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

S. Endrizzi, P. Marsh, and S. Pohl

# 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 <u>during accumulation</u>:
  - Wind redistribution
  - Snow interception by vegetation

- Variability <u>during melting</u>:
  - Effect of topography on radiation
  - Effect of wind variability on turbulent fluxes
  - Effect of vegetation (shrubs) on the surface energy balance

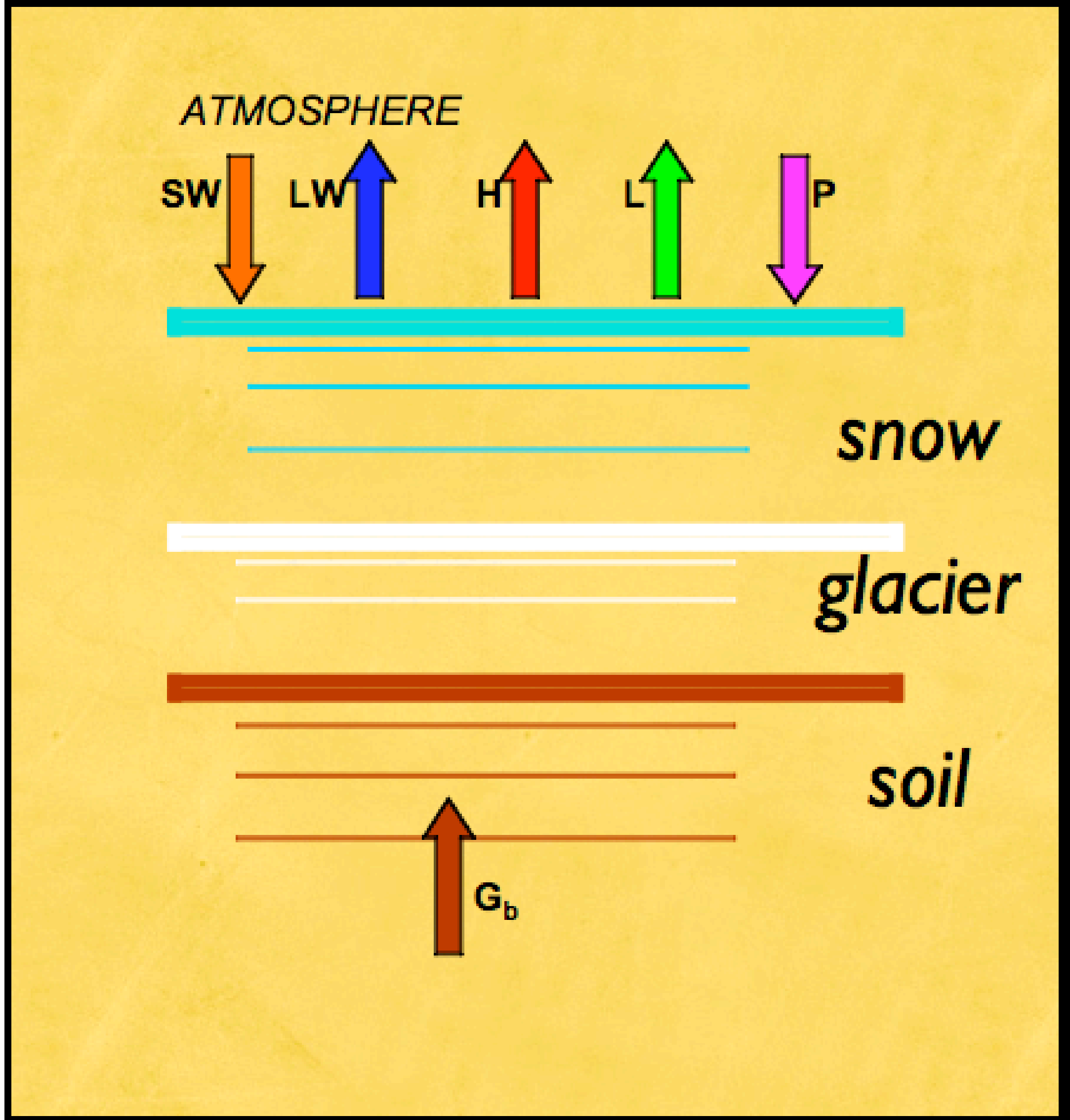
# To understand processes…

- 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

# GEOtop




- State variables:
  - Temperature
  - Water content
  - Ice content

- Non linearity problems

soil water equation

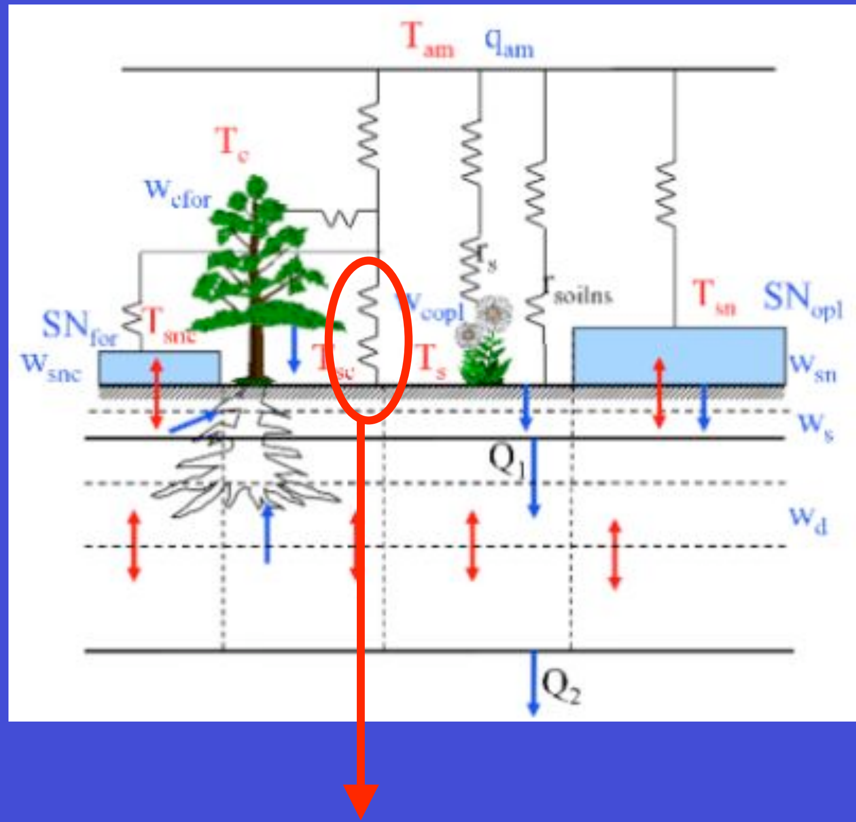
$$c_{rit}(\psi)\frac{\partial\psi(\theta)}{\partial t} = \frac{\partial}{\partial z}\left(-k(\psi) + k(\psi)\frac{\partial\psi(\theta)}{\partial z}\right) + s(\psi)$$

