement for precise classification.

Additionally, software must exist for graphical overlays such as basin masks, elevation masks, or cloud masks. An easy manipulation of these masks including color coding is necessary.

It must be carefully evaluated, whether the transfer to a specific GIS is guaranteed, *i.e.* a raster to vector and vector to raster transform can easily be carried out.

Furthermore, modules must exist for statistically evaluating the processed data, for graphically displaying, and for producing (in a user-friendly way) a proper graphical output of charts and maps.

Hardware Configurations

Hardware is no longer the critical part in an evaluation because most of the commercial companies offer systems with about the same capabilities. Additionally, the development of hardware proceeds so fast that after the evaluation period, significantly improved systems are already available. A closer look at some basic hardware aspects nevertheless must be discussed.

In image processing, complex algorithms, requiring a powerful and fast processor, have to be used. Typical examples are the geometric transform and the classification algorithms. The interpreter has to be comfortable with the processing speed. If the user has to wait several minutes or even hours to achieve the effects wanted, he or she may be reluctant to spend the time and thus take full advantage of the data. 80386 machines with a math co-processor and 25 MHz clock speed are commonly available microcomputer systems for scientific analysis today. Aside from the processor, a very important factor in the performance of a 80386 microcomputer is the type of memory bus (Industry Standard Architecture, Extended Industry Standard Architecture, Micro Channel Architecture) and cache memory. Bus and cache determine the speed of a system considerably. In the worst case, the 80386 system is not faster than a 80286. Recently developed 80486 systems are just becoming available for image processing.

The heart of the hardware represents the frame buffer (or imaging board). Usually, they show a spatial resolution of 512 × 512 or 1,024 × 1,024 pixels, where the larger one is preferred because less mosaicking is necessary. For each color (R, G, B), one board is needed along with one additional graphics overlay board. The resolution is usually 8 bit or 256 grey levels per board. Consequently, a frame buffer with a 1,024 × 1,024 × 32 bit resolution is adequate. It allows the display of the image data in its full resolution (except AVHRR with 10-bit resolution). It must be carefully decided whether the system uses the frame buffer only as display or whether it uses the full capacity of such a component, *i.e.* many of the processing steps make use of the data stored in this board resulting in a significantly higher processing speed because less hard disk input/output interactions are required.

Processing satellite imagery is a data-intensive task, *i.e.* the system has to handle a large amount of data. To take full advantage of satellite remote sensing data, sufficient disk space must be available. This becomes clear if a time series of 40 AVHRR scenes has to be processed. Even if the area to be processed covers only 512 × 512 pixels, the consequences are obvious.

In regard to hardware requirements, it is recomended that a 19″ RGB high resolution monitor be used instead of a 14″ monitor. The larger monitor is appreciated by an interpreter working for extended periods of time on the system. The track ball, instead of a mouse, has proved to be useful for cursor manipulations.

The evalutation of microcomputer-based image processing systems has shown how difficult it is for a prospective user to decide which system would be the appropriate selection. Too many difficulties remain hidden during a demonstration. A final decision can only be reached through extended tests by an experienced interpreter. Additionally, it has to be mentioned that the user must be aware of the need to develop project-related software. It will never suffice to just use the existing software. The available software tool kits can be used for including specially developed software in the existing package.

Tests of Microcomputer-Based Image Processing Systems

To establish the present capabilities and limitations of microcomputer-based image processing systems, snow cover mapping using multitemporal/multisensor/multispectral satellite data and snowmelt runoff simulations were carried out. We were able to perform tests on 80286 and 80386 minimum configurations as well as on a 80386 optimum configuration. In this paper, no brand names are given for two reasons. First, during the time from completion of the study to publication of the results, rapid developments in the computer field will make the features associated with given brand names obsolete. Second, brand names are not mentioned to avoid any semblance of endorsement. An informal report documenting some of the specific products used is available from the authors.

Data of Landsat-MSS and NOAA-AVHRR were available for the tests. Extensive evaluations have been carried out in the Rocky Mountains of Colorado (Rio Grande basin 3,419 km^2) and three basins in the Swiss Alps (Rhine, Inn, and Ticino basins 6,600 km^2).

