Modelling the spatial variability of the snowcover and the surface energy fluxes at TVC

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Purpose of Study

• Study the effects of topography and land cover on snow cover variability and surface energy balance

• Improve the understanding of the processes causing spatial variability of turbulent fluxes

• Improve the parameterization of these processes at the small scale
Snow cover variability at TVC

- Variability during accumulation:
  - Wind redistribution
  - Snow interception by vegetation

- Variability during melting:
  - Effect of topography on radiation
  - Effect of wind variability on turbulent fluxes
  - Effect of vegetation (shrubs) on the surface energy balance
To understand processes…

- Measurements of **surface energy fluxes** at 2 stations (TUP and TTS) - including turbulent fluxes - during and after snow
- Several Landsat **SCA maps** during snowmelt
- **Maps of turbulent fluxes** derived from data from NRCC Twin Otter aircraft carrying EC sensor
To implement the parameterizations...

- Used the **GEOtop** distributed hydrological model
  - It is **grid based**, so it represents well the effect of topography, normally it is run at a smaller scale (10-500m than LSMs)
  - Fully describes the surface energy balance (radiation and turbulent fluxes)
  - Discretizes snow and soil with several layers (the user can choose according to the)
  - Solves heat equation with phase change in the soil and snow column coupled with water flow equation (Richards’ equation in the soil)
  - Fully 3D Richards’ equation solved with iterative methods -> calculates runoff
• State variables:
  – Temperature
  – Water content
  – Ice content

• Non linearity problems

soil water equation

\[ c_{rit}(\psi) \frac{\partial \psi(\theta)}{\partial t} = \frac{\partial}{\partial z} \left( -k(\psi) + k(\psi) \frac{\partial \psi(\theta)}{\partial z} \right) + s(\psi) \]

heat equation with phase change

\[ C(\theta_w, \theta_{ice}) \frac{\partial T}{\partial t} - L\rho_{ice} \frac{\partial \theta_{ice}}{\partial t} = \frac{\partial}{\partial z} \left( k_T(\theta_w, \theta_{ice}) \frac{\partial T}{\partial z} \right) \]
GEOtop for the application in the arctic

- Coupled with PBSM and with MicroMet to represent a wind field including topographic effects and to describe snow transport by wind (of paramount importance in TVC)

- Implemented a dual layer scheme to describe the effects of shrubs on the surface energy balance, in particular the turbulent fluxes

*The parameterization of the “undercanopy” resistance is critical because of uncertainty and high sensitivity*
Turbulent fluxes at shrubs and open tundra sites

- **Measurements** of turbulent fluxes of sensible and latent heat have been performed at TUP and TTS towers during spring since 2003, during and after snowmelt.

- The models has been applied to:
  - understand how shrub tundra affect turbulent exchange in different conditions
  - test to ability of the model to reproduce the fluxes
Turbulent fluxes at shrubs and open tundra sites
Turbulent fluxes at shrubs and open tundra sites

Canopy fraction variable in time
(to account for gradual shrub burial)

\[ f_c = 1 - \left( \frac{D_{sn}}{D_{snB}} \right)^q \leq 1 \]

\( f_c = \) canopy fraction

\( D_{snB} = \) threshold snow depth above which all the shrubs are considered buried has been defined.

\( q = \) exponent (>1) which takes into account that the probability of shrub emergence increases more than linearly the snow depth decreases

In the snow melt period, when the snow depth \( D_{sn} \) becomes smaller than \( D_{snB} \), the shrubs are considered to gradually emerge from the snow cover.
Turbulent fluxes at shrubs and open tundra sites
Turbulent fluxes at shrubs and open tundra sites

DURING MELTING

Sensible heat fluxes [W/m²]

09/05 11/05 13/05 15/05 17/05 19/05 21/05 23/05 25/05 27/05

Measured  Total modelled  Undercanopy  Canopy

TTS  Shrub  Tundra

TUP  Open  Tundra
Turbulent fluxes at shrubs and open tundra sites

• Despite the reduction in the wind speed, the shrubs increase the contribution of sensible heat to the surface energy balance and decrease the heat losses - good agreement observations - results.

• This of great importance in snowmelt acceleration is shrubs tundra.

• The results depend much on the parameterization of the undercanopy resistance. Stable stratifications may occur in the canopy reducing the turbulence exchange.
Turbulent fluxes at shrubs and open tundra sites
Turbulent fluxes at shrubs and open tundra sites

AFTER MELTING

Sensible heat fluxes [W/m²]

- Measured
- Total modelled
- Undercanopy
- Canopy

TTS
Shrub
Tundra

TUP
Open
Tundra
Turbulent fluxes at shrubs and open tundra sites

- Underestimation at TTS - good estimation at TUP
- Higher sensible fluxes at TTS, higher turbulence
- On the other hand, latent heat fluxes are higher at TUP (vegetation is still non transpiring)
Turbulent fluxes at shrubs and open tundra sites

LE

AFTER MELTING

Latent heat fluxes [W/m²]

- Measured
- Modelled

TTS
- Shrub Tundra

TUP
- Open Tundra
Spatial variability of turbulent fluxes

Data from NRCC Twin Otter aircraft carrying EC sensor during the 1999 melting season

Mauder et al. (2008) -> 2D maps at 3 km resolution (footprint model + wavelet method)

Maps for 4 days (27 May - 1 Jun - 3 Jun - 8 Jun)
Spatial variability of turbulent fluxes

Snow water equivalent (mm)
27 May 1999 - SCA approx 70%

Land cover:
Tundra (white) - Shrubs (yellow) - Forest (green) - Lakes (cyan) - No data (red)
Spatial variability of turbulent fluxes

From aircraft

Modelled
Spatial variability of turbulent fluxes

From aircraft  27th May 1999  modelled
Spatial variability of turbulent fluxes

8th June 1999

From aircraft

Modelled
Spatial variability of turbulent fluxes

8th June 1999

From aircraft

Modelled
Discussion

• Reproduced main spatial patterns of sensible flux during snowmelt (higher in snow free areas and over shrubs, lower in snow covered open tundra)

• After snowmelt: measurements at TUP and TTS suggest negative correlation between LE and H; the aircraft data the contrary

• This arises question. Is the model good enough in predicting the fluxes 2D? Are aircraft data really representative of the surface?
Snow spatial variability

Snow water equivalent - SCA

SWE (mm) - 23 May 1999 - model 20 m  SCA - 23 May 1999 - SPOT
Conclusion

- The model allows interpreting the measurements of turbulent fluxes separating the fluxes in canopy and undercanopy components

- The model performs reasonably well and the temporal patterns of the fluxes are in generally well reproduced, during and after snowmelt

- The parameterization of the undercanopy resistance should be improved

- The spatial patterns of turbulent fluxes have to be further investigated, given disagreements between model and aircraft results
Thank you very much