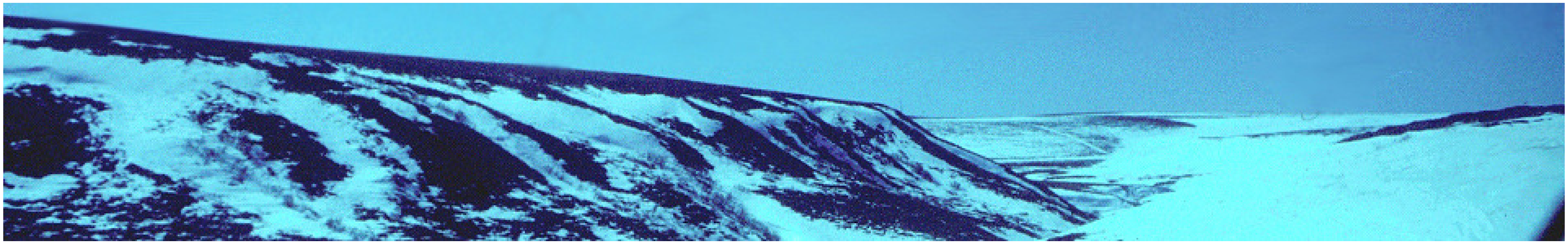
Environment Canada Environnement Canada

Canada



IP3 research in the Western Canadian Arctic

Philip Marsh[1], S. Endrizzi[5], S. Pohl[3], J. Pomeroy[3] , M. Sturm[2], M. Russell[1], C. Onclin[1], W. Quinton, and C. Cuell[1]

1. National Hydrology Research Centre, Saskatoon, SK, Canada

2. CRREL, Fairbanks, Alaska

3. University of Saskatchewan

4. Wilfred Laurier University

5. University of Zurich, Zurich

University of Saskatchewan

Centre for Hydrology

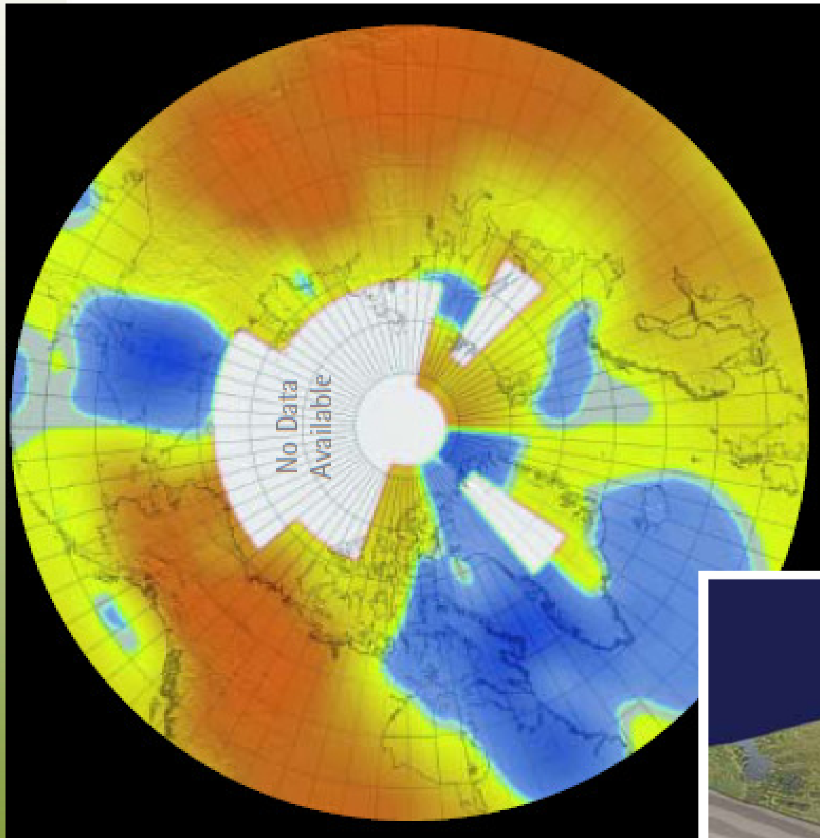
Environment Canada Environnement Canada

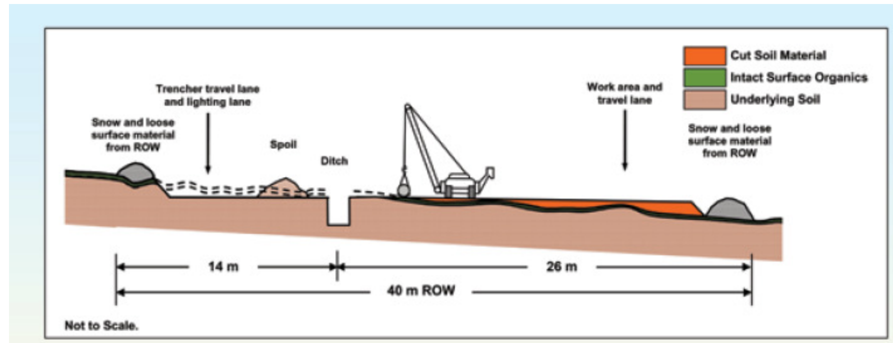
IP3

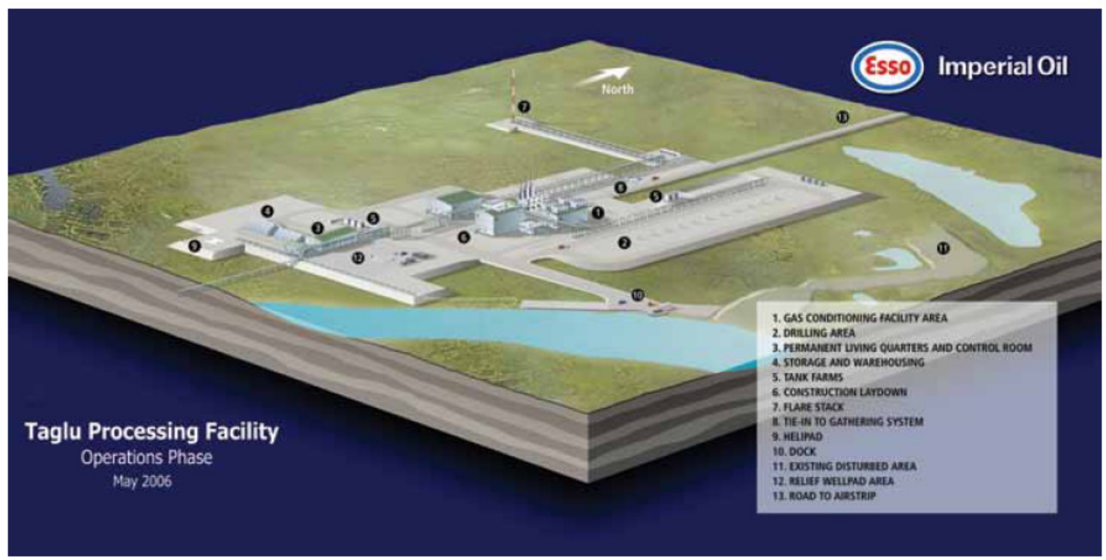
International Polar Year 2007-2008

Année Polaire Internationale

Many issues require an increase in hydrologic knowledge and modelling

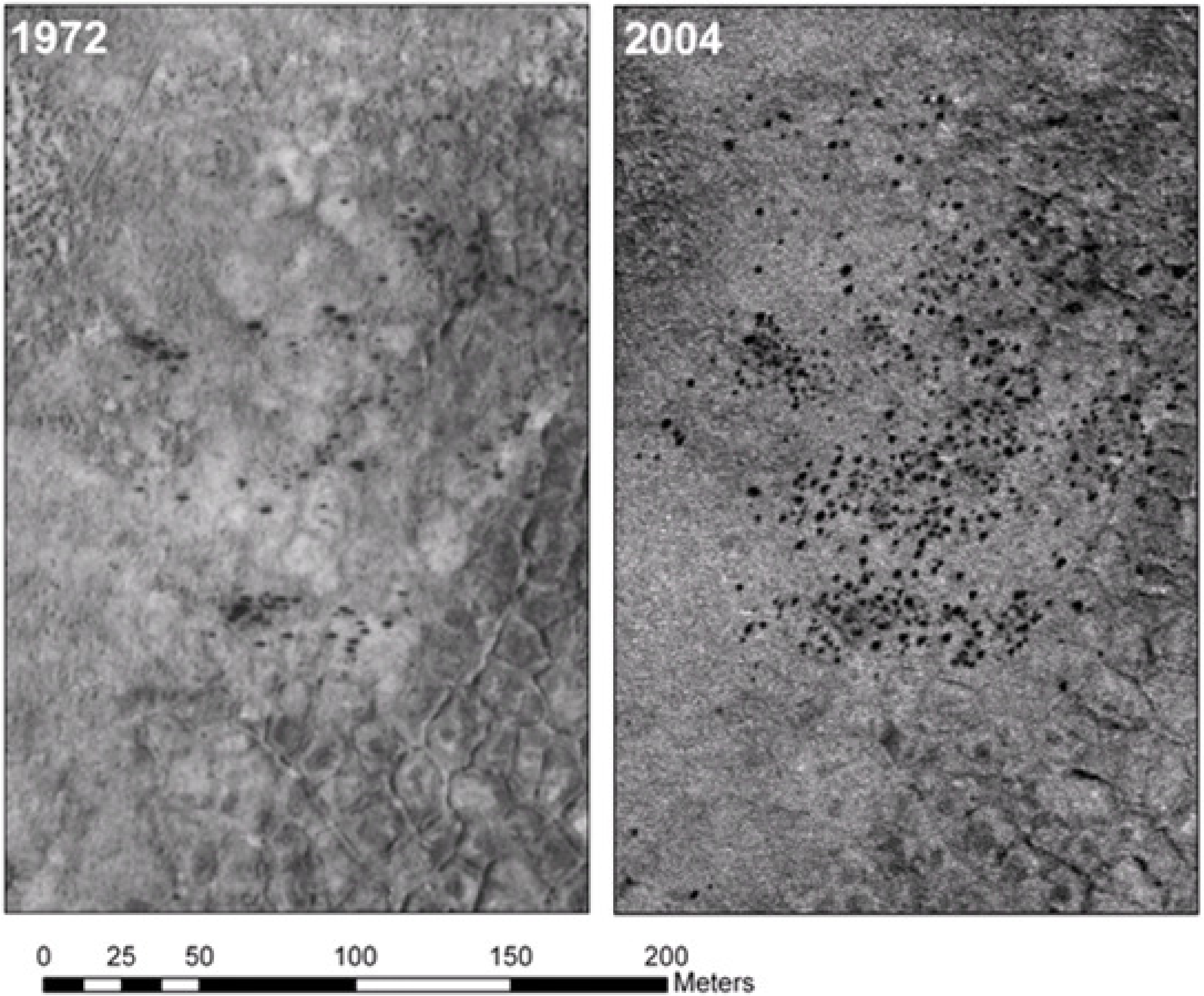






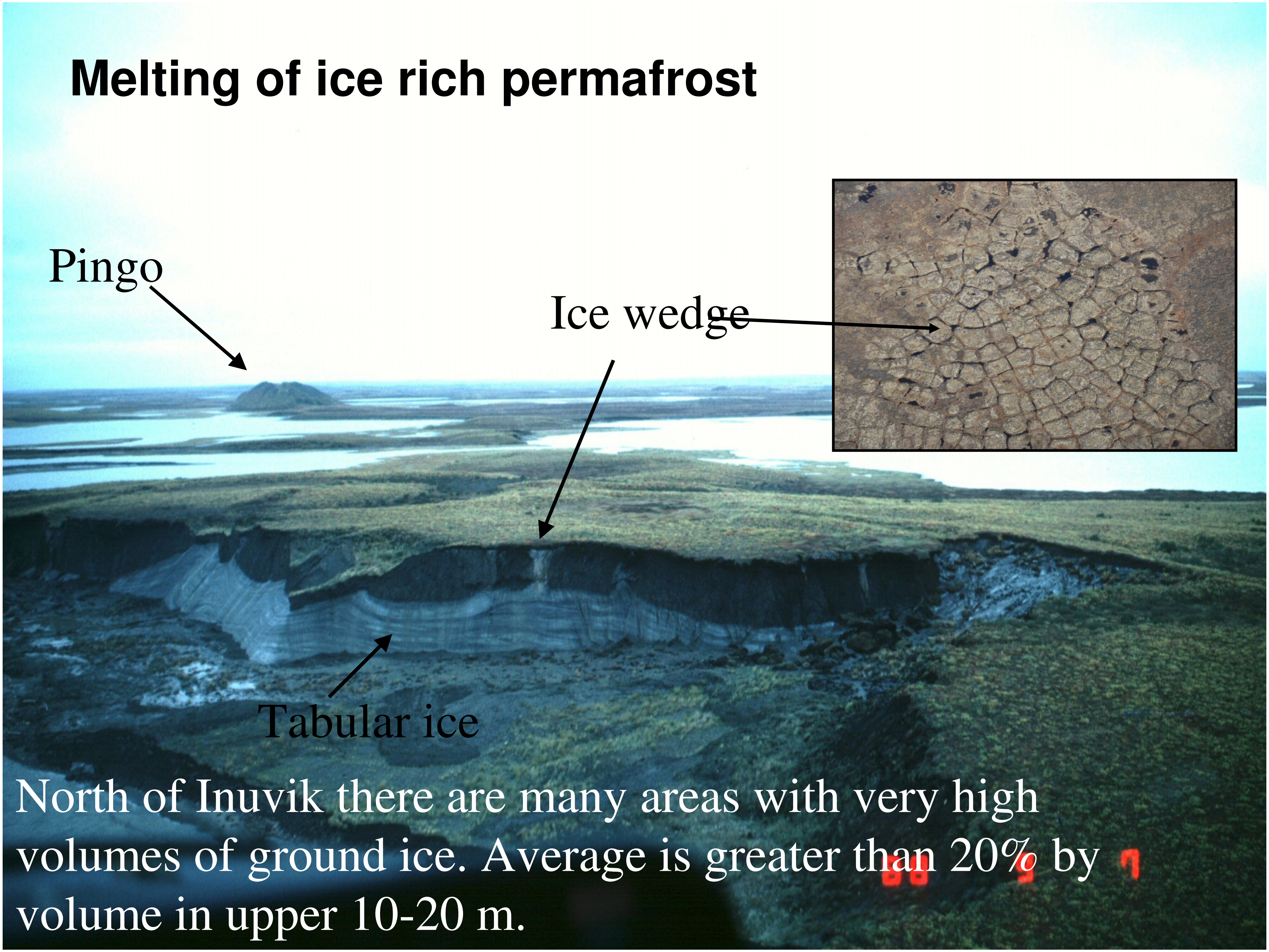
- understanding these impacts is hindered by the small observation network of climate and streamflow

Changing vegetation: Shrub tundra

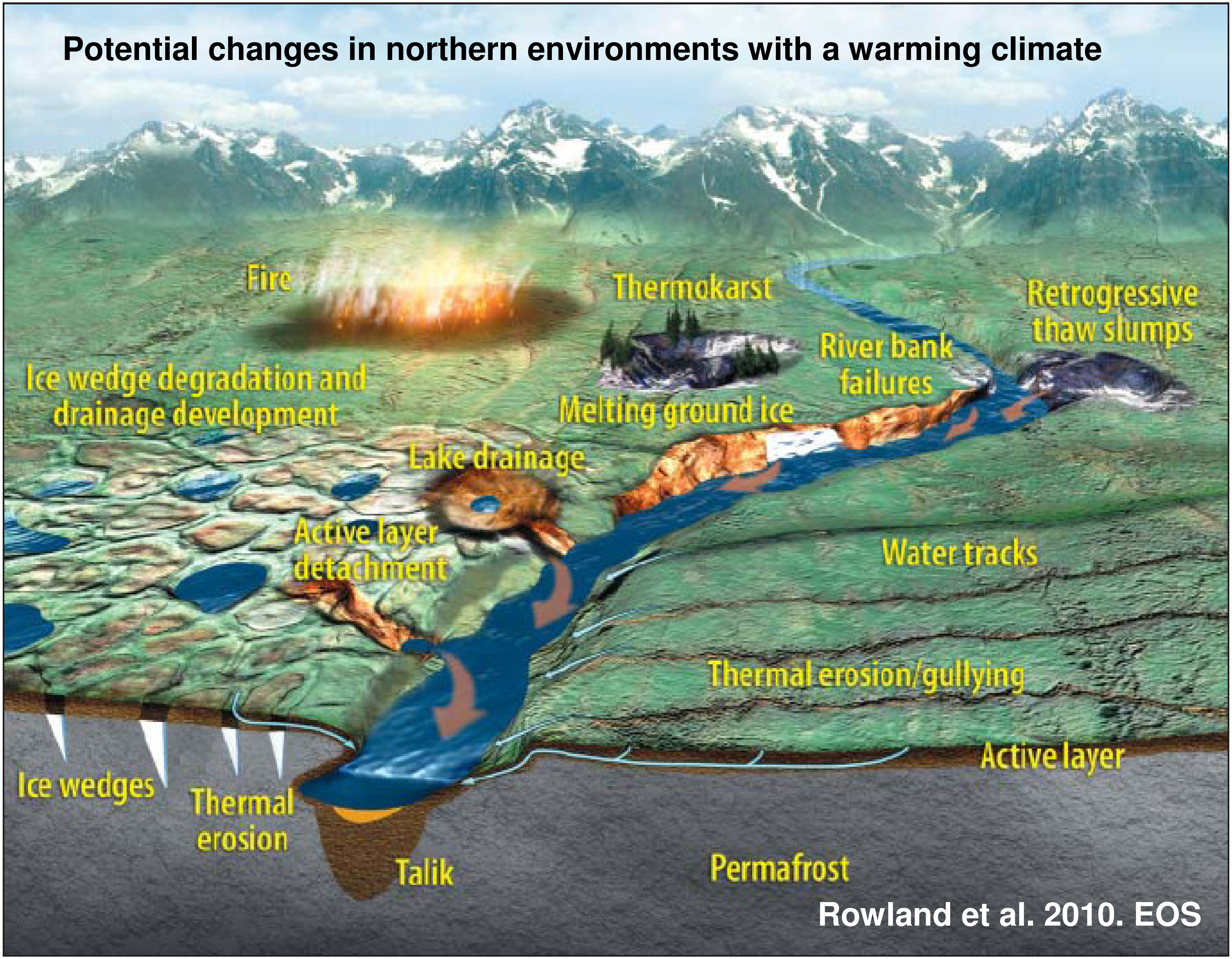


Lantz, Kokelj, and Marsh, in preparation

Melting of ice rich permafrost



North of Inuvik there are many areas with very high volumes of ground ice. Average is greater than 20% by volume in upper 10-20 m.


