Snowcover accumulation and soil temperature at sites in the western Canadian Arctic

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1. Objectives

- **Funding is from, and primary objective is:**

  – <u>GOC Northern Energy Studies</u>: provide support to Indian and Northern Affairs Canada (INAC) to develop appropriate *regulations controlling when industry can access the land in early winter*

- **Science to do this is based on funding from:**

  – <u>IP3 and IPY:</u> improved understanding and prediction of the hydrology of northern environments

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

Land access regulations in northern environments - Alaska

- **Alaska regulations (Bader and Guimond, 2004, Alaska Dept. of Natural Resources)**

    - overland tundra travel by vehicles can occur when

        - soil temperature in upper 30 cm of soil, is less than –5 degrees Centigrade,

        - Snowcover greater than 15 cm to 23 cm depending on vegetation type

- **Timing of land access varies by many weeks depending on the soil temperature used (ie -3C vs -5C).**

Land access regulations in northern environments - Canada

- I believe, but am trying to confirm, that Indian and Northern Affairs Canada (INAC) regulations in northern Canada are simply based on a date in early winter when industry is allowed to access the land

- Problem with this approach: with a warming climate, and large interannual variability on the date of snowcover development and soil freezing, there is a need for methods to estimate when conditions are appropriate to access the land

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Question

- Are we able to predict the 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?

- This presentation will present very preliminary results based on 2009-10 field observations on ongoing model testing and improvement

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2. Study area and field observations

Beaufort Sea

Tuktoyaktuk

TVC

Inuvik

Aklavik

Tsigehtchic

Ft. McPherson

Mackenzie Basin

TVC – Trail Valley Creek
TVC Basin area is approx. 60 km^2

Tundra

Main Met and MSC station

Trail Valley Creek

WSC TVC discharge

Shrub

Tundra station

Shrub

Forest

Drift

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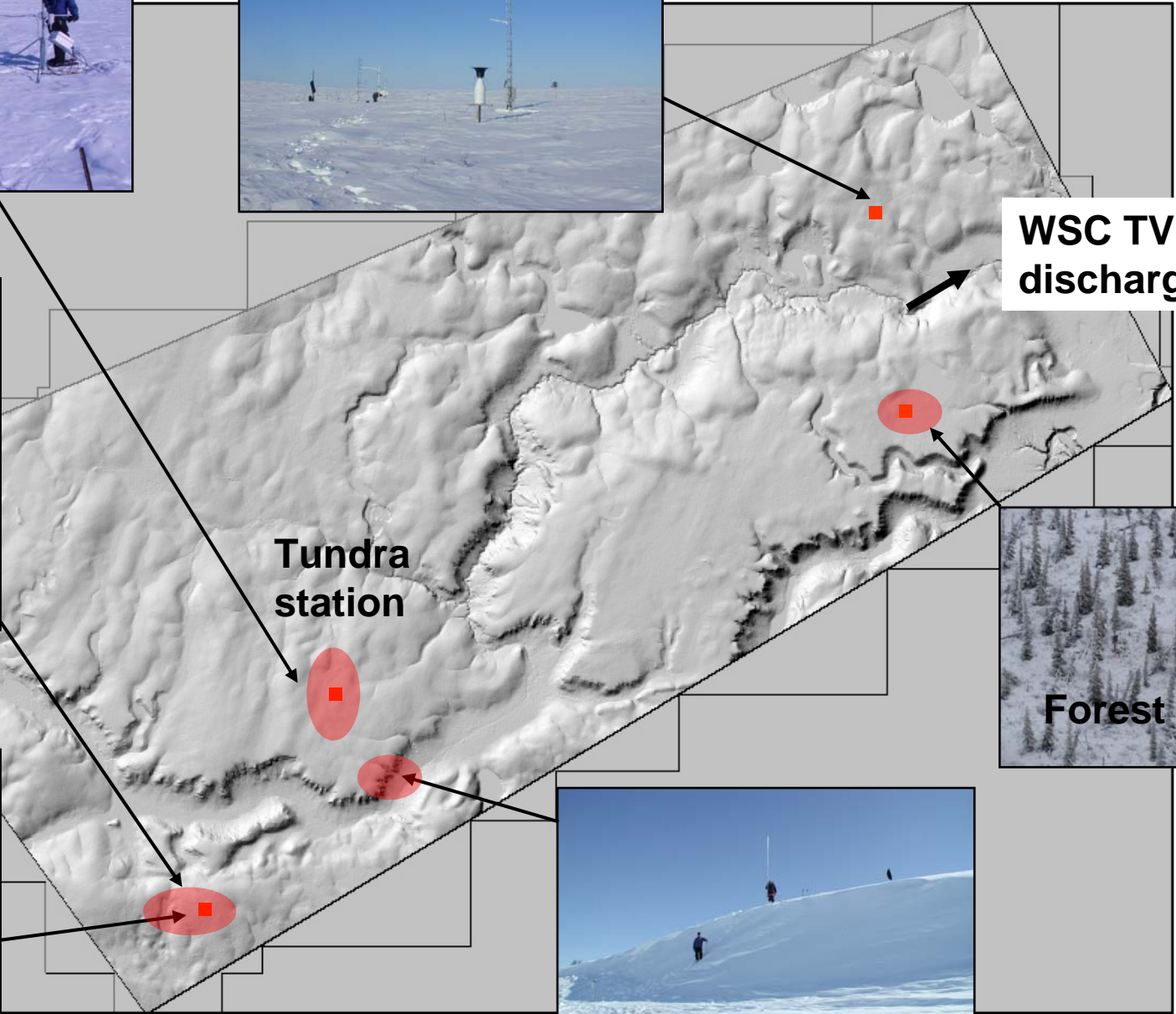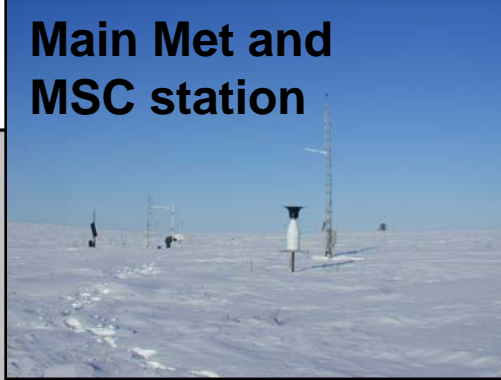
Field Observation of snow and soil temperature

- **<u>Four vegetation & terrain types</u>**
  - Tundra; Tall Shrub; Large drift; and Forest

- **<u>Measurements</u>**
  - 5 sites at each domain (except only 1 at forest)
    - Continuous snow depth: Campbell SR50 sonic ranging sensor
    - Ground temperate at 5, 10, 20, and 40 cm using hobo loggers

  - Meteorological stations at Tundra, Tall Shrub and Forest sites
    - Air temperature, wind speed and direction, precipitation

