STEPWISE MULTIPLE REGRESSION SNOW MODELS: GIS APPLICATIONS IN THE MARMOT CREEK BASIN, (KANANASKIS COUNTRY, ALBERTA) CANADA AND THE NATIONAL PARK BERCHTESGADEN, (BAYERN) GERMANY

K. WAYNE FORSYTHE[1]

ABSTRACT

Geographic Information Systems (GIS) and satellite remote sensing are now used extensively in analyses of natural environments. This research examined the usefulness of a GIS and remote sensing based approach for integrating many different and widely varying data sources. The multisource data sets were used in stepwise, multiple linear regression models that analyzed the variation in snow depth and snow-water equivalent (SWE) depth.

Models were developed in the Marmot Creek Basin using Landsat Thematic Mapper (TM) satellite data, Digital Elevation Model (DEM) data and various mapped data layers in combination with historical snow depth and SWE measurements. The best model for snow depth produced a coefficient of determination or adjusted R^2 of 0.6370. The independent variables of elevation, incidence, tree height and principal component four of the TM data could explain approximately 64% of the variation in snow depth. The best model for SWE depth had an adjusted R^2 of 0.5814. The independent variables that explained the variation in SWE depth were elevation, incidence, and TM band seven.

The National Park Berchtesgaden models build upon the approach used in the Marmot Creek Basin. Landsat TM data and a DEM provided the basis for the regression independent variables. Additional analyses of these data were performed within the GIS to calculate variables such as across and down slope curvature and a Normalized Difference Vegetation Index (NDVI). The best model for snow depth produced an adjusted R^2 of 0.801 while the SWE result was 0.843. The variables providing the explanation in snow depth variation were elevation and NDVI. SWE depth variation was explained by elevation, across slope curvature, TM band seven and principal component four of the TM data.

INTRODUCTION

Snow studies in mountainous areas provide an excellent opportunity to utilize Geographic Information Systems (GIS), Digital Elevation Model (DEM) analysis, and remote sensing. The majority of precipitation in alpine environments occurs as snowfall (Golding and Swanson, 1986; Linsley et al., 1982); however, the actual role that snow plays in the water balance has not been determined precisely. This can be attributed to the difficulty in assessing the snowpack variation of high mountain basins which directly impacts the hydrologic regime. Snow studies often are limited by the high cost involved in the logistics of the study, especially if it involves extensive amounts of field work.

Beginning in the early 1970s, the use of remotely sensed satellite imagery for data collection began. The early studies were primarily concerned with the use of the digital data for land cover classification, however, snow-related aspects of satellite remote sensing also came into effect during this time (Rango, 1992). Sophisticated instrumentation such as satellites, passive microwave radar, Global Positioning Systems (GPS), Synthetic Aperture Radar (SAR) and GIS are now used in some studies of the snowpack and its properties (Rango, 1992; Winther, 1992; Marks et al., 1992; Rott and Nagler, 1993; Rott et al., 1993; Carroll, 1994).

Factors Affecting the Snowpack

Elevation is one of the variables that has been identified as having a positive effect on snow depth (Cote, 1984; Golding and Swanson, 1986). Generally, as elevation increases so does snow depth. Other factors can also influence snow accumulation and the snowpack. Features such as chinooks, prevailing wind direction (Granberg and Irwin, 1991; Lapen, 1991), temperature inversions, solar radiation receipt,

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[1] Institut fuer Geographie, Universitaet Salzburg, Hellbrunnerstrasse 34, A-5020, Salzburg, AUSTRIA.
tel. +43-662-8044-5229 fax. +43-662-8044-525 email. forsythe@geo.sbg.ac.at

snow blowover, precipitation variability, and other factors such as sublimation and vegetative differences can influence the snowpack in a basin. Studies of windy alpine environments indicate that there are problems with wind during snow deposition. Deflation in windswept areas must be taken into account so as to obtain an unbiased estimate of snowpack characteristics.

Some GIS and Remote Sensing Aspects of Snow Modelling

A Snow Geographic Information System (SGIS) was developed to examine the feasibility of winter travel in Quebec (Granberg and Irwin, 1991). The SGIS employed weather and terrain data to predict spatial variations in snow cover properties. Thirkettle et al. (1991) have used passive microwave data to estimate SWE over snow covered areas of Alberta. Using their Geographic Analysis and Display System (GADS), maps can be produced within six hours of the time of the satellite passing over an area.