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

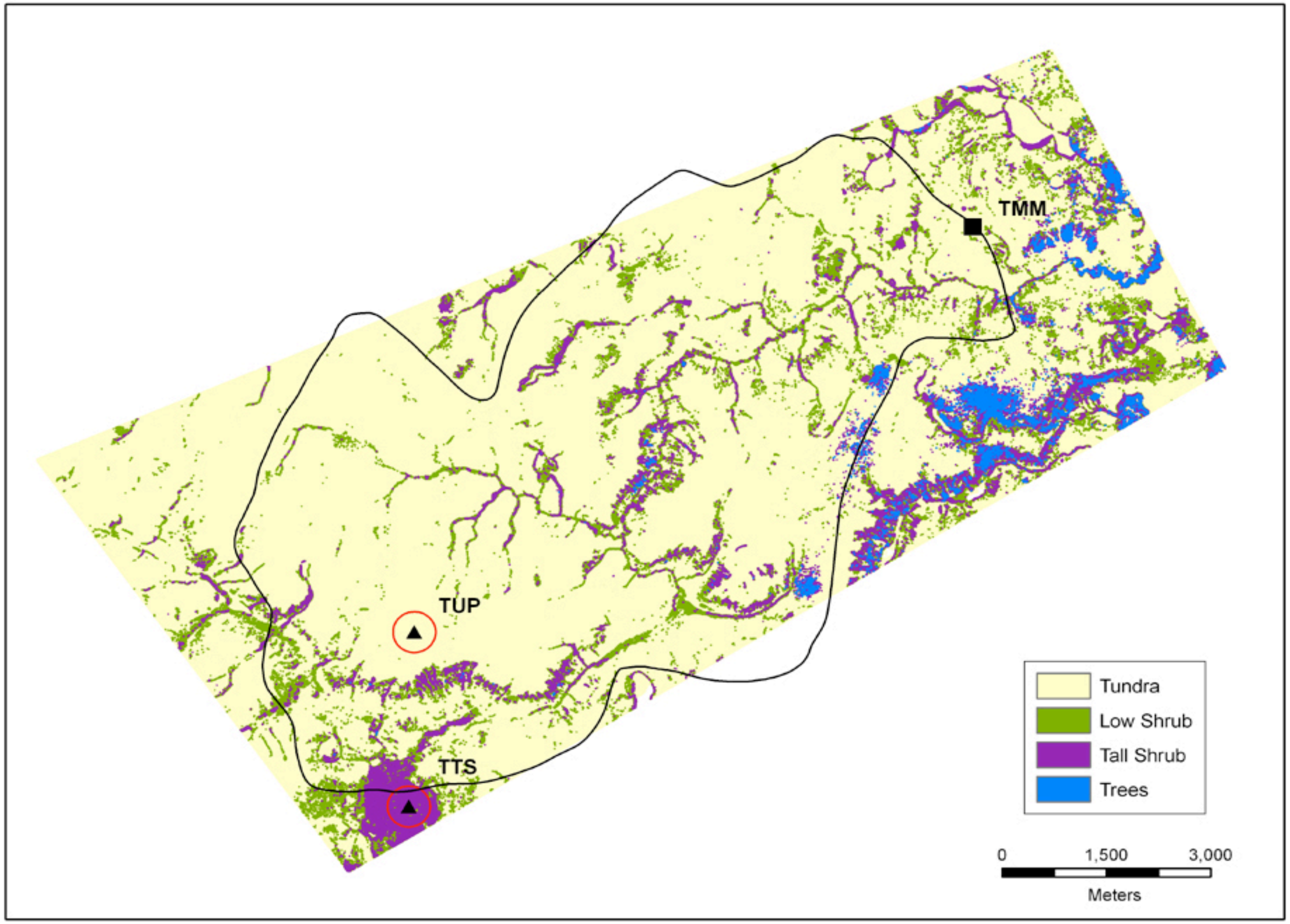



*The parameterization of the "undercanopy" resistance is critical because of uncertainty and high sensitivity*

# 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)

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

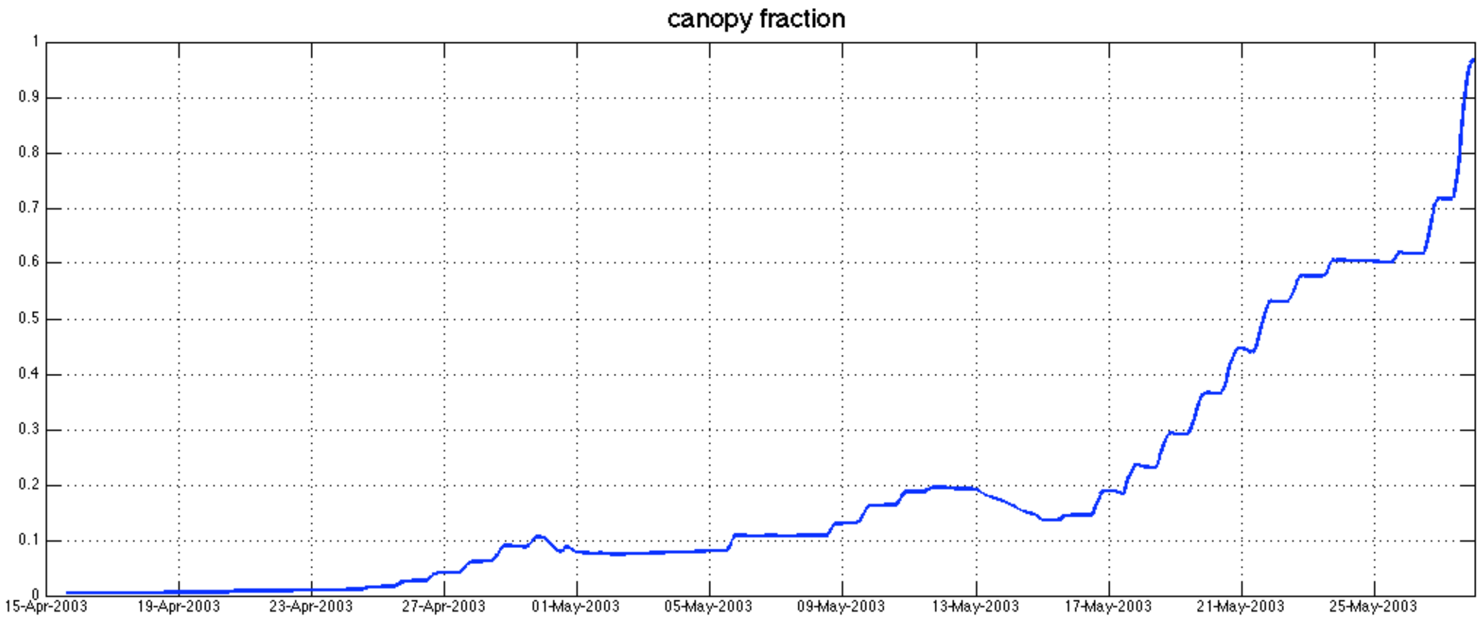
$f_c$= canopy fraction

$D_{snB}$ = 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**

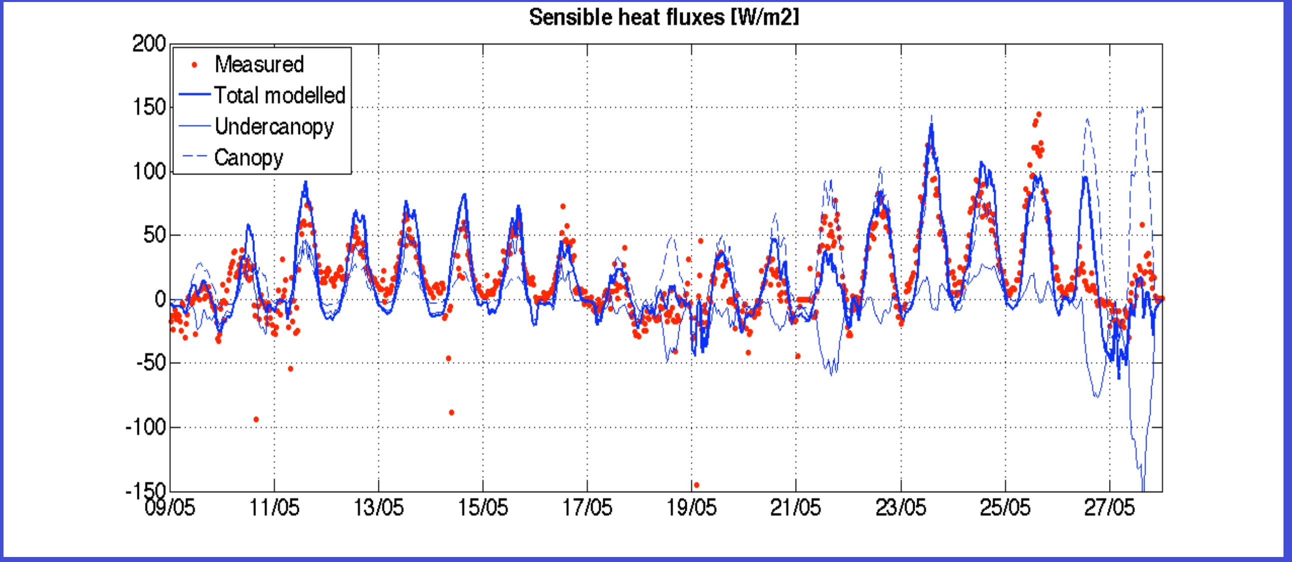
In the snow melt period, when *the snow depth ($D_{sn}$) becomes smaller than $D_{snB}$, the shrubs are considered to gradually emerge from the snow cover*