Potential changes in northern environments with a warming climate
Fire
Thermokarst
Retrogressive thaw slumps
River bank failures
Ice wedge degradation and drainage development
Melting ground ice
Lake drainage
Active layer detachment
Water tracks
Thermal erosion/gullying
Active layer
Ice wedges
Thermal erosion
Talik
Permafrost
Rowland et al. 2010. EOS

Land access issues related to northern energy development

- tundra is very sensitive to disturbances from:
    - various activities related to pipeline construction
    - seismic surveys

- disturbance includes
    - damage to the vegetation
    - compaction of the veg. and soils
    - changing the soil thermal regime
    - with melting of ground ice and slumping

- damage can last for decades to centuries

- need for improved regulations on when land can be accessed, including improved ability to model snow accumulation in the fall, and soil freezeback

Globe and Mail

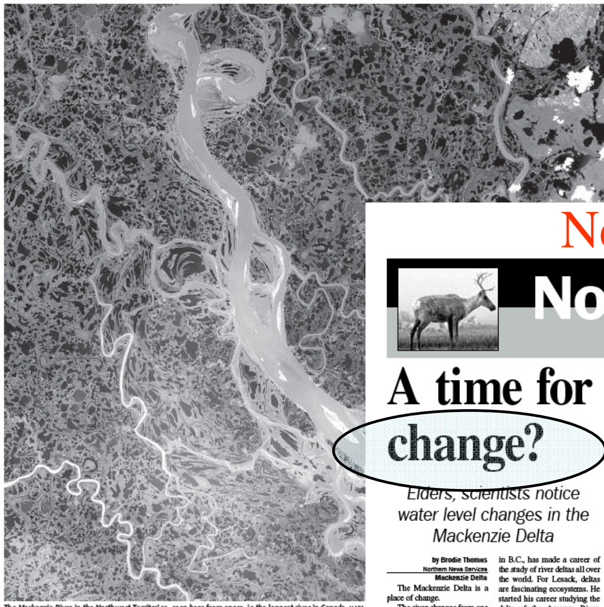
The Globe and Mail, Friday, April 4, 2008 · News A3

THE NEW CLIMATE » INTERNATIONAL POLAR YEAR

River delta's rise puts Arctic's future in flux

Climate change in Arctic seas is driving summer water levels at the Mackenzie's mouth to three times normal, B.C. researchers find

MARK HUME



The Mackenzie River in the Northwest Territories, seen here from space, is the longest river in Canada.

SEA CHANGE » A GLIMPSE INTO THE FUTURE OF THE ...

ARCHEOLOGY

The missing stink is oldest evidence yet of human pre...

These human coprolites, or fossil feces, found in Oregon have been dated to 14,300 years ago.

Edmonton Journal

News North

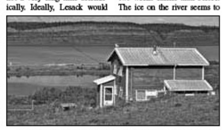
NEWS/NORTH NWT, Monday, April 21, 2008 13

Northern *lives*

A time for change?

Elders, scientists notice water level changes in the Mackenzie Delta

Flooding in Aklavik, such as shown here from May 2006, although still a problem, seems to be less frequent and less intense than in the past.



Tsiigehtchic elder Fred Blake Sr. says he has noticed water levels of the Mackenzie and Arctic Red rivers dropping in the past 20 years.

NOTICE

The Department of Transportation advises that changes to fees charged for services offered at Driver and Vehicle Licensing Offices are now in effect.

The new fee schedule is available on the department's website at www.dot.gov.nt.ca. Look for Fees under the Drivers or Vehicles tabs.

Dehcho First Nations

Member Required

EDMONTON JOURNAL · SUNDAY READER / *Environment* · SUNDAY, FEBRUARY 17, 2008 · E3

MUTATING MAZE / *A warming climate has turned the massive Mackenzie delta into a maddening puzzle that imperils the future of wildlife and aboriginal hunters*

Photos: Ed Struzik

In winter, the frozen channels of the delta serve as iceroads that take people from one community to another. Oil and gas operators also use the roads to service their exploration activities in the Mackenzie delta.

DELTA FACTS

- AREA: 13,500 square kilometres, bordered by Richardson Mountains in the west and Caribou Hills in the east
- DRAINS: the Mackenzie, at 1,738 kilometres, Canada's longest river, drains one-fifth of the freshwater in the country
- COMMUNITIES in or bordering the delta: Fort McPherson, Inuvik, Aklavik, Tsiigehtchic, Tuktoyaktuk

Drying times for a delta

ED STRUZIK

Journal Staff Writer

EDMONTON

A trapper's cabin north of Aklavik. Inuvialuit or Gwich'in trappers are no longer finding animals in the areas that were once rich in wildlife.

Caribou swim across one of the main channels of the delta.

Challenges

- Currently we are not able to predict:
  - the impact of a changing climate, and corresponding changes in vegetation and permafrost, on the hydrology of northern Canada
  - spatial variability in snow depths and ground temperatures with sufficient accuracy to guide regulations on when industry can access the land, and can some areas be accessed earlier than others?
  - Extreme hydrological events that will impact natural systems, as well as northern development projects
  - Streamflow in ungauged basins

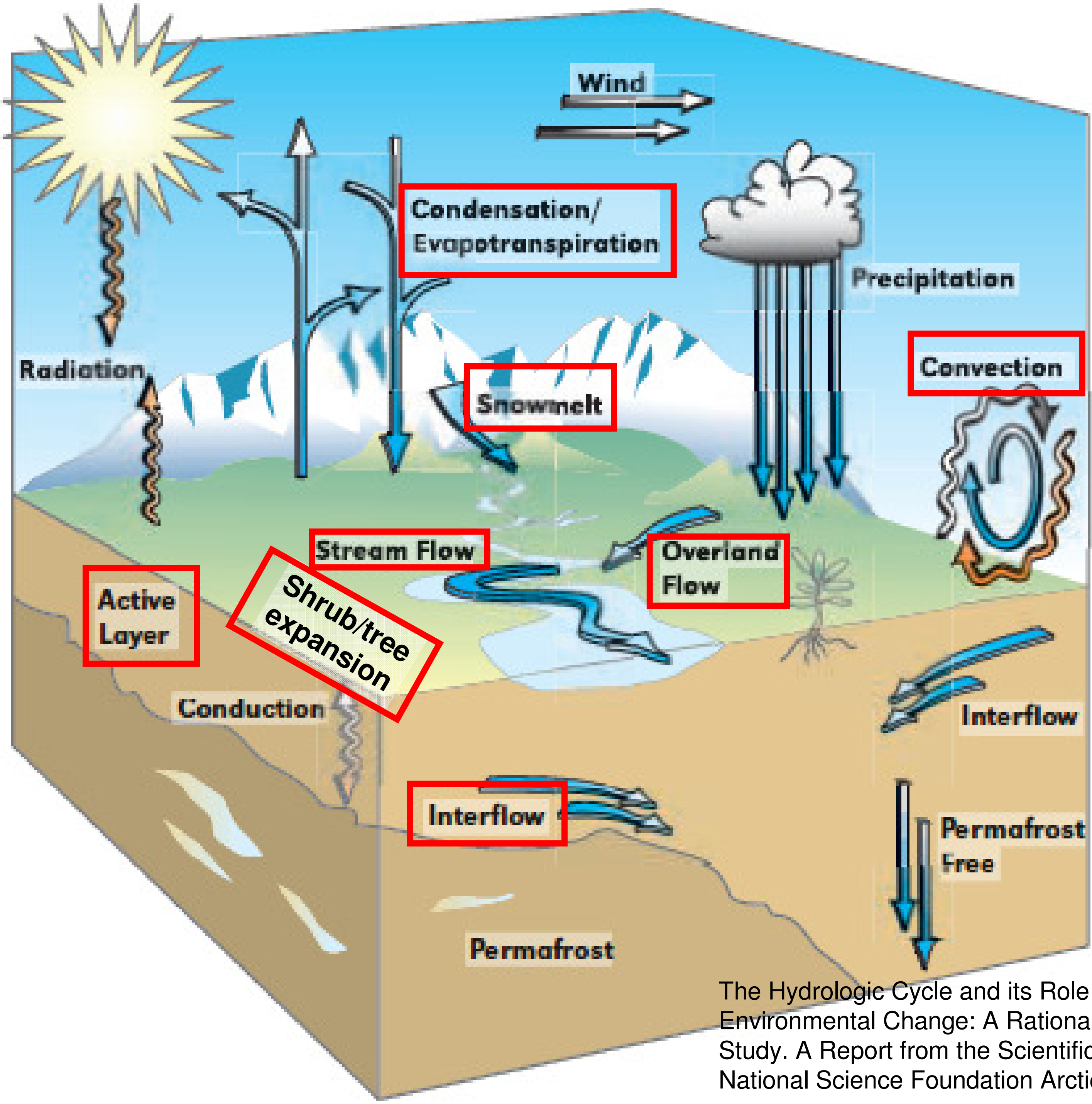
1. Objectives

- improved understanding of the arctic hydrologic system
  - Controlling processes
  - Understanding spatial variability
  - Testing our understanding using field observations and high resolution models
- Testing and improving larger scale hydrological models with an emphasis on MESH

Detailed field observations combined with process based modelling

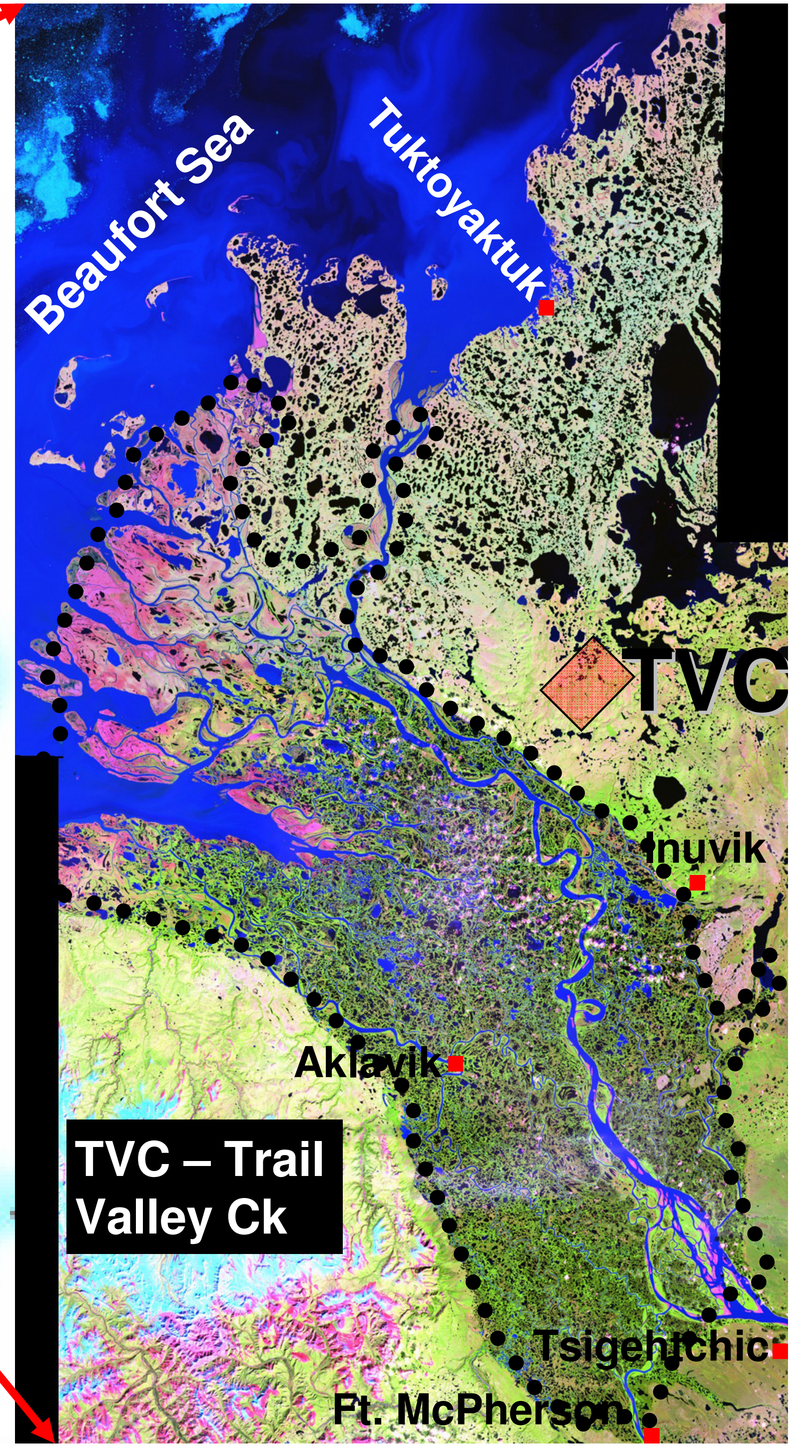
- Models are important for:
  - testing the status of our understanding
  - provide an appropriate method to consider complex interactions, and to consider the spatial and temporal variability which we can't do through observations alone
- To do this, we need appropriate data and hydrological models that::
  - are able to consider the major components of the integrated hydrological system, including vegetation and permafrost
  - Is a tool to help in improving large scale hydrologic and landsurface schemes used in climate models

Processes of Interest



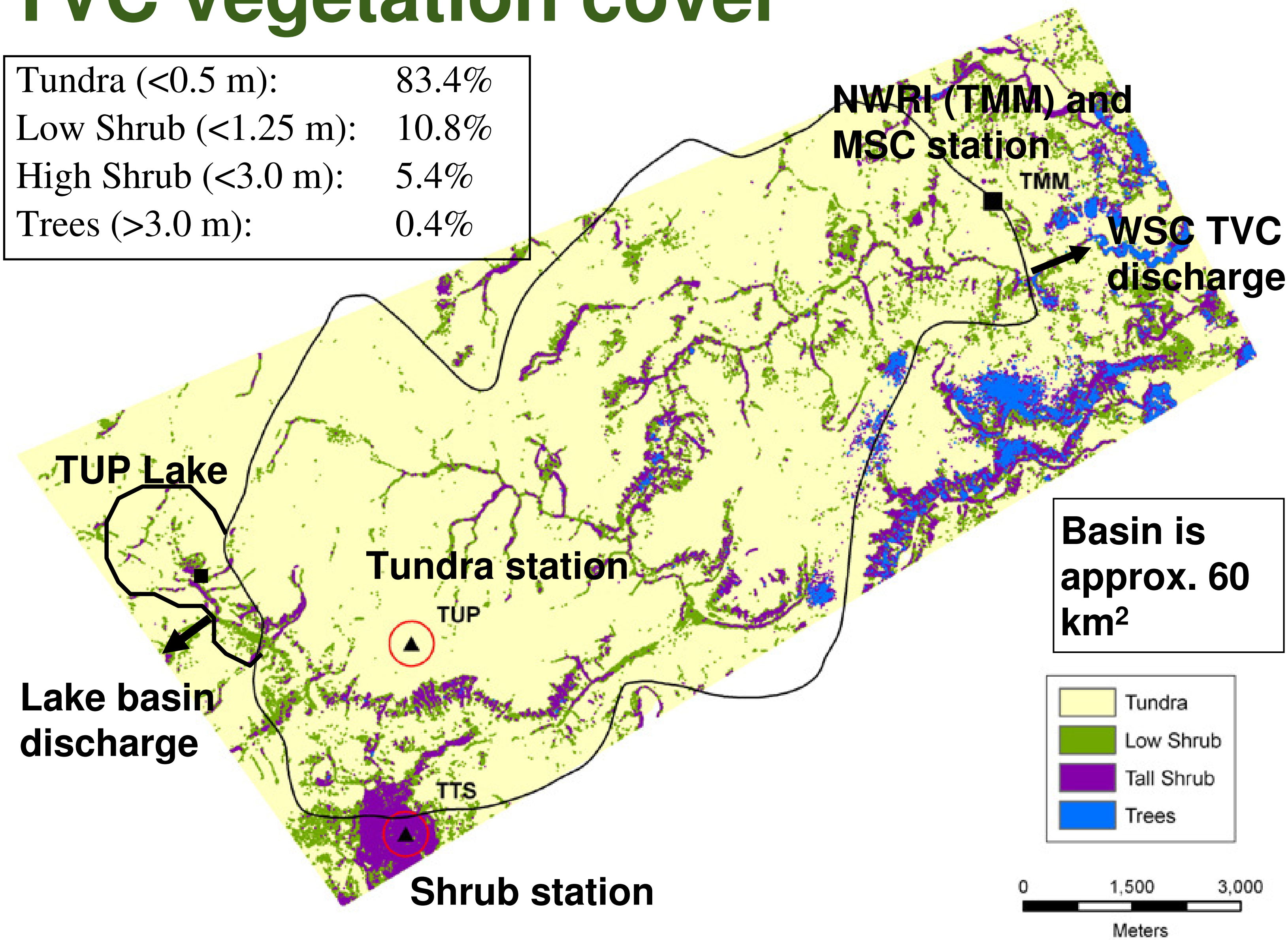
The Hydrologic Cycle and its Role in Arctic and Global Environmental Change: A Rationale and Strategy for Synthesis Study. A Report from the Scientific Community to the National Science Foundation Arctic System Science Program

2. Study area and Env. Canada field observations



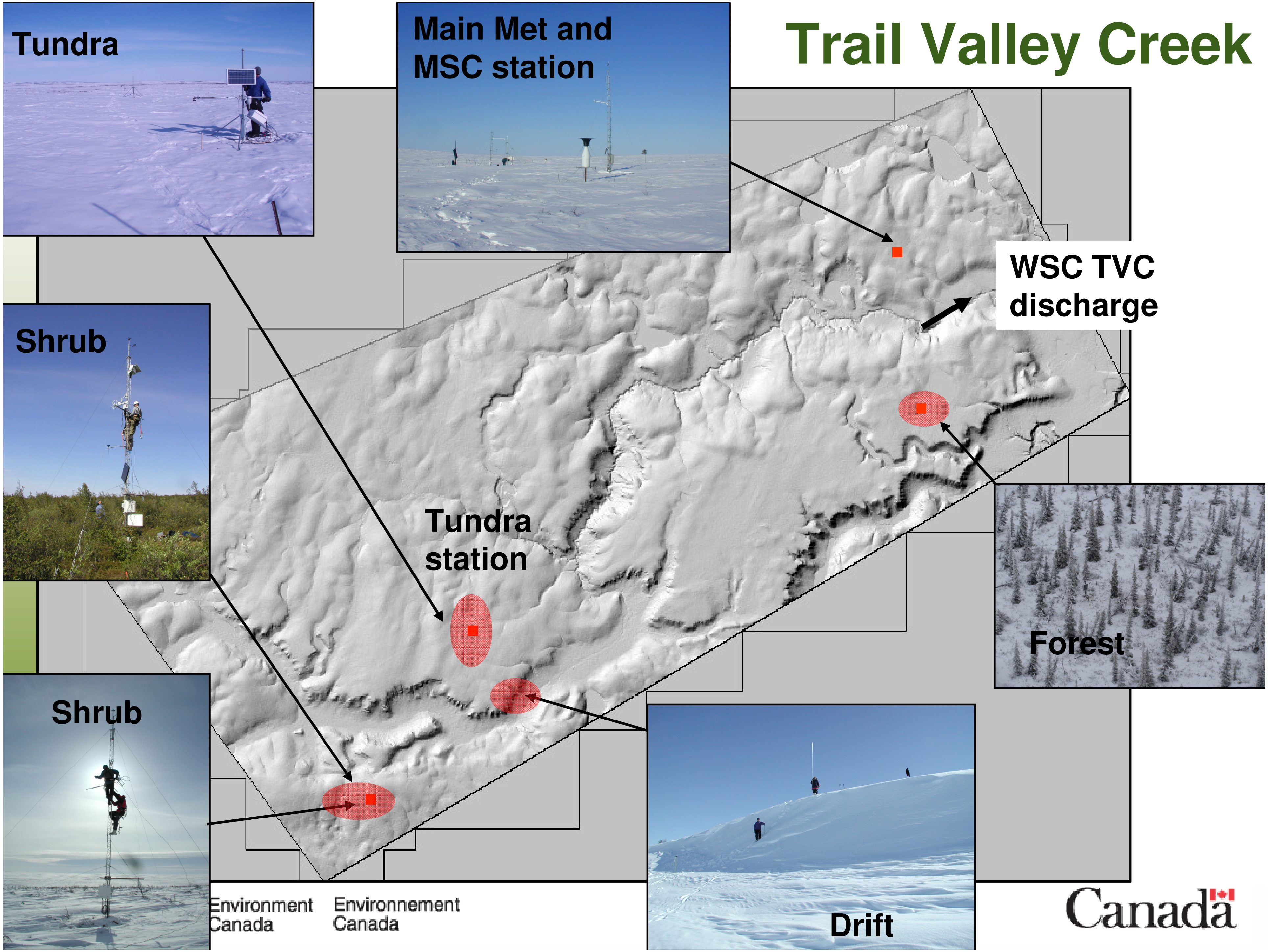
TVC vegetation cover

Tundra (<0.5 m):	83.4%
Low Shrub (<1.25 m):	10.8%
High Shrub (<3.0 m):	5.4%
Trees (>3.0 m):	0.4%