  - snow surveys

  - Digital snow pillow at Forest site – developed by CRREL in Alaska

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Tundra and drift sites

Tundra

Slope drift location
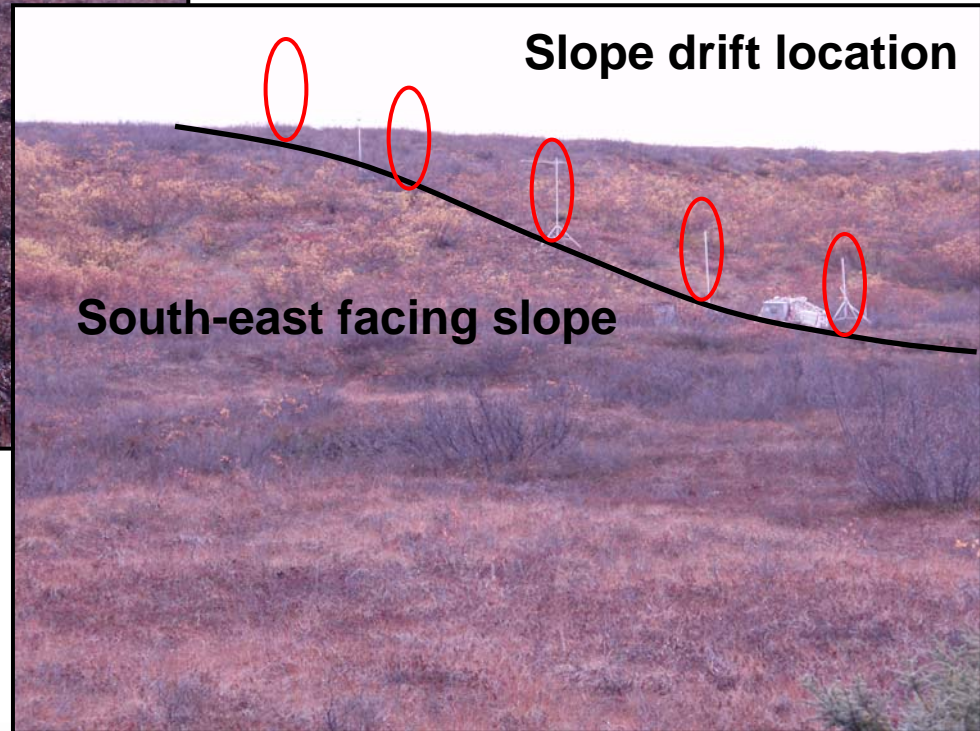
South-east facing slope

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Tall Shrub and Forest Sites

Shrub

Forest

No snow pillow data during winter 2009/10 due to a sensor failure early in the winter

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Digital snow pillow

Timing of field visits

September 2009
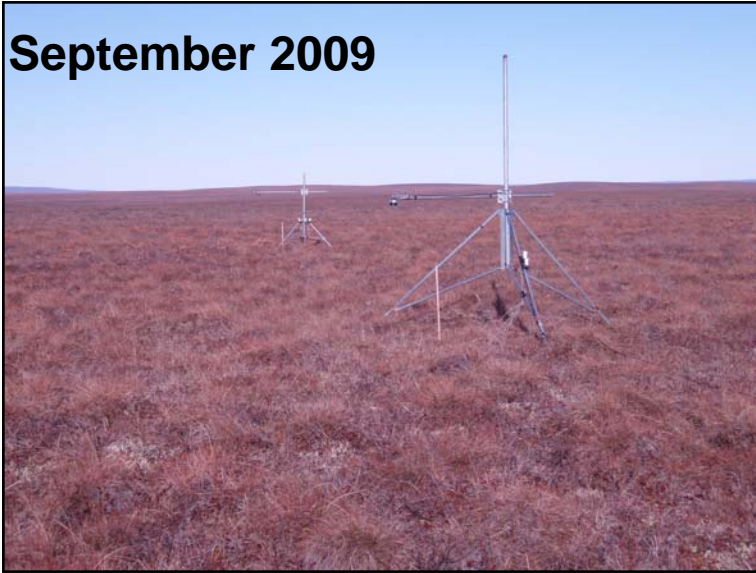
October 2009

March 2010

April 2010
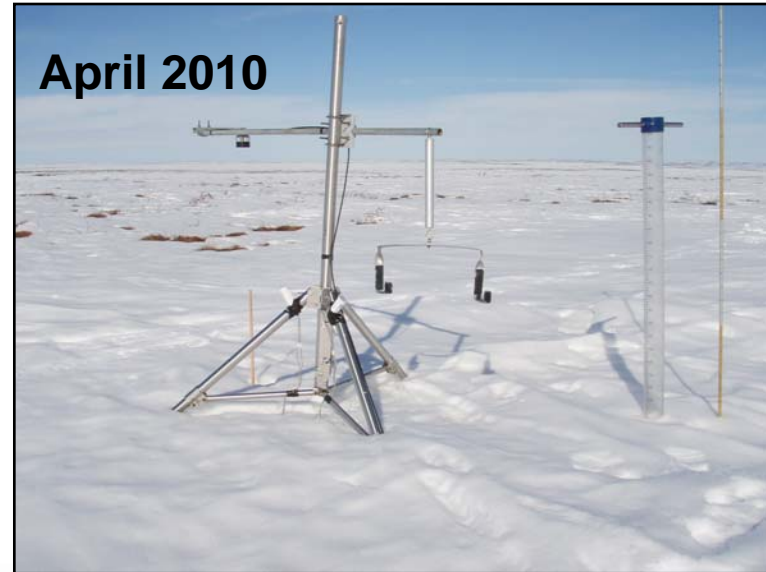
3. Hydrological modelling

- MAGS, IP3 and IPY studies have tested and improved a variety of models at Trail Valley Ck, including:

    – CLASS – Canadian Land Surface Scheme

    – MESH

    – CRHM – Cold Regions Hydrological Model

    – PBSM – Prairie Blowing Snow Model

    – GEOtop

    – Liston wind model

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In this study we will use GEOtop and PBSM

1. __Radiation__

- distributed model
- sky view factor, self and cast shadowing, slope, aspect, drainage directions..:

2. __Water balance__

- effective rainfall
- surface flow (runoff and channel routing)
- subsurface flow (3D Richards equation)

3. __Snow-glaciers__

- multilayer snow scheme
- glacier mass balance
- *PBSM blowing snow*

www.geotop.org

6. __vegetation interaction__

- multi-layer vegetation scheme
- evapotranspiration

5. __soil energy balance__

- soil temperature
- freezing soil

4. __surface energy balance__

- radiation
- boundary-layer interaction

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GEOtop
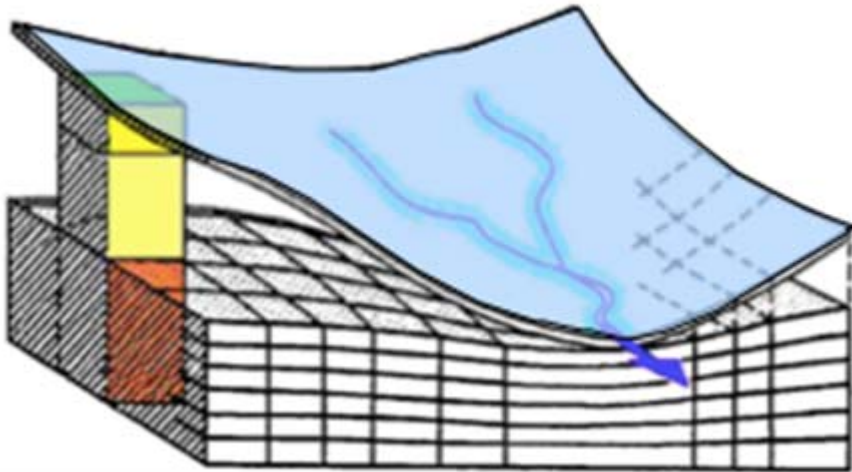
Figure adapted from SHE model (Abbot et al., 1986)
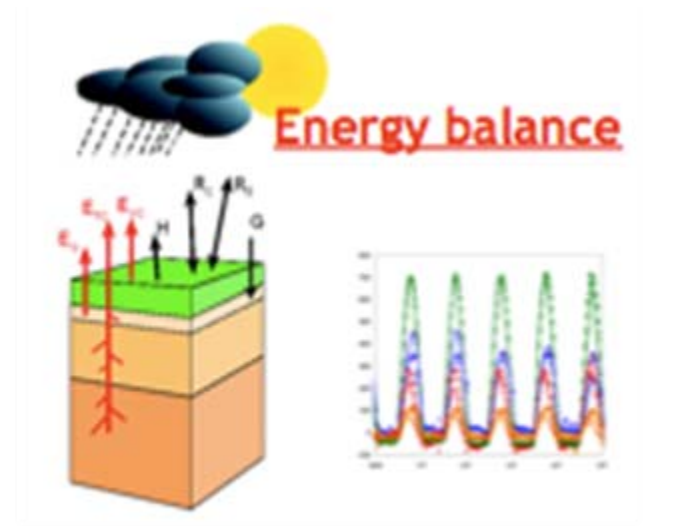
Figures adapted from VIC model (Liang et al., 1994)