# Turbulent fluxes at shrubs and open tundra sites

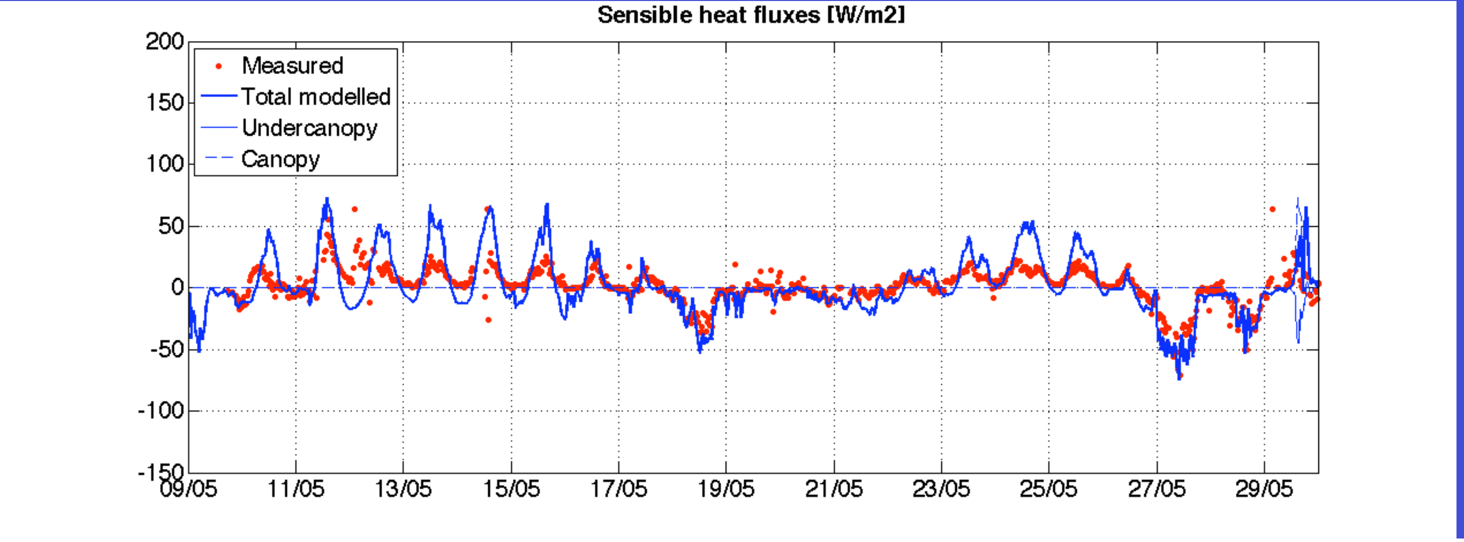


# Turbulent fluxes at shrubs and open tundra sites

DURING MELTING




TTS
Shrub
Tundra

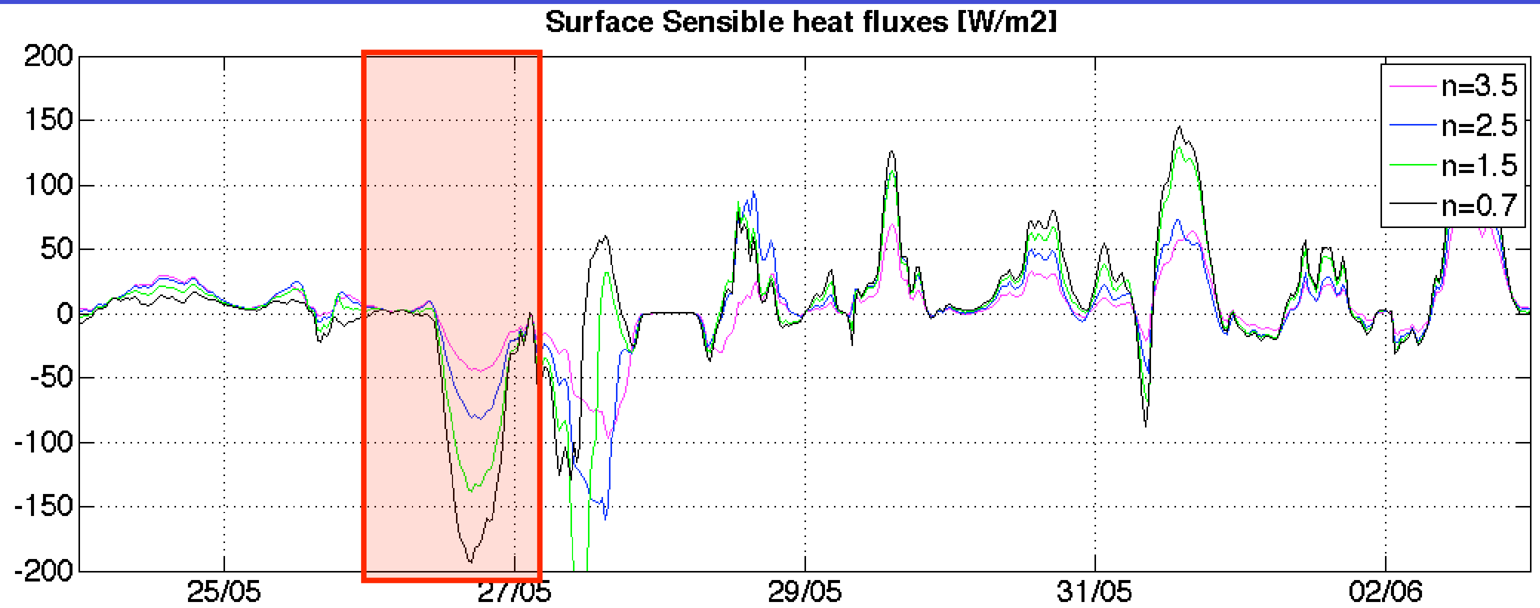



TUP
Open
Tundra

# Turbulent fluxes at shrubs and open tundra sites

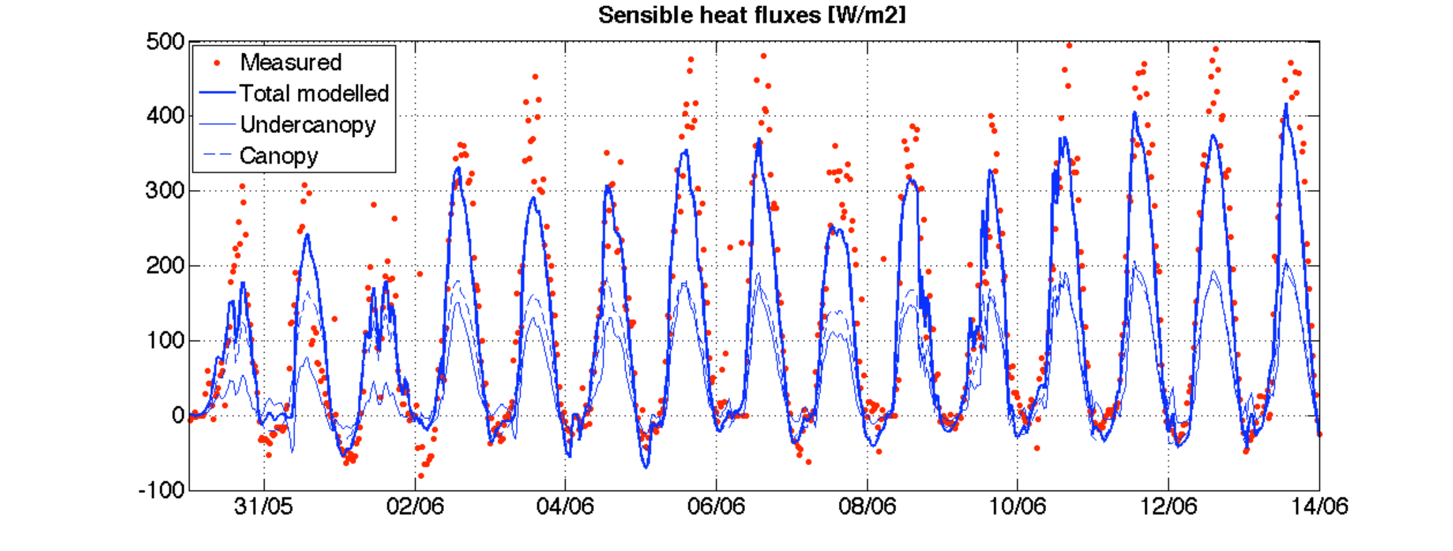
- Despite the reduction in the wind speed, the shrubs increase the contribution of sensible heat to the surface energy balance and decrease the heat losses - good agreement observations - results
- This of of great importance in snowmelt acceleration is shrubs tundra
- The results depend much on the parameterization of the undercanopy resistance. Stable stratifications may occur in the canopy reducing the turbulence exchange.

