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Permafrost Research to Support Northern Hydrocarbon Development and Transportation

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Permafrost presents challenges to pipeline construction and operation

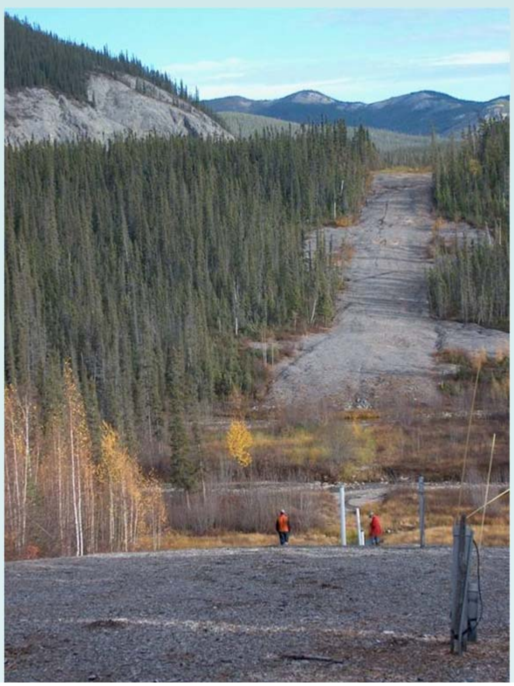
- Clearing of vegetation and surface disturbance leads to changes in ground thermal regime
- Thermal effects of pipe
- Changes in ground thermal regime can result in ground and pipe movements
  - thaw settlement, frost heave, slope instability
  - differential movements due to variable soil and ground ice conditions along route
- Climate change presents an additional challenge

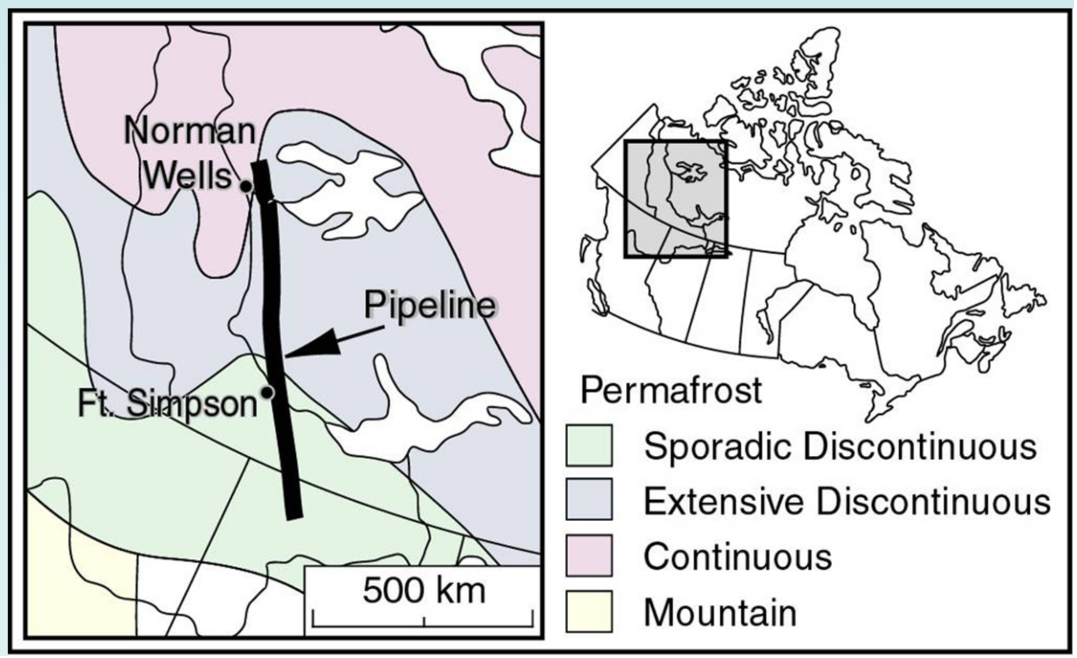
- Terrain conditions vary along route
- Require adequate information on terrain conditions along route (regional scale data)
  - surficial materials
  - ground thermal conditions
  - ground ice conditions
- Consideration of how conditions may change over time
  - in response to construction and operation of pipeline
  - in response to changing climate

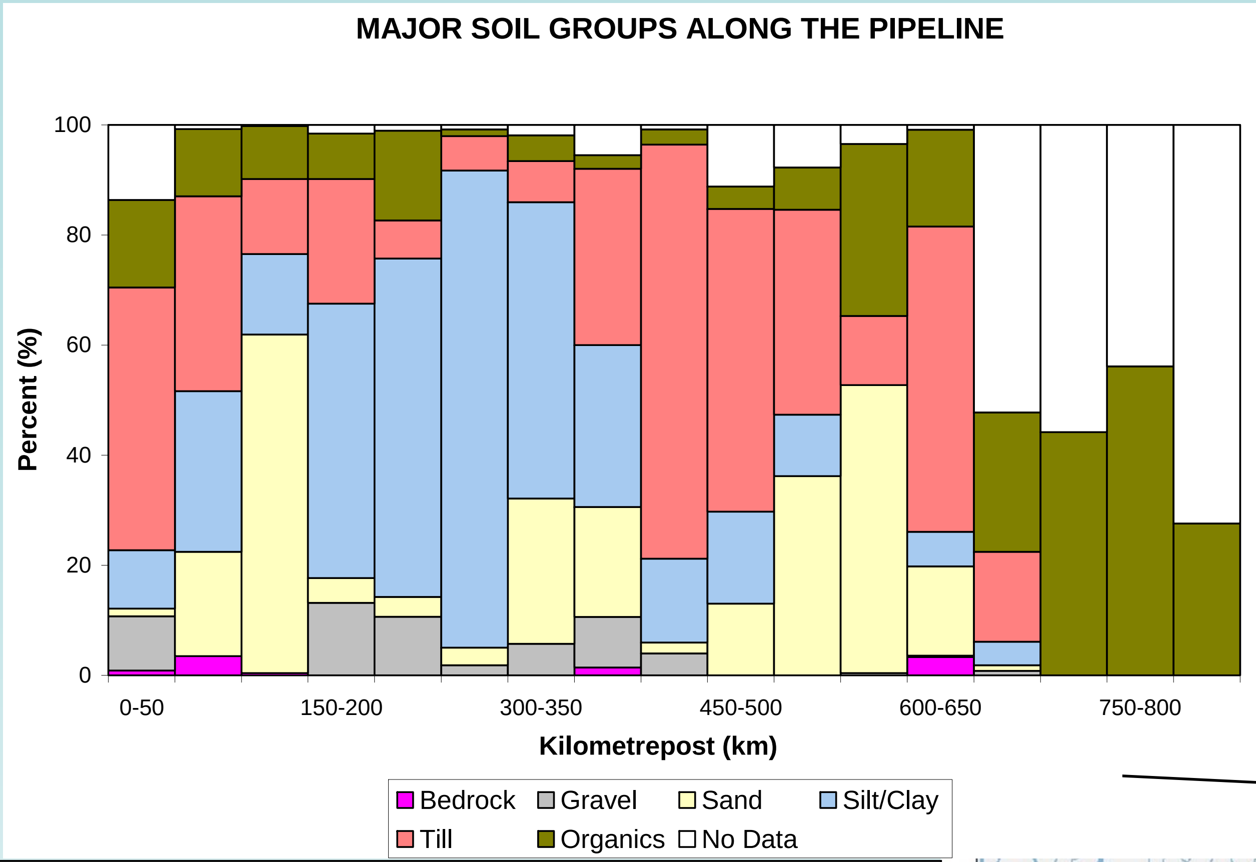
Lessons learned from existing projects can inform design of new projects