Information from satellite sensors, which register surface reflective characteristics, is commonly used to describe remote areas such as snow covered mountainous terrain (Winther, 1992). Spatial and spectral resolution make the LANDSAT Thematic Mapper useful for detailed studies of snow (Winther, 1992). Winter TM satellite scenes have been used by Eyton (1989) and Skoye and Eyton (1992) to map snow covered terrain in prairie environments. Hall and Foster (1994) have used DEM data and a winter TM image to map snow by elevation zone in Glacier National Park, Montana. A Normalized Difference Snow Index (NDSI) was derived using TM bands 2 and 5 (2-5/2+5). It was noted that DEM data registered to the TM data refined the accuracy of the snow mapping algorithm used and improved the determination of snow covered areas in this mountainous environment. One challenge in this study was the inability to determine snow cover in heavily forested areas with a dense tree canopy. Franklin et al. (1990) state clearly that in mountain areas a whole range of digital operations on remote sensing data are far more accurate with the incorporation of DEM data.

Baumgartner and Apfl (1993) describe an Alpine Snow Cover Analysis System (ASCAS) which allows for the quantification of snow cover variation. The ASCAS integrates satellite remote sensing, GIS, database management, snowmelt runoff modelling, and the visualization of results. Elder et al. (1991) chose parameters of elevation, slope, and solar irradiance from DEM data for a regression model because these variables represent physically based parameters that affect accumulation and ablation of snow. These were the independent variables and measured SWE data at corresponding points were the dependent variable in the model.

Stepwise Regression

Stepwise regression is a multiple regression technique that looks for the best combination of independent variables that can explain the variation in a dependent variable. Yeates (1974) states a stepwise, multiple, linear regression is really a search procedure, for the technique enters each variable, one at a time, into the regression equation in the order of its contribution to the total variance, the greatest contributor being entered first. One cannot assume that the subset of variables found by a stepwise regression program necessarily corresponds to the most important set of variables (Sokal and Rohlf, 1981). The only way to be certain is to use an all-possible-subsets regression, but with many independent variables this could be prohibitively expensive in computation time. Variables left out of the predictor set are not necessarily unimportant but may simply be correlated with other variables in the predictor set. The adjusted R^2 is the actual statistic that is now used for determining the amount of explanation in a model. It takes into account the degrees of freedom for the model. It is necessary to use the adjusted R^2 because adding extra regressors will always cause the R^2 to rise but this addition in explanation may not be statistically significant (Kennedy, 1985).

OBJECTIVES

The overall objective of this research is to develop GIS based procedures for modelling the variation in snow depth and snow-water equivalent depth using stepwise, multiple, linear regression statistical analyses. These empirical models are based on variables derived from satellite data, Digital Elevation Model (DEM) data, and data derived from existing map and digital information sources.

MARMOT CREEK BASIN STUDY AREA

The Marmot Creek Basin study area is 9.4 km^2 and is located in the Kananaskis Valley of southwestern Alberta, Canada. It is approximately 80 km west of Calgary, Alberta, and is roughly centred at 50° 57' North Latitude and 115°09' West Longitude (Figure 1).

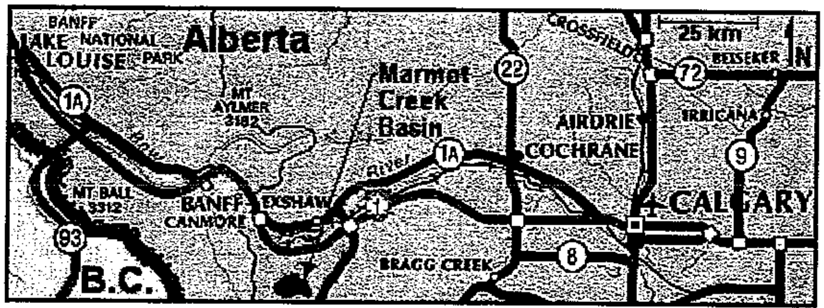

Figure 1: **The Location of the Marmot Creek Basin Study Area**

This area was chosen because of its variable terrain and the availability at no cost of detailed snow data, satellite imagery, topographic data, airphotos, and well documented vegetation maps. Originally, the basin was established as an experimental watershed to determine the effect of forest clearing practices on stream flow (Golding and Swanson, 1986). It was for this reason that in the fall of 1974 approximately 50 percent of the forested portion of the Cabin Creek sub-basin of Marmot Creek Basin was clearcut in five separate blocks, which ranged in area from 8 to 13 hectares. An intensive snow survey was undertaken in 1969 to determine snow accumulation patterns on the forested part of Marmot Creek Basin before and after clearcutting treatment. Snow depth and snow-water equivalent measurements were taken in the last part of March using a 5x10 chain grid of numbered stakes (Water Survey of Canada, 1974). These surveys were developed in order to determine if there were snow accumulation differences in clearcut areas and areas adjacent to them. The results showed that there were increased amounts of snow in clearcut areas which could be attributed mostly to the lack of interception by forest cover.

