Modelling the Spatial Variability of Snowmelt Energy Balance and Meltwater Runoff in an Arctic Catchment

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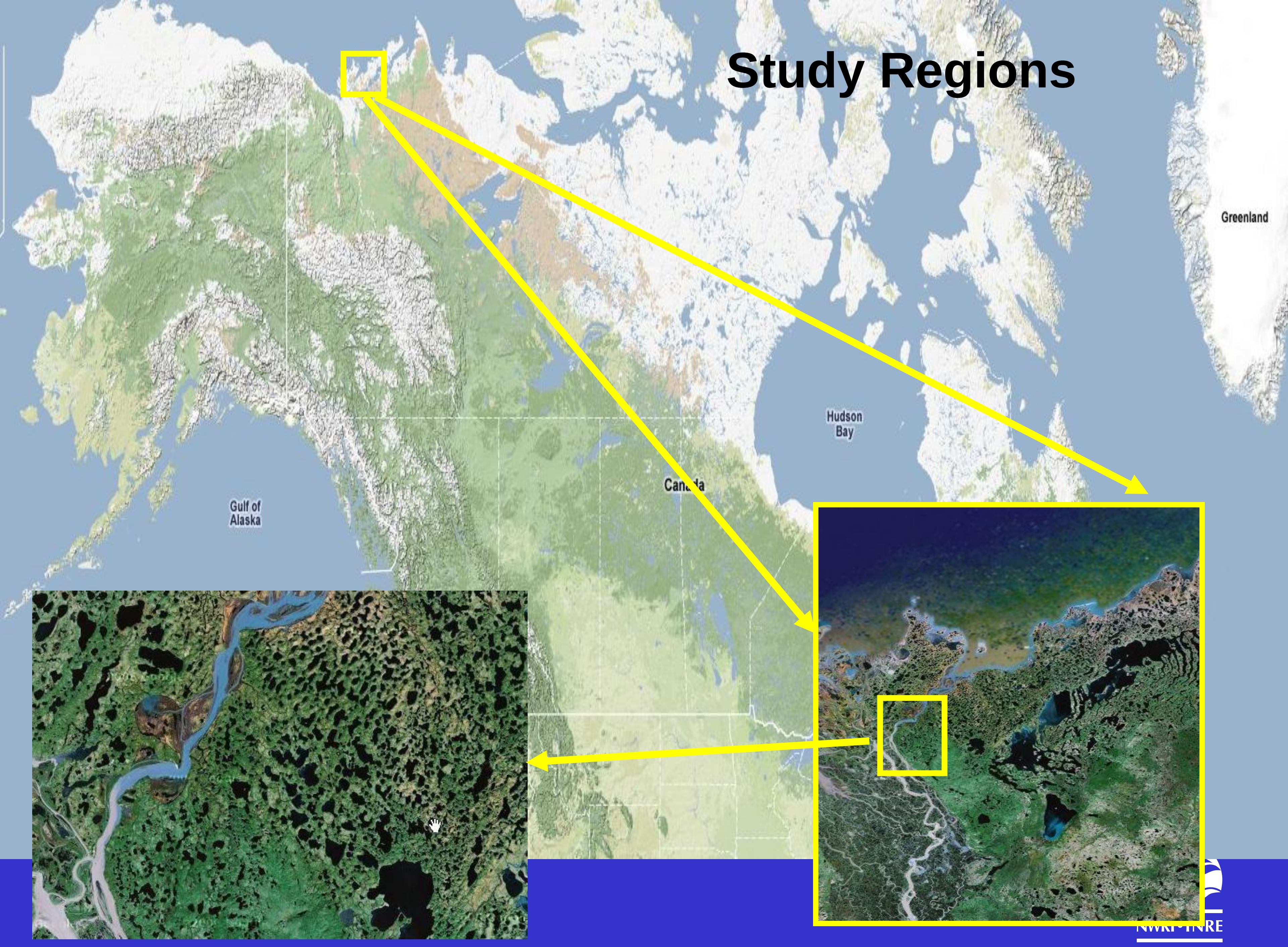
Outline of Talk

- Introduction
- Study Site
- Model Overview
- Model Validation and Results
- Introduction of Approaches to Handle Spatial Variability in Snow Melt in the Model
- Analysis of the Impact on Model Results
- Conclusions

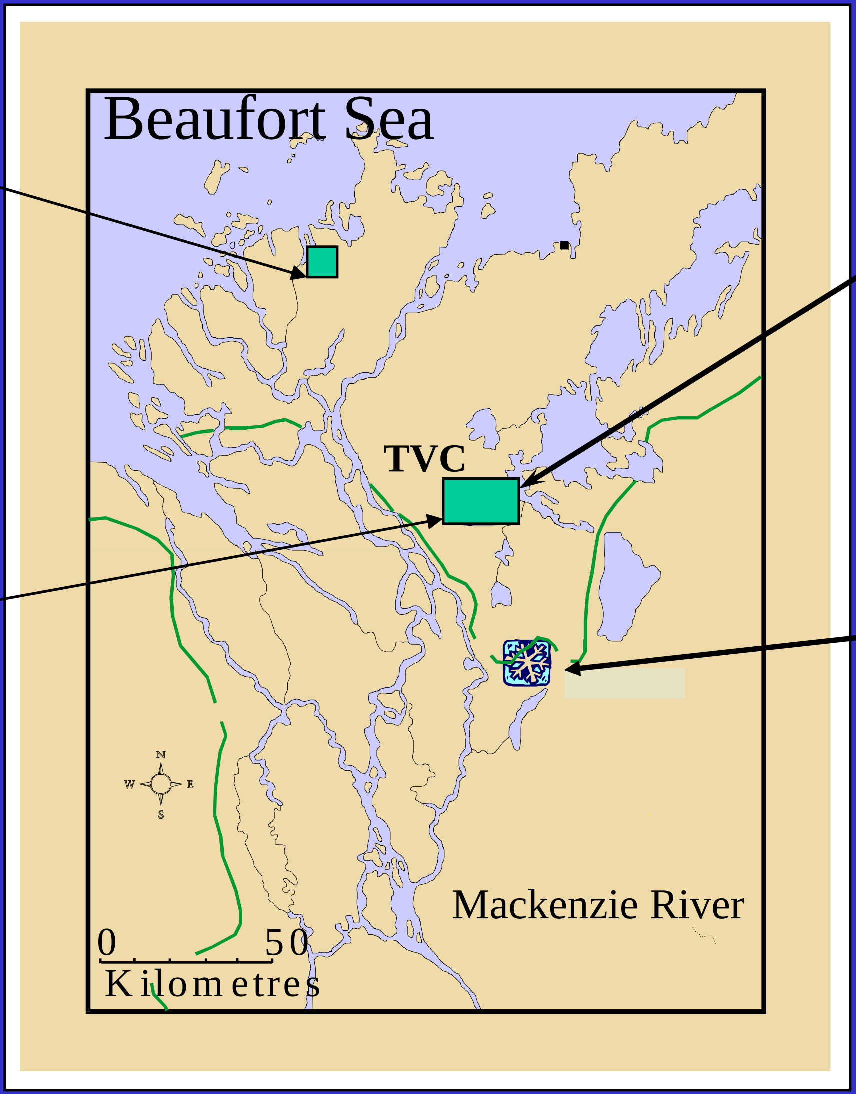
Study Outline

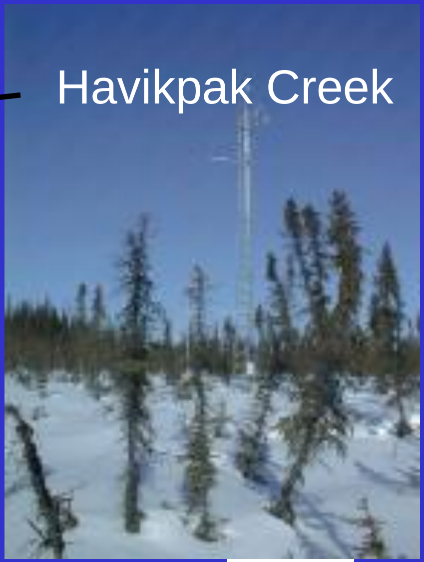
- The coupled hydrologic model – land surface scheme MESH (formerly WATCLASS) is applied at an arctic basin with continuous permafrost
- Model performance is evaluated against observed runoff, snow cover, and surface energy balance factors
- Problem areas of the model are be identified
- Approaches of including the spatial variability in snow cover and surface energy balance factors will be tested and their impact on the model results will be quantified