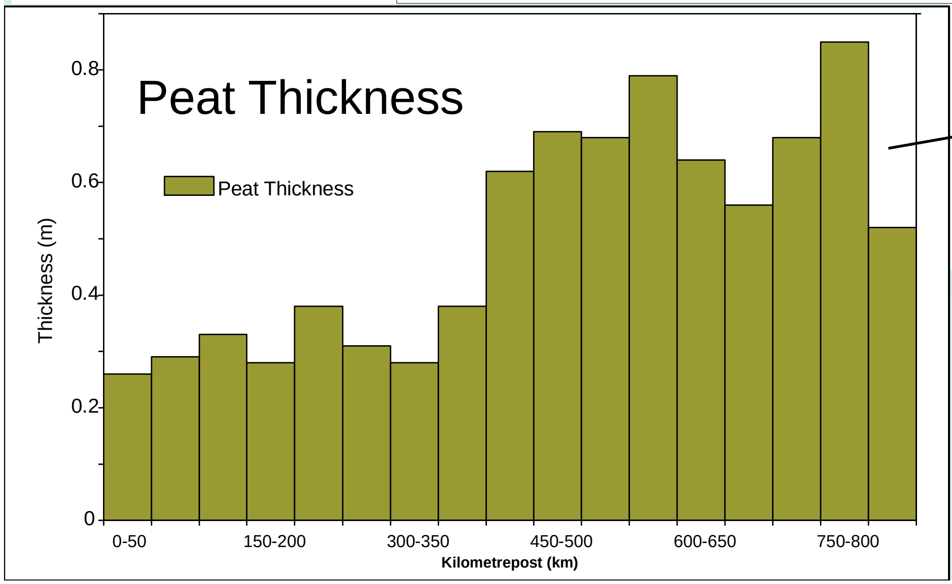
Norman Wells Pipeline

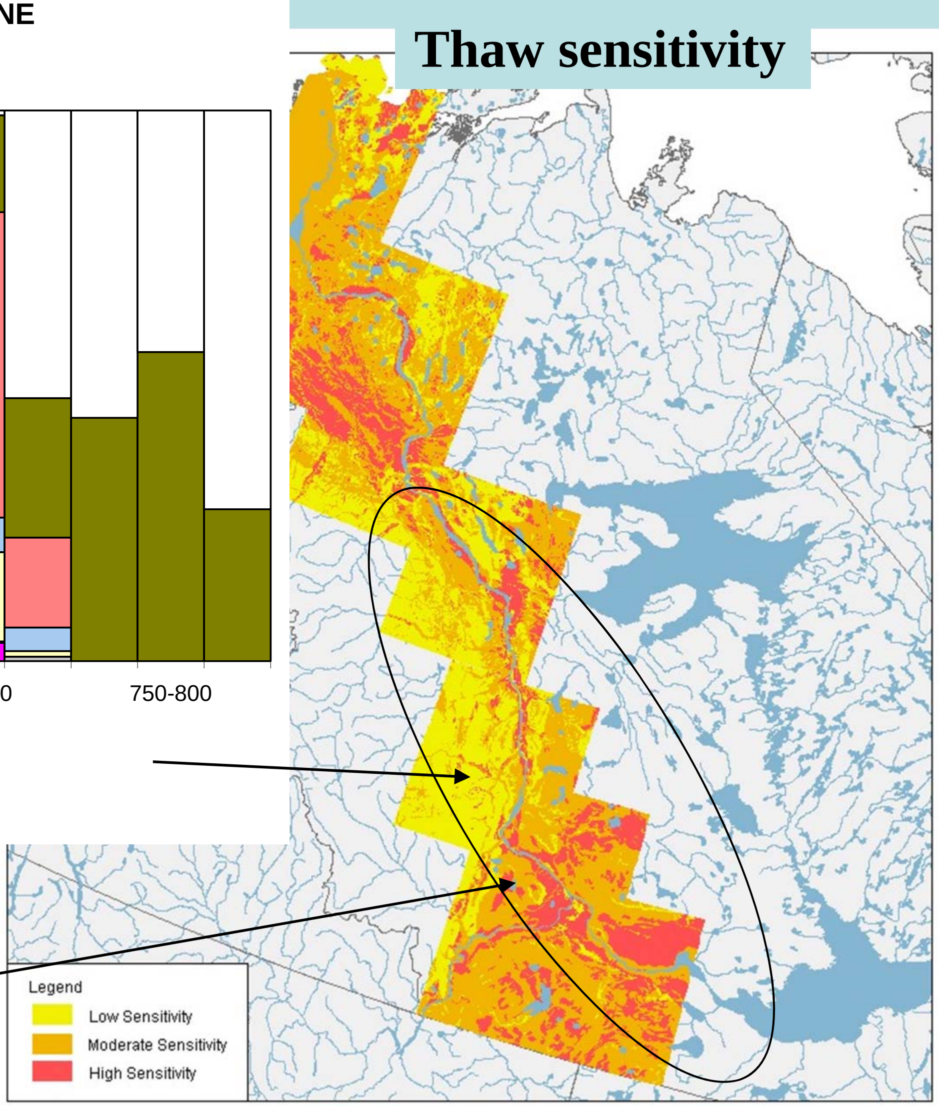
- 869 km pipeline route crosses discontinuous permafrost zone of Mackenzie valley and Alberta Plateau
- Small diameter (328mm) ambient temperature pipeline
- Operation began in 1985






MAJOR SOIL GROUPS ALONG THE PIPELINE
Percent (%)
100
80
60
40
20
0
0-50
150-200
300-350
450-500
600-650
750-800
Kilometrepost (km)
Bedrock
Gravel
Sand
Silt/Clay
Till
Organics
No Data

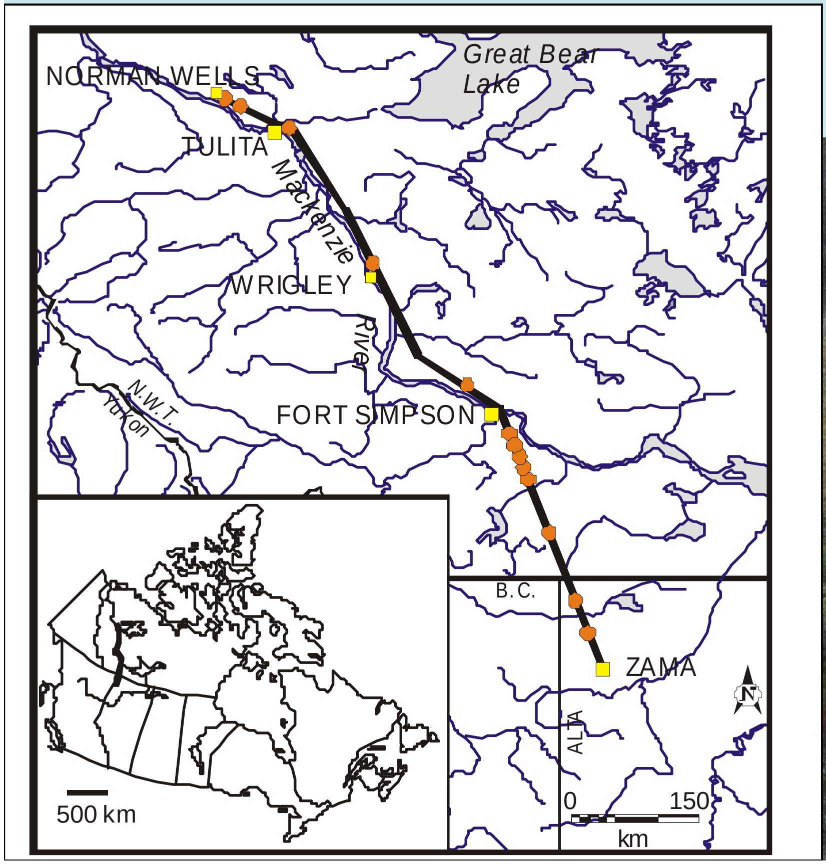

Peat Thickness
Peat Thickness
Thickness (m)
0.8
0.6
0.4
0.2
0
0-50
150-200
300-350
450-500
600-650
750-800
Kilometrepost (km)

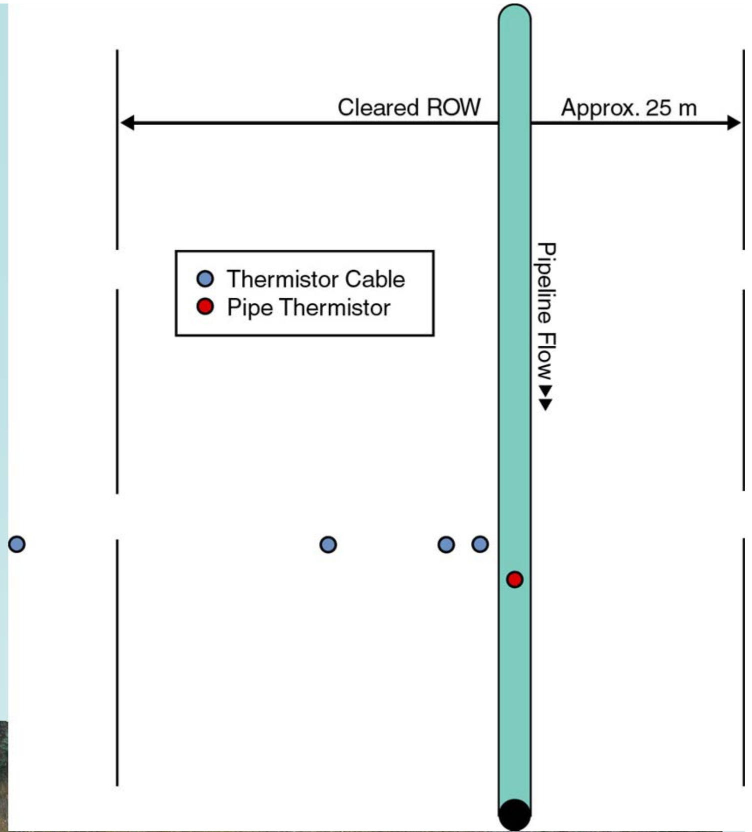

Thaw sensitivity
Legend
Low Sensitivity
Moderate Sensitivity
High Sensitivity

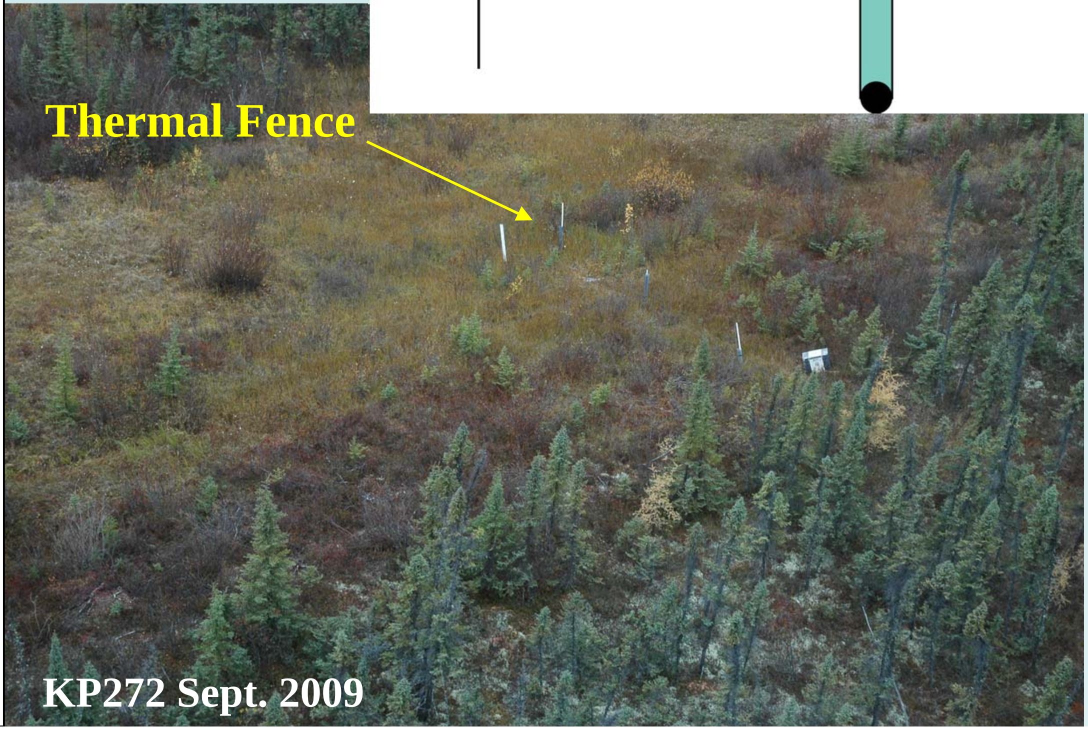
Norman Wells Pipeline Permafrost and Terrain Research and Monitoring

- Collaborative effort between government and Enbridge to develop and implement monitoring program to:
  - ***assess impact prediction***
  - ***improve impact evaluation and mitigation on NW pipeline and future projects***
- Establishment of 23 instrumented sites provided unique opportunity to:
  - ***examine thermal and terrain conditions***
  - ***investigate long-term change in permafrost conditions at undisturbed sites***
  - ***investigate impact of disturbance on permafrost terrain***