NATIONAL PARK BERCHTESGADEN STUDY AREA

The second study area is the National Park Berchtesgaden (Figure 2). It is located in the southeastern most corner of Germany and is bordered by Austria on its west, south, and east sides.

Figure 2: **The Location of the National Park Berchtesgaden Study Area**

The National Park Berchtesgaden was chosen as a study area because of the well documented existing GIS database, and the availability at no cost of detailed snow data, satellite imagery, and DEM data.

METHODOLOGY

The creation of the GIS database and the modelling procedures for both of the study areas involved the use of various software and hardware components. These are outlined in Table 1.

Table 1: **Software and Hardware Components**

Marmot Creek Basin

software
- SPANS GIS 5.3 (OS/2)
- SPANS Tydig 5.3 (digitizing) (OS/2)
- PCI EASI/PACE 5.2 (Image Processing) (unix and OS/2)
- SPSS (unix)
- Quattro Pro 1.0 for Windows

hardware
- IBM RISC 6000 workstation
- Northgate 486/33 PC

National Park Berchtesgaden

software
- Arc/Info 7.0.3 GIS (unix)
- Arcview 3.0 GIS (unix)
- Erdas Imagine 8.2 (Image Processing) (unix)
- SPSS 7.5 for Windows
- DBASE IV
- Microsoft Excel 7.0

hardware
- Sun SPARC 10 workstation
- LOG3000 Pentium/133 PC

The available data for both study areas is summarized in Table 2.

Table 2: **Available Data for GIS and Stepwise Regression Analyses**

Marmot Creek Basin
- Landsat TM bands 1 to 7
- DEM with spatial resolution of approximately 15m
- various map data layers from hardcopy
- snow depth and SWE data collected on twenty snow courses in the basin
- annual snow survey data that were usually collected in the third week of March from 1969 to 1980; 290 grid points for the intensive snow survey which was undertaken in forested portions of the basin

National Park Berchtesgaden
- Landsat TM bands 1 to 5, 7
- DEM with a spatial resolution of 50m
- various Arc/Info data layers from the National Park database including vegetation types and landuse
- snow depth and SWE data collected from 1988 to 1994 in forested and alpine areas within the National Park

Satellite Imagery Acquisition

The TM image data for the Marmot Creek Basin (MCB) were acquired on August 8, 1984, with a sun elevation of 49.3° and azimuth of 138.1°. The data contained in the image covered the lower reaches of the Kananaskis Valley where the MCB study area is located. The Landsat TM data have a spatial resolution of 30 m over six bands (bands 1 to 5, 7) ranging from 0.45 um to 2.35 um. An additional band (band 6) has a spatial resolution of 120 m and covers the 10.4 um to 12.5 um range (Lillesand and Kiefer, 1987). Geocorrection procedures were performed in order to register the satellite data with the Universal Transverse Mercator (UTM) grid system. This was done for the TM data with a resulting RMS error of under 0.25-pixels (X: 0.232 Y: 0.205) for 15 Ground Control Points (GCP). This corresponds to a maximum error of approximately 6 m to 7 m in any compass direction. Registration procedures were completed using a bilinear resampling algorithm (PCI, 1991). The bilinear procedure calculates a weighted average using the four nearest pixel values to determine the resultant individual pixel value.

The National Park Berchtesgaden (NPB) Landsat TM image data were acquired on August 1, 1992. The image covers all of NPB and areas to the north as well as adjacent areas in Austria. The image data are georeferenced to the Austrian Gauss-Krueger grid system. No geocorrection procedures were necessary as the image had been previously georeferenced.

Digital Elevation Model (DEM) Acquisition

A DEM for the MCB was developed from elevation map contours using the SPANS Tydig (Intera-Tydac, 1993) digitizing system. The contour interval on this map was 100 feet or 30.48 m. No error term was given for this map but it is similar to a Canadian 1:50000 National Topographic Series (NTS) map sheet. These map sheets are accurate to within one half of a contour line or approximately 15m (Wilson, 1990). Interpolation procedures using a Triangulated Irregular Network (TIN) model were used to develop the DEM within the SPANS GIS (Intera-Tydac, 1993).