Table 1 describes two possible system configurations. The first version represents a minimum configuration. The optimum second system proved to be useful in practical application. For a stand-alone system, a data input/output (I/O) facility and larger storage capacity with the following characteristics must additionally exist:

Table 1 – Microcomputer system configurations

	Minimum	Optimum
Processor, clock-speed	80286, 12 MHz	80386, 33 MHz
co-processor	80287	80387
RAM	640 KB	>1 MB
floppy disk drives	5¼″	3½″ and 5¼″
hard disk	30 MB	660 MB – 1.3 Gb
frame buffer	512 × 512 × 32 bits	1,024 × 1,024 × 32 bits
RGB monitor, high resolution	19″	19″
PC monitor	monochrome	VGA color
graphics controller (color)	–	640 × 350 × 4 bits
mouse	yes	–
trackball	–	yes
printer	yes	yes
color hardcopy module	ink-jet	thermal wax (300 dpi)
digitiging tablet	36″ × 48″	36″ × 48″
tape cartridge device	–	150 MB (¼″)

- Tape module for data I/O: 9-track 1,600 bpi or 1,600/6,250 bpi.
- Streaming tape device: 1/4 inch tape cartridge device with 150 MB capacity.
- Disk storage: additional 660 MB hard disk or optical disk drives. In case of a networked system, an interface (*e.g.* Ethernet) to the host computer replaces the above mentioned components. In either case, the compatibility with existing hardware (and software) has to be considered.

Test of a 80286 Minimum Version

Basically, it was determined that the snow cover mapping process, using multispectral image processing, could be accomplished on such a 80286 system if serious limitations could be accepted. They were:

- Slow processor 80286/12 MHz. Examples for the processing speed:
  - maximum likelihood classification of two MSS bands (2,100 × 1,400 pixels, 7 categories): 4 hours
  - geometric transform of three MSS bands (2,100 × 1,400 pixels), nearest neighbor resampling: 16 hours
- Limited disk capacity (30 MB)
- The frame buffer is mainly used as display board. Most functions are computed on disk losing the advantage of high-speed processing of the board.
- Missing software: minimum distance classifier (proved to be good for snow cover mapping), panoramic correction for AVHRR data.
- Unsatisfactory finish of some programs: no labeling of scatterplots and historgrams, no legends. Inconsistency of line and record length: start of line and

record must have always the same origin (*e.g.* 0,0) and may not vary within the system. Consequences are obvious if images are mosaicked or superimposed.
- Menu-mode: very slow; can only be used as teaching tool. Many of the parameters can not be set in the menu-mode, *i.e.* tests had to be carried out in command-line mode.
- Poor user manual

Test of 80386 Versions

After it became clear that the 80286 minimum version showed major limitations related to hardware and software, the system was updated to a 80386/20 MHz version with a 120 MB hard disk. The computational time with the maximum likelihood classifier (2,100 × 1,400 pixels × 2 bands, 7 categories) decreased to 25 minutes, *i.e.* by a factor of 1/8.

Similar tests were carried out on one of the most recent systems in the family of 80386 microcomputer based image processing systems. A further reduction in computational time by a factor of 1/2 (15 minutes) was achieved.

All parameters are input in the menu-mode. Because the screen refreshes within a very short time (*i.e.* tenths of seconds) it is not necessary to type all the parameters in the command line mode supporting real interactive work. If a certain procedure has to be repeated several times, a batch file can be written and easily be run.

Many procedures are run on the frame buffer saving computational time. The advantage of the 1,024 × 1,024 × 32 bit frame buffer is obvious if larger scenes have to be processed. It reduces the time consuming mosaicking process considerably. Additionally, it allows a better overview of large scenes than on the 512 × 512 board. Generally, this system currently is the fastest available microcomputer based image processing system using a 80386 machine. Combined with the user-friendliness, the perfect finish of most routines, and the understandable manuals, one has the impression that the developer knows the needs of the users.

Discussion

The evaluation of microcomputer-based image processing systems showed that significant differences exist between available software packages. Some packages can not be recommended because important functions are missing, programs are not carefully completed and menu handling is slow. This reflects the fact that many software developers have no experience in practical satellite image processing. The evaluation and tests made clear that many hardware configurations are not practical for the requirements of operational satellite image processing, *e.g.* insufficient storage capacity and slow CPU. There are, however, a few vendors offering similar systems with carefully designed software and adequate hardware configurations. In this case the final system chosen depends on the user's preferences.

Two major differences in software design could be noticed, namely, input through either command line mode or through the menu mode. It is up to the user