The kernel of the model is a spatially distributed, **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.

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Blowing snow

GEOtop coupled with:

1) **Micromet** (Liston and Elder, 2006) to find a topographically consistent wind field, even if only based on curvature and slope. Tested at TVC by Pohl et al. for the "simple" terrain of TVC

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

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Other aspects of GEOtop have been considered to date

- **Sensible and latent heat flux**
  - Snowcovered and snowfree terrain
  - Tundra and tall shrub tundra
    - Various scales
      - Point (from tower)
      - 3km x 3 km (from aircraft)

- **Snow Covered area (SCA)**
  - Compare modelled SCA to SPOT and air photos during melt

- **Frost table development**
  - Spatial and temporal changes in frost table depth during the summer
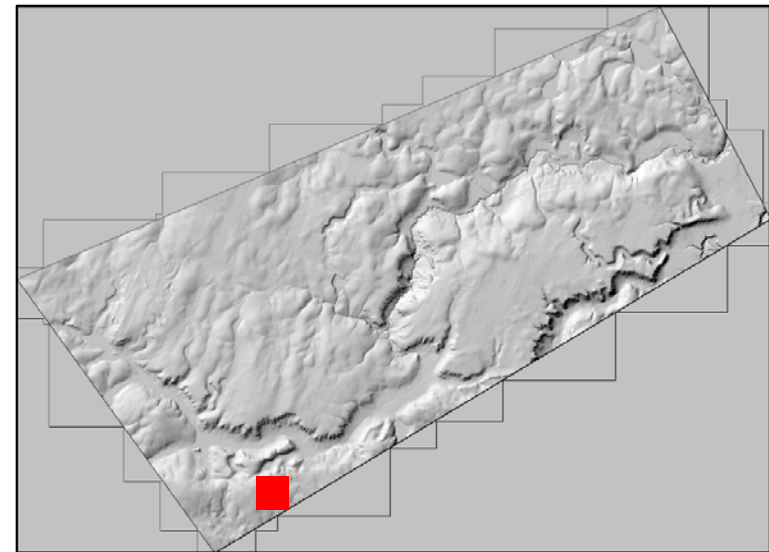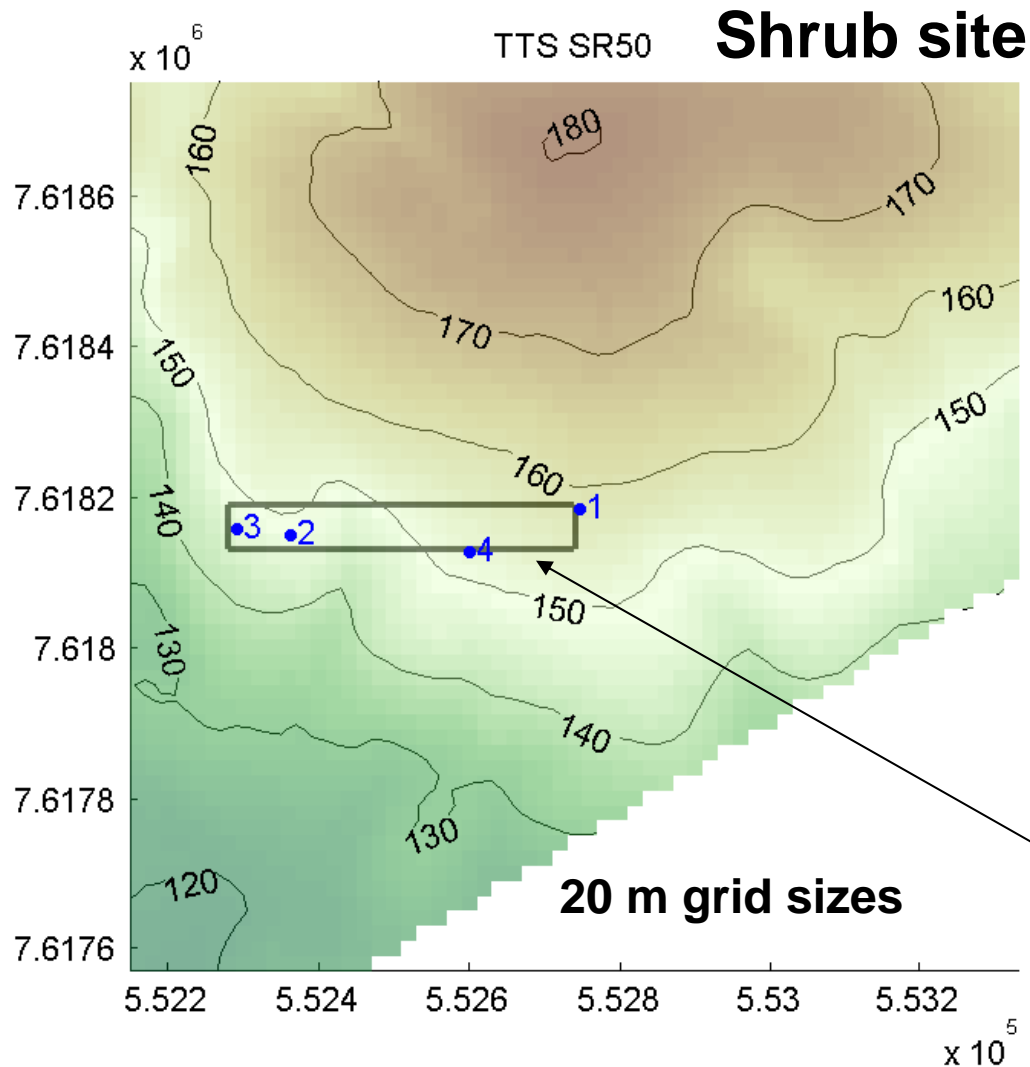
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Modelling domain (1.2 km x 1.2 km)