# Turbulent fluxes at shrubs and open tundra sites

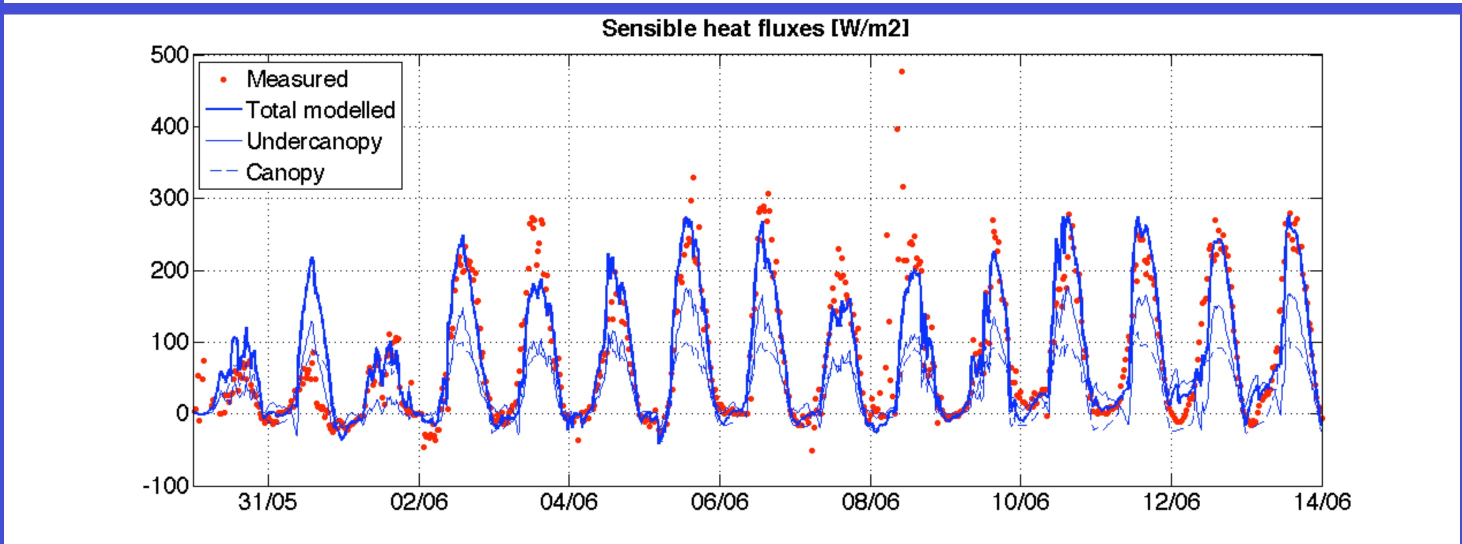


# Turbulent fluxes at shrubs and open tundra sites

AFTER MELTING




TTS
Shrub
Tundra




TUP
Open
Tundra

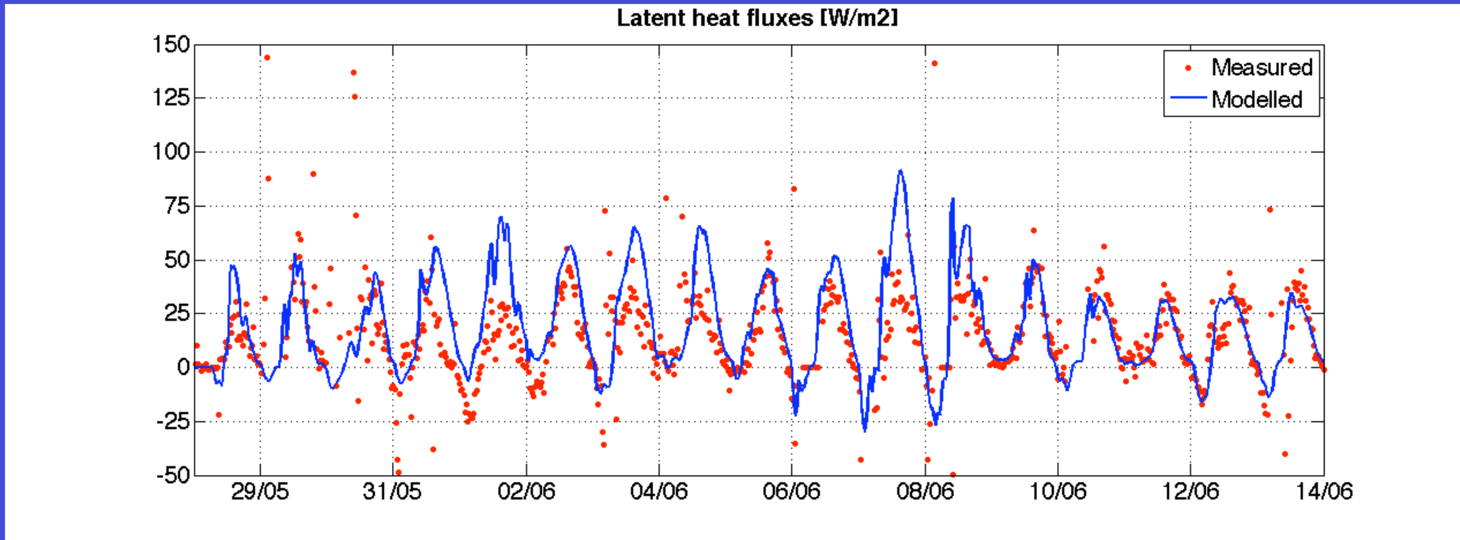
# Turbulent fluxes at shrubs and open tundra sites

- 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)

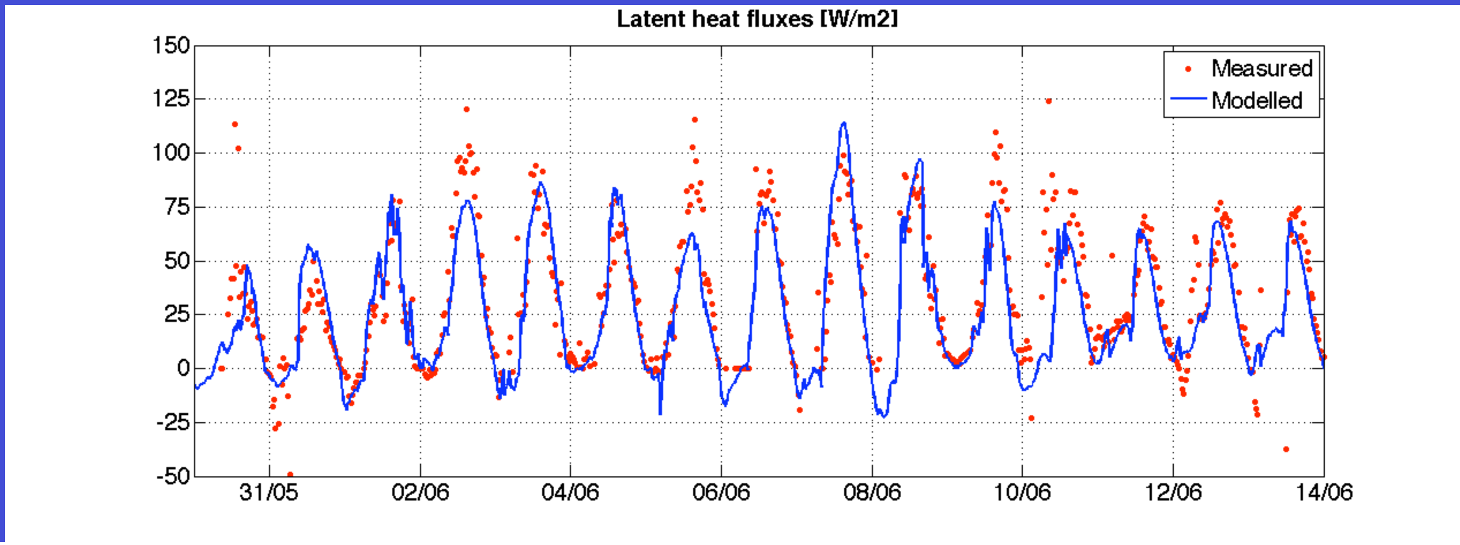
# Turbulent fluxes at shrubs and open tundra sites