The DEM for the NPB was available with a 50m spatial resolution. The DEM data were already georeferenced to the Austrian Gauss-Krueger projection so they matched up with the TM data in the Arc/Info GIS (Esri, 1995) NPB database.

Snow Data Acquisition

The snow data for the MCB consists of annual snow surveys that were usually conducted in the third week of March from 1969 to 1980. There are 290 grid points for the intensive snow survey which was undertaken in forested portions of the basin. Snow depth, SWE, and snow density were recorded at each site. There are missing data for some years as the surveys were not always fully completed. Two different snow course maps were obtained from the literature on the basin. The snow course maps were supposed to show the same twenty snow course locations. This was not the case, however, as some of the snow courses with the same number were located in different areas on the maps. This problem could not be satisfactorily resolved and thus the snow course maps and data were dropped from the analyses. Bernier (1986) mentions alpine snow stake data but these could not be obtained.

Snow data for the NPB consisted of a single data file with 5744 snow depth and SWE depth observations collected at various sites from 1988 to 1994. The data were recorded at irregular intervals during the snow season and there are also missing data for some sites in certain years.

Additional Map Data

There have been many different studies in the MCB area and the literature on these studies is extensive (Bernier, 1986; Golding, 1972; Storr, 1973; Swanson et al., 1986). Maps were obtained which showed tree height, crown density, insolation, and streams (Alberta Forest Service, 1979; Ferguson et al., 1971). The data were in polygon and line format and were entered through digitizing procedures into the database.

Additional Satellite Data Analyses

Principal Component Analysis (PCA) was shown by Walsh et al. (1990) to provide useful information for defining resource characteristics in a mountainous environment. PCA transforms the TM bands into statistically independent axes which account for the variance in the TM data set in a more succinct manner. The PCA was produced using the entire set of seven TM bands for the MCB and the six available bands for the NPB and reduced the image data into four principal components (PCA1 to PCA4). A Normalized Difference Vegetation Index (NDVI), as a measure of biomass, has proven to be useful in the classification of vegetation patterns in mountainous environments in the past (Wheate and Franklin, 1991). In the MCB and NPB, a NDVI was produced using a combination of TM bands 3 and 4 (4-3/4+3). Near Infrared Chromaticity (NIC) which is an index of visible spectral response versus infrared spectral response was used by Franklin and Raske (1994) to look at the differences between damaged and undamaged stands of trees. NIC was calculated only for the MCB using TM bands 2, 3, and 4 (4/(2+3+4)).

GIS Data Integration and Processing

All of the TM satellite band data and additional derived information (PCA, NDVI, NIC) were imported into the respective study area databases using the raster transformation procedures within the SPANS GIS and the Arc/Info GIS. For the MCB, the raster data were enquadded (ie: placed in quadtree format) to map form using the raster to map function. Arc/Info GRID allowed for the raster satellite data and PCA and NDVI data layers to be integrated into the NPB database.

The DEM for the MCB was created through the following procedure. Elevation map contours were digitized as lines and had the appropriate elevation values attached to them. They were then exported as vectors from the TYDIG digitizing package and subsequently imported into the GIS. Further processing was still necessary however because a DEM can only be interpolated in SPANS from point data. Therefore the vectors were exported as lines in a latitude/longitude format. The SPANS utility, arc2pnt, was then used to convert the line data to point data. These point data were then re-imported into the study area for further processing. The Transform/Data Types/Points to Map/Contouring procedure was used to develop a DEM. This technique uses a Triangular Irregular Network (TIN) to calculate the surface (Intera-Tydac, 1993). A non-linear interpolation method was employed. This interpolation procedure creates a continuous surface where the values are smooth and derivatives will also be continuous. Other variables were calculated using the DEM data and various SPANS modules. These included ten different variations of an angle of incidence calculation, surface illumination, slope aspect, slope percent, and slope angle.

The DEM for the NPB was analyzed within Arc/Info GRID to create additional data layers for the regression analyses. Slope aspect, slope gradient, and across and down slope curvature were calculated from the DEM.