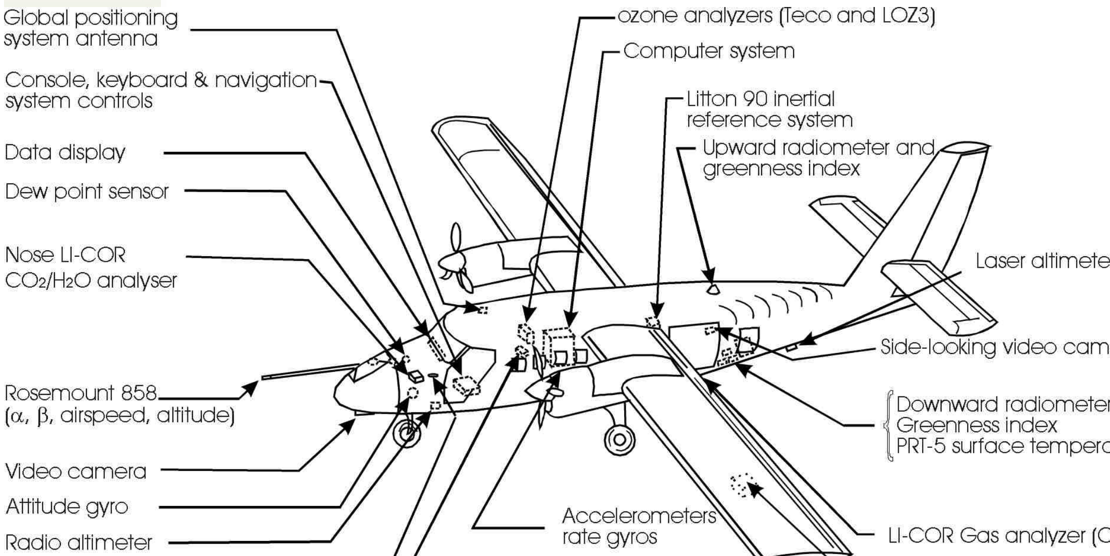


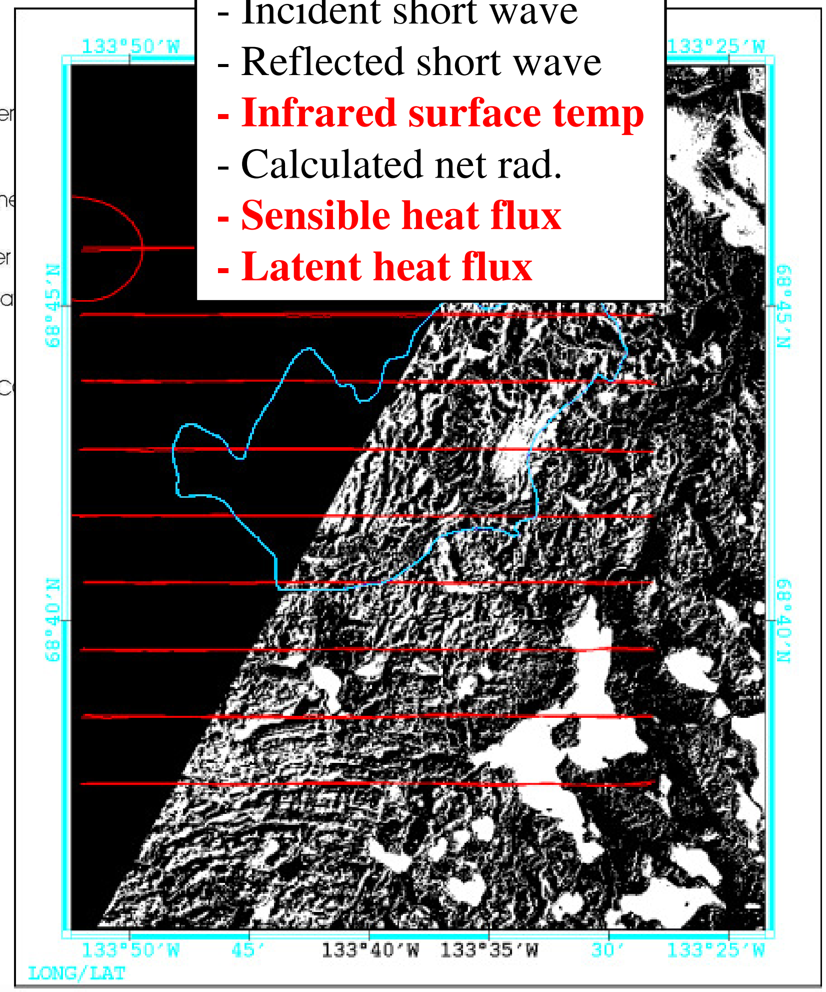
(derived from high resolution LiDAR data)

Trail Valley Creek



Mackenzie GEWEX Study (MAGS)
1999 - NRC Twin Otter Flux Aircraft





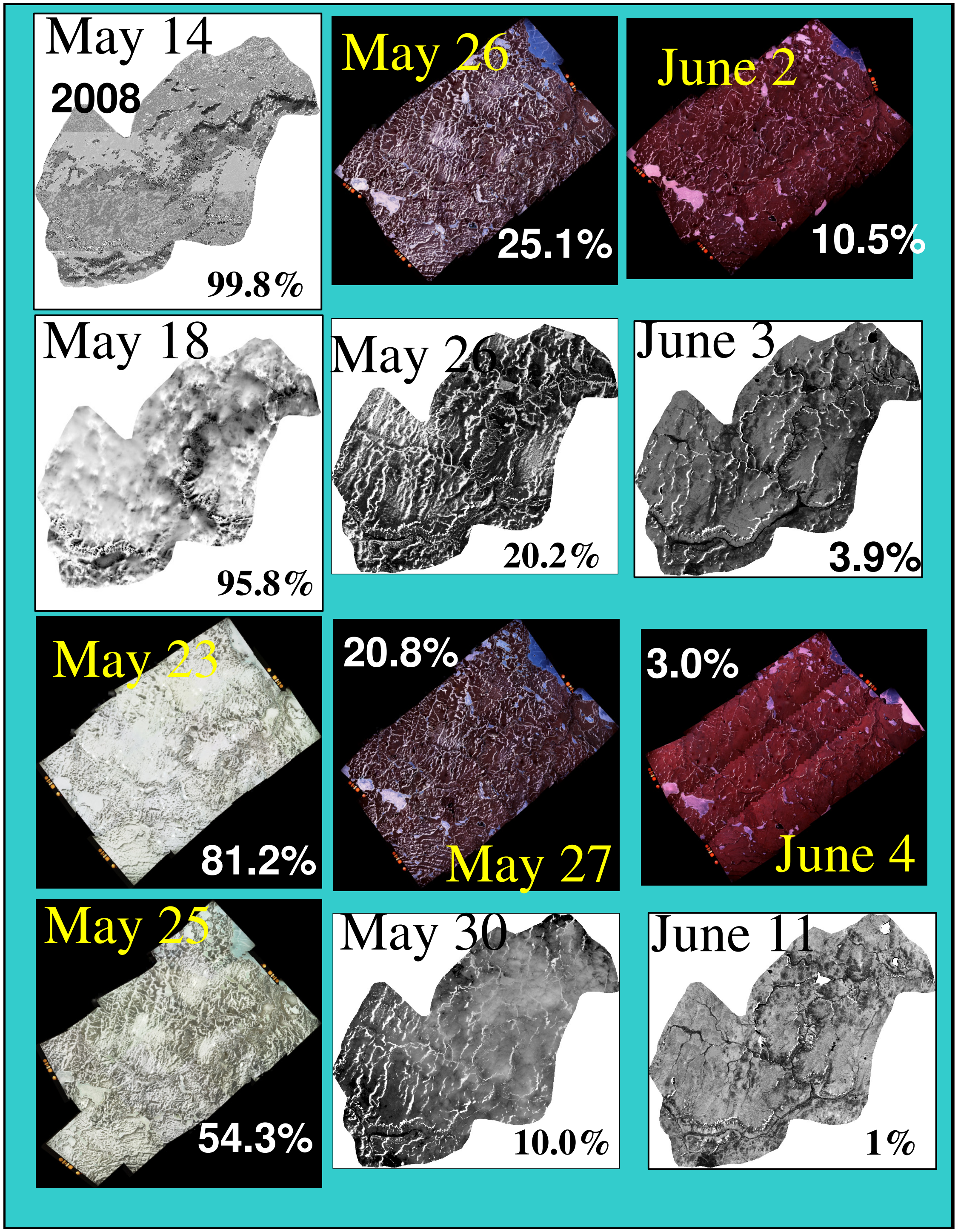
Parameters

- Air temperature
- Incident short wave
- Reflected short wave
- **Infrared surface temp**
- Calculated net rad.
- **Sensible heat flux**
- **Latent heat flux**

Snow Surveys

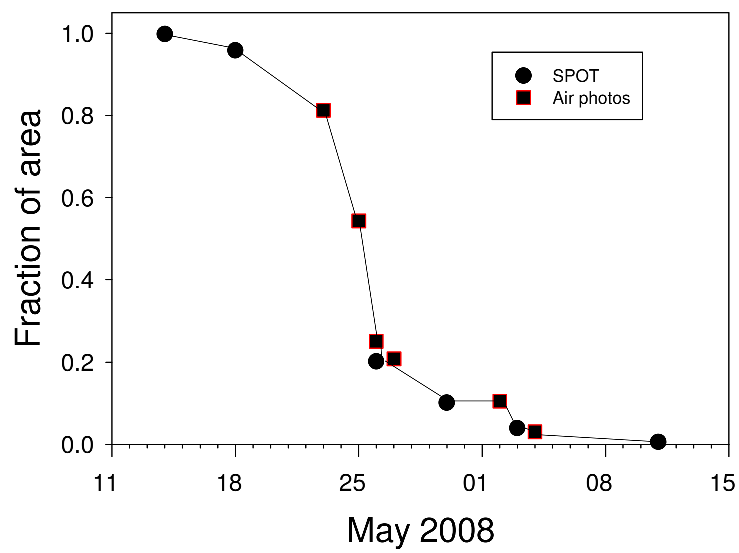
- End of winter vegetation and terrain based snow surveys were conducted at: Trail Valley Creek over many years
- coordinated with additional drift, tundra, and aircraft microwave surveys by Chris Dirksen of Env. Canada during IPY.
- Currently working to combine the two detailed data sets for a complete of end of winter snow distribution.

Canada



Satellite and airphotos of SCA during 3 years (1996, 1999, 2008)

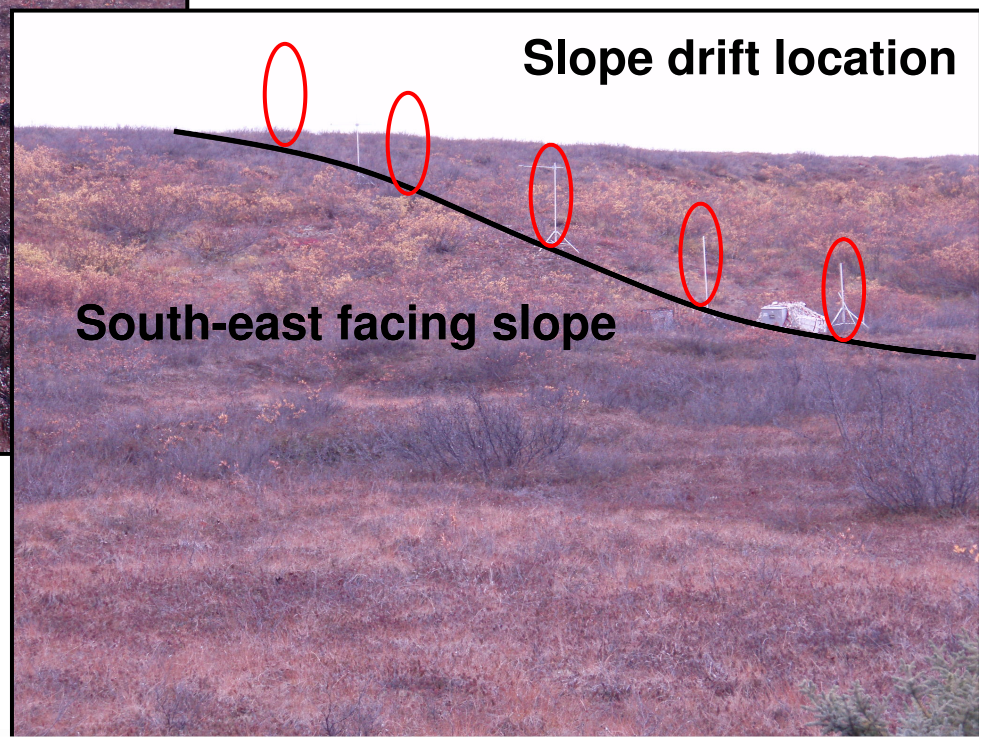
Change in Snow Covered Area (SC)



- next step: similar analysis for smaller, 1x1km areas of the basin

Snow accumulation and soil temperature

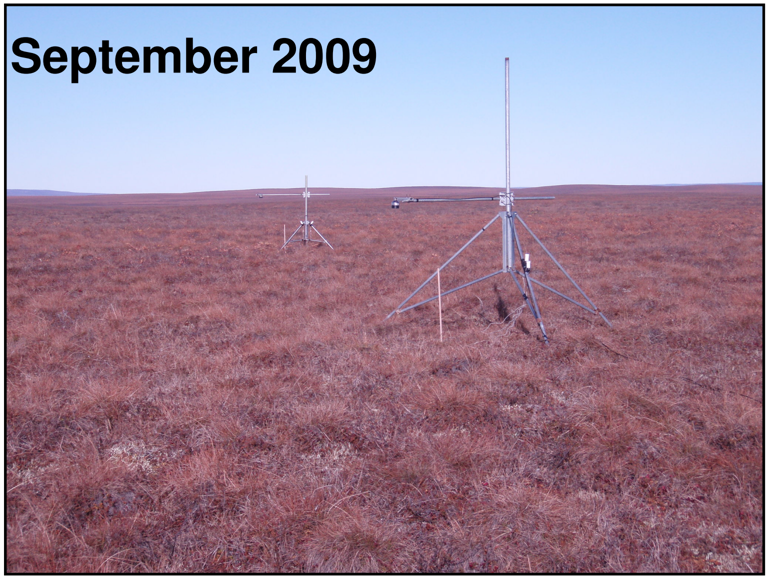
- tundra site
- shrub tundra site
- drift site



Digital Snow Pillow for use in shallow snowpacks

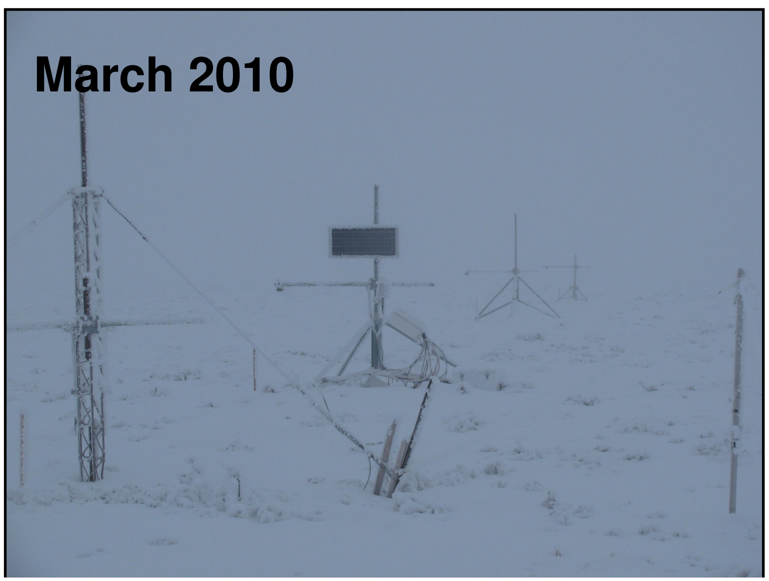
Joint IPY project with Matthew Sturm at USA CRREL, Fairbanks