LE

AFTER MELTING

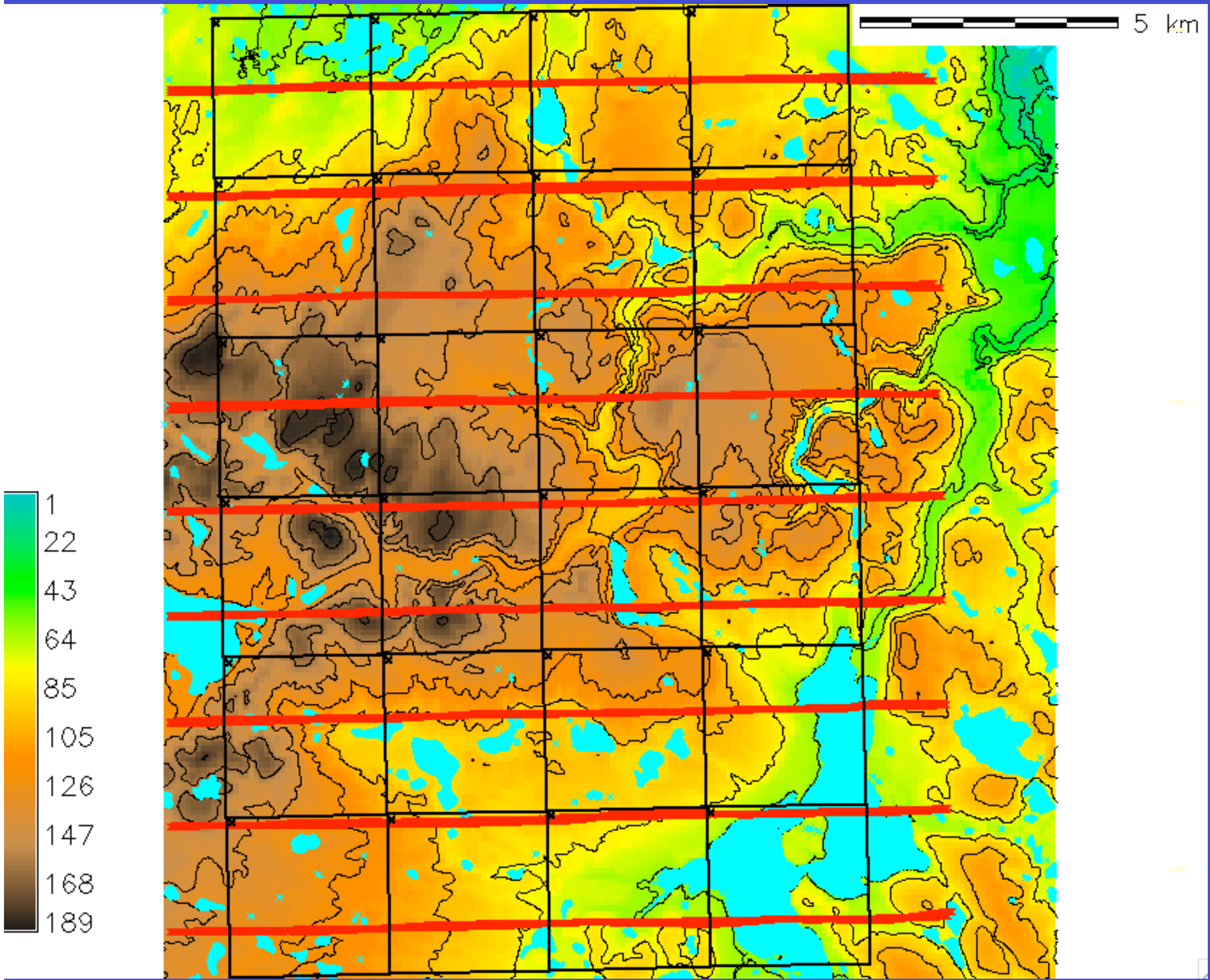



TTS
Shrub
Tundra




TUP
Open
Tundra

# Spatial variability of turbulent fluxes



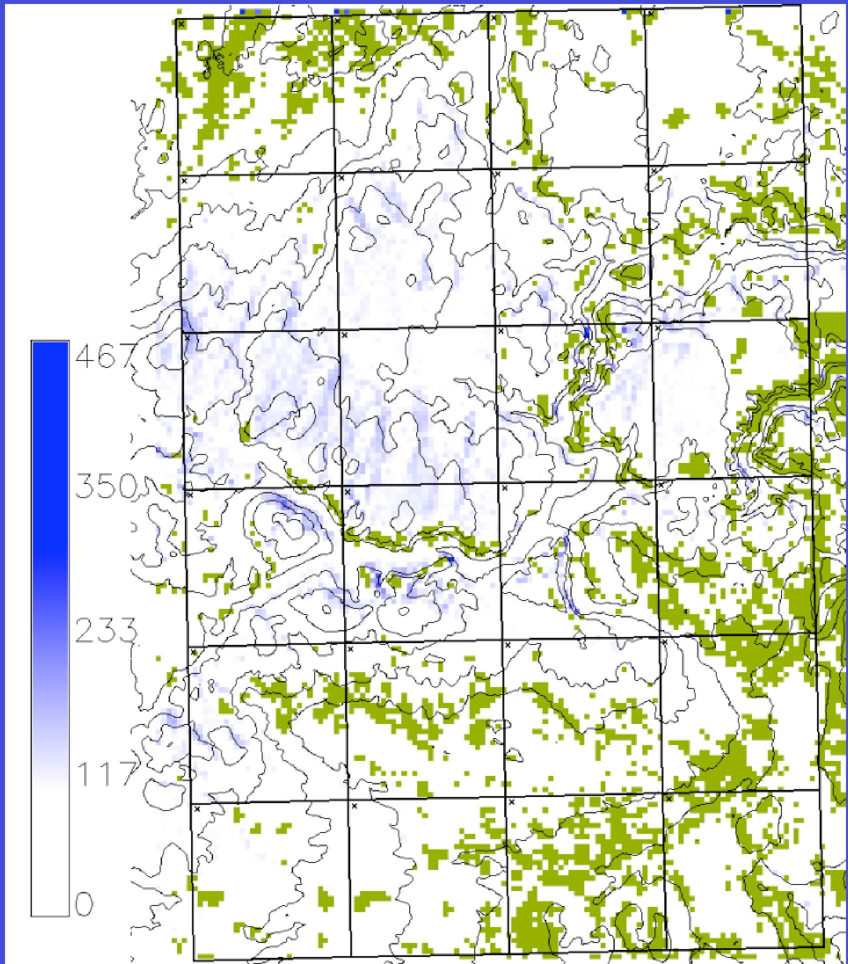

Data from NRCC **Twin Otter** aircraft carrying EC sensor during the 1999 melting season

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

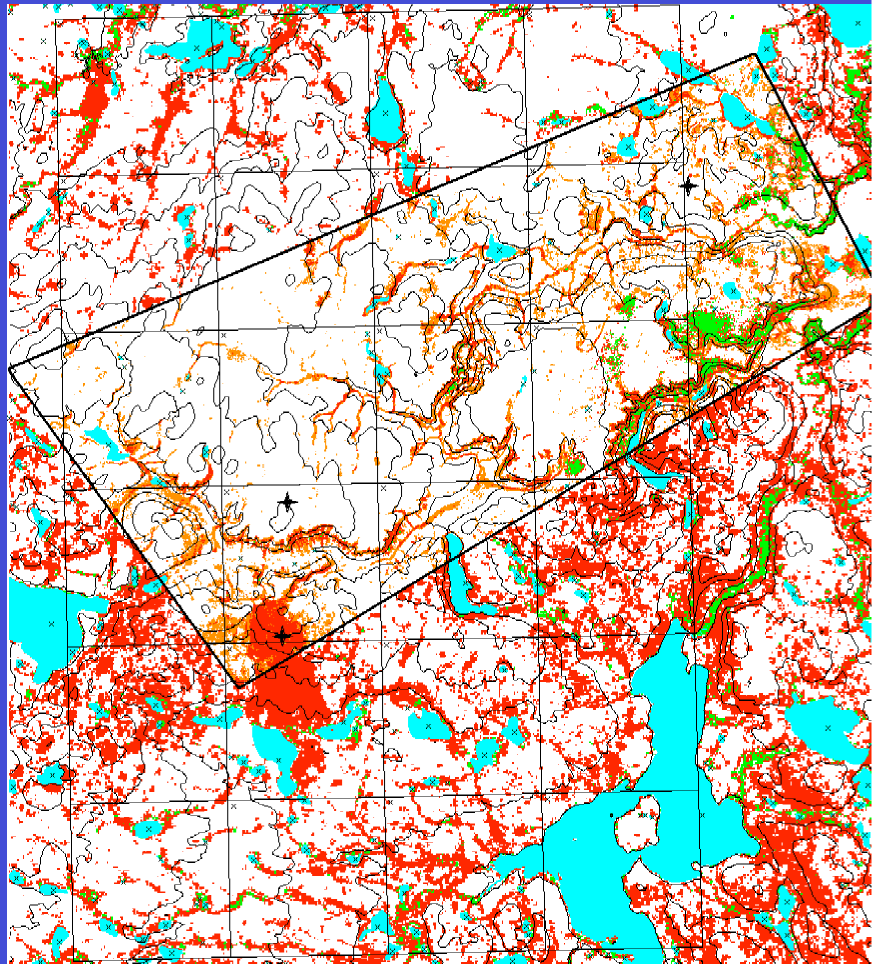
Maps for 4 days (**<u>27 May</u>** - 1 Jun - 3 Jun - 8 Jun)

# Spatial variability of turbulent fluxes

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

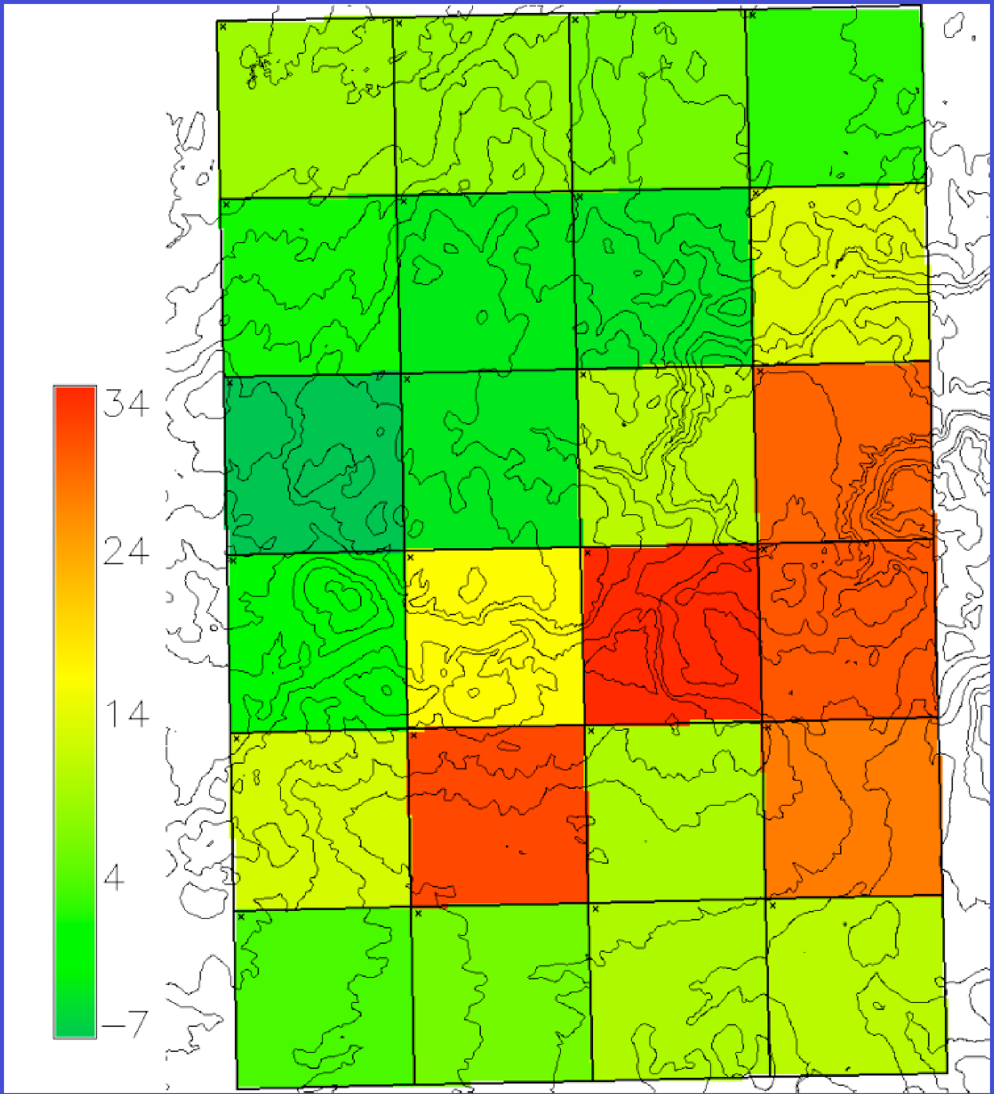



Land cover:
Tundra (white) - Shrubs (yellow) - Forest (green) - Lakes (cyan) - No data (red)