Study Regions

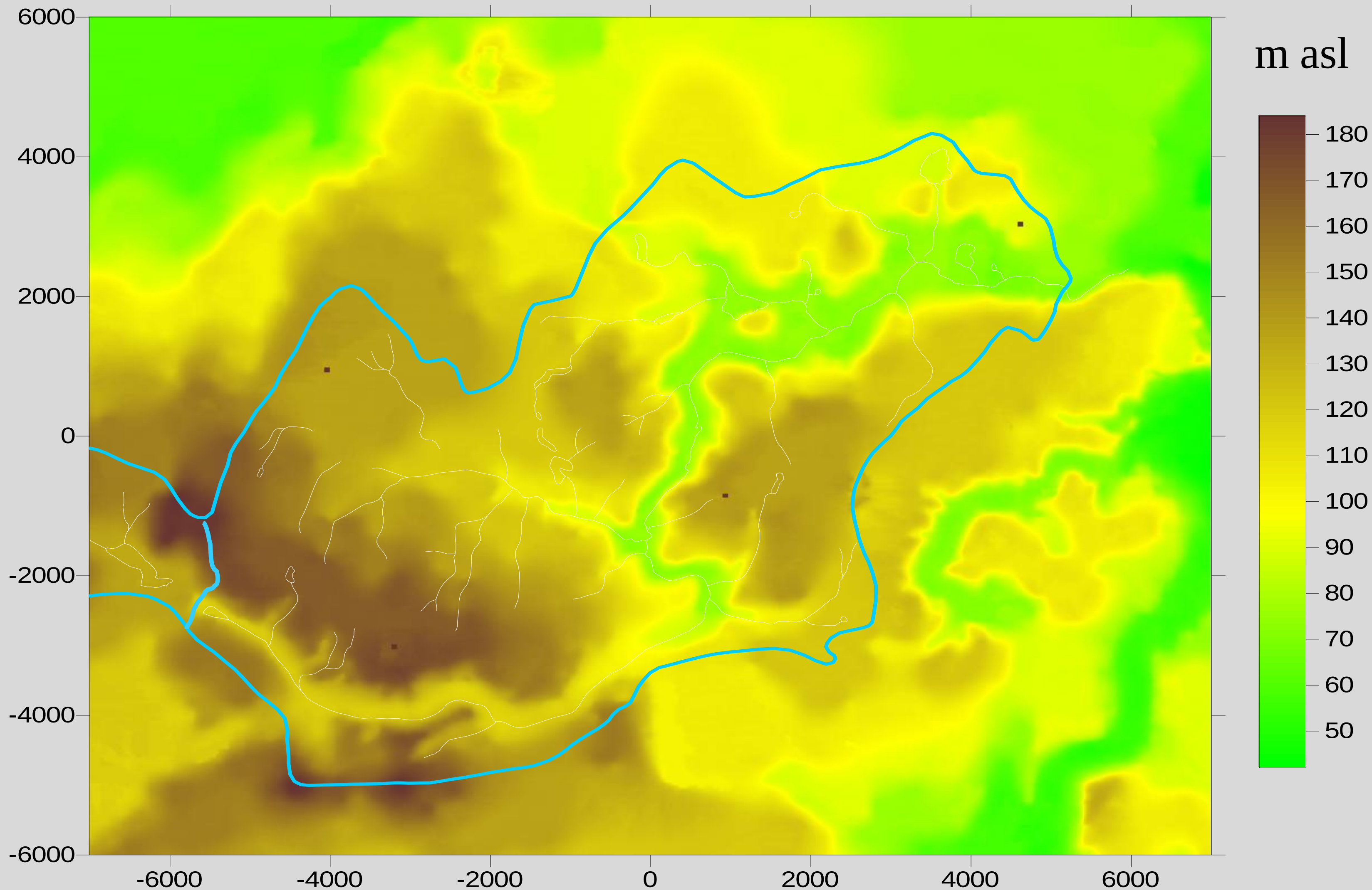


Study Basins





TVC Topography



Basin Area: 55 km^2

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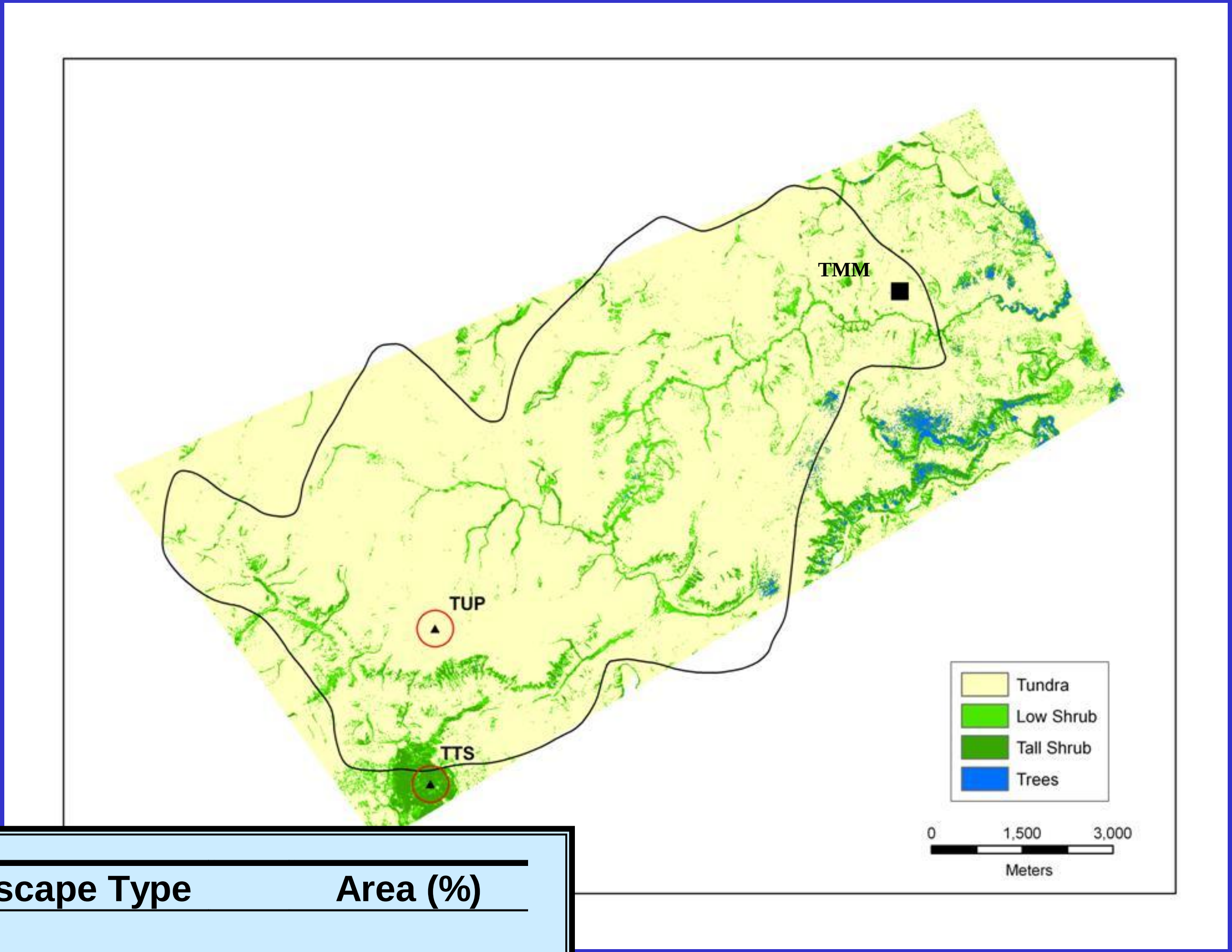
Trail Valley Creek Land Cover