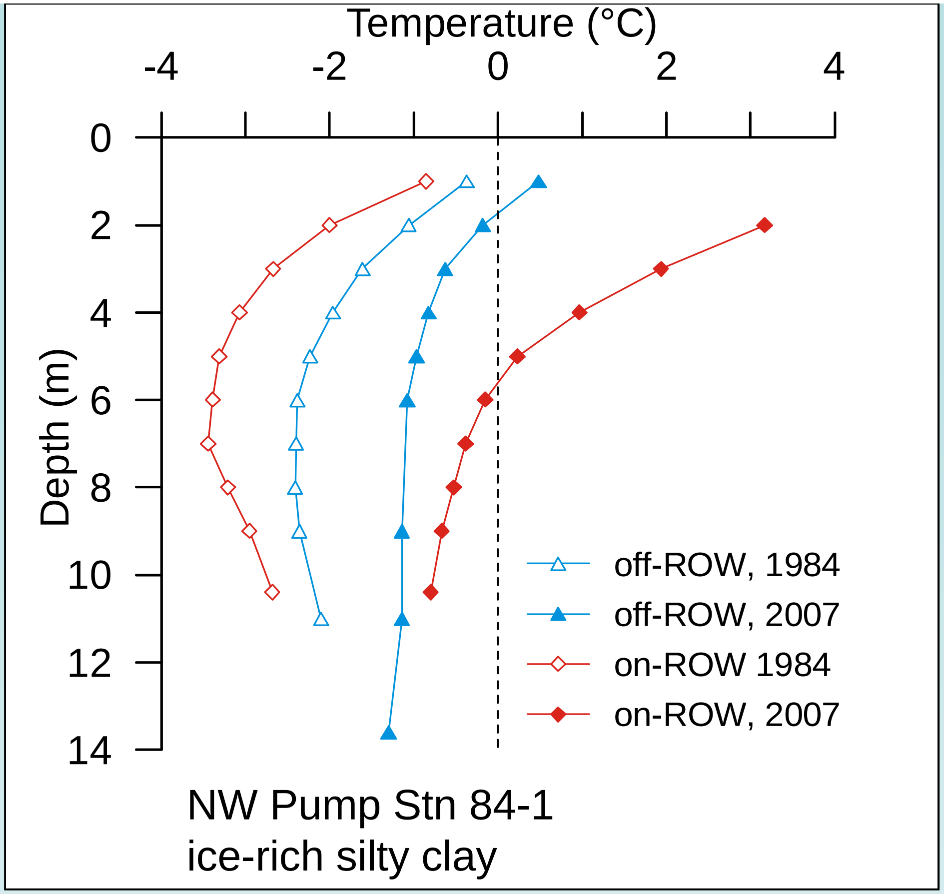
Instrumented Sites





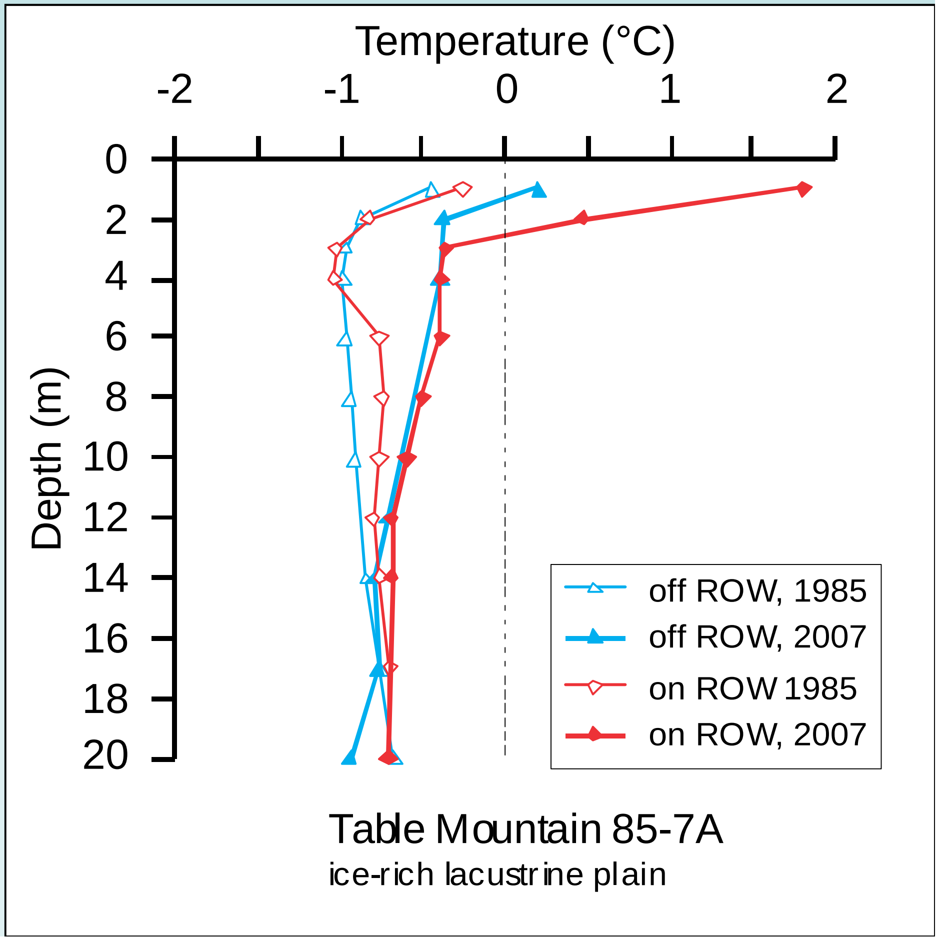


Comparison of on and off-ROW ground temperature

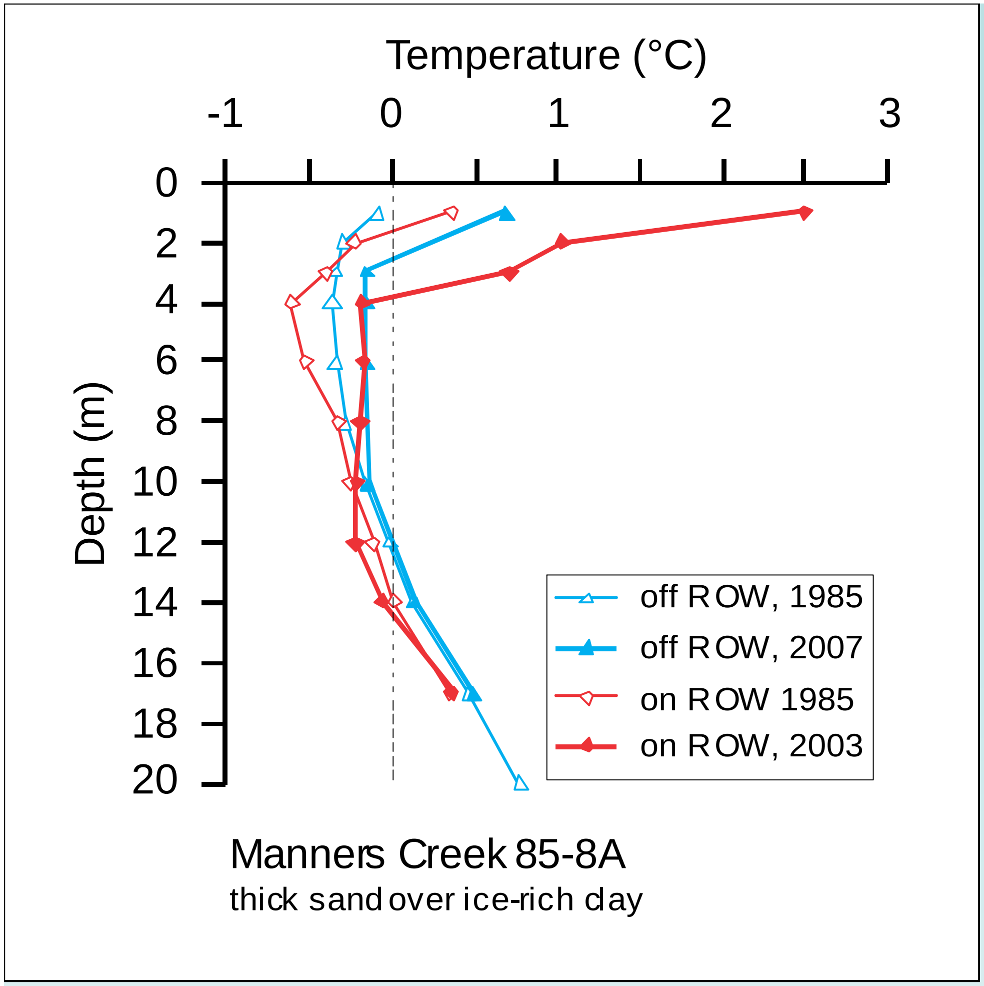


KP 0.2

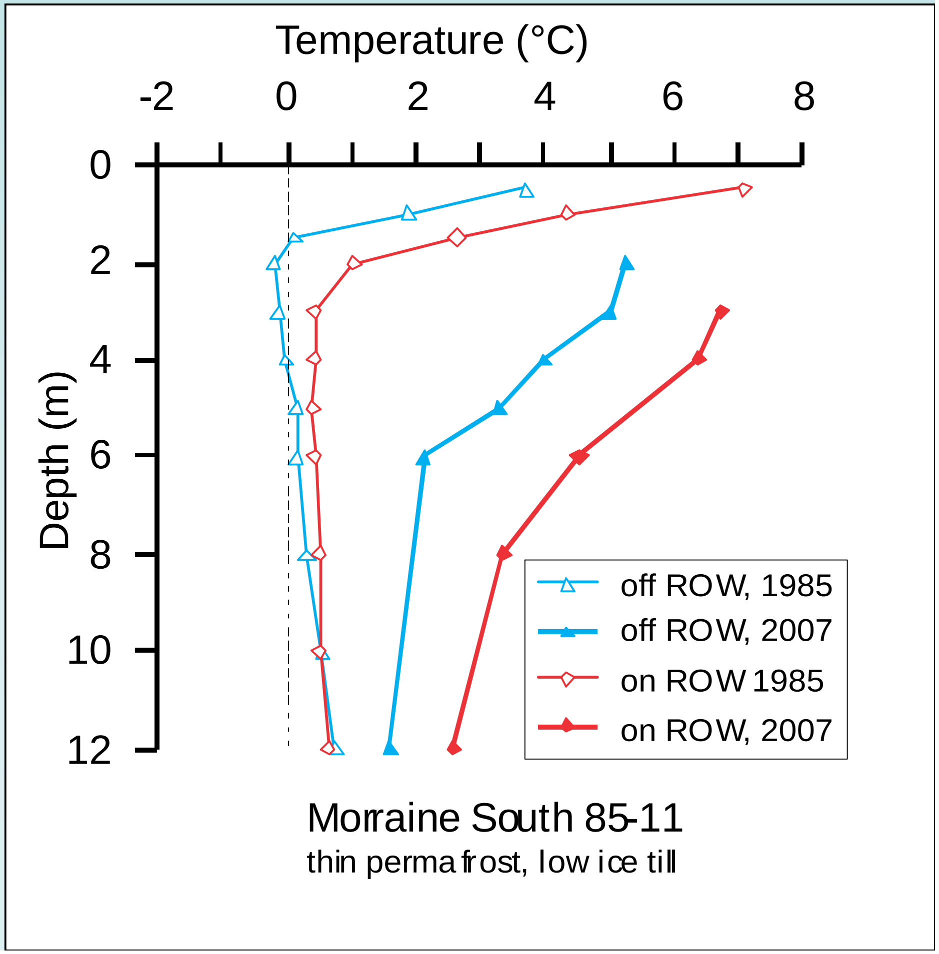
KP 272



Comparison of on and off-ROW ground temperature

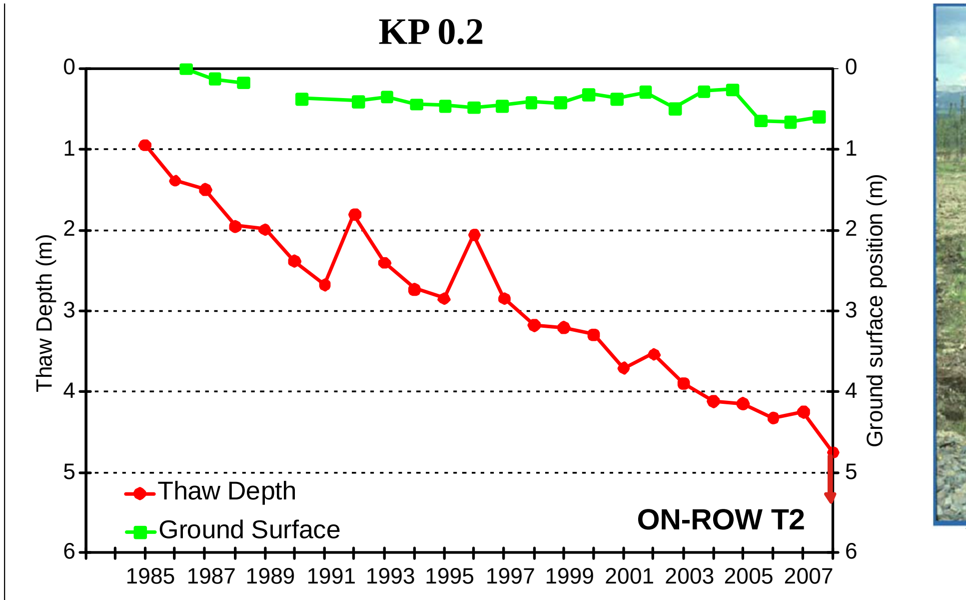


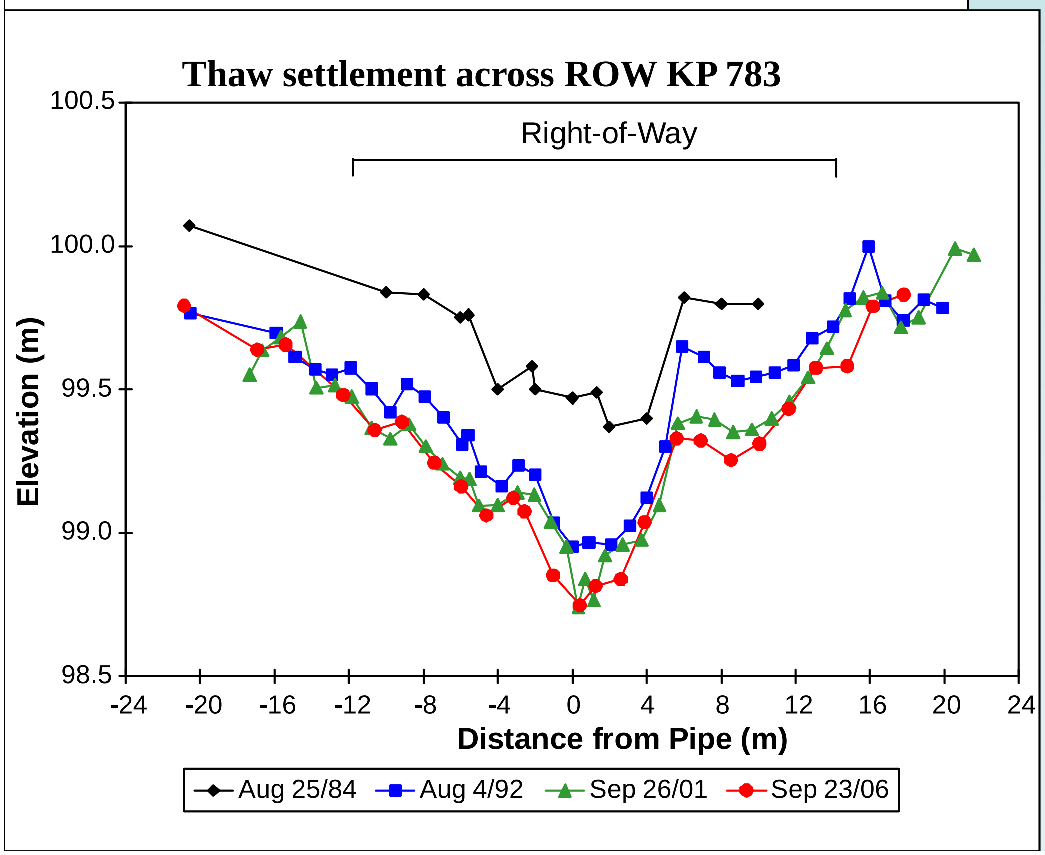