Two years with winter measurements

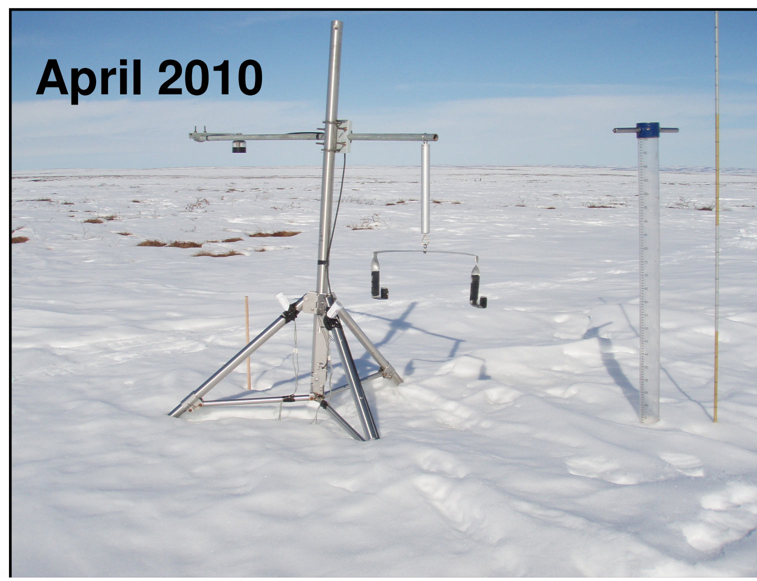


September 2009

October 2009



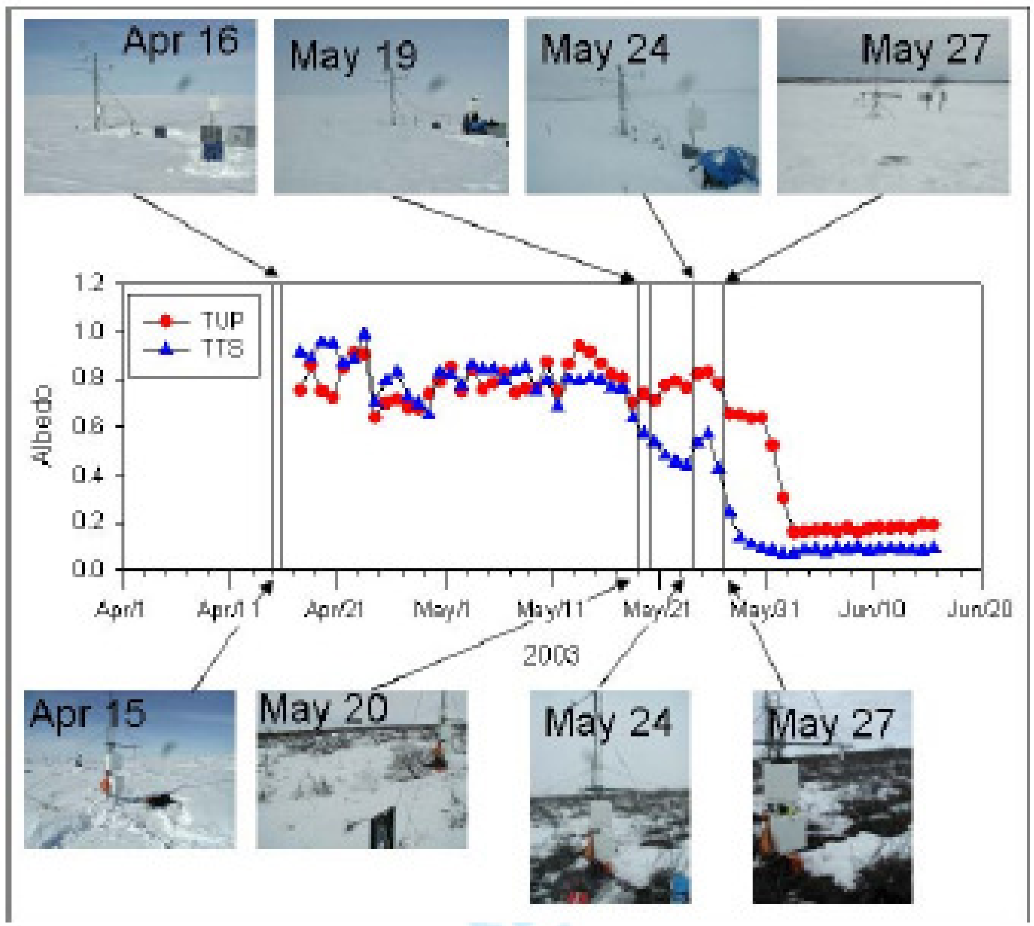
March 2010



April 2010

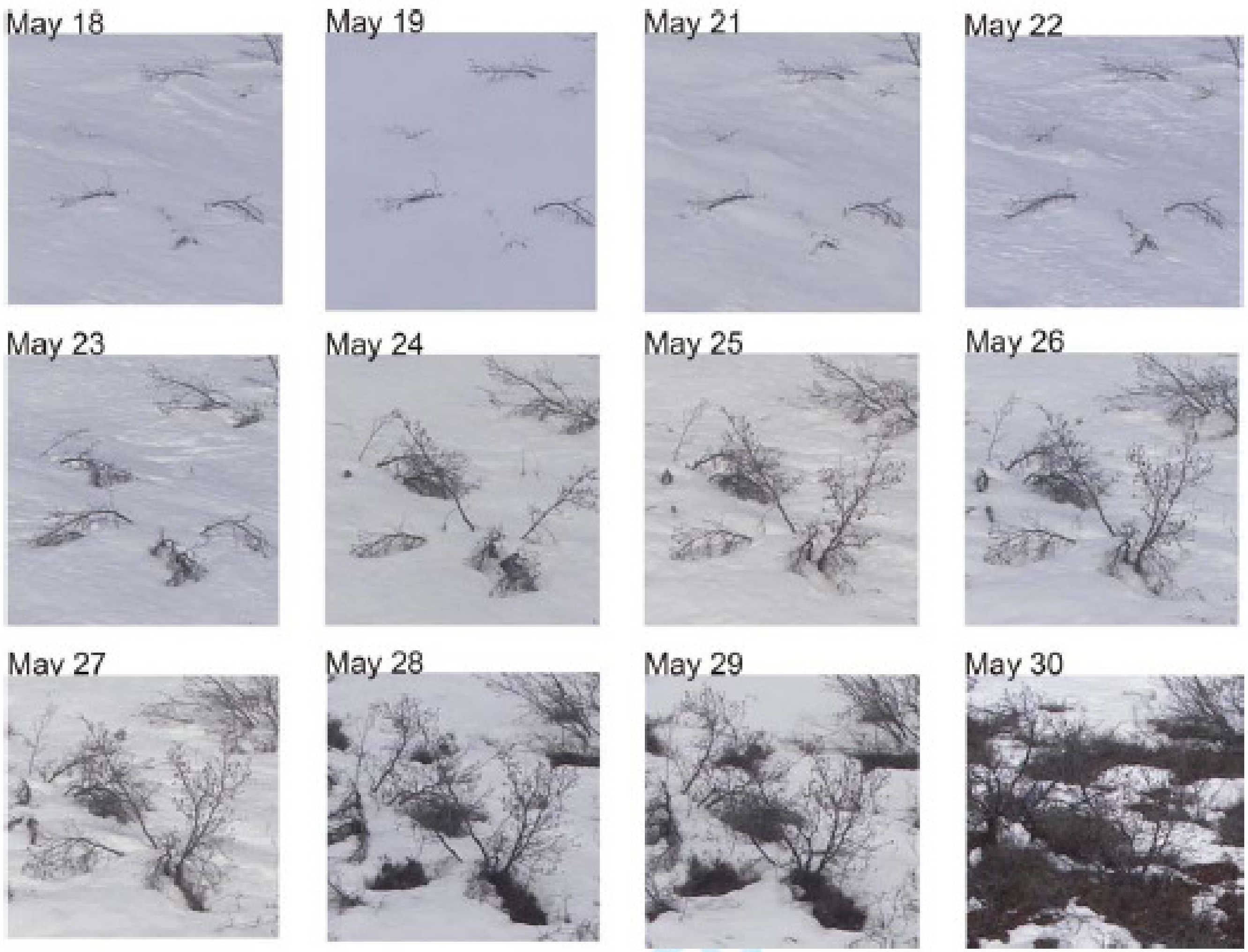
Documenting changes in shrubs during melt

Tundra site

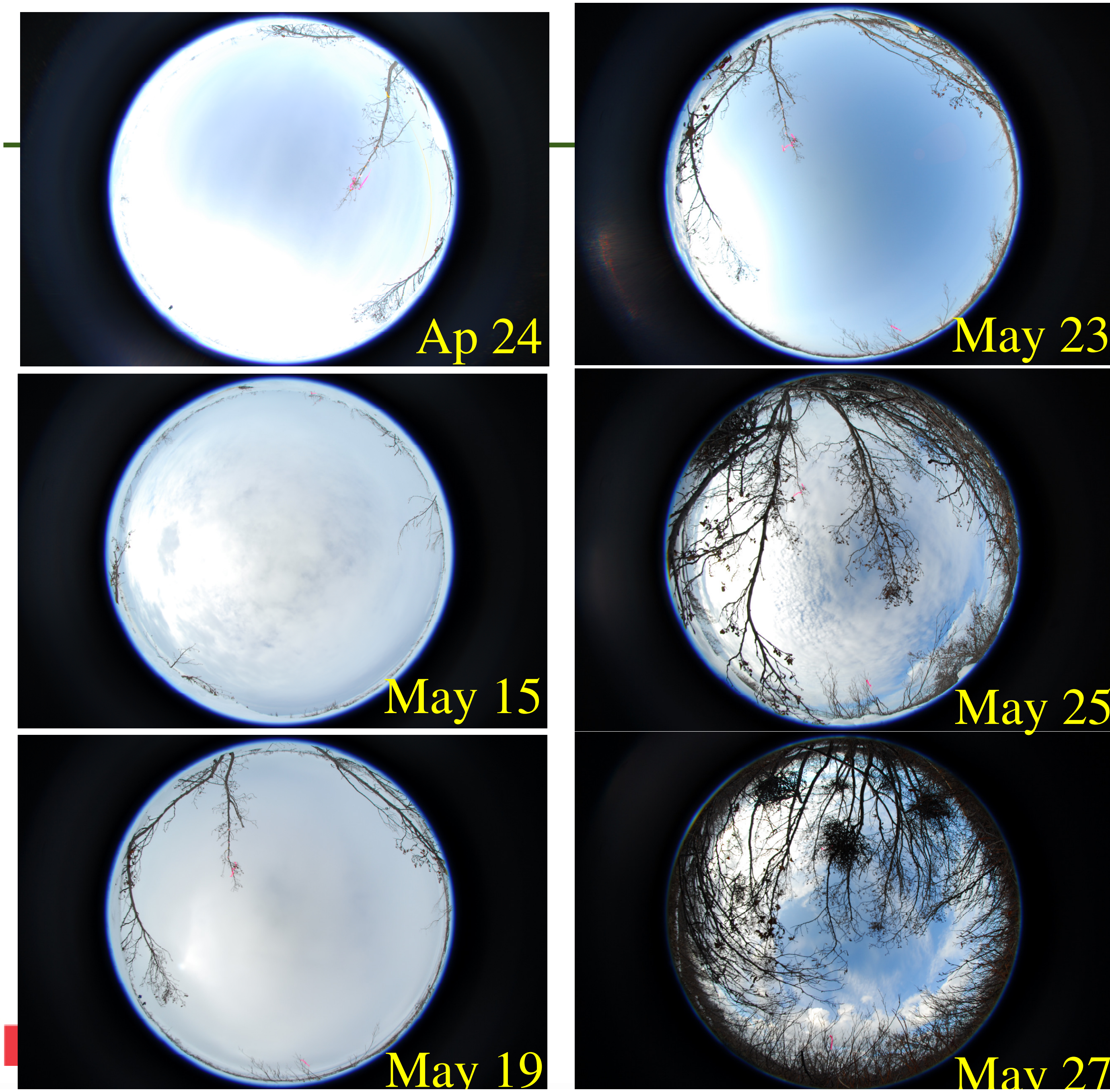


Shrub site

Exposure of Shrubs during melt



Upward looking hemispherical photos at the TVC Shrub site 2008



Leaf Area Index (LAI)

Canada

3. Hydrological modelling

- During IP3 we have concentrated on:
  - using CLASS to better understand the energy fluxes over tundra and shrub sites (recently published in Hyd. Processes)
  - testing, validating, and using CRHM, the Prairie Blowing Snow Model (PBSM) combined with the Liston wind model with the fully distributed model GEOtop (recently published in Hyd. Research)
  - Used GEOtop to consider spatial variation in fluxes and interactions of surface energy balance, soil moisture and active layer melt
  - Using what we have learned above to consider various “types” of Grouped Response Units (GRUs) used in MESH

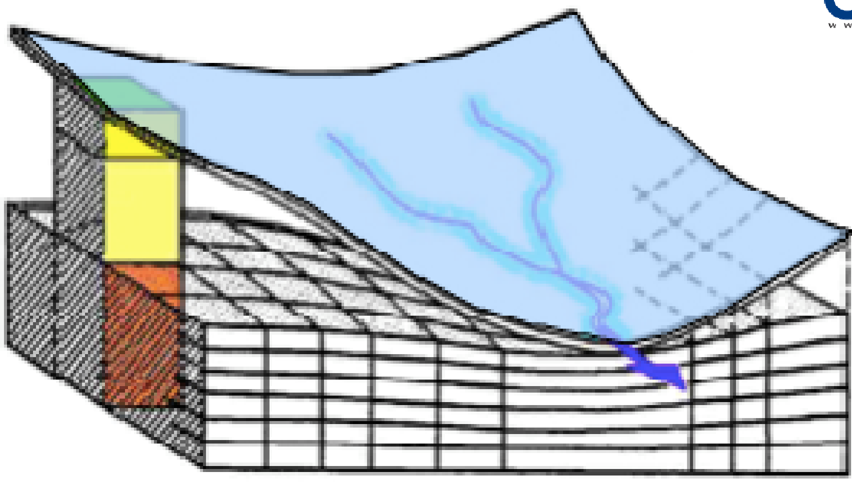
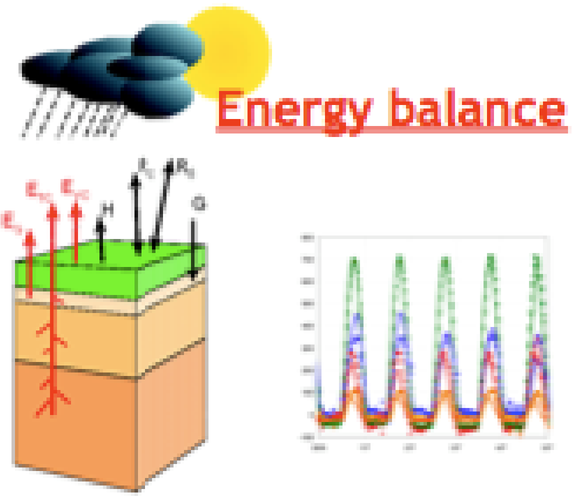


Figure adapted from SHE model (Abbot et al., 1986)



Figures adapted from VIC model (Liang et al., 1994)

- is a spatially distributed model, using a **coupled numerical solution** of the subsurface flow (3D Richards equation) and energy budget (1D heat equation with phase change). This applies for soil and snow cover

- model is fully distributed and can be run at grid sizes from metres to hundreds of metres

Blowing snow

GEOtop coupled with:

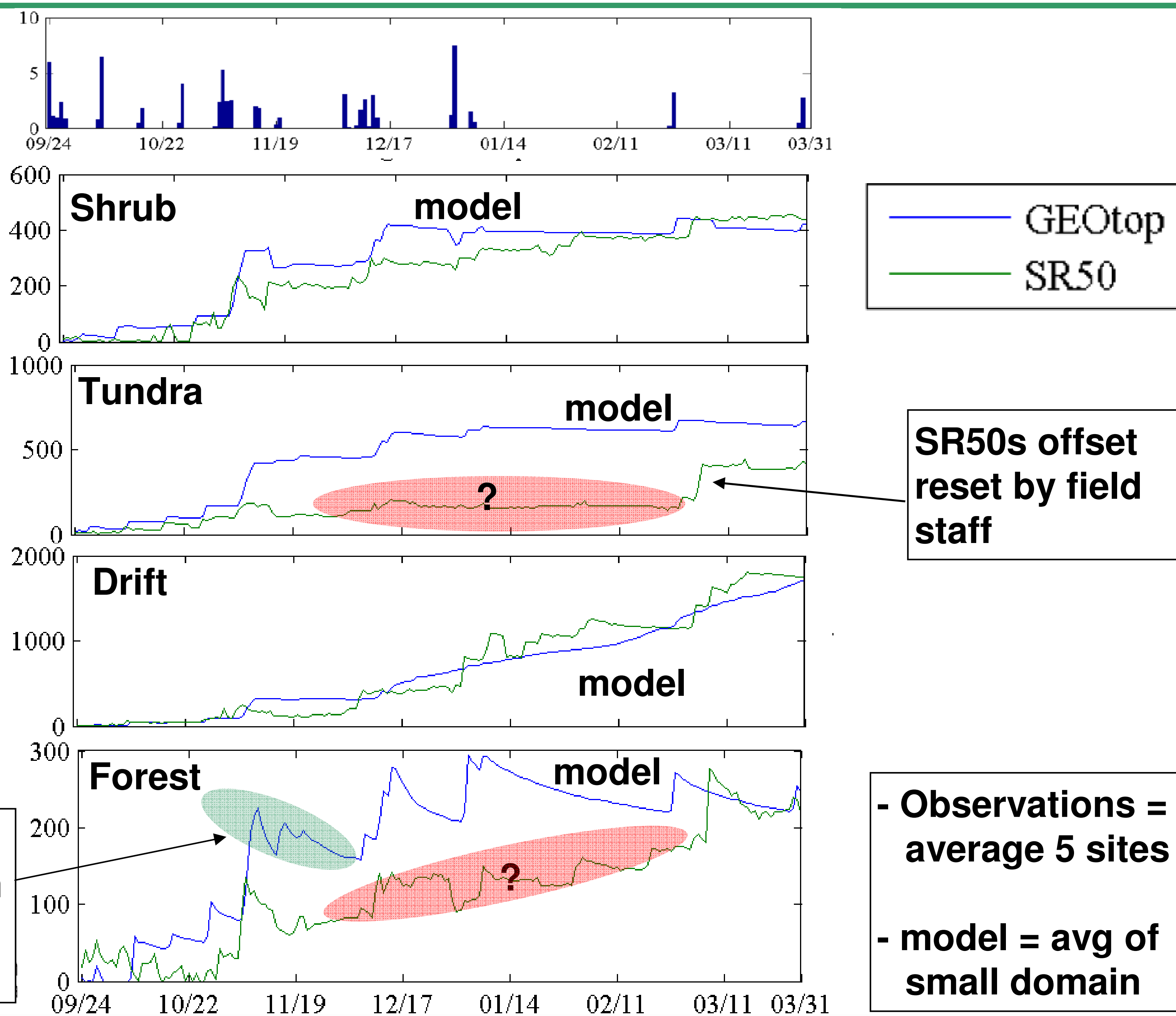
- **PBSM** (Pomeroy et al., 1993) to find snow wind transport rate and sublimation, assuming steady state conditions
- **Liston wind model**

4. Physical Process Studies

A. Snow accumulation
B. Sensible heat flux
C. Soil freeze back
D. Soil thaw
E. Complex, and interrelated, factors controlling one component of the hydrologic system

- for all cases, consider both point and spatial variability

A) Snow accumulation – over a small area



Snow Depth (mm)

