Predicting Water Availability in the Antarctic Dry Valleys Using GIS and Remote Sensing

Glen Stichbury and Lars Brabyn

Dept. of Geography, Tourism and Environmental Planning
University of Waikato,
Private Bag 3105, Hamilton, New Zealand
Telephone: +64 7 838 4466 ext. 8429
Email: larsb@waikato.ac.nz

1. Introduction

Water is one of the most important ingredients for life on Earth. The presence or absence of biologically available water determines whether or not life will exist. In Antarctica most water exists as ice and is not available for sustaining life. It is usually only during December and January that temperatures will rise above zero and melt water becomes available (Kennedy, 1993). For this reason Antarctica is regarded as the driest desert in the world (Peck et al., 2006, McKnight et al., 1999).

Antarctica is an environment where abiotic constraints, particularly water, strongly influence the distribution and diversity of biota (Hemmings, 2001). As Antarctic biology is relatively simple when compared to more temperate climates, it is a prime location for researching constraints on biodiversity, and what may be the impacts of changes to these constraints resulting from climate change and human disturbance.

This research uses Geographic Information Systems (GIS) and remote sensing to develop a relative water availability index of three Dry Valleys in Southern Victoria Land, Antarctica. This study area is being used for the IPY Terrestrial Biocomplexity project, an international collaboration researching the distribution, diversity and complexity of biology in the Dry Valleys. The development of a predictive water availability model will contribute greatly to their main research goal, which is to predict the distribution of terrestrial life in the Dry Valleys.

2. Methodology

Geographic Information Systems and Remote Sensing enable the analysis of large and remote areas without the requirements of field sampling. In a location where the sources of biologically available water are spatially and temporally heterogeneous, satellite remote sensing is able to capture data on these sources on a regular basis. Combined with a Digital Elevation Model (DEM) of the study area, the accumulation and dispersal of water from these sources can be predicted.

While Glaciers and Lakes in the Dry Valleys are relatively spatially and temporarily constant and do not require regular analysis, snow is a transient source of melt water that varies daily. The MODIS instruments aboard the Terra and Aqua Satellites capture images of the study area daily and true-colour and short-wave infrared images are made available free from the *MODIS Rapid Response System* website:
(http://rapidfire.sci.gsfc.nasa.gov/).
These images date from 2004 and are updated daily. Cloud free images of the study area over four summer seasons were classified into areas with and without snow. From this a mean snow cover distribution model was created. This was then combined with glacier

and lake locations to provide a weight index of water sources, representing the uneven distribution of the mean potential for melt water over several seasons.

The weight index of water sources can then be used with a Compound Topographic Index (CTI). A CTI is a steady state index showing the likely accumulation and dispersal of liquid water given the spatial distribution of water sources and the flow of water over the terrain according the influence of gravity (Moore et al., 1993, Evans, 2001/03). To calculate how water will flow over the terrain, Tarboton’s D-Infinity (D-Inf) algorithm (Tarboton, 1997) was used to calculate flow directions. This algorithm allows for flow in any direction (not just the four cardinal directions and the 45° angles between them) by dividing the 3x3 cell window into triangular facets and calculating proportion of flow into multiple cells where necessary. With the use of this algorithm and high resolution LIDAR elevation data of the study area, water flow can be calculated at a high degree of detail. By weighing the flow accumulation calculation with the index of water sources, a representation of water input and flow is achieved. This can then be used in the CTI calculation along with the LIDAR DEM to produce a relative index representing the average accumulation and dispersal of water in the study area.

3. Results and Validation

The output model in this project is an index of the predicted spatial availability of liquid water, given the spatial distribution of water sources and the effects of gravity and topology. The index varies from 26.1575 at the wettest to 1.34418 at its driest. These numbers represent a relative scale of the accumulation and dispersal of water within the study area.

The model shows the increased likelihood of liquid water availability vertically downwards on the valley sides as water is pulled down-slope by gravity. There is evidence of channels forming in many areas where a greater amount of water is accumulating. The lowest predicted water availability is on ridges except for small pools, although some of the smallest pools may have been omitted due to the pit filling process prior to calculating flow paths. The highest areas of accumulation are in the valley floor lakes and rivers.