KP 558



KP 597

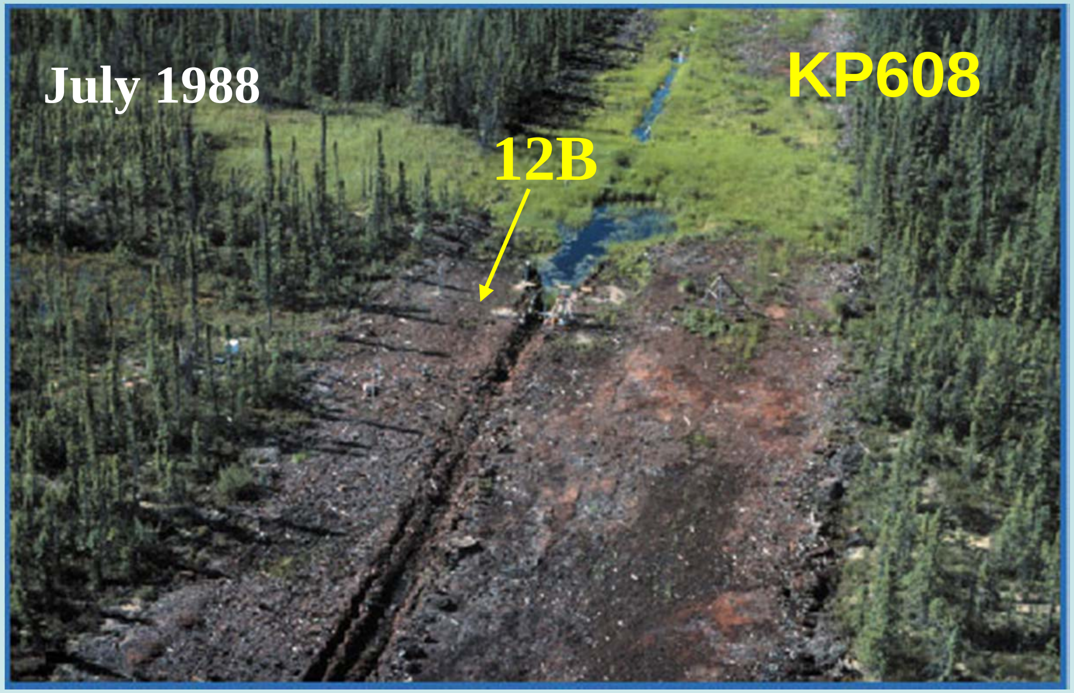
Surface Settlement

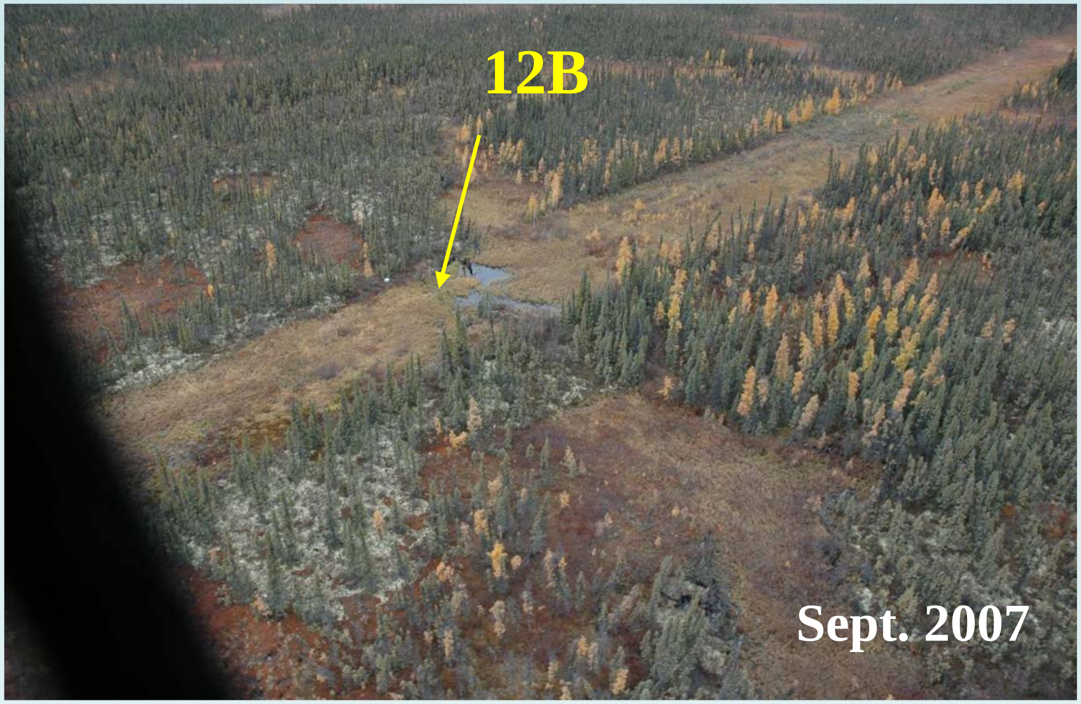




Effect of right-of-way preparation

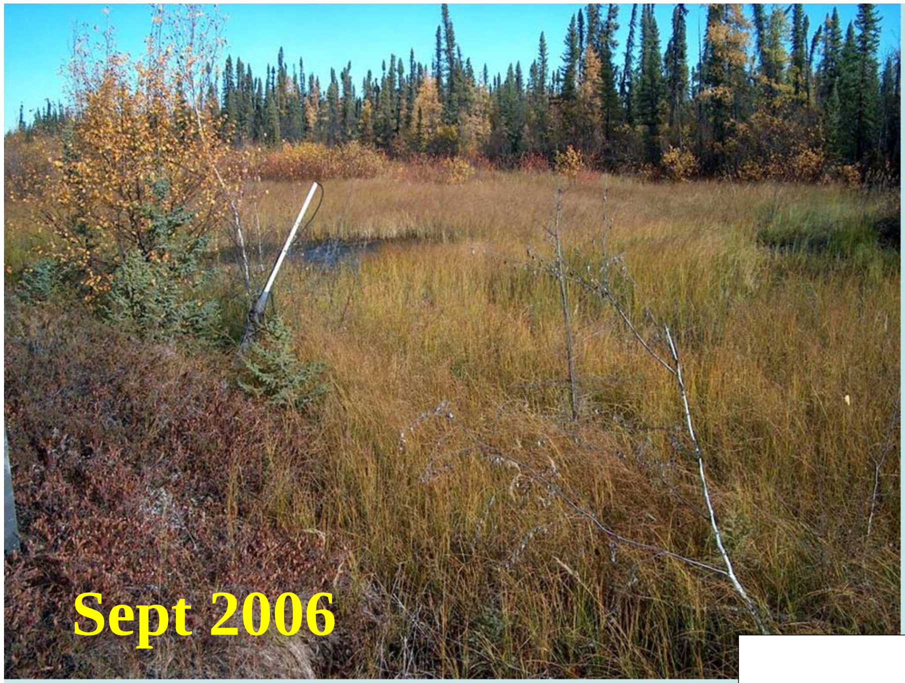
- transition from fen to peat plateau
- permafrost 5-6 m thick
- approx. 25 km downstream of pump station
  - *warm pipe temperature*
- blading and levelling of surface