Landscape Type	Area (%)
Tundra	71
Shrub Tundra	24
Forest	2
Water	3

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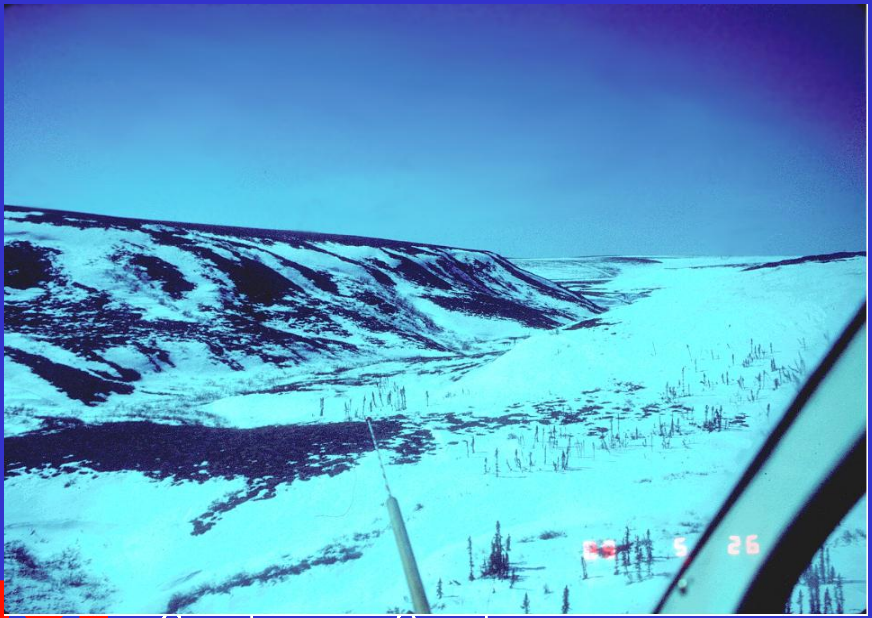
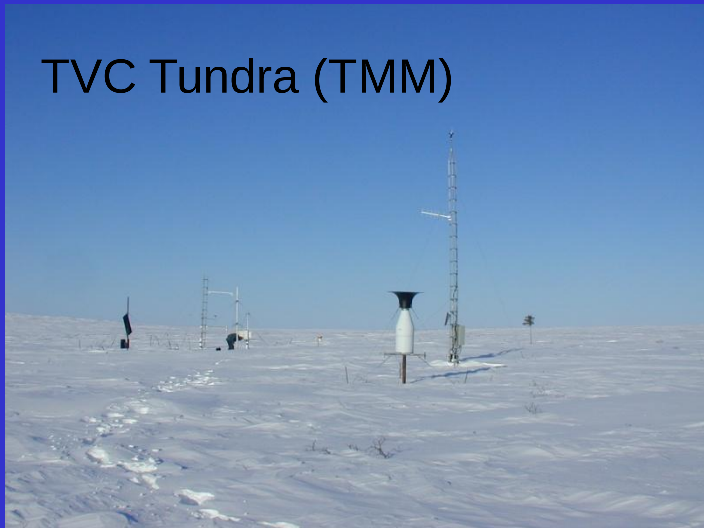
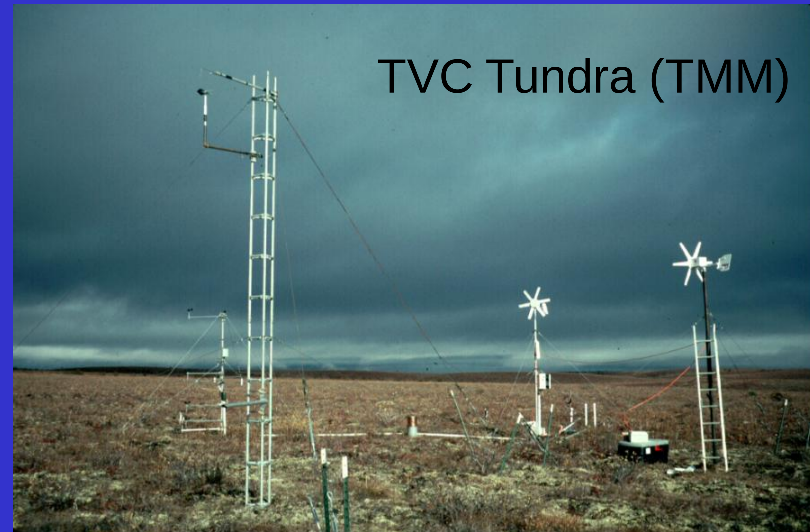
Topography



Vegetation





Measured Variables:

- **Air Temperature**
- **Humidity**
- **Wind speed and direction**
- **Eddy Correlation**
- **Long and short wave radiation**
- **Snow depth**
- **Total Precipitation**
- **Soil moisture and - temperature**

Snow Surveys

- Land cover dependent end-of-winter snow surveys measuring snow depth, density and snow water equivalent are carried out each spring

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The Coupled Hydrologic Model – Land Surface Scheme MESH (WATCLASS)

- MESH is a fully coupled model combining the hydrologic model (WATFLOOD) with the regional climate model (CLASS)
- The model uses “Grouped Response Units“ (GRUs) to simulate the spatial variability
- The model requires calibration

The MESH Modelling System

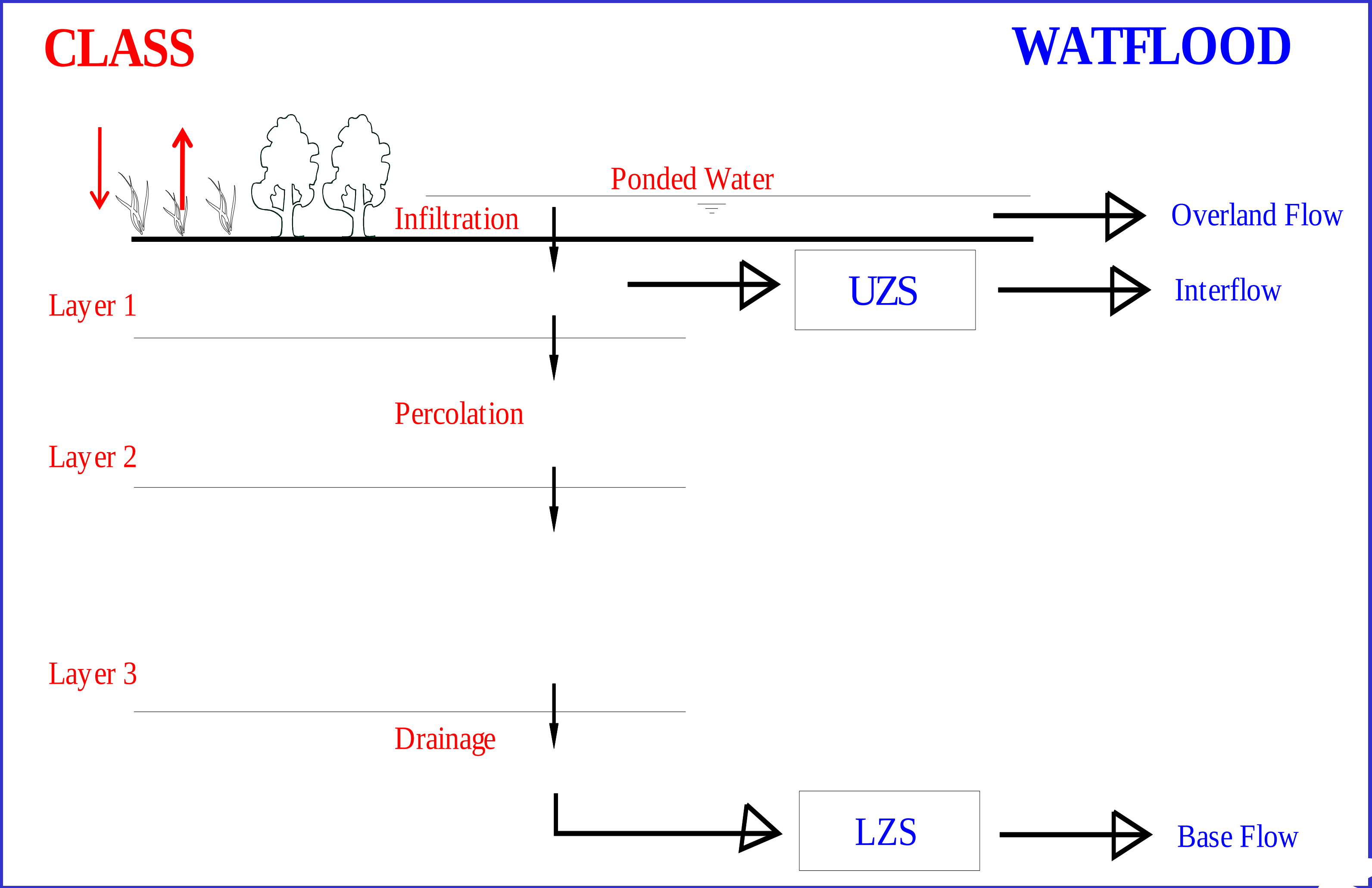
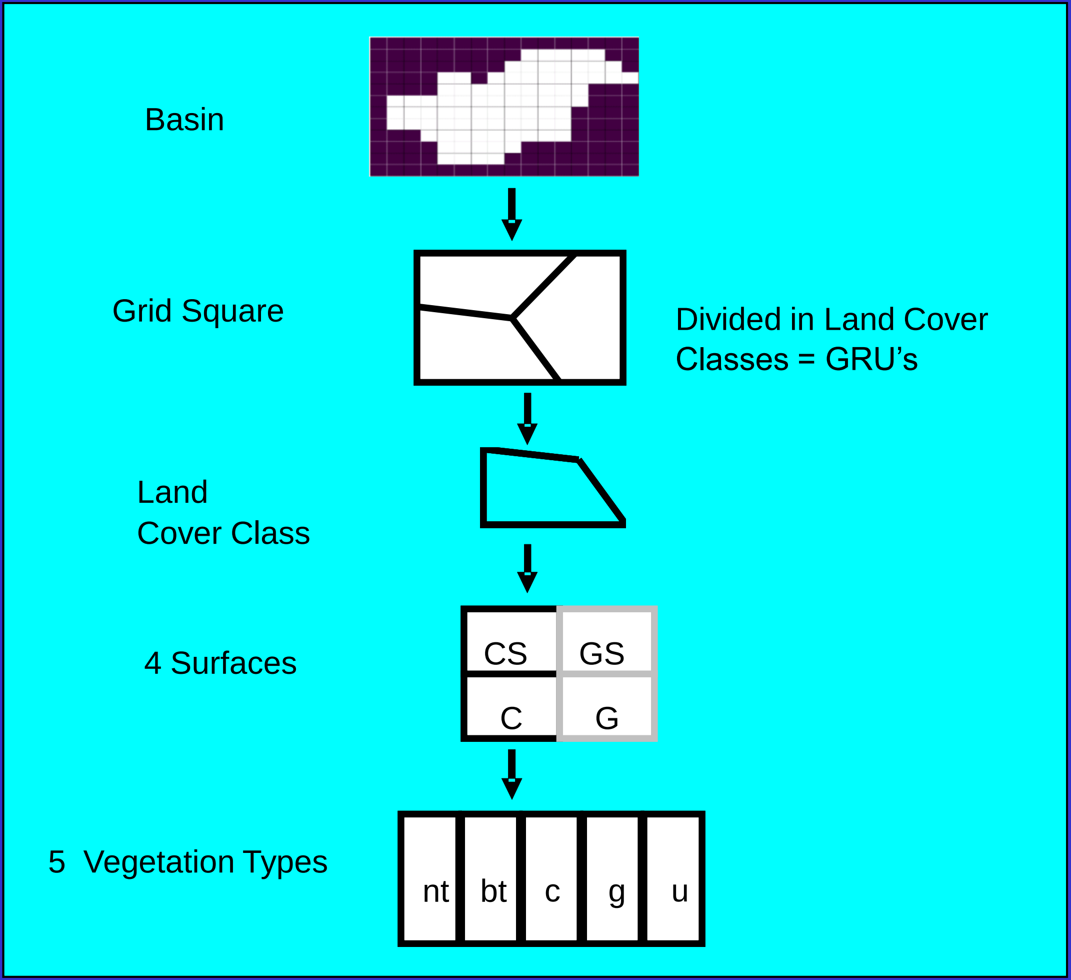