Shrub site
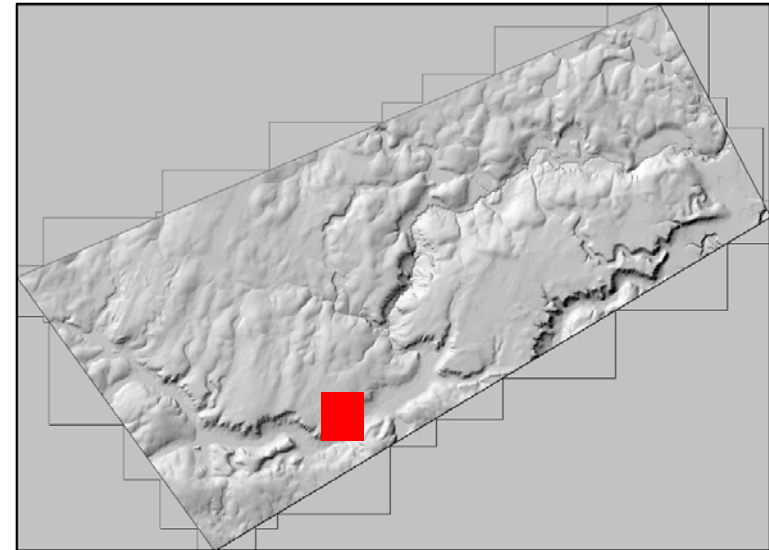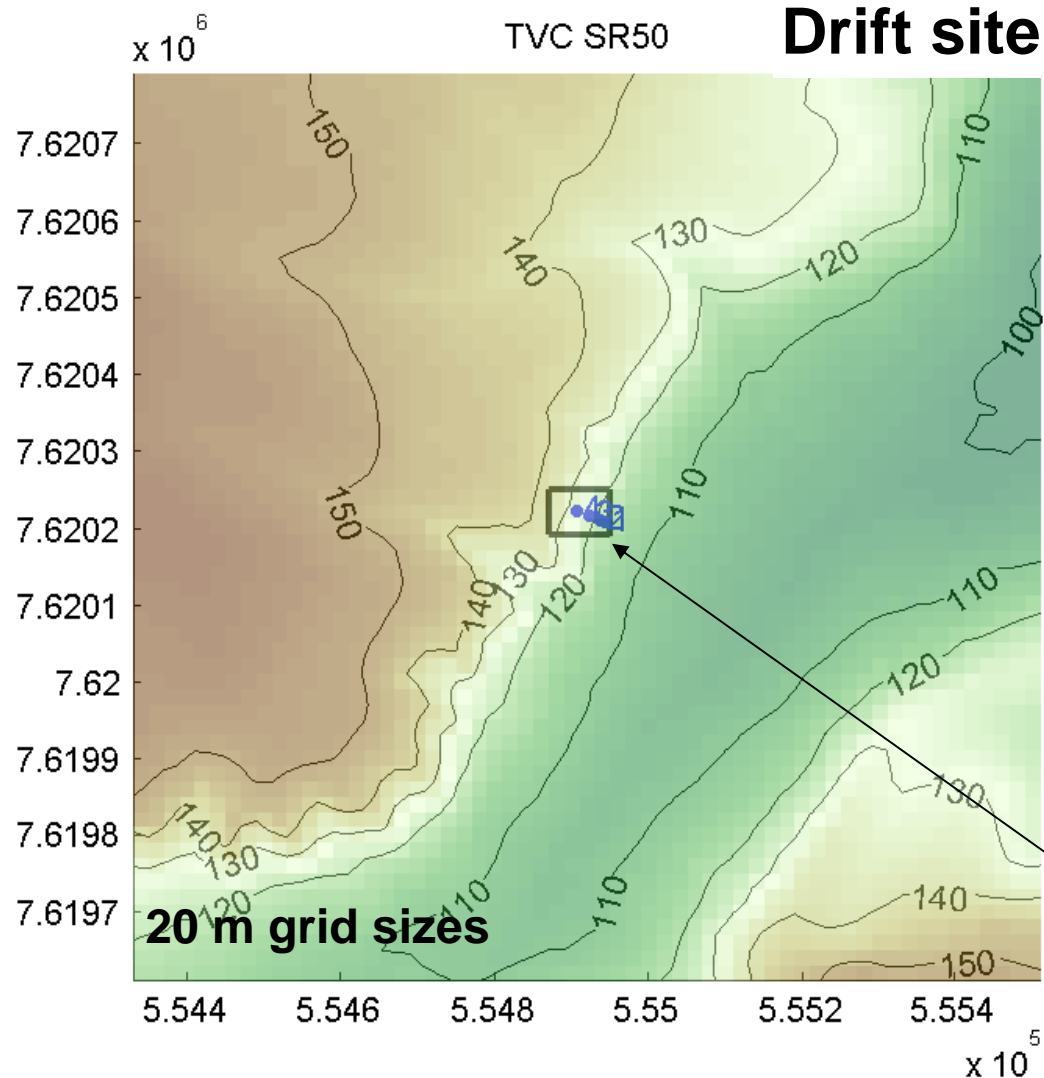
20 m grid sizes

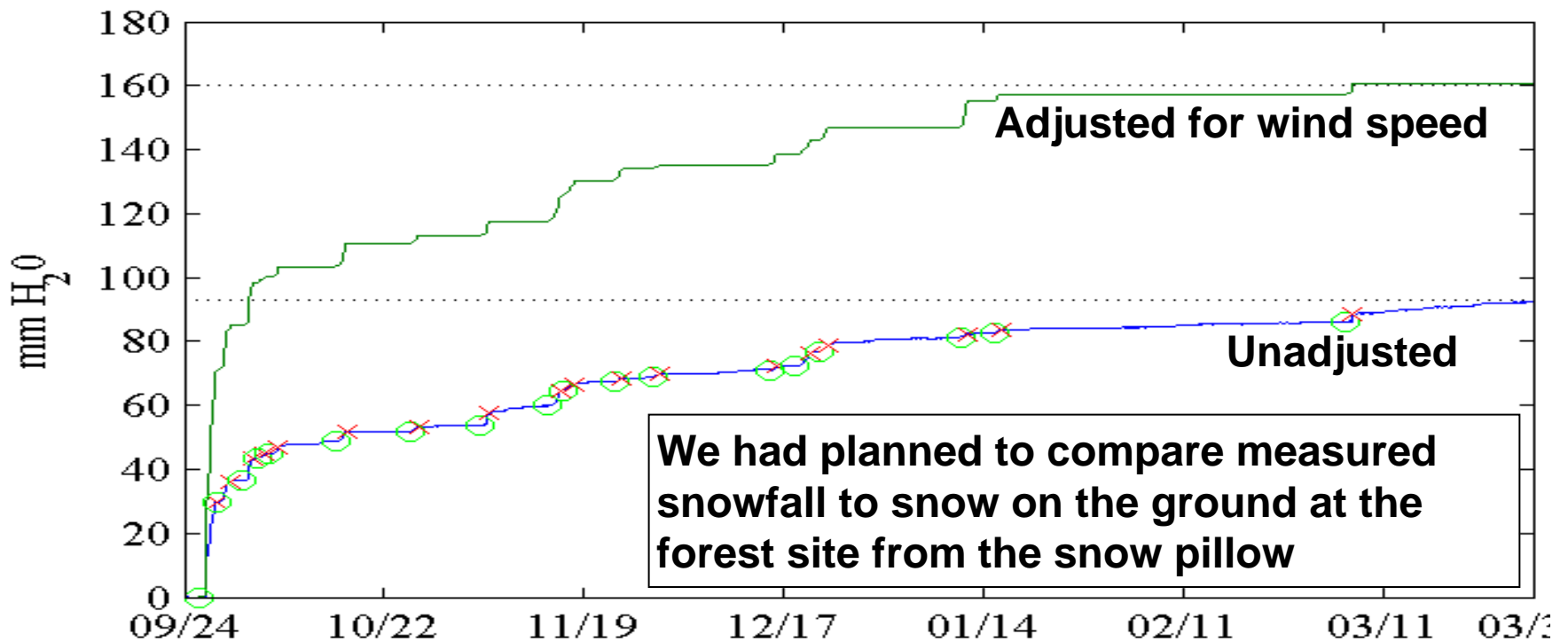- SR50 sites
- Model averaging area

Modelling domain (1.2 km x 1.2 km)