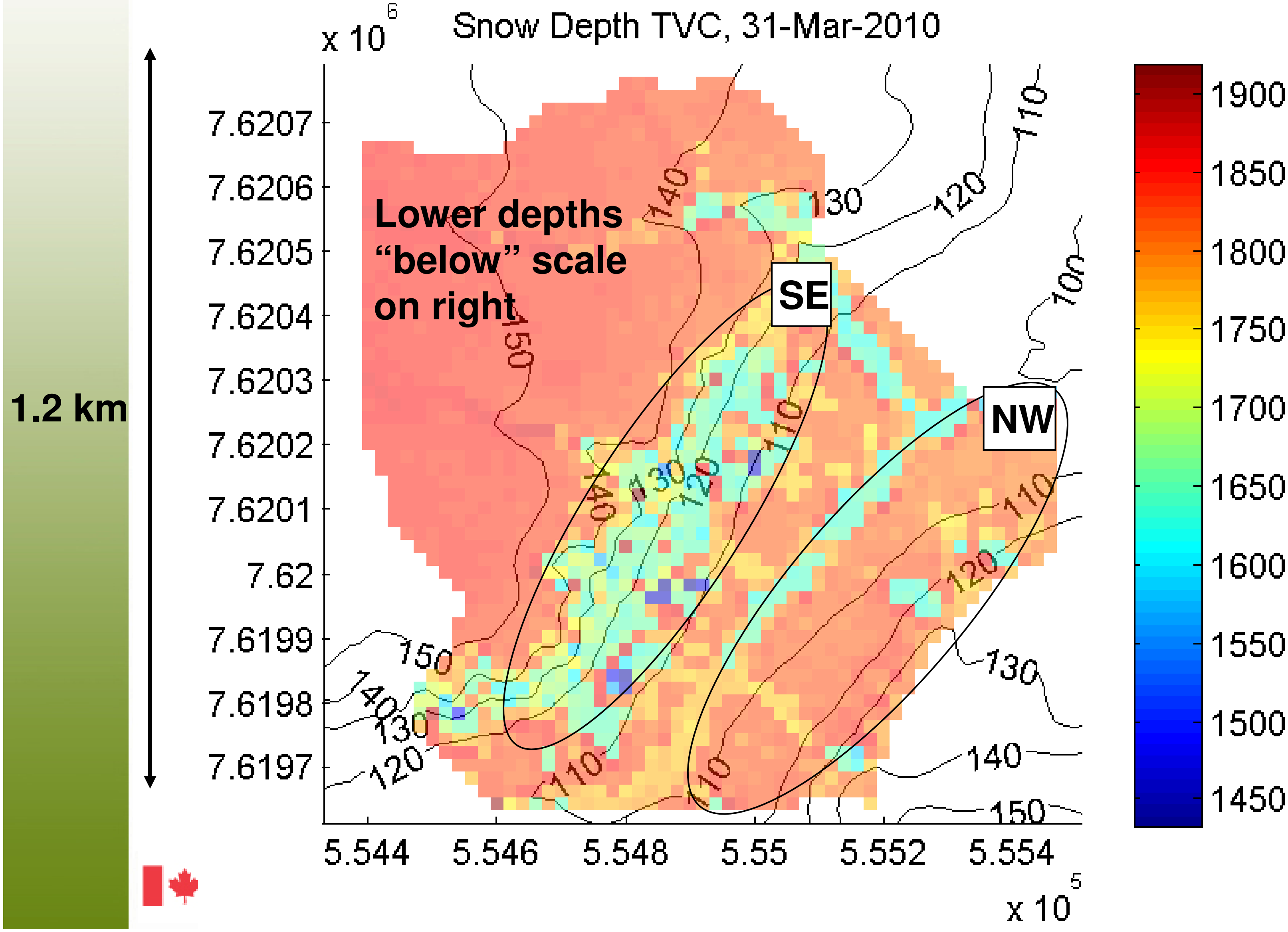
SR50s offset reset by field staff

Modelled Compaction appears to large

- **Observations = average 5 sites**
- **model = avg of small domain**

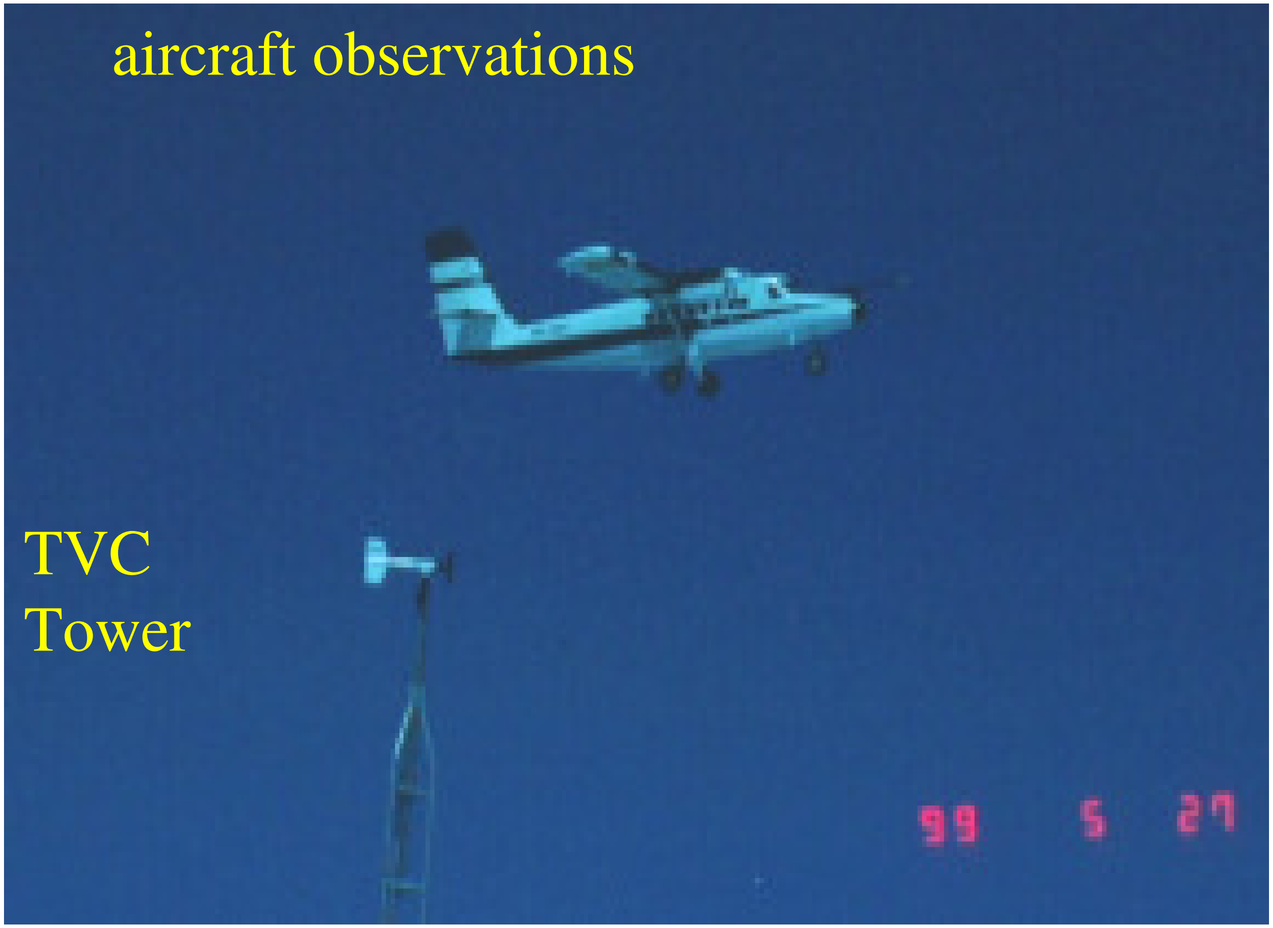
Snow accumulation – larger domain

Note large drift on SE and small or no drift on NW slopes

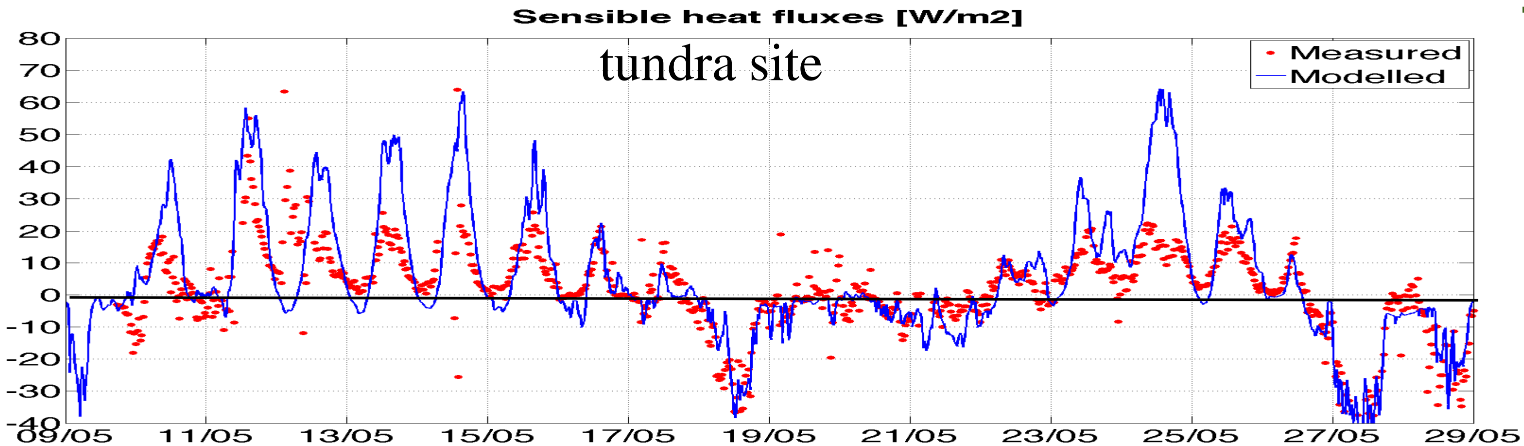


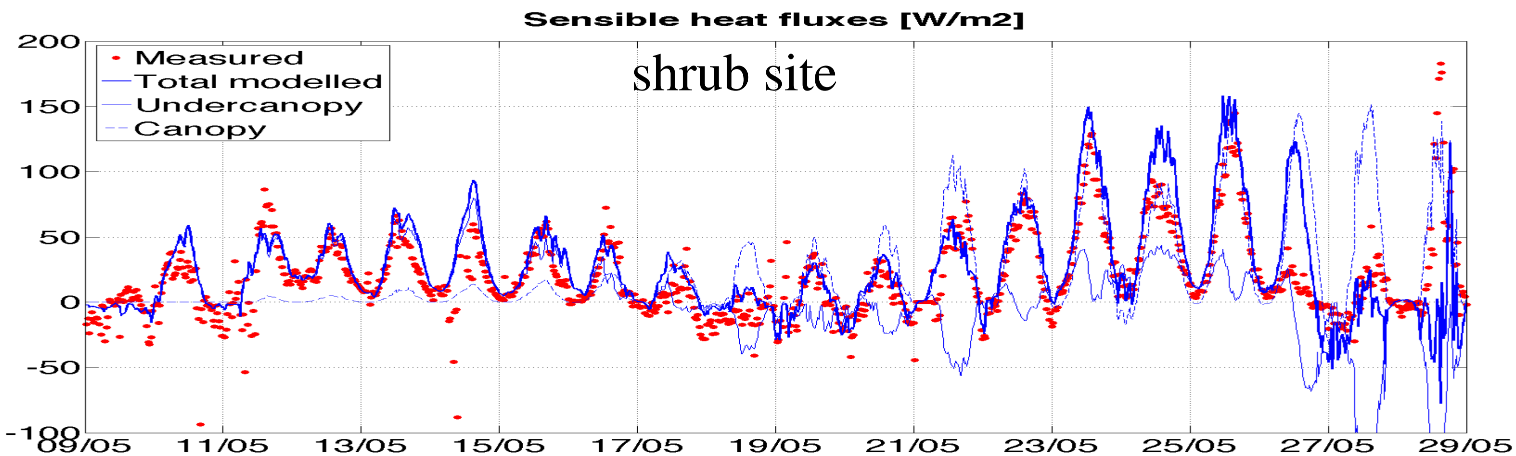
Canada

B) Sensible heat flux



Demonstrated ability to model sensible and latent heat flux for a small footprint (tower), for two different vegetation types





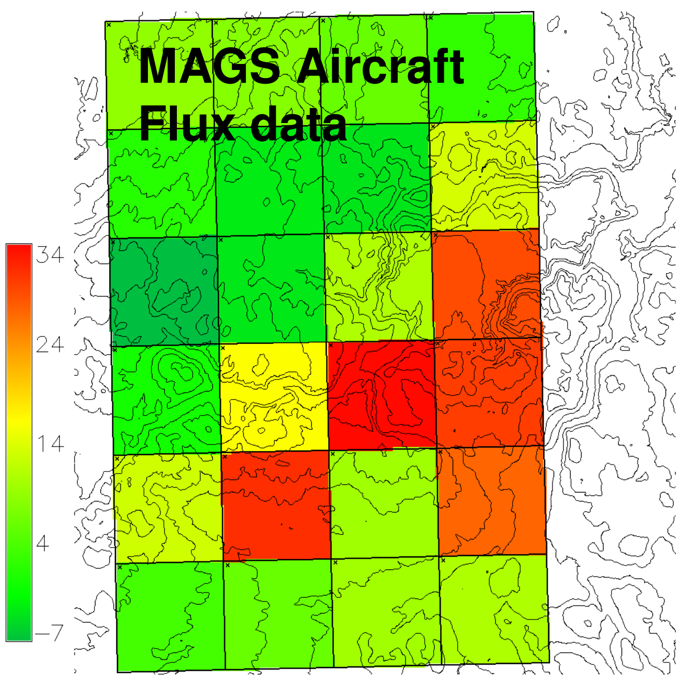
- considered interactions of radiation and turbulent fluxes with vegetation canopy, and “springing up” of shrubs during melt

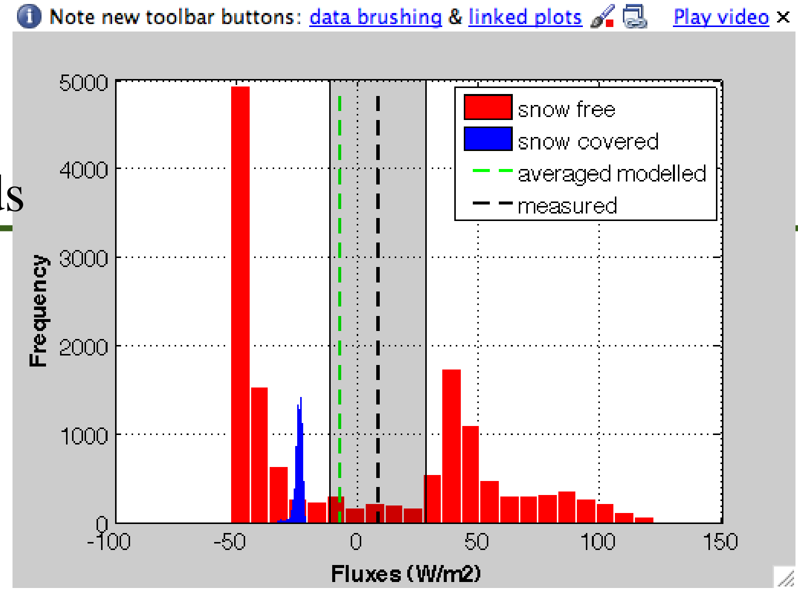
Spatially variable fluxes at “largere”scales

Modelled Sensible heat: 100 m grids

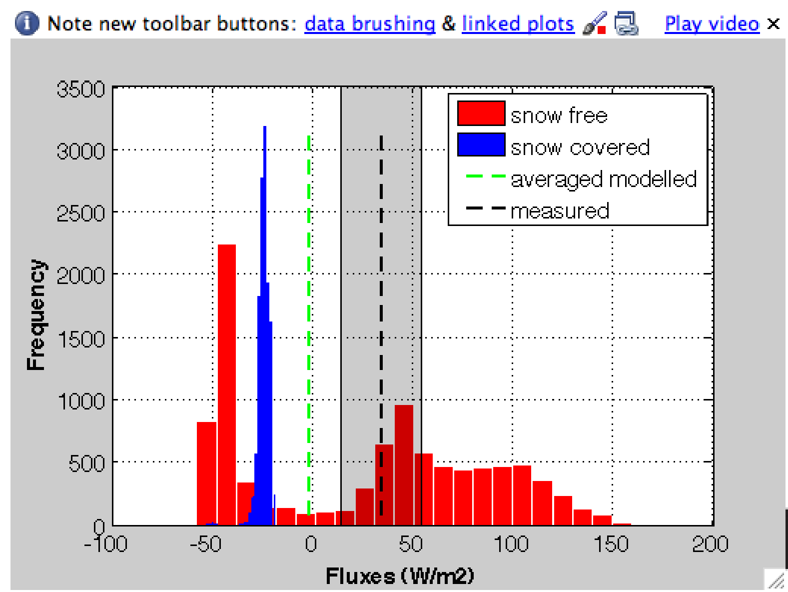
Sensible heat (W/m²): 3km x 3km grids from aircraft flux measurements

May 27, 1999



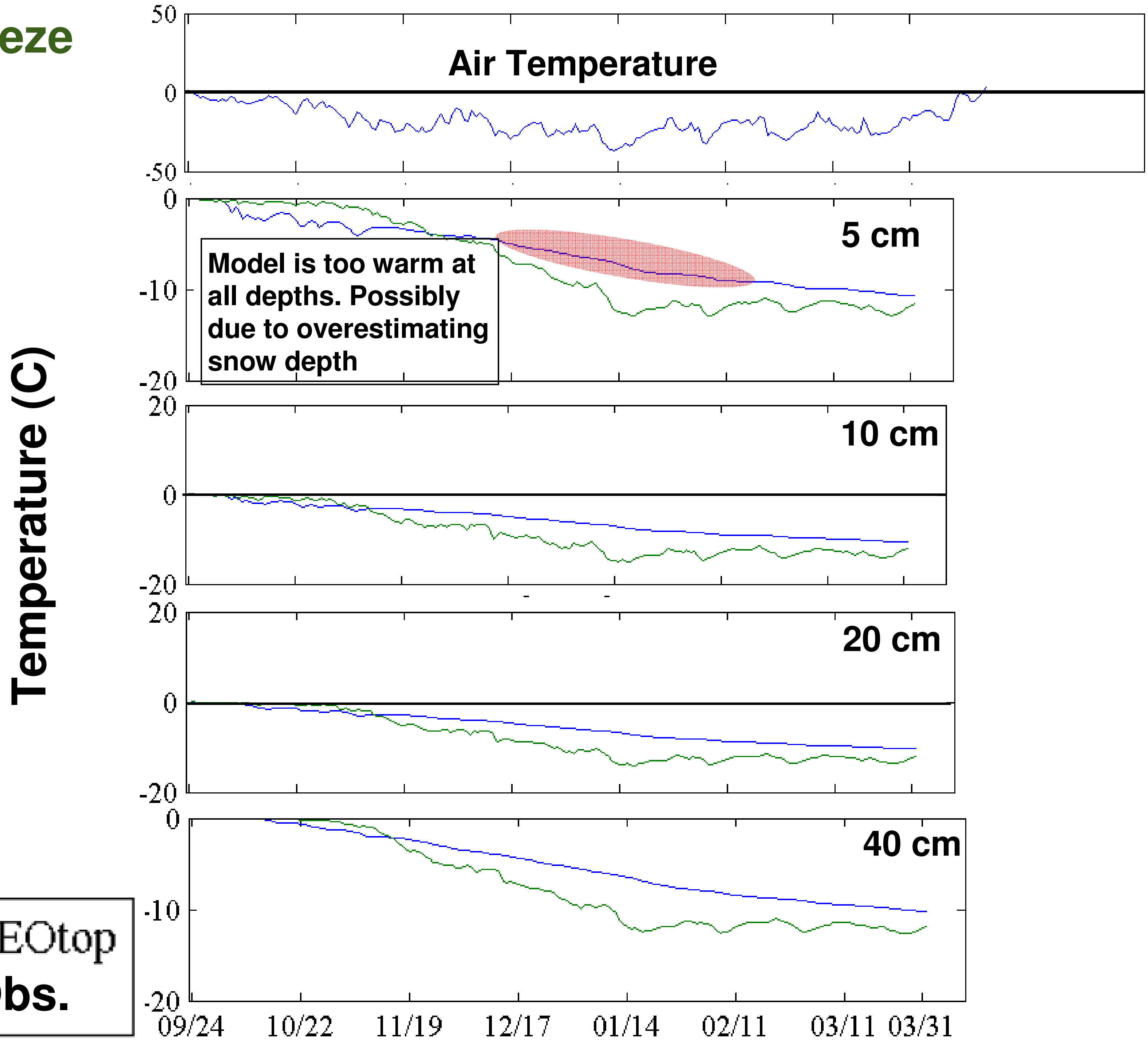


- For 15 of the 24 grids the modelled grid average is within the error bars of the aircraft data