Figure: University of Waterloo

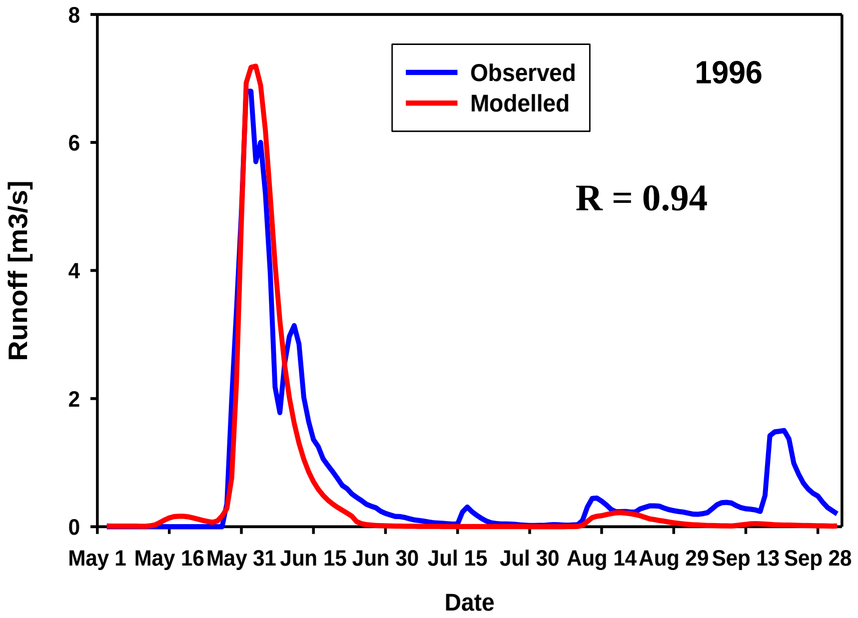
Spatial Variability in MESH

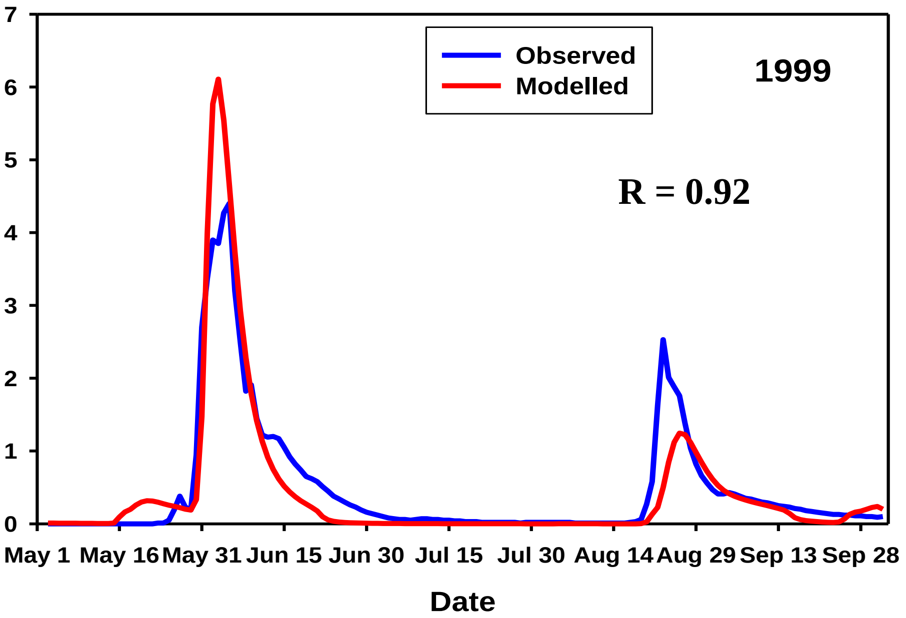


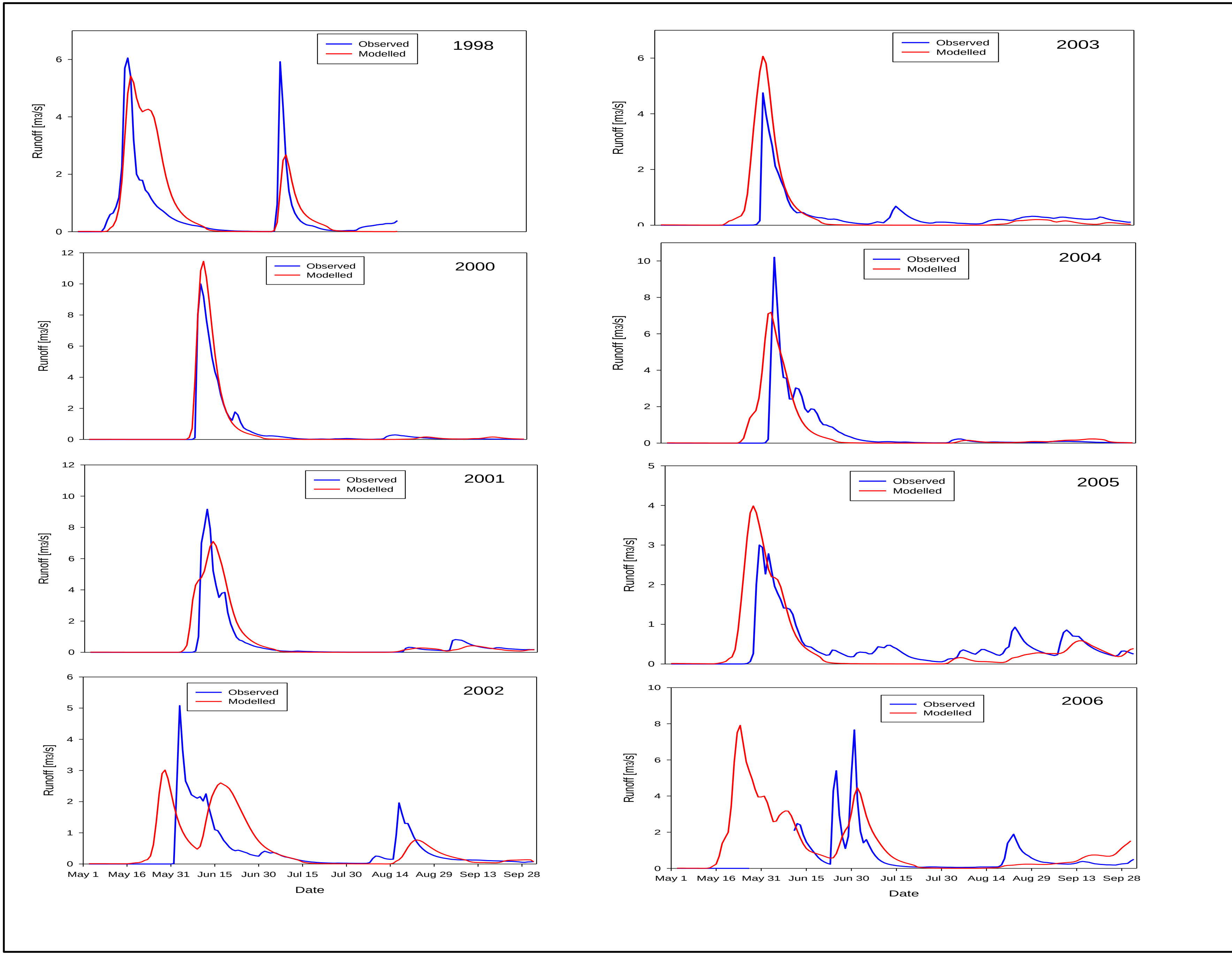
Model Runs

- MESH version 1.3 (released Aug 17, 2009) was run for TVC from 1996 to 2006
- Runs were conducted for each year from May 1st to Sep 30th
- Model was run at resolution of 1 km
- Initial base case runs were carried out using "traditional" vegetation based land cover classes tundra, shrub tundra, forest, water