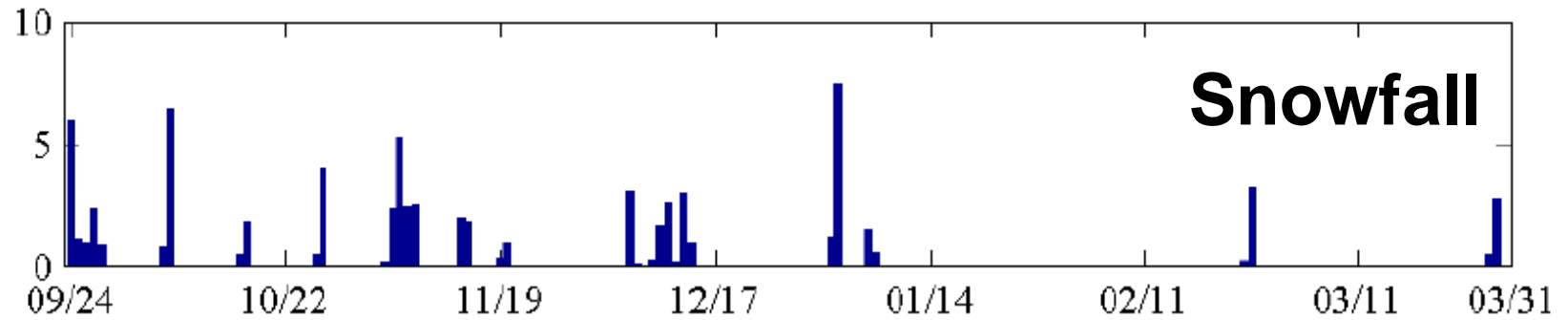**Tundra site**

- SR50 sites
- Model averaging area

20 m grid sizes

Modelling domain (1.2 km x 1.2 km)

Drift site

TVC SR50

x 10⁶

20 m grid sizes

- SR50 sites
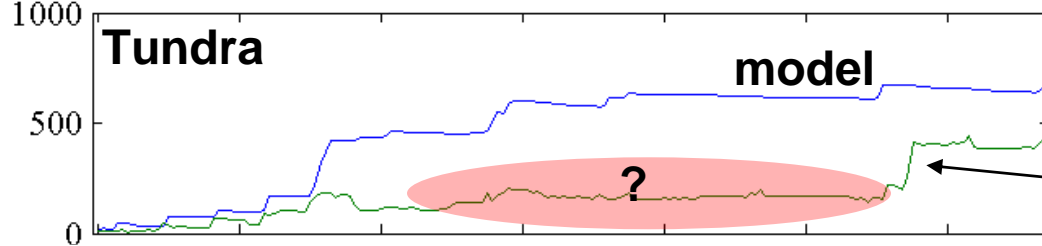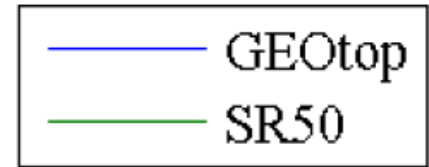- Model averaging area

Modelling domain (1.2 km x 1.2 km)