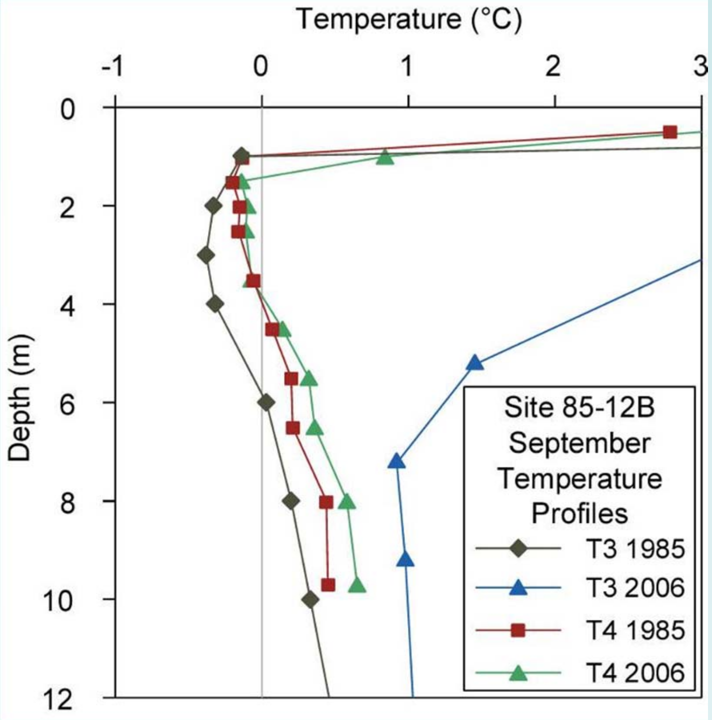


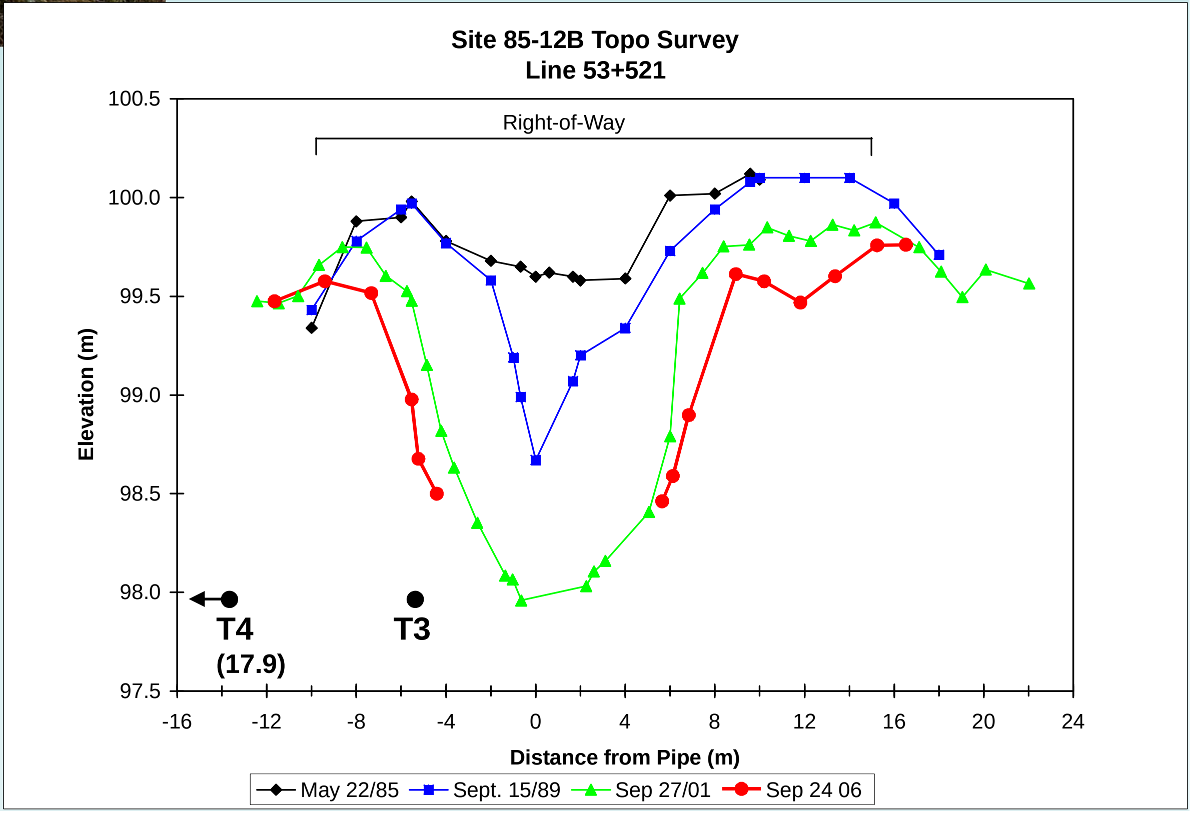


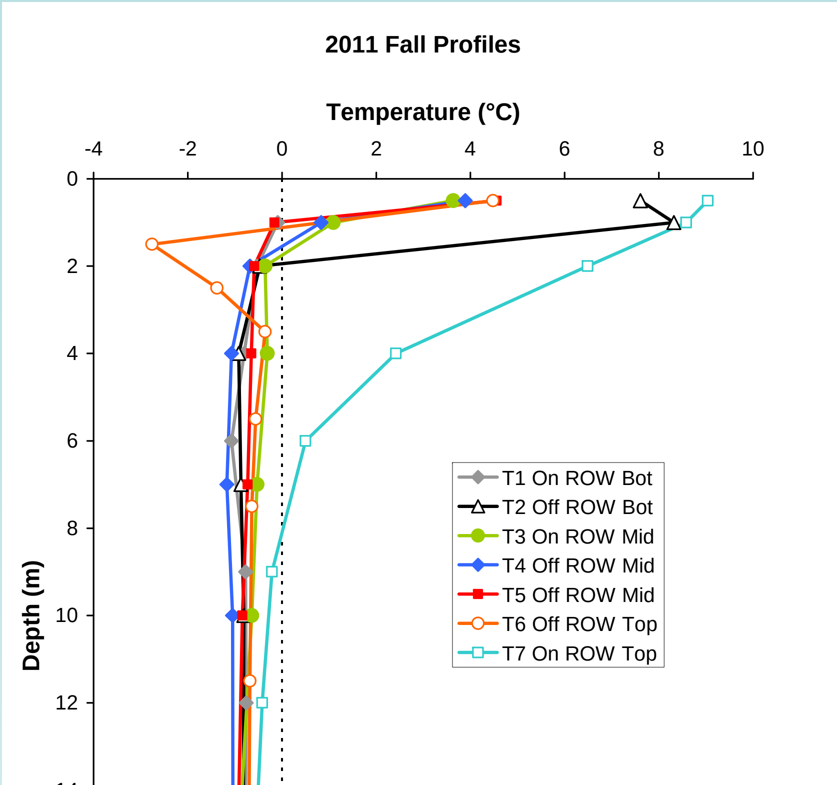
85-12B, KP 608

- ongoing settlement on ROW
- collapse into the ditch and adjacent fen
- settlement extending to edge of ROW