Calibration Years





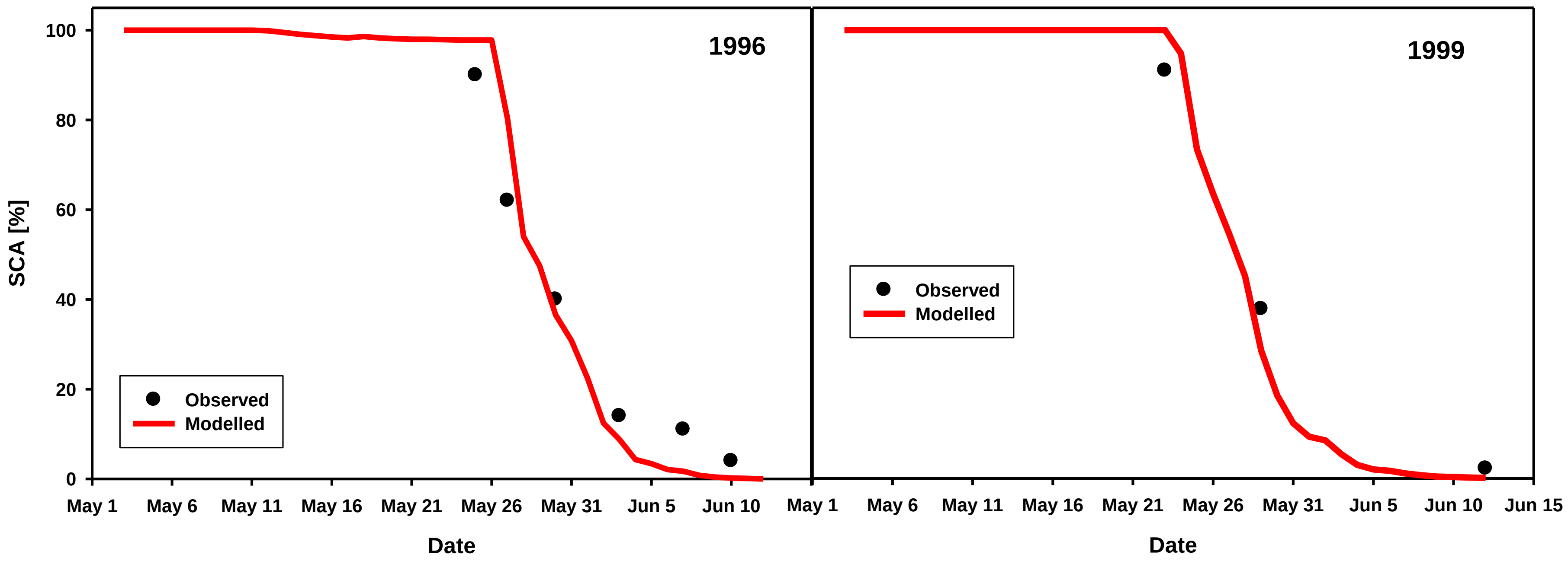


Observed
Modelled
1998
2000
2001
2002
2003
2004
2005
2006
Runoff [m3/s]
May 1
May 16
May 31
Jun 15
Jun 30
Jul 15
Jul 30
Aug 14
Aug 29
Sep 13
Sep 28
Date

Model Base Case Run Statistics

	Modelled Peak Volume %	Modelled Total Flow Volume %	Modelled Spring Flow Volume %	R
1996	106	72	94	0,94
1998	90	132	159	0,72
1999	139	89	102	0,92
2000	114	111	116	0,98
2001	79	122	134	0,86
2002	59	123	151	0,31
2003	128	124	186	0,77
2004	70	108	110	0,73
2005	133	99	144	0,66
AVG	102	109	133	0,77
AVG without Cal. Years	96	117	143	0,72

Basin Average SCA



Spatial Variability of Snow Cover (1999)

Day 141 May 21)

Day 147 (May 27)

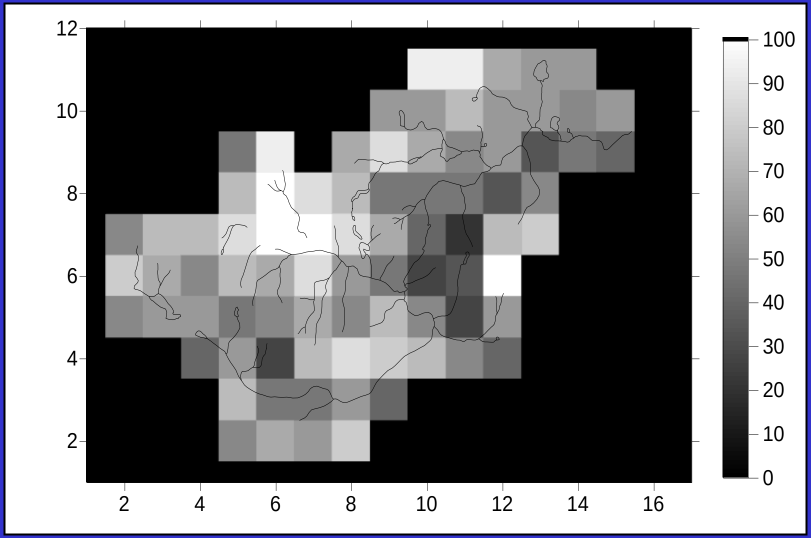
Day 154 (June 3)

Day 149 (May 29)

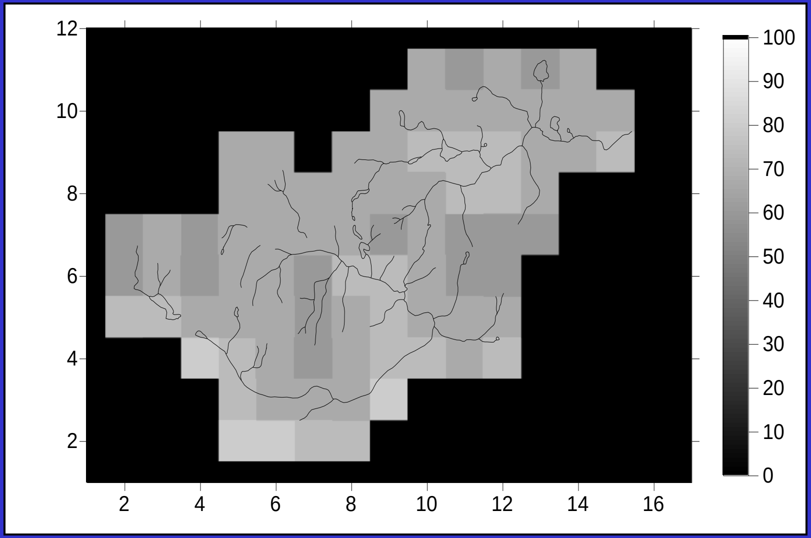
Day 159 (June 8)

Model Validation, Spatial Variability (SCA)

Observed



Simulated



May 25, 1996: SCA Mean = 62%
Range 24% - 99%

May 25, 1996: SCA Mean = 65%
Range 55% - 90%

Spatial Variability (SCA)