GIS Variable Extraction and Snow Data Integration

In total, there were thirty two map data layers in the MCB study area database. These were the independent variable set for the regression analyses. The values for each layer of data were appended to the digitized snow point locations and exported out of SPANS for the stepwise regression analyses. This was accomplished using the Model/Points/Append Class operation of SPANS. Each point had a unique identifier attached to it so it could be referenced to the snow data which were in a separate file. The snow point data were entered into the Quattro Pro spreadsheet package (Borland, 1992). The dependent variable data set consisted of snow depth and snow-water equivalent depth for the years 1969 to 1973, 1975 to 1978, 1980, and 1981. The snow depth and snow-water equivalent depth measurements were recorded in inches for the all of the years. The dependent and independent variable data files were combined using Quattro Pro and sorted according to the snow point identifier.

The snow data for the NPB database had to be imported into ArcView 3.0 in order to change their map projection. The original map projection was a German version of the Gauss-Krueger which was incompatible with the Austrian version as the datum used is different. The snow data were exported as a shapefile and then the Arc/Info project command was used to transform the projection to the Austrian Gauss-Krueger. The Arc/Info Grid NPB database consists of sixteen data layers that were exclusively derived from the TM or DEM data within Arc/Info GRID. The command latticespot appended the data layer values directly to the snow data points. Using the arcshape command the resulting data file with snow data and corresponding independent data layer values was transformed back to an ArcView file format. ArcView was then used to turn the file into a DBASE format.

REGRESSION ANALYSIS

The snow data files for the MCB and the NPB were imported into the Statistical Package for the Social Sciences (SPSS) (Norusis, 1985) for the regression analyses. Initially the MCB data were run through a multiple regression procedure that was not stepwise. The previously mentioned problem of adjusted R^2 and degrees of freedom made it necessary to opt for a stepwise regression procedure (Kennedy, 1985). The straight multiple regression procedure entered 30 of the 32 MCB independent variables into the equations. This resulted in models where the equations were unwieldy and independent variables that were not really making a contribution to the models were included. The P-to-enter (0.05) and P-to-remove (0.10) values were defaulted in the stepwise regression procedures. When the limits were reached no further variables were entered into or removed from the analyses.

The NPB data were only put through a stepwise regression procedure due to the results from the non stepwise procedure run on the MCB data. Subsets of the NPB database were selected based on the year and week the data were collected. The amount of missing data and the number of consecutive days that the snow data were recorded were also taken into account. Generally, this resulted in data groupings in the 3 to 5 day range that covered most of the data points in the Park.

RESULTS OF THE REGRESSIONS

The best snow depth model that was produced for the MCB database had a coefficient of determination or adjusted R^2 of 0.6370. In this case for 1972 (snodep72), the independent variables of elevation, incidence, tree height, and principal component four of the TM data explained approximately 64% of the variation in snow depth. The equation was:

$$\begin{aligned}\text{snodep72} = {} & -568.503764 + 0.228866\,(\text{elevation}) + 1.005163\,(\text{incidence}) \\ & - 5.384195\,(\text{tree height}) - 3.717428\,(\text{PCA4})\end{aligned}$$

The snow-water equivalent high result was 58.14%. The equation was:

$$\text{snowat72} = -336.686578 + 0.068865\,(\text{elevation}) + 0.262278\,(\text{incidence}) + 0.699524\,(\text{TM band 7})$$

The NPB regressions had a best snow depth result with an adjusted R^2 of 0.801. The independent variables of elevation and NDVI explained approximately 80% of the variation in snow depth during the fourth week of January 1989. The equation was:

$$\text{s4jan89} = -134.058 + 0.136(\text{elevation}) + 0.163(\text{NDVI})$$

The top SWE depth result was for the second week of January 1989 (0.843 adjusted R^2) where elevation, across slope curvature, TM band seven, and principal component four of the TM data explained more than 84% of the variation in SWE depth. The equation was:

$$\begin{aligned}\text{sw2jan89} = {} & 336.761 + 0.328(\text{elevation}) - 217.991(\text{across slope curvature}) + 0.981(\text{TM band 7}) \\ & - 3.458(\text{PCA4})\end{aligned}$$

Very good regression results (>60% explained variation) in the NPB for both snow depth and SWE depth were also obtained for weekly periods in 1990, 1991, 1992, and 1993. In 1988 and 1994 there were problems with large amounts of missing data.