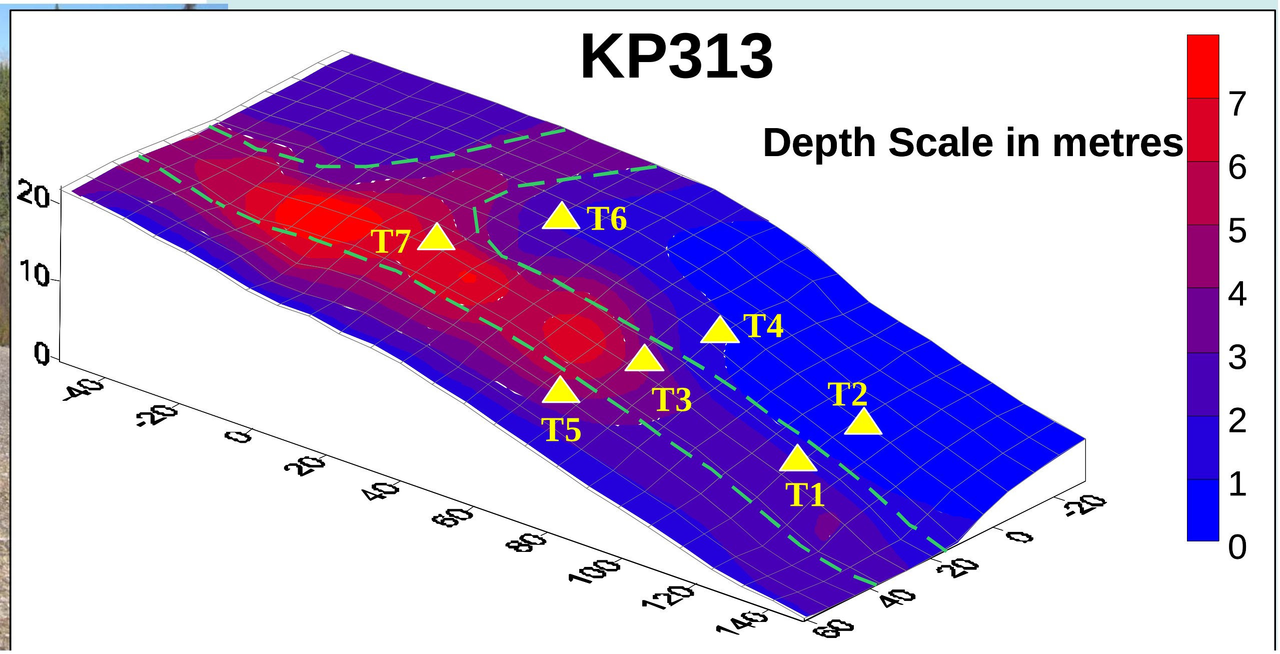




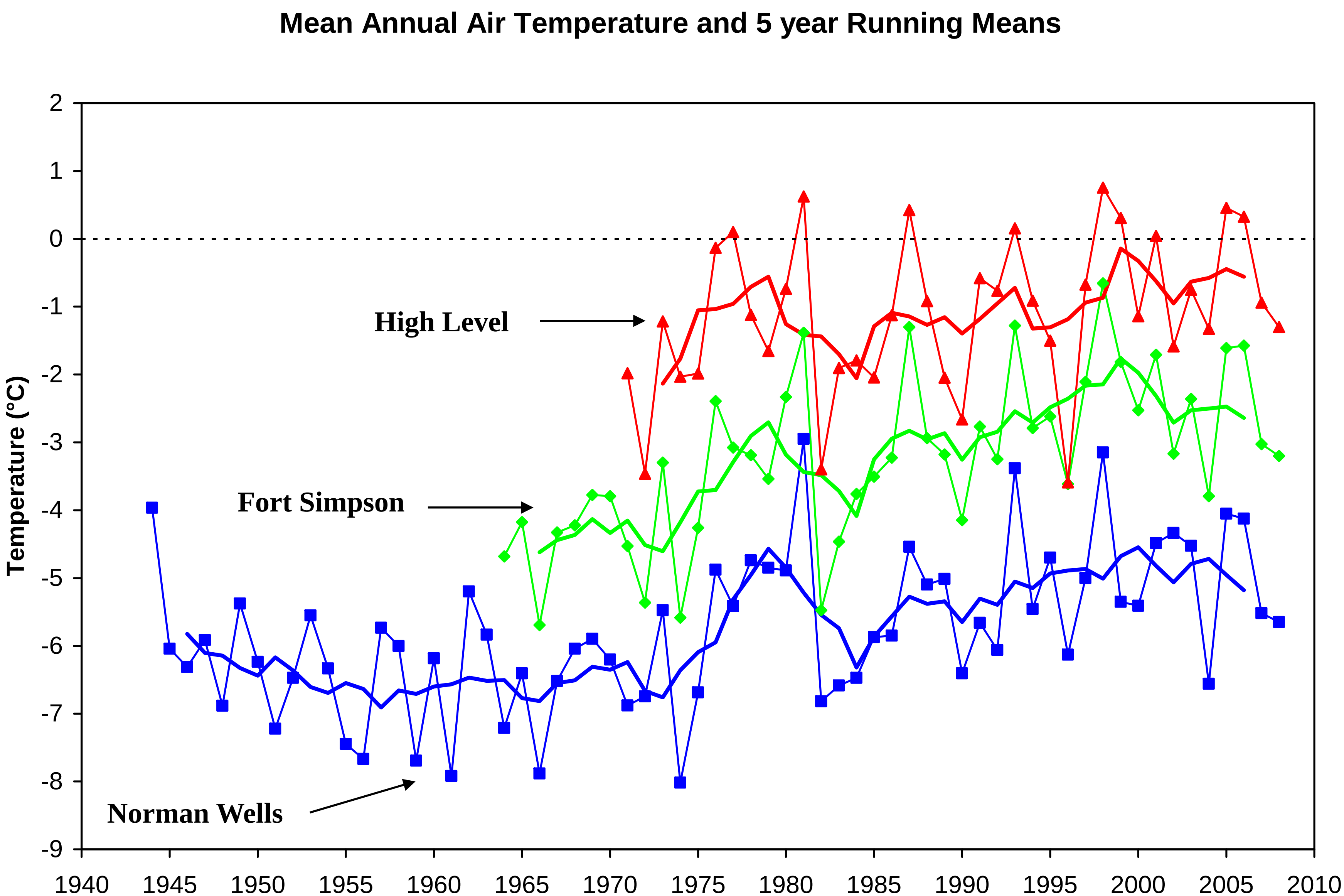


Effect of mitigation techniques

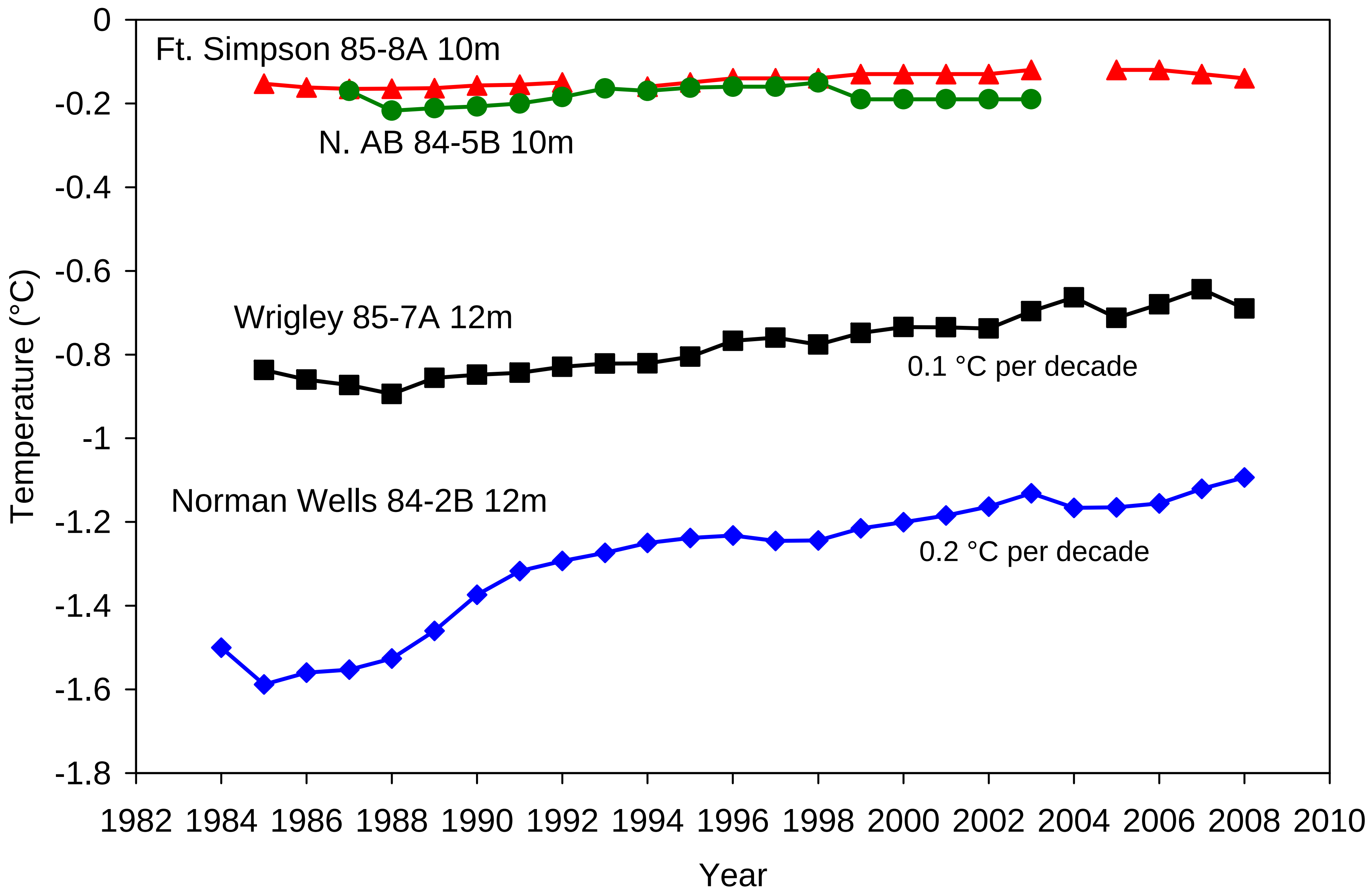
- T1 and T3 on wood chip slope
- No wood chips at T7 – deeper thaw