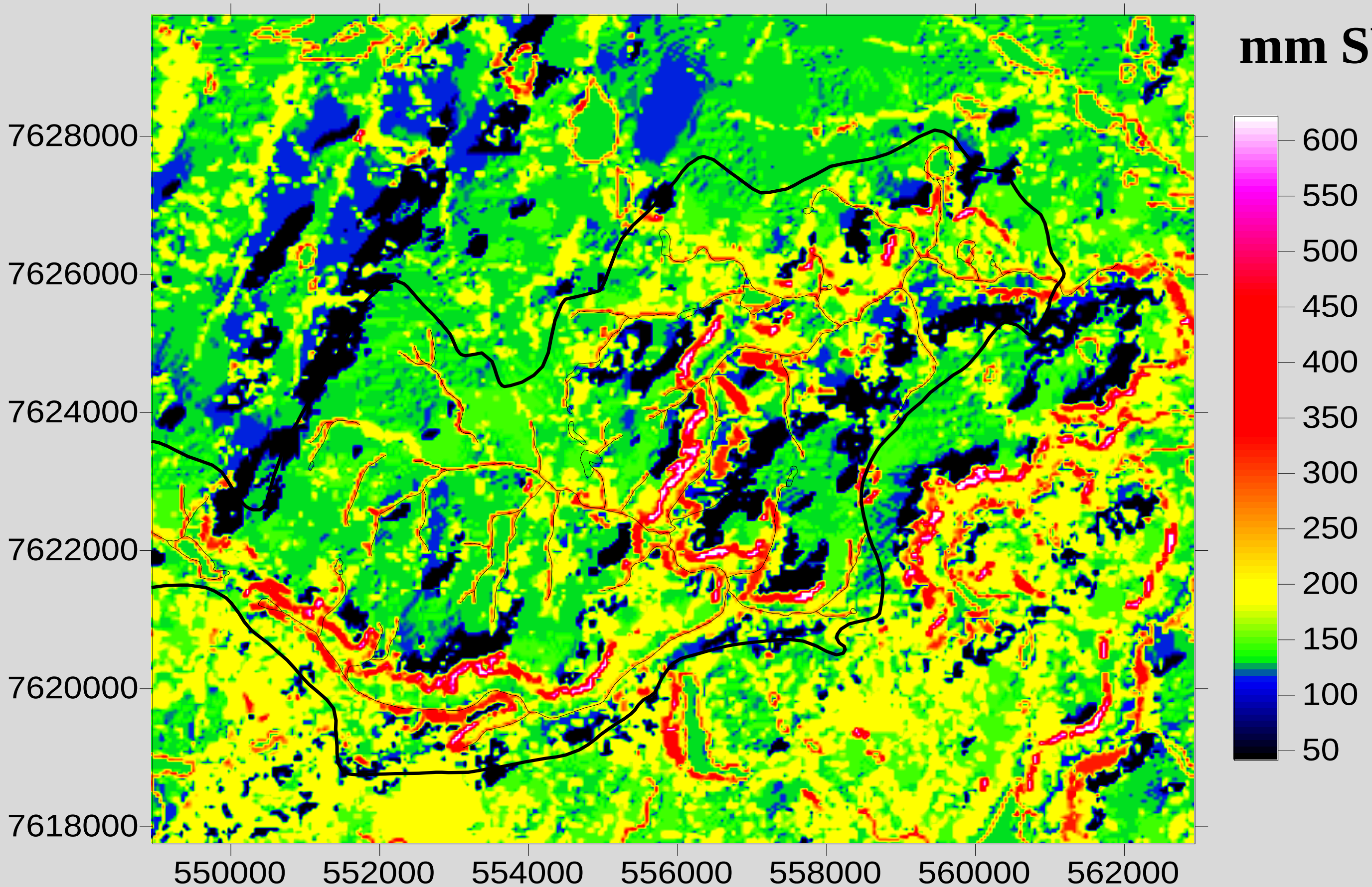
	Observed SCA				Modelled SCA			
Date	AVG %	Max %	Min %	Range %	AVG %	Max %	Min %	Range %
23-May	90	100	55	45	95	97	85	12
25-May	62	99	24	75	65	90	55	35
28-May	40	89	13	76	38	74	27	47
1-Jun	14	40	2	38	8	23	1	22
5-Jun	11	32	0	32	3	0	8	8
8-Jun	4	15	0	15	0	0	0	0

Spatial Variability of End of Winter Snow Cover

- Spatial variability of SCA during melt is underpredicted by the model
- Naturally occurring spatial variability can be attributed to two factors:

  - Spatially variable end of winter snow cover mainly due to blowing snow processes
  - Spatial variability in the snowmelt energy balance factors

End of Winter Snowcover for 1999



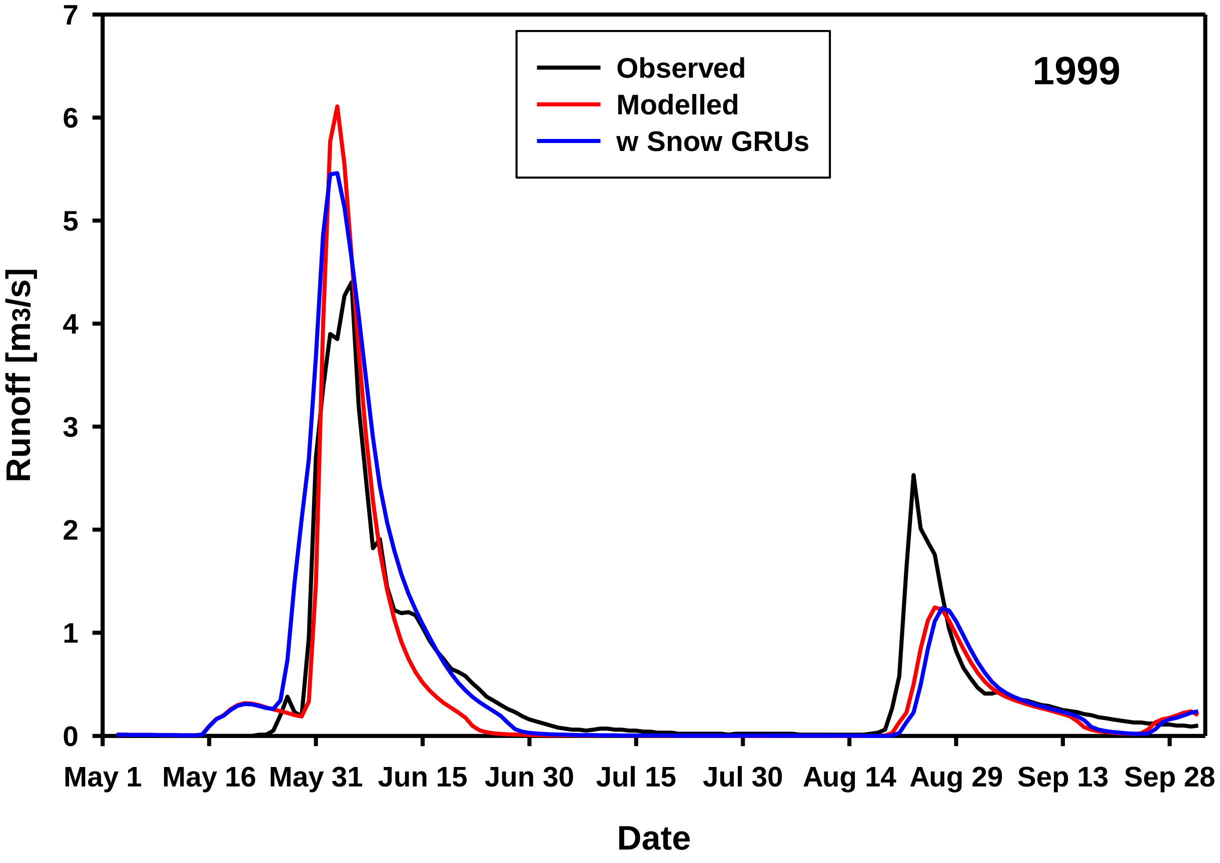
Mean:197 mm

Changes to MESH Runs

- Additional topography based land classes (Snow GRU's); windswept tundra and snow drifts; were added to the existing classes to improve the representation of the end-of-winter snowcover

Modeled Runoff with Snow GRUs

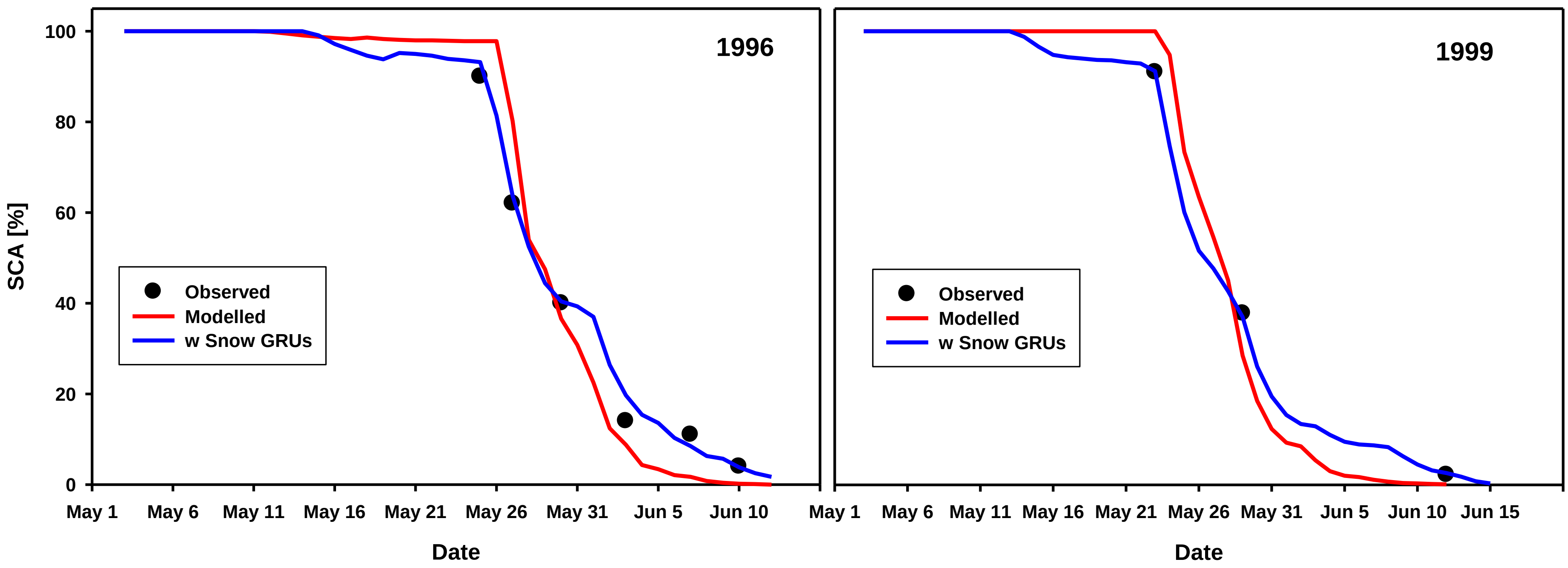
- Extra runoff in the early and receding part of the snowmelt peak, lower peak flow