DISCUSSION

The regression equations were used in GIS procedures to create extrapolated snow surfaces for the study areas. The equations used the beta coefficients (as determined by the regression analyses) to query pixel values in the map layers that were significant for calculating the snow surfaces. The MCB and NPB databases contained many of the same database layers. When the regression results for these two different areas are looked at, many of the same independent variables are significant in the equations. Elevation was the best regressor in all of the analyses. Other variables that were common to both databases and were quite useful regressors included TM band 7, NDVI, slope, aspect, and principal components two and four. The across and downslope curvature variables in the NPB database also provided increased explanation in snow depth and SWE depth in many of the regression models. Tree height and an angle of incidence calculation were very good predictors in the MCB analyses.

Missing snow values are the unknown factors in these analyses. The number of missing values and the location of those values are key to the success of the models. If the missing values were concentrated in areas with low or high snow values it would adversely affect the models. This would not allow for the full variability of all the independent variables to be taken into account. Instead areas of concentration would be developed in the models that may or may not produce a model with a good explanation of the snow variation in the basin.

Multicollinearity occurs where independent variables are highly correlated with each other. The stepwise regression method enters variables until threshold limits are reached. Some significant variables may be left out of the regression procedure because of this but the only way to be certain is to use an all-possible-subsets regression. This would have been very expensive in terms of computation time and was not performed even though other sets of independent variables may have provided better results. Sokal and Rohlf (1981) state that one should not lose sight of the fact that the purpose of stepwise, multiple, regression analysis is simply to find the smallest set of predictor variables that still does an adequate job of predicting the value of the dependent variable.

The MCB study area was heavily altered during the time that snow data were collected. The TM satellite data were collected in 1984. The snow data were collected three to fifteen years before this and modifications were made to the forest characteristics of the basin. If the basin had not been altered, the results may have been improved upon. One half of the snow data were collected before extensive clearcutting in the basin and one half were collected after the clearcuts. The NPB TM image and the snow database were collected at approximately the same time. There were no alterations to the landscape in the National Park and perhaps this helps to explain the better results obtained in the NPB regression procedures.

In a 1972 study using multiple regression models in the MCB, the highest explanation of the variance in snow-water equivalent was 58% unadjusted R^2 (Golding, 1972). This study used powers (ie: squares and cubes) of basic variables such as aspect and elevation as the independent variables. Squaring or cubing was used to transform the data and provided for a more "normal" distribution of the variables in the data set. This technique was not used in the regressions in the MCB or the NPB. It may have also led to an increased amount of explained variation.

Information can be derived from the R^2 values obtained in the regression analyses and examination of which variables were the most effective overall can lead to the possible use of these variables in further research and in new regression procedures. Elimination of insignificant variables would seem to lend itself to developing a model through multiple, linear regression where the independent variables used are already known to be generally effective in explaining variation in the snowpack.

CONCLUSION

Snow is a highly variable phenomenon and attempting to model its accumulation pattern in high mountain environments is especially difficult. A Geographic Information System (GIS) proved to be a valuable tool in the analysis and mapping of snow data. The MCB models established that a GIS, DEM, and remote sensing based procedure could provide better results than had been previously obtained using stepwise, multiple linear regression analysis. This research derived some encouraging results using remotely sensed and geomorphometric variables. The highest amount of explained variation for the NPB in SWE depth was 84.3% while the best result for snow depth was 80.1%.

The time and cost involved in comprehensive studies in the field necessitates that alternative methods be developed. GIS based snow modelling procedures will allow for assessment of snowpack conditions in a timely and cost-effective manner. This will have implications for forestry as well as water management in hydroelectric and irrigation projects. If the amount of water that is available in mountain basins is known then planning decisions can be made based on that knowledge. Improvements in data quality and availability will continue. These new data should provide a better basis for new snow modelling procedures.

FUTURE RESEARCH DIRECTIONS

A 20m DEM will soon be available for the National Park Berchtesgaden; this will be analyzed to determine variables such as across and downslope curvature, slope, and aspect and then integrated into the GIS database. This should provide a more accurate assessment of these variables. An Arc/Info aml to determine the energy inputs at the surface at different times during the snow season will also be integrated into the database. Modelling of snow depth and SWE depth for different aspect zones within the National Park Berchtesgaden will also be performed. The Berchtesgaden models will also be applied to alpine areas in Austria where the model results can be statistically compared with actual data from the winter measurement network at different times during the snow season. The amount of water available from the snowpack based on SWE model results will also be calculated with the GIS. There is also the possibility of integrating new data sources that are currently being used for snow research (e.g. SMMR, SSM/I, ...).