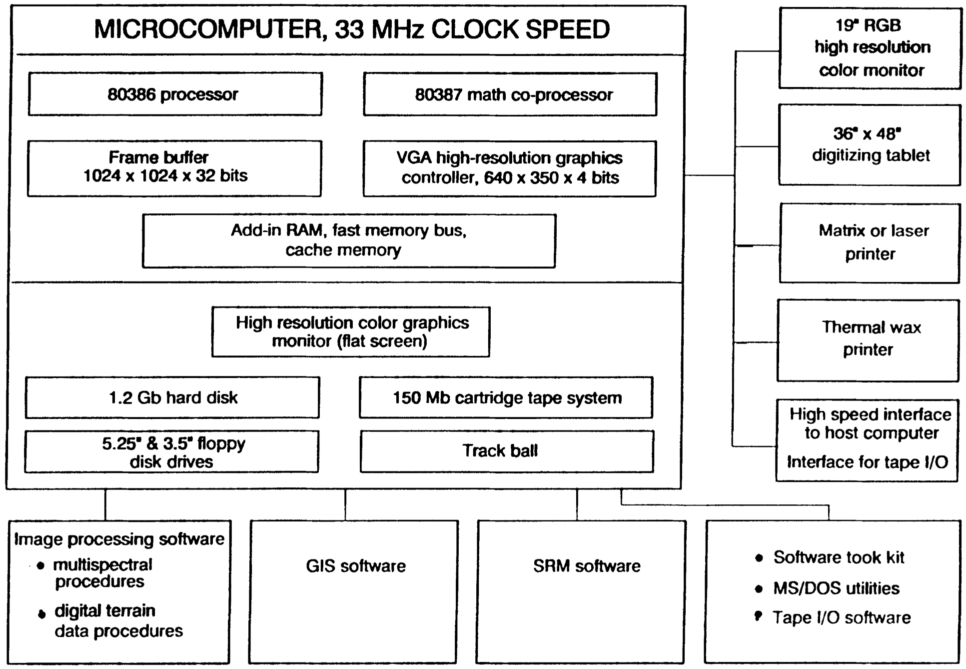

Fig. 2. Proposed hardware and software configuration for microcomputer-based image processing system.

as to which approach is preferred. In the tests performed, it was determined that the most recent menu driven systems are very easy to use because of the high speed of operation.

In the beginning of our tests, we thought it necessary to have a system with the source code available. The tests, however, have shown that the available software tool kits can be used to easily develop special software and integrate it into the menu of the existing package.

All the systems we examined lacked certain features which caused limitations for potential users. The following is a list of the features that were missing:

- Full resolution 10-bit NOAA-AVHRR data
- Solar illumination correction
- Correction for topographic effects
- Panoramic correction for NOAA-AVHRR data
- Calibration of thermal data
- Atmospheric corrections
- Classification algorithms: a full set of all major algorithms is necessary

Based on the experience gained in the tests, Fig. 2 gives an overview of the system configuration we are proposing for snow cover mapping and runoff simulation. Consequently, the optimum system configuration was purchased by the Hydrology Laboratory (USDA/ARS) and the Department of Geography, University of Berne (Switzerland). The experience with these systems has confirmed the conclusions of the tests.

Image processing systems utilizing 80486 microcomputers are now available, and a further speed-up of many procedures is envisaged. These systems offer sufficient power to run software allowing multitasking as far as it is possible using available microcomputer operating systems, a most important improvement for interpreting satellite data. During a calculation, *e.g.* a classification on disk, it is possible to continue work on the RGB monitor, *e.g.* selecting ground control points. The calculation running in the background is only interrupted if CPU-time is needed for the operation in the foreground. Therefore, the speed of CPU-intensive operations is not the first priority anymore. Multitasking makes 80486 microcomputers of considerable importance in processing remote sensing data.

Snowmelt Runoff Simulations

Snowmelt runoff simulations were performed using the SRM model (Martinec *et al.* 1983; Rango and Roberts 1987). The SRM model is designed to simulate or forecast the daily discharge in mountain basins resulting mainly from snowmelt but also from precipitation. The temperature, expressed in degree-days, is used as an index for the energy balance (degree-day method). This design results in low CPU times compared to other models and allows the transfer of the model on microcomputer-based systems. SRM requires three input variables: air temperature, precipitation, and the areal extent of the snow coverage for a defined number of elevation zones. The subdivision into elevation zones is necessary since temperature extrapolations over large elevation ranges can result in large temperature deviations. Snow cover data should be available at least once a week. During the snowmelt season, the runoff produced from snowmelt and rainfall is calculated on a daily basis. The daily runoff is then superimposed onto the recession flow and transformed into the daily discharge following the equation in Martinec *et al.* (1983).

Fig. 3 shows an example of a six-month snowmelt runoff simulation for the basin Rhine-Felsberg (3,400 km^2) (Swiss Alps) during the ablation period of 1982. The difference between measured and calculated runoff amounted to 0.4 %.

