IMPROVING THE PARAMETERIZATIONS OF COLD REGION PROCESSES IN A LAND SURFACE MODEL

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1.Background

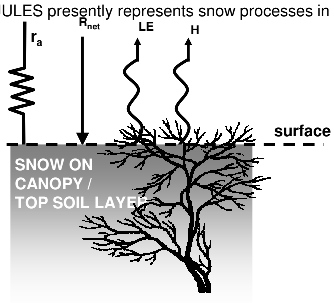
Snow is the single most important feature of land surface-atmosphere interactions at northern latitudes. Its inherent properties play a critical role in the hydrology, ecology and energy and carbon balances of the region.

Shrubs capture and hold more snow than other tundra vegetation types. Field observations, satellite remote sensing data and models all agree that the recent warming has provoked an increase in shrub distribution in the region[1,2,3]. This change in the vegetation structure can significantly affect the distribution and the physical characteristics of snow and as a consequence, the snow-atmosphere-biosphere interactions[4].

2. Model

JULES (Joint UK Land Environment Simulator) is a land surface model developed by the UK Met Office and the CEH with the aim of serving a wide range of disciplines within the scientific community. It comprises an implicit snow scheme, meaning that when snow is present, the snow cover is represented as an extension of the top soil surface layer rather than being a separate entity. This changes the thermal properties of the “hybrid” layer and, as a consequence, the thermal conductivity is re-calculated.

JULES presently represents snow processes in two ways:

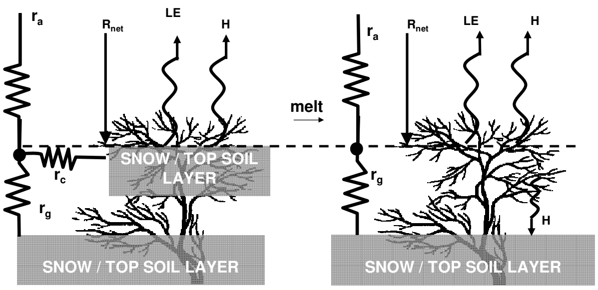


Snow model 1

- Snow is held on the canopy and remains so until complete melt.
- Surface temperature cannot rise above 0°C when there is snow cover.
- Sublimation always occurs at the potential rate because it does not experience resistance from the canopy

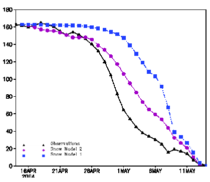
Snow model 2

•Snowfall is partitioned into interception by the canopy and throughfall to the ground.
• Intercepted snow may be removed from the canopy by sublimation, unloading or melting[5].
• The canopy layer shelters the ground snow. As a consequence, snow can not sublimate and is removed by melt.



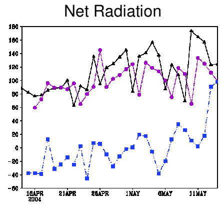
Snow model 2 improves the representation of snow processes during the melt season because: 1/ Snow can now be unloaded from the canopy to the ground rather than remain on the canopy until complete melting 2/ The canopy temperature can now rise above 0°C. Upward turbulent fluxes are now simulated 3/ As the surface now consists of exposed vegetation and snow, the albedo is decreased and net radiation in better agreement with observations.

Snow Mass (Kg m^{-2})



Data collected in 2004 at the Wolf Creek Research Basin, Yukon Territory, Canada. Average shrub height was 120 cm[6,7].

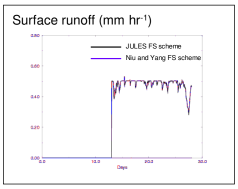
Net Radiation



Observations — Snow Model 1 — Snow Model 2

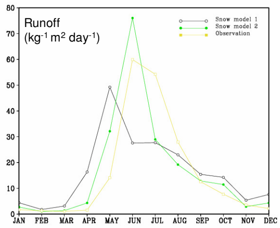
4. Model development: Frozen Soil Processes in JULES

JULES uses the Clapp and Hornberger equations for the soil hydraulic characteristics. The model includes a layered soil representation that uses a finite difference approximation to the Richard’s equation to calculate the vertical fluxes of heat and moisture between layers. When calculating the hydraulic conductivity of soil, the standard scheme only considers the unfrozen fraction of the soil moisture, rather than the total moisture, which has the effect of substantially limiting infiltration into frozen or partly frozen soils.



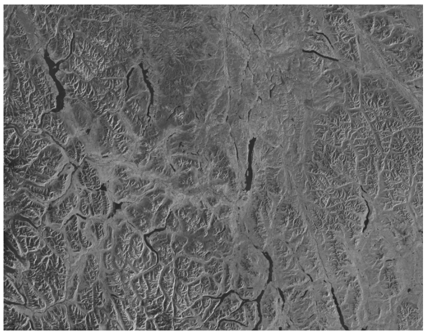
The figure opposite shows surface runoff rates at a single point with the existing frozen soil processes scheme and with a modified scheme that includes the implementation of a fractional permeable area (Niu and Yang, 2006) . Preliminary results using a synthetic rainfall event from day 14 onwards show that the new scheme allows for the infiltration of rain water in deeper soil layers while the existing JULES does not.

The figure opposite shows how the two snow schemes act modify runoff representation and perform against a dataset from the Abisko catchment averaged over 10 years. The increase in snow lying on the ground caused by the modification to the snow scheme in snow model 2 is reflected in an increase in moisture content in all soil layers. This in turn is reflected in runoff rates in snow model 2 which show a higher runoff peak and a shorter recession period than observations because most of the extra water is in a frozen state. As the existing frozen soil scheme does not allow for water storage and for heterogeneity in the landscape, all the snowmelt is translated into immediate runoff.



Observational data were obtained from the PILPS2e experiment[8].

4. Vegetation structure using LiDAR and SAR



JERS-1 SAR image of the region surrounding Wolf Creek Valley. NASDA/MITI

The three-dimensional structure of shrub-tundra vegetation at three sites, Abisko (Sweden), Wolf Creek valley and Trail valley creek (Canada), will be characterised using combinations of multi-spectral sensor, Light Detection and Ranging (LiDAR) and polarimetric Synthetic Aperture Radar (SAR).

First, crown covers will be delineated using LiDAR, then a relationship will be developed with SAR data to extrapolate to the regional scale. The map obtained from this work will inform and validate model outputs and improve existing shrub distribution maps

5. Modelling the effects of northward shrub-tundra expansion on snow and runoff processes in the pan-Arctic

The aim of this PhD is to look at the implication this expansion would have at the global scale, focusing on snow and runoff processes and the surface energy balance in the Arctic. The means to attain this aim will be to :

- Assess the performance of the model against ground and remotely sensed observations. This will be performed first at a single point and on gridded runs at a small scale, using existing studies, then at the global scale.
- Improve cold region processes in JULES (box 2 and 3)
- Improve the present representation of the shrub-tundra canopy structure in the model, using earth observation data (box 5)
- Couple JULES with the climate analogue model IMOGEN (Integrated Model Of Global Effects of climatic aNomalies), used to simulate a range of different climate warming scenarios run in forecast mode at the pan-Artic scale.

6. References

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