# SEVEN YEARS OF SNOW COVER MONITORING WITH MODIS TO ASSESS AND IMPROVE MODELLING OF CATCHMENTS DISCHARGE IN NEW ZEALAND

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## 1. INTRODUCTION

Situated in the Southern Alps, the Waitaki basin is the most important hydro catchment in New Zealand and provides approximately one-third of New Zealand's hydro electricity production. Three sub-catchments receive most of the precipitation: Ohau, Pukaki, and Tekapo. In this alpine region an important fraction of the total precipitation falls as snow, which accumulates during winter months from April to October. Thus, a large part of the water resource is temporarily stored as seasonal snow cover and the snowmelt from these catchments is estimated to contribute from 18% to 24% of the total annual runoff and up to 40% to 50% of the spring and summer inflows [1].

It has been long-established that satellite remote sensing is a very powerful tool to monitor snow cover in remote and hardly accessible areas. Considerable efforts have been made recently to routinely produce maps of sub-pixel snow fraction of the area from NASA's MODderate Resolution Imaging Spectroradiometer (MODIS) [2]. A temporal time series of MODIS-derived snow maps is used to assess the performance of the existing snow pack modelling strategy (SnowSim-Pukaki). Furthermore, daily meteorological data (i.e., temperature and precipitations) and the frequent observations of the snowpack from MODIS enable the use of the Snowmelt Runoff Model (SRM) [3, chap. 11] to simulate the discharge of the three sub-catchments over the hydrological years 2000–2007.

## 2. METHODOLOGY AND RESULTS

### 2.1. Assessment of the SNOWSIM-Pukaki model

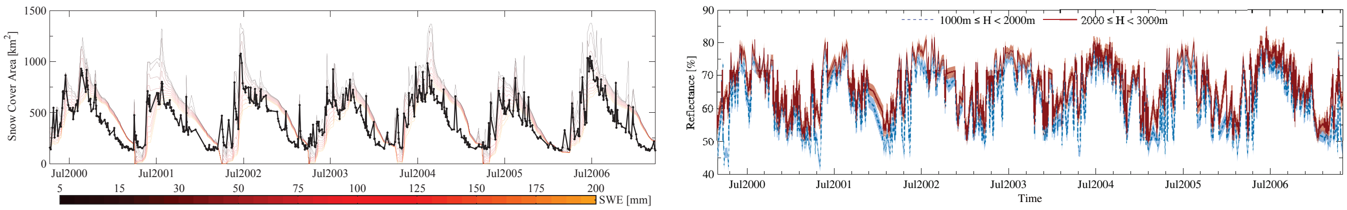
The SnowSim model is a distributed degree-day model developed for New Zealand conditions that simulates the accumulation and ablation of snow using only precipitation and temperature data [4]. The daily maps of Snow Water Equivalent (SWE) from SnowSim are indirectly compared with snow maps obtained from MODIS in the Pukaki catchment. Maps of SWE and observed snow extent are binary segmented to categorize pixels as being snow or not. The comparison of binary maps is conducted using measures obtained from the confusion matrix (i.e., hit rate, false alarm rate, precision, and accuracy).

Figure 1 (a) shows the difference between the areal extent of snow observed from MODIS and modelled with SnowSim for various thresholds of SWE. Based on 600 maps, the highest accuracy between SnowSim and MODIS observations is obtained for a threshold of 50 mm SWE and reached 87%. In addition, the time series of hit rate, false alarm rate, and precision revealed that SnowSim tends to accumulate too much snow and/or the ablation procedure is inappropriate to melt the snowpack fast enough. These sorts of errors for SnowSim arise from an inherent limitation of its modelling strategy, whereby errors tend to be propagated through the whole hydrological year.