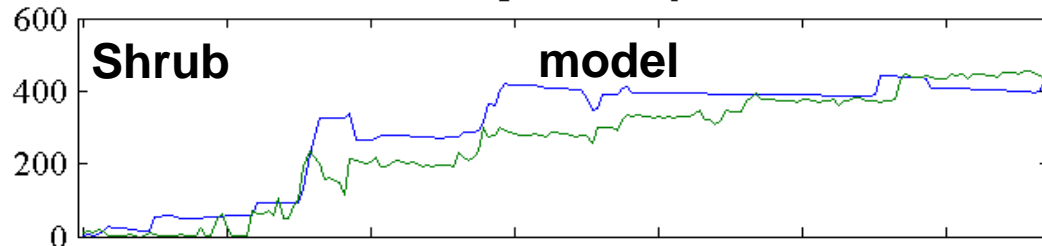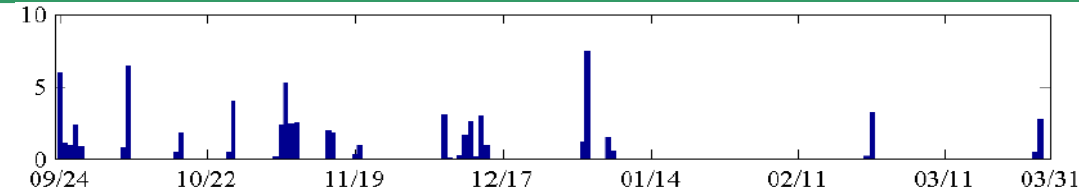
Forest site
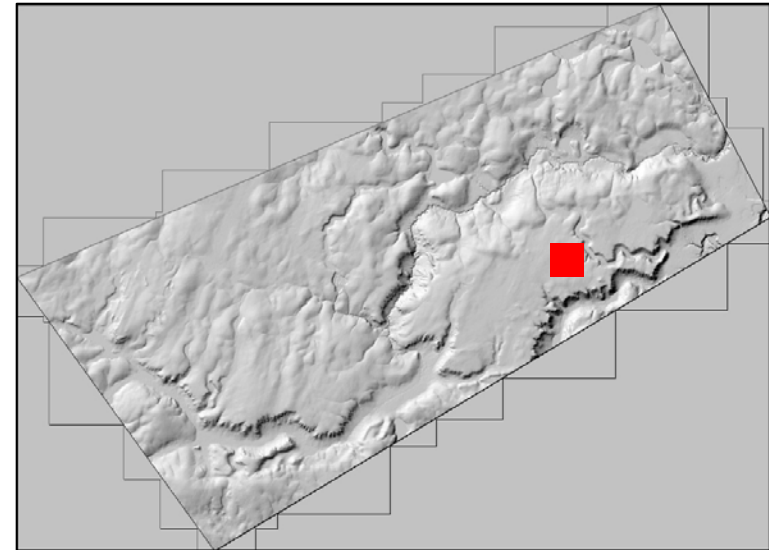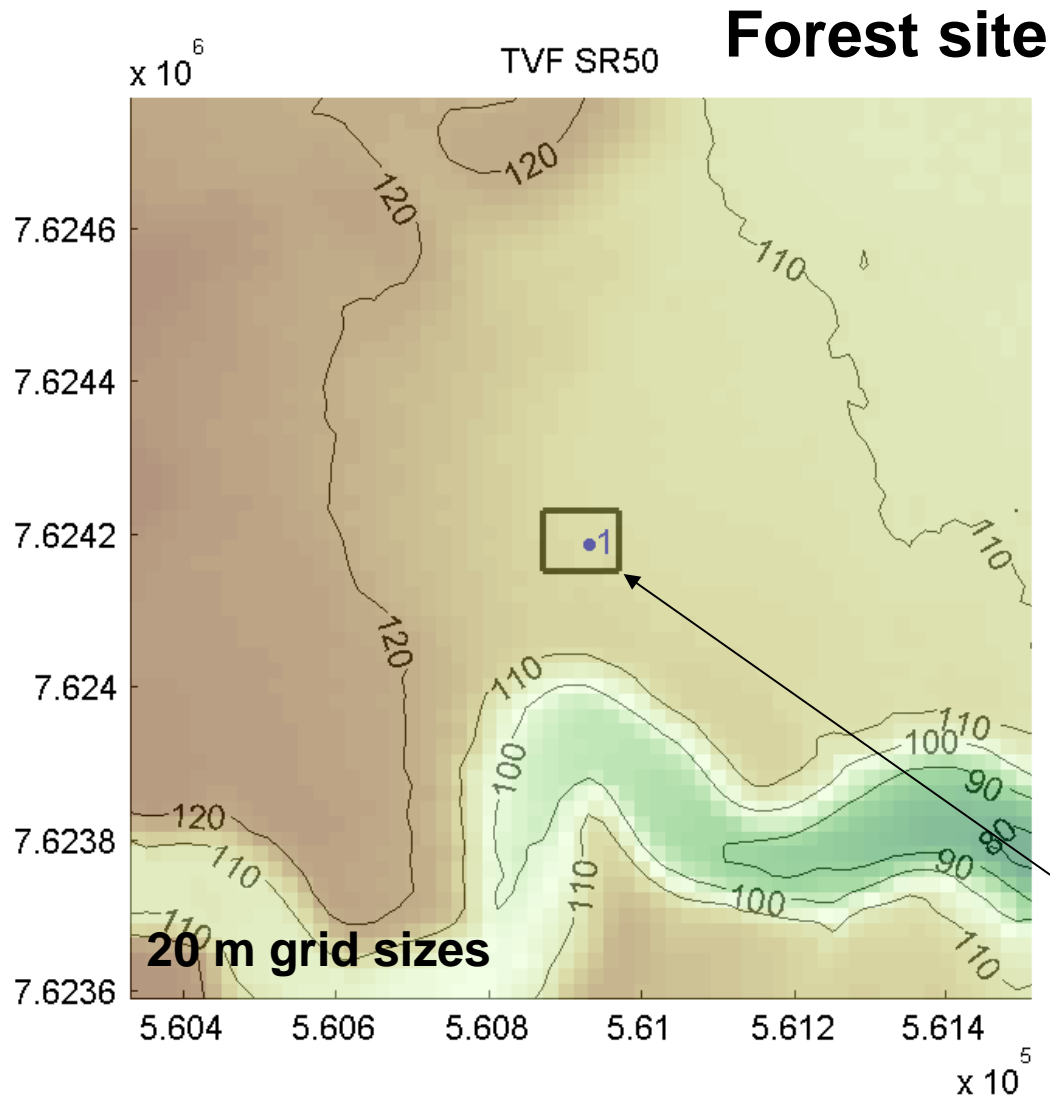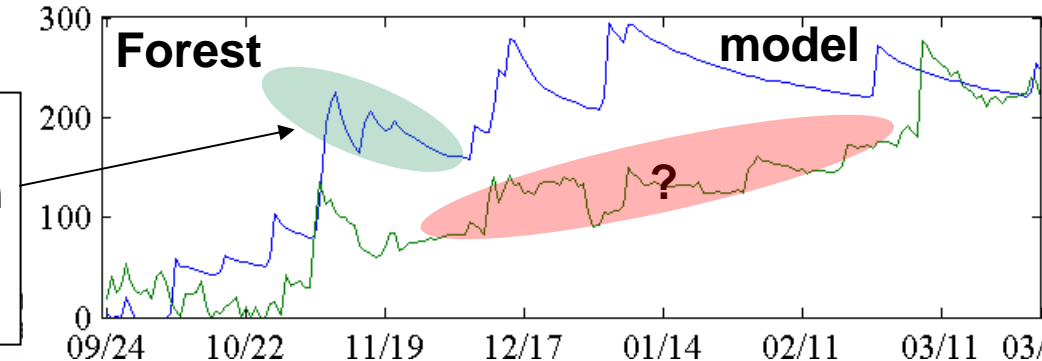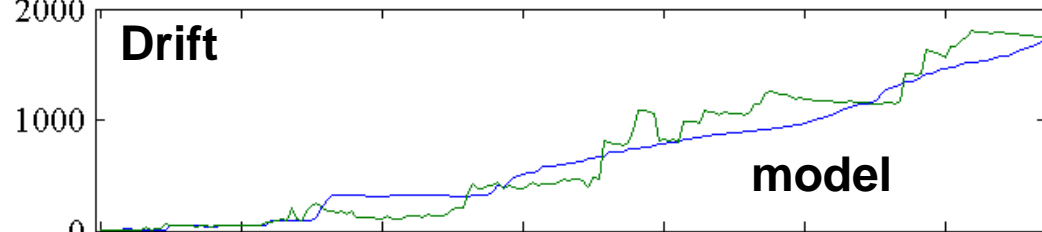
- SR50 sites
- Model averaging area

4. Results to date

Snowfall

Adjusted for wind speed

Unadjusted

We had planned to compare measured snowfall to snow on the ground at the forest site from the snow pillow

Observed and Modelled Snow depth

Snow Depth (mm)

Shrub — model

Tundra — model — ?

Drift — model

Forest — model — ?