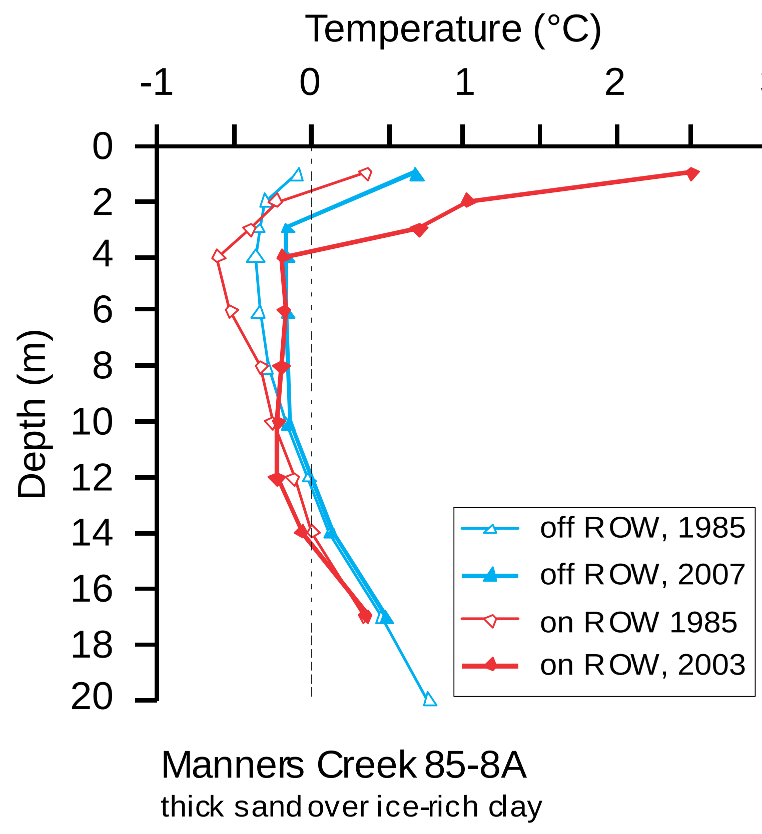


Trends in Air Temperature Mackenzie Valley



Trends in Ground Temperature Mackenzie Valley



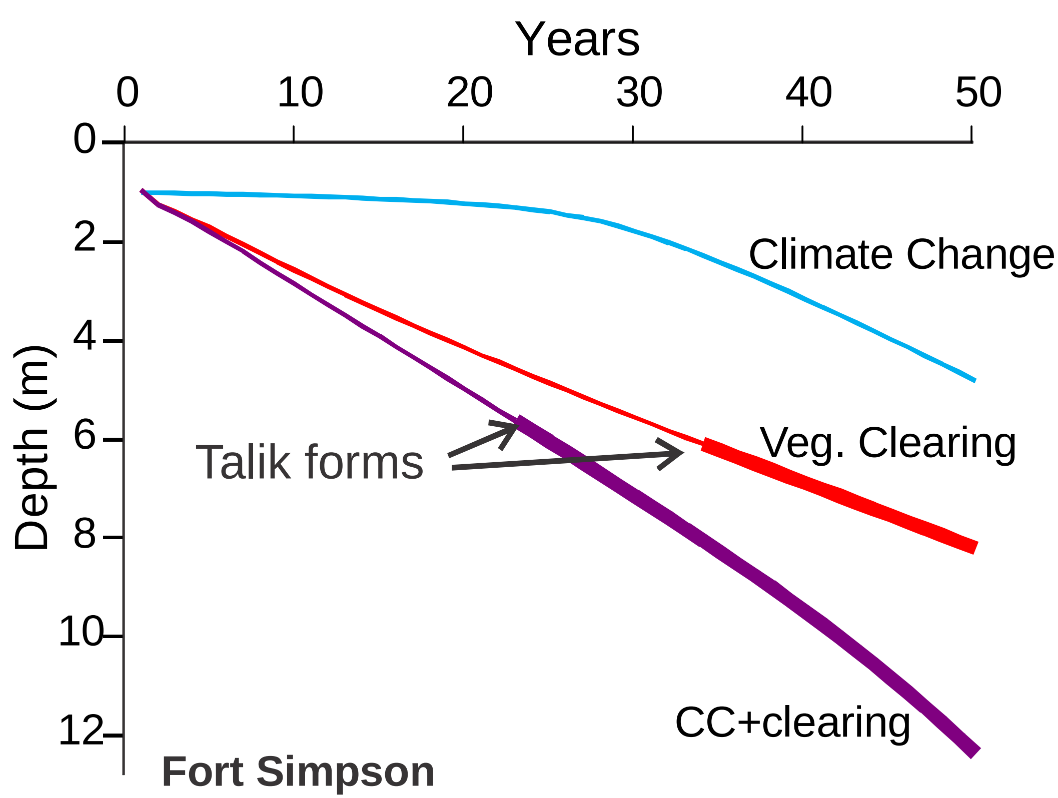


Modelling the impact of vegetation clearing and climate change

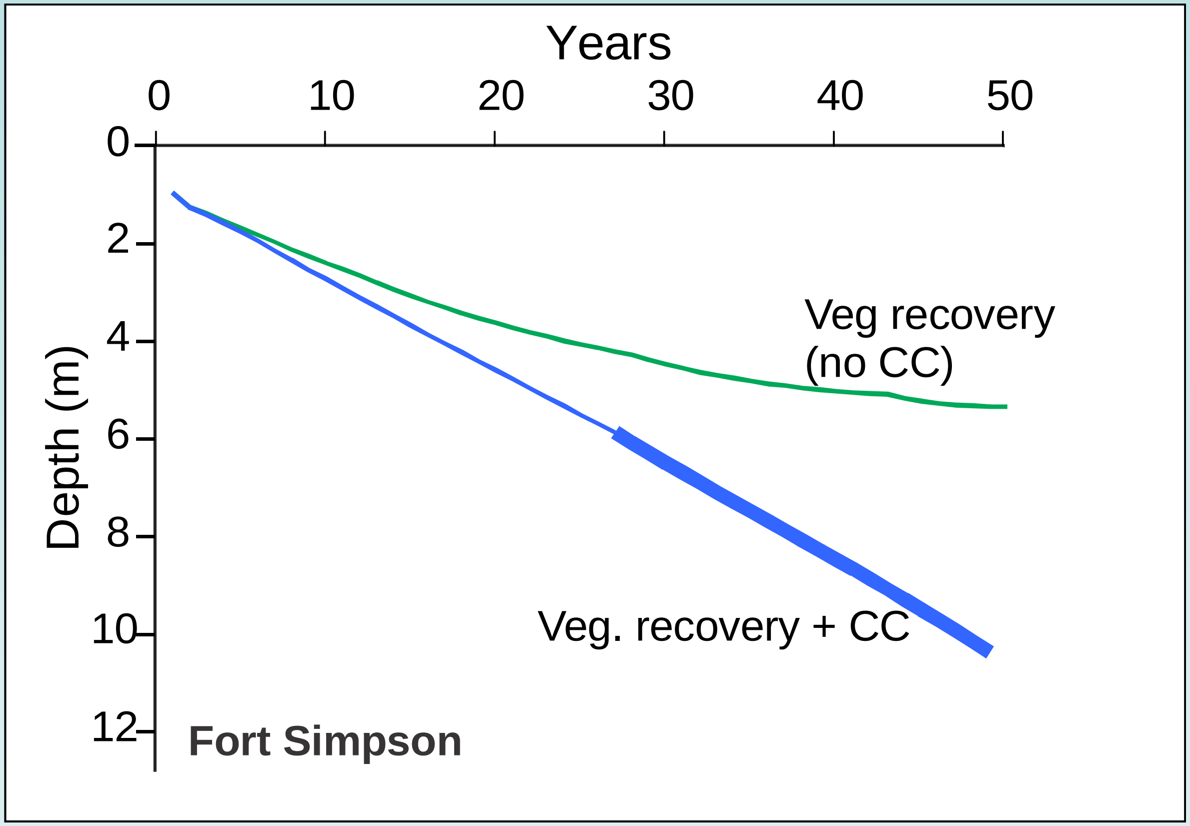
(warm permafrost -0.5°C)

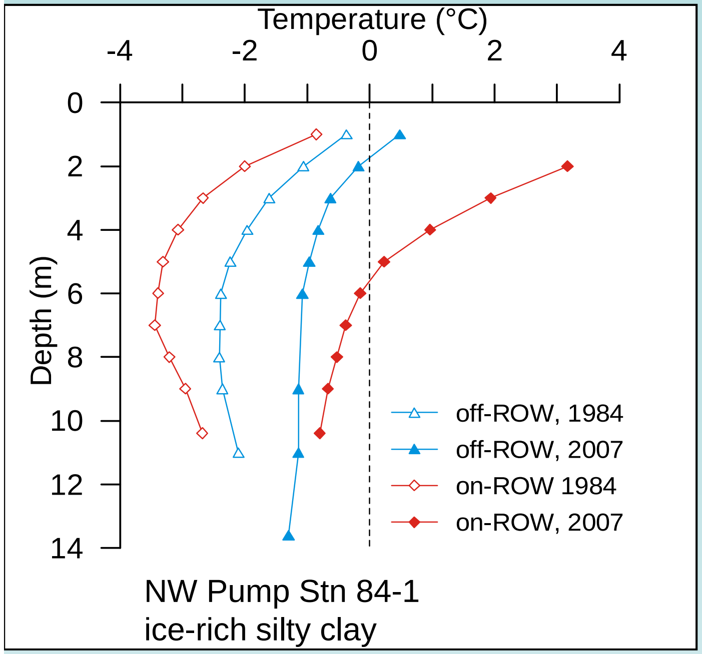
Warming rate 0.5°C per decade

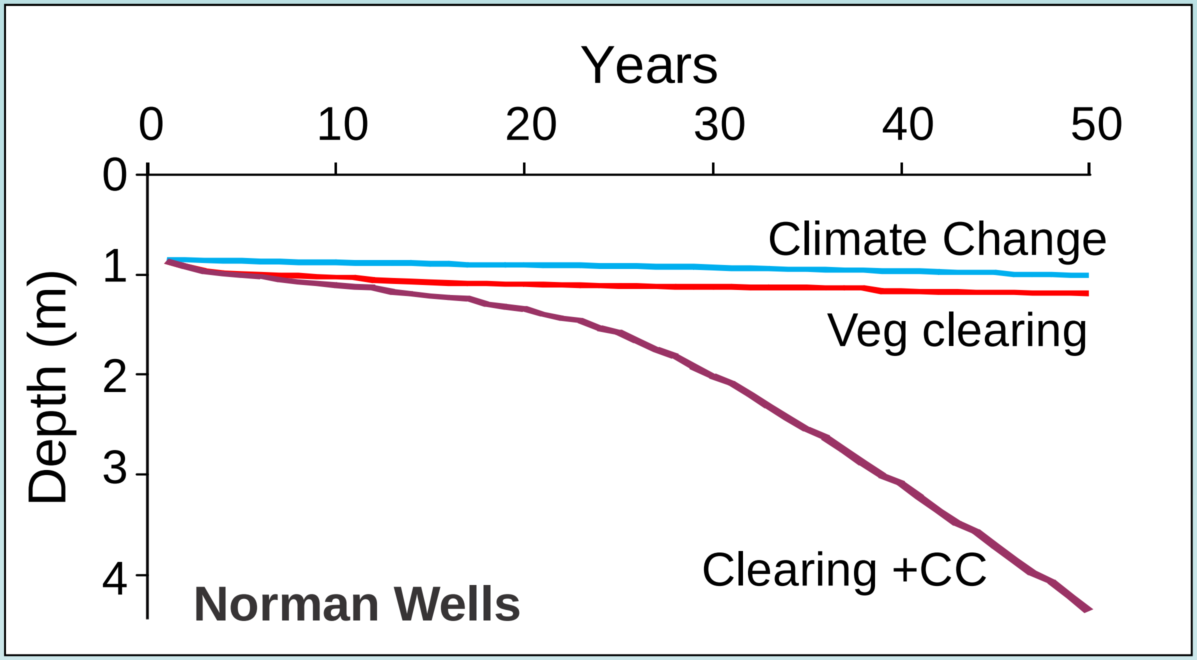
(Smith & Riseborough, 2010)



Effect of re-vegetation



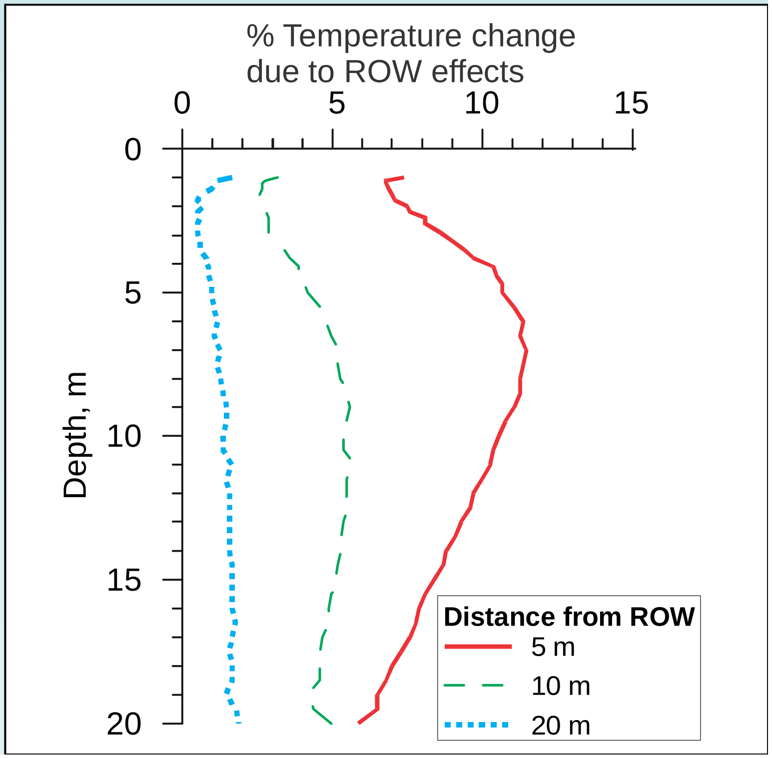




Modelling impact of vegetation clearing and climate change

(colder permafrost -1.7°C)