### 2.2. Application of SRM

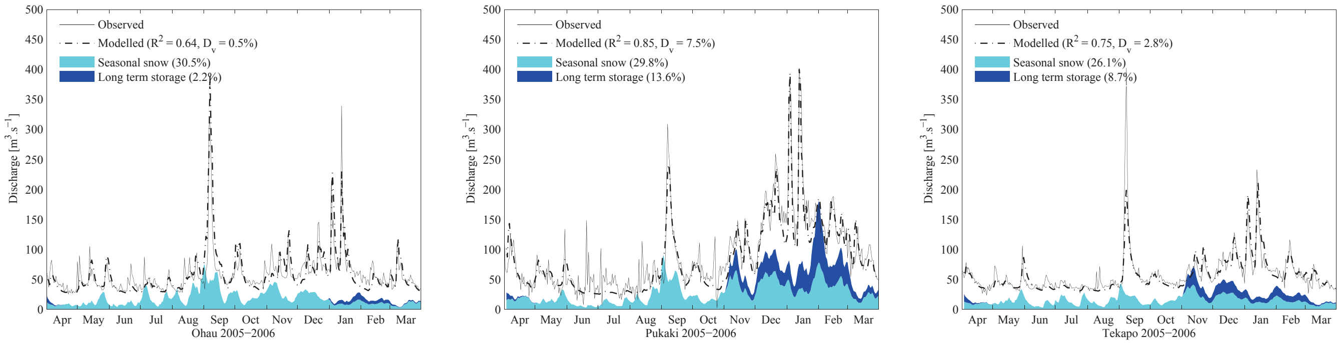
SRM is a semi-distributed degree-day model designed to assimilate observations of snow cover distribution. Each sub-catchment is segmented into zones to accommodate the large range of elevation and the steep north-west to south-east gradient in the precipitation pattern that occurs in the lee of the Southern Alps. The fields of precipitation are interpolated from daily rainfall measured by nearly 50 weather stations using a trivariate thin plate spline interpolator [5]. A long term annual precipitation surface is used as a dependent variable to better represent the orographic effects caused by the mountains. Snow Depletion Curves (SDC) are computed in each zone from the MODIS-derived snow maps. Short-lived snow episodes are automatically removed from the SDC time series using a Savitsky-Golay filtering technique with adaptation to the lower envelope [6]. Finally, the method took advantage of the atmospheric and topographic correction of MODIS imagery [2] to retrieve time series of Near Infrared (NIR) ground reflectance of snow. The latter is indicative of its ageing and is used as a surrogate for determining the snow melt factor [Figure 1 (b)].

Results obtained for the period 2000-2007 show that the use of the information obtained from the satellite, when combined with meteorological observations, greatly benefits the hydrological modelling of the catchment. The mean Nash-Sutcliffe coefficient over the seven hydrological years is 71±8%, 82±6%, and 78±6% for Ohau, Pukaki, and Tekapo, respectively. This compares with a coefficient of 61% when SnowSim-Pukaki is used. The annual total discharge is well modelled, being close to 5% of its measured value and within less than 2% for the whole seven-year period. Over the study period, the results show that the contribution of seasonal snowmelt is substantially larger




(a) (b)

**Fig. 1**. Time series: (a) MODIS- and SnowSim-derived snow cover area in the Pukaki catchment depending on the SWE threshold indicated by the colour bar; (b) average ground reflectance of snow in MODIS band 2 (858 nm). The coloured envelops represent ±1 standard deviation of the samples. The greater reflectance of snow at higher altitude accounts for a more preserved snowpack (i.e., finer grain). The NIR signal also depicts the lowering trend of the snow reflectance during the ablation season as well as the increased albedo of fresh short-lived snow falls.




(a) (b) (c)

**Fig. 2**. Daily discharge, observed and modelled in (a) Ohau, (b) Pukaki, and (c) Tekapo catchments for hydrological year 2005-2006.

than the long term estimations reported by previous studies [1]. Seasonal snow melt accounted for 27±3% (Ohau), 31±5% (Pukaki), and 27±4% (Tekapo) of the total annual runoff. In addition, the results suggest that between April 2005 and March 2006, when a severe drought occurred in the Southern Alps, river flow in the Pukaki catchment was substantially augmented by ice melt due to glacier retreat. Normally, the contribution of glacier melt to annual river flow is about 6%. However, over the drought it contributed nearly 15%, thus permitting to sustain the inflow into Lake Pukaki within 17% of the mean annual inflow for the study period, while the precipitations were reduced by 34%.

## 3. CONCLUSION

MODIS-derived snow maps permitted to identify some limitations of SnowSim. Seven years of MODIS observations are used to calibrate SRM and provide useful estimates of runoff for the three alpine catchments crucial to New Zealand's energy supply. The operational integration of MODIS and meteorological data into SRM now has the potential to provide short to medium term forecasts of water availability in these catchments. In addition, the modelling results show that glaciers can make a notable input to river flow in drought periods. This has implications for water sustainability of New Zealand hydro catchments under global climate change.

## 4. REFERENCES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