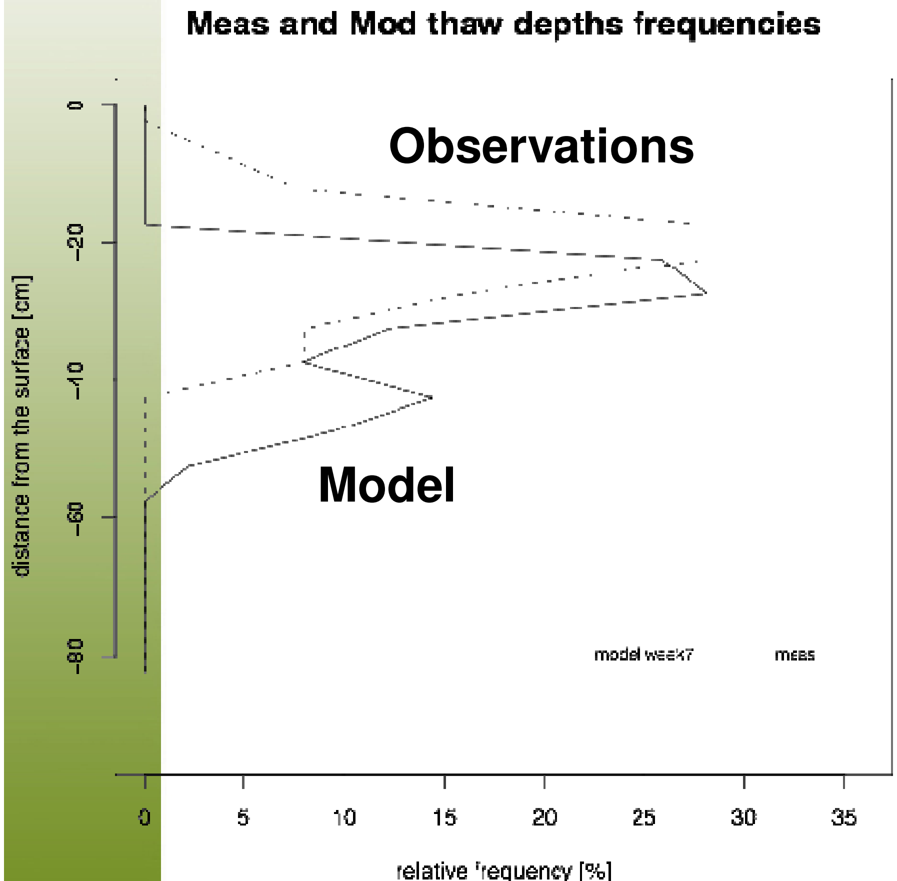
Environment Canada Environnement Canada

C) Soil freeze back

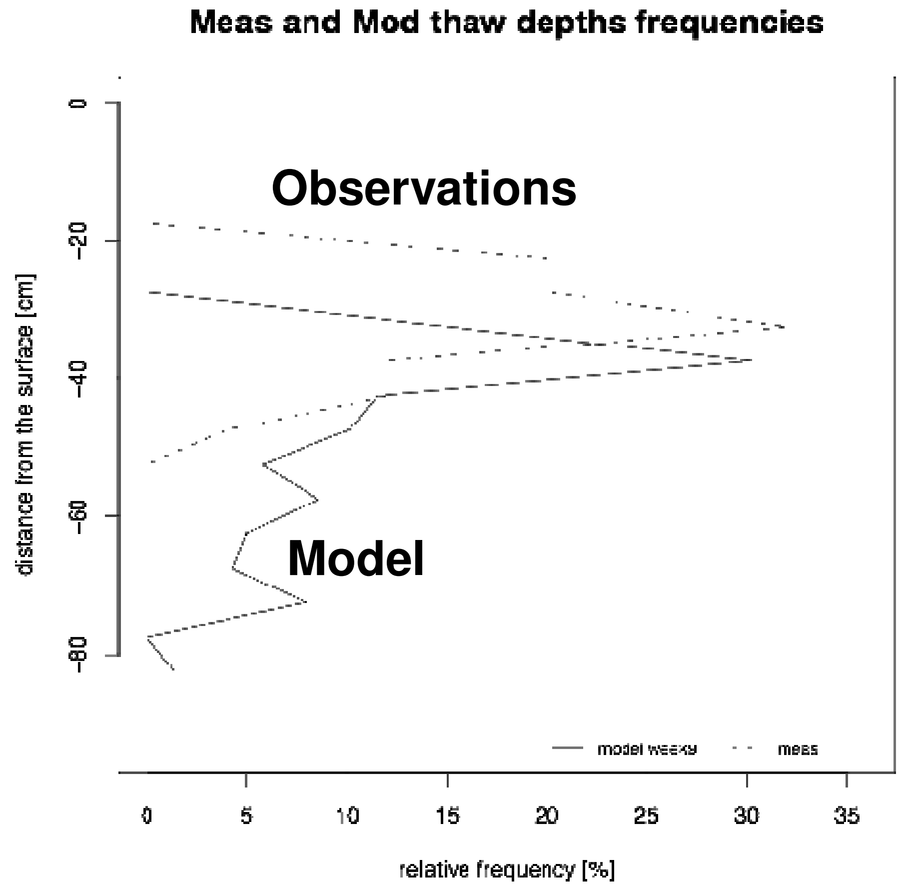


D) Soil thaw - over a small domain

15-16 Jul

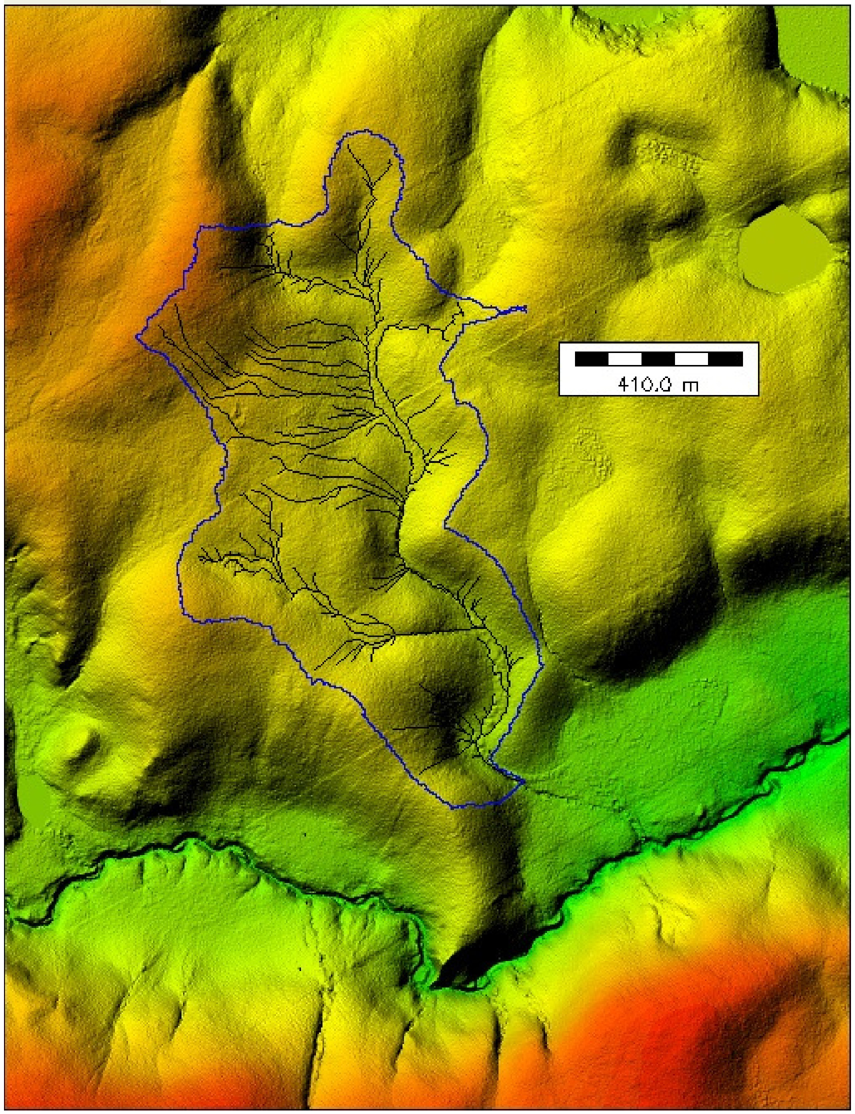


9-10 Sept



Slight overestimation, but captures range of variability

E) What factors control the end of summer thaw depth (mm)

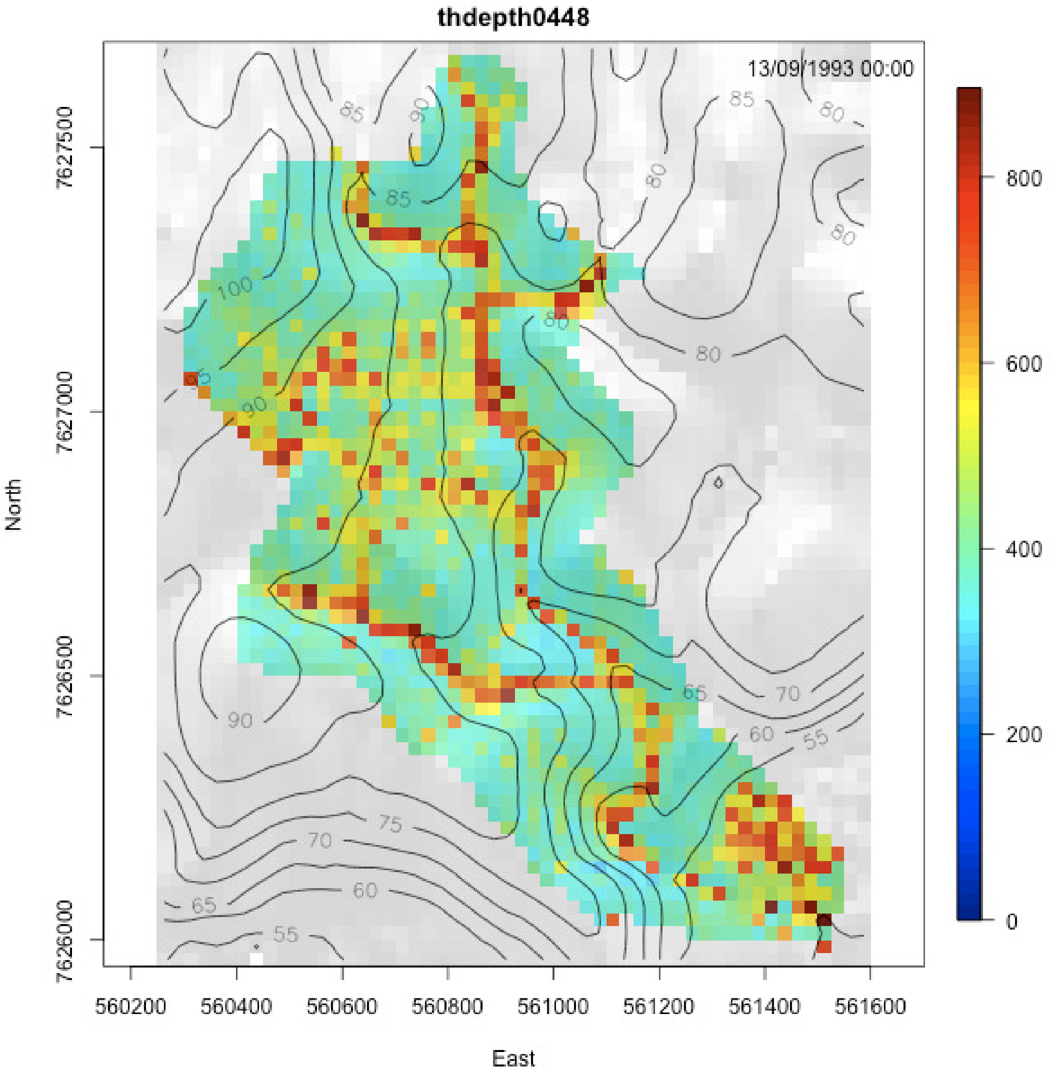


- Consider the integration of snow, radiation, turbulent fluxes, and vegetation on active layer melt over the summer
- also include spatial variability in organic layer depth

Siksik Ck., a sub-basin of Trail Valley Creek

Canada

Spatially variable end of summer active layer depth



“While ground surface topography obviously plays an important role in the assessment of contributing areas, <u>the close coupling of energy to the hydrological cycle in arctic and alpine tundra” is extremely important.</u> Quinton and Carey, 2008

HYDROLOGICAL PROCESSES
Hydrol. Process. **22**, 4649–4653 (2008)
Published online 15 October 2008 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.7164

Towards an energy-based runoff generation theory for tundra landscapes

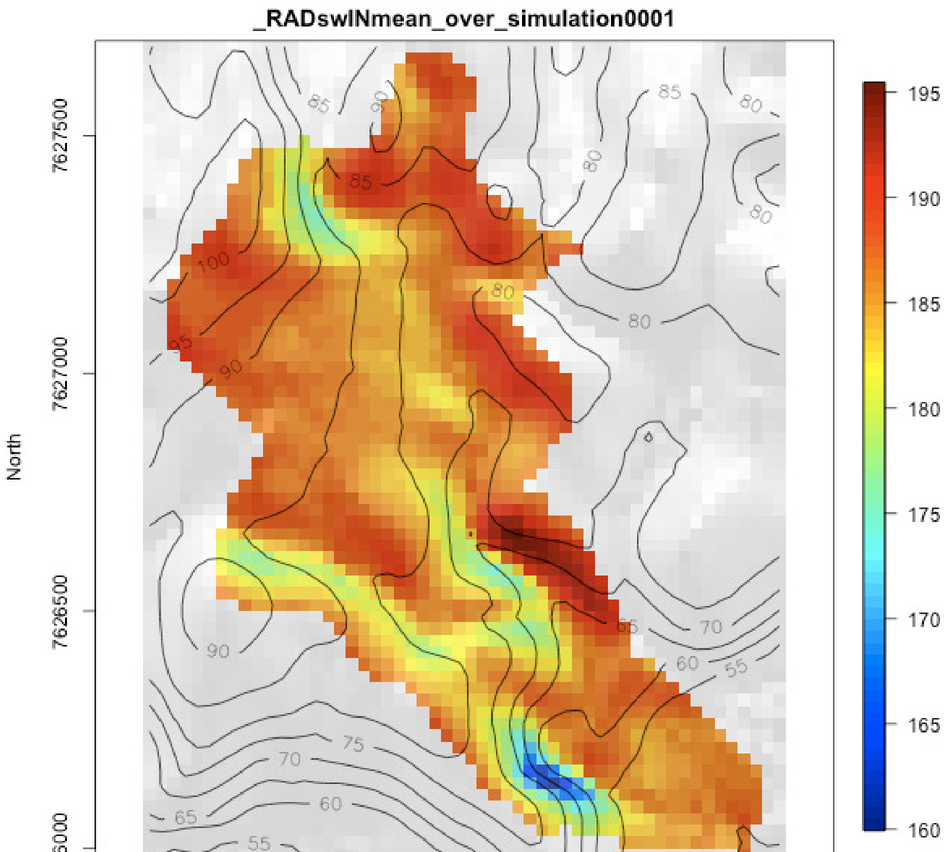
Environment Canada Environnement Canada

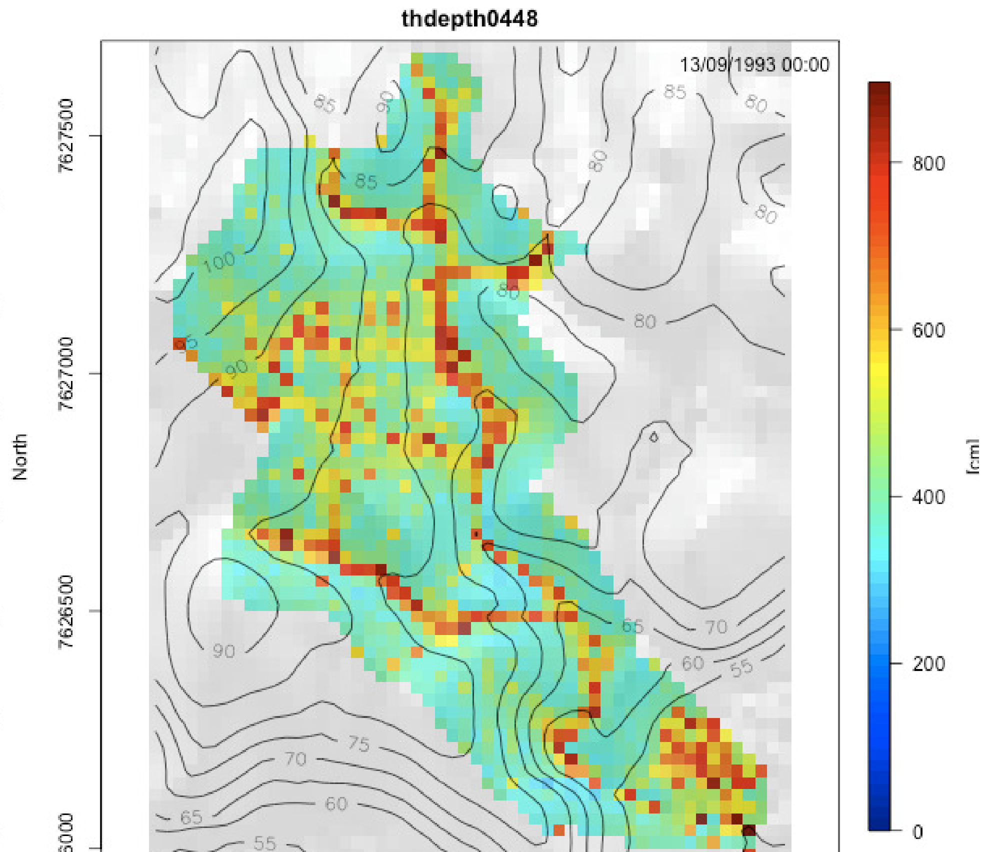
Consider first order effects only. Start simulation with no snow in late May and only tundra veg.

Radiation vs thaw depth

average net shortwave radiation [W/m2]

end-of-summer thawed soil depth [mm]



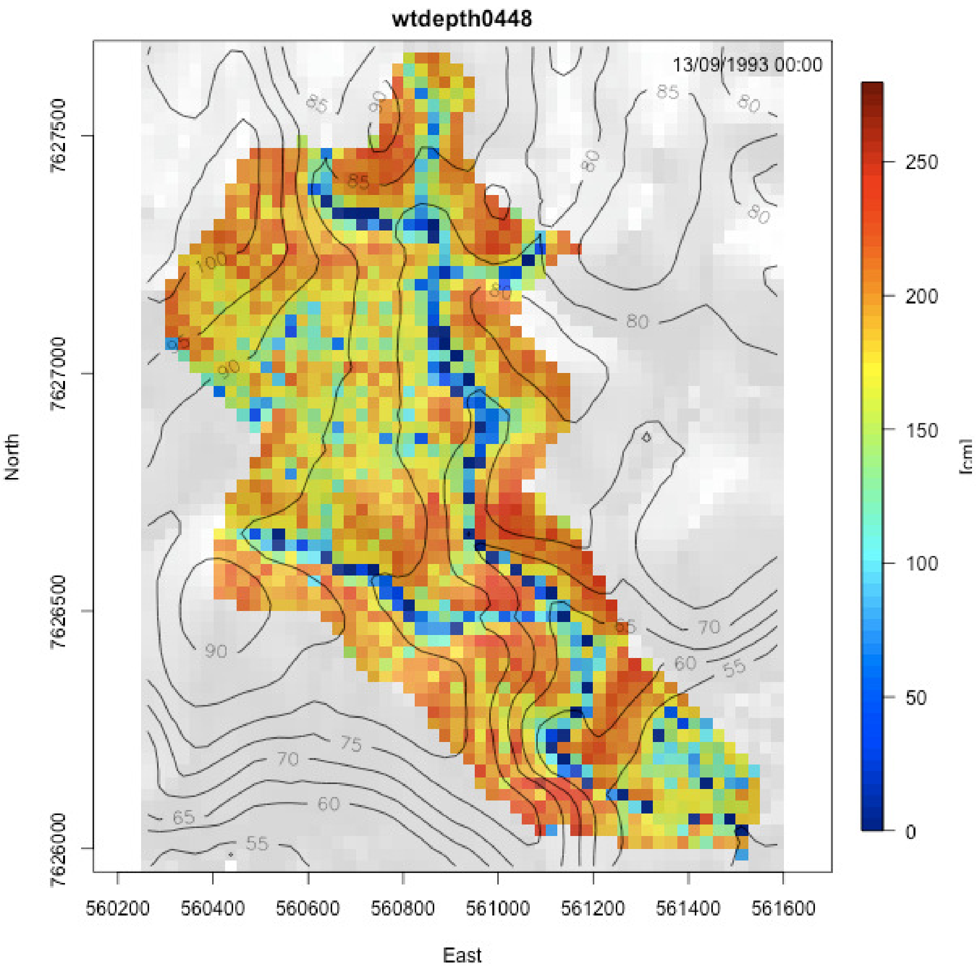


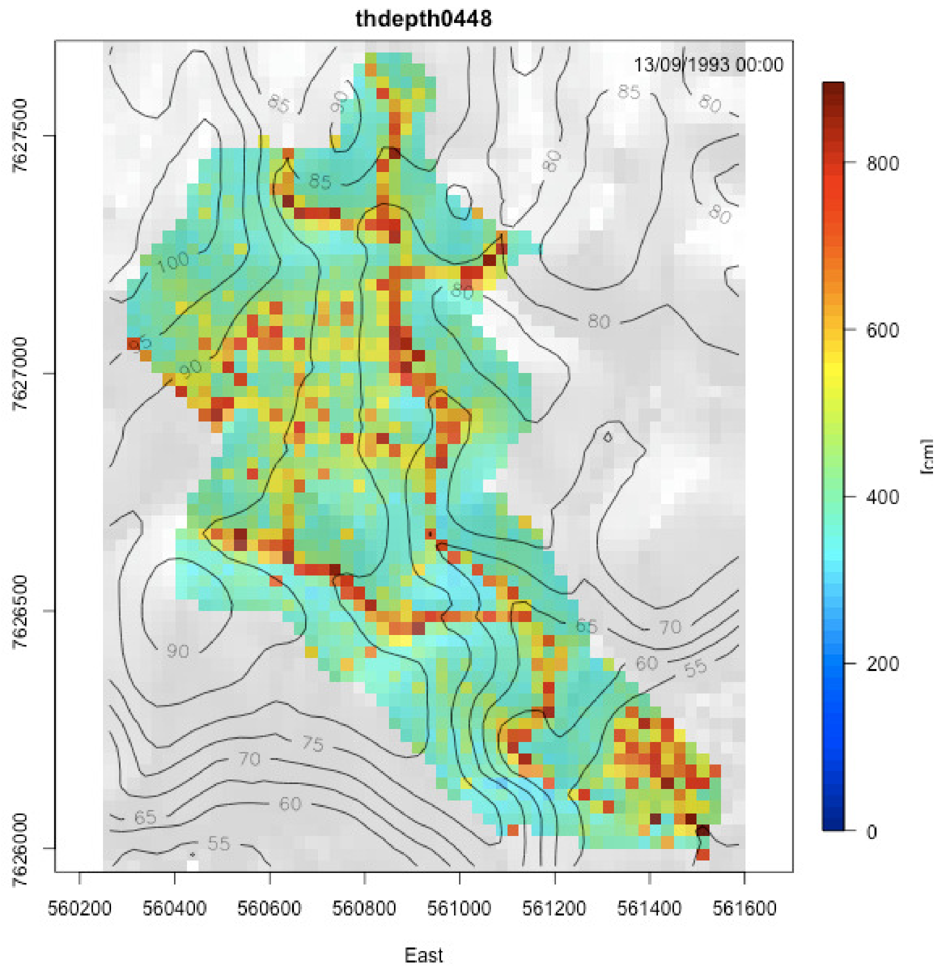
No relationship between surface radiation and thawed soil depth