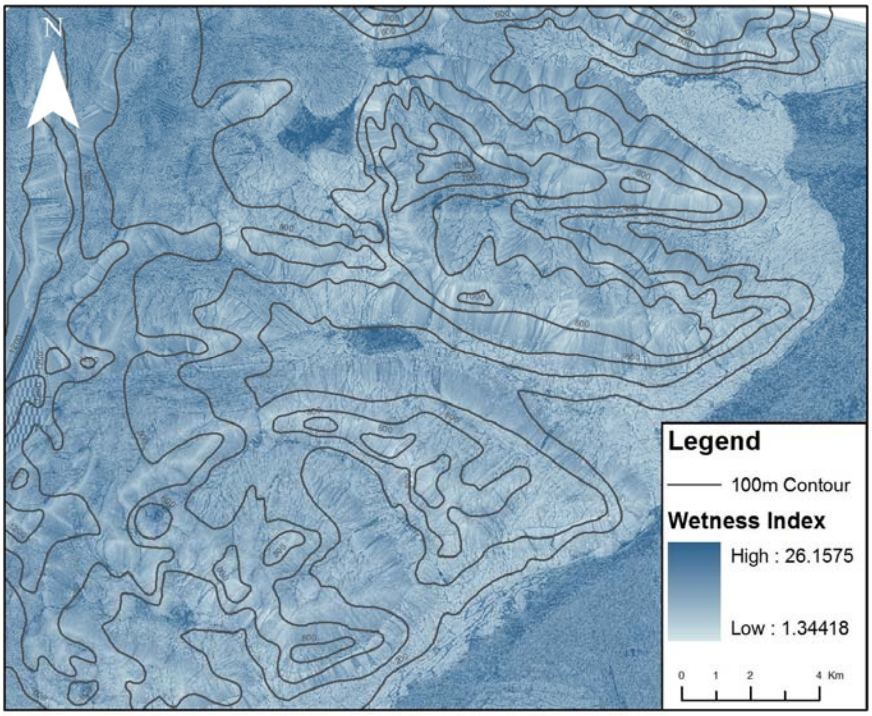

Figure 1. Compound Topographic Index of the Dry Valley Study Area.

Although extensive field data collection has been undertaken in the study area as part of the IPY Terresrial Biocomplexity project, validation through ground samples is as yet unfeasible. As such, a more qualitative means of model validation is required. The use of 3d visualisation and image overlays are useful for assessing key elements, including conformity of flow to known drainage patterns, down-slope flow and the influence of the water source weighting. To compare drainage patterns, a high resolution panchromatic ALOS image was used. This image shows rills and gullies on the valley sides, as well as streams, alluvial fans, lakes and ponds on the valley floors. By using ArcMap's capability to 'Swipe' data layers, the model can be checked for higher wetness values in these areas. In the same manner, comparisons between the weighted wetness model and an unweighted model can be made. As an unweighted CTI is calculated with an even distribution of water over the entire watershed, values tend to be drier in the weighted version compared with the unweighted version due to areas with low mean potential for melt.

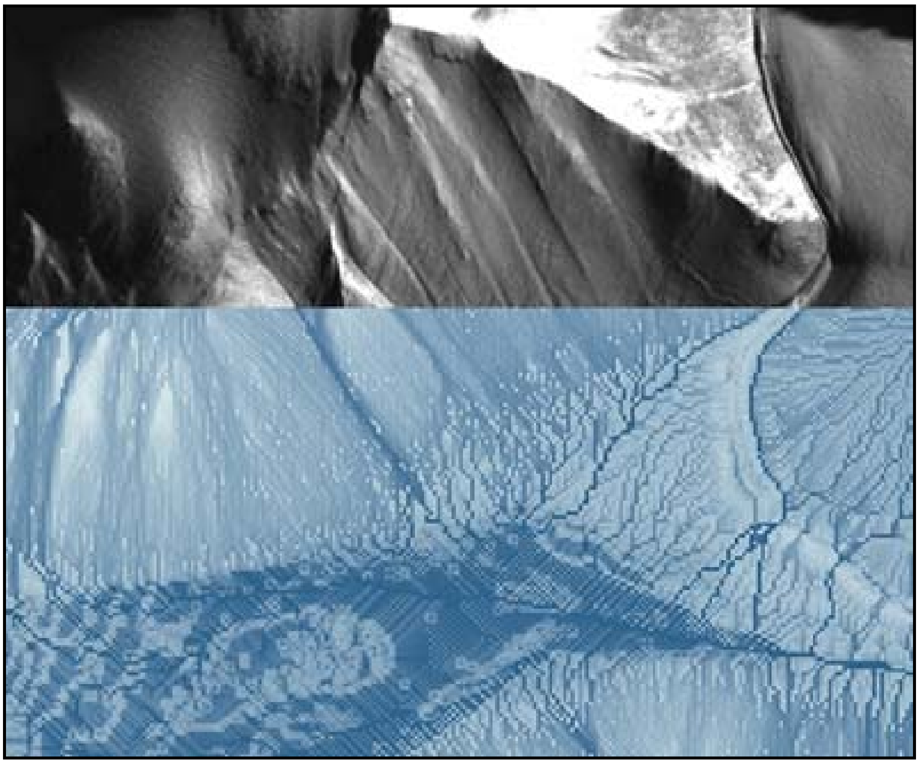

Figure 2. Drainage Comparison in upper Garwood Valley.

4. Discussion

GIS and remote sensing are valuable tools for predicting water distribution in Antarctica. Although cloud cover, varied illumination and differing spatial resolutions can create limitations, remote sensing's cost effective and environmentally sound method of data capture and the computational and spatial modelling capabilities of GIS make their use well suited to the Antarctic environment.

One of the strengths of this model and the use of remote sensing for capturing data is its simplicity and accuracy. Mathematical models for predicting snow cover require complex computations using numerous variables including climate, wind and topology. Using remote sensing to record past snow cover events to create an average distribution index is far simpler and a logical way to gather data.

There are many variables that influence the amount of melt from snow and ice, particularly in such a dry environment where sublimation is a large cause of ablation. As data availability dictated an inability to undertake such calculations, the use of high temporal resolution data allowed for the assumption that the higher the temporal cover of snow and ice, the higher the potential for melt to occur.

The model and methods used in this project are not only useful for predicting biocomplexity. This model is transferable to other study areas and is applicable in other disciplines, including environmental management where this research can be used as part of a high resolution environmental domains analysis.

It can be concluded that such methods of data collection and analysis are highly valuable as they are environmentally friendly, cost effective, safe, and can easily analyse large areas. Given that water is a major constraint on biota in Antarctica, development of a wetness model will be important for predicting the distribution of biota in this significant location.

5. References

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