Model Statistics with Snow GRUs

	Modelled Peak Volume %	Modelled Peak Volume with Snow GRUs %	Modelled Total Flow Volume %	Modelled Total Flow Volume with Snow GRUs %	Modelled Spring Flow Volume %	Modelled Spring Flow Volume with Snow GRUs %	R	R with Snow GRUs
1996	106	66	72	69	94	88	0,94	0,93
1998	90	83	132	139	159	168	0,72	0,68
1999	139	124	89	113	102	138	0,92	0,91
2000	114	90	111	121	116	125	0,98	0,96
2001	79	79	122	128	134	140	0,86	0,83
2002	59	76	123	150	151	192	0,31	0,4
2003	128	124	124	147	186	225	0,77	0,81
2004	70	65	108	126	110	129	0,73	0,74
2005	133	111	99	104	144	153	0,66	0,71
AVG	102	91	109	122	133	151	0,77	0,77
AVG without Cal Years	96	90	117	131	143	162	0,72	0,73

Basin Average SCA with Snow GRUs



Spatial Variability (SCA) with Snow GRUs (1996)

	Observed SCA		Modelled SCA		Modelled SCA with Snow GRUs	
Date	AVG	Range	AVG	Range	AVG	Range
	%	%	%	%	%	%
23-May	90	45	95	12	91	16
25-May	62	75	65	35	62	49
28-May	40	76	38	47	40	60
1-Jun	14	38	8	22	16	38
5-Jun	11	32	3	8	10	26
8-Jun	4	15	0	0	4	14

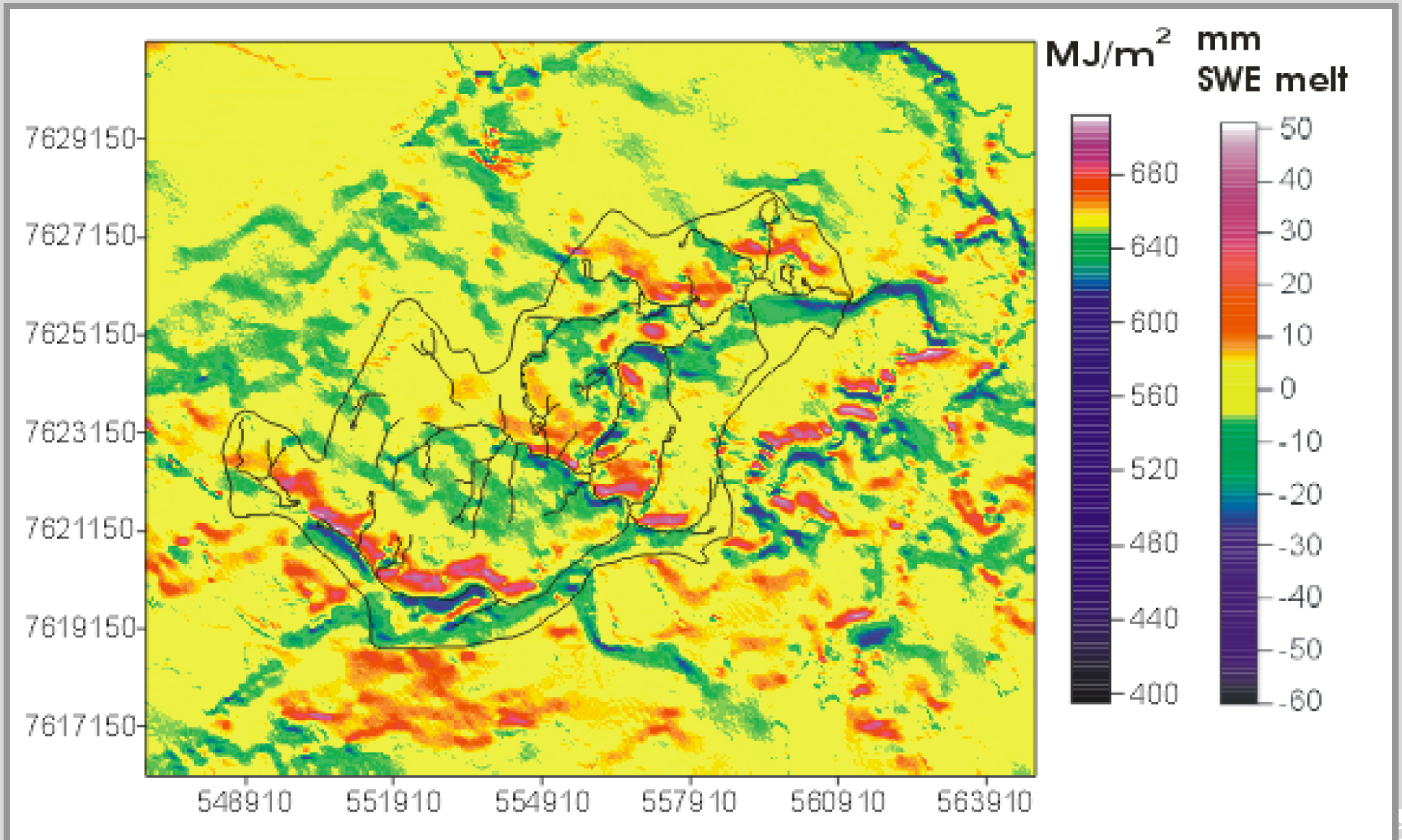
Results When Including Snow GRUs

- MESH simulation results of basin runoff did not change significantly
- Basin wide average SCA improved considerably
- Prediction of spatial variability of SCA is greatly improved

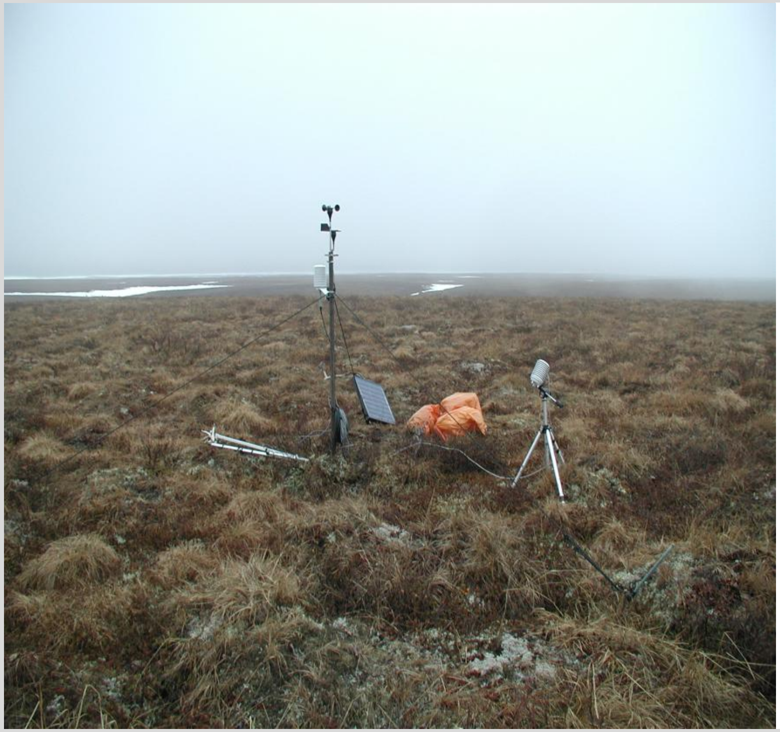
Spatial Variability in Snowmelt Energy Fluxes

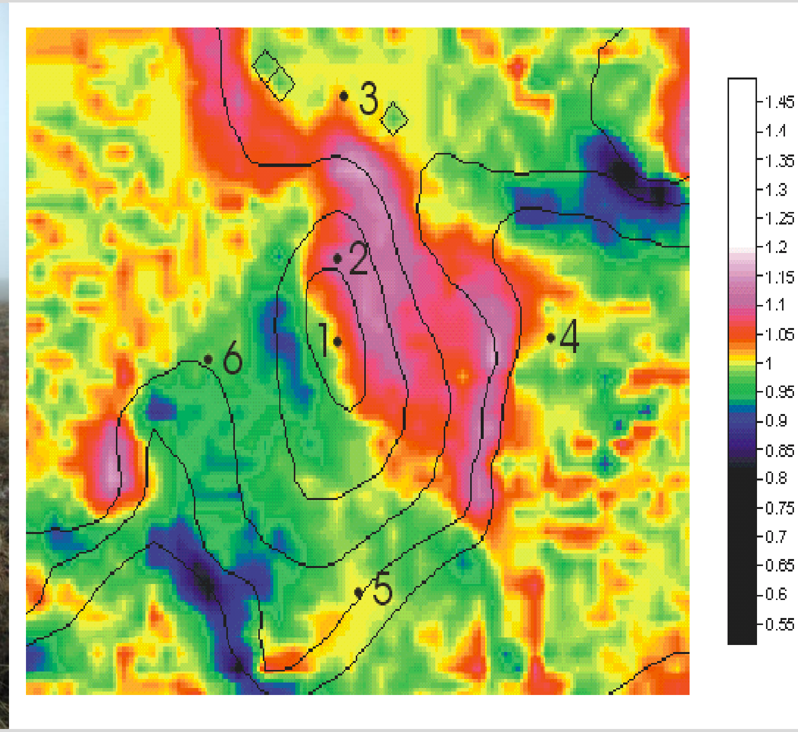
- Topography causes spatial variability in incident solar radiation and surface wind speeds
- Variable surface wind speeds lead to spatially distributed turbulent fluxes of sensible and latent heat
- Small scale (20 m) models were used to simulate these spatially variable surface energy fluxes