Water table depth vs thaw depth

end-of-summer water table depth [mm]

end-of-summer thawed soil depth [mm]

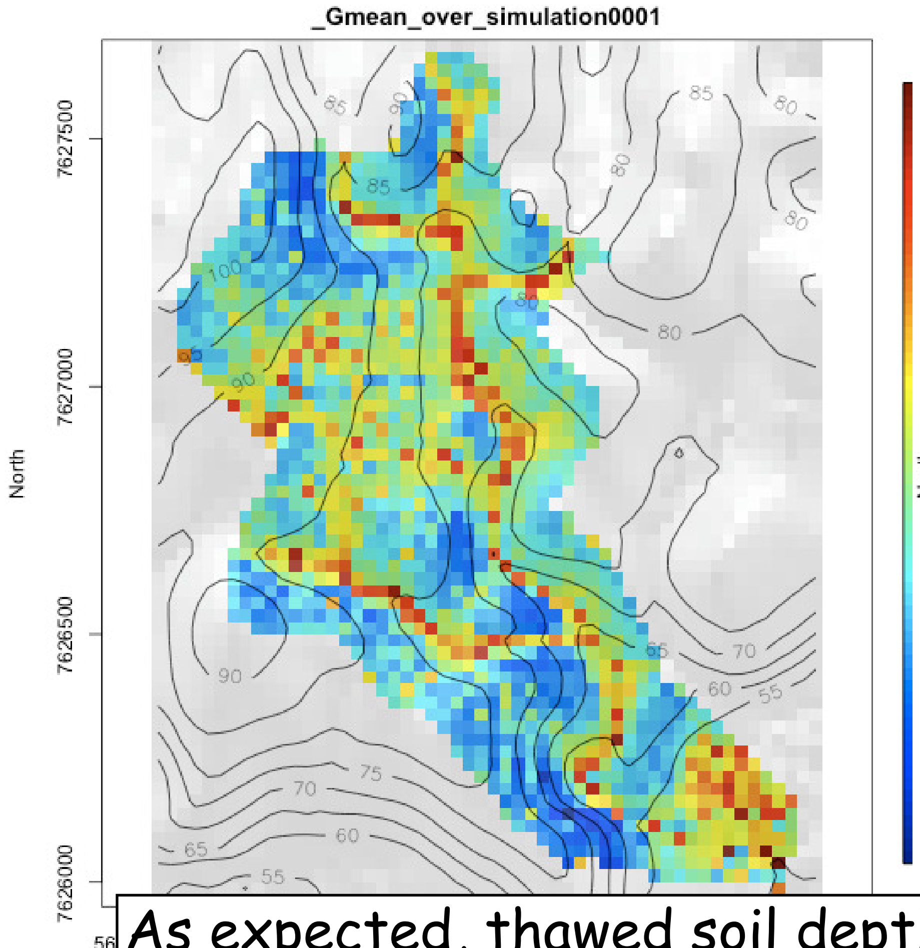


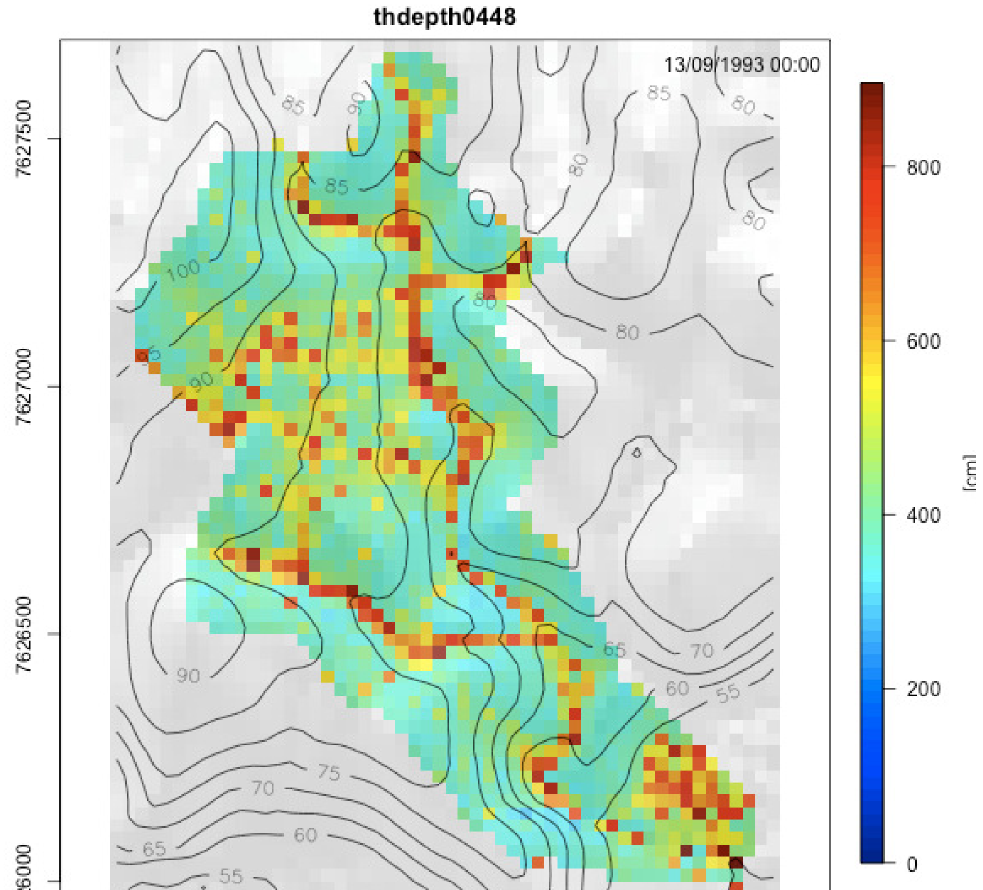


Net surface heat fluxes vs thaw depth

Net surface heat fluxes [W/m2]

end-of-summer thawed soil depth [mm]





As expected, thawed soil depth mirror surface heat flux

Explanation of these relationships

- In an area with gentle topography, little relationship between slope/aspect and thaw depth
- Higher water tables means higher water contents, and <u>increased overall soil thermal conductivity</u>
- Water flowing from areas with deeper water table to areas with shallower water table during thawing process carries energy (<u>advection</u>)
- Wetter areas have higher energy fluxes from the atmosphere (radiation and turbulent fluxes) due to lower albedo and higher sensible flux (ie large gradient between warmer air and cool surface) which offsets the loss of energy to higher evaporation.

5) MESH Model Runs

- will use some of the preceding results to help determine appropriate Grouped Response Units (GRUs) used in MESH

- Following will use the following GRUs
  - Base Runs with:
    - tundra, shrub tundra, forest, water
  - Above + Snow GRUs with:
    - windswept tundra, drifts
    - all GRUs have same energy input
  - Above + Energy GRUs with:
    - North and South slopes
    - GRUs have different energy input

MESH Model Runs

- MESH version 1.3 was run for TVC from May 1st to Sep 30th for 1996 to 2006
- Model was run at resolution of 1 km

- **Base Case**: used "traditional" vegetation based land cover classes:
  - **tundra**
  - **shrub tundra**
  - **forest**
  - **water**

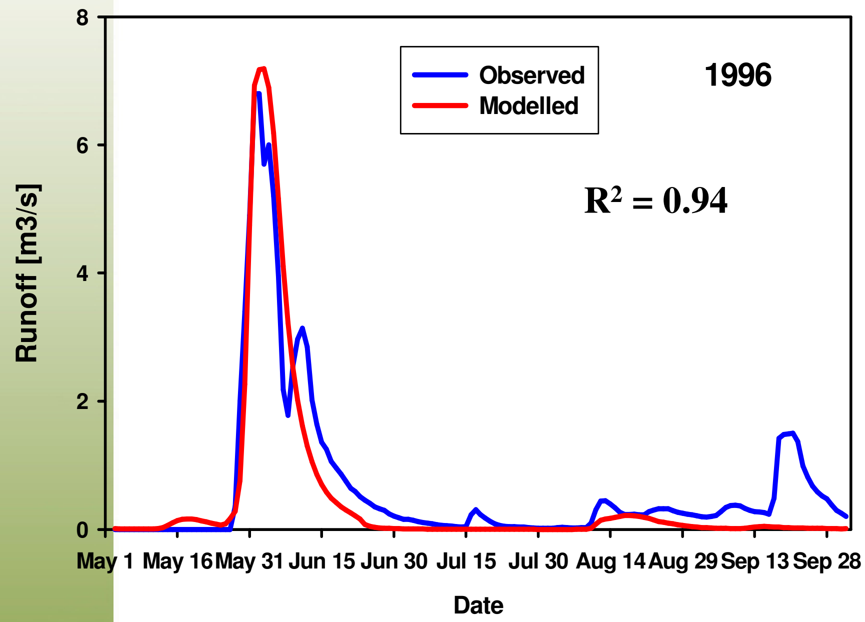
MESH Model Runs: "**Snow GRUs**"

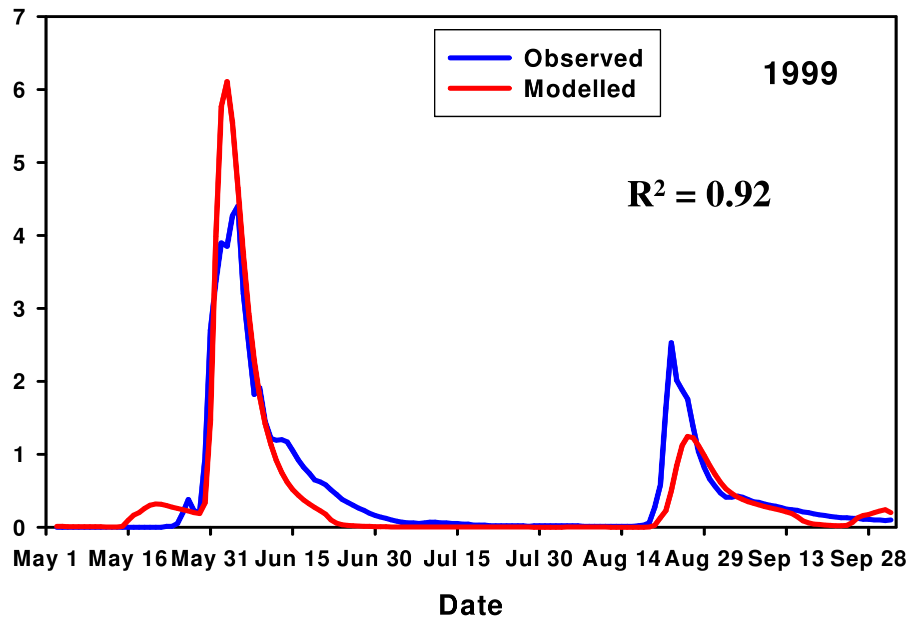
- To better capture end of winter snow cover variability, topography based GRUs were added
- Added were:
  - **windswept tundra and**
  - **snow drifts**
- All GRUs receive the same energy inputs but have a different end of winter snow cover

MESH Model Runs: "**Energy GRUs**"

- Finally, GRUs were chosen according to land cover type and slope orientation to improve the energy, especially solar radiation, input
- Added were:
  - **north facing tundra slopes and**
  - **south facing tundra slopes**
- The added GRUs receive the same end of winter snow cover inputs as the tundra GRU but different solar radiation inputs

Calibration Years





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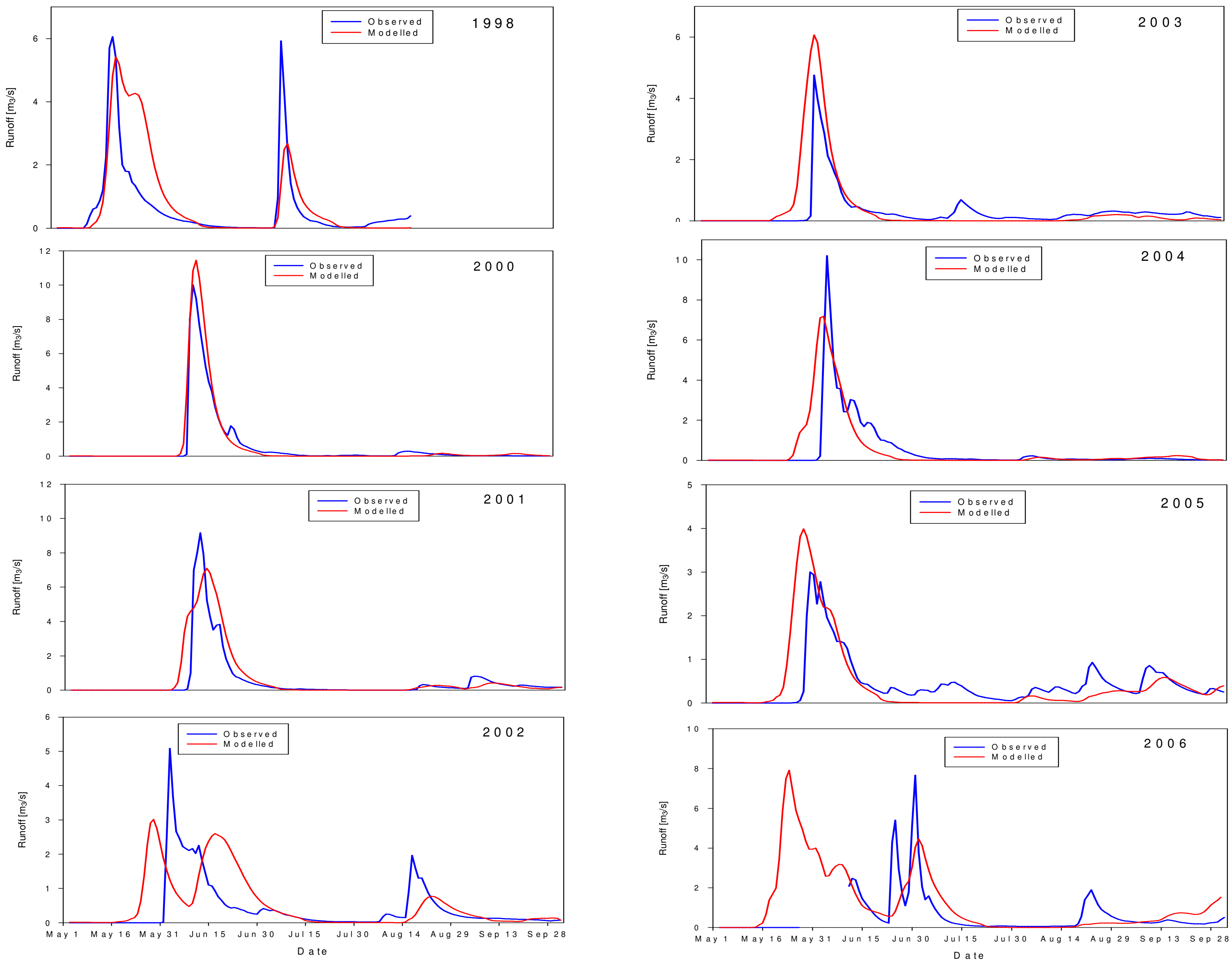
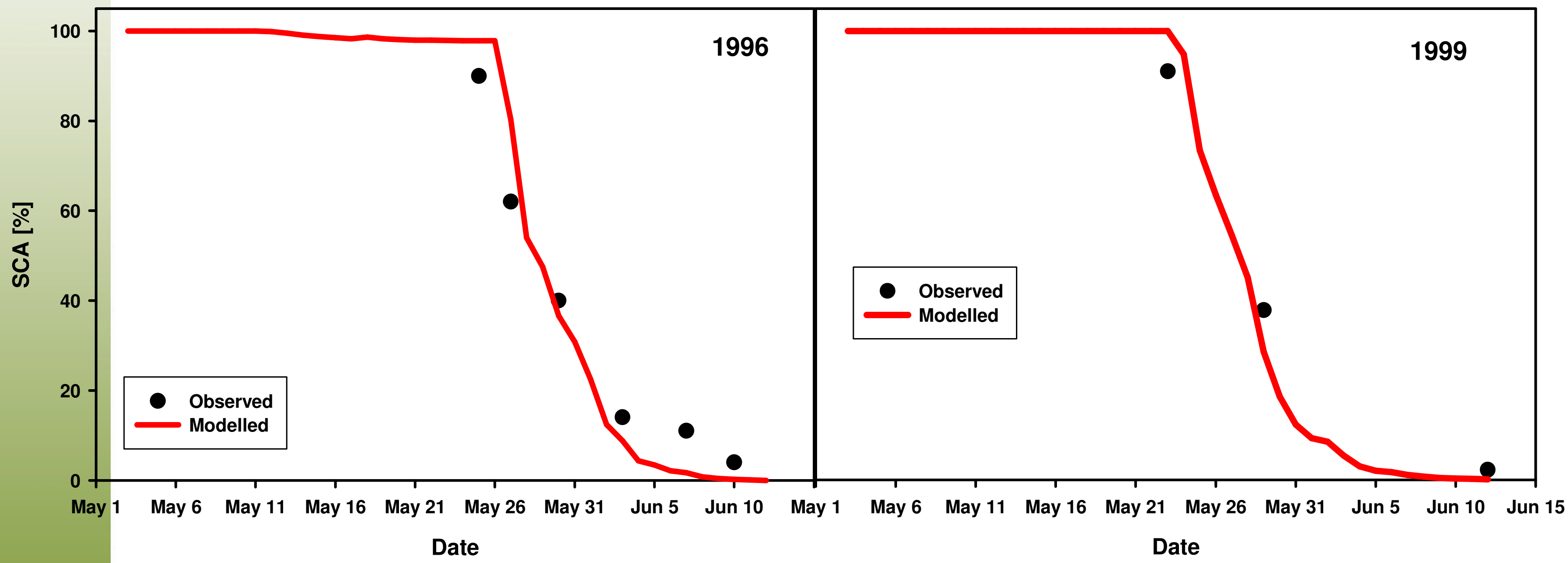
“Base” case: Discharge