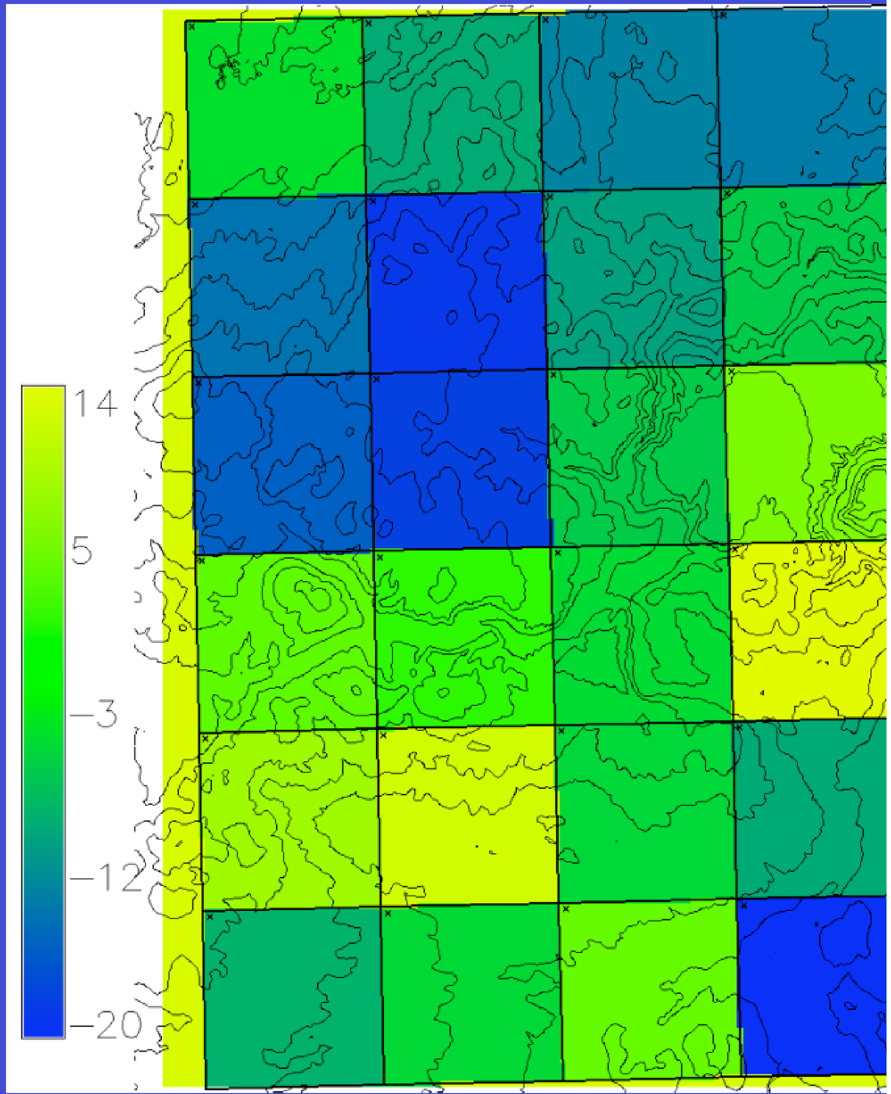


# Spatial variability of turbulent fluxes

From aircraft

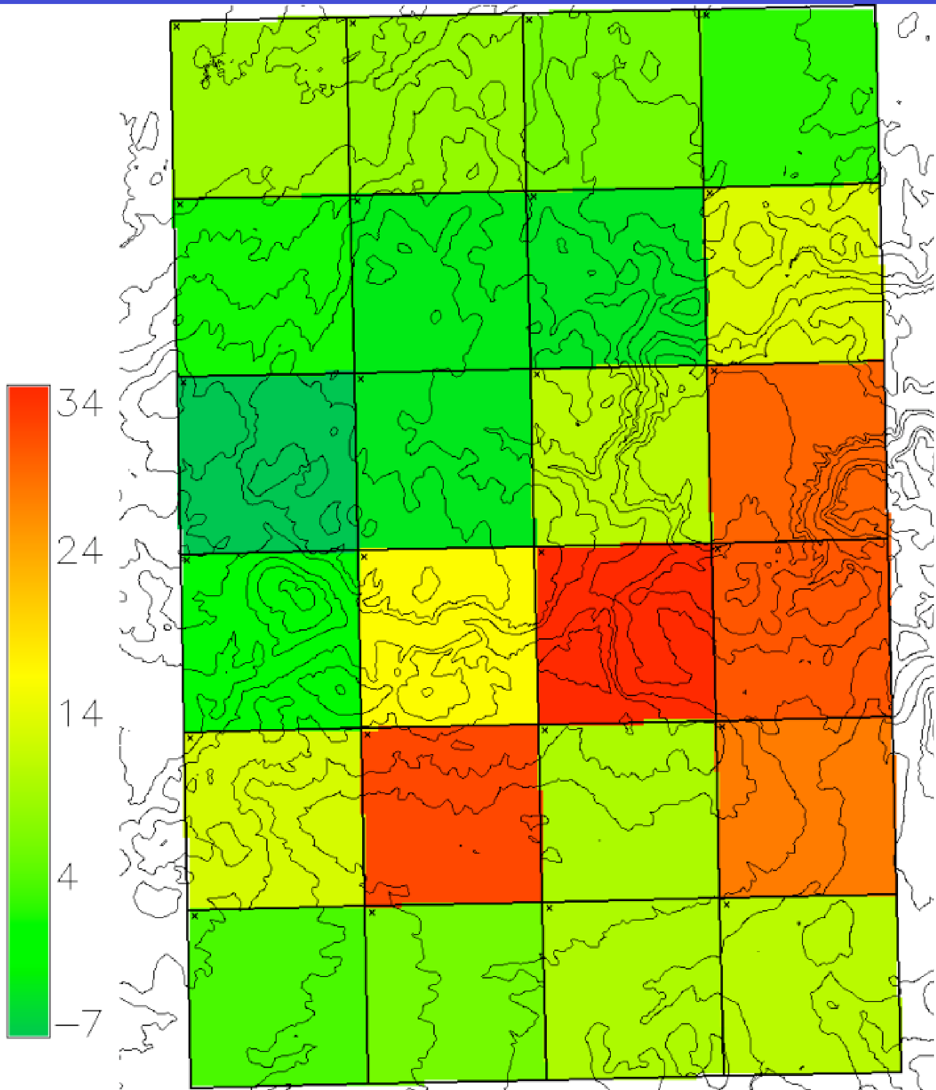


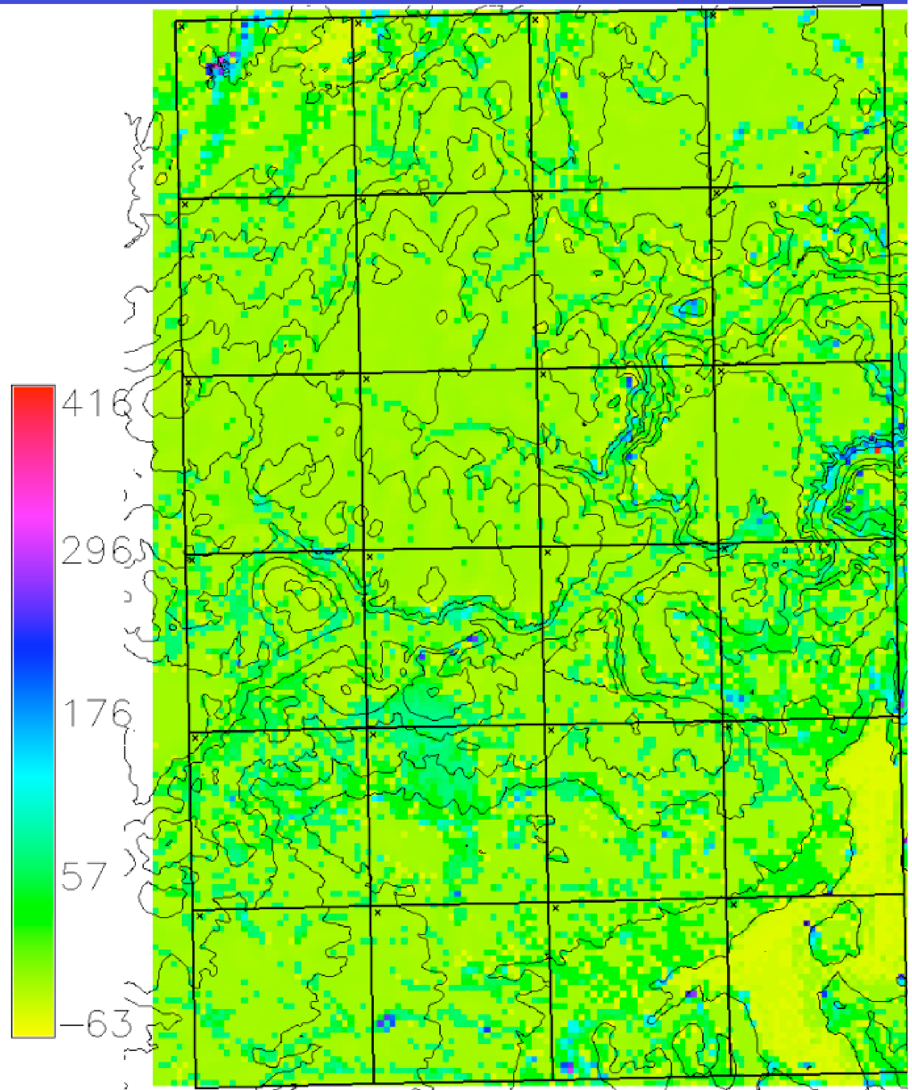

Modelled



# Spatial variability of turbulent fluxes

From aircraft 27th May 1999 modelled