Effects of ROW disturbance can extend off the ROW



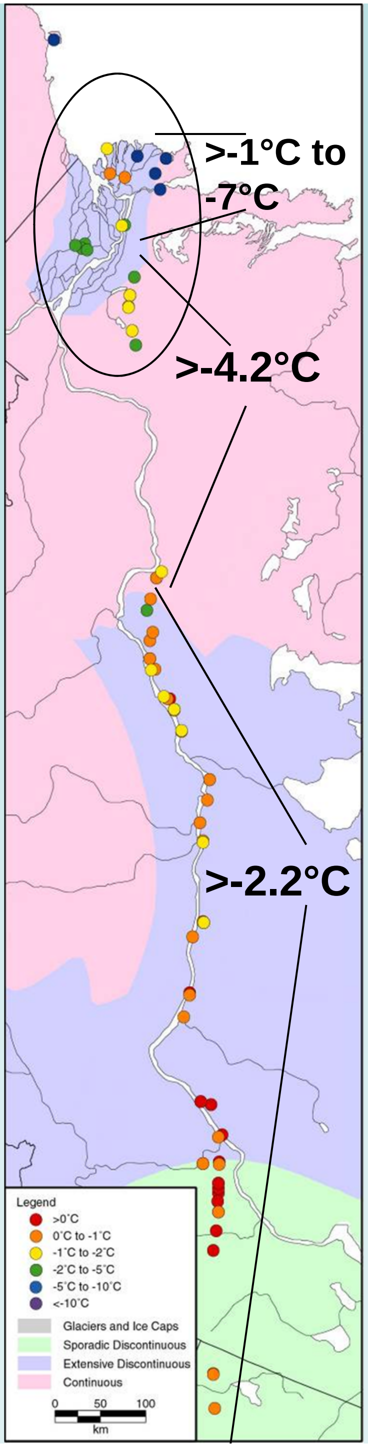
Lessons Learned

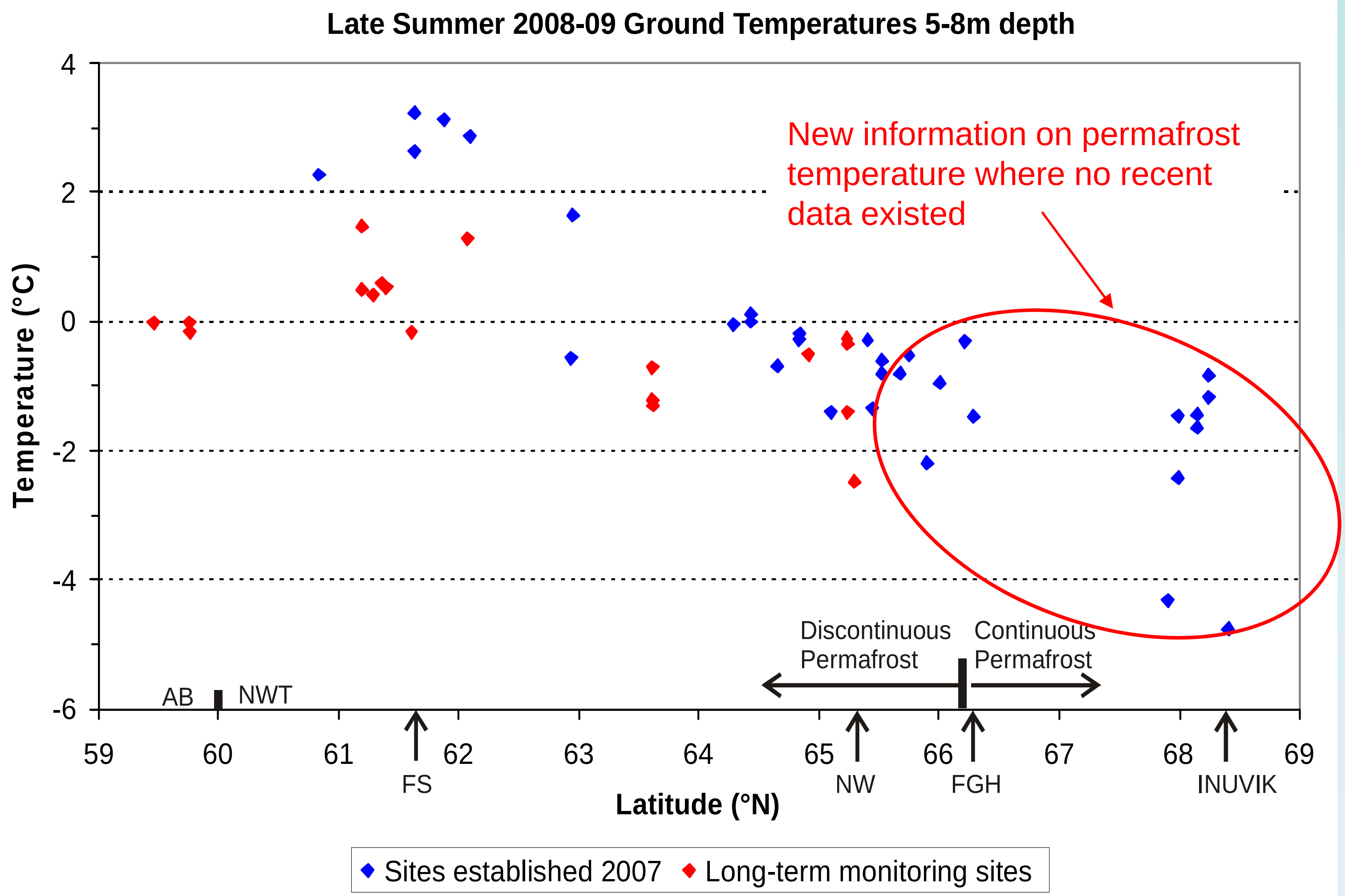
- results from monitoring and modelling studies indicate important impact of terrain disturbance
  - outweigh climate effects during first 10-15 years of pipeline operation
- climate warming effects become more important over time
- important to consider combined effects of environmental disturbance and climate change in engineering design
  - important for infrastructure expected to operate for more than 2 decades and where impacts of permafrost thawing of concern

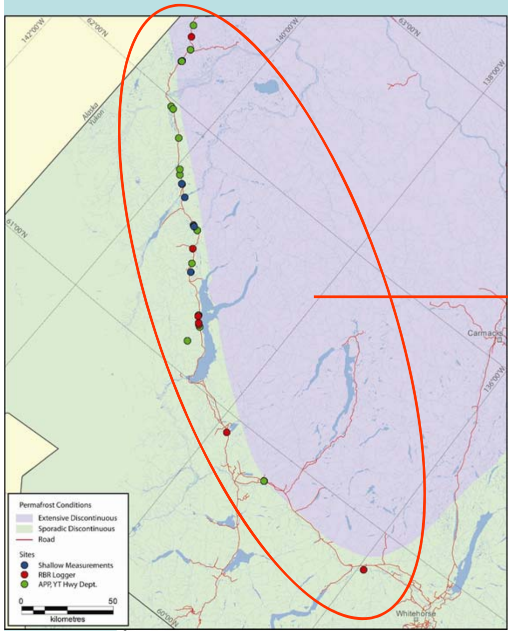
Lessons Learned

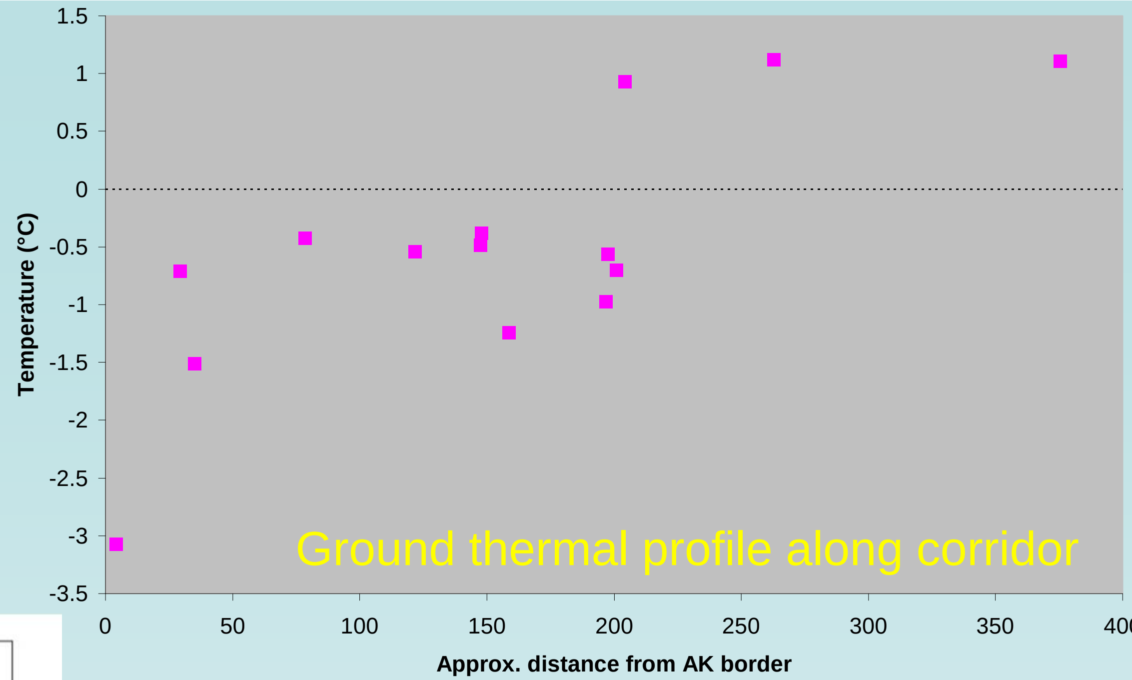
- Effective monitoring programs are essential
  - assessment of environmental impacts
  - monitor infrastructure performance
  - assessment of climate change impacts
- Collaboration increased data sharing and public availability of information
- Results can be used to improve design of future projects
- Monitoring programs can contribute to regional networks to improve baseline information

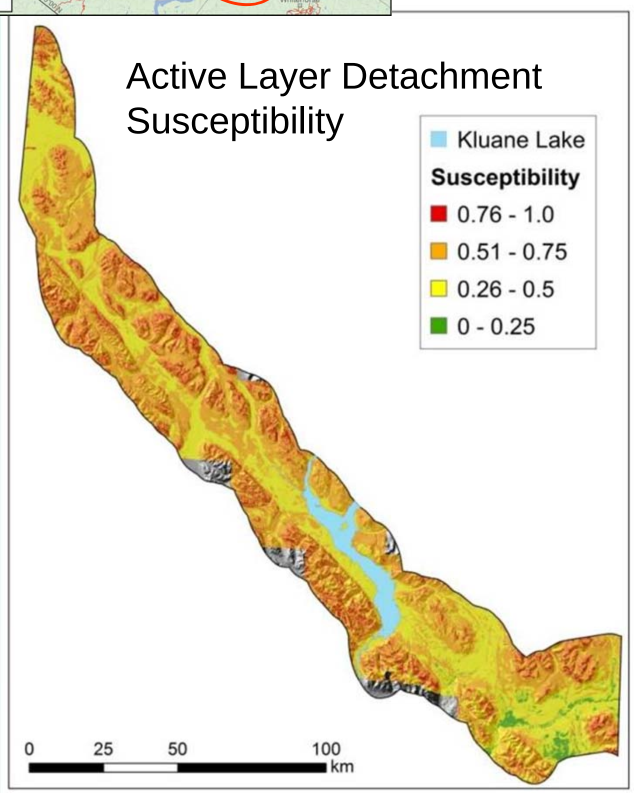
Enhanced monitoring networks and updated baseline ground thermal information for Mackenzie Corridor











Improving knowledge of permafrost and terrain sensitivity in Alaska Highway Corridor

Support provided by:

- Geological Survey of Canada, Natural Resources Canada
- Program for Energy Research and Development (PERD)
- Northern Energy Development Initiative
- Enbridge Pipelines (NW) Inc.
- Aboriginal Affairs and Northern Development Canada
- Northern Oil and Gas Action Plan
- Climate Change Action Plan
- Federal International Polar Year Program
- Numerous colleagues who have contributed to field data collection, management and analysis