Base Case: Discharge Statistics

	Modelled Peak Volume %	Modelled Total Flow Volume %	Modelled Spring Flow Volume %	R^2
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

Base Case: Basin Average SCA



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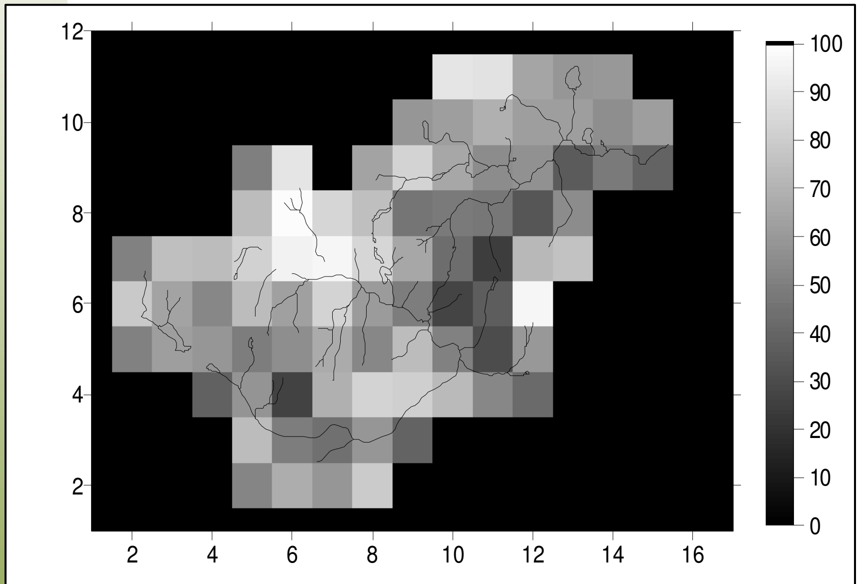
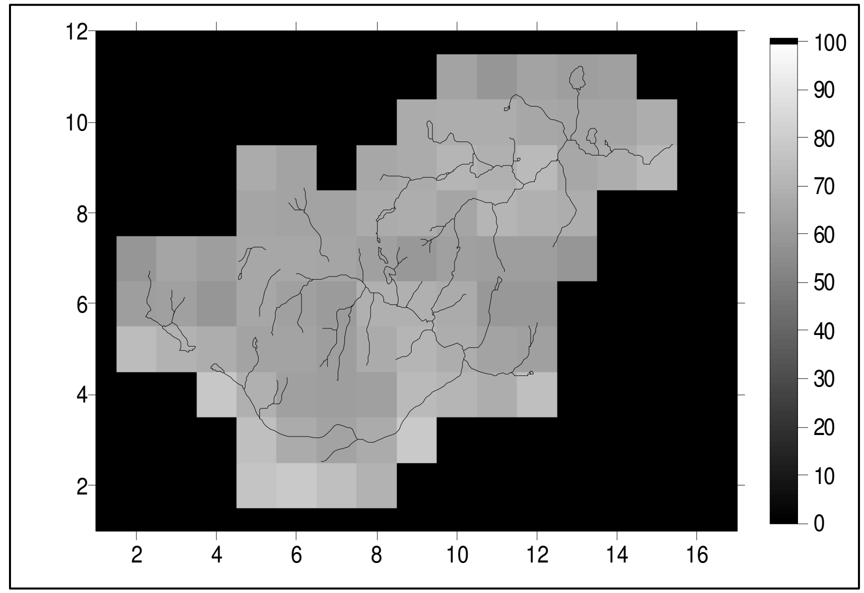
Base Case: Spatial Variability in Snow Cover Area (SCA)

Observed



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

Simulated



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

Base Case: Spatial Variability (SCA)

Date	Observed SCA AVG %	Observed SCA Max %	Observed SCA Min %	Observed SCA Range %	Modelled SCA AVG %	Modelled SCA Max %	Modelled SCA Min %	Modelled SCA 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

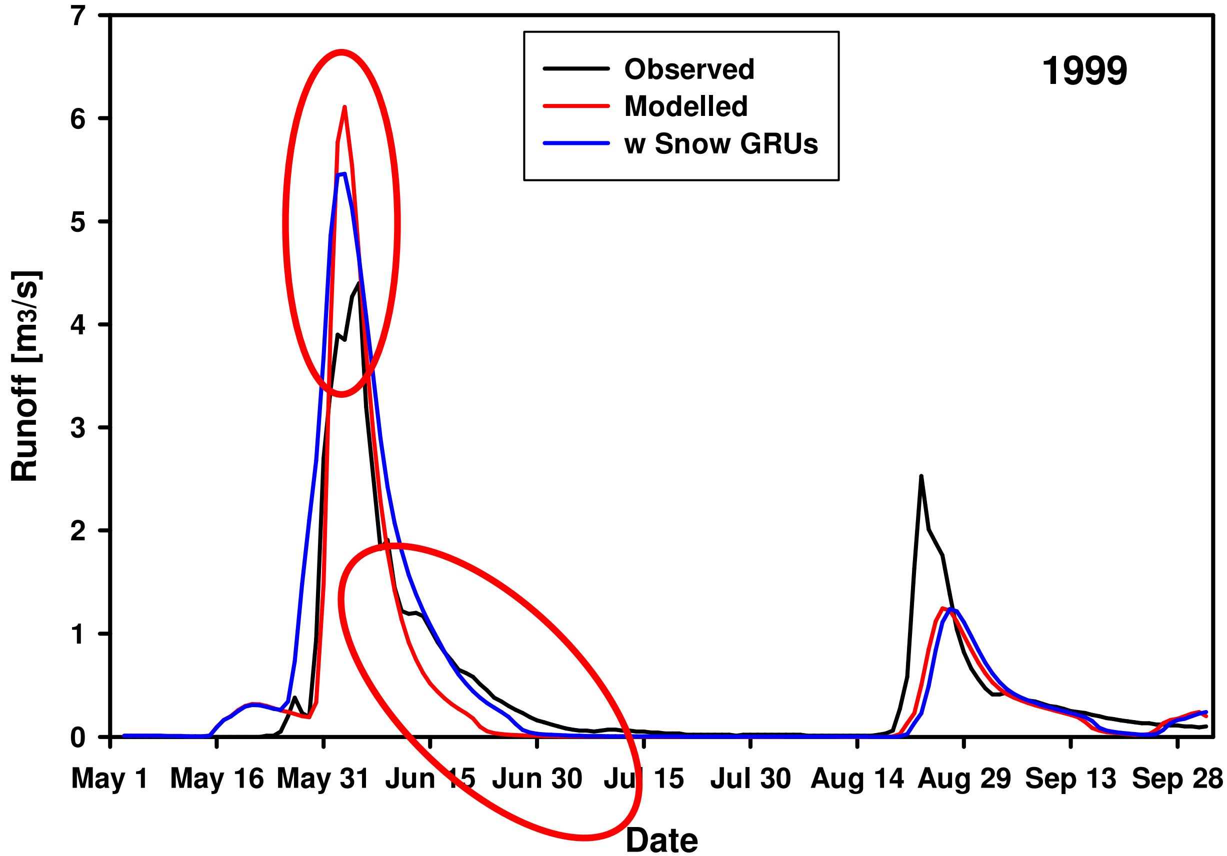
Base Case: Spatial Variability of End of Winter Snow Cover

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

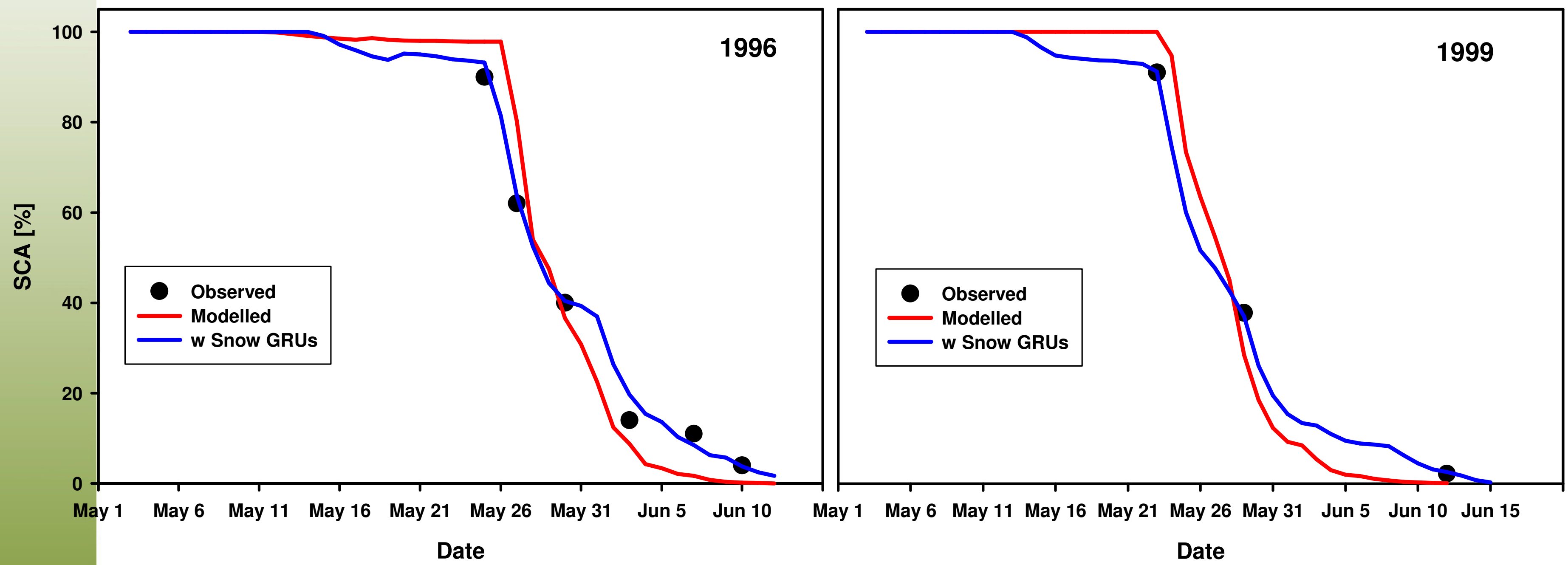
  - Spatially variable end of winter snow cover mainly due to blowing snow processes
  - Spatial variability in the snowmelt energy balance factors

Snow GRUs: Discharge

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



Snow GRUs: Basin Average SCA



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Snow GRUs: Spatial Variability SCA (1996)

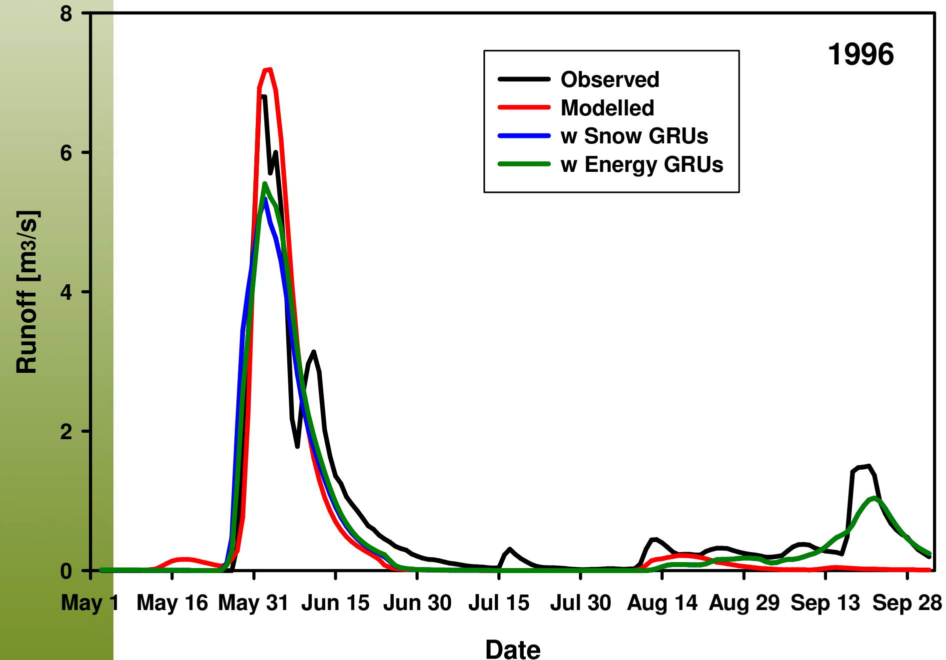
Date	Observed SCA AVG %	Observed SCA Range %	Modelled SCA Base Case AVG %	Modelled SCA Base Case Range %	Modelled SCA with Snow GRUs AVG %	Modelled SCA with Snow GRUs Range %
23-May	90	45	95	12	91	16
25-May	62	75	65	35	62	49
28-May	40	76	38	47	40	60
1-Jun	14	38	8	22	16	38
5-Jun	11	32	3	8	10	26
8-Jun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

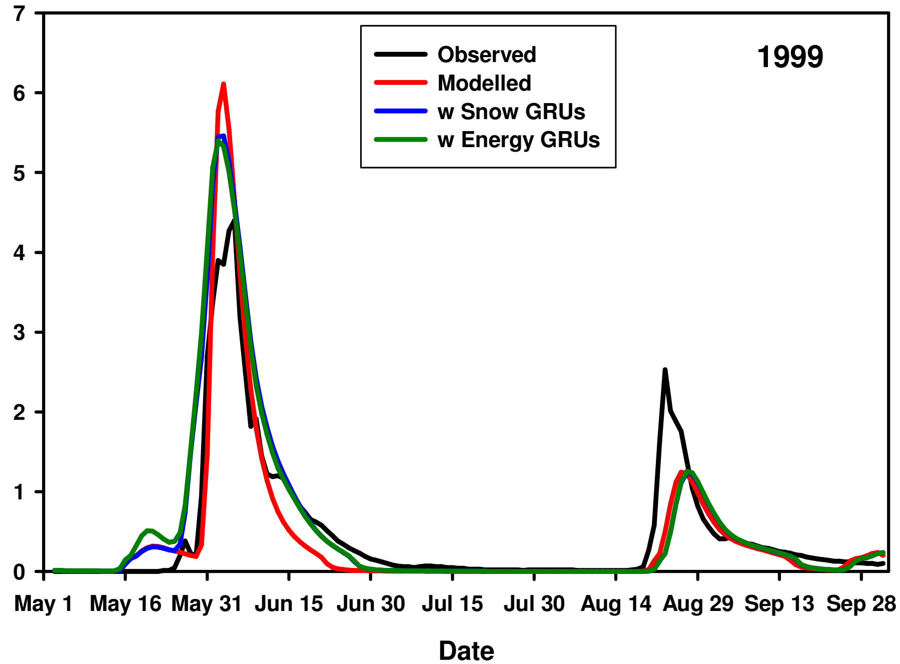
Snow GRUs: Conclusions

- 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

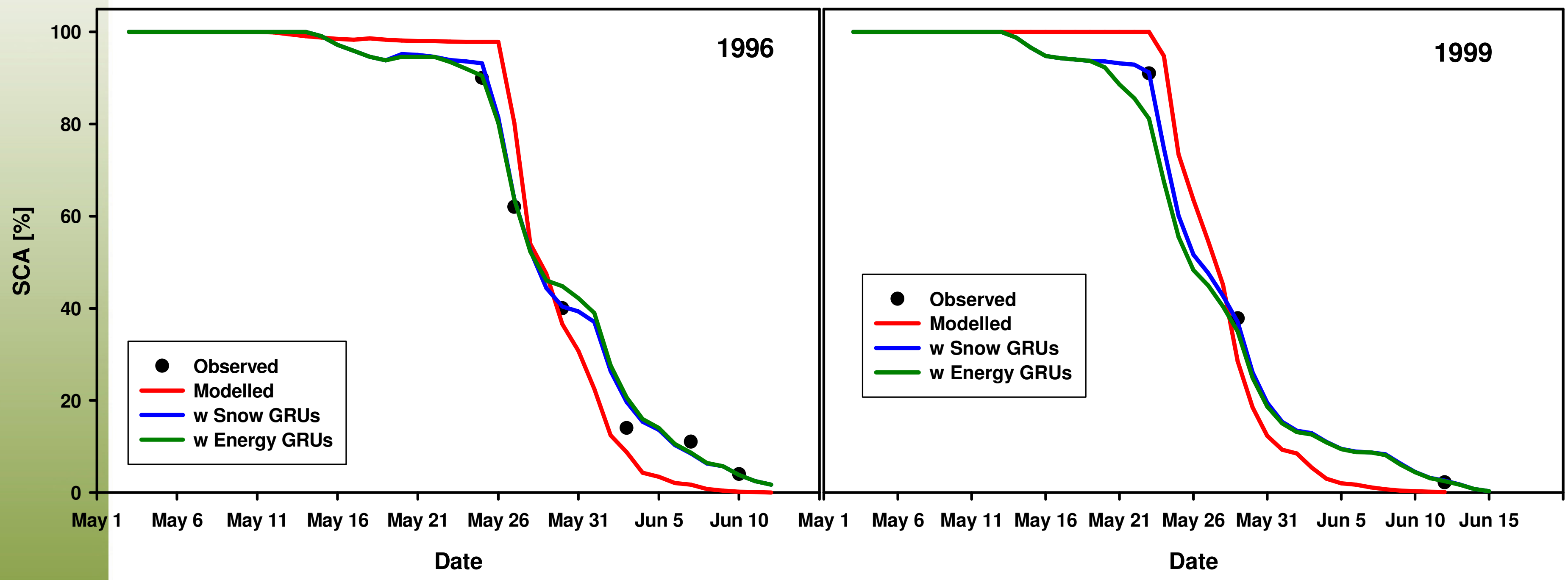
Energy GRUs: Discharge

- Generally: Little change in runoff, some added runoff early (1999) and around the peak (1996)





Energy GRUs: Basin Average SCA



Energy GRUs: Conclusion

- MESH simulation results of basin runoff did not change significantly
- Basin wide average SCA were predicted to drop slightly more quickly in the early part of the melt as a result of the south facing slopes becoming snow free more quickly
- The impact of the slower melt on north facing slopes on the basin average SCA seems to be overshadowed by the drift areas, that dominate the late season SCA in TVC

6. Conclusions

- through EC, MAGS, northern energy R&D, IP3 and IPY a large data set has been obtain for an Environment Canada research site (TVC) in the western Canadian Arctic that provides necessary data for testing models

- a variety of models have been tested, and improved, for considering various aspects of the northern hydrologic system

- demonstrated that our knowledge is sufficient and our models robust to consider the current hydrologic conditions, and begin to consider future changes from development and climate change

7. Next steps

- Model improvement
  - Improved wind flow model
  - addition of a lake model
  - compressible soil layers to consider subsidence with melting of ice rich permafrost
  - dynamic vegetation

- Model application
  - consider past changes in hydrology
    - effect of increase in shrubs over last 30 yrs
    - effect of changes in climate over last 50 yrs
  - Include snow and vegetation in modelled frost table development
  - future climate scenarios, where we can consider integrated effects of changing vegetation and active layer for example
  - Consider the effects of changing channel system due to melting of ice rich permafrost, and resulting thermokarst subsidence