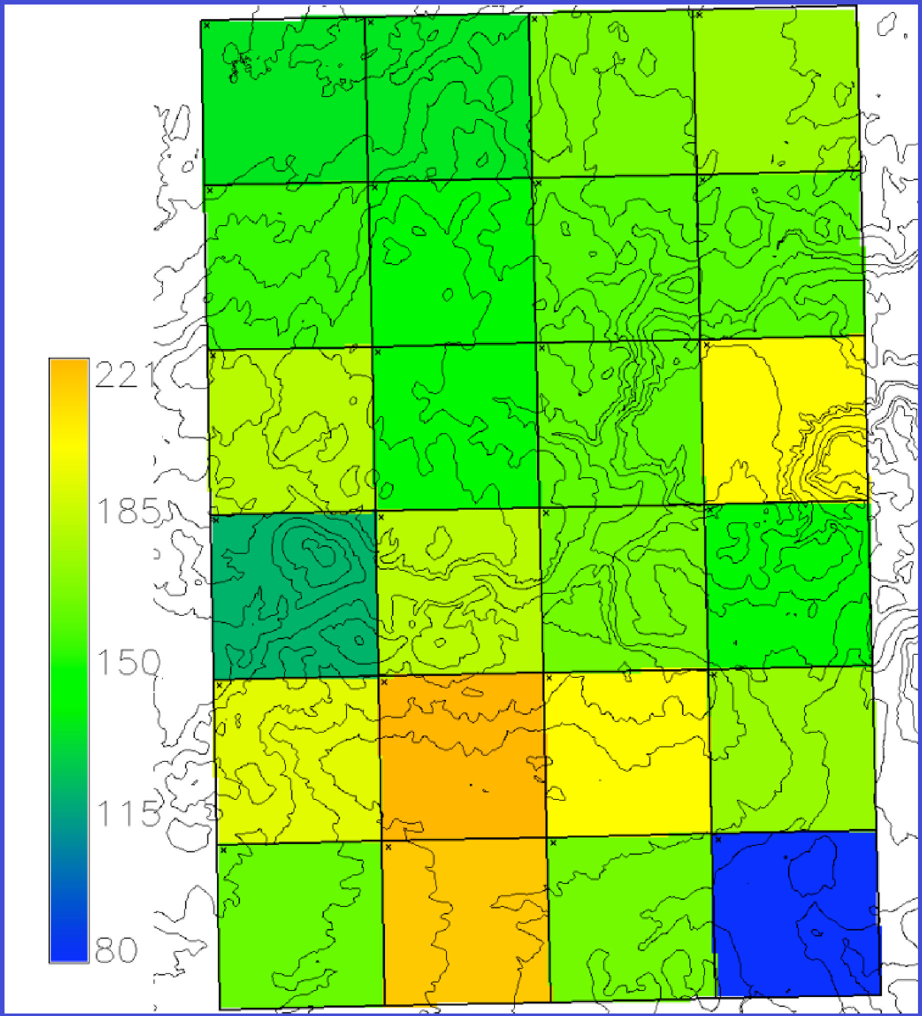



# Spatial variability of turbulent fluxes

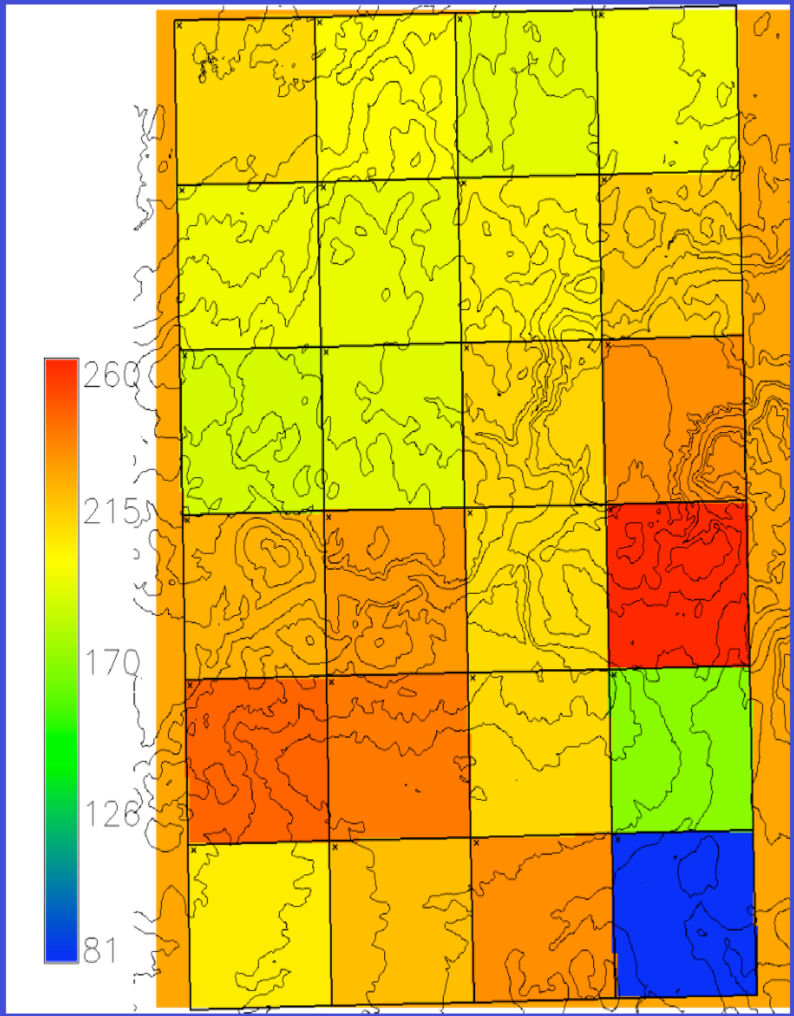
8th June 1999

H

From aircraft




Modelled

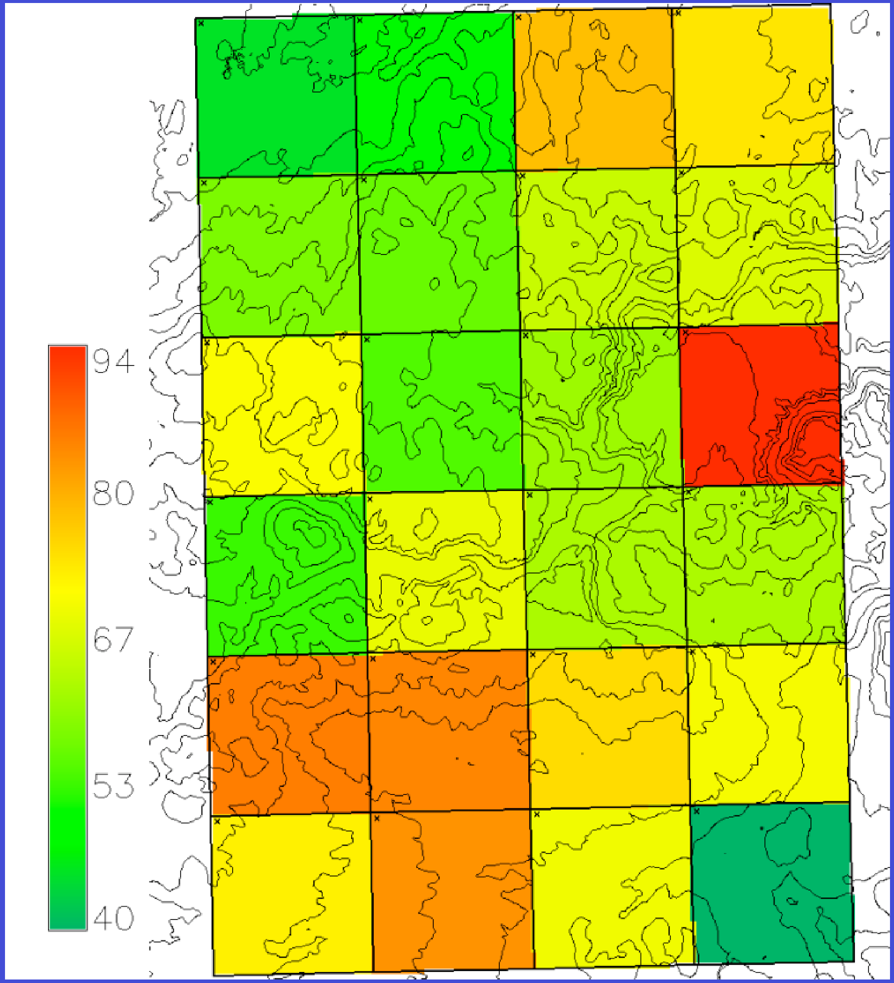


# Spatial variability of turbulent fluxes

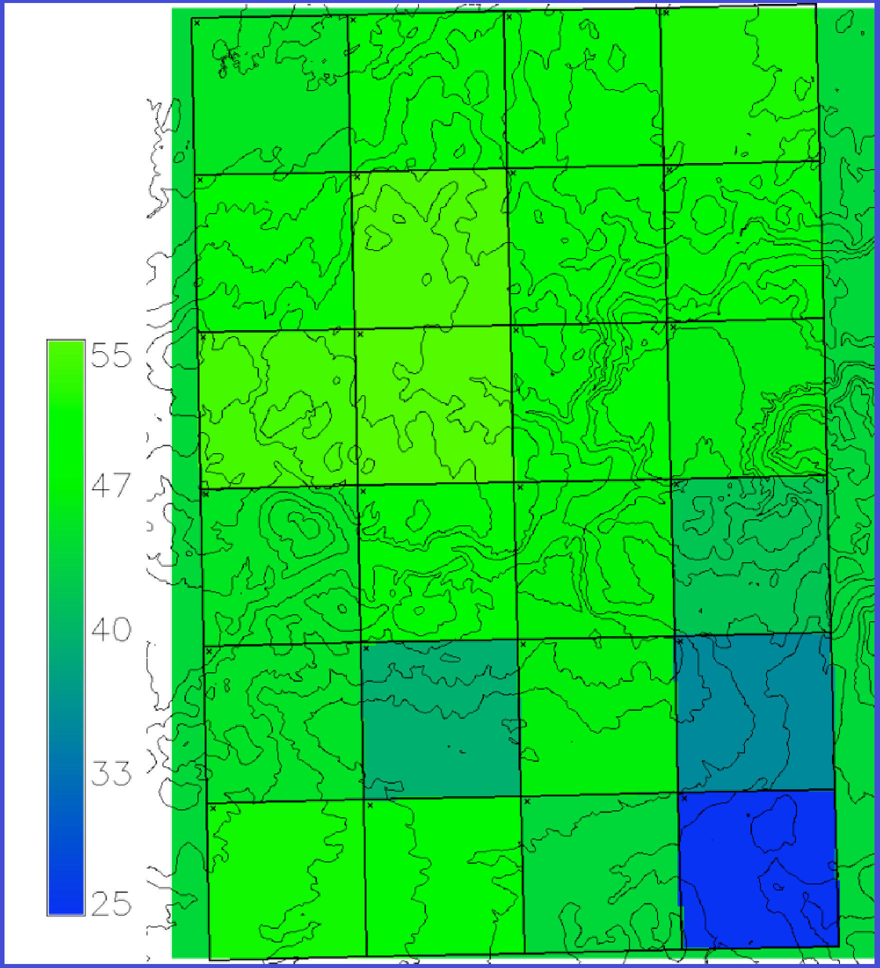