REFERENCES

ALBERTA FOREST SERVICE. 1979. **Forest Inventory Map, TWP. 23, RGE. 9, W. 5, MER**. Alberta Energy and Natural Resources. Edmonton, Alberta.

BAUMGARTNER, M.F. AND G. APFL. 1993. **Alpine Snow Cover Analysis System**. In Proceedings of the 6th AVHRR Data User's Meeting. Belgirate, Italy. June 29-July 2, 1993.

BERNIER, P.Y. 1986. **Extrapolating Snow Measurements on the Marmot Creek Experimental Basin**. Nordic Hydrology. 17: 83-92.

BORLAND. 1992. **Quattro Pro for Windows Manuals**. Borland International Inc. Scotts Valley, California.

CARROLL, T.R. 1994. **Remote Sensing of Snow Cover in North America Using Airborne Gamma Radiation Data and AVHRR, GOES, and SSM/I Satellite Data**. Presented at the 3rd Circumpolar Symposium on Remote Sensing of Arctic Environments. Fairbanks, Alaska. May 16-20, 1994.

COTE, M. 1984. **Climate of Kananaskis**. Environment Canada, Atmospheric Environment Service. Edmonton, Alberta.

ELDER, K., J. DOZIER, AND J. MICHAELSEN. 1991. **Snow Accumulation and Distribution in an Alpine Watershed**. Water Resources Research. 27(7): 1541-1552.

ESRI Inc. 1995. **Understanding GIS: The Arc/Info Method**. Environmental Systems Research Institute. Redlands, California.

EYTON, J.R. 1989. **Low-Relief Topographic Enhancement in a Landsat Snow-Cover Scene**. Remote Sensing of Environment. 27: 105-118.

FERGUSON, H.L., H.F. CORK, R.L. ANDERSON, S. MASTORIS, and B. WEISMAN. 1971. **Theoretical Clear Sky Effective Insolation Over a Small Mountain Basin**. Climatological Studies No. 21. Environment Canada, Atmospheric Environment Service. Ottawa, Ontario.

FRANKLIN, S.E., G.D. LODWICK, AND R.D. WHEATE. 1990. **Research Related to Digital Remote Sensing of Mountain Areas at the University of Calgary**. Canadian Journal of Remote Sensing. 16(2): 50-54.

FRANKLIN, S.E. AND A.G. RASKE. 1994. **Satellite Remote Sensing of Spruce Budworm Forest Defoliation in Western Newfoundland**. Canadian Journal of Remote Sensing. 20(1): 37-48.

GOLDING, D.L. 1974. **The Correlation of Snowpack with Topography and Snowmelt Runoff on Marmot Creek Basin, Alberta**. Atmosphere. 12(1): 31-38.

GOLDING, D.L. 1972. **Snow Accumulation as Influenced by Topography, and its Correlation with Annual and Seasonal Streamflow on Marmot Basin, Alberta**. Presented at the Sixth Annual Congress of the Canadian Meteorological Society. Edmonton, Alberta. May-June 1972.

GOLDING, D.L. AND R.H. SWANSON. 1986. **Snow Distribution Patterns in Clearings and Adjacent Forest**. Water Resources Research. 22(13): 1931-1940.

GRANBERG, H.B. AND G.J. IRWIN. 1991. **Construction of a Digital Transect at Schefferville to Validate a Geographic Snow Information System**. In Proceedings of the 14th Canadian Symposium on Remote Sensing. Calgary, Alberta. May 6-10, 1991.

HALL, D.K. AND J.L. FOSTER. 1994. **Mapping Snow by Elevation Zone in Glacier National Park, Montana**. Presented at the 3rd Circumpolar Symposium on Remote Sensing of Arctic Environments. Fairbanks, Alaska. May 16-20, 1994.

HARRINGTON, A.W. 1953. **Snow Surveys in the Northeast and Uses of Data**. In Proceedings of the Western Snow Conference. 21st Annual Meeting. Boise, Idaho. April 20-22, 1953.

HENDERSON, T.J. 1982. **Western Snow Conference - The First Fifty Years**. In Proceedings of the Western Snow Conference. 50th Annual Meeting. Reno, Nevada. April 19-23, 1982.

INTERA-TYDAC. 1993. **SPANS GIS Manuals**. Intera-Tydac Technologies Inc. Nepean, Ontario.

KENNEDY, P. 1985. **A Guide to Econometrics (Second Edition)**. MIT Press. Cambridge, Massachusetts.