GEOtop
SR50
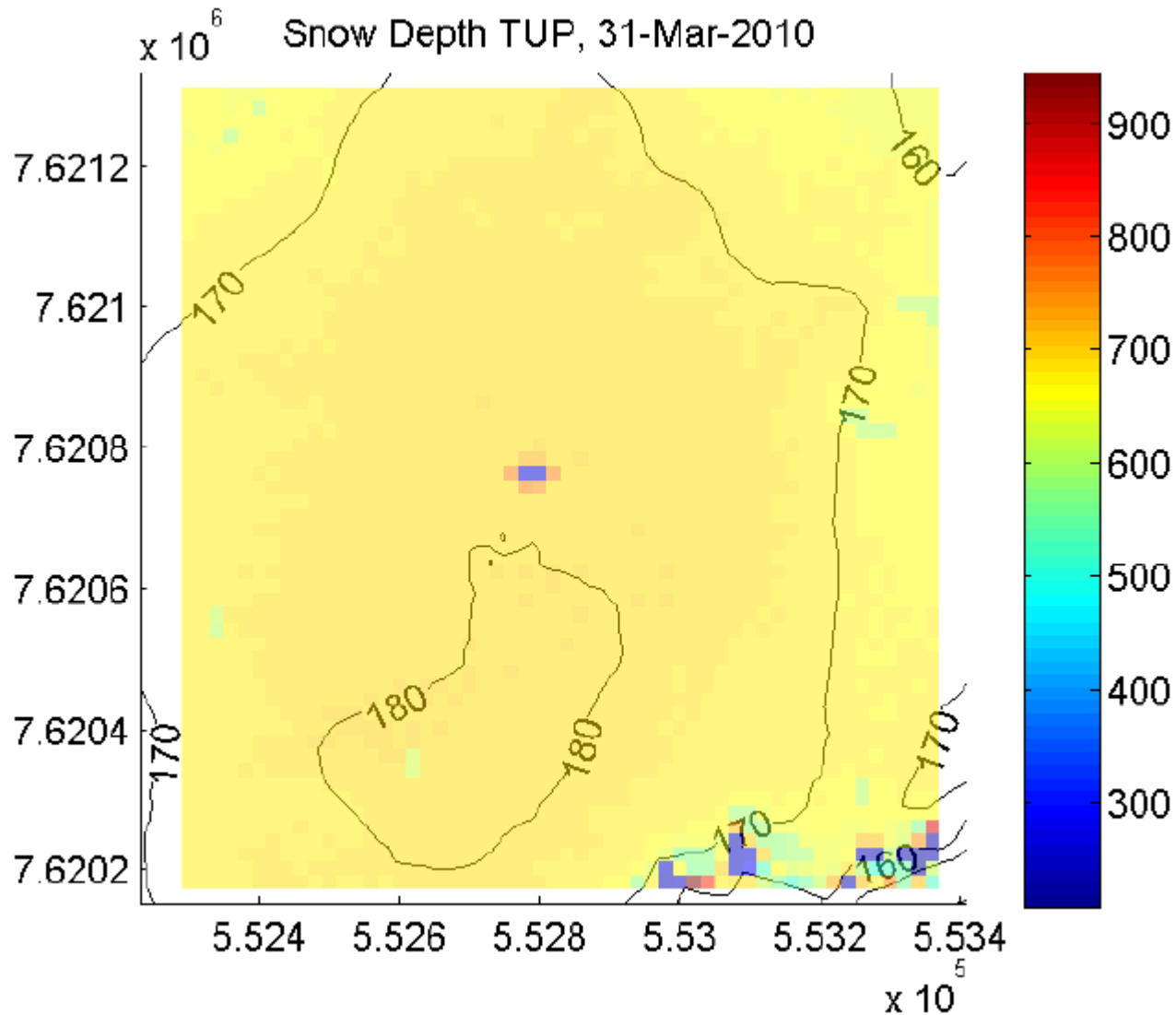
SR50s offset reset by field staff