8th June 1999

LE

From aircraft




Modelled



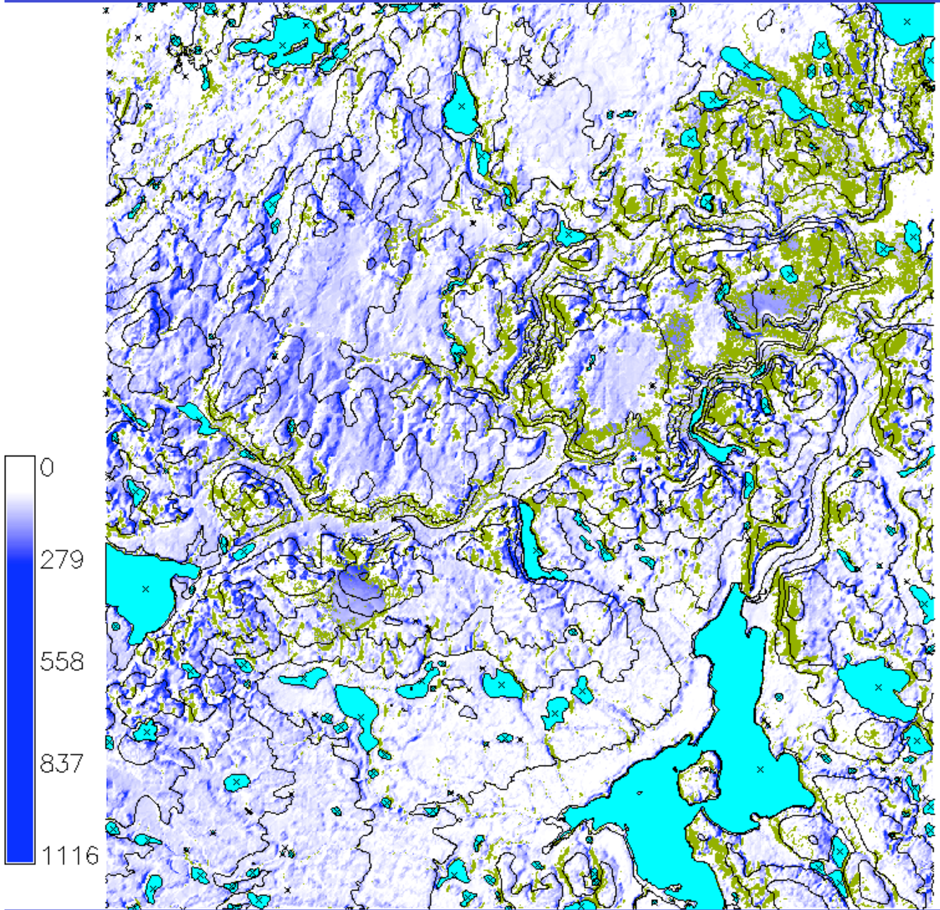
# Discussion

- 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?

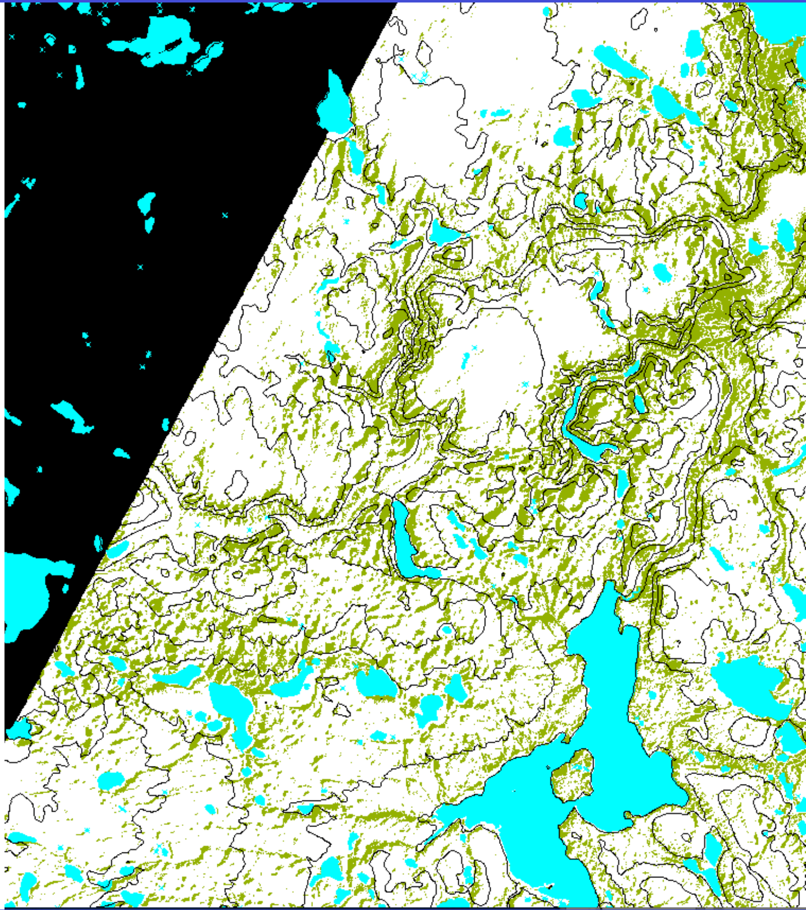
# Snow spatial variability

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