KITE, G. 1989. **Hydrologic Modelling with Remotely Sensed Data**. In Proceedings of the Western Snow Conference. 57th Annual Meeting. Fort Collins, Colorado. April 18-20, 1989.

LAPEN, D.R. 1991. **Modelling the Redistribution of Snow in a Prairie Agricultural Landscape using Digital Terrain and Spatial Entropy Analysis**. Unpublished M.Sc. Thesis. Department of Geography. University of Saskatchewan. Saskatoon, Saskatchewan.

LILLESAND, T.M. AND R.W. KIEFER. 1987. **Remote Sensing and Image Interpretation (Second Edition)**. John Wiley and Sons. Toronto, Ontario. 721pp.

LINSLEY, R.K., M.A. KOHLER, AND J.L.H. PAULHUS. 1982. **Hydrology for Engineers**. McGraw-Hill Book Co. Montreal, Quebec. 508pp.

MARKS, D., J. DOZIER, AND R.E. DAVIS. 1992. **Climate and Energy Exchange at the Snow Surface in the Alpine Region of the Sierra Nevada, 1. Meteorological Measurements and Monitoring**. Water Resources Research. 28(11): 3029-3042.

NORUSIS, M.J. 1985. **SPSS-X Advanced Statistics Guide**. SPSS Inc. 505pp.

P.C.I. Inc. 1991. **Pace Image Analysis Manuals version 5.1**. P.C.I. Inc. Richmond Hill, Ontario.

RANGO, A. 1992. **Worldwide Testing of the Snowmelt Runoff Model with Applications for Predicting the Effects of Climate Change**. Nordic Hydrology. 23: 155-172.

ROCK, N.M.S. 1988. **Numerical Geology**. Springer-Verlag. New York, New York. 427pp.

ROTT, H. AND T. NAGLER. 1993. **Capabilities of ERS-1 SAR for Snow and Glacier Monitoring in Alpine Areas**. In Proceedings Second ERS-1 Symposium - Space at the Service of our Environment. Hamburg, Germany. October 11-14, 1993. (ESA SP-361, January, 1994).

ROTT, H., K. STURM, AND H. MILLER. 1993. **Active and Passive Microwave Signatures of Antarctic Firn by Means of Field Measurements and Satellite Data**. Annals of Glaciology. 17: 337-343.

SHAFER, B. (ed.)., J.K. MARRON, AND C. TROENDLE. 1989. **Proceedings of the Western Snow Conference**. 57th Annual Meeting. Fort Collins, Colorado. April 18-20, 1989.

SKOYE, K.R. AND J.R. EYTON. 1992. **Digital Analysis of Low-Relief Topography in a Landsat Snow-Cover Scene in South-Central Alberta**. Canadian Journal of Remote Sensing. 18(3): 143-149.

SOKAL, R.R. AND F.J. ROHLF. 1981. **Biometry (Second Edition)**. W.H. Freeman and Co. New York, New York.

STORR, D. 1973. **Wind-Snow Relations at Marmot Creek, Alberta**. Canadian Journal of Forest Resources. 3: 479-485.

THIRKETTLE, F., A. WALKER, B. GOODISON, AND D. GRAHAM. 1991. **Canadian Prairie Snow Cover Maps from Near Real-Time Passive Microwave Data: From Satellite Data To User Information**. In Proceedings of the 14th Canadian Symposium on Remote Sensing. Calgary, Alberta. May 6-10, 1991.

WATER SURVEY OF CANADA. 1969-1980. **Compilation of Hydrometeorological Record Marmot Creek Basin**. Volumes 5-16. Water Survey of Canada, Department of the Environment. Calgary, Alberta.

WHEATE, R.D. AND S.E. FRANKLIN. 1991. **Principal Component Transformation of Satellite Imagery in Mountain Areas**. In Proceedings of the 14th Canadian Symposium on Remote Sensing. Calgary, Alberta. May 6-10, 1991.

WILSON, B.A. 1990. **DEM Data into a Spectral Classification**. Unpublished M.Sc.Thesis. Department of Geography. University of Calgary. Calgary, Alberta.

WINTHER, J. 1992. **Landsat Thematic Mapper (TM) Derived Reflectance from a Mountainous Watershed during the Snow Melt Season**. Nordic Hydrology. 23: 273-290.

YEATES, M. 1974. **An Introduction to Quantitative Analysis in Human Geography**. McGraw Hill. Toronto, Ontario.