Accumulated Incident Solar Radiation for Spring 1999 (37 days)



Wind Experiment

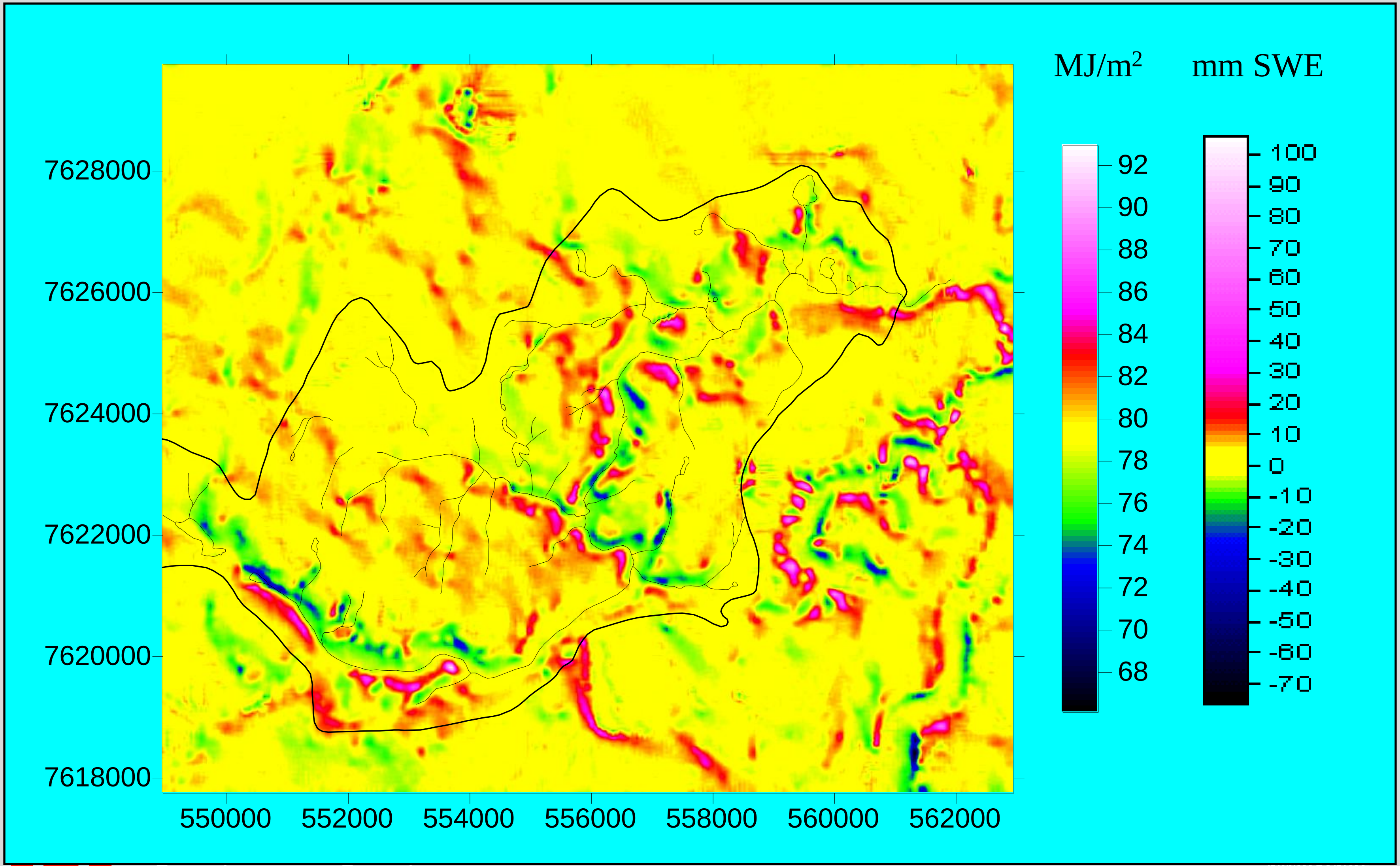




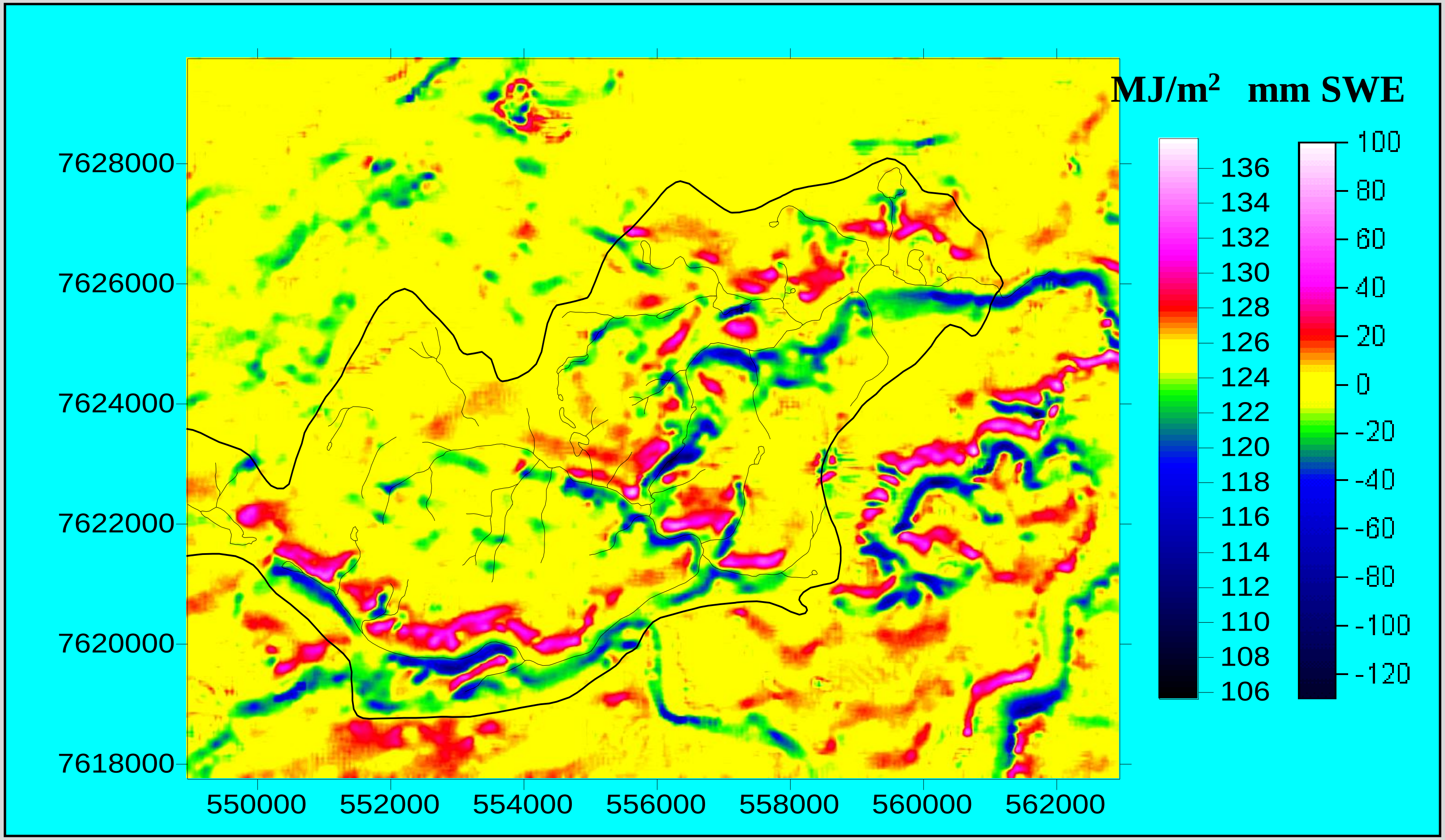
Wind

- Differences in hourly wind speed of up to 30% were measured

Accumulated Turbulent Fluxes for Spring 1999 (37 days)



Accumulated Surface Energy Fluxes for Spring 1999



- Above average values on south facing slopes
- Below average values on north facing slopes and in incised river valleys

Summary and Future Work

- Spatial differences in snowmelt energy balance factors are considerable even in areas of relatively moderate relief and should therefore be included in hydrologic models and land surface schemes
- Existing land classes will be divided according to exposure (i.e. north facing tundra, south facing tundra etc.) to enable the individual input of incoming solar and long wave radiation
- Develop and test alternate approaches of including spatial variability in larger scale models

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