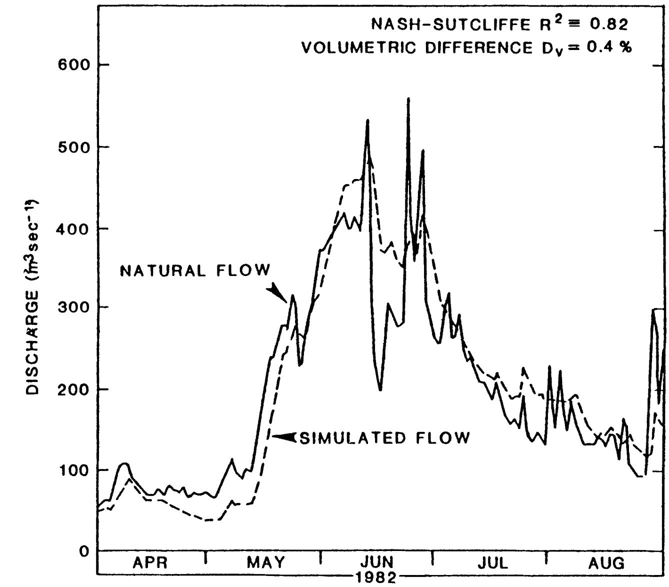

Fig. 3. Snowmelt runoff simulation for the Rhine basin at Felsberg, Switzerland compared to reconstituted natural flow for 1982 (after Rango and Martinec 1987).

Conclusions

Various digital snow cover mapping procedures were surveyed, and a scheme combining several existing approaches was developed for flexibility and use in various snowpack regions. Dependent on the geographic location of the basin, the scale of the evaluations, and the sensor system used, the scheme allows the user to select between change detection, multispectral classification, and fractional snow cover approaches (or any combination of these methods) for snow mapping.

Based on our tests, it is important to select a microcomputer system with optimum software and hardware. The following software features are recommended:

- satellite image processing package
- digital terrain data manipulation
- geographic information system
- software tool kit

The following hardware is recommended depending on resources available:

- microcomputer 80386/33MHz (or 80486/25 or 33 MHz)
- 1,024 × 1,024 × 32 bit frame buffer
- high resolution RGB monitor
- high storage capacity (> 660 MB)

- data import capabilities (tape drive, digitizer)
- high quality printer

Computer advances are still proceeding rapidly, and microcomputer image processing for snow is very feasible. The optimum system can be acquired at present for about $ 60,000 depending on options chosen.

Other tests have shown that the Snowmelt Runoff Model can operate very rapidly on this optimum configuration without problem.

The image processing and snowmelt runoff simulations can be done on one system which makes it a potential valuable tool for hydroelectric power companies or other commercial or public users. For such users, it seems that the use of microcomputers are most efficient and the least expensive approach.

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Appendix 1 – List of Advanced Software Functions

Tape Utilities
- Read formats for GOES, AVHRR, MSS, MOS, TM, SPOT, microwave, and elevation data
- Read unknown formats
- Disk back-up
- Tape archiving utilities

General Features
- Image display (full frame, subscenes of variable size)
- Overlays, masks
- Vector and curve drawing
- Polygon fill
- Text annotation
- Save image (with/without overlay and Look-up Table (LUT))
- Zoom and pan
- Pixel video value reference
- Pixel coordinate reference
- Split screen
- GIS: raster to vector and vector to raster transform

Preprocessing
1. Dynamic Enhancements (LUT)
   - Linear stretch
   - Piecewise linear stretch (manual)
   - Equalization
   - Logarithmic
   - Exponential
   - Density slicing
   - Save/read LUT
   - Define color palette

2. Geometric Corrections
   - Image to map warp
   - Image to image warp
   - Panoramic correction for AVHRR
   - Adaption of GIS data

3. Radiometric Corrections
   - Restore pixels and lines
   - Calibrate thermal data
   - Normalize data (sun angle, topography)
   - Atmospheric corrections
   - Image match (temporal change detection)

4. Scene/Subscene Manipulation
   - Mosaicking of frames
   - Combination of bands of several images
   - Shift data n lines, m records

5. Filter
   - Edge Enhancement
   - Smoothing
   - LaPlacian
   - Fourier (FFT)
   - User defined

6. Terrain Manipulation
   - 2-dim/3-dim views (central perspective)
   - Digital terrain model (elevation, aspect, slope)

Classification Functions
- Training set extraction
- Scatterplot display
- Cluster analysis
- Parallelepiped classifier
- Minimum distance classifier
- Mahalanobis distance classifier
- Maximum likelihood classifier
- Pixel slicing

Spectral Bands Transformation
- Principal component analysis
- Ratios (*e.g.* Normalized Difference Vegetation Index)
- Logic operations (+, −, %, x)
- RGB to IHS (red, green, blue into intensity, hew, saturation) transform

Evaluation of Results and Output
- Statistical analysis
- Statistical output (line printer)
- Graphical output (high resolution color printer)
- Comparison of classification results vs. original image (fading, split screen)

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