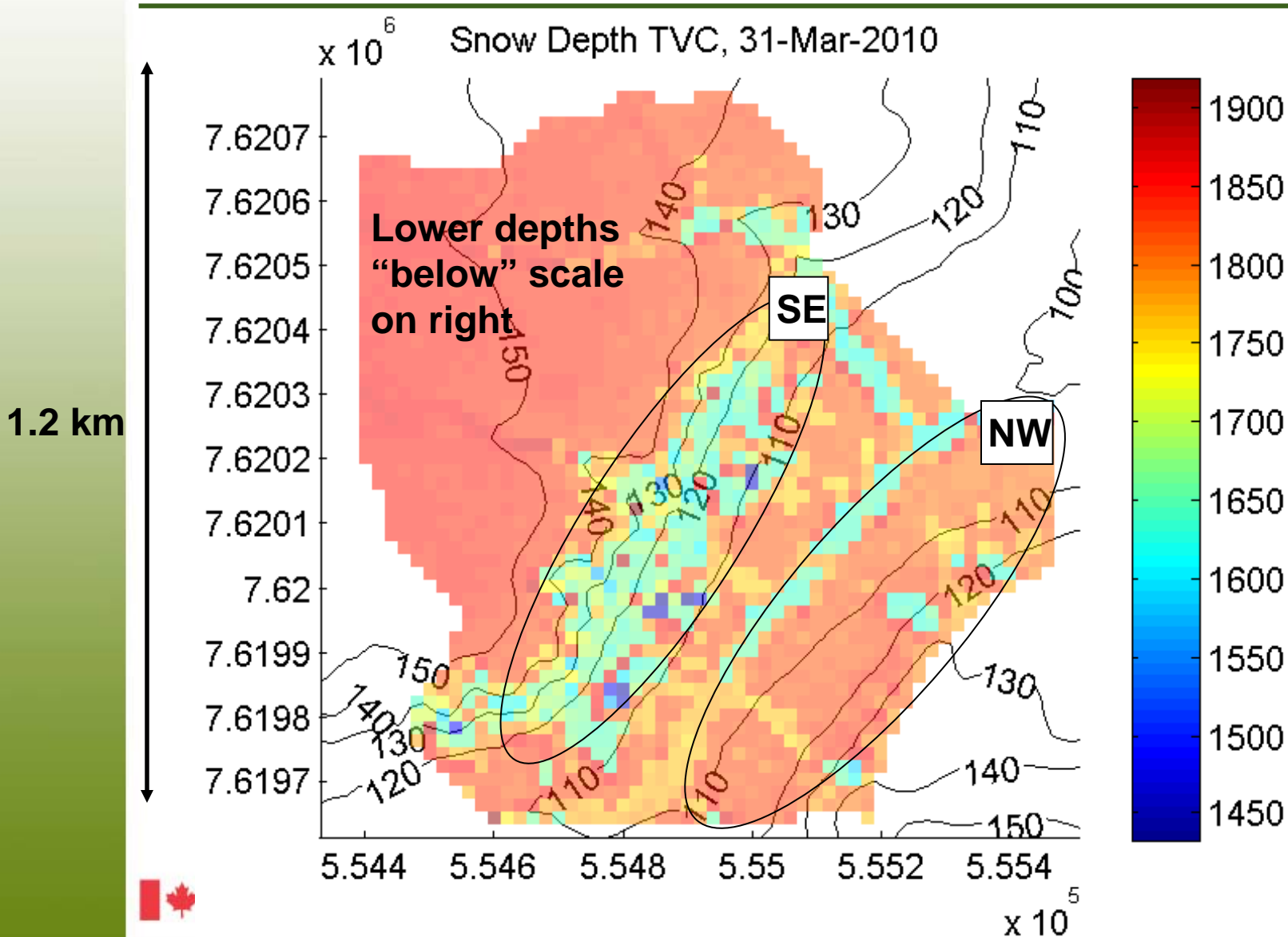Modelled Compaction appears to large

- Observations = average 5 sites

- model = avg of small domain

Snow accumulation – tundra site
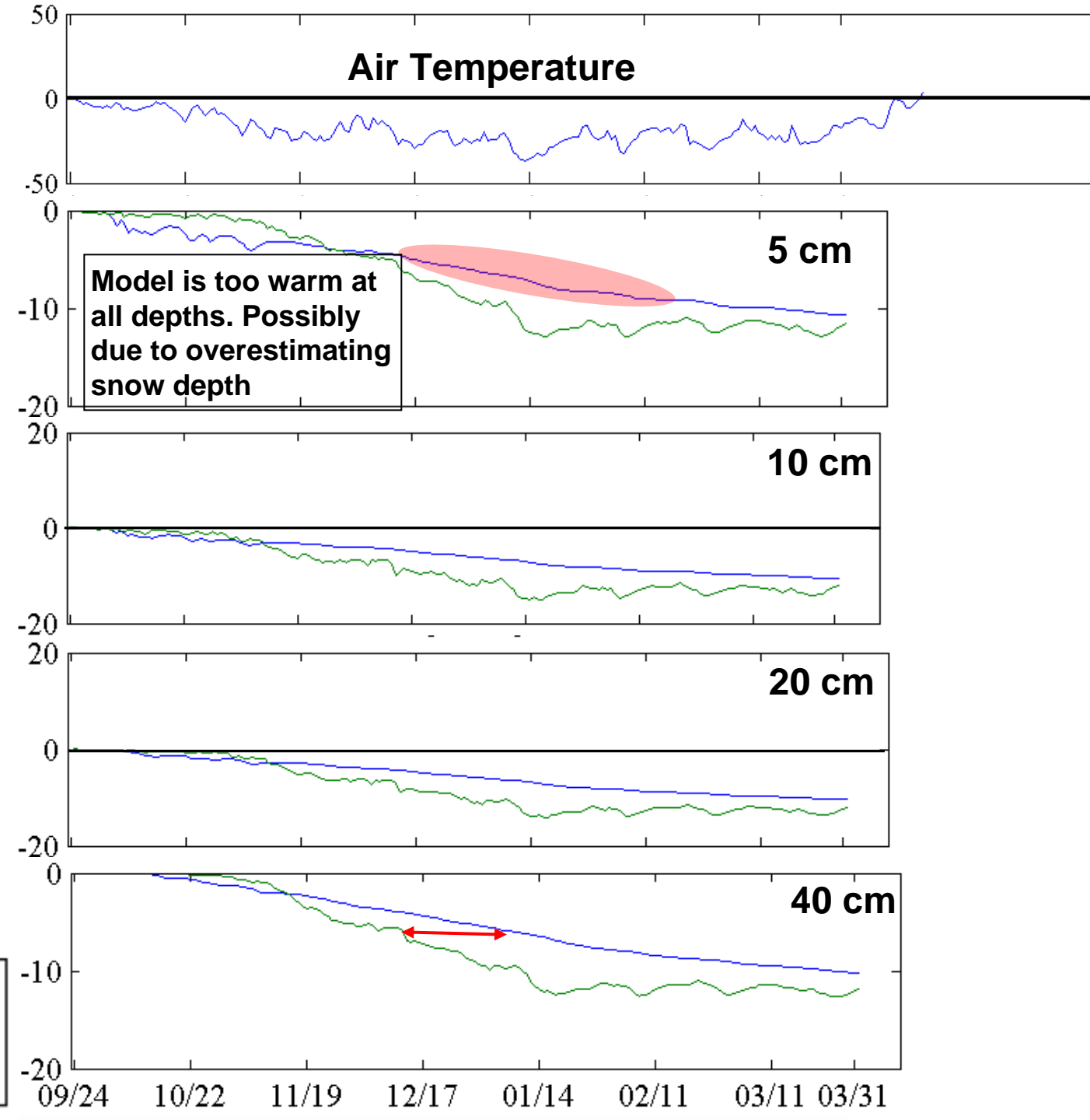
Snow accumulation – drift site
Note large drift on SE and small or no drift on NW slopes

Tundra soil temperature

Temperature (C)

Air Temperature

5 cm

Model is too warm at all depths. Possibly due to overestimating snow depth
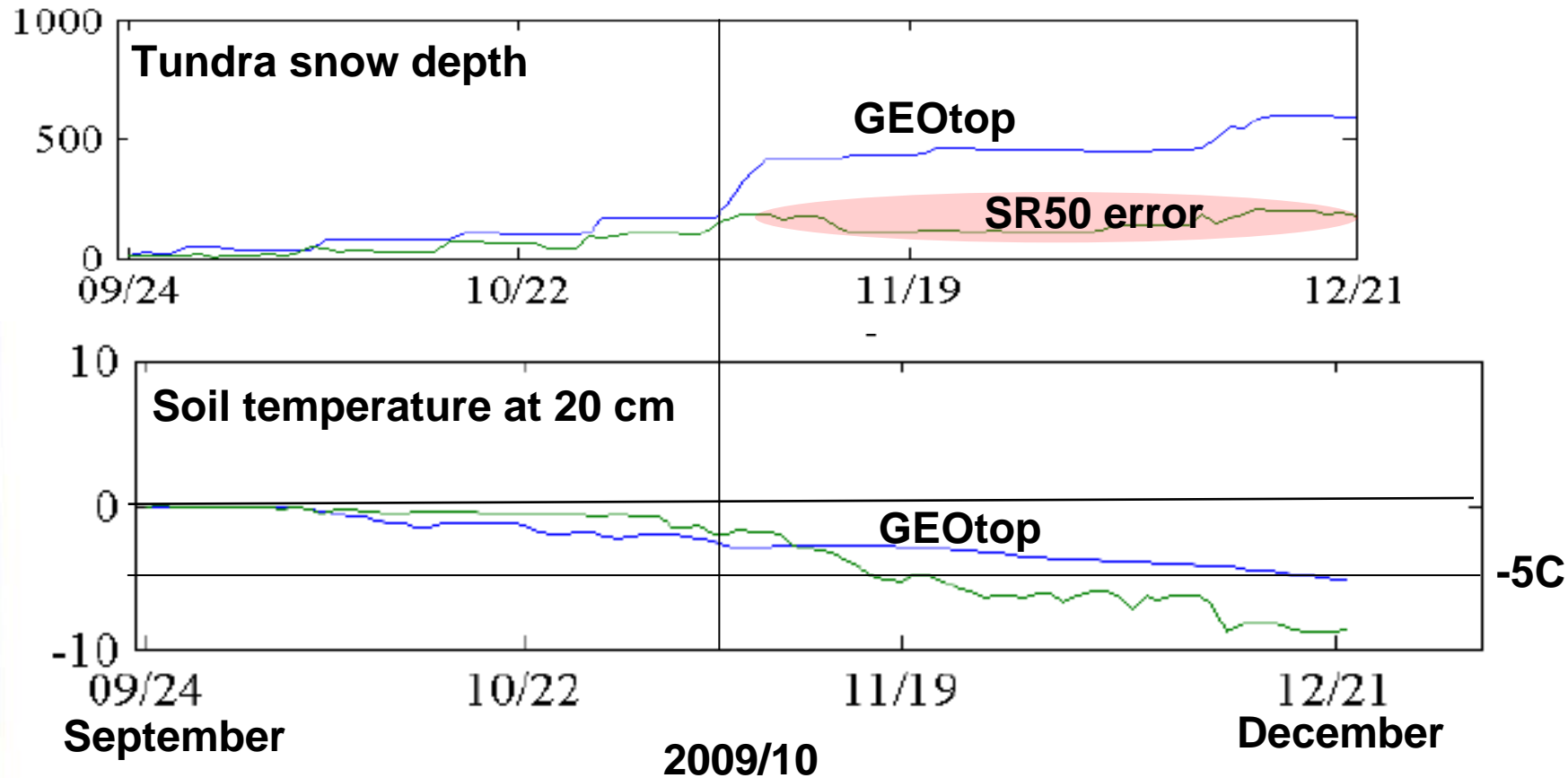
10 cm

20 cm

40 cm

GEOtop

SR50

09/24 10/22 11/19 12/17 01/14 02/11 03/11 03/31

Soil temp during key early winter period

5. Conclusions

- GEOtop + PBS do a reasonable job in modelling snow depth and soil temperature, but not sufficiently good at the moment for regulatory needs
- A number of issues are being investigated
  - SR50 issues at some of the sites – why did they not work during portions of the winter?
  - GEOtop snow compaction and densification routines need improving

- Once these issues are improved
  - Are the models able to estimate not only the avg depth of the snowcover, but also the spatial variability as shown by the coefficient of variation for example
  - Look at the spatial variability in key soil temperatures needed to consider land access. Can we map key soil temperature across large areas so that INAC can use these in developing regulations
- Discussions with INAC re regulations for land access

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